SSCL-SR-1173

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Superconducting Super Collider Laboratory

SECOND ANNUAL SSCL SPRING CONFERENCE

ELECTROWEAK AND FLAVOR PHYSICS: IMPLICATIONS FOR THE SSC

Monday, May 20, 1991–Thursday, May 23, 1991

A COLLECTION OF TRANSPARENCIES SHOWN AT THE CONFERENCE

SSCL ORGANIZING COMMITTEE:

F. Gilman (SSCL)
I. Hinchliffe (LBL)
G. Kane (SSCL/Michigan)
S. Meshkov (SSCL)
F. Paige (SSCL/BNL)
A. Sanda (SSCL/Rockefeller)
G. Yost (SSCL)

PROGRAM

Second Annual SSC Spring Conference
Electroweak and Flavor Physics: Implications for the SSC
Monday, May 20 - Thursday, May 23

Monday, May 20

AM

9:00	**Welcome**	S. Meshkov (SSCL)
	Neutrino Physics and Dark Matter	Chair: W. A. Bardeen (FNAL)
9:10	Non Collider Collaterals at Colliders	A. de Rujula (CERN)
9:50	Neutrino Physics and Future Hadron Colliders	L Camillieri (CERN)
	Break	
11:00	NASA's Long Baseline Neutrino Experiment	T. Wilson (NASA)
	Solar Neutrinos	
11:30	Theoretical Overview	S.P. Rosen (UTA)
PM	**Solar Neutrinos**	Chair: S. P. Rosen (U.T. - Arlington)
2:00	Sage and a bit of Grande	M. Cherry (LSU)
2:40	Kamiokande	K. Nakamura (Tokyo-ICRR)
	Break	
	17 KeV Neutrinos	
3:50	The unbearable heaviness of neutrinos	J. J. Simpson (Guelph)
4:30	Search for emission of a 17 keV neutrino in the beta-spectrum of S-35	D. Imel (Caltech)

Tuesday, May 21

AM	**K-decays**	Chair: M. Perl (SLAC)
9:00	ε'/ε - Fermilab	B. Winstein (Chicago)
9:40	Results from NA31 at CERN and Future Plans	H. Wahl (CERN)
	Break	
10:50	Rare K - decays (BNL)	M. Schmidt (Yale)
11:30	Physics Program at the Frascati Phi-Factory	P. Franzini (Columbia)
PM	**Future Prospects(non SSC)**	Chair: H. Kasha (Yale)
2:00	Tau-Charm Factory: Physics and Construction Plans	M. Perl (SLAC)
	Bottom Quark Physics	
2:40	B-Physics and CP Violation from Lattice QCD	G. Martinelli (Rome)
	Break	
3:50	Physics of the B-Factory	S. Stone (Syracuse)
4:30	Argus & CLEO Results	H. Schroeder (DESY)
5:10	Photoproduction of Heavy Flavors	J. Cumalat (Colorado)
8:00	Banquet	

Wednesday, May 22

AM		Chair: E. C. G. Sudarshan (U.T.-Austin)
9:00	**Status and Physics Aims of SSC**	F. Gilman (SSCL)
	More Future Prospects (non SSC)	
9:40	Neutrino Physics at FNAL after the Upgrade	N. W. Reay (Ohio State)
	Break	
	Bottom Quark Physics	
10:50	LEP Results on b quarks	R. Mount (Caltech)
11:30	Recent results and Future Prospects for B-Physics at CDF	D. Amidei (Michigan)
PM	**Bottom Quark Physics**	Chair: F. Gilman (SSCL)
2:00	Symmetries in Heavy Quark Decay	M. Wise (Caltech)
2:40	Rare Decays of Heavy Flavors	A. I. Sanda (SSCL/Rockefeller)
	Break	
3:50	e^+ - e^- B Factories CLEO, SLAC, KEK	P. Oddone (LBL)
4:30	Prospects for Improvement in CKM Matrix	D. Hitlin (Caltech)

Thursday May 23

AM	**SSC Possibilities for B Physics**	Chair: F. Paige (SSCL/BNL)
9:00	Round Table:	
	Intervening Moderator:	F. Paige (SSCL/BNL)
	Cast:	B. Cox (UVA) N. Lockyer (Pennsylvania) P. Schlein (UCLA) S. Stone (Syracuse)
	Break	
11:30	What Lies Ahead?	R. Schwitters (SSCL)

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ν_τ FACTORIES

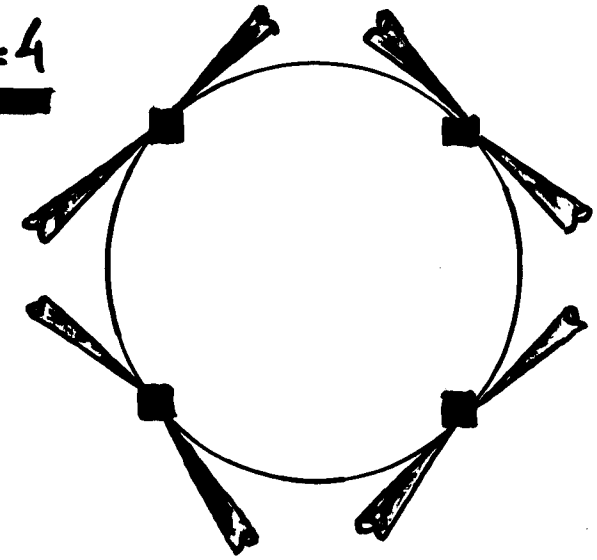
SSC

LHC

A. de Rújula

N = # INT. REGIONS [redacted]

e.g. N=4



$\frac{1}{x_F}(1-x_F)^{n\sim 5}$

$\langle d_c \rangle \simeq 17\,\mathrm{cm}\,\frac{E_p}{8\,\mathrm{TeV}}\left(\frac{7}{n+2}\right)$

"BEAM-BEAM DUMP" PROMPT DECAYS

DeR, RÜCKL 1984

$\frac{1}{10}$ INTS $pp \to c\bar{c} \ldots$

$\downarrow$

<ONE LEFT, ONE RIGHT>

$\frac{1}{10}$ c's $\to \nu_e\, e \ldots$

$\frac{1}{10}$ c's $\to \nu_\mu\, \mu \ldots$

"DC $\nu_{e,\mu}, \mu$ BEAM"

LHC

$\mathcal{L} = 3.8\, 10^{34}\, cm^{-2} s^{-1}$ $\sigma_{pp} \sim 120\, mb$

$$\frac{5\, 10^7\ \nu_e, \nu_\mu, \mu}{\text{SECOND}} = \frac{1\ \text{EACH}}{20\, ns}$$

$\langle E \rangle \sim 400\, GeV$

SSC $\frac{1\ \text{EACH}}{600\, ns}$ $\langle E \rangle \sim 1\, TeV$

FOR FREE, INEVITABLE

- SO MANY $\nu_{e,\mu}$ (μ)

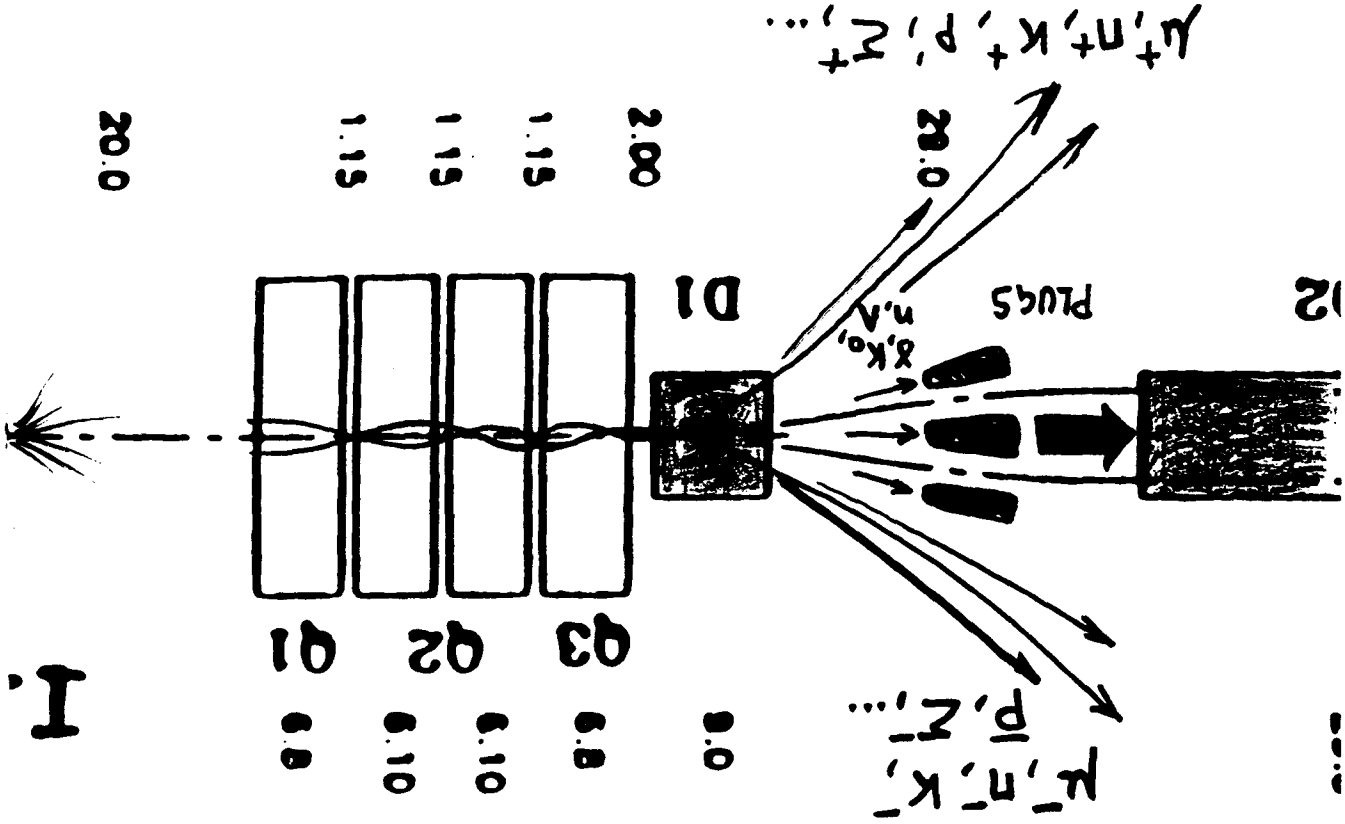
SO ENERGETIC, COLLIMATED

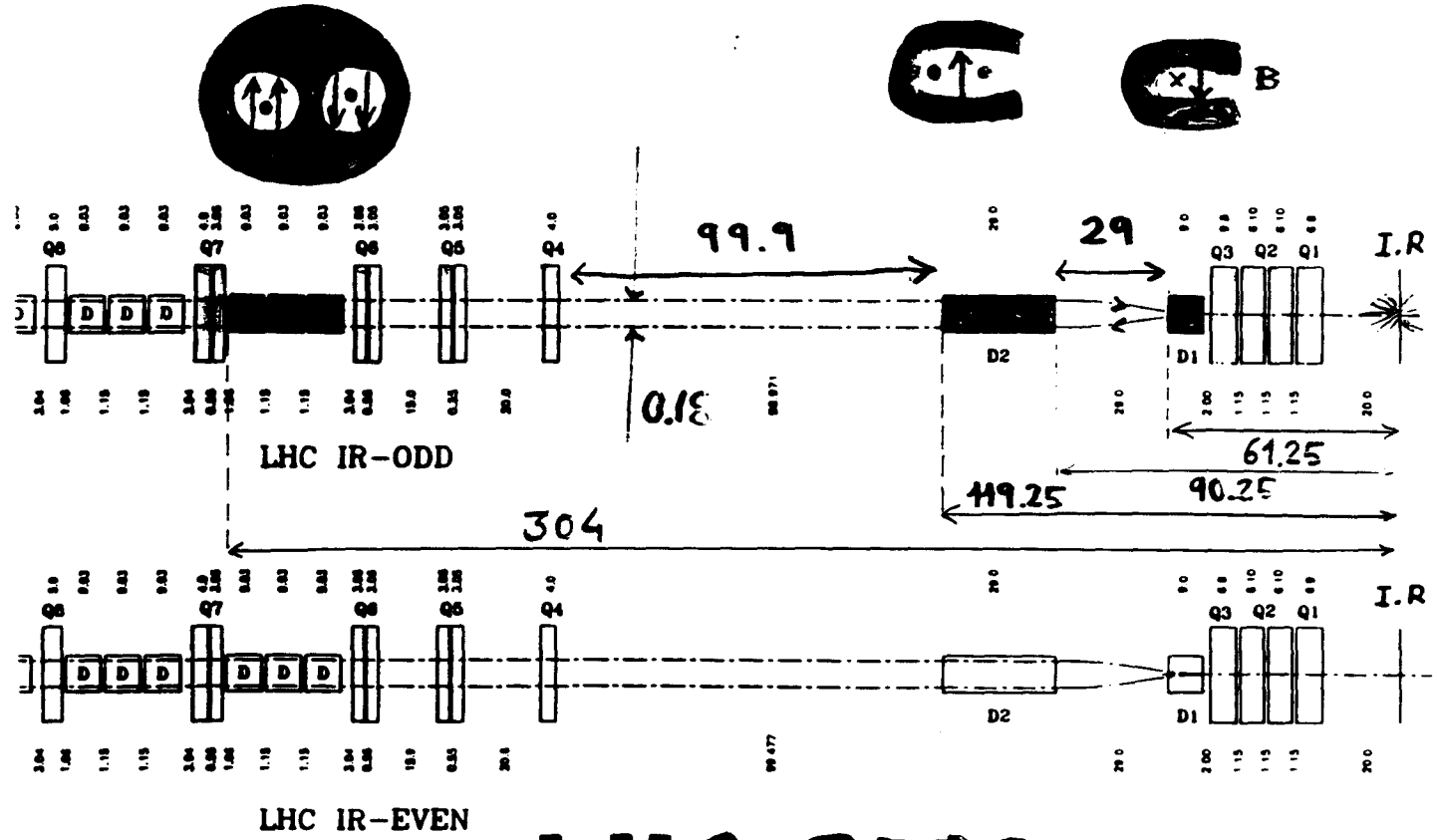
DO HIGH-E PHYSICS WITH

HUNDREDS OF THOUSANDS EVS/YEAR IN "TYPICAL" NEUTRINO DETECTOR (100's ON e^--TARGET)

- SUFFICIENTLY MANY ν_τ's TO DISCOVER 'EM

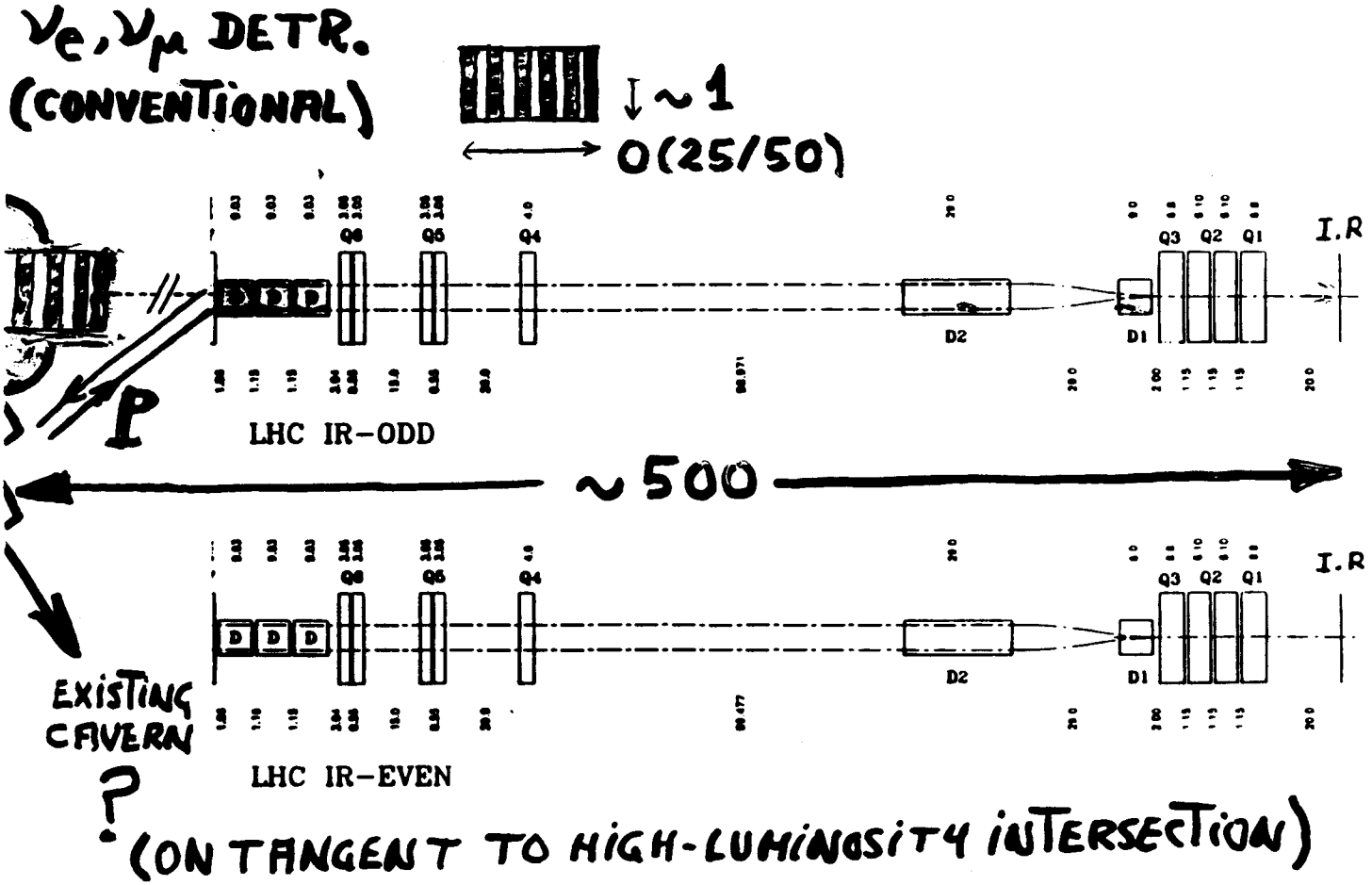
$\nu_\tau \to \tau + \ldots$



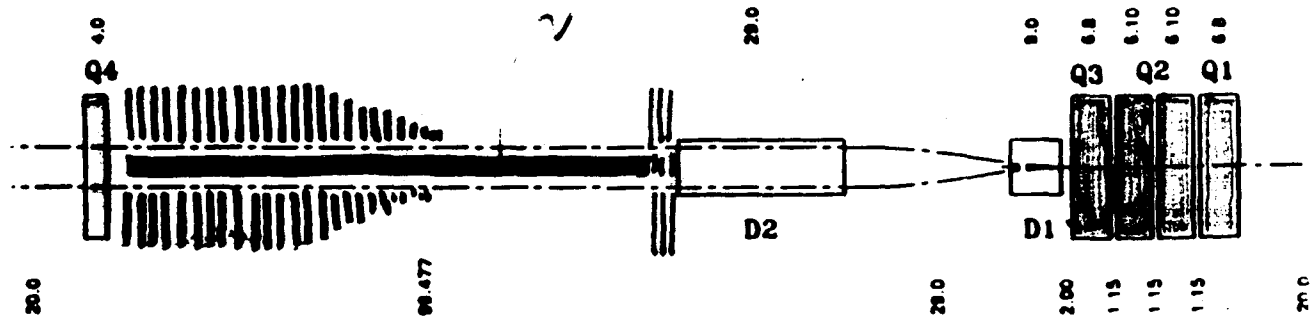


LHC GEOGRAPHY

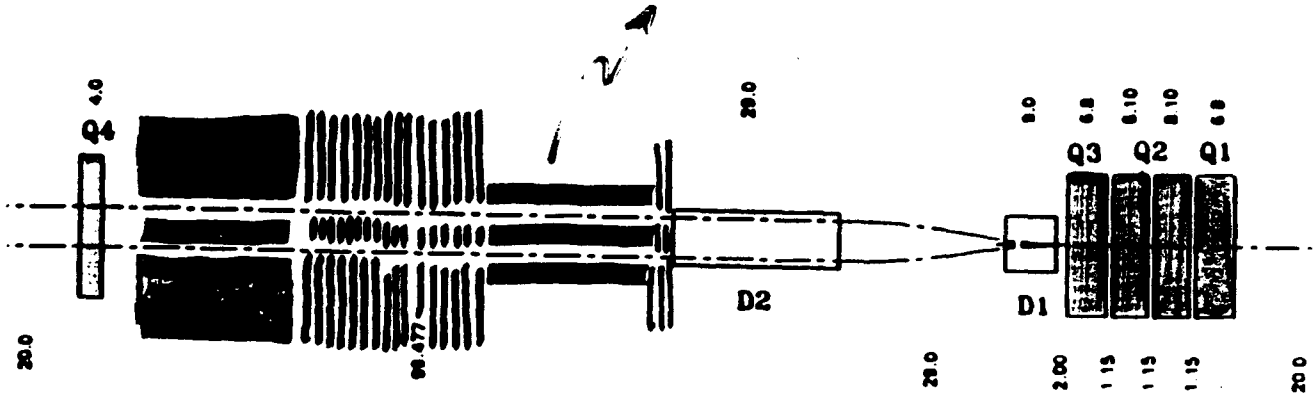
$$E_\nu(\theta)\,\frac{d\Phi_\nu}{d\cos\theta} \sim e^{-\theta/10^{-3}}$$

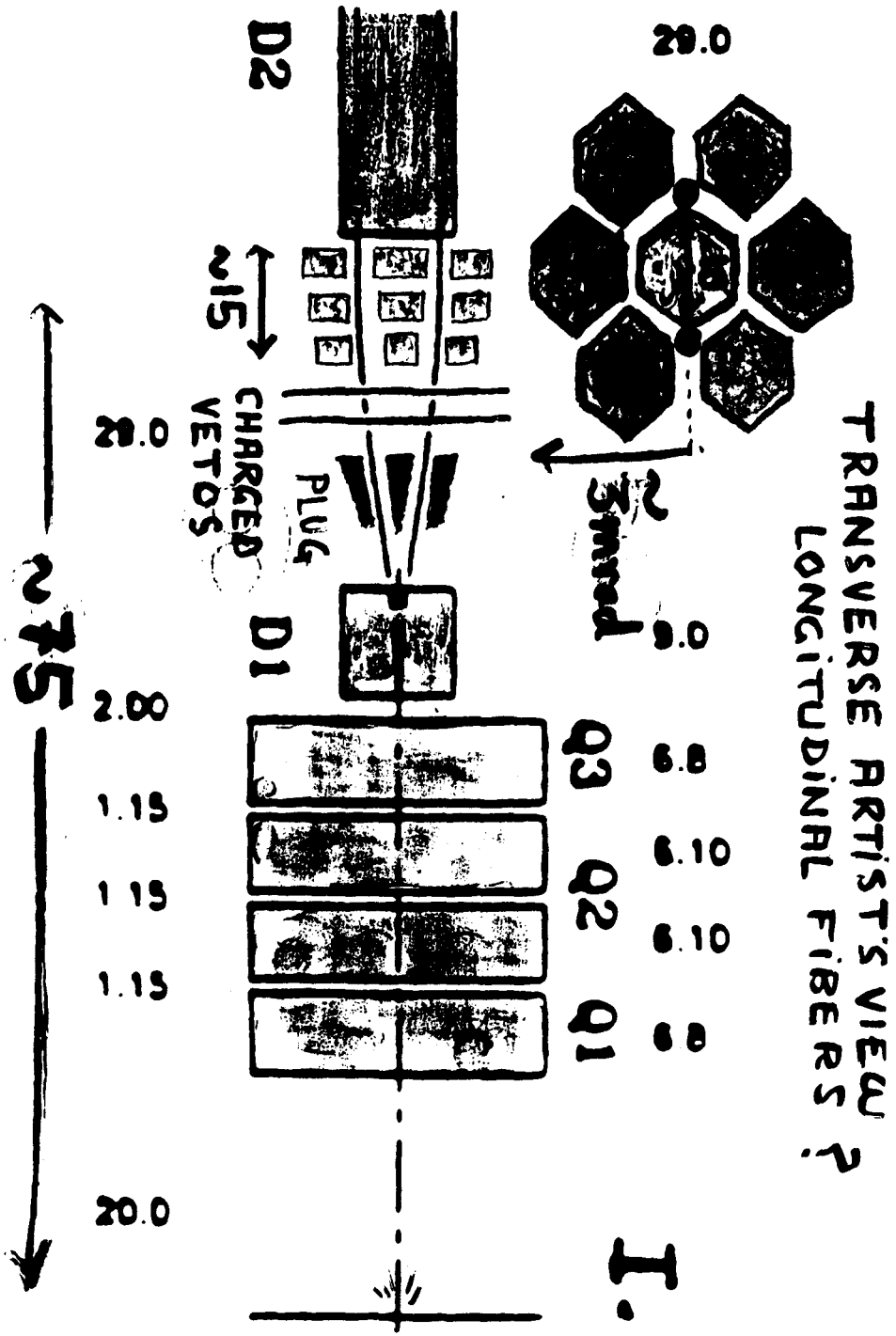


ν_τ ACTIVE TARGET



ν_τ ACTIVE TARGET





$\overset{(-)}{\nu}_{e,\mu}$, $\overset{(-)}{\nu}_{\tau}$, μ EVENTS

$$pp \rightarrow \overset{(-)}{D} \rightarrow \nu_e\, e\, X;\ \nu_\mu\, \mu\, X$$

$$\frac{d\sigma}{dx\, dp_T^2} \quad \overset{(-)}{D_s} \xrightarrow{B.R.} \nu_\tau\, \tau \rightarrow \nu_\tau X$$

- $\mathcal{L}_{pp}$, σ, BR $\Rightarrow$ TOTAL JUICE
- $d\sigma/dx$ $\Rightarrow$ ν-ENERGY SPECTRUM
- $d\sigma/dp_T$ $\Rightarrow$ BEAM APERTURE

NOT A NEW IDEA : A. DE R, R. RÜCKL

"WORKSHOP ON FIXED TARGET ϕ SSC, TEXAS 84"

"ECFA-CERN COLL. ON LHC, LAUSANNE 84"

NUCL. PHYS. 85

BACK IN 84

- $\frac{d\sigma}{dx} \sim (1-x)^n$: HIGHEST C-PRODUCT. MEASUREMENT AT THE TIME + 1 (PESS)

- $\frac{d\sigma}{dp_T^2} \sim e^{-1.1\,\mathrm{GeV}^{-2}\,p_T^2}$ FROM EXPS. THENCE

- $\mathcal{L}_{LHC} = \mathcal{L}_{SSC} = 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ WE WERE TOLD

★ EMPHASIZED ν_e, ν_μ, μ

HIGH-ENERGY EXPERIMENTS

[ν_τ UNINTERESTING, ~~NP~~ a ν]

- $\sigma(pp \to C \ldots)$ EDUCATED GUESS

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

3.2. TOTAL CHARM CROSS SECTIONS

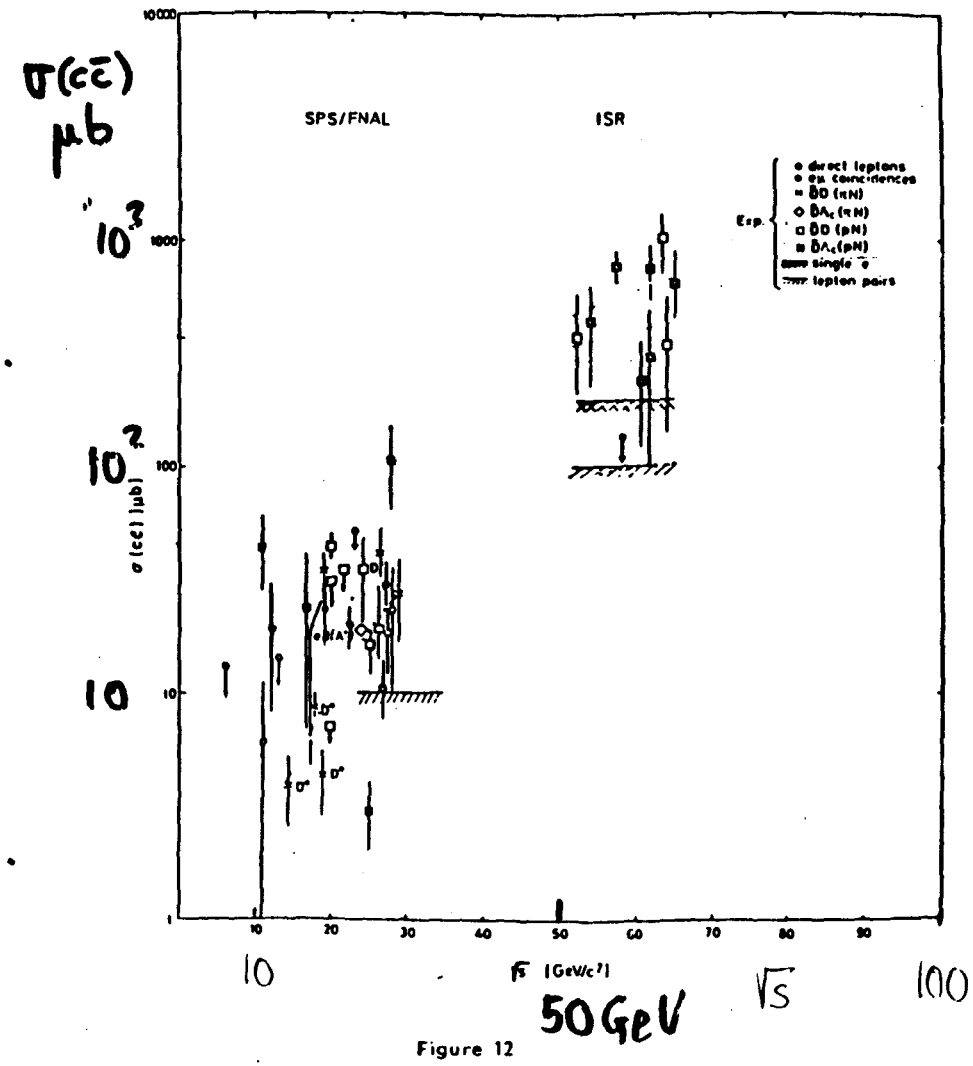
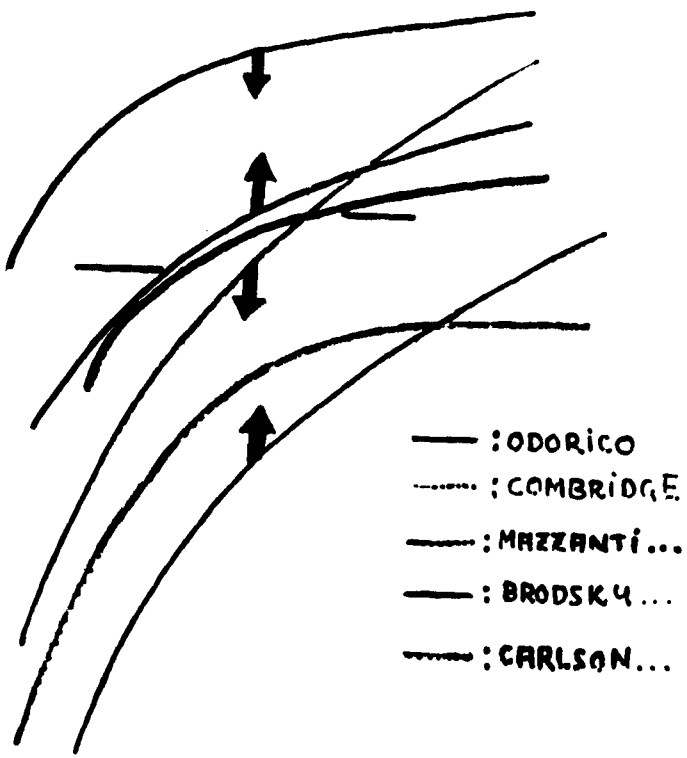
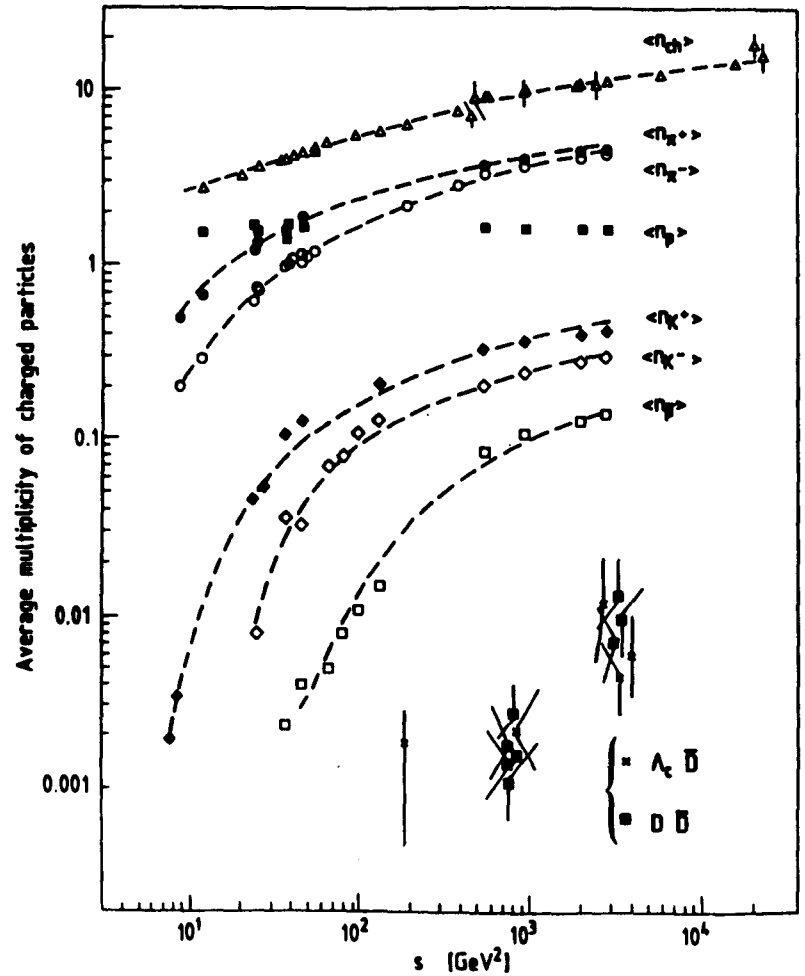


Figure 12
Energy dependence of the total charm cross section





Particle multiplicities as a function of energy in pp collisions (π,K,p,$\bar{p}$ and ch fr

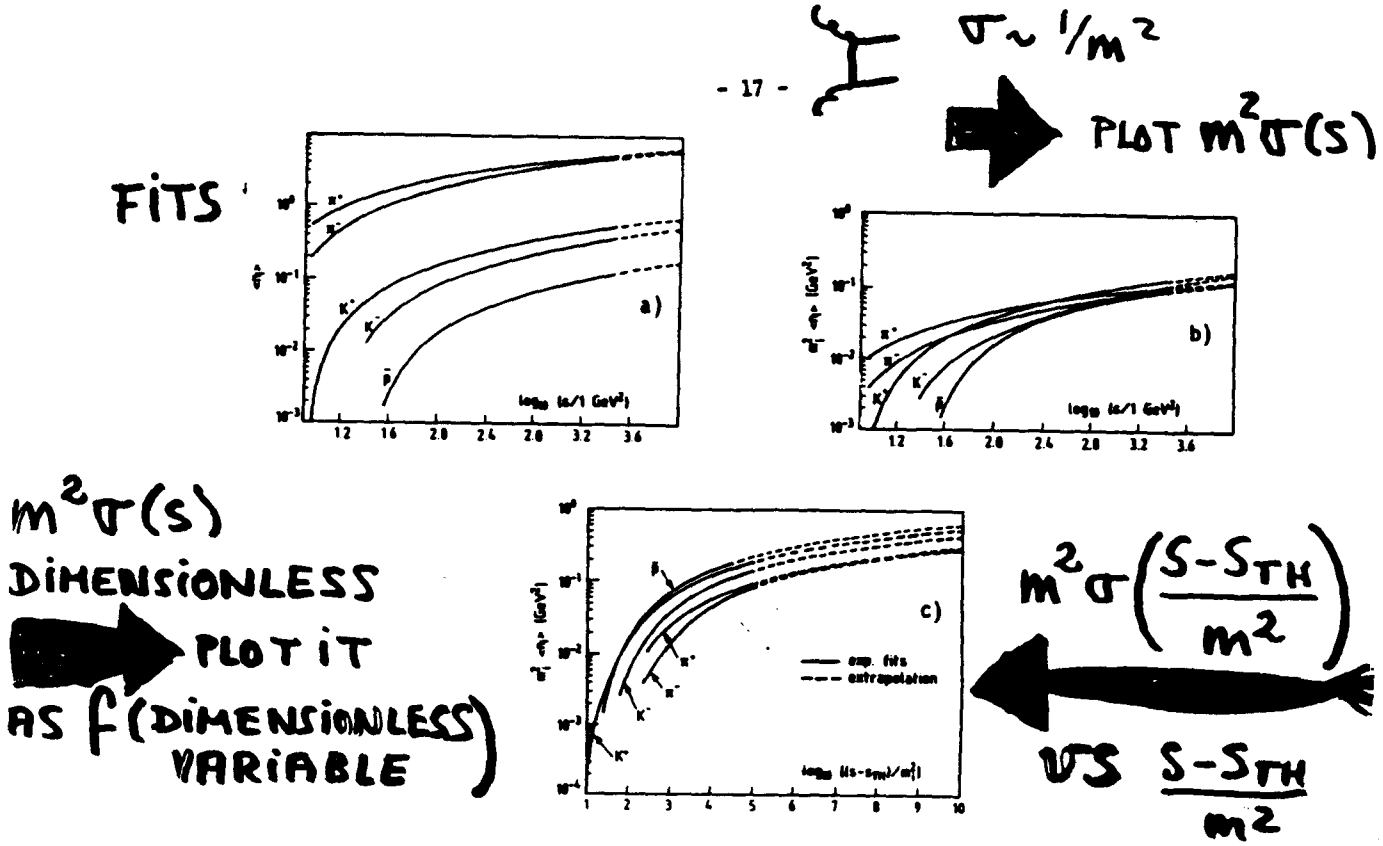


Fig. 5 a) Fits to some of the particle multiplicities of Fig. 4. b) Multiplicities times the square of the produced particle's mass. c) Same as (b), plotted as a function of the variable defined in Eq. (A1).

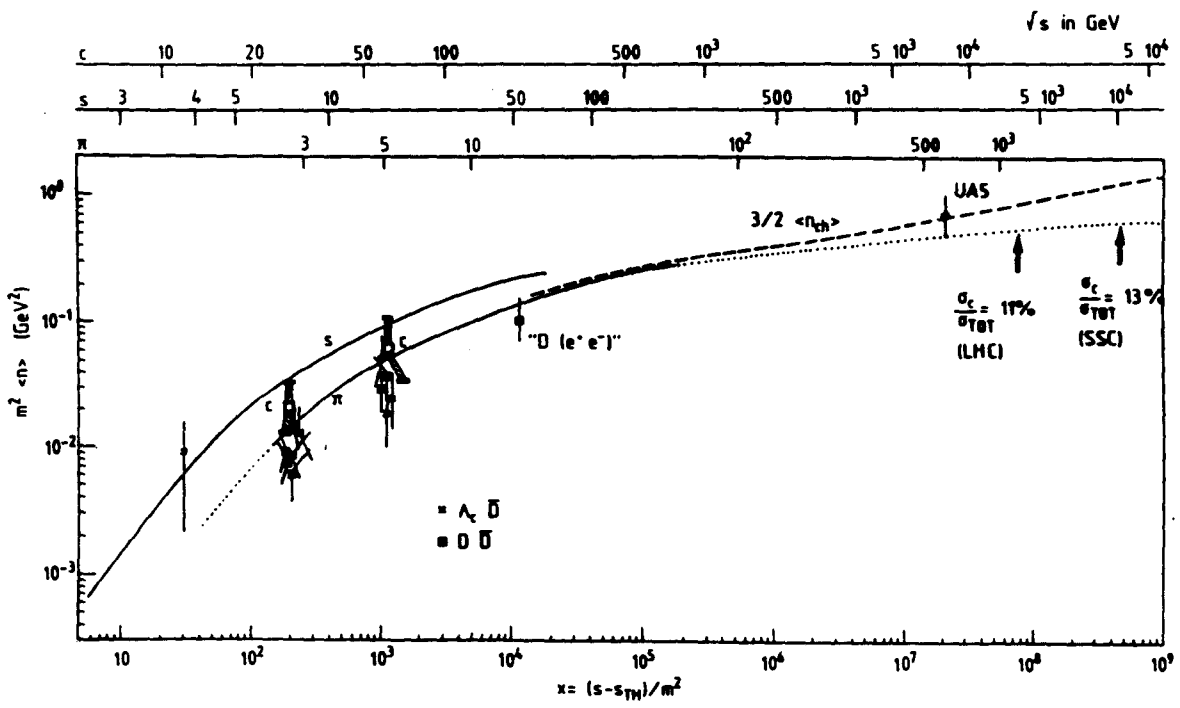


Fig. 6 Comparison of pion, strange particle and charm multiplicities in pp collisions in terms of the approximate scaling law of Eqs. (A1).

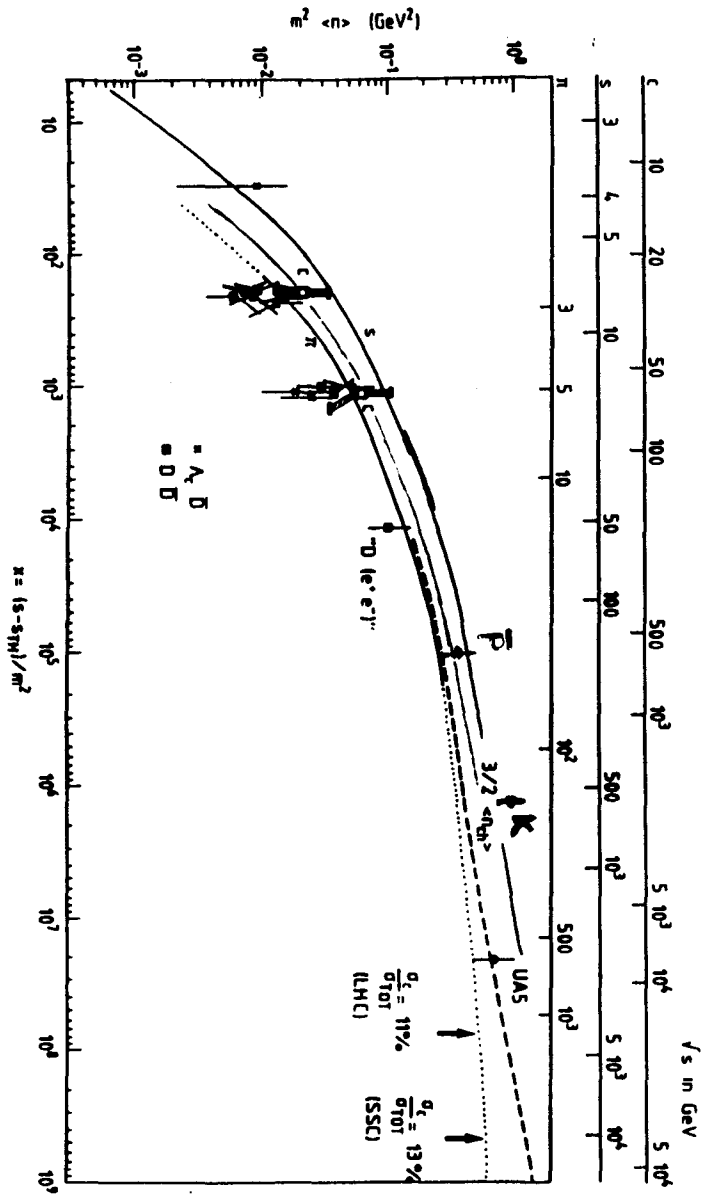


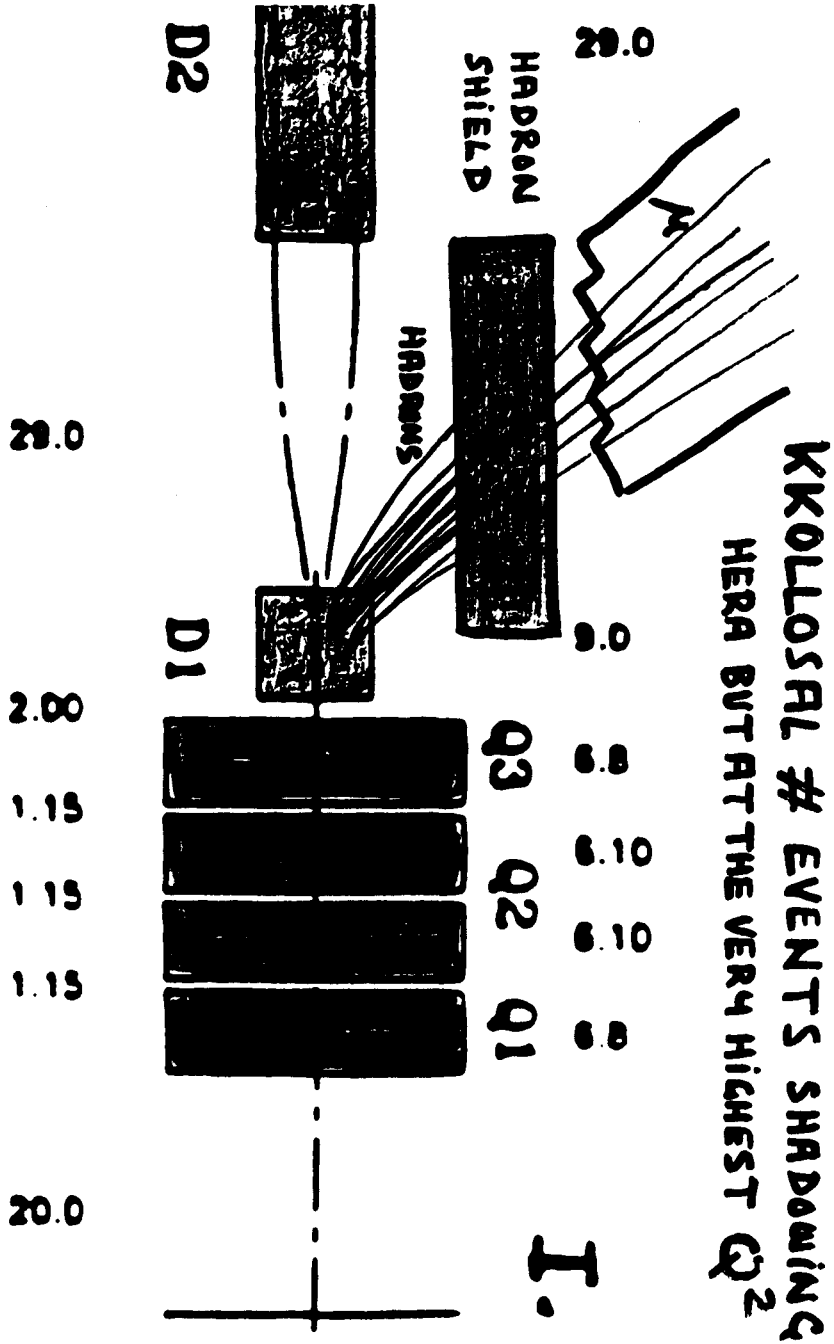
Fig. 6 Comparison of pion, strange particle and charm multiplicities in pp collisions in terms of the approximate scaling law of Eqs. (A1).

>84 UPDATE B4 DeR

E. FERNANDEZ
J.J GOMEZ-CADENAS

1. ν_τ NOT DISCOVERED : VERY CONSIDERABLE INTEREST
2. $\nu_{e,\mu}$ ϕ STILL MERITS : RATHER CONSID. INTER
3. μ ϕ : NOBODY SEEMS TO CARE (→ ⊙)
4. BR $D_s \to \tau$ TH. CONVERGING 3.9% [GOOD]
5. RAIDALOV et al : INMORALLY SUCCESFUL THEORY OF HADRON REACTIONS
   - $\sigma_{TOT}(pp \to D, D_s, \ldots)$ = OUR GUESS
   - $d\sigma/dx$ [TH, EXP] MUCH SOFTER (BAD
6. US : BETTER UNDERST. OF $d\sigma/dp_T$: BEAMS TWICE AS BROAD (BAD)
7. $\mathcal{L}_{pp}$ [LHC] UP B4 * 40 (GOOD)

→ BACK TO ⊡ ZERO [≈ # LHC EVENTS] 84~91



KKOLLOSAL # EVENTS SHADOWING
HERA BUT AT THE VERY HIGHEST Q^2

KAIDALOV et al.

pp, πp, pN, πN → $\pi^{\pm}+\ldots$, $p(\bar{p})\ldots$, $K, \bar{K}, \Lambda, \bar{\Lambda}$, $D, \bar{D}, \Lambda_c \ldots$

σ, $\frac{d\sigma}{dx(y)}$

USEFUL TO US (D_s)

MULTIPLICITIES
MULTIPLIC. DISTRIBUTIONS
DEVIATIONS / KNO SCALING
$d\sigma/dt$ ELASTIC
$\rho = \mathrm{Re}\,T / \mathrm{Im}\,T \,|_{t=0}$
RESOLUTION OF SOME "PUZZLES"

IN TERMS OF (2) PARAMETERS PER PRODUCED FLAVOUR-TYPE

$\sigma(s_0)$, $\alpha_R(0)$

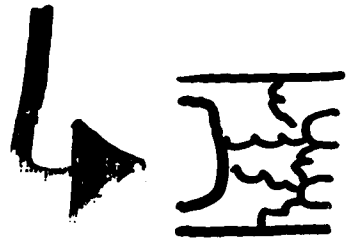
GIST OF KAIDALOV-ISM

K: "QUARK-GLUON STRING MODEL"

- $\left(\frac{1}{N[\text{LIGHT FLAVORS}]}\right)^2$ → TOPOL. CLASSIF OF QCD DIAGRS.

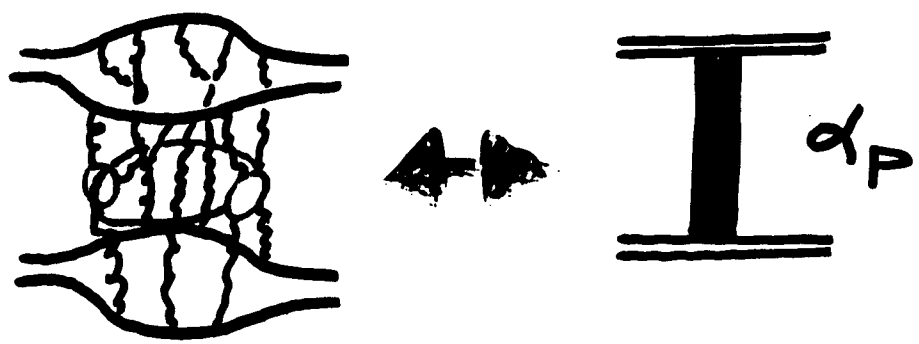
- ANALITICITY + UNITARITY → "REGGEON" CALCULUS

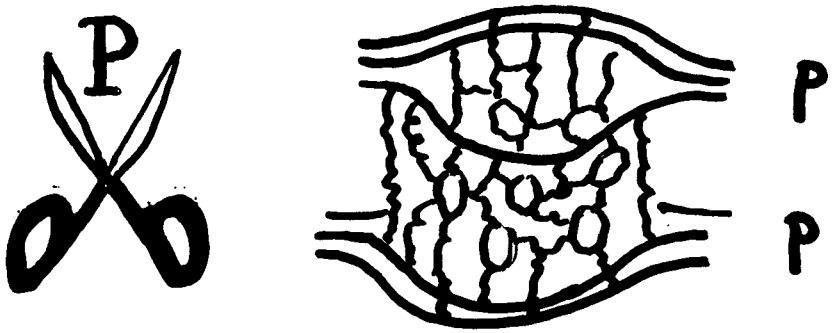
CUT



SINGLE CHAIN $\frac{1}{s^{1-\alpha_R(0)}}$

POMERON ↑ WITH ENERGY

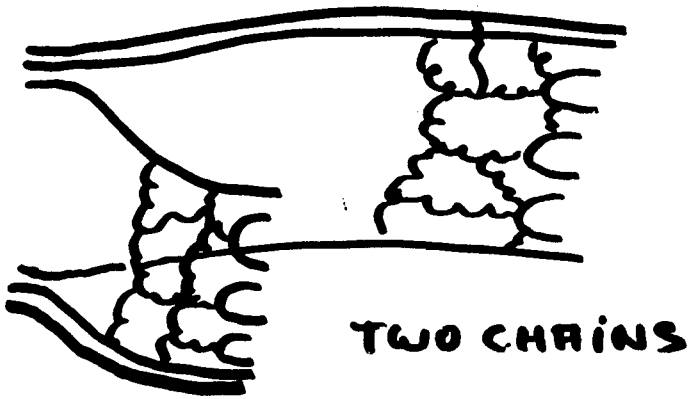




$pp \to \pi + \dots$

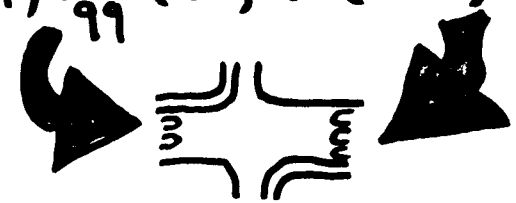
$$\frac{d\sigma^h}{dx} = \sum_n \sigma_n(s)\, \varphi_n^h(s,x)$$

$\sigma_n(s)$ → n cut Pomerons [GRIBOV calculus in QUASI-EIKONAL approx



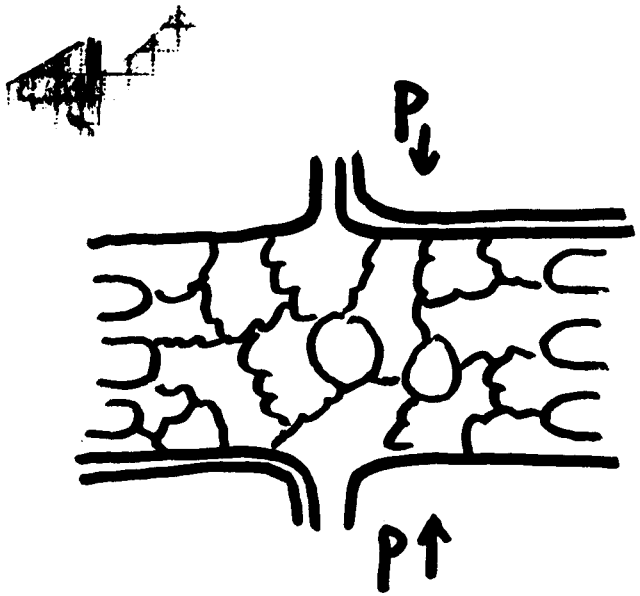
$$\varphi_1^h = F_q^h(x_+)\, F_{qq}^h(x_-) + (+ \leftrightarrow -)$$

F = STRUCT. F. ⊗ FRAG. F.



$$x_\pm = \frac{1}{2}\left(\sqrt{x^2 + x_\perp^2} \pm x\right) \qquad x = \frac{2p_\parallel^h}{\sqrt{s}}$$

$$x_\perp = \frac{2\sqrt{m^2 + p_T^2}}{\sqrt{s}}$$



CORRECT KINEMATICS ABSOLUT. ESSENTIAL, AS IN DEEP INEL. SCATTERING [ξ-SCALING]

TRIVIALLY RESOLVED CONUNDRUM

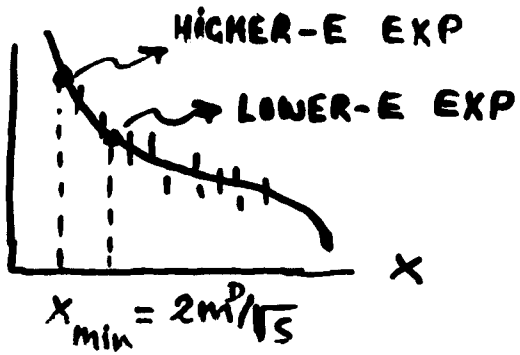
$pp \to D + \dots$ FIXED TARGET

$E_p = 400\,\mathrm{GeV}$ $\quad \frac{d\sigma}{dx} \sim (1-x)^{4.9 \pm 0.5}$

$E_p = 800\,\mathrm{GeV}$ $\quad \frac{d\sigma}{dx} \sim (1-x)^{11.2 \pm 0.9}$

ROUGH TH. $\quad \frac{d\sigma}{dx} \sim \boxed{\frac{1}{x}} (1-x)^m$

THRESHOLD EFFECTS NOT NEGLIGIBLE



$m(400) \sim 3.5 \pm 1.0 \quad m(800) \sim 6.0 \pm 1.5$

NON-ROUGH THEORY GETS RID OF DISCREPANCY

$(x_+ \approx x_-)$ STRING $\Rightarrow h + \dots$

$$\varphi_1 = F(x_+)\,F(x_-) + (+ \leftrightarrow -)$$

$$F_u^h(x) = \int_x^1 dx'\, f^u(x')\, G^h\!\left(\frac{x}{x'}\right)$$

(LOW-Q^2 "STRUCT. FUNCT.") (LOW-Q^2 "FRAGM. FUNCT.)

f, G AT $x \to 0$, $x \to 1$ DETERMINED BY REGGE POLE ARGUMENTS

e.g. $f(x \to 0) \sim x^{-\alpha_M(0)}$

$f(x \to 1) \sim (1-x)^{\alpha_M - 2\alpha_N}$

ANSATZ $\quad f(x) = f(x \to 0) \times f(x \to 1)$

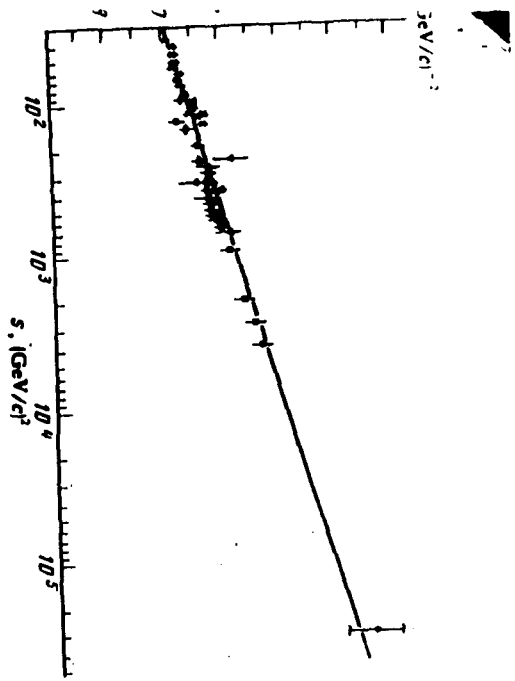


FIG. 2. Prediction of the model of a supercritical Pomeron (Re
of Ref. 1) for the slope of the diffraction peak, $B(t) \mid t \mid \leq 0.1$ G
and its comparison with experiment.

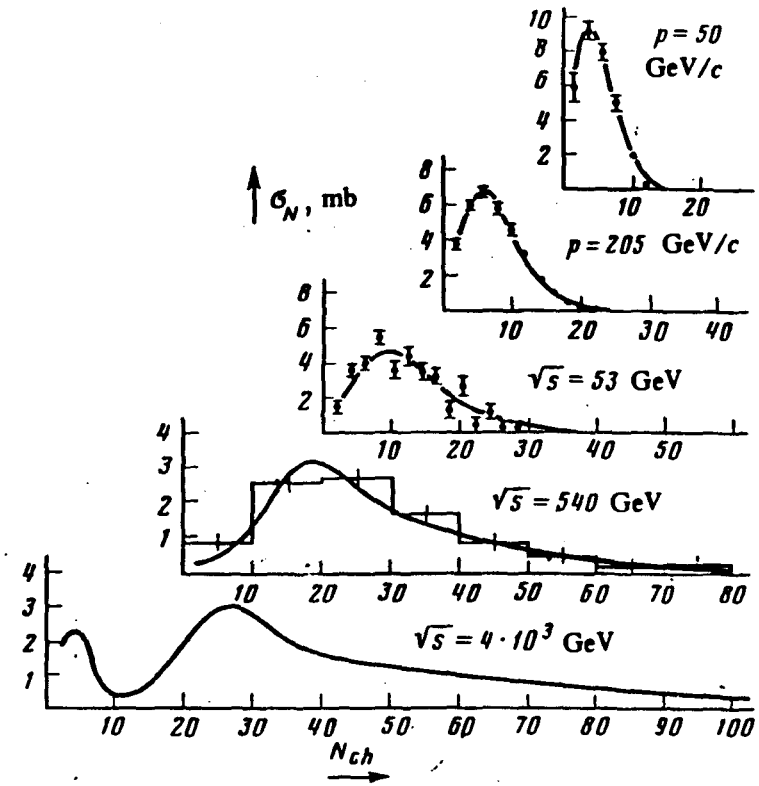


FIG. 4. Predictions of the model and their comparison with experimental data on the multiplicity distributions of charged particles in pp and $\bar{p}p$ interactions[3,5] (at $\sqrt{s} = 540$ GeV, the absolute values of the cross sections are obtained by multiplying $(\sigma_{N_{ch}}/\sigma^{in})_{exp}$ by σ^{in}_{theor}). The theoretical curve at $\sqrt{s} = 540$ GeV, like the experimental data, contains no contribution from single diffracton dissociation (at the other energies, this contribution is included).

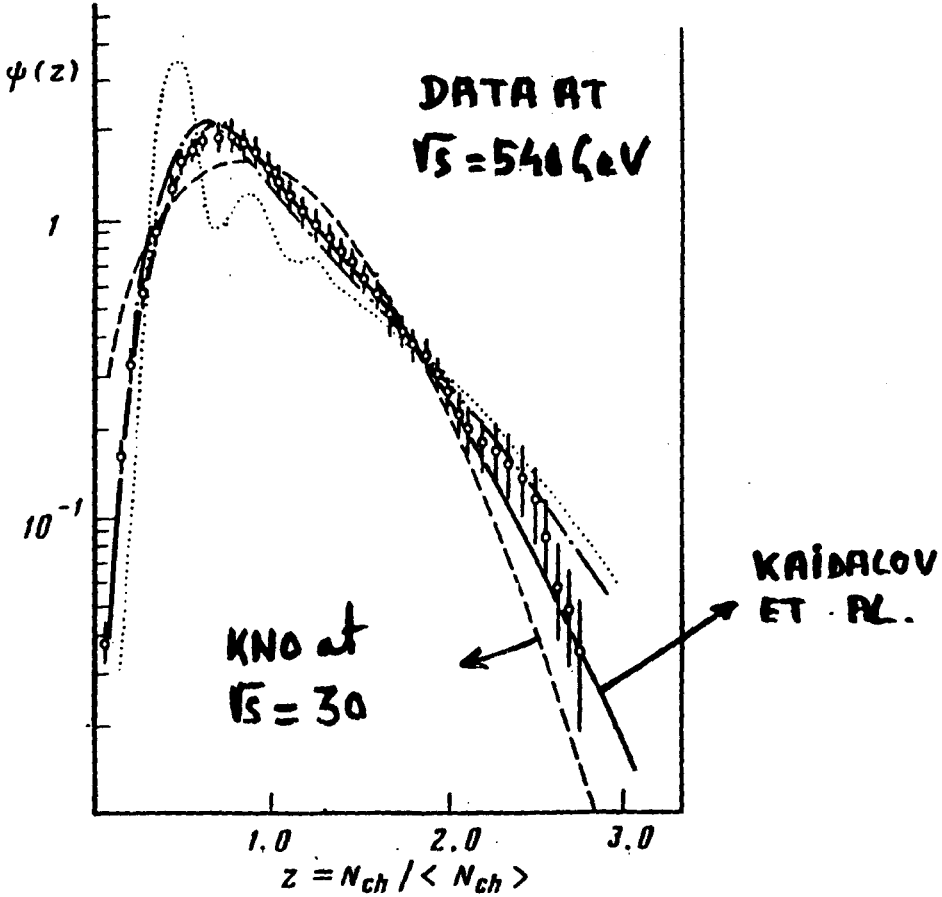


FIG. 6. The KNO function $\psi(z,\xi) = \bar{N}_{ch}\sigma_{N_{ch}}/\sigma^{in}$ as a function of $z = N_{ch}/\bar{N}_{ch}$ at $\sqrt{s} = 540$ GeV.[4] The continuous curve is the predicton of the model (variant 1 of Ref. 1), the broken curve is the KNO curve at $\sqrt{s} \sim 30$ GeV, the chain curve is the prediction of the model (variant 2), and the dotted curve is the prediction of the theory for the distribution at $\sqrt{s} = 10^5$ GeV.

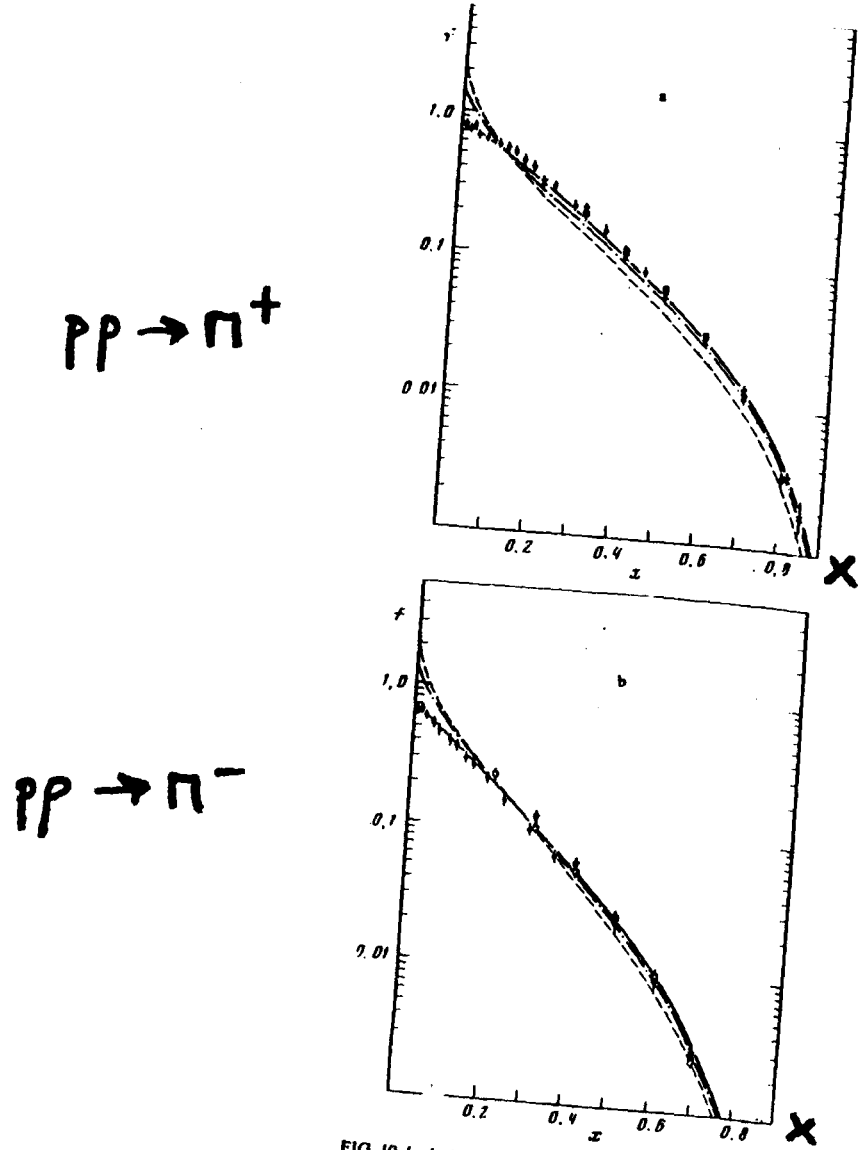


FIG 10. Inclusive cross section f for π^+ mesons (a) and π^- mesons (b) at various energies. The data at $\sqrt{s} \approx 20$ GeV (Ref. 5) are shown. The continuous curve is for $\sqrt{s} = 20$, the chain curve for $\sqrt{s} = 540$, and the broken curve for $\sqrt{s} = 10^6$ GeV. Points for π^+: the crosses are for $p_{lab} = 100$, the dark squares for 175, and the dark circles for 205 GeV/c; for π^-: the inverted triangles are for $p_{lab} = 100$, the open squares for 175, and the open circles for 205 GeV/c.

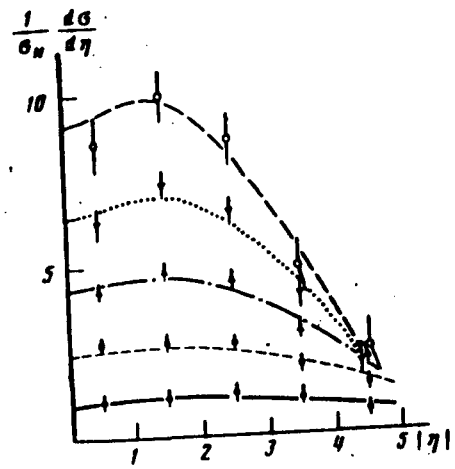


FIG. 9. Description of the data of the UA5 group[3] on the multiplicity dependence of the rapidity distributions. The continuous curves (dark circles) is for $2<N_{ch}<17$, the broken curve (squares) is for $18<N_{ch}<31$, the chain curve (triangles) is for $32<N_{ch}<45$, the dotted curve (inverted triangles) is for $46<N_{ch}<60$, and the curve with long dashes (open circles) is for $60<N_{ch}<90$.

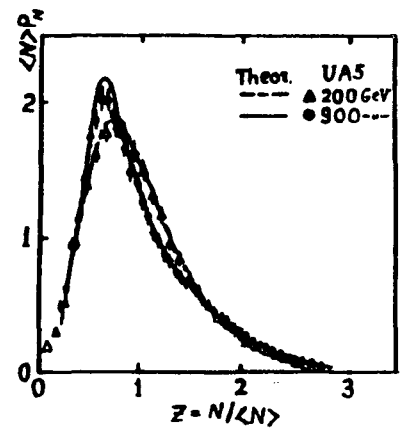


Fig. 14. b) full curve $\sqrt{s}$ = 900 GeV, dashed one $\sqrt{s}$ = 200 GeV

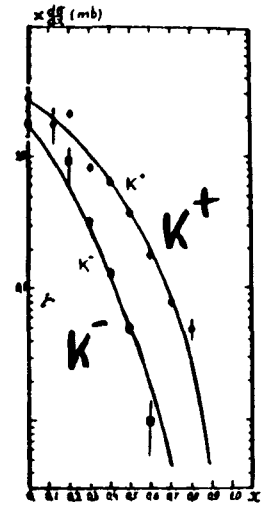


Fig. 16. K^+ and K^- spectra at p_L = 175 GeV

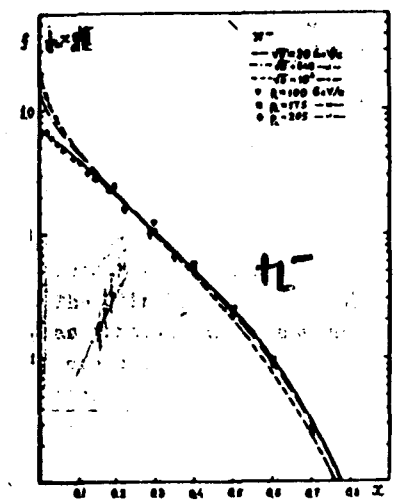


Fig. 15. π^--spectra in pp-interactions

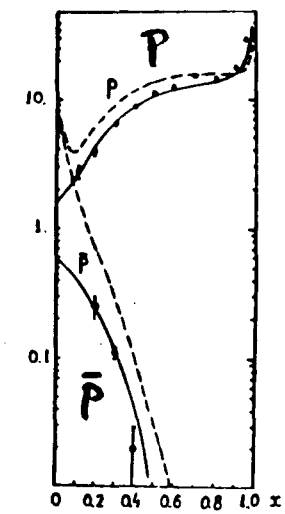
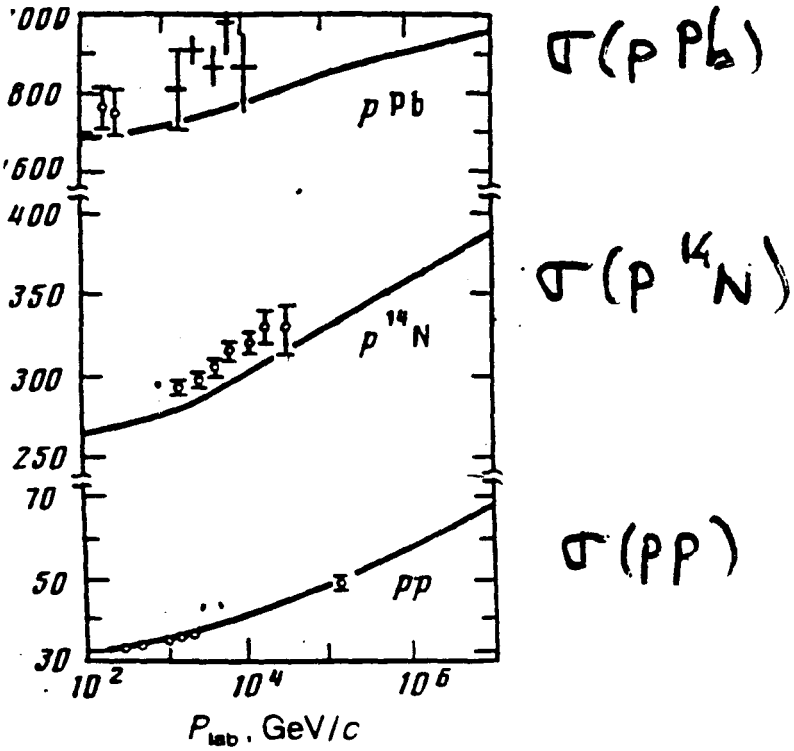
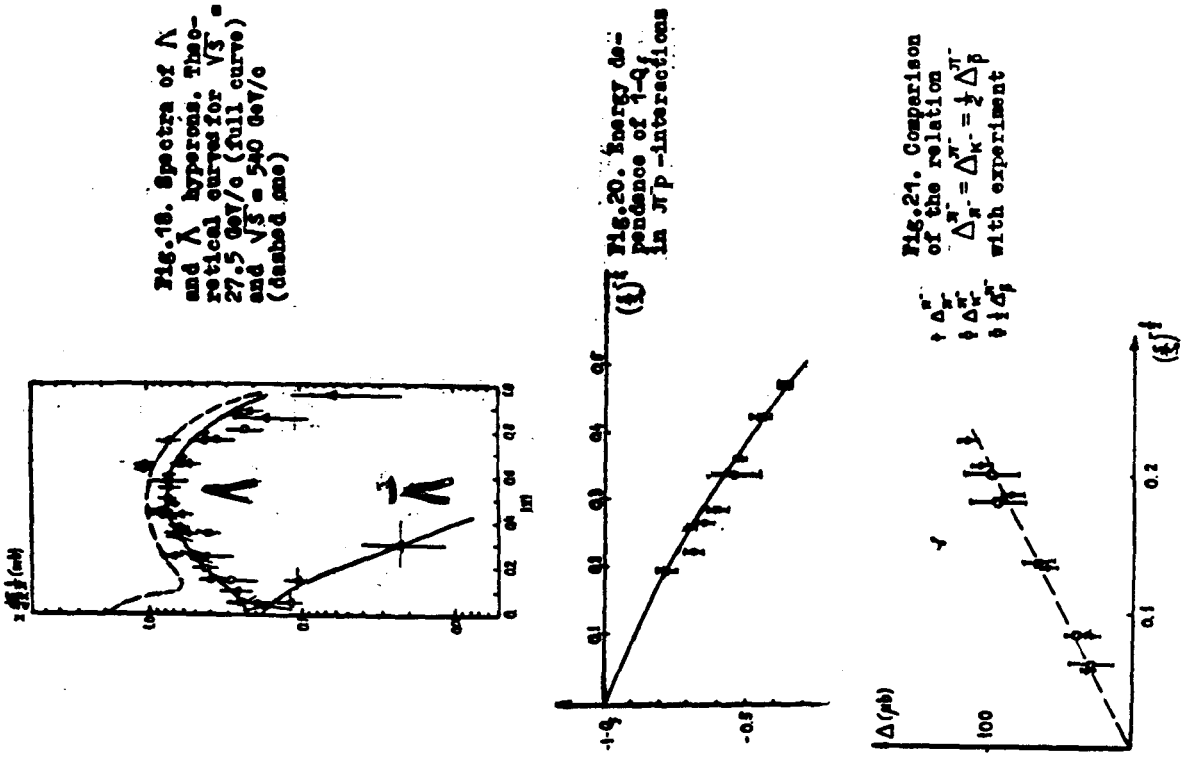


Fig. 17. P and $\bar{P}$ -spectra. Experimental points for p_L = 175 GeV. Full curve for $\sqrt{s}$ = 20 GeV, the dashed one for $\sqrt{s}$ = 540 GeV.



IG. 2. Interaction cross sections for pp, $p^{14}N$, and pPb collisions with condary-particle production.



$\pi^{\pm}$

X- DISTRS.

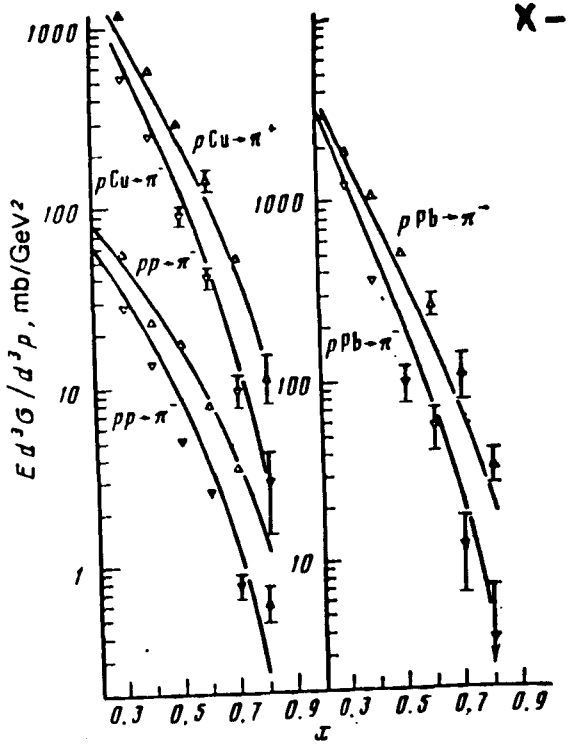
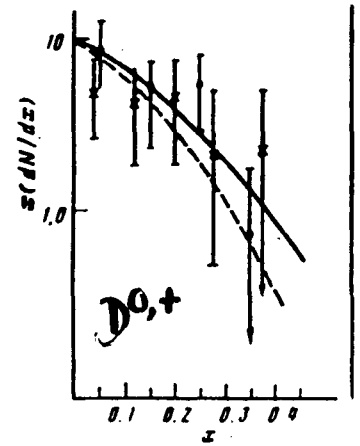


FIG. 3. Spectra of $\pi^{\pm}$ mesons in pPb, pCu, and pp collisions at 100 GeV/c and $p_{\perp} = 0.3$ GeV/c (Ref. 11) and their description in the quark-gluon string model.



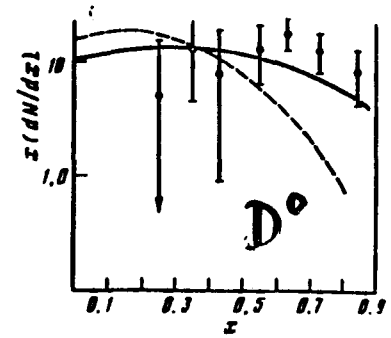
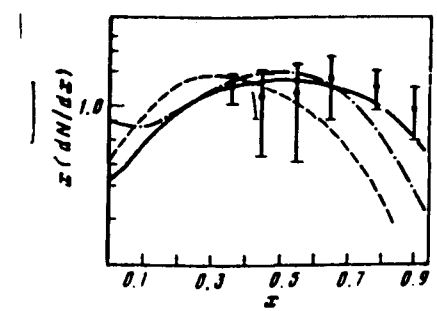


FIG. 3. Spectra of D^0 mesons in the π^-Be in comparison with the theoretical curve sumptions as in Fig. 2.

FIG. 2. Comparison of the results of the calculation with experimental data on the spectra of the D^+ and D^0 mesons in the pp interaction at $\sqrt{s} = 62$ GeV (Ref. 13): [redacted] to $\alpha_\psi(0) = 0$ (the solid curve) and $\alpha_\psi(0) = -2$ (the dashed curve).



Λ_c^+

FIG. 4. Comparison with experiment of the calculation for the spectrum of Λ_c^+ baryons in the pp interaction at $\sqrt{s} = 62$ GeV (Ref. 15). The solid and dashed curves correspond to the same values of $\alpha_\psi(0)$ as in Figs. 2 and 3, while the dashed–dotted curve corresponds to variant (b) (Fig. 1) for the fragmentation functions $D_{1\infty}^{\Lambda_c}$ for $\alpha_\psi(0) = -2$.

— $\alpha_\psi(0) = 0$ IS THE BETTER ONE

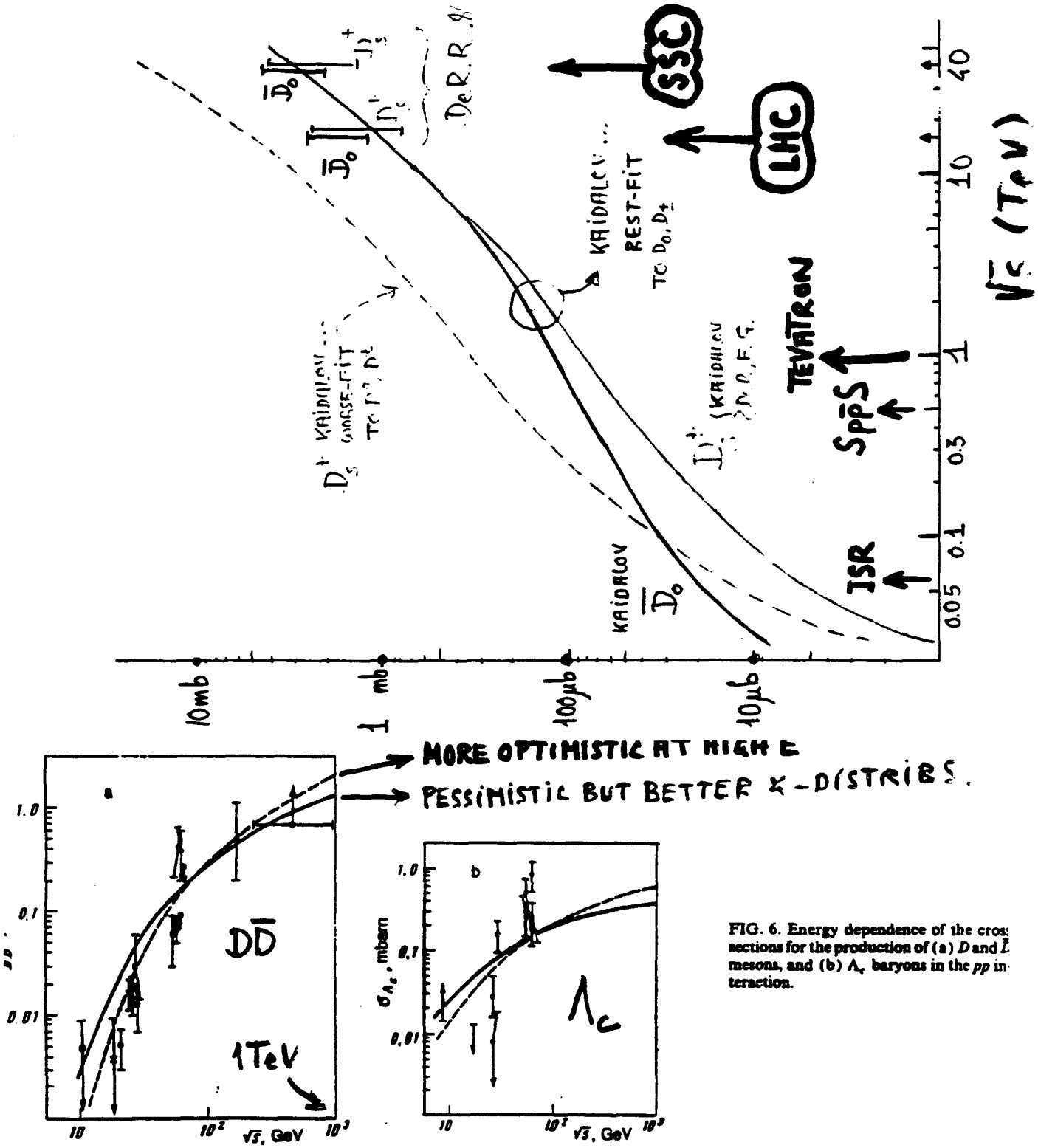


FIG. 6. Energy dependence of the cross sections for the production of (a) D and $\bar{D}$ mesons, and (b) Λ_c baryons in the pp interaction.

$\sigma(pp \to D\bar{D})$ $\sigma(pp \to \Lambda_c \ldots)$

WHO, IN HIS RIGHT MIND, WOULD USE HERWIG PYTHIA...

FOR FORWARD PHYSICS AT LHC/SSC (e.g. BEAUTY PROD.)

WHEN KAIDALOV-ISM IS JUSTIFIABLE MMULCCHH BETTER FASTER ????

NOT US

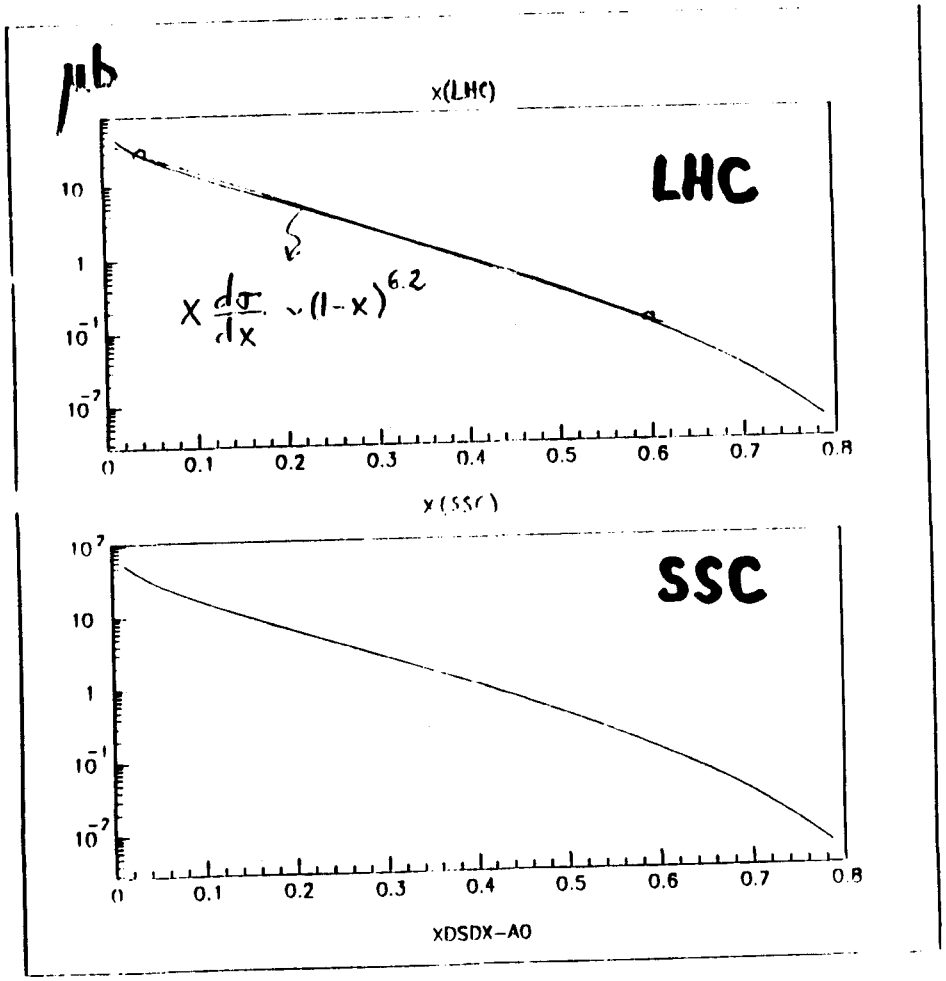
$x \frac{d\sigma}{dx}$ $\quad pp \to \overset{(-)}{D}_s \cdots$

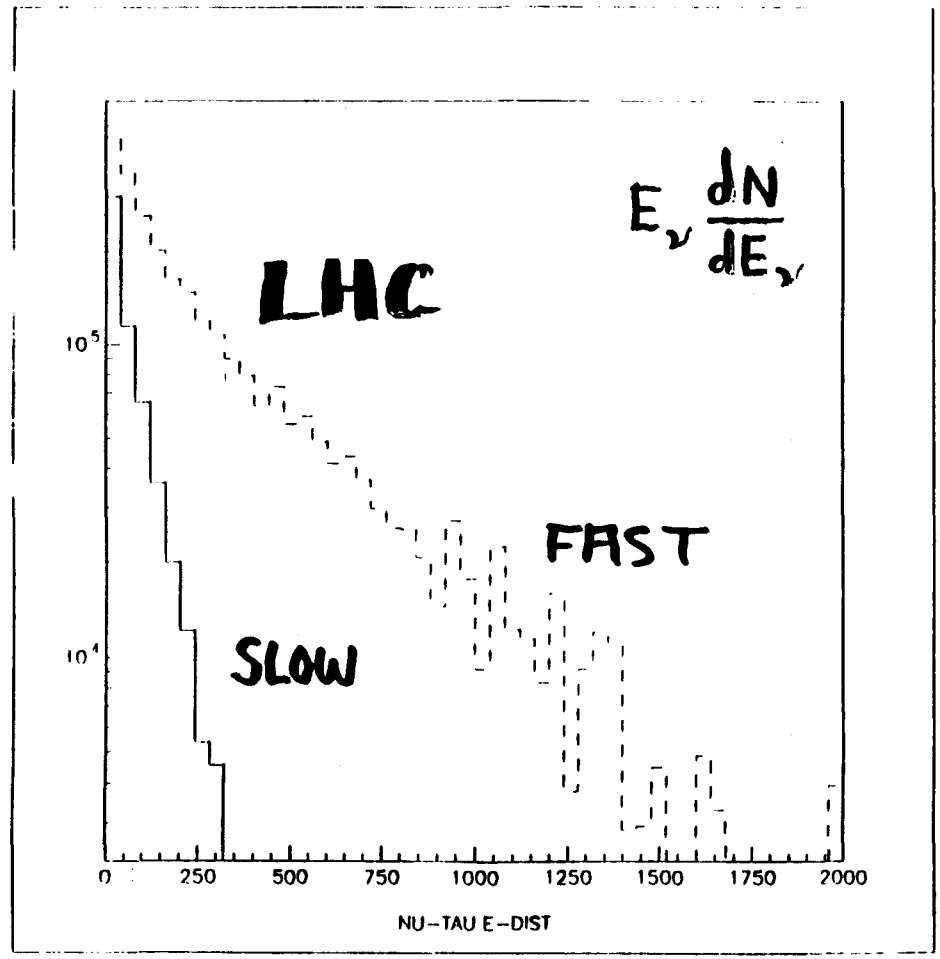
$x \equiv \frac{2P_{\parallel}}{\sqrt{s}}$

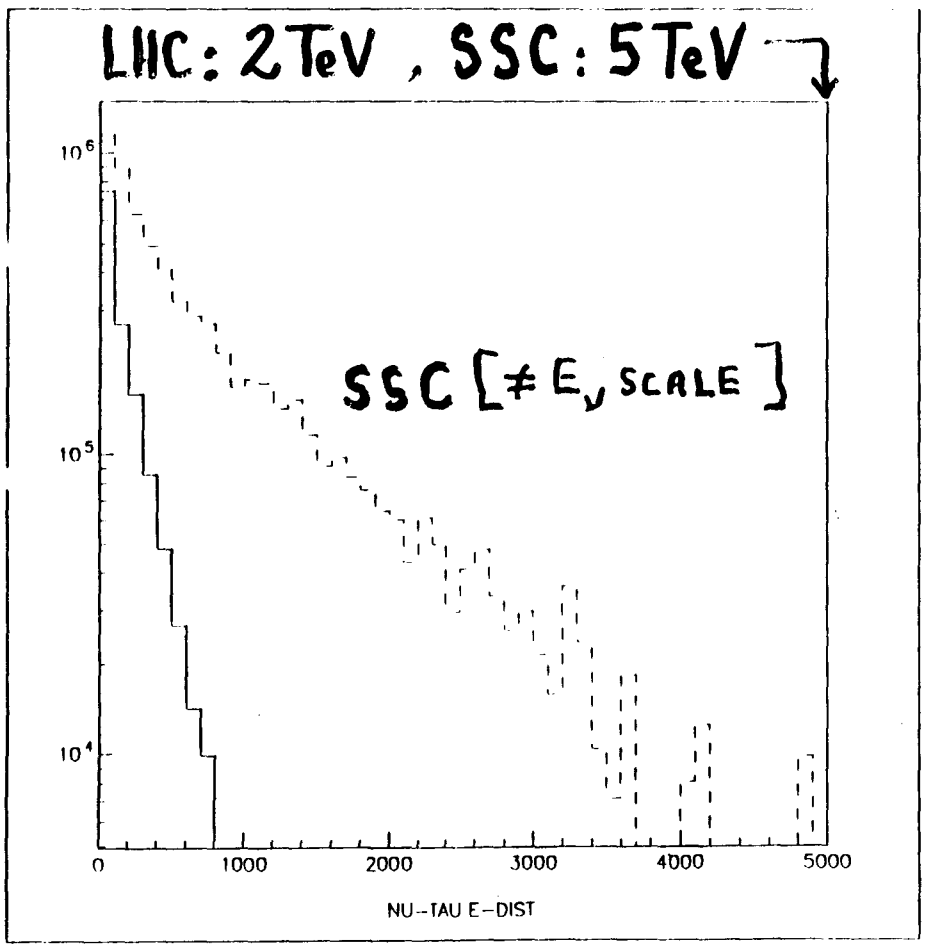
$D_s^+ \to \tau^+ \nu_\tau$ [SLOW]

$\hookrightarrow X\, \bar{\nu}_\tau$ [FAST]

(OR $D_s^+ \leftrightarrow D_s^-$)







P_T - DISTR. ?

$$\frac{d\sigma}{dp_T}\,(pp \to C + \dots)$$

- HAGEDORN'S THERMODYNAMIC MODEL

"TRANSVERSE TEMPERATURE T"

$$\frac{d\sigma}{dp_T} \propto \sqrt{m_T}\; e^{-m_T/T}$$

$$\boxed{m_T = \sqrt{p_T^2 + m^2}}$$

$$m = m(\pi, K, \bar{p}, D, D_s, \Lambda_c, B, \dots)$$

NAIVELY EXPECT $T(s) = a + b\sqrt{s}$

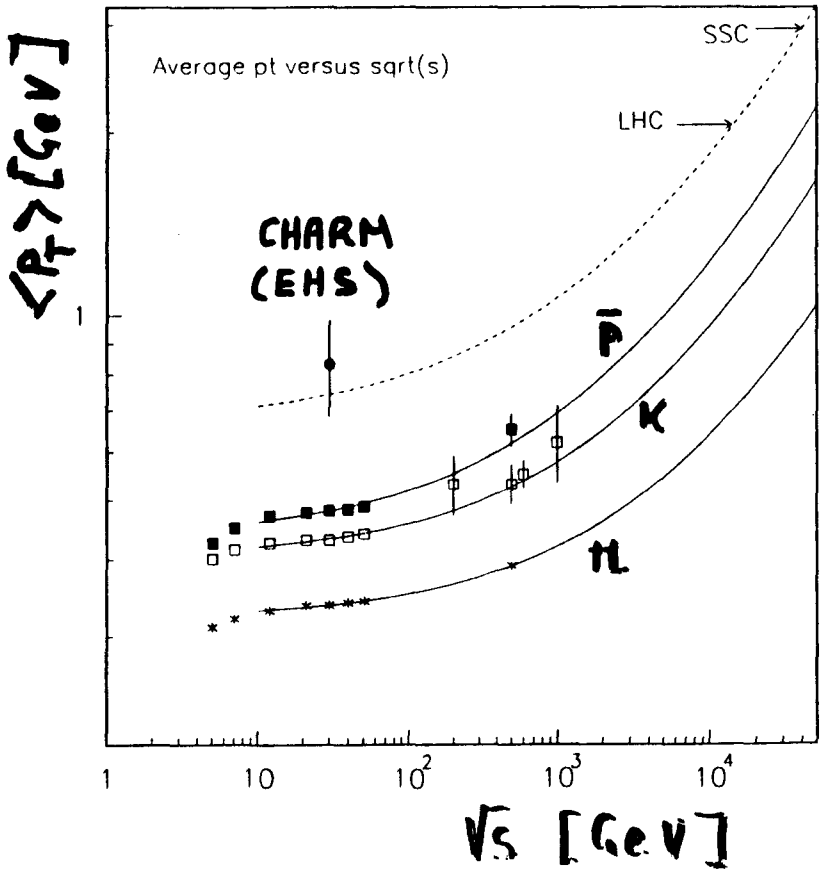
NOT BAD ⇒ PERFECT FIT TO ∃ DATA

$$T(s) = a + b\sqrt{m}\,\sqrt{s}$$

a, b ↓ PARTICLE-INDEP. UNIVERS. CONSTS.

$$T = a + b\sqrt{s\,m}$$

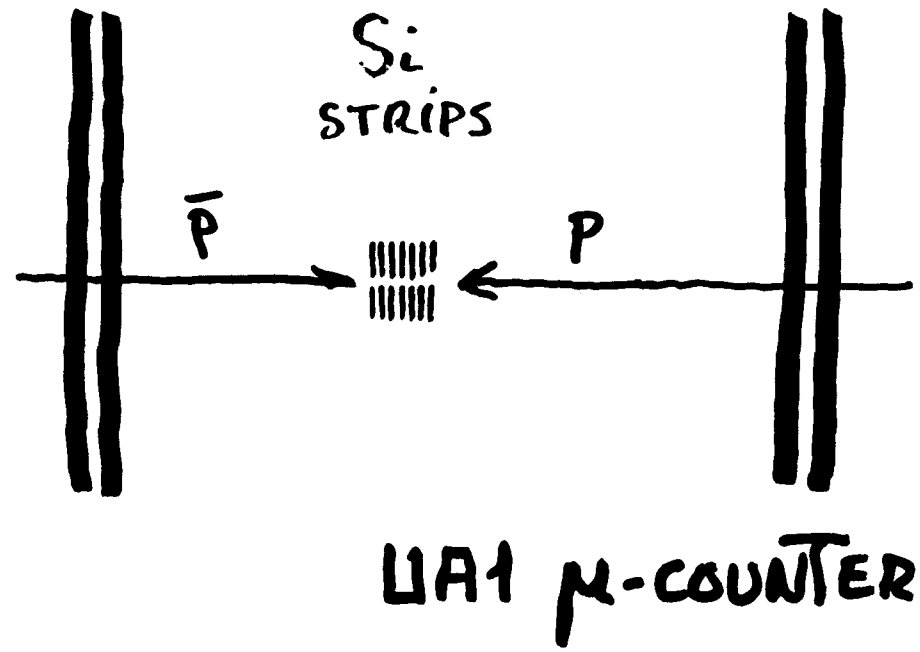
$$\begin{cases} a = 0.12\ \text{GeV} \\ b = 0.035\ \text{GeV}^{-1/2} \end{cases}$$



$\frac{1}{x}(1-x)^{\cdots}$, $d\sigma/dp_T$

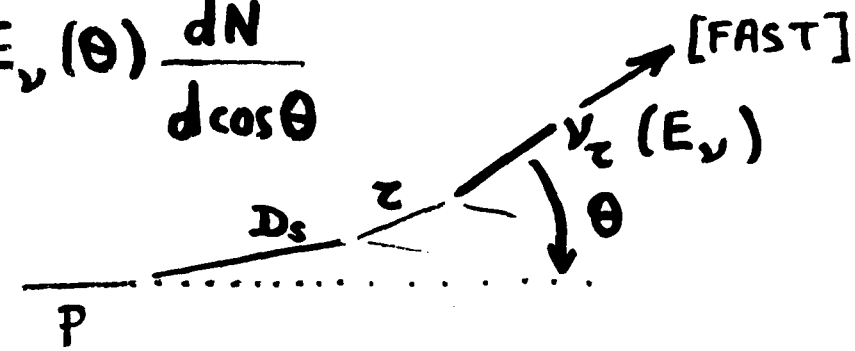
HOW TO MEASURE m, σ_c, Δ

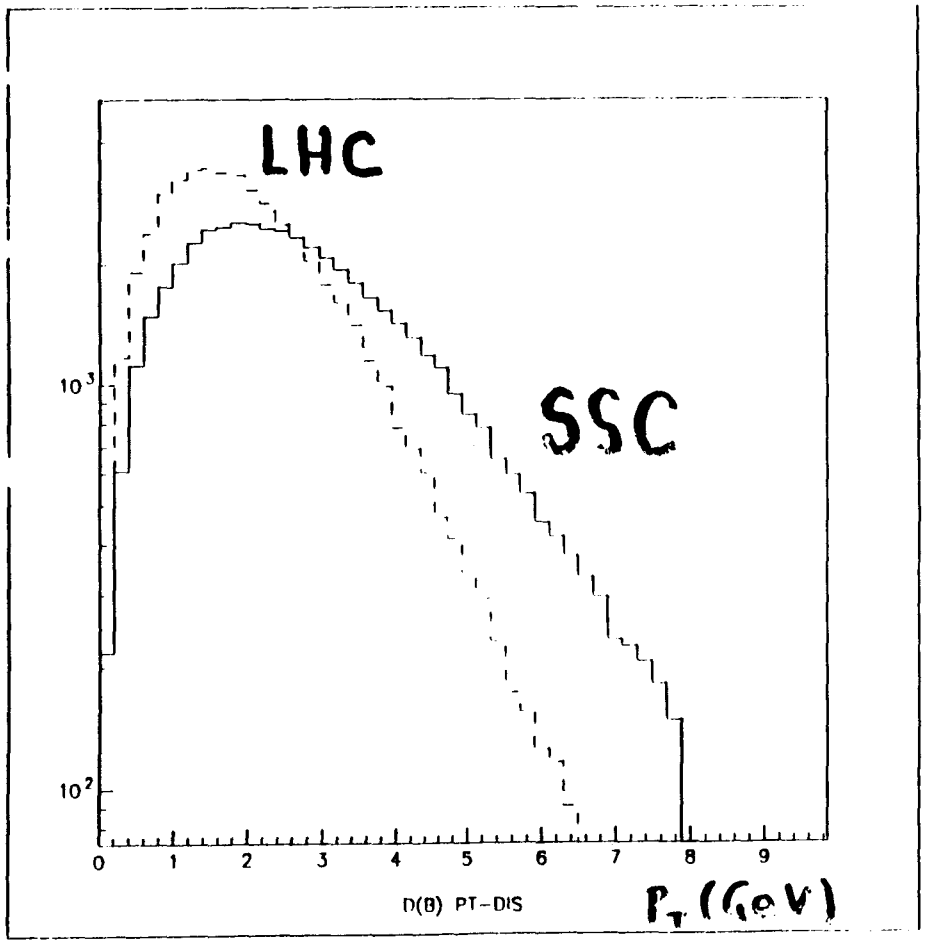
AT FAIRLY HIGH ENERGY $S_{\bar{p}p}$

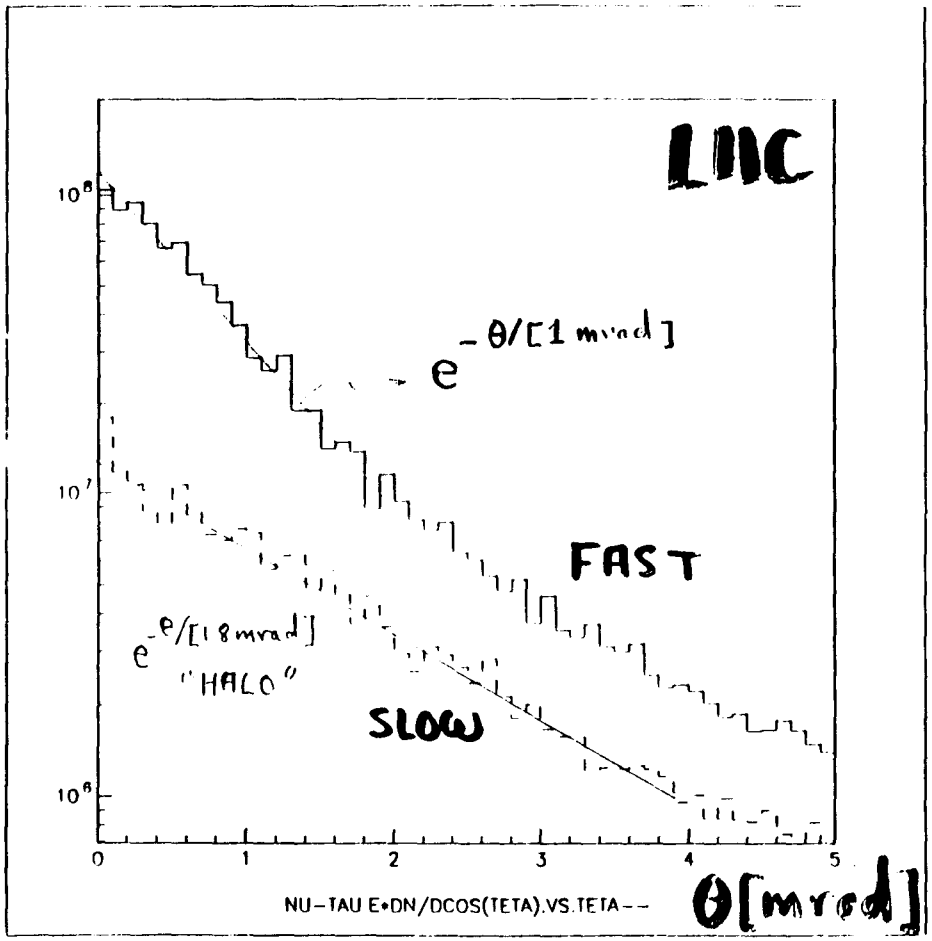


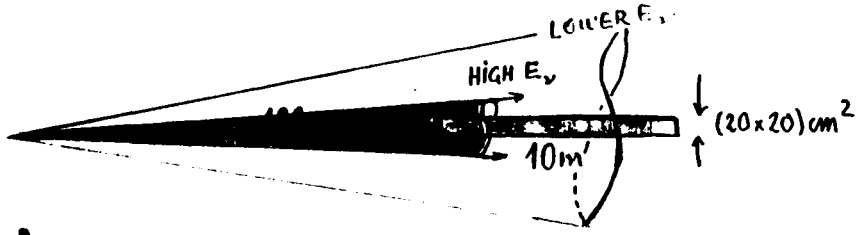
$$\frac{dN[D_s]}{dp_T} \qquad pp \to D_s(p_T) + \cdots$$

$$E_\nu(\theta)\,\frac{dN}{d\cos\theta}$$

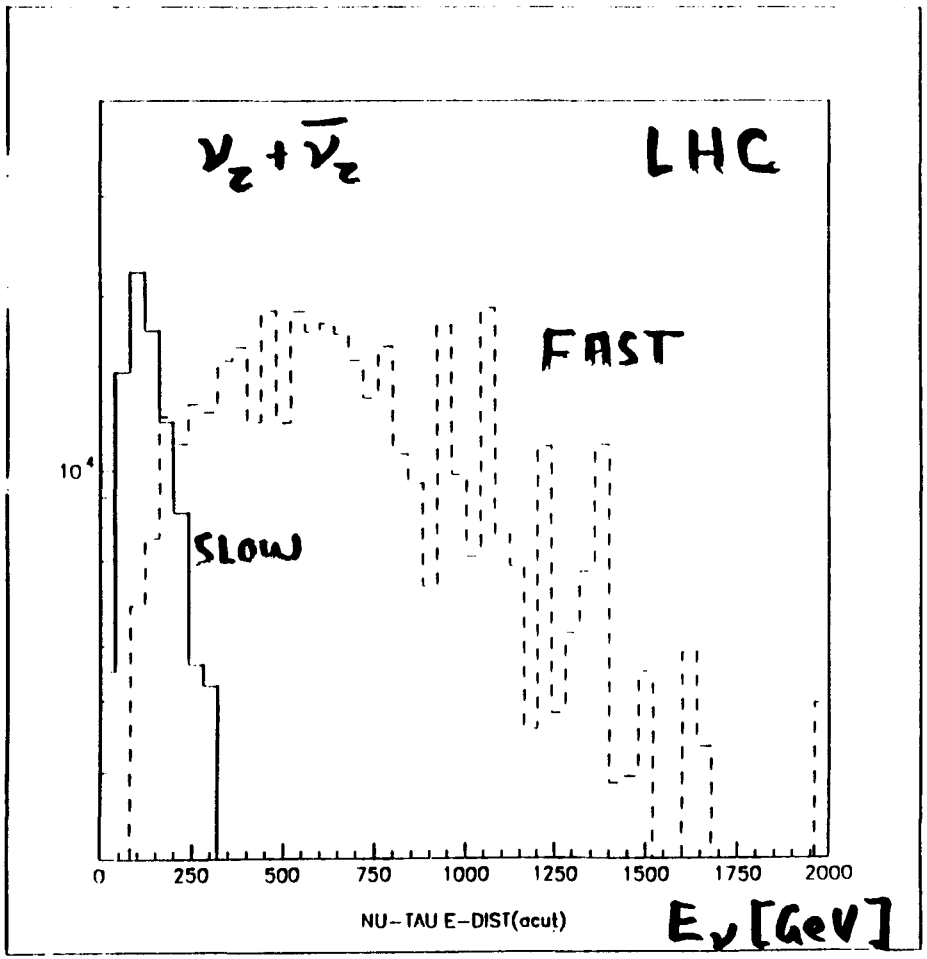








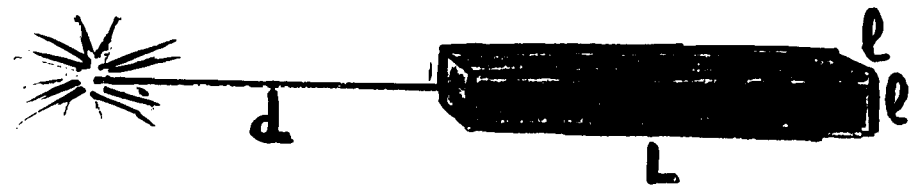
$$\frac{dN[\nu\ \text{INTERS}]}{dE_\nu} \sim E_\nu \frac{dN_\nu}{dE_\nu}\Big|_{\epsilon\ \text{DETECTOR}}$$



$\nu_\tau + \bar{\nu}_\tau$ INTS. / YEAR : N

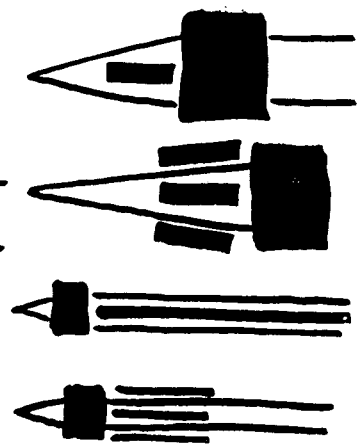
[redacted] $Y = 10^7 s$

$\mathcal{L} = 3.9\ 10^{34}$ [LHC] ; 10^{33} [SSC]



LHC

d(m)	ℓ(cm)	L(m)	M(kg)	[redacted]
60	6	10	72	1150
60	20	10	800	4800
60	20	20	1600	8870
120	6	100	720	1950
120	20	10	800	2380 SSC: 300
120	20	30	2400	6510 SSC: 840



Pt/Ir

TO BE REDUCED BY B.R., EFFIC...

MERELY A 'DISCOVERY' EXPERIMENT

N.P. AWARDED ONLY EVERY SECOND ν.

- FORCED TO ABIDE BY THE RULES OF THE GAME (GUCCI, must de CARTIER)

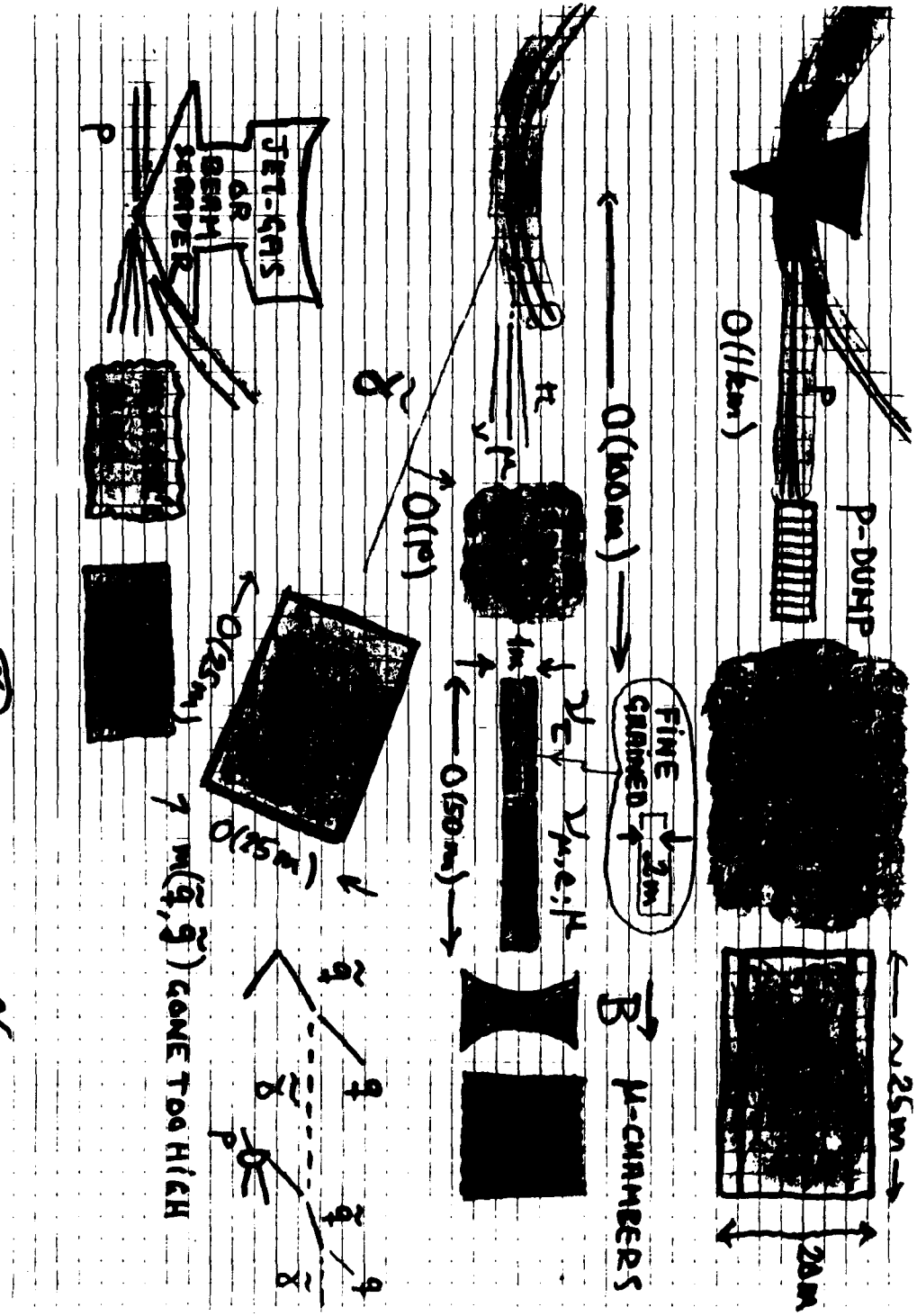
$\tilde{\gamma} \approx \nu$

SAME CHARGE
SAME SPIN
COMPARABLE PENETR-POWER

SIMILAR (BUT WIDER) EXP.

CAN LOOK FOR $\tilde{\gamma}$

$\nu_\tau + \tilde{\gamma} = NP$



CONCLUSIONS

PHYSICS

(μN) • BEAM-BEAM EXCELLENT, "FREE"

($e\,p$) { LEP-LHC collis. BETTER AT HIGH Q^2
IT MUST BE DONE
(NOT SO "FREE" | ACCELERATOR COSMETICS
| TIME AWAY FROM pp)

(νN) { • BEAM-BEAM GOOD, "FREE"
• COLLIDER DUMP A BIT BETTER
(PAY FOR | μ-SHIELD
| SLICED DUMP
| DISTANCE)
• DEDICATED DUMP MUCH BETTER (STATS.)
EXTRA "PAY" MACHINE-TIME
• JET TARGET ALSO PRETTY GOOD
DESERVES SERIOUS STUDY

NEUTRINO AND MUON PHYSICS ARE NOT DEAD

THEY WILL PROCEED AS "FREE" PARASITES OF FUTURE MACHINES

COLLIDERS

~~ACCELERATOR~~

ν PHYSICS AT LHC AND SSC

Leslie Camilleri

CERN

PRODUCE A NEUTRINO BEAM THROUGH

THE ABUNDANT PRODUCTION

and

THE PROMPT DECAY

OF $C\bar{C}$ PAIRS IN 16 TeV or 40 TeV

pp COLLISIONS

$$pp \longrightarrow C\bar{C} + X$$

$$\hookrightarrow X' \mu \bar{\nu}_\mu$$

$$\hookrightarrow X' e \bar{\nu}_e$$

THROUGH D_s ----> $\hookrightarrow X' \tau \bar{\nu}_\tau$

[NON-NEGLIGIBLE (~10%) CONTRIBUTION FROM $B\bar{B}$]

→ HIGH ENERGY (>500 GeV) NEUTRINOS.

→ GOOD SOURCE OF ν_e's (AS MANY AS ν_μ's).

→ POSSIBILITY TO OBSERVE ν_τ's.
(AS YET NOT SEEN).

LHC WORKING GROUP ON NEUTRINO PHYSICS

A. CAPONE
A. De RUJULA
U. DORE
A. EREDITATO
E. FERNANDEZ
J. GOMEZ
A.B. KAIDALOV
P.F. LOVERE
V. PALLADINO
F. PIETROPAOLO
L. ROLANDI
R. SANTACESARIA
S. SCHLENSTEDT
F. VANUCCI
K. WINTER
L. CAMILLERI

- CAN RUN PARASITICALLY
- CAN TAKE ALL THE LUMINOSITY THAT CAN BE THROWN AT IT.

THE NEUTRINOS CAN BE PRODUCED IN

COLLIDER a) BEAM - BEAM INTERACTIONS

AND ALSO IN

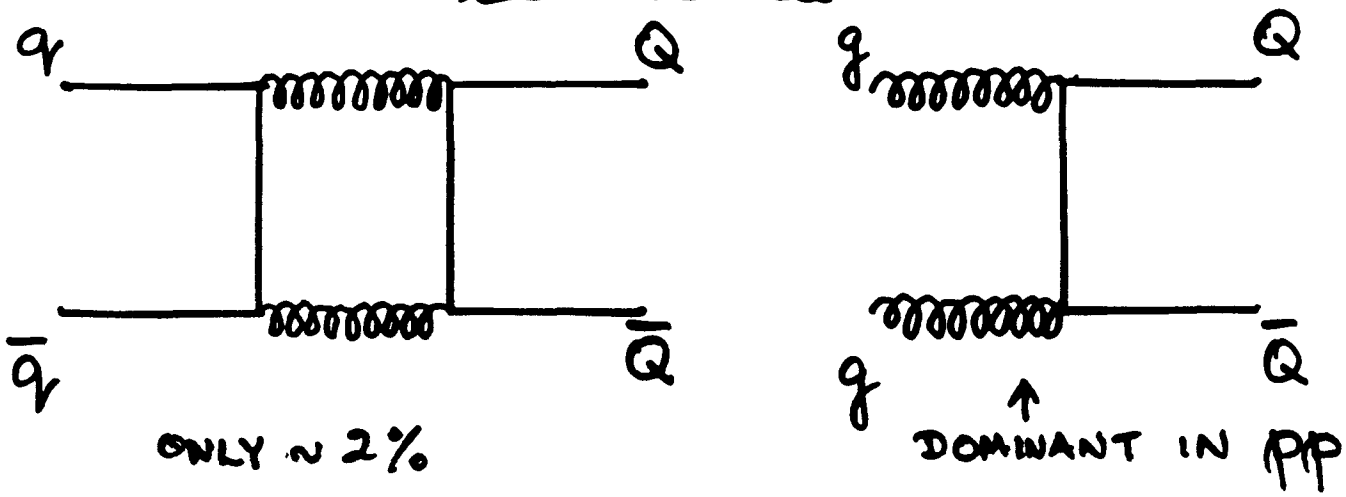
FIXED TARGET
- b) BEAM - INTERNAL GAS JET INTERACTIONS
- c) AN EXTRACTED PROTON BEAM IN A DUMP.

⇓ LOWER PRODUCTION CROSS SECTIONS FOR $C\bar{C}$

$C\bar{C}$ PRODUCTION CROSS-SECTIONS

I. PERTURBATIVE QCD

(i) BORN LEVEL



ONLY ~ 2%

DOMINANT IN $\bar{p}p$

THIS IS WHAT IS INCLUDED IN PYTHIA.

(ii) HIGHER LEVEL

CROSS SECTIONS GO UP BY A FACTOR OF ~ 8 AT LHC, SSC. (NASON et al)

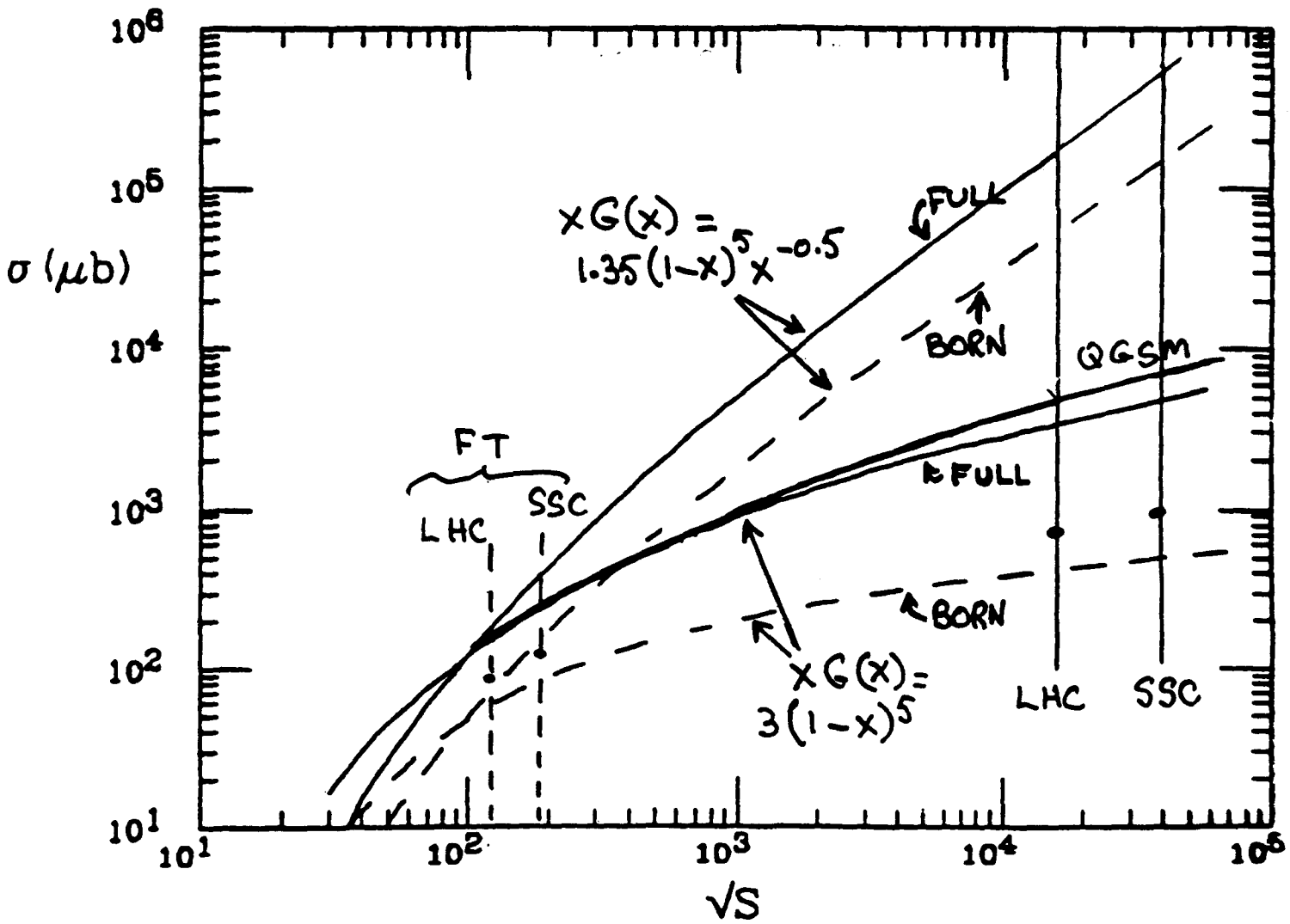
→

BUT NOTE THAT

SINCE gg DIAGRAM IS DOMINANT WE NEED TO KNOW THE GLUON STRUCTURE FUNCTION AT VERY LOW X TO MAKE REASONABLE PREDICTIONS OF $C\bar{C}$ PRODUCTION.

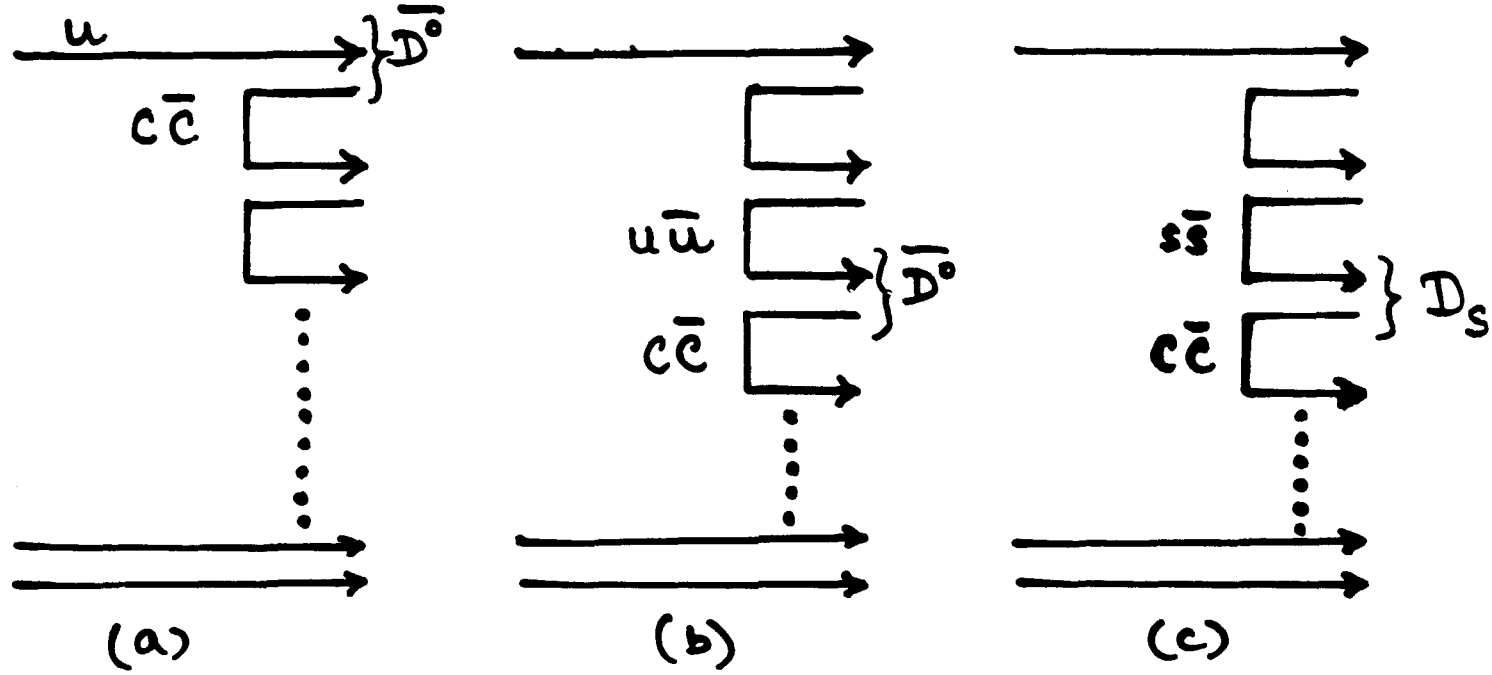
→

$C\bar{C}$ PRODUCTION CROSS-SECTION



a) BORN - Higher Level
b) GLUON SF dependence
c) FT - COLLIDER

II QUARK-GLUON STRING MODEL (KAIDALOV et al) (6)



QGSM

(i) $\sigma_{D\bar{D}}$ AT LHC $\sim$ 5 mb
AT SSC $\sim$ 7 mb

AGREES WELL WITH THE PESSIMISTIC QCD PREDICTIONS →

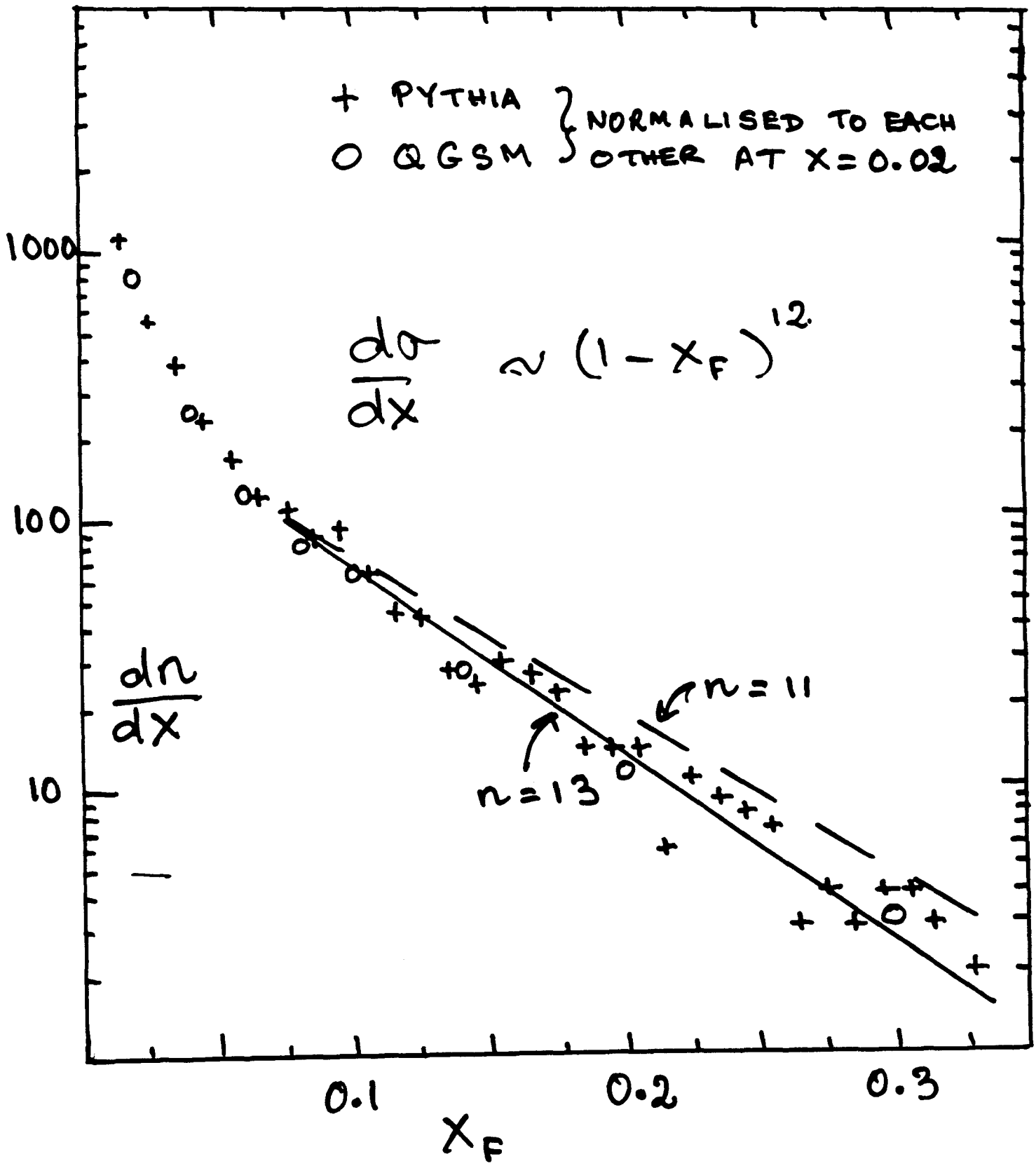
(ii) (b) and (c) DOMINATE → NO LEADING EFFECT
→ CENTRAL PROCESS
→ SOFT X DISTRIBUTION →

X DISTRIBUTION SHAPE AGREES VERY WELL WITH BORN LEVEL PYTHIA.

(iii) AT HIGH ENERGY THERE IS ENOUGH ENERGY IN THE LADDER THAT THE C IS AS LIKELY TO PICK UP AN S AS A u OR d.

$$\rightarrow \quad \sigma_{D_s} = \sigma_D$$

X - DISTRIBUTION OF PARENT CHARM.



GAS - JET IN COLLIDER. [MOLECULAR H_2 CLUSTER JET]

LUMINOSITY

[EXPERIMENT UA6 AT THE SPS COLLIDER HAS PROVED THAT A GAS JET DOES NOT PERTURB THE OPERATION OF A COLLIDER]

	JET DENSITY PROTONS/cm^3		LENGTH OF JET (cm)		#PROTONS/BEAM		REV. FREQ		LUMINOSITY $cm^{-2} \cdot s^{-1}$
LHC	4×10^{14}	x	1	x	4.81×10^{14}		11246	=	2.2×10^{33}
SSC	4×10^{14}	x	1	x	1.2×10^{14}		3444	=	1.7×10^{32}

$\Uparrow$ UA6 H_2 JET.

[TO BE COMPARED TO COLLIDER LUMINOSITIES OF LHC $\sim 10^{34}$ SSC $\sim 10^{33}$]

THE LUMINOSITY COULD BE INCREASED BY USING HEAVY GASES SUCH AS XENON. BUT IN ANY CASE ONE WOULD PROBABLY NOT BE ALLOWED TO HAVE A LUMINOSITY LARGER THAN THE COLLIDER LUMINOSITY IN ORDER NOT TO DEGRADE THE BEAM TOO FAST.

C.O.M. ENERGY

LHC $\Rightarrow \sqrt{s} = 123$ GeV SSC $\Rightarrow \sqrt{s} = 194$ GeV

CROSS SECTIONS FOR $C\bar{C}$ PRODUCTION

ABOUT A FACTOR OF ~ 30 LOWER THAN AT COLLIDER ENERGIES. [0.2 mb INSTEAD OF 7 mb AT SSC] $\rightarrow$

CONCLUSION

PROBABLY <u>NOT</u> VERY USEFUL TO USE A GAS JET TO PRODUCE NEUTRINOS GIVEN THE LOWER $C\bar{C}$ CROSS SECTIONS AT FIXED TARGET ENERGIES AND THE (AT BEST...)

EXTRACTED PROTON BEAM IN A BEAM DUMP

PEEL OFF 10^9 PROTONS/SEC

THROUGH CHANNELING (?). IS IT POSSIBLE?

→ IN BEAM DUMP.

$$N = \sigma \mathcal{L}$$

$$10^9 = (50\ \text{mb})\,\mathcal{L} = 5 \times 10^{-26}\,\mathcal{L}$$

$$\rightarrow \mathcal{L} = \frac{10^9}{5 \times 10^{-26}} = 2 \times 10^{34}\ \text{cm}^{-2} \cdot \text{s}^{-1}$$

CONCLUSION:-

AT LHC — COMPARABLE TO BEAM-BEAM LUMINOSITY SO BECAUSE OF LOWER $\sigma_{c\bar{c}}$ CROSS-SECTIONS NOT VERY USEFUL

AT SSC — EXTRACTED BEAM LUMINOSITY COULD BE X10 BEAM-BEAM LUMINOSITY WHICH WOULD COMPENSATE THE LOWER CROSS-SECTIONS RATE $c\bar{c}$ WOULD BE COMPARABLE.
MAYBE USEFUL ...

BECAUSE OF UNCERTAINTY IN THE EXTRACTION METHOD

EVENT RATE CALCULATION

1. CROSS-SECTIONS

   use QGSM ≡ HIGHER ORDER QCD (LOWER RANGE)

   5 mb at LHC 7 mb at SSC.

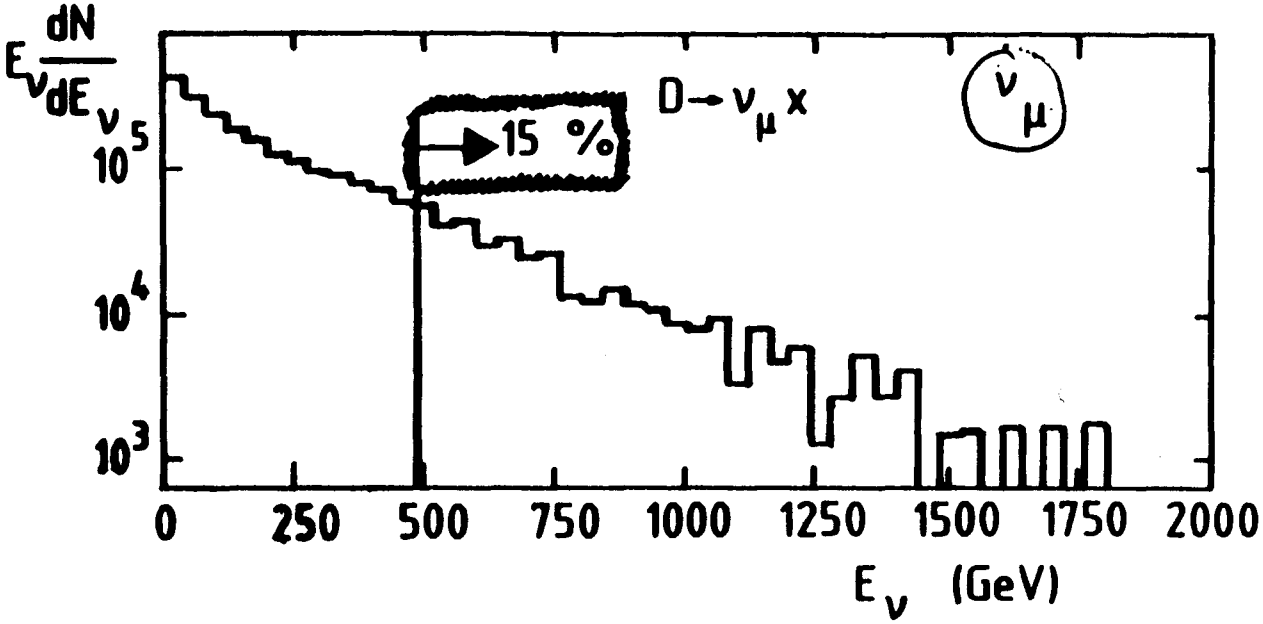
2. ACCEPTANCE.

   use PYTHIA SINCE

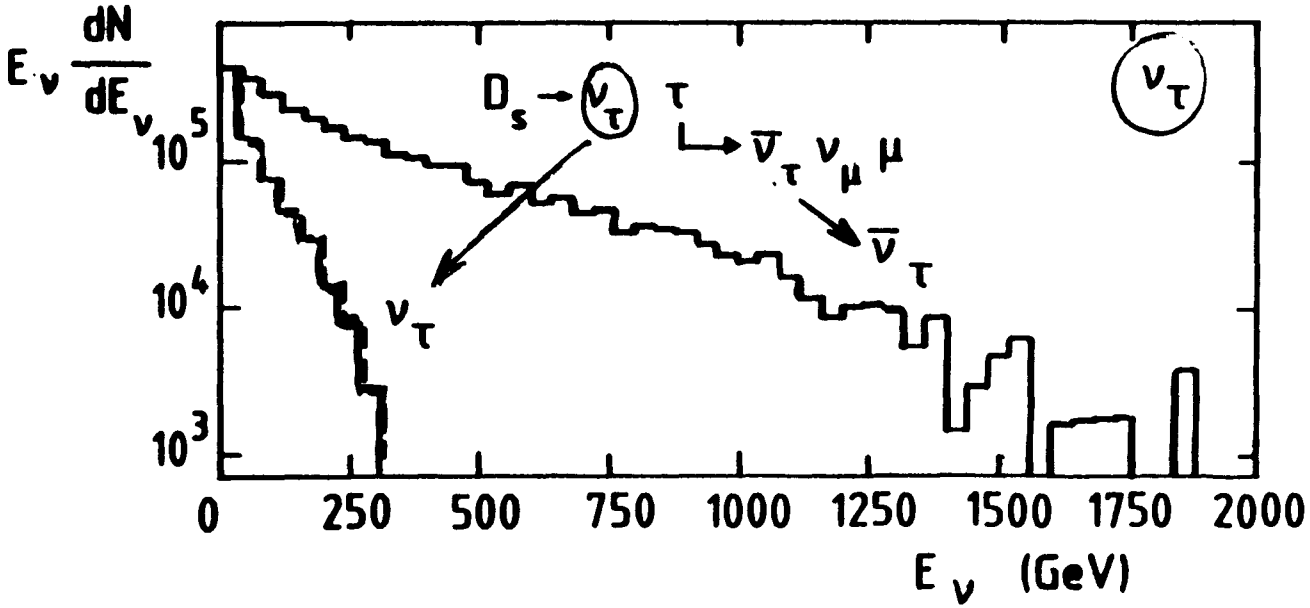
   X-DISTRIBUTION SAME AS QGSM.

3. BRANCHING RATIO FOR $D_s \to \tau$ 4%.

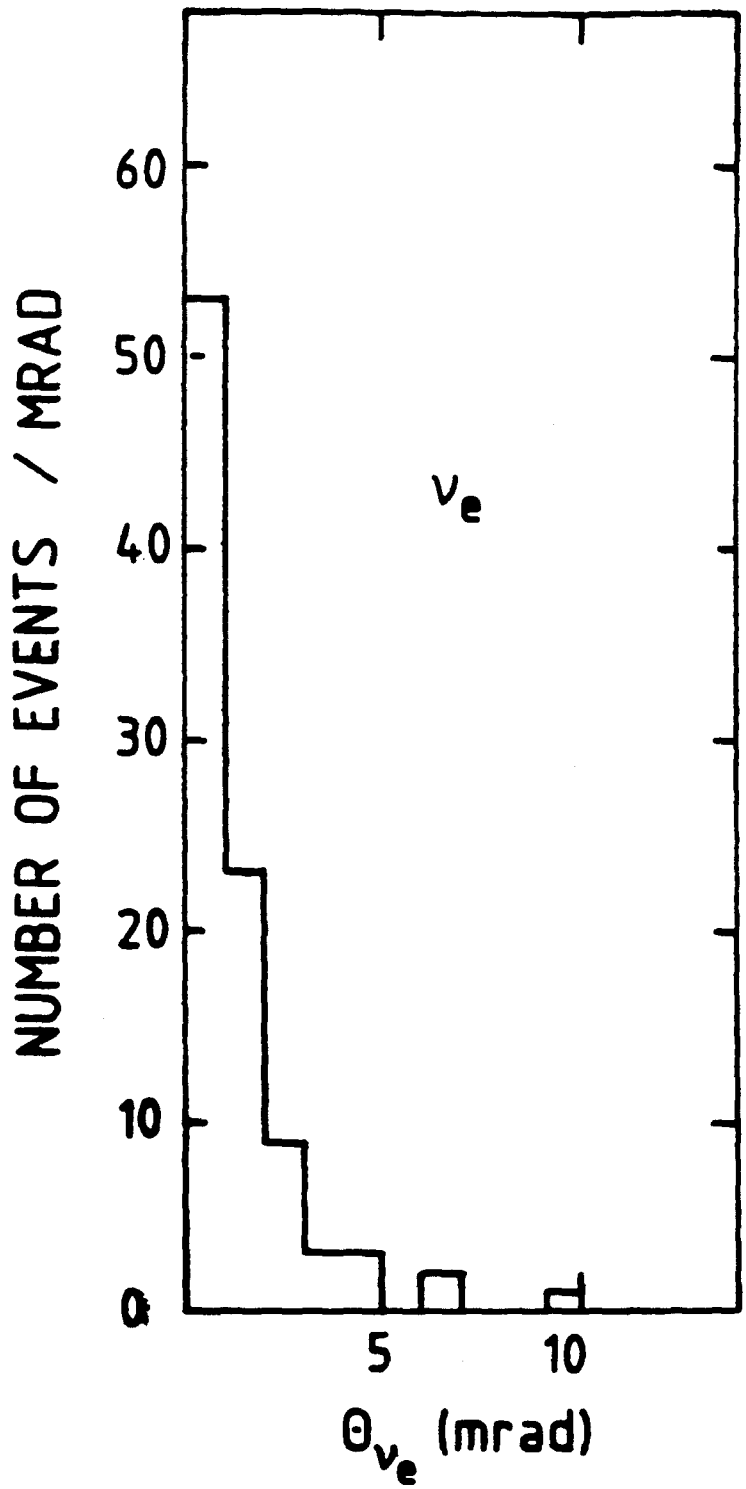
ENERGY WEIGHTED SPECTRA ∝ INTERACTION



LHC



ANGULAR DISTRIBUTION OF NEUTRINOS WITH ENERGY > 500 GeV



MUST HAVE GOOD ACCEPTANCE AT VERY SMALL ANGLES.

→ BEWARE OF BEAM PIPE !

DETECTOR

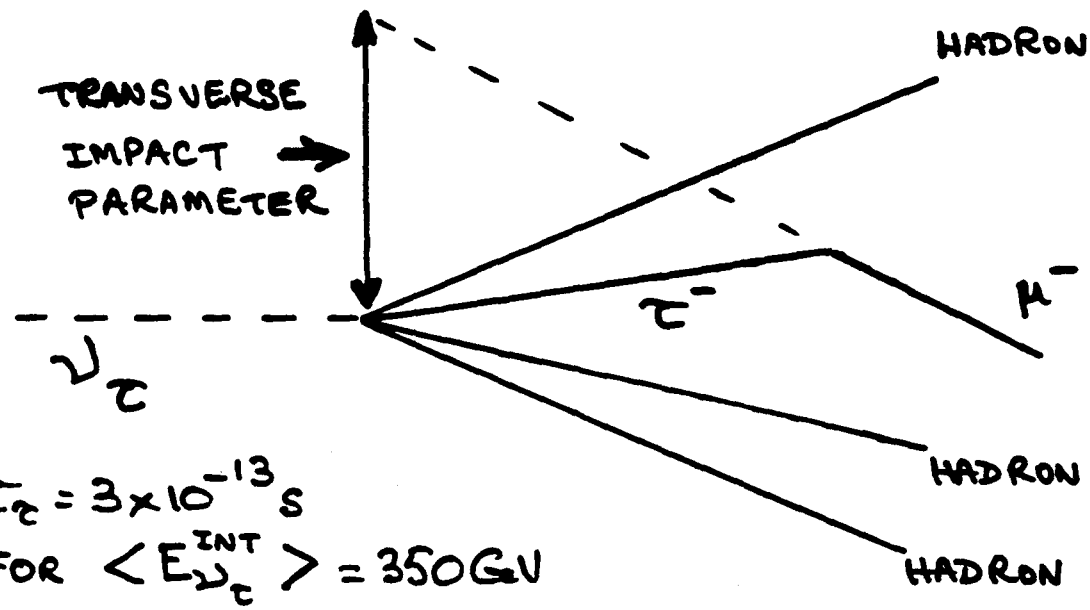
I. τ NEUTRINO DETECTOR

DETECT ν_τ THROUGH THE REACTION :-

$$\nu_\tau + N \rightarrow \tau^- + X$$

WHERE THE τ IS RECOGNIZED
(i) THROUGH FINITE TRAVEL, OR (ii) THROUGH KINEMATICS.

(i) FINITE TRAVEL



$\tau_\tau = 3 \times 10^{-13}$ s
FOR $\langle E_{\nu_\tau}^{INT} \rangle = 350$ GeV
DECAY PATH = 1.8 cm

LOOK FOR TRACKS WITH KINKS
OR NON-ZERO IMPACT PARAMETERS.

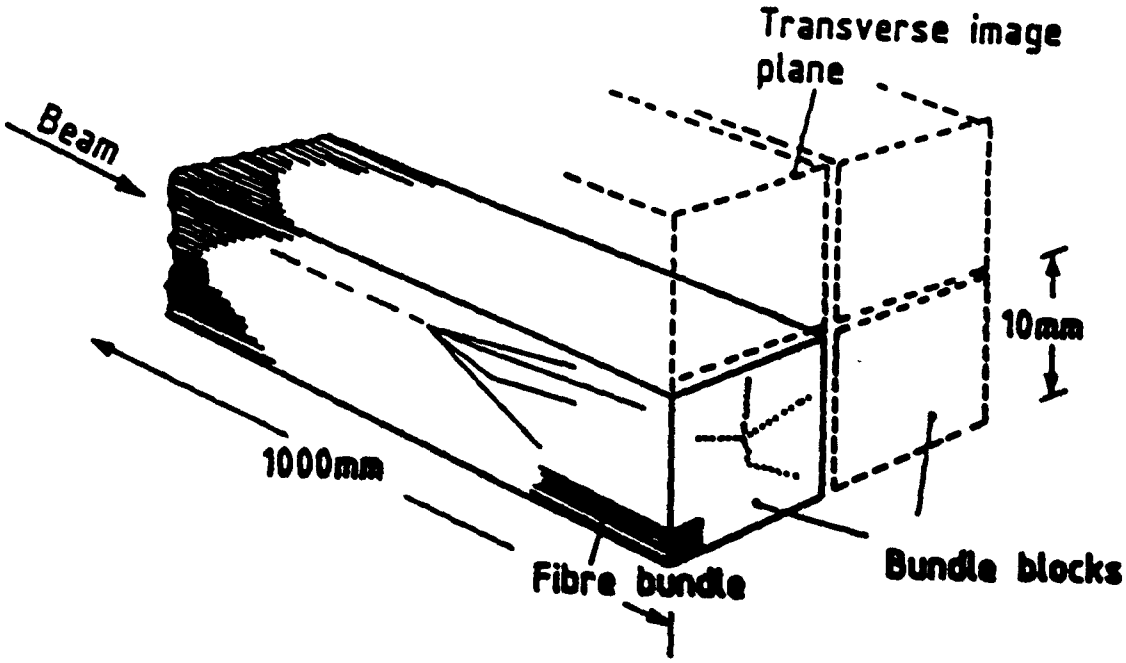
SPACE RESOLUTION $\sim$ 10 μm
GRANULARITY $\lesssim$ 100 μm.

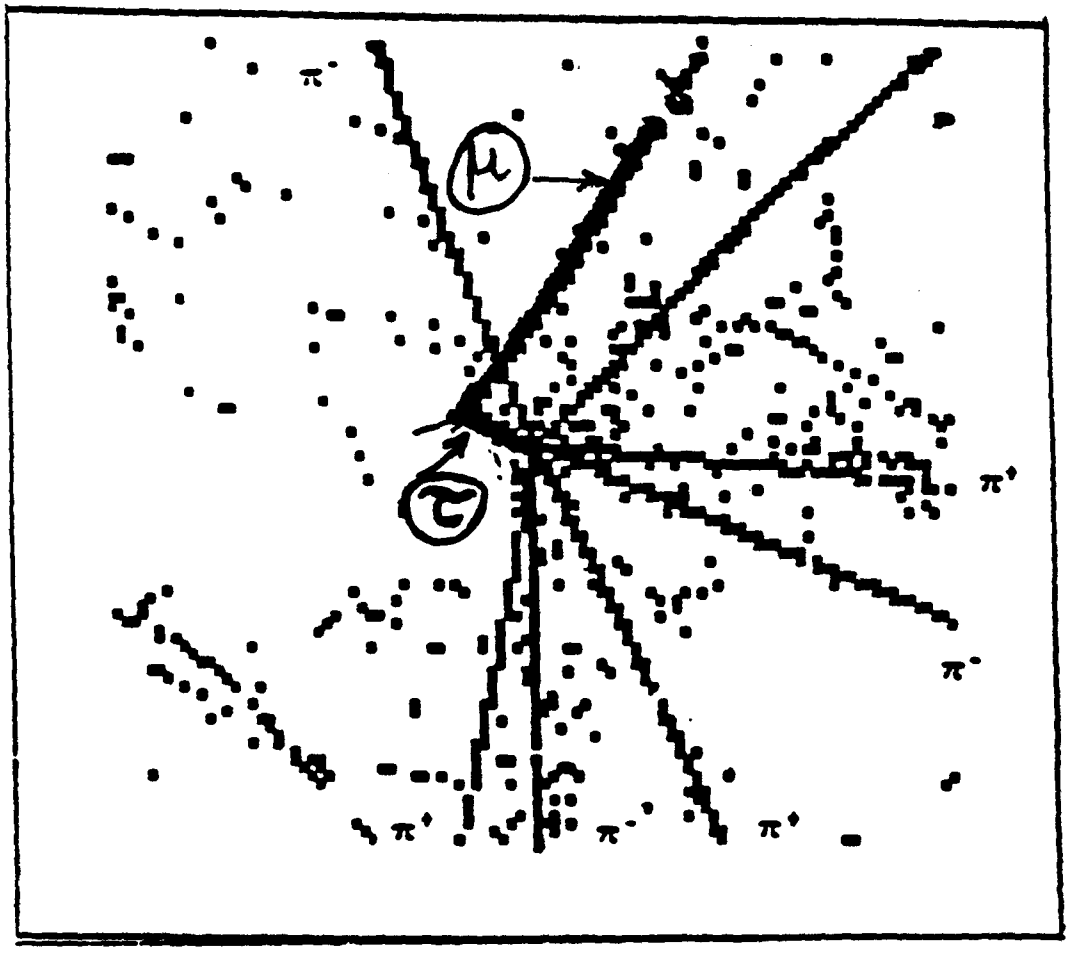
$\rightarrow$ DETECTOR CANNOT BE VERY BIG.

Si STRIPS, LIQUID ARGON TPC SCINT. FIBERS.

FIBERS ALONG NEUTRINO DIRECTION

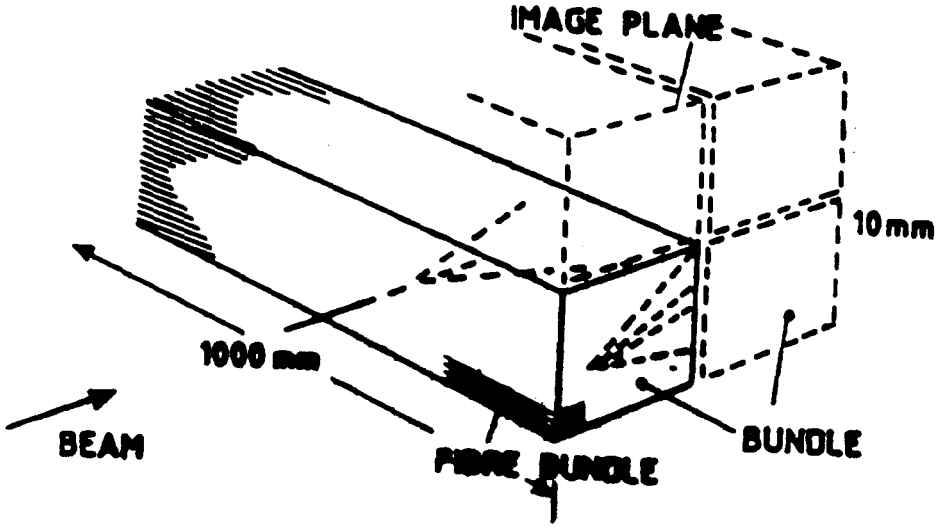
CHARM



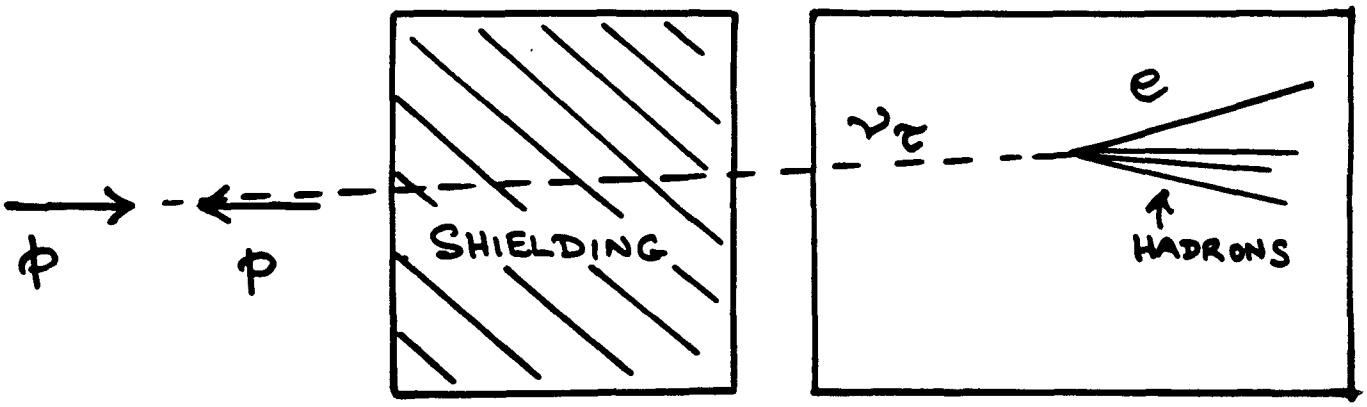


SCINTILLATING FIBERS

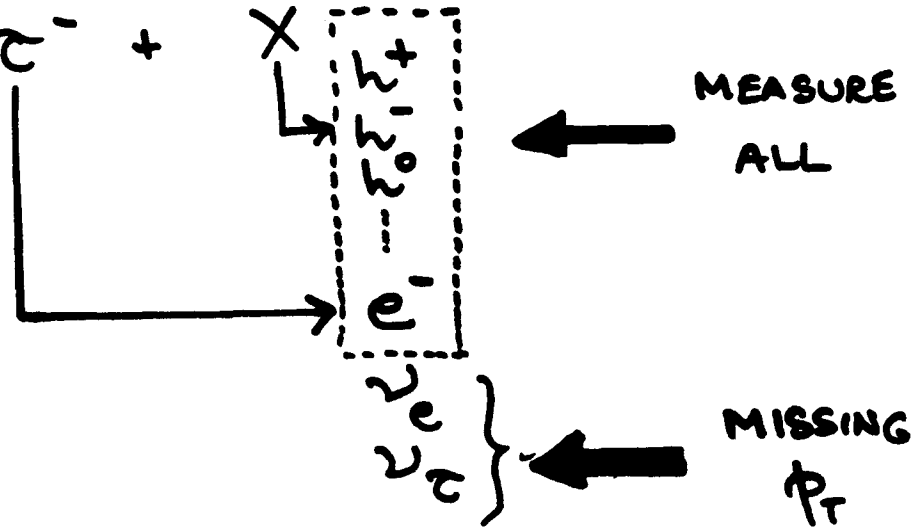
TRANSVERSE TO NEUTRINO DIRECTION



(ii) KINEMATICS METHOD :-



$$\nu_\tau + N \rightarrow \tau^- + X$$



a) MEASURE ALL HADRONS PRODUCED IN THE ν_τ INTERACTION AND THE CHARGED LEPTON FROM τ DECAY.

$\Rightarrow$ ν_τ EVENTS WILL HAVE MISSING p_T FROM THE TWO NEUTRINOS IN τ DECAY.

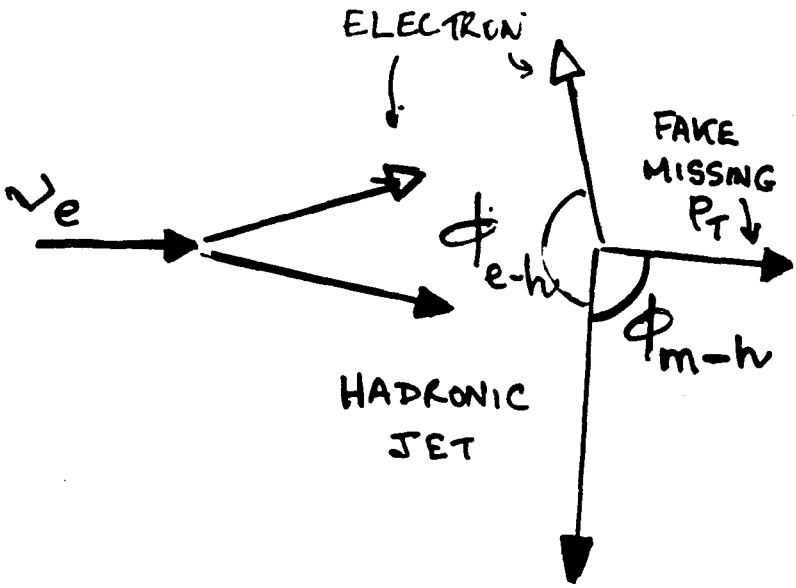
b) USE THE DECAYS OF τ INTO ELECTRON IN ORDER NOT TO BE BOTHERED BY MUONS COMING THROUGH THE SHIELDING.

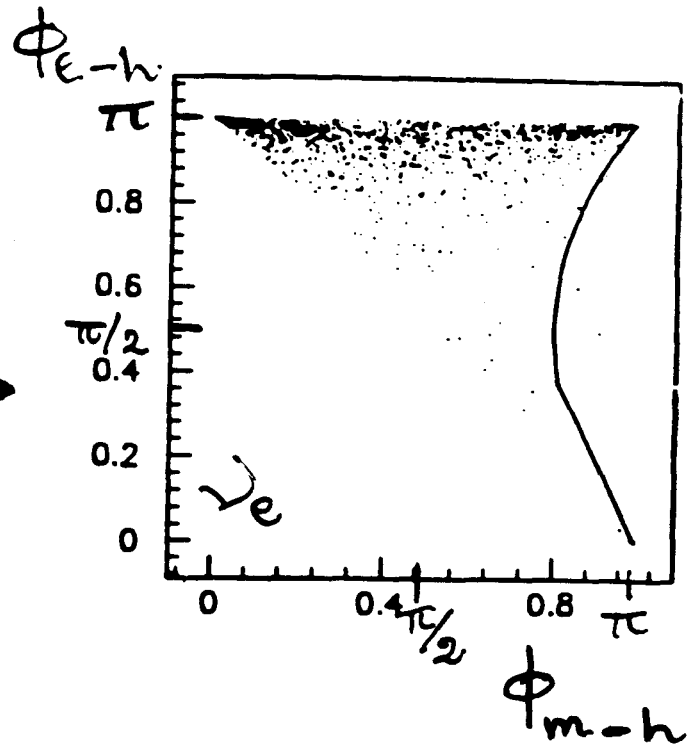
c) THE TARGET CONSISTS OF TRD + DRIFT CHAMBERS TO MEASURE ALL CHARGED PARTICLES AND IDENTIFY ELECTRONS IT IS INSIDE A LARGE MAGNET FOR MOMENTUM MEASUREMENT

d) THE TARGET IS FOLLOWED BY A CALORIMETER TO MEASURE PHOTONS,

AND BY A MUON IDENTIFIER.

(A) ν_e EVENTS



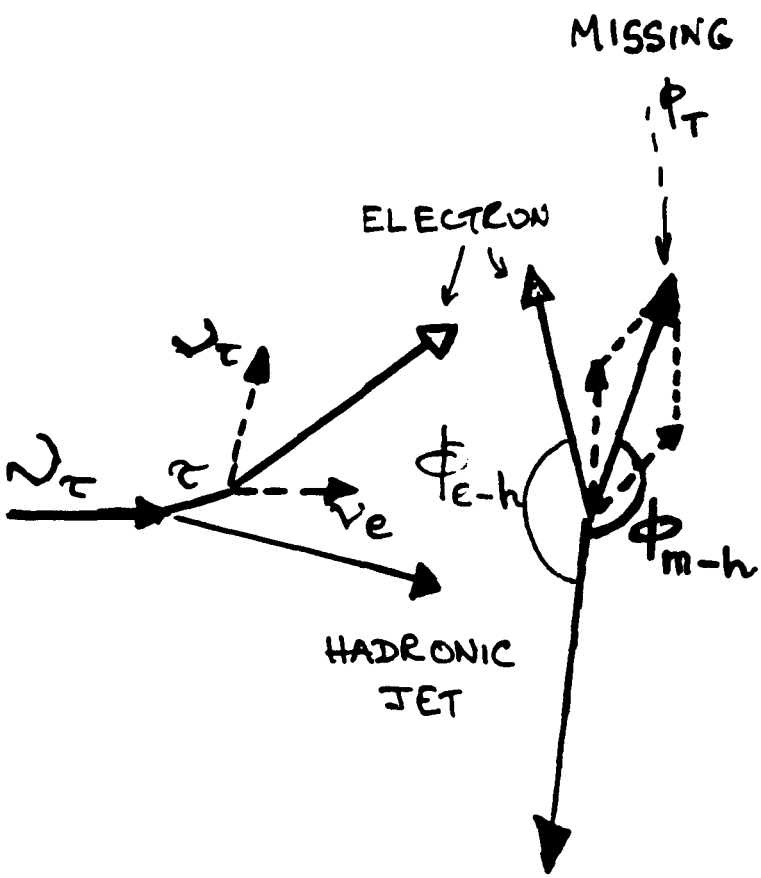


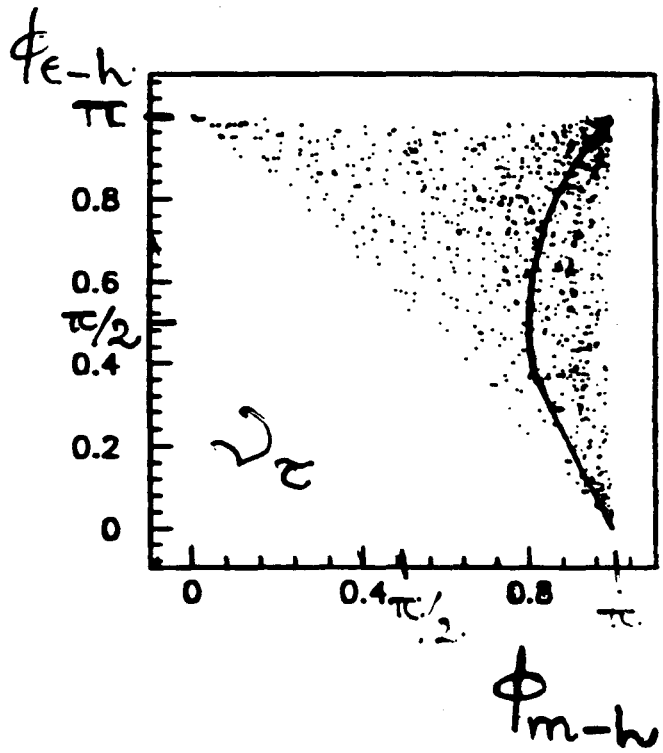
OSCILLATION EXPERIMENT:-

REJECTION AGAINST ν_e

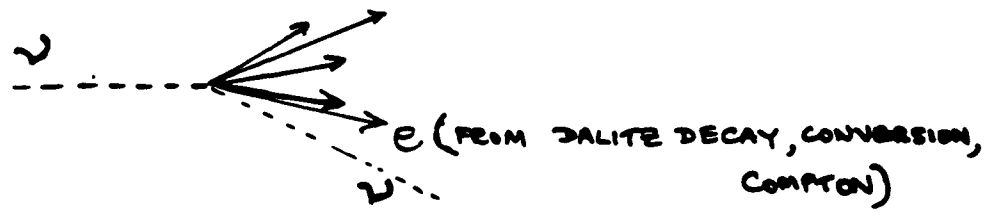
$> 10^3$

[Remember we start with $\nu_e/\nu_\mu \sim 1\%$]





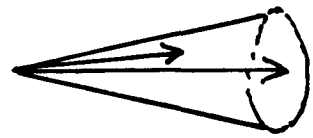
(B) NEUTRAL CURRENT EVENTS



— NEUTRAL CURRENT EVENT IN WHICH THERE IS A π^0 DALITZ DECAY OR A CONVERSION

(i) ISOLATION CUT

REQUIRE THAT THERE BE NO OTHER HADRON WITHIN A CONE



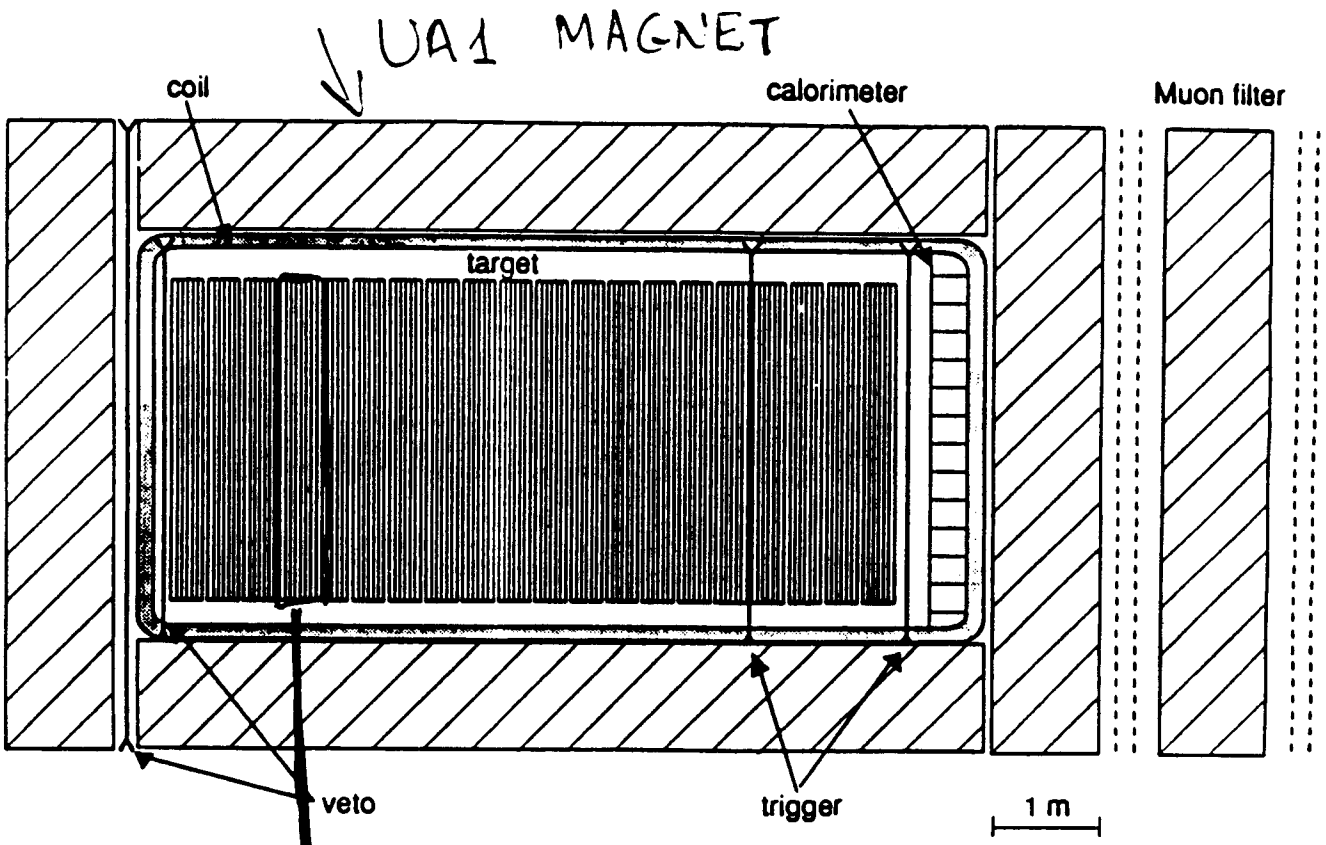
(ii) LARGE TRANSVERSE MOMENTUM OF THE ELECTRON RELATIVE TO THE RESULTANT HADRON MOMENTUM

(iii) RECOGNIZE SECOND MEMBER OF DALITZ OR CONVERSION

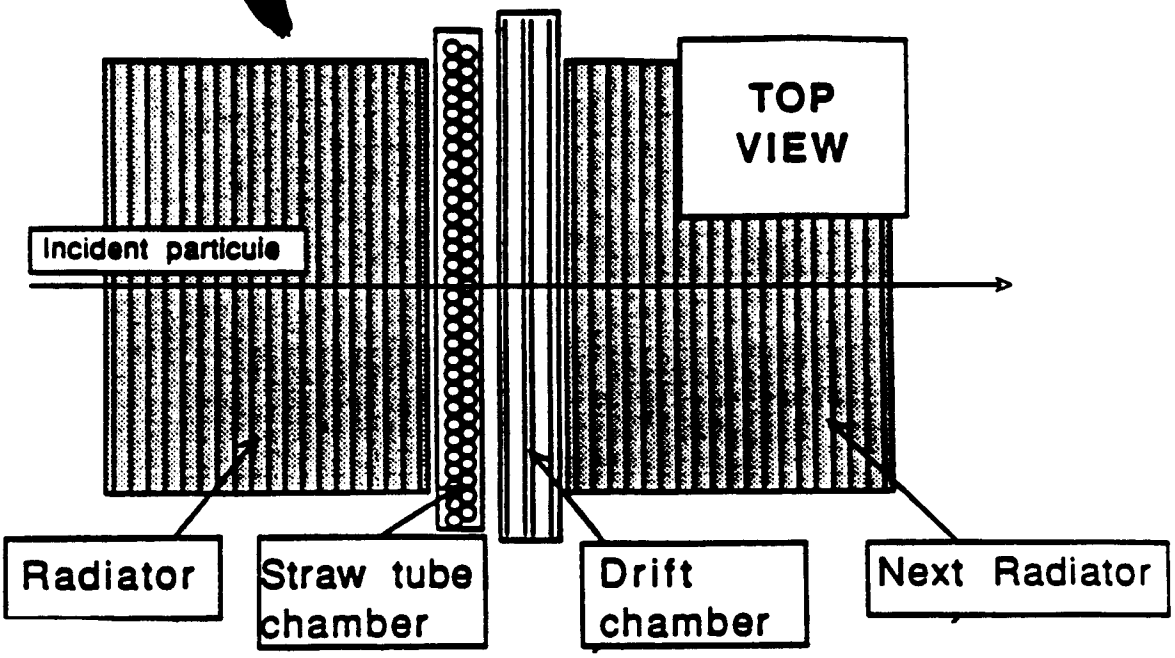
(iv) RECOGNIZE SECOND γ FROM π^0.

OSCILLATION EXPERIMENT:-

REJECTION:- PER CONVERSION $\sim 2\times10^{+3}$
PER DALITZ $\sim 5\times10^{3}$



Transition Radiation Detector



EVENT RATES

I. ν_μ, ν_e EVENTS :-

DETECTOR:- 30m of IRON $\rho = 7.86\ gm \cdot cm^{-3}$
OVERALL LENGTH ~ 60 m ?

		LHC		SSC
INSTANTANEOUS LUMINOSITY ($cm^{-2} \cdot s^{-1}$)		2×10^{34}		2×10^{33}
RUN TIME (s)		2×10^{7}		2×10^{7}
INTEGRATED LUMINOSITY (cm^{-2})		4×10^{41}		4×10^{40}
$\sigma_{c\bar{c}}$ (mb)		5		7
$N_{c\bar{c}}$		2×10^{15}		2.8×10^{14}
CHARGED CURRENT NEUTRINO INTERACTIONS	ν_μ	445 000		152 000
	ν_e	445 000	+ NEUTRAL CURRENTS	152 000
	$\bar{\nu}_\mu$	210 000		72 000
	$\bar{\nu}_e$	210 000		72 000
CC INTERACT. $E_\nu > 500$ GeV	ν_μ	40 000		34 000
	ν_e	40 000	+ NEUTRAL CURRENTS	34 000
	$\bar{\nu}_\mu$	19 000		15 000
	$\bar{\nu}_e$	19 000		15 000

$$N_\nu = N_{c\bar{c}} \underbrace{\frac{N_\nu}{N_{c\bar{c}}} E_\nu}_{} \times 0.7 \times 10^{-38} \times 3000 \times 7.86 \times 6 \times 10^{23}$$

0.33 for $\bar{\nu}$

II ν_τ EVENTS :- EXPENSIVE $\Rightarrow$ SMALL.

DETECTOR: 10 m OF FIBRES (?) $\rho = 2\ gm \cdot cm^{-3}$.

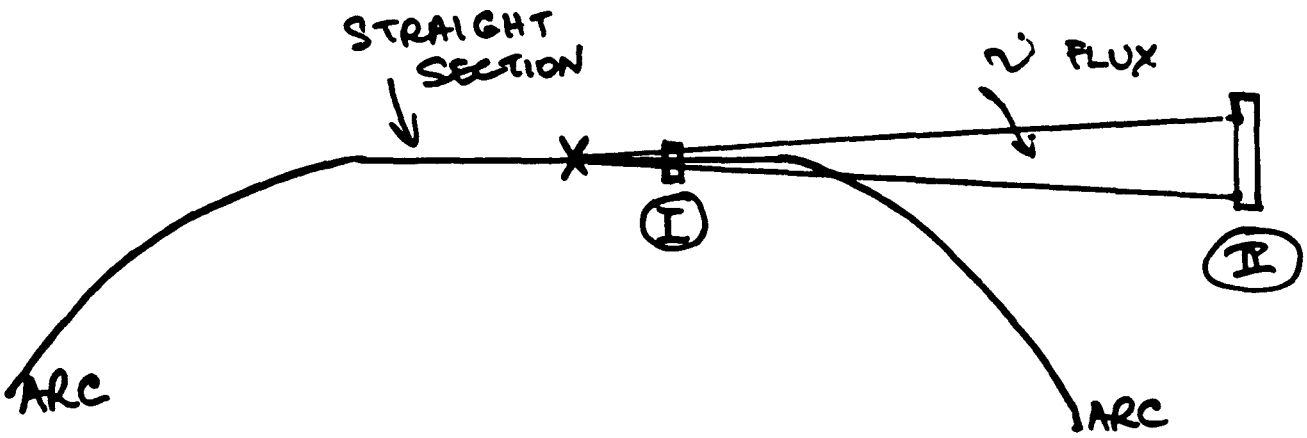
	LHC	SSC
QGSM	15000	7200

CONCLUSION $\Rightarrow$ MANY EVENTS.

I. FOR A ν_τ DETECTOR THERE ARE ADVANTAGES IN BEING AS CLOSE TO THE INTERACTION REGION AS POSSIBLE IN ORDER TO MINIMIZE THE PHYSICAL SIZE OF THE HIGHLY INSTRUMENTED DETECTOR.

II. FOR A HIGH ENERGY ν_μ AND ν_e DETECTOR, DETECTION OF THE RECOIL HADRONS REQUIRE LARGE CALORIMETERS AND THEREFORE A LARGE HALL.
ON THE OTHER HAND THE COARSER INSTRUMENTATION ALLOWS A BIGGER DETECTOR AND THEREFORE A LOCATION FAR FROM THE INTERACTION REGION.

LOCATION OF DETECTOR

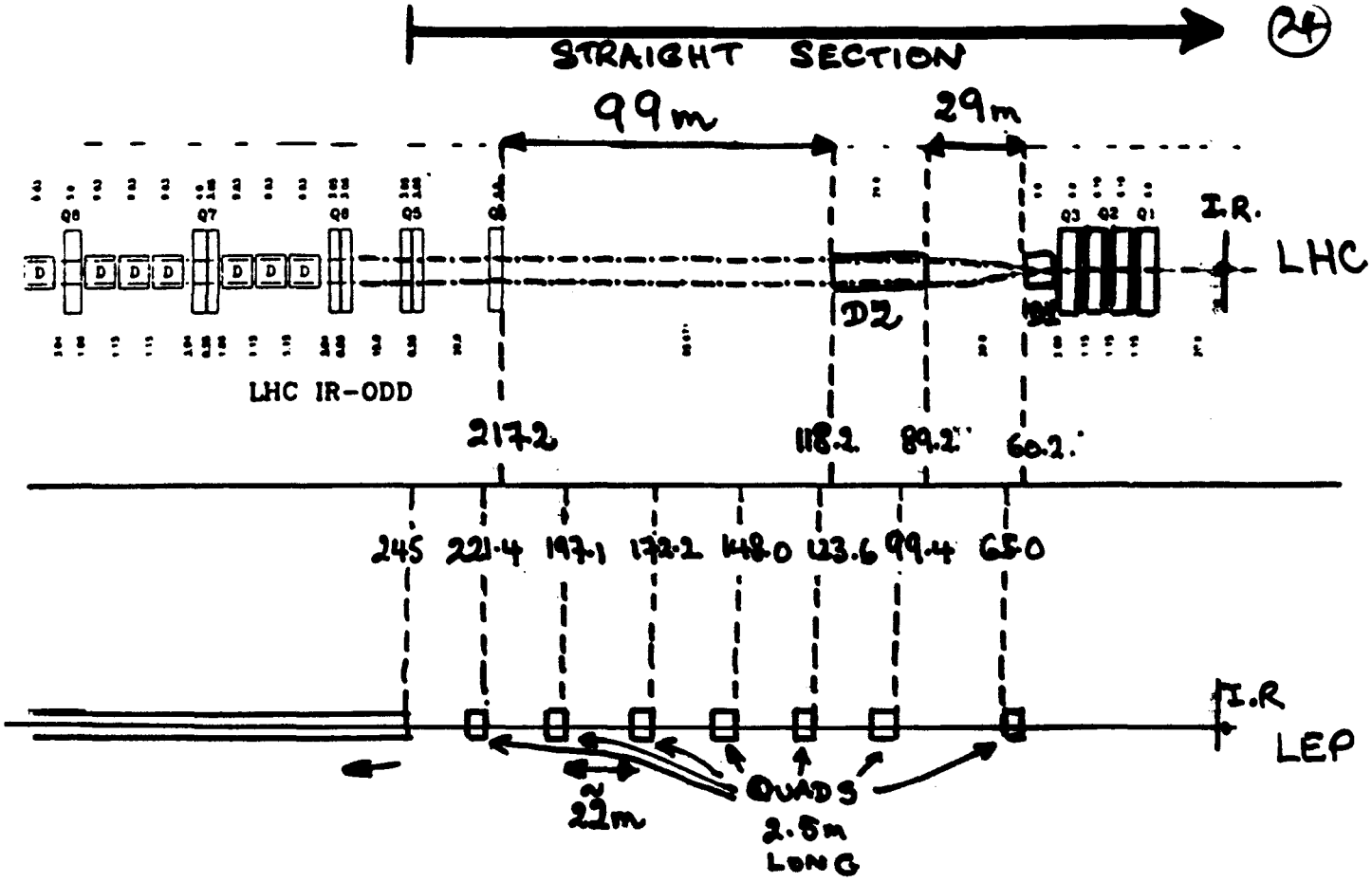


I. CLOSE DETECTOR:- ADVANTAGE: SMALL.

a) BACKGROUND FROM INTERACTIONS
b) BACKGROUND FROM HALO
c) LIMITED SPACE
d) LITTLE ROOM FOR SHIELDING

II. FAR DETECTOR:-

a) REDUCED BACKGROUND FROM INTERACTIONS
b) " " " HALO
[SHIELDING + SWEEPING OF MACHINE MAGNETS]
c) MORE SPACE.



COMMENTS

1- LHC BEAM IS 1.2 m ABOVE LEP BEAM

2- DISTANCE BETWEEN THE TWO LHC PROTON BEAMS IS 18 cm UP TO MAGNETS D2 AT WHICH POINT THEY START COMING TOGETHER.

3- RADIUS OF EACH LHC BEAM PIPE IS 2.5 cm.

4- IN PRINCIPLE LEP QUADS IN STRAIGHT SECTION COULD BE REMOVED DURING LHC OPERATION

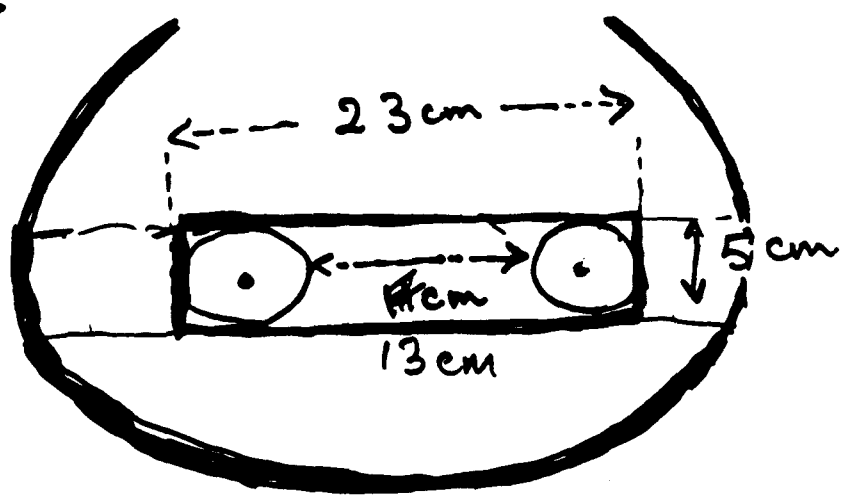
5- CONSTRAINTS ARE THEREFORE MAINLY SET BY LHC LATTICE.

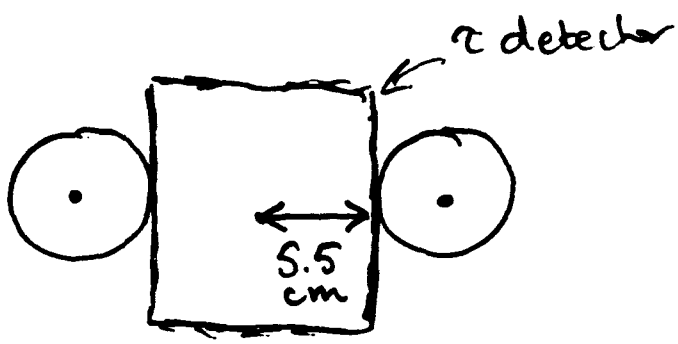
6- MAIN FREE AREAS:- 99m BETWEEN Q4 AND D2
29 m BETWEEN D2 AND D1.

7- ANY INSTALLATION OF DETECTORS IN THESE AREAS WOULD ~~ALMOST~~ SURELY NECESSITATE EXCAVATING TO ENLARGE THE TUNNEL.

ANGULAR COVERAGE OF TWO FREE AREAS (mrad)

	DIST. FROM IP (m)	PIPE RAD. 2.5 cm (VERT. APER.)	$(18+2\times2.5)/2$ 11.5 cm (HORIZ. APER.)	OUTER RAD. OF DET. 1m (?)
D1 →	60.25	0.41	1.91	16.6
29m ↕	89.25	0.28	1.29	11.2
D2 →	118.25	0.21	0.98	8.5
99m ↕	217.221	0.12	0.53	4.6
Q4 →				

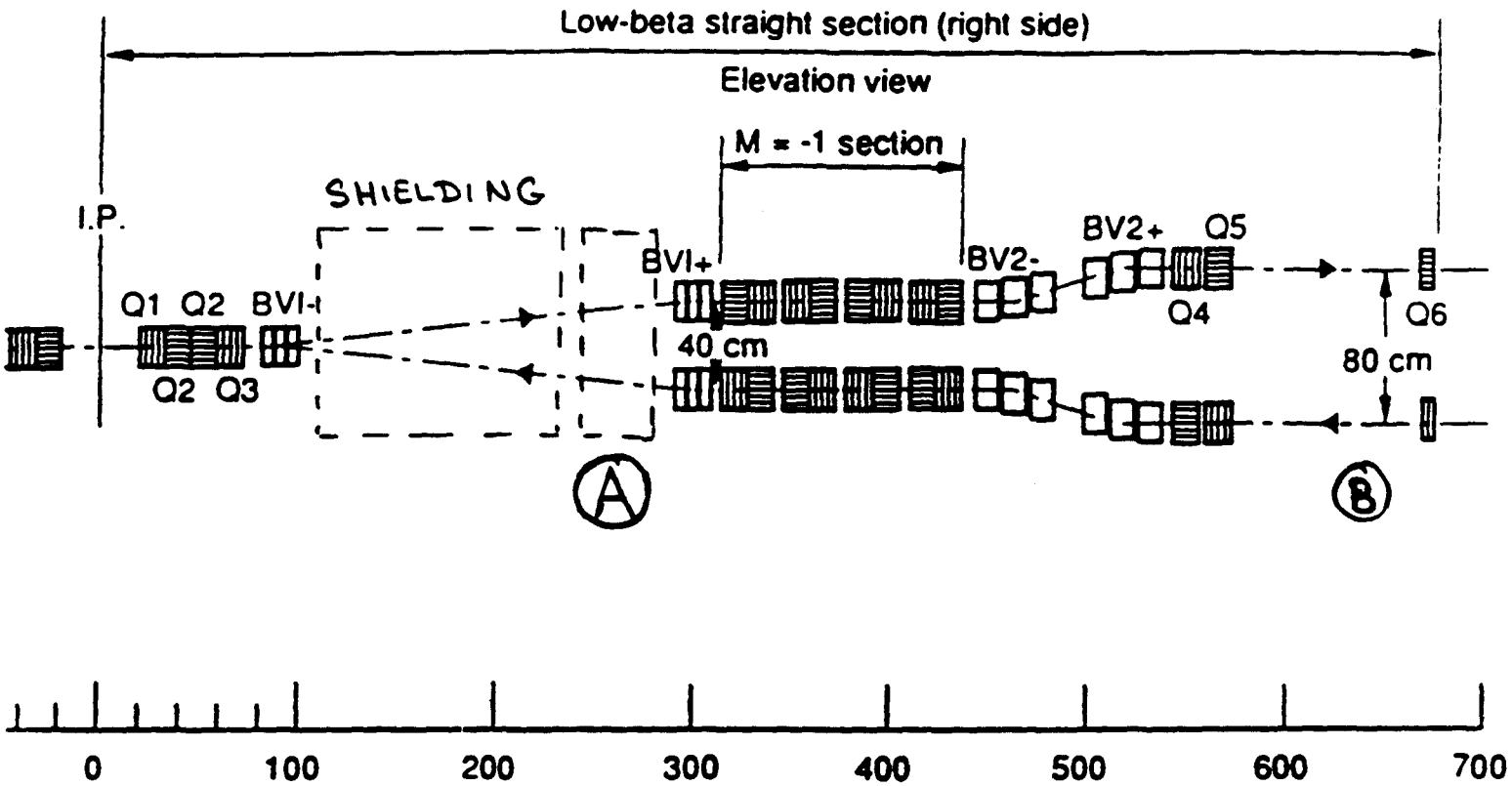




For a 10 m detector the closest it could go would be 80 m

$$10^3 \frac{5.5}{8000} = 0.7 \text{ mrad} \rightarrow 0$$

SSC



LOCATION

A 2.5 mrad at 250 m RADIUS: 63 cm 200 m FREE SPACE

ν_τ

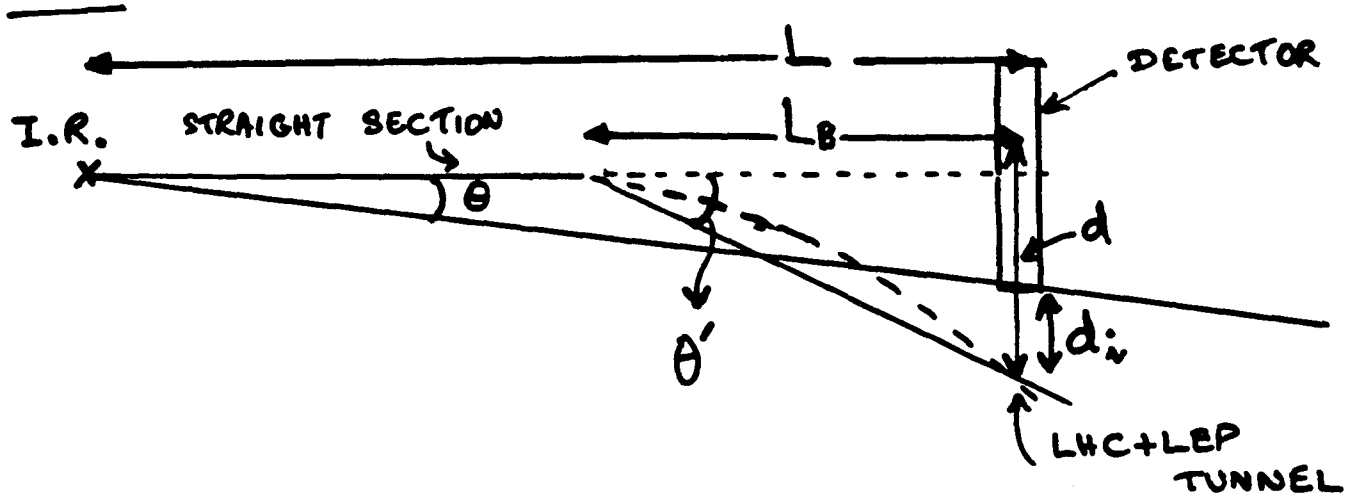
B 2.5 mrad at 650 m RADIUS: 1.6 m 100 m FREE SPACE

↓

TRANSVERSE DIMENSION OF DETECTORS CAN BE MODEST

USE OF MACHINE CURVATURE TO BE SENSITIVE TO NEUTRINOS PRODUCED AT ~ 0°.

LHC



LET L = DISTANCE BETWEEN DETECTOR AND I.R.

L_B = DISTANCE BETWEEN DETECTOR AND END OF STRAIGHT SEC.

θ = MAXIMUM NEUTRINO ANGLE TO BE OBSERVED: 5 mrad

d = DISTANCE BETWEEN 0° LINE AND LHC BEAM AT DETECTOR

d_i = DISTANCE NEEDED BETWEEN EDGE OF DETECTOR AND BEAM FOR CABLE TRAYS, MAGNETS ETC ..... = 1 m

θ_B = BENDING ANGLE PER m = 0.006 rad/23 m FOR LEP.

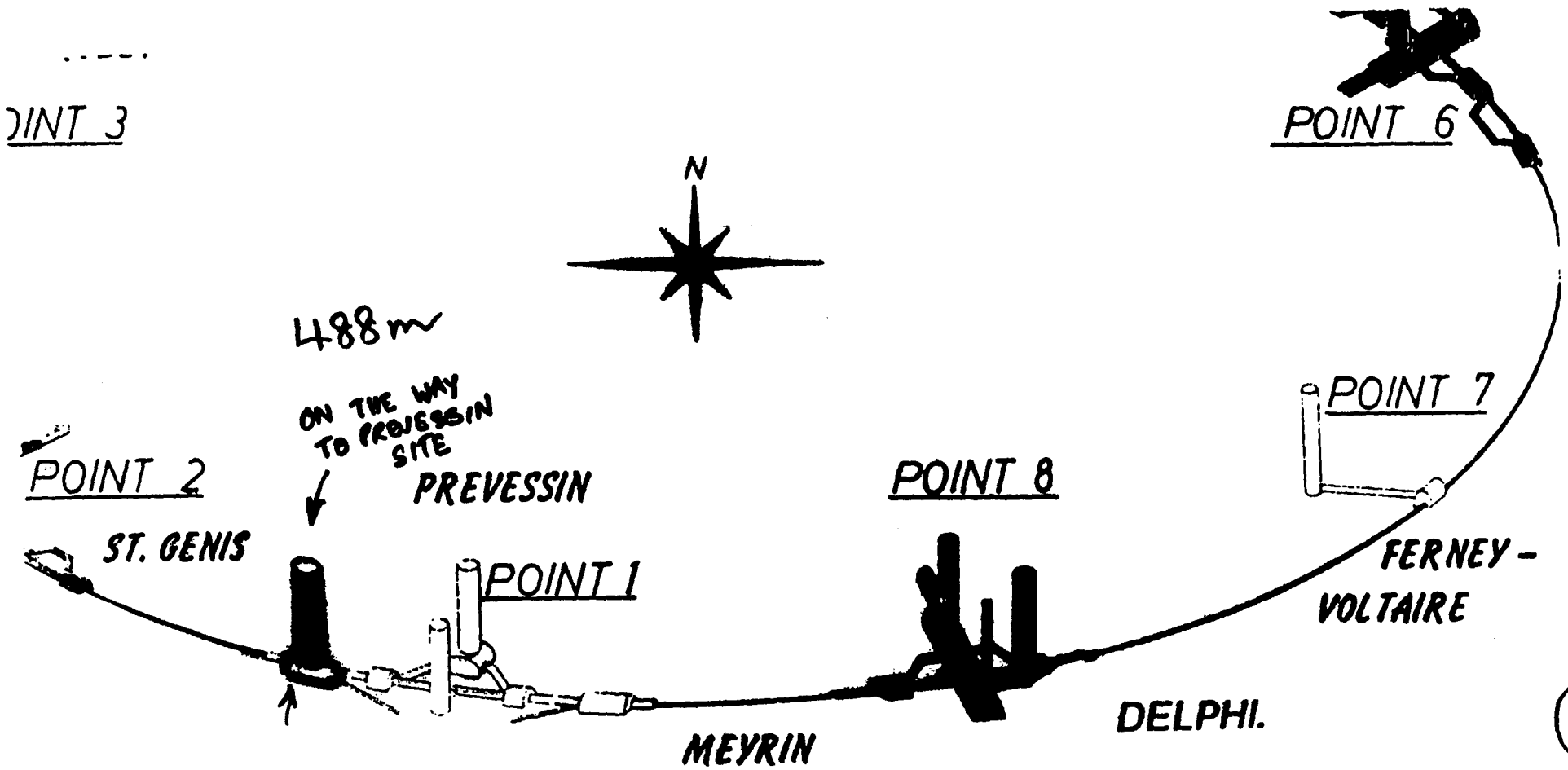
$$d = \theta L + d_i = \theta' L_B = \left(\tfrac{1}{2}\theta_B L_B\right) \cdot L_B = \tfrac{1}{2}\theta_B L_B^2$$

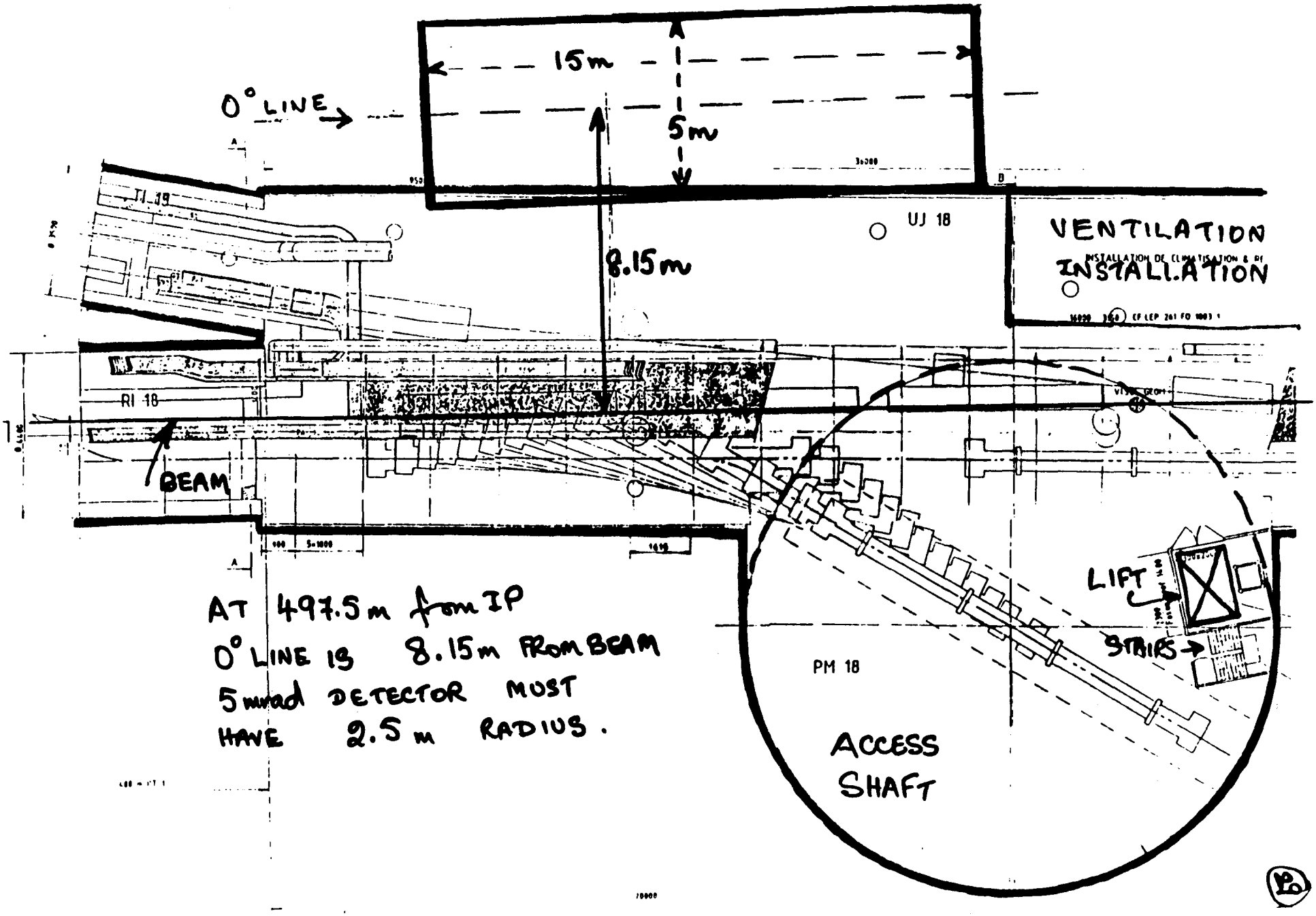
$$= 0.005(L_B + 248) + 1 = \frac{0.006}{46} L_B^2$$

$$\Rightarrow L_B = 152\,\text{m}$$

$$L = 400\,\text{m}$$

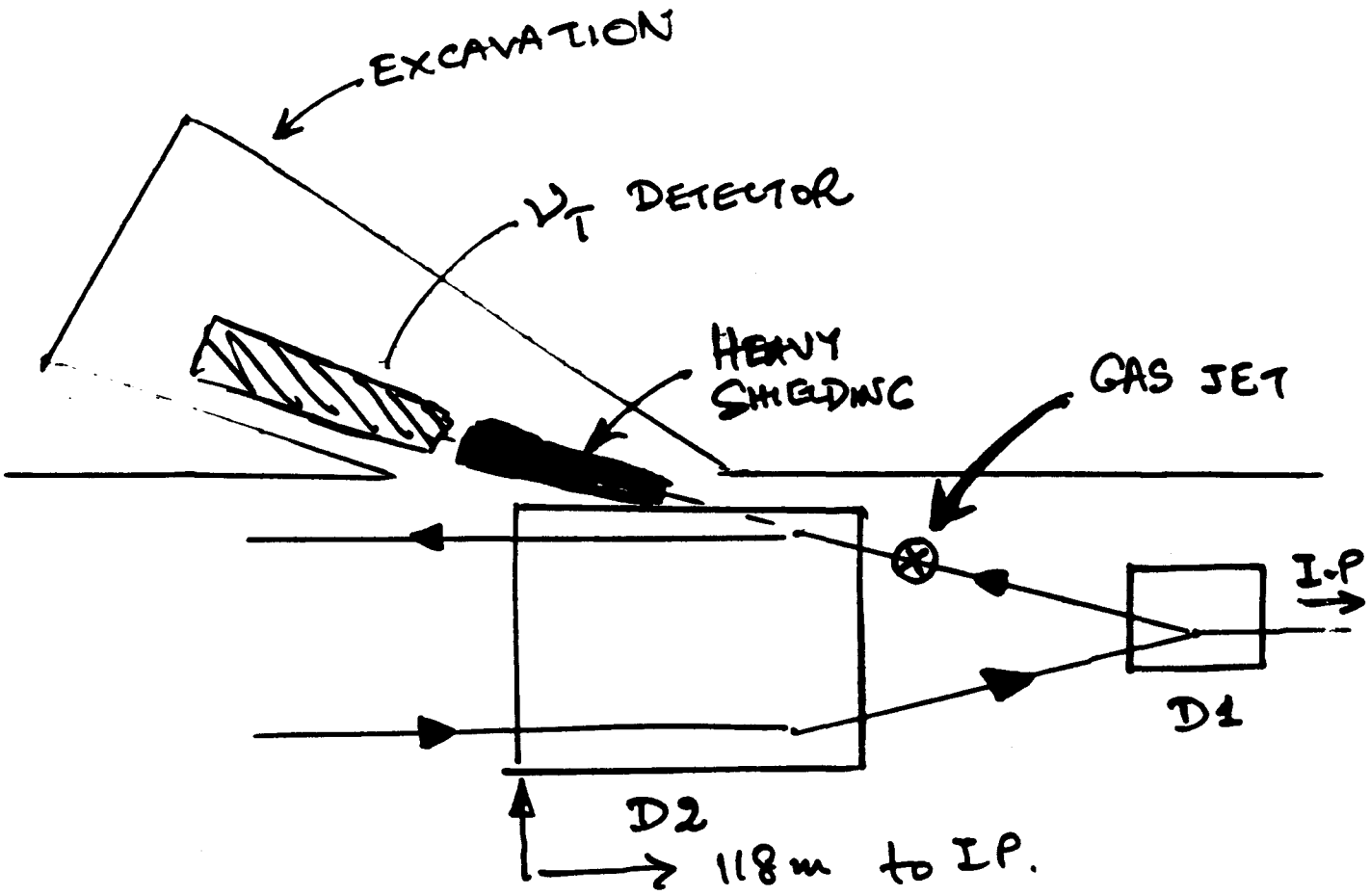
RADIUS OF DETECTOR = 2 m


POINT 3
N
POINT 6
488 m
ON THE WAY TO PREVESSIN SITE
POINT 7
POINT 2
PREVESSIN
POINT 8
ST. GENIS
POINT 1
FERNEY - VOLTAIRE
DELPHI.
MEYRIN



AT 497.5 m from IP
0° LINE IS 8.15 m FROM BEAM
5 mrad DETECTOR MUST
HAVE 2.5 m RADIUS.

GAS JET REVISITED



1) Place jet in OUT going beam

→ No background to IP

2) D2 WILL BEND THE CIRCULATING BEAM AWAY ALLOWING A NEUTRINO DETECTOR TO BE PLACED AT EXACTLY 0°.

3) D2 WILL ALSO SWEEP MUONS AND CHARGED SECONDARIES.

4) DETECTOR CAN BE CLOSE TO PRODUCTION POINT

PROBLEMS AND THINGS TO BE DONE

1. HOW DO WE ESTIMATE THE INCIDENT ν FLUX?
   a) CALCULATE FROM $C\bar{C}$ PRODUCTION (AFTER MEASURING $C\bar{C}$ CROSS-SECTION)?
   b) MEASURE PROMPT MUONS?
      [BACKGROUND FROM π, K DECAYS].

2. IS THE BACKGROUND FROM THE μ FLUX THROUGH THE DETECTOR A PROBLEM? HOW DO WE REDUCE IT?
   - SHIELDING (DOES <u>NOT</u> NEED TO BE VERY LARGE IN THE TRANSVERSE DIRECTION)
   - TOROIDS
   - MACHINE MAGNETS

3. MUST INVESTIGATE PHYSICS TOPICS THAT CAN BE ADDRESSED WITH TeV NEUTRINOS ν_μ, ν_e.

4. CAN A BIG ν_τ DETECTOR BE BUILT?

5. ARE A GAS-JET OR EXTERNAL BEAM USEFUL FOR ν PHYSICS?

CONCLUSIONS

ENOUGH INTERACTIONS TO

(A) OBSERVE ν_τ.

(B) STUDY ν_μ AND ν_E EVENTS AT ENERGIES WELL IN EXCESS OF 500 GeV.

ALL THIS DONE PARASITICALLY –

SO

WHY NOT ?

FOrward Neutrino Interaction Detector

CONCLUSIONS

1. POINT 1 IS FAVOURED.

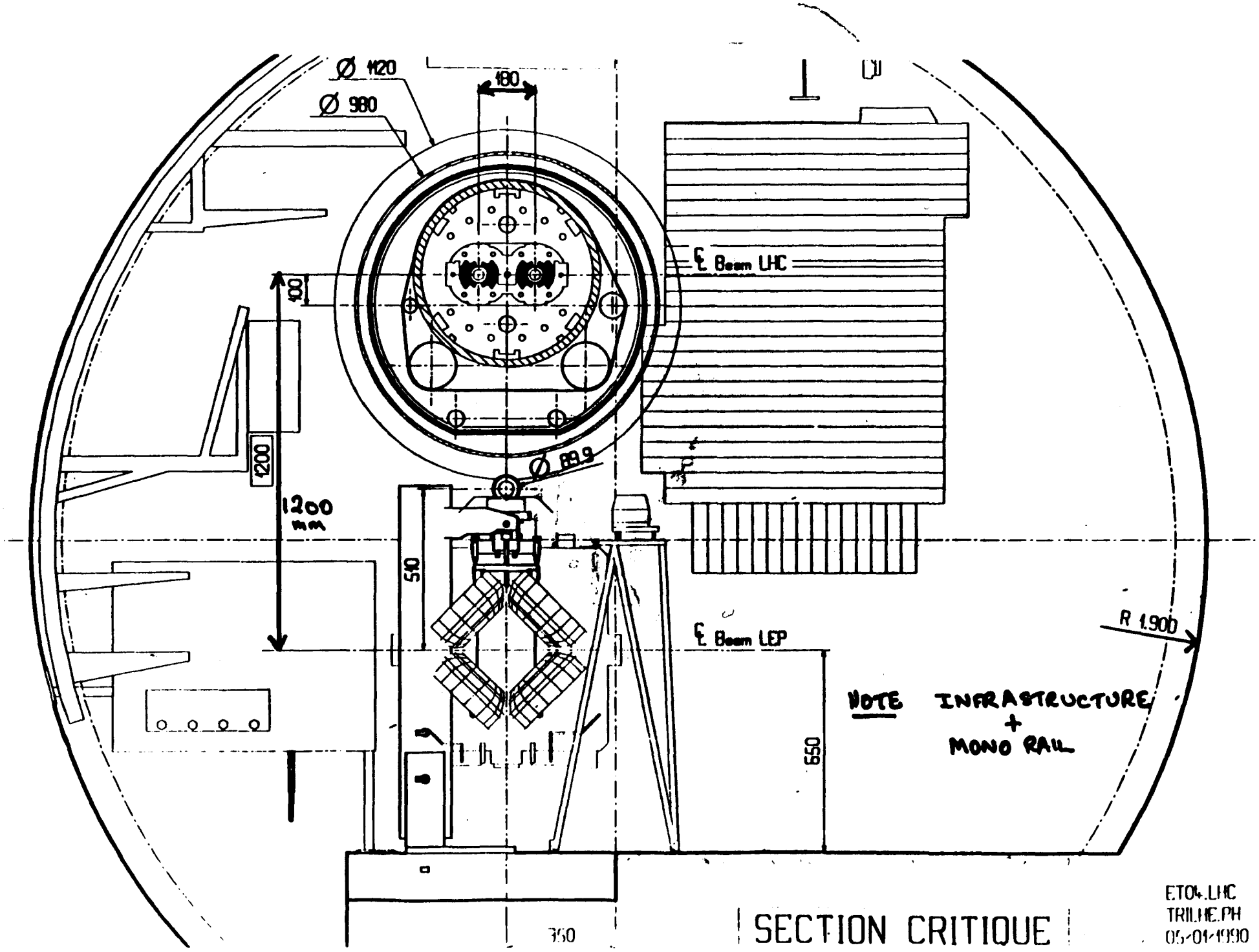
2. HIGH ENERGY ν_τ, ν_μ, ν_e FACILITY COULD BE INSTALLED NEAR PM18 AND BE SENSITIVE TO 0° NEUTRINOS.

   [TOO FAR FOR ν_τ's ?]

3. THE INSTALLATION WOULD REQUIRE SOME MODEST AMOUNT OF EXCAVATION.

4. POSSIBILITY TO INSTALL A SMALL SIZE, HIGHLY INSTRUMENTED ν_τ DETECTOR BETWEEN THE TWO BEAMS NEAR THE INTERACTION REGION. BACKGROUND ?

5. Maybe a gas-jet useful for ν_τ.


Ø 1120
Ø 980
180
℄ Beam LHC
100
1200
1200 mm
Ø 889
510
℄ Beam LEP
R 1.900
650
NOTE INFRASTRUCTURE + MONO RAIL
360
SECTION CRITIQUE
ET04.LHC
TRILHE.PH
05/01/1990

STATISTIQUE AVEC LES COUPURES DU PROPOSAL

	$\nu_\tau \to \tau \to e^-$	$\nu_e \to e^-$	N.C.with γ conv..	N.C.with Dalitz	Knock on	μ decay	Ke_3 decays	Long K0 decays
Origin.number	100	100	100	100	100	100	100	100
e- in calo	77.3	85.4	29.5	20.2		53.9	2.9	3.3
$e^- > 1.5$Gev	72.8	85.1	15.8	12.2		40.2	1.2	1.5
$\Phi 1/\Phi 2$cut	30.9	0.33	14.4	11.2		15.5	1.1	1.3
E vis< 50 Gev	25.0	0.11	10.0	7.7		12.8	.86	1.1
m(eγ) >200 Mev	20.6	.08	1.16	.81		10.4	.18	.74
m(eγ) >240 Mev	19.5	.07	1.05	.72		9.7	.11	.66
m(eγ) >280 Mev	18.5	.06	0.93	.63		9.2	.06	.62
$P_T^{e^-}$ >200 Mev	19.0	.07	0.74	.52		9.7	.074	.45
>300 Mev	18.3	.06	0.47	.34		9.3	.043	.26
>400 Mev	17.2	.05	0.32	.20		9.0	.029	.13
Pe^+ <200 Mev	18.2	.06	.01	.039		9.3	.043	.26
< 100 Mev	18.2	.06	.005	.022		9.3	.043	.26
< 50 Mev	18.2	.06	.003	.012		9.3	.043	.26
		6×10^{-4}	5×10^{-4}					

ν_e = 7700 ⇓ 4.6 ev

tot. prob = 2.4×10^{-3} × 300 000 CN ⇓ 6 ev

tot. prob = 5.3×10^{-4} × 300 000 CN ⇓ 1.6 ev

tot. prob = 1.4×10^{-3} × 770 000 CC ⇓ 1.1 ev

tot. prob = 4.9×10^{-3} × 300 000 CN ⇓ 0.1 ev

tot. prob = 3.0×10^{-5} × 300 000 CN ⇓ 1.0 ev

$0.06\times10^{-2}\times7700 =$ 4.6 ev

7.7×10^{3}

5×10^{-5}

2×10^{-4}

3×10^{-6}

$\frac{1}{5\times10^{-4}} = 2\times10^{-3}$

NASA's Proposed Long–Baseline Neutrino Experiment

Thomas Wilson

National Aeronautics and Space Administration
Solar System Exploration Division
Johnson Space Center
Houston, Texas 77058

Second SSC Spring Conference:
Electroweak and Flavor Physics: Implications for the SSC

SSC Laboratory, Dallas, Texas *May 20, 1991*

Summary

- NASA's Space Exploration Initiative (SEI)
- Grand-Scale Laboratory Physics
- Physics In Space (or On The Moon)
- Quantum Oscillation Physics
  - 1st, 2nd, 3rd Generation Concepts
  - Hilbert Space Mixing
  - Vacuum Oscillation Physics
- Long-Baseline Experiment
- Feasibility Study (NASA)
  - SSC Justification
  - Why do it now?

Synopsis

NASA's Space Physics Division has selected a neutrino telescope as one of the preliminary experiments which have a scientific justification at a lunar base in its Space Exploration Initiative (SEI). The proposal to conduct long-baseline particle beam experiments between the Earth and Moon is examined. In particular, neutrino oscillation experiments between the Superconducting Super Collider and a lunar-based neutrino detector are discussed. Emphasis is placed upon the unique capability of measuring the vacuum oscillations in quantum physics, which no other known circumstance provides over such a distance. An SSC-justification is addressed, and NASA's proposed feasibility study of this emerging experiment in fundamental physics is presented.

Alfven's Universe (1988)

(Reference 1)

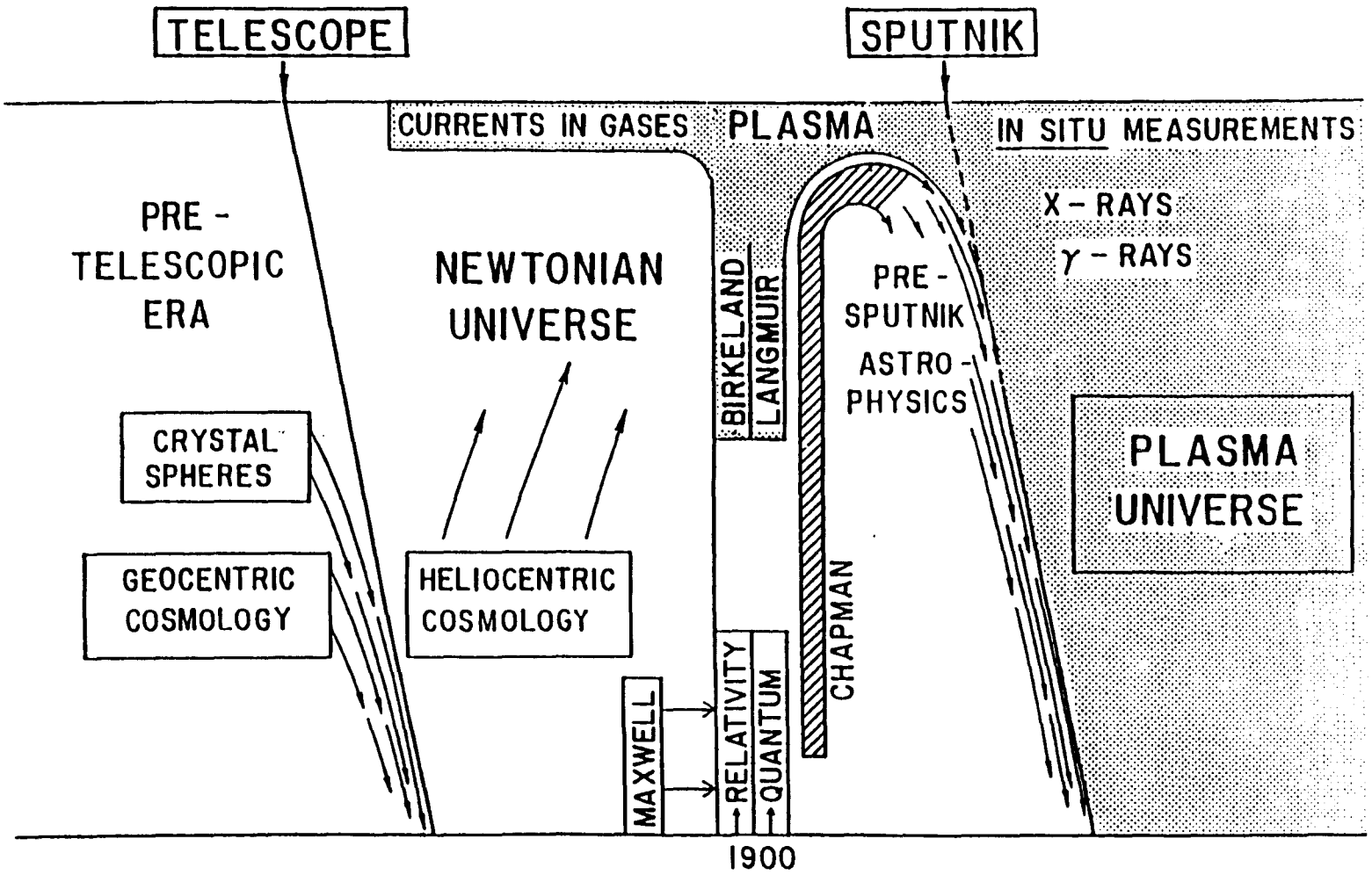
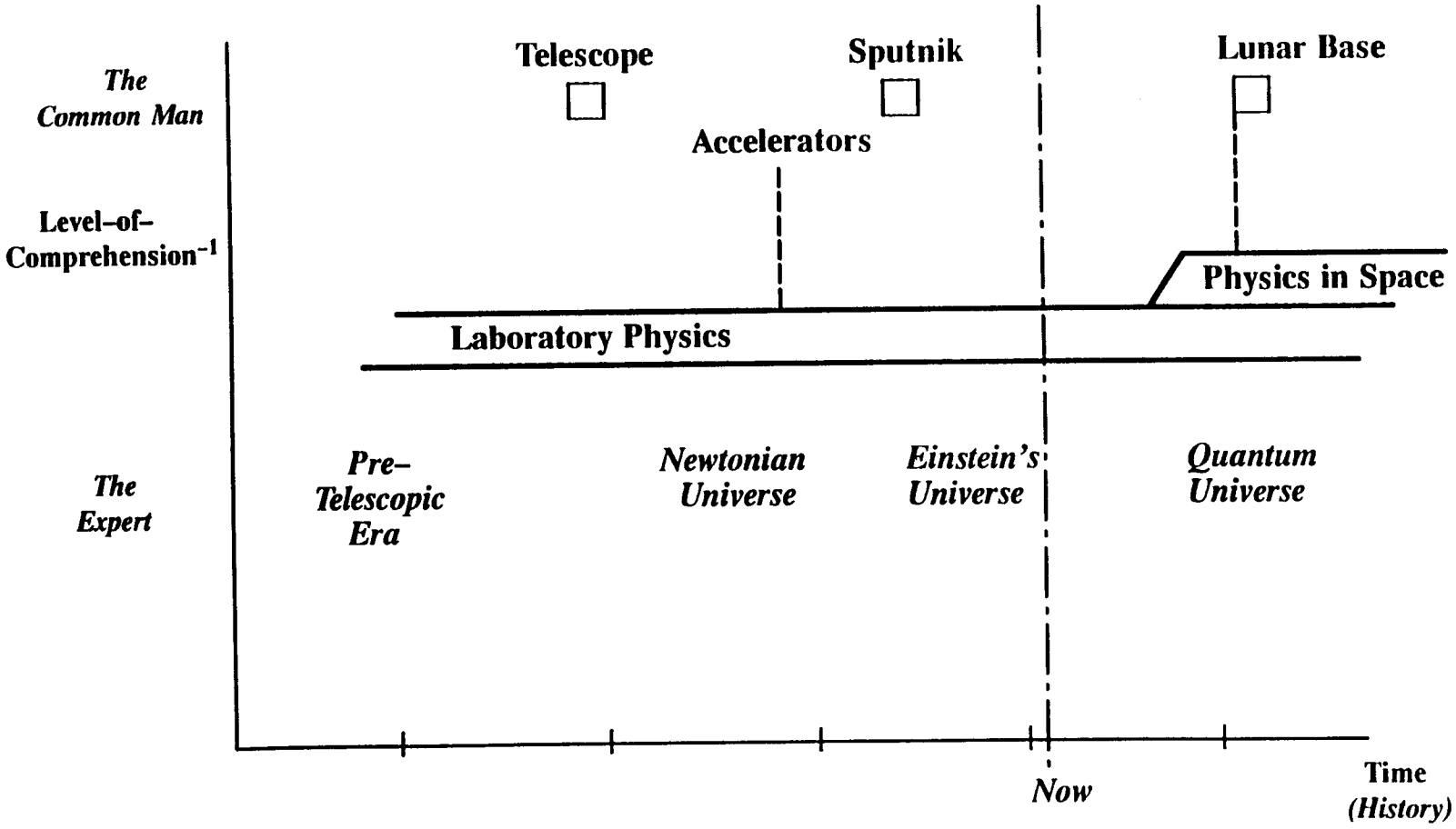


FIGURE 2. Astrophysics in a nutshell.

Physics In The Next Century



Quantum Oscillations – First Principles
(Schrödinger: *Zitterbewegung*)

(References 2 & 3)

SITZUNGSBERICHTE

DER PREUSSISCHEN

AKADEMIE DER WISSENSCHAFTEN

JAHRGANG 1930

PHYSIKALISCH-MATHEMATISCHE KLASSE

VERZEICHNIS DER MITGLIEDER DER AKADEMIE DER WISSENSCHAFTEN AM 1. JANUAR 1930
ÖFFENTLICHE SITZUNG ZUR FEIER DES JAHRESTAGES KÖNIG FRIEDRICHS II. AM 24. JANUAR 1930
ÖFFENTLICHE SITZUNG ZUR FEIER DES LEIBNIZSCHEN JAHRESTAGES AM 3. JULI 1930
VERZEICHNIS DER VOM 1. DEZEMBER 1929 BIS 30. NOVEMBER 1930 EINGEGANGENEN DRUCKSCHRIFTEN

STÜCK I–XXXII. MIT EINER TAFEL

BERLIN 1930

VERLAG DER AKADEMIE DER WISSENSCHAFTEN

IN KOMMISSION BEI WALTER DE GRUYTER U. CO.

Über die kräftefreie Bewegung in der relativistischen Quantenmechanik.

Von E. Schrödinger.

(Vorgelegt am 17. Juli 1930 [s. oben S. 406].)

1. Den Inhalt dieser Mitteilung bilden einige Ergebnisse aus der Anwendung des Operatorkalküls auf dasjenige physikalische System, das durch die Diracsche Wellengleichung

$$\frac{h}{2\pi i}\frac{\partial\psi}{\partial t} + H\psi = 0 \qquad (1)$$

mit

$$H = c\alpha_1 p_1 + c\alpha_2 p_2 + c\alpha_3 p_3 + \alpha_4 mc^2 \qquad (2)$$

beschrieben werden soll — man nennt es gewöhnlich das Diracsche Elektron. Wir beschränken uns auf den feldfreien Fall, weil wir uns gerade dafür interessieren, daß das Diracsche System sich auch beim Fehlen äußerer Kräfte verhältnismäßig kompliziert benimmt. — Den Hamiltonschen Operator (2) stellt man nach Breit[1] am besten in korrespondenzmäßige Parallele mit dem folgenden Ausdruck für die Lorentzsche Elektronenenergie:

$$\frac{mc^2}{\sqrt{1-\beta^2}} = \mathfrak{v}_x\cdot\frac{m\mathfrak{v}_x}{\sqrt{1-\beta^2}} + \mathfrak{v}_y\cdot\frac{m\mathfrak{v}_y}{\sqrt{1-\beta^2}} + \mathfrak{v}_z\cdot\frac{m\mathfrak{v}_z}{\sqrt{1-\beta^2}} + \sqrt{1-\beta^2}\cdot mc^2.$$

Es entsprechen in gewissem Sinne

$c\alpha_1$, $c\alpha_2$, $c\alpha_3$ ... den Geschwindigkeitskomponenten $\mathfrak{v}_x$, $\mathfrak{v}_y$, $\mathfrak{v}_z$

α_4 ...

p_1 ...

m_1 ...

Die Amplitude der Zitterbewegung bietet erhebliches Interesse. Sie läßt sich nach (16)

$$\xi_k = \frac{cx}{2} H^{-1}\eta_k \qquad (16')$$

ohne weiteres abschätzen. η_k ist ebenso wie α_k von der Größenordnung 1, H für langsame Elektronenbewegung von der Größenordnung mc^2; $x = \frac{h}{2\pi i}$.

Der Erwartungswert von ξ^2 ist also von der Größenordnung

$$\xi_k \sim \frac{h}{4\pi mc} \sim 10^{-11}\,cm. \qquad (17)$$

Das B
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Vielmehr
verselbstän

[1] G. B
[2] An d
Anm. a. S. 12
spielt (J. v. Neumann, Z.S. f. Phys. 48, 868, 1928).

Quantum Oscillations – Second Principles

(References 4,5)

- **Pontecorvo: Quantum oscillations have implications for particle physics, in particular neutrinos.**

Quantum Oscillations – Third Principles

(Refs. 6–10; Reviews 11–14)

- **Quantum oscillations in matter may have significant implications for the Standard Solar Model (SSM) and the solar neutrino problem.**
- **See this afternoon's Spring Conference session on neutrino oscillations!**

The Standard Model of Particle Physics †

Force Particles

Photon W Z Gluon

† See Gilman (Ref. 15) for a discussion of 4th family physics.

Matter Particles

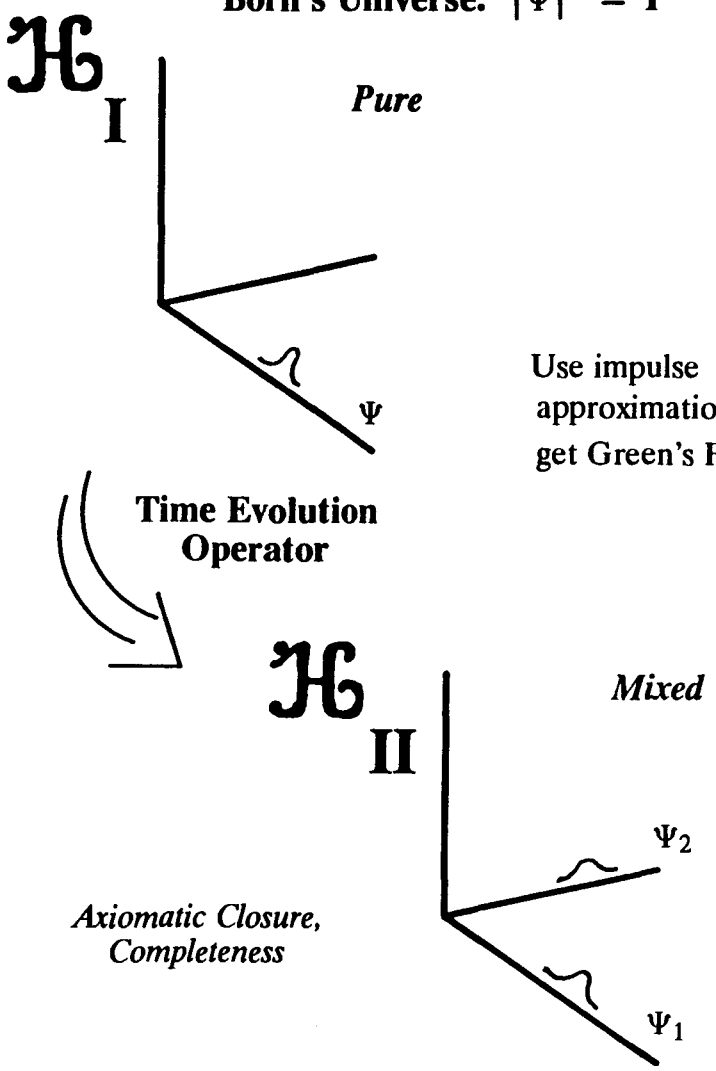
	Quarks		Leptons	
1st Family	u	Up	ν_e	e-Neutrino
	d	Down	e	Electron
2nd Family	c	Charm	ν_μ	μ-Neutrino
	s	Strange	μ	Muon
3rd Family	t?	Top	ν_τ	τ-Neutrino
	b	Bottom	τ	Tau

Hilbert Space Mixing

(New Physics: Hilbert's 6th Problem)

(Reference 8)

Born's Universe: $|\Psi|^2 = 1$



Use impulse approximation to get Green's Functions.

Axiomatic Closure, Completeness

$$\nu_e = (\cos\theta)\nu_1 + (\sin\theta)\nu_2$$
$$\nu_\mu = (\cos\theta)\nu_2 - (\sin\theta)\nu_1 \qquad (1)$$

$$\Delta v_{\mathrm{ph}} = \frac{\Delta m^2}{2k^2}\ , \quad \Delta\varphi(t) = \Delta v_{\mathrm{ph}} \cdot k \cdot t = \frac{\Delta m^2}{2k} \cdot t \qquad (2)$$

$$l_\nu = \frac{4\pi k}{\Delta m^2}\ . \qquad (3)$$

$$\nu_1 = (\cos\theta)\nu_e - (\sin\theta)\nu_\mu$$
$$\nu_2 = (\cos\theta)\nu_\mu + (\sin\theta)\nu_e$$

$$i\frac{d}{dt}\nu = \begin{bmatrix} \frac{m_1^2}{2k} & 0 \\ 0 & \frac{m_2^2}{2k} \end{bmatrix} \nu \qquad (4)$$

$$i\frac{d}{dt}\nu_f = \hat{H}_f \cdot \nu_f \qquad \nu_f = (\nu_e, \nu_\mu), \qquad (5)$$

$$\hat{H}_f = \frac{\Delta m^2}{2k} \begin{bmatrix} \cos 2\theta & -\sin 2\theta \\ -\sin 2\theta & -\cos 2\theta \end{bmatrix}$$

Vacuum Oscillations

(Reference 8)

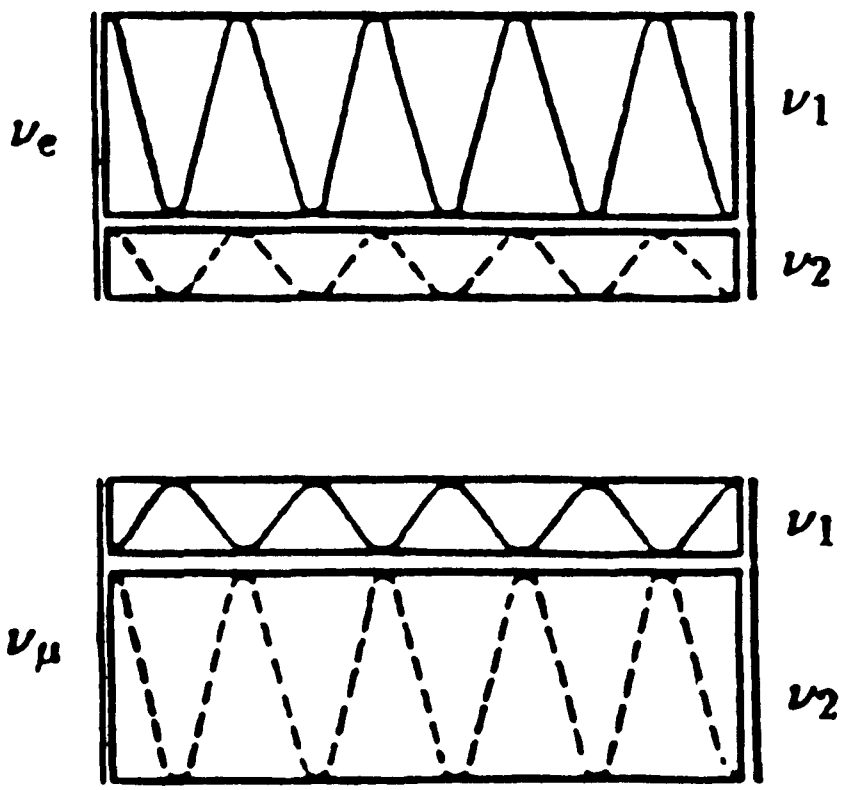


Fig. 1. The wave packets of mixed ν_e and ν_μ states.

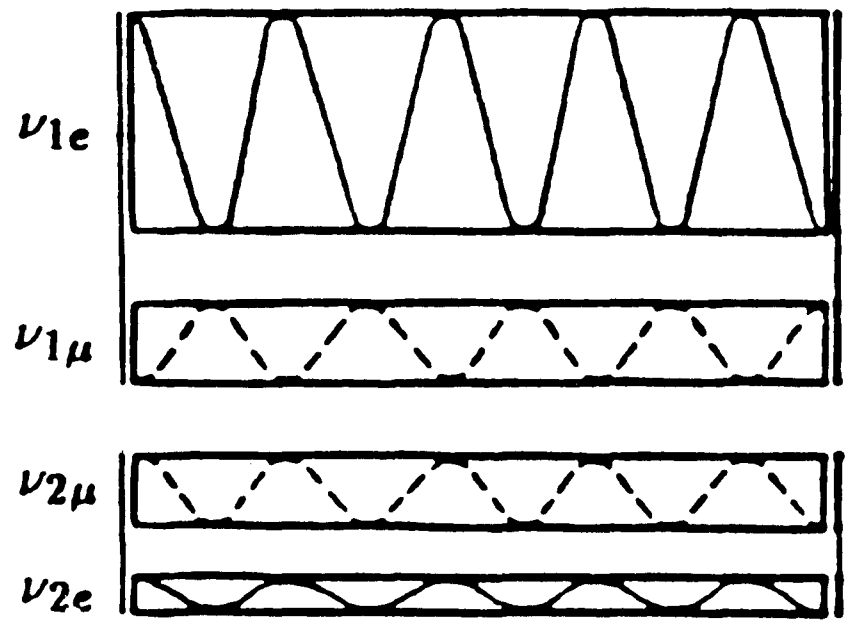
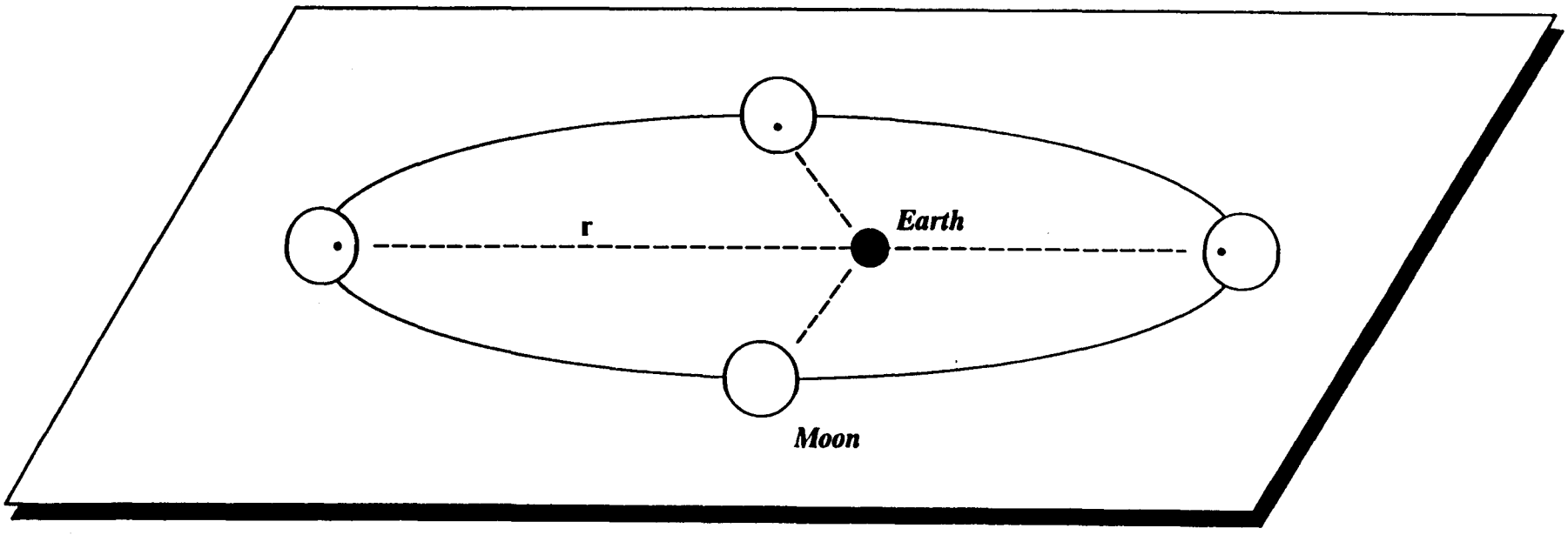


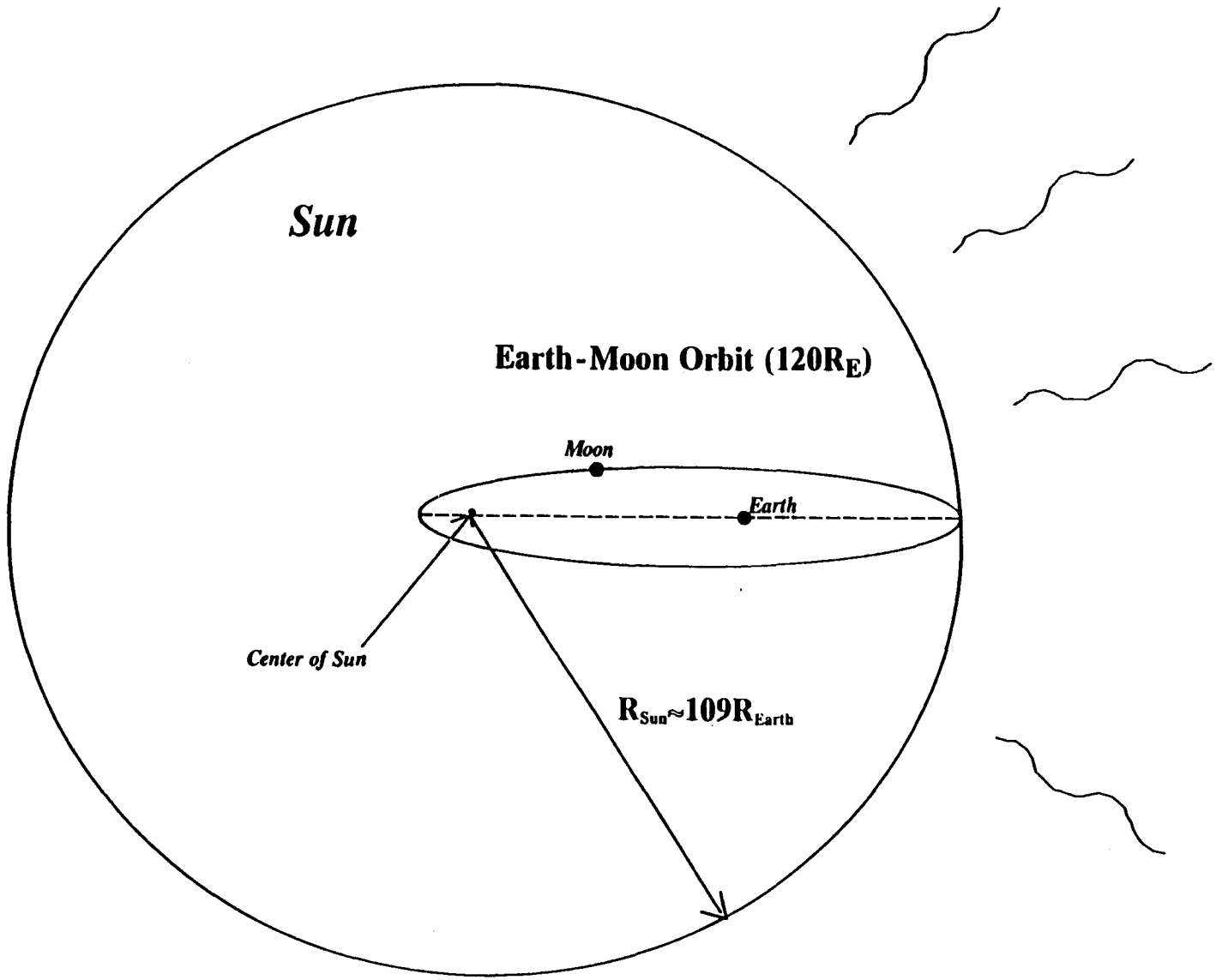
Fig. 2. The flavour decomposition of ν_1 and ν_2 for the ν_e state. Solid and dotted lines are waves with pure e–flavour and μ–flavour, respectively.

The Earth–Moon Laboratory



$r_{mean} = 3.84401 \times 10^8$ m (60.336 R_E)
$r_{min} = 3.564 \times 10^8$ m (55.941 R_E)
$r_{max} = 4.067 \times 10^8$ m (63.836 R_E)
$\epsilon = 0.0549$

The Earth–Moon Laboratory & Our Sun



Long–Baseline Particle Physics

$\theta = E_0^s/E_\nu$. For π–mesons,

$A = 1\ km^2$ when $E_\nu = 1.576 TeV$.

For K–mesons, $A_K = 12.5\ A_\pi$.

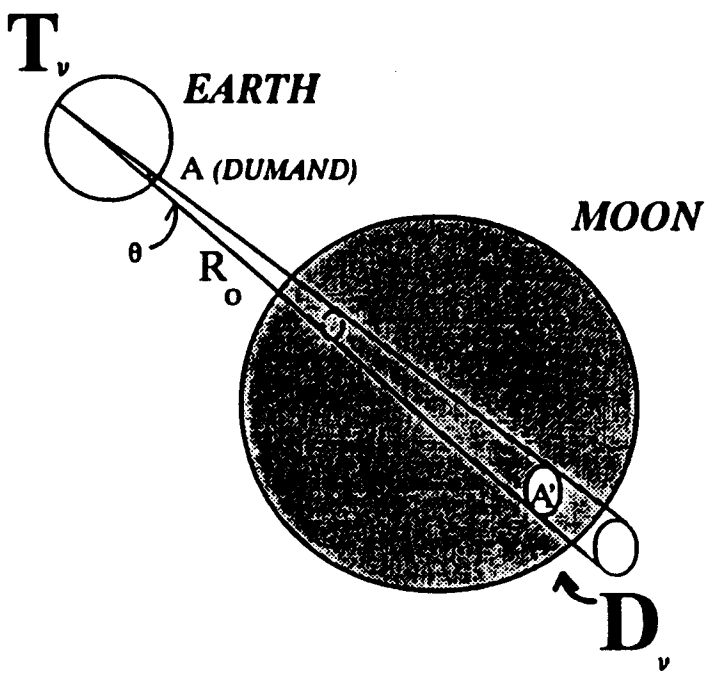


Fig. 12. An Earth–based tevatron T beams ν's to a Moon–based detector D. High–energy ν beams of definite composition and energy (from resultant secondary π and K decay) can be produced by "dumping" a proton beam onto a target. Particle kinematics from Ref. 79 for π and K meson sources are shown, although charm decay has been analyzed.[75] The beam divergence θ is the ratio of meson rest energy to ν beam energy. A beam at 1.576 TeV subtends $A = 1km^2$ (10^{10} cm^2) on the opposite side of the Earth (at 2 R_e.) To hold $A' = 1km^2$ on the opposite side of the Moon, a ν beam energy of 48.57 TeV is required.

NASA's Stanford Workshop (1989)

(Reference 16)

See L. Volkova (Ref. 17, 18) **for analysis of beam decay geometry.**

[$\theta = m_\pi c^2/E_\nu$]

Beam Dumps & Neutrino Beam Sources

(Reference 19)

Neutrinos are produced in weak decays when a high-energy proton beam is "dumped" onto a target. For low average target density, the decaying particles that result are mostly pions and kaons, with some contributed from Λ and Σ hyperons. As the density is increased, these longer-lived particles are reabsorbed before they can decay, and the residual "prompt" neutrinos come mostly from charmed mesons. The latter are expected to produce equal numbers of ν_e and ν_μ, which can then be identified by charged-current events in detectors placed at large distances from the target. After correction for differences in efficiencies and subtraction of the nonprompt neutrino component, any disparity in the cross sections for $\nu_e \rightarrow e$ versus $\nu_\mu \rightarrow \mu$ may be evidence for oscillations. In practice, it appears impossible to eliminate the nonprompt background.

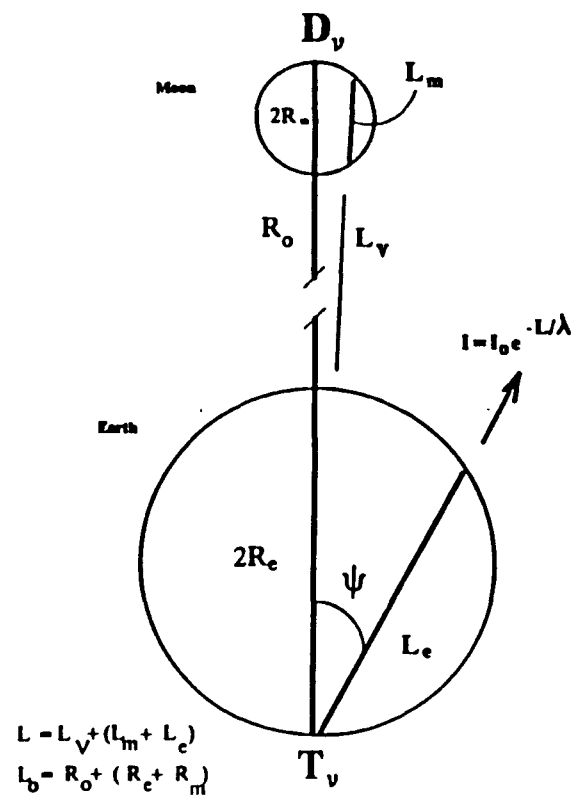
NASA's Stanford Workshop (1989)

(Reference 16)

Fig. 13. Neutrino oscillations can be studied at planetary densities in the Earth–Moon laboratory. Matter (along L_e and L_m) and vacuum (along L_V) oscillations all can be addressed using a pure ν eigenstate (pulsed accelerator beam) in tandem with a lunar–based ν detector. A relevant feature of oscillation studies is the ratio L/E, where L is the length of the baseline and E is the ν beam energy. Mean–free path $\lambda = \kappa^{-1}$ cm.

Neutrino Oscillation Studies

(Earth–Moon Laboratory)



Scaling Up The Laboratory

– L/E Ranges –

(E.g. Boehm, Ref. 20)

It is not true to state that $E_\nu \sim 20$ TeV is the "wrong" energy for studying oscillation physics [Ref. 21]:

(a) We do not know that neutrino oscillations will actually resolve the solar neutrino puzzle. We are "tailoring" the mixing parameters, hoping this will provide a satisfactory explanation.

(b) L/E $\sim$ 10m/MeV (e.g. for Earth-based measurements) is unchanged at L/E $\sim 10^8$ m/10 TeV (Earth-Moon distance $\sim 10^8$m).

Proposed Long–Baseline Neutrino Experiment

Purpose of the Experiment †

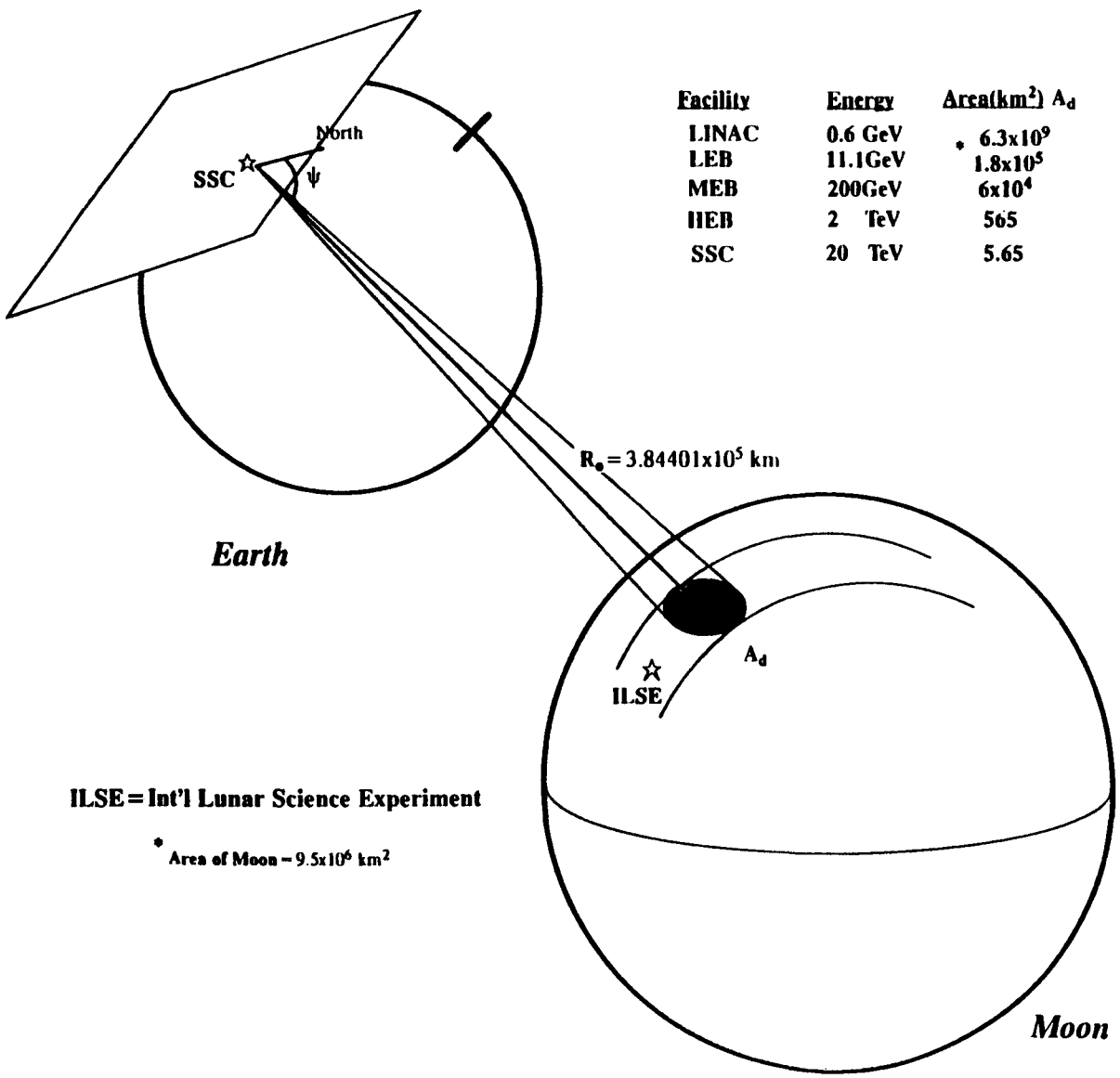
To measure the vacuum oscillation between the Earth and the Moon using a particle accelerator and a neutrino detector on the Moon. No other known circumstance appears to provide this unique capability of measuring quantum vacuum oscillations over such a distance.

The ability to pulse the beam and to attain a purer initial particle eigenstate has marked advantages over using astrophysical sources such as the Sun, whose initial neutrino eigenstates are mixed and unknown.

If a vacuum oscillation measurement is crucial to the ultimate determination of all the neutrino masses, then this long–baseline experiment could prove important.

† The emphasis on vacuum oscillations is due to Kenneth Lande.

Long–Baseline Physics Experiment

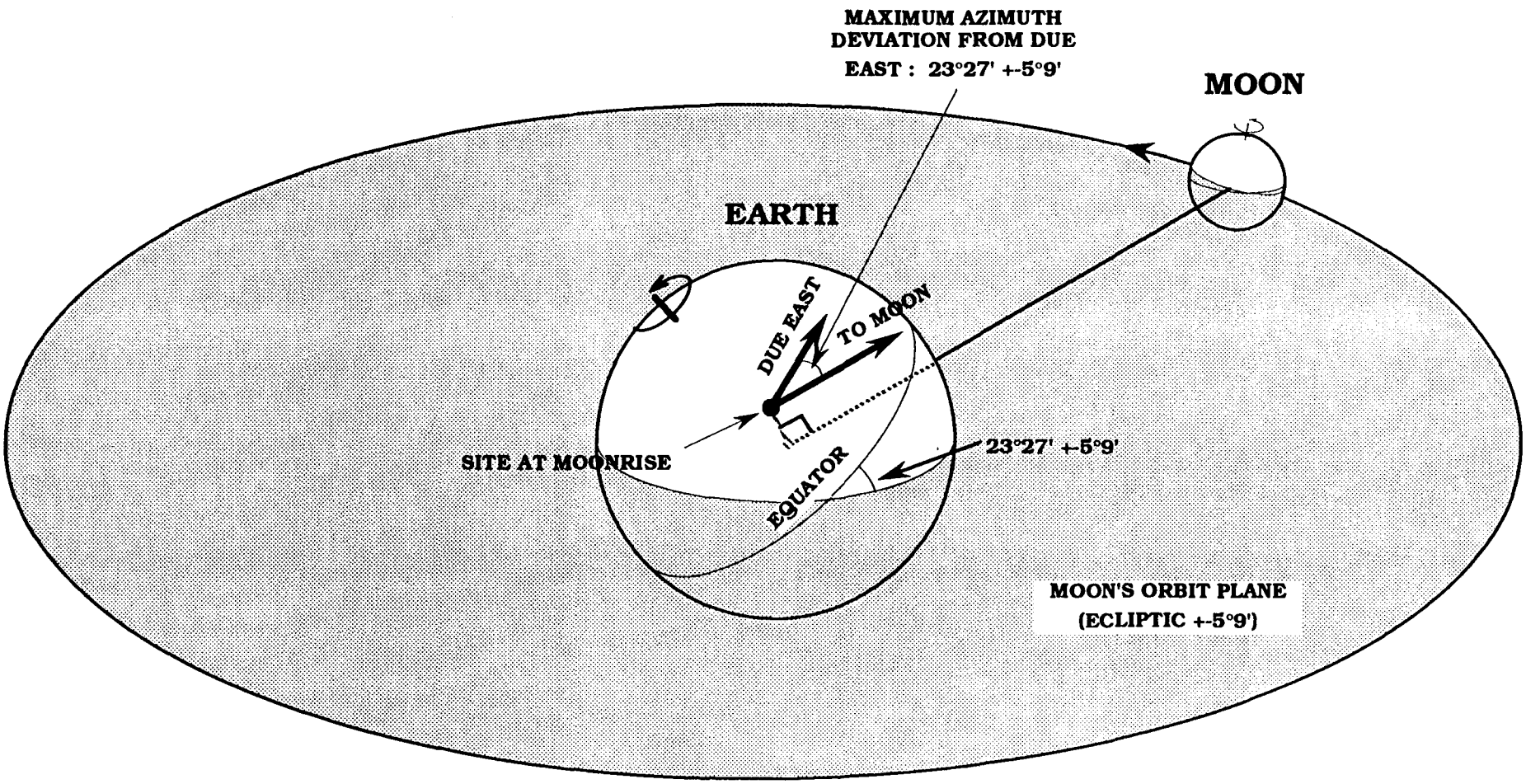


Facility	Energy	Area(km^2) A_d
LINAC	0.6 GeV	* 6.3×10^9
LEB	11.1GeV	1.8×10^5
MEB	200GeV	6×10^4
HEB	2 TeV	565
SSC	20 TeV	5.65

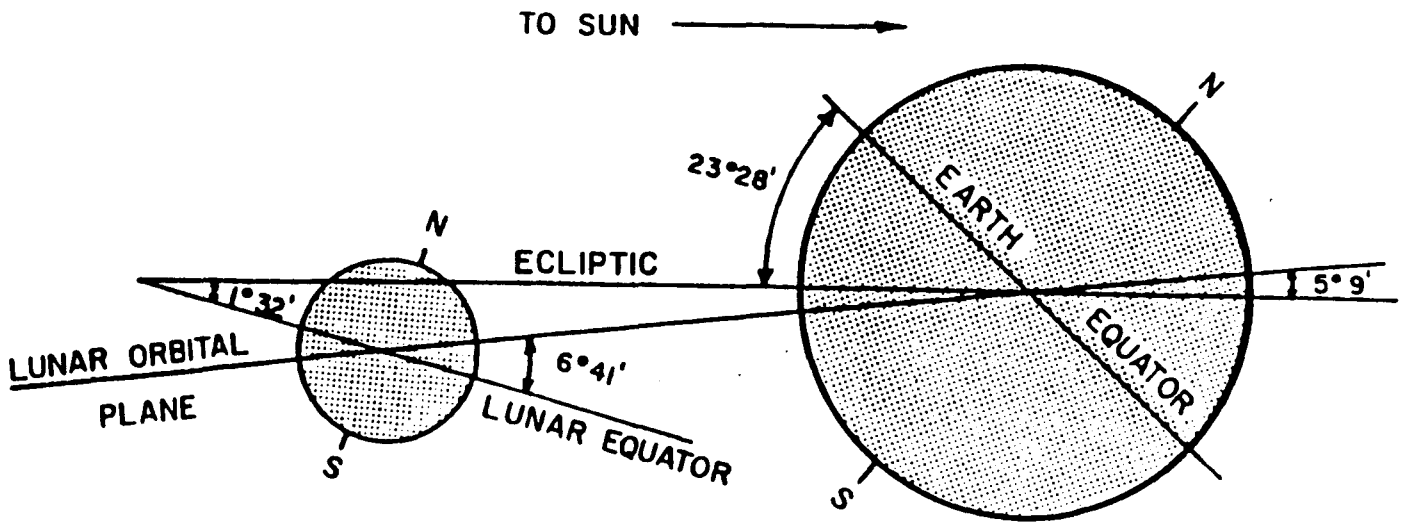
ILSE = Int'l Lunar Science Experiment

* Area of Moon = 9.5×10^6 km^2

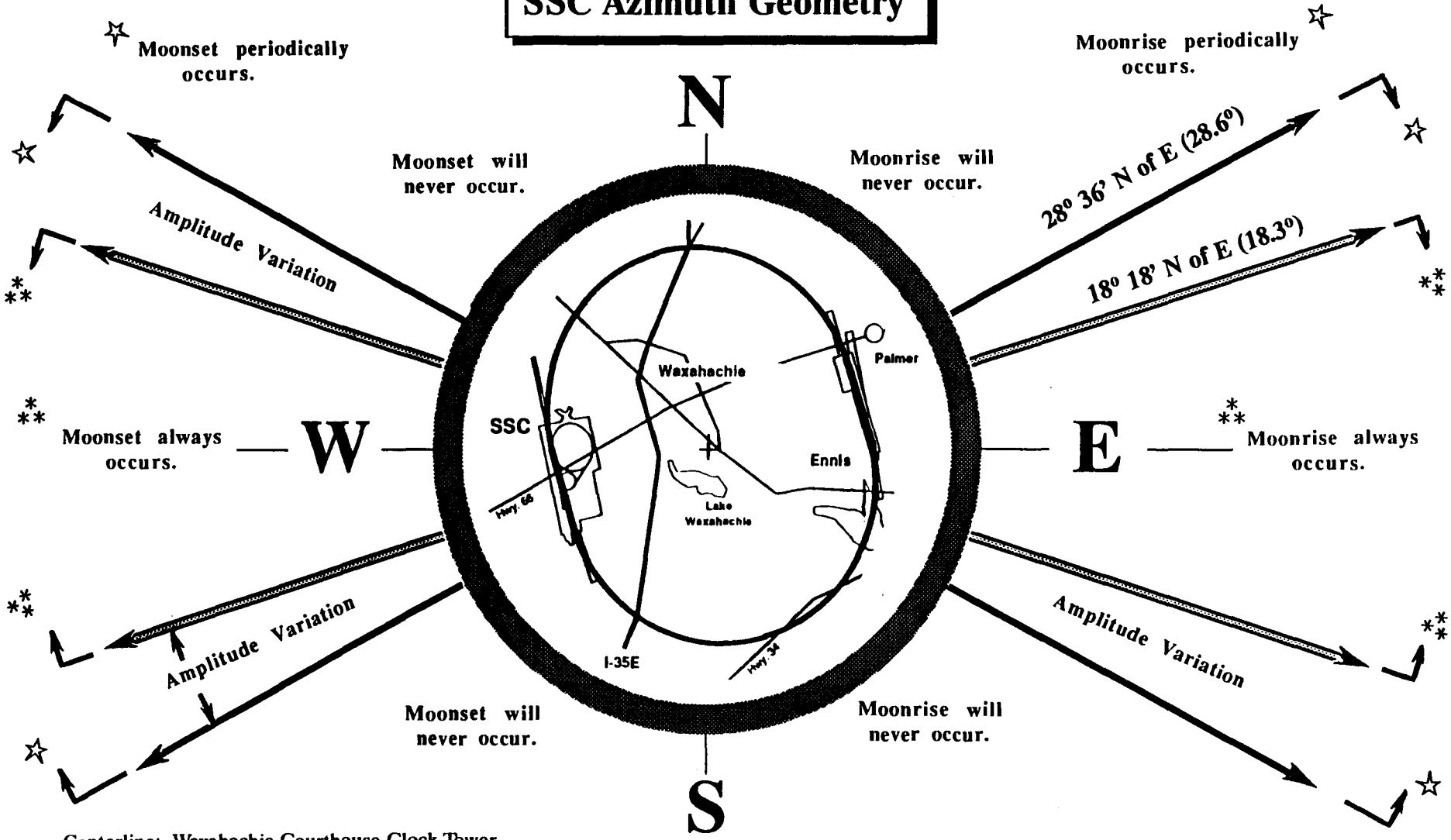
Moonrise Geometry



Earth–Moon Geometry



SSC Azimuth Geometry

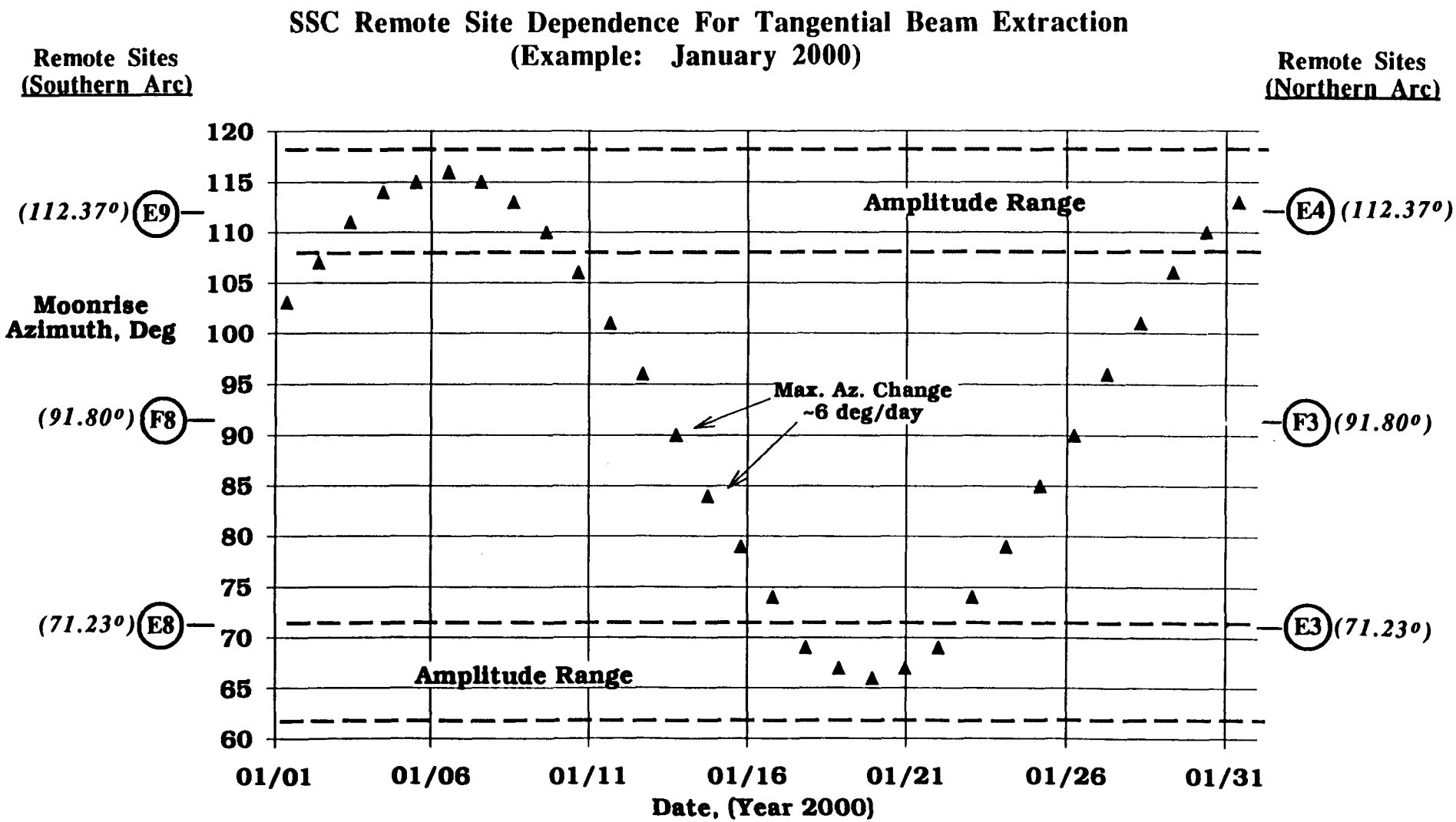


Centerline: Waxahachie Courthouse Clock Tower

-Latitude	*32° 23' 07".204*
-Longitude	*96° 50' 51".306*

Prepared by Thomas Wilson and Kent Joosten

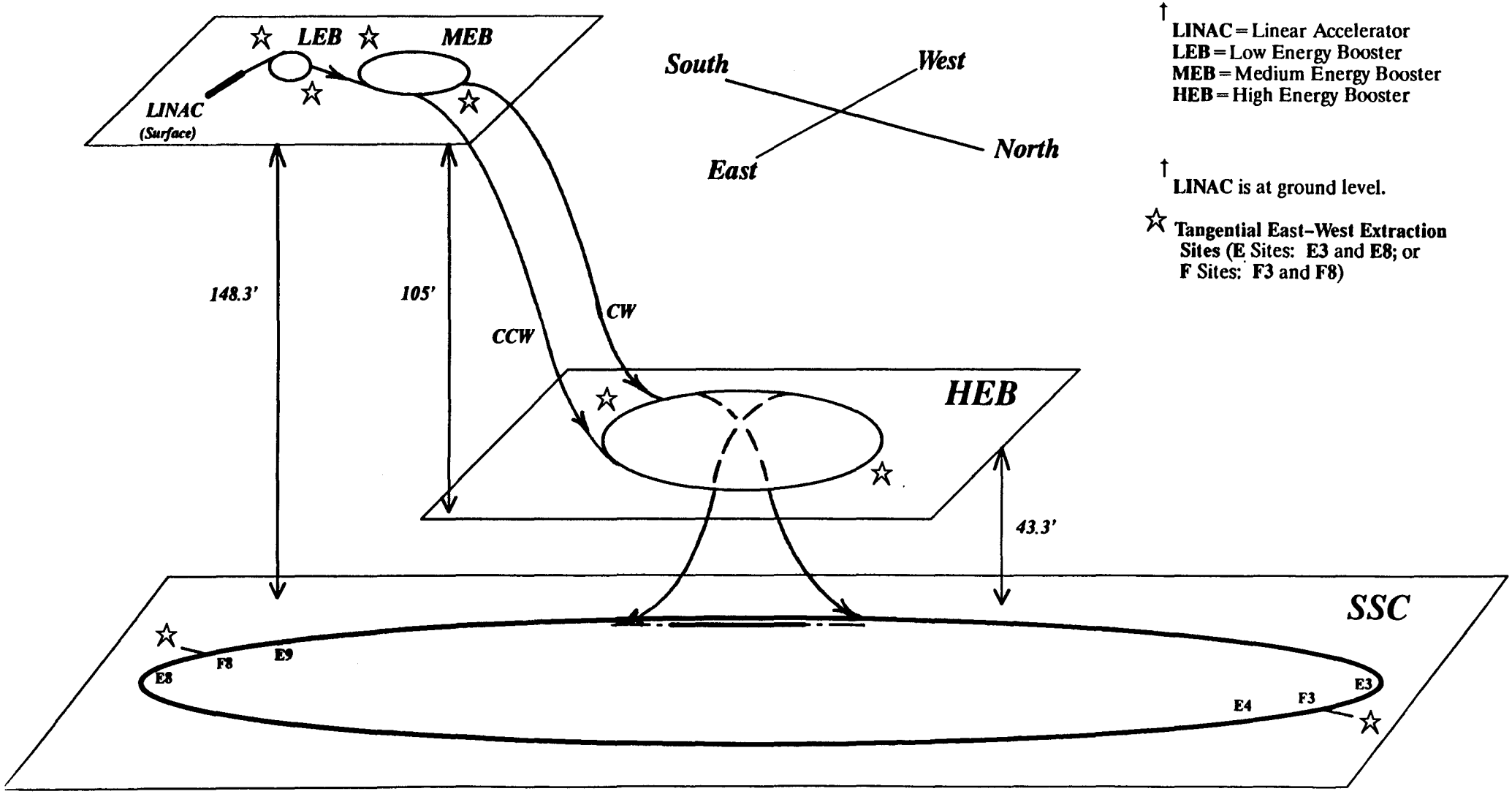
Targets of Opportunity



Thomas Wilson/*NASA, Houston*

SSC: 3-Dimensional Perspective

(Relative to the LINAC)

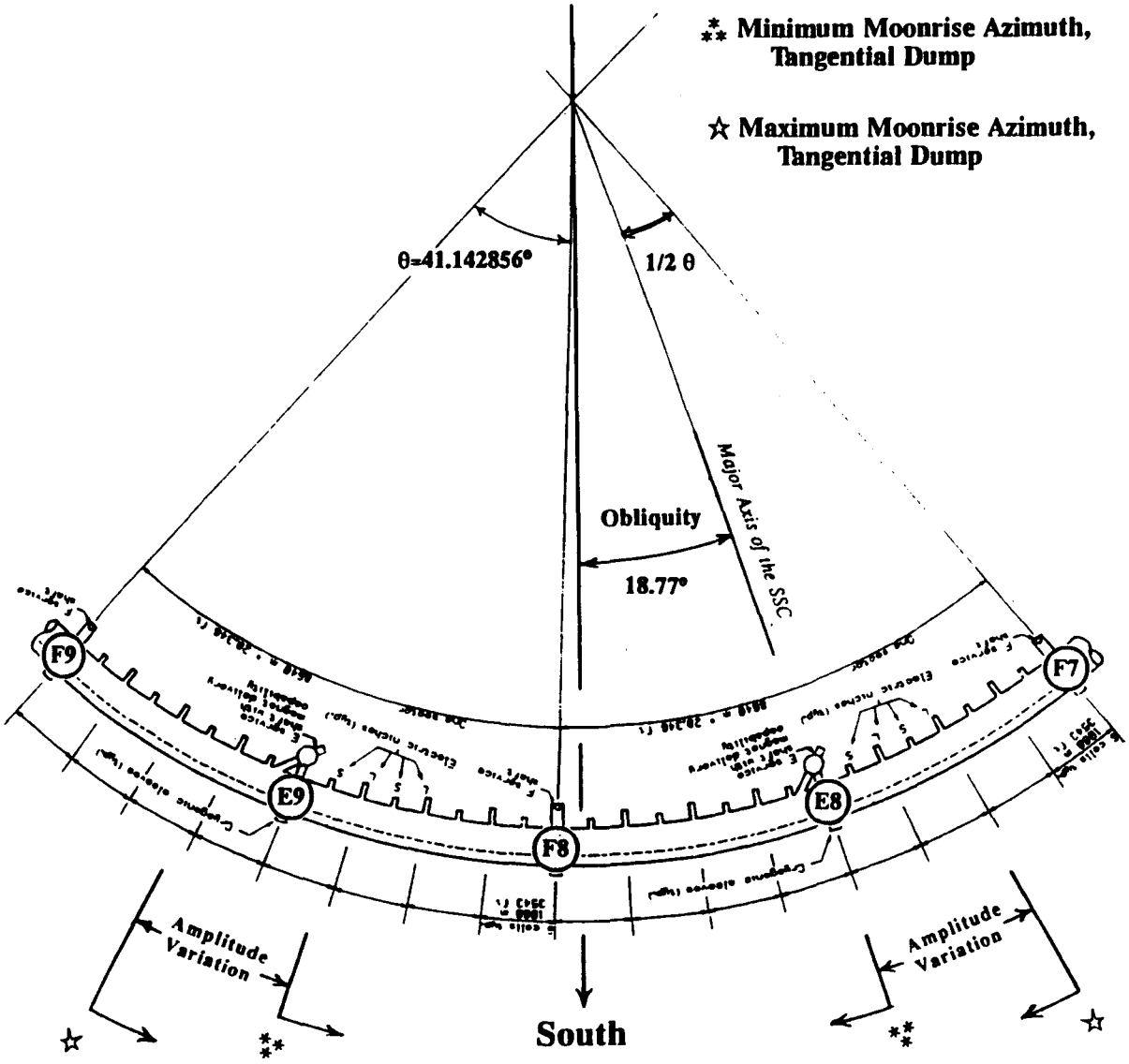


† LINAC = Linear Accelerator
LEB = Low Energy Booster
MEB = Medium Energy Booster
HEB = High Energy Booster

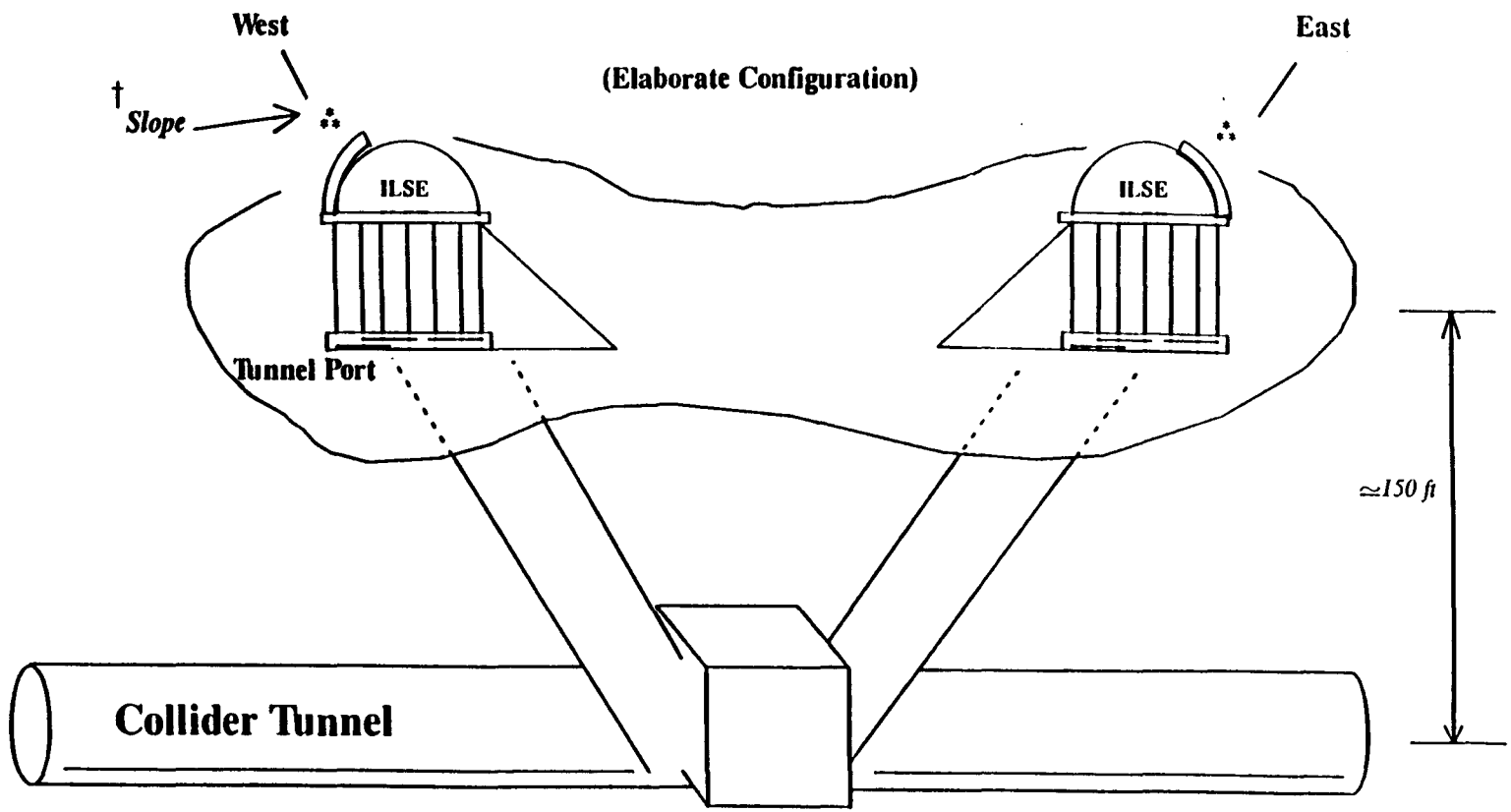
† LINAC is at ground level.

☆ Tangential East-West Extraction Sites (E Sites: E3 and E8; or F Sites: F3 and F8)

Remote Site Moonrise Limits - Southern Arc



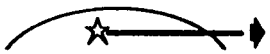
Remote Site ILSE Concept



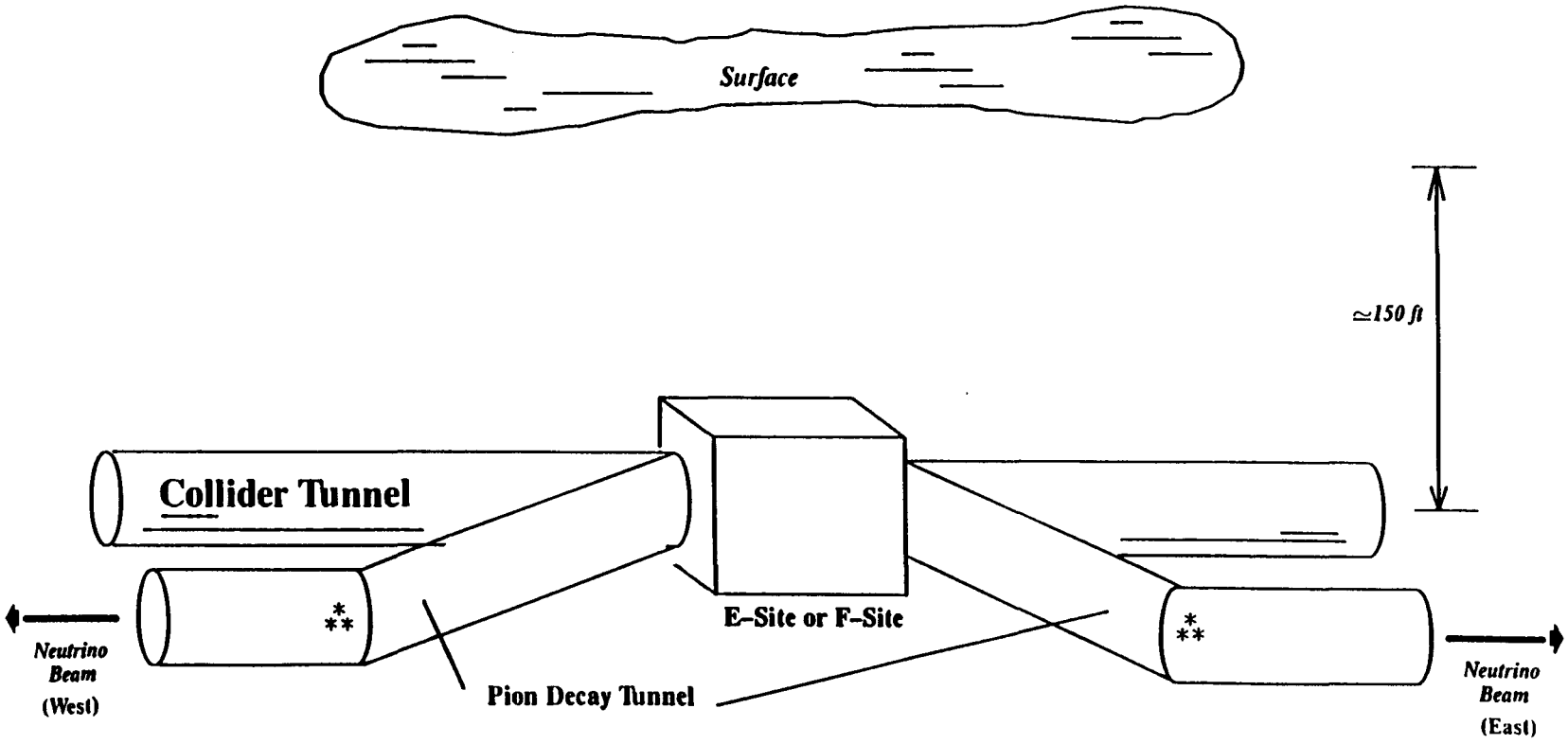
E–Site or F–Site

† *Slope* determined by magnets utilized and fee simple problems at/on the surface.

Remote Site ILSE Concept



(Neutrinos Transit Horizontal Cords Of The Earth Until Exiting from 150 ft depth)



ILSE† Collaboration

Thomas Wilson	National Aeronautics and Space Administration
David Cline	University of California, Los Angeles
Ervin Fenyves	University of Texas, Dallas
Kenneth Lande	Universtiy of Pennsylvania

† **ILSE = International Lunar Science Experiment**

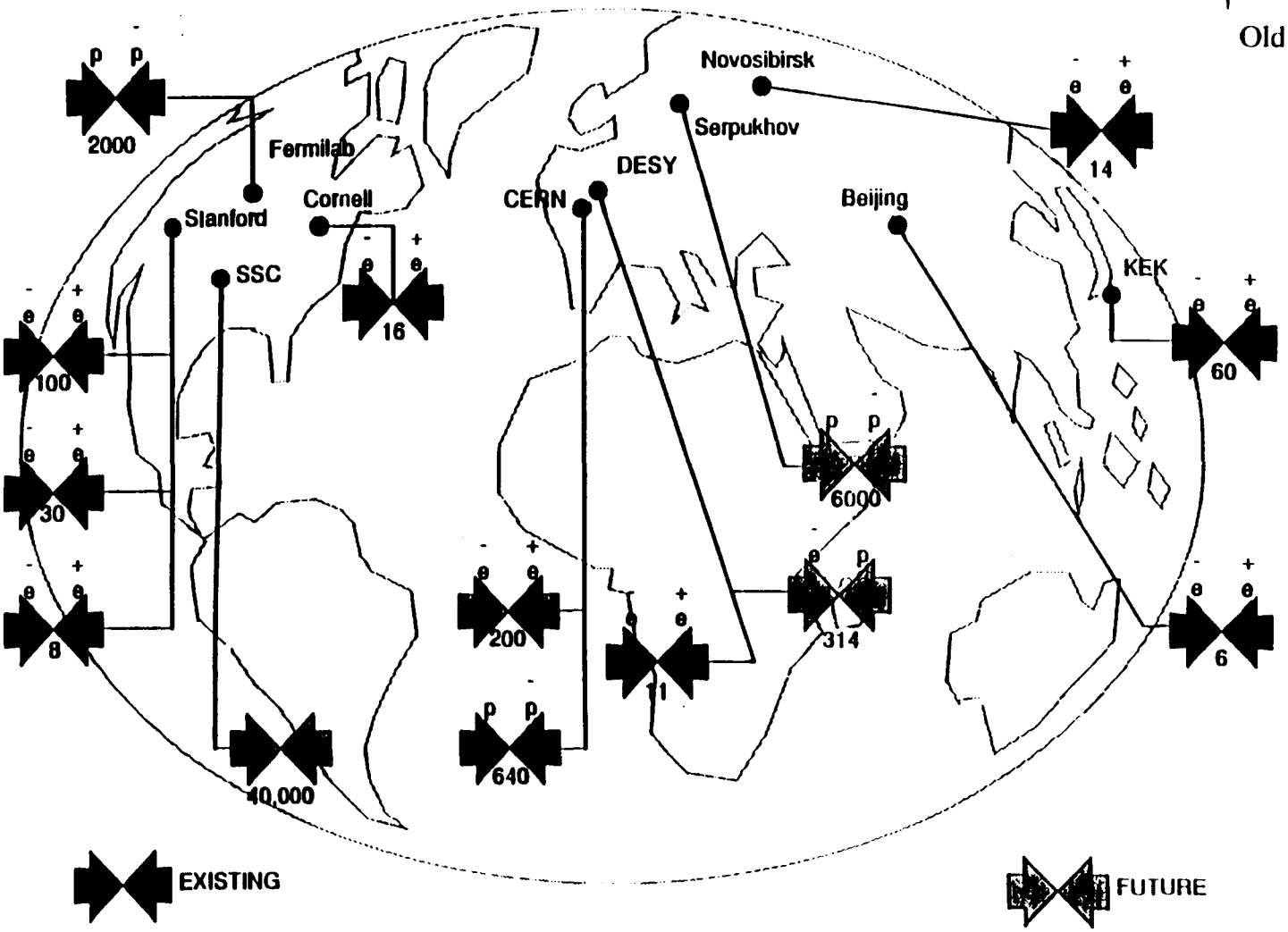
SSC Justification

- **Beam Focus, Collimation at TeV Energies**
- **Luminosity**
- **Pulsed neutrino source, clearer understanding of pure and mixed eigenstates of the source**

Colliding Beam Accelerators †

(E.g. John Ellis, Ref. 22)

† Old Chart



NASA Feasibility Study of Neutrino Experiment (ILSE) †

- **Prepare a preliminary conceptual desgin of the ILSE experiment.**
- **Relate ILSE to SSC goals and objectives.**
- **Present report to SSCL (Gilman *et al.*).**
- **Establish Users' Group?**

† Today's presentation is not a proposal.

– Addenda –

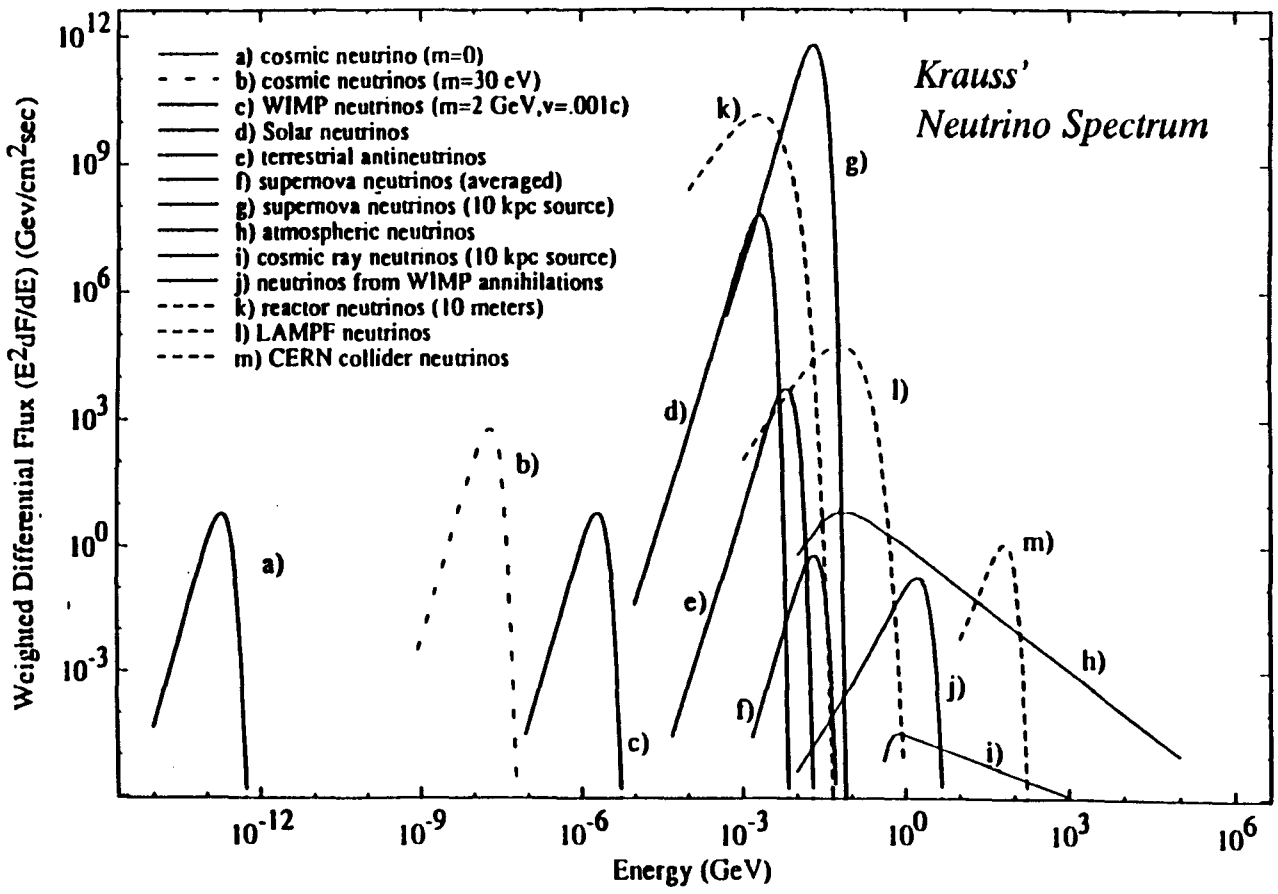
Neutrino Spectra, Detectors, & Proton Decay

Conceptual SEI Space Physics Strategy

– References –

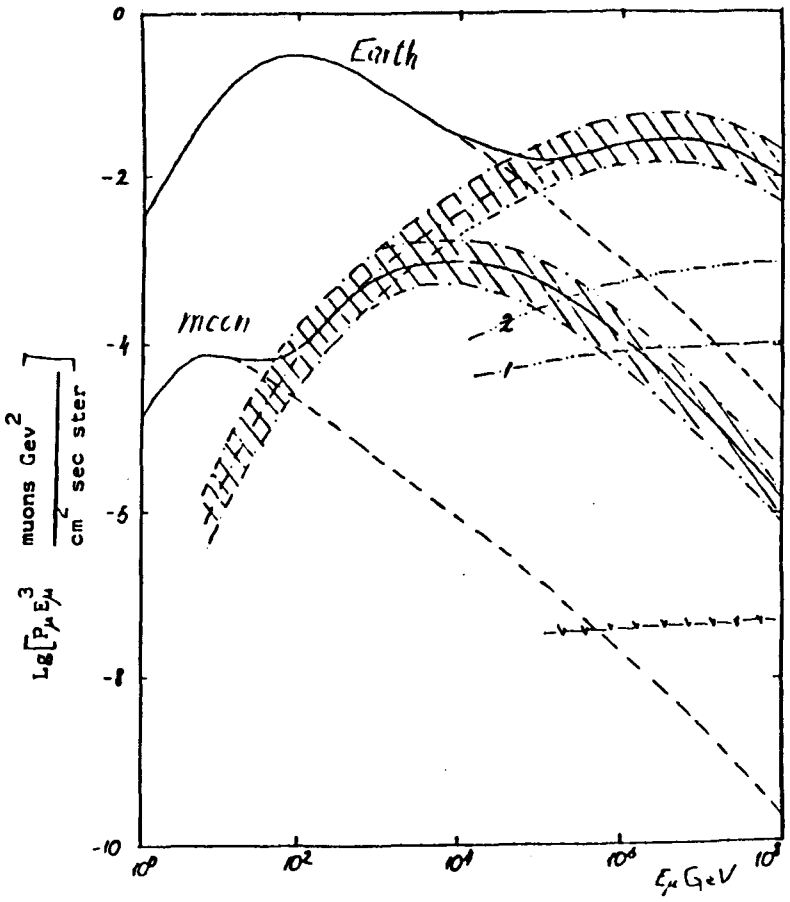
Laboratory & Astrophsyical Neutrino Sources

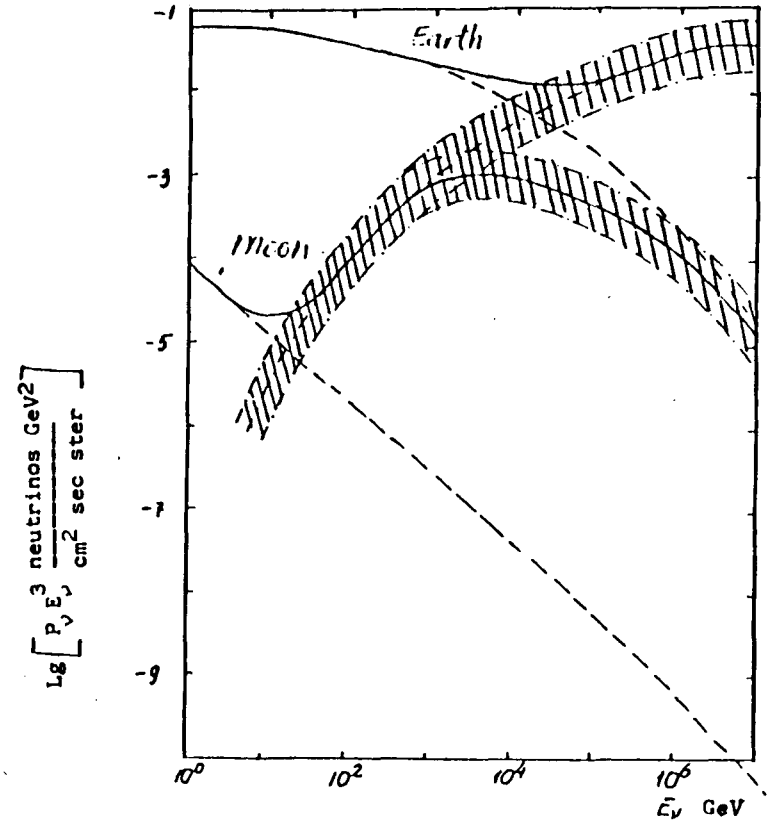
(Reference 23)



Charm & The Lunar Surface

(Reference 24)





Neutrino Detection Techniques

(Reference 25)

TABLE 1

NEUTRINO DETECTION TECHNIQUES

$E_\nu \sim 10^{-3}$ eV – Coherent Interactions with many nuclei

individual σ $[(e^+ e \rightarrow \nu_e + e)\ \sigma \sim 10^{-62}\ cm^2]$

(Relic ν)

Coherent $\sigma \propto N^2$, $N = \text{nuclei in sample}$

but detection very difficult!

$E_\nu \sim$ KeV - MeV – Neutrino Processes

$\sigma \sim 10^{-45} - 10^{-44}\ cm^2$

- ν_e + Nucleus $\rightarrow$ N′ + e

  (eg. $\nu_e + C\ell \rightarrow Ar + e$ – Homestake)

- $\nu_e + e \rightarrow \nu_e + e$

  $\nu_{\mu,\tau} + e \rightarrow \nu_{\mu,\tau} + e$

(Solar Neutrinos)

Coherent $\nu_x + N \rightarrow \nu_x + N$

E_ν 10 – 100 MeV

(Supernova ν detectors – Diffuse $\nu,\bar{\nu}$ in window)

$\bar{\nu}_e$: $\bar{\nu}_e + p \rightarrow e^+ + n\ \sigma \sim 10^{-40}\ cm^2$

ν_e: $\nu_e + N \rightarrow e^- + N'$

ν_x: $\nu_x + N \rightarrow \nu_x + N'_{\rightarrow n,\gamma}$

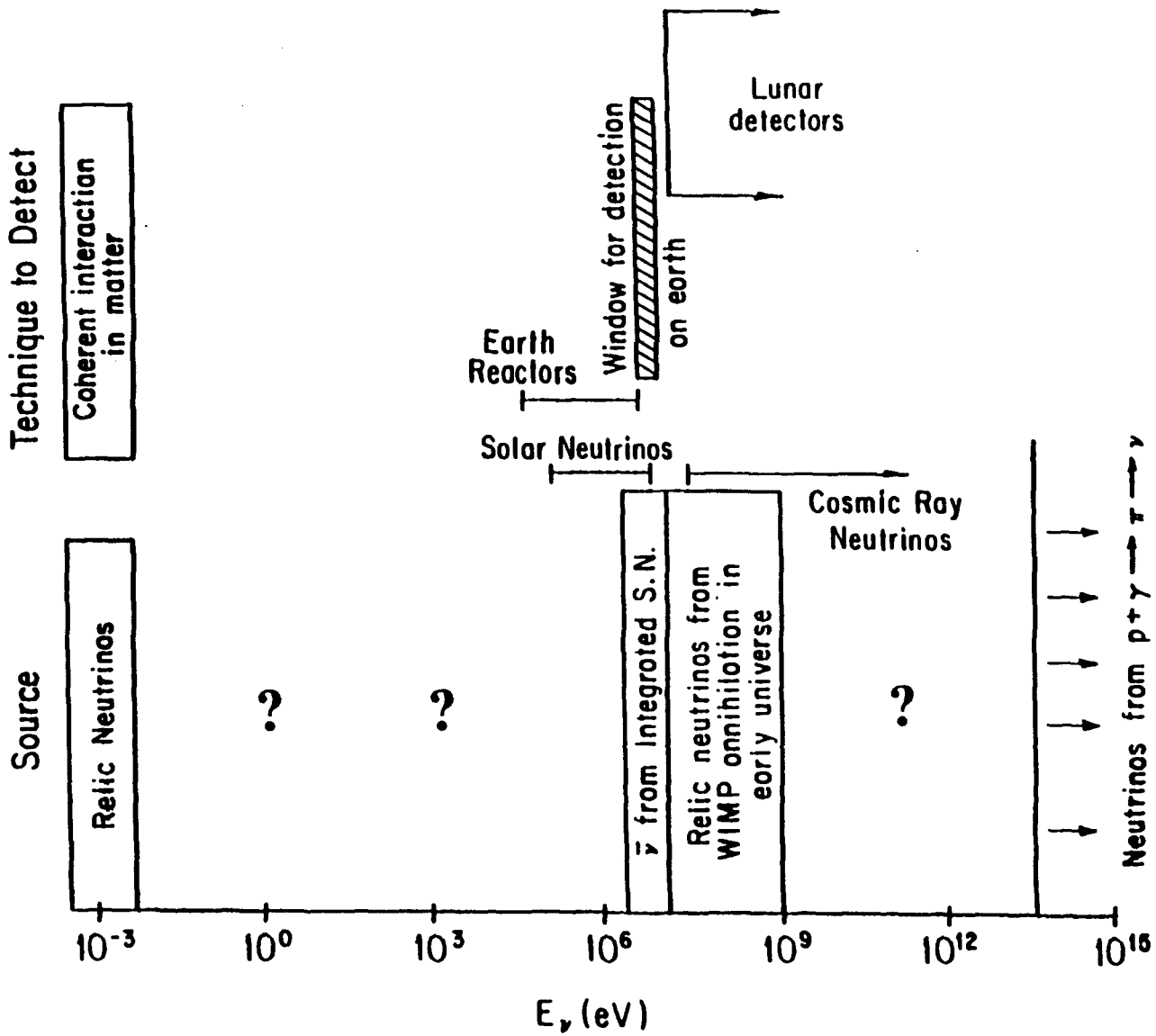
$E \gtrsim 100$ MeV – GeV

$$\left.\begin{array}{l} \nu_e + N \rightarrow e + x \\ \nu_\mu + N \rightarrow \mu + x \\ \nu_x + N \rightarrow \nu_x + x \end{array}\right\} \sigma \sim 10^{-38}\ cm^2$$

E >> GeV – Large Water Detector – DUMAND for example

Diffuse Astrophysical Neutrinos – Detection

(Reference 25)



Proton Decay On The Moon (Pati & Salam)

(References 16 and 26)

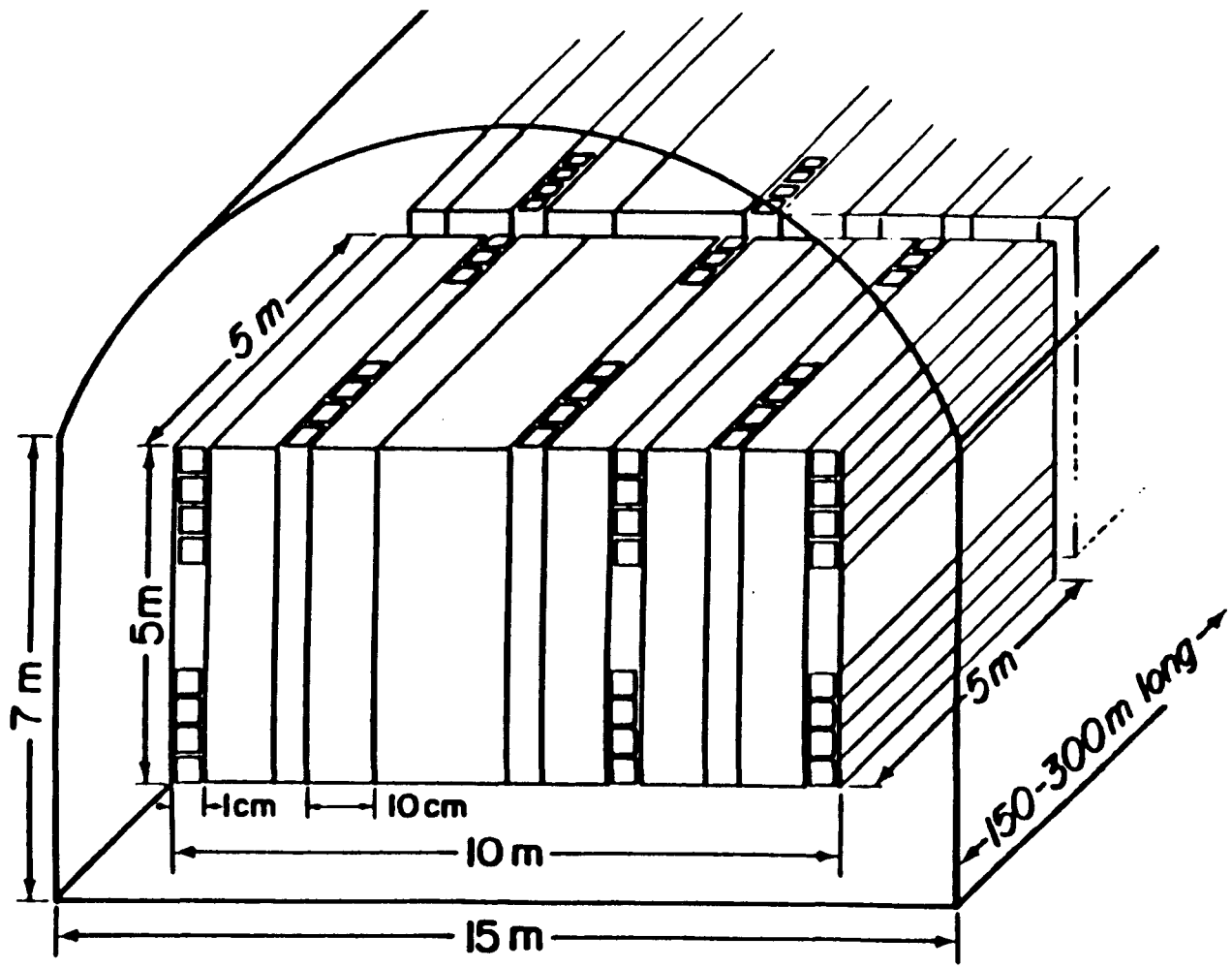
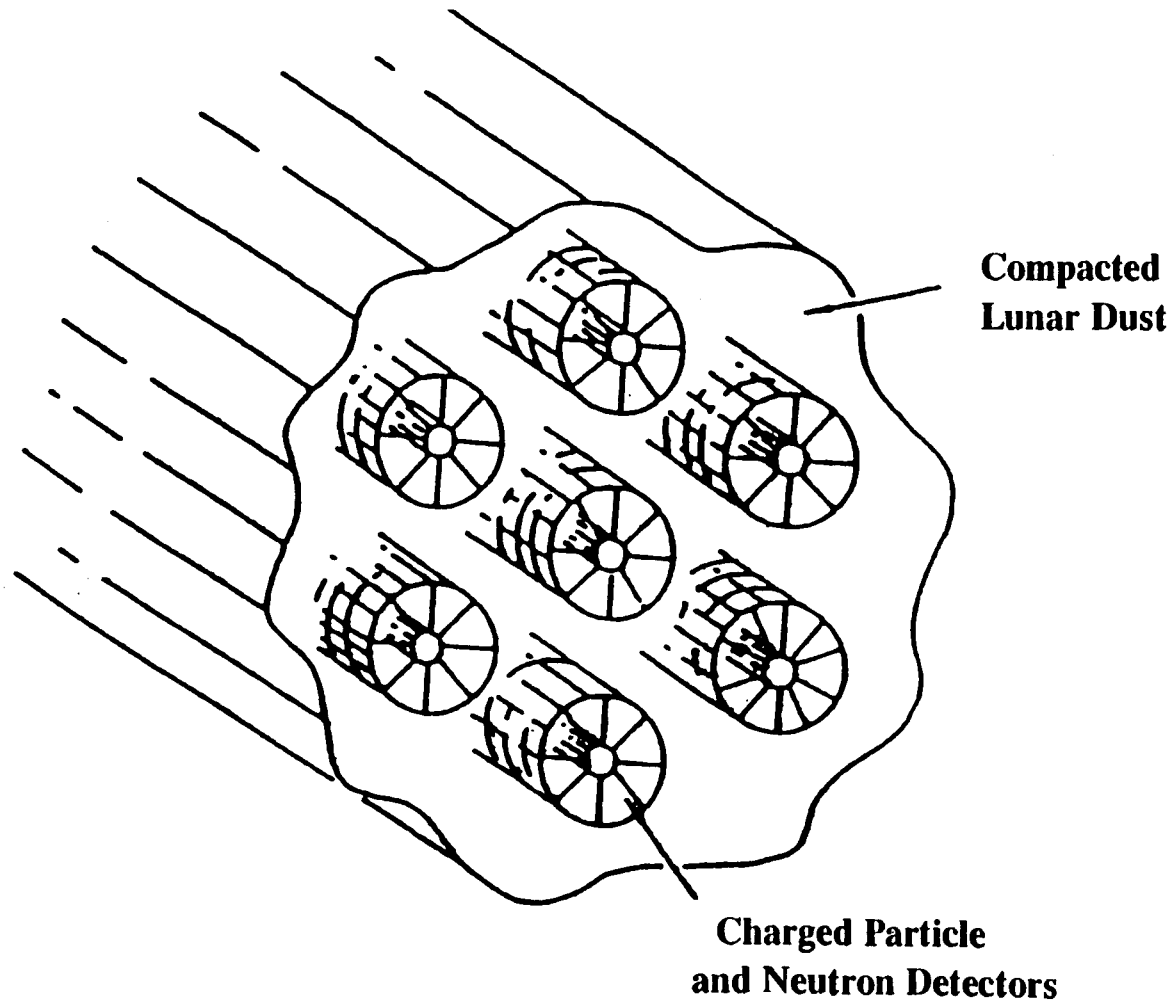


Fig. 1

Proton Decay & Supernova Neutrino Detector at a Lunar Base (Schematic)

(References 16 & 25)

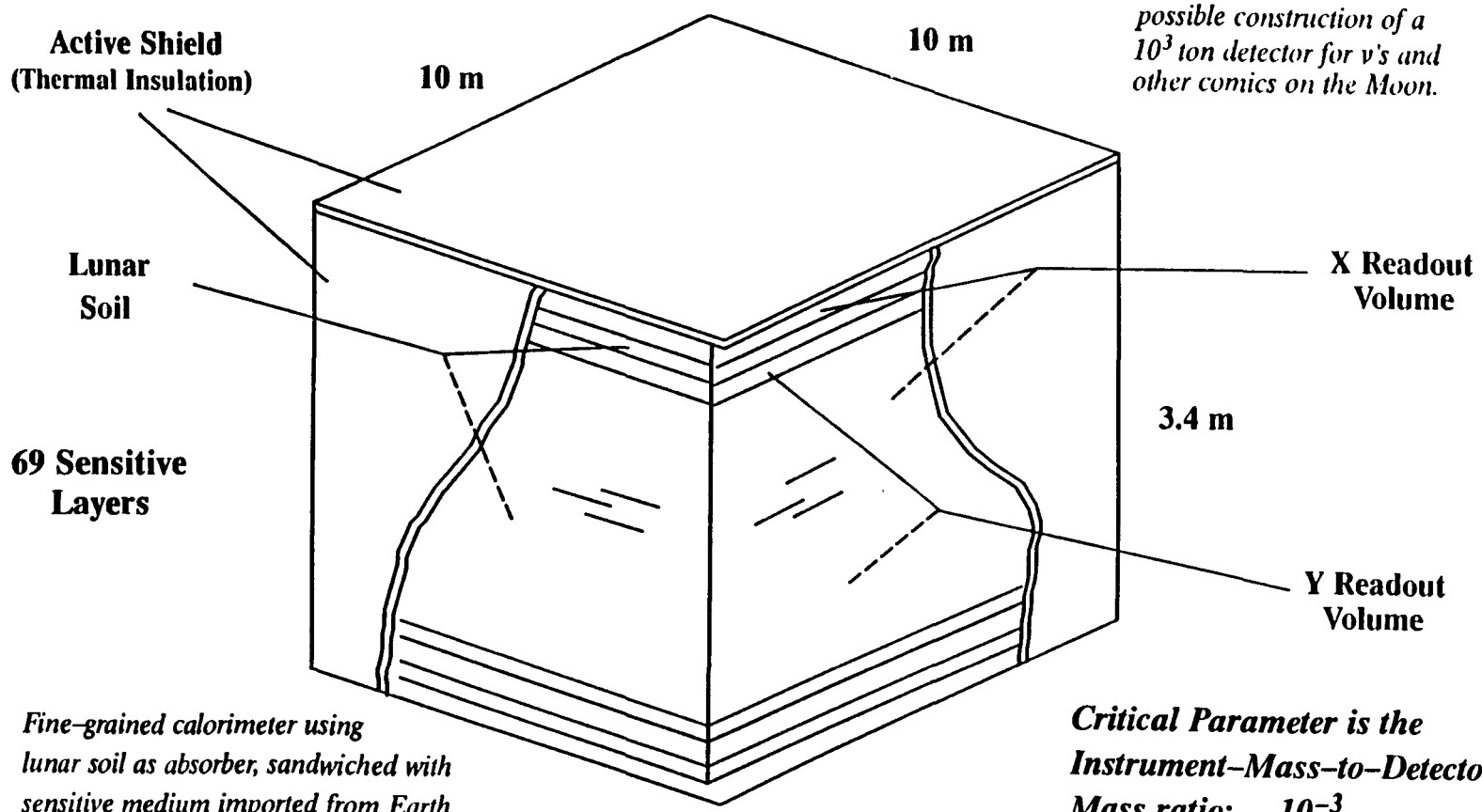


Monoco

(Moon Observatory for Neutrinos And Comics)

(Reference 25)

Speculations about the possible construction of a 10^3 ton detector for ν's and other comics on the Moon.

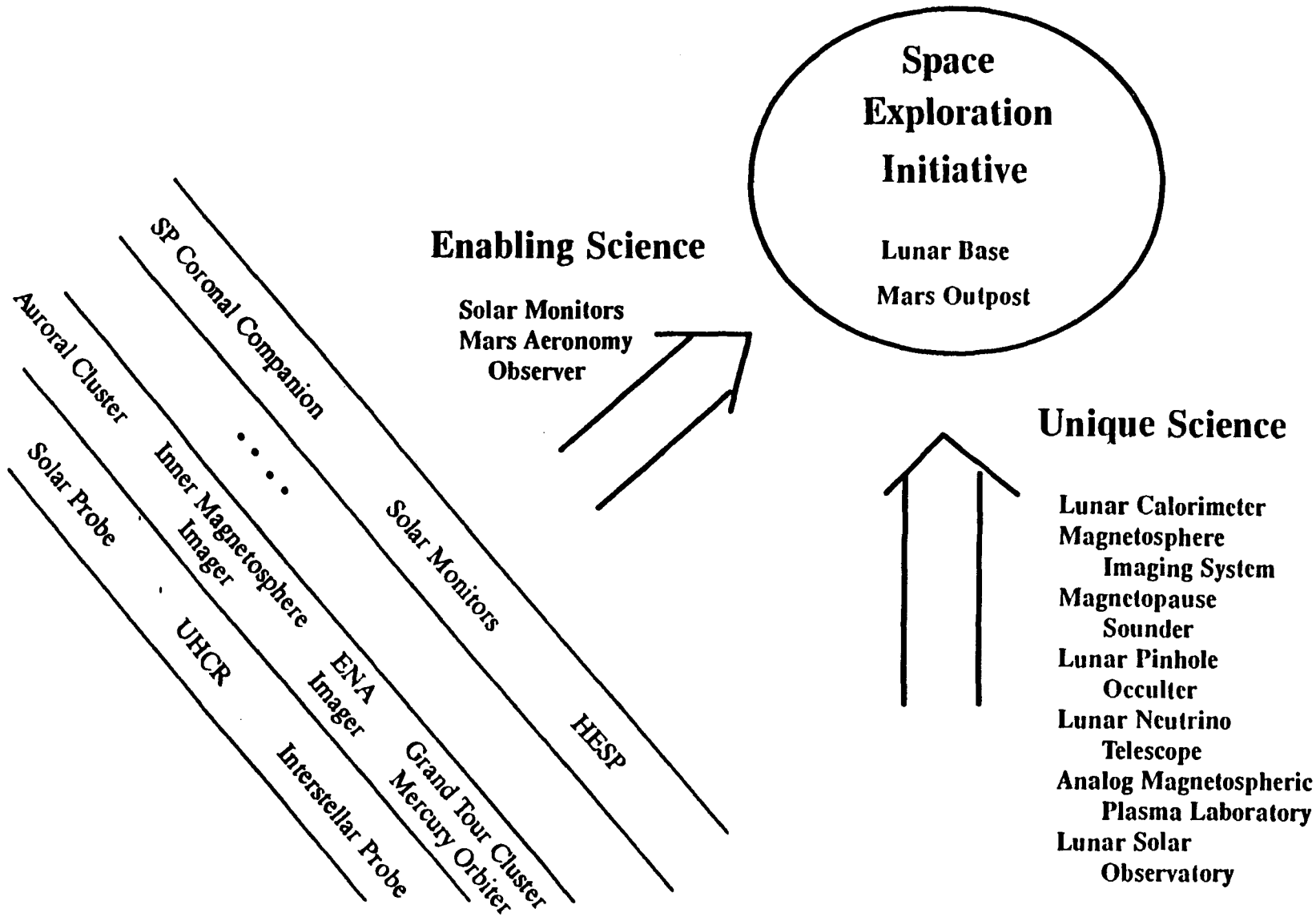


Fine-grained calorimeter using lunar soil as absorber, sandwiched with sensitive medium imported from Earth. (Cf. Nusex, Kolar)

Critical Parameter is the Instrument-Mass-to-Detector-Mass ratio: $\sim 10^{-3}$.

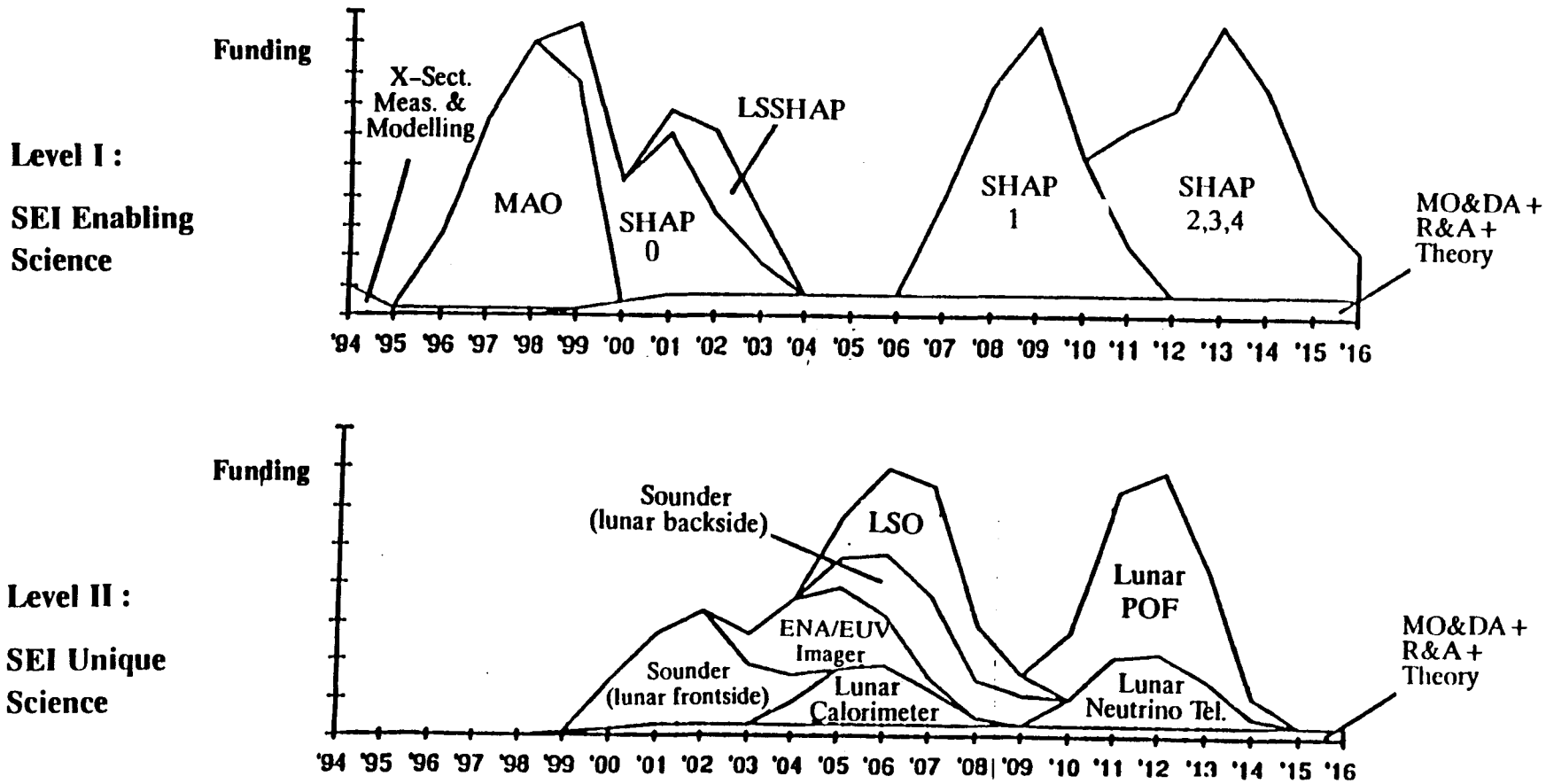
Conceptual SEI Space Physics Strategy

(Reference 27)



Conceptual Space Physics Phasing

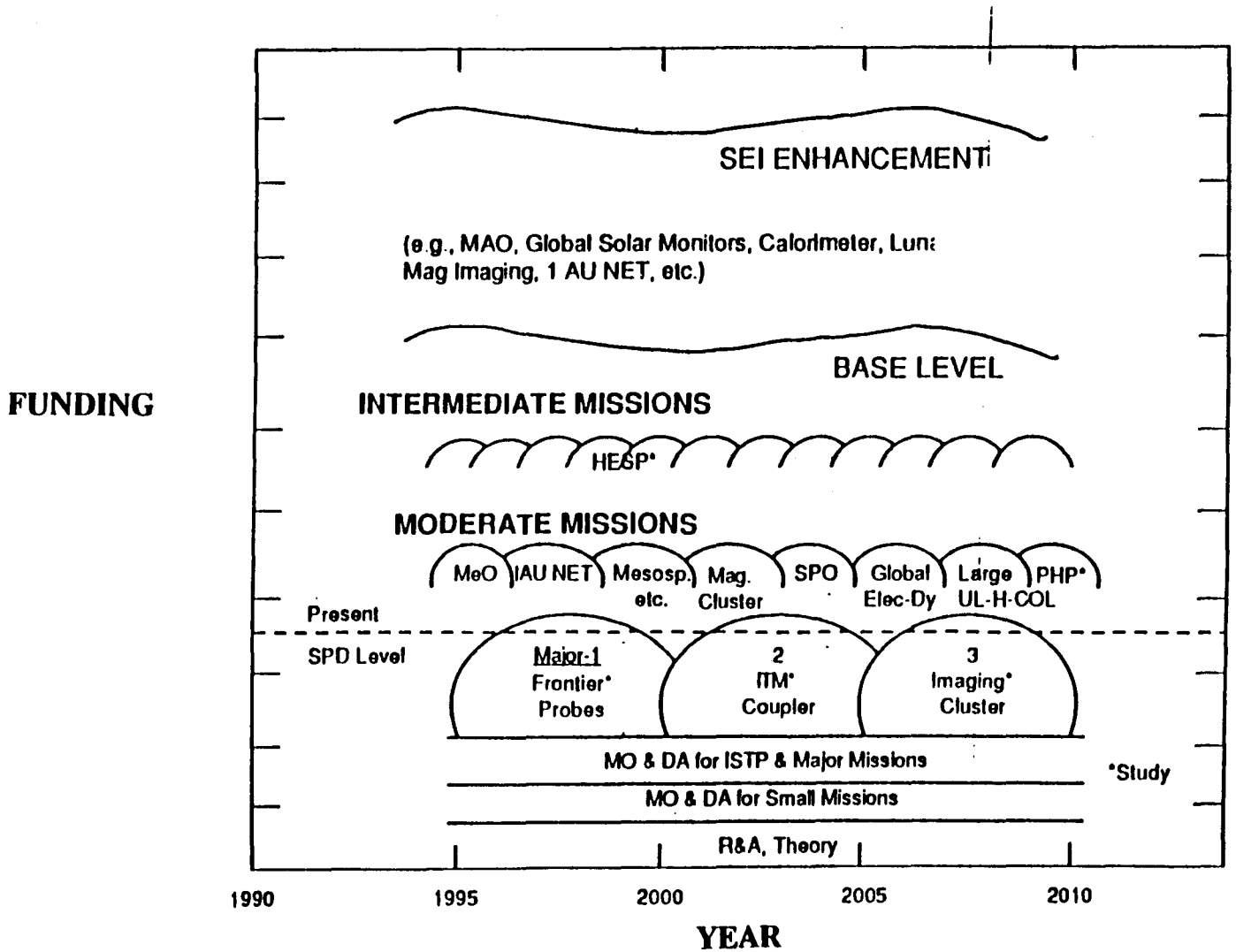
(Reference 27)



Assumes: Lunar Outpost – 2005, Mars Landing – 2019

Conceptual Space Physics Funding

(Reference 27)



SSC Elevation Summary

(Reference 28)

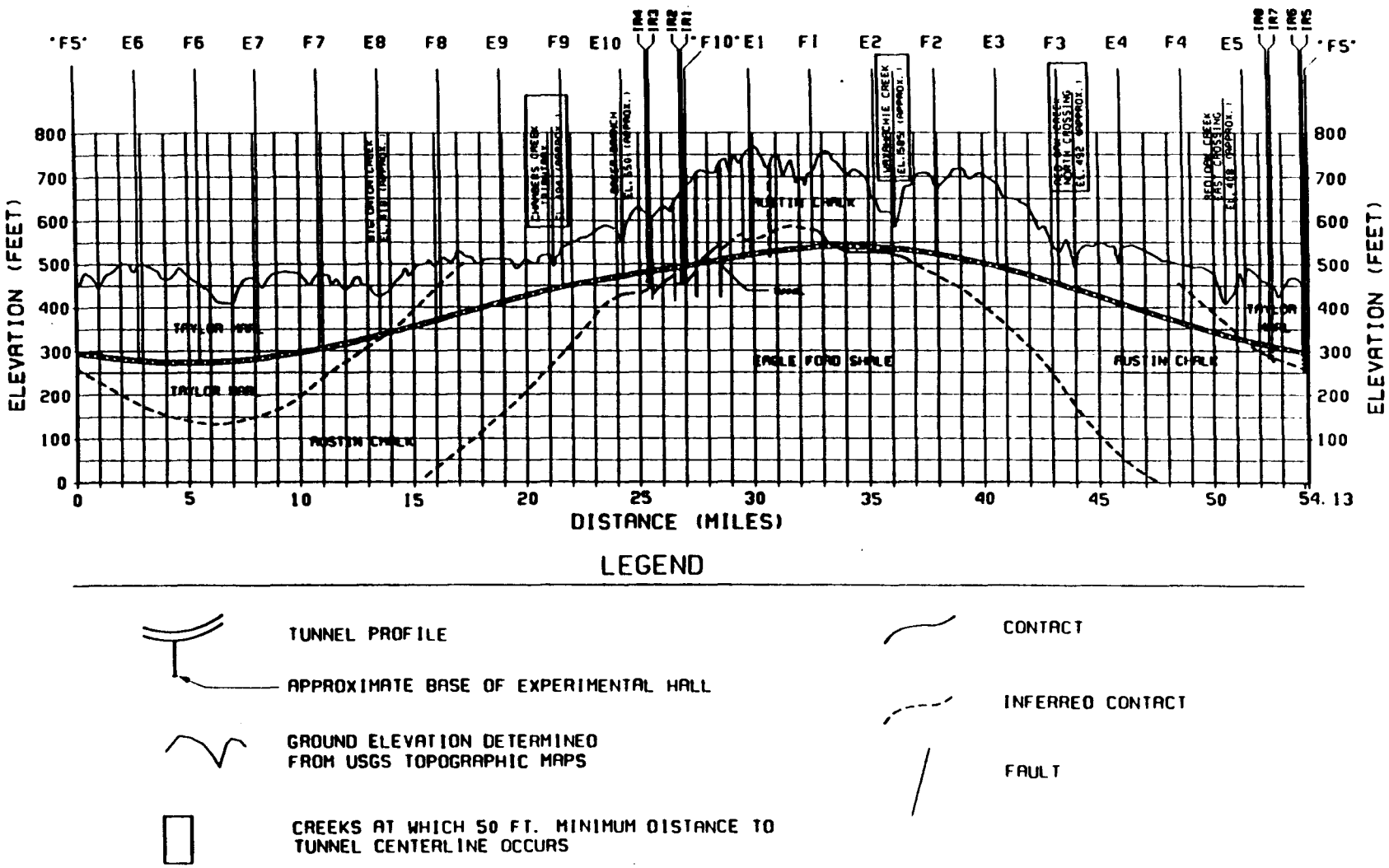
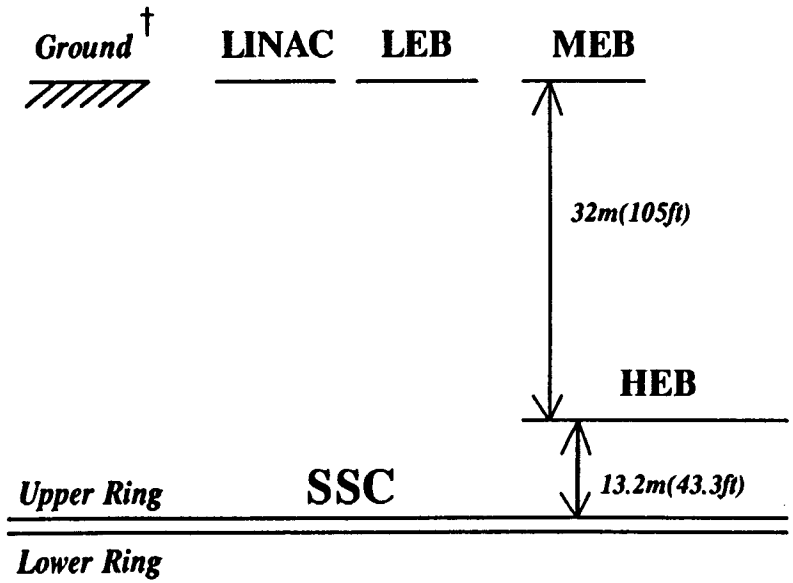


Figure 3.1.2-2. Schematic rendering of collider ring relative to Ellis County geology.

Elevation/Depth Summary
(Relative to the LINAC)

(Reference 28)



Facility	Depth (ft)	Depth (m)	Delta (ft)	Delta (m)	Elevation (ft)	Elevation (m)
Ground †	~0	~0			668.0	203.6
32m(105ft)			105	32		
HEB	105	32			563.0	171.6
13.2m(43.3ft)	148.3	45.2	43.3	13.2		
Upper Ring					519.7	158.4
Lower Ring					517.1	157.6

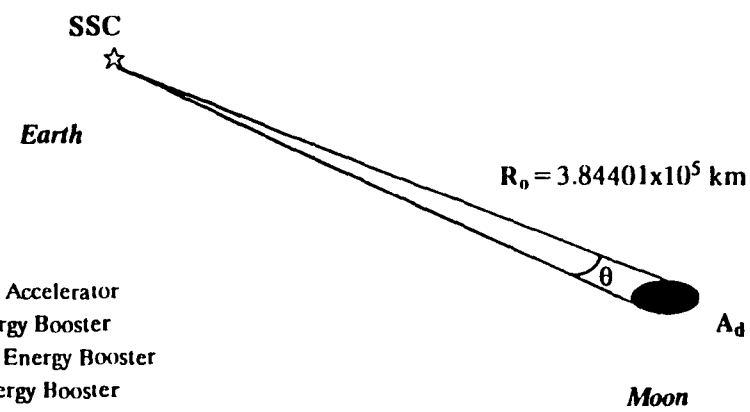
† LINAC is at ground level [SSCL "Site-Specific Conceptual Design," Page 605 (July 1990)].

