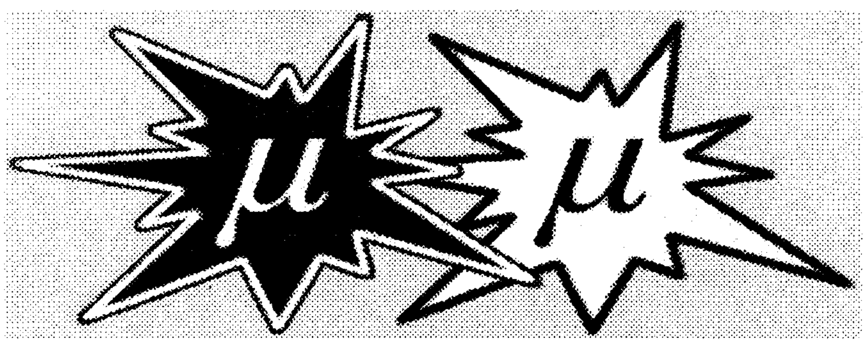
2nd Mini-Workshop on Higgs Factory: Lattice and Detector

UCLA

February 12 and 13, 1998



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Transparency Book

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Table of Contents

R. Palmer (BNL)

TRANSVERSE COOLING

- **Energy Loss lowers $\epsilon_\perp$**
- **Coulomb Scattering Increases $\epsilon_\perp$**
- **At Equilibrium:**

$$\epsilon_\perp(Eq) = \beta_\perp \frac{14\ MeV}{2\beta_v L_R\ dE/dx}$$

- **Need:**
  - **Low Z material (H_2 > Li > Be)**
  - **Low $\beta_\perp$**

- **e.g. If**

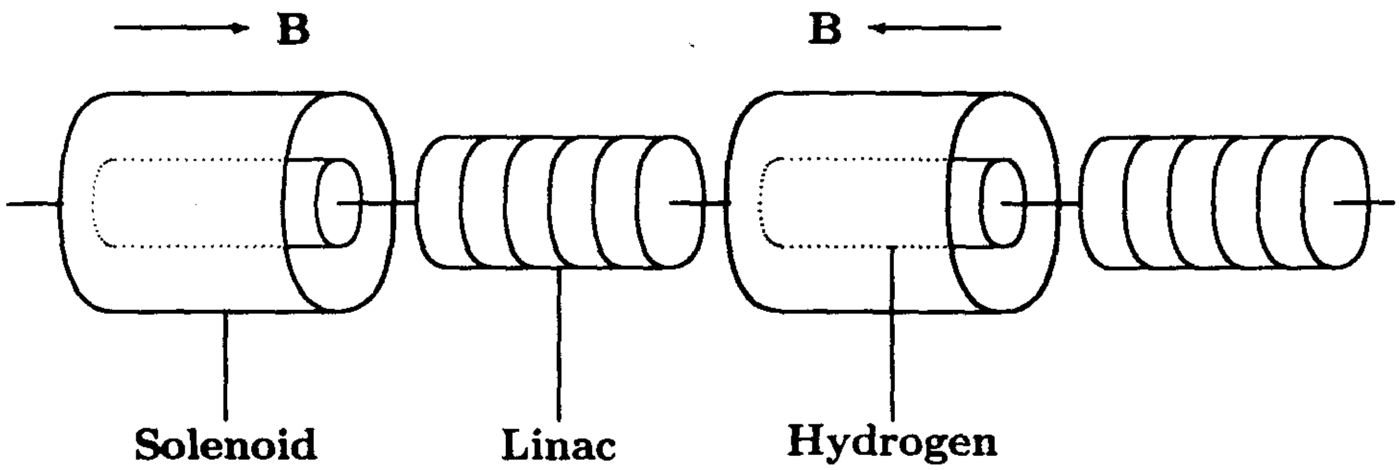
Material = Hydrogen/Lithium/Beryllium
p = 180 MeV
Cooling = 3/4 Max. $(\epsilon_\perp = 4 \times \epsilon_{equ})$
Acceptance = 4 × rms,

$$\theta_{acceptance} = \frac{A}{\sigma_\theta} \times \sqrt{\frac{\epsilon_\perp}{\epsilon_{equilib}} \frac{14\ MeV}{2\gamma\ \beta_v^2\ L_R\ dE/dx}}$$

$$\approx\ \mathbf{0.35}_H/\mathbf{0.5}_{Li}/\mathbf{0.6}_{Be}\ \textbf{radians}$$

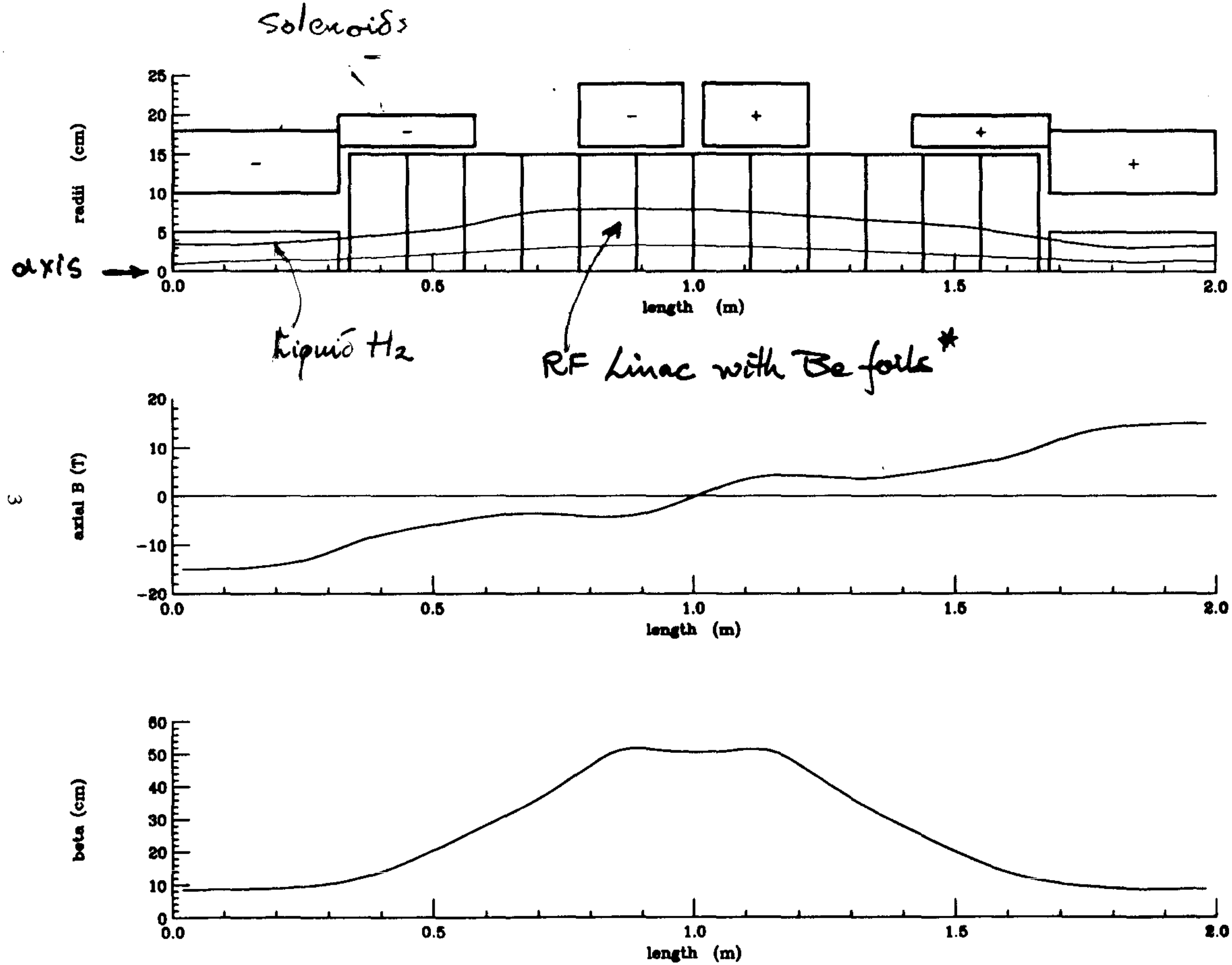
HOW TO GET LOW $\beta_\perp$

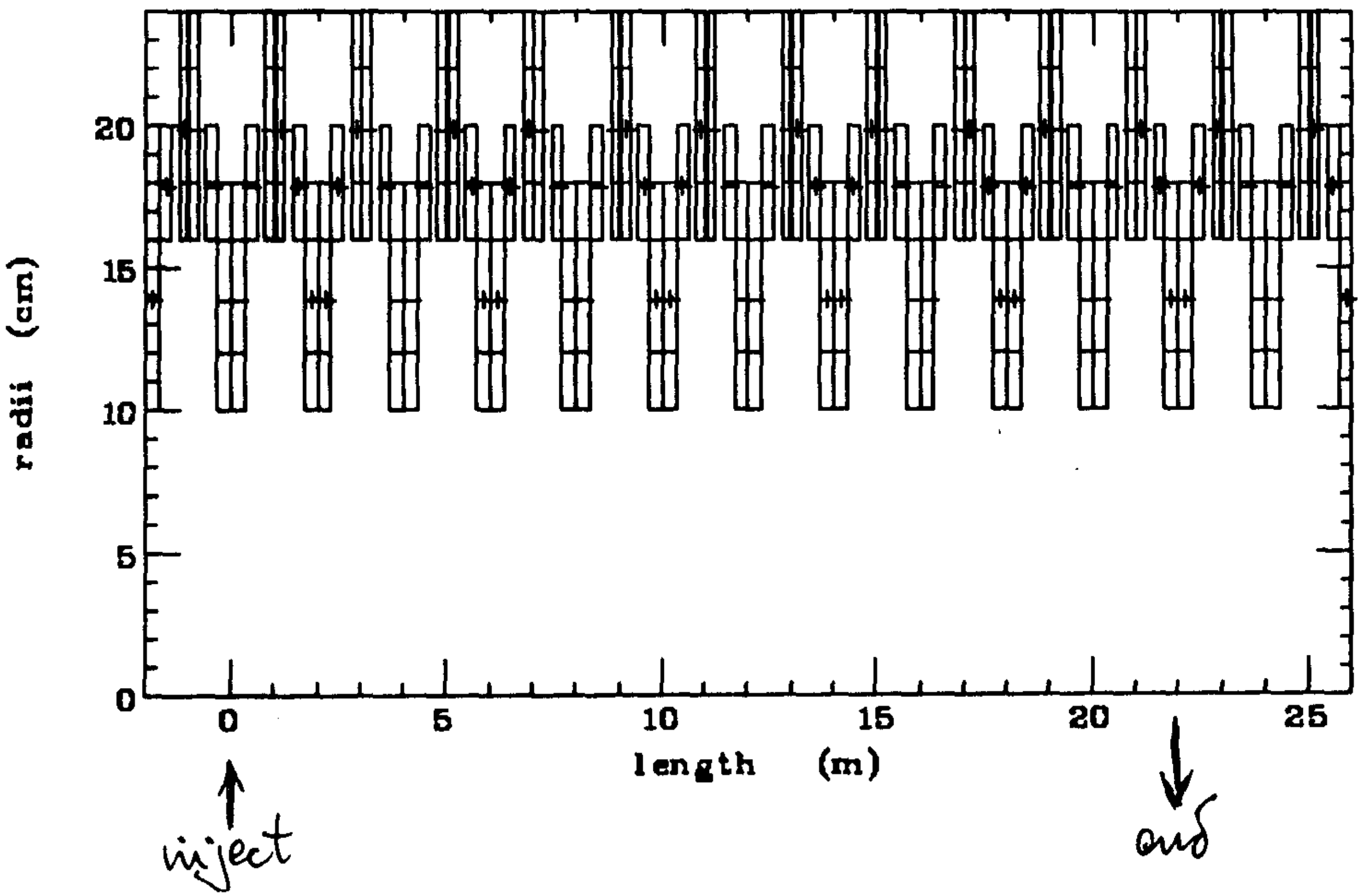
- Alternating solenoids



- B must alternate to avoid Canonical Ang. Mom. buildup

- Problem is to match between reversals


Solenoids
axis
Liquid H_2
RF Linac with Be foils*
radii (cm)
length (m)
axial B (T)
length (m)
beta (cm)
length (m)


radii (cm)
0
5
10
15
20
length (m)
0
5
10
15
20
25
inject
out

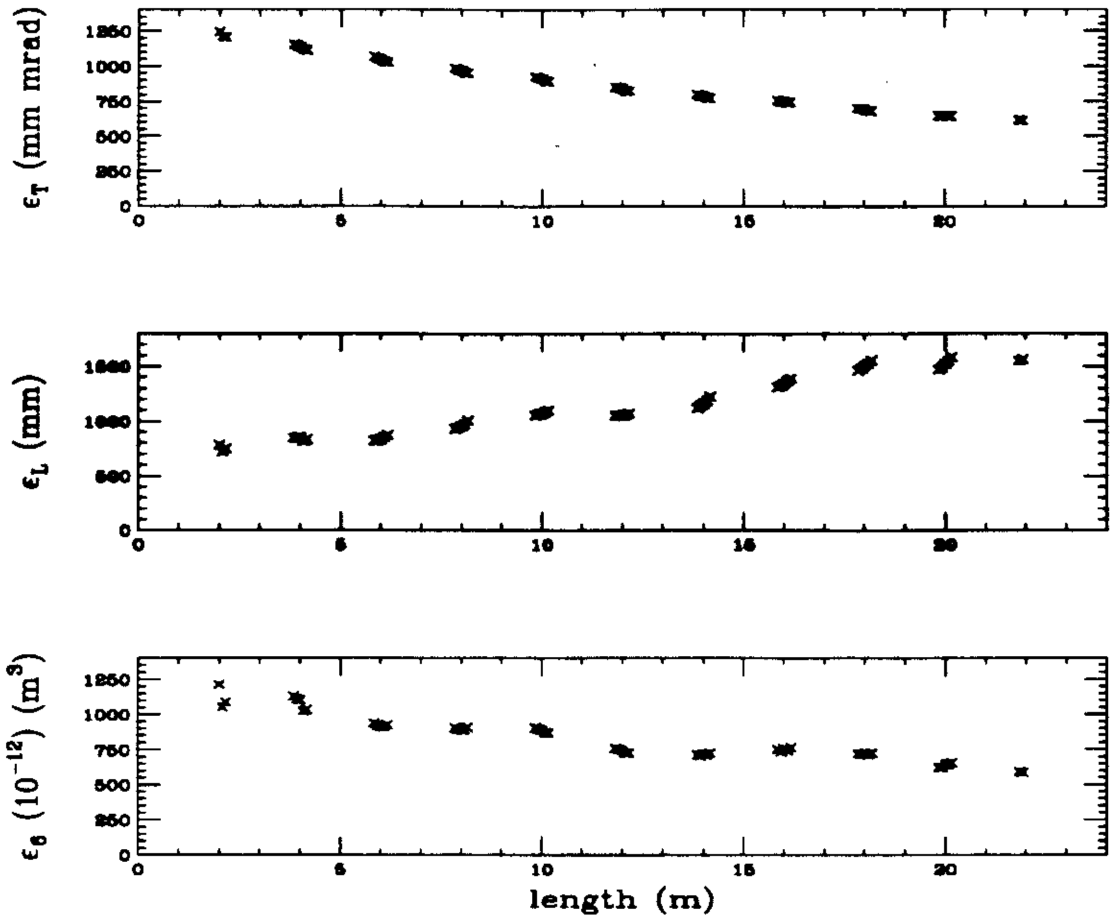
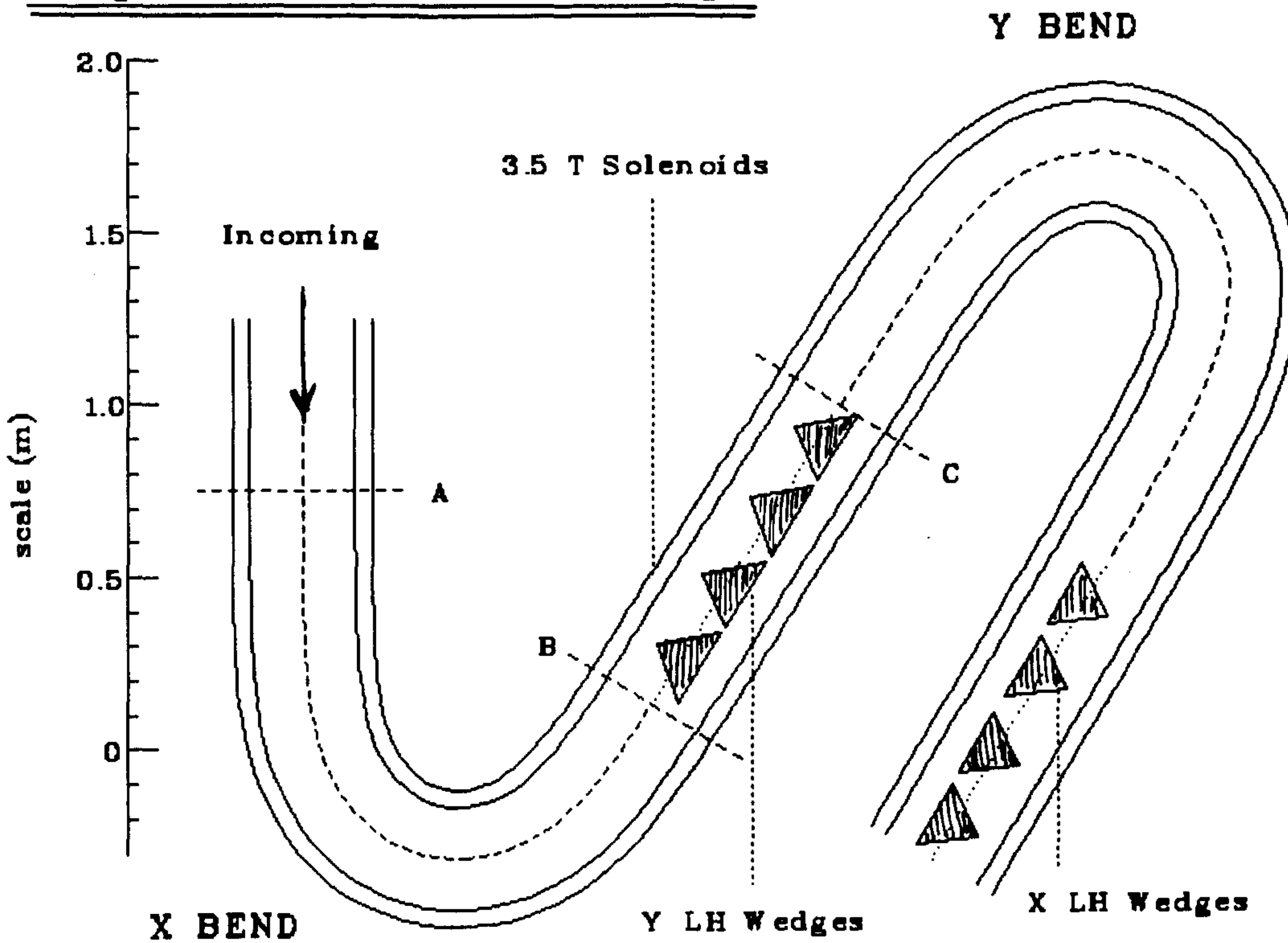
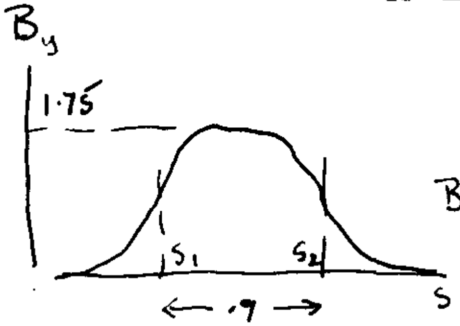


FIGURE 4. emittance vs. length in 10 alternating solenoid cells; TOP: transverse emittance; MIDDLE: longitudinal emittance; and BOTTOM: 6-dimensional emittance

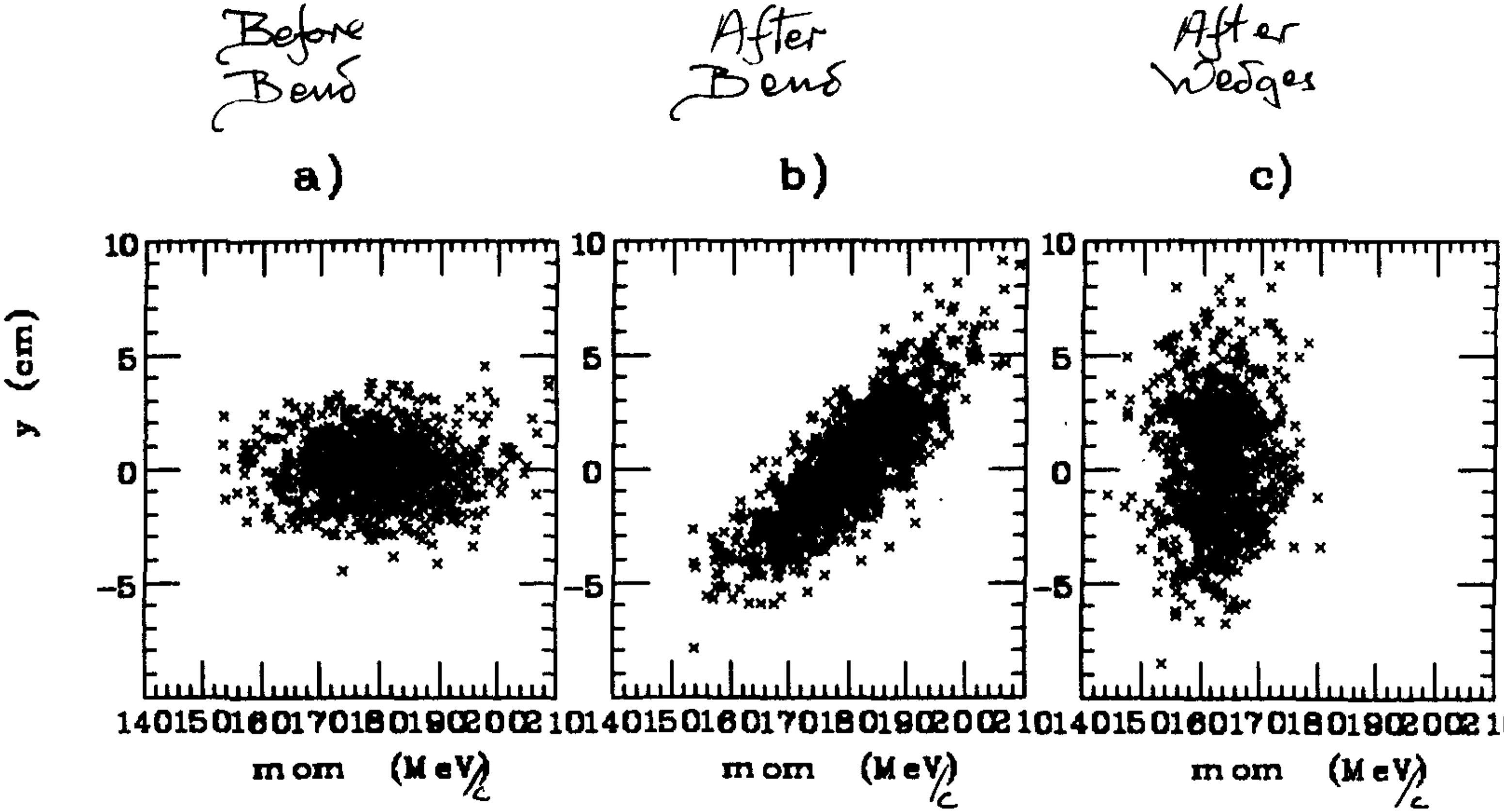
Longitudinal Emittance Exchange





$$B_y = .5\left\{\arctan\left(\frac{s_1 - s_0}{\Gamma}\right) - \arctan\left(\frac{s - s_2}{\Gamma}\right)\right\}$$

$$\Gamma = .3$$



+/- 8 MeV/c | +/- 8 MeV | +/- 4·6 MeV

+/- 1·35 cm | +/- 2·5 cm | +/- 2·6 cm

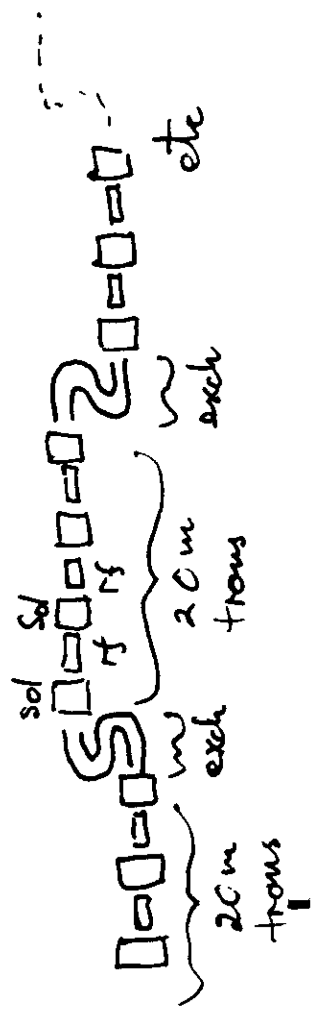
COOLING SYSTEM

- **Initial 6D emittance $\approx$ 1.5 10^{-4} $(\pi m)^3$**
- **Final 6D emittance $\approx$ 1.7 10^{-10} $(\pi m)^3$**

Reduction $\approx 10^6$

- **6D emittance reduction/stage $\approx$ 2**
- **Typical length 20 m**
- **Trans Cool & Long Exch Alternate**

Number of stages $\approx$ 20
Total Length $\approx$ 500 m
Momentum $\approx$ 180 MeV/c
Decay Loss $\approx$ 36 %



- **Parameters awaiting ~~Exch~~ Designs** vs. $\epsilon_\perp$

Scientific Arguments for a Higgs Factory Muon Collider

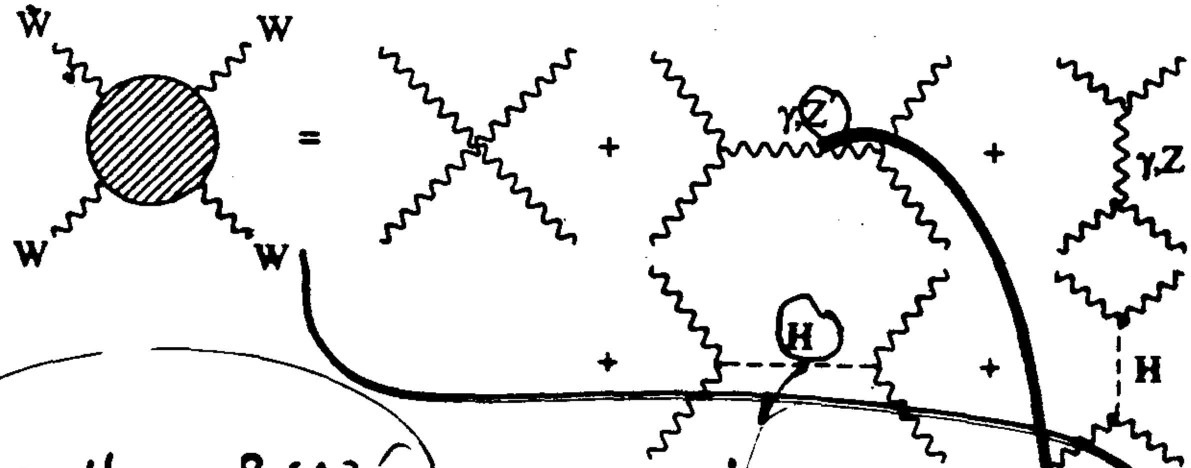
2^{nd} Higgs Factory Meeting
UCLA
February 1998

David Cline

1. **Scalar Sector of the Electroweak Theory**
2. **The Higgs Boson - Normal and SUSY**
3. **Concept of a Higgs Factory μ Collider**
4. **Recent Electroweak Data – The 4^{th} $\mu^{+}\mu^{-}$ Collider Meeting**
5. **CMS LHC Observation of the Higgs**
6. **Possible Time Scale for a Higgs Factory in the USA**

S Willenbrock
JTP mtg
Fall 96

CURE FOR DIVERGENCES
WITH Z and H



THE HIGGS BOSON COULD BE THE LAST PARTICLE TO BE DISCOVERED

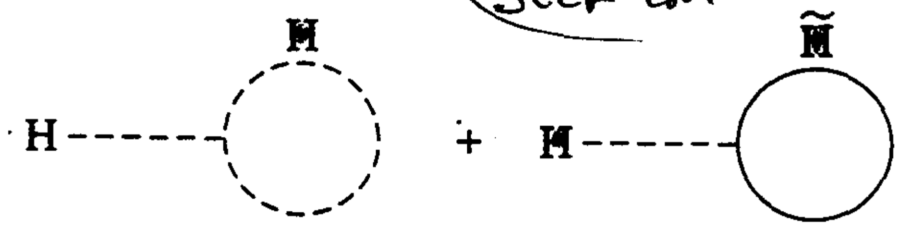
PROBLEM WITH H?

Z° W DISCOVERY!

Z FACTORY CERN

Problem with a Single SM model Higgs

SELF COUPLING



??

Figure 5: (a) Quadratically-divergent one-loop correction to the Higgs vacuum-expectation value from a Higgs loop; (b) the quadratic divergence is cancelled by a Higgsino loop in a supersymmetric theory.

WHAT CUTS OFF THIS DIVERGENCE??

ONE REASON SUSY WAS INVENTED!

