SSCL-SR-1153 A
SSC-LOI0001-A

SOLENOIDAL DETECTOR COLLABORATION (SDC)

Presentation on Letter of Intent to the SSC Laboratory Program Advisory Committee

December 13, 1990

G. Trilling

SDC

SSCL-SR-1153

SOLENOIDAL DETECTOR COLLABORATION

Universities		Nation.Labs
	U.S.A.	
Brandeis	Brown	Argonne
U.C.L.A.	U.C.R.	Fermilab
U.C.S.D.	U.C.S.C.	Lawrence
Chicago	Colorado	Oak Ridge
Duke	Florida	SSCL
Florida State	Harvard	
Hawaii	Illinois (Chicago)	
Illinois (Urbana)	Indiana	
Johns Hopkins	Maryland	
Michigan	Minnesota	
Mississippi	Notre Dame	
Ohio State	Pennsylvania	
Penn. State	Pittsburgh	
Purdue	Rice	
Rochester	Rockefeller	
Rutgers	Texas A&M	
Texas (Dallas)	Tufts	
Virginia Poly.	Washington	
Wisconsin		
CANADA		
Carleton	McGill	
Toronto	York	

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Universities			Nation. Labs
CHINA			
Beijing			IHEP Beijing
JAPAN			
Fukui	Hiroshima	Kyoto	KEK
Nagoya	Niigata	Osaka City	
Osaka	Saga	Tohoku Gakuin	
Tohoku	Tokyo	Tokyo Inst. of Tech.	
Tokyo Metrop.	Tokyo Agr.&Tech.	Tsukuba (Physics)	
Tsukuba (Applied Physics)			

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Universities			Nation. Labs
	BULGARIA		
Sofia State			
	CZECHOSLOVAKIA		
Bratslava State	Slovak Academy of Science (Kosice)		
	FRANCE		
			CEN Saclay
	GREAT BRITAIN		
Bristol	Liverpool	Oxford	Rutherford-Appleton
	ISRAEL		
Tel-Aviv			
	ITALY		
Pisa			
	ROMANIA		
IPNE Bucharest			
	U.S.S.R.		
Erevan Inst. Phys.	Gomel State		J.I.N.R. (Dubna)
Academy of Science BSSR (Minsk)		Physical Tech. Inst.(Tashkent)	
Inst. High Energy Phys. (Tashkent)		Tbilisi State	

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Other Collaborators Involved In SDC Proposal Preparation

IBM FSD Team
- Dallas Marketing Center
- Houston Laboratory
- Manassas Laboratory
- Owego Laboratory

Space Sciences Laboratory, University of California at Berkeley

Hughes Electro-Optical & Data Systems Group and
Hughes Technology Center

Rockwell International Corporation

RTK Engineering

Silicon Dynamics Inc.

Westinghouse Science and Technology Center

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Some SDC Physics Goals

Study of Electroweak Symmetry Breaking

$H \rightarrow Z + Z \rightarrow (l^+ + l^-) + (l^+ + l^-)$

$\rightarrow (l^+ + l^-) + (\nu + \bar{\nu})$

Top Quark Properties

$t \rightarrow W + b \rightarrow (e/\mu + \nu) + \text{b-jet}$

$(\text{jet} + \text{jet}) + \text{b-jet}$

$t \rightarrow$ other modes

Search for New Heavy Gauge Bosons

$W' \rightarrow e/\mu + \nu, \quad Z' \rightarrow e/\mu^+ + e/\mu^-$

Quark and Lepton Substructure

$p + p \rightarrow$ High p_t jets, $l^+ + l^-$ (Drell-Yan)

Supersymmetry

$\tilde{g} \rightarrow q + \bar{q} + \tilde{\gamma}$

EXPLORATION AND SEARCH FOR NEW PHENOMENA

BENEFITS OF A SOLENOIDAL DETECTOR

- The momentum information makes the detector a fine exploratory tool for the study of a wide range of physics at all p_t and at a wide range of luminosities.
- Determination of electron signs up to at least p_t =1 TeV is provided.
- Momentum/calorimetry provides effective electron ID. Reconstructed segments in outer layers allow an effective high-p_t electron trigger.
- Momentum information is necessary to interpret vertex detector measurements.
- Momentum measurement helps provide in-situ monitoring of calorimetry.
- Muon momenta can be precisely measured.
- Jet fragmentation at high p_t can be studied.
- Charged particle multiplicity for tracks of p_t above a fixed value can be useful for removal of some backgrounds.

NOTE: At the Tevatron, the magnetic detector wants to remain magnetic in its upgrades.
The non-magnetic detector wants to upgrade itself into a magnetic one.

SDC DETECTOR SUMMARY

SOLENOID MAGNET
Tracking Volume: 3.4 m diameter by 8m long

CENTRAL TRACKING AND HIGH RESOLUTION VERTEX DETECTION (COVERING $|\eta| < 2.5$)
Inner Silicon Strip and Pixel Systems
Outer Gas/Wire or Scintillating-Fiber System

PRECISION HERMETIC CALORIMETRY(COVERING $|\eta| < 3$)
(TWO TECHNOLOGIES BEING ENGINEERED):
Scintillating Tile with Fiber Readout with Lead/Iron Absorber
Liquid Argon with Lead Absorber

FORWARD CALORIMETRY(COVERING $3 < |\eta| < 5$)

MUON SYSTEM WITH IRON MAGNETIC TOROIDS (covering $|\eta| < 2.5$)
Tracking Chambers, Scintillation and Cerenkov Counters

ID AND ENERGY MEASUREMENT OF ELECTRONS/MUONS
Electrons: Central Tracking Plus Calorimetry
Muons : Central Tracking Plus Muon System

Comparison of the EoI and LoI

	EoI	LoI
Tracking volume(radius x half-length)(m)	1.8 x 4.5	1.7 x 4.0
Silicon tracker area(m^2)	33	28
Outer(wire) tracker channels(K)	311	238
Calorimeter channels(K)	107	65 - 90
Muon chamber channels(K)	100	108
Muon trigger counter channels(K)	14	16
Total(non-silicon) channels	532	426 - 452
Central calorimeter($\|y\|<3$) candidates	5	2
Solenoid styles	3	1
Intermediate muon toroids	S. C. air-core	Iron

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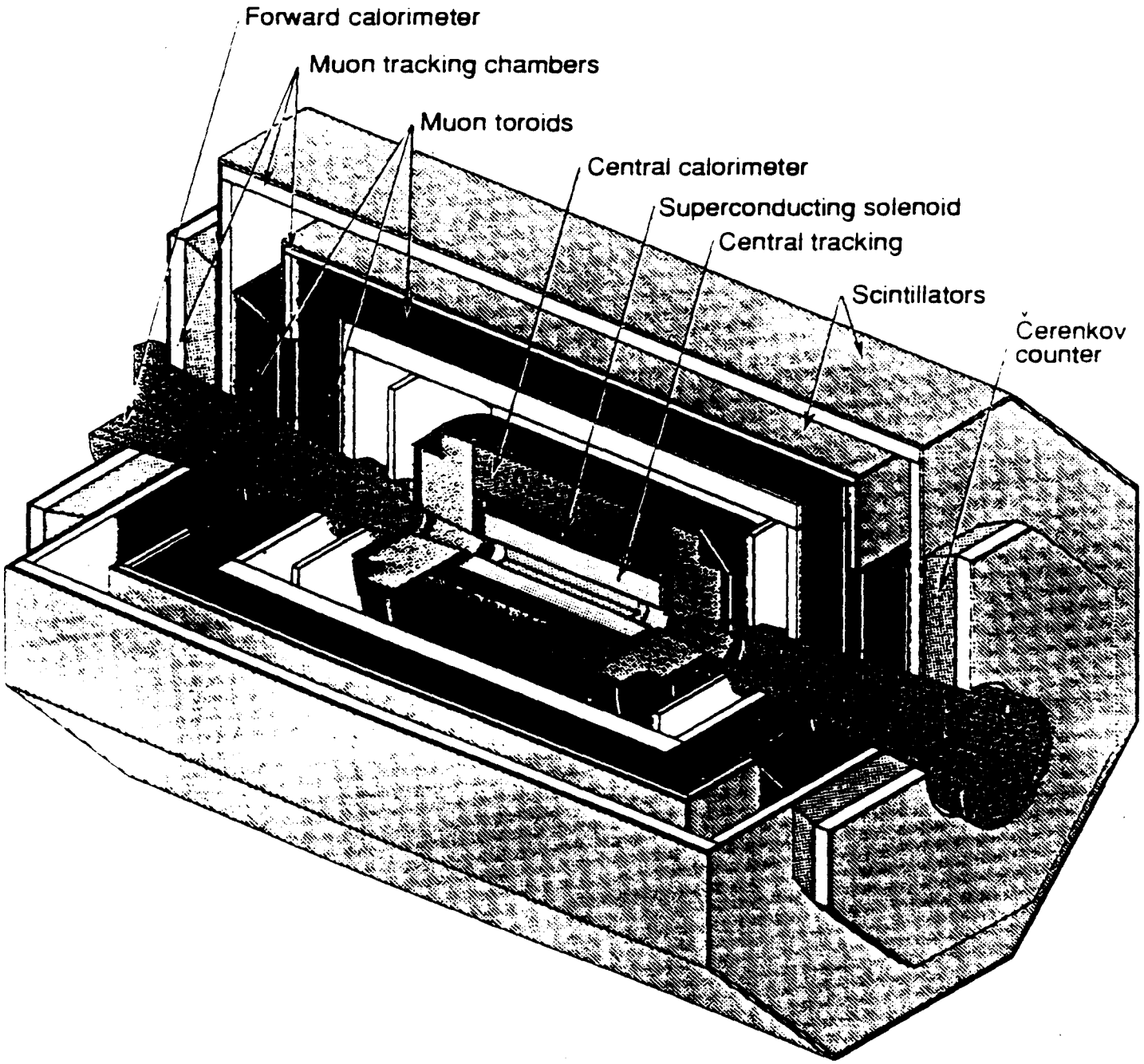
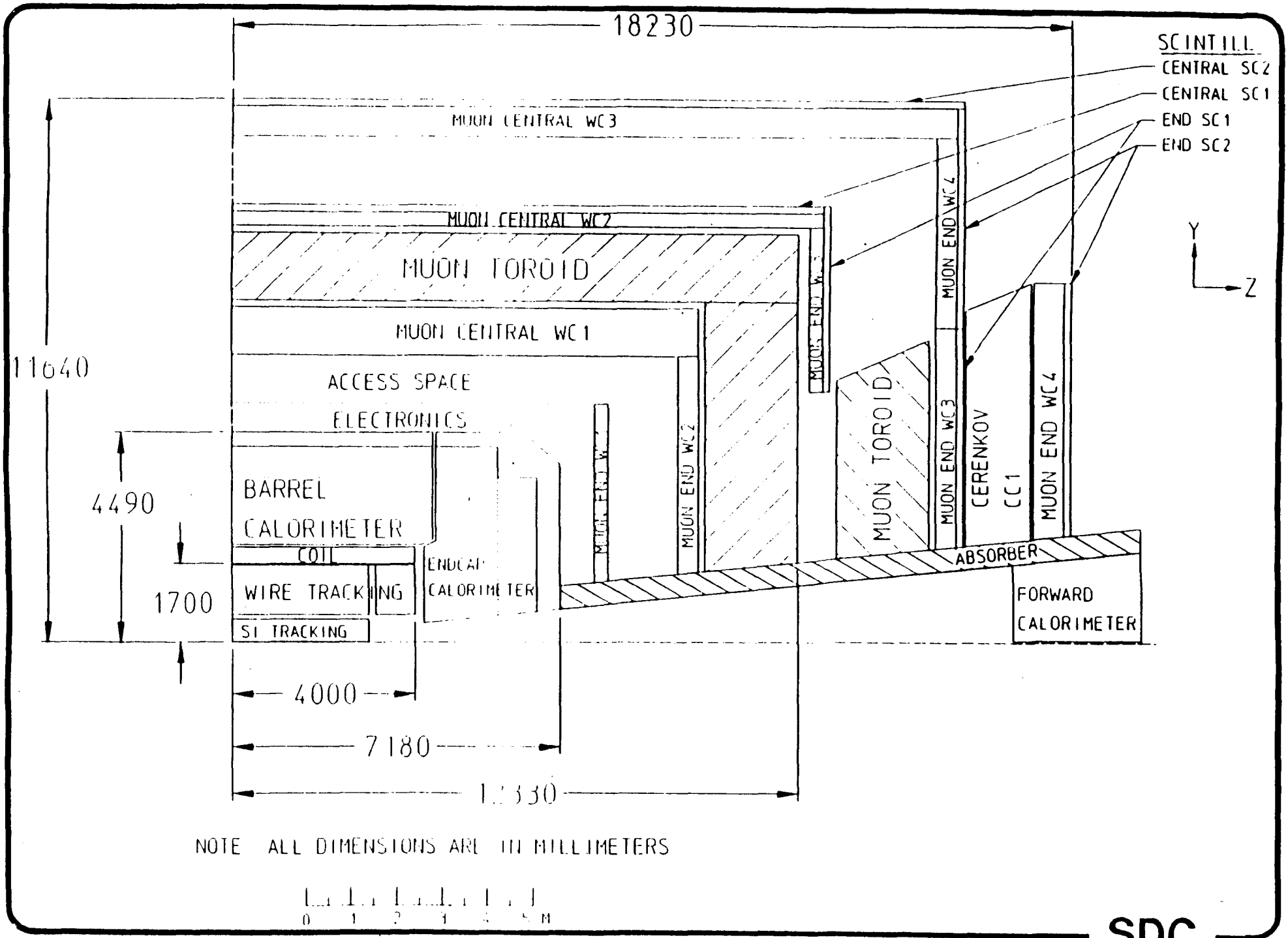

Forward calorimeter
Muon tracking chambers
Muon toroids
Central calorimeter
Superconducting solenoid
Central tracking
Scintillators
Čerenkov counter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SCINTILL.
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CENTRAL SC1
END SC1
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MUON CENTRAL WC3
MUON CENTRAL WC2
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MUON CENTRAL WC1
ACCESS SPACE
ELECTRONICS
BARREL
CALORIMETER
COIL
WIRE TRACKING
SI TRACKING
ENDCAP
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CC1
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ABSORBER
FORWARD
CALORIMETER
11640
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1700
4000
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12330
Y
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NOTE ALL DIMENSIONS ARE IN MILLIMETERS
0 1 2 3 4 5 M

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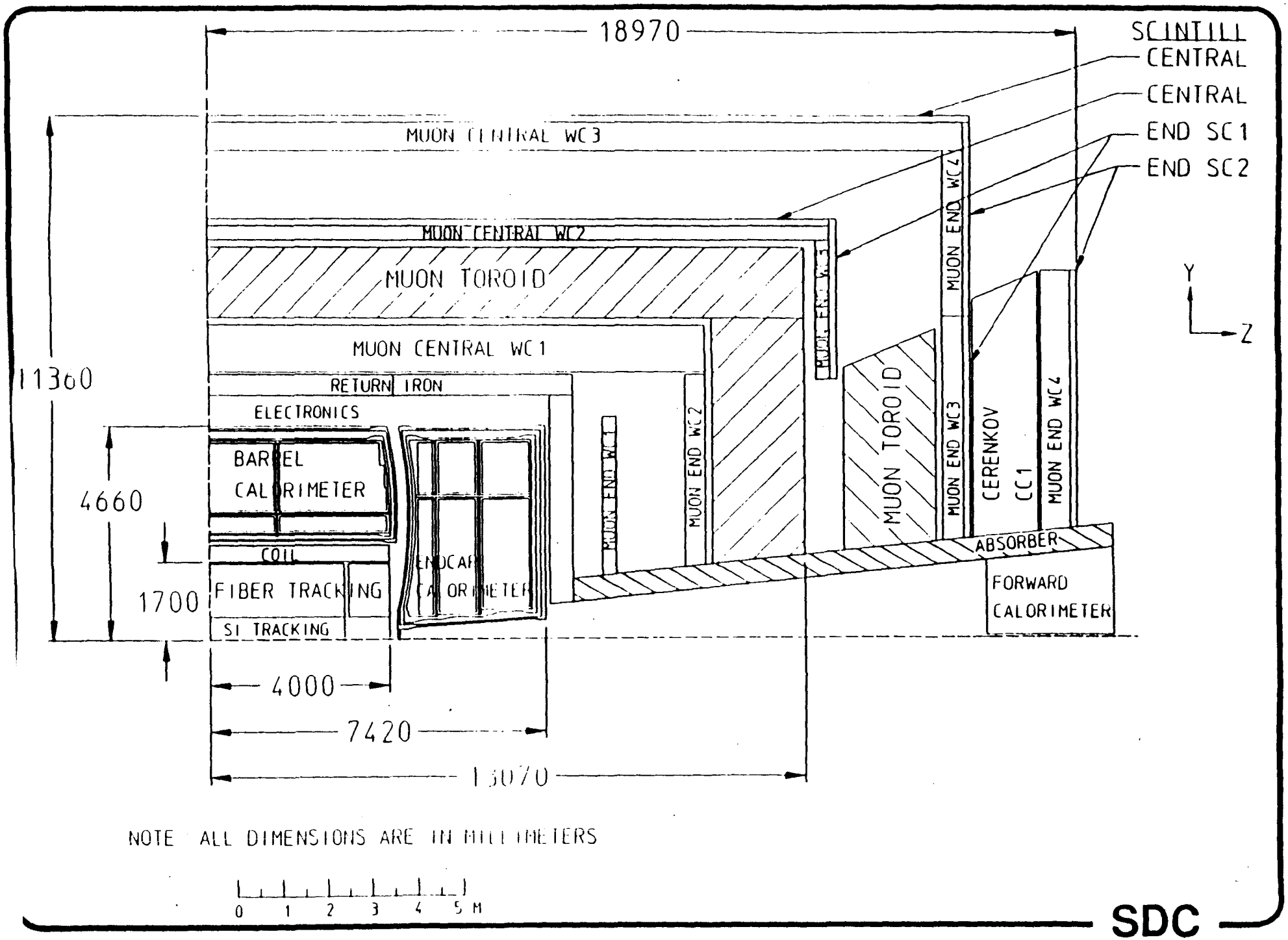
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ELECTRONICS
BARREL CALORIMETER
COIL
FIBER TRACKING
SI TRACKING
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MUON END WC1
MUON END WC2
MUON END WC3
MUON END WC4
MUON TOROID
CERENKOV CC1
ABSORBER
FORWARD CALORIMETER
11360
4660
1700
4000
7420
13070
Y
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NOTE ALL DIMENSIONS ARE IN MILLIMETERS
0 1 2 3 4 5 M
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Detector design goals.