Pion-to-Neutrino Beam Geometries

$$[\ \theta = m_\pi c^2/E_\nu\ ]$$

Facility	Energy (GeV)	E_ν^2 (GeV^2)	θ (rad)	$l = R_0\theta$ (km)	$A_d = \pi l^2/4$ (km^2)
LINAC	0.1395674†	0.0194791	1.0	3.84401×10^5	1.160537×10^{11}
	0.6	0.36	2.326123×10^{-1}	8.94164×10^4	6.279488×10^9
LEB	11.1	1.2321×10^2	1.25736×10^{-2}	4.8333×10^3	1.834752×10^7
	100	10^4	1.395674×10^{-3}	5.364985×10^2	* 2.260616×10^5
MEB	100	10^4	1.395674×10^{-3}	5.364985×10^2	2.260616×10^5
	200	4×10^4	0.697837×10^{-3}	2.682492×10^2	5.65154×10^4
HEB	200	4×10^4	0.697837×10^{-3}	2.682492×10^2	5.65154×10^4
	2,000	4×10^6	0.697837×10^{-4}	2.682492×10^1	5.65154×10^2
SSC	2,000	4×10^6	0.697837×10^{-4}	2.682492×10^1	5.65154×10^2
	20,000	4×10^8	0.697837×10^{-5}	2.682492	5.65154
	40,000	1.6×10^9	0.348919×10^{-5}	1.341246	1.412885

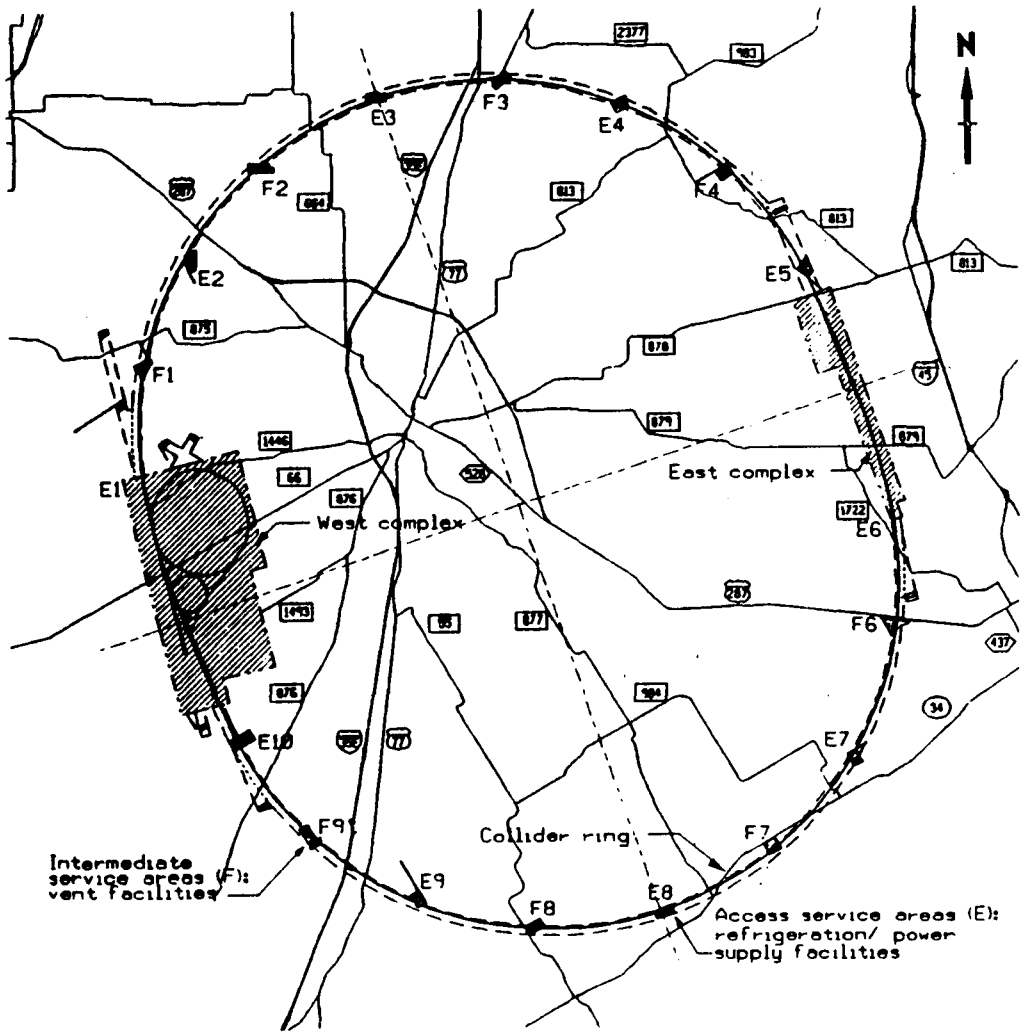
†Pion rest-mass energy [Particle Data Group: Physics Letters B239 (1990)].



LINAC = Linear Accelerator
LEB = Low Energy Booster
MEB = Medium Energy Booster
HEB = High Energy Booster
SSC = Superconducting Super Collider
* Area of Moon = 9.49450×10^6 km^2

SSC Remote Site Allocations

(Reference 28)



DOE property ownership

Stratified fee estate

Figure 6.1.1-1. SSC land areas.

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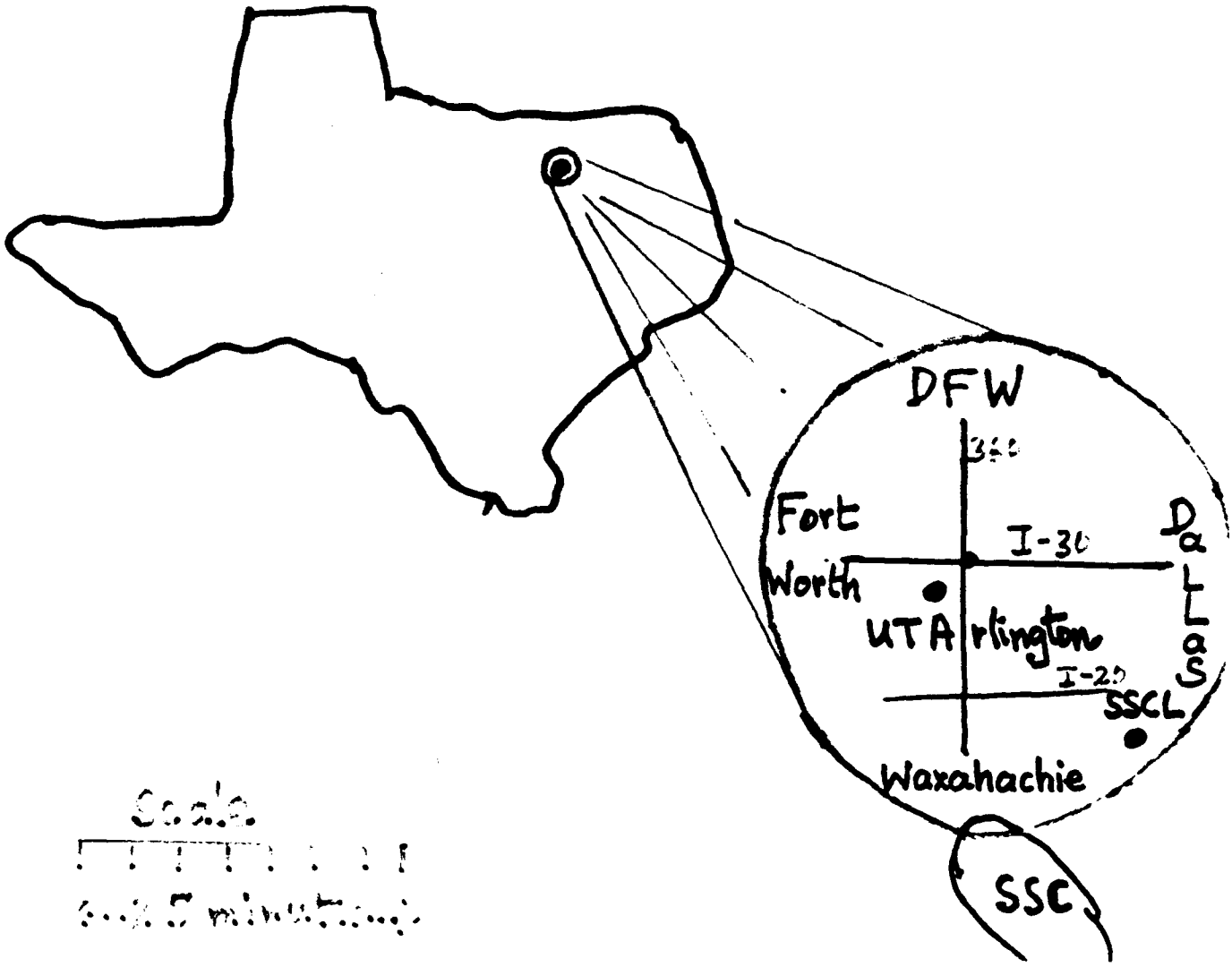
SOLAR NEUTRINOS:

THEORETICAL OVERVIEW.

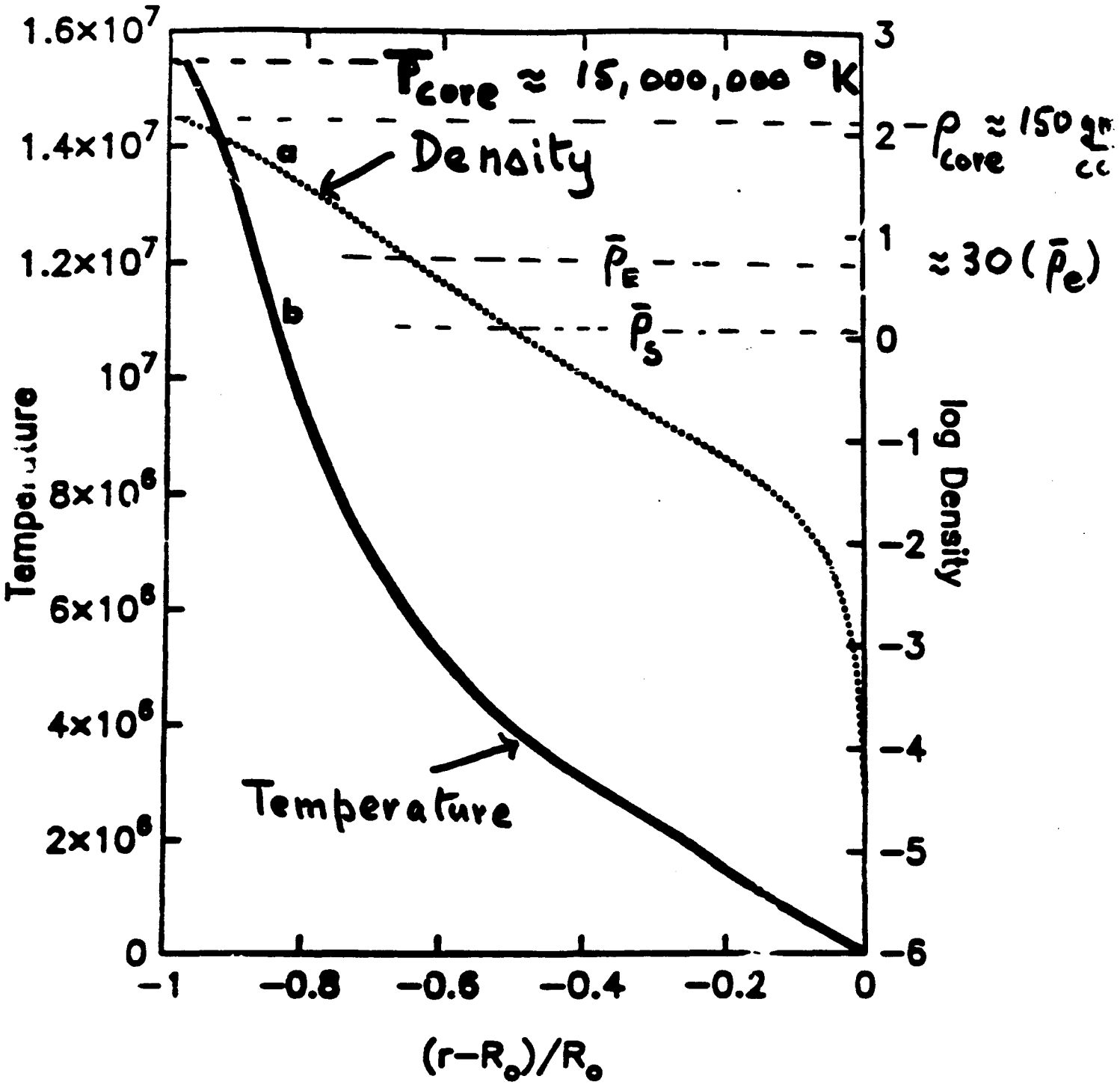
S. PETER ROSEN

The University of Texas

at Arlington



Standard Solar Model



2. Solar Neutrino Spectrum

TABLE I. The proton-proton chain. The numbers in parentheses are the percentages of terminations of the chain in which various reactions are calculated to occur for the standard solar model discussed in Sec. III.

	Reaction	% of terminations	Maximum neutrino energy (MeV)
pp	$p+p\rightarrow {}^2H+e^++\nu$	(99.75)	≤ 0.420 } $2\nu_e$ for ~27 MeV in $4p \rightarrow {}^4He$
	or		
	$p+e^-+p\rightarrow {}^2H+\nu$	(0.25)	1.44(monoenergetic)
	${}^2H+p\rightarrow {}^3He+\gamma$	(100)	
I.	${}^3He+{}^3He\rightarrow {}^4He+2p$	(86)	
	or		
II.	${}^3He+{}^4He\rightarrow {}^7Be+\gamma$		
${}^7Be$	${}^7Be+e^-\rightarrow {}^7Li+\nu$	(14)	0.861 (90%), 0.383 (10%) (both monoenergetic)
	${}^7Li+p\rightarrow 2{}^4He$		
	or		
III.	${}^7Be+p\rightarrow {}^8B+\gamma$		
${}^8B$	${}^8B\rightarrow {}^8Be^*+e^++\nu$	(0.015)	14.06
	${}^8Be^*\rightarrow 2{}^4He$		

$6\times 10^{10}\ \nu/cm^2 sec$

$\phi(pp) \sim T_c^{-1.2}$

T_c = core Temperature

flux $= 4.7\times 10^{9}$ $\nu/cm^2 sec$

$\phi({}^7Be) \sim T_c^{8}$

flux $\approx 5.1\times 10^{6}$ $\nu/cm^2 sec$

$\phi({}^8B) \approx T_c^{18}$

Mix of those components changes with core Temperature

$T_c = 1.56\times 10^7\ {}^\circ K \rightarrow 1.55\times 10^7 \Rightarrow \delta\phi({}^8B) \approx 15\%$

$\Delta T_c \sim 0.6\%$

From Bahcall and Ulrich RMP 60, 297 (1988)

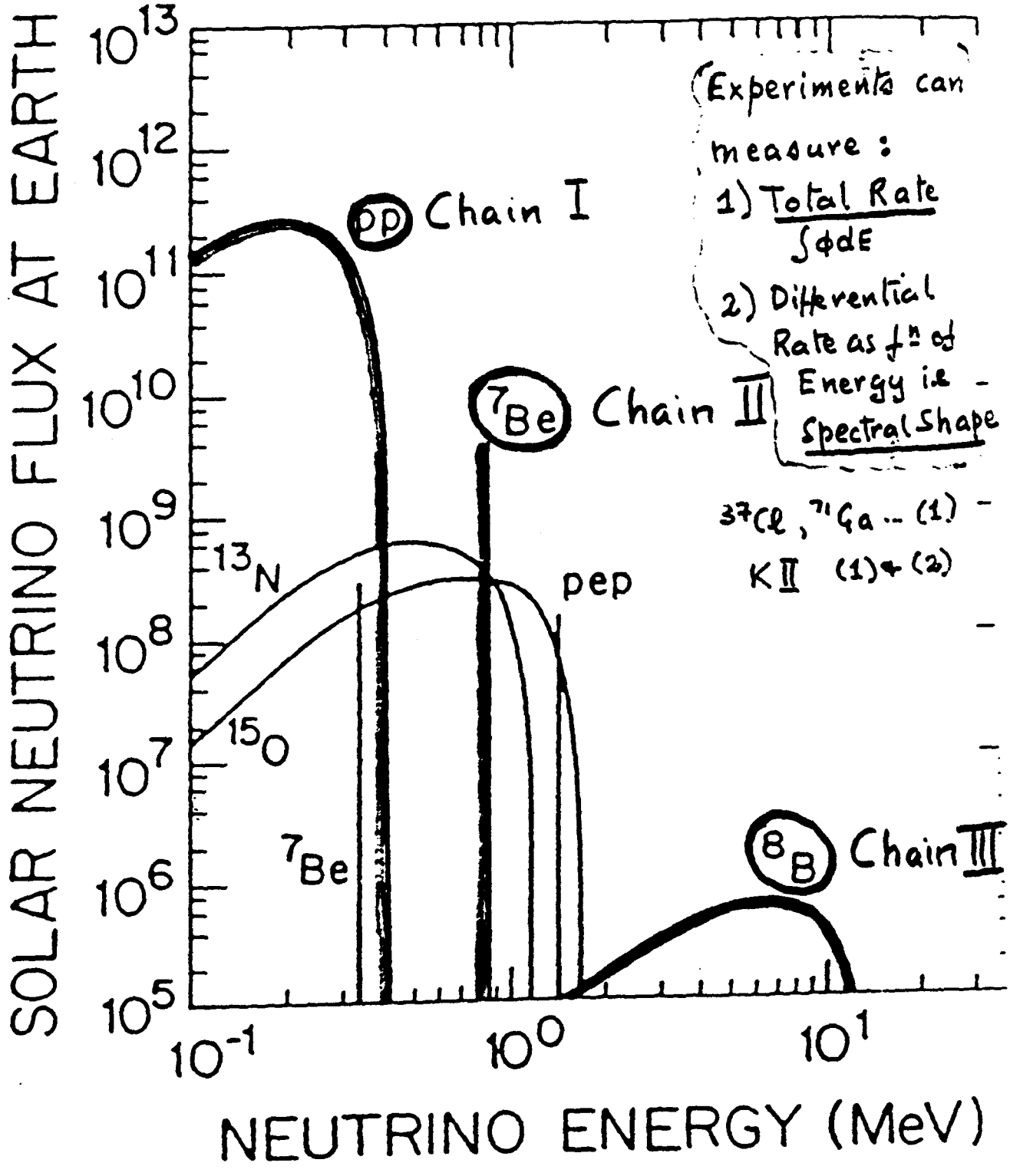


Figure 1. The energy spectrum of solar neutrinos predic by the standard solar model. For monochromatic sources height of the line represents the integrated flux.

Importance of Measuring Spectral Shape : $P(\nu_e \to \nu_e)$ as function of Energy.

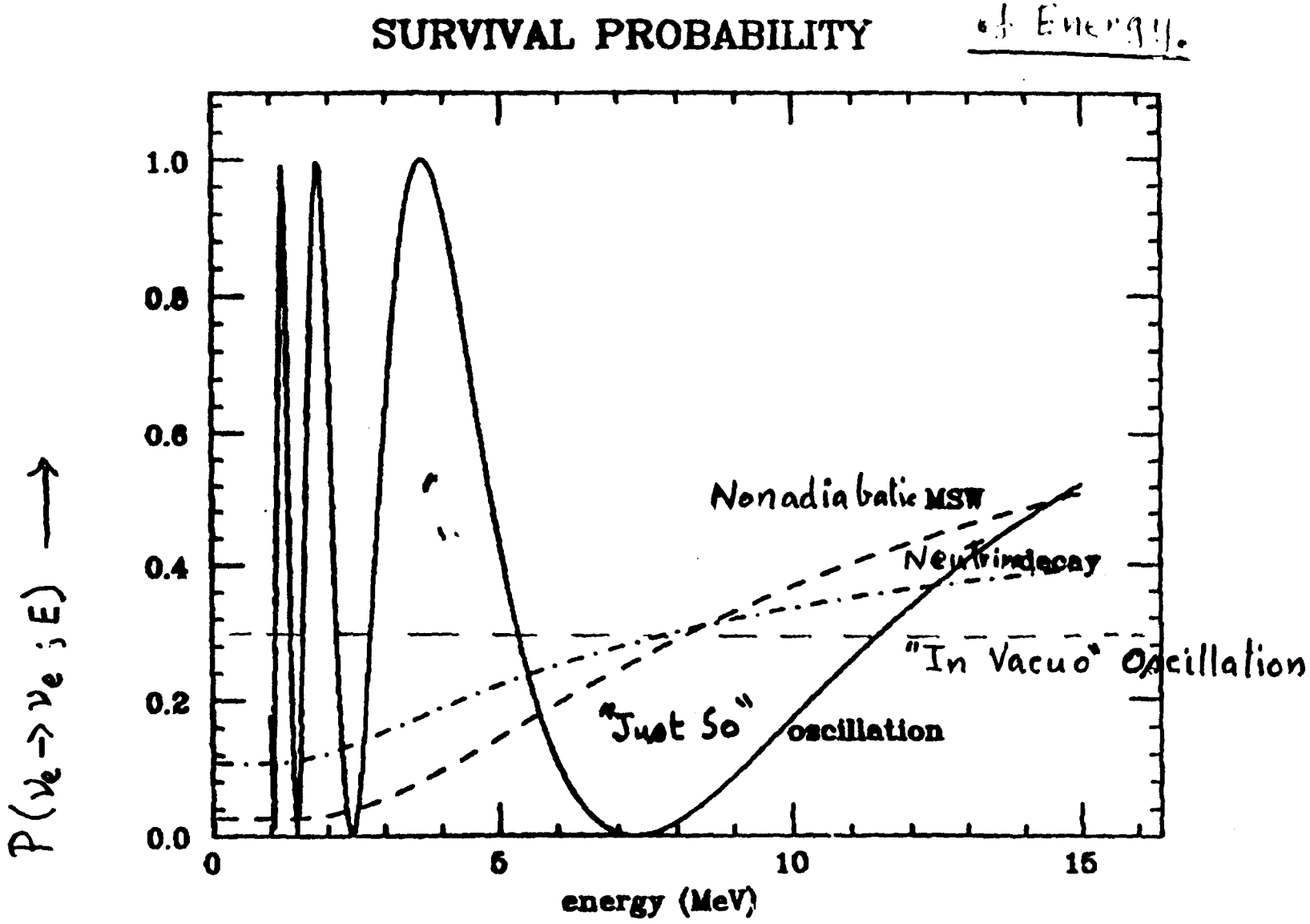


Fig. 1

Adapted from:
Heker, Pakvasa, Parke, Perkins

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3) Standard Solar Model Predictions

Target \ Neutrino	pp	^7Be	^8B	OTHER	TOTAL
^{37}Cl	0	1.1	6.1	0.7	7.9 SNU
^{71}Ga	70.8	34.3	14.0	12.9	132 SNU
K II	•	•	4	•	4 events/wk

- Reduction in ^{37}Cl and K II could arise from a reduction in core temperature T_c.
- pp neutrino flux fixed by solar luminosity; ∴ Reduction in ^{71}Ga below 71 SNU must arise from neutrino properties.
- K II "sees" ^8B $\nu_e \to \nu_e$ via (C.C. + N.C.) and ^8B $\nu_e \to \nu_{\mu,\tau}$ through N.C. alone $\sigma(C.C.+N.C.) \simeq (6-7)\,\sigma(N.C.)$

1) Very Brief Review of Data

a) ^{37}Cl

$$\langle \text{signal} \rangle_{\sim 30\,\text{yrs}} = 2.2 \pm 0.3 \text{ SNU}$$ Davis

$$\text{SSM Prediction} = 7.9 \pm 2.6$$ Bahcall, Ulrich

$$= 5.8 \pm 1.3$$ Turck-Chièze ....

b) K II : ν_e e scattering

- $$\frac{\langle \text{signal} \rangle_{\sim 1100\,\text{days}}}{\text{SSM}} = 0.46 \pm 0.05 \pm 0.06$$
- Some spectral data

c) ^{71}Ga

Expect 18 events in SSM : See none

$$< 70 \text{ SNU} \quad (68\%)$$

Either some exptl problem, or very few events : Assume the latter.

CAN WE EXPLAIN THE DISCREPANCY?

Properties of the Neutrino

or

Revise our model of the Sun.

Neutrino Properties which could explain discrepancy:

1) Neutrino $\boxed{\text{Decays}}$ on way from Sun.

- Requires neutrino to have mass. Ruled out by SN 1987A: much farther away than Sun

2) Neutrino behaves like tiny $\boxed{\text{magnet.}}$

polarity reversed by magnetic fields inside the Sun.

- Requires neutrino to have mass. Could explain apparent anti-correlation with Sunspot Cycle.

  $\boxed{\text{But}}$ hard to make a theory for this magnet.

3) Neutrino Oscillations.

Change of ν_e, into $\nu_{\mu,\tau}$ lowers signal.

- Requires neutrino to have mass.

Changes in Solar Model which could explain discrepancy.

Basic Strategy:

- Production of Chain III (^8B) neutrinos very sensitive to temperature in core of sun: varies like $(T_c)^{18}$!
- $\therefore$ $\boxed{\text{Small}}$ decrease in temperature (say by 7-8%) leads to a $\boxed{\text{Large}}$ decrease in Nº of Chain III neutrinos
- Decrease temperature by transport of heat away from core more efficiently than in standard model.

Several ways to do this:

But must also account for solar oscill.

4) In Vacuo Neutrino Oscillations

Two Flavor Case:

Flavor eigenstates

$$\nu_e(t) = \nu_1 e^{-iE_1 t}\cos\theta + \nu_2 e^{-iE_2 t}\sin\theta$$

$$\nu_\mu(t) = \nu_1 e^{-iE_1 t}(-\sin\theta) + \nu_2 e^{-iE_2 t}\cos\theta$$

Mass Eigenstates

- Common momentum $p \gg m_1, m_2$

$$E_2 - E_1 = \left(\frac{m_2^2 - m_1^2}{2p}\right) = \frac{\Delta m^2}{2p}$$

- Oscillation Length:

$$\begin{pmatrix} L = 1\,\text{Au},\ p = 10 \\ \Delta m^2 = 1.74\times10^{-10}\,\text{eV}^2 \end{pmatrix} \quad L = \frac{4\pi p}{\Delta m^2} \equiv 2.5\left(\frac{p\,\text{MeV}}{\Delta m^2\,\text{eV}^2}\right)\text{Meters}$$

- Probabilities for neutrino flavors distance R from S:

$$P(\nu_e \to \nu_e; R) = 1 - \sin^2 2\theta \sin^2\left(\frac{\pi R}{L}\right)$$

$$P(\nu_e \to \nu_\mu; R) = \sin^2 2\theta \sin^2\left(\frac{\pi R}{L}\right)$$

- $R \gg L$ $\quad (\Delta m^2 \approx 10^{-2} - 10^{-4}\,\text{eV}^2,\ 10^{-8} - 10^{-10}\,\text{eV}^2)$

$$P(\nu_e \to \nu_e) = 1 - \tfrac{1}{2}\sin^2 2\theta = \tfrac{1}{2}\ (\theta = \pi/4) \to 1/n \text{ for } n \text{ flavors}$$

maximal mixing

$$P(\nu_e \to \nu_\mu) = 1/2 \sin^2 2\theta = 1/2\ (\theta = \pi/4)$$

- $R \approx (N+\frac{1}{2})L$ "Just-So"

$\Delta m^2 \approx 2.10^{-10}/(N+\frac{1}{2})\,\text{eV}^2$

$$P(\nu_e \to \nu_e) = 1 - \sin^2 2\theta \ll 1$$

maximal mixing

$R \gg L$ in vacuo Oscillation Solution: three flavors:

Requires Maximal Mixing : $\begin{cases} \text{Contrary to Prejudice} \\ \text{No } \mu \to e\gamma,\ 3e \text{ transitions seen} \end{cases}$

$$^{37}Cl \text{ signal} = \tfrac{1}{3}\,SSM \approx 2.6\ SNU$$

$$K\,II \text{ signal} = \frac{1}{3}\,SSM + \frac{2}{3}\,\frac{\sigma_{NC}(\nu_\mu e)}{\sigma_{CC+NC}(\nu_e e)} \approx \frac{1}{3} + \frac{2}{3}\cdot\frac{1}{6} \approx 0.44$$

Implies $^{71}Ga = \frac{1}{3}\,SSM = 44\ SNU$

$R = (N + 1/2)L$, two flavors:

Fit ^{37}Cl and $K\,II$, and then compute ^{71}Ga:

$$^{71}Ga \text{ Signal} \approx 45 - 75\ SNU$$

$\begin{cases} A, f, f, \ldots \\ B, f, \ldots \end{cases}$

Thus a gallium signal well below 45 SNU would rule out these possibilities. (Let alone the arguments against large mixing angles).

8-355585-( )

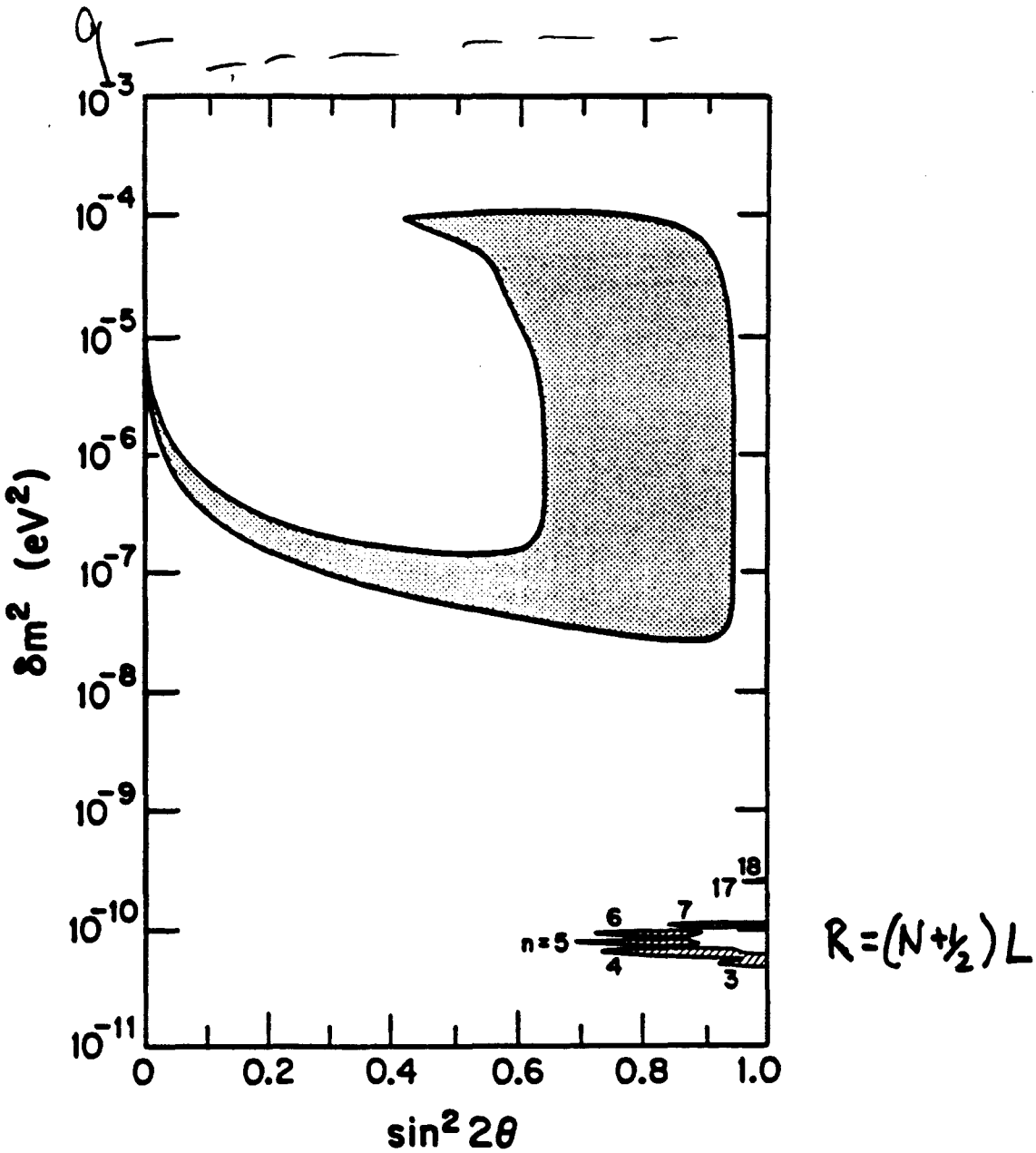


Fig. 16

Neutrino Oscillations – A Phase Phenomenon

$$\nu_e(t) = \nu_1 e^{-iE_1 t}\cos\theta + \nu_2 e^{-iE_2 t}\sin\theta$$

$$\nu_\mu(t) = \nu_1 e^{-iE_1 t}(-\sin\theta) + \nu_2 e^{-iE_2 t}\cos\theta$$

For common momentum $p \gg m_1, m_2$

$$E_2 - E_1 = \left(\frac{m_2^2 - m_1^2}{2p}\right)$$

Probability for $\nu_e \to \nu_\mu$ after distance R:

$$P(\nu_e \to \nu_\mu; R) = \sin^2 2\theta \sin^2(\pi R/L)$$

$$L = \left(4\pi p/m_2^2 - m_1^2\right) = 2.5\left(\frac{p\,\mathrm{MeV}}{\Delta m^2\,\mathrm{eV}^2}\right)\ \text{meters}$$

Refractive Index in MATTER

— Another Phase Phenomenon

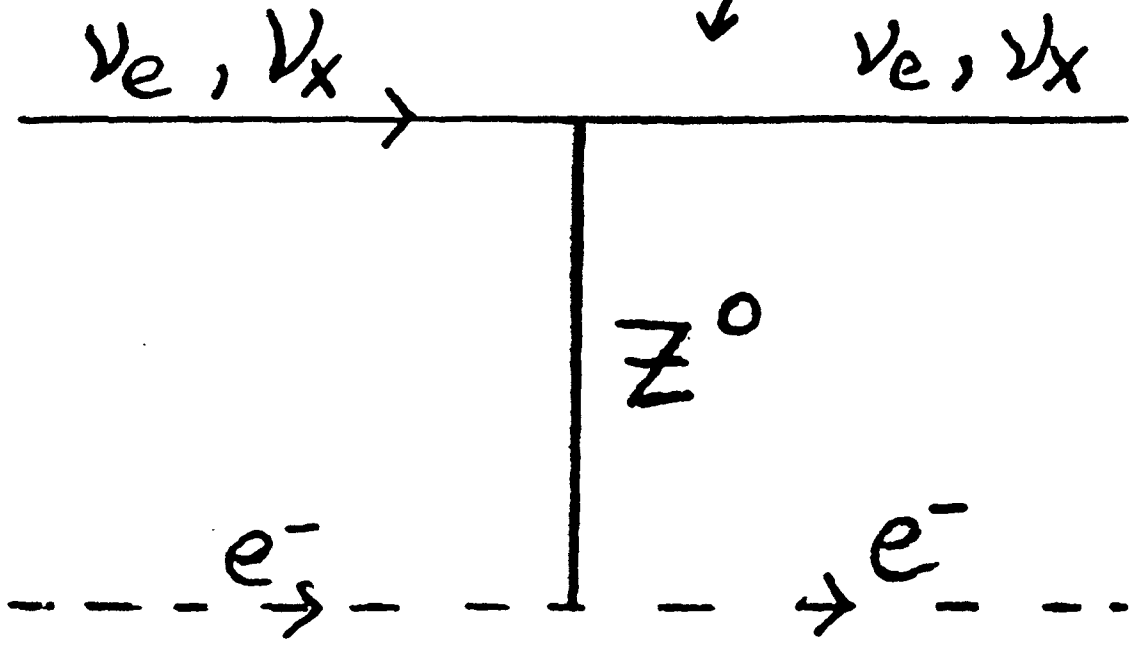
$$e^{ipx\,n_{e,\mu}} \equiv e^{ipx\left(1 + \frac{2\pi N}{p^2} f_{e,\mu}(0)\right)}$$

forward scattering amplitude

$$\boxed{\text{MSW} \equiv \text{Combination of Both Phenomena}}$$

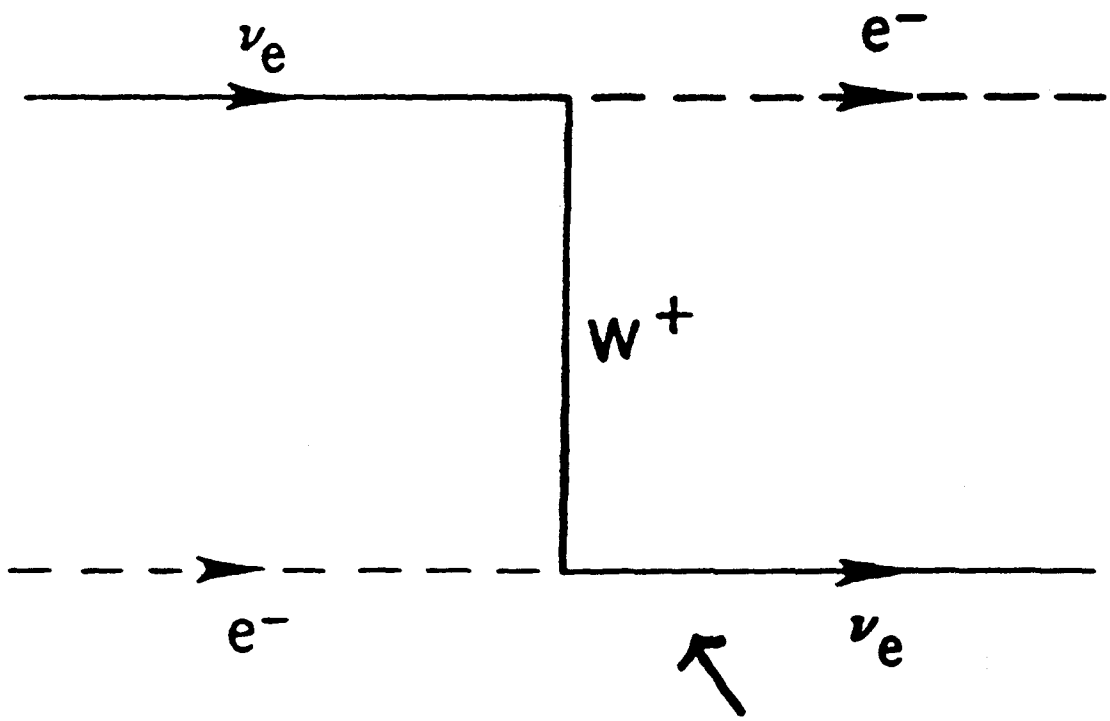
5. Quick Review of MSW

Neutral - Current Diagram for all ν's



$x \equiv \mu, \tau$

Not a sterile neutrino



Charged - Current Diagram only for ν_e.

$\Rightarrow$ { Different refractive index in matter
Larger cross-section for ν-e scattering

Time Development Equation

$$i\frac{d}{dt}\begin{bmatrix} a_e(t) \\ a_x(t) \end{bmatrix} = \overset{\mathcal{M}}{\begin{bmatrix} A, B \\ B, D \end{bmatrix}} \begin{bmatrix} a_e(t) \\ a_x(t) \end{bmatrix}$$

amplitudes for ν_e, ν_x at time t.

In Vacuo Oscillation Terms.

$$A = \frac{1}{2p}(m_1^2c^2+m_2^2s^2) + \sqrt{2}G_FN_e \,,$$

contribution from charged-current diagram.

$$D = \frac{1}{2p}(m_1^2s^2+m_2^2c^2) \,,$$

$c \equiv \cos\Theta$

$s \equiv \sin\Theta$

$$B = \frac{1}{2p}(\Delta m^2)cs \,, \quad \Delta m^2 = m_2^2-m_1^2>0 \,.$$

Resonance Condition: "Tune" matrix $\mathcal{M}$ to maximal mixing. Thus:

$$\boxed{A = D} \quad \text{or} \quad \boxed{\sqrt{2}\,G_FN_e = \frac{\Delta m^2}{2p}\cos 2\Theta}$$

Relation between algebraic signs requires ν_e "lighter" than ν_x

Constant Density N_e :

In Vacuo Oscillation length: $\boxed{L = \frac{4\pi p}{\Delta m^2}}$

Matter Oscillation length : $\boxed{L_0 = \frac{2\pi}{\sqrt{2}\, G_F N_e}}$

$$L \simeq (2.5)\left[\frac{(p/\mathrm{MeV})}{(\Delta m^2/\mathrm{eV}^2)}\right] \text{ meters}$$

$$L_0 \simeq (1.77) \times \left[10^7/\rho_e\right] \text{ meters}$$

$N_e = 6 \times 10^{23}\, \rho_e$

$\rho_e \approx 2\text{-}4$, Earth

$\gtrsim 100$, Solar core

Effective Mixing Angle, Osc. length:

$$\sin^2 2\theta_m = \frac{\sin^2 2\theta}{\left\{\sin^2 2\theta + \left(L/L_0 - \cos 2\theta\right)^2\right\}}$$

$$L_m = L \Big/ \sqrt{\left\{\sin^2 2\theta + \left(\frac{L}{L_0} - \cos 2\theta\right)^2\right\}}$$

Enhancement:

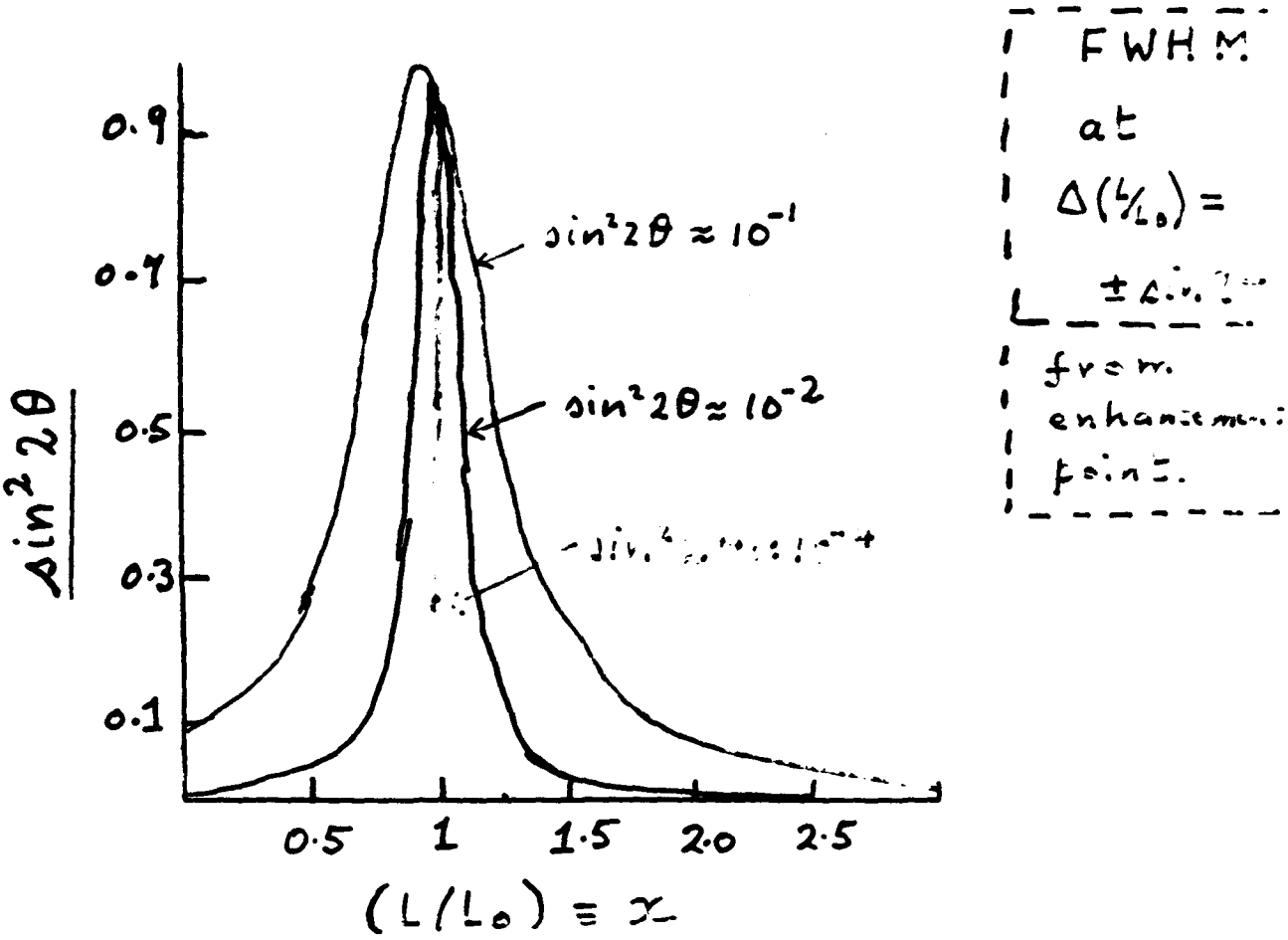
When $x \equiv (L/L_0) = \cos 2\theta$, same as A=D condition

we have $\sin^2 2\theta = 1$; $L_m = (L/\sin 2\theta)$.

∴ Maximal mixing no matter what the in vacuo mixing angle may be.

as small as 10^{-4}, or as large as 10^{-1}

Enhancement Width Decreases with decreasing θ;



Enhancement Region

Constant Density

$$\sin^2 2\theta_m = \frac{\sin^2 2\theta}{\left\{\sin^2 2\theta + \left(L/L_0 - \cos 2\theta\right)^2\right\}}$$

$$= 1 \quad \text{for} \quad \left(L/L_0\right)_R = \cos 2\theta$$

$$= \tfrac{1}{2} \quad \text{for} \quad \Delta\left(L/L_0\right)_R = \pm \sin 2\theta$$

$$\left(L/L_0\right) = 2\sqrt{2}\, G_F N_e\, p/\Delta m^2$$

$$\Delta N_e = (N_e)_R \tan 2\theta$$

$$\Delta x = \Delta N_e \Big/ \left(\frac{dN_e}{dx}\right)_R = \tan 2\theta \Big/ \left(\frac{1}{N_e}\frac{dN_e}{dx}\right)_R$$

For a large part of sun $N_e \approx N_0 e^{-x/R_0}$

$$R_0 \approx 0.1\, R_\odot \approx 7 \times 10^7 \text{ m}$$

$$\therefore \quad \boxed{\Delta x \approx 7 \times 10^7 \tan 2\theta \text{ meters}}$$

Oscillation $\quad L_m = L/\sin 2\theta = \left(4\pi p/\Delta m^2\right)/\sin 2\theta$

Adiabatic Solution

- $2\Delta x \gg L_m$
- Many Oscillations inside enhancement region.
- Prob($\nu_e \to \nu_e$ at Earth) depends on N_e at place of birth.
- Falls rapidly from 1 near $p/\Delta m^2 \approx 10^5$.
- Tends to $\sin^2\theta$ as $p/\Delta m^2 \to \infty$.

Messiah, p.

Nonadiabatic Solution

$2\Delta x \ll L_m$

- One matter oscillation begins and ends far from enhancement pt. cf $2\Delta x$
- Use Landau - Zener level-jumping approach:

$$P(\nu_e \to \nu_e) \approx \exp\left(-\frac{\pi \Delta m^2}{4p} \cdot \left(N_e / \frac{dN_e}{dx}\right)_R \sin^2 2\theta \tan^2\right.$$

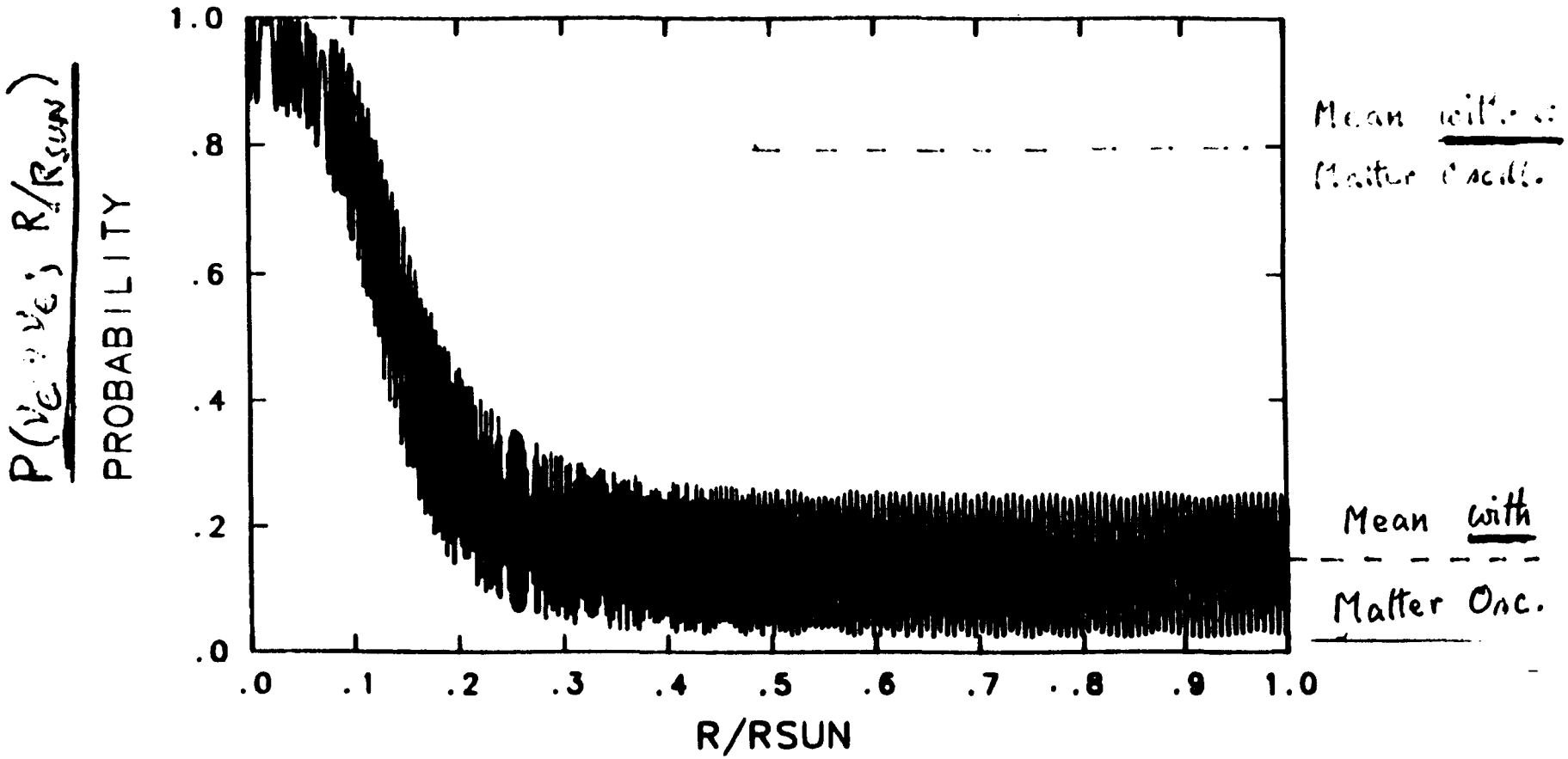
Hastings, Pub. 1991

Adiabatic Case

SIN SQ 2TH= 0.4000
PARAM= 0.1500E+06
DELTA= .10000E-04
MODEL DENSITY

SOLAR2

$\sin^2 2\theta = 0.4$; $E/\Delta m^2 = 1.5\times10^{+5}$



$R_{SUN} \approx 7\times10^{8}\,m$

$$\frac{\text{Enhancement}}{\text{Region}} = 2\Delta x \approx 7.2\times10^{7}\,m \gg L_m \approx 6\times10^{5}\,m$$
$$\approx 10^{-1} R_\odot$$

Adiabatic

$\Delta x \approx \tan 2\theta \times 7.10^{7}\,m$

Change over region $0.2R_\odot \approx 2(2\Delta x)$

Nonadiabatic Case

$\sin^2 2\theta = 10^{-3}$

$(E/\Delta m^2) = 6\times10^5$ (MeV/eV^2)

$2\Delta x \approx 6\times10^{-3} R_\odot$

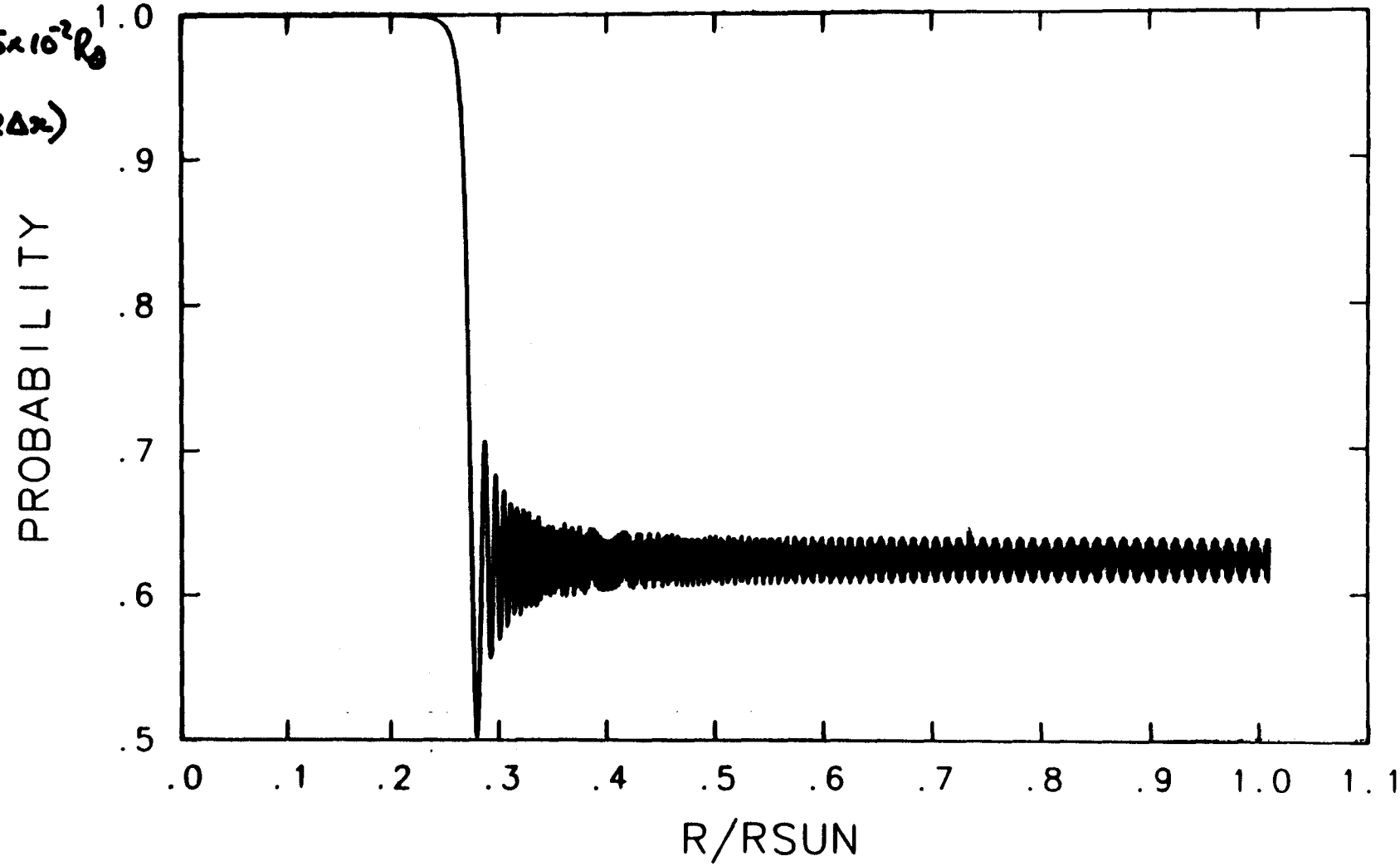
Change over a region $\approx 5\times10^{-2} R_\odot$

$\therefore \approx 10\,(2\Delta x)$

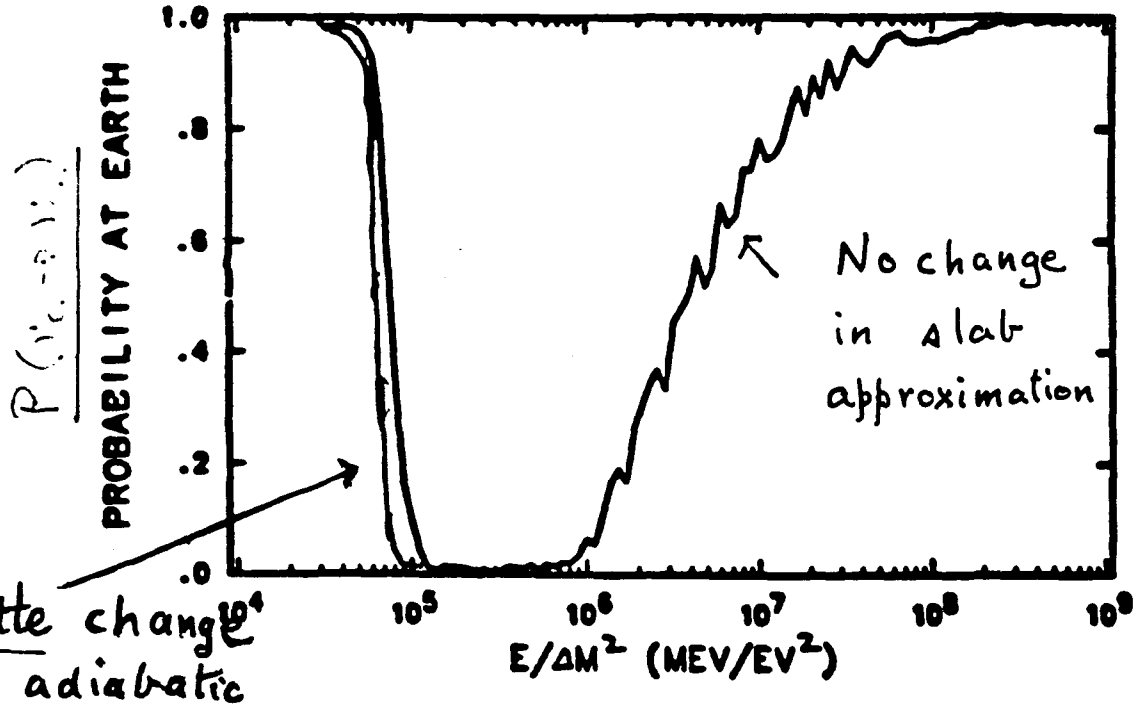
$\approx L_m$

$2\Delta x \ll L_m$

4.6×10^6 m $\quad$ 4.5×10^7 m



Solution depending on Neutrino Production Region.



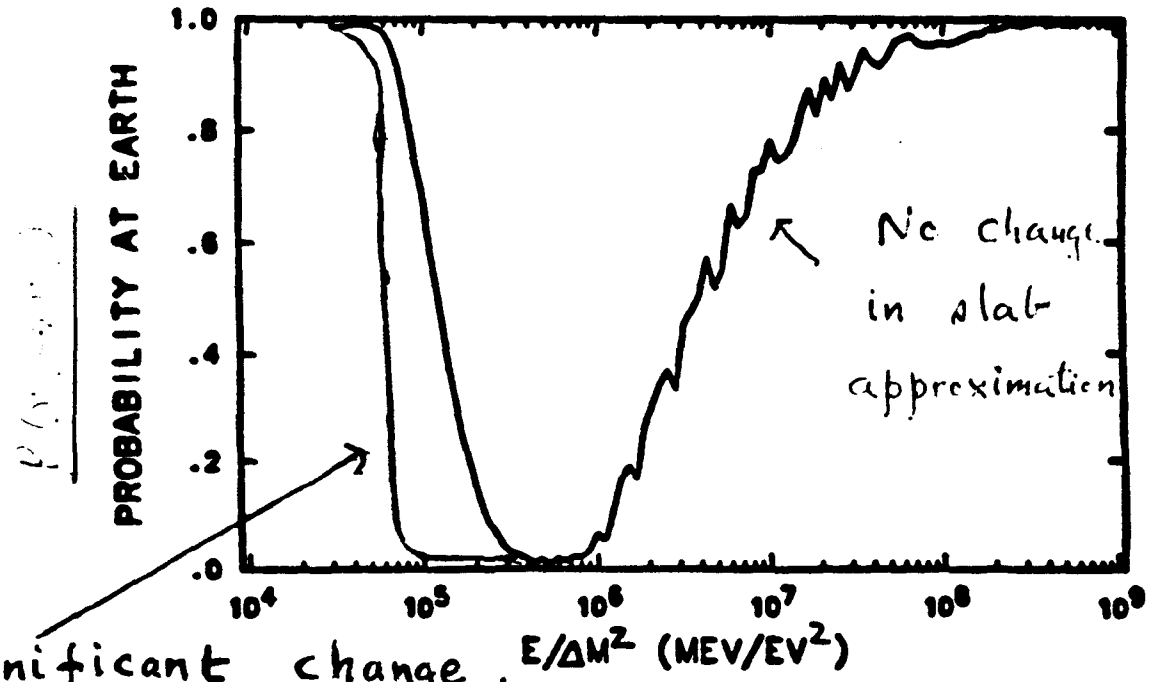
Little change in adiabatic Solution.

FIGURE 3a

$\sin^2 2\theta = 0.01$

^8B neutrinos

produced essentially at core of sun.



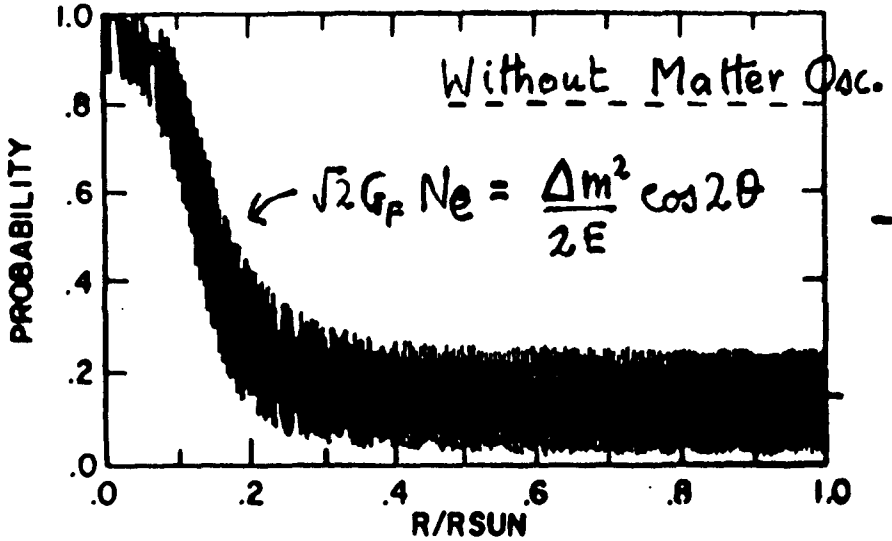
Significant change in adiabatic solution which depends on density at point of production.

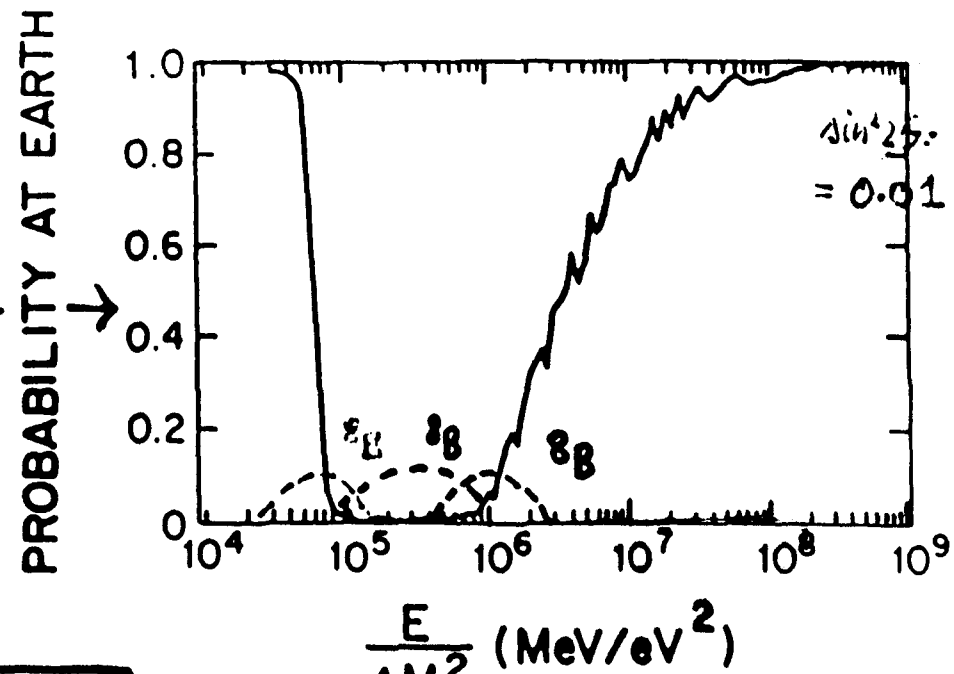
FIGURE 3b

$\sin^2 2\theta = 0.01$

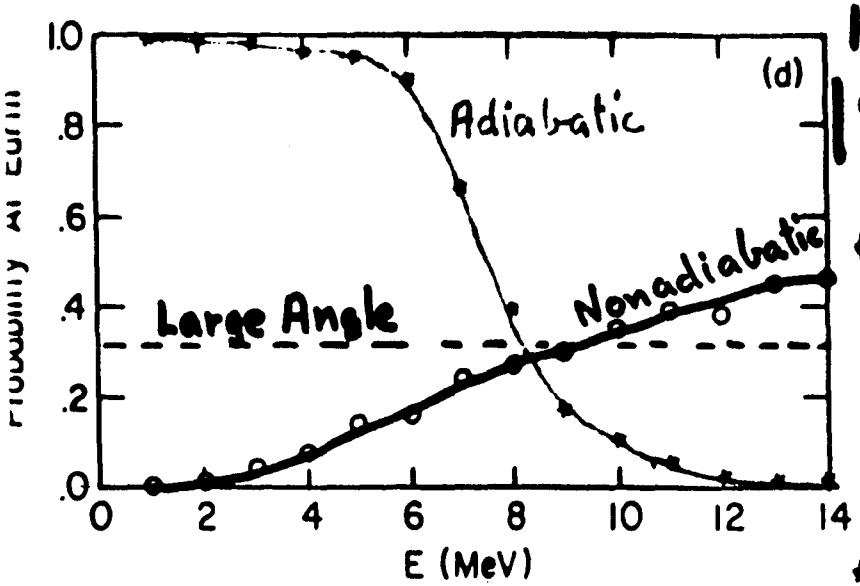
pp neutrinos

produced in first 20% of solar radial distribution

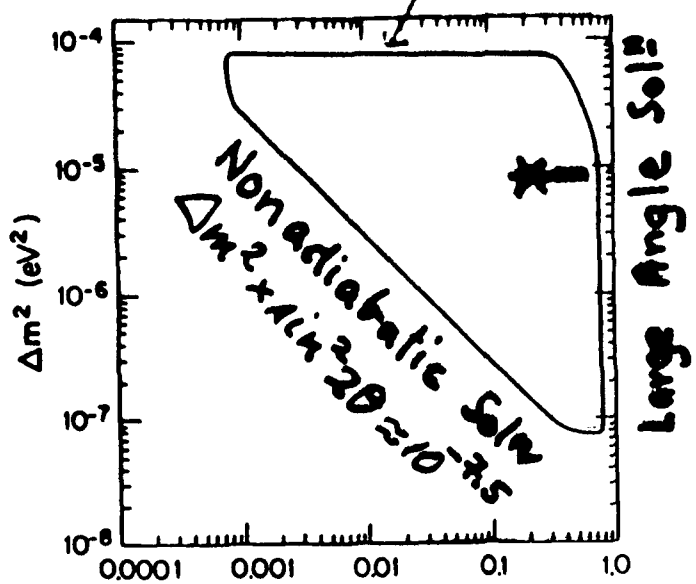




Three Types of MSW Solution for ^{37}Cl Expt. of Davis et al



How to distinguish between them?



* Possibility of Day-Night Effect Here.

Neutrino - Electron Scattering (Std Model)

ν_μ, ν_τ via pure neutral current

ν_e via charged and neutral currents

same diagram as for MSW.

$$\sigma(\nu_e e) \approx (6-7) \times \sigma(\nu_{\mu,\tau} e)$$

Note: If ν_e oscillates into sterile ν_x then $\sigma(\nu_x e) = 0$.

$\therefore$ if $\sigma_{expt} \lesssim \frac{1}{6-7} \sigma(\nu_e e)$

then oscillations into sterile ν_x's.

Assume SSM flux of ^8B ν's:

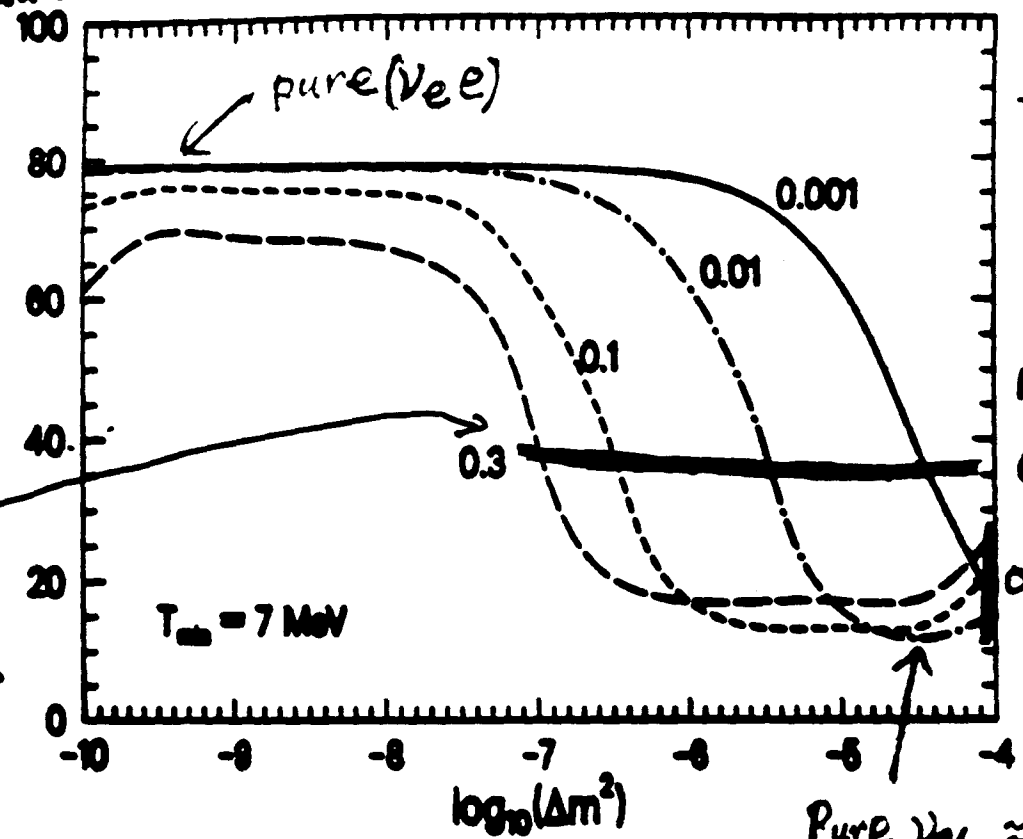
Ratio $\frac{\sigma_{expt}}{\sigma(\nu_e e)}$ between $\frac{1}{6..}$ and 1

. . . . . .

Different MSW solutions give different ratios

SOLAR Neutrino - Electron Scattering

Latest Report from A. Mann



Small Angle Solutions

Non-Adiabatic $\sigma \approx \frac{1}{2}\sigma(\nu_e e)$

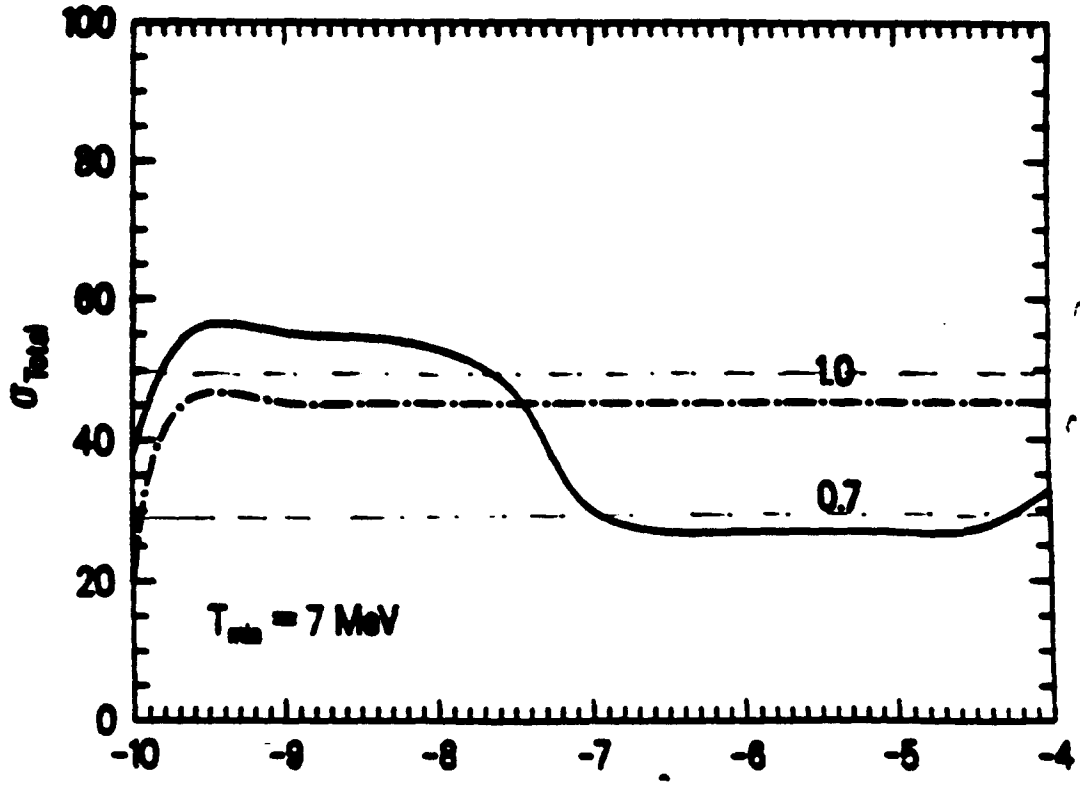
$\sigma \approx \frac{1}{4}\sigma(\nu_e e)$

Adiabatic

If correct then ^{71}Ga likely to be small!

Pure $\nu_{\mu e} \approx (\frac{1}{6} - \frac{1}{7})$

Non adiabatic solution:
high energy ν's $\approx$ 50% ν_e, 50% ν_μ



LOCATION OF Resonance Region

$$\rho_0 = \frac{10^7}{\sqrt{2}} \frac{\Delta m^2}{E} \cos 2\theta \quad \text{gm/cc}$$

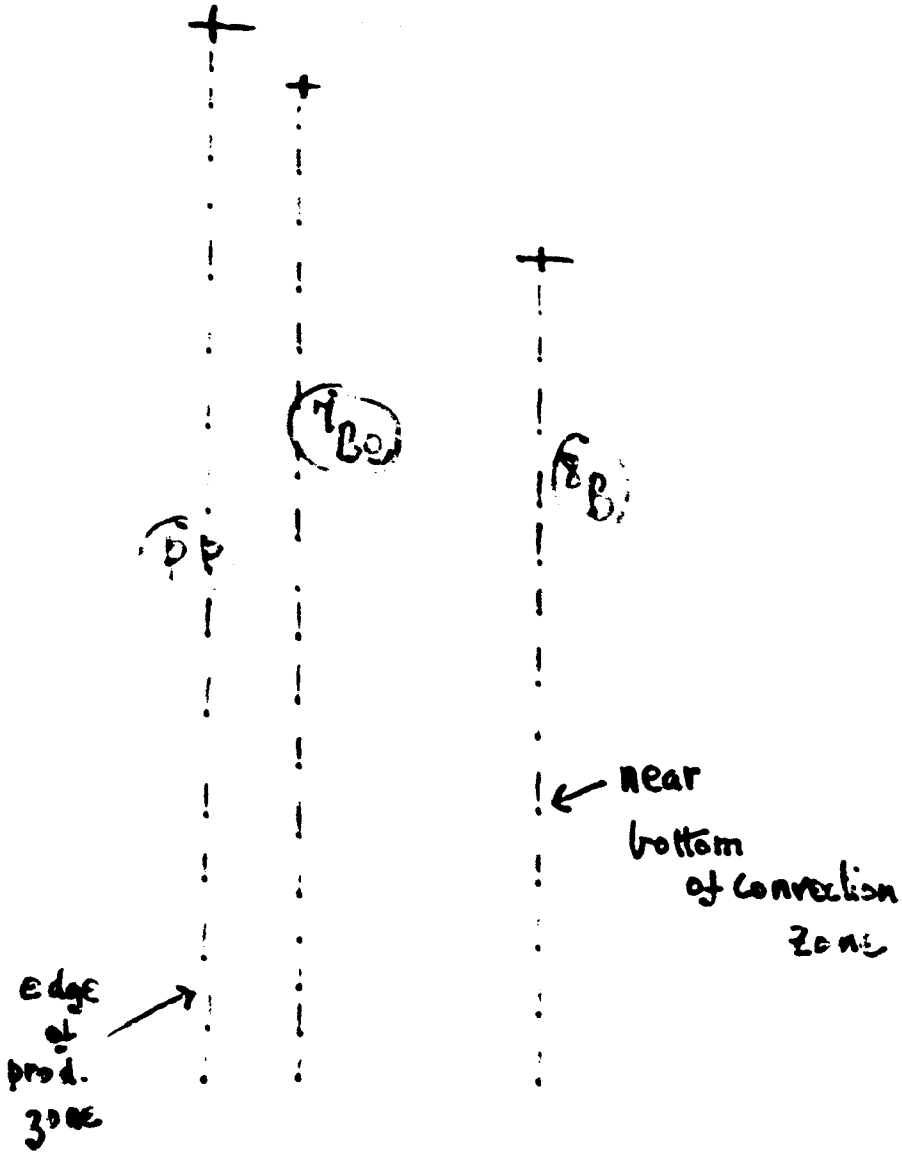
$\Delta m^2 \approx 10^{-6}$, $\rho_0 \approx \frac{7}{E} \cos 2\theta$

$\sin^2 2\theta \approx 0.02 - 0.05$, $\rho_0 \approx \frac{7}{E}$

^8B	$\langle E \rangle \approx 10$	$\rho_0 \approx 0.7$	$L_m \approx 0.5 R_\odot$
^7Be	$E \approx 0.8$	$\rho_0 \approx 9$	$L_m \approx 0.04 R_\odot$
pp	$\langle E \rangle \approx 0.2$	$\rho_0 \approx 35$	$L_m \approx 10^{-2} R_\odot$

$$L_m = \left(2.5\, E/\Delta m^2\right)/\sin 2\theta \approx (3 \times 10^7)\, E \text{ meters}$$

$$\approx \left(R_\odot/20\right) E$$


η_{B_0}
δ_B
δ_P
near bottom of convection zone
edge of prod. zone

$\nu_2 \to \bar{\nu}_1 + \phi$

$P(\nu_e \to \nu_e) = \cos^4\theta + \sin^4\theta \, e^{-t/\tau_0 E}$

$P(\nu_e \to \nu_\mu) = \sin^2\theta \cos^2\theta \, (1 + e^{-t/\tau_0 E})$

Most of allowed Region has ^{71}Ga in 10-40 SNU.

Neutral Currents Reduced.

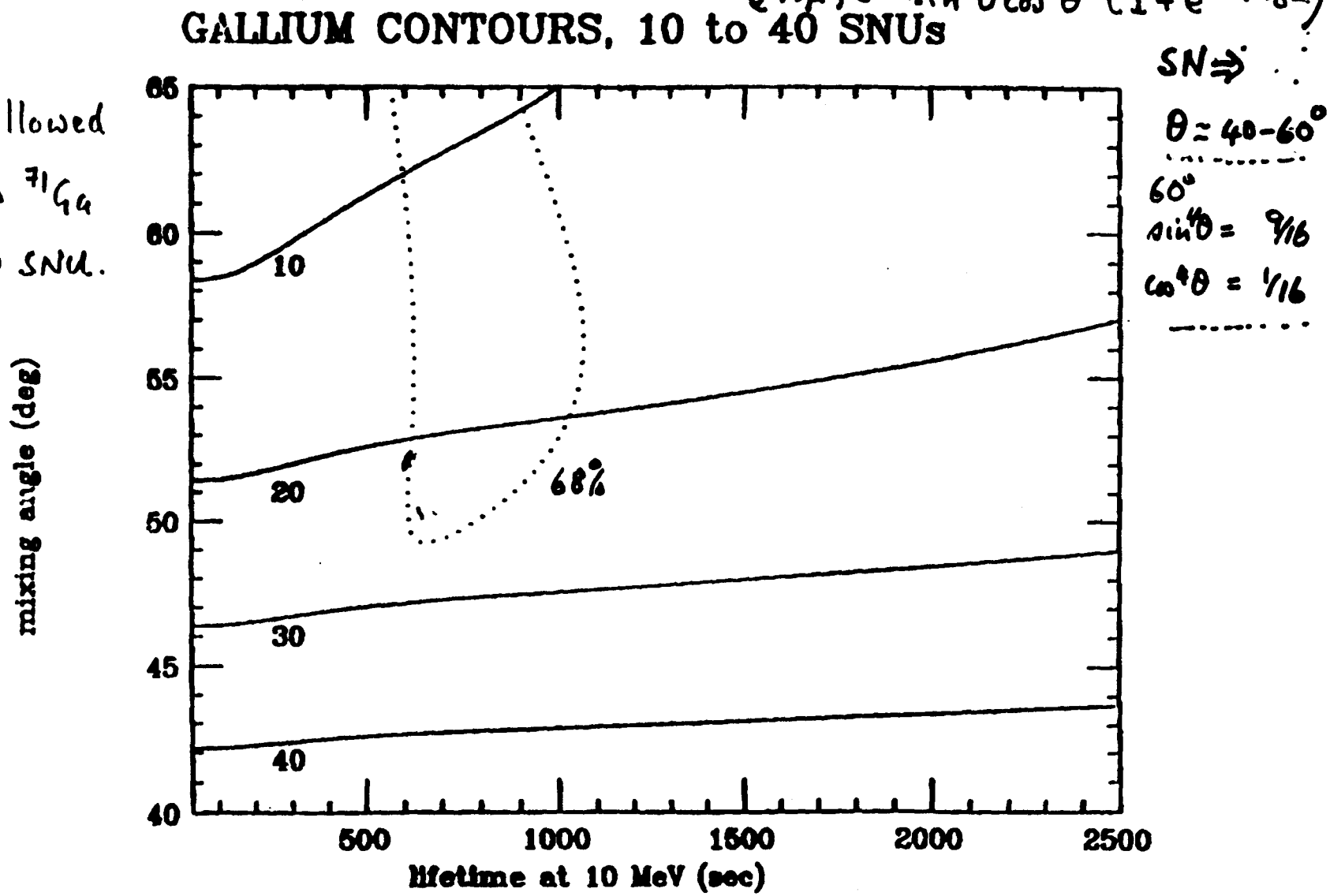


Fig. 5

A. F. P. 1/16

OCT 30 '90 16:35 UHDAC 808 956-2951 P.16

Conclusions

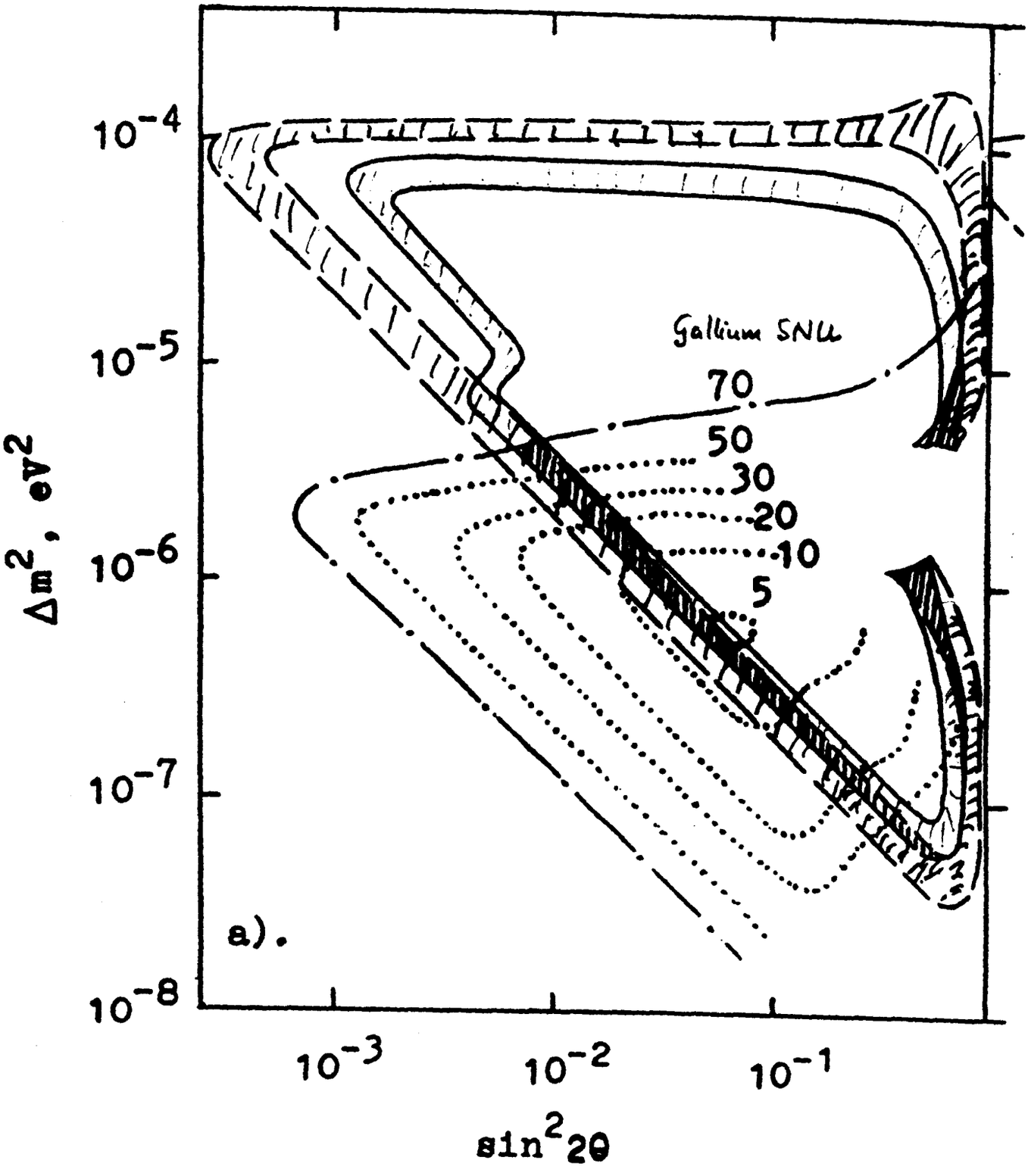
If SAGE continues to find a small signal in ^{71}Ga, and if GALLEX obtains the same result, THEN MSW, plus oscillation parameters:

$$\left\{ \begin{array}{l} \Delta m^2 \approx 10^{-6}\ eV^2 \\ \sin^2 2\theta \approx 0.02 - 0.05 \end{array} \right\}$$

would solve the Solar ν Problem.

An important test of this will be the SNO experiment which will look at charged-current and neutral-current neutrino reactions in deuterium:
Spectrum; see all ν's in NC; high statistics

KII



From P. I. Krastev, [illegible] A. Yu. [illegible]

Results from the Soviet-American Gallium Solar Neutrino Experiment (SAGE)

M. Cherry

The *pp* Reaction Chains

	ppI	*ppII*	*ppIII*
	$p + p \rightarrow d + e^{+} + \nu_e$		
or	$p + e^{-} + p \rightarrow d + \nu_e$		
	$d + p \rightarrow {}^{3}He + \gamma$		
	${}^{3}He + {}^{3}He \rightarrow {}^{4}He + p + p$	–or– ${}^{3}He + {}^{4}He \rightarrow {}^{7}Be + \gamma$	
		${}^{7}Be + e^{-} \rightarrow {}^{7}Li + \nu_e$	–or– ${}^{7}Be + p \rightarrow {}^{8}B + \gamma$
		${}^{7}Li + p \rightarrow {}^{4}He + {}^{4}He$	${}^{8}B \rightarrow {}^{8}Be^{*} + e^{+} + \nu_e$
			${}^{8}Be^{*} \rightarrow {}^{4}He + {}^{4}He$

Main Neutrino Producing Reactions in the Sun, Maximum Neutrino Energy, and the Integrated Flux Predicted by the Standard Solar Model.[2]

Solar Reaction	Max. Neutrino Energy (MeV)	Predicted Total Flux ($cm^{-2}sec^{-1}$)
$p + p \rightarrow d + e^{+} + \nu_e$	0.42	6.1×10^{10}
$p + e^{-} + p \rightarrow d + \nu_e$	1.44	1.5×10^{9}
$e^{-} + {}^{7}Be \rightarrow {}^{7}Li + \nu_e$	0.86	4.0×10^{9}
${}^{8}B \rightarrow {}^{8}Be + e^{-} + \nu_e$	14.10	5.6×10^{6}
${}^{13}N \rightarrow {}^{13}C + e^{+} + \nu_e$	1.15	5×10^{8}
${}^{15}O \rightarrow {}^{15}N + e^{+} + \nu_e$	1.73	4×10^{8}

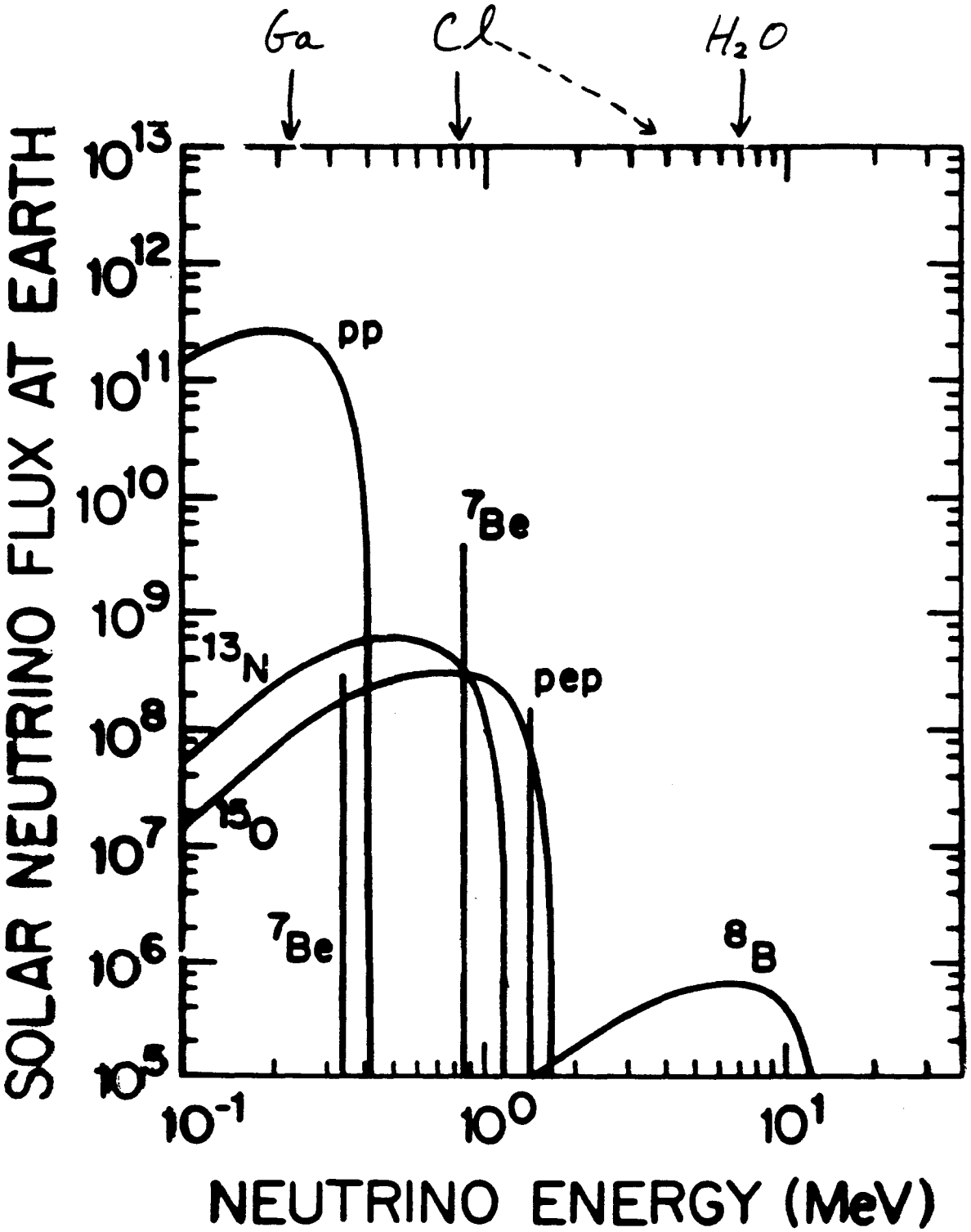

Ga
Cl
H_2O
SOLAR NEUTRINO FLUX AT EARTH
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
pp
^{7}Be
^{13}N
pep
^{15}O
^{7}Be
^{8}B
10^{-1}
10^{0}
10^{1}
NEUTRINO ENERGY (MeV)

Figure 1

THE SOVIET-AMERICAN GALLIUM SOLAR NEUTRINO EXPERIMENT: A STATUS REPORT

V.N. Gavrin, A.I. Abazov, D.N. Abdurashitov, O.V. Bychuk, S.V. Danshin, L.A. Eroshkina, E.L. Faizov, V.I. Gayevsky, S.V. Girin, A.V. Kalikhov, S.M. Kireyev, T.V. Knodel, I.I. Knyshenko, V.N. Kornoukhov, S.A. Mezentseva, I.N. Mirmov, A.I. Ostrinsky, V.V. Petukhov, A.M. Pshukov, N.Ye. Revzin, A.A. Shikhin, Ye.D. Slyusareva, A.A. Tikhomov, P.V. Timofeyev, E.P. Veretenkin, V.M. Vermul, V.E. Yantz, Yu. Zakharov, G.T. Zatsepin, V.I. Zhandarov
Inst. for Nuclear Research, Academy of Sciences, USSR, Moscow 117312, USSR

T.J. Bowles, B.T. Cleveland, S.R. Elliott, H.A. O'Brien, D.L. Wark, J.F. Wilkerson
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Princeton University, Princeton, NJ 08544 USA

$$\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e^- \quad (E_{thresh} = 0.233\ MeV)$$

SSM Capture Rates (SNU)

	pp	pep	hep	^7Be	^8B	^{13}N	^{15}O	^{17}F	Total
^{37}Cl	0.0	0.2	0.03	**1.1**	**6.1**	0.1	0.3	0.003	**7.9**
^{71}Ga	**70.8**	3.0	0.06	**34.3**	**14.0**	3.8	6.1	0.06	**132**

$$\nu_e + {}^{71}Ga \underset{\text{decay}}{\overset{\text{capture}}{\rightleftharpoons}} {}^{71}Ge + e^-$$

(11 days)

Soviet - US collaboration (SAGE)

Soviets have provided: 60 tons of gallium

Baksan laboratory

Extraction system

US has provided: Counting system/low background techniques

Electronics

Chemical expertise

~~30~~ 45 tons now in operation

$$\frac{\text{Expected solar signal}}{\text{Measured background}} \sim 1$$

2nd gallium experiment - GALLEX

30 tons gallium chloride (Gran Sasso)

Soviet gallium belongs to

Ministry of <u>Metals</u>

Gallium metal (Baksan) vs chloride (GALLEX)
60 tons 30 tons

Advantage of $GaCl_3$ ($\rho = 0.6$ g cm^{-3})

simpler distillation and recovery

Advantage of metal ($\rho = 6$ g cm^{-3})

more compact size

Extraction procedure

Liquid gallium (melting point 29.5 C) mixed with HCl & hydrogen peroxide, stirred.

Gallium breaks up into small globules.

Germanium migrates to globule surfaces, oxidized by peroxide.

Acid concentration is then increased to dissolve germanium & gallium oxides.

Stirring stops, gallium metal & acid solution separate

Acid concentrated, water removed, $GeCl_4$ carried out of acid by flowing argon through it.

Remaining acid separated into $GaCl_3$ & HCl, reprocessed & recycled.

HCl frequently contains Ge impurities.

All materials will be recycled to avoid introduction of fresh reagents & contaminan

Extraction technique originally developed in US in 1974

At this point, conversion of $GeCl_4$ into counting gas (germane, GeH_4) is same in chloride and metal experiments:

add $NaBH_4$

Tritium contamination

Auger electrons from ^{71}Ge decay at 10.4 keV

Tritium β spectrum endpoint 18 keV.

Solution: use only tritium-free reagents

Water from deep wells

Tritium-free $NaBH_4$

Expected Ge Production in 30 tons

- Standard solar model (132 SNU)

  <u>1.2</u> atoms / day

- μ spallation ($2.4 \pm 0.3 \times 10^{-9}$ cm^{-2} sec^{-1})

  ^{71}Ge <u>0.005</u> atoms / day

  ^{68}Ge <u>0.013</u> "

  ^{69}Ge <u>0.009</u> "

- External (n, p) background

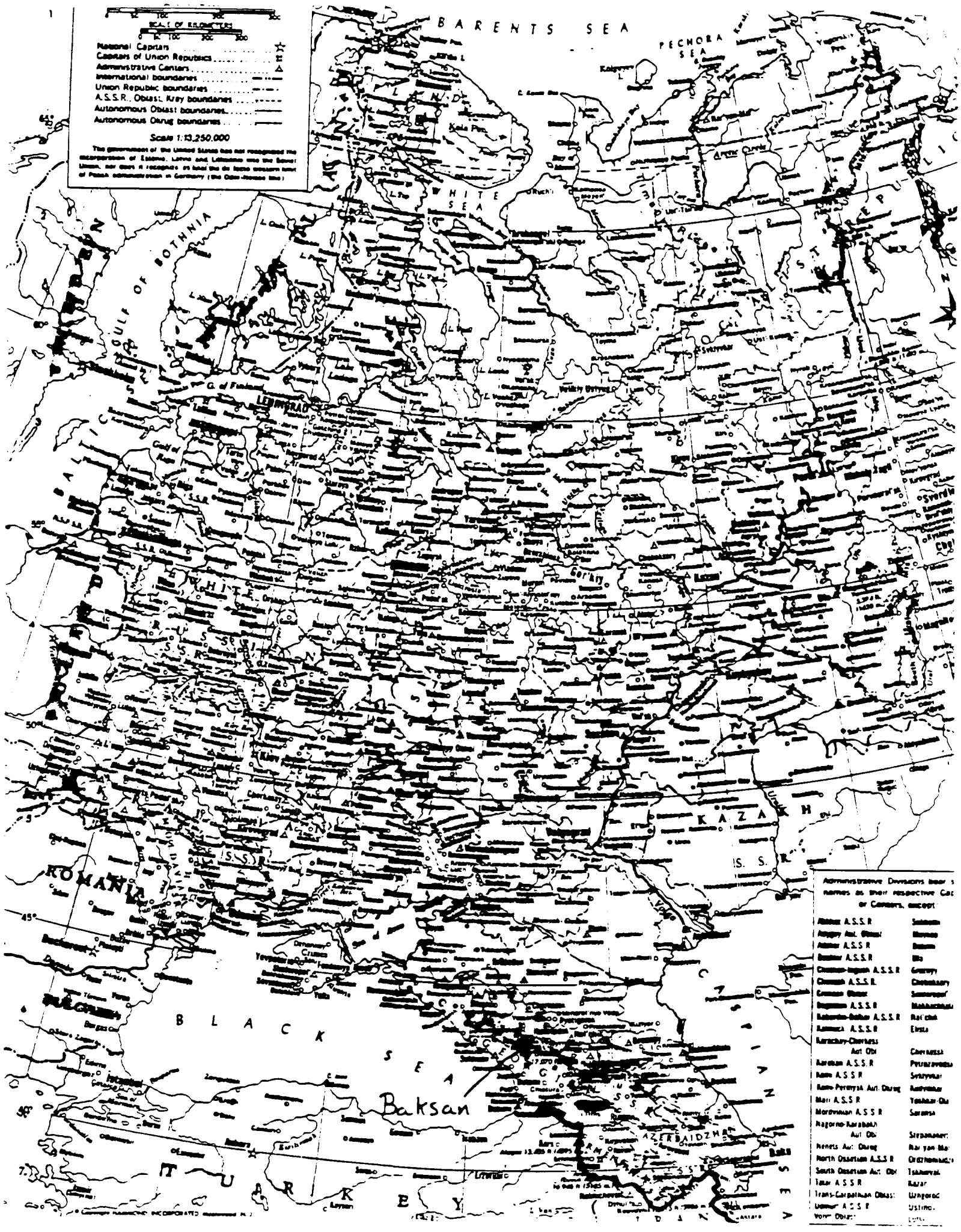
  $\leq$ <u>0.01</u> atoms / day

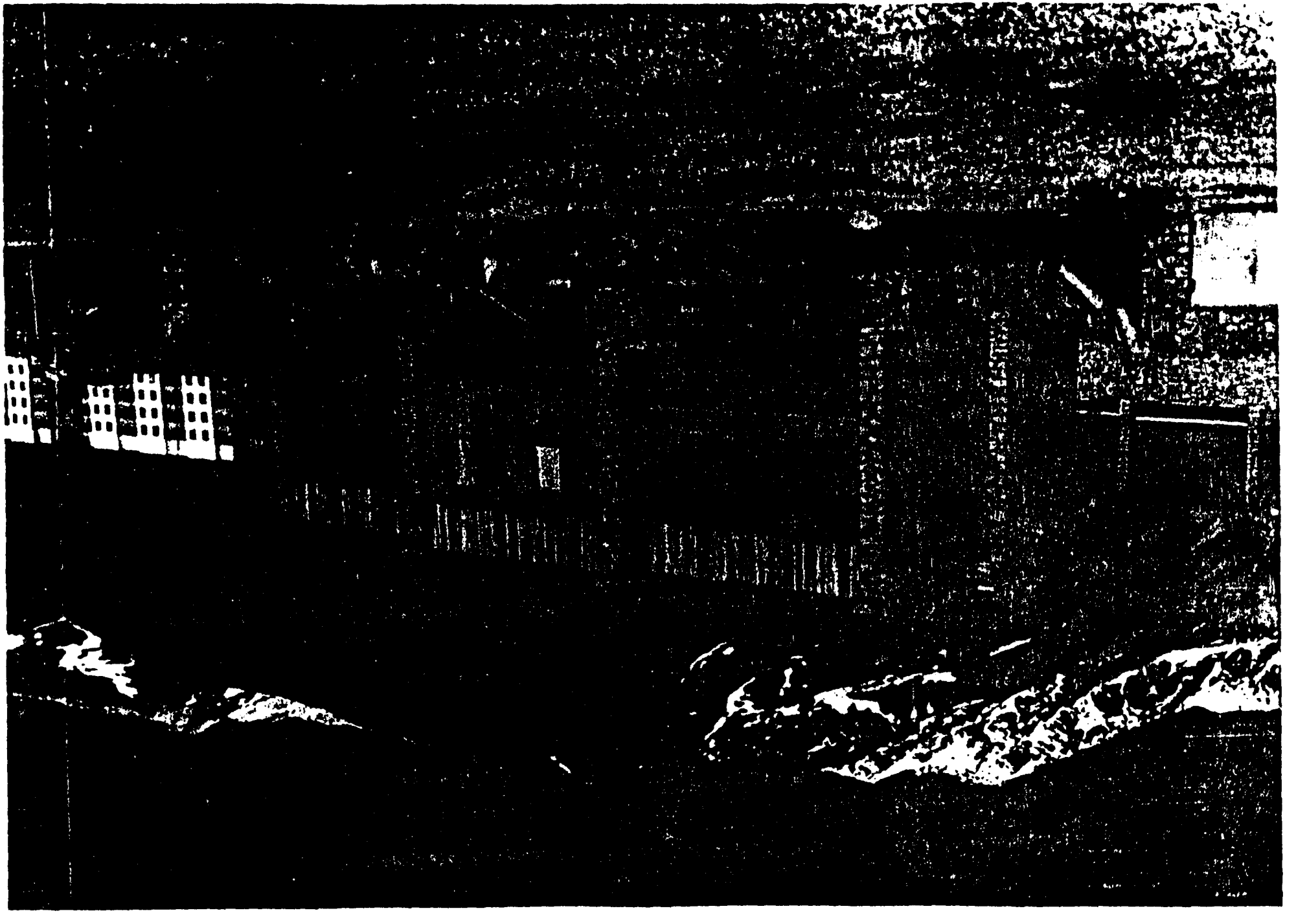
- Internal radioactivity

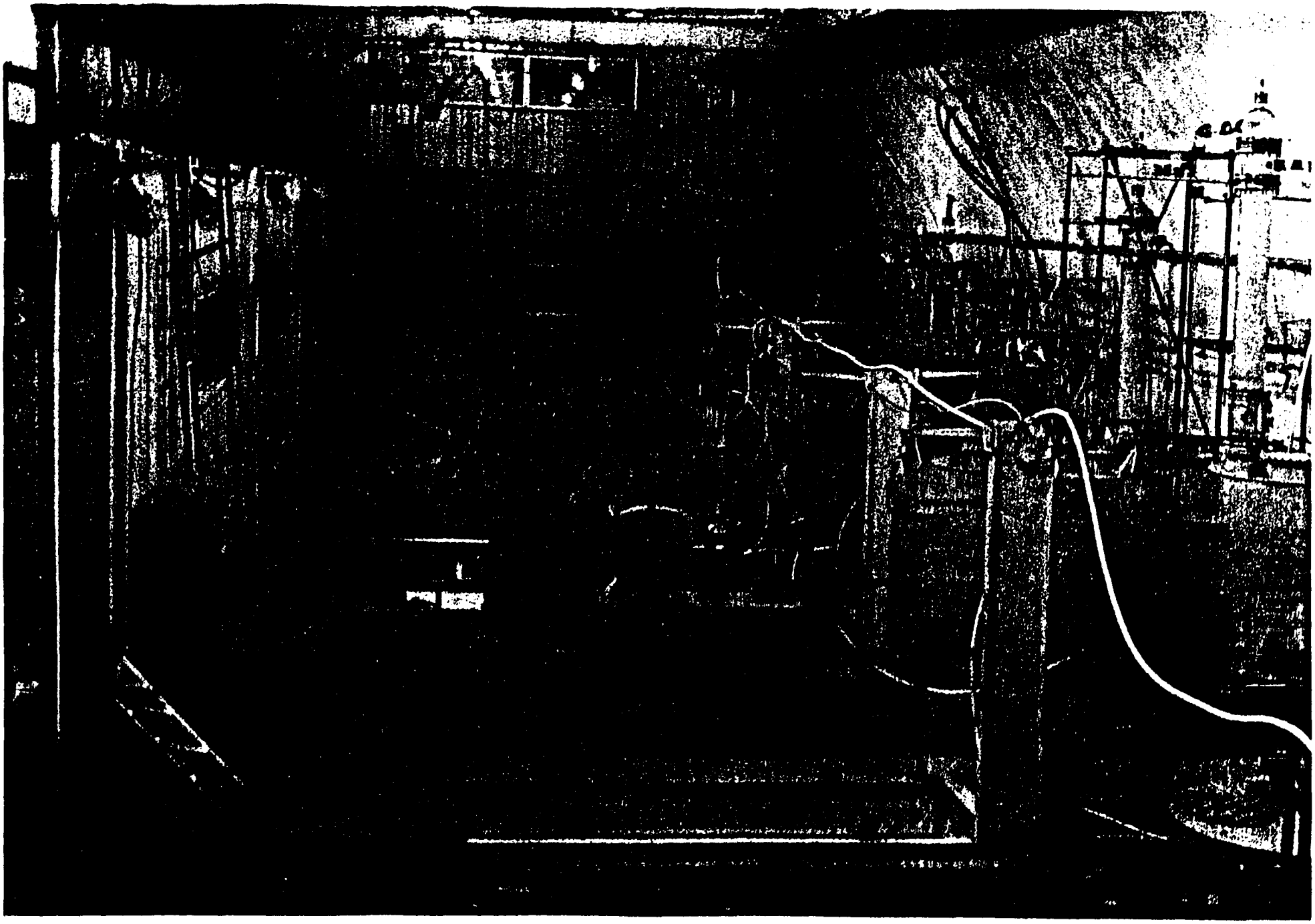
  Measured contaminants:

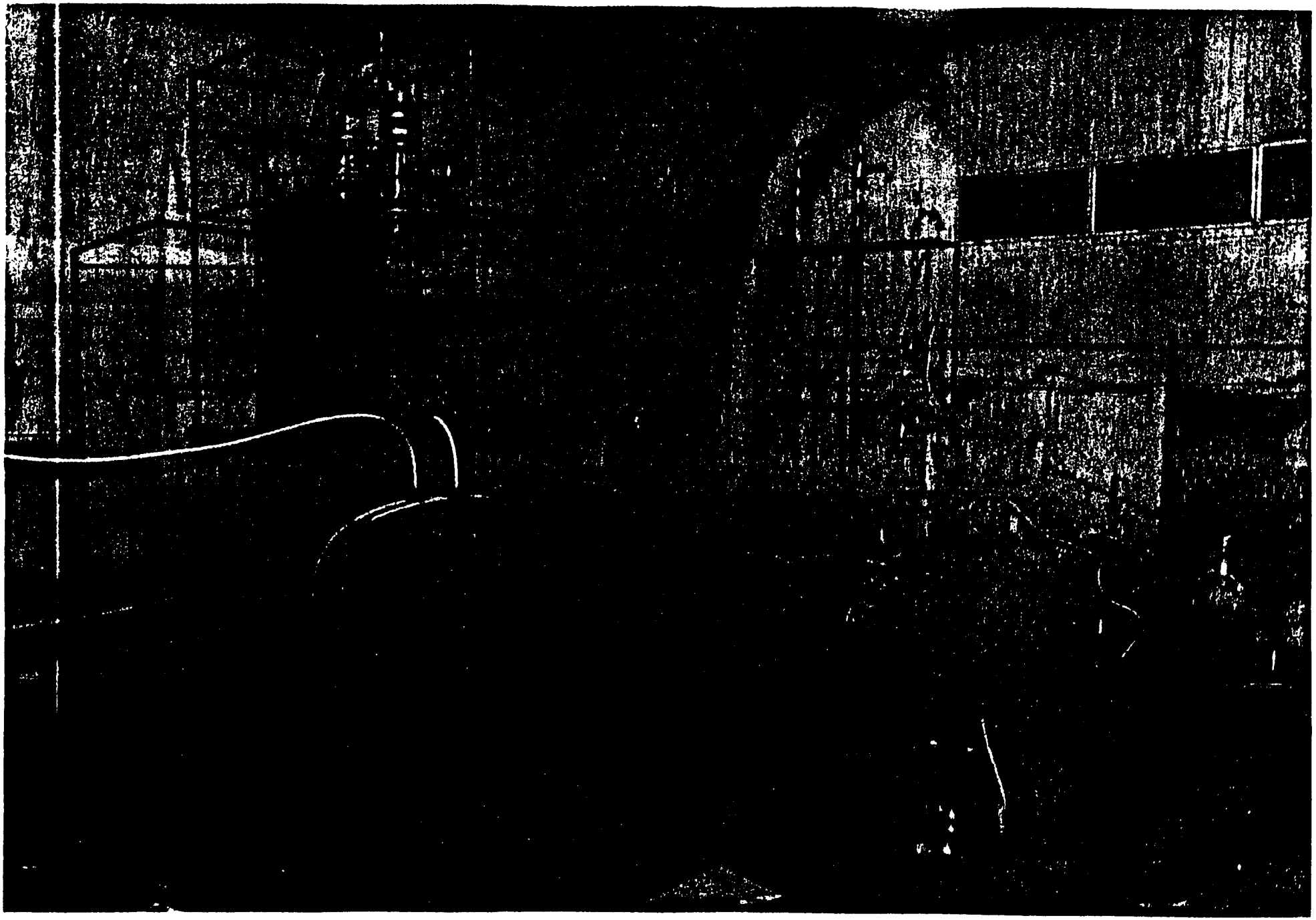
  $< 3.4 \times 10^{-10}$ g U / g Ga $\quad < 8 \times 10^{-10}$ g Th / g Ga

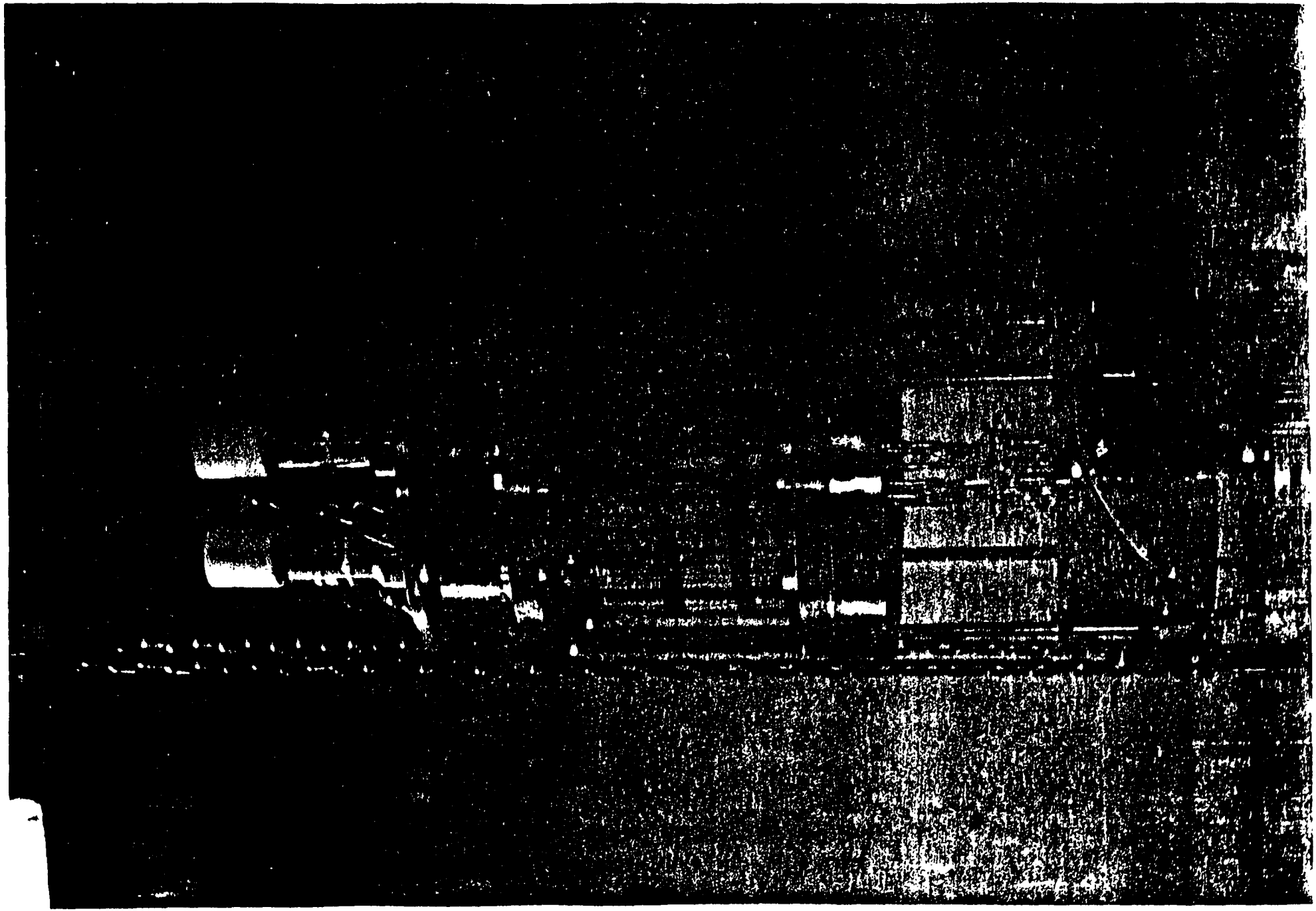
  $<$ <u>0.01</u> atoms / day


SCALE OF KILOMETERS
National Capitals
Capitals of Union Republics
Administrative Centers
International boundaries
Union Republic boundaries
A.S.S.R., Oblast, Kray boundaries
Autonomous Oblast boundaries
Autonomous Okrug boundaries
Scale 1:13,250,000
BARENTS SEA
PECHORA SEA
WHITE SEA
GULF OF BOTHNIA
BALTIC SEA
BLACK SEA
LENINGRAD
Gorky
Kazan
Kiev
Baksan
ROMANIA
TURKEY
KAZAKH S.S.R.
AZERBAIDZHAN
Administrative Divisions bear the names as their respective Capitals or Centers, except:









Phase 1 : 30 ton history

Summer 1988 - Winter 1989:

Cosmogenic ^{68}Ge removal

K peak rate 7700 /day → 0.4 /day (no cuts)

1989 Extractions :

April, June, Sept, Oct, Dec

Dec 1989:

Analysis showed activity with $\tau_{1/2} \sim 4$ days

Radon in reagents confirmed Feb. 1990

Data through Dec. '89 not used due to short-lived contamination

Jan 1990:

H_2O and other reagents distilled before use

Low tritium H_2O used

1990 Extractions:

<u>Jan, Feb, March, April, May, July,</u> Aug, Sept, Oct

Nov, Dec, Jan '91 - ^{51}Cr source runs

$\frac{wr}{2d} = nH = n\frac{7C}{C}$?

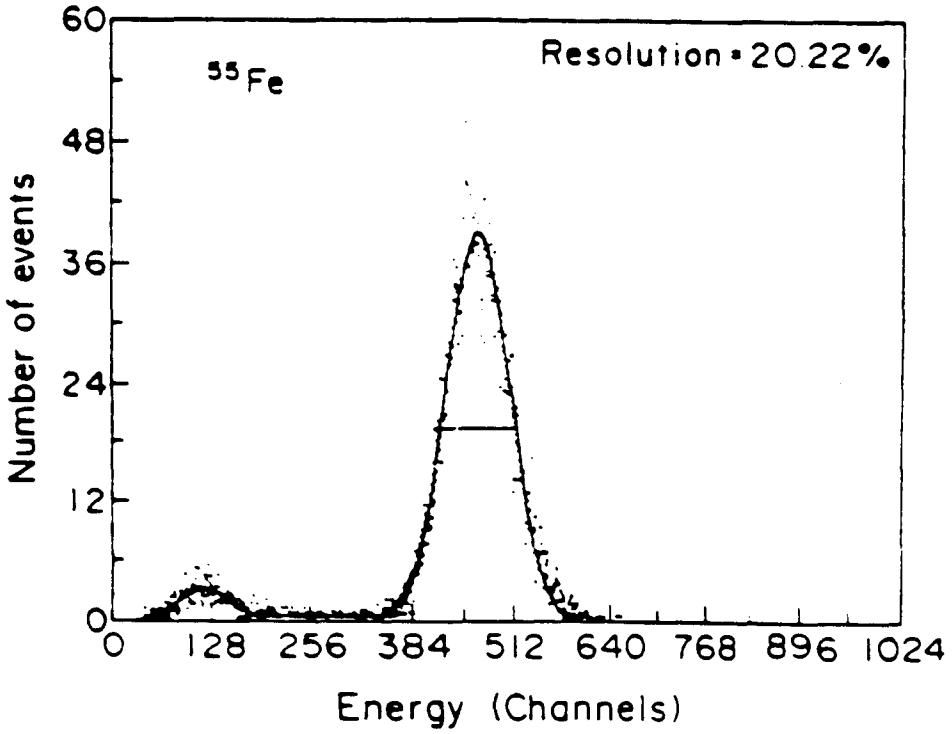


Fig. 2. Pulse Height spectrum of ^{55}Fe calibration source

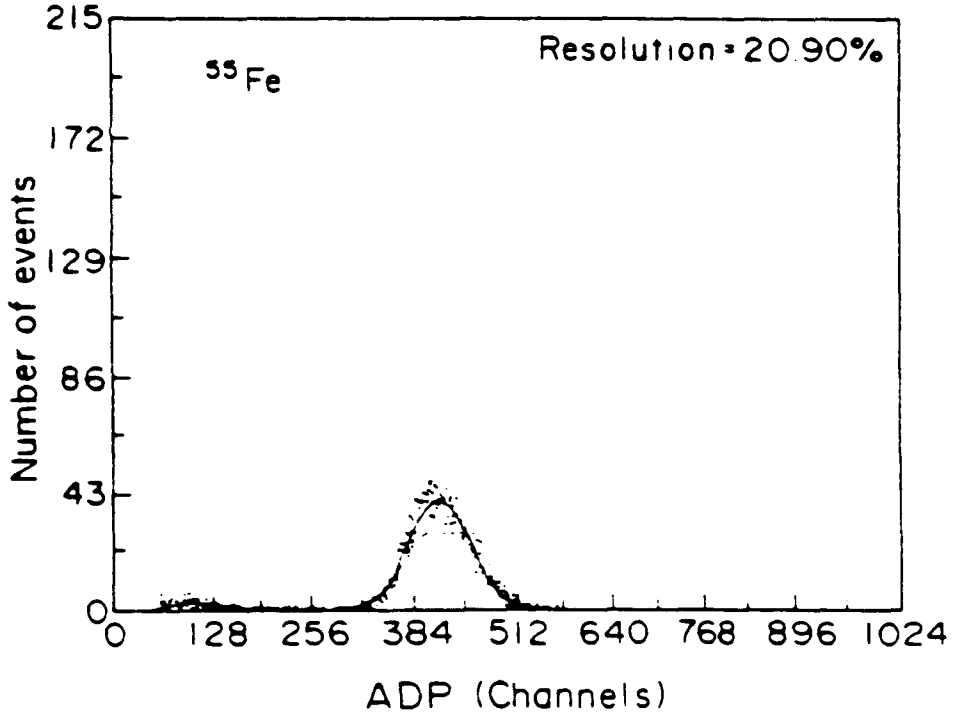


Fig. 3. Rise time spectrum

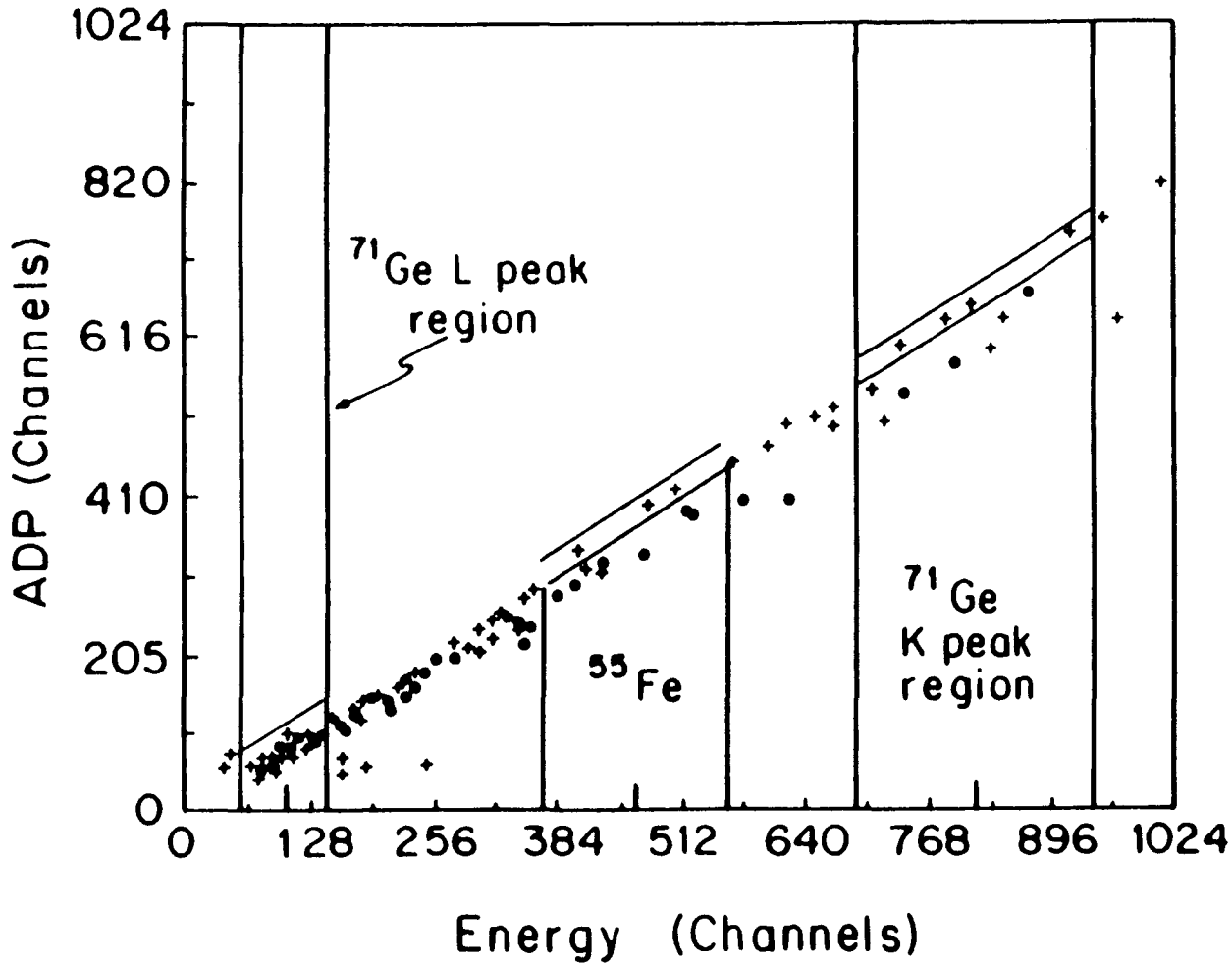
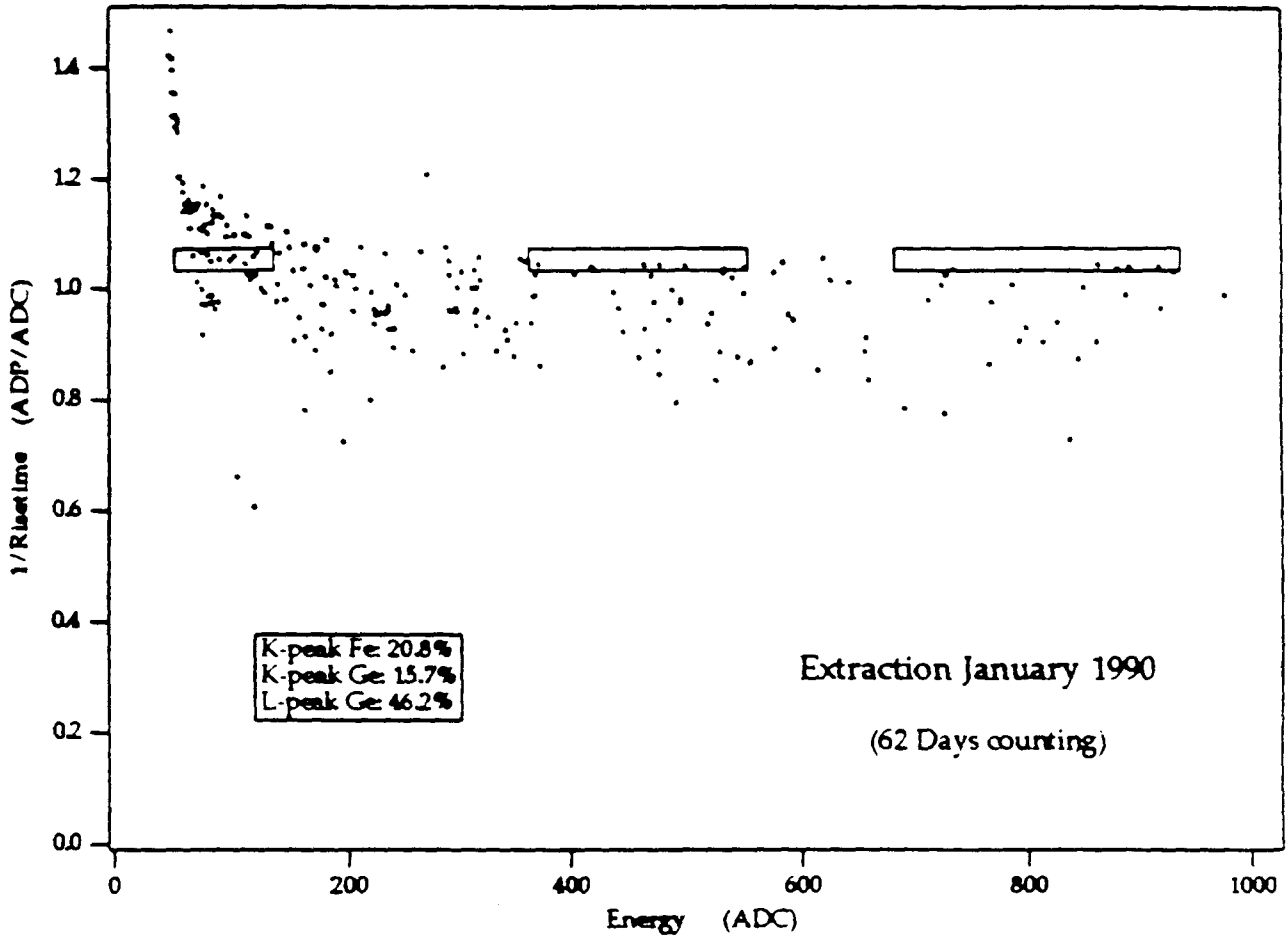
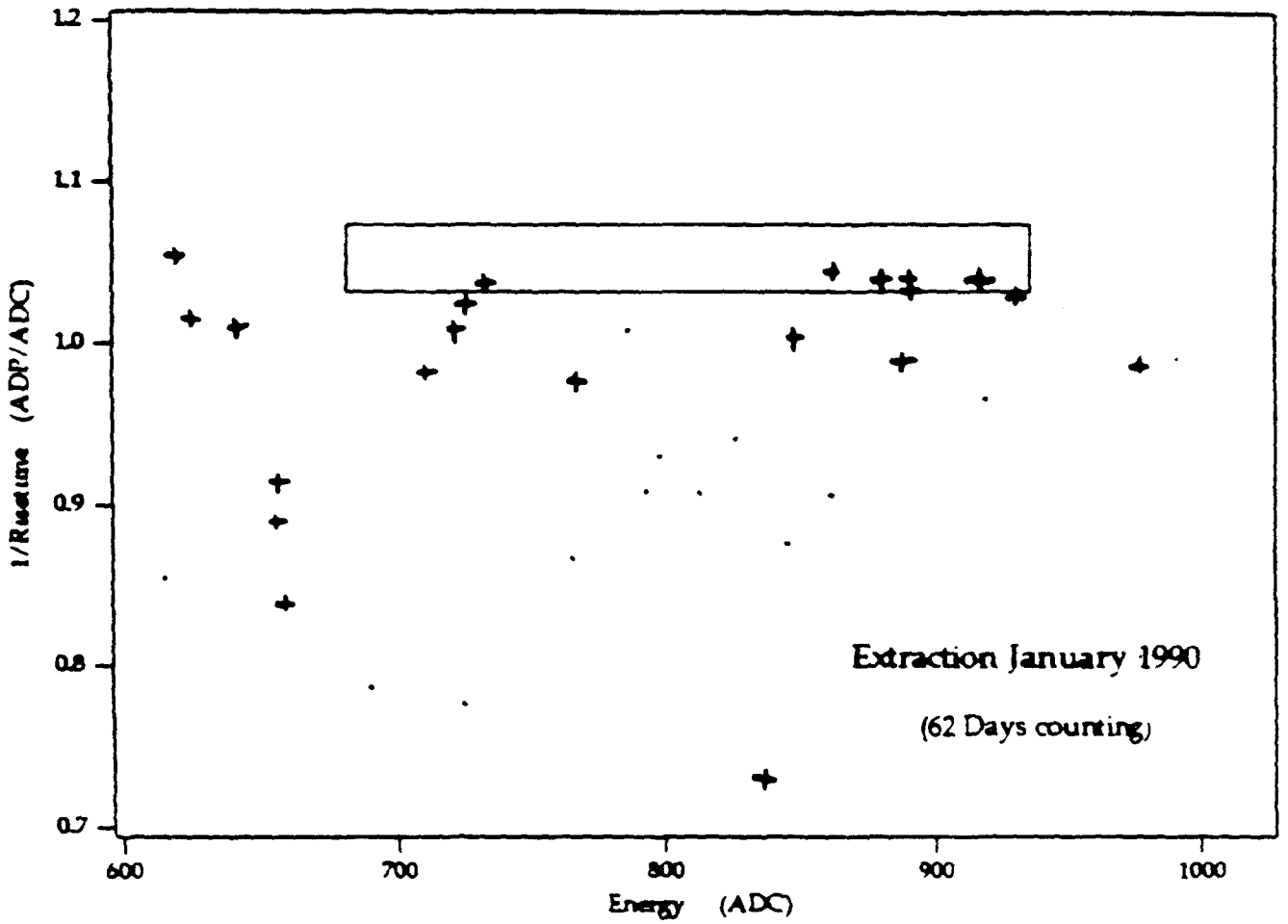


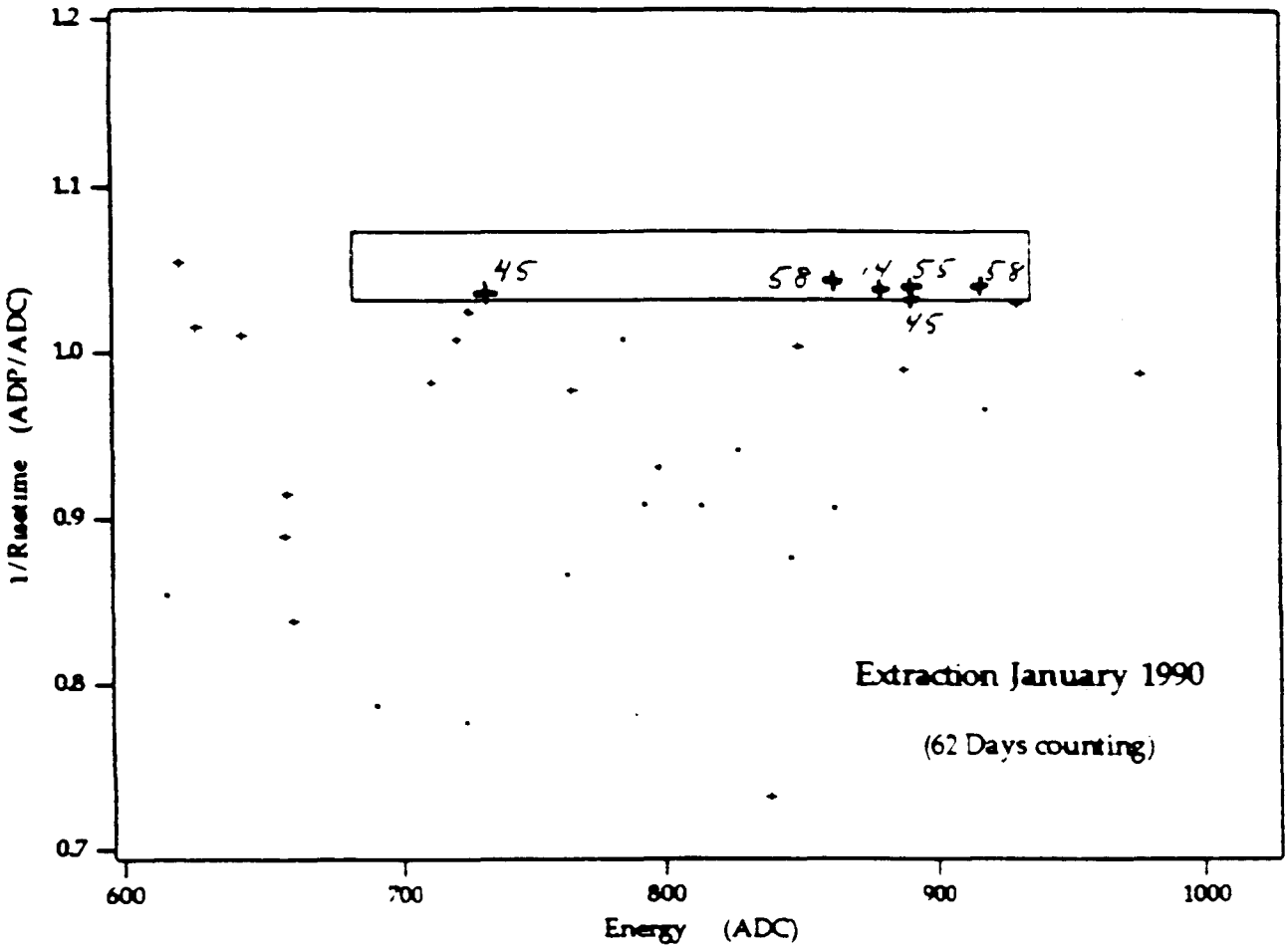
Fig. 4. Typical ADP-energy spectrum.


1/Risetime (ADP/ADC)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
1000
Energy (ADC)
K-peak Fe: 20.8%
K-peak Ge: 15.7%
L-peak Ge: 46.2%
Extraction January 1990
(62 Days counting)

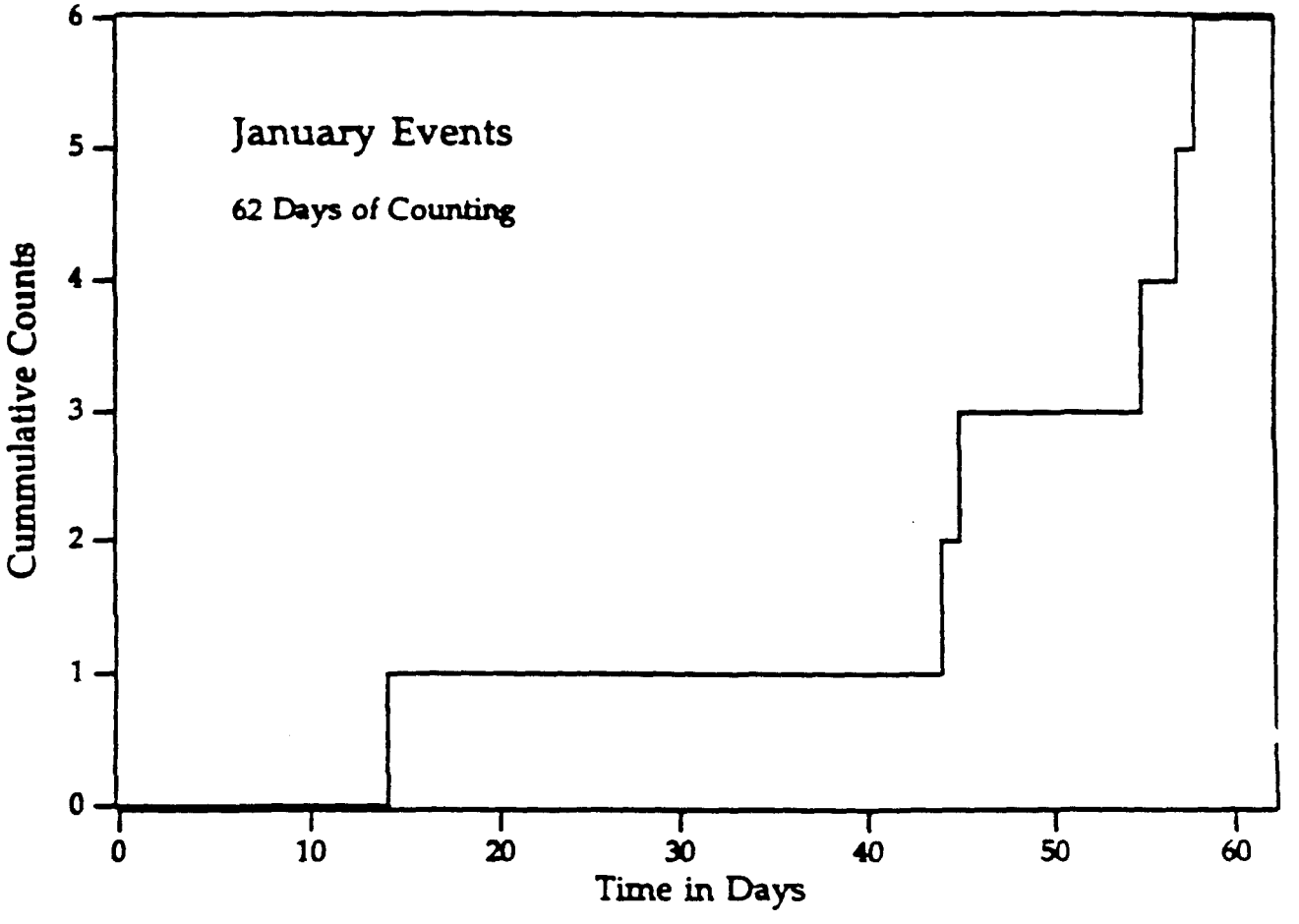


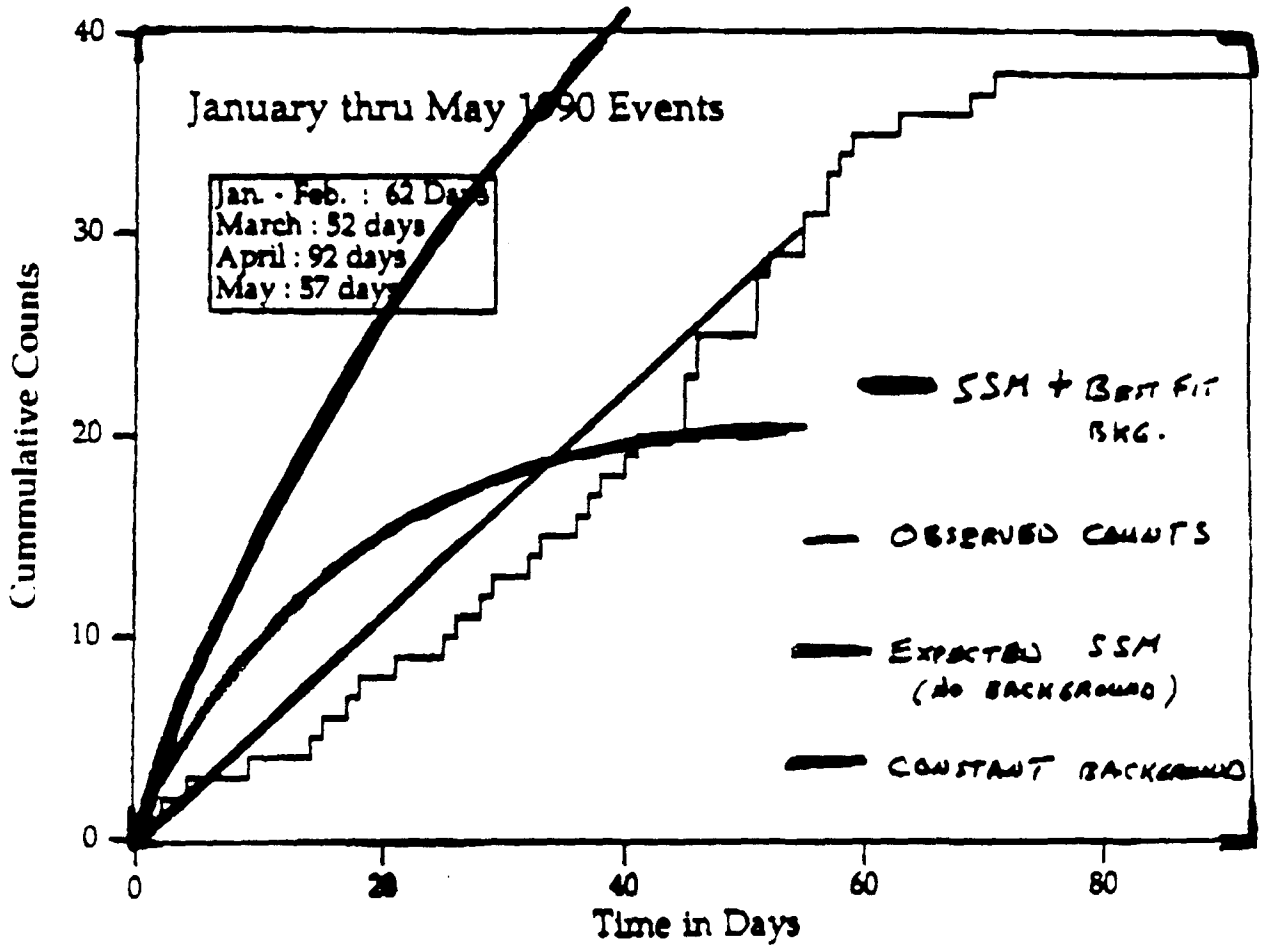
+ No NaI coincidence

• In coincidence with NaI



+ No NaI coincidence


January Events
62 Days of Counting
Cummulative Counts
0
1
2
3
4
5
6
0
10
20
30
40
50
60
Time in Days


January thru May 1990 Events
Jan. - Feb. : 62 Days
March : 52 days
April : 92 days
May : 57 days
SSM + BEST FIT BKG.
OBSERVED COUNTS
EXPECTED SSM (NO BACKGROUND)
CONSTANT BACKGROUND
Cummulative Counts
Time in Days
0
10
20
30
40
0
20
40
60
80

Analysis
1990

Run	Exposure time d.	Total counting time d.	Live time d.	Extraction efficiency %	Counting* efficiency %	Mass of Ga tons	Number of events	Best fit SNU	68% SNU	90% SNU
									Statistical upper limits	
Jan., 24	42	62.6	57.6	78±6	43±4	28.672	8	0	0-57	0-11.
Feb., 28	30	63.6	57.4	79±6	36±5	28.592	1	37	1-80	0-13
Mar., 29	26	53.0	46.9	81±6	45±5	28.508	7	84	0-162	0-25
Apr., 20	19	96.3	89.5	77±6	42±5	28.402	7	0	0-98	0-18
Jul., 24	21	63.1	59.3	78±6	41±4	21.011	11	0	0-144	0-21
Σ							34	20	35	58

Systematics

	68%	90%
Counter efficiency, extraction efficiency	6 SNU	15 SNU
ADP/energy cuts	7	19
Time dependence of backgnd	30	35

Results (Jan-July)

Best fit 20 SNU

Limits 47 SNU/ξ (68%)
72 SNU/ξ (90%)

ξ = efficiency factor (=1 ?)

Total counts in K peak in 5 runs with 30 tons gallium:

18 expected

3 experimental best fit

Preliminary Analysis, Jan-July

	Best fit	Limits 68%	Limits 90%
Pass 5			
Standard analysis 95% ADP + ADC cuts NaI veto consistent with ^{71}Ge	21 SNU	36	60
Pass 6			
No ADP cut	0	44	77
Pass 8			
Check for gain drop - include 1 FWHM above expected ADC window	9	37	62
Pass 10			
Gaussian fit to ADP distribution, scale width by $1/\sqrt{E}$	19	32	54
Pass 11			
[illegible]	0	49	86

Test of ^{71}Ge Extraction & Counting System

- Spike carrier with known amount of ^{71}Ge
- Add spiked carrier to single 7.5 ton reacto
- Carry out normal extractions / counting

Added to reactor	526 μg Ge	6050* deca
Extraction 1	410	4900
Extraction 2	97	980
Extraction 3	21	130
Total	528	6010
	Chemical analysis	Direct countin

* Determined from similar ^{71}Ge sample

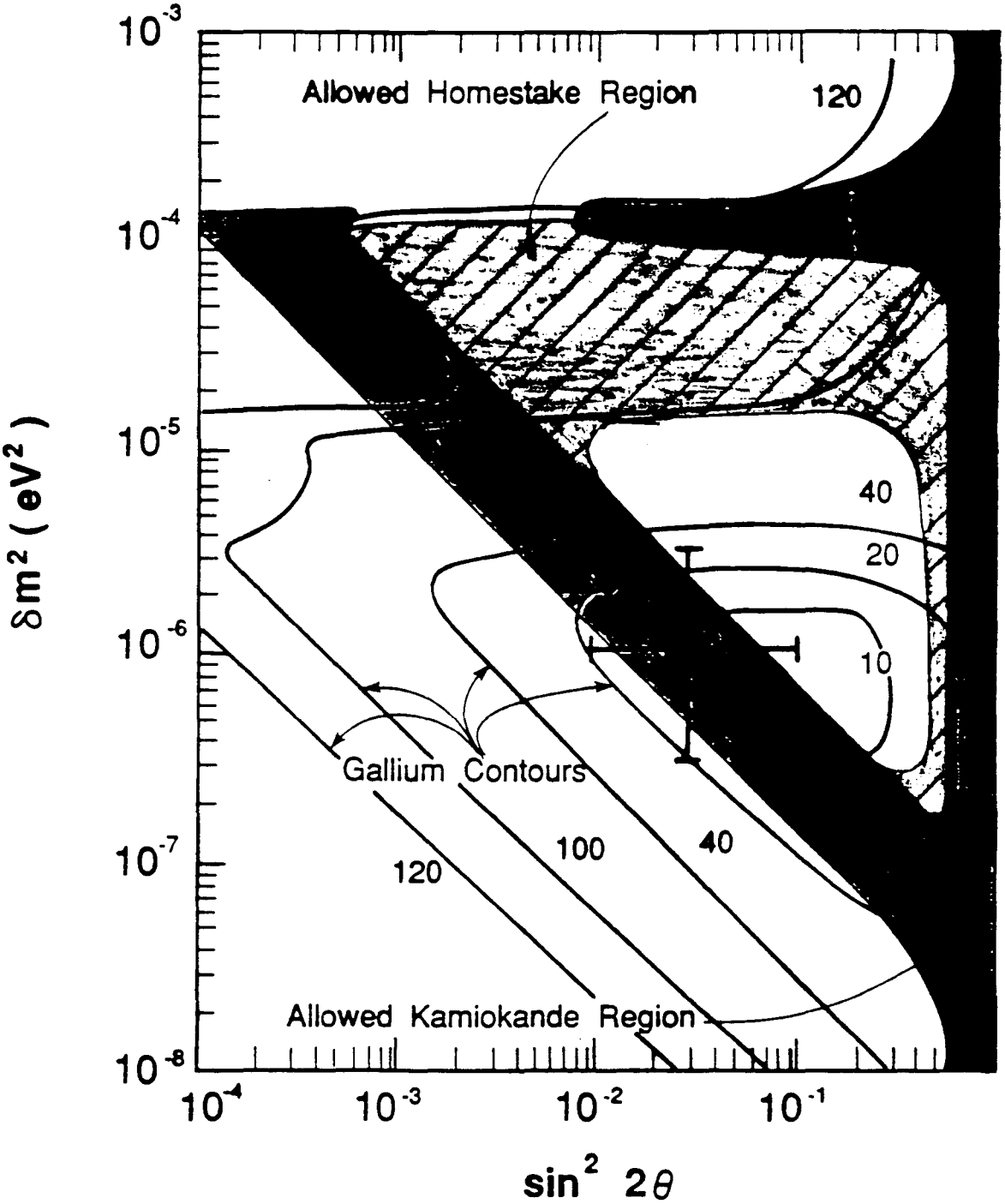
Source calibration experiment

^{51}Cr (0.75 MeV ν's)

1 MCurie tests ground state to ± 5

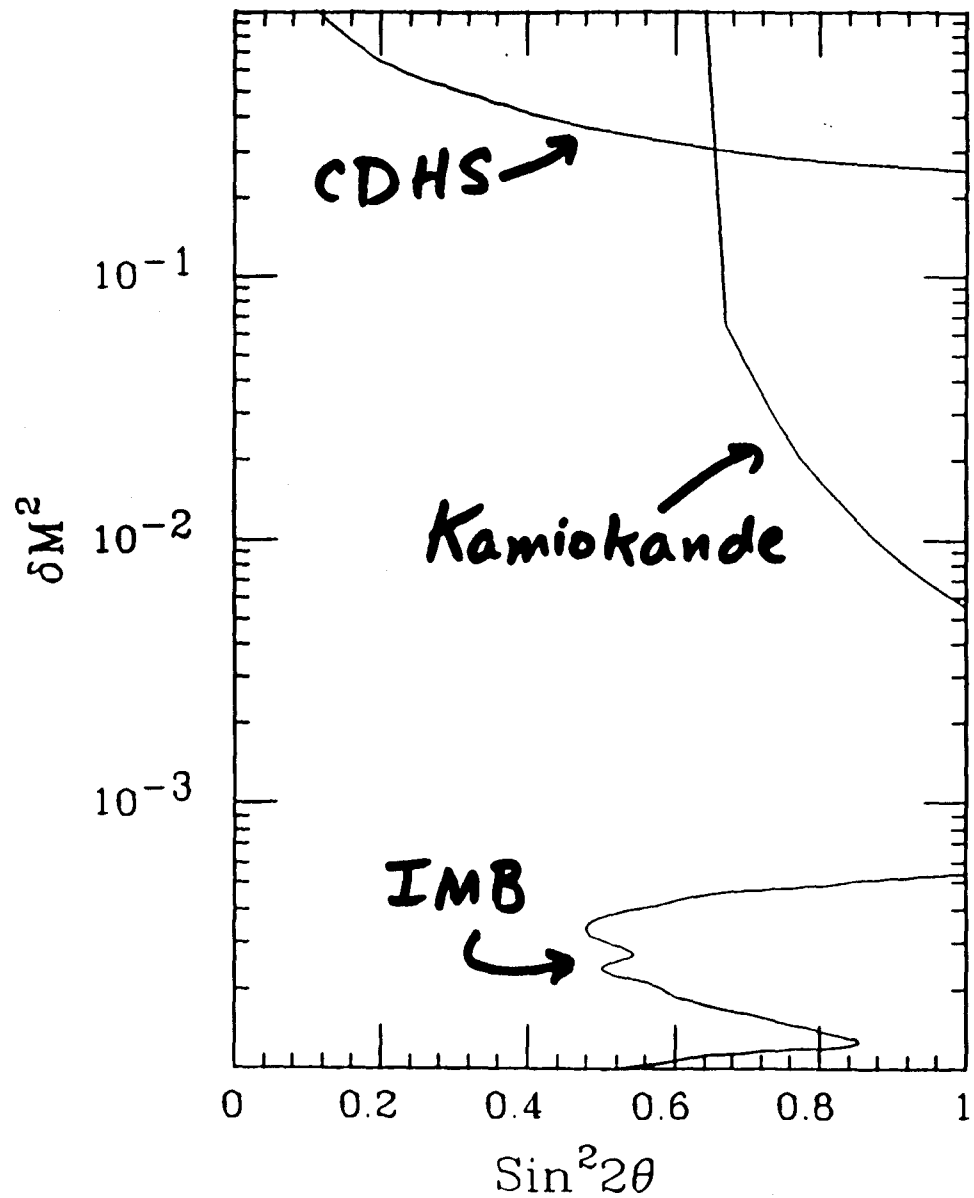
In 1980, attempt to use Oak Ridge HFIR failed. In USSR,

- use isotopically enriched ^{50}Cr (87.7% instead of normal 4.35%)
- disperse Cr through reactor to avoid local loading
- use metal ($\rho = 6$) instead of $GaCl_3$ ($\rho = 0.6$)


Allowed Homestake Region
120
40
20
10
Gallium Contours
120
100
40
Allowed Kamiokande Region
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
δm^2 (eV^2)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
$\sin^2 2\theta$

If solar ν results are due to $\nu_e \to \nu_\mu$ with $\delta m^2 \sim 10^{-6}\,eV^2$,

then seesaw model of ν masses suggests $\nu_\mu \to \nu_\tau$ with $\delta m^2 \sim 3\times10^{-4} - 9\times10^{-2}\,eV^2$



Atmospheric Neutrino Oscillations

- Atmospheric neutrinos above 10 GeV are mainly ν_μ.
- ν_e and ν_τ from ν_μ oscillation have negligible chance of being mistaken for ν_μ.

$\Longrightarrow$ **disappearance experiment** $\nu_\mu \rightarrow \nu_{e,\tau}$.

Look for a deficit of ν_μ of energy E after a distance L :

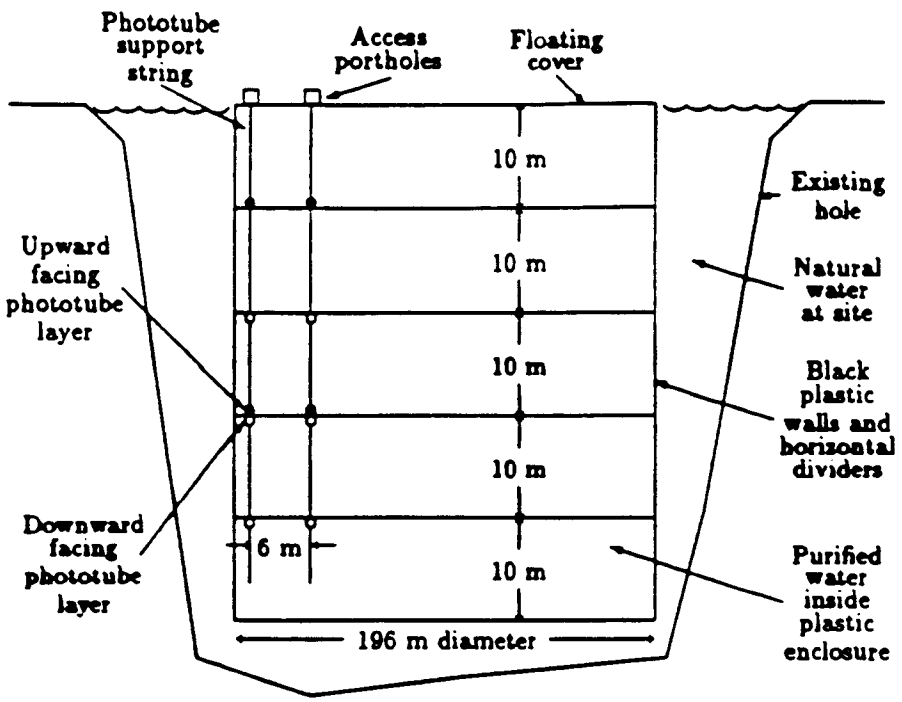
$$P(\nu_\mu \rightarrow \nu_{e,\tau}) = \sin^2 2\theta \sin^2 \left(\frac{\pi \delta m^2 L}{2.5E} \right).$$

To study **minimum possible** δm^2, **cut on low energy muons**:

GRANDE - I

30,000 m^2

$\cos\theta$	Number of events per year
0.9 - 1.	85
0.8 - 0.9	82
0.7 - 0.8	68
0.6 - 0.7	67
0.5 - 0.6	60
0.4 - 0.5	54
0.35 - 0.4	27



Drawing not to scale

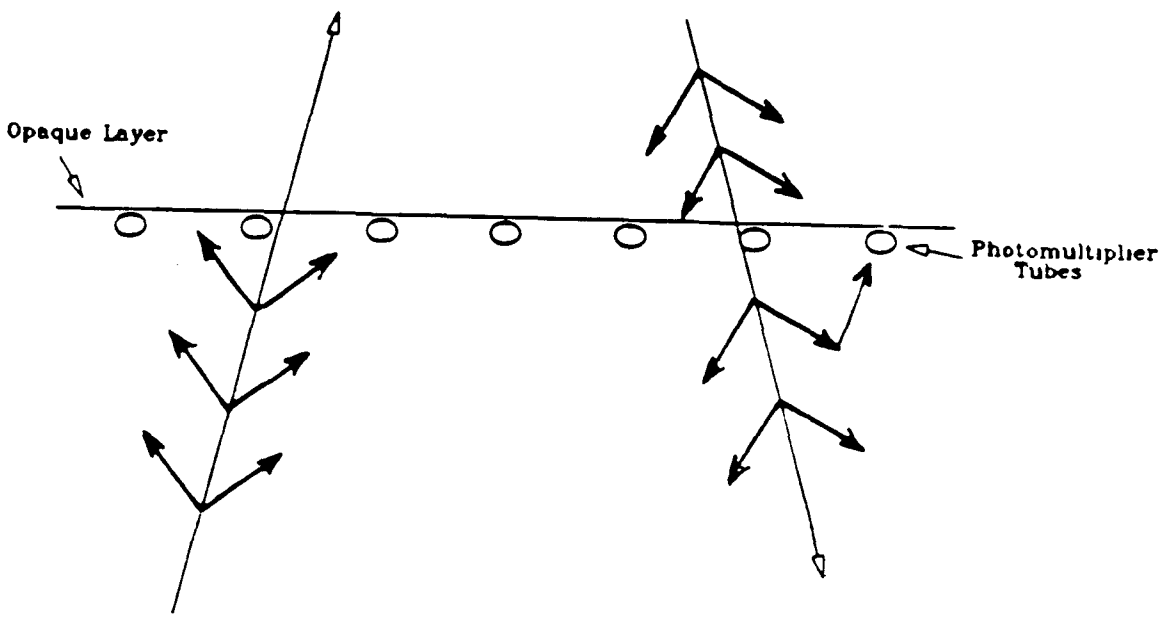
Figure 4: The GRANDE detector.

Up-down discrimination

IMB is a prototype!

IMB: 1 upward ν-induced μ/2 days in presence of
5×10^5 downward μ's

$\Longrightarrow$ up-down discrimination 5×10^5 in a single layer.



Upward μ:
typically > 20 PMT's hit per layer

Downward μ ($\theta < 48°$) :
typically $< 3 - 4$ PMT's per layer due to direct hits or light scattering

Accelerator Neutrino Oscillations – SSC

Oscillation studies with a 20 GeV SSC beam at a distance of 400 km from GRANDE:

- Measure ν_μ disappearance via neutral-charged current ratio or charged current rate at 2 different distances.
- Sensitive to $\sin^2 2\theta \sim 0.005$ and $\delta m^2 \sim 0.003\ eV^2$.
  - Very interesting region theoretically: If the solar neutrino deficit is due to MSW oscillations, then $\nu_\mu \leq 10^{-2}\ eV$. Given a see-saw mechanism, this implies $m_{\nu_\tau} \sim 0.2 - 3$ eV and $\delta m^2 \sim 0.03 - 10\ eV^2$.
  - With L/E as high as 20 (compared to typical accelerator experiments in the range L/E < 1), GRANDE will uniquely explore this region of parameter space.

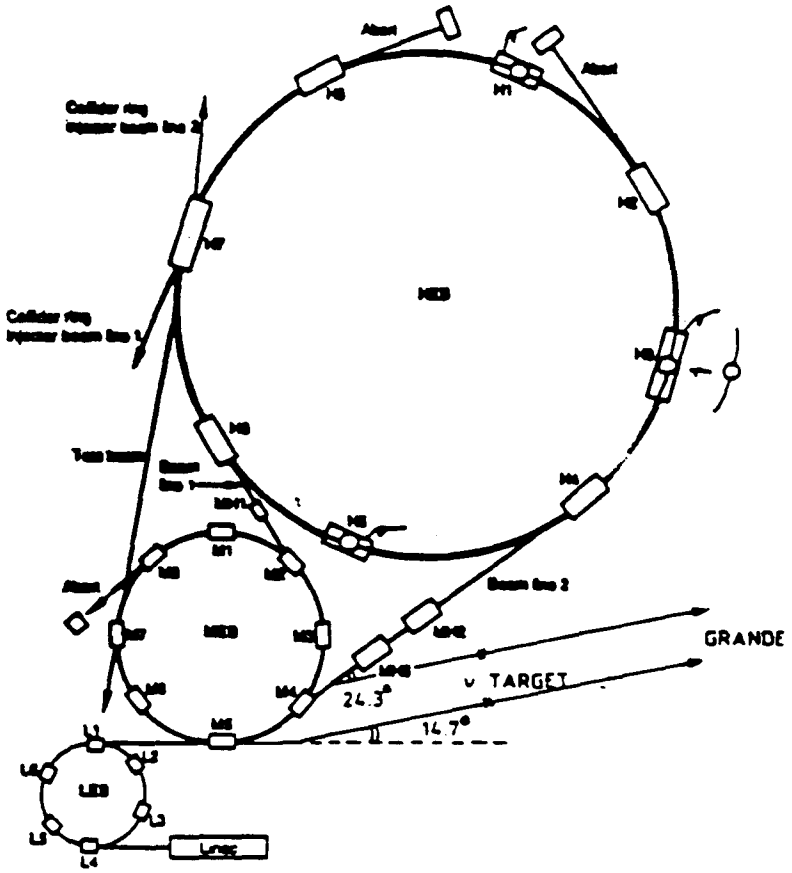


Figure 1: The Medium Energy Booster (MEB) of 200 GeV protons and the two possible beam lines towards GRANDE.

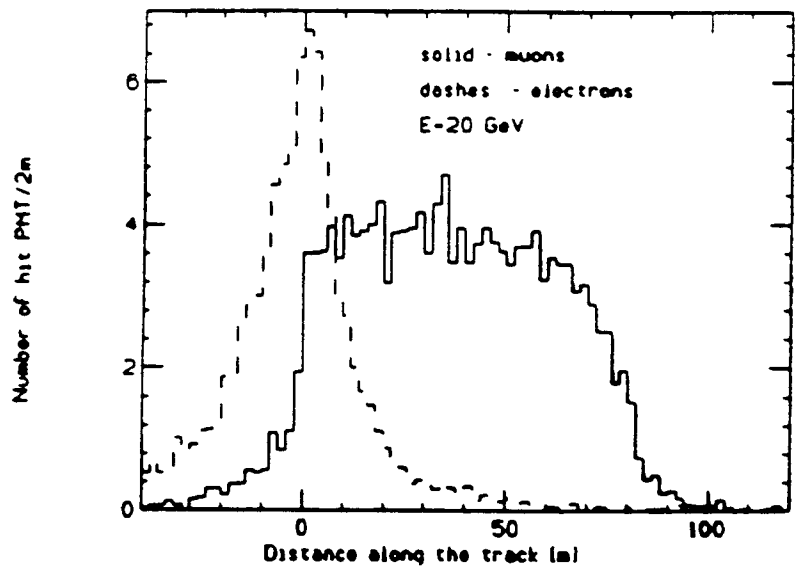


Figure 47: The numbers of photomultiplier tubes illuminated along the track of a 20 GeV muon and a 20 GeV electron.

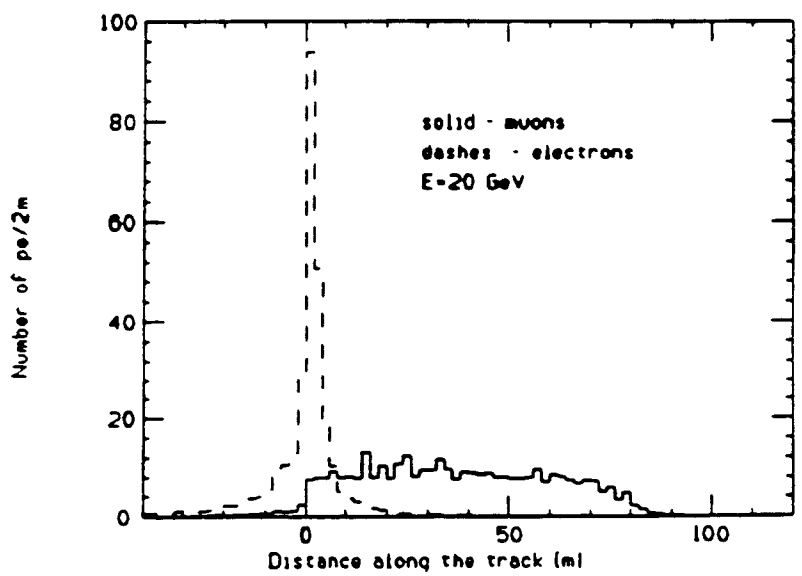


Figure 48: The numbers of photoelectrons collected along the track of a 20 GeV muon and a 20 GeV electron.

KAMIOKANDE SOLAR ν EXP.

K. NAKAMURA
ICRR, UNIV. OF TOKYO

SOLAR NEUTRINO PROBLEM

- SOLAR MODEL ?
- UNCONVENTIONAL NEUTRINO PROPERTIES ?
  - MSW (no fine tuning needed)
    long-distance vacuum oscillation
    neutrino decay with mixing
    neutrino magnetic moment

AN INTERESTING POSSIBILITY — FUKUGITA-YANAGIDA

Simplest version of SO(10)

$\theta_{e\mu} = \theta_c = 0.22$ $\quad \sin^2 2\theta \simeq 0.18$

$\Delta m^2 \sim (1-3) \times 10^{-7}\,eV^2$ (K-II + ^{37}Cl

Seesaw mechanism

$$m_{\nu_e} : m_{\nu_\mu} : m_{\nu_\tau} = m_u^2 : m_c^2 : m_t^2$$

$$\therefore m_{\nu_\mu} = (4 \pm 1) \times 10^{-4}\,eV$$

$$m_{\nu_\tau} \sim 4\,eV \quad (m_t \sim 140\,GeV)$$

right-handed ν : $M \sim (4-6) \times 10^{13}$ GeV

$$\sin^2\theta_W \simeq 0.230 \pm 0.005$$

$$\tau(p) \simeq 2 \times 10^{33 \pm 2}\,yr$$

RESULTS FROM ONE THOUSAND DAYS OF REAL-TIME, DIRECTIONAL SOLAR NEUTRINO DATA

K. S. Hirata, K. Inoue, T. Kajita, T. Kifune, K. Kihara, M. Nakahata, K. Nakamura, S. Ohara, N. Sato, Y. Suzuki, Y. Totsuka and Y. Yaginuma
Institute for Cosmic Ray Research, University of Tokyo, Tanashi, Tokyo 188, Japan

M. Mori, Y. Oyama, A. Suzuki, K. Takahashi and M. Yamada
National Laboratory for High Energy Physics (KEK), Tsukuba, Ibaraki 305, Japan

M. Koshiba
Tokai University, Shibuya, Tokyo 151, Japan

T. Suda and T. Tajima
Department of Physics, Kobe University, Kobe, Hyogo 657, Japan

K. Miyano, H. Miyata and H. Takei
Niigata University, Niigata, Niigata 950-21, Japan

Y. Fukuda, E. Kodera, Y. Nagashima and M. Takita
Department of Physics, Osaka University, Toyonaka, Osaka 560, Japan

K. Kaneyuki and T. Tanimori
Department of Physics, Tokyo Institute of Technology, Meguro, Tokyo 152, Japan

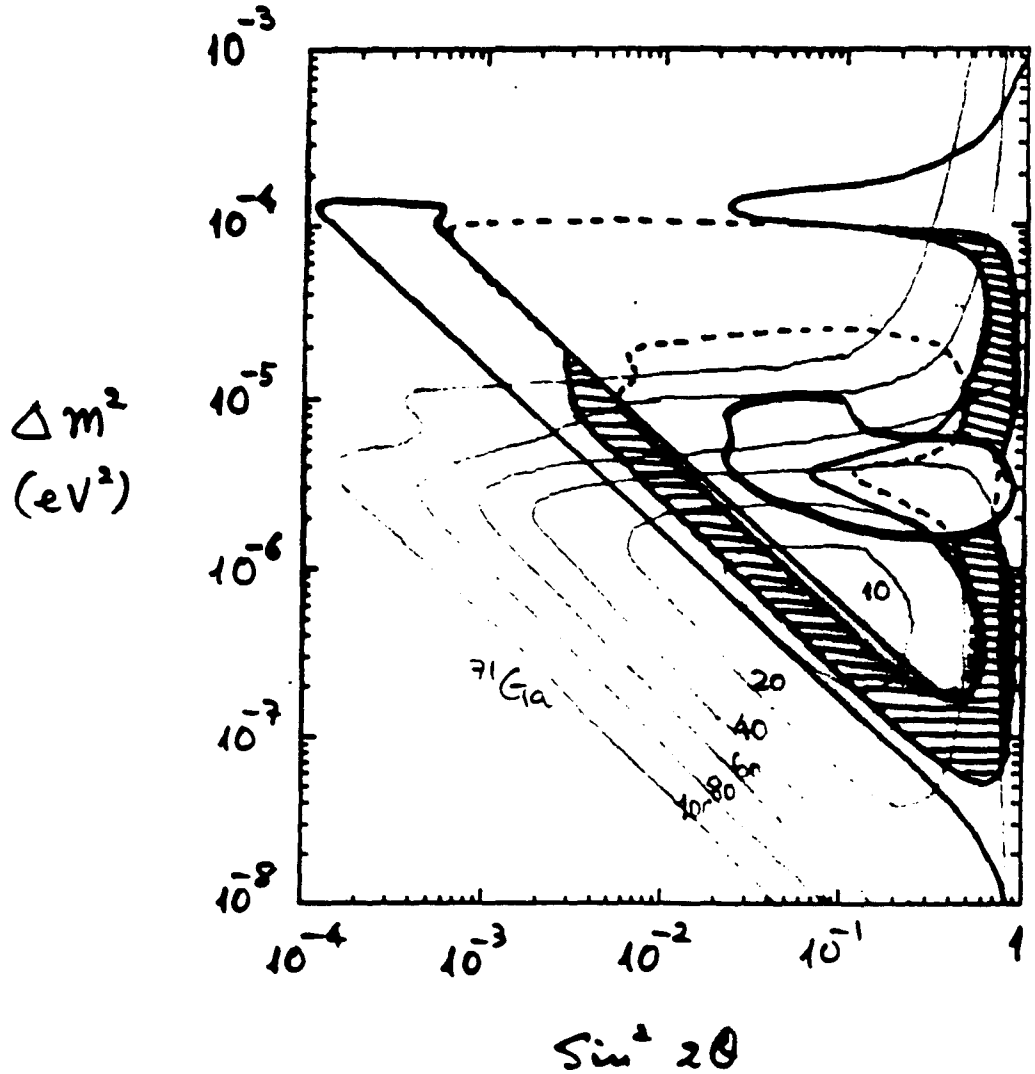
and

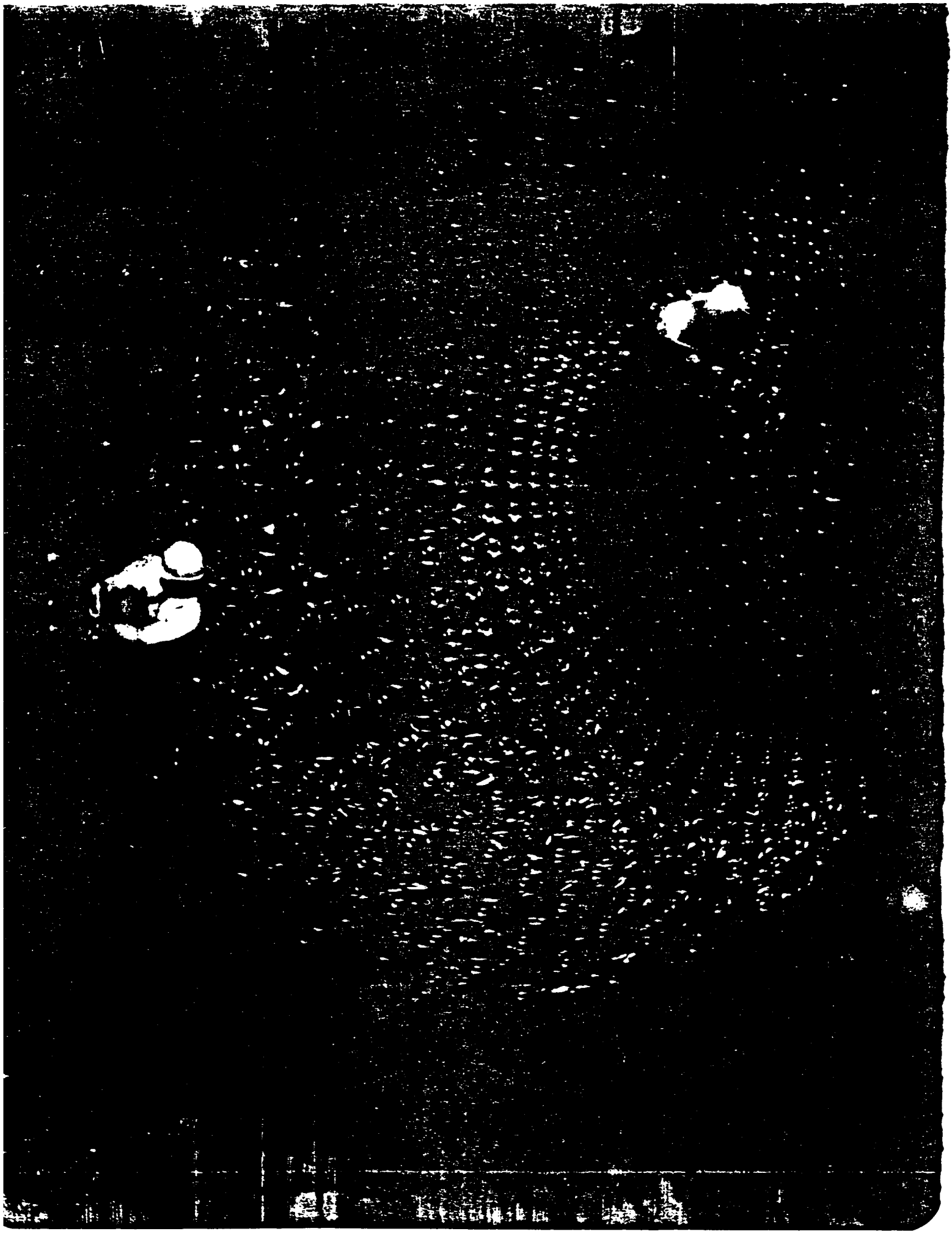
E. W. Beier, L. R. Feldscher, R. D. Frank, W. Busti, S. B. Kim, A. K. Mann, F. M. Newcomer, R. Van Berg and W. Zhang[1]
Department of Physics, University of Pennsylvania, Philadelphia, PA 19104, U.S.A.

Abstract

A data sample of 1040 days from the Kamiokande II detector, consisting of subsamples of 450 days at electron energy threshold $E_e \geq 9.3$ MeV and 590 days at $E_e \geq 7.5$ MeV, yields a clear directional correlation of the solar neutrino-induced electron events with respect to the Sun and a measurement of the differential electron energy distribution. These provide unequivocal evidence for the production of ^{8}B by fusion in the Sun. The measured flux of ^{8}B solar neutrinos from the two subsamples relative to a prediction of the standard solar model is 0.46 ± 0.05 (stat.) ± 0.06 (syst.). The total data sample is tested for short-term time variation; within the statistical error, no significant variation is observed.

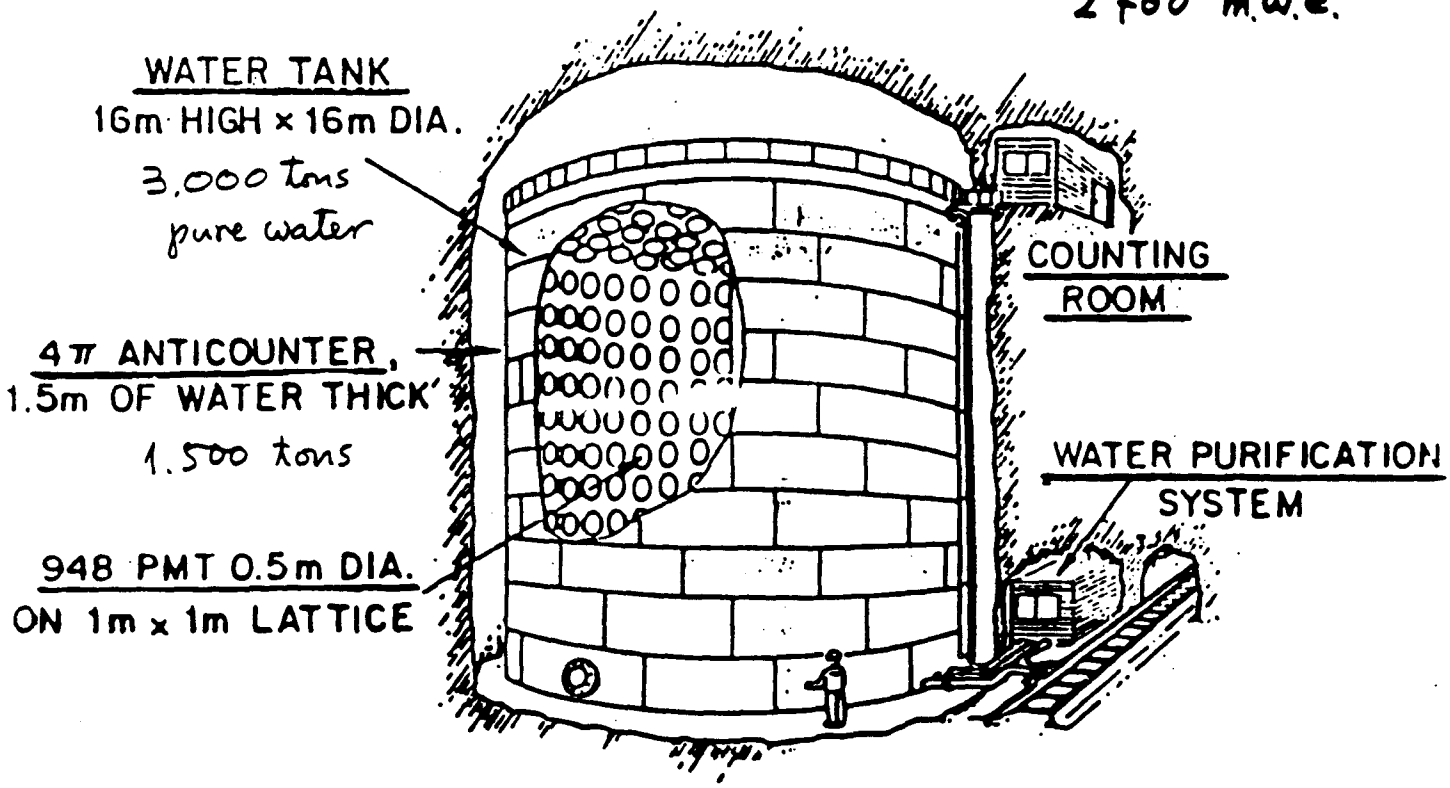
[1]Now at Los Alamos National Laboratory, Los Alamos, NM 87545, U.S.A.

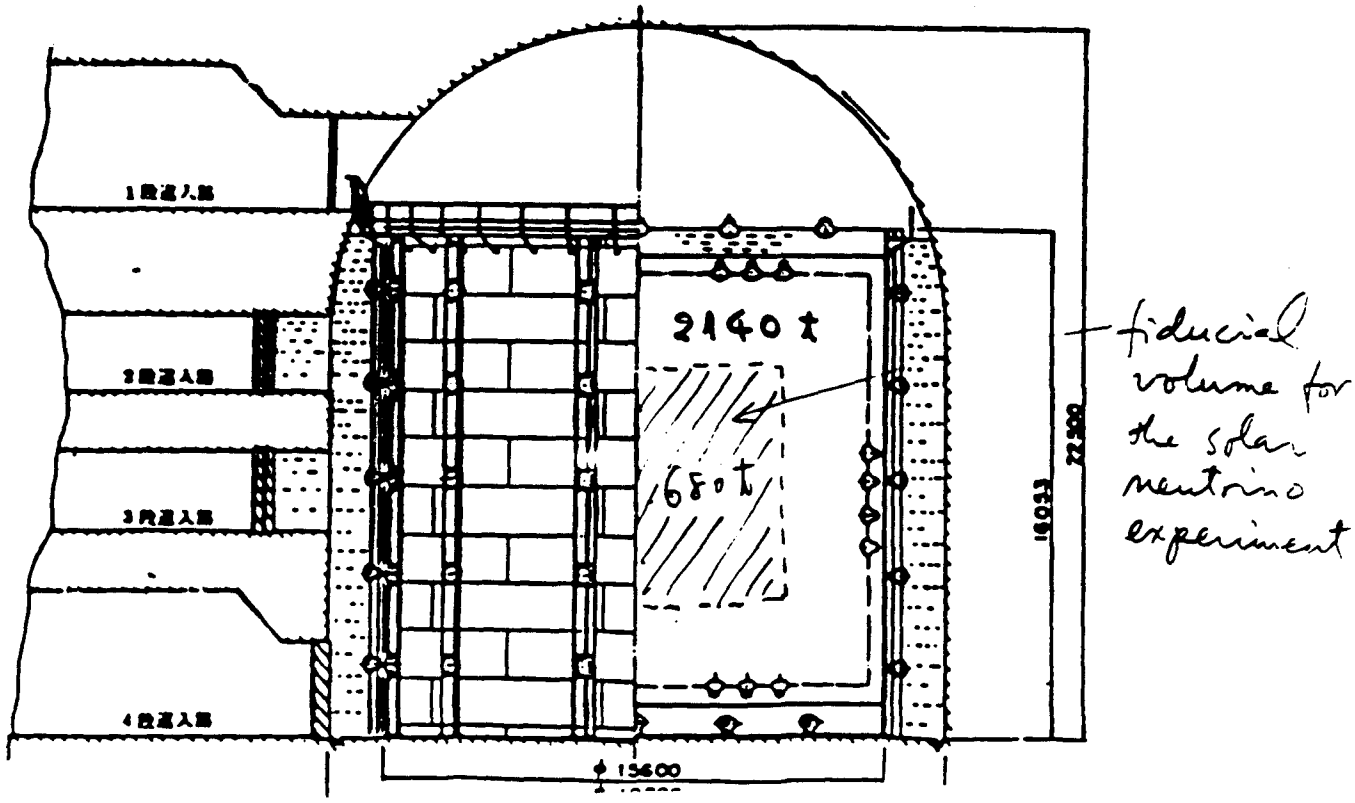

10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
Δm^2
(eV^2)
^{71}Ga
10
20
40
60
80
100
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
$\sin^2 2\theta$

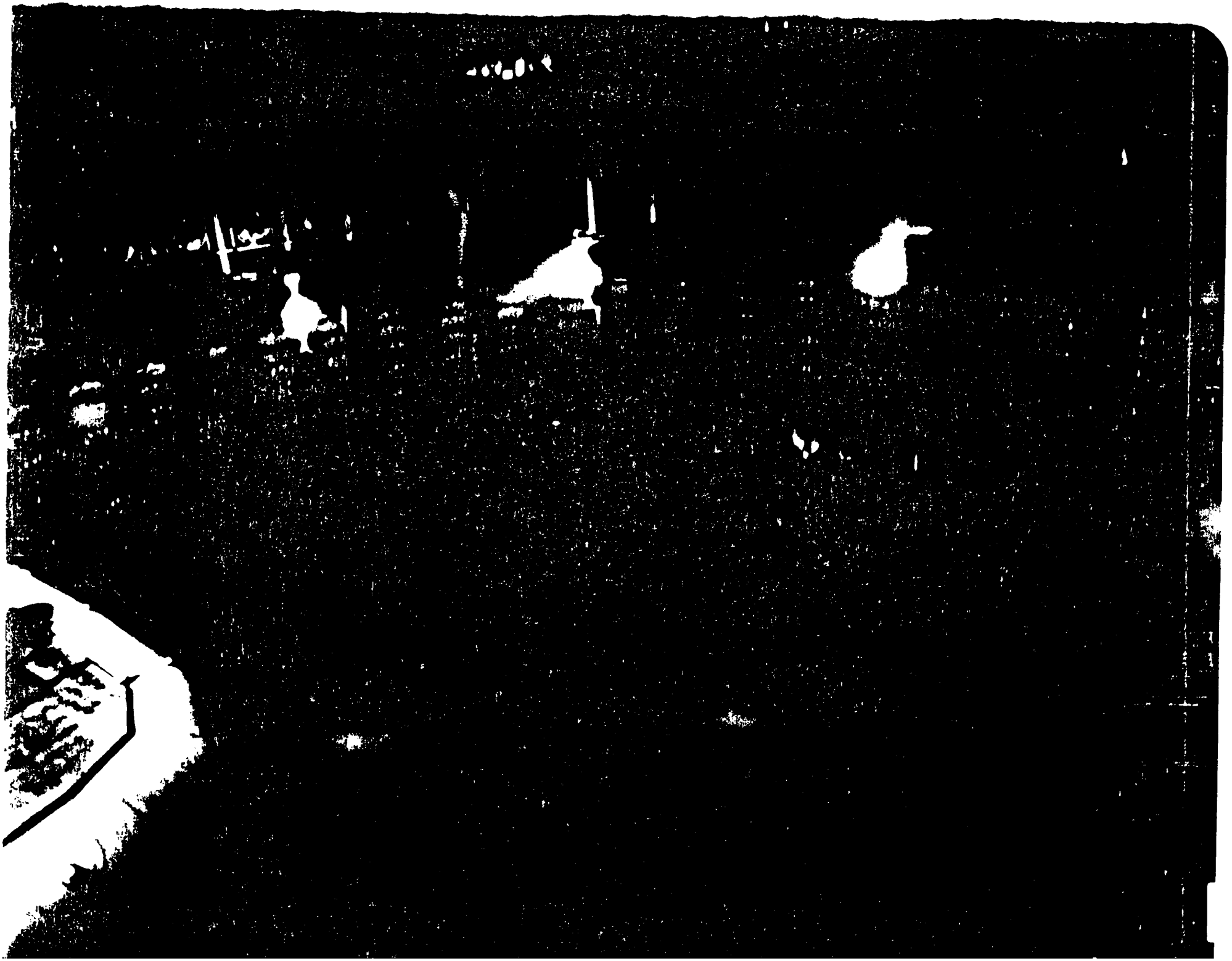


KAMIOKANDE DETECTOR

2700 m.w.e.







νe SCATTERING IN A WATER CHERENKOV DETECTOR

1. STRONG DIRECTIONALITY
   - BACKGROUND REJECTION

   MORE IMPORTANTLY,
   - DIRECT EVIDENCE FOR NEUTRINOS COMING FROM THE SUN

2. MEASUREMENT OF RECOIL e^- ENERGY
   - SENSITIVITY TO THE SOLAR ν SPECTRUM

3. REALTIME EXPERIMENT
   - SHORT-TERM TIME VARIATION

     DAY/NIGHT

     CORRELATION WITH SOLAR FLARE ACTIVITY

4. THRESHOLD: 7.5 MeV
   - (ALMOST) PURE ^8B SOLAR ν

5. INTERACTIONS WITH $\bar{\nu}_e$

$$\nu_{eL} \xrightarrow{SFP} \bar{\nu}_{\mu R} \xrightarrow{MSW} \bar{\nu}_{eR}$$

$$\nu_{eL} \xrightarrow{MSW} \nu_{\mu L} \xrightarrow[SFP]{} \bar{\nu}_{eR}$$

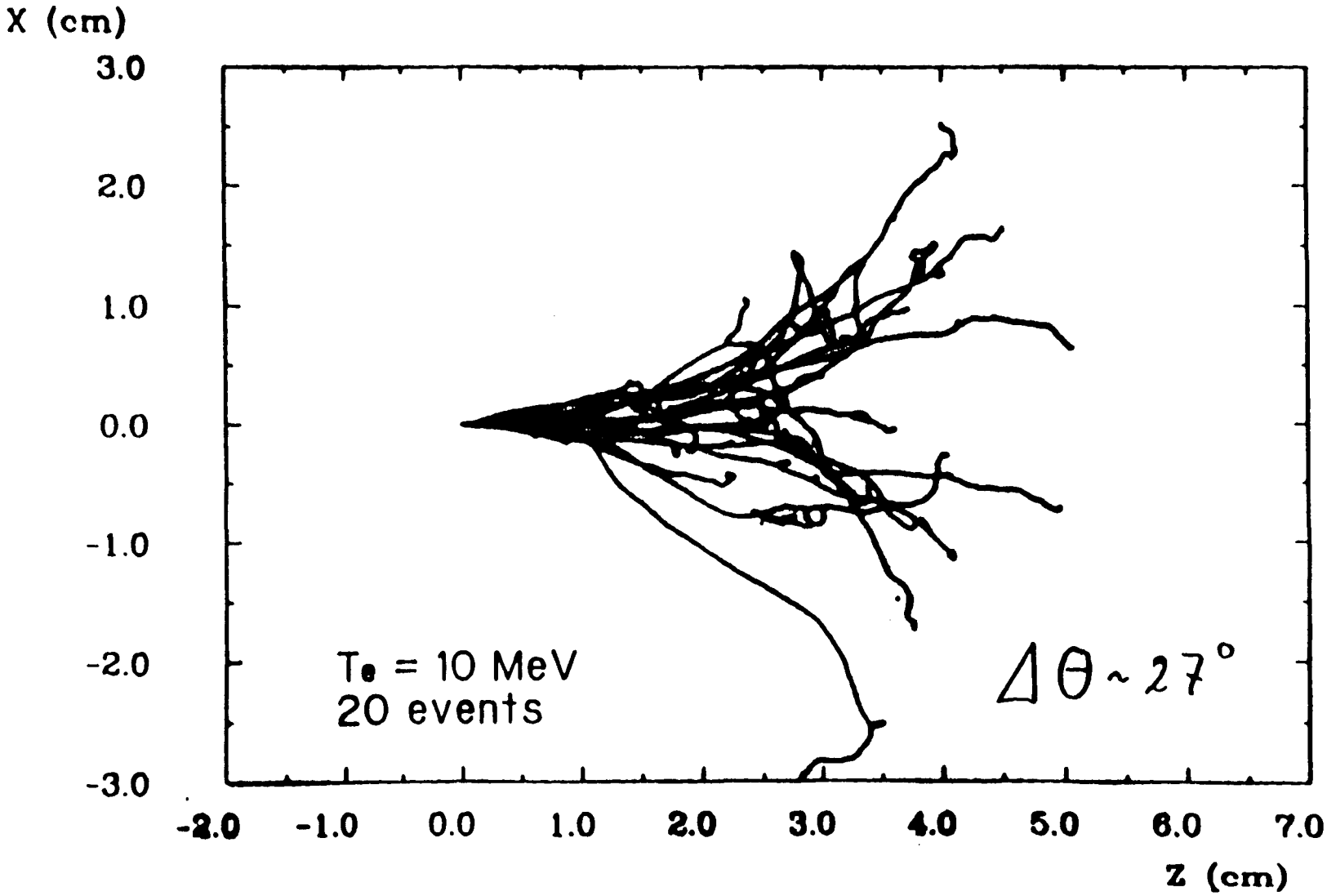
$\sigma_{\bar{\nu}_e p} \gg \sigma_{\nu_e e}$

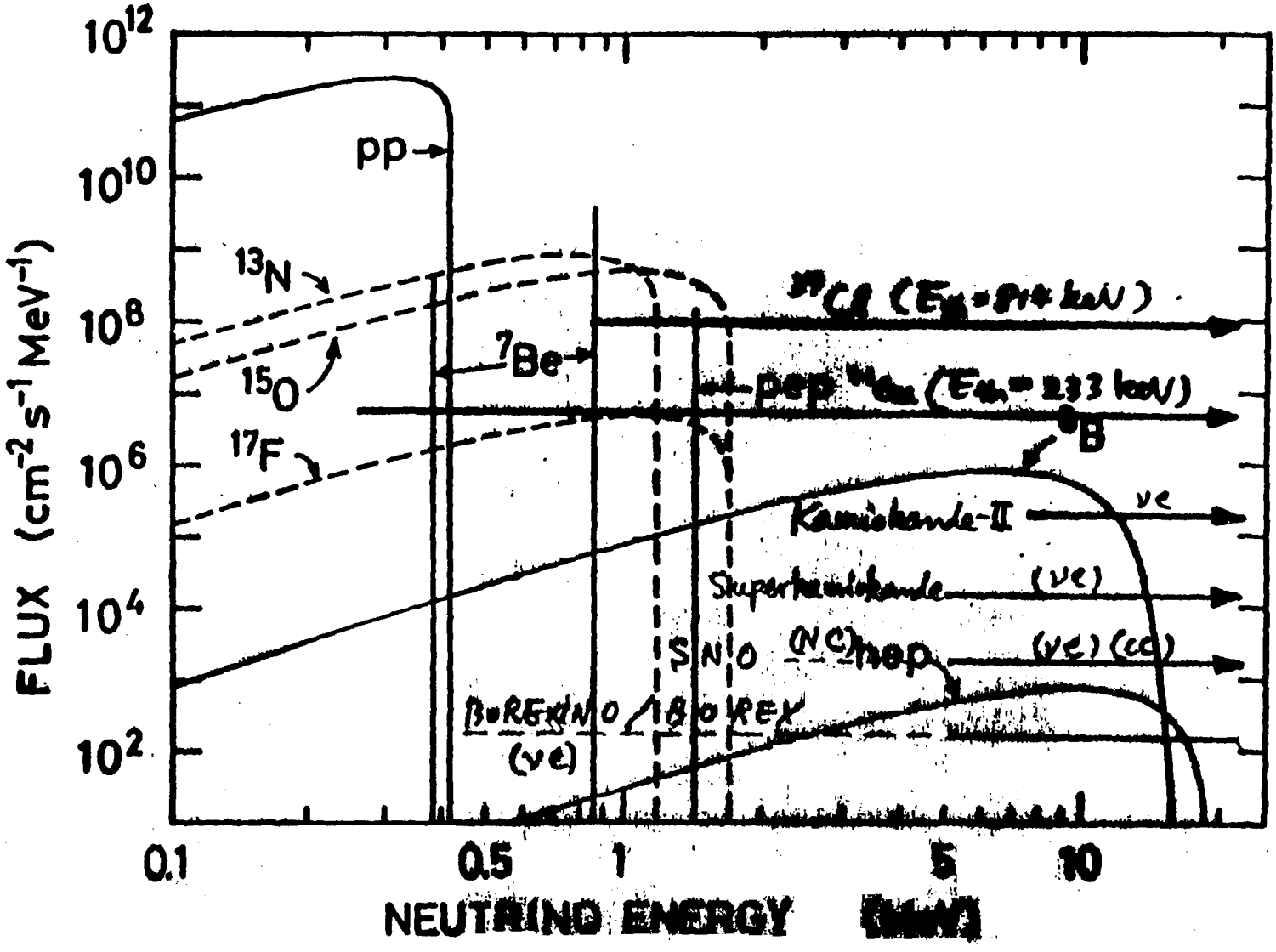
but, no directionality

Barbieri et al.

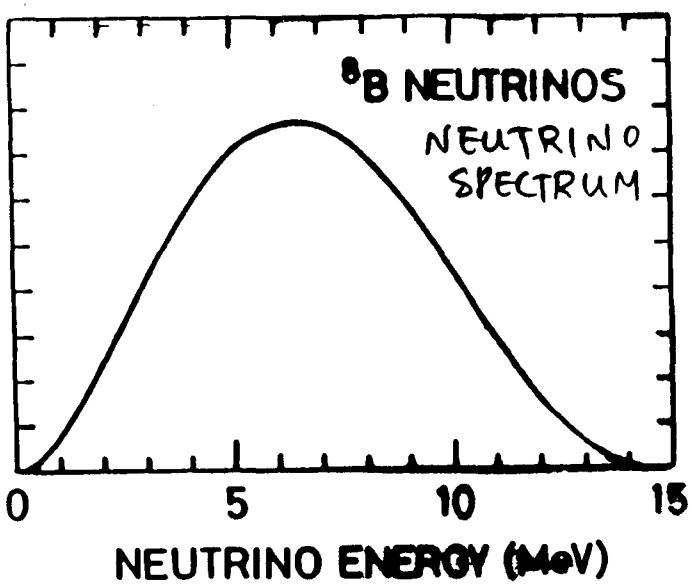
Akhmedov

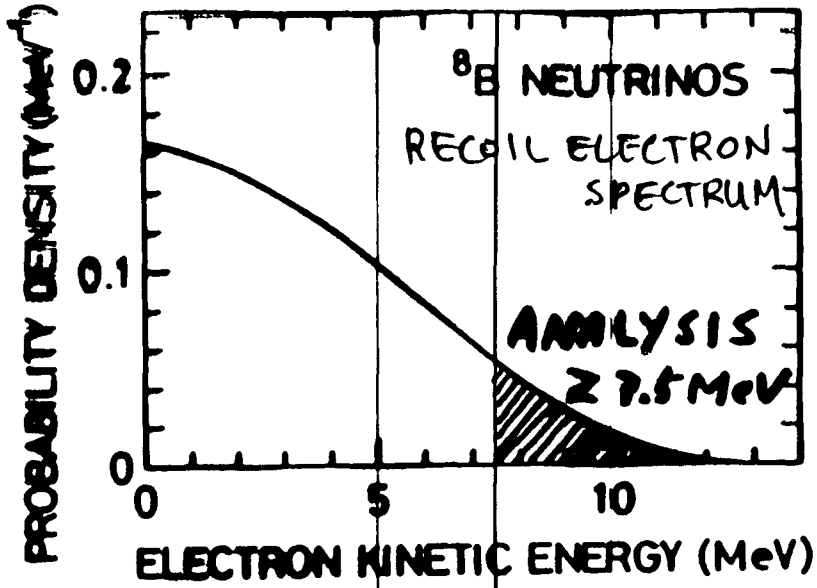
6. IF $\mu_{\nu_e} \neq 0$, ELECTROMAGNETIC $\nu_e e$ INTERACTIONS

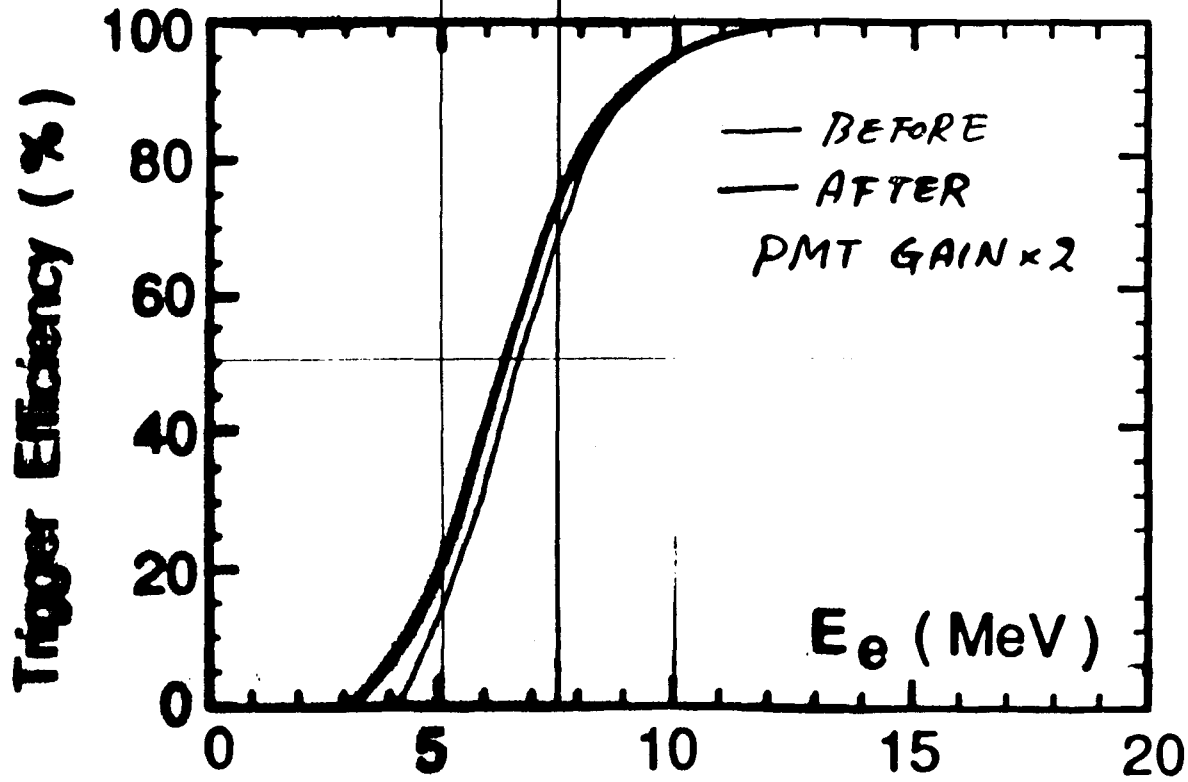

X (cm)
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Z (cm)
Te = 10 MeV
20 events
Δθ ~ 27°

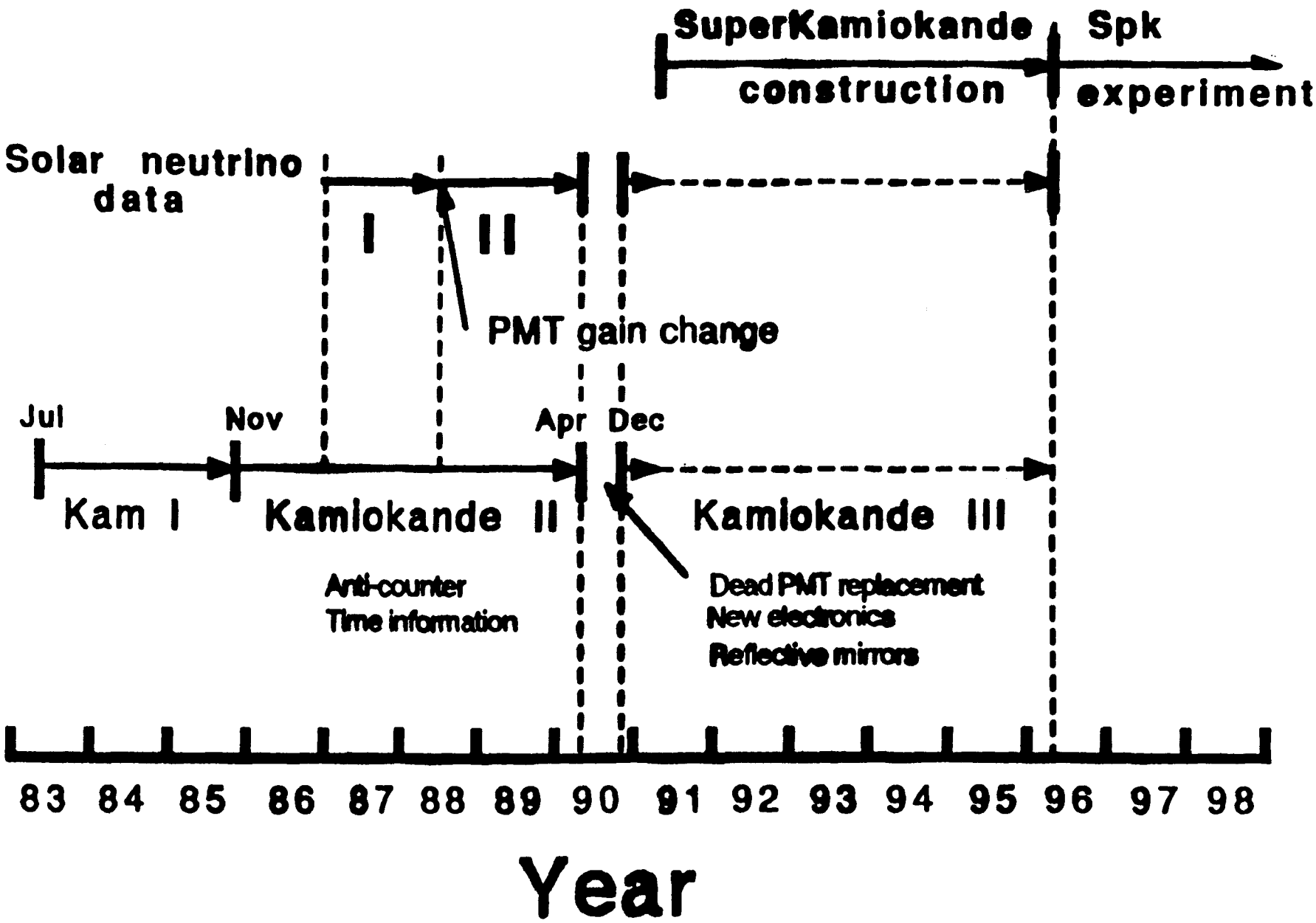

FLUX (cm^{-2} s^{-1} MeV^{-1})
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
pp
^{13}N
^{15}O
^{17}F
^{7}Be
pep
^{8}B
Kamiokande-II
νe
Superkamiokande
(νe)
SNO
(NC)
(νe) (CC)
BOREXINO
BOREX
(νe)
0.1
0.5
1
5
10
NEUTRINO ENERGY

KN-4


^{8}B NEUTRINOS
NEUTRINO SPECTRUM
0
5
10
15
NEUTRINO ENERGY (MeV)


^{8}B NEUTRINOS
RECOIL ELECTRON SPECTRUM
ANALYSIS
≥ 7.5 MeV
PROBABILITY DENSITY (MeV^{-1})
0.2
0.1
0
0
5
10
ELECTRON KINETIC ENERGY (MeV)


BEFORE
AFTER
PMT GAIN × 2
E_e (MeV)
Trigger Efficiency (%)
100
80
60
40
20
0
0
5
10
15
20


SuperKamiokande
Spk
construction
experiment
Solar neutrino data
I
II
PMT gain change
Jul
Nov
Apr
Dec
Kam I
Kamiokande II
Kamiokande III
Anti-counter
Time information
Dead PMT replacement
New electronics
Reflective mirrors
83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98
Year

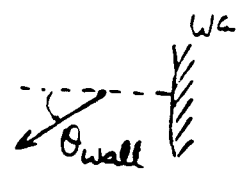
BACKGROUND

✓ RADIOACTIVITY IN WATER

- Water purification system
  Removed ^{238}U, ^{226}Ra $\lesssim 10^{-3}$ pCi/l
- Air-tightening of the detector : 1987 spring
  ^{222}Rn ($\tau_{1/2}$=3.8 d) → ^{218}Po → ^{214}Pb → $\boxed{^{214}Bi}$.
  β (E_{max}=3.26 MeV)
  mine water ~200 pCi/l
  mine air ~ 50 pCi/l
  tank water ~ 0.02 pCi/l (now)
- PMT gain × 2 : 1988 June
  Improved energy resolution → lowered trigger threshold
- Presumably, the background trigger from ^{222}Rn still dominating at $\lesssim$ 7 MeV

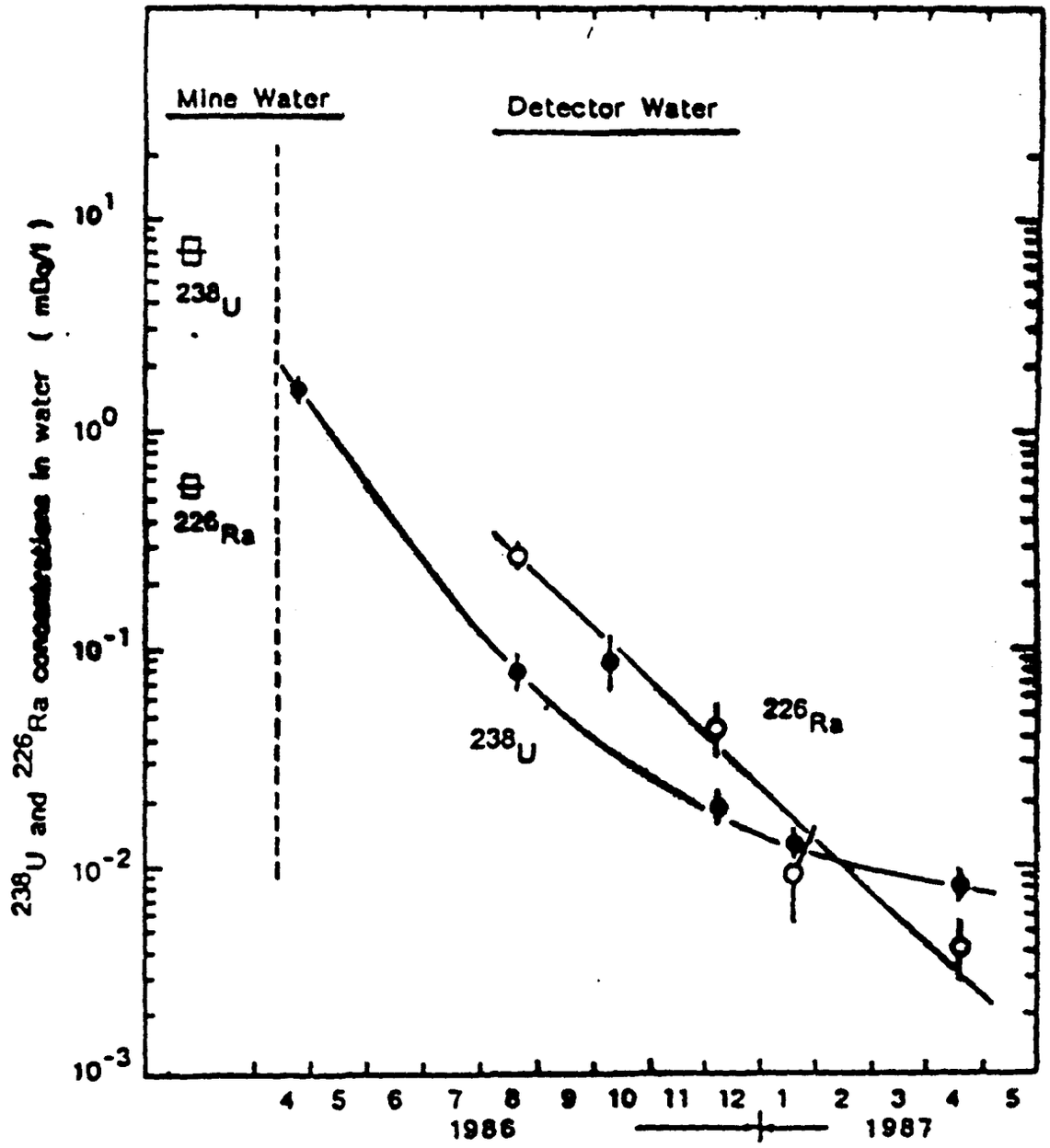
✓ GAMMA-RAYS FROM THE SURROUNDING ROCK

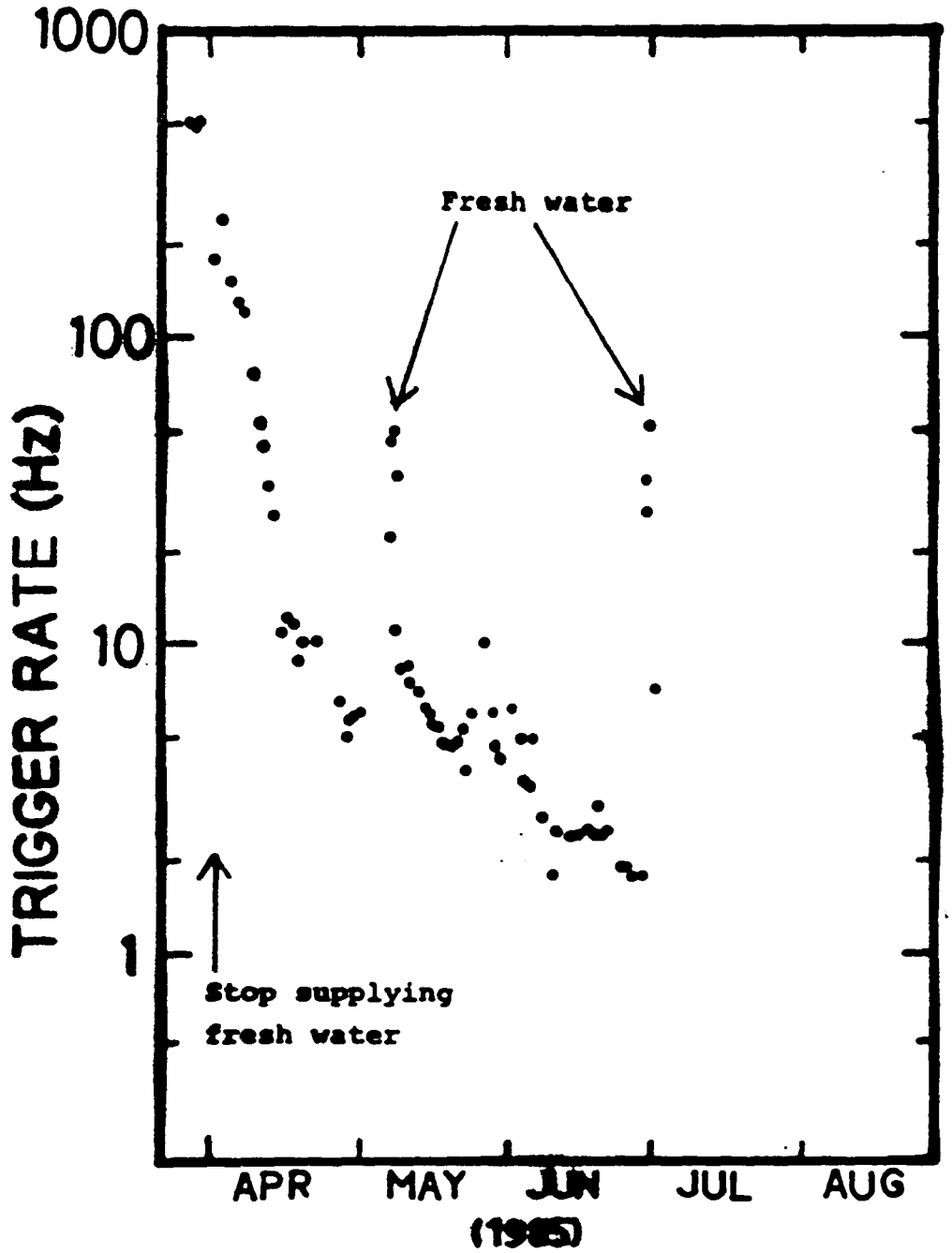
- Anticounter layer ~ 10^{-3}
- Fiducial volume (680 tons) ~ $\frac{1}{400}$
- Remaining γ-ray cut
  Reject if an event vertex is in the outer 1m layer of the fiducial volume and $\cos\theta_{wall} > 0.67$.

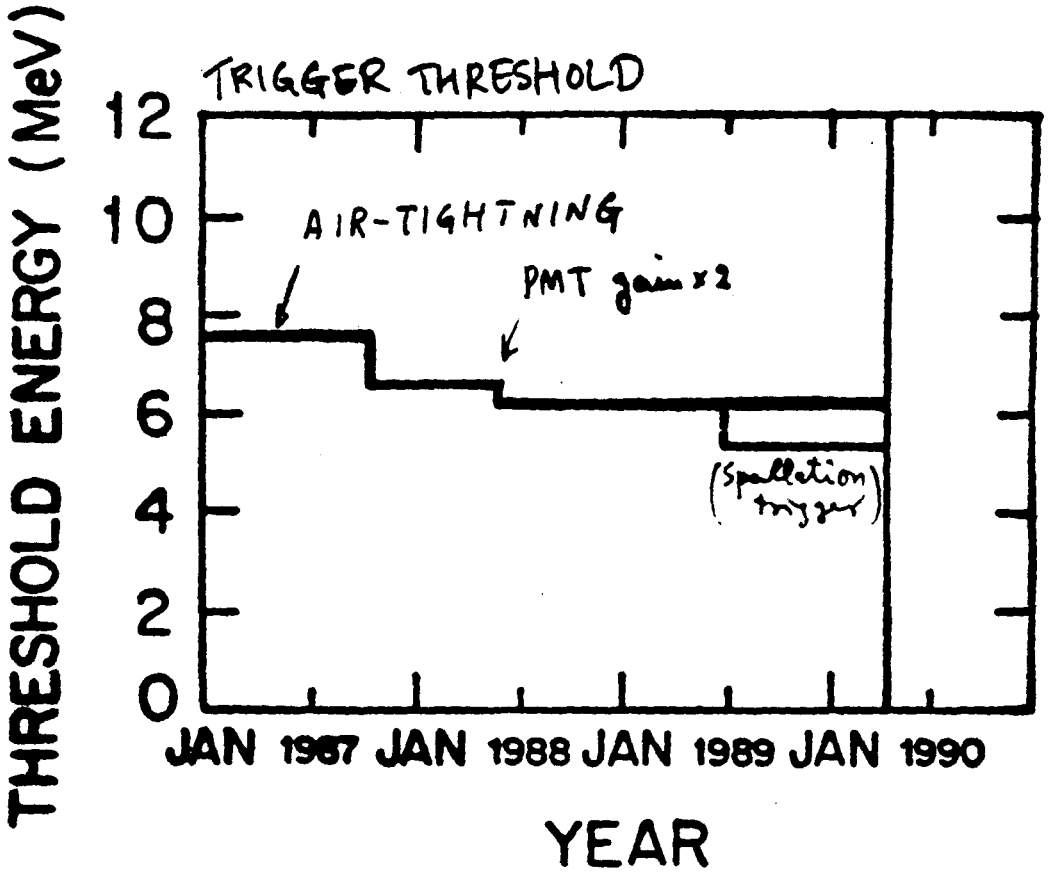


✓ MUON-INDUCED SPALLATION PRODUCTS

- Cut depending on the preceding μ pulse height spatial and timing correlation with the preceding μ track
- PMT gain × 2
  Improved vertex resolution → Better rejection by on spatial correlation


Mine Water
Detector Water
238U
226Ra
238U
226Ra
238U and 226Ra concentrations in water (mBq/l)
10^1
10^0
10^-1
10^-2
10^-3
4 5 6 7 8 9 10 11 12 1 2 3 4 5
1986
1987


1000
100
10
1
TRIGGER RATE (Hz)
Fresh water
Stop supplying
fresh water
APR
MAY
JUN
JUL
AUG
(1985)

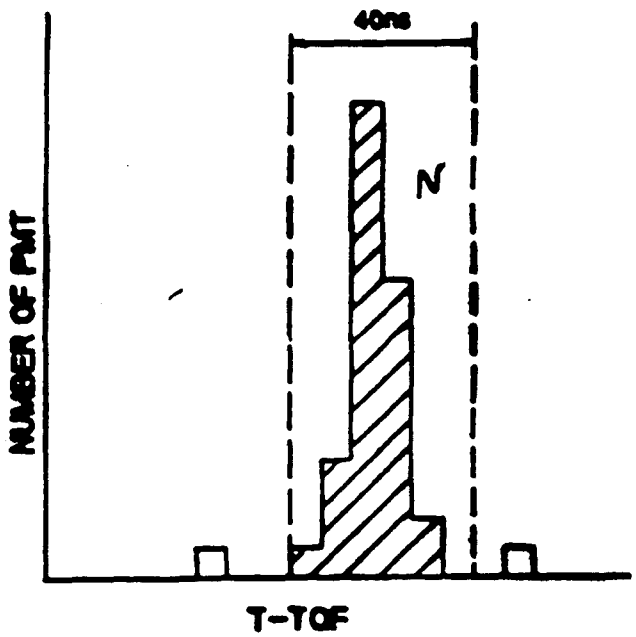

TRIGGER THRESHOLD
AIR-TIGHTNING
PMT gain x2
(Spallation trigger)
THRESHOLD ENERGY (MeV)
12
10
8
6
4
2
0
JAN 1987
JAN 1988
JAN 1989
JAN 1990
YEAR

ENERGY MEASUREMENT

CHERENKOV LIGHT INTENSITY $\propto$ e^- TOTAL ENERGY ($E_e \gtrsim 5$ MeV)

FOR LOW ENERGY ($E_e \lesssim 15$ MeV) ELECTRONS, TYPICAL LIT PMT CORRESPONDS TO <u>ONE p.e.</u>

IN THIS CASE, PULSE HEIGHT IS NOT A GOOD MEASURE FOR TOTAL ENERGY.



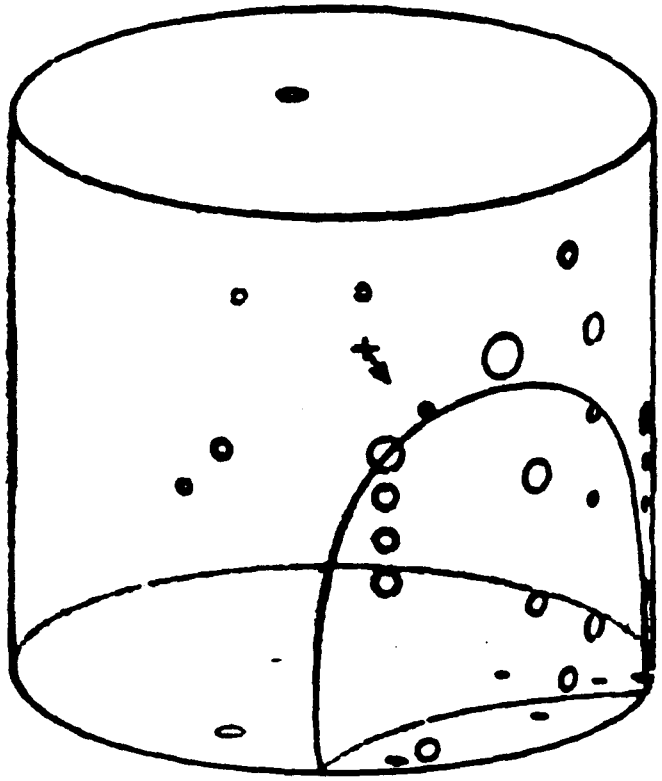
INSTEAD, USE THE NUMBER OF LIT PMTs

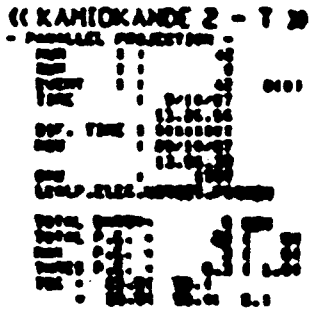
$$N \xrightarrow{\text{geometry, absorption, no. of dead PMTs}} \boxed{N_{eff}} \propto E_e \quad (5 \lesssim E_e \lesssim 20 \text{ MeV})$$

geometry, absorption, no. of dead PMTs } corrected

<u>10 MeV e^-</u>

before gain × 2 $\quad N_{eff} = 26 \quad \Delta E/E = 22\%$





MONTE CARLO

10 MeV ELECTRON

CALIBRATIONS

ENERGY

1. $N_i\,(n,\gamma)\,N_i^*$ — 9 MeV 71%, 7.8 MeV 16%, 6.8 MeV 13%

   ↑ ^{252}Cf

   ~2 MeV n (must be thermalized)

   γ: must be subtracted

2. Decay electrons from stopping μ
3. Muon-induced spallation products

- Adjust Monte Carlo to:

$$\frac{\text{Monte Carlo}}{\text{Data}} = 1.00 \pm 0.03$$

- Position dependence:

  reproduced to within ±2%

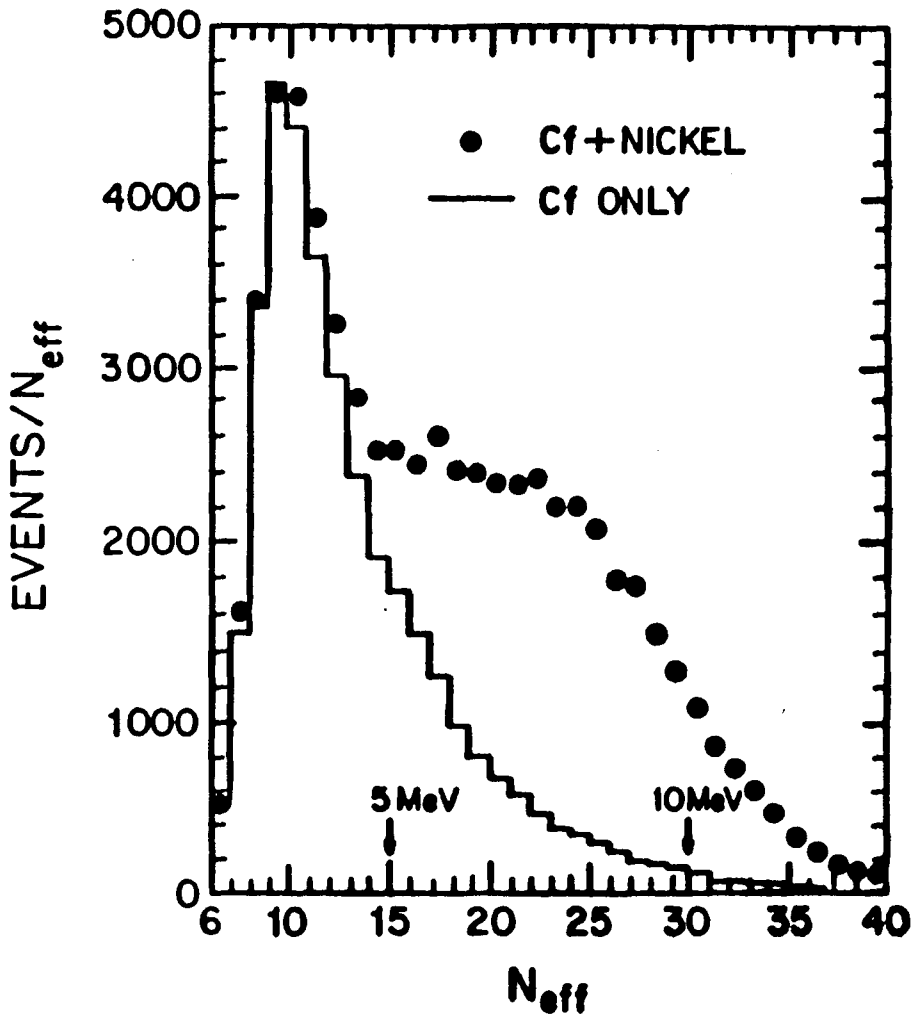
- Stability of the detector gain:

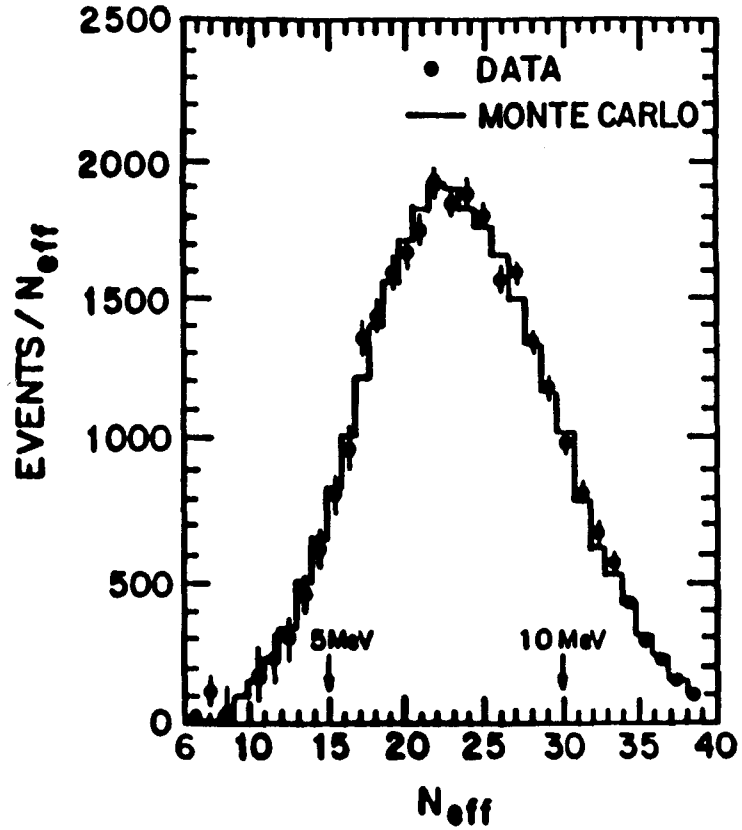
  within ±2% over 4 years

Together,

- uncertainty in the absolute energy scale: ±3%
- This corresponds to the uncertainty of the ^8B solar ν flux of:

  ±12%


Cf+NICKEL
Cf ONLY
5MeV
10MeV
EVENTS/N_eff
N_eff
0
1000
2000
3000
4000
5000
6
10
15
20
25
30
35
40


DATA
MONTE CARLO
5MeV
10MeV
EVENTS/N_eff
N_eff
0
500
1000
1500
2000
2500
6
10
15
20
25
30
35
40

ANGULAR RESOLUTION

$N_i(n,\gamma)N_i^*$

collimated

- consistent with the simulation using EGS-4
- 10 MeV e^- 30° before gain×2
  27° after gain×2
  dominated by multiple scattering

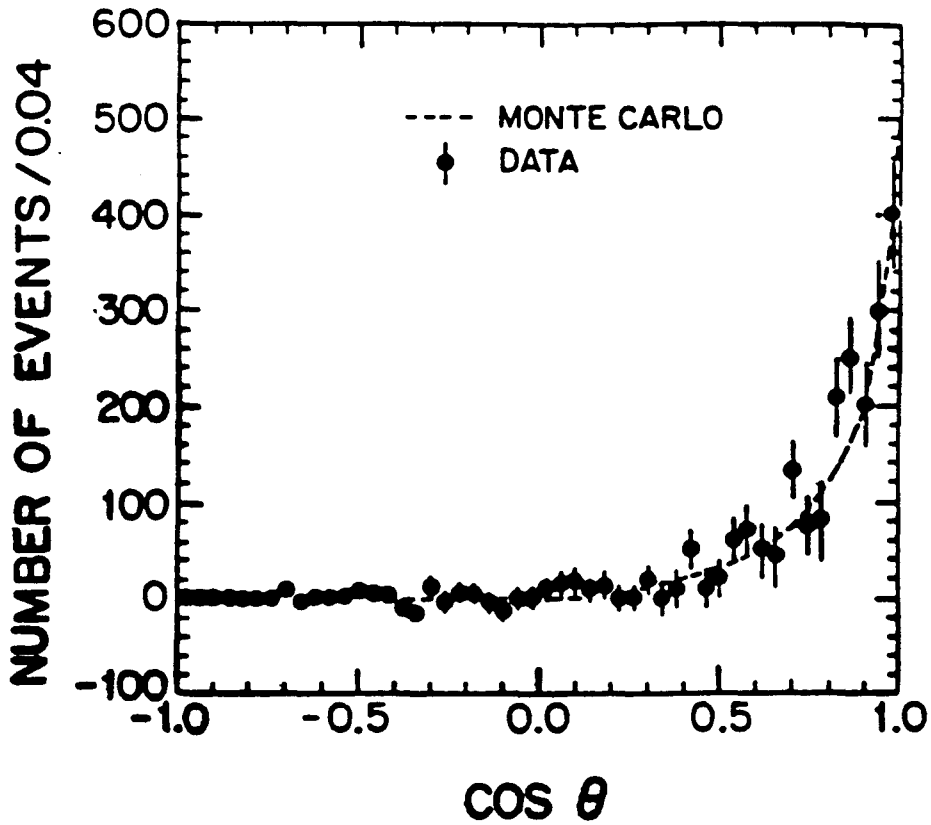
- uncertainty $\lesssim 20\%$
- This corresponds to the uncertainty of the ^8B solar ν flux of:
  $\sim \pm 7\%$

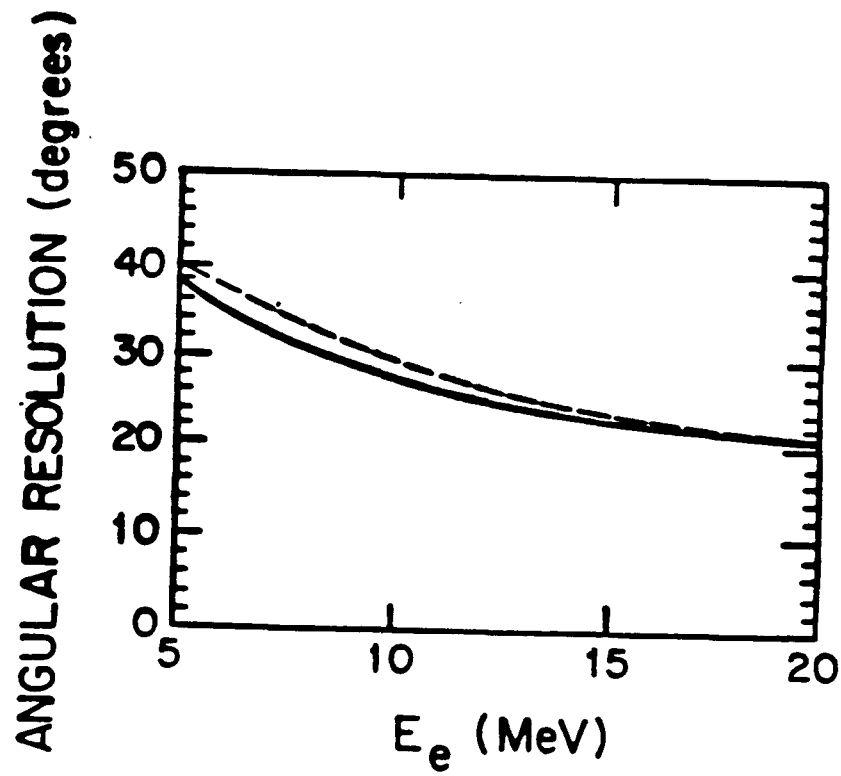
VERTEX RESOLUTION

$N_i(n,\gamma)N_i^*$

- Consistent with the simulation using EGS-4
- 10 MeV e^- 1.2 m before gain×2
  1.0 m after gain×2

- Important to reject background from long-lived spallation products


600
500
400
300
200
100
0
-100
NUMBER OF EVENTS/0.04
MONTE CARLO
DATA
-1.0
-0.5
0.0
0.5
1.0
COS θ


50
40
30
20
10
0
ANGULAR RESOLUTION (degrees)
5
10
15
20
E_e (MeV)

EVENT SELECTION AND BACKGROUND REJECTION

1. Anticounter total pulse height ≤ 30 p.e.

   Remove cosmic μ

2. Time difference from the previous event $\geq 100\ \mu s$

   Remove decay e^- from stopping μ

3. Inner detector total pulse height ≤ 100 p.e.

   $E_e \lesssim 30$ MeV

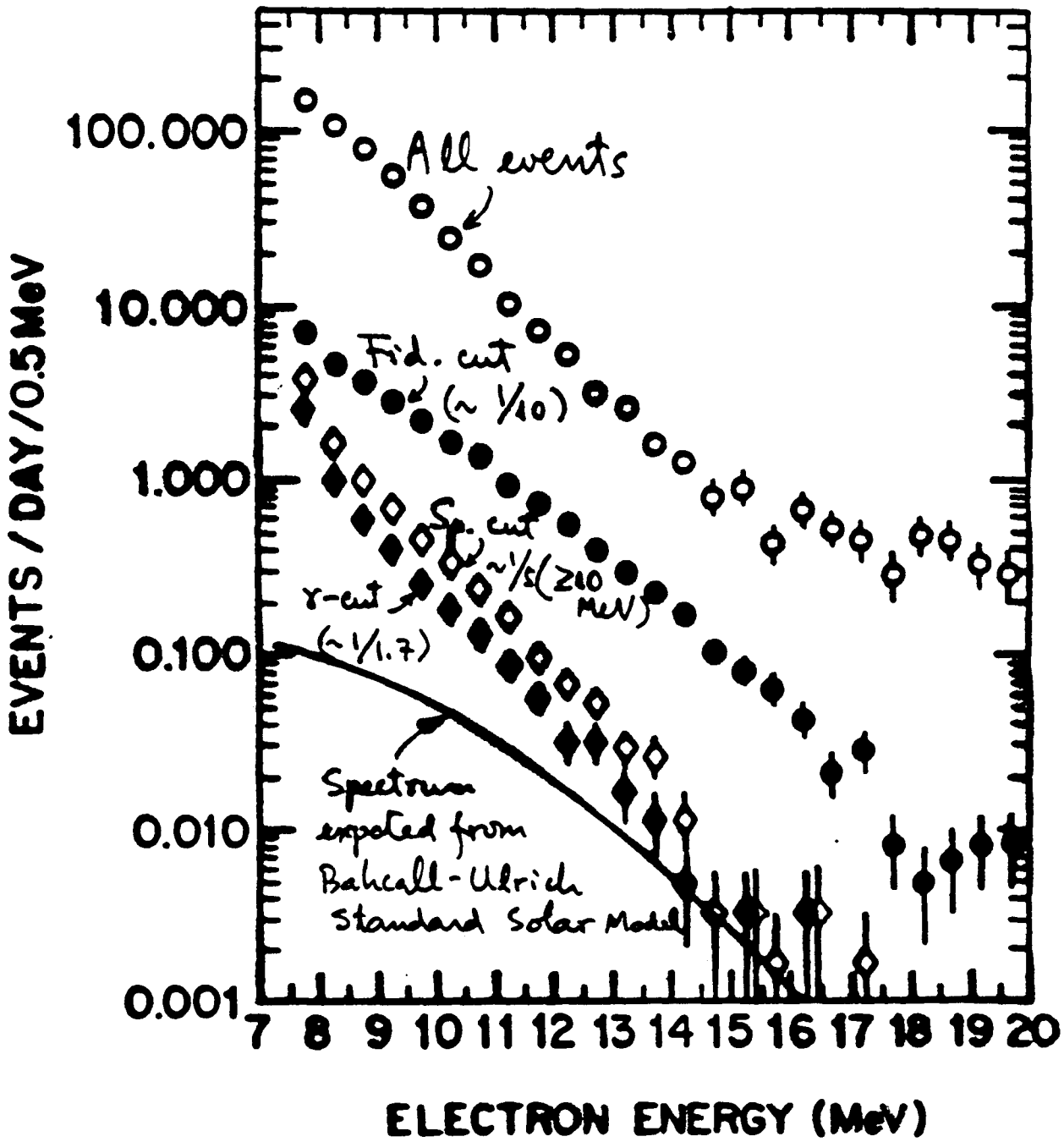
4. Vertex reconstruction

5. Fiducial volume cut

   Inner 680 Tons

6. Spallation cut : dead time ~17%

7. Remaing γ-ray cut : dead time ~1.5%


100.000
10.000
1.000
0.100
0.010
0.001
EVENTS / DAY / 0.5 MeV
7 8 9 10 11 12 13 14 15 16 17 18 19 20
ELECTRON ENERGY (MeV)
All events
Fid. cut
(~ 1/10)
Sp. cut
~1/5 (≥10 MeV)
γ-cut
(~1/1.7)
Spectrum
expected from
Bahcall-Ulrich
Standard Solar Model

RESULTS

1. CLEAR DIRECTIONAL CORRELATION WITH THE SUN

> Unequivocal evidence for the neutrinos really coming from the sun

2. ENERGY SPECTRUM

Max. likelihood analysis at each energy bin

Angular distribution normalized to N_{obs} over $-1 \leq \cos\theta \leq$

$$\underbrace{\frac{1}{2}(N_{obs} - N_\nu)}_{\text{isotropic b.g.}} + \underbrace{N_\nu \boxed{f(\cos\theta_\odot)}}_{\text{solar } \nu \text{ signal}}$$

← expected signal angular distribution (Monte Carlo)

$$N_\nu \equiv x \boxed{N_{SSM}}$$

← event number expected from "SSM"

$$\mathcal{L}(x) = \prod_i \left[\frac{1}{2}\left(1 - x\frac{N_{SSM}}{N_{obs}}\right) + x\frac{N_{SSM}}{N_{obs}} f(\cos\theta_{\odot,i})\right]$$

> Observed energy spectrum is consistent with the ^8B neutrino spectrum ($E \geq$ [illegible])

3. FLUX (RELATIVE TO "SSM")

Max. likelihood analysis with all events combined

$$\boxed{\frac{\text{Data}}{\text{SSM}} = 0.46 \pm 0.07\,(\text{stat}) \pm 0.06\,(\text{syst})}$$

$E_e \geq$ [illegible]

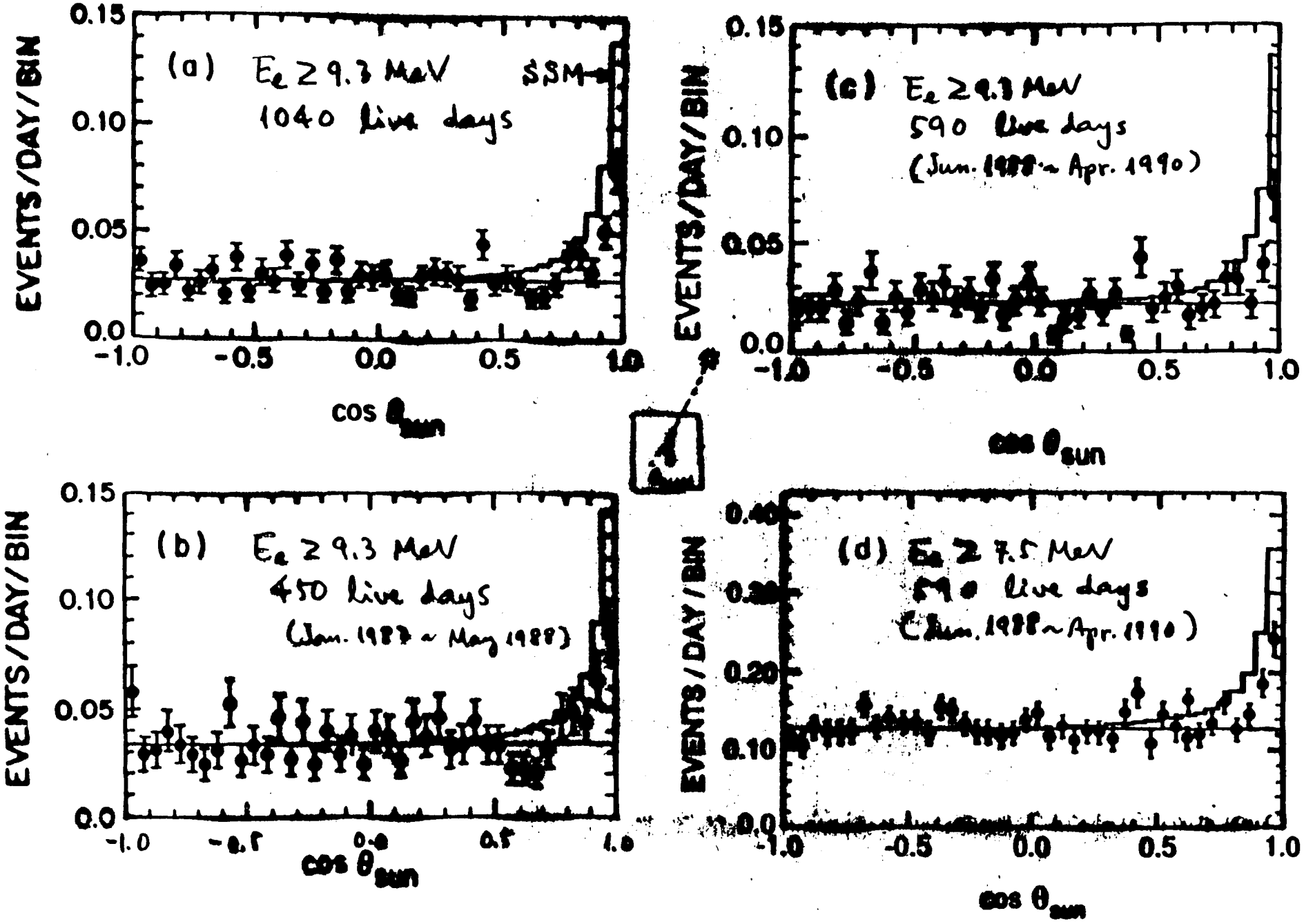
$E_e \geq$ [illegible]

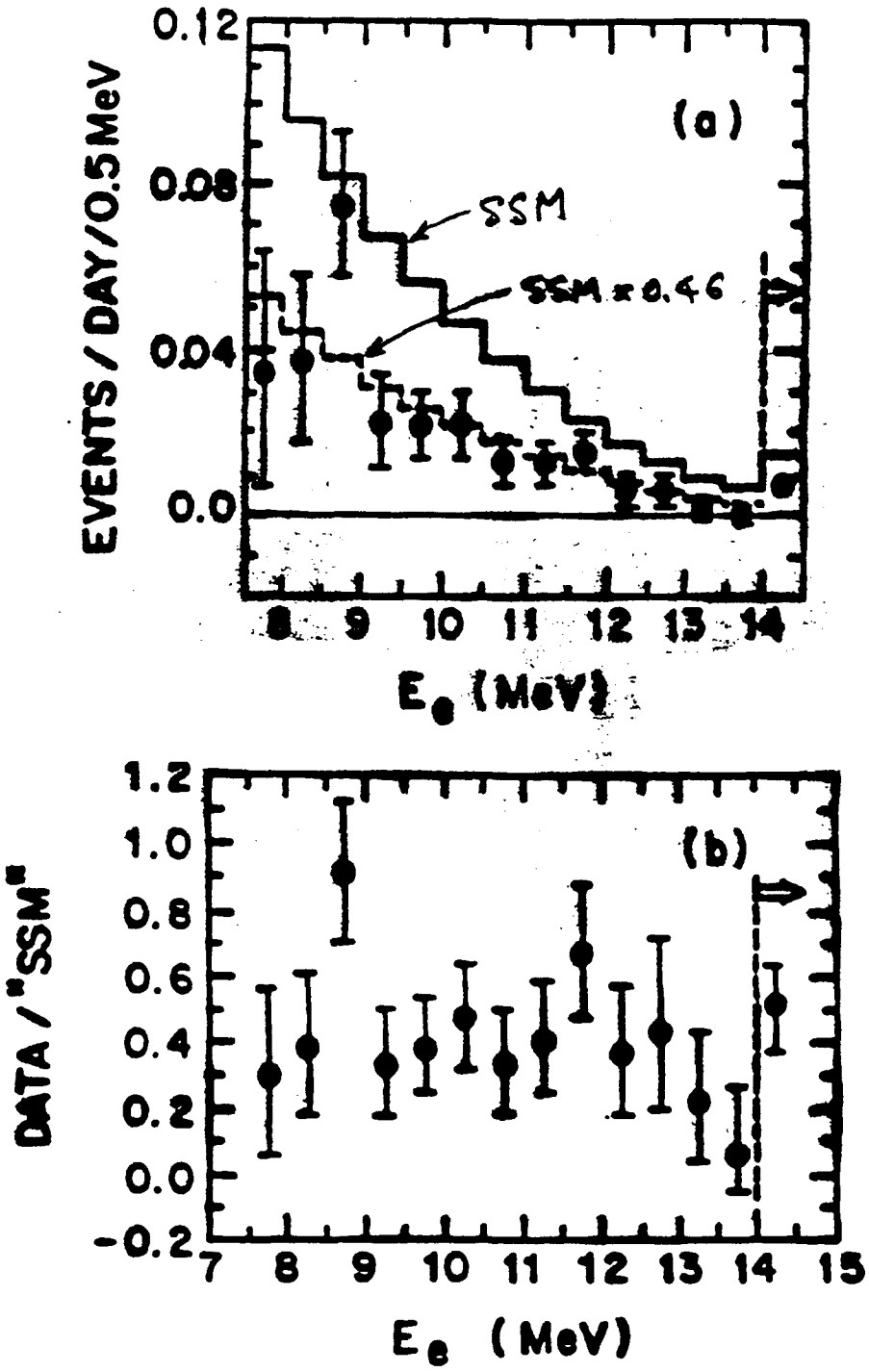
Systematic errors

Absolute [illegible] (±[illegible]) → [illegible]

Angular [illegible] (±2 [illegible]) → [illegible]

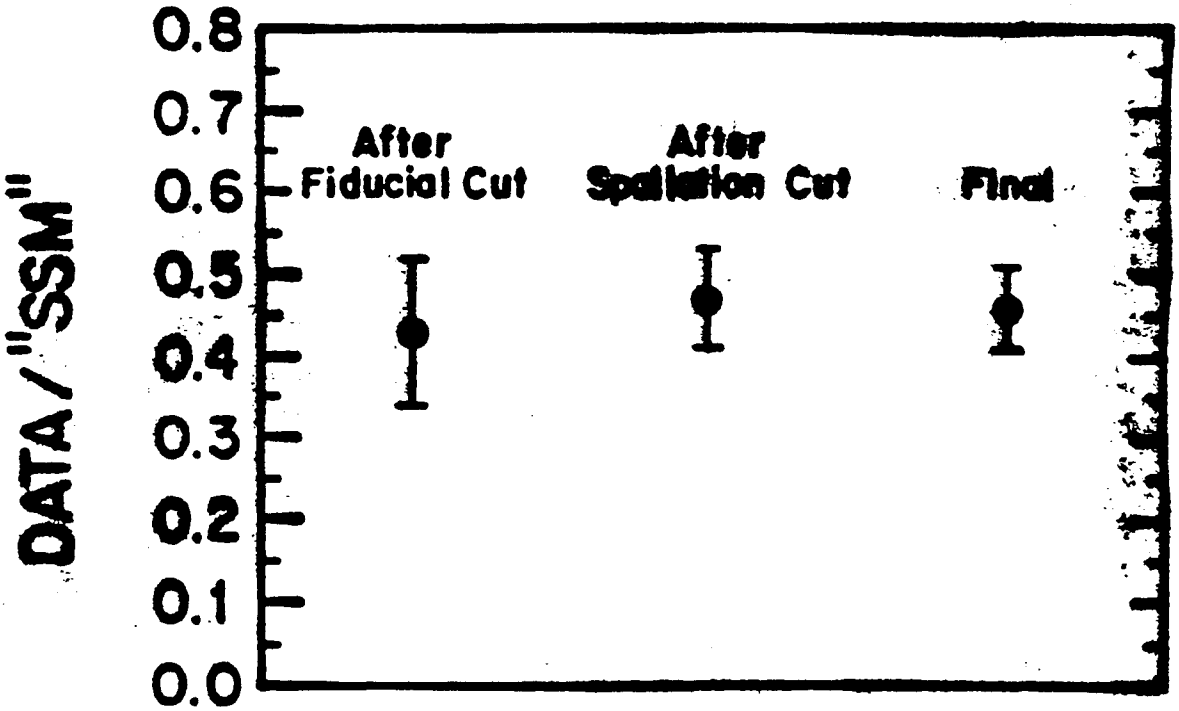
Total [illegible] → [illegible]


(a) $E_e \geq 9.3$ MeV
1040 live days
SSM
(b) $E_e \geq 9.3$ MeV
450 live days
(Jan. 1987 ~ May 1988)
(c) $E_e \geq 9.3$ MeV
590 live days
(Jun. 1988 ~ Apr. 1990)
(d) $E_e \geq 7.5$ MeV
live days
(Jun. 1988 ~ Apr. 1990)
EVENTS/DAY/BIN
$\cos\theta_{sun}$


0.12
0.08
0.04
0.0
EVENTS / DAY / 0.5 MeV
(a)
SSM
SSM × 0.46
8
9
10
11
12
13
14
E_e (MeV)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
DATA / "SSM"
(b)
7
8
9
10
11
12
13
14
15
E_e (MeV)

CHECK

① Change event selection criteria



② Change fiducial volume

Within statistics, consistent results were obtained.

③ Independent analysis

Comparison at all stages of the analysis gave consistent results.

4. MSW ANALYSIS USING THE FLUX VALUE AND THE RECOIL ELECTRON SPECTRUM

Assuming the Bahcall-Ulrich "SSM"

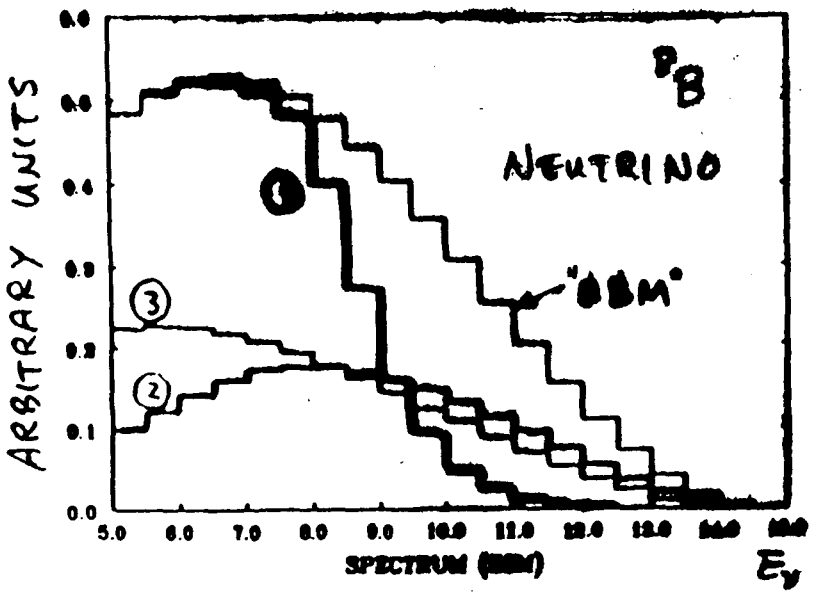
- Kam-II data alone can disfavor part of the adiabatic region.
- With Kam-II and ^{37}Cl results combined, most of the adiabatic region is disfavored.
- The above conclusion is robust against the uncertainties involved in the SSM calculations

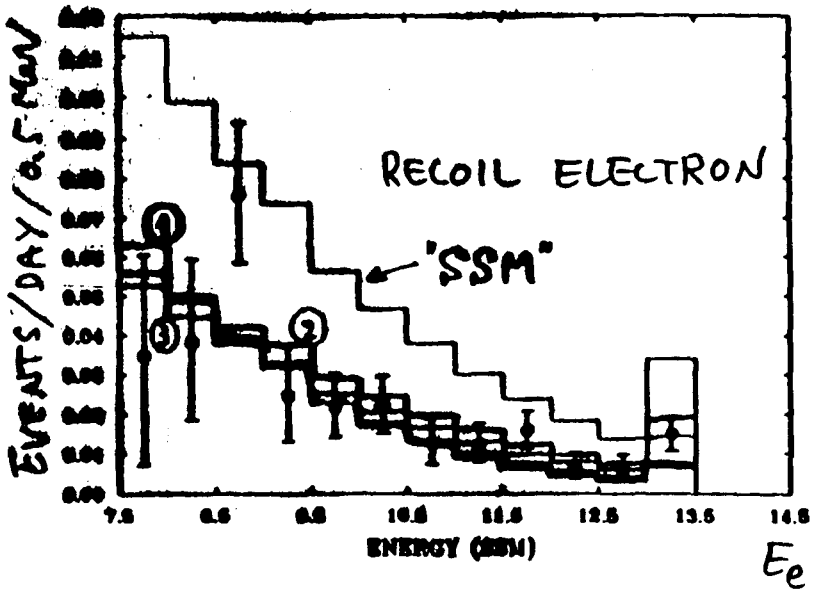
5. TEST OF DAY-NIGHT AND SEMIANNUAL FLUX VARIATIONS

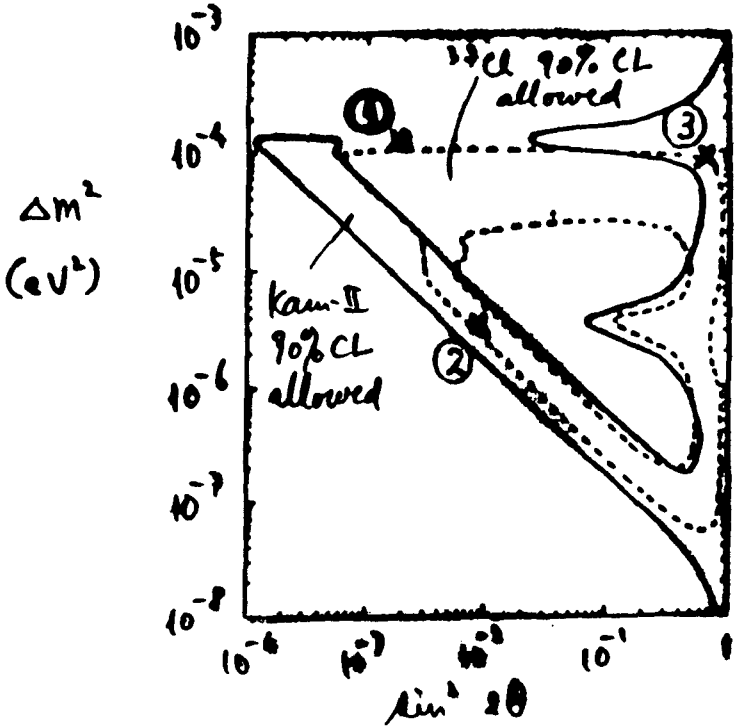
- Within statistics, there is no day-night, semiannual, and seasonal variations.
- Part of the region in the $\sin^2 2\theta - \delta m^2$ plane is excluded.

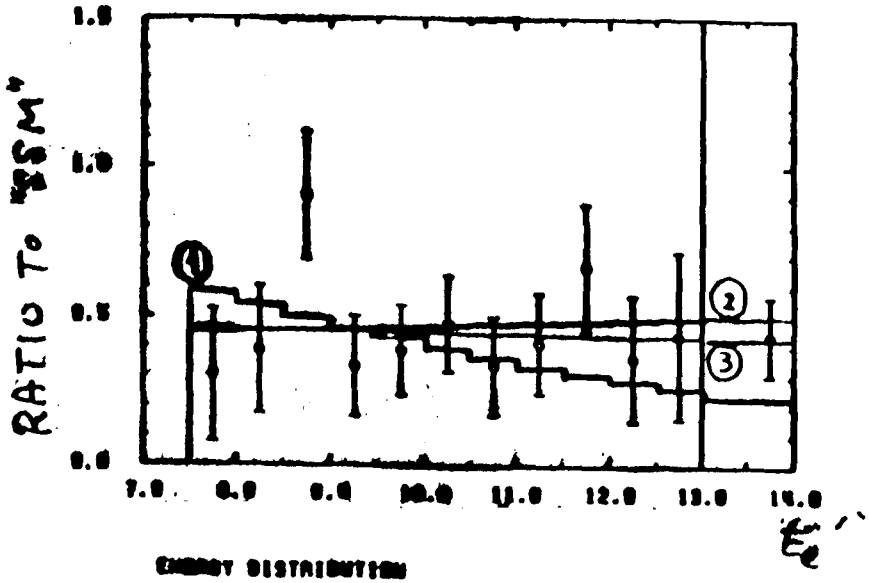
6. TEST OF FLUX TIME VARIATION CORRELATED WITH THE SUNSPOT NUMBERS

Within the statistical error, there is no evidence for a significant time variation.


ARBITRARY UNITS
^8B
NEUTRINO
"SSM"
SPECTRUM (MeV)
E_ν


EVENTS/DAY/0.5 MeV
RECOIL ELECTRON
"SSM"
ENERGY (MeV)
E_e


Δm^2
(eV^2)
3σ CL 90% CL
allowed
Kam-II
90% CL
allowed
$\sin^2 2\theta$

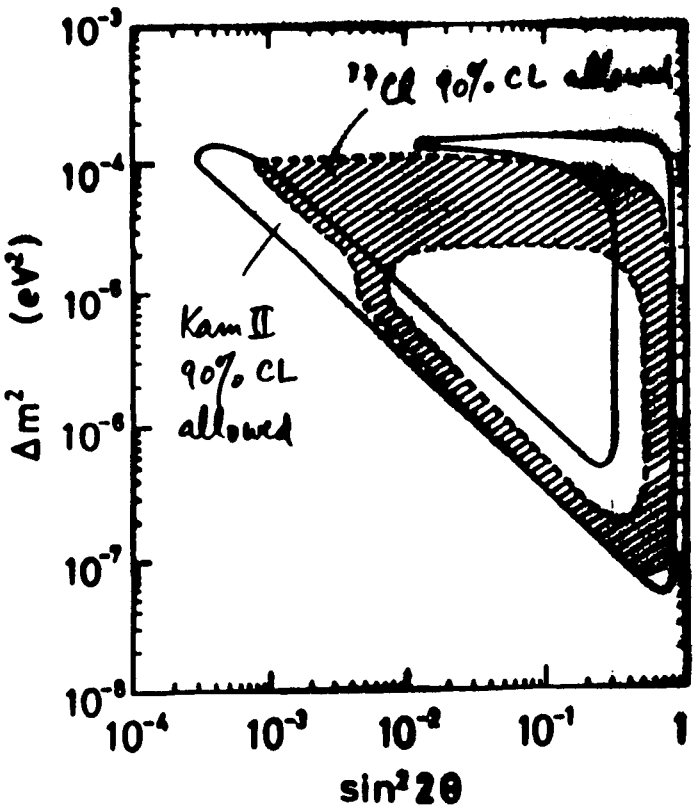

RATIO TO "SSM"
ENERGY DISTRIBUTION
E_e

STANDARD SOLAR MODEL PREDICTIONS

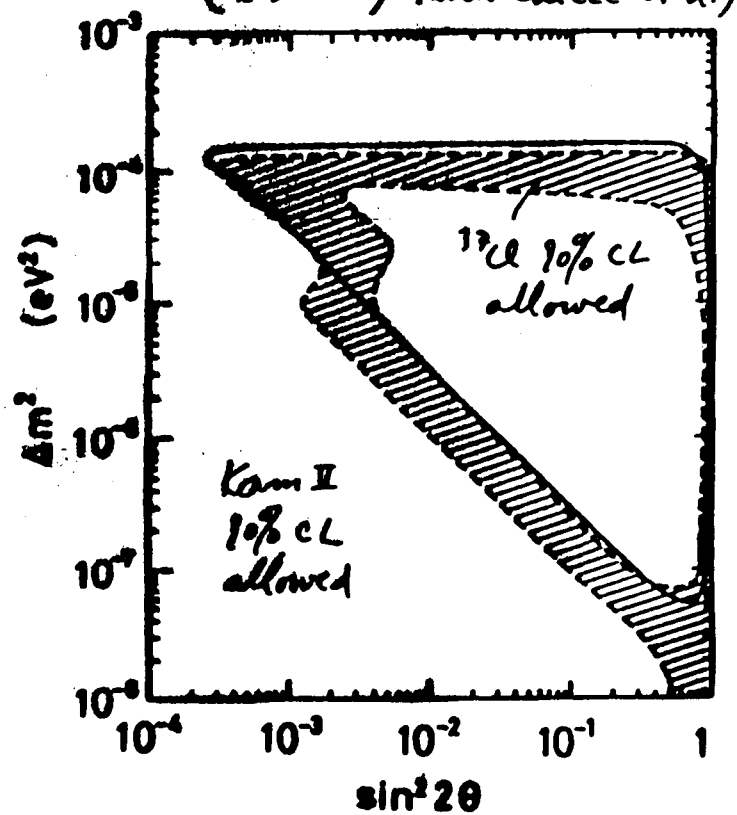
	Bahcall-Ulrich *	Turck-Chièze et al.
Capture rate	(3σ)	(1σ)
^{37}Cl	7.9 ± 2.6 SNU	5.8 ± 1.3 SNU
^{71}Ga	132 ± 20	125 ± 5
Flux ($cm^{-2} s^{-1}$)		
pp	$6.0\ (1 \pm 0.02) \times 10^{10}$	$5.98\ (1 \pm 0.03) \times 10^{10}$
pep	1.4×10^{8}	1.30×10^{8}
^{7}Be	$4.7\ (1 \pm 0.15) \times 10^{9}$	4.18×10^{9}
^{8}B	$5.8\ (1 \pm 0.37) \times 10^{6}$	$3.8\ (1 \pm 0.29) \times 10^{6}$
T_c	1.56×10^{7} K	1.55×10^{7} K

* mostly quoted in this talk

$\phi_\nu(^8B)$ increased by 97%
$\phi_\nu(^7Be)$ increased by 15%

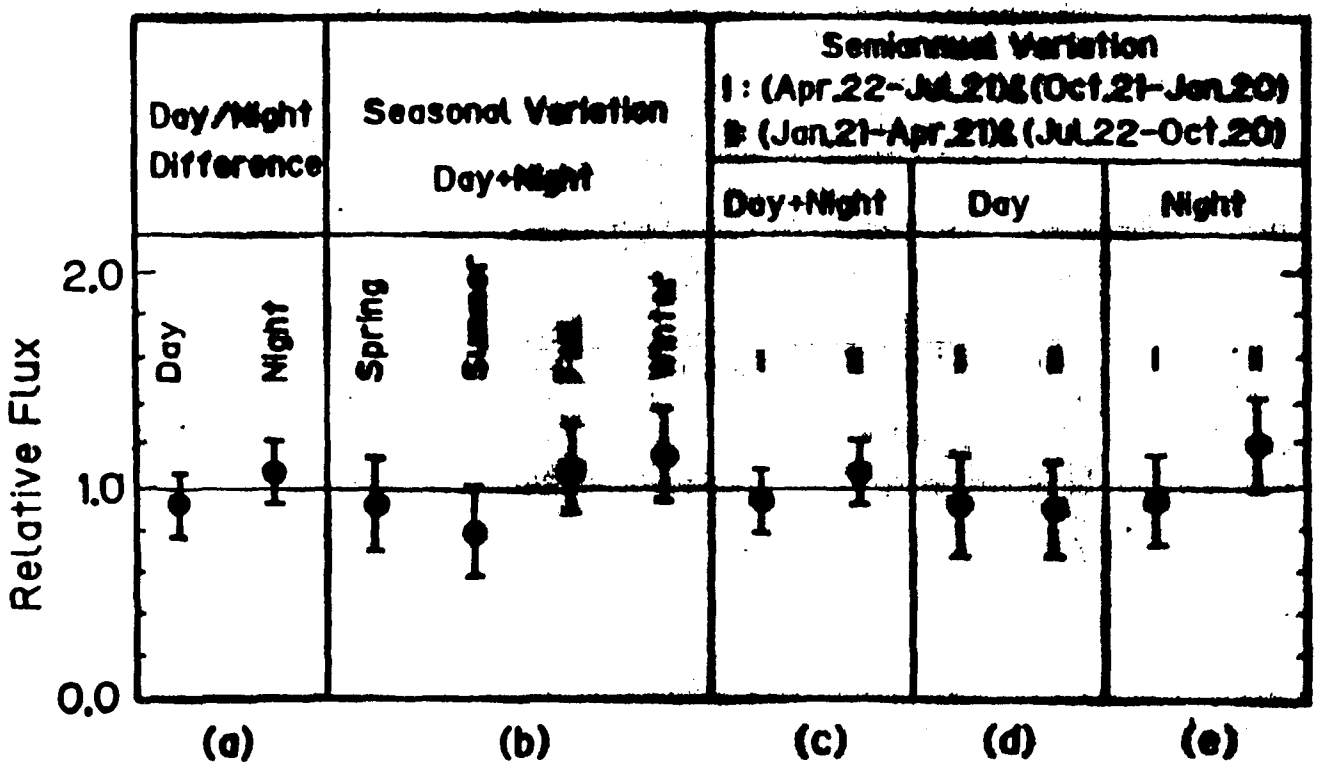


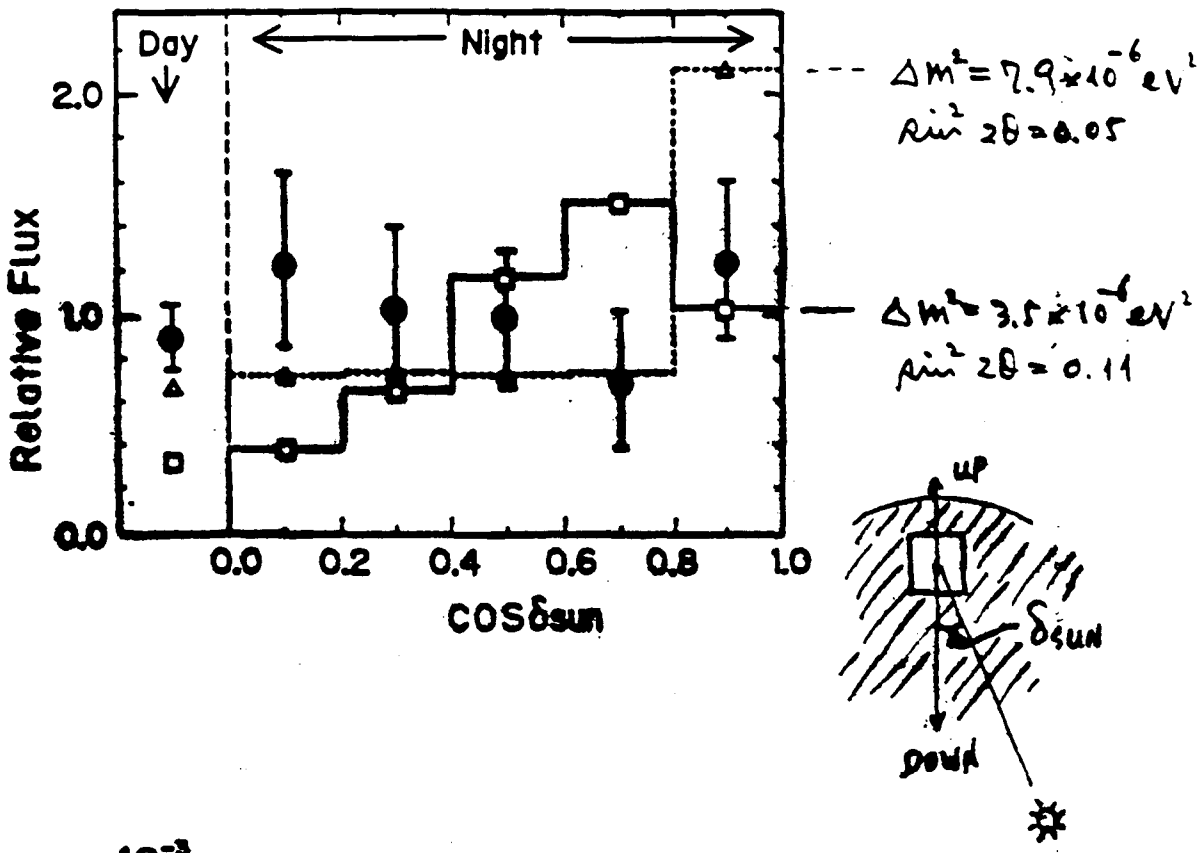
$\phi_\nu(^8B)$ decreased by 37%
$\phi_\nu(^7Be)$ decreased by 15%
(* SSM by Turck-Chièze et al.)

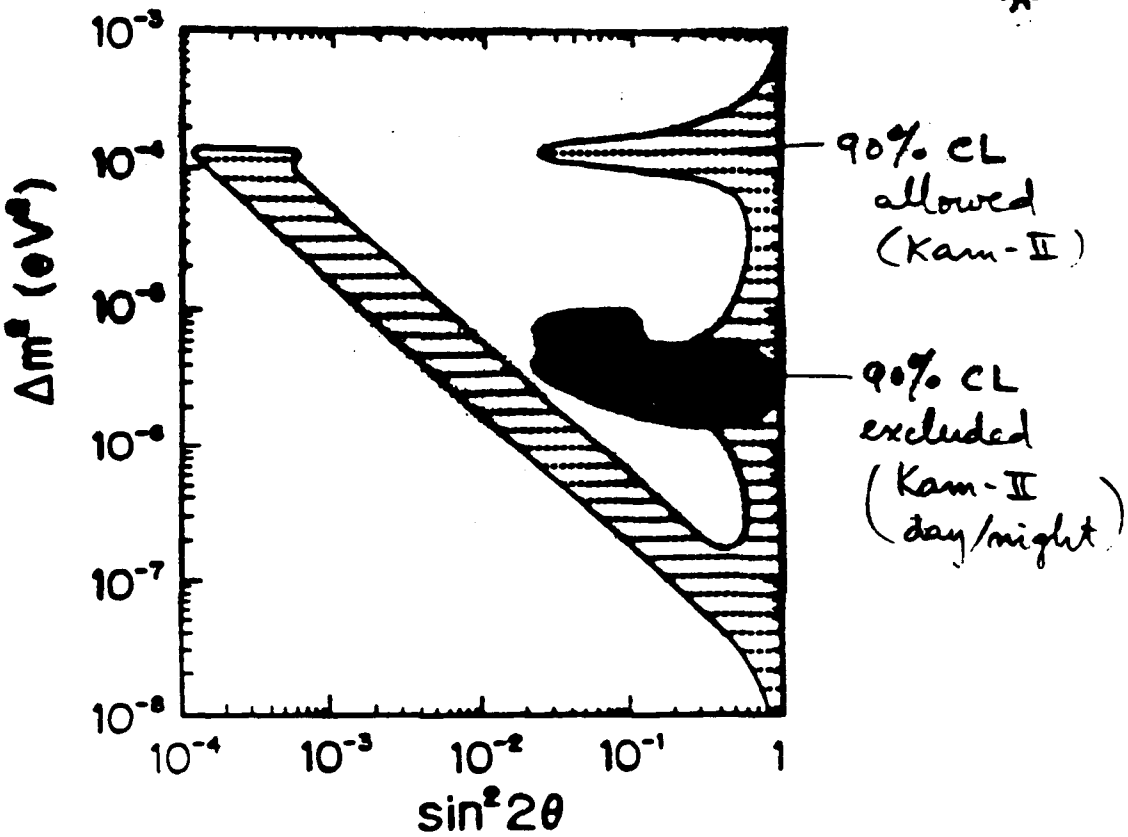


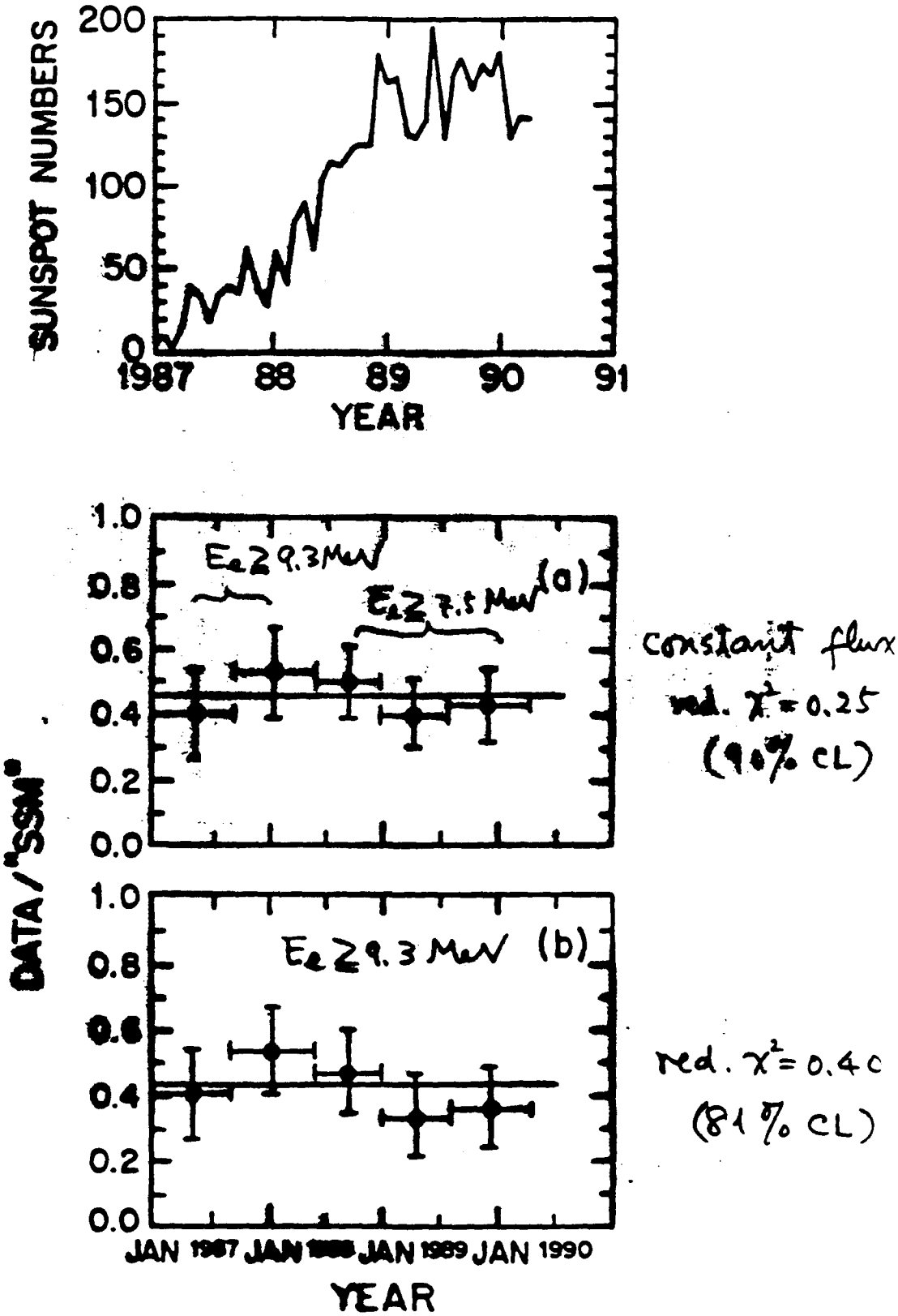
Period I near
Period II far from } the intersection of the ecliptic plane with the solar equatorial plane.

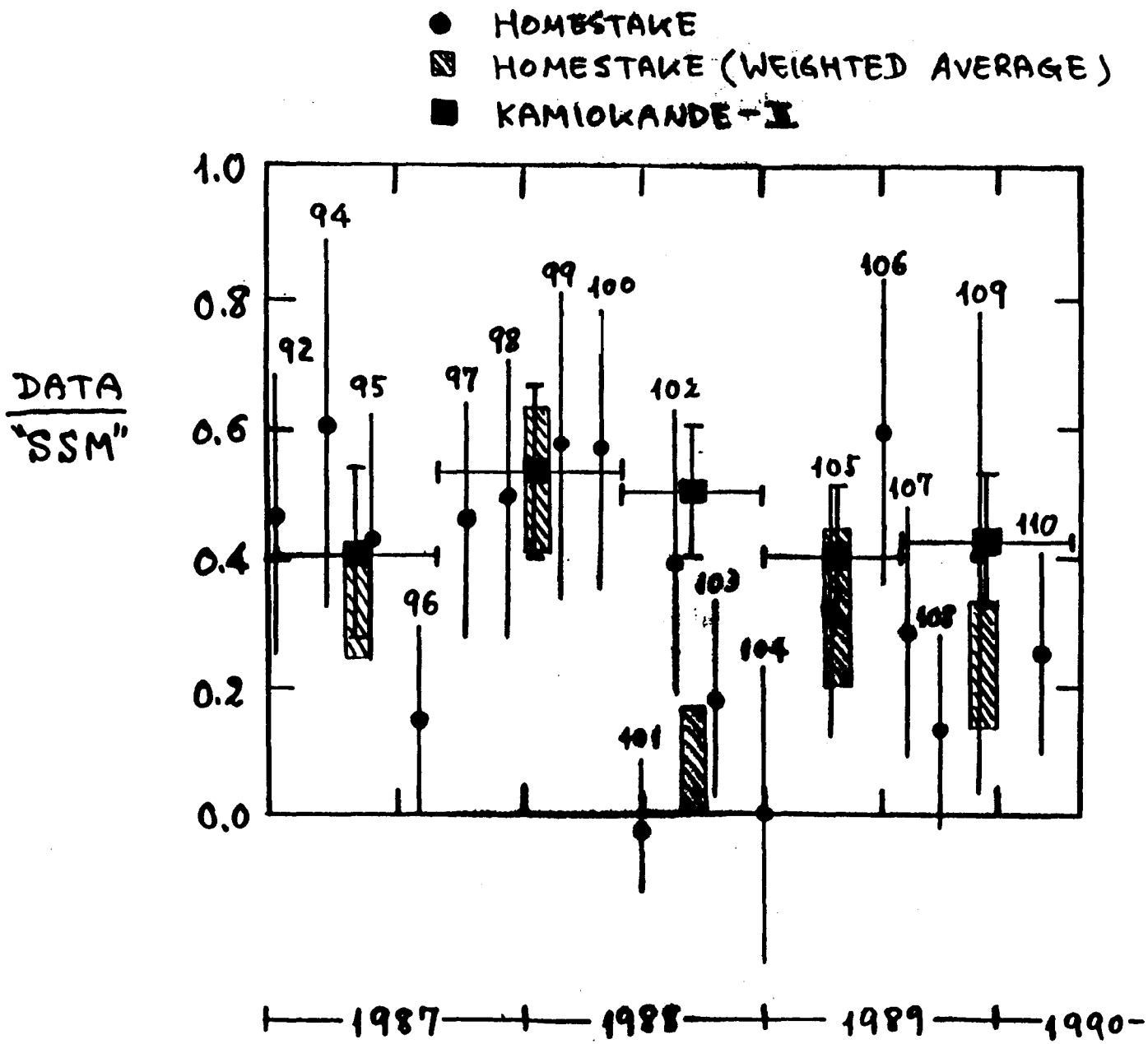
Expect difference if neutrino has a large magnetic moment.




Day
Night
Relative Flux
2.0
1.0
0.0
0.0
0.2
0.4
0.6
0.8
1.0
cosδsun
Δm² = 7.9×10⁻⁶ eV²
sin² 2θ = 0.05
Δm² = 3.5×10⁻⁶ eV²
sin² 2θ = 0.11
UP
δsun
DOWN


Δm² (eV²)
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁴
10⁻³
10⁻²
10⁻¹
1
sin²2θ
90% CL allowed (Kam-II)
90% CL excluded (Kam-II day/night)


SUNSPOT NUMBERS
200
150
100
50
0
1987
88
89
90
91
YEAR
DATA / "SSM"
1.0
0.8
0.6
0.4
0.2
0.0
$E_e \geq 9.3$ MeV
$E_e \geq 7.5$ MeV
(a)
constant flux
red. $\chi^2 = 0.25$
(90% CL)
$E_e \geq 9.3$ MeV (b)
red. $\chi^2 = 0.40$
(81% CL)
JAN 1987
JAN 1988
JAN 1989
JAN 1990
YEAR


HOMESTAKE
HOMESTAKE (WEIGHTED AVERAGE)
KAMIOKANDE-II
DATA / "SSM"
1.0
0.8
0.6
0.4
0.2
0.0
92
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
1987
1988
1989
1990

SUMMARY

1. A CLEAR DIRECTIONAL CORRELATION OF THE NEUTRINO SIGNAL WITH THE SUN WAS OBSERVED.

2. THE OBSERVED RECOIL ELECTRON ENERGY SPECTRUM IS CONSISTENT WITH THE ^8B β DECAY SPECTRUM AT $E_e \geq 7.5$ MeV.

3. THE OBSERVED FLUX IS ONLY $0.46 \pm 0.05 \pm 0.06$ TIMES THAT EXPECTED FROM THE BAHCALL-ULRICH "SSM".

4. WITHIN STATISTICS, NO DAY-NIGHT, SEASONAL, AND SEMIANNUAL VARIATIONS WERE OBSERVED.

5. WITHIN STATISTICS, NO EVIDENCE FOR A SIGNIFICANT TIME VARIATION WAS OBSERVED IN THE PERIOD JAN. 198[illegible] THROUGH APR. 1990.

FUTURE

UP TO 1996 KAM-III

$\gtrsim 5$ years of steady observation

$E_e \geq 7.5$ MeV, $0.46 * SSM \Rightarrow \sim 0.3$ ev./d

FROM 1996 SUPERKAMIOKANDE

$E_e \geq 7.5$ MeV ~ 10 ev./d

$E_e \geq 5$ MeV ~ 30 ev./d

HIGH STATISTICS SOLAR ν EXPERIMENT

- PRECISE MEASUREMENT OF RECOIL SPECTR
- SENSITIVE TO SMALL TIME VARIATION:

  ~6% CHANGE OF THE FLUX DUE TO THE ECCENTRICITY OF THE EARTH'S ORBIT WILL BE A NICE CALIBRATION SOURCE.