Std Model Higgs

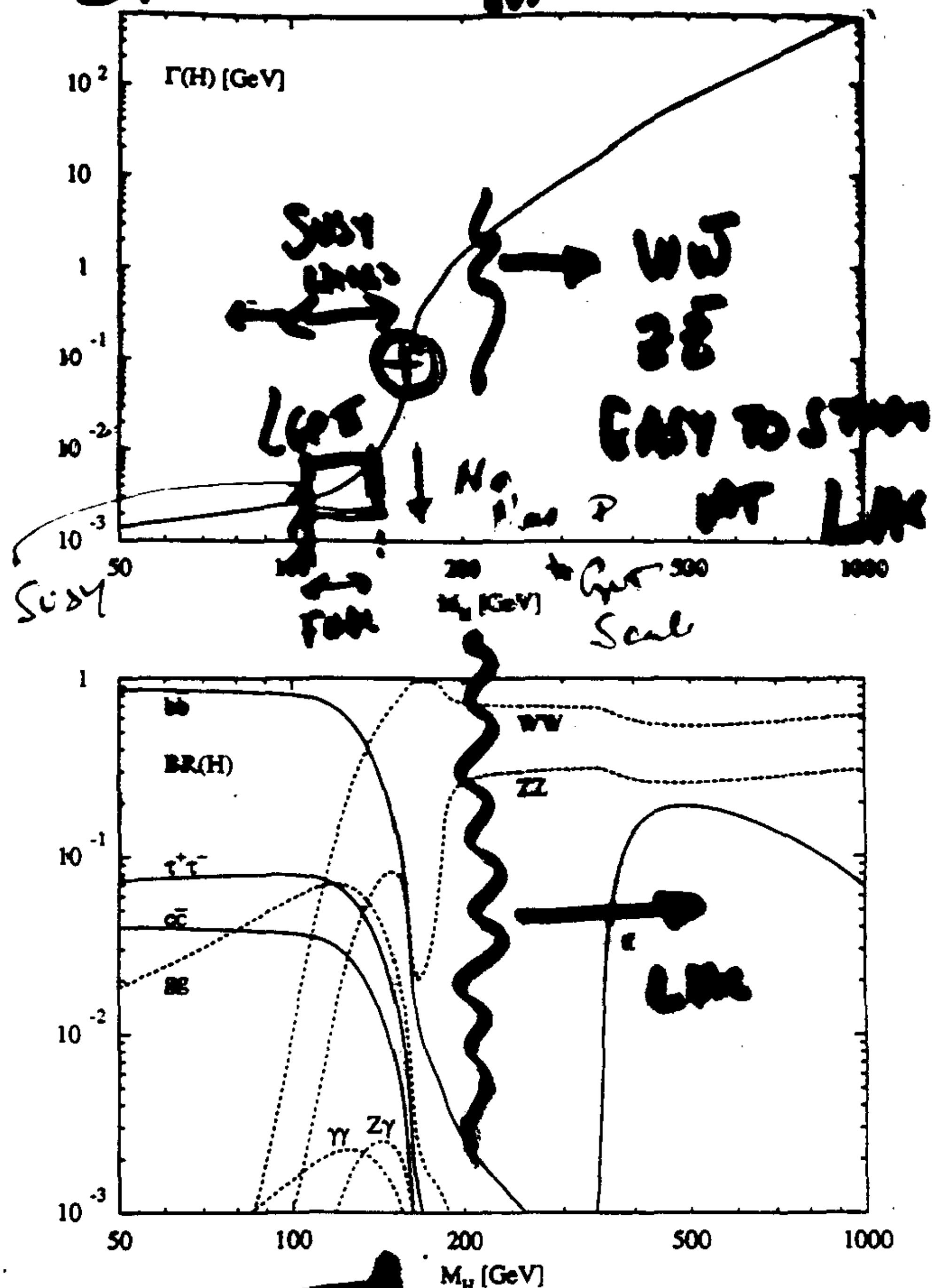


Figure 2: *Total decay width Γ(H) in GeV and the main branching ratios BR(H) of the Standard Model Higgs decay channels, using the inputs of Tab. 2.*

BRANCHING RATIOS VERY DEPENDENT ON MASS

WHY THE STUDY OF H/A. IS HARD

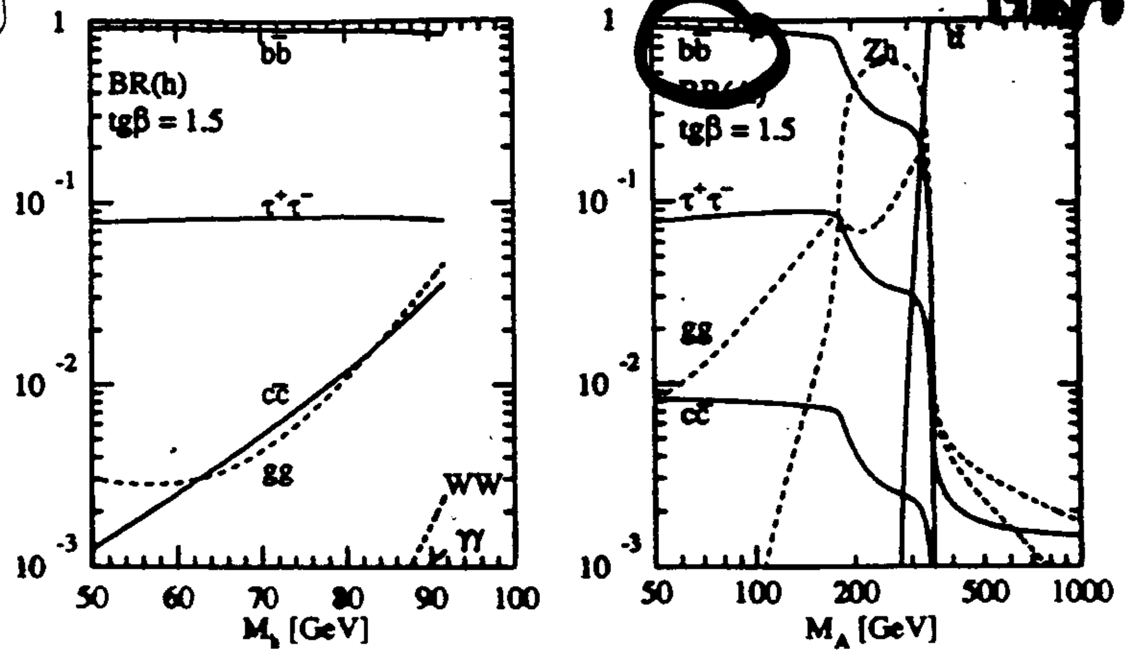
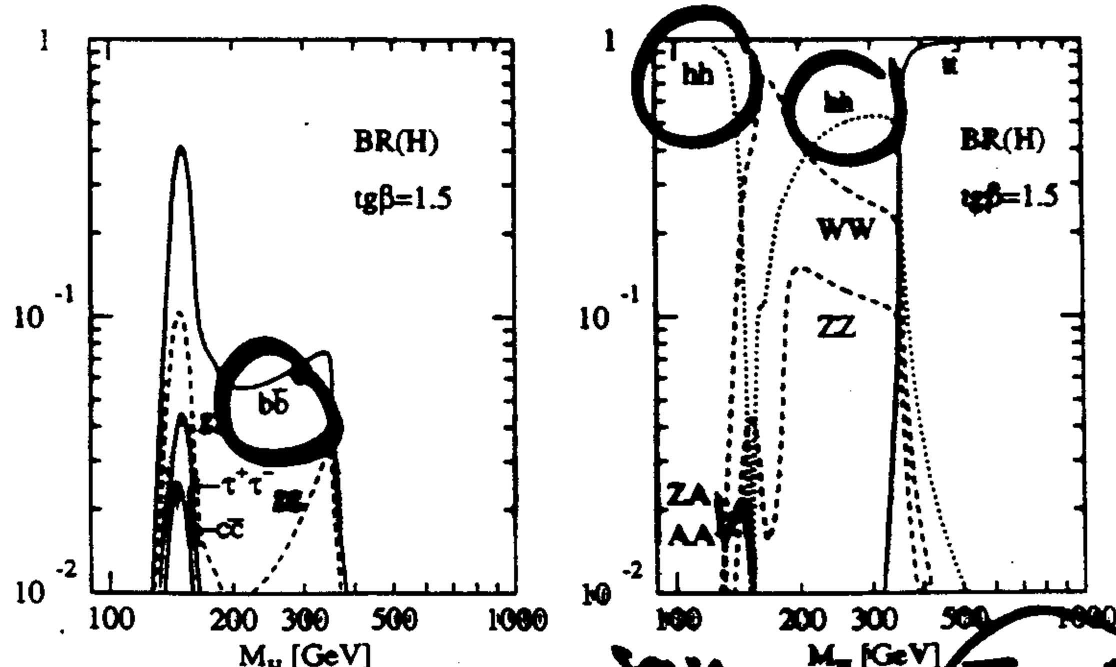


Fig. 3a



Djouadi, Kalinowski, Spira

Fig. 3b

Figure 3: *Branching ratios of the MSSM Higgs bosons h, A(a), H(b), $H^{\pm}$(c) and their total decay widths $\Gamma(\Phi)(c)$, using the inputs of Tab. 2.*

HDECAY – Program with std MSSM Higgs Decays DESY 97-079

WHY IS MASS of h
IMPORTANT FOR HIGGS FACTORY

LOGIC of HIGGS
STUDY IN FUTURE
Why a Higgs Factory

Table 3. Logic of detailed study of the Higgs sector.

If particles in the scalar sector are ever discovered, it will be essential to determine their properties, which will give direct information about the nature of the particle and the underlying theory. Three simple examples can be cited:

1. Suppose a Higgs-like particle is discovered with mass 110 GeV. This could either be the Standard Model (SM) Higgs or an MSSM Higgs. A measurement of the width of the state would presumably tell the difference. However, the SM width is 5 MeV – a formidable measurement!

2. Suppose a Higgs-like particle is discovered with a mass of 150 GeV. This is presumably beyond the MSSM bound, but it could be an NMSSM or an SM Higgs. A measurement of the width could presumably resolve the issue.

3. Suppose a Higgs-like particle of mass 165 GeV is discovered. This is presumably even beyond the NMSSM limits. If this is an SM Higgs, can we learn more by the study of the rare decay modes?

---

1) $M_h > 150$ GeV – SUSY OUT

2) $M_h > 2M_W$ – LHC may do All important physics

[redacted]

→ 1992 NAPA mtg
DBC
Talk at
Snowmass
98
In proceedings

Table I: Arguments for a Higgs-factory $\mu^+\mu^-$ collider.

1. The $m_\mu \backslash m_e$ ratio gives coupling 40,000 times greater to the Higgs particle. In the SUSY model, one Higgs $m_h < 120$ GeV!! Higgs Coupling $\propto m_\ell^2$
2. The low radiation of the beams makes precision energy scans possible.
3. The cost of a "custom" collider ring is a small fraction of the $\mu^\pm$ source.
4. Feasibility report to Snowmass established that $\mathcal{L} \sim 10^{33}$ cm^{-2} s^{-1} is feasible. ? ?

DBC
NIM Paper
94
NAPA
MTG
92

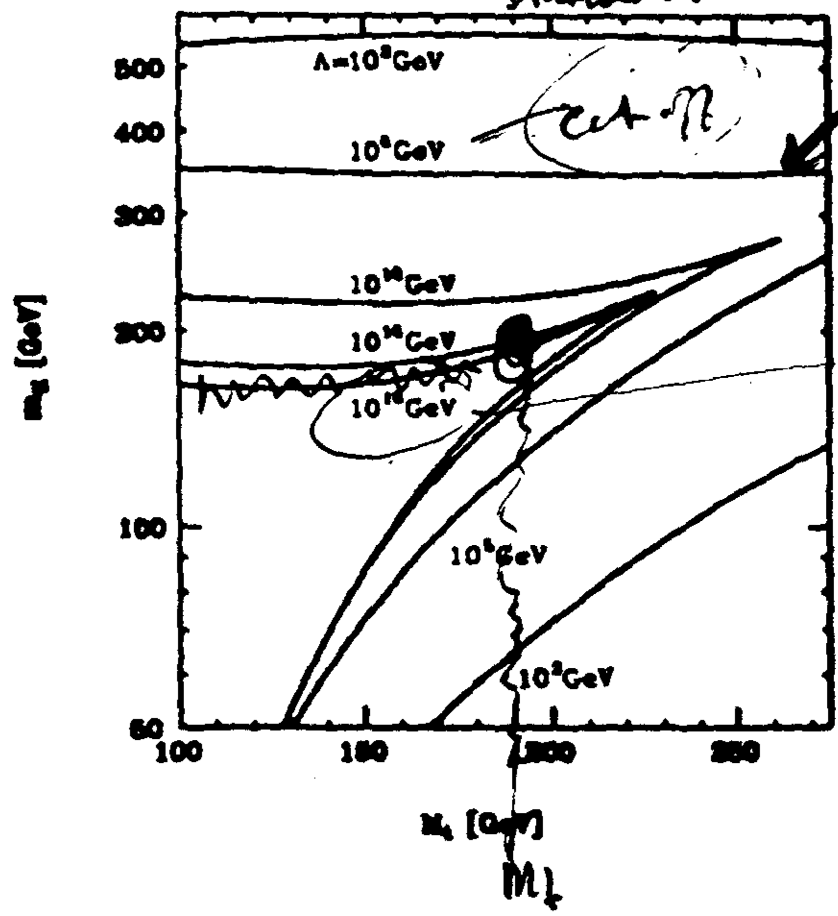
If SUSY is correct the Scalar Sector will be complex – and a $\mu^+\mu^-$ Collider can play a key role to study this sector!

BOUNDS ON HIGGS MASS

THERE ARE BOUNDS OF HIGGS MASS

CABBIBO [illegible]

WHAT CUTS OFF THE DIVERGENCE



For Λ Values

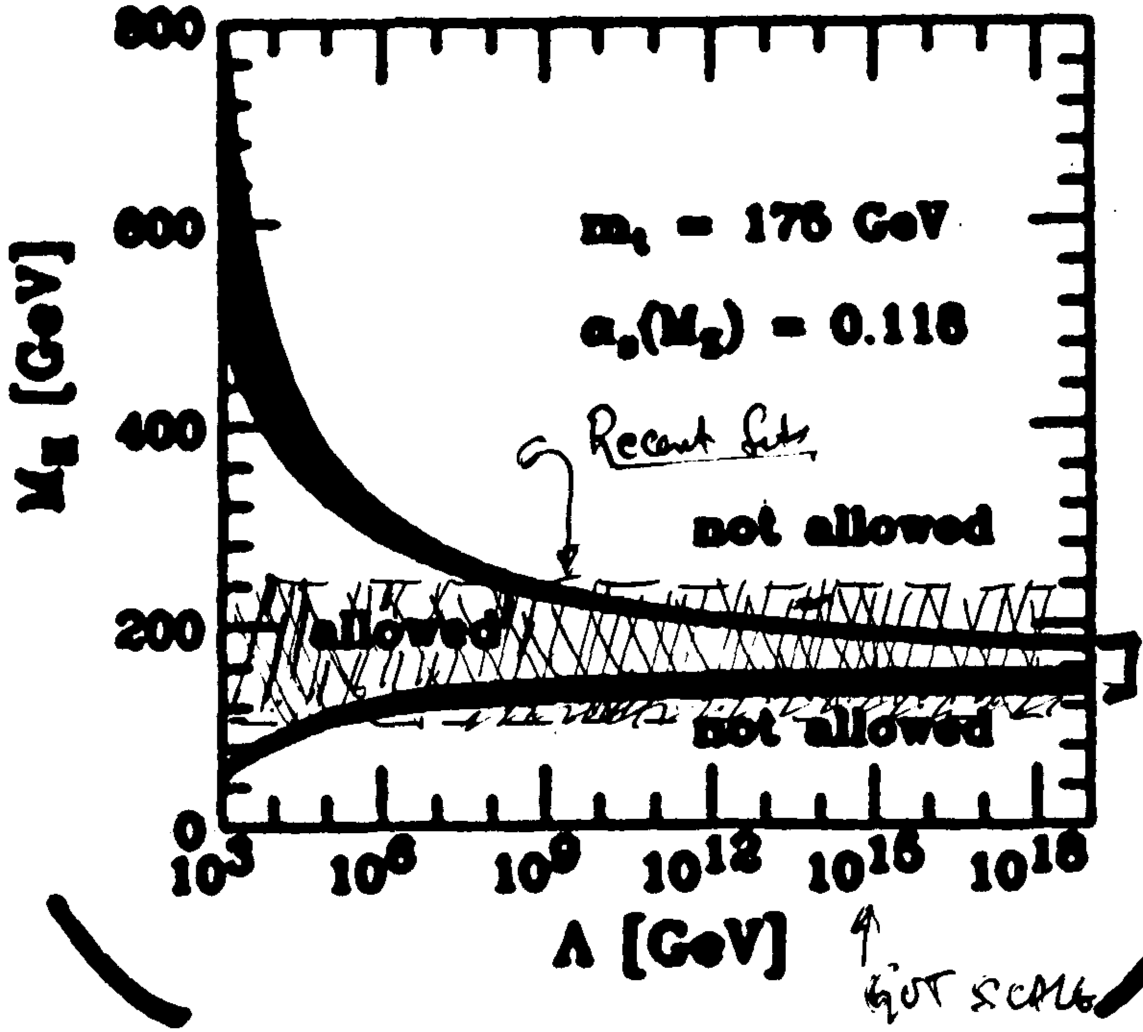
If there is no New Physics up to Planck Scale ⇒ m_H < 190 GeV

Figure 1: *Bounds on the Higgs mass as a function of the top quark mass for different values of the scale* Λ*, at which new physics is expected to appear.*

Fm Kobbe et al

Ellis

etc



Note $M_H \sim$ 175 GeV

No New PHYSICS to GUT scale

Discovery of a Low Mass Higgs DOES not prove SUSY is Correct!!!

OTHER "EVIDENCE" FOR

LOW MASS HIGGS

- USING PRECISION ELECTROWEAK DATA
  (Z^0 parameters, $M_{W^\pm}$, M_t, $\sin^2\theta_W$ etc etc)

Current fits suggest $M_H <$ [illegible] GeV

After LEP 2 provides precision M_W this bound could improve

- By ~ 2000 we may have a limit with an error of ± 10 GeV that is believable (or 50??)

{ All in All it is a good bet that [if the Higgs Exists] AT LEAST ONE WILL BE AT LOW MASS }

4th $\mu^+\mu^-$
Collaboration

San Francisco
Fairmont Hotel
Dec 97

Peter Renton
Oxford

Data from LEP

Renton

- 1989-1995
  LEP I $\Rightarrow \sim 160\ pb^{-1}$ ($\sim 5 \cdot 10^6\ Z^0$ decays) / expt
  Precision scan of the Z peak in 1993, 1995
  $\sim$ [illegible] pb^{-1} of data ± 1.8 GeV off peak.
- November 1995
  LEP 1.5 – 130-136 GeV $\Rightarrow \sim 5\ pb^{-1}$ / experiment
- 1996 LEP2
  161 GeV $\Rightarrow \sim 10\ pb^{-1}$ / experiment
  172 GeV $\Rightarrow \sim 10\ pb^{-1}$ / experiment
- 1997
  183 GeV $\Rightarrow \sim 55\ pb^{-1}$ / experiment
  rerun of 130-136 GeV $\Rightarrow \sim 5\ pb^{-1}$ / experiment

Data from SLC

- e^+e^- on the Z peak
Up to 1996, $\sim 5\ pb^{-1}$, with $\mathcal{P}_e$ up to 80%.

Data from FNAL

- $\bar{p}p$ at 1.8 TeV. Run IA+IB $\sim 110\ pb^{-1}$.

NEW FITS TO ELECTROWEAK PARAMETERS AND HIGGS MASS

Summary of Higgs Talk

More RECENT FITS TO EW PARAMETERS SUCCESS

— LOW MASS HIGGS —

Marciano — statement

Davier & Höcker 97 — $M_h = 129^{+103}_{-92}$ GeV

Erler & Langacker 97 — $M_h = 122^{+137}_{-77}$

EW Fit CERN 97 — $M_h = 115^{+116}_{-66}$ GeV

$M_h < 420$ GeV 95% c.l.

NEW LEP II limit → $M_h > 88$ GeV

WE MAY BE TEMPTED TO ASSUME M_h is Small! ⇒ Higgs Factory!

EUROPEAN ORGANIZATION FOR PARTICLE PHYSICS

IMPRESSIVE WORK

CERN-PPE/97-154
2 December 1997

A Combination of Preliminary Electroweak Measurements and Constraints on the Standard Model

The LEP Collaborations* ALEPH, DELPHI, L3, OPAL,
the LEP Electroweak Working Group†
and the SLD Heavy Flavour Group‡

Prepared from Contributions of the LEP and SLD experiments to the 1997 summer conferences.

Abstract

This note presents a combination of published and preliminary electroweak results from the four LEP collaborations and the SLD collaboration which were prepared for the 1997 summer conferences. Averages are derived for hadronic and leptonic cross-sections, the leptonic forward-backward asymmetries, the τ polarisation asymmetries, the $b\bar{b}$ and $c\bar{c}$ partial widths and forward-backward asymmetries and the $q\bar{q}$ charge asymmetry. The major changes with respect to results presented last year are updated results of A_{LR} from SLD, and the inclusion of the first direct measurements of the W mass and triple-gauge-boson couplings performed at LEP. The results are compared with precise electroweak measurements from other experiments. The parameters of the Standard Model are evaluated, first using the combined LEP electroweak measurements, and then using the full set of electroweak results.

*The LEP Collaborations each take responsibility for the preliminary data of their own experiment.

†D. Abbaneo, J. Alcaraz, P. Antilogus, T. Behnke, B. Bertucci, A. Blondel, C. Burgard, R. Clare, P.E.L. Clarke, S. Dutta, M. Elsing, R. Faccini, D. Fassouliotis, M.W. Grünewald, A. Gurtu, K. Hamacher, J.B. Hansen, R.W.L. Jones, P. de Jong, T. Kawamoto, M. Kobel, E. Lançon, W. Lohmann, C. Mariotti, M. Martinez, C. Matteuzzi, M.N. Minard, K. Mönig, P. Molnar, A. Nippe, S. Olshevski, Ch. Paus, M. Pepe-Altarelli, S. Petzold, B. Pietrzyk, G. Quast, D. Reid, P. Renton, J.M. Roney, R. Sekulin, R. Tenchini, F. Teubert, M.A. Thomson, J. Timmermans, M.F. Turner-Watson, H. Wahlen, C.P. Ward, D.R. Ward, N.K. Watson, A. Weber.

‡N. de Groot, E. Etzion, B. Schumm, D. Su.

BEAUTIFUL CONFIRMATION OF STD MODEL

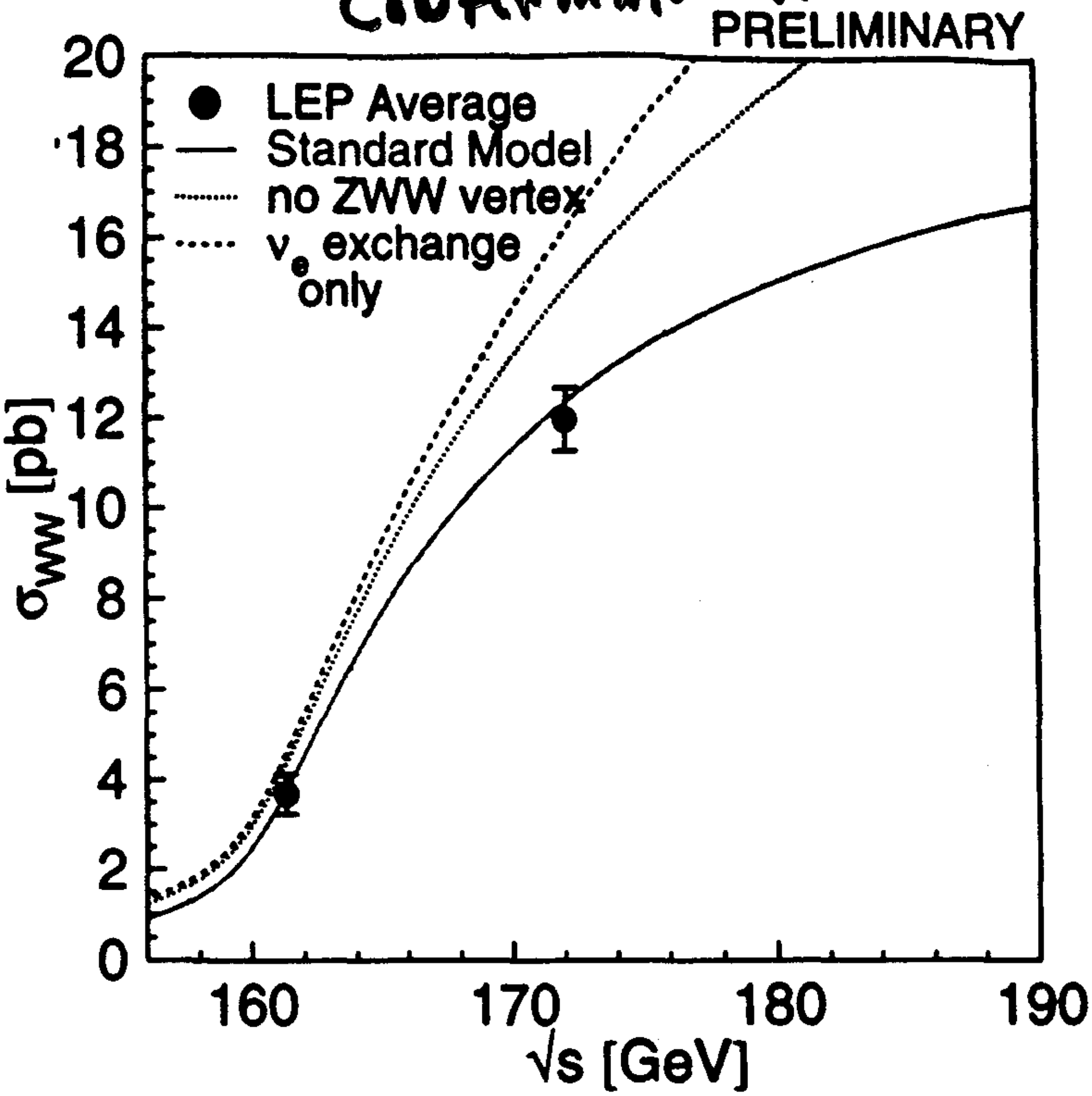


Figure 5: The W-pair cross-section as a function of the centre of mass energy. The data points are the LEP averages. Also shown is the Standard Model prediction (solid line), and for comparison the cross-section if the ZWW coupling did not exist (dotted line), or if only the t-channel ν_e exchange diagram existed (dashed line).

	Measurement with Total Error	Systematic Error	Standard Model	Pull
$\alpha(m_Z^2)^{-1}$ [102]	128.896 ± 0.090	0.083	128.898	0.0
a) <u>LEP</u>				
line-shape and				
lepton asymmetries:				
m_Z [GeV]	91.1867 ± 0.0020	$^{(a)}0.0015$	91.1866	0.0
Γ_Z [GeV]	2.4948 ± 0.0025	$^{(a)}0.0015$	2.4966	−0.7
σ_h^0 [nb]	41.486 ± 0.053	0.052	41.467	0.4
R_ℓ	20.775 ± 0.027	0.024	20.756	0.7
$A_{FB}^{0,\ell}$	0.0171 ± 0.0010	0.0007	0.0162	0.9
+ correlation matrix Table 8				
τ polarisation:				
$\mathcal{A}_\tau$	0.1411 ± 0.0064	0.0040	0.1470	−0.9
$\mathcal{A}_e$	0.1399 ± 0.0073	0.0020	0.1470	−1.0
$q\bar{q}$ charge asymmetry:				
$\sin^2\theta_{\rm eff}^{\rm lept}$ ($\langle Q_{FB}\rangle$)	0.2322 ± 0.0010	0.0008	0.23152	0.7
m_W [GeV]	80.48 ± 0.14	0.05	80.375	0.8
b) <u>SLD</u> [88]				
$\sin^2\theta_{\rm eff}^{\rm lept}$ ($\mathcal{A}_{LR}$)	0.23055 ± 0.00041	0.00014	0.23152	−2.4 ←
c) <u>LEP and SLD Heavy Flavour</u>				
R_b^0	0.2170 ± 0.0009	0.0007	0.2158	1.3
R_c^0	0.1734 ± 0.0048	0.0038	0.1723	0.2
$A_{FB}^{0,b}$	0.0984 ± 0.0024	0.0010	0.1031	−2.0
$A_{FB}^{0,c}$	0.0741 ± 0.0048	0.0025	0.0736	0.1
$\mathcal{A}_b$	0.900 ± 0.050	0.031	0.935	−0.7
$\mathcal{A}_c$	0.650 ± 0.058	0.029	0.668	−0.3
+ correlation matrix Table 18				
d) <u>$p\bar{p}$ and νN</u>				
m_W [GeV] ($p\bar{p}$ [94])	80.41 ± 0.09	0.07	80.375	0.4
$1 - m_W^2/m_Z^2$ (νN [95–97])	0.2254 ± 0.0037	0.0023	0.2231	0.6
m_t [GeV] ($p\bar{p}$ [98–100])	175.6 ± 5.5	4.2	173.1	0.4

Table 29: Summary of measurements included in the combined analysis of Standard Model parameters. Section a) summarises LEP averages, Section b) SLD results ($\sin^2\theta_{\rm eff}^{\rm lept}$ includes $\mathcal{A}_{LR}$ and the polarised lepton asymmetries), Section c) the LEP and SLD heavy flavour results and Section d) electroweak measurements from $p\bar{p}$ colliders and νN scattering. The total errors in column 2 include the systematic errors listed in column 3. The determination of the systematic part of each error is approximate. The Standard Model results in column 4 and the pulls (difference between measurement and fit in units of the total measurement error) in column 5 are derived from the Standard Model fit including all data (Table 30, column 4) with the Higgs mass treated as a free parameter.

$^{(a)}$The systematic errors on m_Z and Γ_Z contain the errors arising from the uncertainties in the LEP energy only.

— ONLY PROBLEM NOW SLD DATA —

	LEP including LEP-II m_W	all data except m_t and m_W	all data
m_t [GeV]	158^{+14}_{-11}	157^{+10}_{-9}	173.1 ± 5.4
m_H [GeV]	83^{+168}_{-49}	41^{+64}_{-21}	115^{+116}_{-66}
$\log(m_H/\mathrm{GeV})$	$1.92^{+0.48}_{-0.39}$	$1.62^{+0.41}_{-0.31}$	$2.06^{+0.30}_{-0.37}$
$\alpha_s(m_Z^2)$	0.121 ± 0.003	0.120 ± 0.003	0.120 ± 0.003
χ^2/d.o.f.	8/9	14/12	17/15
$\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$	0.23188 ± 0.00026	0.23153 ± 0.00023	0.23152 ± 0.00022
$1 - m_W^2/m_Z^2$	0.2246 ± 0.0008	0.2240 ± 0.0008	0.2231 ± 0.0006
m_W [GeV]	80.298 ± 0.043	80.329 ± 0.041	80.375 ± 0.030

Table 30: Results of the fits to LEP data alone, to all data except the direct determinations of m_t and m_W (Tevatron and LEP-II) and to all data including the top quark mass determination. As the sensitivity to m_H is logarithmic, both m_H as well as $\log(m_H/\mathrm{GeV})$ are quoted. The bottom part of the table lists derived results for $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$, $1 - m_W^2/m_Z^2$ and m_W. See text for a discussion of theoretical errors not included in the errors above.

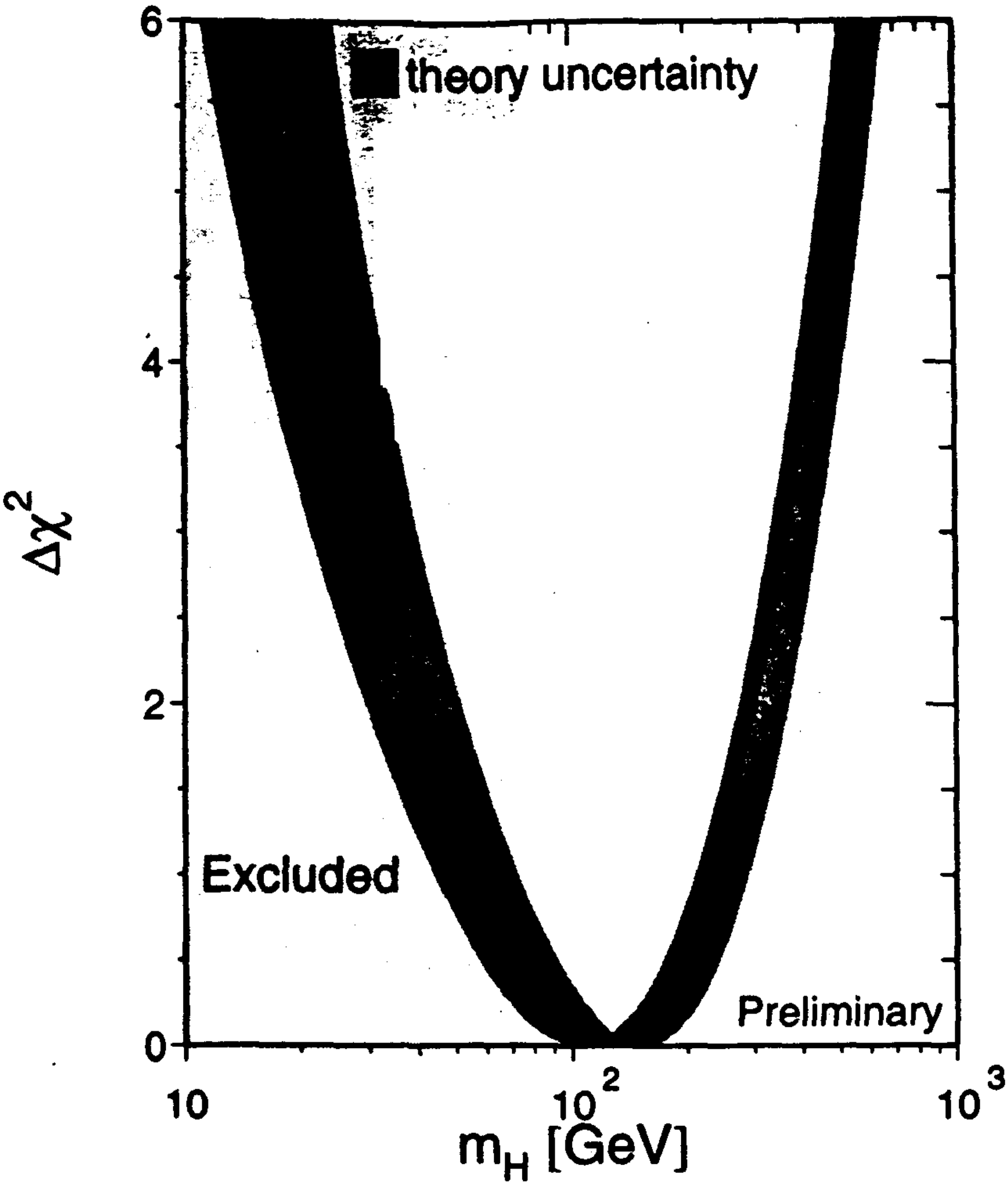


Figure 13: $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ *vs.* m_H curve. The line is the result of the fit using all data (last column of Table 30); the band represents an estimate of the theoretical error due to missing higher order corrections. The vertical band shows the 95% CL exclusion limit on m_H from the direct search.