	Central $\lvert\eta\rvert \lesssim 1.5$	Intermediate $1.5 \lesssim \lvert\eta\rvert \lesssim 3.0$	Forward $\lvert\eta\rvert \gtrsim 3.0$
Tracking:			
Magnetic field	2.0 T	2.0 T	No
Radius	1.70 m	1.70 m	
$\delta p_t/p_t^2$ at 1 TeV/c	$< 0.25\ (\mathrm{TeV}/c)^{-1}$	$< 1.3\ (\mathrm{TeV}/c)^{-1}$ [a]	
Calorimeter:			
Inner boundary[b]	2.05 m	4.2 m	17 m
Depth	$\gtrsim 9\lambda$	$\gtrsim 12\lambda$	$\gtrsim 14\lambda$
Segmentation (Had)	0.05–0.10[c]	0.05–0.10[c]	10 cm × 10 cm
Resolution (Had) $\delta E/E$	$< 0.7/\sqrt{E} \oplus 0.04$[d,e]	$< 0.7/\sqrt{E} \oplus 0.04$	$< 1.0/\sqrt{E} \oplus 0.05$
Resolution (EM) $\delta E/E$	$< 0.25/\sqrt{E} \oplus 0.02$	$< 0.25/\sqrt{E} \oplus 0.02$	
Electron ID	Yes	Yes	None
Muon system:			
Total absorber	$\geq 14\lambda$	$\geq 14\lambda$	—
$\delta p_t/p_t^2$ at 1 TeV/c (central tracker plus toroids)	$\lesssim 0.13\ (\mathrm{TeV}/c)^{-1}$	$\lesssim 0.45\ (\mathrm{TeV}/c)^{-1}$ [a]	—

[a] At $\lvert\eta\rvert = 2.5$; full tracking capabilities extend to $\eta = 2.5$.
[b] Radius for central calorimeter and z-position for intermediate and forward calorimeters.
[c] $\Delta\eta = \Delta\phi$.
[d] E is in GeV unless otherwise specified.
[e] Here and elsewhere, $\oplus$ indicates addition in quadrature.

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Superconducting Solenoid

- At the time of the EoI, three magnet styles were under consideration - Types S,I and L - see figure
- Based on detailed studies {see the Report of the SDC Magnet Task Force - SDC-00095(Oct, 1990)}, a single design, Type U, that unifies the type S and I designs, was selected
- This magnet style will be usable with intermediate endcap calorimetry that is either iron loaded or not iron loaded - see field maps
- Substantial R&D is required to prepare for the construction of this magnet
- The R&D will be done by Fermilab, KEK and industrial contractors

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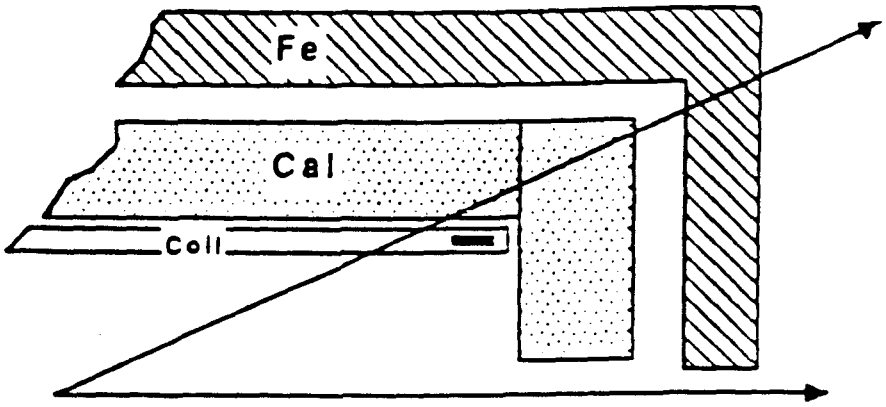
SOLENOID TYPES UNDER CONSIDERATION FOR SDC

TYPE-S



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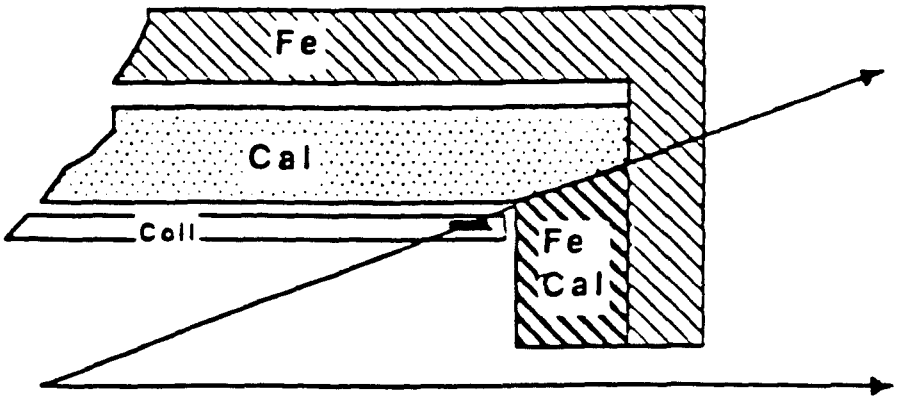

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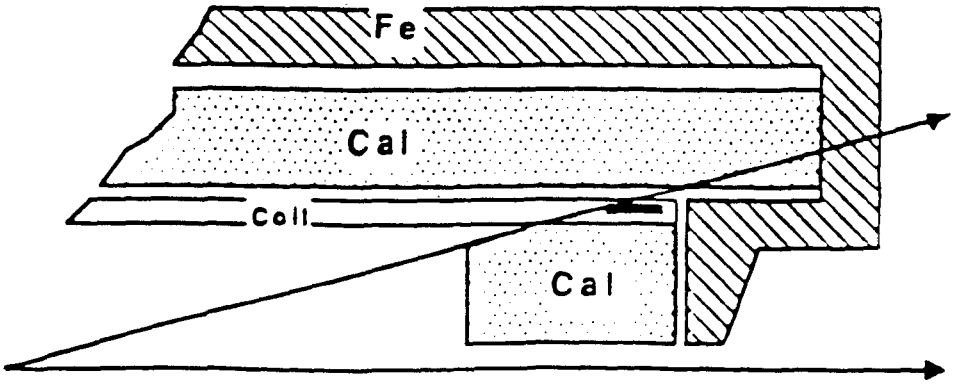
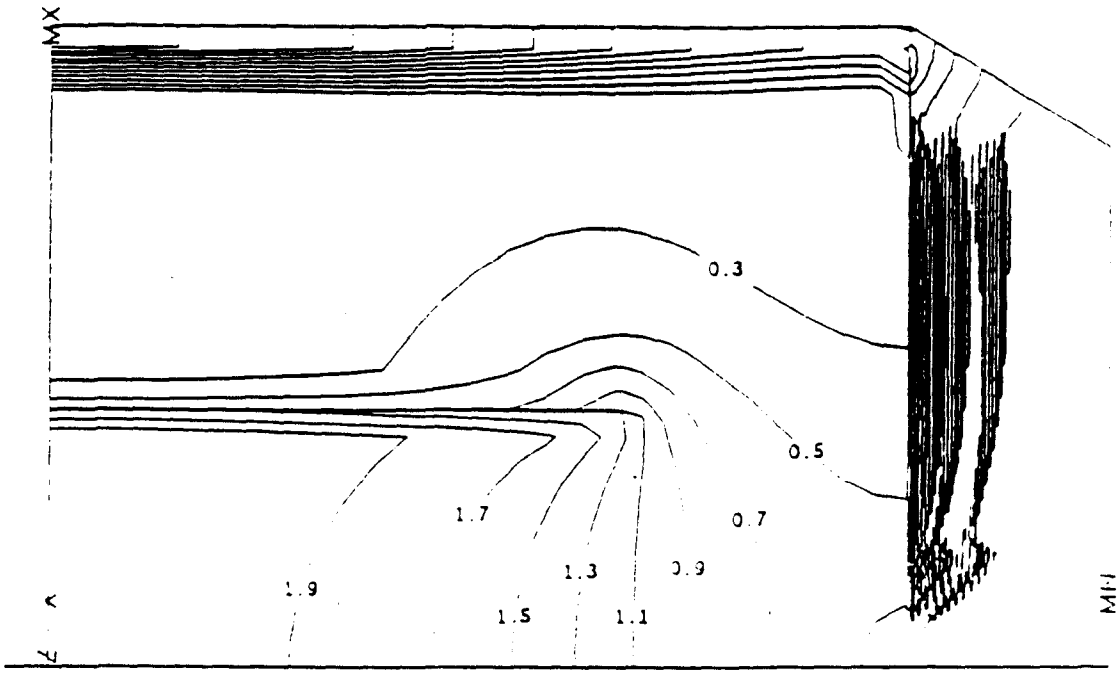
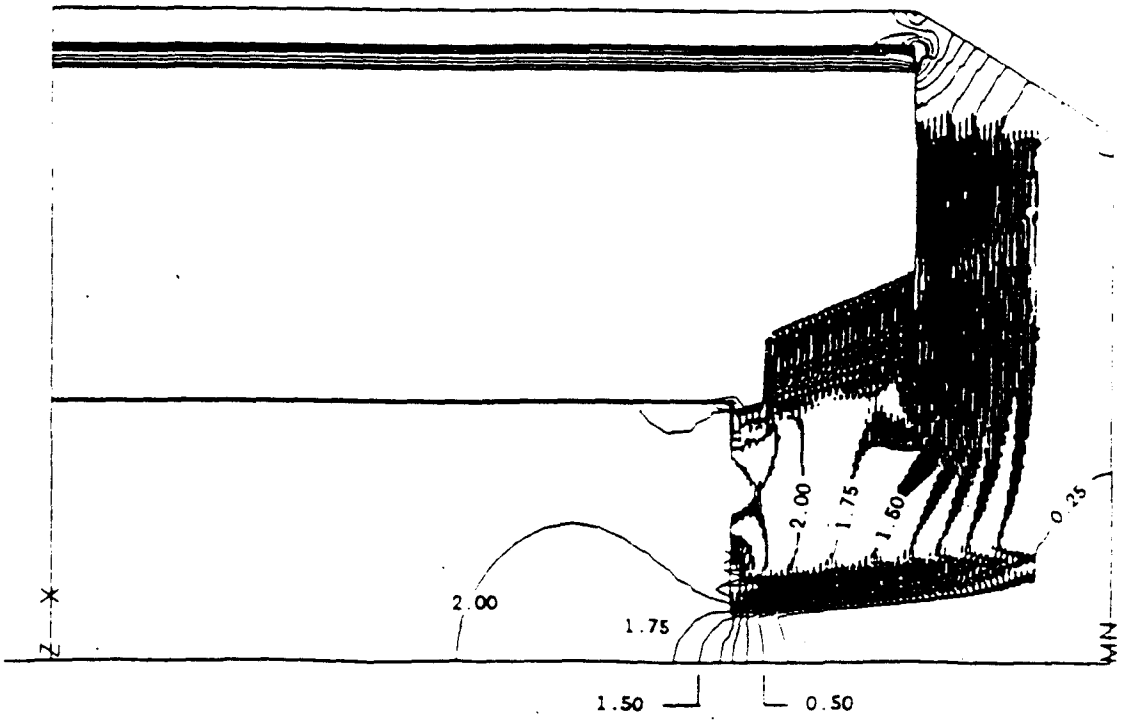


Field map without iron-loaded endcap calorimeter



Field map with iron-loaded endcap calorimeter



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Superconducting Solenoid R&D Plan and Construction Schedule

R&D Schedule
Phase 1: April '91 - April '92
Phase 2: April '92 - April '94

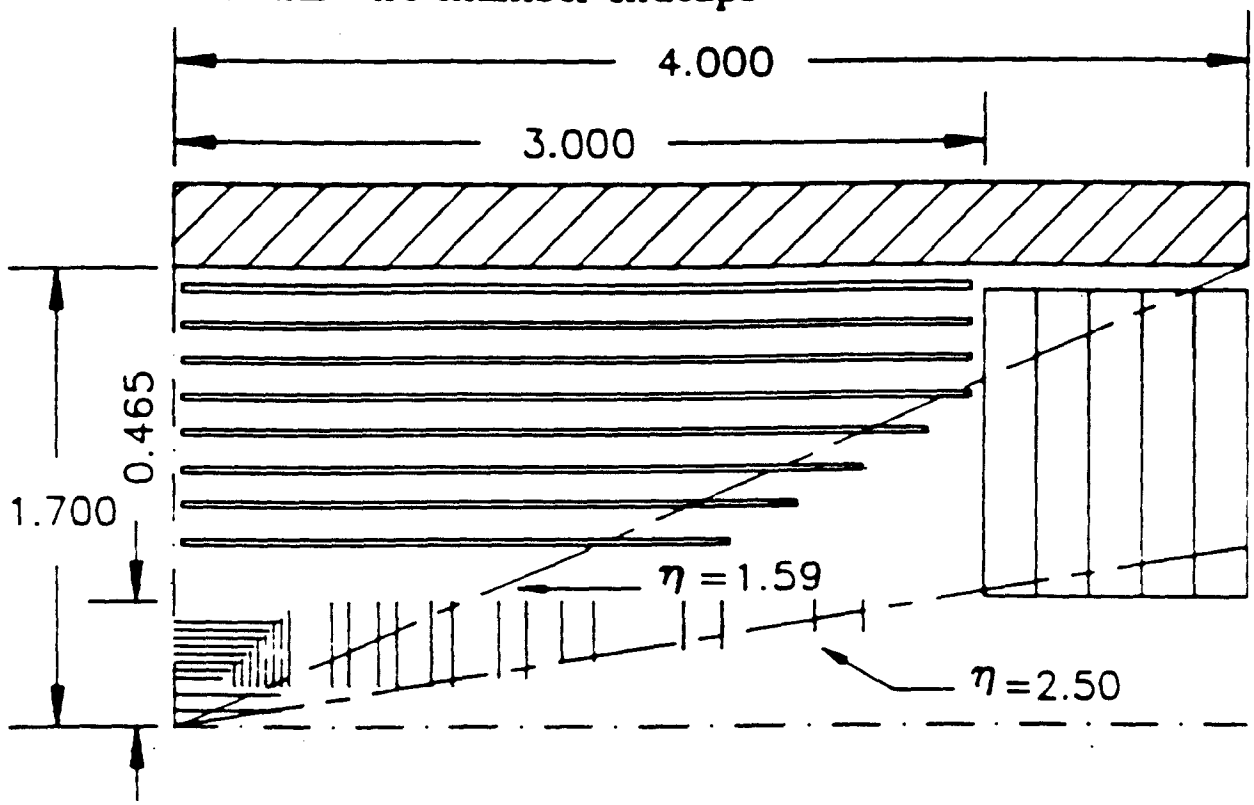
	PHASE 1	PHASE 2
Coil package(KEK)	Al. stabilized conductor Coil winding technique Bonding technique	Prototype coil-full diam. Assemble coil&cryostat
Cryostat&ext. systems (FNAL)	Coil supports Honeycomb studies Cryo.& external systems	Prototype support Proto. honeycomb vessel Cryo&external systems

Preliminary Construction and Installation Schedule
Request for proposal: April '94
Fabricate coil: September '94 - October '96
Test coil in air: November '96 - May '97
Ship coil to SSCL: June '97 - August '97
Install and test coil: September '97 - April '98
Map field: May '98 - June '98

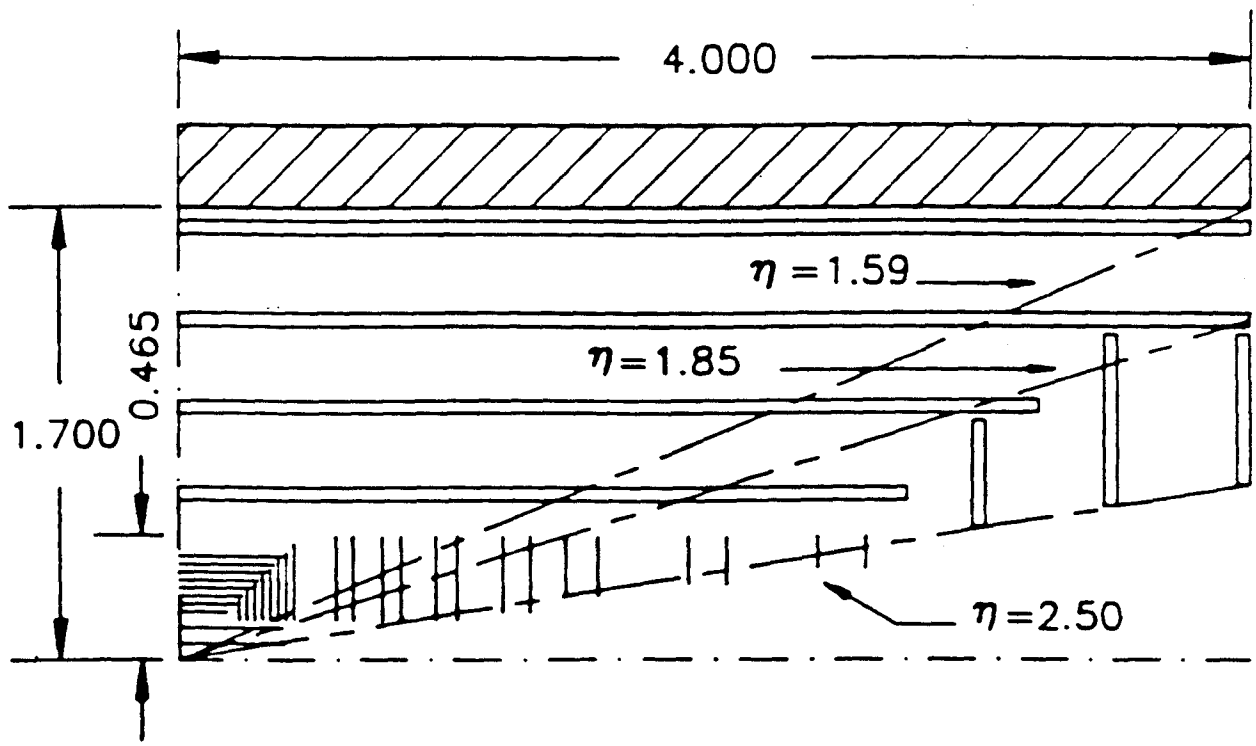
SDC TRACKING SYSTEM

GOALS	Momentum measurement for $\|\eta\| < 2.5$ Provision of fast track trigger
TECHNOLOGIES	Silicon detectors for $R < 50$ cm Wire chambers / Scintillating fibers for $R > 50$ cm
OVERVIEW	$R < 10$ cm Pixel detectors (pattern recognition, vertex detection) $18 < R < 50$ cm Silicon Strips (pattern recognition, momentum meas.) $R > 50$ cm Wire chambers / scintillating fibers (momentum measurement, fast particle trigger)
TRACKING VOL.	R = 1.7 m, Half- length = 4.0 m
GENERAL STATUS	Silicon + gas-wire system look feasible at acceptable cost with adequate performance up to 10^{33}. At higher luminosity, silicon remains viable; however gas-wire appears to have excessive occupancy in most layers. Fibers hold promise of operation at higher luminosity, but feasibility and cost need to be established.