OTHER GOALS OF SUPERKAMIOKANDE

- NUCLEON DECAY $\tau/B(p \to e^+\pi^0) \sim 10^{34}$ y

  $\tau/B(p \to \bar{\nu}K^+) \sim 10^{33}$ y

- NEUTRINO BURST

  ~4.000 ev. for 10 kpc

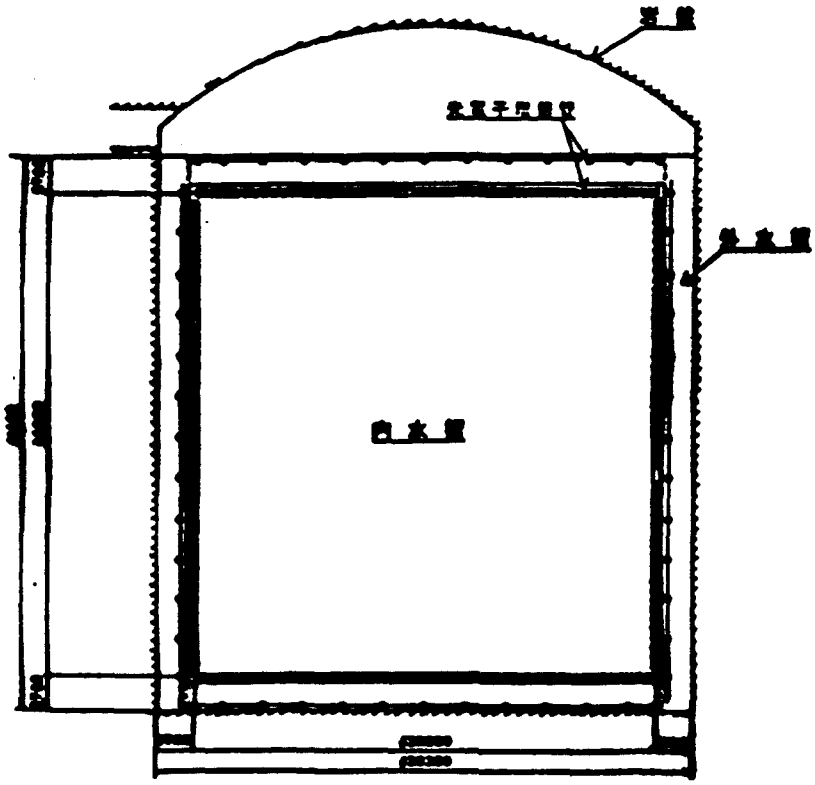
  [illegible] neutronization burst $\Rightarrow \nu_e$ [illegible]

  [illegible] $\nu_\mu + \bar{\nu}_\tau$

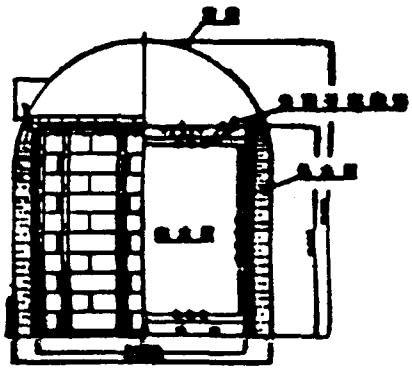
  $\Rightarrow$ [illegible] ν_μ, ν_τ [illegible]

- ATMOSPHERIC NEUTRINOS
- RELIC SUPERNOVA NEUTRINOS

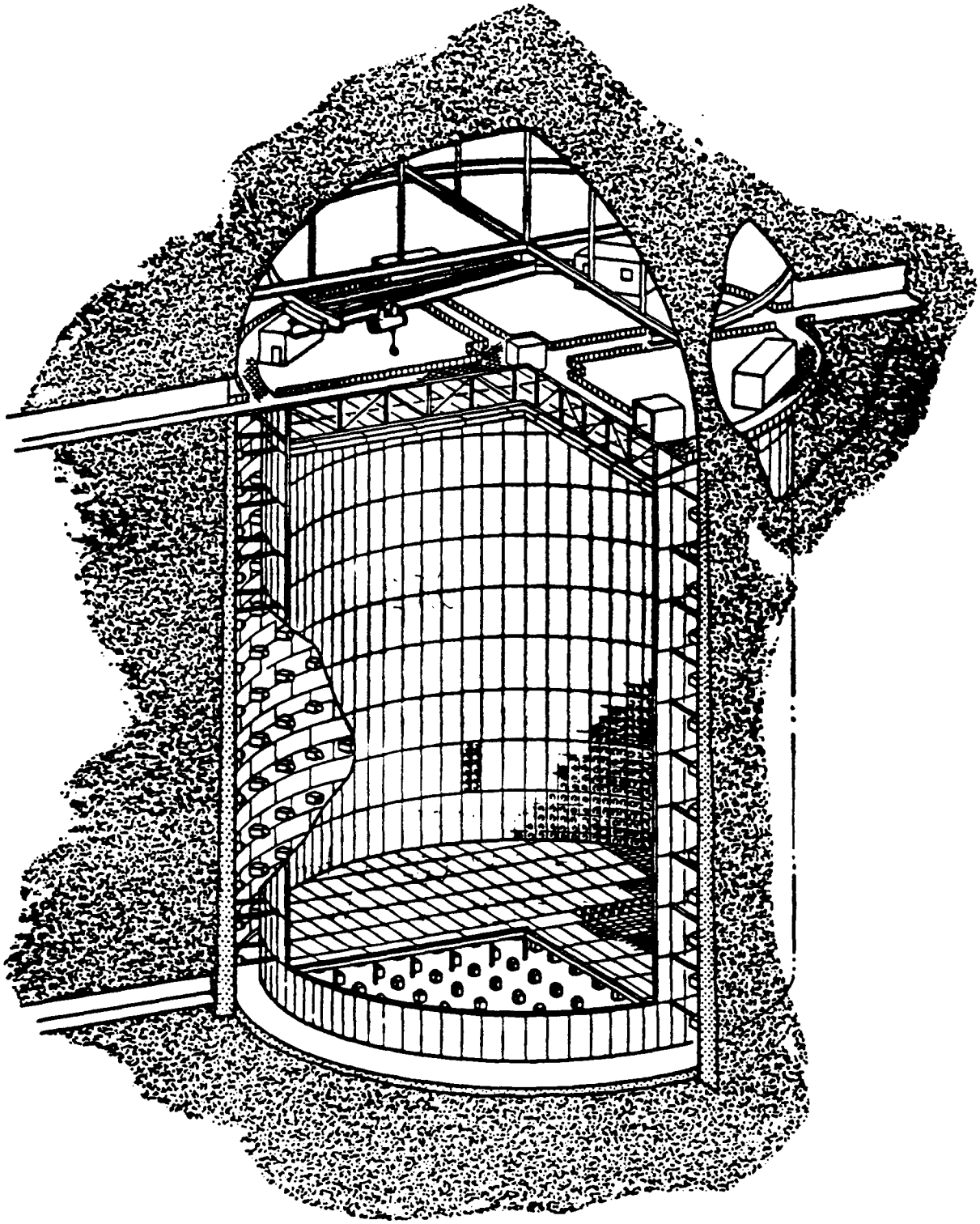
スーパー神岡実験の検出器

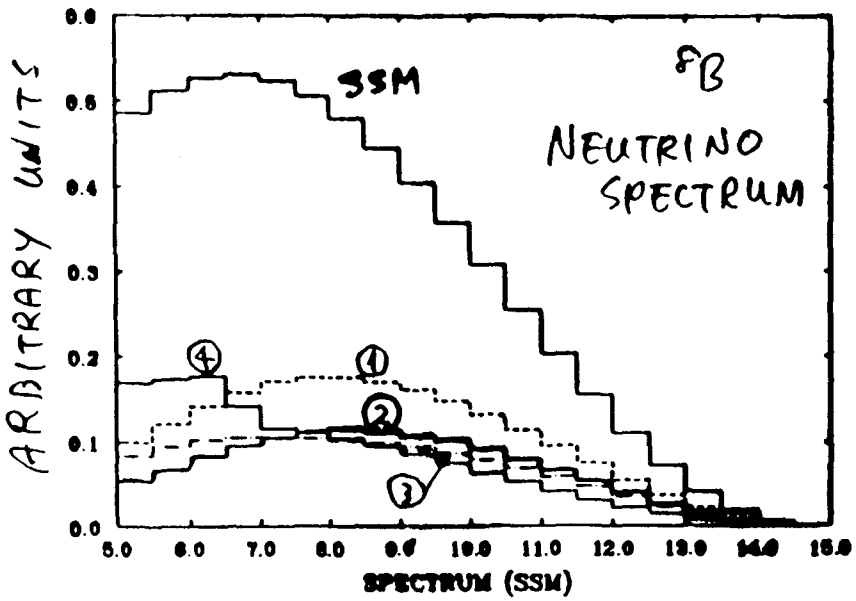


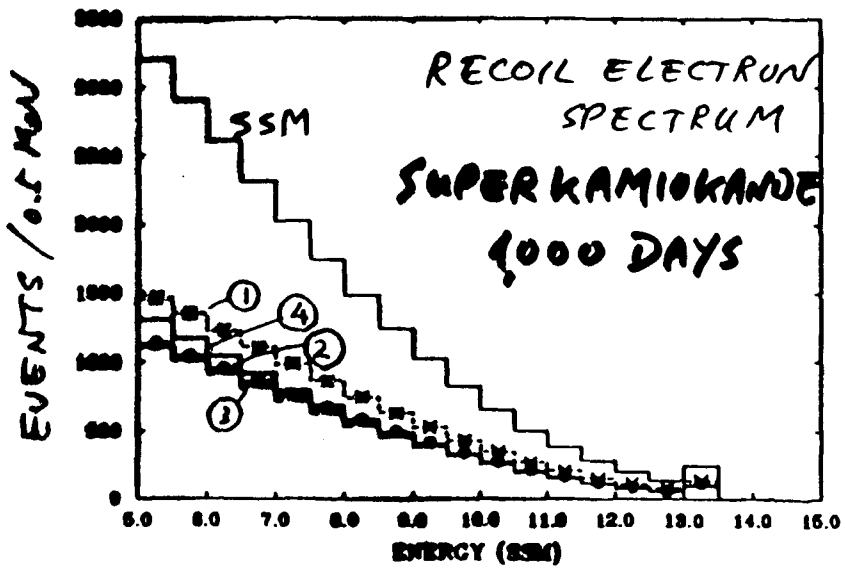
現行神岡実験の検出器

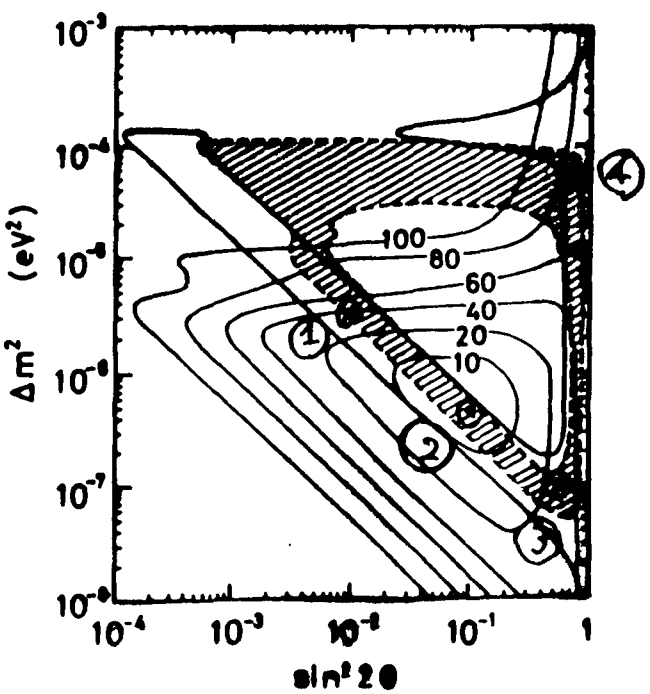


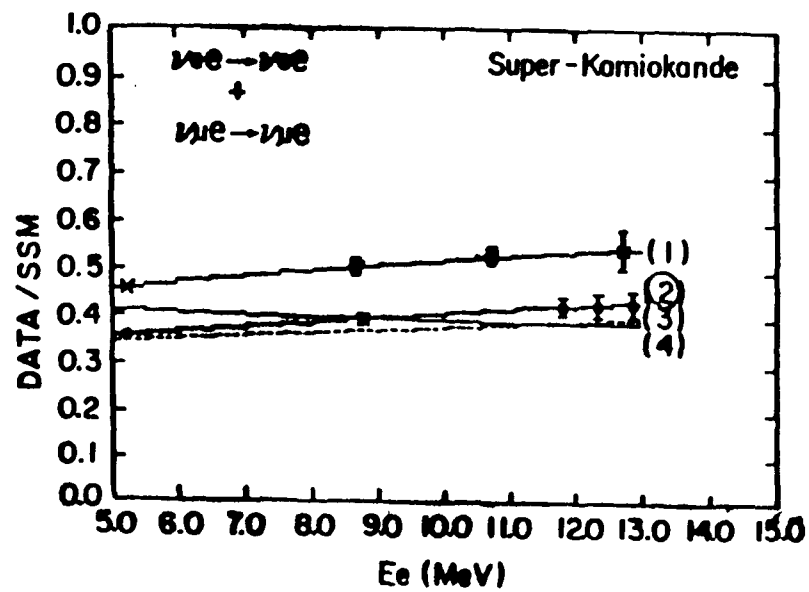
	SuperKAMIOKANDE	KAMIOKANDE
SIZE	41 m^h x 39 m$^\phi$	16 m^h x 19 m$^\phi$
TOTAL MASS	50,000 t	(3,000 + 1,500) t
FIDUCIAL MASS	22,000 t	680 t
ANTICOUNTER	2 m^t	0.8 ~ 1.7 m^t
No. OF PMTs	11,200	948
PMT COVERAGE	40 %	20 %



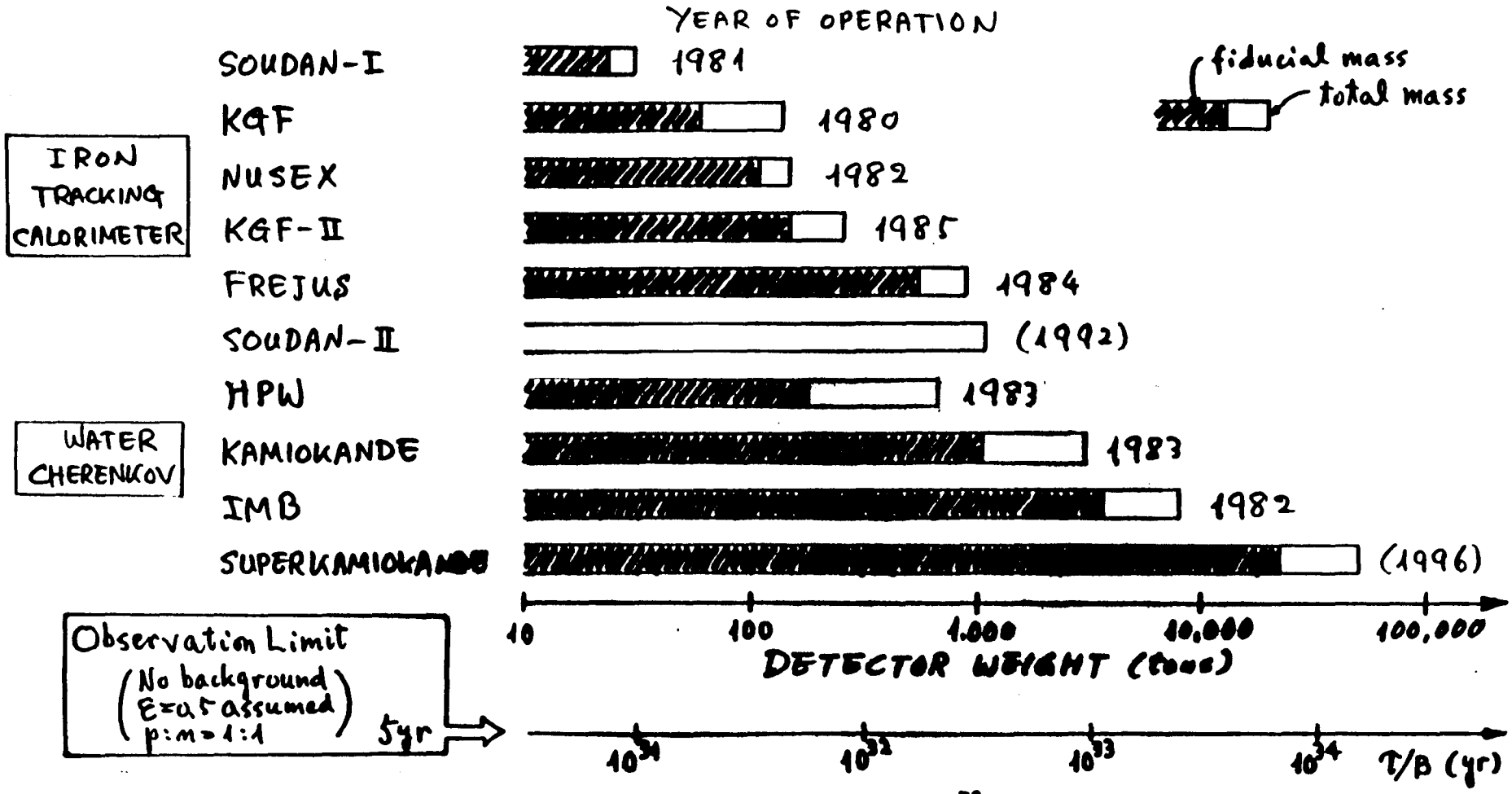

SSM
^8B
NEUTRINO SPECTRUM
ARBITRARY UNITS
SPECTRUM (SSM)


RECOIL ELECTRON SPECTRUM
SSM
SUPERKAMIOKANDE
1000 DAYS
EVENTS / 0.5 MeV
ENERGY (SSM)


Δm^2 (eV^2)
$\sin^2 2\theta$
100
80
60
40
20
10


$\nu_e \to \nu_e$
+
$\nu_\mu e \to \nu_\mu e$
Super-Kamiokande
DATA / SSM
Ee (MeV)

NUCLEON DECAY EXPERIMENTS



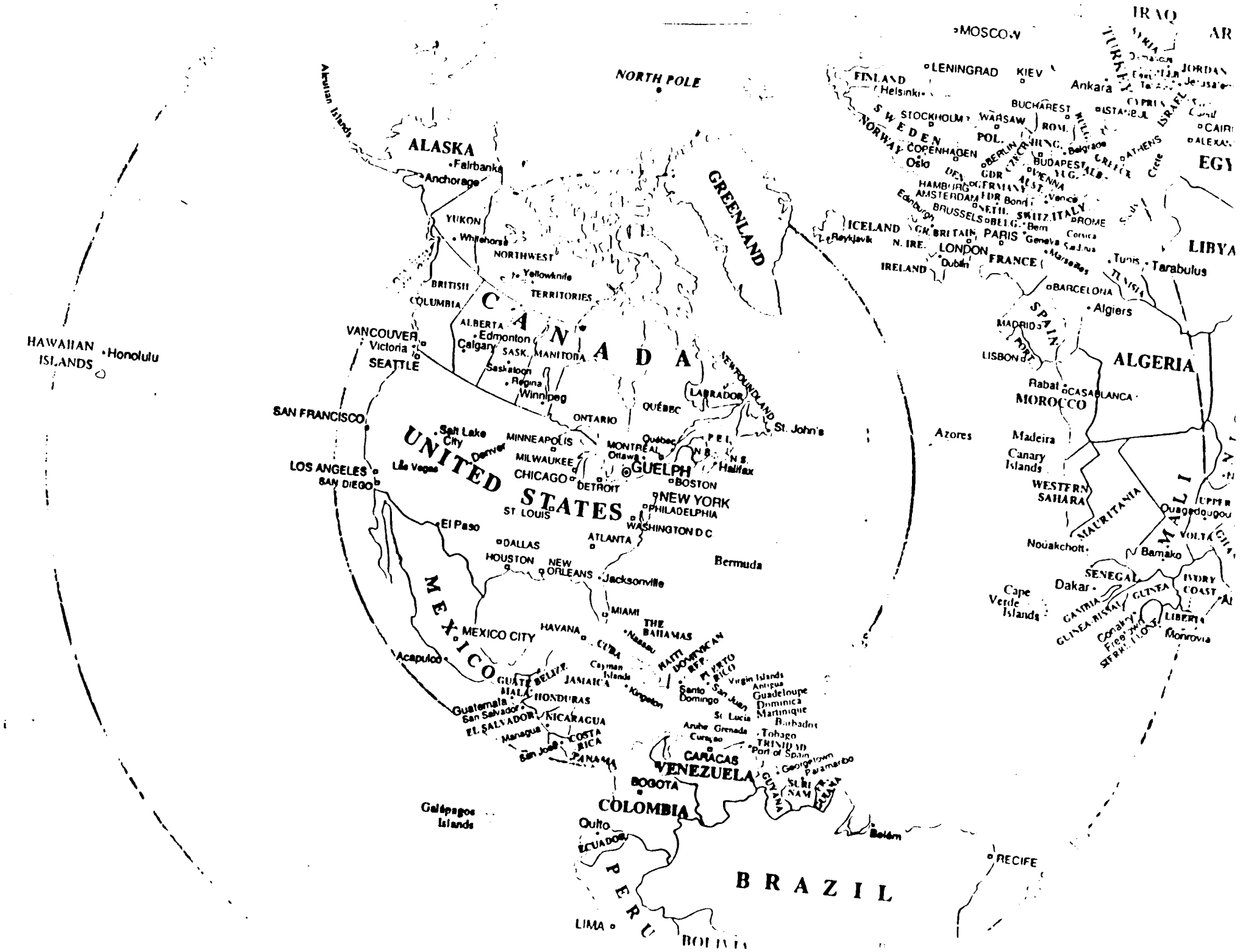
$p \to e^+\pi^0$ Experiment (IMB+Kamiokande+Frejus) $\tau/B > 8.8\times10^{32}$ yr

Some theories
- Naive SU(5) → $\tau/B = 4.5\times10^{29\pm1.7}$ yr
- SO(10) $\tau/B \lesssim (1\sim3)\times10^{34}$ yr →
- Flipped SU(5) ⊗ U(1) (Superstring inspired) $\tau/B = 10^{35\pm2}$ yr ←

The UNBEARABLE Heaviness of Neutrinos

J. J. Simpson

1. Neutrino masses + mixings and β-spectra
2. Summary of experimental evidence for 17-keV/c^2 ν
3. Experimental constraints on nature of 17-keV/c^2 ν

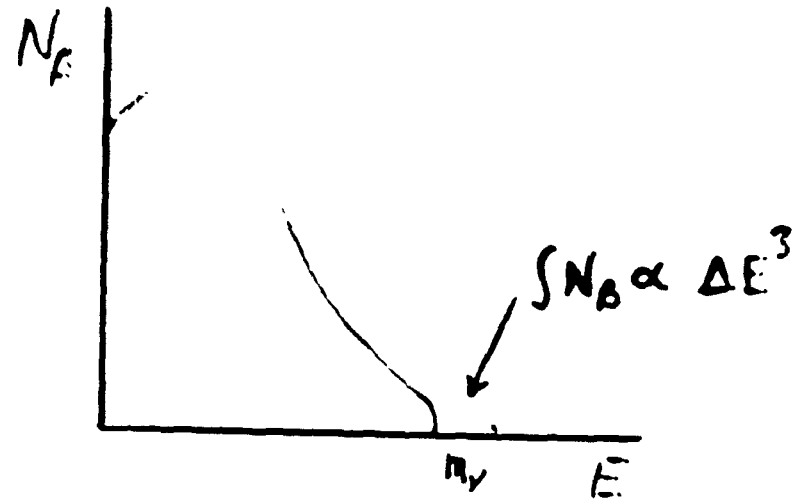

NORTH POLE
ALASKA
Fairbanks
Anchorage
Aleutian Islands
GREENLAND
YUKON
Whitehorse
NORTHWEST
Yellowknife
TERRITORIES
BRITISH
COLUMBIA
CANADA
ALBERTA
Edmonton
Calgary
SASK.
MANITOBA
Saskatoon
Regina
Winnipeg
VANCOUVER
Victoria
SEATTLE
HAWAIIAN ISLANDS
Honolulu
SAN FRANCISCO
LOS ANGELES
SAN DIEGO
Salt Lake City
Denver
Las Vegas
UNITED STATES
MINNEAPOLIS
MILWAUKEE
CHICAGO
DETROIT
ONTARIO
QUÉBEC
MONTREAL
Ottawa
Québec
LABRADOR
NEWFOUNDLAND
St. John's
P.E.I.
N.B.
N.S.
Halifax
GUELPH
BOSTON
NEW YORK
PHILADELPHIA
WASHINGTON D.C.
ST. LOUIS
ATLANTA
El Paso
DALLAS
HOUSTON
NEW ORLEANS
Jacksonville
MIAMI
Bermuda
MEXICO
MEXICO CITY
Acapulco
HAVANA
CUBA
THE BAHAMAS
Nassau
Cayman Islands
JAMAICA
Kingston
HAITI
DOMINICAN REP.
PUERTO RICO
Santo Domingo
San Juan
Virgin Islands
Antigua
Guadeloupe
Dominica
Martinique
St. Lucia
Barbados
Aruba
Grenada
Curaçao
Tobago
TRINIDAD
Port of Spain
BELIZE
GUATEMALA
HONDURAS
Guatemala
San Salvador
EL SALVADOR
NICARAGUA
Managua
COSTA RICA
San José
PANAMA
CARACAS
VENEZUELA
Georgetown
Paramaribo
SURINAM
GUYANA
BOGOTA
COLOMBIA
Galápagos Islands
Quito
ECUADOR
PERU
LIMA
BOLIVIA
Belém
RECIFE
BRAZIL
MOSCOW
LENINGRAD
KIEV
FINLAND
Helsinki
SWEDEN
STOCKHOLM
NORWAY
Oslo
COPENHAGEN
WARSAW
POL.
BUCHAREST
ROM.
ISTANBUL
Ankara
TURKEY
IRAQ
JORDAN
ISRAEL
CYPRUS
ATHENS
GREECE
Belgrade
YUG.
BUDAPEST
VIENNA
BERLIN
HAMBURG
AMSTERDAM
NETH.
BRUSSELS
BELG.
Bonn
Venice
ITALY
ROME
Corsica
Sardinia
Bern
Geneva
PARIS
FRANCE
Marseilles
LONDON
G.B.
N. IRE.
Dublin
IRELAND
Edinburgh
ICELAND
Reykjavik
BARCELONA
MADRID
SPAIN
PORT.
LISBON
Azores
Madeira
Canary Islands
Rabat
CASABLANCA
MOROCCO
ALGERIA
Algiers
Tunis
Tarabulus
LIBYA
WESTERN SAHARA
MAURITANIA
Nouakchott
MALI
Bamako
Ouagadougou
SENEGAL
Dakar
Cape Verde Islands
GAMBIA
GUINEA-BISSAU
GUINEA
IVORY COAST
LIBERIA
Monrovia
Canary Islands
Free Town
SIERRA LEONE

Mass of ν_e

Fermi Theory of β-Decay

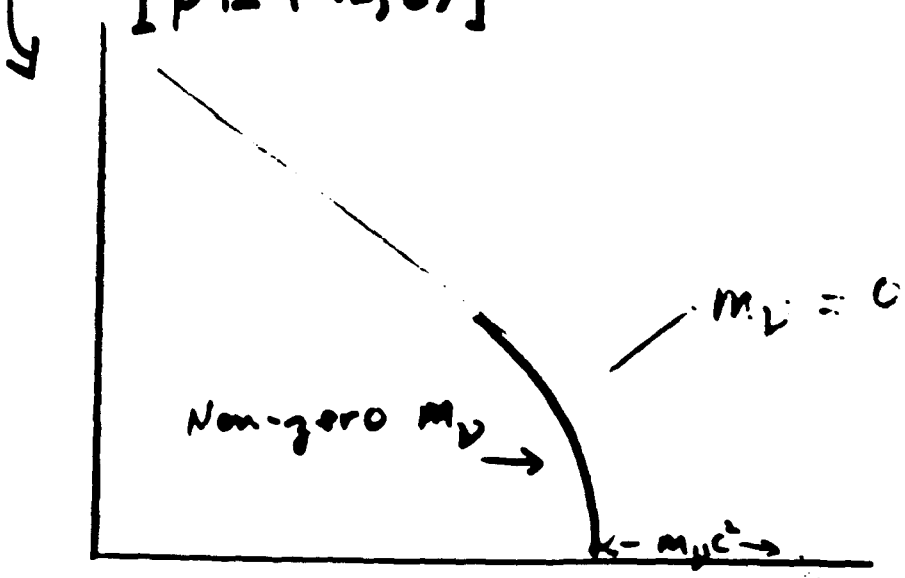
- Single neutrino of definite mass

$$N_\beta \propto pE\left[(Q-E)^2 - m_\nu^2 c^4\right]^{\frac{1}{2}} (Q-E)\, F(E,Z)$$



- Kurie Plot

$$\left[\frac{N_\beta}{pE\,F(E,Z)}\right]^{\frac{1}{2}} \text{ vs } E$$



Neutrino Flavour Mixing

m_1	ν_1	$\overset{?}{=}$	ν_e
m_2	ν_2		ν_μ
m_3	ν_3		ν_τ
mass			weak

eigenstate

$$|\nu_\ell\rangle = \sum_{m=1,2,3} U_{\ell m} |\nu_m\rangle$$

$$\nu_e = \nu_1 \cos\theta + \nu_3 \sin\theta \qquad \nu = |\nu\rangle$$

$$\nu_\tau = \nu_1 \sin\theta - \nu_3 \cos\theta$$

$$N_\beta = \cos^2\theta\, N_\beta(m_1) + \sin^2\theta\, N_\beta(m_3)$$

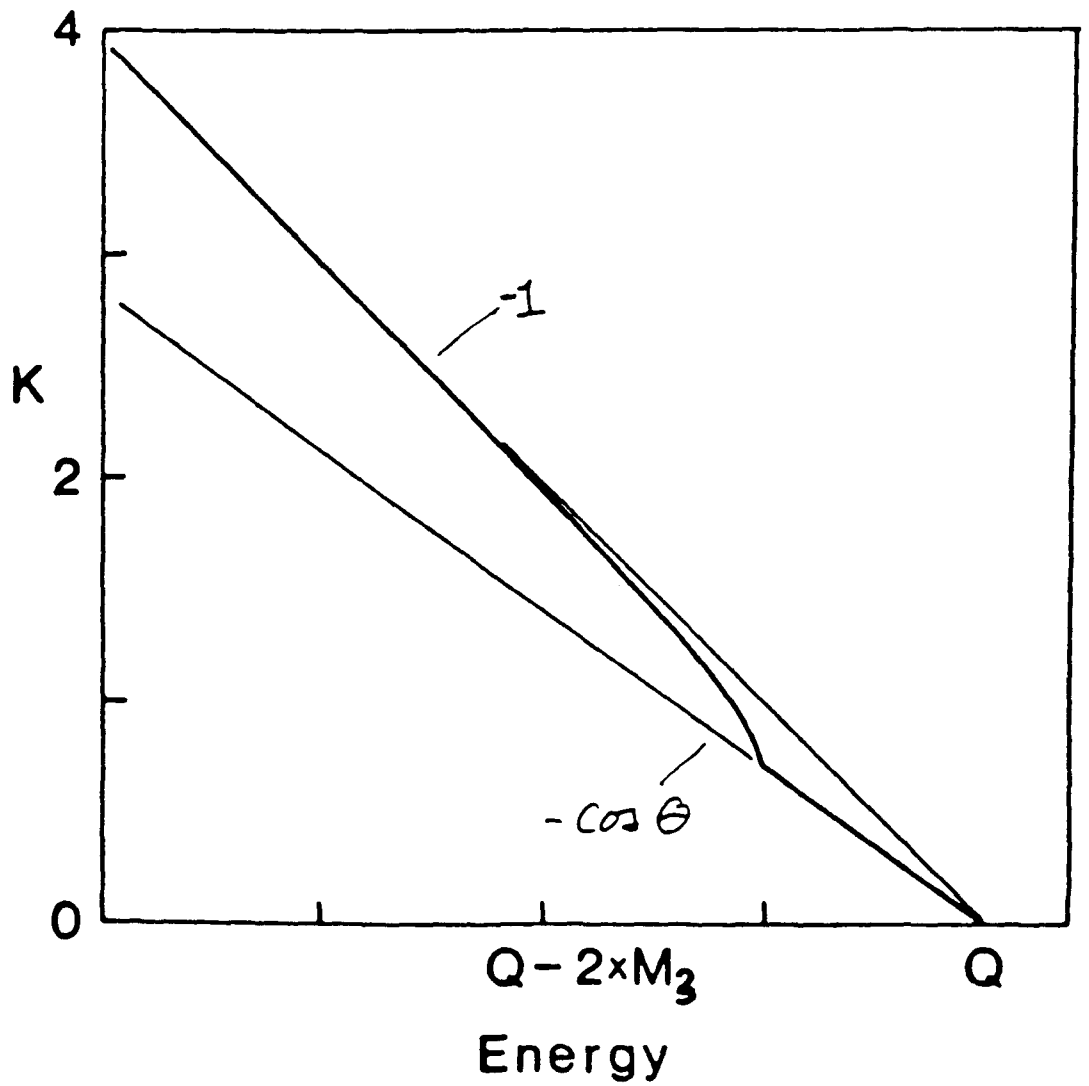
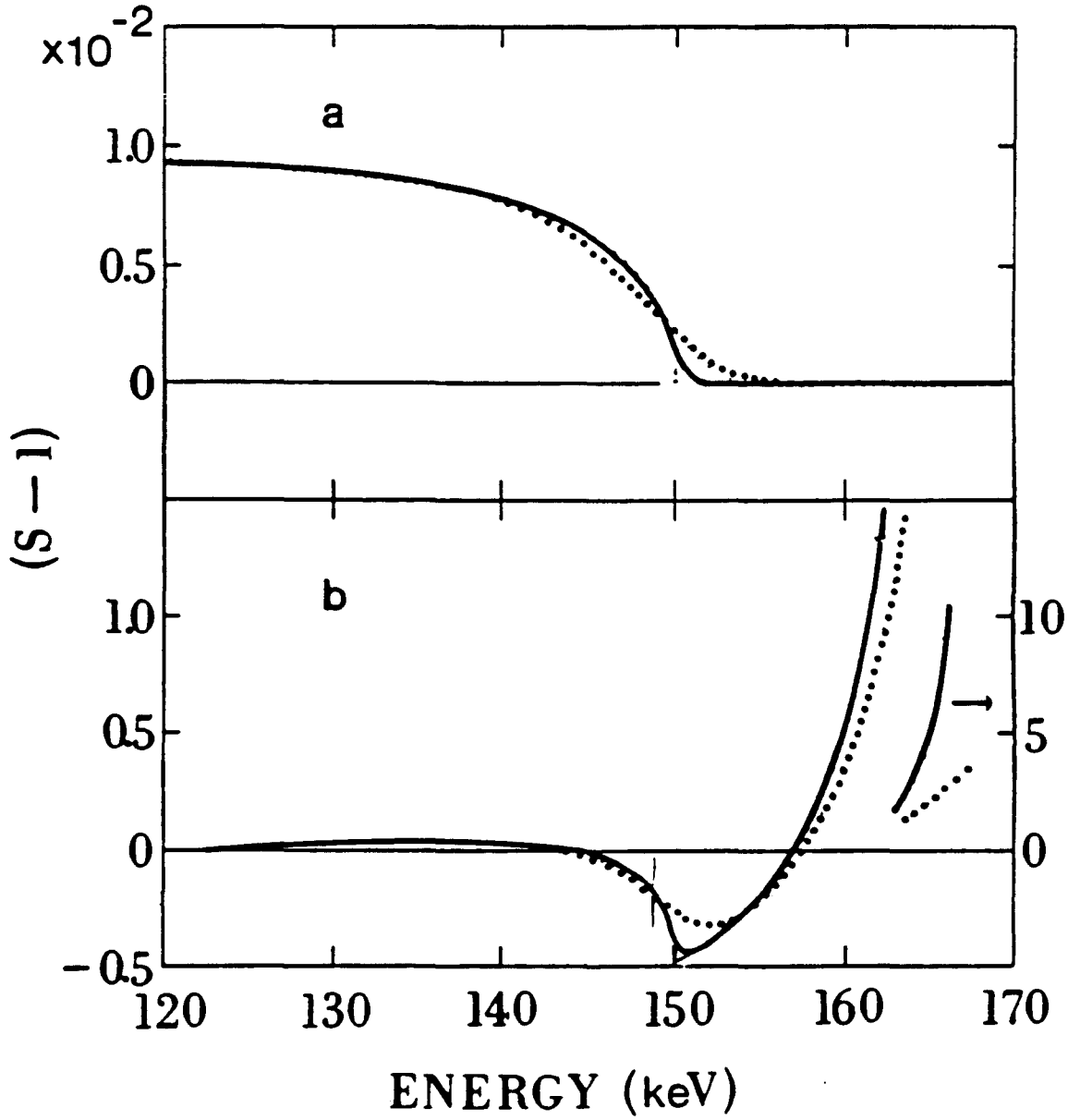
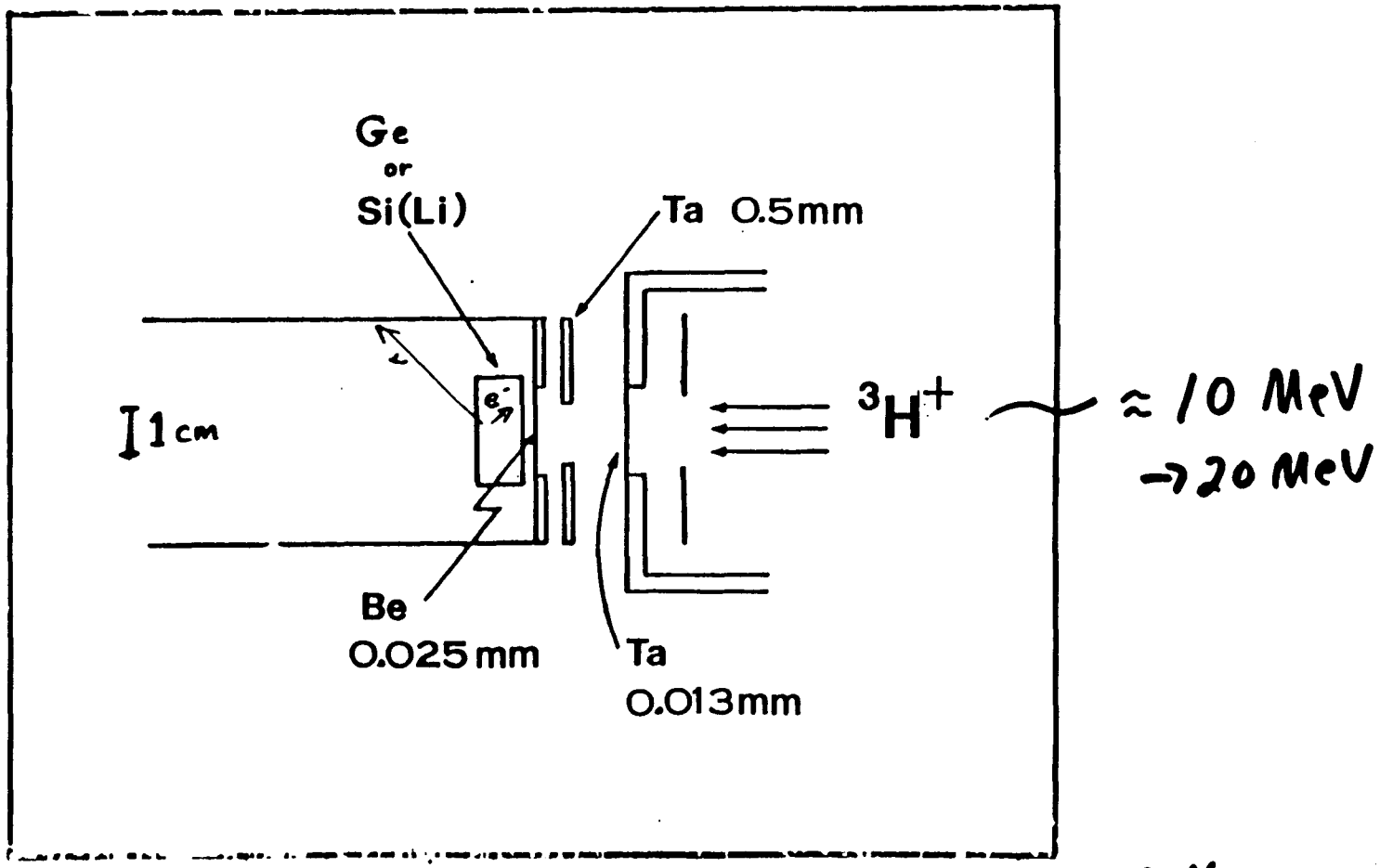


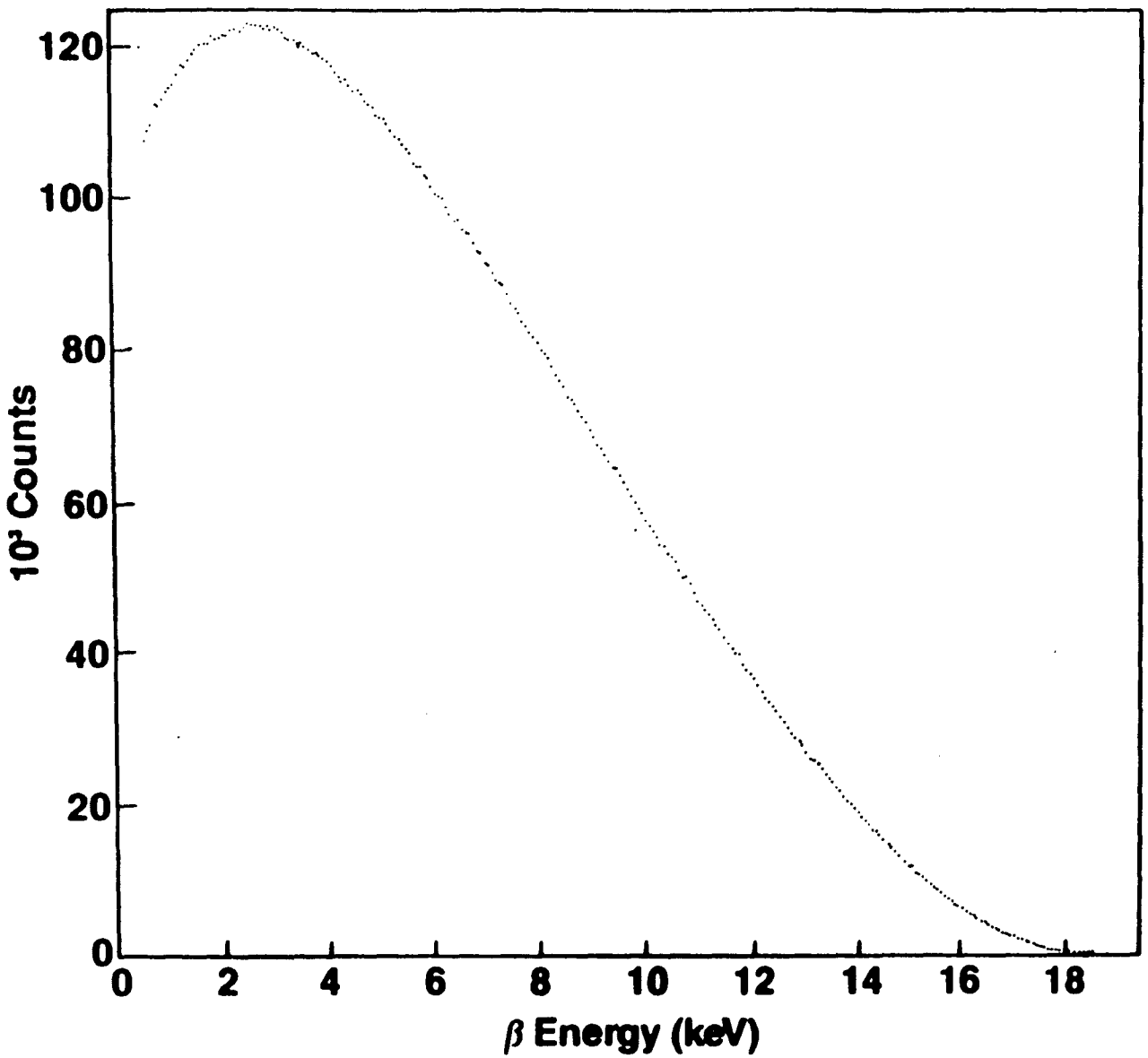
FIG. 1. Schematic of a Kurie plot with the emission of a two-component neutrino, with $M_1 = 0$ and $\sin^2\theta = 0.5$.


x10^-2
a
b
1.0
0.5
0
-0.5
10
5
(S − 1)
120
130
140
150
160
170
ENERGY (keV)

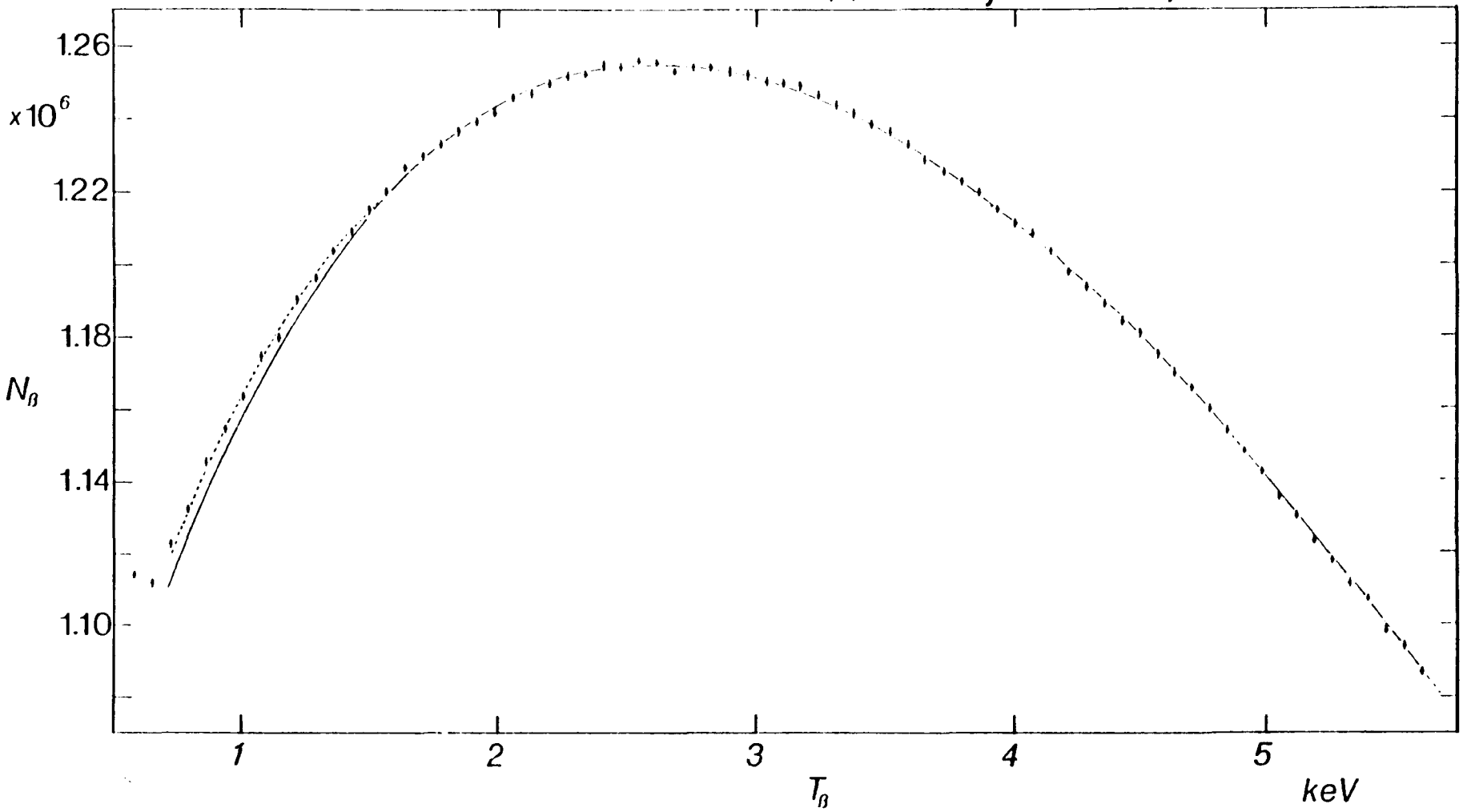
Guelph



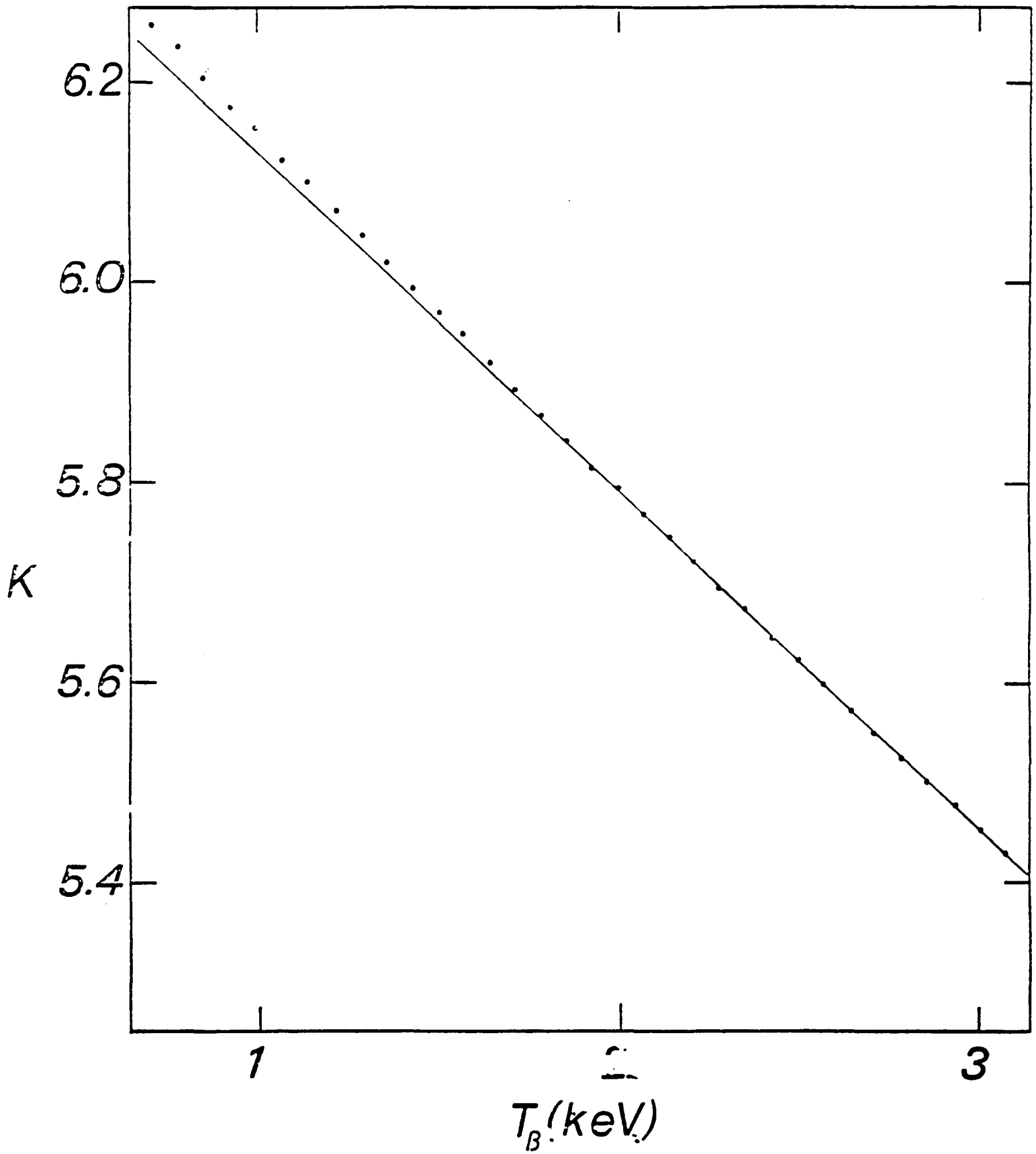
Depth of Implantation ~ 0.2 mm → 0.4 mm
Range of 18 keV β's ~ 2.5 μm
Absorption length of Si K-Xray ~ 14 μm


120
100
80
60
40
20
0
10^3 Counts
0
2
4
6
8
10
12
14
16
18
β Energy (keV)

PRL 54, 1891 (1985)



Simpson


6.2
6.0
5.8
K
5.6
5.4
1
3
T_β (keV)

Non-relativistic

$$F(E, Z) = \frac{x}{1 - e^{-x}} \qquad x = \frac{2\pi Z \alpha}{v/c}$$

"Screening" correction

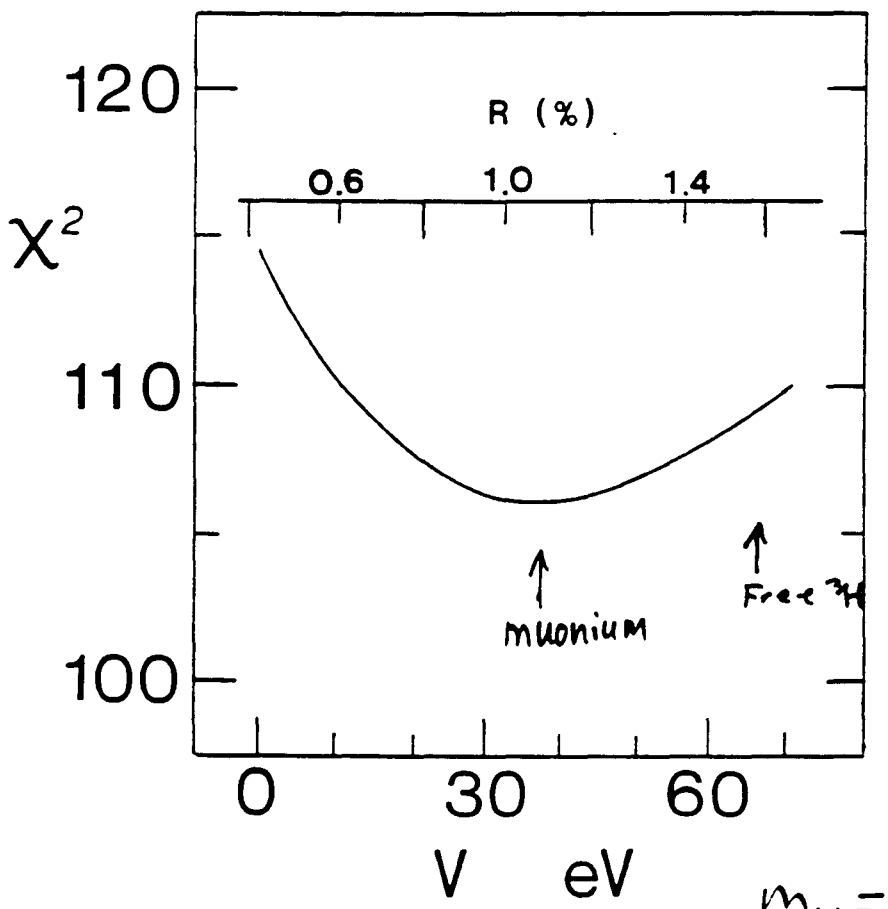
$$F \rightarrow F(E - V, Z)$$

$$Q \rightarrow Q - V$$

$$E \rightarrow E - V$$

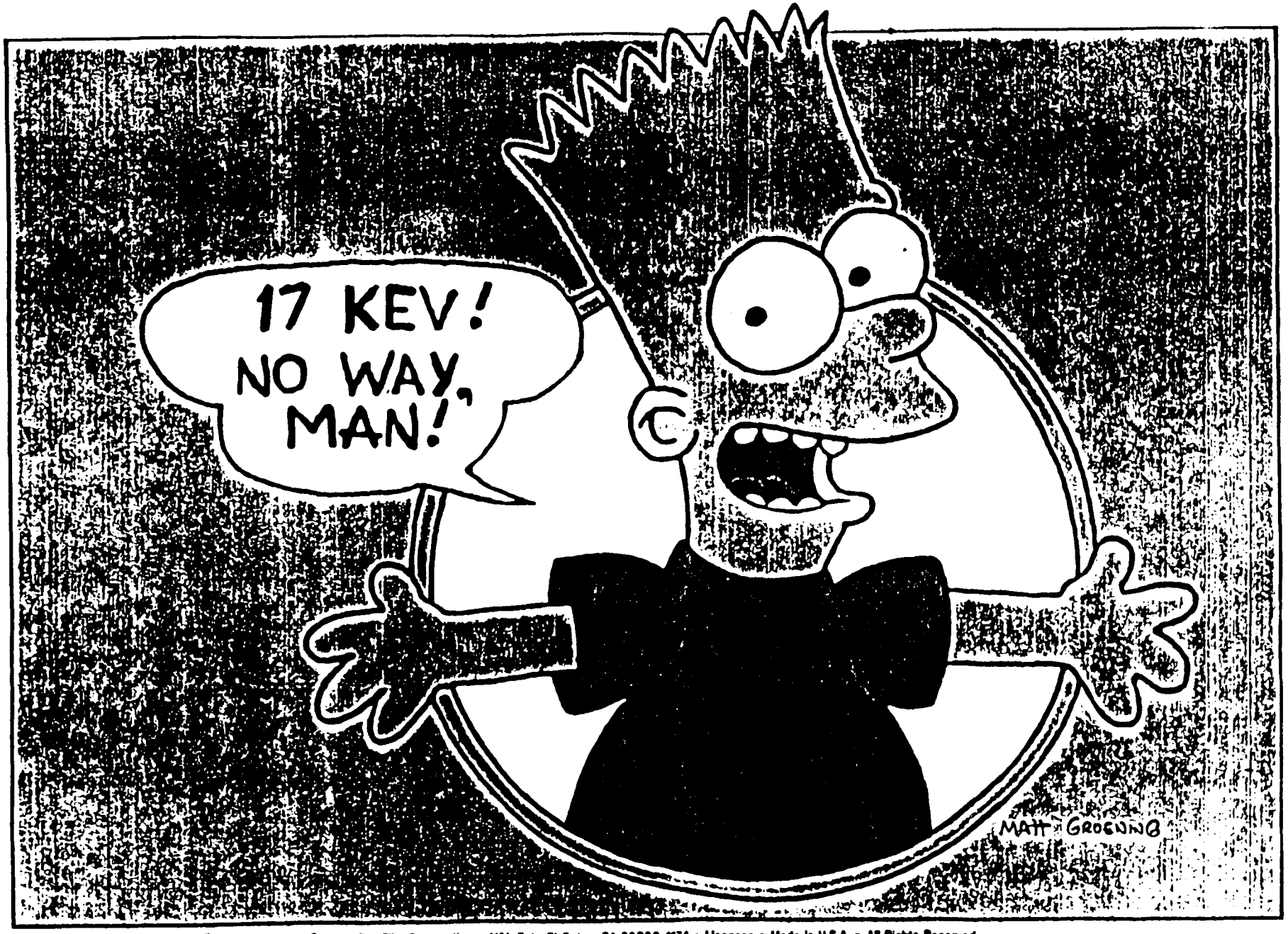
$$p(E) \rightarrow p(E - V)$$

$R = \sin^2\theta$



$m_\nu = 17.1$ keV

$\nu = 102$



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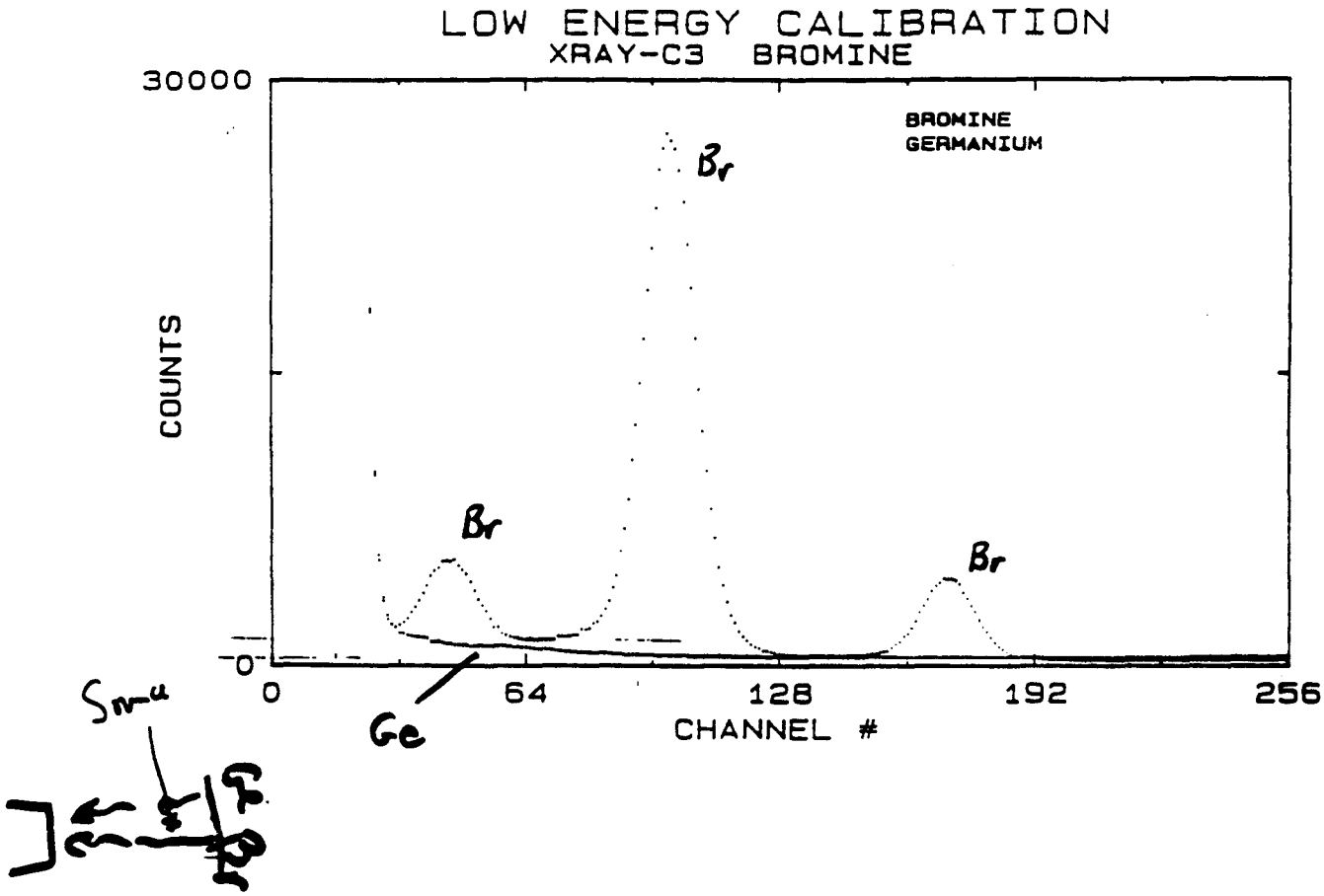
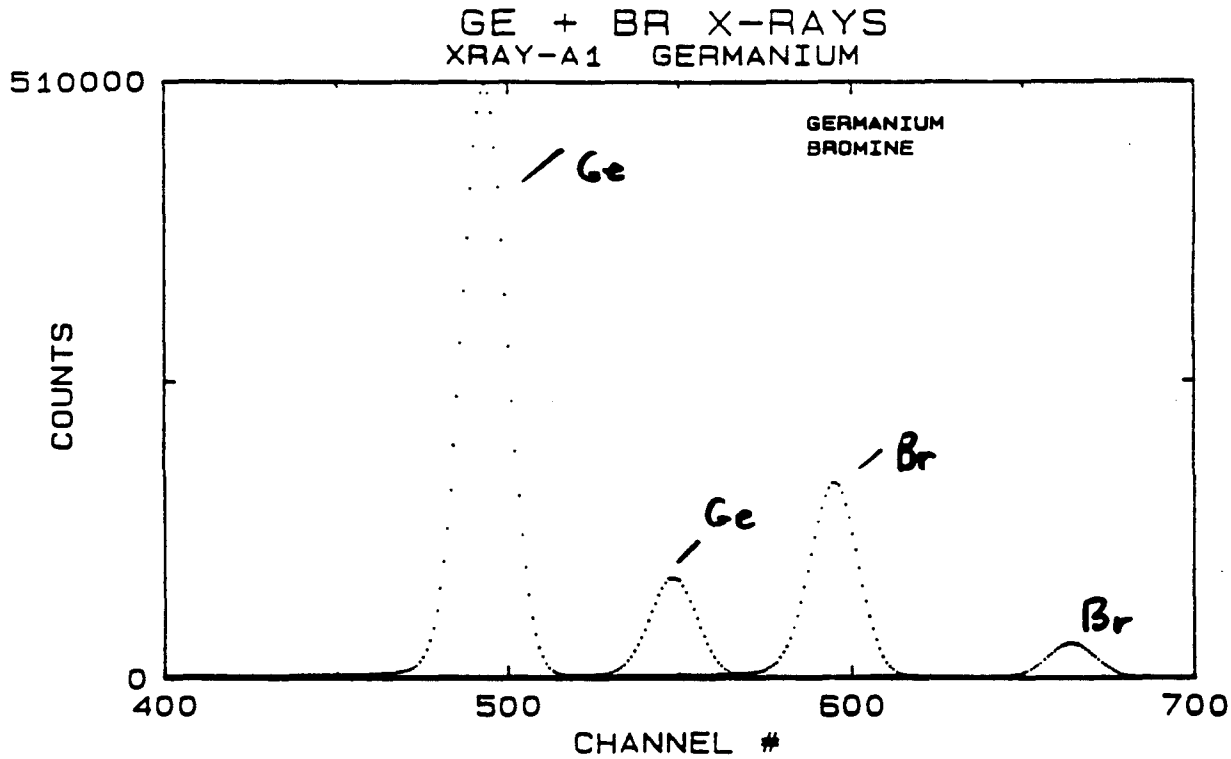
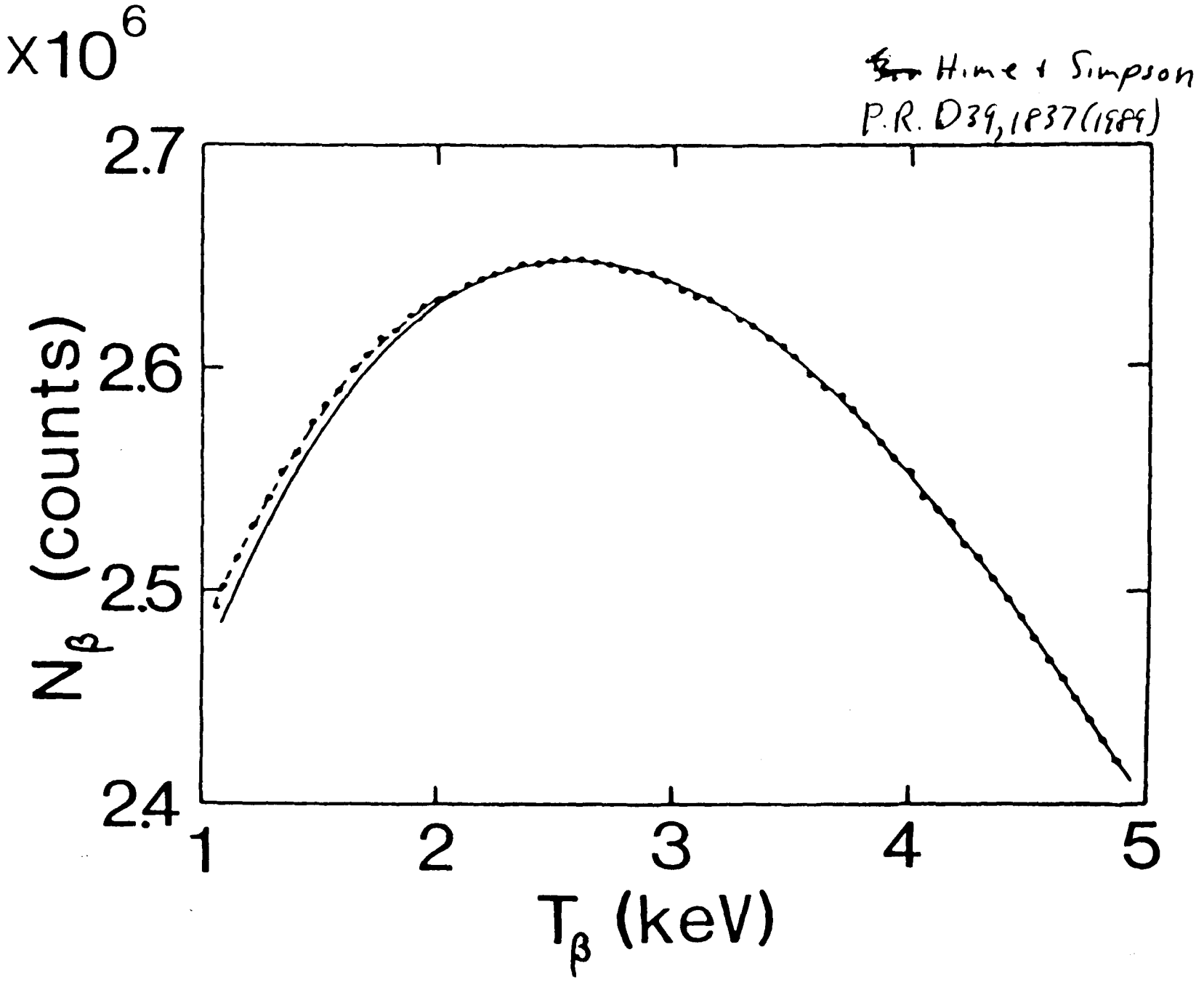

LOW ENERGY CALIBRATION
XRAY-C3 BROMINE
BROMINE
GERMANIUM
30000
COUNTS
0
0
64
128
192
256
CHANNEL #
Br
Br
Br
Ge
Sn-u


GE + BR X-RAYS
XRAY-A1 GERMANIUM
GERMANIUM
BROMINE
510000
COUNTS
0
400
500
600
700
CHANNEL #
Ge
Ge
Br
Br



Hime + Simpson
P.R. D39, 1837 (1989)

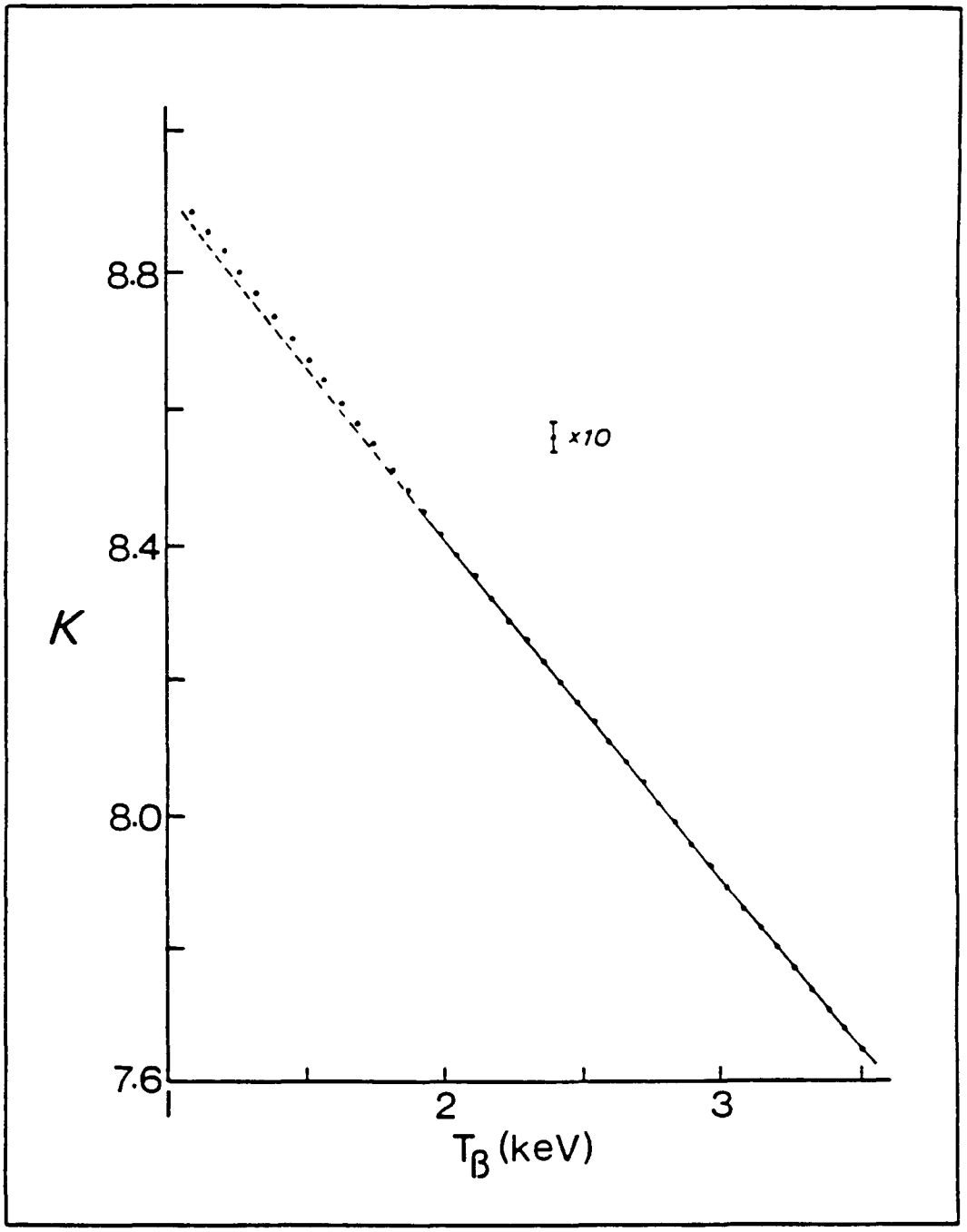


FIGURE 3

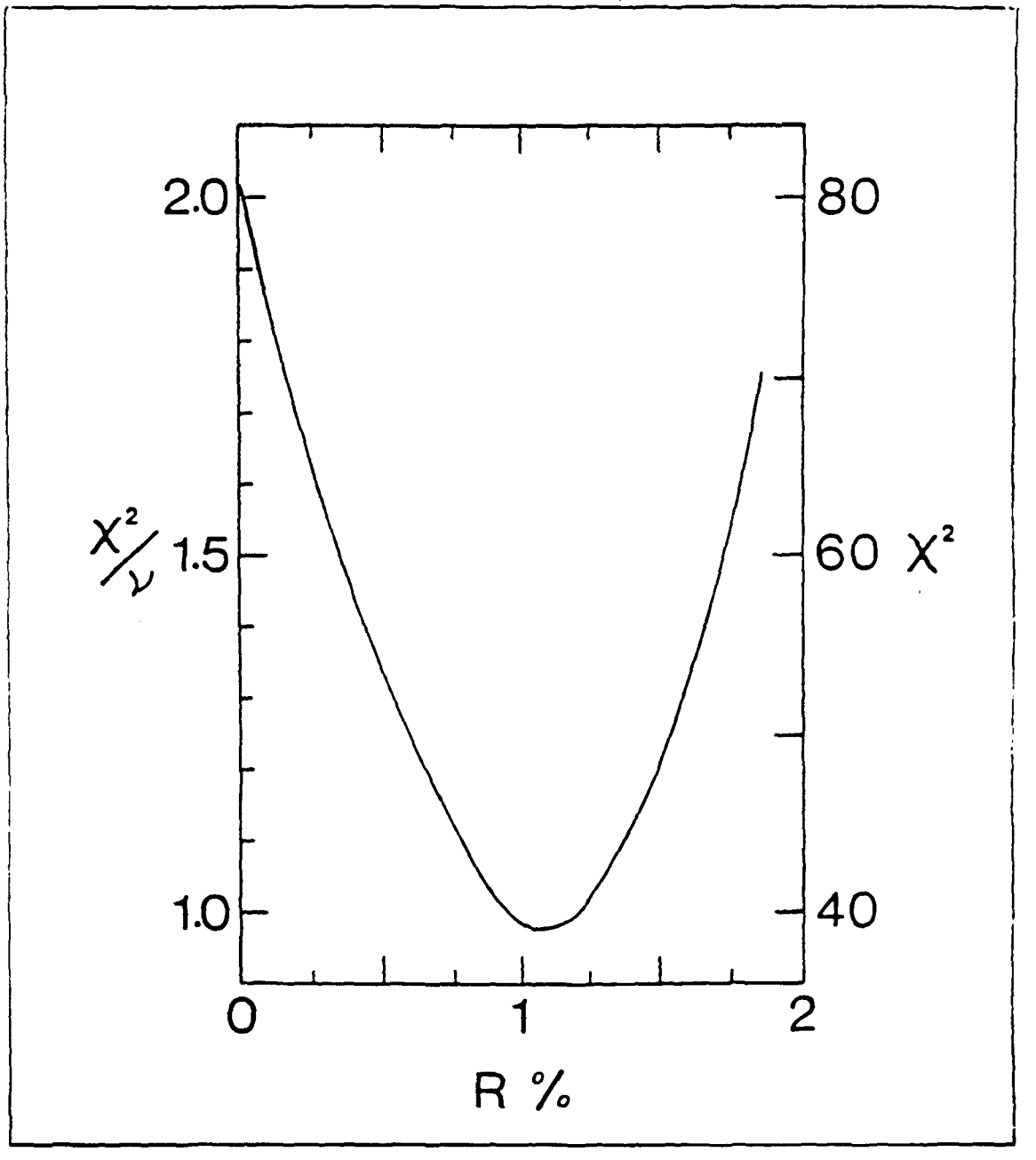


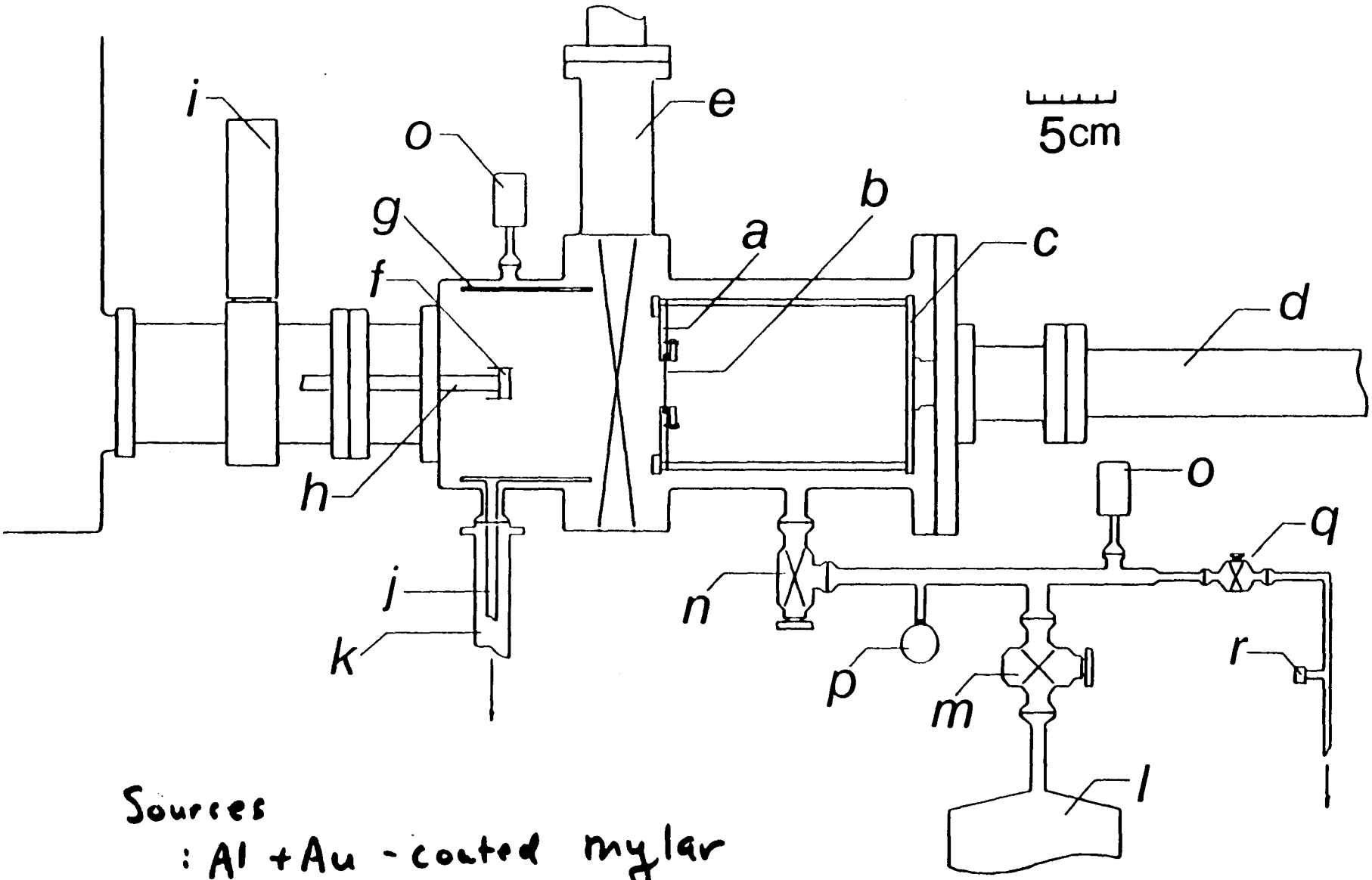
FIGURE 5

$R = \sin^2\theta$

$m_\nu = 16.9$ keV

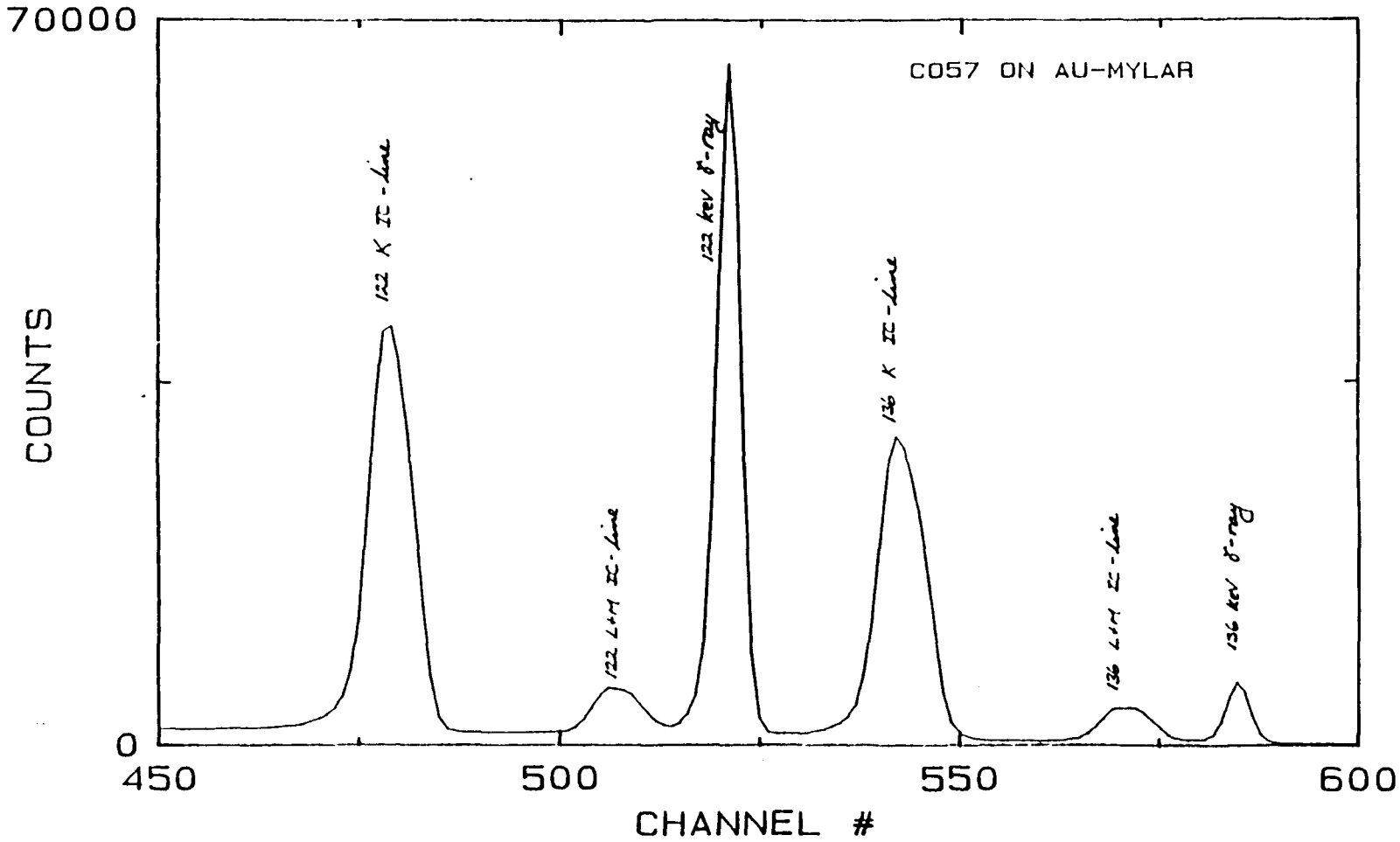
$V = 40$ eV

^{35}S

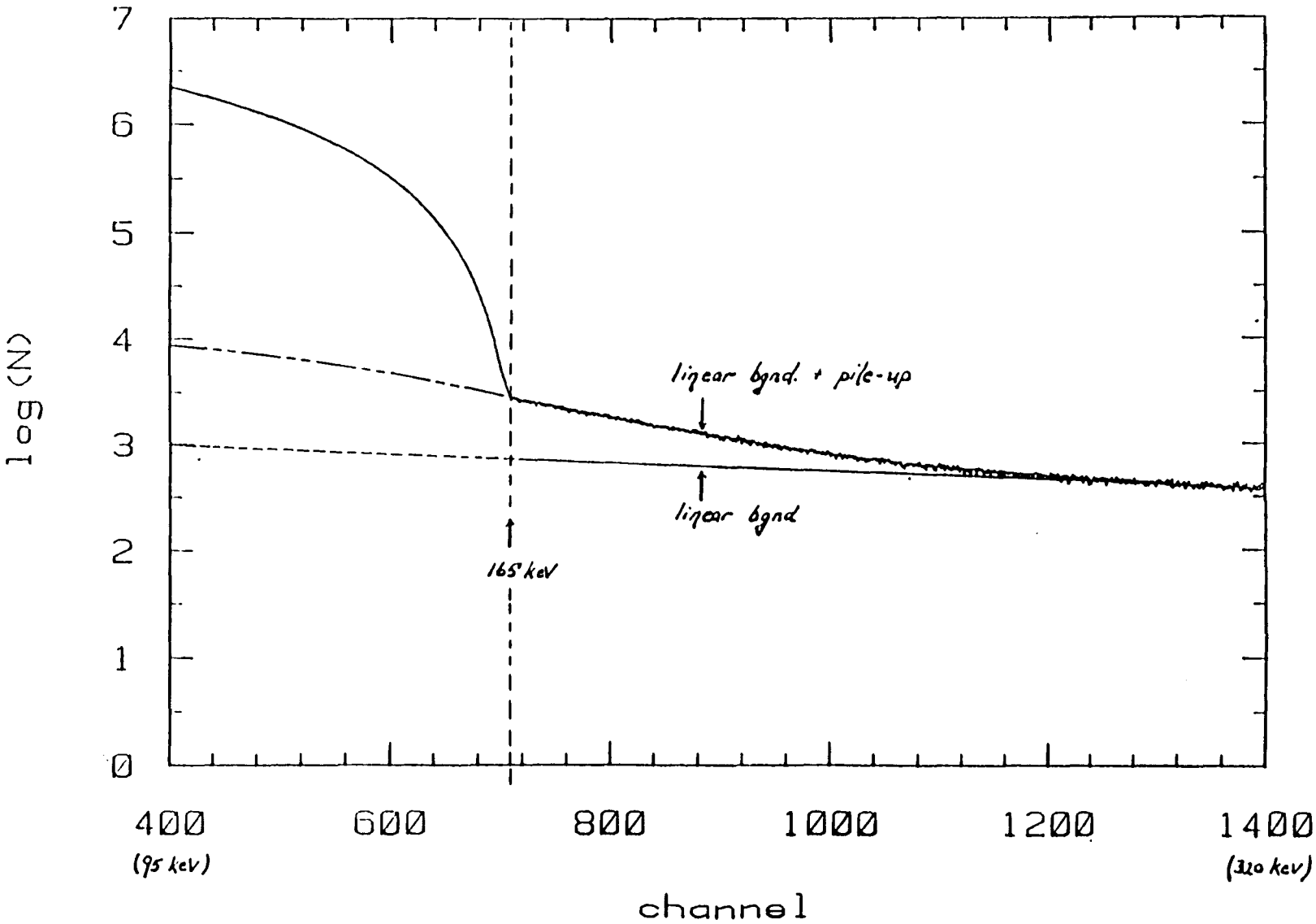


Sources
: Al + Au - coated mylar
~10μm

CO57 CALIBRATION & RESPONSE



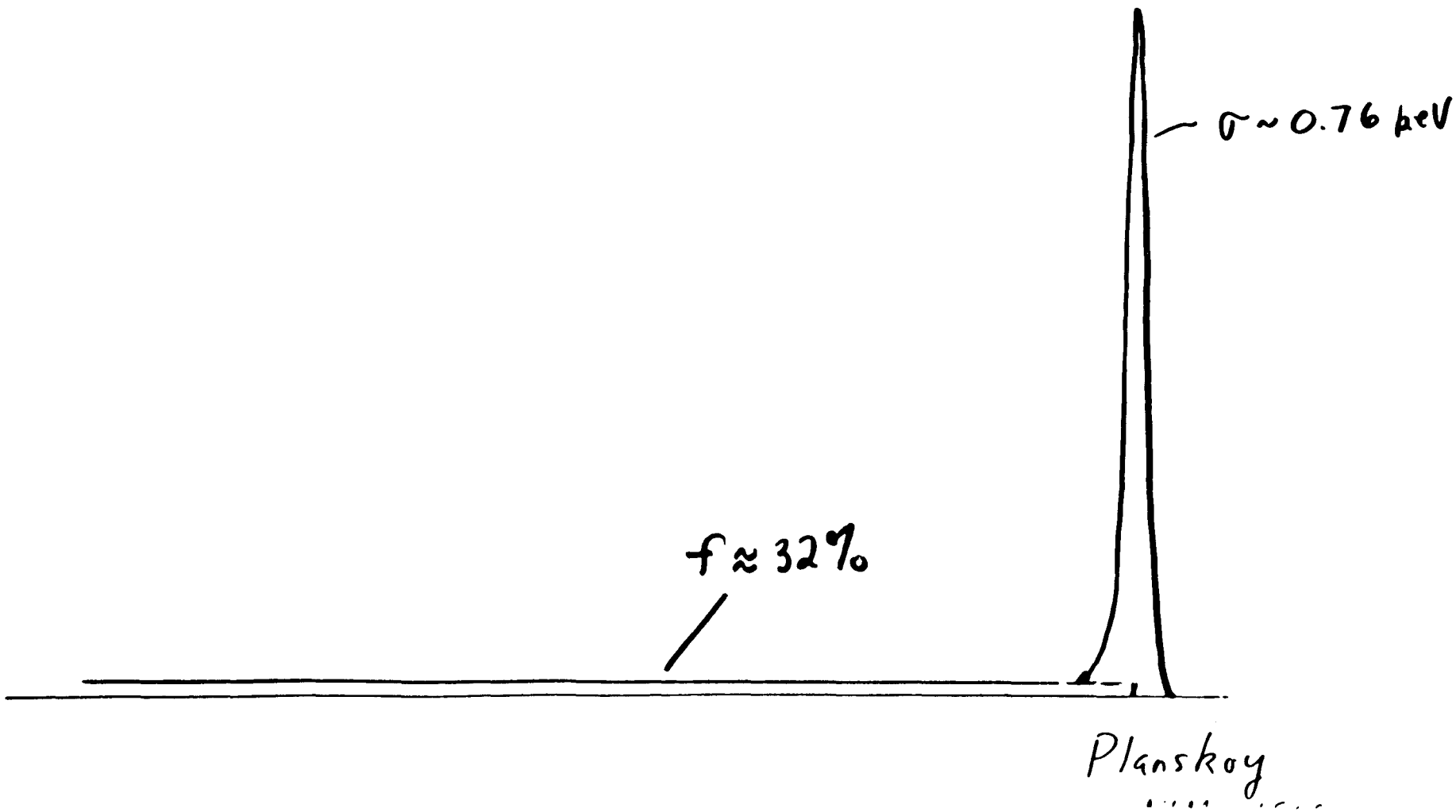
S-35 RAW SIGNAL



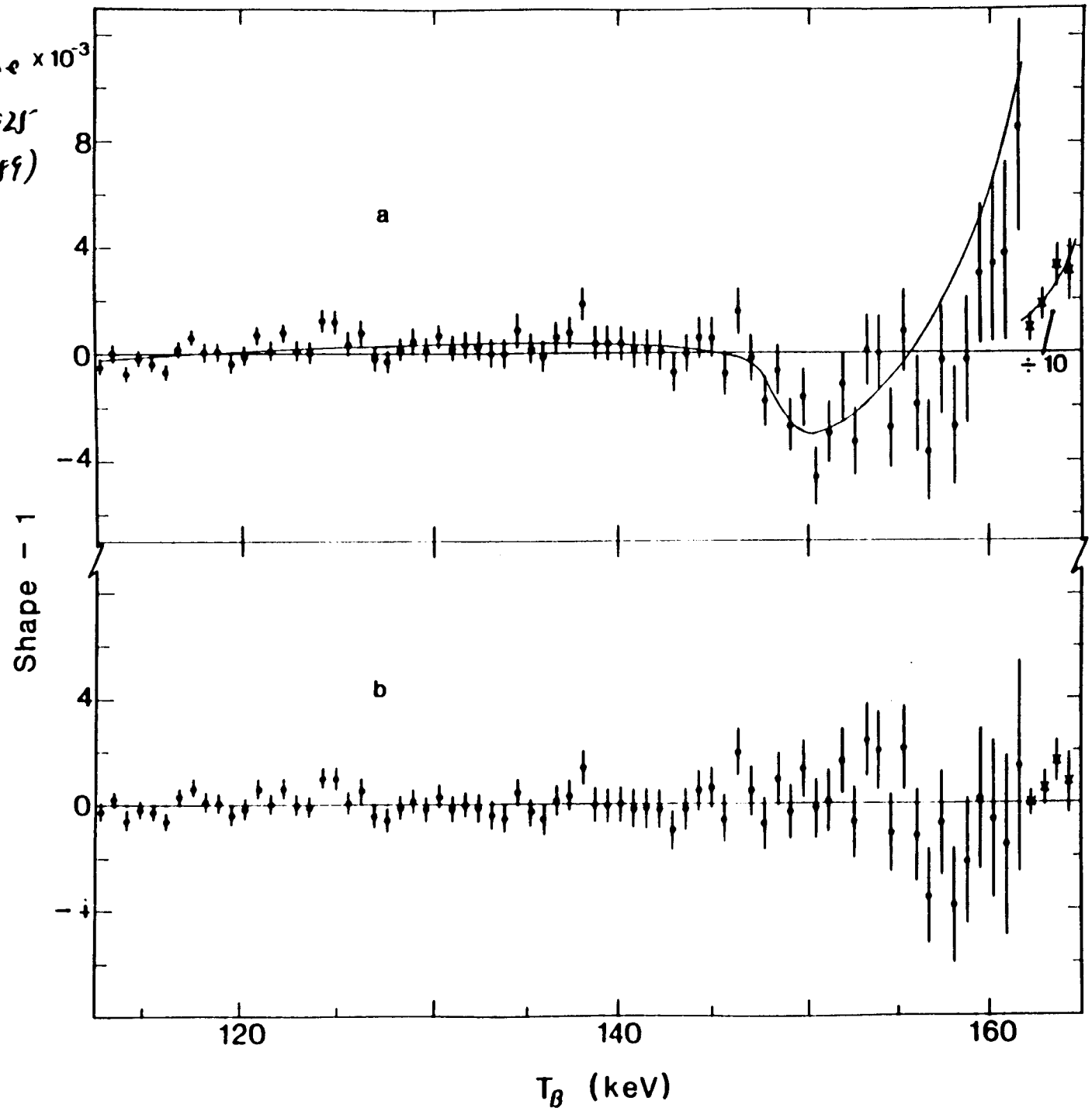
RUN#C 225eV/ch1

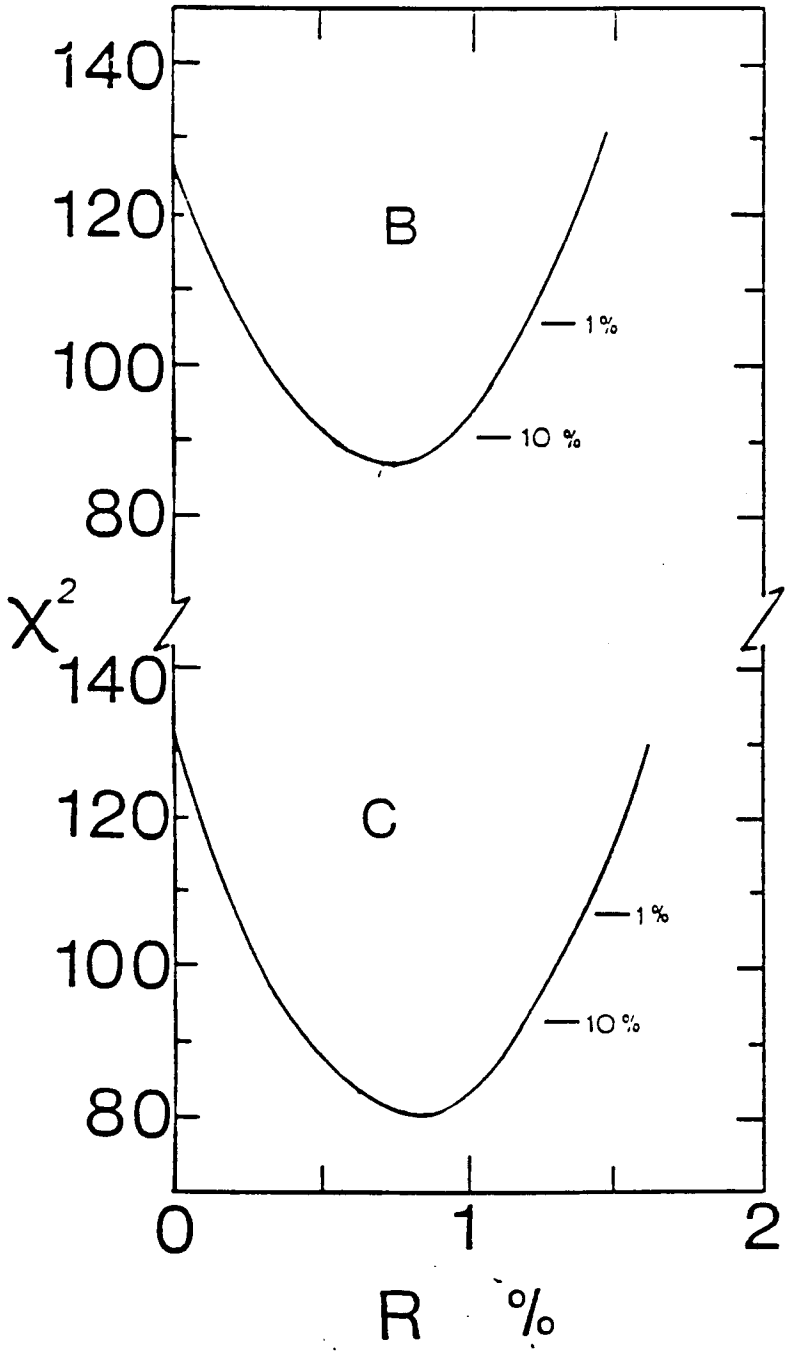
Response Function
convoluted with

$$N_\beta(E,Z) = (1-R)\,N_\beta(E,Z,M_1) + R\,N_\beta(E,Z,M_2)$$



Simpson & Hime
P.R D39, 1825
(1989)




140
120
100
80
B
1%
10 %
X^2
140
120
100
80
C
1%
10 %
0
1
2
R %

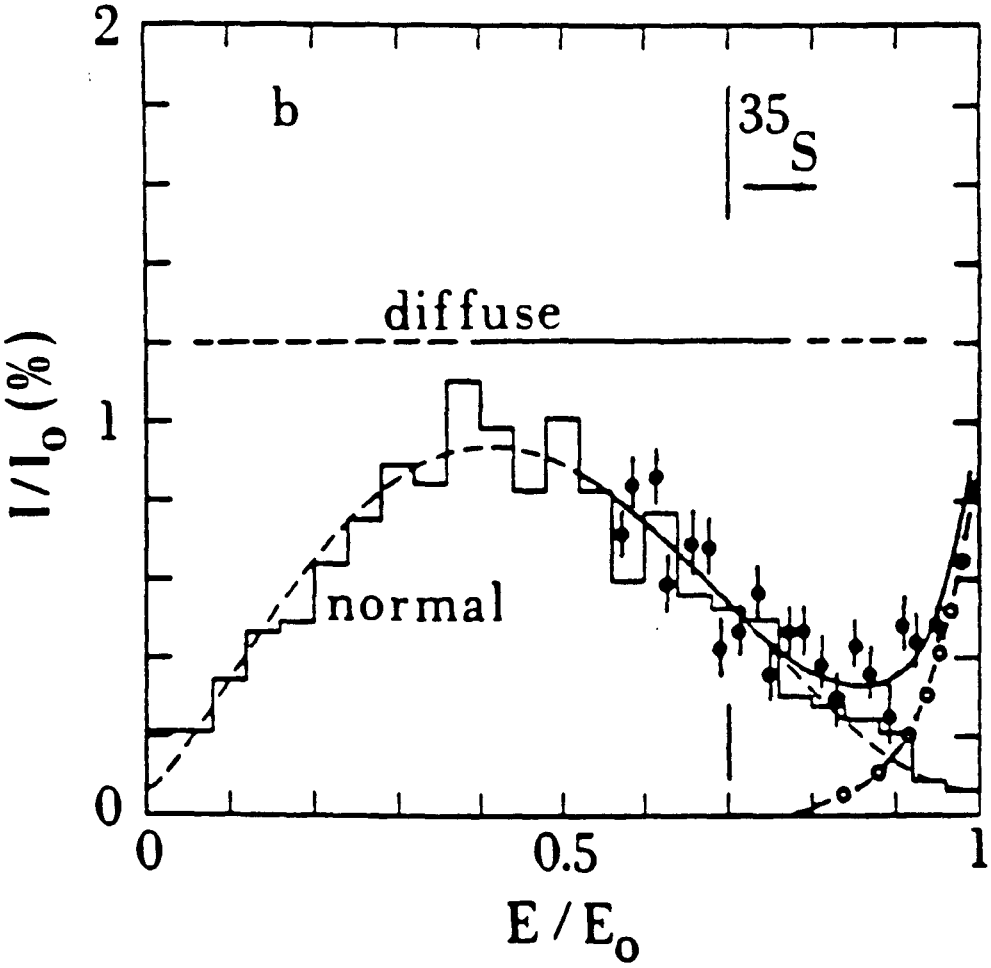
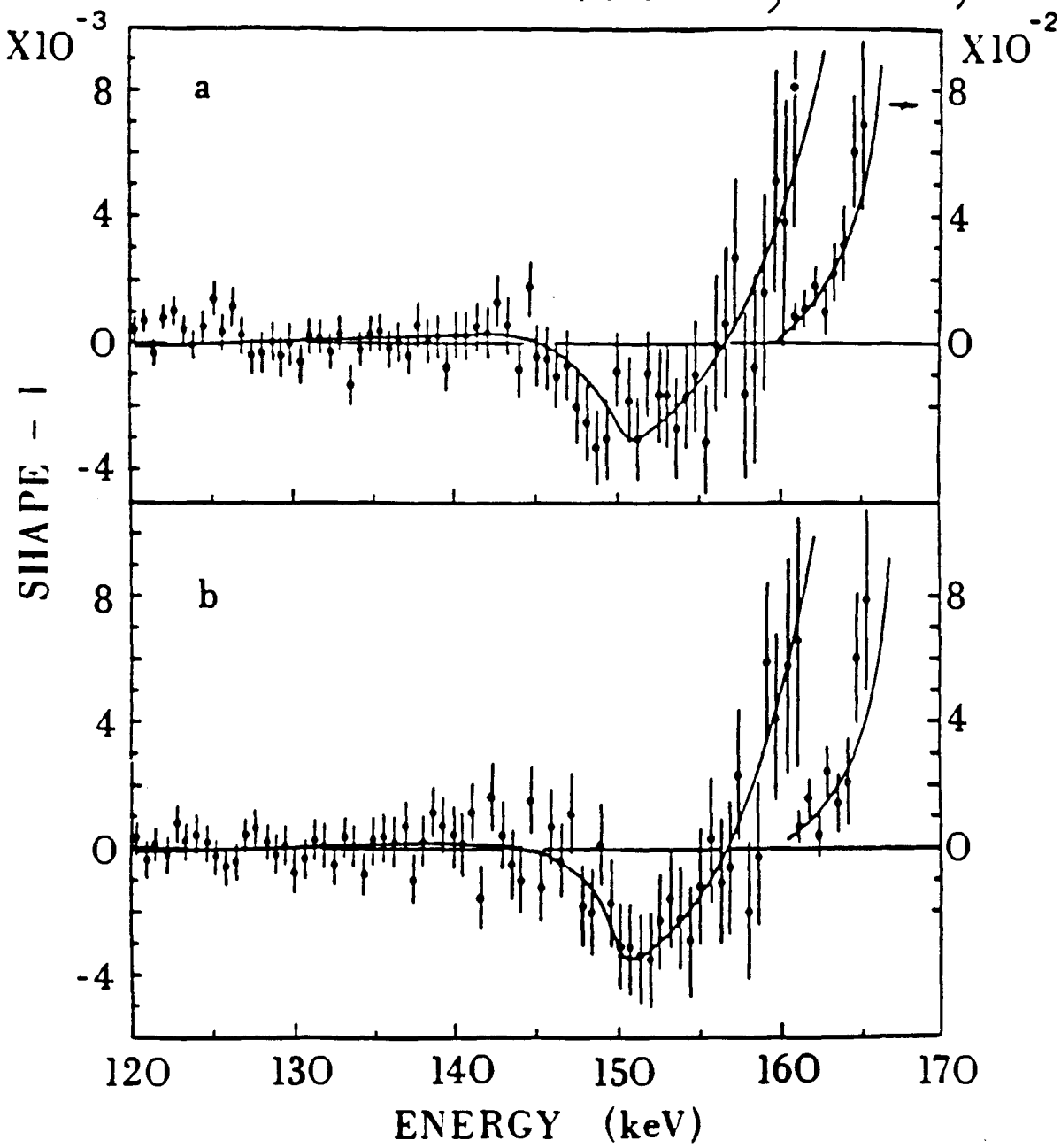
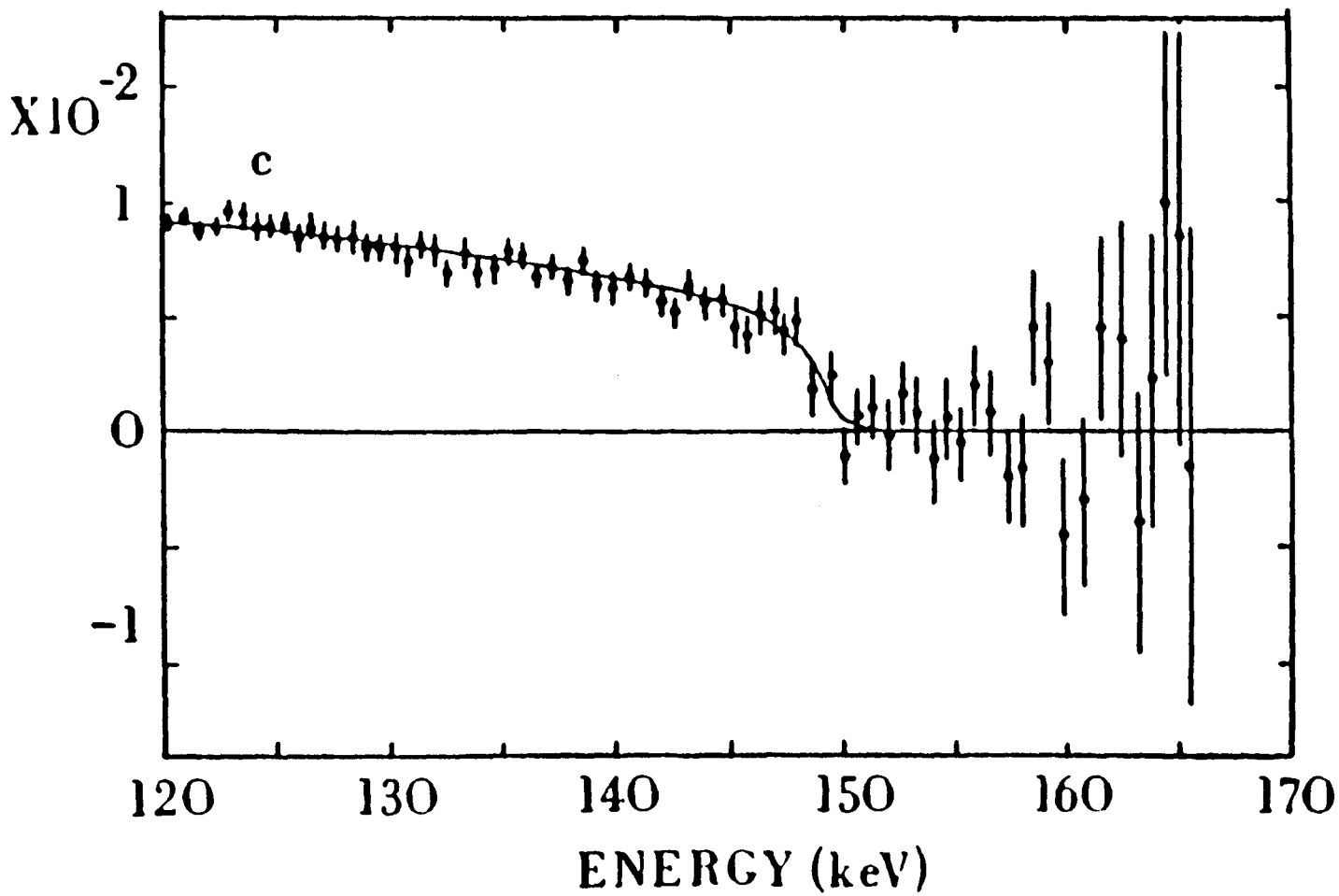
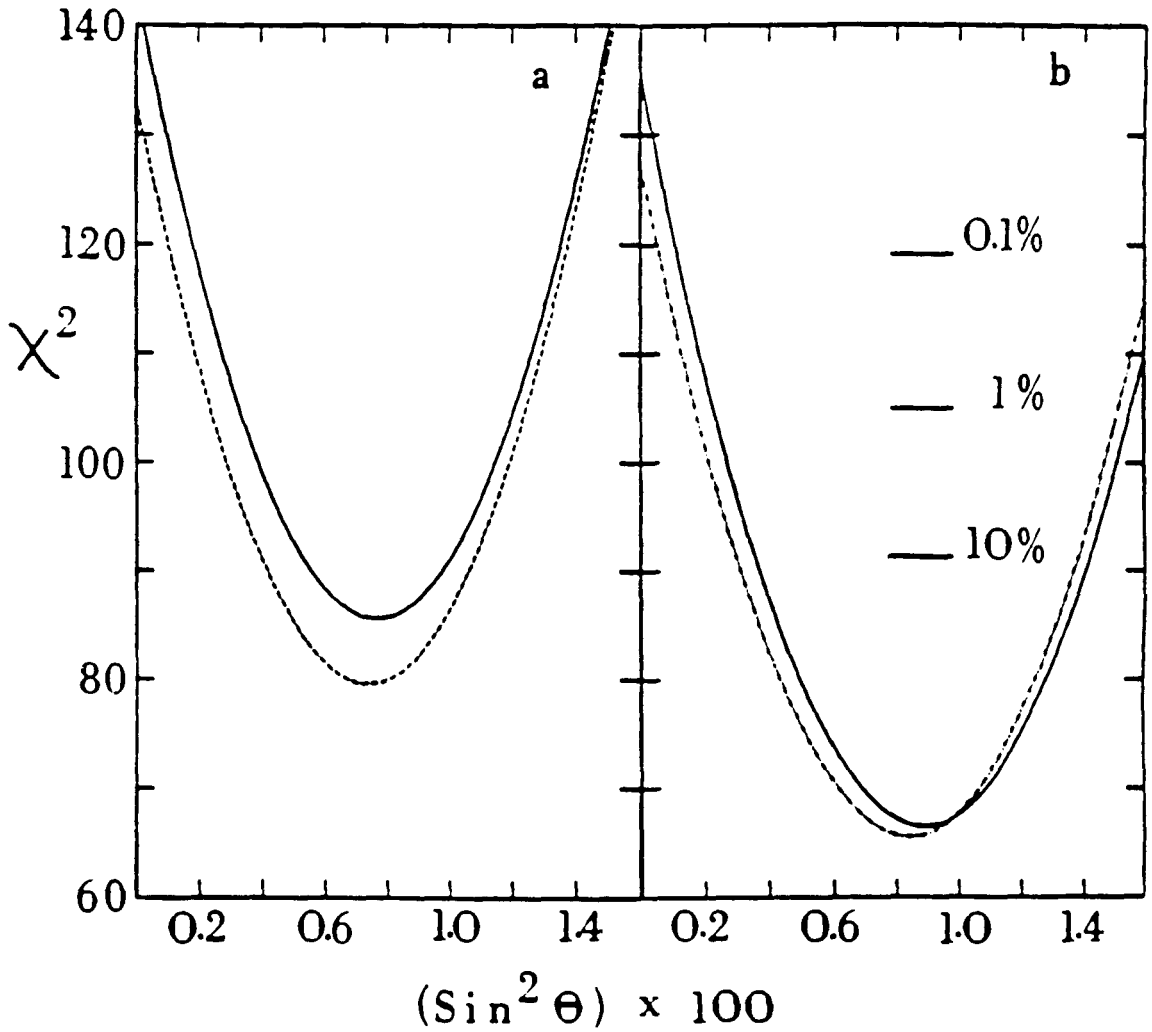


Fig. 3

Hime + Jelley (P.L.)
PLB 257, 441 (1991)



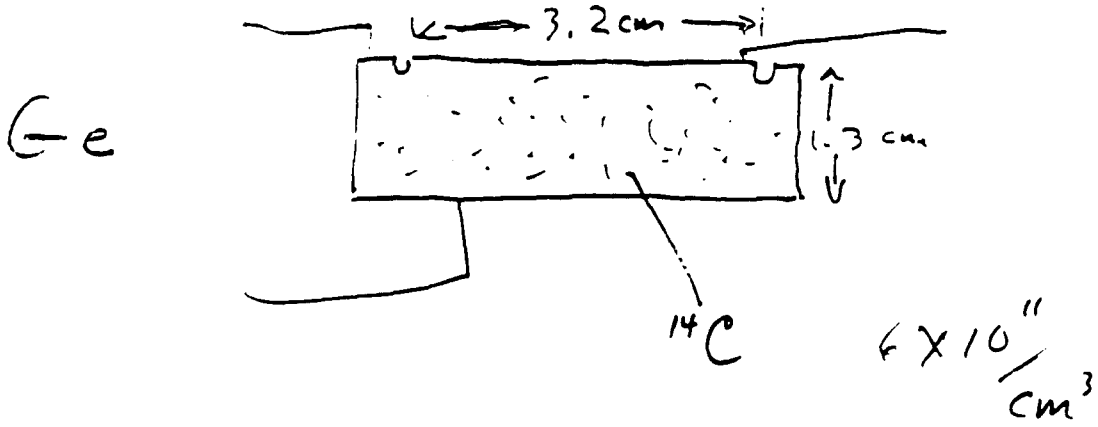

X10^-2
c
1
0
-1
120
130
140
150
160
170
ENERGY (keV)


140
120
100
80
60
χ^2
a
b
0.1%
1%
10%
0.2
0.6
1.0
1.4
0.2
0.6
1.0
1.4
$(\sin^2\theta) \times 100$

B. Sur, Eric B. Norman et al.

(preprint, LBL)

PRL May 13



Sur, Norman et al.

LBL

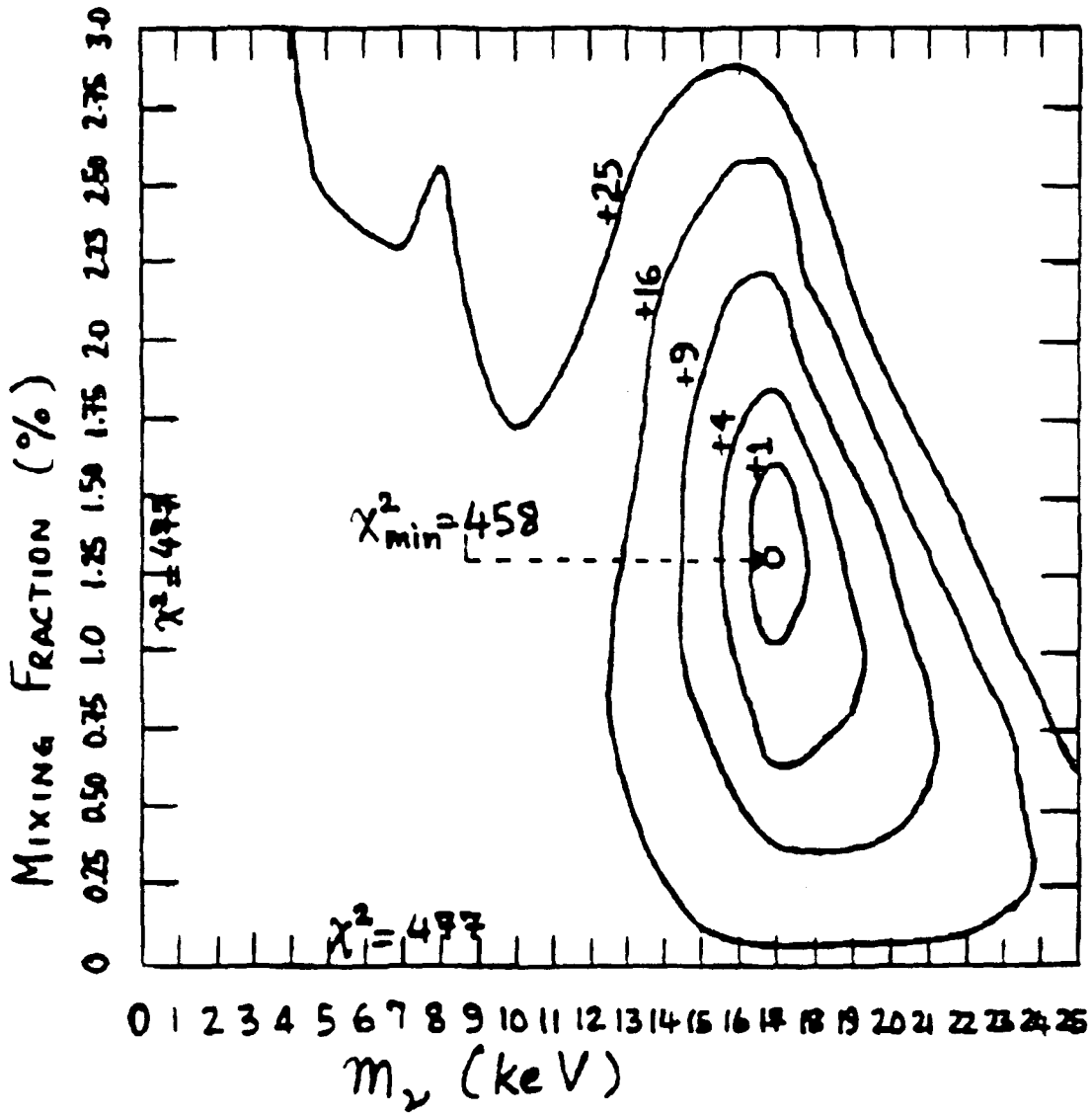


Fig 1

^{14}C grown into intrinsic Ge detector.

Details in Sur et. al. L.B.L. Preprint — to be published in May 13 issue of P.R.L.

New DATA. (2 runs)

^{14}C detector : total of 224 days

B.G. detector : total of 111 days.

VETOED DATA:

Fig 1: Contours of χ^2 in $m_\nu - c$ plane.

# of data points = 420.

Search done by minimising χ^2 for each value of (m_ν, c) with ALL other param free.

Fig 2: Shape for $m_\nu = c = 0$. The curve is the best fit to the data at $m_\nu = 17$, $c = 1.3\%$

Fig 3:- Shape for $m_\nu = 17$, $c = 1.3\%$.

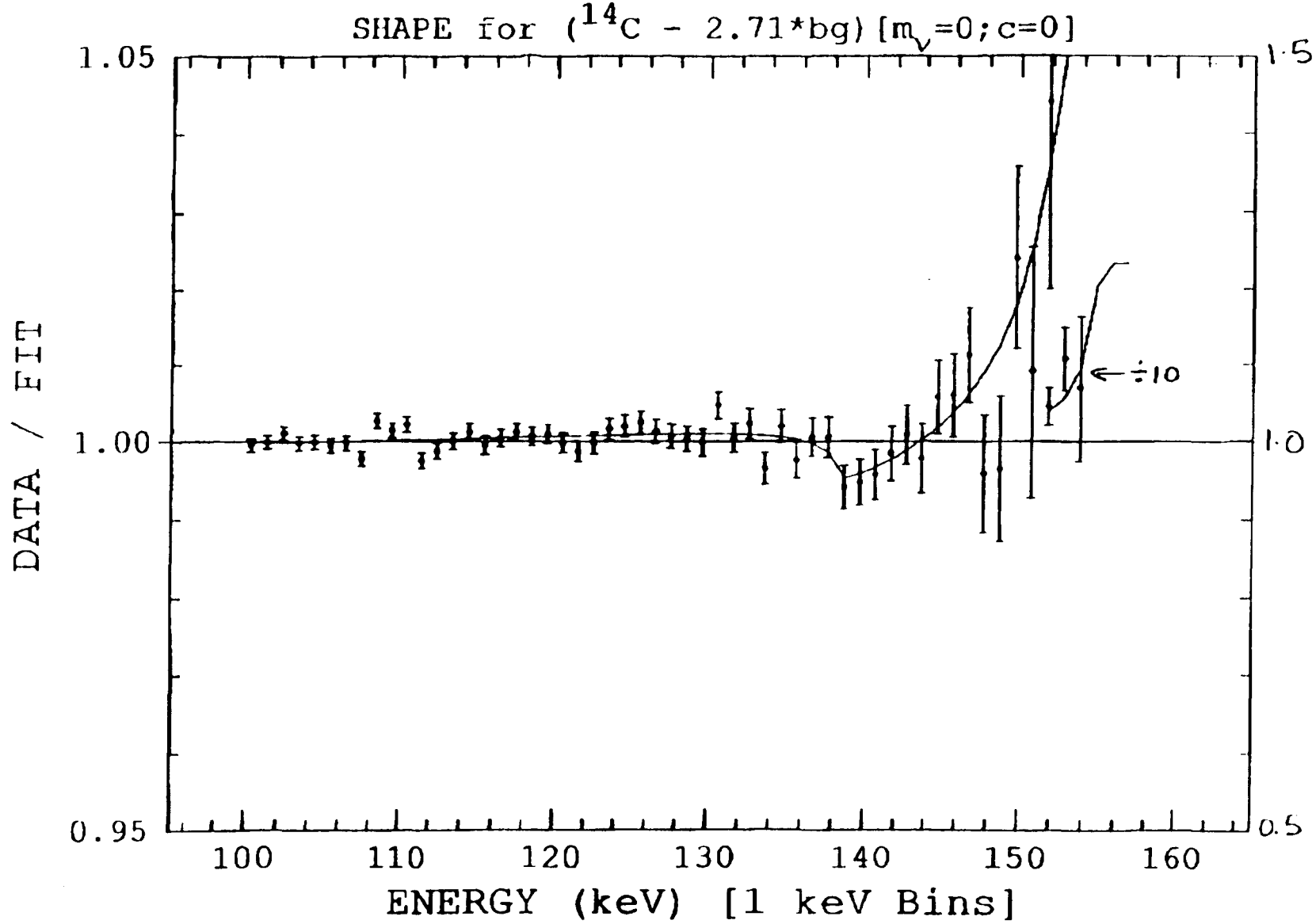

SHAPE for (^{14}C - 2.71*bg) [m_ν=0; c=0]
DATA / FIT
1.05
1.00
0.95
1.5
1.0
0.5
100
110
120
130
140
150
160
ENERGY (keV) [1 keV Bins]
÷10

Fig 2

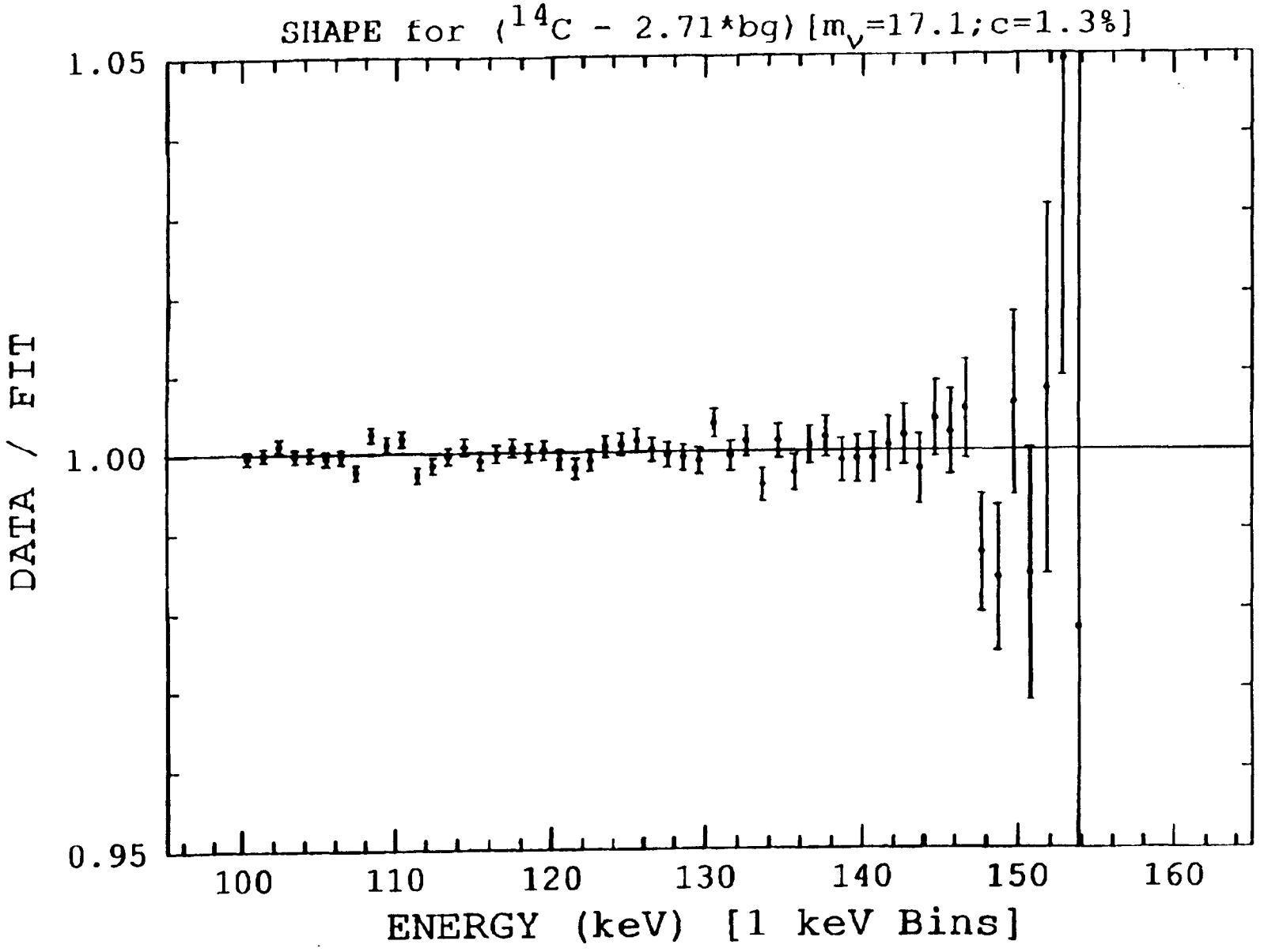

SHAPE for (^{14}C - 2.71*bg) [m_ν=17.1;c=1.3%]
1.05
1.00
0.95
DATA / FIT
100
110
120
130
140
150
160
ENERGY (keV) [1 keV Bins]

Fig 3

RESULTS :-

for ^{14}C detector : total 224 days (2 runs)
b.g. detector. total 111 days (2 runs)

Vetoed data :-

$m_\nu = 17.0 \pm 0.5$ keV.

$c = (1.3 \pm 0.3 \pm \sim 0.1)\%$

stat systematic (mainly due to possible ADC non-linearities).

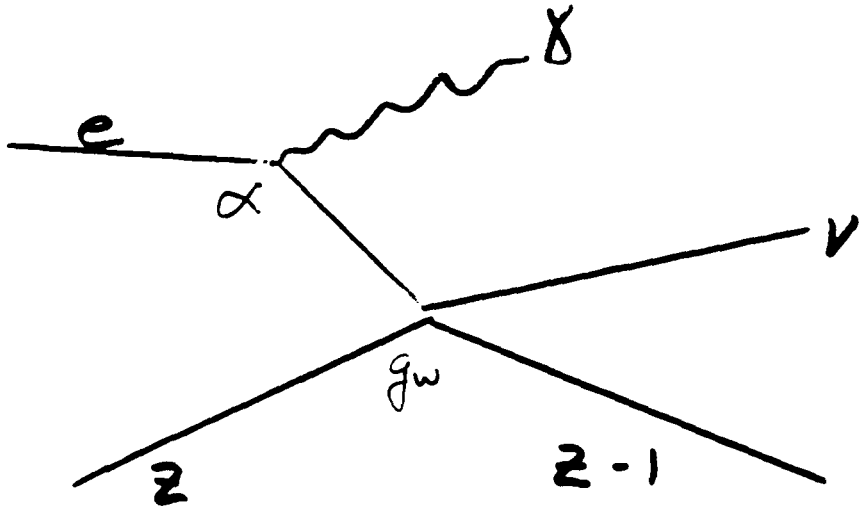
$E_0 = (155.8 \pm 0.025 \pm 0.07)$ keV.

β_1 (linear shape factor) = ~~1.17×10⁻³~~
$(1.17 \pm 0.03) \times 10^{-3}$ keV^{-1}

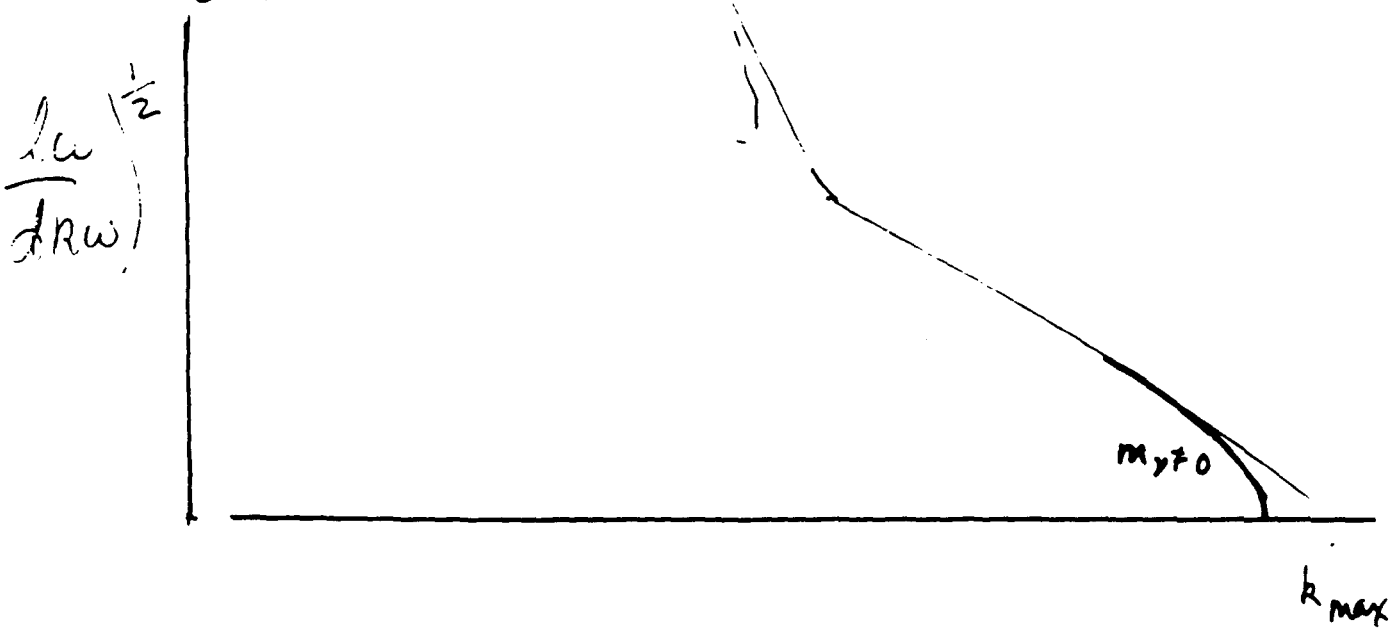
β_1 due to forbidden corrections calculated by E.D. Commins (U.C.B.) $= 1.2 \times 10^{-3}$ keV^{-1}

(Preliminary analysis of Unvetoed − Vetoed data indicates tail/Peak is very small $\lesssim 0.1\%$.)

2. Electron capture with inner bremsstrahlung



$$\frac{d\omega}{dk} \propto F\,|\mathcal{M}(k)|^2\, k\,(k_{max}-k)\left[(k_{max}-k)^2 - m_\nu^2\right]^{\frac{1}{2}}$$



IBEC
^{71}Ge

Zimen
et al

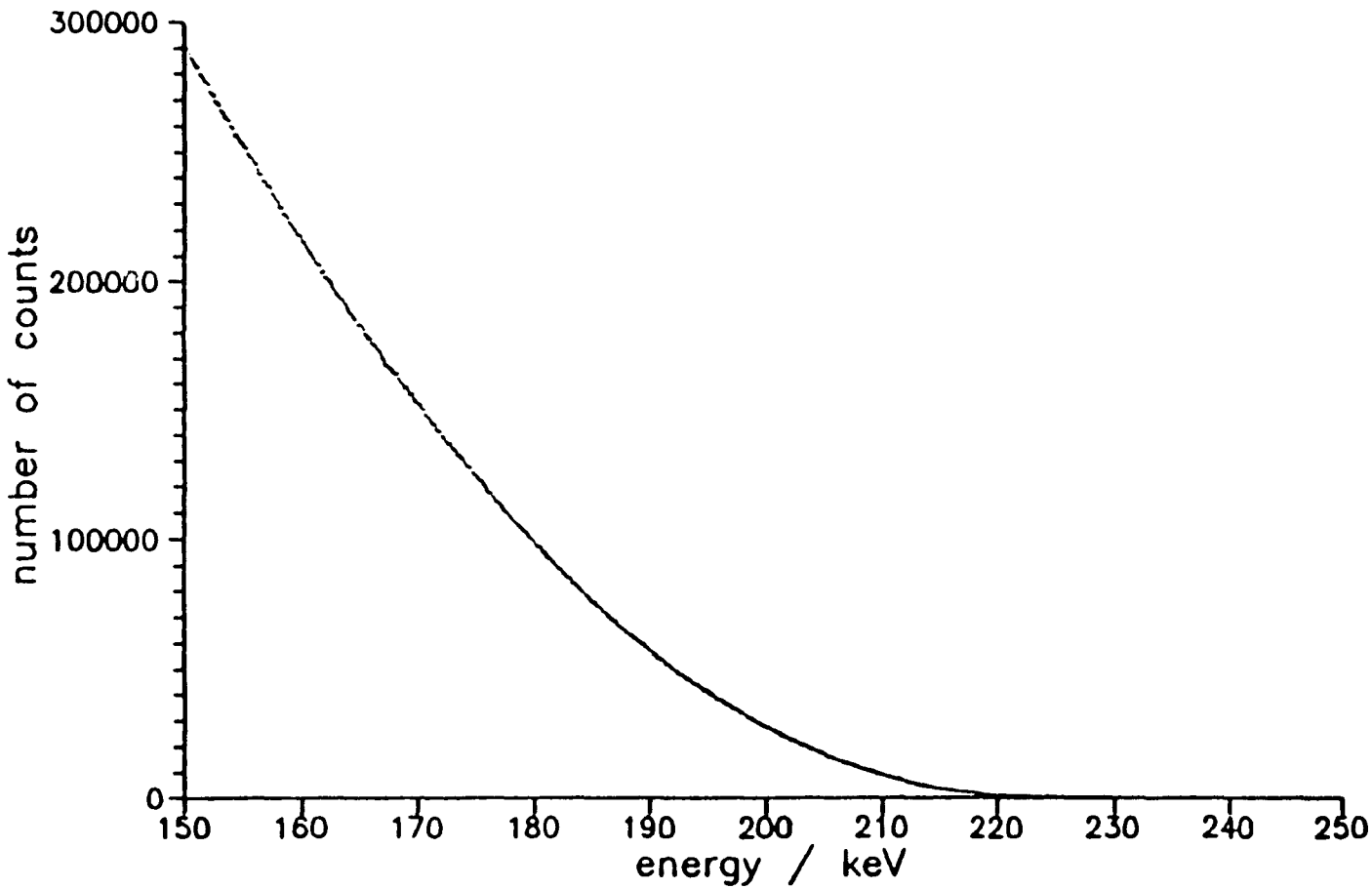


Fig. 1.

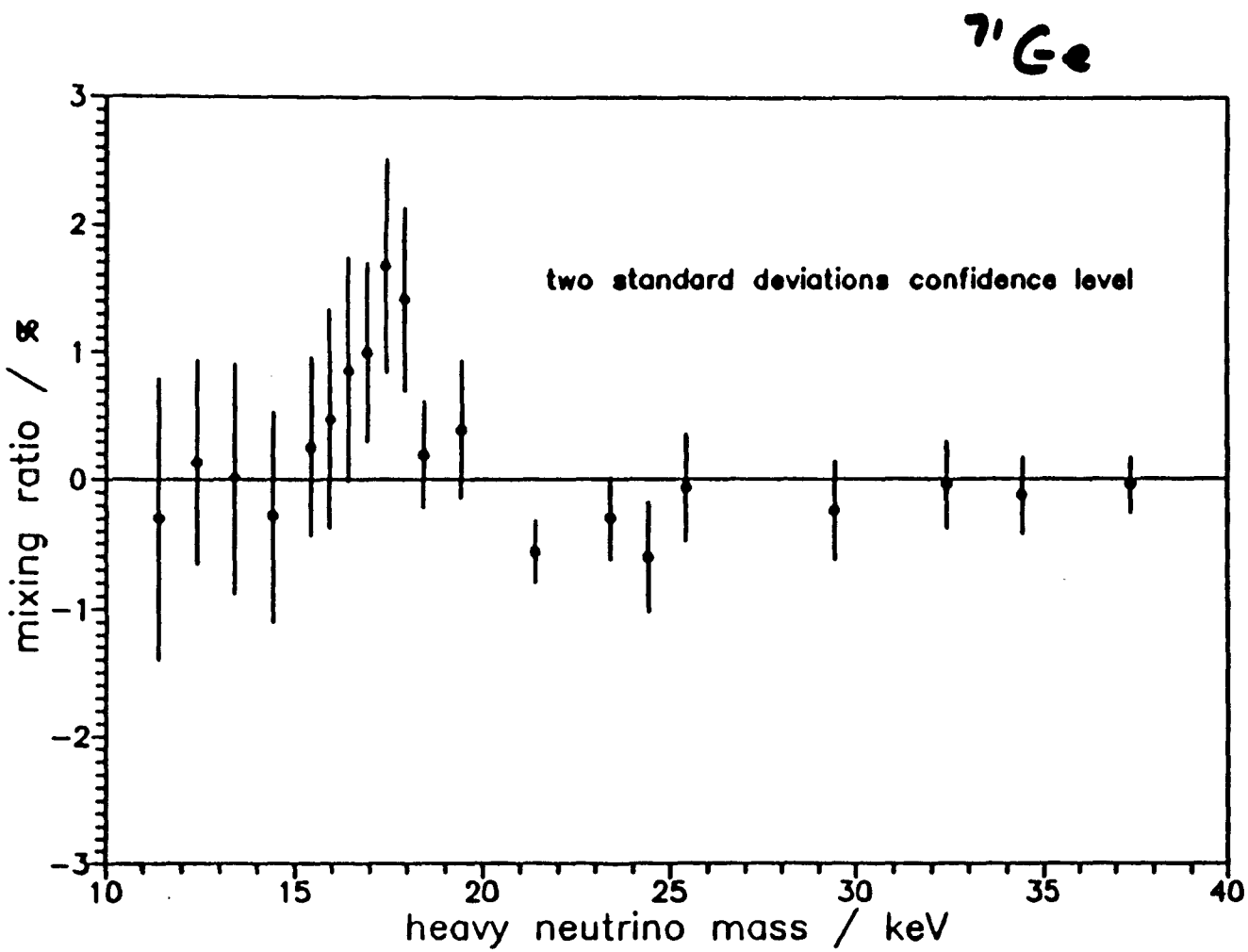
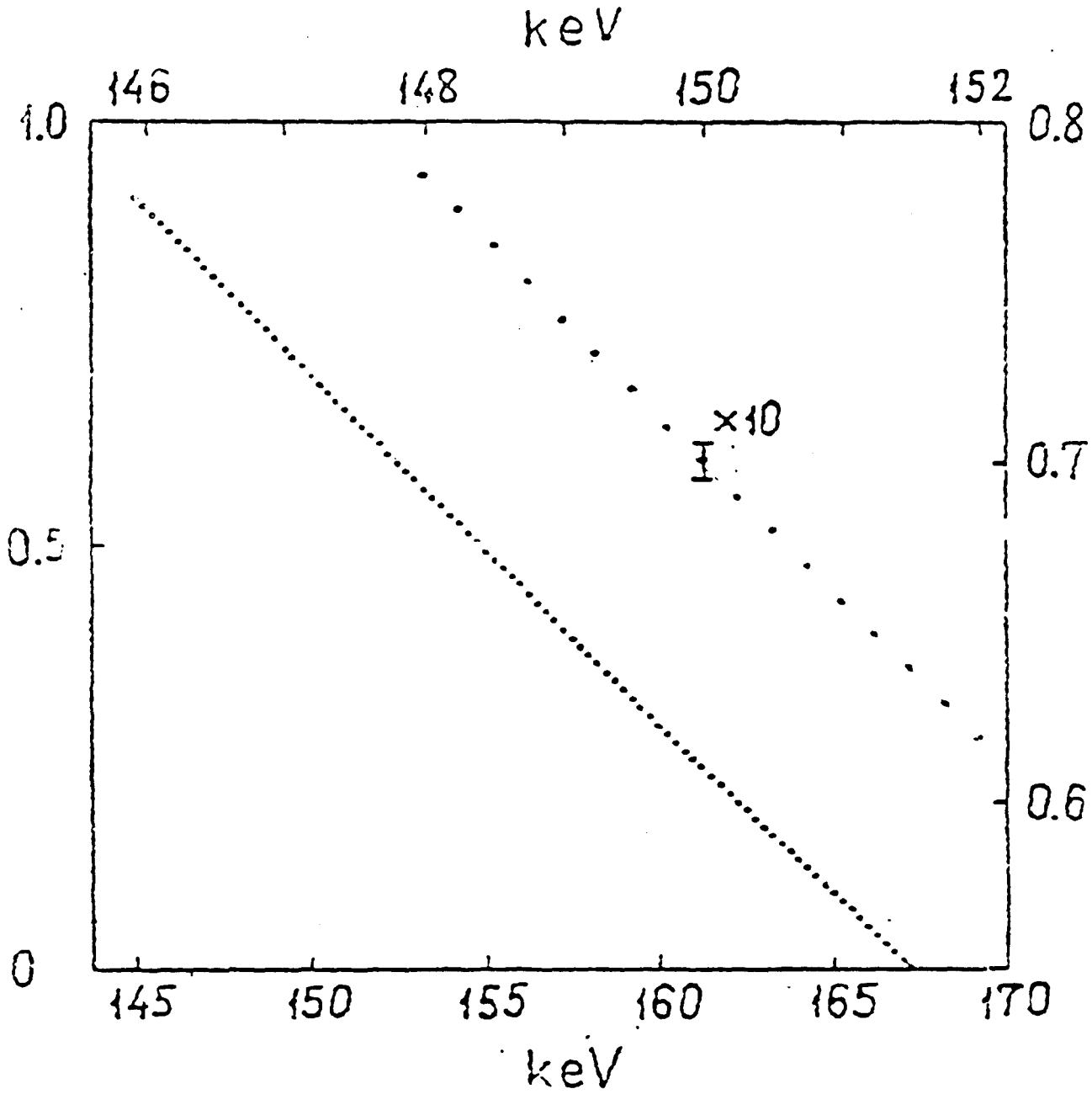

71Ge
two standard deviations confidence level
mixing ratio / %
heavy neutrino mass / keV
3
2
1
0
−1
−2
−3
10
15
20
25
30
35
40

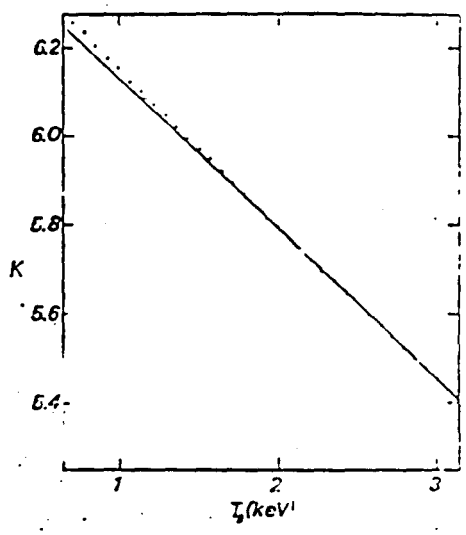
Fig. 2.

Results

		m_ν (keV)	$\sin\theta$
^{3}H	Si(Li)	17.1 ± 0.2	0.10 ± 0.01
	Ge	16.9 ± 0.1	0.10 ± 0.01
^{35}S	ext.	16.9 ± 0.4	0.082 ± 0.008
		17.2 ± 0.4	0.092 ± 0.005
^{14}C	Ge	17.0 ± 0.5	0.114 ± 0.015
^{71}Ge	IBEC	17.2 ± 0.2	0.13 ± 0.02



uric plot $K=[W_{exp}(P)/P^3F(Z,E)]^{\frac{1}{2}}$ ... corresponding the-
erimental statistics for the interval TT. The most ...


6.2
6.0
5.8
K
5.6
5.4
1
2
3
T(keV)

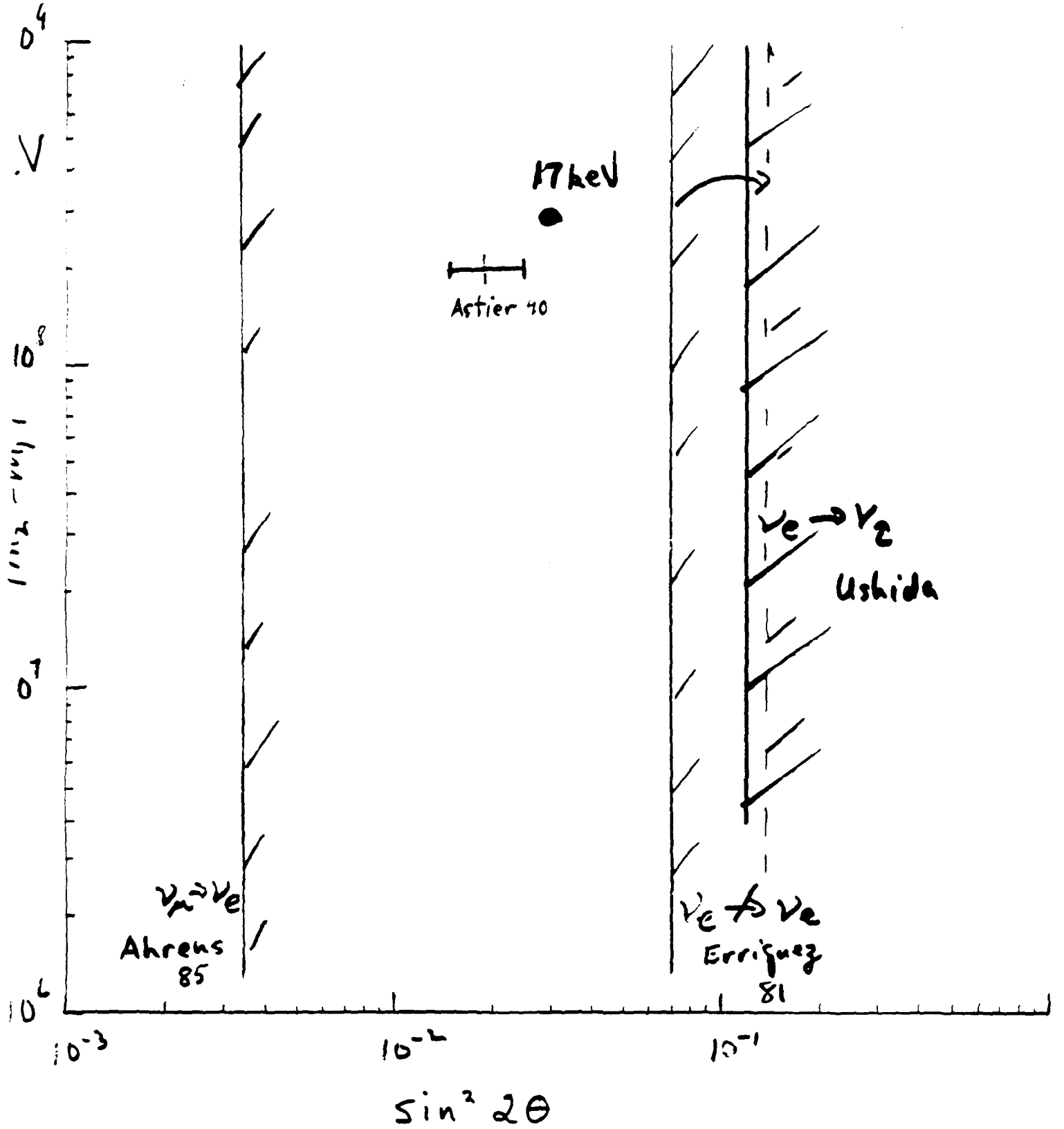
Neutrinoless Double β-decay

1) Majorana neutrino

2) $$\text{"}m_\nu\text{"} = \left| \sum_i (U_{ei})^2 m_i \right|$$

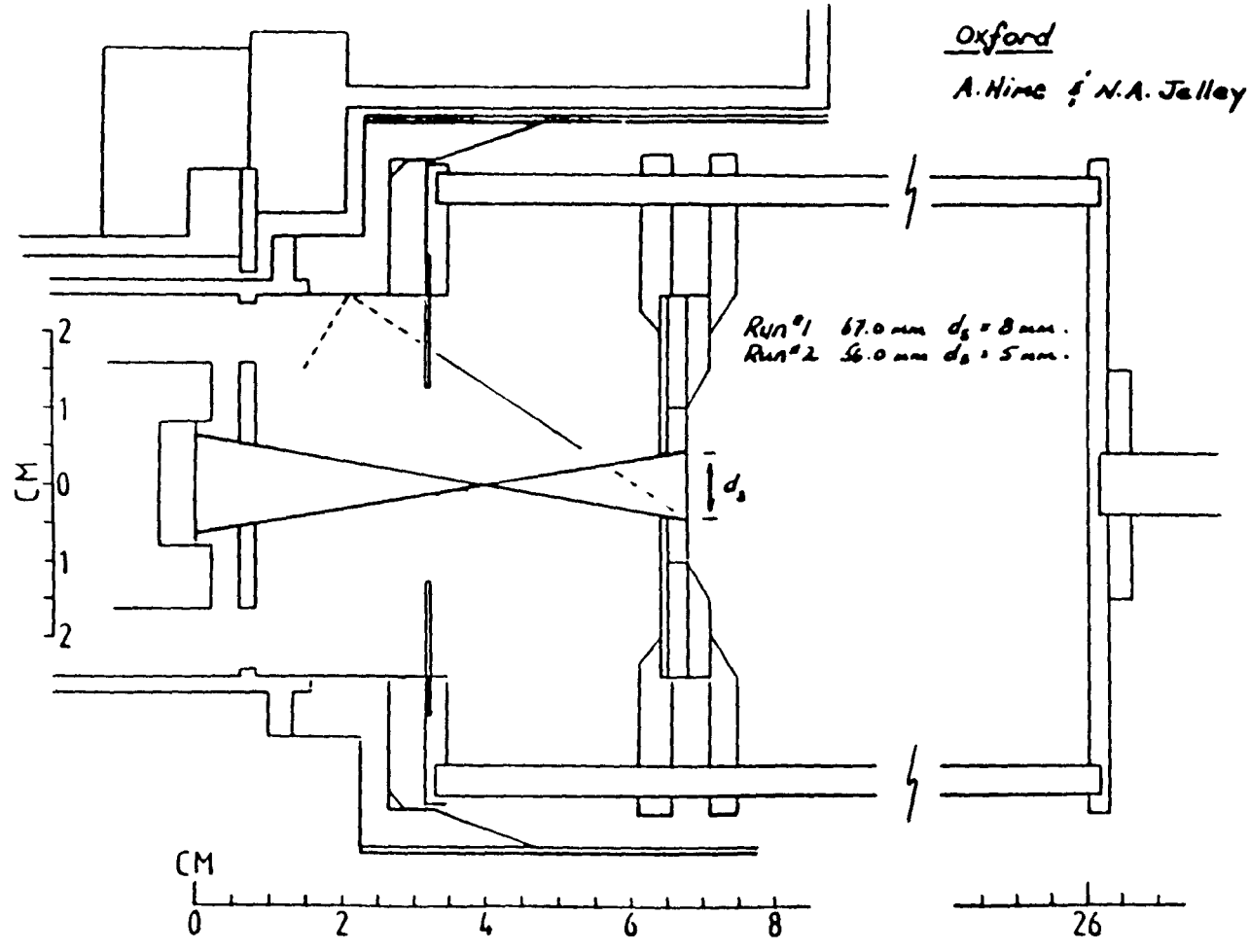
Experimental

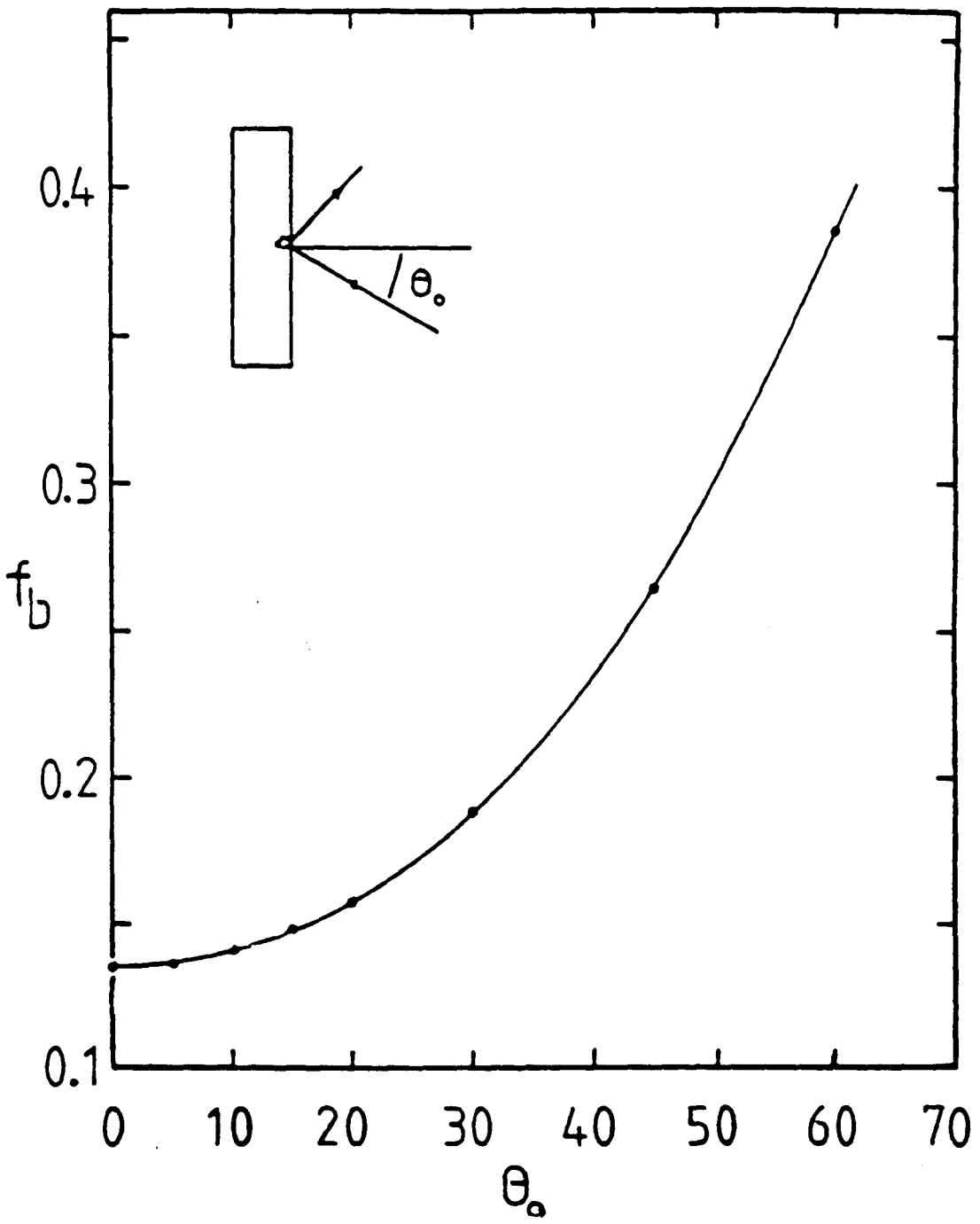
$$\text{"}m_\nu\text{"} \lesssim 1.3 \text{ eV}$$


17 keV
Astier 40
$\nu_e \to \nu_\tau$
Ushida
$\nu_\mu \to \nu_e$
Ahrens 85
$\nu_e \not\to \nu_e$
Errisuriz 81
10^{-3}
10^{-2}
10^{-1}
$\sin^2 2\theta$

Conclusions

1. Strong evidence for massive (17 keV) component of electron neutrino.
2. Mixing angle $\simeq 0.1$
3. Possibly
   - dominant component of ν_τ
   - Dirac type
4. Evidence for physics beyond the standard model.


Oxford
A. Hime & N.A. Jelley
Run #1 67.0 mm d_s = 8 mm.
Run #2 56.0 mm d_s = 5 mm.
d_s
CM
2
1
0
1
2
CM
0
2
4
6
8
26


0.4
0.3
0.2
0.1
f_b
θ_o
0
10
20
30
40
50
60
70
θ_o

Absence of the 17 keV Neutrino in the β-Spectrum of ^{35}S

- David a Imel

- Hans-Werner Becker
- Herb Henrikson
- Vladimir Novikov
- Felix Boehm

★ Many thanks to Petr Vogel

★ Supported by DOE & Caltech

I. Introduction / History

II. Apparatus

III. Data / Analysis

IV. Results / Discussion

"Subdominant ν-Admixture"

$$|\bar{\nu}_e\rangle = \cos\theta\,|\bar{\nu}_{light}\rangle + \underbrace{\sin\theta}_{u}\,|\bar{\nu}_{heavy}\rangle$$

$\Rightarrow u^2$ is mixing strength

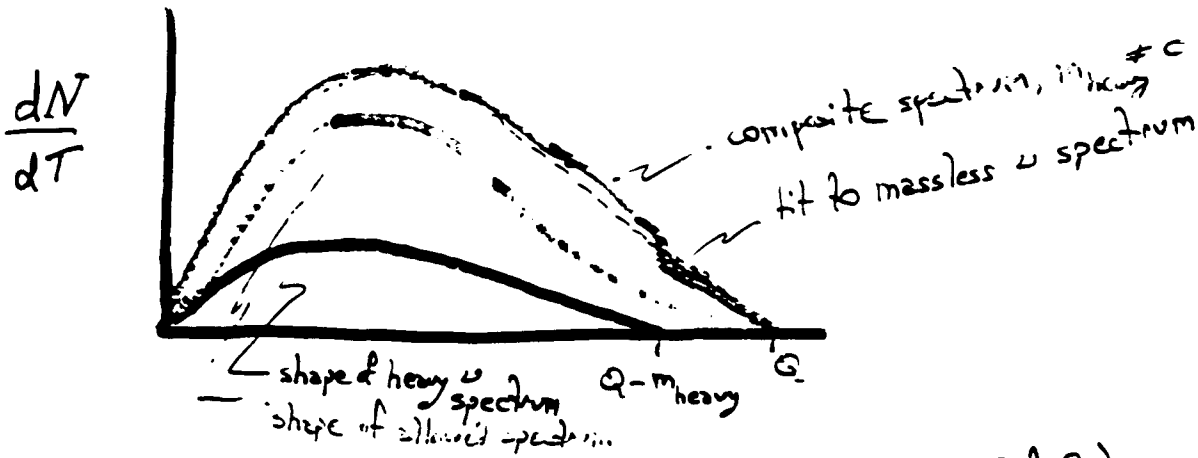
β-Decay

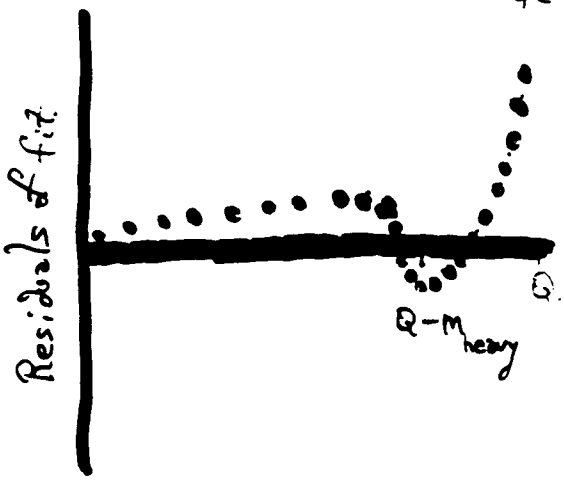
$\{$set $m_{light} \approx 0$; $m_{heavy} \neq 0$ $\}$

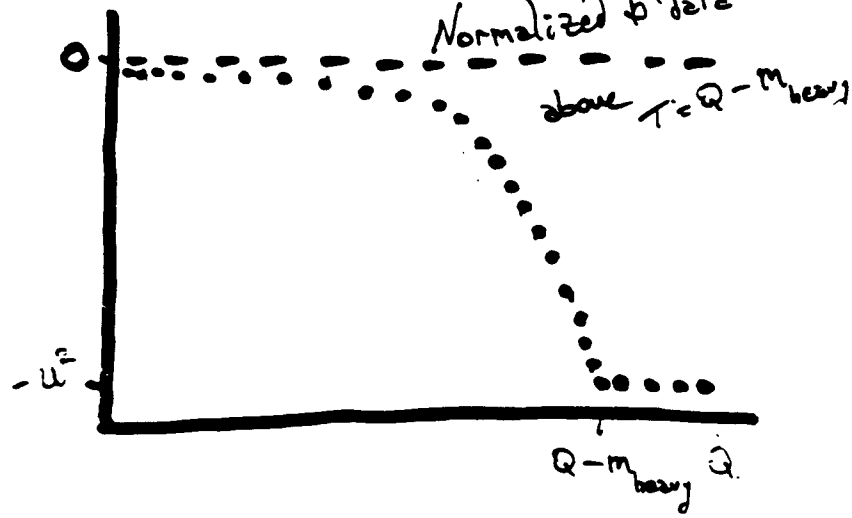
β-spectrum:

$$\frac{dN}{dT} \propto F(Z,T)\, p E (Q-T)^2 \; *$$

$$\Big[\underbrace{(1-u^2)\,\Theta[Q-T]}_{\text{"allowed shape"}} + \underbrace{u^2\left(1-\frac{m_{heavy}^2}{(Q-T)^2}\right)^{1/2}\Theta[Q-m_{heavy}-T]}_{\text{"massive neutrino shape"}}\Big]$$







History

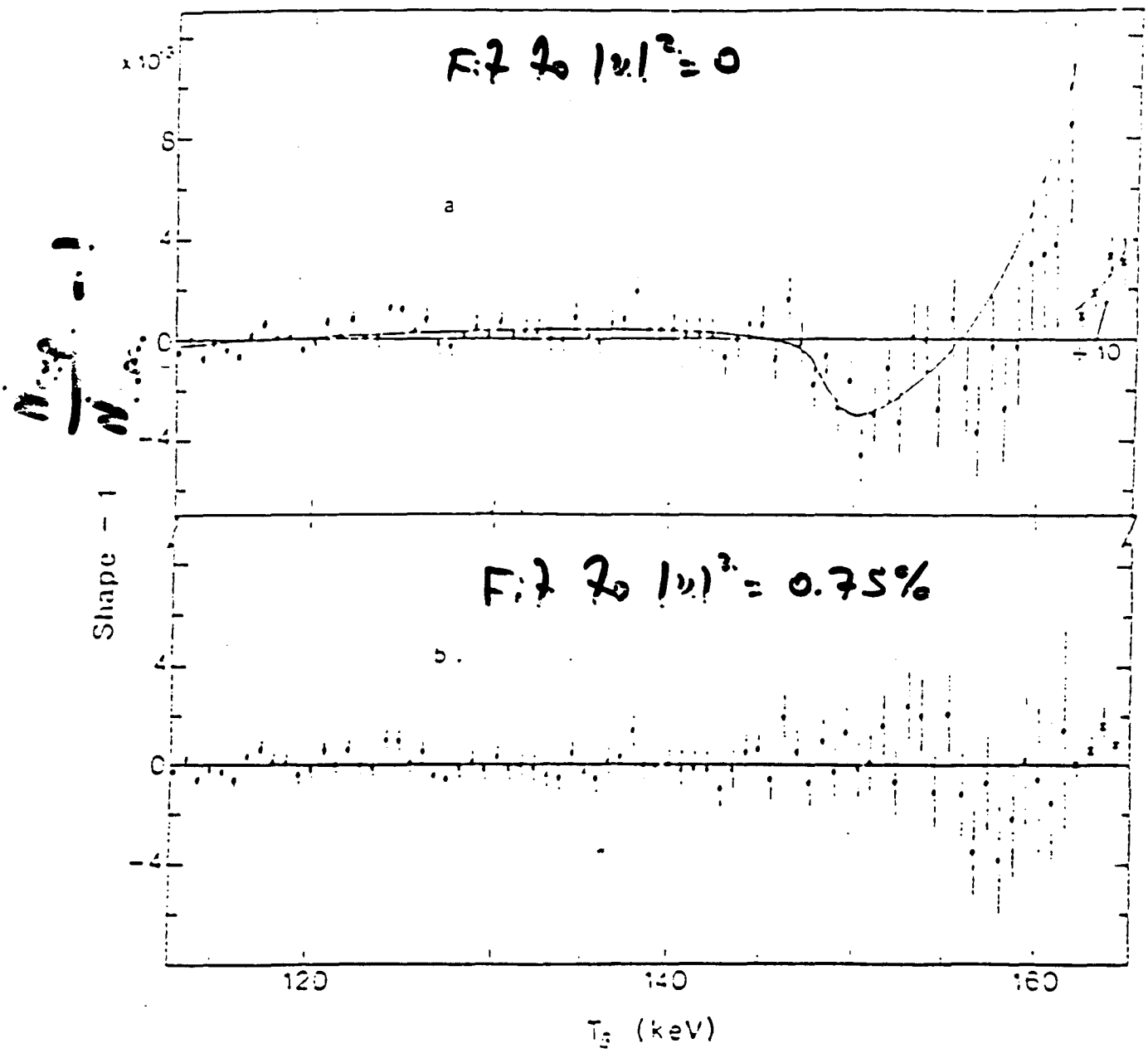
- Schreckenback (^{64}Cu); $m_3 < 30$ keV (1983)
- Simpson (^{3}H); $100\ eV \le m_3 \le 10\ keV$ (1981)
  (20%) — 4%
  (excluded)
- Simpson (^{3}H); $m_3 = 17.1$ keV (1985)
  $|u_{13}|^2 = 3\%$ (−1%)
- Simpson & Hime (^{35}S); $m_3 = 16.9 \pm 0.4$ keV (1989)
  $|u_{13}|^2 = 0.73\% \pm 0.11\%$
- Hime & Simpson (^{3}H); $m = 16.9 \pm 0.1$ keV (1989)
  $|u|^2 = 0.6\% - 1.6\%$
- Datar (1985) $|u|^2 < 0.6\%$ (90% c.l.) ^{35}S
- Ohi (1985) $< 0.15\%$
- Altsitzoglou (1985) $< 0.4\%$
- Apollonio (1985) $< 0.17\%$
- Markey (1985) $< 0.3\%$
- Hetherington (1985) $< 0.44\%$ ^{63}Ni

1 April 1989, PRD (^{35}S)

Simpson:

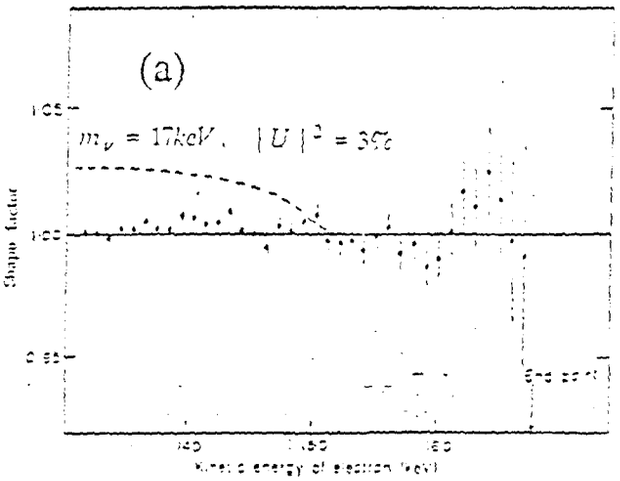
$m_{\nu_H} = 17$ keV

$|U|^2 = 0.73\%$



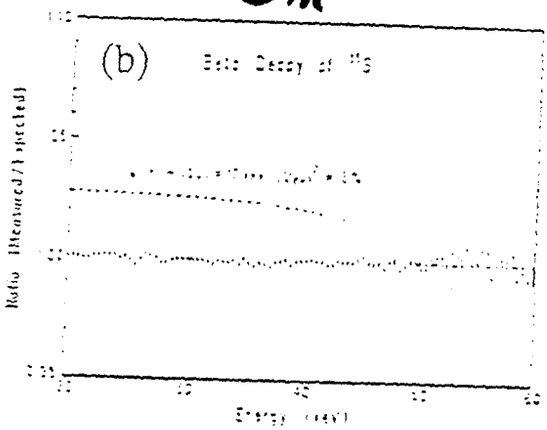
^{35}S Null Results

Datar



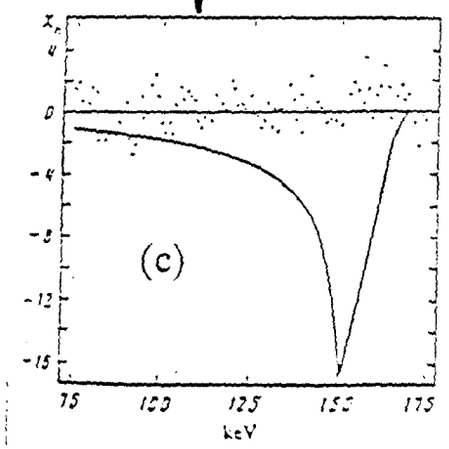
Fit, kink

Ohi



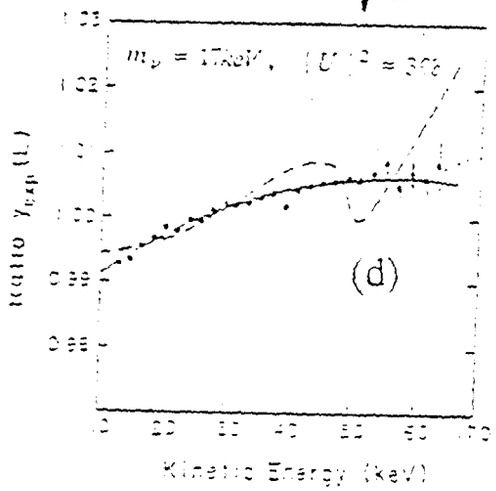
Fit

Apalikov

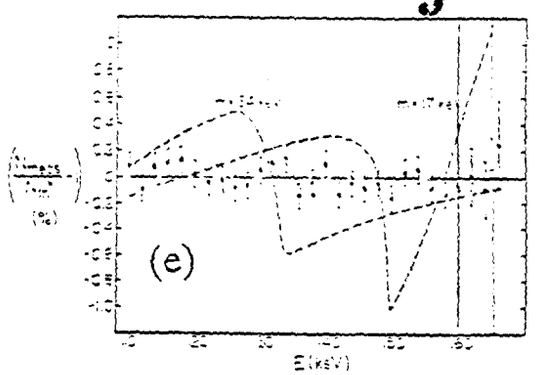


shape

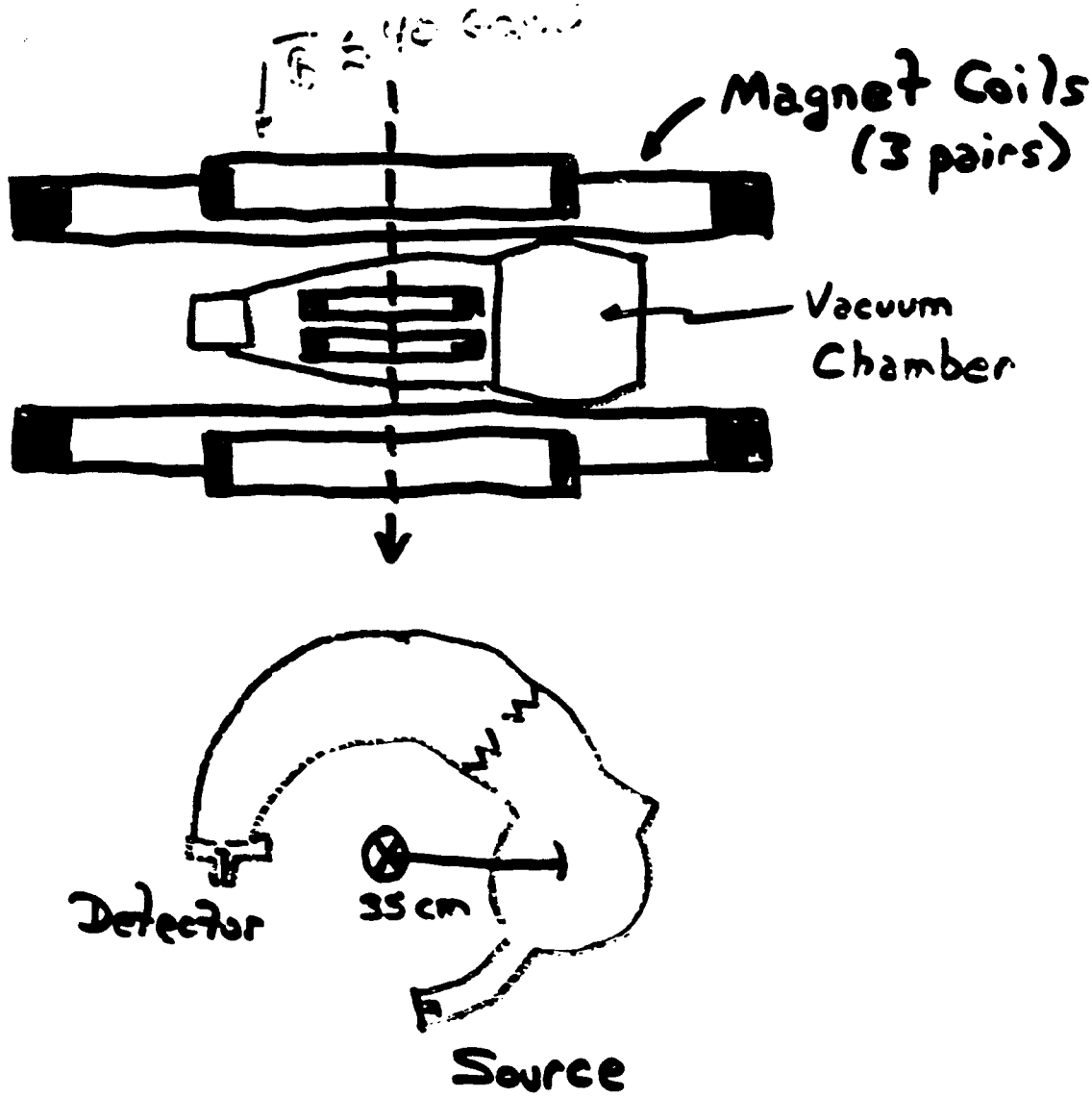
Altzitzoglou shape



Markey scattering



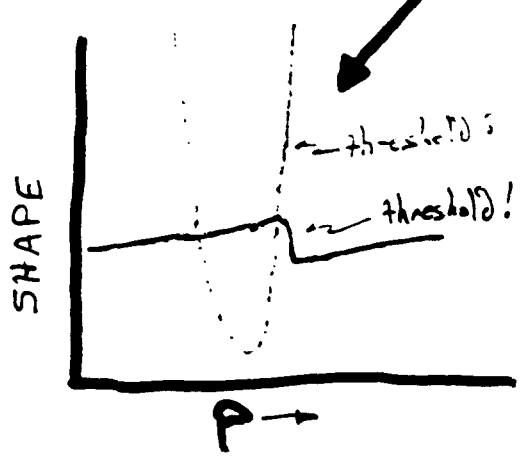
Caltech $\sqrt{2}\,\pi$ Iron-Free Double-Focusing β-Spectrometer

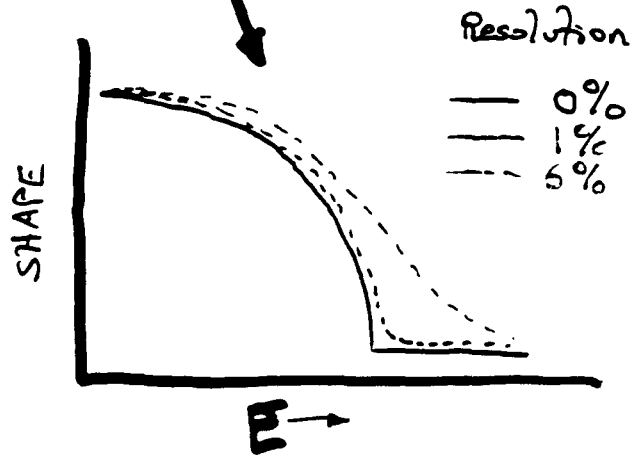


- $\frac{\Delta p}{p} \simeq 0.27\%$
- ~ 2-3 mCi ^{35}S $\{Q = 167\ \text{keV},\ \tau_{1/2} = 87.4\ \text{d}\}$
- Surface-Barrier Detector {cooled to 5°C, $\frac{\Delta E}{E} \simeq 4.7$ keV}

Experimental Considerations

- **Source**
  - allowed shape, one branch
  - $\tau_{1/2}$ & specific activity : $\sim 10^6 \frac{\text{counts}}{\text{keV}} \Rightarrow \sim 10\sigma$ for $\sim 1\% = (u)^2$
  - thickness, backing, metallization, stability, alignment
- **Detector**
  - energy resolution
  - stability
  - beam tests, alignment
- **Spectrometer**
  - momentum resolution vs. transmission
  - magnetic field stability {temperature, hysteresis, current}
  - response function / calibration / scattering
  - instrumental shape factor



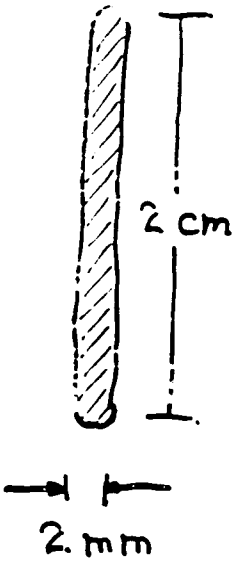


Source Preparation

- stretch thin (0.9 μm) Mylar backing foil across Aluminum holder & glue in place
- Aluminize foil (to prevent charging) {layer thickness < 20 μg/cm²}
- Vacuum evaporate source onto foil (through mask)

1) $^{57}Co\,Cl_2$ w/ Mo boat (~ 20 μCi)

2) $(NH_4)_2\,^{35}SO_4$ w/ W boat (~ 2 mCi)



⇒ very uniform source

⇒ no "high-Z" carrier atom

⇒ low efficiency (~3%) for deposition

<u>^{35}S</u>

< 2 μg/cm² thickness

⇒ < 5 eV energy loss in source

65543
CALTECH
65543
CALTECH

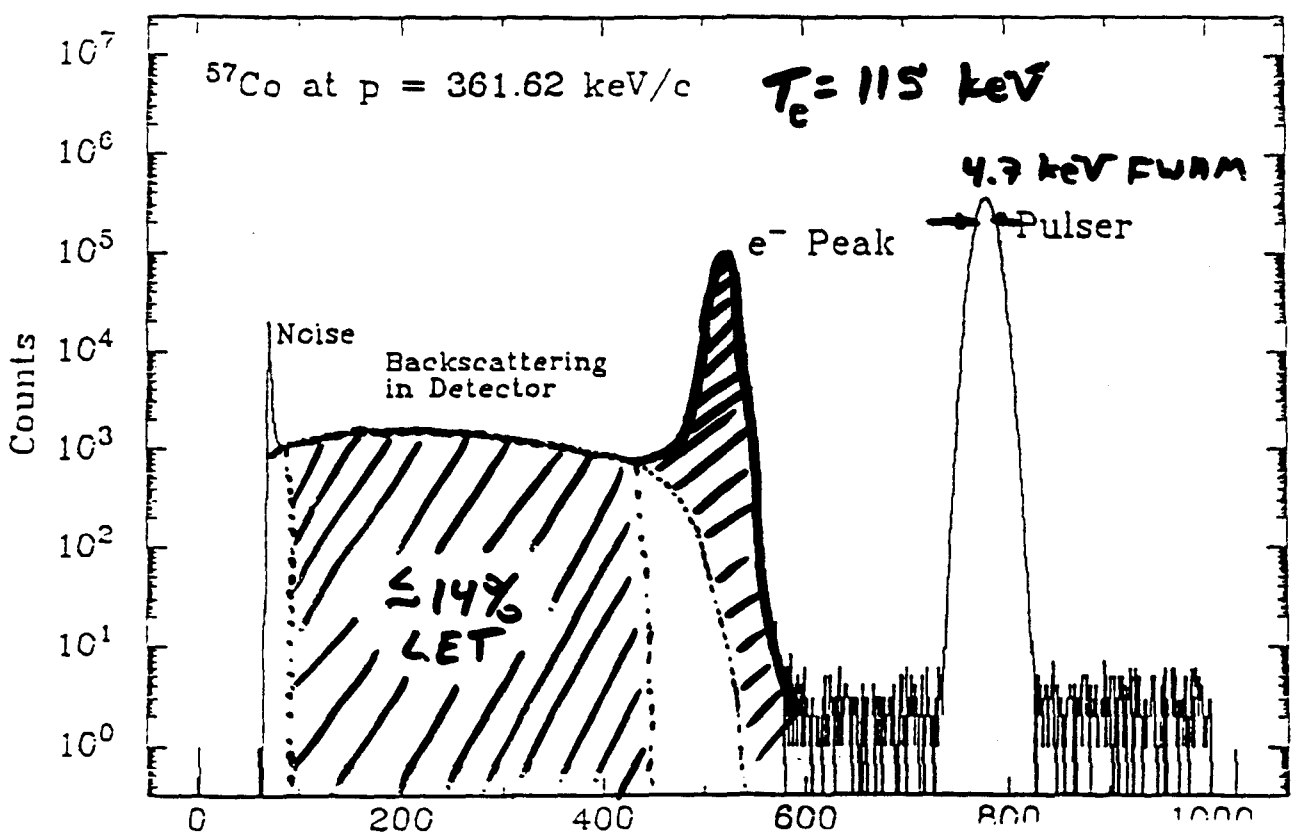
Detector

→ Surface Barrier Detector
300 μm thick
4×25 mm active area

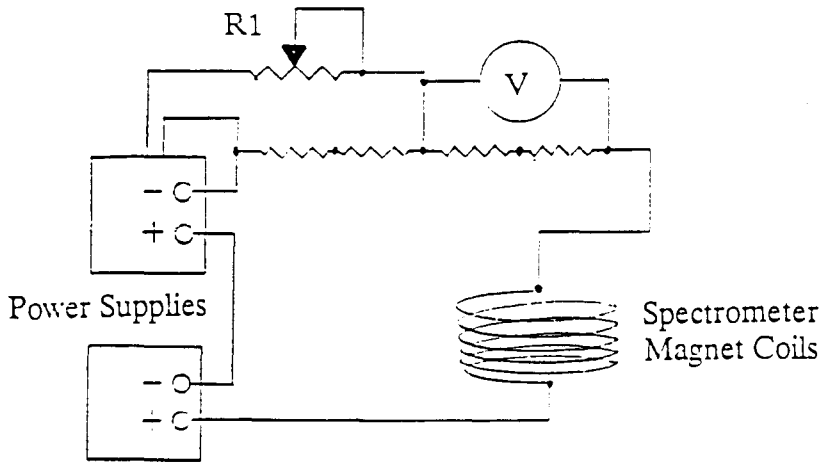
→ Peltier-Element cooling (5°C)
(no cryopumping)

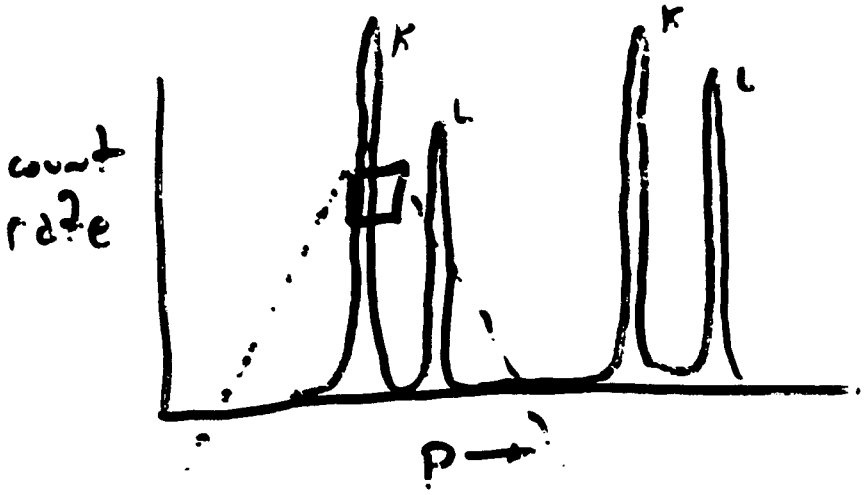
→ Precision pulser monitors dead time, electronic stability

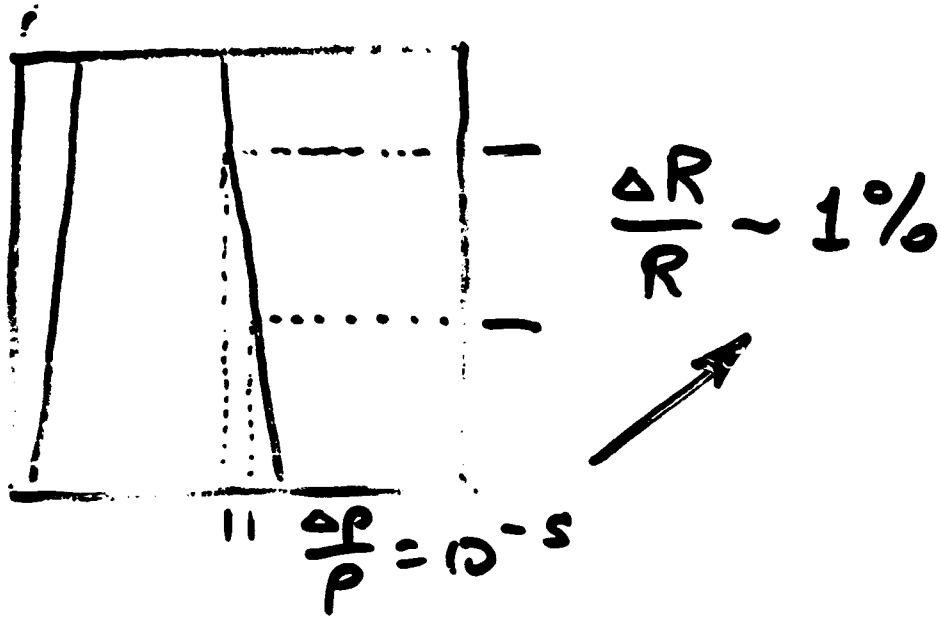
→ monitored detector current

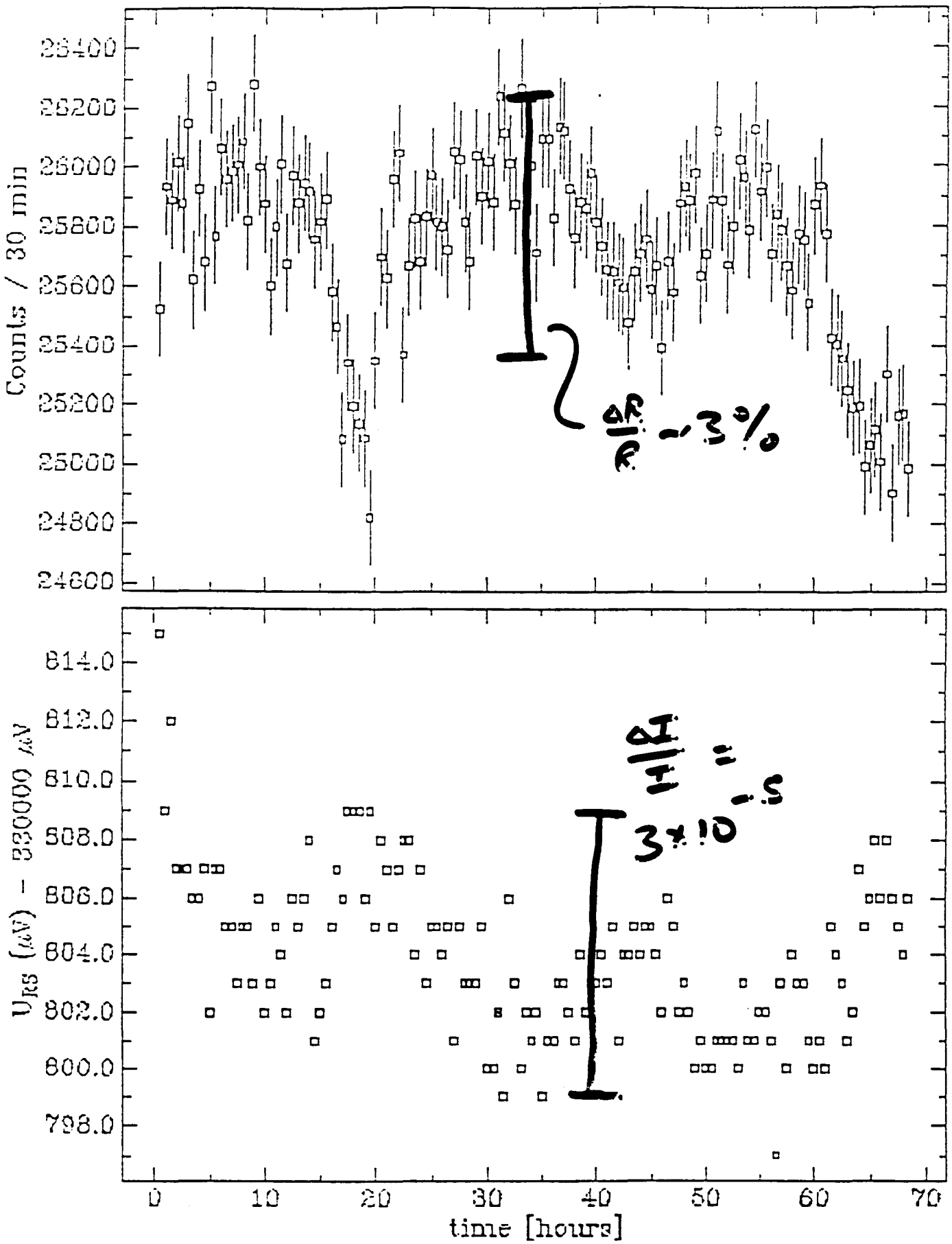


Stability


R1
V
Power Supplies
Spectrometer
Magnet Coils

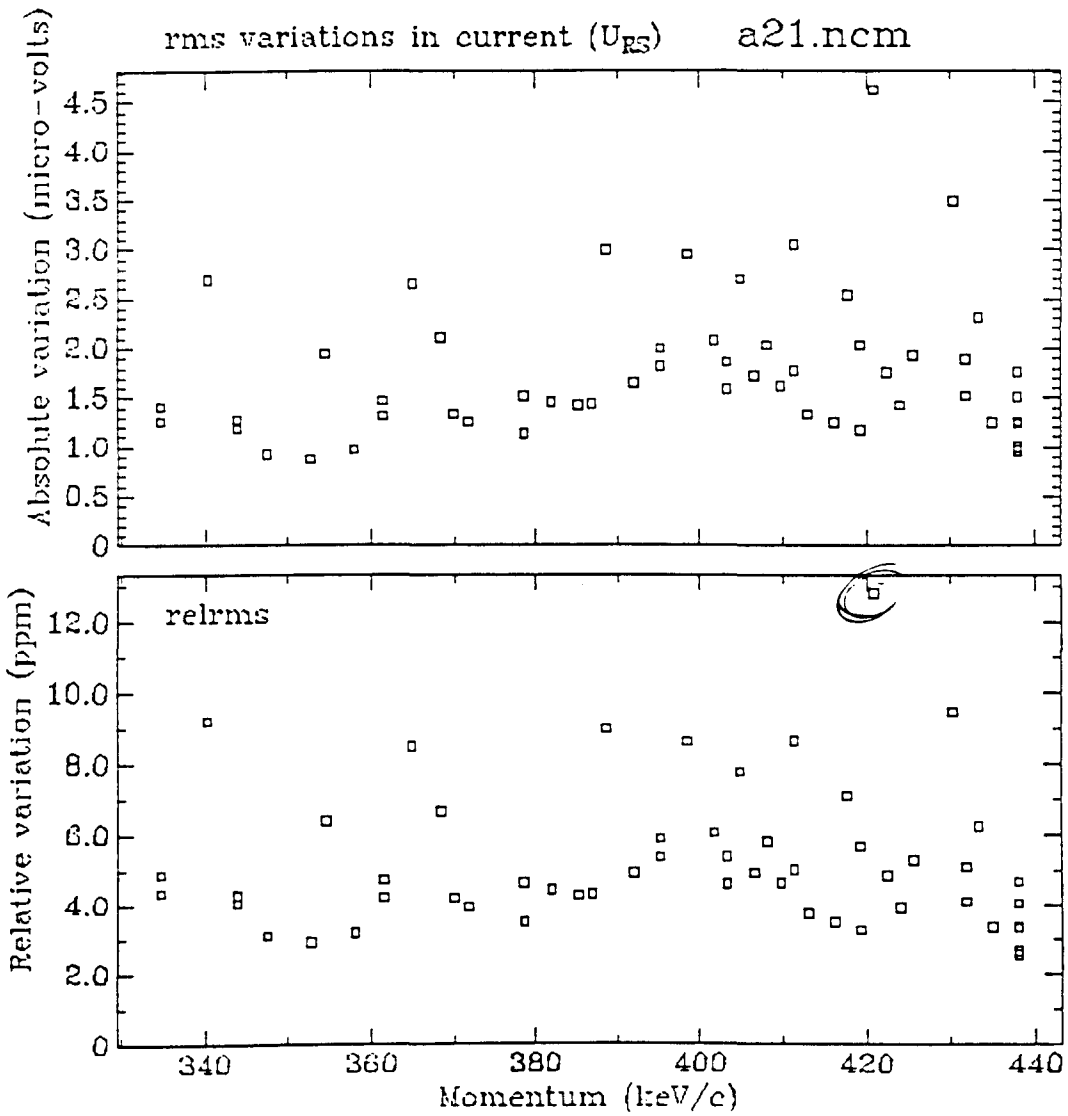

count
rate
K
L
K
L
p


$\frac{\Delta R}{R} \sim 1\%$
$\frac{\Delta p}{p} = 10^{-5}$


Counts / 30 min
26400
26200
26000
25800
25600
25400
25200
25000
24800
24600
$\frac{\Delta R}{R} \sim 3\%$
U_{RS} (μV) − 330000 μV
814.0
812.0
810.0
808.0
806.0
804.0
802.0
800.0
798.0
$\frac{\Delta I}{I} = 3 \times 10^{-5}$
0
10
20
30
40
50
60
70
time [hours]

Magnet Current Stability

R.M.S. Variations < 13 ppm always
~ 5 ppm typically



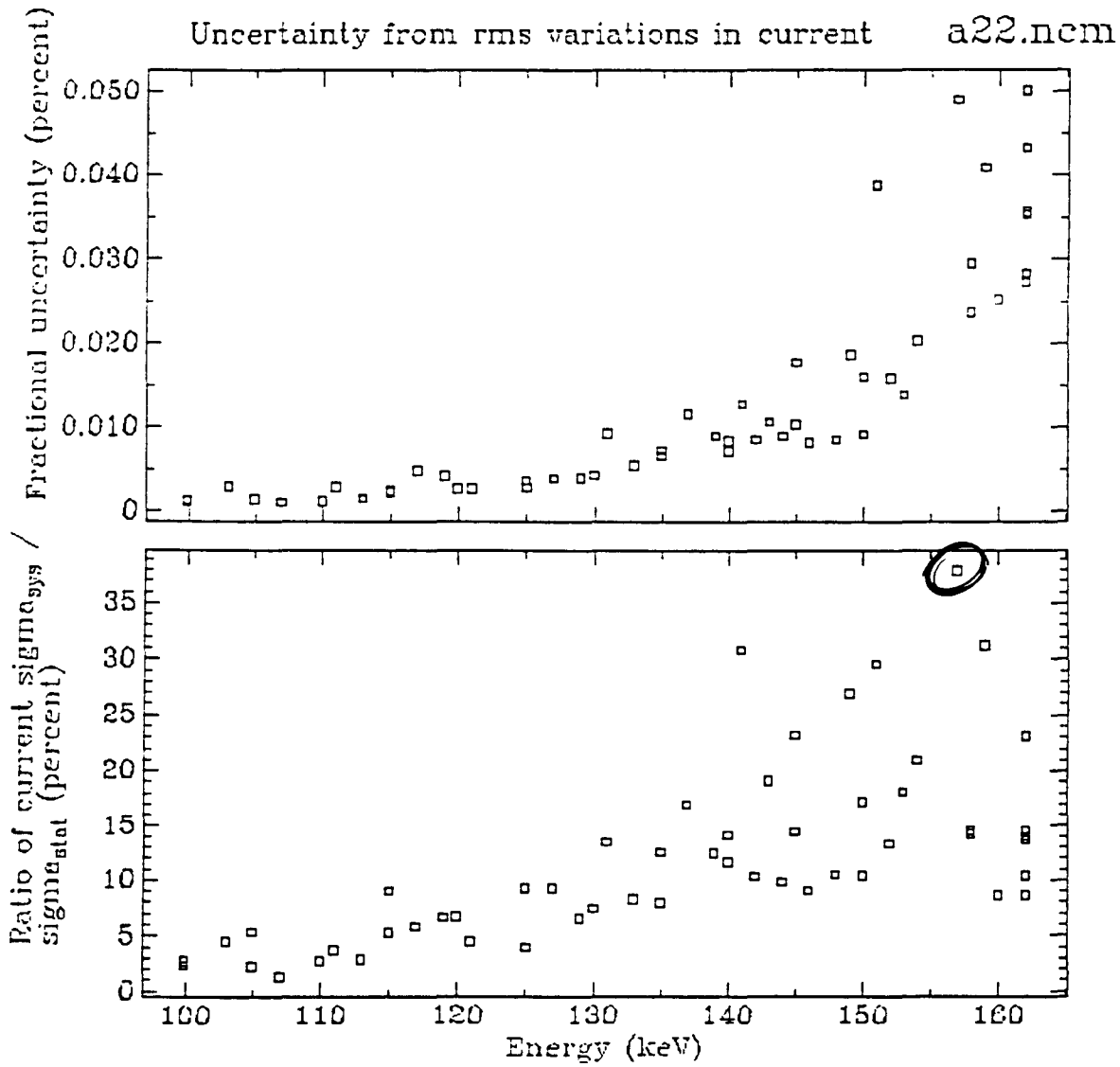
Uncertainty due to Magnet Current Instability

From β-spectrum: $\frac{dR'}{R'} = \frac{dp}{p} \cdot (1 + \alpha)$

$$\alpha \equiv 2\left[1 - \frac{1 - m^2/E^2}{E_0/E - 1}\right]$$

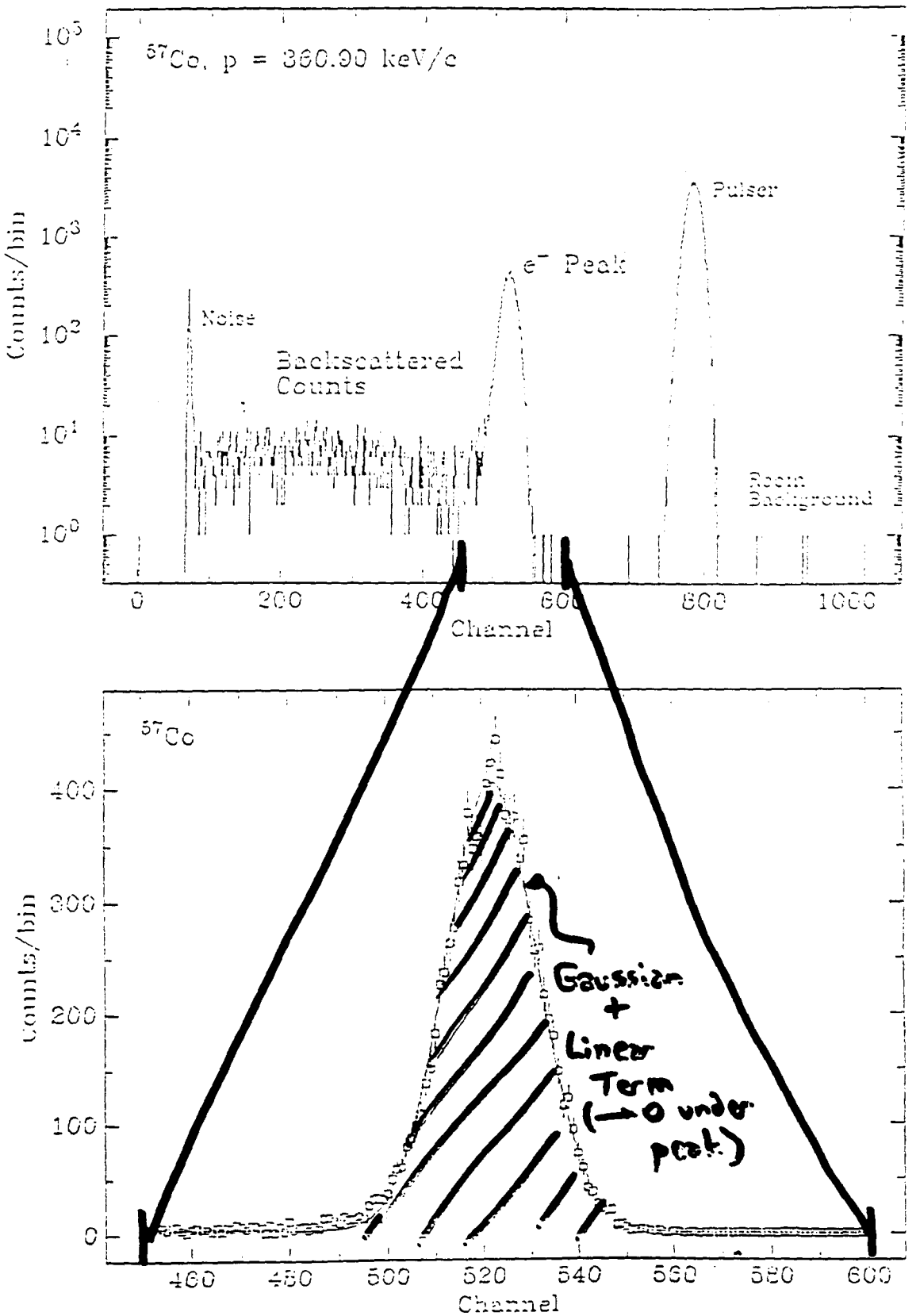
for $E_0 = 166$ keV:

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

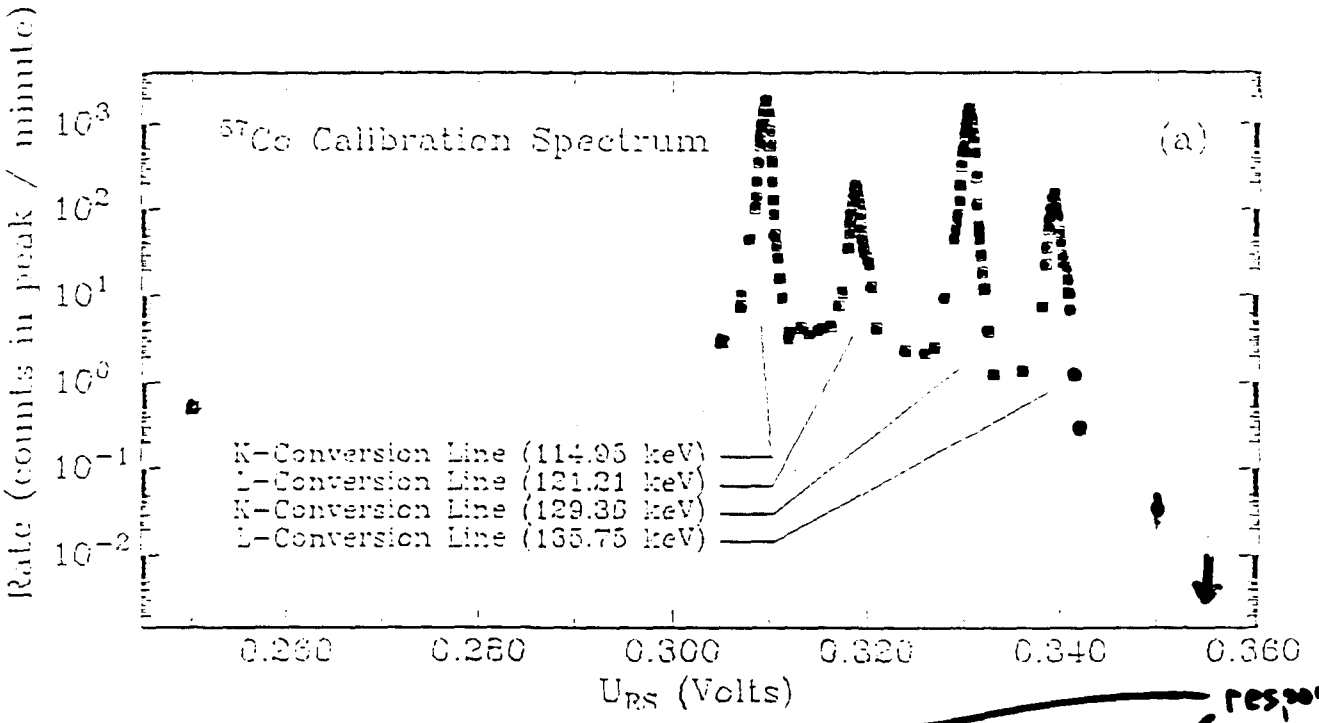


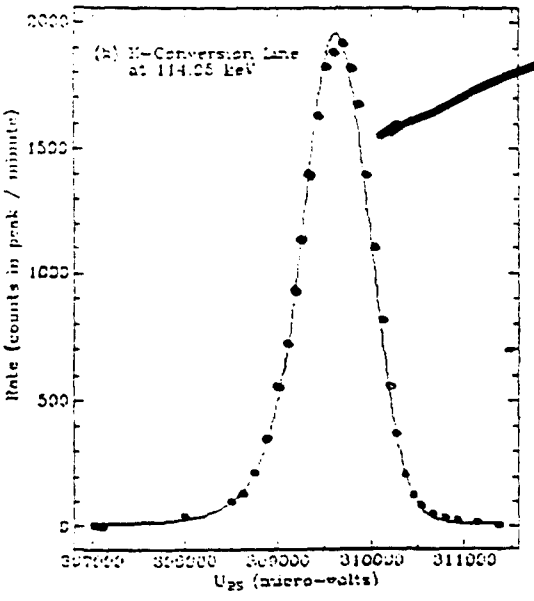
$\Rightarrow$ Maximum Uncertainty in Count Rate is 33% of Statistical Uncertainty

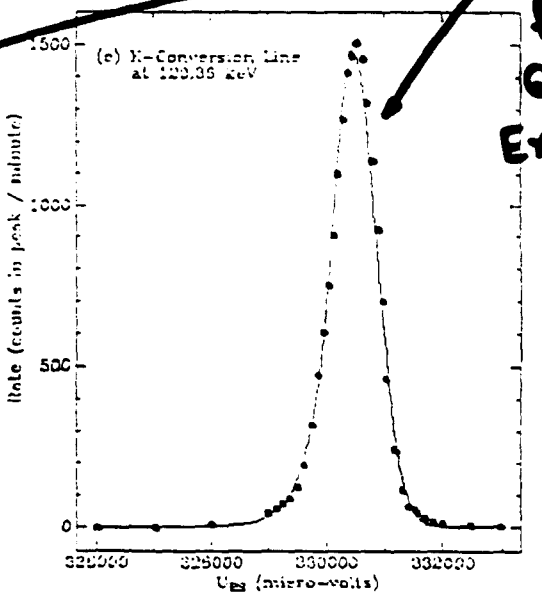
Calibration – 139 points



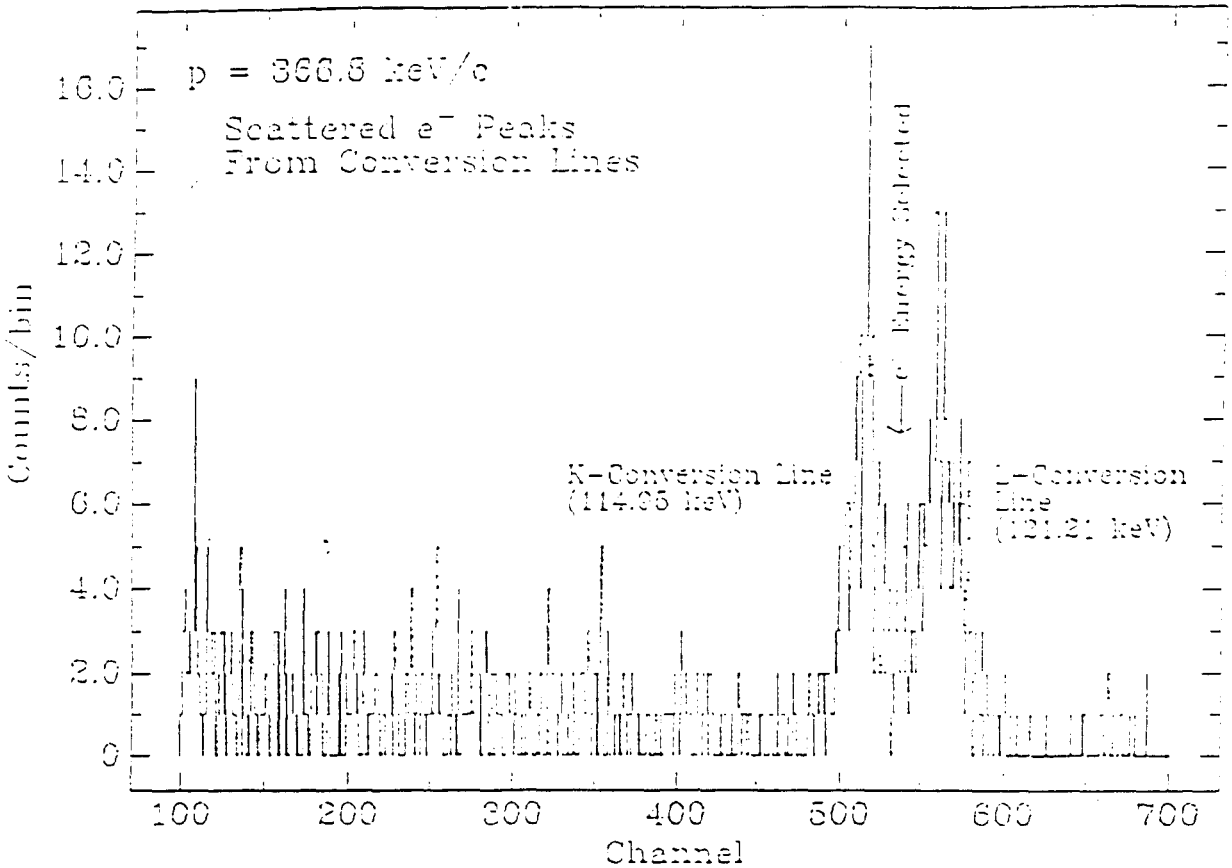
Calibration & Response Function

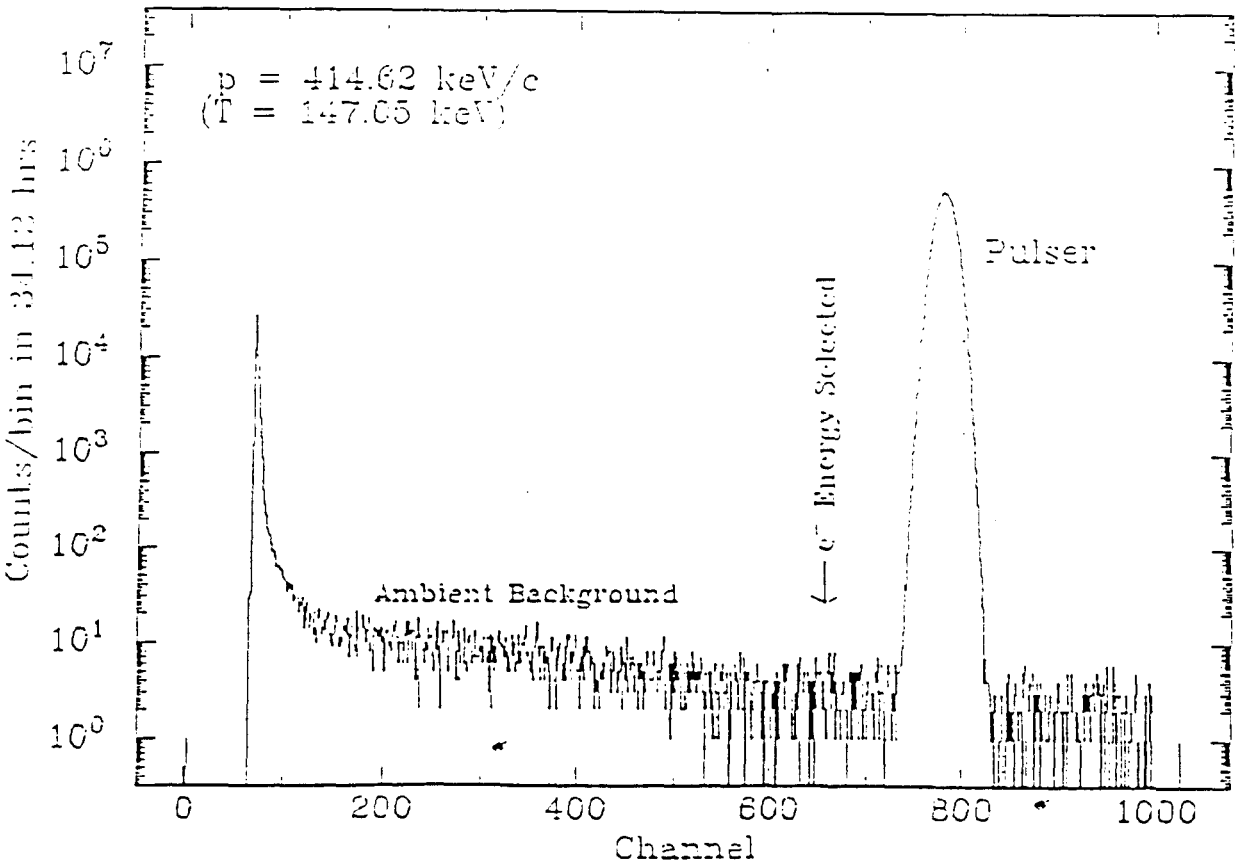






response fn: Gaussian + Exponential Tail


p = 366.8 keV/c
Scattered e⁻ Peaks
From Conversion Lines
K-Conversion Line
(114.05 keV)
L-Conversion
Line
(121.21 keV)
e⁻ Energy Selected
Counts/bin
Channel


p = 414.62 keV/c
(T = 147.05 keV)
Pulser
e⁻ Energy Selected
Ambient Background
Counts/bin in 34.12 hrs
Channel

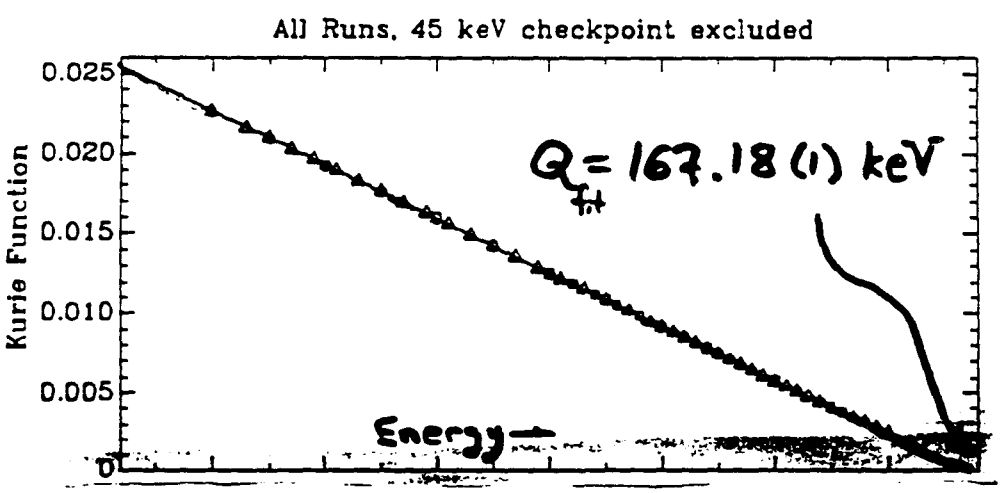
Data — Kurie Plot

$$\frac{dN}{dE} \propto f_p E (Q - T_e)^2$$

$$\Rightarrow K \equiv \left[\frac{dN/dE}{f_p E}\right]^{1/2} \propto Q - T_e$$

Run A: low precision
Run B: "main" data run
Run C: Auxiliary low-energy run

} 85 momentum points @ ~ 10^6 counts/point



Analysis

→ Corrections

- Integrate (full) e^- peak for each detector spectrum to get rate at each momentum

  - correct for live-time
  - Low-Energy Tail (LET)
  - Background

  } "Smooth" Corrections

- Correct for Decay of the source / source Pos

  "Non-smooth correction"

- Deal with "Non-Statistical" scattering of Data ⇒ "external unc"

→ Fit

- Choose theoretical β-spectrum with $m_{heavy} = 17$ keV and some value for α (Include Fermi correction & radiative corrections.)
- Convolute with measured response function of spectrometer
- Compare to Data with χ^2-distribution — normalized to 1 in physical region of parameter space

  (Allow Normalization to vary in the fit.)

  ⇓

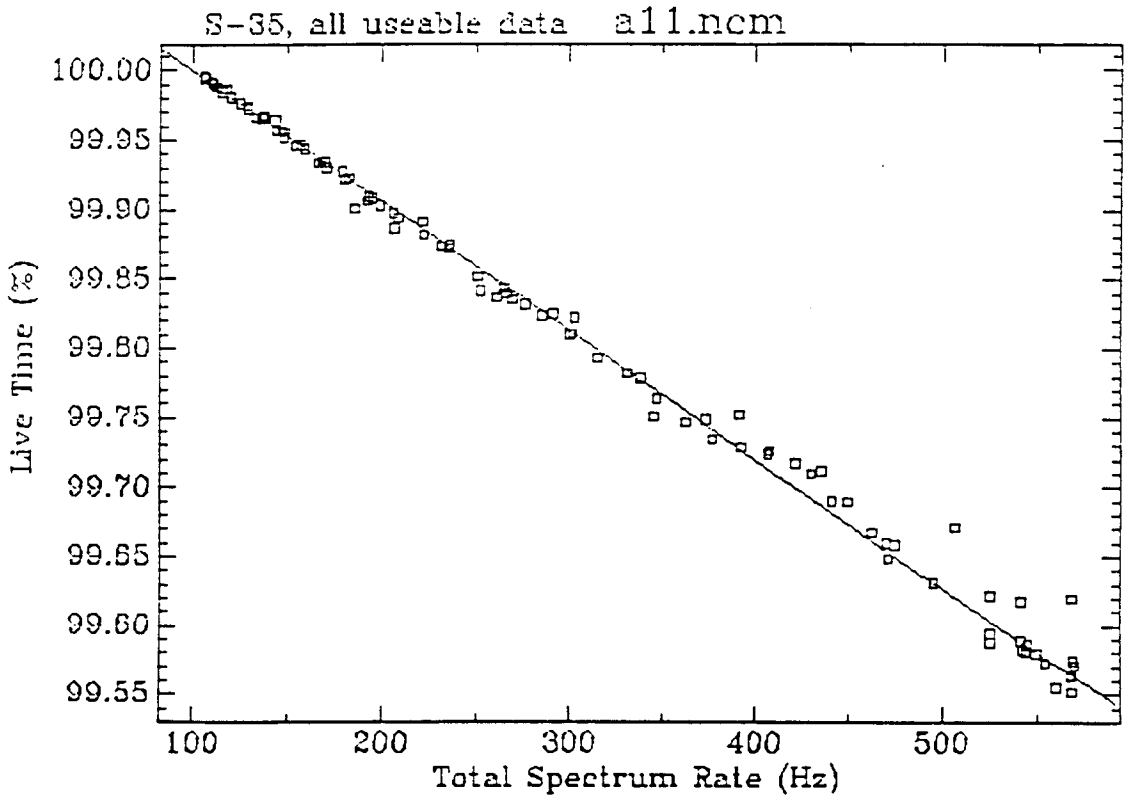
  quadratic instrumental shape

  ⇓

  4 parameters

Live Time Correction

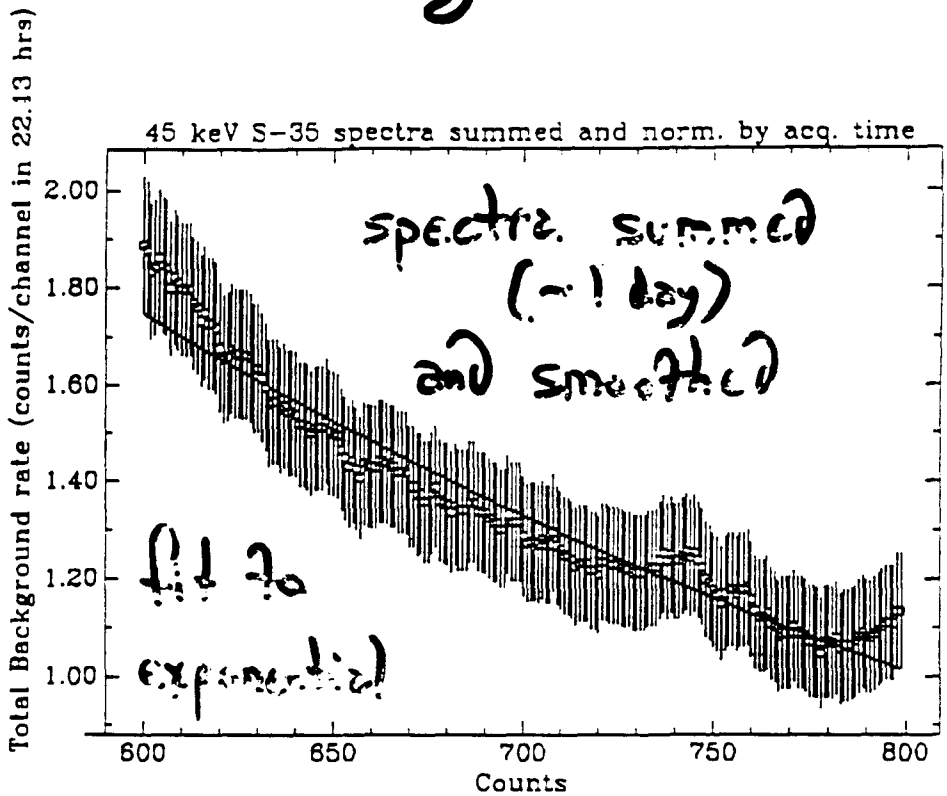
(from pulser/monitor)



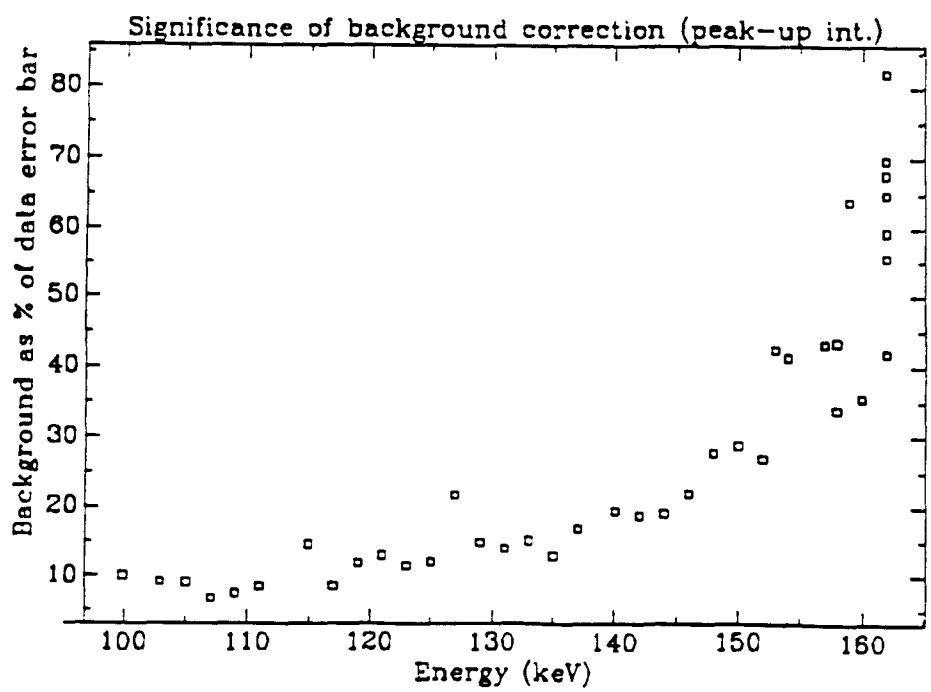
⇒ [illegible]

[illegible]

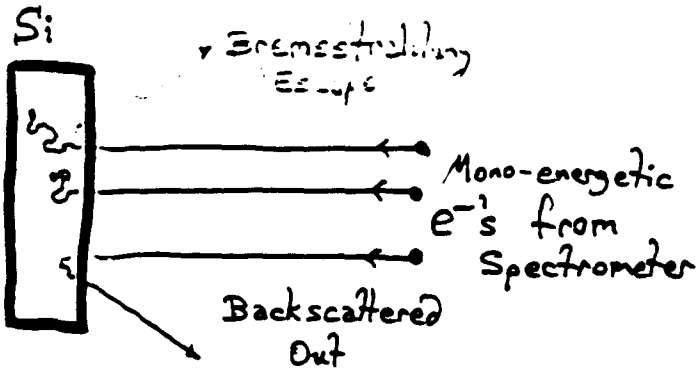
Background Subtraction

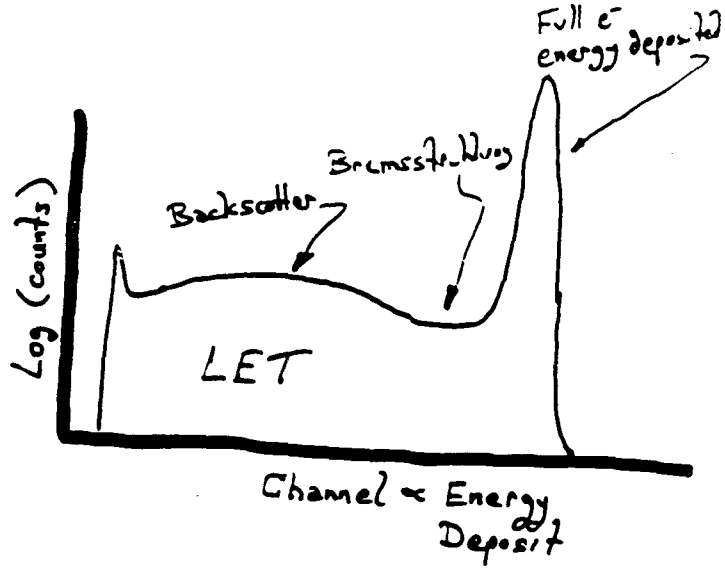


→ less than 1% correction



Low Energy Tail (LET)





LET: Shape & Magnitude vs. Energy

• Damkjaer, NIM 200 '82 p. 377.

$$T(\varepsilon) = \underbrace{A\,\frac{\sin[\beta(1-\varepsilon)\pi]}{1+\sigma e^{-\varepsilon/\alpha}}}_{\text{Backscattering}} + \underbrace{E\,\frac{\varepsilon}{1-\varepsilon+e^{(\varepsilon-1)/\beta}}}_{\text{Bremsstrahlung}}$$

(where $\varepsilon \equiv E/E_0$; E_0 incident energy
$A, E, \alpha, \beta, \sigma$ empirical constants
(functions of E_0 only))

⟹ Agrees with Tabata, et al., and Planskoy

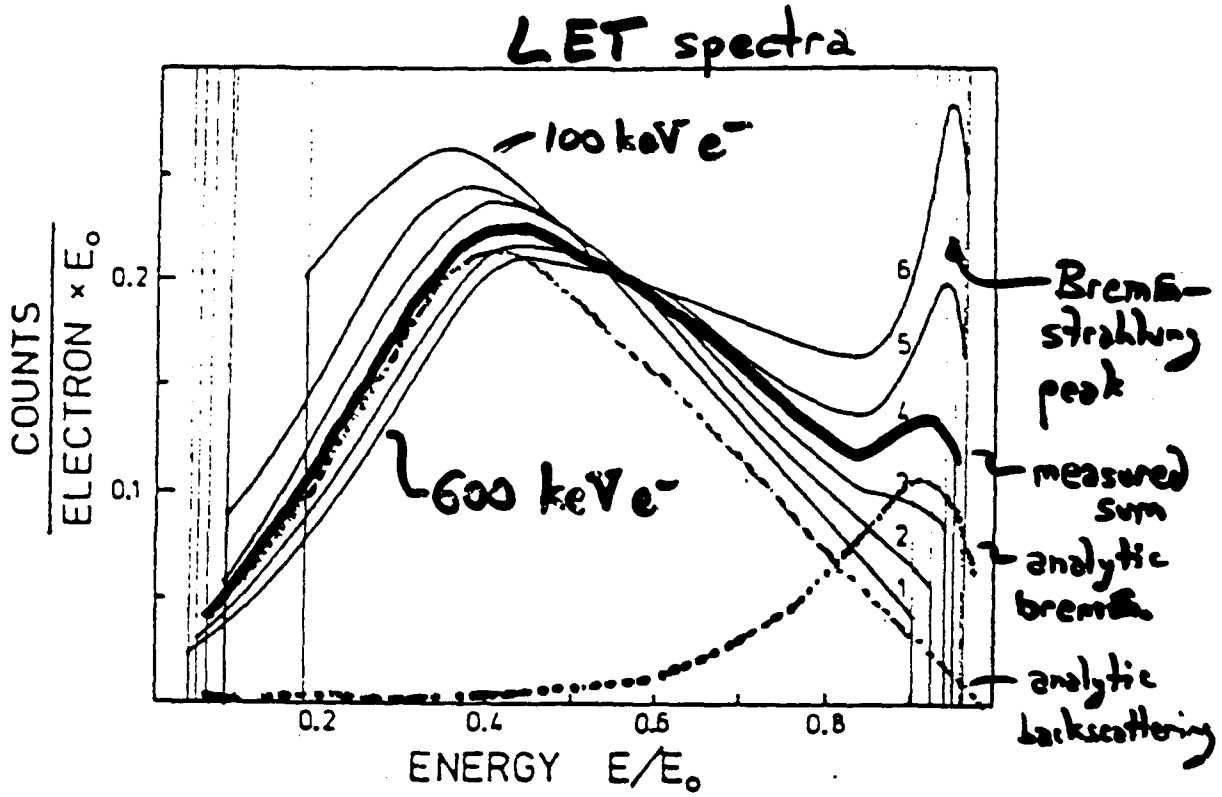
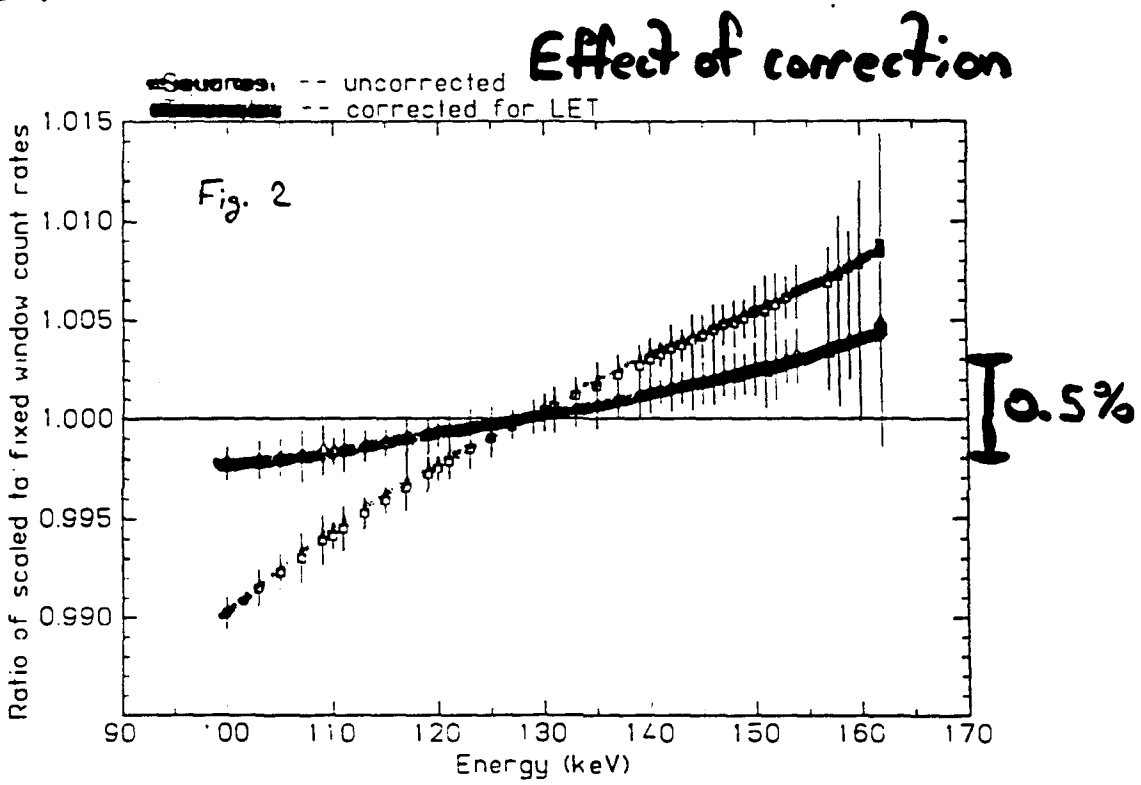


Fig. 1. Measured low-energy tails. The spectra are smoothed and the background and the full-energy peak are subtracted. The numbers 1 to 6 refer to the primary energies 100 to 600 keV.



Source Strength Correction

<u>Decay</u> $\{\tau_{1/2} = 87.4$ days, Table of Isotopes$\}$

→ Some evaporation of source into vacuum system —
Must determine $\tau_{1/2}^{effective}$ from data:

1) Measure at single point for ~ 24 hours:
→ ~80 ± 7 days

2) "Iso-momentum" pairs of data points, widely separated in time.
→ 85 ± 1 days

3) Fit to β-spectrum for both Simpsino & $\chi^2 = 0\%$
→ 85 ± 0.5 days

→ $\boxed{\tau_{1/2}^{effective} = 85 \text{ days}}$

<u>Fluctuations</u> {evaporation process not constant}

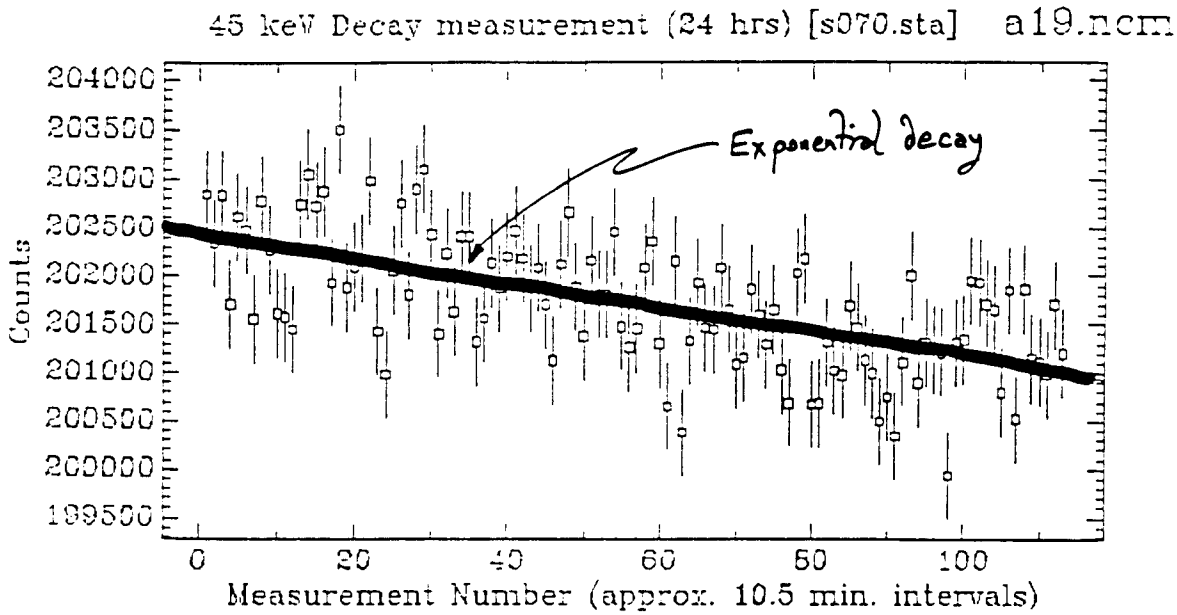
- "Non-Statistical Scattering" especially at low energies

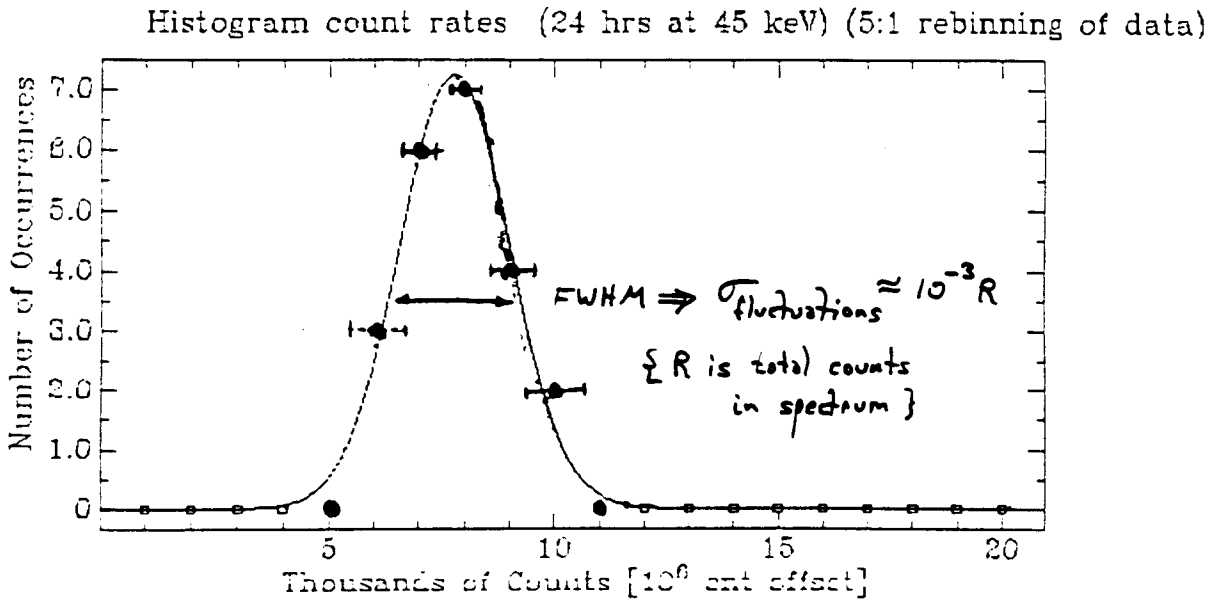
→ Measure uncertainty due to source strength variations -- add in quadrature to statistical uncertainty:

$$\sigma_{TOT} = \sqrt{\sigma^2_{statistical} + \sigma^2_{fluctuations}}$$

$$\Rightarrow \boxed{\sigma_{fluctuations} \simeq 10^{-3}(\text{count rate}) \simeq \sigma_{statistical}}$$

Fluctuations in Source Strength





$$\sigma_{fluctuations} \simeq \sigma_{statistical}$$

Result

$u^2 = 0\%$: $\chi^2/DOF = 83.7/81$ $\Rightarrow$ 40% likely

$Q = 167.35$ keV

$k_1 = +9.9 \times 10^{-4}\ (keV/c)^{-1}$

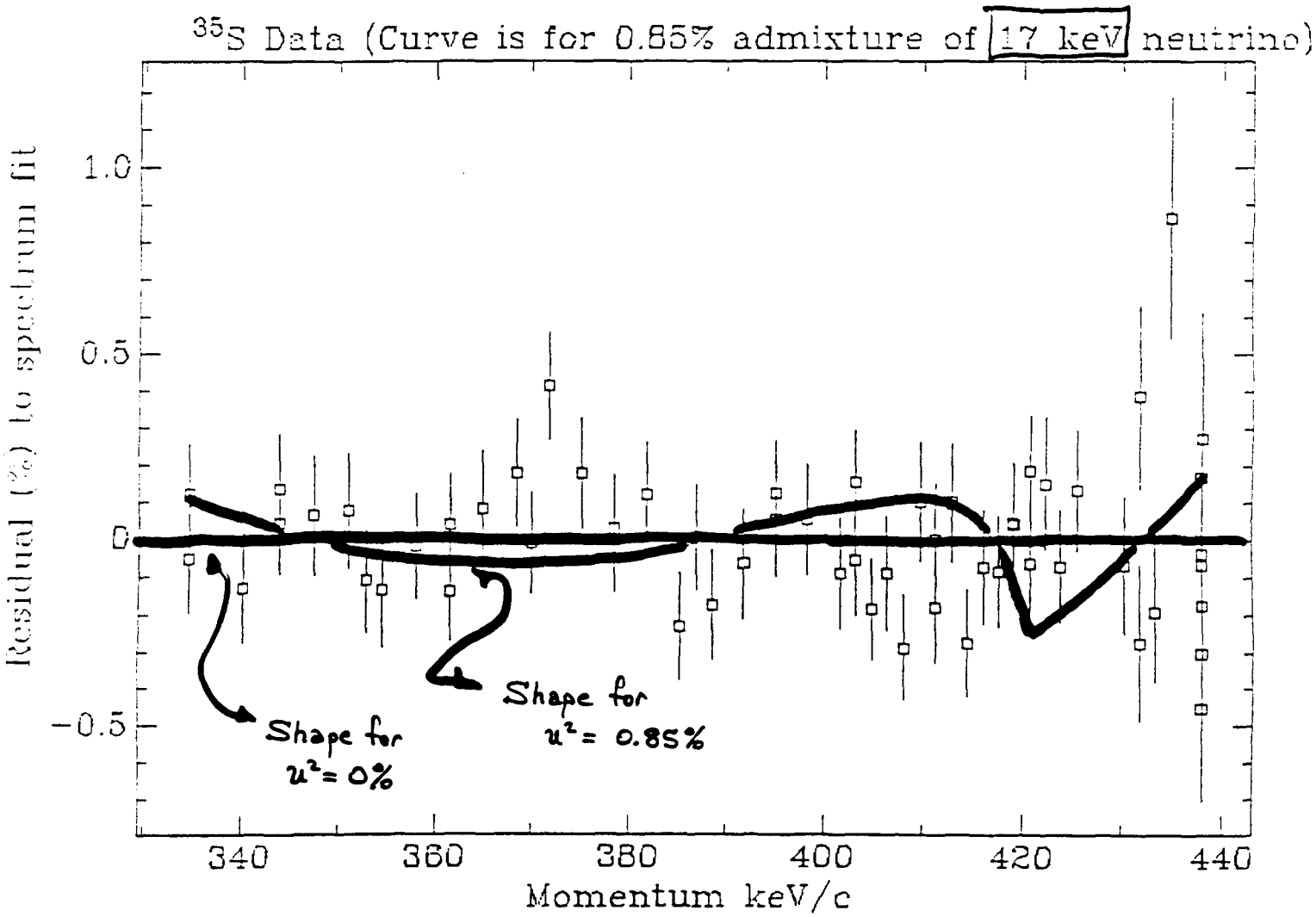
$k_2 = -3.8 \times 10^{-6}\ (keV/c)^{-2}$

$u^2 = 0.85\%$: $\chi^2/DOF = 124/81$ $\Rightarrow$ 0.14% likely

$Q = 167.34$ keV

$k_1 = +6.3 \times 10^{-4}\ (keV/c)^{-1}$

$k_2 = -1.7 \times 10^{-6}\ (keV/c)^{-2}$



[illegible]

[illegible]

p is momentum

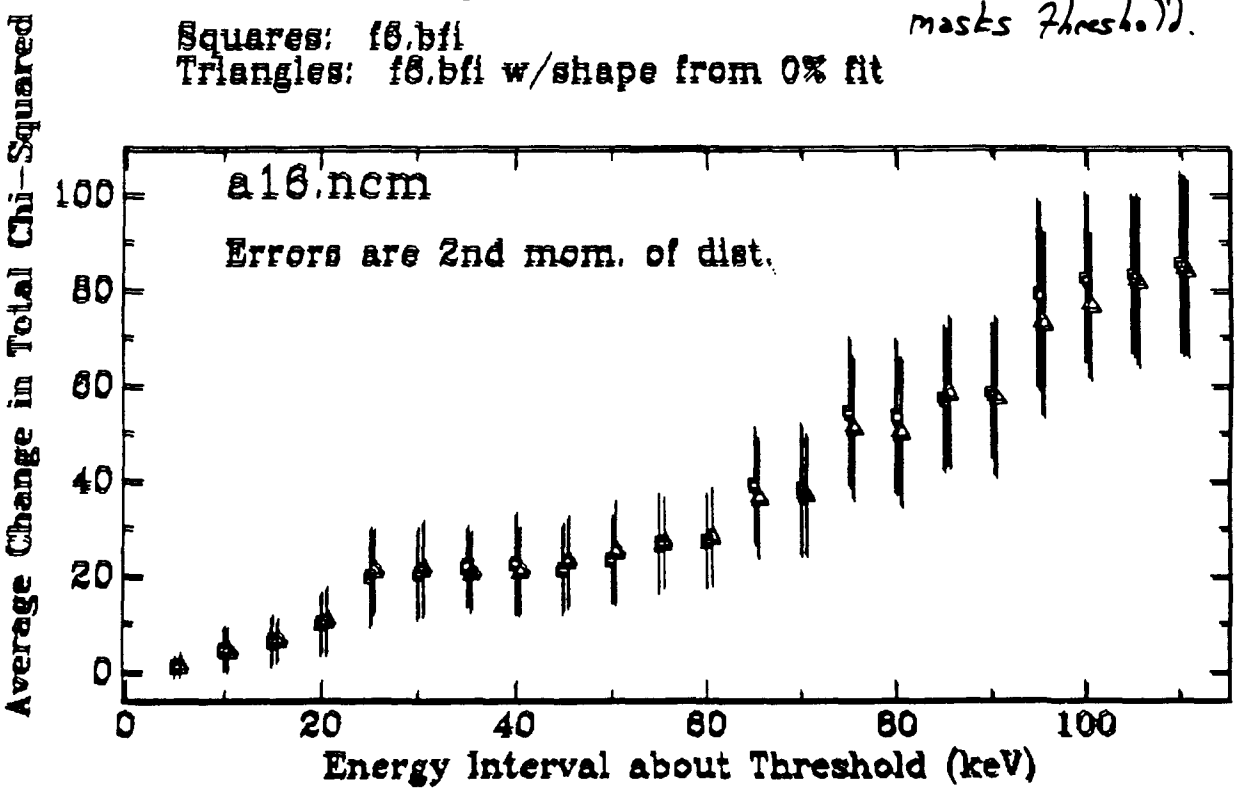
q is [illegible] in keV/c [illegible]

Shape Factor

Does Shape Factor Mask a Threshold ??

Monte-Carlo Effect of Shape Factor:

1) Generate "synthetic datasets" with statistics (error bars / mom. points) of experimental data; with Simpsino spectrum parameters.
2) Fit to both $u^2 = 0\%$ & $u^2 = 0.85\%$ $\Rightarrow$ $\Delta\chi^2$; repeat n times $(n \gg 1)$ $\Rightarrow$ histogram $\Delta\chi^2$; gives "sensitivity" to threshold.
3) Repeat steps (1) & (2) with shape factor in synthetic data $\Rightarrow$ If "sensitivity" $(\langle\Delta\chi^2\rangle)$ decreases, shape factor masks threshold.



$\Rightarrow$ Sensitivity not affected by shape factor in experimental data. $\Rightarrow$ No!

(~ 2-3% variation over 60 keV compared to $\lesssim 1\%$ variation over narrow energy range.)

Conclusion

"We find no evidence for a 17 keV neutrino."

Specifically, for $m_{\nu_{17}} = 17$ keV,

$$u^2 \leq 0.85\% \quad (99.6\% \text{ Confidence Level})$$

Other limits on the mixing strength:

$u^2 \leq 0.4\%$ (90% CL)
$u^2 \leq 0.12\%$ (95% CL)

This agrees with recent semi-conductor detector expt's.
Agrees with all magnetic spectrometer expt's.

- Further work in progress:
  especially in source-strength monitor.
  to reduce major systematic uncertainty
  in the measurement.

PROGRAM

Second Annual SSC Spring Conference
Electroweak and Flavor Physics: Implications for the SSC
Monday, May 20 - Thursday, May 23

Tuesday, May 21

AM	**K-decays**	Chair: M. Perl (SLAC)
9:00	ε'/ε - Fermilab	B. Winstein (Chicago)
9:40	Results from NA31 at CERN and Future Plans	H. Wahl (CERN)
	Break	
10:50	Rare K - decays (BNL)	M. Schmidt (Yale)
11:30	Physics Program at the Frascati Phi-Factory	P. Franzini (Columbia)
PM	**Future Prospects(non SSC)**	Chair: H. Kasha (Yale)
2:00	Tau-Charm Factory: Physics and Construction Plans	M. Perl (SLAC)
	Bottom Quark Physics	
2:40	B-Physics and CP Violation from Lattice QCD	G. Martinelli (Rome)
	Break	
3:50	Physics of the B-Factory	S. Stone (Syracuse)
4:30	Argus & CLEO Results	H. Schroeder (DESY)
5:10	Photoproduction of Heavy Flavors	J. Cumalat (Colorado)
8:00	Banquet	

SSC Spring Conference
May '91

KAON PHYSICS AT FNAL

B. Winstein
Univ. of Chicago

What we are doing

E731 analysis
Detector upgrades

What we are going to do

'91 run:
CFT test
rare decays

What we would like to do

'94 run:
rare decays
ε'/ε
'95 →
Main Injector K secondary

FNAL KAON PHYSICS

E731 proposed (1983) to measure ε'/ε to $\pm 10 \times 10^{-4}$ precision from 1% em calor

(1 6mo. run)

20% data analysis:

ε'/ε to ± 15 (consistent with zero)

$\phi_{00} - \phi_{+-}$ to $\pm 3^\circ$

plus other results arising from the "open geometry":

$K_L \to \pi^0 e^+ e^-$ < [illegible] $\times 10^{-9}$

$K_L \to \pi^0 \gamma\gamma$ (limit; observation)

100% analysis this summer:

ε'/ε to $\pm 6-7$

$\Delta\phi$ to $\pm \sim 1.5^\circ$

Ke_4 study

$K_{L,S} \to \pi^+\pi^-\gamma$ (rates; interference

$K_L \to 3\pi^0$ decay parameter

τ_S

$K_L \to \pi^+\pi^-\pi^0\gamma$

$K_L \to \pi^0 \nu\bar{\nu}$ limit

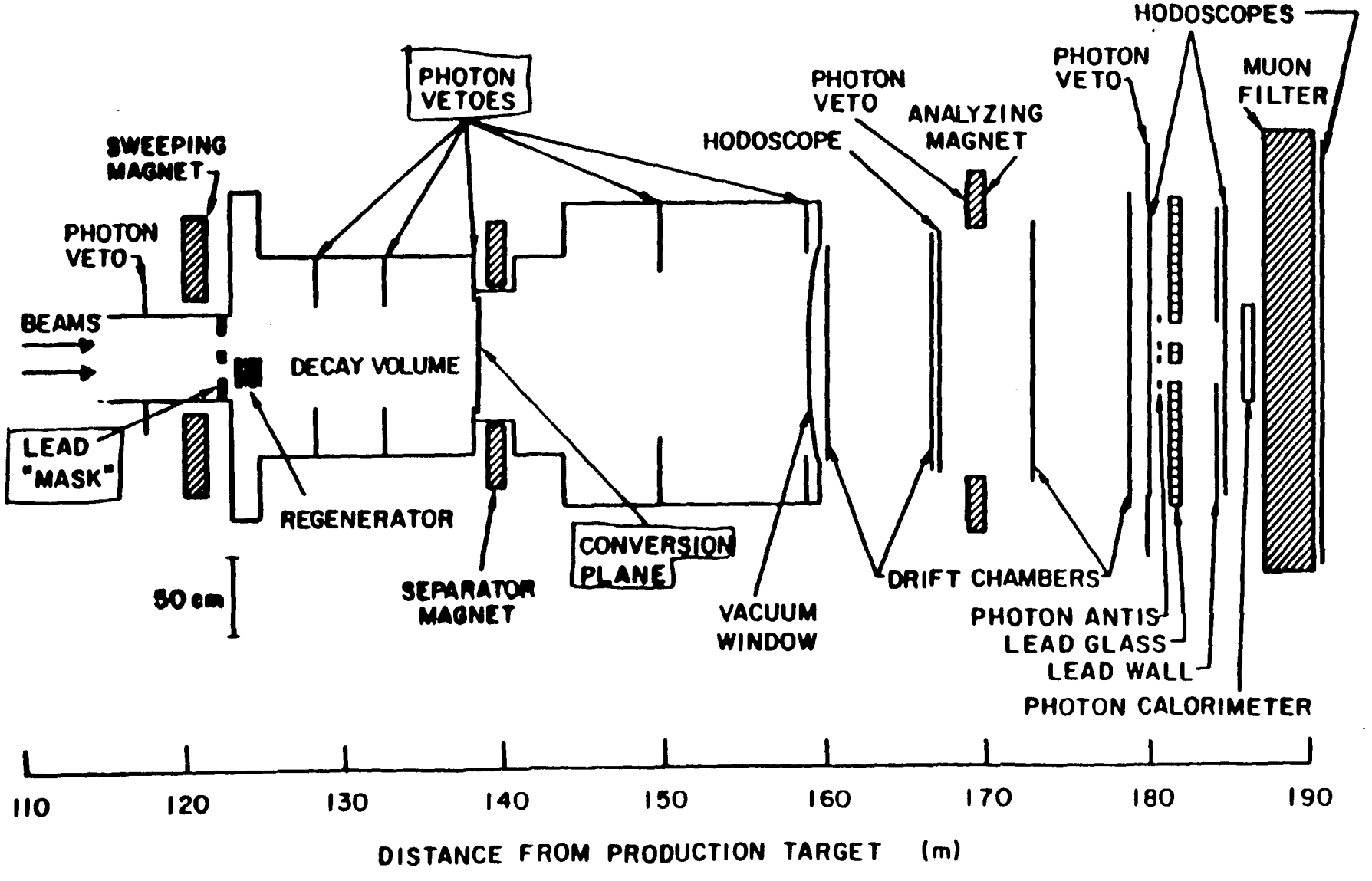
$\hat{\sigma}_E$
Ke_3 form fac
$Ke_3\gamma$

⇒ New initiative (dedicated rare decay stu

E731

Chicago, Elmhurst, Fermilab, Princeton, Saclay

⇓ Illinois ⇓ NA31'



E731 Double Beam Technique

1. Use regeneration to provide K_S component.

   - Coherent effect $\Rightarrow$ identical beam shape
   - regeneration $\propto 1/p^{1.2}$;
     K_L decay probability $\propto 1/p$
     $\Rightarrow$ excellent match in energy spectra

2. In principal, 4 experiments

F_1	$\longrightarrow$	$K_S \to 2\pi^0$	$F_1 \rho^2$	A
F_2	$\longrightarrow$	$K_L \to 2\pi^0$	$F_2 \eta_{00}^2$	B
F_3	$\longrightarrow$	$K_S \to \pi^+\pi^-$	$F_3 \rho^2$	
F_4	$\longrightarrow$	$K_L \to \pi^+\pi^-$	$F_4 \eta_{+-}^2$	

$$\left|\frac{\rho}{\eta_{00}}\right|^2 = \frac{F_2}{F_1}\,\frac{A}{B}$$

$\Longrightarrow$ need accurate flux monitoring

3. Use two identical beams simultaneously

$F_1 \longrightarrow$ $F_1 \rho^2$

$F_1 \longrightarrow$ $F_1 \eta_{00}^2$

$\Rightarrow$ bad pulses, detector noise, etc, will cancel out as both K_L & K_S $2\pi^0$ modes are measured under identical conditions.

$\Rightarrow$ makes unimportant factors over which the experimenter has little control

but,

beam fluxes may differ slightly

$F_1 \rho^2 (1+r)$ A

$F_1 \eta^2$ B

and detector efficiency may vary from beam to beam

$F_1 \rho^2 (1+r)(1+\varepsilon)$ A

$F_1 \eta^2$ B

4. so alternate the roles of the beams

$F_1 \eta^2 (1+r)(1+\varepsilon)$ C

$F_1 \rho^2$ D

by moving the regenerator rapidly on the scale of which r changes. However, may spend unequal times

$(1+f) F_1 \eta^2 (1+r)(1+\varepsilon)$ C

$(1+f) F_1 \rho^2$ D

and the detector dead-time may depend upon the regenerator configuration

$(1-\delta)(1+f) F_1 \eta^2 (1+r)(1+\varepsilon)$ C

$(1-\delta)(1+f) F_1 \rho^2$ D

$$\frac{\text{Total regenerator}}{\text{Total vacuum}} = \frac{A+D}{B+C}$$

$$= \frac{\rho^2}{\eta^2} \frac{(1+r)(1+\varepsilon) + (1+f)(1-\delta)}{1 + (1+f)(1+r)(1+\varepsilon)(1-\delta)}$$

$$= 1 + (r+\varepsilon)(\delta - f)/2 + \ldots$$

r : 2 beam flux difference $\quad \mathcal{O}(10\%)$

ε : 2 beam acceptance difference

f : time difference in configurations

δ : dead-time difference in configurations

$\mathcal{O}(1\%)$

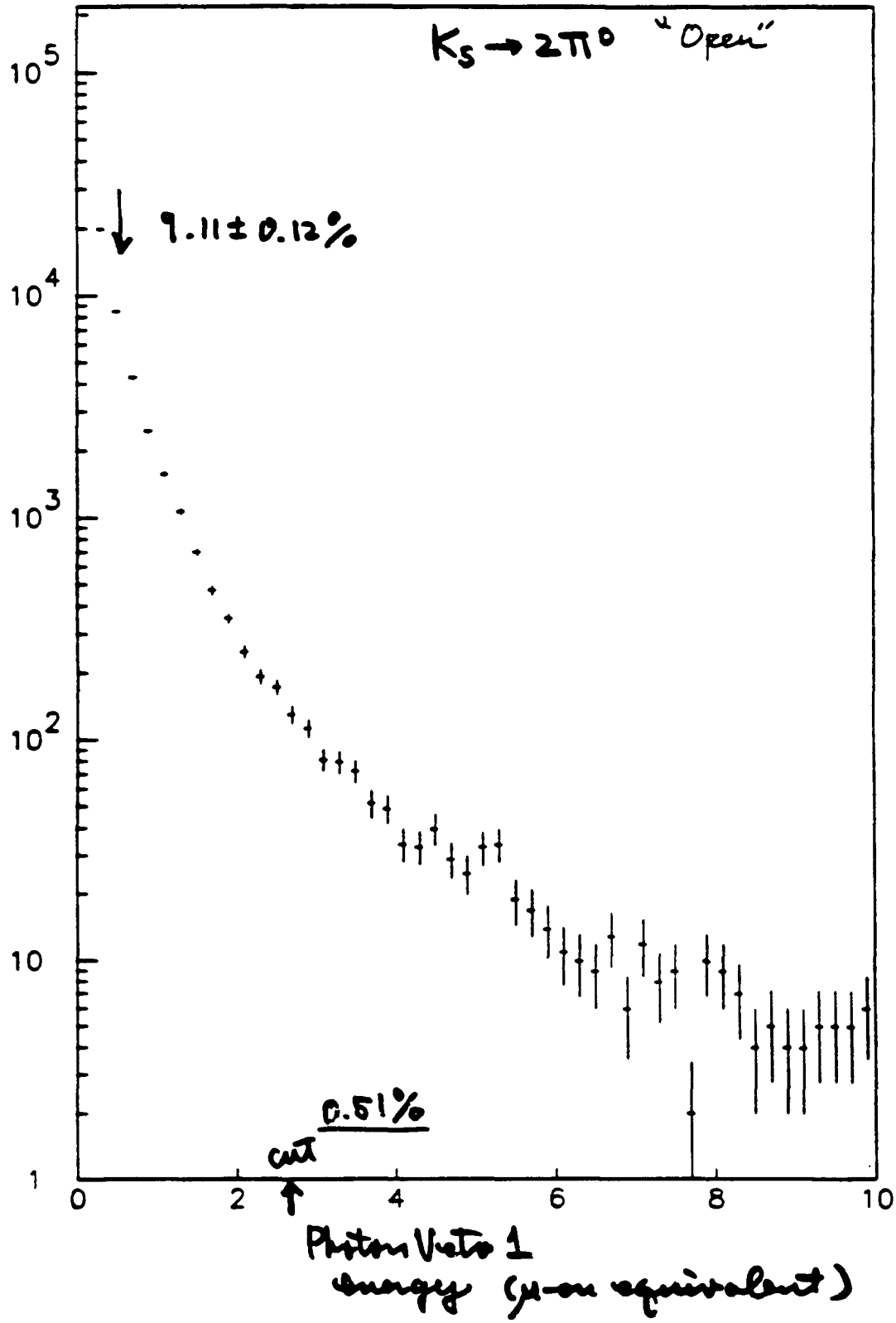
Even better: use geometric mean

$$\sqrt{\frac{A \cdot D}{B \cdot C}} = \frac{\rho^2}{\eta^2},$$ completely independent of $r, \varepsilon, f, \delta$

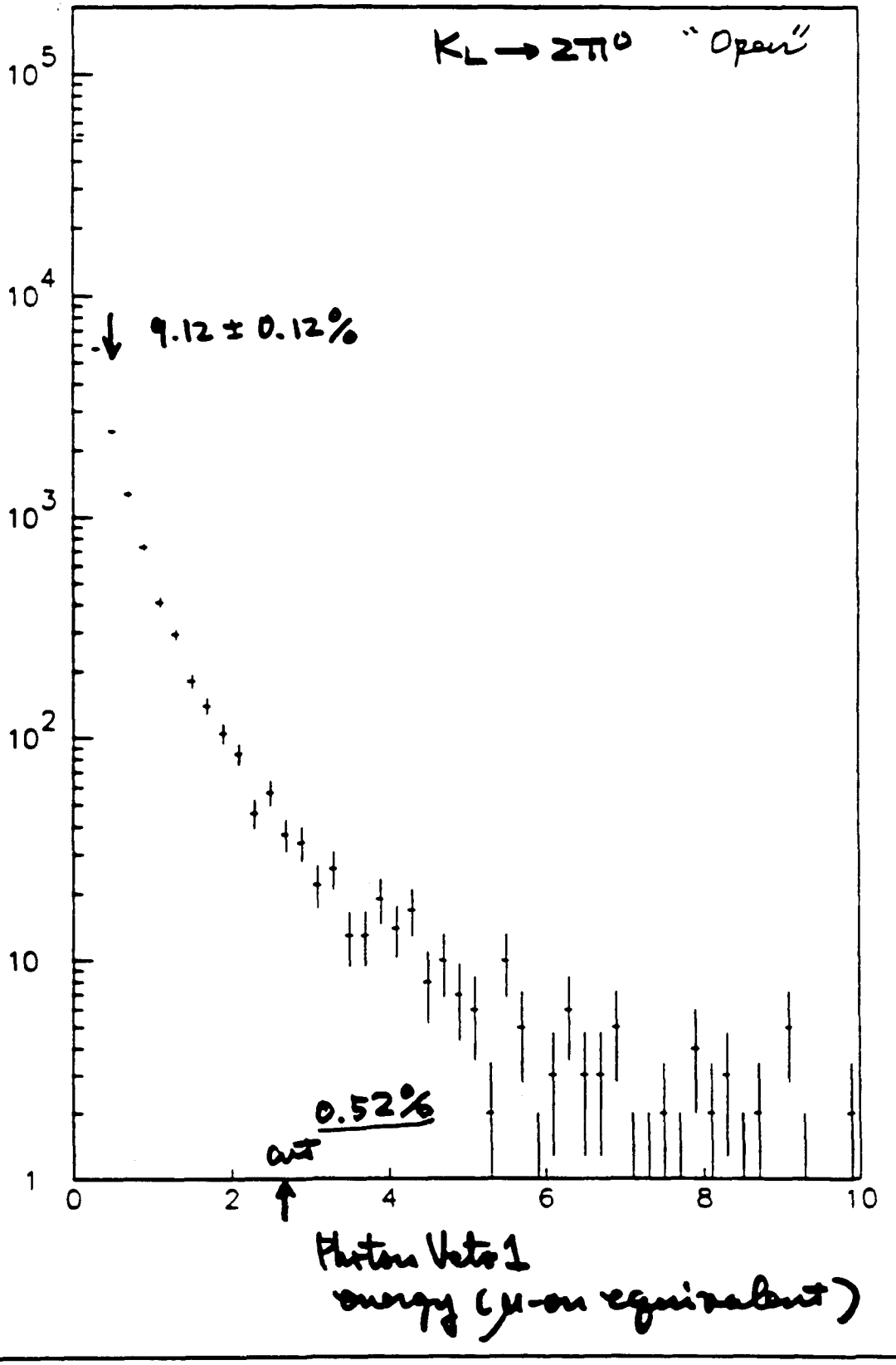
Only remaining difference is acceptance vs. Z of dec

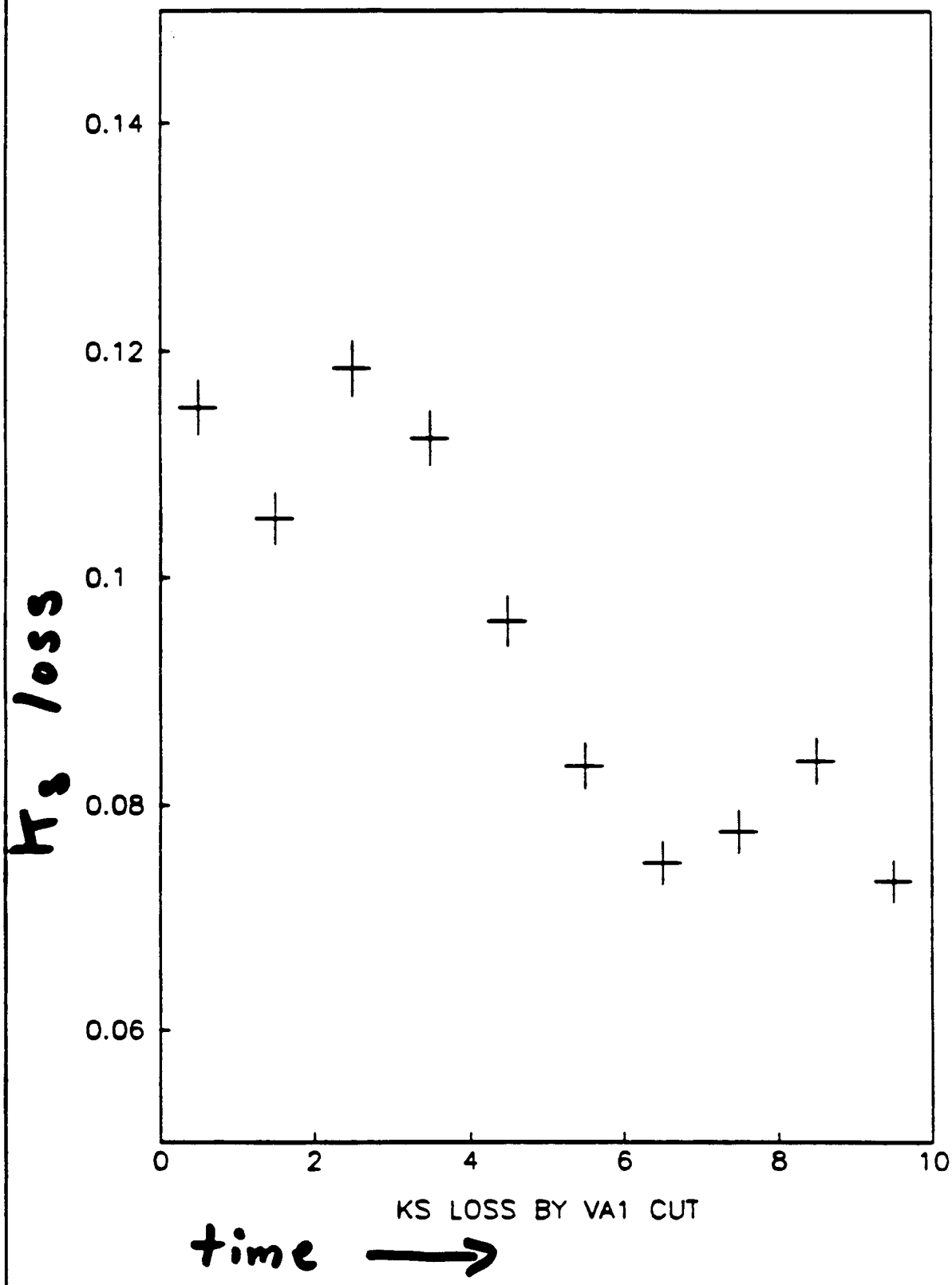
5. All 4 modes simultaneously taken allows for further studies of background systematics

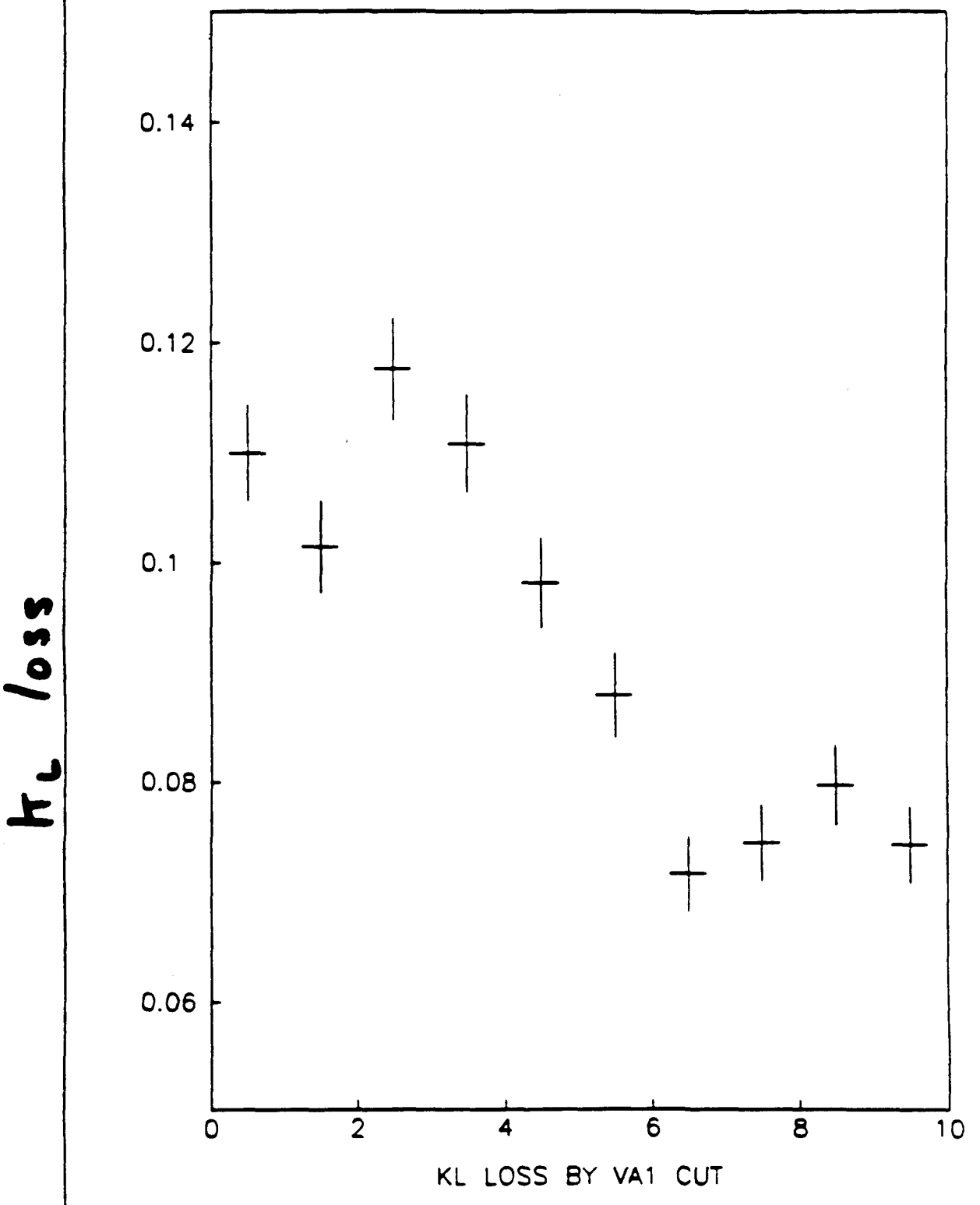
Accidentals Study. Photon Veto Cut

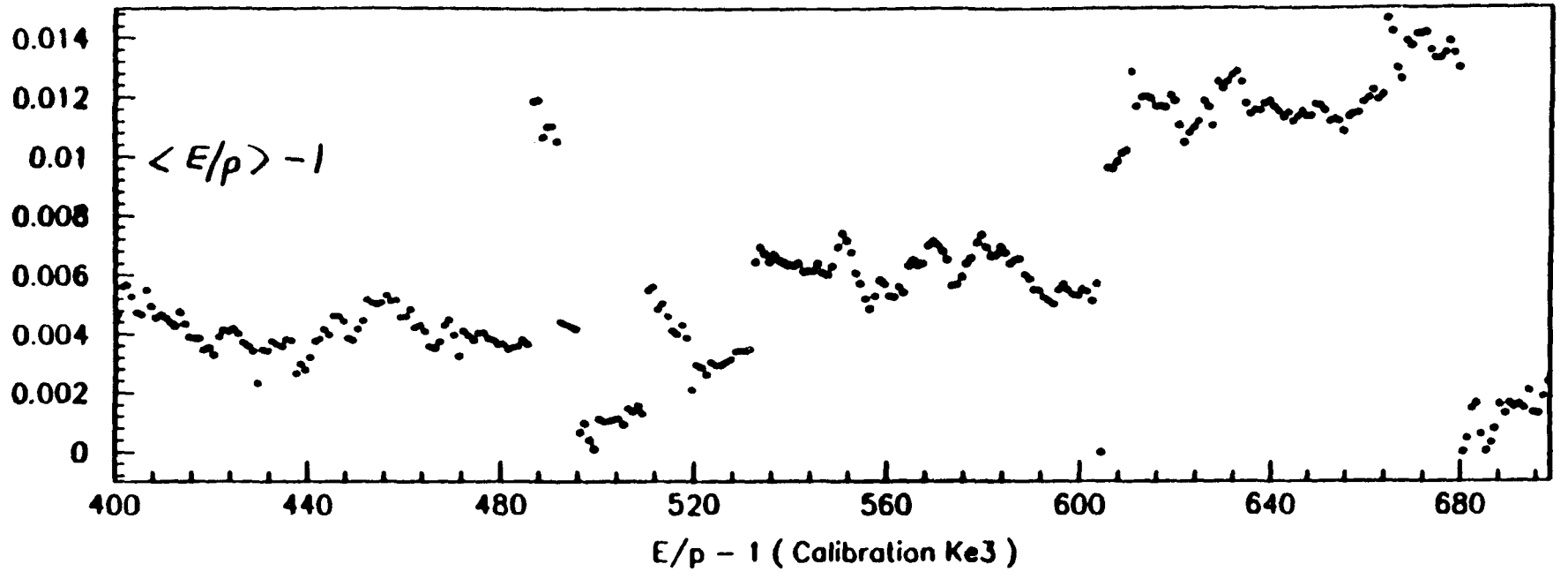


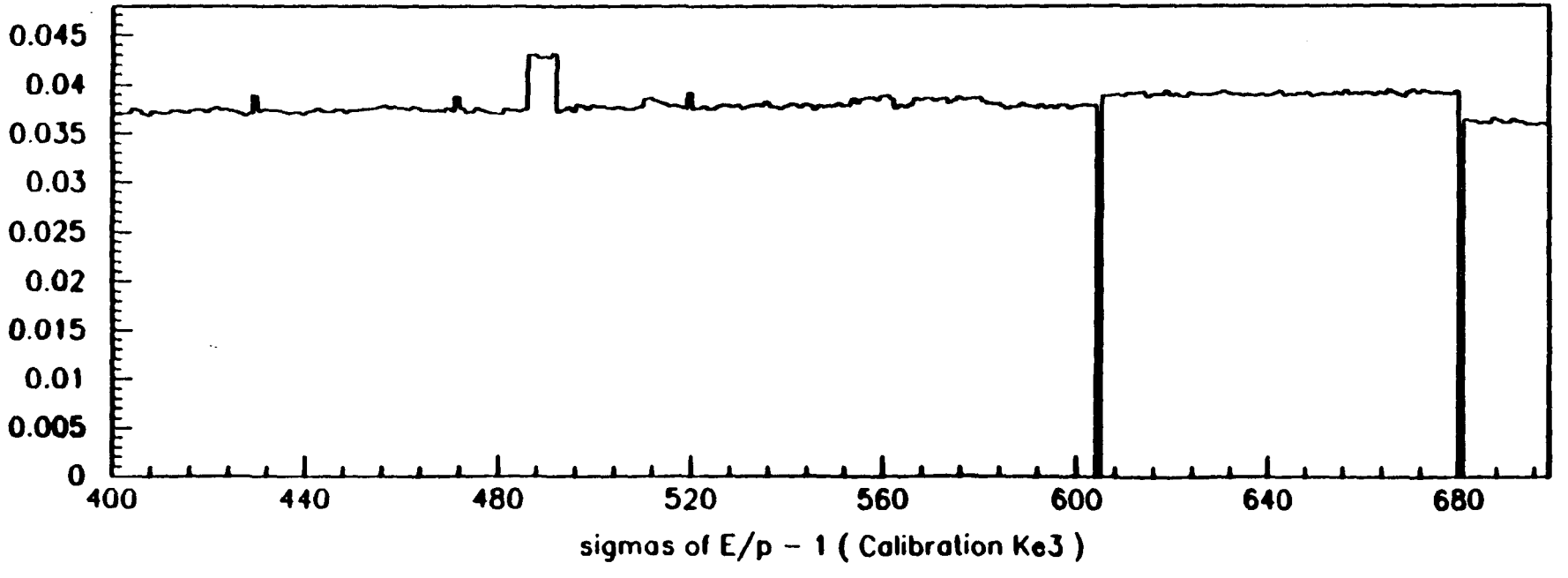
Accidentals Study. Photon Veto cut.




0.14
0.12
0.1
0.08
0.06
0
2
4
6
8
10
KS LOSS BY VA1 CUT
K_s loss
time

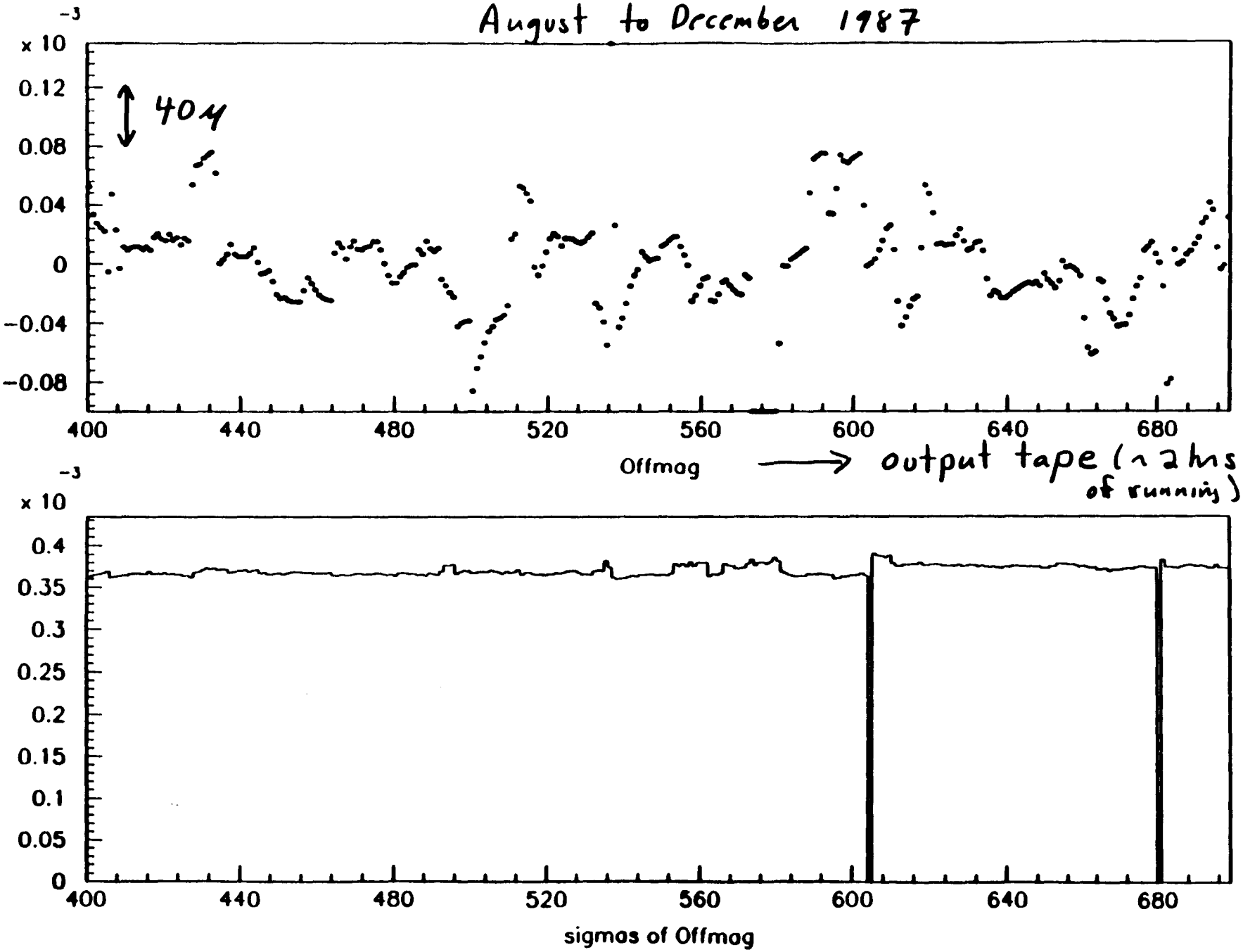

0.14
0.12
0.1
0.08
0.06
0
2
4
6
8
10
KL LOSS BY VA1 CUT
K_L loss

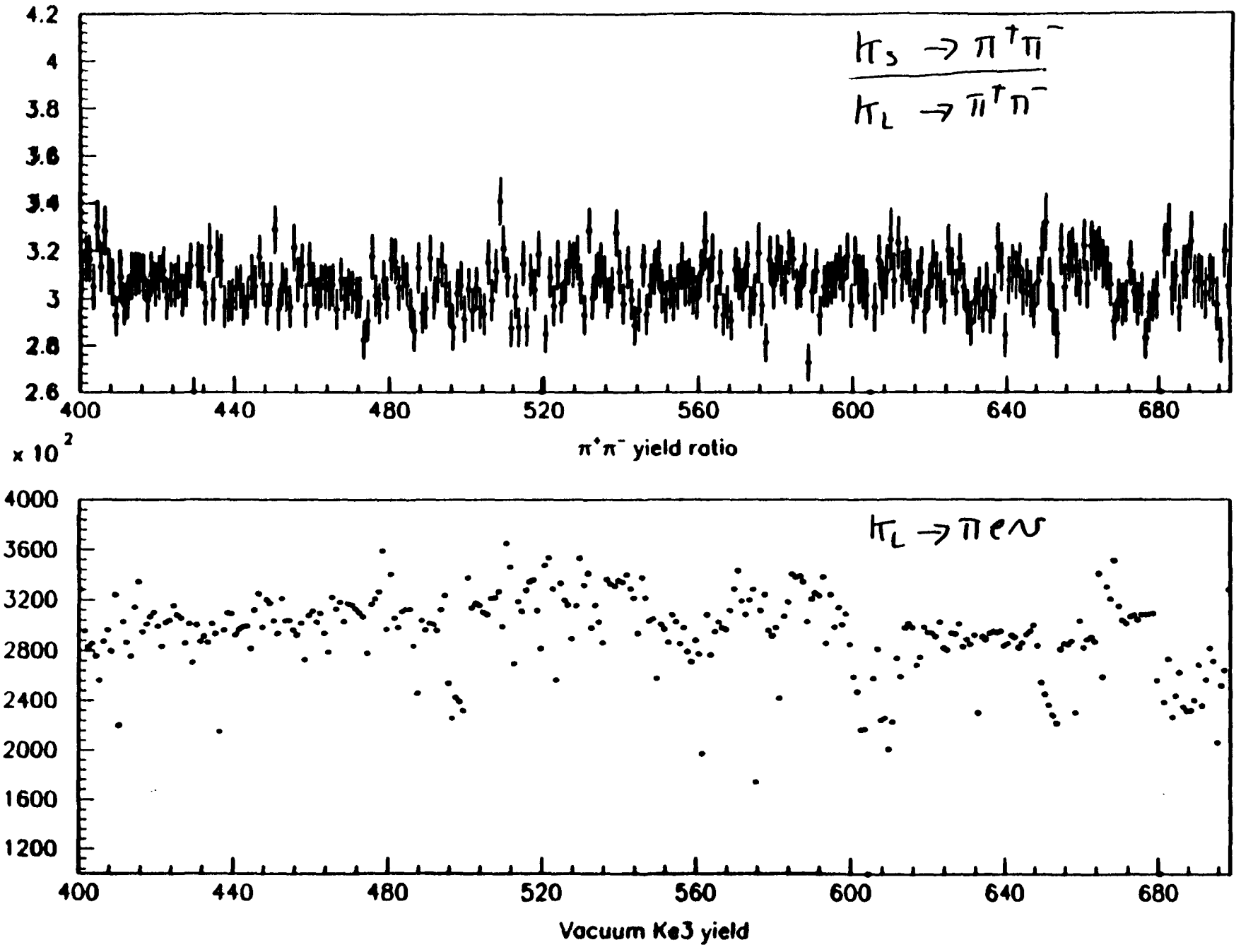

0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
< E/p > - 1
400
440
480
520
560
600
640
680
E/p - 1 (Calibration Ke3)


0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
400
440
480
520
560
600
640
680
sigmas of E/p - 1 (Calibration Ke3)

The other 80% of the data : changed mode

August to December 1987




$\frac{K_S \to \pi^+\pi^-}{K_L \to \pi^+\pi^-}$
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
400
440
480
520
560
600
640
680
x 10^2
π⁺π⁻ yield ratio
$K_L \to \pi e \nu$
4000
3600
3200
2800
2400
2000
1600
1200
400
440
480
520
560
600
640
680
Vacuum Ke3 yield

E731 Statistics

$\not{CP}$ Modes

"20%" result (simultaneous)	[illegible]	[illegible]
additional charged	[illegible]	
neutral w/Pb		[illegible]
neutral w.o./Pb		[illegible]
neutral simultaneous		[illegible]
	[illegible]	[illegible]

$\Rightarrow$ 5.5×10^{-4} statistical error

E731 Systematics

TABLE IV: Systematic Errors

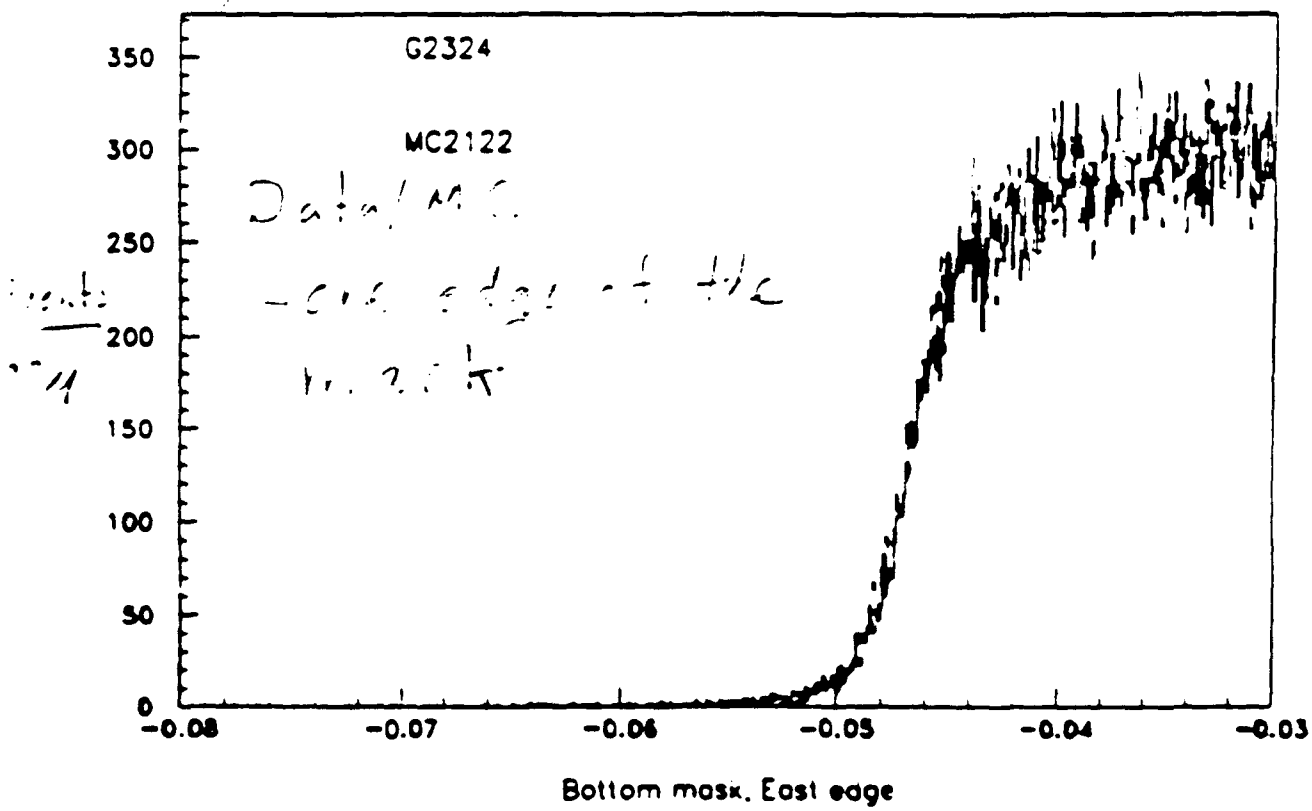
Effect	E731 Correction [%]	E731 Syst. Error [%]	E731' Correction [%] Goal	E731' Syst. Error [%] Goal
$\pi e \nu$	0.31	0.06	0.03	0.005
incoherent regeneration (charged)	0.13	0.01	0.025	0.005
$3\pi 0$	0.31	0.06	0.10	0.01
"cross-over"	4.66	0.14	0.45	0.01
incoherent regeneration (neutral)	2.58	0.07	1.0	0.01
accidental effects (charged)	-	0.07	-	0.01
accidental effects (neutral)	-	0.07	-	0.01
energy scale resolution non-linearity	-	0.20	-	0.02
acceptance charged	0.45	0.18	-2.0 (?)	0.02
acceptance neutral	3.97	0.18	-8.0 (?)	0.02
TOTAL		0.38		0.04

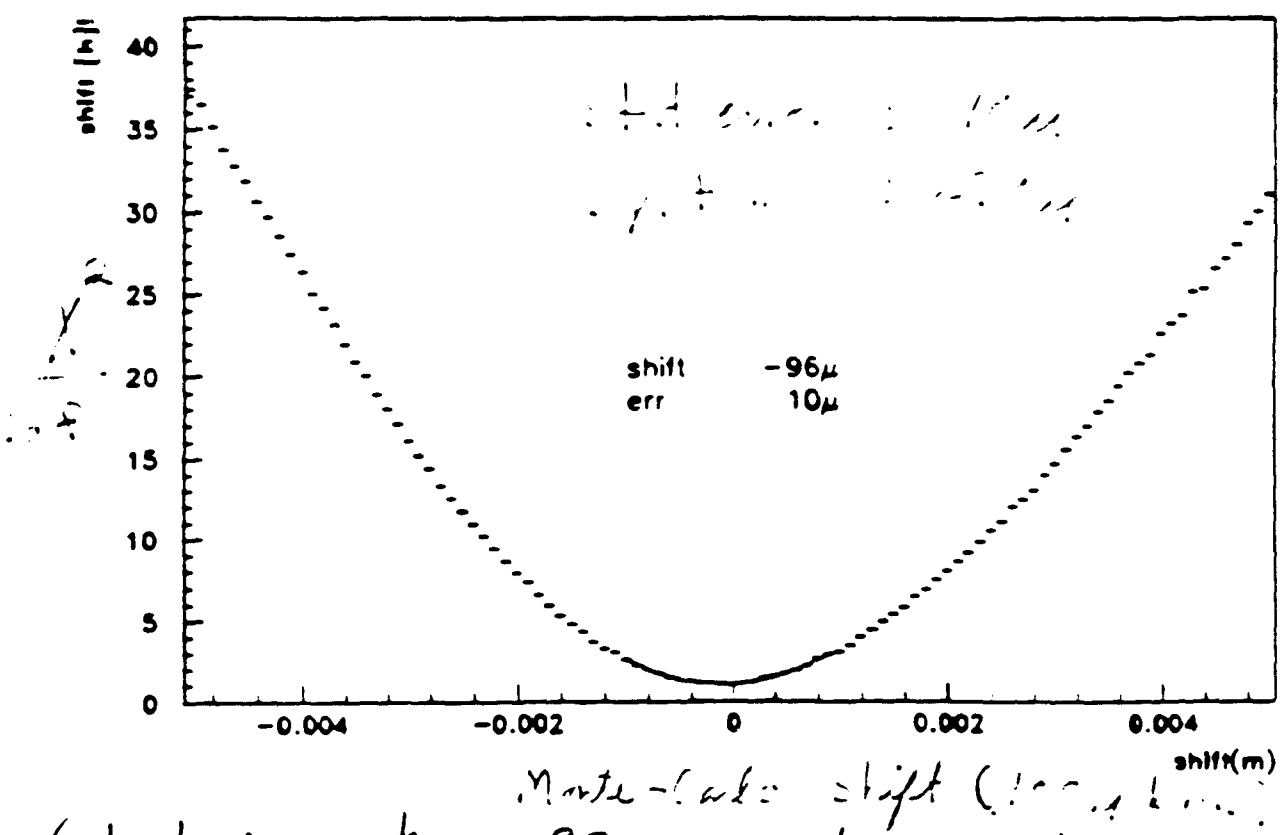
hard"

easy"

Using high statistics Ke_3s to determine aperture offsets

Ke_3

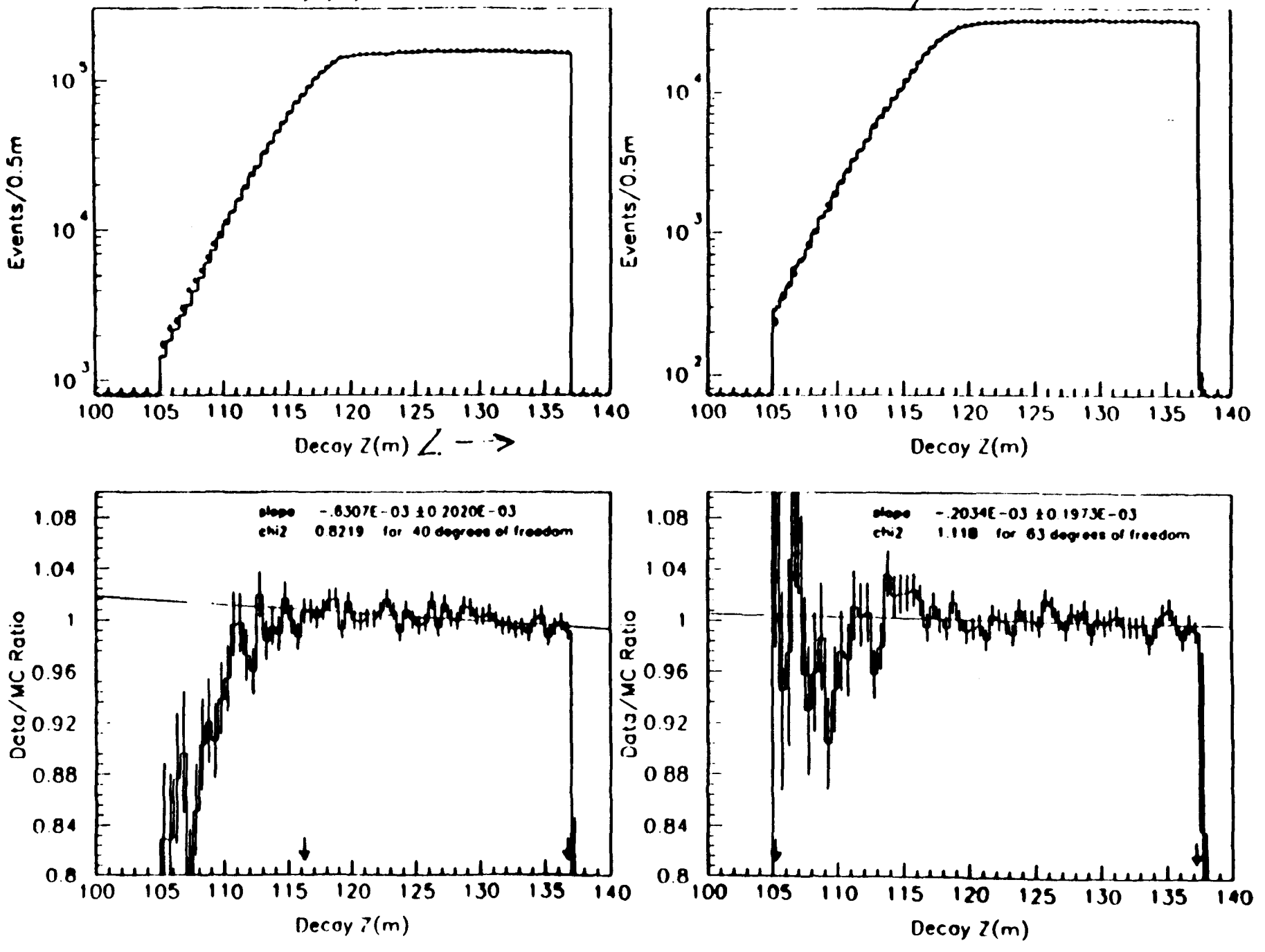


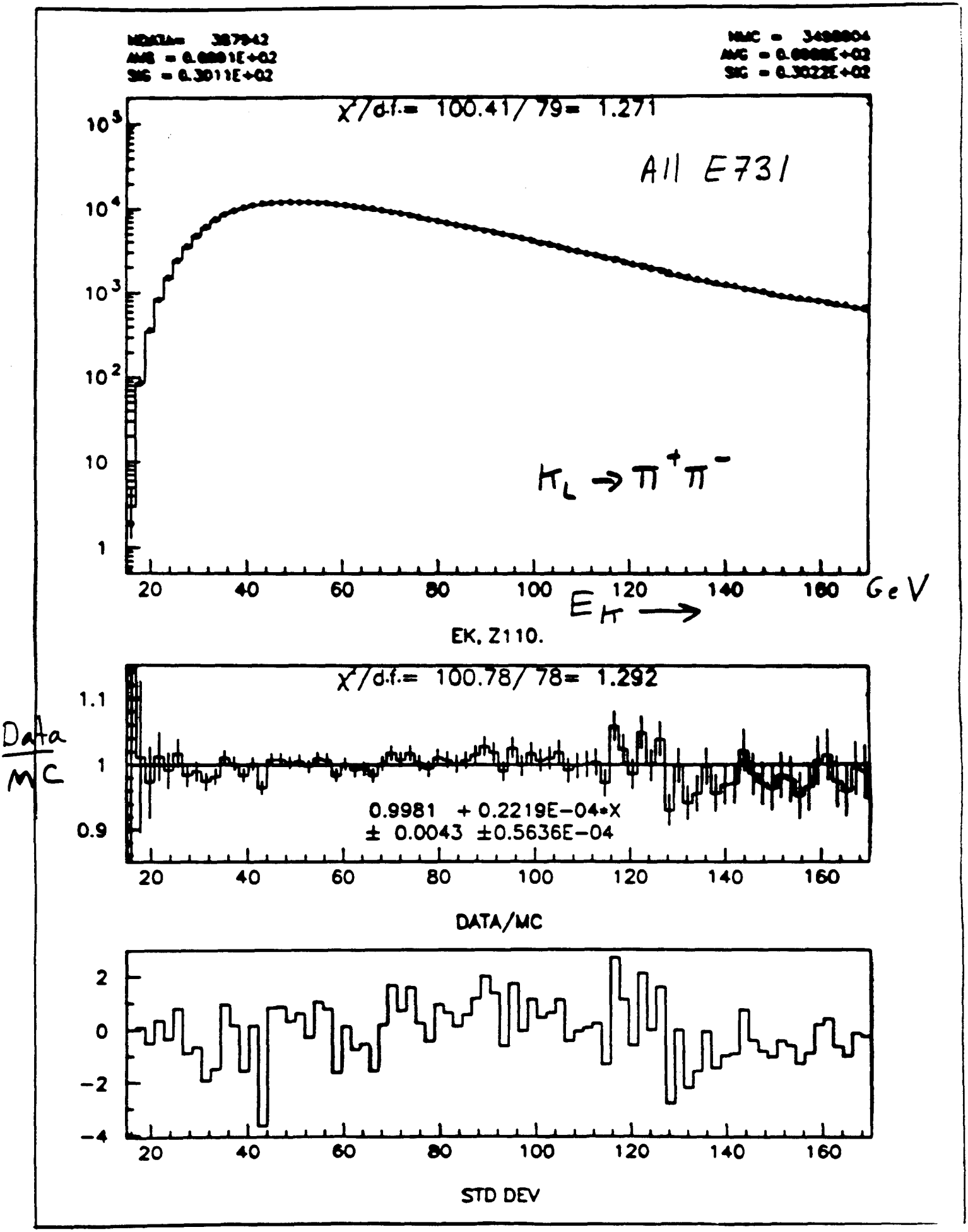


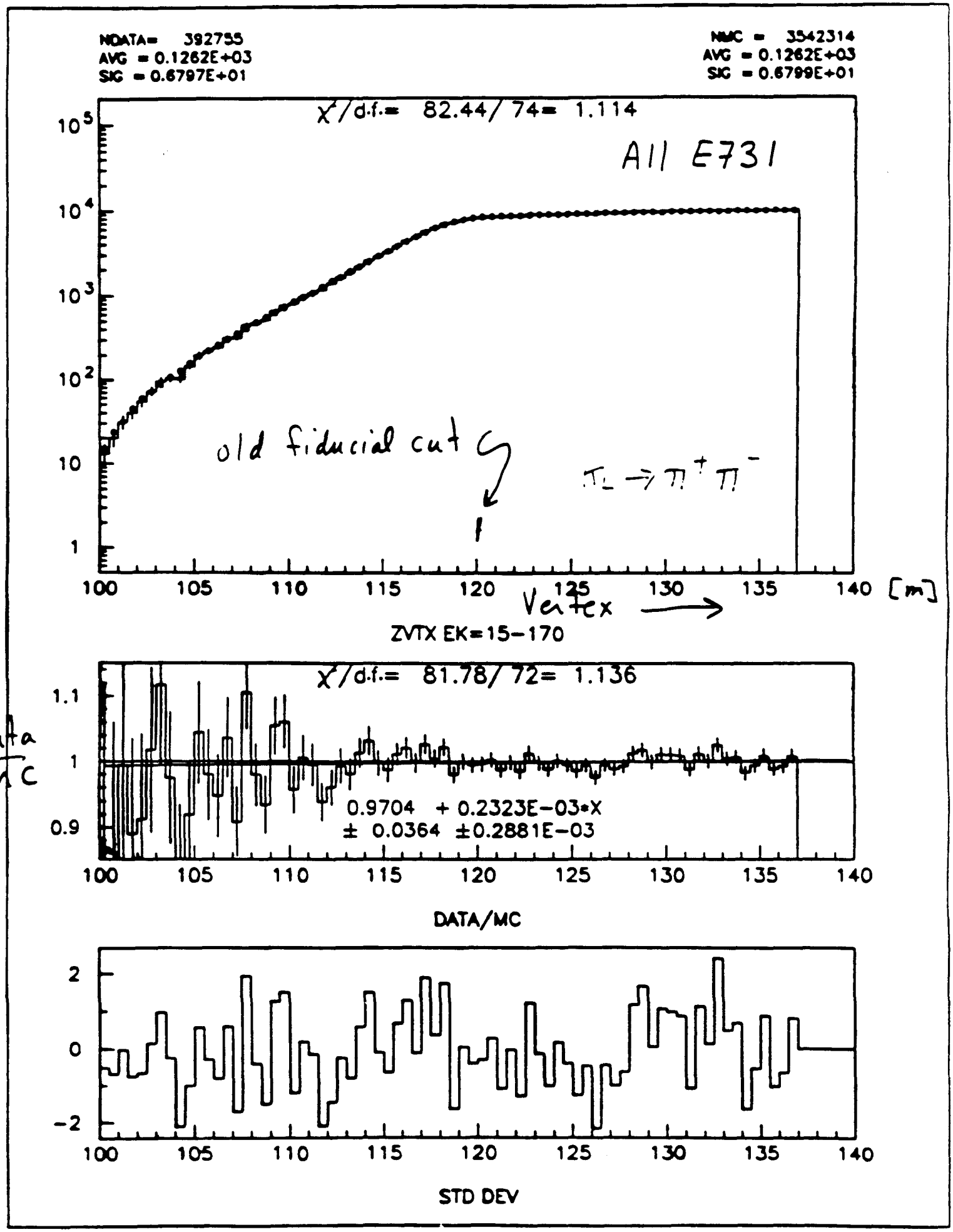
(chambers now have 83μ resolution/plane)

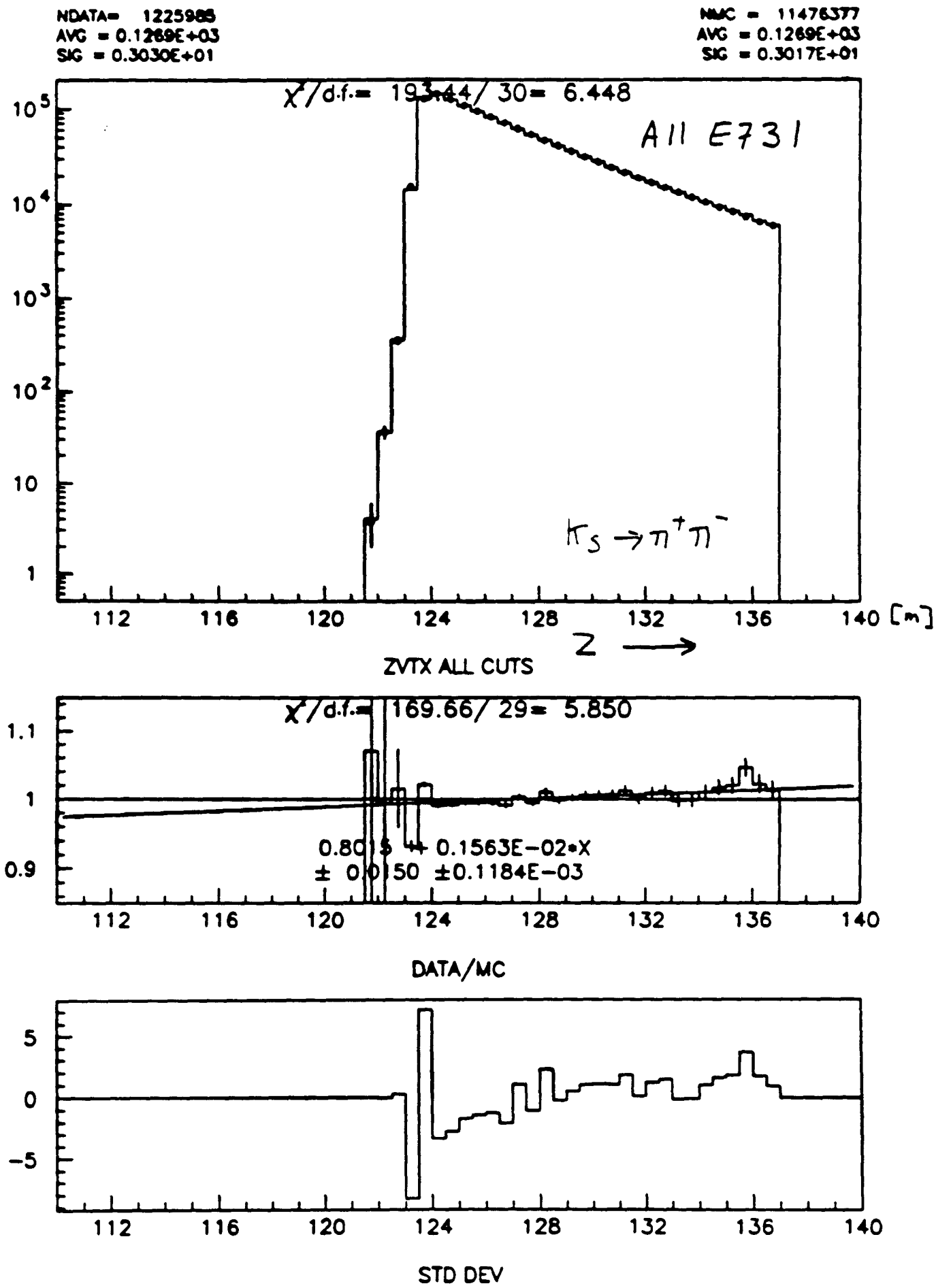
$K e_3$

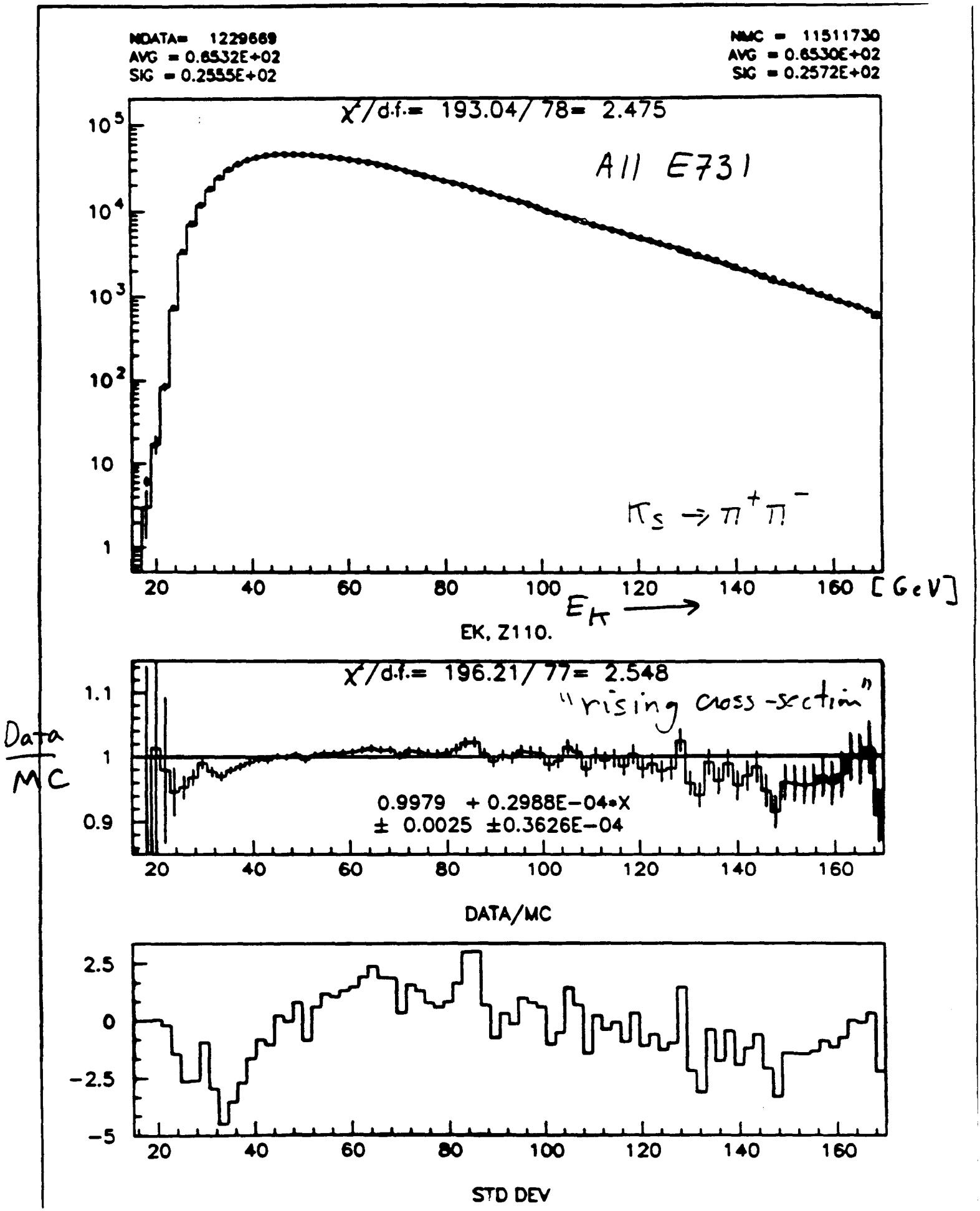
1??? "Today"


Events/0.5m
Decay Z(m)
Data/MC Ratio
slope -.6307E-03 ±0.2020E-03
chi2 0.8219 for 40 degrees of freedom
slope -.2034E-03 ±0.1973E-03
chi2 1.118 for 63 degrees of freedom


NDATA= 387942
AVG = 0.6881E+02
SIG = 0.3011E+02
NMC = 349804
AVG = 0.6888E+02
SIG = 0.3022E+02
χ²/d.f.= 100.41/ 79= 1.271
All E731
$K_L \to \pi^+\pi^-$
$E_K \longrightarrow$
GeV
EK, Z110.
χ²/d.f.= 100.78/ 78= 1.292
Data/MC
0.9981 + 0.2219E-04*X
± 0.0043 ±0.5636E-04
DATA/MC
STD DEV


NDATA= 392755
AVG = 0.1262E+03
SIG = 0.6797E+01
NMC = 3542314
AVG = 0.1262E+03
SIG = 0.6799E+01
χ²/d.f.= 82.44/ 74= 1.114
All E731
old fiducial cut
K_L → π⁺π⁻
Vertex
[m]
ZVTX EK=15-170
χ²/d.f.= 81.78/ 72= 1.136
Data/MC
0.9704 + 0.2323E-03*X
± 0.0364 ±0.2881E-03
DATA/MC
STD DEV


NDATA= 1225985
AVG = 0.1269E+03
SIG = 0.3030E+01
NMC = 11476377
AVG = 0.1269E+03
SIG = 0.3017E+01
χ²/d.f.= 193.44/ 30= 6.448
All E731
$K_S \to \pi^+\pi^-$
Z
[m]
ZVTX ALL CUTS
χ²/d.f.= 169.66/ 29= 5.850
0.8015 + 0.1563E-02*X
± 0.0150 ±0.1184E-03
DATA/MC
STD DEV


NDATA= 1229669
AVG = 0.6532E+02
SIG = 0.2555E+02
NMC = 11511730
AVG = 0.6530E+02
SIG = 0.2572E+02
χ²/d.f.= 193.04/ 78= 2.475
All E731
$K_S \to \pi^+\pi^-$
[GeV]
E_K
EK, Z110.
χ²/d.f.= 196.21/ 77= 2.548
"rising cross-section"
Data/MC
0.9979 + 0.2988E-04*X
± 0.0025 ±0.3626E-04
DATA/MC
STD DEV

E731 "20%"

(calibration e^-e^- data)

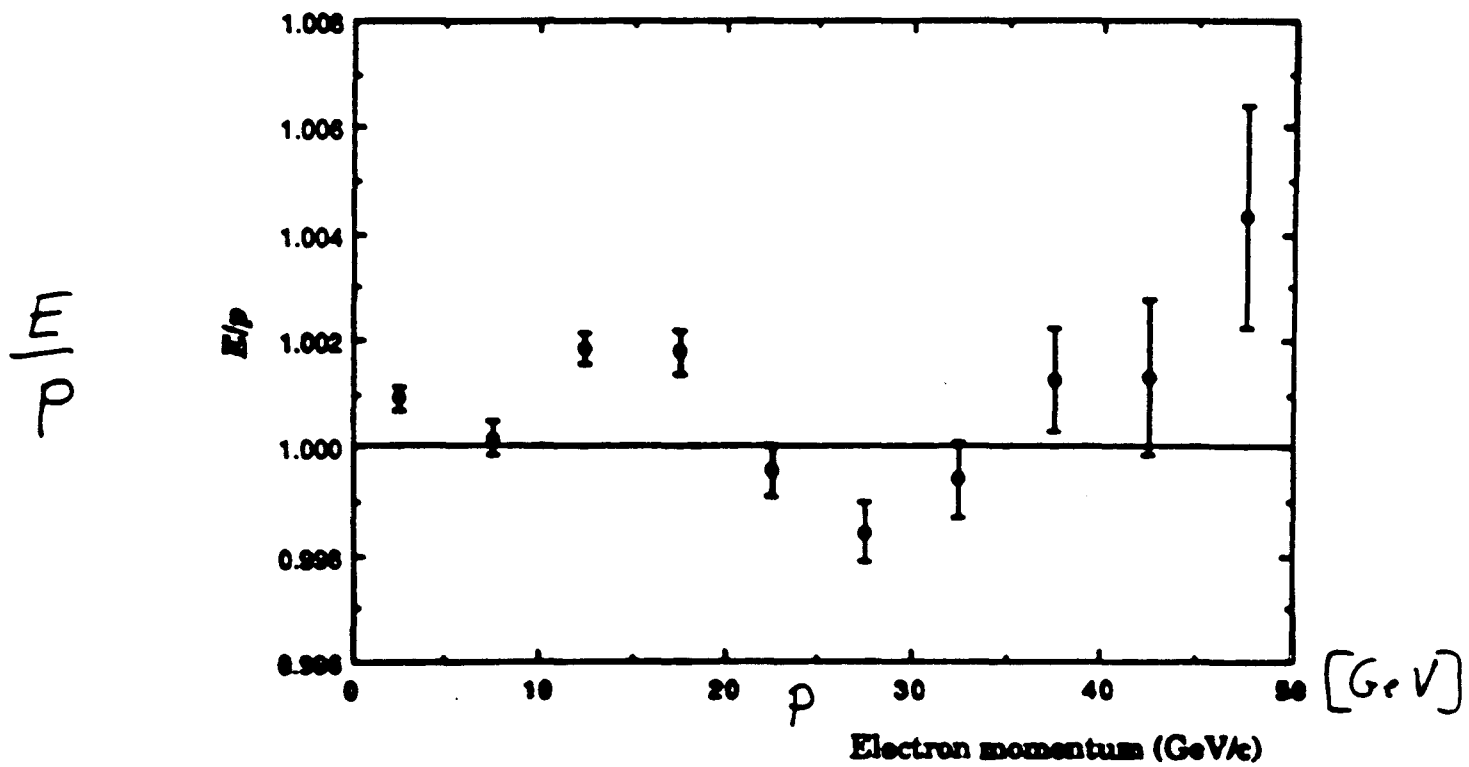
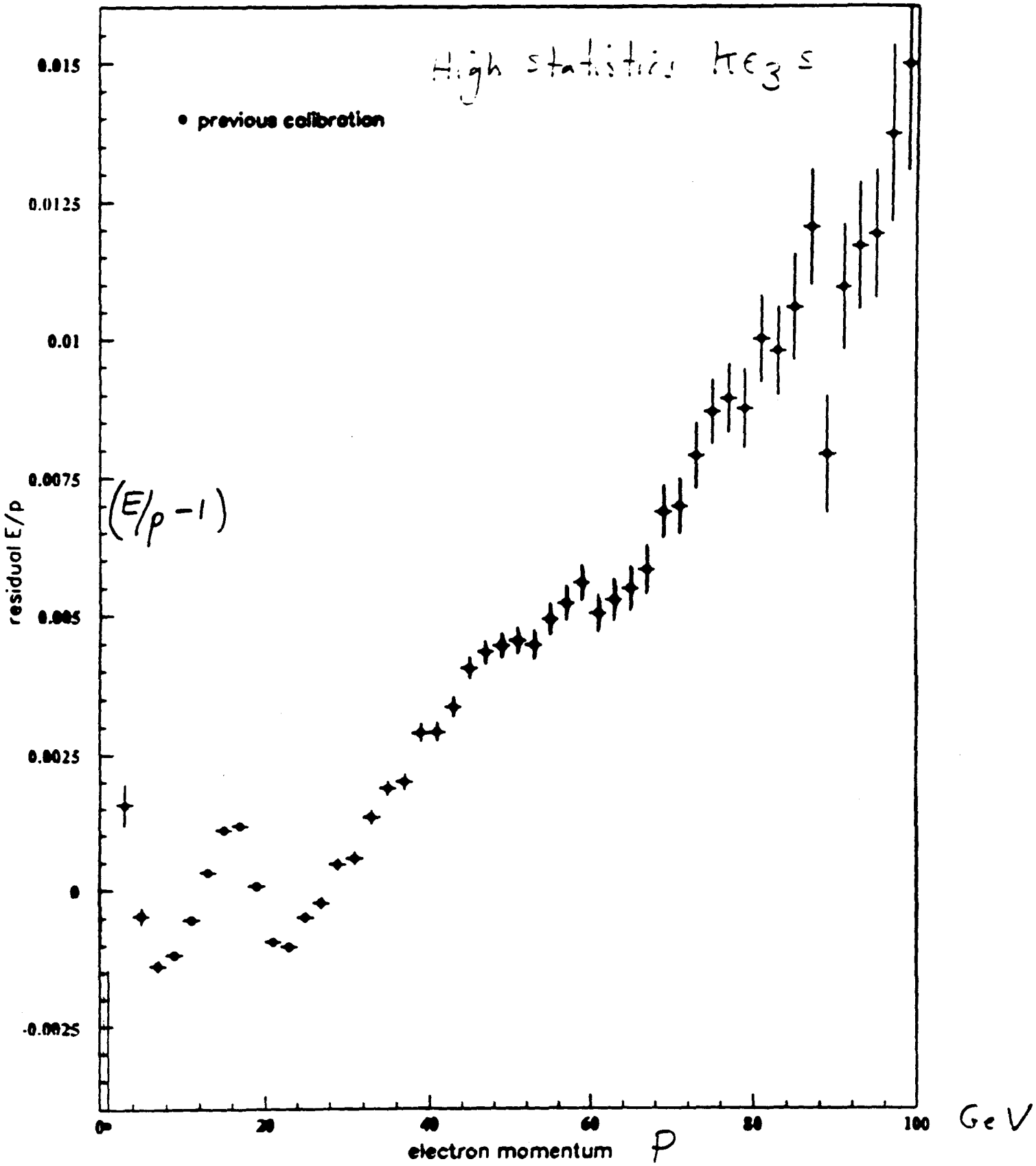
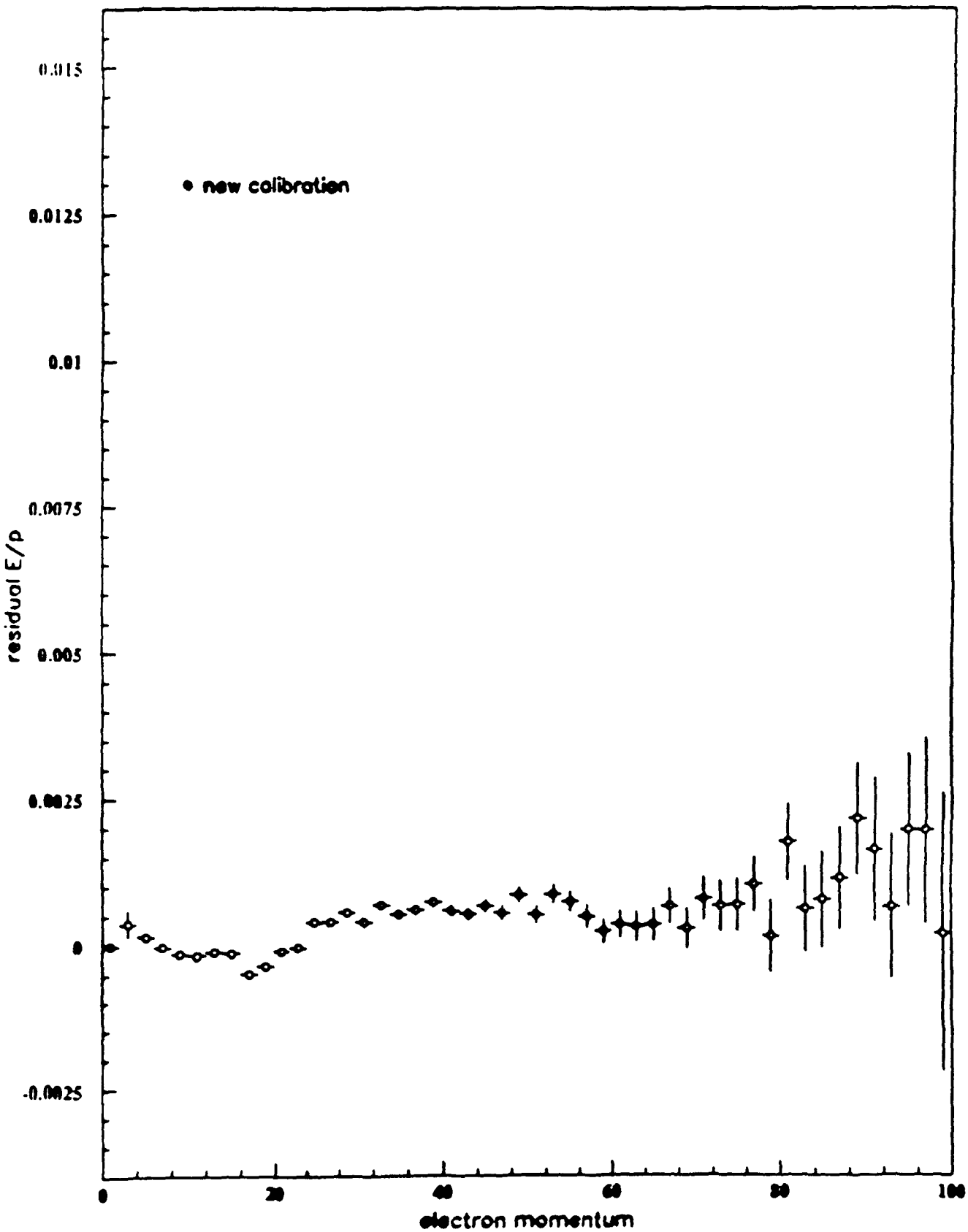


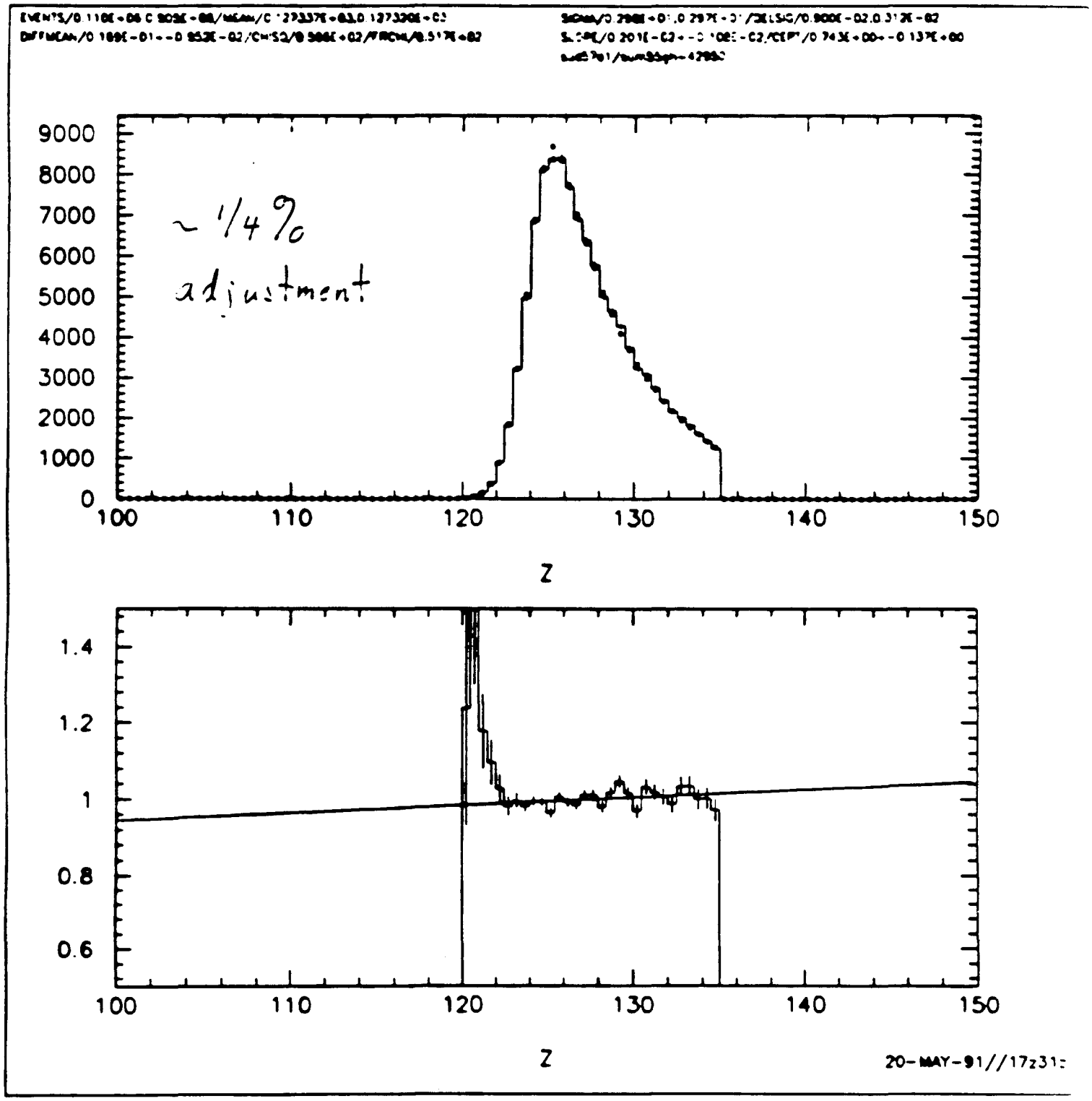
Figure 62. The value of E/p as a function of electron momentum, for calibration data.

E731 20%

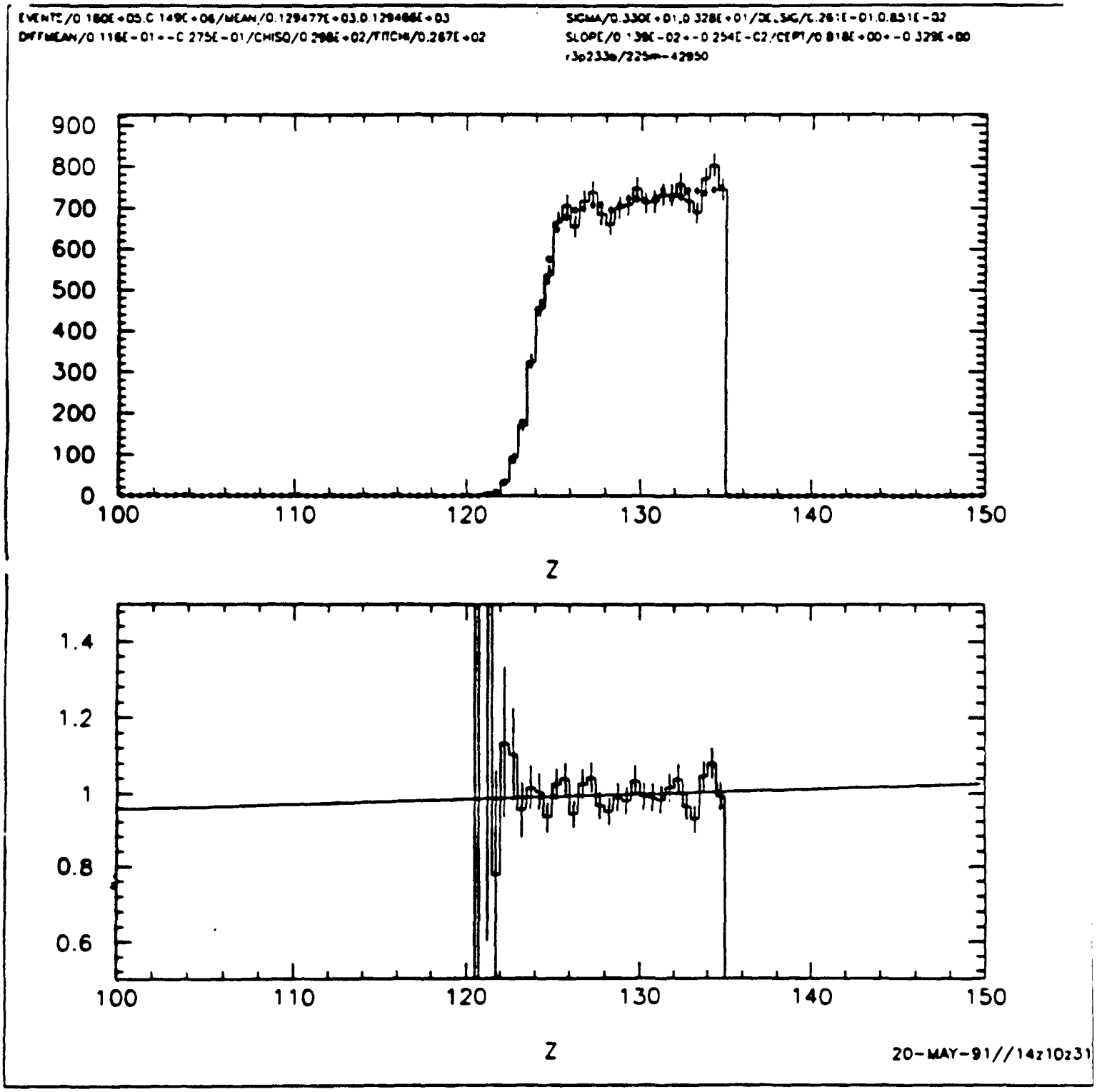

High statistics K_{e3}
• previous calibration
$(E/p - 1)$
residual E/p
0.015
0.0125
0.01
0.0075
0.005
0.0025
0
-0.0025
0
20
40
60
80
100
electron momentum
P
GeV


new calibration
0.015
0.0125
0.01
0.0075
0.005
0.0025
0
-0.0025
residual E/p
0
20
40
60
80
100
electron momentum

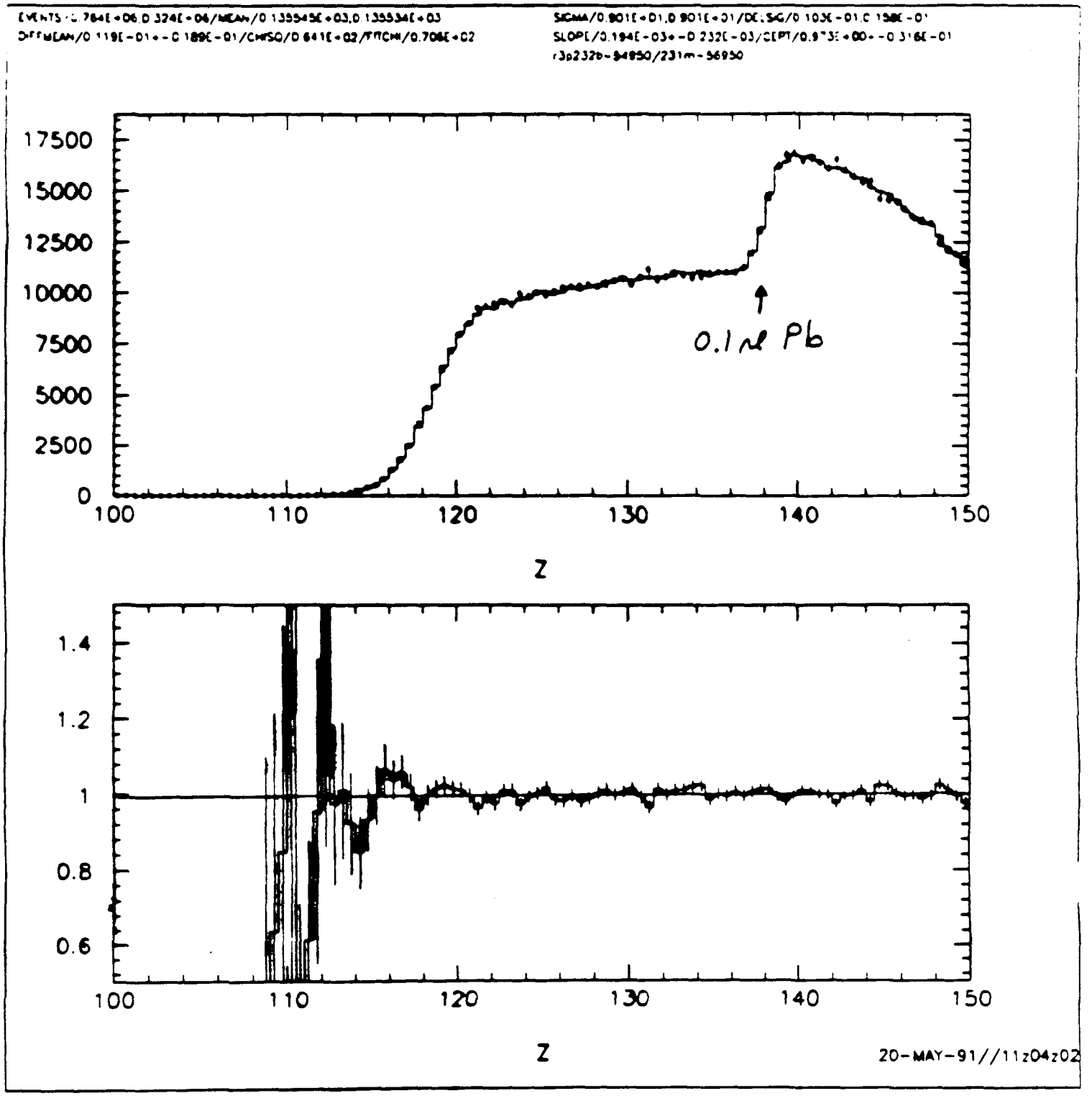
$2\pi^0$ "energy scale" determination



$3\pi^0$ upstream edge



$3\pi^0$ downstream edge



("20%")

With the same data, we measure

$$\tau_s = (0.8902 \pm 0.0021) \times 10^{-10} \text{ sec}$$

World Average = (0.8922 ± 0.0022)

$$\Delta m = (0.534 \pm 0.009) \times 10^{10} \hbar \text{ sec}^{-1}$$

World Average = (0.535 ± 0.002)

Precise determinations of other physical quantities with the same data are important in giving us confidence in the result.

These, of course, will improve.

E731 ε'/ε Conclusion

Stat. Error		14 →	5.5
Syst. Error	Acceptance	4 →	2
Syst. Error	Calibration	3 →	2
Syst. Error	Backgrounds	3 →	2
Syst. Error	Accidentals	2 →	2
Total Systematic Error		6 →	4

Remaining Work

- final gain adjustments
- generate final Monte-Carlo sample
  200 MIPS for ~1 week
- hope for a result this summer

Chicago, Fermilab, Elmhurst, Illinois

1991 run (June 15th → Dec 1st ??)

New hardware:

- TRDs
- Track processor - I
- Active regenerators
- New DAQ

E773 : CPT Symmetry study

$\Delta\phi$ to $\pm \sim 1/2^\circ$

+Rutgers

ϕ_{+-} to $\pm \sim 0.7^\circ$

E799-I: rare decay study

remove regenerators

add preconverter, hole calorimeter [BaF2, PbF]

$K_L \to \pi^0 \gamma\gamma$ (low bkg)

UCLA

$K_L \to \pi^0 e^+ e^-$, $\pi^0 \mu^+ \mu^-$ } $\sim 10^{-10}$

$K_L \to \pi^0 \pi^0 \pi^0 \to e^+ e^-$ clean observation

$K_L \to \pi^0 \nu \bar{\nu}$ limit ($\sim 10^{-6}$?)

Λ β decay (polarization exploited)

$K_L \to e^+ e^- e^+ e^-$ 1st observation

$K_L \to \mu^+ \mu^- e^+ e^-$

⋮

The Future

Given

(a) The success of the technique,

(b) That the errors can be improved, and

(c) The NULL result from the "20%" sample,

We have proposed a new measurement

In 1994, we propose to

(a) measure ε'/ε to 10^{-4}

(b) study rare decays to 10^{-11} BR's

Why pursue ε'/ε further?

We have only one manifestation of $\not{CP}$ which arises from ε.

According to the Standard Model, the best bet for another in this decade is

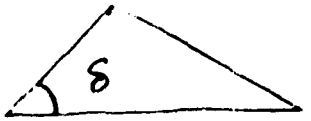
$$\varepsilon'/\varepsilon .$$

However, it is not a sure one, so we are hedging with

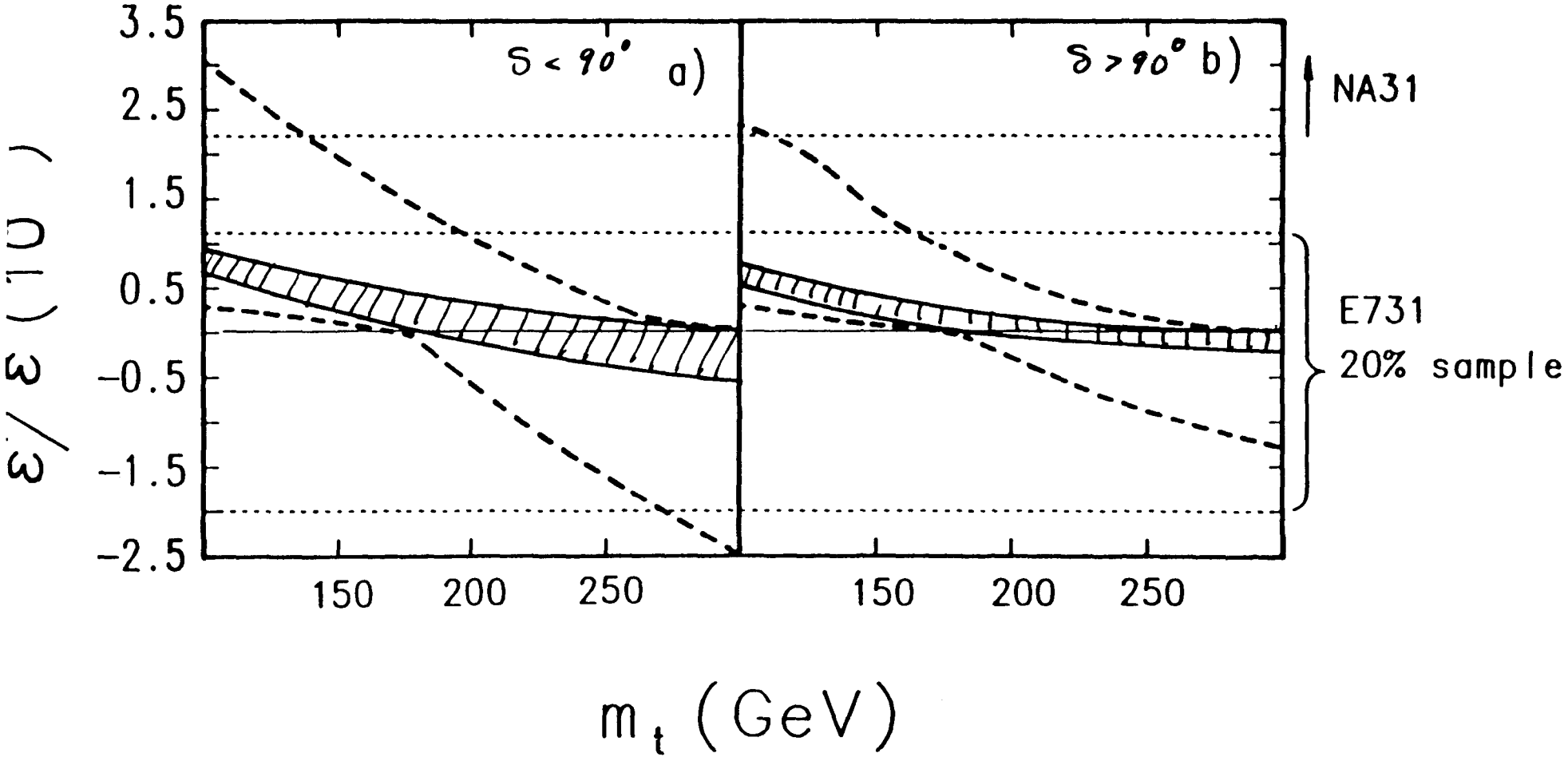
$$\pi\mu\mu \,,\; \pi ee \,,\; \pi\nu\bar{\nu}$$

E731 final result will have some bearing.

ε'/ε Theory



A. Buras et. al.



best values

all parameters relaxed

E 731 Full Data Set	Tevatron (P832)	Main Injector (P804)

1996 and beyond

Main Injector:

3×10^{13} protons per 3 sec 120 GeV

cf

(Tevatron) (8×10^{12} 60 sec) 800 GeV

$\Rightarrow$ Factor of 80 more kaons!

plus, year round operation

What's needed?

high rate chambers, TRDs

very robust beam-line

muon identification

Physics:

ε'/ε to $\sim 10^{-5}$

rare decays to 10^{-13} or better } direct $\not{CP}$

$K_L \to \pi^0 \nu \bar{\nu}$ to 10^{-11}

$K_L \to \mu e, \pi^0 \mu e$

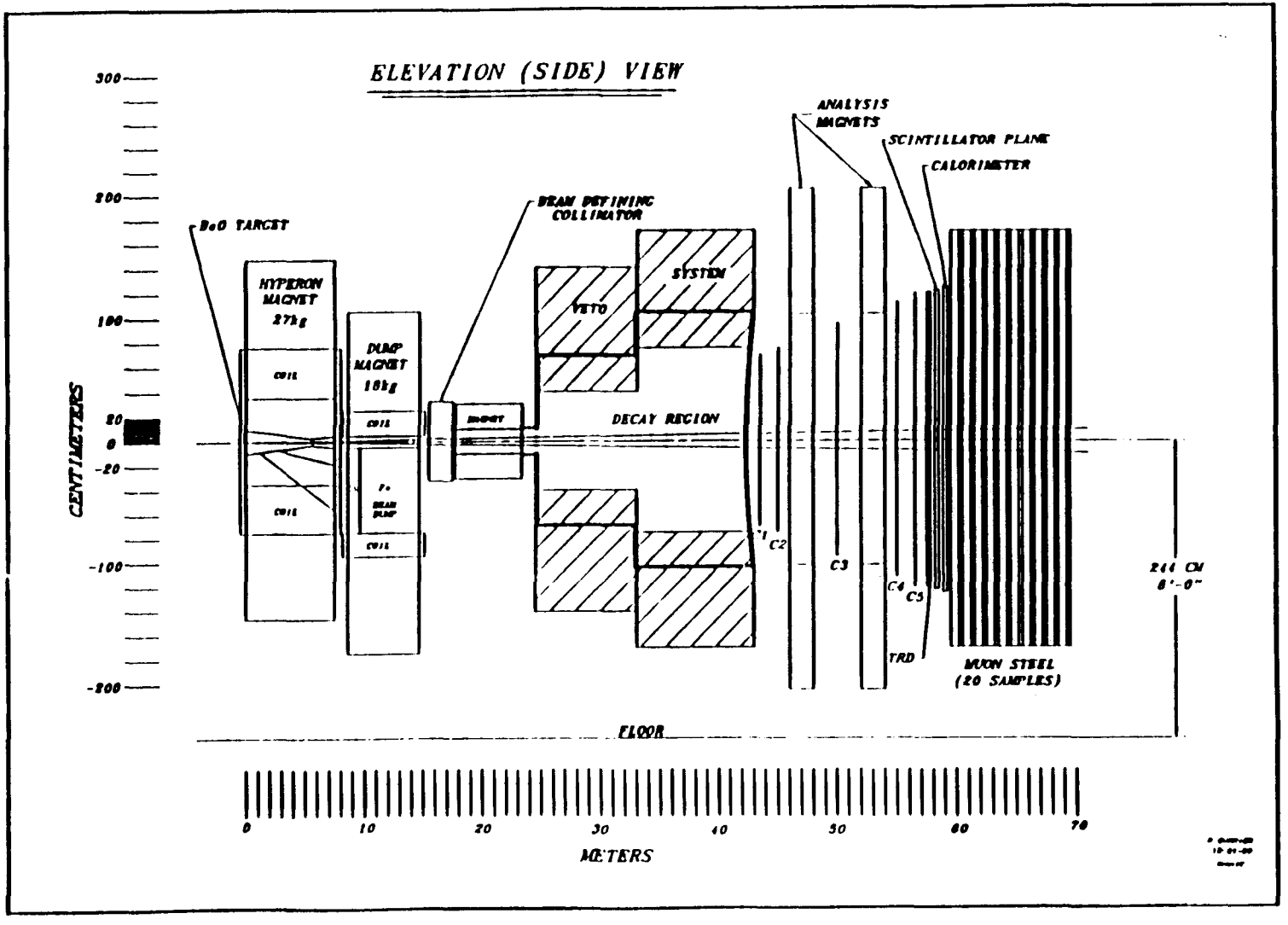
⋮

$\Rightarrow$ many years of study

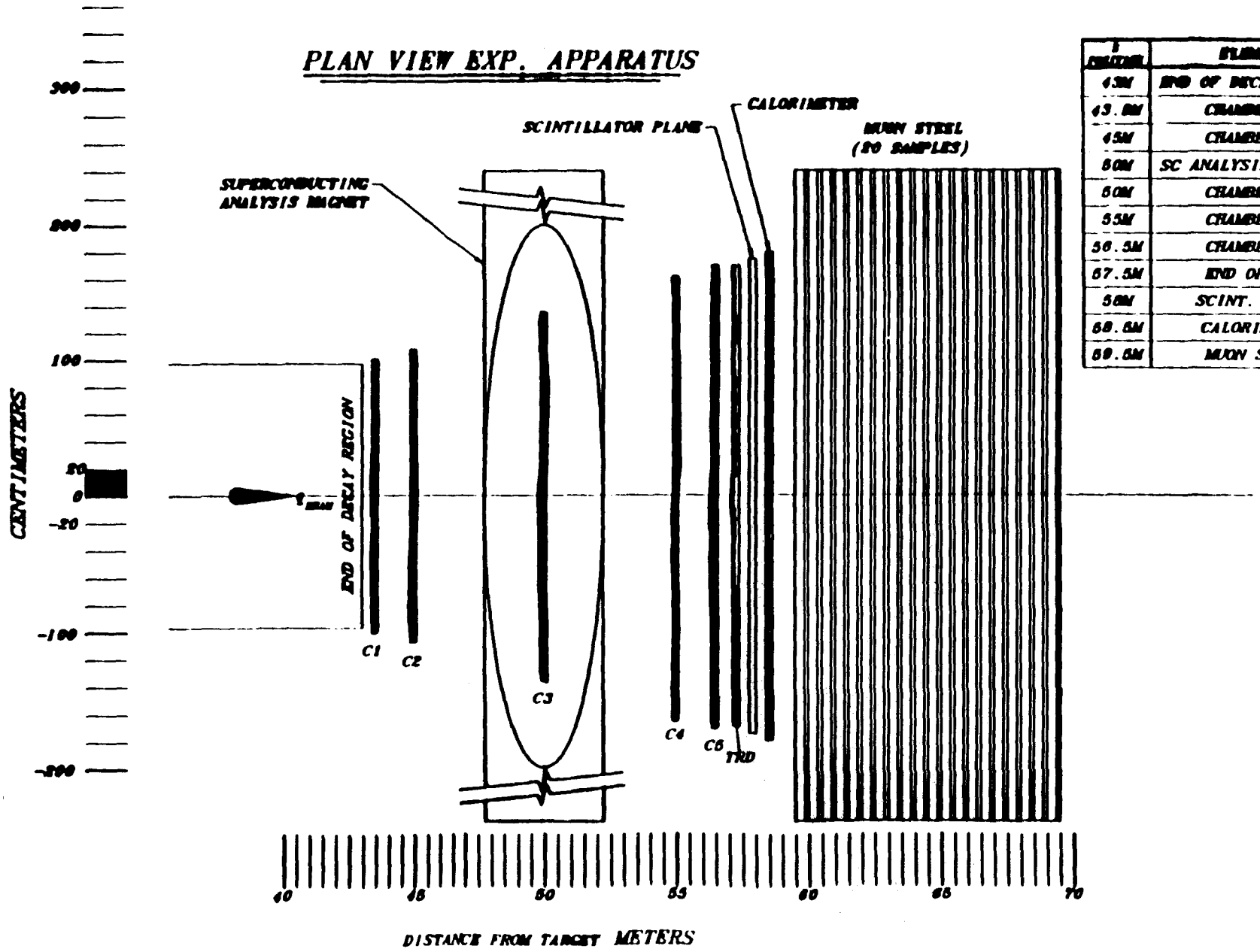
- Natural evolution from Tevatron Main Progra

- One major facility that can perform a variety of experiments

HAMI Facility, K_L modes



— em cal
— TRDs
— wire chambers



Z (METERS)	ELEMENT
43M	END OF DECAY REGION
43.8M	CHAMBER #1
45M	CHAMBER #2
50M	SC ANALYSIS MAGNET
50M	CHAMBER #3
55M	CHAMBER #4
56.5M	CHAMBER #5
57.5M	END OF TRD
58M	SCINT. PLANE
58.5M	CALORIMETER
59.5M	MUON STEEL

R. CURRIER
1 4 81

FNAL KAON PHYSICS IN THE 1990'S

CP VIOLATION, RARE DECAYS

Data in hand	ε'/ε to a precision of $\pm$ 0.0007
	$BR(K_L \rightarrow \pi^0 e^+ e^-) < 7.5 \times 10^{-9}$
	$BR(K_L \rightarrow \pi^0 \gamma\gamma) = (1.9 \pm 0.9) \times 10^{-6}$
	$K_L \rightarrow \pi^+\pi^-\gamma$, $K_S \rightarrow \pi^+\pi^-\gamma$, $K_L \rightarrow \pi^0\pi e\nu$ } High Statistics
	$\Phi_{00} - \Phi_{+-}$ to a precision of $\pm 2^0$
1991 run	$\Phi_{00} - \Phi_{+-}$ to better than $\pm 1^0$
	Measurement of Φ_{+-}
	$BR(K_L \rightarrow \pi^0 e^+ e^-)$ to $\sim 10^{-10}$
	Study of $K_L \rightarrow \pi^0\gamma\gamma$
	Measurement of $\pi^0 \rightarrow e^+e^-$
1993/4 run (proposed CsI em calorimeter)	ε'/ε to $\sim$ 0.0001
	$BR(K_L \rightarrow \pi^0 e^+ e^-)$ to $\sim 10^{-11}$
1996 and on (proposed KAMI facility: -100 times TEV flux -enlarged CsI -new beam line)	ε'/ε to $\sim$ 0.00002 (if necessary)
	$K_L \rightarrow \pi^0 e^+ e^-$, $K_L \rightarrow \mu e$, $K_L \rightarrow \pi^0 \mu e$ } to $\sim 10^{-13}$
	$K_L \rightarrow \pi^0 \nu\nu$ to $\sim 10^{-11}$
	K_S physics

Results from NA31 at CERN and future plans

H. Wahl

NA31 experiment at CERN/SPS

1981/82 Proposal to measure $|\eta_{00}/\eta_{+-}|^2$...

1988 $\mathrm{Re}\,\varepsilon'/\varepsilon = (3.3 \pm 1.1)\,10^{-3}$

1987 $K_L \to 2\gamma/\mathrm{all} = (5.74 \pm 0.04 \pm 0.08 \pm 0.1)\,10^{-4}$ (10^5 events; η_{00})

$K_S \to 2\gamma / K_L \to 2\gamma = 2.3 \pm 1.0 \pm 0.1$

1988 $K_L \to \pi^0 e^+ e^- < 4 \times 10^{-8}$ (90% C.L.)