FMC Higgs Physics

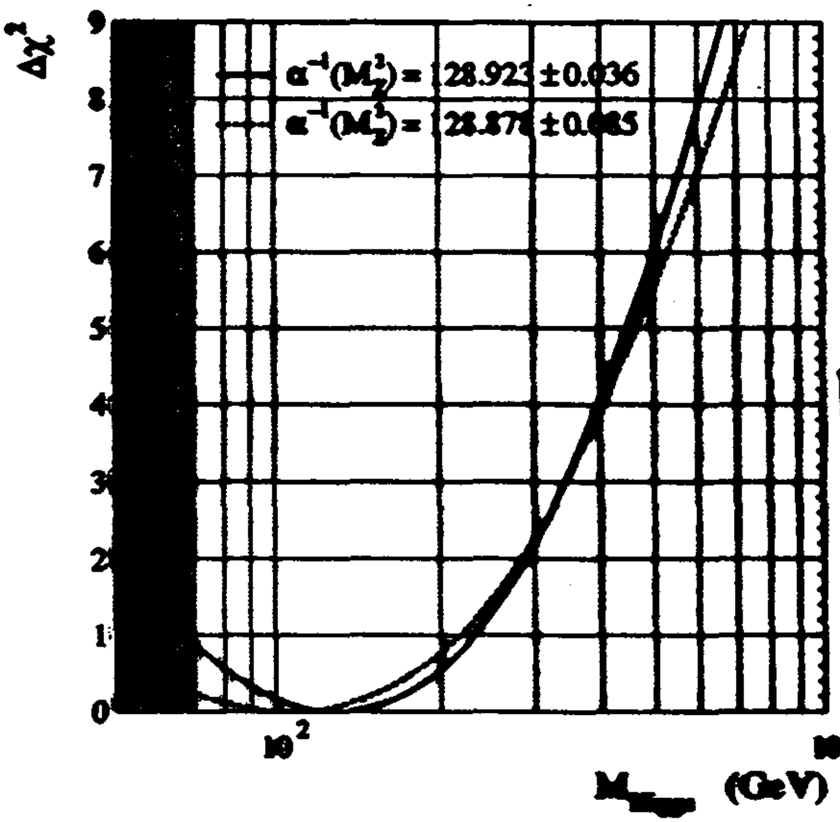
MSSM: 5 Higgs bosons $h^0, H^0, A^0, H^{\pm}$

lightest MSSM Higgs boson

$m_h \leq 125$ GeV

"The jewel in the SUSY crown"

Global EW analyses



Davier & Höcker (1997)

$m_h = 129^{+103}_{-92}$ GeV

Erler & Langacker (1997)

$m_h = 122^{+134}_{-77}$ GeV

Smoking gun for SUSY Higgs

Goals:

- precisely determine Higgs mass, width, and BFs
- differentiate h_{MSSM} from h_{SM}
- find and study H^0, A^0

Are we sure the Higgs is 'light'

fit to all electroweak data

- standard fit

  $M_H = 115^{+116}_{-66}$ GeV $M_H \lesssim 420$ GeV 95% cl

- if exclude SLAC A_{LR} measurement

  $M_H = 220^{+185}_{-109}$ GeV $M_H \lesssim 715$ GeV 95% cl

  See Data [illegible]

- scale errors on Higgs sensitive quantities by 1.5

  $M_H = 188^{+152}_{-91}$ GeV $M_H \lesssim 590$ GeV 95% cl

- CONCLUSIONS:

  best estimate for M_H is relatively light

  but data not fully compatible, so some caution !

Pete Renton $\mu\mu$97 Dec. 1997

B.II Muon

(D. Cline)

B.I.2 i) Higgs Resonance (+ Z Factory) - First Muon Collider

LEP → $m_H \gtrsim 78\ (88)$ GeV! { P. Bambade, Y. Pan

(tan β being tested)

Precision EW $\sin^2\theta_W + m_W$ → Light Higgs (G. Kane) P. Renton

(see table) $m_H \lesssim 160$ GeV! (Narrow)

LEP II → 100 GeV

FNAL → 120 GeV (C. Quigg)

SUSY → $m_H \lesssim 130\ (160)$ GeV

Looks Good For Higgs Resonance Studies

Perhaps $h, H, A, H^{-}, \tilde{\nu}$ — J. Gunion, S. Rajpoot, C. Heusch, J. Feng

Standard Model Higgs. Example $m_H = 110$ GeV

$\Gamma_H \simeq 3$ MeV, $\Delta E/E = 3\times10^{-5}$, $L = 0.05\ fb^{-1}$ (?)

$N_H \simeq 3000$

H →	$b\bar{b}$	$c\bar{c}$	$\tau\bar{\tau}$
N_S (events)	2400	210	270
N_B (events)	2520	2416	945
$\pm \frac{\sqrt{N_S+N_B}}{N_S}$	±0.03	±0.24	±0.13

} B. Kamal, Z. Parsa, W.M.

Scan time ~ 3 yrs! to find (J. Gunion)

WHEN MAY WE KNOW THAT A HIGGS FACTORY IS ESSENTIAL AND START CONSTRUCTION OF HIGGS FACTORY

(1) EW Measurement ~ [illegible]
— SLC ~ [illegible]
~ 2002 — LEP II
— TEV 2 + Mani Injector
or 2001?

may "prove" $m_h < 180$ GeV

OR LEP II → $m_h \gtrsim 105$ GeV

2) FNAL MAY DISCOVER $m_h < 180$ GeV

~ 2003/6P.

3) LHC Discover Higgs but not total SUSY

~ 2007 ?

2001 – earliest
2013 – reasonable
2007 – latest

Note: SLC / SLD HAS PRODUCED A LARGE # OF Z's NOW (~ 200/hr)

this will be very important at the 5th μμ Coll. mtg SF 99

Future expectations

- estimate final errors from LEP 1

    Z lineshape results ~ final

    some improvements expected in τ polarisation

    and heavy flavour results

- for SLD assume $\delta \sin^2\theta^{\rm lept}_{\rm eff} \rightarrow .00025$ (from .00041)
- assume $\delta M_{\rm W} \rightarrow 30$ MeV (LEP2 + Tevatron)

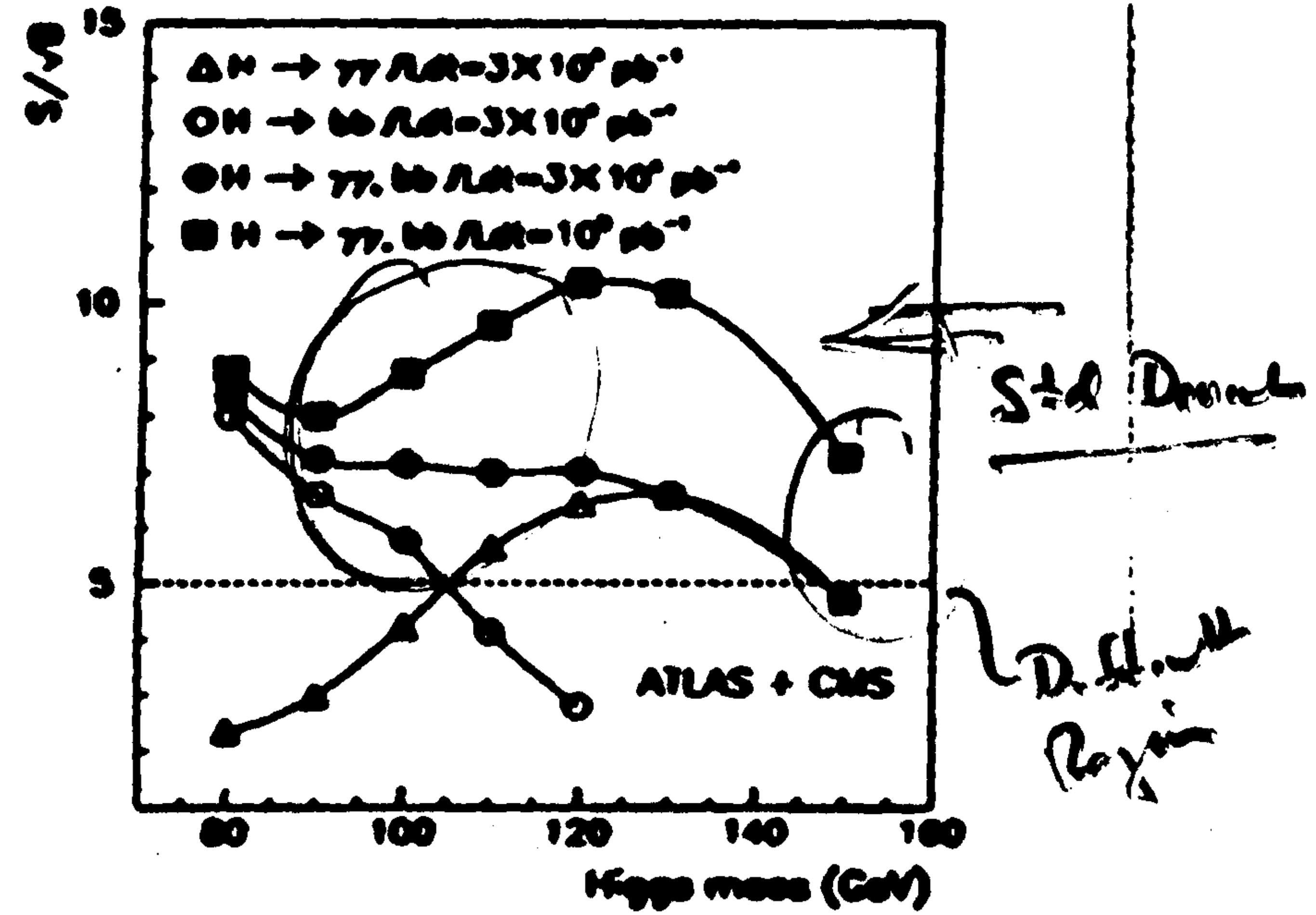
    (present error 76 MeV)

- assume $\delta M_{\rm t} \rightarrow 3$ GeV (from 5.5 GeV) • $\delta\alpha^{-1} \rightarrow 0.05$
- all quantities at SM values for $M_{\rm t}$ = 175 GeV, α_s = 0.120

	$M_{\rm H}$ = 100 GeV	= 300 GeV	= 500 GeV
Stand. assump.	100^{+49}_{-35}	300^{+122}_{-89}	500^{+199}_{-143}
$\delta M_{\rm W}$ = 20 MeV	100^{+46}_{-34}	300^{+108}_{-83}	500^{+175}_{-131}
$\delta \sin^2\theta^{\rm lept}_{\rm eff}$ (A_{LR}) = 0.00015	100^{+45}_{-33}	300^{+111}_{-83}	500^{+182}_{-134}
$\delta M_{\rm t}$ = 0.5 GeV	100^{+39}_{-30}	300^{+90}_{-71}	500^{+146}_{-114}
$\delta\alpha^{-1}$ = 0.09	100^{+62}_{-42}	300^{+141}_{-101}	500^{+229}_{-159}

IF M_H is low in Near Future will be able to Prove it!

WILL LHC – CMS / ATLAS DISCOVER THE LIGHT HIGGS



The crystal calorimeter was assumed to have an energy resolution given by $\Delta E/E = 2\%/\sqrt{E} \oplus 0.5\% \oplus 0.200/E$ in the barrel and $\Delta E/E = 5\%/\sqrt{E} \oplus 0.5\% \oplus 0.200/E$ in the endcap, where there is a preshower detector. At high luminosity, a barrel pre-shower detector covers $|\eta| < 1.1$, resulting in a resolution of $\Delta E/E = 5\%/\sqrt{E} \oplus 0.5\% \oplus 0.200/E$ and an ability to measure the photon direction with resolution $\Delta\alpha = 40$ mrad$/\sqrt{E}$ in this region. For more details concerning both the ECAL configurations and the breakdown of the mass resolution, see Sect. 4.1.

CMS

The background to the $H \rightarrow \gamma\gamma$ signal may be divided into three categories:

- prompt diphoton production from quark annihilation and gluon fusion diagrams, which gives an irreducible background,
- prompt diphoton production from significant higher-order diagrams – primarily bremsstrahlung from the outgoing quark line in the QCD Compton diagram,
- background from jets, where an electromagnetic energy deposit originates from the decay of neutral hadrons in a jet or from 1 jet + 1 prompt photon.

The prompt diphoton background was generated using CTEQ2L structure functions in PYTHIA. For the bremsstrahlung background, a previous PYTHIA calculation for $\sqrt{s} = 16$ TeV, $m_{top} = 150$ GeV, and HMRSB structure functions, was rescaled to take account of the new parameters. The resulting cross-sections are given in Table 12.1. It is assumed that the jet background is reduced to an insignificant level (< 10%) by the combination of isolation and π^0 rejection cuts.

Figure 12.3 shows a background-subtracted two-photon effective mass plot for a simulated single experiment, for an integrated luminosity of 10^5 pb^{-1} (taken at high luminosity) with signals at $m_H = 90, 110, 130$ and 150 GeV. Figure 12.4 shows a similar plot, for an integrated luminosity of 3×10^4 pb^{-1} taken at low luminosity.

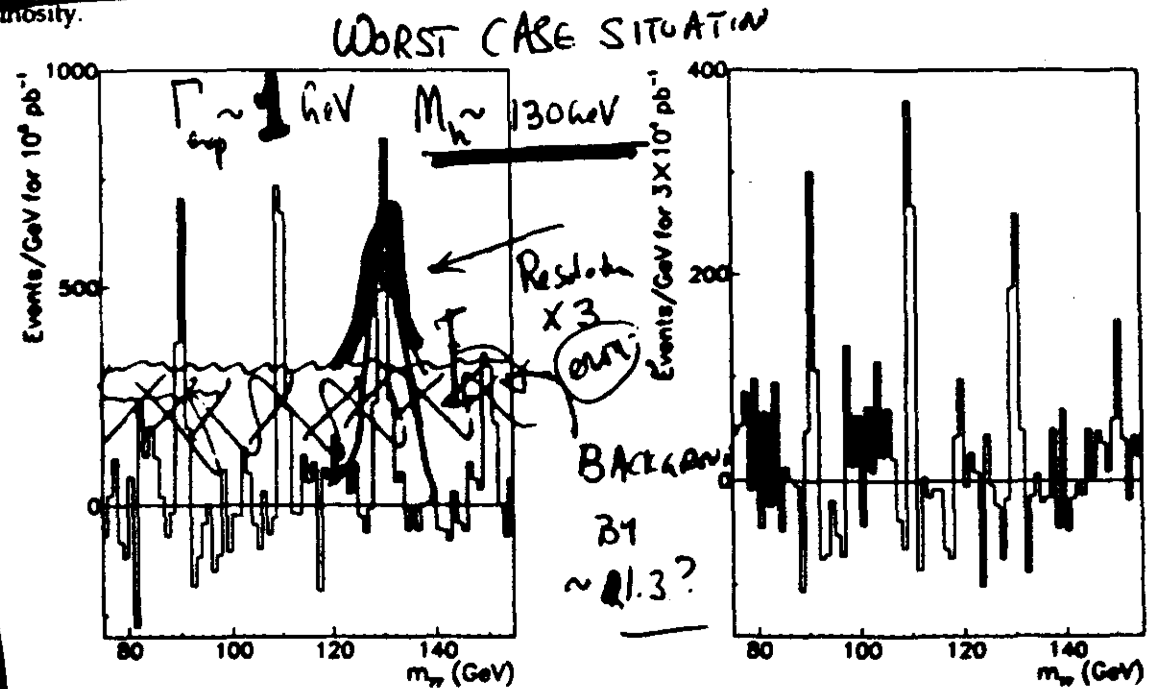


Fig. 12.3: Background-subtracted 2γ mass plot for 10^5 pb^{-1} with signals at $m_H = 90, 110, 130$ and 150 GeV, in the $PbWO_4$ calorimeter.

Fig. 12.4: Background-subtracted 2γ mass plot for 3×10^4 pb^{-1} with signals at $m_H = 90, 110, 130$ and 150 GeV, in the $PbWO_4$ calorimeter.

Figures 12.5 and 12.6 show contours giving the cross-section times branching ratio required to give specified signal significances $(N_S/\sqrt{N_B})$, as a function of mass. The significances were calculated by counting events within a mass window of optimum width, corresponding to the width containing about 75% of the signal. After a single year of running at 10^{34} cm^{-2}s^{-1} (10^5 pb^{-1}, Fig. 12.5), an SM Higgs could be discovered across the full range 85 to 150 GeV. After only 3×10^4 pb^{-1} (Fig. 12.6), taken at low luminosity, an SM Higgs could be discovered between 95 and 150 GeV.

LHC OBSERVES BUT CAN'T REALLY STUDY LIGHT HIGGS

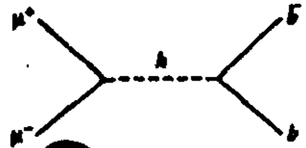
HIGGS FACTORY EFFORT

BARGER et al 95 +

Higgs width measurement

D. Cline
U.C.L.A.

s-channel process $\mu^+\mu^- \to h \to b\bar{b}$ uniquely suited to this task



(2)

Reject light quark background by b-tagging.

Assume b-tagging with 50% efficiency (ϵ)

s-channel resonance cross section

$$\sigma_h = \frac{4\pi\Gamma(h\to\mu\bar{\mu})\Gamma(h\to b\bar{b})}{(s-m_h^2)^2+m_h^2\Gamma_h^2}$$

$$\Gamma(h\to\mu\bar{\mu}) \propto m_\mu^2$$

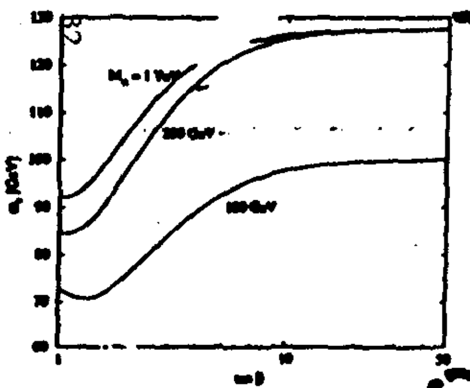
Higgs physics

In minimal supersymmetry (MSSM) there are 5 physical Higgs bosons

$h,\ H^0,\ A^0,\ H^+,\ H^-$

Radiative correction to the mass of the lightest Higgs state is

$$\delta m_h^2 \simeq \frac{3g^2}{8\pi^2 M_W^2} m_t^4 \ln\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right)$$



→ 130 GeV

(1)

...cial upper bound

$m_h \leq 130$ GeV	minimal SUSY SM
≤ 150 GeV	any SUSY GUT
≤ 200 GeV	any model with GUT and ...

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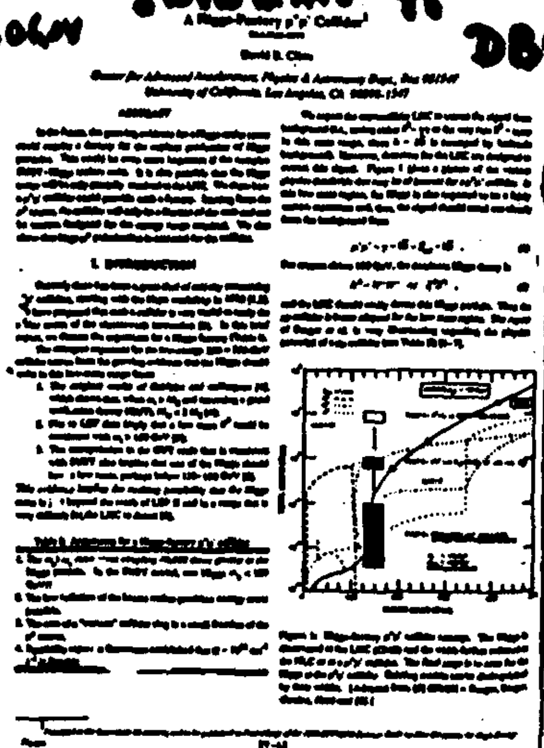
DBC



(3)

Measuring Higgs boson width

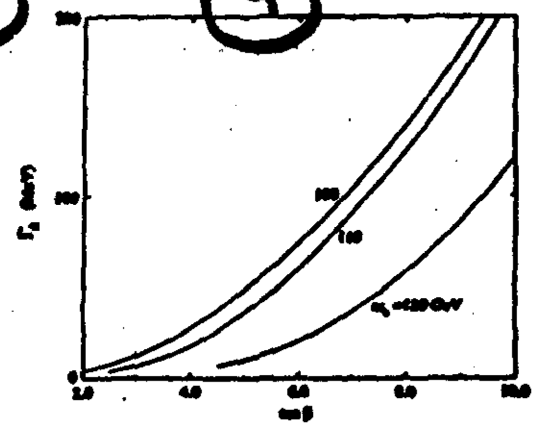
Predictions

SM: $\Gamma_h \sim 2$ MeV $m_h = 80$ GeV
~ 5 MeV $m_h = 100$ GeV

SUSY: Γ_h larger than in SM
$\Gamma_h \sim 50$ MeV ($m_h = 100$ GeV, $\tan\beta = 5$)
grows as $(\tan\beta)^2$

$\tan\beta = v_2/v_1$

(4)



Berger
Barger
Gunion
Han
papers!

Proceedings of Snowmass 96

Higgs-Factory Scan ~130 GeV

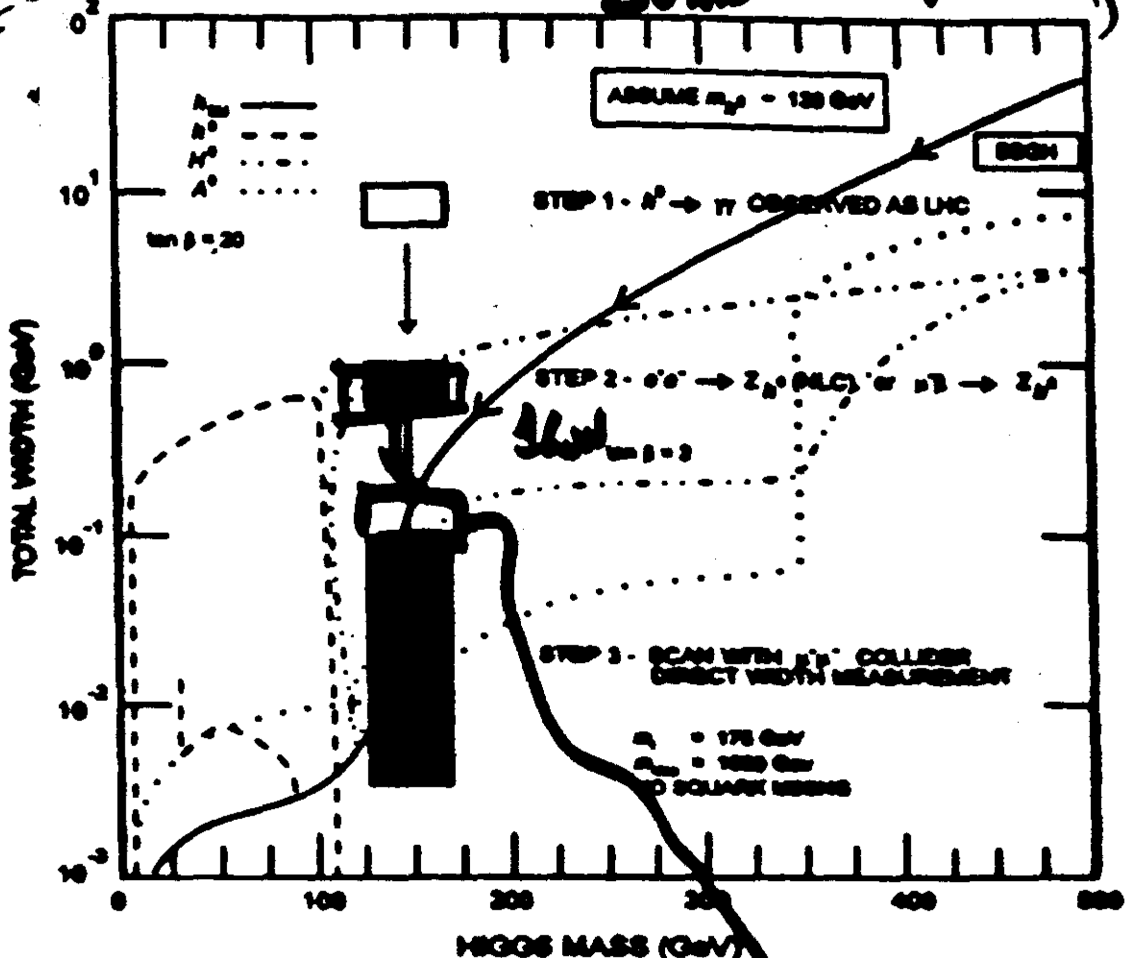


Fig. 2. Higgs-factory $\mu^+\mu^-$ collider concept. The Higgs is discovered at the LHC (CMS) and the width further reduced at the NLC or at a $\mu^+\mu^-$ collider. The final stage is to scan for the Higgs at the $\mu^+\mu^-$ collider. Existing models can be distinguished by their widths. (Adapted from Ref. 12 (BBGH = Barger, Berger, Gunion, Han) and Ref. 14.)

PHYSICAL REVIEW D VOLUME 15, NUMBER 7 1 APRIL 1977

NC 1973
↓
W/Z 1983

Natural conservation laws for neutral currents* ⇒ NFC

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(Received 20 August 1976)

We explore the consequences of the assumption that the direct and induced weak neutral currents in an $SU(2) \otimes U(1)$ gauge theory conserve all quark flavors *naturally*, i.e., for all values of the parameters of the theory. This requires that all quarks of a given charge and helicity must have the same values of weak T_3 and $\vec{T}^2$. If all quarks have charge $+2/3$ or $-1/3$ the only acceptable theories are the "standard" and "pure vector" models, or their generalizations to six or more quarks. In addition, there are severe constraints on the couplings of Higgs bosons, which apparently cannot be satisfied in pure vector models. We also consider the possibility that neutral currents conserve strangeness but not charm. A natural seven-quark model of this sort is described. The experimental consequences of charm nonconservation in direct or induced neutral currents are found to be quite dramatic.

NO FCNC SO FAR

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Natural Flavor Conservation **NFC**

1) 1 Higgs Boson

2) All quarks ⇒ $\begin{pmatrix} +2/3 \\ -1/3 \end{pmatrix} = \begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$

Has Never really been tested directly —

IS KEY COMPONENT of STANDARD MODEL!

OTHER PHYSICS AT HIGGS FACTORY

TESTING NFC at a $\mu^+\mu^-$ Higgs Factory

(If $M_H > 150$ GeV)

Fi[redacted]can.[15]

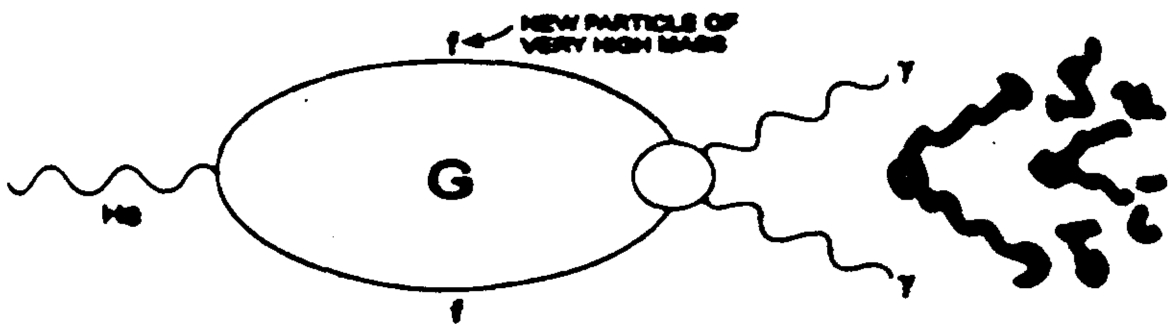

Fig. 6. Possible probe of new physics in a rare Higgs decay mode.

8

This same new Physics may cut off the divergence in the Higgs Sector

WHEN A HIGGS FACTORY IS NEEDED AND WHY

M_{Higgs}^{0}	Standard Model or SUSY	μμ Collider HF Needed	Comments
~88 → 150 GeV ↑ LEP II Limit ↑ Nason Limit?	SUSY Higgs mass Range — Higgs Γ very small	yes(?) (Need to Study)	However if M_{SUSY} is Low LHC may be flooded with $h \to b\bar{b}$ (CMS Study) — BUT problem may still
~150 ~ 200 GeV	Outside of SUSY Higgs — but Self Coupling Stability should be explored	yes!!	In difficult mass range needed to study at LHC
200 — 300 GeV	Outside SUSY Range — but can be observed at LHC with	No? for h^0	{ If low mass SUSY observed and seen if LHC flooded with h^0 H, A difficult to study at LHC }
> 300 GeV	For Std Model Higgs	→ No for h^0	
	For A, H .. SUSY Higgs	→ yes to A, H	

Higgs Factory "Crown Jewel" of μμ Collider

BUT MUST BE JUSTIFIED!

→ However By 2002 we may know if H^0 "Exists" ⇒ HF planning

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Summary

1) All of our current successes in Weak Interaction Physics have come from AVOIDING DIVERGENCES → (Fermi Theory 1950) (WSG 68) → W, Z } 1983 CERN p̄p

2) The Higgs sector has a serious "sickness" GR
   - self coupling ...

   a) SUSY cures → $M_h < 150$ GeV divergences → HA ....
   b) Some unknown physics cures divergences (Study NF ... at HF)

3) A Higgs Factory is to study the Higgs Sector BUT
   - If $M_h > 2M_W$ the LHC (CMS/Atlas) will do a very good job! ~~HF~~
   - $150 \text{ GeV} < M_h < 2M_W$ — SUSY Higgs not HF
   - $M_h < 150$ GeV — Higgs Factory Essential HF

4) If the LHC crosses a threshold so that SUSY is dominant — Higgs study is likely done by SUSY → decays — HF Not Necessary

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Earliest Possible Date for Higgs Factory

→ (μ± Cooling Demonstration) (~2000??)

Table III. Possible scheme for a Higgs-factory $\mu^+\mu^-$ collider.

~ 2003:	Start construction of $\mu^\pm$ source.] US LHC Funding going away
~ 2006:	First observation of h^0 in CMS (ATLAS).
~ 2007:	Design final collider; start construction.
~ 2009:	Higgs factory operates; scan for h^0.
~ 2010:	$\sim 10^5\ h^0$ in direct channel. Higgs Factory ?!

Note LEP Started Before UA1 Observed W/Z 83

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DETECTOR: By 2010+ there are likely to be 7 used large solenoid magnet detectors (4 LEP / 2 FNAL / 1 SLD) – can any be recycled?

Luminosity Requirement for Higgs Resonance studies At The First Muon Collider*

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For the "2nd Mini - Workshop on Higgs Factory"
UCLA Faculty Center, Los Angelas, California
Februatry 12-13, 1997

Abstract. The results of our Higgs resonance studies at the first Muon collider for the on-resonance goal of $\mathcal{L}_{\rm ave} \simeq 5 \times 10^{30}{\rm cm}^{-2}$ and $\mathcal{L}_{\rm ave} \simeq 5 \times 10^{31}{\rm cm}^{-2}$ is given. Our analysis indicates that $\mathcal{L}_{\rm ave} \simeq 5 \times 10^{30}{\rm cm}^{-2}$ is too low and at least an additional order of magnitude increase in luminosity is needed. We investigated [4,7] the effect of beam polarization on Higgs resonance signals and backgrounds ($b\bar{b}$, $\tau\bar{\tau}$, $c\bar{c}$), angular distributions (forward-backward charge asymmetries) and the resulting effective enhancement of the Higgs signal relative to the background, as well as the reduction in scan time required for Higgs "discovery".