(a) Barrel superlayers of straw tubes,
radial wire chamber endcaps



(b) Scintillating fiber superlayers



SDC

Central Tracking

Detector type	Pixels	Silicon Strips	Outer Wires	Outer Scifi
Total number of elements	3.0×10^7	3.6×10^6	1.9×10^5	1×10^6
Number of superlayers	1	4	8	4
Measuring layers/superlayer	2	4	6 (8)	8 (16)
Approx. occupancy per element (in 2 T field at $\mathcal{L} = 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	10^{-4}	10^{-3}	10^{-1}	10^{-2}
Total radiation lengths at normal incidence	1.5%	5%	4.5%	6.7%
Resolution/measurement	10 μm × 100 μm	15 μm	150 μm	(text)
Two-track resolution	100 μm × 500 μm	150 μm	2 mm	1 mm

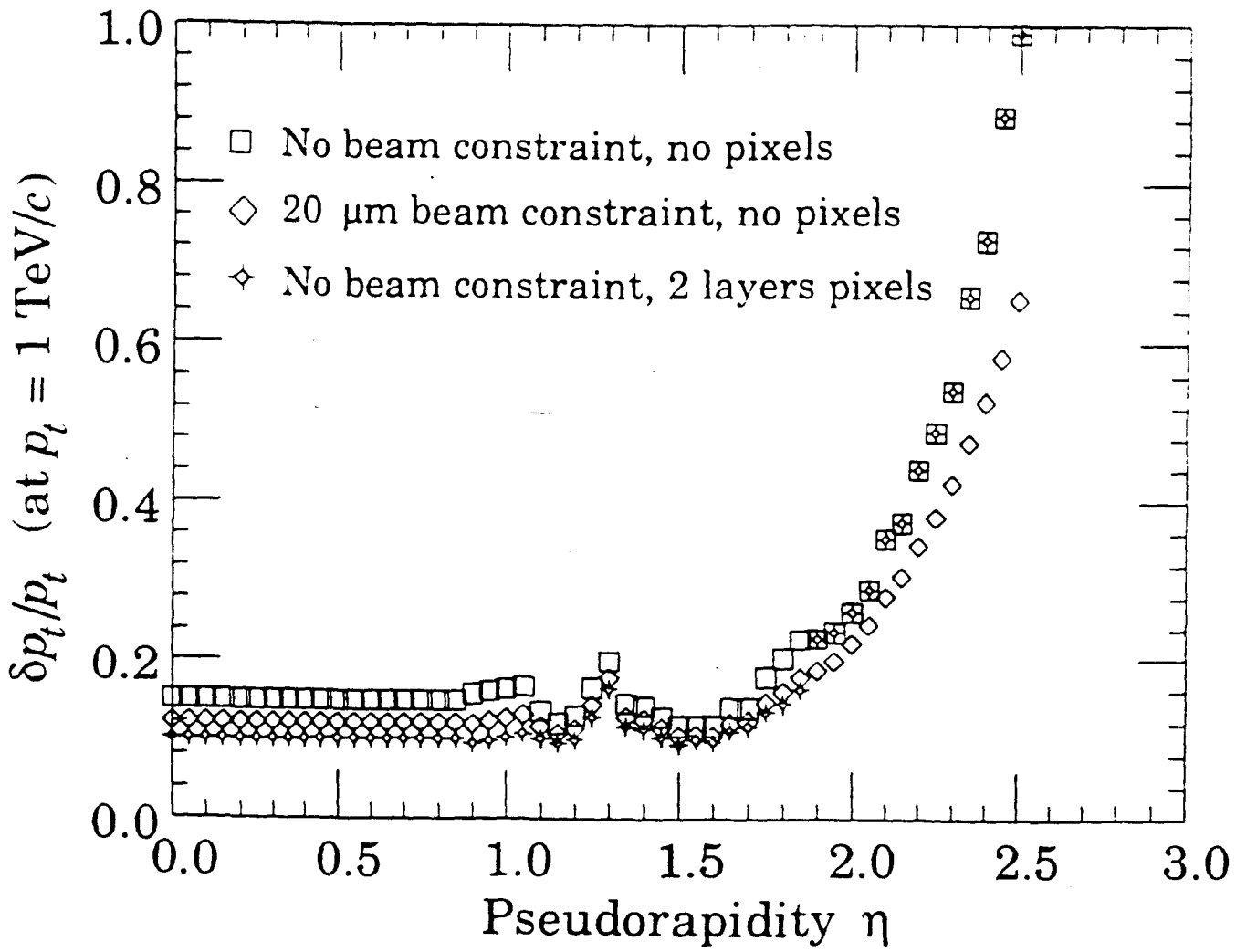
Intermediate Angle Tracking

Detector type	Pixels	Silicon Strips	Outer Wires	Outer Scifi
Total number of elements	9×10^6	4.9×10^6	5×10^4	2×10^5
Number of superlayers	1	5[a]	5	3
Measuring layers/superlayer	2	4	8	12
Approx. occupancy per element (in 2 T field at $\mathcal{L} = 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	10^{-4}	10^{-3}	10^{-1}	10^{-2}
Total radiation lengths at normal incidence	1.5%	6%	6%	8%
Resolution/measurement	10 μm × 100 μm	15 μm	150 μm	250 μm
Two track resolution	100 μ × 500 μm	150 μm	2 mm	1 mm

MOMENTUM RESOLUTION
Central Tracker

Momentum resolution *vs.* η for either
pixel/silicon strip/wire chamber
pixel/silicon strip/scintillating fiber
tracking system

(100% measurement efficiency, resolutions from Tables 2 and 3, no systematic errors)



SDC

Pixel Detector Properties

BARREL ($|\eta| < 1.5$)

Two concentric cylinders at radii 6 and 8 cm, with half-lengths of 15.5 and 17 cm.

DISKS (to $|\eta| = 1.9$)

Disks at $|z| = 18$ and 21 cm, with inner and outer radii of 5.5 and 10 cm.

COVERAGE

Particles originating within one sigma along beam line are measured twice.

ARCHITECTURE

Smart pixels with unambiguous sparse readout of time-stamped data.

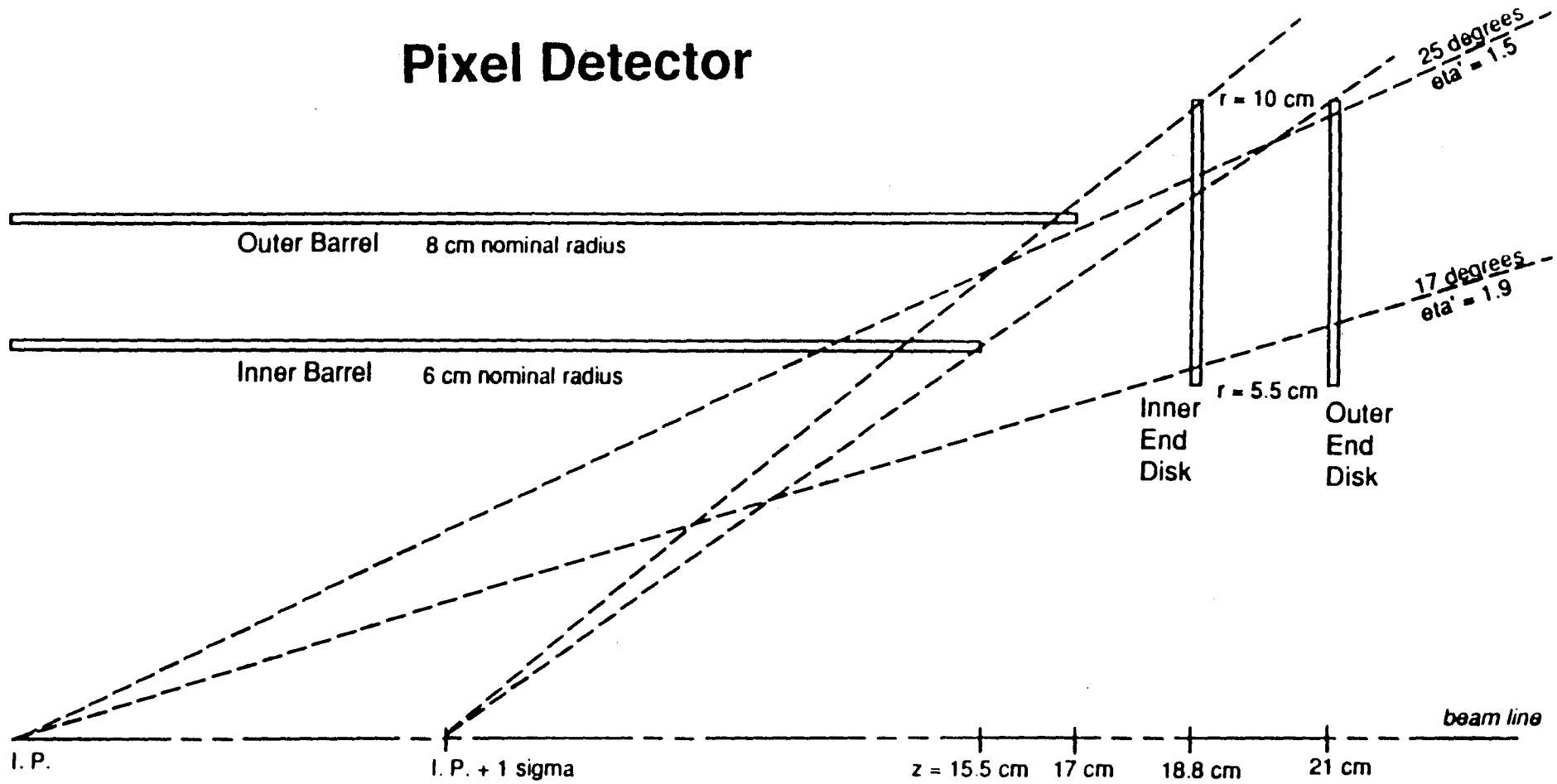
PIXEL SIZE

$30 \times 300\ \mu m^2$.

SYSTEM SIZE

Barrel: 3×10^7 pixels, disks: 9×10^6 pixels.

Pixel Detector



Pixel Array Layout: Barrels and Disks 12/90

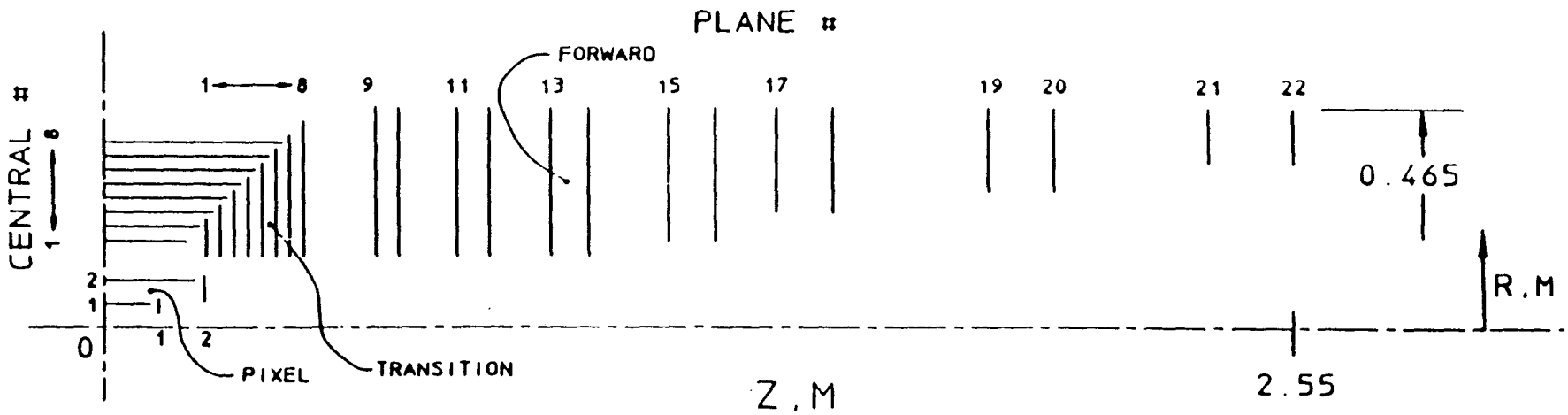
Features:
(a) All arrays outside 5.5 cm radius from beamline.
(b) Cover out to eta' = 1.9 (seen from I. P.)

Assume 30 micron by 300 micron pixels.
Then total number of channels is approx. 3 E+07 in barrels, 9 E+06 in disks.

SDC

Silicon Strip Tracker

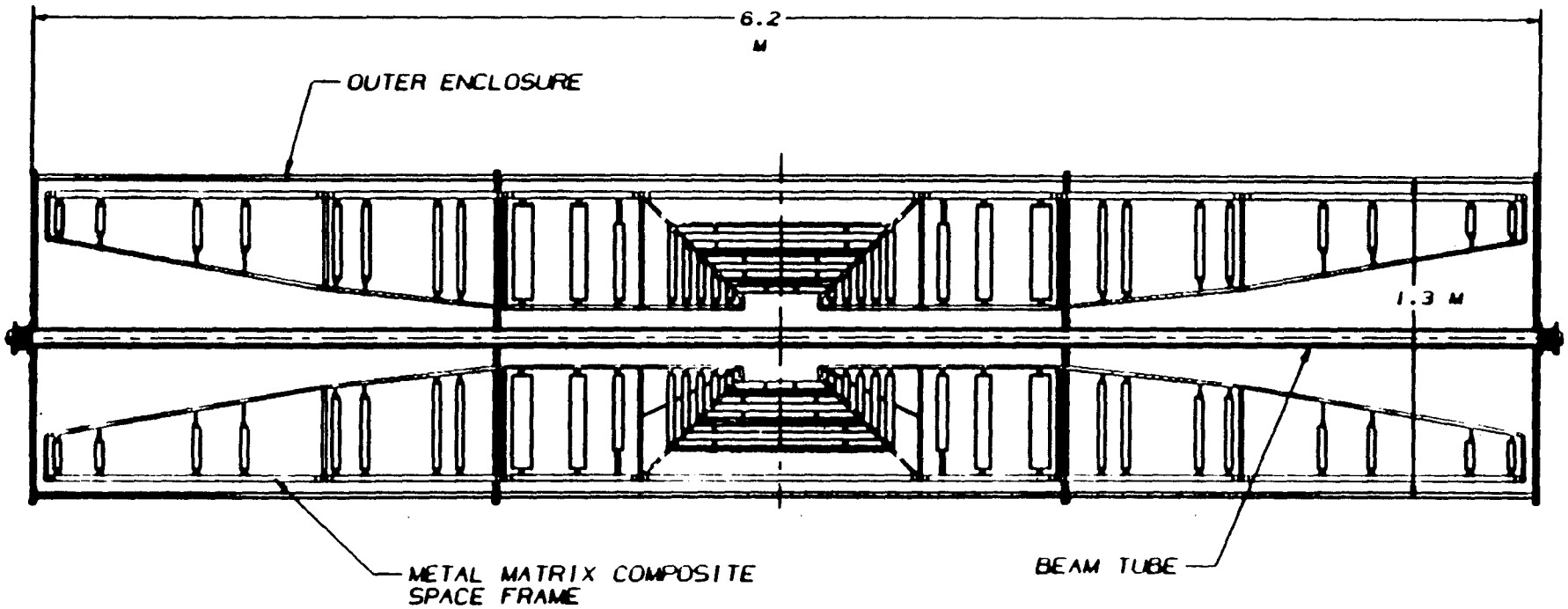
High Spatial Resolution and excellent two-particle separation
---> powerful pattern recognition even within a jet
Detector : 50 micron pitch, double-sided or single-sided short strips
Total silicon area : 28 m^2
Total thickness : < 5 % X_0 at 90^0
Total number of readout channels : ~ 8 M
Heat load : 1 mW/ch, cooled by evaporation-wick techniques