1990 $\arg(\eta_{+-}) = 46.9° \pm 2.2°$

$\arg(\eta_{00}) = 47.1° \pm 2.8°$

$\phi_{00} - \phi_{+-} = 0.2° \pm 2.9°$

$[m(K^0) - m(\bar{K}^0)]/m_K < 5 \times 10^{-18}$

$K_L \to e^+ e^- \gamma/\mathrm{all} = (9.2 \pm 0.5 \pm 0.5)\,10^{-6}$ [illegible]

$K_L \to \pi^0 \gamma\gamma/\mathrm{all} = (2.1 \pm 0.6)\,10^{-6}$ [illegible]

1990/1 $\mathrm{Re}\,\varepsilon'/\varepsilon = (1.9 \pm 1.1)\,10^{-3}$ prel.: for 1/3 of data

1991 $K_L \to 2e^+ 2e^-/\mathrm{all} = (4 \pm 3)\,10^{-8}$ [illegible]

A new measurement of ε'/ε in CP violating $K^o \rightarrow 2\pi$ decays

NA31 experiment at CERN:

CERN–Edinburgh–Mainz–Orsay–Pisa–Siegen Collaboration

Present experimental situation:

$\mathrm{Re}\ \varepsilon'/\varepsilon = (\ 3.3 \pm 1.1\ ) \times 10^{-3}$ (1988) NA31 at CERN

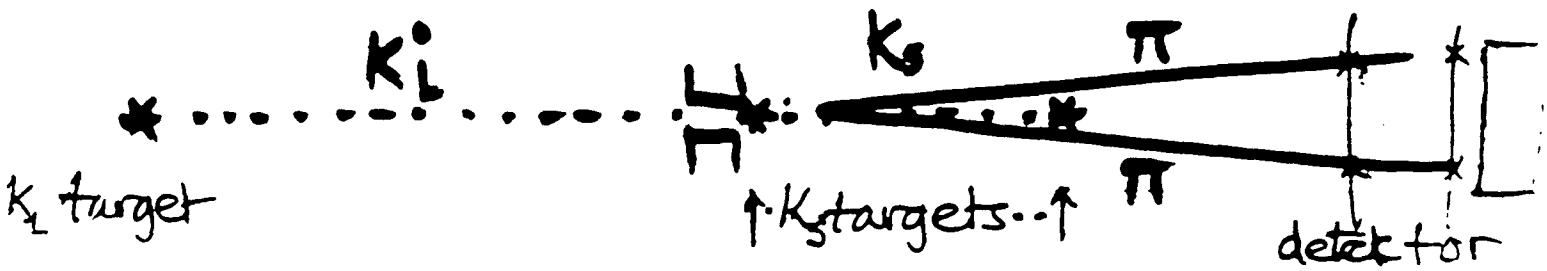
$= (-0.4 \pm 1.5\ ) \times 10^{-3}$ (1990) E731 at Fermilab

principle of the experiment:

$$\varepsilon'/\varepsilon = \frac{1}{6}\left[1 - \frac{\Gamma(K_L \to 2\pi^0)}{\Gamma(K_L \to \pi^+\pi^-)} : \frac{\Gamma(K_S \to 2\pi^0)}{\Gamma(K_S \to \pi^+\pi^-)}\right]$$

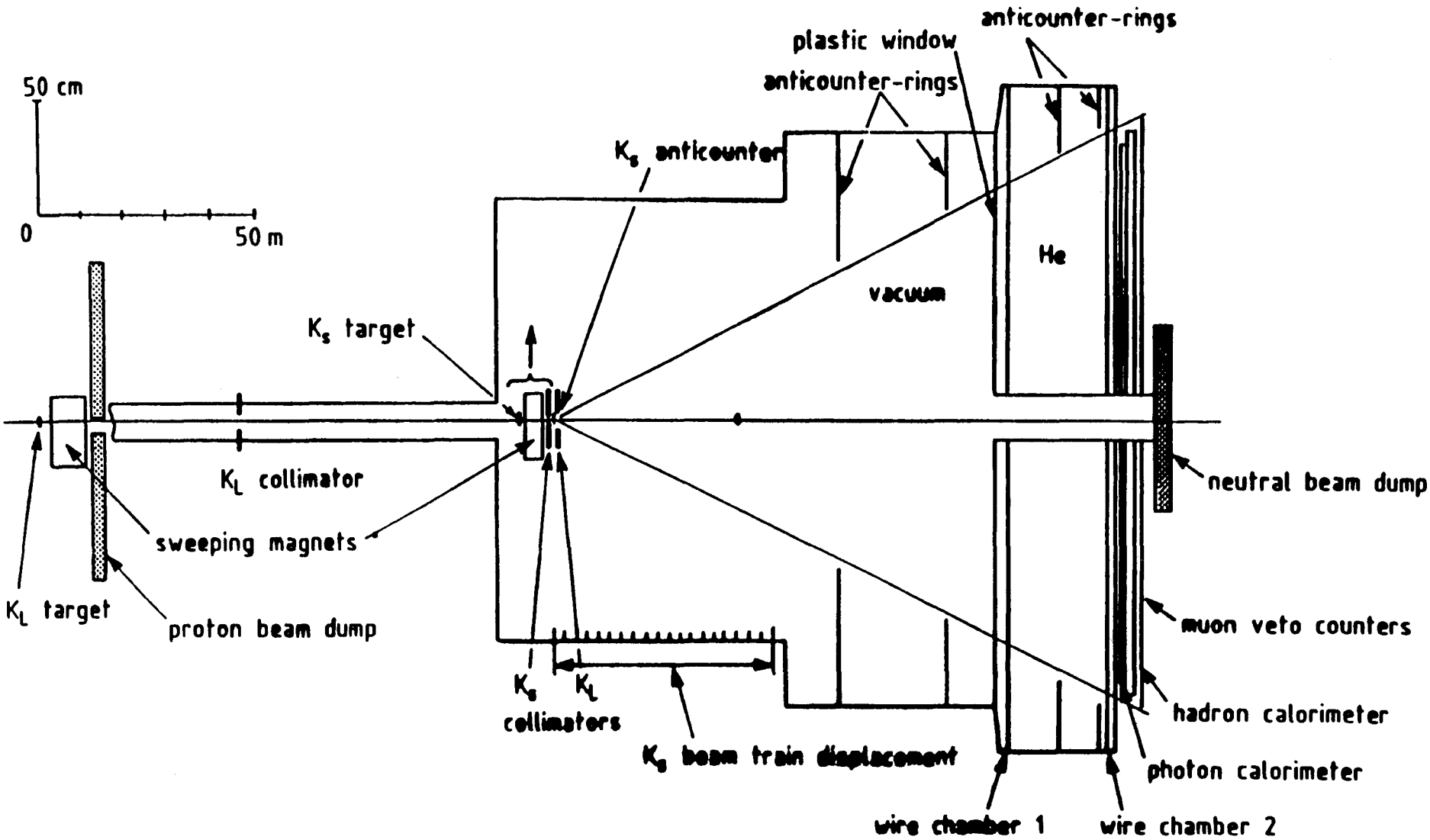
1 detector, $2\pi^0$ and $\pi^+\pi^-$ decays simultan

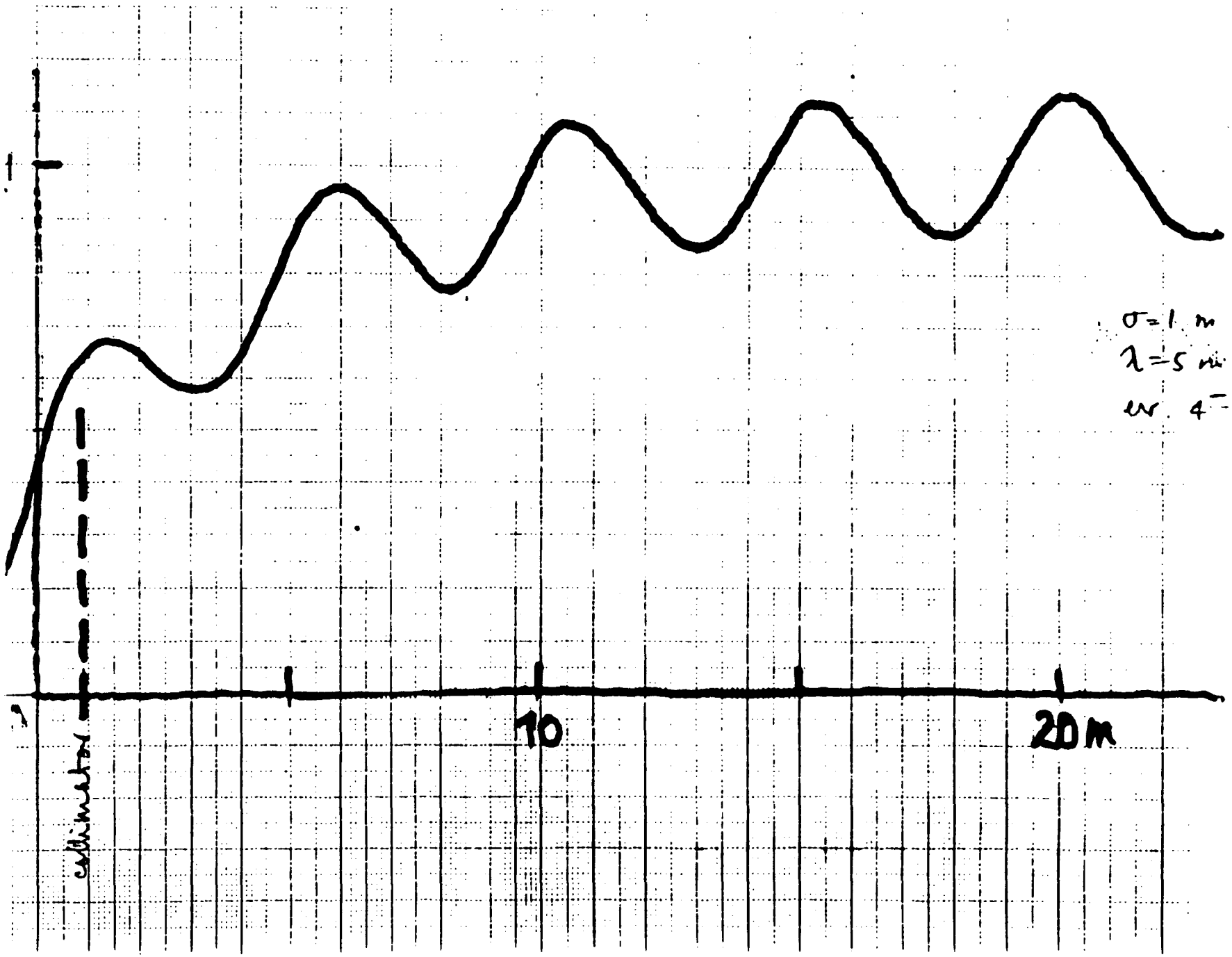
2 beams: K_L and K_S alternatively

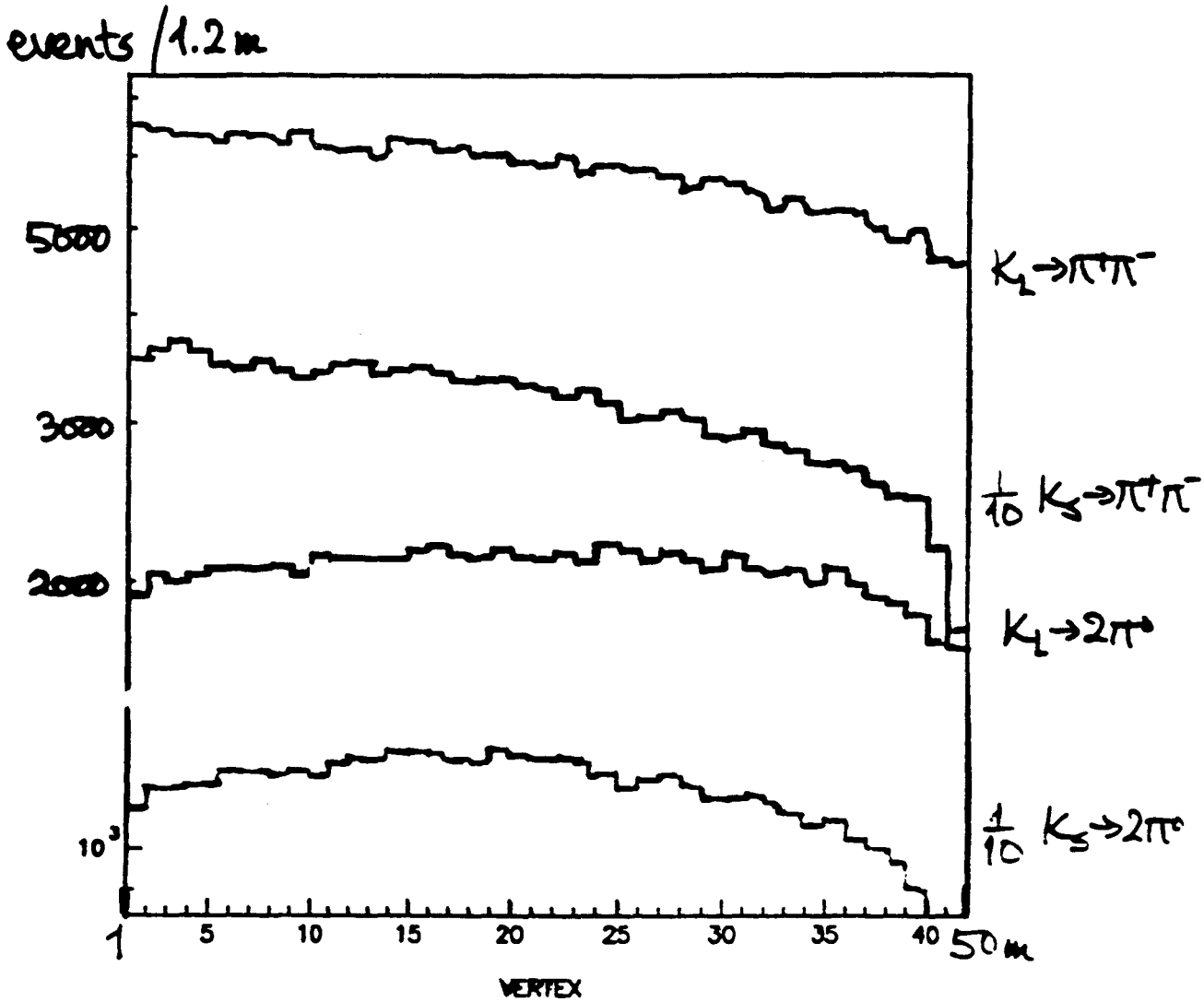


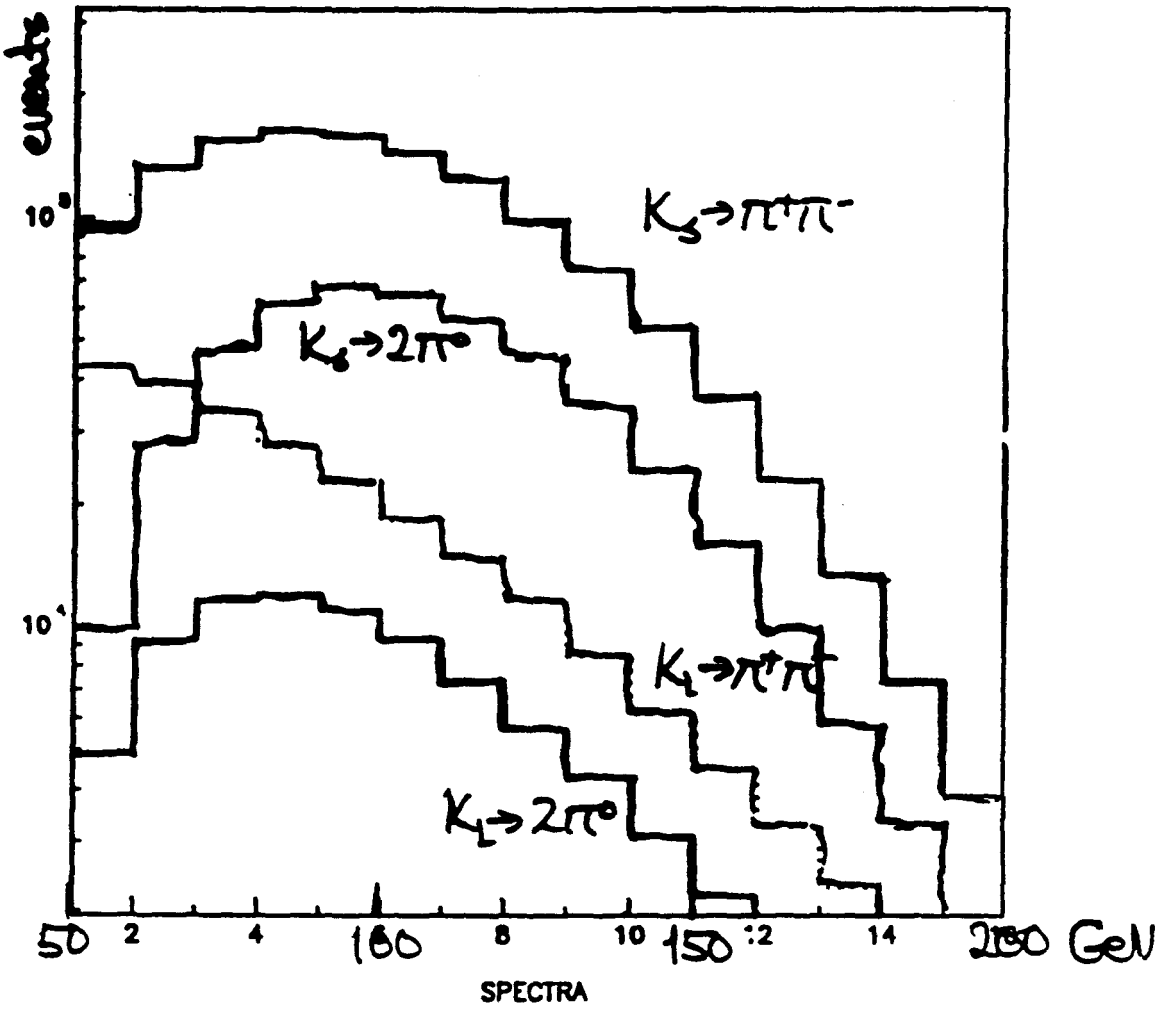
- moving K_S train covering 50 m K_L decay region
- detector stability: high efficiency
- calorimetry, no magnet
- no regenerator to produce K_S: low background

acceptance: coverage in double ratio


50 cm
0
50 m
anticounter-rings
plastic window
anticounter-rings
K_s anticounter
He
vacuum
K_s target
K_L collimator
neutral beam dump
sweeping magnets
K_L target
proton beam dump
muon veto counters
K_s K_L
collimators
hadron calorimeter
K_s beam train displacement
photon calorimeter
wire chamber 1
wire chamber 2


σ = 1 m
λ = 5 m
ev. 4
10
20 m
calibration


events / 1.2 m
5000
3000
2000
10^3
1
5
10
15
20
25
30
35
40
50 m
VERTEX
$K_L \to \pi^+\pi^-$
$\frac{1}{10}$ $K_S \to \pi^+\pi^-$
$K_L \to 2\pi^0$
$\frac{1}{10}$ $K_S \to 2\pi^0$


events
10^3
10^1
$K_S \to \pi^+\pi^-$
$K_S \to 2\pi^0$
$K_L \to \pi^+\pi^-$
$K_L \to 2\pi^0$
50
2
4
100
8
10
150
12
14
200
GeV
SPECTRA

NA31′ upgrade

transition radiation detector

4 x 200 polyethylene foils 20 μ thick
4 x-ray detectors = wire ch with 5 cm Xe + He

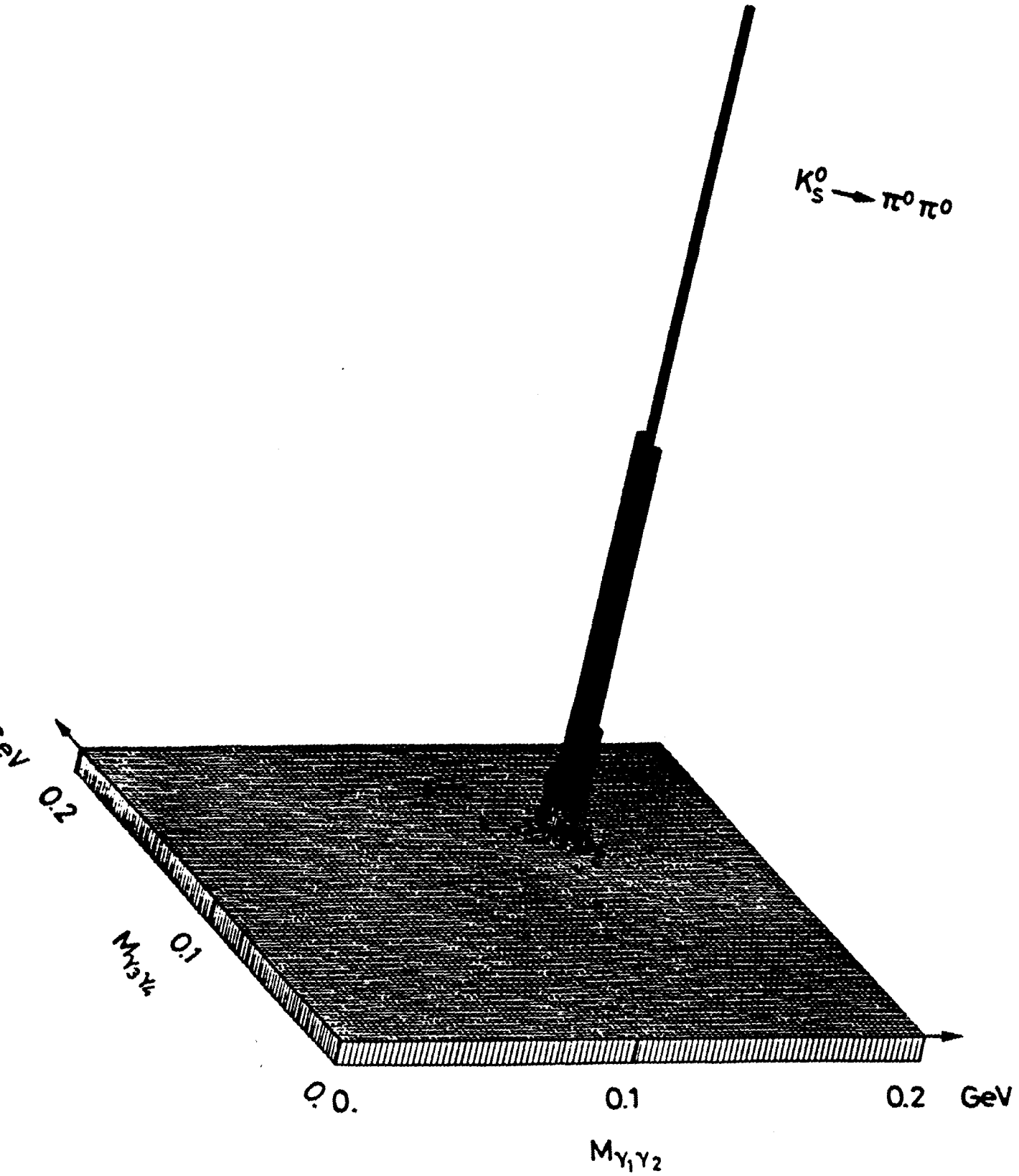
new beam collimation

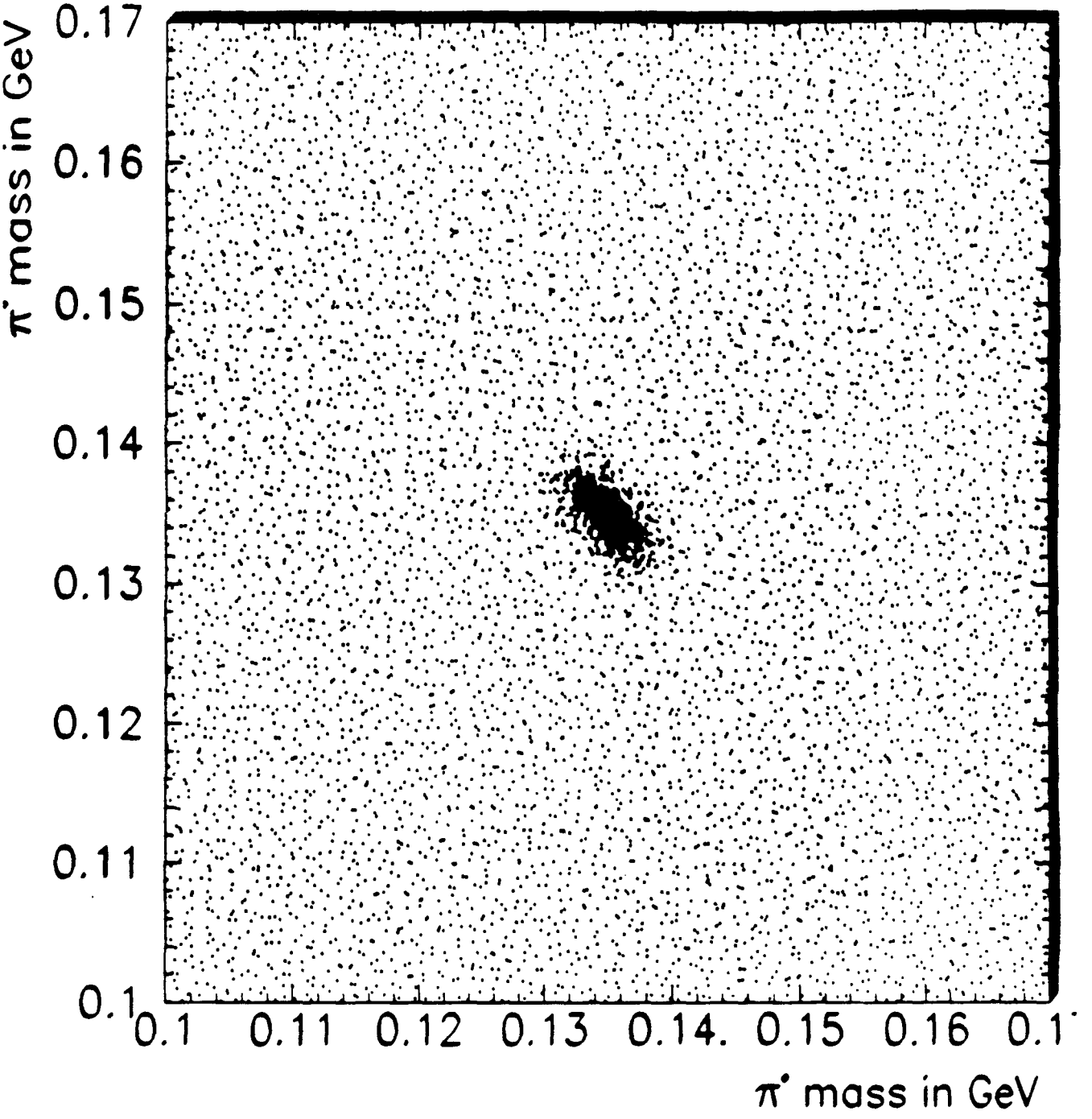
more γ veto counters

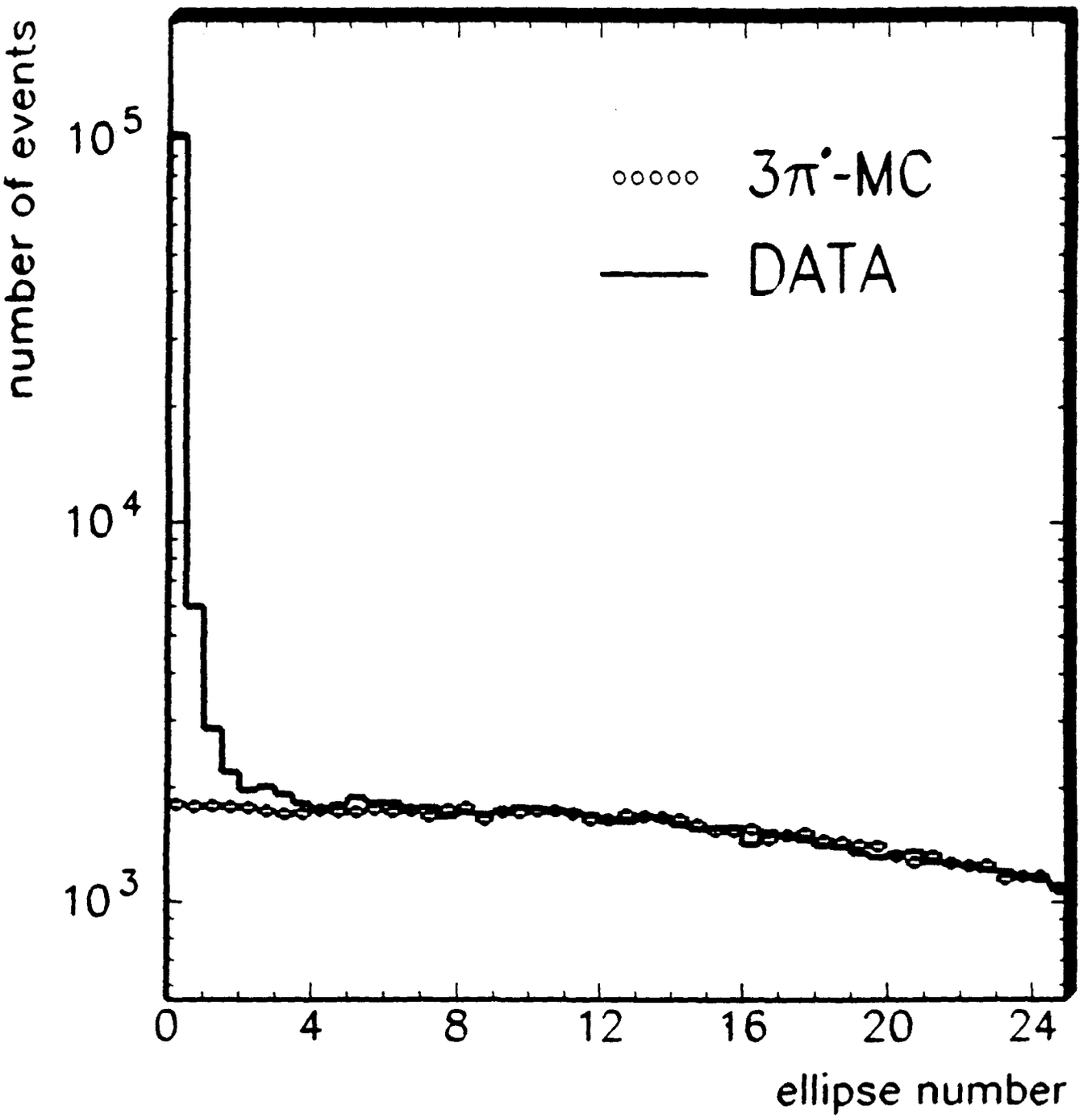
K_S @ 360 GeV , K_L @ 450 GeV

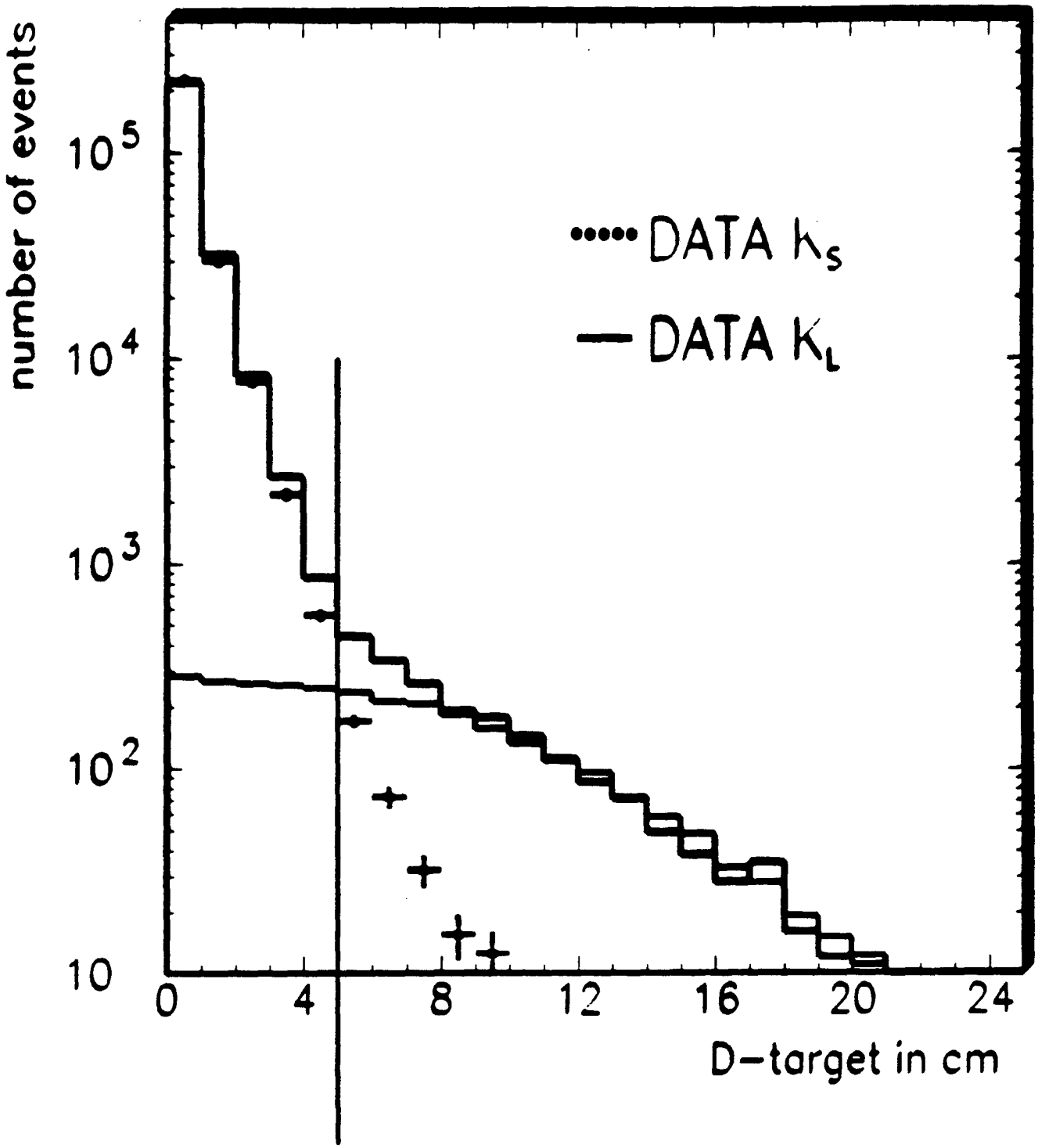
data taken 1988 : being analysed
~ 60 000 $K_L \to 2\pi^0$ equivalent

next run scheduled for July 1989

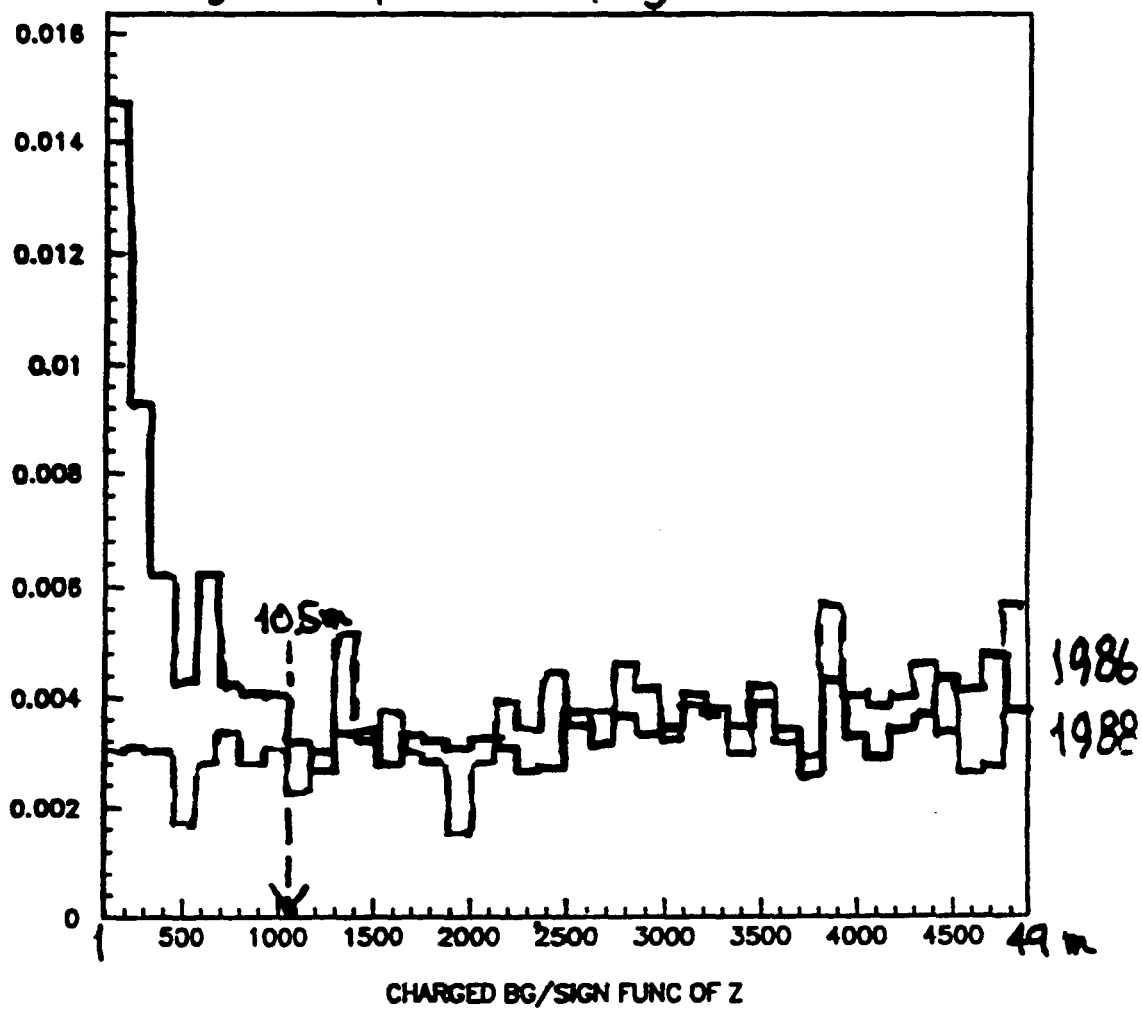

$K_S^0 \to \pi^0 \pi^0$
0.2
0.1
$M_{\gamma_3\gamma_4}$
0.
0.1
0.2
GeV
$M_{\gamma_1\gamma_2}$


0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
π° mass in GeV
0.1
0.11
0.12
0.13
0.14.
0.15
0.16
0.1
π° mass in GeV

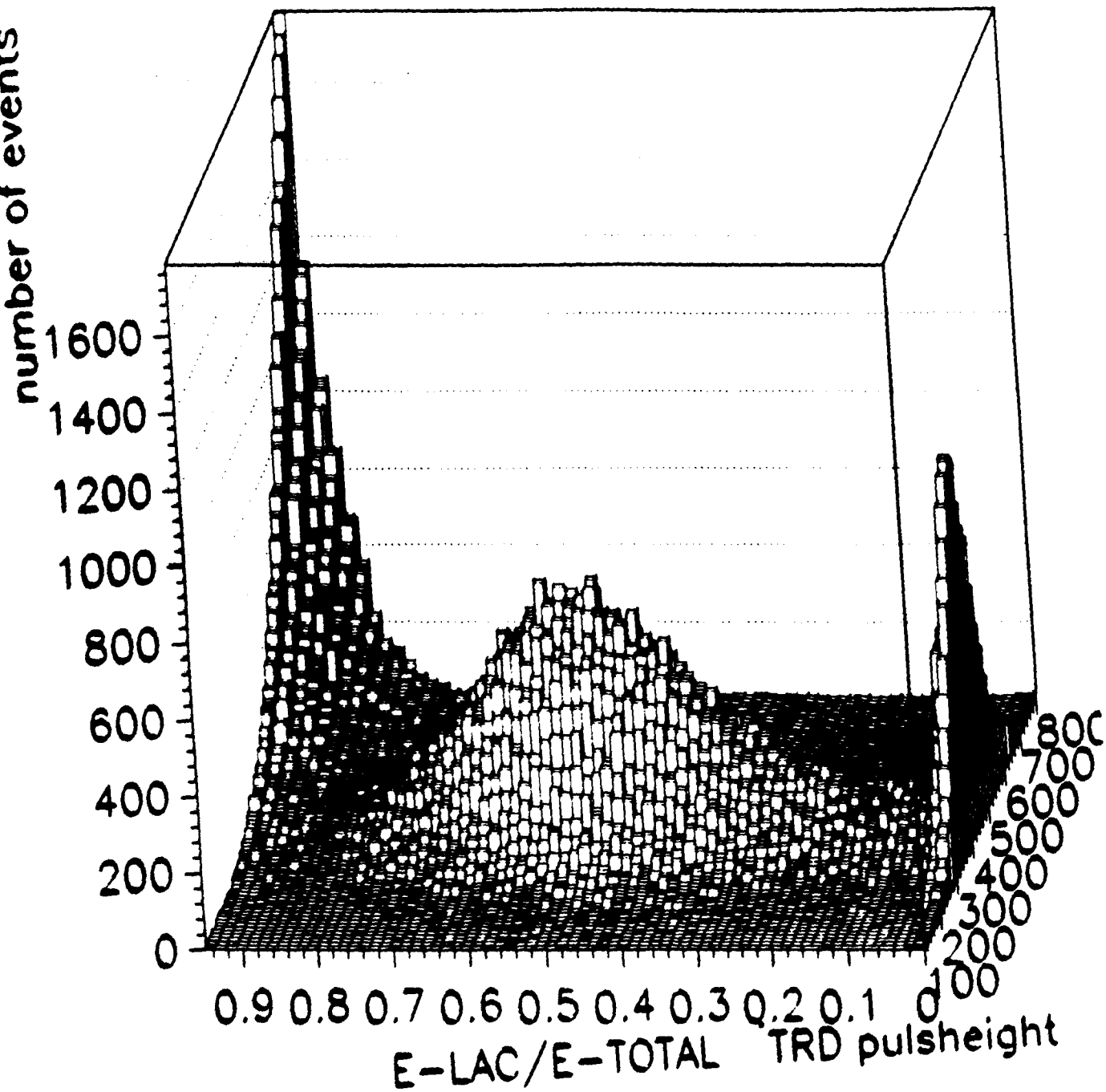

number of events
10^5
10^4
10^3
$3\pi^{\circ}$-MC
DATA
0
4
8
12
16
20
24
ellipse number


number of events
10^5
10^4
10^3
10^2
10
0
4
8
12
16
20
24
D–target in cm
DATA K_S
DATA K_L

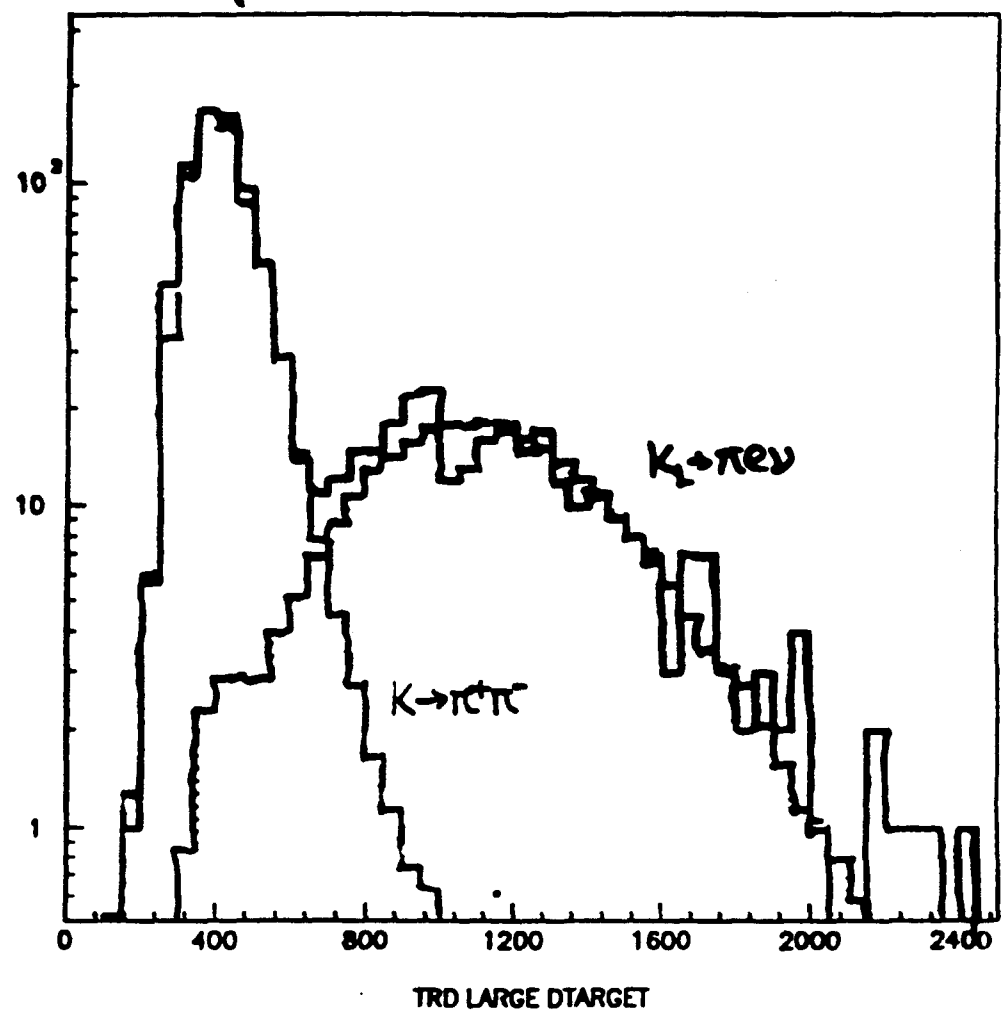
$K_L \to \pi^+\pi^-$ background/control region



vertex


number of events
1600
1400
1200
1000
800
600
400
200
0
0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0
E-LAC/E-TOTAL
800
700
600
500
400
300
200
100
TRD pulsheight

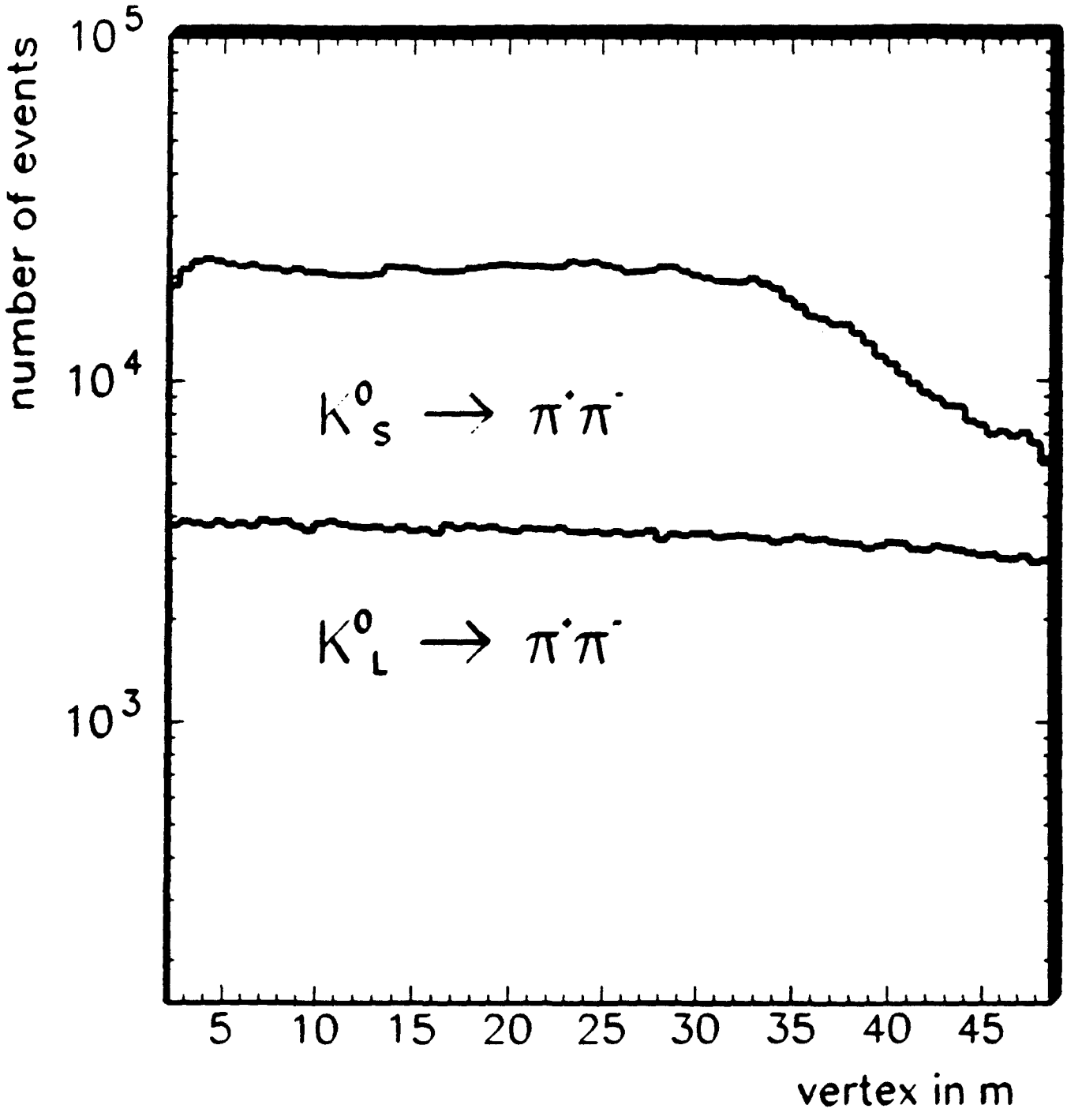
events D_T = 7-12 cm

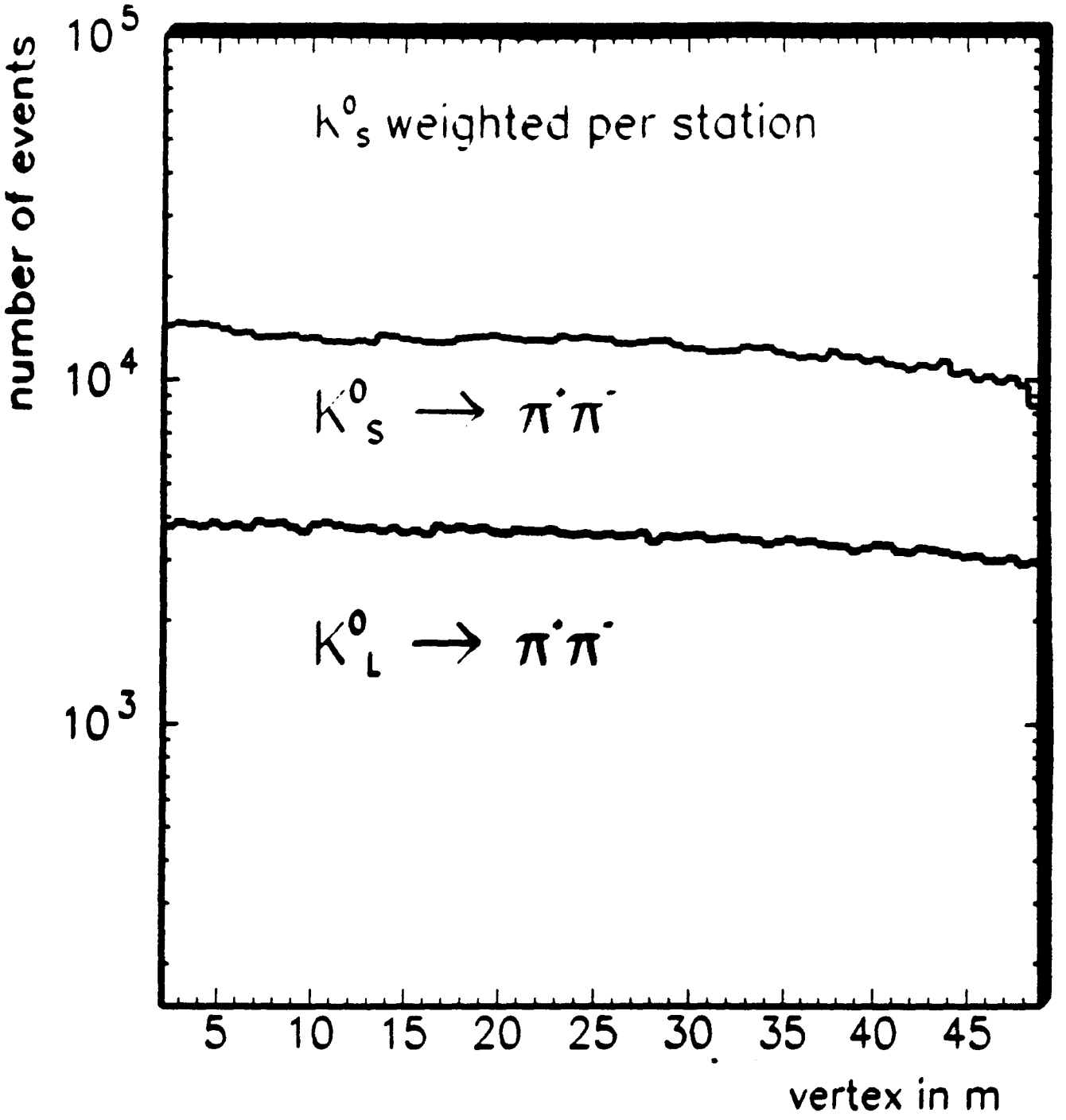


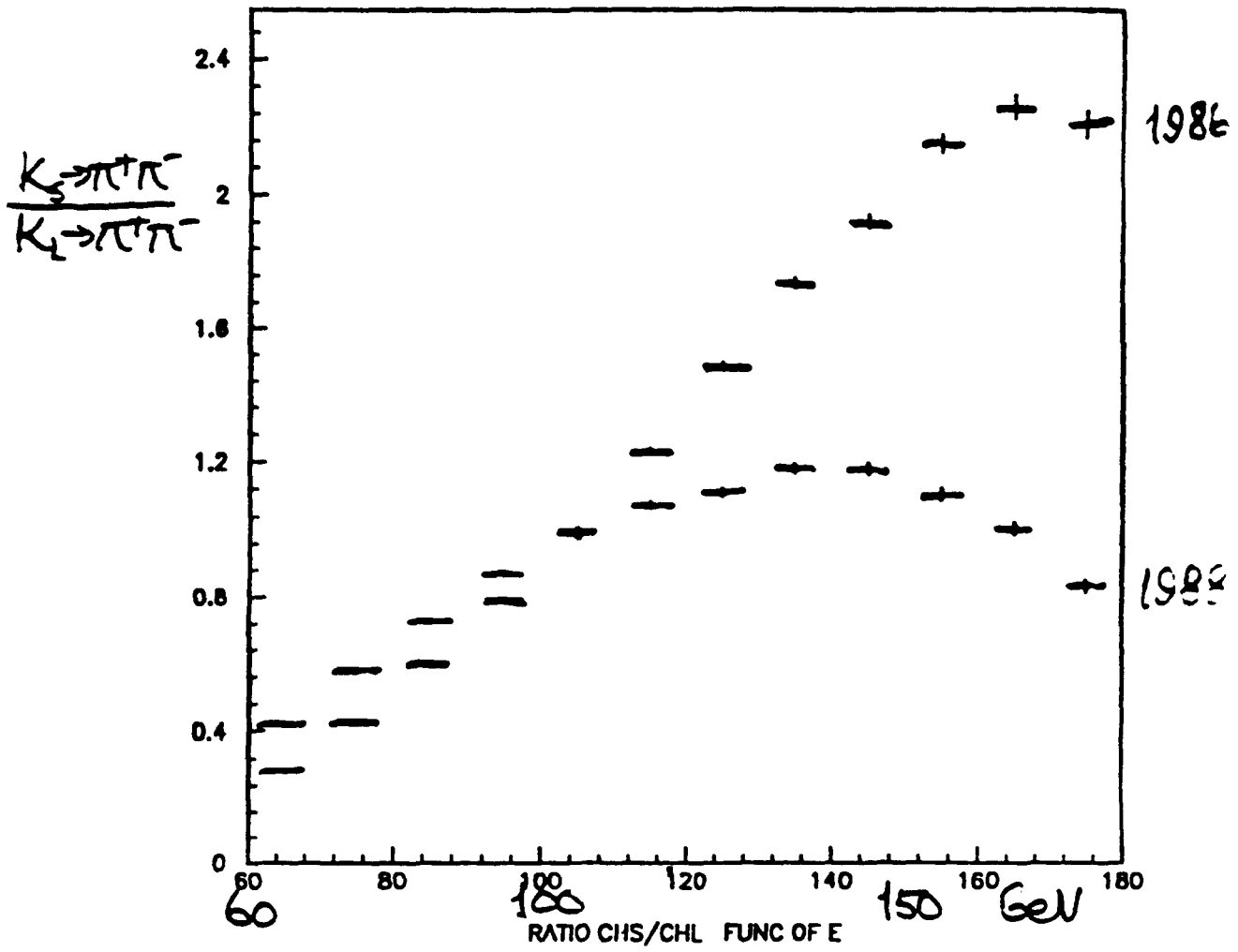
TRD pulse-height

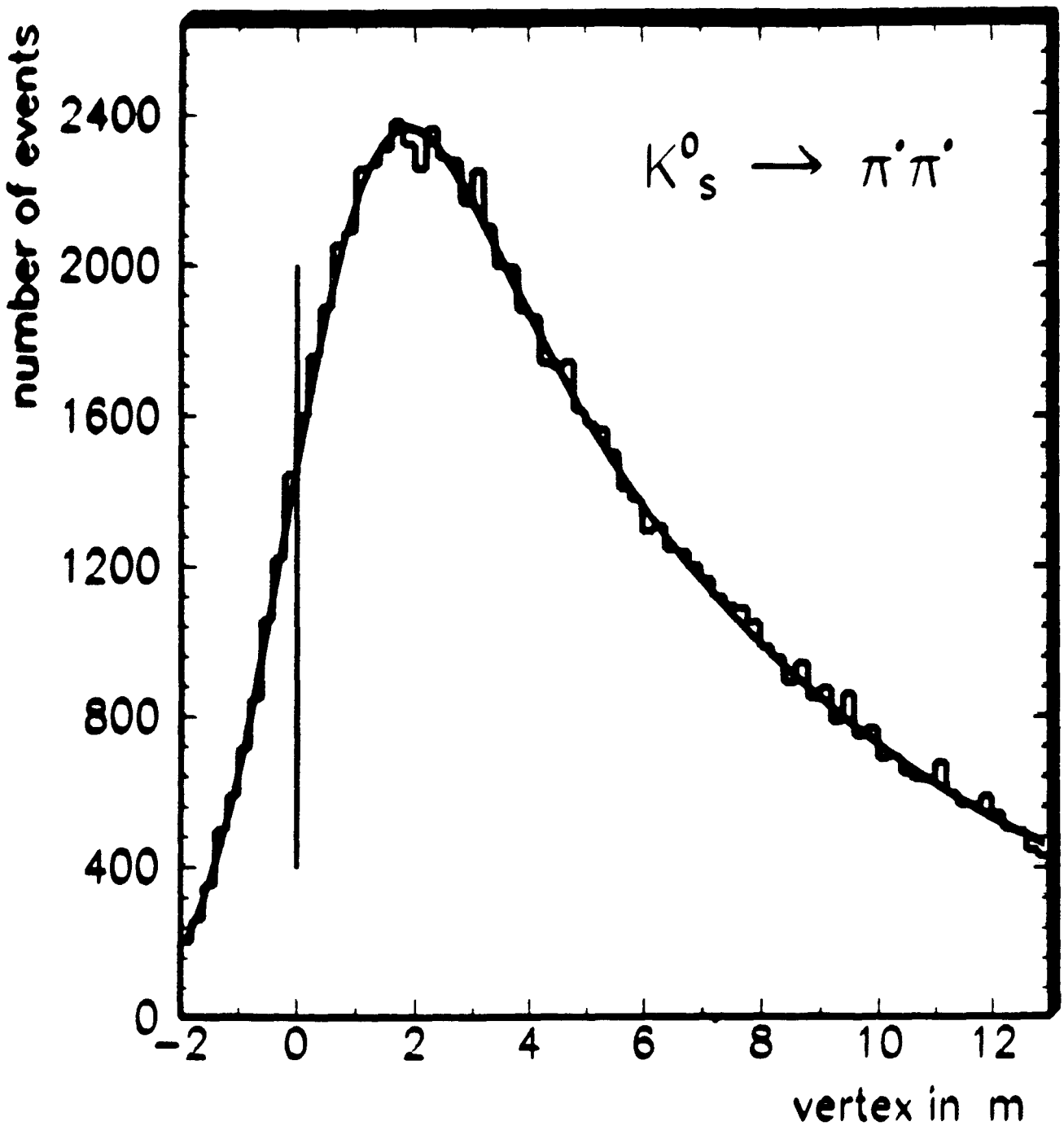
$K_L \to \pi^+\pi^-$ backgrounds

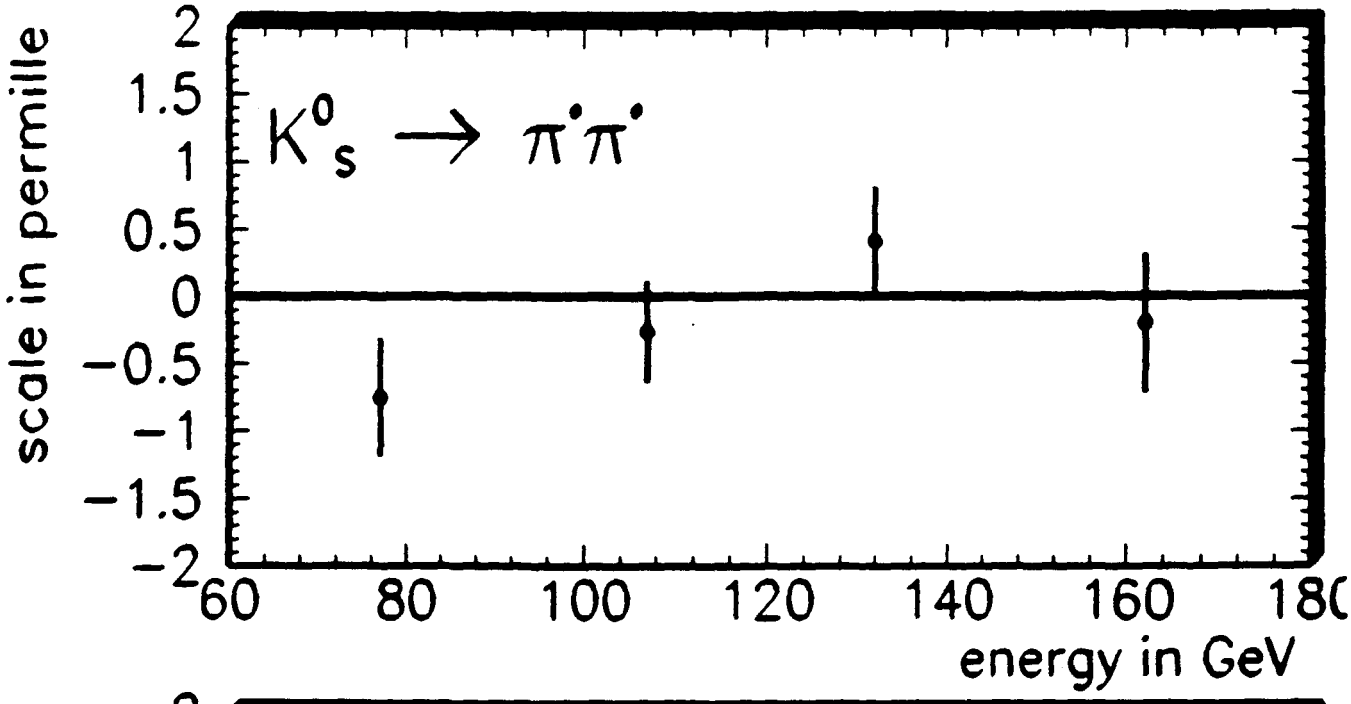
0.16%	$\pi^+\pi^-\pi^0$, 1γ identified	
0.48%	$\pi e \nu$	extrapolated in d_t
0.18%	$\pi \mu \nu$	extrapolated in d_t
0.12%	n-interactions in ref. gas	
0.9 %		

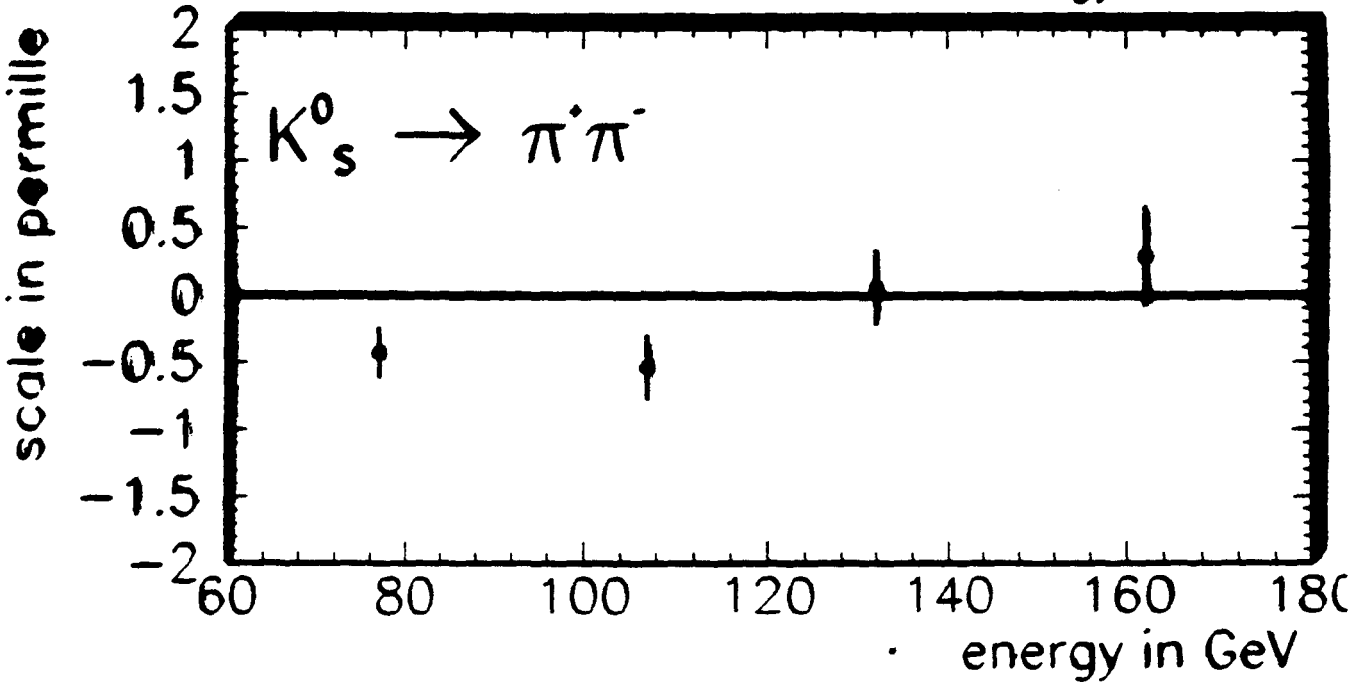

number of events
10^5
10^4
10^3
$K^0_S \rightarrow \pi^+\pi^-$
$K^0_L \rightarrow \pi^+\pi^-$
5
10
15
20
25
30
35
40
45
vertex in m


number of events
10^5
10^4
10^3
K^0_S weighted per station
$K^0_S \rightarrow \pi^+\pi^-$
$K^0_L \rightarrow \pi^+\pi^-$
5
10
15
20
25
30
35
40
45
vertex in m


$\frac{K_S \to \pi^+\pi^-}{K_L \to \pi^+\pi^-}$
2.4
2
1.6
1.2
0.8
0.4
0
60
80
100
120
140
160
180
60
100
150
GeV
RATIO CHS/CHL FUNC OF E
1986
1989


number of events
2400
2000
1600
1200
800
400
0
-2
0
2
4
6
8
10
12
vertex in m
$K^0_s \longrightarrow \pi^+\pi^-$


$K^0_s \rightarrow \pi^+\pi^+$
scale in permille
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
60
80
100
120
140
160
180
energy in GeV


$K^0_s \rightarrow \pi^+\pi^-$
scale in permille
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
60
80
100
120
140
160
180
energy in GeV

Average double ratio

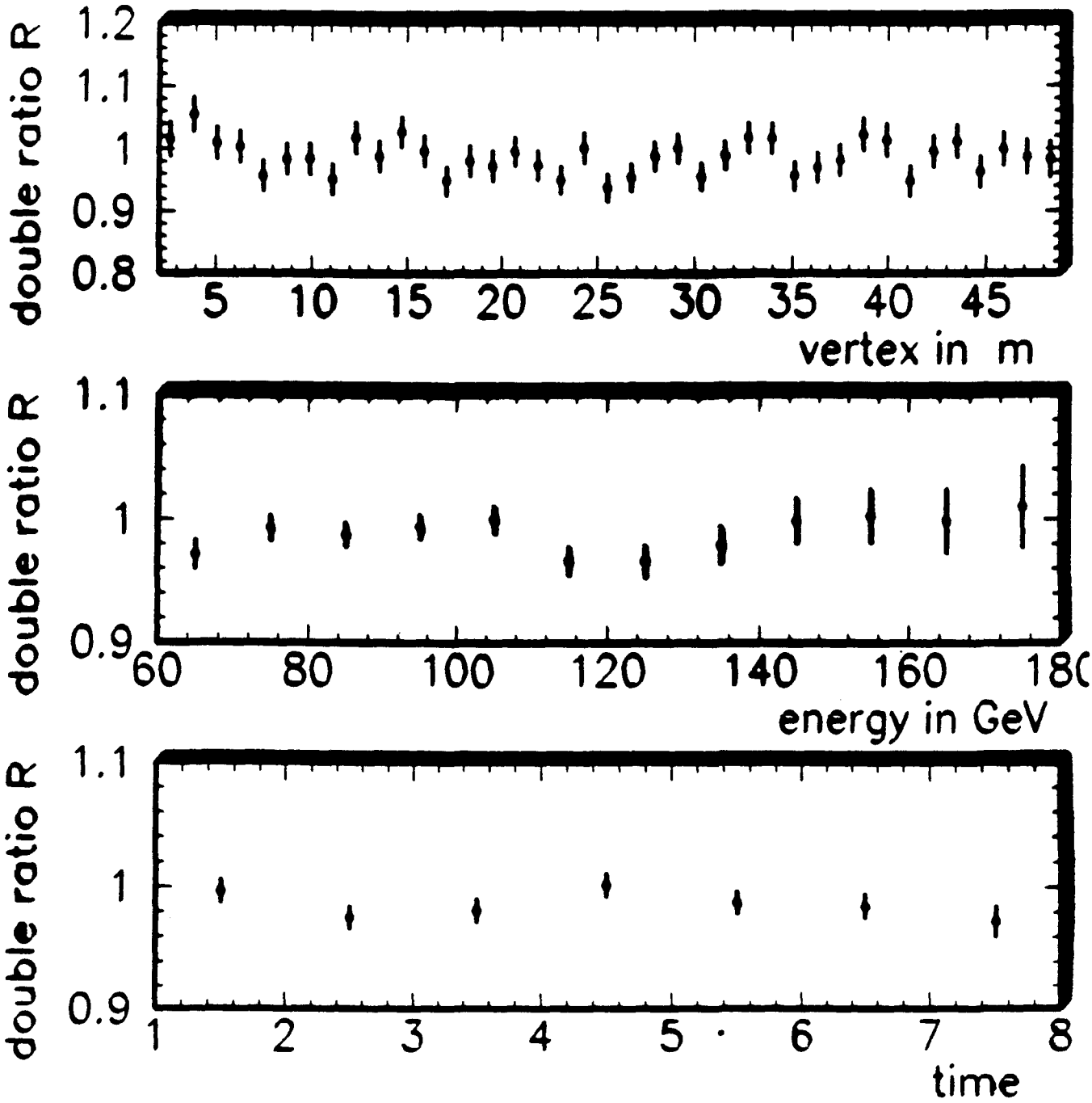
7 time periods/data sets

12 energy bins 60 – 180 GeV

39 vertex bins 2 – 49 m

Statistics:

	$2\pi^0$	$\pi^+\pi^-$
K_L	108 k	285 k
K_S	562 k	1379 k


double ratio R
1.2
1.1
1
0.9
0.8
5
10
15
20
25
30
35
40
45
vertex in m
double ratio R
1.1
1
0.9
60
80
100
120
140
160
180
energy in GeV
double ratio R
1.1
1
0.9
1
2
3
4
5
6
7
8
time

Double ratio $R = \frac{L \to 2\pi}{L \to \pi^+\pi^-} \cdot \frac{S \to \pi^+\pi^-}{S \to 2\pi}$

raw result	$R = 0.983 \pm 0.004$ (stat)
Monte Carlo	$+0.0012 \pm 0.0009 \pm 0.001$
Accidentals	$+0.0009 \pm 0.0023 \pm 0.002$
R ...	0.985
$2\pi^0$ ineff in 8 mm Pb	$+.0005 \pm .0001$
2 cm gap Pb/Sz	$+.002 \pm .0002$
(AFBI) trigger ineff	$+.001 \pm .00015$
R corrected	$0.989 \pm 0.005 \pm 0.004$

$$\mathrm{Re}\, \epsilon'/\epsilon = (1.9 \pm 1.1) \times 10^{-3}$$

Systematic uncertainties on double ratio R

backgrounds

$2\pi^0$	$\pm 5\%$ of 3.4%	$\pm 2.2\times10^{-3}$
$\pi^+\pi^-$	$\pm 0.15\%$	

accidental effects	$\pm 2\times10^{-3}$
energy calibration	$\pm 1.4\times10^{-3}$
Monte Carlo acceptance resolution, scattering	$\pm 1\times10^{-3}$
	$\pm 4\times10^{-3}$

NA31': CERN-Edinburgh-Mainz-Orsay-Pisa-Siegen Collaboration

$$R = 0.989 \pm 0.005 \pm 0.004$$

$$\mathrm{Re}\,\varepsilon'/\varepsilon = 0.0019 \pm 0.0011$$

	Signal Events	Background	
$K_L \to 2\pi^0$	108000	3.3 ± 0.2 %	$3\pi^0$
$K_L \to \pi^+\pi^-$	285000	0.8 ± 0.1 %	$\pi e\nu$, $\pi\mu\nu$
$K_S \to 2\pi^0$	562000	$<.1 \pm 0.01$ %	
$K_S \to \pi^+\pi^-$	1379000	0.1 ± 0.01 %	scatt. K_S
		4.2 ± 0.22 %	

Systematic uncertainties in double ratio R

Backgrounds	± 0.22 %	$\to 2\pi^0$: $\pm 5\%$, $\pi\pi$: $\pm 20\%$
Energy scale	± 0.14 %	$\to \pi^+\pi^-$
Accidentals	± 0.20 %	
Acceptance	± 0.1 %	K_S scattering
	± 0.4 %	

NA31: CERN-Dortmund-Edinburgh-Mainz-Orsay-Pisa-Siegen Collaboration

(Burkhardt et al. 1988)

$$R = 0.980 \pm 0.004 \pm 0.005$$

$$\mathrm{Re}\,\varepsilon'/\varepsilon = (3.3 \pm 1.1) \times 10^{-3}$$

	Signal Events	Background
$K_L \to 2\pi^0$	109000	4.0 ± 0.2 %
$K_L \to \pi^+\pi^-$	295000	0.6 ± 0.1 %
$K_S \to 2\pi^0$	932000	<0.1 %
$K_S \to \pi^+\pi^-$	2300000	<0.1 %
		4.6 ± 0.22 %

Systematic uncertainties in double ratio R

Backgrounds	± 0.3 %
Energy scale	± 0.3 %
Accidentals	± 0.2 %
Acceptances	± 0.2 %
Varia	± 0.1 %
	± 0.5 %

1986 : $R = 0.980 \pm 0.004 \pm 0.005$

1988 : $R = 0.989 \pm 0.005 \pm 0.004$

correlated syst. error ± 0.0034

combined double ratio :

$$R = 0.984 \pm 0.0105$$

NA31 : $\boxed{Re\,\varepsilon'/\varepsilon = (2.7 \pm 0.9) \times 10^{-3}}$

E731 $= (-0.4 \pm 1.4 \pm 0.6) \times 10^{-3}$

Average $^{NA31}_{E731}$ $= (1.9 \pm 0.8) \times 10^{-3}$

A precision measurement of ε'/ε in CP violating $K^0 \to 2\pi$ decays

CERN SPSC proposal P253

CERN Laboratory
Austria : Vienna Inst.
France : Saclay Lab.
Germany : Mainz + Siegen Univ.
Italy : Perugia, Pisa, Torino Univ.
UK : Edinburgh Univ.

Aim : Search for direct CP violation; confirmation of NA31 result.

New proposal:

1. At least 10× the statistics of present experiments
2. Reduction of systematic uncertainties by a factor 3

Principal elements:

1. Concurrent detection of all 4 decay modes in the same detector
2. Tagging of K_S and K_L: coll. beams
3. Fast LKr calorimeter 2.4 m ϕ for photon detection
4. Magnet spectrometer for $\pi^+\pi^-$ to reduce background to 10^{-3} level
5. New method of analysis to reduce systematic errors

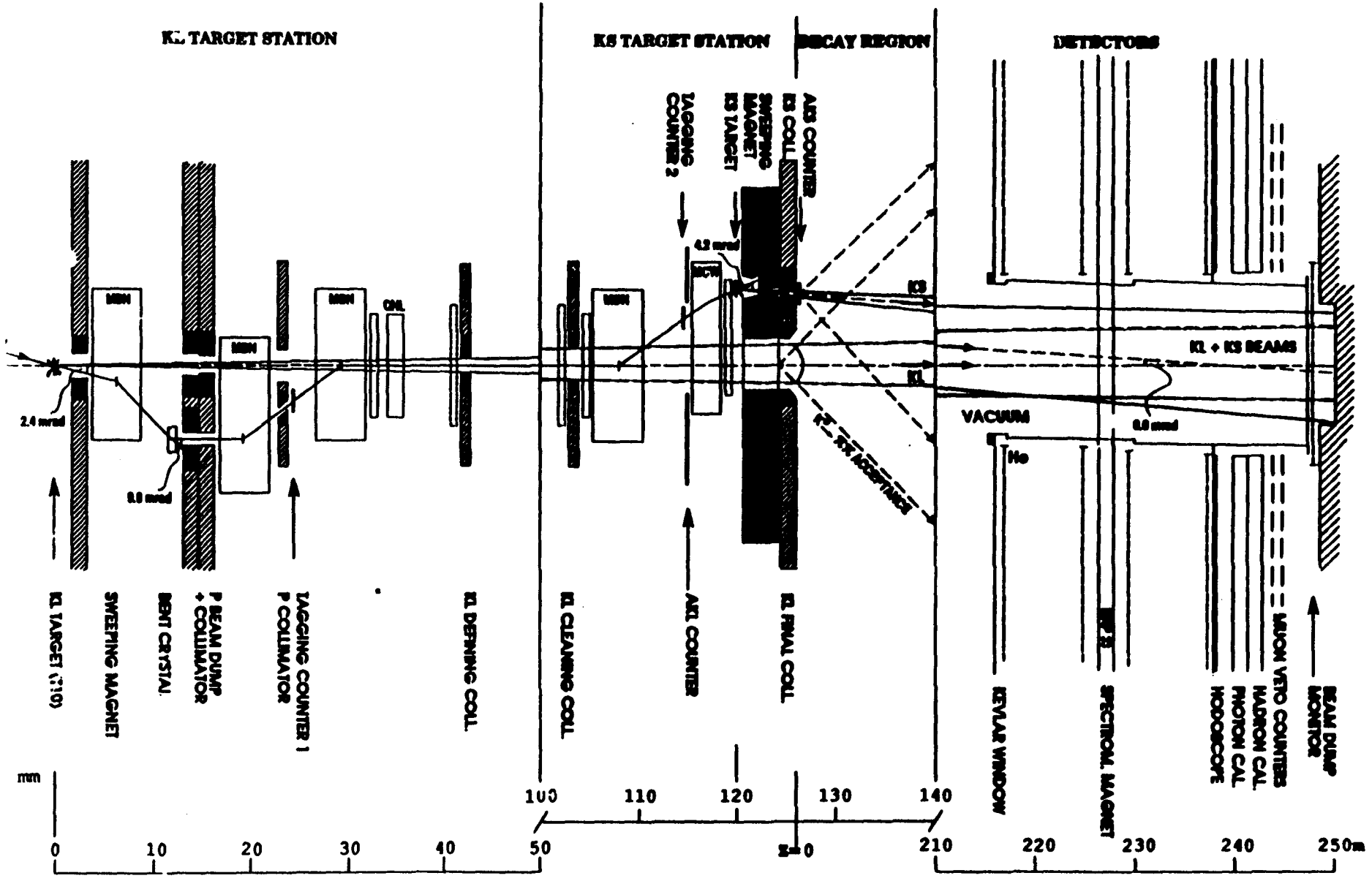


Fig. 1 Schematic layout of combined K_L and K_S beams (vertical section)

LKr Calorimeter

Nominal 2.4 m ϕ +5%
1.2 m depth (25 X_0)

Rates ~ 1 MHz

Energy resol. < $3\%/\sqrt{E}$ ⊕ 0.5%

RH calibration ~10^{-3} (stability)

1 γ space resolution ~ 1 mm

2 γ separation ~ 4 cm

Time resolution < 1 ns

40 MHz FADC read-out

2×2 cm² (tower) cell structure

11000 electronic channels

Cold preamp per (70 pF input capa

Noise ~ 2 MeV/ch ; 30 MeV/ch

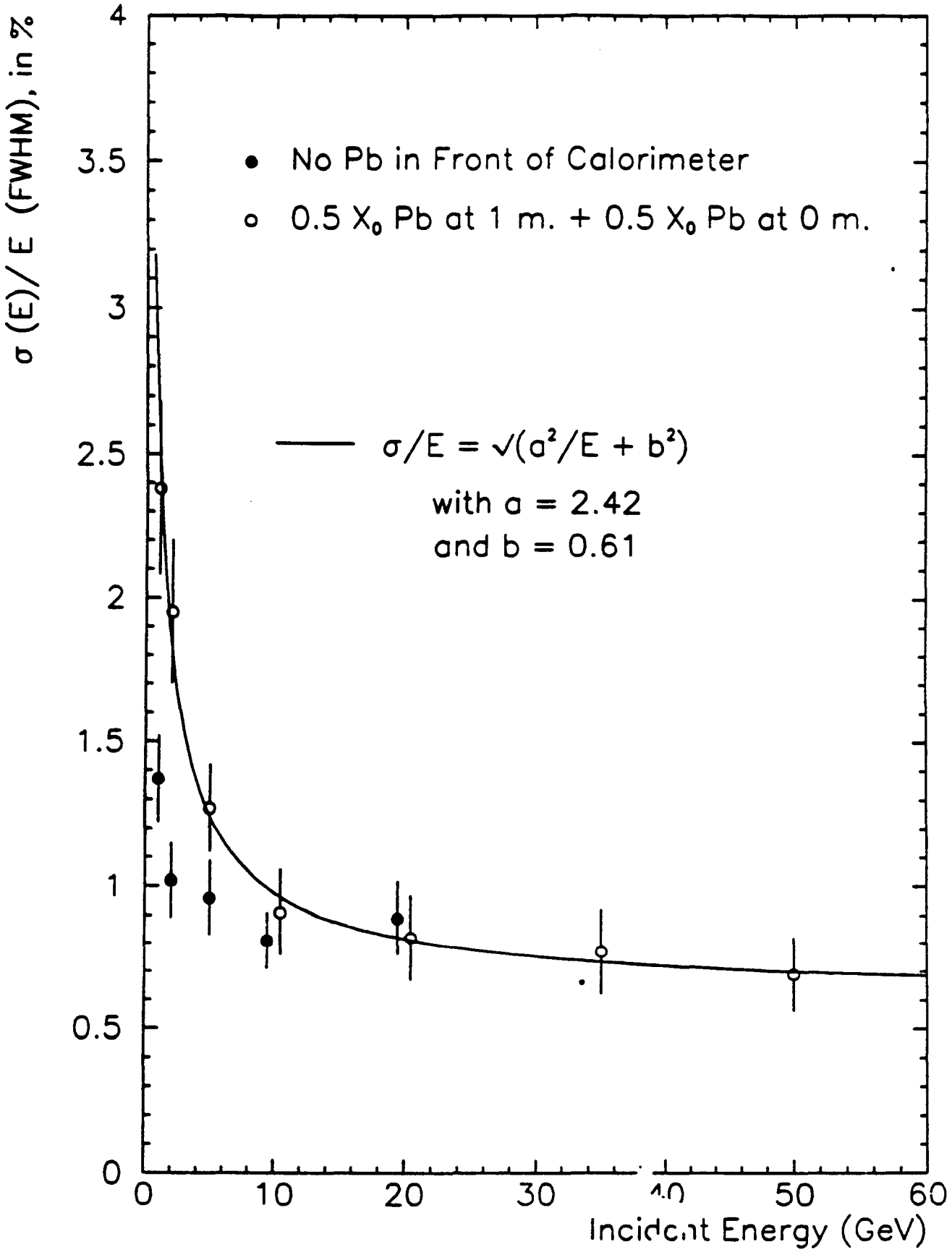
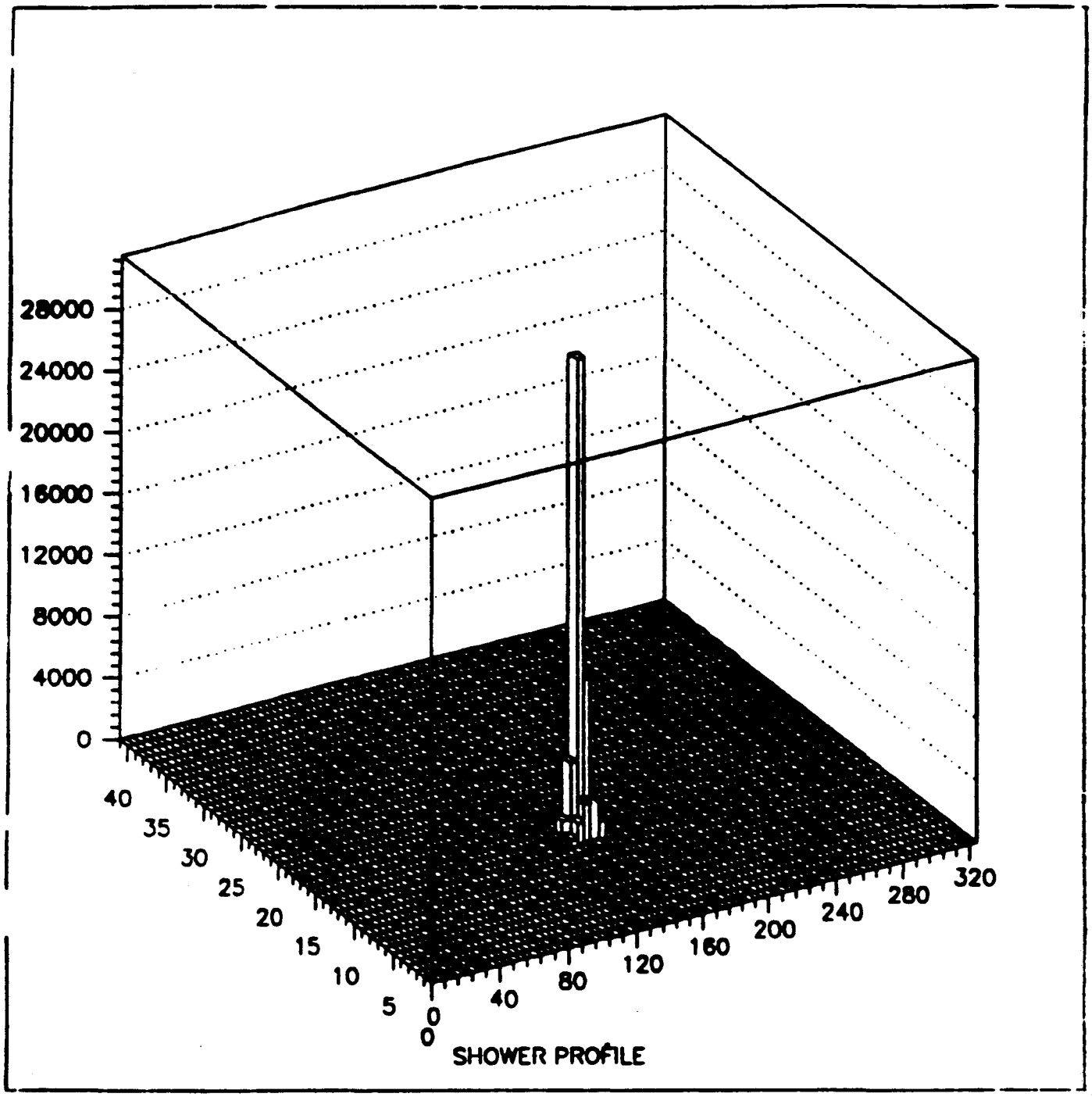


Fig 6 Resolution of liquid xenon calorimeter


28000
24000
20000
16000
12000
8000
4000
0
40
35
30
25
20
15
10
5
0
0
40
80
120
160
200
240
280
320
SHOWER PROFILE

RARE K DECAYS

(A REVIEW OF RECENT
EXPERIMENTAL RESULTS)

M. SCHMIDT
(YALE)

TOPICS & MODES TO BE DISCUSSED

- FORBIDDEN DECAYS

  LEPTON NUMBER VIOLATION

  $K_L \to \mu e$ (1)

  $K^+ \to \pi^+ \mu^+ e^-$ (4)

- SUPPRESSED DECAYS (FCNC)

  $K_L \to \mu\mu$ (2) $(K_L \to ee\gamma)$ (3)

  $K^+ \to \pi \nu \bar{\nu}$ (5)

  $K^+ \to \pi^+ e^+ e^-$ (7)

  $K^+ \to \pi^+ \mu^+ \mu^-$ (8)

- CP VIOLATING DECAYS

  $K_L \to \pi^0 e^+ e^-$ (6) $(K_L \to \pi^0 \gamma\gamma$ (9), $K_L \to ee\gamma\gamma$ (10)

- STATUS & PROSPECTS

BNL E777/E851 $K^+ \to \pi^+ \mu^+ e^-$, $\pi^+ e^+ e^-$

BNL - PSI - Washington - Yale

BNL E780/E845 $K_L \to \mu e, ee, \mu\mu, \pi^0 ee, ee\gamma$

BNL - Vassar - Yale

BNL E787 $K^+ \to \pi^+ \nu\bar{\nu}, \pi^+ \mu^+ \mu^-, \pi^+ \gamma\gamma, \pi^+ f$

BNL - LANL - Princeton - TRIUMF

BNL E791 $K_L \to \mu e, ee, \mu\mu$

Irvine - UCLA - LANL - U. Penn - Stanford - Temple - UT Austin - William & Mary

CERN NA31 $K_L \to \pi^0 ee, \pi^0 \gamma\gamma, e^+ e^- \gamma, \gamma\gamma$

CERN - Edinburgh - Mainz - Orsay - Pisa - Siegen

FNAL E731 $K_L \to \pi^0 ee, \pi^0 \gamma\gamma$

Chicago - Elmhurst - FNAL - Princeton - Saclay

KEK E137 $K_L \to \mu e, ee, \mu\mu$

KEK - Kyoto - Tohoku - Tokyo

(~ 200 physicists)

Lepton Number Violation

definitely beyond the Standard Model

processes with $\Delta N_\mu \neq 0$ $\Delta N_e \neq 0$ are apparently forbidden but we really don't know why

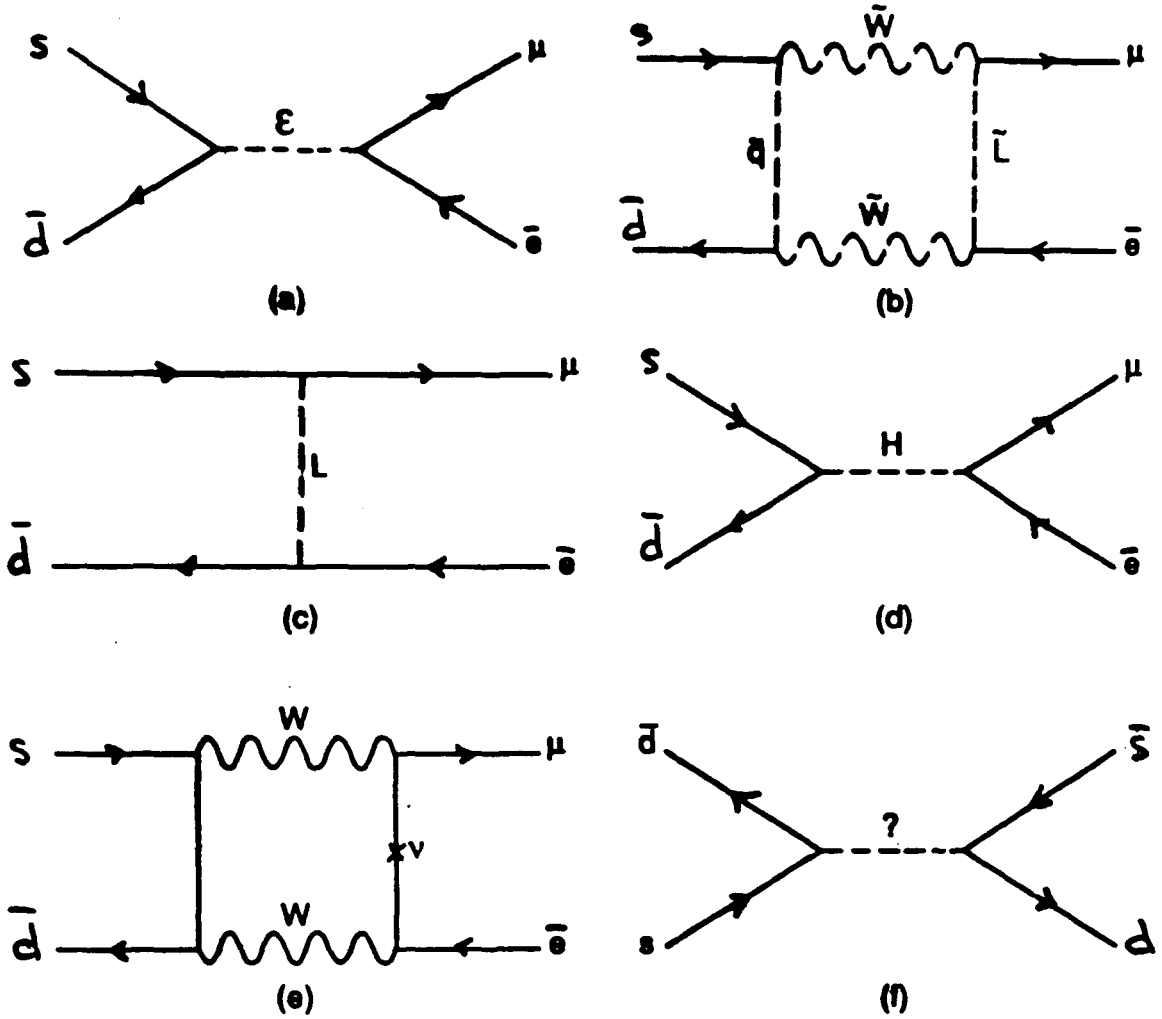
classic tests:

$$\Gamma(\mu \to e\gamma) < 4.9 \cdot 10^{-11}$$

$$\Gamma(\mu \to 3e) < 10^{-12}$$

$$\frac{\Gamma(\mu^- S \to e^- S)}{\Gamma(\mu^- S \to e^- \pi^*)} < 7 \cdot 10^{-11}$$

$K_L \to \mu e$ from physics beyond the Standard Model



Feynman diagrams for various ways of violating lepton flavor number, and the one for K^0 oscillation

(a) extended technicolor

(b) SUSY

(c) leptoquarks

(d) Higgs (extra)

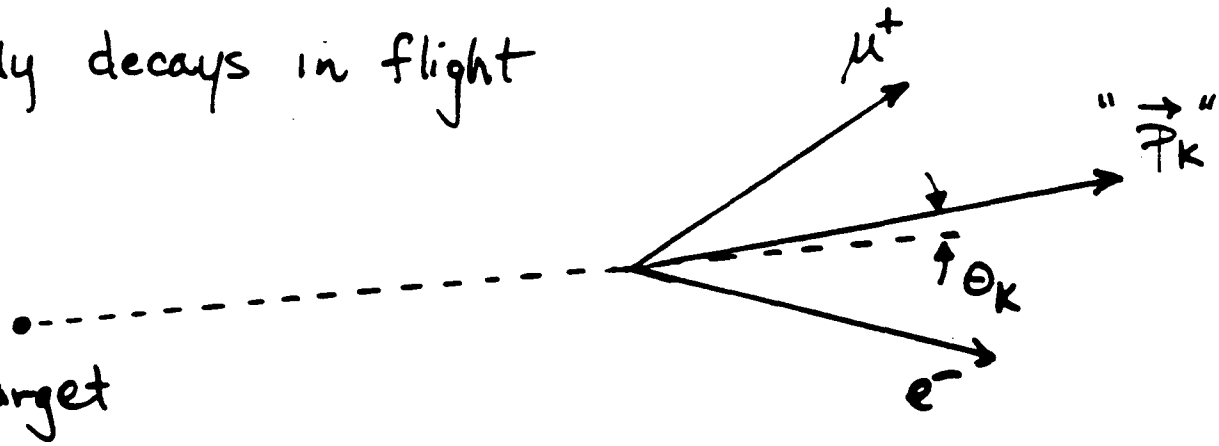
(e) ν mixing

(f) extended technicolor, extra Higgs $(\Delta S = 2)$

$K_L \to \mu e$

experimental method:

study decays in flight

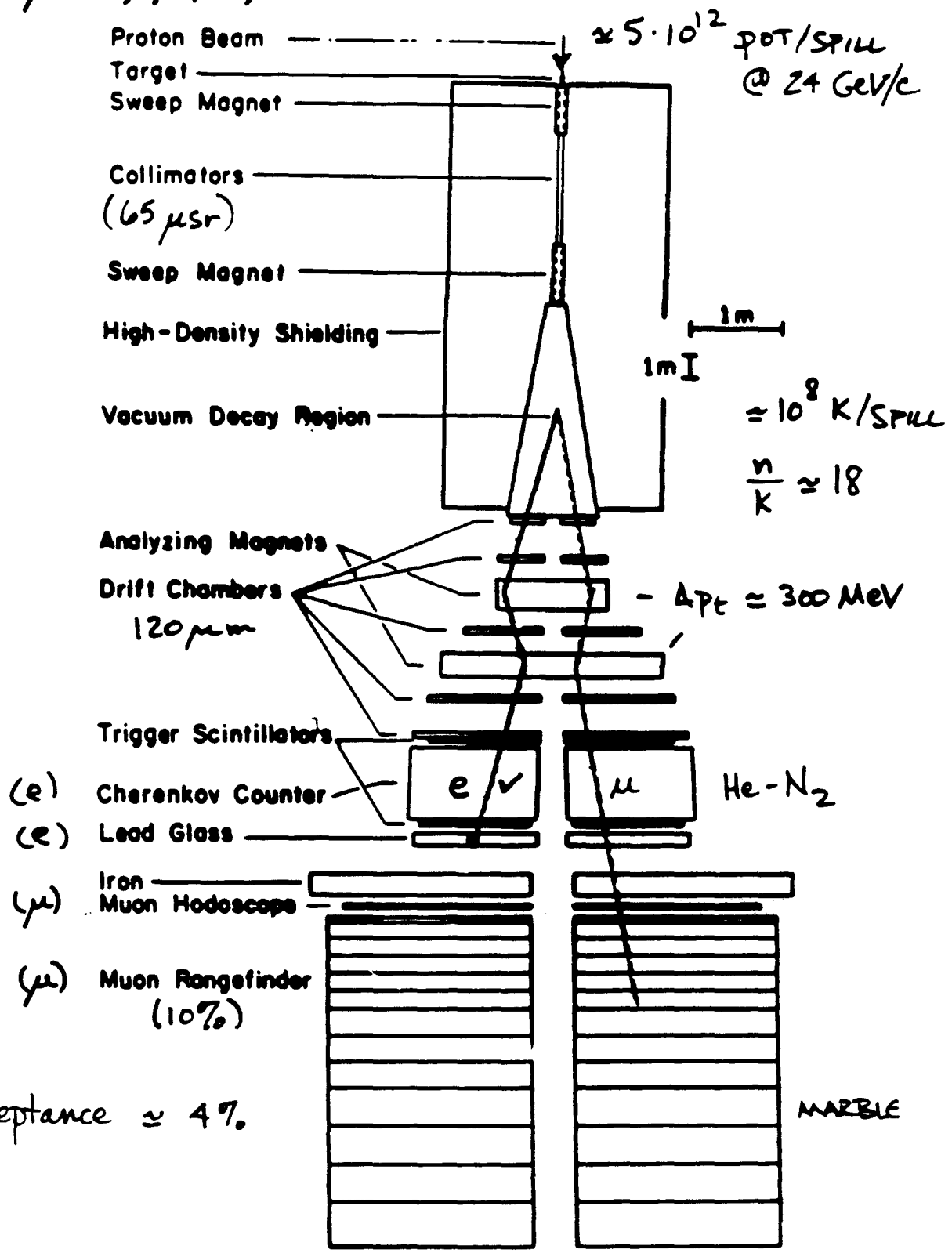


require: $m_{\mu e} \approx m_K$ & $\theta_K \approx 0$

rely on kinematic reconstruction to suppress background from $K_L \to \pi e \nu$
↳ "μ"

$K_L^0 \to \mu e, \mu\mu, ee$

BNL E791



Acceptance ≈ 4%

$P_K \sim 4 - 12$ GeV/c

BNL E791
(1988 data)

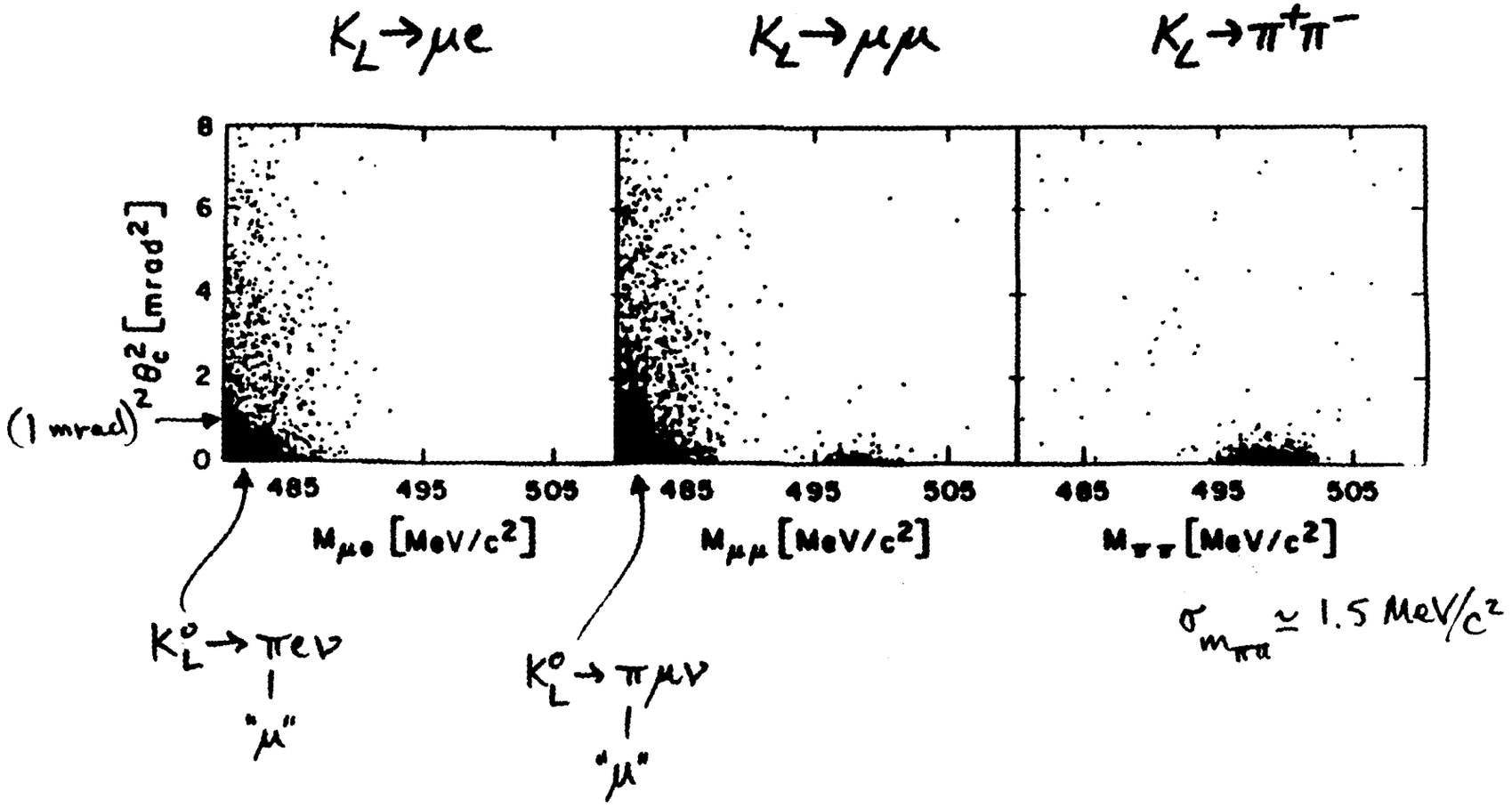
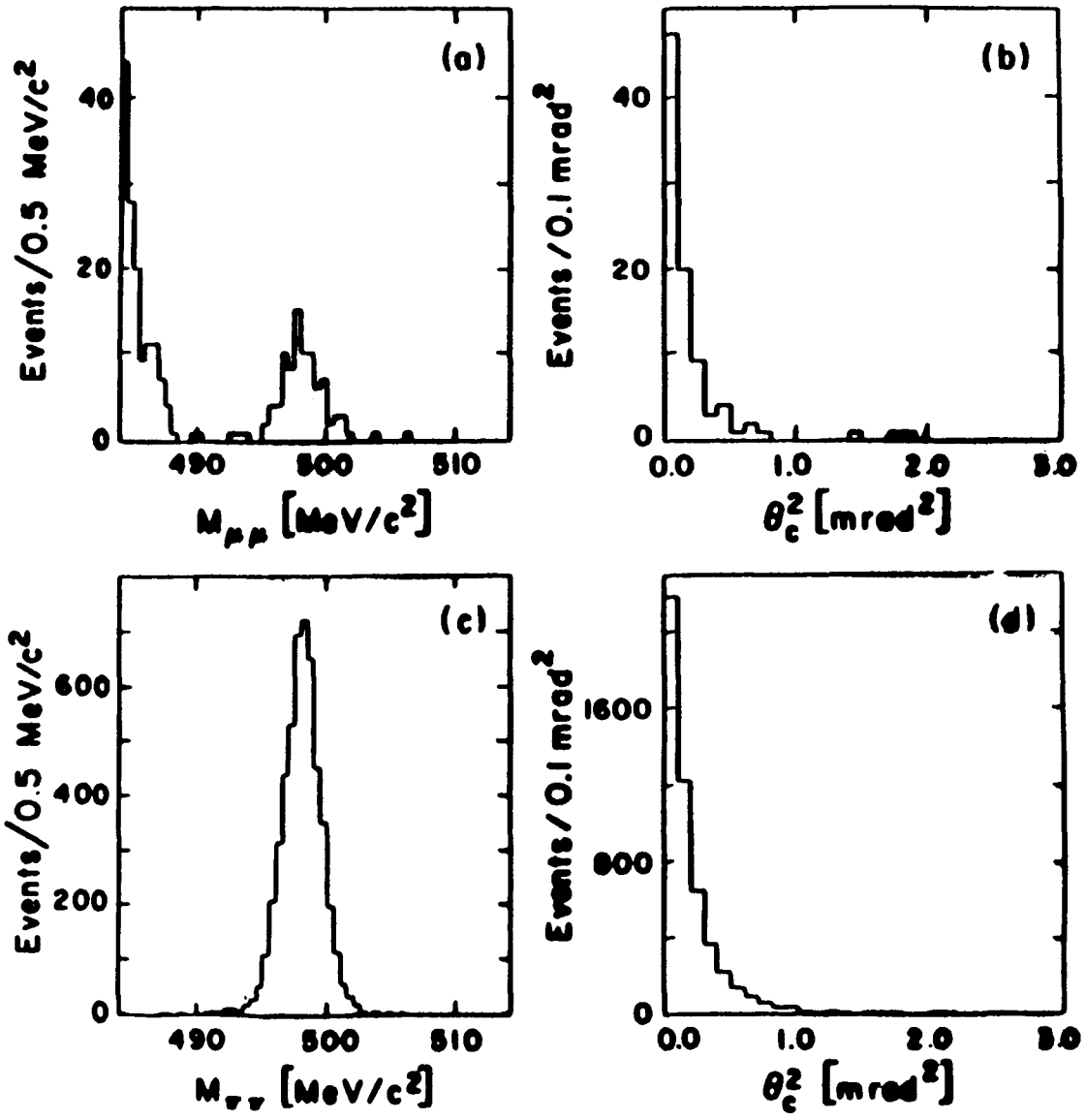


FIGURE 2

BNL E791
(1988 data)

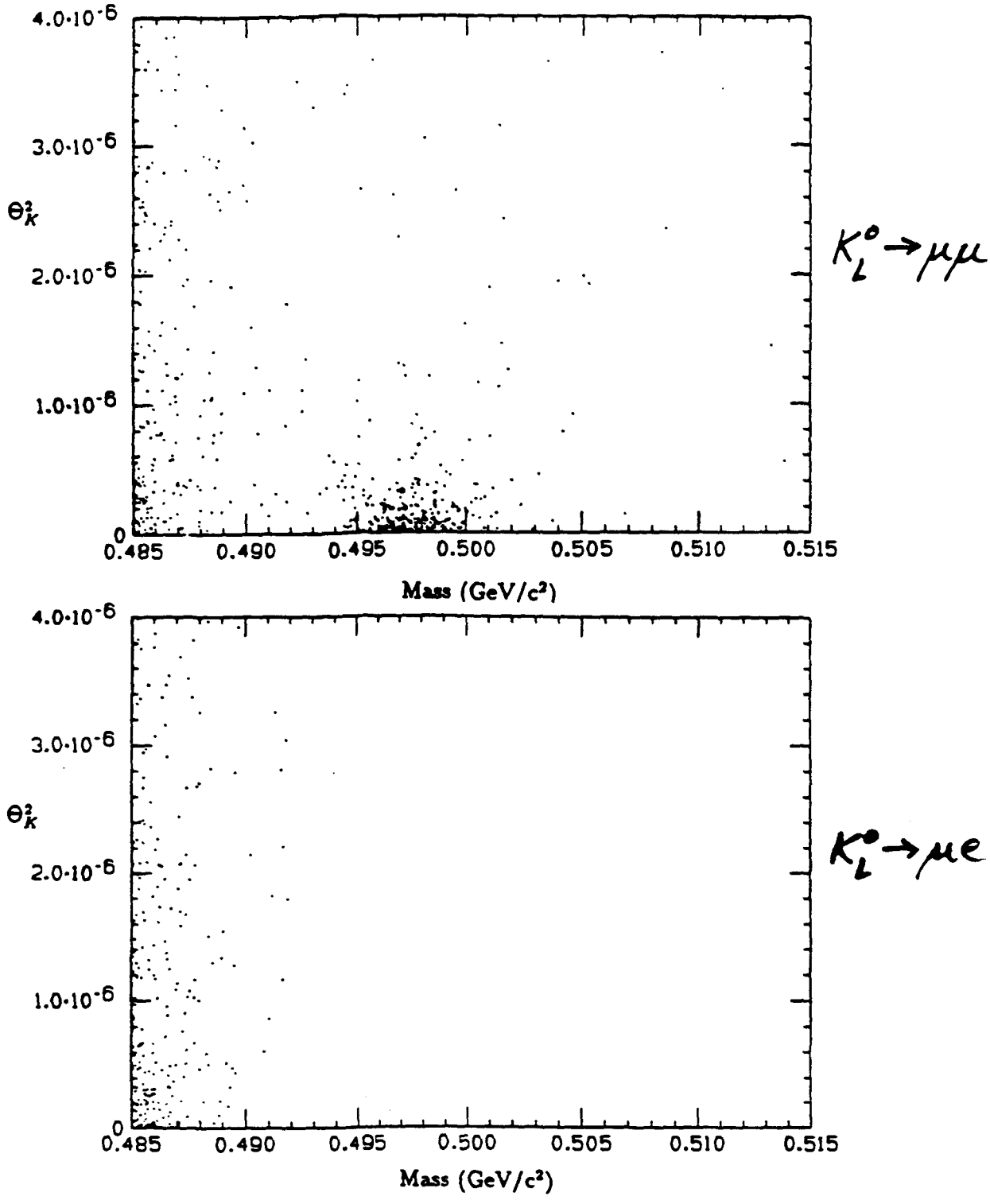


$K_L^0 \to \mu^+\mu^-$
87 EVENTS

$K_L^0 \to \pi^+\pi^-$

$\sigma_{M_{\pi\pi}} = 1.5$ MeV

FIGURE 1



Scatter plots of the square of the angle, Θ_K, between the parent K_L direction and the direction of the reconstructed K_L versus invariant mass, for $K_L \to \mu\mu$ (top) and $K_L \to \mu e$ (bottom).

BNL E791
(1989 data, preliminary)

N.B. All limits given are 90% C.L.

Results on $K_L \to \mu e$

Previous Limit

PDG $\quad BR(K_L \to \mu e) < 6 \cdot 10^{-6}$ †

BNL E780

1987-1988 data $\quad BR(K_L \to \mu e) < 1.9 \cdot 10^{-9}$

KEK E137

1988-1989 data $\quad BR(K_L \to \mu e) < 2 \cdot 10^{-10}$ *

BNL E791

1988-1989 data $\quad BR(K_L \to \mu e) < 6.1 \cdot 10^{-11}$ *

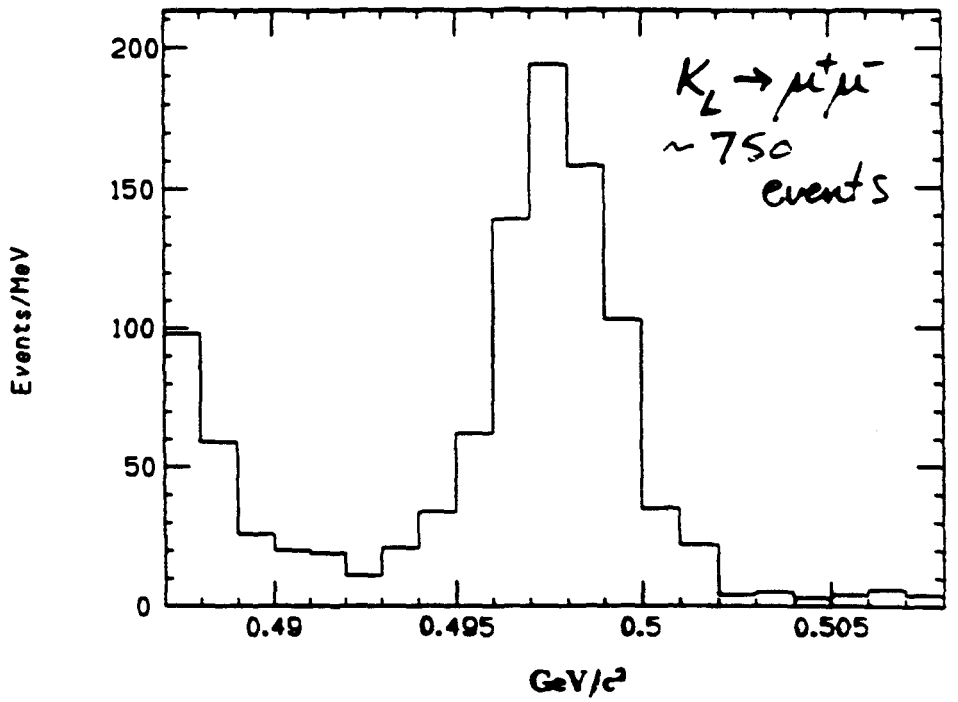
[all together $\quad BR(K_L \to \mu e) < 4.6 \cdot 10^{-11}$]

† does not include result of Clark et al. (71) LBL

* PRELIMINARY (Singapore) (each experiment has more data to analyze)

$\Rightarrow$ x 2 sensitivity

BNL E791 (1988 + 1989 + 1990)
preliminary



$K_L \to \mu^+\mu^-$ events from the full E791 data sample.

RESULTS ON $K_L \to \mu^+\mu^-$

PDG $BR(K_L \to \mu^+\mu^-) = (9.5 \pm^{2.4}_{1.5}) \cdot 10^{-9}$
28 events

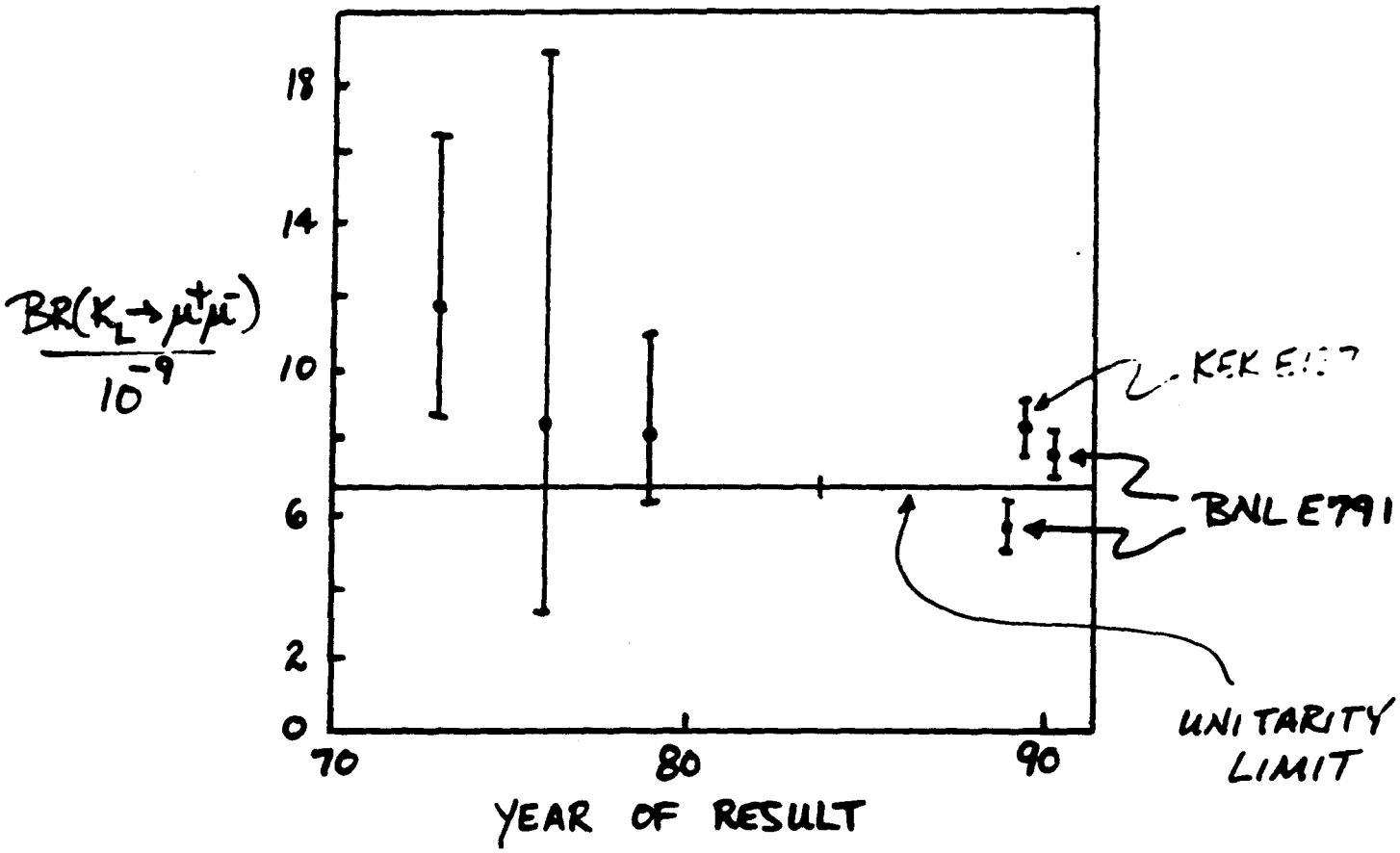
KEK E137 $BR(K_L \to \mu^+\mu^-) = (8.4 \pm 1.1) \cdot 10^{-9}$
54 events

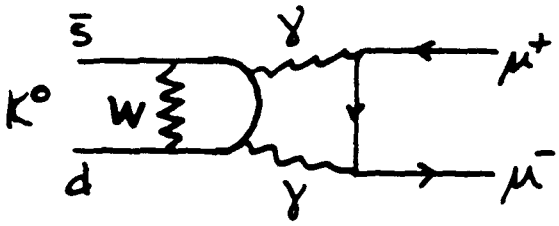
BNL E791 $BR(K_L \to \mu^+\mu^-) = (5.8 \pm 0.6 \pm 0.4) \cdot 10^{-9}$
87 events

* $BR(K_L \to \mu^+\mu^-) = (7.6 \pm 0.5 \pm 0.4) \cdot 10^{-9}$
284 events

$BR(K_L \to \mu^+\mu^-) = (7.2 \pm 0.5) \cdot 10^{-9}$

* PRELIMINARY (Singapore)





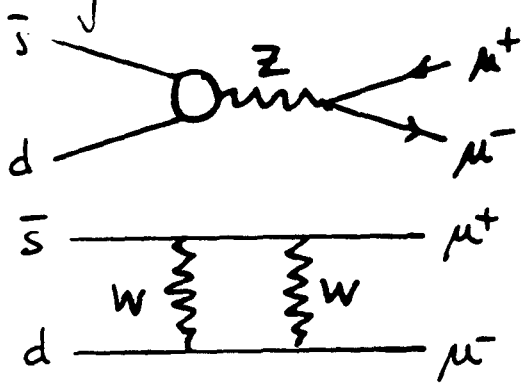
UNITARITY LIMIT:

$$BR(K_L \to \gamma\gamma \to \mu^+\mu^-) = (6.83 \pm 0.28)\cdot 10^{-9}$$

from $BR(K_L \to \gamma\gamma) = (5.7 \pm 0.27)\cdot 10^{-4}$ (NA31)

$$\frac{BR(K_L \to \mu\mu)_{exp}}{BR(K_L \to \gamma\gamma \to \mu\mu)} = 1.05 \pm 0.08$$

Any room left for short distance contributions?



$$A_{\mu\mu} \propto \left(\frac{m_t}{m_W}\right)^2 |V_{ts}^* V_{td}|^2$$

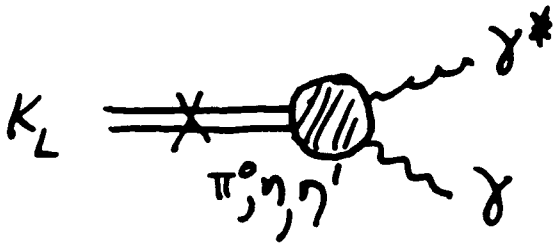
$K_L \to \mu\mu$ & $K_L \to ee\gamma$

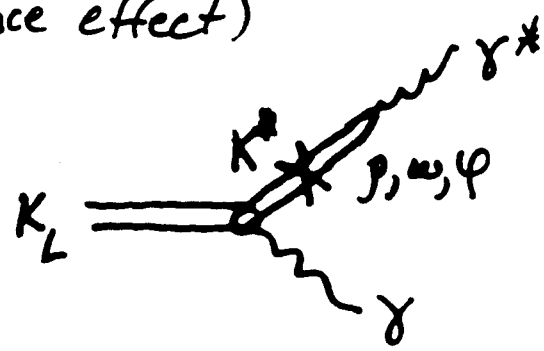
Im $A_{\mu\mu}$ from real $\gamma\gamma$ determined from $K_L \to \gamma\gamma$

to determine the weak (top) contribution we must know & subtract the em contribution to Re $A_{\mu\mu}$ due to virtual photons:

$$K_L \to \gamma\gamma^* \to \mu\mu$$

(long distance effect)

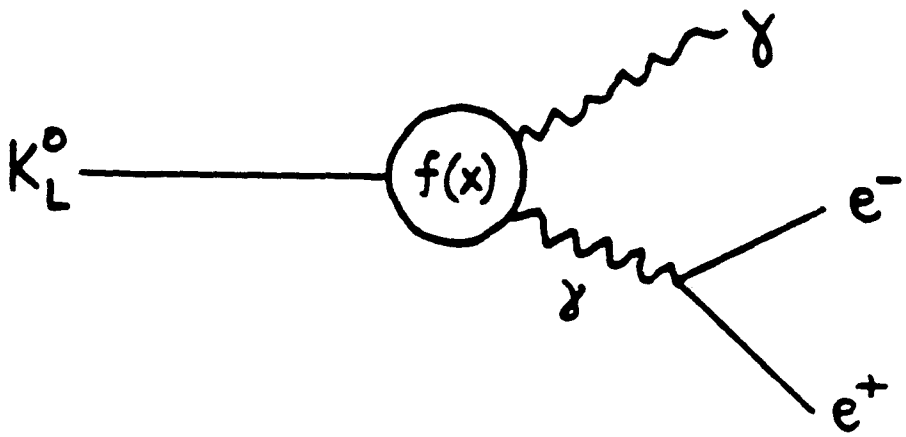




χ_{K^*} relative strength.

measure the m_{ee} spectrum in $K_L \to ee\gamma$ to study the $K_L \to \gamma^*\gamma$ vertex

$K_L \to e^+e^-\gamma$ Phenomenology



Kroll and Wada, PR **98**, 1355 (1955)

$$\Gamma_{\gamma\gamma}^{-1}\frac{d\Gamma}{dx} = \frac{2\alpha}{3\pi}\frac{(1-x)^3}{x}\left(1+\frac{2m_e^2}{xm_K^2}\right)\left(1-\frac{4m_e^2}{xm_K^2}\right)^{1/2}|f(x)|^2$$

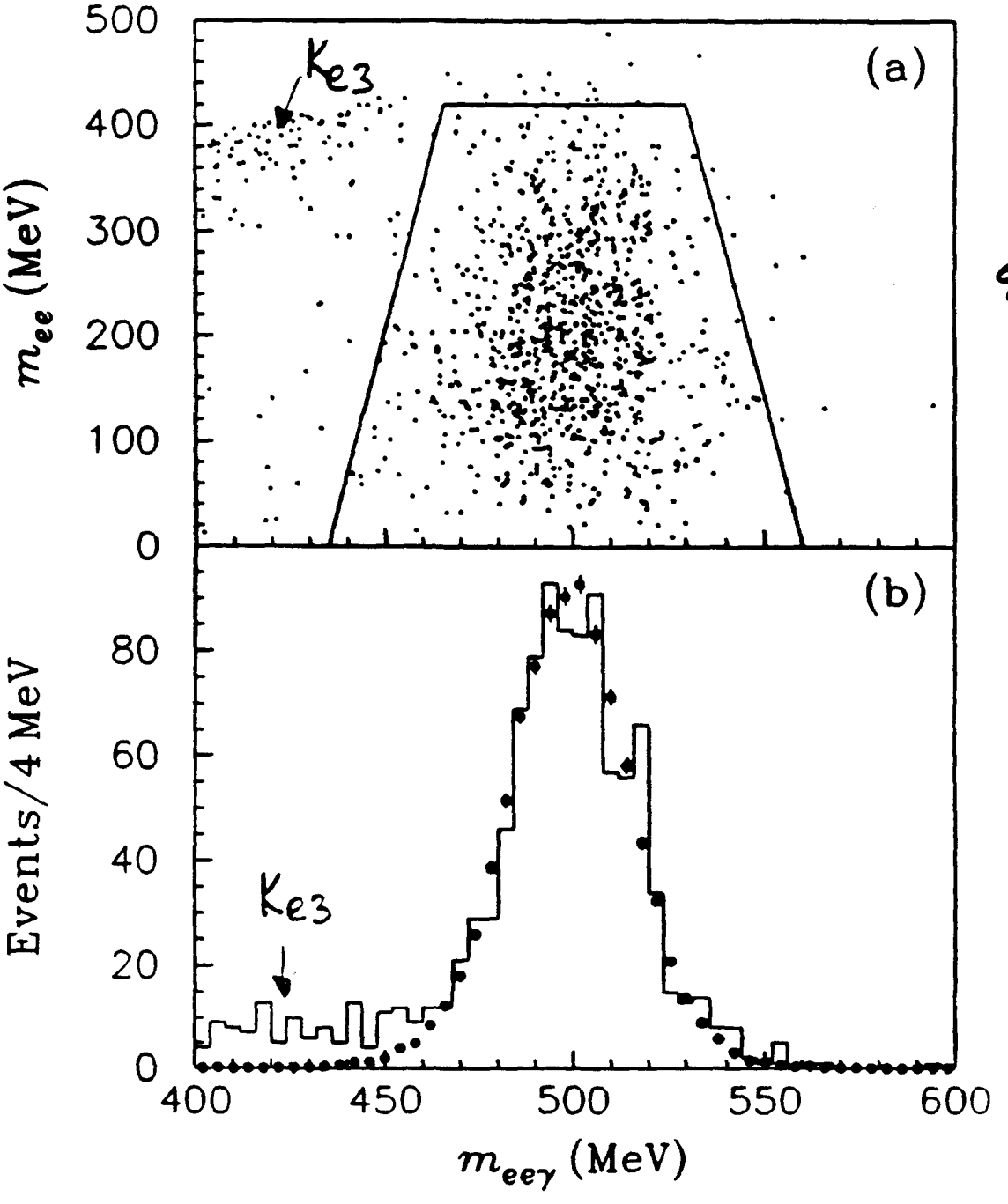
$$x = \frac{m_{ee}^2}{m_K^2} \qquad f(0) = 1$$

$f(x)$ probes structure of K_L-γ-γ^* vertex

$f(x) = 1 \Rightarrow B(K_L \to e^+e^-\gamma) = (9.1 \pm 0.4) \times 10^{-6}$

BNL E845

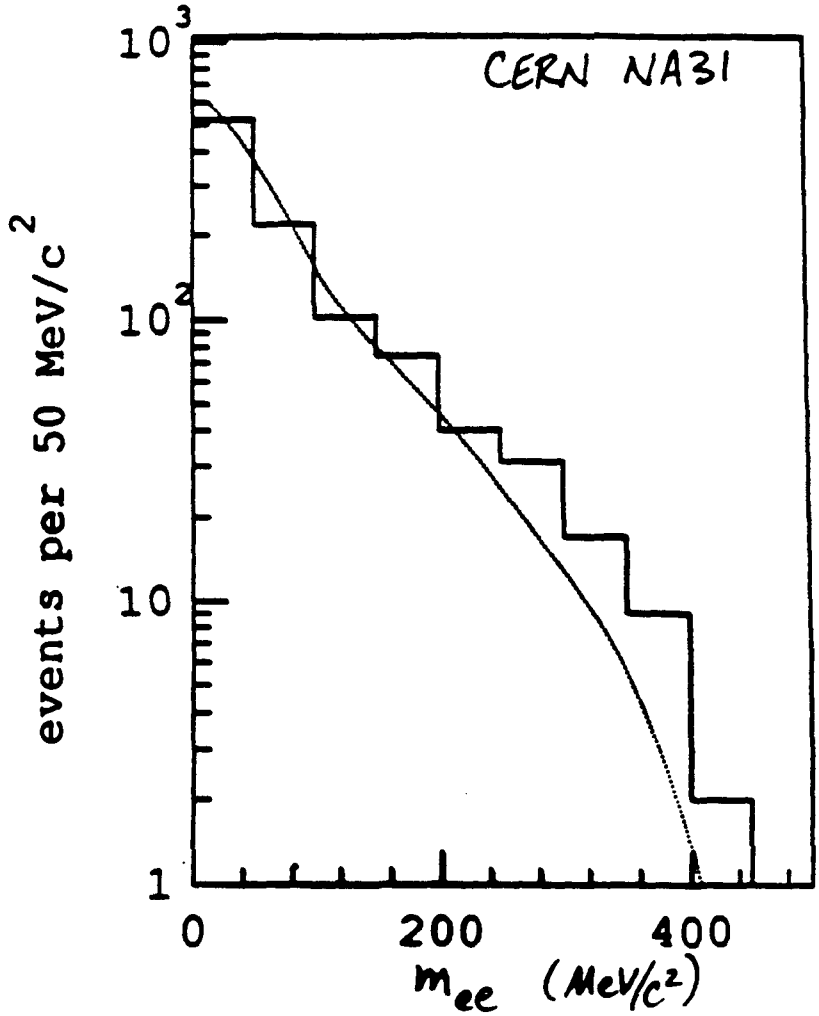
$K_L \to e^+e^-\gamma$



919 events

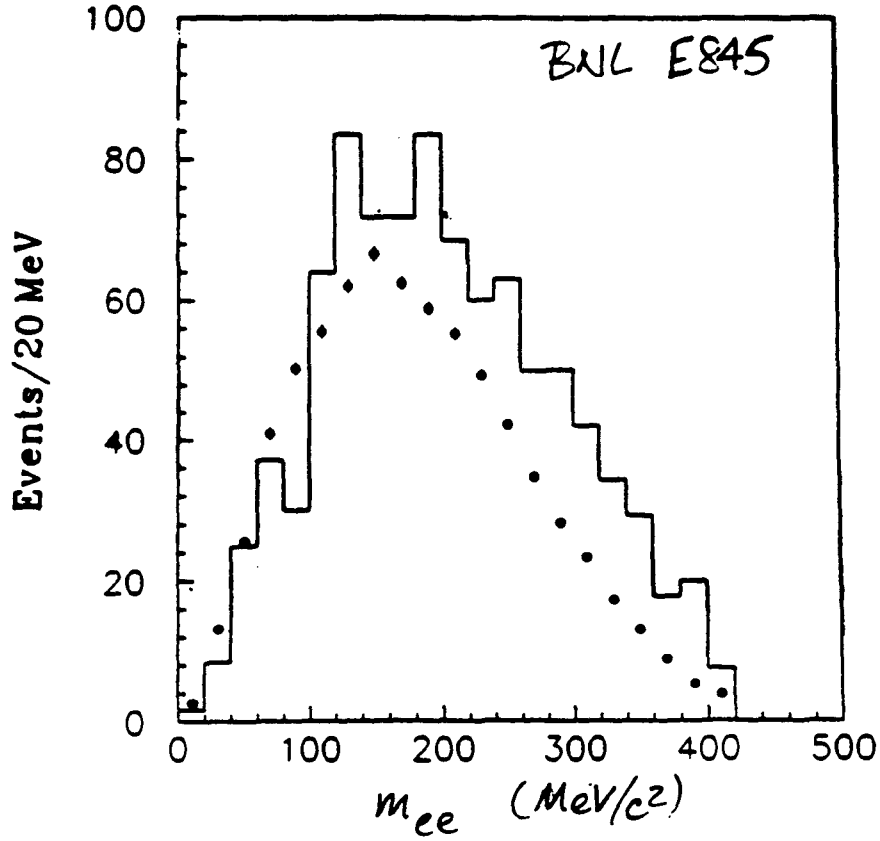
BNL E845

m_{ee} spectrum for $K_L \to e^+e^-\gamma$



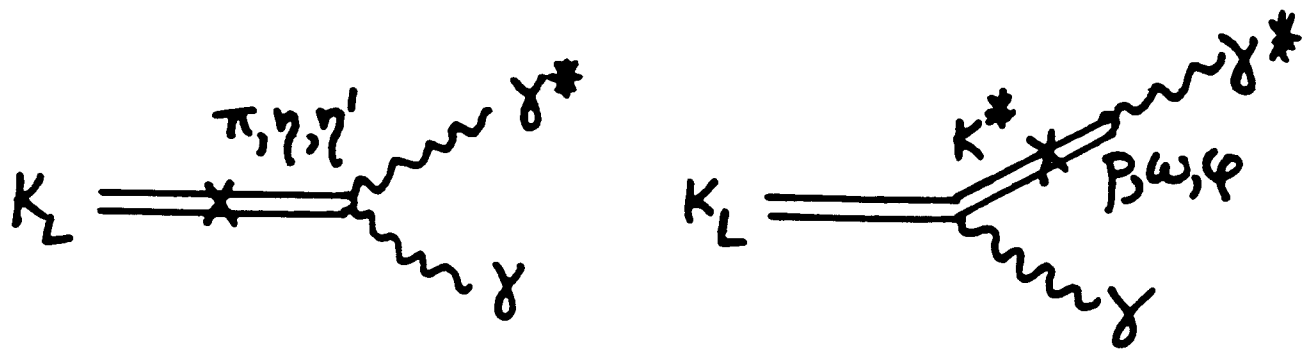
DATA

• MONTE CARLO (QED, ABSOLUTE)



$K_L \to e^+e^-\gamma$ Form Factor

Model of Bergström *et al.* PL **131B**, 229 (1983)



$$f(x) = f(s/m_K^2) = \frac{1}{1 - s/m_\rho^2} +$$

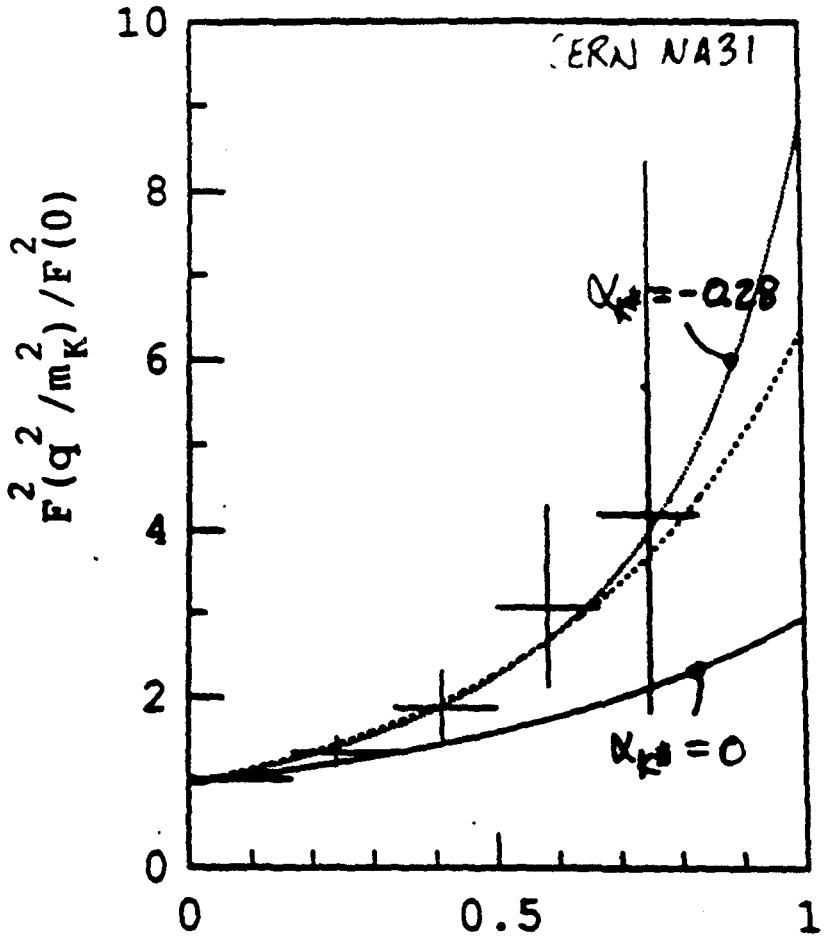
$$\frac{2.5\,\alpha_{K^*}}{1 - s/m_{K^*}^2}\left[\frac{4}{3} - \frac{1}{1 - s/m_\rho^2} - \frac{1}{9(1 - s/m_\omega^2)} - \frac{2}{9(1 - s/m_\phi^2)}\right]$$

α_{K^*} measures relative contributions of two diagrams

Sakurai $|\alpha_{K^*}| = 1.0$ PR **156**, 1508 (1967)

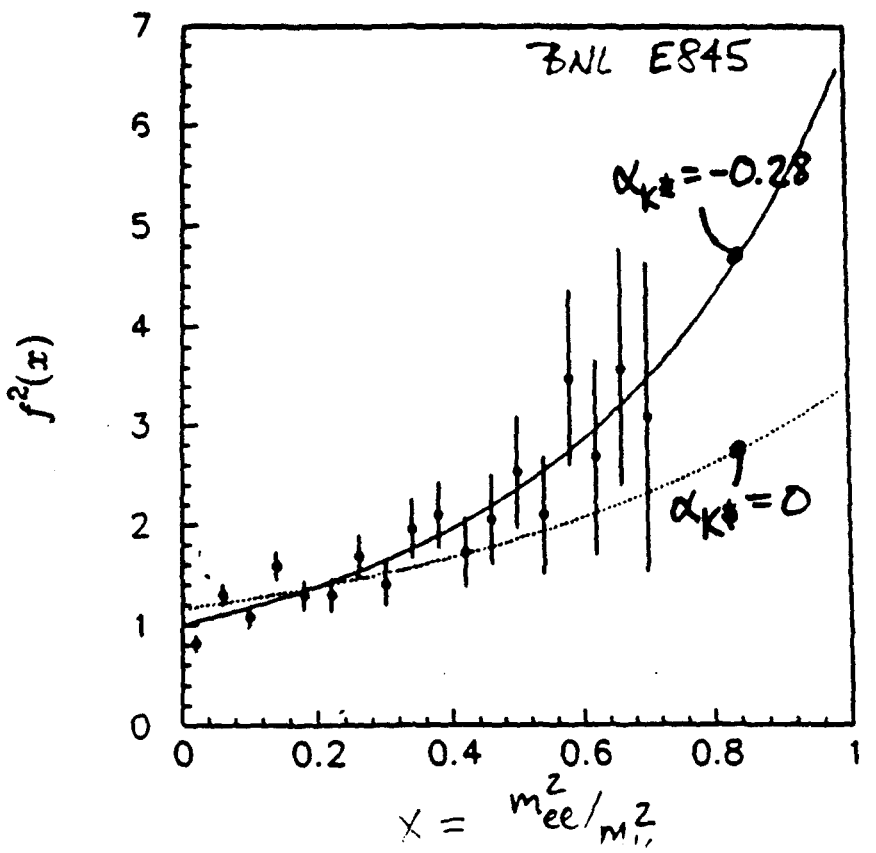
Bergström *et al.* $|\alpha_{K^*}| = 0.2 - 0.3$
applying method of
Shifman *et al.* NP **B120**, 316 (1977)

$K_L \to ee\gamma$ form factor



$\alpha_{K^*} = -0.28 \pm 0.13$

vector-vector weak interaction observed: $K^* \to \rho$

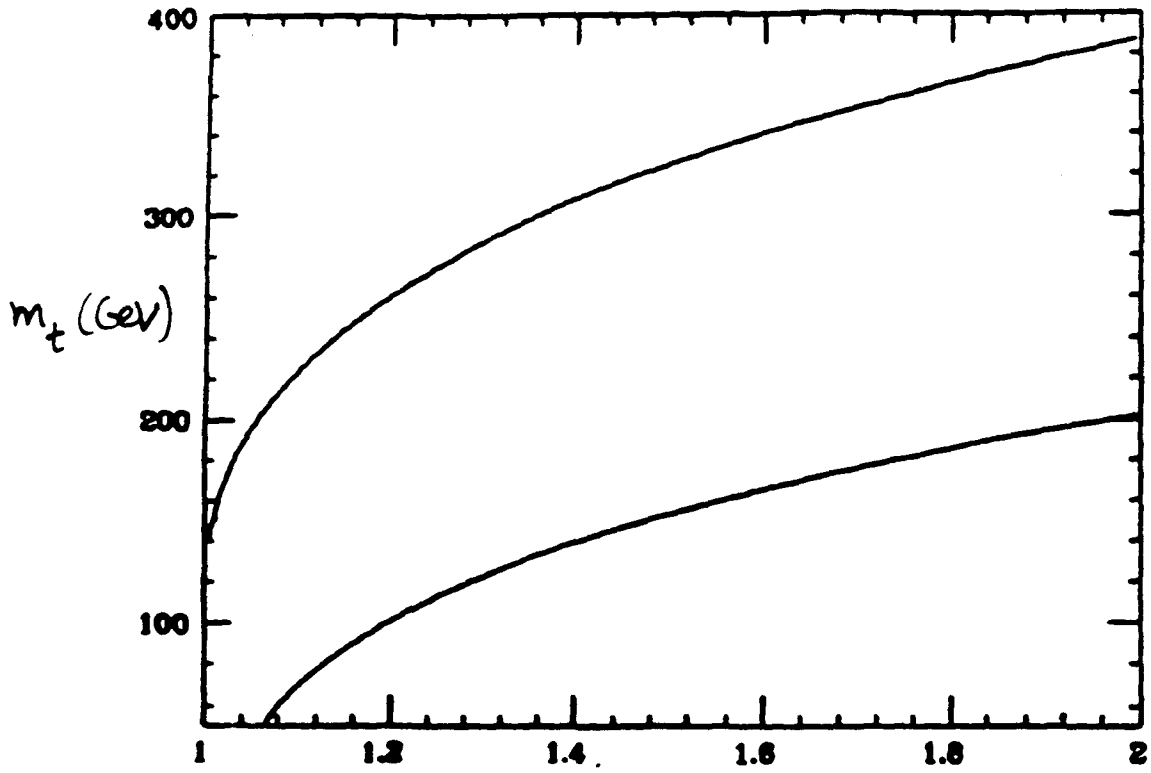


$\alpha_{K^*} = -0.28 \pm {}^{0.10}_{0.09}$

History of $K_L \to e^+e^-\gamma$

Reference	Branching Ratio and Form Factor
A.S. Carroll *et al.* PRL **44**, 525 (1980).	$(17.4 \pm 8.7) \times 10^{-6}$ 4 events
NA31, G.D. Barr *et al.* PL **240B**, 283 (1990).	$(9.2 \pm 0.5 \pm 0.5) \times 10^{-6}$ $\alpha_{K^*} = -0.28 \pm 0.13$
E845, K.E. Ohl *et al.* YAUG-A-90/5	$(9.1 \pm 0.4 {}^{+0.6}_{-0.5}) \times 10^{-6}$ $\alpha_{K^*} = -0.280 \pm 0.083 {}^{+0.054}_{-0.034}$

$$\frac{B(K_L \to \mu^+\mu^-)_{exp}}{B_{UNITARITY}} = 1.05 \pm 0.08$$



$BR(K_L \to \mu^+\mu^-)/BR_{UNITARITY}$

Bergström, Massó, Singer PL 249B 141 (90)

for $\alpha_{K^*} = -0.28$

$\Rightarrow$ em contribution to Re $A_{\mu\mu}$ small!

expect $BR(K_L \to \mu^+\mu^-)/BR_{UNITARITY} = 1.02 \pm 0.02$

in the absence of weak contributions

further predictions

$BR(K_L \to \mu^+\mu^-\gamma) = 4.0 \cdot 10^{-7}$ (30% increase over $\alpha_K^* = 0$)

$BR(K_L \to e^+e^-e^+e^-) \approx \text{few} \cdot 10^{-8}$ (NA31, BNL '45)

Results on $K_L \to e^+e^-$

PDG	$BR(K_L \to e^+e^-) < 2 \cdot 10^{-7}$
BNL E780	$BR(K_L \to e^+e^-) < 1.2 \cdot 10^{-9}$
KEK E137	$BR(K_L \to e^+e^-) < 3 \cdot 10^{-10}$ *
BNL E791	$BR(K_L \to e^+e^-) < 8.5 \cdot 10^{-11}$ *

$$BR(K_L \to e^+e^-)_{\text{UNITARITY}} = \frac{1}{2}\alpha^2 \frac{m^2}{m_K^2} \frac{1}{\beta} \left| \ln \frac{1+\beta}{1-\beta} \right|^2 BR(K_L \to \gamma\gamma)$$

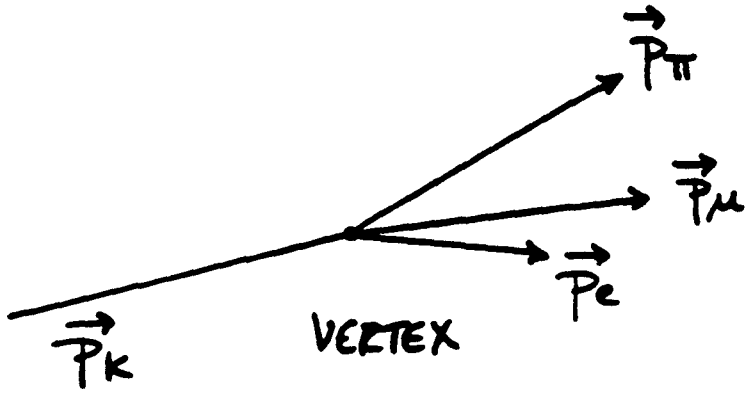
$$\beta = (1 - 4\, m^2/m_K^2)^{1/2}$$

expect $BR(K_L \to ee) \cong 3 \cdot 10^{-12}$

* PRELIMINARY (more data to analyze ~ 2 x sensitivity)

$K^+ \to \pi^+ \mu^+ e^-$

Experimental method



Require: 3 charged tracks to come from a common vertex

π, μ, e identification

$m_{\pi\mu e} \sim m_K$

$\vec{p}_K$ consistent with K^+ from target

Particle identification of paramount importance

Example $K^+ \to \pi^+ \pi^0$ (1/400)

$\hookrightarrow \underline{\underline{e^+}} e^- \gamma$

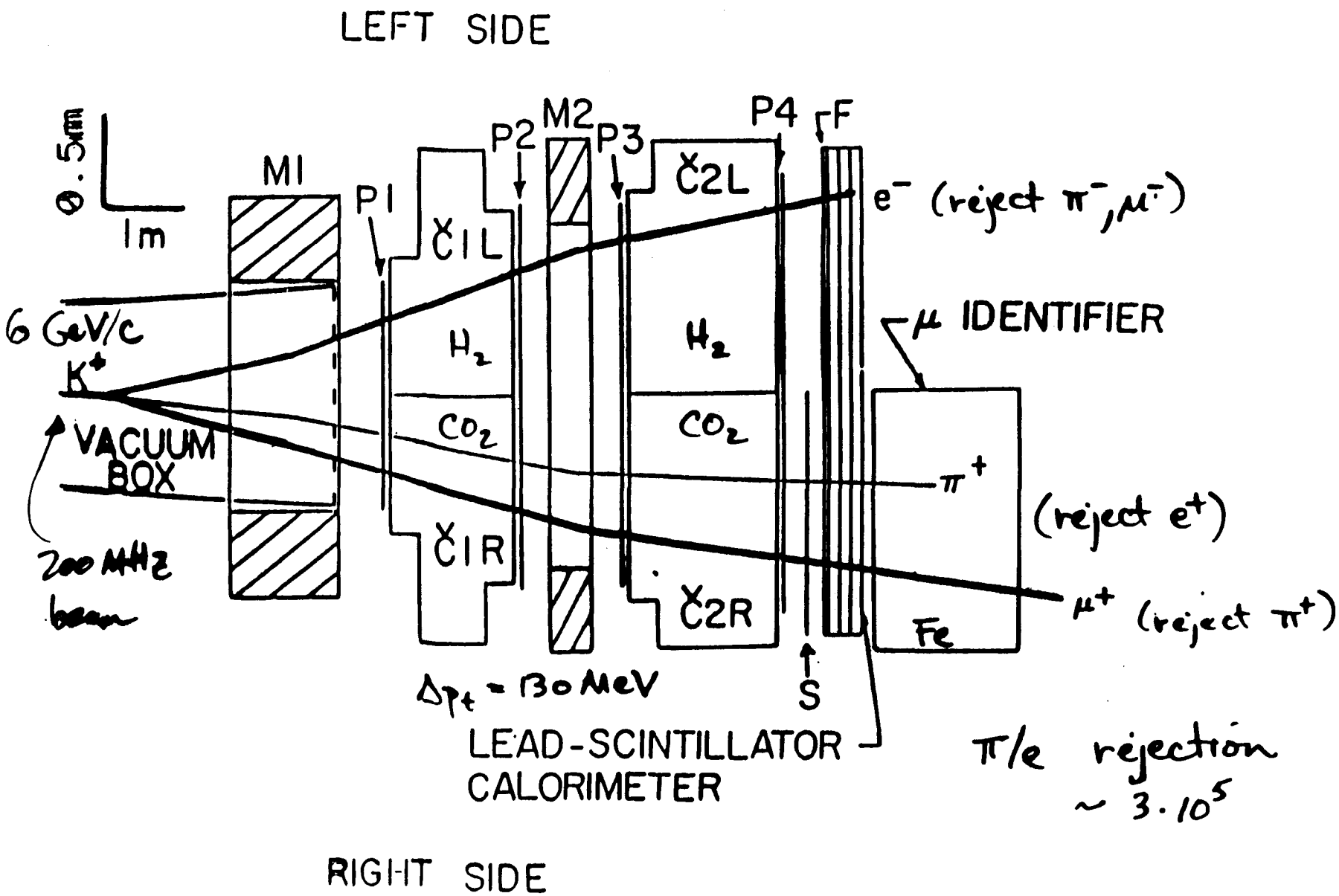
With misidentification

π^+ as μ^+ & e^+ as π^+

or just e^+ as μ^+

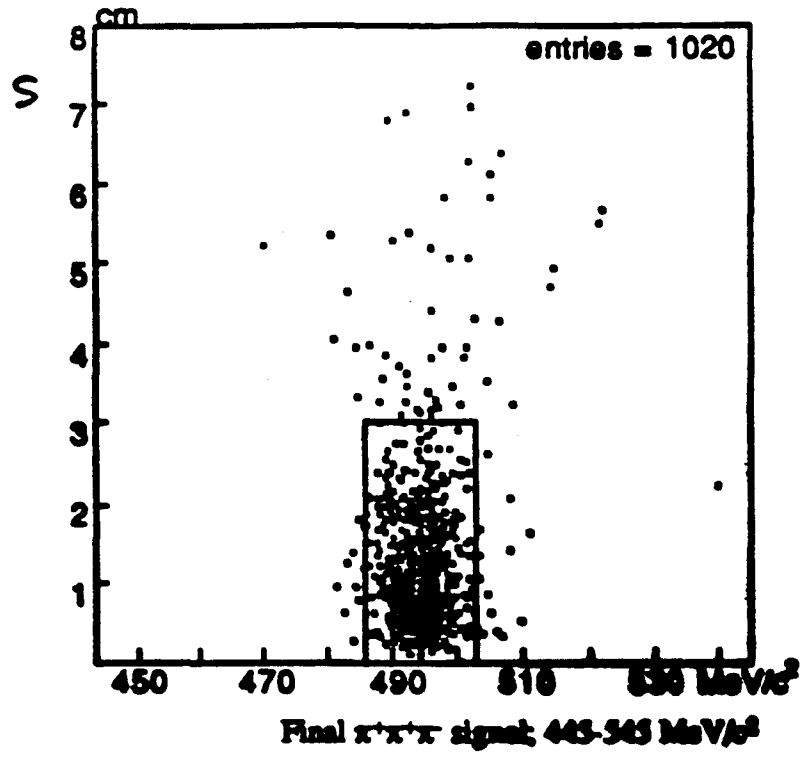
e^+ as π^+ or μ^+ compensates for missing γ energy

BNL E777

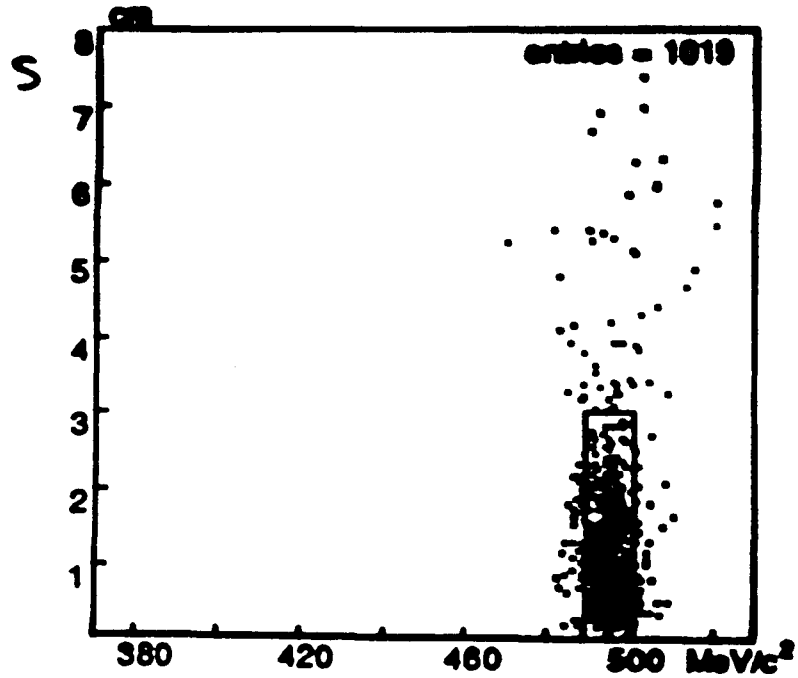

LEFT SIDE
0.5m
1m
M1
P1
P2
M2
P3
P4
F
Č1L
Č2L
H2
H2
CO2
CO2
Č1R
Č2R
6 GeV/c
K+
VACUUM BOX
200 MHz beam
e− (reject π−, μ−)
μ IDENTIFIER
π+
(reject e+)
μ+ (reject π+)
Fe
S
Δpt = 130 MeV
LEAD-SCINTILLATOR CALORIMETER
π/e rejection ~ 3·10^5
RIGHT SIDE

BNL E777

S = rms distance from common vertex



Final $\pi^+\pi^+\pi^-$ signal; 445-545 MeV/c²

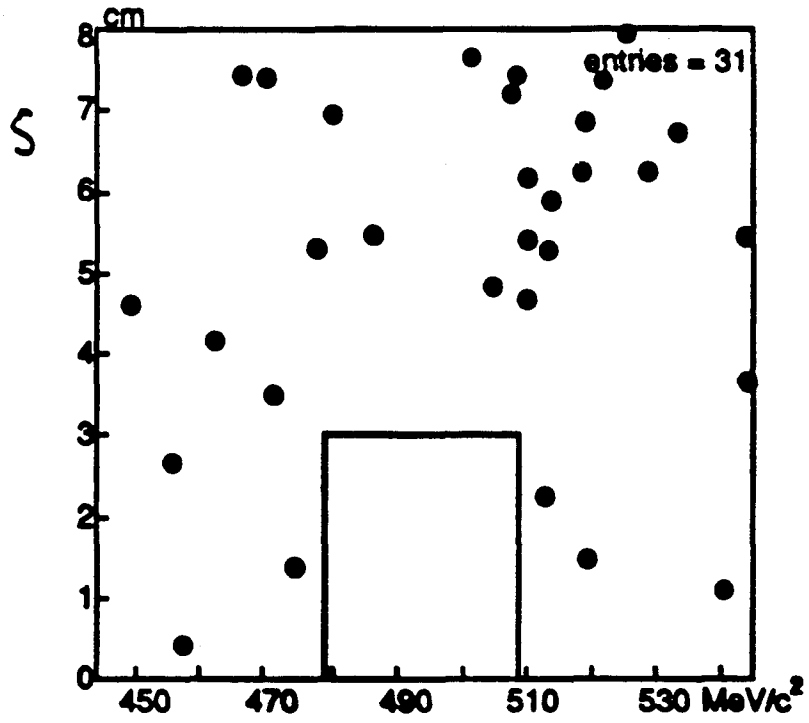


Final $\pi^+\pi^+\pi^-$ signal; 3 sigma box indicated 370-530 MeV/c²

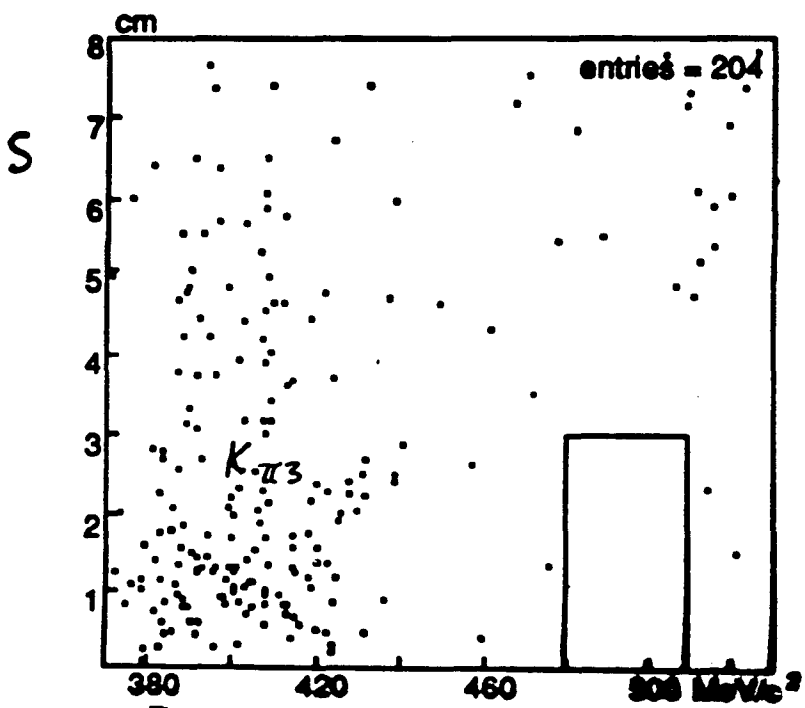
3σ mass

$K^+ \to \pi^+\pi^+\pi^-$

BNL-E777



Final $K^+ \to \pi^+\mu^+e^-$ signal; 445-545 MeV/c²



Final $\pi^+\mu^+e^-$ signal; 3 sigma box indicated

$K^+ \to \pi^+\mu^+e^-$

Results on $K^+ \to \pi^+ \mu^+ e^-$

<u>Previous limit</u>

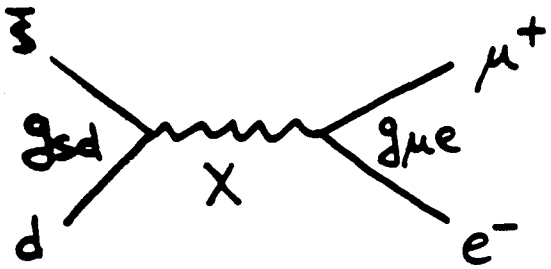
CERN '76 Diamant Berger $\quad BR(K^+ \to \pi^+ \mu^+ e^-) < 4.8 \cdot 10^{-9}$

<u>BNL</u> <u>E777</u>

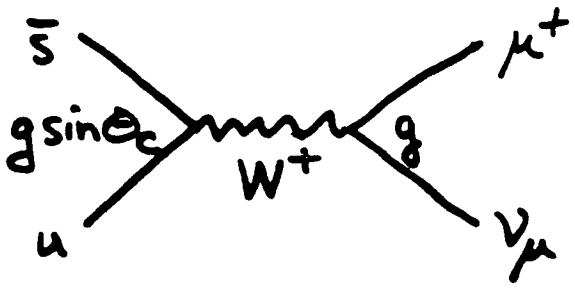
1987 Data $\quad BR(K^+ \to \pi^+ \mu^+ e^-) < 1.1 \cdot 10^{-9}$

1988 Data $\quad BR(K^+ \to \pi^+ \mu^+ e^-) < 2.6 \cdot 10^{-10}$

[all together $\quad BR(K^+ \to \pi^+ \mu^+ e^-) < 2 \cdot 10^{-10}$]



$K_L^0 \to \mu e$



$K^+ \to \mu \nu$

$$\frac{BR(K_L^0 \to \mu e)}{BR(K^+ \to \mu \nu)} = \left(\frac{g_{sd}\, g_{\mu e}}{g^2 \sin\theta_c}\right)^2 \left(\frac{M_W}{M_X}\right)^4 \frac{\tau_L}{\tau_+}$$

Assume $\quad g_{sd} = g_{\mu e} = g \qquad \left(\frac{g^2}{8 m_W^2} = \frac{G_F}{\sqrt{2}}\right)$

$$BR(K_L^0 \to \mu e) \simeq 10^{-10}$$

$$\Rightarrow \quad M_X \simeq 70 \text{ TeV}$$

Similarly for $K^+ \to \pi^+ \mu^+ e^-$

$K_L^0 \to \mu e$ & $K^+ \to \pi^+ \mu^+ e^-$ complimentary

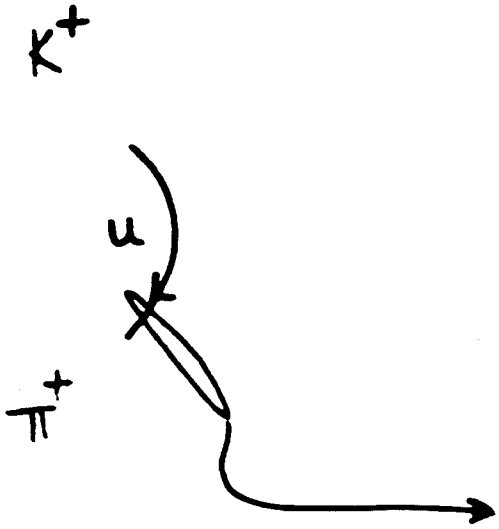
$\langle 0 | A | K^0 \rangle$ $\qquad$ $\langle \pi^+ | V | K^+ \rangle$

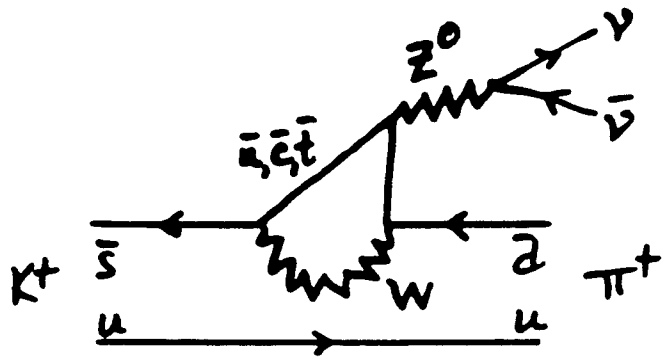
Axial vector $\qquad$ Vector

(pseudoscalar) $\qquad$ (scalar)

Mass bounds in TeV on
new particles (interactions)
giving rise to lepton # violation

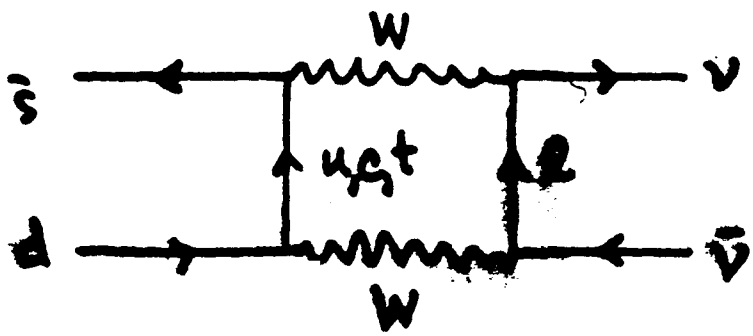
Process	Limit	Horizontal Gauge Boson	4 Fermi interaction	Scalar fields
Δm_K	$3.5\,\mu eV$	400	1000	150
$\mu \to e\gamma$	$4.9 \cdot 10^{-11}$	15 (V)	—	0.3
$\mu \to 3e$	10^{-12}	82 (V-A)	186	2
$\mu A \to eA$	$4.6 \cdot 10^{-12}$	200 (V)	341	24
$K_L \to \mu e$	$4.6 \cdot 10^{-11}$	85 (V-A)	173	3
$K^+ \to \pi \mu e$	$2.1 \cdot 10^{-10}$	38 (V)	44 (V-A)	2

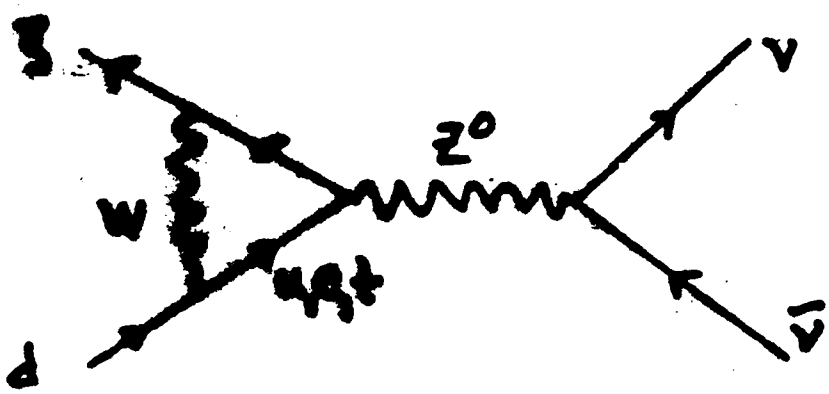

K+
u
π+


Z0
ν
ν̄
ū,c̄,t̄
K+
s̄
d̄
π+
W
u
u

$K^+ \to \pi^+ \nu \bar{\nu}$

SHOULD OCCUR IN THE STANDARD MODEL





Rate depends on:

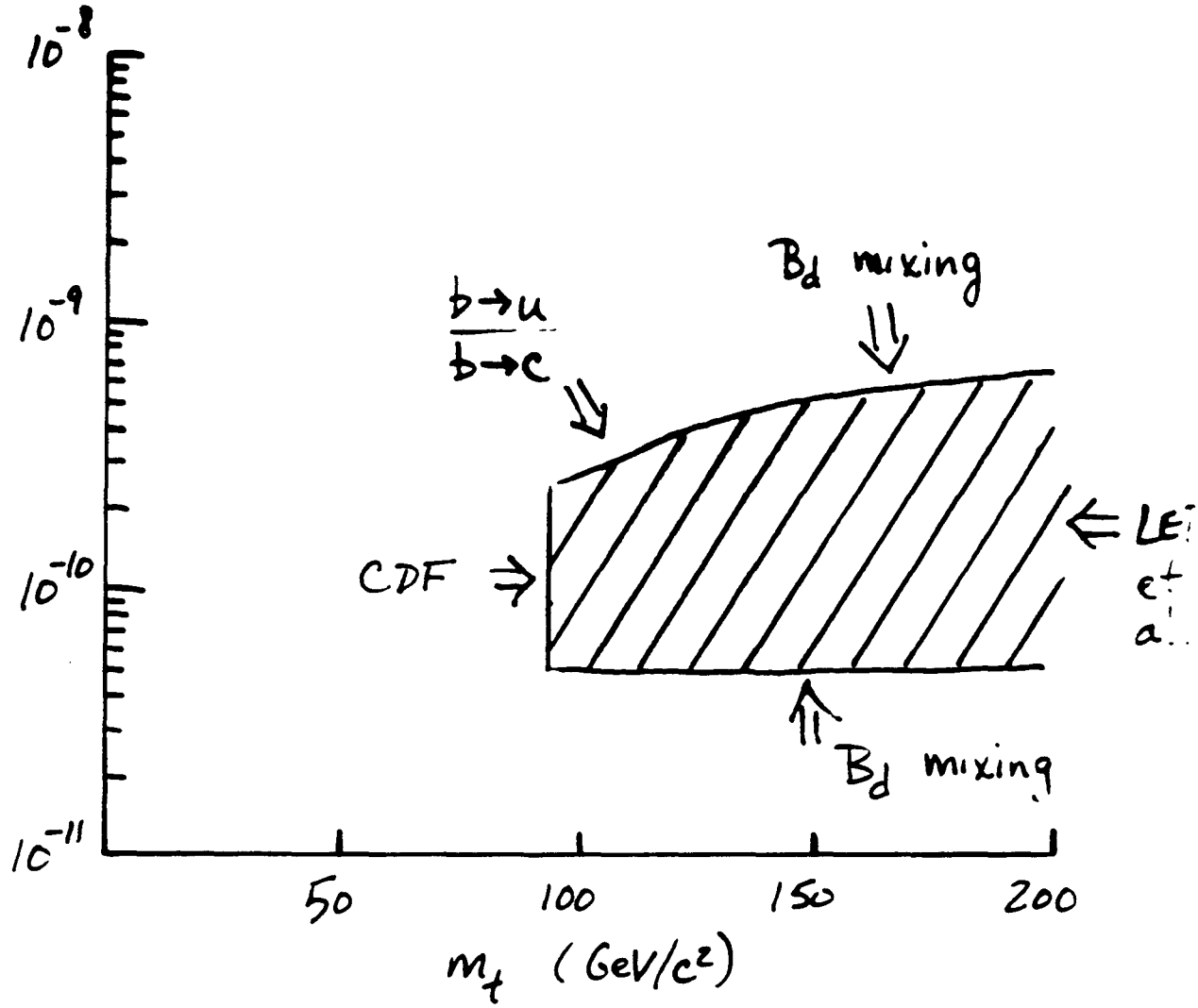
- # of light neutrinos
- KM elements
- top quark mass

$$\frac{BR(K^+ \to \pi^+ \nu_i \bar{\nu}_i)}{BR(K^+ \to \pi^0 e^+ \nu_e)} = 2 \left(\frac{\alpha}{4\pi \sin^2\Theta_W} \right)^2 \frac{|\tilde{D}_i|^2}{|V_{us}|^2}$$ per ν generati

$$\tilde{D}_i = \sum_{j=c,t} V_{js}^* V_{jd} \, \bar{D}_j \left((m_{q_j}/m_W)^2 ; (m_{\ell_i}/m_W)^2 \right)$$

dominated by top

$BR(K^+ \to \pi^+ \nu \bar{\nu})$



$$|V_{td}|^2 = \left(1.30 \begin{smallmatrix} +0.47 \\ -0.32 \end{smallmatrix}\right) \left[\frac{BR(K^+ \to \pi^+ \nu \bar{\nu})}{2 \cdot 10^{-6}} - (2.41 \pm 0.74) \cdot 10^{-5} \right]$$

(see [illegible])

$K^+ \to \pi^+ +$ missing

Experimental Method:

Identify and stop K^+ in active target

Measure p and E of π^+

Identify π^+ by $\pi^+ \to \mu^+ \to e^+$ decay chain

Veto all γ's

Potential background sources

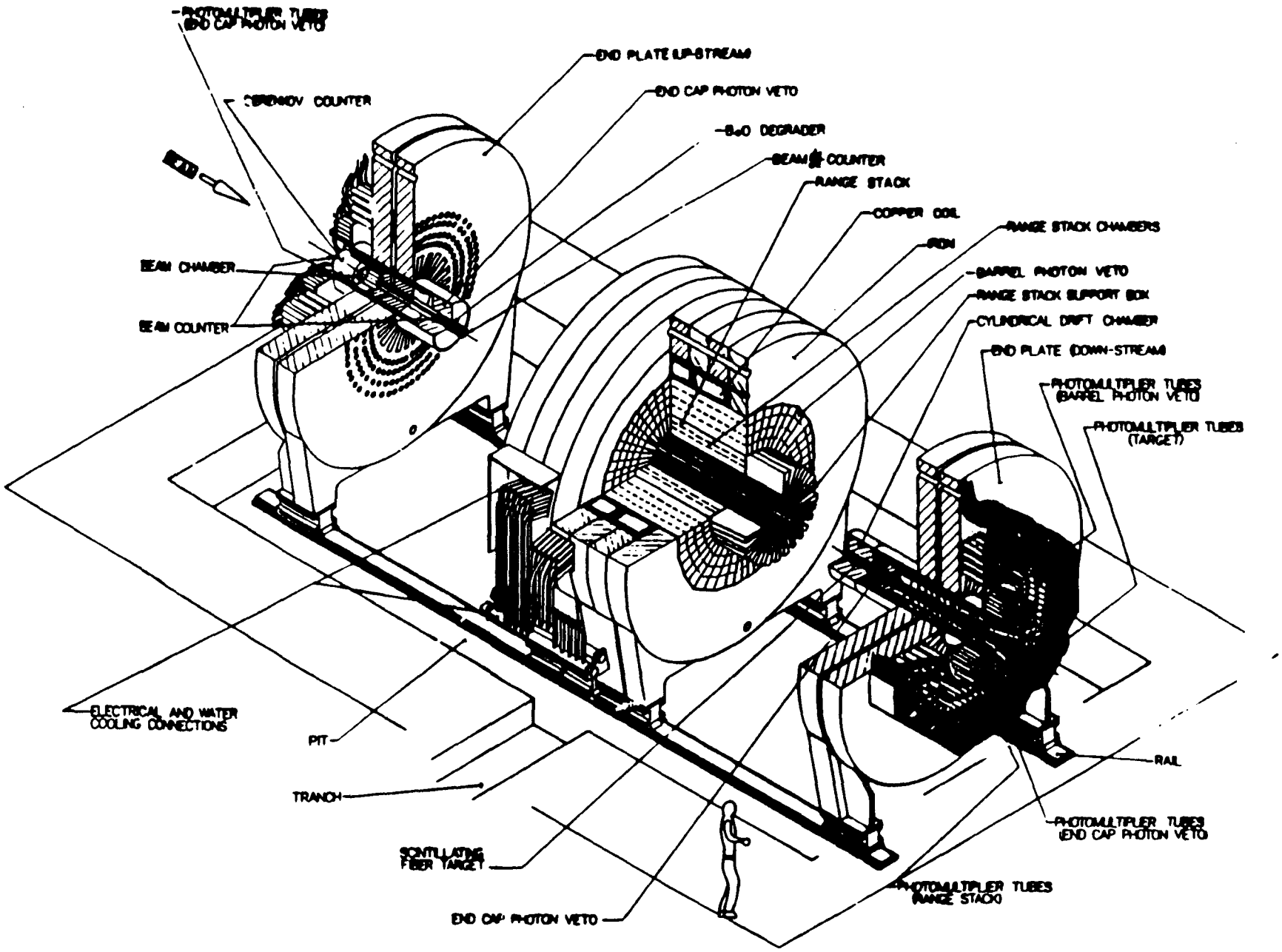
$K^+ \to \pi^+ \pi^0 , \mu^+ \nu_\mu (\gamma)$

$K^+ \to \pi^0 \mu^+ \nu_\mu$

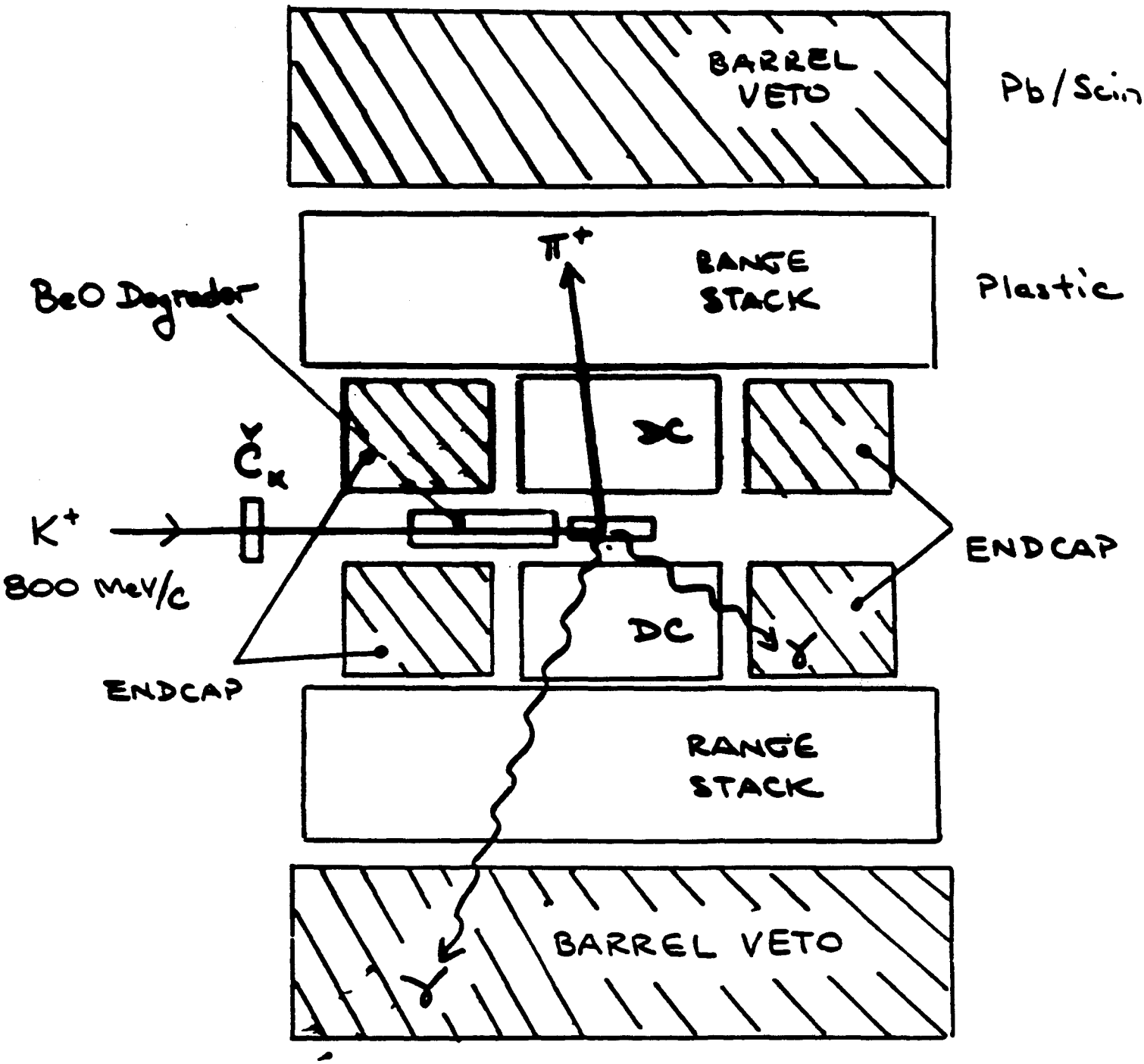
$K^+ N \to K^0 X$

$\quad \hookrightarrow \pi^+ X$ (miss X)

$\vdots$


PHOTOMULTIPLER TUBES (END CAP PHOTON VETO)
END PLATE (UP-STREAM)
END CAP PHOTON VETO
CERENKOV COUNTER
BeO DEGRADER
BEAM COUNTER
RANGE STACK
COPPER COIL
RANGE STACK CHAMBERS
IRON
BEAM CHAMBER
BARREL PHOTON VETO
RANGE STACK SUPPORT BOX
BEAM COUNTER
CYLINDRICAL DRIFT CHAMBER
END PLATE (DOWN-STREAM)
PHOTOMULTIPLER TUBES (BARREL PHOTON VETO)
PHOTOMULTIPLER TUBES (TARGET)
ELECTRICAL AND WATER COOLING CONNECTIONS
PIT
TRANCH
RAIL
PHOTOMULTIPLER TUBES (END CAP PHOTON VETO)
SCINTILLATING FIBER TARGET
PHOTOMULTIPLER TUBES (RANGE STACK)
END CAP PHOTON VETO

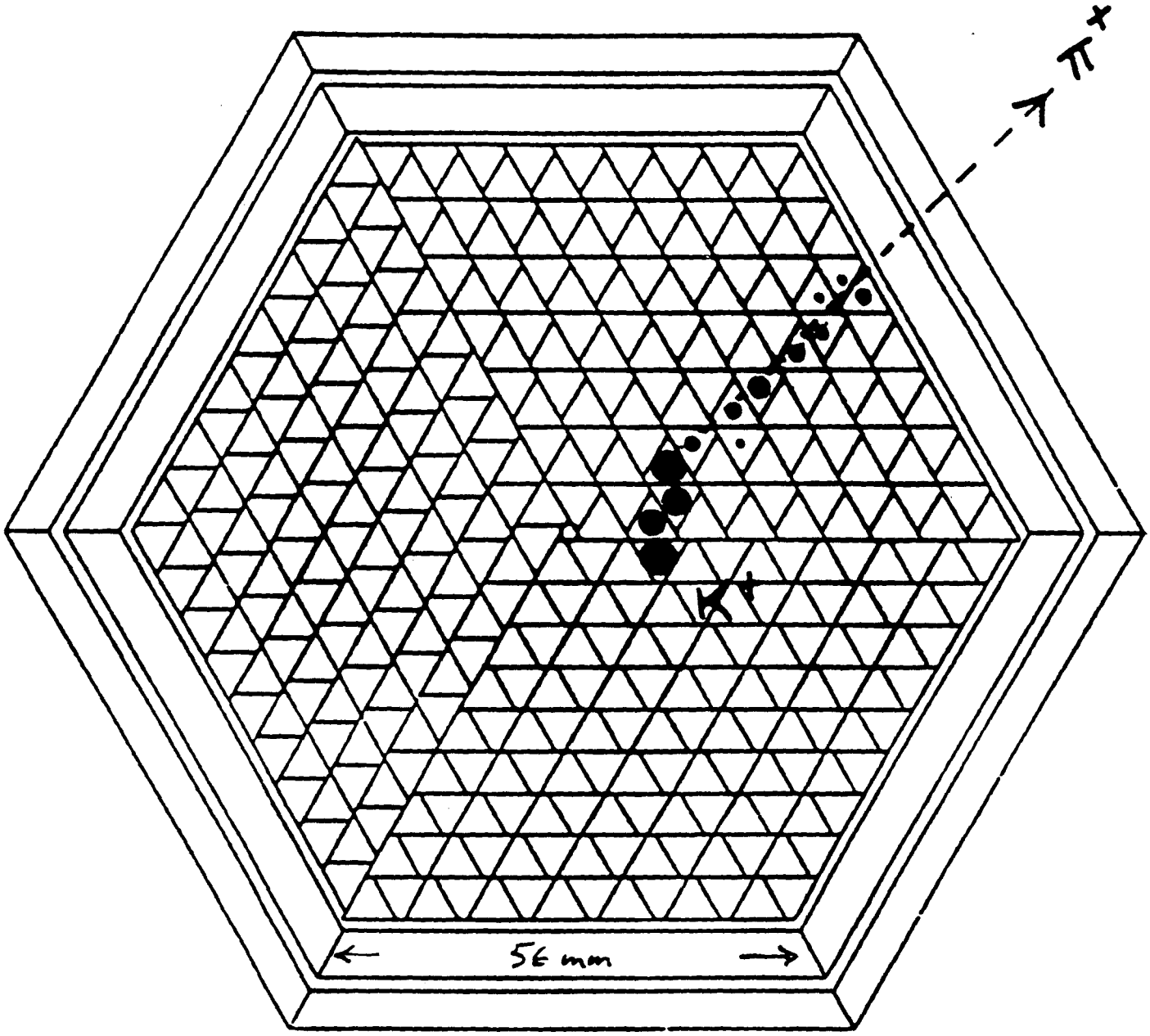
E787 SIDE VIEW



γ veto: t_c $3 \cdot 10^{-6}$

down: t_c $E_\gamma \sim 1$ MeV

BNL E787



Scintillation Fiber
Active Target

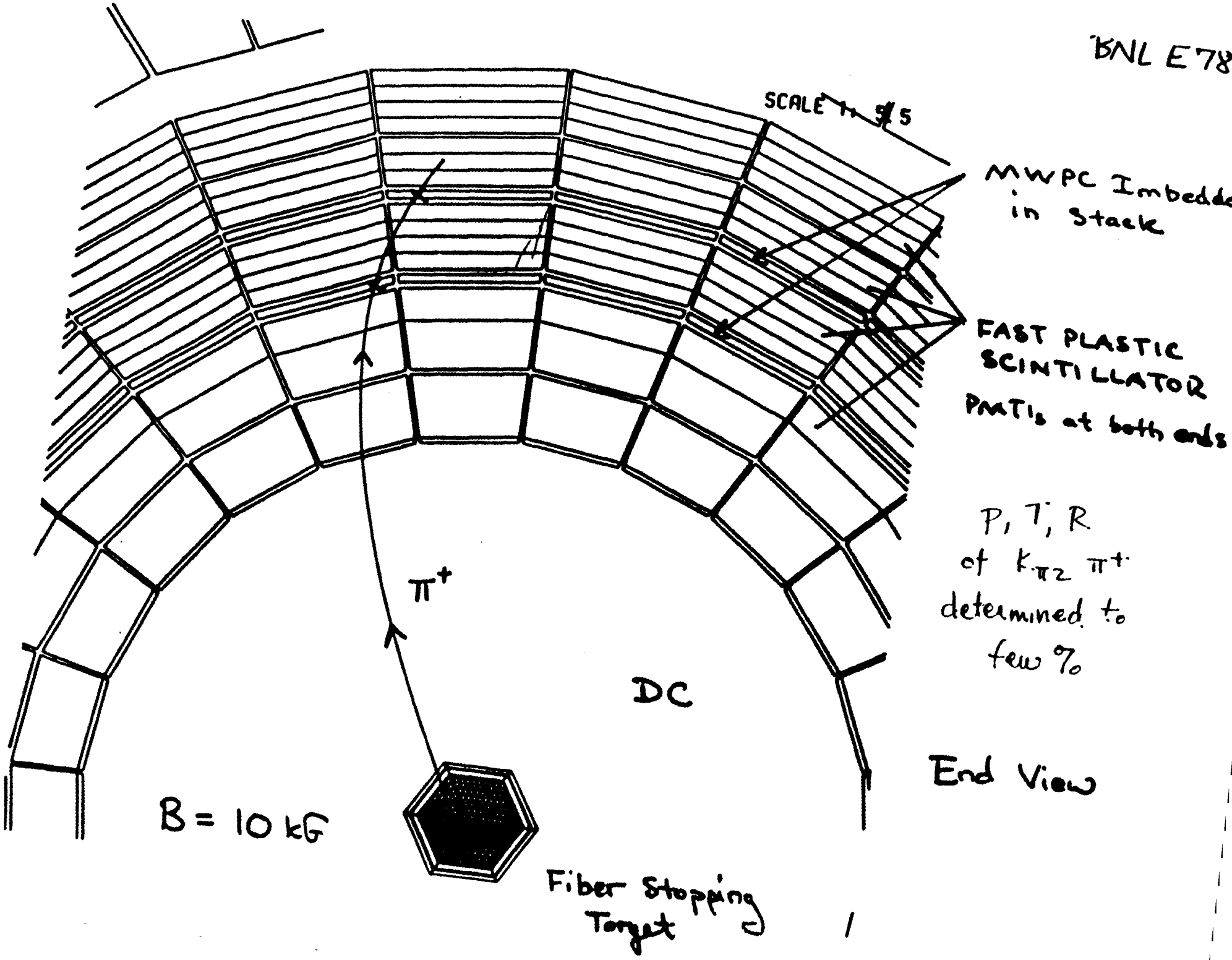
● Prompt

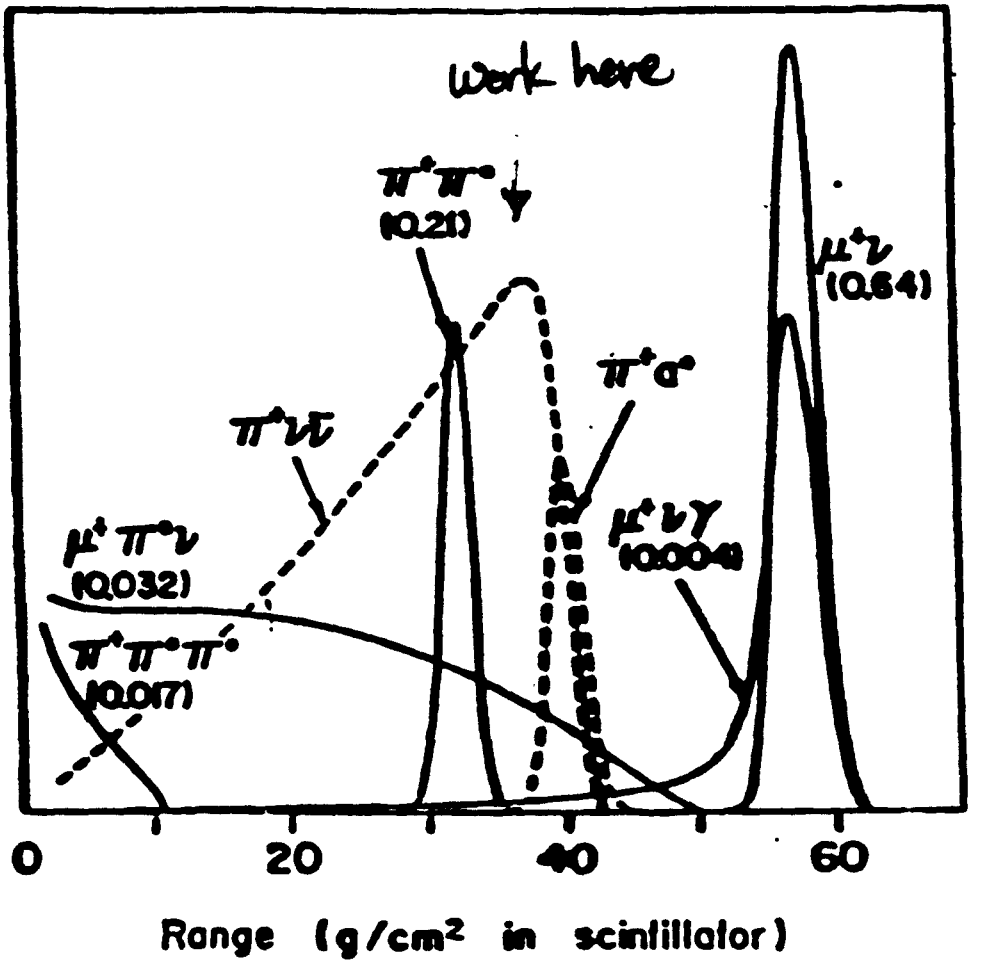
● Delayed by ~ τ_{K^+}

~ 5 MHz into target

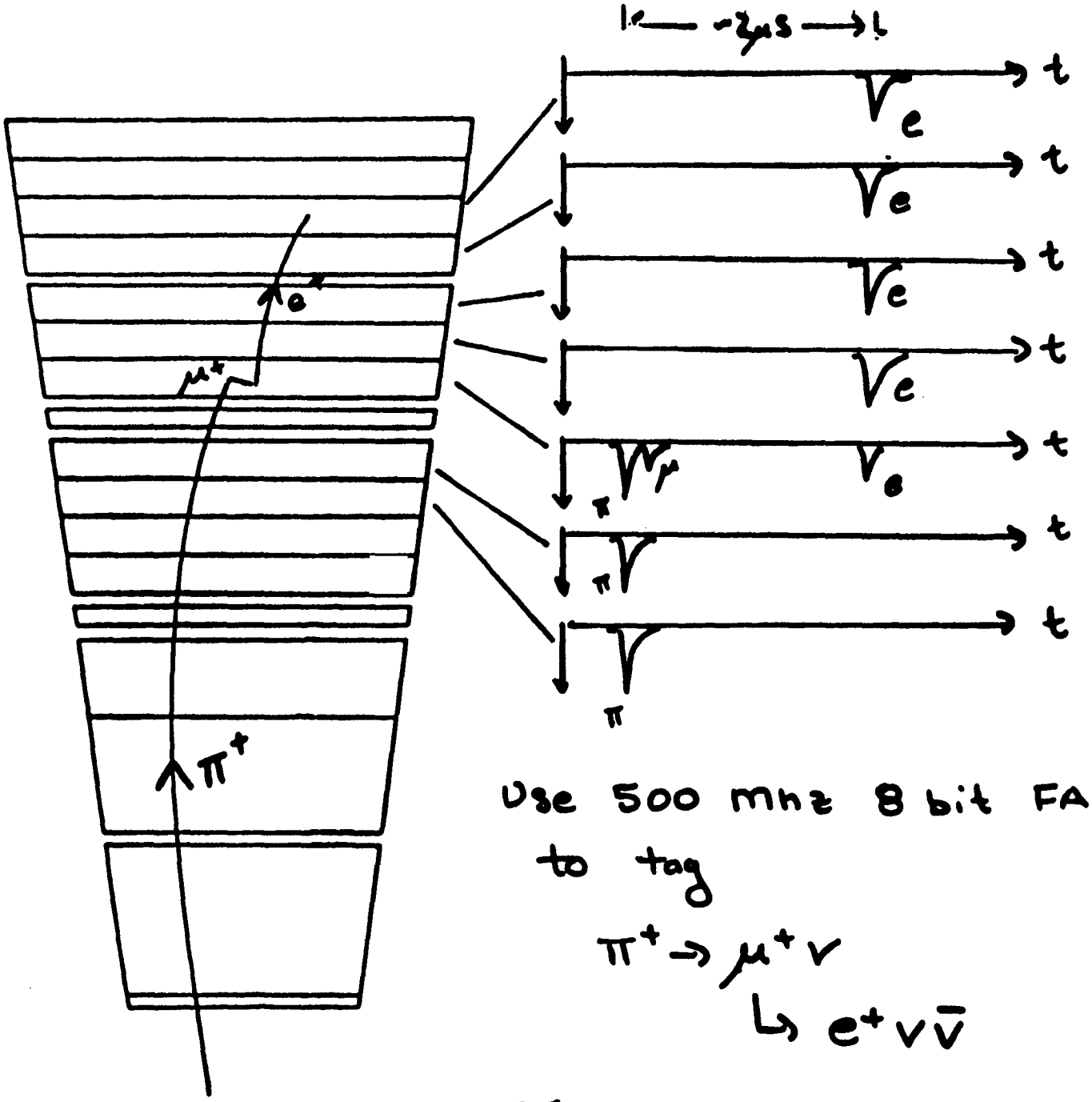
~ 250 K stopping K / spill

BNL E787


SCALE 1 = 5
MWPC Imbedded in Stack
FAST PLASTIC SCINTILLATOR
PMTs at both ends
P, T, R of $K_{\pi 2}$ π^+ determined to few %
π^+
DC
End View
B = 10 kG
Fiber Stopping Target


work here
$\pi^+\pi^0$
(0.21)
$\mu^+\nu$
(0.64)
$\pi^+\sigma^0$
$\pi^+\nu\bar{\nu}$
$\mu^+\nu\gamma$
(0.0041)
$\mu^+\pi^0\nu$
(0.032)
$\pi^+\pi^0\pi^0$
(0.017)
0
20
40
60
Range (g/cm² in scintillator)

BNL E787



Use 500 mhz 8 bit FADC System to tag

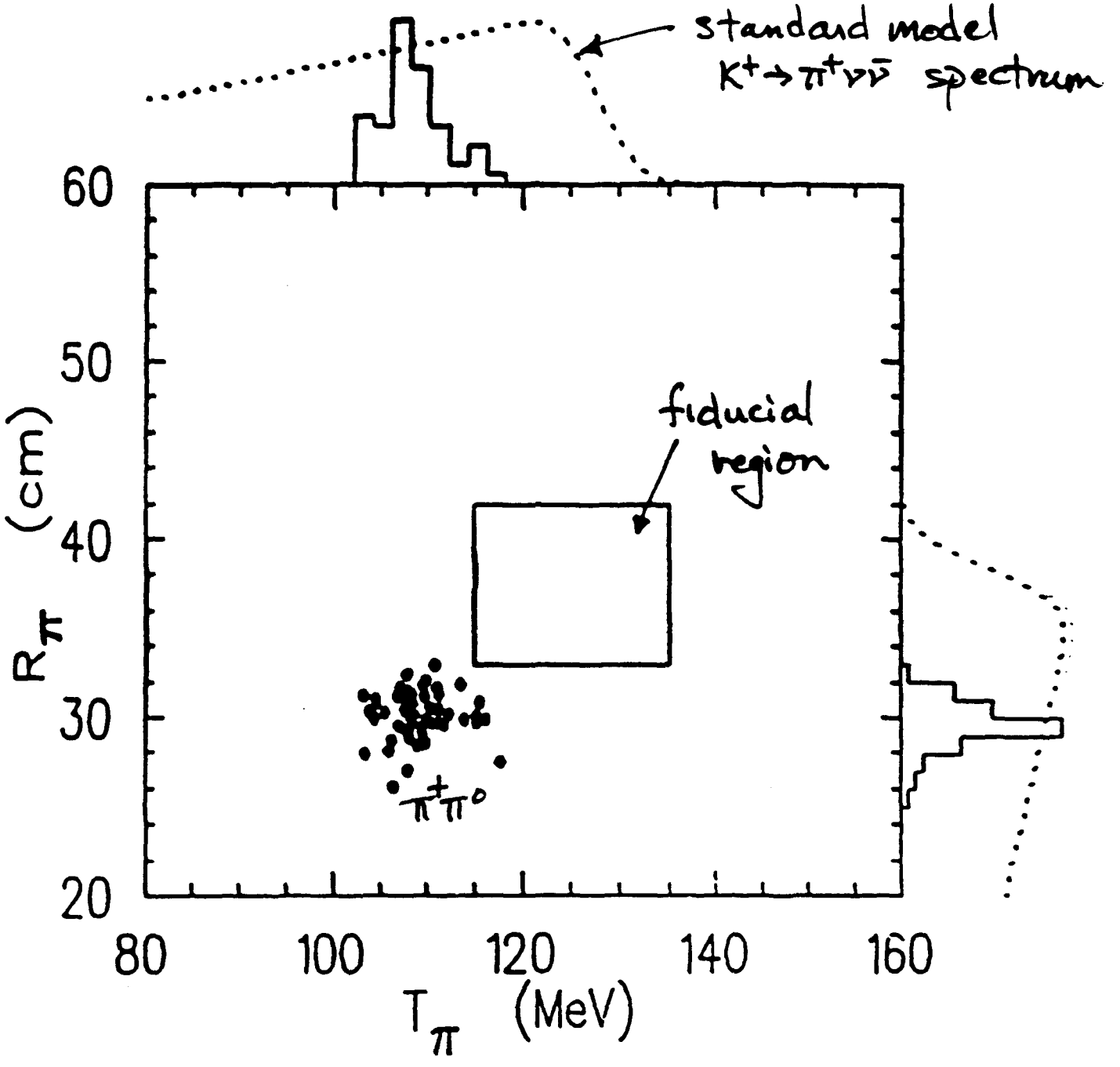
$\pi^+ \to \mu^+ \nu$

$\hookrightarrow e^+ \nu \bar{\nu}$

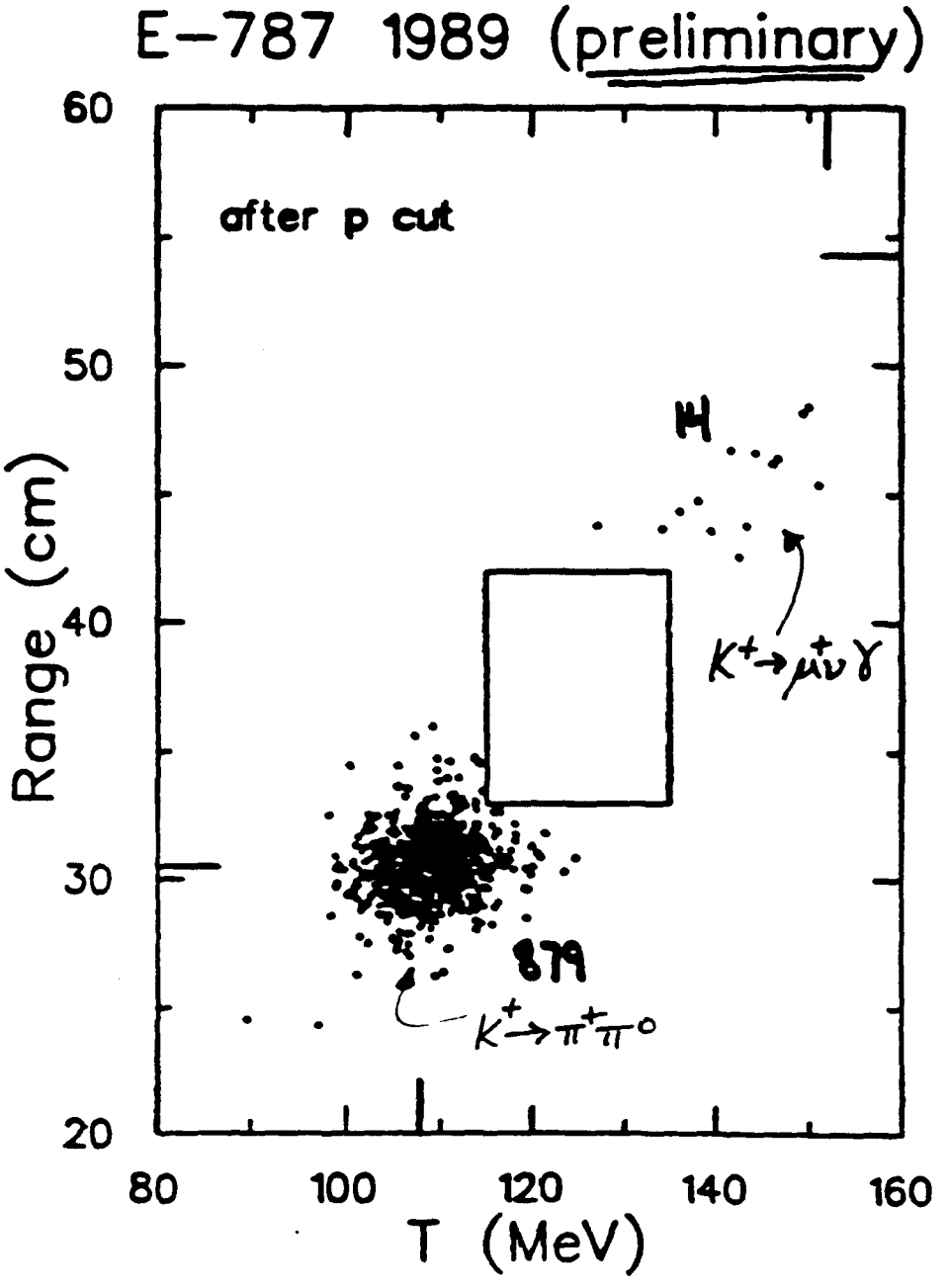
π/μ seperation $\sim 10^{-4}$

$\tau_\pi = 26$ ns $\quad \tau_\mu = 2.2\,\mu s$

BNL E787
1988 data

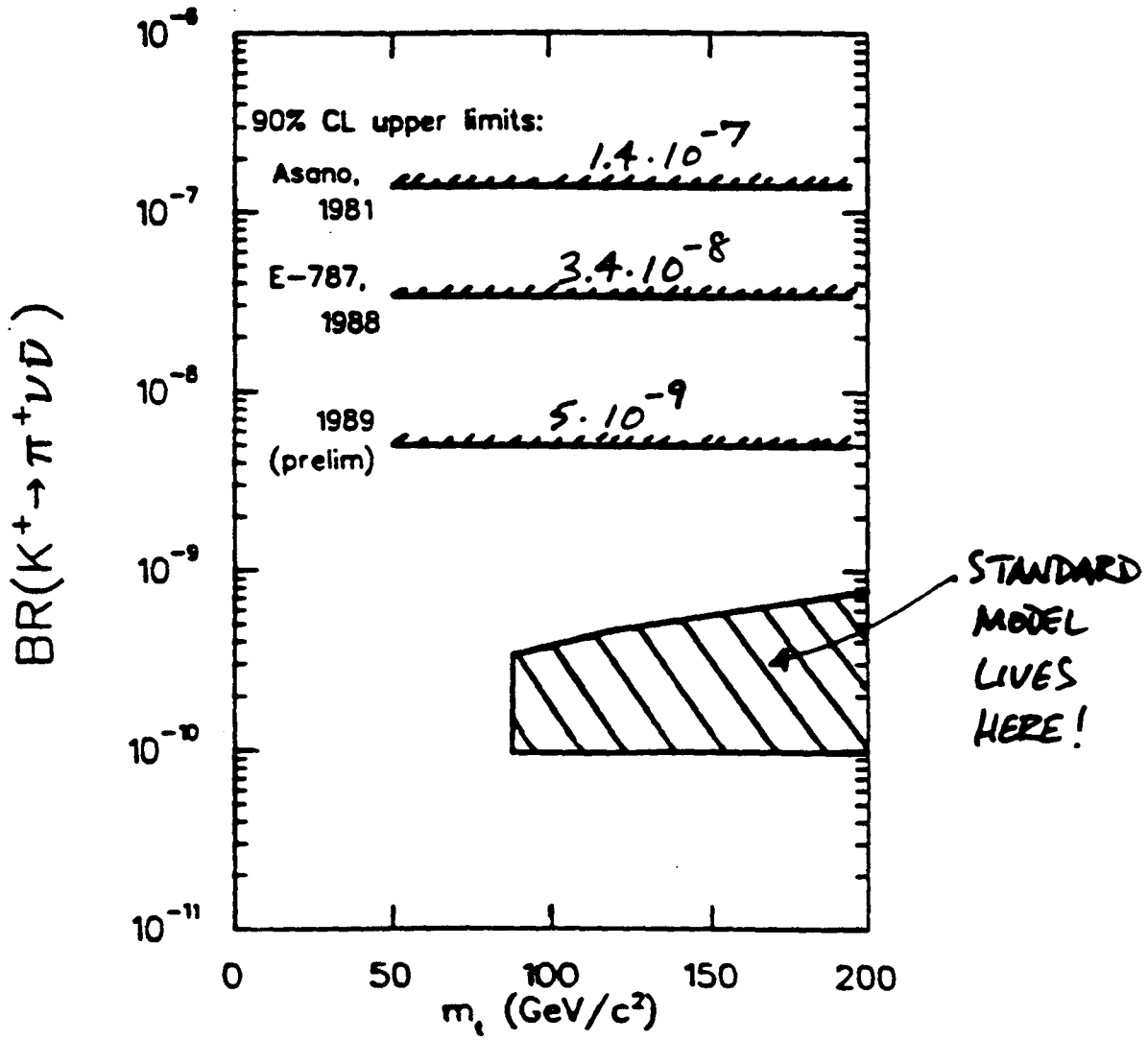


range vs. energy


E-787 1989 (preliminary)
after p cut
Range (cm)
T (MeV)
60
50
40
30
20
80
100
120
140
160
14
879
$K^+ \to \mu^+ \nu \gamma$
$K^+ \to \pi^+ \pi^0$

E-787 1989 (preliminary)

- $BR(K^+ \to \pi^+ \nu\bar{\nu}) < 5 \times 10^{-9}$ (90% CL)
- $BR(K^+ \to \pi^+ f) < 1 \times 10^{-9}$ (90% CL)



In 1990, E-787 stopped about 1.3 times as many kaons as in 1989.

$K_L^0 \to \pi^0 e^+ e^-$

$$\langle \pi(p') | J^\alpha(q) | K_L(p) \rangle = f p^\alpha + g q^\alpha$$

$p^\alpha = (p^0, \vec{p})$ $\qquad$ $p^\alpha = \bar{p}_\alpha$

$\bar{p}^\alpha \equiv (p^0, -\vec{p})$ $\qquad$ METRIC $(1,-1,-1,-1)$

$CP\,|\pi(p')\rangle = -|\pi(\bar{p}')\rangle$ $\qquad$ $C+ \quad P-$

$CP\,|K_L(p)\rangle = -|K_L(\bar{p})\rangle$ $\qquad$ $CP-$

$CP\, J^\alpha(q)(CP)^{-1} = -J_\alpha(\bar{q})$ $\qquad$ $C|Q\rangle = -|Q\rangle$

UNDER CP:

$$\langle \pi(p') | J^\alpha(q) | K_L(p) \rangle \Rightarrow -\langle \pi(\bar{p}') | J_\alpha(\bar{q}) | K_L(\bar{p}) \rangle$$

$$f p^\alpha + g q^\alpha \Rightarrow -(f \bar{p}_\alpha + g \bar{q}_\alpha)$$
$$= -(f p^\alpha + g q^\alpha)$$

$$\Rightarrow \quad f, g = 0$$

NOTE f & g FUNCTIONS OF q^2

IN GENERAL $\quad p \cdot p' = \bar{p} \cdot \bar{p}'$

$K_L \to \pi^0 e^+ e^-$ Phenomenology

both CP violating and CP conserving contributions

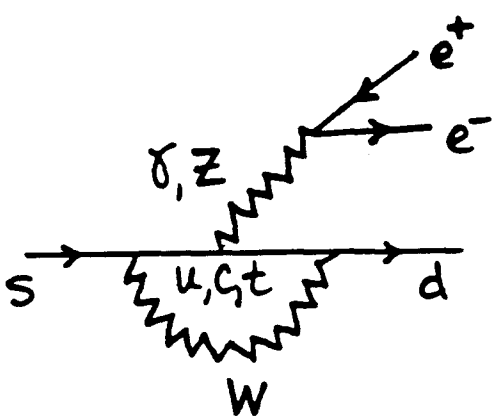
- CP violating amplitudes
  - Indirect (mass matrix)

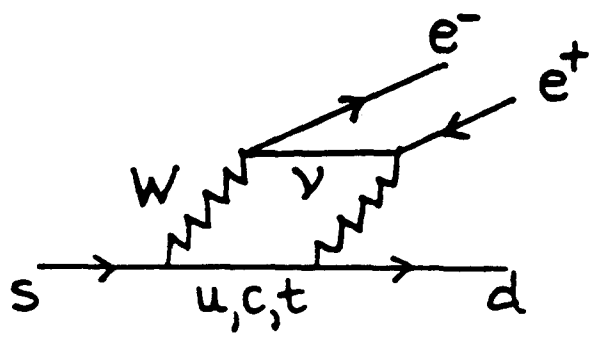
$$K_L \propto K_2 + \epsilon K_1$$

$$B(K_L \to \pi^0 e^+ e^-) = |\epsilon|^2 \, B(K^+ \to \pi^+ e^+ e^-) \, \frac{\tau_L}{\tau_+} \, \frac{\Gamma(K_1 \to \pi^0 e^+ e^-)}{\Gamma(K^+ \to \pi^+ e^+ e^-)}$$

$$\cong 1.5 \cdot 10^{-11} \leftrightarrow 1.5 \cdot 10^{-12}$$

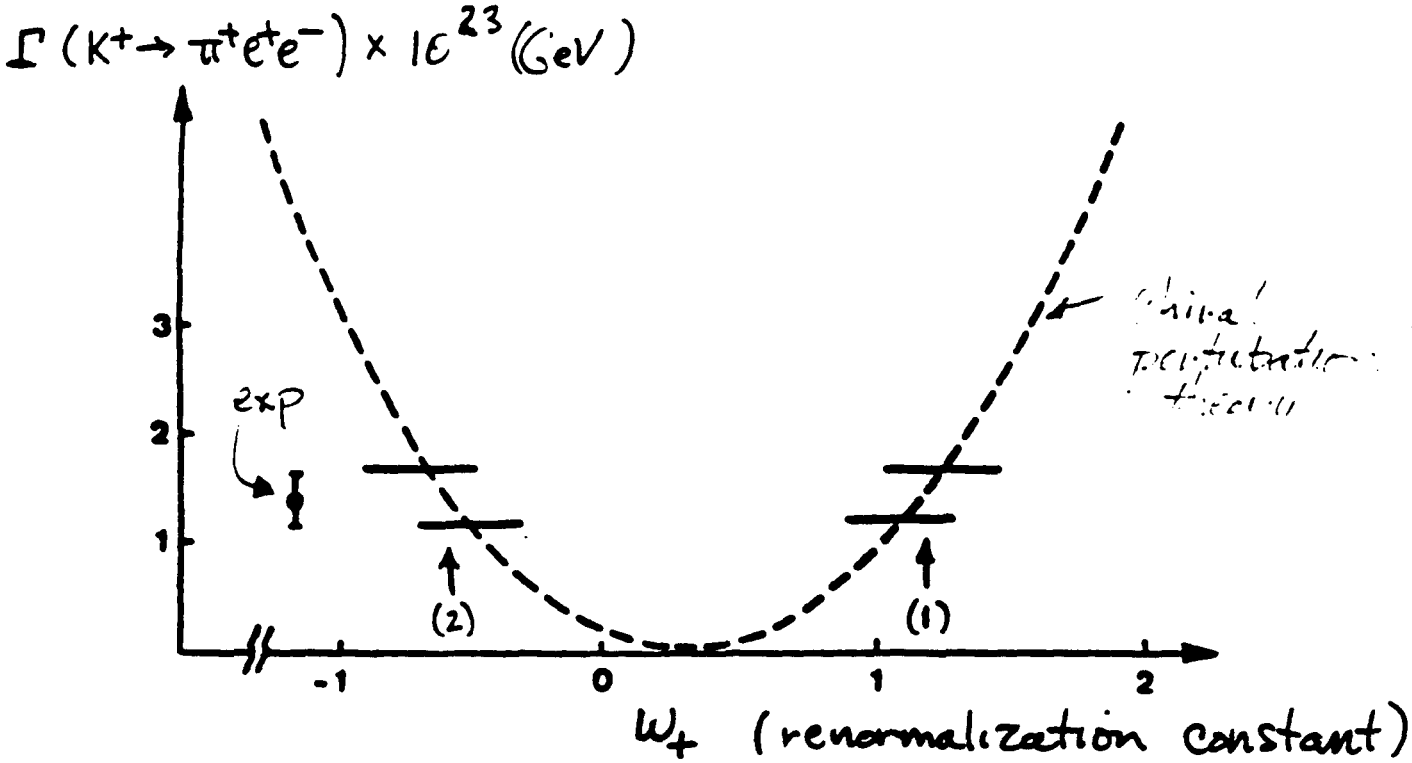
  - Direct (decay amplitude)

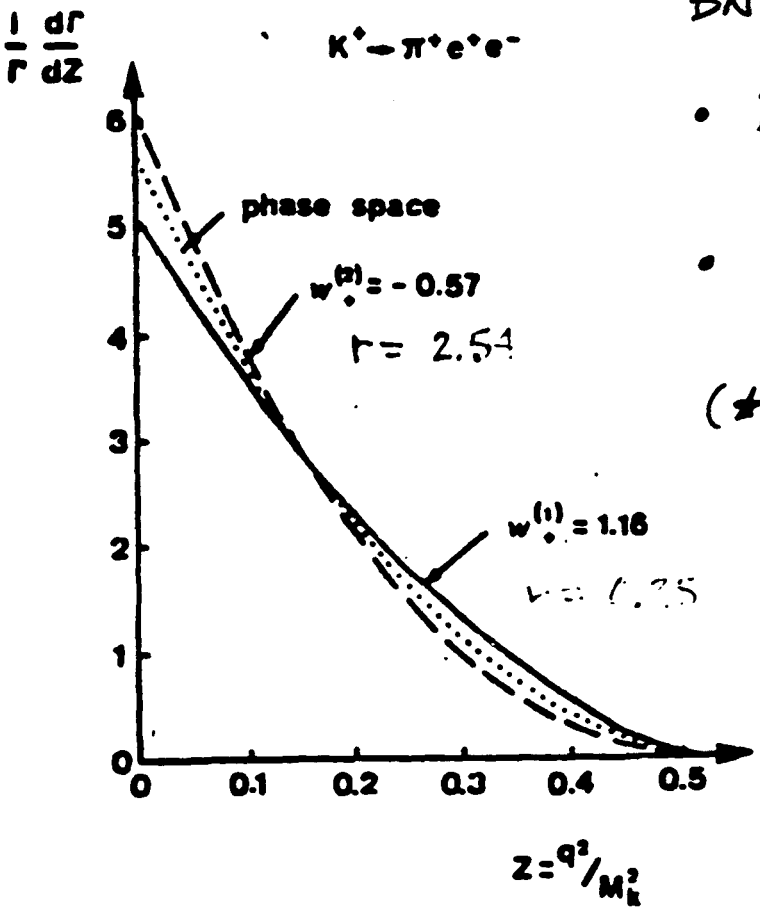




$$B(K_L \to \pi^0 e^+ e^-)_{DIRECT} \cong 8 \cdot 10^{-12} \to 5 \cdot 10^{-13}$$

Buchalla, Burns, Hagelin
m_t < 200 GeV
MFI-IAF ITP



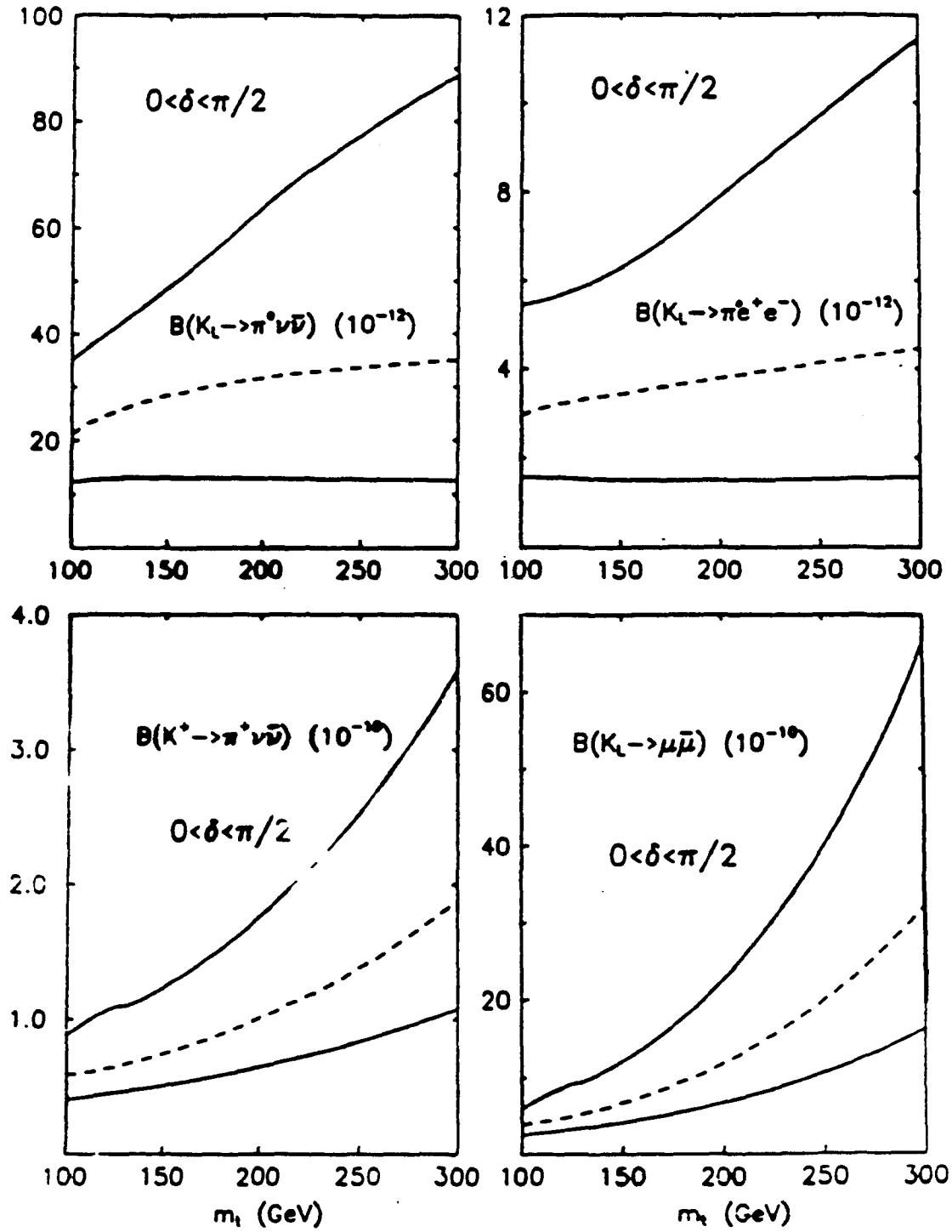


BNL 777/851 results* on $K^+ \to \pi^+ e^+ e^-$:

- BR consistent with PDG value ($2.7 \cdot 10^{-7}$
- m_{ee} spectrum favors $w_+ > 0$

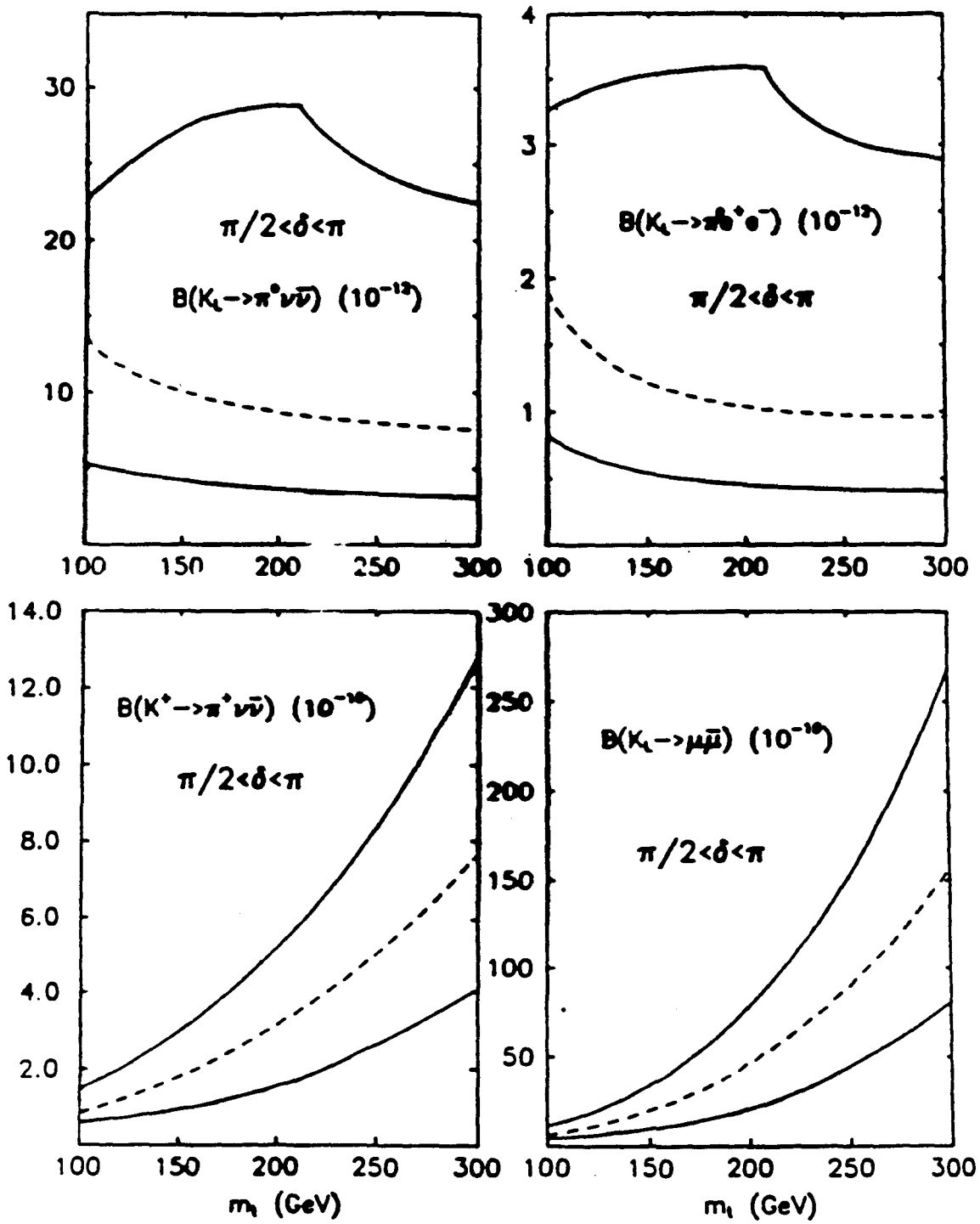
(* private communication)

Plots from Ecker, Pich, de Rafael NP291 (87) 692



7. The branching ratios $K_L \to \pi^0\nu\bar{\nu}$, $K_L \to \pi^0 e^+e^-$, $K^+ \to \pi^+\nu\bar{\nu}$ and $K_L \to \mu\bar{\mu}$ for the first quadrant of δ. The dashed lines represent the results for $\Lambda_{QCD} = 0.2$ GeV, $\bar{R} = 0.02$, $s_{23} = 0.045$ and $B_K = 0.75$. The solid curves correspond to the lower and upper bounds of the branching ratios for the whole parameter range considered.

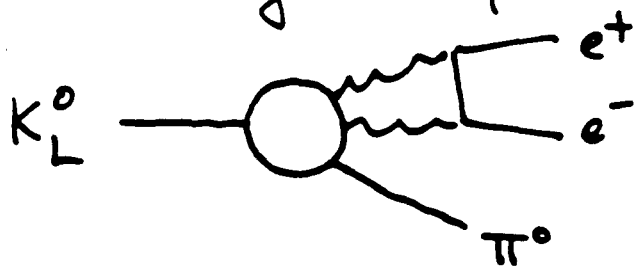
From Buchalla, Buras & Harlander
MPI - PAE/Pth 30/90



The same as fig. 7, but for δ in the second quadrant.

δ KM CP phase

CP conserving 2γ process



Theoretical uncertainties are considerable

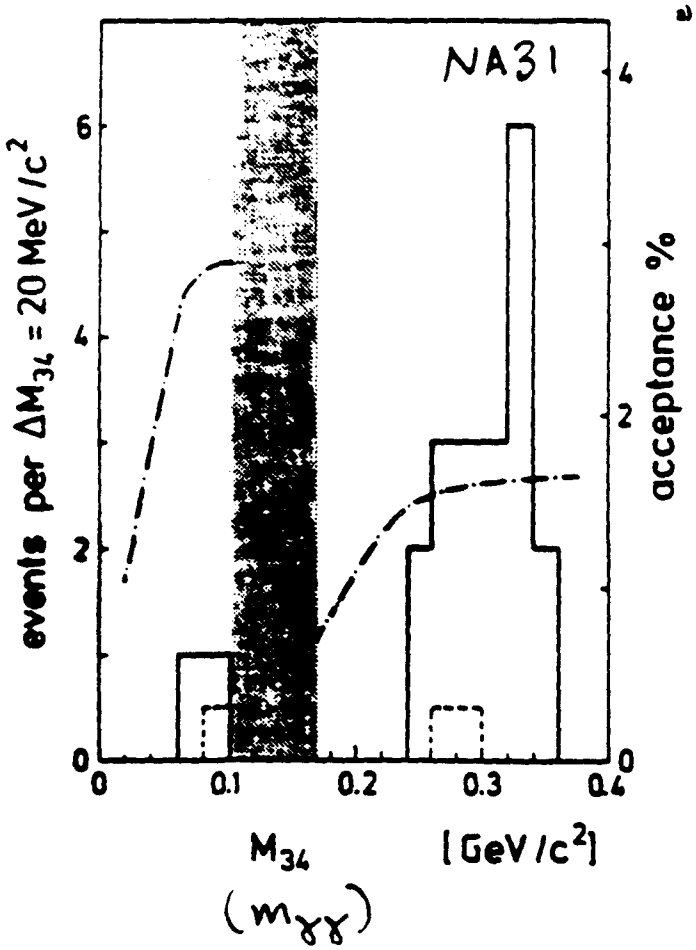
$$BR(K_L \to \pi^0 \gamma\gamma \to \pi^0 e^+ e^-) \sim \underset{(VDM)}{10^{-11}} - \underset{(CPTh)}{10^{-14}}$$

Measurements of $K_L \to \pi^0 \gamma\gamma$ rate and spectrum are needed:

CPTh $\Rightarrow$ $BR(K_L \to \pi^0 \gamma\gamma) = 6.7 \cdot 10^{-7}$

& $m_{\gamma\gamma}$ distribution peaks at 325 MeV

... and results are in from E731 & NA31 which favor these predictions.



21 events observed

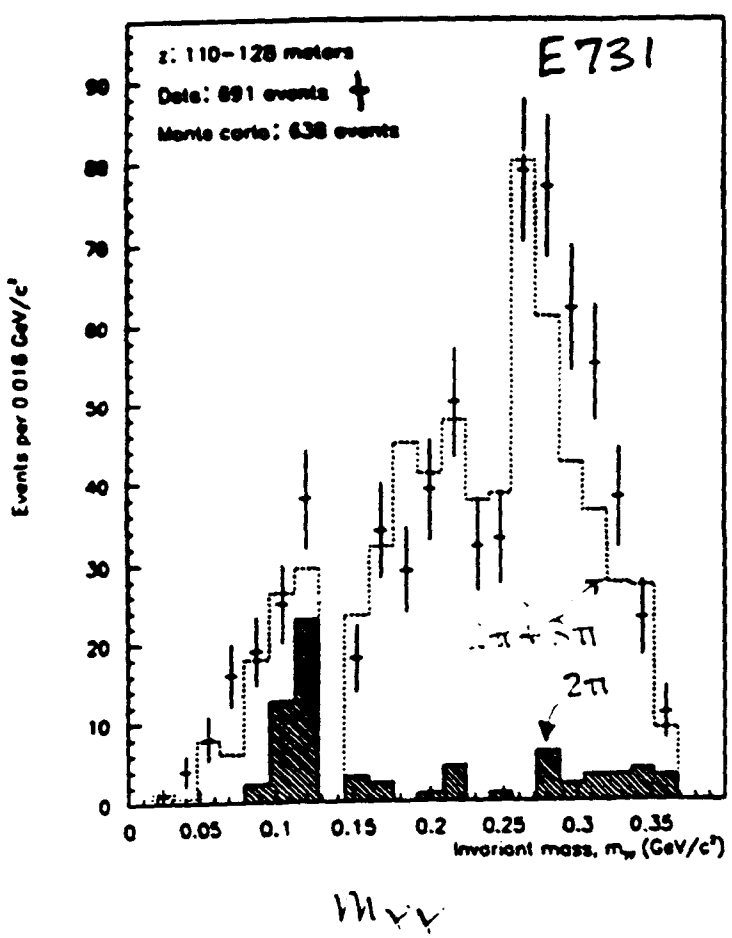
expected backgnd 1.5±0.9 events

$BR(K_L \to \pi^0 \gamma\gamma)$

$= (2.1 \pm 0.6) \cdot 10^{-6}$

for $m_{\gamma\gamma} > 280$ MeV/c^2

(13.5 ± 3.8 events)



for $m_{\gamma\gamma} > 280$ MeV/c^2

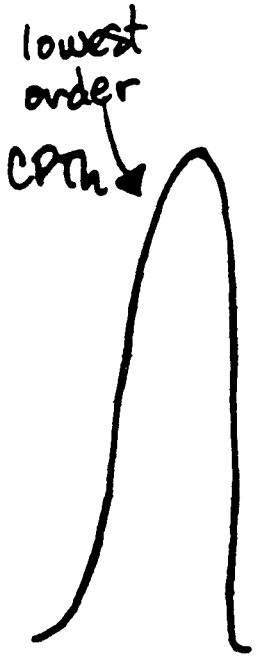
232 events observed

171.9 background events expected

($\pi^0\pi^0$, $\pi^0\pi^0\pi^0$)

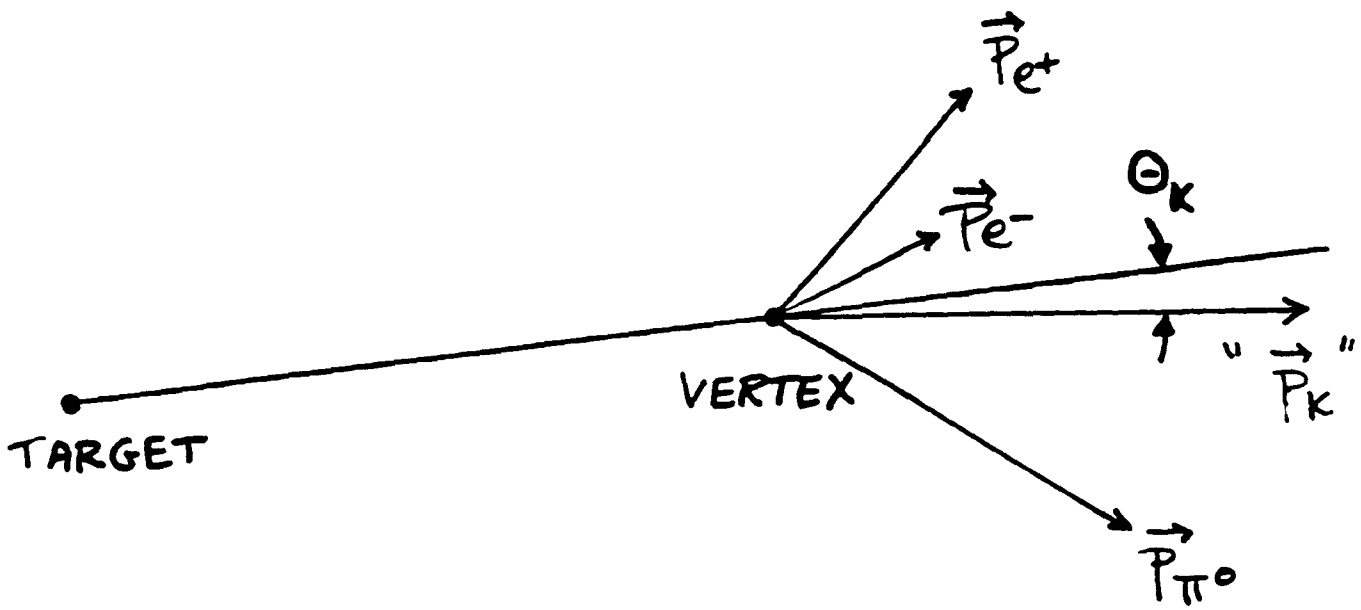
$BR(K_L \to \pi^0 \gamma\gamma)$

$= (1.86 \pm 0.85) \cdot 10^{-6}$


lowest
order
CPTh

General Method for $K_L \to \pi^0 e^+ e^-$ Search

- e^+e^- define decay vertex
- position and energy of γ's measured with lead glass
- mass constraints: $m_{\gamma\gamma} \simeq m_{\pi^0}$, $m_{\pi ee} \simeq m_K$
- reconstructed kaon must come from target: $\theta_K \simeq 0$



Backgrounds to $K_L \to \pi^0 e^+ e^-$

$K_L \to \pi e \nu + 2\gamma$ (e.g. from $K_L \to 3\pi^0$)
$\quad\quad\quad\quad \hookrightarrow$ "e"

- time resolution
- π/e separation
- γ veto
- $m_{\gamma\gamma}$, $m_{\pi ee}$, θ_K

$K_L \to \pi^0 \pi^0$
$\quad\quad\quad\quad \hookrightarrow e^+ e^- (\gamma)$

- require $m_{ee} > m_{\pi^0}$

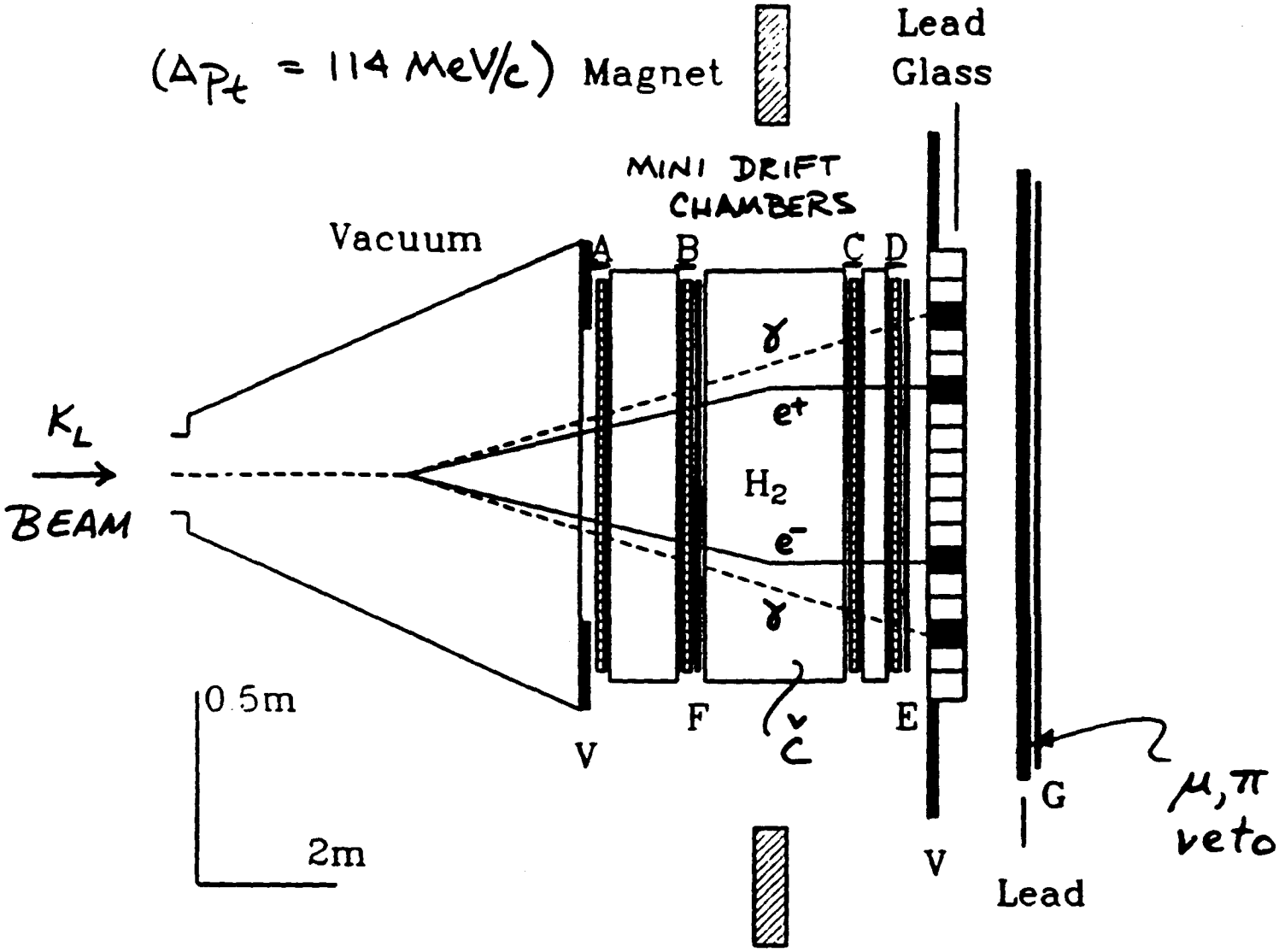
$K_L \to \pi^0 \pi^0$
$\quad\quad\quad\quad \hookrightarrow e^+ e^- \gamma$
$\quad\quad\quad\quad \hookrightarrow e^+ e^- \gamma$

- charged particle multiplicity
- $m_{\gamma\gamma}$

$K_L \to e^+ e^- \gamma + \gamma_{brem}$

- $m_{\gamma\gamma}$, E_γ, $\theta_{e\gamma}$

E845 Detector (plan view)



e^+e^- trigger

$$(F \cdot \check{C} \cdot E \cdot LG \cdot \bar{G})^2 \cdot \bar{V} \cdot (E_{LG} > 4\ \text{GeV})$$

minimum bias trigger ($K_L \to \pi^+\pi^-\pi^0$)

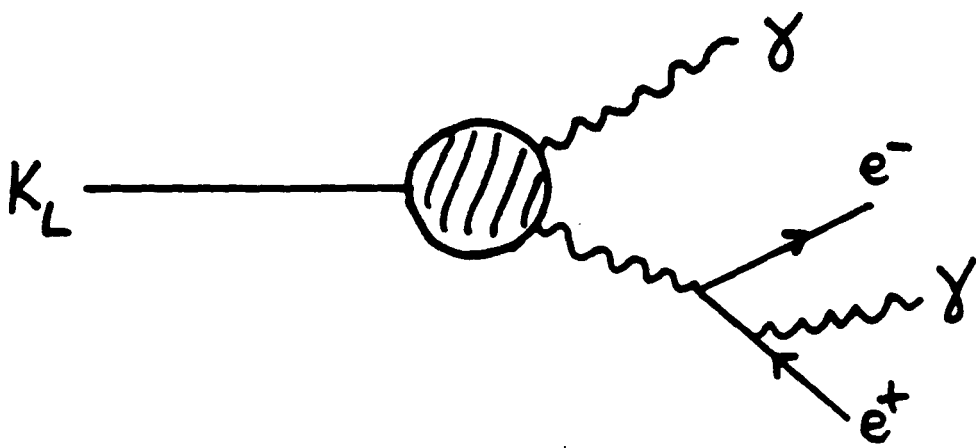
$$(F \cdot E)^2 \div 10{,}000$$

History of $K_L \to \pi^0 e^+ e^-$

Reference	Upper Limit (90% C.L.)
A.S. Carroll *et al.* PRL **44**, 525 (1980).	2.3×10^{-6}
E780, E. Jastrzembski *et al.* PRL **61**, 2300 (1988).	3.2×10^{-7}
NA31, G.D. Barr *et al.* PL **214B**, 303 (1988).	4×10^{-8}
E731, L.K. Gibbons *et al.* PRL **61**, 2661 (1988).	4.2×10^{-8}
E731, A. Barker *et al.* PRD **41**, 3546 (1990).	7.5×10^{-9}
E845, K.E. Ohl *et al.* PRL **64**, 2755 (1990).	5.5×10^{-9}

$K_L^0 \to e^+e^-\gamma\gamma$ as a background to $K_L^0 \to \pi^0 e^+e^-$

$$K_L \to e^+e^-\underbrace{\gamma + \gamma_{brem}}_{\text{trouble if } m_{\gamma\gamma} \cong m_{\pi^0}}$$

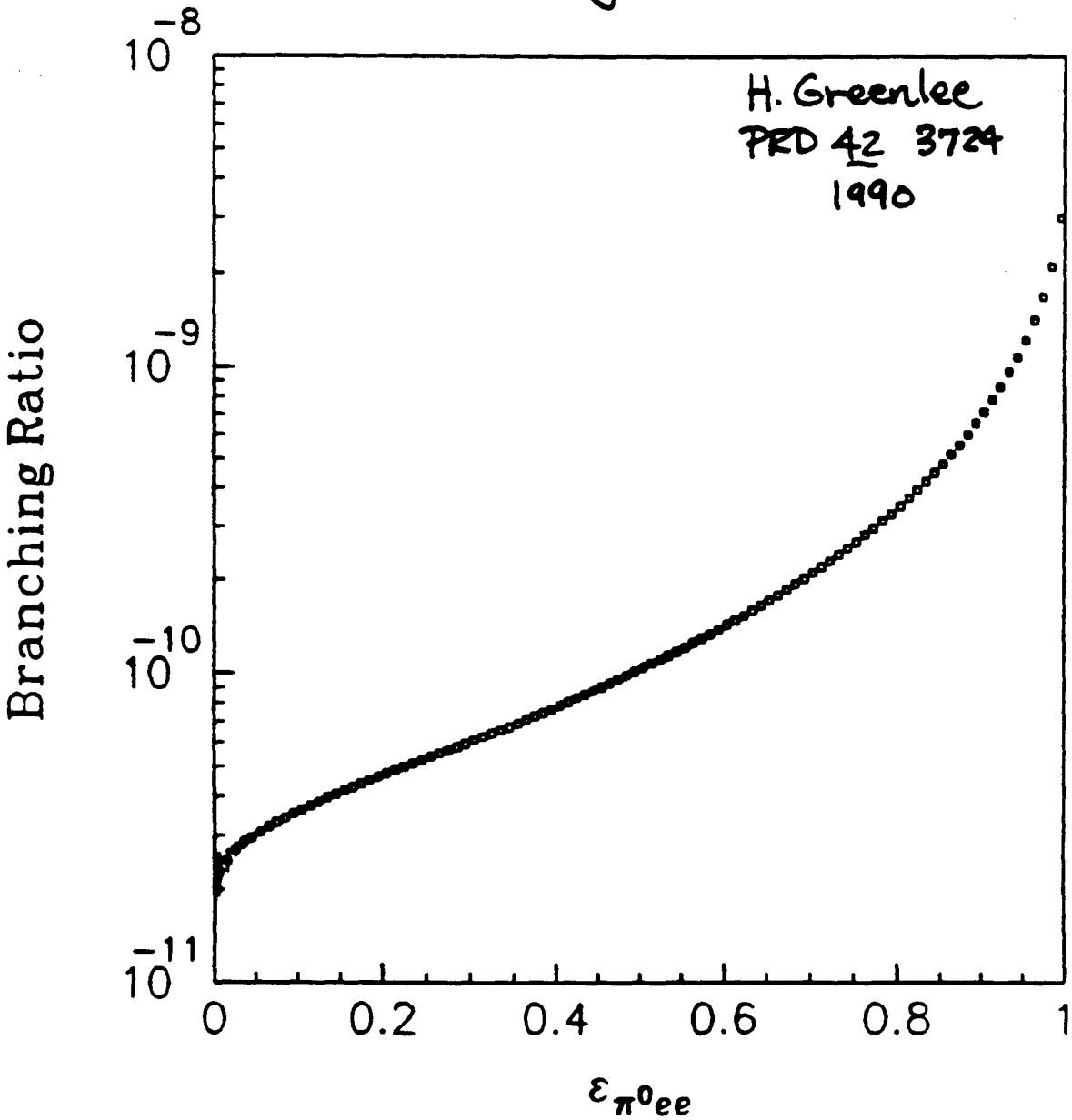


QED prediction:

$$B(K_L \to e^+e^-\gamma\gamma) = 5.8 \times 10^{-7} \quad (E_\gamma^* > 5MeV)$$

non-negligible isotropic component for the radiation

$K_L \to \gamma\gamma e^+e^-$ background to $K_L \to \pi^0 e^+e^-$



$\varepsilon_{\pi^0 ee}$ efficiency for accepting $\pi^0 ee$ decays of an optimized phase space cut against $\gamma\gamma ee$.

assumptions: $m_{ee} > m_{\pi^0}$

$m_{\gamma\gamma} = m_{\pi^0} \pm 5\ MeV/c^2$

BRICK WALL @ $2.2 \cdot 10^{-11}$

A DECADE OF PROGRESS IN RARE K DECAY PHYSICS

DECAY MODE	SENSITIVITY*	IMPROVEMENT*	COMMENTS
$K_L \to \mu e$	$\sim 10^{-11}$	$\sim 250{,}000$	probes $M_X \sim 100$ TeV
$K_L \to ee$	$\sim 1.5 \cdot 10^{-11}$	~ 6000	? new scalar int
$K_L \to \mu\mu$	~ 935 events	~ 34	test SM
$K^+ \to \pi^+ \mu^+ e^-$	$\sim 10^{-10}$	~ 23	compliments $K \to \mu e$
$K^+ \to \pi^+ e^+ e^-$	~ 2000 events	~ 50	test SM
$K^+ \to \pi^+ \nu\bar{\nu}$	$\sim 9 \cdot 10^{-10}$	~ 80	SM constraints
$K^+ \to \pi^+ X^0$	$\sim 2 \cdot 10^{-10}$	~ 180	exotic search
$K^+ \to \pi^+ \mu^+ \mu^-$	$\sim 3 \cdot 10^{-9}$	~ 300	test SM
$K_L^0 \to \pi^0 e^+ e^-$	$\sim 10^{-9}$	~ 780	expect few $\cdot 10^{-8}$ nonstandard $\not{C}\not{P}$
$K_L \to e^+ e^- \gamma$	~ 4000 events	~ 1000	long distance effects

* My estimate of single event sensitivity (BR) or number of events collected through the end of 1990.

* with respect to situation circa 1970.

Prospects for the 90's

Brookhaven AGS booster goes into operation in 1993 $\Rightarrow$ increased intensity (x3)

$K^+ \to \pi^+ \nu \bar{\nu}$ E787 continues to run

upgrades : 2nd beam separator (x3 K/dose)
new target (thinner, brighter fibers)
lower mass drift chamber
CsI endcap vetos

long term goal
few $\cdot 10^{-11}$ sensitivity

$K^+ \to \pi^+ \mu^+ e^-$ E777/E851 $\to$ E865 approved

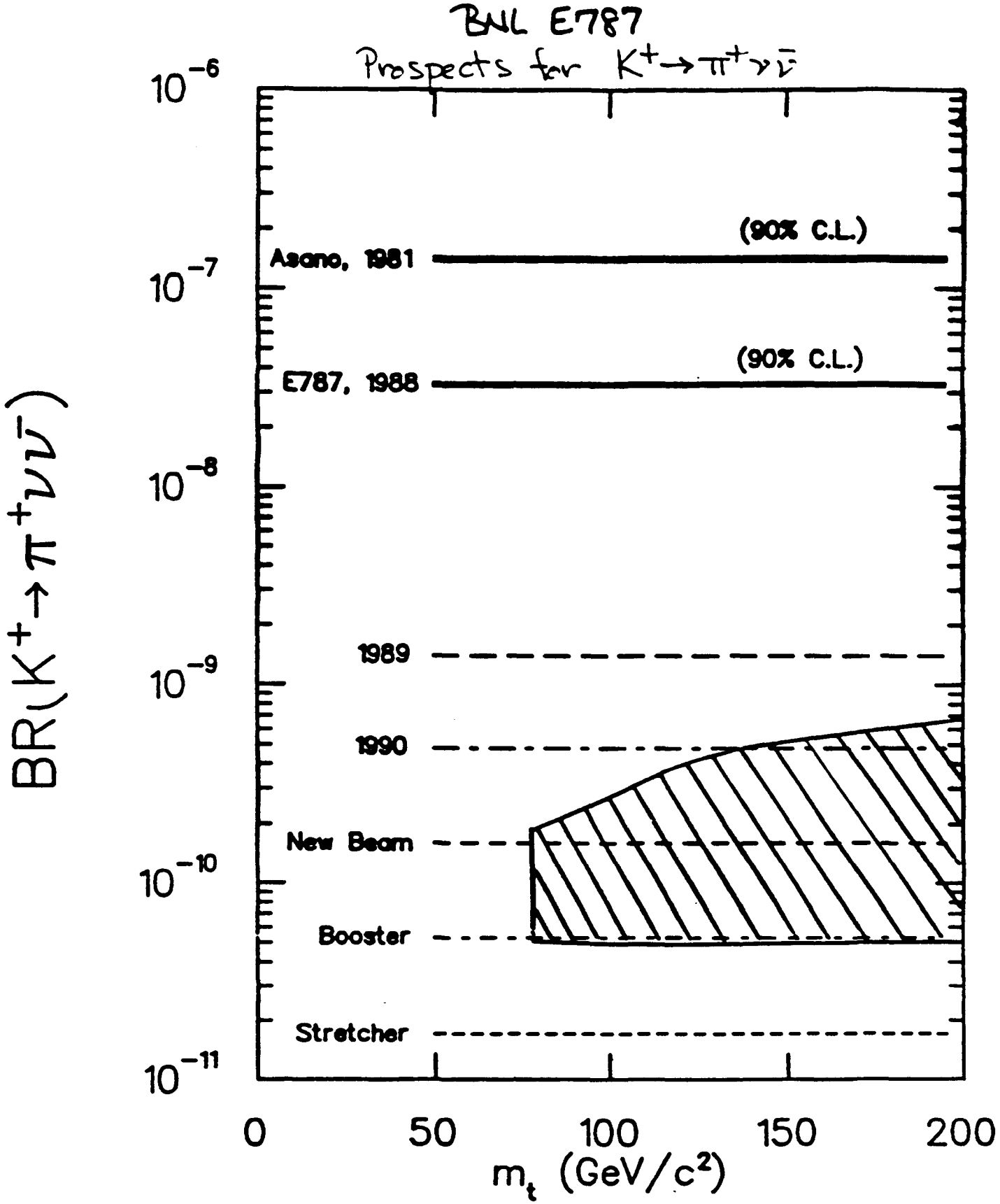
long term goal
10^{-12} sensitivity

new beam
new detector
same basic approach

$K_L^0 \to \mu e$ E791 $\to$ P871

long term goal
10^{-12} sensitivity

reconfiguration of E791
'stop' the neutral beam
after the decay region

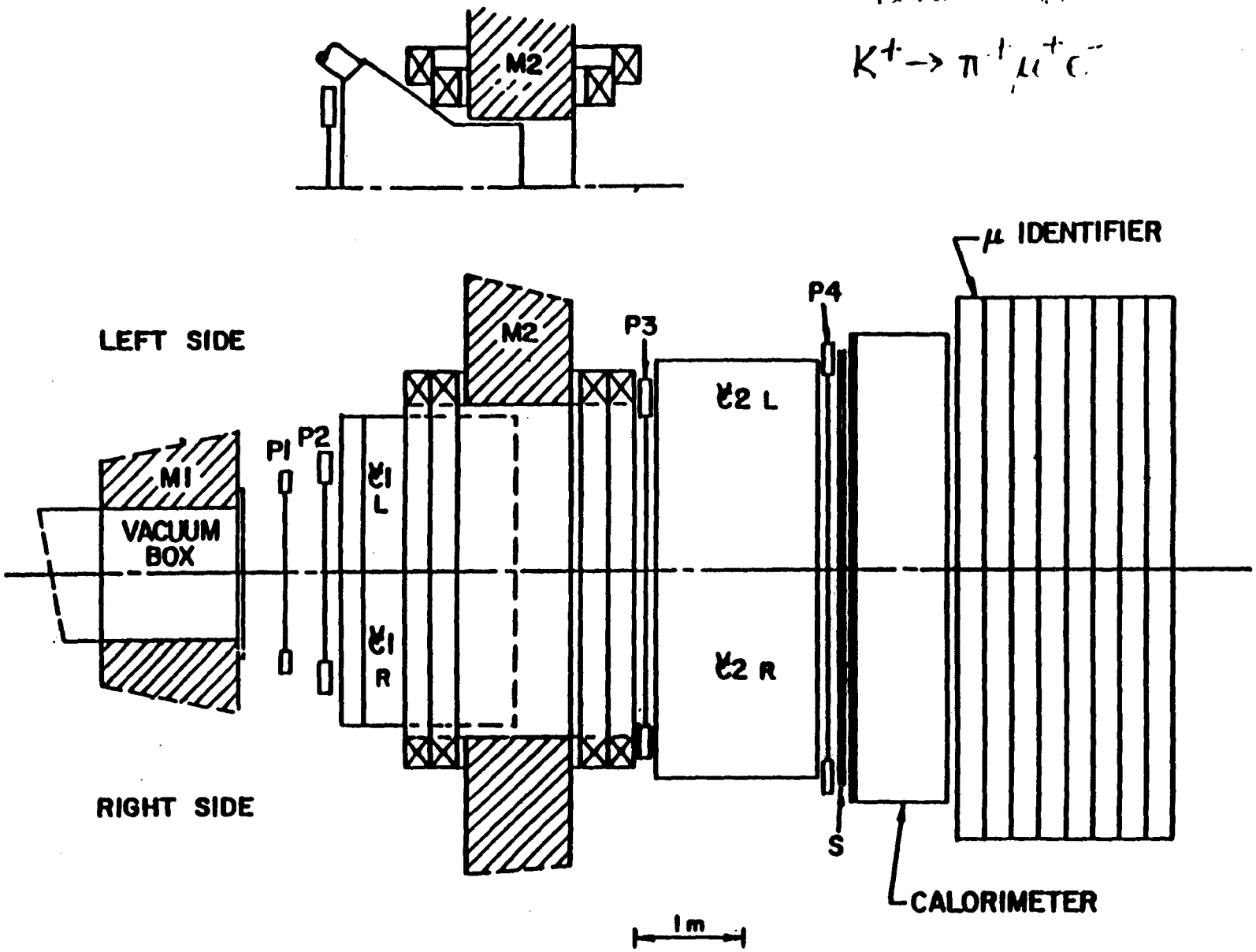


* Sensitivities are per event unless otherwise indicated.

Detector Layout

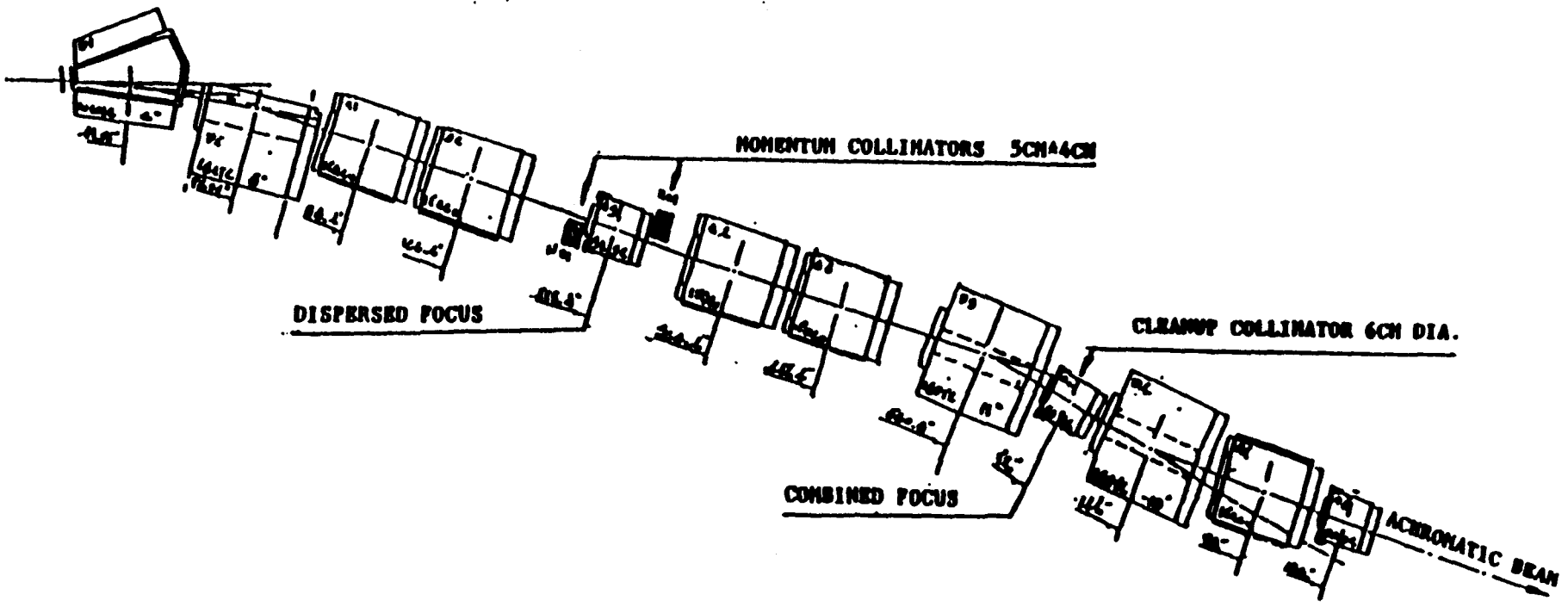
BNL E865

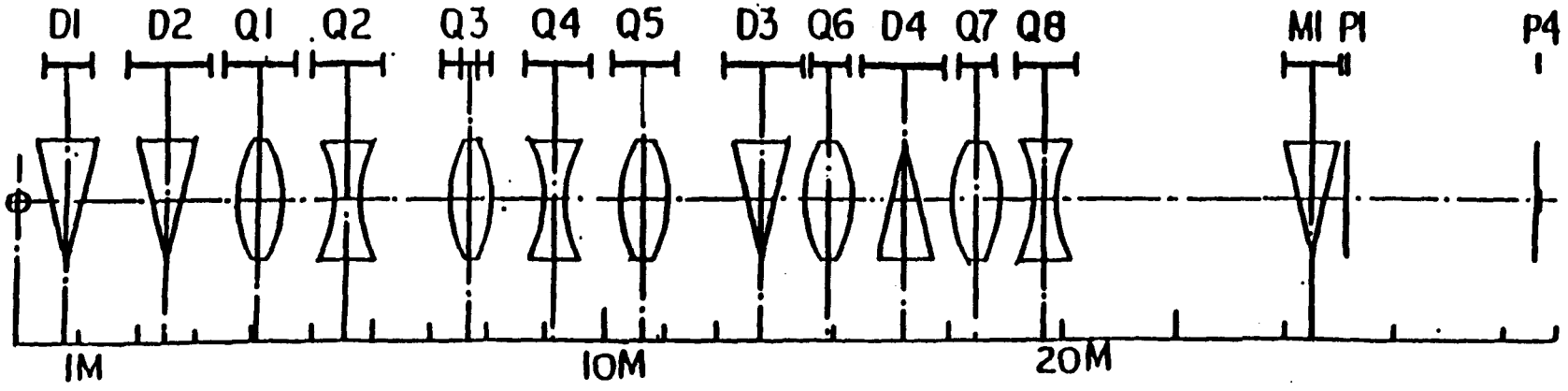
$K^+ \to \pi^+ \mu^+ e^-$



[illegible] K^+ beam

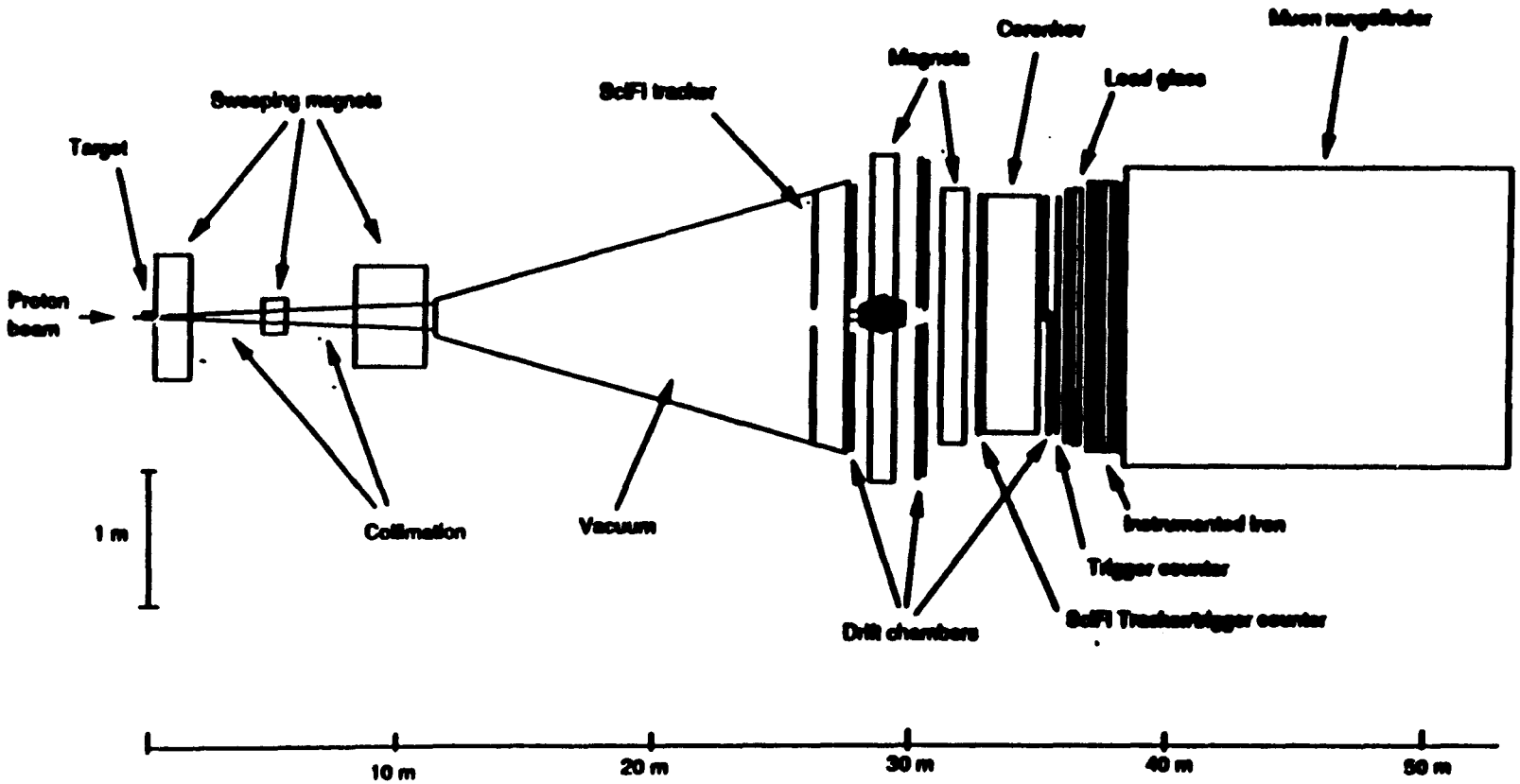
[illegible] EXP 5 : $K^+ \to \pi^+ \mu^+ e^-$ [illegible]





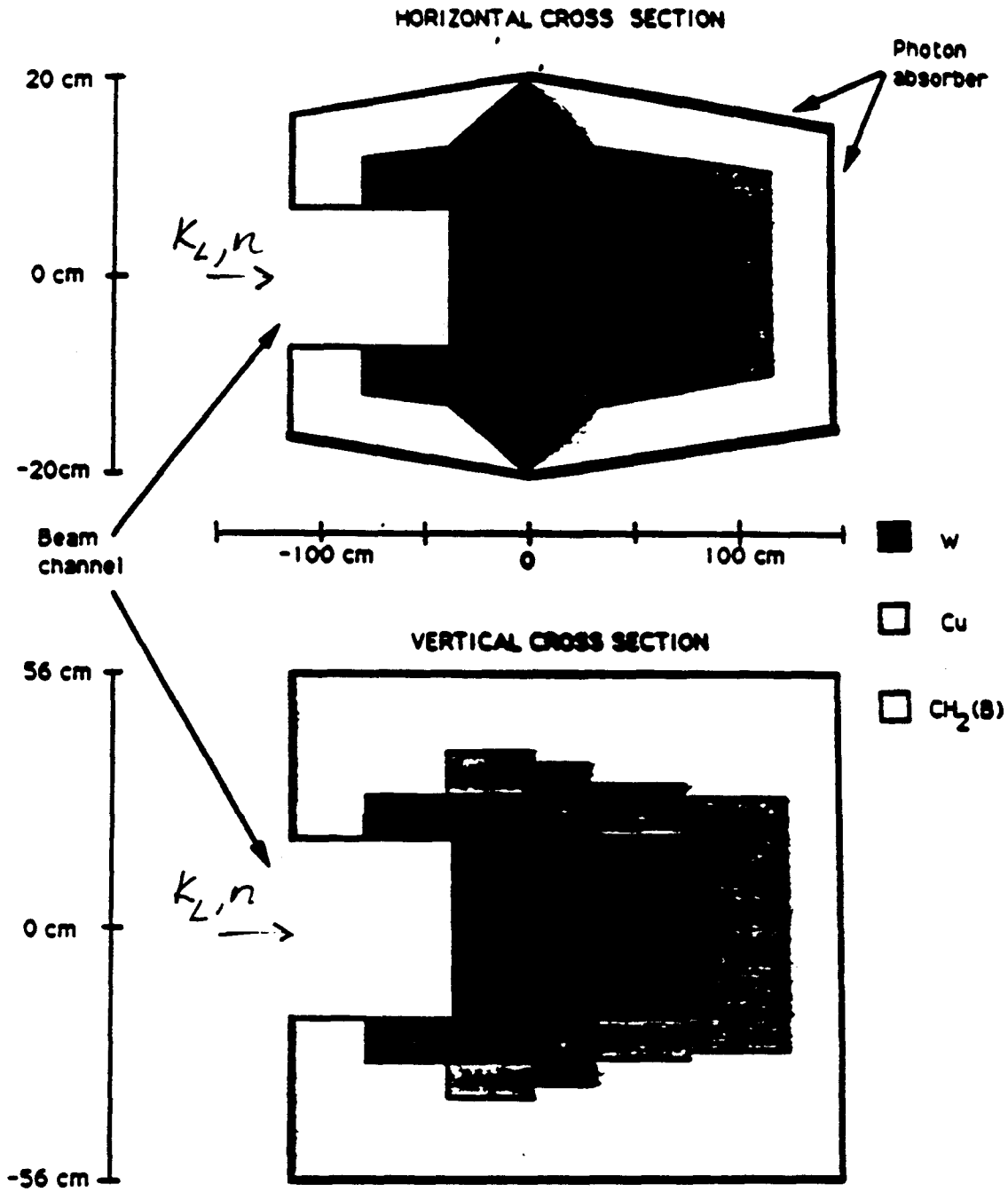
BNL PS71 $K_L \to \mu e$ search

Detector layout



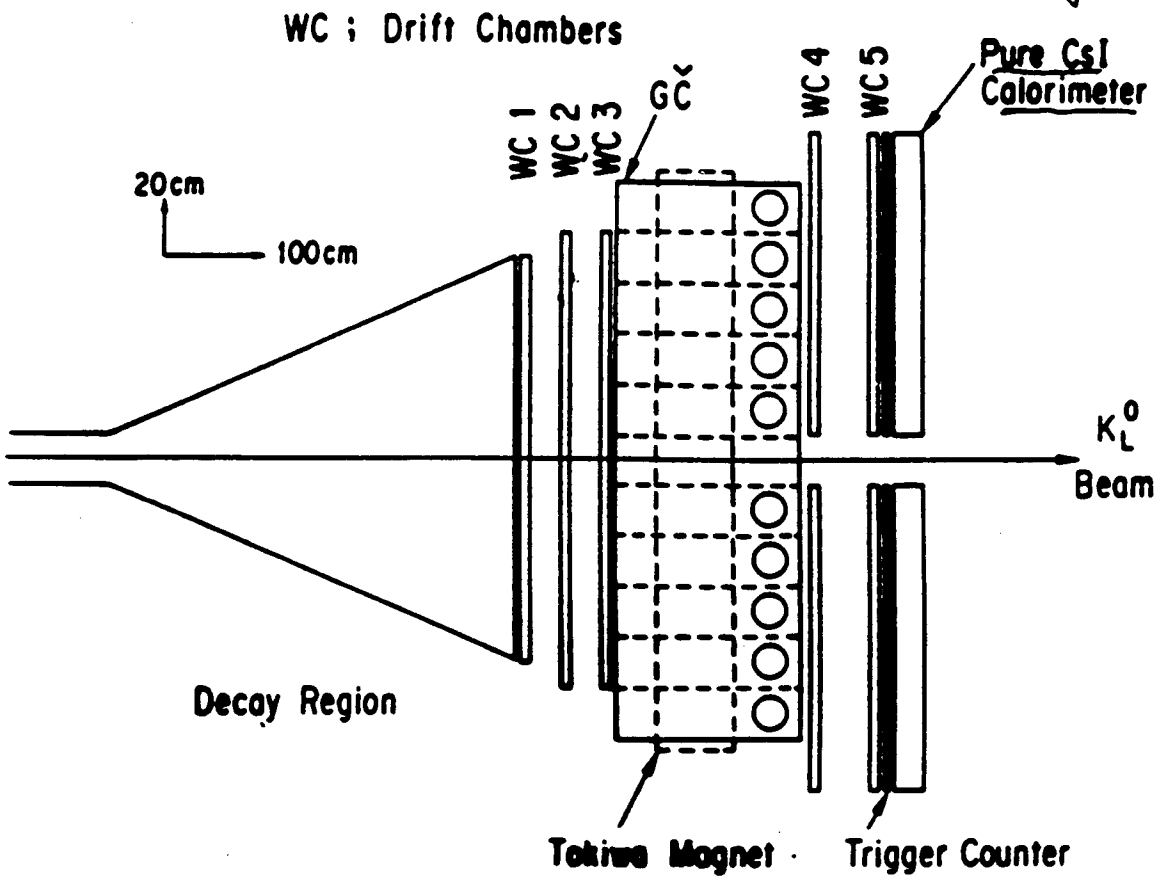
BNL PS71 ($K_L \to \mu e$ search)

Neutral beam stop

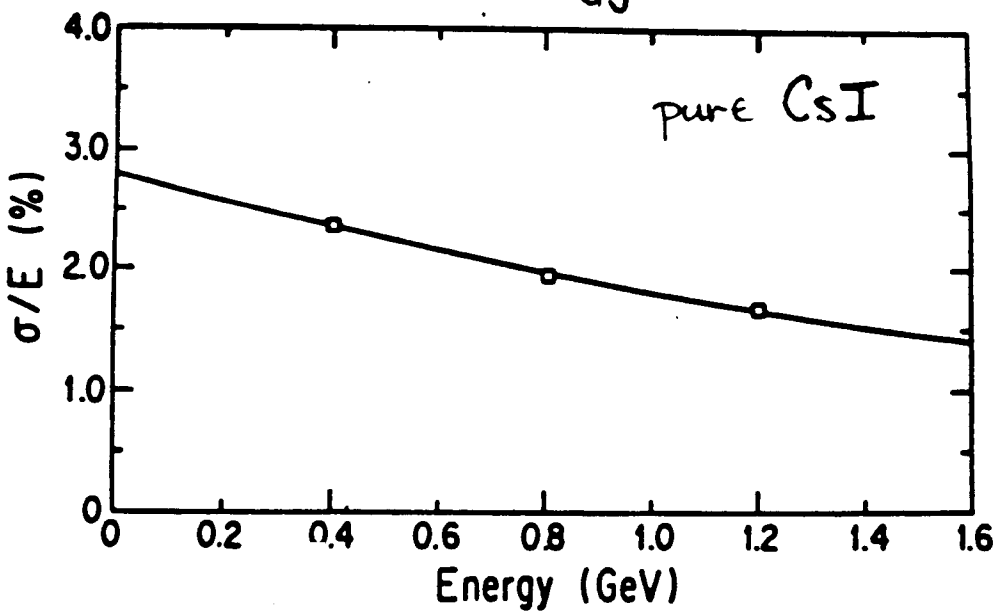


KEK E162 $K_L^0 \to \pi^0 e^+ e^-$

10^{-10} goal
begin late 91



(electron) energy resolution



9 blocks
(7×7× 30 cm)

Published Results

$K_L \to \mu e, ee, \mu\mu$

E787 S. Schaffner et al., PRD 40 990 (89)
E791 C. Mathiazhagan et al., PRL 63 2181, 2185 (89)
E137 T. Inagaki et al., PRD 40 1712 (89)

$K^+ \to \pi^+ \mu^+ e^-$

E777 A. Lee et al., PRL 64 165 (90)

$K^+ \to \pi^+ \nu \bar{\nu}$

E787 M. Atiya et al., PRL 64 21 (90)

$K_L^0 \to \pi^0 e^+ e^-$

E799 E. Jastrzembski et al., PRL 61 2300 (88)
NA31 G. Barr et al., PL 214B 303 (88)
E731 L. Gibbons et al., PRL 61 2661 (88)
" A. Barker et al., PRD 41 3546 (90)
E845 K. Ohl et al., PRL 64 2755 (90)

$K_L \to e^+ e^-\gamma$

NA31 G. Barr et al., PL 240B 283 (90)
E845 K. Ohl et al., PRL 65 1407 (90)

$K_L \to \pi^0 \gamma\gamma$

E731 V. Papadimitriou et al., PRL 63 28 (89)
NA31 G. Barr et al., PL 242B 523 (90)

SLC
SPRING
'91

Physics at DAΦNE
the FRASCATI φ-FACTORY

P. FRANZINI
COLUMBIA
FRASCATI
ROMA

28 and 27
— years ago —

First e^+e^- collisions
in AdA '63
ADONE '71
⋮ e^+e^- physics
e^+e^- - factories

$K_L \to \pi\pi$

$$|K_L\rangle = \frac{|K_1\rangle + |K_2\rangle \cdot \varepsilon}{\sqrt{2}\sqrt{1+|\varepsilon|^2}} \ldots$$

But: ?
Is $\langle \pi\pi | K_2 \rangle \neq 0$?
or $\varepsilon'/\varepsilon \neq 0$

1990 DAΦNE
funded for construction

1990 $\mathrm{Re}\,\frac{\varepsilon'}{\varepsilon} \lesssim 10^{-3}$

φ-factories at various stages of reality

KEK
LNF FRASCATI
MAINZ
NOVOSIBIRSK UCLA
[Triumf - K's]

FRASCATI is very much real - Cost $ 80 × 10^6

This year	$ 10 M	
92 - 93	30	
94 assemble in ADONE Hall	20	+ DETECTOR
95	Begin operation at $\mathcal{L} \sim 2 \times 10^{32}$	

Target $\mathcal{L} \sim 10^{33}$

- DAΦNE conservative & conventional
  one small new twist.

- Two "large" rings, 120 bunches, 5 A
- Accumulator for fast filling
- $\beta_V/\beta_H = 1/100$
- Collisions at 10 mrad ½ angle

Scale from present d's (Vepp 2M, CESR) work on understood components.

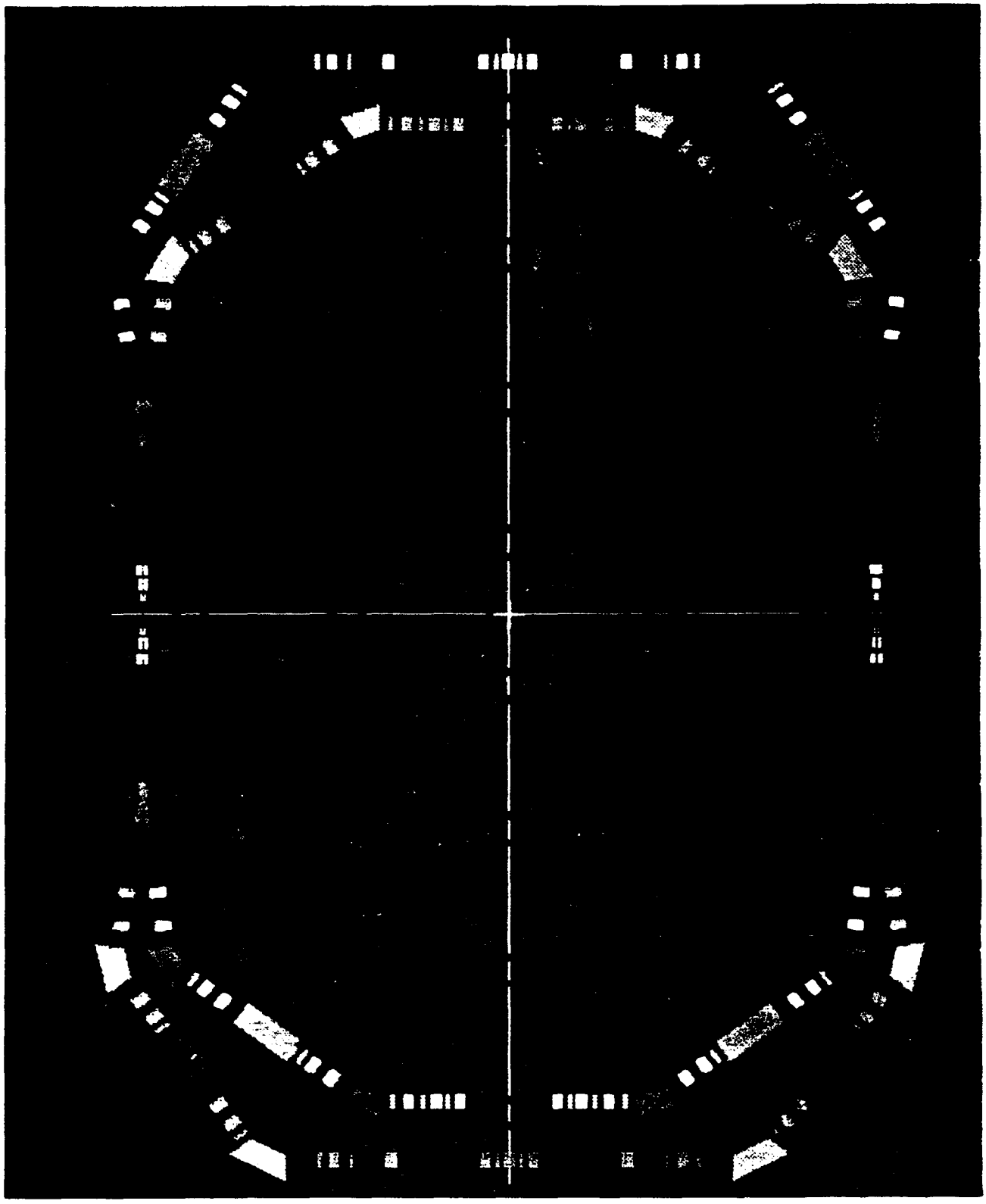
single mode RF cavities
Many correcting elements
4+4 Wigglers

NEW —
Rings are coplanar
⇒ Transverse kick smaller

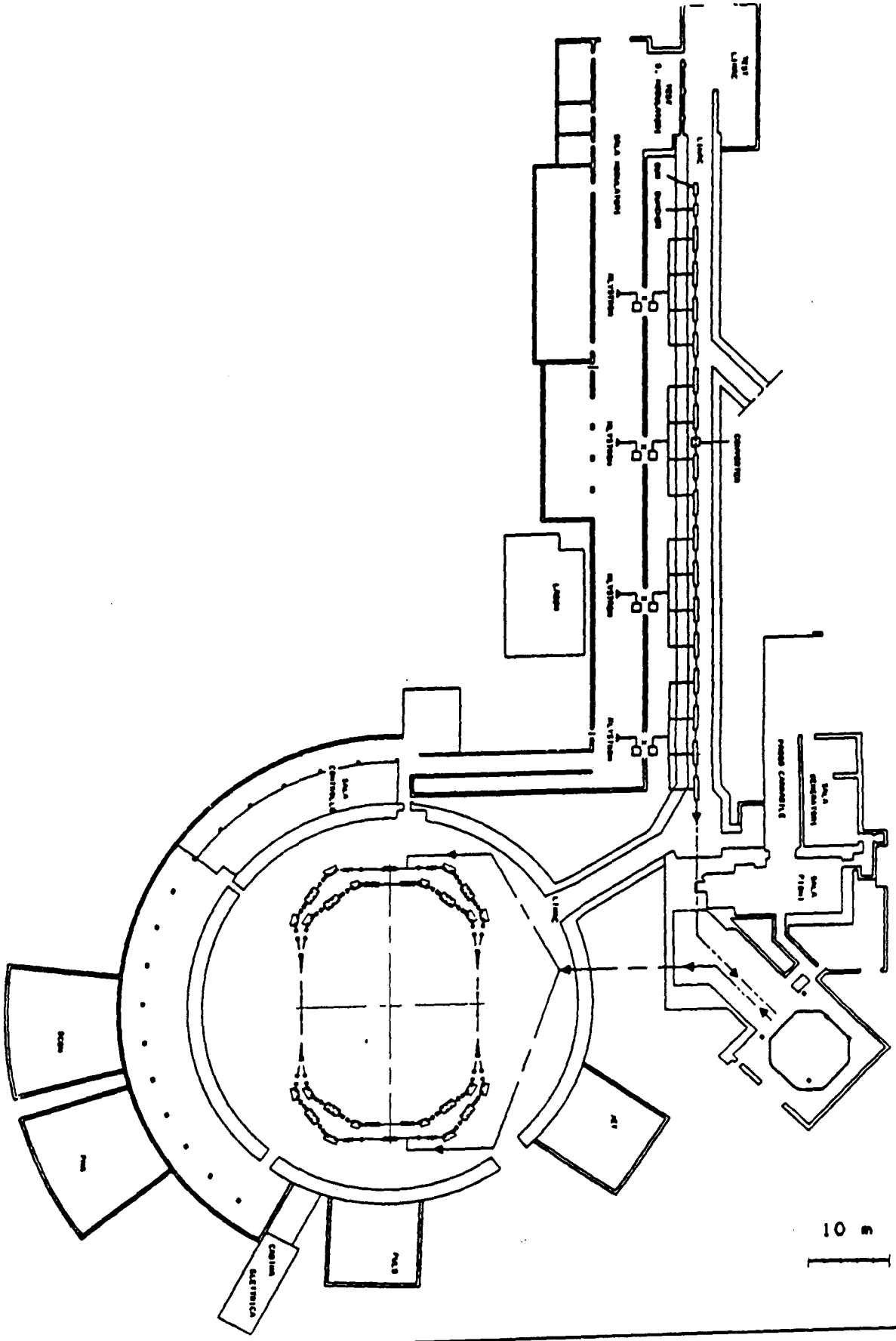
Crab cavity require

$$V_{RF} \propto \frac{1}{\sqrt{\beta_H \text{ or } \beta_V}}$$ ⇒ 10 times less voltage

To be implemented if necessary



DAΦNE PRELIMINARY LAYOUT



What is a ϕ-factory? A *strange factory*? A K-factory?

ϕ- vs K-factory

10^{10} K's/year $\ll$ K-factory intensity, but:

1. Pure QM state – 2 body kin
2. Tagged K's: short, long, s=1 or -1
3. Almost no background
4. K_S beam
5. K and $\overline{K}$ beams

[redacted]

e^+e^- ANNIHILATIONS

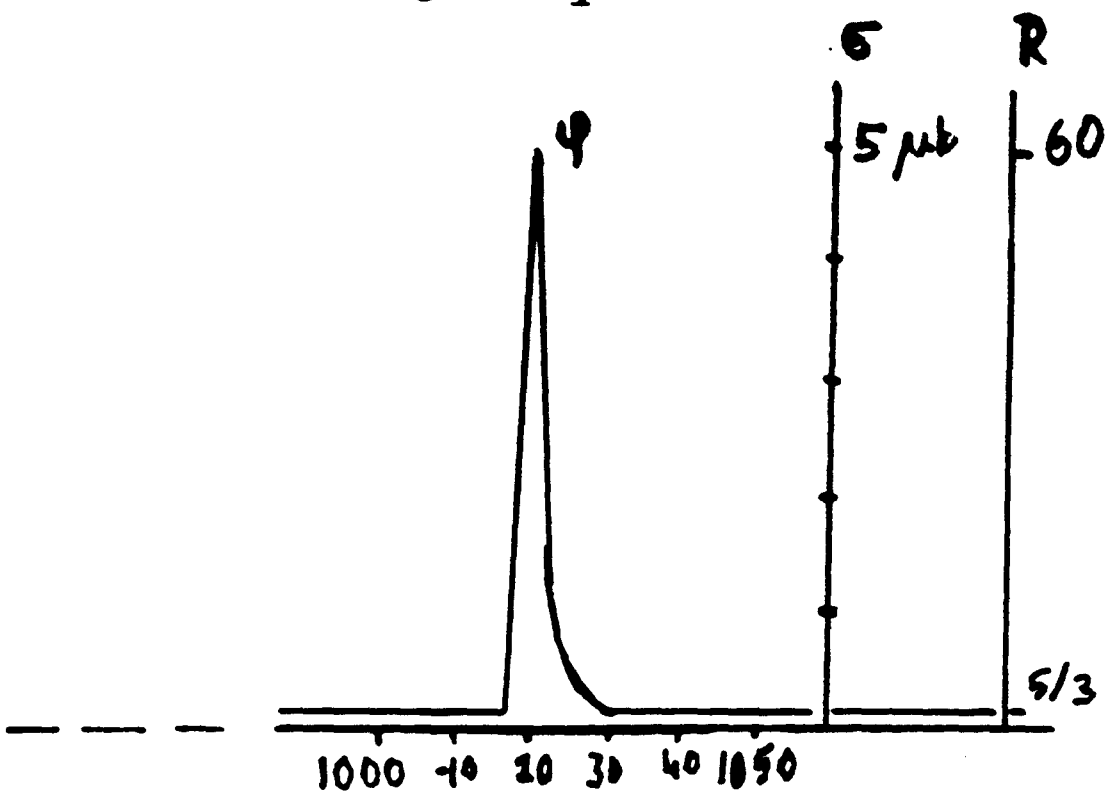
$$e^+e^- \to \gamma \to e^+e^- \qquad \text{Bhabha}$$

$$\to \mu^+\mu^- \qquad \sigma_{\text{point}}$$

$$\to q\bar{q} \qquad \to \text{hadrons}$$

$$\sigma_{\text{point}} = \frac{87 \text{ nb}}{s\ (\text{GeV}^2)} \times e^2$$

$$\text{J}^{\text{PC}} = 1^{--}$$



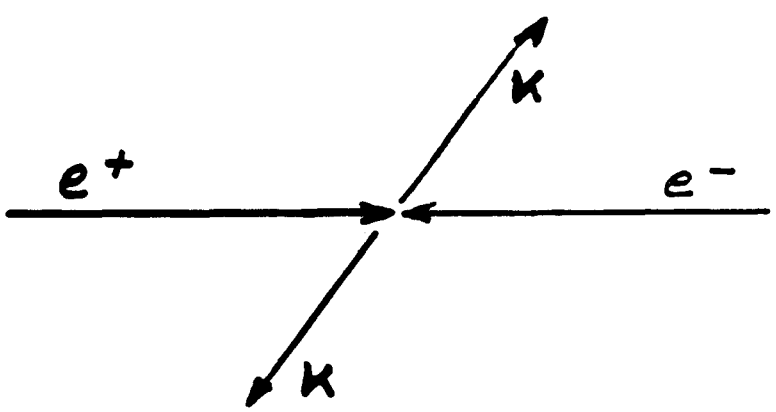
$\sigma(e^+e^- \to \text{hadrons}) \sim 5\ \mu\text{b}$ at 1020 MeV

ϕ DECAYS

$$M = 1019.412 \pm 0.008 \text{ MeV}$$
$$\Gamma = 4.41 \text{ MeV}$$
$$\Gamma_{ee} = 1.37 \text{ keV}$$

$\phi \to K^+K^-$	49%
K_SK_L	34%
$\rho\pi$	13%
$\pi^+\pi^-\pi^0$	2%
$\eta\gamma$	1.3%
$\cdots$	$\sim 10^{-3}$ %

also η-factory



$E_K = 510 \pm 0.25$ MeV, from beam energy spread

$$\phi \to K^0 \overline{K}^0$$

In the reaction

$$e^+e^- \to \text{“}\gamma\text{”} \to \phi \to K^0\overline{K}^0$$

$C(K^0\overline{K}^0) = C(\phi) = C(\gamma) = -1.$

Let $|\, i\,\rangle = |\, K\overline{K},\ t = 0,\ C = -1\,\rangle$, then:

$$|\, i\,\rangle = \frac{|\, K^0, \mathbf{p}\,\rangle |\, \overline{K}^0, -\mathbf{p}\,\rangle - |\, \overline{K}^0, \mathbf{p}\,\rangle |\, K^0, -\mathbf{p}\,\rangle}{\sqrt{2}}$$

Assuming CPT, K_S and K_L, to lowest order in ϵ are given, in the usual (wrong) notation by:

$$|\, K_S\,\rangle = \frac{(1+\epsilon)|\, K^0\,\rangle + (1-\epsilon)|\, \overline{K}^0\,\rangle}{\sqrt{2}\sqrt{1+|\epsilon|^2}}$$

$$|\, K_L\,\rangle = \frac{(1+\epsilon)|\, K^0\,\rangle - (1-\epsilon)|\, \overline{K}^0\,\rangle}{\sqrt{2}\sqrt{1+|\epsilon|^2}}$$

and

$$|\, K^0\,\rangle = \frac{\sqrt{1+|\epsilon|^2}}{(1+\epsilon)\sqrt{2}}(|\, K_S\,\rangle + |\, K_L\,\rangle)$$

$$|\, \overline{K}^0\,\rangle = \frac{\sqrt{1+|\epsilon|^2}}{(1-\epsilon)\sqrt{2}}(|\, K_S\,\rangle - |\, K_L\,\rangle)$$

$$|\,i\,\rangle = \frac{1}{\sqrt{2}}\,\frac{1+|\epsilon|^2}{1-\epsilon^2}\times$$
$$\left(|\,K_S,-\mathbf{p}\,\rangle|\,K_L,\mathbf{p}\,\rangle - |\,K_S,\mathbf{p}\,\rangle|\,K_L,-\mathbf{p}\,\rangle\right)$$

so that finally we conclude:

$$e^+e^- \to \text{“}\gamma\text{”} \to \phi \to K^0\overline{K}^0 \to K_SK_L \text{ at } t=0$$

To obtain the amplitude for decay of $K(\mathbf{p})$ into a final state f_1 at time t_1 and of $K(-\mathbf{p})$ to f_2 at time t_2 we time evolve the initial $K^0\overline{K}^0$ state according to:

$$|\,t_1,\ \mathbf{p};\ t_2,\ -\mathbf{p}\,\rangle = \frac{1+|\epsilon^2|}{(1-\epsilon^2)\sqrt{2}}\times$$
$$\Big(|\,K_S(-\mathbf{p})\,\rangle|\,K_L(\mathbf{p})\,\rangle e^{-i(\mathcal{M}_St_2+\mathcal{M}_Lt_1)} -$$
$$|\,K_S(\mathbf{p})\,\rangle|\,K_L(-\mathbf{p})\,\rangle e^{-i(\mathcal{M}_St_1+\mathcal{M}_Lt_2)}\Big)$$

where $\mathcal{M}_{S,L} = M_{S,L} - i\Gamma_{S,L}/2$ are the complex K_S, K_L masses. Defining

$$\eta_i = \frac{\langle\, f_i|\,K_L\,\rangle}{\langle\, f_i|\,K_S\,\rangle}$$

$$\Delta t = t_2 - t_1 \quad t = t_1 + t_2$$

$$\Delta \mathcal{M} = \mathcal{M}_L - \mathcal{M}_S \quad \mathcal{M} = \mathcal{M}_L + \mathcal{M}_S$$

we get for the amplitude for decay to states 1 and 2:

$$\langle f_1, t_1, \mathbf{p};\ f_2, t_2, -\mathbf{p} | i \rangle = \frac{1 + |\epsilon|^2}{(1-\epsilon^2)\sqrt{2}} \times$$

$$\langle f_1 | K_S \rangle \langle f_2 | K_S \rangle e^{-i\mathcal{M}t/2} \left(\eta_1 e^{i\Delta\mathcal{M}\Delta t/2} - \eta_2 e^{-i\Delta\mathcal{M}\Delta t/2} \right)$$

The above implies

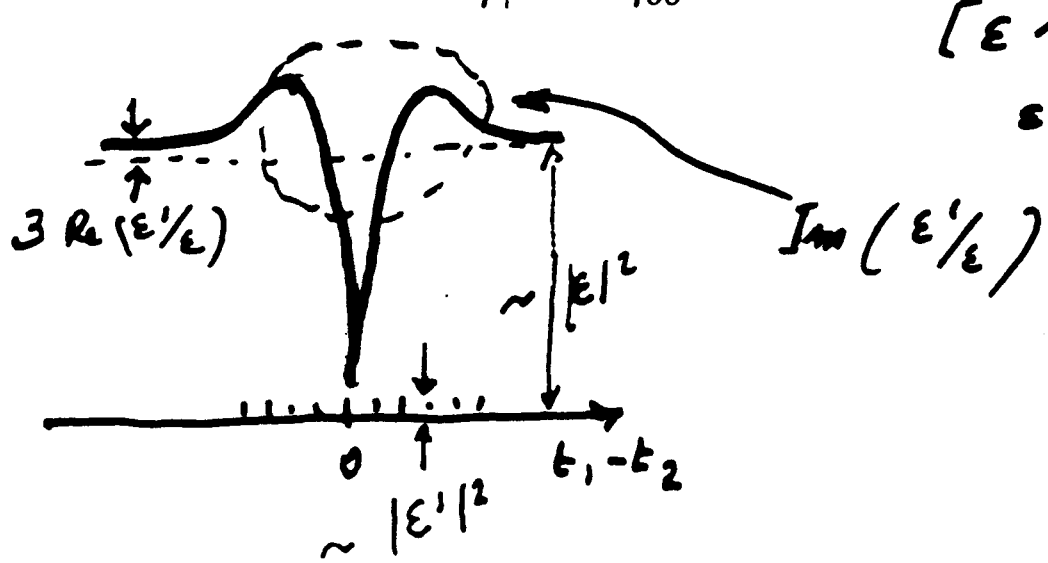
$$A(e^+e^- \to \phi \to K^0\overline{K}^0 \to f_1 f_2) = 0$$

for $t_1 = t_2$ and $f_1 = f_2$ (Bose statistics).

For $t_1 = t_2$, $f_1 = \pi^+\pi^-$ and $f_2 = \pi^0\pi^0$ instead:

$$A \propto \eta_{+-} - \eta_{00} = 3 \times \epsilon'$$

[$\varepsilon \sim 10^{-3}$, $\varepsilon' \sim 10^{-6}$]



DAΦNE' POTENTIAL for ε'/ε

(STATISCS ONLY)

$$\int \mathcal{L}\, dt = 10^7 \text{sec} \times 10^{33}\, \text{cm}^{-2} s^{-1} = 10\,000\, \mu b^{-1}$$

1 year

Use $(L \to +-/S \to +-)/(L \to \infty/S \to \infty)$

$$\delta\left[\mathrm{Re}\, \frac{\varepsilon'}{\varepsilon}\right] = 10^{-4}$$

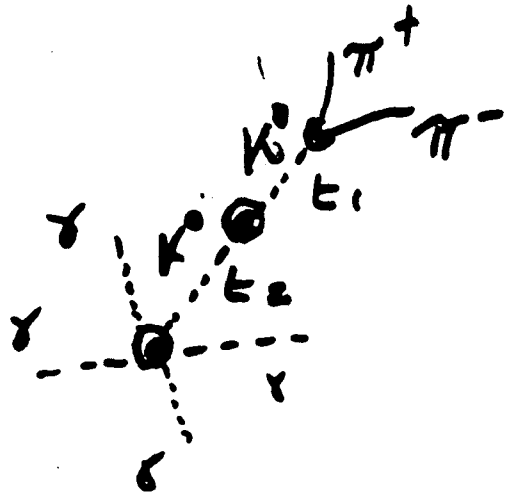
$\Longrightarrow$ Observe $\sim 4 \times 10^6\, K_L \to \pi^0\pi^0$

$+ \ldots$

$$N_L^0 = 5\mu b \times 10^3 \mu b^{-1} s^{-1} \times 10^7 s \times 0.34 \times 10^{-3} \times \left(1 - e^{-\frac{150}{250}}\right) =$$

6×10^6 !

$\mathrm{Im}\ \epsilon'/\epsilon$?



$$\Delta t = t_2 - t_1$$

$$(-\infty < \Delta t < \infty)$$

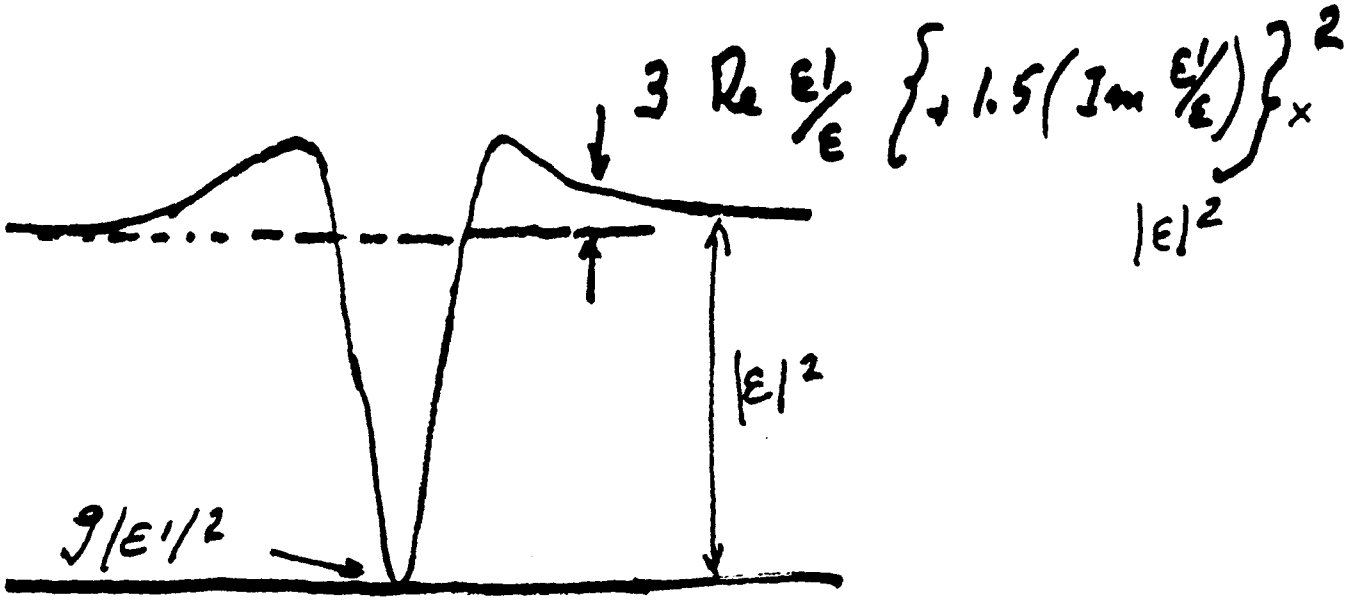
$$I(\Delta t) \simeq |\varepsilon|^2 \left\{ 1 \begin{matrix} +2\,\mathrm{Re}\,\epsilon'/\epsilon \\ -4\,\mathrm{Re}\,\epsilon'/\epsilon \end{matrix} + \cdots \right.$$

$$\gtrless 0$$

$$\left. \pm\ 6\,\mathrm{Im}\,\frac{\epsilon'}{\epsilon}\ \sin \Delta m\,\Delta t\ e^{-\frac{|\Delta t|\,\Gamma_S}{2}} \right\}$$

$$\boxed{\delta\left(\mathrm{Im}\,\frac{\epsilon'}{\epsilon}\right) \simeq 10^{-3} \quad \text{for } \Delta\ell \sim 8\,\mathrm{mm}}$$

from $A(t_1, t_2, +-, 00) \longrightarrow I(t_1 - t_2)$



$\pm 5 \cdot 10\, \tau(K_S) \longrightarrow \mathrm{Im}\,\varepsilon'/\varepsilon$

$\longleftarrow \qquad \longrightarrow$

$\dfrac{A-B}{A+B} \longrightarrow \mathrm{Re}\,\varepsilon'/\varepsilon$

$\dfrac{A-B}{A+B} \sim 70\%$ at $\Delta t \sim 10^{-3}\, \tau_{K_S}$!?

At a ϕ-factory we can use many (statistically not independent) methods, for instance:

$$\frac{N(+-+-)}{N(0000)} \times \left(\frac{BR(K_S \to 00)}{BR(K_S \to +-)}\right)^2 = 1 + 6 \times \mathrm{Re}(\epsilon'/\epsilon)$$

$$\frac{N(+-+-)}{N(+-00)} \times \frac{BR(K_S \to 00)}{BR(K_S \to +-)} = 1 + 3 \times \mathrm{Re}(\epsilon'/\epsilon)$$

in addition to:

$$\frac{K_L \to +-}{K_S \to +-} \Big/ \frac{K_L \to 00}{K_S \to 00} = 1 + 6 \times \mathrm{Re}(\epsilon'/\epsilon)$$

A measurement of CP violation in the decay amplitude, unique to a ϕ–factory is obtained from:

$$\frac{N(\Delta t > 0) - N(\Delta t < 0)}{N(\Delta t > 0) + N(\Delta t < 0)} = -3 \times \mathrm{Re}(\epsilon'/\epsilon)$$

CP violation in $K_S \to 3\pi^0$

Mass matrix CP violation $\Rightarrow BR \sim 10^{-9}$, but the direct term is not suppressed by the $\Delta I = 1/2$ rule. Still probably very small.

From $|K_S\rangle = \dfrac{|K_1\rangle + \varepsilon |K_2\rangle}{\sqrt{1+|\varepsilon|^2}}$ $\quad \eta_{000} = \varepsilon + \varepsilon'_{000}$

$BR(K_S \to 3\pi^0) = 2 \times 10^{-9}$

at φ-factory 27 events from CP imp.

could measure $\varepsilon'_{000} \gtrsim 0.2 \times \varepsilon$

ANYWAY FIRST OBSERVATION OF

$\not{CP}$

OTHER THAN IN K_L DECAYS

$$BR(K_S \to 3\pi^0) = |\varepsilon|^2 \frac{\Gamma_L}{\Gamma_S} BR(K_L \to 3\pi^0)$$

POSSIBLE BECAUSE OF TAG

CP violation in other channels

Dalitz plot slope difference in $K^{\pm} \to 3\pi$

$$\frac{d^2\Gamma}{d(E_1-E_2)\,dE_3} \propto 1 + g E_3 + \cdots$$

$g(K^+ \to \pi^+\pi^+\pi^-) \neq g(K^- \to \pi^-\pi^-\pi^+) \Rightarrow$ DIRECT CP VIOLAT.

$g(K^+ \to \pi^0\pi^0\pi^+) \neq g(K^- \to \pi^0\pi^0\pi^-) \Rightarrow$

$\frac{\Delta g}{g} \approx 10^{-3}$ for $|\varepsilon'/\varepsilon| = 3\times10^{-3}$ Bel'kov.. '89

10^{-4}–10^{-5} CHENG '83 (no fin. state int)

Present limits $\sim$ few $\times 10^{-2}$–10^{-3}

$$\Delta g\Big]_{\varphi\text{-factory}} \simeq 3\text{-}5 \times 10^{-4}$$

Also $\Gamma(\tau^+) \neq \Gamma(\tau^-)$, $\Gamma(\tau'^+) \neq \Gamma(\tau'^-)$ $\Rightarrow$ DIRECT CP VIOLATION

$\times$ 100 improv. possible at φ-factory $\left(\frac{\delta\Gamma}{\Gamma} < 10^{-5}\right)$

Could be observable

T and CPT

Kabir, comparison of:

$$\Gamma(K \to \overline{K}) \quad \text{and} \quad \Gamma(K \leftarrow \overline{K})$$

OBSERVE $K^0 \to \ell^+$ at $t = t_1$
TAGGED $\overline{K}^0$ at $t = t_1$ } *
and vice versa

- No experimental information
- CPLEAR: good statistics, large bckgnd
- ϕ-Factory

Sensitivity ~ 10% of effect due to CPT good, $T \rightleftarrows CP$

$$\boxed{A_T(\Delta t) = \text{const} = 4\,\mathrm{Re}\,\varepsilon}$$

* $\Delta S = \Delta Q$ good – CAN ALSO BE TESTED at ϕ-factory

SEMI – RARE K DECAYS

FROM BARBIERI, MAIANI, MARTINELLI, PAOLUZI, PAVER, PETRONZIO, REMIDDI

	Teoria	Eventi/anno attesi	Esperimento
$K_S \to \gamma\gamma$	$2\ 10^{-6}$	(520)	$(2.4 \pm 1.2)\ 10^{-6}$
$K_S \to \gamma e^+e^-$	$3.2\ 10^{-8}$	(8)	--
$K_S \to \gamma\mu^+\mu^-$	$7.5\ 10^{-10}$	-	--
$K_L \to \gamma\gamma$	$[10^{-4}]$	$(6\ 10^4)$	$(4.9 \pm 0.4)\ 10^{-4}$
$K_L \to \gamma e^+e^-$	$9.1\ 10^{-6}$	$(6\ 10^3)$	$(1.7 \pm 0.9)\ 10^{-5}$
$K_L \to \gamma\mu^+\mu^-$	$2.3\ 10^{-7}$	(150)	$(2.8 \pm 2.8)\ 10^{-7}$
$K_L \to \pi^0\gamma\gamma$	$6.8\ 10^{-7}$	(440)	$< 2.7\ 10^{-6}$
$K^\pm \to \pi^\pm\gamma\gamma$	$5.8\ 10^{-7}$	$(1.6\ 10^3)$	$<1.0\ 10^{-6}$
$K_S \to \pi^0\gamma\gamma$	$3.3\ 10^{-8}$	(8)	--
$K^\pm \to \pi^\pm e^+e^-$	10^{-7} (input teorico)	(700, no tag)	$(2.7 \pm 0.5)\ 10^{-7}$
$K^\pm \to \pi^\pm\mu^+\mu^-$	$6.1\ 10^{-8}$	(170)	$<2.3\ 10^{-7}$
$K_S \to \pi^0 e^+e^-$	$5\ 10^{-9} - 5\ 10^{-10}$	(≤ 1)	$<4.5\ 10^{-5}$
$K_S \to \pi^0\mu^+\mu^-$	$10^{-9} - 10^{-10}$	(≤ 0.2)	--
$K^\pm \to \pi^\pm\pi^0\gamma \mid_{IB}$	$2.9\ 10^{-4}$	$(8\ 10^5)$	$(2.75 \pm 0.16)\ 10^{-4}$
$K^\pm \to \pi^\pm\pi^0\gamma \mid_{DE}$	$1.05\ 10^{-5}$	$(1.4\ 10^4)$	$(1.56 \pm 0.35)\ 10^{-5}$, $(2.05 \pm 0.46)\ 10^{-5}$, $(2.3 \pm 3.2)\ 10^{-5}$
$K_L \to \pi^+\pi^-\gamma \mid_{IB}$	$1.4\ 10^{-5}$	$(9\ 10^3)$	$(1.52 \pm 0.16) 10^{-5}$
$K_L \to \pi^+\pi^-\gamma \mid_{DE}$	$(1\text{-}8)\ 10^{-5}$	$(2\ 10^4)$	$(2.89 \pm 0.28) 10^{-5}$
$K_S \to \pi^+\pi^-\gamma \mid_{IB}$	$2.4\ 10^{-3}$	$(6\ 10^5)$	$(1.82 \pm 0.10)\ 10^{-3}$
$K_S \to \pi^+\pi^-\gamma \mid_{DE}$	$(2\text{-}20)\ 10^{-8}$	(5)	$< 6\ 10^{-5}$

Form Factors in $K_{\ell 3}$. Rates and FF in $K_{\ell 4}$

Resolve experimental discrepancies. Cnfr. validity of chiral lagrangian methods.

$\langle \pi | V_\mu | K \rangle = f_+(q^2)(K+\pi)_\mu + f_-(q^2)(K-\pi)_\mu$

f's and their q^2 dependence poorly known.

Also μ-polarization.

T inv. $\rightarrow$ no pol. $\perp$ decay plane.

At φ-factory $\sim 10^9$ $K^{\pm}_{\ell 3}$

$\sim 10^9$ $K^0_{\ell 3}$

$\sim 10^5$ $K^{+,-,0}_{\ell 4}$

η and η'

Mixing angles and gluon content.

$$|\eta\rangle = X_\eta \frac{\bar{u}u + \bar{d}d}{\sqrt{2}} + Y_\eta \bar{s}s + Z_\eta g$$

$$|\eta'\rangle = X_{\eta'} \frac{\bar{u}u + \bar{d}d}{\sqrt{2}} + Y_{\eta'} \bar{s}s + Z_{\eta'} g$$

Need $\Gamma(\rho \to \eta\gamma)$

$\Gamma(\phi \to \eta\gamma)$

$\Gamma(\phi \to \eta'\gamma)$

$BR(\phi \to \eta'\gamma) < 4 \times 10^{-4}$, exp.

Expect: (– for η-η' mixing of 20° and no glue –)

$BR \sim 10^{-4}$

at φ-factory can do better than that!

$\eta = \cos\theta\, \eta_8 - \sin\theta\, \eta_1 \quad \theta = -20°$

$\eta' = \sin\theta\, \eta_8 + \cos\theta\, \eta_1$

$\eta_8 = \frac{u\bar{u} + d\bar{d} - 2s\bar{s}}{\sqrt{6}}$

$\eta_1 = \frac{u\bar{u} + d\bar{d} + s\bar{s}}{\sqrt{3}}$

The $f_0(975)$ 0^{++} meson

Radiative transitions, two vs four quark state. Glue?

$\phi \to \gamma f_0$ is not observed yet

(similar to $\psi' \to \chi_{c,J=0}$
$\Upsilon \to \chi_{b,J=0}$)

Isgur, Close, Pennington, Khemna would like to know its partial width.

Photon propagator and muon anomaly.

The muon anomaly measured to .35 ppm (BNL, in construction) could be sensitive to new physics up to the 10 TeV scale, but:

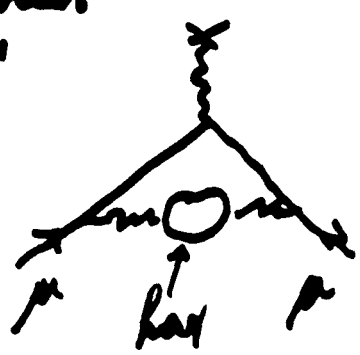
$$a_\mu = \left.\frac{g-2}{2}\right)_\mu \qquad \mathcal{O}(\alpha^4) \qquad 19.5\times10^{-10}$$

$$a_\mu = \underset{\pm 3\times10^{-10}}{a_\mu^{QED}} + \underset{\pm .1\times10^{-10}}{a_\mu^{weak}} + a_\mu^{hadr}$$

$$a_\mu^{hadr} = (702 \pm 19)\times10^{-10}$$

$$\delta(a_\mu) \sim 2\,ppm$$

a_μ^{hadr}



;

$\leftarrow \sigma_T(e^+e^- \to had)$

$$\left(\int_{s=4m_\pi^2}^{\infty} \sigma_T\right)$$

$\sigma_{had} > 10^{-31}$

$\int \sigma$: to be measured to 0.5% $\Rightarrow$

$\mathcal{L}$ of 10^{30} for few days!

light by light?

A practical problem [among many]
at DAΦNE

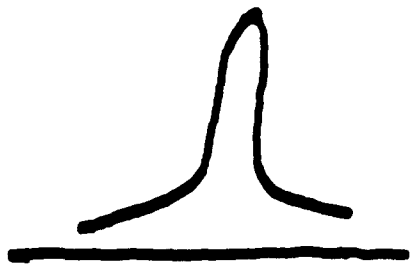
How do we measure

$L_{K \to 2\pi^0}$ (and $L_{K \to +-}$ → "no problem")

→ $K \to 2\pi^0 \to 4\gamma$'s

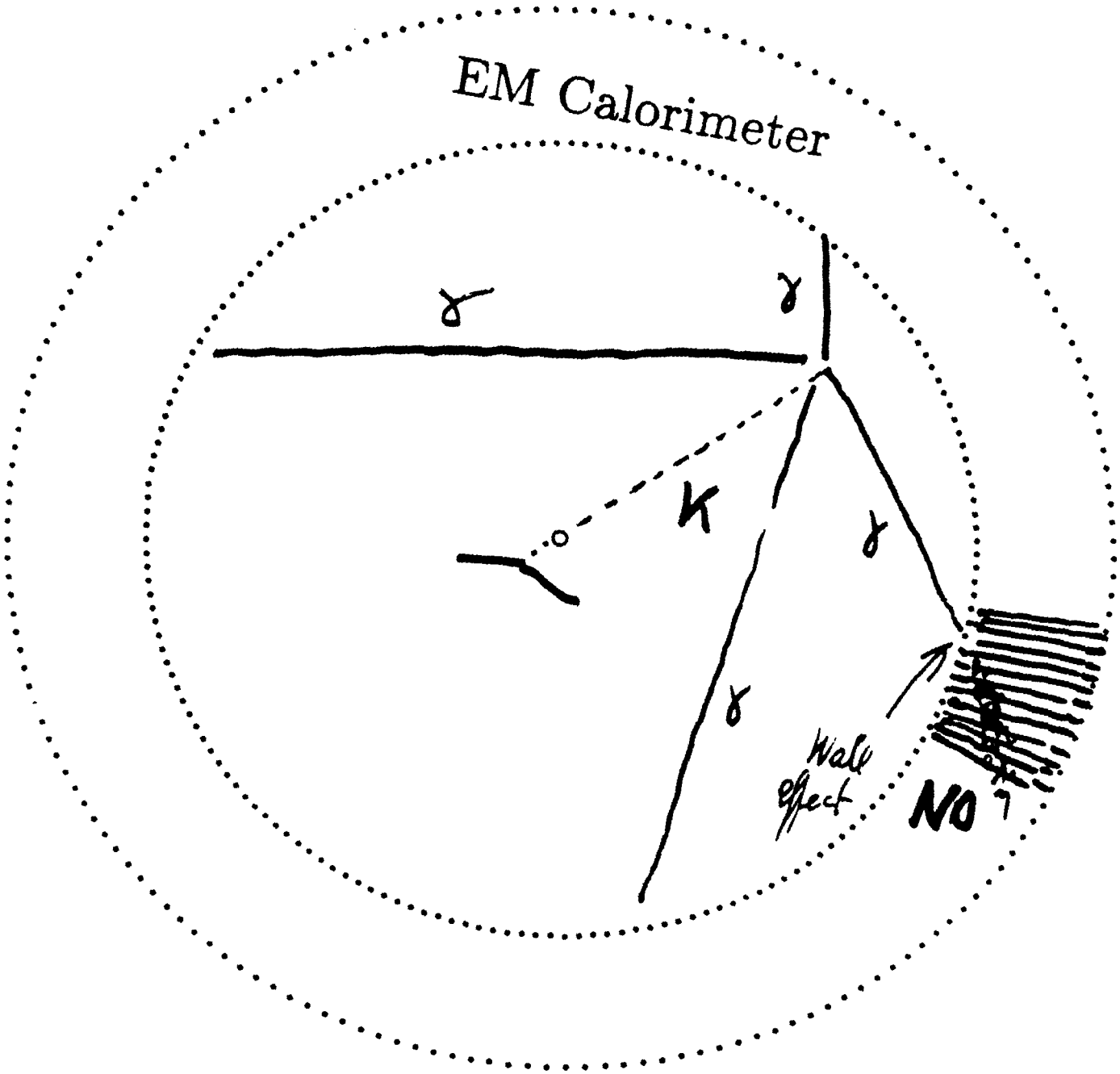
From direction of K_L and a point on the path of each γ → L_K

But



$L - L_{true}$

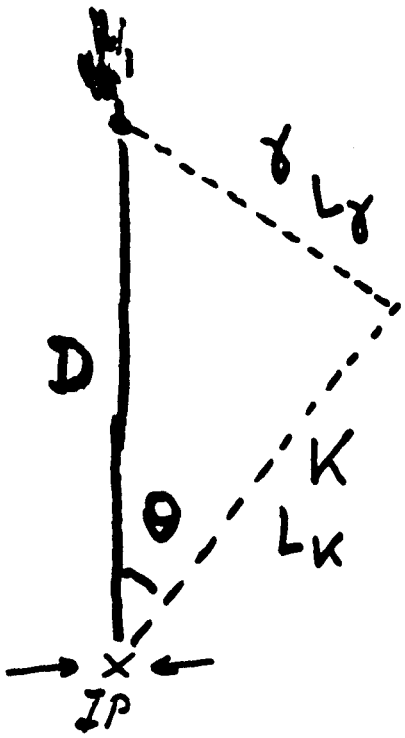
- Beam energy spread
- π^0 mispairing
- not enough E resolution


EM Calorimeter
γ
γ
K
γ
γ
Wale
effect
NO

- An imaging calorimeter is necessary

- Homogeneous Cryoliquid calorimeters – in general – require cryostats → walls are not very hermetic (are also fragile devices, coherent noise must be controlled etc.

- But $\beta_{K_0} \sim .2$ → time → L_{K^0}



$D + \theta$ are known

$$L_K^2 + D^2 - 2 D L_K \cos\theta = L_\gamma$$

$$\frac{L_K}{\beta} + L_\gamma = cT$$

Each photon gives L_K from T (2 sol.)

Imaging Calorimeter $\rightarrow L_K$

Time of flight $\rightarrow > L_K$

Simult. Fit

$\longrightarrow \Delta L_K \sim 0.8$ cm

mostly dominated by machine energy spread $\rightarrow$ direction of K

for $\beta_K = .21$

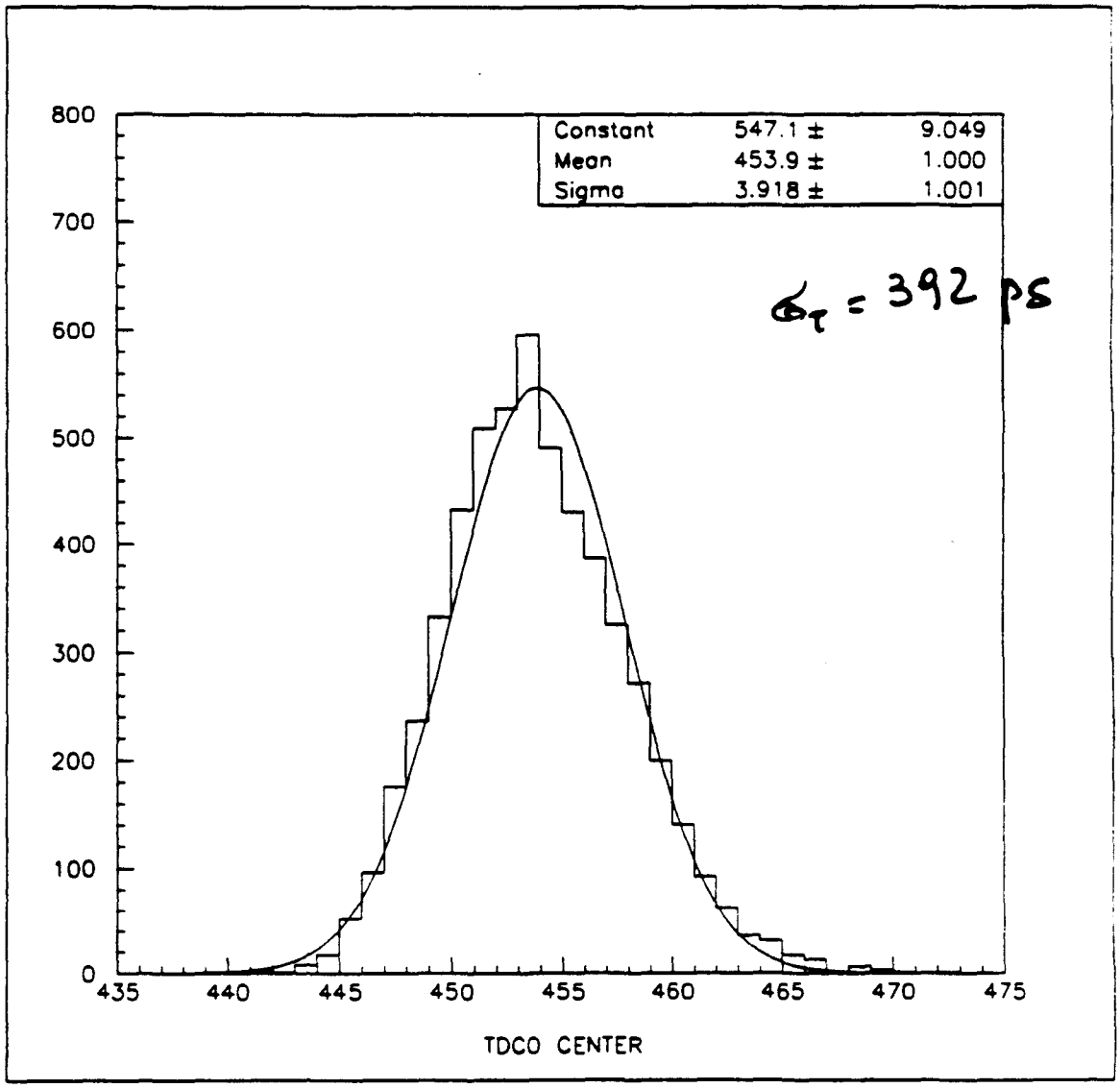
$\delta t = .16\,ns \rightarrow \delta L = 1\,cm$

If $\delta t \propto \frac{1}{\sqrt{E}}$ [4 γ's Many samples]

and $\sim 10\%$ of K^0 energy $\rightarrow$ fiber cores

$\delta t/MeV \sim .15 \times \sqrt{51} = 1\,nsec$

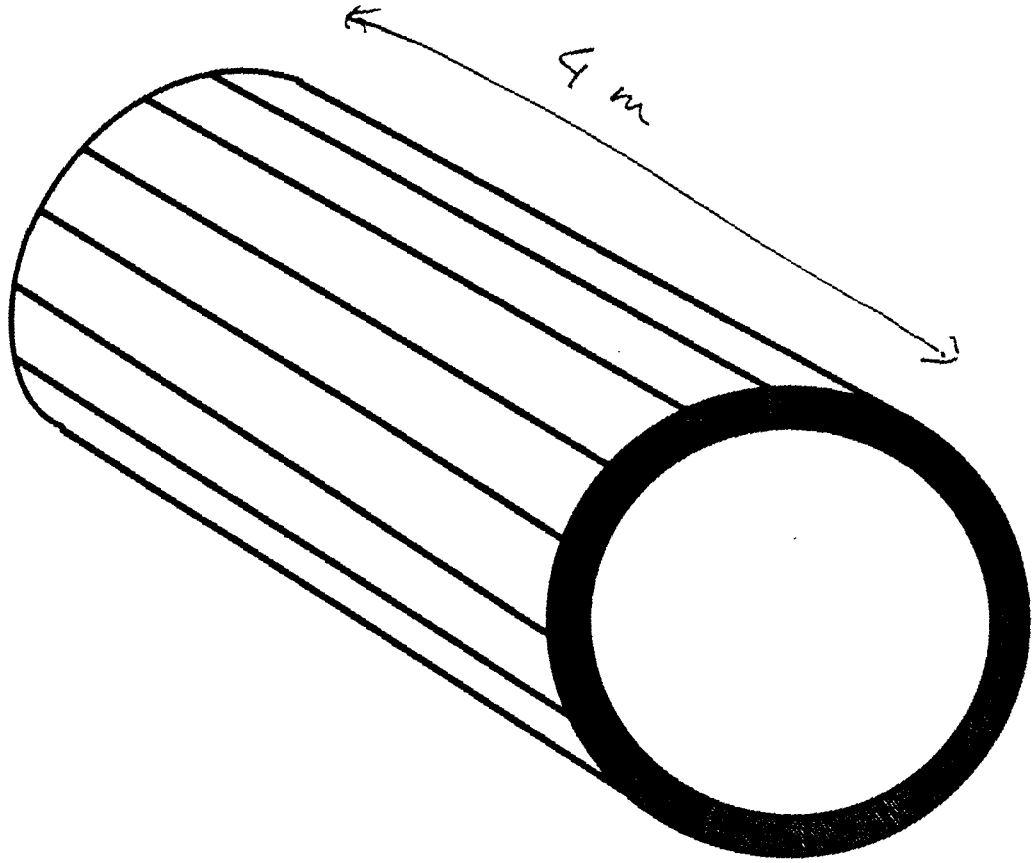
Can do better



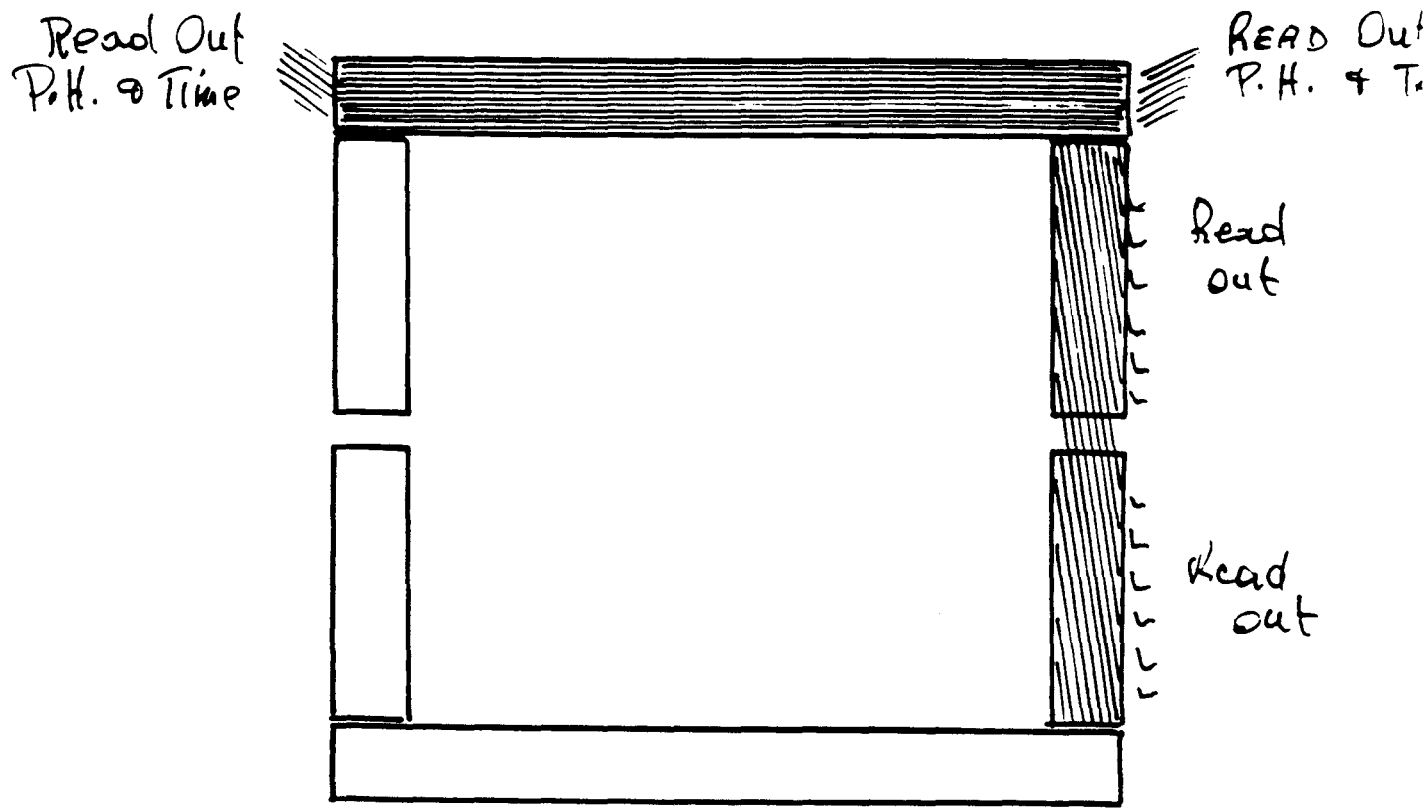
9 layers
1 mm ϕ fibers

2 m. long

Average dep. energy ≈ 1.3 MeV


4 m

CALORIMETRY, cont.



Measured performances

- 1 mm Pb ($\lambda_0 = 5.6$ mm) + 5 mm scintillator

  Efficiency $1 - 10^{-2}$ at 20 MeV
  $1 - 10^{-4}$ at 100 MeV

- $0.1\,\lambda_0$ Pb + Fibers (Rad. resist.)

$$\sigma_E/E = 6\%/\sqrt{E(\mathrm{GeV})}$$

TOF

$$\sigma_t \sim 250\,\mathrm{ps}/\sqrt{E/2\,\mathrm{MeV}} \Rightarrow \sim 50\,\mathrm{ps} \Rightarrow \delta l \sim 6\,\mathrm{mm}$$

Conclusions : the challenges

- $\mathcal{L}$ up by 250
  → appears possible –
- Large but empty detector with new calorimetry.
  → we are working on it.
- Physics to begin by end '95.
  → we are working even harder on it.

But if $\frac{\varepsilon'}{\varepsilon} \sim 10^{-4}$ we better have a few experiments

The Tau-Charm Factory in Spain

SSC Spring Conference
Martin Perl
21 May 1991

- Concept and Physics

- The Seville Tau-Charm Meeting: 29 April-2 May 1991

Studies of Z^0 decays at LEP and SLC show there are just 3 generations of conventional fermions. There are two general directions for further experimental progress in particle physics

One direction is Z^0 and higher energies: SLC, LEP, Tevatron, HERA, SSC, LHC

The other direction is large statistics, <u>small error</u> studies of the heaviest accessible fermions:

τ ← Most massive lepton. Very rich decay system. Theory should be complete and known. Only fermion with anomaly discussed in Particle Data Book.

b ← Important in KM matrix. Can study CP violation in a data sample of sufficiently large size.

c ← Important in KM matrix. Only up-type quark whose decays can be studied in detail since top will decay via $t \to Wb$.

Tau-Charm Factory

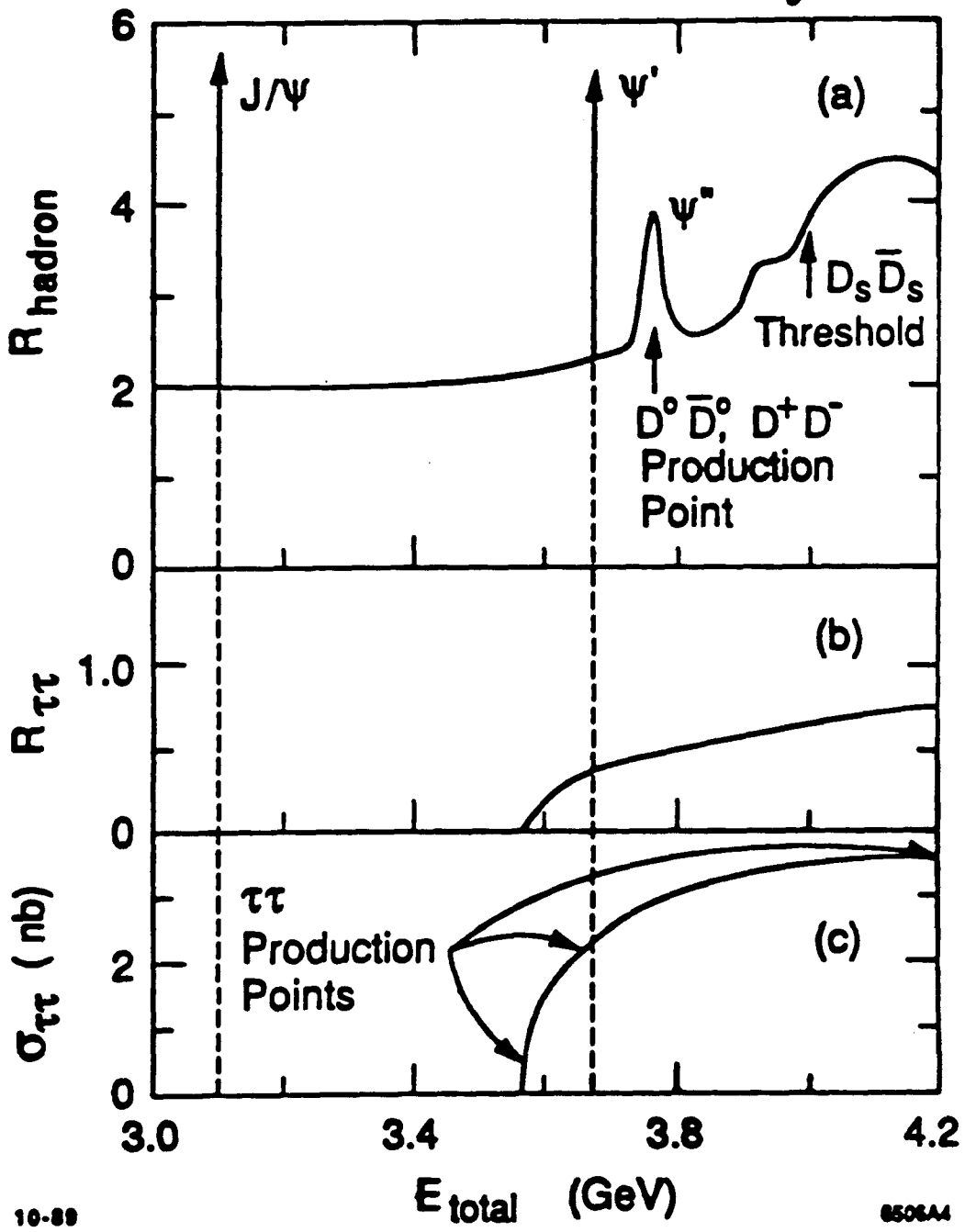
The Physics

- Charm quark
- τ and ν_τ
- J/ψ and ψ' decays

→ Increase precision by factors of 10 to 100

→ Probe more deeply by factors of 10 to 1000

Control and direct measurement of backgrounds



*Concept developed by J. Kirkby
CERN EP 87-210 (1987)

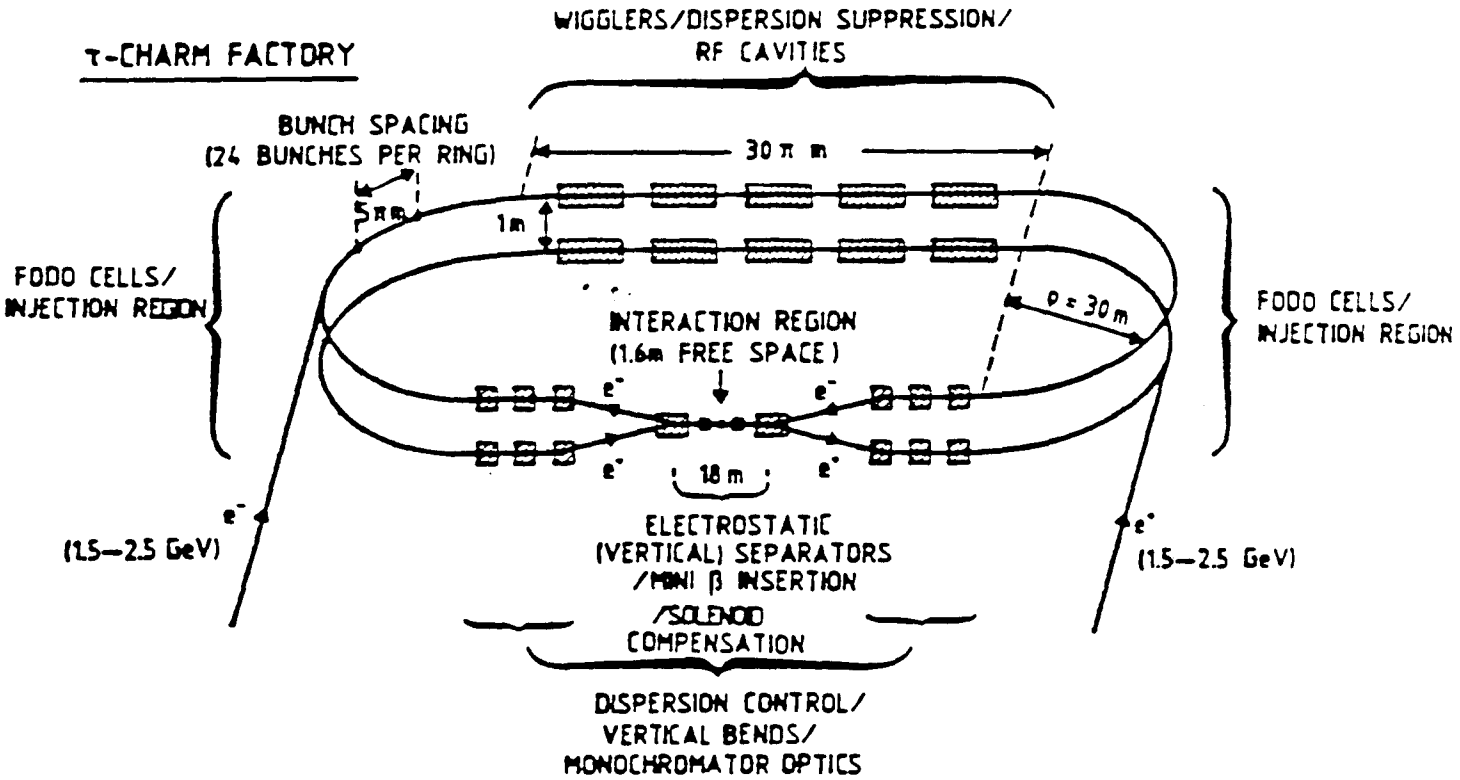
Very Large Statistics

from

Luminosity $= 10^{33}\ cm^{-2}s^{-1}$

Particle	τ-charm Factory * ($10\ fb^{-1}year^{-1}$)
D^0 (single)	5.8×10^7 (ψ'')
D^+ (")	4.2×10^7 (ψ'')
D_s^+ (")	1.8×10^7 (4.14 GeV)
$\tau^+\tau^-$ (pairs)	0.5×10^7 (3.57 GeV)
	2.4×10^7 (3.67 GeV)
	3.5×10^7 (4.25 GeV)
J/ψ	1.7×10^{10}
ψ'	0.4×10^{10}

* Based on $L = 10^{33} cm^{-2}s^{-1}$ with 10^7 sec/year.
  ↳ Increase to 2×10^7 sec/yr



Schematic design of a tau-charm factory collider from Jowett (1988).

Comparison: e^+e^-

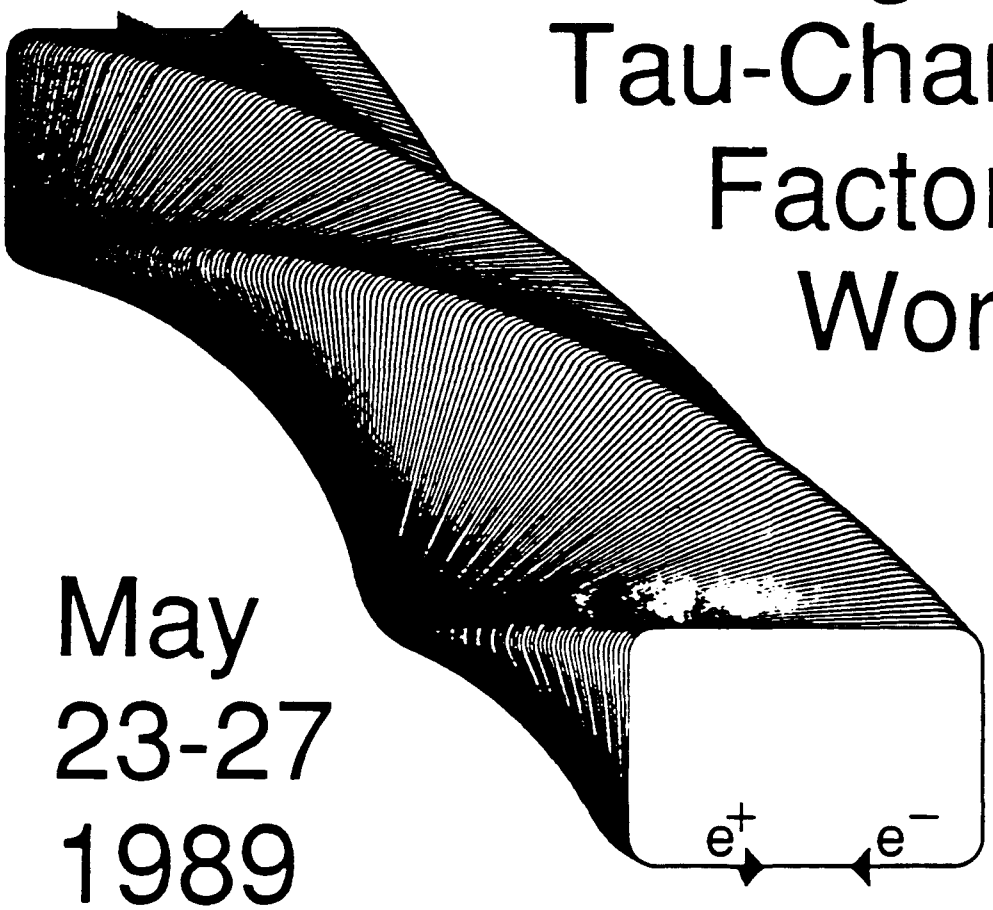
Particle	Z^0 Factory † ($2\ fb^{-1}year^{-1}$)	B Factory * ($10\ fb^{-1}year^{-1}$)	τ-charm Factory * ($10\ fb^{-1}year^{-1}$)
D^0 (single)	1.2×10^7	1.5×10^7	5.8×10^7 (ψ'')
D^+ (")	0.5×10^7	0.7×10^7	4.2×10^7 (ψ'')
D_s^+ (")	0.3×10^7	0.3×10^7	1.8×10^7 (4.14 GeV)
$\tau^+\tau^-$ (pairs)	0.3×10^7	0.9×10^7	0.5×10^7 (3.57 GeV) 2.4×10^7 (3.67 GeV) 3.5×10^7 (4.25 GeV)
J/ψ	—	—	1.7×10^{10}
ψ'	—	—	0.4×10^{10}

† Assumptions: $L_{peak} = 2 \times 10^{32} cm^{-2}s^{-1}$
$\int L dt = 2\ fb^{-1}year^{-1}$
$\# Z^0 = 6 \times 10^7$ per year

* Assumptions: $L_{peak} = 10^{33}\ cm^{-2}s^{-1}$
$\int L dt = 10\ fb^{-1}year^{-1}$

SLAC-343 9

Proceedings of the Tau-Charm Factory Workshop



May 23-27 1989

Study of Tau, Charm and J/ψ Physics

Development of High Luminosity e^+e^- Rings

Design of e^+e^- detectors for Tau-Charm Physics

Stanford Linear Accelerator Center
Stanford University Stanford, California 94309

SLAC-Report-343
June 1989

Prepared for the Department of Energy
under contract number DE-AC03-76SF00515

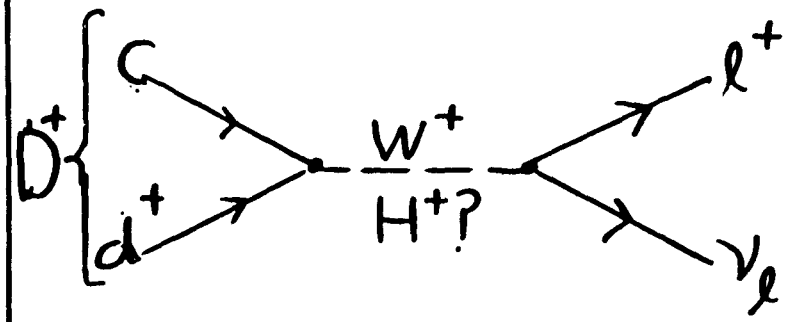
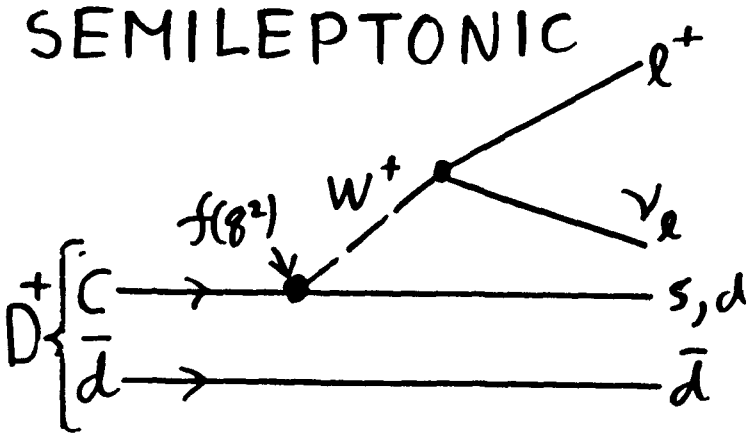
Workshop on Tau Lepton Physics

Orsay, France
September
1990

$D^{\pm,0}$, D_s Physics with Examples

- Single-tag D, D_s data samples.
- Kinematic constraints.
- No backgrounds from B's.
- None-charm backgrounds directly measured.