- If the Higgs boson has a mass $\lesssim 160$ GeV (i.e. below the W^+W^- decay threshold), it will have a very narrow width and can be resonantly studied in the s-channel via $\mu^-\mu^+ \to H$ production at the First Muon Collider (FMC) [1,2]. A strategy for "light" Higgs physics studies would be to first find the Higgs particle at LEPII, the Tevatron, or the LHC and then thoroughly scrutinize

*) Supported by U.S. Department of Energy contract number DE-AC02-76CH00016.

its properties on resonance at the FMC. There, one would hope to precisely determine the Higgs mass, width, and primary decay rates [3].

- The FMC Higgs resonance program would entail two stages: 1) "Discovery" via an energy scan which pinpoints the precise resonance position and (perhaps) determines its width. Since pre-FMC efforts may only determine the Higgs mass to $\sim \pm 0.2$–1 GeV and its width is expected to be narrow $\mathcal{O}(1\sim 30$ MeV) for $m_H \lesssim 160$ GeV, the resonance scan may be very time consuming [3]. 2) Precision measurements of the primary Higgs decay modes. Deviations from standard model expectations could point to additional Higgs structure or elucidate the framework of supersymmetry [3].

- The Higgs resonance "discovery" capability and scan time will depend on $N_S/\sqrt{N_B}$ (the scan time is proportional to N_B/N_S^2), where N_S is the Higgs signal and N_B is the expected background. The precision measurement sensitivity will be determined by $N_S/\sqrt{N_B + N_S}$. For both, it will be extremely important to enhance the signal and suppress backgrounds as much as possible. To that end, one should employ highly resolved $\mu^+\mu^-$ beams with a very small energy spread. The proposed $\Delta E/E \simeq 3 \times 10^{-5}$ is well matched to the narrow Higgs width. It allows $N_S/N_B \sim \mathcal{O}(1)$ for the primary $H \to b\bar{b}$ mode (see Table 1 and 2). Unfortunately, high resolution is accompanied by luminosity loss. The original on-resonance goal of $\mathcal{L}_{\rm ave} \simeq 5 \times 10^{30}{\rm cm}^{-2}{\rm s}^{-1}$ is too low. Hence, we have assumed in Table 2 and throughout this paper that an additional order of magnitude increase in luminosity to $5\times 10^{31}{\rm cm}^{-2}{\rm s}^{-1}$ is attainable while maintaining outstanding beam resolution.

- For example, a factor of 10 increase in Luminosity (Table 2) reduces the running (scan) time by factor 10 less. Thus instead of a "3 year" running time, it will be reduced to ($\frac{3}{10}$ year) over "3 months".

- Expectations for $m_H = 110$ GeV are illustrated in Table 1 for luminosity $\mathcal{L}_{\text{ave}} \simeq 5 \times 10^{30}\text{cm}^{-2}\text{s}^{-1}$ and in Table 2 for luminosity $\mathcal{L}_{\text{ave}} \simeq 5 \times 10^{31}\text{cm}^{-2}\text{s}^{-1}$.

TABLE 1. Expected signals and backgrounds (fully integrated) for a standard model Higgs with $m_H = 110$ GeV, $\Gamma_H \simeq 3$ MeV. Muon collider resonance conditions with no polarization, $\Delta E/E \simeq 3 \times 10^{-5}$, and $L = 0.05\ \text{fb}^{-1}$ are assumed. The total number of Higgs scalars produced is ~ 3000. Realistic efficiency and acceptance cuts are likely to dilute signal and backgrounds for $b\bar{b}$ and $c\bar{c}$ by a 0.5 factor.

$H \to$	$b\bar{b}$	$c\bar{c}$	$\tau\bar{\tau}$
N_S (events)	2400	120	270
N_B (events)	2520	2416	945
$\pm\sqrt{N_S + N_B}/N_S$	±0.03	±0.42	±0.13

TABLE 2. Expected signals and backgrounds (fully integrated) for a standard model Higgs with $m_H = 110$ GeV, $\Gamma_H \simeq 3$ MeV. Muon collider resonance conditions with no polarization, $\Delta E/E \simeq 3 \times 10^{-5}$, and $L = 0.5\ \text{fb}^{-1}$ are assumed. The total number of Higgs scalars produced is $\sim 30,000$. Realistic efficiency and acceptance cuts are likely to dilute signal and backgrounds for $b\bar{b}$ and $c\bar{c}$ by a 0.5 factor.

$H \to$	$b\bar{b}$	$c\bar{c}$	$\tau\bar{\tau}$
N_S (events)	24,000	1,200	2,700
N_B (events)	25,200	24,160	9,450
$\pm\sqrt{N_S + N_B}/N_S$	±0.009	±0.13	±0.04

- In these tables $c\bar{c}$ branching ratios have been reduced compared to those given previously [4,7]. The values given here assume smaller charm quark mass. The prediction is quite sensitive to the mass value assumed.

The selection of the energy and luminosity depends on 1) the reduced scan time to normal time needed, and 2) to improve precision to do physics. For example, to measure $c\bar{c}$, a factor of 10 increase in luminosity results in the improvement from 42%,

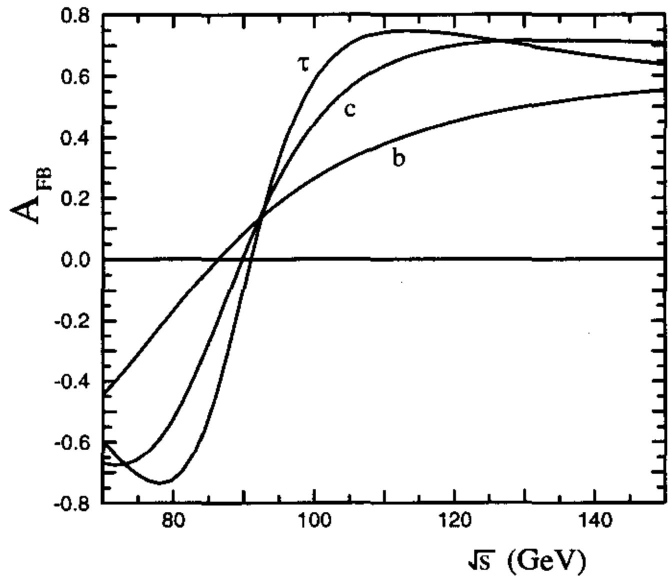

FIGURE 1. Forward-backward asymmetry for $\mu^-\mu^+ \to f\bar{f}$.

(Table 1) to about 13% (Table 2).

Other decays such as WW^* and ZZ^* are very small for this mass regions and to measure them need to improve precision. The parameter $\pm\sqrt{N_S + N_B}/N_S$ in Tables 1 and 2 was included for convenient. Further note, the values listed in Tables 1 and 2 should be reduced by $\frac{1}{\sqrt{2}}$ to include the effect of acceptance.

- Here we describe additional ways of potentially enhancing the Higgs signal to background ratio. The Higgs signal $\mu^-\mu^+ \to H \to f\bar{f}$ results from left-left (LL) or right-right (RR) beam polarizations and leads to an isotropic (i.e. constant) $f\bar{f}$ signal in $\cos\theta$ (the angle between the μ^- and f). Standard model backgrounds $\mu^-\mu^+ \to \gamma^*$ or $Z^* \to f\bar{f}$ result from LR or RL initial state polarizations and give rise to $(1 + \cos^2\theta + \frac{8}{3}A_{FB}\cos\theta)$ angular distributions. Similar statements apply to WW^* and ZZ^* final states, but those modes will not be discussed here.

- To illustrate the difference between signal, $\mu^-\mu^+ \to H \to f\bar{f}$, and background, $\mu^-\mu^+ \to \gamma^*$ or $Z^* \to f\bar{f}$, we give the combined differential production rate with respect to $x \equiv \cos\theta = 4\mathbf{p}_{\mu^-}\cdot\mathbf{p_f}/s$ for polarized muon beams and fixed luminosity

$$\frac{dN(\mu^-\mu^+ \to f\bar{f})}{dx} = \frac{1}{2}N_S(1+P_+P_-) + \frac{3}{8}N_B[1-P_+P_- + (P_+ - P_-)A_{LR}](1+x^2+\frac{8}{3}xA_{eff}). \tag{1}$$

$P_+(P_-)$ is the $\mu^+(\mu^-)$ polarization with $P=-1$ pure left-handed, $P=+1$ pure right handed, and $P=0$ unpolarized. N_S is the fully integrated $(-1 < x \leq 1)$ Higgs signal and N_B the integrated background for the case of unpolarized beams, $P_+ = P_- = 0$. In that general expression,

$$A_{LR} \equiv \frac{\sigma_{LR\to LR} + \sigma_{LR\to RL} - \sigma_{RL\to RL} - \sigma_{RL\to LR}}{\sigma_{LR\to LR} + \sigma_{LR\to RL} + \sigma_{RL\to RL} + \sigma_{RL\to LR}}, \tag{2}$$

where, for example, $LR \to LR$ stands for $\mu_L^-\mu_R^+ \to f_L\bar{f}_R$. The effective forward-backward asymmetry is given by

$$A_{eff} = \frac{A_{FB} + P_{eff}A_{LR}^{FB}}{1 + P_{eff}A_{LR}}, \tag{3}$$

with

$$P_{eff} = \frac{P_+ - P_-}{1 - P_+P_-}, \tag{4}$$

$$A_{FB} = \frac{3}{4}\frac{\sigma_{LR\to LR} + \sigma_{RL\to RL} - \sigma_{LR\to RL} - \sigma_{RL\to LR}}{\sigma_{LR\to LR} + \sigma_{RL\to RL} + \sigma_{LR\to RL} + \sigma_{RL\to LR}}, \tag{5}$$

$$A_{LR}^{FB} = \frac{3}{4}\frac{\sigma_{LR\to LR} + \sigma_{RL\to LR} - \sigma_{LR\to RL} - \sigma_{RL\to RL}}{\sigma_{LR\to LR} + \sigma_{RL\to LR} + \sigma_{LR\to RL} + \sigma_{RL\to RL}}. \tag{6}$$

and the $\mu_i^-\mu_j^+ \to f_{i'}\bar{f}_{j'}$, cross sections $(i \neq j)$ are to lowest order

$$\begin{aligned} \sigma_{ij\to i'j'} &= (N_C)\sigma_0\left[1 - \frac{s}{m_Z^2}\left(1 + \frac{(T_{3\mu_i} - Q_\mu\sin^2\theta_W)(T_{3f_{i'}} - Q_f\sin^2\theta_W)}{Q_\mu Q_f \sin^2\theta_W\cos^2\theta_W}\right)\right]^2, \\ T_{3\mu_L} &= T_{3\tau_L} = T_{3b_L} = -T_{3c_L} = -1/2, \\ T_{3f_R} &= 0, \quad Q_\mu = Q_\tau = 3Q_b = -\frac{3}{2}Q_c = -1 \qquad (N_C = 3 \text{ for } f = b, c). \end{aligned} \tag{7}$$

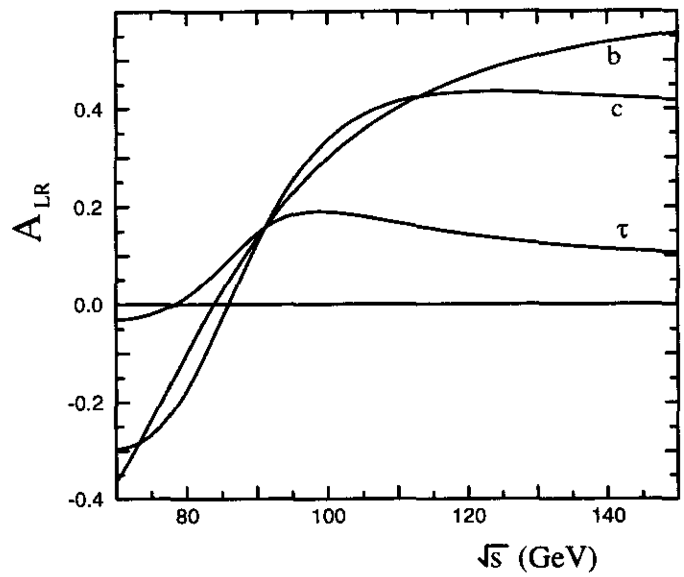

FIGURE 2. Left-right asymmetry for $\mu^-\mu^+ \to f\bar{f}$.

Realistic cuts, efficiencies, systematic errors etc, will not be considered. They are likely to dilute the $b\bar{b}$ and $c\bar{c}$ event rates by a factor of 0.5. In addition, we ignore the radiative Z production tail under the assumption such events are vetoed.

- The (unpolarized) forward-backward asymmetries are illustrated in Fig. 1. Note that A_{FB} is large (near maximal) for $\tau\bar{\tau}$ and $c\bar{c}$ in the region of interest. As we shall see, that feature can help in discriminating signal from background.

- In principle, large polarization in both beams can be important for enhancing "discovery" and precision measurement sensitivity for the Higgs. From Eq. (1), we find for fixed luminosity that $N_S/\sqrt{N_B}$ is enhanced (for integrated signal and background) by the factor

$$\kappa_{\rm pol} = \frac{1 + P_+ P_-}{\sqrt{1 - P_+ P_- + (P_+ - P_-) A_{LR}}} \, , \tag{8}$$

where the A_{LR} are shown in Fig. 2. That result generalizes the

$P_+ = P_-$ case [5]. For natural beam polarization [1], $P_+ = P_- = 0.2$ (assuming spin rotation of one beam), the enhancement factor is only 1.06. For larger polarization, $P_+ = P_- = 0.5$, one obtains a 1.44 enhancement factor (statistically equivalent to about a factor of 2 luminosity increase). Similarly, $P_+ = P_- = 0.7$ leads to a factor of 2 enhancement or equivalently a factor of 4 scan time reduction. Unfortunately, obtaining even 0.5 polarization simply by muon energy cuts reduces each beam intensity [1] by a factor of 1/4, resulting in a luminosity reduction by 1/16. Such a trade-off is clearly unacceptable. Polarization will be a useful tool in Higgs resonance "discovery" and studies only if high polarization is achievable with little luminosity loss. Ideas for increasing the polarization are still being explored [1,6]. Tau final state polarizations can also be used to help improve the $H \to \tau\bar{\tau}$ measurement.

- Some "discovery" or sensitivity enhancement can also be obtained from angular discrimination. A proper study would include detector acceptance cuts and maximum likelihood fits. Here, we wish to only approximate the gain. For that purpose, we assume perfect (infinitesimal) binning and obtain a (maximal) measurement sensitivity enhancement factor

$$\frac{1}{2}(1 + P_+P_-)\sqrt{N_S + N_B}\left[\int \frac{dx}{dN/dx}\right]^{1/2}, \tag{9}$$

which becomes, from Equations (1) and (8),

$$\kappa_{\rm pol}\sqrt{\frac{2}{3}}\sqrt{\frac{N_S + N_B}{N_B}}\left(\frac{\tan^{-1}\left(\frac{2}{\zeta}\sqrt{1 - \frac{16}{9}A_{eff}^2 + \zeta}\right)}{\sqrt{1 - \frac{16}{9}A_{eff}^2 + \zeta}}\right)^{1/2}, \quad \zeta \equiv \frac{4}{3}\frac{N_S}{N_B}\frac{\kappa_{\rm pol}^2}{1 + P_+P_-} . \tag{10}$$

- In the case of "discovery", high polarization and/or a near maximal forward-backward asymmetry can significantly reduce the scan time. Additional analysis and detail will be given in [7].

Conclusion

We conclude that $\mathcal{L}_{\rm ave} \simeq 5 \times 10^{30}{\rm cm}^{-2}$ is too low and at least an additional order of magnitude increase in luminosity is needed for the Higgs resonance studies at the First Muon Collider. A factor of 10 in luminosity reduces the scan time by a factor of 10 and increases the resolution by about a factor of 3. The choice of energy and luminosity depends on 1) the scan time needed and 2) how precise a measurement is needed to do physics. For example, to measure $c\bar{c}$, a factor of 10 increase in luminosity provides the improvement from 42% , (Table 1) to about 13% (Table 2), and reduces the scan time from 3 years to over 3 months. Other decays such as WW^* and ZZ^* are very small for this mass regions and to measure them need to improve precision, thus the need for increase in Luminosity, etc.

We have shown that polarization is potentially useful for Higgs resonance studies, but only if the accompanying luminosity reduction is not significant. Large forward-backward asymmetries can also be used to enhance the Higgs "discovery" signal or improve precision measurements, particularly for $\tau\bar{\tau}$. However, to make the s-channel Higgs "factory" a compelling facility, we must attain a very good beam resolution and the highest luminosity possible. An additional "discovery" or sensitivity enhancement can be obtained from angular discrimination. For additional discussion see [7].

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2. Cline, D., "The Problems and Physics Prospects for a $\mu^+\mu^-$ Collider", in *Future High Energy Colliders*, edited by Z. Parsa, AIP Conference Proceedings **397**, 1997, pp. 203–218.
3. Barger, V., Berger, M.S., Gunion, J.F., and Han, T., "The Physics Capabilities of $\mu^+\mu^-$ Colliders", in *Future High Energy Colliders*, edited by Z. Parsa, AIP Conference Proceedings **397**, 1997, pp. 219–233; *Phys. Rep.* **286**, 1–51 (1997); *Phys. Rev. Lett.* **75**, 1462–1465 (1995).

4. Kamal, B., Marciano, W., Parsa, Z., BNL Report BNL-65193 (1997), hep-ph/9712270.
5. Parsa, Z., $\mu^+\mu^-$ Collider and Physics Possibilities (1993) (unpublished).
6. Skrinsky, A., *Presentation, Dec 1997.*
7. Kamal, B., Marciano, W., Parsa, Z., to be published.

HIGGS FACTORY COLLIDER RING LATTICE STUDIES

Al Garren

MUMU97

December 11, 1997

Designs for a 50 GeV collider ring lattice are progressing well, but have not yet converged.

This talk, and the next ones by Carol Johnstones and Bill Ng, are about the current status of this work - which has been done mainly by Carol, Dejan Trbojevic and myself.

We have had essential help and input from:

Weishi Wan - tracking runs with COSY

A. Drozdin - designs for halo scraping and injection

I. Stumer and N. Mokhov - shielding studies and designs

Bill Ng and Ernest Courant for lattice contributions

Juan Gallardo and Martin Berz for helpfull advice

Two lattices

Currently there are two lattice designs, one by Trbojevic and one by Johnstone and myself. For this talk, I will designate them by authors initials : T for Trbojevic's and JG for Johnstone-Garren's.

These rings have both similarities and differences:

Both use the same approach for sextupole correction..

The designs of the Interaction Region, which contains the collision point (IP) and the low-beta quadrupoles, are similar but not identical.

The designs of the Chromatic Correction Section are also similar.

The modules that provide bending and give the ring zero momentum compaction are different in both design and number.

The matching sections between the regions differ.

The JG lattice contains a long straight section for scraping and injection, has zero momentum compaction the ring closes geometrically.

The T lattice is incomplete; therefor it does not close and has no provision for injection and scraping.

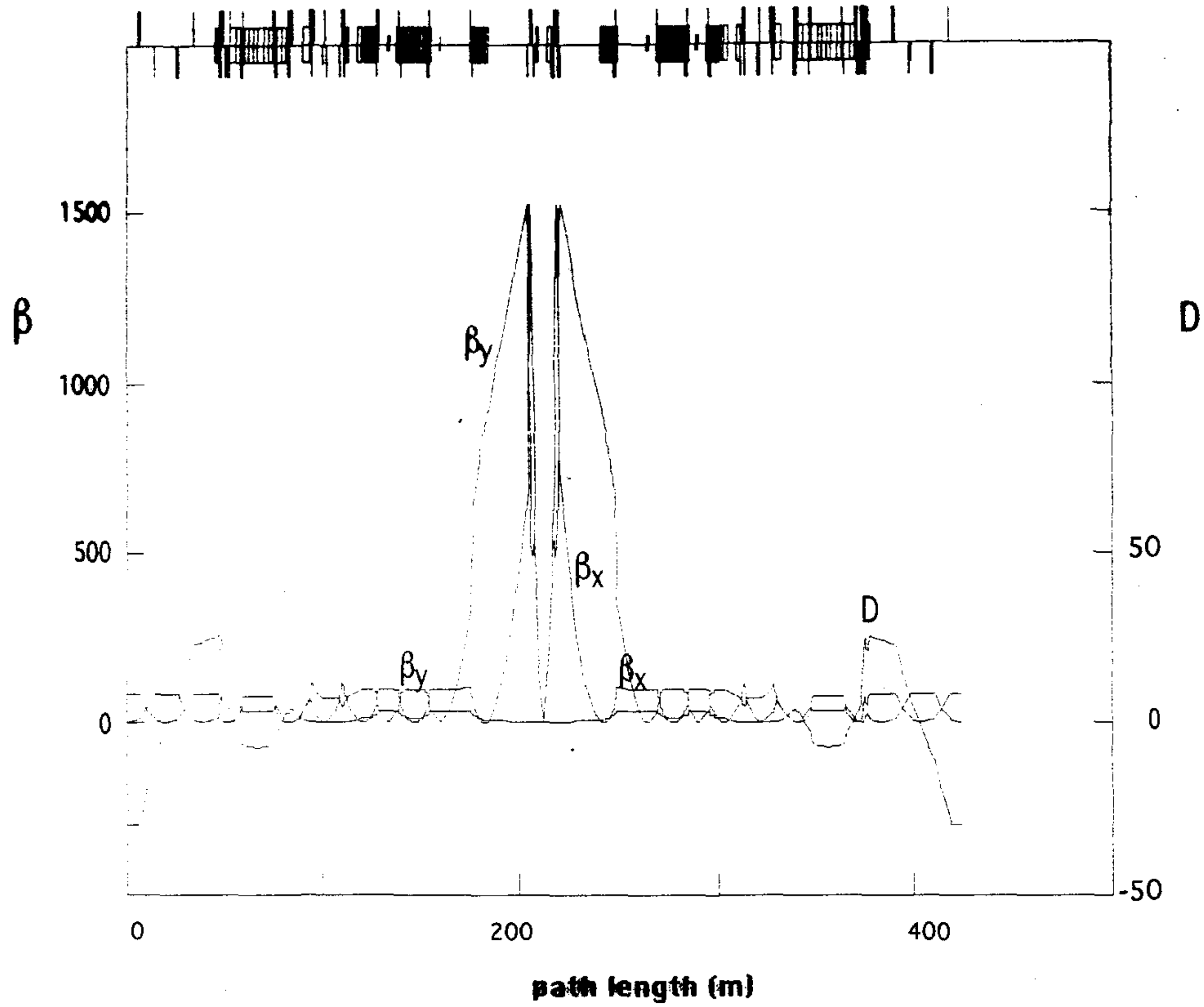
The T lattice has more arc modules, which give it more tuning range and possibly larger dynamic aperture.

The JG lattice

I will give an overview of the lattice. In the next talk, more of the design and performance, especially of the interaction region and chromatic correction section will be given.

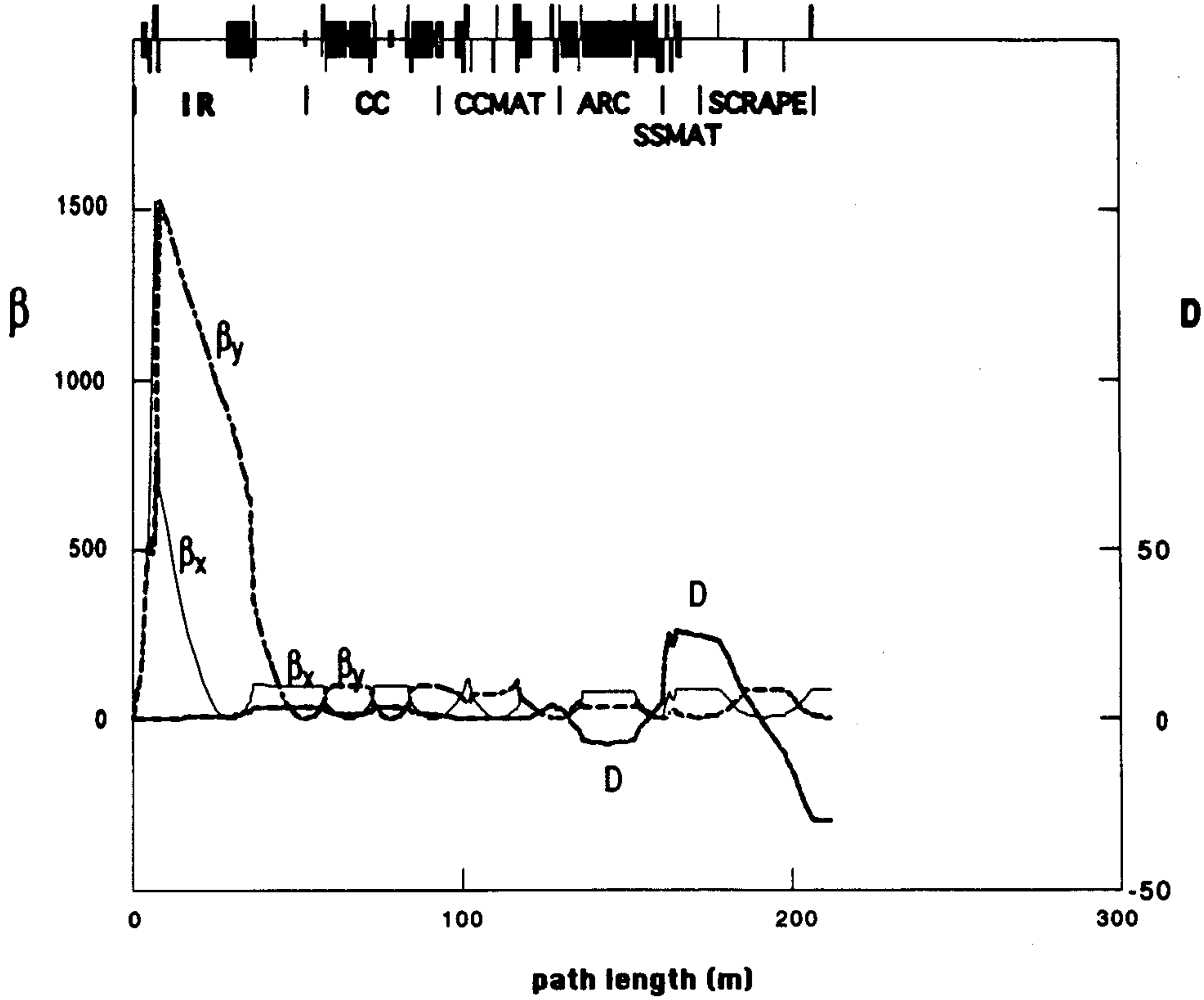
The only symmetry in this ring is bilateral reflection. The first three figures show a beta function plot of the full and half rings and a purely lattice schematic that shows the six component parts of each half ring.

Following these are six plots of each lattice component.