SILICON LAYOUT

SILICON TRACKING SYSTEM

CROSS SECTION



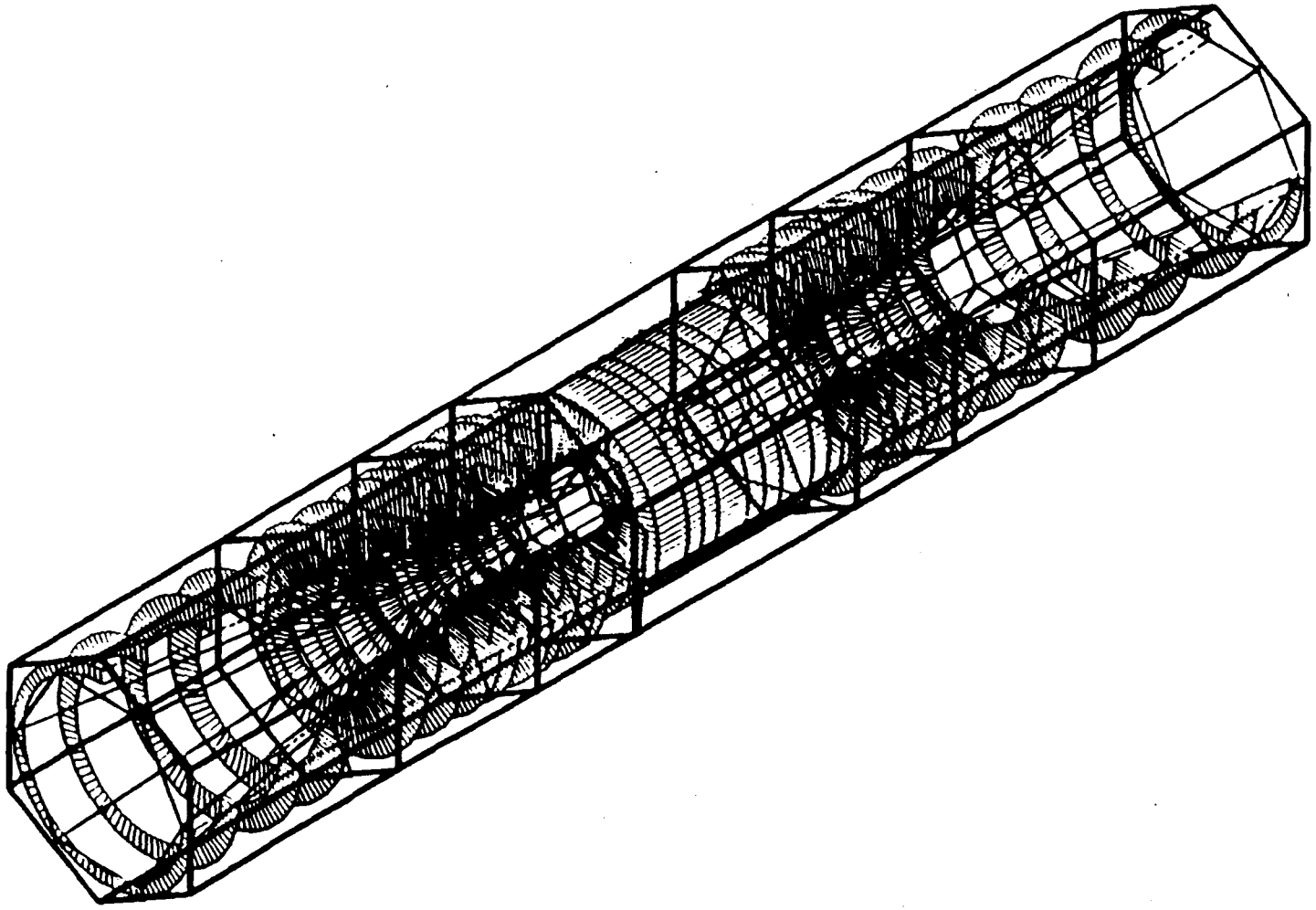
LOS ALAMOS

MEE-12
MECHANICAL AND ELECTRONIC
ENGINEERING DIVISION

SIL-LAY-VG 06-28-90

SILICON TRACKING SYSTEM

SILICON WAFERS AND SPACE FRAME



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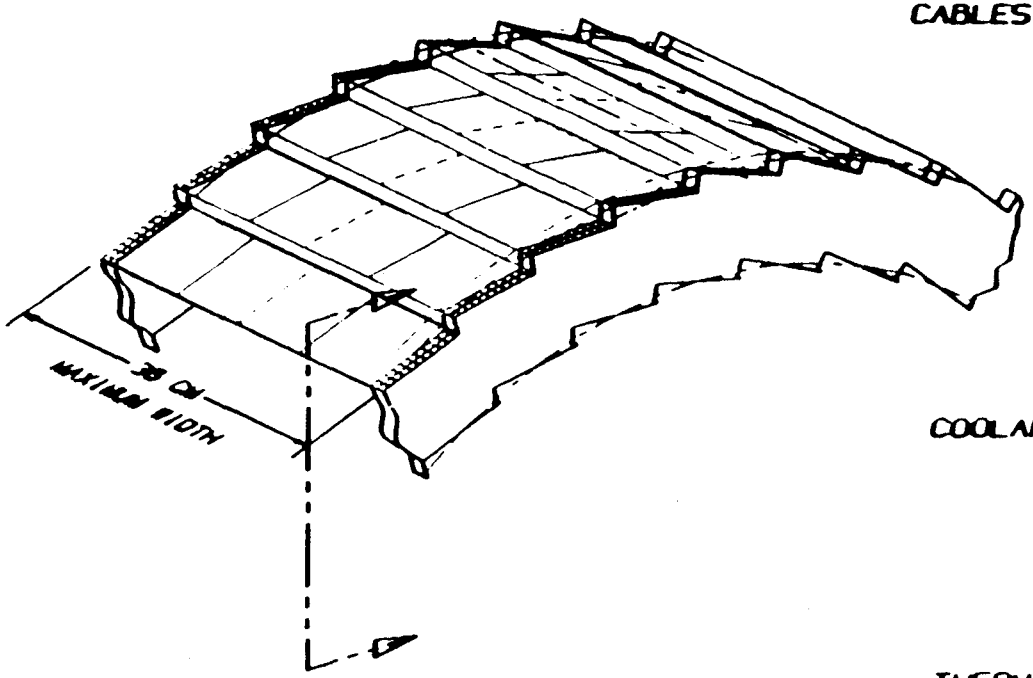
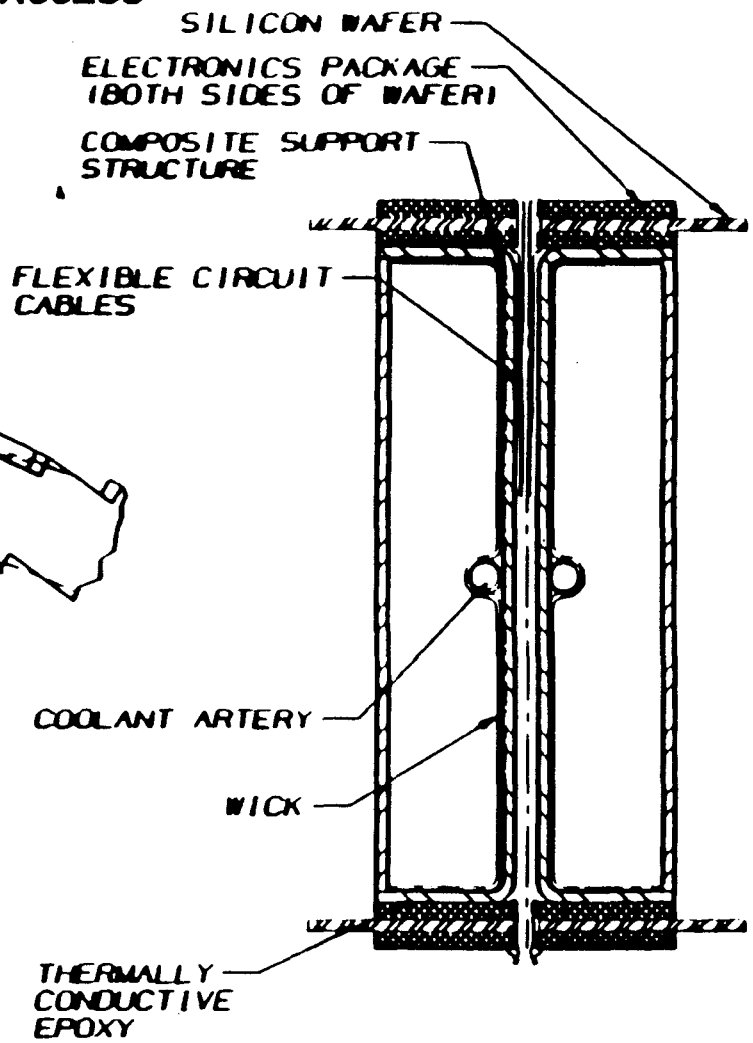
MEE-12
MECHANICAL AND ELECTRONIC
ENGINEERING DIVISION

SIL-TRACK-A 08-20-90

SILICON TRACKING SYSTEM

MECHANICAL SUPPORT FOR SILICON WAFERS.
COOLING, AND CABLE ACCESS





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Progress in Silicon Strip Development

ELECTRONICS:

Small feature-size, fast bipolar transistors shown to be sufficiently rad-hard for > 30 years at 10^{33}.
Hardened CMOS for digital applications has been shown to work for > 10 years at 10^{33}.

DETECTORS:

Detector biasing structures and small double-sided detectors shown to work at > 2 megarad.

MECHANICS:

Radiation tests of carbon fiber support panels show no dimensional change for fluence of 3×10^{13} neutrons/cm^2.

SIMULATION:

Pattern recognition studies show good ability to reconstruct all 4 leptons from Higgs decay even up to 10^{34}.

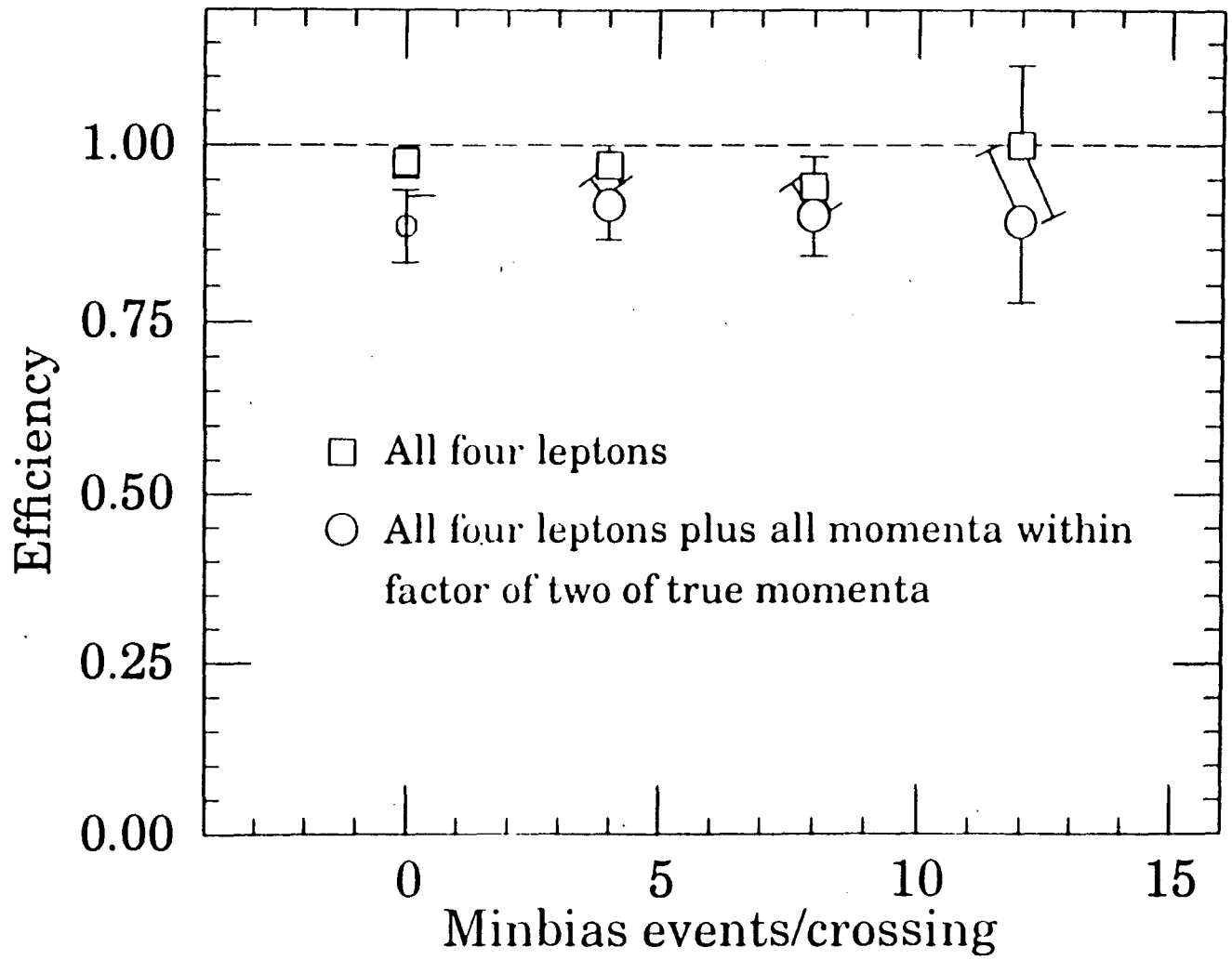
CONCLUSION:

For chosen dimensions, we can build system which will survive at least 10 - 20 years at 10^{33}. More work needed to quantify and maximize the expected lifetime.

PATTERN RECOGNITION VS. LUMINOSITY FOR HIGGS LEPTONS
(using the silicon system)

Efficiency for finding all 4 leptons for process

Higgs $\rightarrow ZZ \rightarrow e^+e^-\mu^+\mu^-$



SDC

Silicon Strip R&D Efforts for 1991

ELECTRONICS AND READOUT:

- Finalize amplifier design and narrow vendor options.
- System level simulation of data storage chip, decision on best architecture.
- Begin effort on fiber optics readout.
- Finish conceptual design of silicon-based trigger.

MECHANICAL ISSUES:

- Finalize wick and cooling design.
- Preliminary design of kinematic mounts.
- Study alignment technique for attaching detector to support.
- Prototype full-size mechanical module.

DETECTORS:

- Continue work on rad-hardness, minimum capacitance and optimum biasing scheme.
- Choose between double-sided long & single-sided short strips.
- Specification of alignment goals & design of alignment scheme.

Wire Chamber Tracker

Central: 4 mm straws in 8 superlayers (1.9 x 10^5 straws).

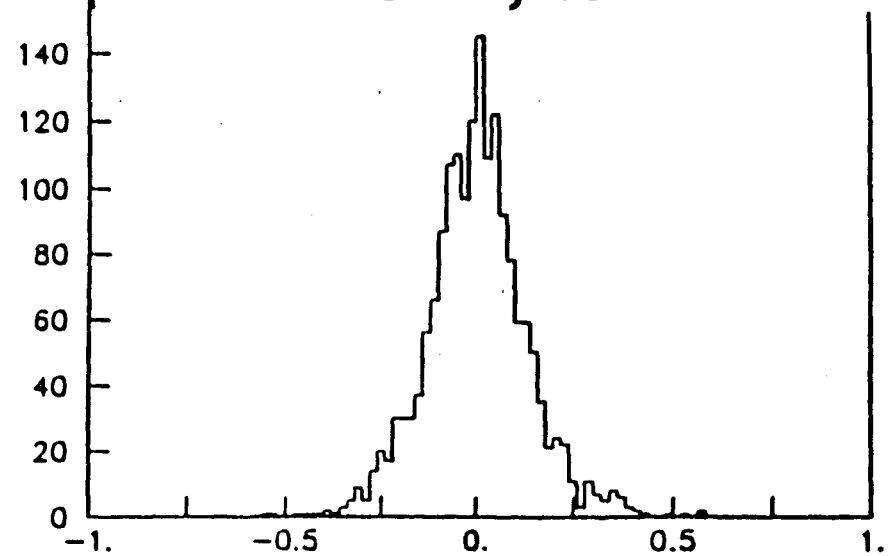
Intermediate: radial drift chambers with MWPC crossing taggers design very preliminary (~5 x 10^4 channels).

Two engineering approaches:
1) Multiple straw modules (Westinghouse, Indiana etc.).
2) Cylinders from carbon composites (Oak Ridge, Duke etc.).

Well-established technology, but becomes problematic at luminosities above 10^{33} except in outermost layers.

Residuals in mm for cosmics with 2.7 m long 4 mm diameter straws in 8-layer array. (Duke)

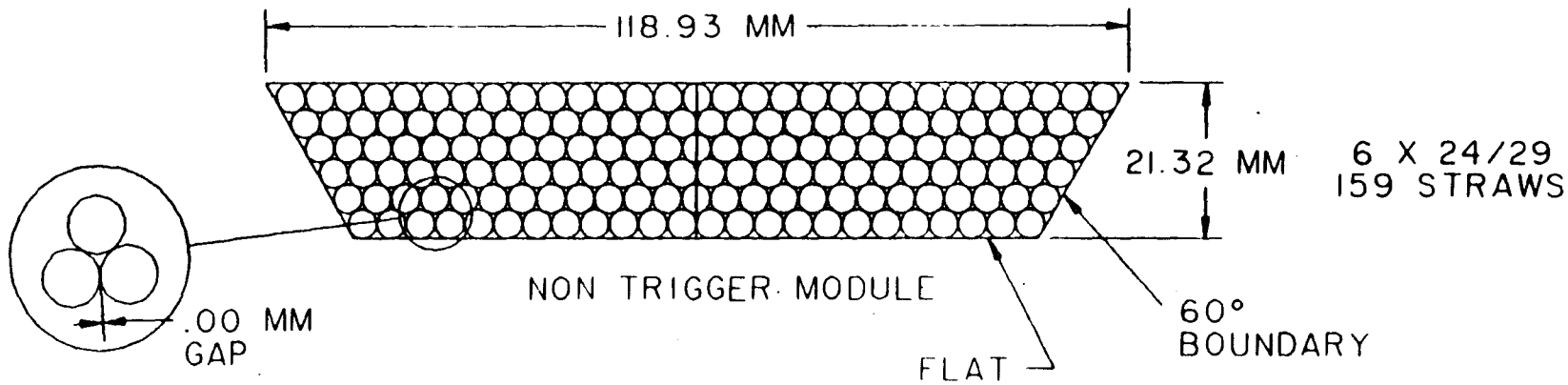
$\sigma = 110\ \mu m$



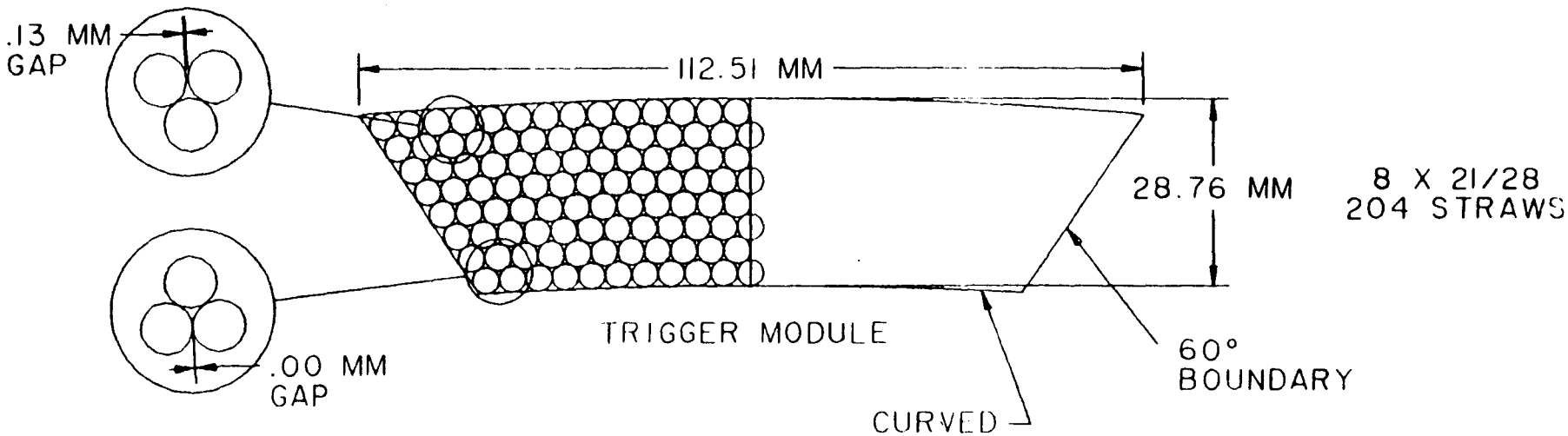
SDC

MODULAR CENTRAL TRACKING SUPERLAYER MODULES

SUPERLAYER 9° INCLUDED ANGLE
WITH 3 MM GAP FOR INSIDE STEREO OR AXIAL LAYER



SUPERLAYER 3.75° INCLUDED ANGLE
WITH 3 MM GAP FOR OUTSIDE AXIAL TRIGGER LAYER



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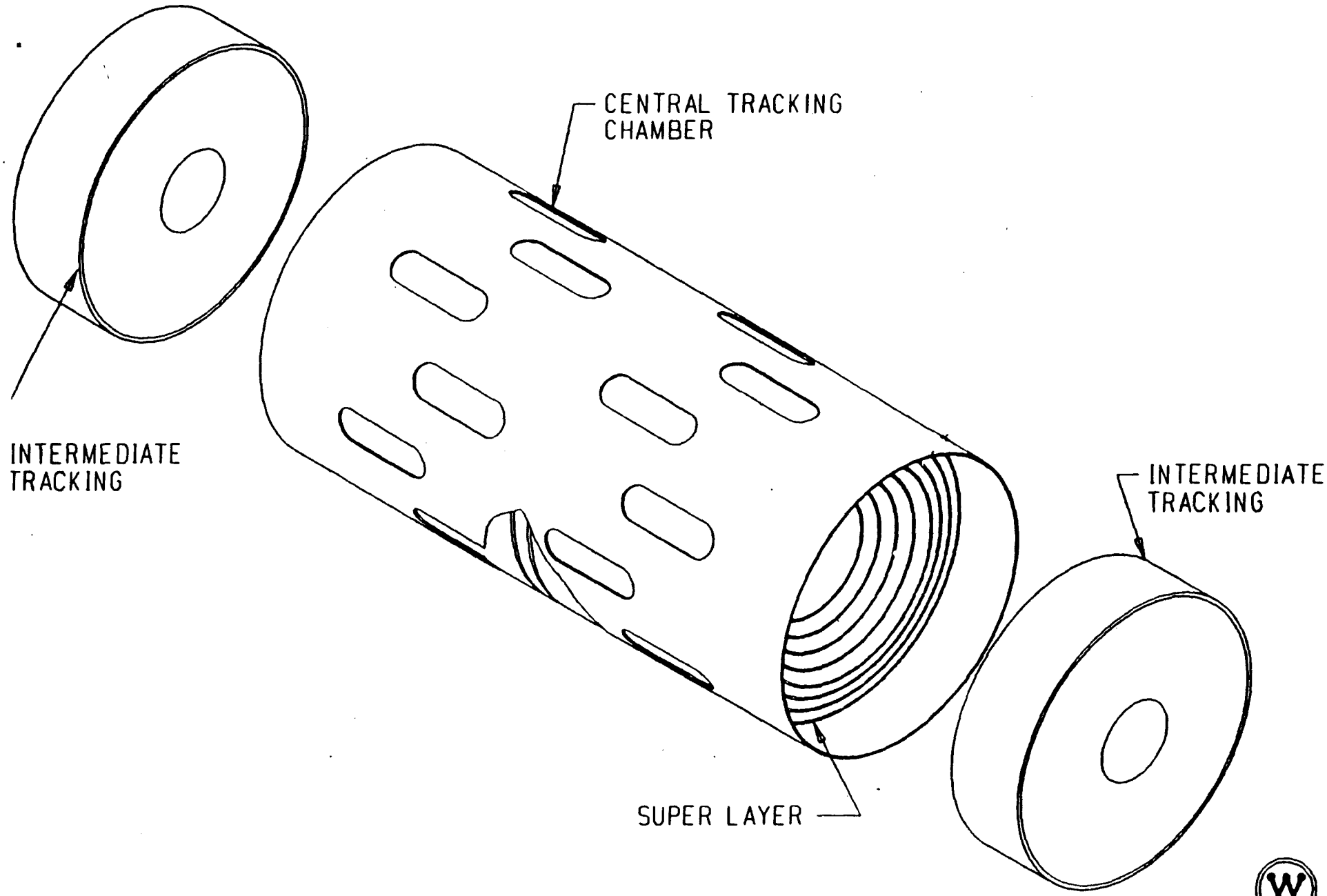
MODULAR STRAW TUBE TRACKING SYSTEM
EXPLODED VIEW