Charm Physics at Tau-Charm Factory

DECAY PROCESS	Present	Future: CKM	Future: QCD	Future: New Phys
PURE LEPTONIC  $\ell = e, \mu, \tau$	No data Expect $B = 10^{-2}$ to 10^{-4}	Obtain V_{cd} V_{cs}	Measure f_D, f_{D_s} well	$H^\pm$...?
SEMILEPTONIC  $\ell = e, \mu$	Confused $B = 10^{-2}$ to 10^{-3}	Obtain V_{cd} V_{cs}	Measure $f_+(q^2)$; V, A_1, A_2	$D^0 \bar{D}^0$ Mixing Glueballs

two methods

Pure Leptonic

weak decay constant

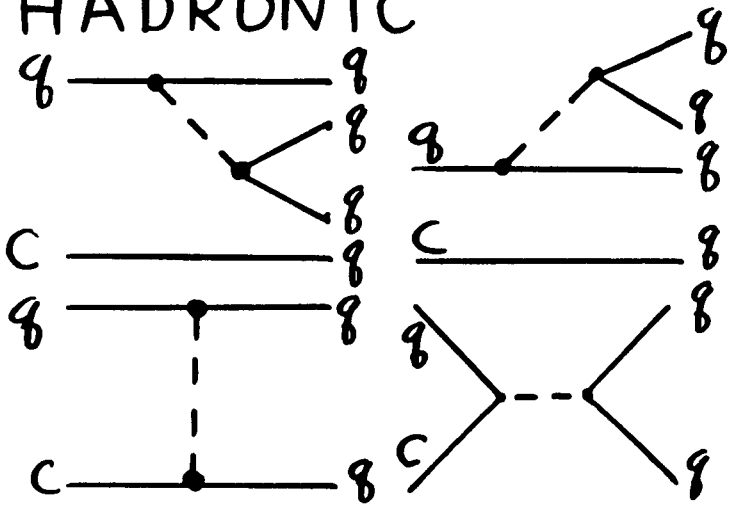
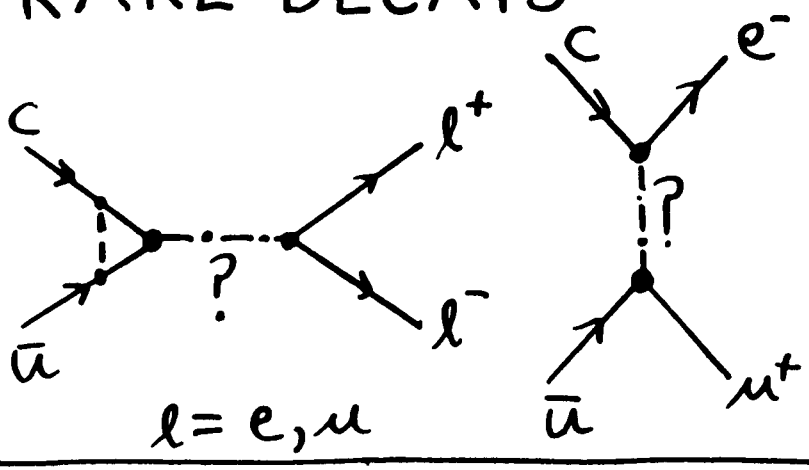
$$\Gamma(D^+ \to \ell^+ \nu_\ell) = \frac{G_F^2}{8\pi} f_D^2 m_D m_\ell^2 |V_{cd}|^2 \times \left[1 - \frac{m_\ell^2}{m_D^2}\right]^2$$

$$D^+ \to \mu^+ + \nu_\mu$$

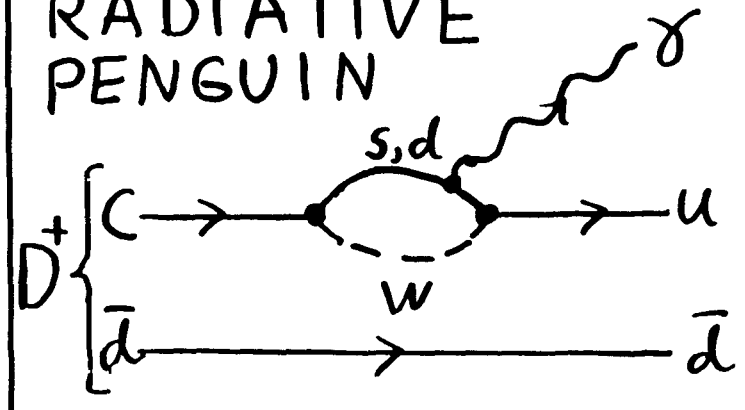
$$D^+ \to \tau^+ + \nu_\tau$$

$$D_s^+ \to \mu^+ + \nu_\mu$$

$$D_s^+ \to \tau^+ + \nu_\tau$$

DECAY PROCESS	Present	Future		
		CKM	QCD	New Phys.
HADRONIC 	Incomplete $B = 10^{-2}$ to 10^{-5}	Final state interact confuse	Simple 2-body Valuable	$D^0 \bar{D}^0$ Mixing ?
RARE DECAYS 	Present Limits $B = 10^{-4}$ to 10^{-5}			Will probe to 10^{-7}-10^{-8}

$\ell = e, \mu$

DECAY PROCESS	Present	FUTURE		
		CKM	QCD	New Phys.
RADIATIVE PENGUIN 	No data Expect $B = 10^{-5}$ to 10^{-7}		Needed for b and t decays	

$D^0\bar{D}^0$ Mixing

$$r_D = \frac{\text{Events with mixing}}{\text{Events without mixing}}$$

$$\approx \frac{1}{2}\left[\left(\frac{\Delta M}{\Gamma}\right)^2 + \left(\frac{\Delta \Gamma}{2\Gamma}\right)^2\right]$$

TCF allows many different measurements of r_D. For example:

$D^0\bar{D}^0 \to (K^-\pi^+)(K^-\pi^+)$

$D^0\bar{D}^0 \to (K^-e^+\nu_e)(K^-e^+\nu_e)$

Present upper limit: $r_D < 4\times10^{-3}$

SM: Expect: $r_D = 10^{-4}$ to 10^{-5}

TCF can probe to: $r_D = 10^{-5}$ in several years running

A long range goal:

Once $D^0\bar{D}^0$ mixing is measured and understood searches for CP violation in D decay can begin!

τ, ν_τ Physics with Examples

- Single-tag τ data samples.
- No backgrounds from D's and B's.
- Other backgrounds measured directly.
- Very large statistics

Subject	Search for New Physics	Test Standard Model	Tau-Charm Factory
Understand 1-charged particle modes puzzle			
Untangle multiple π^0 and η modes in 1-charged particle modes		✓	✓
Precise measurement of $B(e\nu\nu)$, $B(\mu\nu\nu)$, $B(\pi\nu)$, $B(\rho\nu)$, and their ratio to 0.5%	✓	✓	✓
Precise measurement of Cabibbo-suppressed modes	✓	✓	✓
Full study of dynamics of $\tau \to e\nu\nu$, $\tau \to \mu\nu\nu$ analogous to $\mu \to e\nu\nu$ in detail	✓	✓	✓
Detailed study of 3-, 5-, 7-charged particle modes		✓	✓
Find and study rare allowed modes such as radiative decays and second-class currents	✓	✓	✓
Explore forbidden decay modes	✓	✓	✓
Precise measurement of τ lifetime	✓	✓	
Explore ν_τ mass to a few MeV/c^2	✓	✓	✓
Detect ν_τ	✓	✓	
Study interactions of ν_τ	✓	✓	
Precise low energy study of $e^+e^- \to \tau^+\tau^-$, $\tau^+\tau^-\gamma$	✓	✓	✓
Precise high energy study of $e^+e^- \to \tau^+\tau^-$, $\tau^+\tau^-\gamma$	✓	✓	
Study of $Z^0 \to \tau^+\tau^-$	✓	✓	
Study of $W^- \to \tau^-\bar{\nu}_\tau$	✓	✓	
Measure $B(D^- \to \tau^-\bar{\nu}_\tau)$	?	✓	✓
Measure $B(D_s^- \to \tau^-\bar{\nu}\tau)$	?	✓	✓
Measure $B(B^- \to \tau^-\bar{\nu}_\tau)$	?	✓	
Make and study $\tau^+\tau^-$ atom	✓	✓	?

Example of <u>present</u> problem in τ research: the 1-charged particle decay modes

Behrend et al
Z. Phys. C46, 537 (1990)
CELLO

Particle Data Group

Decay channel	this experiment	world av.
$\tau \to e\nu\nu$	18.4 $\pm 0.8 \pm 0.4$	17.5 ± 0.4
$\tau \to \mu\nu\nu$	17.7 $\pm 0.8 \pm 0.4$	17.8 ± 0.4
$\tau \to$ hadron ν	12.3 $\pm 0.9 \pm 0.5$	
$\tau \to \pi\nu$	11.1 $\pm 0.9 \pm 0.5$	10.8 ± 0.6
$\tau \to K\nu$		0.7 ± 0.2
$\tau \to$ hadron $+ 2\gamma\nu$	22.6 $\pm 1.5 \pm 0.7$	
$\tau \to \rho\nu$	22.2 $\pm 1.5 \pm 0.7$	22.3 ± 1.1
$\tau \to K\pi\nu$		1.4 ± 0.3
$\tau \to$ hadron $+ > 2\gamma\nu$	14.0 $\pm 1.2 \pm 0.6$	
$\tau \to \pi 2\pi^0 \nu$	10.0 $\pm 1.5 \pm 1.1$	7.5 ± 0.9
$\tau \to \pi \geqq 3\pi^0 \nu$	3.2 $\pm 1.0 \pm 1.0$	3.0 ± 2.7
$\tau \to 3$ hadrons ν	9.0 $\pm 0.7 \pm 0.3$	
$\tau \to 3\pi\nu$	8.7 $\pm 0.7 \pm 0.3$	6.8 ± 0.6
$\tau \to 3(5)$ hadrons $+ \geqq 1(0)\gamma\nu$	5.8 $\pm 0.7 \pm 0.2$	
$\tau \to 3\pi \geqq 1\pi^0 \nu$	5.6 $\pm 0.7 \pm 0.3$	4.4 ± 1.6
$\tau \to 5\pi \geqq 0\pi^0 \nu$	0.16 ± 0.14	0.12 ± 0.03
$\tau \to K\pi\pi\nu$		0.22 ± 0.14
$\tau \to K\bar{K}\nu$		
$\tau \to K\bar{K}\pi\nu$		0.22 ± 0.15
$\tau \to 5\pi\nu$		0.06 ± 0.02
$\tau \to 6\pi\nu$		0.05 ± 0.02
Sum	99.8 $\pm 2.6 \pm 1.2$	92.8 ± 3.6

Preliminary from ALEPH experiment at LEP [Zhang et al]

$$e^+ + e^- \to Z^0 \to \tau^+ + \tau^-$$

$$B(\tau^- \to \nu_\tau + \pi^- + \pi^0 + \pi^0)$$

$$\parallel$$

$$10.0 \pm 0.5 \pm 0.5\%$$

Looking to the future.
Examples of τ research
using τ-C Factory

Example:

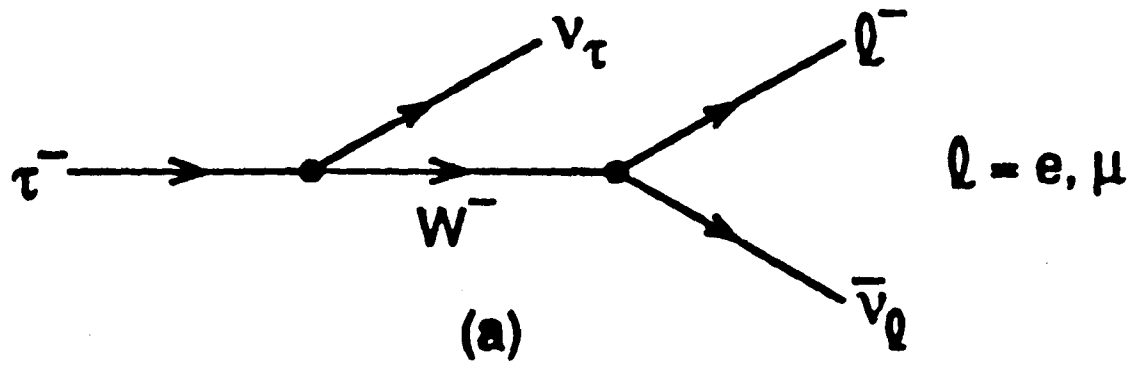
Precision measurement of branching ratios:

$$\tau^- \to \nu_\tau + e^- + \bar{\nu}_e$$

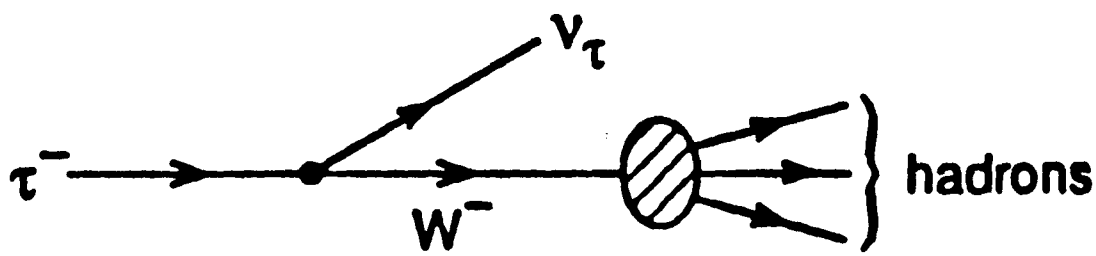
$$\tau^- \to \nu_\tau + \mu^- + \bar{\nu}_\mu$$

$$\tau^- \to \nu_\tau + \pi^-$$

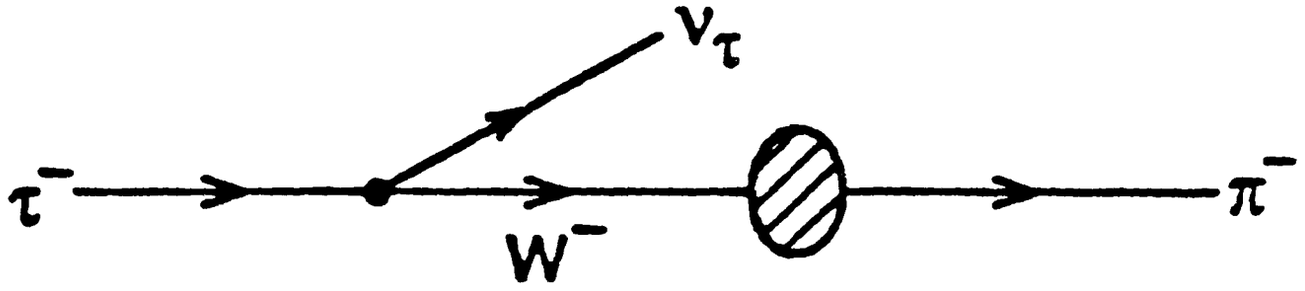
$$\tau^- \to \nu_\tau + K^-$$



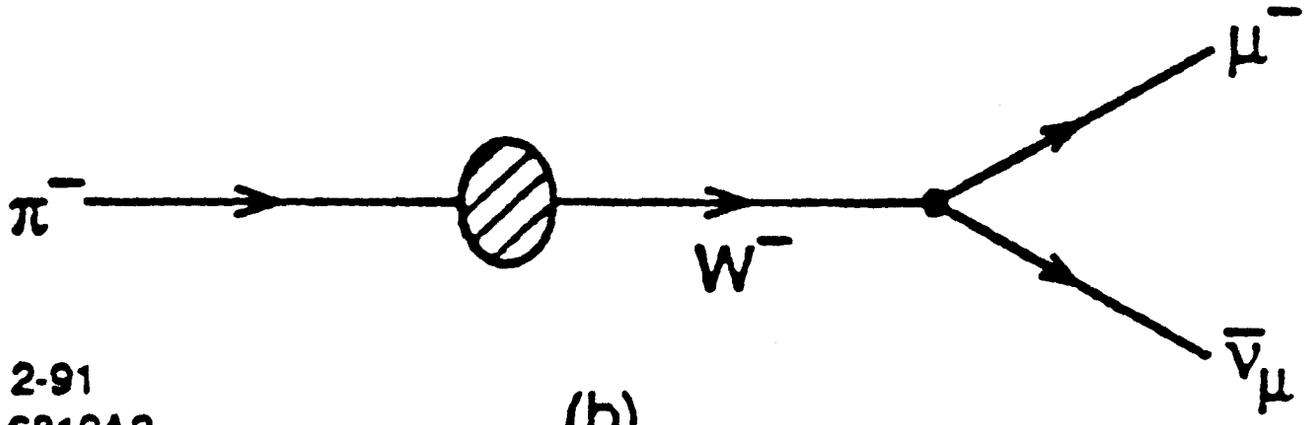
(a)



2-91 (b) 6819A1



(a)



2-91
6819A2

(b)

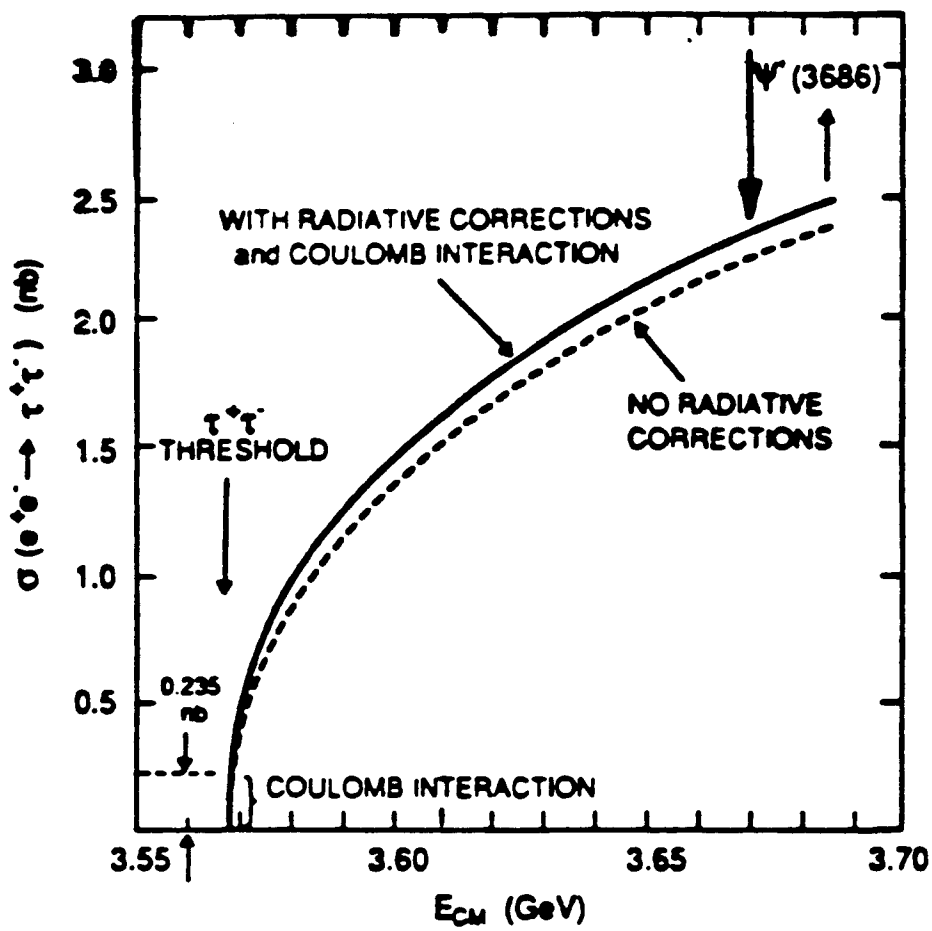
Precision branching ratios (cont.)

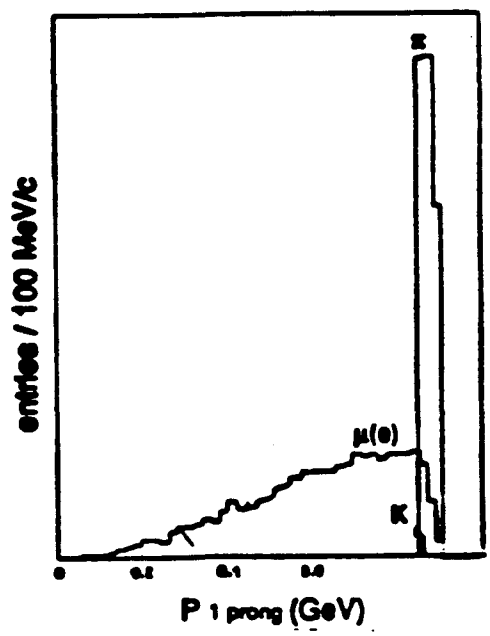
- **Method:**
  - $E = 3.57$ GeV.
  - 2.5×10^6 single-tagged τ's per year ($L = 10^{33}$).
  - τ decays separated *kinematically*.
  - Calibrate backgrounds (<0.1%) at 3.56 GeV.

- **Results:**
  - σ(b.r.)/b.r. precision:

	$e\bar{\nu}\nu$	$\mu\bar{\nu}\nu$	$\pi\nu$	$K\nu$
today:	2.3%	2.3%	5.6%	29.%
τcF:				
1 year at 10^{32}	0.5%	0.5%	0.6%	2.5%
3×10^{32}	0.3%	0.3%	0.4%	1.5%
10^{33}	0.15%	0.15%	0.2%	0.8%

Backgrounds and systematic errors will dominate these b.r. measurements.
$\Rightarrow$ We choose to run at the energy of *lowest* statistics but *highest* systematic precision.


ψ (3686)
WITH RADIATIVE CORRECTIONS
and COULOMB INTERACTION
NO RADIATIVE
CORRECTIONS
τ⁺τ⁻
THRESHOLD
0.235
nb
COULOMB INTERACTION
σ (e⁺e⁻ → τ⁺τ⁻) (nb)
3.0
2.5
2.0
1.5
1.0
0.5
3.55
3.60
3.65
3.70
E_CM (GeV)

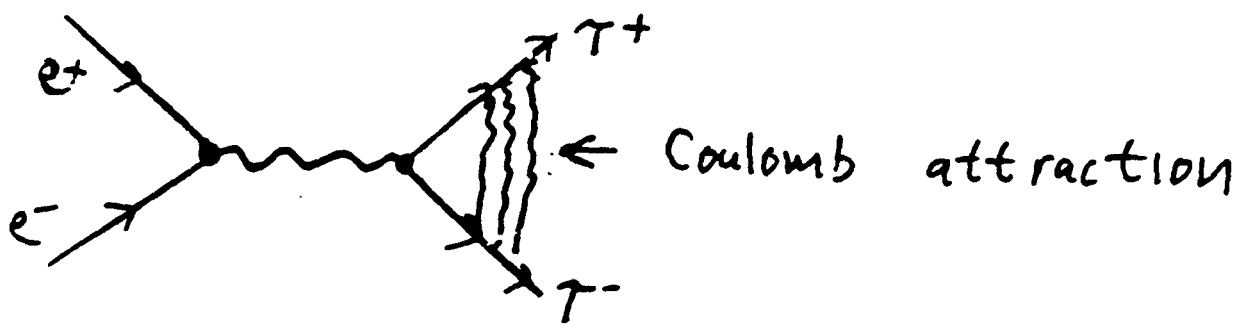

π
μ(e)
K
entries / 100 MeV/c
P 1 prong (GeV)

Above threshold:

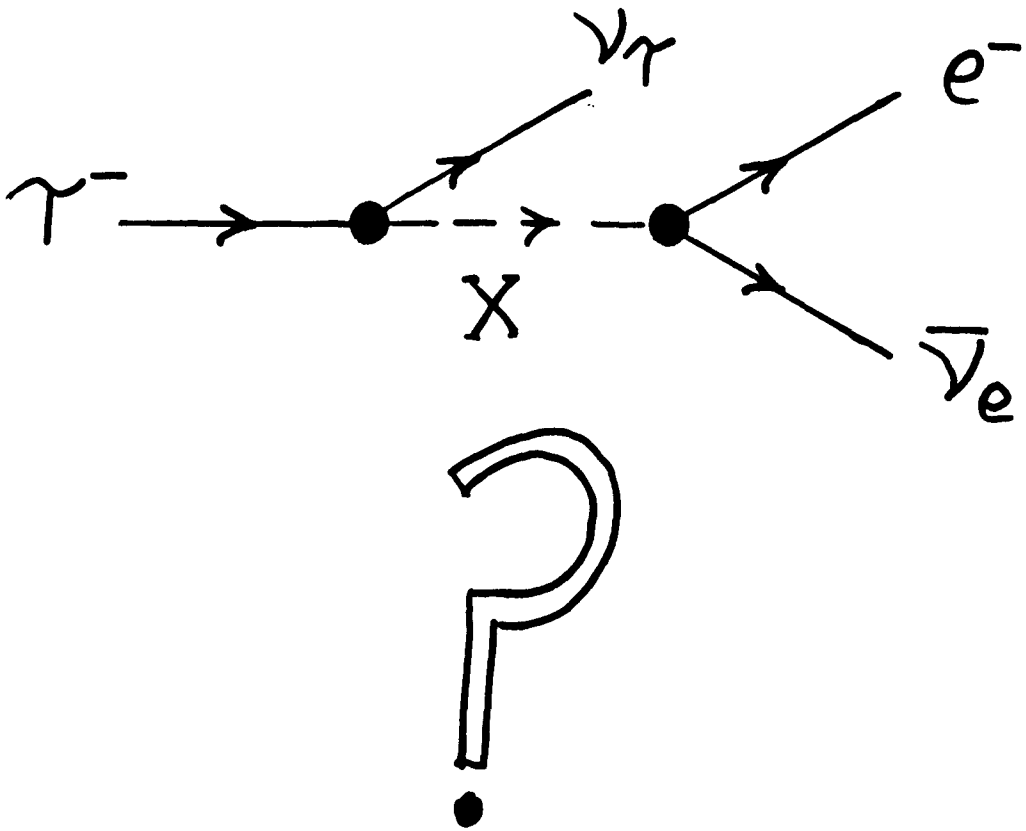
$$\sigma = \frac{4\pi\alpha^2}{3E_{tot}^2}\left[\frac{\beta(3-\beta^2)}{2}\right]$$

$$\beta = (v/c)_\tau$$

At threshold



$$\sigma = \frac{4\pi\alpha^2}{3E_{tot}^2}\left[\frac{3}{2}\,\frac{\pi\alpha}{1-\exp(-\pi\alpha/\beta)}\right]$$


τ^-
ν_τ
X
e^-
$\bar{\nu}_e$

Example:

Untangle multiple π^0, η modes:

$$\tau^- \to \nu_\tau + \pi^- + n\pi^0 \,, \quad n > 2$$

$$\tau^- \to \nu_\tau + \pi^- + \eta$$

$$\tau^- \to \nu_\tau + \pi^- + \eta + n\pi^0$$

Is there anything new hidden here?

second-class weak current
b.r. $\sim 10^{-4}$ to 10^{-6}

Example: ν_τ Mass

Much better measurement of mass of τ neutrino: m_{ν_τ}

→ Present limit is < 35 MeV/c^2

→ τ-Charm Factory

use $\tau^- \rightarrow \underbrace{\pi^- + \pi^+ + \pi^- + \pi^+ + \pi^- + \nu_\tau}$ $\left\{ \begin{array}{l} \text{BR} = \\ 6 \times 10^{-4} \end{array} \right.$

Fit mass (5π) spectrum

→ Must also measure m_τ to ± 0.6 MeV/c

→ At τ-Charm Factory with 10^7 τ-pairs can find, or set upper limit:

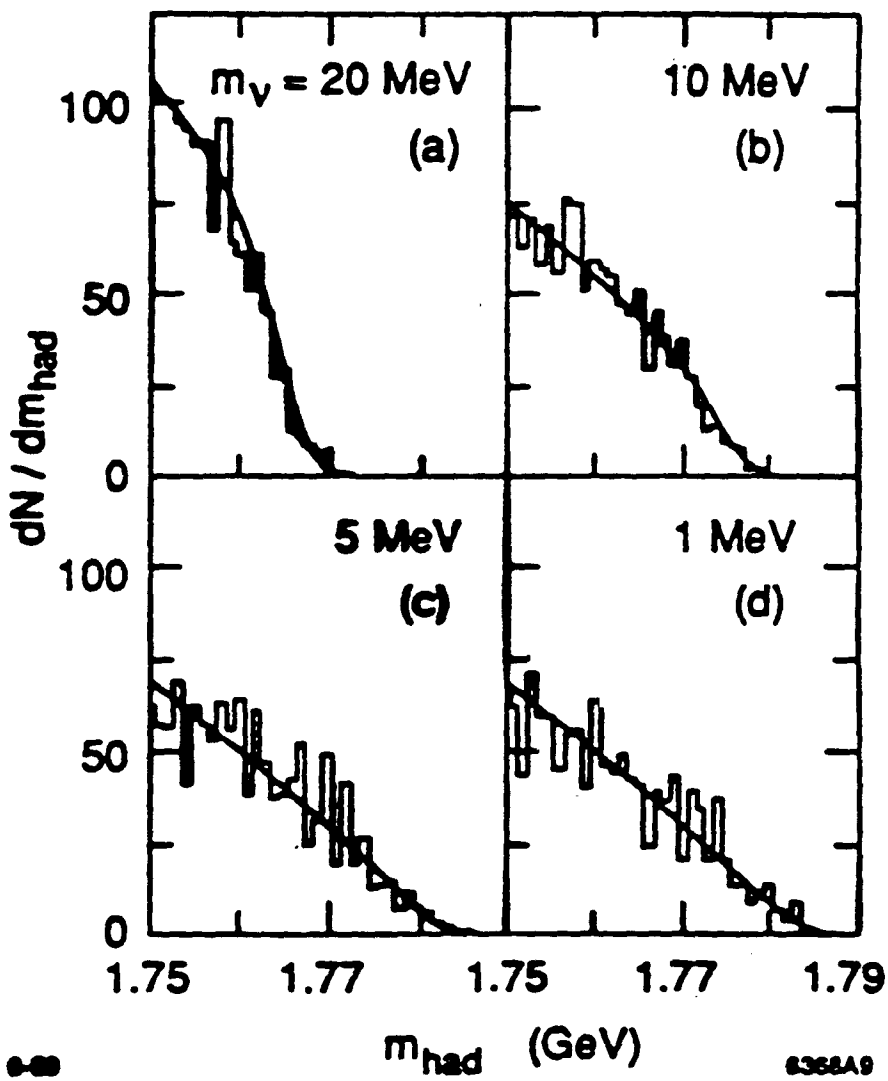
$$\boxed{m_{\nu_\tau} \sim 3 \text{ MeV/c}^2}$$

May eventually probe to 1-2 MeV/c^2

From: Gomez-Cadenas et al Phys. Rev. 41, 2179 (1990)

$$\tau^- \to \nu_\tau + \underbrace{3\pi^- + 2\pi^+}_{m_{had}}$$

$E = 3.68$ GeV



At present:

$$m_{\nu_e} < 17 \text{ eV}$$

$$m_{\nu_\mu} < 0.27 \text{ MeV}$$

$$m_{\nu_\tau} < 35. \text{ MeV}$$

If $\dfrac{m_{\nu_1}}{m_{\nu_2}} \propto \dfrac{m_1^2}{m_2}$

$$m_{\nu_\mu} \left(\frac{m_e}{m_\mu}\right)^2 < 5.9 \text{ eV}$$

$$m_{\nu_\tau} \left(\frac{m_e}{m_\tau}\right)^2 < 2.9 \text{ eV}$$

Example:

<u>Searches for unconventional and forbidden Υ decays.</u>

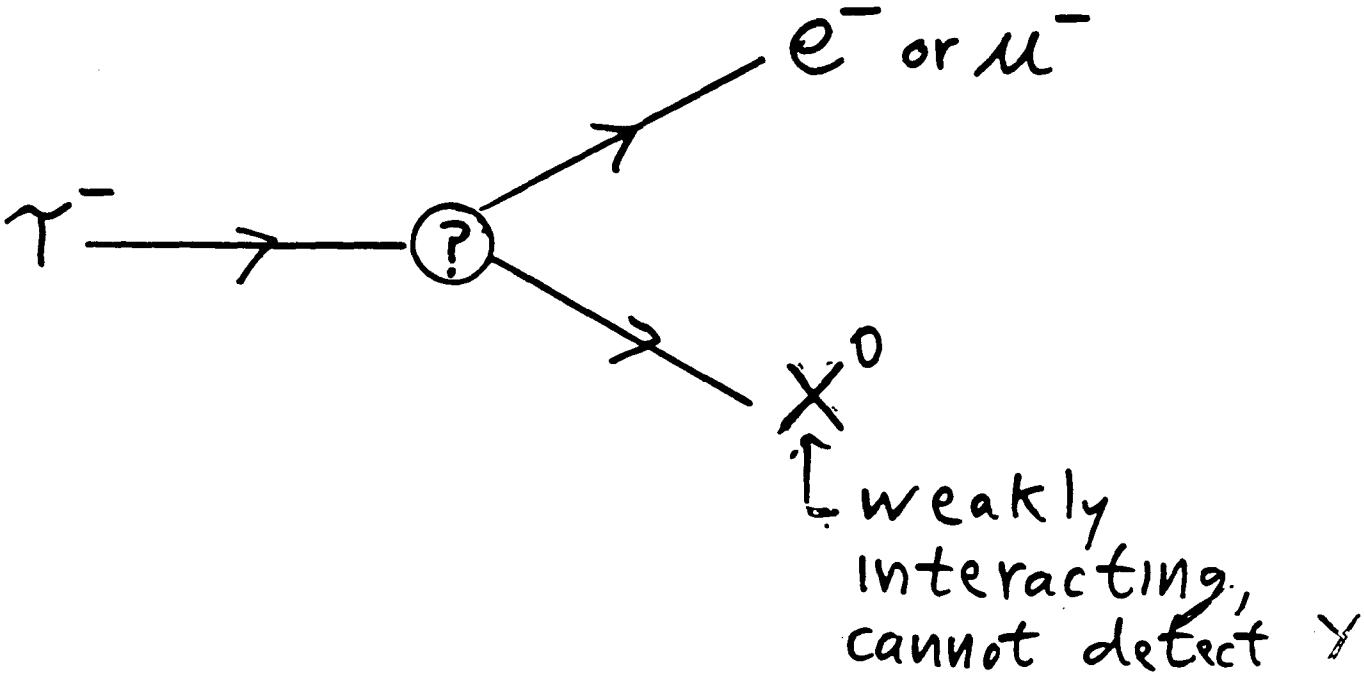
Present Upper limits on branching ratios for forbidden decay modes of τ with 90% CL (Aguilar-Benitez 1990).

Mode	Upper Limit on Branching Ratio
$\mu^-\gamma$	5.5×10^{-4}
$e^-\gamma$	2.0×10^{-4}
$\mu^-\pi^0$	8.2×10^{-4}
$e^-\pi^0$	1.4×10^{-4}
$\mu^-\mu^+\mu^-$	2.9×10^{-5}
$e^-\mu^+\mu^-$	3.3×10^{-5}
$\mu^-e^+e^-$	3.3×10^{-5}
$e^-e^+e^-$	3.8×10^{-5}
μ^-K^0	1.0×10^{-3}
e^-K^0	1.3×10^{-3}
$\mu^-\rho^0$	3.8×10^{-5}
$e^-\rho^0$	3.9×10^{-5}
$e^-\pi^+\pi^-$	4.2×10^{-5}
$e^+\pi^-\pi^-$	6.3×10^{-5}
$\mu^-\pi^+\pi^-$	4.0×10^{-5}
$\mu^+\pi^-\pi^-$	6.3×10^{-5}
$e^-\pi^+K^-$	4.2×10^{-5}
$e^+\pi^-K^-$	1.2×10^{-4}
$\mu^-\pi^+K^-$	1.2×10^{-4}
$\mu^+\pi^-K^-$	1.2×10^{-4}
$e^-K^*(892)^0$	5.4×10^{-5}
$\mu^-K^*(892)^0$	5.9×10^{-5}
$e^+\mu^-\mu^-$	3.8×10^{-5}
$\mu^+e^-e^-$	3.8×10^{-5}
$e^-\eta$	2.4×10^{-4}

Will probe to 10^{-7}–10^{-8}

Difficult Search: Requires T-CF

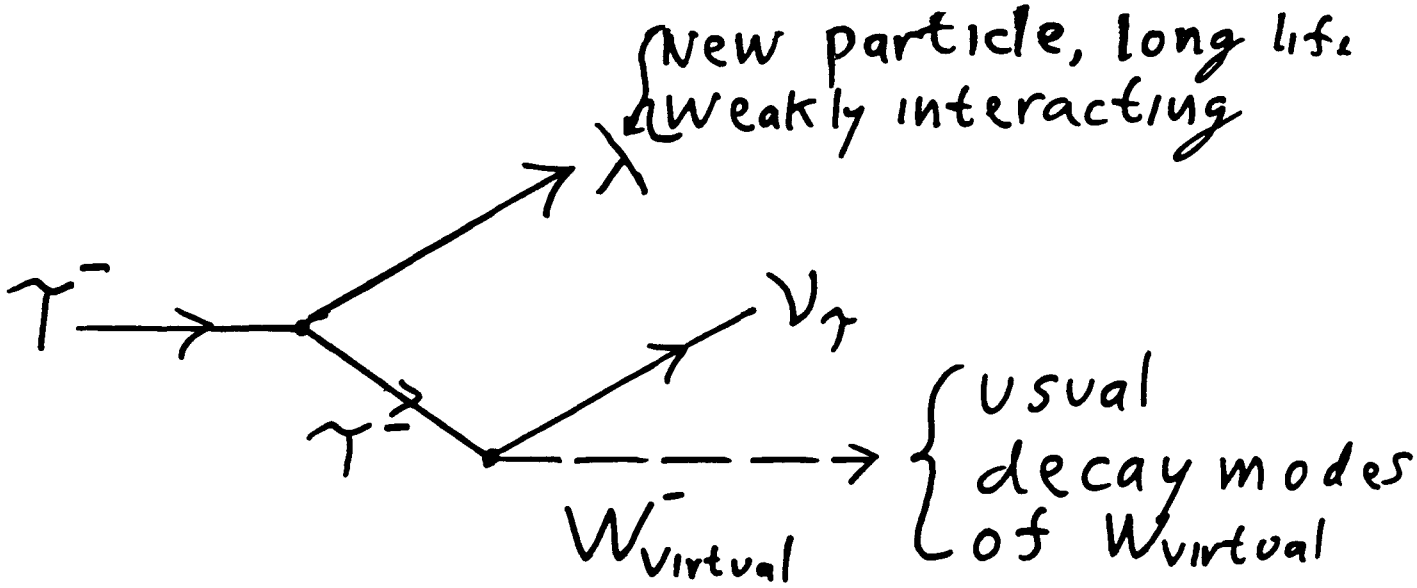
(New physics aspects of this idea discussed by Jose Valle at meeting)



Backgrounds from:

$\tau^- \to \nu_\tau + \pi^-,\ \nu_\tau + \rho^-,\ \nu_\tau + e^- + \bar{\nu}_e, \ldots$

Difficult Search: Requires τ-CF



$$\tau^- \to \overbrace{\nu_\tau + \lambda + \bar{\nu}_e}^{\text{Missing energy}} + e^-$$

$$\tau^- \to \underbrace{\nu_\tau + \lambda}_{\text{Missing energy}} + \pi^-$$

J/Ψ and Ψ'

Will probably take total of 3-4 weeks/year data on J/Ψ and Ψ' for physics and calibration

J/Ψ Physics Examples*:

- Radiative decays:
  glueballs, resonances ...
- Hadronic decays:
  glueballs, meson and baryon spectroscopy, exotics ...
- η_c
  decay modes, properties ...
- Rare processes:
  week decay $\Psi \to D_s + X$ ...

* 10^9 J/Ψ decays in 3–4 weeks

M. Perl
3 May 91

4/c

The Tau-Charm Factory Meeting at Sevilla*

29 April–2 May, 1991

- The meeting
- The overview
- The detector: conclusions
- The collider: conclusions

*at Universidad de Sevilla

TAU-CHARM FACTORY HISTORY

- Initial Concept/Physics Arguments and Machine Design
  - J. Kirkby (CERN-EP-87-210)
  - J. Jowett (CERN-LEP-87-56)
- SLAC and SLAC User Community Interest Since 1988
  - Replacement For SPEAR Program
  - Competitive With Fixed Target in Year 1995
  - SLAC Machine Study SLAC-PUB 5180
- Also Serious Interest at ORSAY - In Late 1989:
  - Davier commissions independent machine study: LAL/RT 90-02 and LAL/RT 90-05
  - Results and costing similar to SLAC study.
  - Other projects in pipeline for funding
  - Would support project in other countries.
- In Jan. '90 Spanish Physicists Sign Letter to Spanish Government Expressing Interest in the Project
- SPAIN Requests Technical Advice From CERN & ECFA
  - ECFA Review 2-90
  - CERN Initiated Technical Study of TCF & New Lab That Includes VUV Source (CERN/AC/90-07)

- Complete Report Delivered to Spanish Government (11-90)

  - Authored by CERN, ORSAY, CIEMAT Physicists
  - Endorses technical feasibility of machine
  - Outlines a scenario for construction & staffing
  - Contains a full costing of the facility

Lab+Machine:	300 MSF
Detector:	90 MSF

- In Feb.- 91 Spanish Completed Review of this Technical Report and Indicated to CERN That They Would Provide the Funding for The Tau-Charm Machine and Detector in Spain.

  -- *along the lines proposed in (CERN/AC/90-07)*
  -- *approximately 5yr construction & commissioning*

The Meeting

	participants
Spain: physicists	32
Spain: industry, government	5
CERN: physicists, engineers	22
Other Europe: physicists, engineers	16
U.S.A: physicists	16
Total =	91

NON-US INSTITUTIONS WITH MEMBERS INTERESTED IN TAU-CHARM COLLABORATION

- **CERN**
- **SPAIN:**
  - CIEMAT - MADRID
  - U.A. MADRID
  - U.A. BARCELONA
  - IFIC - VALENCIA
  - U. SEVILLA
  - U. SANTANDER
  - SANTIAGO de COMPOSTELLA
- **FRANCE:**
  - LAL - ORSAY
  - STRASBOURG
  - MARSEILLE
- **GERMANY:**
  - U. HEIDELBERG
  - U. HAMBURG
  - U. MUNICH

THE US TAU-CHARM COLLABORATION

- MANY OF THE ORIGINAL MARKIII INSTITUTIONS
- NOW SEVEN UNIVERSITIES PLUS SLAC (3 NSF, 5 DOE)
- SENIOR COLLABORATION MEMBERS:
  - M. Perl, R. Schindler, D. Coward, D. Stoker
    Stanford Linear Accelerator Center
  - J. Brau, R. Frey
    University of Oregon
  - T. Burnett, P.Mockett, V. Cook
    University of Washington
  - T. Schalk, W. Lockman, A. Seiden, C. Heusch
    U. of California, Santa Cruz
  - B.Eisenstein, G. Gladding, J. Thaler
    University of Illinois, Champagne-Urbana
  - I. Stockdale, R. Johnson,M.Sokoloff, B.Meadows
    University of Cincinatti
  - R.Yamamoto, R. Cowan
    Mass. Inst. of Technology
  - R. Plano, M. Kalelkar
    Rutgers University

Purpose:

- Report on and discuss ongoing studies of TCF machine design
- Report on and discuss ongoing R&D and studies for TCF detectors
- Begin interaction between non-Spanish physicists and Spanish technical industry
- Continue to develop internation collaboration on TCF
- New physics using TCF

Meeting on the τ-charm Factory Detector and Machine

Universidad de Sevilla, Andalucia, Spain

29 April - 2 May 1991

26 April 1991

PROGRAMME[1]

Monday, 29 April 1991

a.m.	INTRODUCTION I (chairman: Jasper Kirkby)	
09:00 - 09:30	Welcome:	
	Rector, Univ. de Sevilla	Javier Perez Royo
	Vice Rector of Research, Univ. de Sevilla	Manuel Lozano
	Director, Andalucian Plan for Research	Jose Luis Huertas
09:30 - 10:30	Physics perspectives	Alvaro de Rújula
10:30 - 11:00	Coffee	
11:00 - 12:00	Experimental perspectives	Martin Perl
12:00 - 12:30	τ physics beyond the Standard Model	Jose Valle
12:30 - 13:00	CP violation experiments at the J/ψ	Enrique Gonzalez
13:00 - 13:30	CERN conceptual study	Yves Baconnier
p.m.	INTRODUCTION II & PANEL DISCUSSION I (chairman: John Jowett)	
15:30 - 16:15	Discussions	
16:15 - 16:45	Tea	
16:45 - 17:00	Synchrotron light source at the τcF	Pierre Marin
17:00 - 18:00	Detector layout & I.R. hall:	
30'	*Overview of detector layout*	Michael Price
30'	*Assembly issues*	Claude Hauviller
18:00 - 19:30	Panel discussion: *Industrial participation in the τ-charm Factory*	Robert Dobinson
	Jose Salicio (secretary)	Jose Maria Gimenez Marin
		Greg Loew
		Miguel Angel Rodriguez Borra
		Thomas Taylor
		Edmund Wilson

[1] chairmen to be confirmed

Tuesday, 30 April 1991

a.m. DETECTOR I (chairman: Enrique Fernandez)

09:00 -10:00	Tracking detector:	
15'	*Design considerations*	Bernard Jean-Marie
15'	*He-based DC gases; Santa Cruz tests*	Bill Lockman
15'	*He-based DC gases; SLAC tests*	Paschal Coyle
10:00 -10:30	Superconducting solenoid	Thomas Taylor
10:30 -11:00	Coffee	
11:00 -12:00	Particle identification:	
20'	*Time-of-flight option*	Antonio Ferrer
20'	*RICH option*	Rui Ribeiro
12:00 -13:30	EM calorimeter & small-angle dets:	
15'	*Introduction*	Rafe Schindler
20'	*Readout electronics*	Martin Suffert
15'	*Calibration issues*	Vic Cook/ Richard Yama
10'	*Position measurement*	Norbert Wermes
15'	*Leakage, material and albedo effects*	Ray Frey
5'	*Alternatives to crystal calorimetry*	Clem Heusch
10'	*Open discussion*	Rafe Schindler/ Martin S

p.m. MACHINE I (chairman: Edmund Wilson)

15:30 -16:30	Optics:	
20'	*Overview of τ-charm Factory optics*	John Jowett
20'	*Orsay τ-charm Factory design*	Joel LeDuff
20'	*Soviet τ-charm Factory design*	Alexander Skrinsky
16:30 -17:00	Tea	
17:00 -17:30	Backgrounds & masking:	
20'	*Backgrounds & masking for the τcF*	David Stoker
10'	*Experience with the LEP detectors*	Georg Von Holtey
17:30 -18:30	Injector:	
30'	*Full-energy booster option*	Michel Sommer
30'	*Full-energy linac option*	Greg Loew

evening ANDALUCIAN VISIT (Alcazar palace)

Wednesday, 1 May 1991

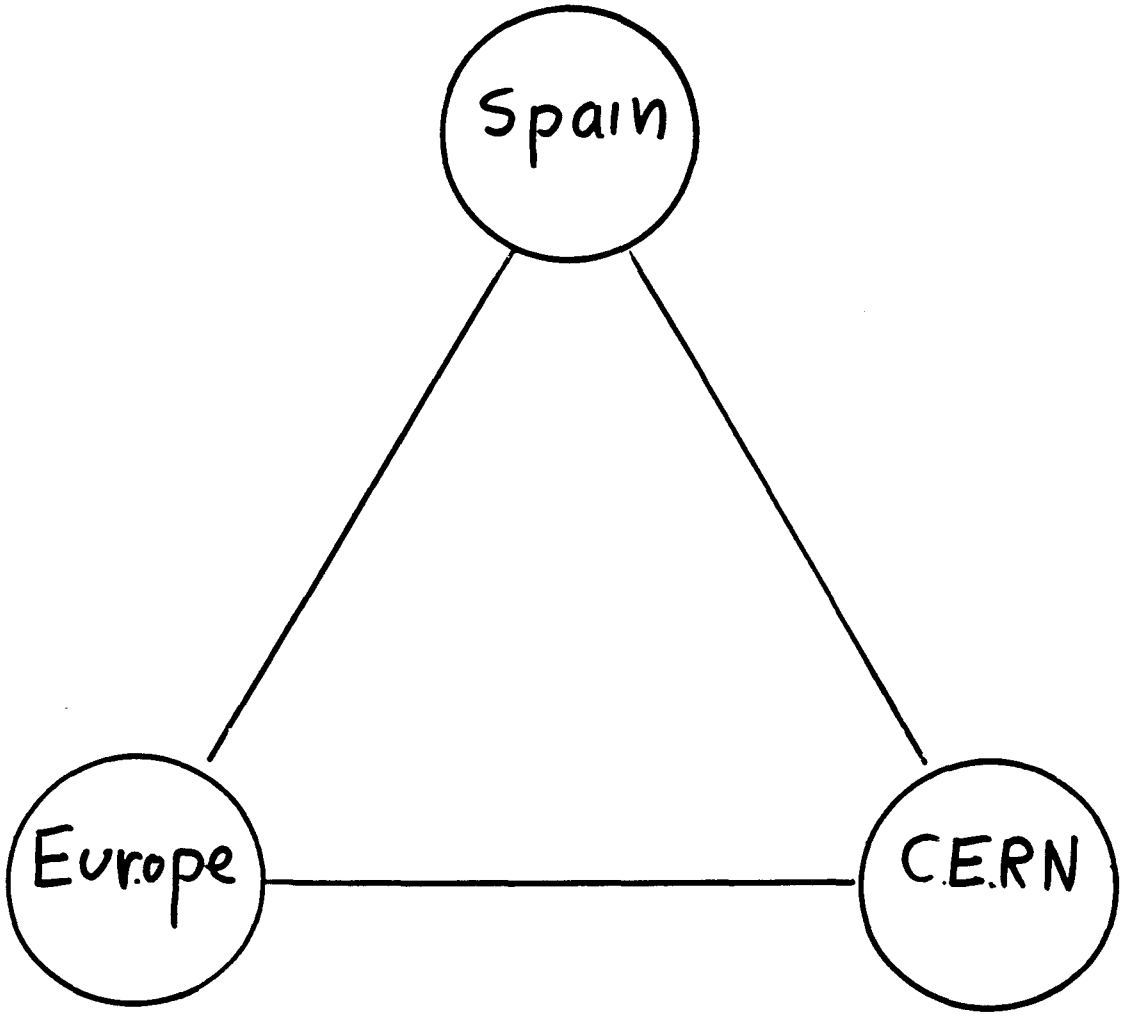
a.m.	DETECTOR II (chairman: Rafe Schindler)	
09:00 - 10:30	Hadron calorimeter & μ detector:	
15'	*Hadron calorimeter & μ range aspects*	Bernardo Adeva
15'	*Multi-wire detector*	Ronen Mir
10'	*Engineering studies*	Carlos Burgos
10:30 - 11:00	Coffee	
11:00 - 11:50	Trigger & data-acquisition:	
20'	*General considerations*	Luciano Romero
20'	*Transputers in the τ-charm Factory*	Robert Dobinson
11:50 - 12:40	Computing & communications:	
15'	*Slow control system*	Herve Milcent
15'	*Networking in Spain*	Antonio Mollinedo
15'	*Computing environment*	Ronen Mir
15'	*Overview of general-purpose computing*	Les Robertson
12:40 - 13:30	Offline analysis & Monte-Carlo:	
10'	*Offline*	Pedro Vaz
10'	*Monte Carlo*	Jose Salt
10'	*Forward region*	Javier Cuevas
p.m.	MACHINE II (chairman: Bernard Jean-Marie) & PANEL DISCUSSION II	
15:30 - 16:30	Vacuum chamber & instrumentation:	
15'	*Overview of vacuum chamber & inst.*	Alain Poncet
10'	*Photon-stimulated desorption*	Pierre Marin
10'	*Ion clearing in the e^- ring*	Alain Poncet
10'	*Trapping of dust particles in the e^- ring*	Pierre Marin
15'	*I.R. & booster considerations*	Alain Poncet
16:30 - 17:00	Tea	
17:00 - 18:00	Beam-current limitations & RF:	
15'	*Overview of instability limits*	John Jowett
45'	*Superconducting RF cavities*	Ernst Haebel
18:00 - 19:30	Panel discussion: *International collaboration on the τ-charm Factory*	Juan Antonio Rubio (chairman)
	Bernardo Adeva (secretary)	Roger Cashmore
		Victor Cook
		Michel Davier
		Cayetano Lopez
		Martin Perl

Thursday, 2 May 1991

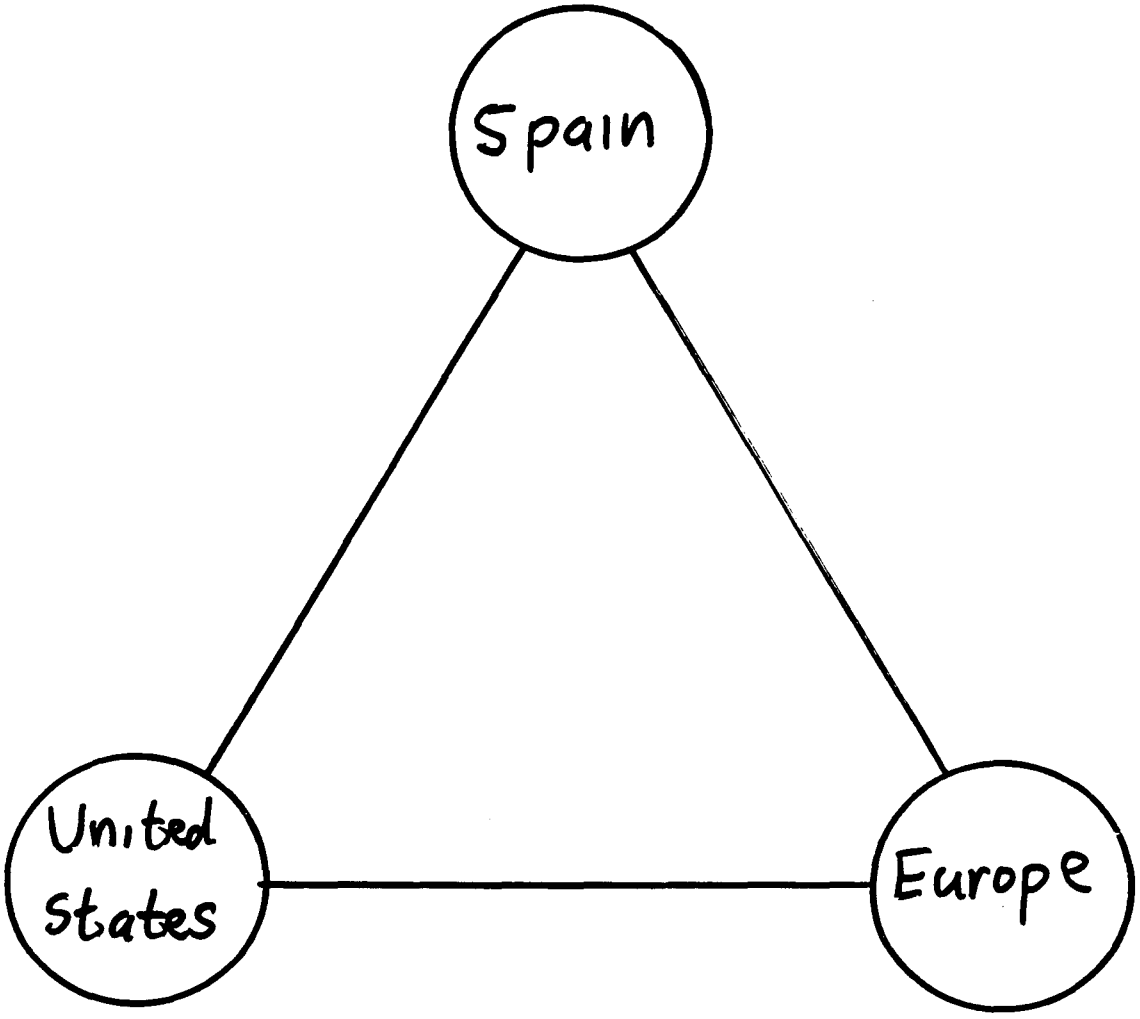
a.m.	SUMMARY (chairman: Cayetano Lopez)	
08:30 - 09:30	Machine summary	John Jowett
09:30 - 09:45	Coffee	
09:45 - 10:45	Detector summary	Jasper Kirkby
10:45 - 11:30	Meeting summary	Juan-Antonio Rubio
13:00	MEETING LUNCHEON	

Overview Of Tau-Charm Factory In Europe: History And Status

Machine and Laboratory



Detector [1st one]

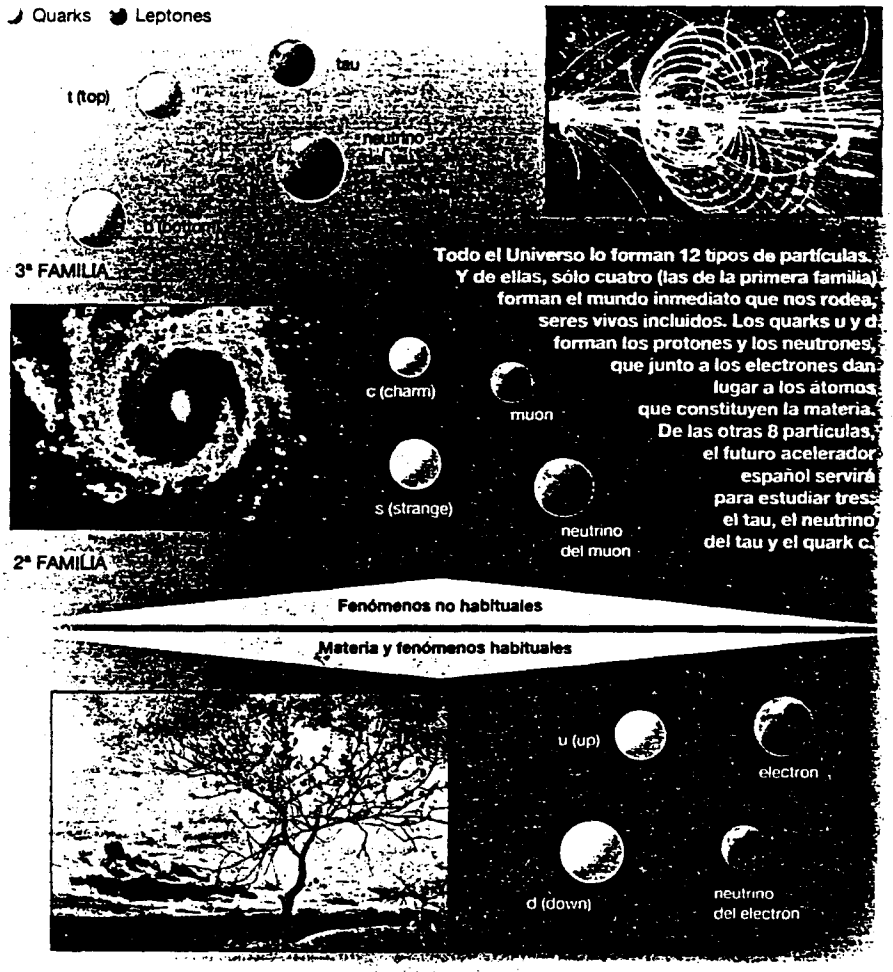


EL PAIS

AÑO III, NÚMERO 71, SEGUNDA ÉPOCA / MIÉRCOLES 8 DE MAYO DE 1991

Futuro
SUPLEMENTO DE CIENCIA, TÉCNICA E INFORMÁTICA

Las doce partículas fundamentales



M. A. DE LARA

La 'fábrica de taus', un reto a la física española

El futuro acelerador de partículas se caracterizará por su gran precisión

SEBASTIÁN SERRANO

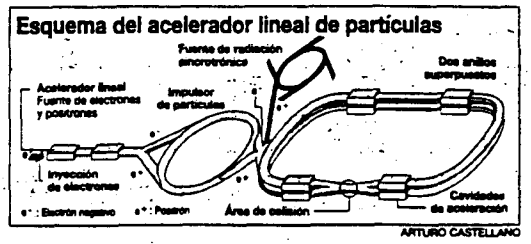
La física de partículas es una singular disciplina en que las cosas no siempre significan lo que aparentan. Por ejemplo, un mesón con encanto no es una fonda paradisíaca: es una partícula fugaz y diminuta de la que forma parte el quark *charm* (encanto). Se trata de una especialidad que practican sólo unos miles de científicos en todo el mundo, a pesar de ser básica para profundizar en el conocimiento de las leyes de la física y entender el universo que nos rodea. Además de ser pocos, los investigadores trabajan agolpados en torno a unos grandes aceleradores de partículas que pueden contarse con los dedos de las manos. Profundizar en el conocimiento íntimo de la materia requiere enormes inversiones que no permiten la proliferación de laboratorios. Pues bien, Sevilla podría albergar antes de final de siglo una de esas instalaciones reservadas a los elegidos, la denominada *fábrica de taus*, un acelerador cuya principal característica será la precisión y cuya construcción obligaría a la física de partículas española a hacer un esfuerzo para situarse entre la élite mundial.

El Comité de Política Científica del Laboratorio Europeo de Física de Partículas (CERN) llegó el viernes pasado a la conclusión de que conviene construir esa *fábrica*, pero no avaló todavía la petición del Gobierno de que la instalación se construya en España. La decisión definitiva deberá tomarla el consejo del CERN en su reunión de junio o en la de diciembre. Si es positiva, se instalará por primera vez fuera de su sede suiza un centro del laboratorio europeo.

La función de cualquier acelerador de partículas es generar materia a partir de la energía, dando cumplimiento a la célebre fórmula de Einstein. Para ello se construyen unas conducciones más o menos circulares —que pueden llegar a ser de decenas de kilómetros— en las que se crea el vacío más absoluto y por las que se hace circular haces de una determinada partícula —por ejemplo, el electrón— en una dirección, y de su correspondiente antipartícula —el positrón— en la dirección contraria. Al desplazarse a velocidades próximas a la de la luz, las partículas acumulan una gran energía. Y al chocar entre sí, el electrón y el positrón desaparecen como tales, pero la energía de ambos se suma y da lugar a una pareja de partículas cuya masa es mucho mayor que la del electrón y el positrón originales.

Pasa a la página 3

Esquema del acelerador lineal de partículas



ARTURO CASTELLANO

Correo en bits. Renovarse o morir es el lema de los servicios de correos en la mayor parte de los países, que se plantean incorporar paulatinamente las nuevas tecnologías para atraer al cliente, enganchado al teléfono, al ordenador o al fax. El cariño que siente el ser humano por el medio de comunicación escrito impedirá que muera el servicio de correos, según el presidente de La Poste francesa, que aposta por transmitir la mayor parte de las cartas por medios electrónicos y recuperarlas en forma de papel en el otro extremo. Este modelo es el que va seguir el servicio español de correos.

Página 6

Un acelerador para obtener más colisiones

La instalación ayudará a comprender por qué la materia predomina sobre la antimateria

Viene de la **página 1**

Apenas hace dos años, los físicos llegaron a la conclusión de que todo el universo está construido por 12 partículas fundamentales —más sus correspondientes antipartículas—, que se dividen en tres familias de cuatro componentes cada una. Con sólo una de ellas —la formada por los quarks u (*up*) y d (*down*), el electrón y el neutrino del electrón— puede explicarse la materia que nos rodea: el aire, la tierra y el mar, los animales y las plantas.

Las ocho partículas restantes sólo existen en el ámbito de la astrofísica o en el mundo creado por los aceleradores de partículas. La *fábrica de taus*, que imprimirá a sus electrones una moderada energía de dos gigaelectronvoltios (miles de millones de electronvoltios) permitirá profundizar en el estudio de tres de esas partículas: el tau y su neutrino (similares al electrón y su neutrino pero de mayor masa) y el quark c (*charm*), a través de algunas de las partículas que forma, porque ningún quark ha sido observado aisladamente.

De las 12 partículas fundamentales, sólo la de mayor masa sigue sin ser detectada: el quark t (*top*), que son el objetivo de dos futuros enormes aceleradores —uno en Ginebra y otro en Texas— mucho más potentes que los actuales. En palabras de Michel Davier, director del acelerador lineal de Orsay (Francia), esas grandes máquinas se sitúan en "la frontera de la energía", mientras que los aceleradores de tipo *fábrica* tratan de superar otro límite: "la frontera de la luminosidad".

Como sucedía con el mesón con encanto, la luminosidad no significa lo que parece a primera vista. La luminosidad es una característica que define a cada acelerador y determina el número de colisiones que se producirán en él. Se prevé que la *fábrica de taus* sea 100 veces más *luminosa* que el gran acelerador de Ginebra. Ese incremento vendrá determinado fundamentalmente por la construcción de dos anillos de aceleración de 360 metros cada uno (en lugar de uno como es habitual) y por una serie de mejoras que permitirán concentrar mejor el haz de partículas en la zona de colisión.

A propósito de la *luminosidad*, el físico español Antonio Ferrer comenta que mientras que en el gran acelerador de Ginebra se trabaja con un suceso cada segundo, "con la *fábrica de taus* se habla de hasta 2.000 por segundo, lo que obliga a mejorar otros componentes". Ferrer explica que algunos detectores no podrán usarse por tener un periodo de respuesta demasiado largo y subraya que los equipos informáticos tendrán que mejorar mucho para aprovechar bien las ingentes cantidades de información que serán generadas.

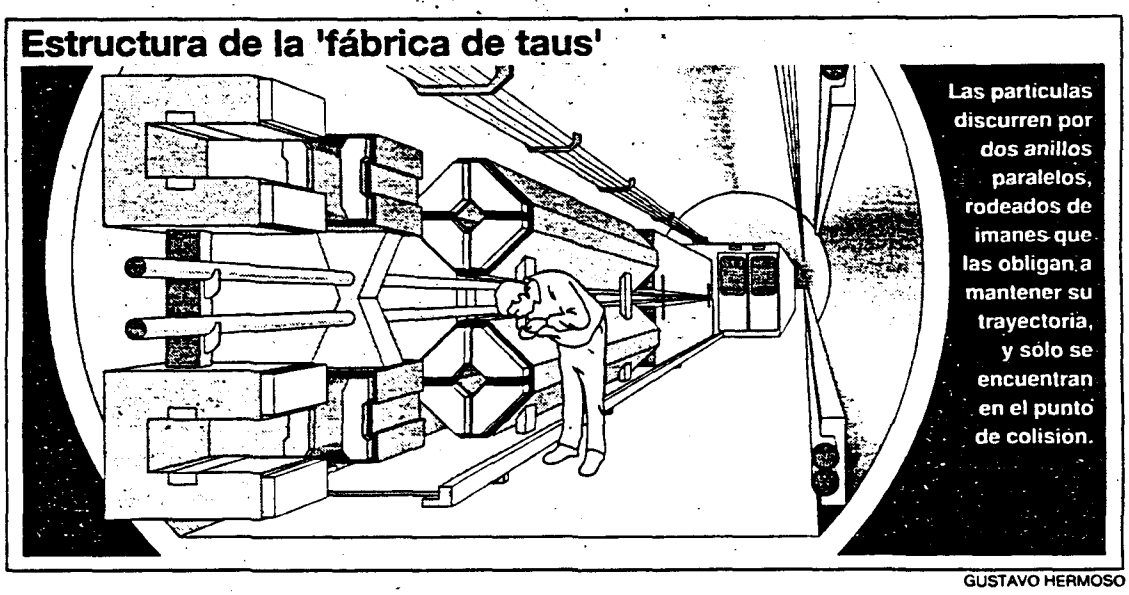
Los detectores, que se colocan en forma de capas cilíndricas en torno al área de colisión, forman el componente que ha de ser capaz de registrar la traza de partículas de inusitada fugacidad: el tau, por ejemplo, tiene una vida un billón de veces más corta que un segundo.

Juan Antonio Rubio, asesor científico del director general del CERN, subraya que la *fábrica de taus* permitirá profundizar en aspectos no explicados aún por el *modelo estándar* de la física actual. Así, además de establecer con mayor precisión la masa del tau o determinar la del neutrino del tau (una cuestión que sigue totalmente abierta), la observación sistemática de la desintegración de partículas con *encanto* puede ayudar a entender la ruptura de simetría que hace que el mundo esté formado de materia y no de antimateria.

Junto al acelerador, que costará al menos 22.000 millones de pesetas y será dedicado a la investigación básica, se prevé la construcción de un anillo generador de radiación sincrotrón, que aprovechará el sistema de inyección de partículas del acelerador y costará unos 3.000 millones más. Este anillo podrá ser utilizado por un amplio sector de industrias. La definición de la máquina se estudió en una reunión científica la pasada semana en Sevilla.

PEREZ CABO

Los físicos Juan Gómez Cadenas, Juan Antonio Rubio, M. Perl y J. Kirkby, de izquierda a derecha, participaron en Sevilla en la reunión que avanzó la pasada semana en la definición de la fábrica de taus.



GUSTAVO HERMOSO

The Detector: Conclusions

Special detector requirements for some measurements at a tau-charm factory (Kirkby 1990).

	Detector emphasis				
Experiment	Charged particles	Photons	πKp i.d.	$e\mu$ i.d.	Hermeticity
$\tau^{\pm}$ physics:					
ν_τ, $\tau^{\pm}$ masses	•	•	•	•	•
$\tau \to \ell\nu_\ell\nu_\tau$ spectra	•	•		•	•
Precise branching ratios		•	•	•	•
Second class currents		•		•	•
Weak hadronic current	•	•	•	•	•
$\tau^{\pm}$ electric dipole moment		•	•	•	•
Rare decays	•	•	•	•	•
D, D_s physics:					
V_{cs}, V_{cd} (semileptonic decays)		•	•	•	•
f_D (pure leptonic decays)		•		•	•
Hadronic decays (CA, CS, DCS)	•	•	•		
$D^0\bar{D}^0$ mixing, CP violation	•		•	•	•
Rare decays	•			•	•
$J/\psi(3.10)$, $\psi(3.69)$ physics:					
Spectroscopy ($c\bar{c}$, gg, hybrid, uds)	•	•	•		
Rare decays		•	•	•	•

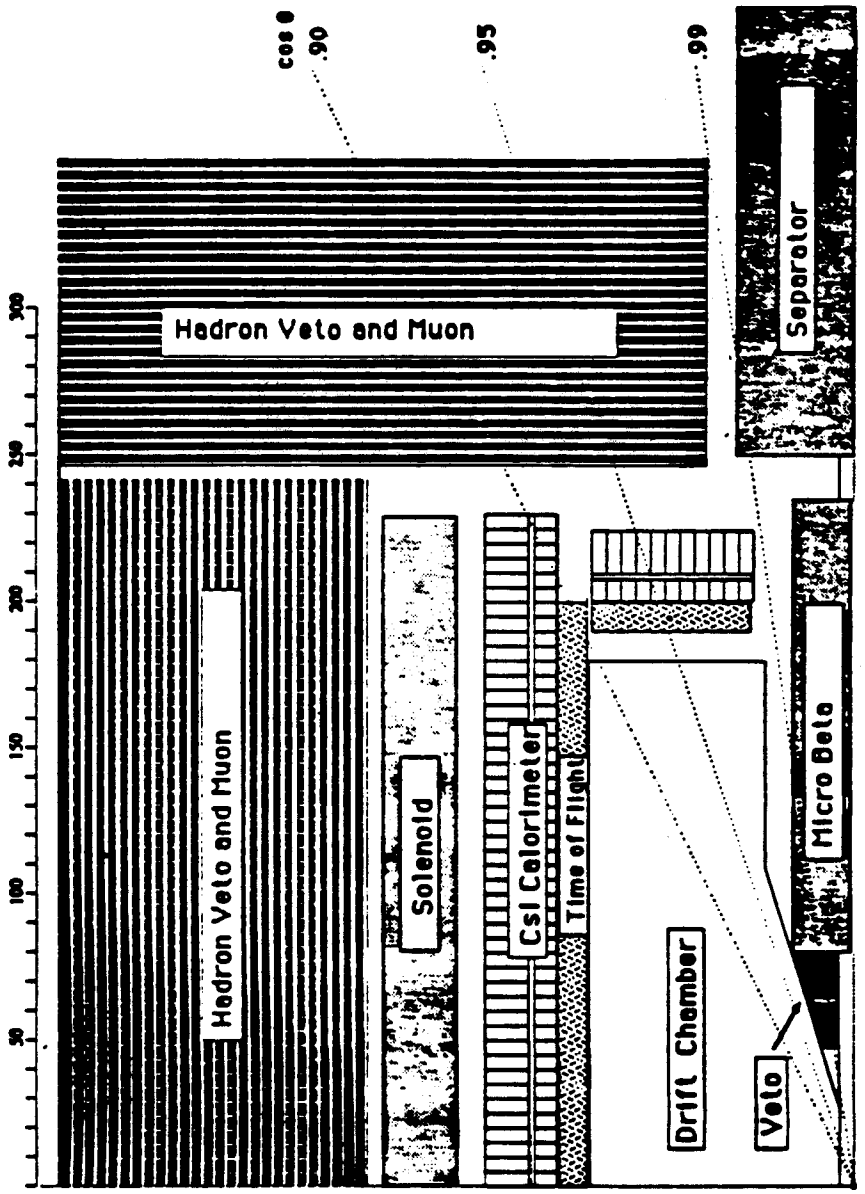
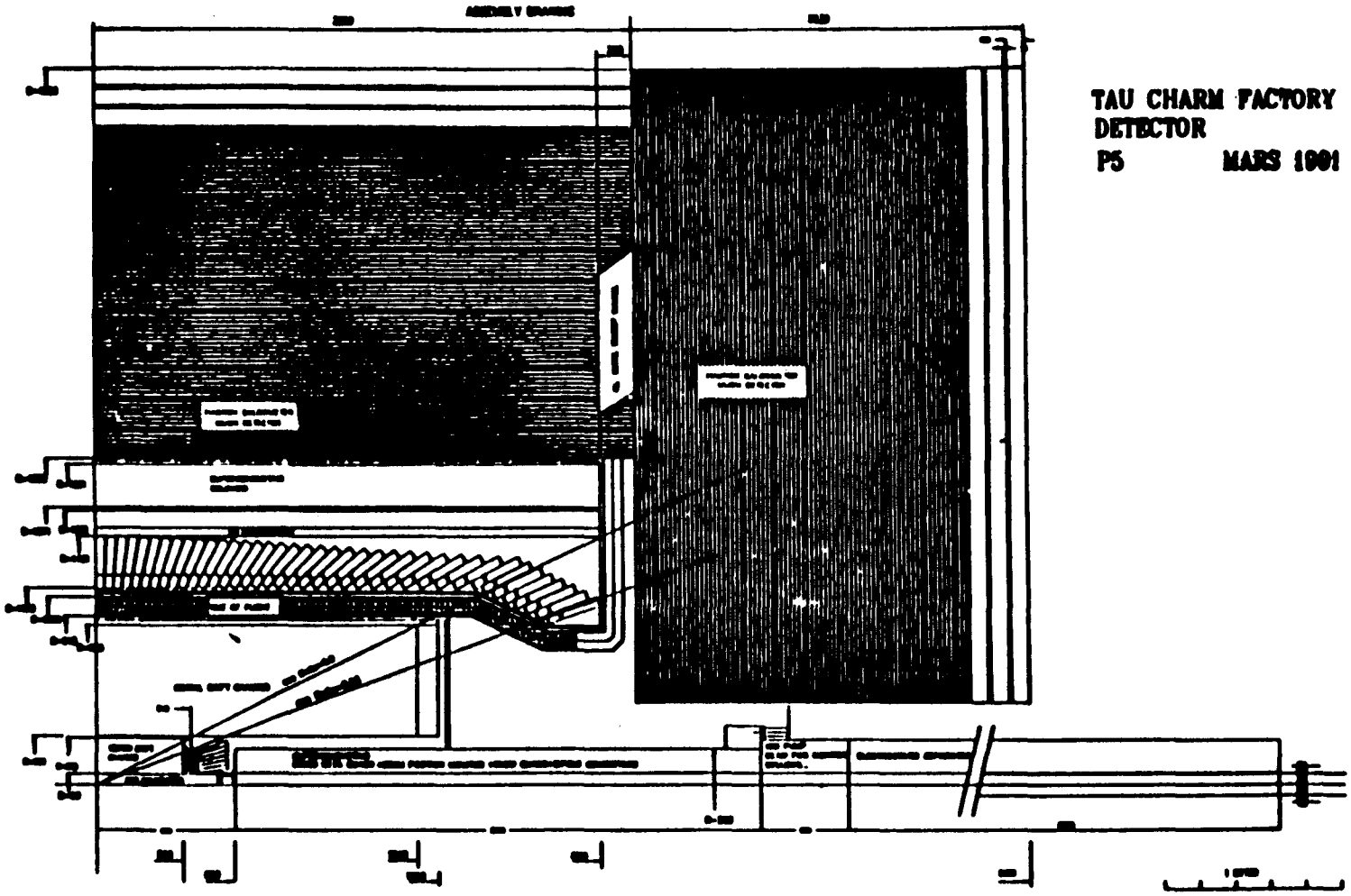


Fig. 4. Schematic design of detector for tau and charm physics research at a tau-charm factory.



TAU CHARM FACTORY
DETECTOR
P5 MARS 1991

Detector: Conclusions

- About 60 physicists + 10 engineers now working on design and R&D:
  - Britain
  - CERN
  - France
  - Germany
  - Portugal
  - Spain
  - United states
- In detailed design stage
- Emphasize:
  - minimum number of subsystems
  - reliability and redundancy
  - use conventional techology
  - use industry standard for electronics, computer

- Detector design and R&D proceeding in Spain on:
  - hadron calorimeter
  - EM calorimeter
  - TOF
  - Luminosity monitor
  - software and networks

- Cost ~ 90 MSF
  - 1/3 Europe
  - 1/3 Spain
  - 1/3 United states

- Construction time = 5 years

- Little discussion of second detector. Collider will have space for a second interaction region.

The Collider: Conclusions

Summarizing, there are four required properties

(i) $3.0 \leq E_{tot} \lesssim 5.0$ GeV

(ii) $L_{max} \approx 10^{33}$ cm^{-2} s^{-1}

(iii) Highly reliable operation

(iv) $\Delta E_{tot} \sim$ few MeV

Present design adds

(v) synchrotron light source using same injector

Since original τcF machine design

J.M. Jowett, CERN LEP-TH/87-56 (1987),

further machine studies at ...

- SLAC

  B. Barish et al., SLAC-PUB 5180 (1990).

- LAL-ORSAY

  J. Gonichon et al., LAL/RT 90-02 (1990).

- Moscow/Novosibirsk

  M.V. Danilov et al., ITEP 67-90 (1990).

- CERN

  Y. Baconnier et al., CERN/AC/90-07 (1990).

All confirm feasibility of $10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$

63

EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CERN/AC/90-07

A TAU-CHARM FACTORY LABORATORY IN SPAIN combined with a SYNCHROTRON LIGHT SOURCE (A conceptual study)

Y. Baconnier, J.-L. Baldy, J.-P. Delahaye, R. Dobinson, A. De Rújula, F. Ferger, A. Hofmann, J.M. Jowett, J. Kirkby, P. Lefèvre, D. Möhl, G. Plass, L. Robertson, J. A. Rubio, T.M. Taylor and E.J.N. Wilson
CERN, Geneva, Switzerland

F. Dupont and J. le Duff
LAL, Orsay, France

C. Willmott
CIEMAT, Madrid, Spain

Abstract

A conceptual design for a τ-charm factory and its associated laboratory is given. It includes the physics interest, a description of the scope and layout of the new laboratory in Spain, the τ-charm factory collider and detector, the injector system and a synchrotron light source, together with estimates of the time-scale and necessary resources.

Geneva, Switzerland

20 November 1990

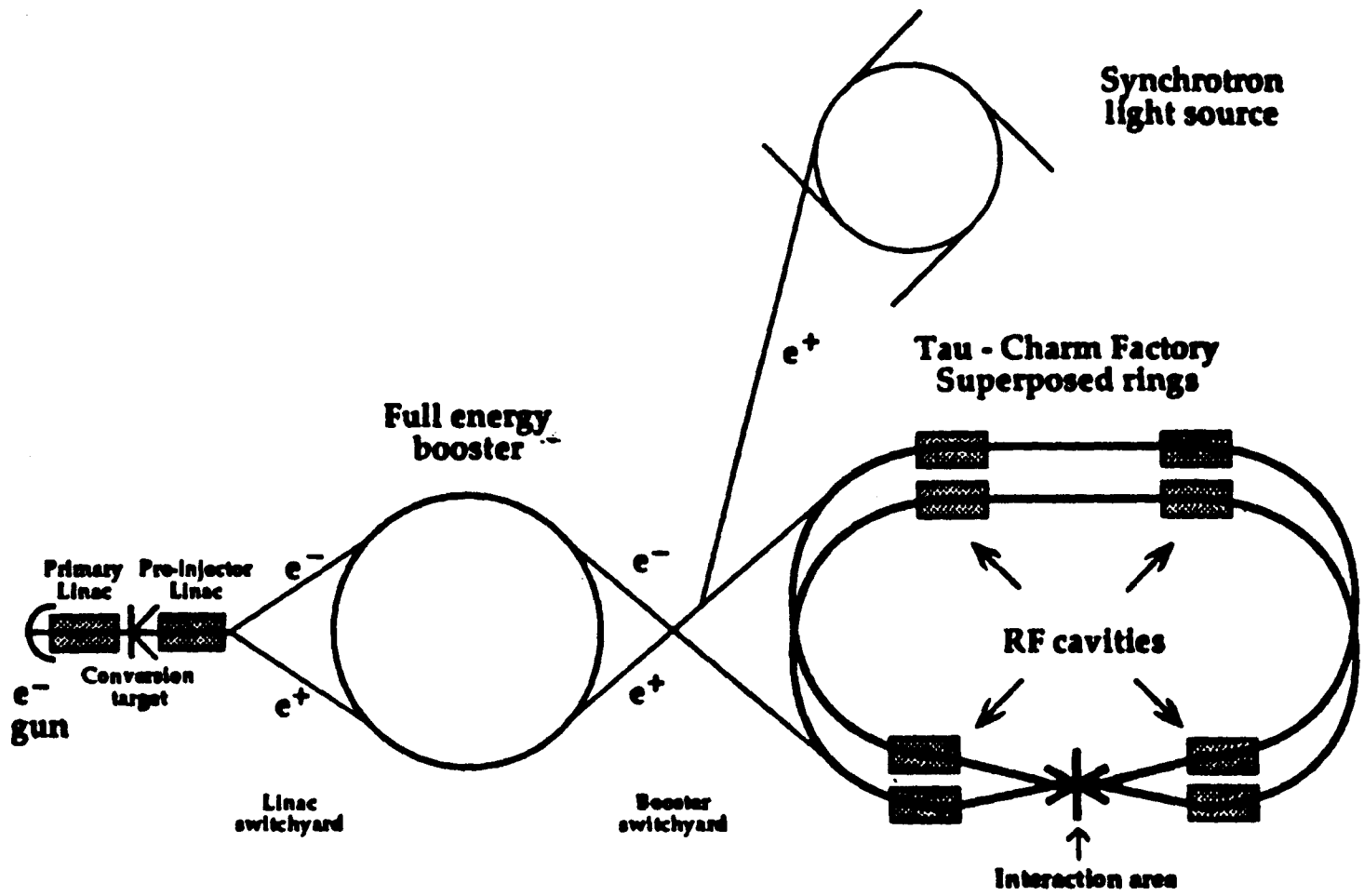

Synchrotron light source
Tau - Charm Factory Superposed rings
Full energy booster
Primary Linac
Pre-injector Linac
Conversion target
e⁻ gun
e⁻
e⁺
e⁻
e⁺
e⁺
RF cavities
Linac switchyard
Booster switchyard
Interaction area

Table 4: Typical collider parameter list at its energy of maximum luminosity

Energy (GeV)	2.0
Energy (max.)(GeV)	2.5
Luminosity ($cm^{-2}\,s^{-1}$)	10^{33}
Circumference (m)	360
Bending radius (m)	10
RF frequency (MHz)	500
Number of bunches	30
Distance between bunches (m)	12
Harmonic number	600
Momentum compaction	0.027
Horizontal tune	10.xx
Vertical tune	11.xx
Total current (A)	0.6
SR linear power density ($kW{\cdot}m^{-1}$)	1.9
Beam–beam parameter	0.04
Disruption	0.3
Peak RF voltage (MV)	19
Total RF power (MW)	0.24
Number of RF cavities per ring	8
HOM power per cell (kW)	6
HOM power dissipated in vacuum chamber (kW)	100
Vertical beta at interaction point (m)	0.01
Horizontal beta at interaction point (m)	0.2
Vertical emittance (m)	2×10^{-8}
Horizontal emittance (required*)(m)	4×10^{-7}
Bunch length (m)	0.006
Energy spread	6×10^{-4}
Max. tolerable impedance $(Z/n_0)(w \rightarrow 0)(\Omega)$	4.2
Max. tolerable impedance (Z/n_{eff})(effective)(Ω)	0.28
Expected impedance $(Z/n_0)(w \rightarrow 0)(\Omega)$	2.1

* Achieved with wigglers.

Comparison with previous machines

$$L \propto (I\xi_y/\beta_y^*)E$$

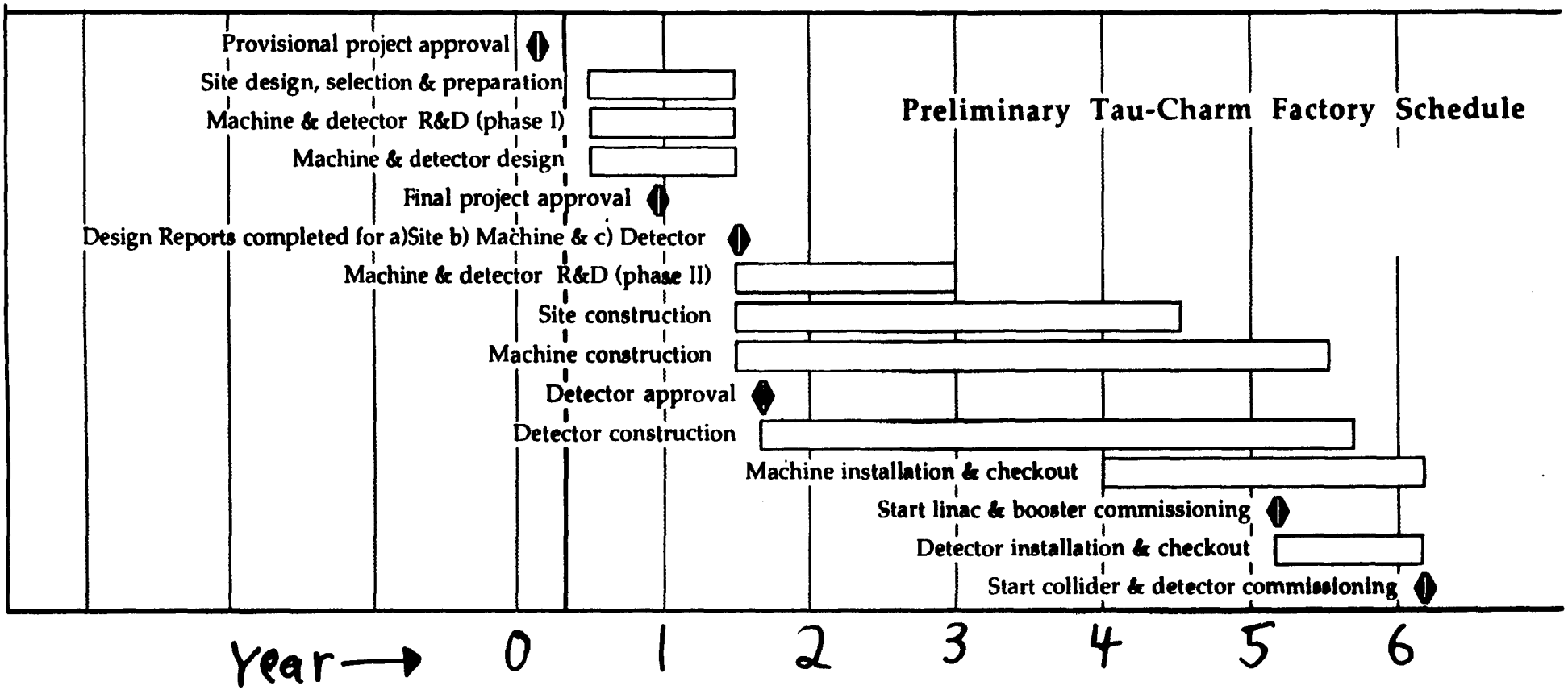
(assuming flat beams and optimum coupling)

	SPEAR	BEPC	τcF
Number of bunches	1	1	30
Eff. bunch separation [m]	234	240	12
Total beam current, I [mA]	10	50	570
Vert. β-fn. at IP, β_y^* [m]	0.08	0.10	0.01
Beam-beam tune shift, ξ_y	0.025	0.04	0.04
Luminosity [$cm^{-2}s^{-1}$]	2×10^{30}	1×10^{31}	1×10^{33}

From Baconnier et al:

Cost of collider + laboratory excluding synchrotron light source:

300 MSF [material & personnel]



Approval to commissioning ≈ 6 years

Collider: Conclusions

- $L = 10^{33}\ cm^{-2}s^{-1}$ can be achieved using the present design.

- There are a number of design issues which need to be settled: RF frequency, vacuum chamber, background control, I.P. mechanical design ....

- Spanish industry is able to supply most of the construction and components:
  - → civil engineering
  - → magnets (warm and cryogenic)
  - → mechanical components
  - → vacuum systems
  - → electrical power and cooling systems
  - → control systems
  - → communication systems

- Thus most work can be contracted out.

- A few items require specialized work in laboratories and industry: RF superconducting cavities, some aspects of beam pipe manufacture, feedback systems

- The development of a cadre of Spanish accelerator engineers, physicists and technicians is a crucial part of the proposal. That development thru training and exchange programs has begun.

- The collider will be useful for studies in accelerator physics:
  - → optimum σ_z/β_y^*
  - → large I
  - → instability studies

- The collider will have enough flexibility to allow luminosity upgrades above $10^{33}\,cm^{-2}\,s^{-1}$

B-Physics and CP Violation from Lattice

G. Martinelli

[redacted]

PLAN OF THE TALK:

- GENERAL INTRODUCTION
- BRIEF DESCRIPTION OF THE LATTICE METHOD
- PSEUDOSCALAR MESON DECAY CONSTANTS AND KAON B-PARAMETE
- D- AND B- PHYSICS
- OUT LOOK

ALMOST ALL ASPECTS OF PARTICLE PHYSICS ARE CURRENTLY STUDIED ON THE LATTICE

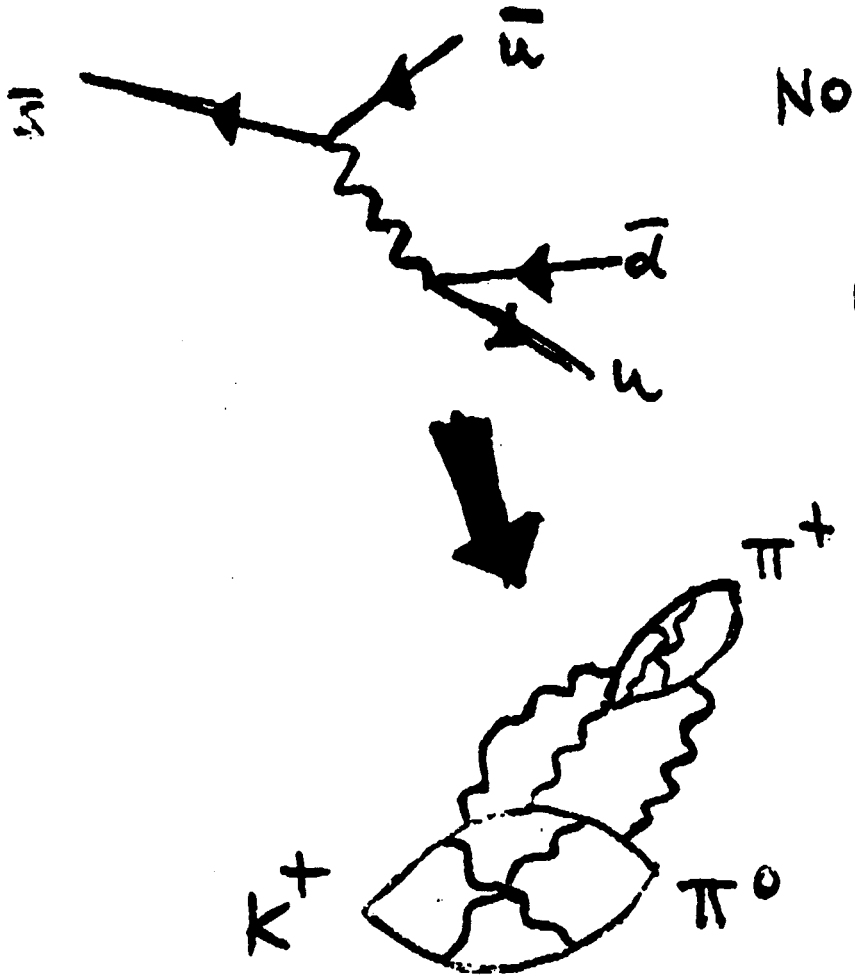
ALREADY WITH PHENOMENOLOGICALLY RELEVANT RESULTS

HADRONIC MATRIX ELEMENTS

- ELECTRO-MAGNETIC FORM FACTORS $\langle N | J_\mu(0) | N' \rangle$
- STRUCTURE FUNCTIONS $\langle N | \bar{q} D^\mu \gamma^\nu q | N \rangle$
- SIGMA TERM $\langle N | \bar{q} q | N \rangle$
- PROTON SPIN $\langle N | \bar{q} \gamma^\mu \gamma_5 q | N \rangle$
- EDM OF THE NEUTRON $\langle N | \vec{d} | N \rangle$
- WEAK DECAYS OF KAONS $\epsilon, \epsilon'/\epsilon, \Delta I = \frac{1}{2}$ ...
- D- AND B^*- WEAK DECAYS $\langle D | J_\mu^W | K, K^* \rangle$ $\langle D | H_W | PP \rangle$ $\langle D | H_W | VV \rangle$

THEORY OF WEAK DECAYS

[OR BETTER A THEORY OF STRONG INTERACTIONS]



NO STRONG INTERACTIONS

NO NEED FOR THEORISTS

- THE DETERMINATION OF THE PARAMETERS OF THE STANDARD MODEL CRUCIALLY DEPEND ON THE THEORETICAL ACCURACY IN PREDICTING THE HADRONIC AMPLITUDES

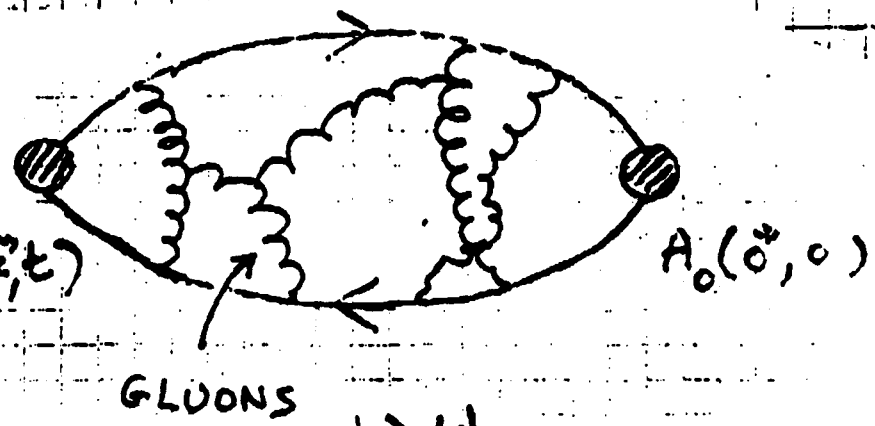
HADRON SPECTRUM AND MESON DECAY CONSTANTS

- DEFINE A SOURCE WITH THE CORRECT QUANTUM NUMBERS:

COLOUR

$$\text{"}\pi\text{"} \equiv A_0(\vec{x},t) = \bar{u}^A_\alpha(\vec{x},t)(\gamma^0\gamma_5)_{\alpha\beta}\, d^A_\beta(\vec{x},t)$$

SPIN



$$G(t) = \sum_{\vec{x}} \langle A_0(\vec{x},t)\, A_0^\dagger(\vec{0},0)\rangle \equiv$$

$|n\rangle\langle n|$

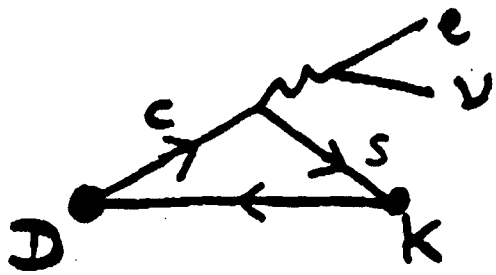
$$\sum_n \frac{|\langle 0|A_0|n\rangle|^2}{2m_n} e^{-m_n t} \xrightarrow[t\to\infty]{}$$

$$\frac{|\langle 0|A_0|\pi\rangle|^2}{2m_\pi} e^{-m_\pi t} = \frac{f_\pi^2 m_\pi}{2} e^{-m_\pi t}$$

- m_π FROM THE LOGARITHMIC SLOPE
- f_π FROM THE CONSTANT

$\langle h | O | h' \rangle$ FROM 3-POINT FUNCTIONS

$$D \to K e \nu$$

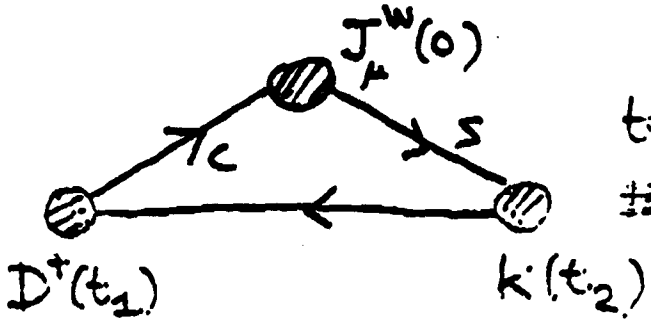


$$\to \langle D | J_\mu^W | K \rangle$$

$$D^\dagger(t_1) = \sum_{\vec{x}} D^\dagger(\vec{x}, t_1)\, e^{-i \vec{p}_D \cdot \vec{x}}$$

$$K(t_2) = \sum_{\vec{x}} K(\vec{x}, t_2)\, e^{i \vec{p}_K \cdot \vec{x}}$$

$t_1 \to -\infty$



$t_2 \to +\infty$

$$\langle D^\dagger(t_1)\, J_\mu^W(0)\, K(t_2) \rangle \sim$$

$$\left\{ \frac{\langle 0 | D^\dagger | D \rangle \langle K | K | 0 \rangle}{2E_D\, 2E_K} e^{-E_D |t_1| - E_K t_2} \right\} \times$$

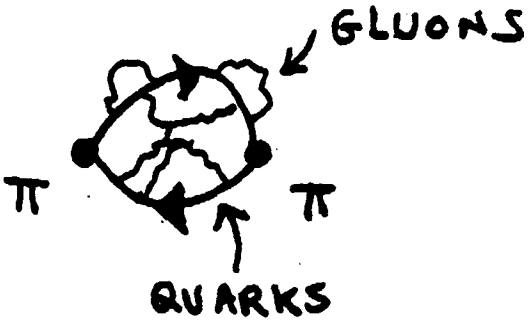
FROM 2-POINT FUNCTIONS

$$\langle D | J_\mu^W(0) | K \rangle$$

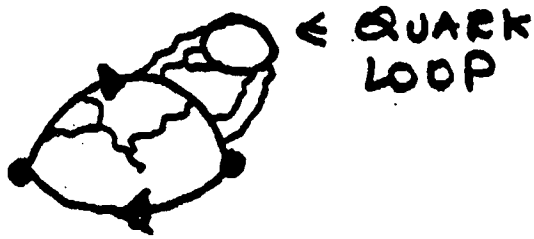
LATTICE VERSUS CONTINUUM

MAIN LIMITATIONS AND SOURCES OF SYSTEMATIC EFFECTS

i) QUENCHING ← HARD TO AVOID



YES



NO

CONSEQUENCES $\frac{m_{PROTON}}{m_\rho}$ 20 % (10 %)

LARGER THAN ITS EXP. VALUE

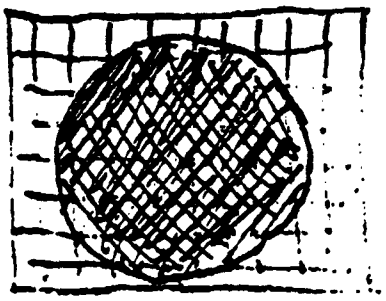
ii) TERMS OF ORDER $\Lambda_{QCD} a$

$\sim 20 \div 30\,\%$ ON MATRIX ELEMENTS

LATTICE SPACING

iii) EXTRAPOLATION TO THE PHYSICAL VALUES OF MASSES FOR LIGHT QUARK

$m_{u,d}$ $(m_q)^{MIN} \gtrsim m_{strange}$



← FINITE SIZE EFFECTS

FINITE SIZE EFFECTS

USUALLY UNDER CONTROL DOWN TO $M \sim M_K$

THE PION REQUIRES AN EXTRAPOLATION - FOR MOST OF THE QUANTITIES THIS IS POSSIBLE WITH A SMALL INCREASE OF THE FINAL ERROR

$\Lambda_{QCD}\, a$ EFFECTS

$\sim 20 \div 30\%$ ($a^{-1} \sim 2 \div 3$ GeV $\Lambda_{QCD}\, a \sim 10\%$)

CAN BE REDUCED IN A SYSTEMATIC WAY - USUALLY IS NOT A PROBLEM

$\boxed{\text{NEW} \lesssim 4\%}$

Shanpe et al.

$B = 0.94(3)$ $\quad a^{-1} = 1.3$ GeV

$= 0.70(2)$ $\quad a^{-1} = 2.0$ GeV

$= \boxed{0.70(3)}$ $\quad a^{-1} = 3.0$ GeV

$m_q a \ll 1$ YOU CANNOT PUT THE BOTTOM QUARK ON A LATTICE WITH AN U.V. CUTOFF $a^{-1} \sim 1.5$ GeV

QUENCHING!

HARD BUT NECESSARY TO GO BEYOND THIS APPROXIMATION

THE SYSTEMATIC ERROR INDUCED BY THE QUENCHED APPROXIMATION DEPENDS ON THE QUANTITY UNDER STUDY

$\frac{m_p}{m_\rho}$ $\sim 20\%$ (10%)

$\Gamma_{\rho \to \pi\pi}$ $\sim 100\%$

EXPECTED TO BE SMALL FOR HEAVY MESON PHYSICS [?]

IN SPITE OF THE ABOVE WARNINGS LATTICE QCD IS SUPERIOR TO ANY OTHER NON PERTURBATIVE APPROACH

- IT IS BASED ON THE FUNDAMENTAL THEORY (+ RENORMALIZATION GROUP) WITH <u>NO EXTRA ASSUMPTION</u>

- THERE ARE NO FREE PARAMETERS A PART Λ_{QCD} [TO BE FIXED ON A PHYSICAL QUANTITY] AND QUARK MASSES

- IT IS <u>SYSTEMATICALLY IMPROVABLE</u> AND ERRORS (Λ_{QCD}, FINITE SIZE QUENCHING, ETC.) ARE DECREASING IN TIME

UNLIKE ANY OTHER METHOD ($\frac{1}{N_c}$, QUARK MODELS, CHIRAL MODELS, ...) see below $D \to K, K^*$

A FLASH

ON

- PSEUDOSCALAR DECAY CONSTANTS
- KAON B-PARAMETER

MESON DECAY CONSTANTS: $\langle 0|A_\mu|M\rangle = i p_\mu f$ [22] (7)

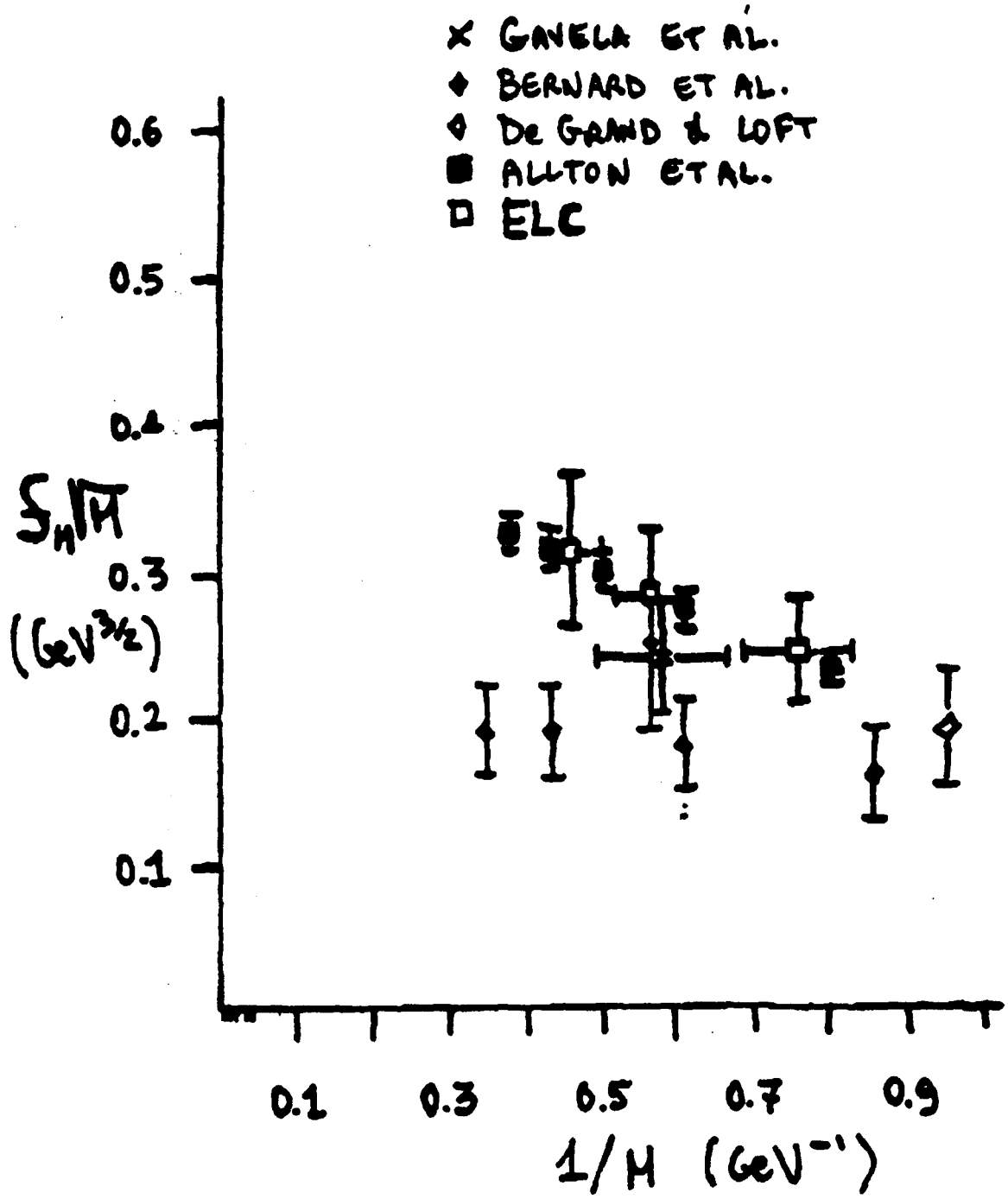
MESON	f (MeV)	EXP
π	$140 \pm 20 \pm 20$	132
K	158 ± 13 173 ± 13 161^{+38}_{-17}	~164
D PREDICTION →	180 ± 30 215 ± 60 174 ± 52 215 ± 48	[190±20] < 290 agreement with QCD SumRules
D_s	218 ± 30 ~220 234 ± 70	—
B_d / B_s } $f \sim m_Q^{-1/2}$	~120 105 ± 34	— MORE LATER
	~150	—

TO REDUCE SYSTEMATIC ERRORS

$$f_M = \left(\frac{f_M}{f_\pi}\right)_{\text{LATTICE}} \times f_\pi^{\text{EXP}}$$

● = EUROPE ● Deforand+Loft ● UCLA

SCALING VIOLATED FOR $M_Q \sim m_{charm}$



KNOWN FACTORS

$$|\epsilon| = \left(\frac{G_F^2 M_W^2 M_K f_K^2}{6\sqrt{2}\,\pi^2 \Delta m} \right) \times (A^2 \lambda^6 \rho) \times \underline{\sin\delta}$$

$$\times \left[F_{ct} - F_{cc} + A^2 \lambda^4 (1 - \rho \underline{\cos\delta}) F_{tt} \right]$$

$$\times B_K$$

SHORT DISTANCE QCD EFFECTS — Dalla et al. Buras et al.

δ = CP-VIOLATING PHASE

$V_{12} = \lambda$ $\quad V_{23} = A\lambda^2$ $\quad |V_{13}| = A\lambda^3 \rho$

(Wolfenstein)

$$\langle K^0 | [\bar{d}\gamma^\mu (1-\gamma_5) s]_\mu^2 | \bar{K}^0 \rangle = \frac{8}{3} f_K^2 M_K^2 B_K(\mu)$$

$$\boxed{B_K = (\alpha_s(\mu))^{-6/25} B_K(\mu)}$$

$\mu > m_c$

sign of B_K $\longrightarrow$ $\sin\delta > 0$

$\lambda = 0.2205 \pm 0.0018$ $\quad \rho = 0.50 \pm 0.14$

$A\lambda^2 = 0.047 \pm 0.004$

ERROR DOMINATED BY ρ, $A\lambda^2$ AND

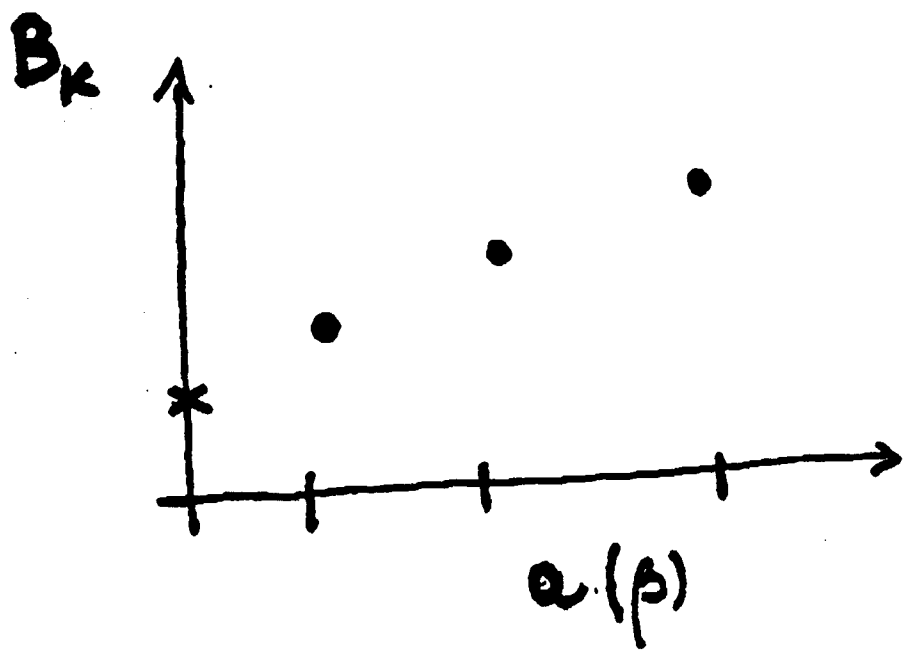
$\longrightarrow B_K \longleftarrow$ + m_t

Tab.6.1 Lattice QCD results for B_K. $\beta=6/g_0^2$, where g_0 is the lattice QCD coupling constant and a denotes the lattice spacing.

B_K

Reference	fermions	$\beta(a^{-1}\sim\mu)$	lattice size	$B_K(\mu)$	B_K
Bernard et al.[39]	Wilson	6.0(2 GeV)	24^3x40	0.76±0.04±0.02	1.03±0.07
Gavela et al.[40]	Wilson	" "	20x10^2x40	0.65±0.15	0.88±0.20
Kilcup et al.[41]	staggered	2 GeV	24^3x40	0.70±0.01	0.94±0.01
	" "	6.4(3.5GeV)	32^3x48	0.55±0.05	0.77±0.07
Brown et al.[42]	staggered unquenched 2-flavours	5.7(2GeV)	16^3x32	0.67±0.02	0.92±0.03
	staggered	6.2(3GeV)	18^3x40	0.7 → 0.64 (?)	

ASSUME $B_K = 0.94 \pm 0.10$



$B_K(0) \approx 0.65$?? [G. Kilcup private comm.]

$B_{K-\bar{K}}$ THEORETICAL ESTIMATES

0.33 ± 0.33		Donoghue et al. PCAC + SU(3) + experimental $\Delta I = 3/2$ $f_\pi = f_K$ $0.33 \to 0.49$ $C_4(\mu) \equiv$?
0.33 ± 0.09 [0.39 ± 0.10] $0.5 \pm 0.1 \pm 0.2$	QCD SUM RULES	De Raphael + Pich; Bilich et al
0.7 ± 0.1	$1/N_c$	Buras et al.
$\sim 0.94 \pm (0.10)$	LATTICE	ELC, UCLA, STAG

STATISTICAL ERROR AT THE LEVEL OF 2-3 %

$B(2\,\mathrm{GeV}) = 0.70 \pm 0.01$

QUENCHING !!

$B_{phys} = f\, B(2\,\mathrm{GeV})$

REQUIRES A 2-LOOP CALCULATION

$D \to K$ → MEASURE V_{cs}

$D \to K$ → ASSUMING $V_{cs} = 0.975$ TESTS THE MODEL

$D \to K^*$ TESTS THE MODEL

$B \to \pi, \rho$ PROBABLY WILL BECOME THE BEST WAY TO DETERMINE V_{bu} IF THEORISTS WORK WELL

2 EXAMPLES

i) SEMILEPTONIC $D \to K, K^*$
($D \to \pi, \rho$) DECAYS

ii) B-physics – SCALING LAWS (Wise)

- PHENOMENOLOGICALLY RELEVANT FOR V_{cs}, V_{cd}, B^0-$\bar{B}^0$ AND THE TOP MASS, V_{bu} etc.

- EXAMPLE OF HOW LATTICE WORK

- COMPARISON WITH OTHER POPULAR APPROACHES

D-decays in pseudoscalar mesons

$\boxed{D \to K \ell \nu_e}$ $\boxed{D \to \pi \ell \nu_e}$

DIFFICULT TO MEASURE EXP.

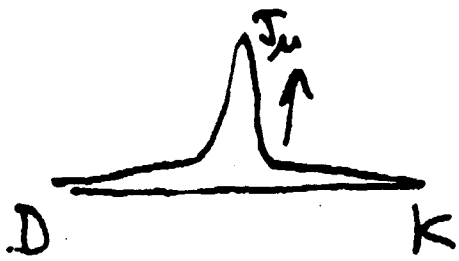
$$M = \frac{G_F}{\sqrt{2}} V_{cs} \left(\bar{u}_e \gamma^\mu_L u_\nu\right) \times \langle K | J^H_\mu | D \rangle$$

FROM THE LATTICE

TWO FORM FACTORS:

$$\langle K | J^H_\mu | D \rangle = f_+(q^2)(p_D + p_K)_\mu + f_-(q^2)(p_D - p_K)_\mu$$

BY ASSUMING VECTOR MESON DOMINANCE:



$$\boxed{f_+(q^2) = \frac{f_+(0)}{1 - \frac{q^2}{m^2_{D^*}}}}$$

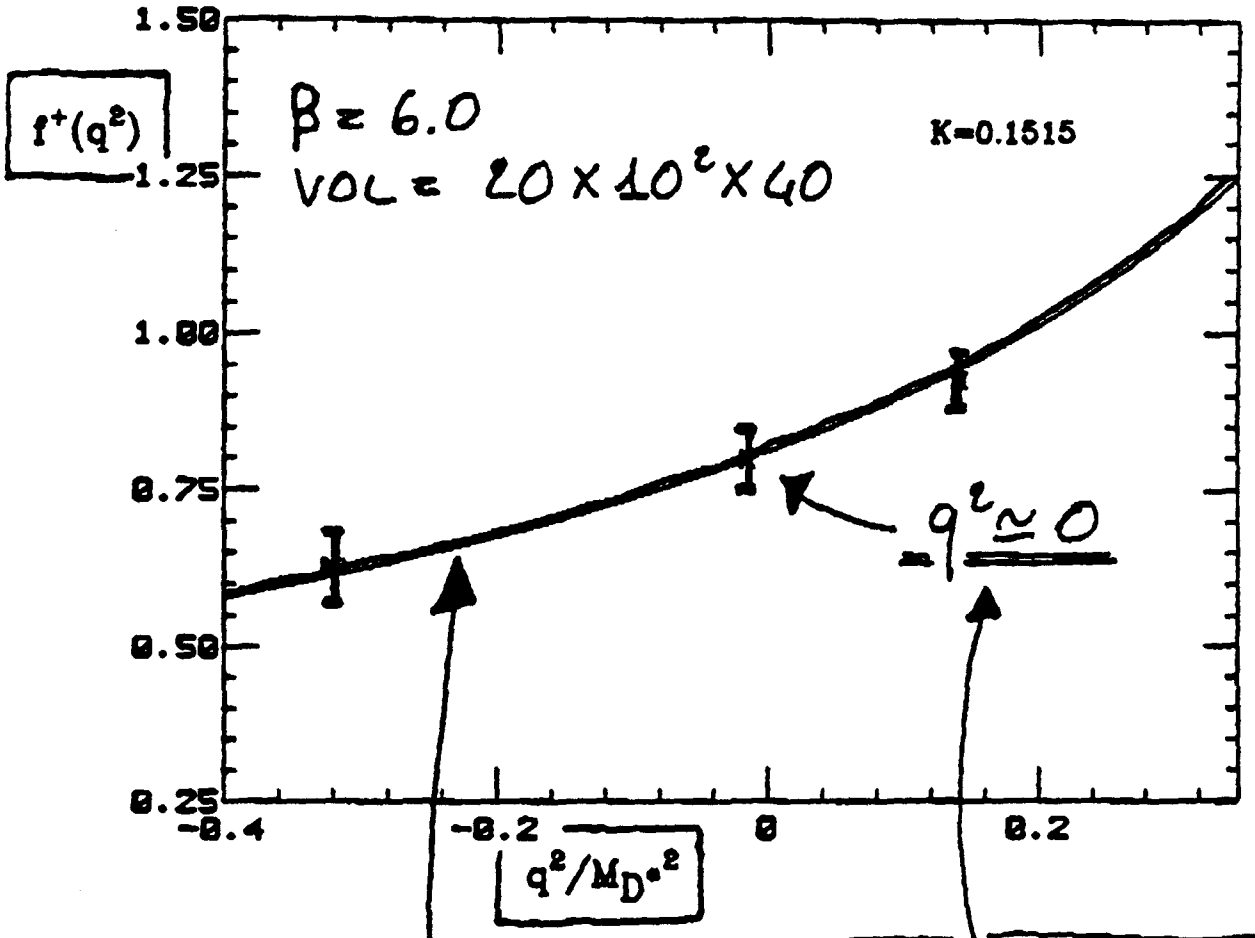
$$\Gamma(D^0 \to K^- e^+ \nu_e) = |f_+(0)|^2 |V_{cs}|^2 1.53 \times 10^{11} s^{-1}$$

E691, MARK III $\to$ $|f_+^K(0)|^2 |V_{cs}|^2 = 0.55 \pm 0.06 \pm 0.0$

$$|f_+^K(0)| = \underline{0.76} \pm 0.04 \pm 0.0$$

E653 : $|f_+^K(0)| = 0.59 \pm 0.06 \longrightarrow 0.69 \pm 0.04$

GOOD AGREEMENT WITH VECTOR MESON DOMINANCE



$$f_+(q^2) = \frac{f_+(0)}{1 - q^2/M_{D^*}^2}$$

OBTAINED BY HAVING A KAON WITH MOMENTUM $\vec{p} \neq 0$ AS SOURCE

- CAN BE CHECKED ONLY ON THE LATTICE:

- OTHER FORM FACTOR: $f_-(q^2) \neq 0$ AT LARGE Q^2

$f_+^{\pi}(0) = 0.58 \pm 0.09$

$f_+^{K}(0) = 0.63 \pm 0.08$

EXP $= 0.69 \pm 0.04$

V	A_1	A_2	Γ_L/Γ_T	
0.86 ± 0.1	0.53 ± 0.03	0.19 ± 0.21	1.51 ± 0.27	Lubicz et al.
$0.9 \pm 0.3 \pm 0.1$	$0.46 \pm 0.05 \pm 0.05$	$0.0 \pm 0.2 \pm 0.1$	$1.8 +^{0.6}_{-0.4} \pm 0.3$	EXP
~ 0.9	~ 0.8	~ 0.7		QM

$\Gamma(D \to K^*) = (5.00 \pm 0.86)\, 10^{10}\, s^{-1}$

EXP $\quad 4.00 \pm 0.5 \pm 0.9$

$$\frac{\Gamma(D \to K^*)}{\Gamma(D \to K)} = 0.85 \pm 0.37$$

EXP (NEW!) $\quad 1.0 \,^{+0.3}_{-0.2}$

[RESULTS FOR $D \to \pi, \rho$]

$D_s \to \eta, \eta', \phi$

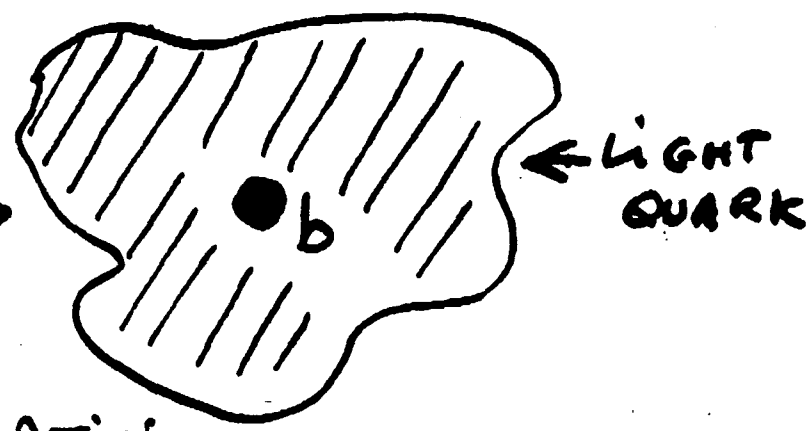
D PHYSICS

D AND B ON THE LATTICE FOLLOWS DIFFERENT ROUTES

HEAVY FLAVOUR $m_Q \gg \Lambda_{QCD}$

$(\Lambda_{QCD} \sim 1\ \mathrm{GeV})$

$\bar{Q}q$ SYSTEMS:



$|p| \sim \Lambda_{QCD}$

NON PERTURBATIVE EFFECTS ARE IMPORTANT

PROBLEMS WITH b-QUARKS

- $m_Q a \ll 1$ TO AVOID LATTICE ARTIFACTS
- $a^{-1} \sim 2 \div 3$ GeV

a^{-1} → RELATIVELY GOOD FOR CHARM

a^{-1} → BAD FOR BEAUTY

EICHTEN PROPOSAL FOR THE LATTICE:

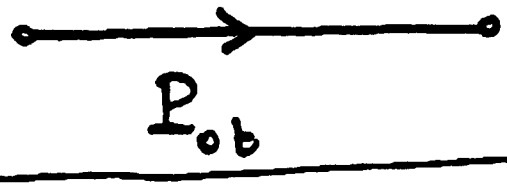
$$(\not{D} + M_Q)\bar{S}_Q(x) = \delta(x)$$

$$(\gamma^0 D_0 + M_Q + \underline{\underline{\vec{\gamma}\cdot\vec{D}}})S_Q(x) = \delta(x)$$

→ PERTURBATION SINCE $|q| \sim \Lambda_{QCD} \ll M_Q$

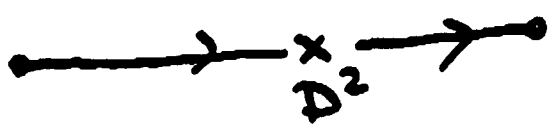
$$S_Q(x) = e^{-m_Q t}\left[S^{(0)}(x) + \frac{1}{2m_Q} S^{(1)}(x) + \cdots\right]$$

$$S^{(0)}(x) = \left(\frac{1+\gamma^0}{2}\right)\delta^3(\bar{x})\, P_{0,t}$$

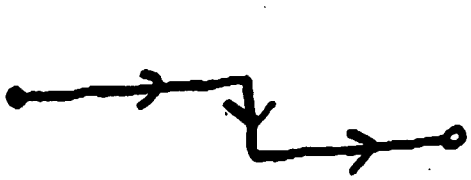


$$= e^{ig\int_0^t A_0(z)\,dz}$$

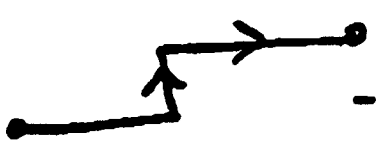
$S^1_{D^2}(x) =$



$=$

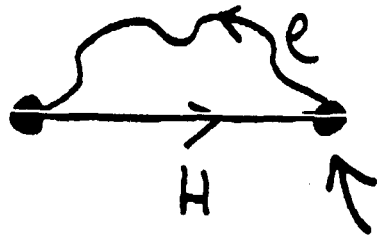


$+$

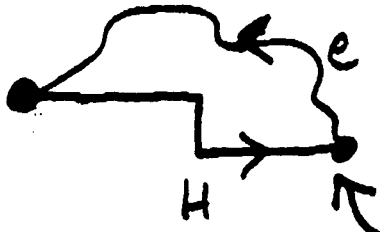


-2

$+$ OTHER OPERATORS $+$ VERTEX CORRECTIONS

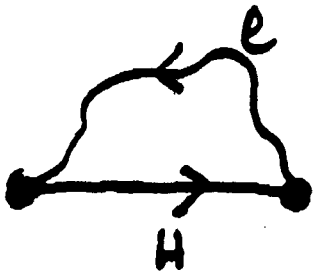
$\langle A_0(x) A_0(x) \rangle_{\bar{Q}e} =$ 

$+$ $O(1)$



$+ \cdots$, $O\left(\frac{1}{m_Q}\right)$

– E.E. + FEINBERG ($\bar{Q}Q$) ; EFFECTIVE ACTIONS
E.E. + HILL, GEORGI, CASWELL + LEPAGE + THACKER ;
ISGUR + WISE ; GRINSTEIN .....



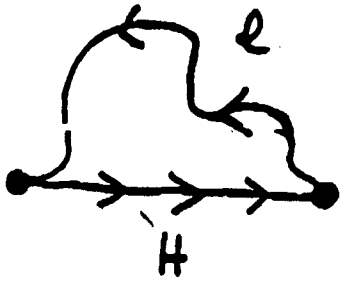
$\equiv e^{-m_Q t} \, \mathrm{tr}\left[\frac{(1+\gamma_0)}{2} S_e(\vec{0}, t | \vec{0}, 0) \Gamma_{0t}\right]$

$\bullet \equiv \gamma^0\gamma^5$ OR γ^k FOR B OR B^*

$$\langle A_0 A_0 \rangle = \frac{f_B^2 M_B}{2} e^{-M_B t} = e^{-m_Q t} \, \mathrm{tr}\left[\ldots\right]$$

$$= e^{-m_Q t} A e^{-\Delta E t}$$

INDEPENDENT OF m_Q



$$\equiv -e^{-M_Q x_0} \mathrm{Tr}\left[\frac{(1+\gamma_0)}{2} S_\ell(\vec{0}, x_0 | \vec{0}, 0)\, \Gamma\right]$$

LIGHT QUARK PROP.

ORDER PATH $e^{ig_0 \int A_\mu dx^\mu}$

$\bullet \equiv \gamma^0\gamma_5, \vec{\gamma}. \quad \rightarrow \quad B$ OR B^*

$$\langle A_0 A_0 \rangle = \frac{f_B^2 M_B}{2} e^{-M_B x_0} \equiv e^{-M_Q x_0} \underline{A e^{-\Delta E x_0}}$$

INDEPENDENT OF M_Q AND $\gamma^0\gamma^5$ OR $\vec{\gamma}$

$$\bullet \quad M_B = M_{B^*} = M_Q + \Delta E$$

"BINDING ENERGY" $\sim (1/a)$

NON-PERTURBATIVE

$$\bullet \quad f_B = \frac{(\sqrt{2A})}{\sqrt{M_B}} \times \left[\frac{\alpha_s(\frac{1}{a})}{\alpha_s(M_B)}\right]^{\gamma}$$

← Shifman + Voloshin Politzer Wise

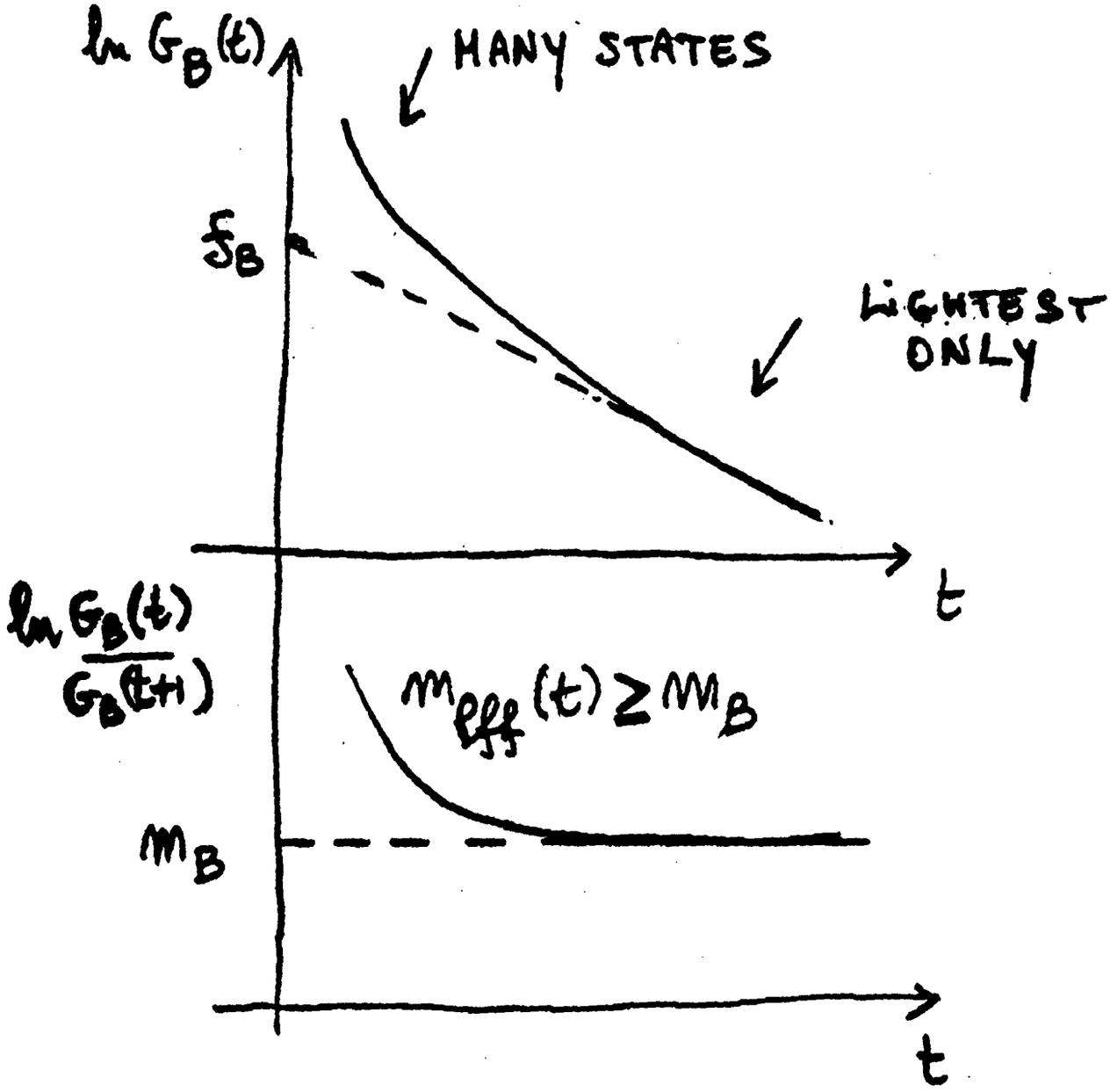
OTHER SCALING LAWS BY Wisgur = Isgur + Wise ; Bjorken $\frac{\Gamma(B \to D^* e \nu)}{\Gamma(B \to D e \nu)} \simeq 3$ ...

FORM FACTORS ; SEMILEPTONIC DECAYS, etc.

$$G_B(t) = \frac{f_B^2 M_B}{2} e^{-M_B t} \quad \text{FOR } t \to \infty$$

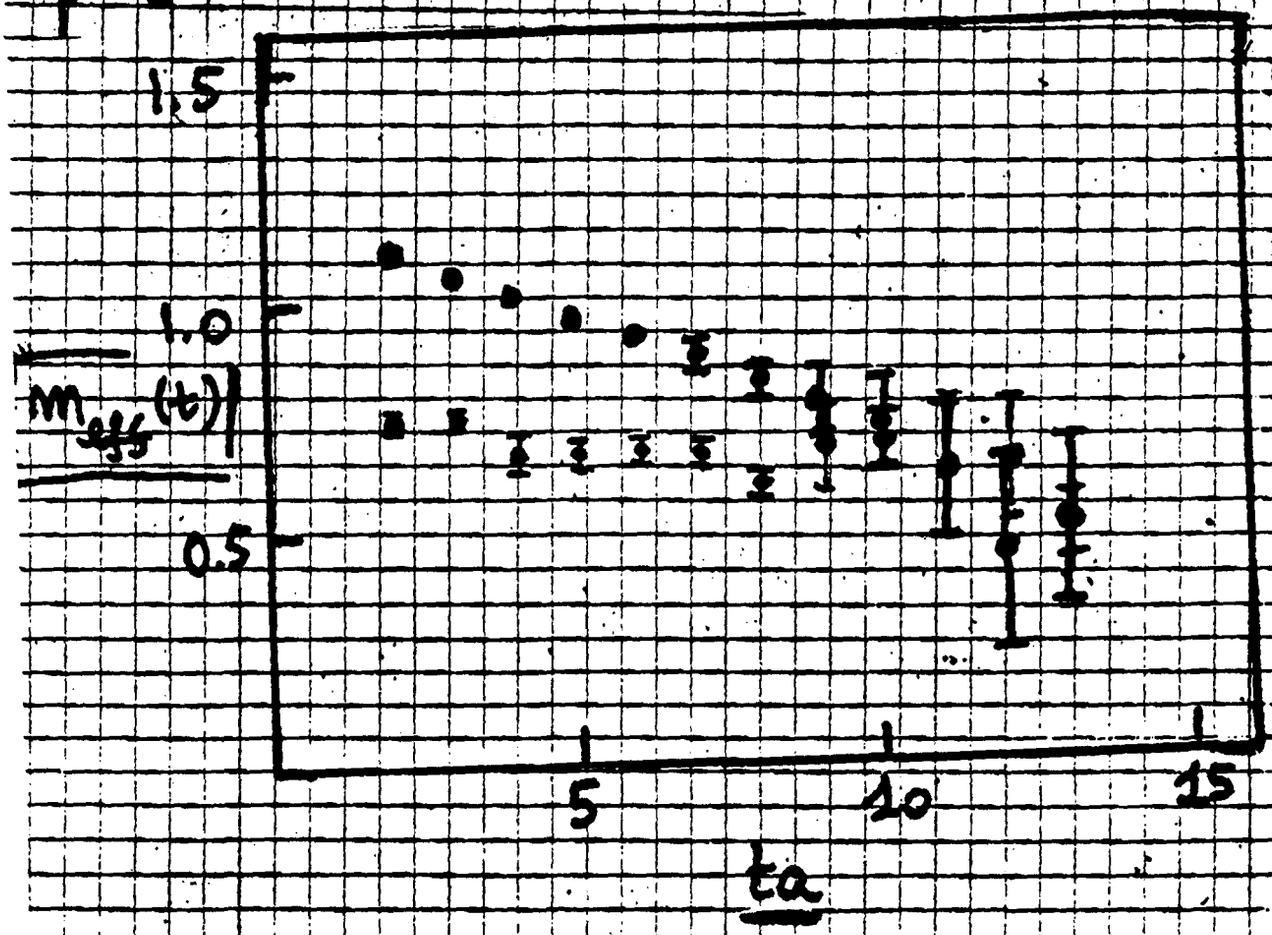
IF t IS NOT LARGE ENOUGH

$$G_B = \sum_n Z_n e^{-M_n t}$$



Ph. Boucaud, G.M., O. Pene, C.T. Sachrajda

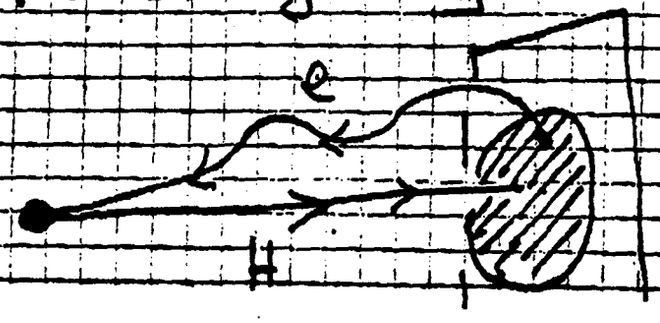
$\beta = 6$ 50 CONFS $V = 20 \times 10^3 \times 40$



→ SHEARED SOURCE (Parisi et al.)

ENHANCES THE COUPLING OF THE SOURCE TO THE LIGHTEST STATE

[C. Allton, V. Lubicz, L. Maiani, G.M., C.T. Sachrajda]



Rome - Southampton
[Allton, Lubicz, Martinelli, M., Sachrajda]

$f_B = (310 \pm 25 \pm 50)$ MeV

FROM LATTICE CALIBRATION

Wuppertal
[Alexandrou, Güsken, Shilling, Sommer]

$f_B = (366 \pm 22 \pm 55)$ MeV

UCLA [Bernard, Soni, Lebrenz]

$f_B = (320 \pm 20 \pm (?))$ MeV

NOT QUOTED

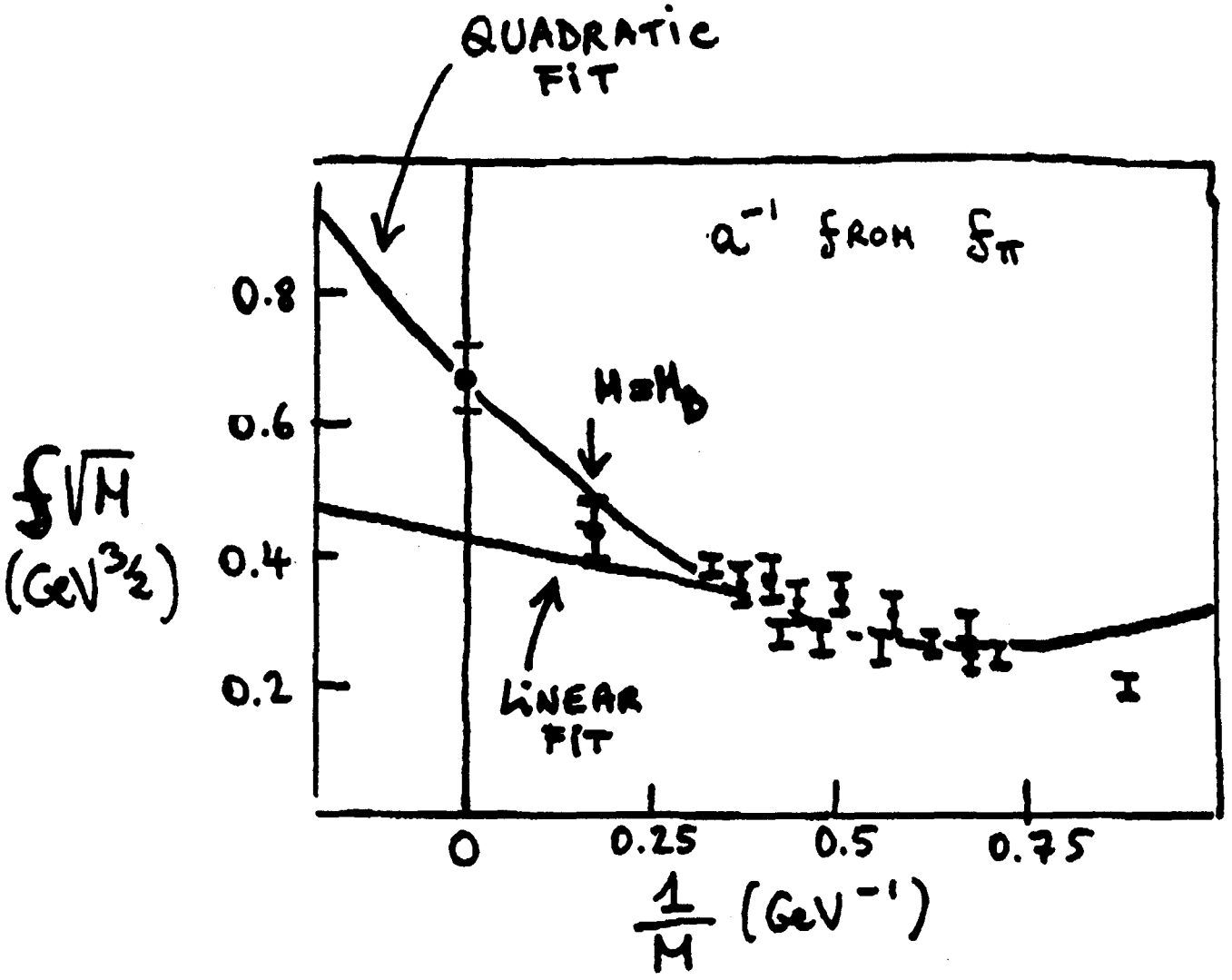
PRESENTED AT LAT '90
(OCTOBER '90)

By using $f\sqrt{M} = \text{cost.}\left[1 - \frac{c}{M}\right]$

$$\boxed{c \simeq 1.2 \text{ GeV} \sim \frac{2\pi f}{M}}$$

$$f_B \gtrsim 200 \text{ MeV}$$

- results with a larger statistical error presented by Eichten, Hockney, Thacker


QUADRATIC FIT
a^{-1} FROM f_π
$M = M_D$
LINEAR FIT
$f\sqrt{M}$ (GeV$^{3/2}$)
0.8
0.6
0.4
0.2
0
0.25
0.5
0.75
$\frac{1}{M}$ (GeV^{-1})

$$f\sqrt{M} = \phi_\infty + \frac{\phi'}{M} + \frac{\phi''}{M^2} + \cdots$$

ϕ'	GIVES	-35%	B
		-90%	D
ϕ''		$+5\%$	B
		$+35\%$	D

$f_B = (200-240)$ MeV (a^{-1} from m_ρ or f_π)

LINEAR FIT 170-210 MeV

$$\boxed{f_B = (210 \pm 40)\ \text{MeV}}$$

$B^0 - \bar{B}^0$ MIXING

$$X_d = \left(\frac{G_F^2 M_W^2 M_B^2}{6\pi^2} \right) \tau_B \frac{A^2 \lambda^6}{M_B} F_{tt}$$

DATTA et al.

$$\otimes f_B^2 B$$

B-PARAMETER

NOT KNOWN
AS IN THE KAON CASE

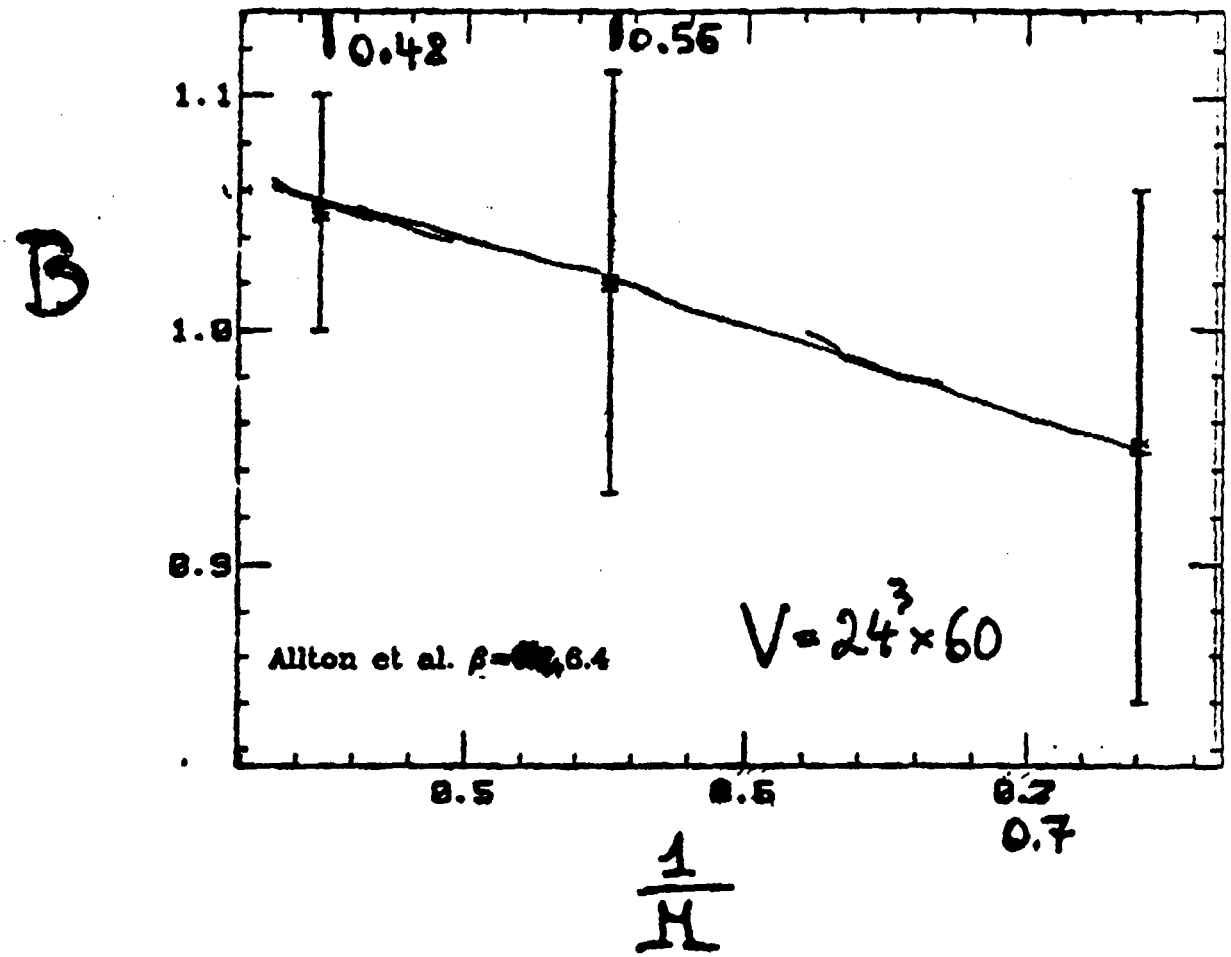
$$\otimes (1 + \rho - 2\rho \cos\delta)$$

2 SOLUTIONS FOR f_B

THEORETICAL ERROR DOMINATED BY f_B

ORSAY - WUPPERTAL
SOUTHAMPTON - ROME

B-parameter (ELC)

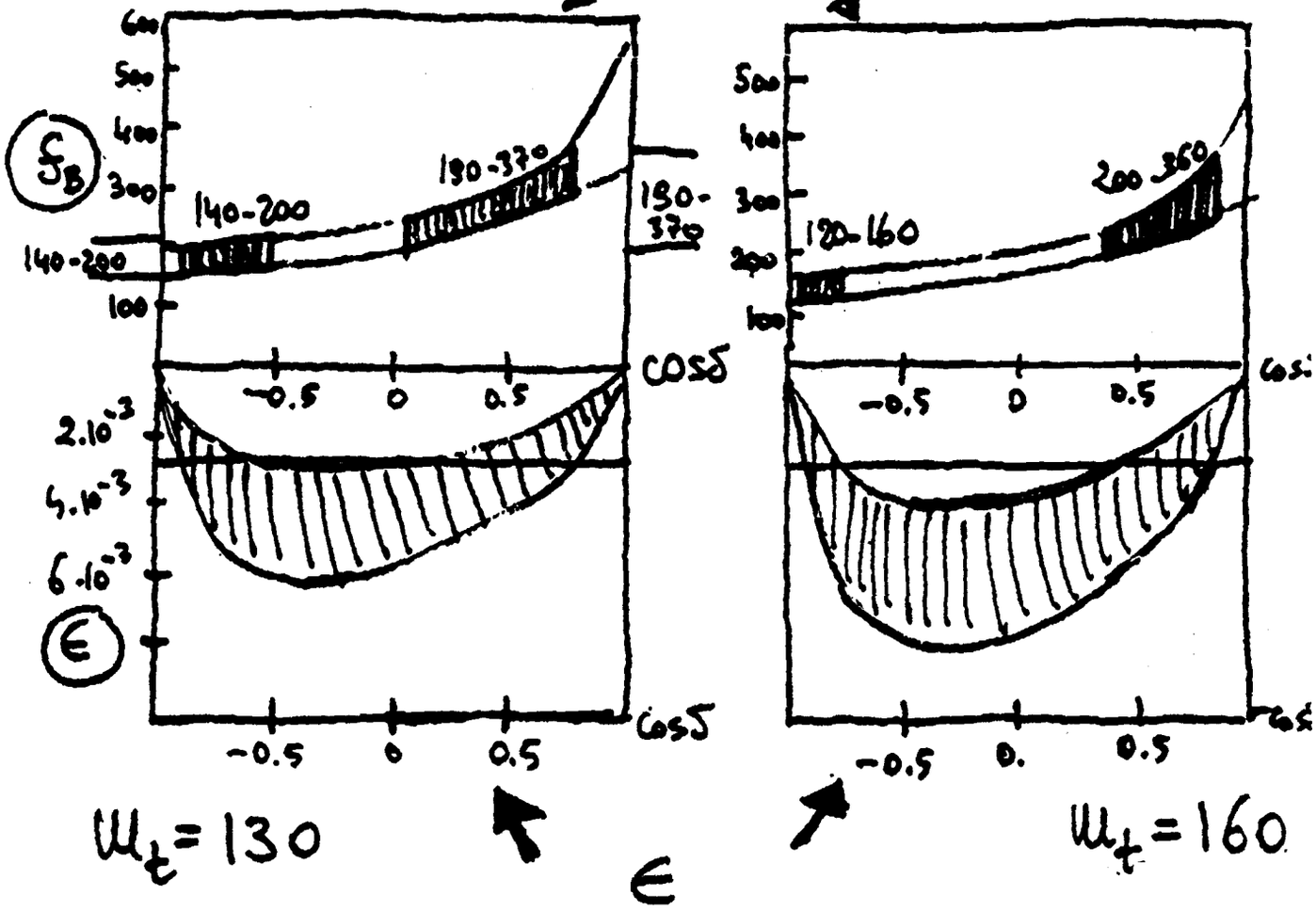


$$\langle B^0 | (\bar{b}\gamma^\mu_L d)^2 | \bar{B}^0 \rangle = \frac{8}{3} f_B^2 M_B^2 B$$

$B = 1$ SAFE !

THE ERROR IS ESSENTIALLY DUE TO f_B

B-$\bar{B}$ MIXING



$\delta \equiv$ CP-violating phase in K-M matrix

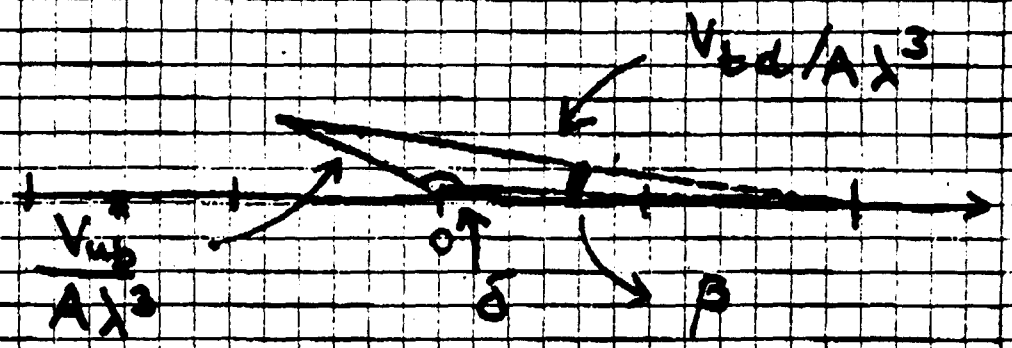
$B_{B\bar{B}}$: $\langle B | (\bar{b}\gamma^\mu_L d)^2 | \bar{B} \rangle = \frac{8}{3} m_B^2 f_B^2 B_B$.

$$\boxed{B_{B\bar{B}} = 1}$$

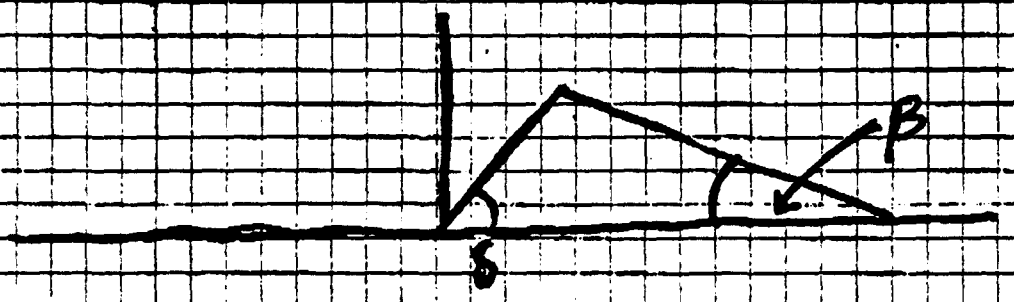
Altton et. al.

$+ \; O(\alpha_s(\frac{1}{a}))$ corrections

Nakada et al. – B-meson factory in the ISR tunnel
PSI-PR-90-CP



$\cos\delta < 0$



$\cos\delta > 0$

- $f_B \sim (150 \pm 50)$ MeV $\longrightarrow$ $\underline{\sin 2\beta \sim 0.3}$

- $f_B \gtrsim 200$ MeV, $m_t \gtrsim 130$ GeV $\rightarrow$ $\underline{\sin 2\beta \gtrsim 0.6}$

  $f_B \gtrsim 300$ MeV, $m_t \gtrsim 100$ GeV

GOOD FOR

$$\frac{(B \to \psi K_S)_{t_1} - (\bar{B} \to \psi K_S)_{t_1}}{(B \to \psi K_S)_{t_1} + (\bar{B} \to \psi K_S)_{t_1}} = \sin 2\beta \sin \Delta m t$$

36

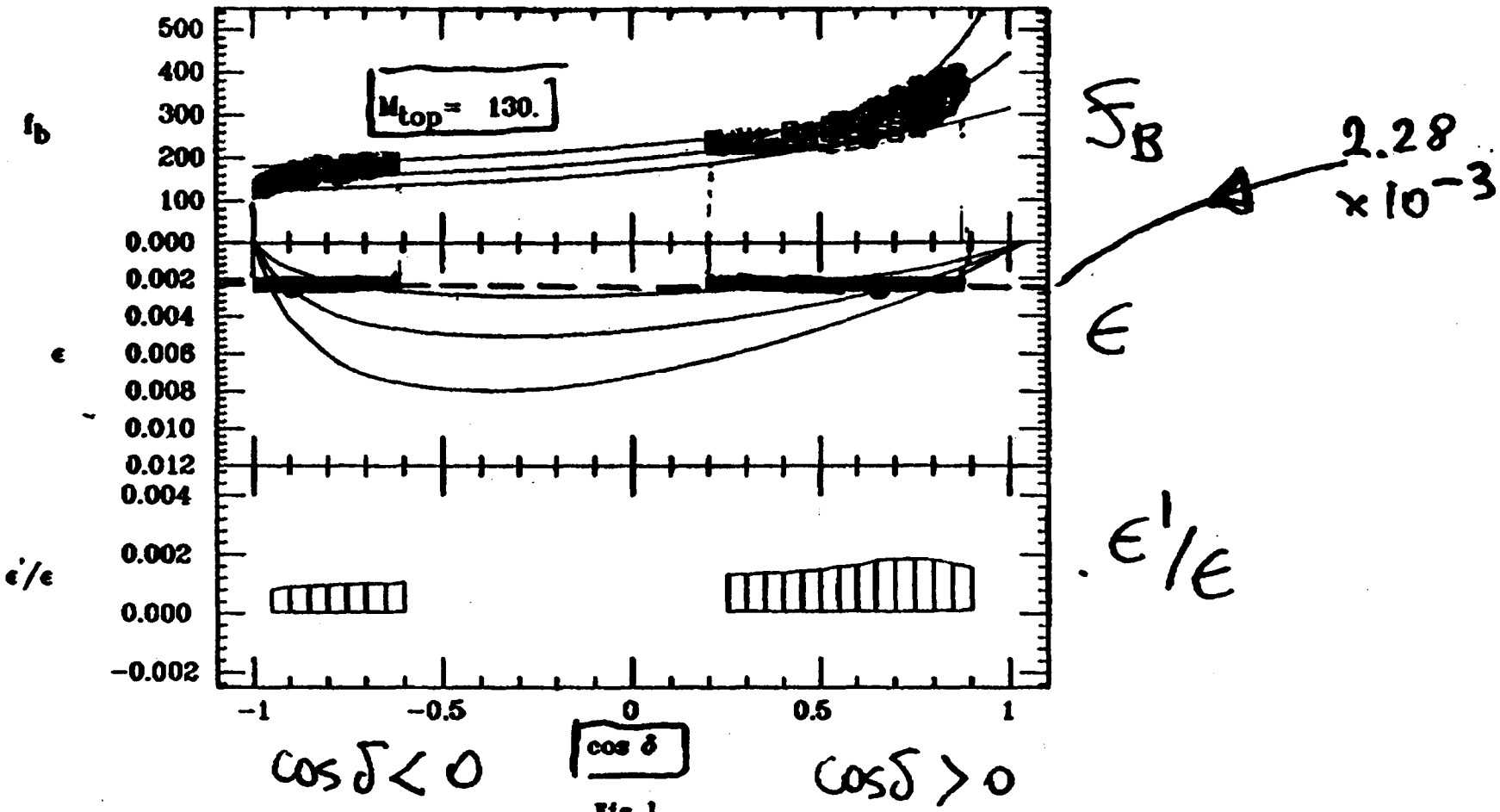
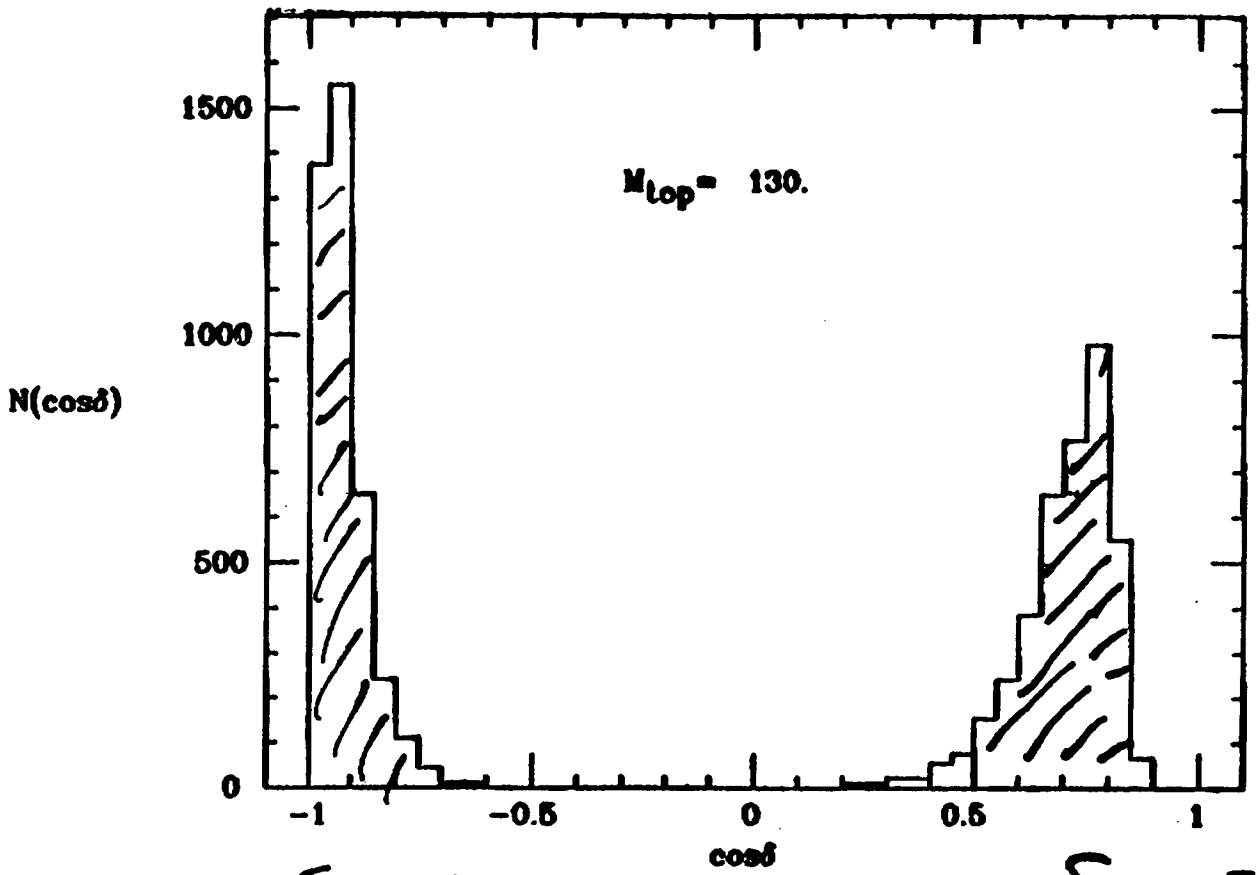
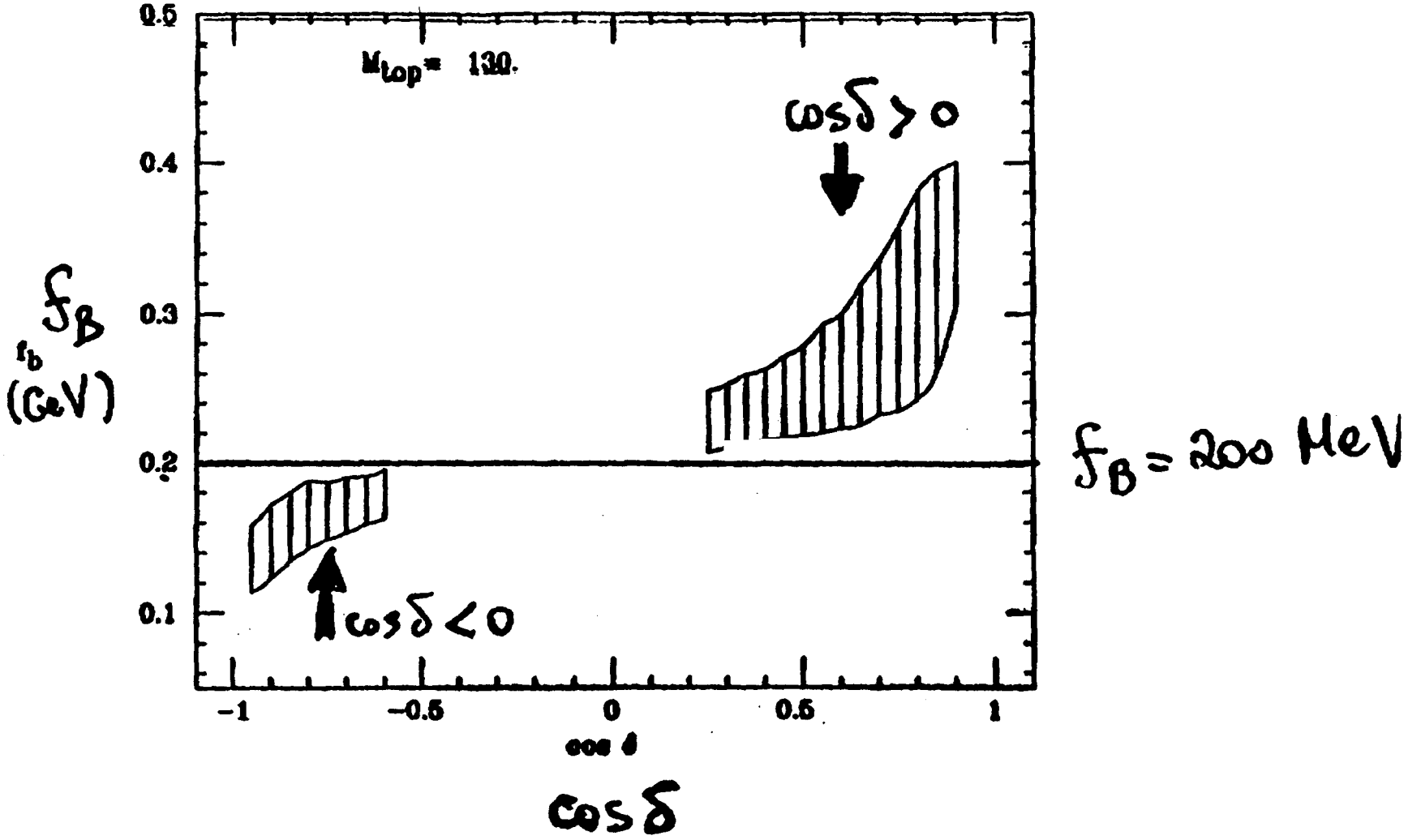
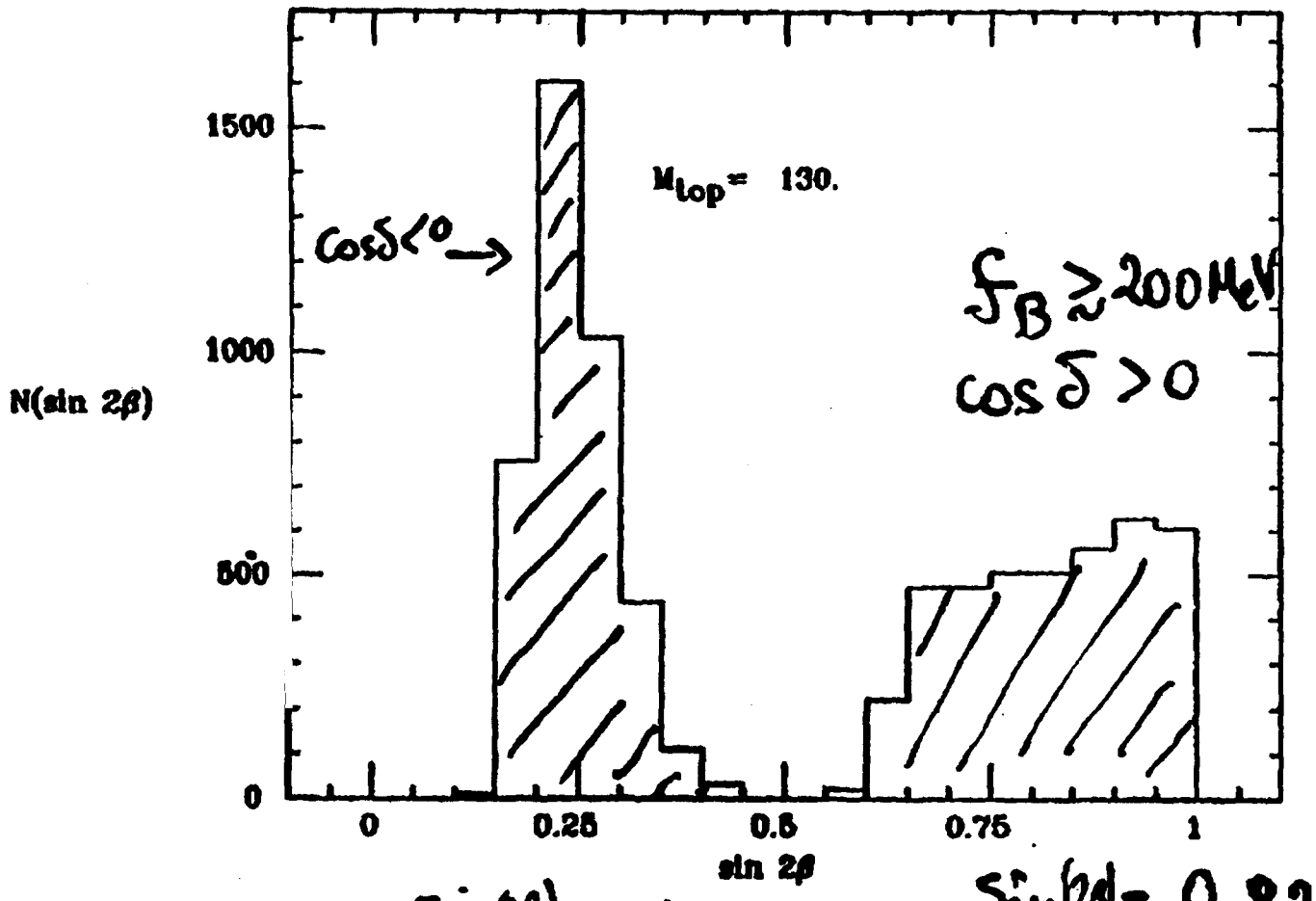

M_{top} = 130.
f_b
ϵ
ϵ'/ϵ
500
400
300
200
100
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.004
0.002
0.000
−0.002
−1
−0.5
0
0.5
1
cos δ
f_B
2.28 × 10⁻³
ϵ
ϵ'/ϵ
cos δ < 0
cos δ > 0

Fig. 1



$\cos\delta = -0.92 \pm 0.12$ $\cos\delta = 0.70 \pm 0.11$


M_{top} = 130.
$\cos\delta > 0$
$\cos\delta < 0$
f_B
f_b (GeV)
0.5
0.4
0.3
0.2
0.1
−1
−0.5
0
0.5
1
cos δ
$\cos\delta$
$f_B = 200$ MeV



$\sin(2\beta) = 0.24 \pm 0.05$

$\sin(2\beta) = 0.82 \pm 0.11$

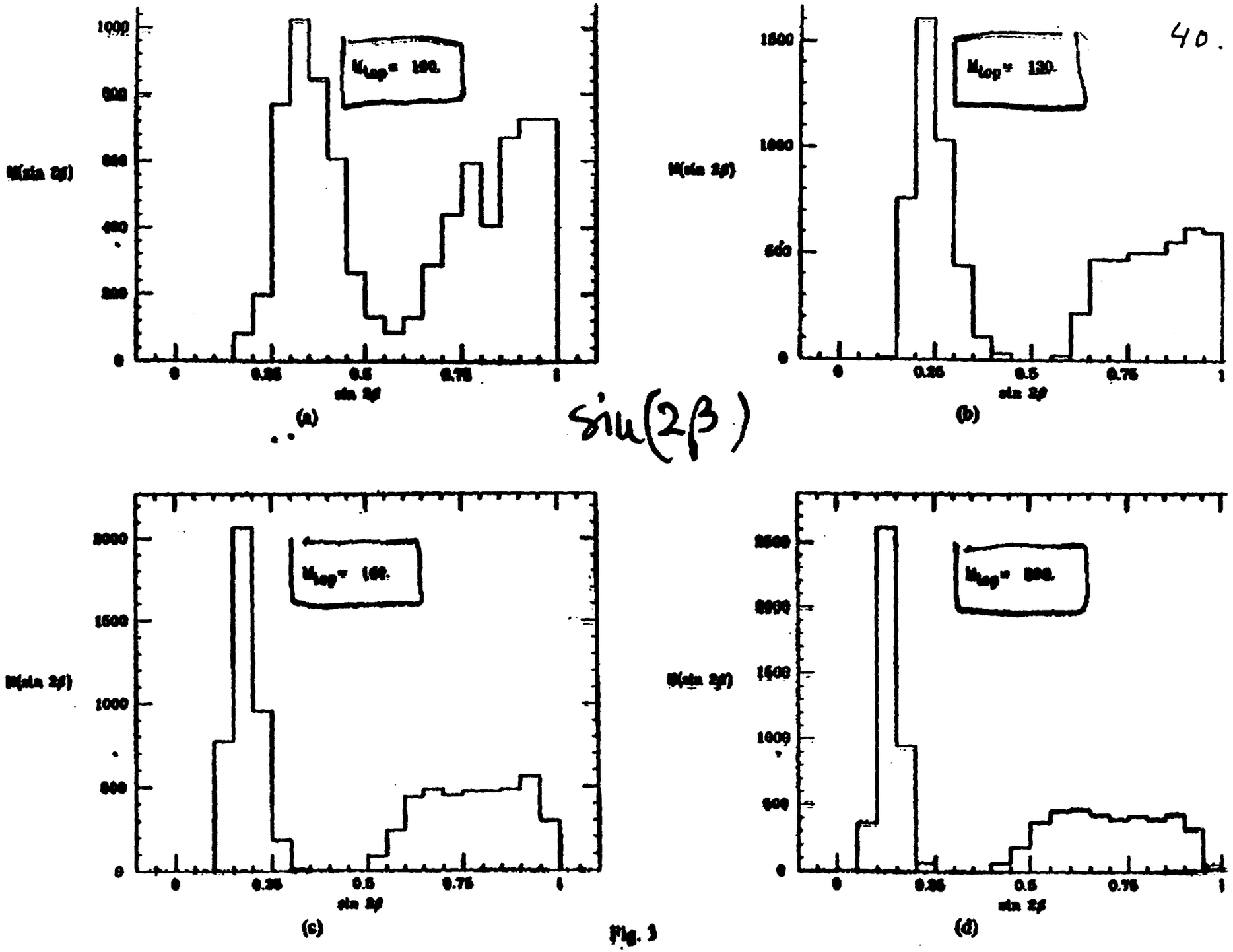
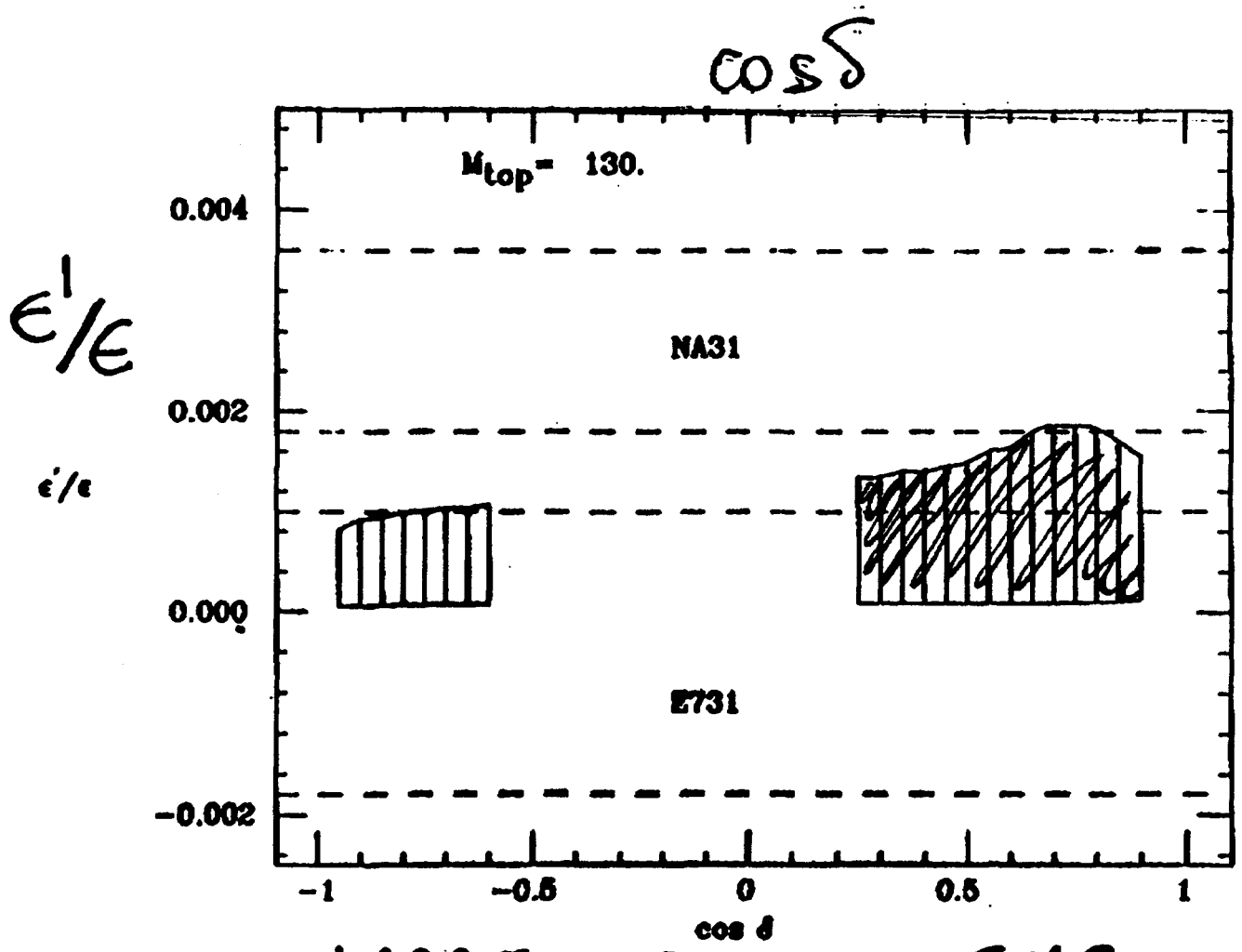
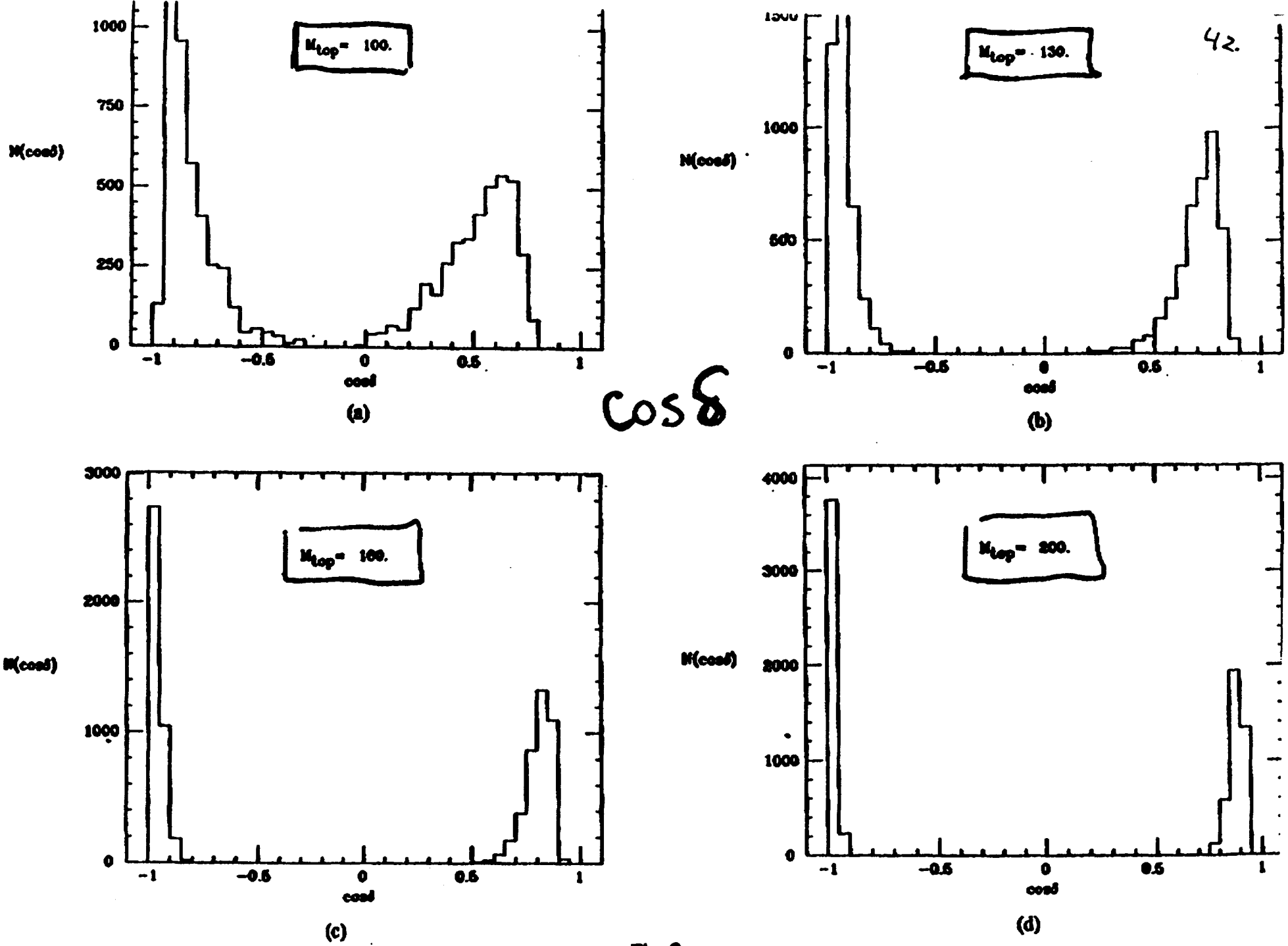


Fig. 3



LARGE TH AND EXP ERRORS

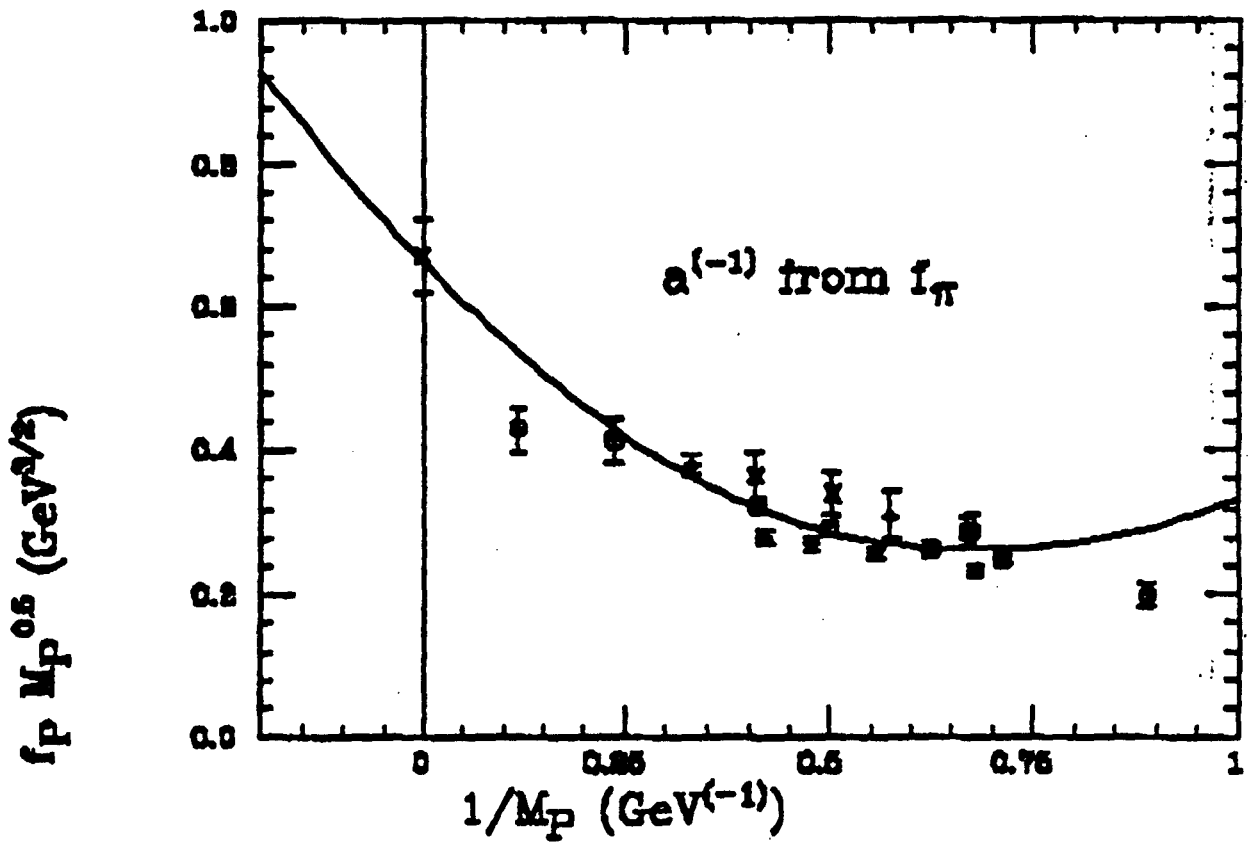
IT IS NOT POSSIBLE TO CHOOSE THE SIGN OF cos δ ON THE BASIS OF ε'/ε

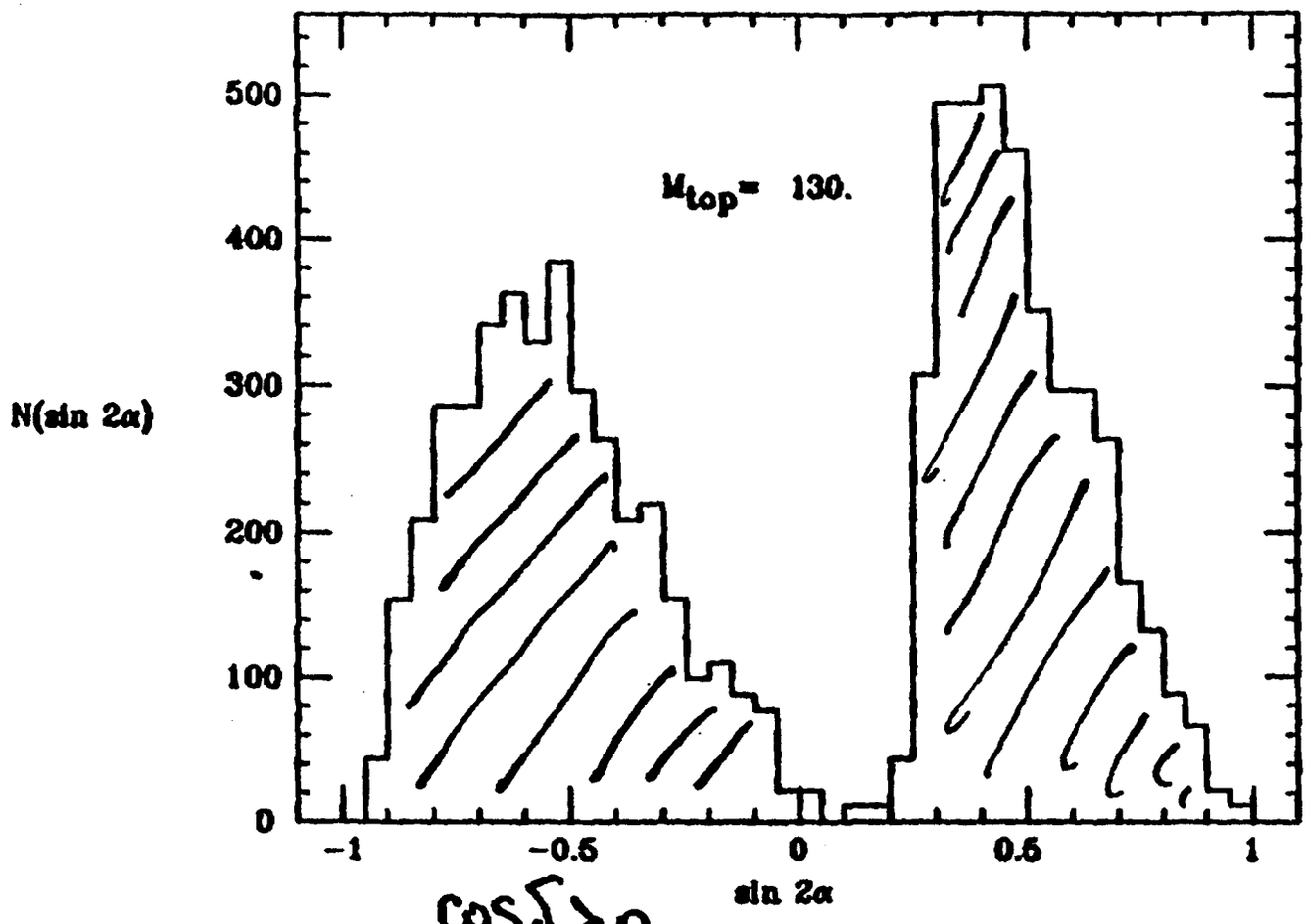


cosδ

Fig. 2

Plot .1 done.





$\cos\delta > 0$

$f_B \gtrsim 200\,\mathrm{MeV}$

$\sin 2\alpha = -0.53 \pm 0.22$

CONCLUSION & OUTLOOK

- LATTICE SUGGESTS $f_B \gtrsim 200$ MeV
  $\rightarrow \sin 2\beta \sim 0.6 - 0.8$ GOOD FOR B-FACTORIES

- m_{B_s} AND m_{Λ_b} } ALMOST DONE
- $f_B = f_{B^0}\left(1 + \frac{c}{M_B}\right)$

- $D \rightarrow K, K^*$ AGREES WITH EXPS
  $\downarrow$

$B \rightarrow D \ell \nu$
$B \rightarrow D^* \ell \nu$
$B \rightarrow \pi \ell \nu$
$B \rightarrow \rho \ell \nu$
$\Lambda_b \rightarrow \Lambda_c \ell \nu$

IN PROGRESS

INCLUSIVE $B \rightarrow X \ell \nu$ UNDER STUDY

Sheldon Stone

Physics of the B-Factory

I) Introduction

A) Definition B-Factory:

"High Luminosity e^+e^- Collider Operating in the Υ region"

B) Physics: Multitude of topics

1. Standard Model tests
   CP-Violation in B decays
   D-$\bar{D}$ Mixing
   τ decays - lifetimes, br's
2. Beyond the Standard Model
   CP-Violation in B decays
   Forbidden B decays, i.e. $B \to \mu e$, etc
   Rare B decays, i.e. $B \to \mu\mu$...
3. Measurement of SM parameters
   V_{cb} V_{ub}
   ν_τ mass
4. QCD - Strong Interactions
   B decay br's
   Charm decay br's
   Υ decays

Emphasis is ~~CP~~ in B Decays

~~CP~~ is of fundamental importance in testing the SM a looking beyond, (complementary to Higgs sector <=> mass) what is source of CKM angles and relation to quark masses?

II) Manifestations of ~~CP~~ in B decays

A) CKM matrix

In SM ~~CP~~ occurs because quark mixing ratio is not real and quark masses change with generations

$$V_{ij}=\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}=\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

This is the 1st order parametrization of Wolfenstein

<u>What is known</u>:

V_{ud}= 0.9744±0.0010 from Nuclear β decay

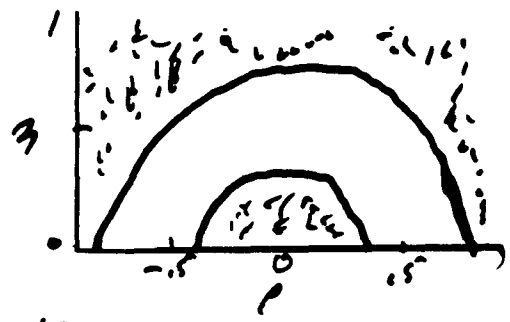
V_{us}=0.2205 ±0.0018 from $K\rightarrow\pi e\nu$ and hyperon β decay

=> λ= 0.22

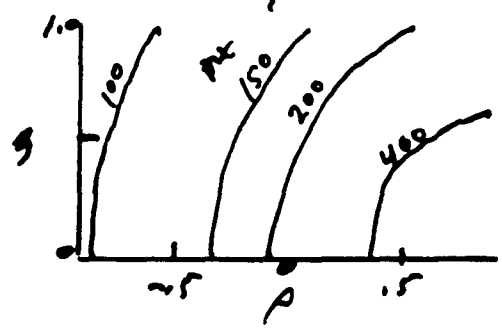
Similarly, τ_B and semileptonic B decay br's determine $V_{cb}=0.042\pm0.04$
=> A=0.87

Left with ρ and η
Information from:

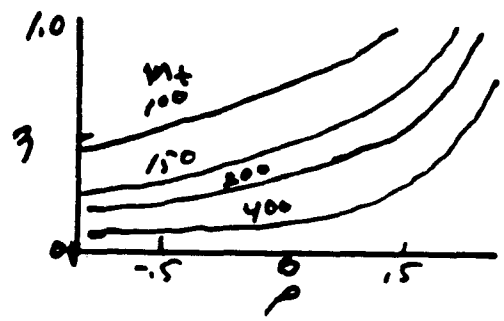
1) measurements of V_{ub}/V_{cb} from CLEO and ARGUS



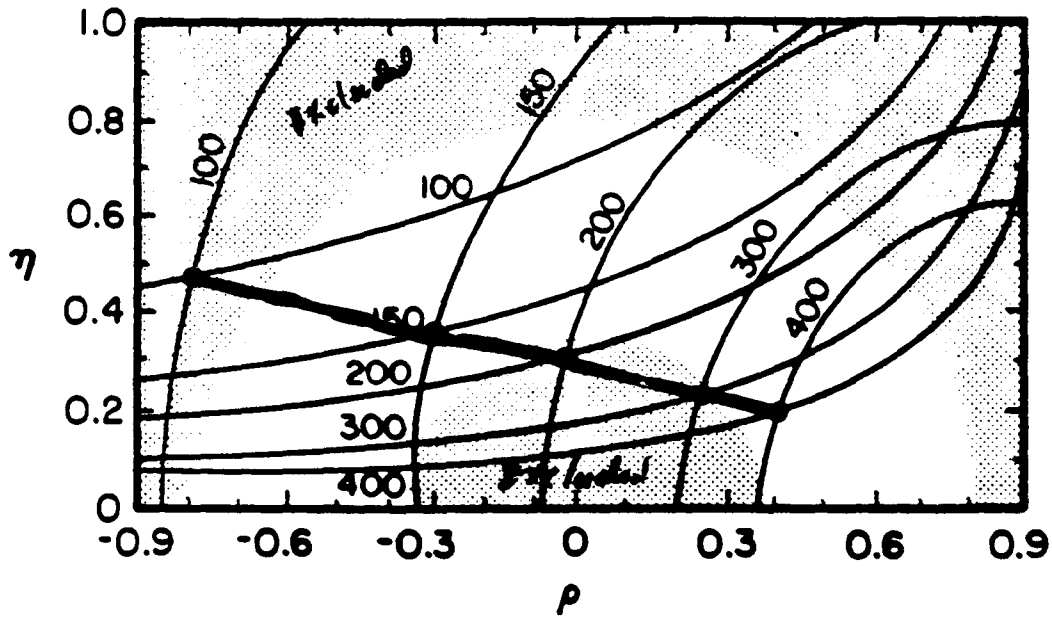
2) measurements of $x=\Delta m/\Gamma$ from $B\bar{B}$ mixing. Function of m_t.

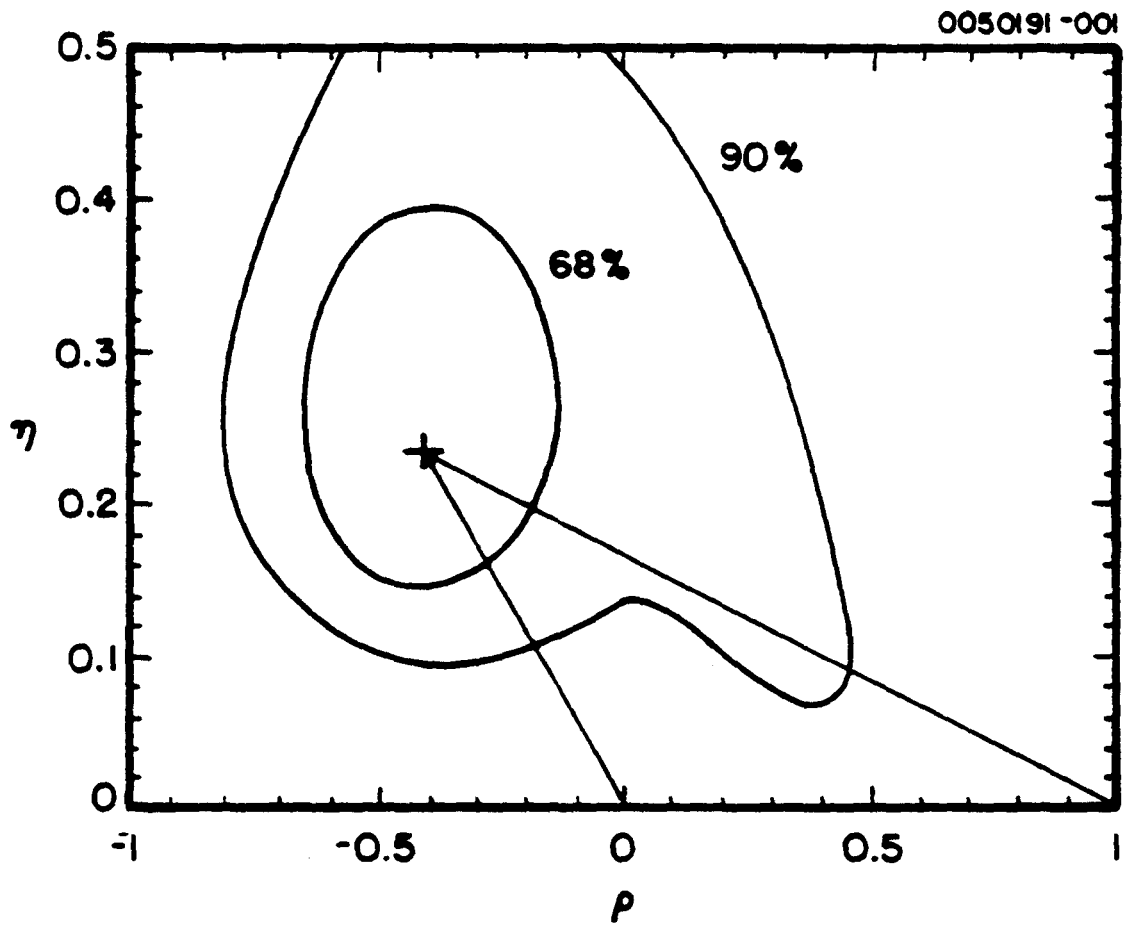


3) measurements of ε ~~CP~~ in K^o system. Also function of mt.



In addition:
$Re(\varepsilon'/\varepsilon)=(1.9\pm.9)\times10^{-3}A\eta^2[1-.9(m_t/140-.5)^2]$
Summary plot *(fig)*


1.0
0.8
0.6
0.4
0.2
0
η
-0.9
-0.6
-0.3
0
0.3
0.6
0.9
ρ
100
150
200
300
400

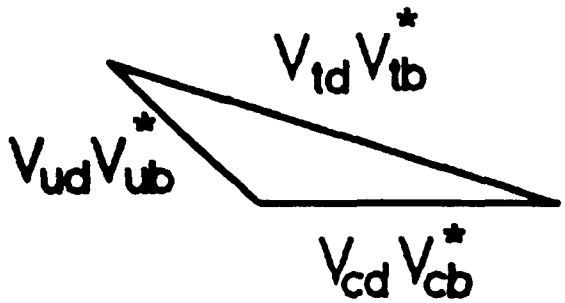


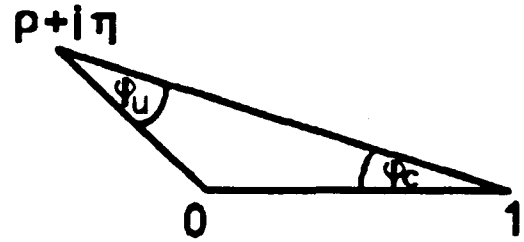
from Kim Rosner + Yuan

B) Predictions of ~~CP~~ in B decay

Unitarity Triangle:

$$V_{td}V_{tb}^* + V_{cd}V_{cb}^* + V_{ud}V_{ub}^* = 0$$





Proper predictions of φ_c and φ_u due to Kim, Yuan and Rosner *(fig)*

These predictions lead to possibly rather large ~30% asymmetries!

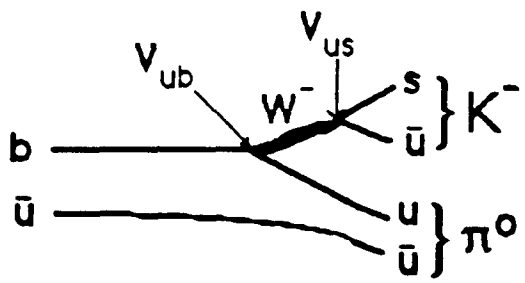
(Other solution for large m_t) First discussion of CP in B decay see Bigi + Sanda and Carter + Sanda

C) ~~CP~~ in Charged B decays

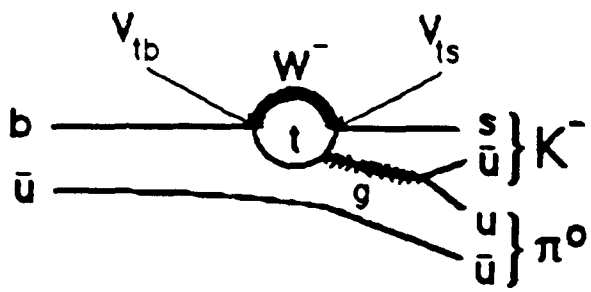
Example: $B^- \to K^-\pi^0$ versus $B^+ \to K^+\pi^0$

To get ~~CP~~ two interfering processes are always necessary. In this case:

Spectator



Penguin



for B^- : Let $\mathcal{A}=ae^{i\alpha}V_{ub}V_{us}^*$, $\mathcal{B}=be^{i\beta}V_{tb}V_{ts}^*$

for B^+: Let $\mathcal{A}=ae^{i\alpha}V_{ub}^*V_{us}$, $\mathcal{B}=be^{i\beta}V_{tb}^*V_{ts}$

$$A = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}$$

$$= \frac{2ab\eta\sin(\alpha-\beta)}{a^2\lambda^2(\rho^2+\eta^2)+b^2/\lambda^2+2ab\rho\cos(\alpha-\beta)}$$

Requires:

(1) $\mathcal{A} \approx \mathcal{B}$

(2) $\alpha \neq \beta$

(3) Unequal CKM phases

How big is A?

How big is the branching ratio?

Current upper limits on $\bar{B}^o \to K^-\pi^+ < 9\times10^{-5}$

Some predictions~few $\times10^{-5}$, in some mode

How many events are needed?

Here $A = \dfrac{N_+ - N_-}{N_+ + N_-}$

For $A < 1$, $\delta A \approx 1/\sqrt{N}$

Let us require a 4σ effect ($s=4$)

$A/\delta A = s = A\sqrt{N}$

So $N = (s/A)^2$

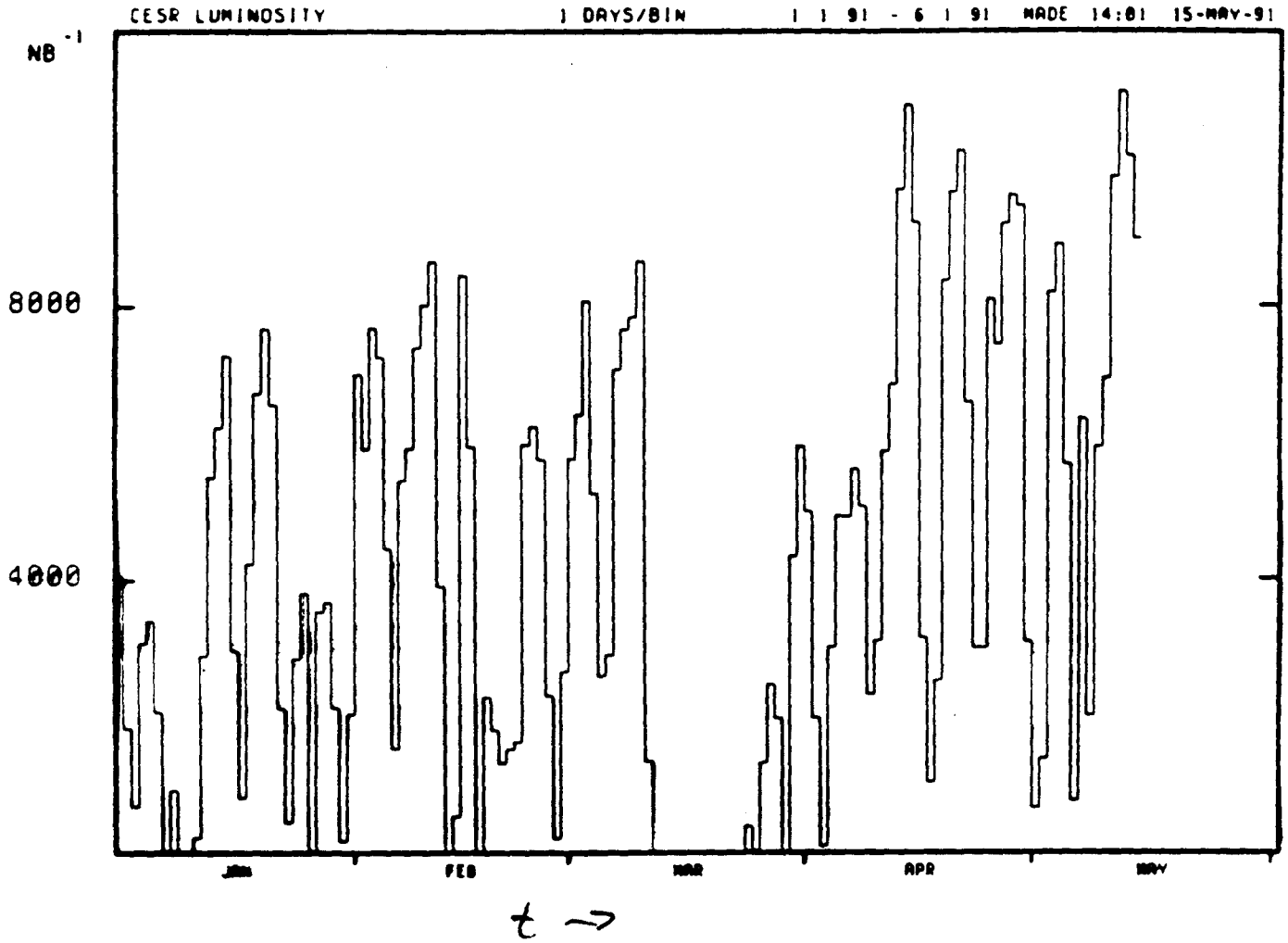
For $br = 2\times10^{-5}$ and $A = 10\%$,

$$\mathcal{L} = \frac{s^2}{\underbrace{2\sigma}_{1.15\text{nb}}\, br\, \epsilon\, A^2}$$

B reconsruction efficiency

$= 140\ \text{fb}^{-1}$, a large #, present CESR L *(fig)*

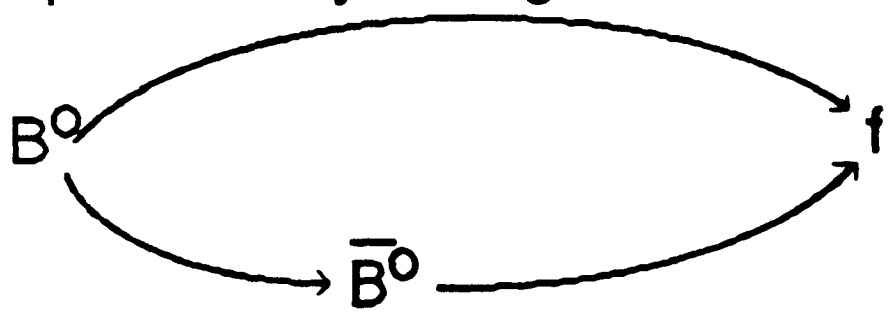
If observed interpretation is very uncertain theoretically


CESR LUMINOSITY
1 DAYS/BIN
1 1 91 - 6 1 91
MADE 14:01 15-MAY-91
NB -1
8000
4000
JAN
FEB
MAR
APR
MAY
t →

for 1991

D) ~~CP~~ via $B\bar{B}$ mixing

Here we choose a final state which is accessible to both B^0 and $\bar{B}^0$ decays. The second amplitude necessary for interference is provided by mixing:



In this case we need to determine the flavor of the other B in the event at its decay time. A convenient tag is provided by a high momentum lepton from semileptonic B decay. $B^0 \to e^+$, while $\bar{B}^0 \to e^-$

At the $\Upsilon(4S)$, $e^+e^- \to \gamma \to B^0 \bar{B}^0$ (C=-1)

Just above, $e^+e^- \to \gamma \to B^* \bar{B}$ or $B\bar{B}^* \to B\bar{B}\gamma$

In either case

$$|i_0\rangle = \frac{1}{\sqrt{2}} |B^0(k)\bar{B}^0(\bar{k})\rangle + (-1)^C |B^0(\bar{k})\bar{B}^0(k)\rangle$$

writing the Pais-Treiman relations

$|B_L\rangle = p|B^o\rangle + q|\bar{B}^o\rangle$

$|B_H\rangle = p|B^o\rangle - q|\bar{B}^o\rangle$

with

$$p = \frac{1}{\sqrt{2}} \frac{1+\varepsilon_B}{\sqrt{1+|\varepsilon_B|^2}}$$

$$q = \frac{1}{\sqrt{2}} \frac{1-\varepsilon_B}{\sqrt{1+|\varepsilon_B|^2}}$$

Then defining $a = \mathrm{Amp}(B \to f)$ & $\bar{a} = \mathrm{Amp}(\bar{B} \to f)$

$$A = \frac{d\Gamma/dtdt'(B\bar{B} \to fe^+X) - d\Gamma/dtdt'(B\bar{B} \to \bar{f}e^-X)}{d\Gamma/dtdt'(B\bar{B} \to fe^+X) + d\Gamma/dtdt'(B\bar{B} \to \bar{f}e^-X)}$$

$$= 2\sin\Delta m(t \pm t')\,\mathrm{Im}\left(\frac{p}{q}\,\frac{a\bar{a}^*}{|a|^2 + |\bar{a}|^2}\right)$$

where t is the decay time of f

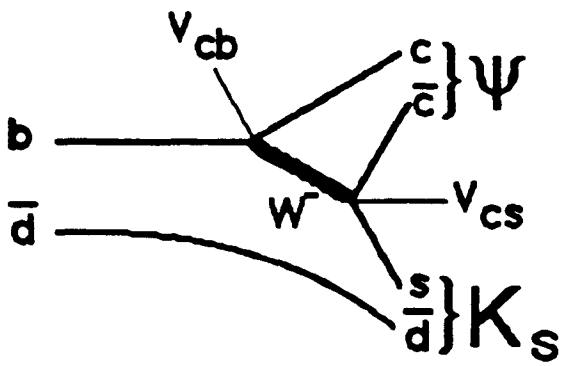
and t' is the decay time of of $e^{\pm}$

For CP eigenstates $f = \bar{f}$, $\left|\frac{p}{q}\right| = 1$, $\left|\frac{a}{\bar{a}}\right| = 1$

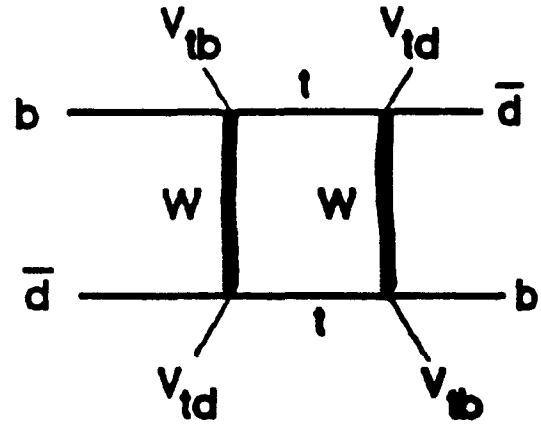
$$A = \sin\Delta m(t \pm t')\sin 2\varphi$$

For a particular f can easily compute $\sin 2\varphi$ in terms of CKM matrix elements
Example $B \to \psi K_S$

Color Suppresed Spectator



Mixing



$$\sin 2\varphi_c = \mathrm{Im}\,\frac{(V_{tb}^* V_{td})^2}{|V_{tb} V_{td}|^2}\frac{(V_{cb} V_{cs}^*)^2}{|V_{cb} V_{cs}|^2}$$
$$= -2\eta(1-\rho)/\{(1-\rho)^2+\eta^2\}$$

Similar expression is derived for $B \to \pi^+\pi^-$
KRY predictions are:

$$\sin 2\varphi_c = 0.32^{+0.16}_{-0.11} \quad \text{(fig)}$$

$$\sin 2\varphi_u = 0.66^{+0.30}_{-0.27}$$

90%
68%
$\phi_c = 3.3°$
$\phi_a = 30.6°$
0.5
0.4
0.3
0.2
0.1
0
-1
-0.5
0
0.5
1
ρ
η

E) Choice of Machine

Since $A = \sin\Delta m(t \pm t')\sin 2\varphi$

Time integrated A=0 for C=-1, ≠0 for C=+1

σ for $BB\gamma$ from CLEO *(fig)*

Conclude that we want to work on Υ(4S) with *asymmetric* beam energies so that time dependent measurements are possible *(fig)*

The larger the energy difference between the beams the larger the boost

$\beta\gamma = (E_{high} - E_{low})/M_{4S}$, where $4E_{high}E_{low} = M_{4S}$

Thus the physical separation in decay vertices between the two B's is

$z - z' = \beta\gamma\, c(t - t')$

Don't want too much asymmetry because too many particles would be lost down the beam pipe.

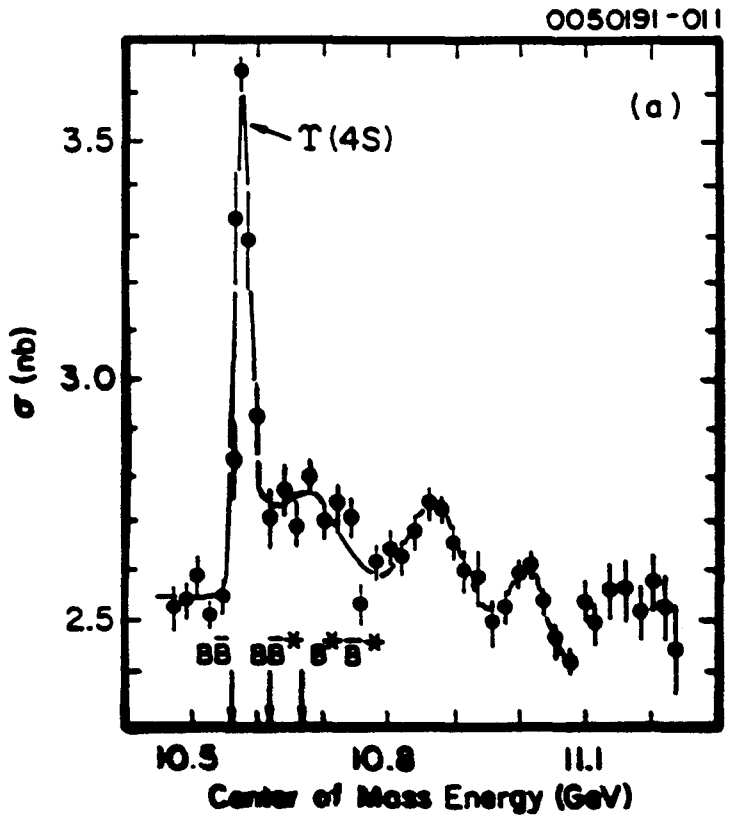
How much is enough? *(fig)*

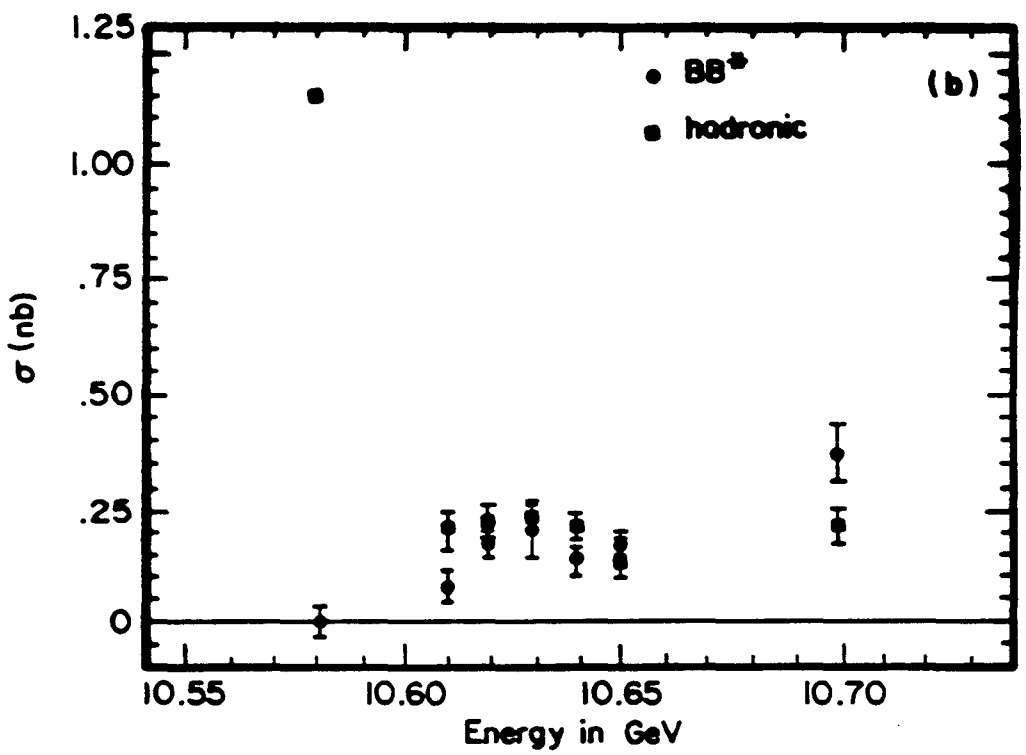
For 8GeV X 3.5GeV and τ_B=1.24ps,

$z - z' \sim 150\mu m$ - measurable

III) Techniques for ~~CP~~ Measurement Using Asymmetric Collider

CLEO


0050191-011
(a)
Υ(4S)
3.5
3.0
2.5
σ (nb)
$B\bar{B}$ $B\bar{B}^*$ $B^*\bar{B}^*$
10.5
10.8
11.1
Center of Mass Energy (GeV)


1.25
1.00
.75
.50
.25
0
σ (nb)
$B\bar{B}^*$
hadronic
(b)
10.55
10.60
10.65
10.70
Energy in GeV

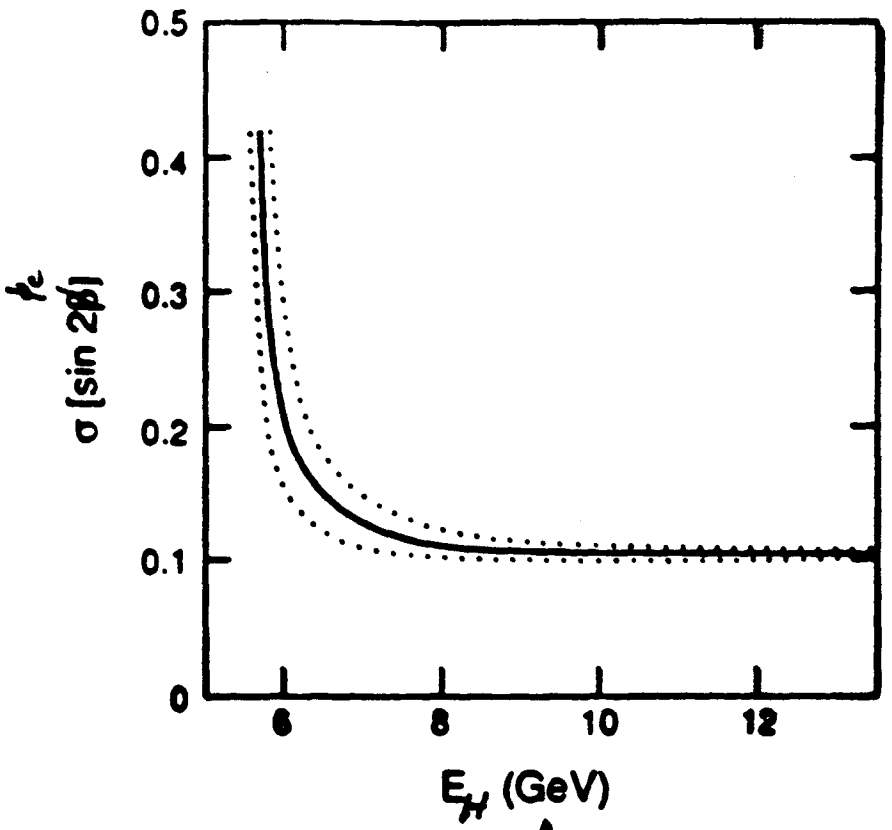


Fig. 2-7. The resolution for measuring sin 2β as a function of the energy of the electron (high-energy) beam. The upper (lower) dotted curve assumes a vertex resolution of 120 μm (50 μm); the solid line assumes 80 μm.

(from SLAC B Factory Proposal)

A) General Considerations

Consider CP eigenstates at the Υ (4S)

Individual time dependent rates are:

$$d\Gamma/_{dtdt'}[f(t)e^{+}(t')]\alpha e^{-(t+t')}(1-\sin\Delta m(t-t')\sin 2\varphi)$$

e^{-} $+$

At Υ (4S) we can only measure (t-t′) not (t+t′) so integrating over (t+t′) we are left with: [define T= (t-t′)]

$\mathcal{R}(T)\ \alpha\ e^{-|T|}(1-\sin\Delta mT\ \sin 2\varphi)$ (for f,e^{+})

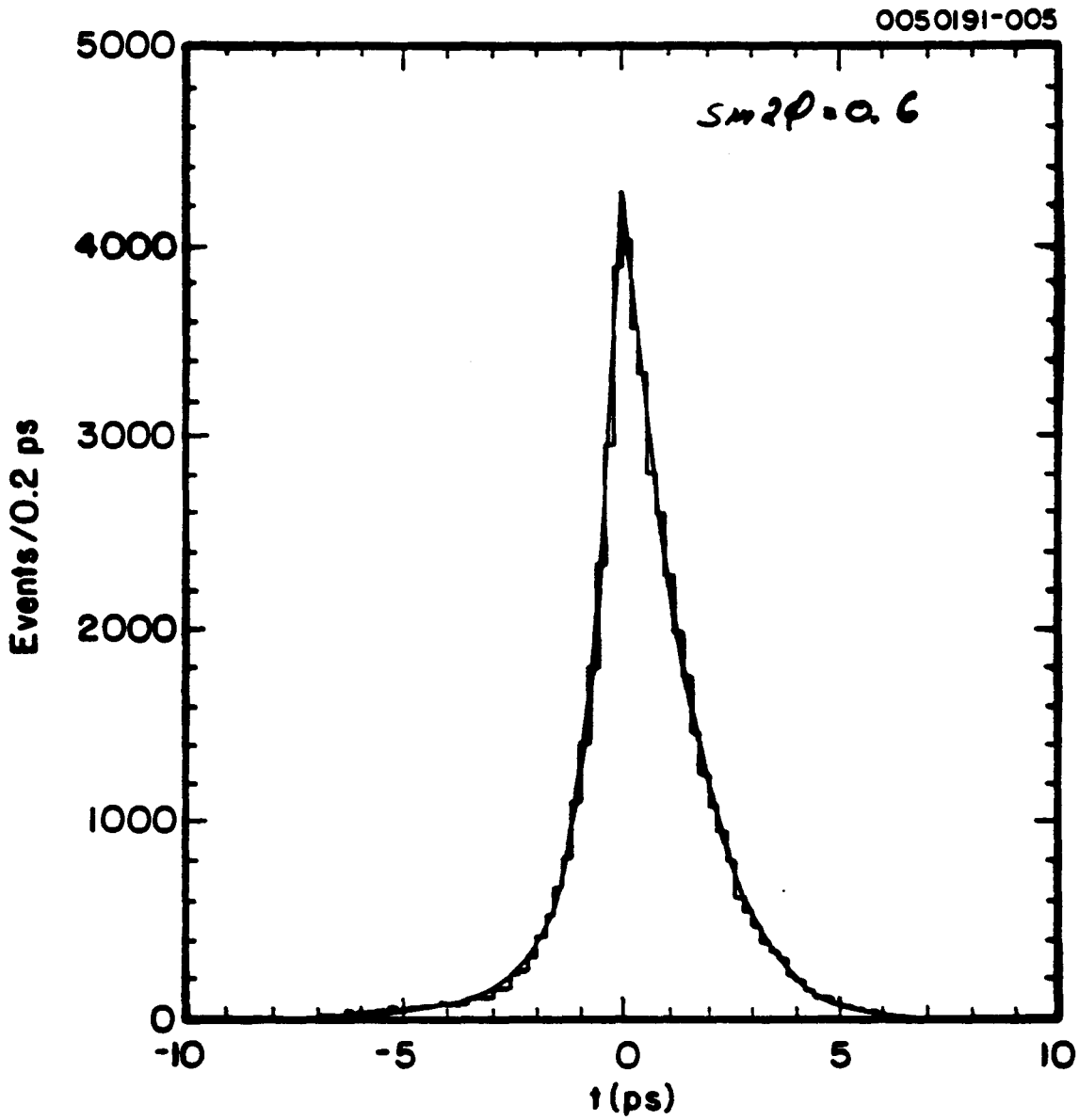
$\mathcal{R}(T)\ \alpha\ e^{-|T|}(1+\sin\Delta mT\ \sin 2\varphi)$ (for f,e^{-})

CP is inherent in these time distributions.

Need only to measure f, and e^{+} or e^{-}. Not necessary to measure Asymmetry (but useful)

Note $\bar{\mathcal{R}}(T)=\mathcal{R}(-T)$

To measure with maximum accuracy construct the sum $\bar{\mathcal{R}}(T)+\mathcal{R}(-T)$ and fit the distribution *(fig)*


0050191-005
sin2β = 0.6
5000
4000
3000
2000
1000
0
Events/0.2 ps
-10
-5
0
5
10
t (ps)

How accurate is this procedure?
Compare with "time ordered asymmetry" i.e. if T is positive or negative (reversed for e^+ relative to e^-)
$\sin\Delta mT \rightarrow \sin\Delta m|T|$, now time integral $\neq 0$

$A_{obs}=[x/(1+x^2)]\sin 2\varphi = d(x)\sin 2\varphi$

since $x=\Delta m/\Gamma=0.66$, $d(x)=0.46$ and

$A_{obs}=0.46A$

Empirically fitting generated distributions gives $d(x)=1.2*0.46=0.55$, (providing resolution doesn't degrade things)

B) Formula for required luminosity

1. Degradations to the measurement

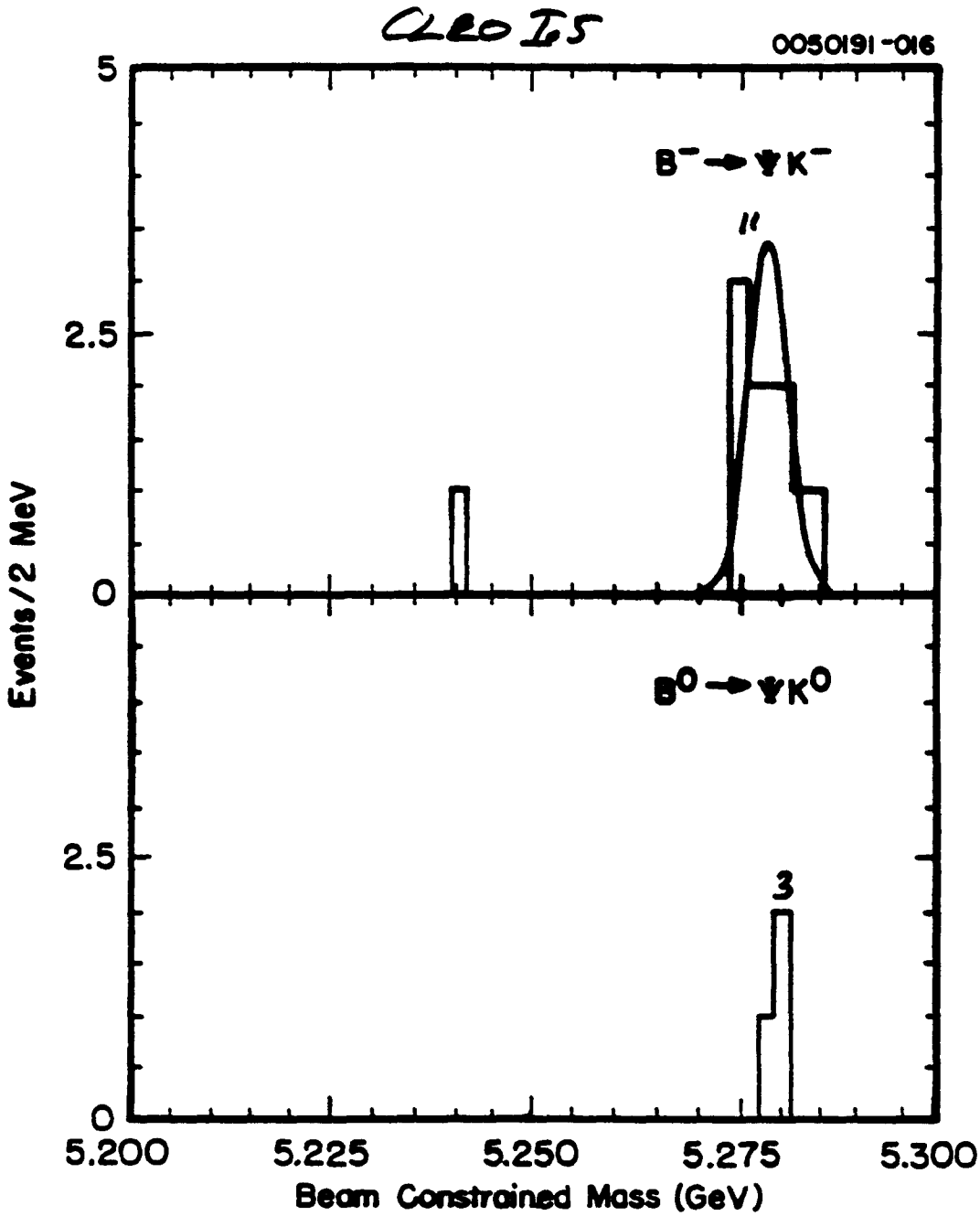
<u>Vertex measurement accuracy</u> - will discuss this later

<u>Wrong tagging</u>

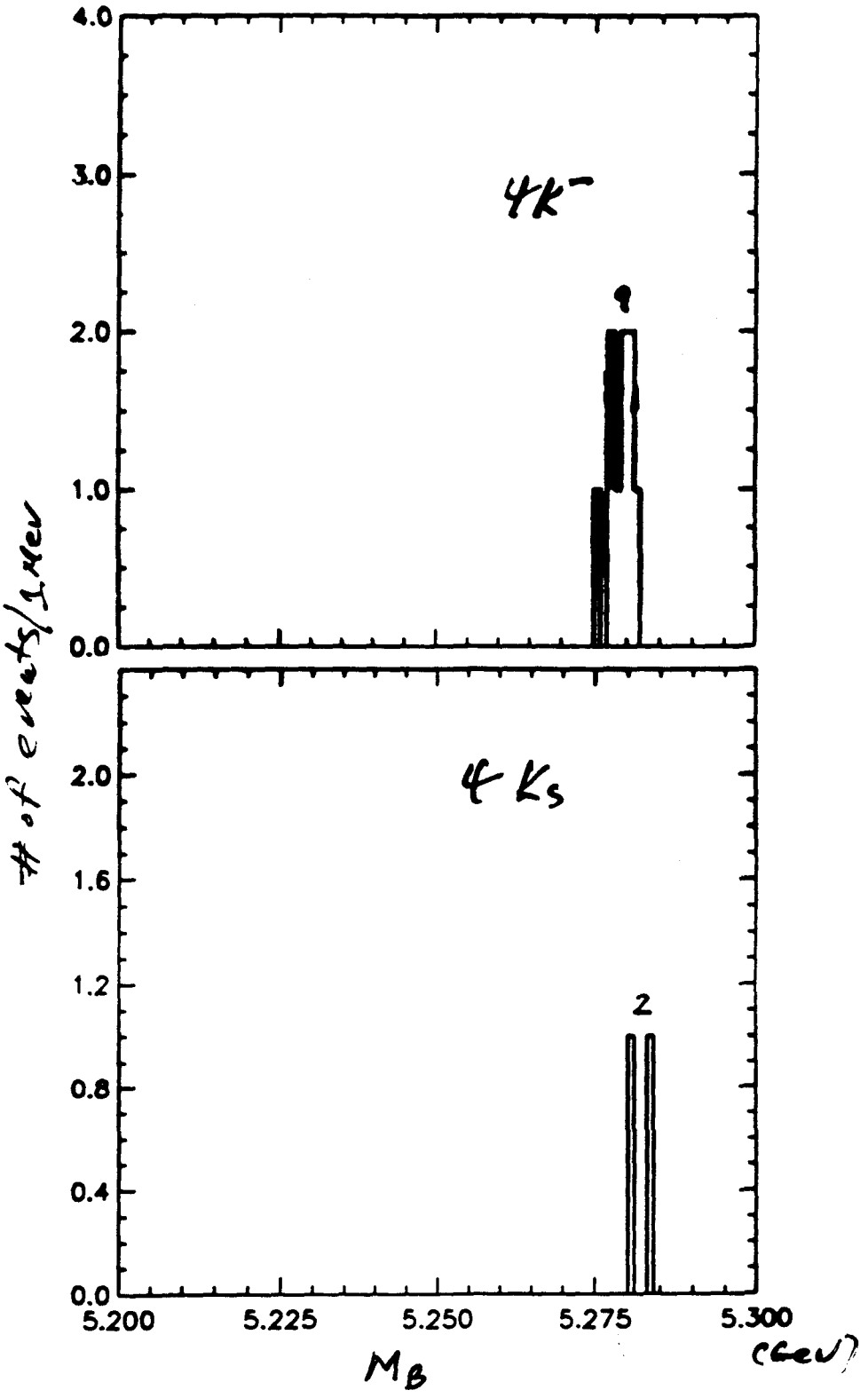
Total tagging efficiency is ε_{tag}, a fraction of which, ω, are wrong. Then A_{obs} is degraded by a factor of $(1-2\omega)$

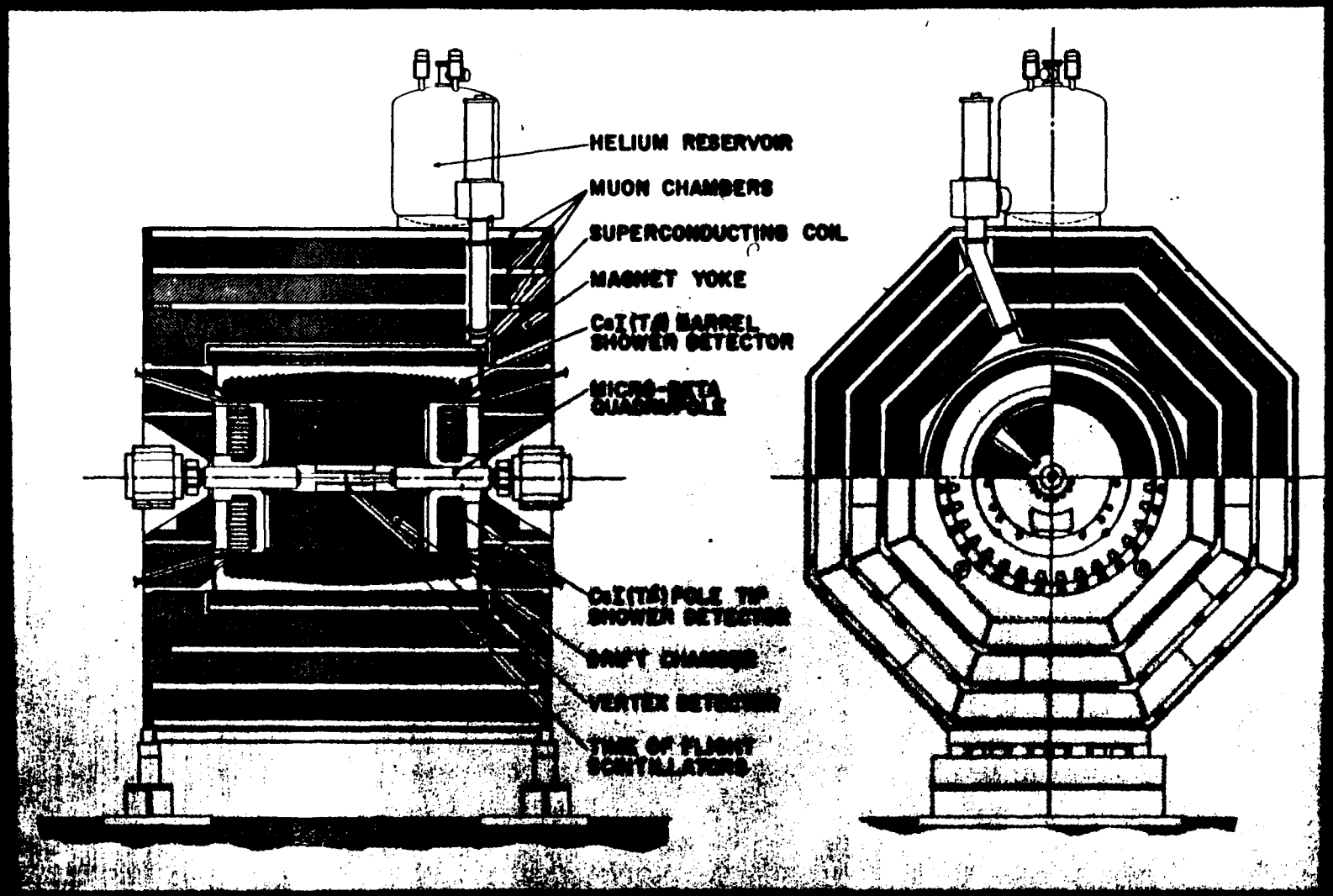
<u>Background in reconstructed B sample</u>

$r_{sig}=\text{Signal}/(\text{Signal}+\text{Background})$


CLEO I.5
0050191-016
5
2.5
0
2.5
0
$B^- \to \Psi K^-$
11
$B^0 \to \Psi K^0$
3
Events/2 MeV
5.200
5.225
5.250
5.275
5.300
Beam Constrained Mass (GeV)

CLEO II


4.0
3.0
2.0
1.0
0.0
ψK^-
9
2.0
1.6
1.2
0.8
0.4
0.0
ψK_S
2
# of events/1 MeV
5.200
5.225
5.250
5.275
5.300
(GeV)
M_B


HELIUM RESERVOIR
MUON CHAMBERS
SUPERCONDUCTING COIL
MAGNET YOKE
CsI(Tl) BARREL SHOWER DETECTOR
MICRO-BETA CHAMBERS
CsI(Tl) POLE TIP SHOWER DETECTOR
DRIFT CHAMBER
VERTEX DETECTOR
TIME OF FLIGHT SCINTILLATORS

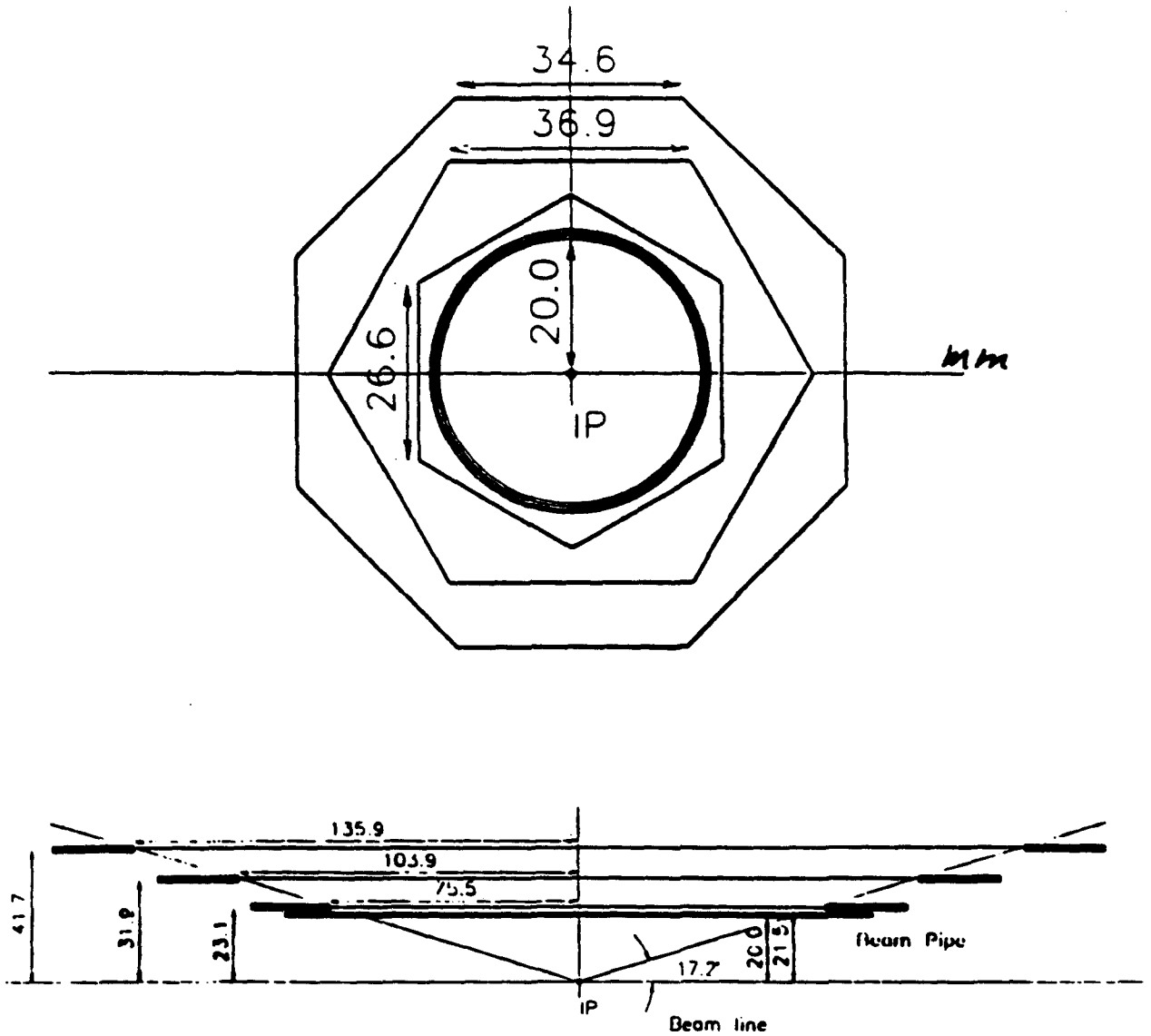


Fig. 3.2 Front and side views of the silicon microstrip vertex detector for a 2cm radius beam pipe. Dimensions are in mm.

the number of B's observed is equal to the branching ratio $\mathcal{B}$ / r_{sig}

Then:

$A_{obs}=r_{sig}\,(1-2\omega)d(x)\sin 2\varphi$

and the required luminosity

$$\mathcal{L} = s^2/2\sigma\ \mathcal{B}\, r_{sig}\, \varepsilon\varepsilon_{tag}(1-2\omega)^2\, d(x)^2 \sin^2 2\varphi$$

$\downarrow$ 1.15nb

$\downarrow$ B reconstruction efficiency

We now need to evaluate these terms

C) Decay modes and ε for φ_c

Several classes of decays *(fig)*

1. Best mode is ψK_S, CLEO data *fig)*

$\mathcal{B}$ estimate from ψK^- => $B(\psi K_S)=4\times10\text{-}4$

ε estimate from fast MC simulation checked with CLEO data

(fig. of detector)

Table: ψK_S

Mode	Branching Ratio, $\mathcal{B}$	efficiency, ε	$\mathcal{B} \times \varepsilon$
$K_S \to \pi^+\pi^-$	2.7×10^{-4}	0.38	1.4×10^{-5}
$K_S \to \pi^0\pi^0$	1.3×10^{-4}	0.12	2.2×10^{-6}
Sum	4.0×10^{-4}		1.6×10^{-5}

2. Double D modes

$\mathcal{B}$ estimate from measured $B \rightarrow DD_S$ modes

<u>The $B \rightarrow D^+D^-$ mode</u>

$\mathcal{B}(D^+D^-)=\mathcal{B}(D^+D_S)X|V_{cd}/V_{ud}|^2=3.7x10\text{-}4$

(For $\mathcal{B}(D_S \rightarrow \varphi\pi)=3.1\%$)(overall error is 2X)

Must detect both $D^{\pm}$

total $\mathcal{B}$ X ε to detect one D^+ for all possible modes is $\approx$9% ($K^-\pi^+\pi^+$, $K_S\pi^+$ etc...)

Thus $\mathcal{B}$ X ε for $B \rightarrow D^+D^-$ is $2.2x10^{-6}$

Much smaller than ψK_S

<u>The $B \rightarrow D^{*+}D^-$ (D^+D^{*-}) mode</u>

This mode is not a CP eigenstate but is similar enough that it can be analyzed

(See Aleksan, Dunietz, Kayser and Le Diberder, Saclay - DPhpe-90-17)

Need to measure separately all 4 reactions

$D^{*+}D^-$, e^+

$D^{*+}D^-$, e^-

D^+D^{*-}, e^+

D^+D^{*-}, e^-

need $\mathcal{B}(B \to D^{*+}D^-) \approx \mathcal{B}(B \to D^+D^{*-})$
to be within a factor of 4, then lose 1/2 in statistical power *(fig for $\rho^\pm\pi^\pm$)*

$\mathcal{B} X \varepsilon$ for $B \to D^{*+}D^- + D^+D^{*-}$ is 5.4×10^{-6}

<u>The B → D*+D*- mode</u>
This mode is not a CP eigenstate
An example of a vector-vector decay mode
Decay can be in *S, P or D* wave
P wave opposite CP
Can use, however if equal mixture lose factor of 6 in statistical power
(Dunietz, Quinn, Snyder, Toki Phys.Rev. D43, 2193(1991))

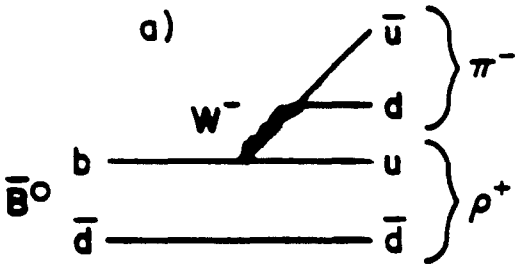
$\mathcal{B} X \varepsilon$ for $B \to D^{*+}D^{*-}$ is 4.5×10^{-6}

3. D^0 Decays into CP eigenstates

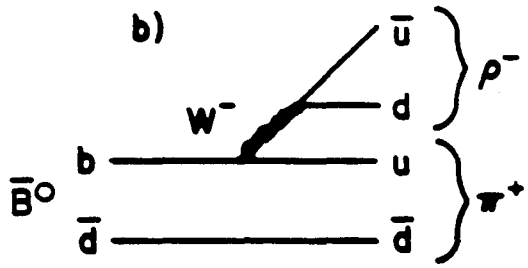
Example: $B \to D^0\pi^0$, $D^0 \to K^+K^-$, $K_S\pi^0$, $K_S\varphi$..

Predict from ratio of color suppressed to non-suppressed spectator diagrams

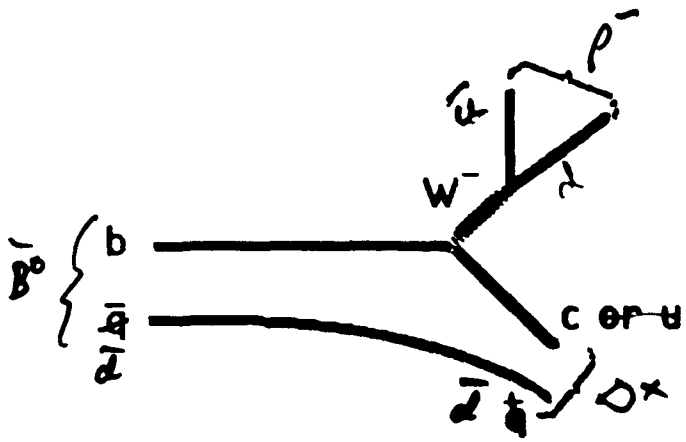
0050191-027



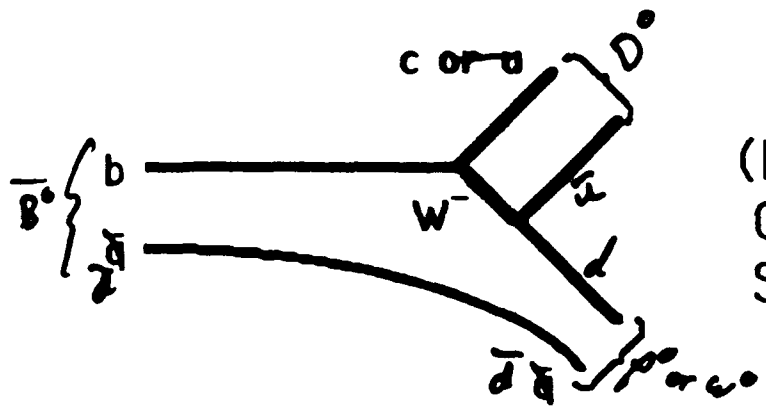
$\bar{B}^0 \to \rho^+ \pi^-$



$\bar{B}^0 \to \rho^- \pi^+$



(a)
Spectator



(b)
Color Suppressed
Spectator

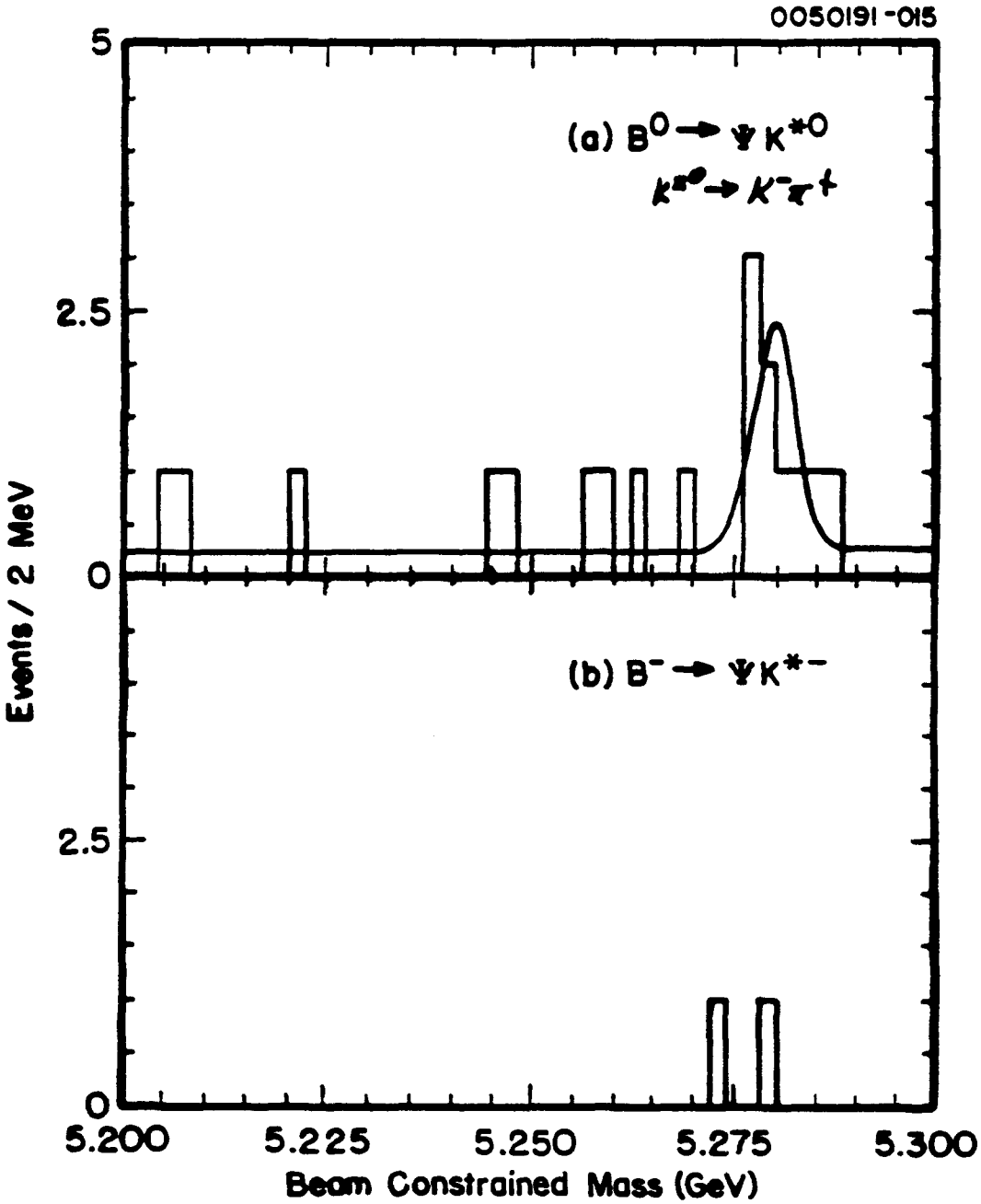
$\mathcal{B}(B \to D^0(\omega^0+\rho^0)) = 1/9\ \mathcal{B}(B \to D^+\rho^-)$
$= 1/9(0.9\%) = 0.1\%$

However BSW prediction is 10X smaller making these modes too small to use

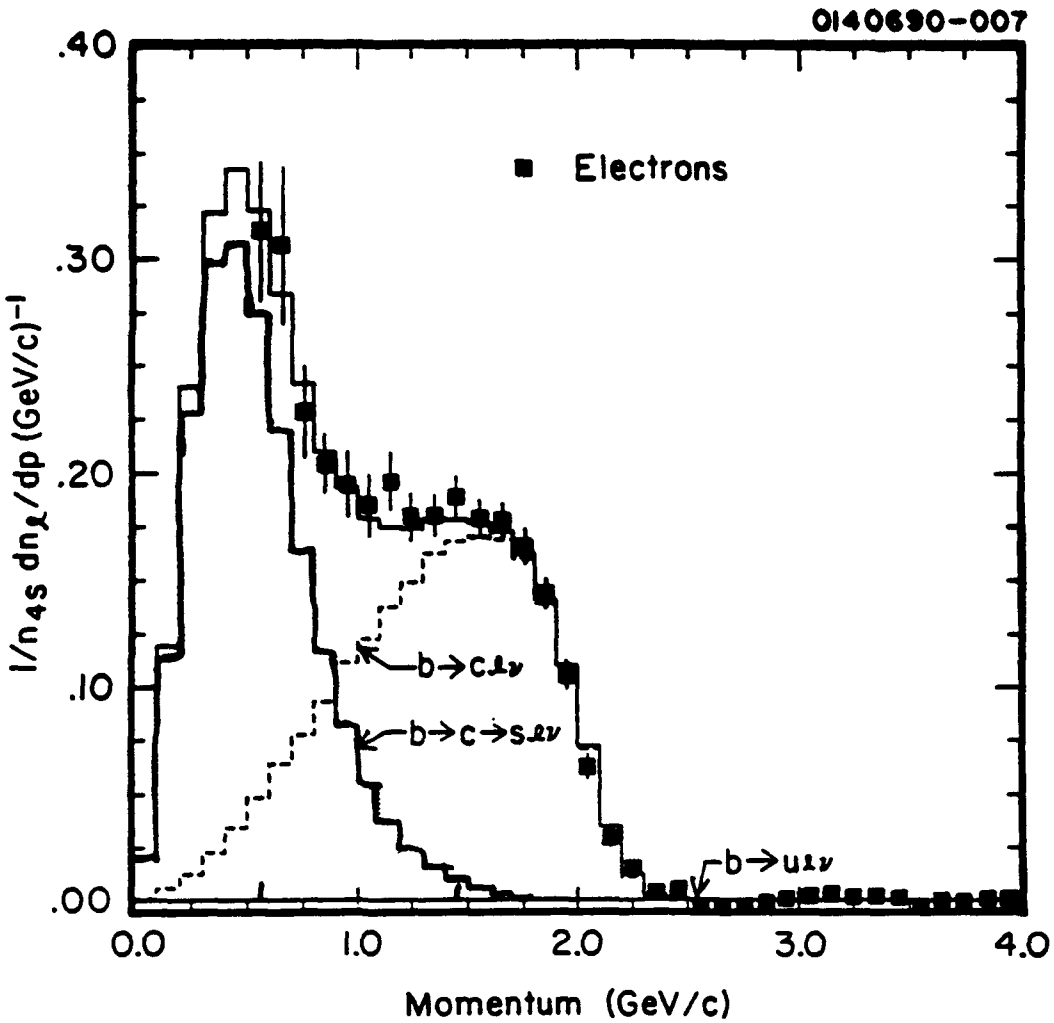
Summary of $\mathcal{B} X \varepsilon$, Table:

Table 4.1: Modes Useful for Measuring φ_c

Mode	Branching ratio, B	efficiency, ϵ	$B \times \epsilon$
Case(a)			
ψK_S^0	4×10^{-4}		
$K_S^0 \to \pi^+\pi^-$	2.7×10^{-4}	0.38	1.4×10^{-5}
$K_S^0 \to \pi^0\pi^0$	1.3×10^{-4}	0.12	2.2×10^{-6}
$\psi' K_S^0$	$< 3 \times 10^{-4}$		$< 6 \times 10^{-6}$
$\psi K^{*0}(K^{*0} \to K_S^0\pi^0)$	4×10^{-4}		
$K_S^0 \to \pi^+\pi^-$	2.7×10^{-4}	0.19	7.1×10^{-6}
$K_S^0 \to \pi^0\pi^0$	1.3×10^{-4}	0.062	1.1×10^{-6}
χK_S^0 or χK^{*0}	?		?
Case(b)			
D^+D^-	3.7×10^{-4}	5.9×10^{-3}	2.2×10^{-6}
$D^{*+}D^-$, D^+D^{*-}	1.5×10^{-3}	3.6×10^{-3}	5.4×10^{-6}
$D^{*+}D^{*-}$	1.6×10^{-3}	2.8×10^{-3}	4.5×10^{-6}
Case(c) $D^0 \to CP$ eigenstate			
$D^0\pi^0$	8.8×10^{-5}	0.008	7.0×10^{-7}
$D^0\rho^0$	5.6×10^{-5}	0.010	5.6×10^{-7}
$D^0\omega^0$	5.6×10^{-5}	0.007	3.9×10^{-7}
$D^{*0}\pi^0$	1.5×10^{-4}	0.008	1.2×10^{-6}
$D^{*0}\rho^0$	3.4×10^{-5}	0.007	2.4×10^{-7}
$D^{*0}\omega^0$	3.4×10^{-5}	0.005	1.7×10^{-7}


0050191-015
(a) $B^0 \to \Psi K^{*0}$
$K^{*0} \to K^- \pi^+$
(b) $B^- \to \Psi K^{*-}$
Events / 2 MeV
5
2.5
0
2.5
0
5.200
5.225
5.250
5.275
5.300
Beam Constrained Mass (GeV)

17a


0140690-007
Electrons
b→cℓν
b→c→sℓν
b→uℓν
.40
.30
.20
.10
.00
0.0
1.0
2.0
3.0
4.0
Momentum (GeV/c)
1/n4s dnℓ/dp (GeV/c)-1

D) Background Estimates

1. ψK_S

Using CLEO data for ψK^-, can set a limit that background is <2% at 90% c.l.

2. ψK^{*0}, $K^{*0} \rightarrow K_S \pi^0$ *(fig)*

Backgrounds not trivial
Estimate r_{sig}=0.95

3. Double D modes

From data find that D^+D^- has large background but D^{*+} modes are clean enough
Backgrounds in all modes are different for different B flavor tags

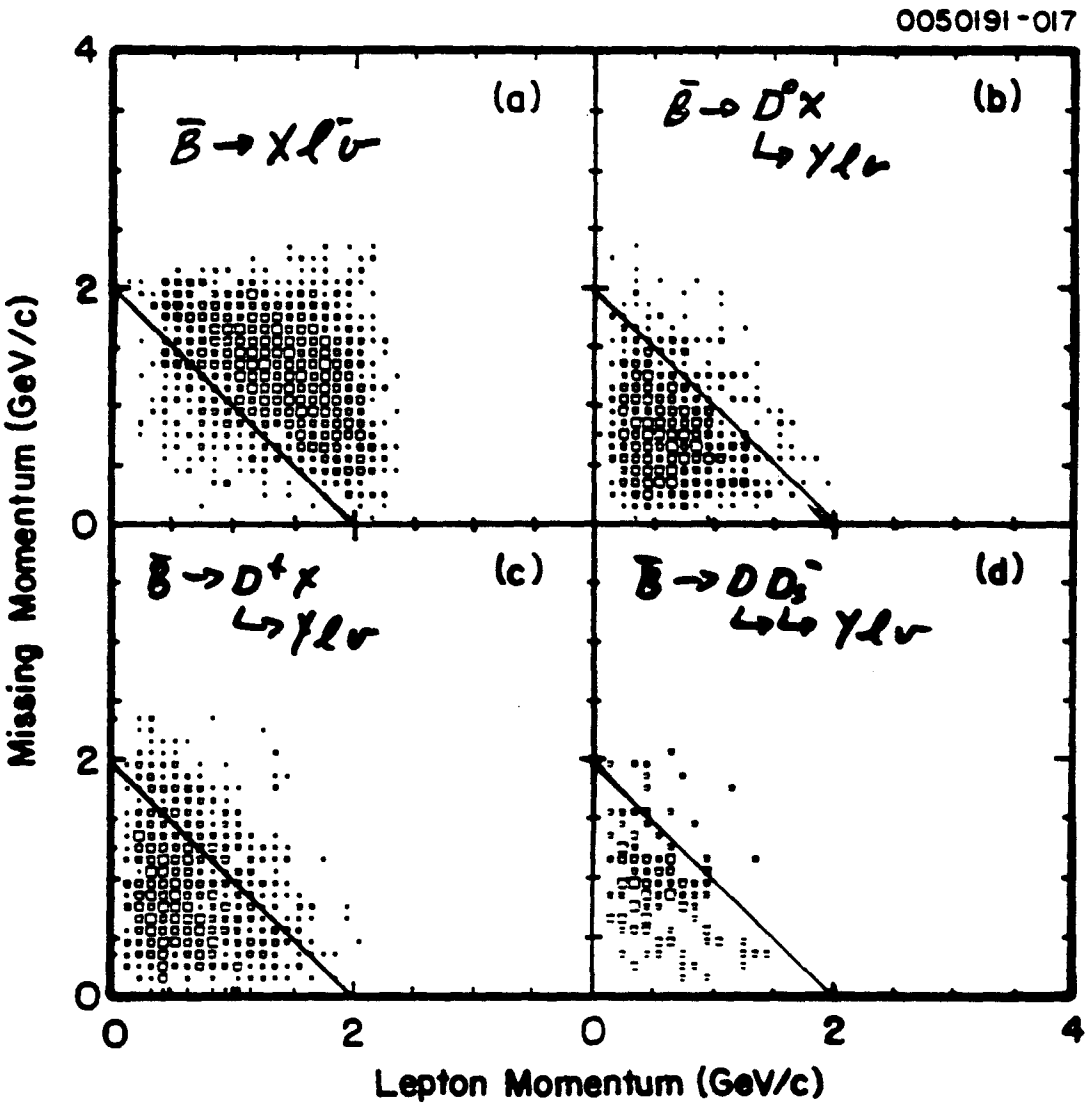
E) Tagging

1. High Momentum Leptons

$\bar{B}^0 \rightarrow X\ell^-\nu$, while $B^0 \rightarrow X\ell^+\nu$ *(fig)*
The sum of the e + μ br is 20% so this is a very good tag

For p_ℓ>1.4 GeV/c estimate:

right sign eff, r_{tag}=9.30%
wrong sign eff, w_{tag}=0.37%


0050191-017
(a)
$\bar{B} \to X \ell \bar{\nu}$
(b)
$\bar{B} \to D^0 X$
$\hookrightarrow Y \ell \nu$
(c)
$\bar{B} \to D^+ X$
$\hookrightarrow Y \ell \nu$
(d)
$\bar{B} \to D D_s^-$
$\hookrightarrow\hookrightarrow Y \ell \nu$
Missing Momentum (GeV/c)
Lepton Momentum (GeV/c)
0
2
4

$$\varepsilon_{eff}=(r_{tag}+w_{tag})X\left[1-2w_{tag}/(r_{tag}+w_{tag})\right]$$

$$=e_{tag}(1-2\omega)^2$$

$$=9.0\%$$

2. Low Momentum Leptons

Below 0.6 GeV/c lepton spectrum is dominated by $D \rightarrow X\ell^+\nu$, need to worry about backgrounds, pair conversions etc.. but still useful.

For $1.4>p_\ell>0.6$ GeV have a mix of leptons.

Consider p_ν. In this p_ℓ range p_ν is much larger for a B Decay than for a D decay. We can estimate p_ν, by calculating the missing momentum in the event. (This works because we have fully reconstructed one B in the event.) *(fig)*

If $|P_\ell + P_{miss}|>2$ GeV/c accept as B tag

If $|P_\ell + P_{miss}|<2$ GeV/c " " D "

Table of results:

Table 4.5: Tagging Efficiencies (in %)

Tag	r_{tag}	w_{tag}	ϵ_{eff}
B lepton, p_ℓ >1.40GeV/c	9.3	0.37	9.0
D lepton, p_ℓ <0.60GeV/c	5.7	1.1	3.0
B lepton,† 0.6 < p_ℓ <1.4GeV/c	3.3	1.0	1.2
D lepton,‡ 0.6 < p_ℓ >1.4GeV/c	4.8	1.0	2.6
$K^\pm$, p_K <1.25 GeV/c	29.4	4.3	18.7
$K^\pm$, Aerogel Counter*	33.0	5.5	20.0
D $n\pi$ reconstruction	8.8	0.1	8.7

† $|p_\ell| + |P_{miss}|$ >2 GeV/c
‡ $|p_\ell| + |P_{miss}|$ <2 GeV/c
* Not used for luminosity estimates

3. Charged Kaons

Use $b \rightarrow c \rightarrow s$ sequence to tag B flavor

Unfortunately many wrong sign kaons

Some from D decay others from $B \rightarrow DD_s$

and dikaon production

For perfect detector but including decays and solid angle to $r_{tag} = 33\%$, $w_{tag} = 5.5\%$

4. Partially Reconstructed B decays

Idea here that is since we have fully reconstructed one B and we KNOW that what remains is all from the other B, we can use kinematic constraints to allow us to find the flavor of the other B by reconstructing its final state even if we miss one particle

Ex: $B^0 \rightarrow D^- \pi^+$

look only for π^+ allow the D^- to be missing (still a 3C fit)

How many modes can we get with small backgrounds? Work still in progress.

Table:

Table 4.6: Branching Ratios and Efficiencies for Partial Reconstruction

Mode	$\mathcal{B}(\%)$	ϵ_{tag}	$\mathcal{B}\times\epsilon_{tag}(\%)$
D^+ modes			
$D^+\pi^-$	0.32	0.90	0.29
$D^+\rho^-$	0.9	0.54	0.49
$D^+\pi^+\pi^-\pi^-$	2.0	0.73	1.5
D^{*+} modes			
$D^{*+}\pi^-$	0.32	0.90	0.29
$D^{*+}\rho^-$	0.8	0.54	0.39
$D^{*+}\pi^+\pi^-\pi^-$	1.3	0.73	0.95
$D^{*+}\pi^+\pi^-\pi^-\pi^0$	4.1	0.44	3.4
$D^{*+}\pi^+\pi^-\pi^-\pi^0\pi^0$	4.1	0.26	1.1

Overall tagging efficiency estimated at 40%

F) Vertex Resolution

Recall $\beta\gamma = (E_{high} - E_{low})/M_{4S} = 0.42$

Separation along beam axis of two B's is $\Delta z = \beta\gamma\, c\Delta t$

maximum difference between (f, e^+) and (f, e^-) occurs at $\Delta t/\tau_B = 0.88$ or $\Delta z = 130\mu m$

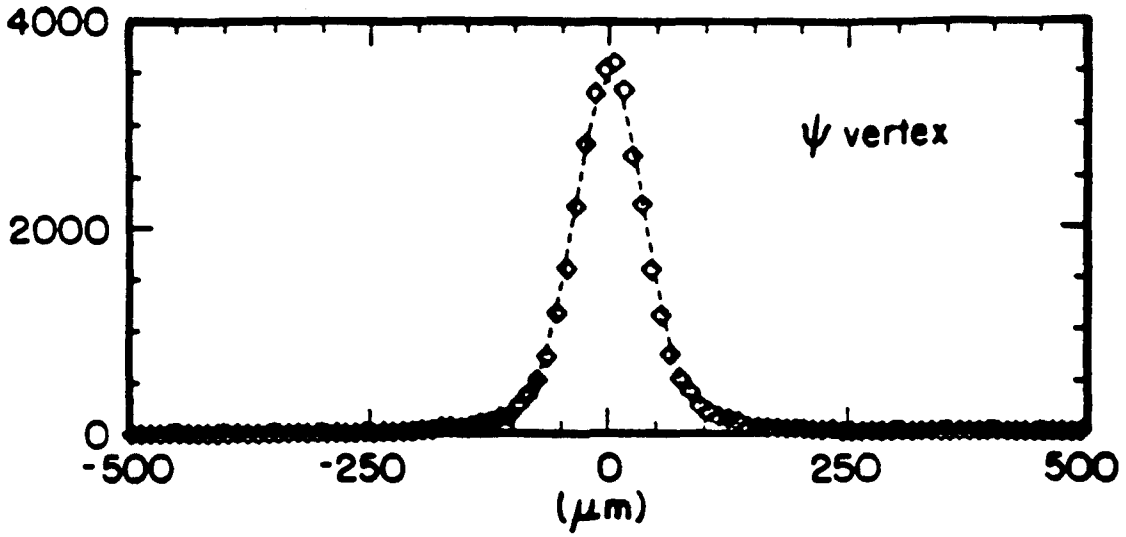
Vertex separations smaller than $130\mu m$ will not cause a problem

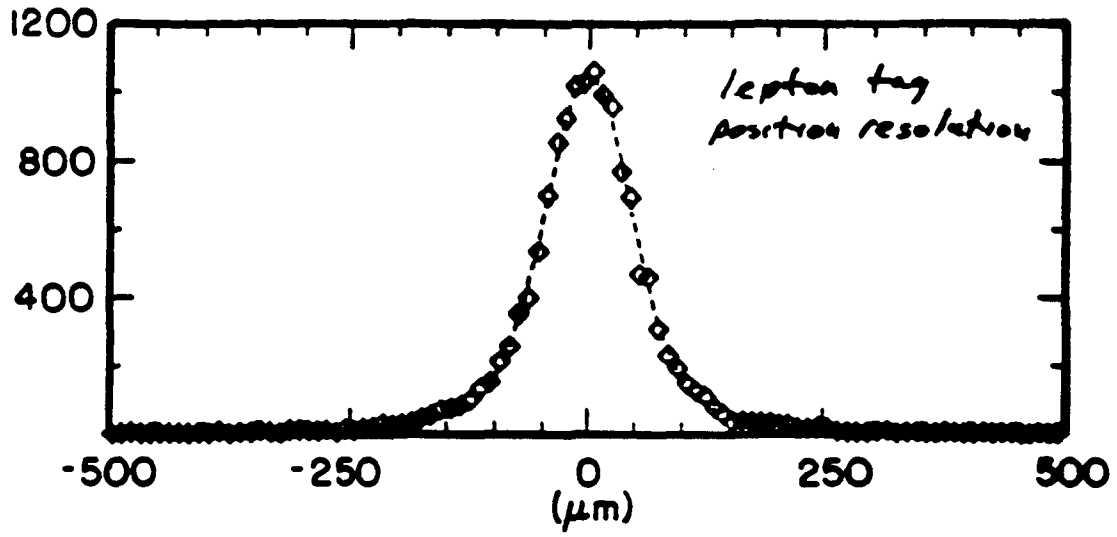
Vertex resolutions are in general non-Gaussian, we have found that the sum of two Gaussians gives a good descripition *(figs)*

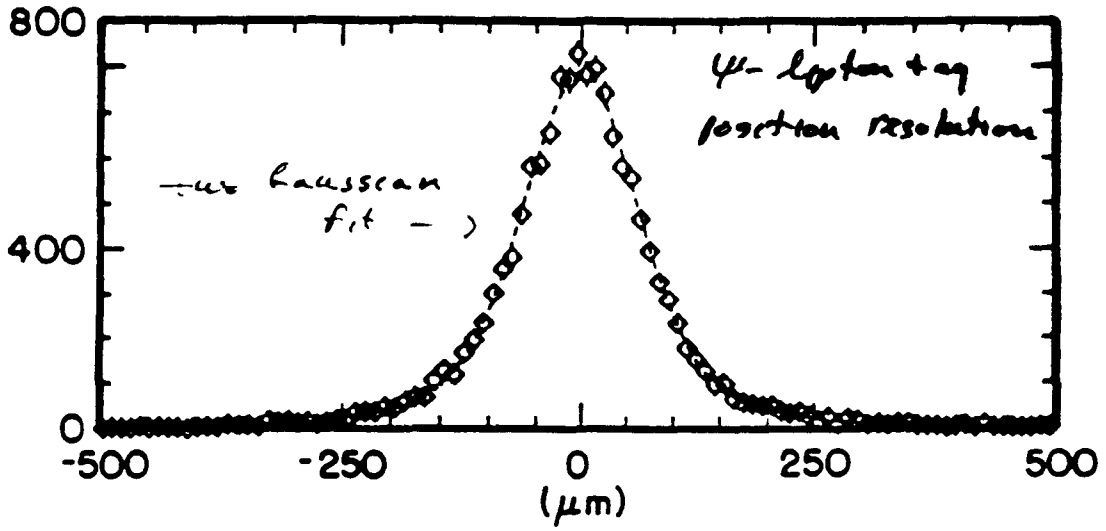
Fit CP asymmetry for ψK_S - lepton *(fig)*

d(x) gets degraded by the vertex resolution

Table:


4000
2000
0
-500
-250
0
250
500
(μm)
ψ vertex

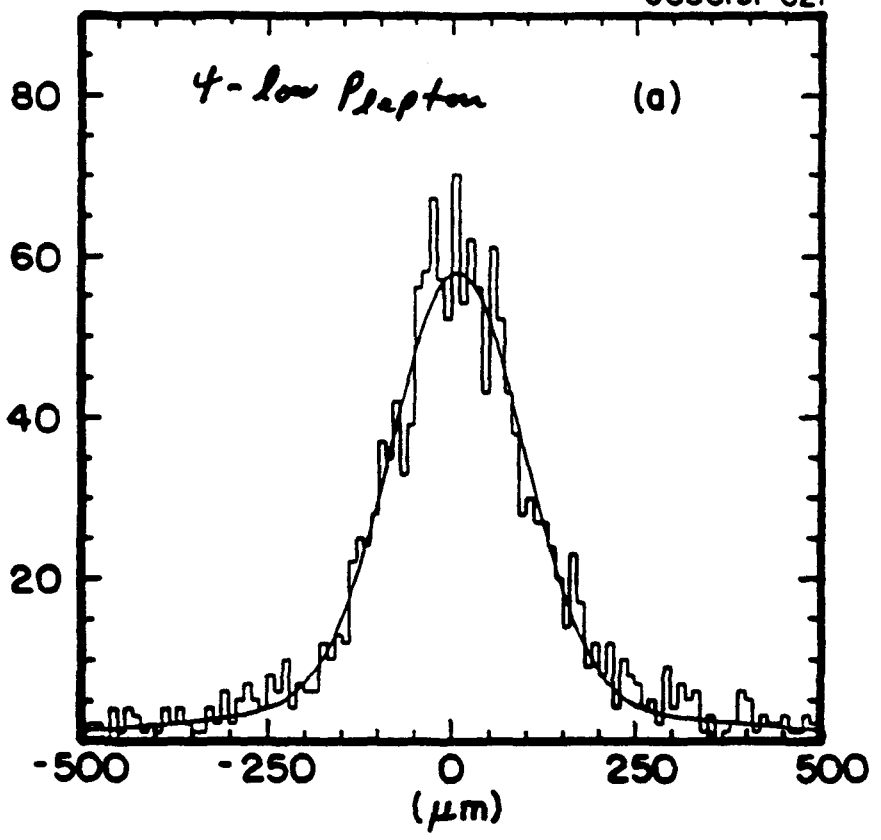

1200
800
400
-500
-250
0
250
500
(μm)
lepton tag
position resolution

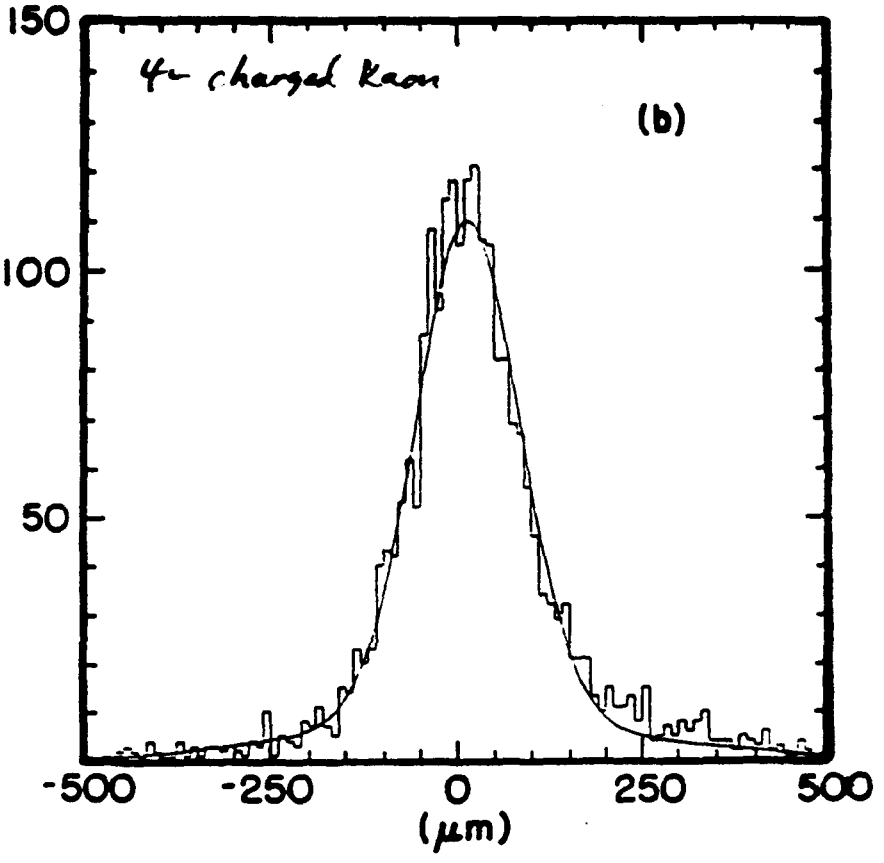

800
400
0
-500
-250
0
250
500
(μm)
ψ- lepton tag
position resolution
Gaussian
fit

Δz

0050191-021

Fits to sum of two Gaussians





Δz

206

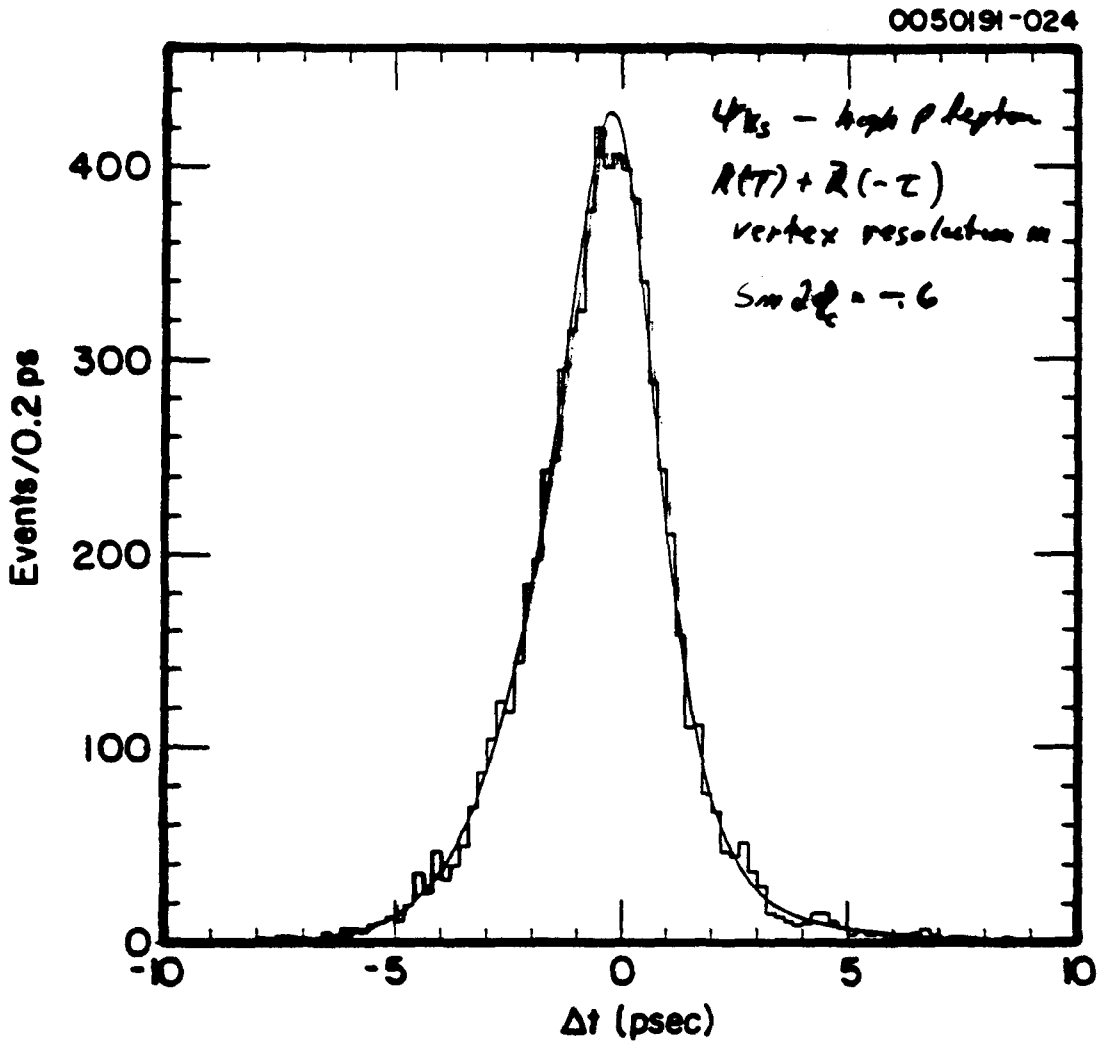

0050191-024
ψK_S – high p lepton
$R(T) + R(-\tau)$
vertex resolution on
$\sin 2\phi_c = -.6$
Events/0.2 ps
400
300
200
100
0
-10
-5
0
5
10
Δt (psec)

Table 4.7: Parameters of two-Gaussian Resolution Functions for Δz_v

Tag	σ_1 (μ)	σ_2 (μ)	% in wider Gaussian	$d(x)$
High p lepton	56	130	29	0.53
p < 0.6 GeV/c electron	88	314	22	0.44
Charged kaon	70	240	20	0.46
D $n\pi$ partial reconstruction				
$n\pi = \pi^-$	56	123	24	0.55
$n\pi = \pi^-\pi^0$	68	180	35	0.51
$n\pi = \pi^+\pi^-\pi^-$	66	125	20	0.53
$n\pi = \pi^+\pi^-\pi^-\pi^0$	77	175	16	0.51

G) Charmless modes - φ_u

1. Channels - none yet found

$\pi^+\pi^-$: Best upper limit from CLEO $<9\times10^{-5}$
BSW prediction $\approx 2\times10^{-5}$

efficiency estimates are lowered by necessity to reduce backgrounds - sphericity cut
Background source is exclusively the continuum below resonance

Using CLEO data *(fig)*, we estimate $r_{sig}=0.65$
However for high quality tags, high p lepton, and partial reconstruction, the background is reduced by 30x to a negligible level

Vertex reconstruction also helps reduce the background ≈40%, useful for "low quality" tags

Background from $K\pi$ not a problem with 1.5 T field and dE/dx system

$\rho^+\pi^- + \rho^-\pi^+$: BSW prediction 6.7×10^{-5}

estimate backgrounds using $a_1{}^+\pi^-$ analysis (may be conservative). Can also use ρ polarization. To be conservative use only high quality tags, and take 2X loss for non-eigenstates

(Table)

CLEO: $B \to \pi^+\pi^-$ search

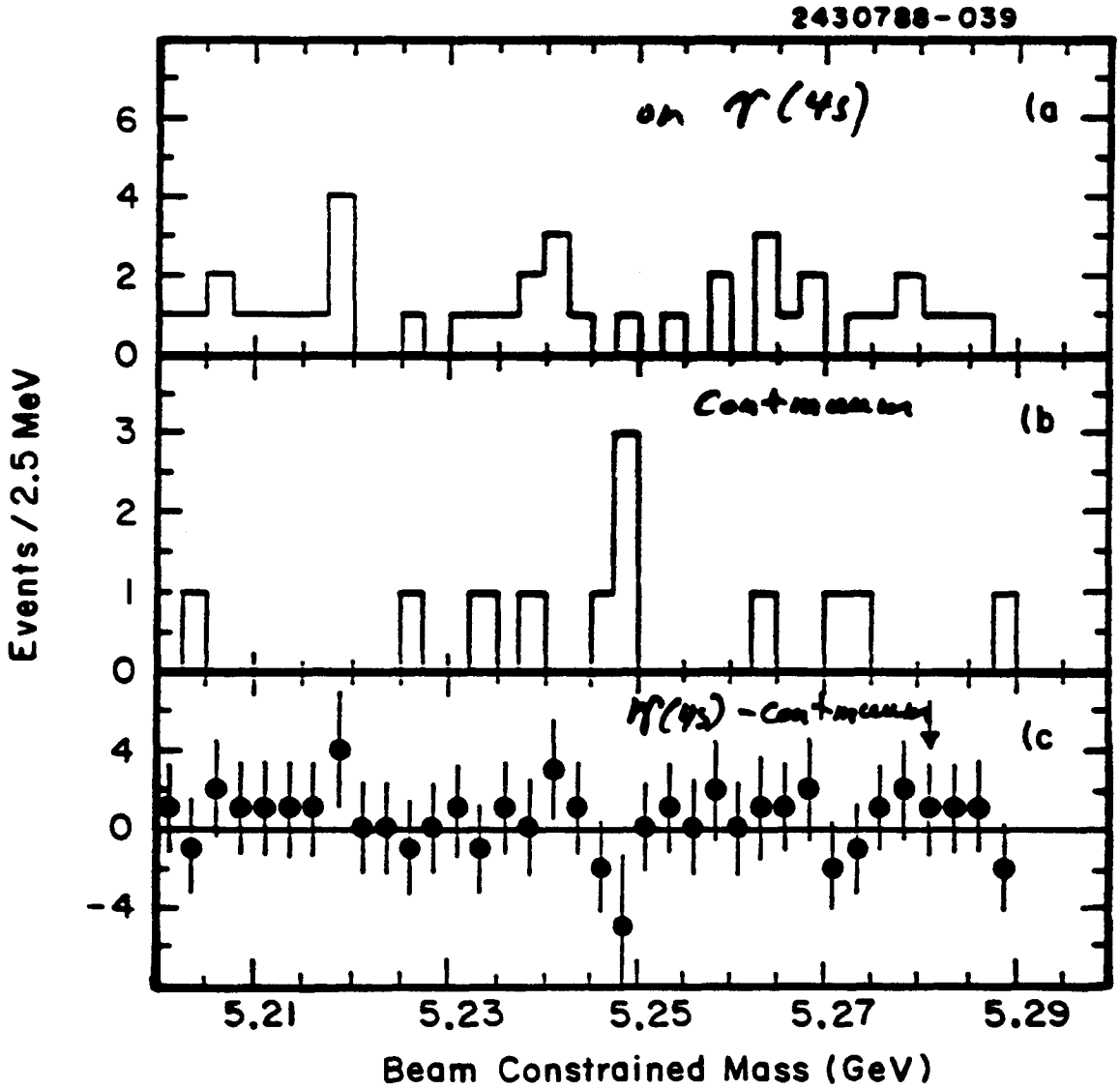
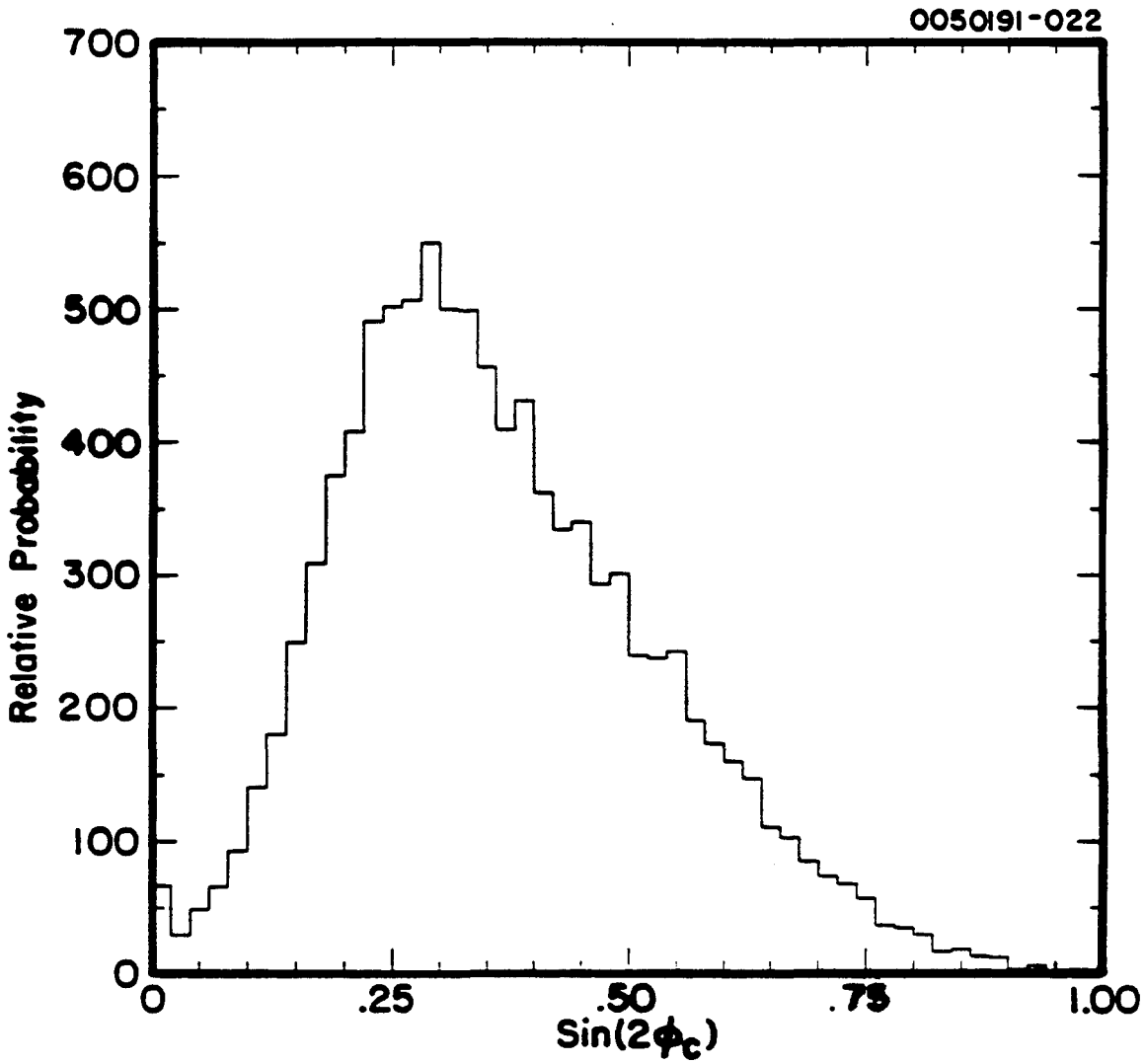


Table 4.8: Modes Useful for Measuring ϕ_u

Mode	$\mathcal{B}$ theory($\times 10^{-5}$)	$\epsilon(\times 10^{-5})$	$\mathcal{B}\times\epsilon(\times 10^{-5})$	$\frac{D_{deg}}{D_{deg}(\pi^+\pi^-)}$
$\pi^+\pi^-$	2.0	0.69	1.4	1
$\rho^\pm\pi^\mp$	6.7	0.40	2.7	1/2
$a_1^\pm\pi^\mp$	5.6	0.25	1.1	1/5
$\rho^+\rho^-$	2.2	0.25	0.6	1/9

Table 4.8: Modes Useful for Measuring ϕ_u

Mode	$\mathcal{B}$ theory($\times 10^{-5}$)	$\epsilon(\times 10^{-5})$	$\mathcal{B}\times\epsilon(\times 10^{-5})$	$\frac{D_{deg}}{D_{deg}(\pi^+\pi^-)}$
$\pi^+\pi^-$	2.0	0.69	1.4	1
$\rho^\pm\pi^\mp$	6.7	0.40	2.7	1/2
$a_1^\pm\pi^\mp$	5.6	0.25	1.1	1/5
$\rho^+\rho^-$	2.2	0.25	0.6	1/9


0050191-022
700
600
500
400
300
200
100
0
Relative Probability
0
.25
.50
.75
1.00
Sin(2φc)

The area of the (ρ,η) plane for which a 4σ is accesible is defined by:

$$\left[\frac{\sin 2\Phi_c}{0.06}\right]^2 + \left[\frac{\sin 2\Phi_u}{0.06}\right]^2 = 4^2$$

(fig)

D) Proposed Machines

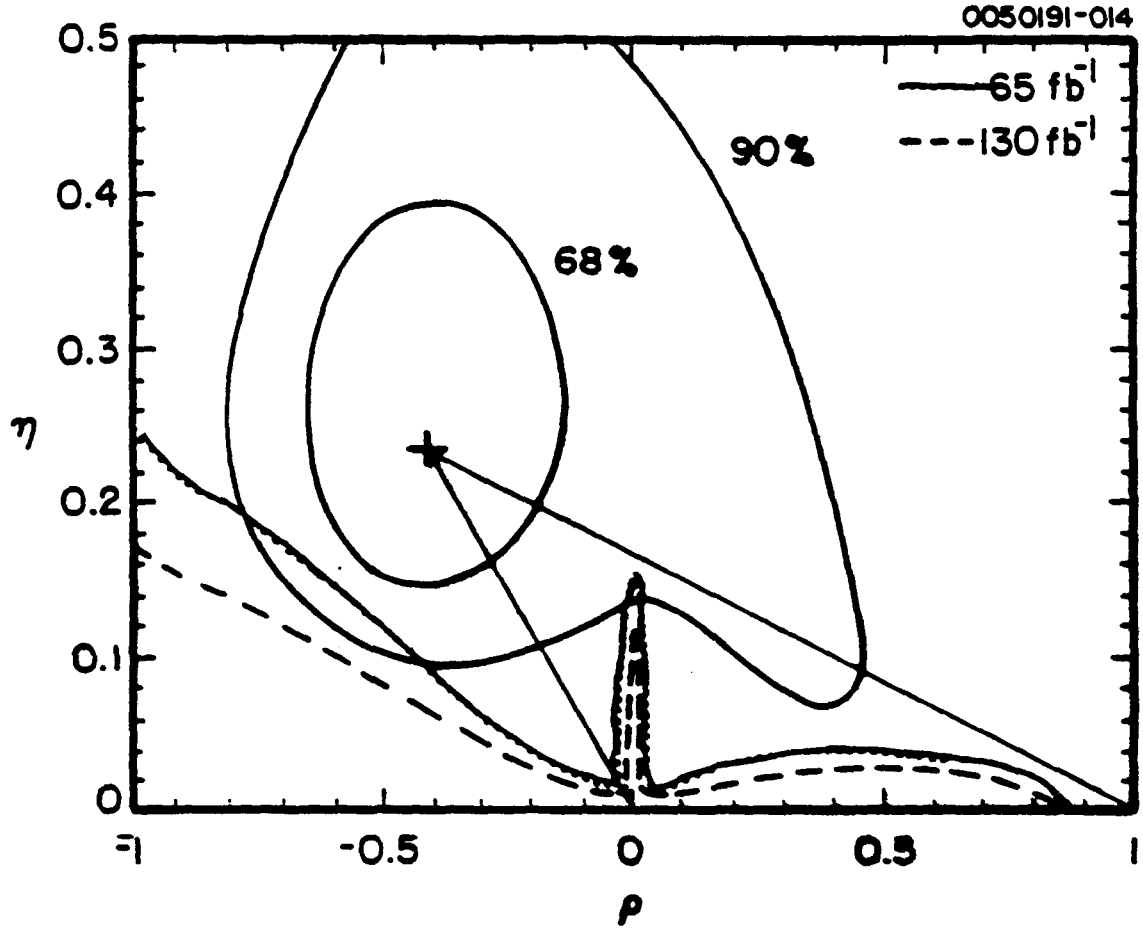
Cornell, KEK, SLAC

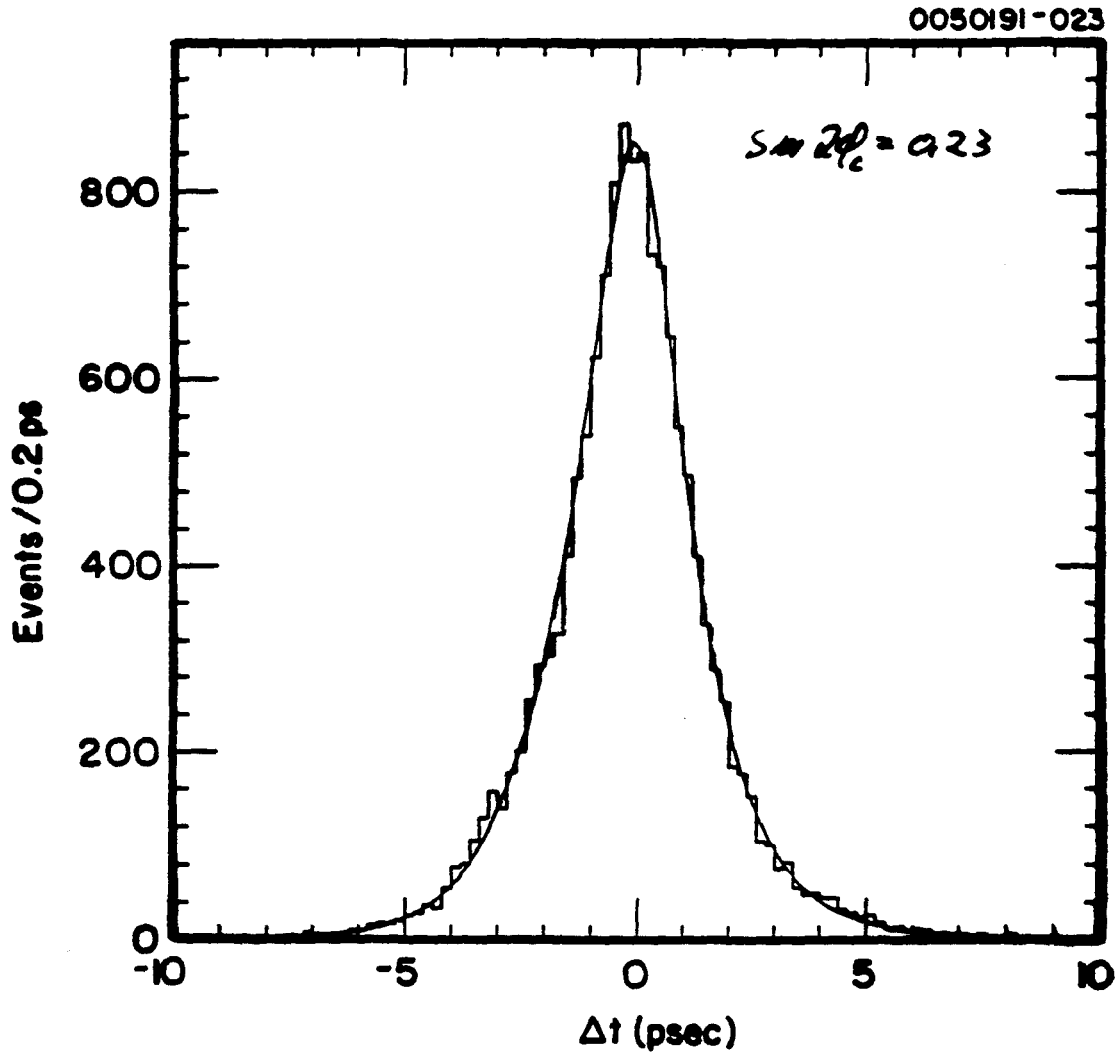
(Plans at DESY)

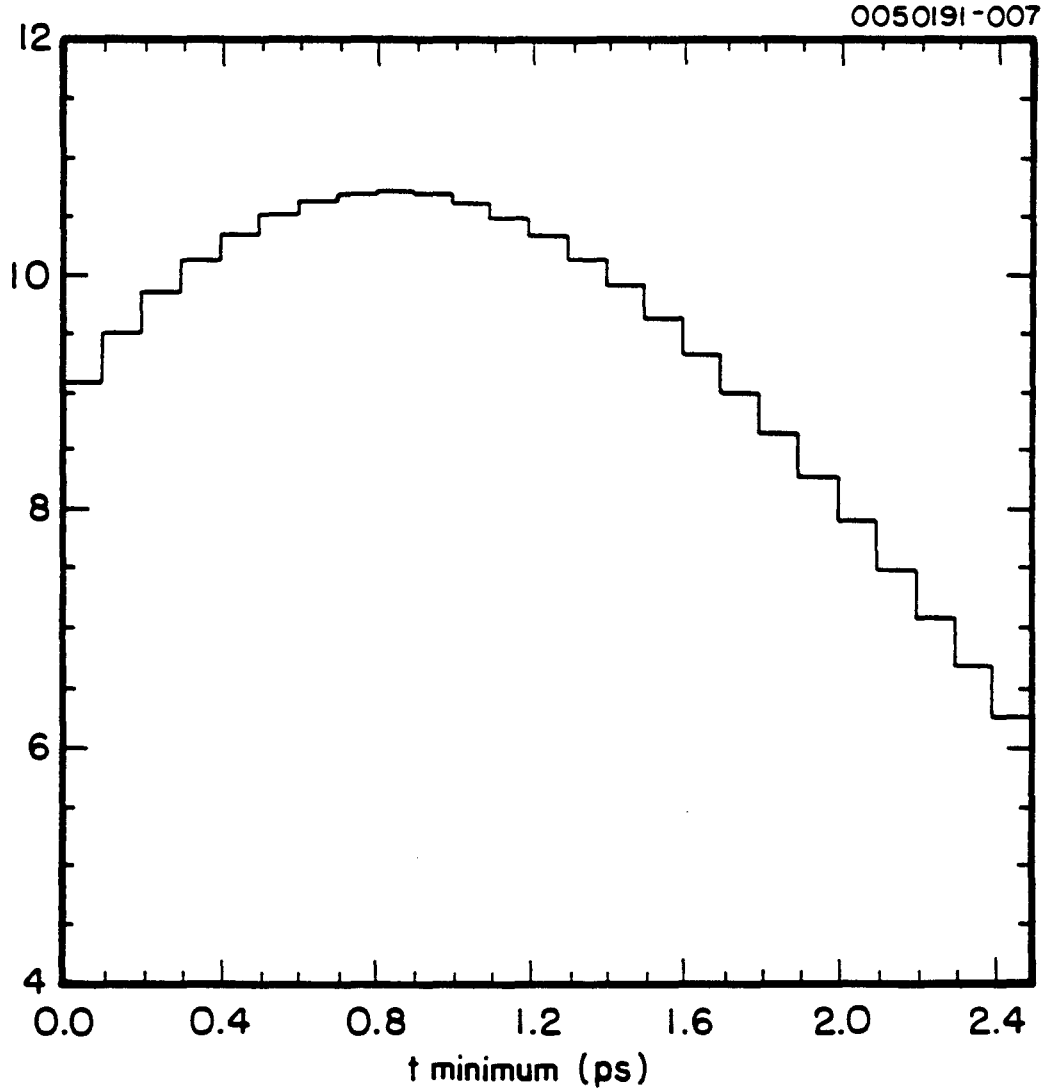
$L_{peak} \approx 3 \times 10^{33} cm^{-2} s^{-1}$

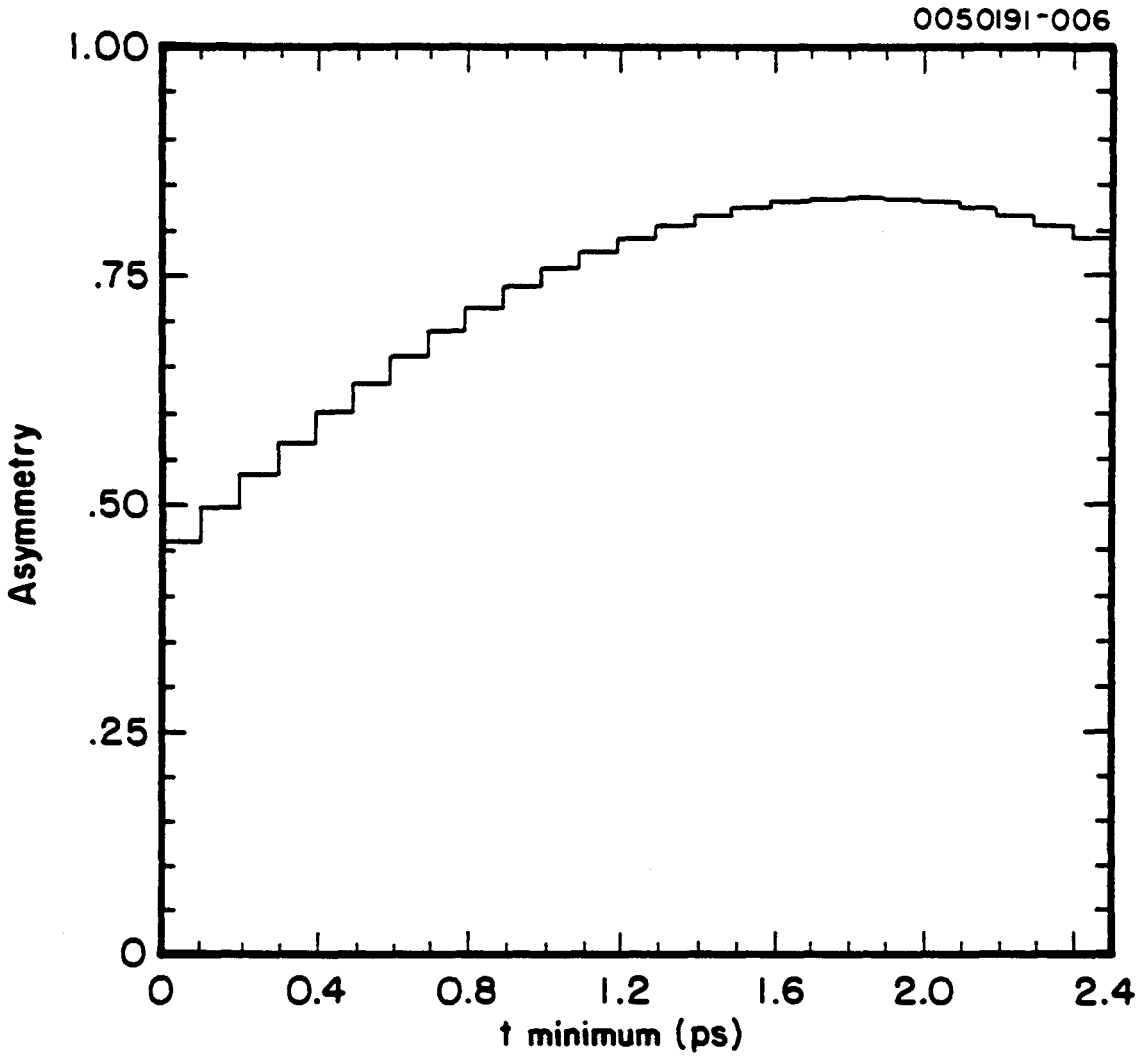
In one year with $\langle L_{avg} \rangle = 1.5 \times 10^{33}$ and 50% duty cycle

Can accumulate $25 fb^{-1}$


0050191-014
0.5
0.4
0.3
0.2
0.1
0
η
-1
-0.5
0
0.5
1
ρ
65 fb⁻¹
130 fb⁻¹
90%
68%

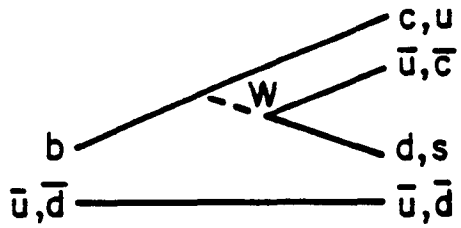

0050191-023
$\sin 2\phi_c = 0.23$
800
600
400
200
0
Events/0.2 ps
-10
-5
0
5
10
Δt (psec)


0050191-007
12
10
8
6
4
0.0
0.4
0.8
1.2
1.6
2.0
2.4
t minimum (ps)

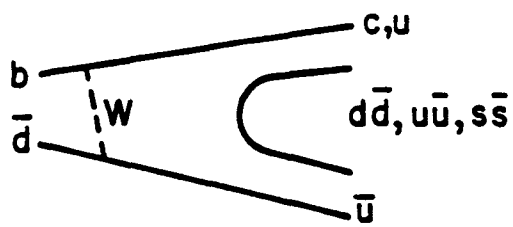

0050191-006
1.00
.75
.50
.25
0
Asymmetry
0
0.4
0.8
1.2
1.6
2.0
2.4
t minimum (ps)

(a) Spectator External

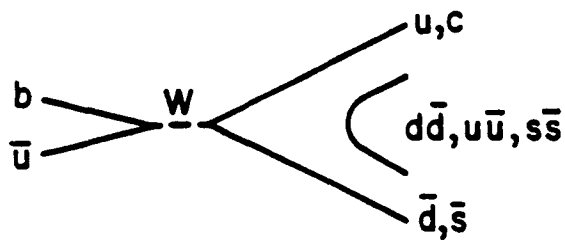
(b) Spectator Internal



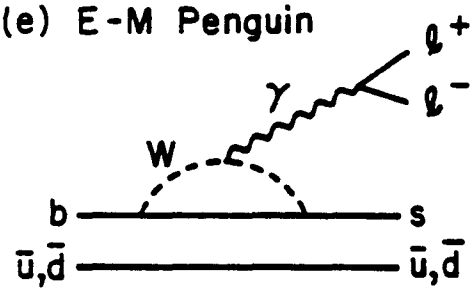
(c) Exchange



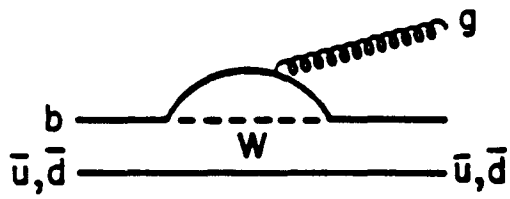
(d) Annihilation



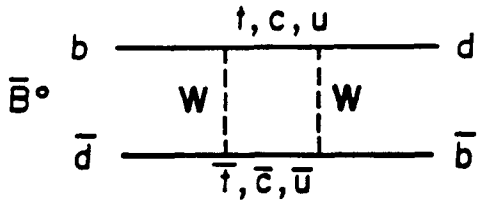
(e) E-M Penguin



(f) Gluonic Penguin

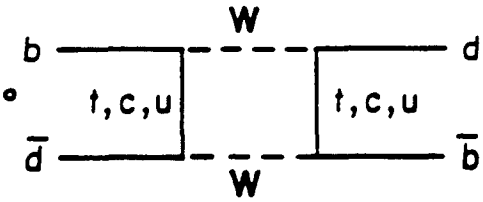


(g) Mixing



$B^\circ + \bar{B}^\circ$

(h) Mixing



B°

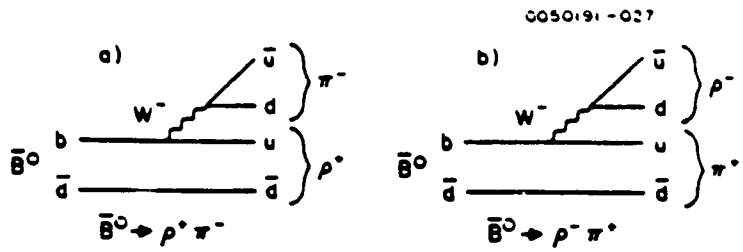


Fig. 4.13 Tree level decay diagrams for (a) $\overline{B}^0 \to \rho^+\pi^-$ and (b) $\overline{B}^0 \to \rho^-\pi^+$.

but we would be unable to extract a value of ϕ_u. Henceforth, we will assume that these additional amplitudes do not exist and now show how to measure ϕ_u with these decays. (For more details see Ref. 61.)

Equations (2.16) (and (2.17)) for the time evolution of B^0 (and $\overline{B}^0$) and the state f are replaced by the following equations:

$$\mathcal{R}_f(T) \propto e^{-|T|}\left(1 - R\cos xT - D\sin xT \sin(2\phi_u + \Delta\alpha)\right) \quad (\text{for } f, \ell^+), \tag{4.3}$$

$$\overline{\mathcal{R}}_f(T) \propto e^{-|T|}\left(1 + R\cos xT + D\sin xT \sin(2\phi_u + \Delta\alpha)\right) \quad (\text{for } f, \ell^-), \tag{4.4}$$

Recall $T = t - t'$ in units of mean lifetime, $R = \frac{\rho^2-1}{\rho^2+1}$, $D = \frac{2\rho}{\rho^2+1}$. Here ρ is the ratio of the two tree level amplitudes M/M' and $\Delta\alpha$ is the strong phase difference between the B^0 and $\overline{B}^0$ amplitudes for decay into f. There are two additional equations for decays into the CP conjugate state $\overline{f}$

$$\mathcal{R}_{\overline{f}}(T) \propto e^{-|T|}\left(1 + R\cos xT - D\sin xT \sin(2\phi_u - \Delta\alpha)\right) \quad (\text{for } \overline{f}, \ell^+), \tag{4.5}$$

$$\overline{\mathcal{R}}_{\overline{f}}(T) \propto e^{-|T|}\left(1 - R\cos xT + D\sin xT \sin(2\phi_u - \Delta\alpha)\right) \quad (\text{for } \overline{f}, \ell^-). \tag{4.6}$$

By measuring all four distributions we extract values for the four unknowns R, D, S and $\overline{S}$, where $S = \sin(2\phi_u + \Delta\alpha)$ and $\overline{S} = \sin(2\phi_u - \Delta\alpha)$.[77] We can then determine ϕ_u up to a four-fold ambiguity:

$$\sin^2 2\phi_u = \frac{1}{2}\left(1 + S\overline{S} \pm \sqrt{(1-S^2)(1-\overline{S}^2)}\right).$$

This ambiguity can be resolved either by using a CP eigenstate mode, such as $\pi^+\pi^-$ for a crude measurement or using other data as discussed in section 1.4.

B - PHYSICS

FROM

ARGUS & CLEO

$\Upsilon 4S \rightarrow B\bar{B}$

ARGUS : 200 000 $B\bar{B}$

CLEO 4.5 : 240 000 $B\bar{B}$

" 2 :

HENNING SCHRÖDER DESY

OUTLINE

I. PROPERTIES OF B MESONS

MASSES, SPIN

LIFETIMES, LIFETIME RATIO

EXCLUSIVE AND INCLUSIVE BR

B MESONS IN THE SPECTATOR MODEL

II KM MATRIX ELEMENTS

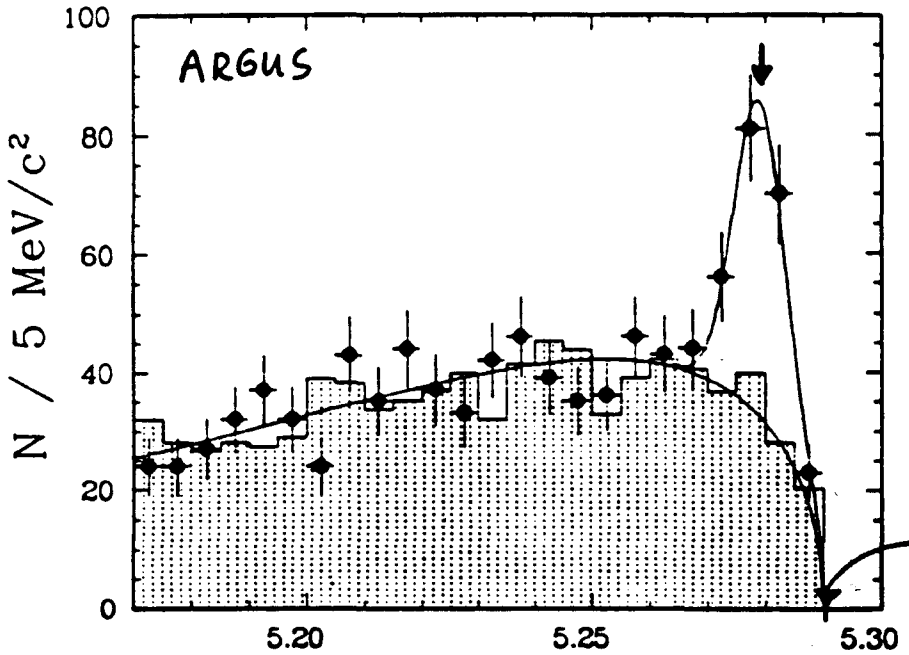
V_{cb} EXCLUSIVE S.L. B DECAYS

V_{ub} INCL. + EXCL. "

V_{td} $B\bar{B}$ MIXING

I. B RECONSTRUCTION

$$B \to D^{(*)} + n\pi \quad , \quad n \leq 4$$



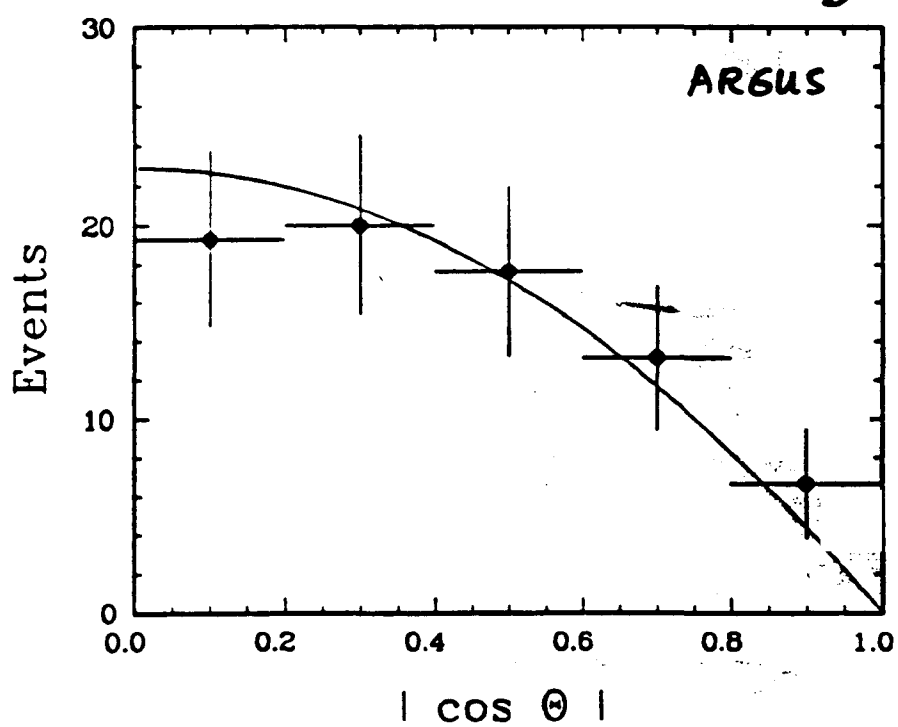
$D^{*+} + n\pi$
$(n \leq 3)$

$\frac{1}{2} M_{\Upsilon 4S}$

$$M\ (\mathrm{GeV}/c^2) \approx \left(E^2_{BEAM} - P_B^2 \right)^{1/2}$$

$$E_{BEAM} = E_B$$

Figure 1



SPIN 0
OF B MESONS

1.1.2

B - MESON MASSES

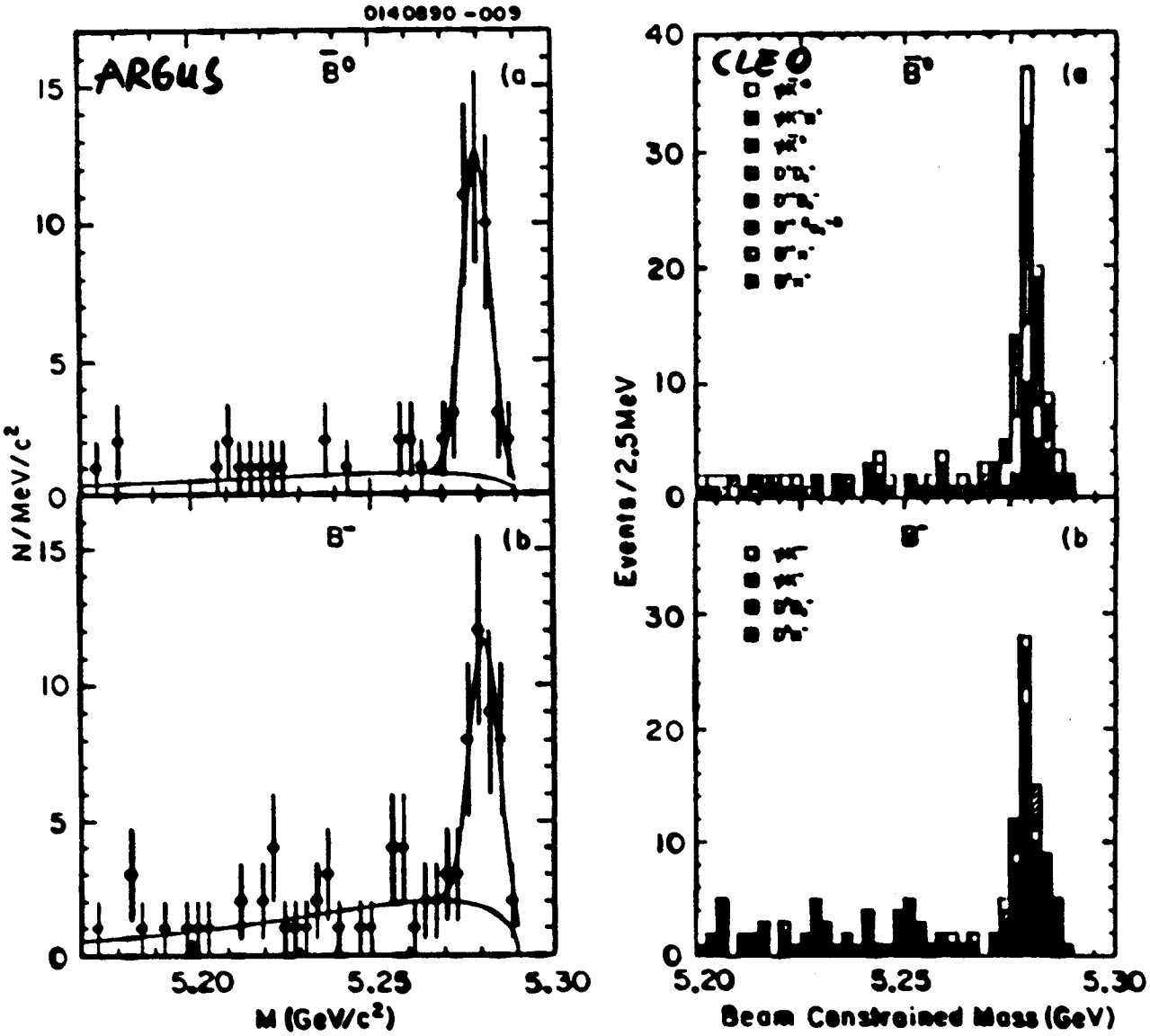


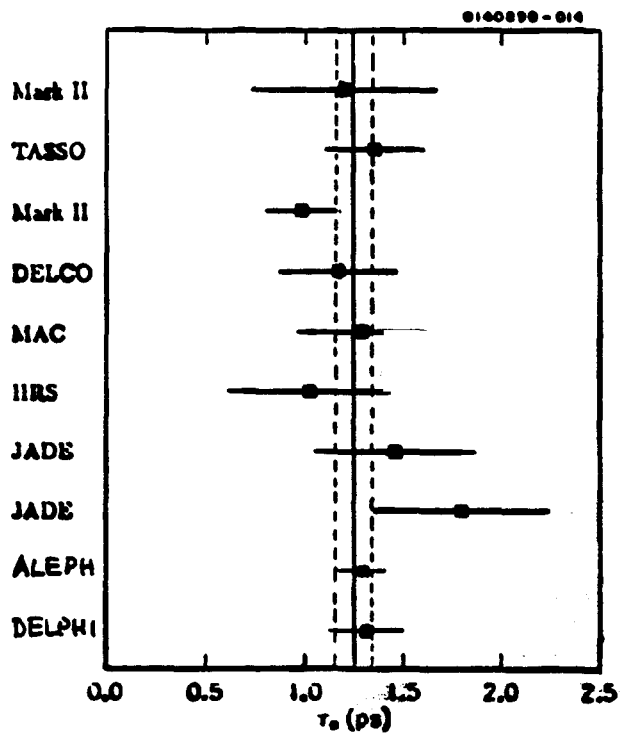
TABLE 2. CLEO and ARGUS results for B meson masses.