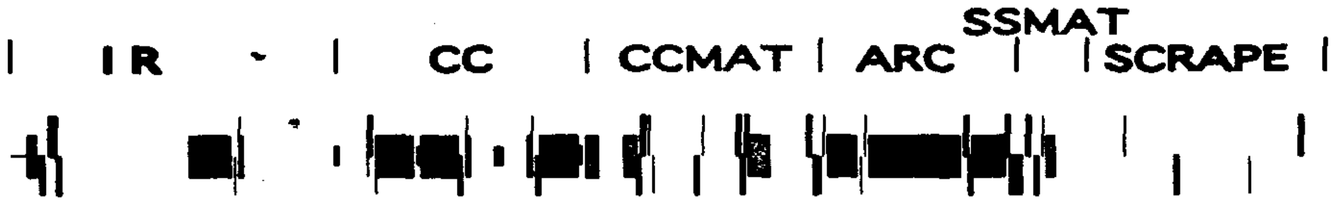
RING

RING
7 DEC 1997



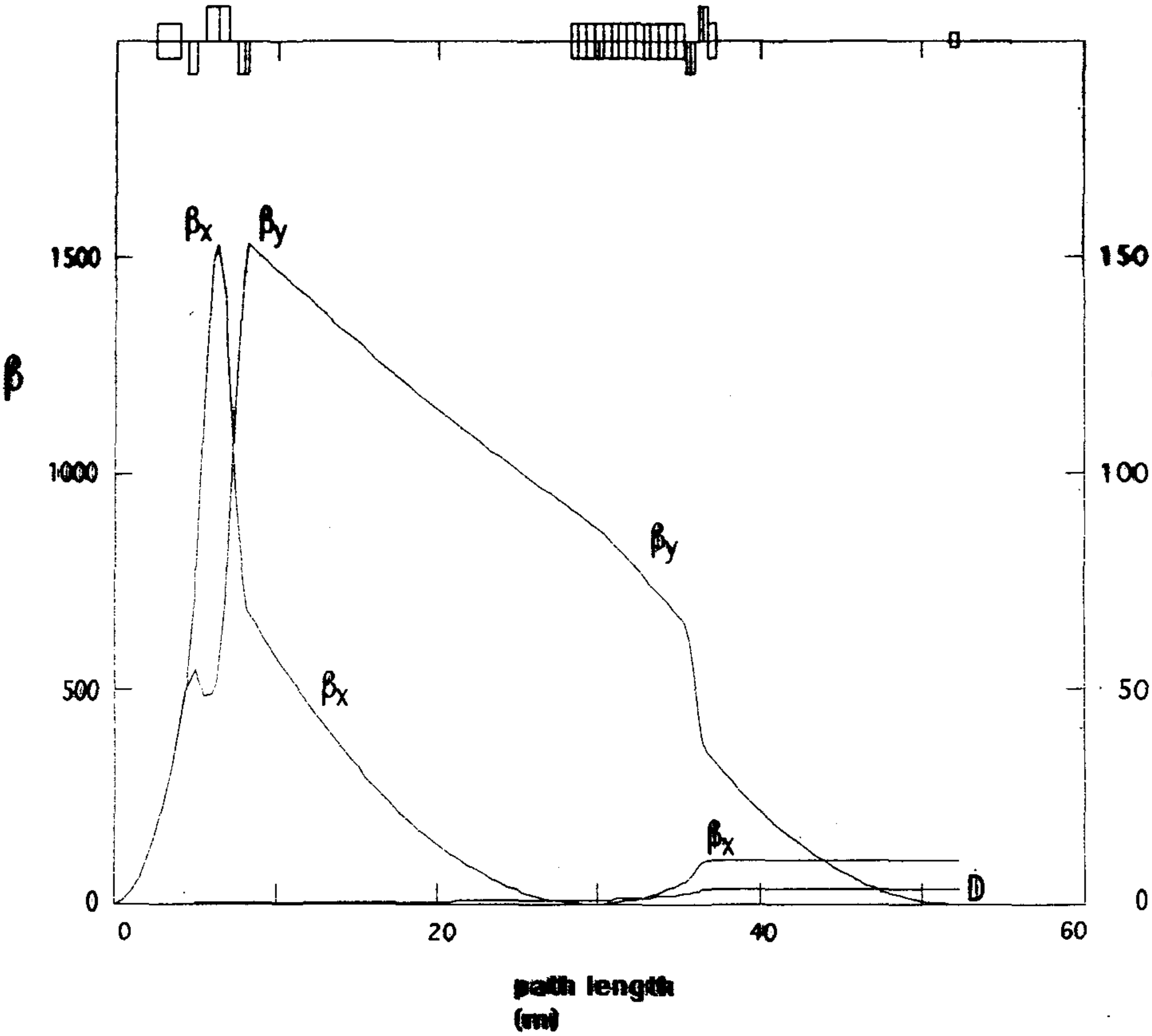
HALF RING

HALF RING
7 DEC 1997



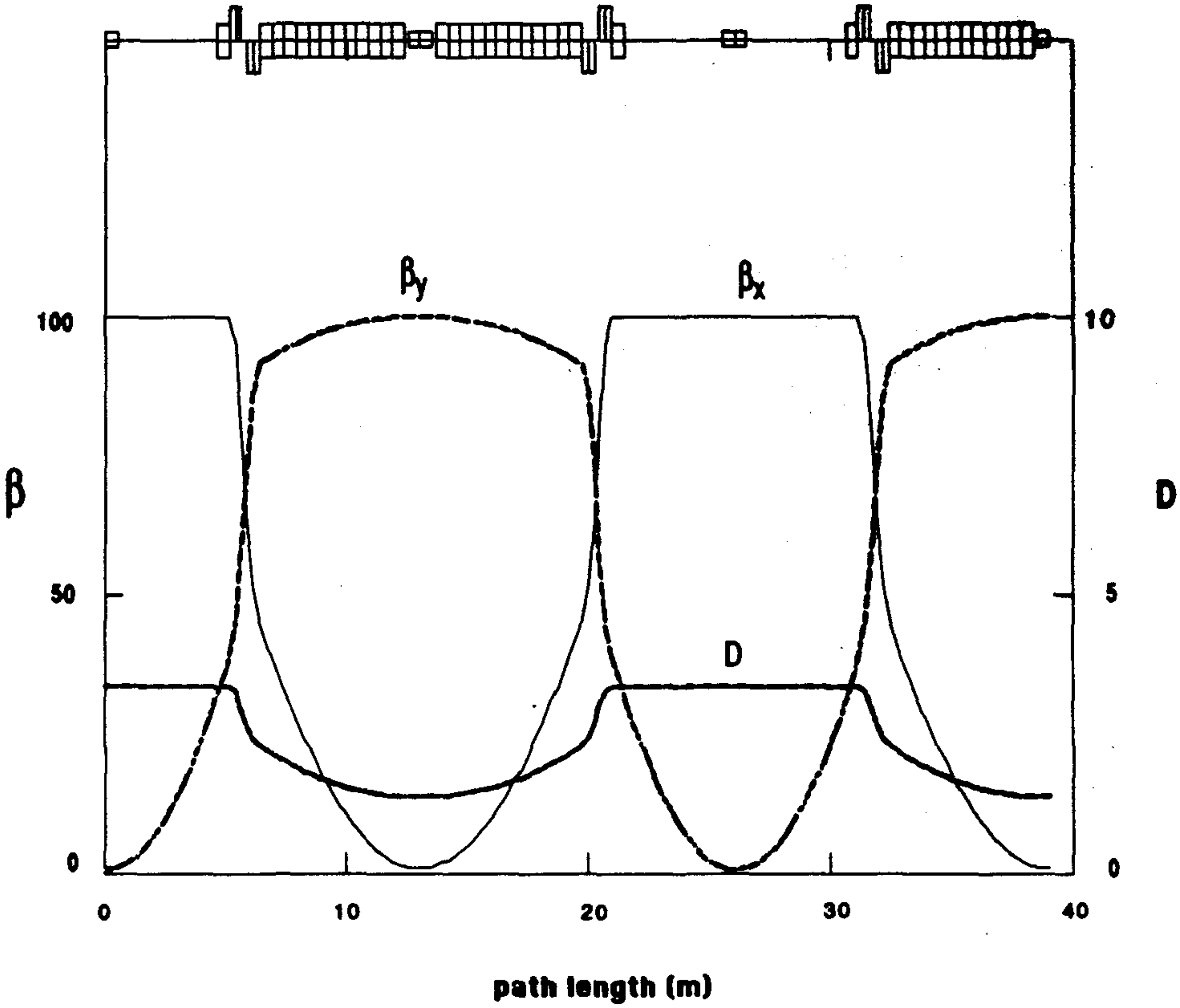
BEAMLINE OF HALF RING

7 DEC 1997



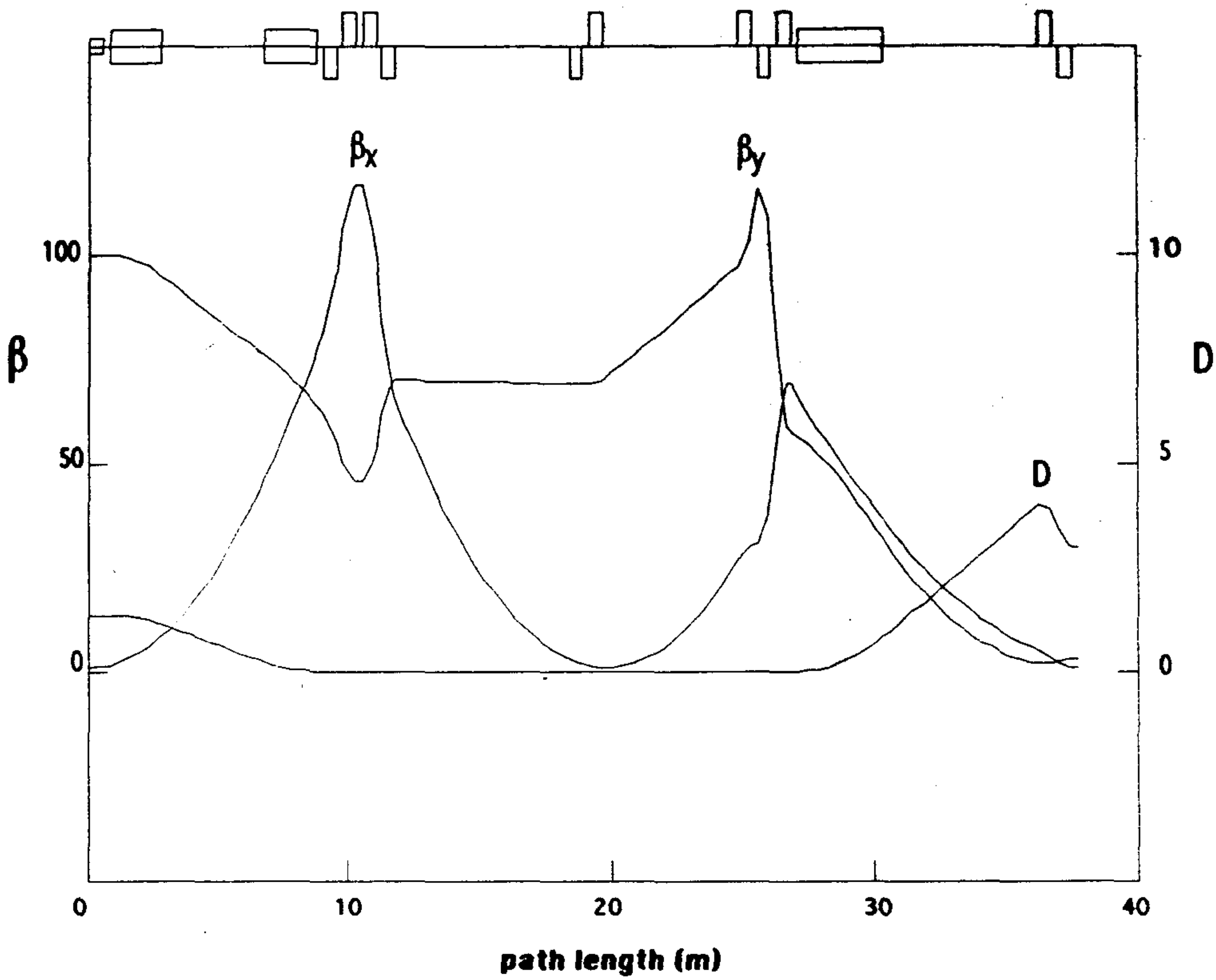
INTERACTION REGION

IR
7-DEC-1997



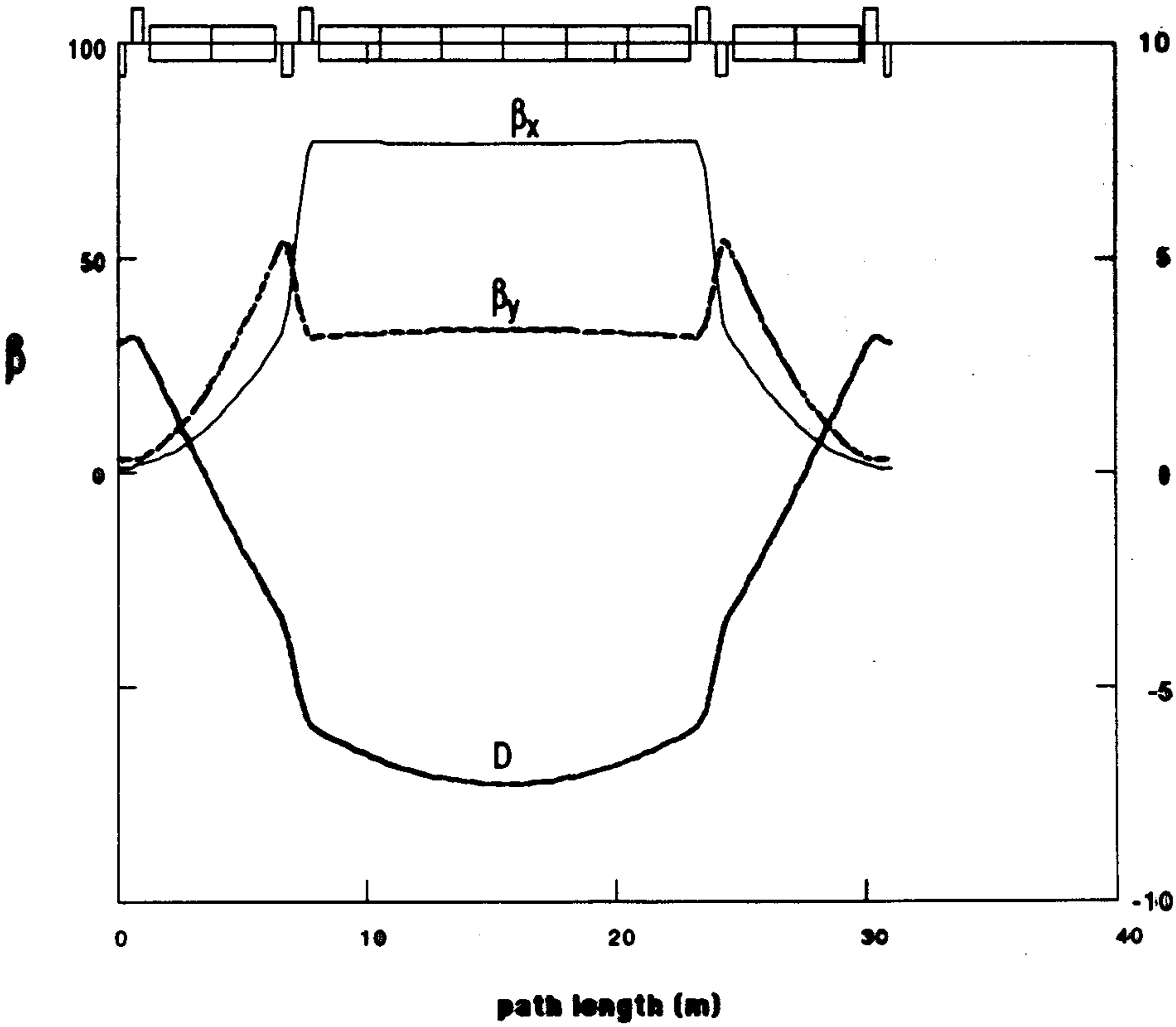
CHROMATIC CORRECTION SECTION

CC
7-DEC-1997



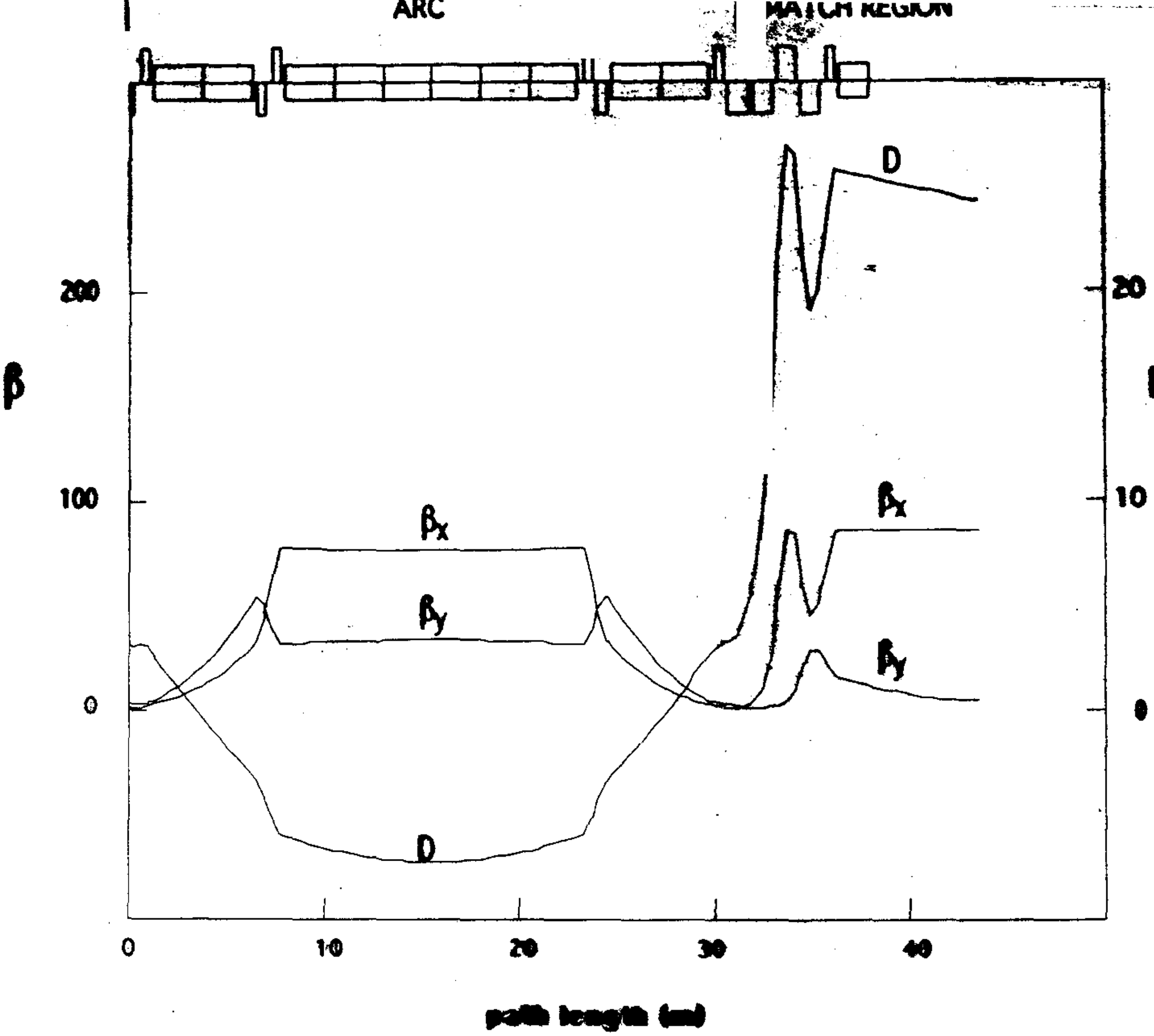
MATCHING REGION BETWEEN CHROMATIC CORRECTION SECTION AND ARC

CC-ARC
7-DEC-1997



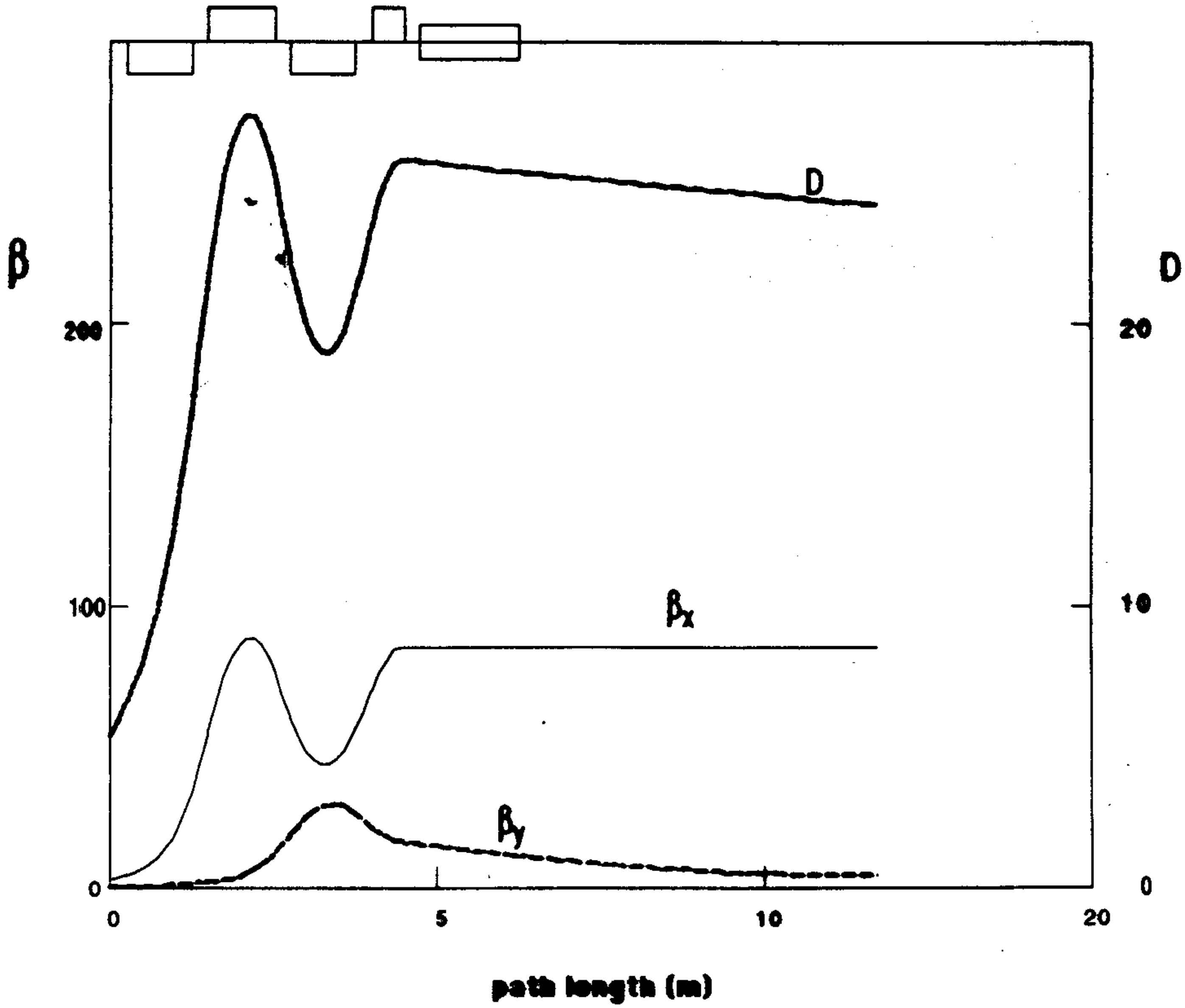
LOW MOMENTUM COMPACTION ARC

ARC
7-DEC-1997



ARC AND MATCHING REGION TO SCRAPING STRAIGHT SECTION

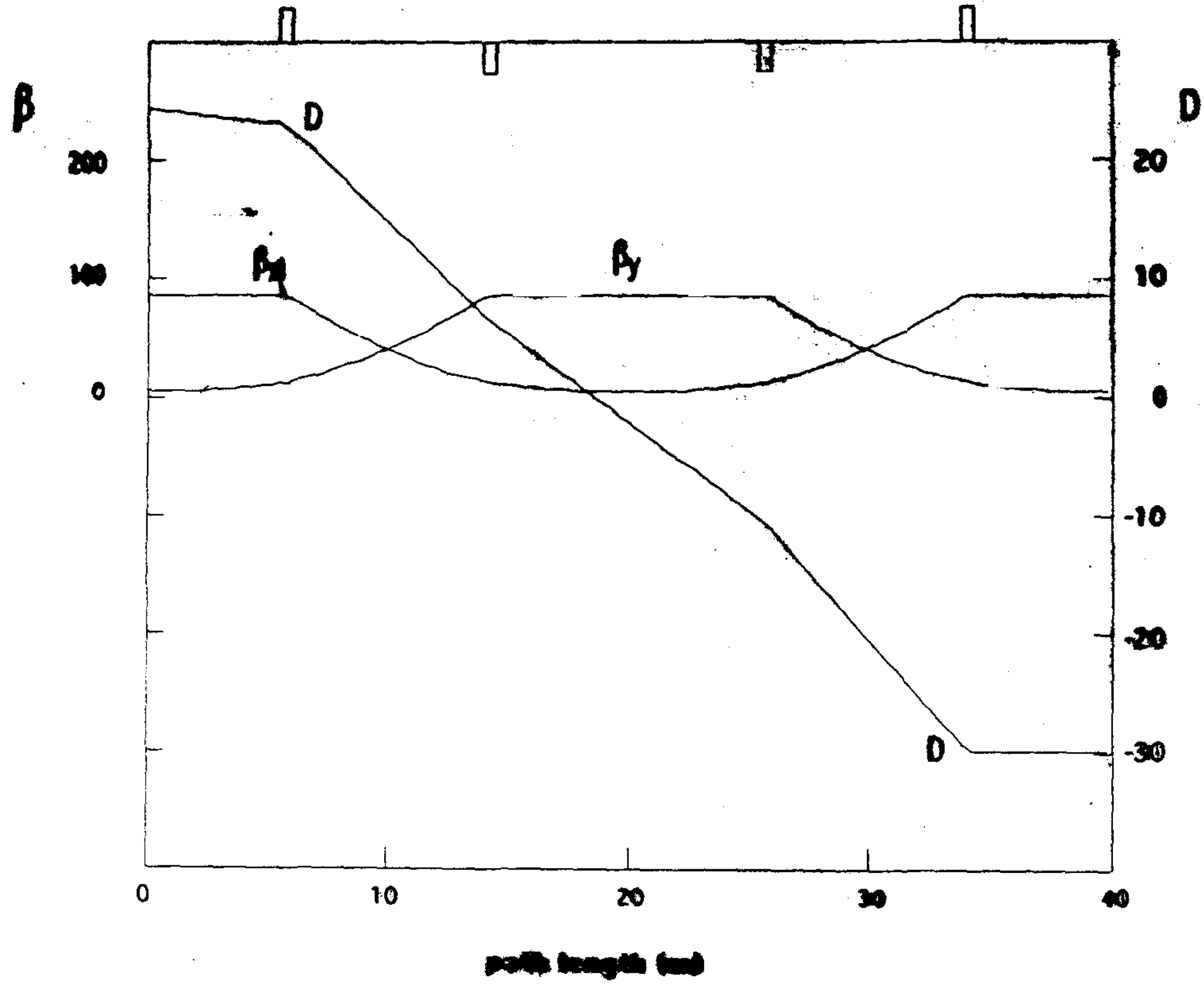
ARC
7-DEC-1997



MATCHING SECTION TO SCRAPING STAIGHT SECTION

SSMAT

7-DEC-1997



LEFT SIDE OF SCRAPING STRAIGHT SECTION

SCRAPE
7-DEC-1997

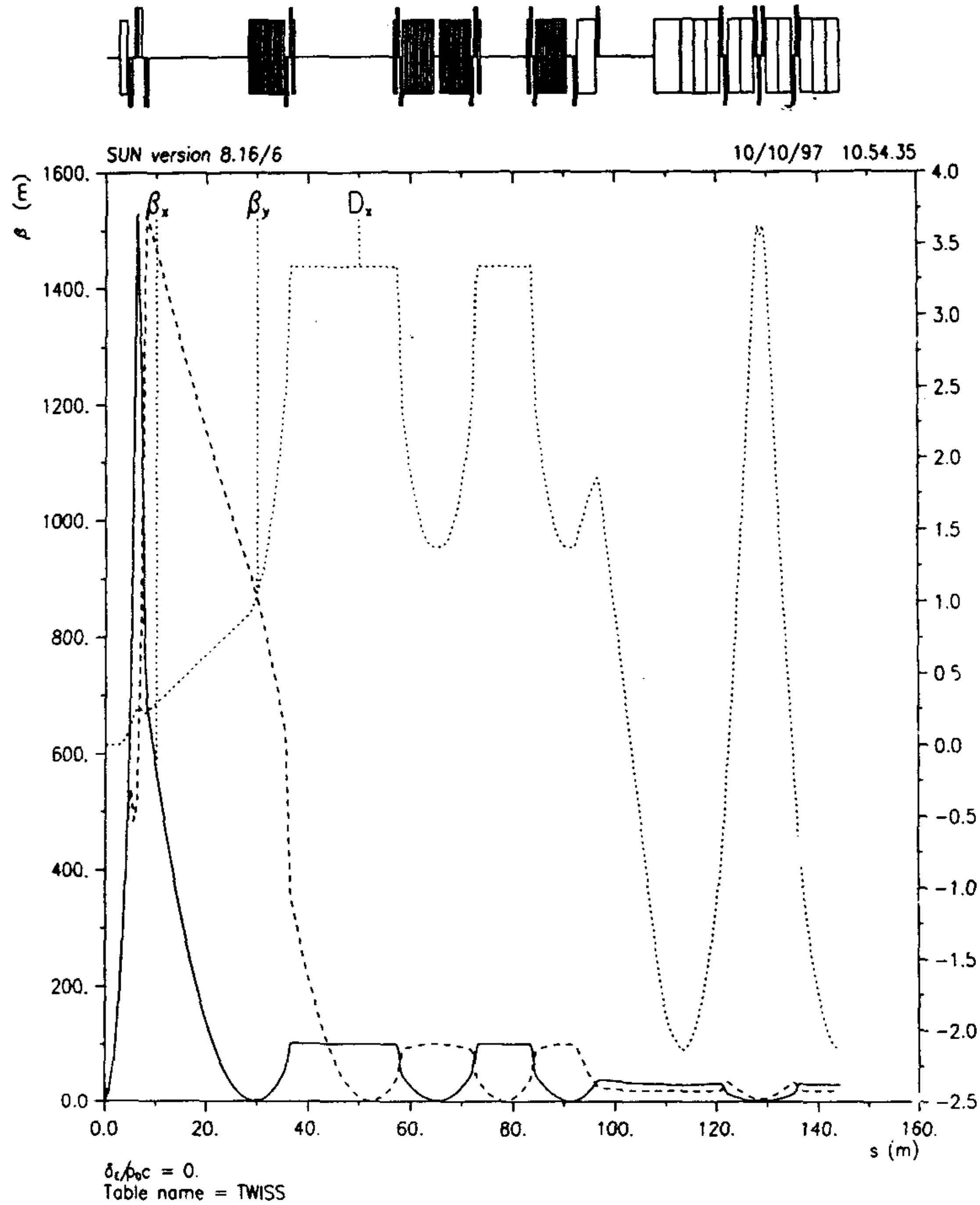
C. Johnstone(FNAL)