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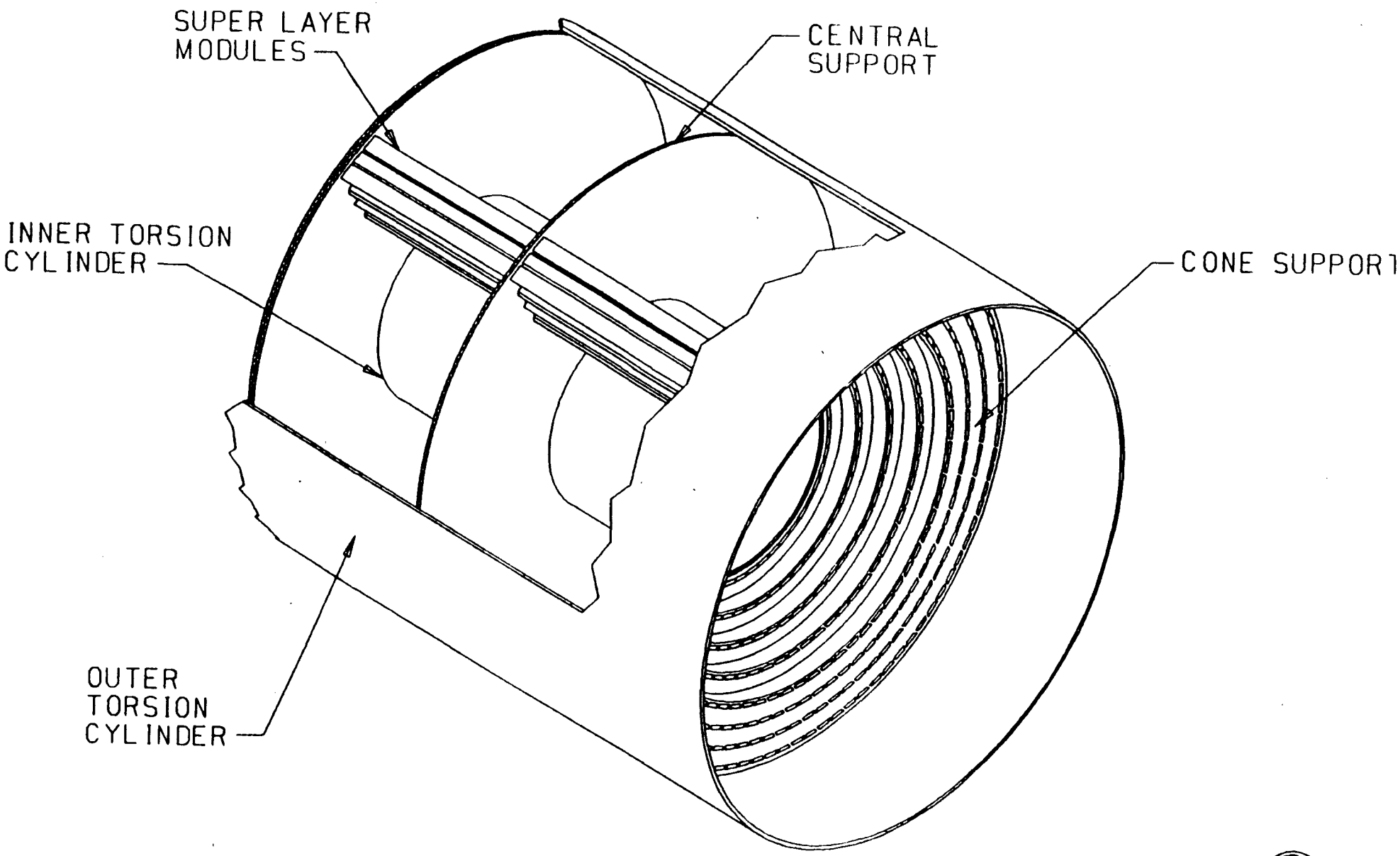
KEPES 12-4-90

MODULAR STRAW TUBE CENTRAL TRACKING SUB SYSTEM ASSEMBLY



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Progress in Straw Tracker Development

Studies of straw tube performance
- High efficiency
- Resolution ~ 100 μm
- Attenuation length ~ 4 m
- Stability with intermediate wire supports

Gas avalanche heating effects understood (and small)

Preliminary design of modular straw tube tracker under development

Alternative carbon composite cylinder design also under way

Good progress on front-end and trigger electronics as well as module-electronics interface

Simulation efforts on effects of scope reduction on pattern recognition and occupancy

Straw Tracker Effort in 1991

Beam tests with 64-straw modules with prototype front-end and trigger electronics.

Fabrication of full-scale prototype straw module with evaluation of efficiency, resolution, attenuation.

Continue conceptual design of modular system and investigate manufacturing and assembly procedures.

Study carbon composite cylinder design with fabrication of prototype cylinder and studies of straw tube layout on cylinder surfaces.

Continue efforts in front-end and trigger electronics.

Improved simulation incorporating both silicon and outer tracking systems.

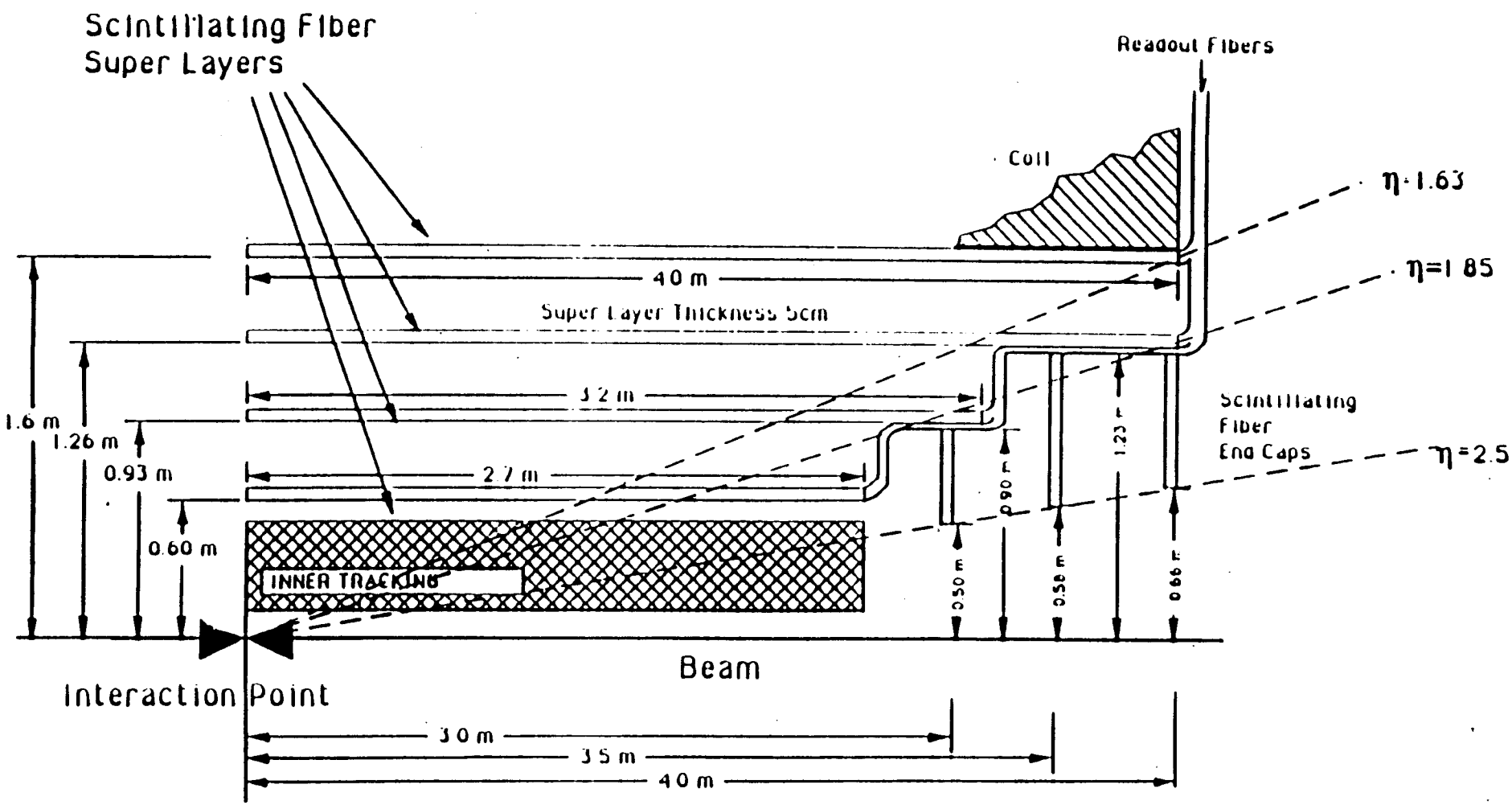
Scintillating Fiber Tracking

Central :	0.75 mm	1.0×10^6 fibers
Intermediate angle :	1.0 mm	2×10^5 fibers

Advantages:
- Low Occupancy (< 10% at 10^{34})
- Insensitive to B field
- No heat in tracking volume
- Intrinsically fast

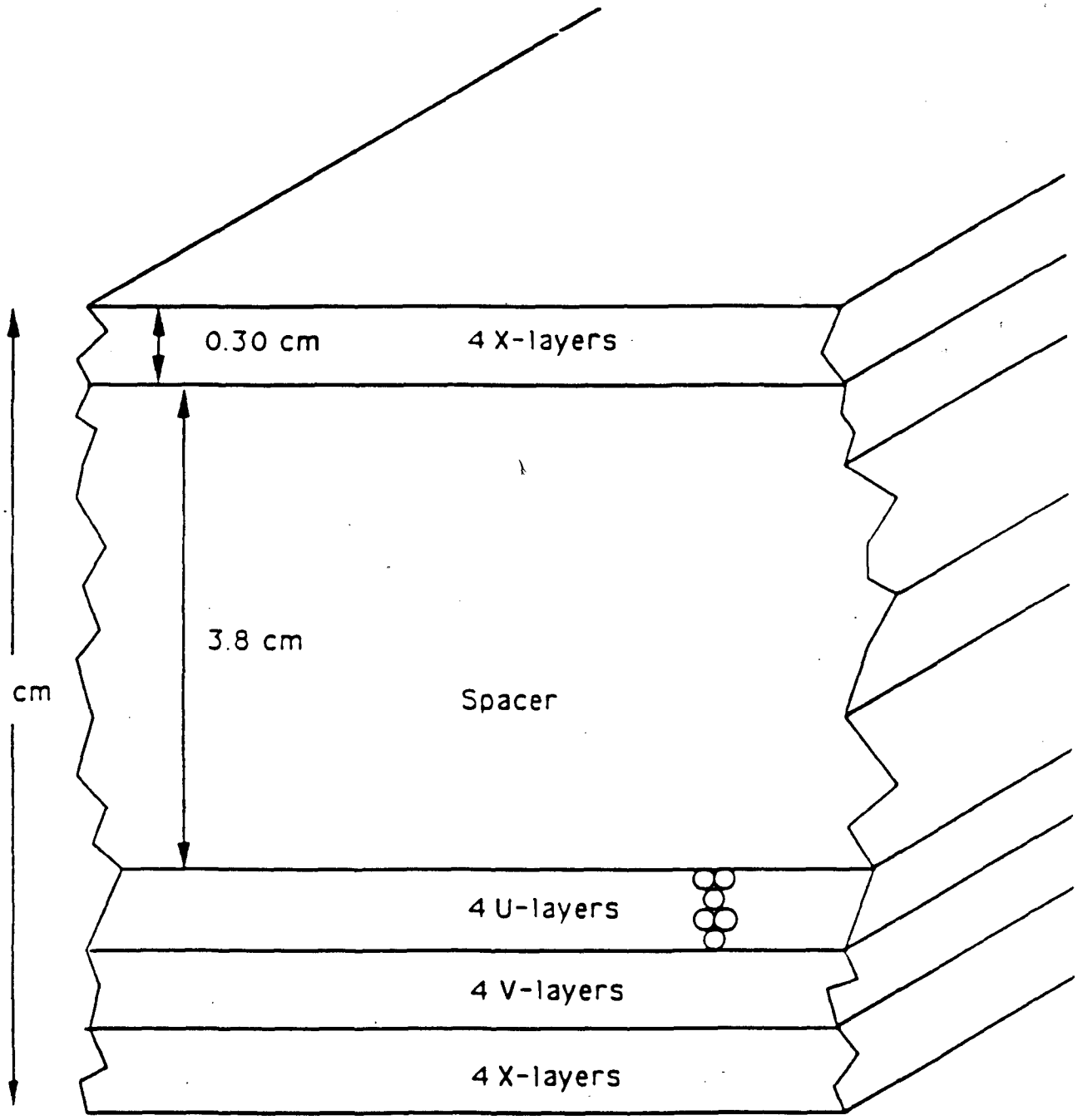
Readout : Scintillating fibers-->optical fibers-->VLPC
VLPC (Visible light photon counter) under development at Rockwell
Quantum efficiency ~ 80%, operates near 7K temperature

Major issue, given large channel count, is cost per channel.


Scintillating Fiber
Super Layers
Readout Fibers
Coil
η=1.63
η=1.85
η=2.5
40 m
Super Layer Thickness 5cm
3.2 m
2.7 m
1.6 m
1.26 m
0.93 m
0.60 m
INNER TRACKING
Scintillating
Fiber
End Caps
Beam
Interaction Point
3.0 m
3.5 m
4.0 m

SDC

Cross-section of a Super layer



$$\frac{\#\text{fibers}}{\text{super layer}} = \#\ \text{layers} \times 2\pi R_{\text{average}} \frac{1}{d_{\text{fiber}}} \qquad (d_{\text{fiber}} = .075\text{cm})$$

Superlayer	ave. Radius (cm)	# of Layers	No. of fibers
1	62.5	8	41,890
2	96	8	64,340
3	129	16	172,920
4	162.5	16	217,790
			496,940

Total no. of fibers =2 halves x 496,940= 993,880

SDC

Progress in Fiber Tracker Development

Measurements of SSPM performance and collaboration with Rockwell to develop VLPC (Visible Light Photon Counter)

Measurements of photon yields, attenuation lengths and other properties of available scintillating fibers

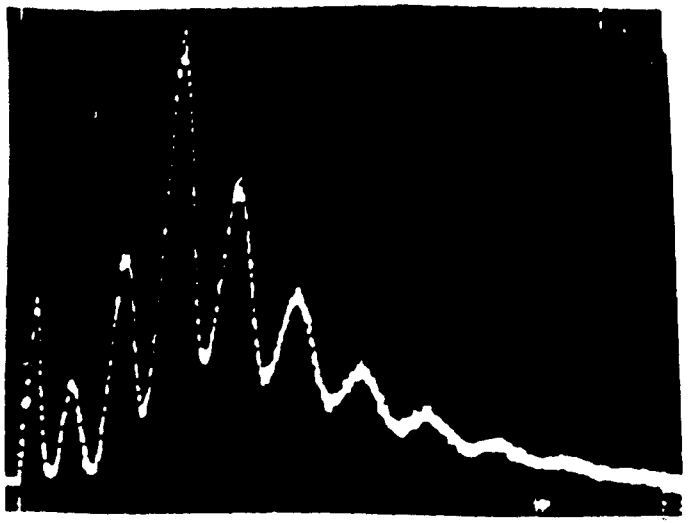
Development of new fluorescent dyes

Carbon composite cylinder design for fiber ribbon support under way

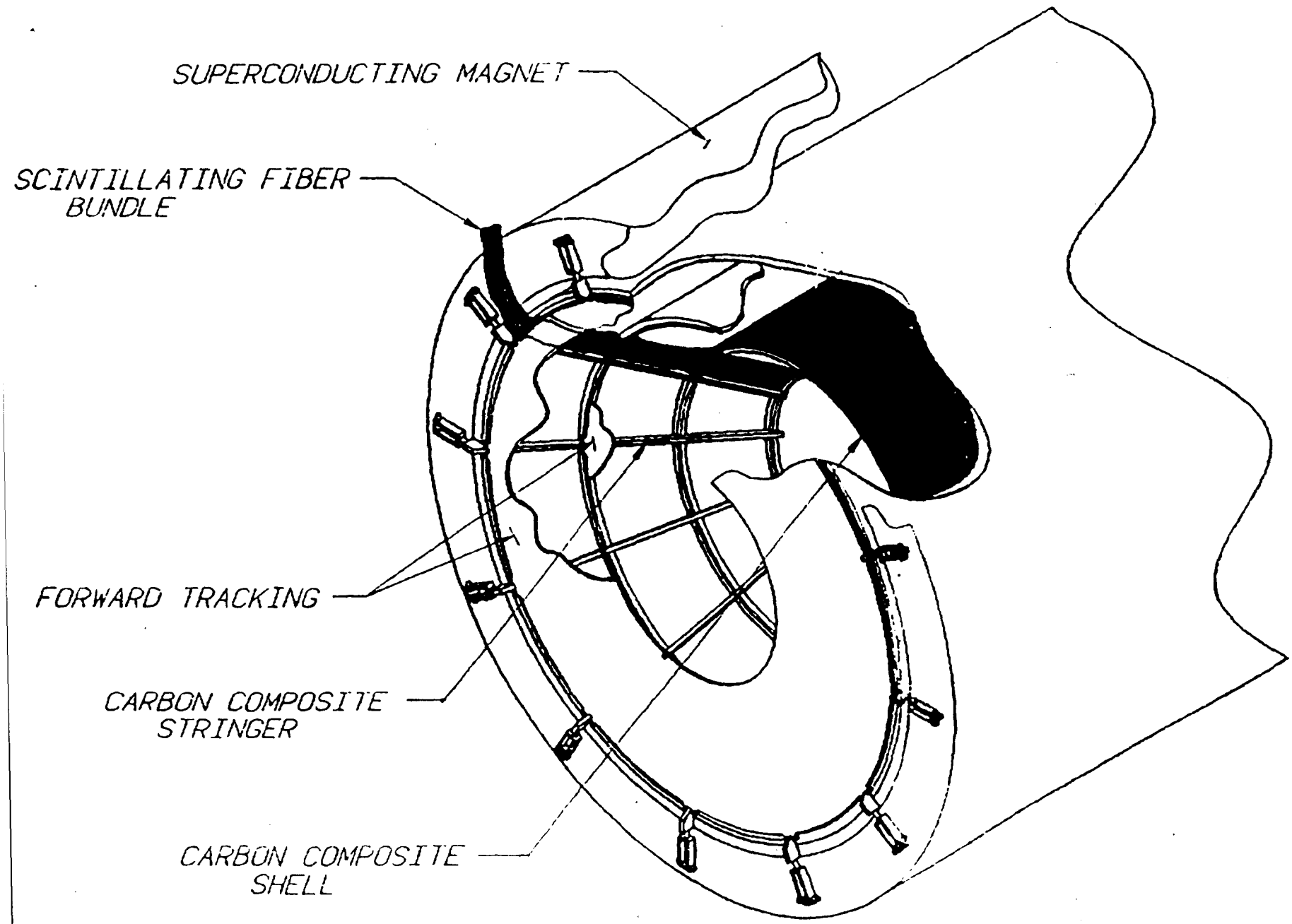
Progress on design of front-end and trigger electronics

Simulation efforts to optimize performance of fiber tracker in both pattern recognition and trigger functions

0.5 mm fiber exposed to Bi^{207}
1 MeV beta source, viewed by SSPM
(Atac)



SCINTILLATING FIBER CENTRAL TRACKING



Fiber Tracker Effort in 1991

Beam test at Fermilab
- 4 meter 750 micron scintillating fibers and 5 meter wave guides
- 256 channels of VLPC in a continuous flow cryostat
- Tests of trigger electronics

Scintillating fiber development aimed at high-efficiency, fast yellow emitters resistive to radiation damage. Development of fiber-optic wave guides.