Particle	CLEO 1.5 (MeV/c²)	ARGUS (MeV/c²)
$M(\bar{B}^0)$	$5,278.0 \pm 0.4 \pm 2.0$	$5,279.6 \pm 0.7 \pm 2.0$
$M(B^-)$	$5,278.3 \pm 0.4 \pm 2.0$	$5,280.5 \pm 1.0 \pm 2.0$
$M(\bar{B}^0) - M(B^-)$	$-0.4 \pm 0.6 \pm 0.5$	$-0.9 \pm 1.2 \pm 0.5$

$$M(B^0) \simeq M(B^-)$$

$$\Rightarrow \quad f^0 = \frac{BR(\Upsilon 4S \to B^0\bar{B}^0)}{} \simeq 1$$

B -MESON LIFETIME



$$\tau_B = (1.24 \pm 0.08)\ \text{ps}$$

LIFETIME -RATIO

ARGUS
CLEO

$$\frac{\tau_-}{\tau_0} = 0.94 \pm 0.17$$

USES $\Gamma(B^- \to D^0 \ell^- \bar{\nu}) = \Gamma(\bar{B}^0 \to D^+ \ell^- \bar{\nu})$

BRANCHING RATIOS FOR HADRONIC B DECAYS

Mode	CLEO 1.5 (%)	CLEO I (%)	ARGUS (%)	BSW Model (%)
$\overline{B}^0 \to D^+\pi^-$	$0.25 \pm 0.06 \pm 0.04$	$0.51 \pm 0.27 \pm 0.14$	$0.48 \pm 0.11 \pm 0.11$	$0.48a_1^2$
$\overline{B}^0 \to D^+\rho^-$			$0.9 \pm 0.5 \pm 0.3$	$1.25a_1^2$
$\overline{B}^0 \to D^+\pi^-\pi^+\pi^-$	$0.6 \pm 0.2 \pm 0.1$			
$\overline{B}^0 \to D^{*+}\pi^-$	$0.36 \pm 0.09 \pm 0.07$	$0.27 \pm 0.13 \pm 0.08$	$0.28 \pm 0.09 \pm 0.06$	$0.37a_1^2$
$\overline{B}^0 \to D^{*+}\rho^-$	$1.9 \pm 0.9 \pm 1.3$		$0.7 \pm 0.3 \pm 0.3$	$1.18a_1^2$
$\overline{B}^0 \to D^{*+}\pi^-\pi^+\pi^-$	$1.5 \pm 0.4 \pm 1.0$	< 4.0	$1.2 \pm 0.3 \pm 0.4$	
$\overline{B}^0 \to D^{*+}a_1^-$	$1.8 \pm 0.4 \pm 0.5$			$1.63a_1^2$
$\overline{B}^0 \to J/\psi\overline{K}^0$	$0.06 \pm 0.03 \pm 0.02$		$0.08 \pm 0.06 \pm 0.02$	$1.02a_2^2$
$\overline{B}^0 \to J/\psi\overline{K}^{*0}$	$0.11 \pm 0.05 \pm 0.03$	$0.35 \pm 0.16 \pm 0.03$	$0.11 \pm 0.05 \pm 0.02$	$4.36a_2^2$
$\overline{B}^0 \to J/\psi K^-\pi^+$	$0.10 \pm 0.04 \pm 0.03$		< 0.10	
$\overline{B}^0 \to \psi'\overline{K}^0$	< 0.15		< 0.28	
$\overline{B}^0 \to \psi'\overline{K}^{*0}$	$0.14 \pm 0.08 \pm 0.04$		< 0.23	

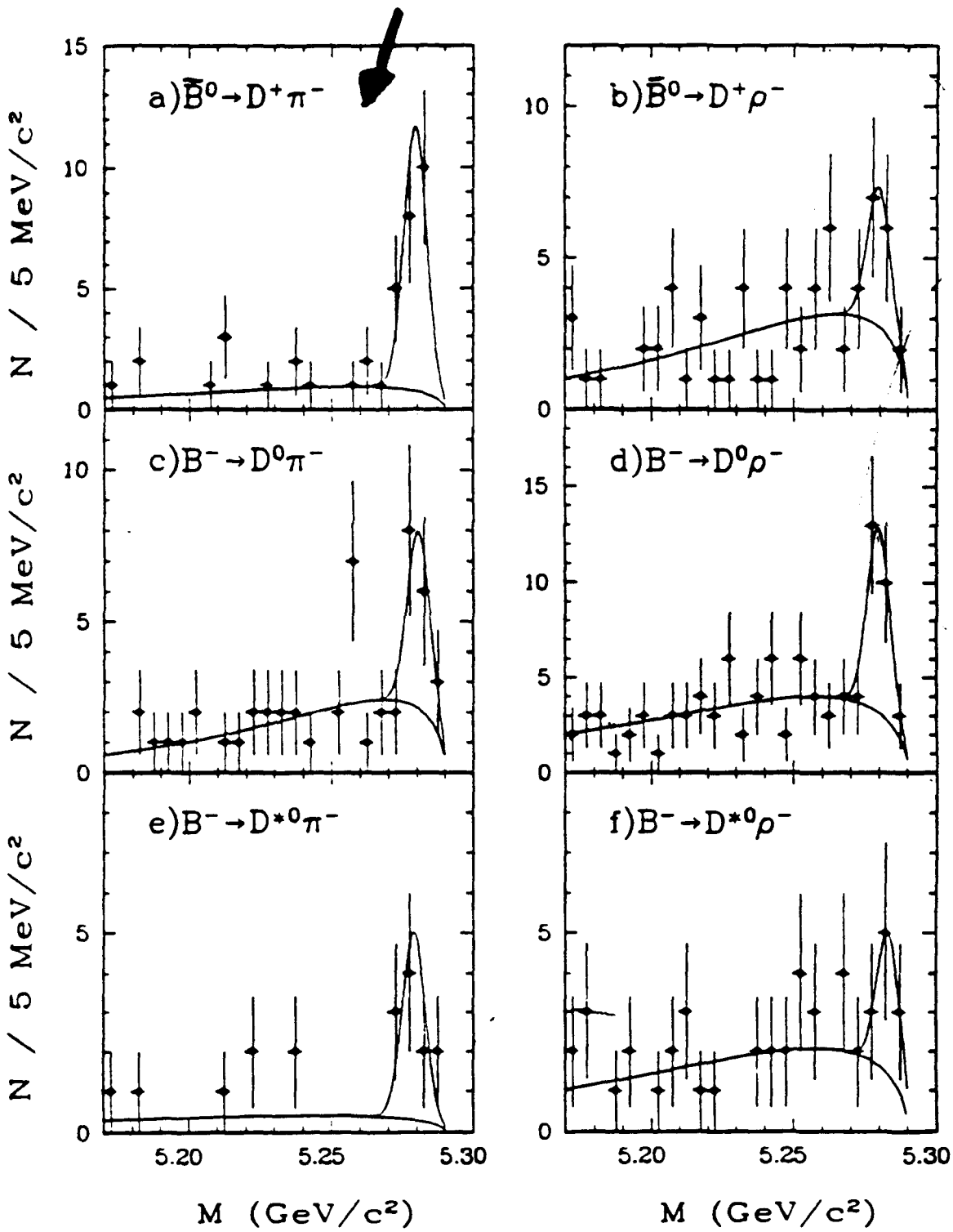
Mode	CLEO 1.5 (%)	CLEO I (%)	ARGUS (%)	BSW Model (%)
$B^- \to D^0\pi^-$	$0.44 \pm 0.07 \pm 0.07$	$0.54 \pm 0.17 \pm 0.11$	$0.29 \pm 0.09 \pm 0.06$	$0.48(a_1 + 0.75a_2)^2$
$B^- \to D^0\rho^-$			$1.3 \pm 0.4 \pm 0.4$	$1.25(a_1 + 0.34a_2)^2$
$B^- \to D^0\pi^-\pi^+\pi^-$	$1.1 \pm 0.3 \pm 0.2$			
$B^- \to D^{*0}\pi^-$	$0.72 \pm 0.18 \pm 0.25$		$0.40 \pm 0.14 \pm 0.12$	$0.37(a_1 + 1.04a_2)^2$
$B^- \to D^{*0}\rho^-$			$1.0 \pm 0.6 \pm 0.4$	$1.18(a_1 + 0.79a_2)^2$
$B^- \to D^{*+}\pi^-\pi^-$	< 0.4	$0.23 \pm 0.15 \pm 0.07$	$0.26 \pm 0.14 \pm 0.07$	
$B^- \to D^{*+}\pi^-\pi^-\pi^0$			$1.8 \pm 0.7 \pm 0.5$	
$B^- \to J/\psi K^-$	$0.08 \pm 0.02 \pm 0.02$	$0.10 \pm 0.07 \pm 0.2$	$0.07 \pm 0.03 \pm 0.01$	$1.01a_2^2$
$B^- \to J/\psi K^{*-}$	$0.13 \pm 0.09 \pm 0.03$		$0.16 \pm 0.11 \pm 0.03$	$4.33a_2^2$
$B^- \to J/\psi K^-\pi^+\pi^-$	$0.12 \pm 0.06 \pm 0.03$		< 0.16	
$B^- \to \psi' K^-$	< 0.05		$0.18 \pm 0.08 \pm 0.04$	
$B^- \to \psi' K^{*-}$	< 0.35		< 0.49	
$B^- \to \psi' K^-\pi^+\pi^-$			$0.19 \pm 0.11 \pm 0.04$	

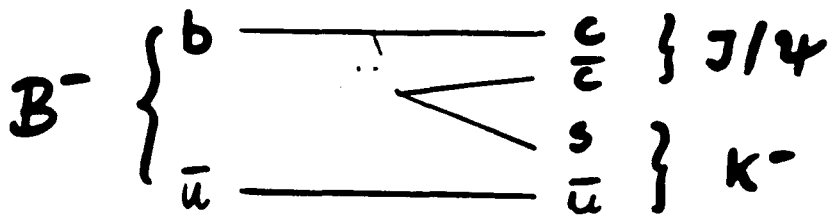
$\approx$ 15% OF HADRONIC B DECAYS

RATE

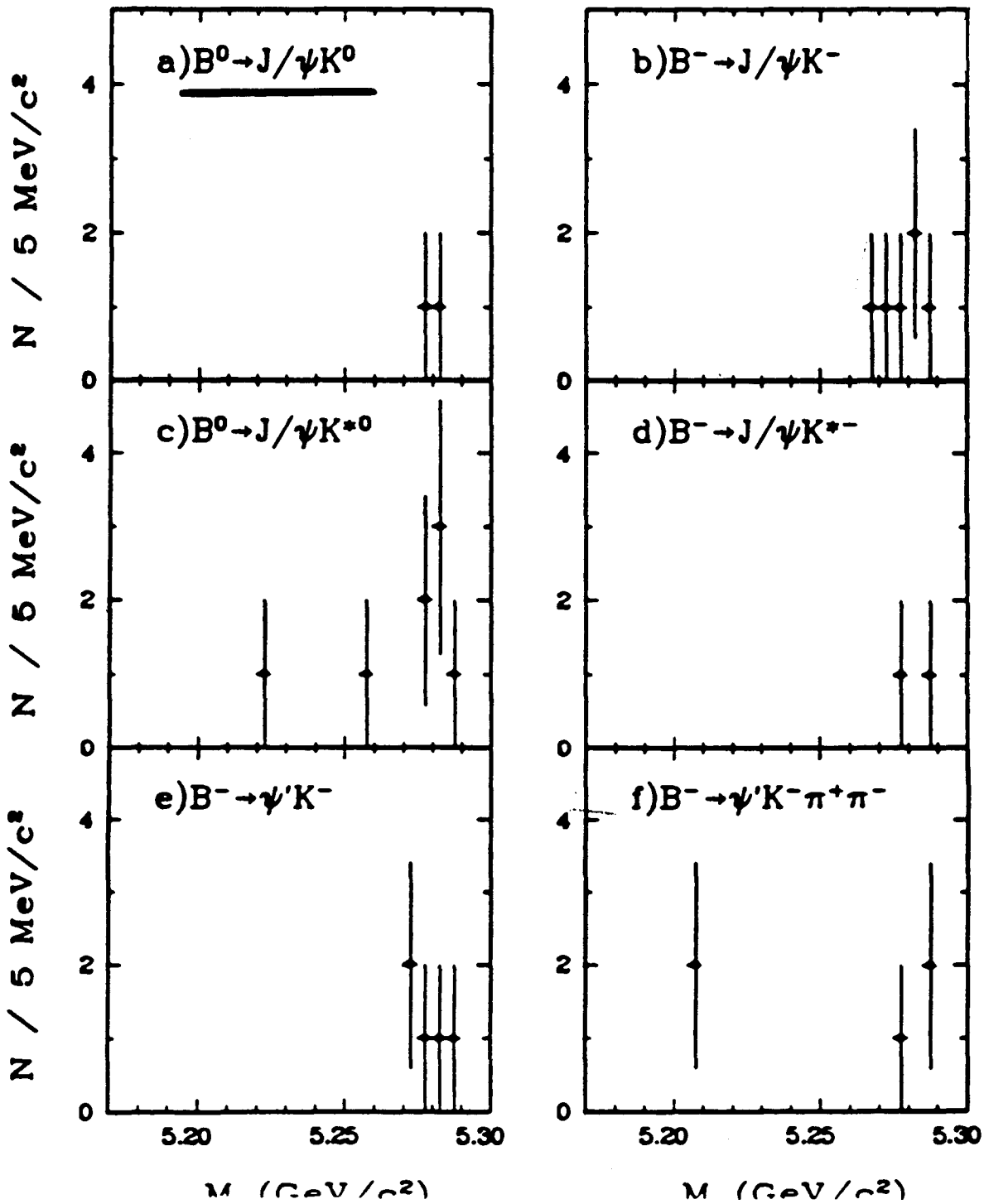
$\propto a_1^2$

(WBS)





RATE $\propto a_2^2$

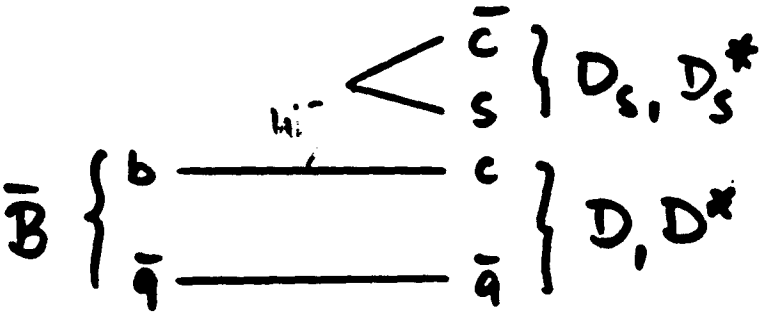


COMPARISON TO BSM-MODEL:

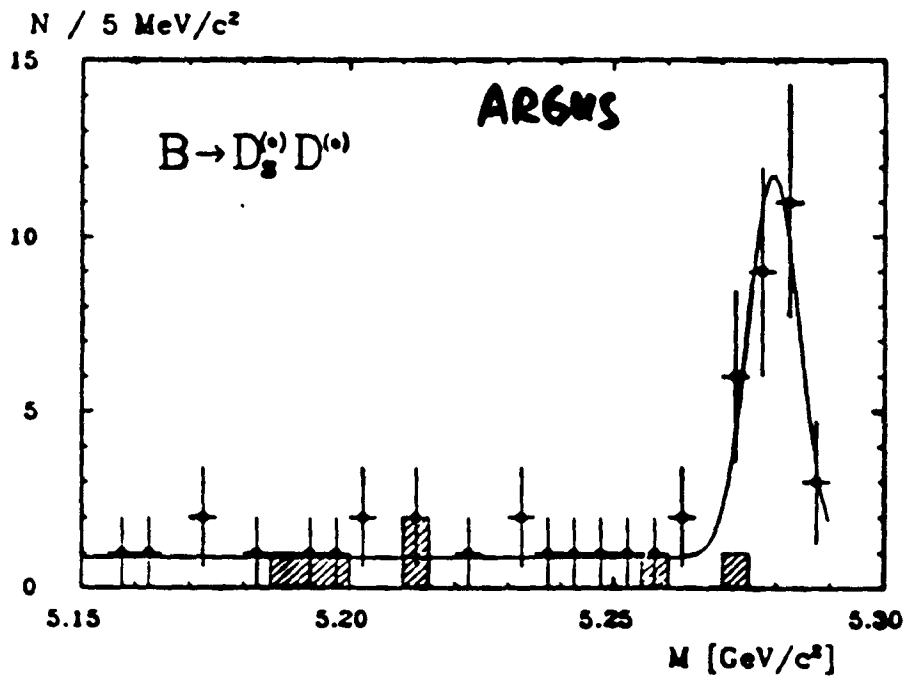
$$BR(\bar{B}_0 \to D_+\pi^-) \propto |\langle D_+|(\bar{c}b)_{V-A}|\bar{B}_0\rangle|^2 \, a_2^{eff} \cdot |V_{cb}|^2 \cdot \tau^{B_0}$$

$a_2^{eff} = 0.55 \pm 0.03$ $\quad a_2^{eff} = 0.48 \pm 0.05$ $\quad \tau^{B_0} = 1.54$ ps $\quad \tau^{B_-} = 1.65$ ps

THE DECAY $B \to D_s^{(*)} D^{(*)}$

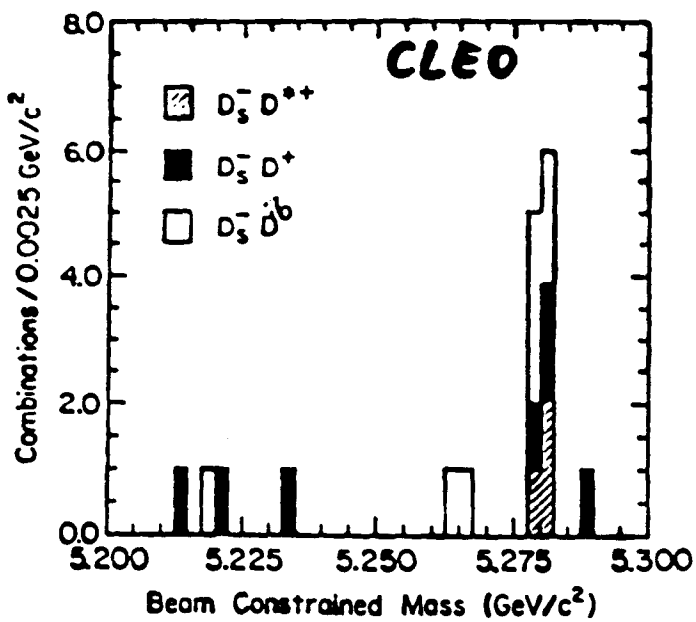


$$BR \sim \underbrace{a_1^2 |V_{cb}|^2}_{\text{FROM OTHER DATA}} \tau_B \, f_{D_s^{(*)}}$$



25.6 B_s' IN

8 CHANNELS



11 B_s' IN

3 CHANNELS

DECAY CHAINS $B \to D^{(*)} D_s^{(*)}$

$D_s \to \phi \pi^+$

$\phi \pi^+ \pi^0$

$\phi \pi^+ \pi^- \pi^+$

$K_s^0 K^{*+}$

$K_s^0 K^+$

$\bar{K}^{*0} K^{*+}$

$\bar{K}^{*0} K^+$

$\eta' \pi^+$

$\eta_{REC} \simeq 1\%$

$D^0 \to K^- \pi^+$

$K^- \pi^+ \pi^0$

$K_s^0 \pi^+ \pi^-$

$K^- \pi^+ \pi^- \pi^+$

$D^+ \to K^- \pi^+ \pi^-$

$K_s^0 \pi^+$

$K^- \pi^+ \pi^+ \pi^0$

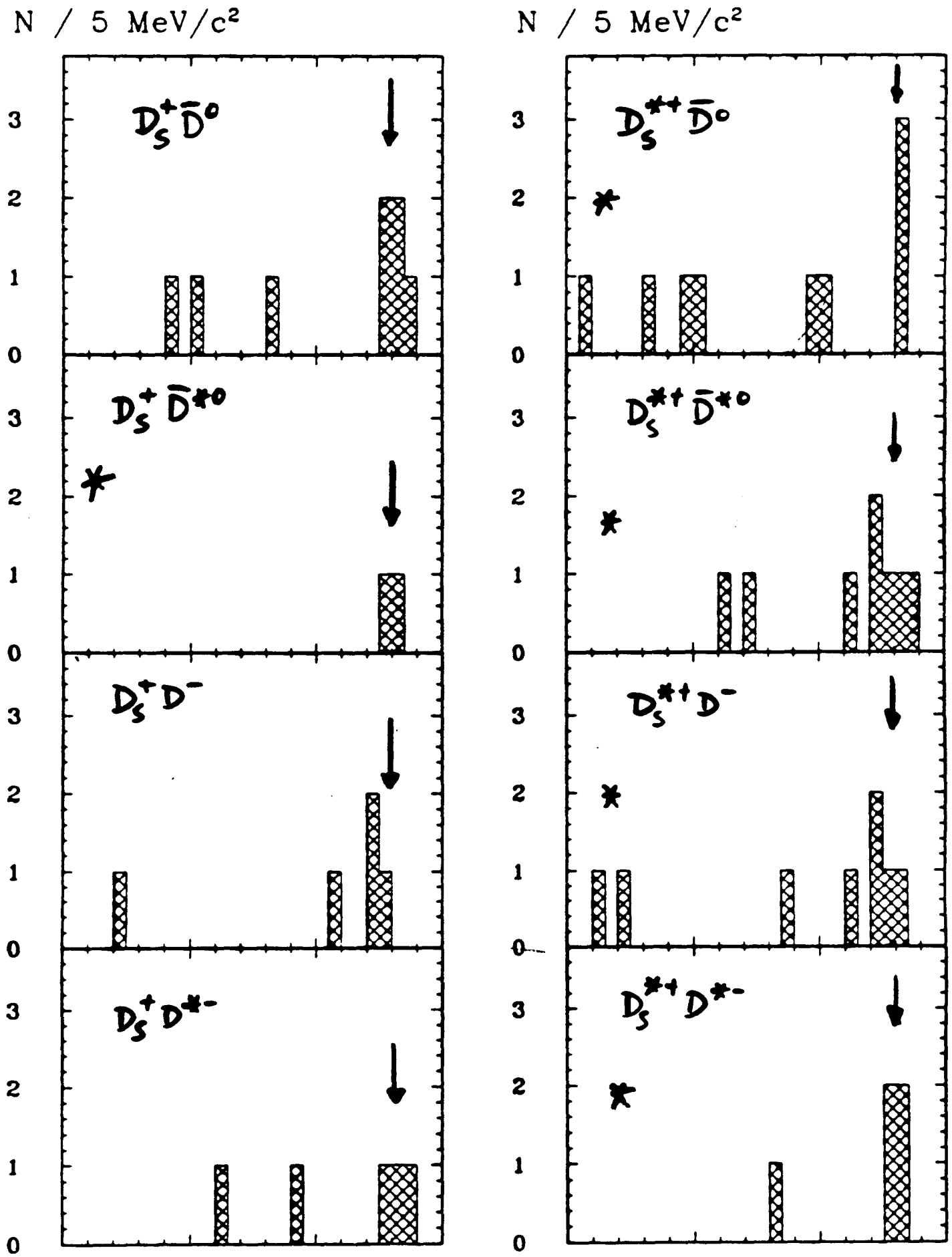
2.88 DECAY CHAINS

$D^{*+} \to D^0 \pi^+$

$D^{*0} \to D^0 \pi^0$

$D^0 \gamma$

$D_s^{*+} \to D_s^+ \gamma$


N / 5 MeV/c²
N / 5 MeV/c²
$D_s^+ \bar{D}^0$
$D_s^{*+} \bar{D}^0$
$D_s^+ \bar{D}^{*0}$
$D_s^{*+} \bar{D}^{*0}$
$D_s^+ D^-$
$D_s^{*+} D^-$
$D_s^+ D^{*-}$
$D_s^{*+} D^{*-}$
0
1
2
3

BRANCHING RATIOS (PDG '90)

BR [%]

DECAY	ARGUS	CLEO	 	BR_{THEOR}
$B^+ \to D_s^+ \bar{D}^0$	2.4 ± 1.3	2.4 ± 1.2	2.4 ± 1.1	1.8
$D_s^{*+} \bar{D}^0$	1.6 ± 1.2			1.0
$D_s^+ D^{*0}$	1.3 ± 0.9			0.8
$D_s^{*+} D^{*0}$	3.1 ± 1.6			2.9
$B^0 \to D_s^+ D^-$	1.7 ± 1.3	1.1 ± 0.6	1.2 ± 0.6	1.8
$D_s^{*+} D^-$	2.7 ± 1.8			1.0
$D_s^+ D^{*-}$	1.4 ± 1.0	2.4 ± 1.1	1.8 ± 0.8	0.8
$D_s^{*+} D^{*-}$	2.6 ± 1.3			2.9

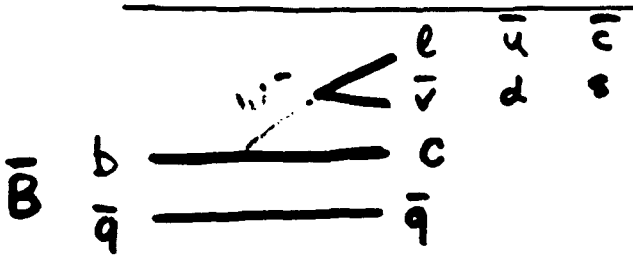
FOR $f_{D_s}^{(*)} = (270 \pm 30)$ MeV

[$a_1 = 1.13$, $|V_{cb}| = 0.043$,

$\tau_B = 1.24$ ps]

LATTICE QCD: $f_D \simeq 200 \ldots 300$ MeV

B - DECAYS IN SIMPLE SPECTATOR MODEL



$\Gamma / \Gamma_{sl.}$

b - DECAY	$B^-(b\bar{u})$	$\bar{B}^0(b\bar{d})$
$b \to c e^- \bar{\nu}$	1	1
$\to c \mu^- \bar{\nu}$	1	1
$\to c \tau^- \bar{\nu}$	0.23	0.23
$\to c \bar{u} d$	$3(a_1 + a_2)^2$	$3(a_1^2 + a_2^2)$
$\to c \bar{c} s$	$1.3(a_1^2 + a_2^2)$	$1.3(a_1^2 + a_2^2)$

$+ (b \to u) +$ CABIBBO-SUPP.

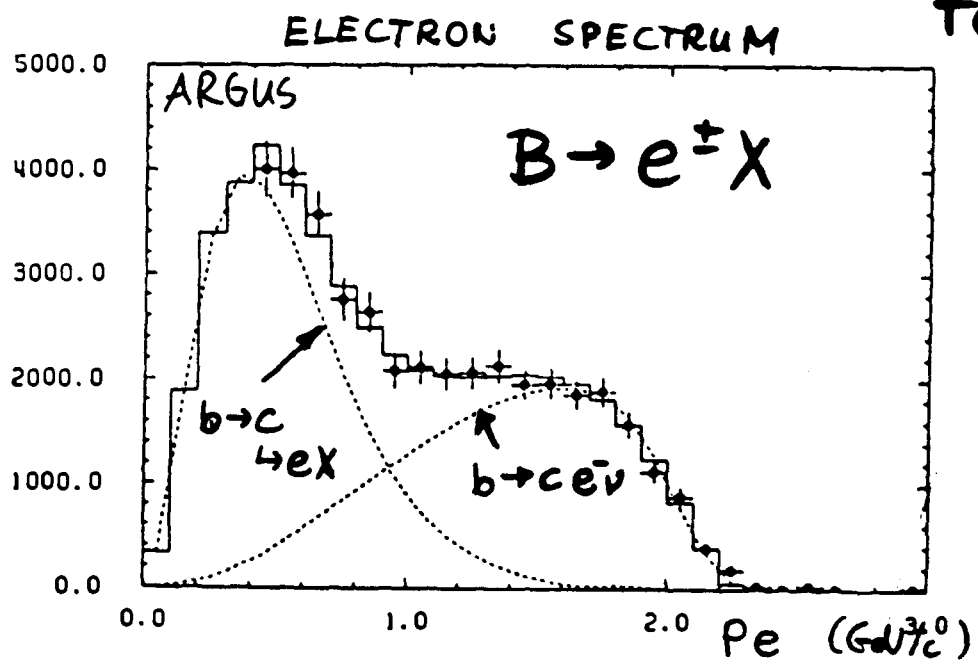
$a_1 = 1.13$; $a_2 = -0.22$:

$BR(B^- \to e^- X) = 14\%$; $BR(\bar{B}^0 \to e^- X) = 12\%$

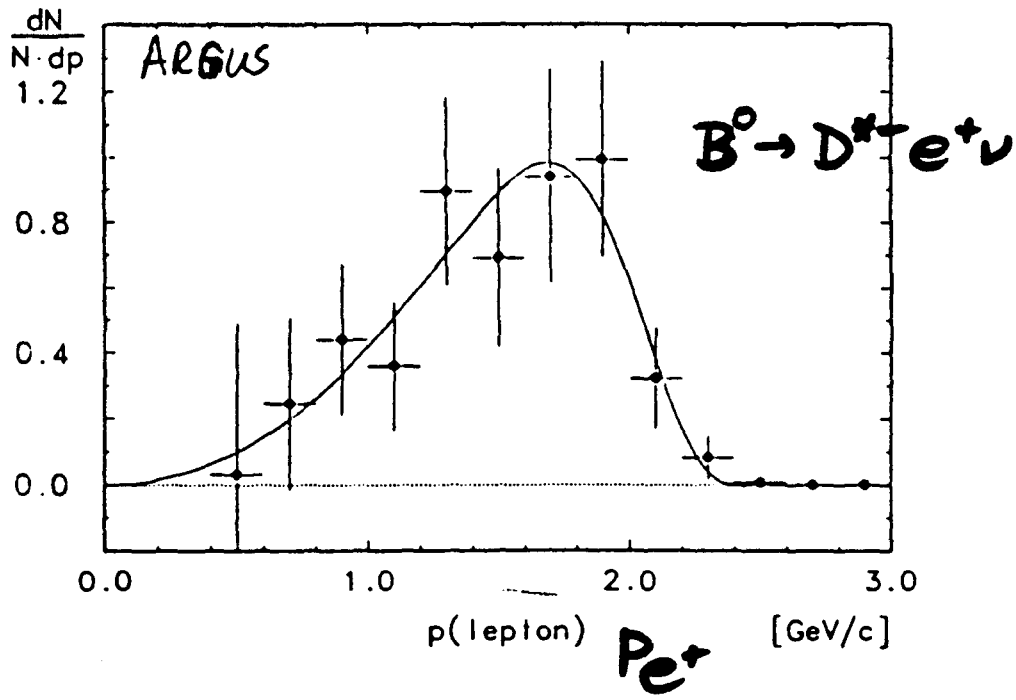
$$\left.\begin{array}{l} \tau_{B^-}/\tau_{B^0} = 1.2 \\ BR(B \to e^- X) = 13\% \end{array}\right\} \text{PREDICTE}$$

$BR(B \to \ell^{\pm} X) = (10.2 \pm 0.5 \pm 0.2)\%$ (ACM)

TOO LOW?



EXTRAPOLATION TO $p_e = 0$ O.K. :



NO BARYONS IN S.L. B DECAYS : $BR(B \to \bar{p} e^+ X) < 0.3\%$

$$\underline{|V_{cb}| = 0.046 \pm 0.004}$$

FOR $\frac{|V_{cb}|}{|V_{us}|}$ [illegible]

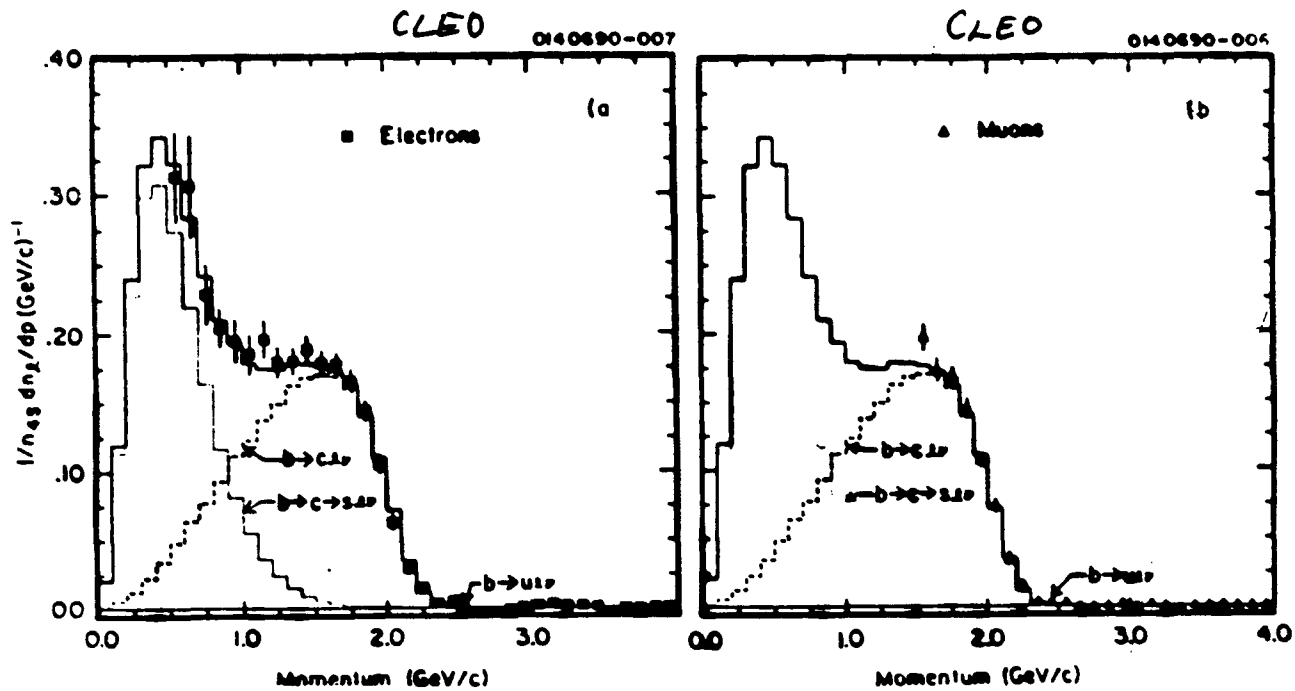


TABLE 9. Inclusive B meson semileptonic branching ratios and values of $|V_{cb}|$.

Model	ACCMM Branching Ratio (%)	ISGW Branching Ratio (%)	ACCMM $\lvert V_{cb}\rvert$	ISGW $\lvert V_{cb}\rvert$
CLEO	$10.4 \pm 0.2 \pm 0.4$	$10.0 \pm 0.1 \pm 0.3$	0.046 ± 0.003	0.045 ± 0.003
ARGUS	$10.2 \pm 0.4 \pm 0.2$	9.8 ± 0.4	0.046 ± 0.003	0.045 ± 0.003

$BR(B \to \ell X) \approx 10\%$ SMALL!

PENGUINS ?

ANNIHILATION ?

$\Upsilon(4S) \to B\bar{B}$?

INCLUSIVE $b \to c$ DECAYS

DECAY	$\langle BR \rangle$ [%] ARGUS, CLEO
$B \to D^0 X$	$59 \pm 3 \pm 8$
$D^+ X$	$30 \pm 3 \pm 8$
$D_s^+ X$	$9 \pm 2 \pm 4$
$\to J/\psi X$	$1.1 \pm 0.1 \pm 0.2$
$\psi' X$	$0.4 \pm 0.1 \pm 0.1$
$\to \chi_c X$	$1.1 \pm 0.4 \pm 0.3$
$\Lambda_c X$	$6.7 \pm 0.7 \pm 1.2$
	$107 \pm 5 \pm \underline{10}$

(PDG'90)

EXPECT $\underline{115}$

WITH MARK III BR:

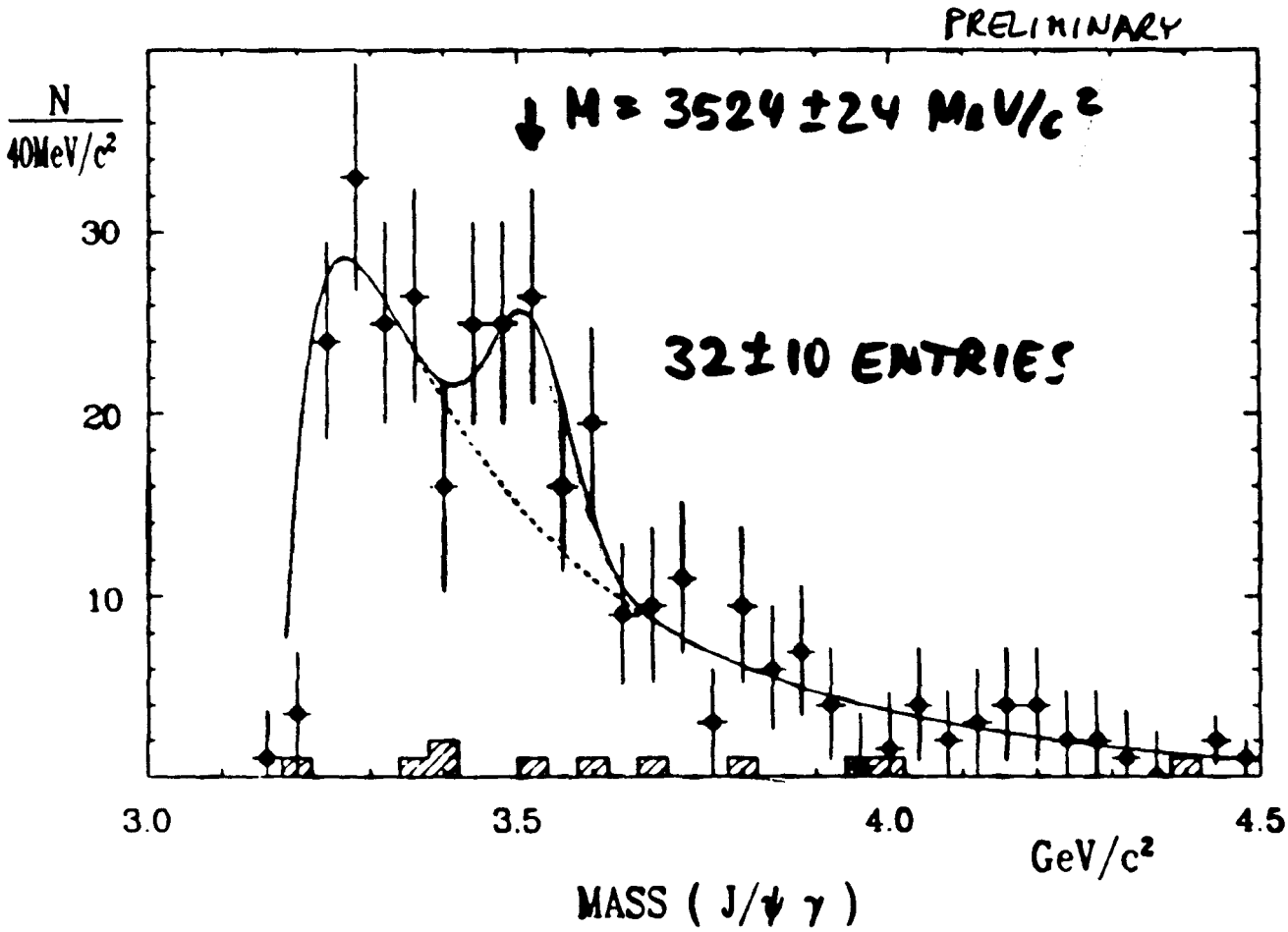
$97 \pm 5 \pm \underline{10}$

SOME LITTLE ROOM LEFT FOR OTHER B-DECAYS

$B \to \chi_{c_1} X$

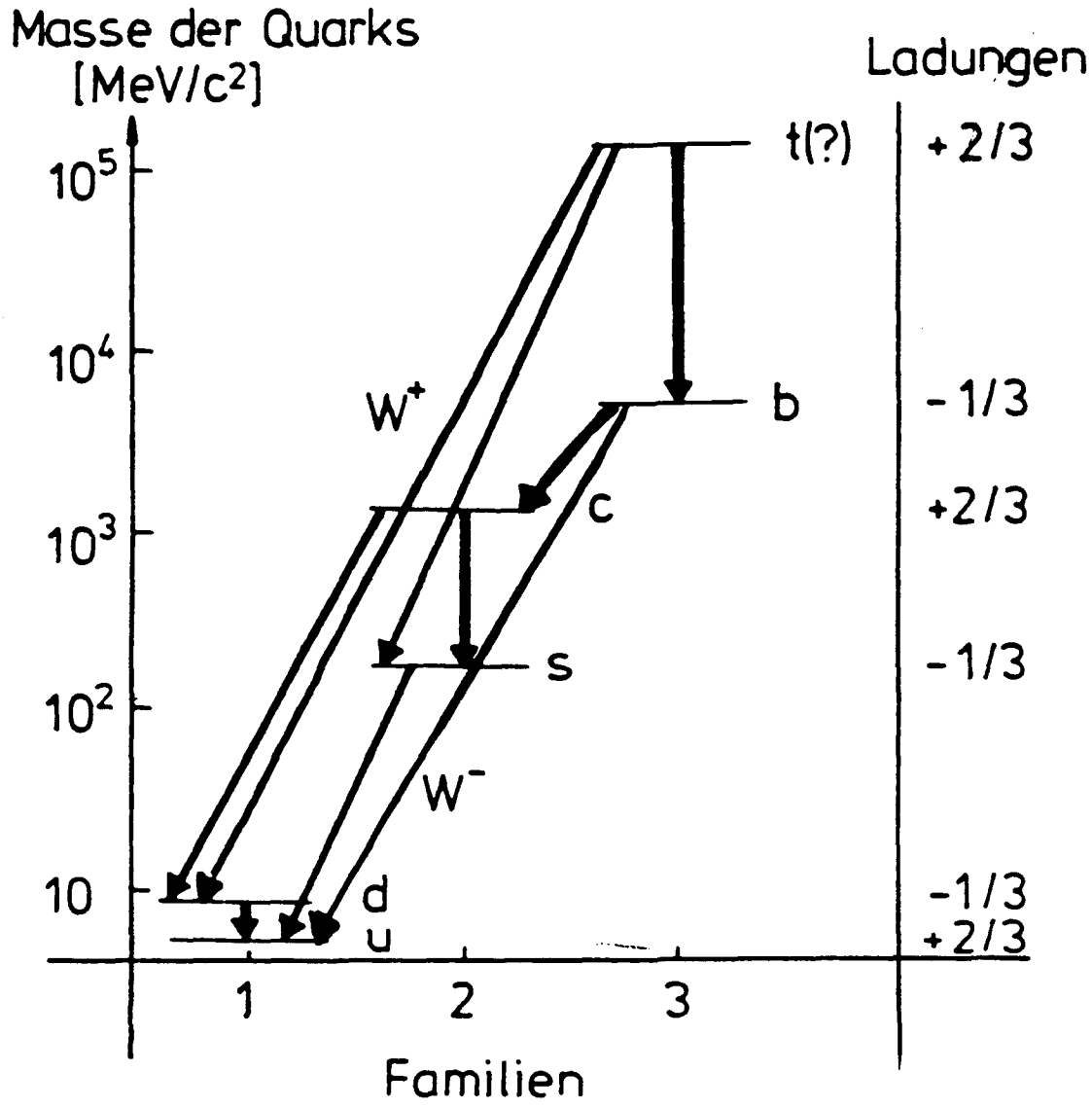
(27%) $\hookrightarrow \gamma\, J/\psi$

$\hookrightarrow e^+e^-,\ \mu^+\mu^-$



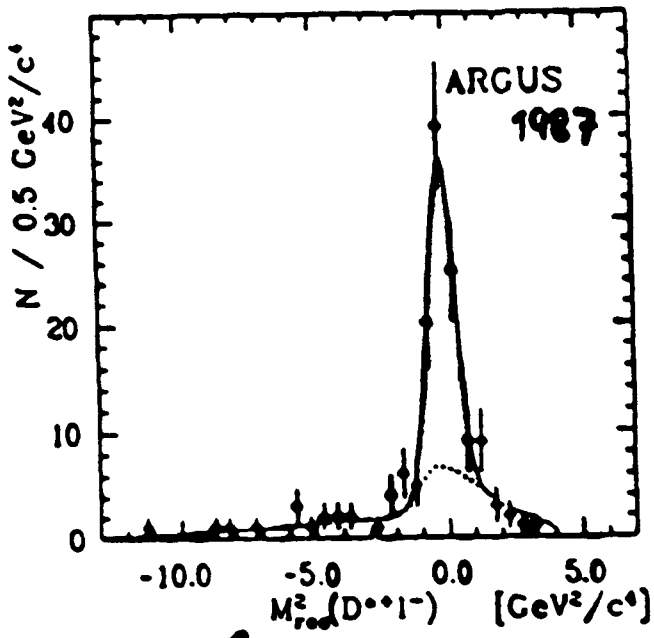
$BR(B \to \chi_{c_1} X) = (1.1 \pm 0.4 \pm 0.3)\%$

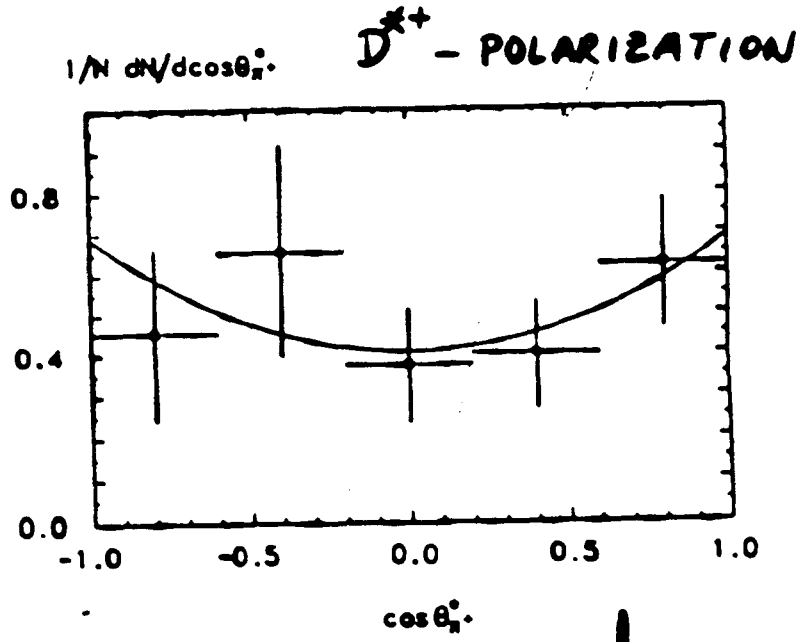
I. KM MATRIX - ELEMENTS



a. $|V_{cb}|$ FROM EXCLUSIVE SEMILEPTONIC B DECAYS

1. $\bar{B}^0 \to D^{*+} \ell^- \bar{\nu}$

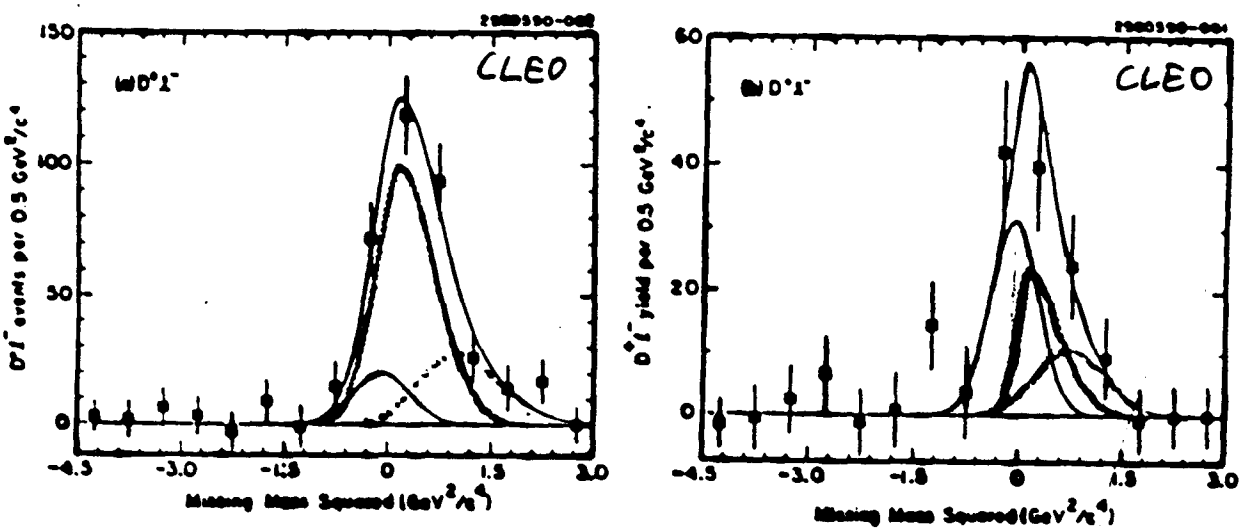




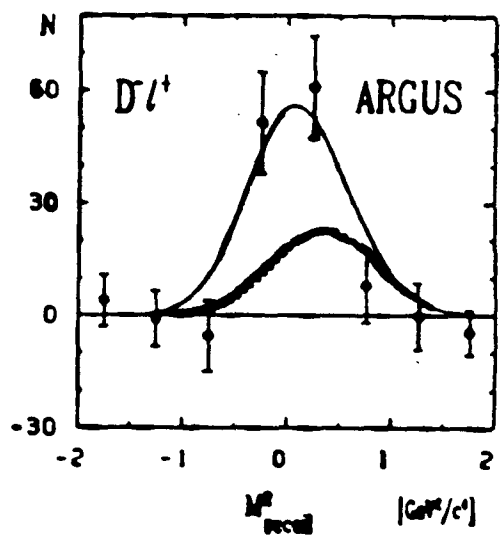
V_{cb} :

		CLEO 1.5	ARGUS
$B(\bar{B}^0 \to D^{*+} \ell^- \bar{\nu}_\ell)$		$(4.6 \pm 0.5 \pm 0.7)\%$	$(5.4 \pm 0.8 \pm 1.3)\%$
$\frac{\Gamma_L}{\Gamma_T}(\bar{B}^0 \to D^{*+} \ell^- \bar{\nu}_\ell)$		$0.83 \pm 0.33 \pm 0.13$	$0.85 \pm 0.4 \pm 0.2$
$\lvert V_{cb}\rvert$	ISGW	0.039 ± 0.005	0.043 ± 0.007
$\lvert V_{cb}\rvert$	KS	0.039 ± 0.005	0.042 ± 0.007
$\lvert V_{cb}\rvert$	WSB	0.042 ± 0.005	0.046 ± 0.007

$B^- \to D^0 \ell^- \nu$ $\qquad$ $\bar{B}^0 \to D^+ \ell^- \bar{\nu}$



$MM^2(D\ell^-)$



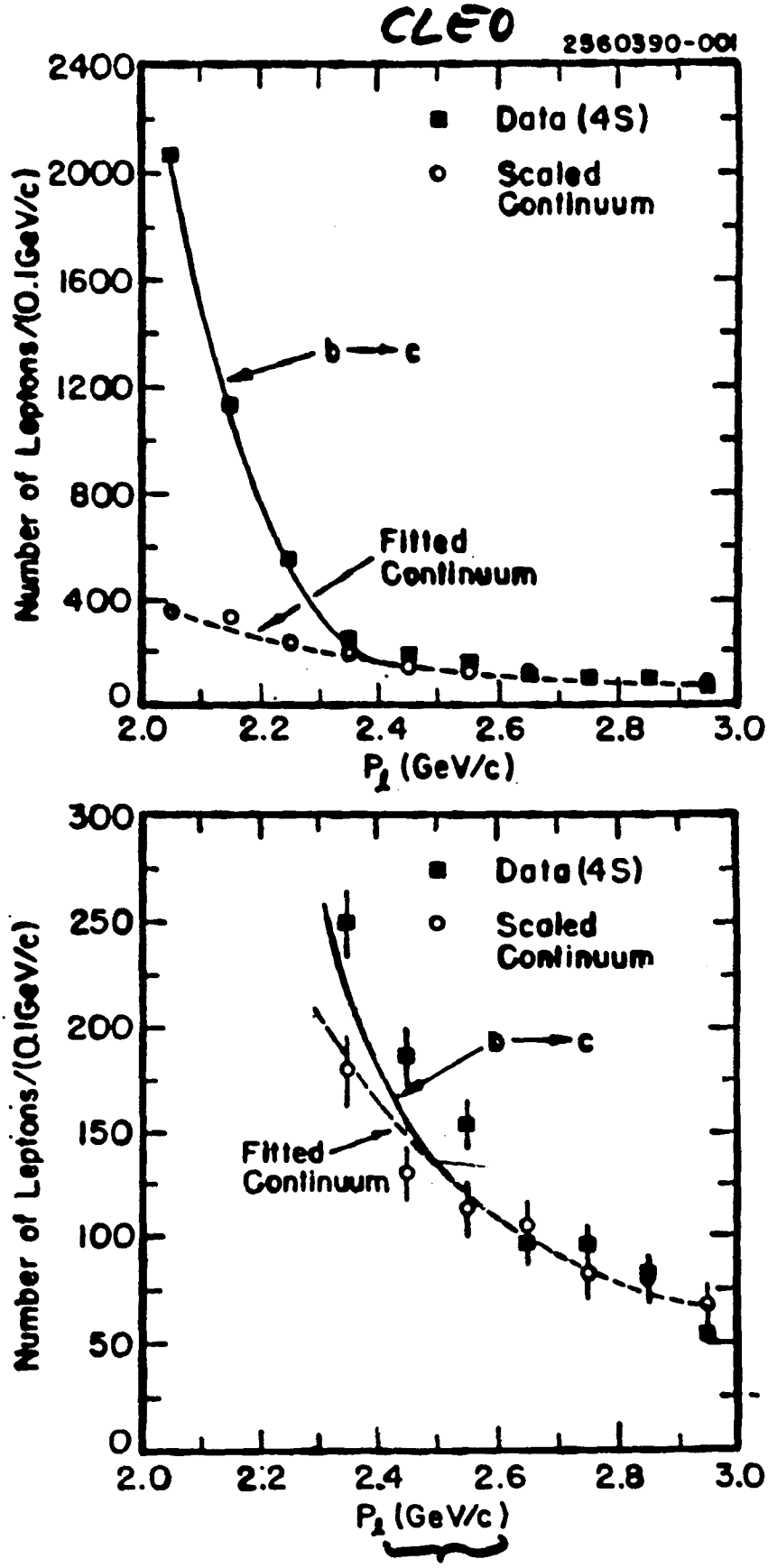
		CLEO 1.5	ARGUS
BR	$B(\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell)$	$(4.6 \pm 0.5 \pm 0.7)\%$	$(5.4 \pm 0.8 \pm 1.3)\%$
	$B(\bar{B}^0 \to D^+\ell^-\bar{\nu}_\ell)$	$(1.8 \pm 0.6 \pm 0.3)\%$	$(1.6 \pm 0.5 \pm 0.5)\%$
	$B(B^- \to D^{*0}\ell^-\bar{\nu}_\ell)$	$(4.1 \pm 0.8 \pm 0.9)\%$	
	$B(B^- \to D^0\ell^-\bar{\nu}_\ell)$	$(1.6 \pm 0.6 \pm 0.3)\%$	
V / P →	$\frac{B(B \to D^*\ell^-\bar{\nu}_\ell)}{B(B \to D\ell^-\bar{\nu}_\ell)}$	$2.6^{+1.1+1.0}_{-0.6-0.8}$	$3.0^{+2.7}_{-1.1}$
V_{cb}	$\lvert V_{cb}\rvert$ ISGW	0.036 ± 0.006	0.035 ± 0.008
	$\lvert V_{cb}\rvert$ KS	0.042 ± 0.006	0.040 ± 0.009
	$\lvert V_{cb}\rvert$ WSB	0.042 ± 0.007	0.041 ± 0.009

b. V_{ub}

1. ENDPOINT OF LEPTON SPECTRUM

2. EXCLUSIVE $b \to u$

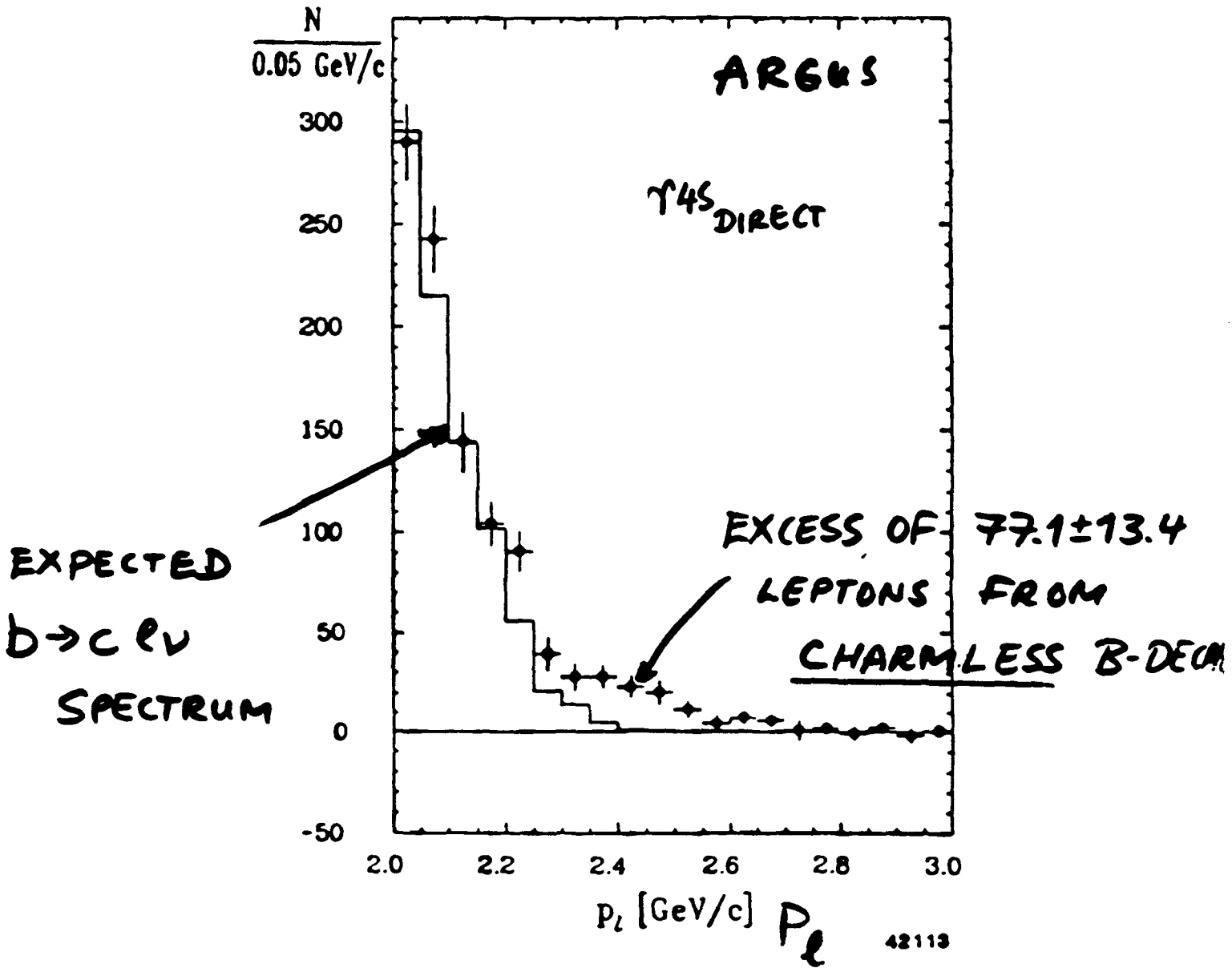
1. ENDPOINT OF INCLUSIVE LEPTON SPECTRUM



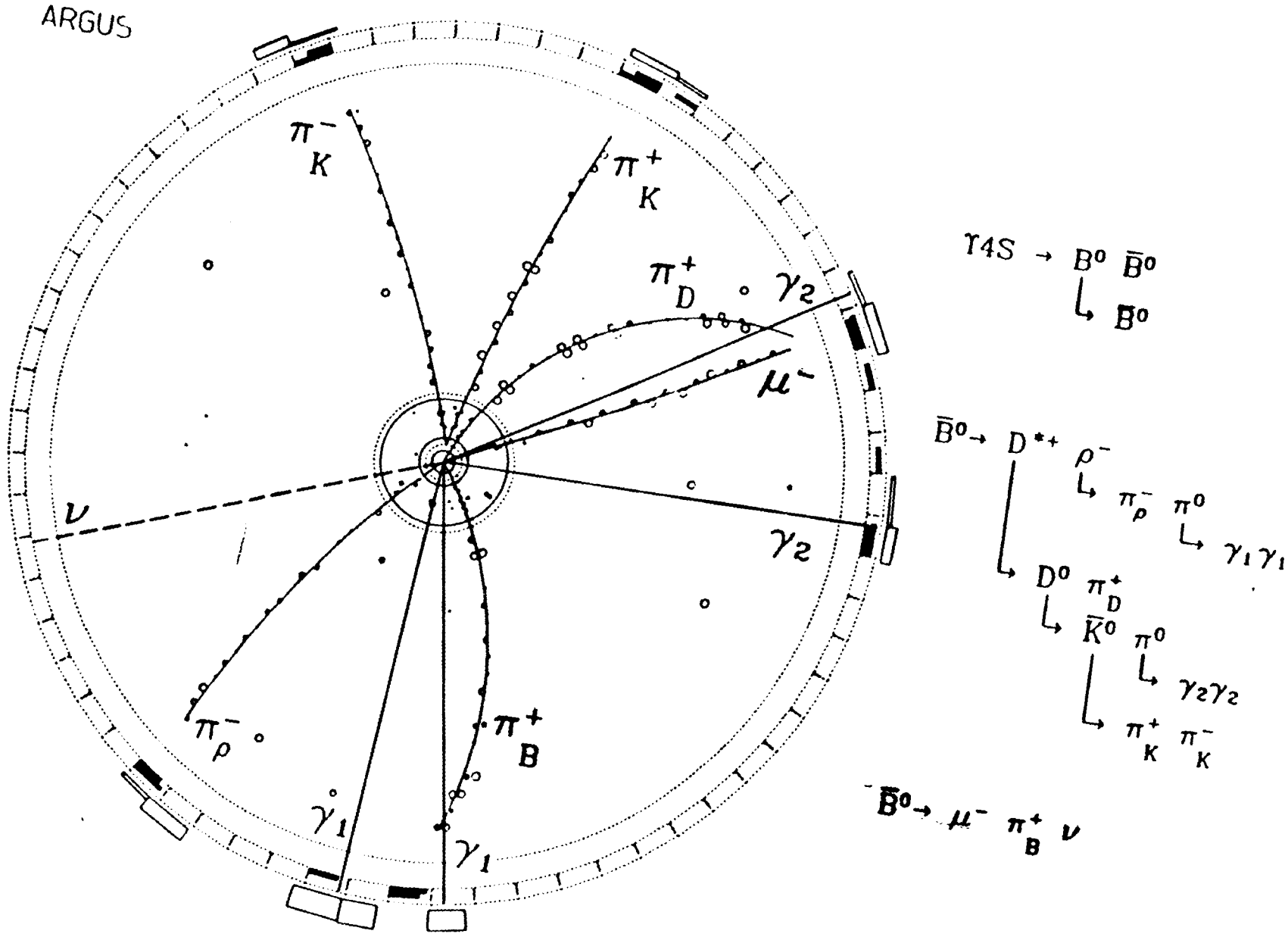
$b \to u$ TRANSITIONS

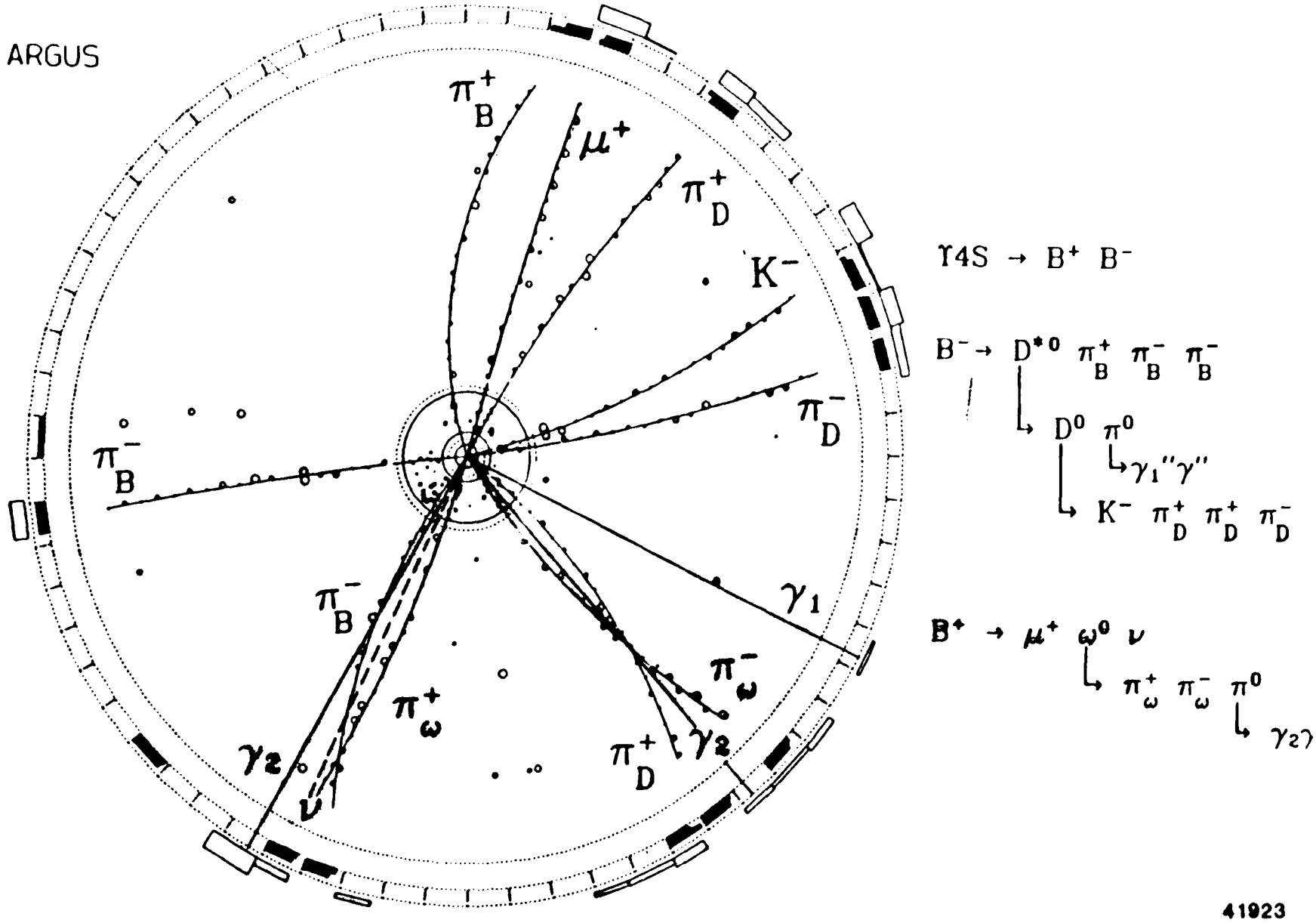
INCLUSIVE LEPTON SPECTRUM

$B \to \ell X$



EXCESS DUE TO $b \to u$ TRANSITIONS:


ARGUS
π^-_K
π^+_K
π^+_D
γ_2
μ^-
ν
γ_2
π^-_ρ
π^+_B
γ_1
γ_1
$\Upsilon 4S \to B^0 \bar{B}^0$
$\hookrightarrow \bar{B}^0$
$\bar{B}^0 \to D^{*+} \rho^-$
$\hookrightarrow \pi^-_\rho \pi^0$
$\hookrightarrow \gamma_1 \gamma_1$
$\hookrightarrow D^0 \pi^+_D$
$\hookrightarrow \bar{K}^0 \pi^0$
$\hookrightarrow \gamma_2 \gamma_2$
$\hookrightarrow \pi^+_K \pi^-_K$
$\bar{B}^0 \to \mu^- \pi^+_B \nu$
41924


ARGUS
π_B^+
μ^+
π_D^+
K^-
π_D^-
π_B^-
γ_1
π_B^-
π_ω^-
π_ω^+
γ_2
ν
π_D^+
γ_2
$\Upsilon 4S \to B^+ B^-$
$B^- \to D^{*0} \pi_B^+ \pi_B^- \pi_B^-$
$D^0 \pi^0$
$\gamma_1 \text{"}\gamma\text{"}$
$K^- \pi_D^+ \pi_D^+ \pi_D^-$
$B^+ \to \mu^+ \omega^0 \nu$
$\pi_\omega^+ \pi_\omega^- \pi^0$
$\gamma_2 \gamma$
41923

2. ANALYSIS OF $B^- \to \rho^0 e^- \bar{\nu}$

$\hookrightarrow \pi^+\pi^-$ PRELIMINARY

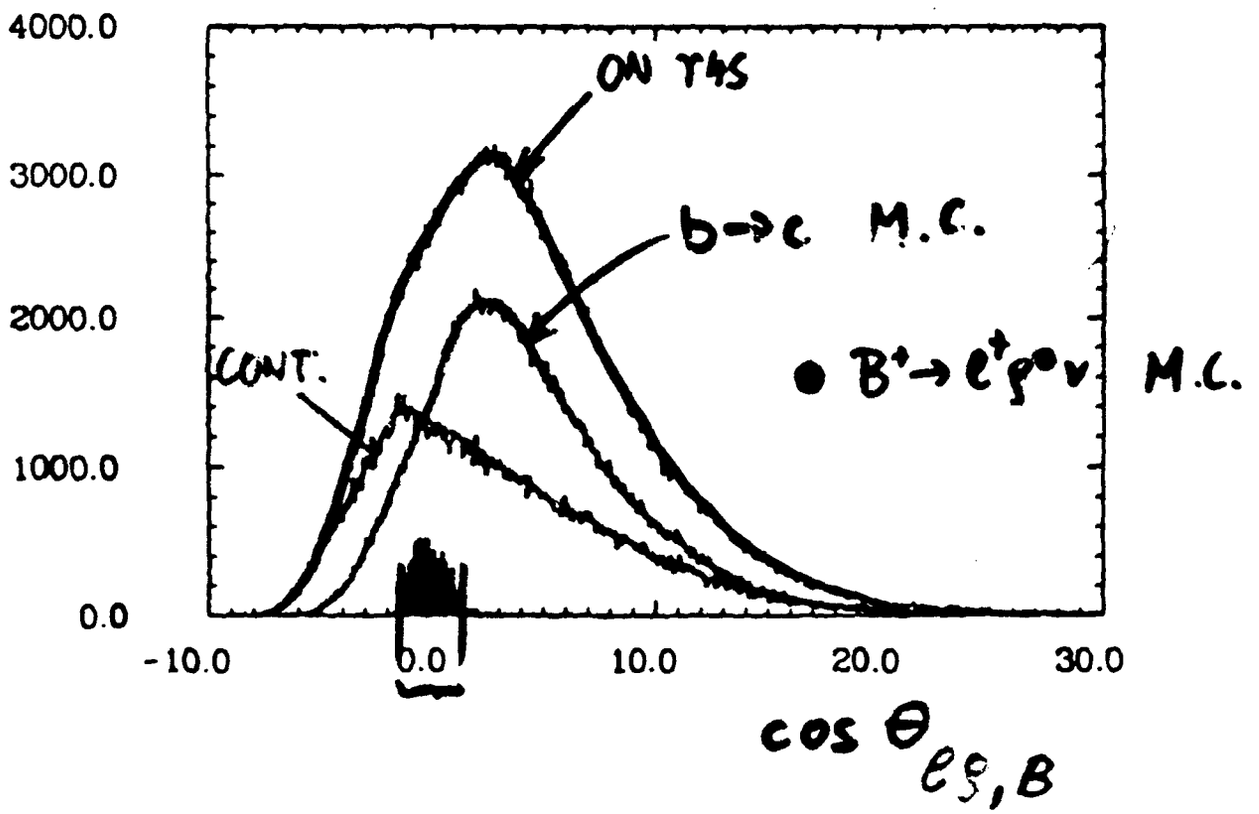
KINEMATICAL CUTS SUPPRESS

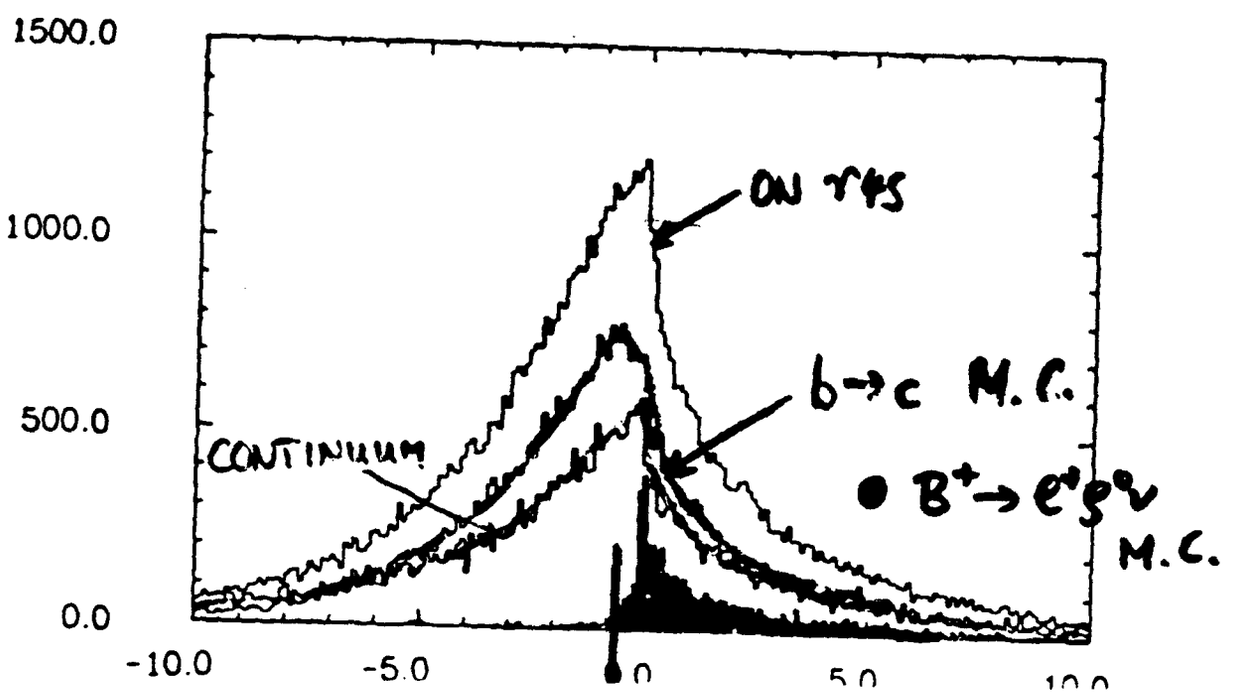
$b \to c\, e\nu$ TRANSITIONS AND CONTINUUM

* $M_\nu^2 = M_B^2 + M_{e\rho}^2 - 2E_B E_{e\rho} + 2|\vec{p}_B||\vec{p}_{e\rho}| \cdot \cos\theta_{e\rho}$

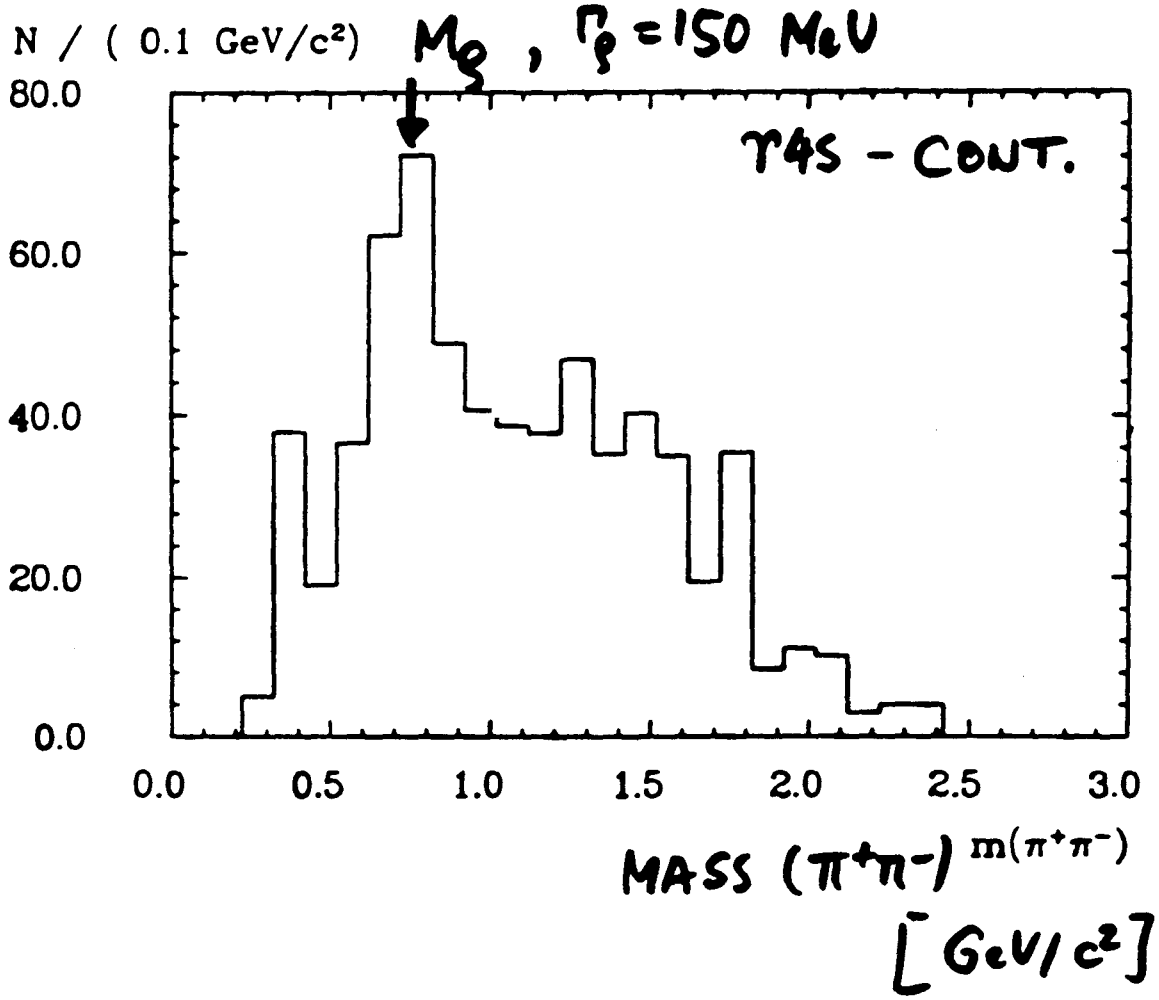
$\overset{!}{=} 0$

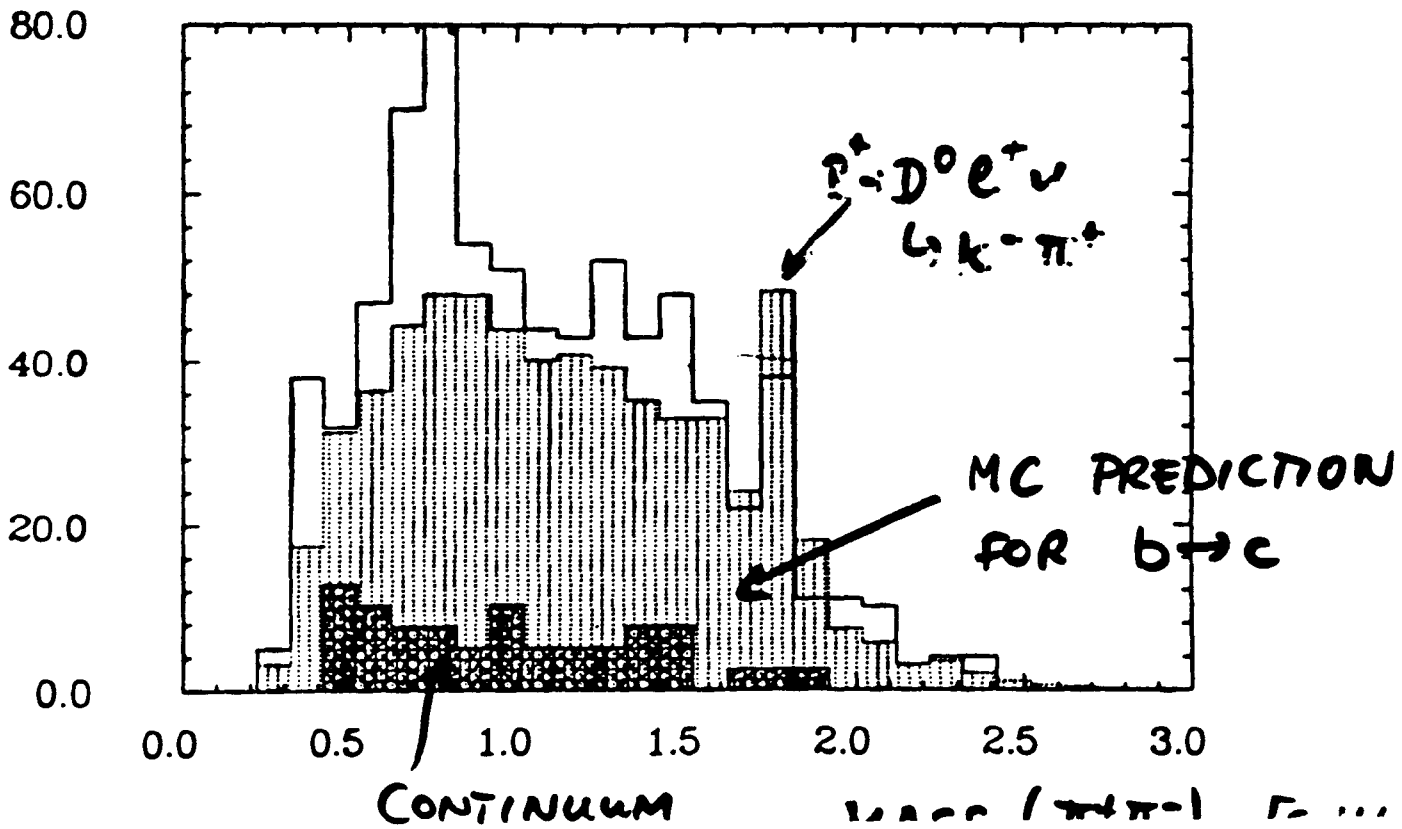
* $M_{LOSS}^2 = (P_B - P_X)^2$: LOST MASS IN THE EVENT


4000.0
3000.0
2000.0
1000.0
0.0
-10.0
0.0
10.0
20.0
30.0
ON Υ4S
b→c M.C.
CONT.
● B⁺→e⁺ρ⁰ν M.C.
cos θ_{eρ,B}

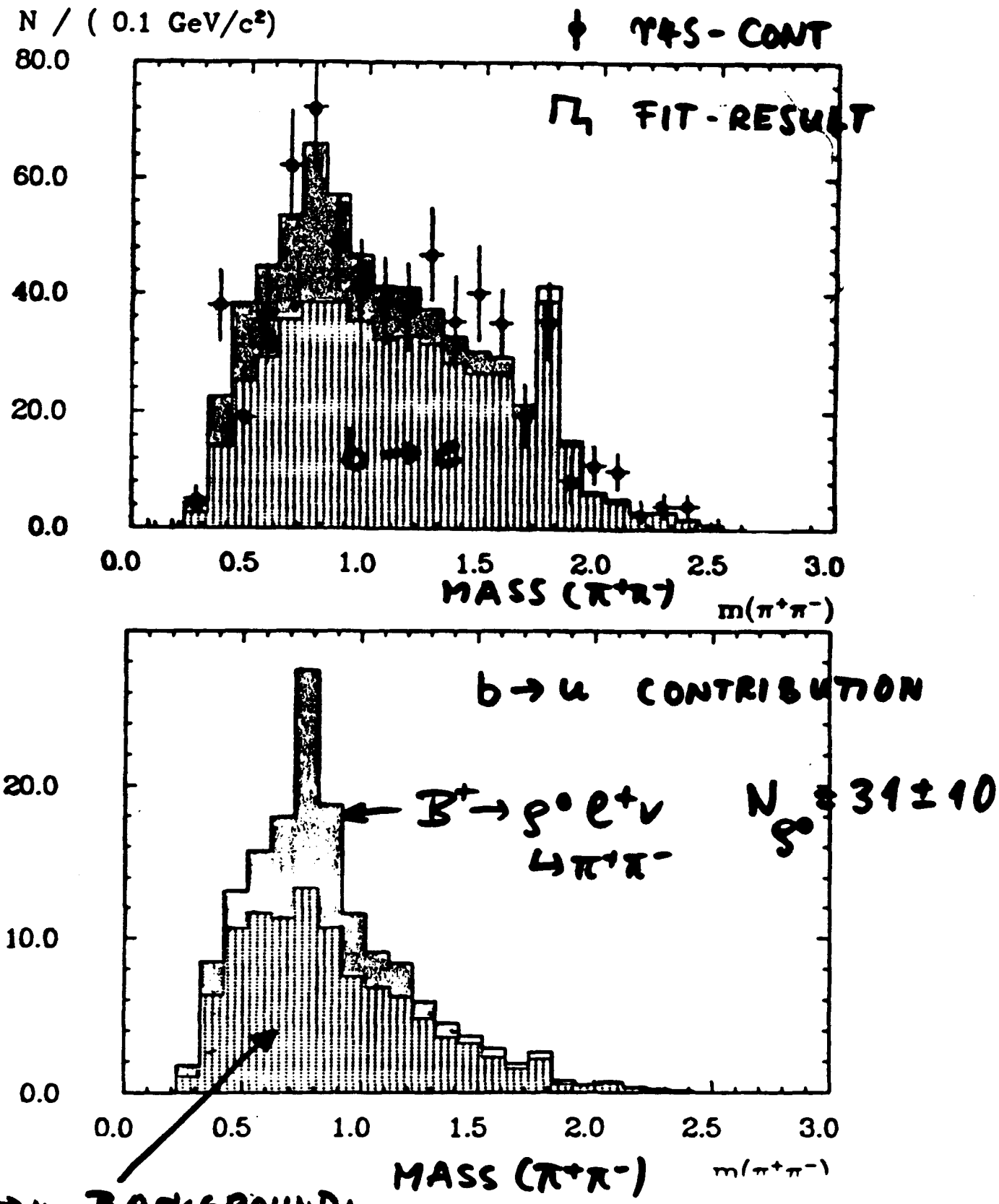

1500.0
1000.0
500.0
0.0
-10.0
-5.0
0
5.0
10.0
ON Υ4S
b→c M.C.
CONTINUUM
● B⁺→e⁺ρ⁰ν M.C.

FINAL $\pi^+\pi^-$ - SPECTRUM





$\pi^+\pi^-$ - SPECTRUM



RESULT:

$$BR(B^+ \to e^+ \rho^0 \nu) = (1.13 \pm 0.36 \pm 0.30) \cdot 10^{-3}$$

(PRELIMINARY)

$|V_{ub}|/|V_{cb}|$

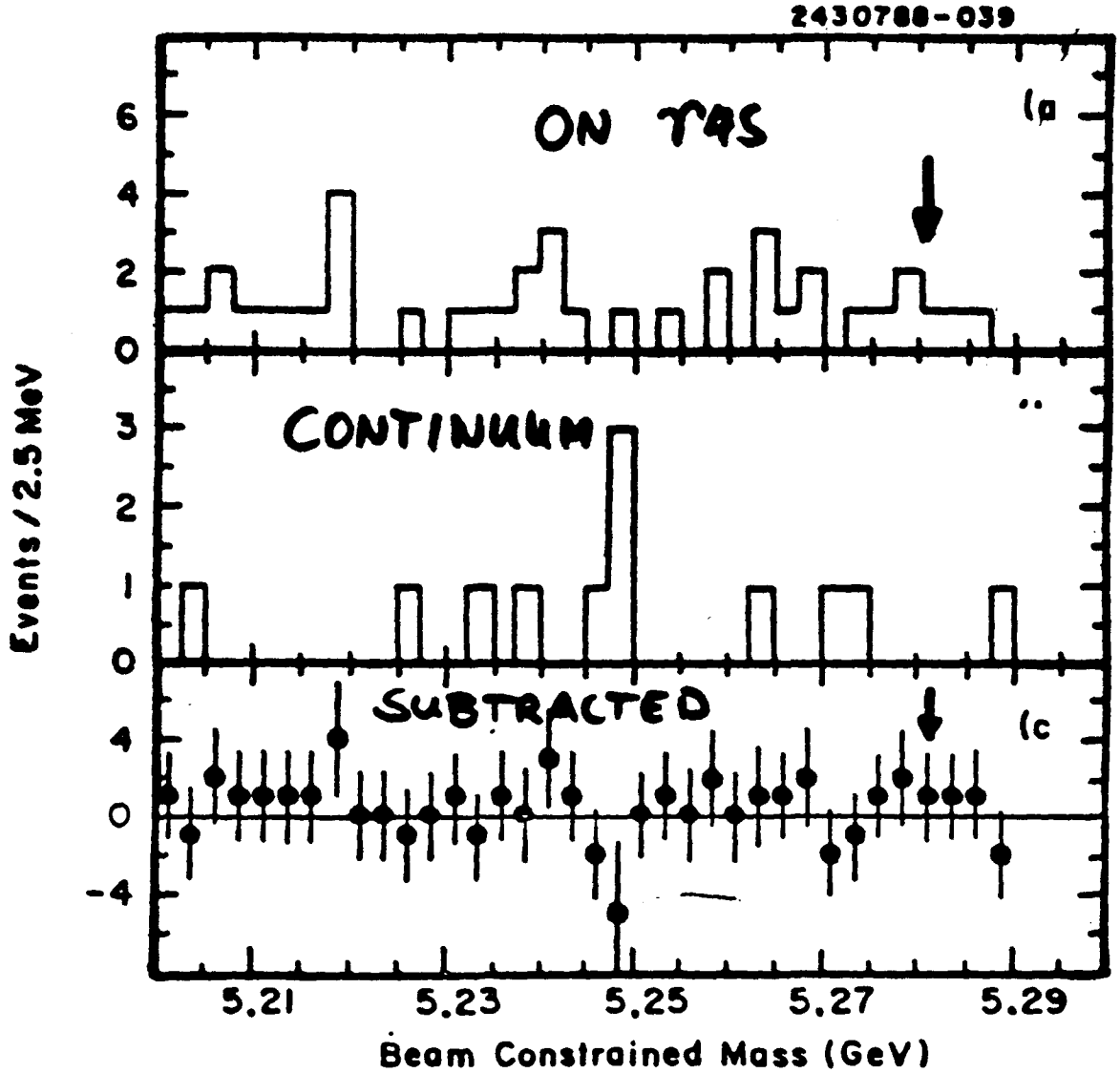
MODEL	$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ INCLUSIVE
KS (Z. PHYS. C38, 1988)	0.15 ± 0.03	0.14 ± 0.02
WBS (Z. PHYS. C42, 1989)	0.19 ± 0.03	0.12 ± 0.07
ISGW (PR D39, 1989)	0.30 ± 0.06	0.17 ± 0.03
KP (DESY 90-14)	0.15 ± 0.03	0.15 ± 0.02
KSM (DESY 90-168)	0.14 ± 0.02	

$|V_{cb}| = 0.05$

EXCLUSIVE HADRONIC $b \to u$ DECAYS

SEARCH !

CLEO : $B^0 \to \pi^+ \pi^-$

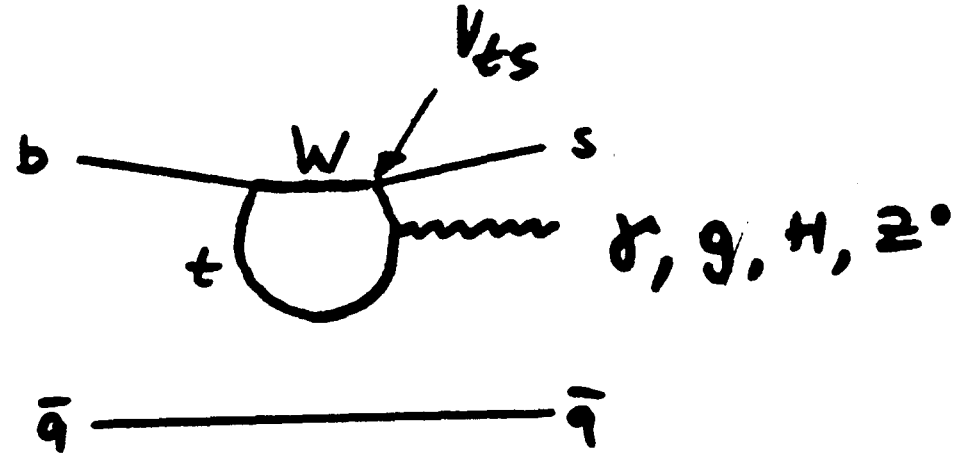


NO SIGNAL 90% C.L. LIMIT < 8.9 EVENTS

OR $BR(B^0 \to \pi^+\pi^-) < 0.9 \cdot 10^{-4}$

$b \to s$ DECAYS

OR 'PENGUIN' DECAYS



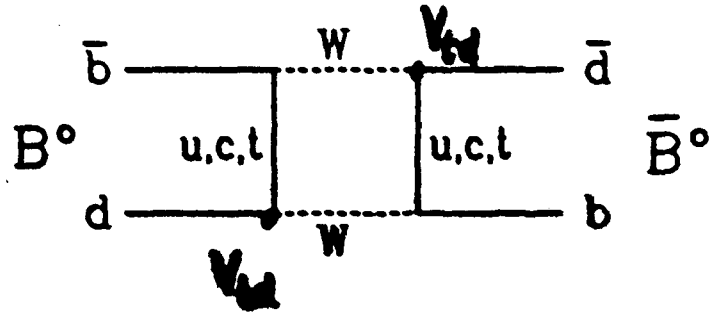
* 'PENGUIN'-DECAYS CAN ONLY BE IDENTIFIED IN B-DECAYS, e.g. $B^0 \to \phi K^0$.
* IMPORTANT FOR UNDERSTANDING THE K-MESONS ($\varepsilon' \neq 0$, CP-VIOLATION)
* WINDOW FOR NEW PHYSICS
* THEORETICAL ESTIMATES:

$$BR(b \to s\gamma) \approx 5 \cdot 10^{-4} \cdot \left(\frac{V_{ts}}{0.05}\right)^2 \left(\frac{m_t}{130\,\text{GeV}}\right)^{1.2}$$

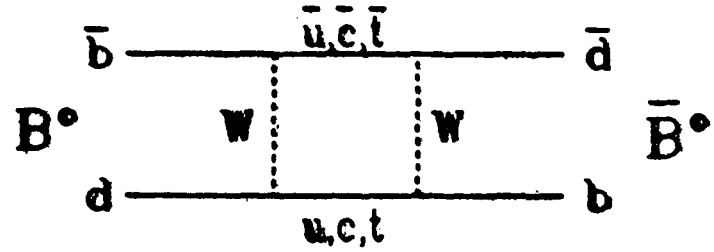
EXCLUSIVE:

$$\frac{BR(B \to K^*\gamma)}{BR(b \to s\gamma)} = ? \quad (0.05 \cdots 0.4)$$

$B^0\bar{B}^0$ - MIXING



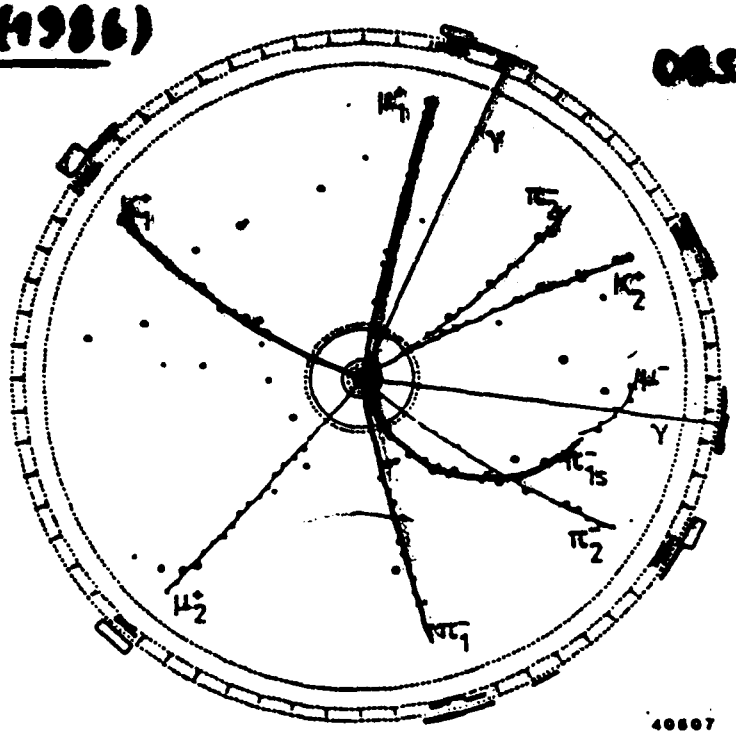
"BOX DIAGRAM



MIXED EVENT (1986)

$\Upsilon(4S) \to B^0 B^0$

$B^0 \to D^{*-} \mu^+ \nu$



OBSERVATION OF $B^0\bar{B}^0$ MIXING

ARGUS: (1987)

$$r = \frac{\text{PROB}(B^0 \to \bar{B}^0)}{\text{PROB}(B^0 \to B^0)} = 0.21 \pm 0.08$$

$$x = \frac{\Delta M}{\Gamma} = \frac{G_F^2}{6\pi^2} B_B f_B^2 m_b \tau_b |V_{td}|^2 \cdot m_t^2 F\left(\frac{m_t^2}{m_W^2}\right) \eta_{QCD}$$

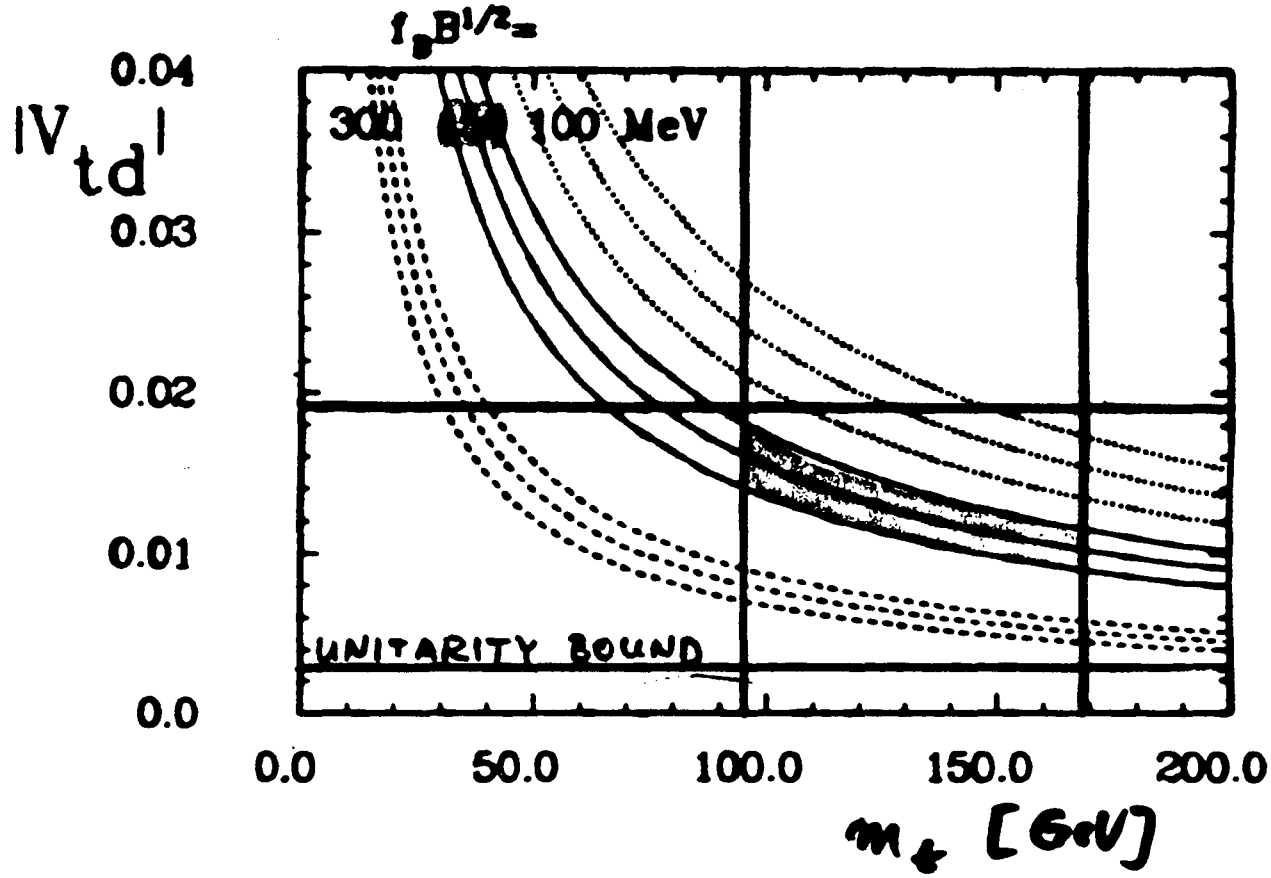
$$= 0.67 \pm 0.11 = \sqrt{\frac{2r}{1-r}}$$

m_t : ELECTROWEAK DATA

$m_t = 132 \,^{+31}_{-37}$ GeV/c² J. ELLIS G.L. FOGLI

DIRECT SEARCH (CDF)

$m_t > 89$ GeV/c²



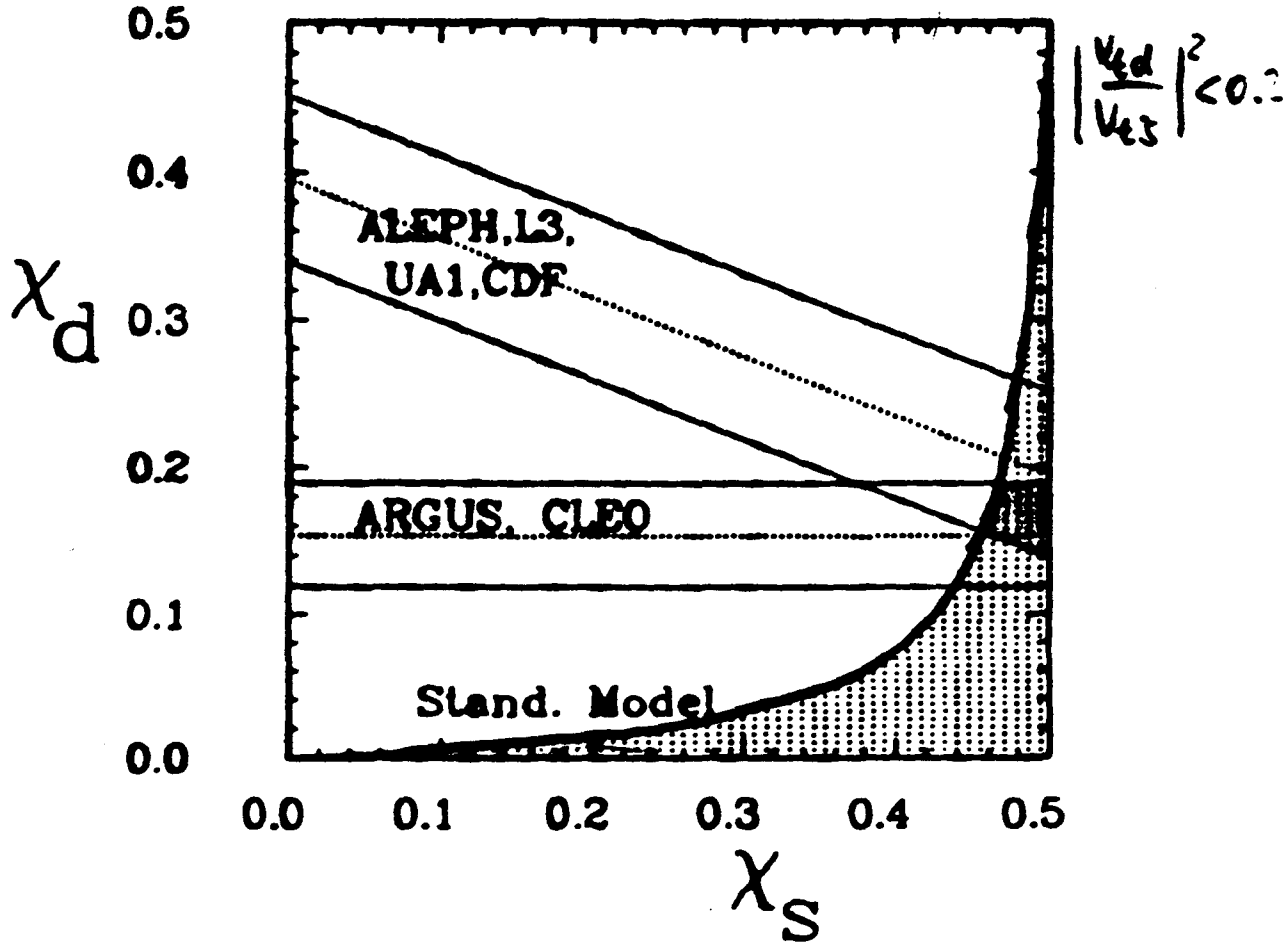
$0.009 < |V_{td}| < 0.018$ FOR $f_B B^{1/2} = 150$ MeV

$B\bar{B}$ MIXING

COMPARISON TO ALEPH, L3
UA1, CDF :

$$\chi = 0.375\,\chi_d + 0.15\,\chi_s \quad ; \quad \chi = \frac{r}{1+r}$$

$$\langle \chi \rangle = 0.148 \pm 0.024$$



ARGUS, CLEO : $\chi_s > 0.44$

SUMMARY

* GROSS FEATURES OF B DECAYS KNOWN
* FUNDAMENTAL PARAMETERS CAN BE MEASURED, THE PROCESSES ARE OBSERVED
* PRECISION MEASUREMENTS NEEDED
* RARE DECAYS POSSIBLY DETECTABLE
* ~~CP~~

PHOTOPRODUCTION

OF

HEAVY

FLAVORS

by

John Cumalat

University of Colorado

1. Types of Photon Beams

a) Bremsstrahlung

b) 0° Beam

c) Possible Combination

2. B - production

3. C - production

a) E687 at FNAL

b) Future run

c) Absolute Branching Ratio

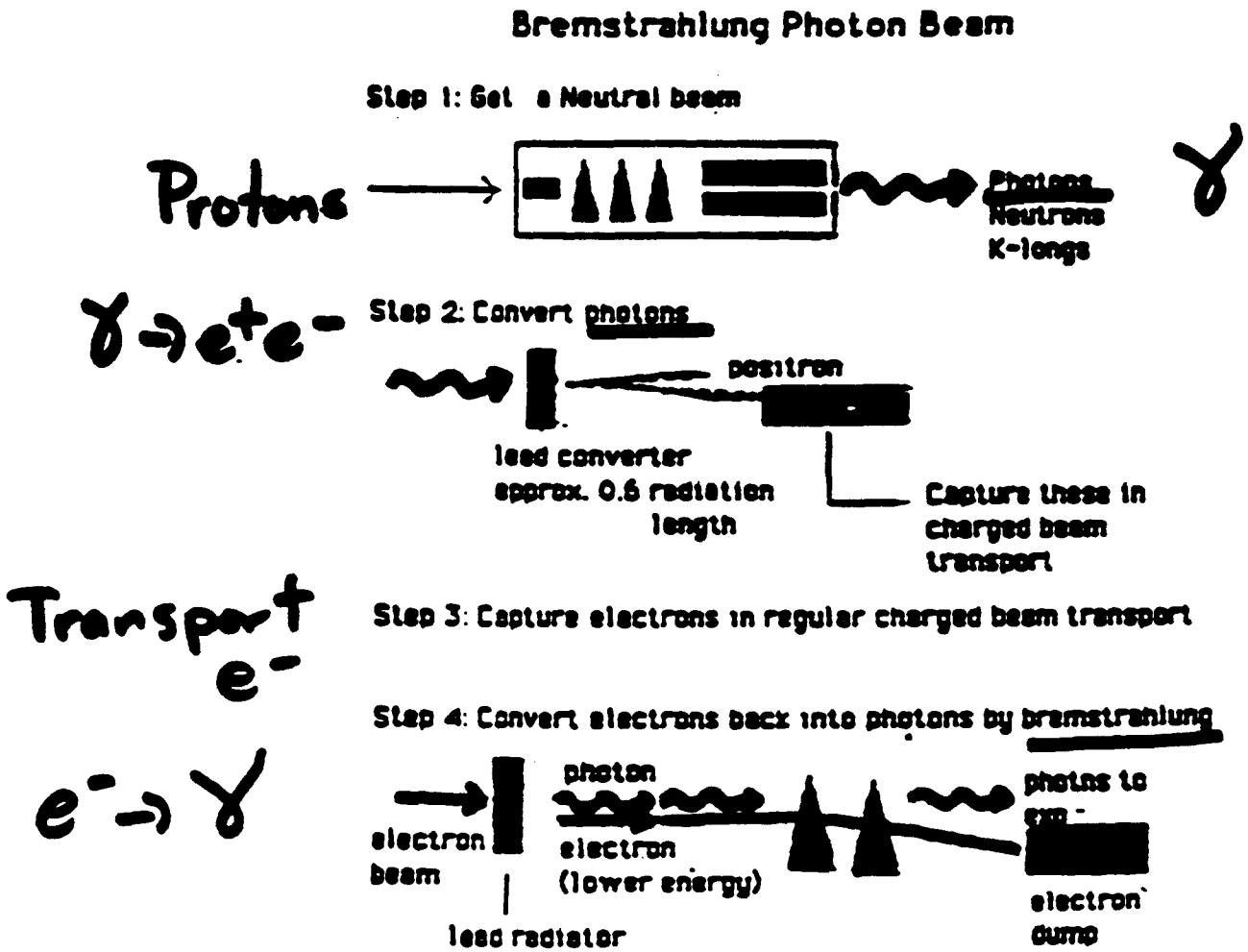
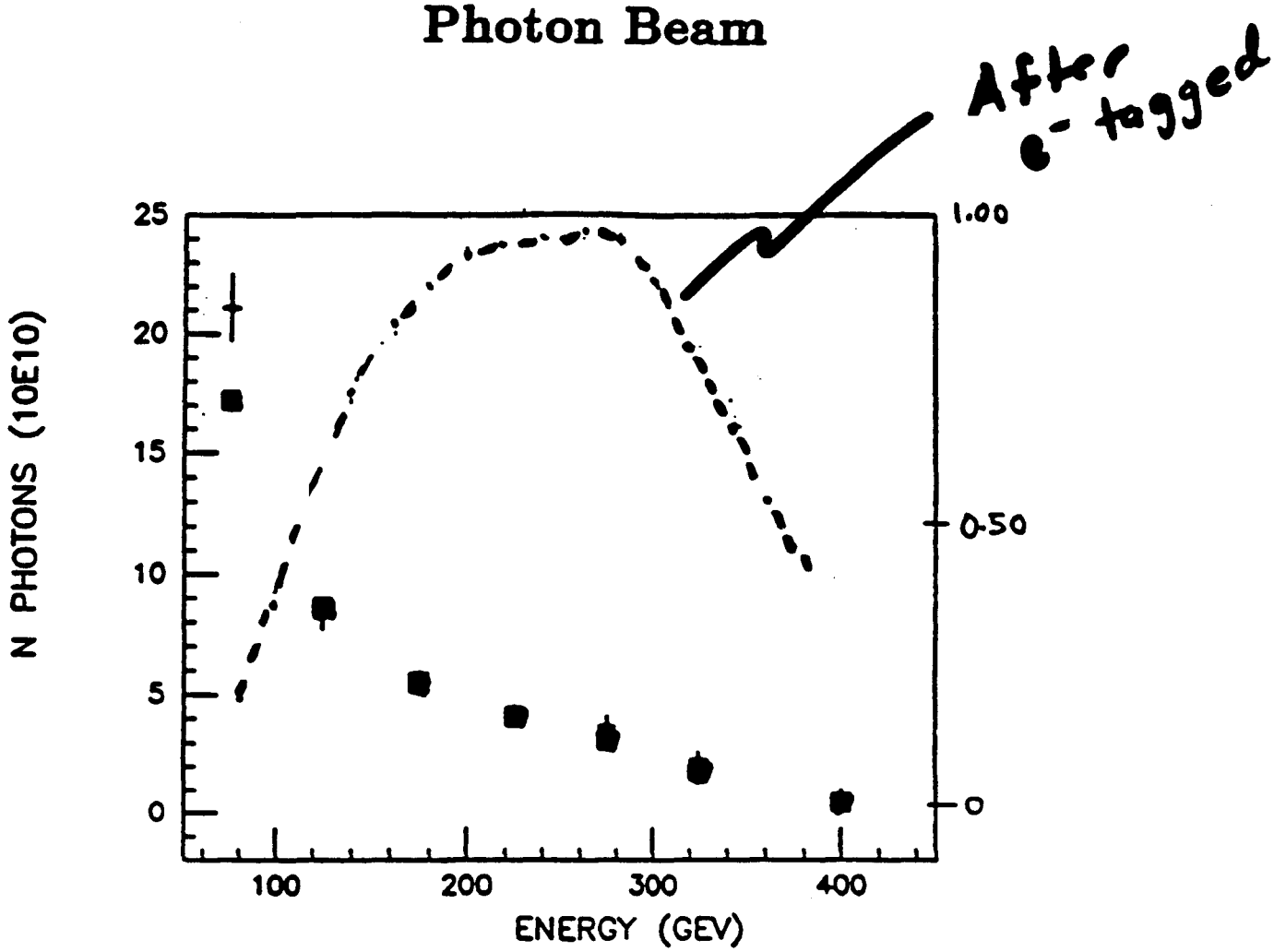
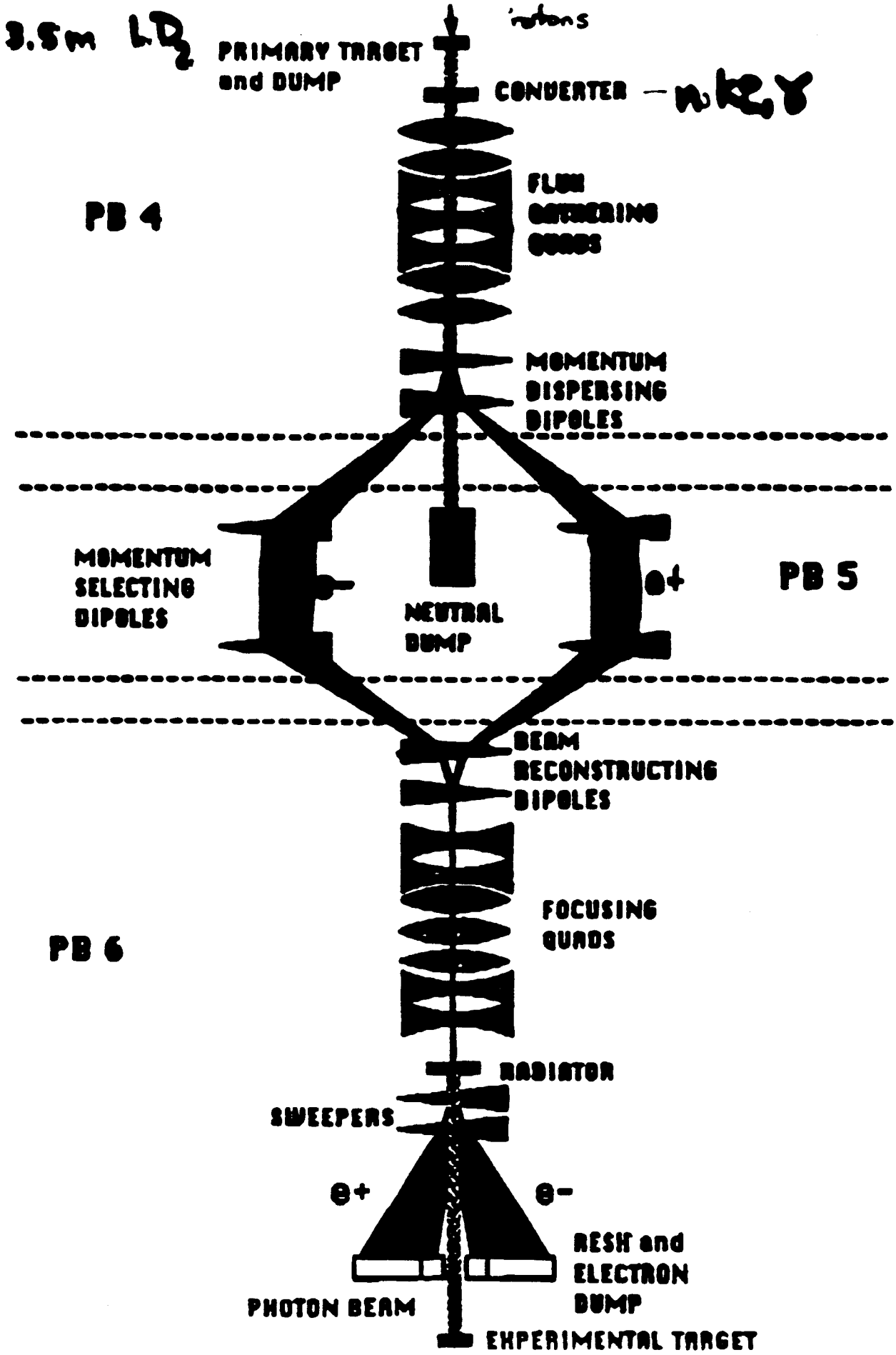


Figure 3: Steps required to produce a bremsstrahlung photon beam

Photon Beam



- 350 GeV electron beam with ± 13% momentum spread.
- 30% radiator.


3.5m LD2
PRIMARY TARGET and DUMP
CONVERTER
PB 4
MOMENTUM DISPERSING DIPOLES
MOMENTUM SELECTING DIPOLES
NEUTRAL DUMP
e+
PB 5
BEAM RECONSTRUCTING DIPOLES
FOCUSING QUADS
PB 6
RADIATOR
SWEEPERS
e+
e-
RESH and ELECTRON DUMP
PHOTON BEAM
EXPERIMENTAL TARGET

In E687 We use

1) 50% Pb-converter currently changing to a Uranium converter to lower the pion-contamination

2) Achieve an electron flux of $6 \times 10^{-8} e^- / p$

for <u>800</u> GeV incident protons with a secondary beam tune of <u>350</u> GeV

3.) With a 30% radiator + tagging we get

$\sim 1 \times 10^{-5} \frac{\gamma}{p}$ with γ energy Greater than 200 GeV.

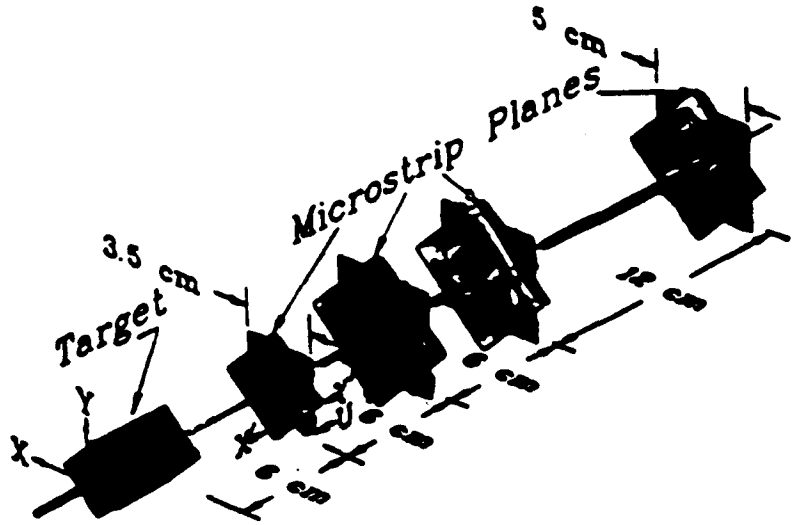


Figure 21: Silicon microstrip detector layout

Table 6: Properties of the Silicon Microstrip Detector

	I station	II station	III station	IV station
z position of				
1st detector	-.5 cm	5.5 cm	11.5 cm	23.5 cm
2nd detector	0.cm	6.0 cm	12.0 cm	24.0 cm
3rd detector	.5 cm	6.5 cm	12.5 cm	24.5 cm
active area	$2.5 \times 3.5\,cm^2$	$5 \times 5\,cm^2$	$5 \times 5\,cm^2$	$5 \times 5\,cm^2$
high res area	$1 \times 3.5\,cm^2$	$2 \times 5\,cm^2$	$2 \times 5\,cm^2$	$2 \times 5\,cm^2$
strip pitch	25 μm, 50 μm	50 μm, 100 μm	50 μm, 100 μm	50 μm,100 μm
# of channels	688 x 3	688 x 3	688 x 3	688 x 3

at $-90°$ with respect to the horizontal x axis of the spectrometer reference frame.

The innermost central region of the system, covering the very forward production cone, has a resolution two times better than the outer one. This region is crossed by the most energetic tracks which are very close one to each other and are less affected by Multiple Coulomb Scattering (MCS). The first station, which is the most crucial in determining the extrapolated error to the production point in the target, has twice the position accuracy of the other ones.

The actual geometry of the microstrip system is given by the table 6. All the detectors of the system are mounted on a high precision granite support which ensures the correct alignement inside $\pm 3\mu m$ over 5 cm. Actually, there are four granite frames, each of them holding the three detectors of a station; the four frames are aligned against the two orthogonal reference surfaces of an underlying granite bench.

Each strip is read out by means of a front-end preamplifier, a remote-end amplifier and a charge integrating FLASH ADC [2,1,3]; the analog signal at the amplifier output has a semigaussian shape with a base width of $\sim 140ns$.

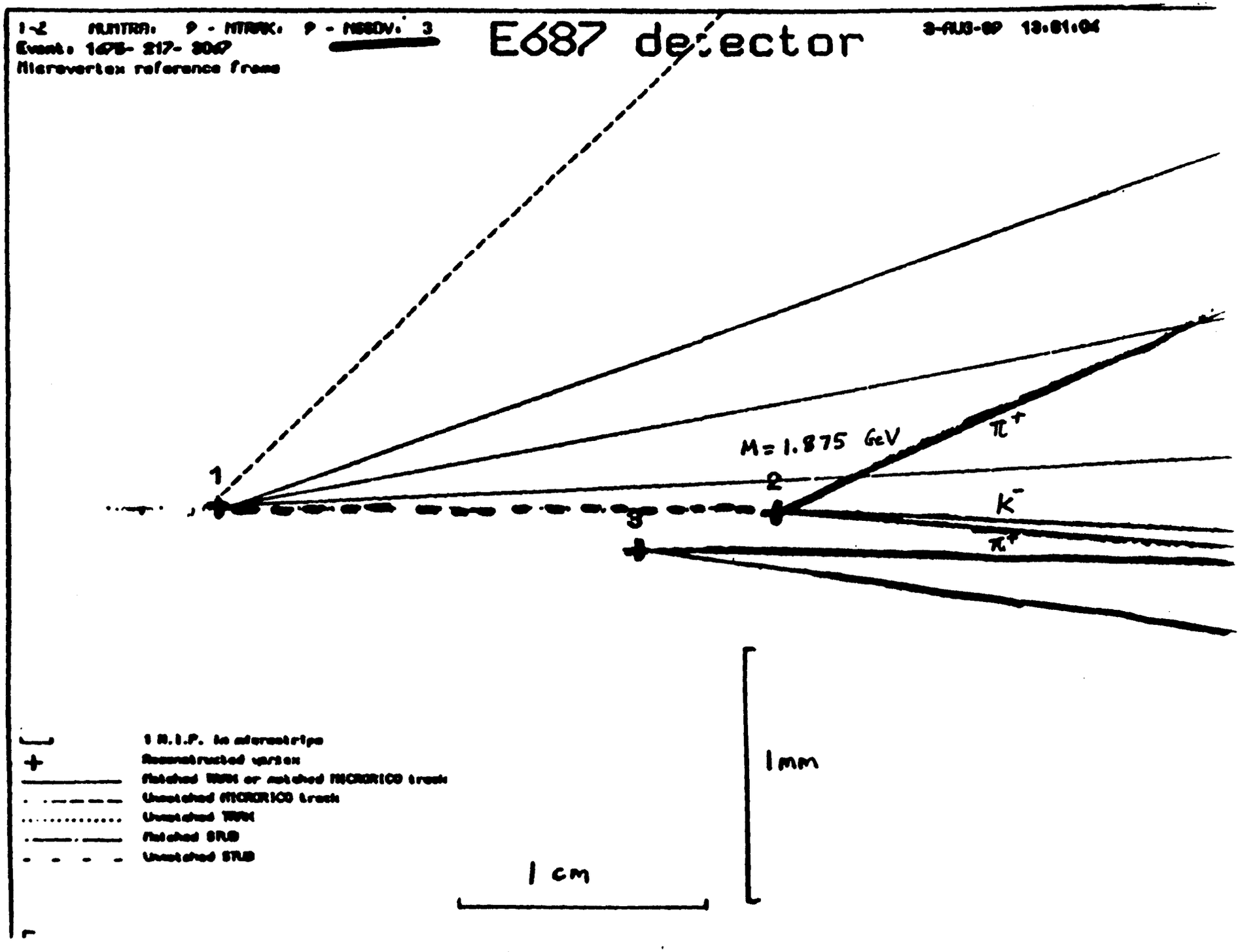
FNAL Experiment 687

- E687 is an international collaboration of about 60 physicists from:

  I.N.F.N. Bologna
  Univ. of Colorado
  Fermilab
  I.N.F.N. Frascati
  Univ. of Illinois
  Univ. of Notre Dame
  I.N.F.N. Milan
  Univ. of Milan
  Northwestern Univ.
  Univ. of Pavia
  Univ. of Puerto Rico - Mayaguez
  I.N.F.N. Pavia

- 8 months of running
  - 2 months fire repair
  - 2 months good data (350 GeV e^-)
- 60 million triggers, 1200 data tapes.

(1987 - 1988)


1-2 MUNTRA: 9 - NTRAK: 9 - NSEOV: 3
Event: 1475- 217- 3047
Microvertex reference frame
E687 detector
3-AUG-89 13:01:04
M=1.875 GeV
π^+
K^-
π^+
1
2
3
1 cm
1mm
1 R.I.P. in microstrips
Reconstructed vertex
Matched TRAK or matched MICRORICO track
Unmatched MICRORICO track
Unmatched TRAK
Matched STUB
Unmatched STUB

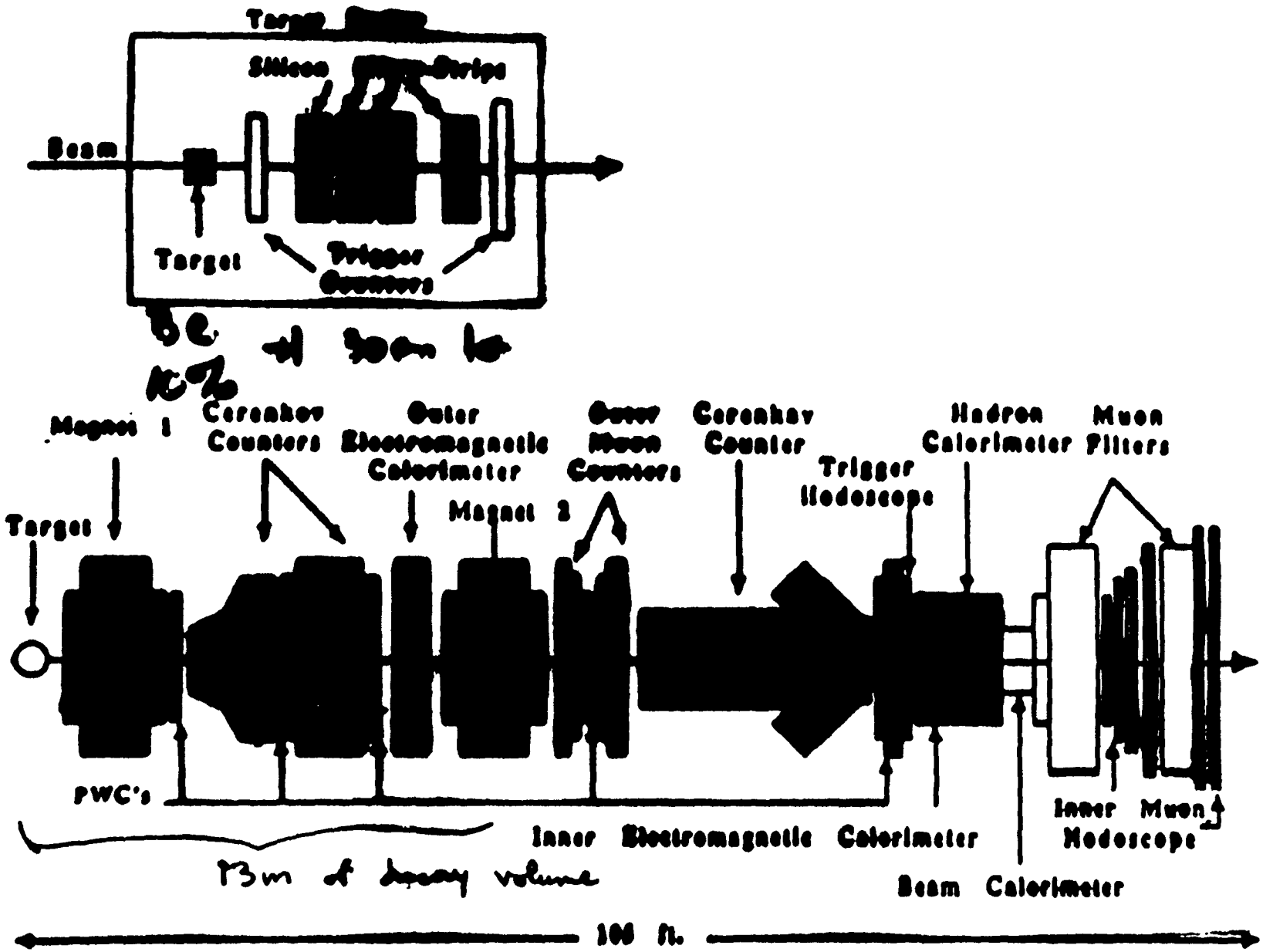
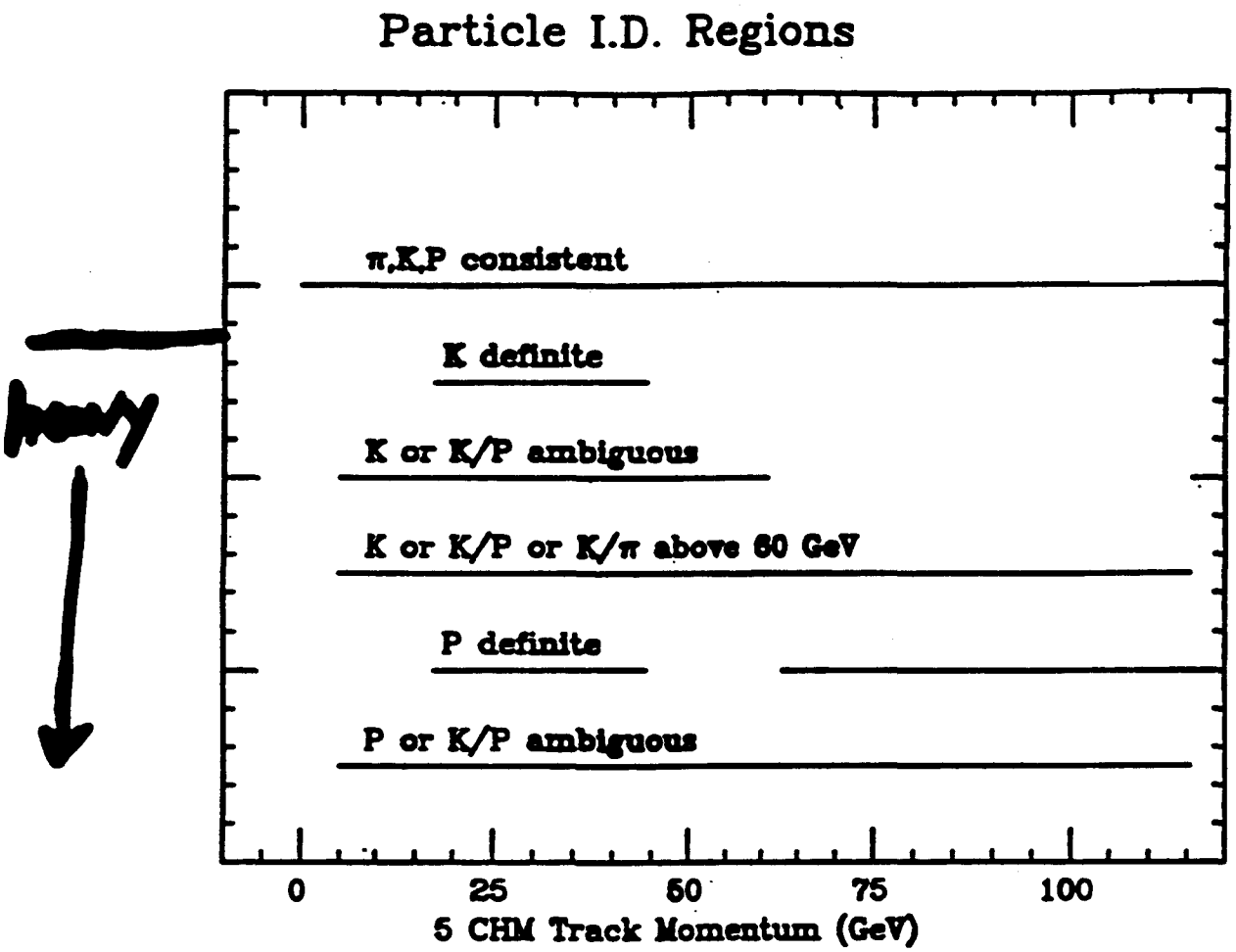


Fig. 6. Schematic view of the E-687 spectrometer

3. Cerenkov performance



Method	I.D.'ed as	ϵ
$\phi \rightarrow K^+K^-$	K, K/P, 7	.80
$K_s \rightarrow \pi^+\pi^-$	π cons.	.88
$\Lambda \rightarrow P\pi^-$	P or K/P	.75

Vertex Reconstruction

1. Stand alone vertexing
   (a) Description
      (i) Start with 1 vertex hypothesis
      (ii) Remove worst tracks
      (iii) Look for secondary vertices with rejected tracks
   (b) Properties
      (i) Inefficient for short life times
      (ii) Allows for missing neutrals (eg ν , π^o)
      (iii) No specific decay mode required for skim
2. Candidate driven
   (a) Algorithm
      (i) Charm candidate forms "seed" track
      (ii) Nucleate tracks around "seed" track to find primary vertex
   (b) Properties
      (i) Even 1 track primaries are found
      (ii) No efficiency problem at short lifetime

3. **Vertex cutting tools**

   (a) significance of detachment $(\frac{L}{\sigma})$

   (b) Vertex confidence levels

      (i) Secondary vertex (DCL)

      (ii) Primary vertex (PCL)

      (iii) Global fit requiring the secondary vertex to point back to the primary (LCL)

   (w) Secondary Vertex isolated from any other track.

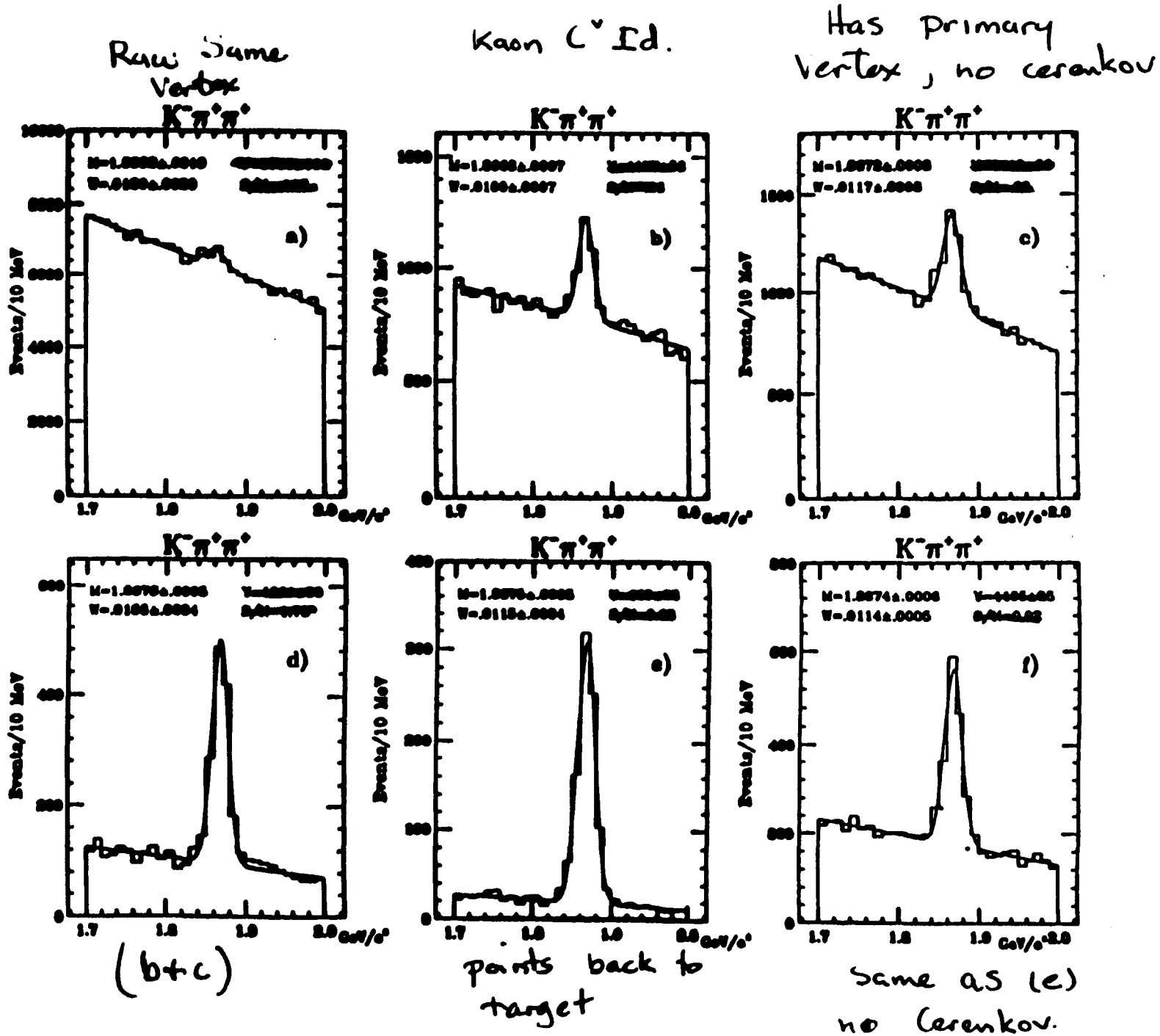

Raw Same Vertex
Kaon C˘ Id.
Has primary Vertex, no cerenkov
K⁻π⁺π⁺
a)
b)
c)
d)
e)
f)
Events/10 MeV
GeV/c²
(b+c)
points back to target
same as (e) no Cerenkov.

Fig.2

Candidate Driven Approach

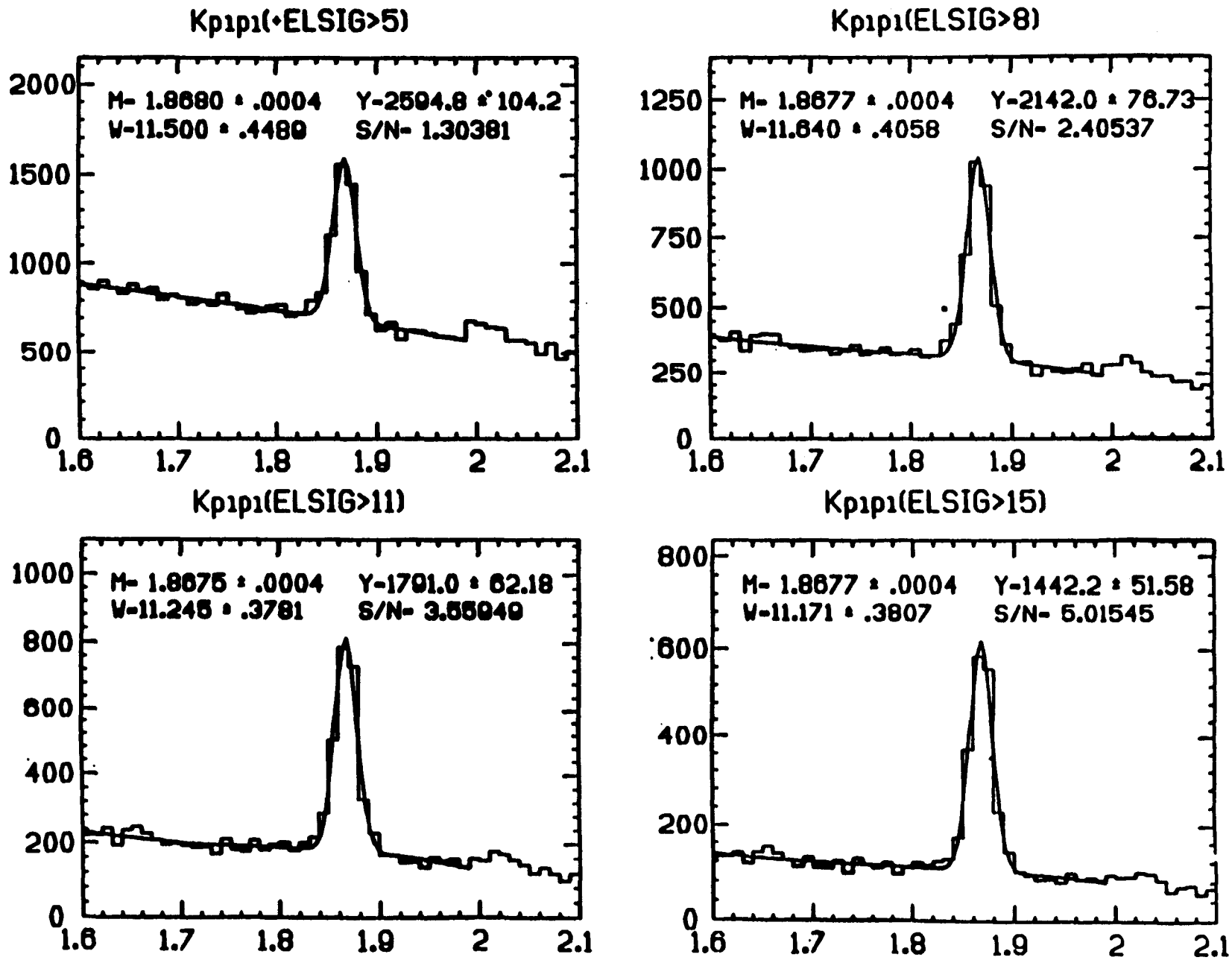


Fig.3

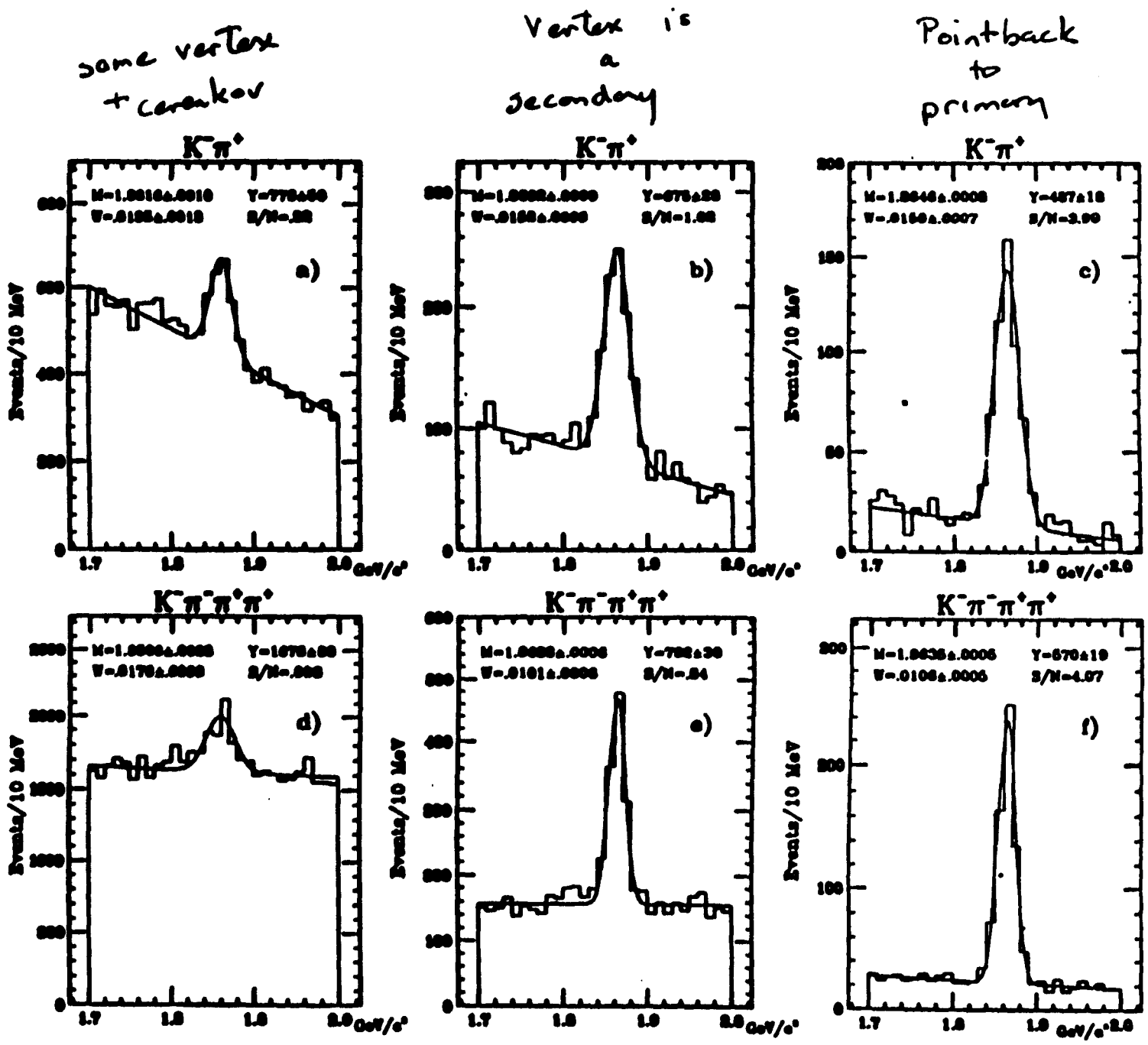

same vertex + cerenkov
Vertex is a secondary
Pointback to primary
K⁻π⁺
K⁻π⁻π⁺π⁺
a)
b)
c)
d)
e)
f)
Events/10 MeV
GeV/c²

Fig.4

B's Produced in

1. 1987-1988 run

— $\sim 3 \times 10^3$ —

none observed!

x10 Current 1990-1991 run

$\sim 4 \times 10^4$

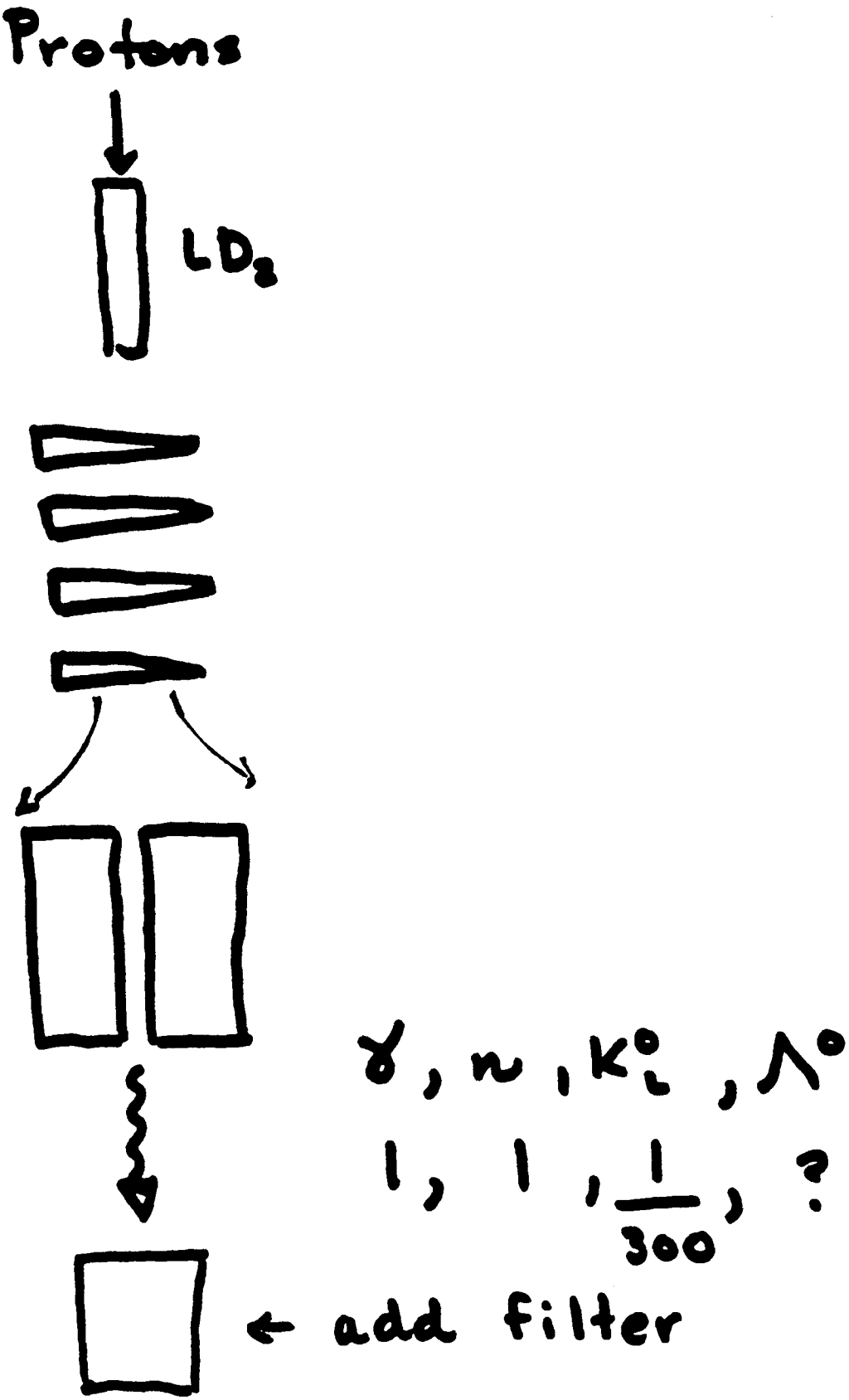
a) Multimuons ← Set σ_{bb} level
b) D's + $n\pi$
c) Detached J/ψ

x100 Proposed 1993-1994

estimate $\sim 2 \times 10^5$

Not emphasis of the experiment!

b) 0° Beam



For the filter use

34 meters of LD_2 embedded in magnets - old idea by Wonyong Lee.

34 meters $\approx$ 10 neutron interaction lengths

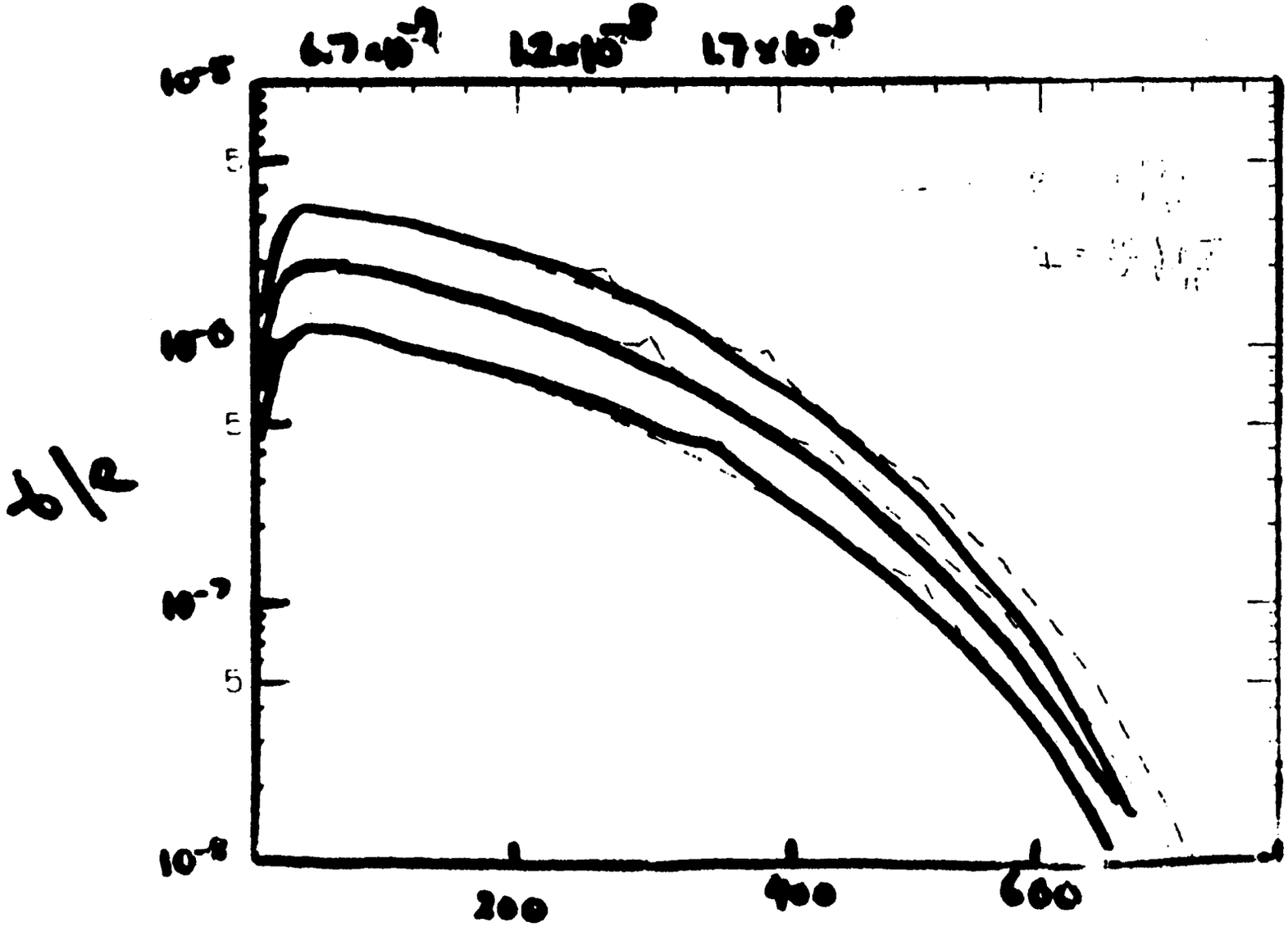
$\approx$ 3.5 $\gamma \to e^+e^-$ lengths

Thus $\gamma : n$ at target
$1 : 1$

goes to $\gamma : n$ at expt.
$1 : 1/400$

$\gamma p \to$ hadrons $\approx$ 100 μb
$np \to$ hadrons $\sim$ 40 mb

Thus 1 γ interaction to 1 neutron int at target



Shape of 0° beam, 3× more intense than Bremstrahlung Beam!

$B\bar{B}$ Calculation

Original estimate by Jim Wiss

Assumptions:

1) $\underline{2.5 \times 10^{16}}$ protons in the expt.

$$= \frac{5 \times 10^{12}\ \text{pps} \cdot 3 \times 10^{7}\ \text{sec}}{60\ \text{sec/spill}}$$

2) $\underline{10\text{cm}}$ experimental target

3) $\underline{34}$ meters of LD_2

4) Primary target $\underline{140\text{m}}$ away from expt. target

5) 2 TeV incident protons

$$N_{b\bar{b}} = 103\ \text{nb}^{-1} \int d\omega \frac{d^2 N_\gamma}{d\omega\, d\Omega} \sigma(\omega)$$

$$\sigma(\omega) = \int_{x_{min}}^{1} dx\, G(x)\, \sigma(\hat{s})$$

$$x_{min} = \frac{4M_B^2}{s}$$

$$x\,G(x) = \frac{1}{2}(N+1)(1-x)^N$$ Gluon Structure Function

$$\sigma(\hat{s}) = \frac{2\pi\alpha\alpha_s}{\hat{s}}\left(\frac{e_q}{e}\right)^2\left[\left(1+\gamma-\frac{\gamma^2}{2}\right)\ln\frac{(1+\beta)}{(1-\beta)} - \beta(1+\gamma)\right]$$

Lowest order

$$\gamma = \frac{4m_b^2}{\hat{s}} \qquad \beta = \sqrt{1-\gamma}$$

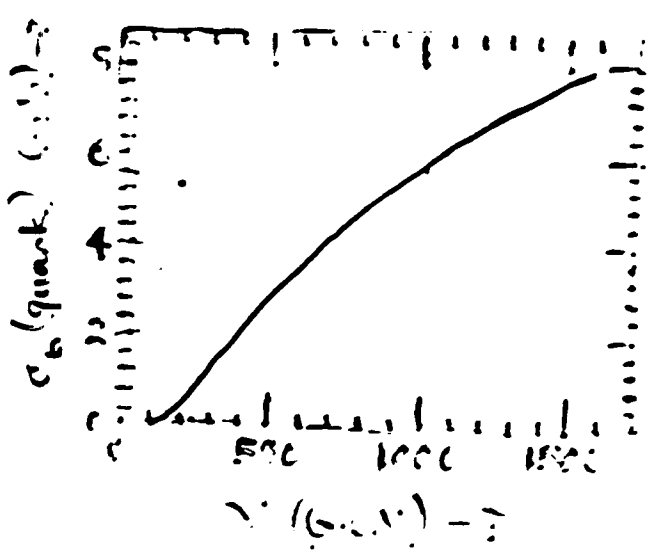
$\alpha_s = .2$

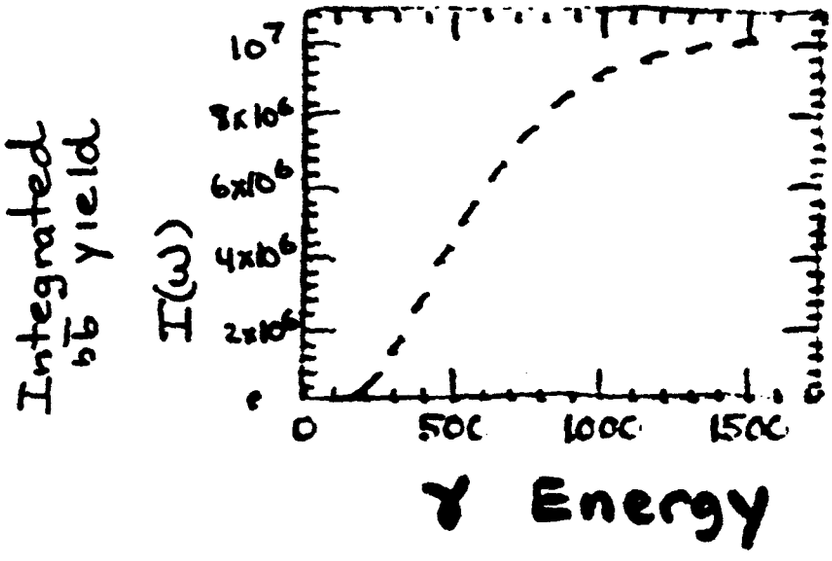
$N = 5$

$e_q = -1/3$

$m_b = 5.0$

$M_B = 5.2$





2 TeV protons

$\Delta\Omega$	$b\bar{b}$ Yield
1.5×10^{-7}	8×10^6
2.5×10^{-7}	9.4×10^6
4.0×10^{-7}	10.4×10^6

Discussion

1.) Photon flux only good to a factor of 3. Calculation overestimates measured γ flux. Actual yield might be 3×10^6

2.) γg fusion is a lower limit to heavy flavor photo-production.

At $E_\gamma = 120$ GeV model gives ~ 250 nb. True cross section is about factor of 3 larger.

$$\boxed{\text{Estimate of } 10^7\ b\bar{b} \text{ pairs is uncertain to at least a factor of 3.}}$$

At 20 TeV

the # $b\bar{b}$ pairs produced would be increased a factor of 100. The problem is proton economics. At 10^8 protons/s for a dedicated year we could possibly produce only 10^5 $b\bar{b}$.

Beauty Production with photon beam does not appear to be competitive with other options

Expression of Intention to Continue the Study of States Containing Heavy Quarks Using the Wideband Photon Beam and the E687 Multiparticle Spectrometer

Submitted by the Wideband Beam Photon Collaboration

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J. Filasetta, University of Western Kentucky

J. Wilson, University of South Carolina

Joo Sang Kang, Korea University, Seoul, Korea

Jae Wan Kim, Seoul National University, Seoul, Korea

Jae Kwan Kim, Korea Advanced Institute of Science and Technology, Cheongryang, Seoul, Korea

Govorkov, Lebedev Institute, USSR

10^8 Produced Charm

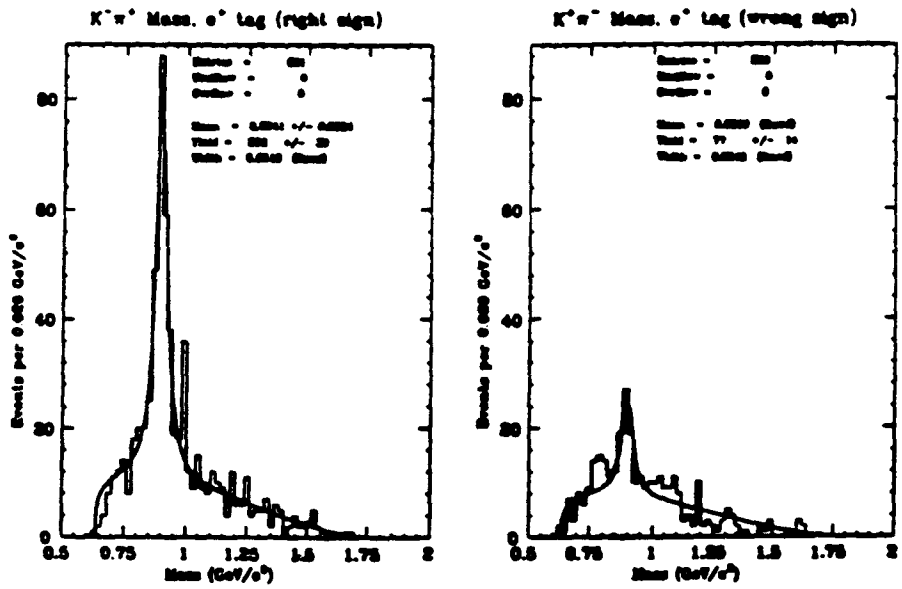
Physics of a High Statistics Charm Experiment

1. $D^0 - \overline{D^0}$ Mixing and Doubly-Suppressed Cabibbo Decays
   (a) Classic Mechanism using the well-known box diagram predicts mixing at the 10^{-6} level, but long distance effects may be important and estimates are as large as 5×10^{-4}. E691 $r < 3.7 \times 10^{-3}$
   (b) Identify several doubly-suppressed modes such as $K^+\pi^-$ $D^+ \to K^+\pi^+\pi^-$ and $D^+ \to K^+K^-K^+$ and check model predictions. Maybe few examples from Mk III
2. Semileptonic Decays
   (a) Measurement of $|V_{cs}|$ to 1% E691 ~10%
   (b) Measurement of $|V_{cd}|$ to 2%
   (c) Measurement of $|V_{cd}|/|V_{cs}|$ to 1.5% Mk III ~10%
   (d) Measurement of vector and axial vector form factors might be used to predict the Beauty form factors
3. Leptonic Decays – f_D pseudoscalar decay constant
   (a) This involves observing $D^+ \to \mu\nu_\mu$. $D^{*+} \to \pi^0 D^+$
4. D_s^+ Decays ~10^3 $\phi e \nu$ See D^+ in μ strip
5. Λ_c^+ Decays ~10^4 $pK\pi$
6. D^{**} States
7. Charmed Baryon Spectroscopy and Lifetimes

   Ξ_c^0, Ξ_c^+

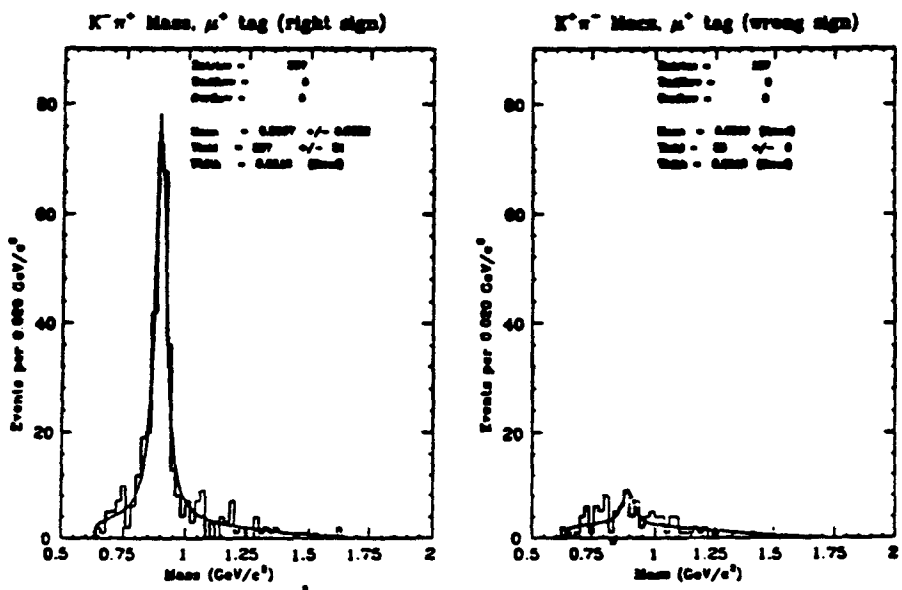
8. Charm Production Dynamics and compare to Models
   (a) Double charm events particularly useful ~1% Double
   (b) Try to pin down photon-gluon fusion parameters
   (c) Look for production mechanisms that are not explained via photon-gluon fusion. Should be gluon gluon and quark-quark fusion, but we have seen no evidence of this yet. (Associated production has been observed.)
   (d) As get more events study relative production of ground state versus the excited state production.
9. Rare Decays
   (a) Set limits for D^0 decays to $\mu^+\mu^-$ and e^+e^-
10. Forbidden Decays
   (a) μ^+e^-
11. CP Violation Sensitivity
   (a) Difference in rates between D^0 and $\overline{D^0}$ decays using the D^* as a tag
   (b) Polarization tests using $D^+ \to \overline{K^{0*}}K^{+*}$

$D^+ \to K^{\mp}\pi^{\pm}e^+\nu$ (+c.c.)

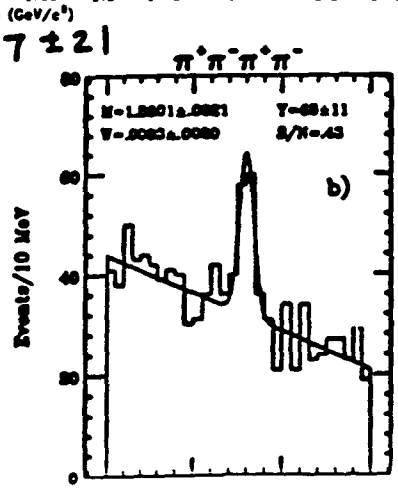


292 ± 30

$D^+ \to K^{\mp}\pi^{\pm}\mu^+\nu$ (+c.c.)

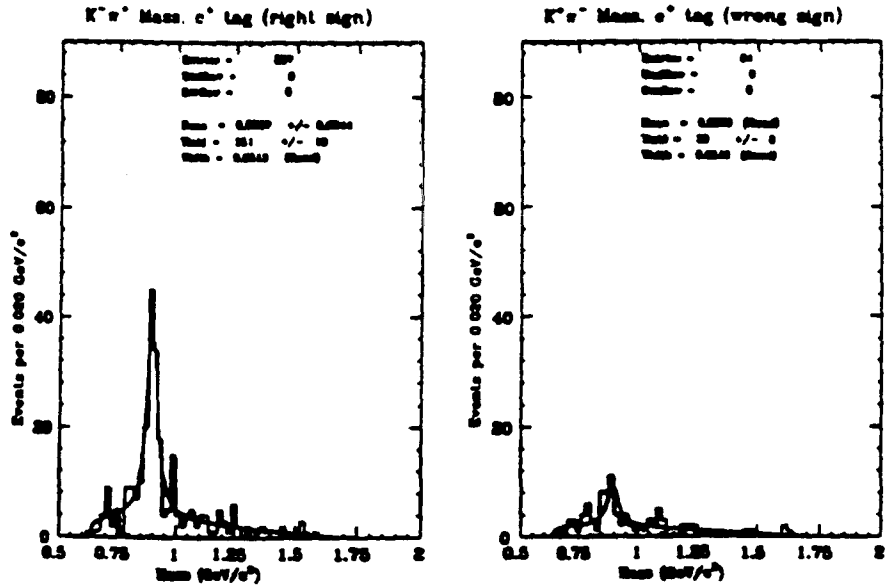


307 ± 21



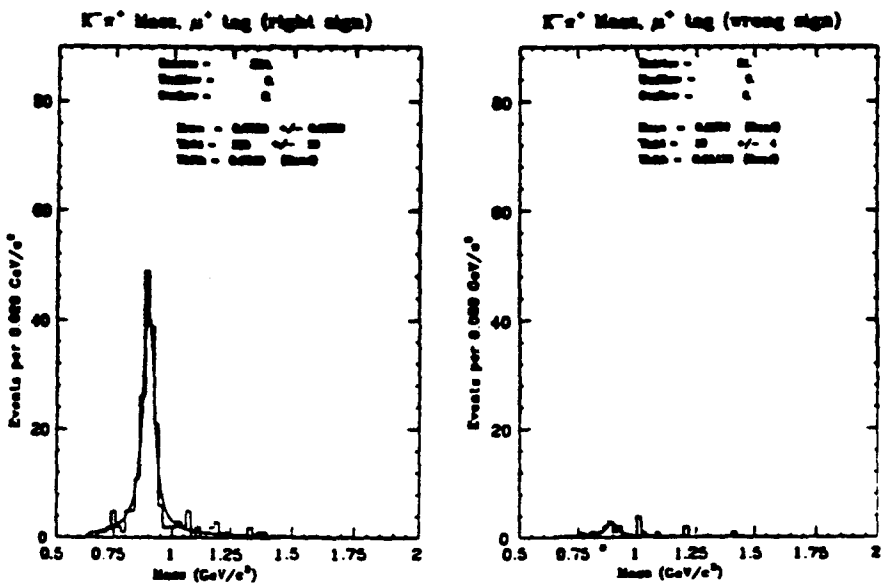
68 ± 11

$D^+ \to K^\mp \pi^\pm e^+ \nu$ (+c.c.)

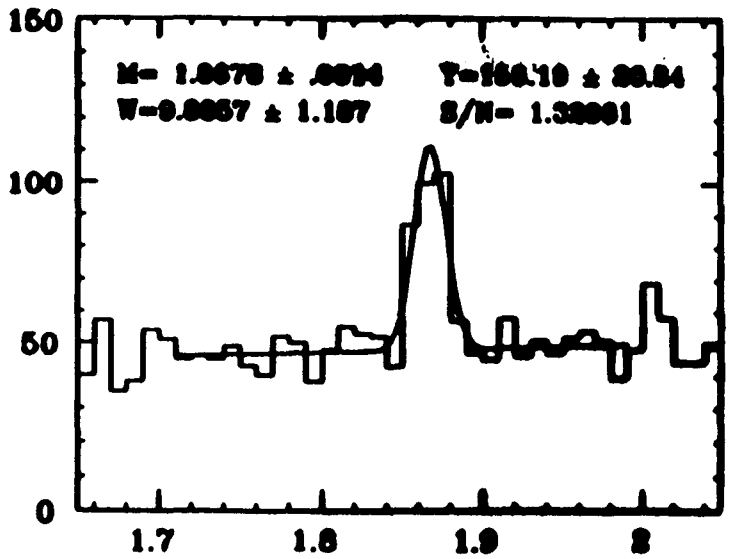


191 ± 19

$D^+ \to K^\mp \pi^\pm \mu^+ \nu$ (+c.c.)

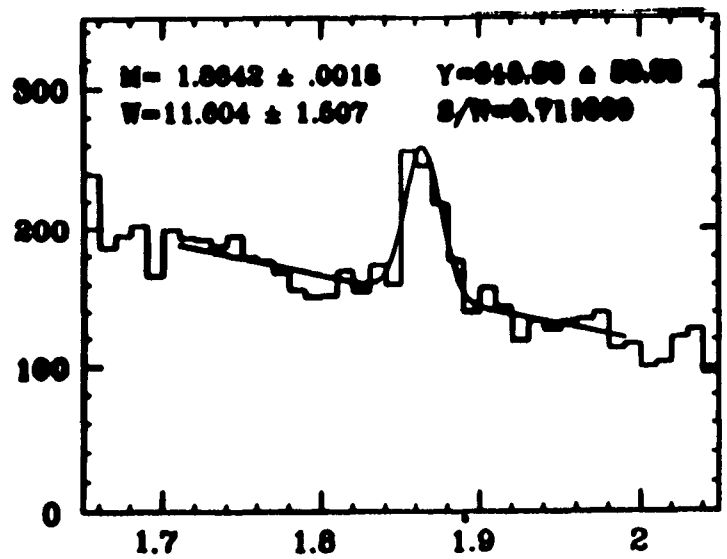


185 ± 13



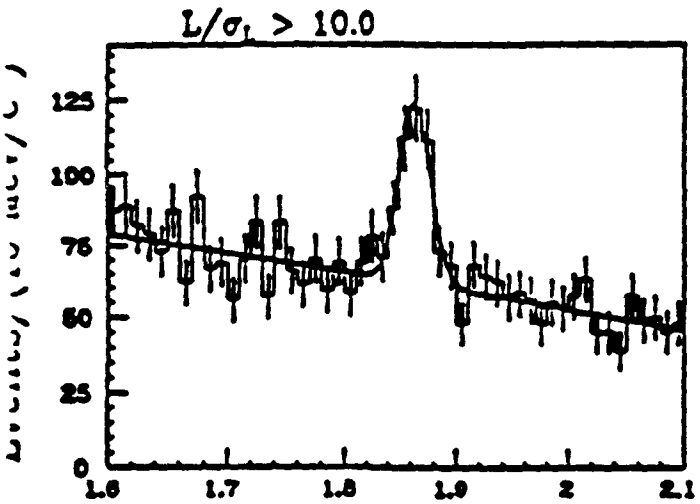
$D^+ \to K_S^0 \pi^+ \pi^- \pi^+$

$L/\sigma > 10$



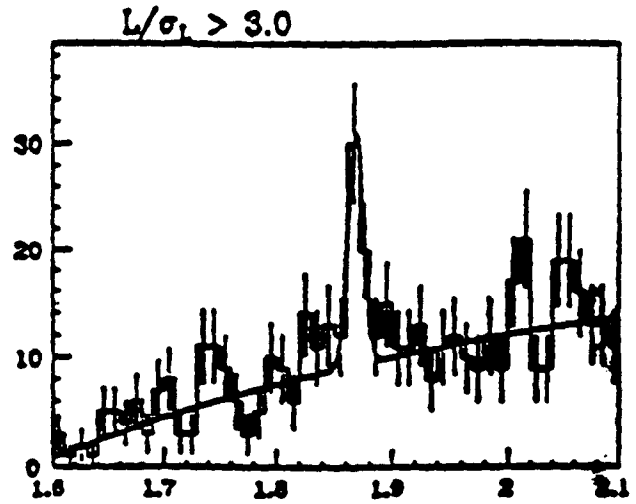
$D^0 \to K_S \pi^+ \pi^-$

$L/\sigma > 5$



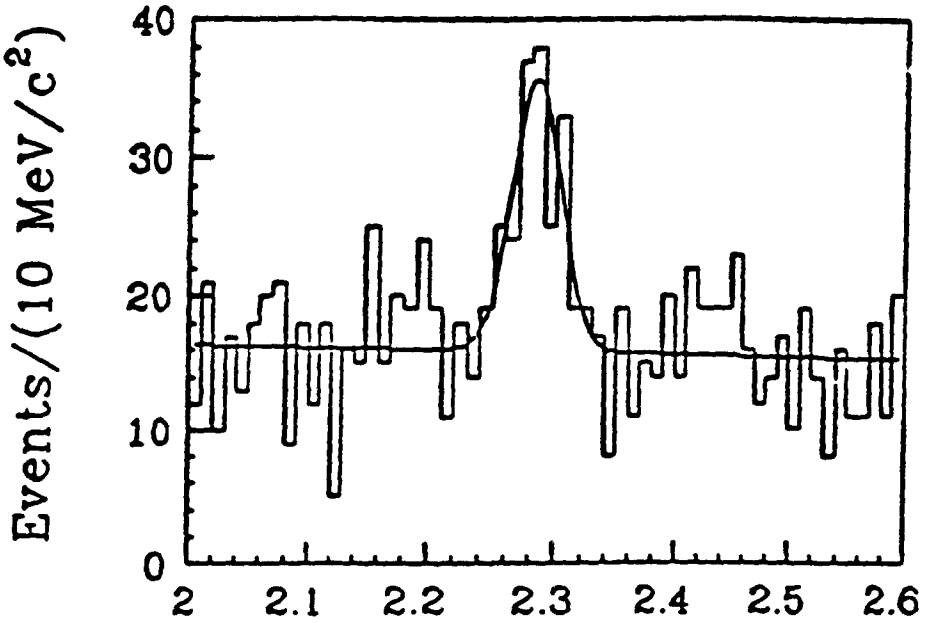
$M(K_S^0\pi^+\pi^-)$ Gev/c^2

215 ± 28 events



$M(K_S^0K^+K^-)$ Gev/c^2

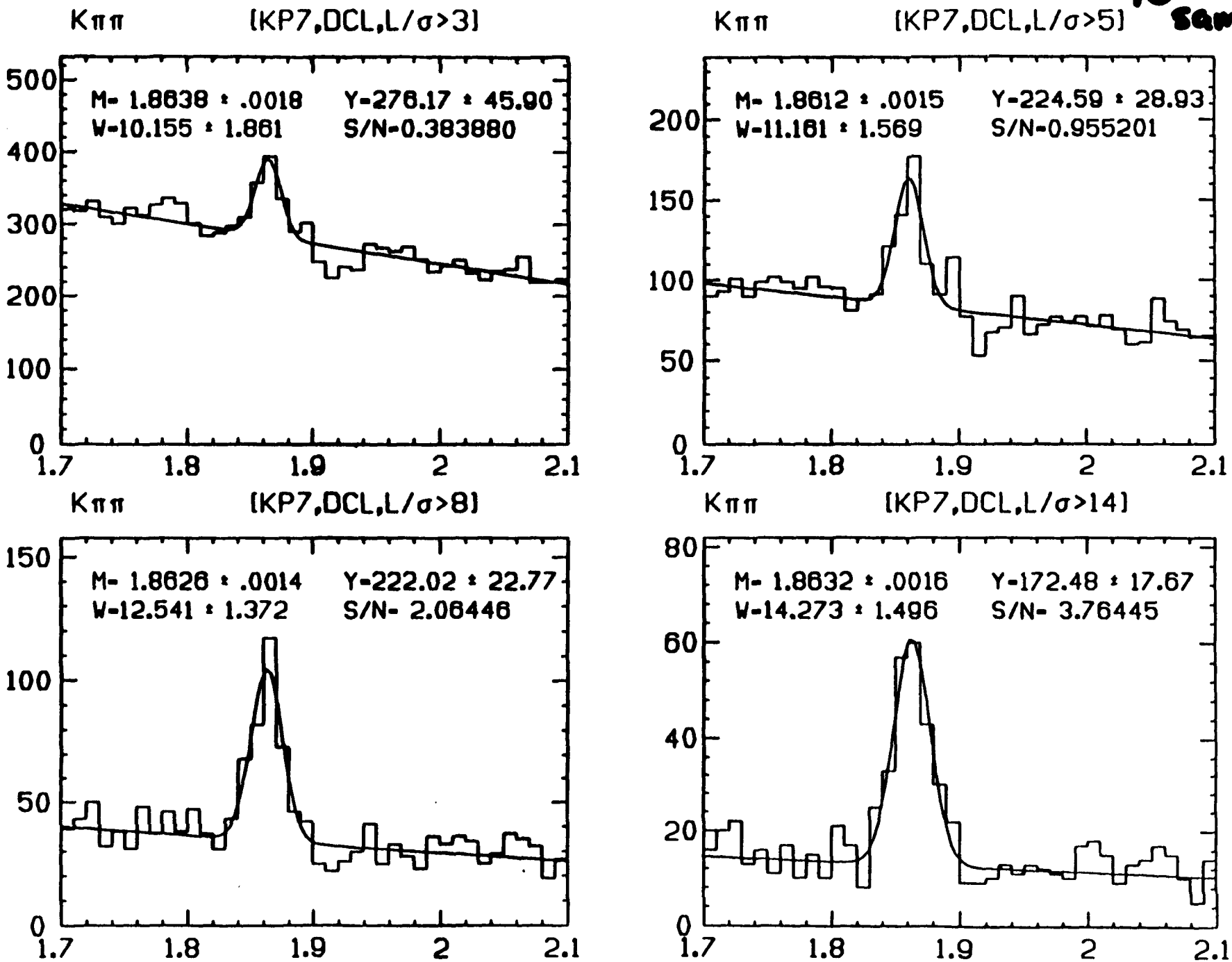
35 ± 8 events



Mass ($pK^-\pi^+$ + C.C.) (GeV/c^2)

40 ± 19 events

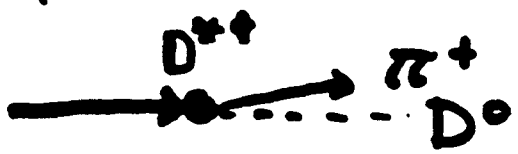
1990 Kun ~ 8 million triggers 1/40 of sample



Absolute Branching Ratios in E687

Make use of $D^{*+} \to \pi^+ D^0$ + kinematic correlation between soft decay pion and the momentum of the recoiling anti-charmed particle.

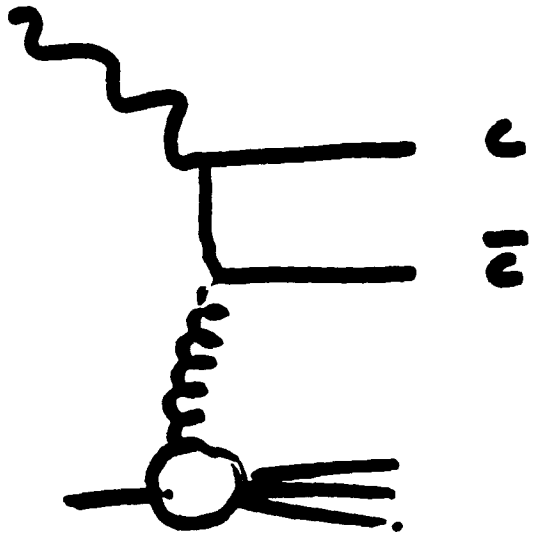
Much of the correlation comes from the low Q value of $D^{*+} \to \pi^+ D^0$. In the $Q=0$ limit the pion will have a lab momentum collinear with the parent D^{*+}.



Actual Q value of 5.5 MeV implies scaled up soft momentum serves as a $\pm 16\%$ measurement of parent D^{*+}.

Rest of correlation comes from an expected dynamical correlation between momenta of the D^{*+} and recoiling anti charm.

$P_\perp$'s of charm particles balance to within $\approx \pm 1$ GeV and appear in the lab with roughly equal energies.



Total $P_\perp$ of charm system is dominated by effective $P_\perp$ of gluon which is roughly 1 GeV.

Both E687 + E691 see inclusive D mesons with a median $P_\perp$ of ~ 700 MeV. Bulk of PQF cross section occurs with the c + $\bar{c}$ particles produced with

low momentum with respect to the γg center of mass. Hence c particles have roughly equal lab momenta.

$$\therefore \quad E_{D^*} \approx 13.8\, E_{\pi^+}$$

$$\Delta_x = 13.8\, p_x^{(\pi)} + p_{*x}^{(r)}$$

$$\Delta_y = 13.8\, p_y^{(\pi)} + p_y^{(r)}$$

$$\alpha = \frac{13.8\, p_z^{(\pi)} - p_z^{(r)}}{13.8\, p_z^{(\pi)} + p_z^{(r)}}$$

Finally expect charge of soft pion opposite the charm of recoil state. Use wrong sign as a measure of soft pion background.

Specifically measure

$$D^{*+} \to \pi^+ D^0 \to \pi^+ (K^- \pi^+)$$

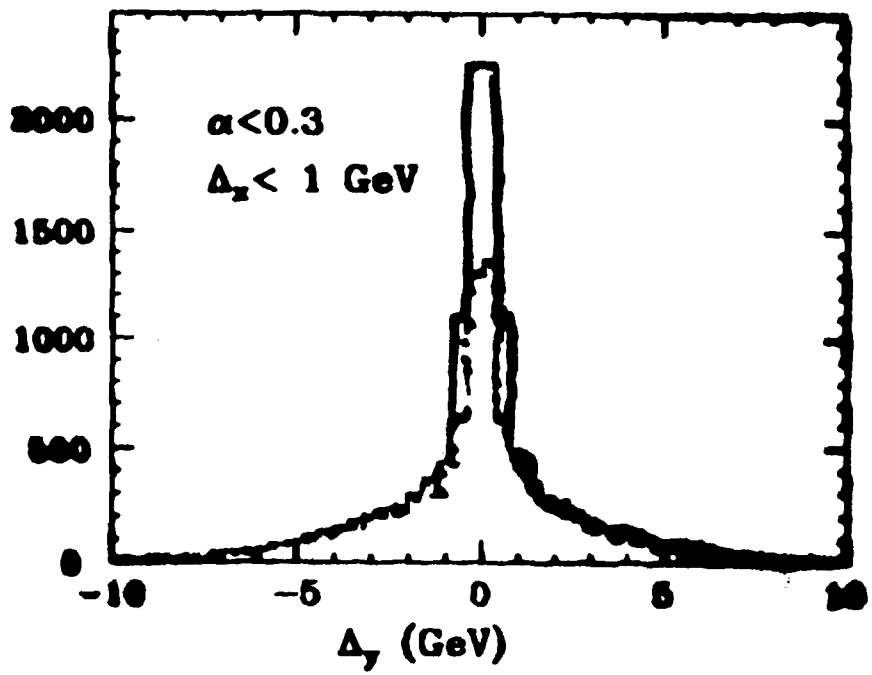
to the total yield of

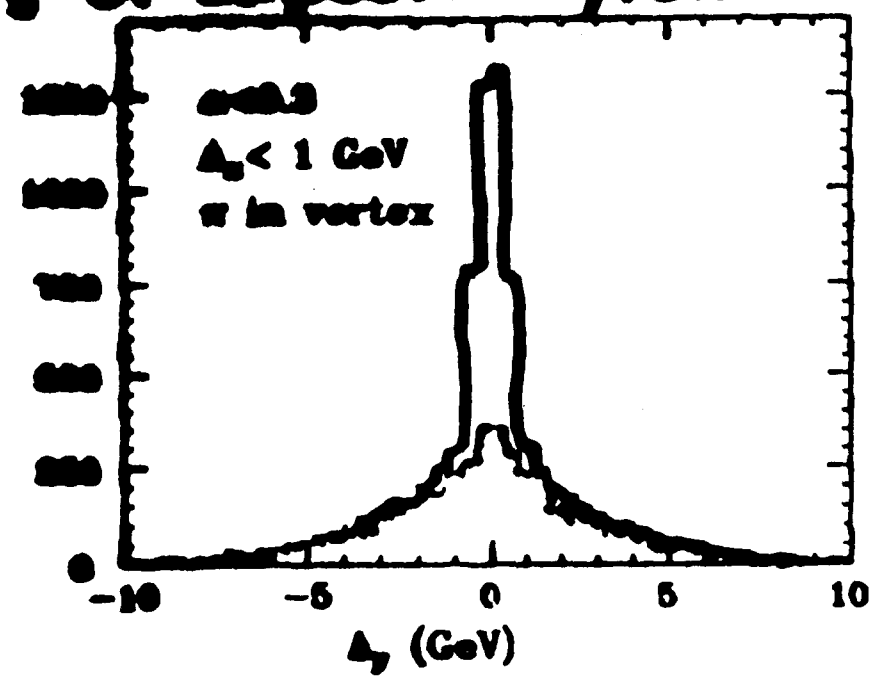
$$D^{*+} \to \pi^+ D^0$$

Search was made in 1989 data where both D and $\bar{D}$ were reconstructed in 3 decay modes - $D^0 \to K\pi$, $K3\pi$ + $D^+ \to K2\pi$

53 ± 9 events, expect 62 from MC.

MC 46,000 fully reconstructed D mesons
1/10 of expected yield

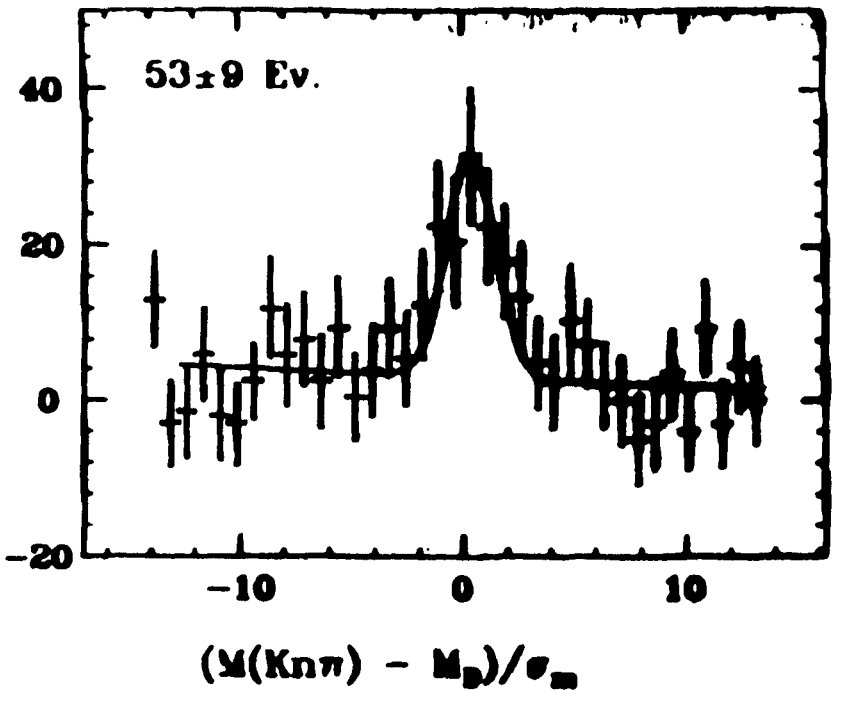




70% of geometrically accepted pions survive.

Require soft pion comes from primary

Normalized Mass Distribution



Scaling from 1988 run, we expect 4240 double D events.

Correcting for

1) Only $K^-\pi^+$ mode (1/3)

2) D^0 from D^{*+} (.24)

3) K and Δ_x cuts (.70)

This gives $\approx$ 240 $K\pi$ events from a D^* decay. $\Rightarrow$ 6.5%

$\frac{K\,3\pi}{K\pi}$ will be known very precisely

So using $K3\pi$ $\Rightarrow$ 4.5%

Other modes $K_S\pi\pi$, K^+K^-, 4π $\Rightarrow$ $\boxed{3.5\%}$

Conclusion

PHOTOPRODUCTION

NOT COMPETITIVE

FOR BEAUTY !

VERY COMPETITIVE

FOR STUDYING

CHARM

PROGRAM

Second Annual SSC Spring Conference
Electroweak and Flavor Physics: Implications for the SSC
Monday, May 20 - Thursday, May 23

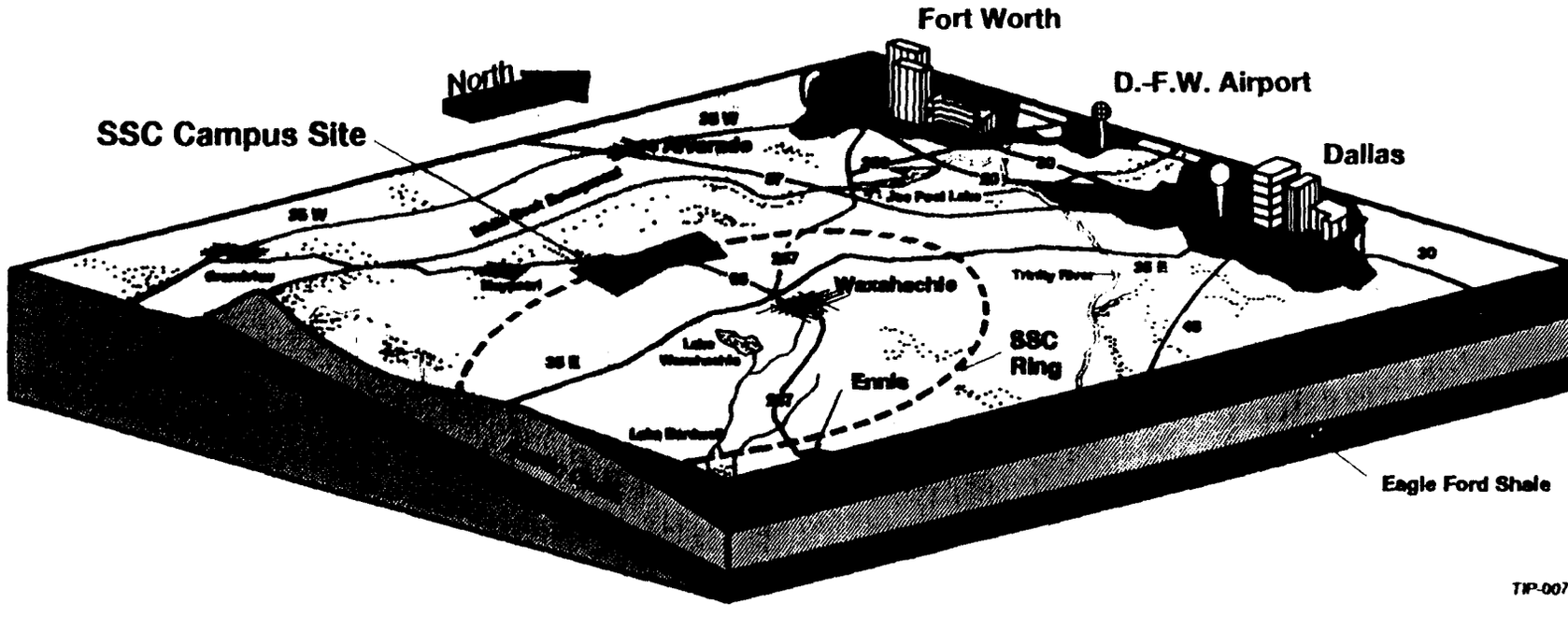
Wednesday, May 22

AM		Chair: E. C. G. Sudarshan (U.T.-Austin)
9:00	**Status and Physics Aims of SSC**	F. Gilman (SSCL)
	More Future Prospects (non SSC)	
9:40	Neutrino Physics at FNAL after the Upgrade	N. W. Reay (Ohio State)
	Break	
	Bottom Quark Physics	
10:50	LEP Results on b quarks	R. Mount (Caltech)
11:30	Recent results and Future Prospects for B-Physics at CDF	D. Amidei (Michigan)
PM	**Bottom Quark Physics**	Chair: F. Gilman (SSCL)
2:00	Symmetries in Heavy Quark Decay	M. Wise (Caltech)
2:40	Rare Decays of Heavy Flavors	A. I. Sanda (SSCL/Rockefeller)
	Break	
3:50	e^+ - e^- B Factories CLEO, SLAC, KEK	P. Oddone (LBL)
4:30	Prospects for Improvement in CKM Matrix	D. Hitlin (Caltech)

Status of the SSC Project and Experimental Program

Fred Gilman
SSC Laboratory

Schematic Location of SSC Facilities



TIP-00783

BBC 894-3741

Conventional Facilities Overview

Total Cost:	$1.2 Billion	
Real Estate:	16,553 Acres	1,272 Parcels
Buildings:	102 Structures	2.1 Million SF
Excavation:	7.5 Million CY	400,000 LF Tunnels
Electrical Demand:	185 MW	

A-E/CM

- Selection Process
- Parsons Brinckerhoff/Morrison Knudsen JV
- Contract Status
  - — Letter Contract
  - — Definitized Contract

SDC Hall Definition

- Meetings May 8-9 at SSCL with participation of SDC, Physics Research Division, Conventional Construction Division, PB/MK

- Conclusion

  - Cut and Cover Construction
  - IR4
  - Width of 31m
  - Length 105m

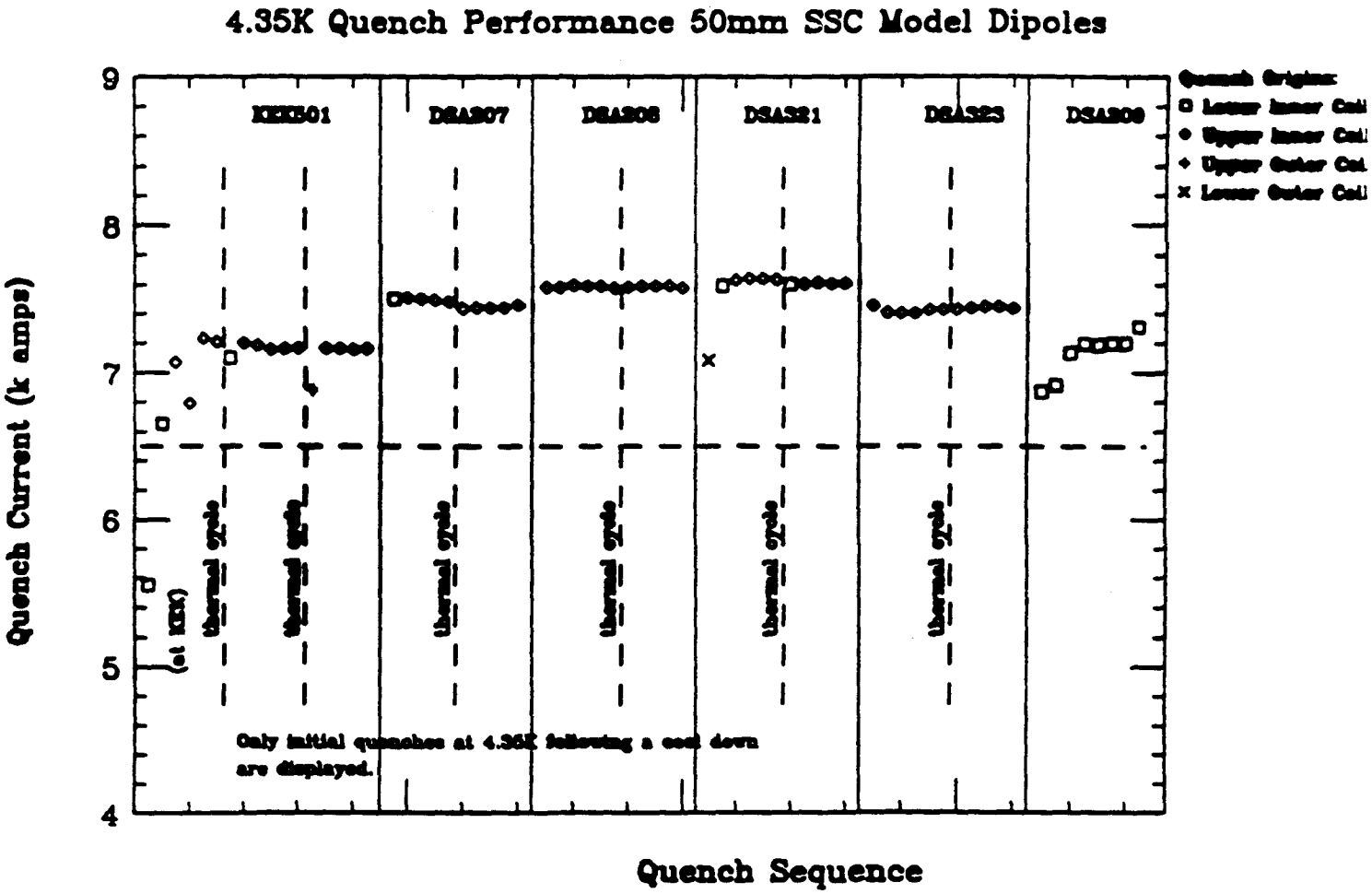
Collider Dipole Magnet

Vendors Selected – 23 Oct. 90

Leader General Dynamics Corporation
Follower Westinghouse Electric Corporation

- Leader build 15 prototype, 35 pre-production, and 251 LRIP
- Follower build 0 prototype 35 pre-production, and 251 LRIP
- First production magnet due June 1994

Quench Performance - 50mm Model Dipoles



COLLIDER QUADRUPOLE MAGNETS

Vendor selected May 3, 1991

BABCOCK & WILCOX

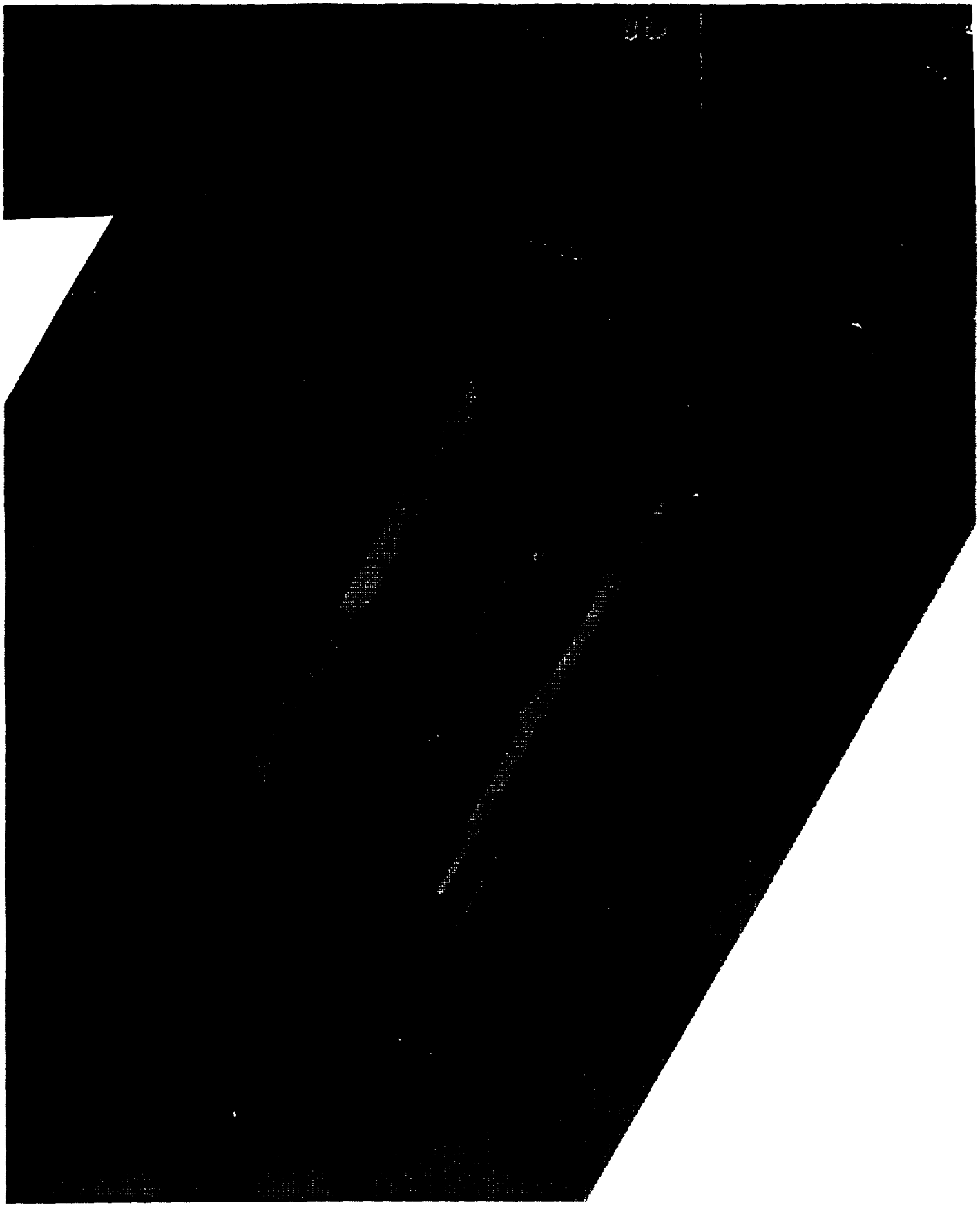
- **147 Superconducting Magnets**
- **Eventually 1,664 Quadrupoles**

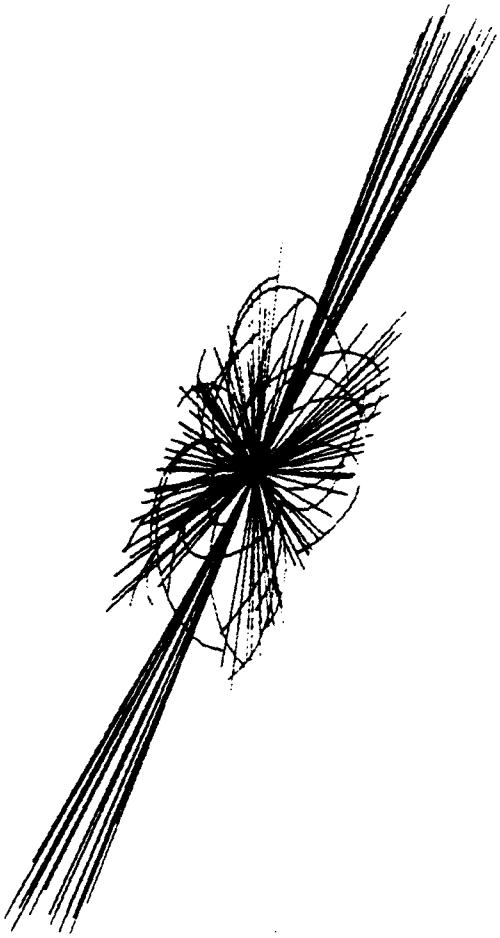
First Delivery: Fall, 1994

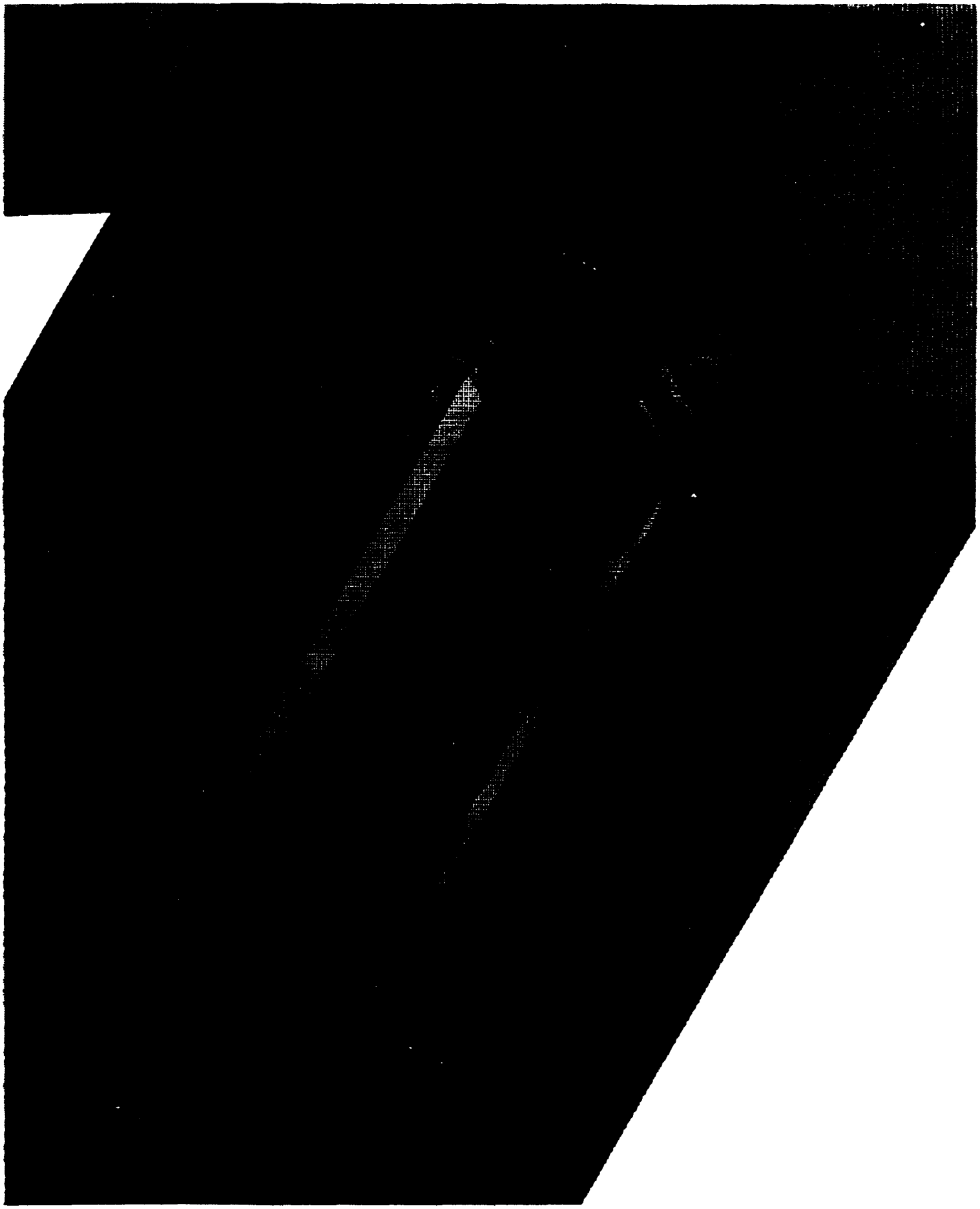
PHYSICS/DETECTOR SIMULATION FACILITY

First Implementation of the SSC Laboratory's Computing Strategy for Physics Research

- **Major computing resource for SSC detector designers worldwide**
- **Test platform for parallel computing concepts**







Overall Financial Constraints

- $752.1M (FY1990 Dollars) in SSC project funds for detector R & D, detectors, and detector-related computing
- Approximately $625M for detectors themselves
- Reserve $75M for smaller experiments
- Leaves approximately $550M for the major detectors, including internal SSCL detector project management, engineering, detector-specific R & D, etc.

Detector R & D

- $40M total in SSC Project Funds
- In FY90, $17M allocated to Generic and SSC Detector Subsystem R & D
- In FY91, $15M budgeted for Subsystem R & D
- Budgets for FY91 have been finalized for 25 Subsystem R & D efforts

Engineering, Systems Integration, and Coordination Funds

- SDC, L*, and EMPACT/TEXAS each received $500K in FY90
- An additional $200K was given in December, and $300K in January, for a total of $1M to each collaboration submitting a Letter of Intent
- Support being given to SDC to proceed toward a proposal: $1.5M given in March and further support soon for remainder of FY91.

SDC Cost Review Panel

Formed in March to perform an independent evaluation for the SSC Laboratory of the SDC cost estimate

Panel Membership

Dennis Theriot	(Fermilab) Chairman
Ray Stefanski	(SSCL) –Vice Chairman
P. Clee	(Rutherford)
H. Hoffman	(CERN)
P. Innocenti	(CERN)
D. Lehman	(DOE)
R. Johnson	(General Dynamics)
M. Montgomery	(Martin Marietta)
V. Radeka	(BNL)
D. Etherton	(SSCL)
M. Harris	(SSCL)

Consultant

H. Lynch	(SLAC)

SDC Cost Review Panel (cont'd)

- Panel met April 15-16,1991, analyzed cost reference documents and drew up questions for SDC
- SDC response at second meeting of Panel on April 29-30,1991
- Costing done without international participation ("US Basis")
- Final Report due in May

The Second Detector

- Program Advisory Committee has strongly recommended that there be two large detectors as part of the initial experimental program
- One Detector, SDC, is currently being supported to proceed toward a formal proposal/design report
- Great scientific opportunity is presented by a second detector and a substantial community has indicated interest in designing and building it

The Second Detector (cont'd)

- December and March meetings of the PAC led to consideration of the L* Letter of Intent as the candidate for the second detector.
- Unresolved questions pertaining to funding and collaboration management have led the SSCL to conclude that L* should not be supported to proceed in the preparation of a full proposal
- Much excellent technical work has been done

The Second Detector (cont'd)

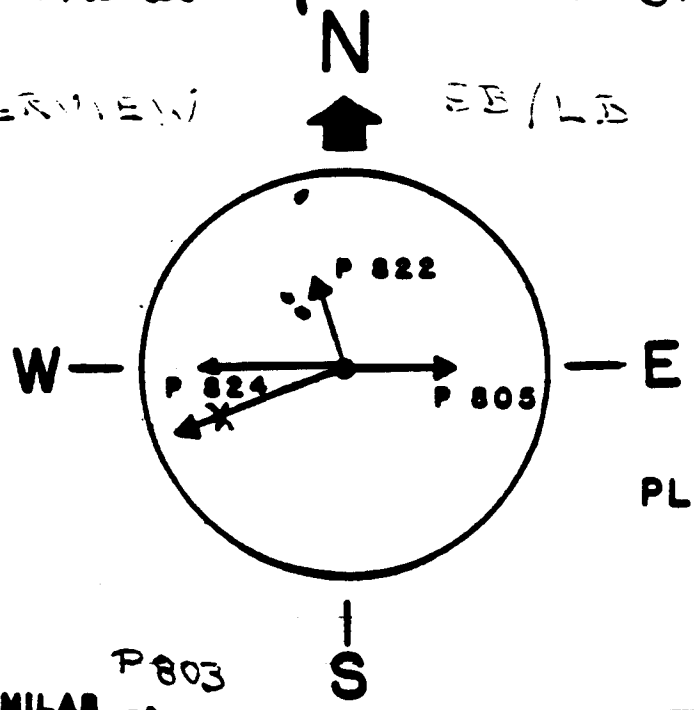
- SSC Laboratory is inviting all interested parties from the international community to discuss with us the formation of an international collaboration for a second detector that would be part of the initial experimental program

- As a first step, an open workshop will be held June 11-13 at the SSCL to discuss the possibilities for such a detector

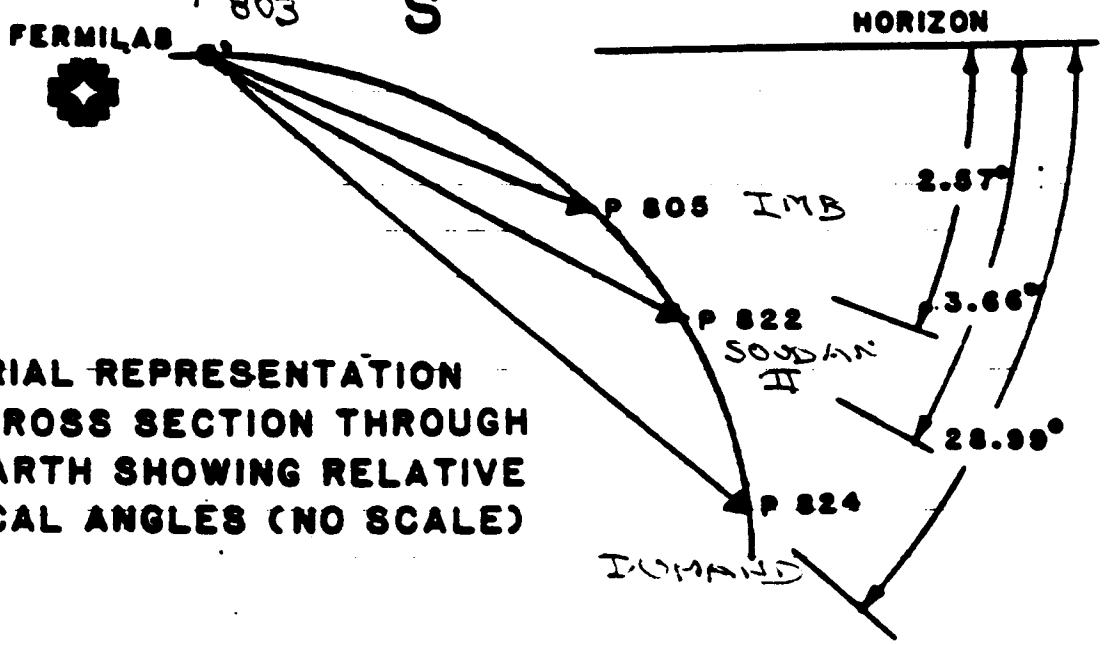
N.W. Reay

Fermilab after Main Injector Upgrade!

OVERVIEW SB/LB OSCILLATIONS



PLAN VIEW OF EARTH
(NO SCALE)



PICTORIAL REPRESENTATION
OF A CROSS SECTION THROUGH
THE EARTH SHOWING RELATIVE
VERTICAL ANGLES (NO SCALE)

OSCILLATIONS

SHORT BASELINE → TINY MIXING
"FRONT DETECTOR"

LONG BASELINE → SMALL Δm^2
(LOOK Δm^2)

LEPTONS (NO STRONG FORCES)

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix} \ldots$$ AND NO MORE

--TWO BIG QUESTIONS--

1) DO LEPTONS MIX?

RELIGION: WILL HAPPEN IF NOT FORBIDDEN

- STANDARD MODEL ALLOWS

- MANY UNIFIED THEORIES REQUIRE

NOT FORBIDDEN!

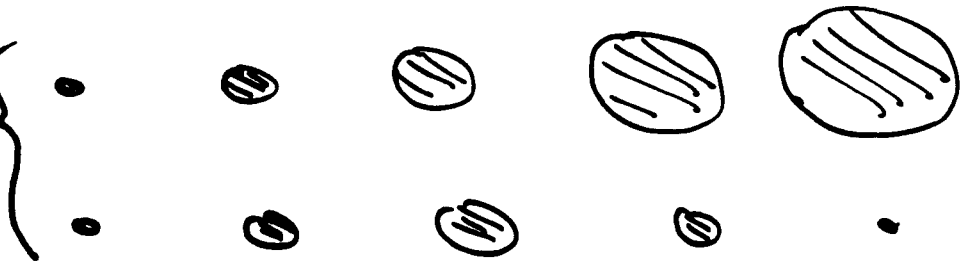
2. IS $M_\nu \neq 0$?

STANDARD MODEL ALLOWS!

$M_\nu > 0$ HAS ALMOST RELIGIOUS CONSENSUS!

IS UNIVERSE CLOSED OR OPEN

BIG BANG



(OPEN)

(CLOSED)

GAMMA RAYS ⇒ [illegible] FOOD!

$\sim 415\ \nu/cm^3$

BIG BANG THEORY [illegible]

IF $M_\nu \neq 0$ [illegible]

UNIVERSE IS CLOSED [illegible]

MASSIVE ν ⇒ "BORN AGAIN"

AT FIRST GLANCE, NO EVIDENCE

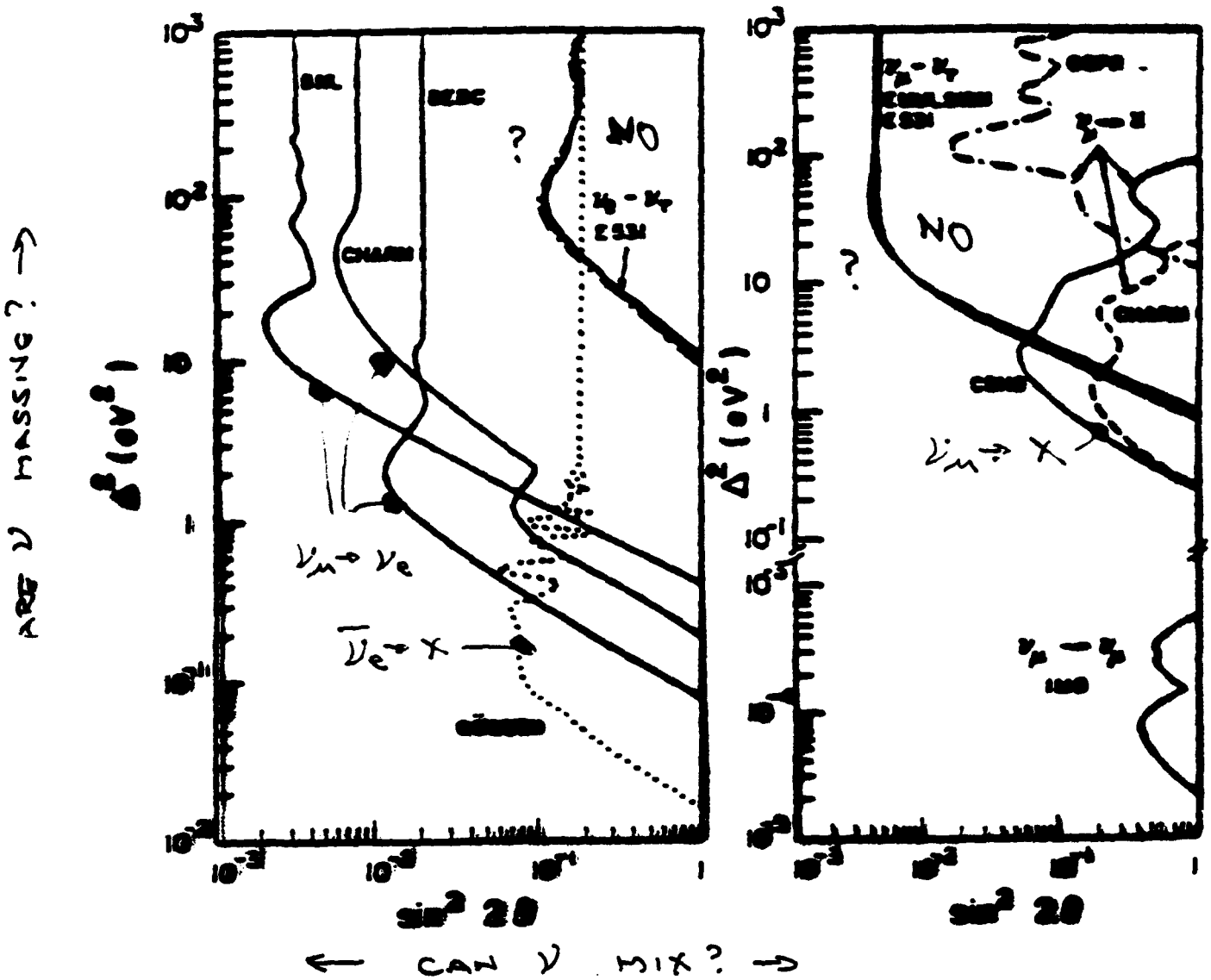


FIG. 1. Limits (90% C.L.) on $\nu_\mu \to \nu_e$, $\nu_e \to \nu_\tau$ and $\bar{\nu}_e \to x$ (left) and $\nu_\mu \to x$ and $\nu_\mu \to \nu_\tau$ (right). The allowed areas are to the left of the curves (Eichler, 1988).

BUT IF QUARK & LEPTON MIXING ANGLES ARE SIMILAR, NEED

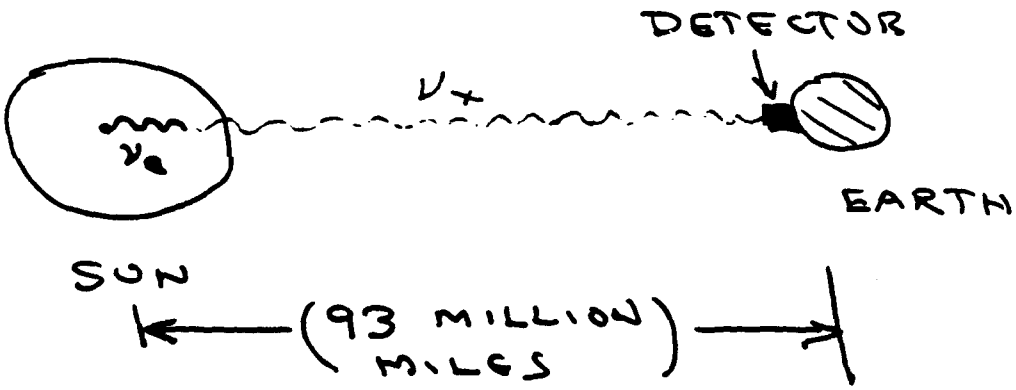
$\sin^2 2\theta < 2 \times 10^{-3}$

MANY THEORIES INDICATE

$M_{\nu_\tau} \gg M_{\nu_\mu} \gg M_{\nu_e}$

& SEESAW MECHANISM

TOO FEW SOLAR ν_e



(NOT TO SCALE)

OSCILLATIONS

?

CIRCUMSTANTIAL EVIDENCE!

^{37}Cl $\phi(\nu_e)$

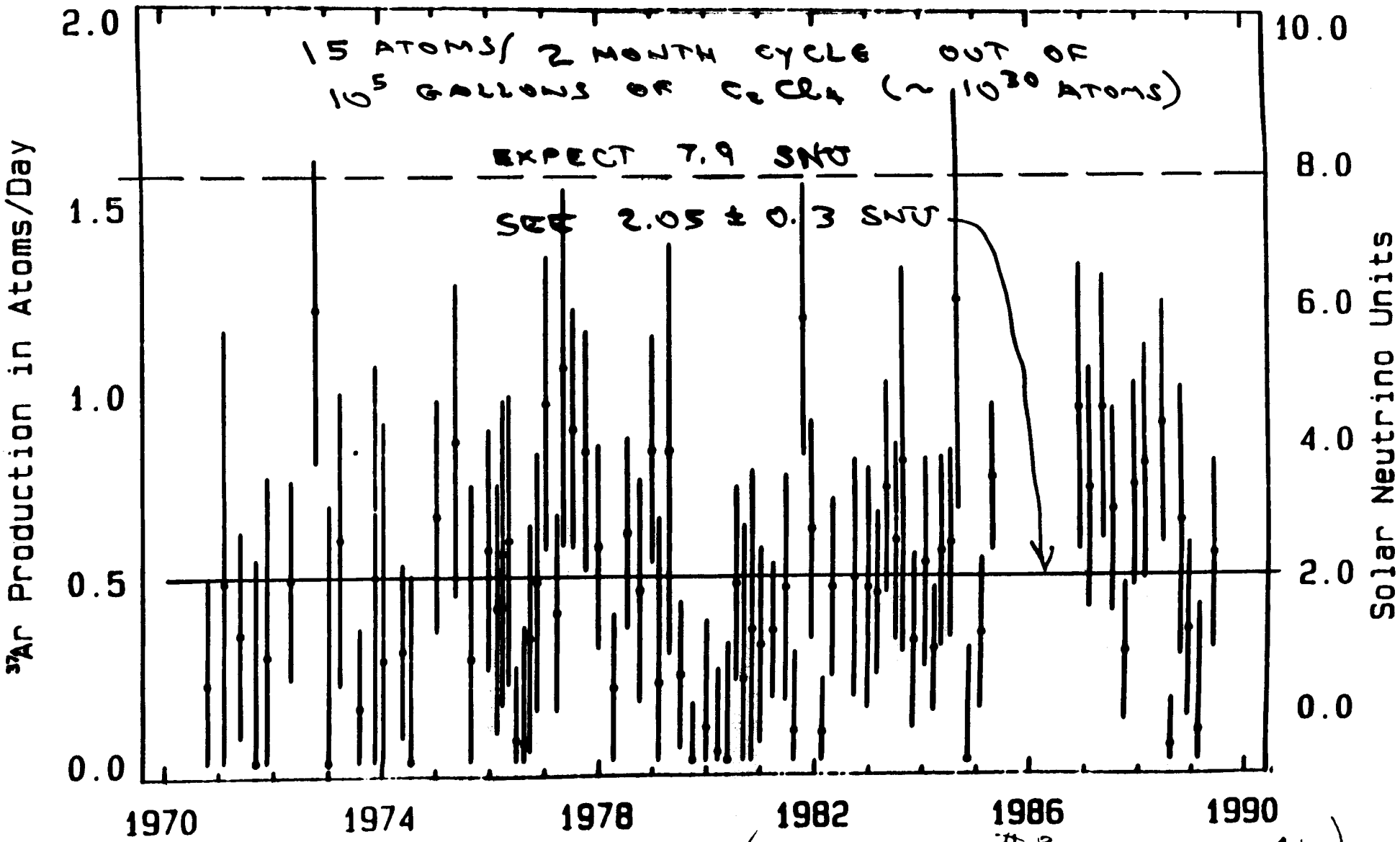
SEE $E_\nu > 0.8$ MeV

ARGON PRODUCTION RATE

Runs 18 - 105

$\nu_e + {}^{37}Cl \rightarrow e^- + {}^{37}Ar$

EXTRACT & COUNT



(+ Kamiokande [illegible])

BUT WAIT

⇒ { UNTIL GALLIUM, THERE'S LOOPHOLES

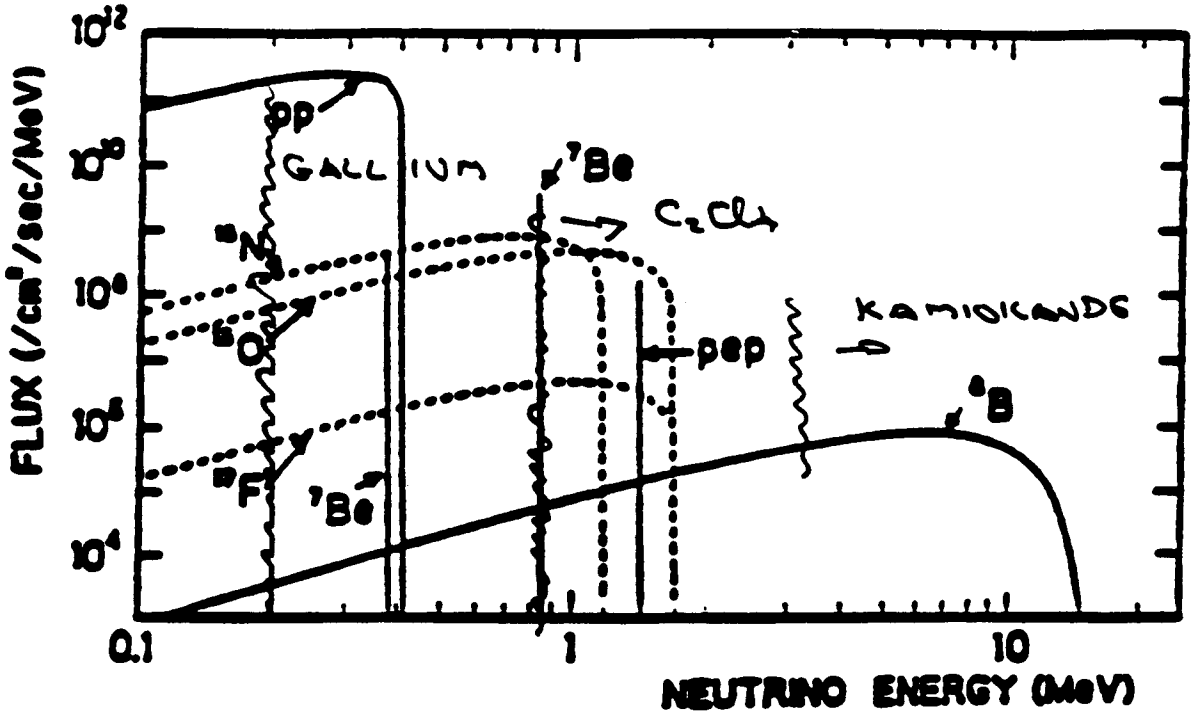


FIG. 7. Solar neutrino spectra predicted by the standard solar model (Bahcall and Ulrich, 1988). The neutrino fluxes from continuum sources are given in units of number per cm^2 per second per MeV, and the line fluxes are given in number per cm^2 per second, both at a distance of 1 AU.

TINY HIGH ENERGY BRANCHES
AFFECTED BY MODELLING OF SUN

GALLIUM $p + p \rightarrow d + e^+ + \nu_e$ ≲ 0.4 MeV

C₂Cl₄ — SOME ($^3He + {}^4He \rightarrow {}^7Be + \gamma$; ${}^7Be + e^- \rightarrow {}^7Li + \nu_e$) 90% 0.86 MeV

MOSTLY (${}^7Be + p \rightarrow {}^8B + \gamma$; ${}^8B \rightarrow {}^8Be^* + e^+ + \nu_e$) ≲ 15 MeV

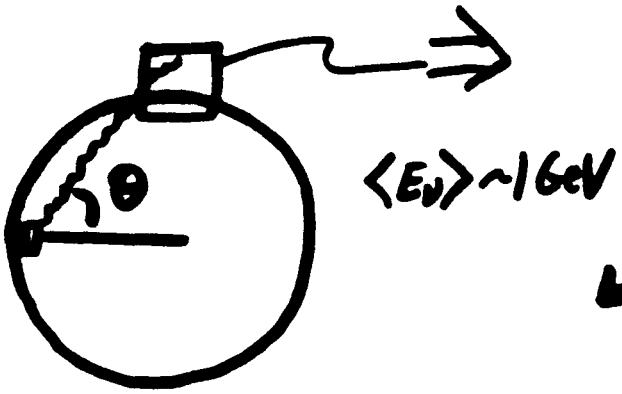
KAMIOKA

"Atmospheric" neutrinos

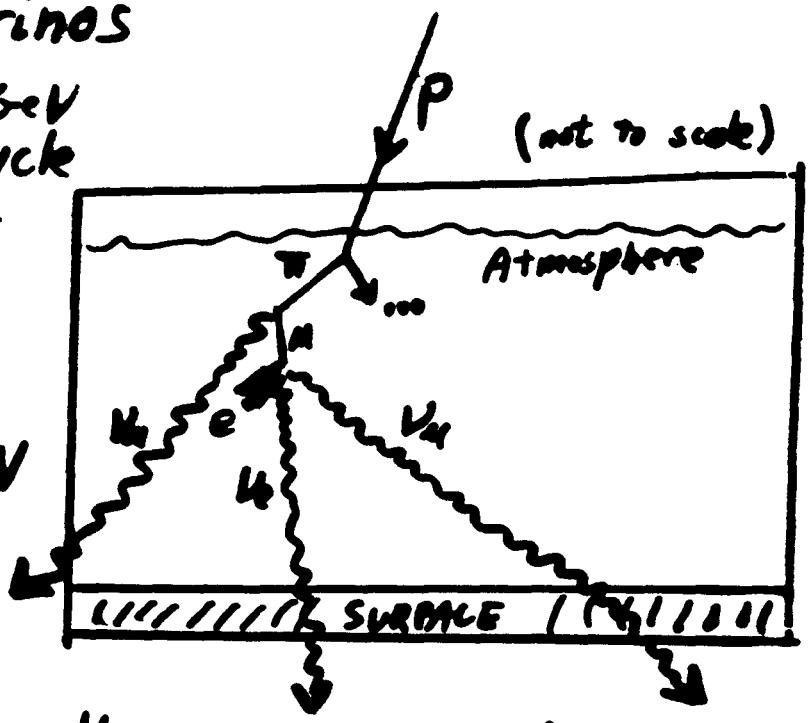
$\langle E_p \rangle \sim 10\,GeV$

modulated by solar cycle

every Solar Max different



$\langle E_\nu \rangle \sim 1\,GeV$



In the absence of oscillations, we expect:

$$\frac{dN}{d(\cos\theta)} \text{ flat} \; ; \quad \frac{n(\text{"}\mu\text{"})}{n(\text{"}e\text{"})} \cong \frac{n(\nu_\mu + \bar{\nu}_\mu)}{n(\nu_e + \bar{\nu}_e)} \sim 2$$

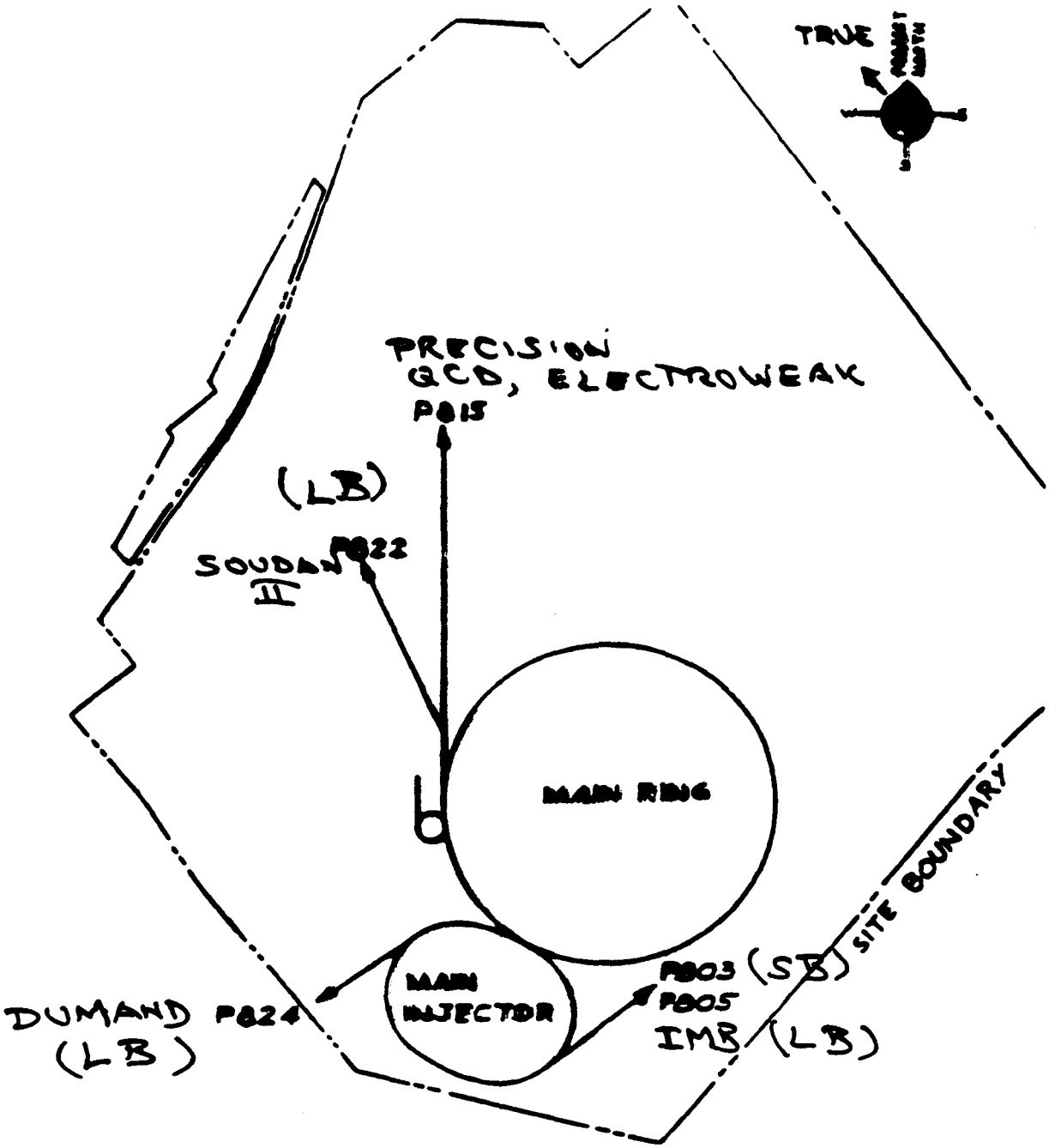
Underground Experiments measure:

$$r \equiv \left.\frac{n(\mu)}{n(e)}\right)_{measured} \Big/ \left.\frac{n(\mu)}{n(e)}\right)_{monte\ carlo}$$

$$\boxed{r < 1 \text{ may be evidence for } \nu_\mu \to \nu_x}$$

TOO FEW ν_μ

1988	Kamioka	$r = .71^{+.10}_{-.08} \pm .05$
1989	Frejus	$1.01 \pm .10$
shower events	— Frejus "contained"	$(.81 \pm .09)$
1991	IMB-3 (preprint)	$.67 \pm .18$
	NUSEX (low stats)	1.0 ± 0.2

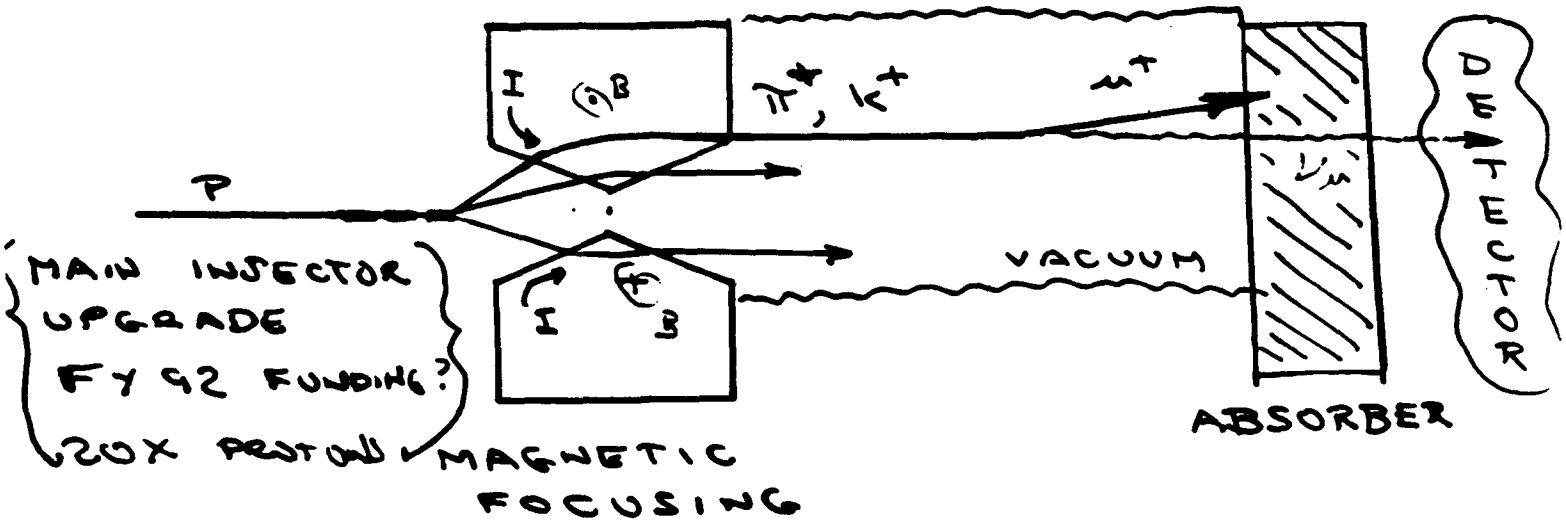

TRUE
PRECISION
QCD, ELECTROWEAK
P815
(LB)
SOUDAN
II
P822
MAIN RING
SITE BOUNDARY
MAIN
INJECTOR
P803 (SB)
P805
IMB (LB)
DUMAND P824
(LB)

ν BEAM KIT

1) PROTON INTERACTIONS MOSTLY MAKE $\pi^\pm$, $K^\pm$.

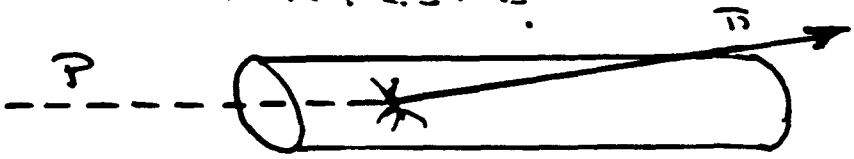
2) FOCUS π^+, K^+, WAIT FOR DOMINANT $\pi^+ \to \mu^+ \nu_\mu$ AND $K^+ \to \mu^+ \nu_\mu$ MODES

3) STOP EVERYTHING BUT ν.

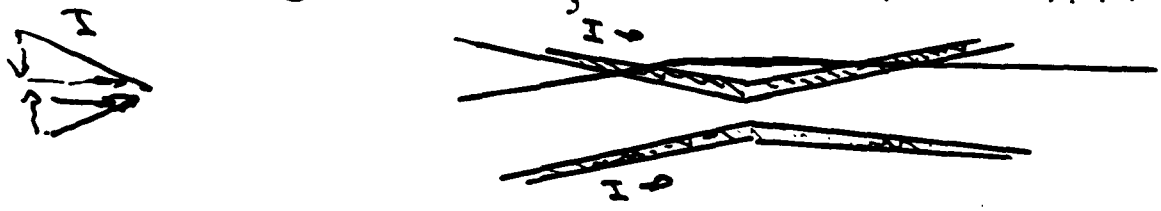


MAIN INJECTOR UPGRADE
FY 92 FUNDING?
20X PROTONS

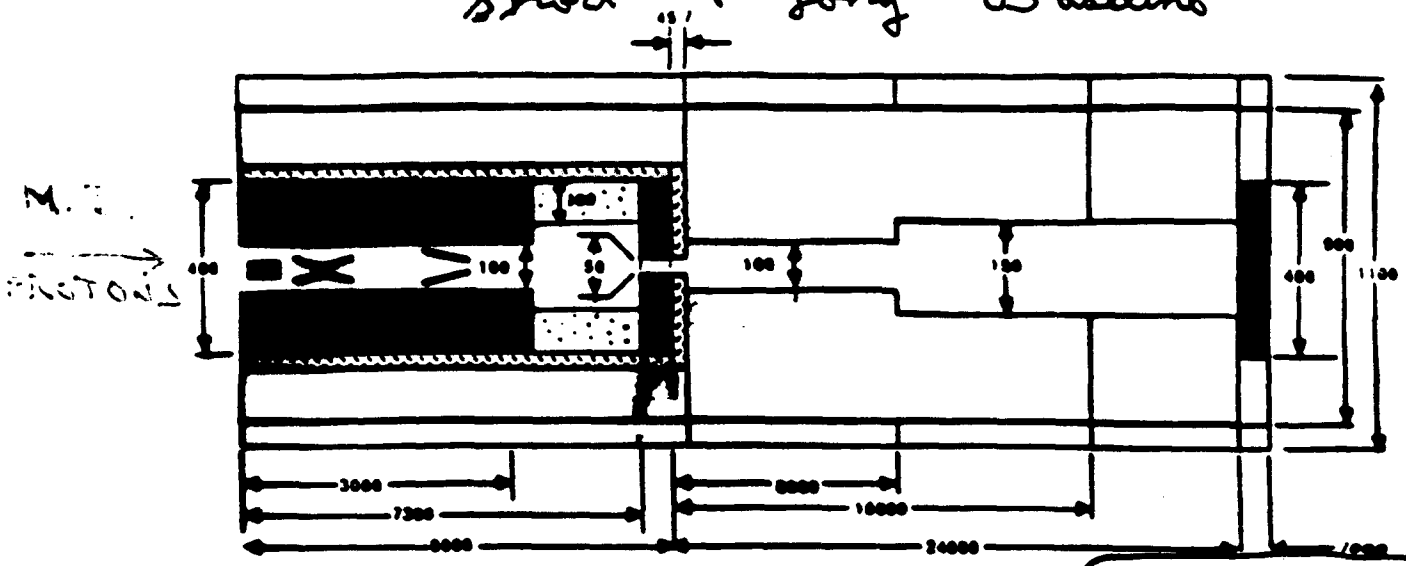
PROTONS



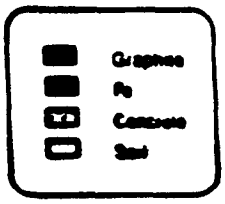
WANT SMALL T_0, BUT TARGET COULD BLOW UP, LOTS OF HEAT.



120 GeV Neutrino Beam
Short + Long Baseline



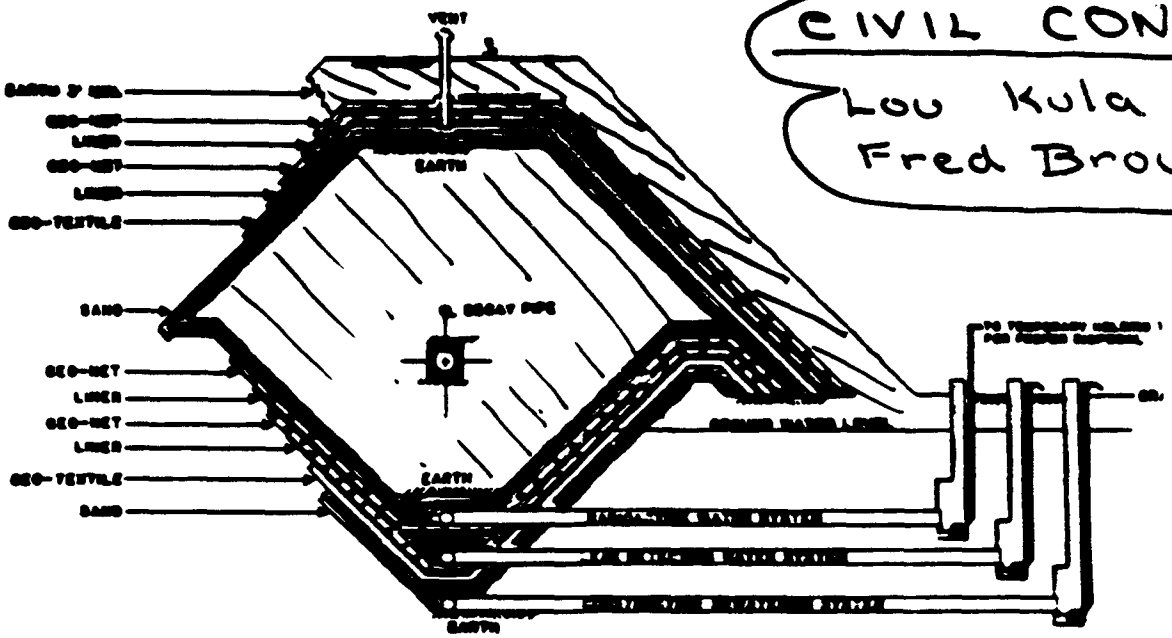
TRADIATION
Bill Freeman



Main Injector Neutrino Facility
Geometry for CASIM Calculation 004

Not to Scale

CIVIL CONST
Lou Kula
Fred Browning



NO SCALE

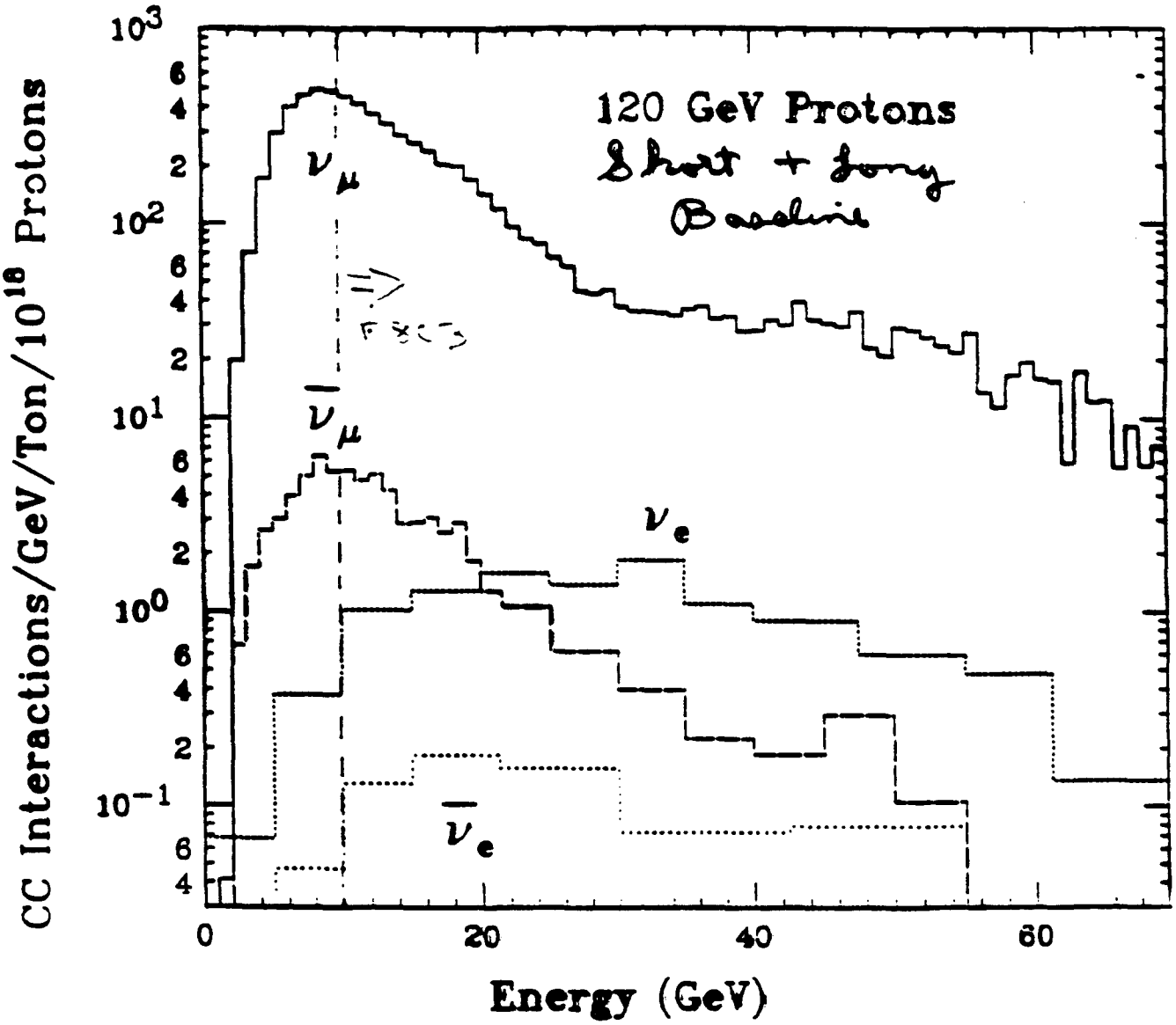
Contained Earth

Radiation is Big Problem!

[illegible]

PROPOSAL	BASELINE	REL. COST
SHORT BASELINE (P803)	0.5 KM	1.0
SB + IMB (P805)	577 KM	~~1.19~~ 1.08
SB + SOUDAN 2 (P822)	822 KM	~~1.36~~ 1.22
SB + DUMAND (P824)	6239 KM	2.03

(SNO IS 970 KM AND IS THE SAME SIZE AS IMB, BUT THE INSTRUMENTED PART IS ONLY ROUGHLY A THIRD)

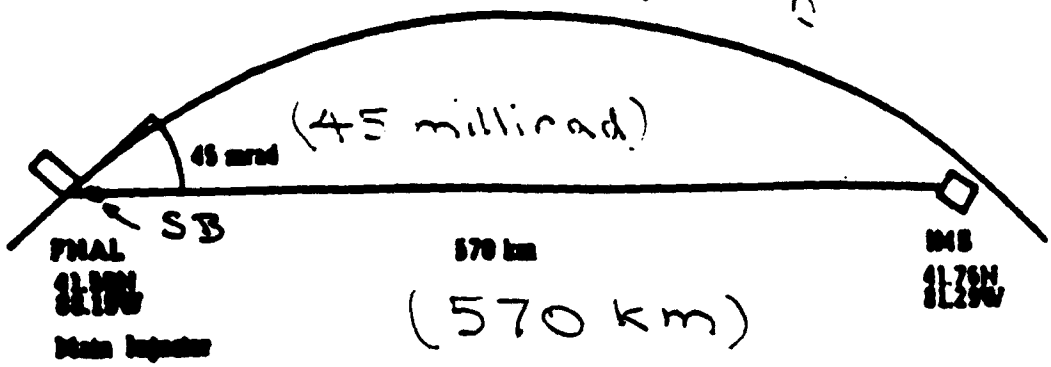


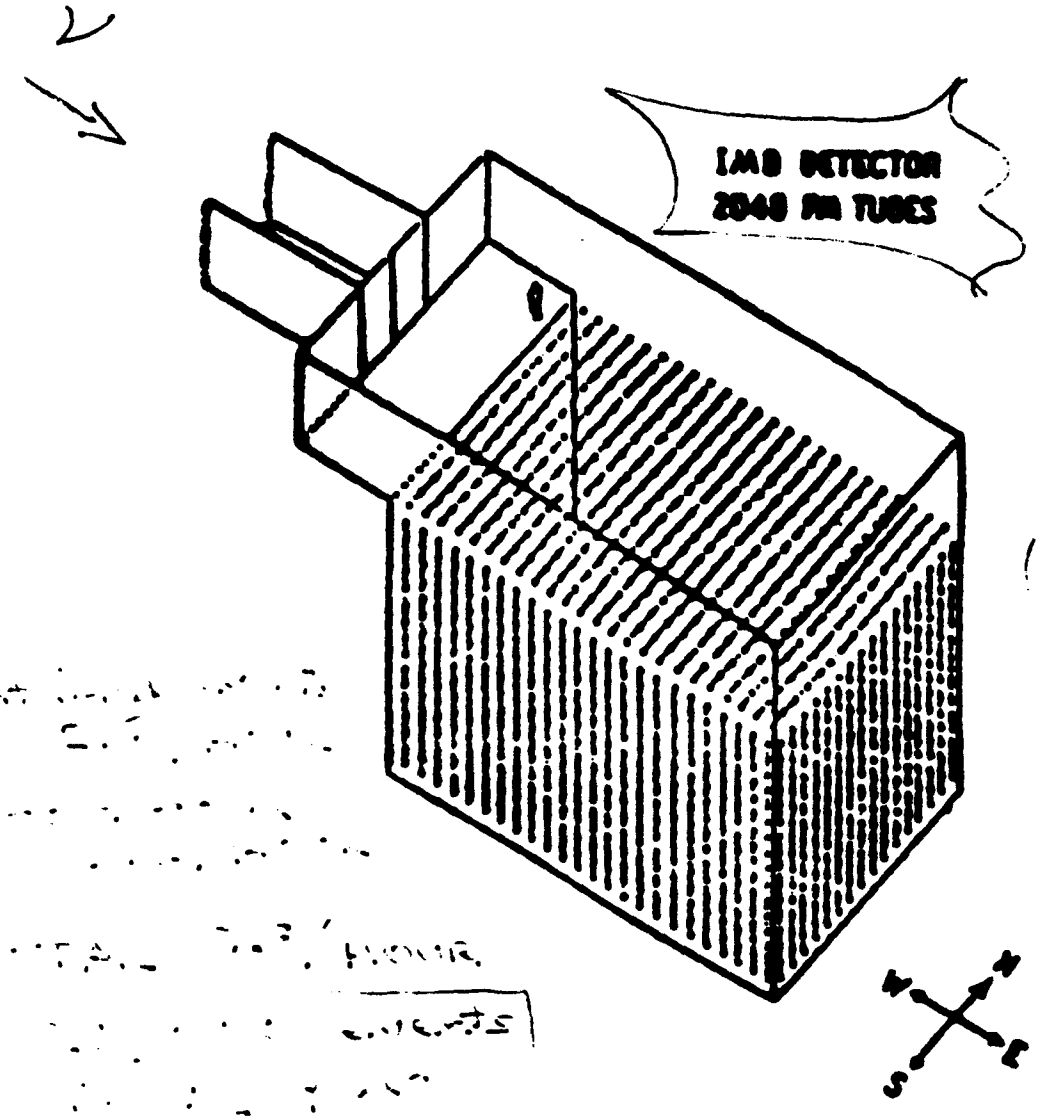
Fluxes (In short detector)

Bob Bernstein
Wojtek Gajewski
Anthony Malensek
Noel Stanton

low yield of $\bar{\nu}_\mu$, $\bar{\nu}_e$

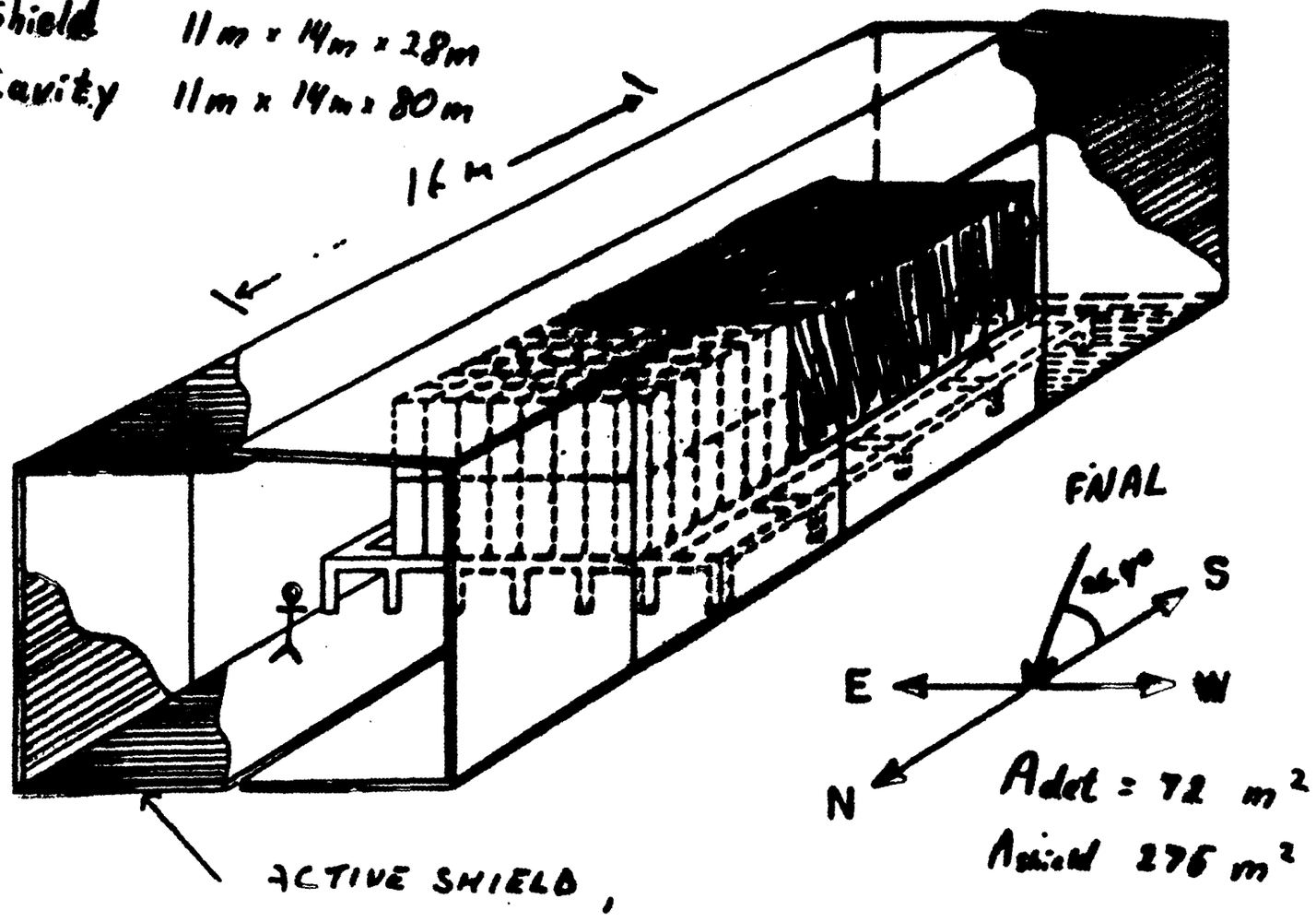
T-905 Example of long baseline

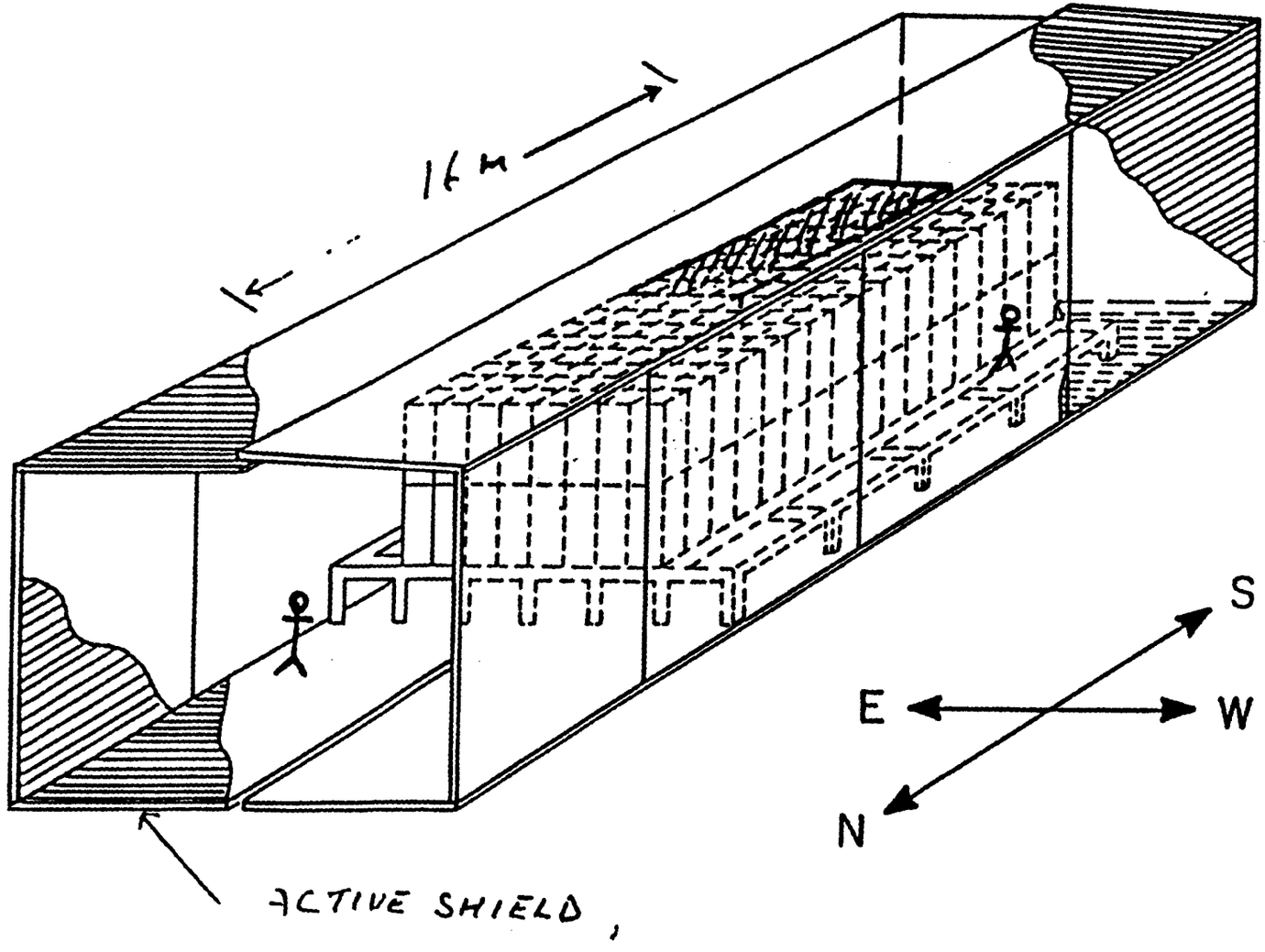




SOUDAN 2

Detector 5m x 8m x 16m
Shield 11m x 14m x 28m
Cavity 11m x 14m x 80m




16 m
S
E
W
N
ACTIVE SHIELD

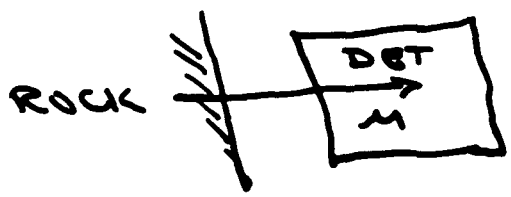
$\nu_\mu \to$ STERILE, ν_e, ν_τ

MANY LB METHODS

1) <u>APPEARANCE:</u> <u>BEST</u>

BUT $\nu_\mu \to$ STERILE ν X NO!
& TOO COARSE FOR $\nu_\mu \to \nu_\tau$

2) <u>μ's FROM ROCK:</u>



BIG TARGET, BIG SYSTEMATICS

3) <u>SAME FRONT & BACK DET.:</u>

OK., BUT FRONT DETECTOR COARSE.

4) <u>$\frac{NC}{CC}$, REAL OR EFFECTIVE:</u>

IN MOST OSC, NC GROWS & CC SHRINKS.

GOOD! <u>SOMEWHAT</u> SELF NORMALIZING.

BUT $\nu_\mu \to$ STERILE ν X NO!

TRICK

ν_e CC "LOOKS LIKE" NC

ν_τ CC "LOOKS LIKE" NC

ALMOST $\tau \to \mu\nu\nu$ (18%)

ALSO, $\left(\frac{\sigma_\tau}{\sigma_\mu}\right) \sim 0.3$

WITH PERFECT NC, CC SEPARATION

LET $R_0 = \left(\frac{NC}{CC}\right)_{NO\ OSC}$

$\nu_\mu \to \nu_e$: $R_{MEAS} = R_0 \left[1 + 4P(\nu_\mu \to \nu_e) \right]$

$\nu_\mu \to \nu_\tau$: $R_{MEAS} = R_0 \left[1 + 1.7P(\nu_\mu \to \nu_\tau) \right]$

SOUDAN 2: [illegible] CC, NC [illegible]

[illegible]

SEE CHANGE IN $\left(\frac{NC}{CC}\right)$ ONLY.

ALSO, CAN DO ENTERING μ's

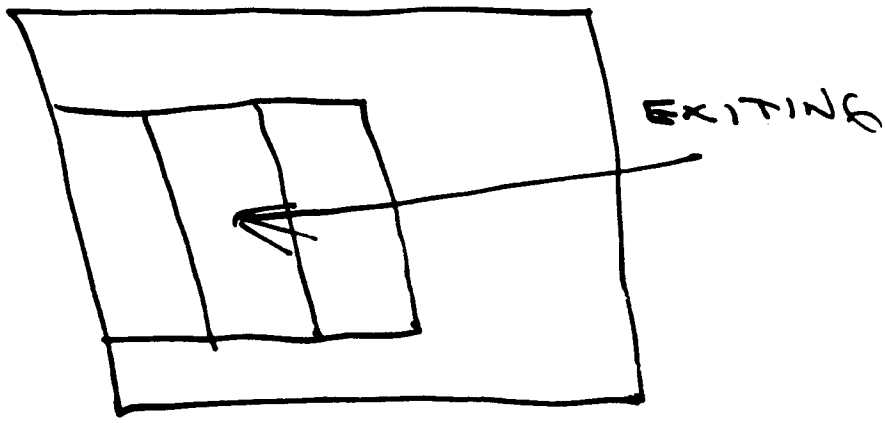
COMPARE UPSTRM TO DOWNSTRM

(DIFFERENT SYSTEMATICS

IMB

<u>NOT</u> COMPLETE NC, CC SEPARATION

BUT 11,000 EVENTS (8 MO. RUN)



FORM $\sigma = \left(\frac{N_{EXIT}}{N_{TOTAL} - N_{EXIT}} \right)^{-1}$

CAN DO $\nu_\mu \to \nu_e$ APPEARANCE!

$\nu_\mu \to \nu_\tau$: [illegible]

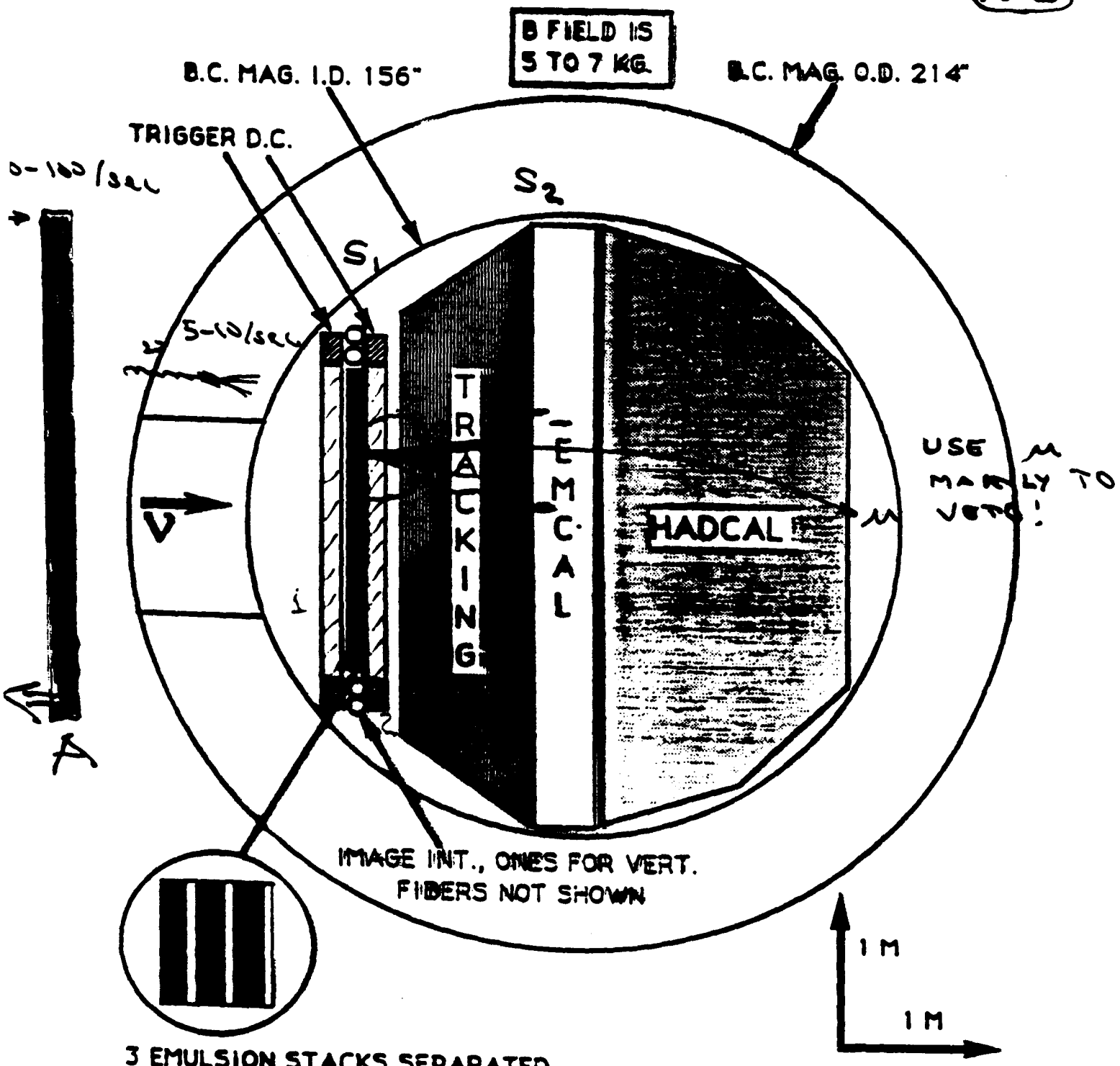
SEPARATE $\nu_\mu \to \nu_\tau$ [illegible]

$\nu_\mu \to \nu_e$ [illegible]

$\nu_\mu \to$ [illegible]

[illegible]

P803 Short Baseline



3 EMULSION STACKS SEPARATED BY SCINTILLATING FIBERS; IMAGE INTENSIFIERS NOT SHOWN.

Maybe NO trigger (Dick Sumner LeCroy)

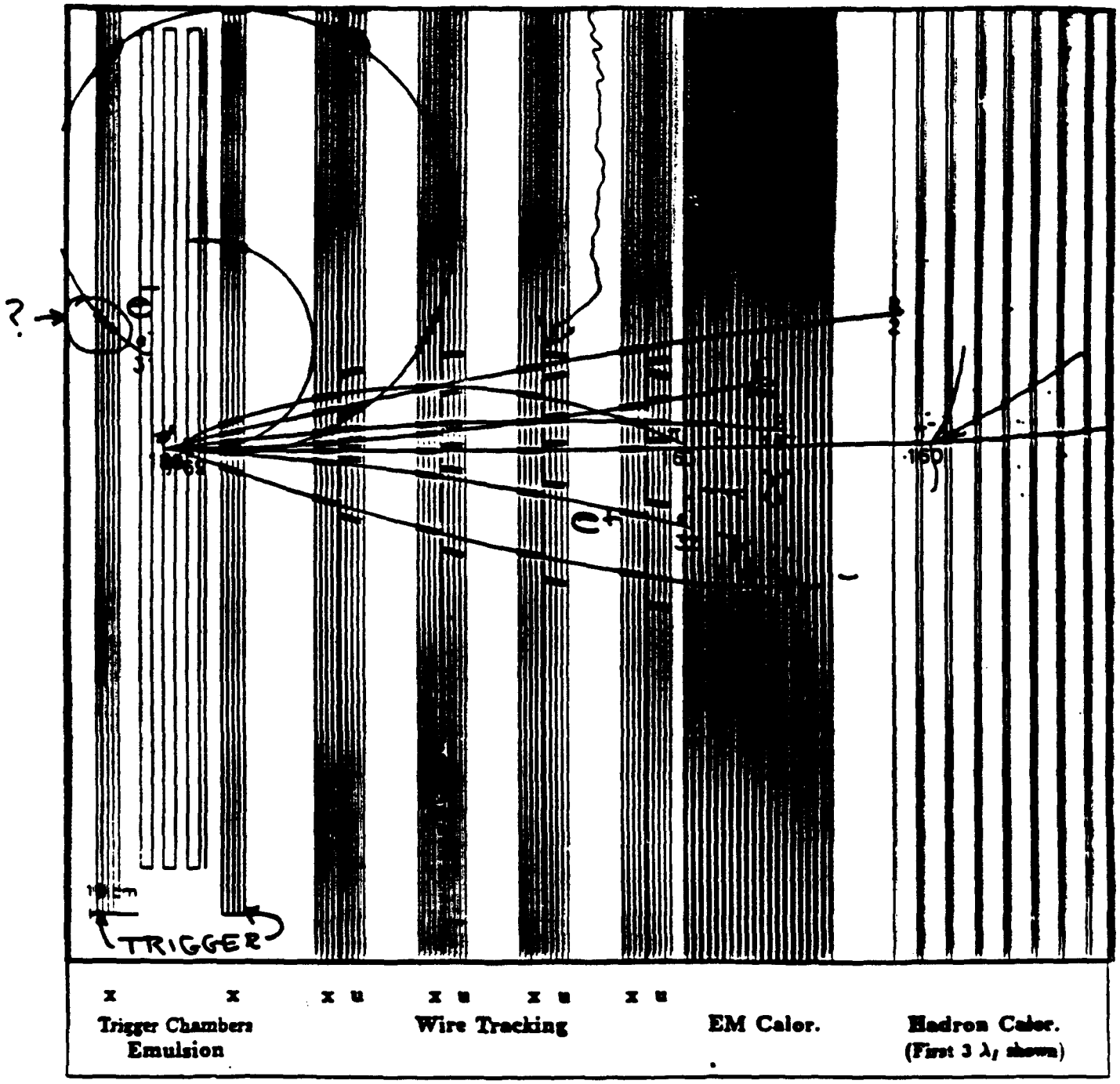
Level I $\bar{A} \cdot S_1 \cdot S_2$

Level II

DC1

DC2

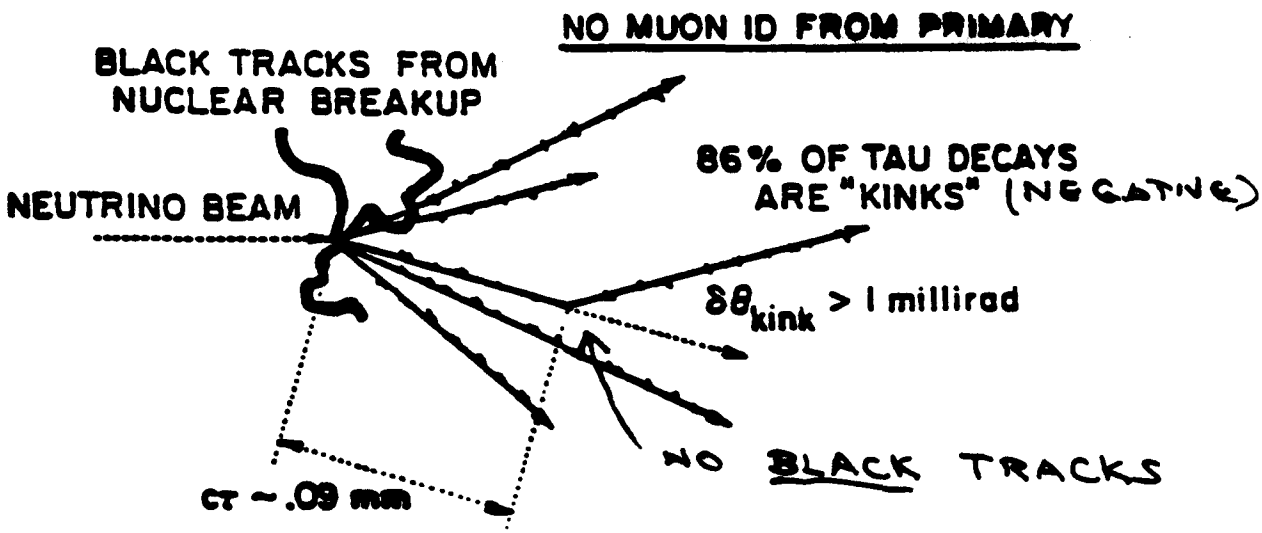
MISPLACED HITS → U-VIEW



$$\nu_\tau + Em \rightarrow \tau^- X$$
$$\hookrightarrow \rho^- \nu_\tau$$
$$\hookrightarrow \pi^- \pi^0$$
$$\hookrightarrow \gamma\gamma$$
$$\hookrightarrow e^+e^-$$

Typical Fund-Geant Event

ν_τ CC Interaction in Emulsion



NO PRIMARY MUON — COULD BE NEUTRAL CURRENT

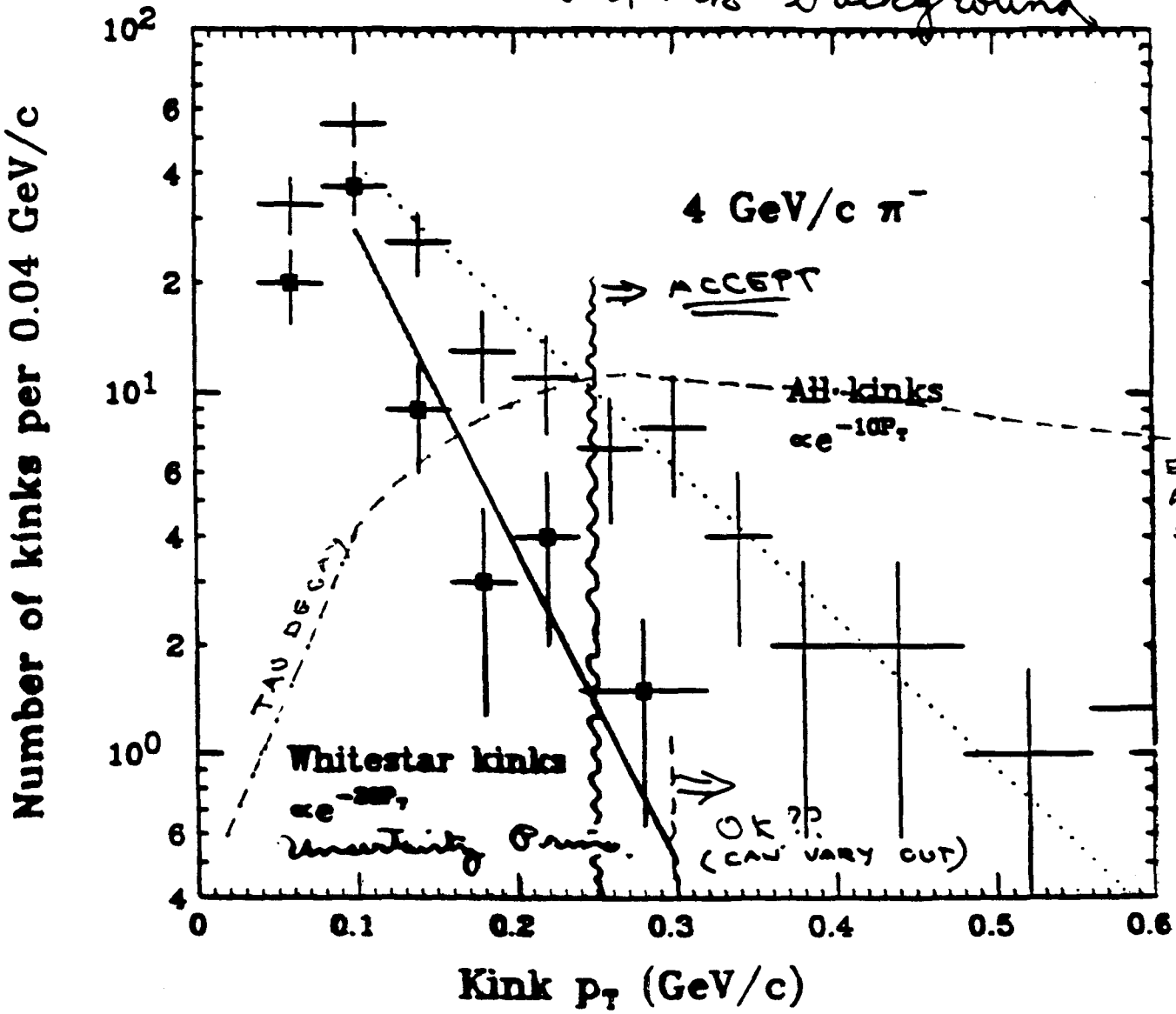
{Set primary direction to ~ ± 1 milliradian}

1.5 million CC events

Background < $\frac{1}{2}$

1)	"White star" elastic scat.	0.30
2)	("charm background") $\bar{\nu} + Em \to C^- \mu^+ X$ ↳ miss ↳ negative kink	0.10
3)	DIRECT ν_τ	0.07
4)	STRANGE DECAYS	0.01 <

White star kink background



New method for seeing ultra-short black tracks tested against KEK new data. ~ 2μ TRACKS

MFP depends on P_T cut.
Very long for $P_T > 0.3$ GeV/c

RUN TIME ~ 8 MONTHS

EMULSION ~ 200 LITERS

TOTAL PROTONS ~ 2.4×10^{20}

N_{CC} ~ 1.5×10^{6}

BACKGROUND ~ 0.47 EVENTS

0.30	WHITE STAR
0.10	CHARM
0.07	DUMP
0.01 <	STRANGE

$$\text{EFFIC.} = (\text{CONST EFF.})\left(\frac{\sigma_\tau}{\sigma_m}\right)(\text{DET. EFF.})$$

0.64 0.24 0.61

$$\text{EFF} = 0.039$$

90% CL FOR 0.47 IS 2.8

$$\text{PROB}(\nu_\mu \to \nu_\tau) \leq \frac{N_{CC}}{(\text{EFF})(N_{CC})} \cdot \frac{2.8}{(0.039)(1.5 \times 10^{6})}$$

$$\leq 4.8 \times 10^{-5}$$

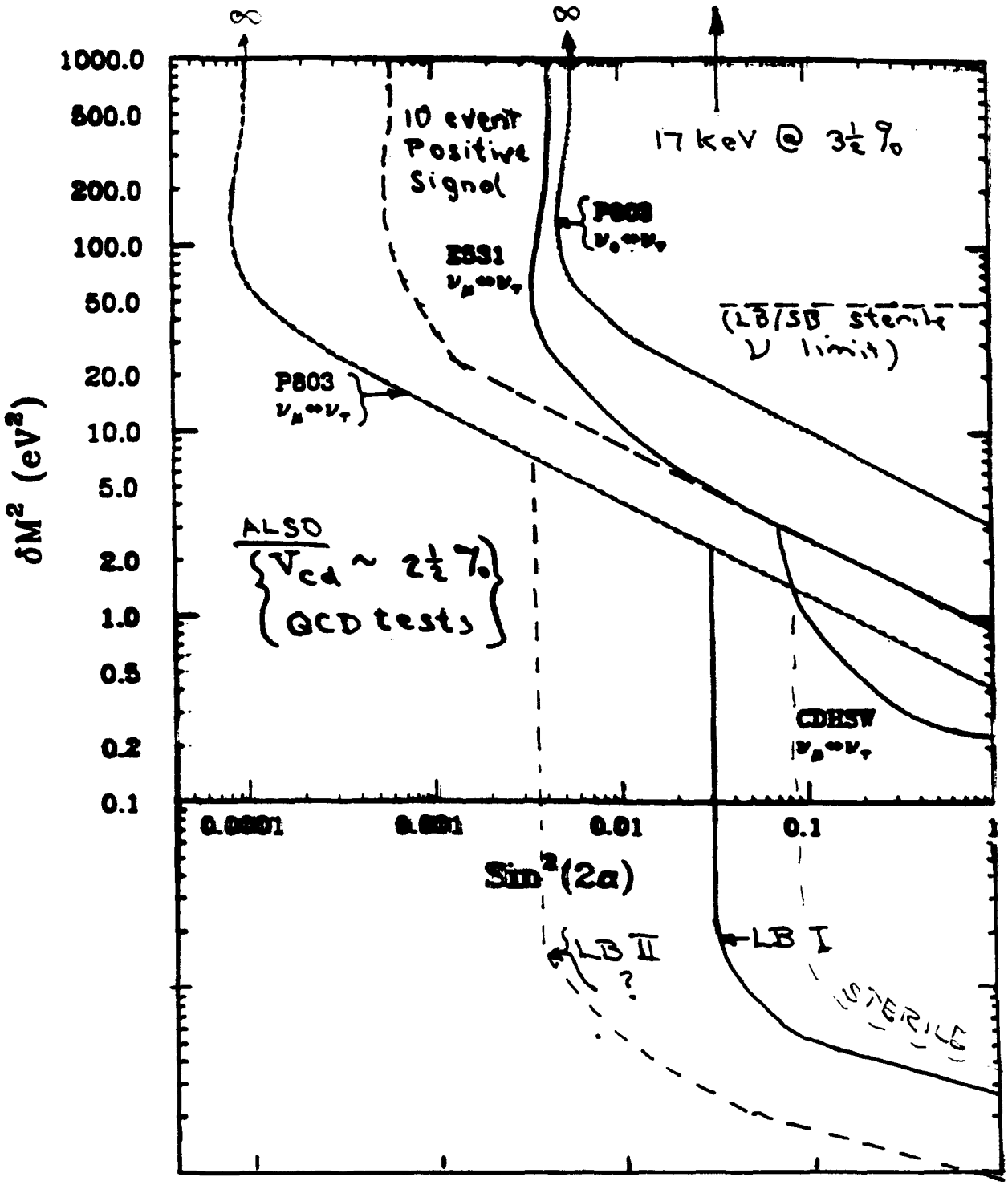
$$\text{PROB}(\nu_\mu \to \nu_\tau) = \sin^2 2\alpha \left(\sin^2\frac{\Delta m^2 L}{4E}\right) \approx \sin^2 2\alpha \left(\sin^2 1.27 \frac{\Delta m^2 L}{E}\right)$$

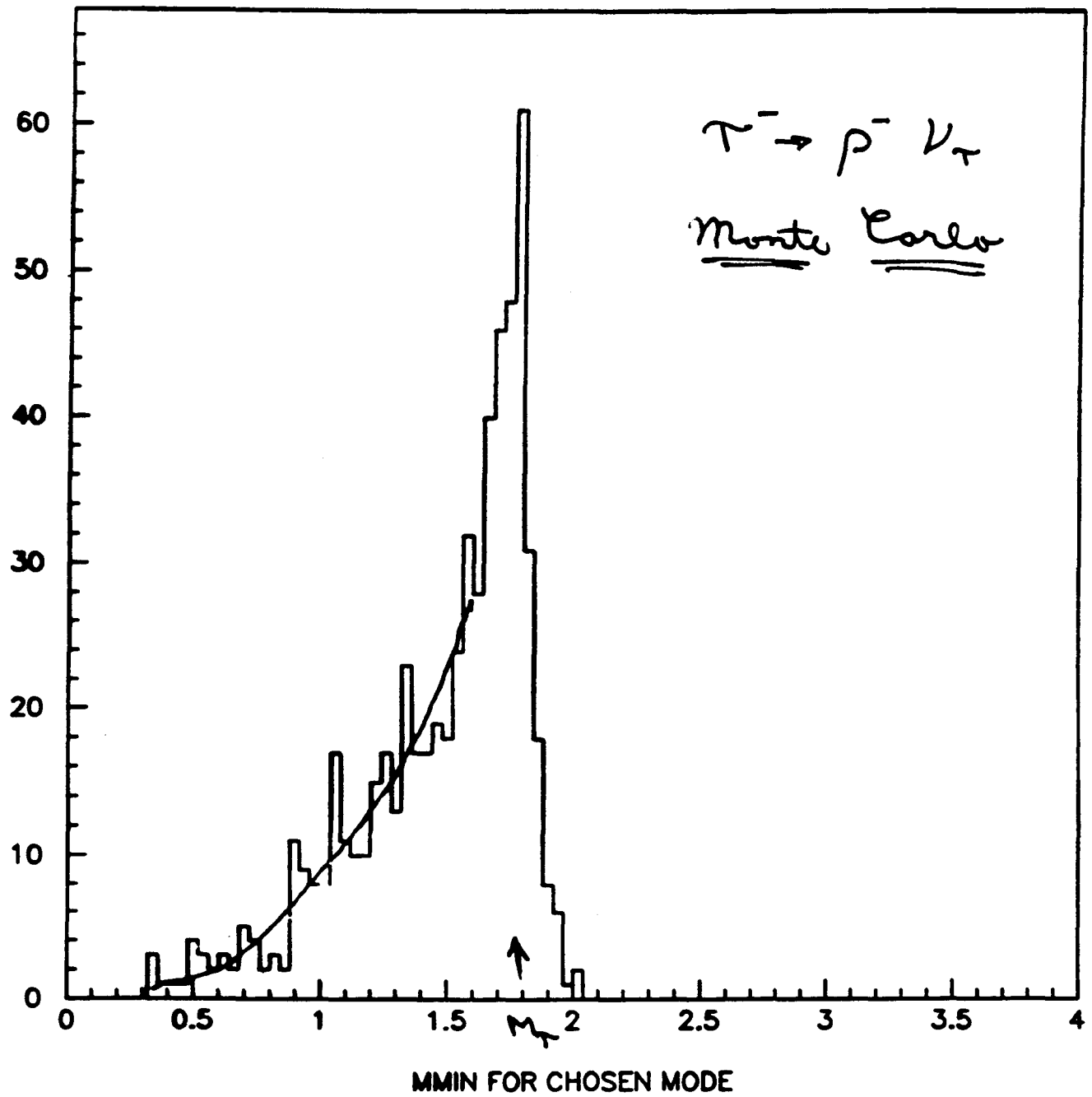
$$\approx \frac{1}{2} \sin^2 2\alpha \quad \text{for } \frac{\Delta m^2 L}{E} \gg 1$$

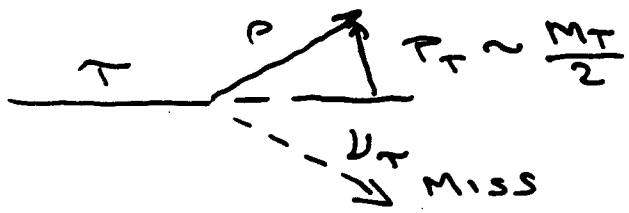
(HI MASS LIMIT): $\sin^2 2\alpha \sim 9.6 \times 10^{-5}$

But what if signal exists?

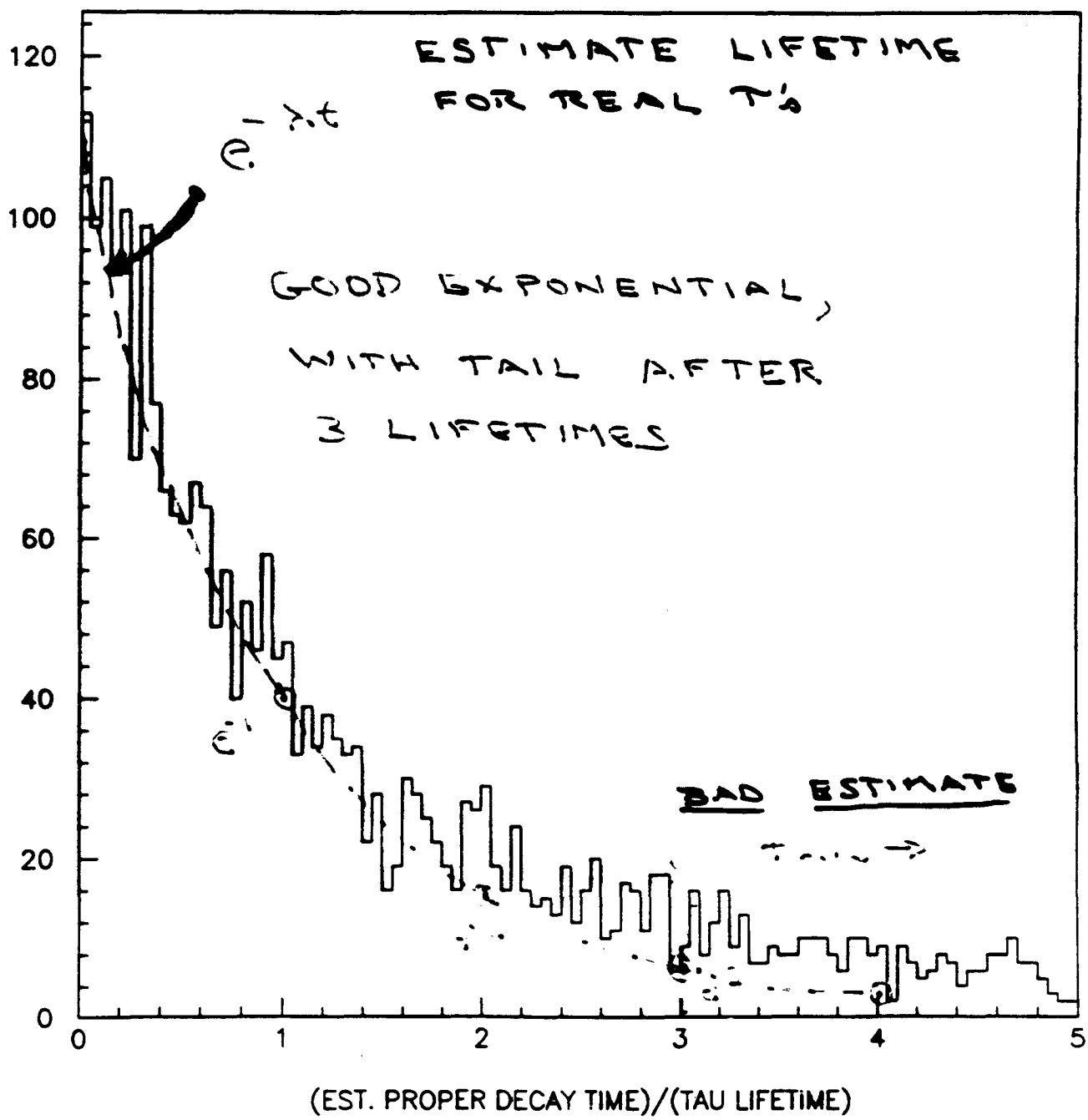
F 203 (8 months)




$\tau^- \to \rho^- \nu_\tau$
Monte Carlo
60
50
40
30
20
10
0
0
0.5
1
1.5
M_τ
2
2.5
3
3.5
4
MMIN FOR CHOSEN MODE


τ
ρ
$p_T \sim \frac{M_\tau}{2}$
ν_τ
MISS

MONTE CARLO



{IN E653: M, τ ESTIMATES
WORK ON DATA FOR CHARM,
BEAUTY}

(8 MONTH RUN)

IF POSITIVE SIGNAL @ 5×10^{-4}

(14 EVENTS, 7-8 2 BODY)

$4.1 > \tau_\tau > 2.1 \times 10^{-13}$ sec

$1.9 > M_\tau > 1.7$ GeV/c^2

SEE <u>MORE</u> THAN EXCESS,
GET <u>MASS</u> & LIFETIME

WITH 2X STATS, DO $1\frac{1}{2}$X
BETTER.

SB/LB HISTORY

1987 - NOW — TALKS, WORKSHOPS, ETC.
SOLAR ν, ATMOS. ν & SMOKING GUN

1990 — ν CDR GROUP FORMED
PROPOSALS: P803 (SB), P805 (IMB-LB)
LOI: P822 (SOUDAN 2-LB), P824 (DUMAND)

1991 — DRAFT ν CDR COMPLETED
- PASSES INTERNAL REVIEW
P822 (SOUDAN 2) <u>PROPOSAL</u>
ν CDR REVISED TO PRESENT FORM

MAY, 1991 — THIS MAJOR REVIEW
↓
JUNE, 1991 — ASPEN PAC
- SB/LB AFFIRMED?
- CHOOSE BEAM DIRECTION?

1991-92 — ~ 4/3 YR. TO FINISH R&D, ENGRING

1993-94 — 2 YRS. TO BUILD

1995 — 1 YR. TO INSTALL

1996 — Run!

Update in 7 years!

A longshot,

but

a positive result could

change

our view of

The Universe

SSC Spring Conference

LEP Results on b Quarks

Richard P. Mount

California Institute of Technology

May 22, 1991

b PHYSICS RESULTS FROM LEP

OUTLINE

- INTRODUCTION / COMMERCIALS

- LEP 1990 DATA:
  - WHO MEASURED WHAT?
  - HOW WELL?

- TECHNIQUES AND SYSTEMATICS
  - ESPECIALLY $Br(b \to \ell)$, χ_b, τ_b

- RESULTS

b QUARK PHYSICS AT LEP

LOTS OF b QUARKS!

~ 23% OF $Z^0 \to$ hadrons

($b\bar{b}$ EVENT EVERY 30 SECONDS)

EASY TO SEE:

b MASS → JETS WITH HIGH INTERNAL $p_\perp$

→ HARD FRAGMENTATION

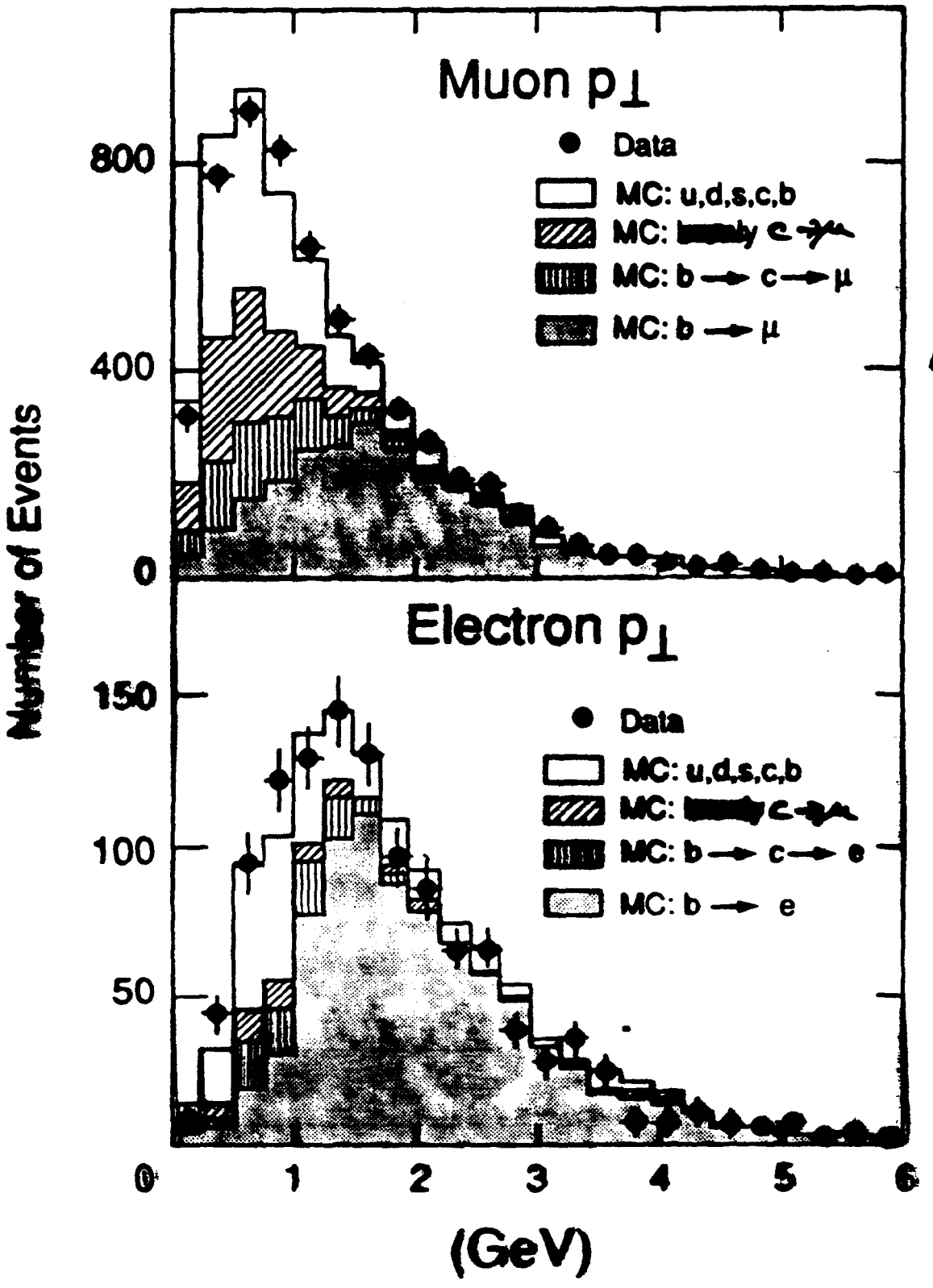
b LIFETIME → HIGH $Br(b \to \ell)$

($\approx 41\%$ OF $b\bar{b}$ → MORE THAN ONE e OR μ)

→ MEASURABLE DECAY LENGTH

1990: CLEAN $b\bar{b}$ SAMPLES FROM EVENTS WITH HIGH $p_\perp$, HIGH p LEPTONS.

FUTURE: ALSO DECAY VERTEX TAG FOR $b\bar{b}$


Muon p⊥
Data
MC: u,d,s,c,b
MC: b → c → μ
MC: b → μ
800
400
0
Number of Events
Electron p⊥
Data
MC: u,d,s,c,b
MC: b → c → e
MC: b → e
150
100
50
0
1
2
3
4
5
6
(GeV)

L3

Figure 1a

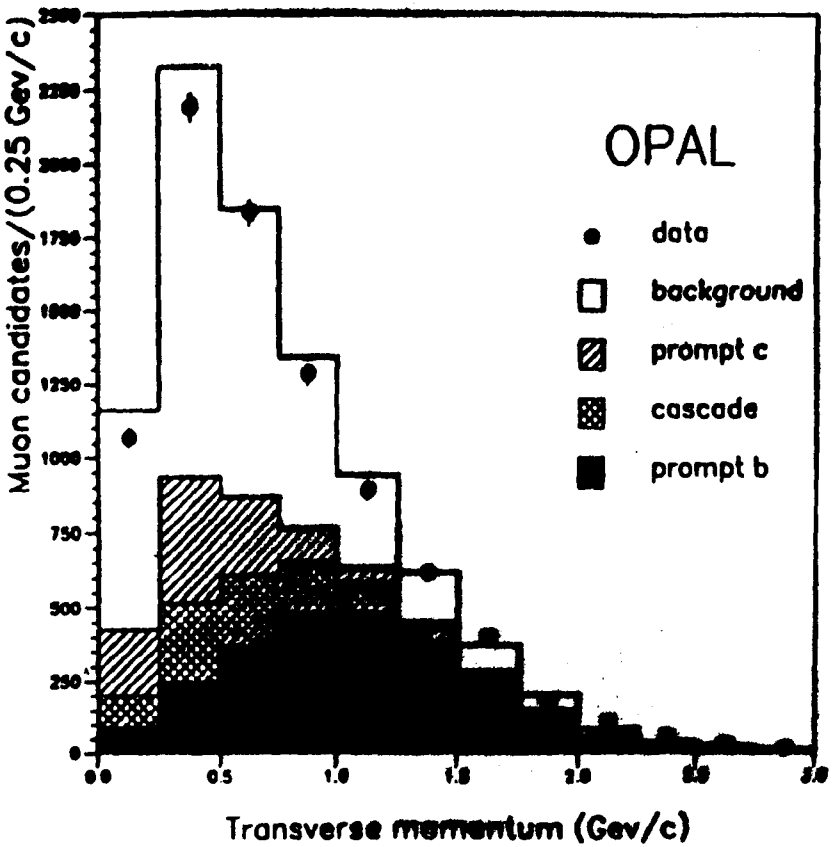
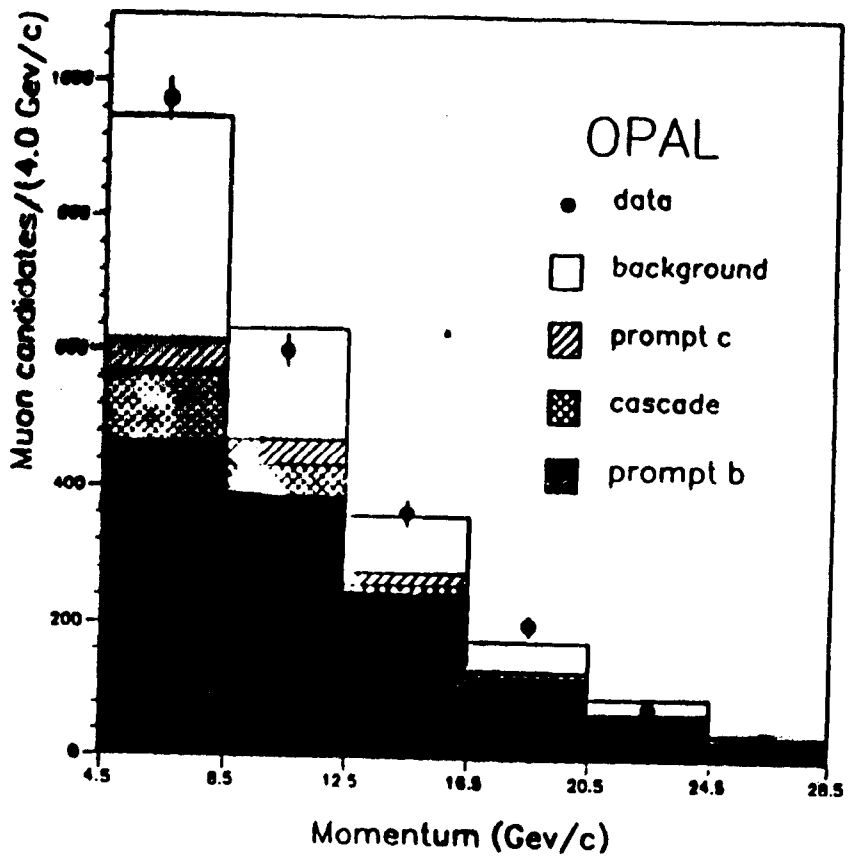
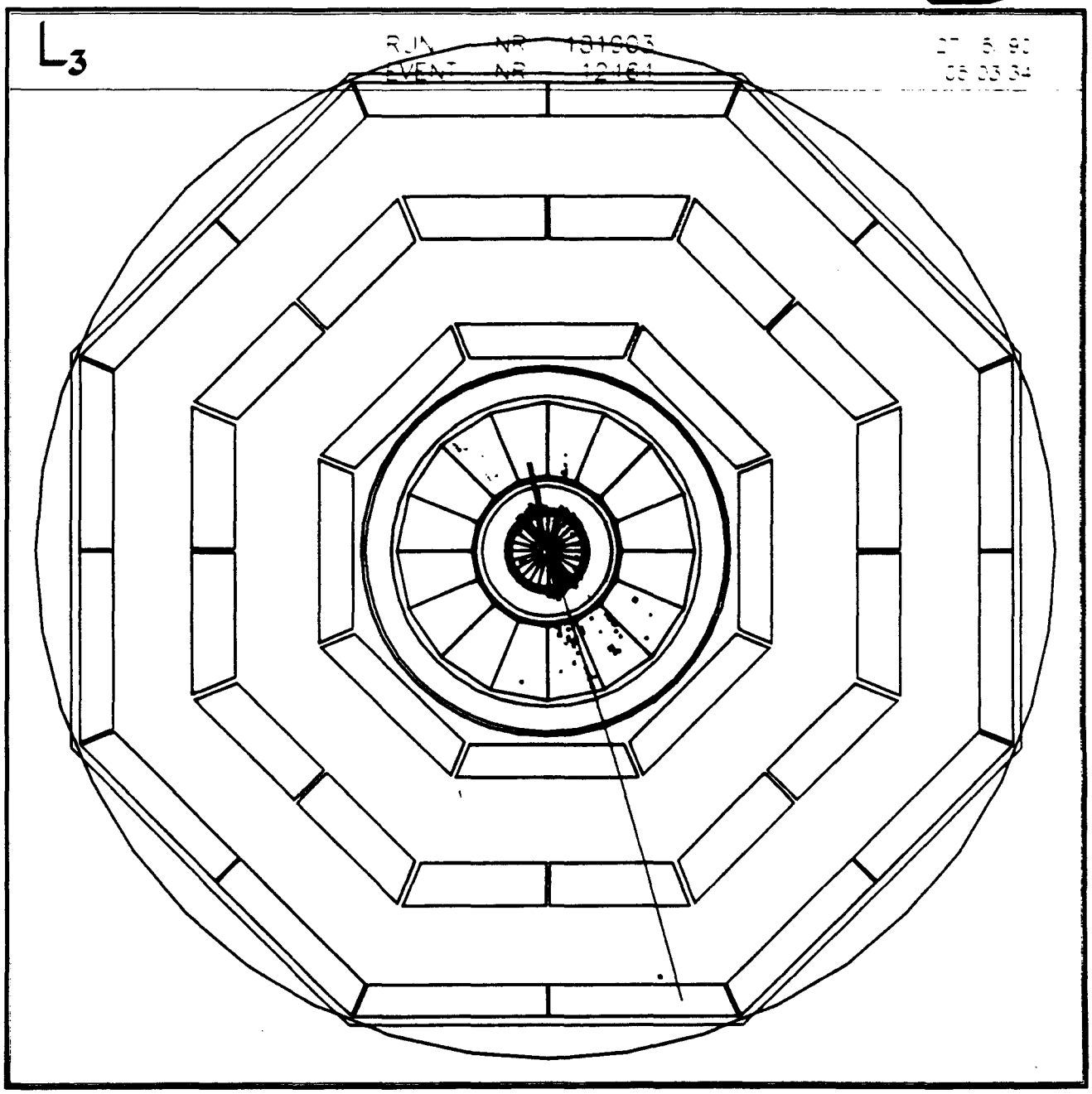
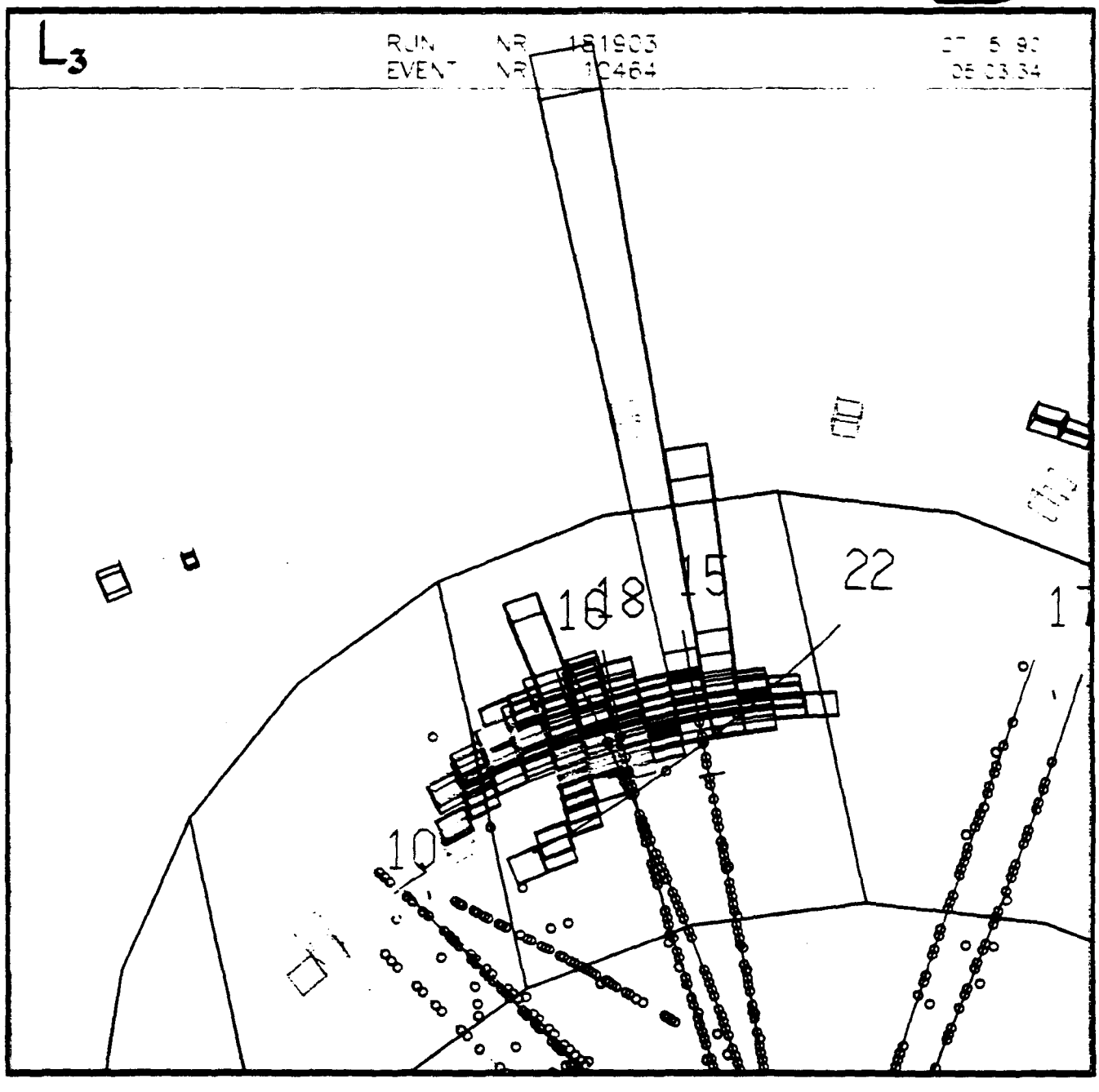


Figure 1b



Y
X
Z
200. cm.


L3
RUN NR 131903
EVENT NR 12161
27 5 90
06 03 34


L3
RUN NR 181903
EVENT NR 10464
07 5 90
05 03 34
18
15
22
10

LOTS TO MEASURE:

SINGLE LEPTON	RATE	$\rightarrow$	$Br(b \to \ell) \times \Gamma_{bb}$
" "	MOMENTUM	$\rightarrow$	ϵ_b Fragmentation
	ANGLE, CHARGE	$\rightarrow$	A_{bb}^{FB}
	IMPACT PARAM.	$\rightarrow$	τ_b
DILEPTON	RATE	$\rightarrow$	$Br(b \to \ell)$
"	ANGLE, CHARGE	$\rightarrow$	χ_b

PHYSICS!

Γ_{bb} = 378 MeV ?

A_{bb}^{FB} $\sin^2\theta_W^{eff}$, m_{top}

$$\left.\begin{array}{l} Br(b \to \ell) \\ \tau_b \end{array}\right\} \approx |V_{cb}|^2 + |V_{ub}|^2$$

χ_b CONSTRAINS m_{top} at $p\bar{p}$ energies

LEP 1990 DATA

WHO MEASURED WHAT? QUOTED % ERRORS

	ALEPH	DELPHI	L3	OPAL
Γ_{bb}/Γ_{had}		9%		
$Br(b\to\ell)\times\Gamma_{bb}/\Gamma_{had}$	coming		3%	7%
$Br(c\to\ell)\times\Gamma_{cc}/\Gamma_{had}$	coming			28%
$Br(b\to\ell)$	coming		10% (6% with Γ_{bb}^{exp})	$\gtrsim$10%
$\langle x_b \rangle$	coming		2.5%	3%
$\langle x_c \rangle$	coming			6.4%
χ_b	20%		25%	~25%
A_{bb}^{FB}	3%		4%	~7%
A_{cc}^{FB}	5%			
τ_b	9%	12% (μ) 9% (μ+th)	8%	$\lesssim$8%

BLUE = PUBLISHED GREEN = IN PREPARATION/PRELIMINARY

TECHNIQUES

AND

SYSTEMATICS

DELPHI
(PRELIMINARY)

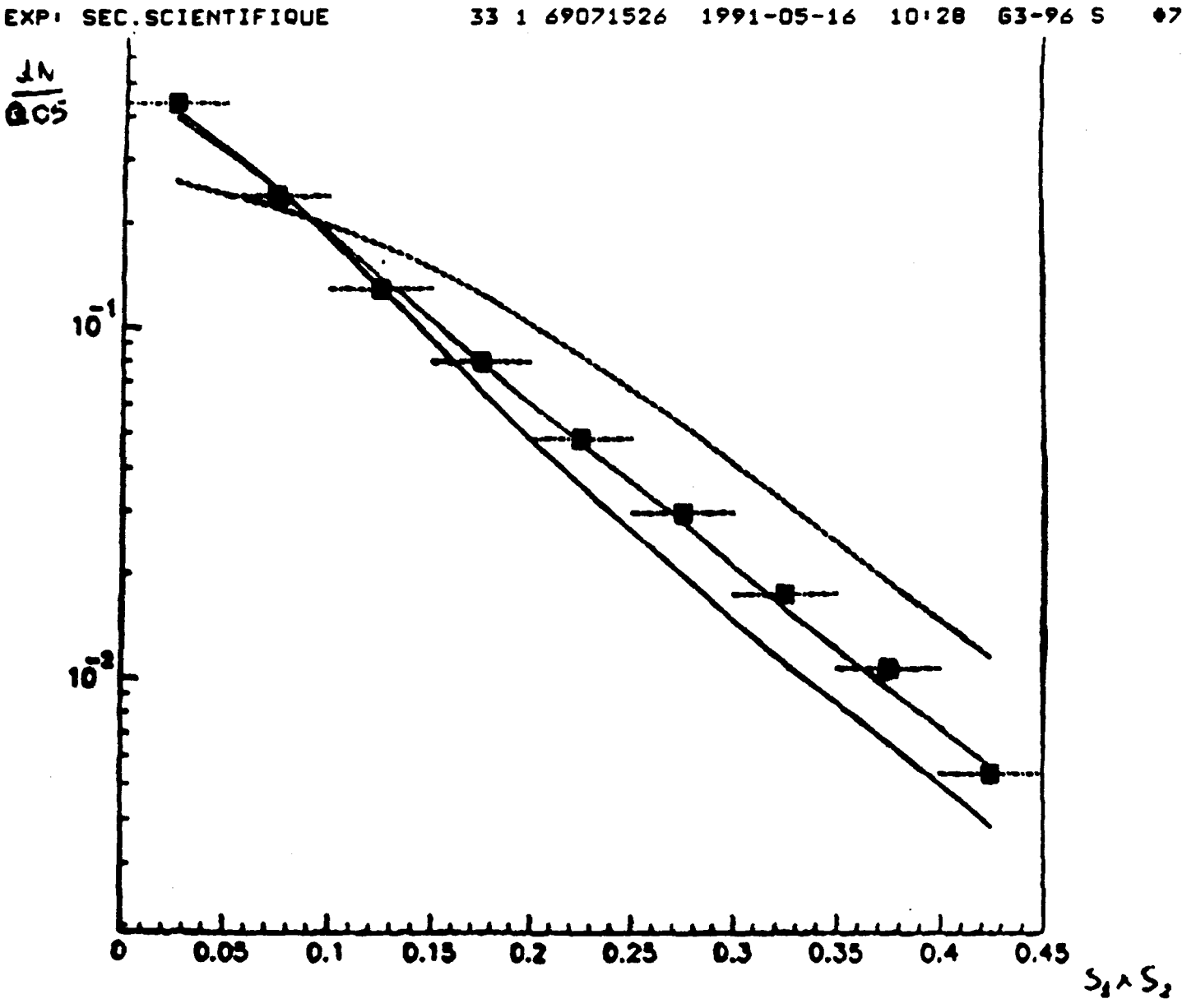
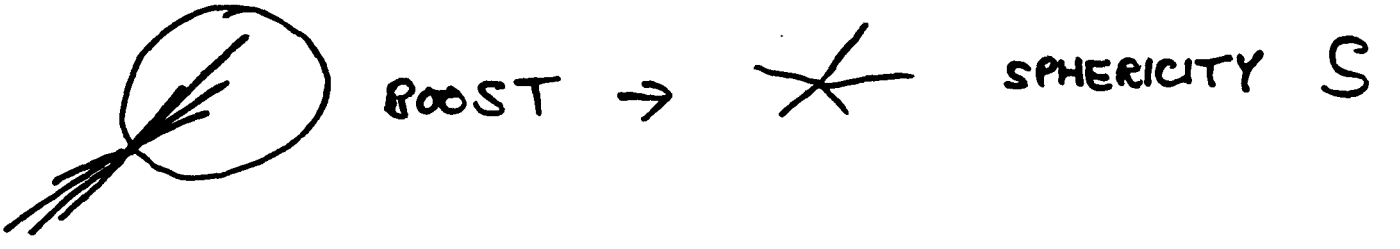


Figure 2: *$S_1 \times S_2$ differential distribution, for $\beta = 0.96$. The lines superimposed correspond to the predictions of JETSET PS for a $b\bar{b}$ branching fraction of 1. (dashed line), 0.217 (dotted line), 0. (solid line).*



TECHNIQUES & SYSTEMATICS

$Br(b \to \ell)$

DATA SAMPLE (L3):

μ + hadrons	2621
e + hadrons	1085
$\mu\mu$ + hadrons	83
μe + hadrons	78
ee + hadrons	26

METHOD:

1. ASSUME $\Gamma_{bb} = \Gamma_{bb}^{SM} = 378$ MEV

   ONE PARAMETER FIT FOR $Br(b \to \ell)$

   (DOMINATED BY SINGLE LEPTON EVENTS)

2. NO ASSUMPTION ABOUT Γ_{bb} (ALMOST)

   (DOMINATED BY DILEPTON/SINGLE LEPTON RATIOS)

$Br(b-\ell)$

SYSTEMATICS:

Γ_{bb} 10% CHANGE	0.002	"Γ_{bb} INDEPENDENT" FIT
Γ_{bb} 3 MeV CHANGE	0.001	Γ_{bb}^{SM} FIT
$Br(c \to \ell)$	0.001-2	$e-\mu$
ϵ_b, ϵ_c	0.002	
BACKGROUND	0.001	
SELECTION μ	0.001	μ only
SELECTION e	0.006	e only
$p_\perp$ CUT	0.003-2	$e-\mu$
$Br(b \to D_2^*(2460)\,\ell)$	0.002	

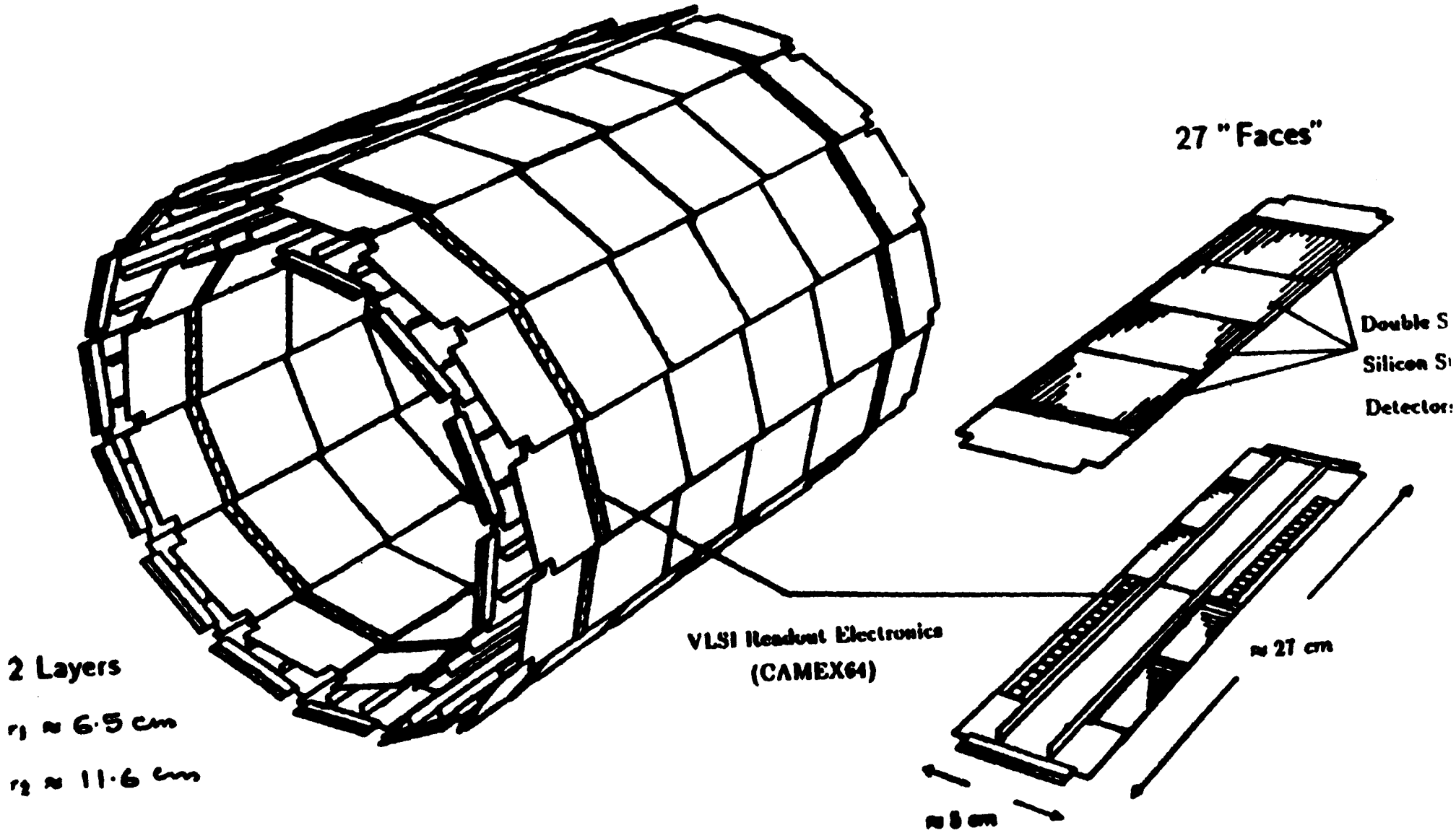
Γ_{bb} free $\to$

$$Br(b \to \ell) = 0.113 \pm 0.010 \pm 0.006$$

$\Gamma_{bb}^{SM} \to$

$$Br(b \to \ell) = 0.119 \pm 0.003 \pm 0.006$$

The ALEPH Minivertex Detector



TECHNIQUES & SYSTEMATICS

τ_b

DATA SAMPLES:

ALEPH:	1215 e	1758 μ	$p_\perp' > 2$ GeV * $p > 5$ GeV
L3:	673 e	713 μ	$p_\perp' > 1.5$ GeV (μ) $p_\perp' > 1$ GeV (e) $p > 4$ GeV
DELPHI:	(24 920 h)	610 μ	$p_\perp' > 1$ GeV $p > 3$ GeV

METHOD:

FIT DISTRIBUTION OF IMPACT PARAMETERS MEASURED W.R.T. "FILL VERTEX" (ALEPH, L3),

INCLUDE EVENT-BY-EVENT PRIMARY VERTEX (DELPHI)

"FILL VERTEX": $\sigma_H \approx 200\mu m$

$\sigma_V \approx 15\mu m$

$\sigma_{CENTROID} \approx 30\mu m$

* ($p_\perp'$ is calculated after excluding the lepton from its jet)

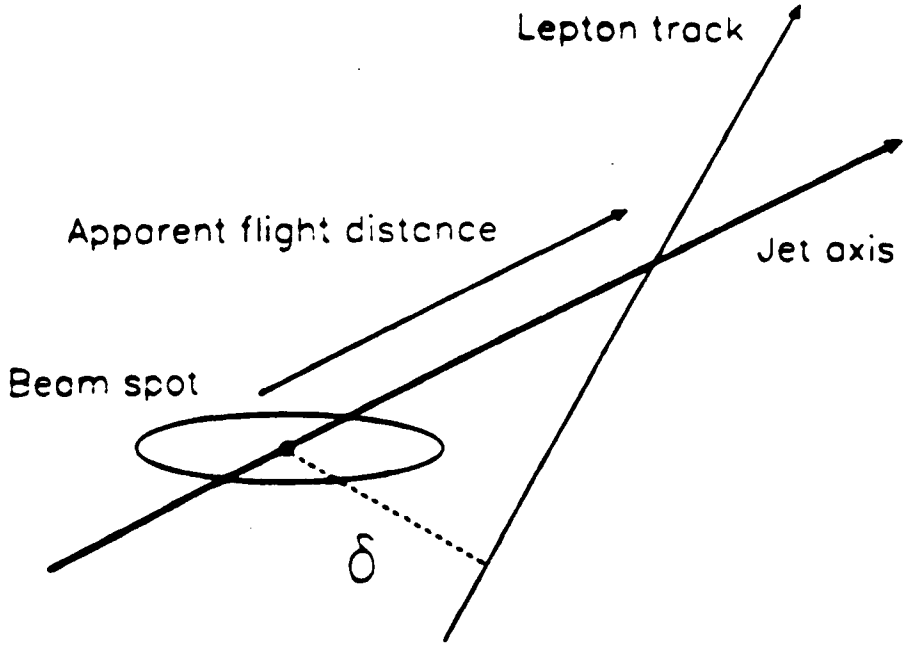


Figure 1 Definition of the impact parameter δ, in the plane transverse to the beam axis.

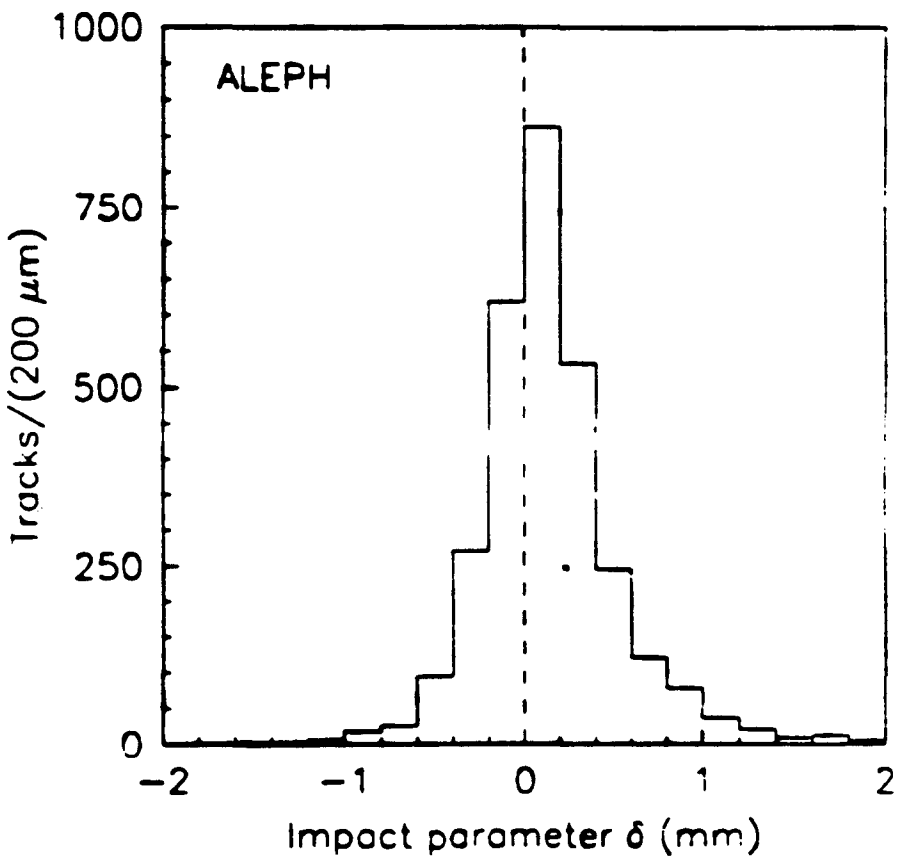


Figure 2 Impact parameter of lepton tracks that pass the B selection requirements.

RESOLUTIONS:

σ_{DCA} (DCA = DISTANCE OF CLOSEST APPROACH TO FILL VERTEX)

ALEPH: 140 μm (mean impact par. 142 ± 7 μm)

DELPHI: 62 μm (" " " 161 ± 5 μm)

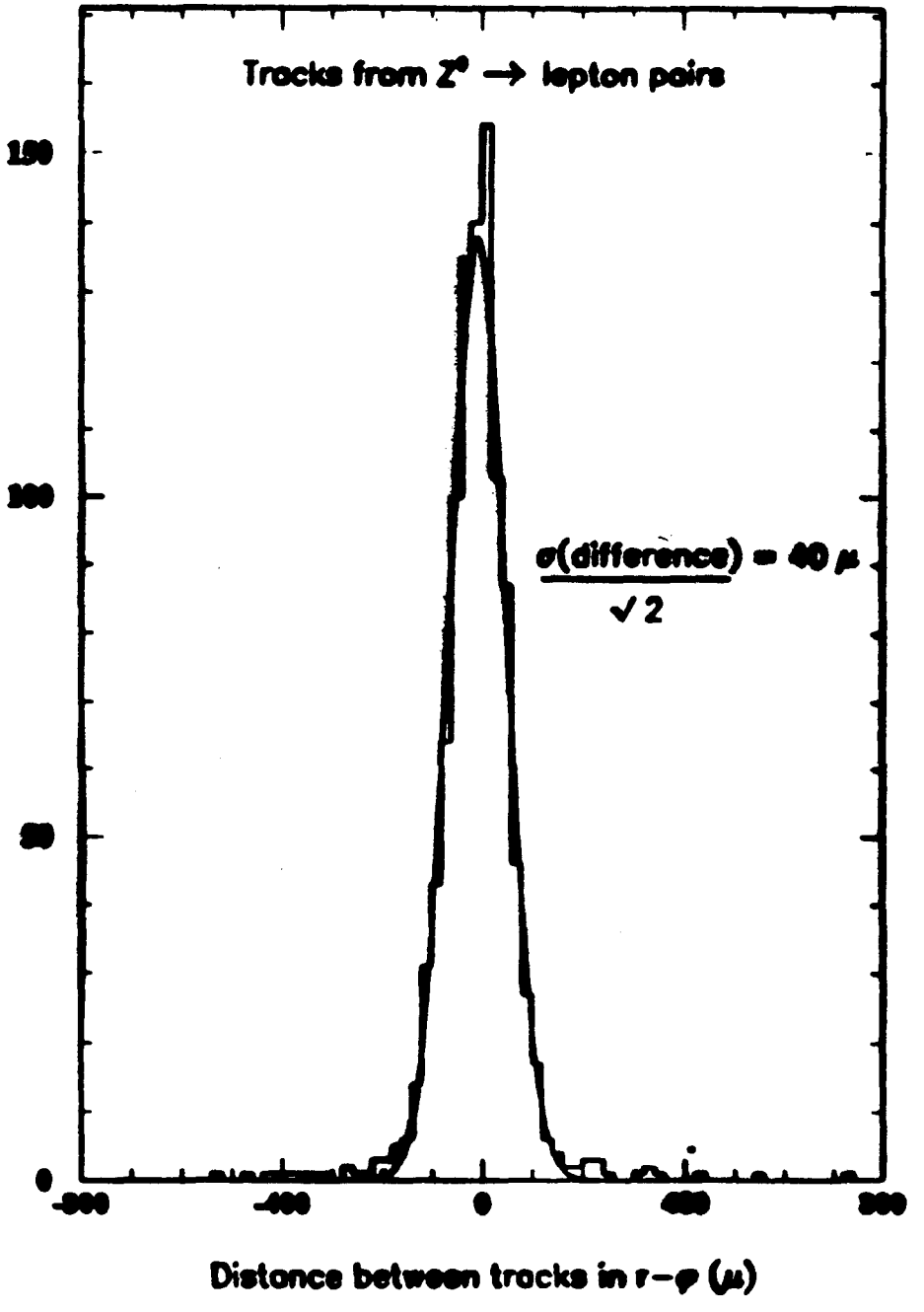
L3: 144 μm (" " " 176 ± 20 μm)

OPAL: (~40 μm)

SAMPLE COMPOSITION:

	$b \to \ell$	$b \to c \to \ell$	$c \to \ell$	hadrons	decays
ALEPH	66%	7%	10%	13%	4%
DELPHI (μ)	49%	10%	9%	24%	8%
L3 (μ)	80%	7%	5%	7%	1%
L3 (e)	83%	7%	2%	8%	0%

OPAL



cf ALEPH 140 μ

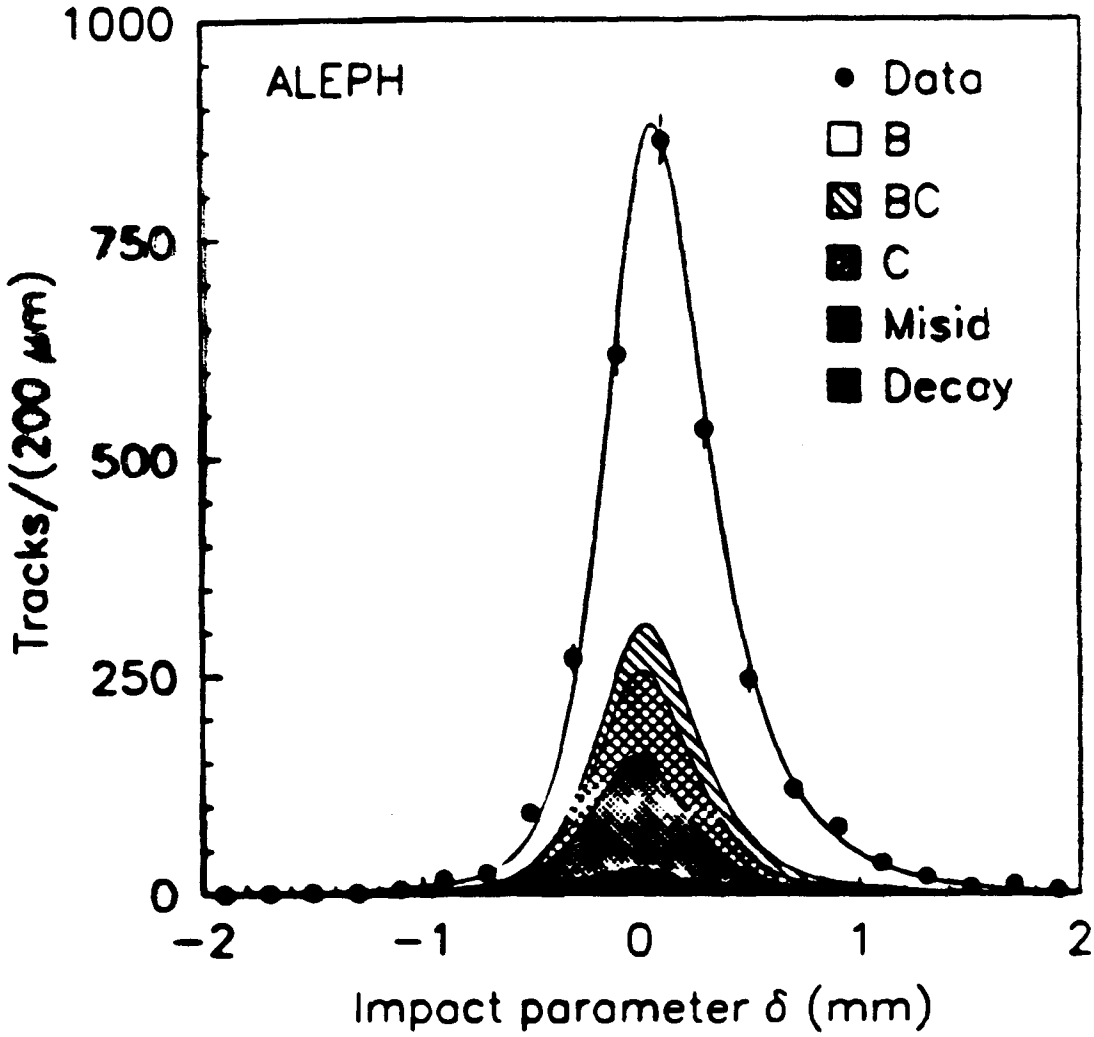


Figure 4 Impact parameter of lepton tracks that pass the B selection requirements, with the result of the lifetime fit superimposed. The contributions to the fit from the different lepton sources are shown.