50 GeV Lattice Studies

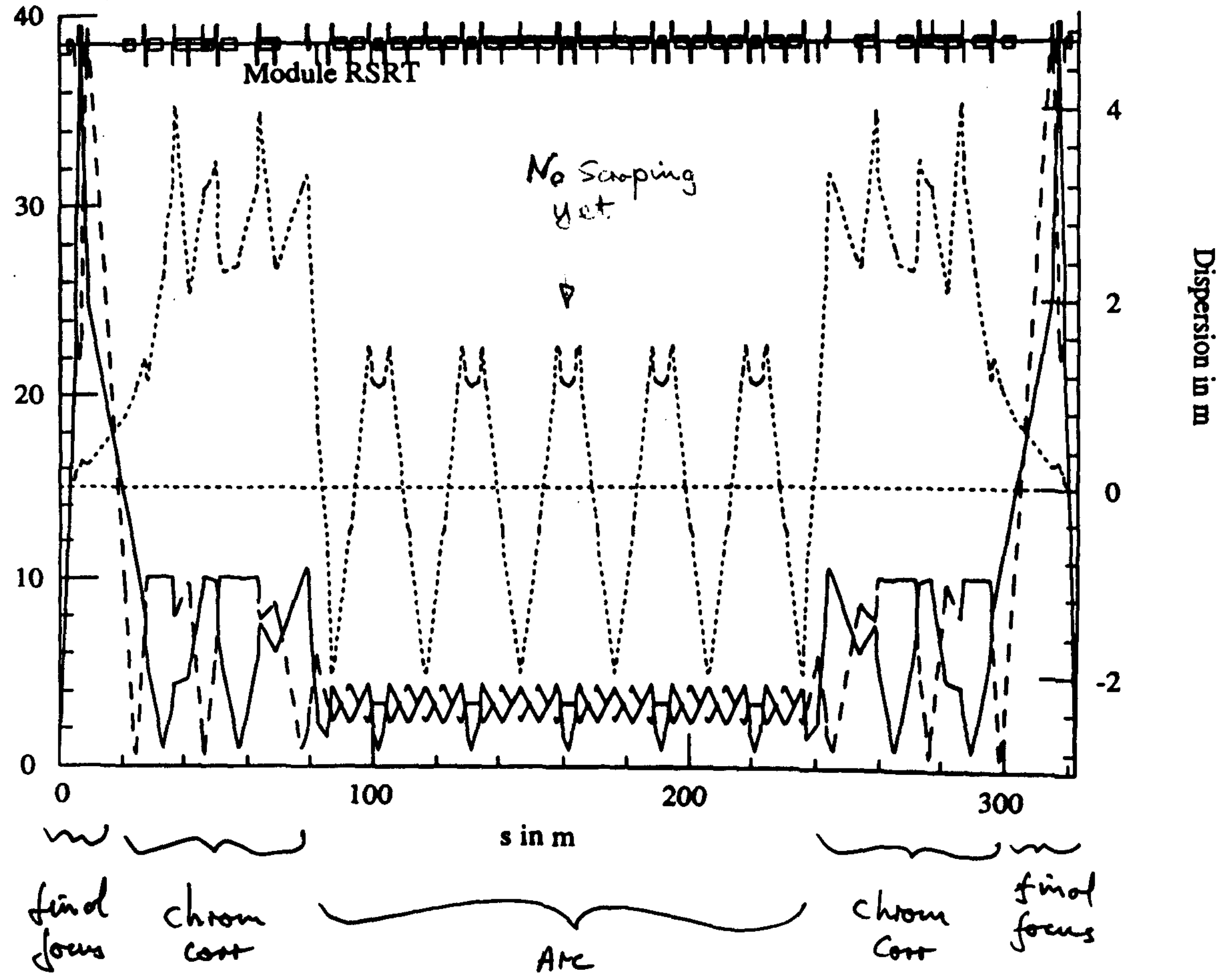
Feb 12-13, 1998

- Scraping
- Chromatic correction
- Dynamic aperture
- New 300 meter ring

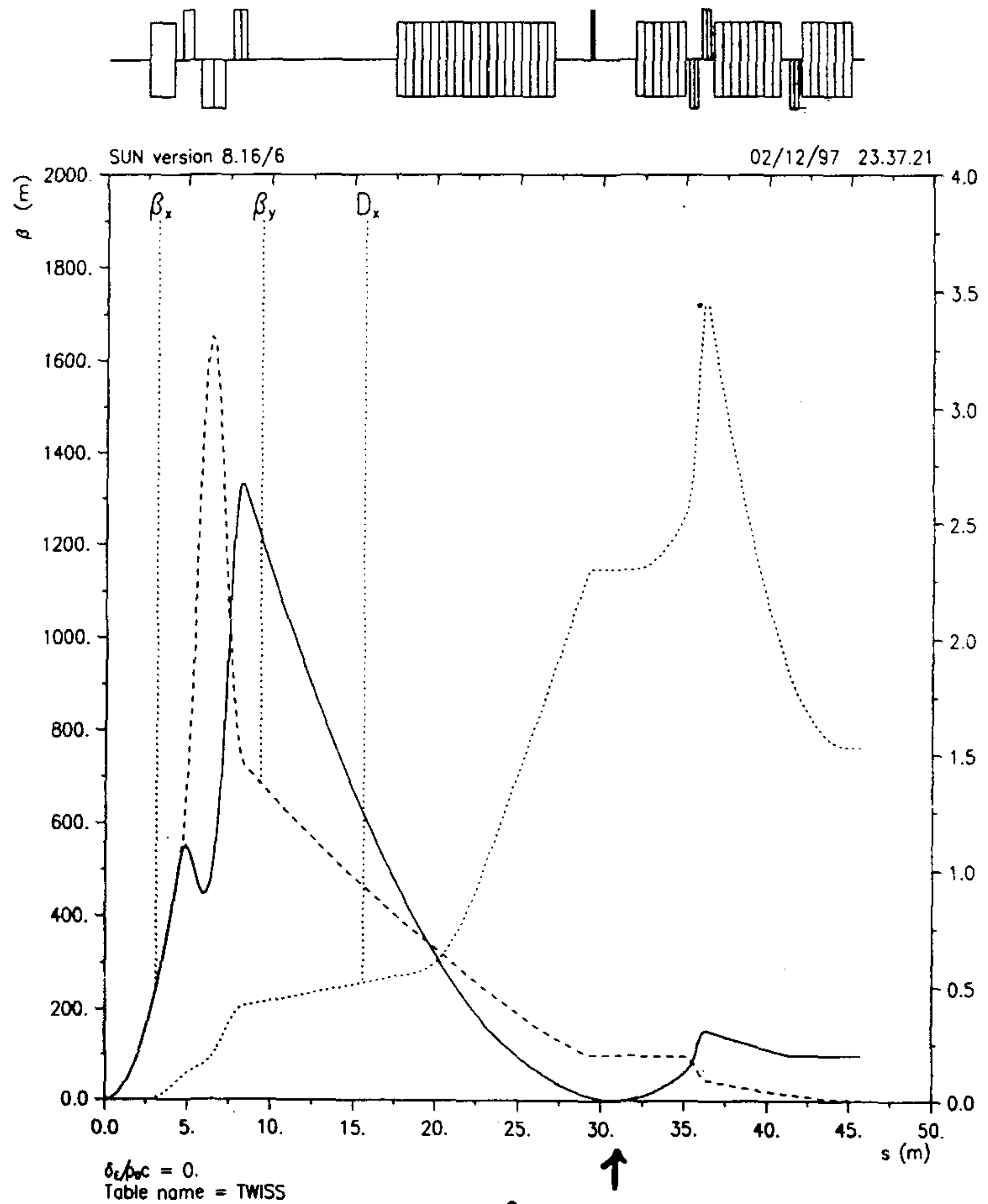
no scraping/injection



Trbojevic

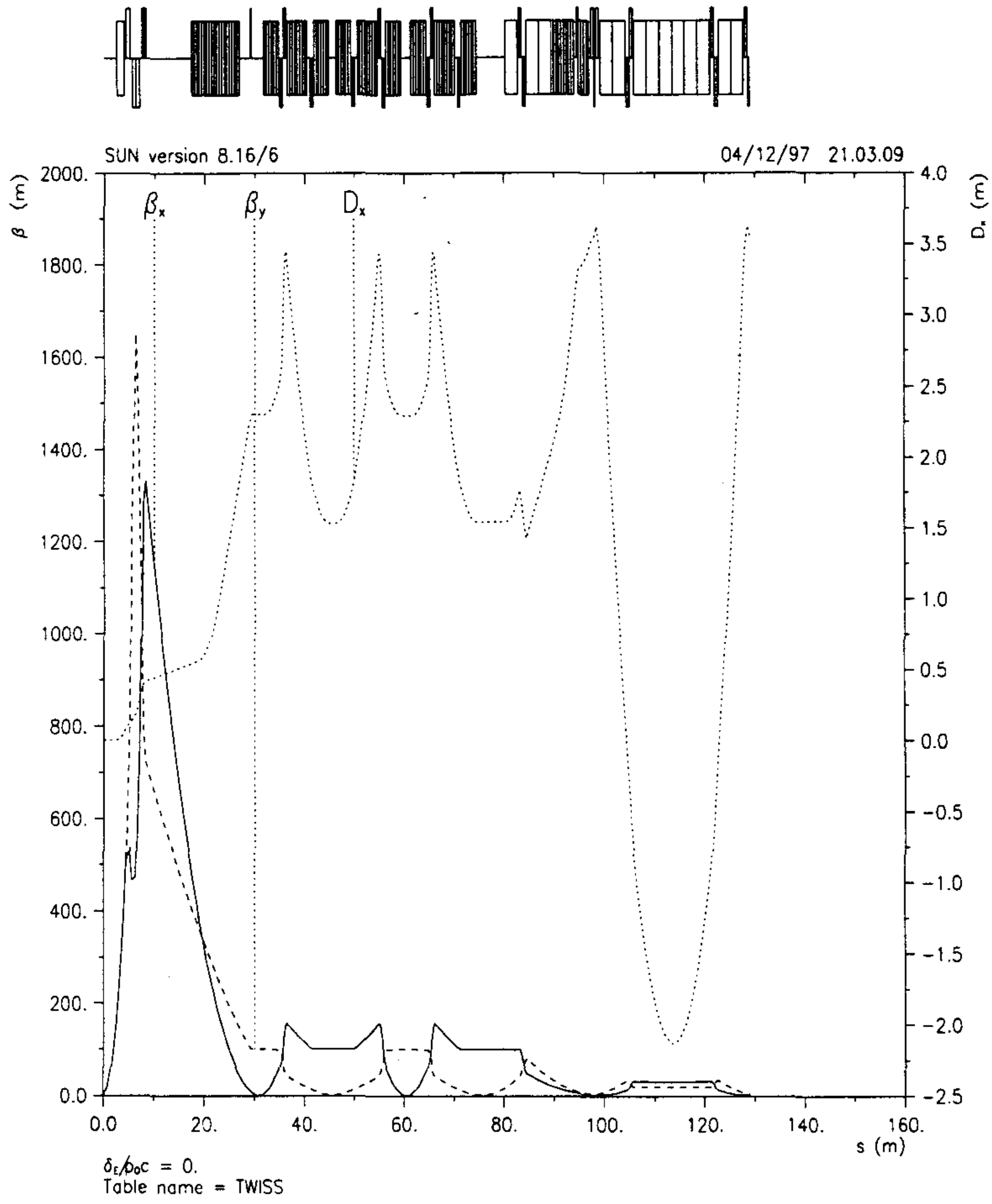

Module RSRT
No Scoping yet
40
30
20
10
0
0
100
200
300
s in m
4
2
0
-2
Dispersion in m
final focus
chrom corr
Arc
chrom Corr
final focus

KINDER GENTLE IR



β_x ≈ .25 m

300-m circumference Ring



"MAD" Version: 8.17 Run: 11/02/98 12.53.53

Linear lattice functions for beam line: RING *Range: #S/#E*

delta(p)/p = 0.000000 symm = F

ELEMENT SEQUENCE				I	HORIZONTAL							I	VERTICAL						
pos. no.	element name	occ. no.	dist [m]	I	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	I	betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
begin	RING	1	0.000		0.040	0.000	0.000	0.000	0.000	0.000	0.000		0.040	0.000	0.000	0.000	0.000	0.000	0.000
end	RING	1	258.183		0.040	0.000	4.335	0.000	0.000	0.000	0.000		0.040	0.000	3.372	0.000	0.000	0.000	0.000

total length =	258.183281	Qx =	4.334774	Qy =	3.371945
delta(s) =	0.000000 mm	Qx' =	-71.093044	Qy' =	-84.262402
alfa =	0.311073E-01	betax(max) =	1331.406875	betay(max) =	1651.124623
gamma(tr) =	5.669815	Dx(max) =	3.625188	Dy(max) =	0.000000
		Dx(r.m.s.) =	2.192494	Dy(r.m.s.) =	0.000000
		xco(max) =	0.000000	yco(max) =	0.000000
		xco(r.m.s.) =	0.000000	yco(r.m.s.) =	0.000000

Survey of beam line: RING range: #S/#E

ELEMENT SEQUENCE					I	POSITIONS			I	ANGLES		
pos. no.	element name	occ. no.	sum(L) [m]	arc [m]	I	x [m]	y [m]	z [m]	I	theta [rad]	phi [rad]	psi [rad]
begin	RING	1	0.000000	0.000000		0.000000	0.000000	0.000000		0.000000	0.000000	0.000000
end	RING	1	258.183281	258.215961		-7.501954	0.000000	56.834891		-6.545659	0.000000	0.000000

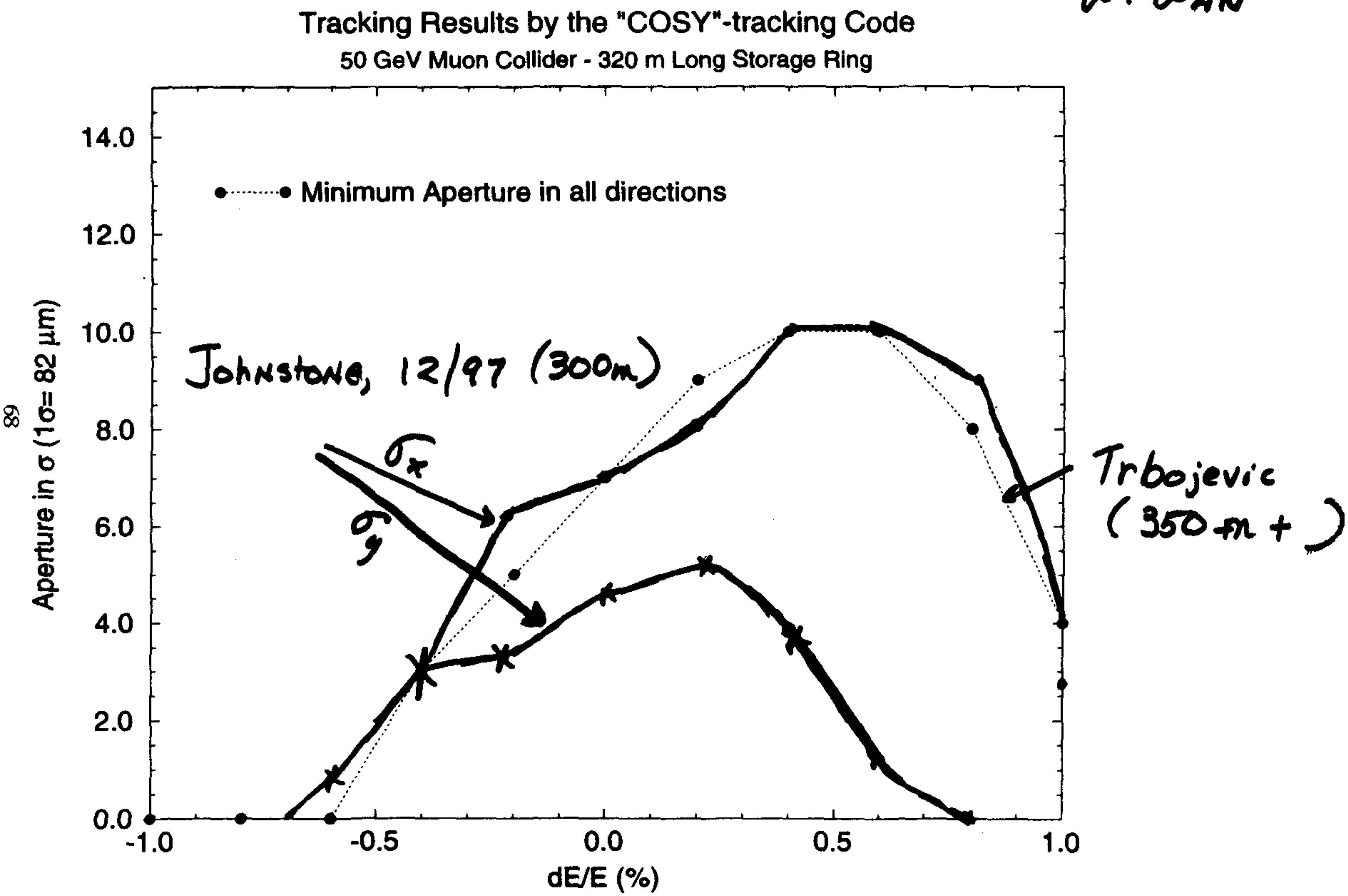
total length = 258.183281 arc length = 258.215961

error(x) = -0.750195E+01 error(y) = 0.000000E+00 error(z) = 0.568349E+02

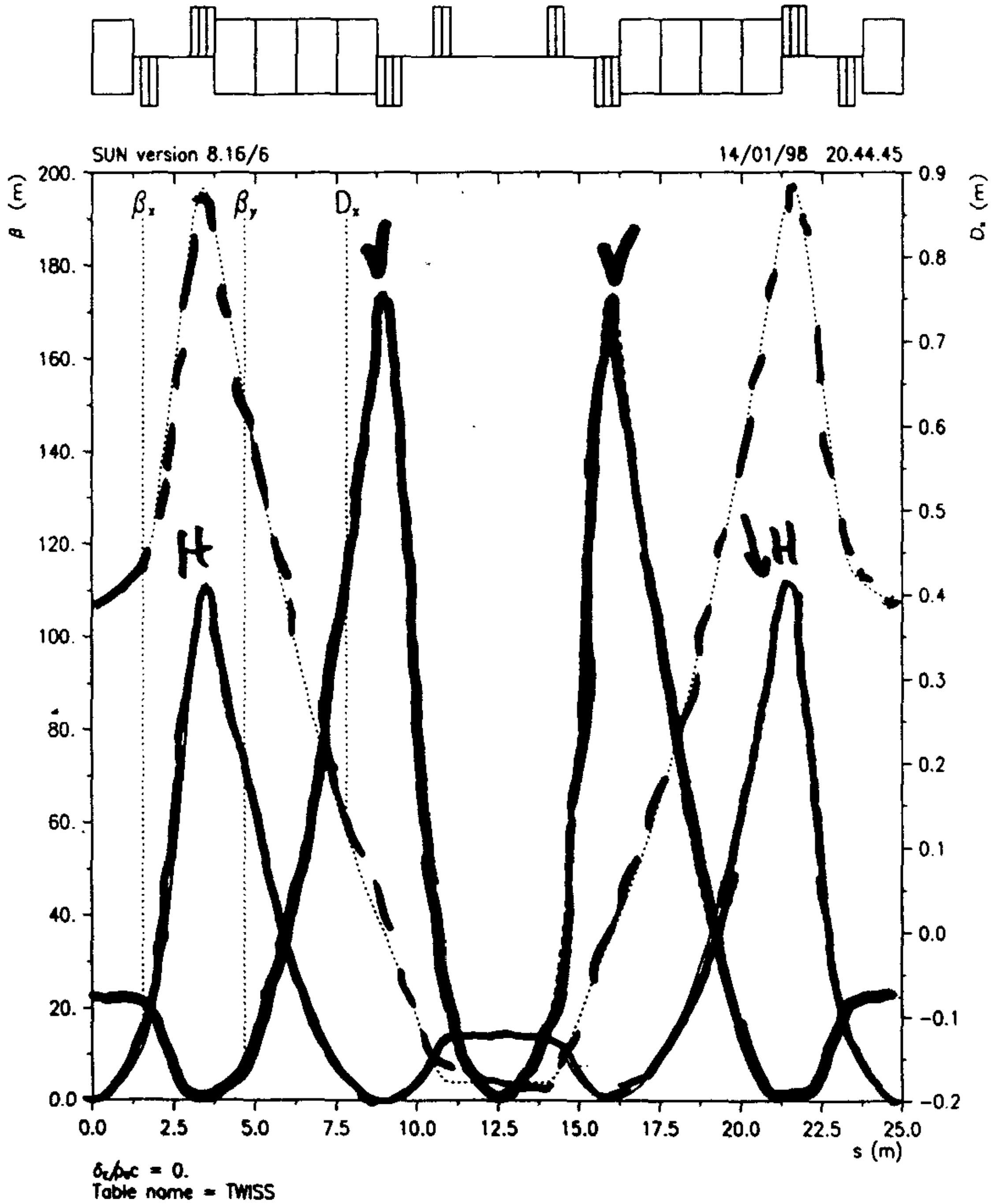
error(theta) = -0.262474E+00 error(phi) = 0.000000E+00 error(psi) = 0.000000E+00

Apertures

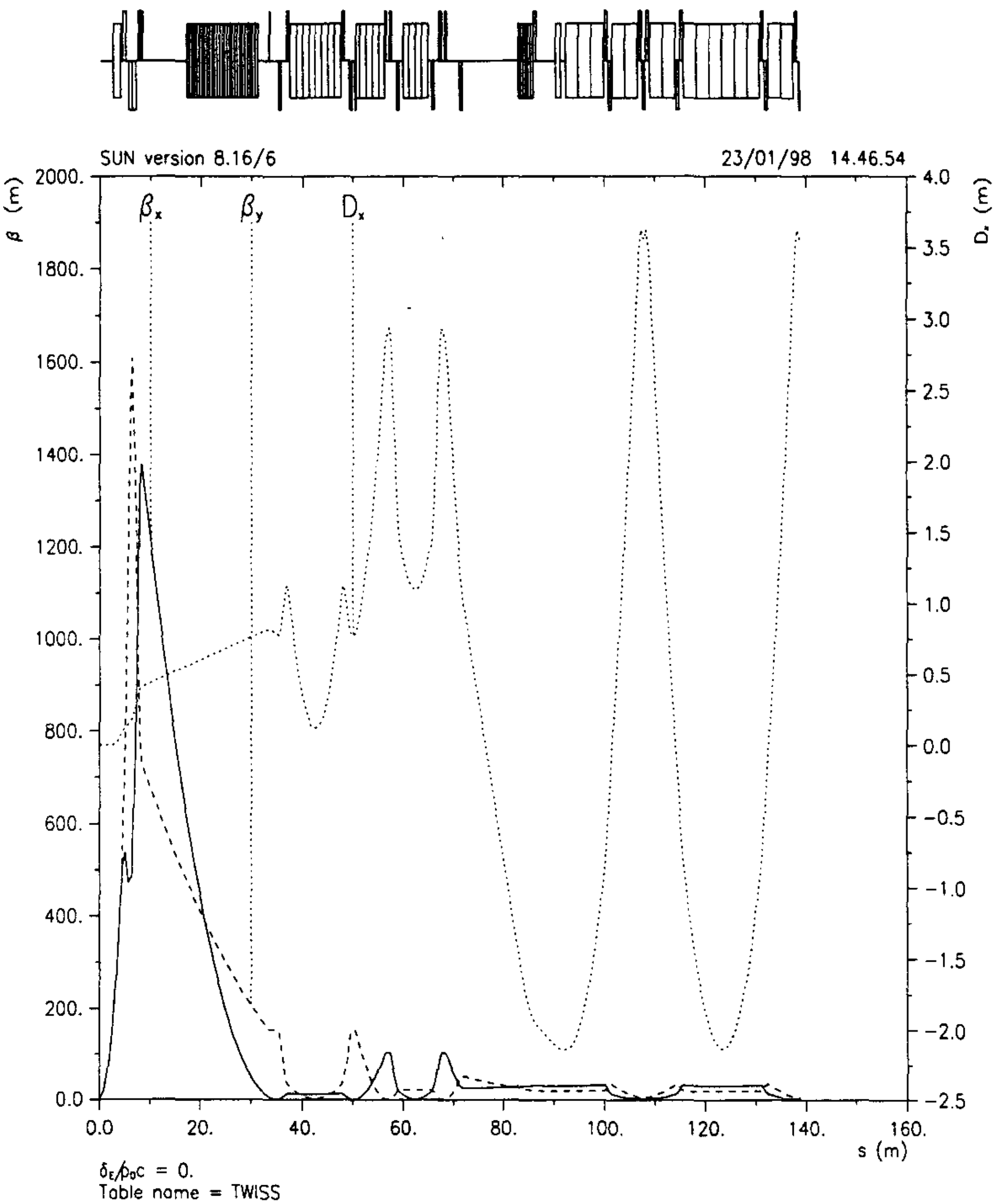
W. Wan



Chromatic Correction Section Redesign



300-m Ring, new CCS



new CCS 300-m Ring Reduced α

"MAD" Version: 8.17 Run: 11/02/98 13.02.25

Linear lattice functions for beam line: RING

Range: #S/#E

delta(p)/p = 0.000000 symm = F

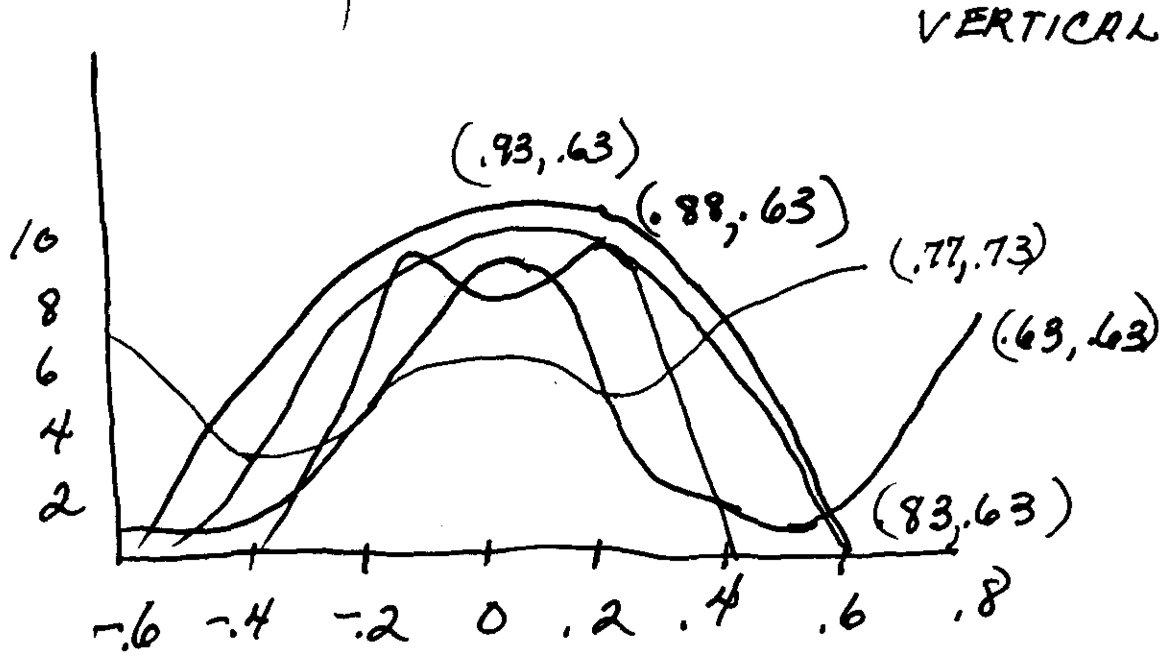
ELEMENT SEQUENCE				HORIZONTAL								VERTICAL							
pos. no.	element name	occ. no.	dist [m]	betax [m]	alfax [1]	mux [2pi]	x(co) [mm]	px(co) [.001]	Dx [m]	Dpx [1]	betay [m]	alfay [1]	muy [2pi]	y(co) [mm]	py(co) [.001]	Dy [m]	Dpy [1]
begin	RING	1	0.000	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.000	0.000	0.000	0.000	0.000	0.000
end	RING	1	277.791	0.040	0.000	5.630	0.000	0.000	0.000	0.000	0.040	0.000	4.628	0.000	0.000	0.000	0.000

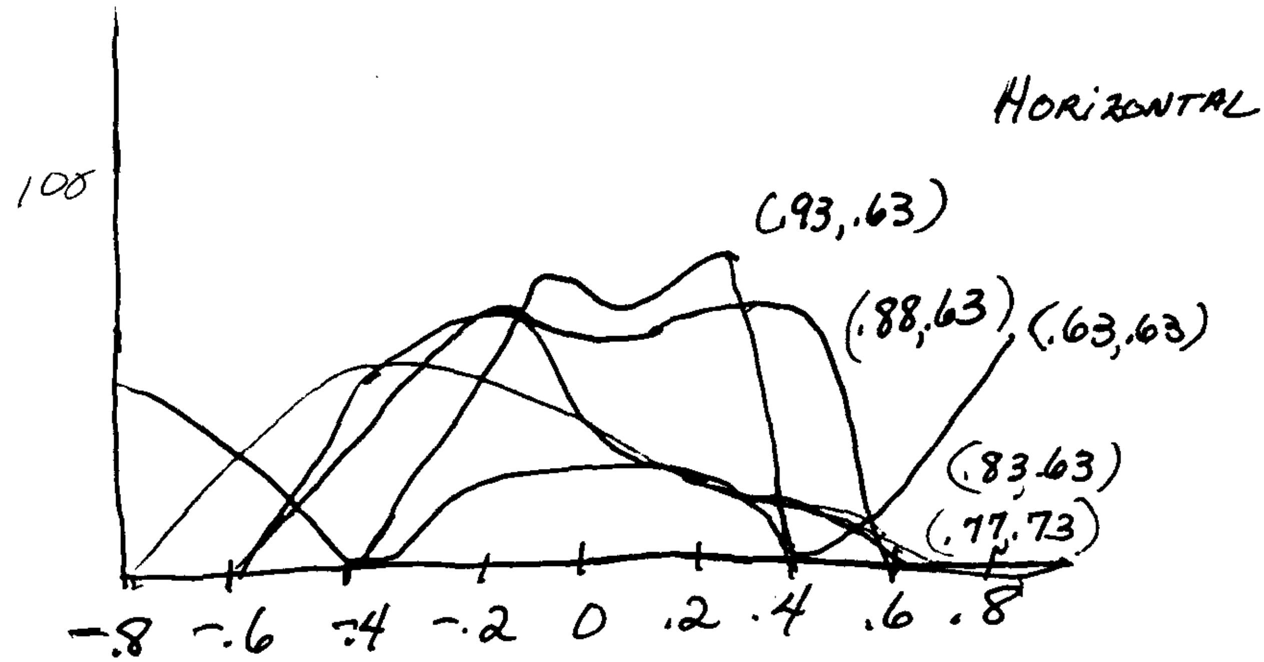
total length =	277.790814	Qx =	5.629717	Qy =	4.628156
delta(s) =	0.000000 mm	Qx' =	0.378107	Qy' =	-0.434743
alfa =	0.254724E-02	betax(max) =	1379.165360	betay(max) =	1608.697409
gamma(tr) =	19.813680	Dx(max) =	3.625123	Dy(max) =	0.000000
		Dx(r.m.s.) =	1.684661	Dy(r.m.s.) =	0.000000
		xco(max) =	0.000000	yco(max) =	0.000000
		xco(r.m.s.) =	0.000000	yco(r.m.s.) =	0.000000

ELEMENT SEQUENCE					I	POSITIONS			I	ANGLES		
pos. no.	element name	occ. no.	sum(L) [m]	arc [m]	I	x [m]	y [m]	z [m]	I	theta [rad]	phi [rad]	psi [rad]
begin	RING	1	0.000000	0.000000		0.000000	0.000000	0.000000		0.000000	0.000000	0.000000
end	*RING*	1	277.790814	277.842969		-16.474205	0.000000	69.212888		-6.750533	0.000000	0.000000

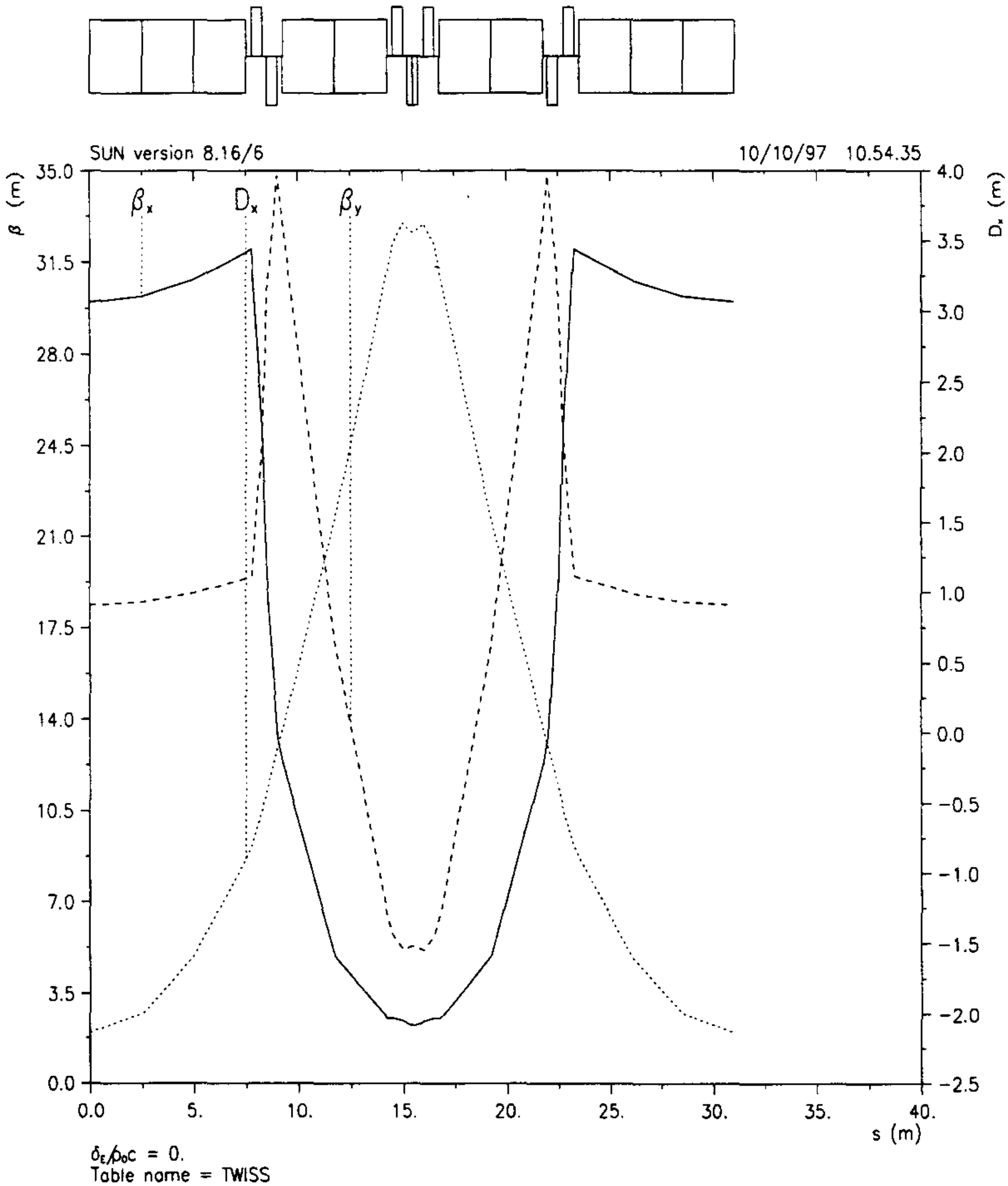
total length =	277.790814	arc length =	277.842969		
error(x) =	-0.164742E+02	error(y) =	0.000000E+00	error(z) =	0.692129E+02
error(theta) =	-0.467348E+00	error(phi) =	0.000000E+00	error(psi) =	0.000000E+00

Dynamic Aperture Tune Studies
300m Ring

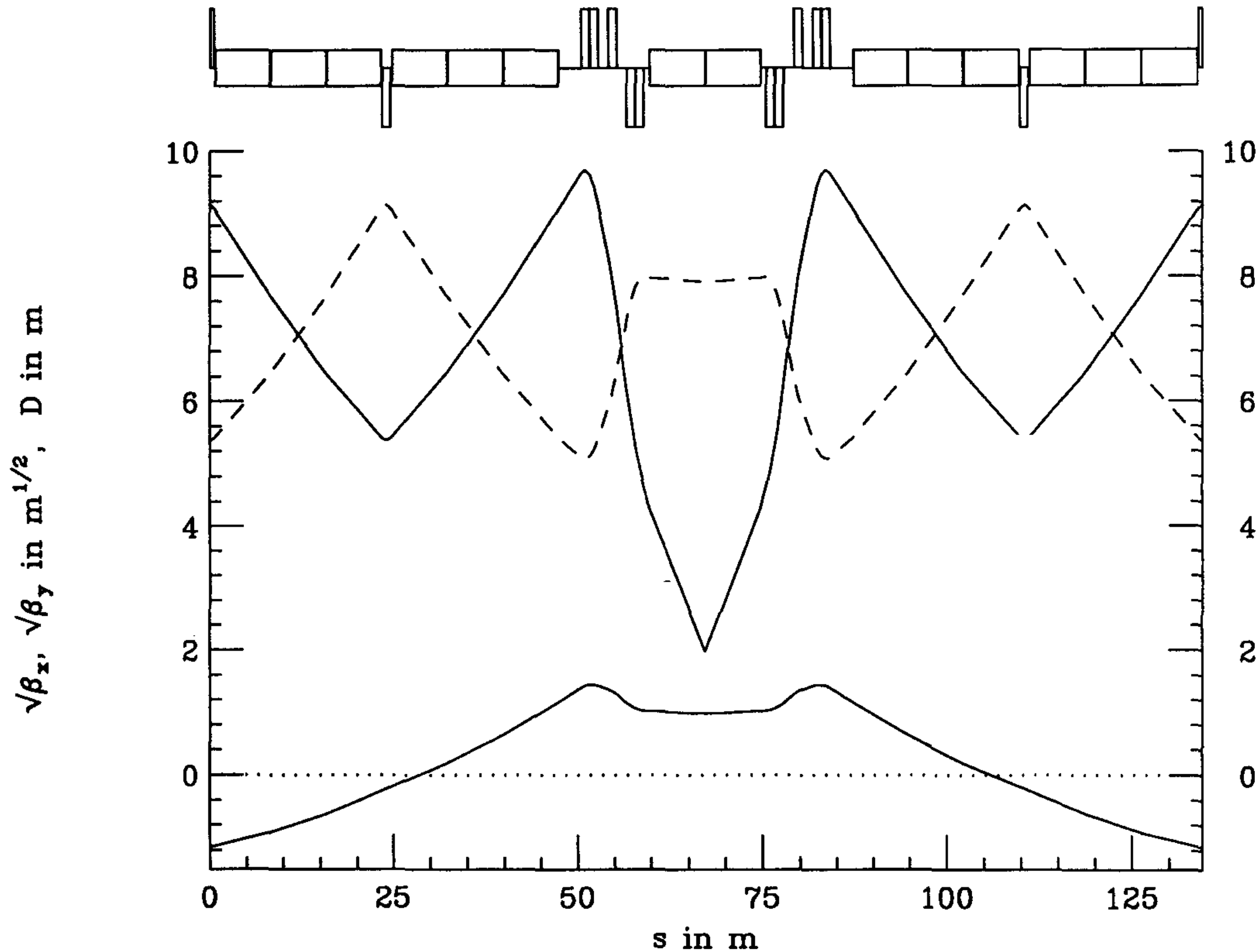




Arc Module 300m Ring



Standard FMC module (D. Trbojevic's lattice)