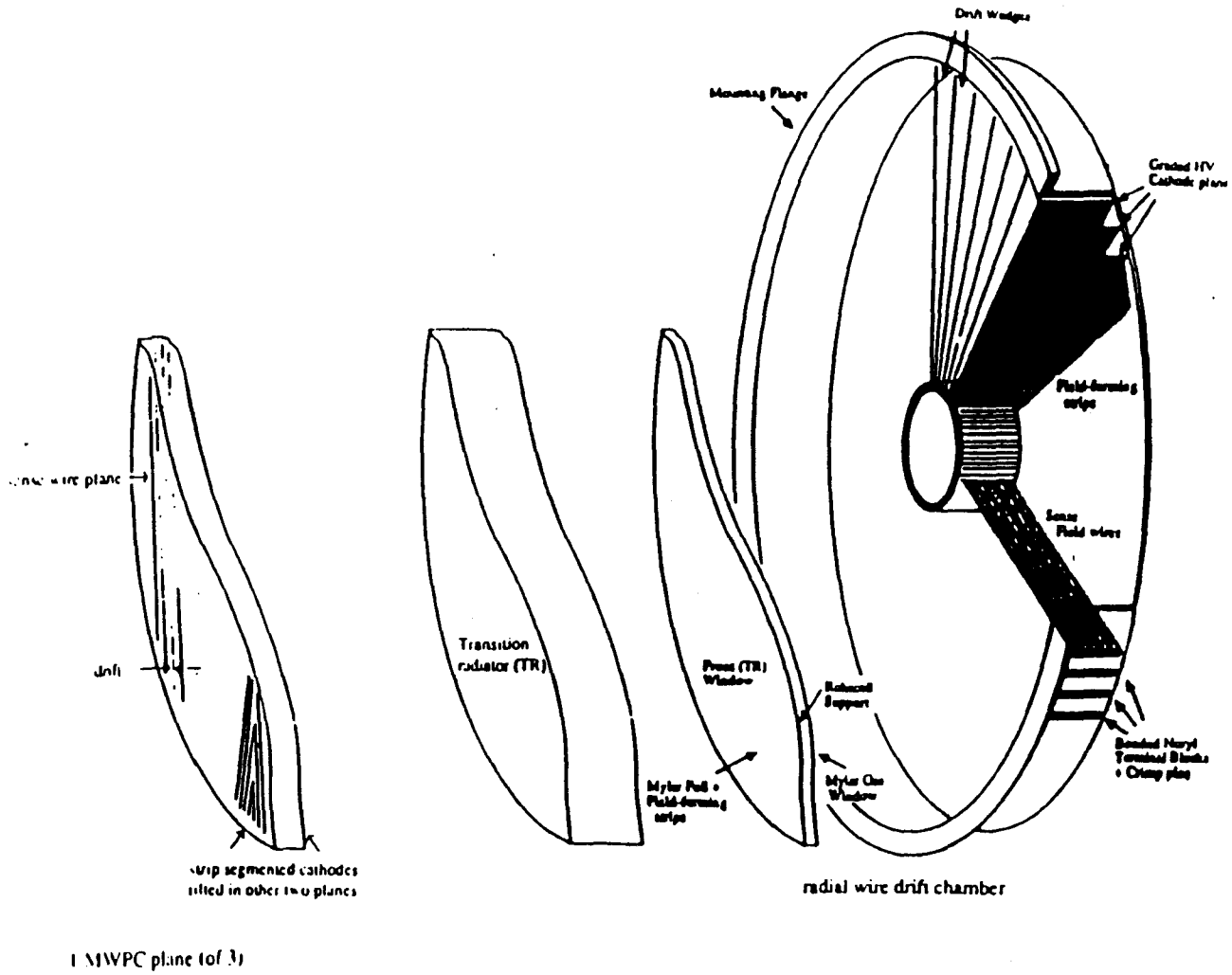
Studies of mass-production techniques for making fiber ribbons to the desired tolerances

Engineering design work on composite-material cylinders for supporting fibers in an SDC fiber tracker

Development, design, and construction of prototype cryostat able to support about 2000 VLPC channels. Delivery of about 1000 channels is expected by October 1991

Continuing development of VLPC and cryogenic preamps

Simulation efforts aimed at designing an optimized fiber tracker for SDC



1 MWPC plane (of 3)

schematic - not to scale

SDC

Table 4

Tracking System Milestones (FY1991)

Milestone	Date
Pixels	
Conceptual design review	Dec. 1990
Fabrication of pixel array prototype	March 1991
Pixel array beam tests	July 1991
Mechanical systems prototype	Sept. 1991
Silicon Strips	
Prototype full-size mechanical module	Sept. 1991
Test of full-size double-sided silicon detector	Sept. 1991
Prototype front-end electronics	Sept. 1991
Establish radiation limits for detectors	Sept. 1991
Wire Drift Chambers	
Beam tests with prototype front-end/trigger electronics	May 1991
Intermediate tracker radial drift chamber sector prototype	June 1991
Full-size barrel module/superlayer prototypes	June 1991
Evaluation of full-scale full-length barrel module prototype	Sept. 1991
Scintillating Fibers	
Beam tests of full-size superlayers using multi-anode phototubes	Feb. 1991
Prototype commercial fabrication of wide fiber ribbons	April 1991
Beam test of 256-channel 4 m long fiber superlayer with VLPCs plus front-end/trigger electronics	May 1991
Delivery of 1000 channels of VLPCs from Rockwell	Oct. 1991

Selection of Tracking Technologies

- By April 1991 we will identify in detail the R&D priorities for the SDC detector tracking system and the major R&D milestones for the next two years.
- This process may result in the reduction of options for the tracking system
- This evaluation is necessary to determine the schedule for making choices of technology eg. the relative mix of fibers and wires
- Given the rapid progress in R&D now underway, we do not want to make a premature selection of technologies but will make the selection consistent with a conservative assessment of the R&D, design, construction and installation schedules

Calorimetry

- When the EoI was submitted, five calorimeter technologies were under consideration for the central region, $|y|<3$.
- After review, two technologies have been chosen for engineering development in preparation of a proposal.
- The two choices are (1) scintillating tile with fiber readout and lead/iron absorber and (2) liquid argon with lead absorber.
- Engineering design and R&D will continue on these two until an informed choice can be made by fall of 1991.
- See table of parameters of the two options.

PARAMETERS FOR THE CALORIMETRY OPTIONS

	Scintilator Tile Fiber Pb/Fe Absorber	Liquid Argon Lead Absorber
Channel count—towers	41000	87400
Channel count—strips	25000	0[a]
EM depth (X^0) at 90°	25	25
Full depth (λ) at 90°	~ 10	~ 9
Depth segmentation	2 EM, 2 HAD	MG,[b] 2 EM, 2 HAD
$\Delta\phi \times \Delta\eta$	$\sim 0.05 \times 0.05$	$0.025\text{–}0.05 \times 0.025\text{–}0.05$
Peaking time, EM/HAD	15–30/15–30 ns	100/200 ns
EM resolution	$15\%/\sqrt{E} \oplus < 1\%$	$15\%\sqrt{E} \oplus 0.5\%$
Hadronic resolution	$\sim 40\%/\sqrt{E} \oplus \sim 2\%$	$\sim 60\%\sqrt{E} \oplus < 4\%$
EM position resolution	2–3 mm[c]	2–5 mm[c]
Electronic plus pileup noise, $\Delta R = 0.15$ cone at $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$	0.2 GeV	1.2 GeV

[a]EM position resolution is provided by fine tower segmentation. If strips are used, channel count will remain about the same.

[b]MG = Massless gap.

[c]EM position resolutions for one transverse direction for scintillator, and both transverse directions for liquid argon.

SDC

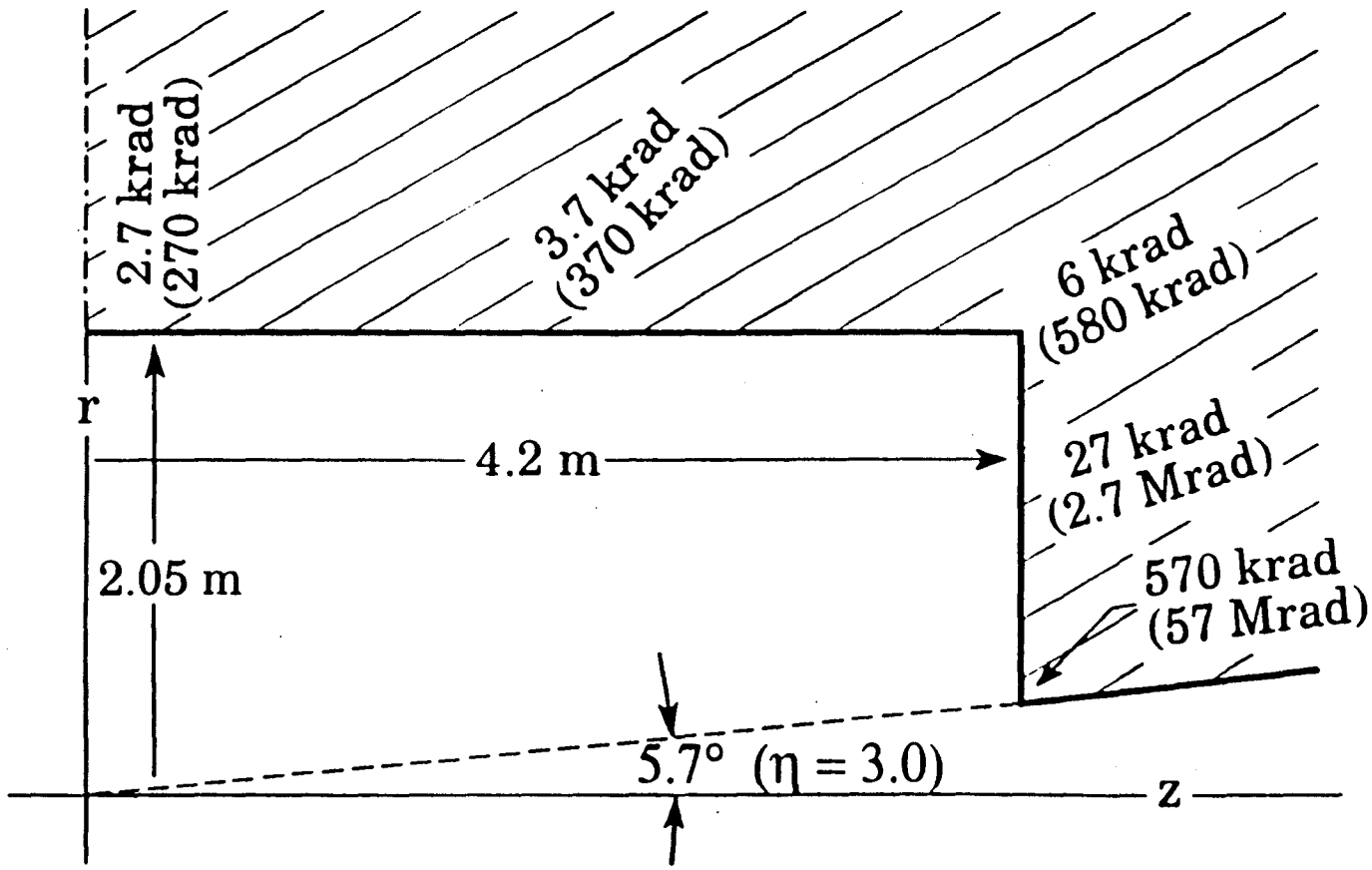
Radiation Environment

- Radiation damage effects are of critical concern for both technologies under consideration - to scintillator itself for that option and to preamplifiers located inside the cryostat for the liquid argon option

- The maximum ionizing dose occurs in the electromagnetic section of the calorimeter, as shown in the accompanying figure

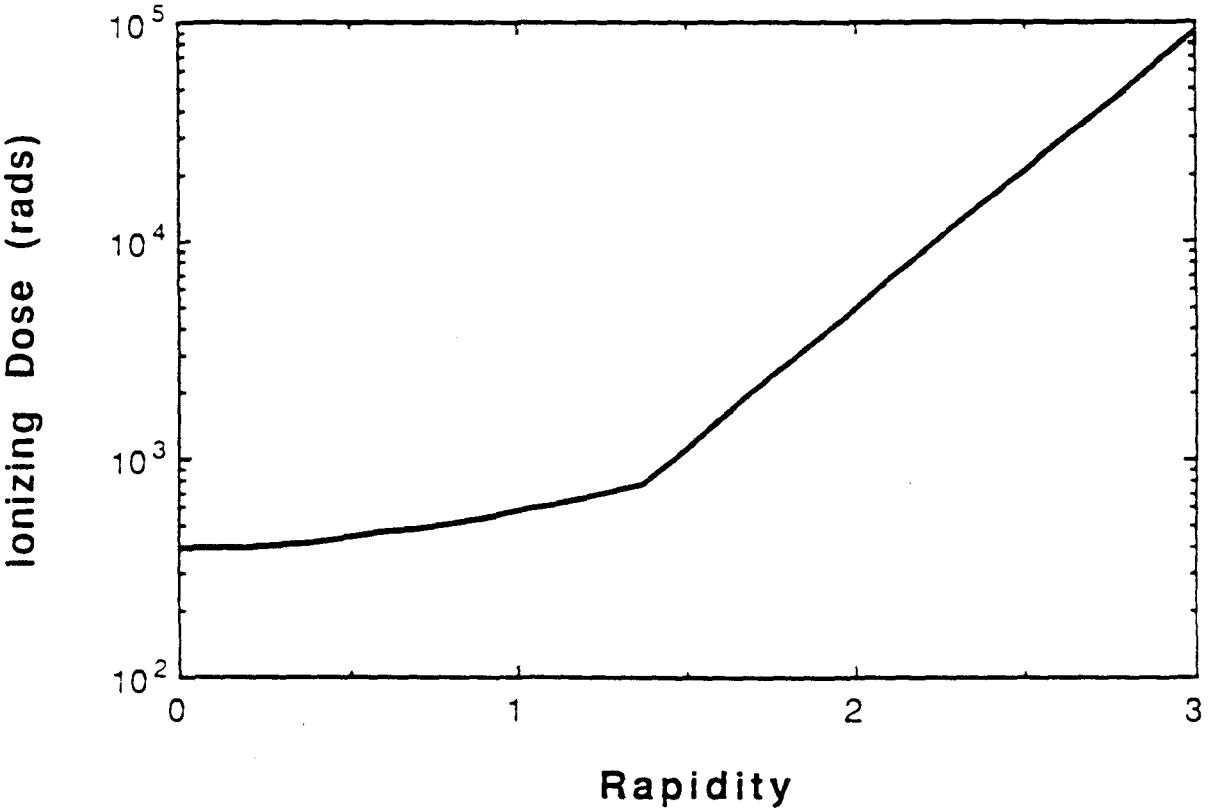
- Ionizing doses in the hadronic section are lower but there are substantial neutron fluences within(and outside) the calorimeters, as shown.

Maximum Ionizing Dose in the SDC Calorimeter

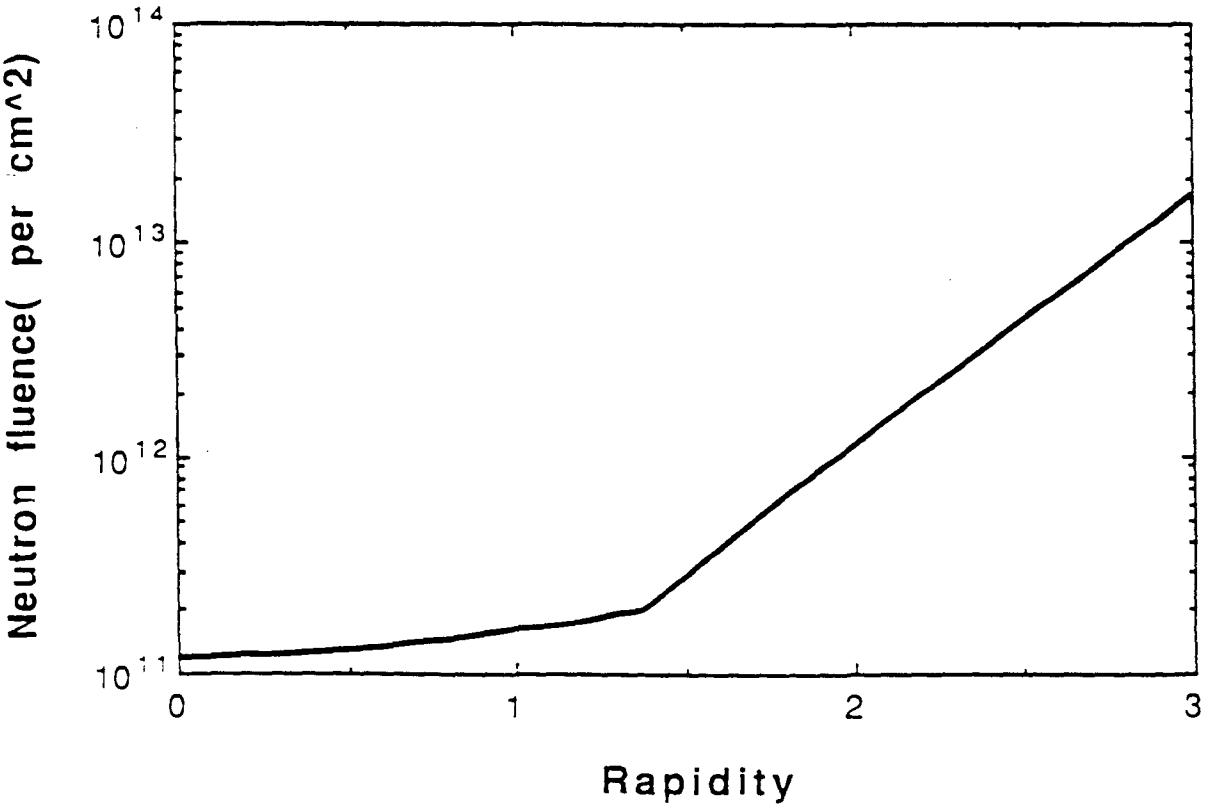


Maximum ionizing dose in calorimeter (at EM shower maximum) for 1 year at 10^{33} and in parentheses for 10 years at 10^{34} .