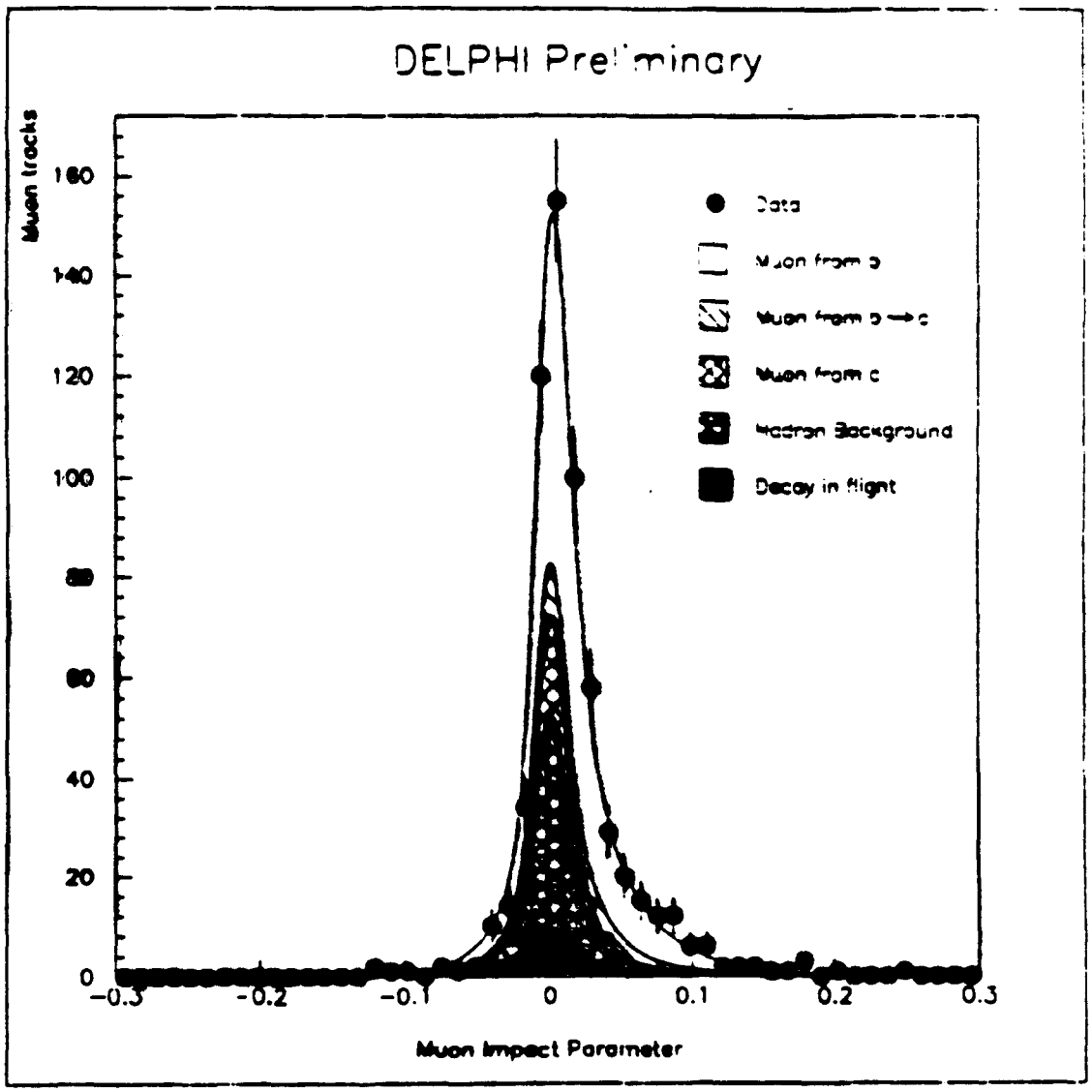


Figure 10: Impact parameter of high p_t muons with fitted probability density functions, as derived from the likelihood fit, and split into the five components considered in the fit. The result of the fit gives $tau_b = (1.31 \pm 0.12(stat))ps$.

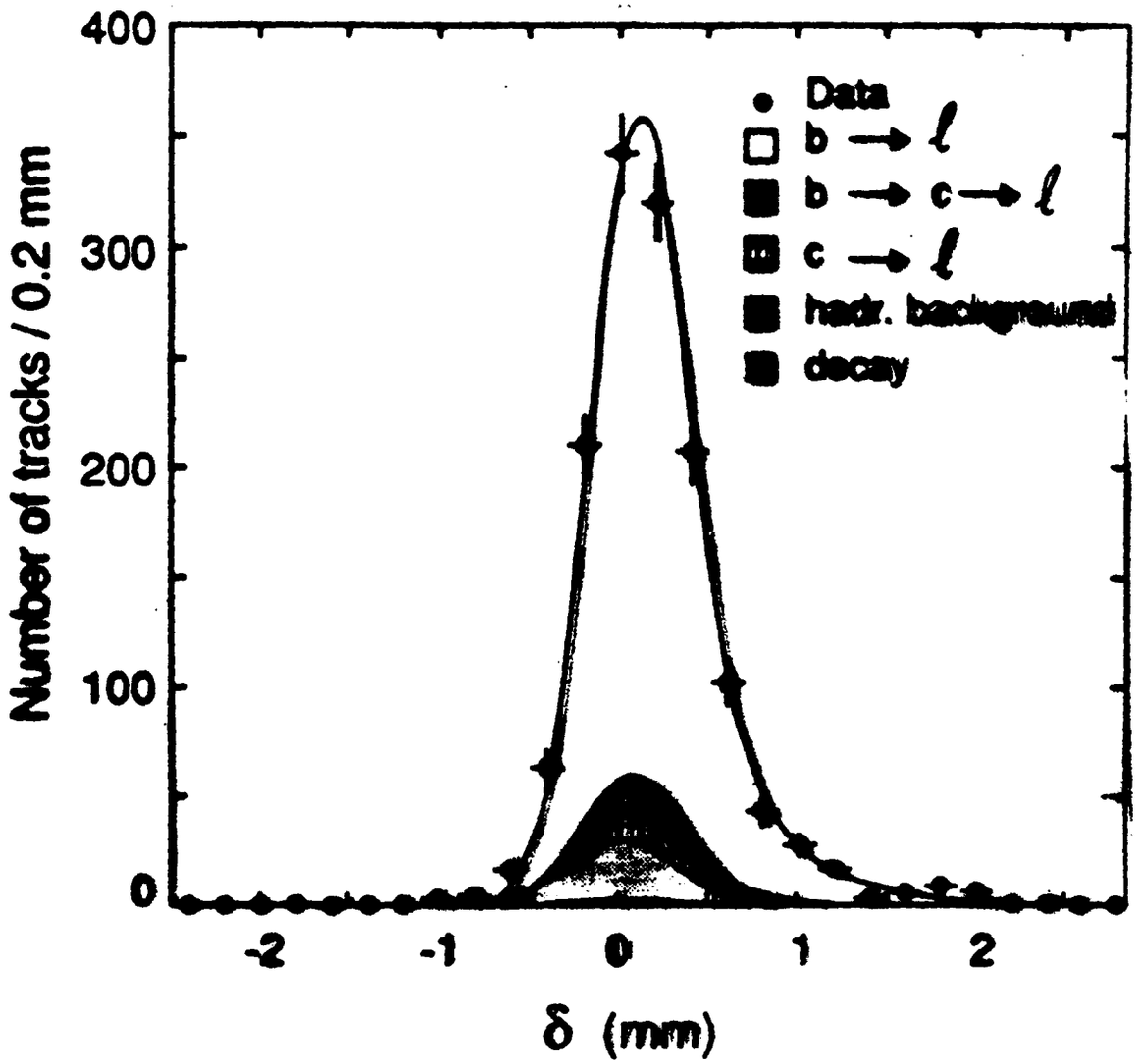

400
300
200
100
0
Number of tracks / 0.2 mm
-2
-1
0
1
2
δ (mm)
Data
b → ℓ
b → c → ℓ
c → ℓ
hadr. backgrounds
decay

Fig.5

τ_b

SYSTEMATICS : (ps)

	ALEPH	L3	DELPHI μ	DELPHI had
LEPTON SAMPLE COMPOSITION	.05	.02	.08	–
PARAMETRIZATION OF IDEAL b IMPACT PARAM.	.05	.05	.02	–
RESOLUTION FUNCTION	.04-5	.03	.05	.08
CHAMBER CALIBRATION	–	.05	–	–
DECAY BACKGROUND	.035	–	.02	–
HADRON BACKGROUND	.01	.03	.02	
FRAGMENTATION	.01	.001	.01	.07

TYPICAL STATISTICAL ERROR 0.06 ps

TECHNIQUES & SYSTEMATICS

χ_b

DATA SAMPLES:

	ALEPH	L3
$\mu\mu$	140	29
μe	202	30
ee	98	9

ALEPH	$p > 5.0$ GeV,	$p_\perp' > 1.0$ GeV	OPPOSITE SIDE
L3	$p_\mu > 4.0$ GeV,	$p_{\perp\mu}' > 1.5$ GeV	OPPOSITE SIDE
	$p_e > 3.0$ GeV,	$p_{\perp e}' > 1.0$ GeV	OPPOSITE SIDE

χ_b

METHOD:

ALEPH: MAX. LIKELIHOOD FIT IN Prob 1, Prob 2 PLANE.

Prob i = Probability that lepton i comes from prompt b decay

L3: MAX. LIKELIHOOD FIT IN $P_1, P'_{\perp 1}, P_2, P'_{\perp 2}$ SPACE

SAMPLE COMPOSITION: %

	ALEPH	L3
$b \to \ell$, $b \to \ell$	64	80
$b \to \ell$, $b \to c \to \ell$	18	10
$b \to c \to \ell$, $b \to c \to \ell$	2	3
$c \to \ell$, $c \to \ell$	3	0
background	14	7

NOTE: BOTH ALEPH AND L3 USE LARGER SAMPLES IN THE FITS (NO $P_\perp$ CUTS).

χ_b

SYSTEMATICS:

	ALEPH	L3
$Br(b \to \ell)$, $Br(c \to \ell)$	·004	·0015
$Br(b \to c \to \ell)$	·013	
b FRAGMENTATION	·004	·0005
c FRAGMENTATION	·002	–
BACKGROUND	·006	·0005
DEFINITION OF 'OPOSITE SIDE'	–	·003
$p_\perp$ RESOLUTION	–	·005
CHARGE CONFUSION	–	·010
PROBABILITY CALCULATION (LOW STATISTICS PROBLEM)		·012

STATISTICAL ERRORS ~·027 ~·045

LEP 1990 DATA: RESULTS

$\boxed{\Gamma_{bb}/\Gamma_{had}}$ 0·217 ± ·002 (SM)

DELPHI: PRELIMINARY 0·225 ± ·015 ± ·013

$\boxed{Br(b \to \ell) \times \Gamma_{bb}/\Gamma_{had}}$

ALEPH: IN PREPARATION

L3: 0·0259 ± ·0005 ± ·0007

OPAL: 0·0226 ± ·0007 ± ·0013

$\boxed{Br(c \to \ell) \times \Gamma_{cc}/\Gamma_{had}}$

ALEPH: IN PREPARATION

OPAL: 0·0176 ± ·0025 ± ·0042

$$\boxed{Br(b \to \ell)}$$

ALEPH: IN PREPARATION

L3: $Br(b \to \ell)\ (\Gamma_{bb}\ \text{FREE}) = 0.113 \pm .010 \pm .006$

$(b \to \mu)\ (\Gamma_{bb}\ \text{SM}) = 0.123 \pm .003 \pm .006$

$(b \to e)\ (\Gamma_{bb}\ \text{SM}) = 0.122 \pm .004 \pm .008$

$(b \to \ell)\ (\Gamma_{bb}\ \text{SM}) = 0.119 \pm .003 \pm .006$

OPAL: IN PREPARATION

$$\boxed{\langle x_E \rangle_b}$$

ALEPH: IN PREPARATION

L3: $0.686 \pm .006 \pm .016$

ALSO $f(x_E)$

OPAL: $0.726 \pm .007 \pm .022$

$$\boxed{\langle x_E \rangle_c}$$

ALEPH: IN PREPARATION

OPAL: $0.56 \pm .02 \pm .03$

$$\boxed{\chi_b}$$

ALEPH: $0.132 \begin{smallmatrix} +.027 \\ -.026 \end{smallmatrix}$

L3: $0.178 \begin{smallmatrix} +.049 \\ -.040 \end{smallmatrix}$

OPAL: IN PREPARATION

$$\boxed{A_{bb}^{FB}}$$

ALEPH: (for $\chi_b = \chi_b$(ALEPH)) $0.126 \pm .028 \pm .012$

L3: (for $\chi_b = \chi_b$(L3)) $0.130 \pm .043 \pm .02$

OPAL: (for $\chi_b = 0$) $0.072 \pm .042 \pm .01$

$$\boxed{A_{cc}^{FB}}$$

ALEPH: $0.064 \pm .039 \pm .030$

$$\boxed{\tau_b}$$

ALEPH: $1.29 \pm .06 \pm .10$ ps

DELPHI: (μ only) (μ + hadrons coming) $1.31 \pm .12 \pm .11$ ps

L3: $1.32 \pm .06 \pm .09$ ps

OPAL: (IN PREPARATION) COMPETITIVE!

LEP/WORLD AVERAGES ETC.

$$Br(b \to \ell) = 0.117 \pm 0.006$$

(PEP, PETRA, L3)

$\downarrow$

PLUS $Br(b \to \ell) \dfrac{\Gamma_{bb}}{\Gamma_{had}}$ (OPAL, L3, ALEPH(89))

$\downarrow$

$\Gamma_{bb} / \Gamma_{had}$

$\downarrow$

PLUS $\Gamma_{bb} / \Gamma_{had}$ (DELPHI)

$\downarrow$

$$\frac{\Gamma_{bb}}{\Gamma_{had}} = 0.210 \pm 0.012$$

$\downarrow$

$\Gamma_{had}(LEP) \approx \Gamma_{had}(SM) = 1738$ MeV

$\downarrow$

$$\Gamma_{bb} = 368 \pm 19 \text{ MeV}$$

$$\chi_b = 0.150 \pm 0.017$$

(L3, ALEPH, UA1, CDF)

$\downarrow$

CORRECT LEP A_{bb}^{FB} MEASUREMENTS FOR χ_b

$\downarrow$

$$A_{bb}^{FB} = 0.125 \pm 0.024$$

(ALEPH, L3, OPAL)

$\hookrightarrow \sin^2\bar{\theta}_W (s = m_Z^2) = 0.226 \pm 0.004$

$$\langle x_E \rangle_b = 0.697 \pm 0.013$$

$$\langle x_E \rangle_c = 0.56 \pm 0.03$$

$$\tau_b = 1.31 \pm 0.09 \text{ ps}$$

(ALEPH, DELPHI(μ), L3)

$\downarrow$

PLUS $Br(b \to \ell)$ + THEORY + ARGUS, CLEO $\frac{|V_{ub}|}{|V_{cb}|}$

$\hookrightarrow |V_{cb}| = 0.047 \pm 0.003 \pm 0.002$ (THEORY)

LEP 1991, 2, 3....

χ_b MUCH MORE PRECISE

$$\left.\begin{array}{l} A_{bb}^{FB} \\ Br(b-\ell) \\ \tau_b \end{array}\right\} \text{MORE PRECISE}$$

EVENT-BY-EVENT LIFETIMES

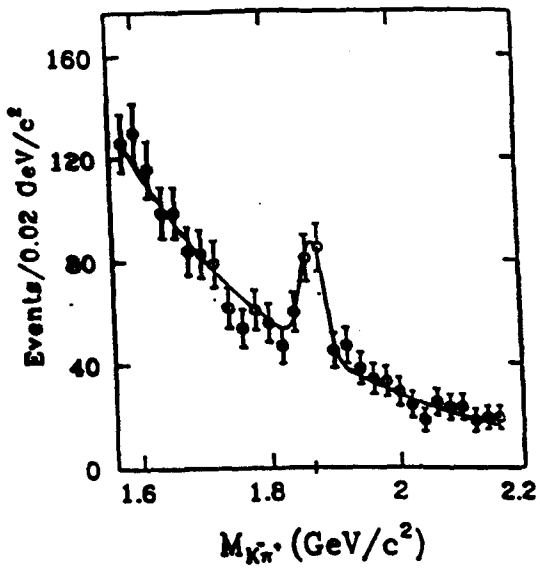
EXCLUSIVE AND SEMI-EXCLUSIVE CHANNELS

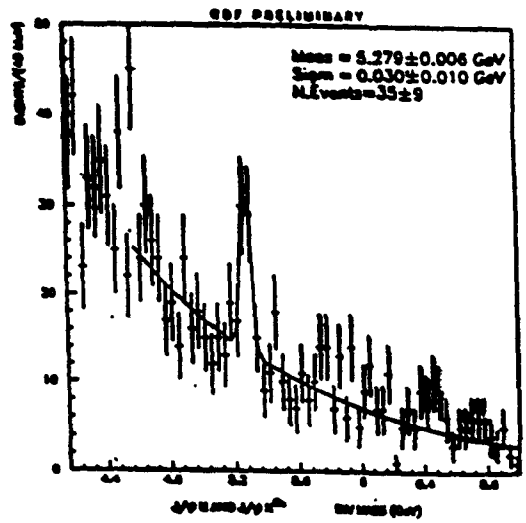
e.g. B^0, $B^\pm$ DISCRIMINATION
B_s B_d

B Physics at CDF: Results and Prospects

D. Amidei, U of Michigan
for the
CDF Collaboration

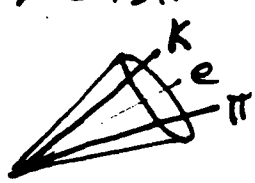
Where we left off...



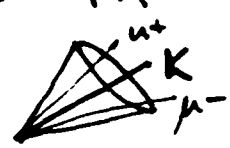


Reconstruction of B decays in the vicinity of leptonic "tags":

$B \to e \nu D X$



$B \to \psi K$



This talk:

1a. Measurement of $d\sigma/dp_T$ with $B \to e \nu X$ and $B \to \psi K$

b. Measurement of $\bar{\chi}$ with an $e\mu$ sample

2a. Tevatron plan

b. CDF Upgrades

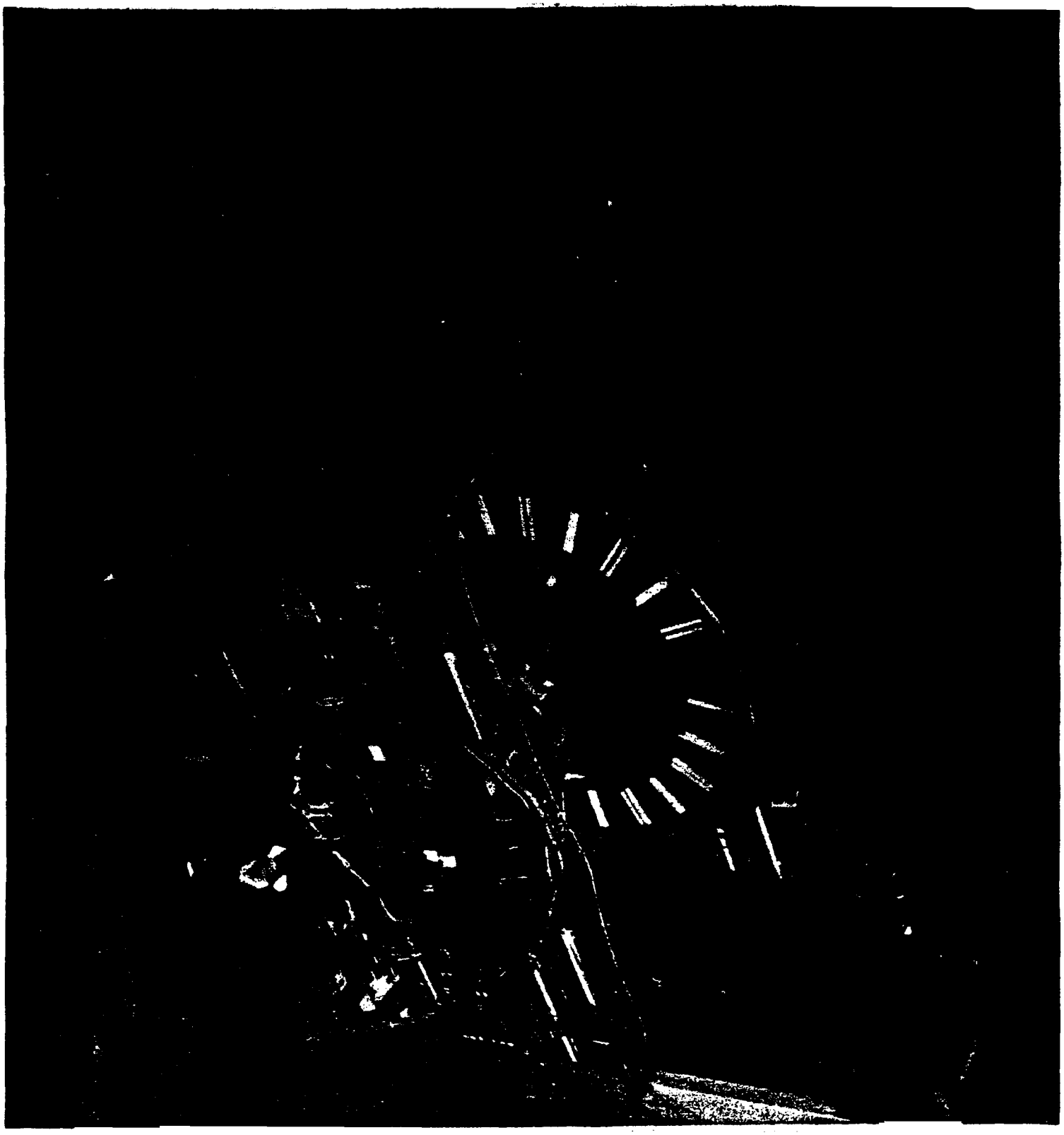
c. B Physics Potential

CDF Collaboration
Physics Run 1988/89

F.Abe[a], D.Amidei[d], G.Apollinari[h], G.Ascoli[g], M.Atac[d], P.Auchincloss[n], A.R.Baden[f], A.Bamberger[d], A. Barbaro-Galtieri[i], V.E.Barnes[j], F.Bedeschi[h], S.Behrends[l], S.Belforte[h], G.Bellettini[h], J.Bellinger[o], J.Bensinger[b], A.Beretvas[d], P.Berge[d], S.Bertolucci[e], S.Bhadra[p], M.Binkley[d], R.Blair[a], C.Blocker[b], A.W.Booth[d], G.Brandenburg[f], D.Brown[f], A.Byon[i], K.L.Byrum[c], C.Campagnari[c], M.Campbell[e], R.Carey[f], A.Cardini[h], W.Carithers[i], D.Carlsmith[q], J.T.Carroll[d], R.Cashmore[d], F.Cervelli[h], K.Chadwick[d], T.Chapin[m], G.Chiarelli[e], W.Chinowsky[i], S.Cihangir[d], A.G.Clark[d], D.Connor[j], M. Contreras[b], J.Cooper[d], M.Cordelli[e], M.Curatolo[e], C.Day[d], R.DelFabbro[h], S.Dell'Agnello[h], M.Dell'Orso[h], L.DeMortier[k], P.F.Derwent[d], T.Devlin[n], D.DiBitonto[p], R.B.Drucker[i], J.E.Elias[d], R.Ely[i], S.Errede[g], B.Esposito[e], B.Flaugher[n], E.Focardi[h], G.W.Foster[d], M.Franklin[f], J.Freeman[d], H.Frisch[c], Y.Fukui[k], Y.Funayama[p], A.F.Garfinkel[j], A.Gauthier[g], S.Geer[f], P.Giannetti[h], N.Giokaris[m], P.Giromini[e], L.Gladney[j], M.Gold[i], K.Goulianos[m], H.Grassmann[h], C.Grosso-Pilcher[c], J.Grunhaus[m] C.Haber[i], S.R.Hahn[d], R.Handler[q], R.M.Harris[i], J.Hauser[a], T.Hessing[g], R.Hollebeek[j], L.Holloway[g], P.Hu[n], B.Hubbard[i], R.Hughes[j], P.Hurst[g], J.Huth[d], M.Incagli[h], T.Ino[p], H.Ito[p], H.Jensen[d], C.P.Jessop[j], R.P.Johnson[d], U.Joshi[d], R.W.Kadel[d], T.Kamon[o], S.Kanda[p], D.A.Kardelis[g], I.Karliner[g], E.Kearns[f], R.Kephart[d], P.Keton[b], R.M.Keup[g], H.Kourlitis[g], S.Klein[g], L.Kirsch[b], K.Kondo[p], S.E.Kuhlmann[a], A.T.Laasanen[j], J.I.Lamoureux[q], M.E.Levi[i], W.Li[a], T.Liss[g], E.Lockyer[j], C.B.Luchini[d], J.P.Marriner[d], R.Markeloff[q], L.A. Markosky[q], P.Maas[d], P.McIntyre[o], A.Menzione[h], T.Meyer[o], S.Miller[b], M.Miller[c], T.Minowa[p], S.Miscetti[e], M.Mishina[k], S.Miyashita[p], N.Morokoff[q], S.Moss[g], Y.Morita[p], A.Mukherjee[d], L.Nakae[b], I.Nakano[p], C.Newman-Holmes[d], J.S.T.Ng[f], M.Nimmo[g], L.Nodulman[a], T.Ogawa[p], R.Paoletti[h], E.Pare[f], A.Pare[d], J.Patrick[d], T.J.Phillips[f], R.Plunkett[d], L.Pondrom[q], J.Proudfoot[a], G.Punzi[h], D.Quarrie[d], K.Ragan[j], G.Redlinger[c], J.Rhoades[q], F.Rimondi[h], L.Ristori[h], T.Rohaly[j], A.Roodman[c], A.Sansoni[e], R.Sard[g], A.Savoy-Navarro[d], V.Scarpine[g], P.Schlabach[g], E.E.Schmidt[d], P.Schoessow[a], M.H.Schub[j], R.Schwitters[f], A.Scribano[h], S.Segler[d], Y.Seiya[p], M.Sekiguchi[p], P.Sestini[h], M.Shapiro[f], M.Shaevitz[q], M.Shibata[p], M.Shochet[c], J.Siegrist[i], P.Sinervo[j], J.Skarha[q], K.Sliwa[d], D.A.Smith[h], F.D.Snider[a], R.St.Denis[f], A.Stefanini[h], R.L.Swartz,Jr.[g], Y.Takiwa[p], M.Takano[p], K.Takikawa[p], S.Tarem[b], D.Theriot[d], M.Timko[o], P.Tipton[i], A.Tollestrup[d], G.Tonelli[h], W.Trischuk[f], Y.Tsay[c], F.Ukegawa[o], D.Underwood[a], R.Vidal[d], R.G.Wagner[a], R.L.Wagner[d], J.Walsh[f], T.Watts[n], R.Webb[o], C.Wendt[q], W.C.Wester,III[i], T.Westhusing[b], S.White[m], A.Wicklund[a], H.H.Williams[j], B.Winer[j], A.Yamashita[p], K.Yasuoka[p], G.P.Yeh[d], J.Yoh[d], M.Yokoyama[p], J.Yun[d], F.Zetti[h]

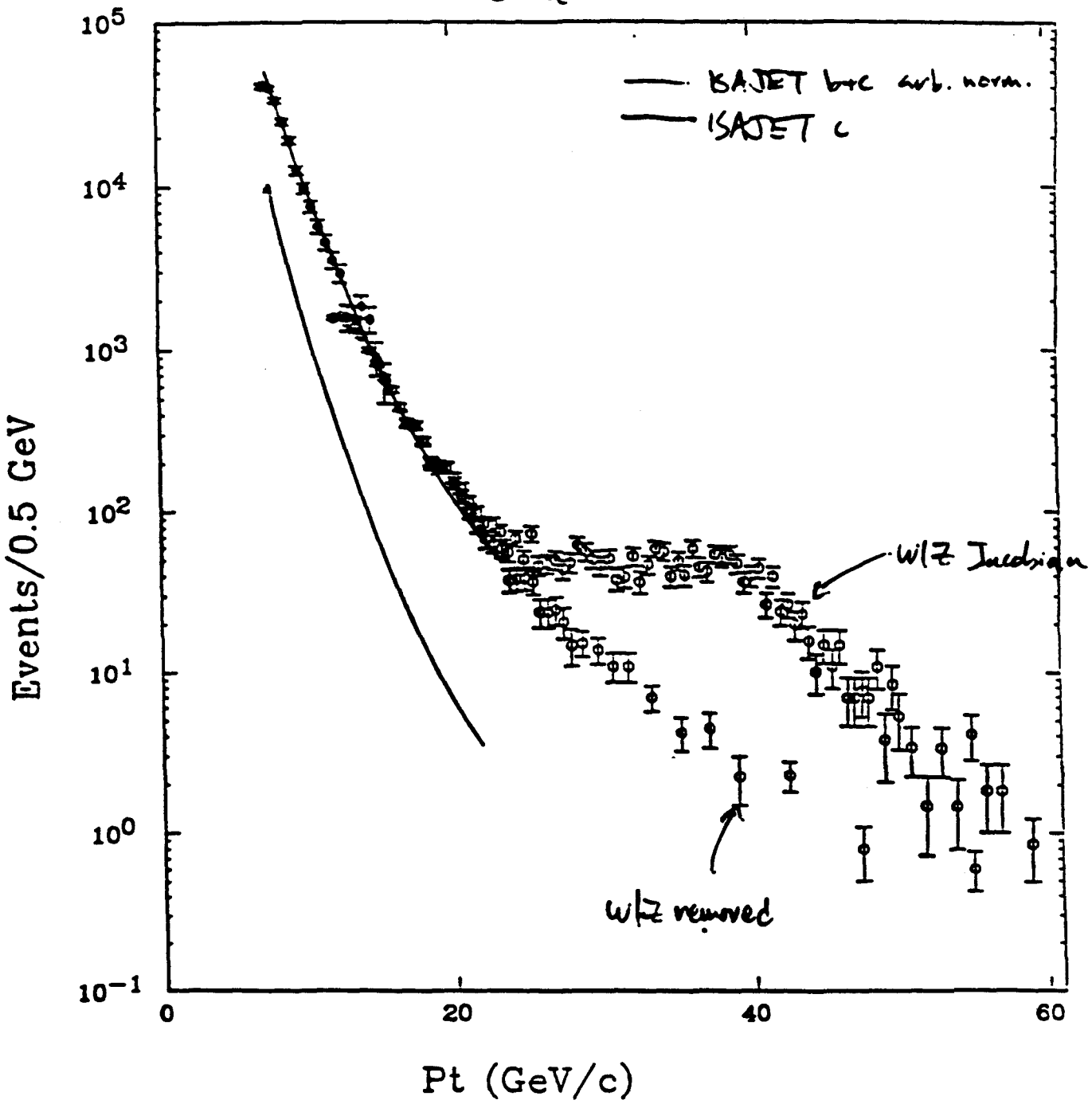
CDF Member Institutions

[a] Argonne National Laboratory- [b] Brandeis University- [c] University of Chicago
[d] Fermi National Accelerator Laboratory- [e] INFN, Laboratori Nazionali di Frascati, Italy
[f] Harvard University- [g] University of Illinois- [h] KEK, Japan
[i] Lawrence Berkeley Laboratory- [j] University of Pennsylvania
[k] INFN, University and Scuola Normale Superiore of Pisa, Italy- [l] Purdue University
[m] Rockefeller University- [n] Rutgers University- [o] Texas A&M University
[p] University of Tsukuba, Japan- [q] University of Wisconsin



CDF Inclusive Electron Spectrum

$p_T > 7$ 225 nb^{-1} 17K $e^\pm$
$p_T > 12$ 4400 nb^{-1} 23k $e^\pm$
40K
fakes ~ same

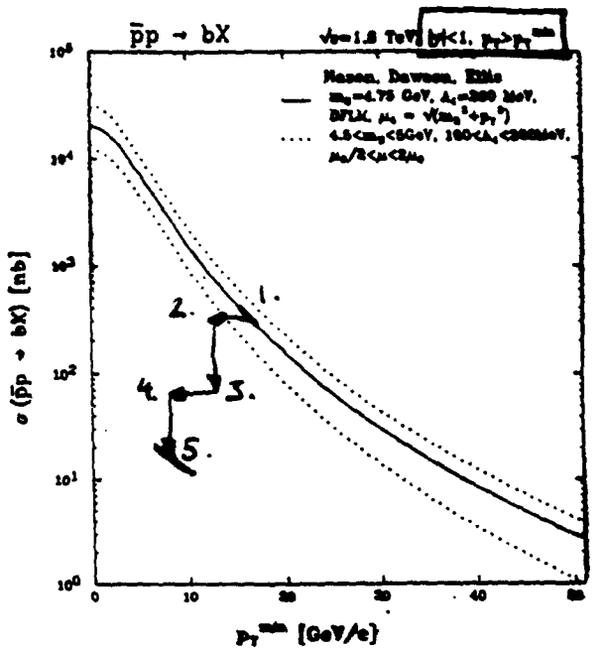


- "standard" CDF electron selection
- remove conversions
- remove if $\not{E}_T$ or m(pair) / E_T (no bremsstrahlung!)

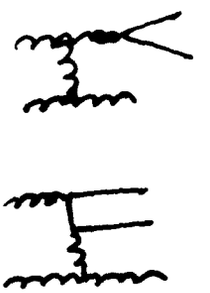
Theoretical Prediction to $O(\alpha_s^3)$: Nason, Dawson, Ellis NUCB335, 260

$O(\alpha_s^2)$

etc



$O(\alpha_s^3)$



etc

Experimental Method

1. Correct for residual conversions, 20±5%, hadron bkgnd 15±15%, charm 10±10%.
2. Relate resultant spectrum to b spectrum using "ISAJET"

$$\sigma_b(\text{data}) = \sigma_e(\text{data}) \cdot \frac{\sigma_b(MC)}{\sigma_e(MC)}$$

1. Assume NDE shape
2. Fragmentation: Peterson form, tuned for $\langle z \rangle = 0.83$
3. $Br(B \to eX)$: $10.3 \pm 0.1 \pm 0.2$ % CLEO
4. B decay: CLEO Monte Carlo
5. Electron efficiency: reject any candidate with hadronic energy
   pure e.m. types amenable to MC treatment
   $\epsilon \sim 50\%$ @ $p_T(e) = 15$ GeV/c

Results

$$\sigma_b = \frac{(N_{e^-} + N_{e^+})_{data}}{2 \cdot \mathcal{L} \cdot (\sigma_e/\sigma_b)_{MC} \cdot Br(B \to e)}$$

$\mathcal{L} = 4.4\,pb^{-1}$

p_T^e	$p_T^{min}(b)$	Number of $e^+ + e^-$	$(\sigma_e/\sigma_b)_{MC}$	σ_b (nb)	σ_b (nb) NDE
10 - 15	15	40650/23780	0.0273	1220	450^{+250}_{-200}
15 - 20	23	4083/2389	0.0153	220	90^{+40}_{-45}
20 - 25	32	772/452	0.0109	56	23^{+12}_{-13}

raw spectrum

after background subtraction

Source	Uncertainty
Photon conversion $e^\pm$ subtraction	5%
Hadron background subtraction	15%
Charm subtraction	10%
Electron finding efficiency	10%
Underlying event contribution	8%
L2 Trigger efficiency	10%
b-quark fragmentation	15%
B hadron semileptonic decay branching ratio	10%
Luminosity	7%
Total	38%

$$\sigma(\bar{p}p \to bX;\ p_T > 15\,\text{GeV},\ |y| < 1) = 1220 \pm 340\ \text{nb},$$

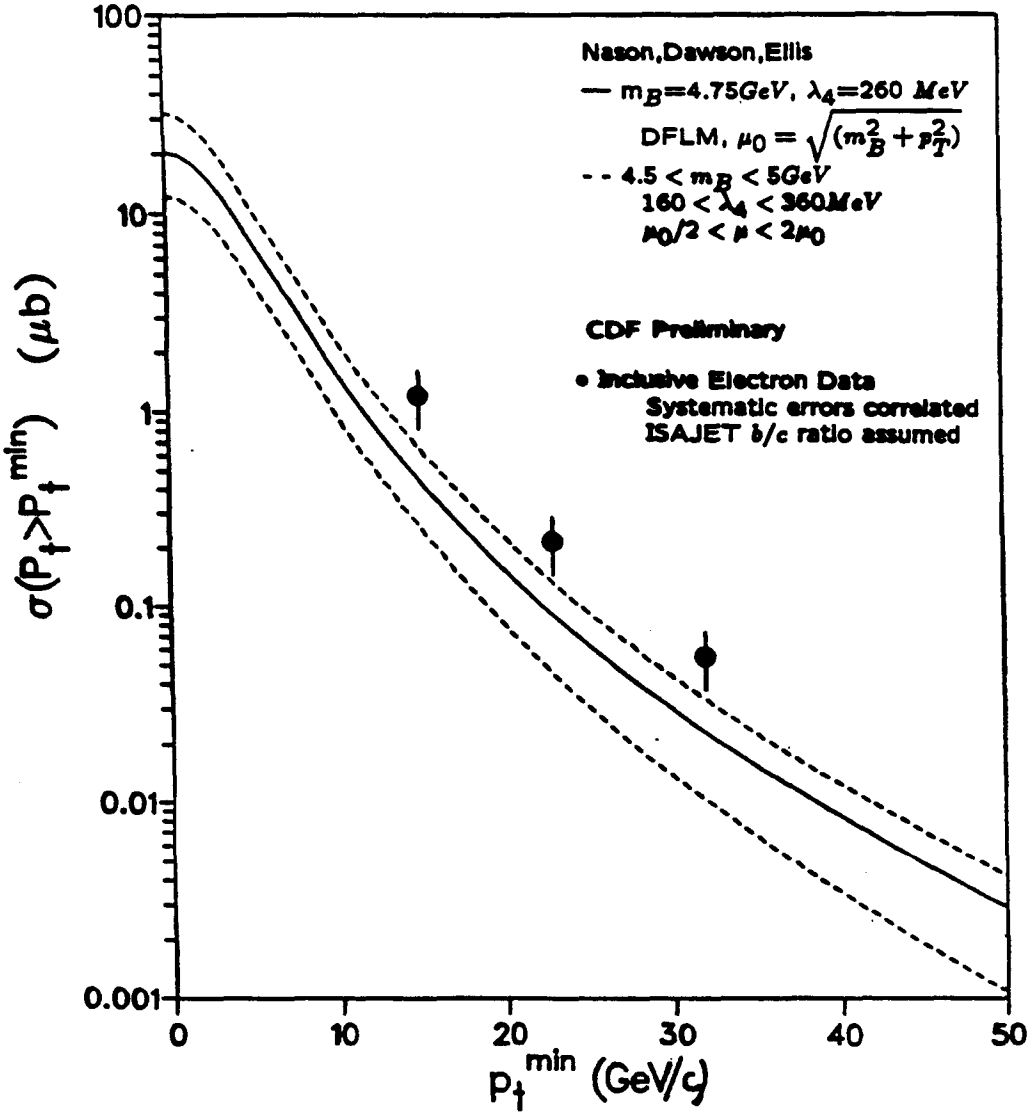
$$\sigma(\bar{p}p \to bX;\ p_T > 23\,\text{GeV},\ |y| < 1) = 220 \pm 65\ \text{nb},$$

$$\sigma(\bar{p}p \to bX;\ p_T > 32\,\text{GeV},\ |y| < 1) = 56 \pm 17\ \text{nb},$$

51.

CDF

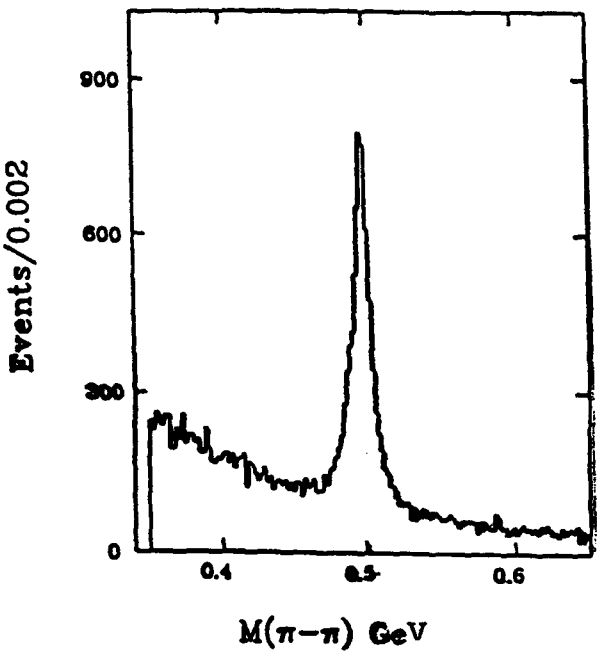
$\bar{p}p \to bX \quad \sqrt{s} = 1.8\,\mathrm{TeV} \quad |y| < 1 \quad p_T > p_T^{min}$



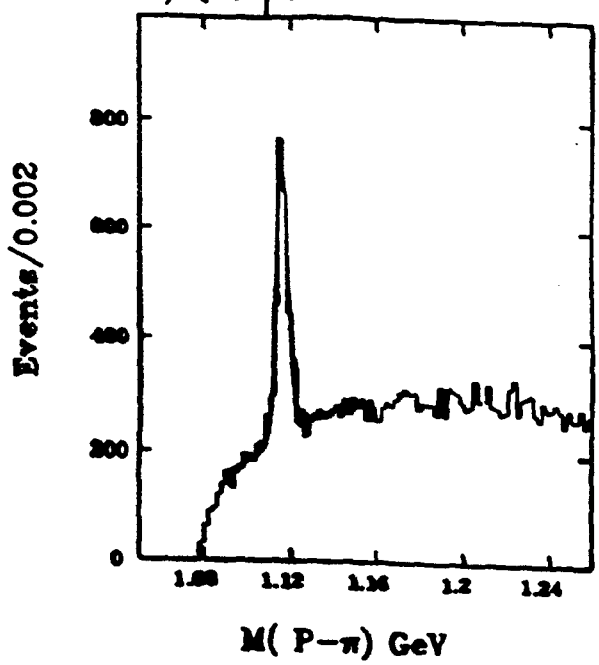
Bump Hunter Heaven

In the $\Delta R \leq 0.6$ cone, find:

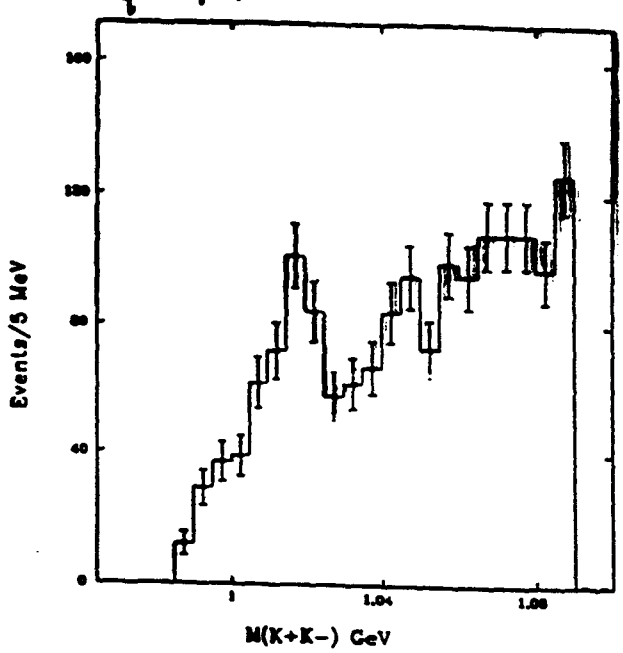
$K^0 \to \pi^+\pi^-$



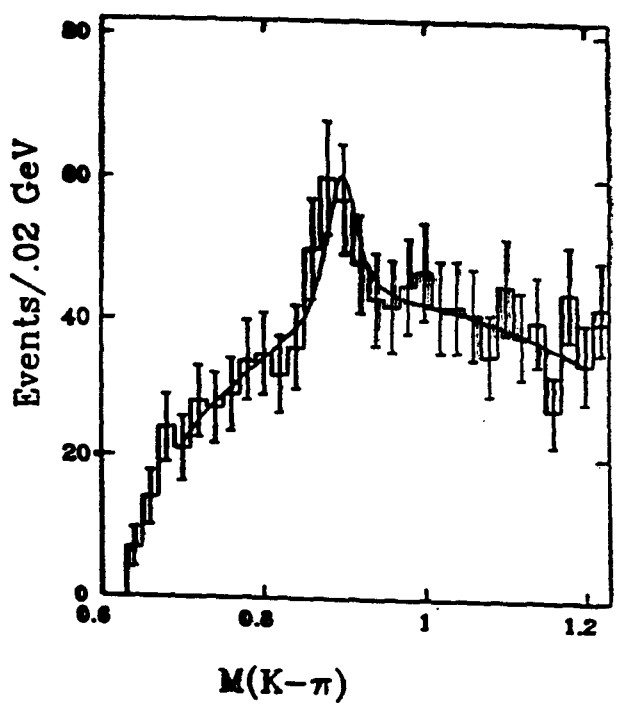
$\Lambda \to p\pi$



$\phi \to K^+K^-$



$K^* \to K\pi$

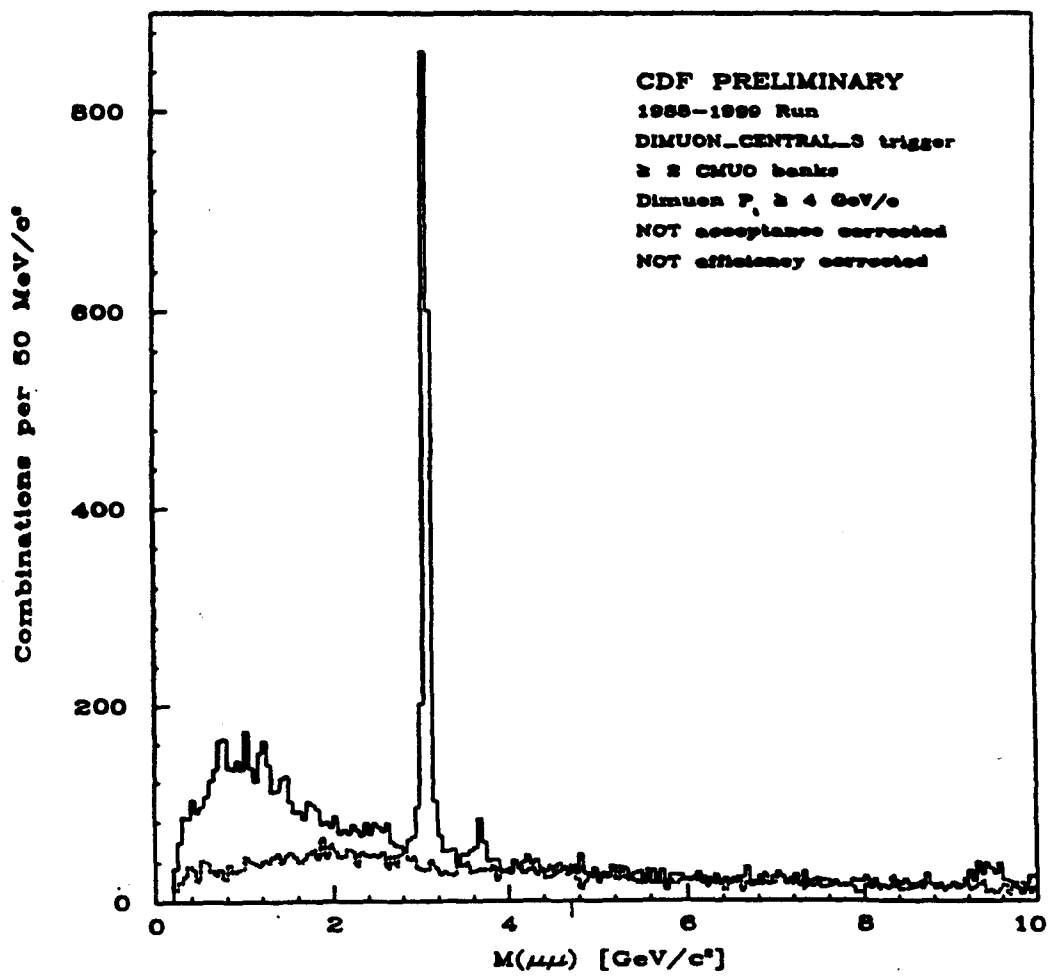


CDF Inclusive J/ψ Sample

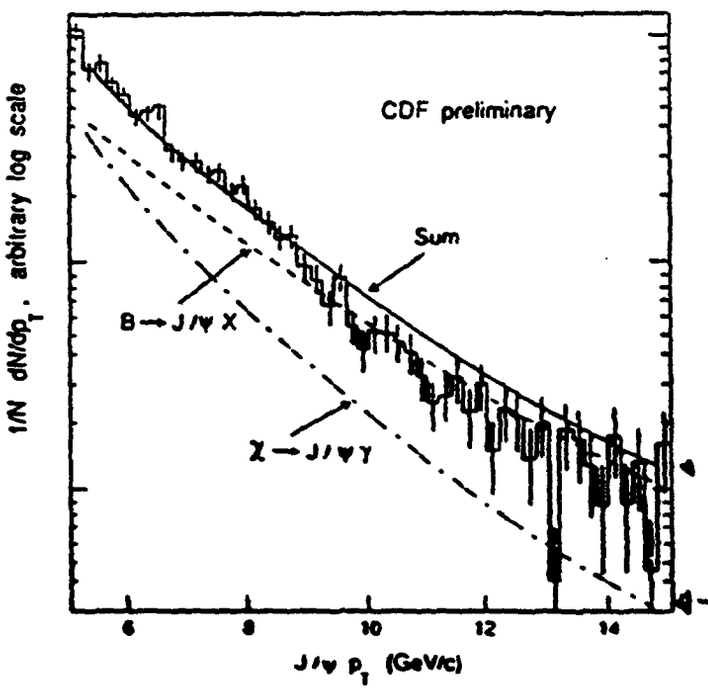
Trigger: L1 : 2 stubs, $p_T \geq 2$ GeV/c
L2 : 2 stubs matching processor tracks, $p_T \geq 3$ GeV/c

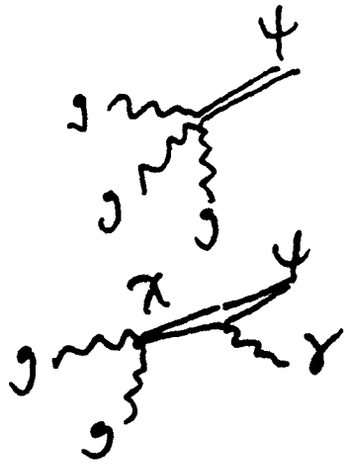
Offline: 2 stubs matched to real tracks, $p_T \geq 3$ GeV/c
$3.05 \leq M(\mu^+\mu^-) \leq 3.14$ GeV/c^2

$\Rightarrow$ 1100 events



Origin of J/ψ

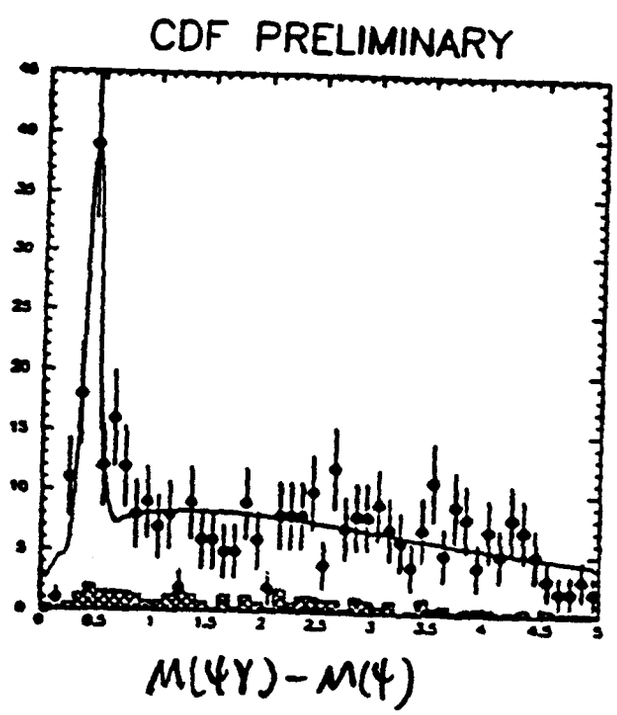




$B \to J/\psi\, X$ Br 1.12%

Glover et al, Z Phys C38(1988) 473

Evidence for χ



Case of very isolated γ near the ψ

Isolation: $E_T < 2.5$ GeV in 5x5 array

$\Sigma p_T^{track} < 2.5$ GeV in 30° cone

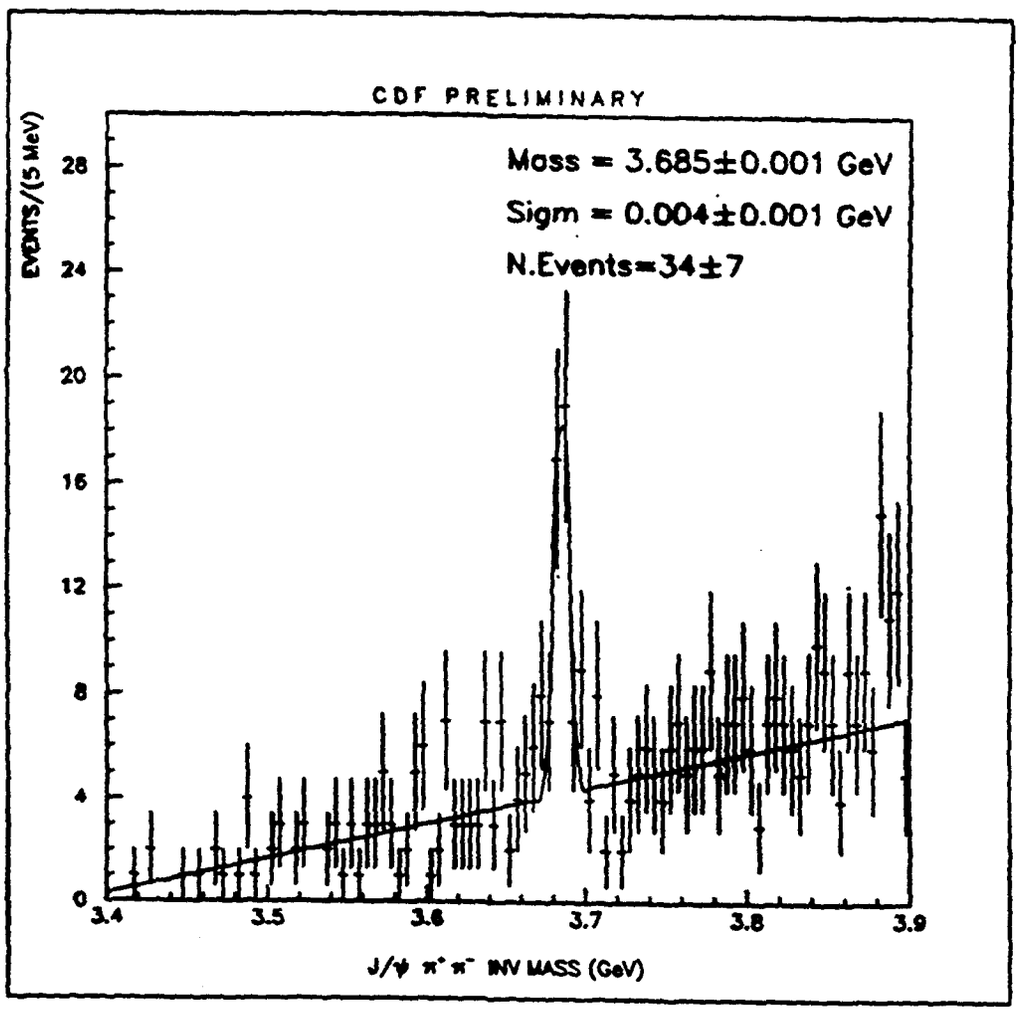
$E_\gamma \geq 1$ GeV

Good shower profile

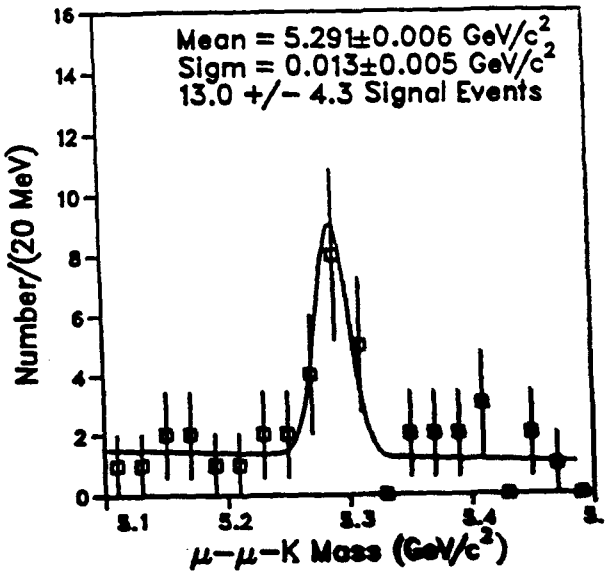
note: $M(\chi_1) - M(\psi) = 414$ MeV

$M(\chi_2) - M(\psi) = 460$ MeV

$\psi' \to J/\psi\, \pi^+\pi^-$ (Bump Heaven, 2nd level)



$\sigma(\bar{p}p \to bX)$ from the Exclusive Decay $B \to J/\psi K$



To find:

1. "K" in cone $\Delta R < 1.5$ around J/ψ
   ($\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$)
2. $p_T^{"K"} > 2$ GeV/c
3. K mass assumed

FIT1: Gaussian + Linear background: 13 ± 4.3 events

FIT2: Constrain to World Mass + Width: 11.4 ± 4.0 events
use this

Rest: a la electrons, use MC to relate to parent b spectrum

b-quark Efficiency

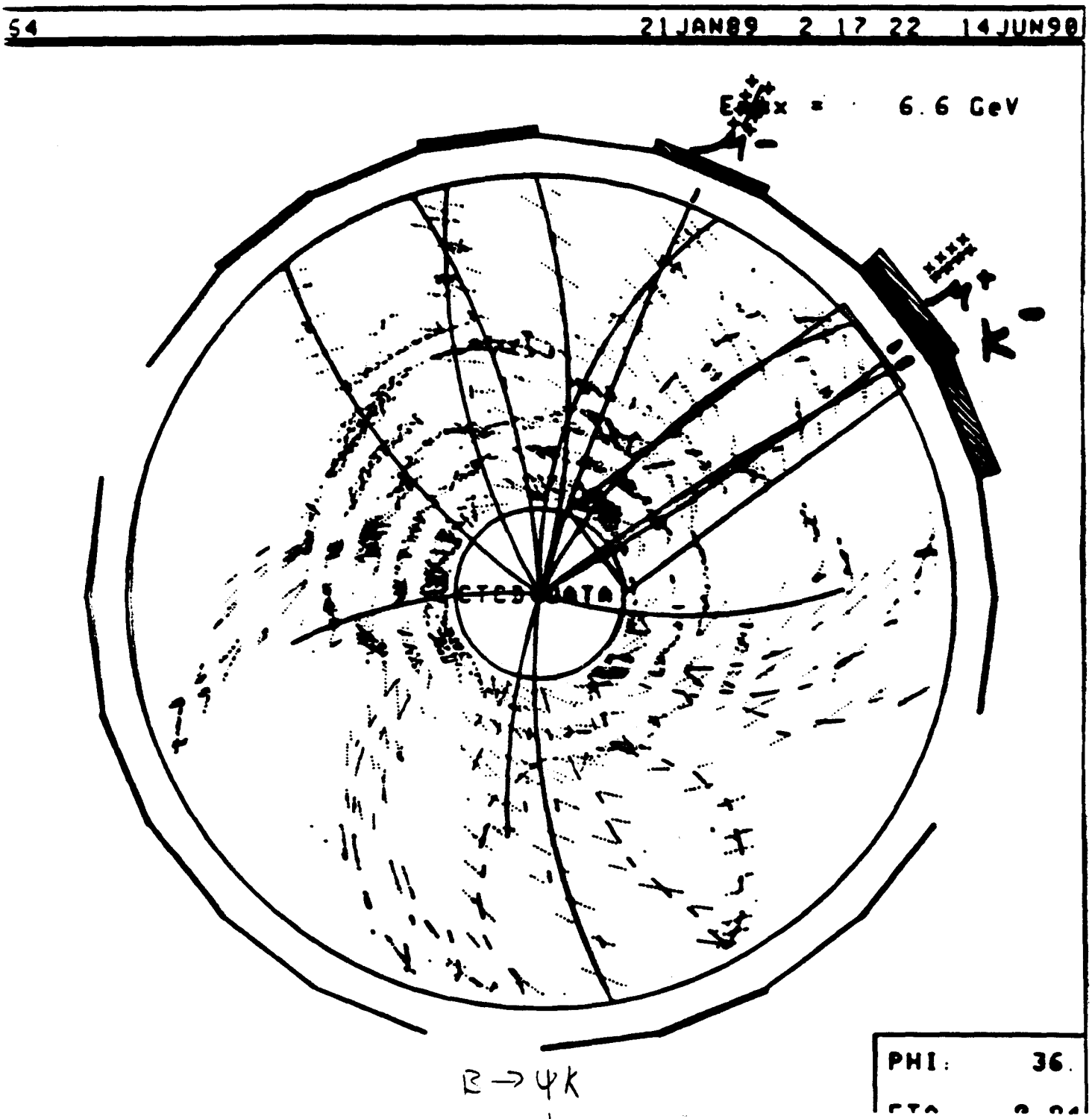
Source	Efficiency
fragmentation to B mesons	40%
Muon fiducial region	22%
L1 and L2 Trigger	21%
Kaon P_t cut	35%
Track reconstruction	90%
Muon track matching	87%
Total efficiency	0.51%

assume ☹

← p.i.d!

Systematic Uncertainties

Source	Uncertainty
Mass fitting	15%
Muon efficiency	9%
Tracking efficiency	10%
Decay in flight kaons	7%
L1 Trigger efficiency	7%
L2 Trigger efficiency	10%
b-quark fragmentation	10%
Combined branching ratios	28%
Luminosity	7%
Monte Carlo Statistics	6%
Total	40%



$B \to \psi K$

$\hookrightarrow \mu\mu$

CDF PRELIMINARY

We use the following formula to determine the cross section:

$$\sigma = \frac{N}{2\epsilon L Br(B \to J/\psi + K^{\pm}) Br(J/\psi \to \mu^+\mu^-)}$$

$N = 11.44 \pm 4.0$
$L = 2.628\ \mathrm{pb}^{-1}$
$Br = (5.21 \pm 1.16) \times 10^{-5}$
$\epsilon = 0.51\%$

$$\sigma(\bar{p}p \to bX; p_T > 10GeV, |y| < 1.) =$$

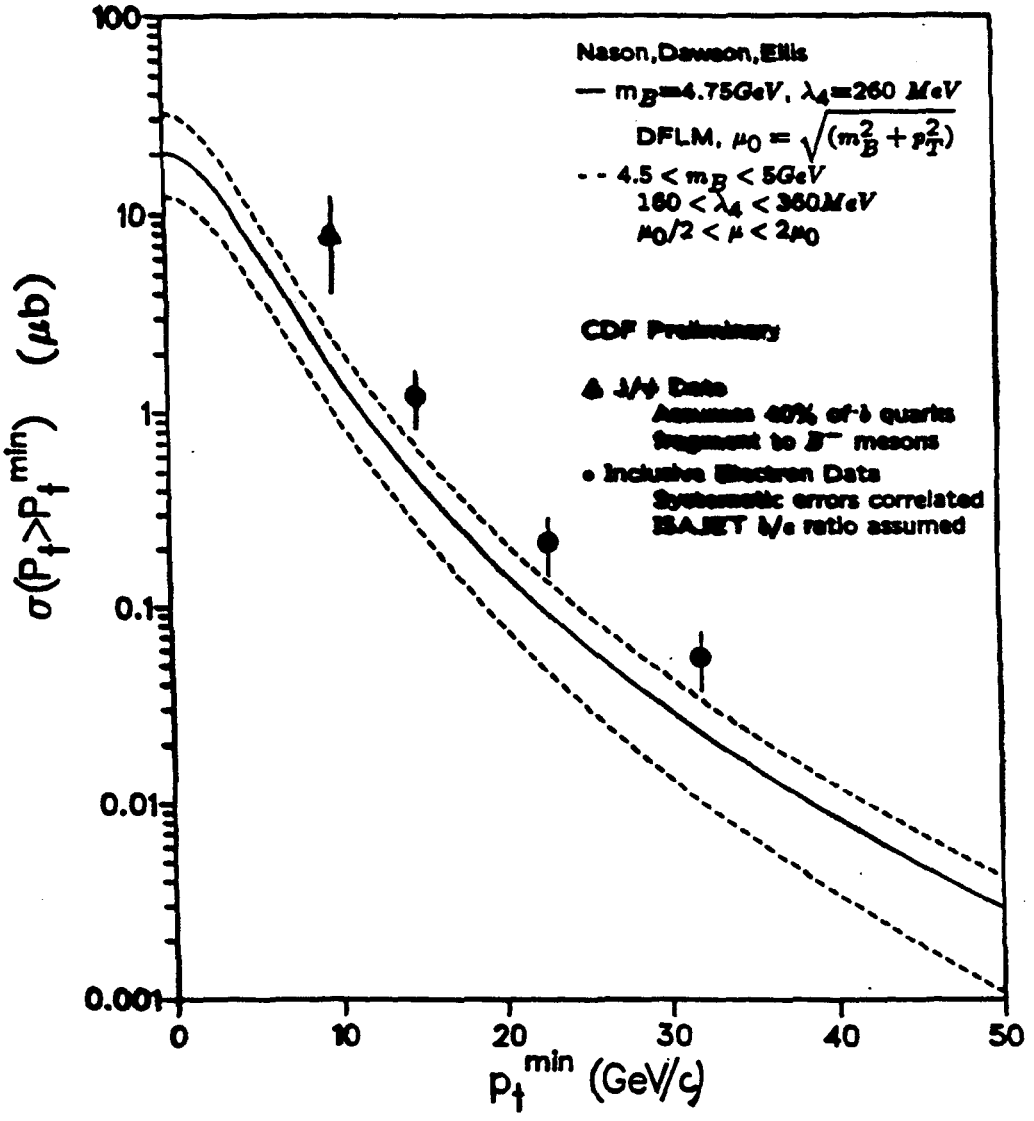
$$8.2 \pm 2.9(\mathrm{stat.}) \pm 3.3(\mathrm{syst.})\mu b$$

Note: $Br \sim 5 \times 10^{-5}$

In some cases, we have shocking sensitivity!

CDF: $\bar{p}p \to bX$; $\sqrt{s} = 1.8\,TeV$

$|y| < 1$, $p_T > p_T^{min}$



UA1 shows better agreement with $O(\alpha_s^3)$ at $\sqrt{s} = 630$ GeV

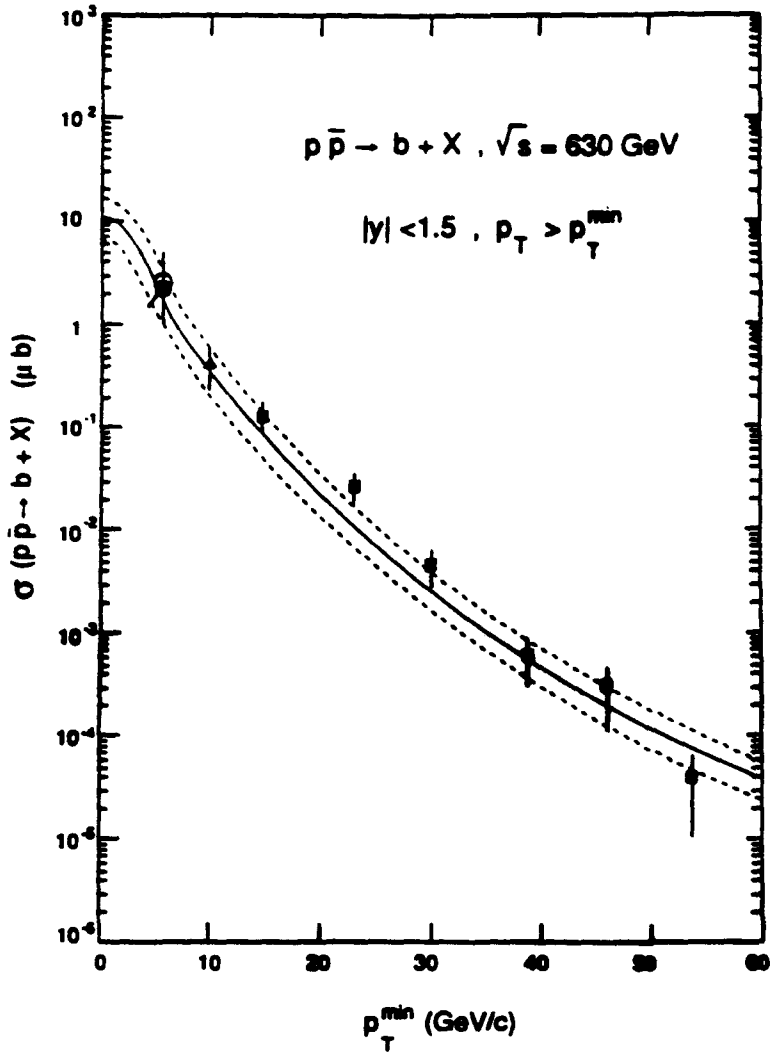


Fig. 4. The inclusive b-quark ($Q = -\frac{1}{3}$) cross-section for $|y| < 1.5$ versus the b-quark transverse-momentum threshold. The curve is the $O(\alpha_s^3)$ QCD prediction of Nason et al. [11]. The experimental points come from independent measurements discussed in this paper: $J/\psi \to \mu^+\mu^-$ (solid circle), high-mass dimuons (open circle), low-mass dimuons (triangle), muon-jets (squares).

B^0–$\bar{B}^0$ mixing

- $B^0 \to \ell^+ \nu X$, $\bar{B}^0 \to \ell^- \bar{\nu} X$ $\Rightarrow$ mixed events have likesign dileptons.

- $\chi = \dfrac{\text{prob}(b \to \bar{B}^0 \to B^0 \to \ell^+ X)}{\text{prob}(b \to B \to \ell^\pm X)} = \frac{1}{2}\dfrac{x^2}{1+x^2}$; $x = \dfrac{\Delta m}{\Gamma}$

- $\bar{\chi} = P_d \chi_d + P_s \chi_s$

- $R = \dfrac{N(\ell^+\ell^+ + \ell^-\ell^-)}{N(\ell^+\ell^-)} = f(\bar{\chi}, f(b \to c \to 2\ell), f(c,c \to 2\ell))$

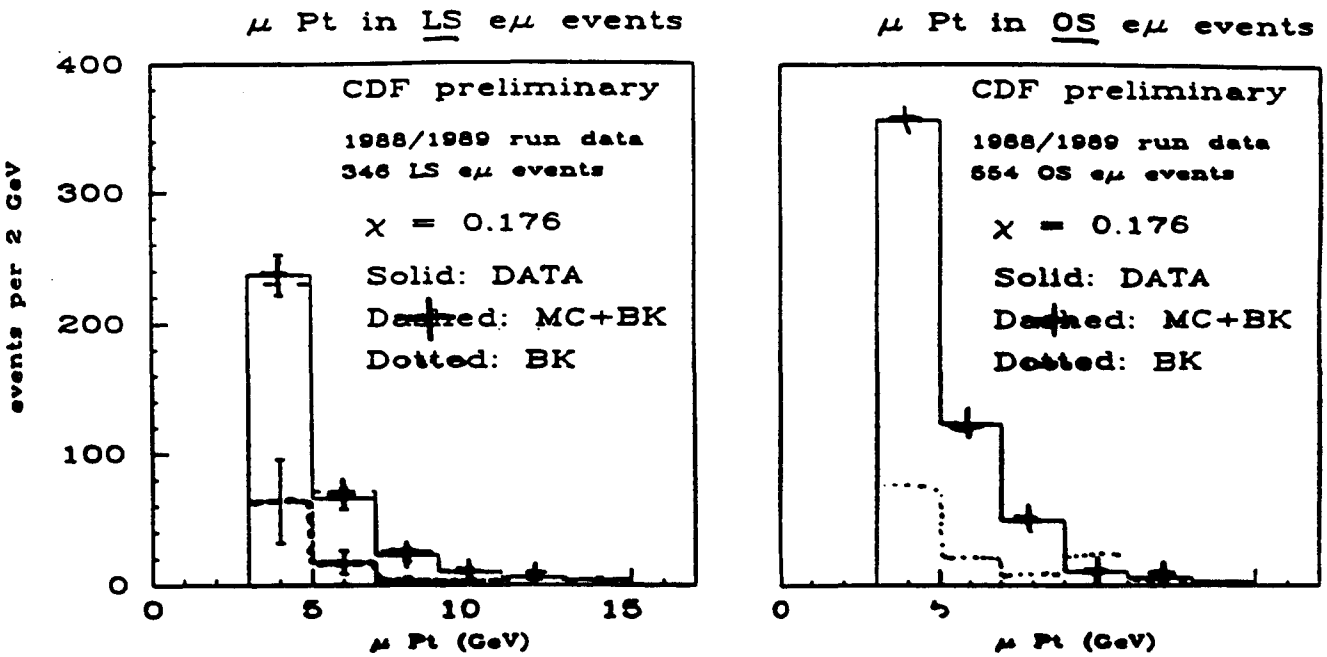
- <u>at CDF</u>

  $e\mu$ sample
  trigger: 5 GeV central e + 3 GeV central μ
  standard e and μ identification
  $m(e\mu) > 5.0$ GeV/c^2 to cut sequential 2ℓ decays
  remaining background: punchthrough, other μ fakes
  $\sim 20 \pm 10\%$

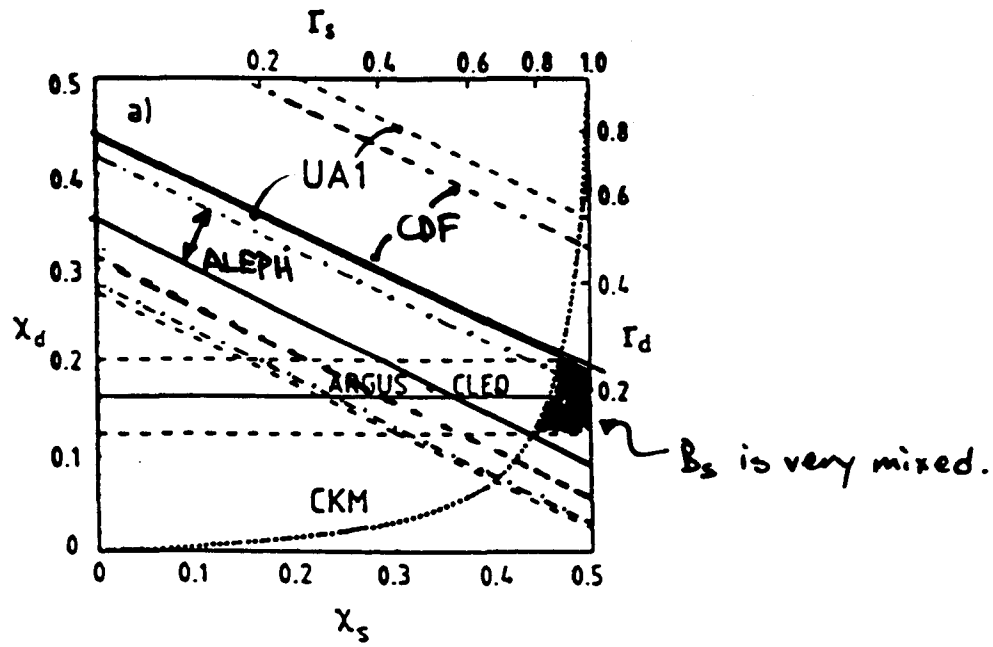
  final: 346 like sign
  554 opposite sign

$$\bar{\chi} = 0.176 \pm \underset{\text{stat}}{0.028} \pm \underset{\text{sys}}{0.025} \pm \underset{\text{MC}}{0.032}$$

P_T distribution of muons

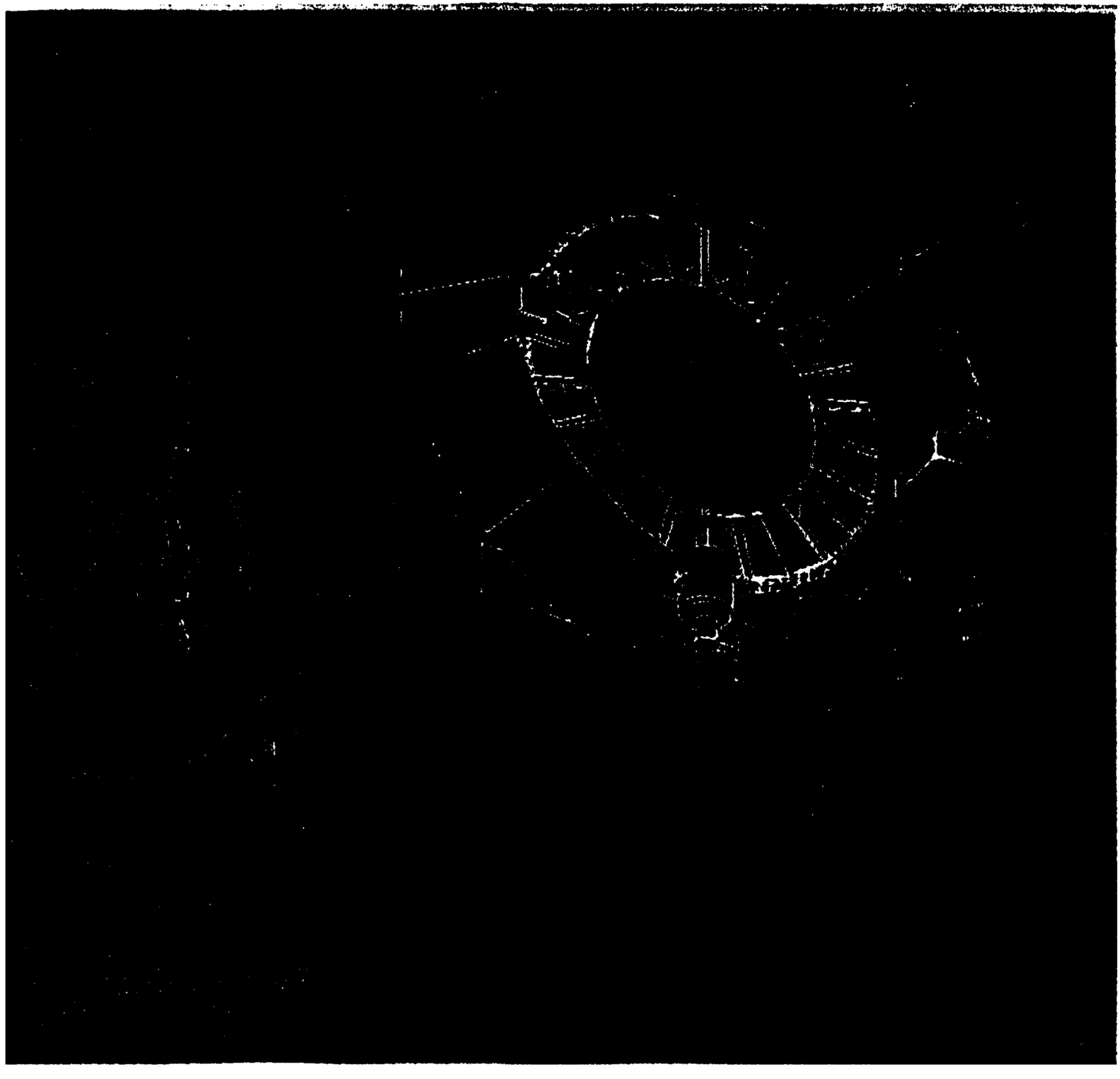


Comparison with other results



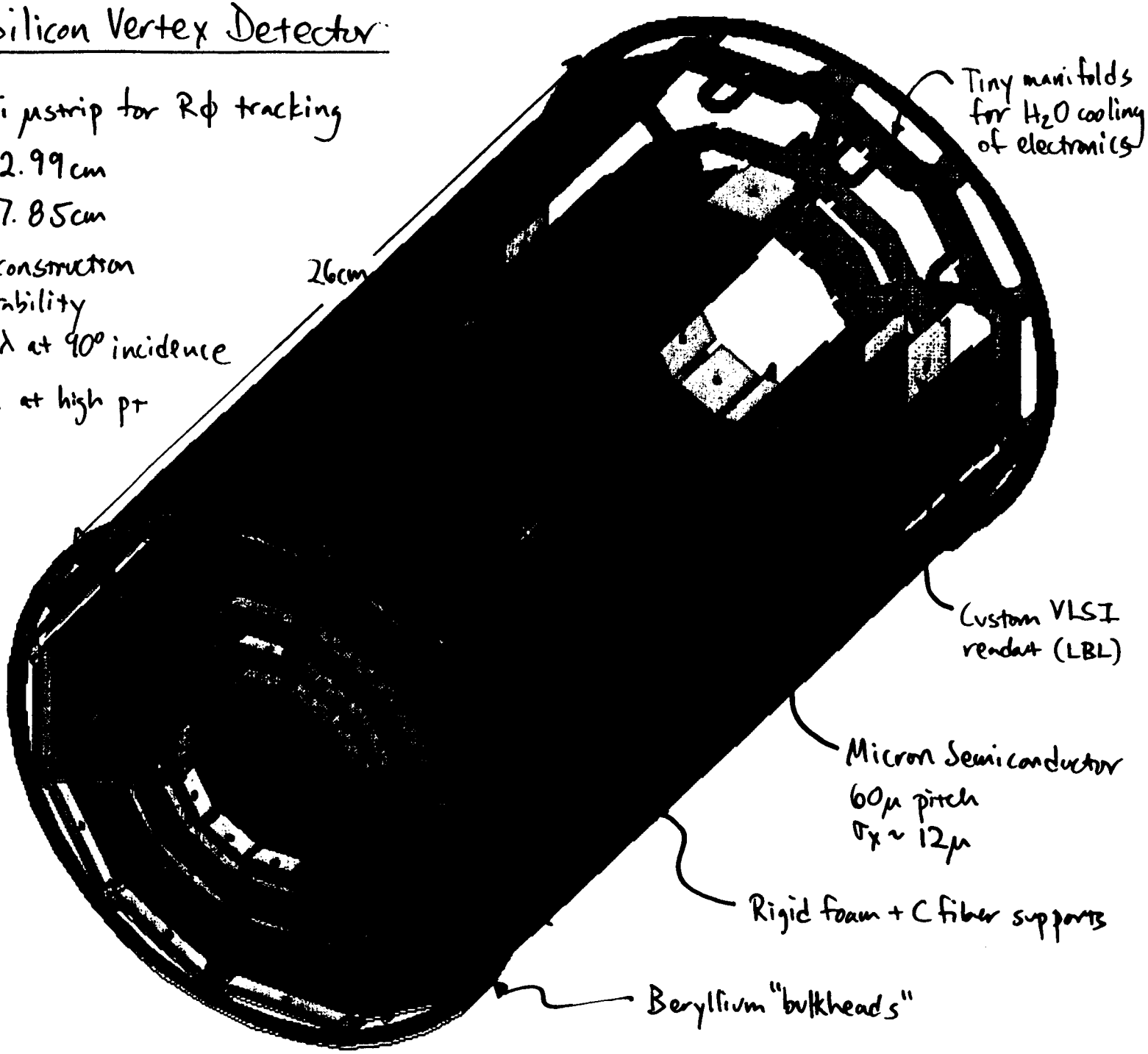
Tevatron Plan

Run	Date	Configuration	$\mathcal{L}_{peak}$	$\int \mathcal{L}dt$ on tape
0	88-89	6 bunches	2×10^{30}	$4.4\,pb^{-1}$
1a.	jan 92 june 92	6 bunches electrostatic separators low β	6×10^{30}	75-100 pb^{-1}
1b.	jan 93 june 93	6 bunches new linac E_{beam} = 1 TeV ?	1.2×10^{31}	
2.	95	36 bunches	3×10^{31}	$100\,pb^{-1}$
3.	beyond	Main Injector	5×10^{31}	0.5-1.0 fb^{-1}/year

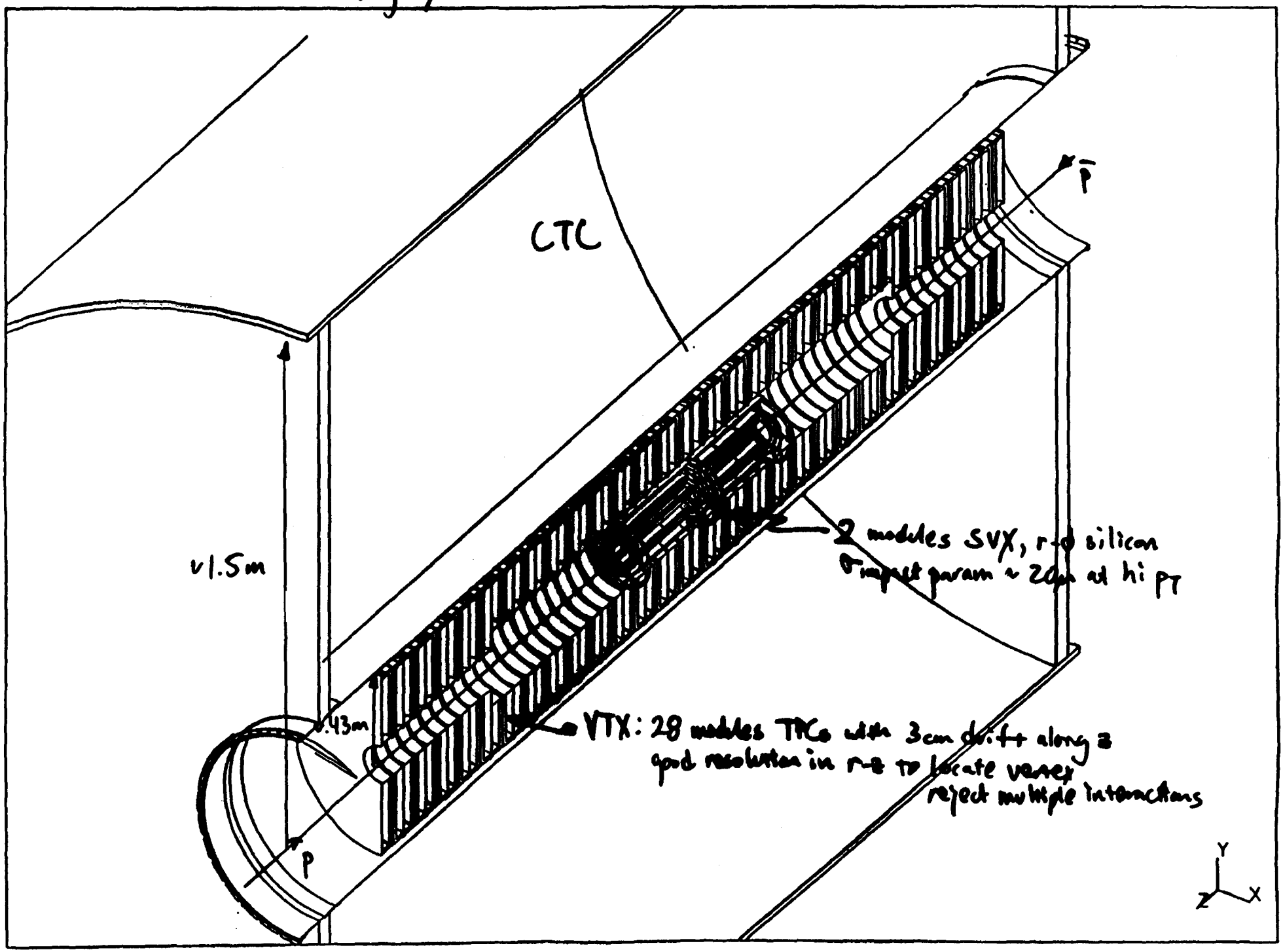


CDF Silicon Vertex Detector

- 4 layers Si μstrip for Rφ tracking
- $R_{inner} = 2.99$ cm
- $R_{outer} = 7.85$ cm
- Low mass construction
  - 10μ stability
  - 3.5% λ at 90° incidence
- $\sigma_{i.p.} \sim 20\mu$ at high p_T



11 CDF Central Tracking System



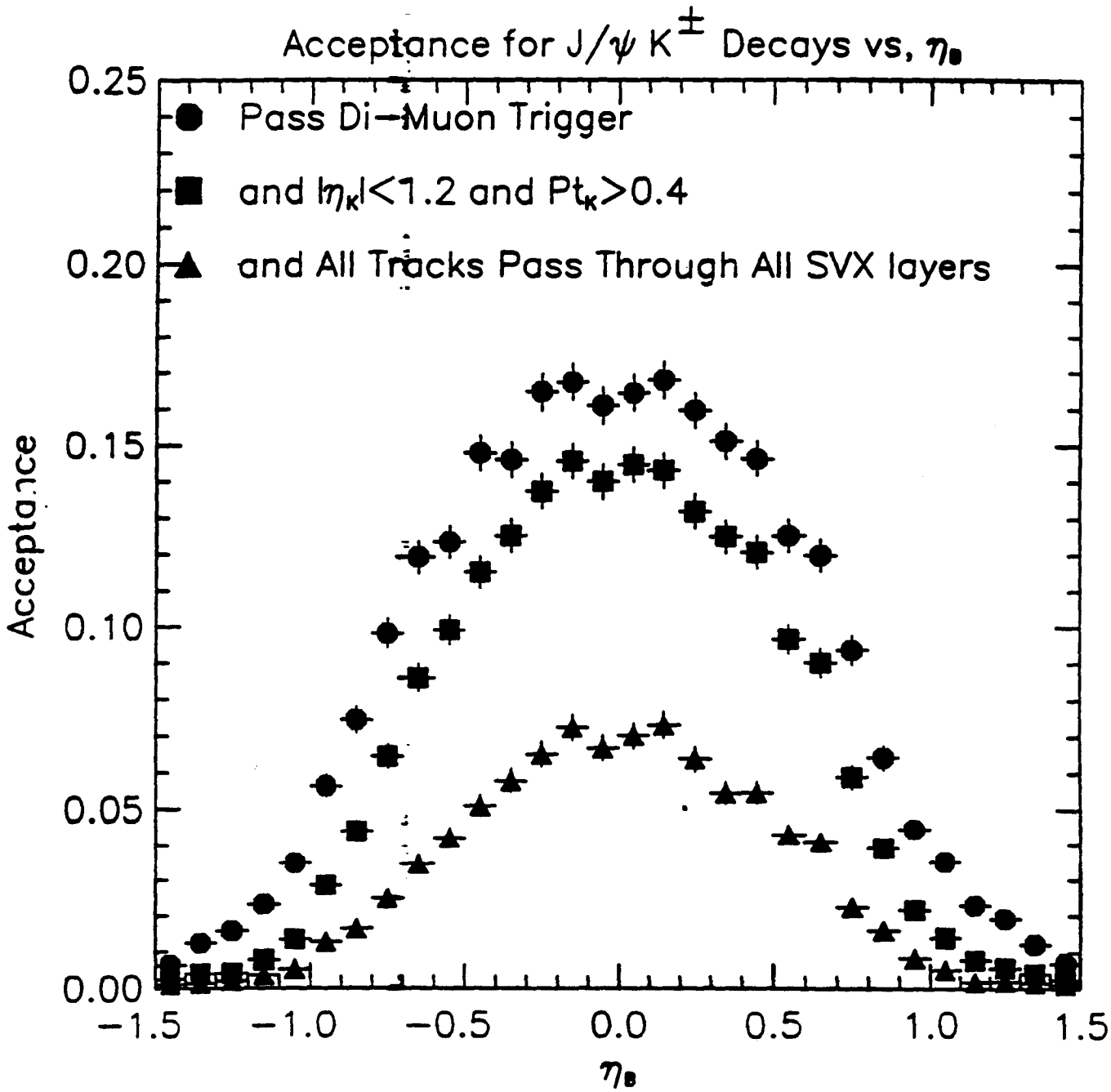

Acceptance for J/ψ K± Decays vs, ηB
Pass Di−Muon Trigger
and |ηK|<1.2 and PtK>0.4
and All Tracks Pass Through All SVX layers
Acceptance
0.25
0.20
0.15
0.10
0.05
0.00
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
ηB

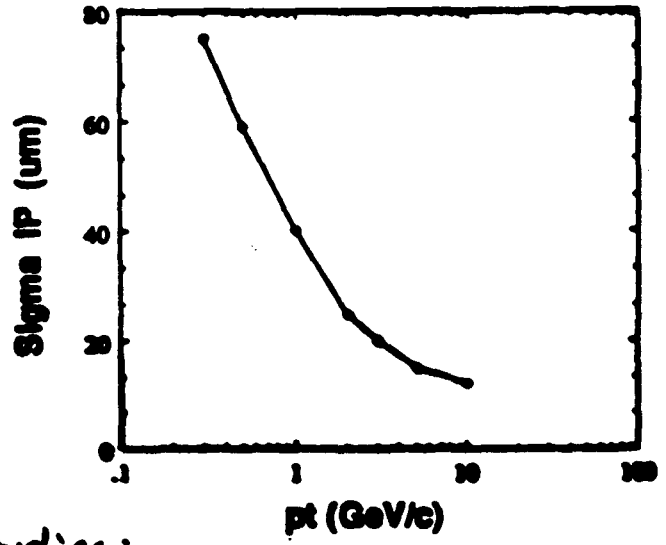
Fig. 2.2

Anticipated SVX performance

Fig. 1 SVX extrapolated impact parameter resolution vs. track p_t

$$\sigma_{ip} \simeq \sqrt{15^2 + (38/p)^2} \text{ microns}$$

(p in GeV/c)



Lowest order Monte Carlo studies:

Fig. 2 Single track tag efficiency This is probability that any track from a b parton of a given p_t will have i.p > 3σ.

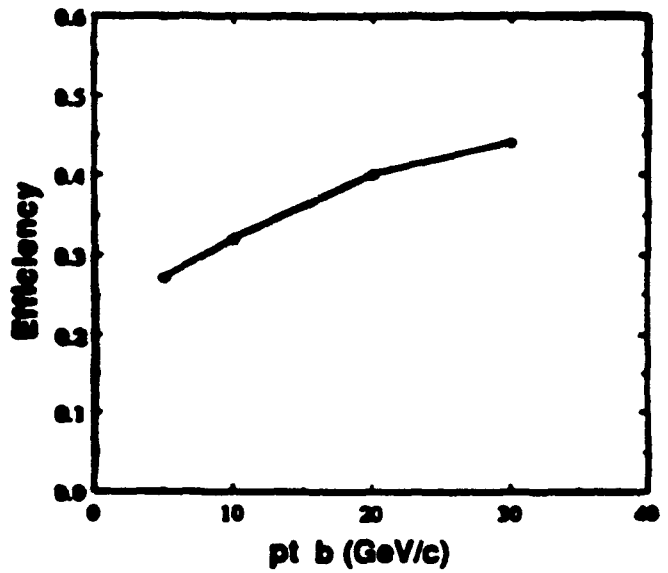
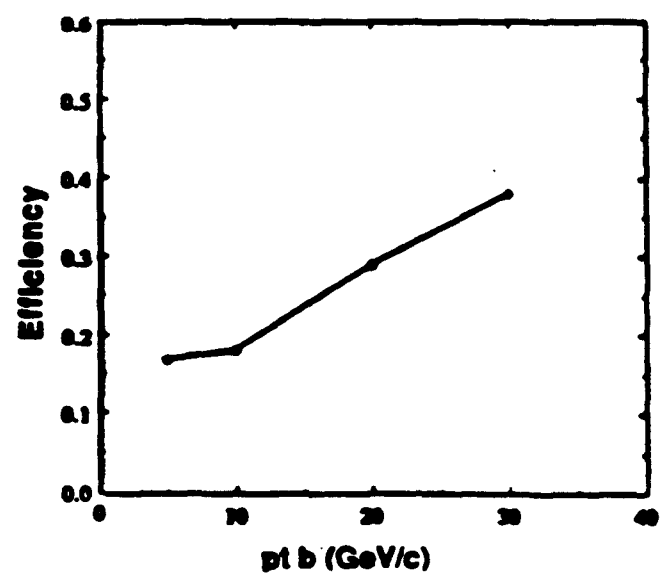


Fig. 3 B tag efficiency This is probability that a jet from a b parton of a given p_t will satisfy the 3 track tag.

Require 3 tracks with impact parameters $\geq 3\sigma$.



Components of a CDF B Physics Program for 92-93

Benchmarks: $\sigma(p\bar{p} \to bX;\ p_T > 10\,\mathrm{GeV/c},\ |\eta| < 1) = 8\,\mu b$
"known" trigger & detection efficiencies
$100\,pb^{-1}$ @ $\langle \mathcal{L} \rangle \sim 10^{31}$

1. Dilepton modes ($B \to \psi X$, $B \to \mu^+\mu^- X$, ...)

Trigger: $2 \times (p_T^\mu \geq 1.8\,\mathrm{GeV/c})$. $R_{L2} \sim 10\,Hz$ @ 10^{31}. $S/N \sim 0.3\%$

Sample: 300 K $B \to \psi X$

Topics:

Spectroscopy: 4000 each $B_d^0 \to \psi K^{*0}, \psi K^0$
$B_u^\pm \to \psi K^\pm$

200 $B_s \to \psi\phi$

50 $\Lambda_b \to \psi p \pi$

? $B_c \to \psi\pi$

Lifetimes: $c\tau/\sigma_{ip}$ @ 2 GeV $\sim 300\mu/30\mu \sim 10/1$
$\sim$ few % on $\tau_{B_d}, \tau_{B_u}, \tau_{B_s}, \tau_{\Lambda_b}$

Production: B_s/B_d ratio
use SVX to find "other B". study $O(\alpha_s^{3,4})$

Decays: 1000 $b \to s\mu\mu \Rightarrow 100\ B \to \mu\mu K$
$B \to \mu^+\mu^-, \mu e$

CDF B Program (cont.)

2. Semileptonic Modes

Triggers:
- $p_T^e > 9$ GeV, hard E/p cut
  $R_{L2} \sim 3$ Hz @ 10^{31}, S/N ≈ 0.10
- $p_T^\mu \geq 9$ GeV in CMUP
  $R_{L2} \sim 2$ Hz @ 10^{31}, S/N ≈ 0.12

Sample: 3 million each $B \to e\nu X$, $B \to \mu\nu X$

Topics

Toward side:
1-10K each charm mode (D^0, D^+, D_s, etc)
production fractions
decay dynamics
B_s/B_d
$|V_{ub}|/|V_{cb}|$?

Away side:
use leptons or SVX to find "other B."
study $O(\alpha_s^{3,4})$
study tagging ε for CP violation

Both sides:
mixing!
use SVX to resolve time development of mixing in tagged or like sign sample
see x_b, x_s in Fourier transform
? only way to see x_s, i.e. know $|V_{ts}|$?

Conclusions

- A promising, long term B program is underway at CDF
- We think we have

  the cross section
  the hardware
  the triggers
  the sensitivity
  the luminosity
  and the wherewithall

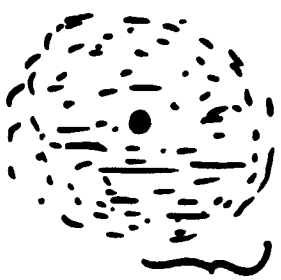
  to exploit the "window of opportunity" that exists in the B sector before the B factory / SSC.

- The competition is LEP: less rate, but less background
- Stay tuned!

OLD ~~NEW~~ SYMMETRIES OF THE STRONG INTERACTIONS

Physical situation: A heavy quark Q $m_Q \gg \Lambda_{QCD}$ interacting with light degrees of freedom that (typically) have four momentum small compared with m_Q.

e.g. Low lying $Q\bar{q}$ meson



$r \sim 1/\Lambda_{QCD}$ determined by nonperturbative strong interactions

In such situations it is appropriate to take a limit of QCD where $m_Q \to \infty$ with its four velocity fixed. This gives rise to an effective heavy quark theory that has new symmetries. that arise because interactions of heavy quark independent of its mass and spin.

This limit is similar to an approx. used in classical mechanics. Baseball churns up air in its path, but air has negligable impact on the baseball's path

baseball $\leftrightarrow$ heavy quark

air $\leftrightarrow$ light degrees of freedom (i.e. light quarks and gluons)

For N heavy quarks Q_i, $i=1,\ldots,N$ the effective theory has a SU(2N) spin flavor symmetry (Isgur + Wise, Phys. Lett. [redacted] B232, 113 (1989); B237, 527, (1990)) that enables one to predict many properties of hadrons containing a single heavy quark. Used much like chiral-symmetry is for hadrons containing only light quarks. The physics of symmetries is quite simple and had been incorporated in phenomenological models (M. Suzuki, Nucl. Phys. B258 553 (1985); Grinstein et. al Phys. Rev. Lett 56 298 (1986); Altomari and Wolfenstein Phys. Rev. Lett 58, 1583 (1987); Isgur et. al. Phys Rev D39 799 (1989))

What is new is that this simple physics is understood as arising from symmetries of an effective theory that is a systematic limit of QCD so that model independent predictions are now possible.

I The effective Theory

Can get Feynman rules for the effective theory by taking limit of Feynman rules for QCD. Write for heavy quark four momentum

$$p_Q = m_Q v + k$$

residual momentum

four velocity $v^2 = 1$

Limit $m_Q \to \infty$, v fixed

$$\frac{i(\not{p}_Q + m_Q)}{p_Q^2 - m_Q^2} \longrightarrow \frac{i(\not{v}+1)}{2v\cdot k} \longrightarrow \frac{i}{2v\cdot k}$$

$$-igT^a\gamma_\mu \to -igT^a \frac{(1+\not{v})}{2}\gamma_\mu \frac{(1+\not{v})}{2} = -igT^a v_\mu \frac{(1+\not{v})}{2}$$

$$\longrightarrow -igT^a v_\mu$$

So in effective theory Feynman Rules are

Propogator: $\frac{i}{v\cdot k}$ (Eichten + Hill, Phys. Lett B234, 511 (1990); H. Georgi, Phys. Lett B240 447 (1990))

Vertex : $-igT^a v_\mu$

Not a nonrelativistic approximation!

Interactions of a heavy quark independent of its mass and spin. If N heavy quarks Q_i $i=1,\ldots N$ then effective theory has $SU(2N)$ spin-flavor symmetry. Symmetry interchanges quarks of same four velocity (generally very different momentum)

Can get same result using field theory

$$Q = e^{-im_Q v\cdot x} h_v^{(Q)} \quad ; \quad \not{v} h_v^{(Q)} = h_v^{(Q)}$$

$$\mathcal{L} = \bar{Q}(i\not{D} - m_Q)Q$$
$$= \bar{h}_v^{(Q)} i v\cdot D h_v^{(Q)}$$

derivative brings down residual momentum because of rescaling!

Symmetries of QCD

Quark	Mass	Symmetry
up	~0.005 GeV	$m_q \ll \Lambda_{QCD}$, for $m_q \to 0$
down	~0.01 GeV	$SU(3)_L \times SU(3)_R \to SU(3)_V$
strange	~0.15 GeV	on an equal footing.
charm	1.8 GeV	$m_Q \gg \Lambda_{QCD}$, for $m_Q \to \infty$
bottom	5.2 GeV	$SU(4)$

For remainder of this lecture I will describe some applications of the heavy quark symmetry

II Spectroscopy with heavy quark Symmetry

Usually Label one particle states at rest by the quantum numbers (s, m_s). But for hadrons containing a single heavy quark Q not only $\vec{S}$ but also the spin of the light degrees of freedom

$$\vec{S}_\ell \equiv \vec{S} - \vec{S}_Q$$

commute with the Hamiltonian. This means states are also labelled by s_ℓ. Since the dynamics don't depend on $\vec{S}_Q$ for a given s_ℓ one gets in general two degenerate states with

$$\underbrace{s_\pm}_{\text{total spin}} = \underbrace{s_\ell}_{\text{spin of light degrees of freedom}} \pm \underbrace{1/2}_{\text{heavy quark spin}}$$

Exception when $s_\ell = 0$ in which case just one state with $s = 1/2$.

To see how this works explicitly consider ground state mesons with $Q\bar{q}$ flavor quantum #s. This has $s_\ell^{\pi_\ell} = 1/2^-$. From this form negative parity doublet with $s_+ = 1$, $s_- = 0$. For $Q = c$ these are D^*, D mesons and for $Q = b$ these are the $\bar{B}^*, \bar{B}$ mesons. In general call them P_Q^*, P_Q.

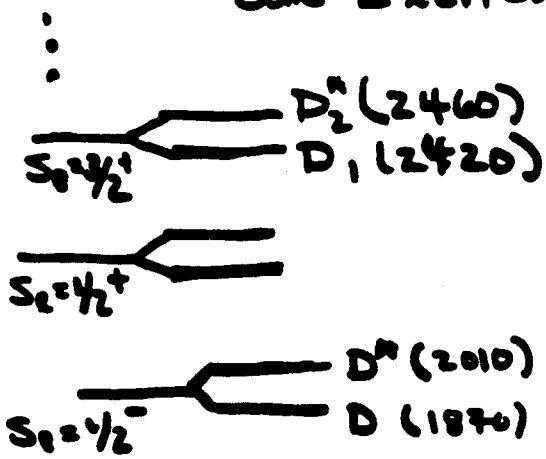
$$|P_Q\rangle = \frac{1}{\sqrt{2}}\left[\,|\underbrace{\uparrow}_{\text{heavy quark}}\underbrace{\downarrow}_{\text{light degree of freedom}}\rangle - |\downarrow\uparrow\rangle\right]$$

$$|P_Q^*\rangle = \frac{1}{\sqrt{2}}\left[|\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle\right]$$

$$S_Q^3 |P_Q\rangle = |P_Q^*\rangle$$

Splittings between multiplets with different s_ℓ's independent of Q flavor.

Some Excited mesons observed for Q=c.



Excited states can decay to Lower ones by pion emission. At hadron level four transitions but really only $s_\ell \to s_\ell' + \pi$ so four transitions related by Clebsch Gordon coefficients (Isgur and Wise, Phys. Rev. Lett. 66, 1130 (1991))

For $s_\ell = 3/2^+ \to s_\ell = 1/2^-$ transition orbital angular momentum of pion L=0 or 2. Predict

$$A(D_2^* \to (D^*\pi)_{L=2}) : A(D_2^* \to (D\pi)_{L=2}) : A(D_1 \to (D^*\pi)_{L=2})$$

$$\sqrt{3/5} \qquad \sqrt{2/5} \qquad 1$$

$$A(D_1 \to (D^*\pi)_{L=0}) = 0$$

(Rosner, Comm. Nucl. Part. Phys. 16 109 (1986))

Compare with experiment. Take out factor of $(p_\pi^{2L+1})^{1/2}$ then find

$$\frac{A(D_2^* \to D\pi)}{A(D_2^* \to D^*\pi)} = 0.8 \pm 0.1 \quad \left(\text{Theory } \sqrt{\frac{2}{3}}\right) \checkmark$$

may have L=0 component

$$\frac{A(D_1 \to D^*\pi)}{A(D_2^* \to D^*\pi)} = 2.3 \pm 0.6 \quad \left(\text{Theory } \sqrt{\frac{5}{3}}\right)$$

The degenerate multiplets get split at order Λ_{QCD}/m_Q. It is possible to incorporate Λ_{QCD}/m_Q corrections systematically

(Lepage + Thacker, Nucl. Phys. B4 (Proc. Suppl) 199 (1988); Eichten and Hill, Fermilab-Pub-90/54-T (1990); Falk et al HUTP-90/A044 (1990))

$$\mathcal{L}_v = \bar{h}_v^{(Q)}\, iv\cdot D h_v^{Q} + \frac{\bar{h}_v^{(Q)}}{2m_Q}\Big[a_1 (iD)^2 - \frac{a_2}{2}\, g\, \sigma_{\mu\nu} G^{a\mu\nu} T^a\Big] h_v^{(Q)} + \text{c.t.}$$

$$a_2(\mu) = \left[\frac{\alpha_s(m_Q)}{\alpha_s(\mu)}\right]^{-9/(33-2N_f)}$$

Predict:

$$(m_{B^*} - m_B) = \left(\frac{m_c}{m_b}\right)\left[\frac{\alpha_s(m_b)}{\alpha_s(m_c)}\right]^{-9/(33-2N_f)} (m_{D^*} - m_D) \checkmark$$

Agrees well with experiment.

(Lepage + Thacker, Nucl. Phys. B4 (Proc. Suppl) 199 (1988))

III B Decay

Just like applying $SU(3)_L \times SU(3)_R$ chiral symmetry to semileptonic kaon decay $SU(4)$ symmetry of heavy quarks tells us much about the semileptonic decays $\bar{B} \to D e \bar{\nu}_e$, $\bar{B} \to D^* e \bar{\nu}_e$. These decays are determined by $|V_{cb}|$ and matrix elements of the axial vector and vector current. In transition $\bar{B}(v) \to D(v')$ momentum transfer felt by light degrees of freedom $\sim \Lambda_{QCD}^2 (v-v')^2$ so can use effective theory. Find

depends on normalization

depends on normalization at zero recoil of heavy quark mass universal.

$$\langle D(v') | \bar{c} \gamma_\mu b | \bar{B}(v) \rangle = \sqrt{m_B m_D}\, C_{cb}\, \xi(v\cdot v')\, (v+v')_\mu$$

$$\langle D^*(v',\epsilon) | \bar{c} \gamma_\mu \gamma_5 b | \bar{B}(v) \rangle = \sqrt{m_B m_{D^*}}\, C_{cb}\, \xi(v\cdot v') \left[(1+v\cdot v')\, \epsilon^*_\mu - (\epsilon^* \cdot v)\, v'_\mu \right]$$

[Isgur + Wise Phys. Lett. B232 113 (1989); Phys. Lett. B237 527 (1990)]

$$\langle D^*(v',\epsilon) | \bar{c} \gamma_\mu b | \bar{B}(v) \rangle = \sqrt{m_B m_{D^*}}\, i C_{cb}\, \xi(v\cdot v')\, \epsilon_{\mu\nu\alpha\beta}\, \epsilon^{*\nu} v^\alpha v'^\beta$$

Furthermore form factors normalized at zero recoil

$$\xi(1) = 1$$

[Nussinov + Wetzel, Phys. Rev. D36 130 (1987); Voloshin + Shifman Sov. J. Nucl. Phys. 47 199 (1988)]

C_{cb} takes into account logarithms of m_b, m_c that arise in QCD perturbation theory. In l.l.a.

$$C_{cb} = \left[\frac{\alpha_s(m_b)}{\alpha_s(m_c)}\right]^{-6/25} \left[\frac{\alpha_s(m_c)}{\alpha_s(\mu)}\right]^{a_L(v\cdot v')}$$

[Voloshin and Shifman, Sov. J. Nucl. Phys. 45 292 (1987); Politzer + Wise, Phys. Lett. B206, 681 (1988); B208 504 (1988); A. Falk et. al Nucl Phys B343 1 (1990)]

$$a_L = \frac{8}{27}\left[v\cdot v'\, r(v\cdot v') - 1\right]$$

$$r(v\cdot v') = \frac{1}{\sqrt{(v\cdot v')^2-1}} \ln\left(v\cdot v' + \sqrt{(v\cdot v')^2-1}\right)$$

$$r(1) = 1$$

$$\Rightarrow a_L(1) = 0$$

Corrections to this have been examined. There are two types

(i) Perturbative $\alpha_s(m_Q)$ corrections. These are computable and don't cause a loss of predictive power.

[Falk et. al Nucl Phys. B343 1, (1990), Grinstein + Falk Phys. Lett B254 [illegible]; Ji, X, MIT CTP#1965 (1991)]

Everything still expressed in terms of $\xi(v\cdot v')$.

(ii) Λ_{QCD}/m_Q corrections do cause a loss of predictive power. New functions like ξ are induced.

However at <u>zero recoil no Λ_{QCD}/m_c corrections</u>.

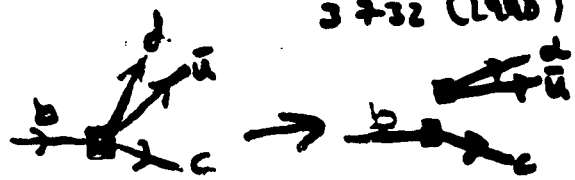
Analogous to Ademollo Gatto thm. and called Lukes thm. [Luke, Phys. Lett B252 447 (1990)] Allow extraction of $|V_{cb}|$ from data comparable in precision with $\sin\theta_c$ from Kaon and hyperon decays.

Bjorken, Nucl. Phys B4 (Proc. Suppl) 325 (1989); Dugan + Grinstein Phys. Lett B255, 583 (1991)

Because of large b-quark mass factorization holds for decays $\bar{B} \to D\pi^-$, $\bar{B} \to D^*\pi^-$, etc.

These nonleptonic decays are related to semileptonic decays predict (Rosner Phys Rev D42 3732 (1990))

$$\frac{\Gamma(\bar{B} \to D\pi^-)}{\Gamma(\bar{B} \to D^*\pi^-)} = 1$$



$$\frac{\Gamma(\bar{B} \to D\rho^-)}{\Gamma(\bar{B} \to D\pi^-)} = \frac{\Gamma(\bar{B} \to D^*\rho^-)}{\Gamma(\bar{B} \to D^*\pi^-)} = \left(\frac{f_\rho}{f_\pi}\right)^2$$

neglecting the pi masses

Compare with experiment (Stone + Bortoletto Phys Rev Lett. 65 2951 (1990)):

$$\frac{\Gamma(\bar{B} \to D\pi^-)}{\Gamma(\bar{B} \to D^*\pi^-)} = 1.1 \pm 0.2 \quad \checkmark$$

Perturbative $\alpha_s(m_b)$ corrections to factorization small [Politzer + Wise, Phys. Lett B257 399 (1991)]

Also useful for $|V_{ub}|$. Flavor symmetry + isospin implies

$$\langle \rho(k,\epsilon)|\bar{u}\gamma_\mu(1-\gamma_5)b|\bar{B}(v)\rangle$$

$$= \left(\frac{m_B}{m_D}\right)^{1/2}\left[\frac{\alpha_s(m_b)}{\alpha_s(m_c)}\right]^{-6/25}\langle \rho(k,\epsilon)|\bar{d}\gamma_\mu(1-\gamma_5)c|D(v)\rangle$$

Many other relations. For Heavy meson form factors

$$f_B = \sqrt{\frac{m_b}{m_B}} \left[\frac{\alpha_s(m_b)}{\alpha_s(m_c)}\right]^{-6/25} f_b$$ ← Lattice calculation find large Λ_{QCD}/m_c corrections. (Martinelli's Talk)

[Voloshin + Shifman, Sov. J. Nucl. Phys 45 292 (1987); Politzer + Wise Phys. Lett B206 681 (1988); B208 504 (1988)]

IV Λ_b Decays

Λ_b has flavor quantum numbers bud and $S_\ell = 0$. The spin of hadron is carried by heavy quark. This gives a remarkable simplification in semileptonic $\Lambda_b \to \Lambda_c e \bar{\nu}_e$.

$$\langle \Lambda_c(v',s') | \bar{c}\gamma^\nu b | \Lambda_b(v,s)\rangle = \bar{u}(v',s')[F_1\gamma^\nu + F_2 v^\nu + F_3 v'^\nu] u(v,s)$$

$$\langle \Lambda_c(v',s') | \bar{c}\gamma^\nu\gamma_5 b | \Lambda_b(v,s)\rangle = \bar{u}(v',s')[G_1\gamma^\nu\gamma_5 + G_2 v^\nu\gamma_5 + G_3 v'^\nu\gamma_5] u(v,s)$$

Leading order prediction

$$F_2 = F_3 = G_2 = G_3 = 0$$

$$F_1 = G_1 = \left[\frac{\alpha_s(m_b)}{\alpha_s(m_c)}\right]^{-6/25} \left[\frac{\alpha_s(m_c)}{\alpha_s(\mu)}\right]^{a_L(v\cdot v')} \eta(v\cdot v')$$

$$\eta(1) = 1$$

[Isgur + Wise, Nucl. Phys. B348, 276 (1991); H. Georgi, Nucl Phys. B348, 293 (1991)]

Including Λ_{QCD}/m_c corrections only introduces one new parameter

$$\bar{\Lambda} \equiv m_{\Lambda_b} - m_b = m_{\Lambda_c} - m_c$$

Prediction becomes [H. Georgi et. al., Phys. Lett. B252, 456 (1990)]

$$F_1 = G_1 \left[1 + \frac{\bar{\Lambda}}{m_c} \left(\frac{1}{1+v\cdot v'} \right) \right]$$

$$F_2 = G_2 = -G_1 \frac{\bar{\Lambda}}{m_c} \left(\frac{1}{1+v\cdot v'} \right)$$

$$F_3 = G_3 = 0$$

with normalization

$$G_1(1) = \left[\frac{\alpha_s(m_b)}{\alpha_s(m_c)} \right]^{-6/25}$$

Most of the predictive power retained!

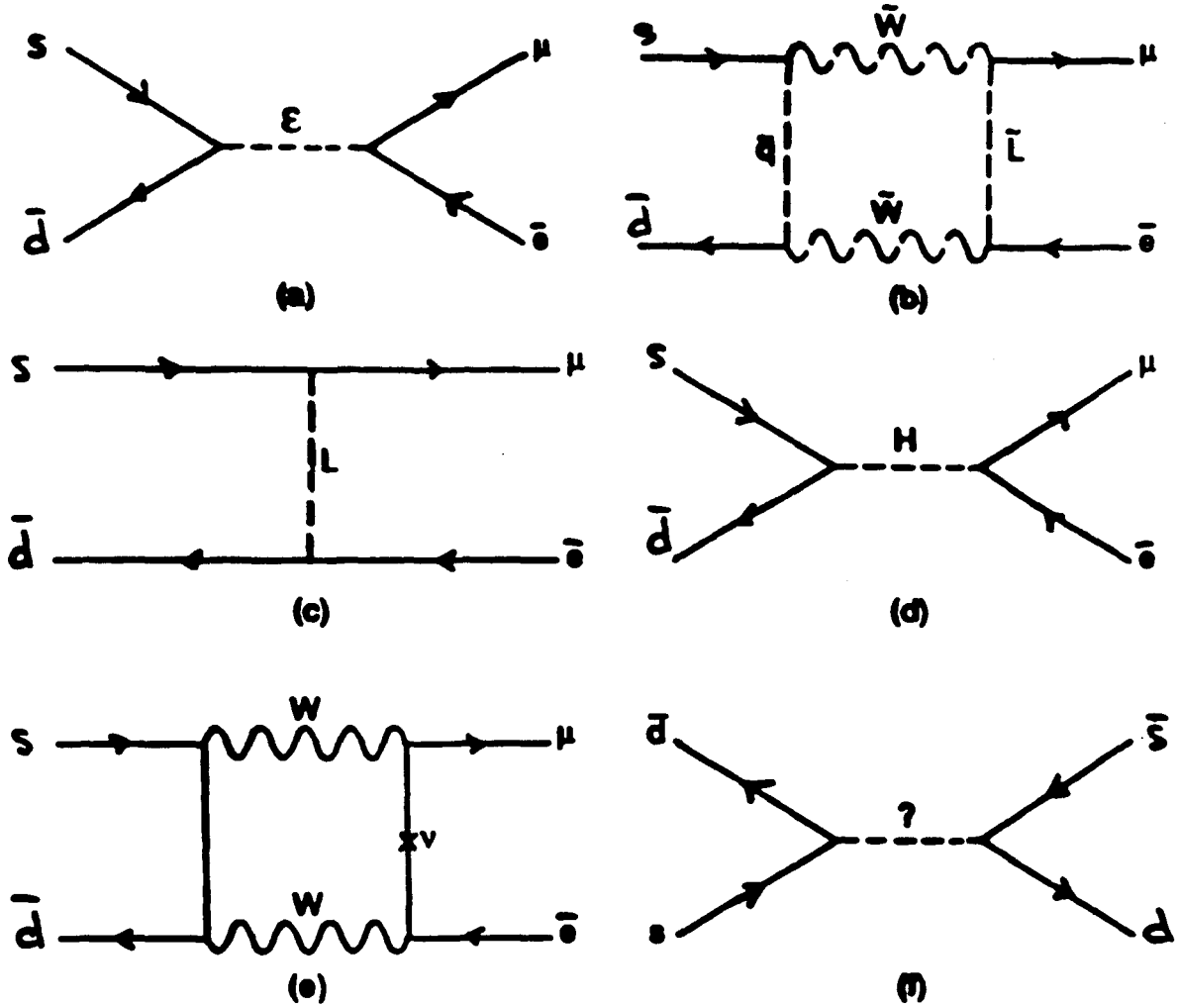
Rare decays of heavy quarks

A. Sanda
SSCL

May

Schmidt

$K_L \to \mu e$ from physics beyond the Standard Model



Feynman diagrams for various ways of violating lepton flavor number, and the one for K^0 oscillation

(a) extended technicolor

(b) SUSY

(c) leptoquarks

(d) Higgs (extra)

(e) ν mixing

(f) extended technicolor, extra Higgs ($\Delta S = 2$)

$B \to \mu e \pi$

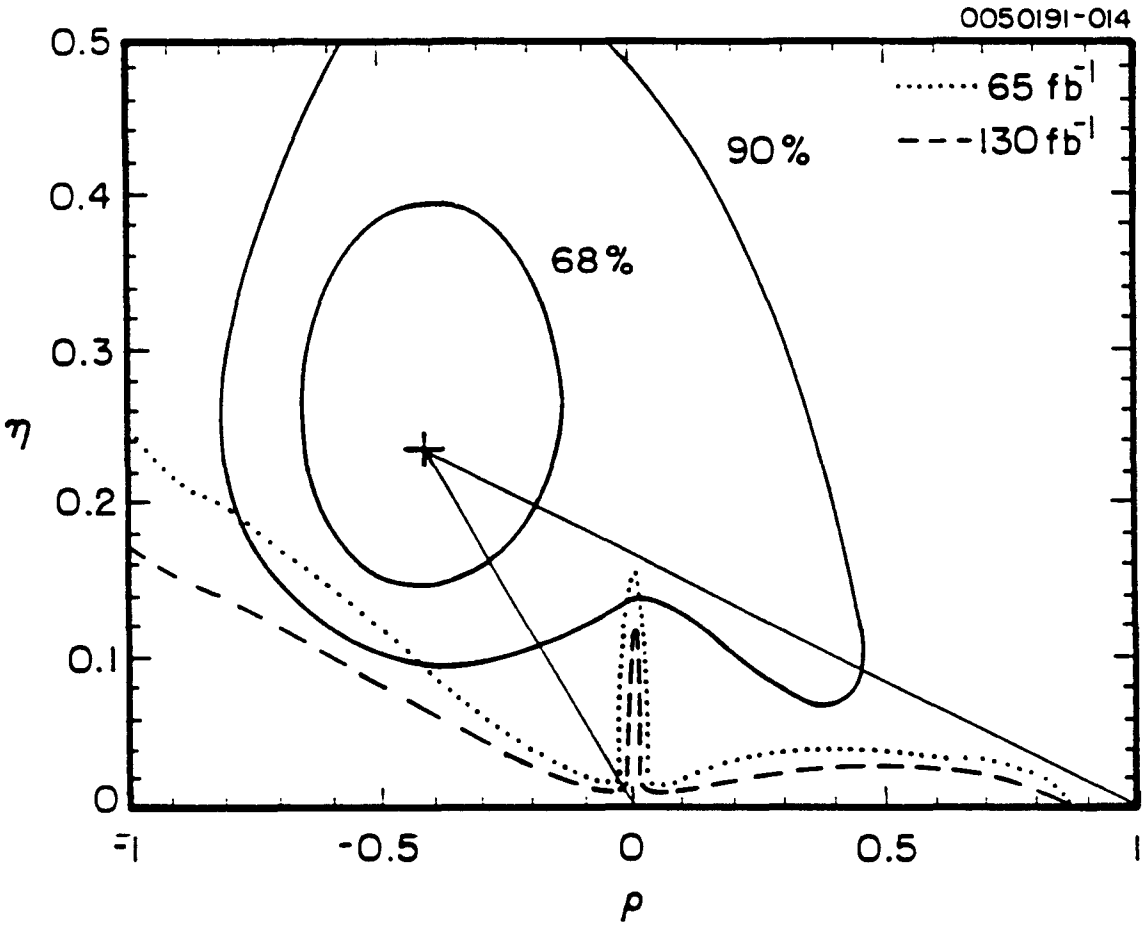
$B \to \tau \mu \pi$

$B \to \tau \mu$ ....

May be there

M. Shen

Y. Yuan


0050191-014
65 fb^{-1}
130 fb^{-1}
90%
68%
0.5
0.4
0.3
0.2
0.1
0
η
-1
-0.5
0
0.5
1
ρ

Contents

1. General review of K decays

   what can we milk out of K decays?
   what are the difficulties?

2. B rare decays

   $B \to \mu^+\mu^-$

   $B \to \gamma\gamma$

   $b \to s\gamma$

   $b \to s e^+e^-$

3. Can we measure $\gamma = \phi_3 = \phi$?

Will not discuss SM forbidden decay

rare D decay $\begin{pmatrix} c \\ \downarrow \\ s \end{pmatrix}$

rare T decay $\begin{pmatrix} t \\ \downarrow \\ b \end{pmatrix}$

Gaillard + Lee (1974)

TABLE I. The result of this investigation. The parameter ϵ is the GIM suppression factor. Depending on the relevant Feynman integrals, this parameter is either of order $(|\Delta m^2|/m_W^2 \sin^2\theta)\ln(m_W^2/m_\rho'^2)$ or order $|\Delta m^2|/(m_W^2 \sin^2\theta)$. In this table we take ϵ to be 10^{-2}.

Process	Order of magnitude of the amplitude	Order of magnitude of branching ratio	Experimental rate or bound [c]
$K_L^0 \to \mu\bar{\mu}$	$G_F\alpha^2$	10^{-8}	~~10^{-8} (Ref. 5)~~ $(6.3 \pm 1.1) \times 10^{-7}$
$K_S^0 \to \mu\bar{\mu}$	$G_F\alpha^2$	10^{-10}	$<3.1\times10^{-7}$ (Ref. 23)
$K^+ \to \pi^+\nu\bar{\nu}$	$G_F\alpha\epsilon$	10^{-10}	~~$<5.6\times10^{-7}$ (Ref. 24)~~ $< 24 \times 10^{-8}$
$K_L^0 \to \pi^0\nu\bar{\nu}$	forbidden		...
$K_S^0 \to \pi^0\nu\bar{\nu}$	$G_F\alpha\epsilon$	10^{-12}	...
$K_L \to \gamma\gamma$	$G_F\alpha$	10^{-4}	5.7 ± .27 ~~$(4.9 \pm 0.4)\times10^{-4}$~~
$K_S \to \gamma\gamma$	$G_F\alpha$	$\sim1.4\times10^{-6}$	~~$<0.7\times10^{-3}$~~ $(2.4 \pm 1.2)\times10^{-6}$
$K^+ \to \pi^+\gamma\gamma$	$G_F\alpha$	10^{-6}–10^{-7}	~~$<3.5\times10^{-6}$~~ $< 8.4 \times 10^{-6}$
$K_L^0 \to \pi^0\gamma\gamma$	$G_F\alpha\epsilon$	$<10^{-7}$	~~$<2.4\times10^{-4}$~~ $(2.1 \pm .0) \times 10^{-6}$
$K_S^0 \to \pi^0\gamma\gamma$	$G_F\alpha$	10^{-8}–10^{-9}	...
$K^+ \to \pi^+e\bar{e}$	$G_F\alpha$	10^{-6}	~~$<0.4\times10^{-6}$ (Ref. 22)~~ $(7 \pm .5) \times 10^{-7}$
$K_L^0 \to \pi^0e\bar{e}$	strongly suppressed		$< 4 \times 10^{-8}$
$K_S^0 \to \pi^0e\bar{e}$	$G_F\alpha$	10^{-8}	$< 4.5 \times 10^{-5}$

[a] The 2π contribution gives $\Gamma(K_S \to \gamma\gamma) \sim 2\times10^4\ \text{sec}^{-1}$.

[b] Not clear in the Gaard-Glashow model

Questions

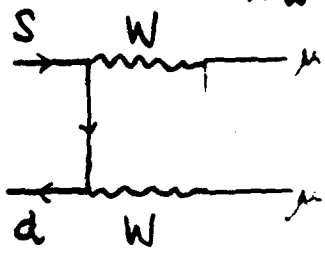
1. Can we do $g-2$ type test of the standard model?

2. Can we detect $\not{CP}$ decay $K_L \to \pi^0 e^+ e^-$?

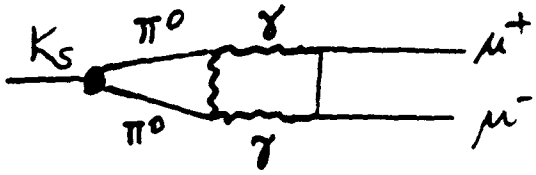
3. What do we learn from rare decays?

$K_L \to \mu\mu$

$\frac{m_c^2 - m_u^2}{m_W^2}$

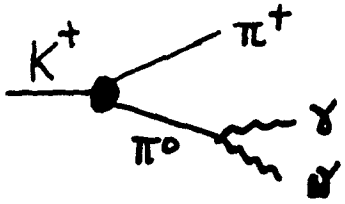


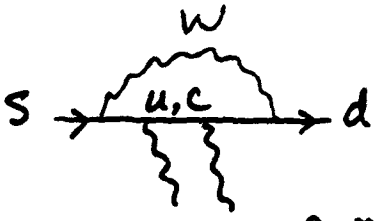
$K_S \to \mu\mu$



$K^+ \to \pi^+\gamma\gamma$

$K_S \to \pi^0\gamma\gamma$

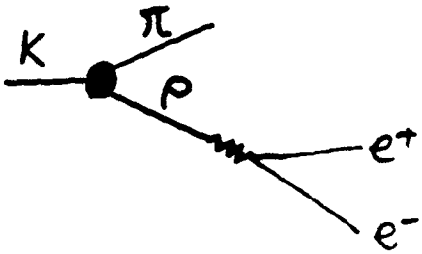


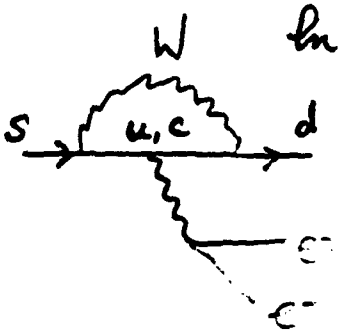


$\ln \frac{m_c^2}{m_u^2}$

$K_L \to \pi^0\gamma\gamma$

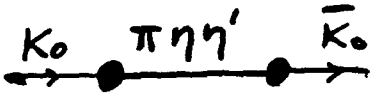
$K \to \pi e^+ e^-$

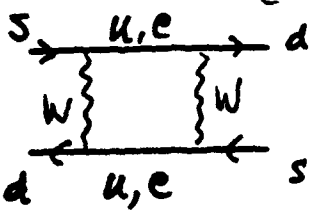




$\ln \frac{m_c^2}{m_u^2}$

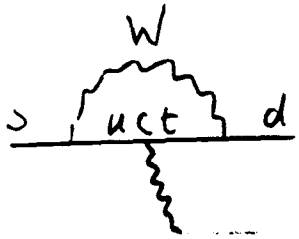
$\Delta m_{K_L K_S}$

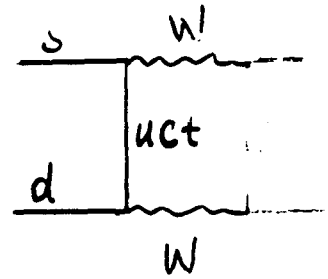




$\frac{m_c^2 - m_u^2}{m_W^2}$

$K^+ \to \pi^+ \nu \bar{\nu}$

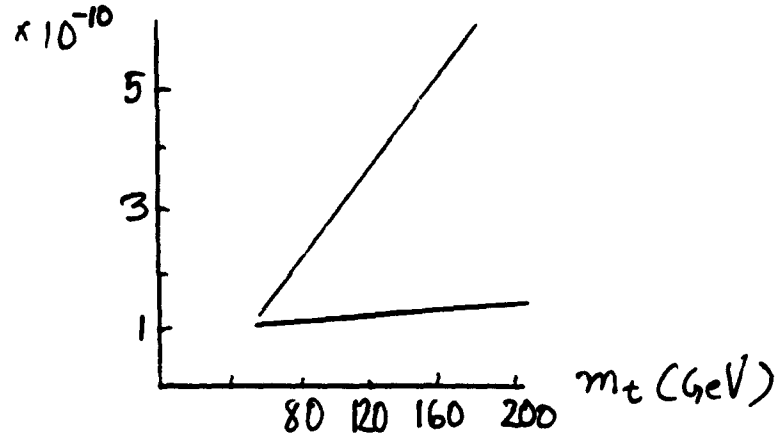


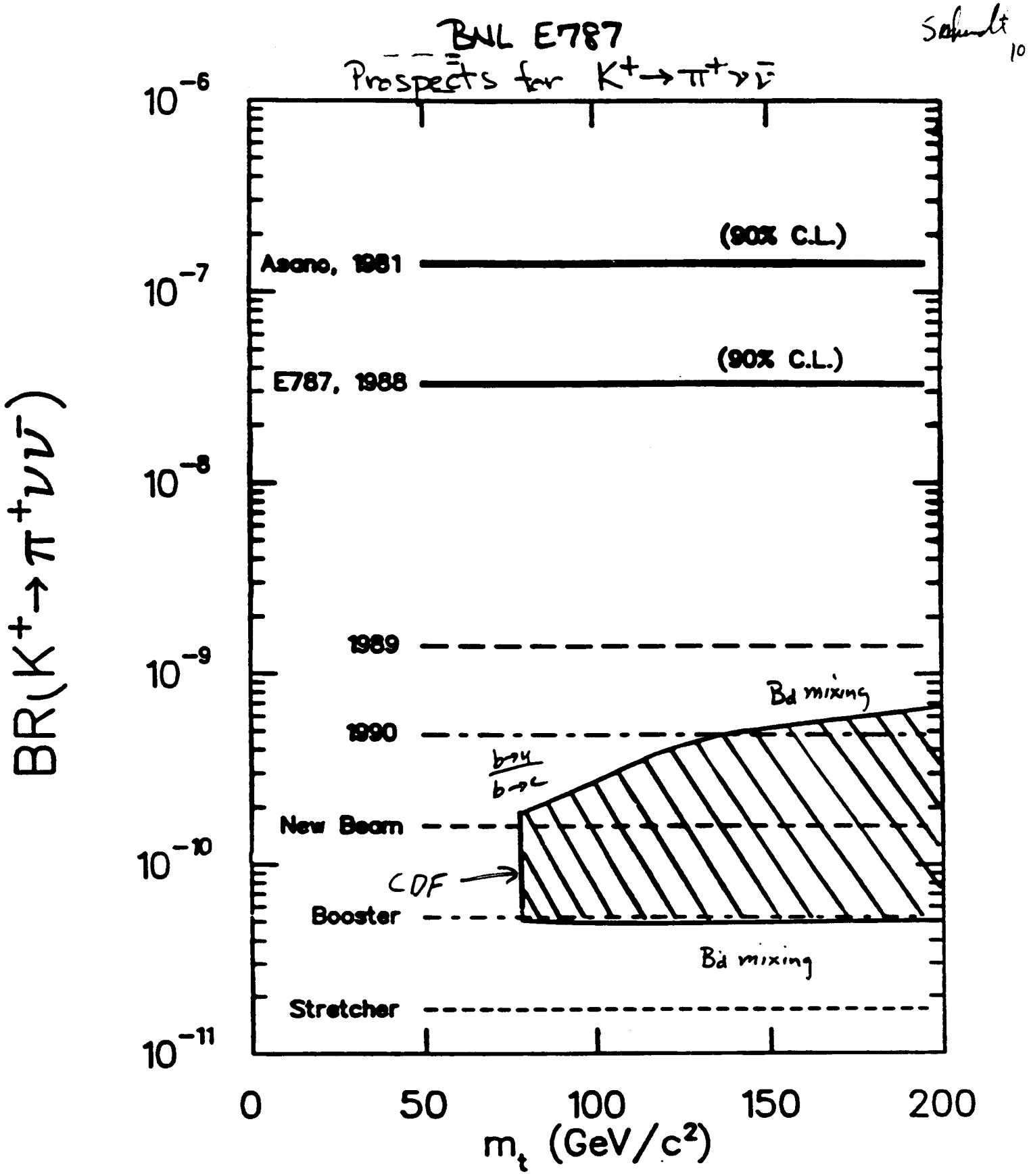


$$\mathcal{L}_{eff} = \frac{G_F}{\sqrt{2}} \sum_{\ell} A_\ell \, \bar{s} \gamma_\mu (1-\gamma_5) d \; \bar{\nu}_\ell \gamma^\mu (1-\gamma_5) \nu_\ell$$

$$B(K^- \to \pi^- \nu \bar{\nu}) = 2 \sum_{\ell} \frac{|A_\ell|^2}{|V_{us}|^2} B(K^- \to \pi^0 e^- \bar{\nu}_e)$$

$Br(K^- \to \pi^- \nu \bar{\nu})$ $\quad < 3.4 \times 10^{-8}$ exp.





* Sensitivities are per event unless otherwise indicated.

Bigi + Gabbiani:

non minimal Higgs

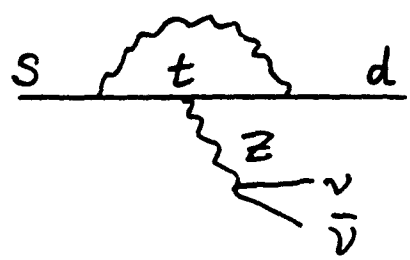
4th family extensions

SUSY minimal or non minimal version

after constraint from

$B\bar{B}$, $K\bar{K}$, $B \to K^* \gamma$

will have no influence on $K^+ \to \pi^+ \nu\bar{\nu}$.



$V_{td} V_{ts}^*$ measurement to 10%

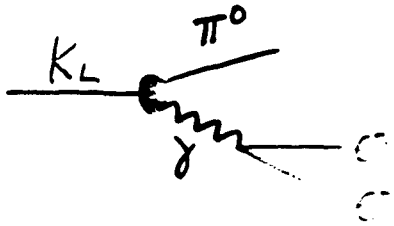
once m_t is known.

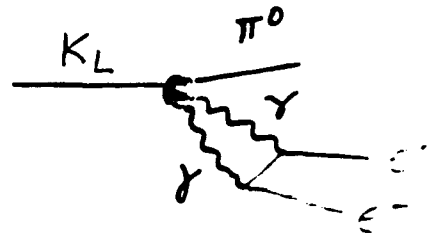
1. Can we perform g-2 type test of the standard model?

No. except $K^+ \to \pi^+ \nu \bar{\nu}$

20% test

What about $\not{CP}$ $K_L \to \pi^0 e^+ e^-$ decay?





CP violating

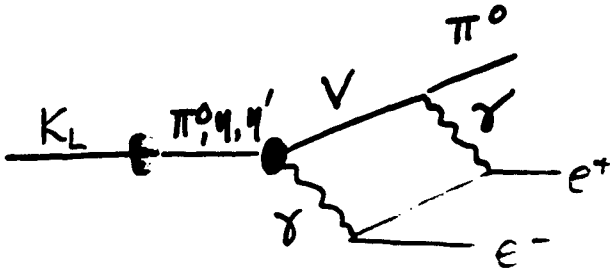
$Br(K_L \to \pi^0 e^+ e^-) \sim 10^{-11}$

CP conserving

$Br(K_L \to \pi^0 e^+ e^-)_{2\gamma} \sim 10^{-14}$

CPT $O(p^6)$

Ecker, Pich, de Rafael



$Br(K_L \to \pi^0 e^+ e^-)_V \sim 10^{-11}$

Sehgal

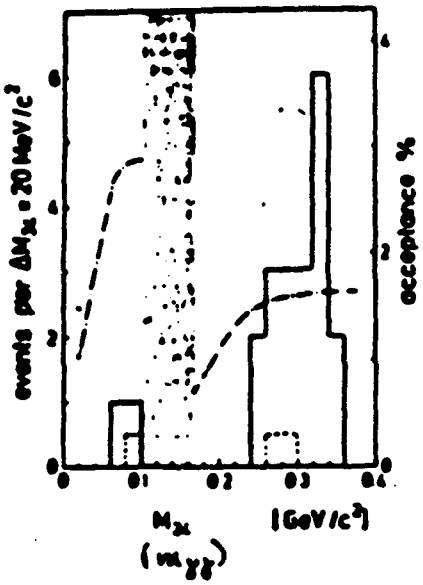
Morozumi, Iwasaki

"Chirally improved" VDM de Rafael et al

$Br(K_L \to \pi^0 e^+ e^-) \sim 5 \times 10^{-13}$

Schmidt

CERN NA31 (#2 DATA TO MALVEE)



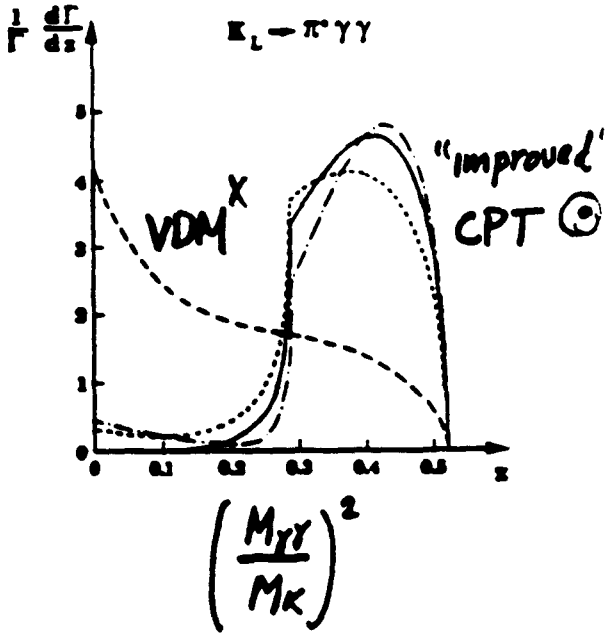
21 events observed

expected bckgnd of 1.5 ± 0.4 events

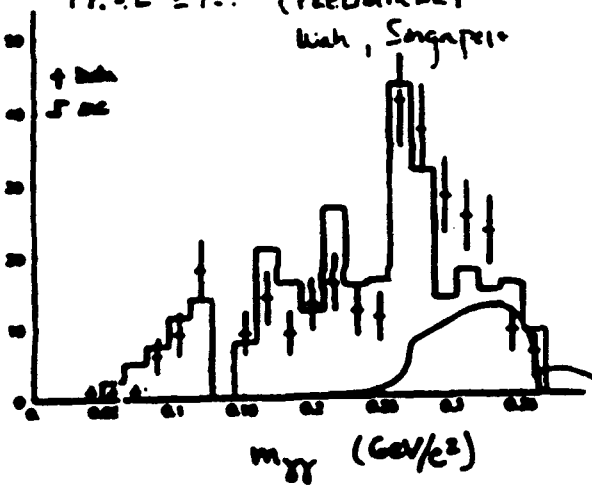
$BR(K_L \to \pi^0\gamma\gamma) = (2.1 \pm 0.6)10^{-6}$ for $m_{\gamma\gamma} > 280$ MeV/c²

VDM ⊙ $Br \sim (1.6 \sim 3) \times 10^{-6}$

CPT + VDM ✗ $Br \sim (.6 \sim .9) \times 10^{-6}$



FINAL E731: (PRELIMINARY)
Hsiao, Singapore



$m_{\gamma\gamma} > 280$ MeV/c²

111 events observed

81 events expected background

$BR(K_L \to \pi^0\gamma\gamma) = (1.7 \pm 0.7)10^{-6}$

$2.7 \cdot 10^{-6}$

Neither model [illegible]

[illegible]

[illegible]

Decreasing the error on $K_L \to \pi^0\gamma\gamma$ is very important

Ecker, Pich + De Rafael

$B(K_L \to \pi^0 \gamma\gamma) = 2.1 \pm .1 \times 10^{-6}$

a_V	$B(K_L \to \pi^0\gamma\gamma) \times 10^6$	$B(K_L \to \pi^0 e^+ e^-)\|_{abs} \times 10^{13}$
0	0.67	8×10^{-2}
0.32	(0.60	4.5
−0.32	0.89)	4.5
1.5	1.6	100
−1.5	3.0	100

$A(K_L \to \pi^0 \gamma\gamma) \sim f_1(M^2_{\gamma\gamma}) + f_2(M^2_{\gamma\gamma})\, a_V$

$A(K_L \to \pi^0 e^+ e^-) \sim f_3(M^2_{e^+e^-})\, a_V$

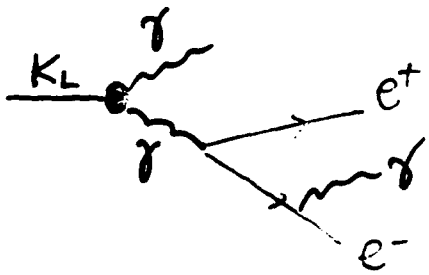
Exp $\Rightarrow$ f_1 is too small

<u>something is wrong with CPT</u>

Can we detect $\not{CP}$ decay $K_L \to \pi^0 e^+ e^-$?

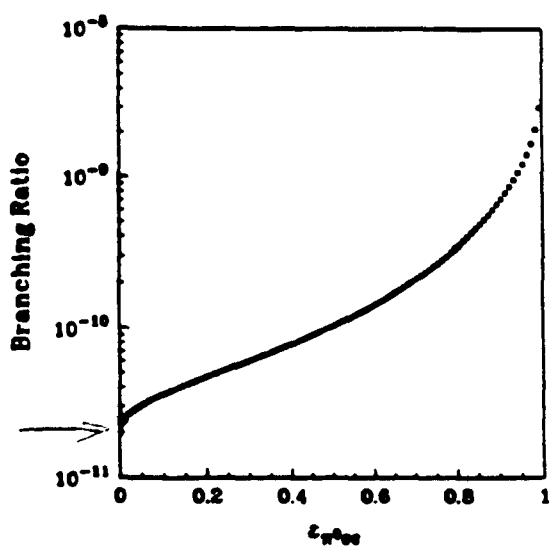
ML- No

$K_L \to e^+ e^- \gamma\gamma$ observed by BNL E-845



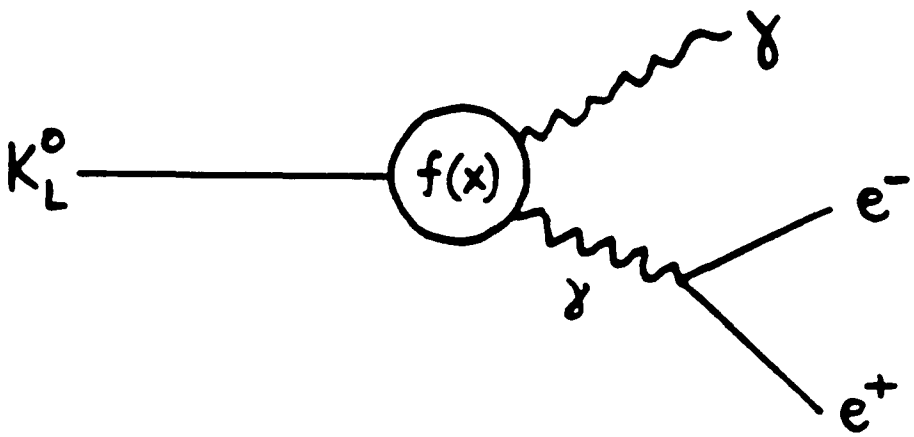
Expected $Br \sim 6.8 \times 10^{-7}$ $E_\gamma^* > 5\,MeV$

Can't do better than 2×10^{-11}



Schmitt

$K_L \to e^+e^-\gamma$ ~~Phenomenology~~ Physics



Kroll and Wada, PR 98, 1355 (1955)

$$\Gamma_{\gamma\gamma}^{-1}\frac{d\Gamma}{dx} = \frac{2\alpha}{3\pi}\frac{(1-x)^3}{x}\left(1+\frac{2m_e^2}{xm_K^2}\right)\left(1-\frac{4m_e^2}{xm_K^2}\right)^{1/2}|f(x)|^2$$

$$x = \frac{m_{ee}^2}{m_K^2} \qquad f(0) = 1$$

$f(x)$ probes structure of K_L-γ-γ^* vertex

$$f(x) = 1 \Rightarrow B(K_L \to e^+e^-\gamma) = (9.1 \pm 0.4) \times 10^{-6}$$

Only hope

$K_L \to \pi^0 \nu \bar{\nu}$

$$\mathcal{B}(K_L \to \pi^0 \nu \bar{\nu}) = 1.8 \times 10^{-6} F^2(x) A^4 \lambda^8 \rho^2 \sin^2\delta$$

$$4 \times 10^{-13} < \mathcal{B}(K_L \to \pi^0 \nu \bar{\nu}) < 2 \times 10^{-11}$$

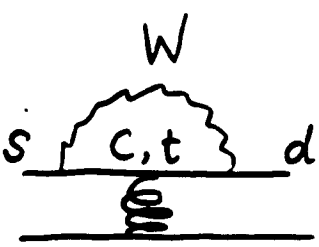
ε'/ε

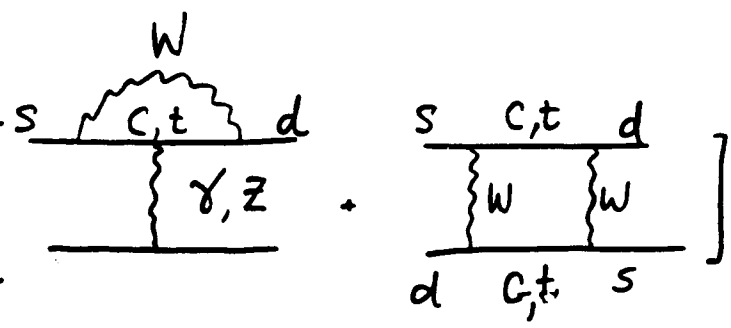
$$\varepsilon' = \frac{e^{i(\delta_2 - \delta_0 + \frac{\pi}{2})}}{\sqrt{2}} \frac{\mathrm{Re}\,A_2}{\mathrm{Re}\,A_0}\left(\frac{\mathrm{Im}\,A_0}{\mathrm{Re}\,A_0} - \frac{\mathrm{Im}\,A_2}{\mathrm{Re}\,A_2}\right)$$

$$A_0 = \langle (\pi\pi)_{I=0} | H | K \rangle$$
$$A_2 = \langle (\pi\pi)_{I=2} | H | K \rangle$$

$$\left|\frac{\mathrm{Re}\,A_0}{\mathrm{Re}\,A_2}\right| = \frac{1}{\omega} = 20$$

$$\varepsilon' = -\frac{\omega}{\sqrt{2}} \frac{\mathrm{Im}\,A_0}{\mathrm{Re}\,A_0}\left(1 - \frac{1}{\omega}\frac{\mathrm{Im}\,A_2}{\mathrm{Im}\,A_0}\right)$$

$\mathrm{Im}\,[$  $] = \mathrm{Im}\,A_0$

$\mathrm{Im}\,[$  $] \sim \mathrm{Im}\,A_2$

No quantitative prediction can be made.

What we need to know is if $\epsilon' \neq 0$.

extracting parameters out of ϵ' may be impossible.

CERN - FERMILAB - ϕ FACTORY agreement

B factory time scale

Summary

1. Rare K decays are in qualitative agreement with the SM predictions

2. Prospect for studying $\not{CP}$ in $K_L \to \pi^0 e^+ e^-$ very bad. except $K_L \to \pi^0 \nu \bar{\nu}$

3. Quantitative test of the SM not possible today. except $K^+ \to \pi^+ \nu \bar{\nu}$

   a. Lattice
   b. Better chiral sym + vectordominance
      Chiralweak dynamics Lim, Morozumi Rebelo, AIS

What can we learn from rare K decays

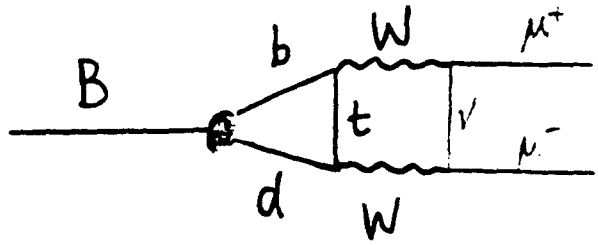
Laboratory for strong-weak interaction dynamics. As illustrated by $K_L \to \pi^0 \gamma \gamma$.

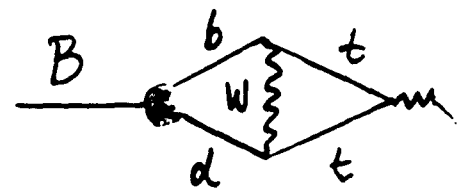
References for B decays

Campbell + O'Donnell	PR D25	1989	(1982)
Hewett Nandi + Rizzo	PR D39	250	(1989)
Bertolini, F. Borzumati + A Masiero	PL B192	437	(1987)
Grigjanis, O'Donnell + Sutherland	PL B223	239	(1989)
Lim, Morozumi + AIS	PL B218	343	(1989)
Albajar et.al	CERN-PPE/91-54		

$B \to \mu^+\mu^-$

1984 Shaw-Mann $\quad Br(B\to\mu\mu) \sim 10^{-8}$





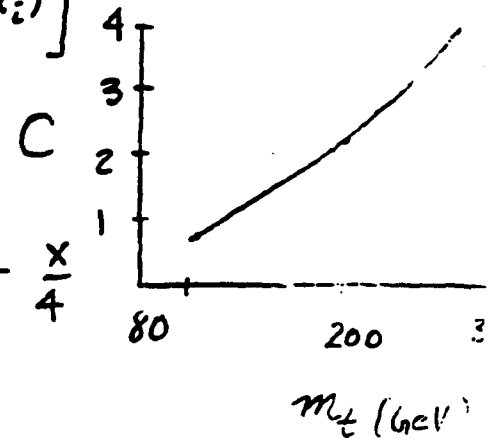
Inami & Lim

$$\Gamma(B_q \to \mu\mu) = \left(\frac{G_F \alpha}{4\pi \sin^2\theta_W}\right)^2 \frac{f_B^2}{8\pi} m_B m_\mu^2 \left(1 - \frac{4 m_\mu^2}{m_B^2}\right)$$

$$\left[\sum_i V_{iq} V_{ib}^* C(x_i)\right]^2$$

$$x_i = \left(\frac{m_i}{m_W}\right)^2$$

$$C(x) = -\frac{3}{4}\frac{x}{x-1}\left(\frac{x}{x-1}\ln x - 1\right) - \frac{x}{4}$$



for $m_t = 200$ GeV $\quad f_B = 150$ MeV

$Br(B_d \to \mu\mu) = 4.3 \times 10^{-11}$

$Br(B_s \to \mu\mu) = 8.6 \times 10^{-10}$

$Br(B \to \mu\mu) < 8.3 \times 10^{-6}$ UA(1)

Multi Higgs Models can generate larger BR

Hewett, Nandi Rizzo

$B \to \gamma\gamma$

$$\Gamma(B_q^0 \to \gamma\gamma) = \left(\frac{G_F \alpha}{4\pi}\right)^2 \frac{f_B^2}{4\pi} M_B^3 \left| \sum_i V_{iq} V_{ib}^* I(x_i) \right|$$

$$I(x) = \frac{4(Q_q+1)^2}{(1-x)} f\left(x \frac{M_W^2}{M_B^2}\right)$$

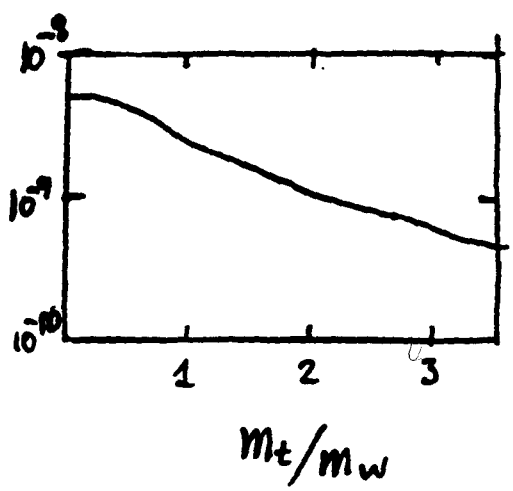
$$+ Q_d^2 \left(\frac{1-5x-2x^2}{(1-x)^3} - \frac{6x^2 \ln x}{(1-x)^4} \right)$$

$$+ Q_d \left(\frac{3-9x}{(1-x)^2} - \frac{6x^2 \ln x}{(1-x)^3} \right)$$

$$f(\beta) = 2 - 2\pi^2\beta \quad \text{if } 4\beta \le 1$$

$$f(\beta) = 2 - 8\beta \left(\sin^{-1}(1/\sqrt{2\beta})\right)^2 \quad \text{if } 4\beta \ge 1$$

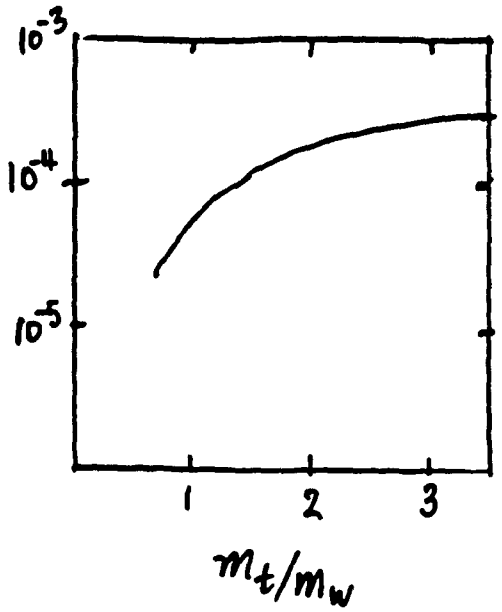
$Br(B_d \to \gamma\gamma)$



$b \to s\gamma$

$$\Gamma = \frac{\alpha G_F^2}{32\pi^4} M_b^5 \left(1-\frac{M_s}{M_b}\right)^3 \left(1+\frac{M_s}{M_b}\right) \left| \sum V_{is} V_{ib}^* F^i \right|^2$$

$Br(b \to s\gamma)$



$B^0 \to K^* \gamma \quad < 2.8 \times 10^{-4}$

$B^+ \to K^{*+} \gamma \quad < 5.5 \times 10^{-4}$

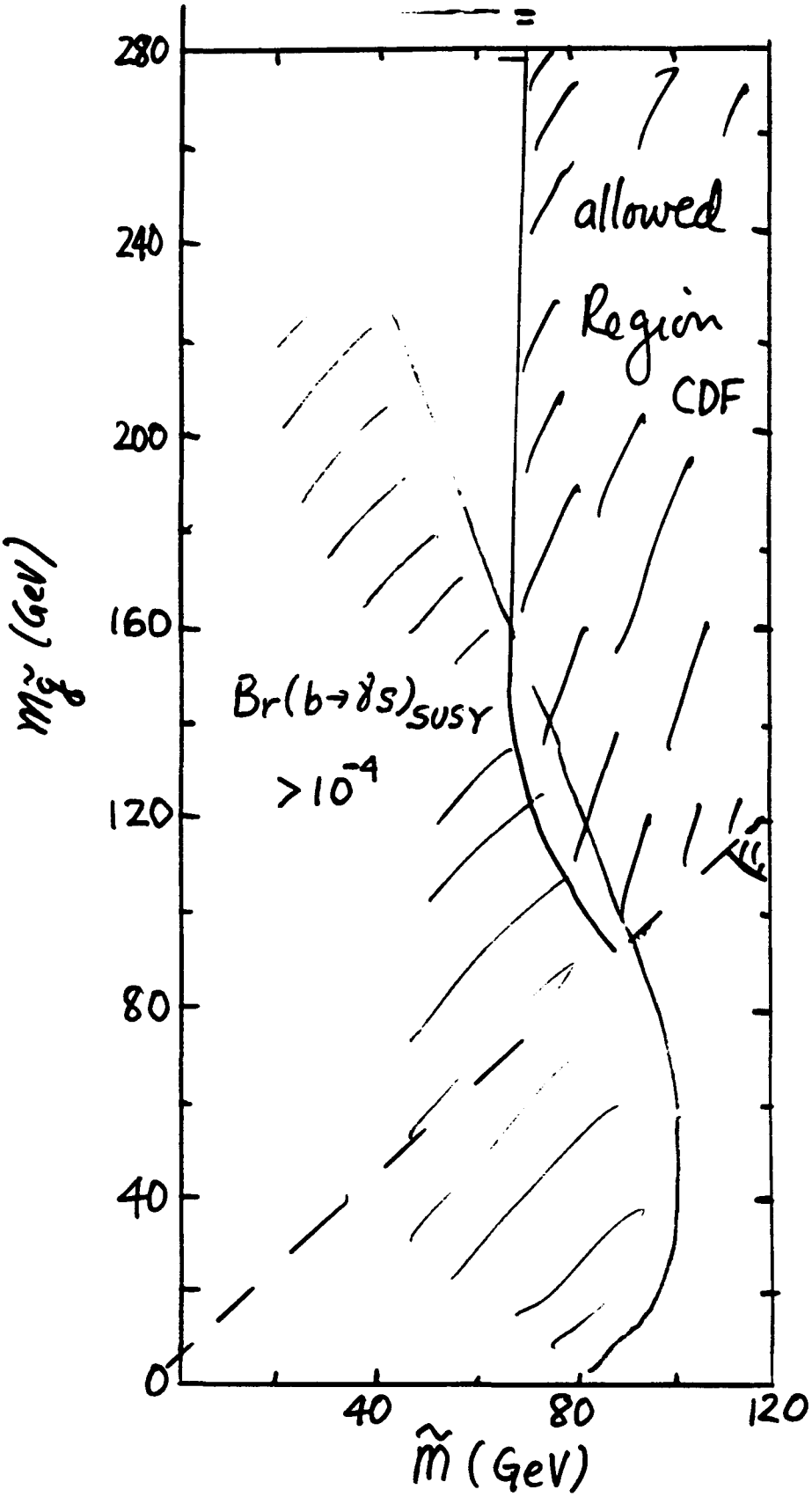
$\langle K^* | \bar{b} \sigma_{\mu\nu} \gamma^\nu s | B \rangle$?

Γ at least factor of 4 error ?

$$\Gamma(B \to K^* \gamma) = (4.5 \sim 7) \times 10^{-2} \, \Gamma(B \to \gamma + X)$$

$B(B^0 \to \gamma + X) < 6.2 \times 10^{-3}$

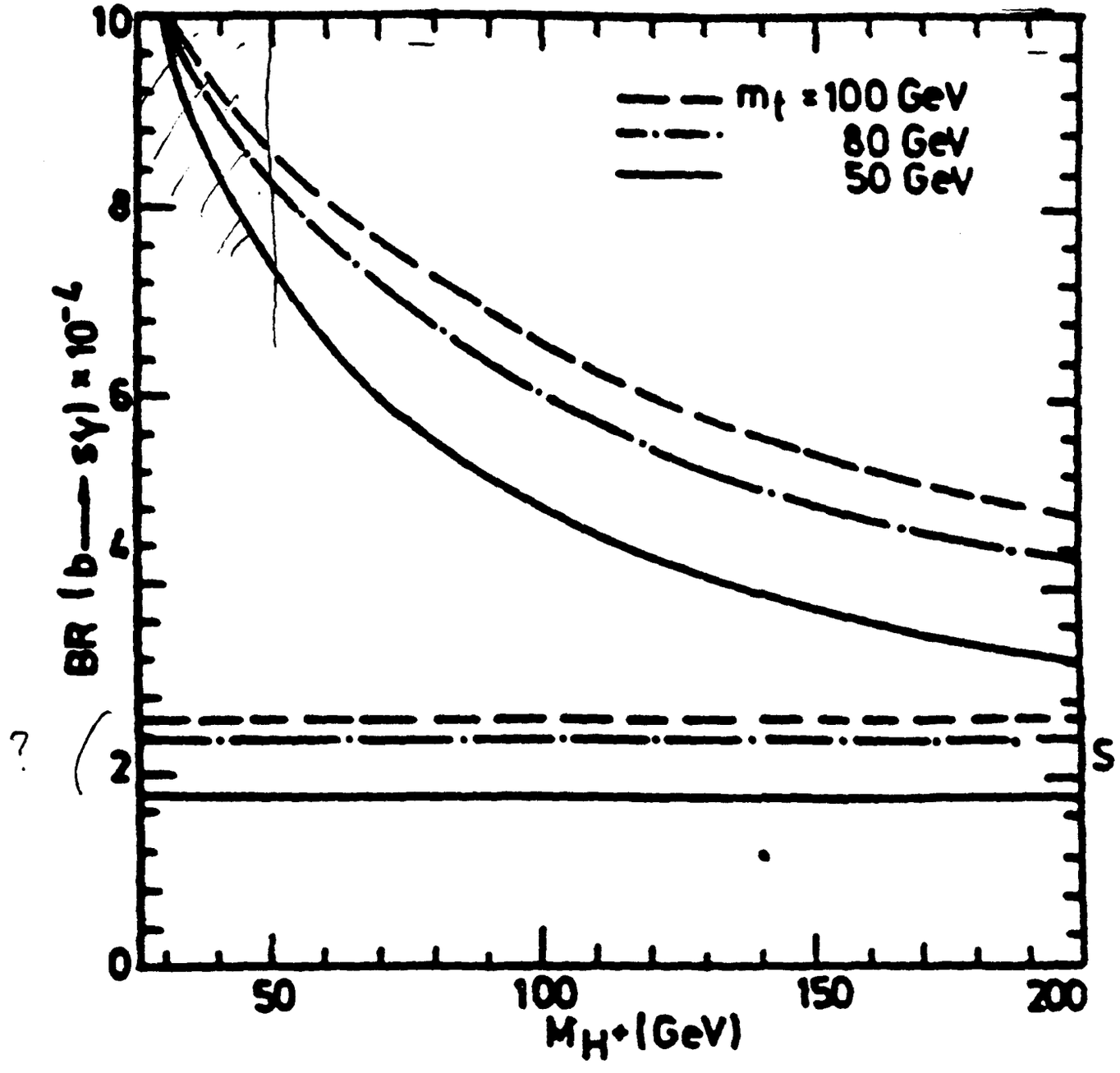
$B(B^+ \to \gamma + X) < 1.2 \times 10^{-2}$



$b \to s\gamma$ decay is unlikely to show SUSY effects.

Bertolini Borzumati & Masiero

LEP?


m_t = 100 GeV
80 GeV
50 GeV
BR (b → sγ) × 10^{-4}
10
8
6
4
2
0
50
100
150
200
M_{H^+} (GeV)
?
S

Geng + Ng

$b \to s\, \mu^+ \mu^-$

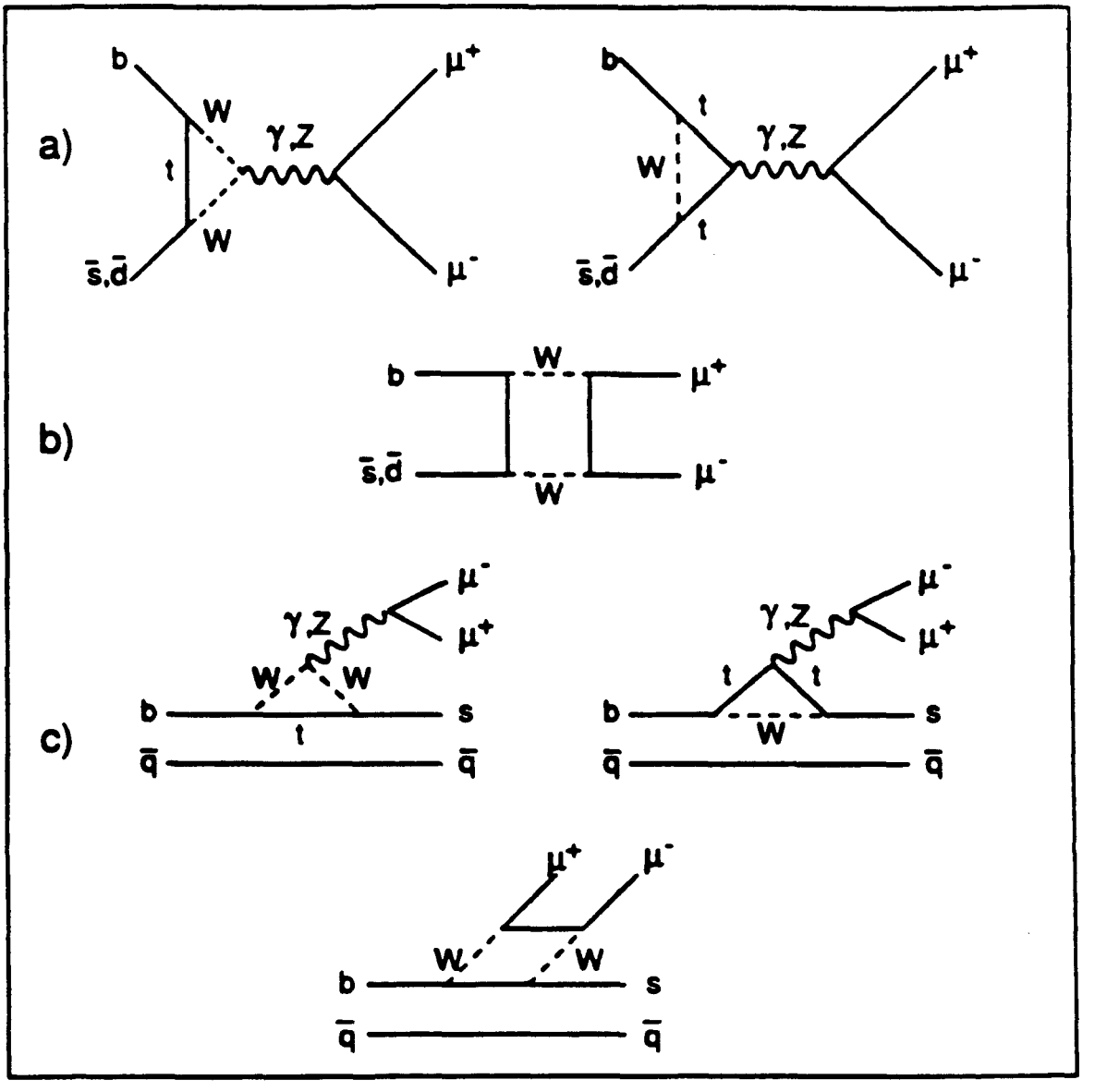
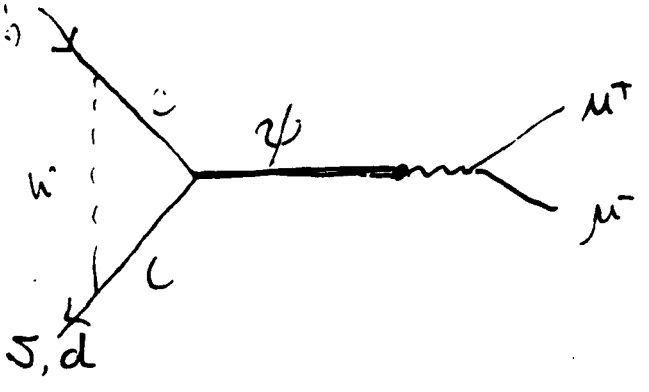
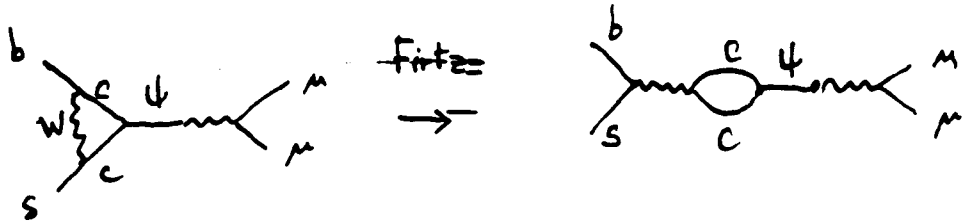
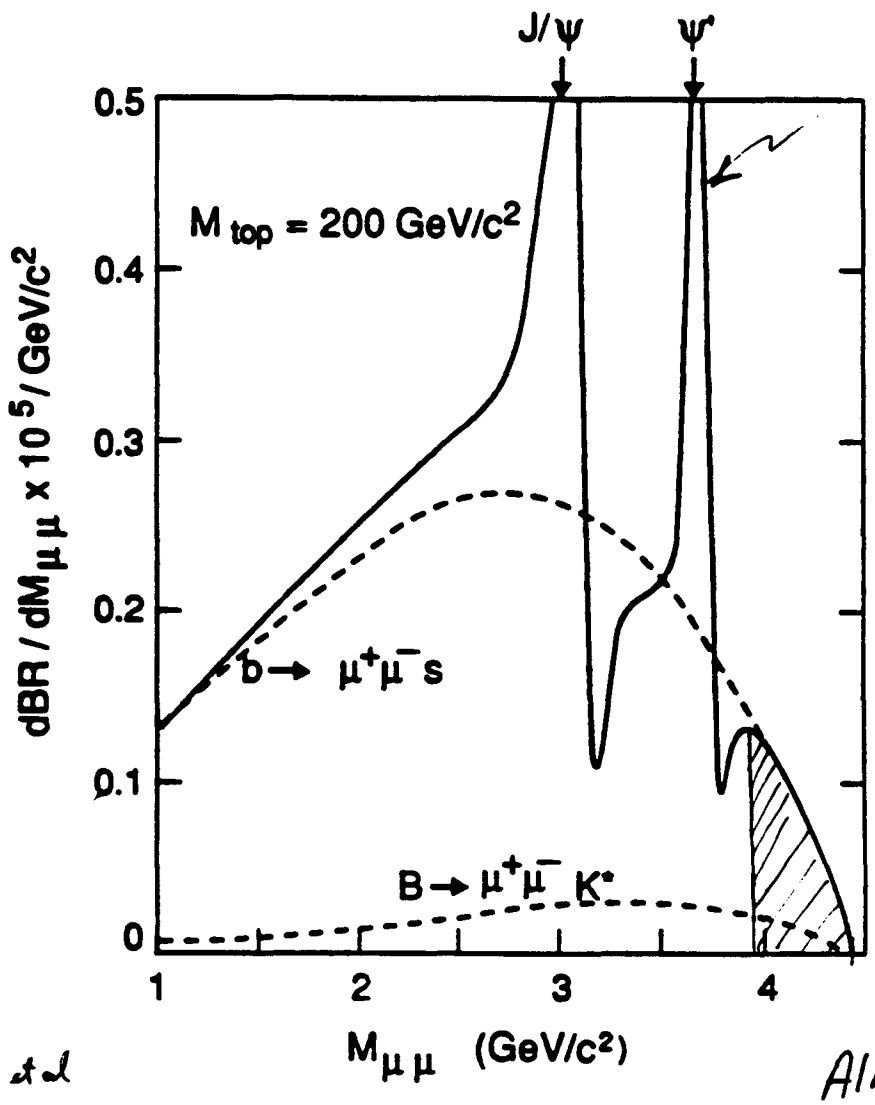


FIG. 1





Morozumi
Lim
AIS



μμ dist Grinstein et al

total BR Grigjanis et al

FIG. 2

Albajar et al

$(3.4 < M_{\mu\mu} < 4.4)$ GeV

$B(B \to \mu^+\mu^- X) < 5 \times 10^{-5}$ UA(1)

B_d, $B^\pm$, B_s not separated

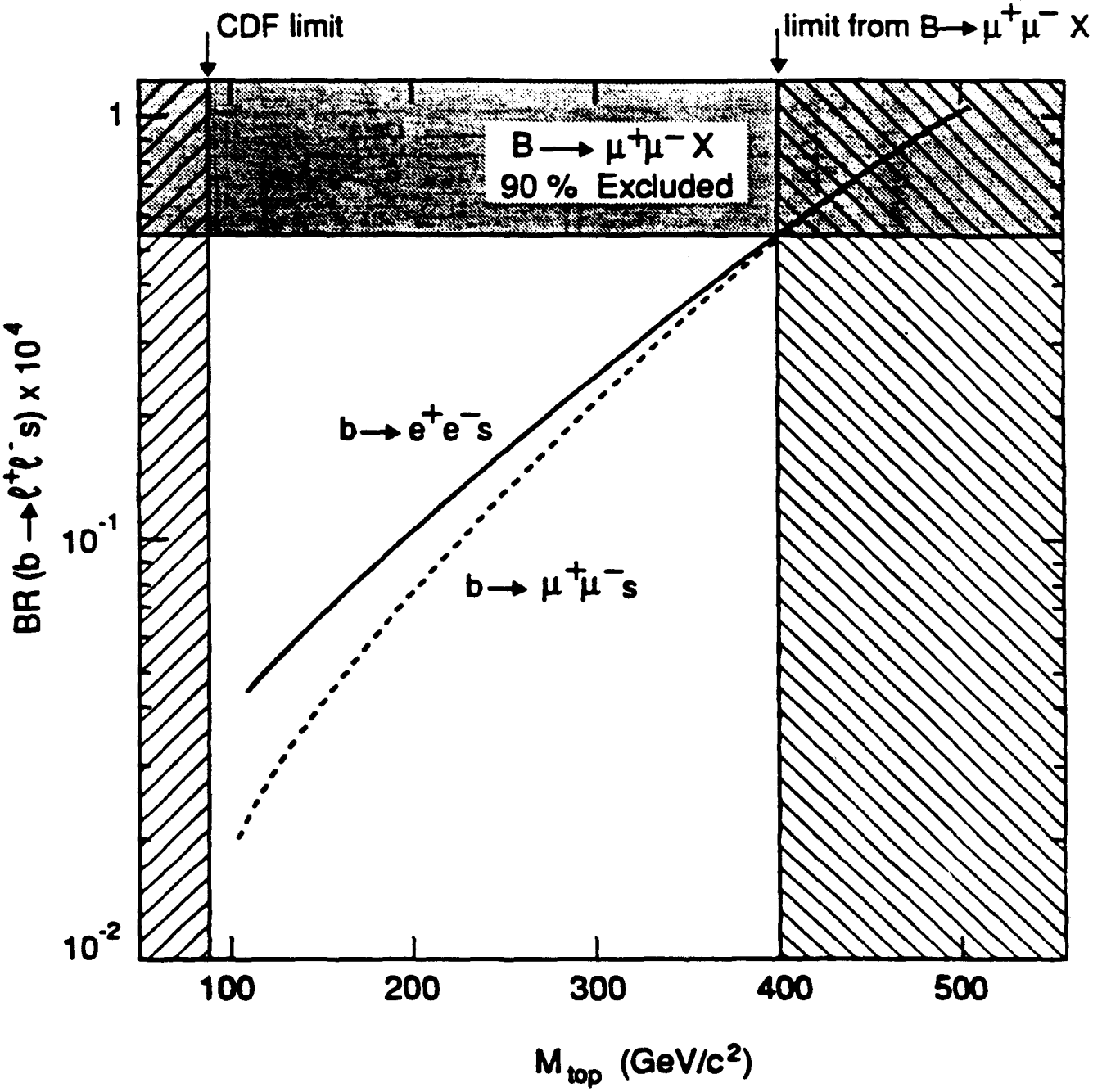
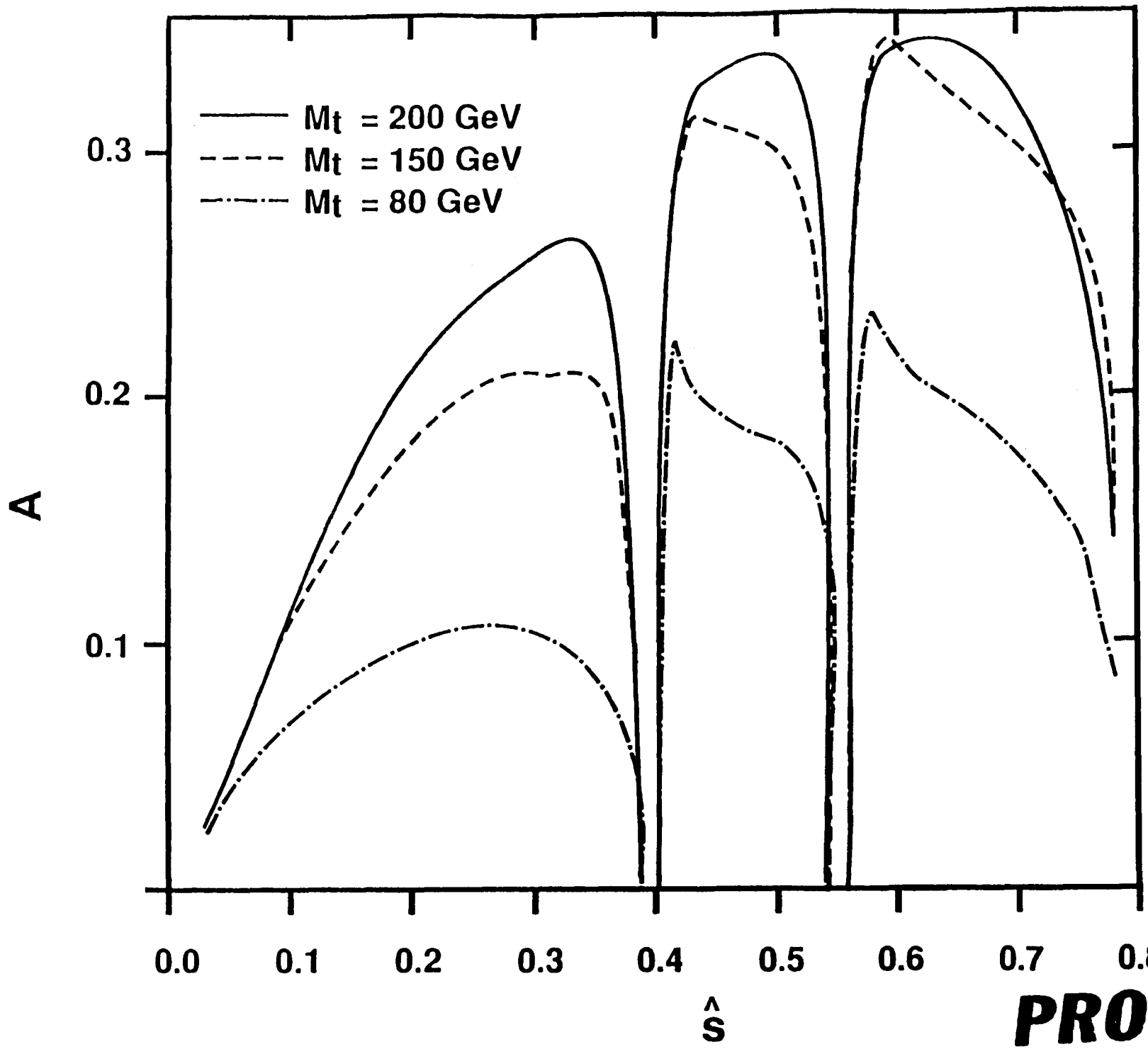

CDF limit
limit from B→μ+μ− X
B→μ+μ−X
90 % Excluded
b→e+e−s
b→μ+μ−s
BR (b→ℓ+ℓ− s) x 10^4
1
10^-1
10^-2
100
200
300
400
500
M top (GeV/c2)

FIG. 6

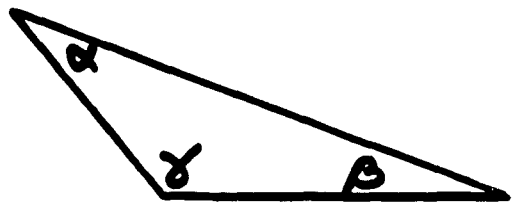


PROOF

$$\bar{A}(\bar{D})_n = |A(D)_n| e^{i\delta_{D_n}}$$

$$\bar{A}(D)_n = |A(\bar{D})_n| e^{i\delta_{\bar{D}_n}} e^{-i\gamma}$$

$$\bar{A}(D_1)_n = \frac{1}{\sqrt{2}} \left(\bar{A}(\bar{D})_n + \bar{A}(D)_n \right)$$

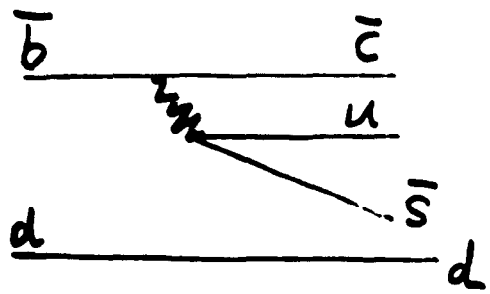


$\sin 2\alpha$: $\pi\pi$

$\sin 2\beta$: ψK_S

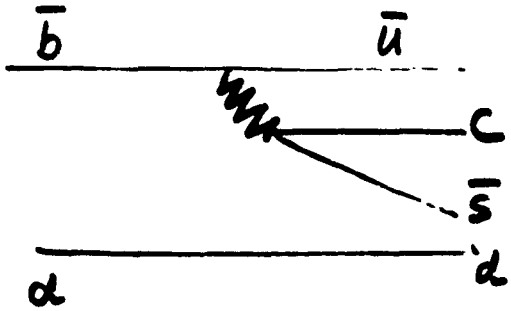
How can we measure γ ?

(a) $B \to D^0 + K + X_n$



$A(D)_n = |A(D)_n| e^{i\delta_{D_n}}$

(b)



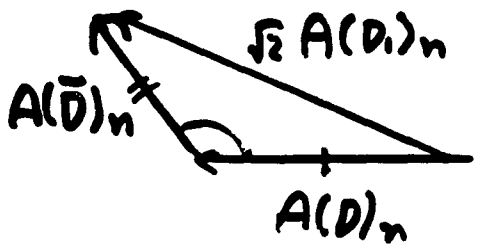
$A(\bar{D}_n) = |A(\bar{D})_n| e^{i\delta_{\bar{D}_n}} e^{i\gamma}$

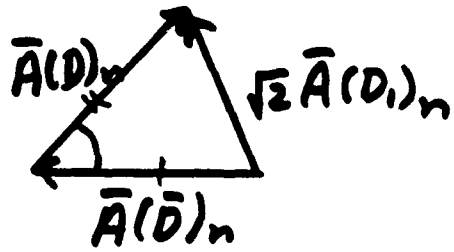
$B \to \bar{D}^0 + K + X_n$

(c) $B \to D_1 + K + X_n$

$D_1 = \frac{1}{\sqrt{2}}(D^0 + \bar{D}^0)$

$A(D_1)_n = \frac{1}{\sqrt{2}}\left(A(D)_n + A(\bar{D})_n\right)$





if $\gamma \neq 0$

$$|\delta_{\bar{D}_n} - \delta_{D_n} + \gamma| \qquad |\delta_{\bar{D}_n} - \delta_{D_n} - \gamma|$$

If $|A(\bar{D})_n|$, $|A(D)_n|$, $|A(D_1)_n|$, and $|\bar{A}(D_1)_n|$ are known, γ can be measured.

Analysis can be done for any X_n

$\Gamma(B \to D^0 + K + X_n)$ $\quad$ K can be K^+ or K^0

$\Gamma(B \to \bar{D}^0 + K + X_n)$

$\Gamma(B \to D_1 + K + X_n)$

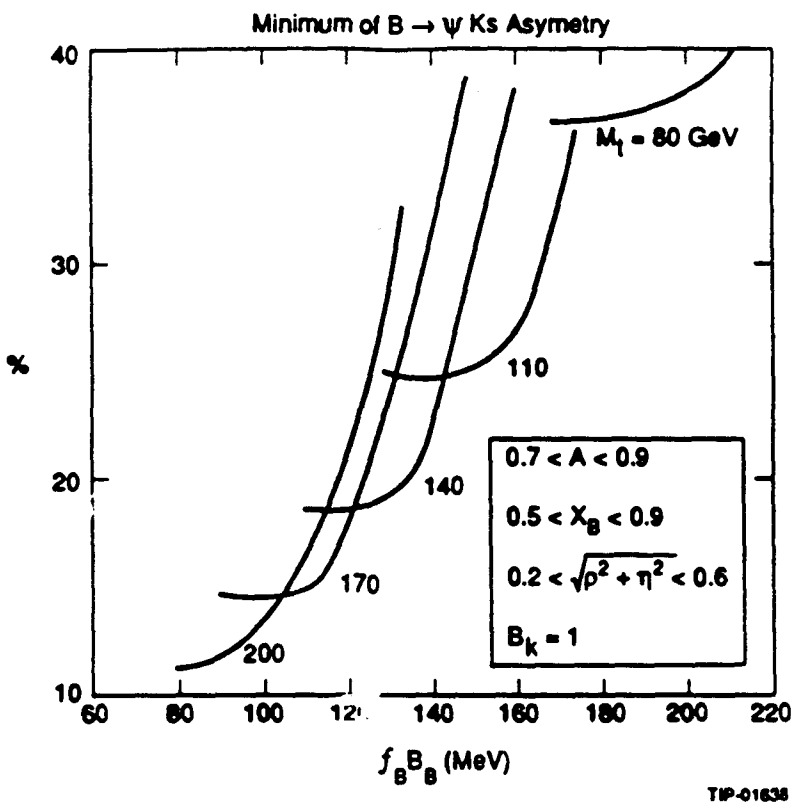
$\Gamma(\bar{B} \to D_1 + K + X_n)$

D_1 can be identified by $K_S + X$

$\pi\pi$

KK etc

Why are we interested in f_B?



Conclusion

1. Physics is clean in B decays

   You can do g-2 type test

2. α, β, γ of unit. Δ can be measured

   theory: Penguin pollution can be cleaned up.

3. Can α, β, γ be measured before ϵ is seen?

P. J. Oddone
5/22/91
SSC Spring mtg.

e^+e^- B-factories

CESR-B
PEP-B
KEK-B

Outline

1. Introduction: Physics requirements
2. Basic parameters
3. The challenges:
   a. Beam-beam effects
   b. Lattice—IR design
   c. RF
   d. Stability/Feedback
   e. Vacuum
   f. Injection

   and how the different proposals address them.

1. Physics Requirements

A. General

- Measure asymmetry in multiple channels: more than one angle in the CKM unitarity triangle
- Measure CP asymmetry over the range allowed by the Standard Model

$$\delta A \sim \frac{1}{\sqrt{N}}$$

$$A = d(x) \sin 2\phi$$

$$N_{needed} = \left[\frac{n_\sigma}{d(x) \sin 2\phi} \right]^2$$

with $\sin 2\phi = \frac{1}{4}$; $d(x) = \frac{1}{2}$
need ~ 1000 events to measure $\sin 2\phi$ to 4 standard dev. ($n_\sigma = 4$)

For typical

$$BR \sim 10^{-4}$$

$$\varepsilon_{tag} \cdot \varepsilon_{recons} \sim 10\%$$

$$\Rightarrow \geq 10^{8} \; B's$$

How to do it?:

large production $\sigma_{B\bar{B}}$
large luminosity $\mathcal{L}$

ENERGY	σ (nb)	$\mathcal{L}_{peak}$ ($cm^{-2} sec^{-1}$) for 3SN years	
$\Upsilon(4S)$	1 nb	3×10^{33}	less difficult
$B\bar{B}\gamma$	0.2 nb	1.5×10^{34}	difficult
Z^0	7 nb	5×10^{32}	difficult

at $\Upsilon(4S)$ [CP=-1] time integrated asymmetry vanishes $\Rightarrow$ asymmetric collisions in order to see time evolution

<u>Advantages:</u>

- lowers $\mathcal{L}$ requirements
- signal/background favorable at $\Upsilon(4S)$
- beam energy constraint: x10 mass resol.
- vertex constraint: ~ x4 signal/background
- time evolution of decays.

All efforts that are ready to go make this choice

1. Novosibirsk
2. SLAC/LBL/LLNL ....
3. CORNELL
4. KEK

once the choice is made .....

B. Specific Requirements

For the asymmetric $\Upsilon(4S)$ machine:

- $\mathcal{L} \gtrsim 3\times10^{33}\ cm^{-2}\ sec^{-1}$
- $E_{HIGH}/E_{LOW} \geq 8/3.5$

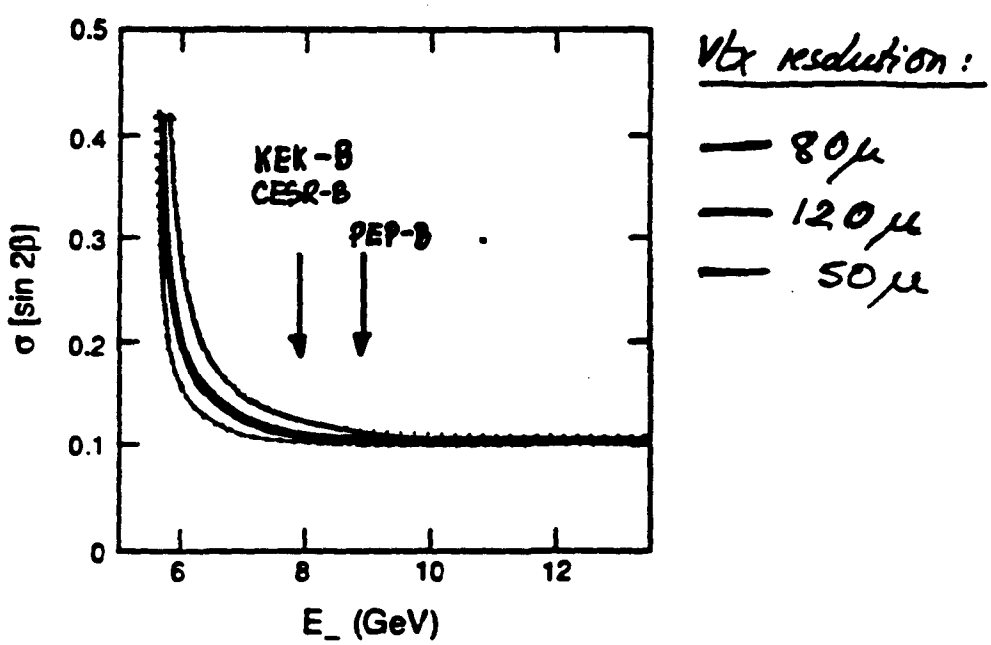


Fig. 2-7. The resolution for measuring sin 2β as a function of the energy of the electron (high-energy) beam. The upper (lower) dotted curve assumes a vertex resolution of 120 μm (50 μm).

o small radius IR beampipe $R \leq 3cm$

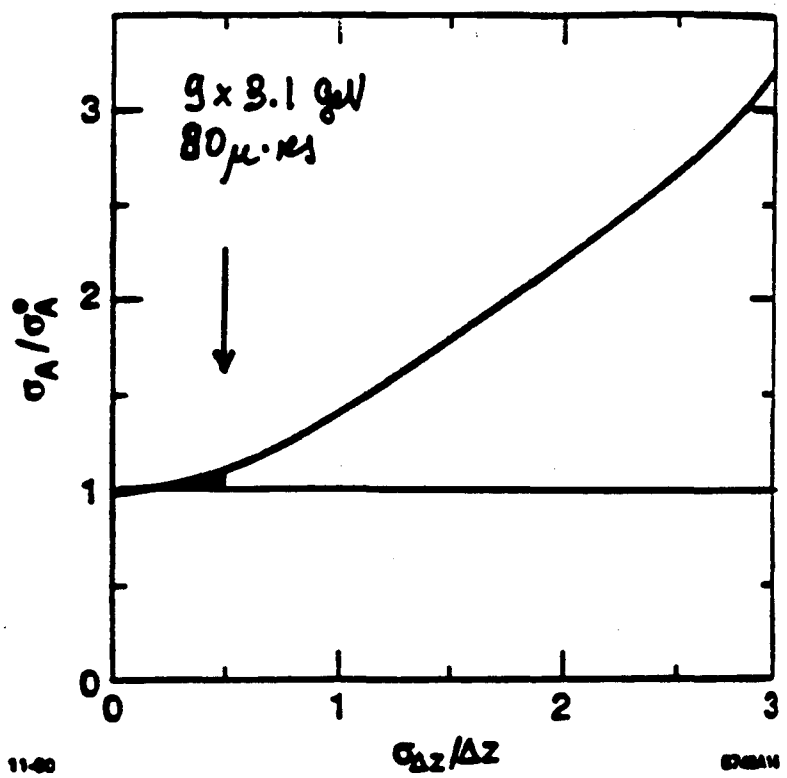


Figure 1. *Dilution of the measurement of the CP asymmetry as a function of $\sigma_{\Delta z}$, the resolution in the decay distance of the two B^0 mesons.*

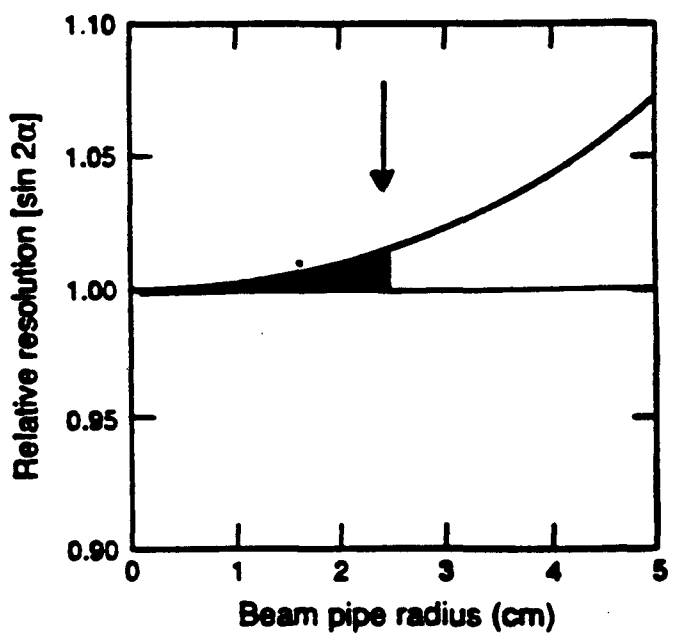


Fig. 2-10. The sensitivity of the measurement error for sin 2α, as a function of the radius of the beam pipe. The resolution worsens slowly as the beam pipe radius (that is, the radius of the first vertex detector layer) increases.

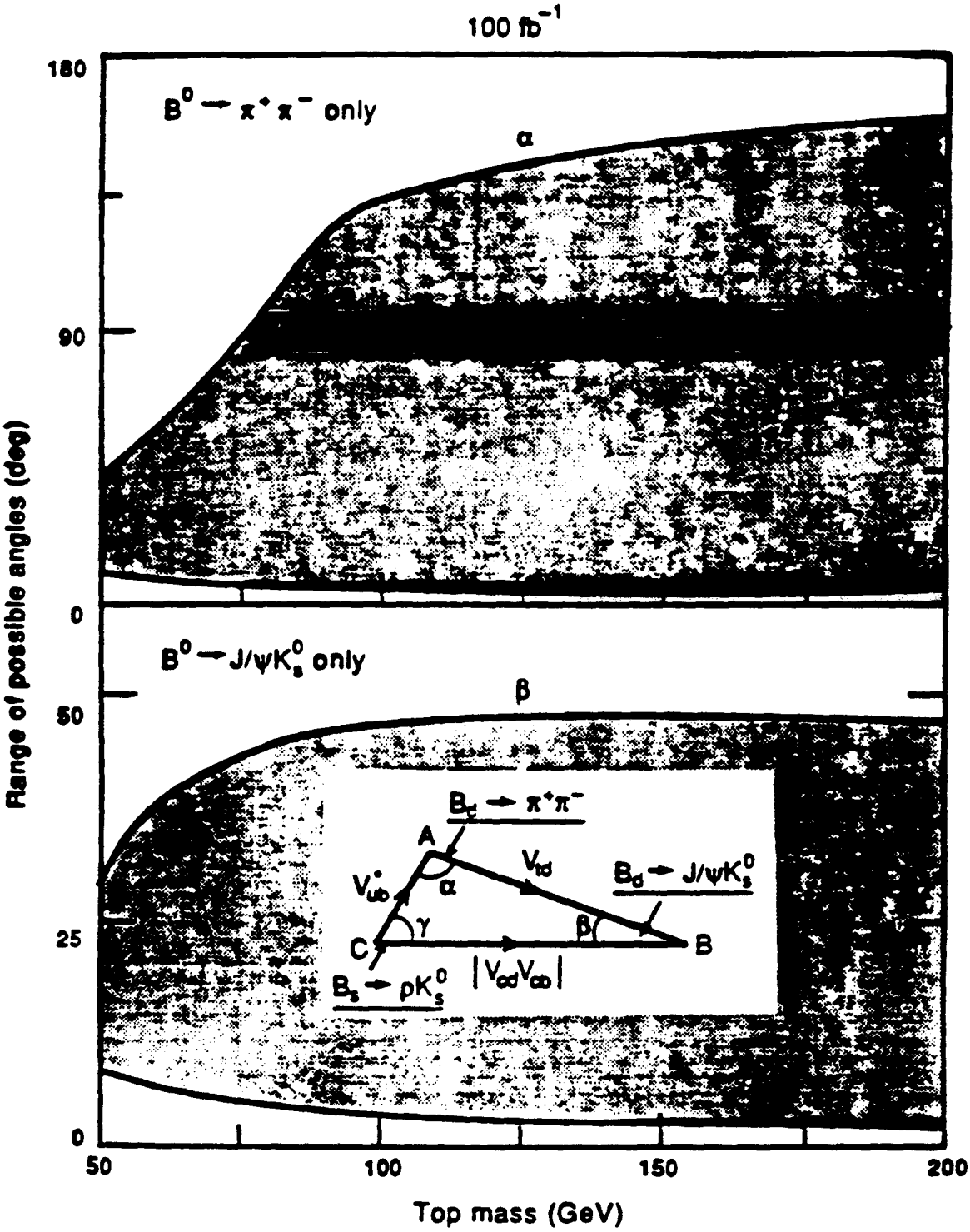
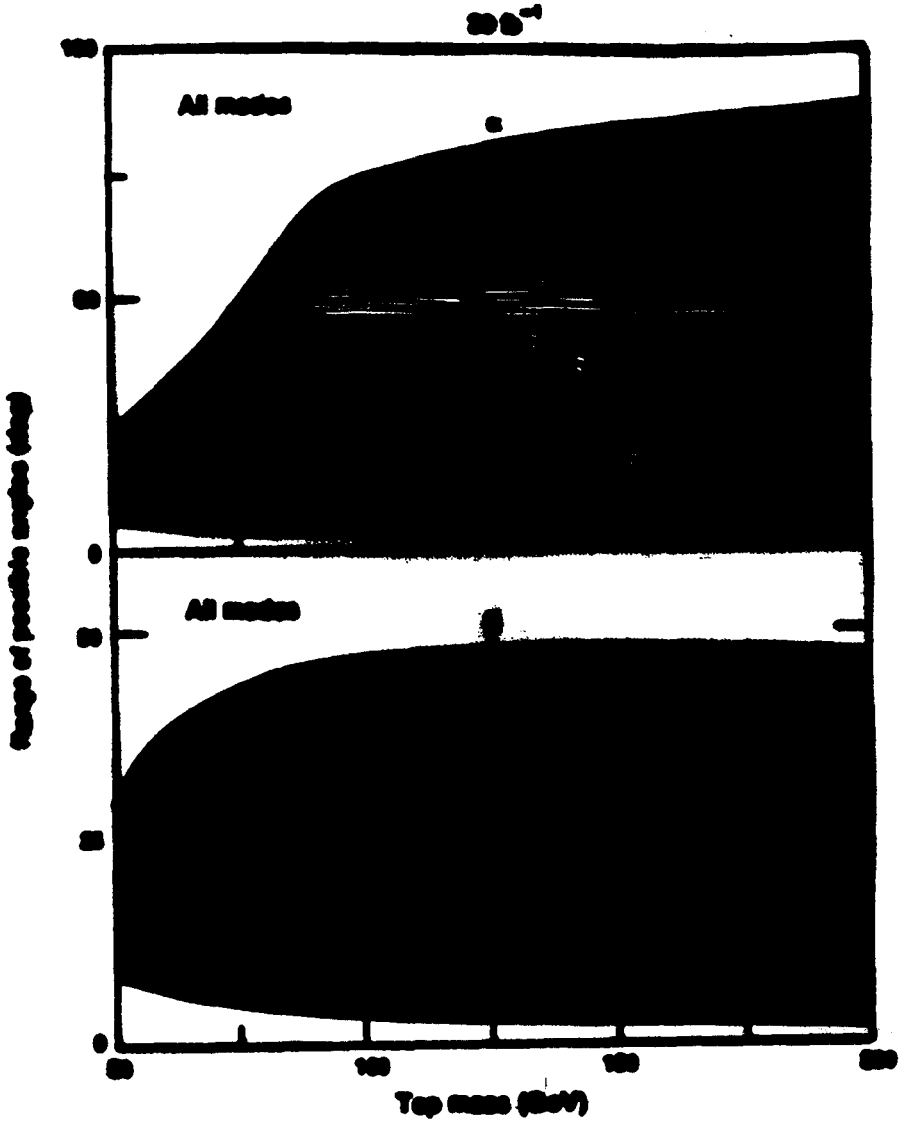


Fig. 2-8. The range of the Standard Model predictions for α and β. The shaded region represents the portion of this range covered (with 3σ precision) by measurements using the CP decay modes $J/\psi K_s$ (for β) and ππ (for α). A data set of 100 fb^{-1} was assumed.



Mode	Assumed branching fraction	Tagging efficiency (%)	Reconstruction efficiency (%)	$\sigma(\sin 2\beta)$ (30 fb^{-1})
$B^0 \to J/\psi K_S$	7.4×10^{-4}	45	58	0.077
$\to D^{*+}D^{*-}$	6×10^{-4}	45	46	0.14
$\to J/\psi K^{*0}$	12.5×10^{-4}	45	30	0.17
$\to D^{*+}D^{*-}$	16×10^{-4}	45	28	0.08
Combined (2β)				0.050
$B^0 \to \pi^+\pi^-$	2×10^{-6}	45	43	0.18
$\to \rho^\pm\pi^\mp$	6×10^{-6}	37	58	0.12
$\to a_1^\pm\pi^\mp$	6×10^{-6}	32	60	0.18
Combined (2α)				0.086

2. Basic Parameters

Requiring beam overlap and equal tune shifts $\Longrightarrow$

$$\mathcal{L} = K(1+r)\,\xi\left(\frac{E\cdot I}{\beta^*}\right)_{\substack{\text{HIGH OR}\\ \text{LOW RING}}}$$

$$K = \frac{1}{2 e r_0 m c^2}$$

$$\Longrightarrow \mathcal{L} \doteq 2.17\times10^{34}\,\xi(1+r)\,\frac{E(\text{GeV})\cdot I(\text{amps})}{\beta^*(\text{cm})}\ \text{cm}^{-2}\text{sec}^{-1}$$

$r = 0$ flat beam, 1 for round beam

How do machines differ?

ξ = tune shift : set by experience
$r \cong 0$: practicalities of IR design
$E \simeq$ not much milage by varying it
$\Longrightarrow$ All the action : I, β^*

	CESR-B	KEK-BI	KEK-BII	PEP B
ξ	0.03	0.05	0.05	0.03
$E_H\cdot I_H$	$8.\times 0.87$	$8.\times 0.22$	$8.\times 1.1$	$9.\times 1.48$
$E_L\cdot I_L$	3.5×1.98	3.5×0.52	3.5×2.6	3.1×2.14
β^*_L(cm)	1.5	1.0	1.0	1.5
β^*_H(cm	1.5	1.0	1.0	3.0
$\mathcal{L}$ cm^{-2}sec^{-1}	3×10^{33}	2×10^{33}	10^{34}	3×10^{33}

Underlying above table:

β^* limit $\sim 1-2$ cm

$\Rightarrow$ low β^* $\rightarrow$ high chromaticity

$\beta^* \simeq \sigma_L$ $\rightarrow$ high RF voltage

Density of bunches limited by ξ

$\Rightarrow$ gain in $\mathcal{L}$ by number of bunches

<u>not</u> by requiring more of bunch-bunch collision

But there must be differences; after all circumferences are very different!

	CESR-B		KEK-BII		PEP-B
C(km)	.765	$\longrightarrow$	1.273	$\longrightarrow$	2.199
ρ_M(m)	86.4 reg 45 hard		90.9		165
P_{SR}^H(Kw)	4.5		4.4		5.3
$\overline{D_{SR}}$($\frac{Kw}{m}$)	58	$\longrightarrow$	3.4	$\longrightarrow$	2.4

$$P_{SR} = k \frac{E^4}{\rho}.$$

$$D_{SR} = k' \frac{E^4}{\rho^2}$$

$\Longrightarrow$ Take compensatory measures for underlying differences. Smaller $R \rightarrow$ lower asymmetry, more pumping to take care of increased photodesorption.

3. The challenges

a. Beam-beam effects

Present colliders share the same guide field: matched in all respects

For asymmetric machine: what should we match? initial scaling first argued for PEP

$E_1 N_1$ $\qquad$ $E_2 N_2$ $\qquad \ni E_1 E_2 = E_0^2$

match optical parameters: ε's, β's, ξ

and maintain tune shift

$$N_H \propto N_0 \frac{E_L}{E_0} \qquad N_L \propto N_0 \frac{E_H}{E_0}$$

$$\mathcal{L}_{\text{bunch-bunch}} = K N_H N_L = K N_0^2 \frac{E_H E_L}{E_0^2} = \mathcal{L}_{0\,\text{bunch-bunch}}$$

$\Longrightarrow$ all gains come from the number of bunches not the requirements of bunch-bunch

What are the right "transparency" conditions?
Approaches range from purely analytical (Hamiltonian formulation of Siemann & Krishnagopal)

$$\beta_1^* = \beta_2^*$$
$$\sigma_1 = \sigma_2$$
$$Q_{s1}' = Q_{s2}'$$
$$\varepsilon_1 = \varepsilon_2$$
$$N_1 \gamma_1 = N_2 \gamma_2$$

x, y

no explicit dependence on damping –

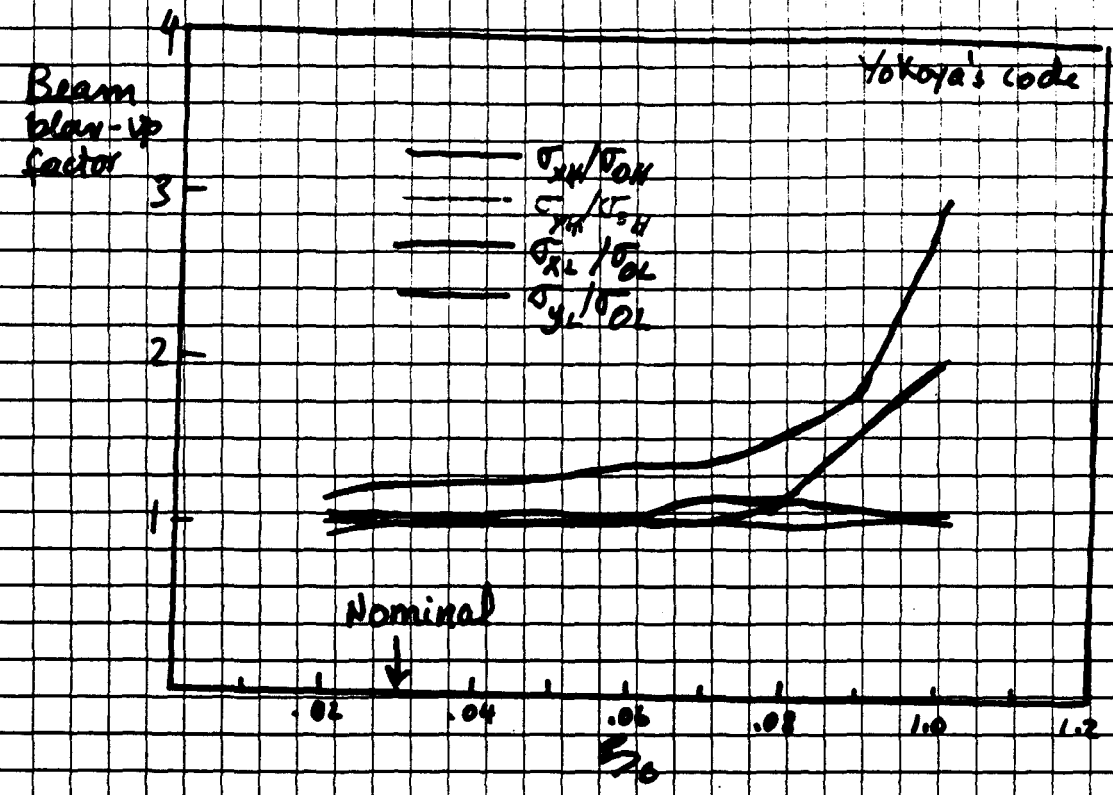
$$\varepsilon_1 = \varepsilon_2$$
$$\sigma_1 = \sigma_2$$
$$\frac{\sigma_{e1} \gamma_{s1}}{\beta_1} = \frac{\sigma_{e2} \gamma_{s2}}{2}$$
$$\lambda = \frac{\bar{r}_0}{r_{SR}}$$

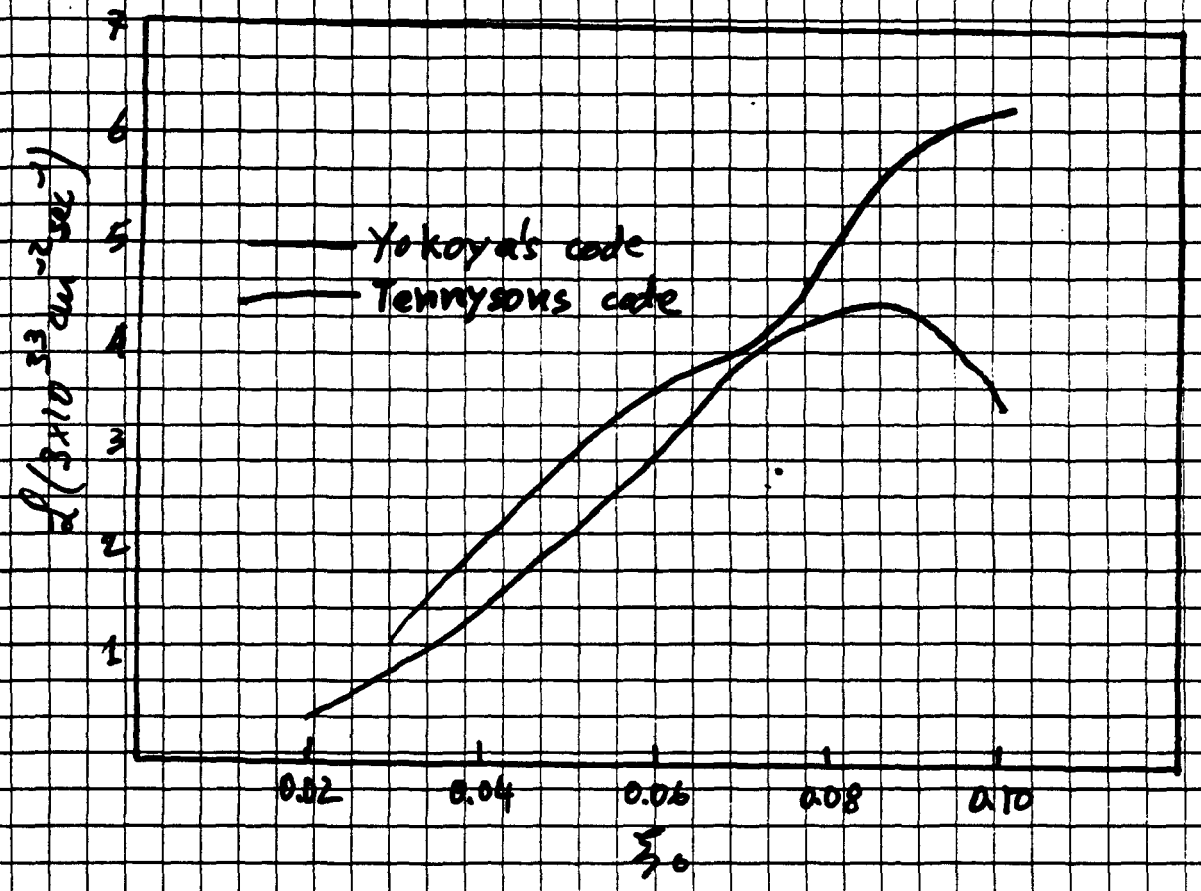
x, y

Degree of "orthodoxy" differs — Problem is investigated by detailed simulations (matched to existing machines)

- vary parameters
- understand beam blow-up conditions

$\Rightarrow$ high degree of confidence that $\Delta\nu = 0.03$ can be achieved.


Beam blow-up factor
Yokoya's code
σ_{xH}/σ_{0H}
σ_{yH}/σ_{0H}
σ_{xL}/σ_{0L}
σ_{yL}/σ_{0L}
Nominal
4
3
2
1
.02
.04
.06
.08
1.0
1.2
ξ_0


$\mathcal{L}$ (3×10^{33} cm^{-2} sec^{-1})
Yokoya's code
Tennysons code
7
6
5
4
3
2
1
0.02
0.04
0.06
0.08
0.10
ξ_0

b. Lattice design

Do the usual things: match optical functions, control emittances, compensate chromaticity, provide dynamic aperture ....

Critical issue: IR-arrangement determines background to the detector (synchrotron radiation and beam gas)

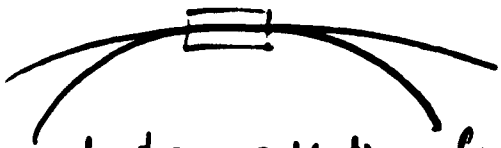
a) magnetic separation only (head-on)

b) crab-crossing - large angle

c) hybrid

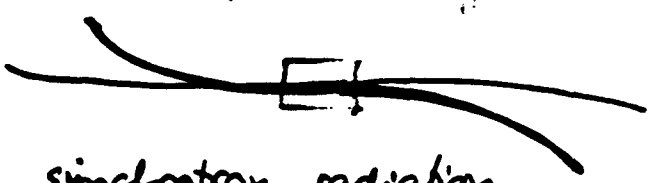
Separation scheme

osculating ×



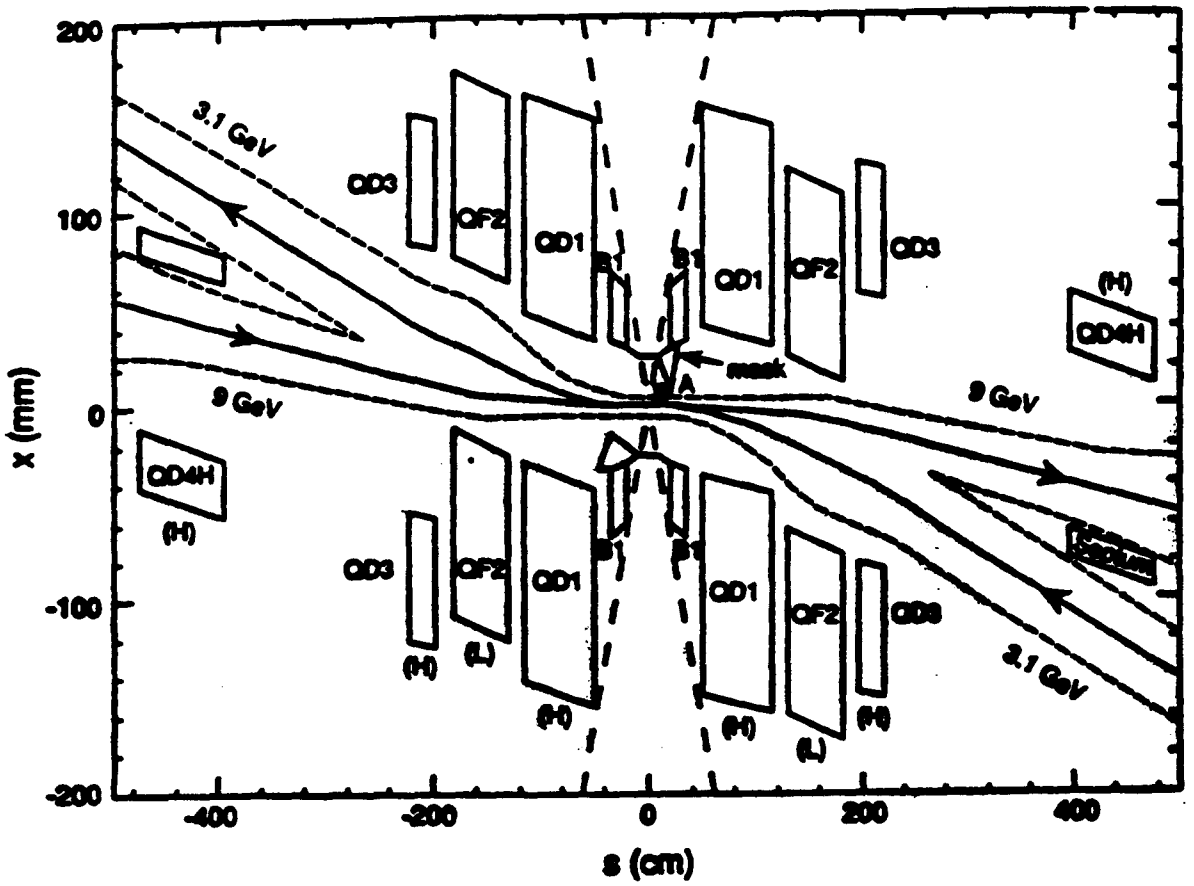
- synchrotron radiation fans "crash" on opposite side

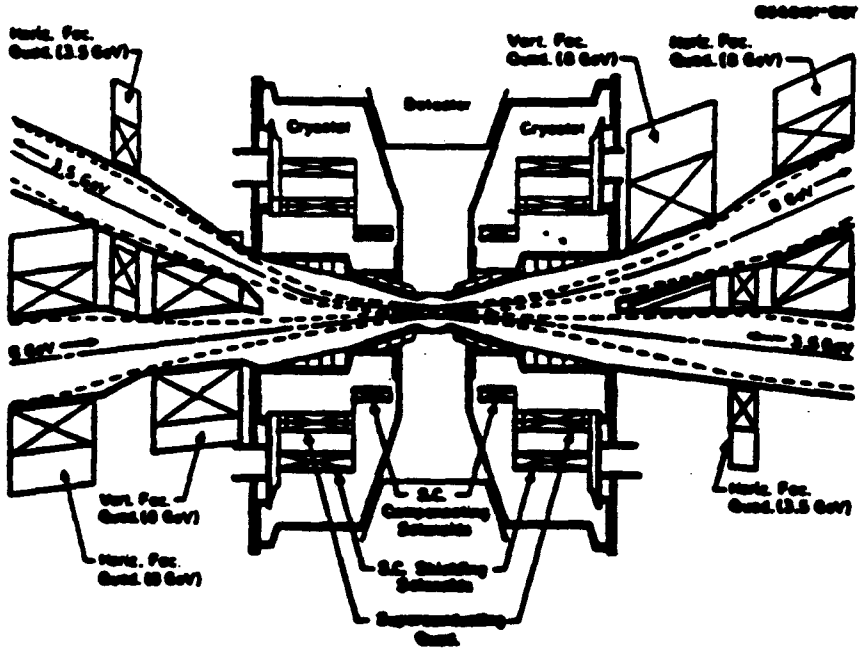
osculating ✓

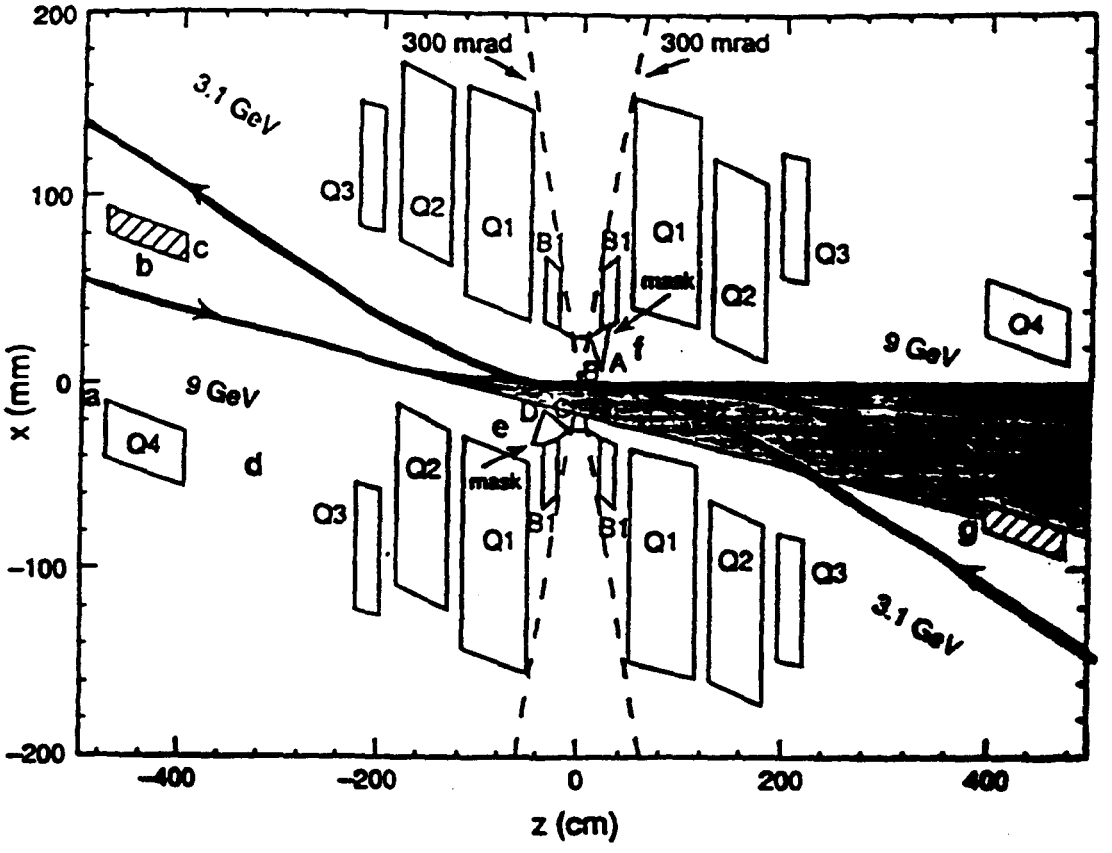


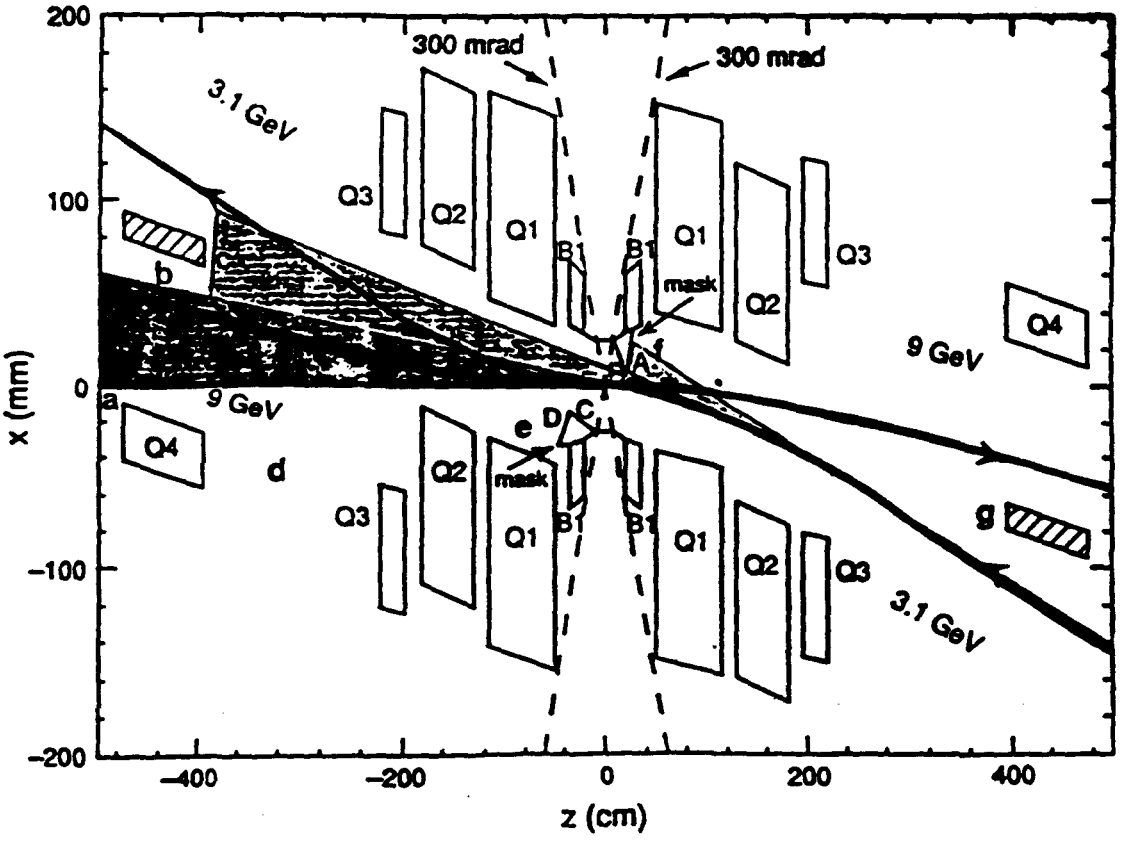
- synchrotron radiation fans go largely down beam pipes
- permits easy change over to crab crossing.

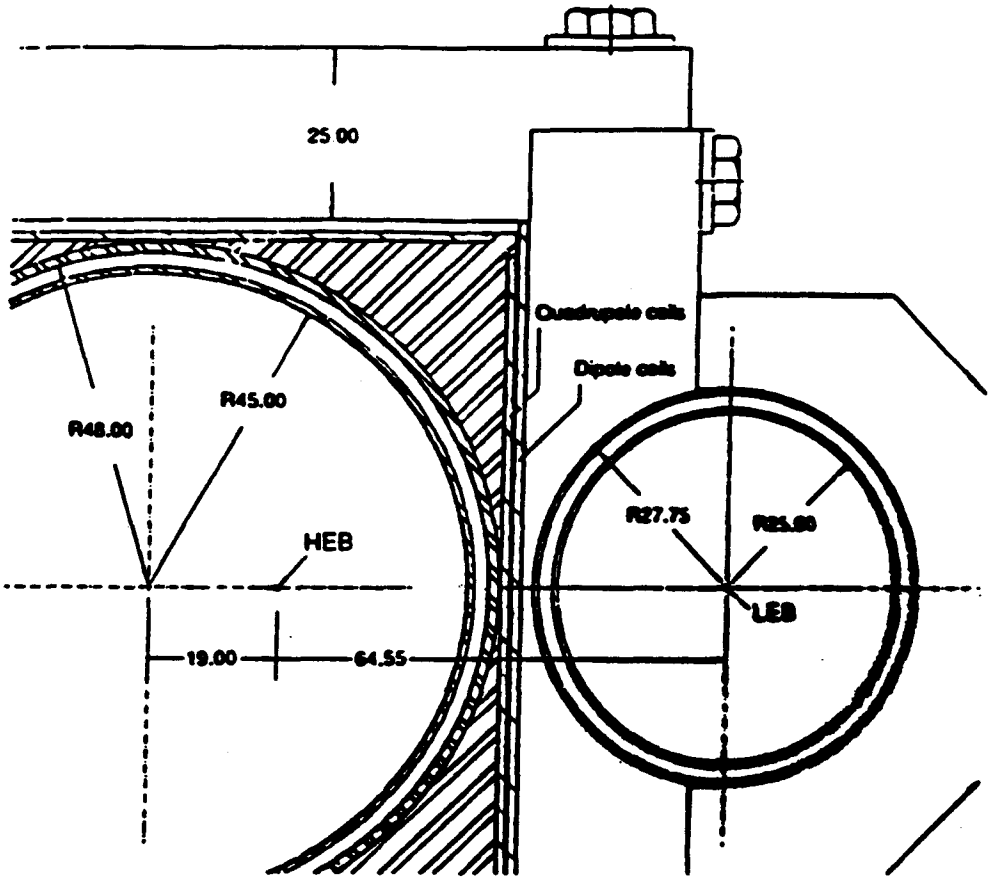
Generally machine design is iterated until backgrounds 1-2 orders of magnitude below limits.

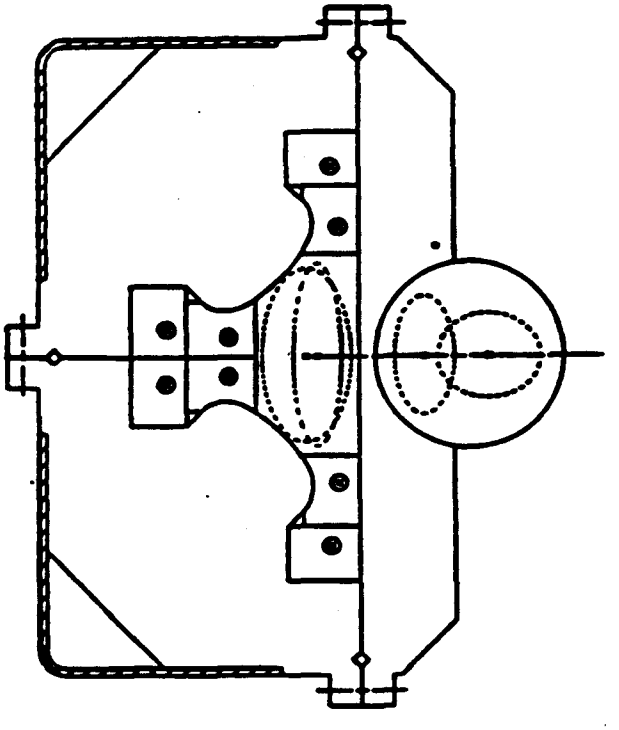

200
100
0
-100
-200
x (mm)
-400
-200
0
200
400
s (cm)
3.1 GeV
9 GeV
QD3
QF2
QD1
B1
mask
QD4H
(H)
(L)


Crystal
Detector
Crystal
Vert. Foc.
Horiz. Foc.
3.5 GeV
9 GeV


300 mrad
300 mrad
3.1 GeV
9 GeV
9 GeV
3.1 GeV
Q1
Q2
Q3
Q4
B1
mask
A
B
C
D
e
f
a
b
c
d
g
x (mm)
z (cm)
200
100
0
−100
−200
−400
−200
0
200
400

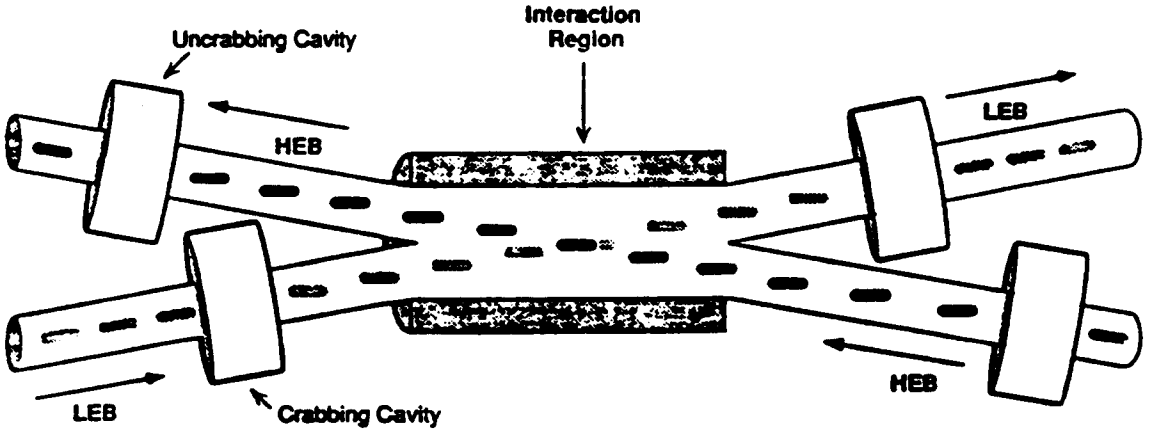

300 mrad
300 mrad
3.1 GeV
9 GeV
9 GeV
3.1 GeV
Q1
Q2
Q3
Q4
B1
mask
A
B
C
D
e
f
a
b
d
g
x (mm)
z (cm)
200
100
0
−100
−200
−400
−200
0
200
400


25.00
Quadrupole coils
Dipole coils
R48.00
R45.00
R27.75
R25.00
HEB
LEB
19.00
64.55



— to permit non-zero crossing angle while avoiding excitation of synchrobetatron resonances, can use crab crossing technique

- transverse deflecting mode of crab cavity at $\Delta\phi = (n \pm 1/4)\, 2\pi$ from IP tilts head and tail of bunch



— required voltage is

$$V_c = \frac{(E/e)\phi\lambda_c}{2\pi\sqrt{\beta_{xc}\beta_x^*}}$$

o for typical parameters, $V_c \approx 2$ MV

— simulations to date give reasonable tolerances

$$\frac{\Delta V}{V} \approx 10\%, \quad \Delta\Psi \approx 5\text{–}10^\circ$$

— prudence dictates small crab angle ($\approx$ 10 mrad)

o this does <u>not</u> avoid having common quads

— technique is promising, but untested

c. System for RF cavities / klystrons

- o high current → high power ~ 5 mW
- o small σ_B → high voltages → up to 50 m

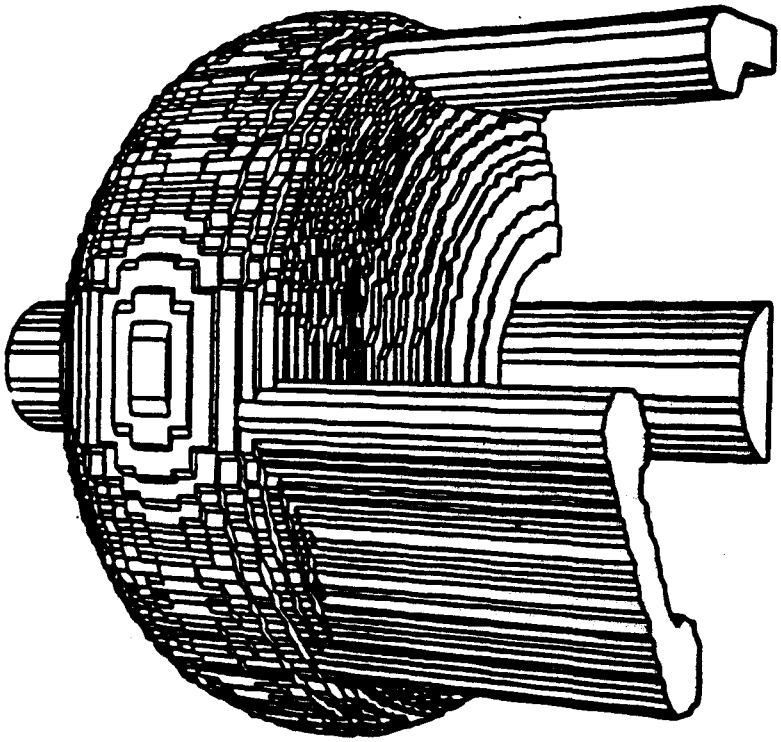
The critical issue in high $\mathcal{L}$ is many bunches → close spacing s_B

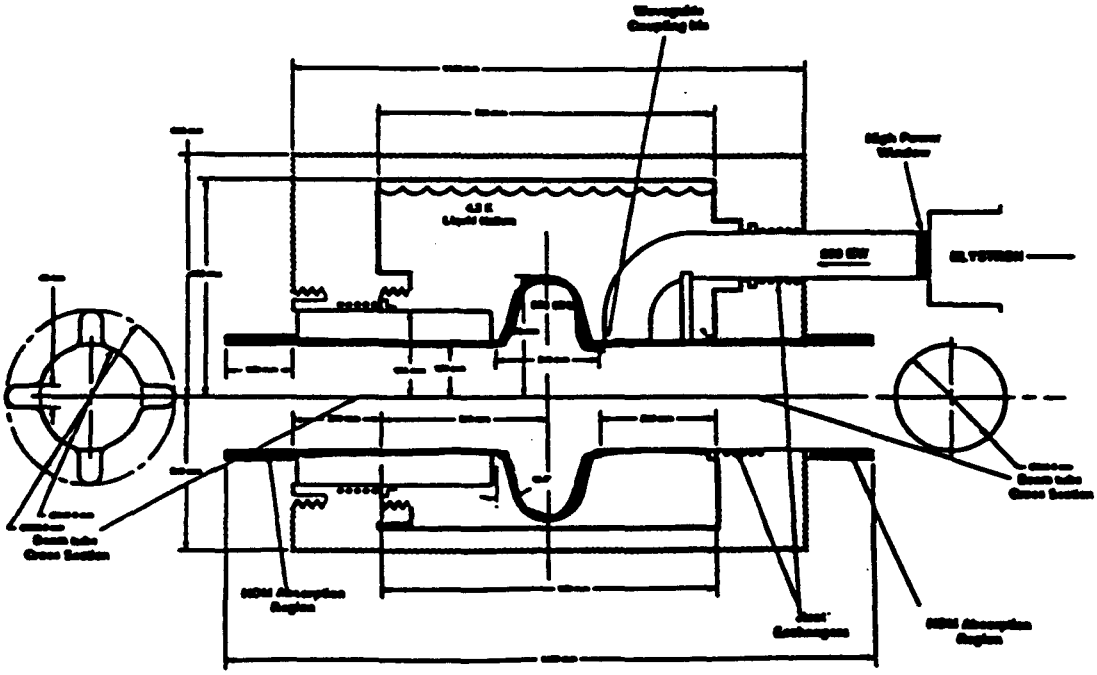
Higher order modes (HOM) excited in the vacuum system (including RF cavities) couple the bunches and lead to multi-bunch instabilities.

Both SC and RT cavities have to minimize HOM impedance per cell

RT : use wave guides and slots to couple out HOM — High damping ~~[illegible]~~ achieved $Q = 30$

SC : use large aperture to "leak" HOM to RT load — calculated $Q \simeq 70$.




Waveguide Coupling Iris
High Power Window
4.2 K Liquid Helium
ELECTRON
Cross Section
Cross Section
Beam Exchangers

d. Feedback / stability

General problem is to control longitudinal and transverse coupled bunch instabilities with growth times ~ 1 msec.

More elaborate for longer damping times (PEP-

Also power requirements have to take into consideration injection

Trade-offs

Cavity design ⟷ feedback system

less HOM less power

Quite extensive studies

PEP-B has very ambitious scheme to work on bunch to bunch feedback
⟶ deal with any perturbation no matter what origin.

d. Vacuum

a) Temperature

b) Gas desorption

Currents are much higher
[at PEP energy much lower than original, compensated]

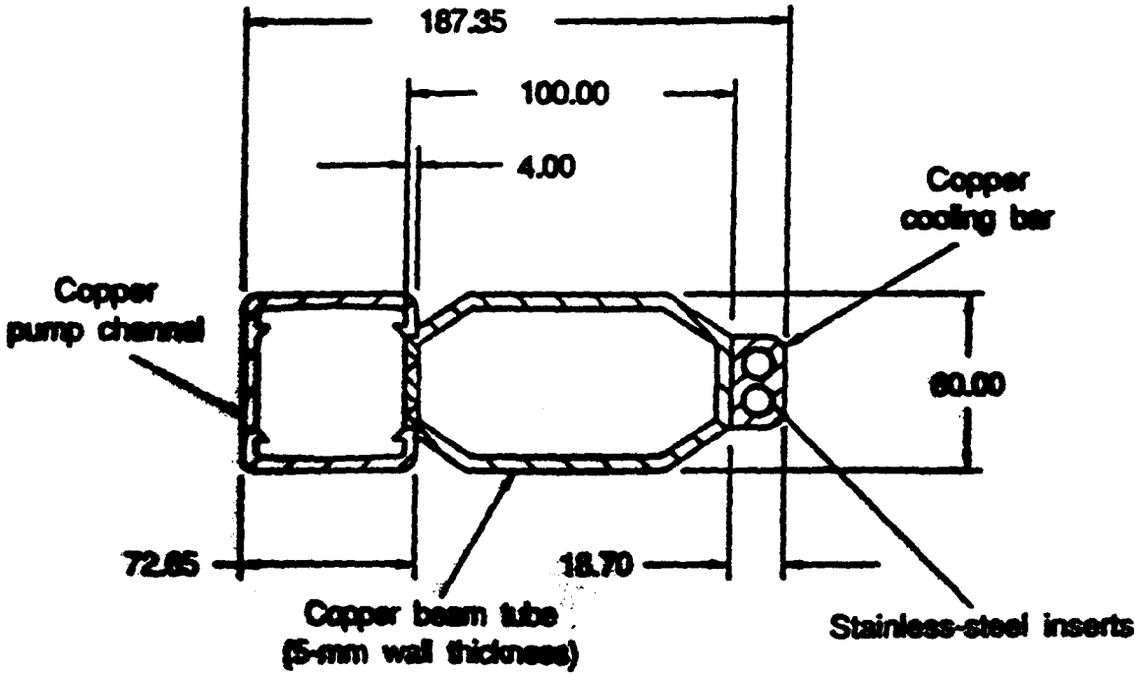
50ma x 2 = 100 ma @ 15 GeV
2A @ 9 GeV

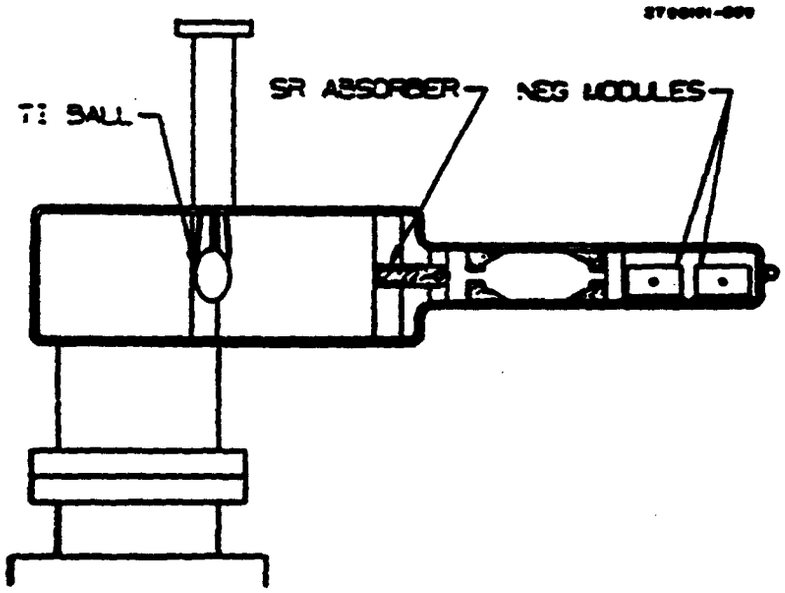
20x the current
But $\left(\frac{9}{15}\right)^4 \sim 1/20$

⇒ Most designs go to new vacuum chambers made of copper

- x 10 less photodesorption
- self shielding

⇒ Solutions range in pumping speed by order of magnitude – highest requirements at CESR-B – hard bends.


187.35
100.00
4.00
Copper
cooling bar
Copper
pump channel
60.00
72.65
18.70
Copper beam tube
(5-mm wall thickness)
Stainless-steel inserts


SR ABSORBER
NEG MODULES
TI BALL

8. Injection

Need to inject frequently and effectively

$\frac{\text{fill time}}{\text{life time}}$ ~ few percent

a) PEP-B

use Linac — significantly upgraded to pick e^+e^- at the right energies — very fast injection <5 minutes total

b) CESR

more bunches in the synchrotron
→ also few minute injection

→ could inject with detector on?

c) KEK

→ also upgraded injector

Significant for all facilities but a solvable problem

So : conclusions

a) Technical solutions to all challenges: extensively reviewed

b) Different facilities optimize in different ways to fit within site constraints: feasible solutions.

LESR-B → KEK BI,II → PEP-B - KEK BIII

- Lowest R
- Highest ε, highest damping
- Highest SR/m → more pumping
- Small β (HER), high ε → backgrounds harder
  → crab crossing solution
- High V_c, small space → Superconducting

- Highest R
- lowest [redacted]ittance (HER) ⇒
  more bunches, parasitic crossing
- Higher β, low [redacted]mittance ⇒ head on collision OK
- Lower V_c requirement ⇒ conventional RF OK
- Lowest damping ⇒ more elaborate feedback
  shorter S_z.

PROSPECTS FOR IMPROVEMENT OF THE CKM MATRIX

DAVID HITLIN

SSC SPRING CONFERENCE

MAY 22, 1991

- THE ULTIMATE GOAL IS CONSISTENCY TESTS OF THE CKM MATRIX INVOLVING THE $\not{CP}$ PHASE – UNITARITY TRIANGLE

  TESTS CAN BE SHARPENED BY:

  - MEASUREMENT OF f_D [BETTER: f_B]
  - PROGRESS IN LATTICE CALCULATIONS
  - IMPROVED τ_d
  - MEASUREMENT OF τ_s
  - MEASUREMENT OF $B(K^+ \to \pi^+ \nu \bar{\nu})$

+ MEASUREMENTS OF $\sin 2\alpha$, $\sin 2\beta$ IN B DECAYS TO CP EIGENSTATES AT AN ASYMMETRIC B FACTORY

CONCLUSIONS

- DETERMINATIONS OF $|V_{Qq}|$ CAN IN MANY CASES BE IMPROVED, EITHER EXPERIMENTALLY OR THEORETICALLY OR BOTH

V_{ud} : $\tau_\mu / 0^+ \to 0^+$ DOMINATED BY CORRECTIONS
τ_n / G_A NOT IN GOOD AGREEMENT
$\pi^+ \to \pi^0 e \nu$ CAN BE IMPROVED

V_{us} : K_{e3} PROTECTED BY ADEMOLLO-GATTO THM
EXPERIMENTAL ABSOLUTE BR SHOULD BE IMPROVED
RADIATIVE CORRECTIONS

V_{cs} : NEW e^+e^- + FIXED TARGET MEASUREMENTS OF $B(D \to Ke\nu)$ CAN REDUCE EXP. ERROR SUBSTANTIALLY.
DOMINATED BY $f_+(0)$ [OR USE UNITARITY]

V_{cd}: ONE MORE ROUND OF $\nu \to \mu^+\mu^-$
$D \to \pi e \nu$ CAN BECOME COMPETITIVE

V_{cb} : CAN BE IMPROVED BY

- MORE DATA
- IMPROVED $D \to K\pi$ ABSOLUTE BR'S
- HEAVY QUARK LIMIT

V_{ub} : AS ABOVE + USE OF EXCLUSIVE TAGGED MODES

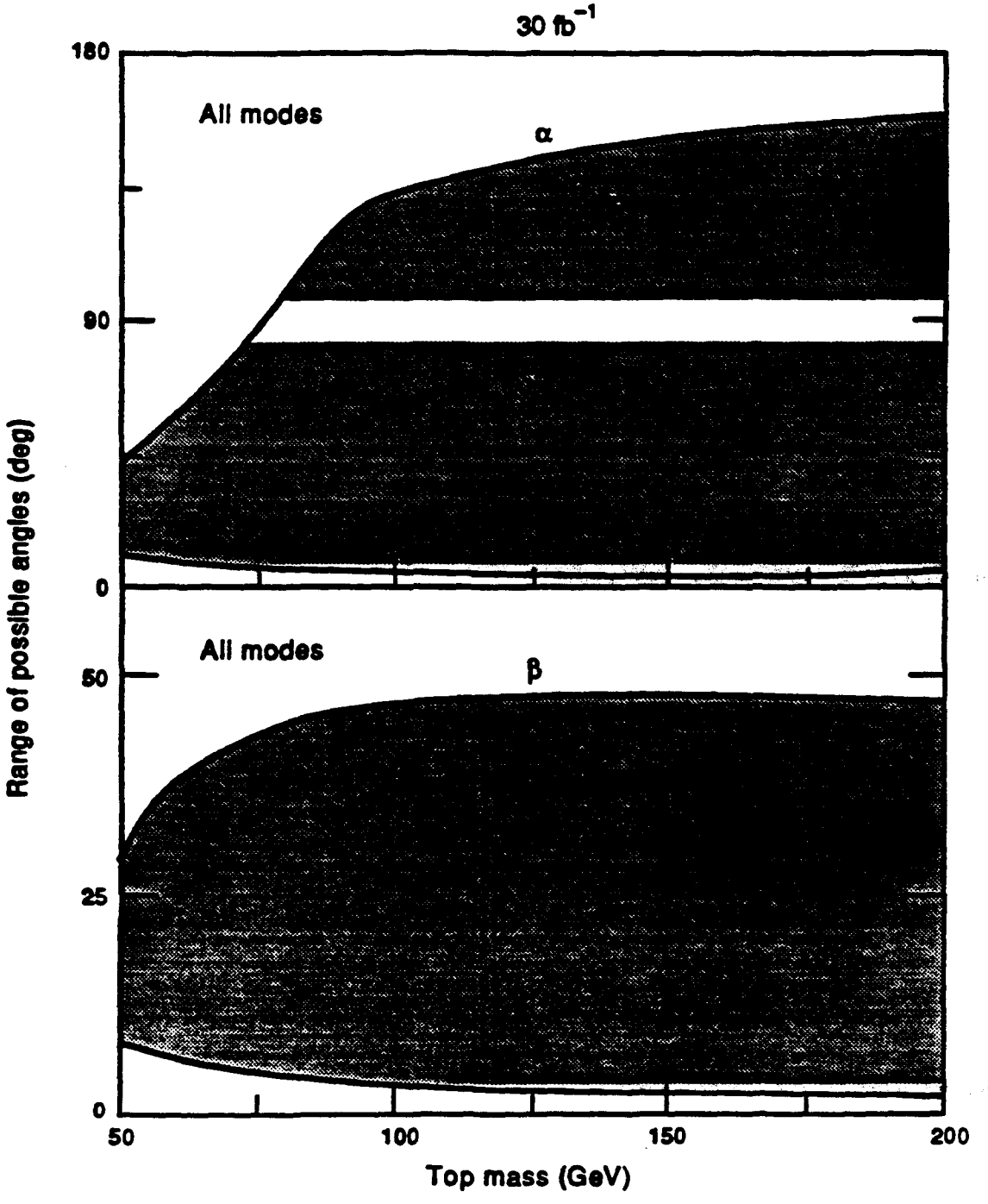
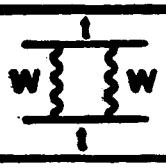
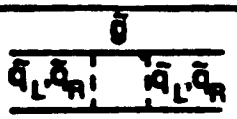
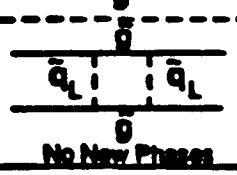


Fig. 2-9. The range of α and β predicted by the Standard Model that can be covered (3σ) by a 30-fb^{-1} data set, using a spectrum of CP decay modes (see Table 2-3).

TABLE III

Effects of new physics on CP asymmetries

D I B, LONDON & NIR

Model	CKM Unitarity	B - $\bar{B}$ Mixing	SM Predictions for A^{CP}
SM			
Four Quark Generations			Modified
Multi-Scalar with NFC (General)			Unmodified
(+ SCPV)	—	No New Phases	All Asymmetries Vanish
Z-Mediated FCNC			Modified
LRS			Unmodified
SUSY (General)			Modified
(Minimal)			Unmodified
"Real Superweak"			Modified for B_d Unmodified for B_s

8-90 6708A1

Table 2-3. Summary of the assumptions used in the simulations of Fig. 2-9 to establish the measurement errors for sin 2α and sin 2β (here generalized as sin 2φ). In addition, we have used as input a wrong-sign fraction of 8%, a $B\bar{B}$ cross section of 1.2 nb, and a neutral B fraction of 0.5.

Mode	Assumed branching fraction	Tagging efficiency (%)	Reconstruction efficiency (%)	σ (sin 2φ) (30 fb^{-1})
$B^0 \to J/\psi K_s$	7.4×10^{-4}	45	58	0.077
$\to D^+D^-$	6×10^{-4}	45	46	0.14
$\to J/\psi K^{*0}$	12.5×10^{-4}	45	30	0.17
$\to D^{*+}D^{*-}$	16×10^{-4}	45	28	0.08
Combined (2β)				0.050
$B^0 \to \pi^+\pi^-$	2×10^{-5}	45	43	0.18
$\to \rho^+\pi^-$	6×10^{-6}	37	58	0.12
$\to a_1^+\pi^-$	6×10^{-5}	32	60	0.18
Combined (2α)				0.086

USE OF ADDITIONAL MODES TO MEASURE sin 2α AND sin 2β IS OF UTMOST IMPORTANCE:

- USE OF ALL ACCESSIBLE MODES ALLOWS A ONE-YEAR (30 fb^{-1}) RUN AT THE B FACTORY TO PROVIDE FULL COVERAGE OF ALLOWED STANDARD MODEL VALUES AT 3σ LEVEL.
- WITH IMPROVED PRECISION, ADDITIONAL CONSISTENCY TESTS OF THE STANDARD MODEL ARE POSSIBLE, AS IS DIAGNOSIS OF ANY DISCREPANCIES WHICH MAY BE UNCOVERED

$\not{CP}$ BEYOND $B \to \psi K_S^0, \pi^+\pi^-$

- CONTROL OF PENGUIN POLLUTION

GRONAU, LONDON

CAN EXPERIMENTALLY ASCERTAIN POSSIBLE PENGUIN CONTRIBUTION FROM TIME DEPENDENCE

- EXTEND USABLE $\not{CP}$ MODES BEYOND "CONVENTIONAL" DECAYS TO SPINLESS CP EIGENSTATES:

NIR, SILVERMAN, QUINN

  - $\not{CP}$ PATTERN CAN BE USED TO EXPLORE SPECIFIC EXTENSIONS OF STANDARD MODEL
  - ADDITIONAL STATISTICS CAN BE USED TO REDUCE LUMINOSITY REQUIRED TO ESTABLISH $\not{CP}$ (BY ~ FACTOR OF 2)

SNYDER, WAGNER

1) $B^0 \to f, \ \overline{B}^0 \to f$

ψK_S^0
$\pi^+\pi^-$
D^+D^-

SNYDER

2) $f = A_{CP} B_{CP}$ OR $A\overline{A}$
A, B HAVE SPIN

$\psi \rho^0$
$D^{*+}D^{*-}$

DUNIETZ, SNYDER

KAYSER, KURODA, DECLEI, SANDA

LIPKIN, DUNIETZ, QUINN, SNYDER, TOKI

3) $f = A_{CP} \xrightarrow{B} C_{CP}$

$\overline{D}^0 \pi^0$
$\hookrightarrow \pi^+\pi^-$
ψK^{*0}
$\hookrightarrow K_S^0 \pi^0$
ψK^{*0} + MOMENTS

LIPKIN

4) f = 3 BODY STATE: CP ESTATE: $\eta_c K_S^0 \pi^0$
MIXTURE: $\psi K_S^0 \pi^0$

5) $f = A_1 \overline{A}_2$ WHERE

ALEKSAN, KAYSER, LIDIBERDER, DUNIETZ

$$A_1 \overline{A}_2 = (\bar{q} \times \bar{q}_y)(\bar{q}_x q_y)$$

$d\bar{d}c\bar{c}$ $D^{*+}D^-$
$d\bar{d}s\bar{s}$ $K^{*0}\overline{K}^0$
$d\bar{d}u\bar{u}$ $\rho^+\pi^-, a_1^+\pi^-$

IF $A(B^0 \to f_{CP}) = A_1 e^{i\delta_1} + A_2 e^{i\delta_2}$

$\left[\mathrm{Im}\,\xi \equiv \sin 2\alpha, \sin 2\beta \ldots \right]$

THEN

$$\Gamma(t) = \Gamma(B \to f) e^{-\Gamma t} \left[\frac{1+|\xi|^2}{2} + \frac{1-|\xi|^2}{2} \cos \Delta m t - \mathrm{Im}\,\xi \sin \Delta m t \right]$$

$$\bar{\Gamma}(t) = \Gamma(\bar{B} \to f) e^{-\Gamma t} \left[\qquad - \qquad + \qquad \right]$$

$$\xi = \frac{q}{p} \frac{\bar{A}}{A} \quad ; \quad \frac{q}{p} = \frac{1-\varepsilon_B}{1+\varepsilon_B} \simeq e^{-2i\phi_M}$$

$\neq 1$?

MEASURED (IN PRINCIPLE) IN SAME SIGN DILEPTON EVENTS

$$\mathcal{CP} \simeq \frac{1}{2}\left(1-|\xi|^2\right) \cos \Delta m t - \mathrm{Im}\,\xi \sin \Delta m t$$

$\therefore$ MEASURING TIME DEPENDENCE TELLS YOU NOT ONLY $\mathrm{Im}\,\xi$ ($= \sin 2\beta$ for example)

BUT ALSO IF $\exists$ A SECOND AMPLITUDE

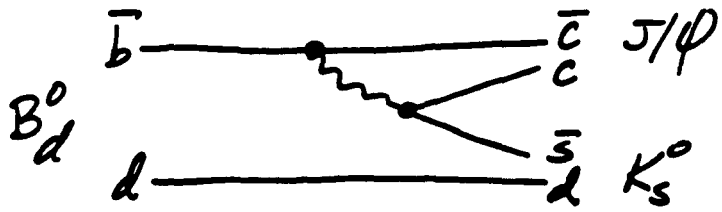
GRONAU

SPECTATOR COUPLINGS IN B_d^0 DECAYS TO CP EIGENSTATES

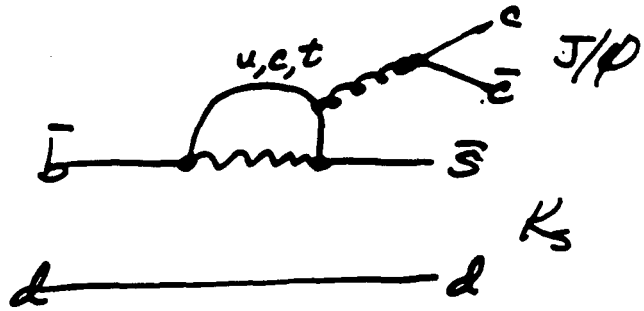
PROCESS	FINAL STATE	A_{SPEC}	$A_{PENGUIN}$
$\bar{b} \to c\bar{c}\bar{s}$	$J/\psi K_S^0$	λ^2	$(\lambda^4 \text{ TO } \lambda^5)\frac{\alpha_s}{12\pi}\ln\frac{m_t^2}{m_c^2}$
$\bar{b} \to c\bar{c}d$	D^+D^-	λ^3	$(\lambda^3 \text{ TO } \lambda^4)\frac{\alpha_s}{12\pi}\ln\frac{m_t^2}{m_c^2}$
$\bar{b} \to \bar{u}ud$	$\pi^+\pi^-$	$\lambda^3 \text{ TO } \lambda^4$	$(\lambda^3 \text{ TO } 2\lambda^3)\frac{\alpha_s}{12\pi}\ln\frac{m_t^2}{m_c^2}$
$\bar{b} \to u\bar{u}\bar{s}$	$K_S^0\pi^0$	$\lambda^4 \text{ TO } \lambda^5$	$\lambda^2 \underbrace{\frac{\alpha_s}{12\pi}}_{.03} \underbrace{\ln\frac{m_t^2}{m_c^2}}_{9}$ $\sim .3$

CAN YOU EXPERIMENTALLY FIND OUT IF PENGUIN AMPLITUDES ARE SMALL?

$B_d^0 \to J/\psi K_s^0$



SPECTATOR



PENGUIN

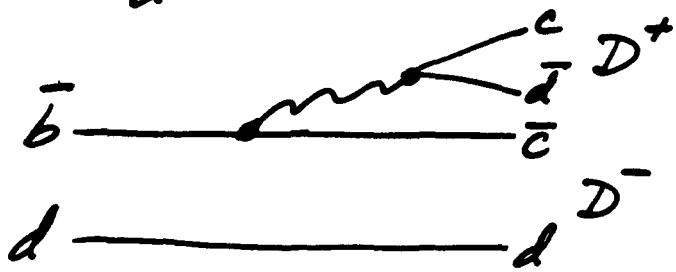
Is $A_{SPEC} \gg A_{PENGUIN}$?

YES $\dfrac{A_{SPEC}}{A_{PENGUIN}} \simeq 10\text{-}100$

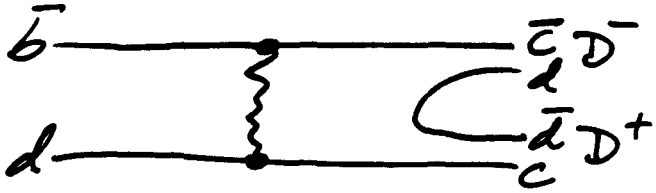
AND SAME WEAK PHASE

BUT:

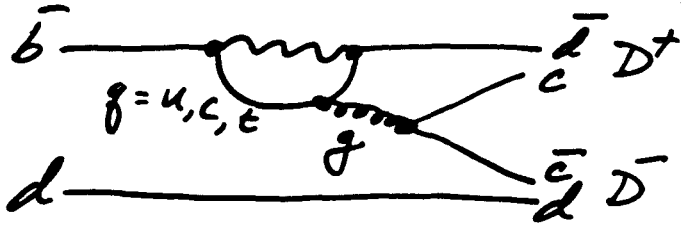
$B_d^0 \to D^- D^+$:



$V_{cb}V_{cd}^* \sim \lambda^3$



$V_{cb}V_{cd}^* \, |\psi(0)|$



$V_{qb}V_{qd}^* \sim \lambda^3$

NA31: $\frac{\varepsilon'}{\varepsilon} = (2.7 \pm 0.9) \times 10^{-3}$

$m_t = 120\,\text{GeV} \Rightarrow \quad \eta_{120} = 1.9 \pm 0.8 \,{}^{+1.7}_{-0.6}$

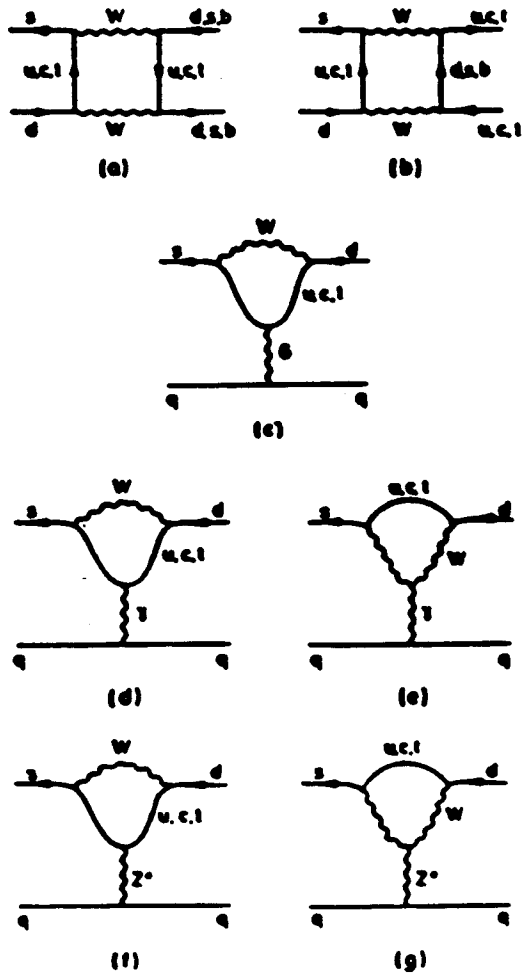
E731: $\frac{\varepsilon'}{\varepsilon} = (-0.4 \pm 1.5) \times 10^{-3}$

$\eta_{120} = -0.3 \pm 1.1 \,{}^{+0.1}_{-0.25}$

<u>PROSPECTS:</u>

HIGHER PRECISION MEASUREMENTS OF ε'/ε CAN SERVE TO RESOLVE NA31/E731 DIFFERENCES AND TO RULE OUT (?) SUPERWEAK MODEL

THEORETICAL UNCERTAINTIES DOMINATE RELATIONSHIP OF $\frac{\varepsilon'}{\varepsilon}$ TO η


s
W
d,s,b
u,c,t
u,c,t
d
W
d,s,b
(a)
s
W
u,c,t
u,c,t
d,s,b
d
W
u,c,t
(b)
W
s
d
u,c,t
G
q
q
(c)
W
s
d
u,c,t
γ
q
q
(d)
u,c,t
s
d
W
γ
q
q
(e)
W
s
d
u,c,t
Z°
q
q
(f)
u,c,t
s
d
W
Z°
q
q
(g)

$$\frac{\varepsilon'}{\varepsilon} \propto \eta$$

ONE LOOP DIAGRAMS INCLUDING G, γ, Z PENGUINS

BY BUCHALLA, BURAS, HARLANDER

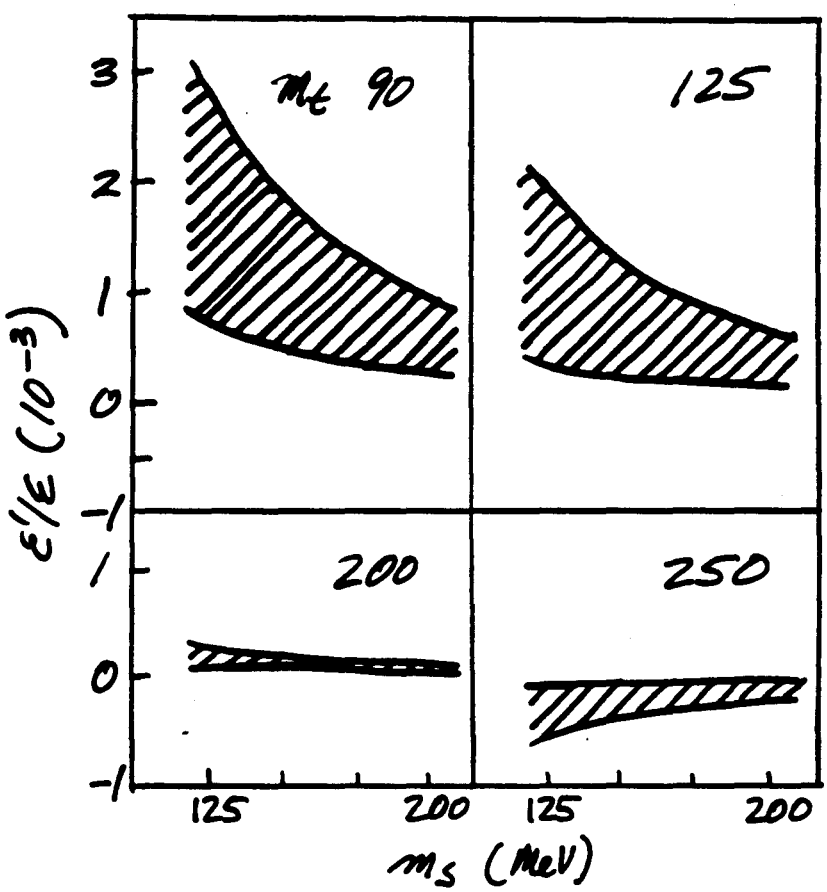
$$\frac{\varepsilon'}{\varepsilon} = 290\, \lambda^6 A^2 \eta\, H(m_t)$$

RESULT DEPENDS ON $100\ \text{MeV} < \Lambda_{QCD} < 300\ \text{MeV}$

$0.043 < s_{23} < 0.052$

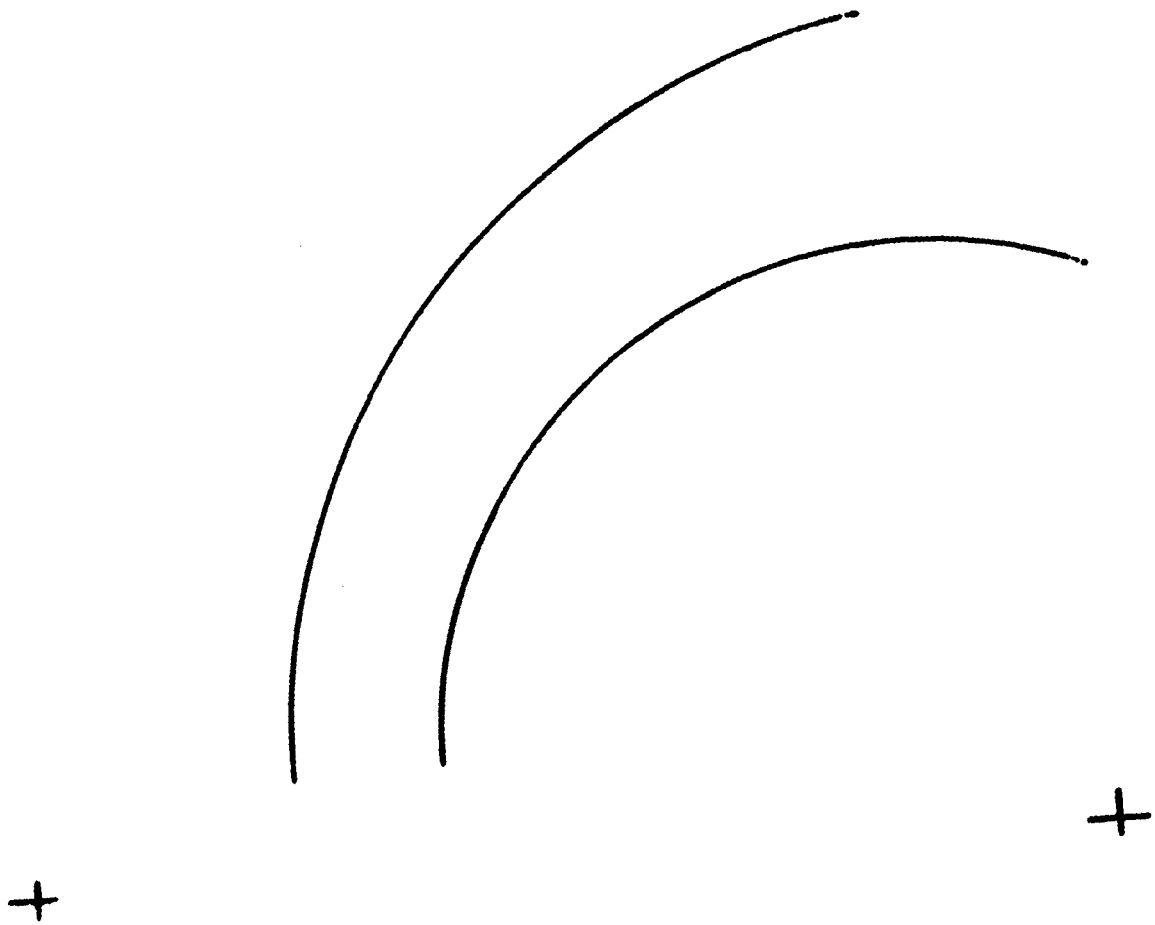
$0.6 < B_K < 0.9$

$0.01 < \bar{R} = \frac{b \to u}{b \to c} < 0.03$



PARAMETRIZATION BY KIM, ROSNER & YUAN:

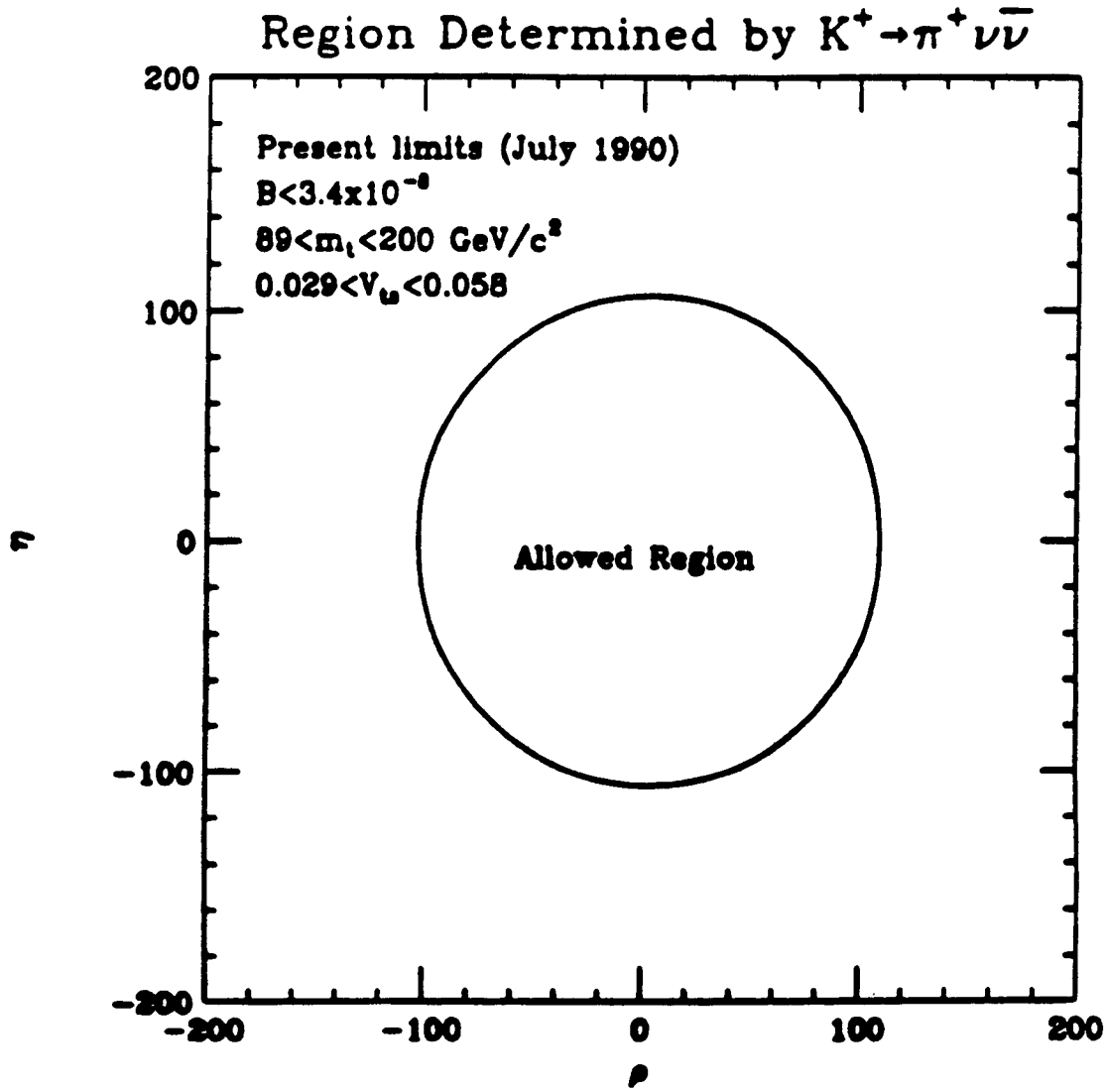
$$\frac{\varepsilon'}{\varepsilon} = (0.19 \pm 0.09) \times 10^{-2} A^2 \eta \left[1 - 0.46 \left(\frac{m_t}{100\,\text{GeV}} - 0.7 \right)^2 \right]$$



Assume

$B(K^+ \to \pi^+ \nu \bar{\nu}) = 2 \times 10^{-10}$

$m_t = 150$; $0.141 < V_{ts} < 0.$


Region Determined by $K^+ \to \pi^+ \nu\bar{\nu}$
Present limits (July 1990)
$B<3.4\times10^{-8}$
$89<m_t<200$ GeV/c^2
$0.029<V_{ts}<0.058$
Allowed Region
200
100
0
−100
−200
−200
−100
0
100
200
η
ρ

$\Gamma(K^+ \to \pi^+ \nu\bar{\nu})$ PROVIDES A MEANS OF MEASURING $|V_{td} V_{ts}|$ WHICH IS LARGELY INSENSITIVE (BIG!) TO NEW PHYSICS

HAGGERTY:
$$\frac{B(K^+ \to \pi \nu\bar{\nu})}{B(K^+ \to \pi^0 e^+ \nu)} \cdot \frac{8\pi^2 \sin^4\theta_W}{3\alpha^2} \frac{1}{A^4 \lambda^8 D_t^2}$$
$$= \eta^2 + \left(1 + \frac{1}{A^2\lambda^4}\frac{D_c}{D_t} - \rho\right)^2$$

DESCRIBES A CIRCLE IN ρ, η PLANE

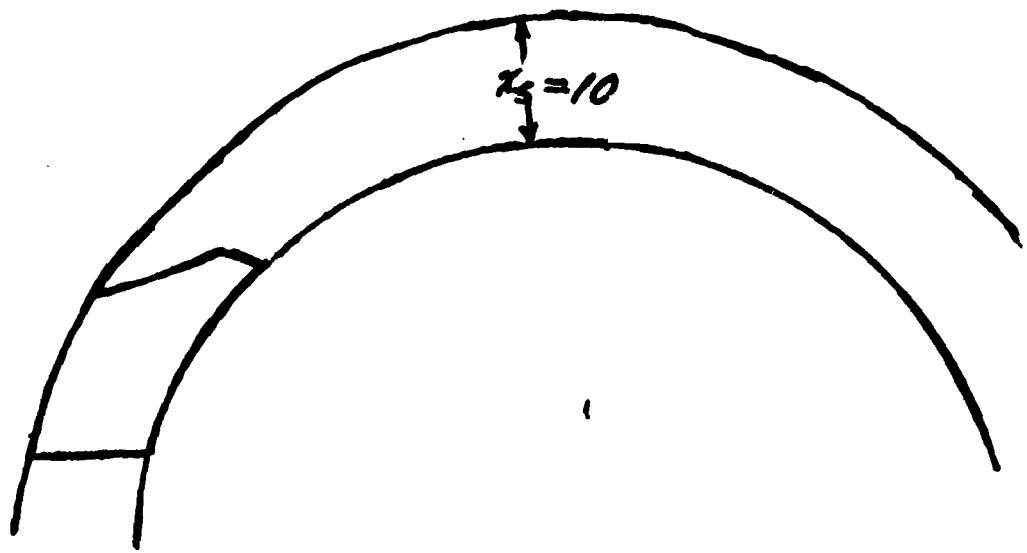
CENTER: $\rho = 1 + \frac{1}{V_{ts}^2}\frac{D_c}{D_t}$

RADIUS: $\frac{1}{V_{ts}^2 D_t}\sqrt{\frac{B(K^+ \to \pi \nu\bar{\nu})}{1.84 \times 10^{-6}}}$

CURRENT LIMIT IS $< 3.4 \times 10^{-8}$ 4.4×10^{-9}

EXAMPLE $B = 2 \times 10^{-10}$ ASSUMED

AKERIB: $|V_{td}|^2 = \left[1.3 \begin{smallmatrix} +0.47 \\ -0.32 \end{smallmatrix}\right]\left[\frac{B(K^+ \to \pi^+ \nu\bar{\nu})}{2 \times 10^6} - (2.41 \pm .74) \times 10^{-5}\right]$



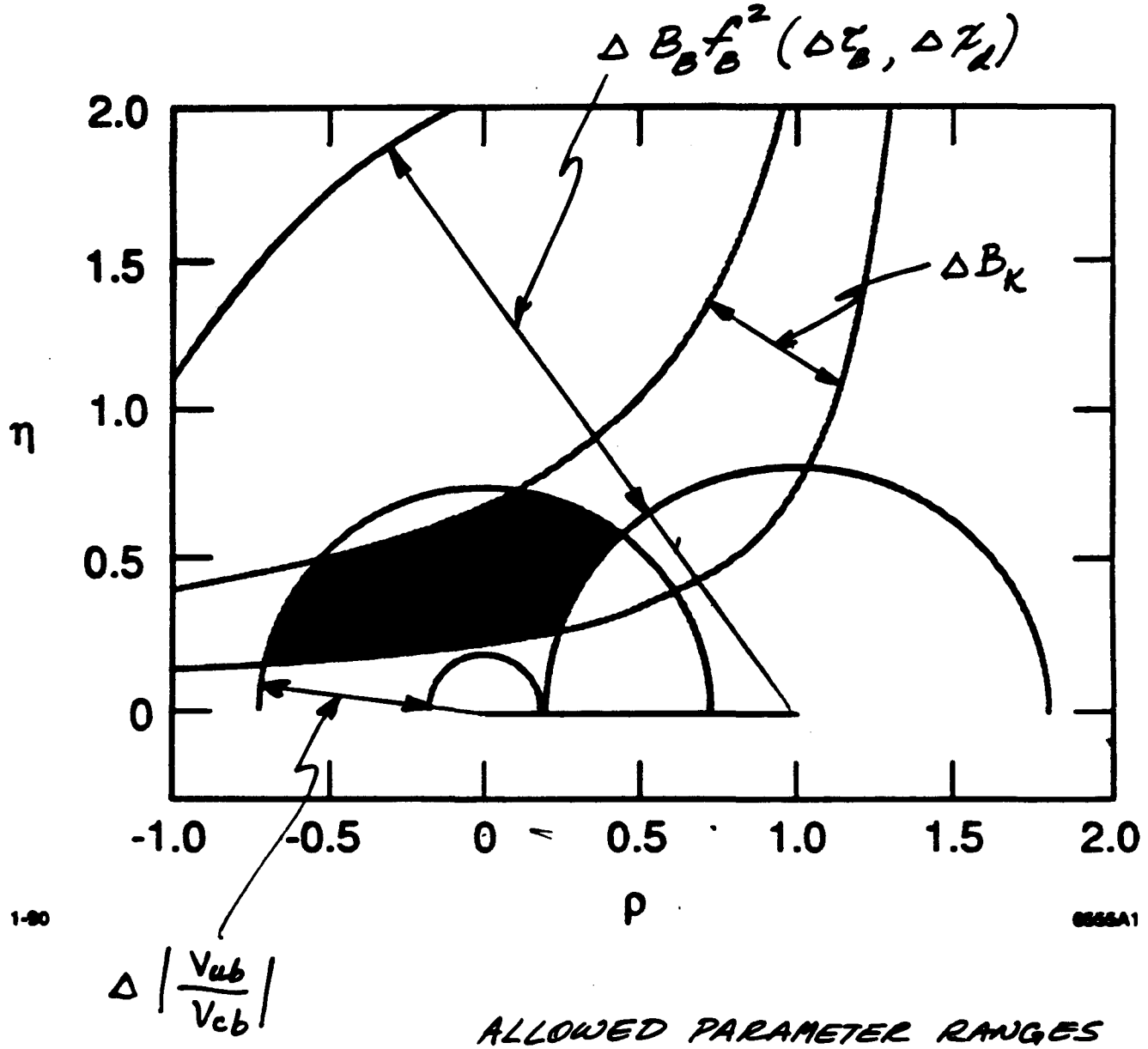
ASSUME:

$x_s = 11 \pm (20\% @ 1\sigma)$

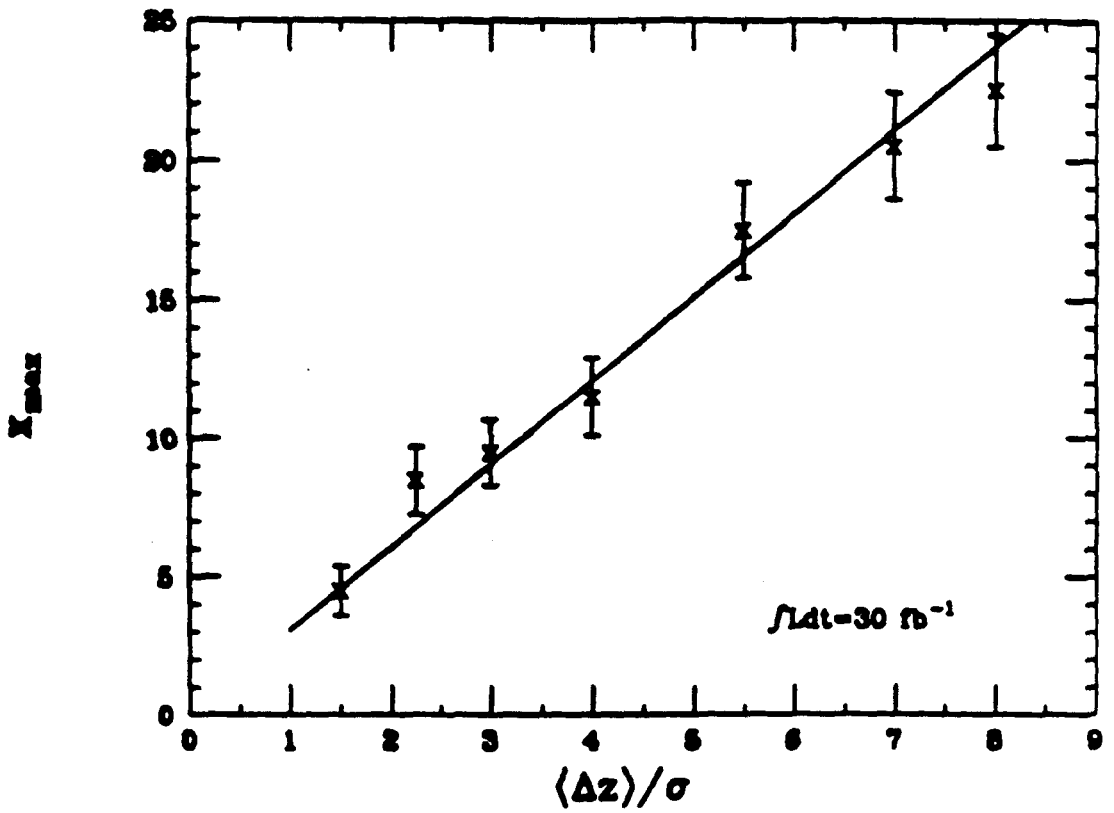
EXP

TH ON x_s/x_1

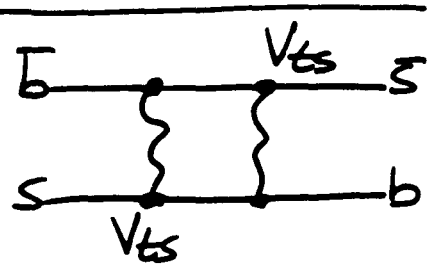
What Range of η,ρ is Permitted by Current Data?
Pick the Example with m_t = 120 GeV, $|V_{cb}|$ = 0.046

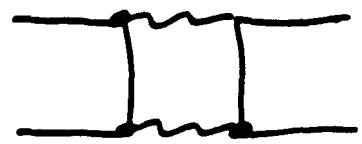


ALLOWED PARAMETER RANGES ARE DOMINATED BY THEORETICAL, NOT EXPERIMENTAL, UNCERTAINTIES


25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
X_{max}
$\langle \Delta z \rangle / \sigma$
$\int L dt = 30\ fb^{-1}$

$B_s^0 - \bar{B}_s^0$ MIXING





$$x_s = \frac{\Delta M_{B_s}}{\Gamma_{B_s}} = \frac{G_F^2}{6\pi^2}\frac{M_{B_s}}{\Gamma_{B_s}} B_{B_s} f_{B_s}^2 \left|V_{tb}^* V_{ts}\right|^2 I(m_t, m_W)\,\eta_{QCD}$$

$$\frac{x_s}{x_d} \sim \left|\frac{V_{ts}}{V_{td}}\right|^2 \frac{f_{B_s}^2}{f_{B_d}^2} = \frac{1}{\lambda^2\left[(1-\rho)^2+\eta^2\right]}$$

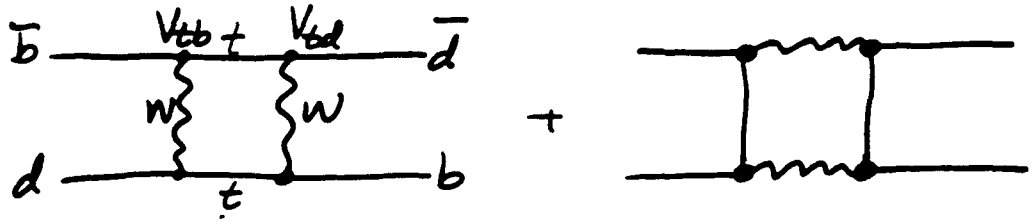
INDEPENDENT OF m_t

x_s CAN BE MEASURED IN NEXT DECADE AT $\Upsilon(4S)$, Z^0 OR IN HADRON COLLISIONS

EXAMPLE: ASSUME $x_s = 10 \pm 2$

AND 10 % THEORETICAL UNCERTAINTY ON $\frac{x_s}{x_d}$

$B_d^0 - \overline{B}_d^0$ MIXING



GOVERNS SCALE OF $\not{CP}$ IN DECAYS TO CP EIGENSTATES

$$x_d \equiv \frac{\Delta M_{B_d}}{\Gamma_{B_d}} = \frac{G_F^2}{6\pi^2} \frac{M_{B_d}}{\Gamma_{B_d}} f_{B_d}^2 B_{B_d} |V_{tb}^* V_{td}|^2 I(m_t, m_W) \eta_{QCD}$$

ARGUS : $x_d = 0.66 \pm 0.14$

CLEO : 0.57 ± 0.12

$\Rightarrow \langle x_d \rangle = 0.61 \pm 0.09$

<u>PROSPECTS</u> : CAN PERHAPS BE IMPROVED TO $\sim 5\%$ MEASUREMENT

RELATING x_d TO V_{td} REQUIRES KNOWLEDGE OF $B_{B_d}, f_{B_d}, m_t, \eta_{QCD}$

CAN EXTRACT V_{td} TO $\sim 10\%$ IF f_B, m_t ARE MEASURED

PROSPECTS FOR MEASURING f_M:

f_B: $B^+ \to \tau^+ \nu_\tau$ (VERY DIFFICULT - SCAR 353)

f_{D^+}: $D^+ \to \mu^+ \nu_\mu$ POSSIBLE AT BES
IF $f_D \gtrsim 200$ MeV
(TO 30-50 %) [ALSO E687]

$f_{D_S^+}$: $D_S^+ \to \mu^+ \nu_\mu$ ALSO POSSIBLE AT BES
STATISTICALLY HARDER,
LESS BACKGROUND

ULTIMATELY CAN BE DONE WELL
AT τ/CHARM FACTORY

MEASUREMENT OF PSEUDOSCALAR DECAY CONSTANTS

$$\langle 0 | A_\mu | M^+ \rangle \equiv i q_\mu V_{Q\bar{q}} f_M \qquad (M = Q\bar{q})$$

IN A NON-RELATIVISTIC QUARK MODEL:

$$f_M^2 \propto \frac{|\psi(0)|^2}{m_M}$$

$$B(M^+ \to \ell^+ \nu_\ell) = \frac{G_F^2}{8\pi} f_M^2 \tau_M m_M m_\ell^2 |V_{Qq}|^2 \left(1 - \frac{m_\ell^2}{m_M^2}\right)^2$$

	f_M (MeV) 100	200	300
$B(D^+ \to \mu^+ \nu)$	8.8×10^{-5}	3.5×10^{-4}	7.9×10^{-4}
$B(D_s^+ \to \mu^+ \nu)$	7.5×10^{-4}	3.0×10^{-3}	6.7×10^{-3}
$B(D_s^+ \to \tau^+ \nu)$	7.4×10^{-3}	2.7×10^{-2}	6.2×10^{-2}
$B(B^+ \to \mu^+ \nu)$	1.1×10^{-7}	4.4×10^{-7}	1.0×10^{-6}
$B(B^+ \to \tau^+ \nu)$	2.5×10^{-5}	9.9×10^{-5}	2.2×10^{-4}

CLEO: L MARK III $f_B < 2.90$ [illegible]

f_B ENTERS INTO MANY CKM MATRIX ELEMENT DETERMINATIONS

f_{D^+} OR $f_{D_s^+}$ MAY BE MORE ACCESSIBLE THEN SCALE TO GET f_B

2) EXCLUSIVE $B^+ \to \pi l \nu, \rho l \nu, \omega l \nu$

POTENTIALLY LESS MODEL DEPENDENT

<u>ARGUS</u> : $B^+ \to \rho^0 l^+ \nu_l$: $m_\nu^2 = 0$

$m^2_{MISSING} = (p_B - p_x)^2$

$\Rightarrow$ 31 ± 10 ρ's

$$B(B^+ \to \rho^0 e^+ \nu_e) = (1.13 \pm 0.36 \pm 0.30) \times 10^{-3}$$

MODEL	$\lvert V_{ub}\rvert / \lvert V_{cb}\rvert$
KS	0.15 ± 0.03
WBS	0.17 ± 0.03
ISGW	0.30 ± 0.06
KP	0.15 ± 0.03
KSM	0.11 ± 0.02

<u>PROSPECTS</u> : TAGGED SAMPLES AT A B FACTORY

$30 fb^{-1} \to 3 \times 10^7$ $B\bar{B}$ PAIRS

YIELDS $\sim 6 \times 10^5$ TAGS $D^* l \nu$

- SLAC $B \to \pi l \nu$: 440 TAGGED EVENTS $(\frac{S}{B} \sim 1)$
  $\sim 5\%$ MEASUREMENT
- DESY $B \to \rho l \nu$: 1400 TAGGED EVENTS
  $\sim 3\%$ MEASUREMENT

IT WILL ALSO BE POSSIBLE TO MEASURE q^2 DEPENDENCE OF FORM FACTORS IN PARTICULAR EXCLUSIVE CHANNELS

$|V_{ub}|$

1) INCLUSIVE ELECTRONS FROM $b \to u \ell \nu_\ell$ ABOVE THE KINEMATIC LIMIT FOR $b \to c \ell \nu_\ell$

- REQUIRES KNOWLEDGE OF $f_0 b_0 + f_- b_-$

  WHERE $b_0 = B(\overline{B}^0 \to X^+ \ell^- \nu_\ell)$

  $b_- = B(B^- \to X^0 \ell^- \nu_\ell)$

- MODELS OF SEMILEPTONIC DECAY

	CLEO	ARGUS
SAMPLE (pb^{-1})	212	237
$N_{B\overline{B}}$	244K	202K
EVENTS ($b \to u \ell \nu_\ell$)	$75.6 \pm 18.0 \pm 8.2$	77.1 ± 13.4
MOMENTUM INT:	2.2 – 2.6	2.3 – 2.6

EXTRACTION OF $|V_{ub}|/|V_{cb}|$

MODEL	CLEO	ARGUS
ISGW	0.15 ± 0.03	0.17 ± 0.03
KS	0.094 ± 0.014	0.11 ± 0.02
WSB	0.11 ± 0.06	0.12 ± 0.02
ACM	0.089 ± 0.044	0.11 ± 0.01

CONCLUSION: $|V_{ub}|/|V_{cb}| \cong 0.12 \pm ?$

APPLICATION OF HEAVY QUARK SYMMETRY

IN ISGUR-WISE <u>HEAVY QUARK SYMMETRY LIMIT</u>,

$B \to D l \bar{\nu}_l$, $D^* l \bar{\nu}_l$ ARE GOVERNED BY A <u>SINGLE</u> UNIVERSAL FORM FACTOR $\xi(y)$ $(y = v \cdot v')$

ZERO RECOIL $\xi(1) = 1$

NEUBERT:

$$\frac{d\Gamma}{dy} = \frac{G_F^2}{48\pi^3} |V_{cb}|^2 m_B^2 m_{D^{(*)}}^3 (y^2-1)^{1/2} (y+1)^2 F(r,y)$$

$r = \frac{m_{D^{(*)}}}{m_B}$

$$F(r,y) = \begin{cases} (1+r)^2 \frac{y-1}{y+1} \xi^2(y) & D l \bar{\nu}_l \\ \frac{4y}{y+1}(1-2yr+r^2)\xi^2(y) & D^*_T l \bar{\nu}_l \\ (1-r)^2 \xi^2(y) & D^*_L l \bar{\nu}_l \end{cases}$$

$D l \bar{\nu}_l$ SUPPRESSED BY $(y-1)$ AS $y \to 1$

CLAIMS $D^* l \nu_l$ MORE RELIABLE (CONTROVERSIAL ?)

USING $D^* l \bar{\nu}$, HE DETERMINES

$$|V_{cb}| = 0.045 \pm 0.007 \left(\frac{1.18\ ps}{\tau_{B^0}}\right)^{1/2}$$

UNCERTAINTY COMPARABLE TO THAT CLAIMED IN SPECIFIC MODELS, BUT THIS RESULT IS <u>MODEL-INDEPENDENT</u>.

MODEL DEPENDENCE OF $|V_{cb}|$ EXTRACTION

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & \blacksquare \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

MODEL	$\Gamma(\bar{B} \to D^{*}\ell\bar{\nu}_\ell)$ $(10^{12}\,sec^{-1})$	
ISGW	$11.1\ |V_{cb}|^2$	$\pm 16\%$
KS	8.3 "	
WBS	8.1 "	

$|V_{cb}|$	CLEO	ARGUS
KS	$0.039 \pm .005$	0.043 ± 0.007
WSB	$0.042 \pm .005$	0.046 ± 0.007
ISGW	0.039 ± 0.005	0.043 ± 0.007

PDG90: $|V_{cb}| = 0.044 \pm 0.009$ ← INCLUDES ESTIMATE OF TH. UNCERTAINT.

3 GEN UNITARITY 90% CL $0.030 - 0.058$

NB: THESE VALUES ASSUME $\Upsilon(4S) \to B\bar{B}$ ONLY

FUTURE PROSPECTS

$30\,fb^{-1} \Rightarrow 3\times10^7\ B\bar{B}$ PAIRS $\Rightarrow 6\times10^5$ SEMILEPTONIC TAGS

ALLOWS ABSOLUTE BR MEASUREMENT IN RECOIL:

$\sim 10^4$ DETECTED $B \to D\ell\nu$, $D \to K\pi^+$, $K\pi^+\pi^+$

$\Rightarrow 1\%$ STATISTICAL ERROR

REQUIRES IMPROVED ABSOLUTE BR'S

IF TH. ERROR REDUCED BY 2 $\Rightarrow \Delta|V_{cb}| \simeq .003$ ($\sim 7\%$)

$|V_{cb}|$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

1) INCLUSIVE SEMILEPTONIC b DECAYS

$$\Gamma(b \to c\ell\bar{\nu}_\ell) = \frac{G_F^2}{192\pi^3} m_b^5 \, F\left(\frac{m_c}{m_b}\right) |V_{cb}|^2$$

CASSEL

$B(b \to c\ell\bar{\nu}_\ell)(\%)$	ISGW	ACM	$\lvert V_{cb}\rvert$
CLEO	$10.0 \pm 0.1 \pm 0.2$	$10.4 \pm 0.1 \pm 0.2$	0.046 ± 0.003
ARGUS	$9.8 \pm 0.1 \pm 0.5$	$10.2 \pm 0.1 \pm 0.5$	0.045 ± 0.004

+ UNCERTAIN THEORETICAL ERROR

2) EXCLUSIVE SEMILEPTONIC B DECAYS

$$\Gamma(B \to D\ell\bar{\nu}_\ell) = \frac{G_F^2}{16\pi^3} M_B^5 |V_{cb}|^2 \int f_+^B(q^2) \times (E_D^2 - M_D^2)^{3/2} dq^2$$

	$B(\bar{B}^0 \to D^+\ell^-\bar{\nu}_\ell)$	$B(B^- \to D^0\ell^-\bar{\nu}_\ell)$
CLEO	$(1.8 \pm 0.6 \pm 0.3)\%$	$(1.6 \pm 0.6 \pm 0.3)\%$
ARGUS	$(1.8 \pm 0.6 \pm 0.5)\%$	

39 EVTS

EXTRACTING $|V_{cb}|$ REQUIRES

- [illegible] $\to 1.24$
- [illegible]
- [illegible] MODEL DEPENDENCE
- [illegible]
- [illegible] $f_+(q^2)$

PROSPECTS (CONT)

$$\left|\frac{V_{cd}}{V_{cs}}\right|^2 = \frac{B(D^0\to\pi^-e^+\nu_e)}{B(D^0\to K^-e^+\nu_e)}\left|\frac{f_+^{D\to K}(0)}{f_+^{D\to\pi}(0)}\right|^2 \frac{\int \frac{M_{D_s}^2}{M_{D_s}^2-q^2}(E_K^2-M_K^2)^{3/2}dq^2}{\int \frac{M_{D^0}^2}{M_{D^0}^2-q^2}(E_\pi^2-M_\pi^2)^{3/2}dq^2}$$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ \blacksquare & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

MARK III : 7 EVENTS $D^0\to\pi^-e^+\nu_e$

$$\left|\frac{V_{cd}}{V_{cs}}\right|^2 = 0.057\,^{+0.038}_{-0.015} \pm 0.005$$

ASSUMING $\dfrac{f_+^{D\to K}(0)}{f_+^{D\to\pi}(0)} = 1$ (c.f. LATTICE)

$\Rightarrow |V_{cd}| = 0.23\,^{+0.14}_{-0.06}$ INCLUDES ERROR ON $|V_{cs}|$

E687: EXPECTS 500 EVENTS

$\Rightarrow \dfrac{|V_{cd}|}{|V_{cs}|}$ to $\sim 3\%$, i.e. $\pm .006$

τ/charm : ~ 6000 $\pi\ell^+\nu_\ell$ EVENTS

$\dfrac{|V_{cd}|}{|V_{cs}|}$ to $\sim 1\%$ STATISTICAL.

$\therefore$ ULTIMATE ERROR ON $|V_{cd}|$ FROM $\pi e\nu$ WILL BE UNCERTAINTY ON $f_+^{D\to K}(0)$ OR $f_+^{D\to\pi}(0)$

ie, PERHAPS 5%

$|V_{cd}|$

1) $\nu, \bar{\nu}$ PRODUCTION OF $\mu^+\mu^-$ FROM VALENCE d QUARKS:

$$\frac{d^3\sigma^\nu}{d\xi\, dy\, dz} = \left(\frac{G_F^2 M E_\nu}{\pi}\right)\xi\left(\left[u(\xi)+d(\xi)\right]V_{cd}^2 + 2s(\xi)V_{cs}^2\right)\times$$

$$\times\left(1-\frac{m_c^2}{2ME_\nu\xi}\right)D(z)\,B_{c\to\mu}$$

WHERE $\xi = x + \frac{m_c^2}{2ME_\nu y}$; $\kappa = \frac{2s}{\bar{u}+\bar{d}}$; $x s(x) \propto (1-x)^\beta$

REQUIRES 4 PARAMETER FIT:

$$|V_{cd}|^2 B_c,\ \kappa|V_{cs}|^2 B_c,\ m_c,\ \beta$$

USE MEASURED $q(x), \bar{q}(x)$:

$$x\bar{q}(x) \propto (1-x)^{6.9}$$

$$x s(x) \propto (1-x)^{10.4\pm0.8\pm0.5} \quad \text{(CCFR)}$$

$$|V_{cd}|^2 B_c = \frac{2}{3}\,\frac{R^\nu - RR^{\bar{\nu}}}{1-R}$$

WHERE $R^\nu = \frac{\sigma^\nu_{2\mu}}{\sigma^\nu_{1\mu}}$ $\quad R = \frac{\sigma^{\bar{\nu}}_{1\mu}}{\sigma^\nu_{1\mu}}$

B_c FROM CHARMED PARTICLE FRACTIONS: $B_c = 0.110 \pm 0.0$
+ MEASURED $\Gamma(D^+\to \ell^+ X)$ (E531)
+ $D^0, D^+, D_s^+, \Lambda_c^+$ LIFETIMES

$\Rightarrow |V_{cd}| = 0.210 \pm 0.012$ AVERAGE

PROSPECTS: NEW FERMILAB PROPOSAL

60K $\mu^+\mu^-$ ($p_K > 4$ GeV)

$\Rightarrow |V_{cd}|$ TO ± 0.007

$|V_{cd}|$

1) $\nu, \bar{\nu}$ PRODUCTION OF $\mu^+\mu^-$ FROM VALENCE d QUARKS:

$$\frac{d^3\sigma^\nu}{d\xi\, dy\, dz} = \left(\frac{G_F^2 M E_\nu}{\pi}\right) \xi \left(\left[u(\xi) + d(\xi)\right] V_{cd}^2 + 2 s(\xi) V_{cs}^2 \right) \times$$

$$\times \left(1 - \frac{m_c^2}{2 M E_\nu \xi}\right) D(z)\, B_{c\to\mu}$$

WHERE $\xi = x + \frac{m_c^2}{2 M E_\nu y}$; $\kappa = \frac{2s}{\bar{u}+\bar{d}}$; $x s(x) \propto (1-x)^\beta$

REQUIRES 4 PARAMETER FIT:

$$|V_{cd}|^2 B_c, \quad \kappa |V_{cs}|^2 B_c, \quad m_c, \quad \beta$$

USE MEASURED $q(x), \bar{q}(x)$:

$$x\bar{q}(x) \propto (1-x)^{6.9}$$

$$x s(x) \propto (1-x)^{10.4 \pm 0.8 \pm 0.5} \quad \text{(CCFR)}$$

$$|V_{cd}|^2 B_c = \frac{2}{3} \frac{R^\nu - R R^{\bar{\nu}}}{1-R}$$

WHERE $R^\nu = \frac{\sigma^\nu_{2\mu}}{\sigma^\nu_{1\mu}}$ $\quad R = \frac{\sigma^{\bar{\nu}}_{1\mu}}{\sigma^\nu_{1\mu}}$

B_c FROM CHARMED PARTICLE FRACTIONS: $B_c = 0.110 \pm 0.00$ (E531)

+ MEASURED $\Gamma(D^+ \to \ell^+ X)$

+ $D^0, D^+, D_s^+, \Lambda_c^+$ LIFETIMES

$\Rightarrow |V_{cd}| = 0.210 \pm 0.012$ AVERAGE

PROSPECTS: NEW FERMILAB PROPOSAL

60K $\mu^+\mu^-$ ($p_K > 4$ GeV)

$\Rightarrow |V_{cd}|$ TO ± 0.007

PROSPECTS

$$\begin{pmatrix} V_{uc} & V_{us} & V_{ub} \\ V_{cd} & \blacksquare & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

FIXED TARGET:

CUMALAT e.g. E687 : 5000 $D^0 \to K^- e^+ \nu_e$ EVENTS

$\to$ 2% STATISTICAL ERROR

HOWEVER $|V_{cs}|$ REQUIRES ABSOLUTE NORMALIZATION

CUMALAT: D^{*}'s $\Rightarrow$ 4 – 5% STAT. ERROR

e^+e^-: ABSOLUTE $B(D^0 \to K^-\pi^+)$ TO NORMALIZE

BCS: 10 x MARK III $\to$ 3% STAT. ERROR

τ/CHARM (?): $\to$ ~.3% "

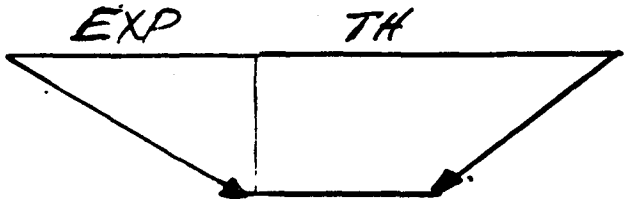
OR

ABSOLUTE $B(D^0 \to Ke\nu)$

BCS: $\to$ 3%

τ/CHARM: $\to$ ~.6%

$\therefore$ DOMINANT SOURCE OF ERROR REMAINS $f_+^D(0)$



$|V_{cs}|$

$$\begin{pmatrix} V_{uc} & V_{us} & V_{ub} \\ V_{cd} & \blacksquare & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

BY ANALOGY WITH $|V_{us}|$ FROM K_{e3}:

$$\Gamma(D \to K\ell\nu) = \frac{G_F^2}{16\pi^3} M_D^5 |V_{cs}|^2 \int |f_+^D(q^2)|^2 (2x_e - 2x_K x_e - x_e^2 - 1 - \lambda^2)\, dq^2$$

$$\simeq |V_{cs}|^2 \, |f_+^D(0)|^2 \, (1.54 \times 10^{11}\ s^{-1})$$

ASSUMING $f_+^D(q^2) = f_+^D(0) \dfrac{M_{pole}^2}{M_{pole}^2 - q^2}$

AND $M_{pole} = 2.1$ GeV $\left\{ \begin{array}{l} \text{MARK II} \\ \text{E691} \end{array} \right.$

CURRENT STATUS

MARK III : $B(D^0 \to K^- e^+ \nu_e) = (3.9 \pm 0.6 \pm 0.6)\%$ ABSOLUTE

E691 : $= (3.8 \pm 0.5 \pm 0.6)\%$ REL $K^-\pi^+$

E691 : $\tau(D^0) = (4.28 \pm 0.11) \times 10^{-13}$ s

$B(D^0 \to K^-\pi^+)$
$= (4.2 \pm 0.4 \pm$

$$\Rightarrow |f_+^D(0)|^2 |V_{cs}|^2 = 0.51 \pm 0.07$$

$f_+^D(q^2)$ IS BEST DETERMINED AT $q^2_{max} = (M_D - M_K)^2$

ISGW, etc : $f_+^D(0) = 0.7 \pm 0.1$

$$\Rightarrow |V_{cs}| = 1.02 \pm 0.18$$

3 GEN. UNITARITY: $0.9734 - 0.9752$
90% CL

$|V_{us}|$

1) $$\Gamma(K \to \pi \ell \nu) = \frac{G_F^2}{16\pi^3} M_K^5 |V_{us}|^2 \int |f_+^K(q^2)|^2 (2x_\ell - 2x_\pi x_\ell - x_\ell^2 - 1 - \lambda^2)\, dq^2$$

ASSUME $$f_K^+(q^2) = f_+^K(0) \frac{M_{K^*}^2}{M_{K^*}^2 - q^2}$$

(ADEMOLLO-GATTO)

USE BOTH $K^+ \to \pi^0 e^+ \nu_e$ AND $K_L^0 \to \pi^- e^+ \nu_e$ (1% MEASUREMENTS)

WITH ISOSPIN CORRECTIONS

$$\Rightarrow |V_{us}| = 0.2196 \pm 0.0023$$

2) HYPERON DECAY

LARGER THEORETICAL UNCERTAINTIES DUE TO SU(3) BREAKING IN AXIAL-VECTOR COUPLING

WA2: $|V_{us}| = 0.222 \pm 0.003$

PDG 90: USE BOTH MEASUREMENTS:

$|V_{us}| = 0.2205 \pm 0.0018$

3 GEN UNITARITY: $0.218 - 0.224$

PROSPECTS: $B(K^+ \to \pi^0 e^+ \nu_e)$ COULD LIKELY BE SUBSTANTIALLY IMPROVED WITH A NEW EXPERIMENT

a) BNL K DECAYS

b) ϕ FACTORY – 10^9 DECAYS

USE TAGS

$\Rightarrow |V_{us}|$ TO FEW $\times 10^{-3}$

NB: RADIATIVE CORRECTIONS

$|V_{us}| = \lambda$: λ^n ENTERS EVERYWHERE

$|V_{ud}|$

3) PION β DECAY — PURE VECTOR TRANSITION

$$B(\pi^+ \to \pi^0 e^+ \nu_e) = (1.025 \pm^{0.033}_{-0.034}) \times 10^{-8}$$

[MUST IMPROVE PRECISION BY FACTOR OF ~20
<u>AND</u> IMPROVE $\Delta(m_{\pi^+} - m_{\pi^0})$

$$\Longrightarrow \quad |V_{ud}| = 0.968 \pm 0.018$$

NEW: CRAWFORD et.al $\Delta m = 4.59366 \pm 0.00048$ MeV

1986 PDG $= 4.6043 \pm 0.0037$

2.9σ FACTOR: 7.7

- NEW PSI EXP PROPOSES $B(\pi^+ \to \pi^0 e^+ \nu_e)$ TO 0.25%
- PILAC NOTE (MACPHERSON) TO 0.1–0.2%

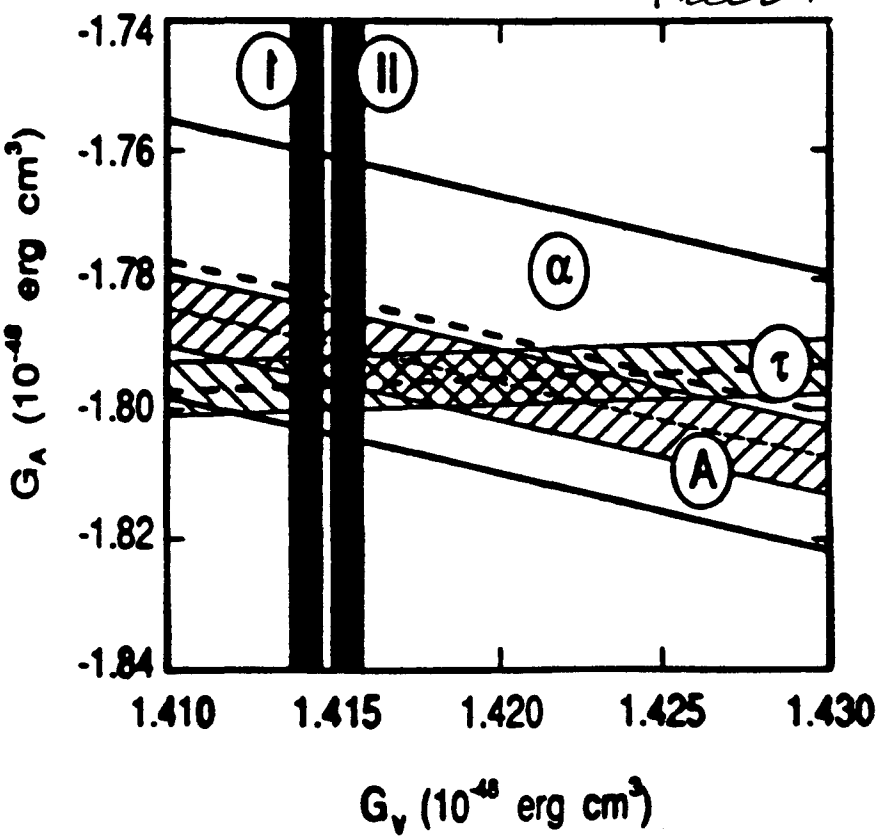
3 GENERATION UNITARITY:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9992 \pm 0.0015$$

ft, τ_μ PDG 90 SCHRODER

<u>PROSPECTS</u>: CONSISTENCY CAN BE IMPROVED, BUT PRECISION OF $|V_{ud}|$ IS UNLIKELY TO GET MUCH BETTER

FREEDMAN


-1.74
-1.76
-1.78
-1.80
-1.82
-1.84
G_A (10^{-48} erg cm^3)
I
II
α
τ
A
1.410
1.415
1.420
1.425
1.430
G_V (10^{-48} erg cm^3)

$|V_{ud}|$

N.B. QUOTED 0.1% ERROR IS DOMINATED BY UNCERTAINTIES IN δ_c, Δ_β

UNCERTAINTIES IN MEASUREMENT OF τ_μ, ft VALUES CONTRIBUTE 0.02%

2) NEUTRON DECAY

MEASURE τ_n AND G_A/G_V FROM

β ASYMMETRY AND

β-ν ANGULAR CORRELATION

HOWEVER: PRIOR TO 1986 $\tau_n = 903.7 \pm 6.4$ s

NEW: MAMPE, et al 887.6 ± 3

BYRNE, et al 893.6 ± 5.3

$G_A/G_V = 1.260 \pm 0.003$ KLEMT, et al.

$\Rightarrow |V_{ud}| = 0.9778 \pm 0.0029$

→ 0.0005 RAD COR

0.0014 τ_n

0.0018 G_A/G_V

- UNCERTAINTY DOMINATED BY MEASUREMENT
- AGREEMENT WITH ft/τ_μ VALUE POOR
- RUMORED NEW NEUTRON RESULTS FROM SOVIET UNION INCREASE DISCREPANCY

HAGRY et al

$|V_{ud}|$

1) COMPARISON OF RADIATIVELY CORRECTED MUON LIFETIME:

$$G_F^2 = \frac{192\pi^3}{\tau_\mu m_\mu^5} \frac{1}{\left(1 - 8\frac{m_e^2}{m_\mu^2}\right)\left[1 + \left(\frac{25}{4} - \pi^2\right)\frac{\alpha}{2\pi}\right](1+\Delta_\mu)}$$

$$\tau_\mu = 2.197035 \pm 0.000040 \times 10^{-6}\,s$$

$$\Longrightarrow G_F = 1.16637 \pm 0.00002 \times 10^{-5}\,GeV^{-2}$$

WITH RATES OF SUPER-ALLOWED $0^+ \to 0^+$ β DECAYS:

$$|V_{ud}|^2 G_F^2 = \frac{\pi^3 \ln 2\; ft(N_i \to N_f e^+ \nu_e)}{m_e^5 (1-\delta_c)(1+\delta_r)(1+\Delta_\beta)}$$

"COULOMB" "OUTER" INNER (SCALE DEPENDENT)

MARCIANO & SIRLIN: $\Delta_\beta - \Delta_\mu = 0.0243 \pm 0.0018$

NEW COMPILATION OF CHALK RIVER GROUP DOES <u>NOT</u>, AFTER δ_c & δ_r CORRECTION, SHOW RESIDUAL Z DEPENDENCE OF ft VALUES OF 8 BEST-MEASURED $0^+ \to 0^+$ TRANSITIONS

$$\langle ft \rangle = 3073.8 \pm 0.9\ s$$

$$\Longrightarrow |V_{ud}| = 0.9736 \pm 0.0010$$

$$[\,0.9744 \pm 0.0010 \quad \text{PDG 90}\,]$$

EMPIRICAL CORR:
RASCHE & WOOLOCK $\sim Z$
WILKINSON $\sim Z^2$ ✗

ALL DETERMINATIONS OF $|V_{Qq}|$ INVOLVE DETERMINATION OF AN ABSOLUTE SEMILEPTONIC DECAY WIDTH.

- INCLUSIVE DECAY WIDTHS $\propto m_Q^5$.

  $\therefore$ INCLUSIVE SPECTRA USEFUL FOR RATIOS:

  e.g. $|V_{ub}/V_{cb}|$

- EXCLUSIVE WIDTHS ($0^- \to 0^-$ EXAMPLE)

$$\Gamma\left(M(Qq) \to m(qq)\ell\nu_\ell\right) = \frac{G_F^2 |V_{Qq}|^2}{16\pi^3} M(Qq)^5 \times$$

$$\times (1+\delta_r) \times \int |f_+^M(q^2)|^2 \left(2x_\ell - 2x_m x_\ell - x_\ell^2 + x_m - 1 - \lambda^2\right) dq^2 dx_\ell$$

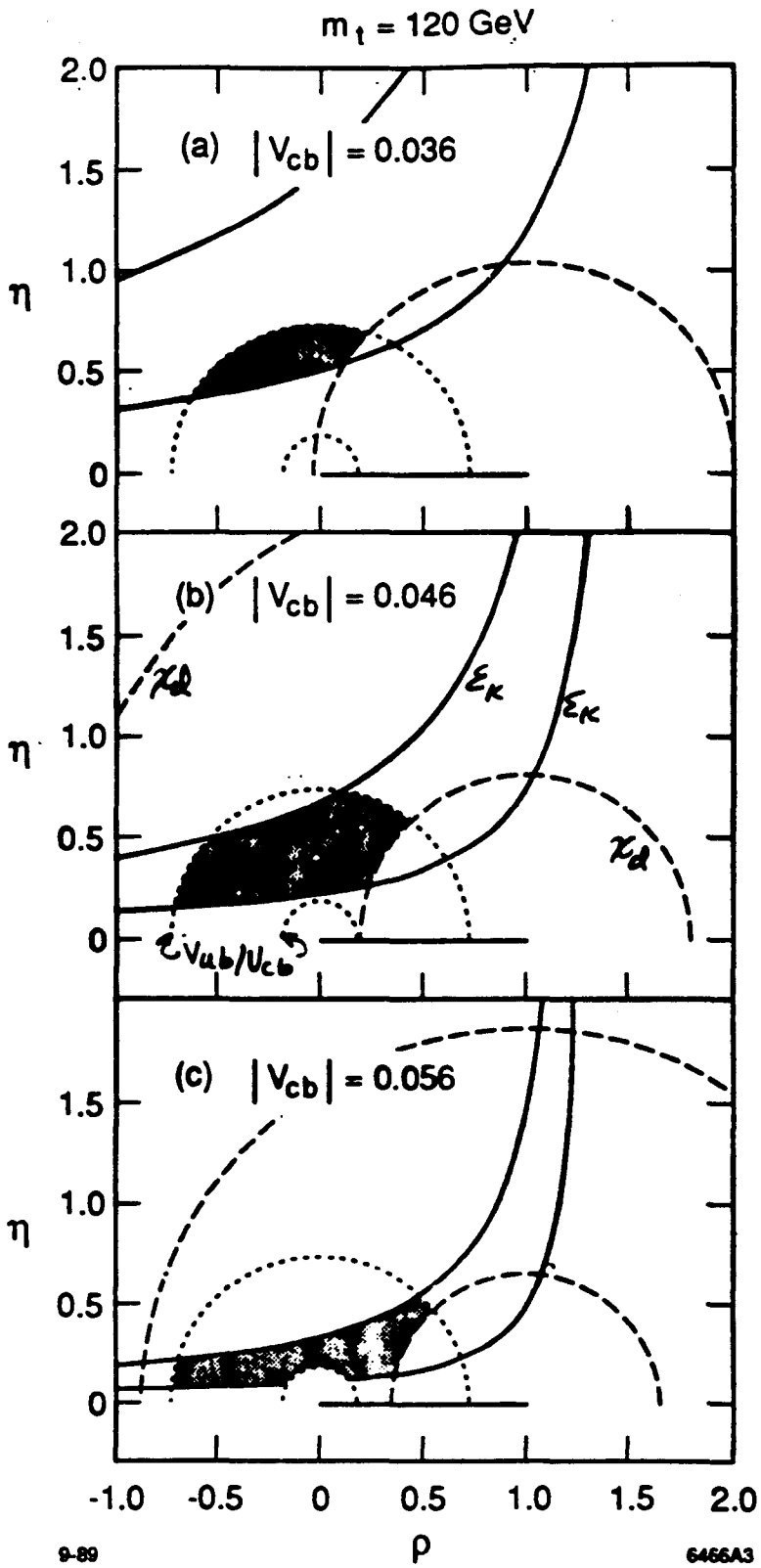
WHERE: $x_\ell = \frac{2E_\ell}{m_M}$ $\quad x_m = \frac{2E_m}{m_M}$ $\quad \lambda = \frac{m_m}{m_M}$

$$\langle m | V_\mu | M \rangle = (p_M + p_m) f_+^M(q^2) + (p_M - p_m) f_-^M(q^2)$$

δ_r = RADIATIVE CORRECTION

APPLIED ONLY IN $|V_{ud}|$ CASE, BUT SHOULD BE USED ELSEWHERE, e.g. $|V_{us}|$ AND PERHAPS IN OTHER CASES.

DIB, DUNIETZ, GILMAN, NIR



$0.04 \le |V_{ub}/V_{cb}| \le 0.16$

χ_d

$(0.1\ \mathrm{GeV})^2 \le B_B f_B^2 \le (0.2\ \mathrm{GeV})$

$1.04\ \mathrm{ps} \le \tau_B \le 1.32\ \mathrm{ps}$

$\Rightarrow 0.50 \le \chi_d \le 0.78$

ε_K

$1/3 \le B_K \le 1$

Combining the small-angle approximations of the Wolfenstein parametrization: $(\lambda = \sin\theta_c)$

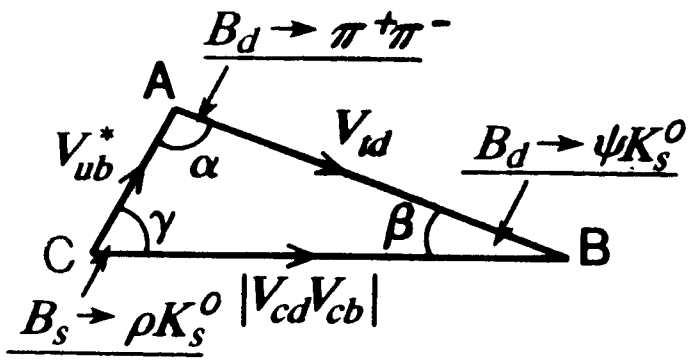
$$\begin{array}{c} \\ u \\ c \\ t \end{array} \begin{array}{c} \begin{array}{ccc} d & s & b \end{array} \\ \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} \end{array}$$

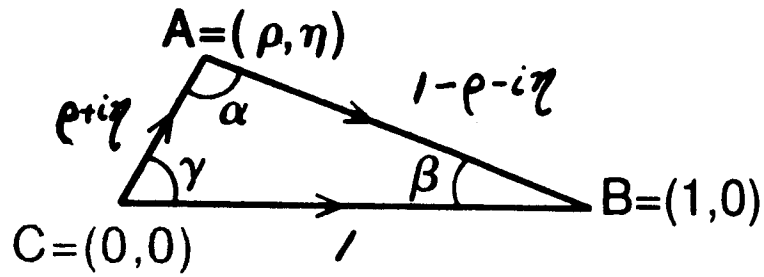
with the unitarity condition:

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

and recognizing that $V_{ud} \simeq 1$, $V_{tb} \simeq 1$ **and** $V_{cd} \simeq -\sin\theta_c$,

yields the UNITARITY TRIANGLE:





$\cos\delta > 0$ ($\cos\delta < 0$)

PDG "STANDARD PARAMETRIZATION"

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$\begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{13}} \\ -s_{12}c_{23}-c_{12}s_{23}s_{13}e^{i\delta_{13}} & c_{12}c_{23}-s_{12}s_{23}s_{13}e^{i\delta_{13}} & s_{23}c_{13} \\ s_{12}s_{23}-c_{12}c_{23}s_{13}e^{i\delta_{13}} & -c_{12}s_{23}-s_{12}c_{23}s_{13}e^{i\delta_{13}} & c_{23}c_{13} \end{pmatrix}$$

WOLFENSTEIN PARAMETRIZATION

$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$$\lambda = 0.22 \qquad A \doteq 1.0$$

- TESTS OF THE CONSISTENCY OF THE CKM MATRIX ARE BASIC TO AN UNDERSTANDING OF THE QUARK SECTOR OF THE STANDARD MODEL.

- DETERMINATION OF CKM MATRIX ELEMENTS INVOLVES AN INTERPLAY BETWEEN THEORETICAL AND EXPERIMENTAL UNCERTAINTIES

  - WHAT ARE THE PROSPECTS FOR IMPROVEMENT IN BOTH AREAS ?