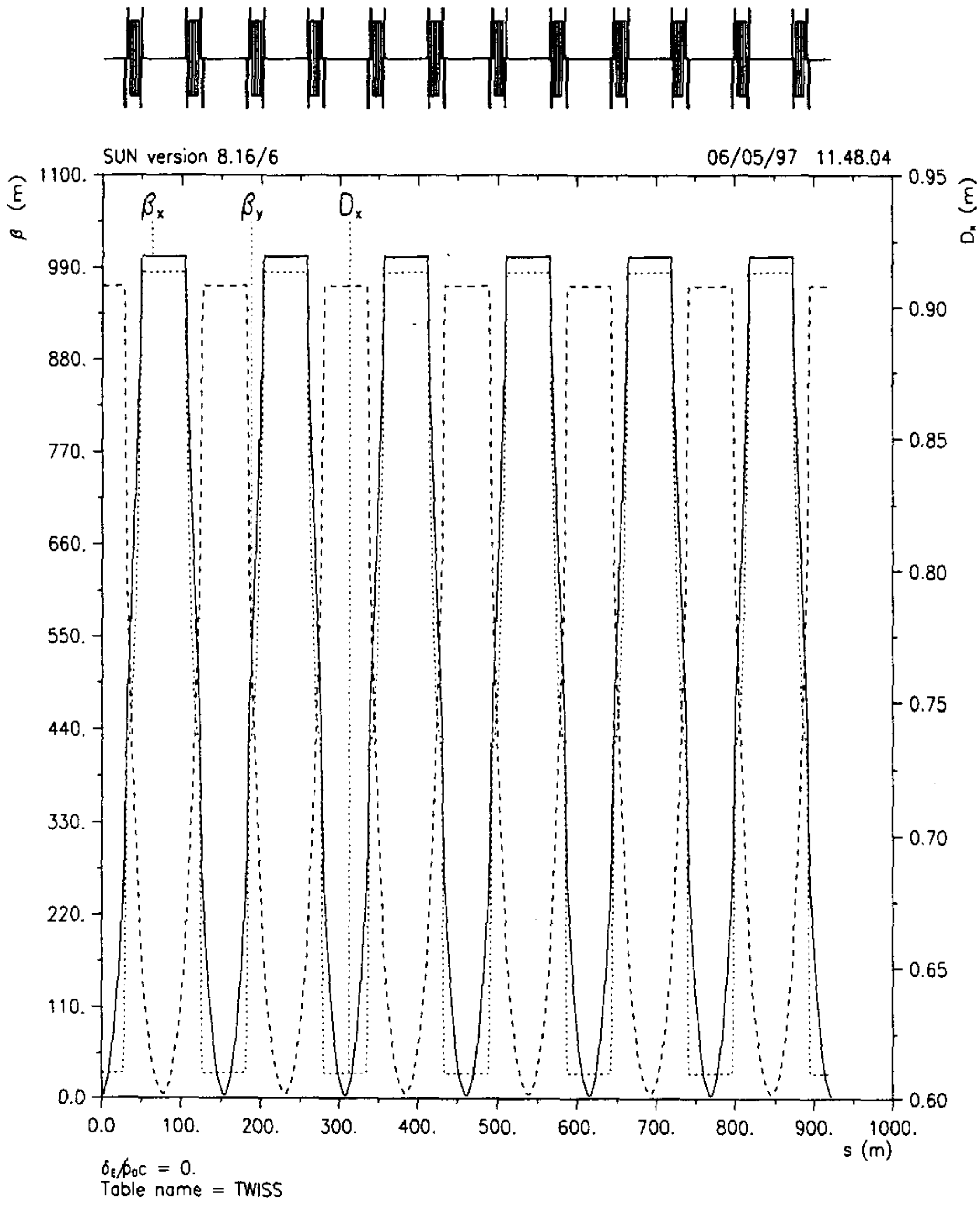


Dispersion max/min: 1.44238/−1.14854m, γ_t: (902.37, 0.00)

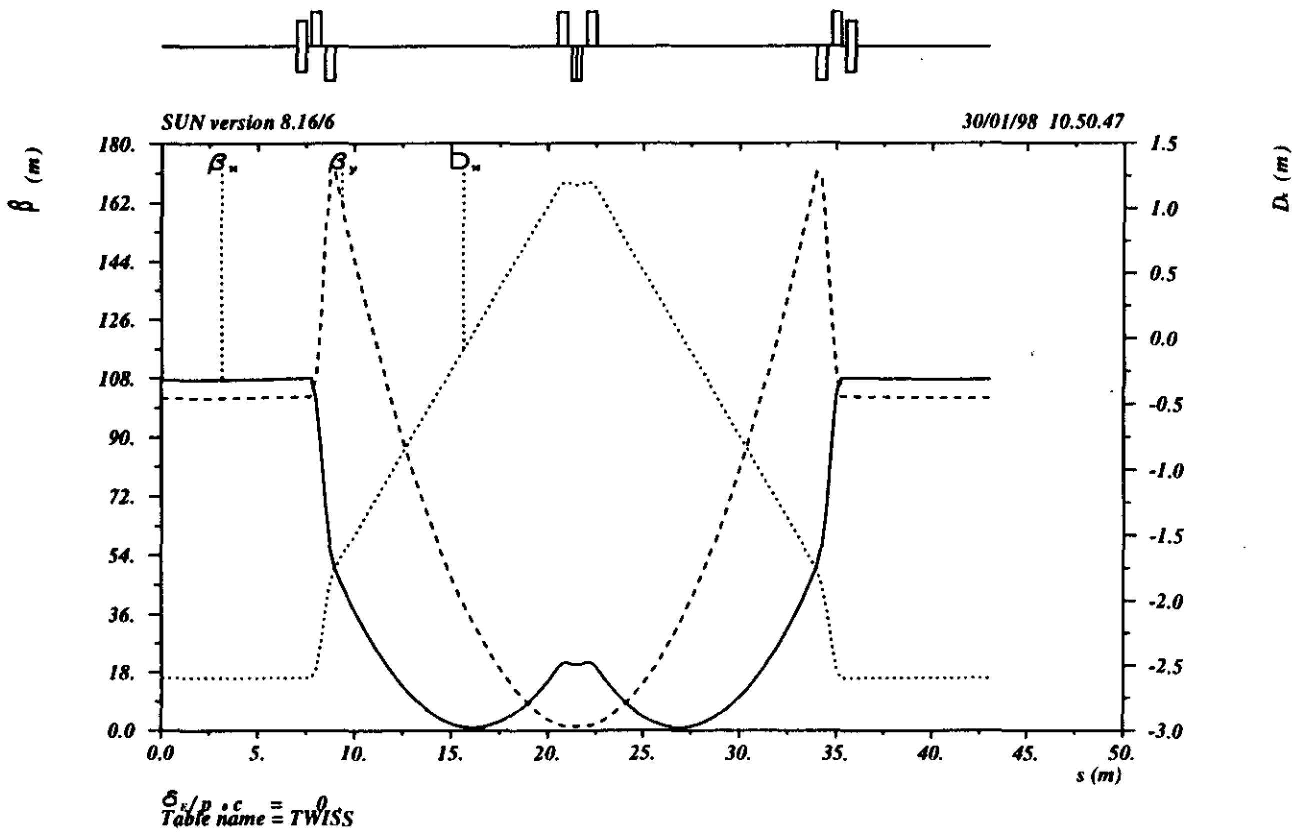
β_x max/min: 93.96/ 3.90443m, ν_x: 0.75000, ξ_x: 0.00, Module length: 134.5706m

β_y max/min: 83.43/25.67548m, ν_y: 0.46951, ξ_y: 0.00, Total bend angle: 0.14074335 rad

2-TeV Scraping Section



New 50-GeV Scraping Section



Tracking Study

W. Wan (FNAL)
Feb 12-13, 1998

Status and Plan

- New tools:
  - — COSY v8.0 (7 - 10 times faster)
  - — new ULTRA SPARC (2 times faster)
- More integrated with design
  - — tune span.
  - — tune shift with amplitude
- Next step
  - — Add resonance strength
  - — Fringe field effect
  - — resonance correction

Feb.12, 1998

M.Atac,FNAL/UCLA

DETECTOR CONCEPTS OF HIGH LUMINOSITY MUON COLLIDERS

OUTLINE

GENERAL PURPOSE STRAWMAN DETECTOR CONCEPTS

a. VERTEX TRACKING

b. INNER TRACKING

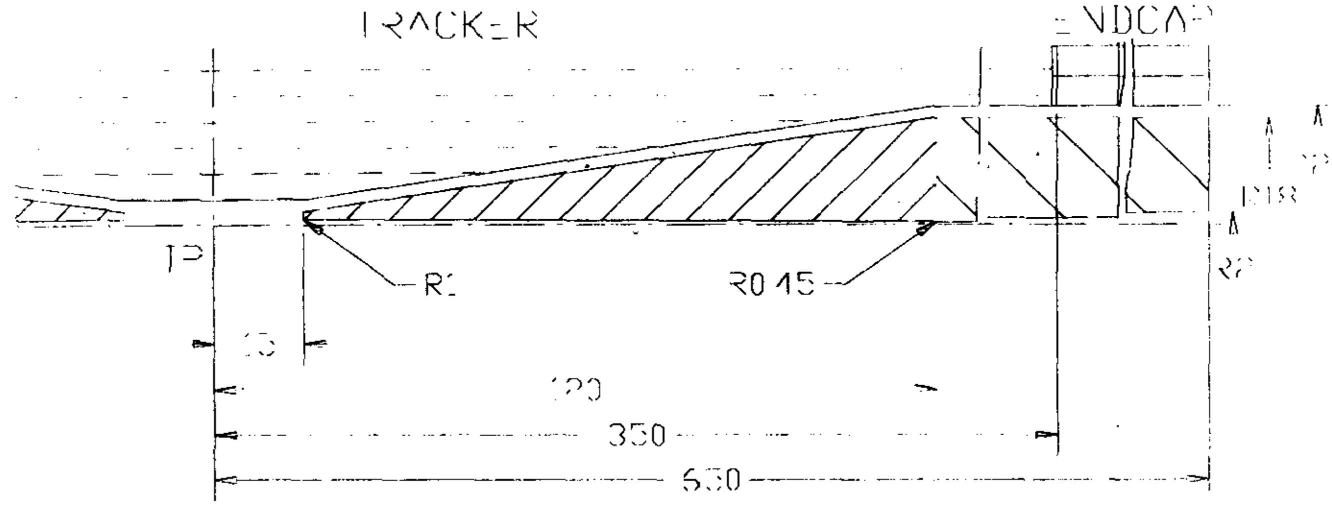
c. OUTER TRACKING

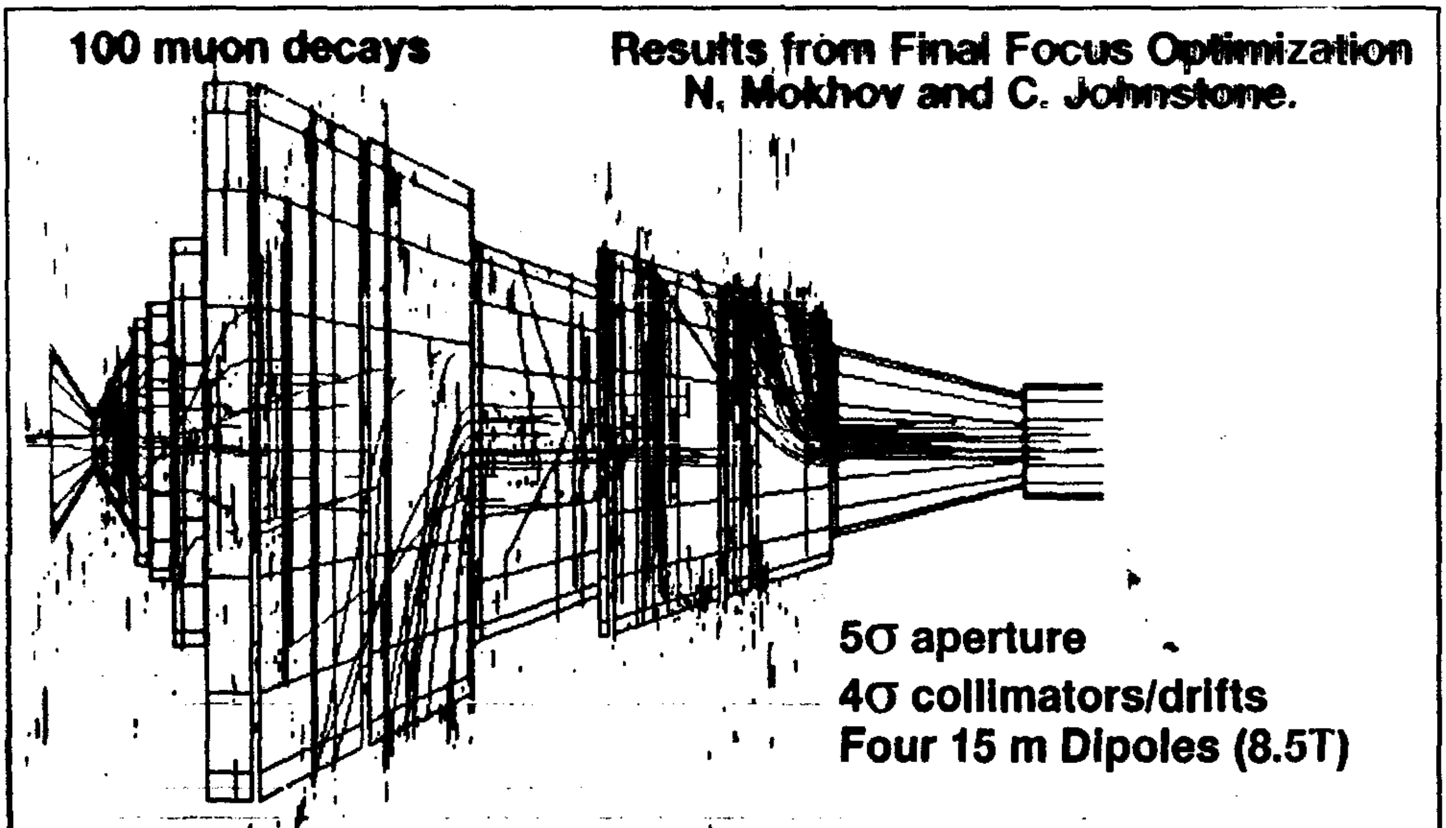
d. EM AND HADRON CALORIMETERS

e. MUON CHAMBERS

MARS Calculation

Uses a somewhat different shielding configuration than the GEANT calculation:





Background List

• Decay Backgrounds:

Two detailed complementary calculations have been performed: GEANT calculation (I. Stumer, BNL), MARS calculation (N. Mokhov, FNAL). The assumed final focus system and shielding configurations assumed for the two calculations are similar in general, but the details are very different.

Both the GEANT and MARS calculations track all particles through the final focus and 2 Tesla detector solenoidal fields and fully simulate:

- Electron showers
- Synchrotron radiation
- Photonuclear interactions
- Bethe–Heitler muon pair production

• Beam Halo:

Beam halo model and beam scraping design being developed, but no results yet.

• Beam–Beam Interactions:

Believed to be small compared with other backgrounds

Hit Density in a Vertex Detector

- Consider a layer of Silicon at a radius of 10 cm. The GEANT results for the radial particle fluxes per crossing yield:

750 photons/cm^2	–>	2.3	Hits/cm^2
110 neutrons/cm^2	–>	0.1	Hits/cm^2
1.3 charged tracks/cm^2	–>	1.3	Hits/cm^2
TOTAL		3.7	Hits/cm^2

- –> 0.4% occupancy in 300 x 300 μm^2 pixels.
- The corresponding numbers at 5cm radius are 13.2 Hits/cm^2 –> 1.3% occupancy.
- This doesnt sound too bad. For comparison, SLD has about 40 Hits/cm^2 on the inner layer of their CCD detector.

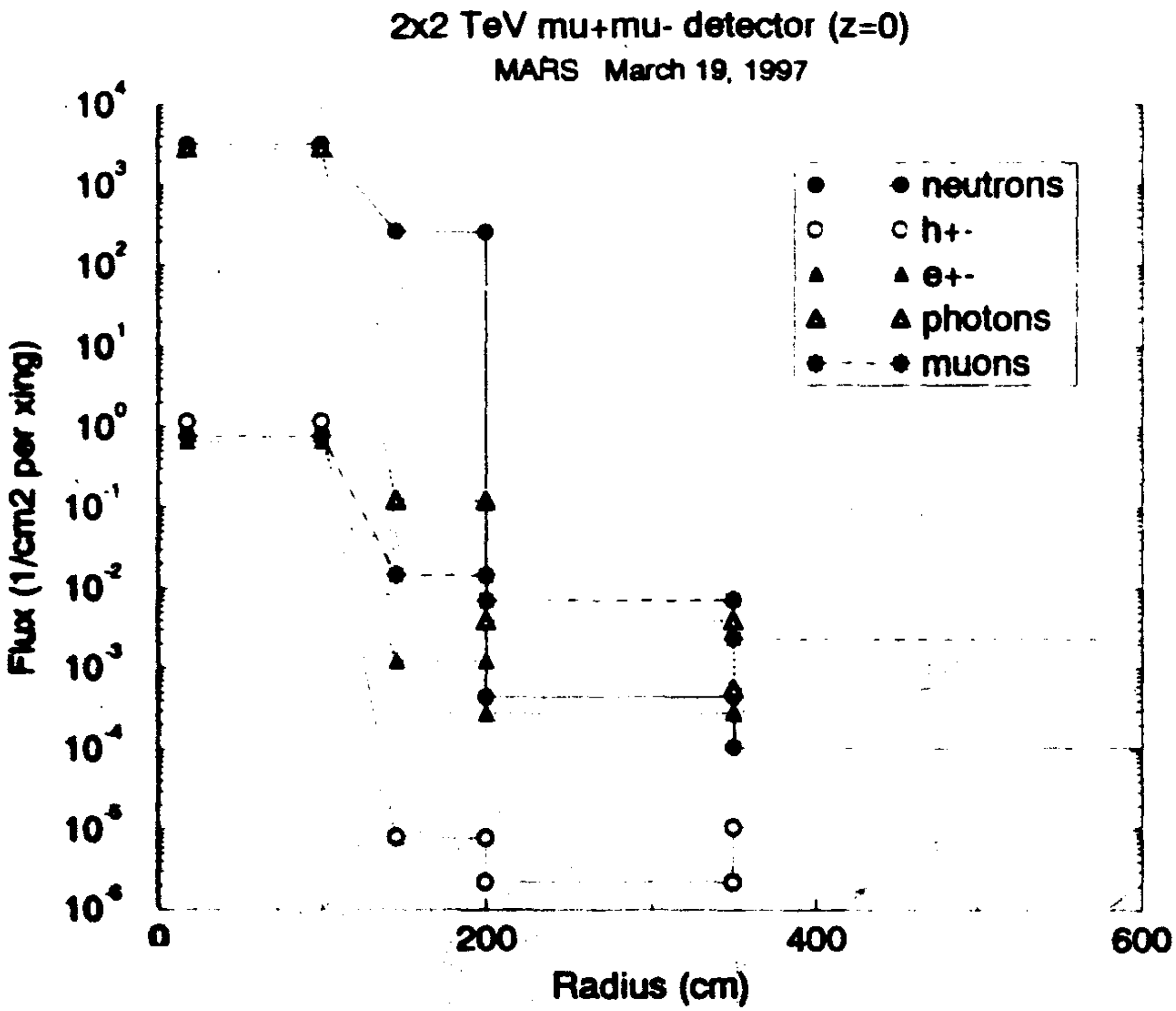
Radiation Dose in Silicon Vertex Detector

- Consider a silicon layer at a radius of 10 cm. The dose due to non-ionizing energy loss can be calculated from the MARS or GEANT results (which give consistent results) taking into account particle type, energy spectra, and fluxes.

$$\phi_{NIEL} = \phi_p + \phi_\pi + 0.5\phi_\mu + 0.1\phi_e + \phi_{n > 0.1\,MeV} + 0.01\phi_\gamma$$

- -> ϕ_{NIEL} = 240 per cm^2 per crossing.

MARS predictions for 1 year (= 10^7 secs) of operation:	
2 x 2 TeV muon collider	$7 \times 10^{13}\ cm^{2}$
LHC at $10^{34}\ cm^{-2}s^{-1}$ (CMS)	$8 \times 10^{13}\ cm^{2}$

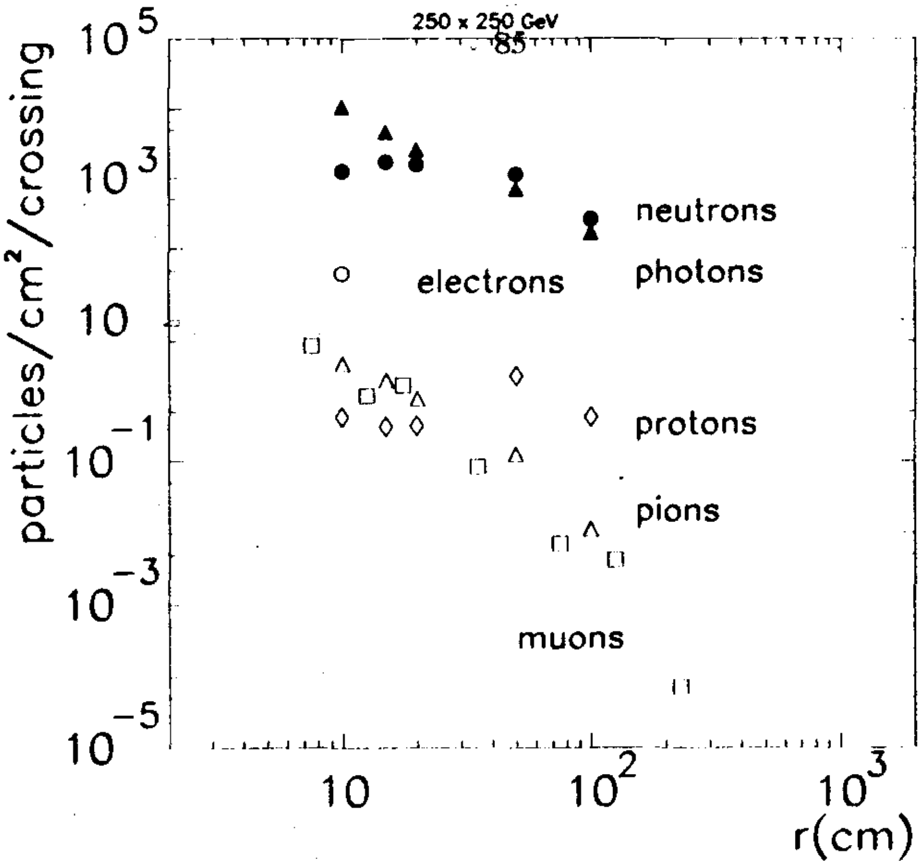


2x2 TeV mu+mu- detector (z=0)
MARS March 19, 1997
Flux (1/cm2 per xing)
Radius (cm)
neutrons
h+-
e+-
photons
muons

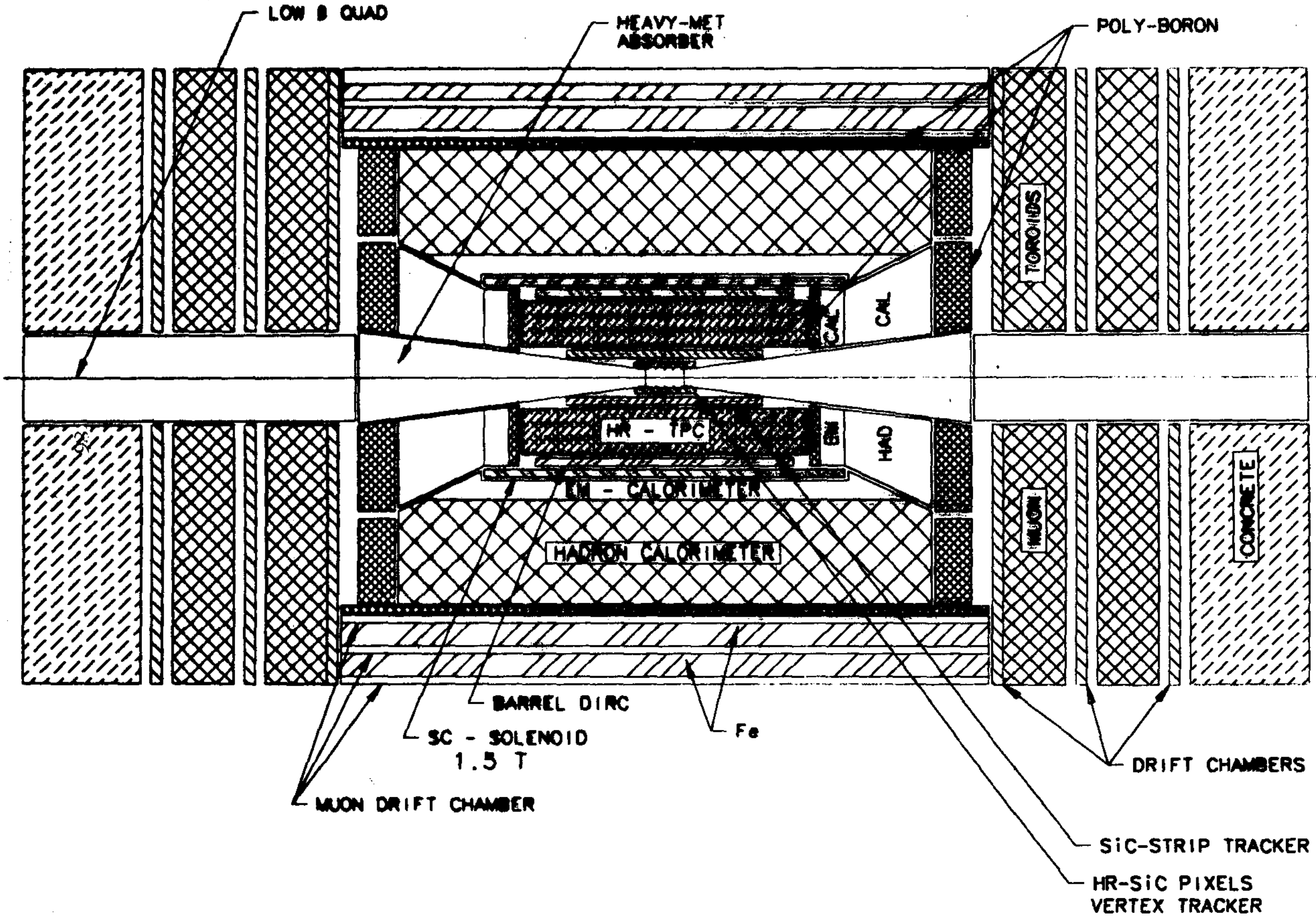
First Muon Collider

- Some GEANT work has been done to calculate backgrounds at a lower enerhy muon collider -> 250 x 250 GeV. This was before the recent improvements to the final focus which led to an order of magnitude reduction in backgrounds:

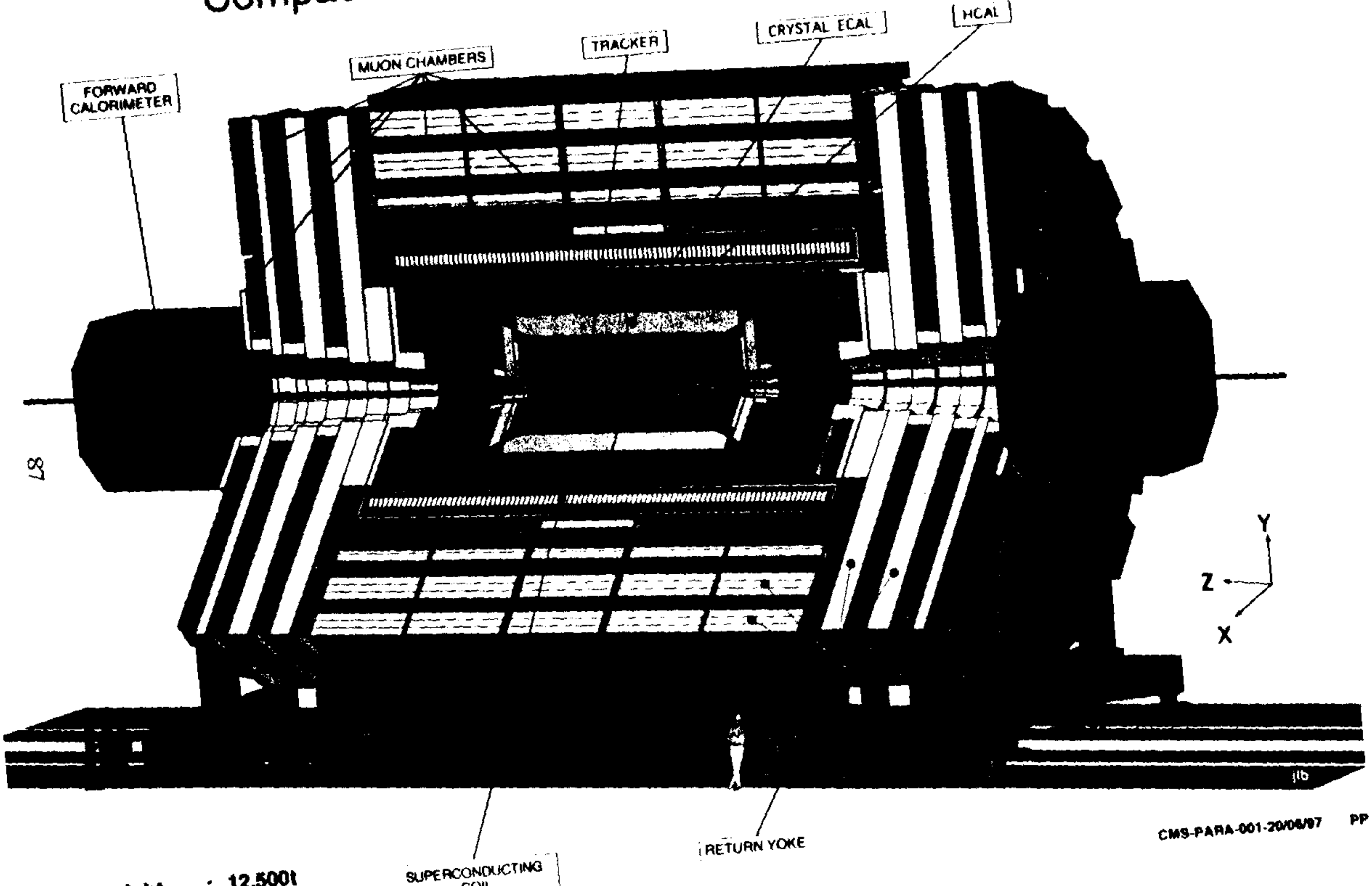
250 x 250 GeV -> 1.5 x 10^6 decays / m



- These background fluxes are comparable to those computed for a 2 x 2 TeV collider .... so we anticipate that the backgrounds at a lower energy machine will be similar to those at the 2 x 2 TeV machine .... EXCEPT the Bethe–Heitler muon background which is much better. A more detailed calculation is being done at BNL.