Maximum hadronic dose for one year at design luminosity



Maximum neutron fluence in one year at design luminosity



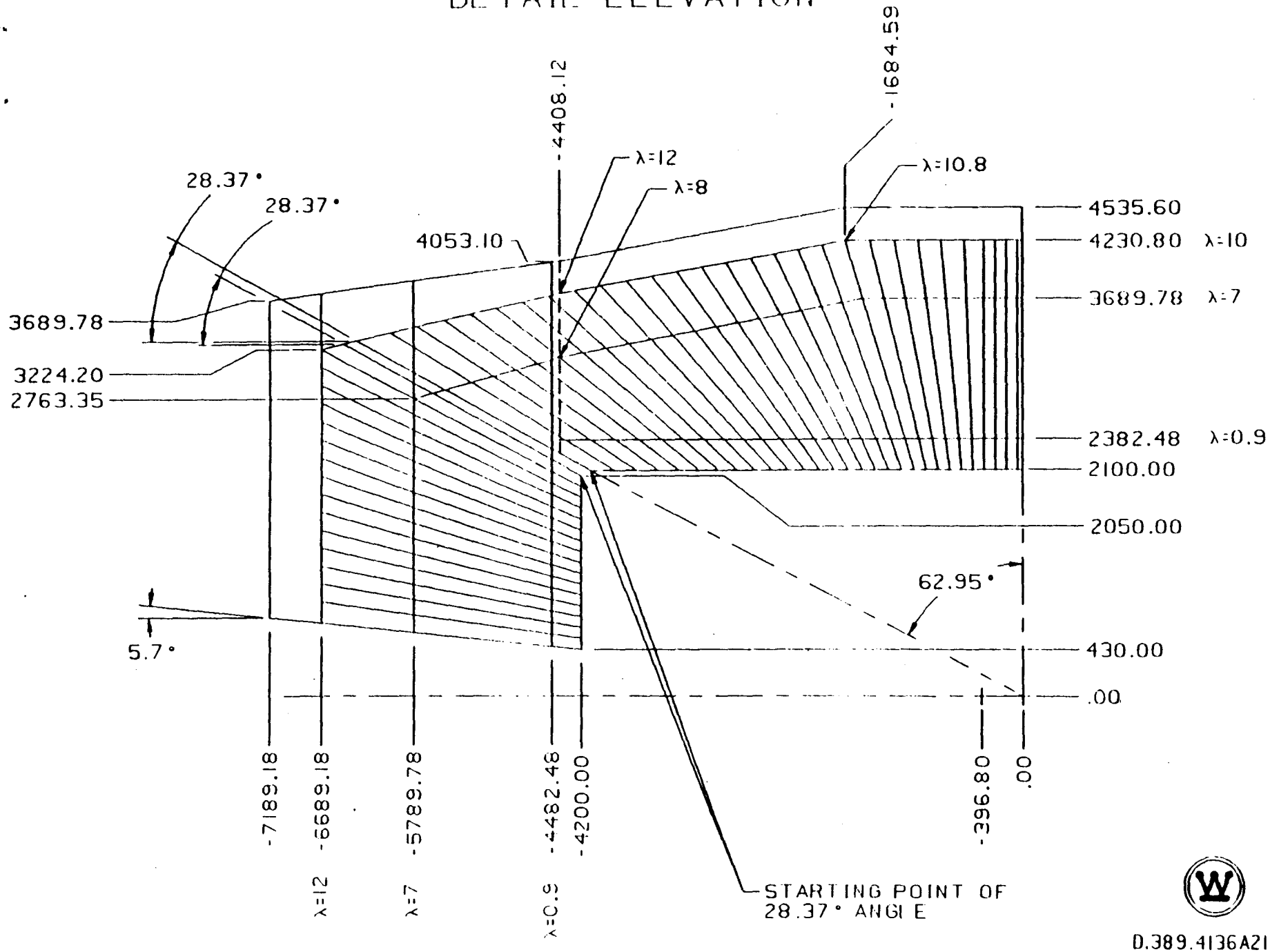
Scintillator Option

- Members of the SDC have substantial experience with scintillating plate calorimetry via the CDF and ZEUS experiments

- A concept for scintillator tile with fiber readout, with lead followed by iron absorber, is illustrated in the accompanying figures.

- We are also exploring the possibility of using iron absorber(with small amounts of lead to attempt to make $e/h \approx 1$) in the hadronic sections. If used in the endcaps this would allow a uniform magnet field in the tracking volume.

LEAD IRON CALORIMETER
DETAIL ELEVATION

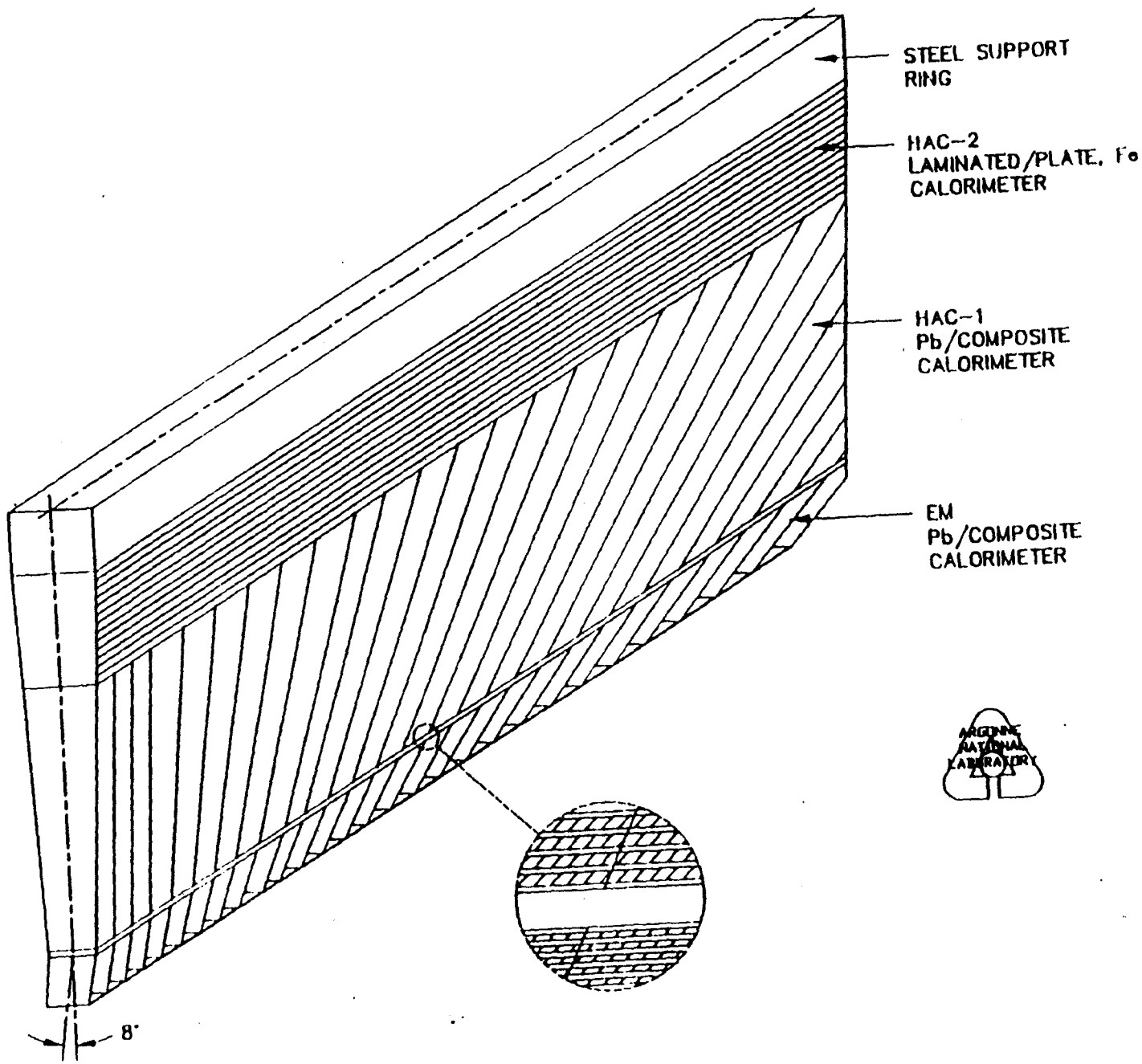


CALORIMETER VOLUME = 673 CUBIC METERS
CALORIMETER WEIGHT = 5837 SHORT TONS
5295 METRIC TONS

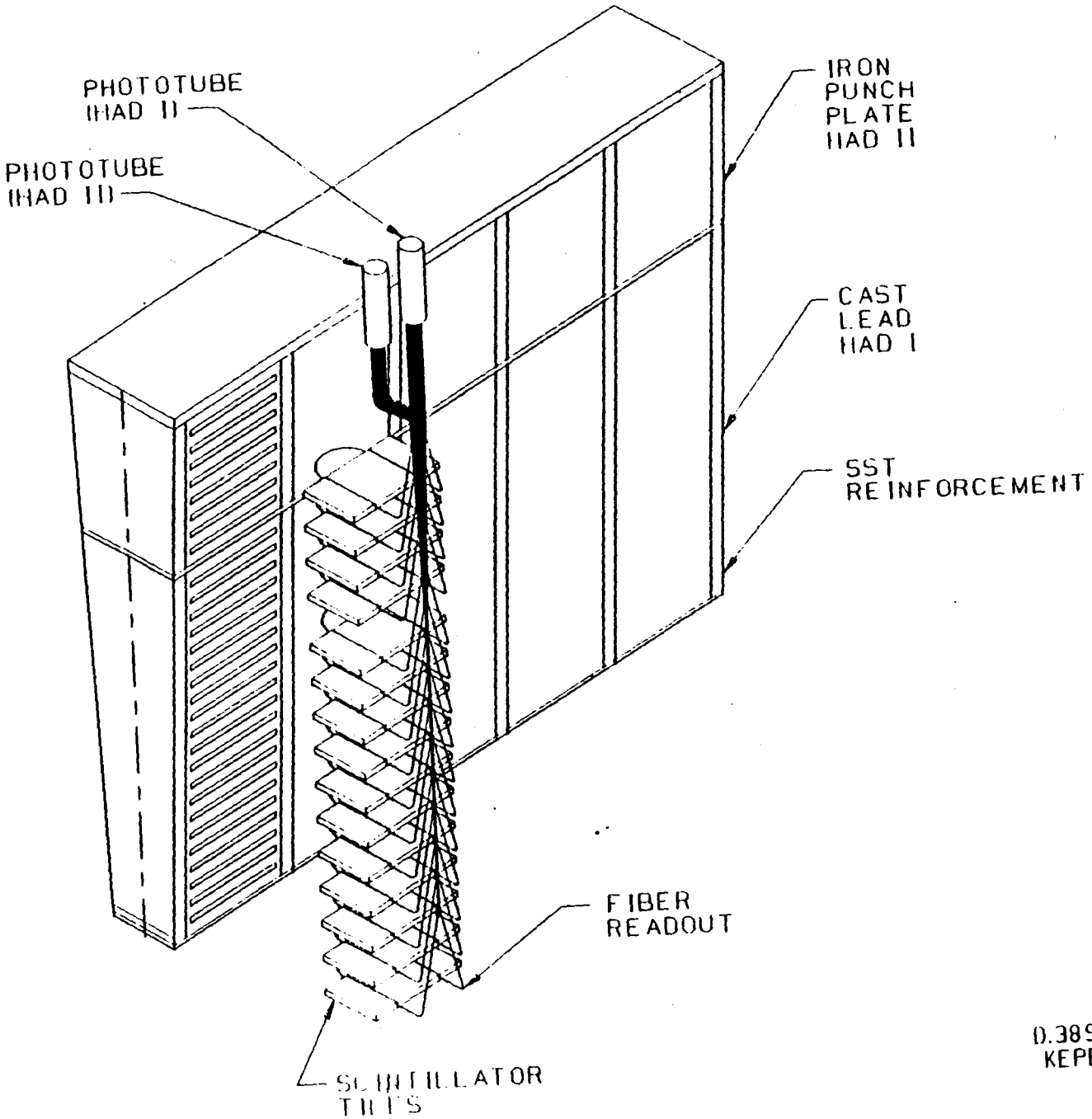
D.389.4136A21.R6
DIM.IN MILLIMETERS
SCALE :.02=1.00
KEPES 12-5-90

SDC TILE/FIBER CALORIMETER

Single Module (Half Length)



LEAD IRON CALORIMETER HADRONIC SECTION WITH READOUT



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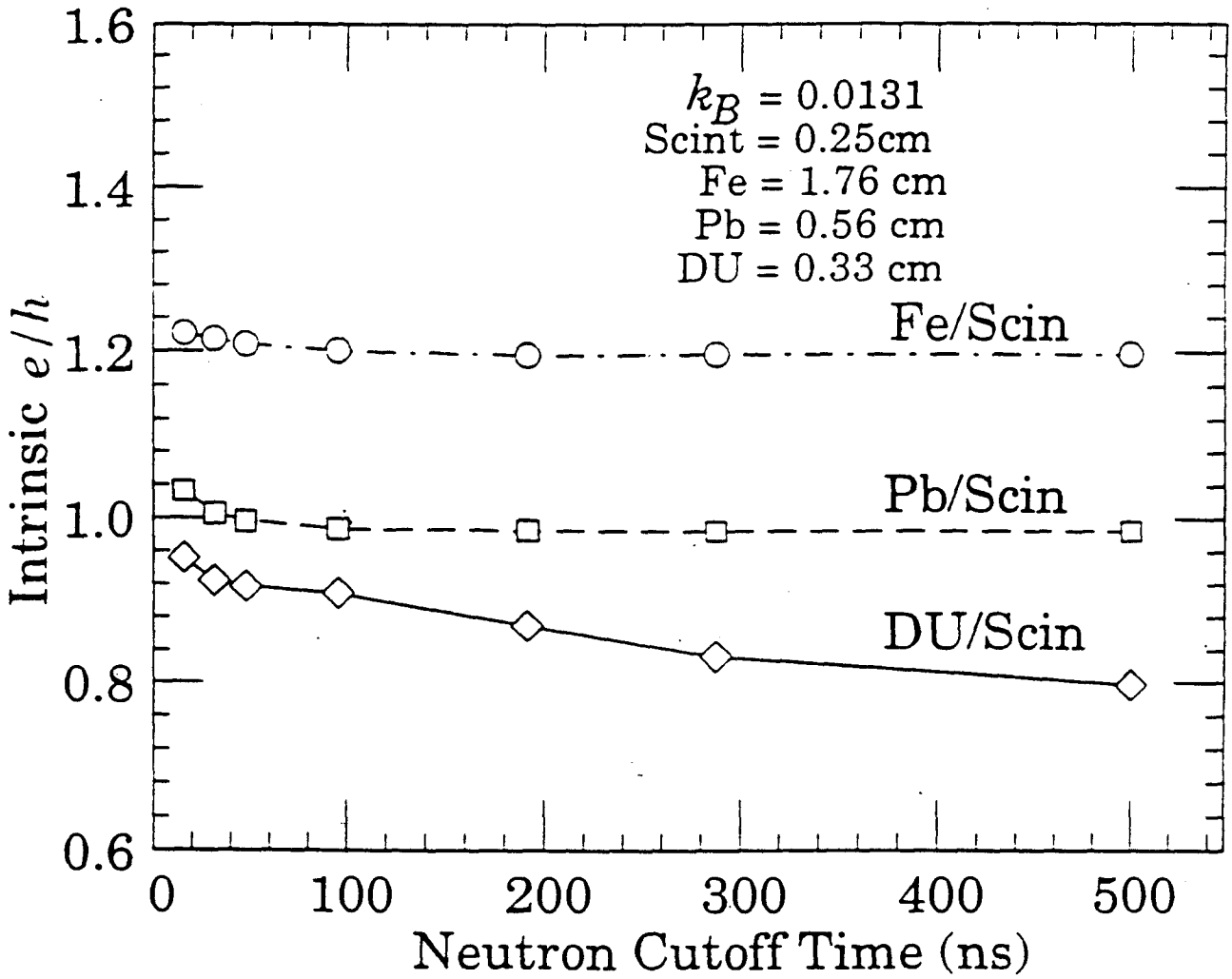
KEPES 12-7-90

Status of the Scintillator Design

- Proof-of-principle beam tests of the fiber readout concept with small test modules have been completed successfully at Fermilab in the context of the upgrade of the CDF endplug calorimetry.
- About 250 photoelectrons/GeV achieved in EM module
- Uniformity of about 1% achieved across three towers in small module
- Conceptual engineering design of lead/iron structure underway(ANL, Westinghouse Science and Technology Center(WSTC))
- Detailed study of automated assembly of ≈ one million tile assemblies inititiated(WSTC)
- Conceptual design of all-iron hadronic section initiated(Fermilab)
- Preliminary cost and schedule estimates for the lead/iron design completed
- Extensive Monte Carlo studies of performance underway - see figure

e/h as a function of integration time for different calorimeter compositions



SDC

Status of the Scintillator Design cont.