- ASCERTAINING WHETHER THE CKM PHASE δ ACCOUNTS FOR CP-VIOLATING EFFECTS IN THE K AND B MESON SYSTEMS IS A MAJOR GOAL OF THE PHYSICS OF THE NEXT DECADE

- PRECISION OF THE DETERMINATION OF <u>ALL</u> CKM MATRIX ELEMENTS IS RELEVANT TO SHARPENING CONSTRAINTS ON THE UNITARITY TRIANGLE

PROGRAM

Second Annual SSC Spring Conference
Electroweak and Flavor Physics: Implications for the SSC

Monday, May 20 - Thursday, May 23

Thursday May 23

AM	**SSC Possibilities for B Physics**	Chair: F. Paige (SSCL/BNL)
9:00	Round Table: Intervening Moderator:	 F. Paige (SSCL/BNL)
	Cast:	B. Cox (UVA) N. Lockyer (Pennsylvania) P. Schlein (UCLA) S. Stone (Syracuse)
	Break	
11:30	What Lies Ahead?	R. Schwitters (SSCL)

A Super Fixed Target Beauty Physics Facility at the Superconducting Super Collider

SFT

B. Cox
University of Virginia

20 TeV Fixed Target B Physics
using
A 20 TeV Crystal Channeled
Proton Beam

EOI-14

Super Fixed Target B Facility
Participants
(139 Physicists, 36 Insititutions)

University of Athens:	S.E. Anassontzis, S. Katsenevas, C. Kourkoumelis, P. Ioannu, G. Kalkanis, T. Premantiotis, A. Manousakis-Kaftsikakis, L.K. Resvanis, P. Spentzouris, G. Voulgaris
Bratislava University:	B. Sitar, S. Tokar
Univ. of Cal., Berkeley:	H.C. Ballach, H. Bingham, J. Lys
Univ. of Cal. , Los Angeles:	A. Boden, D. Cline, J. Rhoades
Carnegie Mellon:	J. Russ
Duke University:	L. Fortney, W. Kowald
Dubna:	J.A. Budagov, N.S. Angelov, A.G. Asmolov, N.I. Chernov, I.N. Churin, I. E. Chirikov-Zorin, J.I. Davidov, V.H. Dodohov, A. T. Filippov, V.B. Flyagin, V.V Glagolev, V.M. Grebeniuk, V.V. Ivanov, B.A. Khachaturov, D.M. Khazins, S.M. Korenchenko, S.N. Maliukov, V.I. Moroz, G.A. Ososkov, N.O. Poroshin, V.I. Prihod'ko,S.I. Merzliakov, N. A. Russakovich, G. G. Takhtamyshev, A.G. Volodko, ; E.N. Tsyganov, S.V. Borodin, Y.N. Gotra, V.N.Pozdnjakov, V.N. Ryzkov, A.B. Sadovsky, A.M. Taratin, V.G. Timofeev, S.A. Zaporozhets
Erevan State University:	S.L. Bagdasarov, G.S. Pogosian
Fermilab:	R. Carrigan, D. Christian, M. Haire, P.O. Mazur, C.T. Murphy, S. Peggs, S. Pruss, R.P.Smith, L. Spiegel
University of Houston:	G. Mo, K. Lau
Gomel State University:	A.M. Dvornik, N.V. Maksimenko
Inst. of Exp. Physics, Kosice:	E. Kladiva, J. Nemchik, L. Sandor
Lebedev Physical Institute:	B. Govorkov, L.N. Shtarkov, G. Sokol
University of Lecce and INFN:	P.Creti, E. Gorini, F. Grancagnolo, M. Panareo,O. Palamara, F. Palama, P. Pistilli
Leningrad Nuclear Phys. Inst.:	A. Khanzadeev, V. Samsonov, A. Vorobyov
Los Alamos National Lab.:	P.L. McGaughey
Northwestern University:	M. Block, M. Recagni
Belorussian Acad. of Sc.	A.S. Kurilin, V.S. Rumiantsev
McGill University:	J. Trischuk
Univ. of New Mexico:	J. Ellison
Oak Ridge National Lab:	H. Brashear, N. Ericson, T. Gabriel, T. Moore
Nanjing University:	T.Y. Chen, N.Yao
Northern Illinois Univ.:	D. Kaplan
Univ. of Pavia and INFN:	L. Antoniazzi, G. Boca, M. Cambiaghi, G. Introzzi, G. Liguori, S. Ratti, P. Torre
Univ. of Pennsylvania:	W. Kononenko, W. Selove
Shandong University:	M. He, N.J. Zhang, C.R. Wang, Z.L. Cao, C. Wei,B.T. Zou
Univ. of South Alabama:	K. Clark, M. Jenkins
Univ. of South Carolina:	F. Avignone, R. Childers, C. Darden
State Univ. of New York, Suny:	C.R. Sun
Inst. of HEP of Tbilisi Univ.	G.A. Chlachidze, D.Q. Djincharadze, I.A. Minashvili, M.S. Nioradze, Z.R. Salukvadze,
Sofia University	L. Litov
SSC Laboratory:	J. Kuzminski, T. Toohig
Univ. of Texas, Austin:	B. Newberger
University of Wisconsin:	A. Erwin, M.A. Thompson
Vanier College:	M. Cooper
Univ. of Virginia:	M. Arenton, S. Conetti, B. Cox, C. Dukes, A. McManus, K. Nelson

- EOI-14 for the SFT submitted to the SSCLab — May 25, 1990
- EOI-14 presented to the PAC — June 7, 1990
- Discussions with PAC — July, 1990
- Submission of answers to PAC questions — July 12, 1990
- PAC Recommendations — July 31, 1990
- R. Schwitters's Letter to SFT collaboration — July 31, 1990
- Development of simulations of SSC extraction — Fall, Winter, 90
- Testing of crystal performance at CERN — Summer, 90
- Crystal Channeling Workshop — May, 1991
- Submission of proposal to test extraction technique at FNAL — May, 1991
  (proposal in process at CERN to test crystal extraction at the SPS for the LHC) — April

<u>Future activities</u>

- More crystal testing at CERN — Summer, 1991
- Operation of open geometry fixed target B experiment at FNAL (E771, E791, E789) — Summer, 1991 Fall
- Definition of procedures for 'small' exp by SSCLab — Summer, 1991
- Extraction tests at FNAL — Spring, 1991
- Detector R+D for SFT — Summer, 91 →

<u>Need FY92 R+D funds</u>

- Decision to proceed to Technical proposal — Spring, 92

Superconducting Super Collider
Laboratory

2550 Beckleymeade Avenue, MS 1070
Dallas, TX 75237-3946
(214) 708-1036 • FAX (214) 708-0000

Director's office

July 31, 1990

Professor Brad Cox
Physics Department
J.W. Beams Laboratory
University of Virginia
McCormick Road
Charlottesville, VA 22901

Dear Brad:

Thank you for your response to the questions posed by the Program Advisory Committee about your Expression of Interest in an experiment at the SSC (EOI-14 – "Super Fixed Target Beauty Facility"). The PAC met for a week (July 14–20) at Snowmass and discussed all the EOIs and the associated responses.

The Committee recognized that B physics is an important and promising area of elementary particle physics research, especially in the study of CP violation and other rare phenomena which may give us an insight into physics that lies beyond the Standard Model. The PAC also felt that the SSC has some special capabilities for B physics. In its report it stated that "Given the strong interest of the physics community, it would be desirable to incorporate B physics into the initial SSC program. We note, however, that considerable evolution of the field may occur over the next few years. The cost and technical risk associated with a collider detector for B physics make it premature to encourage such a proposal at this time; it may be more appropriate a few years from now. For the initial SSC program a fixed-target experiment may prove a better choice."

With respect to your particular EOI, the Committee felt that an external target experiment had some important advantages over an internal target approach if extraction of an external beam is shown to be feasible without impairing the operation of the collider. There are serious concerns here, and the Committee recommended that tests on the viability of the proposed crystal extraction scheme deserve a high priority within this context. In particular, a test at Fermilab in a realistic environment was deemed as one appropriate course of action that would hopefully give us some hard evidence on the likelihood of the extraction technique working at the SSC. ← ①

While the number of produced B's is acknowledged to be at least competitive with the sample at other electron-positron and hadron colliders likely to be operating at the time of turn-on of the SSC, the PAC found that the reconstruction efficiency assumed in the EOI for seeing the B and the $\bar{B}$ was far beyond the state-of-the-art with a "live" target. A high efficiency will indeed be necessary to be fully competitive with proposed electron-positron projects. Consequently, the PAC will follow closely the physics results and the progress that is made in reconstruction/tagging efficiencies in on-going experiments, including your own. ← ②

Central Ideas of the SFI

- Will run concurrently and in a non interfering way with the SSC collider program

- will produce a beam of $\sim 10^8$ protons/sec allowing operation of the B experiment at $\sim 10^7$ int/sec
  $\rightarrow$

  $2 \times 10^{10} \rightarrow 10^{11}$ B's/year (10^7 sec)

- be designed to take advantage of the unique features of $\sqrt{s} = 193$ GeV B production in a fixed target mode

- Economical way to do B physics relative to other proposed e^+e^- or hadron options

  Present Estimate

  \$ $\sim$ 43.7 M

  for spectrometer, experimental hall, extraction system and beam line

- Open Geometry – Large Acceptance Forward Spectrometer with a 'live' target/tracker microvertex detector (planar silicon)

- Extraction by crystal channeling of RF manipulated beam (backup with ordinary electrostatic septa under design)

Special Attributes / Features of a 20 TeV Fixed Target B Configuration

- $\frac{\sigma(B\bar{B})}{\sigma_T} \sim \frac{1}{2000} \to \frac{1}{8000}$ (compared to $\frac{1}{200} \to \frac{1}{500}$ for SSC collider)

- $2\times10^{10} \to 10^{11}$ B's / 10^7 sec (completely sufficient to measure CP violation in several modes)
  order of charm production at Fermilab

- Allows microvertex detector to be configured so that B production and decay takes place inside the detector $B^\pm$, $D^\pm$, $\tau^\pm$ can be directly observed with many, many measurements on each track because of the high momenta, low multiple scattering (and resulting large number of measurement planes that are permitted) Entire event topology is laid out for experimenter.
- High momentum of B's and their secondaries allow relatively easy triggering on leptons ($\langle p_B \rangle \sim 445$ GeV/c, $\langle p_K \rangle \sim 280$ GeV/c)

- Determination by direct observation of charge of B ($B^\pm$ vs B^0) aids in $B^\pm_u$ tagging for CP violation measurements

- Relatively low multiplicity from primary vertex ($\lesssim 20$) makes for clean events

- All of these features lead to high triggering, acceptances, and reconstruction efficiencies for reconstructable modes (few% to 10% of all exclusive $\bar{B}$ decays such as $B^{\pm} \to \psi K^{\pm}$ and $B^0 \to \psi K^0_S$ ($K^0_S \to \pi\pi$) are reconstructed compared to .1%'s in collider configuration experiments)

  [illegible] more than comparable with collider [illegible] of $\bar{B}$'s.

- Spectrometer can be implemented with modest extensions of present day technology

- Spectrometer need only cover a very limited solid angle and therefore is relatively inexpensive (entire SFT facility only costs $^{\$}$15M; spectrometer approximately $^{\$}$25M)

- Techniques are proven or under development in real experiments at Fermilab (E771, 791, 687, 789 ....). Proof of ability of technique to get out physics already exists in the form of charm measurements E691, 791, 687

Table I

Important Parameters of Beauty Production
in Various Hadronic Experimental Configurations

	TeV II Fixed Tgt	TeV I Collider	SSC Collider	SSC Fixed Tgt	
Int Rate	10^7-10^8/sec	10^5/sec*	10^7/sec**	10^7/sec	
$\sigma(pN \rightarrow B\bar{B})$	10 nb	20 μb	200-500 μb	2.5 -10 μb	
$B\bar{B}/10^7$ sec	10^7-10^8	4×10^8	2×10^{11}-5×10^{11}	1×10^{10}-5×10^{10}	
$\sigma(B\bar{B})/\sigma_T$***	1/1250000	1/2500	1/500-1/200	1/7700-1/1900	← reasonable richness
Multiplicity	≈15	≈45	"few" hundred	≈20	← relatively 'clean' event
$\langle p_b \rangle$	143 Gev/c	38 GeV/c	51 GeV/c	635 GeV/c	
$\langle p_B \rangle$	118 GeV/c	22 GeV/c	43 GeV/c	445 GeV/c	← Ease of trigger
$\langle p_\mu \rangle$	32 GeV/c	13 GeV/c	36 GeV/c	280 GeV/c	← Negligible multiple scattering
Median B Decay Length	8mm	1.5mm	3mm	42mm	Direct observation of B meson tracks
Mean B Decay Length	16mm	4.7mm	13mm	95mm	

* Present luminosity ≈ 10^{30} cm^2 s^{-1} for the Fermilab Collider. Presuming the injector upgrades and corresponding detector upgrades to take advantage of the higher luminosity, this may be increased to 5×10^{31} cm^2 s^{-1}.

** 10^7 interactions per second is taken as a limit for a high rate 4π B physics collider detector to avoid the problem of multiple high multiplicity events per bucket.

*** Taking into account the atomic number enhancement of the heavy flavor cross sections in heavy targets relative to the total cross section.

Experimental Issues
with Hadronic Experiments

- [illegible] data acquisition
- We must worry about radiation damage

- **Individual elements of the spectrometer may degrade because of <u>rate effects</u> or <u>radiation damage</u>**
  - have run Z705 at 10^6 int/sec routinely
  - have tested to 3.5×10^6 int/sec

  } OK at 10^7 int/sec for 10^7 sec

- **We may saturate data taking capability of the spectrometer if trigger is too loose or D.A. too slow.**
  - Estimates of trigger rates using different B trigger strategies at the SSC show that we need only to record 1000 events/sec
  - Trigger strategies (and available technologies) exist that allow reductions

    $10^7/\text{sec} \rightarrow$ few hundred/sec $\approx \underline{5 \times 10^{-5}}$

    (for the sum of dimuons and single muon triggers [illegible])

    B events in 20 TeV Fixed Target interaction are quite distinguishable from total cross section events

  - Requires three levels of muon trigger plus additional triggers to strengthen the single muon trigger (multiplicity jump + intermediate $p_\perp$ particle)

- We must maintain good silicon vertex detector response – (good vertex resolution

SSC Super Fixed Target Beauty Spectrometer

SFT

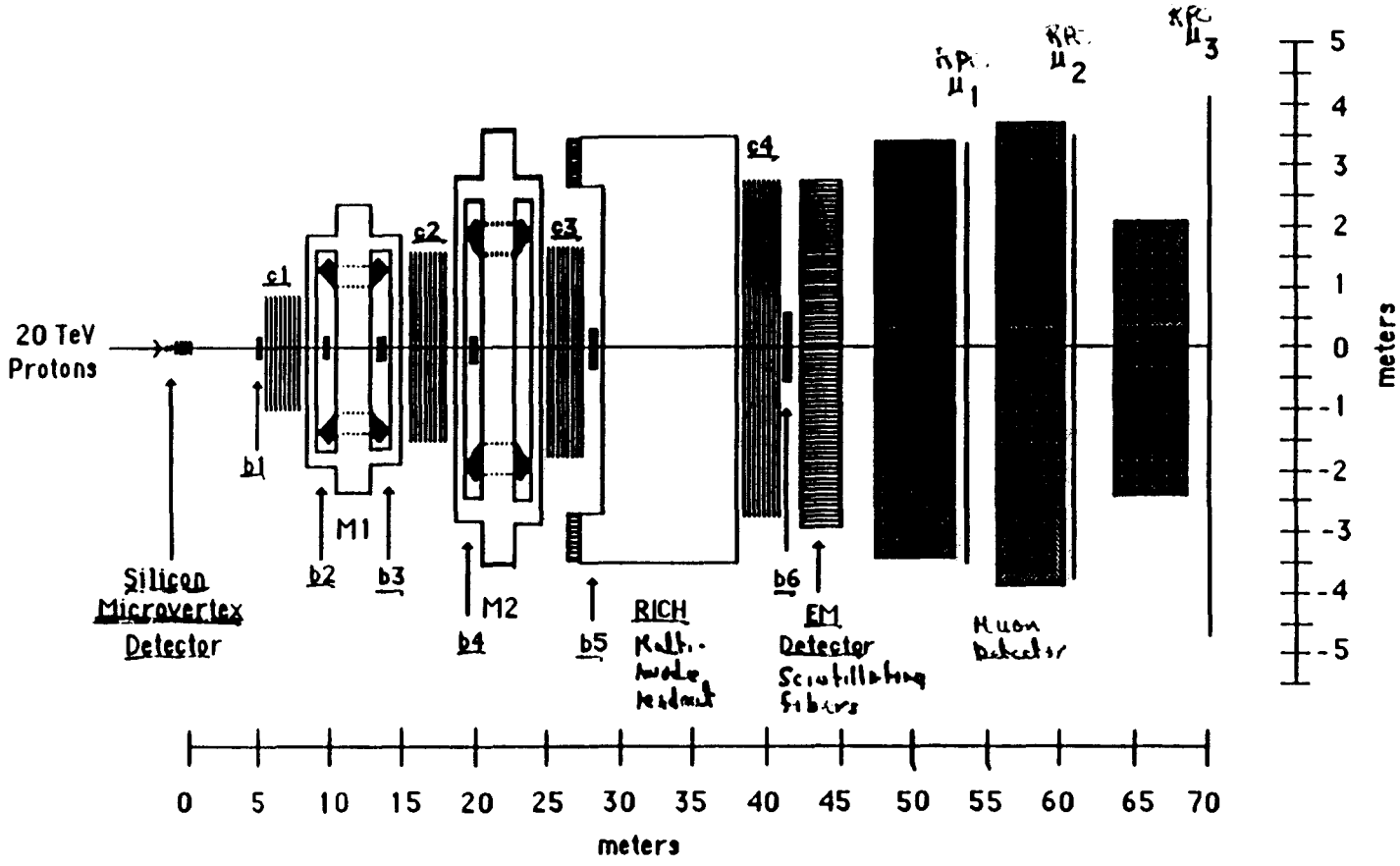
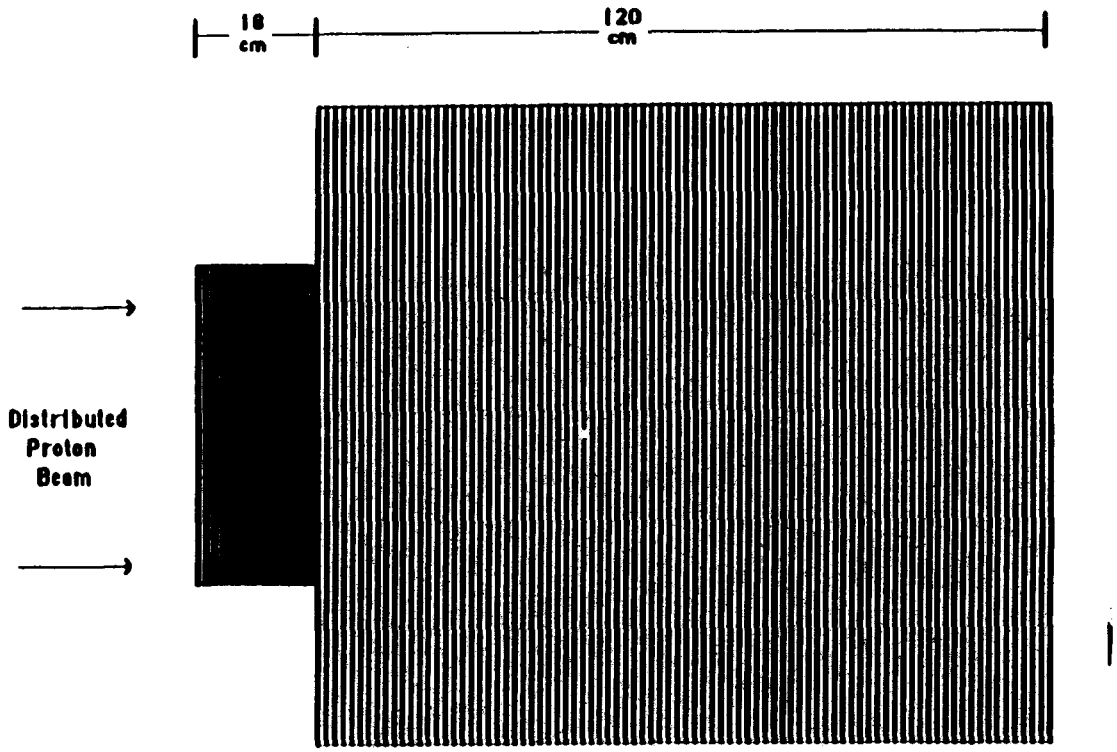


Fig. 4

Acceptance 3 mrad → 75 mrad

Similar to present day spectrometers
No unusable technology needed

SFT Silicon Microvertex Detector
Schematic



May distribute beam by

1. Large beam spot
2. Small beam spot but move vertex detector periodically

1. Simple planar geometry
2. B's are produced and decay in the target region of the SFT detector
3. Unresolved discussion Magnetic field on the silicon vertex region

Live Target Section

30 - 200 micron planes
0,30,60 Degree Orientation
10/10/10
6 mm spacing
25 micron pitch
30 Be Foils - 850 micron
0.076 λ 0.137 X_0

Tracking Section

30 - 200 micron planes
0,30,60 Degree Orientation
10/10/10
4 cm spacing
50 micron pitch
0.013 λ_0 0.06 X_0

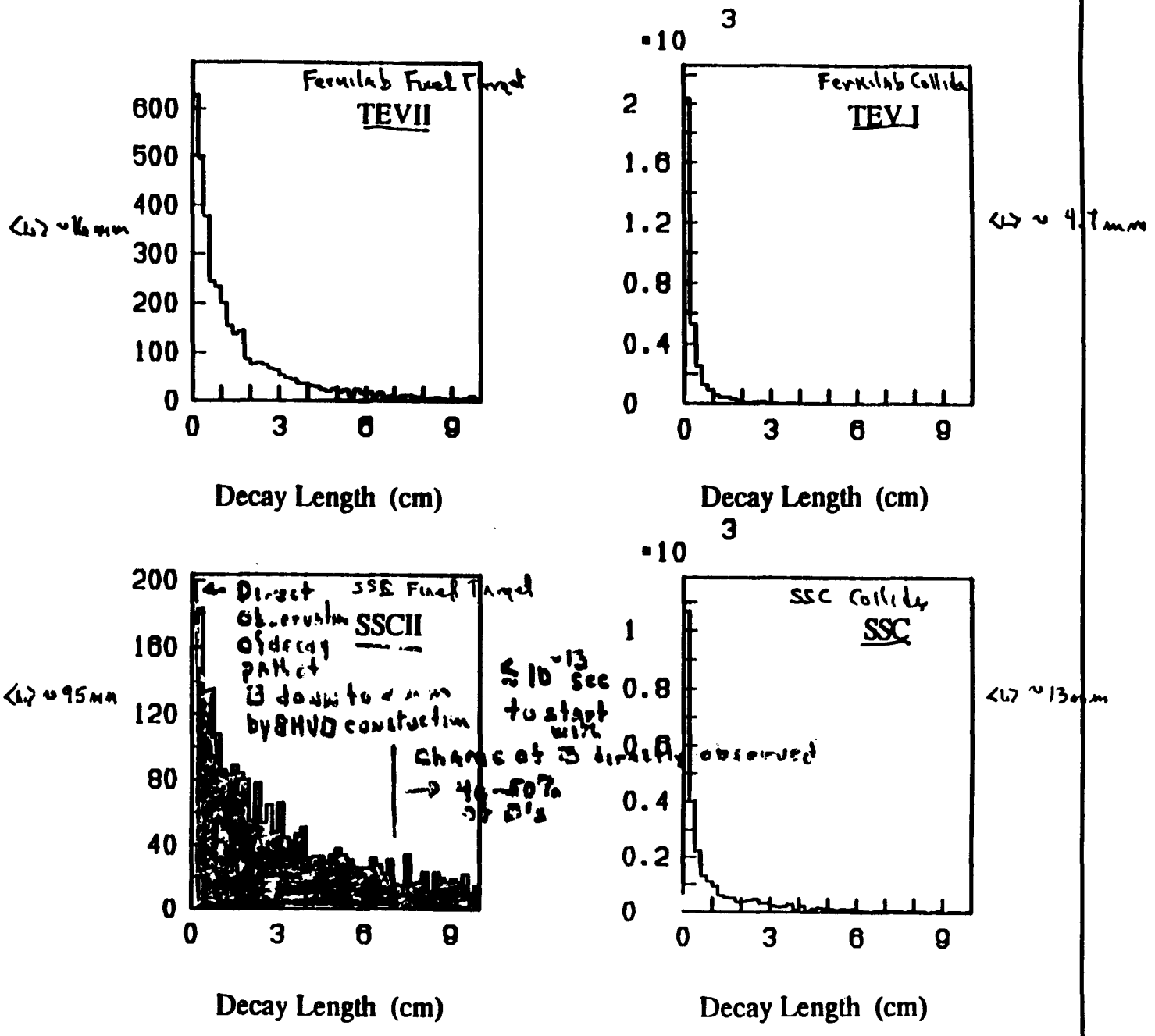
Fig. 8

Radiation damage per year is acceptable.

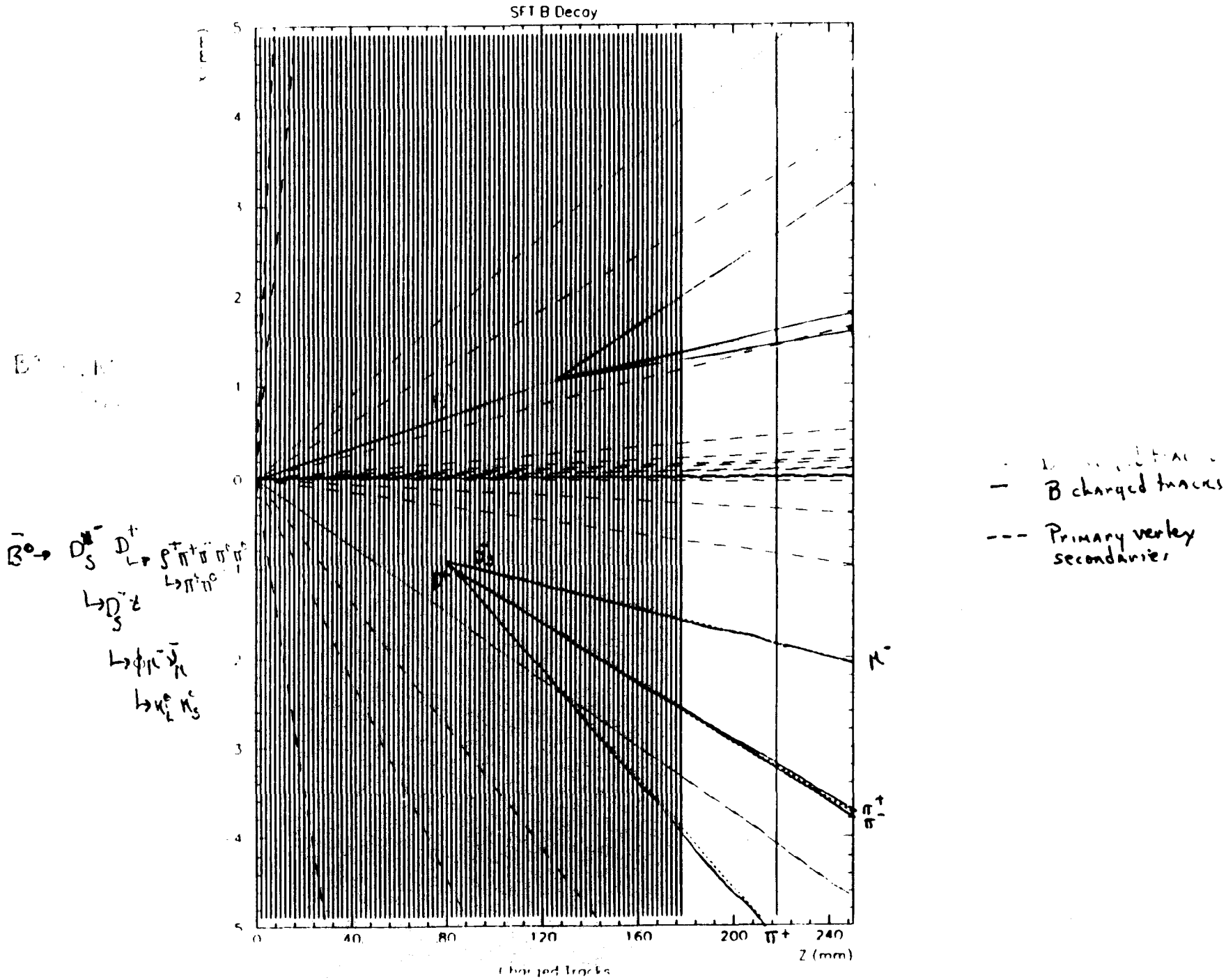
$\sim 2 \times 10^{14}$ p/cm^2/year

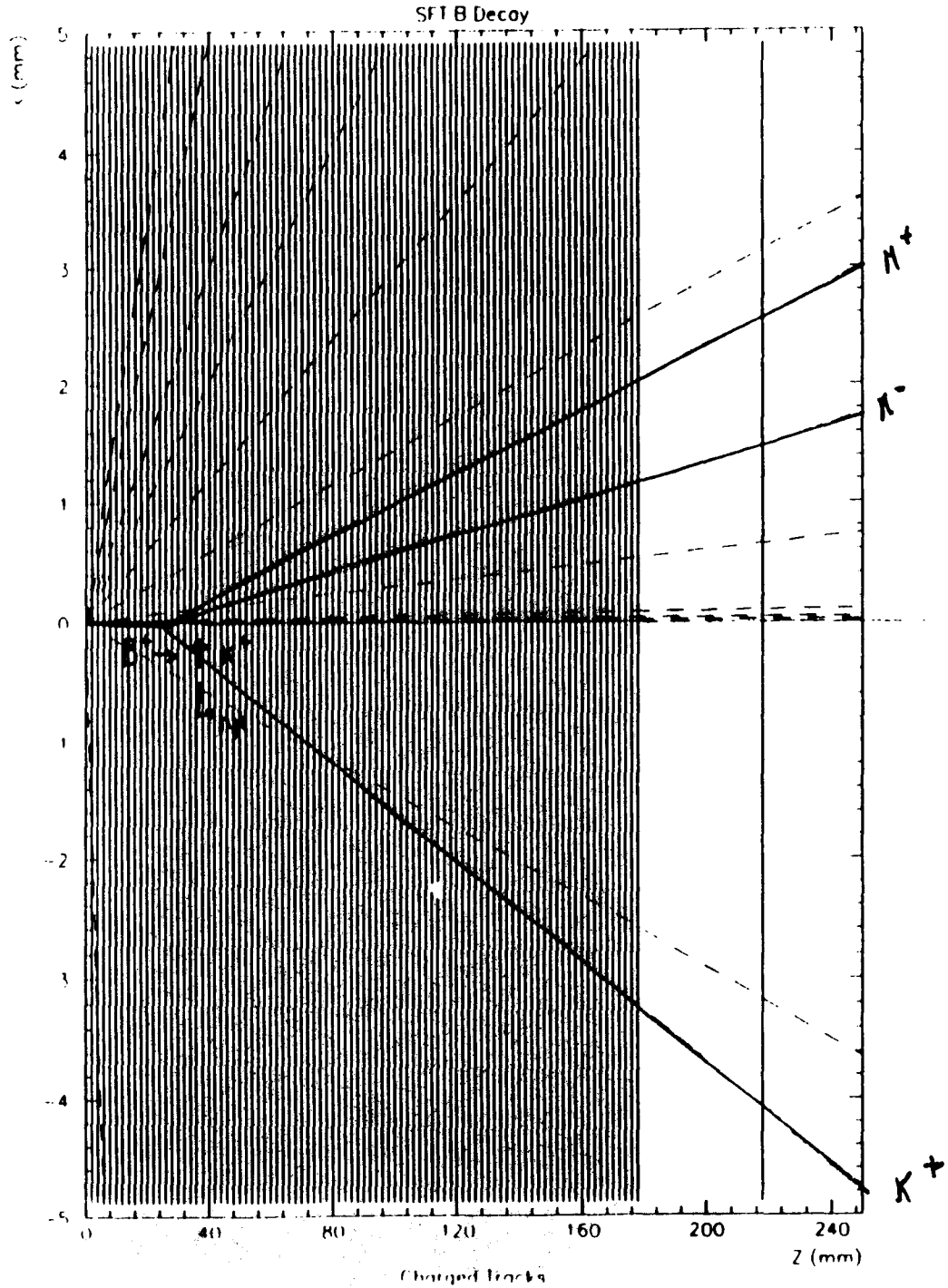
- Half due to proton beam
- Half due to secondaries from interactions

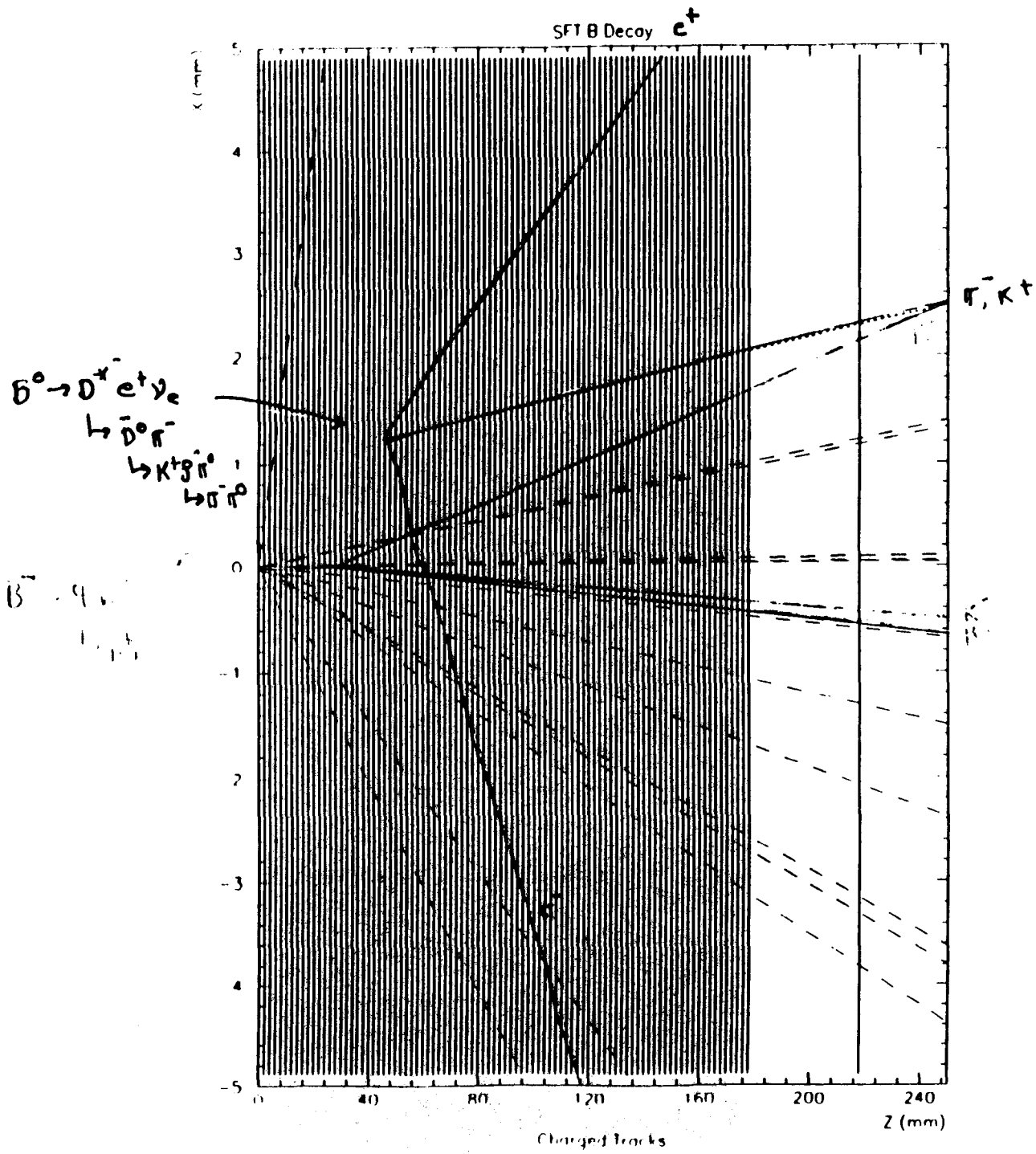
Triple density of read out planes (90)
- [illegible]



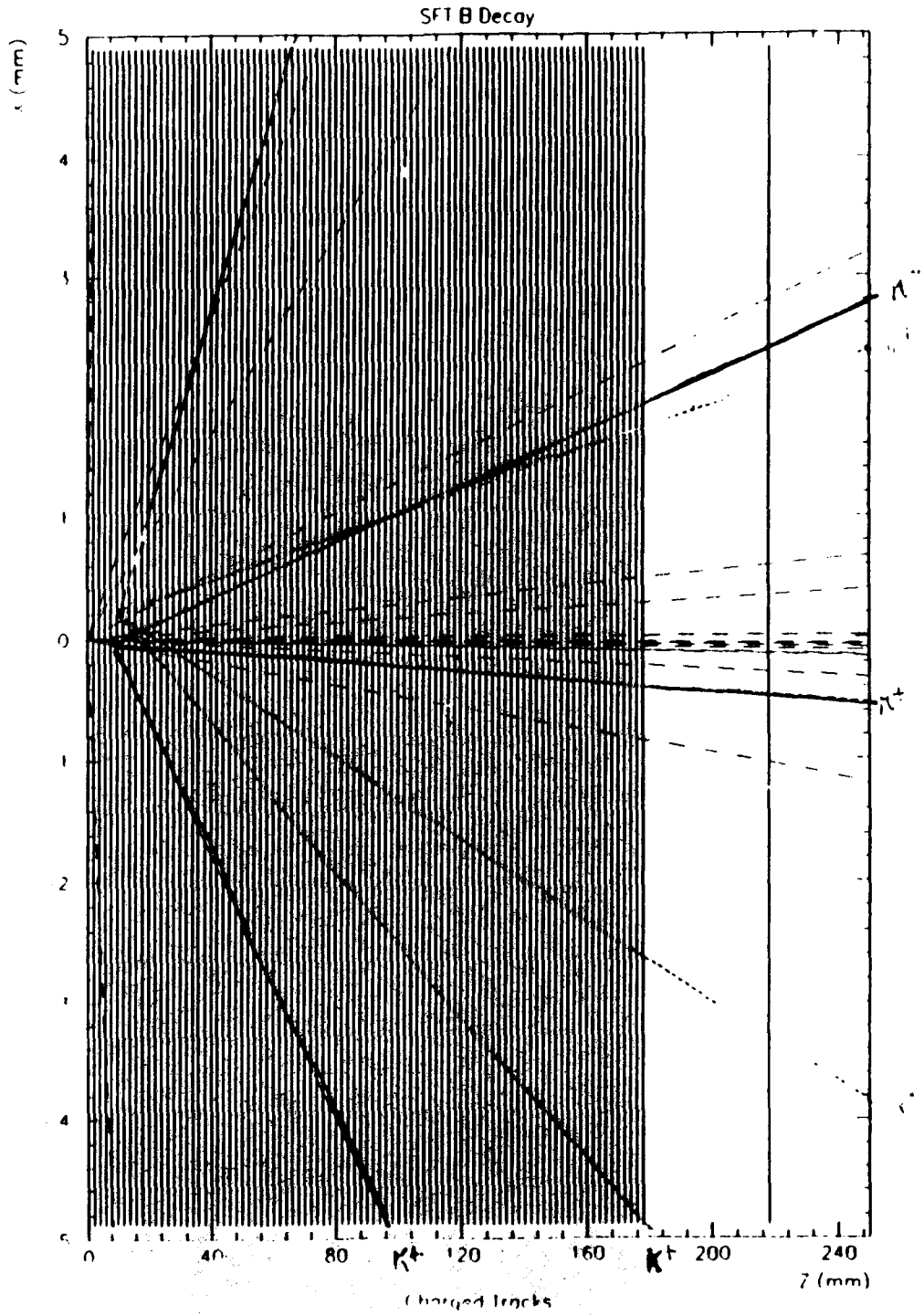
Comparison of TevII, TevI, SSC collider, SSC Fixed Target


SFT B Decay
Z (mm)
Charged tracks
$\bar{B}^0 \to D_S^{*-} D^+$
$\hookrightarrow \rho^+ \pi^+ \pi^- \pi^0 \pi^+$
$\hookrightarrow \pi^+ \pi^0$
$\hookrightarrow D_S^- \ell$
$\hookrightarrow \phi \mu^- \bar{\nu}_\mu$
$\hookrightarrow K_L^0 K_S^0$
K^-
π^+
π^-
B charged tracks
Primary vertex secondaries


SFT B Decay
r (mm)
Z (mm)
Charged tracks
π+
π-
K+
0
40
80
120
160
200
240


SFT B Decay
e^+
π^-, K^+
$B^0 \to D^{*-} e^+ \nu_e$
$\hookrightarrow \bar{D}^0 \pi^-$
$\hookrightarrow K^+ \pi^-$
$\hookrightarrow \pi^- \pi^0$
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
40
80
120
160
200
240
Z (mm)
Charged Tracks

D1


SFT B Decay
x (mm)
z (mm)
Charged tracks
0
40
80
120
160
200
240
5
4
3
1
0
1
2
1
4
5
K+
K+
π+
π-

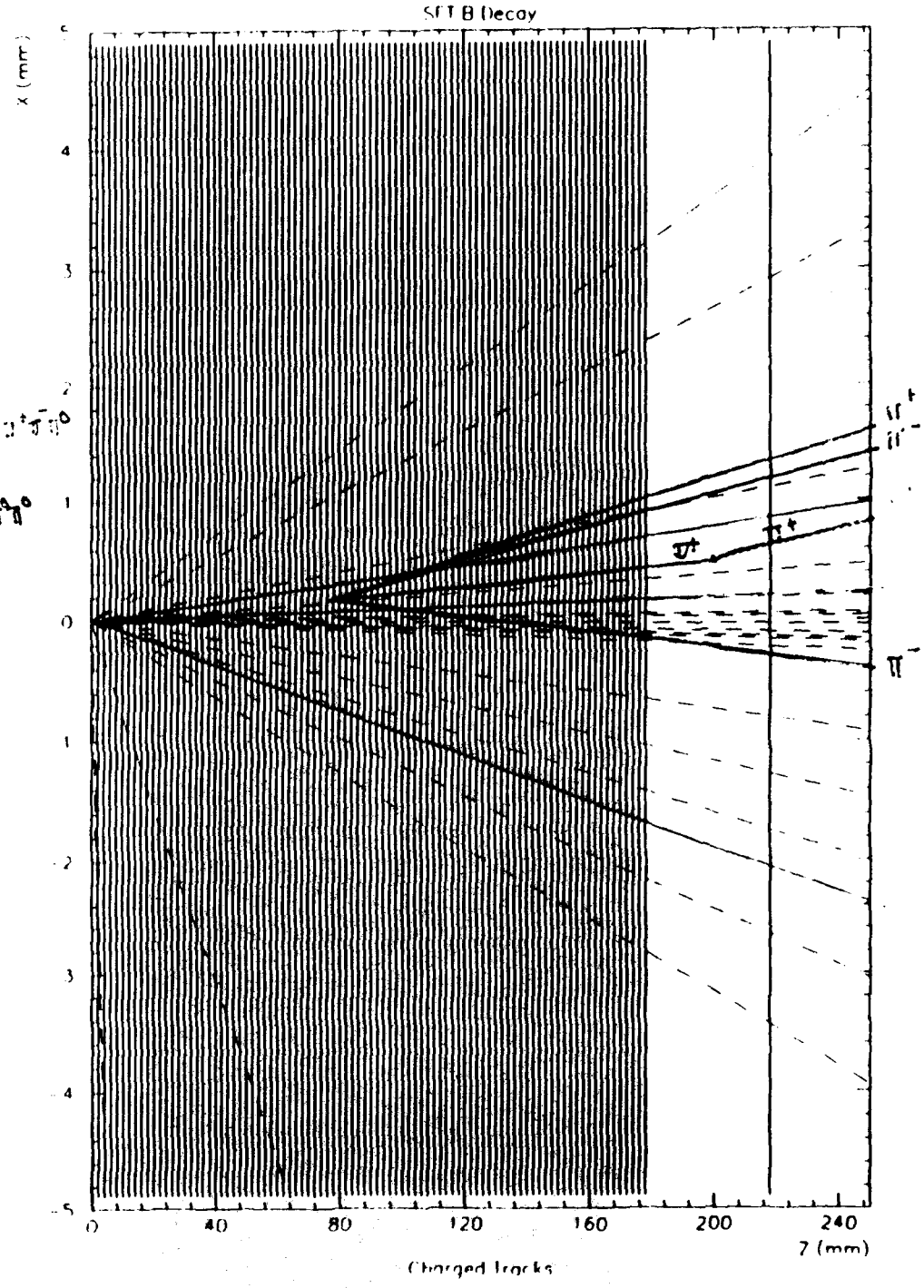
B

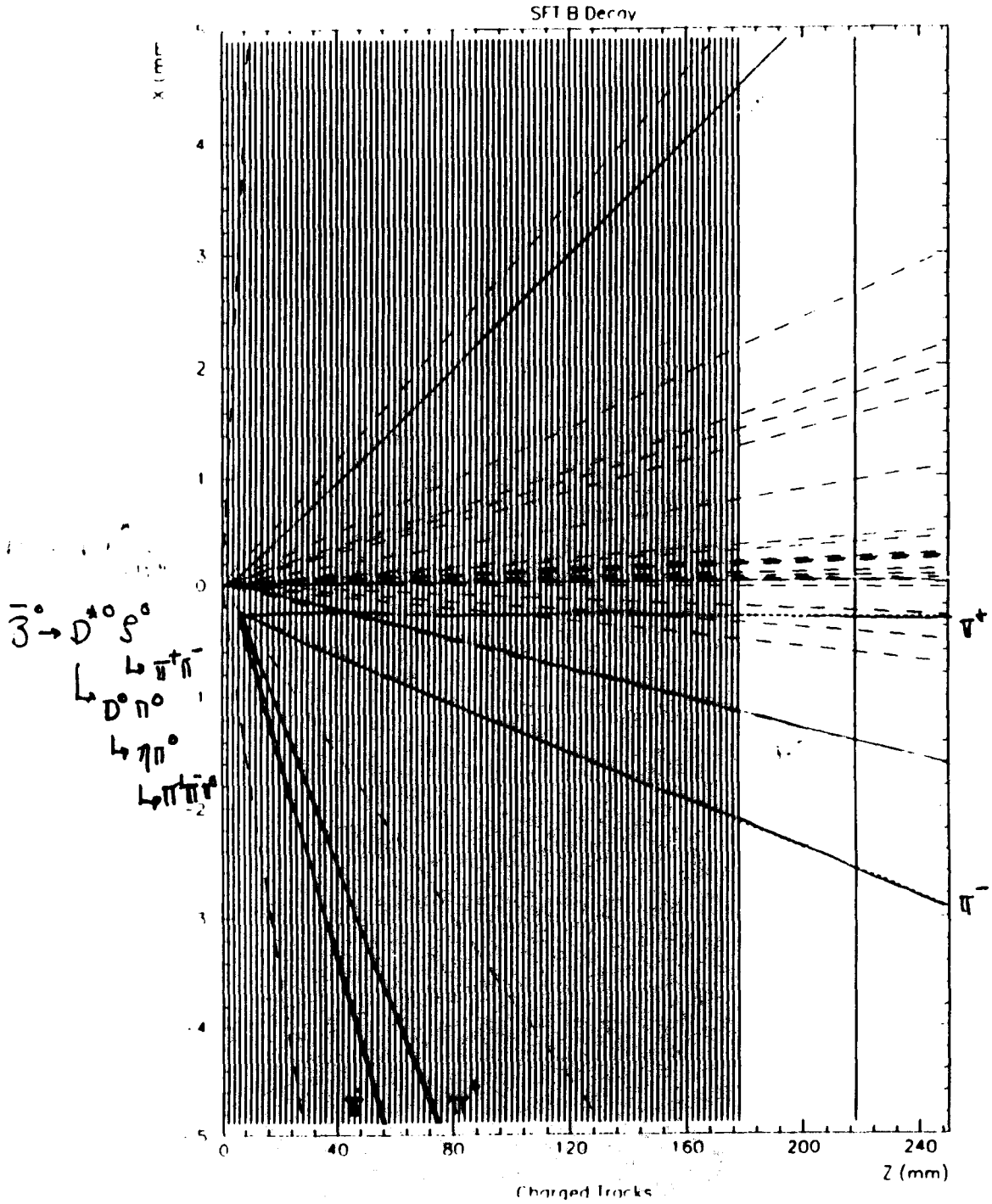
$B^+ \to \pi K^+$

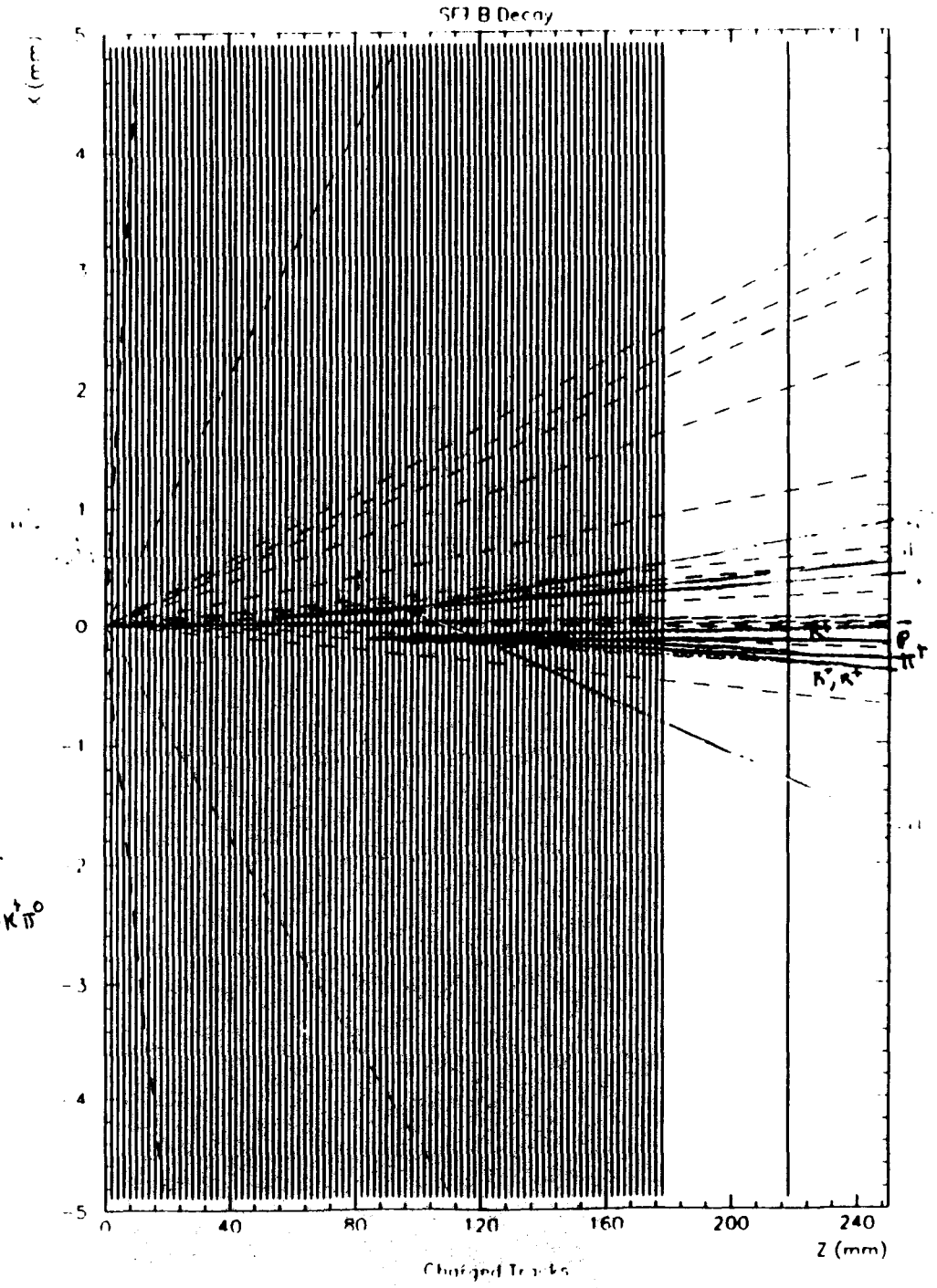
$\bar{B}^0 \to D^{*+}\pi^- \omega^0$, $\omega^0 \to \pi^+\pi^-\pi^0$

$\hookrightarrow D^+\pi^0$

$\hookrightarrow K^-\pi^+\pi^-\pi^0$




SFT B Decay
x (mm)
Z (mm)
Charged Tracks
0
40
80
120
160
200
240
4
3
2
1
0
1
2
3
4
5
π^+
π^-
$\bar{B}^0 \to D^{*0} \rho^0$
$\hookrightarrow \pi^+\pi^-$
$\hookrightarrow D^0 \pi^0$
$\hookrightarrow \eta\pi^0$
$\hookrightarrow \pi^+\pi^-\pi^0$

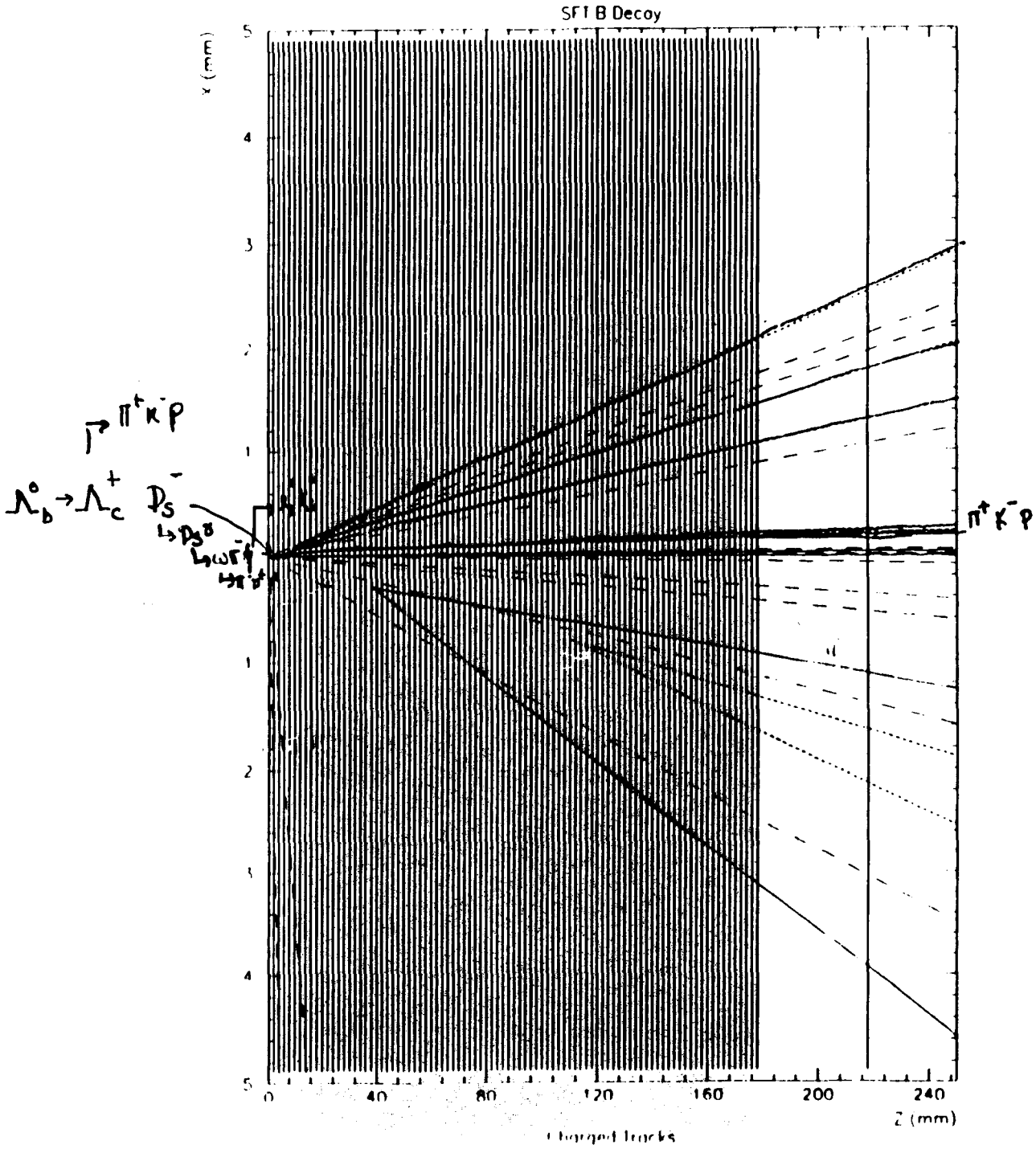


$\bar{B}^0 \to D^{*+} \bar{p} n$

$\hookrightarrow D^0 \pi^+$

$\hookrightarrow K^- K^{*+}$

$\hookrightarrow K^+ \pi^0$


SFT B Decay
x (mm)
z (mm)
Charged tracks
$\Lambda_b^0 \to \Lambda_c^+ D_s^-$
$\hookrightarrow D_s^0$
$\hookrightarrow \omega \pi^-$
$\hookrightarrow \pi^+ \pi^0$
$\pi^+ K^- p$
$\pi^+ K^- p$

J/Ψ Trigger Strategy for Selecting B's

$$pN \longrightarrow B\ \bar{B} + x$$

$$\text{Anything} \longrightarrow B \qquad \bar{B} \longrightarrow J/\Psi + x$$

$$J/\Psi \longrightarrow \mu\mu$$

Cumulative BR ~ .011 x .07 ~ 0.8x 10^{-3}

The J/Ψ decay modes are extremely nice because of the following features:

o The μμ is easy to trigger on; reductions of 10^5 in trigger rate relative to total cross sections are straightforward to obtain.

o Observation of a J/Ψ at a secondary vertex is an unambiguous signature of beauty; cannot be charm.

o The focus on the muon pair (which forms a J/Ψ) provides a way for searching for secondary vertices which avoids combinatorial problems plaguing more general searches for the presence of secondary vertices.

o The J/Ψ modes of both B mesons and baryons are more easily reconstructed:

- They have relatively low multiplicity since the J/Ψ both locks up the cc in a μ pair by definition and the presence of a J/Ψ in the event leaves relatively little phase space for extra particles.
- A large number of J/Ψ decays are totally charged

o Excellent mass resolution is possible since the constraint of the J/Ψ mass can be used on the final state of the decay.

o J/Ψ modes are expected to have large CP violation (for example, B-> J/Ψ K^0_S)

o Many of the J/Ψ modes (such as B-> J/Ψ K^0_S, B -> J/Ψ Φ, B -> J/Ψ π π) end up in final states which are CP eigenstates. CP violation in these final states has a particularly elegant and simple signature:

$$\Gamma_{B\to f} \sim 1 + \lambda_i \sin(\Delta M * \tau)$$

$$\Gamma_{\bar{B}\to f} \sim 1 - \bar{\lambda}_i \sin(\Delta M * \tau)$$

Fixed Target τ resolution ~10^{-13} sec - more than adequate to do both B^0_d and B^0_s mixing

- several hundred B→ψ+a completely reconstructed at Fermilab year
- [illegible] thousand B→ψ+a at the SSC

Single Lepton Trigger Strategy for Selecting B's

$$\text{Anything} \xrightarrow{pN \to B\,\bar{B}+x} B\,\bar{B} \to D\,\mu\,(e)\,\nu \;\ldots\ldots$$

BR ~ 0.24
(for both e and μ)

- Semileptonic decays are nice because:
  - large branching ratio --> more B's on tape
  - The B events accumulated by this means are already tagged (but not unimpeachably!) by the charge of the lepton as to the particle or antiparticle nature of the parent B.
  - There are b->u transition modes ($B \to \pi\mu\nu$ or $B \to \rho\mu\nu$) with relatively large branching ratios which offer the possibility of zero c reconstruction.

- Semileptonic decays are more difficult to handle because:
  - Single lepton trigger rates are much higher than the dimuon trigger rates because of π and K decays.
  - accordingly the trigger requires a cut on the muon p_t at the very first level of the trigger (> approximately 1 GeV/c) $\times 10^3$ suppression of π
  - More than a muon trigger is required to produce suppressions of trigger rate by factors of 10^5:
    - Multiplicity jump trigger
    - Secondary vertex trigger
    - Presence of several intermediate p_t hadrons in the event

      [illegible]

  - Irreducible backgrounds from charm [redacted]. At trigger level, offline analysis can reject!
  - In searching for the other B in the event, the entire track population must be interrogated to find the second secondary vertex and all modes are sampled (only a few % of all charm decays are fully reconstructable)

- At Fermilab, we expect several hundred thousand decays $B \to \mu$ on tape
- At the SSC, 250 million to one billion $B \to \mu$ on tape.

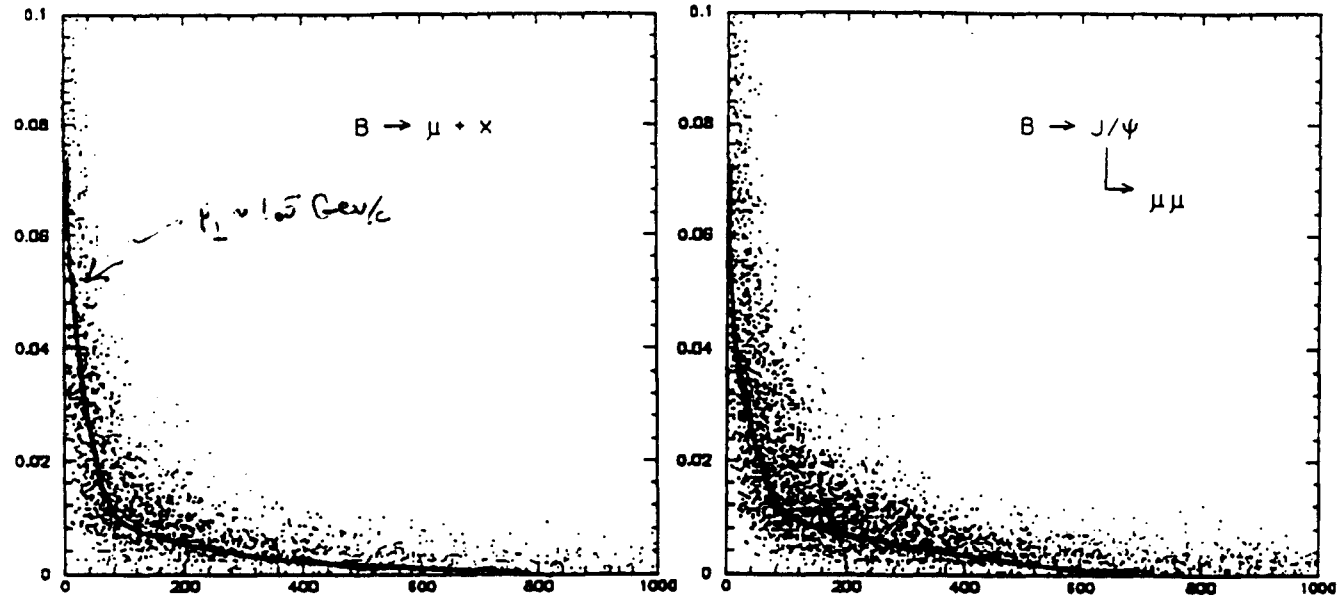
SFT B Trigger Strategies: (Implemented or planned for ETTI)

As a particular example of a possible SFT trigger strategy to select B events:
(implemented in a particular way)

Muon dominated strategy to select $B \to \mu$
$B \to J/\psi \to \mu\mu$
⋮

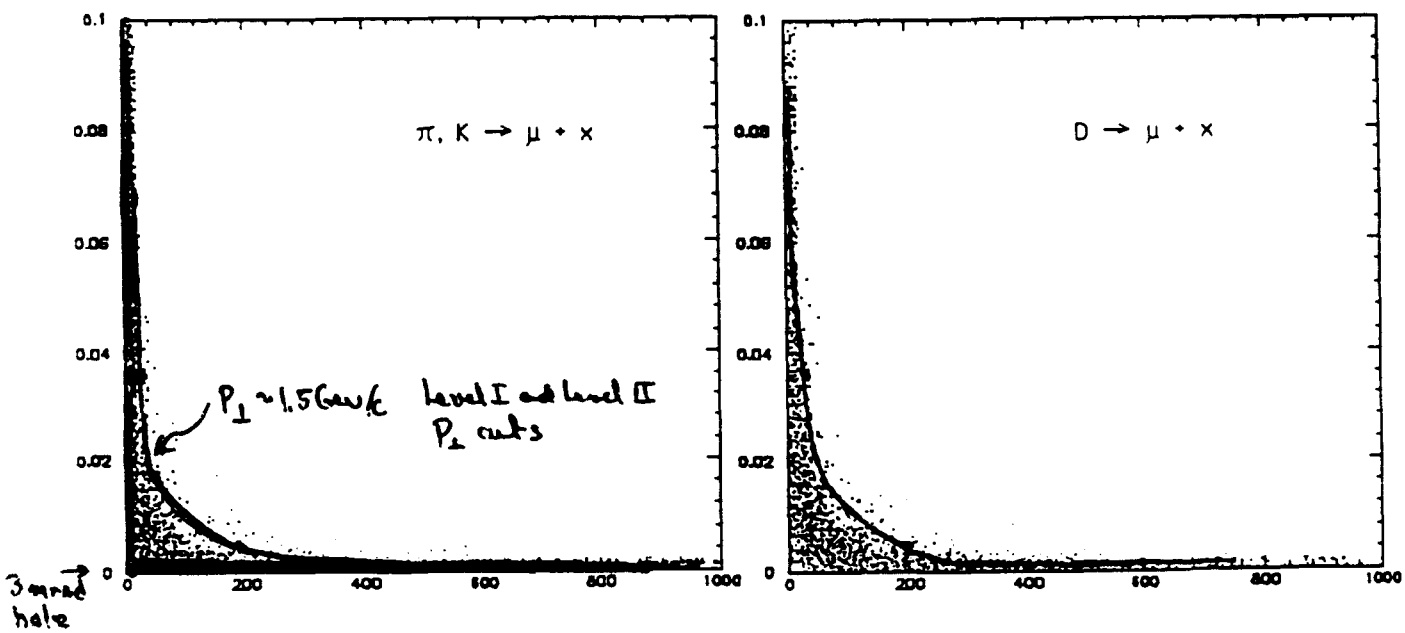
Level I –	one or more muons as detected by coincidences of the RPC pads level I $p_\perp$ cut > 1.5 GeV/c	PAL electronics operation at $\simeq 10^7$ int/sec
Level II –	$P_\perp$ cut on muons Presence of secondary vertices in microvertex detectors Requirement of a few moderate $P_\perp$ hadrons	Associative memories form tracks in a few microseconds
Level III –	Thought not to be needed at present	Microprocessor farm 50 msec/event

- B events look quite different in a fixed target experiment than the total cross section events. The B mass is still an appreciable, significant fraction of the CM energy.



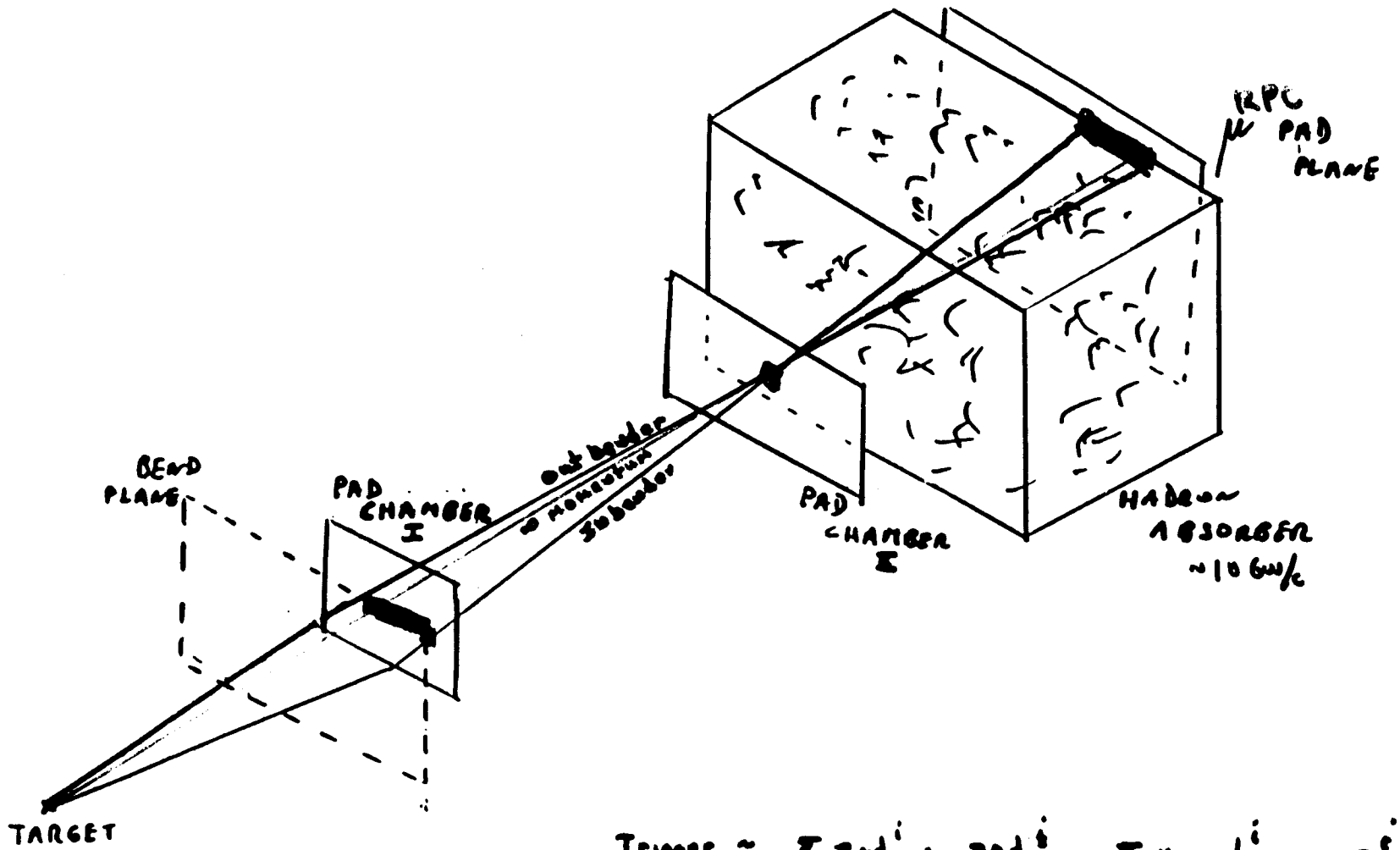
θ_μ vs P_μ θ_μ vs P_μ

Nu side, shielding



θ_μ vs P_μ θ_μ vs P_μ

Level I_L Single μ Mom P_t Trigger
(R.L.)



Trigger ~ $\sum_{region} pad^i_I \cdot pad^i_{II} \cdot \sum_{region} \mu pad^i \cdot \sum_i CP^i$

Implemented in Programmable Array logic technology

$\sim 10^4$ coincidences

Scintillation Counters

Table IV
$B \to J/\Psi \to \mu\mu$ and $B \to \mu + x$
Muon Acceptances and Efficiencies

	$B \to J/\Psi \to \mu\mu$	$B \to \mu + x$
Level I		
Geometric Acceptance for muon tracks (including steel attenuation)	0.85	0.87
Level I detector efficiencies	0.74	0.86
Level II		
Level II detector efficiencies	0.80	0.80
Multihadron and Secondary Vertex Requirements	0.70	0.70
Level II P_t cut efficiency for muons	0.95	0.42
Composite Acceptance/Eff. for single or dimuons triggers	0.33	0.18

Table V
Expected Trigger
Suppression Factors
per Interaction

Trigger Level	DiMuon Trigger	Single Muon Trigger
I	$O(10^{-4})$	5×10^{-3}
II	10^{-1}	2×10^{-2}
I * II	$O(10^{-5})$	$O(10^{-4})$

Table VI
Beauty Enrichment Factors at Various Levels

Level	DiMuon Trigger (signal = $B \to J/\Psi \to \mu\mu$)	Single Muon Trigger (signal = $B \to \mu + x$)
BB/interaction	$1/7.7 \times 10^3 \to 1/1.9 \times 10^3$	$1/7.7 \times 10^3 \to 1/1.9 \times 10^3$
Produced signal/interaction	$1/5.1 \times 10^6 \to 1/1.3 \times 10^6$	$1/3.2 \times 10^4 \to 1/8.2 \times 10^3$
Accepted signal/ Level I	$1/8.1 \times 10^2 \to 1/2.0 \times 10^2$	$1/2.1 \times 10^2 \to 1/5.3 \times 10^1$
Accepted signal/Level I* Level II	1/150->1/40*	1/20->1/5*
Offline Step I Sig./background	1/18->1/5	1/2->2/1
Offline Step II Sig./background	>>10/1	5/1->20/1

*This is the enrichment factor for events written to tape

Particular Example of Possible CP Asymmetry Measurement

Table VII

relatively rare chain

$B^0_d \to J/\Psi\ K^0_S$, $K^0_S \to \pi^+\pi^-$, $J/\Psi \to \mu\mu$

Condition Imposed	Event Sample
$B\bar{B}$ produced	1.3 $\to 5.2\times10^{10}$
$B \to J/\Psi \to \mu\mu$ (7.7×10^{-4})	2.0 $\to 8.0\times10^{7}$
Trigger Acceptance (.33)	0.66 $\to 2.6\times10^{7}$
Hadronization to B_d (40%)	0.26 $\to 1.1\times10^{7}$
$B_d \to J/\Psi\ K^0_S$ (5% of $B_d \to J/\Psi$ +x)	1.4 $\to 5.6\times10^{5}$
$K^0_S \to \pi^+\pi^-$ (69%)	1.0 $\to 4.0\times10^{5}$
K^0_S Acceptance (42%)	0.42 $\to 1.7\times10^{5}$
$B \to J/\Psi\ K^0_S$ Track Reconstruction (90%/track)	0.28 $\to 1.1\times10^{5}$
"Other" B Decay track Acceptance (65%)	1.8 $\to 7.2\times10^{4}$
Hadronization to B_u (40%)	0.7 $\to 2.8\times10^{4}$
Determination of Charge of B_u (50%)	0.34 $\to 1.4\times10^{4}$

← Completely reconstructed and tagged (with B_{ad}) $B^0_d \to \Psi K^0_S$

$$\frac{dN}{d\tau} \sim e^{-\tau}\left(1 \pm \lambda \sin \Delta M \tau/\gamma\right)$$

for first oscillation

$$A = \frac{\Delta N}{N_T} = \frac{N-\bar{N}}{N+\bar{N}} = \lambda \frac{\Delta M/\gamma}{1+(\Delta M/\gamma)^2} \cdot \frac{1+e^{-\gamma\pi/\Delta M}}{1-e^{-\gamma\pi/\Delta M}}$$

for B_d $\quad \frac{\Delta M}{\gamma} \sim 0.78$

$$A \approx 0.5\,\lambda$$

A measurement of A to n standard deviations requires

$$N_T \sim \left(\frac{n\sigma}{A}\right)^2$$

Measurement of a 15% asymmetry with 3σ significance requires $N_T \sim 4000$

- Only one B decay chain. Many others can be reconstructed and analyzed, ie $B \to 4\phi$, $B \to 4\pi\pi$, $B \to 4K\pi$ ...
  $\gtrsim 10^5$ completely reconstructed B decays

- In addition, the single muon events allow examination of the entire spectrum of B decays. We expect to accumulate between 250 million and one billion $B \to \mu$ events on tape. These events are already 'partially' tagged by the charge of the lepton.

On Tape/year

	$B \to J/\psi + X$	$B \to \mu + X$
Fermilab	7×10^3	1.1×10^6
↓		
SSC	$7 \times 10^6 \to 3 \times 10^7$	$6 \times 10^8 \to 2 \times 10^9$ $(3 \times 10^8 \to 1 \times 10^9)$ (all decay products of both B's in acceptance of spectrometer)

Physics Reach of the SFT

V_{ub} from $B_d^0 \to \pi^+ \mu^- \nu$, $B_u^- \to \rho^0 \mu^- \bar{\nu}$

(10^{10} $B\bar{B}$'s) 70,000 300,000 o-c fits to hypothesis

B_s^0 mixing from $B_s^0 \to D_s^- \pi^+$ tagged by other $B \to \mu$

(10^{10} $B\bar{B}$'s

↳ all charged ($\pi^+\pi^-\pi^-$, $\phi\pi^-$ ↳ K^+K^-, K^{*0} ↳ $K^+\pi^-$ K^- ...)

14,000 reconstructed events tagged with μ charge

500 such events yield <10% measurement of x_s depending on dilution factor from μ tag

CP violation from B_d^0 B_u^-

(10^{10} $B\bar{B}$'s)

↳ 4 K_s^0 ↳ $\pi^+\pi^-$

3600 reconstructed events tagged with B_u^-

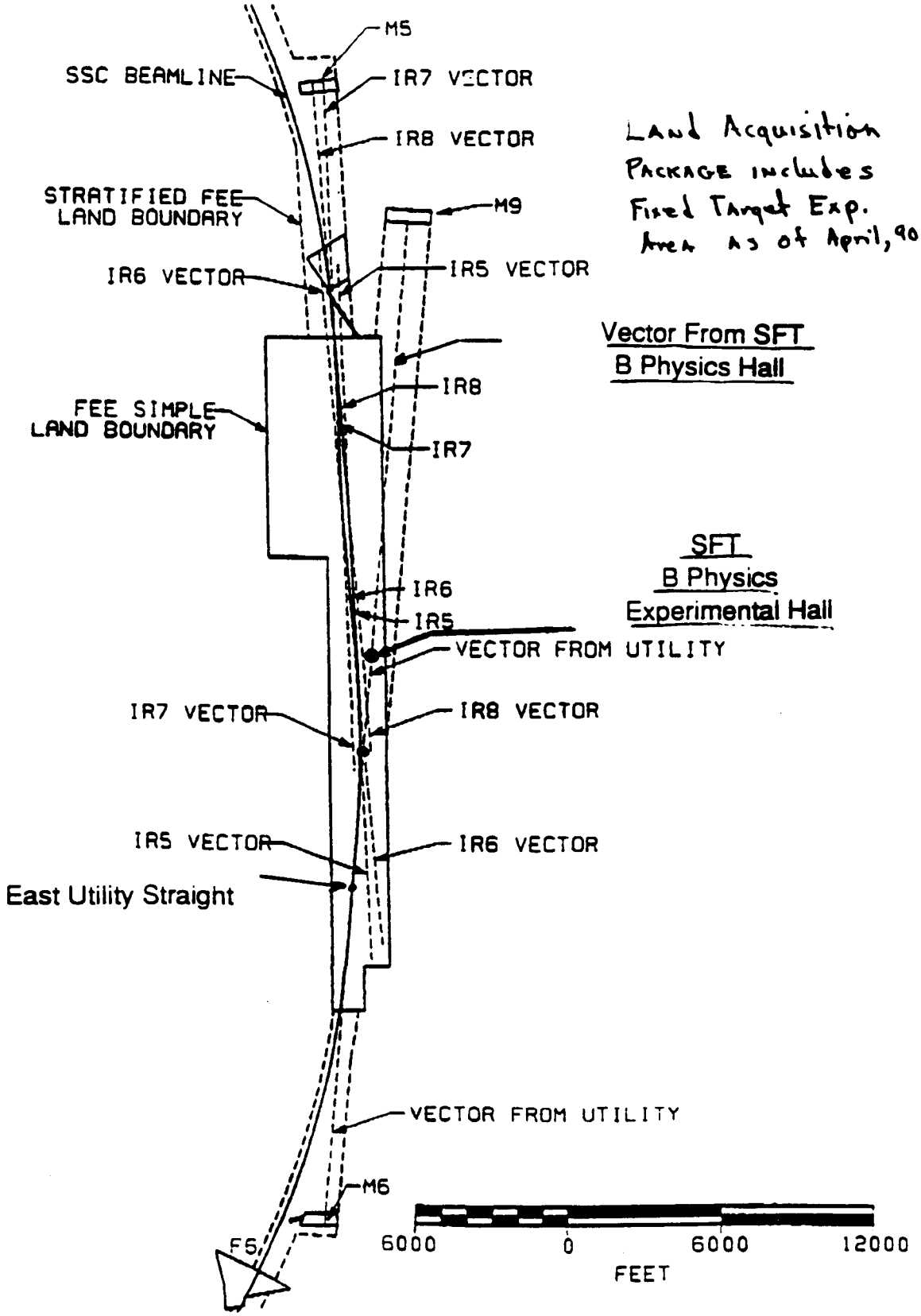
3σ measurement of ϕ_1 for $\phi_1 > 0.03$

CP violation from B_d^0 ↳ $\pi^+\pi^-$ B ↳ μ

(10^{10} $B\bar{B}$'s)

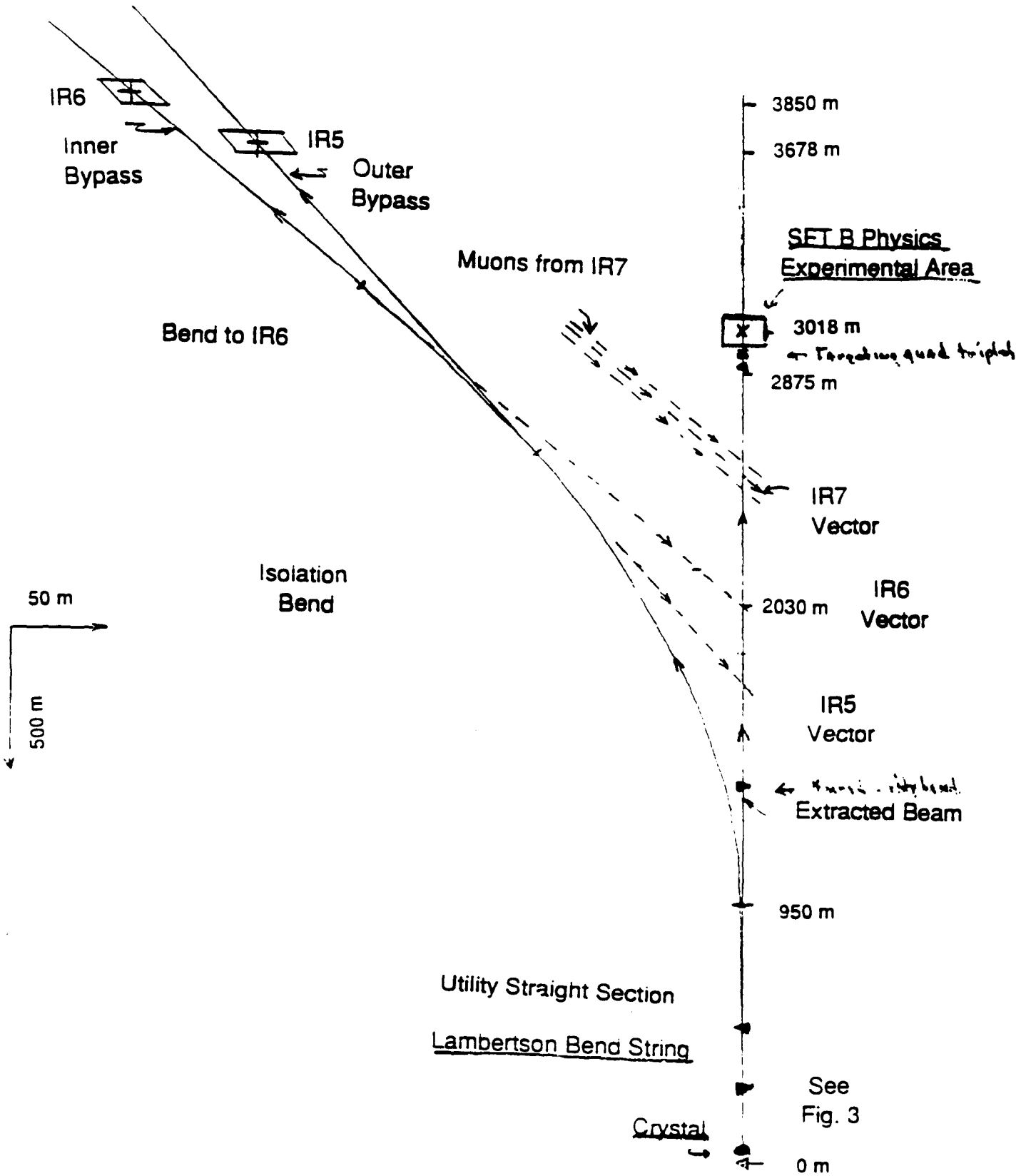
1200 reconstructed events tagged with $B \to \mu$

3σ measurement of ϕ_2 for $\phi_2 > 0.08$



EAST CAMPUS SITING OF
20 TEV SUPER FIXED TARGET B PHYSICS FACILITY (SFT)

Fig. 1


IR6
Inner
Bypass
IR5
Outer
Bypass
Muons from IR7
Bend to IR6
3850 m
3678 m
SET B Physics
Experimental Area
3018 m
2875 m
IR7
Vector
Isolation
Bend
50 m
500 m
2030 m
IR6
Vector
IR5
Vector
Extracted Beam
950 m
Utility Straight Section
Lambertson Bend String
See
Fig. 3
Crystal
0 m

Fig, 2

Low Intensity 20 TeV Beam

Need $1 \rightarrow 2 \times 10^8$ protons/second to produce 10^7 interactions per second in SFT microvertex detector

from [illegible] proton circulating beam

Crystal channeling matches the criteria well

No greater useage of beam than a $L \sim 10^{33}$ cm^{-2} sec^{-1} interaction region

- With crystal channeling only $\sim$ few $\times 10^6$ int/sec are produced to generate $1 \rightarrow 2 \times 10^8$ int/sec

- Will run concurrently with high $p_\perp$ detectors

Backup configuration using electrostatic septa is possible

Two Aspects to crystal channeling

- How much beam intercepts the crystal

- How well does the crystal channeling work.

Generation of Low Intensity 20 TeV Proton Beam

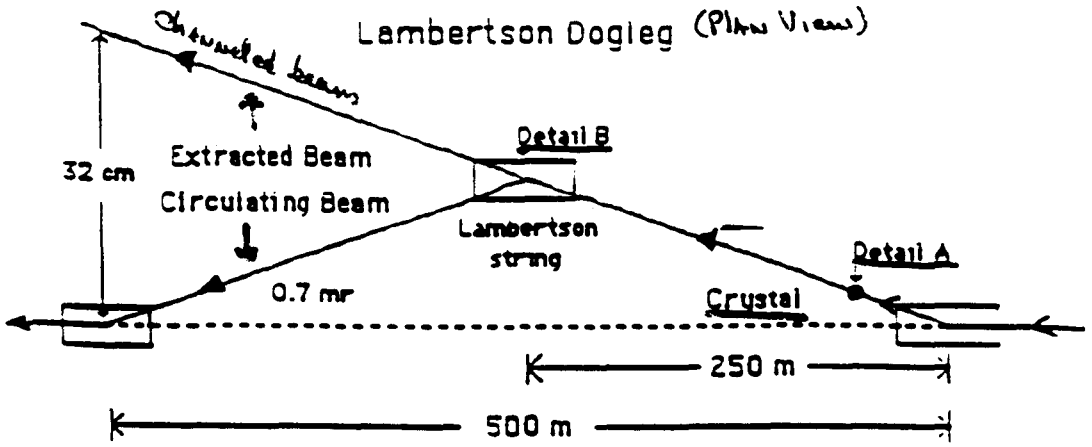
- Deflect the circulating beam by 0.7 mrad horizontally into a dogleg containing the crystal and a Lambertson magnet string

- Bent silicon crystal is positioned (in the plane of the circulating beam) immediately following the 0.7 mrad bend. Crystal bend angle ~ 100 μradians

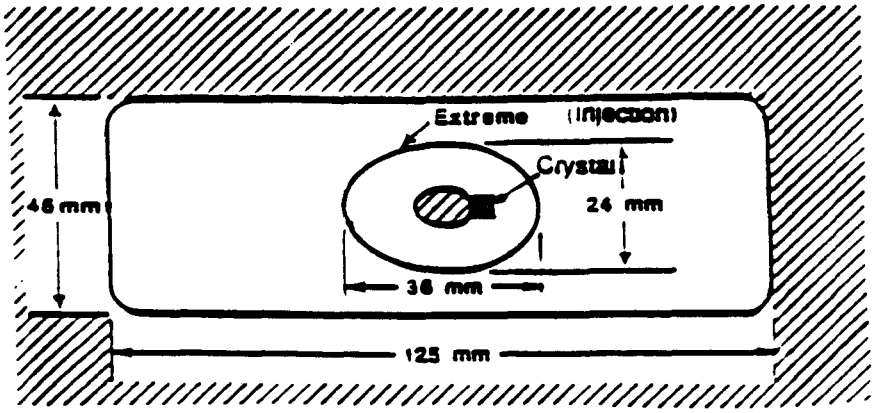
- The silicon crystal intercepts 1 → 2 × 10^8 protons per second and deflects ≳ 10^8 protons by 100 μradians vertically. (from the 10^{11} protons in the circulating beam)

- After a 250 m drift to the Lambertson string the channeled beam is separated from the circulating beam and passes through a magnetic field free region in the Lambertson string into the external beam line for a 3000 meter drift to the SFT area

- The circulating beam is deflected by the Lambertsons back into the 'standard' orbit.

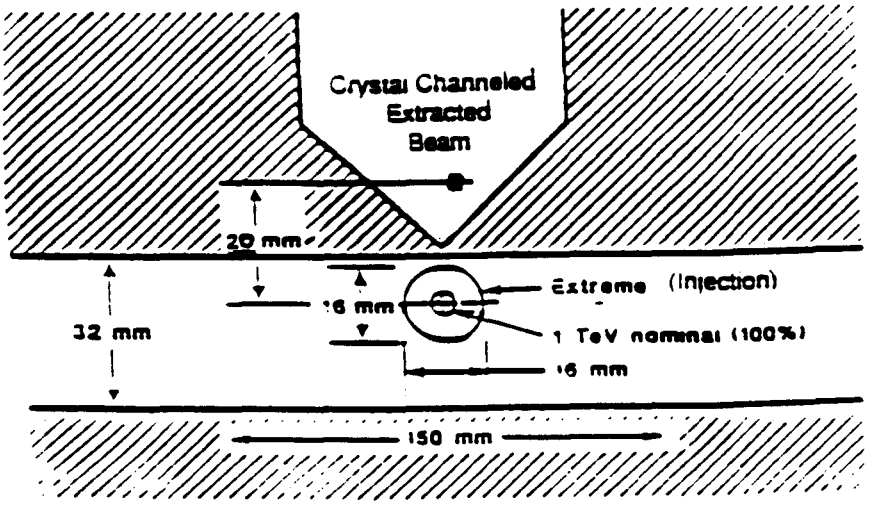


Detail A



Present positioning of crystal
1.6 mm from beam

Detail B



250 meter downstream of crystal

Fig. 3

Expected Performance of the Crystal Channeling

- Parameters of the crystal

Size: 3 cm × 3 mm × 3 mm
~6% of an interaction length (~ 4% for dechanneled protons)

Material: Silicon

Bend: 100 microradians (vertical deflection)
small bend

- Efficiency of Channeling
(Dechanneled protons are not lost but may be channeled on subsequent passes)

  - Bending dechanneling 17% (function of P/R)
  - Multiple Scattering negligible
  - Critical angle acceptance (1 microradian) < 1% for β = 50 m
  - 'Surface' acceptance due to fraction of surface area occupied by atoms in crystal lattice ~ 20%

Single pass dechanneling ~ 37%

⇓

Single pass channeling ~ 63%

⇓

Multiple pass channeling ≳ 80%

Bending Dechanneling Losses

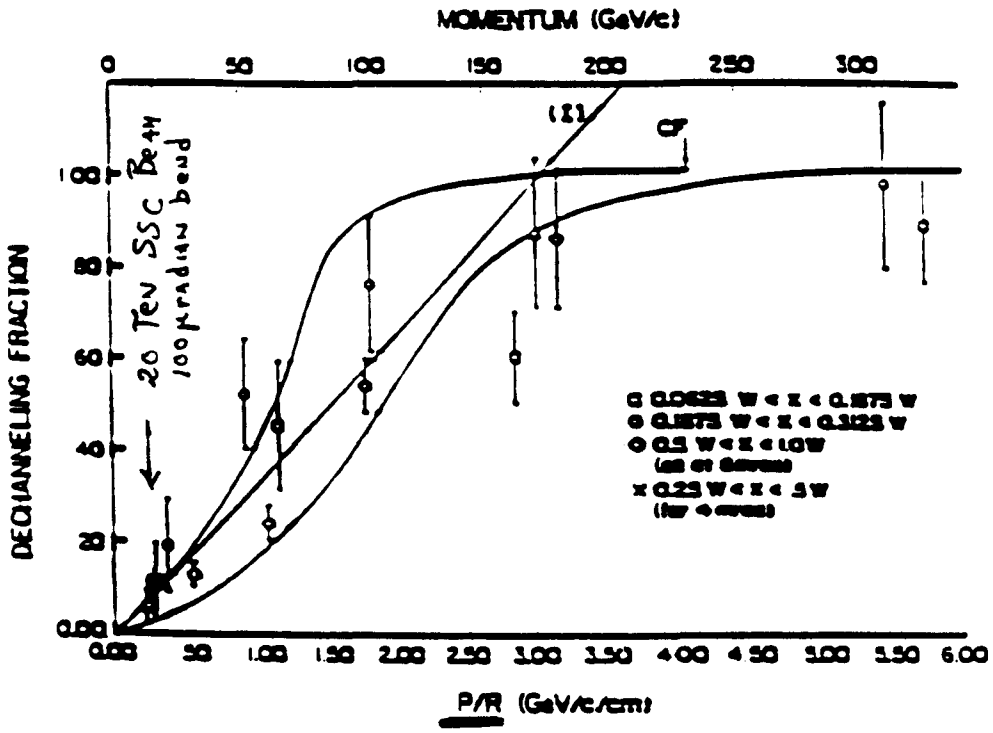


Fig. 7

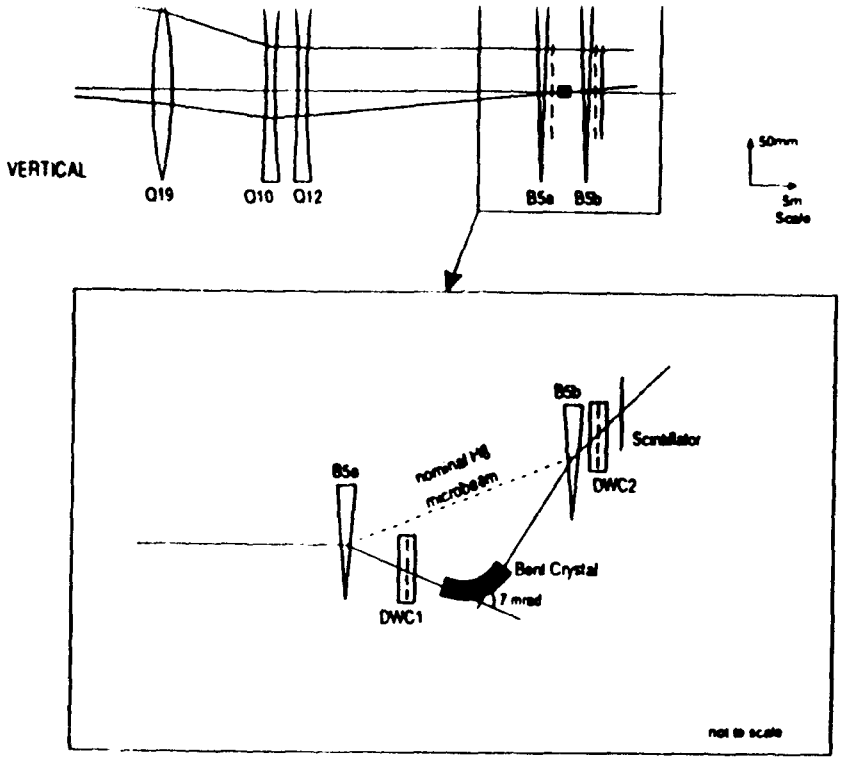


Fig. 1. Part of the H8 beam and experimental set-up for the channeling experiment. Q designates quadrupoles, B designates bending magnets and DWC designates delay-wire chambers.

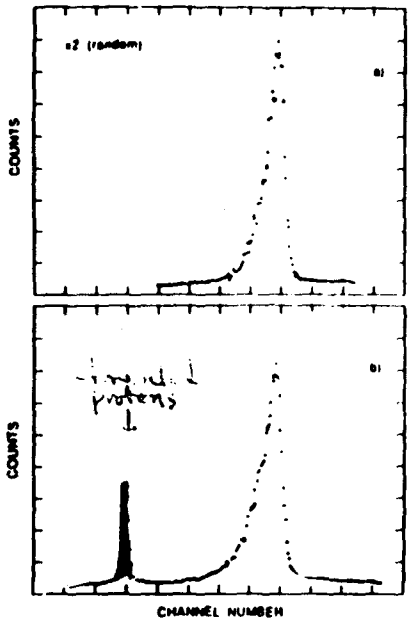


Fig. 4. Intensity distributions of the transmitted beam measured 4 m behind the crystal, (a) for random incidence, (b) for aligned incidence

(1990)

(compared SSC

20,000 GeV/c

.1 mrad bent

$\frac{P}{R} = .67$

~ 15%

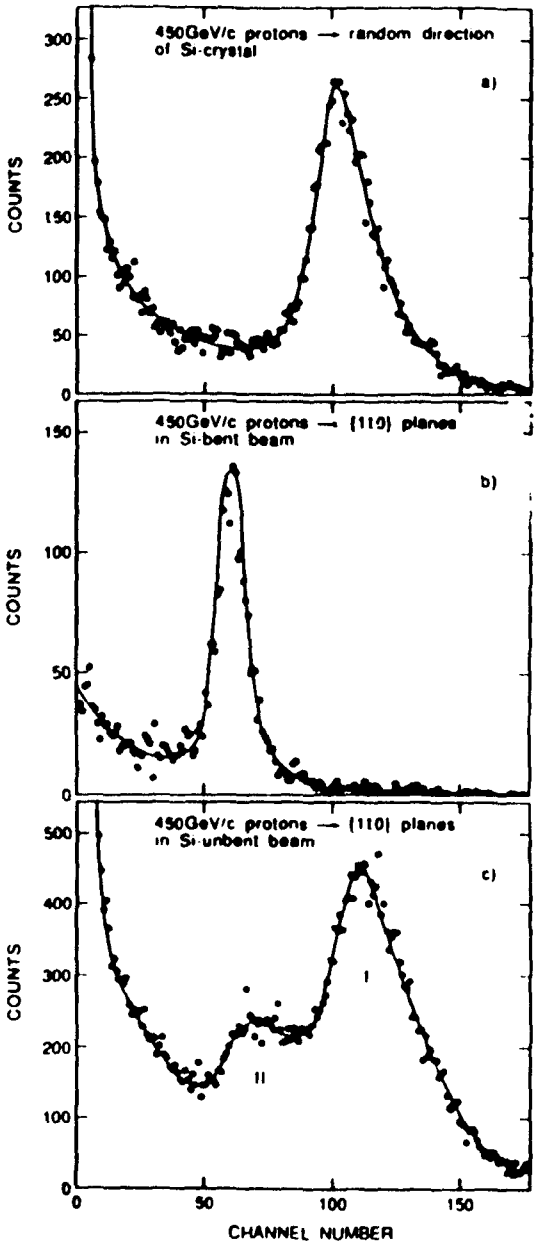


fig. 5. Energy loss distribution in the front detector, for (a) random incidence, (b) bent particles for aligned incidence, (c) unbent particles for aligned incidence.

- Sources of protons for refreshing the phase space swept by the crystal

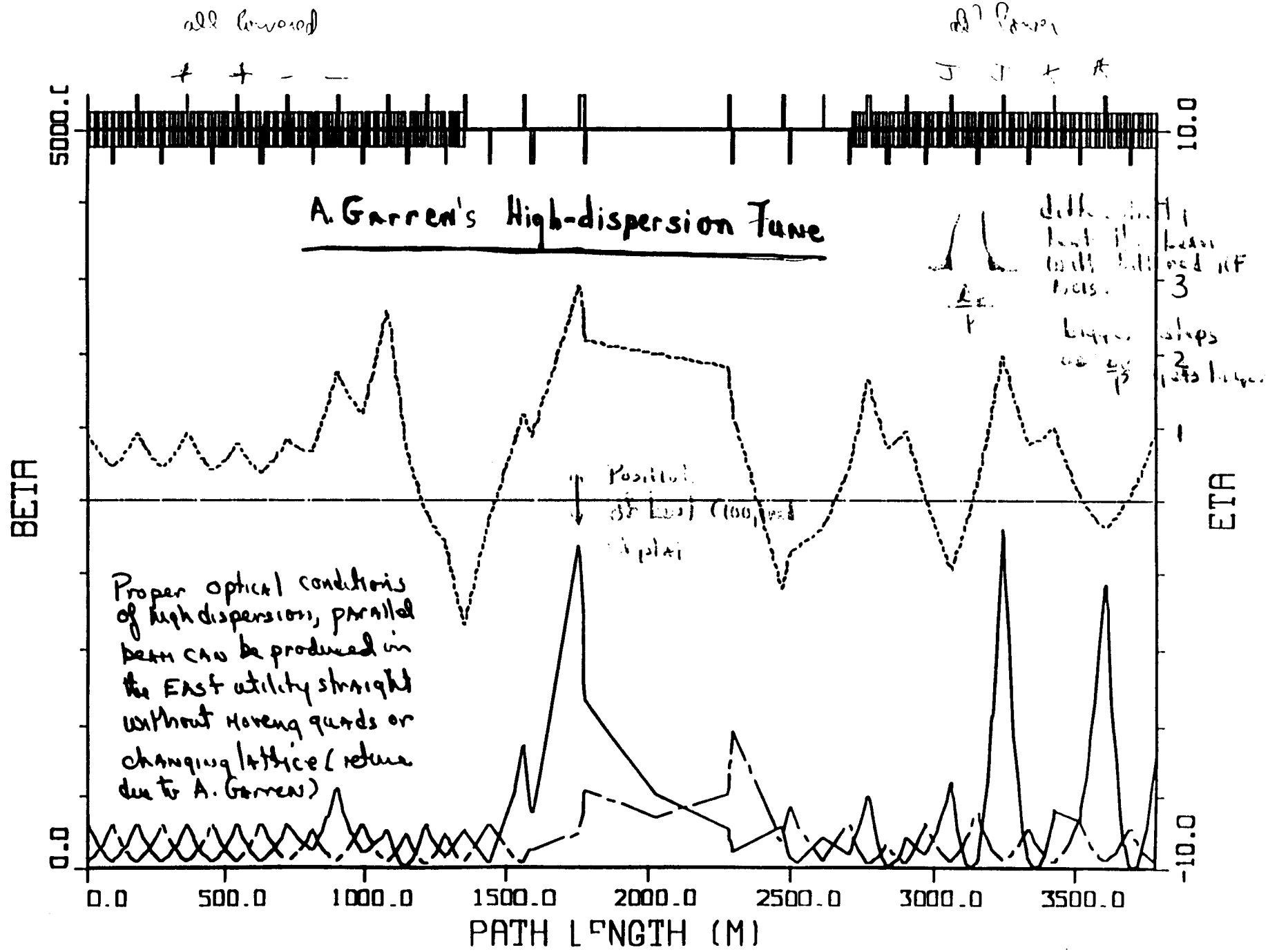
  - Halo from beam-gas scattering
  - Debris from interaction region
  - High $\frac{\Delta p}{p}$ tails of beam produced by RF manipulations (phase or amplitude)
    - [illegible]
    - [illegible]
    - [illegible]

- Since crystal is positioned at high dispersion point, high momentum deviation becomes a halo

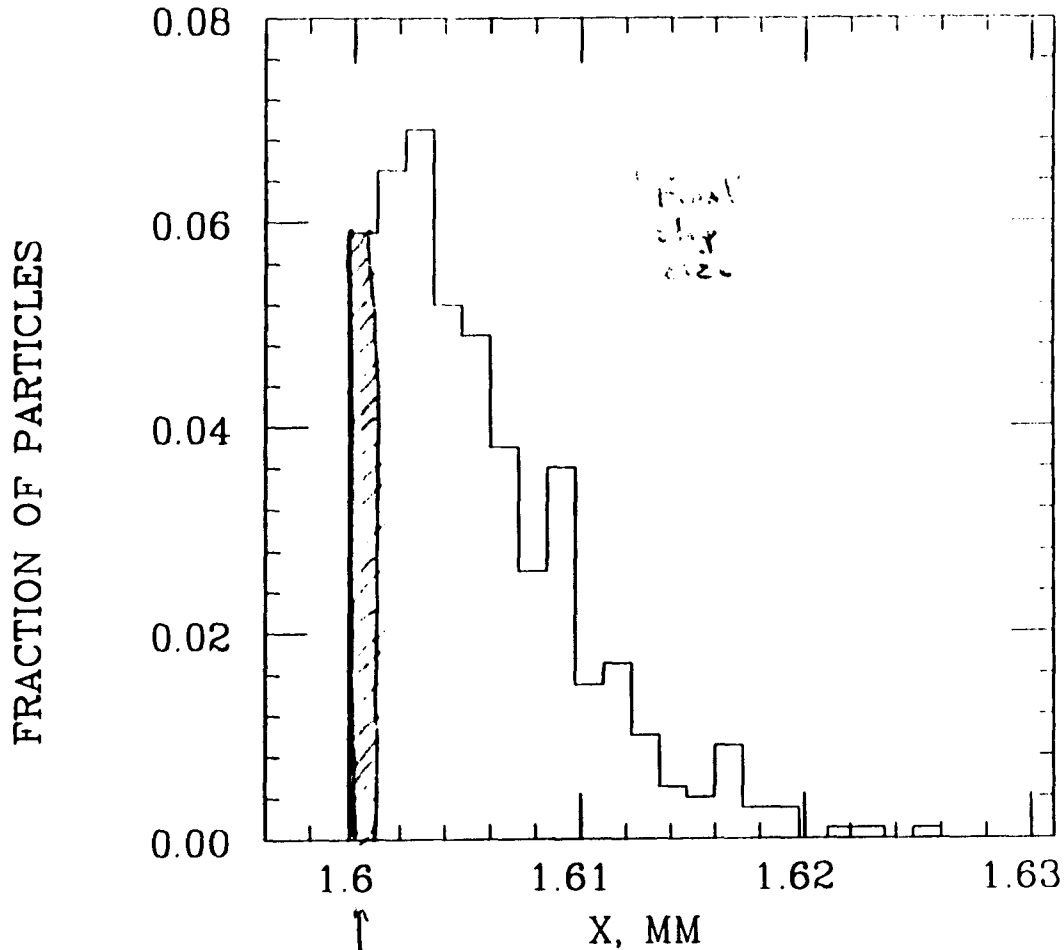
- At least three different types of RF manipulation appear to satisfy the criteria

  - Putting 10^8 protons/sec. on crystal
  - with adequate step size (microns) to cross effective septum width
  - leave central core of beam unchanged

FORTR' ' STOP
ssc>



X SPECTRUM



J. Shih SSC lab

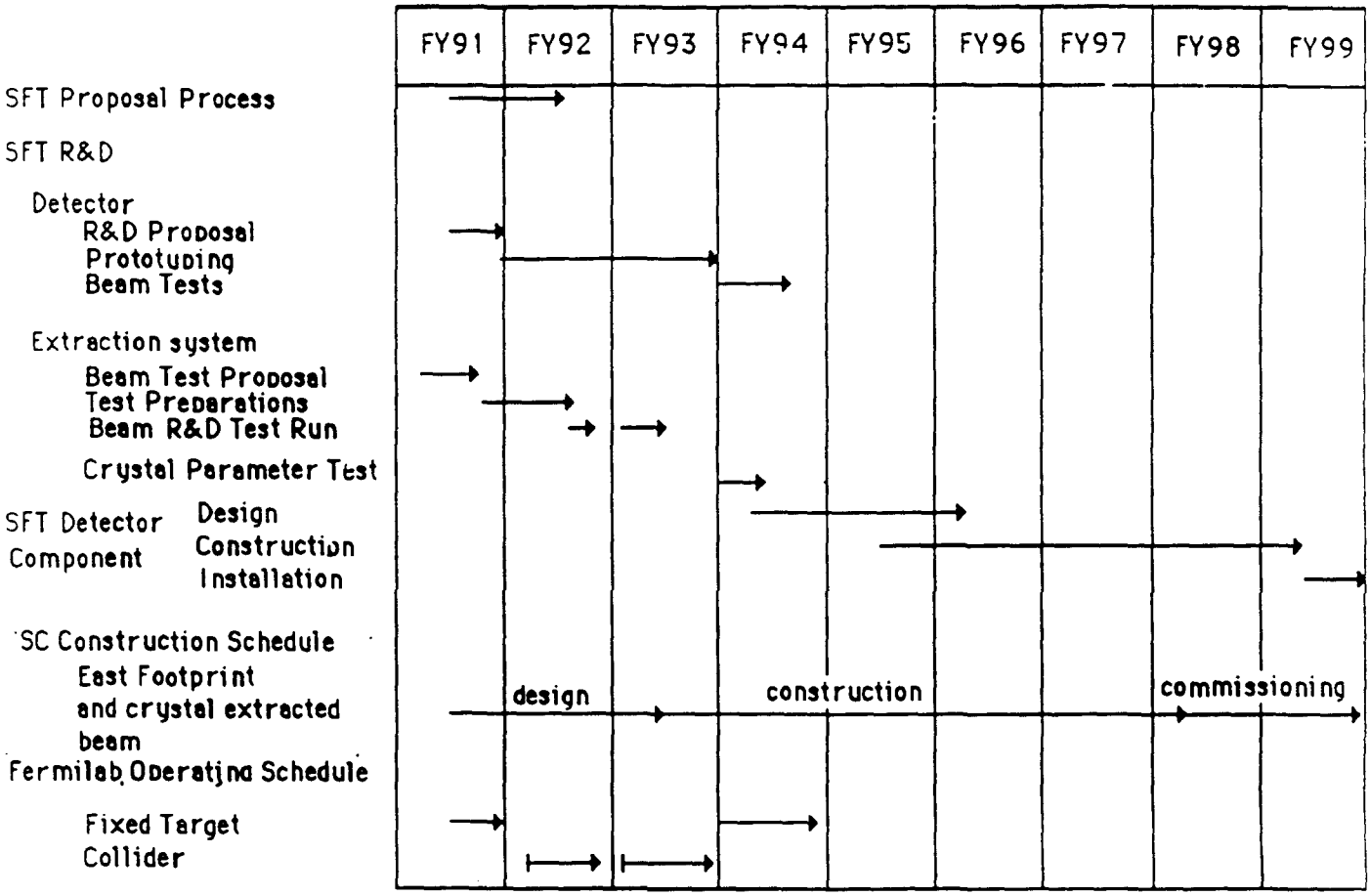
- Random noise simulation: Not yet 'filtered'
- Must simultaneously achieve large 'final' step size **And** very gradual (10^8 p/sec from 10^{14} circulating) depletion of beam
- Differential 'heating' of momentum bits required

$\sigma_{\hat{\phi}} = 0.15524$

Alignment!

Radiation damage issue for an 'intact' silicon crystal is on $> 10^{18}$–10^{19} p/cm^2

Draft Schedule for SFT



Summary

- The SFT B Facility offers a way to economically (~ \$40M) produce $2\times10^{10} \to 10^{11}$ B's/year in an experimental configuration which offers good detection and reconstruction efficiencies and unique advantages of producing the B's in a 'live' target and directly observing $B^{\pm}$'s, $D^{\pm}$'s, $\tau^{\pm}$'s, ... CP Asymmetry measurements are very accessible to this experiment.

- The low intensity of the 20 TeV protons required for the SFT B Facility allows operation of this facility in a concurrent and non interferring way with the high $p_{\perp}$ collider program

- Crystal channeling is an intriguing option to generate the 20 TeV proton beam. It offers the advantage of producing only a few $\times 10^6$ interactions to obtain a beam of 10^8 protons/sec

- Experiment is modest enough to insure early readiness at the time the SSC turns on ($\geq$ 1999?) if we get started soon.

Proceedings of the 1984 Summer Study on the Design and Utilization of the Superconducting Super Collider

June 23-July 13, 1984, Snowmass, Colorado

Editors
Rene Donaldson and Jorge G. Morfín

REPORT OF THE WORKING GROUP ON CP VIOLATION AND RARE DECAYS

J.W. Cronin, University of Chicago; N.G. Deshpande, University of Oregon; G.L. Kane, University of Michigan; V.C. Luth, Stanford Linear Accelerator Center; M.E. Machacek, Northeastern University; A.C. Odian, Stanford Linear Accelerator Center; F. Paige, Brookhaven National Laboratory; M.P. Schmidt, Yale University; J. Slaughter, Yale University; G.H. Trilling, Lawrence Berkeley Laboratory; M. Witherell, University of California at Santa Barbara; S.G. Wojcicki, Stanford University.

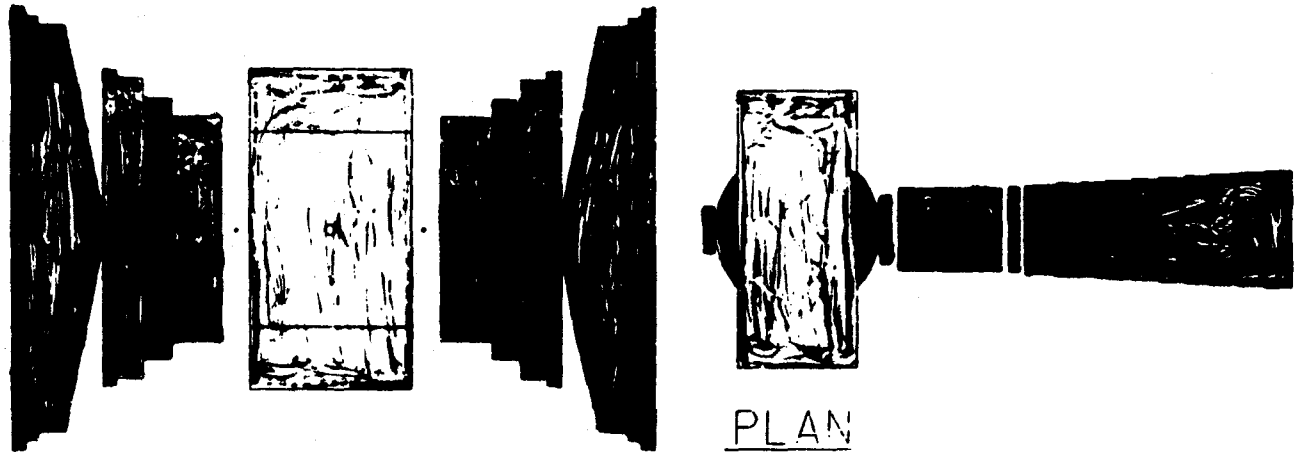
With respect to the SSC, these calculations suggest an a-priori two-order-of-magnitude advantage for operation in the collider mode as opposed to the fixed target mode. It is conceivable that the acceptance in a fixed-target experiment can be better for less cost, but it seems doubtful that the two orders of magnitude can be regained. For this reason, we have chosen to emphasize experiments in the SSC collider mode.

B-Physics Proposals to the SSC, cont.

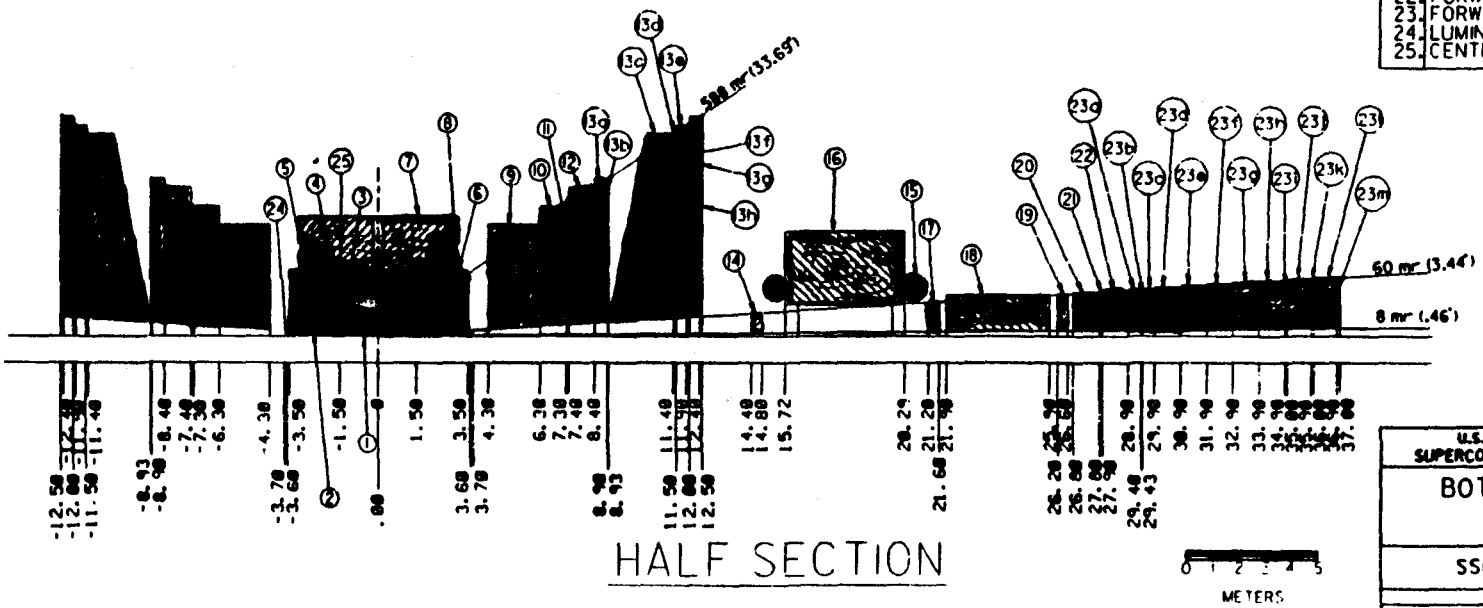
III. EOI-8 'BCD' (N. Lockyer *et al.*).

- Collider experiment with 4π detector based on a dipole magnet.
- Rates $\sim$ 25 times those in the fixed-target experiments.
- Cost $\sim$ 3 times that of the fixed-target experiments.

Bottom
Collider
Detector



I.D.	COMPONENT
1.	CENTRAL VERTEX DETECTOR
2.	CENTRAL TRACKING
3.	CENTRAL RICH
4.	CENTRAL TRD
5.	CENTRAL TOF
6.	CENTRAL CALORIMETER
7.	CENTRAL MAGNET IRON
8.	CENTRAL MAGNET COIL
9.	INTERMEDIATE RICH
10.	INTERMEDIATE TRD
11.	INTERMEDIATE TOF
12.	INTERMEDIATE CALORIMETER
13.	INTERMEDIATE MUON
14.	FORWARD TRACKING #1
15.	FORWARD MAGNET COIL
16.	FORWARD MAGNET IRON
17.	FORWARD TRACKING #2
18.	FORWARD RICH
19.	FORWARD TRACKING #3
20.	FORWARD TRD
21.	FORWARD TOF
22.	FORWARD CALORIMETER
23.	FORWARD MUON
24.	LUMINOSITY MONITOR
25.	CENTRAL SUPPORT SHELL

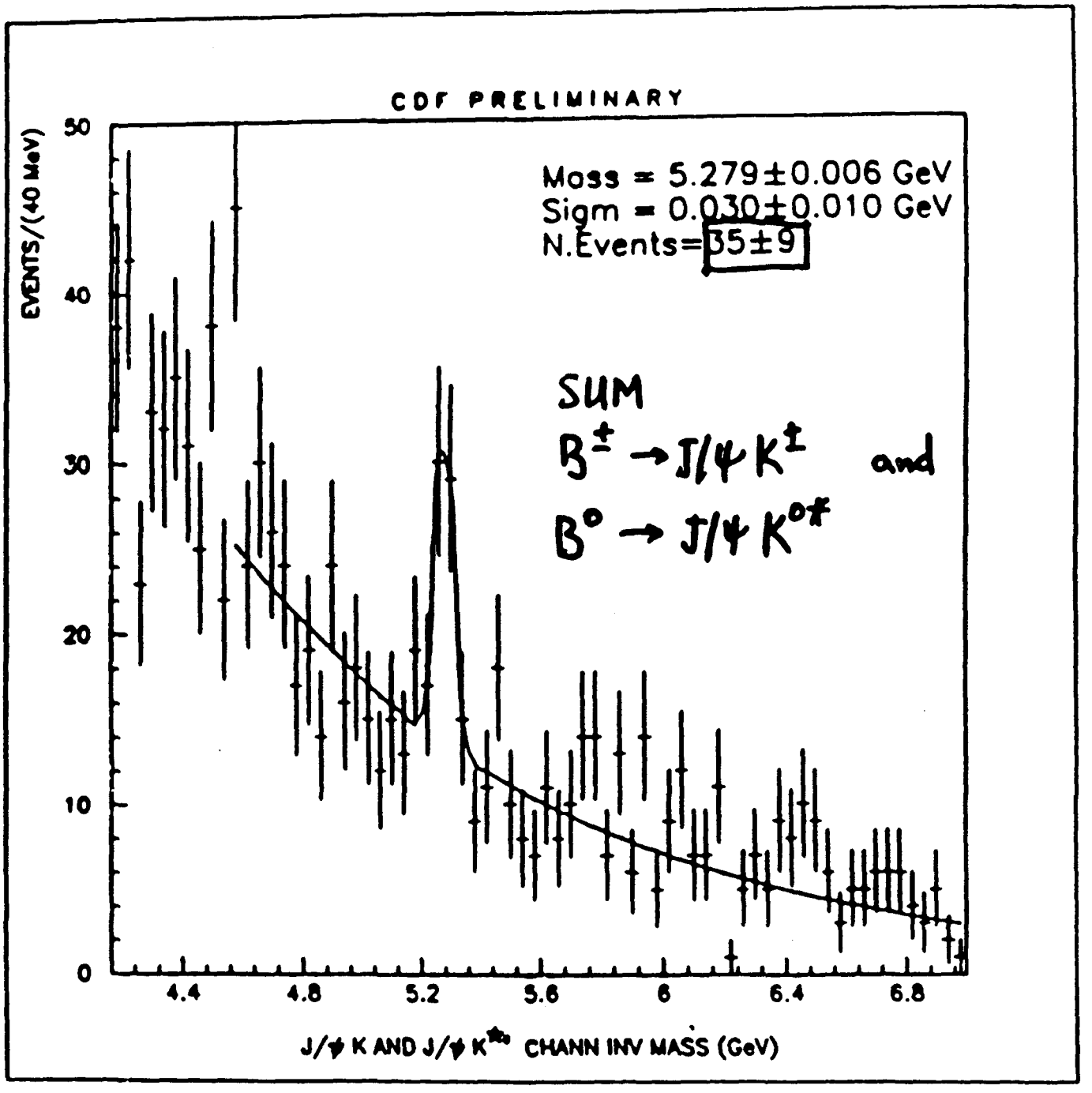


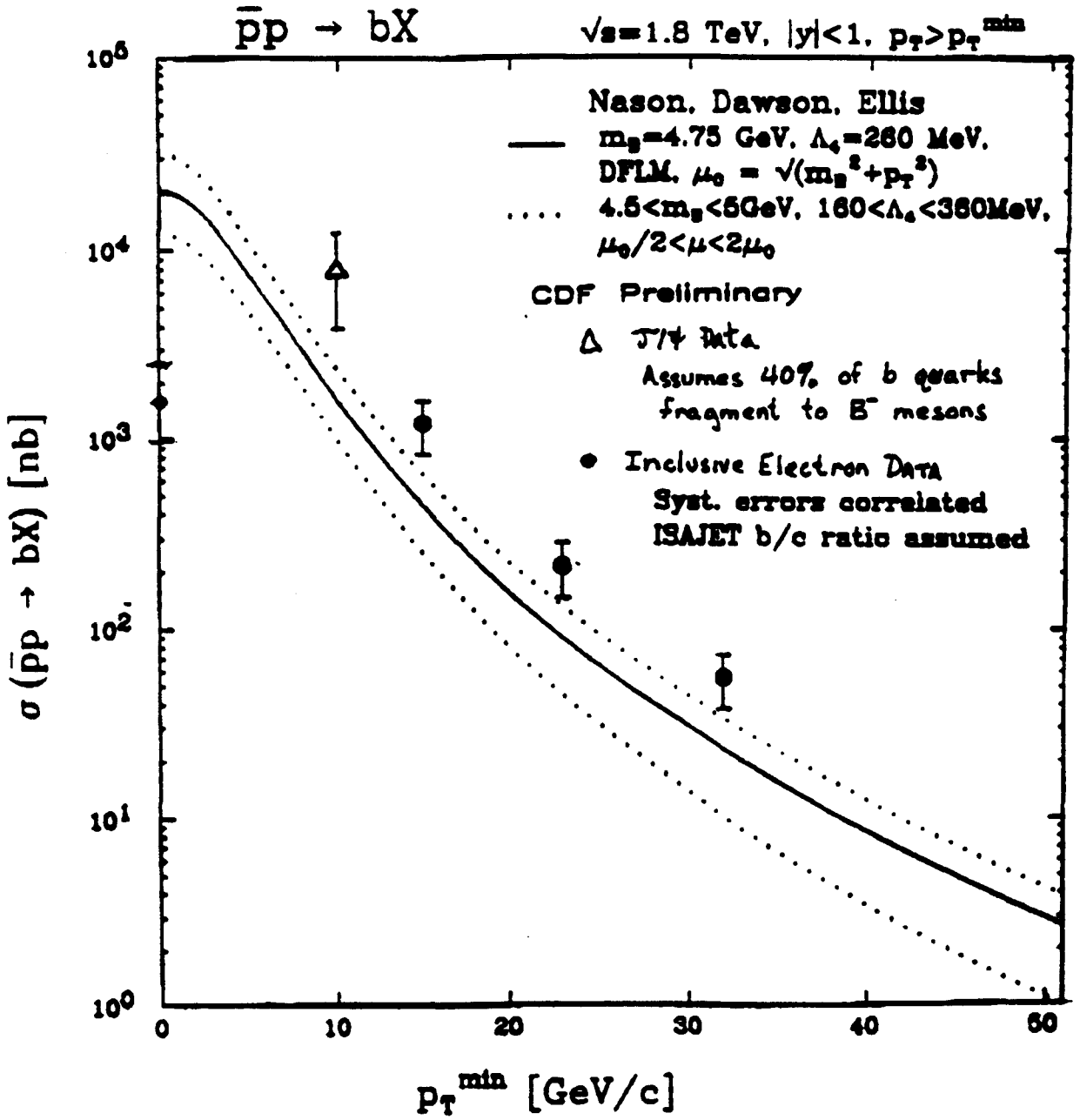
U.S. DEPARTMENT OF ENERGY
SUPERCONDUCTING SUPER COLLIDER

BOTTOM COLLIDER DETECTOR

SSC LABORATORY

DRAWING: 0024 | DATE: | REV | SHEET 1


CDF PRELIMINARY
Mass = 5.279±0.006 GeV
Sigm = 0.030±0.010 GeV
N.Events=35±9
SUM
$B^{\pm} \to J/\psi K^{\pm}$ and
$B^{0} \to J/\psi K^{0*}$
EVENTS/(40 MeV)
0
10
20
30
40
50
4.4
4.8
5.2
5.6
6
6.4
6.8
J/ψ K AND J/ψ K* CHANN INV MASS (GeV)

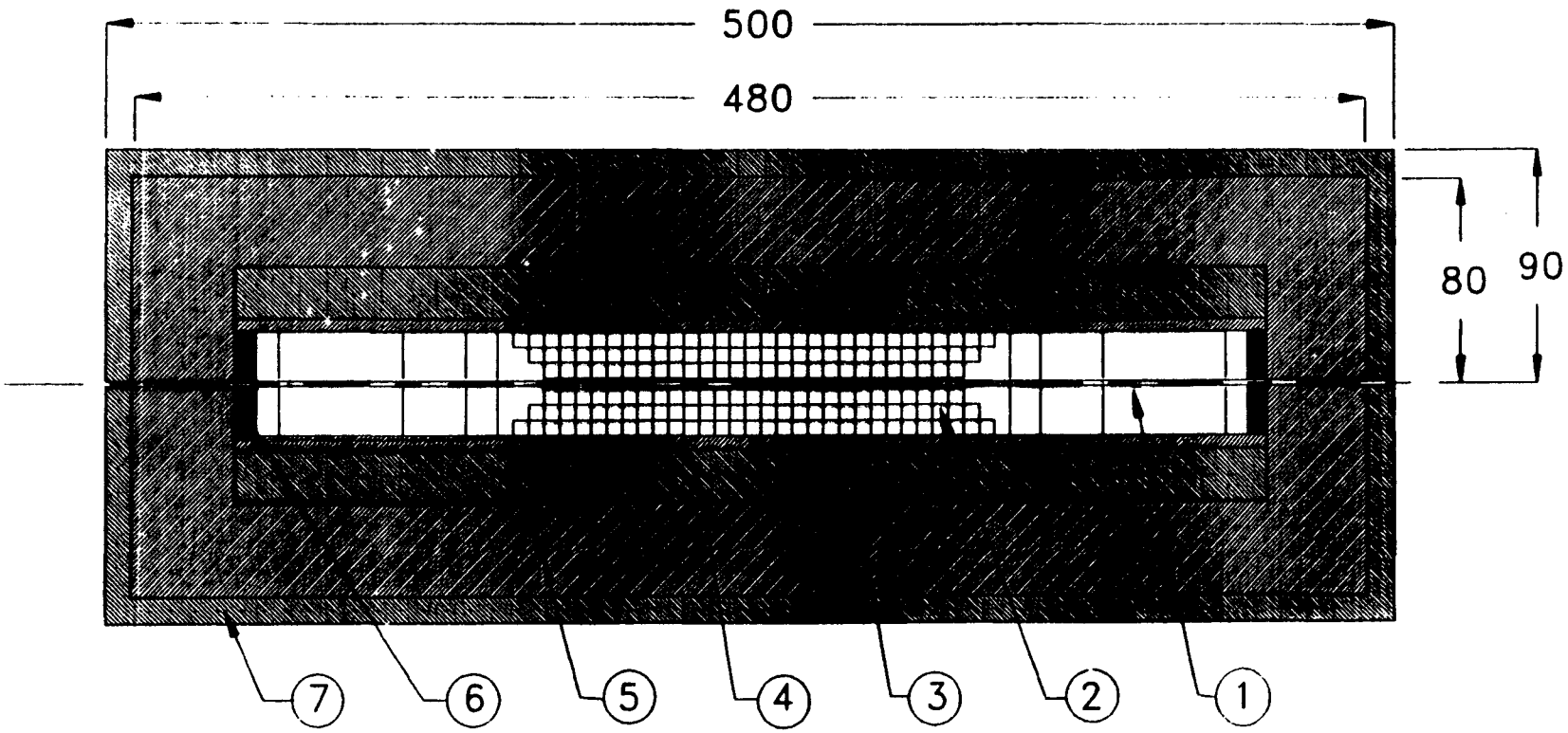

$\bar{p}p \rightarrow bX$
$\sqrt{s}$=1.8 TeV, |y|<1, $p_T > p_T^{min}$
Nason, Dawson, Ellis
m_B=4.75 GeV, Λ_4=260 MeV,
DFLM, $\mu_0 = \sqrt{(m_B^2+p_T^2)}$
4.5<m_B<5GeV, 160<Λ_4<360MeV,
$\mu_0/2<\mu<2\mu_0$
CDF Preliminary
J/ψ Data
Assumes 40% of b quarks fragment to B^- mesons
Inclusive Electron Data
Syst. errors correlated
ISAJET b/c ratio assumed
$\sigma(\bar{p}p \rightarrow bX)$ [nb]
p_T^{min} [GeV/c]
10^0
10^1
10^2
10^3
10^4
10^5
0
10
20
30
40
50

BCD Ongoing R&D

- Silicon Vertex Detector
  - BVX readout chip: 1 ADC per channel
  - Robotic assembly of interleaved disks and barrels; air cooling
  - Beam tests of double-sided AC-coupled detector (Micron)
- Straw Tracker prototype: Penn bipolar preamp
  - 200 channel system test Summer 91
- RICH Counter: solid CSI-TMAE photocathode
  - 400 channel system test Summer 91
- Barrel Switch Event Builder
  - 600 event/sec demo in 1/2 crate
- Processor Farm: high bandwidth network
  - 1991: 512 i860 cpu's on mesh network

The μBCD Proposal

- A 3-D **Silicon Vertex Detector/Tracker** with interleaved 'disks' and barrels.' $R = 20$ cm, $L = \pm 160$ cm, $|\eta| < 3$, 1.5-2M strips on double-sided, AC-coupled wafers with next-generation BVX readout chips.
- A **Ring-Imaging-Čerenkov Counter** operating a low pressure with a solid CsI-TMAE photocathode. $20 < R < 25$ cm, π/K separation for $0.3 < P < 4$ GeV/c, 200k pad channels with BVX readout.
- A **Conventional Solenoid Magnet**, $B = 1.5$ kG, coil at $25 < R < 45$ cm, flux return at $45 < R < 52$ cm, 10 tons, 1 MWatt.
- A **High-Speed Data Acquisition System**, capable of recording 1000 events/sec, via a 1-crate, 64-channel barrel-switch event builder.
- **No Trigger** $\Rightarrow$ 1 B-$\bar{B}$ pair/sec. (Equivalent to $\mathcal{L} = 10^{33}$ cm^{-2}sec^{-1} at an e^+e^- collider.)
- Estimated **Cost = \$7M**.


500
480
80
90
7
6
5
4
3
2
1

Cuts Used in the Fermilab Rate Estimates

Cut	CDF	D0	BSD	BCD
$\eta_{\mathrm{max},\pi}$	1.0	2.8	2.8	4.0
$P_{t,\mathrm{min},\pi}$ (GeV/c)	0.3	0.3	0.3	0.3
$\eta_{\mathrm{max},K}$	1.0	–	2.8	4.0
$P_{t,\mathrm{min},K}$ (GeV/c)	0.3	–	0.3	0.3
$P_{\mathrm{max},K}$ (GeV/c)	4.0	–	4.0	60.0
$\eta_{\mathrm{max},e}$	1.0	2.8	2.8	4.0
$P_{t,\mathrm{min},e}$ (GeV/c)	2.0	2.0	1.0	1.0
$\eta_{\mathrm{max},\mu}$	1.0	2.8	2.8	4.0
$P_{t,\mathrm{min},\mu}$ (GeV/c)	2.0	1.0	1.0	1.0
$P_{\mathrm{min},\mu}$ (GeV/c)	2.0	3.0	3.0	3.0

CDF

BSD = Bottom Solenoid Detector.

BCD = Bottom Collider Detector, based on a dipole magnet.

Table 1: The numbers of tagged, reconstructed $B \to J/\psi K_S$ decays in a run of 1000 pb^{-1} at CDF, at an upgraded D0, at a Bottom Solenoid Detector (BSD), and a Bottom Collider (dipole) Detector (BCD) for J/ψ decays to $\mu\mu$ and ee and for tagging of the second B via $\mu^{\pm}$, $e^{\pm}$, and $K^{\pm}$. Also listed is the minimum value of the CP-violating asymmetry A that could be resolved to three standard deviations. The numbers in parentheses might be obtained in CDF with the addition of Kaon identification, which is not part of the present CDF-upgrade plan.

Technique	CDF		D0		BSD		BCD	
	Events	A_{min}	Events	A_{min}	Events	A_{min}	Events	A_{min}
μ only	50	1.00	140	1.00	140	1.00	200	0.85
e only	50	1.00	50	1.00	500	0.52	500	0.52
$\mu + e$	200	0.85	400	0.60	1200	0.35	1250	0.34
$\mu + K$	(250)	(0.76)	—	—	1400	0.32	2250	0.25
$e + K$	(250)	(0.76)	—	—	3750	0.20	4650	0.18
$\mu + e + K$	(1000)	(0.38)	—	—	5600	0.16	8400	0.13

3σ

Table 4: B-$\bar{B}$ production at hadron accelerators. In this comparison we suppose that the experiments all operate at 10^7 interactions/sec, and that corresponding luminosity $\mathcal{L}$ can be achieved. We then consider $\sigma_{b\bar{b}}/\sigma_{tot}$, as the figure of merit of the various accelerator options.

Accelerator	$\sqrt{s}$ (TeV)	$\sigma_{b\bar{b}}$ (μb)	σ_{tot} (mb)	$\sigma_{b\bar{b}}/\sigma_{tot}$	$\mathcal{L}_{ave}$ (cm^{-2}sec^{-1})	$\cdot\ N_{b\bar{b}}/10^7$ sec	Figure of Merit
TEV II (p-W)	0.04	0.003	6	5×10^{-5}	1.7×10^{33}	1.7×10^7	1/2500
SSC (p-Si)	0.2	3	15	1/5000	6.7×10^{32}	2×10^{10}	1/25
RHIC (p-p)	0.5	10	40	1/4000	2.5×10^{32}	2.5×10^{10}	1/20
TEV I (p-$\bar{p}$)	1.8	40	40	1/1000	2.5×10^{32}	10^{11}	1/5
LHC (p-p)	16	250	75	1/300	1.3×10^{32}	3.3×10^{11}	2/3
SSC (p-p)	40	500	100	1/200	10^{32}	5×10^{11}	1

Table 1: Update of Table 11 of the BCD EOI to include a Kaon tag. The minimum values of $\sin 2\varphi_i$ resolvable to three standard deviations in 10^7 sec of running at luminosity of 10^{32} $cm^{-2}sec^{-1}$. The factor $1-2p$ is the analyzing power of the tag which has a probability p for a wrong tag. b is the background to signal for the final-state reconstruction. The dilution factor D due to mixing is given by $x_q \coth(\pi/2x_q)/(1+x_q^2)$.

Angle	Mode	Tag	Tagged Events	$1-2p$	b	x_q	D	$\sin 2\varphi_{min,3\sigma}$
φ_1	$B_d^0 \to J/\psi K_S^0$	$e^\pm$	14,400	0.60	0.1	0.7	0.47	0.094
φ_1	$B_d^0 \to J/\psi K_S^0$	$K^\pm$	110,000	0.40	0.1	0.7	0.47	0.053
φ_2	$B_d^0 \to \pi^+\pi^-$	$e^\pm$	60,000	0.60	1.0	0.7	0.47	0.062
φ_2	$B_d^0 \to \pi^+\pi^-$	$K^\pm$	460,000	0.40	1.0	0.7	0.47	0.033
φ_3	$B_s^0 \to \rho^0 K_S^0$	$e^\pm$	400	0.60	1.0	~ 10	0.64	0.55
φ_3	$B_s^0 \to \rho^0 K_S^0$	$K^\pm$	3500	0.40	1.0	~ 10	0.64	0.28
φ_3	$B_s^0 \to K^+K^-$	$e^\pm$	1,560	0.60	~ 0.1	~ 10	0.64	0.21
φ_3	$B_s^0 \to K^+K^-$	$K^\pm$	13,800	0.40	~ 0.1	~ 10	0.64	0.10
φ_4	$B_s^0 \to J/\psi\phi$	$K^\pm$	160,000	0.40	~ 0.1	~ 10	0.64	0.031

Table 3: The sensitivity of an asymmetric e^+e^- collider to $\sin 2\varphi_2$ at 3-σ statistical significance via the decay $B_d^0 \to \pi^+\pi^-$. The BCD sensitivity is 0.06 in one year of running.

$\mathcal{L}$	Running Time (Years)		
$cm^{-2}sec^{-1}$	1	3	10
10^{33}	0.61	0.35	0.19
3×10^{33}	0.35	0.20	0.11
10^{34}	0.19	0.11	0.06

Table 2: The sensitivity of an asymmetric e^+e^- collider to $\sin 2\varphi_1$ at 3-σ statistical significance via the decay $B_d^0 \to J/\psi K_S^0$. A 'year' consists of 10^7 sec. The BCD sensitivity is 0.05 in one year of running.

$\mathcal{L}$	Running Time (Years)		
$cm^{-2}sec^{-1}$	1	3	10
10^{33}	0.48	0.28	0.15
3×10^{33}	0.28	0.16	0.09
10^{34}	0.15	0.09	0.05

Cuts Used in the SSC Rate Estimates

Cut	C	I	F	BSD
η_{min}	-1.2	1.2	3.5	-2.5
η_{max}	1.2	3.5	5.5	2.5
$P_{t,\mathrm{min},\pi,K}$ (GeV/c)	0.3	0.3	0.3	0.3
$P_{\mathrm{min},K}$ (GeV/c)	0.3	4.0	7.5	0.3
$P_{\mathrm{max},K}$ (GeV/c)	4.0	60.0	240.0	4.0
$P_{t,\mathrm{min},e,\mu}$ (GeV/c)	1.0	1.0	1.0	1.0
$P_{\mathrm{min},\mu}$ (GeV/c)	3.0	3.0	3.0	3.0
$\lvert\phi\rvert_{\mathrm{max}}$	15°			

C = Central dipole detector.

I = Intermediate dipole detector

F = Forward dipole detector.

BSD = Bottom Solenoid Detector.

Sensitivity to $\sin\varphi_1$ at the SSC

The numbers of tagged, reconstructed $B \to J/\psi K_S$ decays in a run of 1000 pb^{-1}.

$A_{\text{min}} = 12/\sqrt{N}$ = minimum value of the CP-violating asymmetry that could be resolved to three standard deviations.

Technique	C + I		F		I + F		BSD	
	Events	A_{min}	Events	A_{min}	Events	A_{min}	Events	A_{min}
μ only	420	0.58	190	0.87	1315	0.33	400	0.60
e only	1195	0.35	160	0.94	1405	0.32	2420	0.24
μ, e	3015	0.22	700	0.45	5405	0.16	5145	0.16
μ, K	5650	0.16	2550	0.24	14020	0.10	7730	0.14
e, K	13020	0.11	2520	0.24	14520	0.10	24590	0.08
μ, e, K	20007	0.08	5430	0.16	31225	0.07	34650	0.06

C = Central dipole detector.

I = Intermediate dipole detector.

F = Forward dipole detector.

BSD = Bottom Solenoid Detector.

Table 12: Alternative detector configurations that maintain a broad-based B-physics program while expanding the solid-angle coverage. Refer to Table 11 for a description of the detector types. The acceptance for B physics is based on Table 7 of the BCD EOI, and is taken as the relative measure of the physics capability of each detector configuration. The cost estimate is based on Table 23 of the BCD EOI and includes contingency and EDIA of 40%. 'P/P' is a relative measure of performance/price and is proportional to Acc./Cost.

Config.	Detector														Acc.	Cost	P/P
	μ F 1	e F 1	h F 1	μ I 1	e I 1	h I 1	e C	h C	μ I 2	e I 2	h I 2	μ F 2	e F 2	h F 2		($M)	
A							Y								0.004	66	0.07
B							Y	Y							0.007	72	0.11
C					Y	Y									0.006	81	0.09
D				Y	Y	Y									0.012	98	0.14
E	Y		Y												0.003	59	0.06
F	Y	Y	Y												0.005	63	0.09
G					Y	Y	Y	Y							0.031	109	0.33
H				Y	Y	Y	Y	Y							0.055	126	0.50
I		Y	Y		Y	Y									0.027	106	0.29
J	Y	Y	Y	Y	Y	Y									0.053	133	0.46
K		Y	Y	Y	Y	Y	Y	Y							0.080	155	0.59
L	Y	Y	Y	Y	Y	Y	Y	Y							0.106	165	0.74
M					Y	Y	Y	Y	Y	Y					0.079	160	0.57
N				Y	Y	Y	Y	Y	Y	Y	Y				0.103	193	0.61
O		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y				0.131	200	0.75
P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y				0.154	208	0.85
Q		Y	Y		Y	Y	Y	Y		Y	Y		Y	Y	0.102	182	0.65
R	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	0.204	235	1

Table 13: Alternative detector configurations that specialize in reconstruction of $B \to J/\psi K_S^0$ via emphasis on leptons. Refer to Table 11 for a description of the detector types. The acceptance for B physics is based on Table 7 of the BCD EOI, and is taken as the relative measure of the physics capability of each detector configuration. The cost estimate is based on Table 23 of the BCD EOI and includes contingency and EDIA of 40%. 'P/P' is a relative measure of performance/price and is proportional to Acc./Cost.

Config.	Detector														Acc.	Cost	P/P
	μ F 1	e F 1	h F 1	μ I 1	e I 1	h I 1	e C	h C	μ I 2	e I 2	h I 2	μ F 2	e F 2	h F 2		($M)	
S					Y										0.005	52	0.05
T				Y	Y										0.020	69	0.14
U					Y		Y								0.020	67	0.14
V				Y	Y		Y								0.035	83	0.20
W				Y	Y		Y		Y	Y					0.080	95	0.40
X	Y	Y		Y	Y		Y								0.090	121	0.35
Y	Y	Y		Y	Y		Y		Y	Y		Y	Y		0.240	172	0.67

V - W - Y - R, or S - U - V - X - Y - R. Configurations T, U, and even S already have very competitive capabilities for measurements of $\sin 2\varphi_1$ and $\sin 2\varphi_2$.

We consider the mini-BCD to be an important stage towards BCD. It should measure B_s mixing and provide evidence of CP violation if the latter is fairly strong.

Schedule for the BCD Program

1. Bench-top and test beam demonstrations of the 3-D vertex detector and compact RICH counter through 1992.

2. Installation of prototype segments of the vertex detector and RICH counter in C0 at the end of the 1993 collider run.

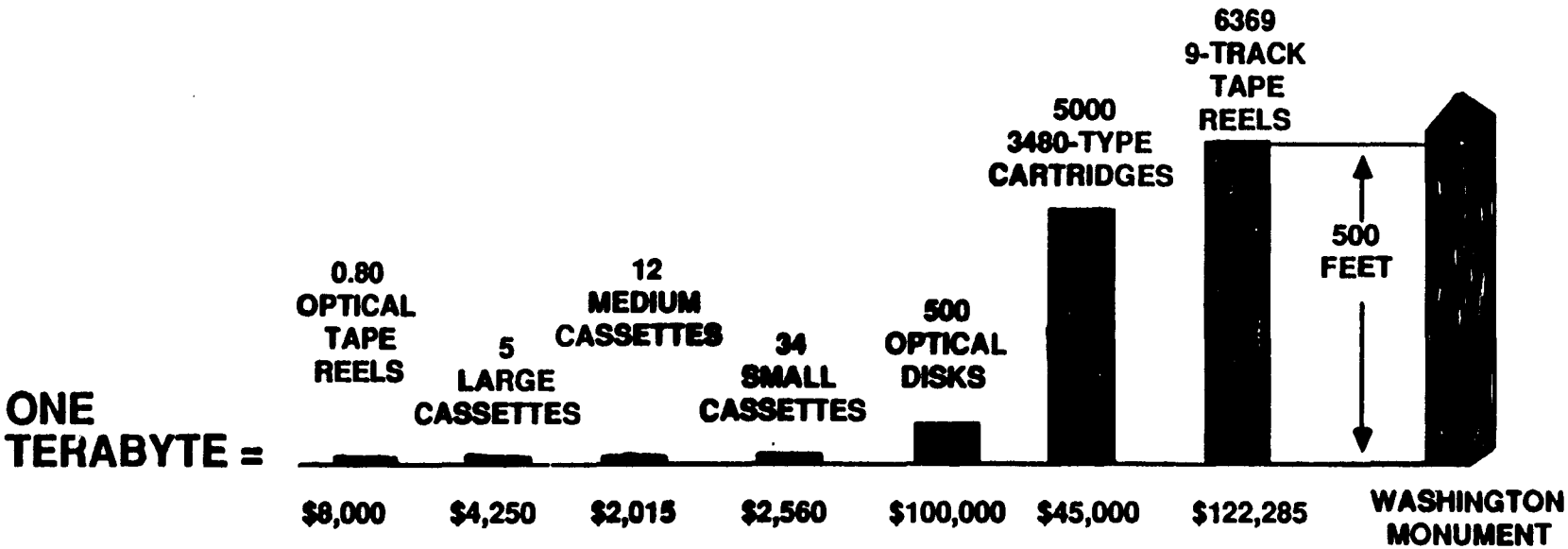
3. Installation and test run of the μBCD detector in C0 for the 1995 collider run.

4. Installation of the μBCD detector as the inner detector of CDF or D0 for a full-luminosity run in 1997. The physics goal would be a study of B_s mixing.

5. Construction of a dedicated B-physics experiment through $\sim$ 1999, leading to a measurement of CP violation.

VOLUME

- **EVEN THE HIGHEST DENSITY STORAGE TECHNIQUES WILL REQUIRE SUBSTANTIAL STORAGE VOLUMES...**



1 SMALL CASSETTE CONTAINS 29,500 MEGABYTES or 187 REELS OF TAPE

1 MEDIUM CASSETTE CONTAINS 86,625 MEGABYTES or 551 REELS OF TAPE

1 LARGE CASSETTE CONTAINS 189,875 MEGABYTES or 1,185 REELS OF TAPE

Observation of $B_u^{\pm} \rightarrow J/\psi + K^{\pm}$

- Find $J/\psi \rightarrow \mu^+\mu^-$, mass constrain the J/ψ
- Beam constrain all other tracks - assume these are charged kaons
- Select all tracks within a cone of 60° about the J/ψ with $p_T > 2.5$ GeV/c
- Make invariant mass of J/ψ with these kaon candidates

Observation of $B_d^0 \rightarrow J/\psi + K^{0*}$

- Find $J/\psi \rightarrow \mu^+\mu^-$, mass constrain the J/ψ
- Beam constrain all other tracks
- Select the three highest momentum tracks in a cone of 60° about the J/ψ (reduces combinatorics)
- Form opposite-signed track pairs, calculate the invariant mass for both assignments of the K and π mass.
- Require M($K\pi$) to be within 50 MeV of the K^{0*} mass

BCD Ongoing R&D

- Silicon Vertex Detector
  - BVX readout chip: 1 ADC per channel
  - Robotic assembly of interleaved disks and barrels; air cooling

  Beam tests of double-sided AC-coupled detector (Micron)

- Straw Tracker prototype: Penn bipolar preamp
  - 200 channel system test Summer 91

- RICH Counter: solid CSI-TMAE photocathode
  - 400 channel system test Summer 91

- Barrel Switch Event Builder
  - 600 event/sec demo in 1/2 crate

- Processor Farm: high bandwidth network
  - 1991: 512 i860 cpu's on mesh network

J.G. Heinrich
K.T. McDonald
Princeton University
May 19, 1991

Peripheral Production of Fermion Pairs in Heavy-Ion Collisions

Recently several groups have made estimates of the Higgs-boson production rate in heavy-ion collisions in which there is no strong interaction, but rather the heavy ions emit a pair of virtual photons which collide and materialize as the Higgs boson.[1, 2, 3, 4, 5, 6, 7] Such processes were first considered by Landau and Lifshitz in 1934.[8] The cross section varies as Z^4, so the rates can be quite large for heavy ions.

Here we estimate the rates for the production of various fermion-antifermion pairs, which were considered only as backgrounds in Refs. [1-7] (except for Ref. [4]). Such pairs would be produced in a collision in which the heavy ions remain intact, and go down the beam pipes. That is, pair production by virtual photons in heavy-ion collision is as clean as pair production in an e^+e^- collider. One would devise a veto on any forward tracks outside the beam pipes to reject the unwanted hadronic interactions. If the rates are high enough, a heavy-ion collider could be the most favored source of heavy-quark pairs in the future.

The Landau and Lifshitz cross section, as improved by Racah,[9] for production of a pair of fermions each of charge q and mass m in a collision of a pair of heavy ions each of charge Z and γ per nucleon in the center-of-mass frame is

$$\sigma_{\rm LL} = \frac{28}{27\pi} Z^4 q^4 \alpha^2 r_e^2 \left(\frac{m_e}{m}\right)^2 (A^3 - 6.36A^2 + 15.7A - 13.8),$$

where r_e is the classical electron radius, and $A = \ln 4\gamma^2$. From this expression, rather large rates are predicted at RHIC and the SSC, where $\gamma = 100$ and 8000 per nucleon, respectively. However, the Landau-Lifshitz calculation is based on a model of nuclei as point charges, which overestimates the actual effect for large masses of the produced particles.

Here we follow the prescription of Ref. [3] to include a model of the nuclear eleastic form factor:

$$\sigma_{ZZ\to ZZff} = Z^4 \int dx_1 dx_2 F(x_1) F(x_2) \sigma_{\gamma\gamma\to ff}(x_1 x_2 s).$$

In this, s is the square of the center-of-mass energy of the heavy ion collision, and x is the fraction of the energy of a heavy ion that is taken by the virtual photon. The equivalent-photon spectrum of the field of a Pb^{206}_{82} nucleus is taken from [3] as

$$F(x) = \frac{\alpha}{\pi}\left[-\frac{\exp(-x^2M^2/Q_0^2)}{x} + \left(\frac{1}{x} + \frac{x^2M^2}{Q_0^2}\right) \mathrm{Ei}(x^2M^2/Q_0^2)\right],$$

where M is the mass of the nucleus, $Q_0 \approx 60$ MeV, and $\mathrm{Ei}(x)$ is the exponential integral $\int_x^\infty (e^{-t}/t)dt$. The spectrum $F(x)$ falls rapidly with increasing x to 10^{-4} of its peak value at $x = 4 \times 10^{-4}$, beyond which F falls extremely rapidly.

The cross section for fermion-pair production by light was first calculated by Breit and Wheeler.[10] We take the cross section from eq. (13-40) of Ref. [11] as

$$\sigma_{\gamma\gamma\to f\bar{f}} = \frac{\pi}{2} q^4 r_e^2 \left(\frac{m_e}{m}\right)^2 \frac{1}{\gamma_f^2} \left[(3-\beta_f^4)\ln\left(\gamma_f^2(1+\beta_f)^2\right) - 2\beta_f\left(1+\frac{1}{\gamma_f^2}\right)\right].$$

In this, $\gamma_f^2 = s/4m^2$ where s is the square of the center-of-mass energy of the photon-photon collision.

The results of a numerical integration of these expressions are given in Table 1.

Table 1: The cross sections for fermion-antifermion production via virtual photons in Pb-Pb collisions at RHIC and the SSC. We suppose that the γ per nucleon is 100 at RHIC, and 8000 at the SSC. Also shown are the estimates of Landau and Lifshitz. The total hadronic interaction rates are a few barns.

Fermion	Mass	$\sigma_{ZZ\to ZZf\bar{f}}$		σ_{LL}	
	(GeV/c^2)	(mb) RHIC	(mb) SSC	(mb) RHIC	(mb) SSC
e	0.000511	1.4×10^8	3.5×10^8	4.0×10^7	3.3×10^8
μ	0.105	226	2468	940	7716
τ	1.784	3.2×10^{-3}	2.6	3.3	26.7
u	0.333	1.0	32.5	18.5	152
d	0.333	0.065	2.0	1.1	9.4
s	0.5	0.014	0.76	0.51	4.2
c	1.5	1.7×10^{-3}	0.79	0.91	7.48
b	5.0	1.3×10^{-8}	1.9×10^{-3}	5.1×10^{-3}	0.042

The rate for $b\bar{b}$ production at RHIC is too low to be of interest, but the rate at the SSC, some 10^{-7} of the ($\approx$ 10 b) total hadronic cross section, is almost high enough. If one ran with 10^7 hadronic interactions/sec, there would be about 1 clean $b\bar{b}$ pairs/sec from the virtual photons. This is equivalent to a luminosity of 10^{33} at an e^+e^- collider. However, a luminosity of 10^{28} for heavy-ion collisions at the SSC is already quite ambitious. This would yield only 1 $b\bar{b}$ event every 100 seconds.

1 References

[1] E. Papageorgiu, *Coherent Higgs-Boson Production in Relativistic Heavy-Ion Collisions*, Phys. Rev. D **40**, 92 (1989).

[2] M. Grabiak *et al.*, *Electroweak Physics at Relativistic Heavy-Ion Colliders*, J. Phys. G **15**, L25 (1989).

[3] M. Drees, J. Ellis and D. Zeppenfeld, *Can One Detect an Intermediate Higgs Boson in Heavy-Ion Collisions?*, Phys. Lett. **223B**, 454 (1989).

[4] E. Gotsman and D. Lissauer, *Heavy Quark Production in Heavy Ion Collisions*, Phys. Lett. **240B**, 16 (1990). Their numerical results for $b\bar{b}$ production at RHIC are signficantly larger than ours.

[5] R.N. Cahn and J.D. Jackson, *Realistic Equivalent Photon Yields in Heavy Ion Collisions*, LBL-28592 (March, 1990). This paper claimed that the results of Ref. [3] were in error because they neglected nuclear breakup. However, the consensus now is that Ref. [3] did in fact take breakup into account by use of the elastic form factor.

[6] C. Bottcher *et al.*, *Coherent Higgs Production at Heavy-Ion Colliders*, Particle World **1**, No. 6, 174 (1990).

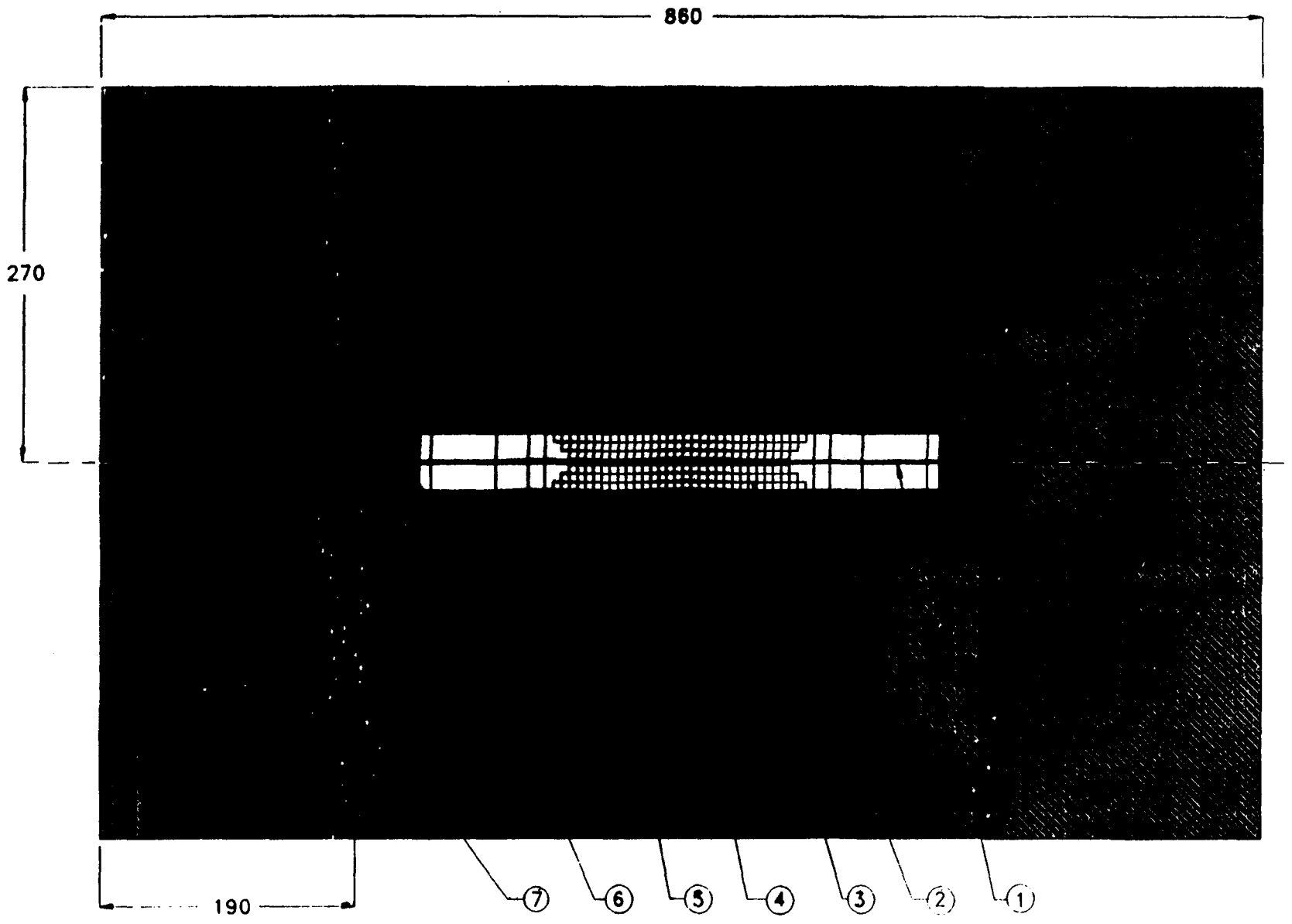
[7] B. Müller and A.J. Schramm, *Higgs Boson Production in Heavy Ion Collisions*, Duke U. preprint DUK-TH-90-4 (June, 1990).

[8] L. Landau and E. Lifshitz, *On the Production of Electrons and Positrons by a Collision of Two Particles*, Phys. Zeits. d. Sov. Union **6**, 244 (1934) [in english!].

[9] G. Racah, Nuovo Cim. **14**, 93 (1937).

[10] G. Breit and J.A. Wheeler, *Collision of Two Light Quanta*, Phys. Rev. **46**, 1087 (1934).

[11] J.M. Jauch and F. Rohrlich, *The Theory of Photons and Electrons*, 2nd edition, Springer-Verlag (New York, 1976).


860
270
190
7
6
5
4
3
2
1

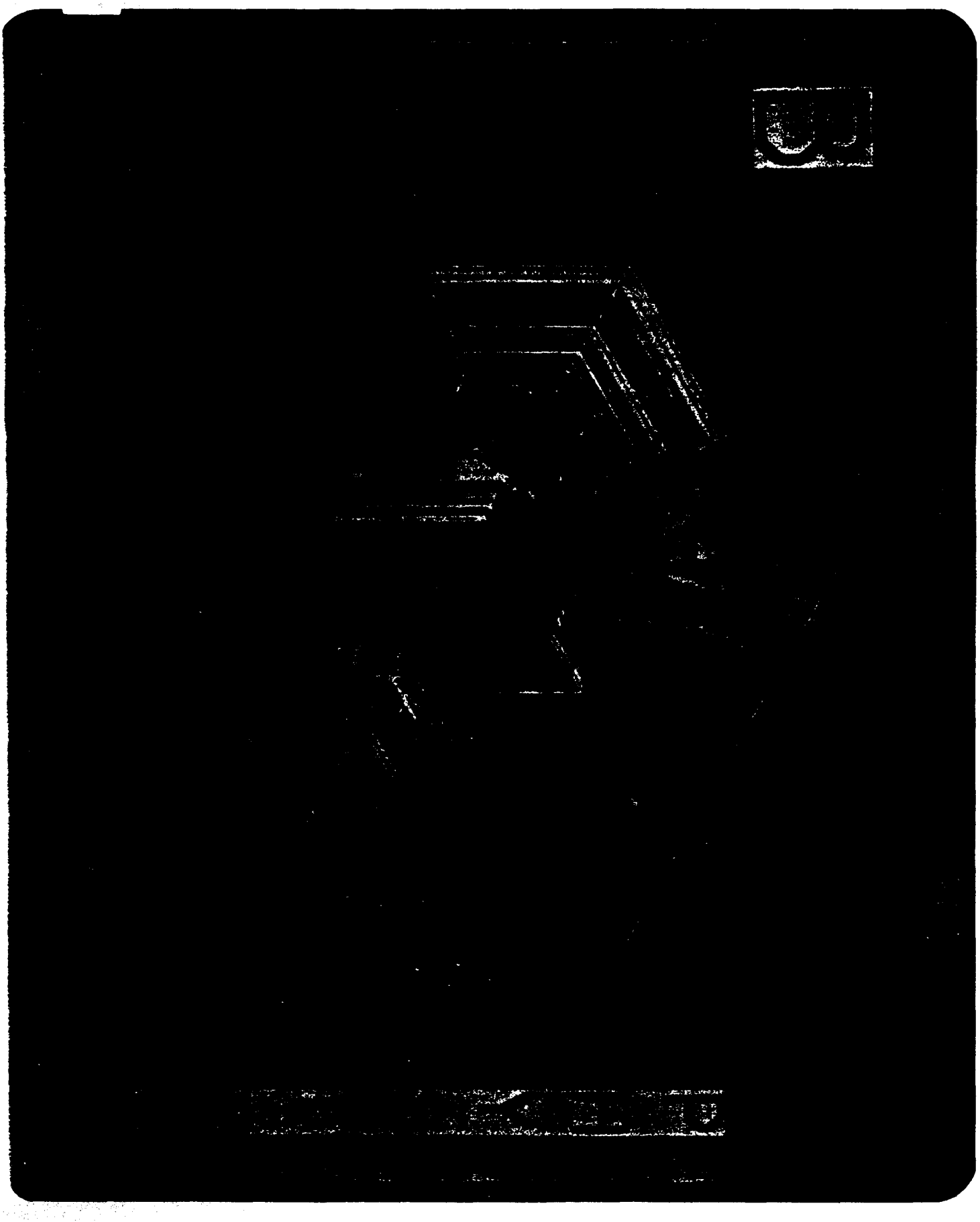
B-Physics Proposals to the SSC

I. EOI-14 'SFT' (B. Cox *et al.*).

- Fixed-target experiment in an extracted beam-line.
- Detector similar to the successful E-691 experiment at Fermilab.

II. EOI-13 (J. Rosen).

- Fixed target experiment with a gas-jet target at a collider ring.
- Detector and rates essentially the same as for EOI-14.
- Avoid the expense of an extracted beam.



Issues Relevant to Design of OPTIMAL b-Experiment

P. Schlein

- **ACCEPTANCE**

  OPEN-GEOMETRY
  FORWARD

- **TRIGGERING**

  NOT WITH LEPTON
  TRIGGER ON SVX ← CONFIGURATION ? / BACKGROUNDS ? / REAL-TIME CALCS.

- **TAGGING**

  RELY ON $K^{\pm}$

- **RECONSTRUCTION**

  - NEED RICH
  - GOOD $\frac{\delta T}{T}$ RESOLUTION

  GOOD MASS RESOLUTION
  GOOD e.m. CAL. ENHANCES PHYSICS
  e.g. $B_s \to D_s^* \to D_s \gamma$ ✓
  $D^{*0} \to D^0 \gamma$ ✓

OPTIMAL EXP. CAN DO B_s-MIXING

P845 EVOLUTION

1/89 P238 PROPOSED TO CERN $S\bar{p}pS$

600 mrad QUAD+DIPOLE spect
Triggered by SVX. (OPEN GEOM. FORWARD)

LOI TO SSC →

2/90 Approved for Test Run of **SVX** at $S\bar{p}pS$

4-12/90 $S\bar{p}pS$ RUN (background-free events 1.5 mm from beams)

1/91 P845 PROPOSED TO FNAL
P238-TYPE APPARATUS

3/91 P28 PROPOSED TO CERN DRDC
(builds on P238 success)

"R+D FOR COLLIDER BEAUTY PHYSICS AT THE LHC"

(a) 1992 - RUN P238 SVX + Processor

(b) 1993 - TRIGGER MINIMAL SPECTROMETER TO DEMONSTRATE b-signal ($\frac{1}{2}$ pb^{-1})
[EXISTING S.C. DIPOLE]

4/91 Revise & Adapt P28 APPARATUS FOR TEVI

PROPOSE TO RUN B_s-MIXING EXP WITH CDF OR DØ IN GARAGE POSITION
JUST BEFORE UPGRADE: 1994-1996

7 January, 1991

PROPOSAL TO FNAL

A DEDICATED BEAUTY EXPERIMENT FOR THE TEVATRON COLLIDER

P845

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University of California, Los Angeles, CA, U.S.A.

P. Weilhammer
CERN, Geneva, Switzerland

J. Seguinot, T. Ypsilantis
College de France, Paris, France

A. Czermak
Institute of Nuclear Physics, Cracow, Poland

K.T. Knöpfle, T. Kihm
Max-Planck Institute for Kernphysik, Heidelberg, F.R.G.

C. Joseph, J.P. Perroud, M.T. Tran - Univ. Lausanne, Switzerland

T.Y. Chen, D. Xi
Nanjing University, Nanjing, P.R.C.

R. Dzhelyadin, V. Obraztsov, A. Ostankov
IHEP-Serpukhov, Protvino, U.S.S.R.

R. Harr, P. Karchin, C. Lispis, J. Sinnott
Yale University, New Haven, CT, U.S.A.

PAC
PRELIMINARY
2r do 2.1L

Abstract

We propose a high statistics study of the physics of Beauty particles at the Tevatron $p\bar{p}$ Collider with a new dedicated detector which covers a 600 mrad forward aperture with magnetic spectrometers, RICH counters and electromagnetic calorimeters. The detector is triggered by real-time calculations on data obtained from a silicon micro-vertex detector installed inside the vacuum chamber throughout the interaction region. With $\int \mathcal{L} dt < 10\ pb^{-1}$, $\Delta M/\Gamma$ can be measured with an error of ± 0.1 from the observed time oscillations in the decay of tagged B_s mesons. With $\int \mathcal{L} dt \approx 200\ pb^{-1}$, rare branching fractions as small as 10^{-8} could be measured, although CP-Violation will only be accessible if the asymmetries are larger than about 30%.

*) Spokesperson

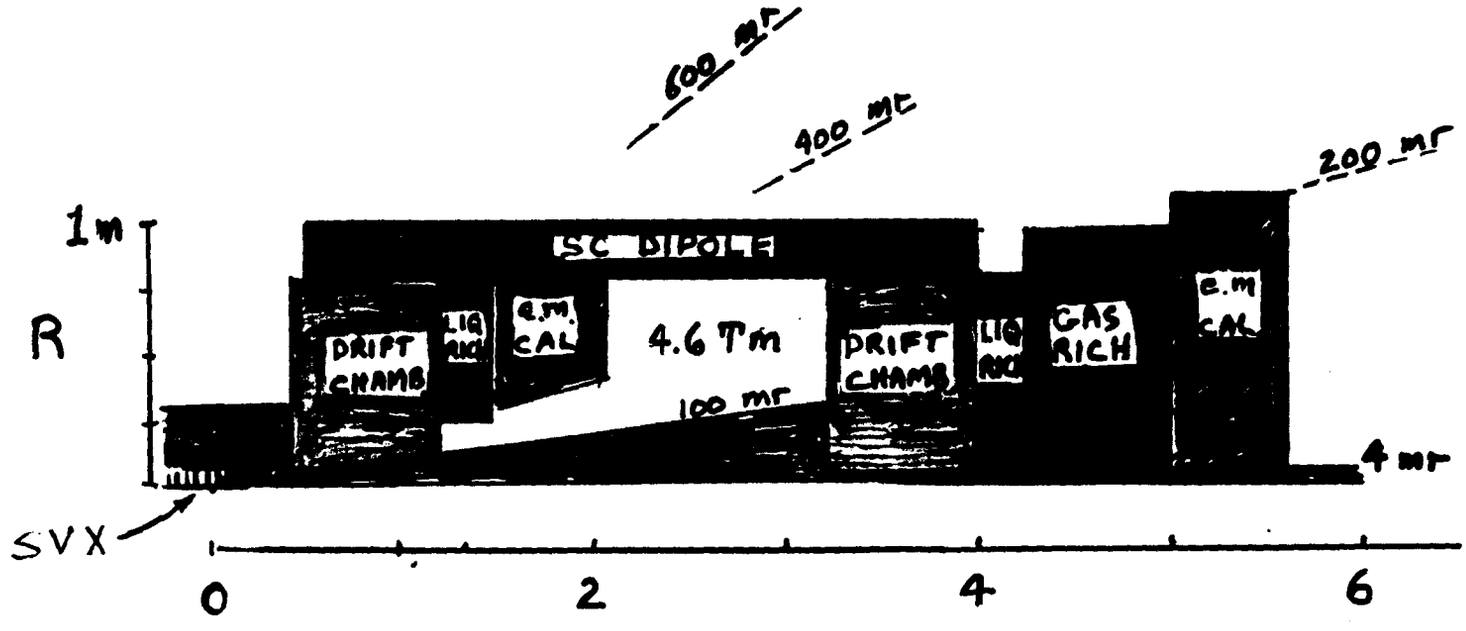
P845

Forward Beauty Collider Detector

ALSO GOOD FOR SSC

at Fermilab

FBCDF



USE $\mathcal{L} = 10^{31}$ AT TEV. AND SSC

→ AT TEVATRON WITH $\int \mathcal{L} dt < 10 pb^{-1}$

MEASURE $\frac{\Delta M}{\Gamma} \sim 15 \pm 0.1$

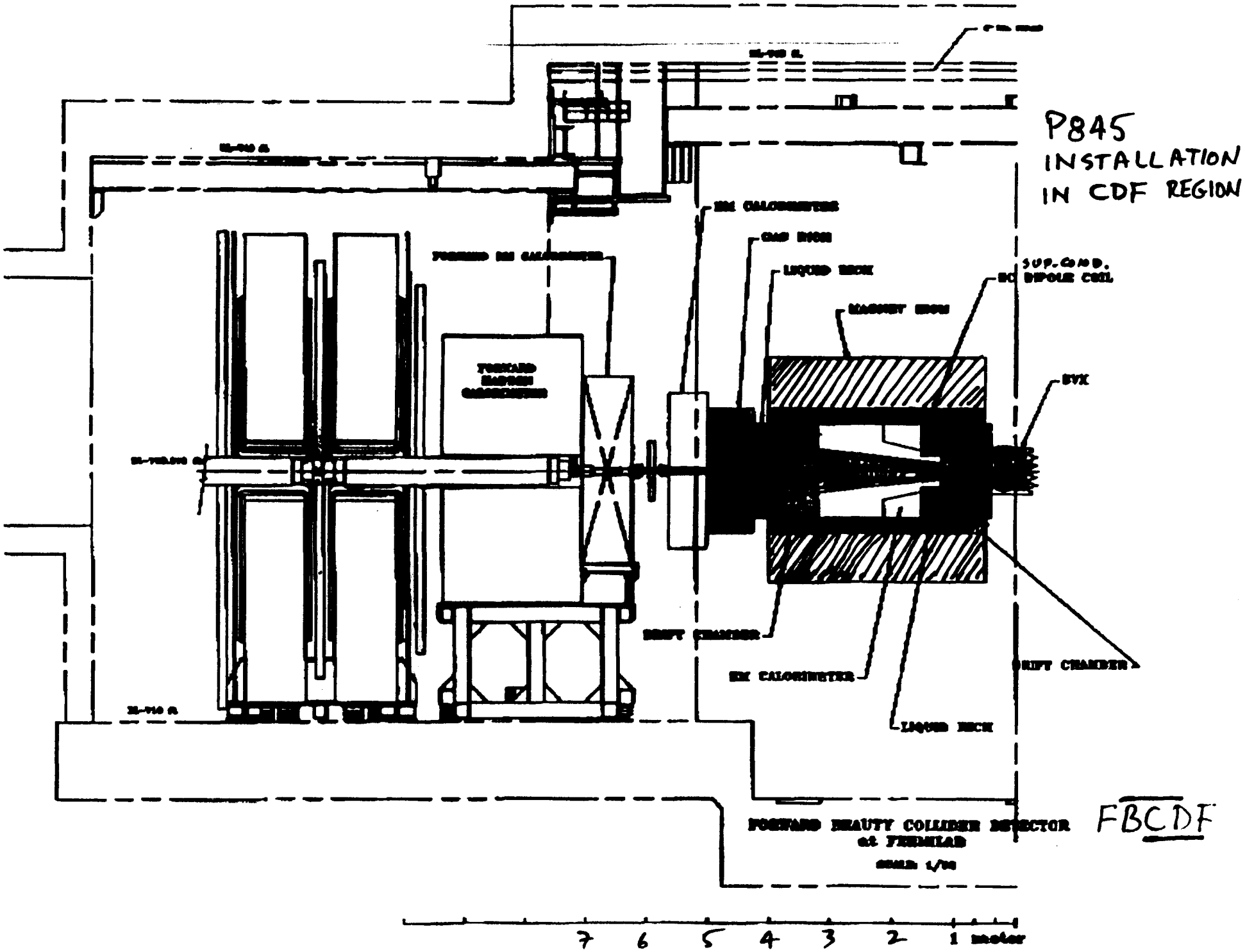
→ AT SSC 200 pb^{-1} GIVES 3σ ΣR in J/ψ's for A<10%

ISSUES

- ACCEPTANCE: 48% / 2 arm (70% at SSC)
- TRIGGERING: SVX (30-50%)
- TAGGING: $K^{\pm}$ >26% + 10%
- RECONSTRUCTION: 29-45%
  - → RICH
  - → $\frac{\delta\Gamma}{\Gamma} \sim 6\%$

EXCLUSIVE STUDIES

- COST: $3.5M ± $2.5 (MAGNET)
  - → 1 arm


P845
INSTALLATION
IN CDF REGION
EM CALORIMETER
GAP DOOR
LIQUID NECK
SUP. COND.
DIPOLE COIL
MAGNET DOOR
SVX
DRIFT CHAMBER
EM CALORIMETER
LIQUID NECK
DRIFT CHAMBER
FORWARD BEAUTY COLLIDER DETECTOR
at FERMILAB
FBCDF
7 6 5 4 3 2 1 meter

APPENDIX

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

DRAFT
22 January 1991

Development and Test of a Large Silicon Strip System for a Hadron Collider Beauty Trigger

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University of Perugia and INFN, Italy

Y. Guz, Y. Ivanuschenkov
IHEP-Serpukhov, Protvino, U.S.S.R.

C. Biino, S. Palestini, L. Pesando
University of Torino and INFN, Italy

R. Harr, P. Karchin
Yale University**), New Haven, Connecticut, U.S.A.

Abstract

Large aperture forward spectrometers with planar geometry perpendicular to the beam line are the natural detectors to accomodate the expected forward peaking of heavy flavor production at high energy hadron colliders. Such systems, together with silicon strip detectors for triggering, which are configured perpendicular to and close to the beam inside the vacuum pipe at the center of the interaction region should make possible the exploitation of hadron colliders as Beauty Factories. We have designed, built and tested such a silicon system at the CERN Sp$\bar{p}$S-Collider. Running 1.5 mm from the Sp$\bar{p}$S beams, clean background-free events are seen.

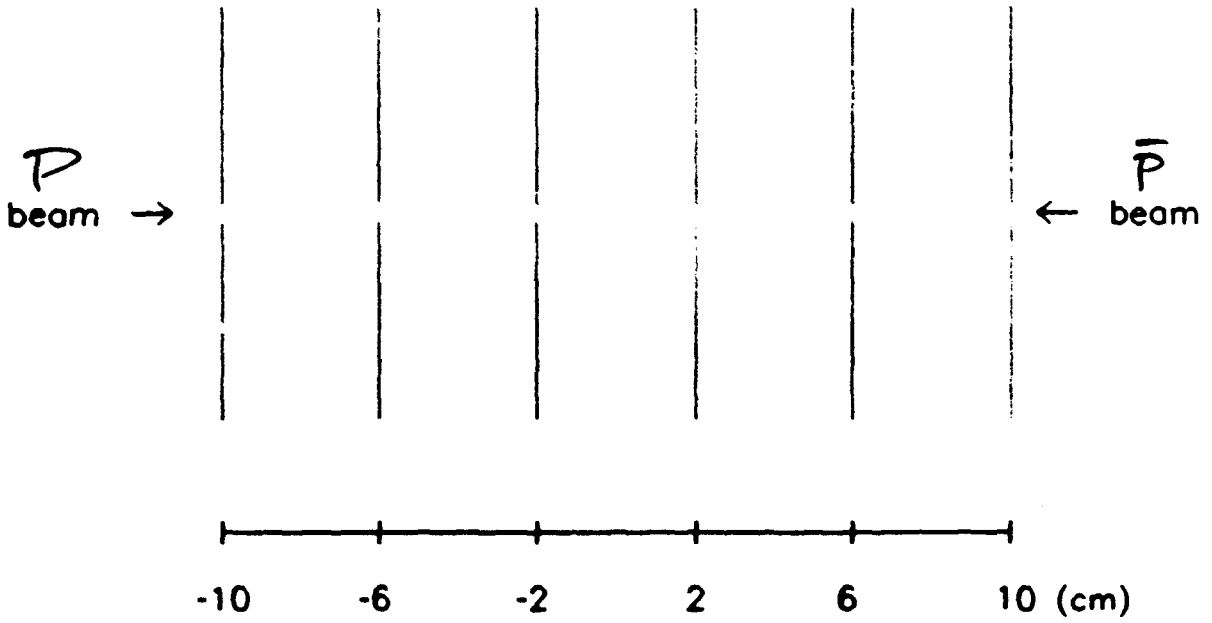
To be submitted to Nuclear Instruments and Methods

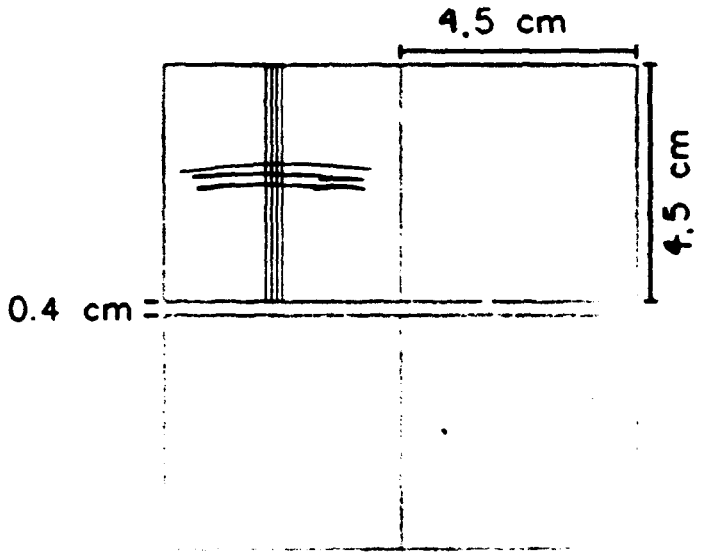
---

*) Supported by U.S. National Science Foundation, Grants PHY90-08221 and PHY85-09175.
**) Supported by the U.S. Department of Energy
1) Ecole Polytechnique, Lausanne, Switzerland
2) Visitor from Institute of Nuclear Physics, Krakow, Poland.
3) Present Address: Stavanger Tekniske Fagskole, Stavanger, Norway.

SILICON DETECTOR (16 PLANES TYP.)

✱ CENTERED ON INTERACTION REGION





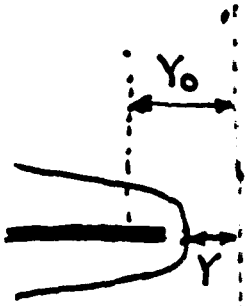
NEXT TIME (full exp)

16-20 planes
~30 μ pitch
100 μ Al shield
double-sided readout.

P238 SYSTEM RUN IN LSS5
9-12/90

200 μ Al RF SHIELDING

6-plane test: { independent x, y
50 μ pitch
43 mm channels.



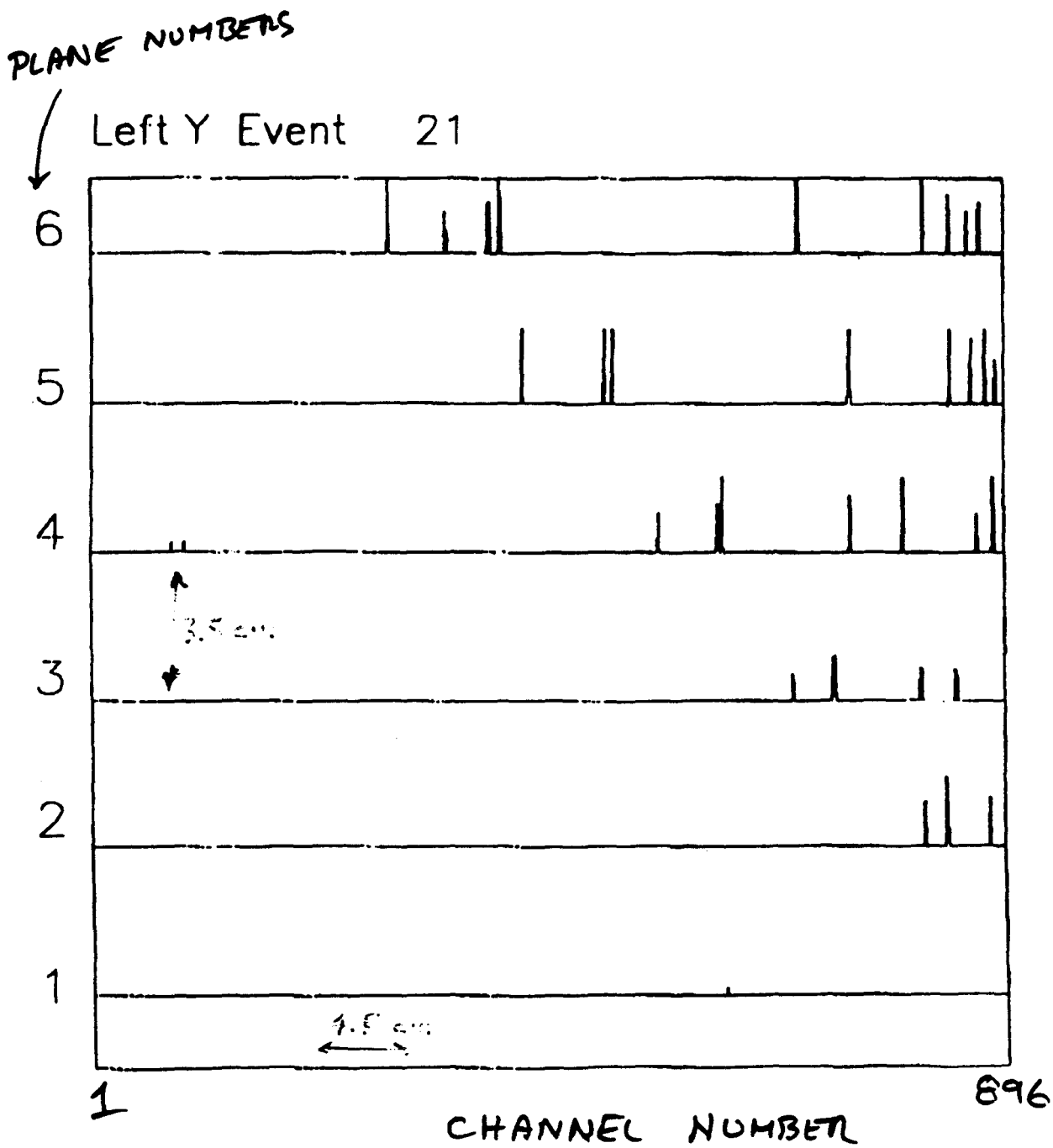
$Y_0 = Y + 1.6$ mm

$Y = 3.1 - 1.6 \pm 1.5$ mm

P238 28 oct 1990

CERN SPS - COLLIDER

ONLY PULSE HEIGHTS $> 4\,\sigma_{noise}$



TRIGGER ALGORITHM STEPS

LINE FINDING - in all sets of 3 consequtive planes

DUPLICATE REJECTION

VERTEX Z ESTIMATION - project all lines to $x=y=0$

BAD TRACK REMOVAL - if impact param > 1 mm

χ^2-MINIMIZATION - in $(x,y,z)_{vertex}$ space
- → REJECT IF $\chi^2 < \chi^2_{cut}$
- → RETAIN IF $\chi^2 > \chi^2_{cut}$

WORST TRACK REJECTION

NO X-Y MATCHING ON LINE
NO ADC INFORMATION (CLUSTER CENTER = p_T)
ROAD WIDTH ±25μ (~MULT. SCAT. 2 GeV TRACK)

LEVEL 1 (SVX)

PYTHIA, GEANT SIMULATION } SUPPRESS

MIN. BIAS	$< \frac{1}{100}$	[illegible]
$B\bar{B}$	$\sim \frac{1}{3} - \frac{1}{2}$	[illegible]

NEXT STEP

SILICON $\xrightarrow[\text{ENGINEERING}]{\text{DIGITAL}}$ **BEAUTY TRIGGER**

PRESENTLY INTERFACING SILICON READOUT TO DATA-DRIVEN PROCESSOR

Bruce Knapp, Mike Kreisler, Ed Hartouni
NEVIS - UMASS DDP

end 1991 → COMPLETE PROCESSOR

R+D Proposal to CERN

RUN Silicon + Processor at SPS-COLLIDER Fall 1992

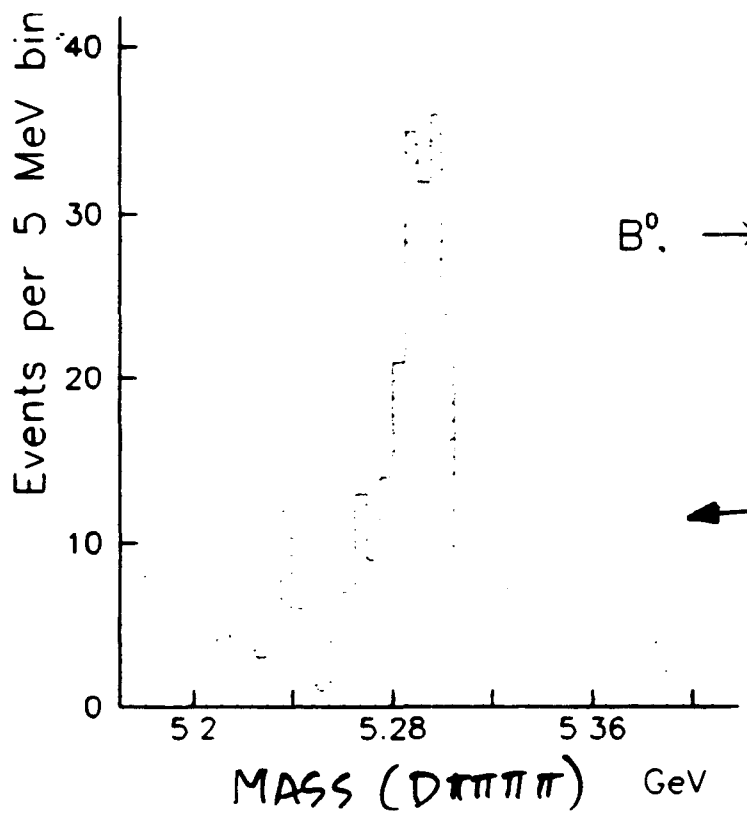
EVENT RECONSTRUCTION SIMULATION

- FULL MULTI-VERTEX RECONSTRUCTION
  REQUIRE: $z_B - z_{primary} > 0.5$ mm

- FINITE B, D DECAY PATHS
  $\Rightarrow$ USE TRANSVERSE p_T BALANCE
  TO REDUCE COMBINATORIC BACKGROUND

- RECONST. SOFTWARE WRITTEN FOR MANY DIFFERENT FINAL STATES – RUN ON MONTE-CARLO DATA SAMPLES TO FIND EFFICIENCY

- SAME SOFTWARE PACKAGES ALSO RUN ON INCLUSIVE $b\bar{b}$ M.-C. SAMPLE TO DETERMINE COMBINATORIC BACKGROUND



$B^0_s \rightarrow D^{*-}\pi^+\pi^+\pi^-$
$\hookrightarrow D^0\pi^-$
$\hookrightarrow K^+\pi^+\pi^-\pi^-$

TYPICAL EXCLUSIVE SIGNAL

BACKGROUND IS DOMINATED BY COMBINATORICS FROM SAME FINAL STATE

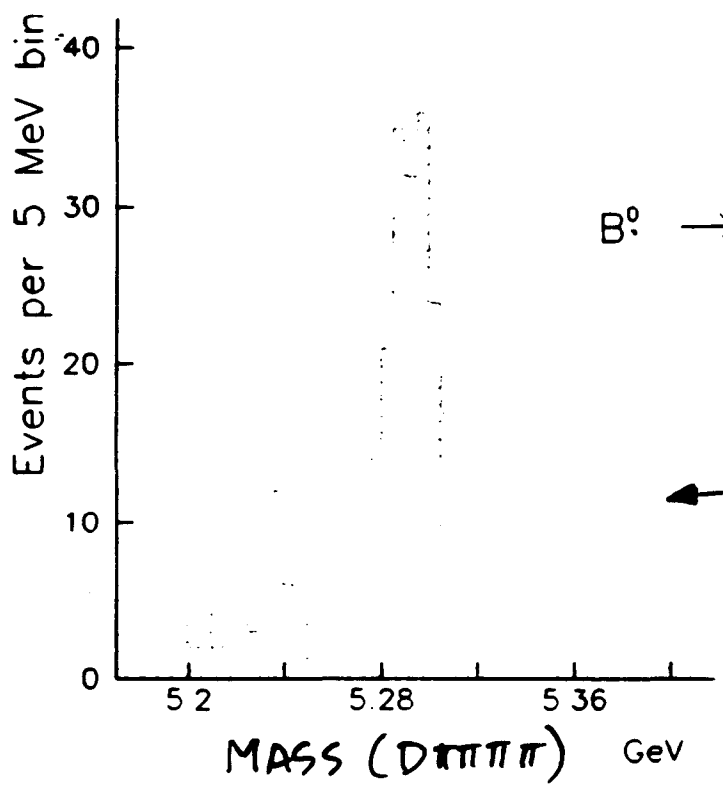
EVENT RECONSTRUCTION SIMULATION

- FULL MULTI-VERTEX RECONSTRUCTION
  REQUIRE: $z_B - z_{primary} > 0.5$ mm

- FINITE B, D DECAY PATHS
  $\Rightarrow$ USE TRANSVERSE p_T BALANCE
  TO REDUCE COMBINATORIC BACKGROUND

- RECONST. SOFTWARE WRITTEN FOR MANY DIFFERENT FINAL STATES – RUN ON MONTE-CARLO DATA SAMPLES TO FIND EFFICIENCY

- SAME SOFTWARE PACKAGES ALSO RUN ON INCLUSIVE $b\bar{b}$ M.-C. SAMPLE TO DETERMINE COMBINATORIC BACKGROUND

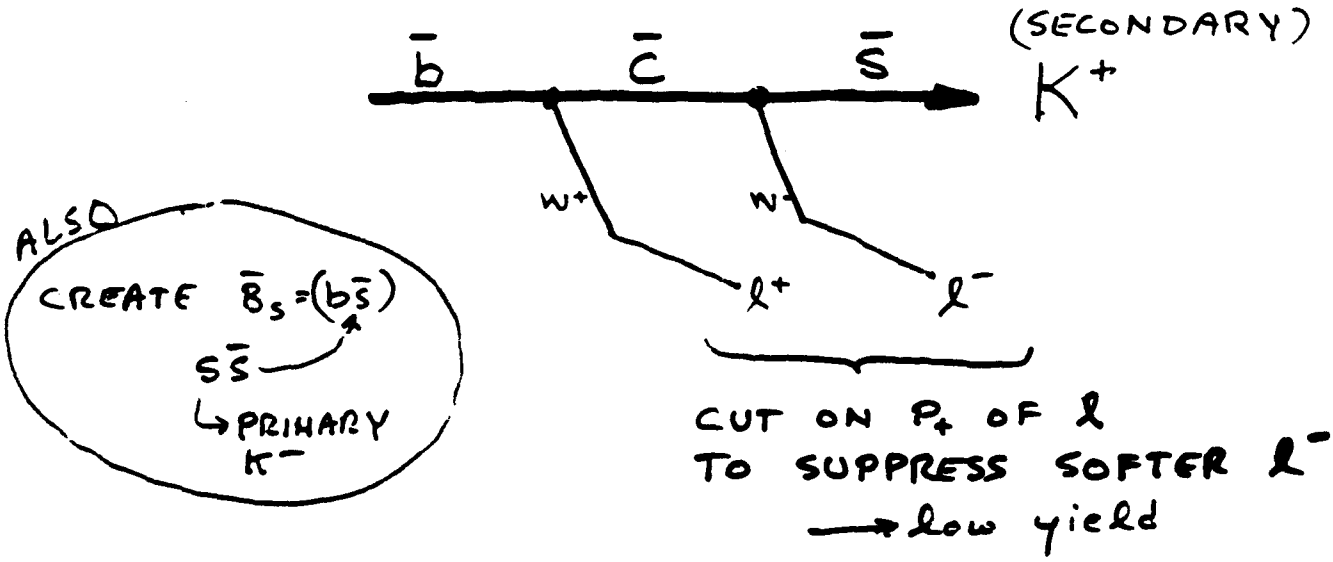


$B^0 \rightarrow D^{*-}\pi^+\pi^+\pi^-$
$\hookrightarrow D^0\pi^-$
$\hookrightarrow K^+\pi^+\pi^-$

TYPICAL EXCLUSIVE SIGNAL
BACKGROUND IS DOMINATED BY COMBINATORICS FROM SAME FINAL STATE

FLAVOR TAGGING

ACCOMPANYING B



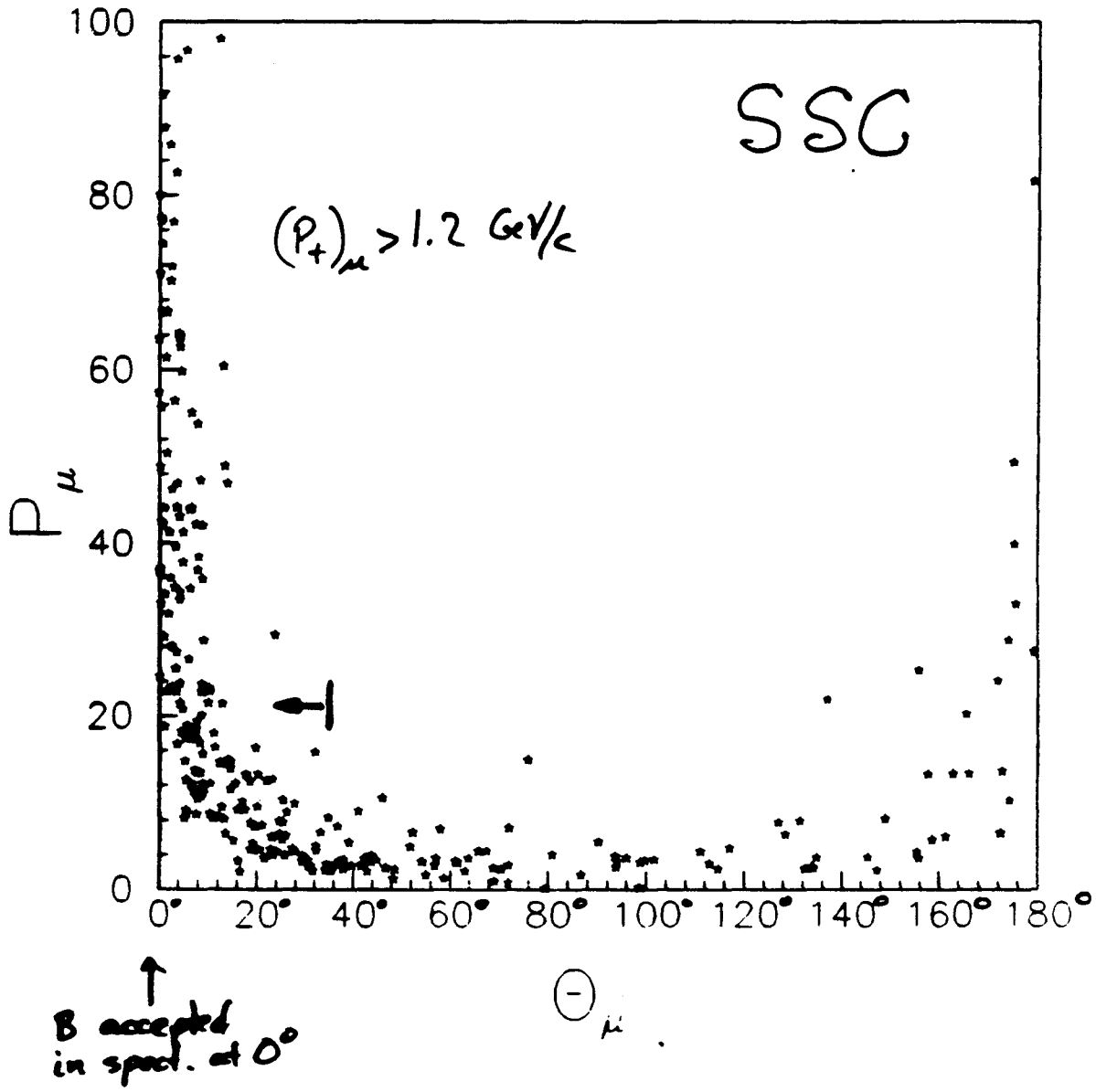
USE $\boxed{\text{PYTHIA}}$ (depend on its hadronization schem
to STUDY EFFECTIVENESS

1. SELECT $K^\pm$ RECONSTRUCTED IN SPECTROMETE
2. USE SVX TO DECIDE IF GIVEN $K^\pm$ IS INCONSISTENT WITH PRIMARY CLAN

$\sqrt{s} = 2$ TeV, 600 mrad "RESULT" (PYTHIA MC)

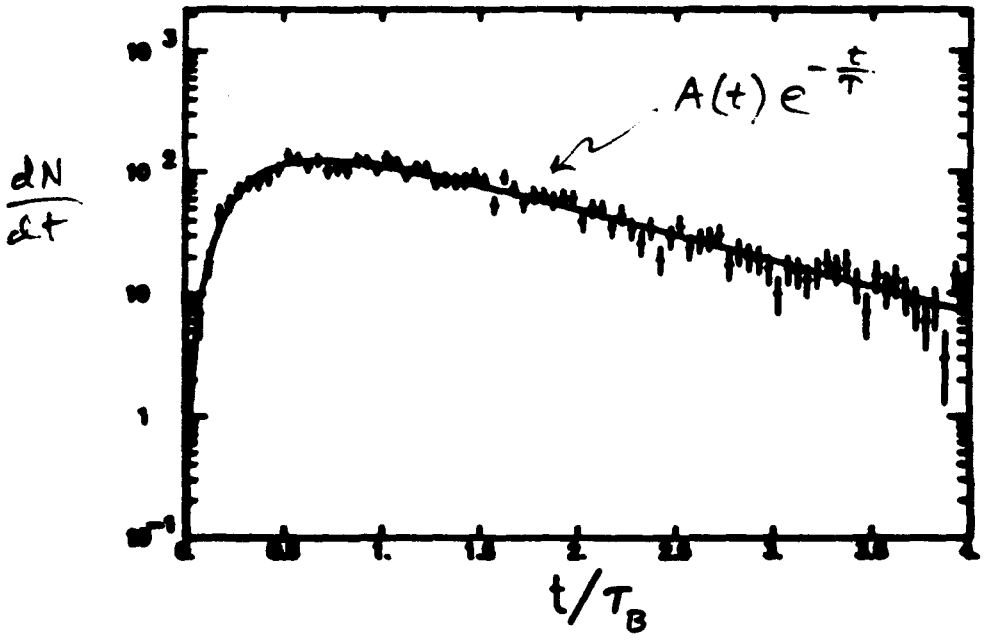
- 26% of ACCEPTED B_s ARE TAGGED BY SECON $K^\pm$ IN SPECTROMETER. $\frac{\text{GOOD TAGS}}{\text{TOTAL TAGS}} = 8[illegible]\%$
- ADDITIONAL 10% FROM μ, e IN SPECTROMETER
- ALSO EXPECT SIGNIFICANT CONTRIBUTION FROM $K^\pm$ FROM PRIMARY VERTEX – AT SPPS, ENHANCE [illegible] $K^\pm$ AT SPPS, 58% RECONSTRUCTED B_s TAGGED BY $K^\pm$ (PRIM. + SECOND

TAGGING (PYTHIA ANALYSIS)



	% TAGGED	GOOD TAGS / ALL TAGS
● LEPTONS: $\Theta < 600$ mr, $P_+ > 1.2$ GeV/c	< 9 % (e+μ)	.82
● $K^\pm$ { NOT FROM " PRIMARY VERTEX	33%	.75

Proper Time Distribution of Reconstructed B-Mesons which Pass Trigger Simulation.



<u>Acceptance:</u> $$A(t) = \frac{4t^2}{1+4t^2}$$

Uncertainty in reconstructed B flight path

$$\sigma(\Delta z) < 180\ \mu.$$

$$\Delta z = ct\frac{P}{M} \Longrightarrow \frac{\sigma(t)}{t} < 0.0[illegible]$$

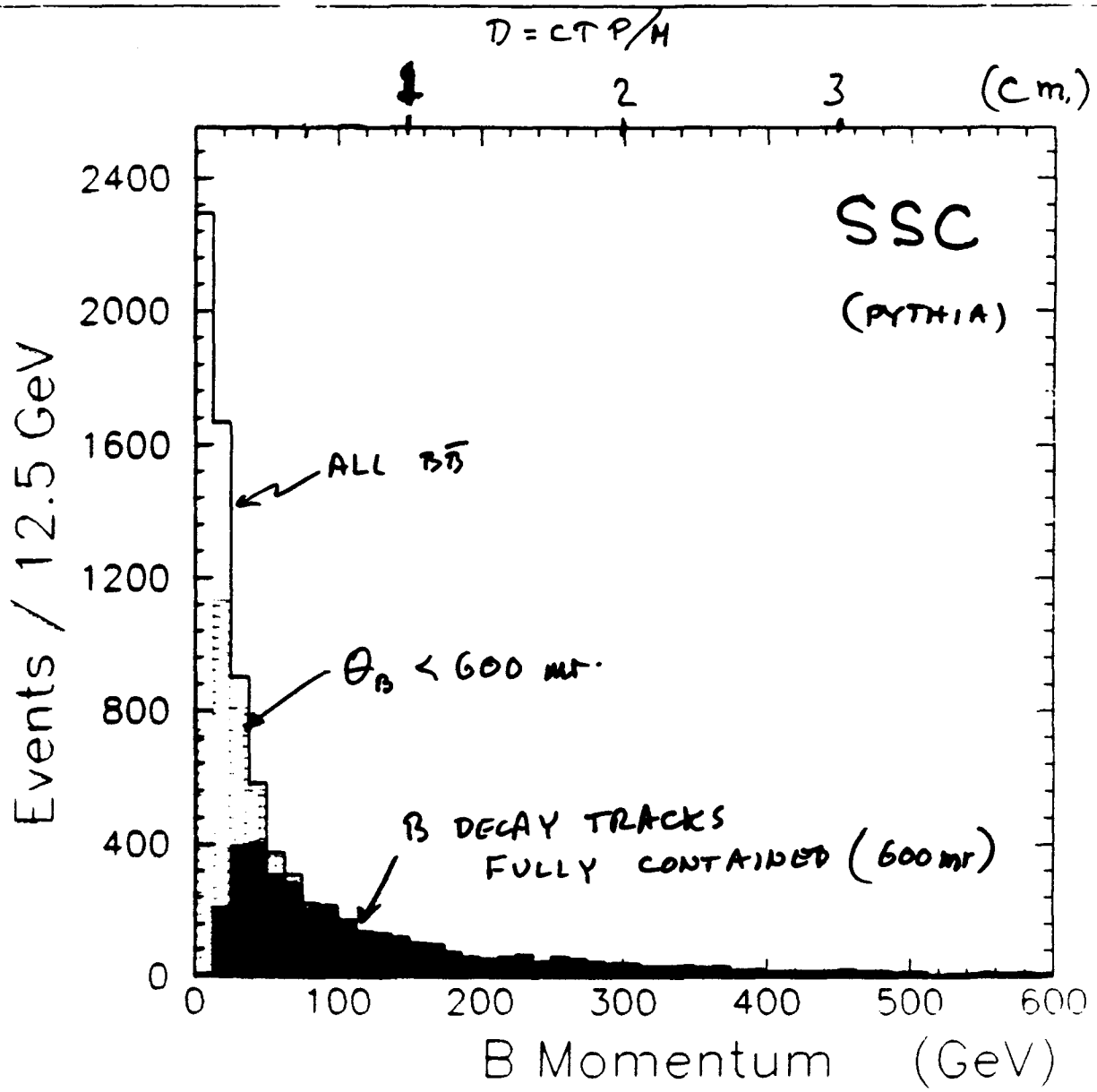

D = CTP/M
1
2
3
(cm.)
SSC
(PYTHIA)
ALL BB̄
θB < 600 mr.
B DECAY TRACKS
FULLY CONTAINED (600 mr)
Events / 12.5 GeV
2400
2000
1600
1200
800
400
0
0
100
200
300
400
500
600
B Momentum (GeV)

Table 9: *B_s & $\bar{B}_s$ Event Yields at the Tevatron Collider*

$5 \times 10^8\ b\bar{b}$ using: $\int \mathcal{L} dt = 10\ \text{pbarn}^{-1}\ (10^{31} \times 10^6)$
$\sigma(b\bar{b}) = 50\ \mu b.$

$6.0 \times 10^7\ B_s$	$6.0 \times 10^7\ \bar{B}_s$	0.12 = B_s Production
1.8×10^7	1.8×10^7	0.30 = 2-Arm Geometrical Acceptance
8.1×10^6	8.1×10^6	$4.5 \cdot 10^{-3}$ = Branching Ratios ($B_s \to D_s^*, D_s$ and DK^- with $n\pi$) ($D_s^* \to D_s \gamma$) ($D_s \to KK\pi, KK3\pi, K^*K$)
5.7×10^6	5.7×10^6	0.70 = Live Time
2.6×10^6	2.6×10^6	0.45 = Trigger Efficiency ($D_s^* 3\pi \to D_s\gamma\ 3\pi$)
8.9×10^3	8.9×10^3	0.35 = Tagging Efficiency
1.3×10^3	1.3×10^3	0.15 = Reconstruction Efficiency (allowing for γ)
2.7×10^3		Total Reconstructed B_s and $\bar{B}_s$ Events

2.700

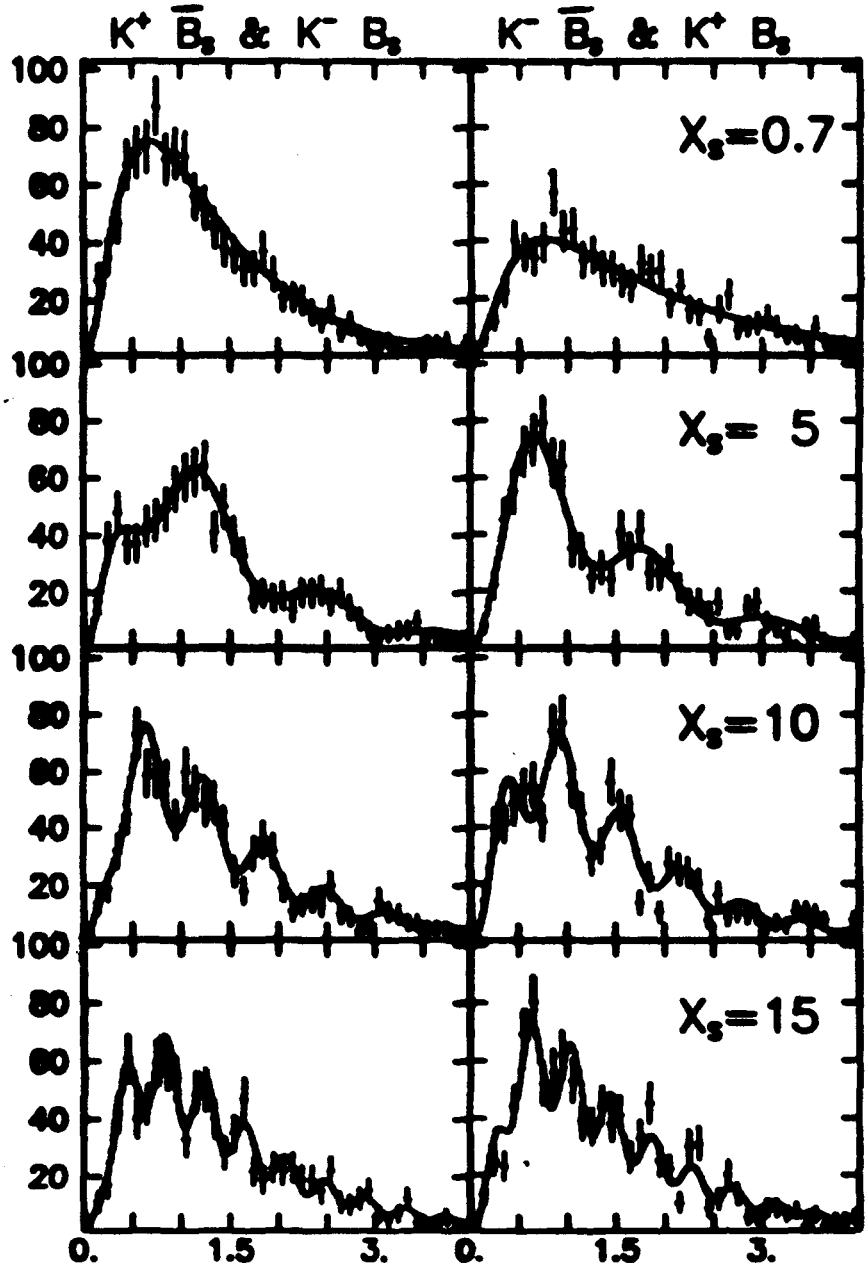
1000 NEEDED FOR $\frac{\Delta M}{M} \sim 15 \pm 0.1$ MEASUREMENT

3000 event sample (58% $K^\pm$ tagged)

CURVES RESULT FROM MAX. LIK. FIT WITH 3 FREE PARAMETERS

τ, K, X_s

$B_s \to D_s^* 3\pi$
$\hookrightarrow D_s \gamma$



$$A(t)e^{-\frac{t}{\tau}}\left[1+K\cos\left(x\frac{t}{\tau}\right)\right] \qquad t/\tau_B \qquad A(t)e^{-\frac{t}{\tau}}\left[1-K\cos\left(x\frac{t}{\tau}\right)\right]$$

Used $K = 0.34$ "Dilution" Factor $\approx \underbrace{0.67}_{\left\langle \frac{1}{1+x^2}\right\rangle} \times \underbrace{0.46}$

from $\frac{\text{good}}{\text{all}} \sim 0.73$
(good − bad)/all.

4 Yields of Potential CP-Violating Channels

Table 11 gives a summary of the various factors which determine the event sample size a
r a CP-Violation measurement at the Tevatron Collider. The estimates assume a 50 μb cross
r $B\bar{B}$ production and are given for an integrated luminosity, $\int \mathscr{L} dt = 200$ pbarn^{-1}. Referring
we can see that the 1150 tagged events obtained in this run would permit a 3σ or more measu
sin(2β) only for asymmetries larger than about 0.3.

Table 11: $B^0_d \to J/\psi\, K^0_s$ *Event Yields at Tevatron Collider*

$10^{10}\ b\bar{b}$ using: $\int \mathscr{L} dt = 200$ pbarn^{-1} ($10^{31} \cdot 2 \cdot 10^7$)
$\sigma(b\bar{b}) = 50\ \mu$b.

$4.0 \times 10^9\ B_d$	$4.0 \times 10^9\ \bar{B}_d$	0.40 = B_d Production
1.2×10^9	1.2×10^9	0.30 = 2-Arm Geometrical Acceptance
4.7×10^4	4.7×10^4	$3.9 \cdot 10^{-3}$ = Branching Ratios $B \to J/\psi K_s \to \ell^+\ell^-\pi^+\pi^-$
3.3×10^4	3.3×10^4	0.70 = Live Time
6.6×10^3	6.6×10^3	0.20 = Trigger Efficiency
2.3×10^3	2.3×10^3	0.35 = Tagging Efficiency
5.7×10^2	5.7×10^2	0.25 = Reconstruction Efficiency
	11.5×10^2	Total Reconstructed $J/\psi K_s$ Events

115C

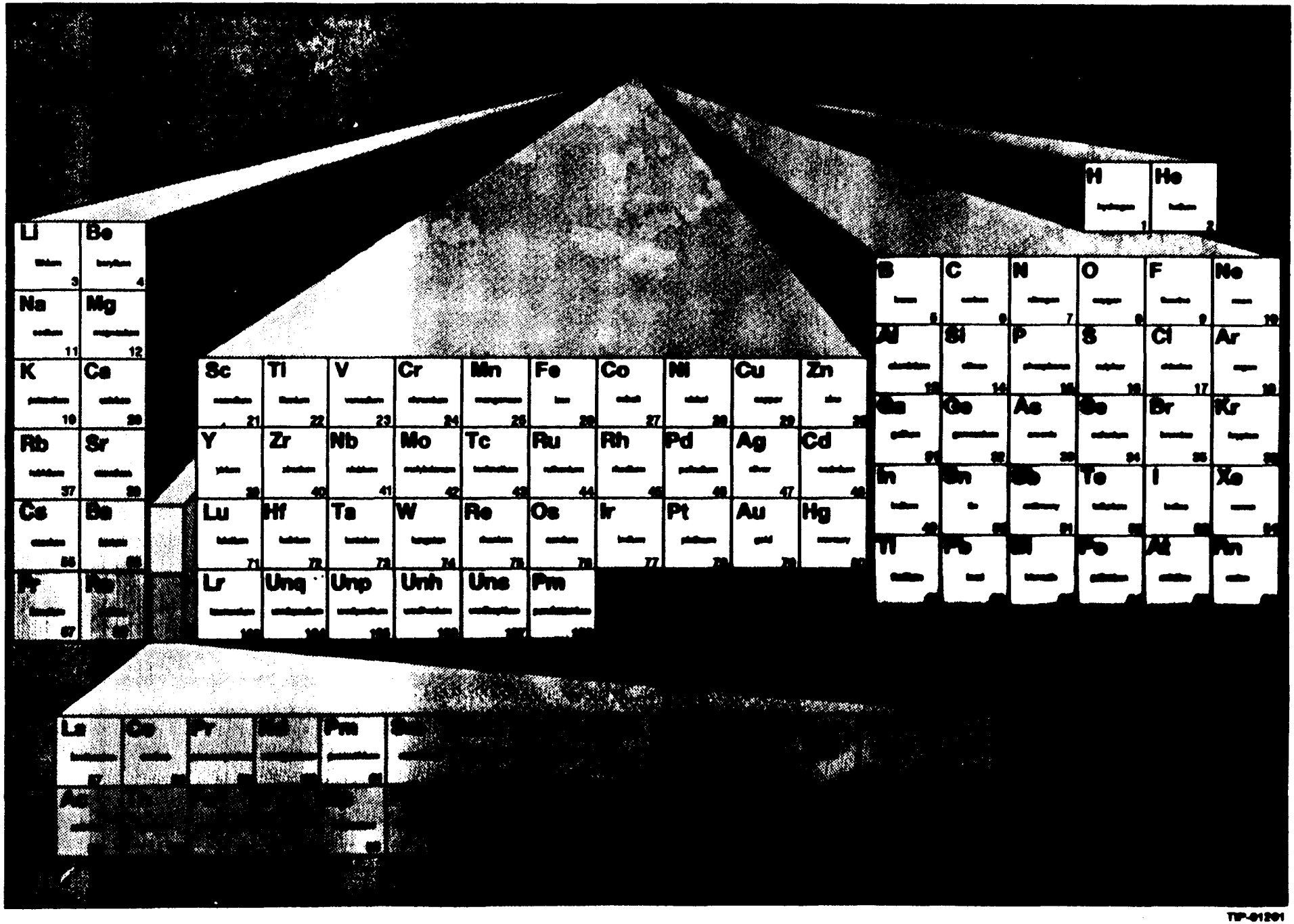
B AND/OR $\bar{B}$ Rates

	CERN R+D Proposal	P845 2 ARM 600 MF	LHC SSC	e^+e^- b-Fact	CLEO [illegible]
$\sigma(b\bar{b})$	$15 \cdot 10^{-30}$	$50 \cdot 10^{-30}$	$300 \cdot 10^{-30}$	10^{-33}	
$\mathcal{L}$	$6 \cdot 10^{29}$	10^{31}	10^{31}	$3 \cdot 10^{33}$	$\cancel{1.5}\ 2 \cdot 10^{3}$
ACCEPT B AND/OR $\bar{B}$	11%	48%	70%	80%	
$(\sigma \cdot \mathcal{L} \cdot A)$ Hz	1.5	240	2100	2	0.15

Rates For Fictitious Final States with Unit B.R.
+ trigger efficiency

⇒ P845 Triggering Efficiency 30-50% (see proposal)

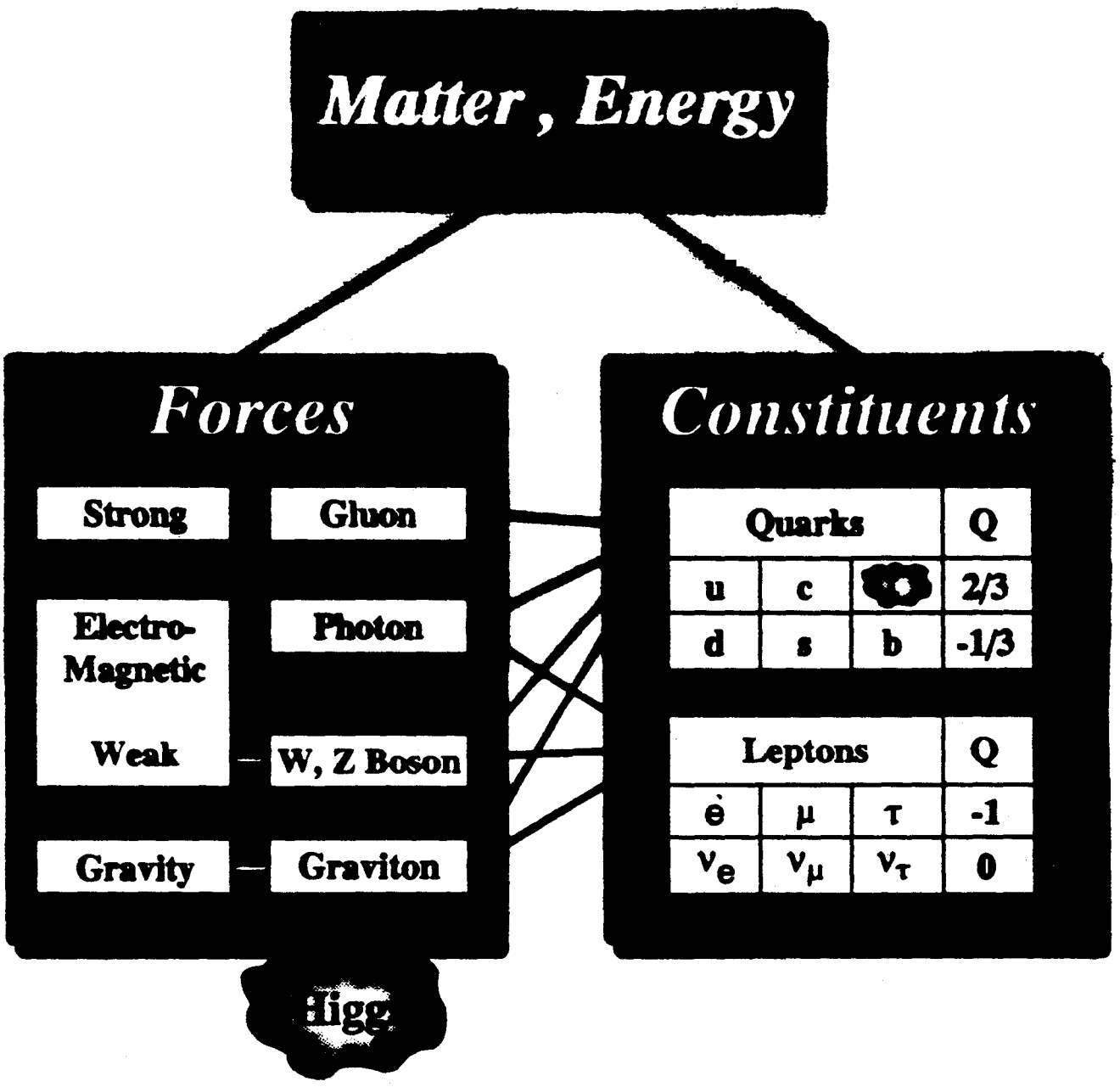
|| HADRON COLLIDER B-EXPERIMENTS CAN OVERTAKE e^+e^- EXPS. IN 3-4 YEARS, IF GIVEN GREEN LIGHT



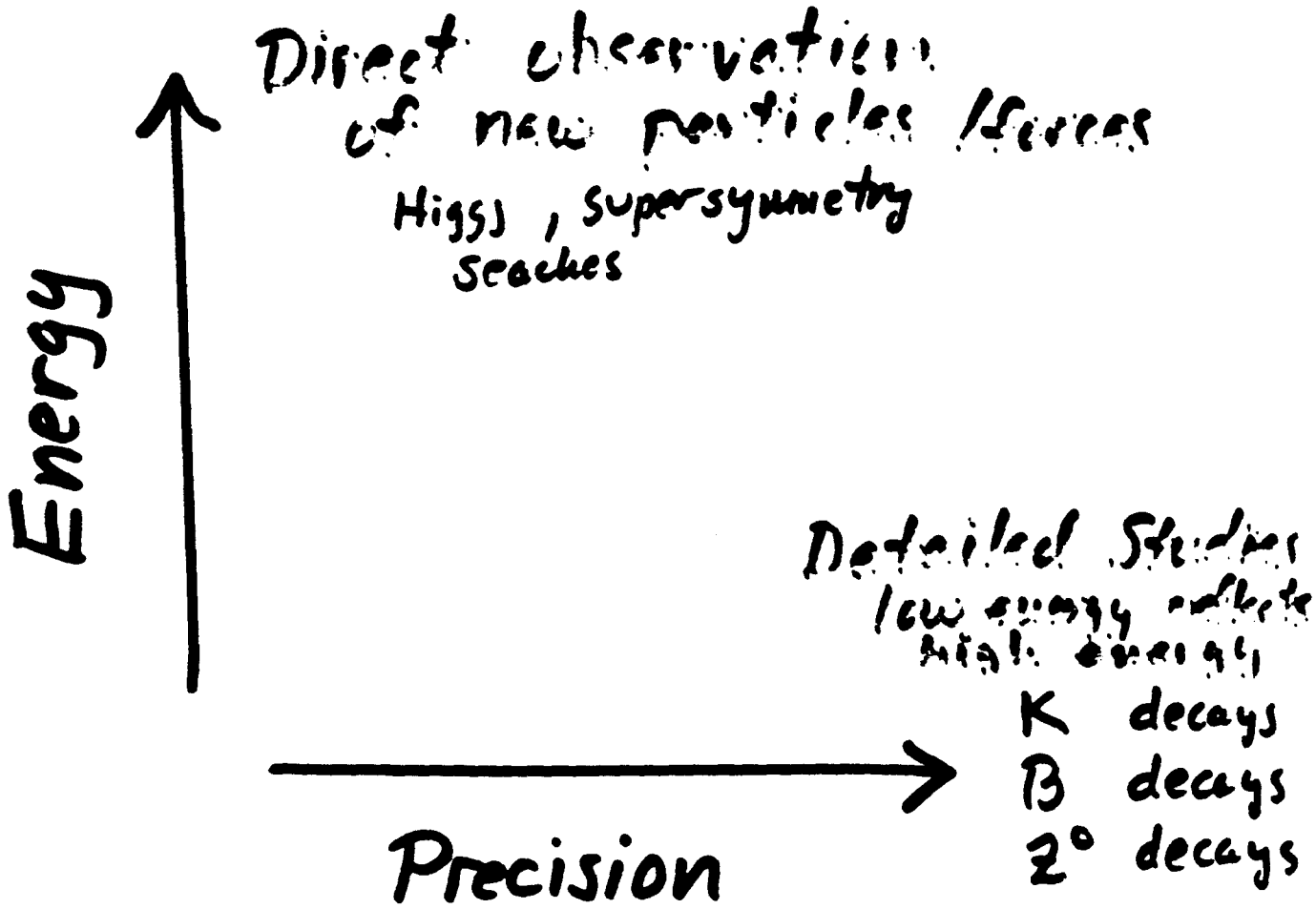
R. Schwitters

TIP-61201

The Standard Model



Frontiers in HEP



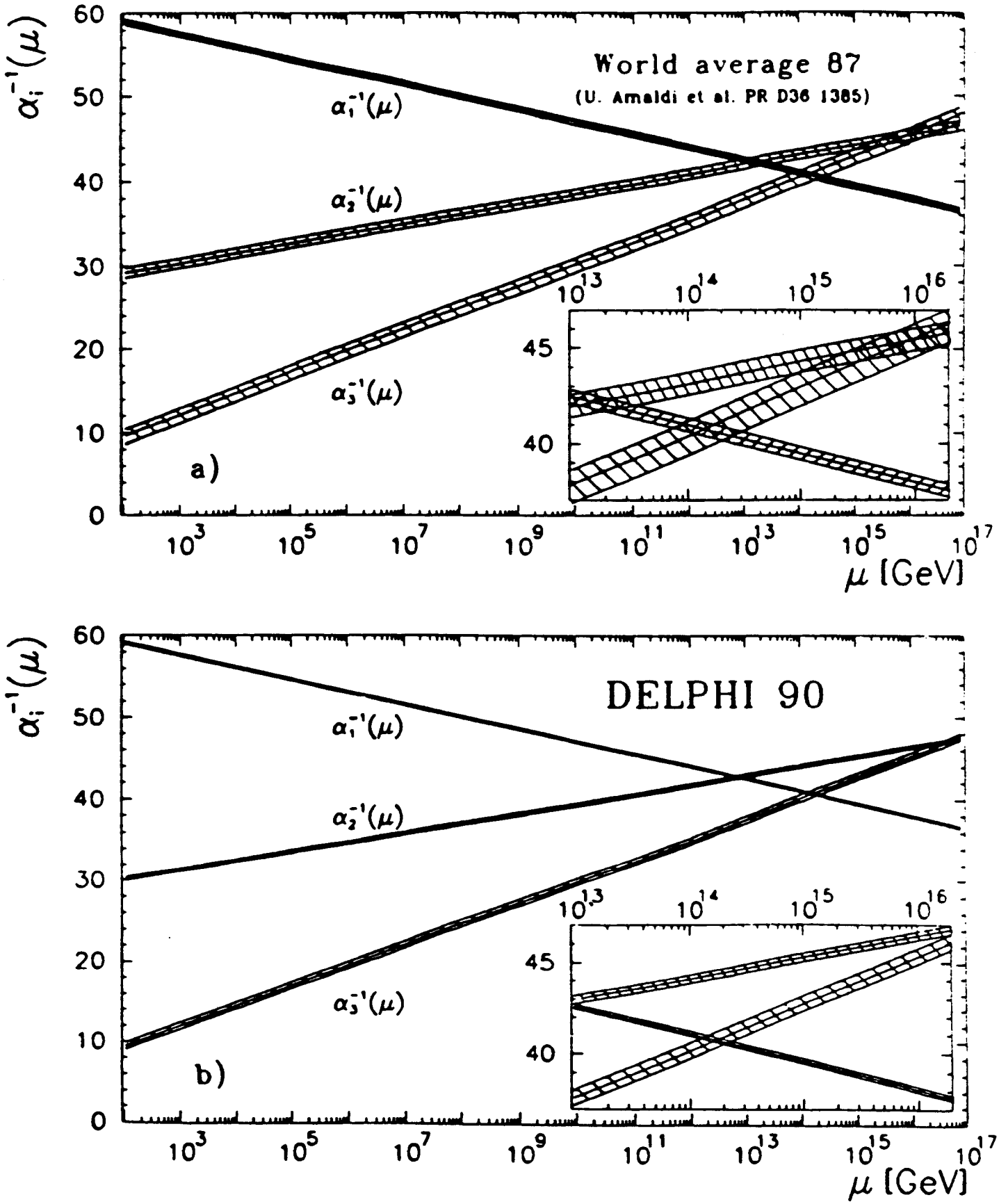
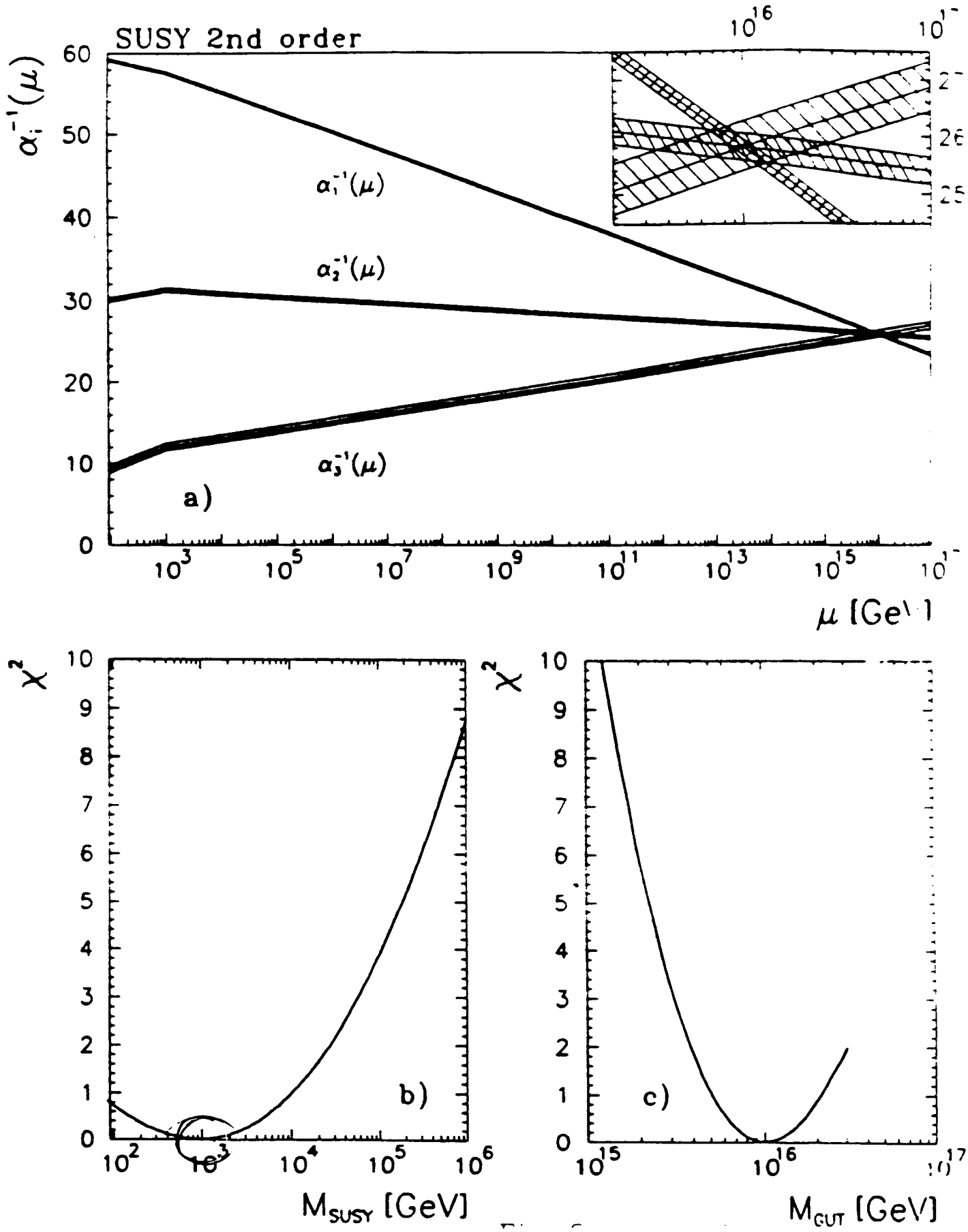
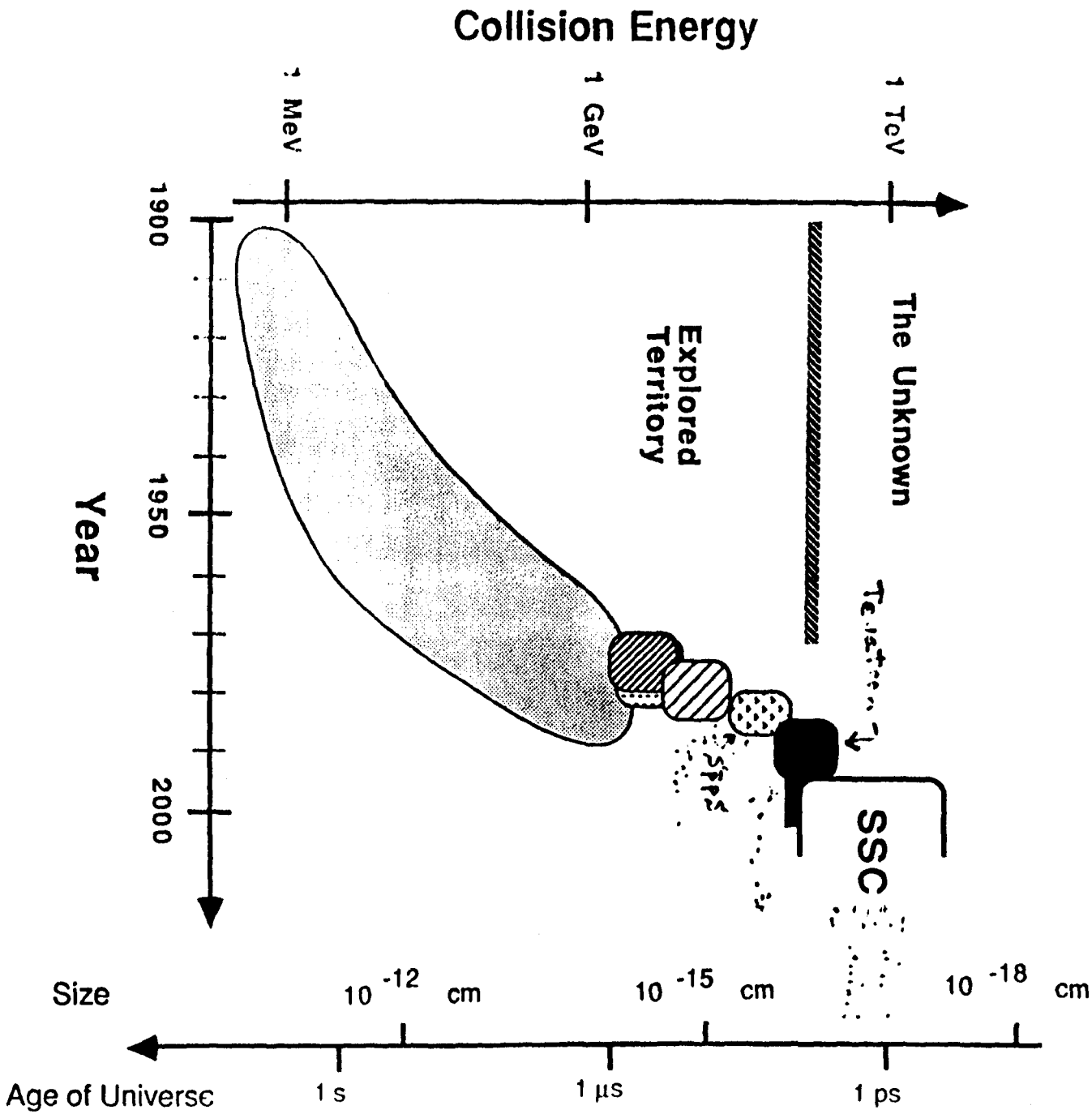

World average 87
(U. Amaldi et al. PR D36 1385)
$\alpha_1^{-1}(\mu)$
$\alpha_2^{-1}(\mu)$
$\alpha_3^{-1}(\mu)$
a)
$\alpha_i^{-1}(\mu)$
μ [GeV]
DELPHI 90
$\alpha_1^{-1}(\mu)$
$\alpha_2^{-1}(\mu)$
$\alpha_3^{-1}(\mu)$
b)
$\alpha_i^{-1}(\mu)$
μ [GeV]

Fig. 1


SUSY 2nd order
$\alpha_i^{-1}(\mu)$
$\alpha_1^{-1}(\mu)$
$\alpha_2^{-1}(\mu)$
$\alpha_3^{-1}(\mu)$
a)
μ [GeV]
χ^2
b)
M_{SUSY} [GeV]
c)
M_{GUT} [GeV]


Collision Energy
1 TeV
1 GeV
1 MeV
The Unknown
Explored Territory
SSC
Year
1900
1950
2000
Size
10 -18 cm
10 -15 cm
10 -12 cm
Age of Universe
1 ps
1 μs
1 s

SSC

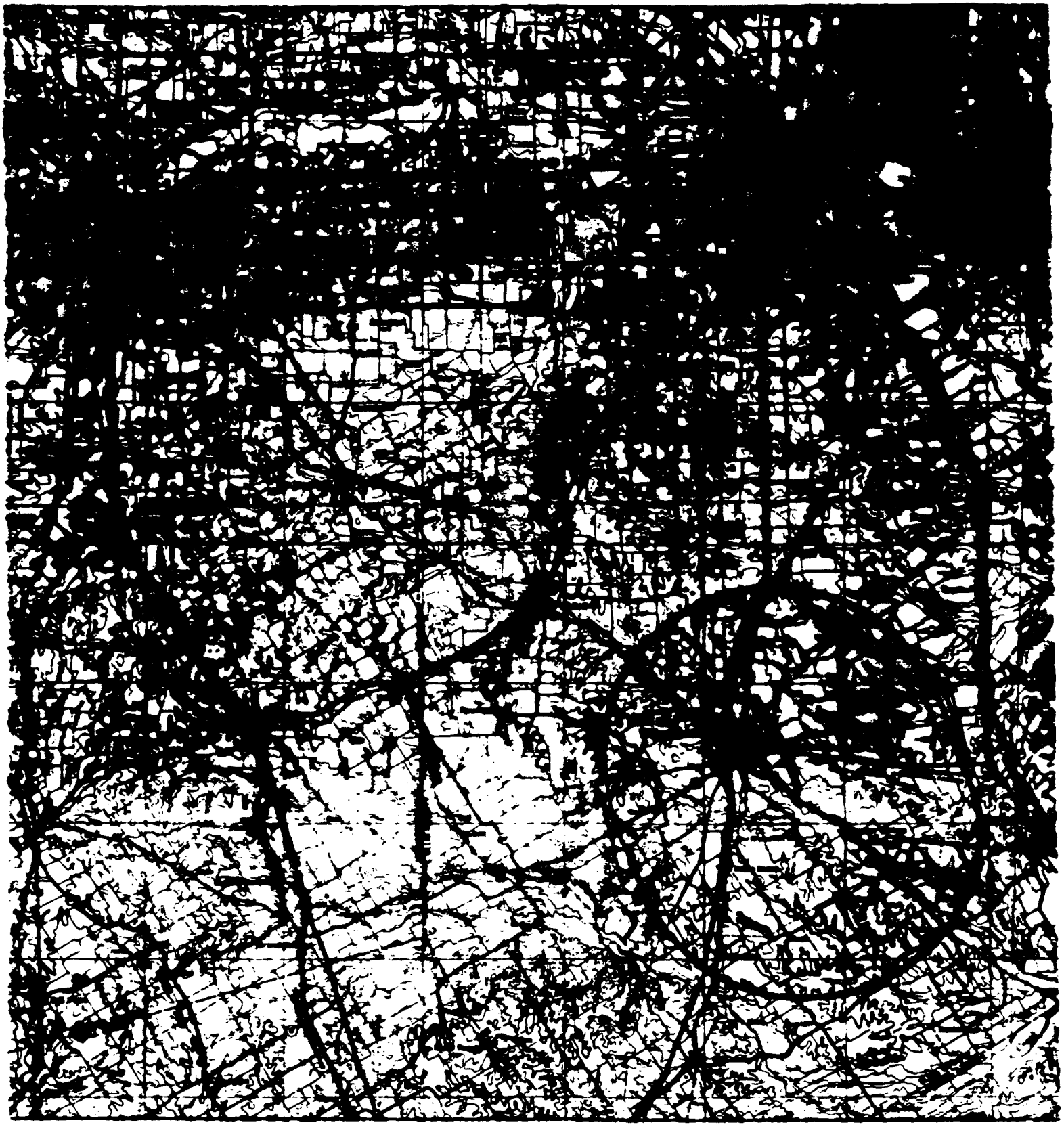
•

SSC

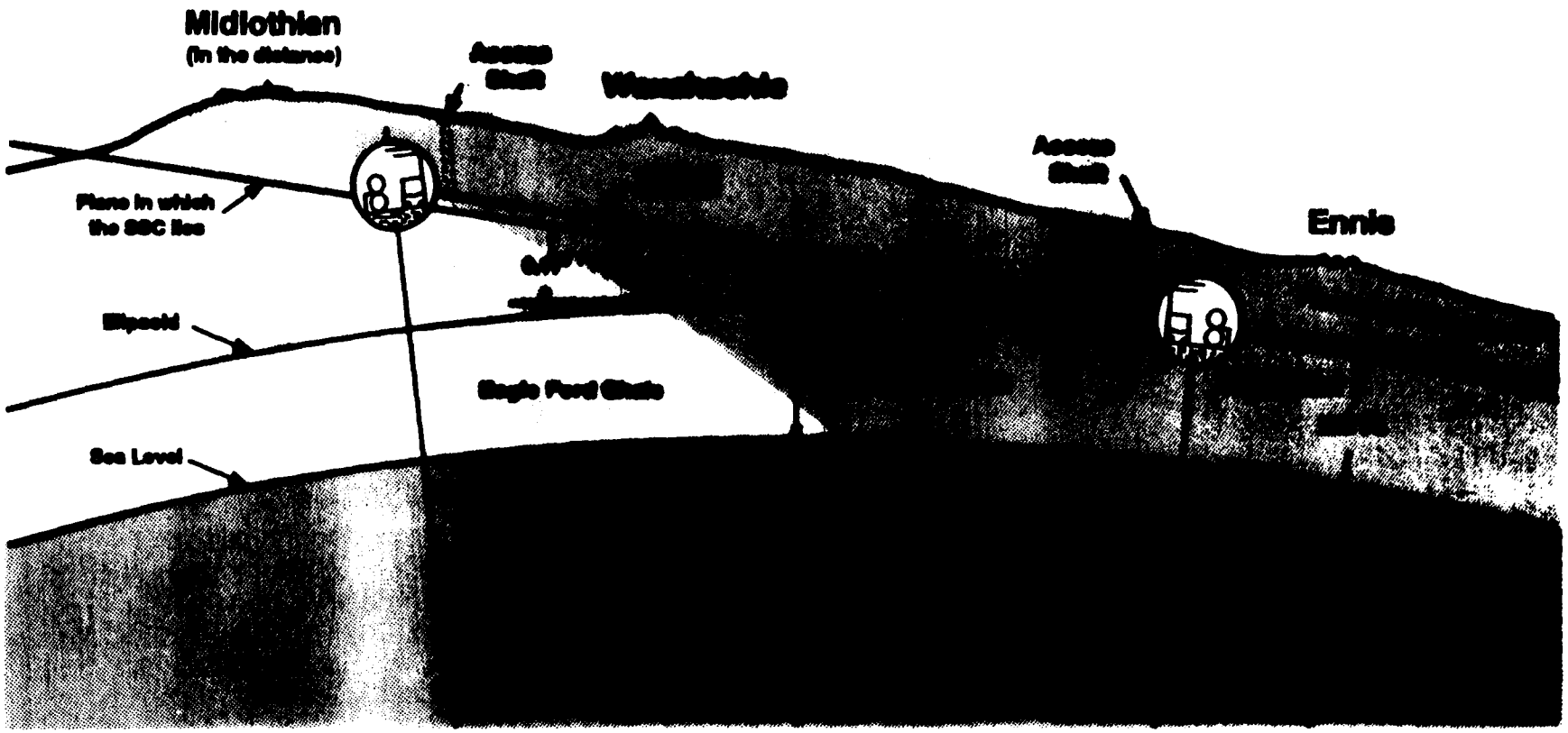
6.6 T
13 km
$\$8 \cdot 10^9$
20 TeV
40 TeV
9 years

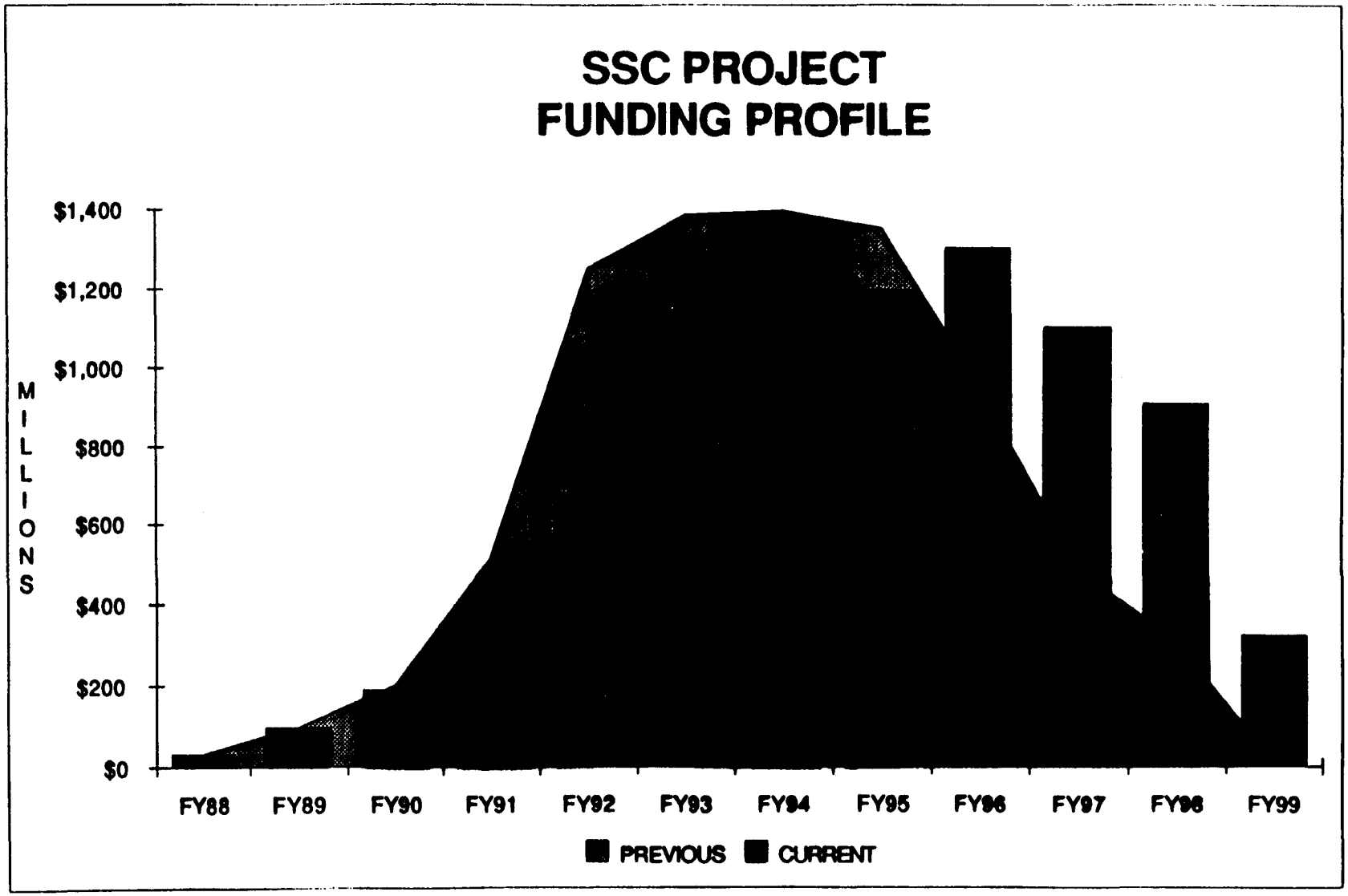
Fermi's Dream Accelerator (ca. 1954)

Magnetic field	2 T
Radius	8000 km
Cost	$\$170 \cdot 10^9$
Beam energy	5000 TeV
Center of mass energy	3 TeV
Time to construct	40 years



Effects of Earth's Curvature on The SSC




SSC PROJECT
FUNDING PROFILE
MILLIONS
$1,400
$1,200
$1,000
$800
$600
$400
$200
$0
FY88
FY89
FY90
FY91
FY92
FY93
FY94
FY95
FY96
FY97
FY98
FY99
PREVIOUS
CURRENT

General Parameters

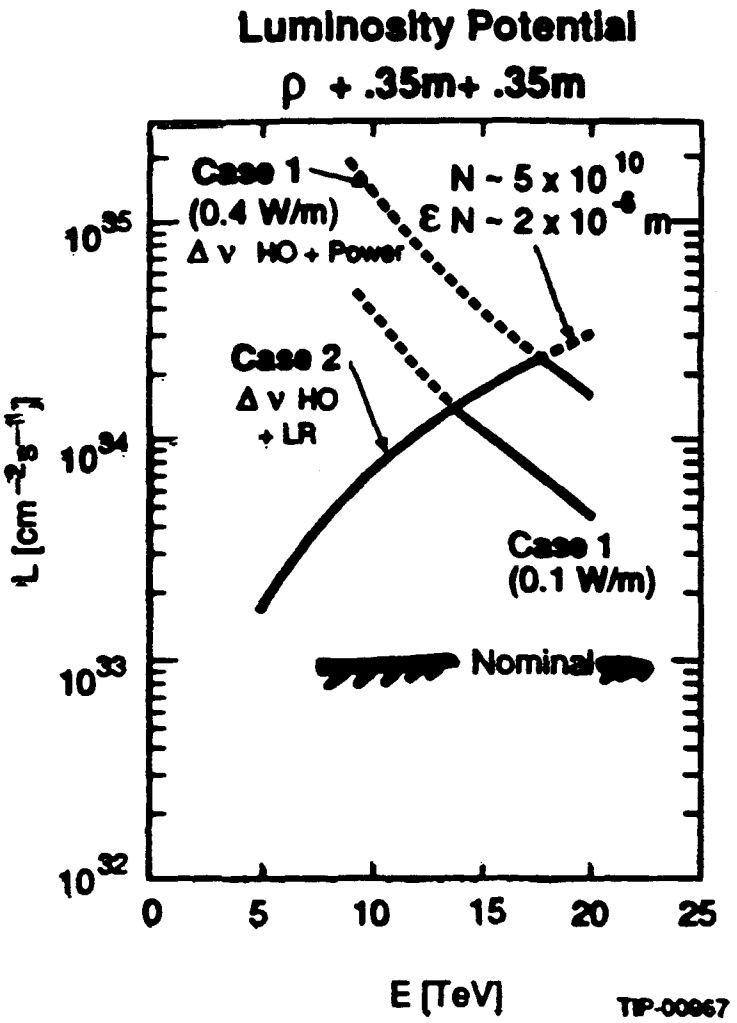
Collider Performance Parameters

Energy	E_{max}/E_{inj}	20TeV/2TeV
Gamma	γ_{max}	21,315.78
Luminosity	L	$1 \times 10^{33} cm^{-2} s^{-1}$
Luminosity Reduction Factor	R	9%
Events per Crossing	N_{event}	1.7 (100mb)
Collision Frequency	$f_{collisions}$	60MHz
Rotation Frequency	f_{rot}	3.441 kHz
Beam/L lifetime	t_{life}	(180)/90 hrs
Number of Interaction Points	N_{IP}	4
Number of Bunches (full)	N_b	17,424 (15794)
Particles per Bunch	N	0.8×10^{10}
Total Number of Particles	N_{total}	1.3×10^{14}
Bunch Spacing	S_b	5.0m
Filling Factor	$F_{filling}$	0.906
Circulating Current	I	0.072A
Circumference	C	87,120 m
Ring Spacing	d_{sepa}	90 cm
Crossing Angles (typ)	ϕ	100μrad
Transverse Emittance rms normalized	$\varepsilon_N(\sigma)$	1πmm-mrad
β in Interaction Point (hi L) (med L)	β^*	1/2m, 10m
σ in Interaction Point (hi L)	σ^*	5μm
Luminosity per hit	L/hit	$1.67 \times 10^{25}/cm^{-2}$
Head On beam-beam Tune Shift	$\Delta\nu_{HO}$ (total)	0.004
Long Range beam-beam Tune Shift	$\Delta\nu_{LR}$ (total)	0.003
Synchrotron Radiation Pwr. at $N_{tot}=1.3 \times 10^{14}$	P_S	8.9 kW/ring
Detector Free Space (hi L) (med L)	l	±20m, ±120m

In the following table, the word "extraction" is often found in the descriptor. For the Collider column, this refers to storage.

Accelerator Parameters	Collider	HEB	MEB	LEB	Linac
LATTICE PARAMETERS					
Kinetic Energy	20 TeV	2 TeV	199.1 GeV	11.1 GeV	0.6 GeV
Momentum	20 TeV/c	2 TeV/c	200 GeV/c	12 GeV/c	1.219GeV/C
> gamma (ext)	21,322	2,132	213.2	12.79	1.64
β (ext)					0.79
Mono-bipolar	(2 rings)	Bipolar	Monopolar	Monopolar	-
Superconducting/normal	SC	SC	Normal	Normal	Normal
Harmonic Number	17424x6	2160	792	114	-
(factored)	$(2^4 3^2 11^2)6$	$(2^4 3^3 5\ )$	$(2^3 3^2 11)$	$(2 \cdot 3 \cdot 19)$	
Bunch Spacing (m)	5	5	5	5	-
Circumference (km)	87.12	10.80	3.96	0.57	-
Arc Bend Radius (km)	12.032	1.043	.516	.07019	-
Types of Dipoles	2+4 spec	1	2	1	_
Number of Dipoles	7956/504/192	432	352/12	48	-
Effective Dipole Length (m)	15.2/12.7	15.2	6.591/6.065	4	-
Peak Dipole Field (T)	6.6	6.3962	1.752	1.31	-
Bρ (TM)	66713	6671	667.12	40.03	_
ρ (km)	10.187	1.043	0.3808	.03056	_
Types of Quadrupoles	1 + 9 spec	6	3	≤8	_
Number of Quadrupoles arc/special	1664/296	234/44	206/24	90	-
Effective Quadrupole Length (m)	5.2	1.2	2.286	0.57-0.71	-
Field Gradient Quads (T/m)	206	208.55	23.61	14.9	-

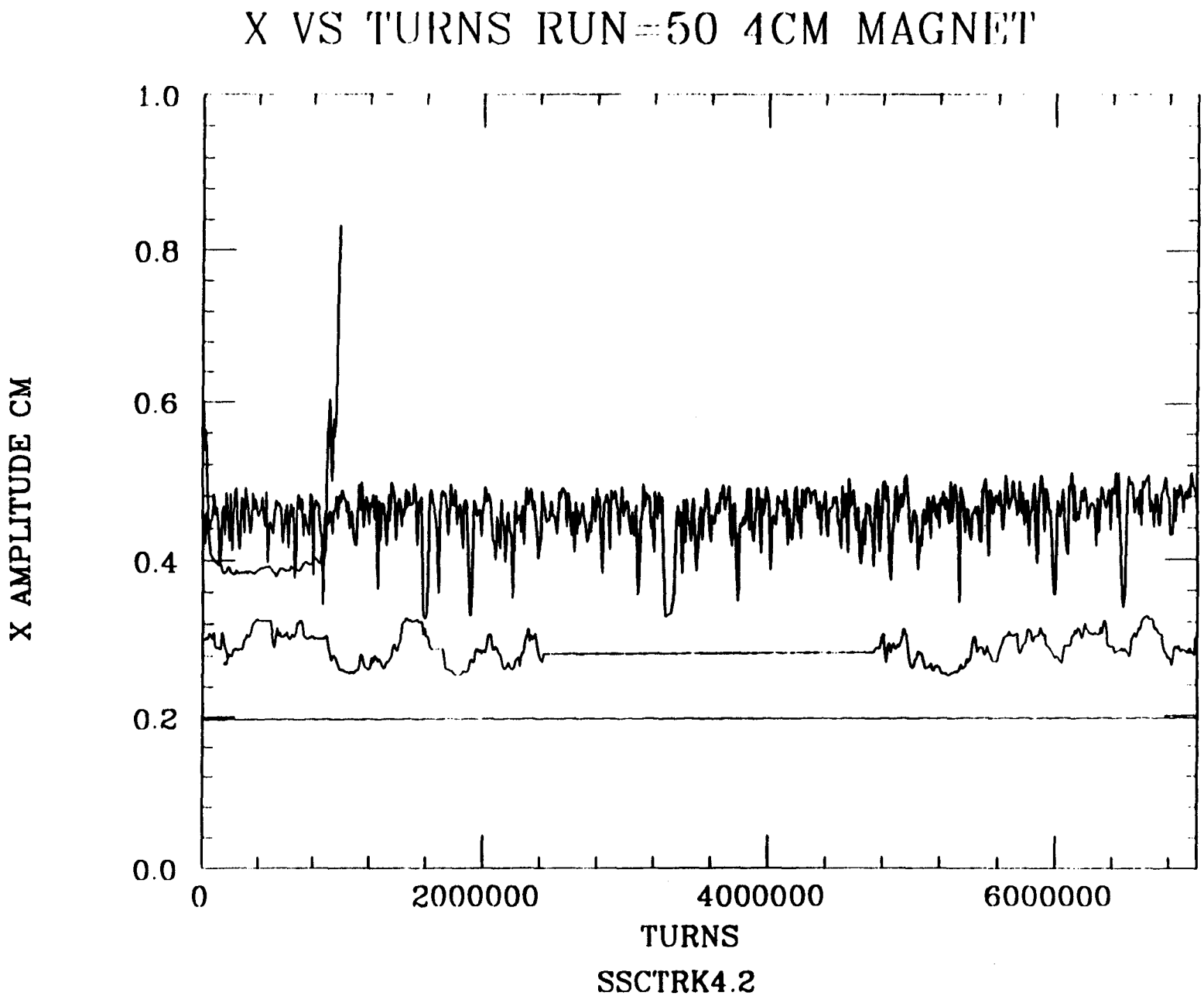
Accelerator Parameters	Collider	HEB	MEB	LEB	Linac
GENERAL CYCLE TIME PARAMETERS					
Cycle Time For Collider Operation	_	4.5 min.	7.0 sec.	0.1 sec.	_
Cycle Time For Test Beam Operation	_	5.5 min.	8.0 sec.	0.1 sec	_
Fill Time - collider op	72 min	6.5 sec	1/2 sec	8μ sec	_
Turns at flat bottom	1.5×10^7	5.5×10^5	38,000	-	_
Revolution Time μs	290	36.025	13.2	2.4	_
Revolution Frequency KHz	3.441	27.758	75.7	417	_
Acceleration Time. Up	16.7min	90sec	3.2sec	.05sec	_
Flat Top Time	_	6.5 sec	.05	_	_
Filling Scenario #batch(total batch/filled batch) gap	$8 \times \frac{2057}{1962}$, 110g	$3 \times \frac{669}{654}$, 25g	$6 \times \frac{109}{109}$, 3g	_	_
Abort gap	198	103	121		
BEAM CURRENT PARAMETERS					
N For collider Operation	0.75×10^{10}	1×10^{10}	$.1 \times 10^{10}$	1×10^{10}	_
N_{tot} For Collider Operation	1.3×10^{14}	2×10^{13}	8×10^{12}	1.1×10^{12}	_
Current - For Collider Operation (mA)	73	81	83	93	_
N For Test Beam Operation	-	5×10^{10}	5×10^{10}	5×10^{10}	_
N_{tot} For Test Beam Operation	-	10^{14}	4×10^{13}	5×10^{12}	_

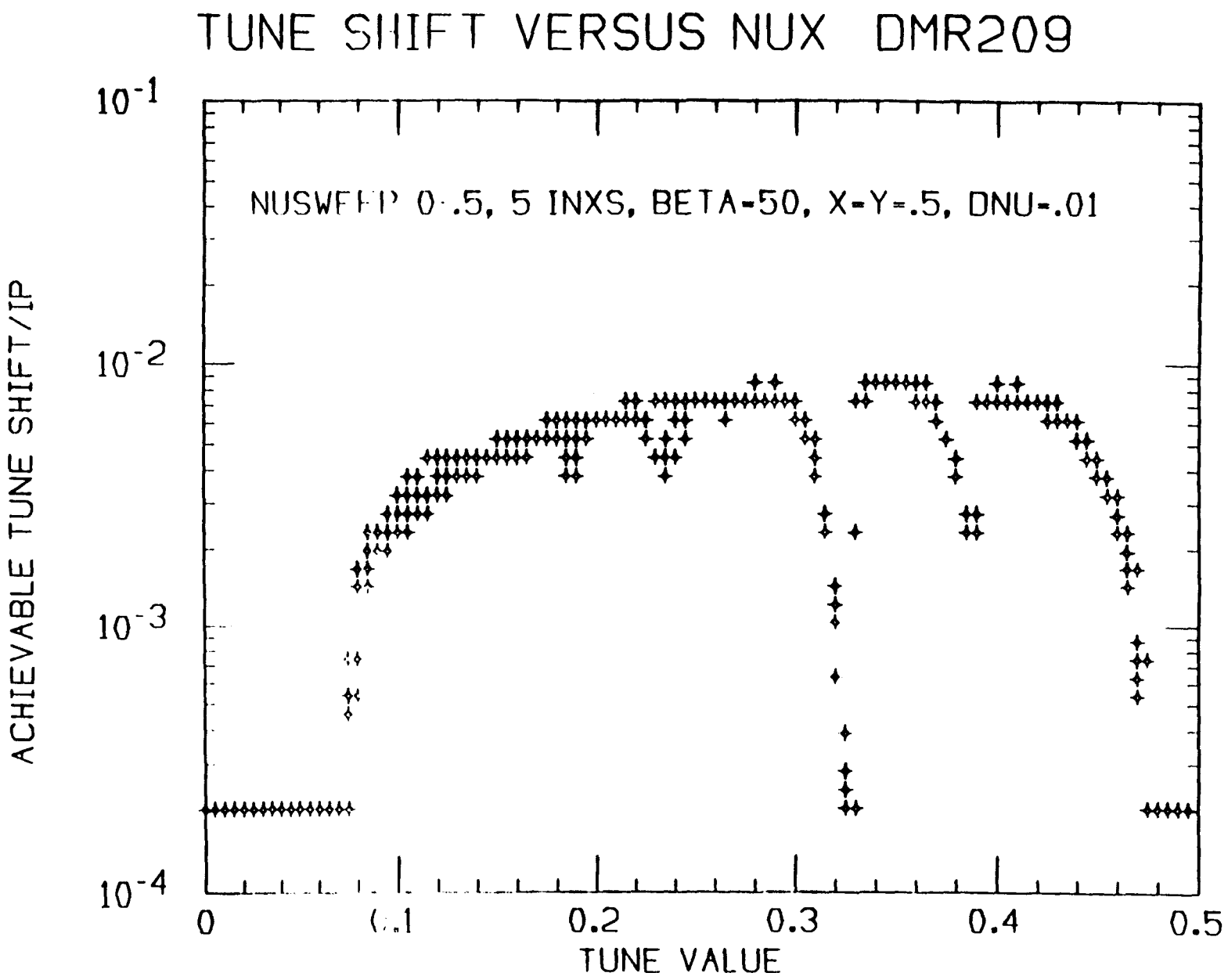


$$\mathcal{L} \sim B \cdot I$$

$$B = \frac{N_B}{\epsilon_N} \quad \text{Brightness}$$

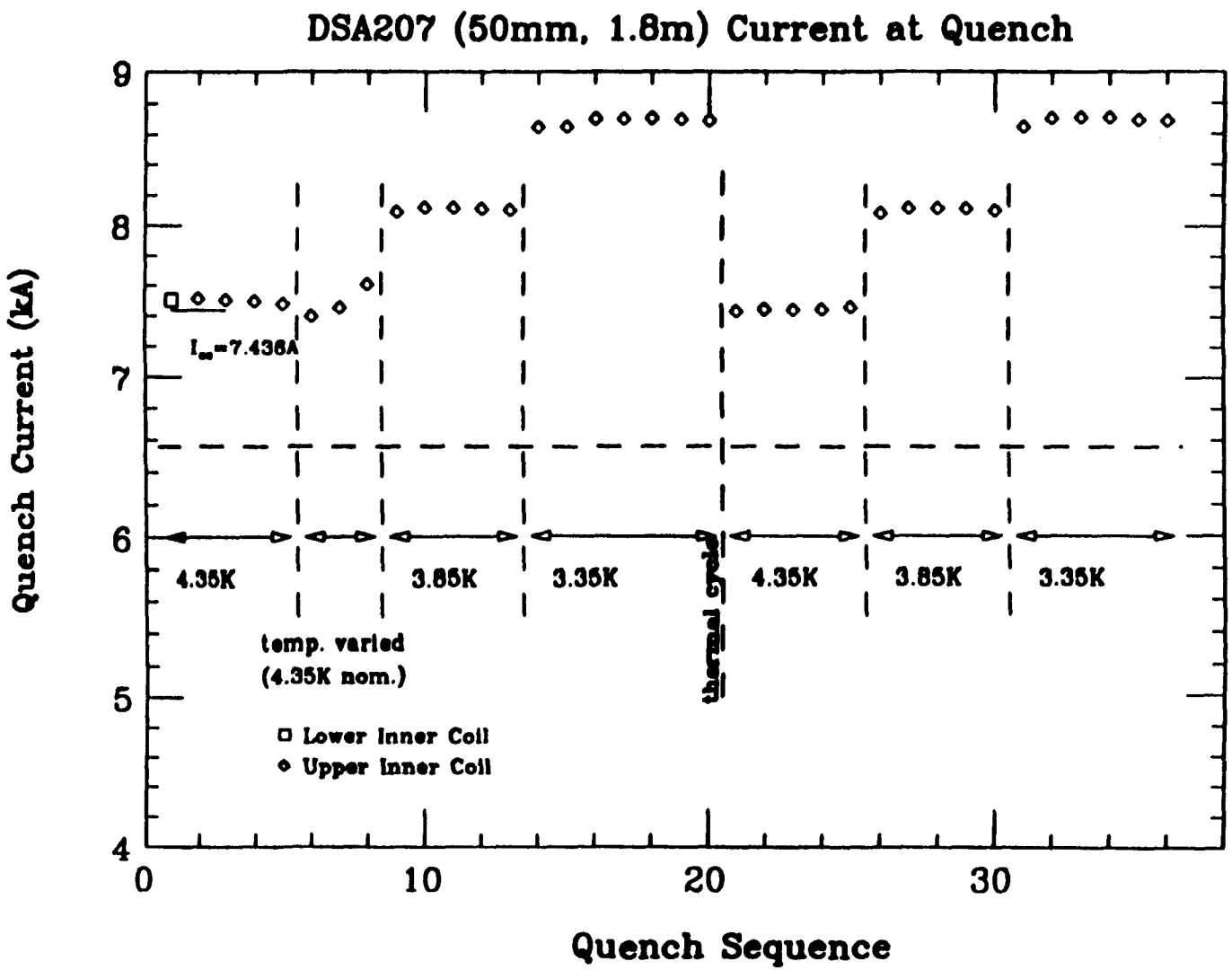
$$I = \text{Total current}$$

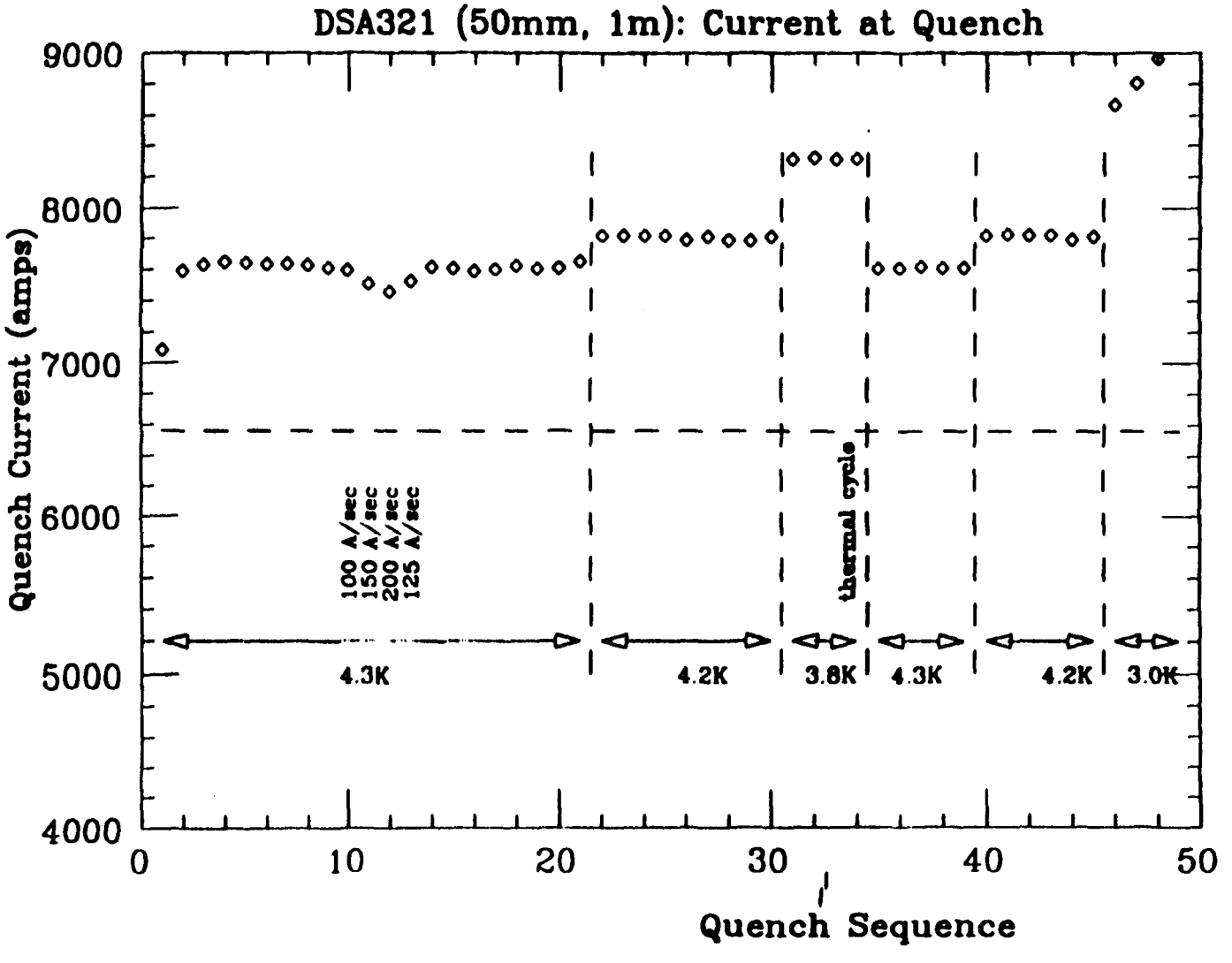

X VS TURNS RUN=50 4CM MAGNET
1.0
0.8
0.6
0.4
0.2
0.0
X AMPLITUDE CM
0
2000000
4000000
6000000
TURNS
SSCTRK4.2

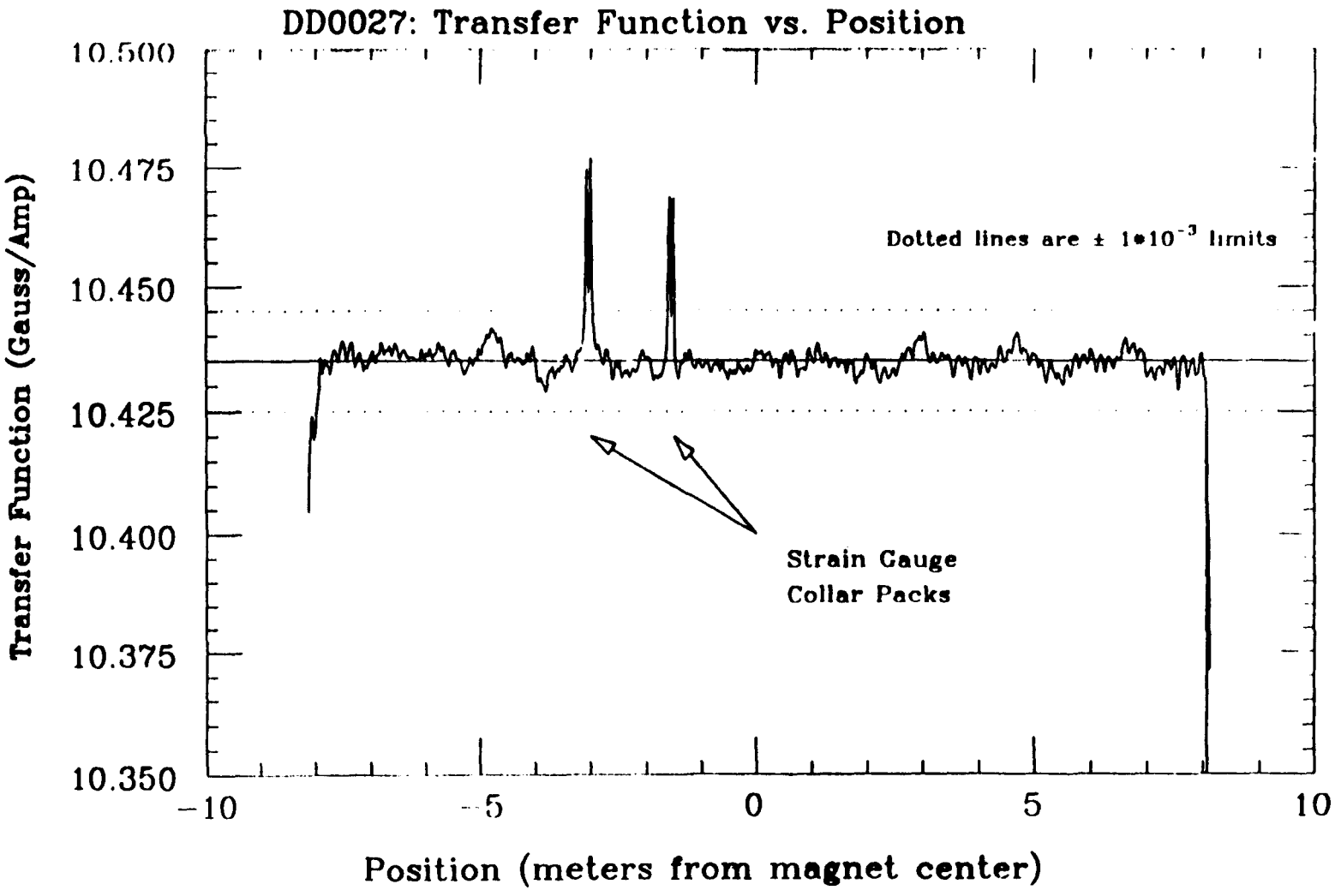

TUNE SHIFT VERSUS NUX DMR209
NUSWEEP 0-.5, 5 INXS, BETA-50, X-Y=.5, DNU-.01
ACHIEVABLE TUNE SHIFT/IP
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
0.1
0.2
0.3
0.4
0.5
TUNE VALUE

BNL 25cm DIBOSE X-SECTION

SCALE-FULL

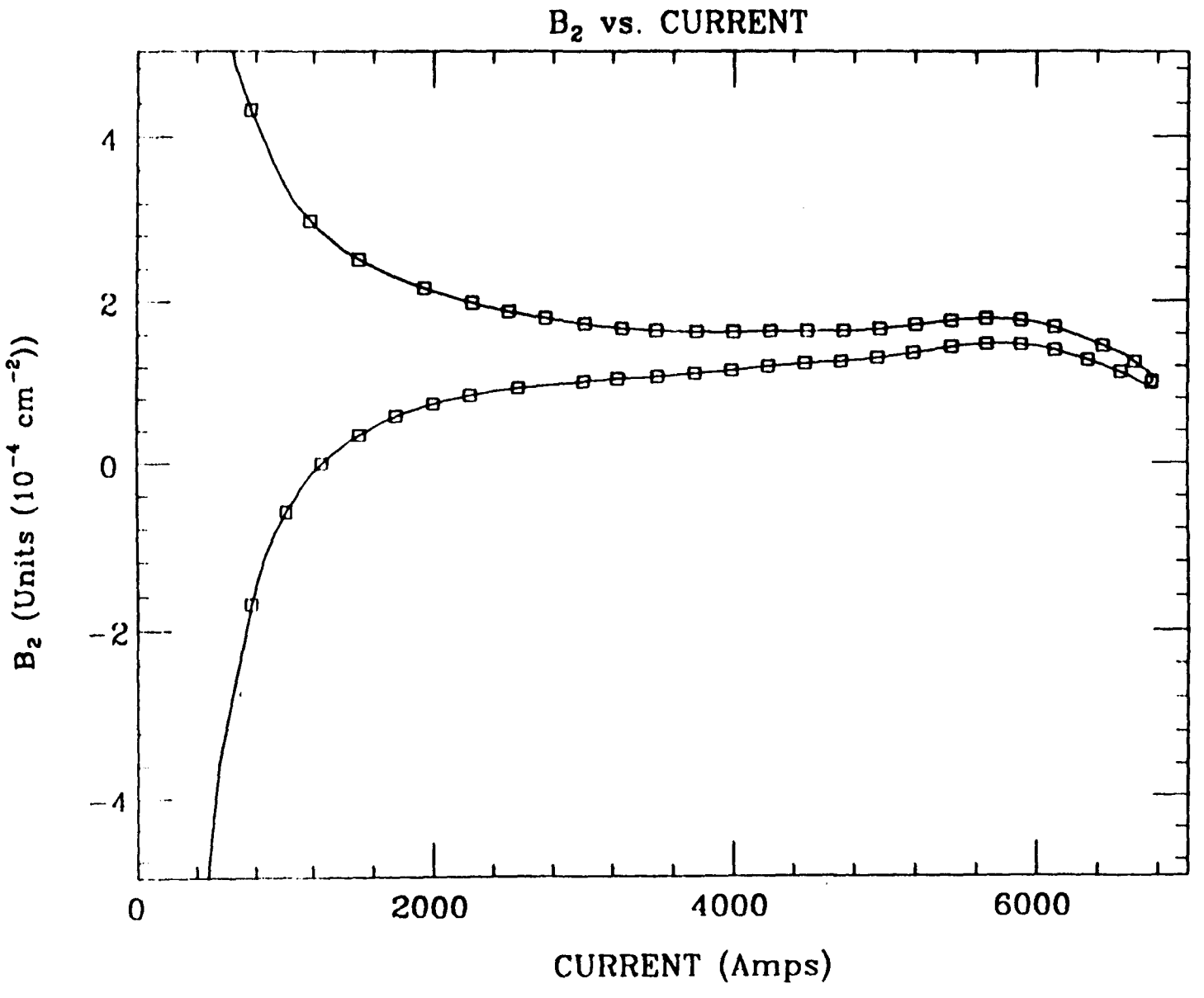

DSA207 (50mm, 1.8m) Current at Quench
Quench Current (kA)
Quench Sequence
9
8
7
6
5
4
0
10
20
30
I_{ss}=7.436A
4.35K
3.85K
3.35K
4.35K
3.85K
3.35K
temp. varied
(4.35K nom.)
thermal cycle
Lower Inner Coil
Upper Inner Coil


DSA321 (50mm, 1m): Current at Quench
Quench Current (amps)
9000
8000
7000
6000
5000
4000
0
10
20
30
40
50
Quench Sequence
100 A/sec
150 A/sec
200 A/sec
125 A/sec
thermal cycle
4.3K
4.2K
3.8K
4.3K
4.2K
3.0K



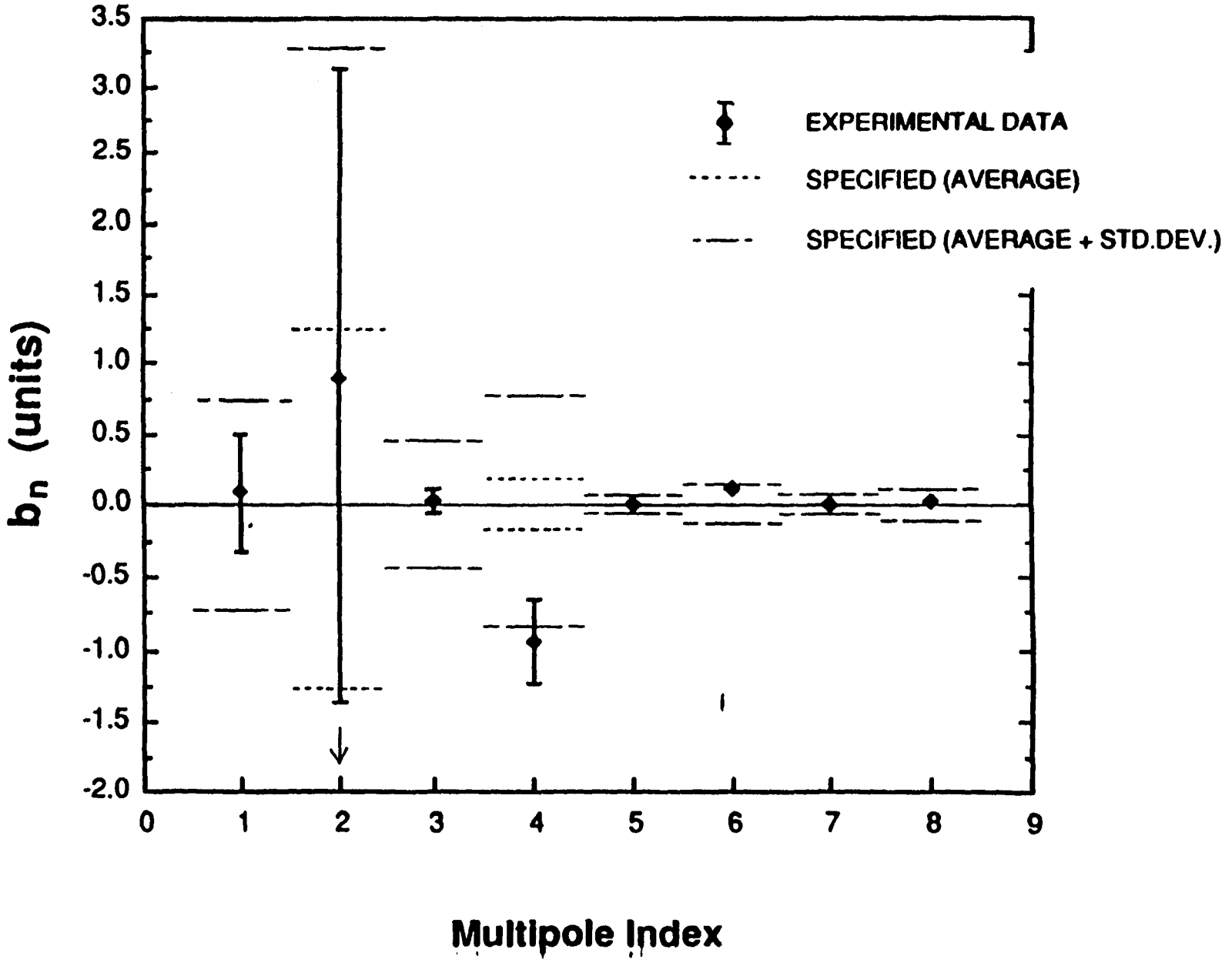
DD0027 1800A 14-MAY 1990

NMR meas. after second T C



□ DD0028 36 20 Nov 1990 cold data to 7000 Amps Current loop w/ no pre-ramp
position: 7.010 meters

Normal Harmonic Coefficients
Average for 8 Long Dipoles



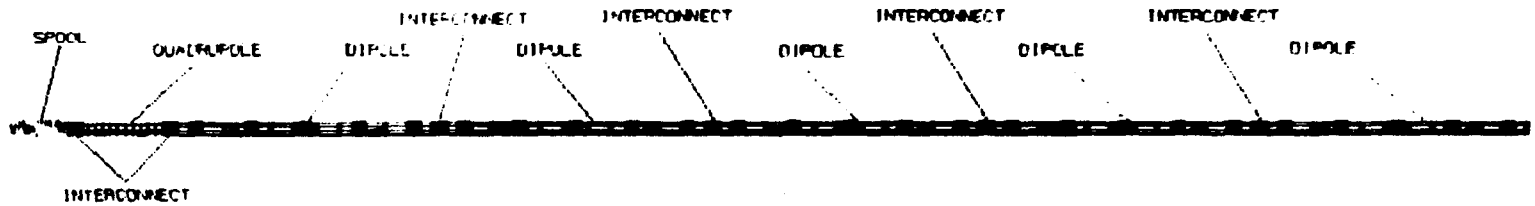
Correlation MTBW Sd
Intercept = 0.302E+00
Slope = 0.154E+01
Correl. coeff.: 0.903
ps (Mrad)
Sd (cold)

Correlation MTBW Sa
Intercept = -0.325E-01
Slope = 0.819E+00
Correl. coeff.: 0.931
gs (Mrad)
Sa (cold)

Correlation MTBW Id
Intercept = 0.145E+00
Slope = 0.988E+00
Correl. coeff.: 0.949
pi (Mrad)
Id (cold)

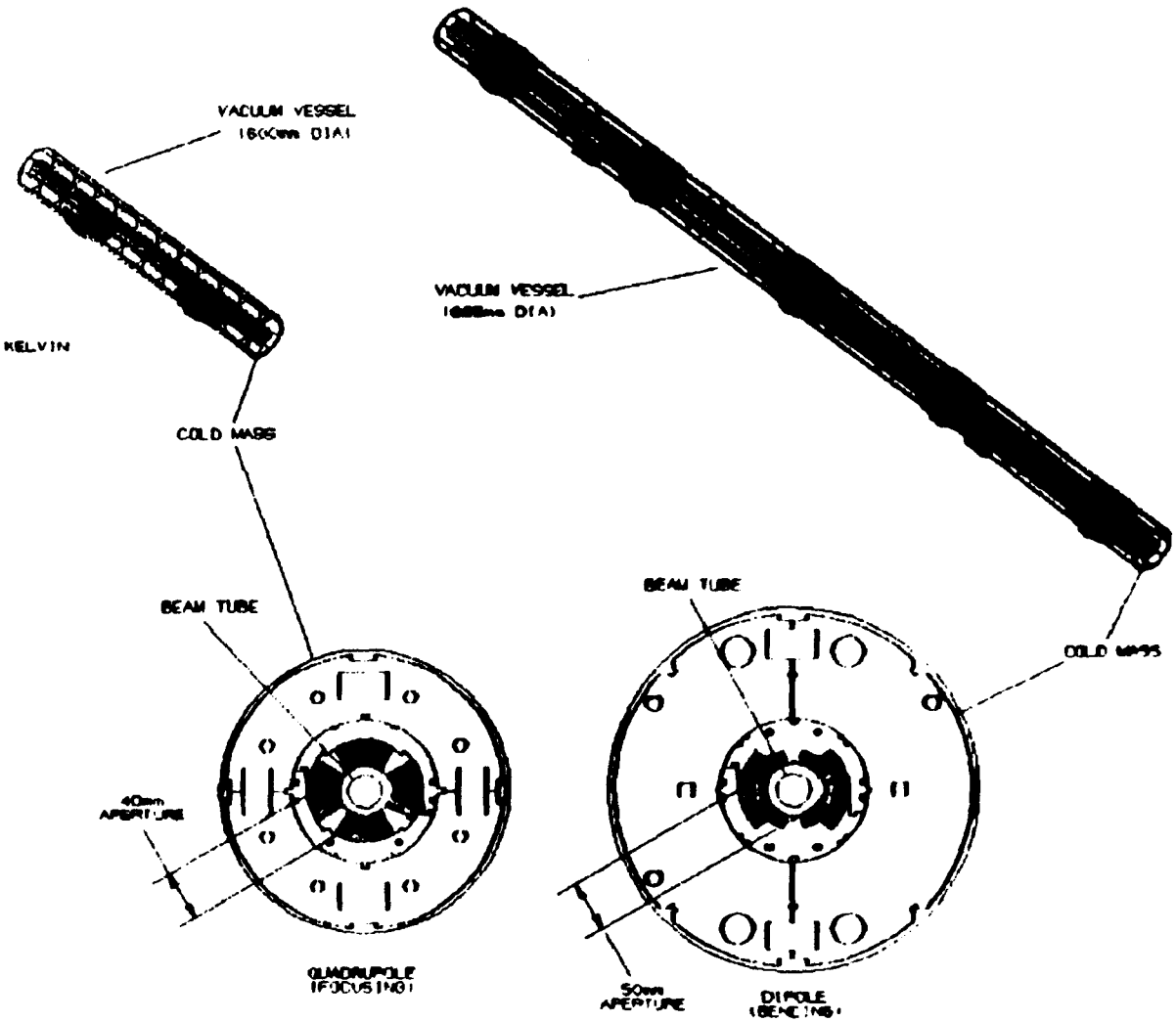
Correlation MTBW Ia
Intercept = -0.424E-01
Slope = 0.972E+00
Correl. coeff.: 0.984
gi (Mrad)
Ia (cold)

STRING TEST CONFIGURATION



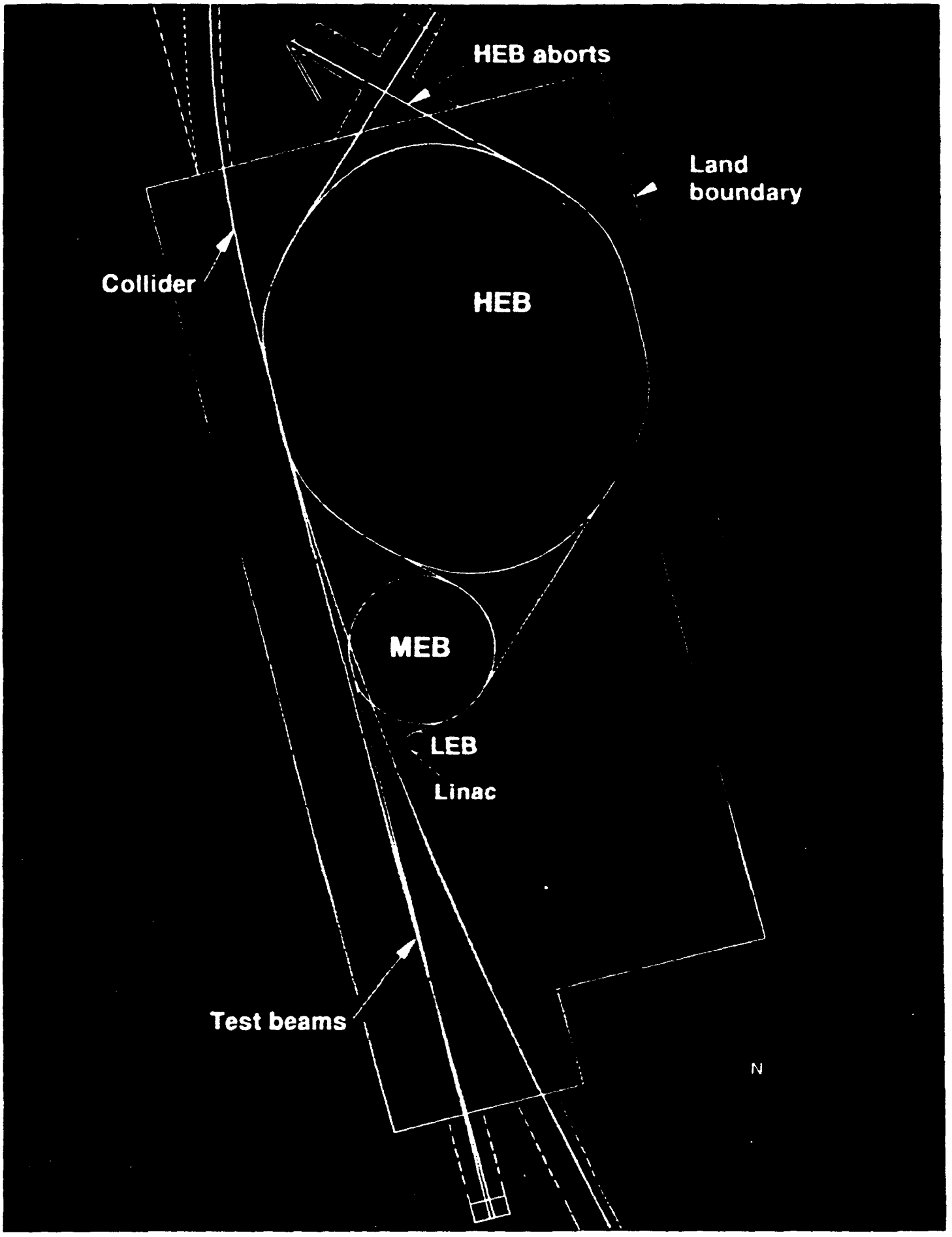
COLD MASS IS "ACTIVE" PART OF MAGNET

VACUUM VESSEL & HEAT SHIELDS KEEP COLD MASS AT 4.3 KELVIN

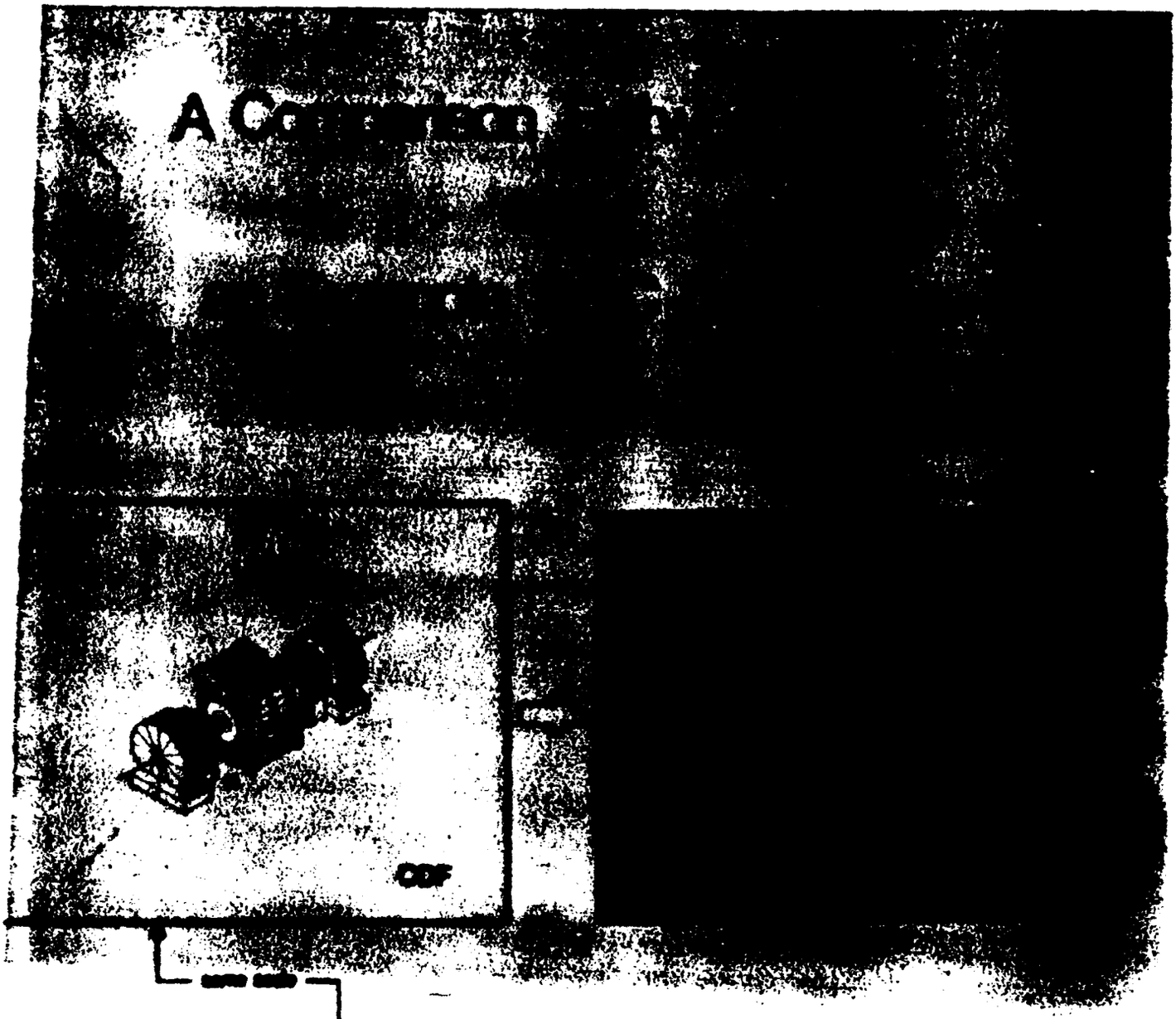


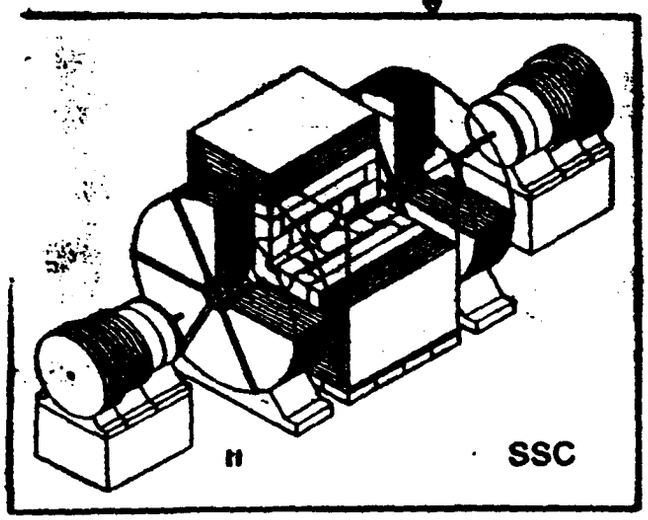
	DIPOLE	QUADRUPOLE
CURRENT	6500 A	6500 A
FIELD	5.6 T	213 T/M
NUMBER PER RING	4300	980
MAGNETIC LENGTH	15.05 m	5.07 m
APERTURE	50 mm	40 mm
TOTAL BEAM PATH	64700 m	4970 m
BEAM TUBE I.D.	32mm	32mm
BEAM DYNAMIC APER. (INJECT)	16mm	

COLLIDER RING MAGNETS


HEB aborts
Land boundary
Collider
HEB
MEB
LEB
Linac
Test beams
N

WEST
CAMPUS
N





	CDF	SSC
Collision Energy (TeV)	[illegible]	[illegible]
Interaction rate per sec	70,000	[illegible]
Time between collisions (sec)	[illegible]	[illegible]
Weight (tons)	4,000	[illegible]
Electronics channels	100,000	[illegible]

Isometric view of detector

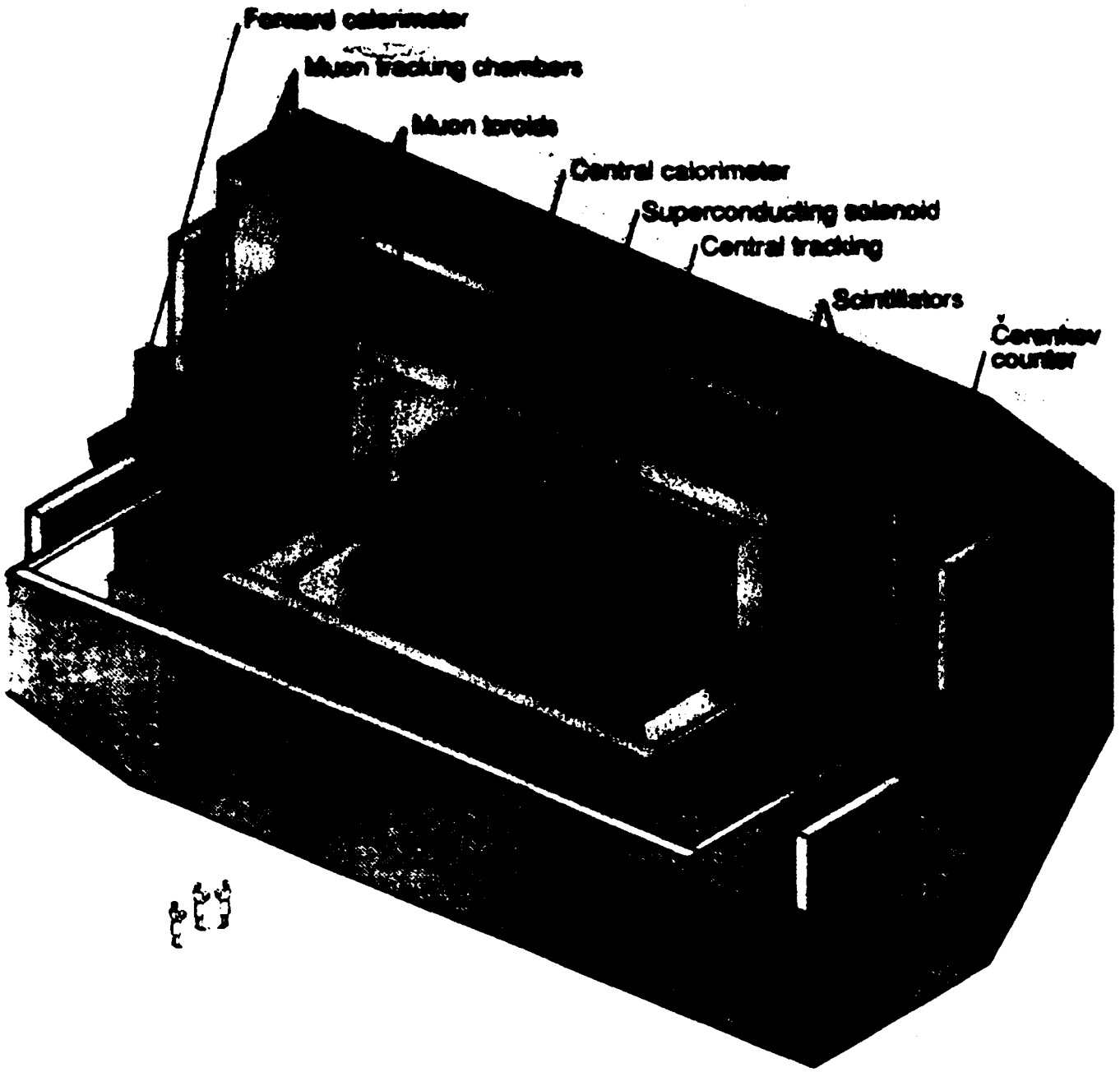
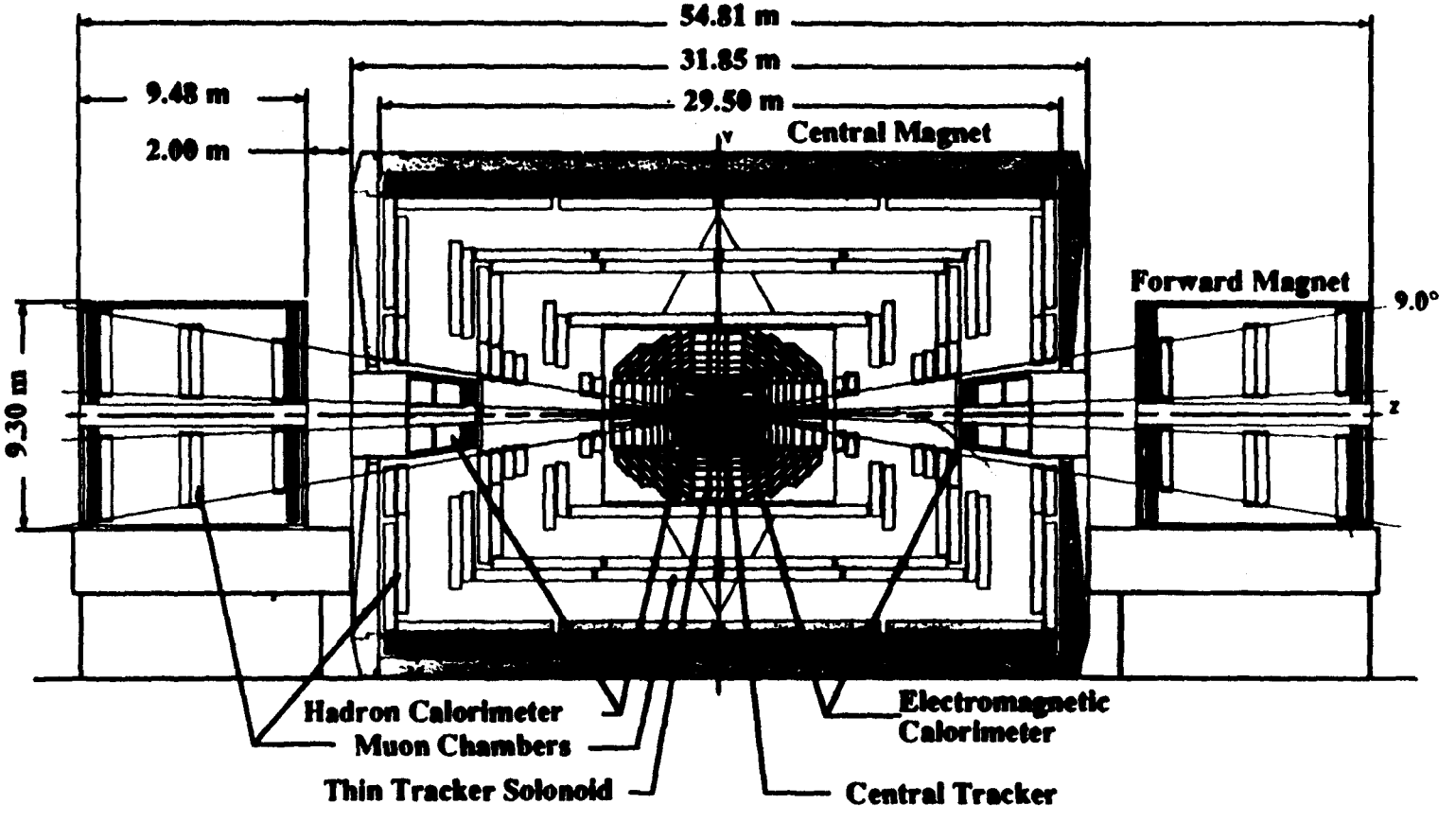


FIG. 1 Overall view of the solenoid detector

Jun 11-13


54.81 m
31.85 m
29.50 m
9.48 m
2.00 m
Central Magnet
Forward Magnet
9.0°
9.30 m
z
Hadron Calorimeter
Muon Chambers
Thin Tracker Solonoid
Electromagnetic Calorimeter
Central Tracker

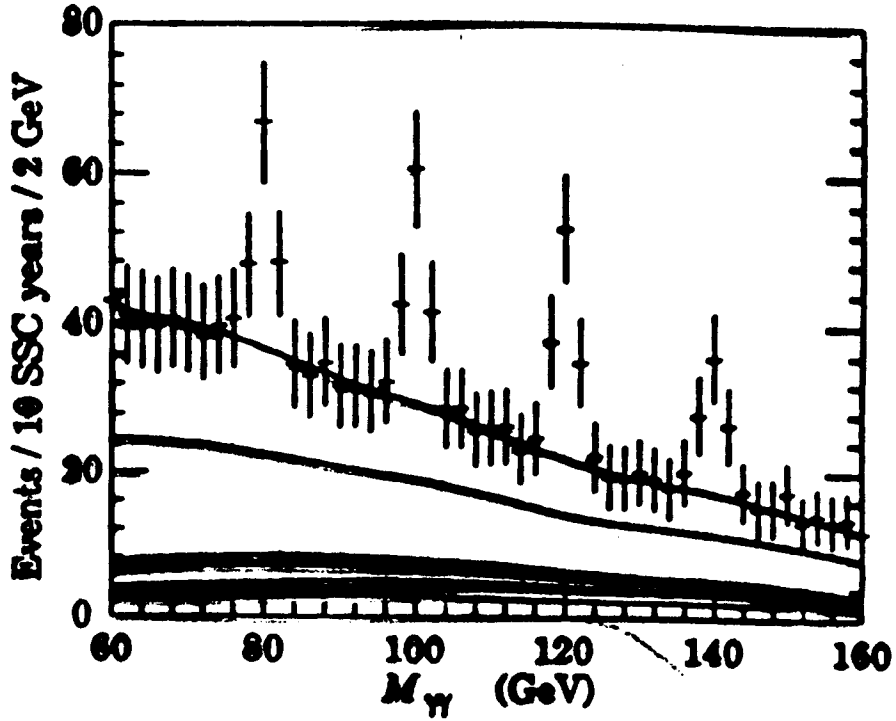


FIG. 22. The $\gamma\gamma$ invariant mass distribution for the process $W + H \to \ell\nu\gamma\gamma$, including all backgrounds. The signal contains peaks from $M_H = 80, 100, 120, 140$ GeV. The lepton and photons were all required to satisfy $p_t > 20$ GeV/c, and to be separated in η–ϕ space by a distance of 0.4. A jet misidentification probability of 5×10^{-4} was assumed in plotting the QCD backgrounds. An isolation cut reduces the b backgrounds by a factor 10. The background curves are cumulative, and are (from lowest to highest): $2 - jet$, $2 - jet + \gamma$, $jet + \gamma\gamma$ combined, then $b + \gamma\gamma$, $b + \gamma + jet$, $b\bar{b} + \gamma$, followed by $W + jets$, $W + \gamma + jet$ and $W + \gamma\gamma$.

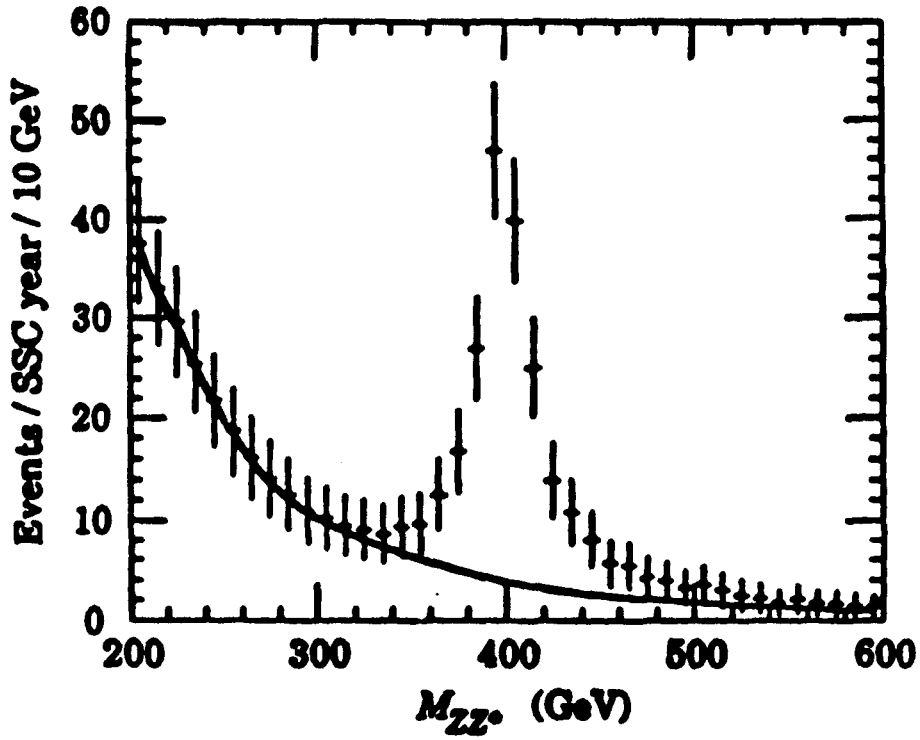


FIG. 18. Same as Fig. 17 except that the Higgs mass is 400 GeV.

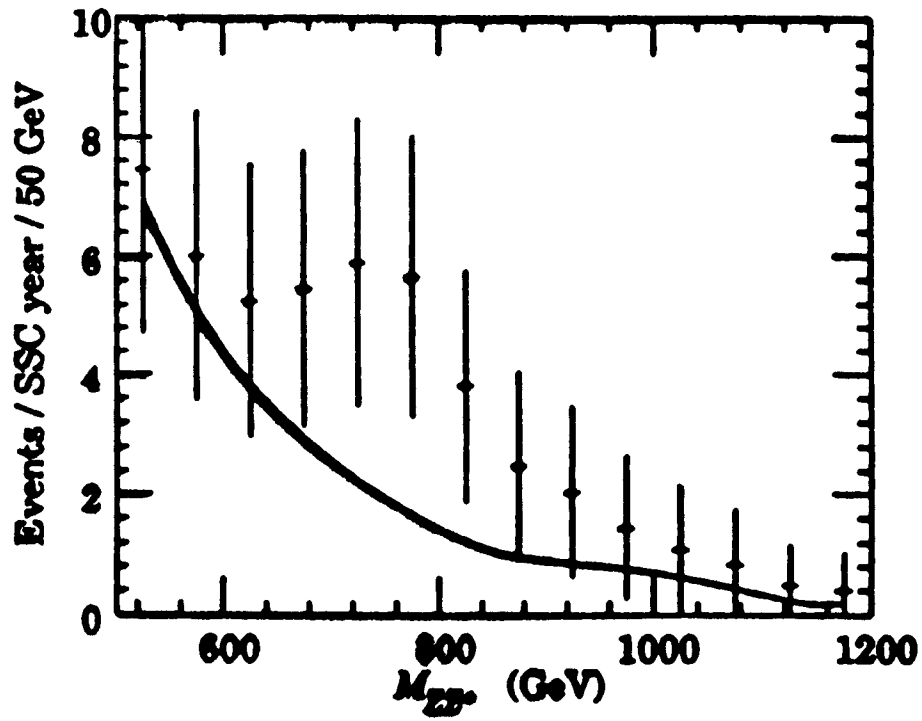
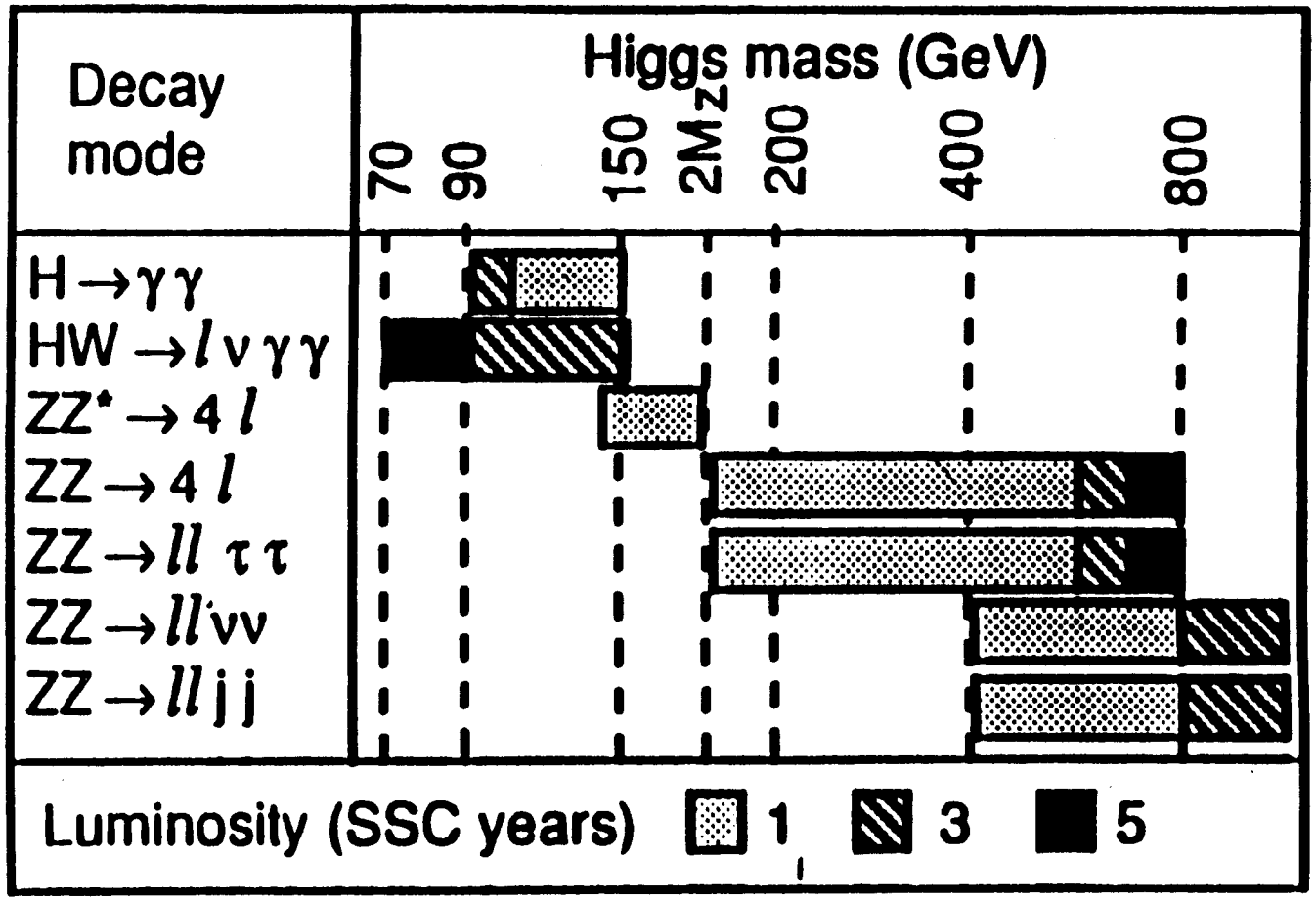
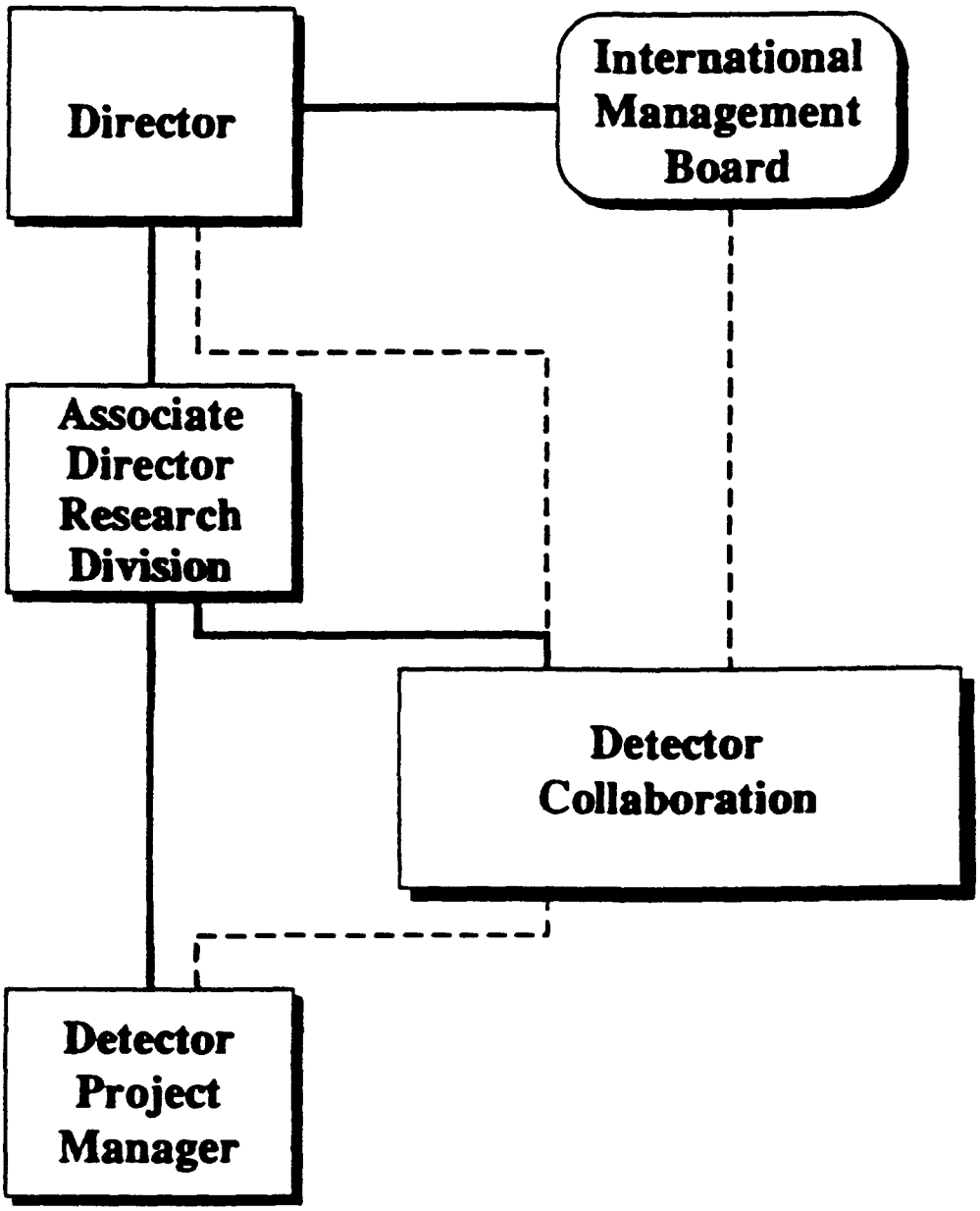


FIG. 19. Same as Fig. 17 except that the Higgs mass is 800 GeV.


Decay mode
Higgs mass (GeV)
70
90
150
2Mz
200
400
800
H→γγ
HW→lνγγ
ZZ*→4l
ZZ→4l
ZZ→llττ
ZZ→llνν
ZZ→lljj
Luminosity (SSC years)
1
3
5

SSCL Detector Management Responsibilities



Scientific Targets of the SSC

Clarification of the Nature of Electroweak Symmetry Breaking

- **Higgs**

Searches for New Physics Beyond the Standard Model

- **Supersymmetry**
- **Technicolor**
- **Compositeness**
- •
- •
- •

Detailed Studies of Standard Model Processes

- **Top-Quark Search**
- **B-Quark Studies – CP Violation?**

Tiresite! Imagination!

→ 5 new, state-of-art accelerators ←

EXPERIMENTAL OBSERVATION OF ISOLATED LARGE TRANSVERSE ENERGY ELECTRONS WITH ASSOCIATED MISSING ENERGY AT $\sqrt{s}$ = 540 GeV

UA1 Collaboration, CERN, Geneva, Switzerland

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Aachen [a]–Annecy (LAPP) [b]–Birmingham [c]–CERN [d]–Helsinki [e]–Queen Mary College, London [f]–Paris (Coll. de France) [g]–Riverside [h]–Rome [l]–Rutherford Appleton Lab. [j]–Saclay (CEN) [k]–Vienna [i] Collaboration

Received 23 January 1983

We report the results of two searches made on data recorded at the CERN SPS Proton–Antiproton Collider: one for isolated large-E_T electrons, the other for large-E_T neutrinos using the technique of missing transverse energy. Both searches converge to the same events, which have the signature of a two-body decay of a particle of mass ~80 GeV/c^2. The topology as well as the number of events fits well the hypothesis that they are produced by the process $\bar{p} + p \to W^{\pm} + X$, with $W^{\pm} \to e^{\pm} + \nu$; where $W^{\pm}$ is the Intermediate Vector Boson postulated by the unified theory of weak and electromagnetic interactions.

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NEWSPAPER

PHYSICAL REVIEW LETTERS

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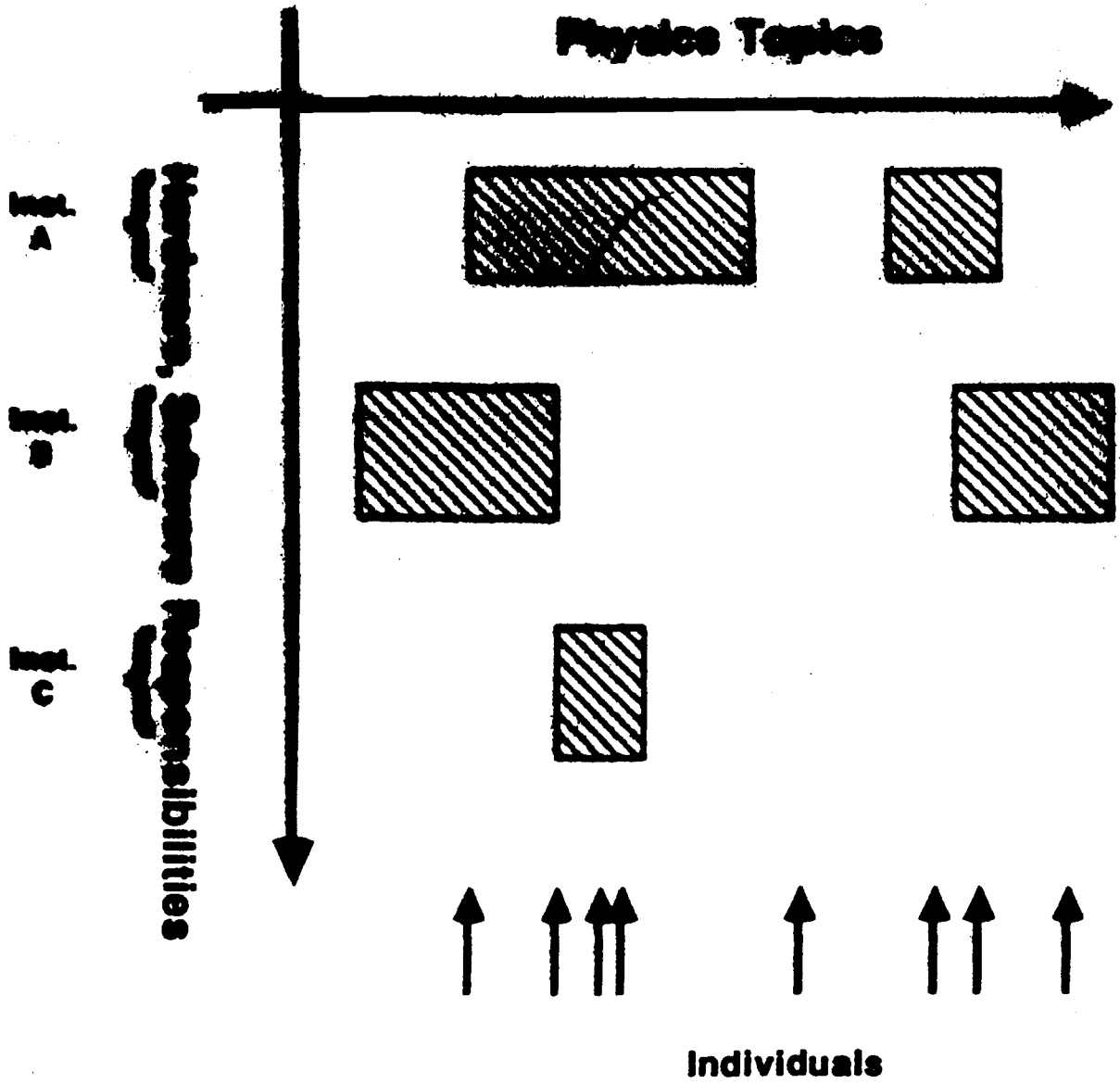
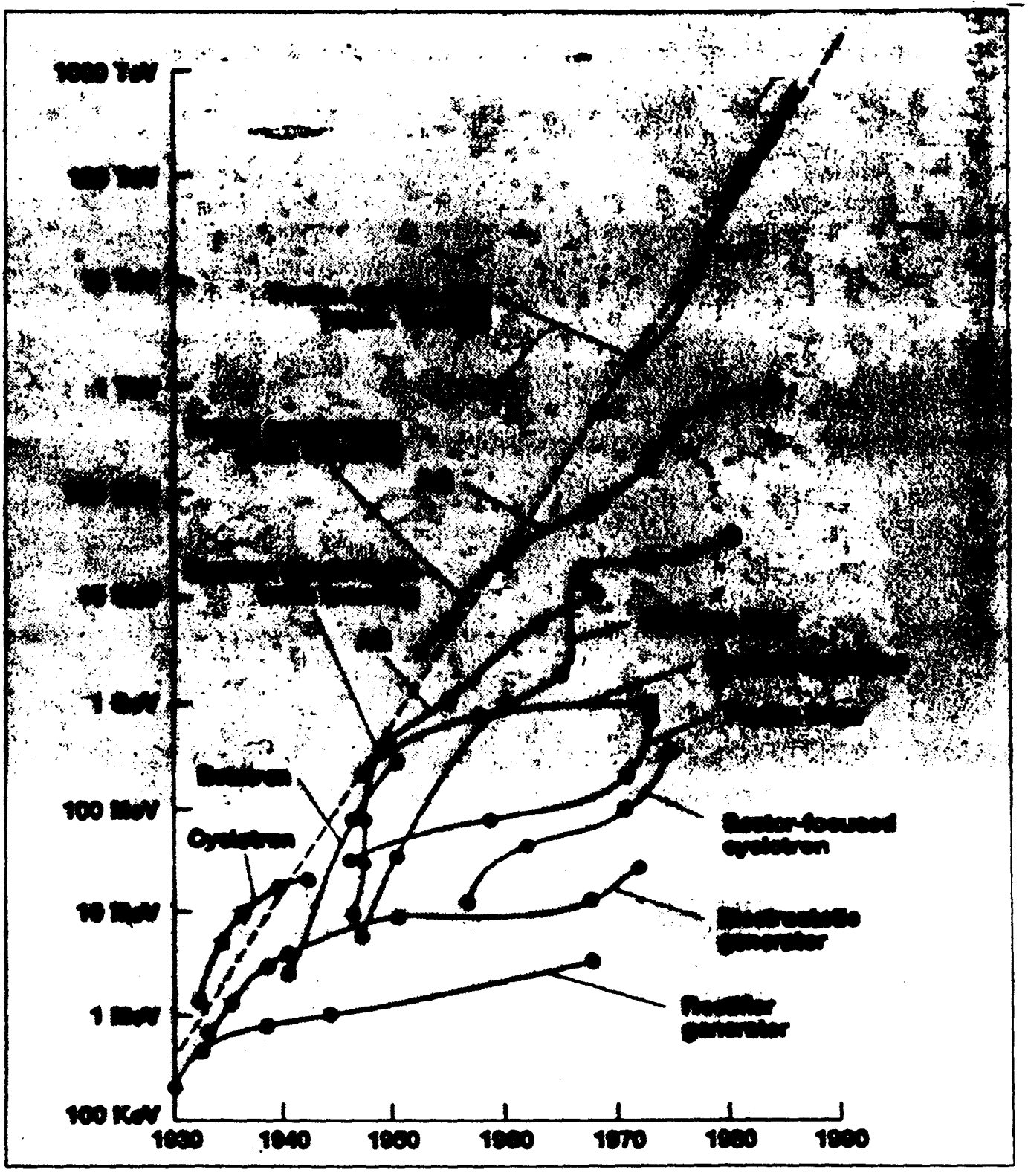
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