LOW β QUAD
HEAVY-MET
ABSORBER
POLY-BORON
TOROIDS
CAL
CAL
HR - TPC
EM
HAD
EM - CALORIMETER
HADRON CALORIMETER
MUON
CONCRETE
BARREL DIRC
SC - SOLENOID
1.5 T
Fe
DRIFT CHAMBERS
MUON DRIFT CHAMBER
SiC-STRIP TRACKER
HR-SiC PIXELS
VERTEX TRACKER

CMS
Compact Muon Solenoidal Detector for LHC



Total weight : 12,500t
Overall diameter: 15.00m
Overall length : 21.60m
Magnetic field : 4Tesla

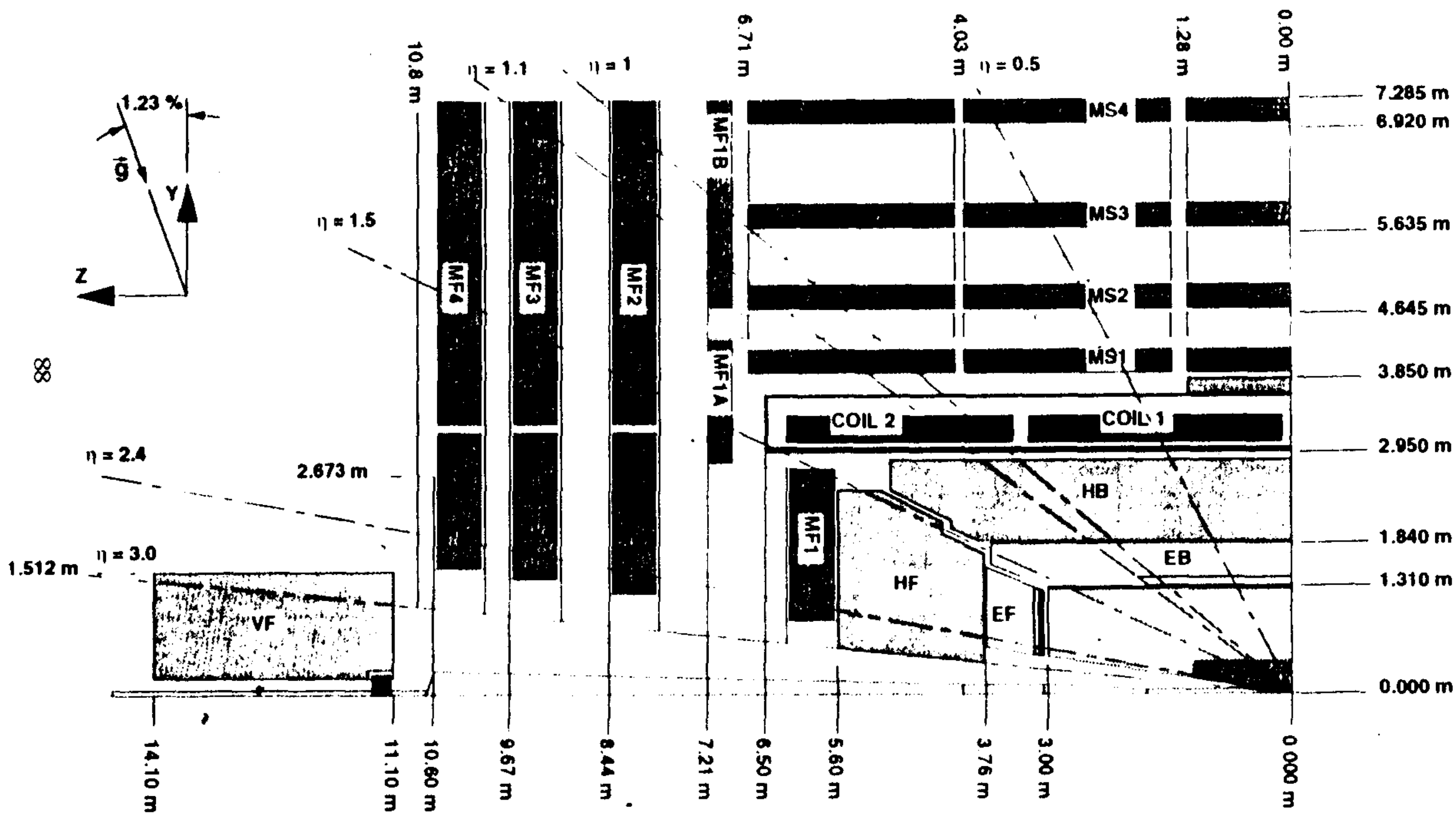


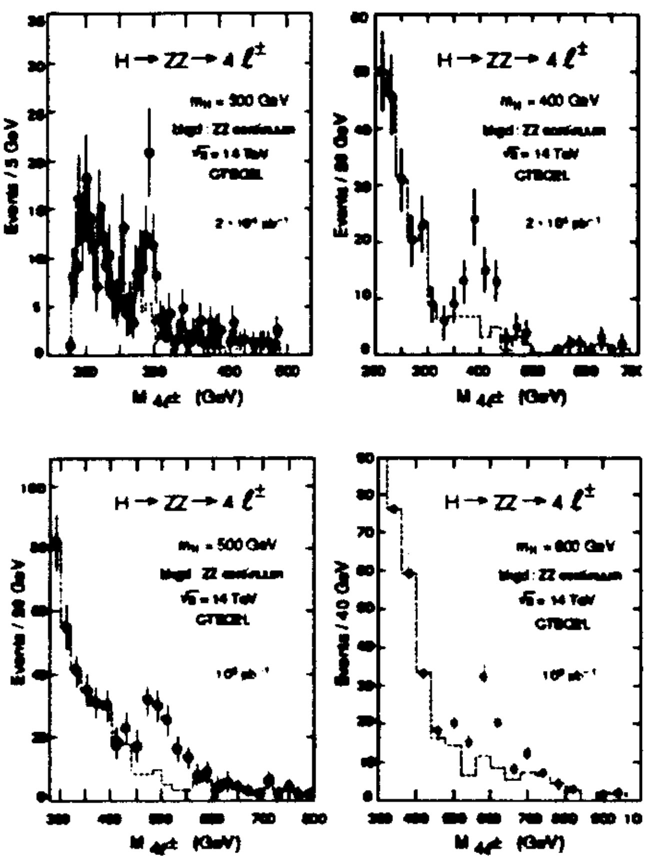
Fig. 1.3: Longitudinal view of the CMS detector

The Higgs → ZZ → 4 Lepton Search will Yield a 5 σ Resonant Signal in 1 year at LHC Design Luminosity

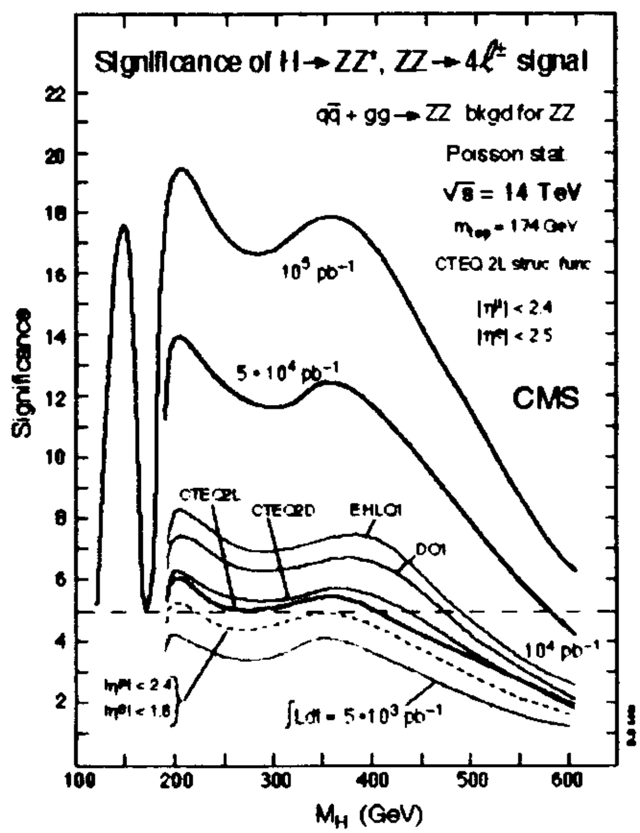
H → ZZ → 4ℓ±

$E_T^e > 20, 15, 10, 10$ GeV; $|\eta^e| < 2.5$

$p_T^\mu > 20, 10, 5, 5$ GeV, $|\eta^\mu| < 2.4$



H → ZZ*, ZZ → 4ℓ±



$h \to b\bar{b}$ in mSUGRA

$m_0 = 500$ GeV, $m_{1/2} = 500$ GeV, $A_0 = 0$, $\tan\beta = 2$, $\mu < 0$

$M(\tilde{g}) = 1224$ GeV $M(\tilde{u}_L) = 1170$ GeV $M(\tilde{t}_1) = 852$ GeV

$M(\tilde{\chi}_2^{\pm}) = 427$ GeV $M(\tilde{\chi}_1^{\pm}) = 217$ GeV $M(h) = 89.7$ GeV

$E_T^{miss} > 400$ GeV
≥ 4 jets, $p_T^{jet} > 40$ GeV, $|\eta^{jet}| < 4.5$
≥ 2 b-jets, closest bb pair, $|\eta^{b-jet}| < 1.75$
circularity > 0.1

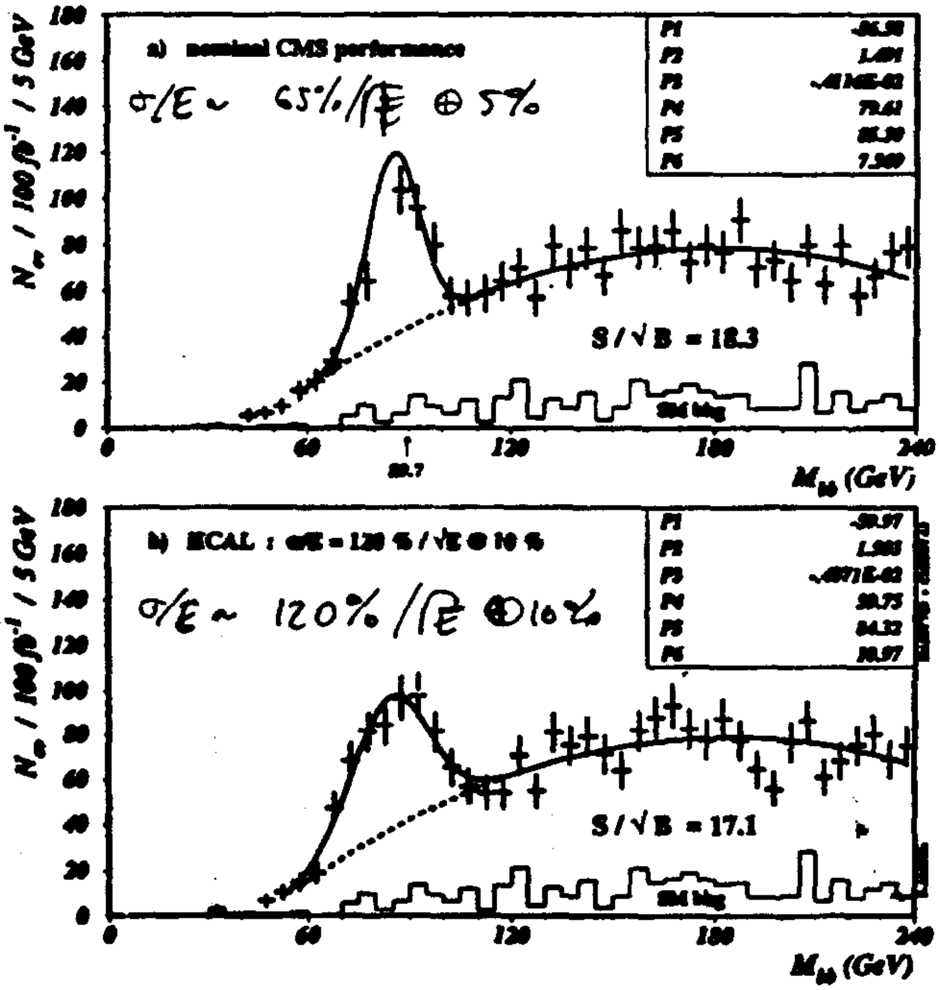
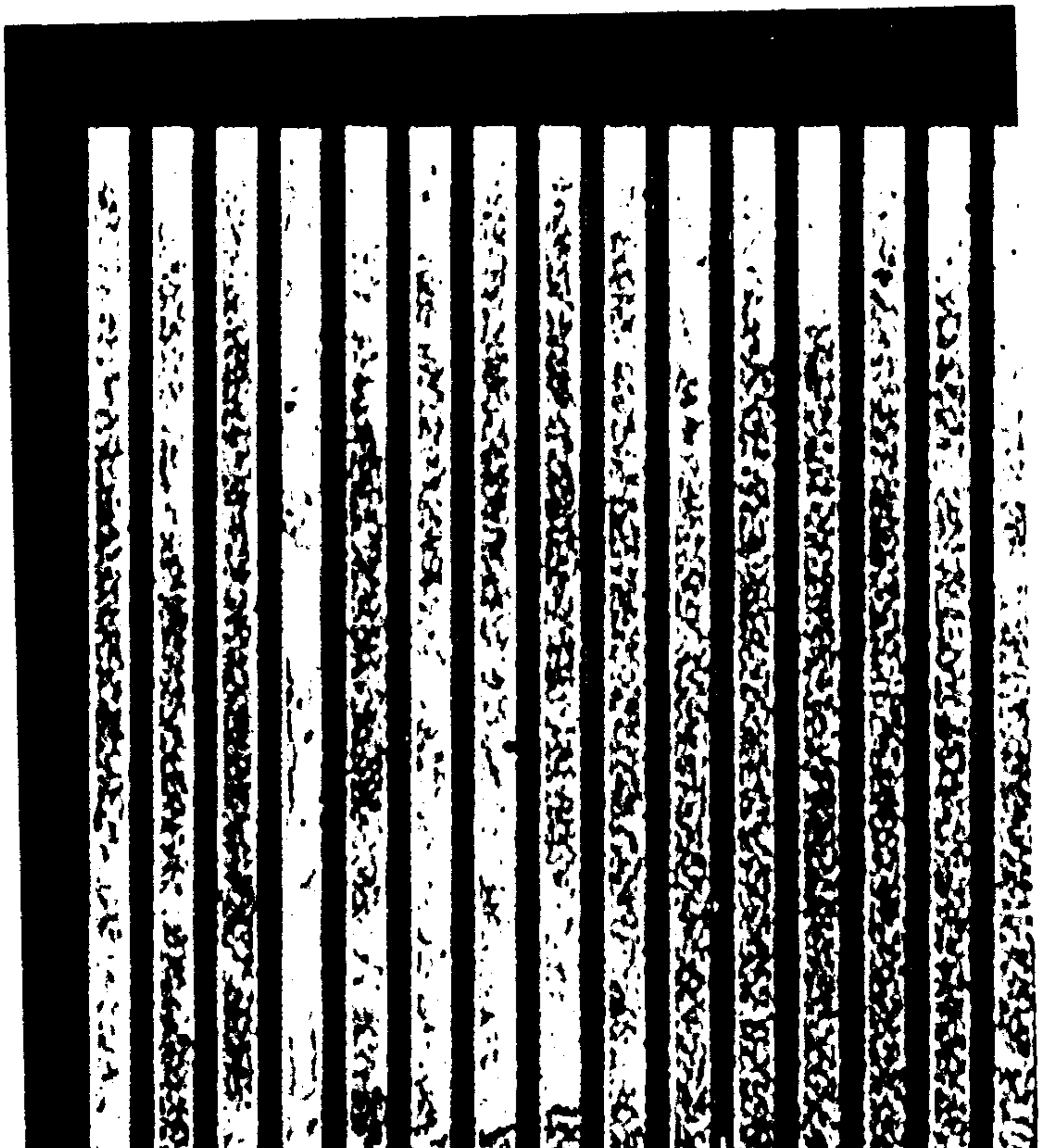


Figure 1

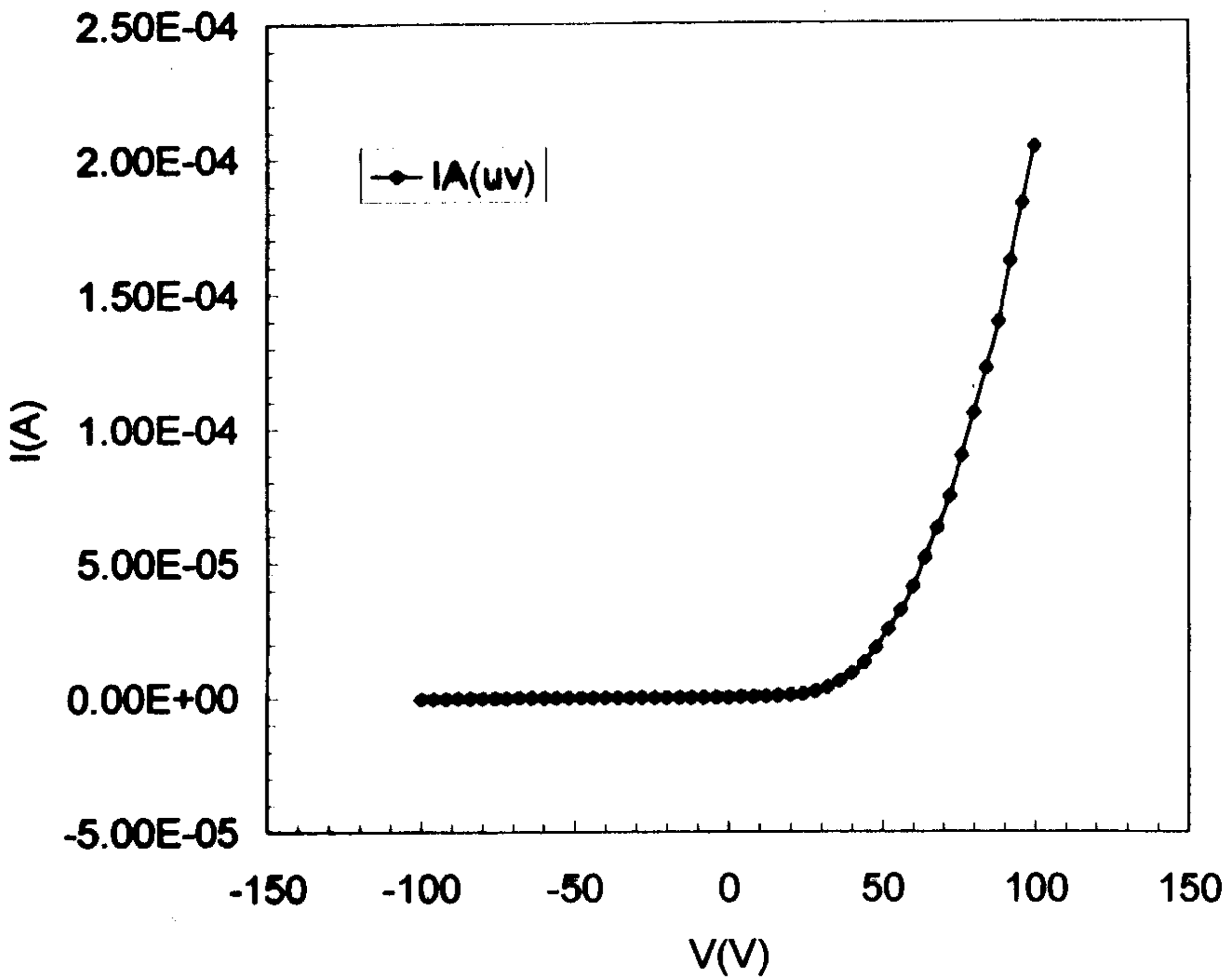
Material property	Silicon	GaAs	3C SiC	4H SiC	Diamond
Bandgap (eV)	1.1	1.43	2.3	3.2	5.5
Resistivity (Ω-cm)	$\sim 10^5$	$\sim 10^8$	-	$\sim 10^7$	$>10^{11}$
Breakdown field (V/cm)	$\sim 10^5$	$\sim 10^5$	1.5×10^6	3×10^6	10^7
Electron mobility ($cm^2/V\text{-}s$)	1350	6000	750	800	1800
Hole mobility ($cm^2/V\text{-}s$)	~480	~400	40	115	1200
Saturation drift velocity (cm/s)	10^7	10^7	2.5×10^7	2×10^7	2.2×10^7
Dielectric constant	11.9	13.1	-	-	5.7
Cohesive energy (eV/atom)	4.63	-	-	-	7.37
Energy to create e-h pair (eV)	3.6	4.2	8.3 (est'd.)	8.3 (est'd.)	13
Ave. Ionized signal/100 μm (# e^-)	9200	13000	6400 (est'd.)	6400 (est'd.)	3600

Table I. Comparison of potential particle detector material properties

SiC

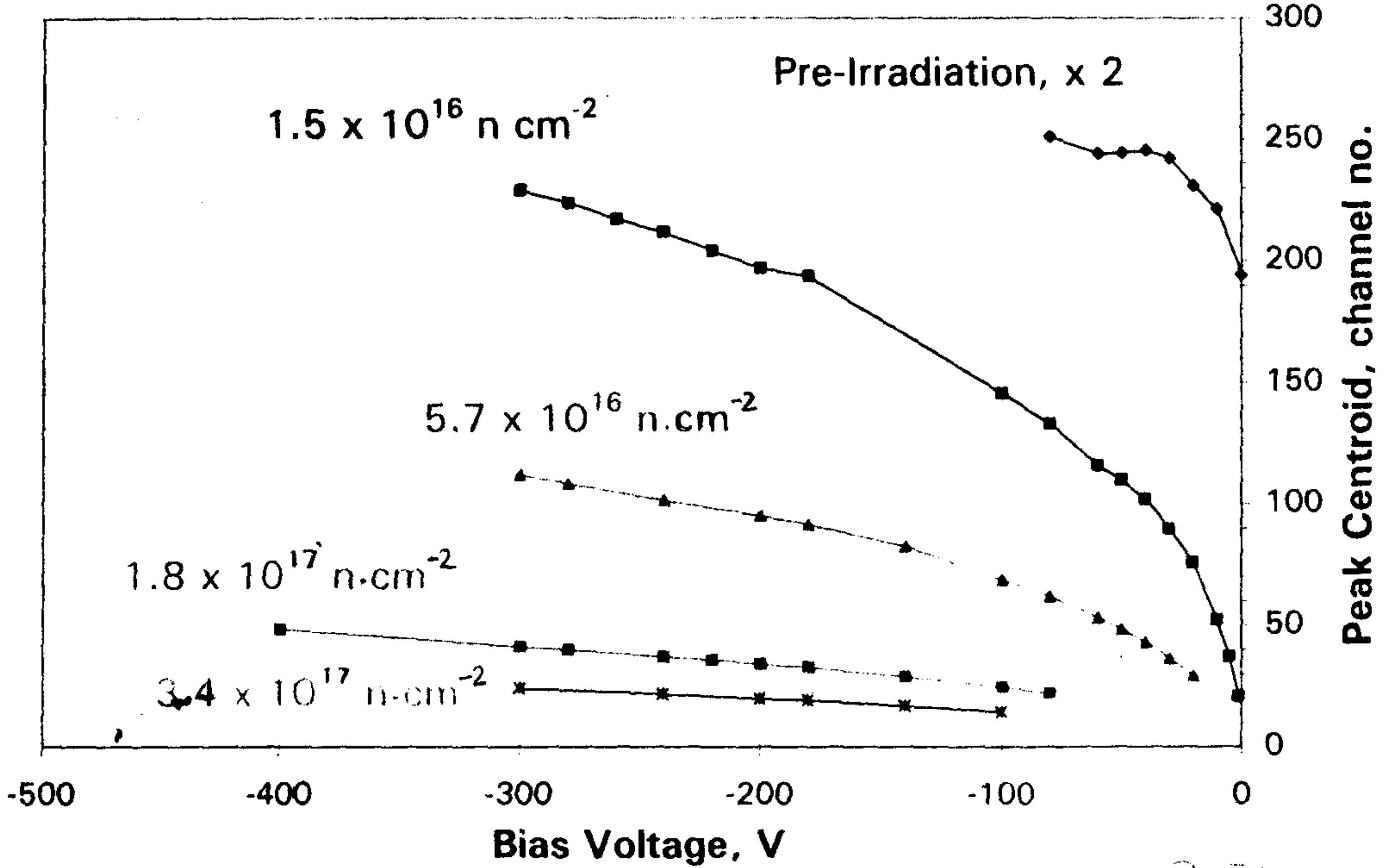


M. ATAC



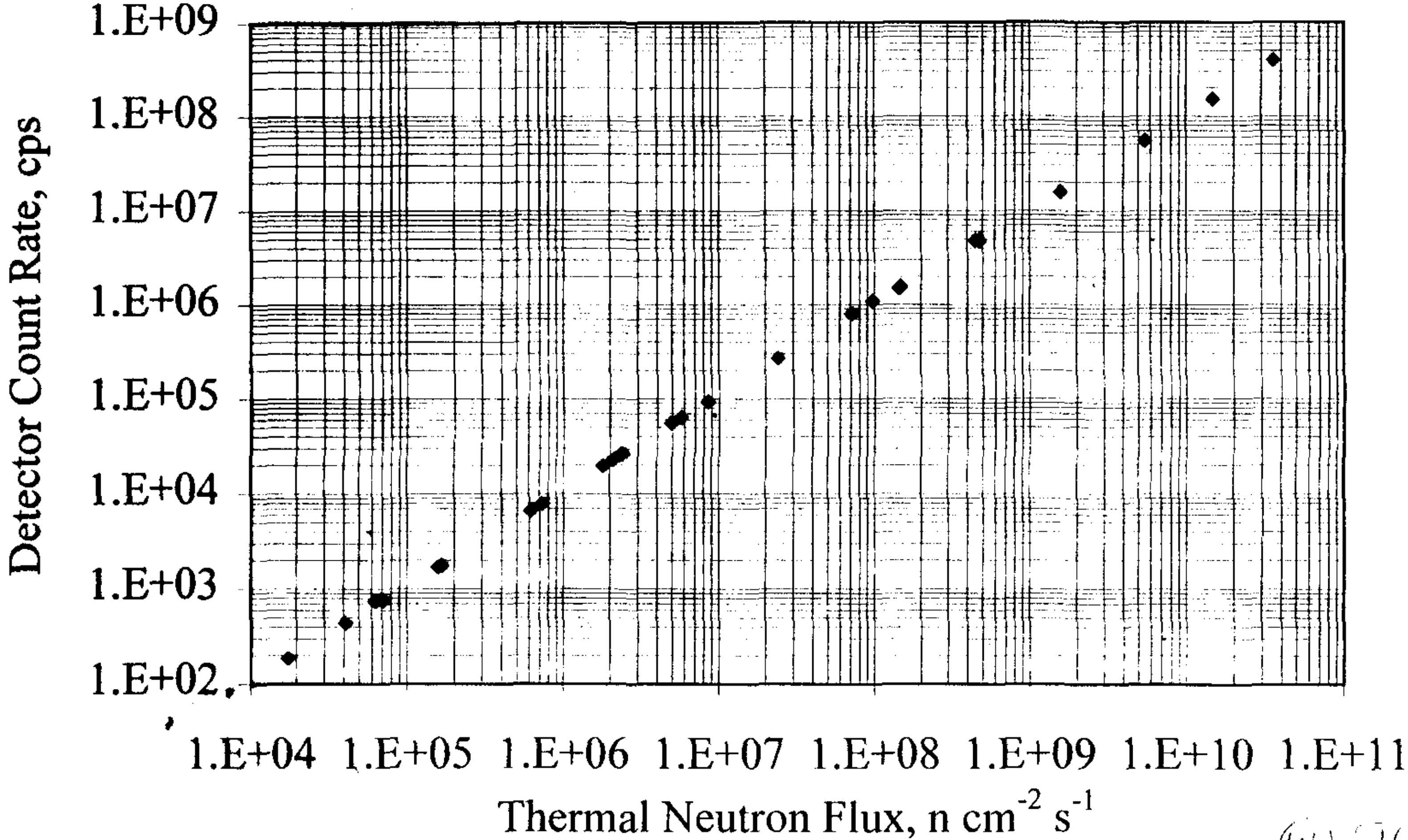
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
-5.00E-05
I(A)
IA(uv)
-150
-100
-50
0
50
100
150
V(V)

Peak Centroid versus Applied Voltage for PN-Junction Diode L12-4

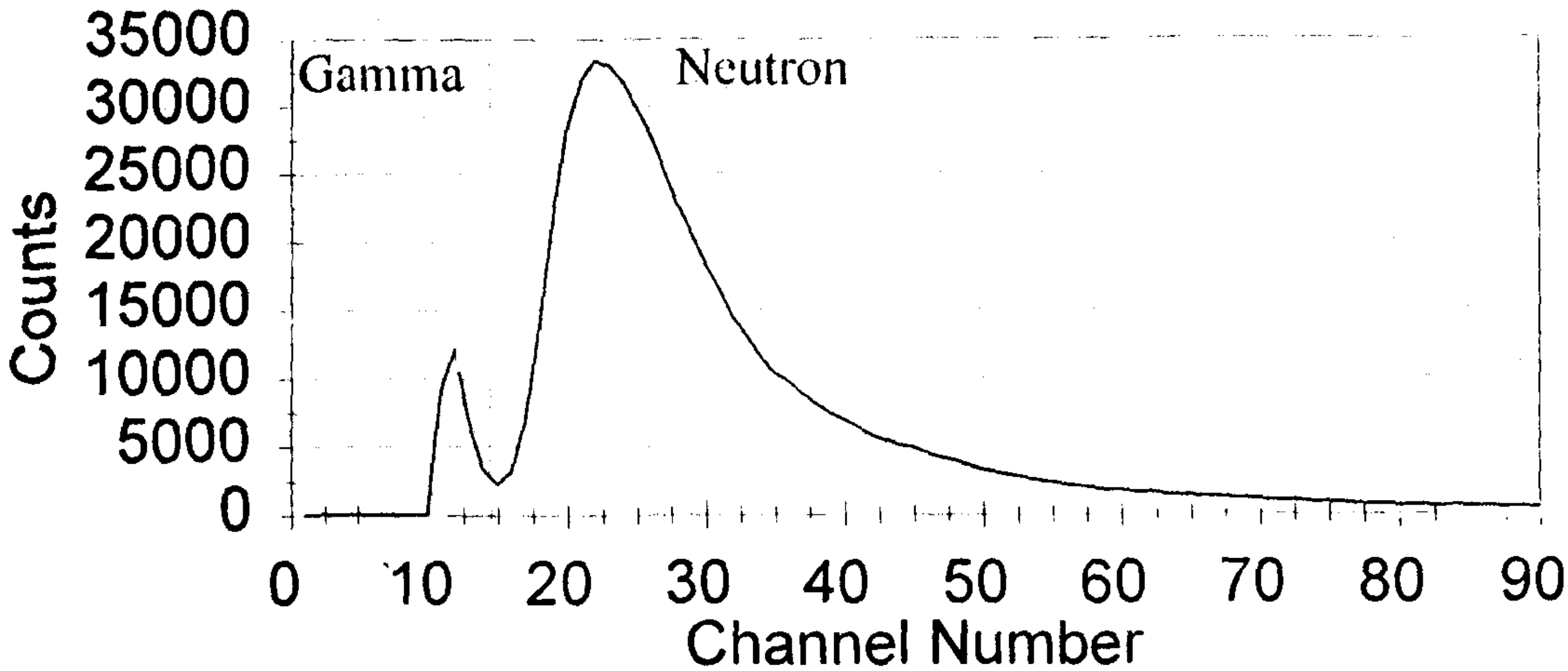


Calibration Function of SiC Detector

Flux Range: 1E4 - 3E10 n cm^{-2} s^{-1}



Separation of Neutron and Gamma Signals



Thermal neutron flux = 3.2E 10 n/sq. cm/s
Gamma field = 50,000 R/h