- **Extensive radiation damage studies of new scintillators have been performed - see example below**

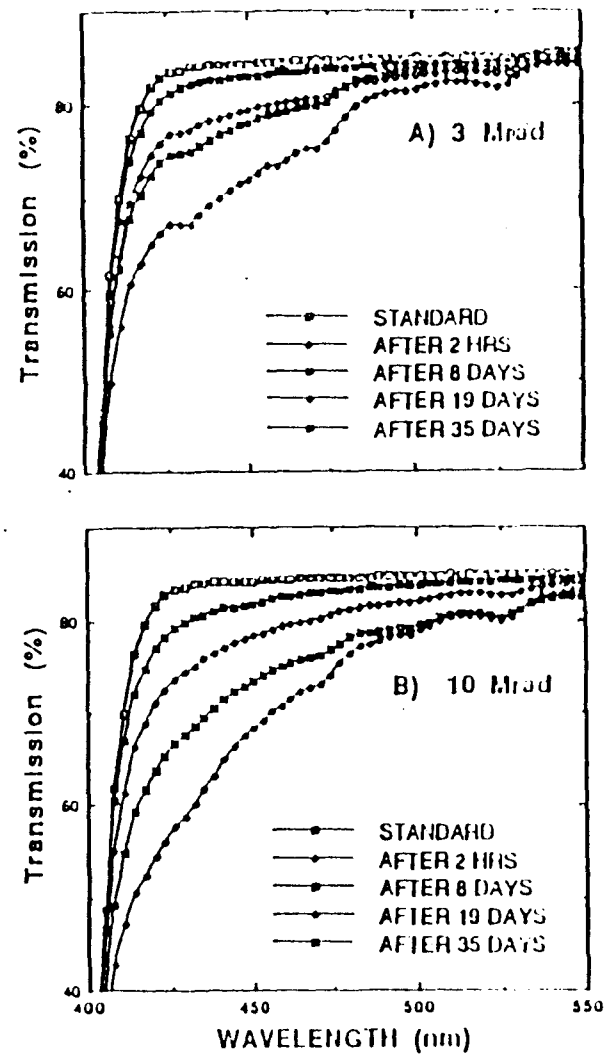


Fig.3. Transmission accross 5 mm BH-1 scintillator plate before and after radiation.

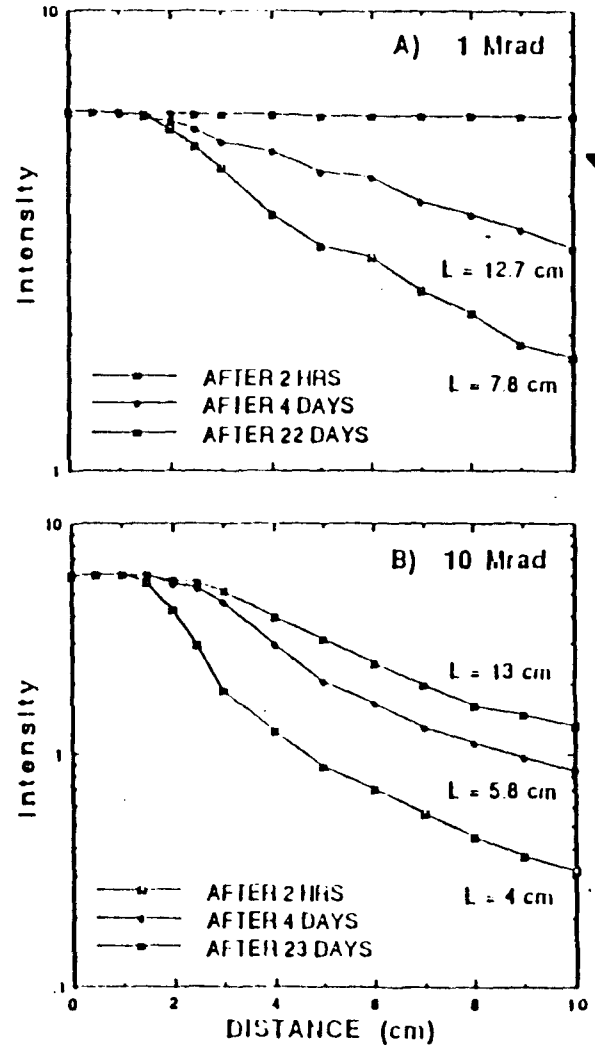


Fig.4. Light yield of 10x2x0.5 cm³ BH-1 plate scintillator. L is attenuation length.

Full recovery after 3 weeks

SDC

Status of the Scintillator Design cont.

- We have also evaluated the effects of radiation damage on calorimeter performance, as indicated by the tests on new materials

- We plan to take full advantage of calibration of the EM section by sources and by *in situ* calibration provided by the very large rate of $Z \rightarrow e^+ e^-$ and $W \rightarrow e\nu$ events. Using both of these techniques, each EM tower may be calibrated to an accuracy of 1% or better about every two weeks at the design luminosity.

- Our present assessment is that calorimeter performance will be viable to at least $|y|=2$ for an integrated luminosity of 10^{42}, based upon the observed radiation-induce losses in light yield and decreases in attenuation lengths and taking full advantage of the calibration.

- The alternative for $2<|y|<3$ is to continue the development of radiation-hardened scintillators, design the endcap to replace the scintillator in this region every few years or use another technology eg warm liquid for the EM section in this region. We plan to pursue all of these options in the next year.

R&D and Engineering Needs for the Scintillator Option in FY91

- Although the results of radiation tests on small samples of new scintillator materials are encouraging, much more must be done in this area. In the next year we plan to
  - continue the development and test of new materials with US and Japanese manufacturers of scintillator(Florida State, LSU, Fermilab, Tsukuba)
  - study low dose rate effects
  - test EM modules with the best available scintillators at KEK, Orsay(by SDC members at Saclay) and in China and the USSR
- Beam tests at Fermilab of a "hanging-file" iron calorimeter with the ability to insert lead sheets will be completed by summer '91 to evaluate e/h in mostly iron mixtures
- Prototype EM modules will be built and tested for tower-to-tower uniformity, also at Fermilab
- An EM module using the cast lead technique will be constructed by ANL and WSTC and tested at Fermilab
- CALOR and other Monte Carlo studies will continue to address e/h and other fundamental properties(ANL, ORNL)

R&D and Engineering Needs for the Scintillator Option in FY91 cont.

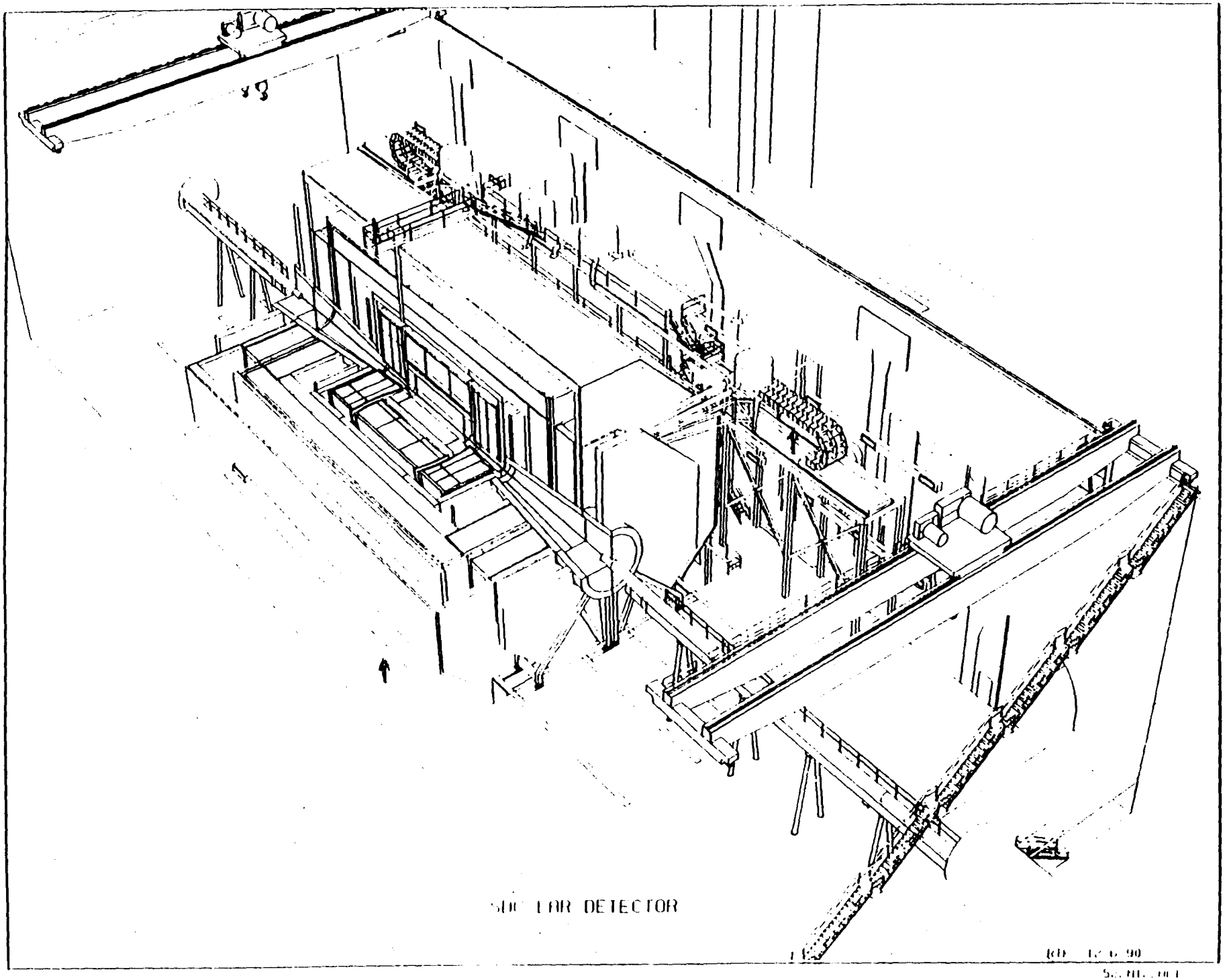
- A conceptual design for the lead/iron option and its support inside the muon steel will be completed(ANL, WSTC, PSL)
- A conceptual design of the iron-hadronic option will be completed(Fermilab)
- Tile assembly techniques will be studied(ANL, Fermilab and WSTC)
- Mechanical designs will be evaluated using GEANT(ANL, Fermilab)
- A revised cost and schedule estimate will be produced by summer '91(ANL, Fermilab and WSTC)
- Adequate support of both R&D via the scintillating plate large subsystem proposal and of engineering design is critical to meet our goal of technology selection by fall of '91

Liquid Argon Option

- Liquid argon is mature technology and members of the SDC have substantial experience in this technique via the MARKII, D0 and VENUS experiments

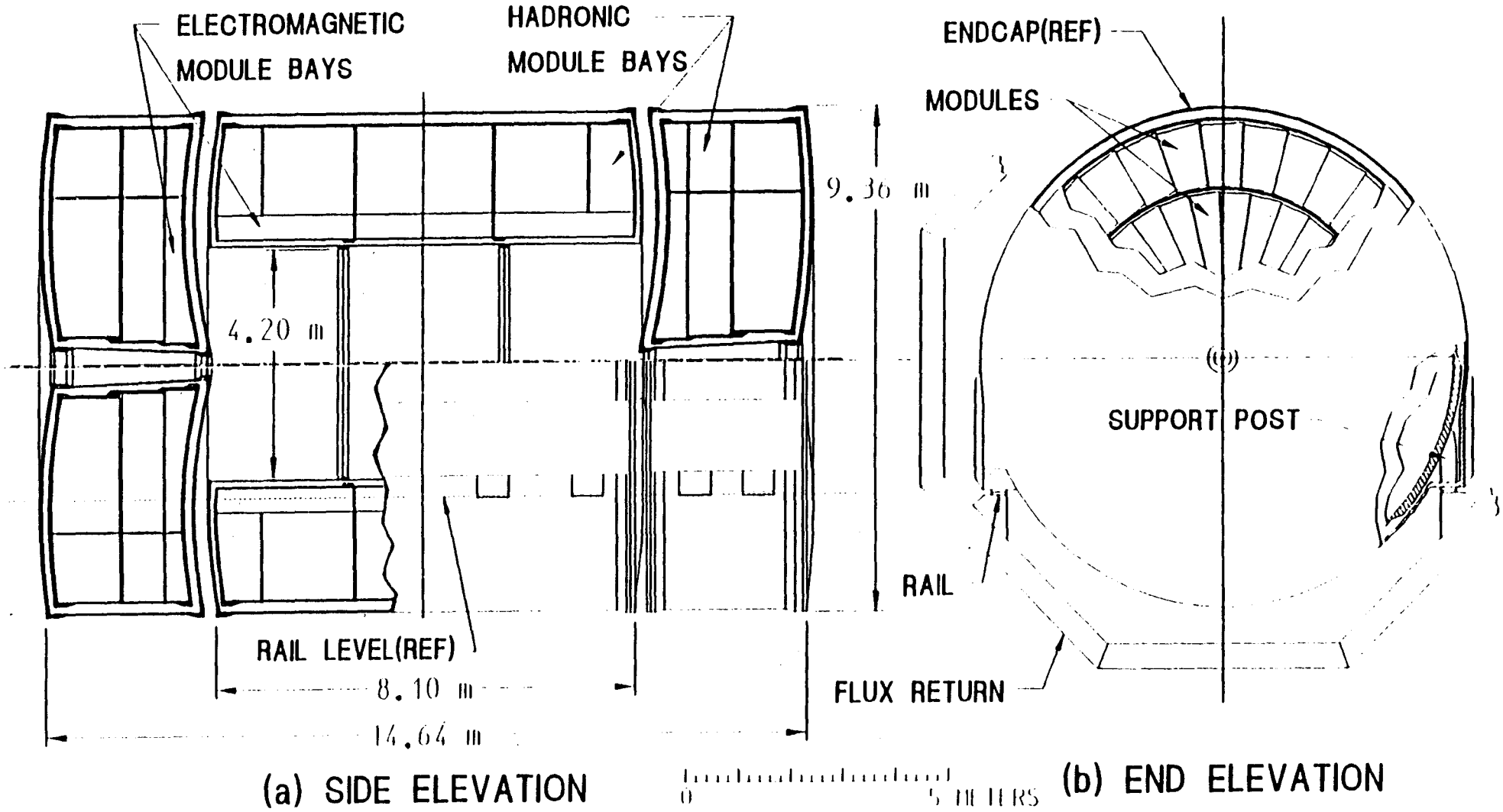
- Preliminary design choices
  - Lead absorber
  - Magnetic transformers and preamplifiers inside cryostat to minimize electronic noise
  - "Massless gaps" before EM section to improve response to electrons and photons

- The liquid argon concept for the SDC detector is shown in the accompanying figures


LAR DETECTOR

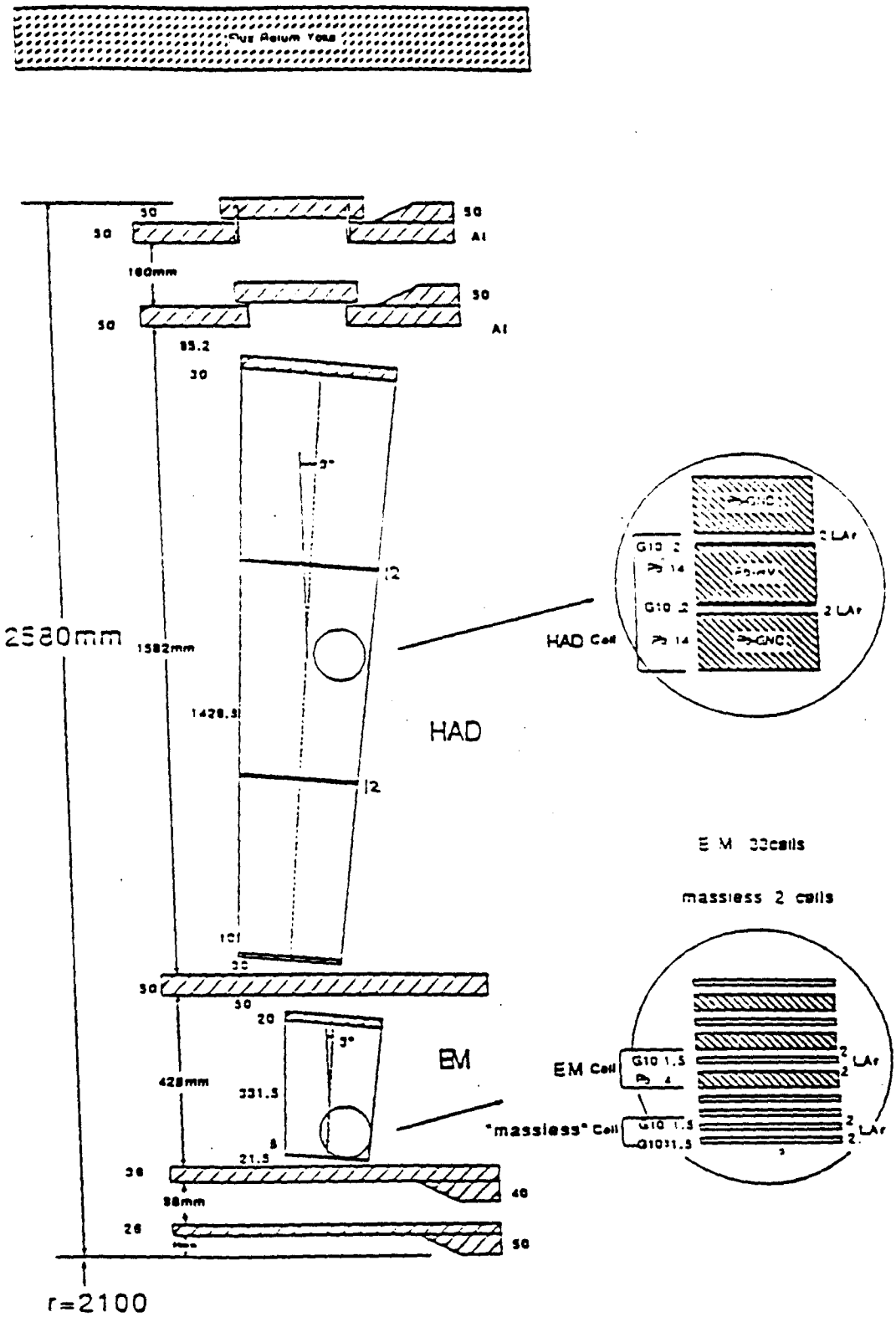
Status of the Liquid Argon Design

- Conceptual cryostat design and assembly sequence by Kawasaki Heavy Industries with guidance from KEK/LBL - see figure
- Conceptual module design by KEK/LBL - see figure
- Cryogenics, system and hall design by LBL/Kaiser Engineers/ SSCL
- Safety analysis started by LBL/SSCL
- Shielding of magnetic transformers to $\approx$ 0.7T demonstrated by Univ. of Rochester
- Detailed EGS studies of electron response started
- GEANT studies started of hadronic response
- Transformer, preamplifier and cabling layout internal to cryostat initiated
- Preliminary cost and schedule estimate completed
- Preliminary assessement of radiation damage to preamps and materials completed, which indicates viability of liquid argon for $|y|<3$ to at least integrated luminosities in excess of 10^{41}
- SDC members contributing to beam test at BNL in spring '91



(a) SIDE ELEVATION

(b) END ELEVATION



Radial dimensions and cell structures of the Barrel

R&D and Engineering Needs for Liquid Argon in FY91

- Completion of beam test at BNL with lead absorber and fast readout to evaluate e/h(SDC members of liquid argon subsystem proposal)
- Revise cryotstat design based on EGS, GEANT and physics simulation studies(KHI, KEK, LBL)
- Complete conceptual electromechanical baseline design of module structure with transformers, cooled preamps, cables and readout boards inside cryostat(LBL, KEK, Univ. of Rochester)
- Complete reliability analysis of electronics system design with preamps inside cryostat(LBL, industrial contractor?)
- Complete and document preliminary cryogenic system design and safety analysis(LBL, SSCL)
- Continue EGS and GEANT studies to guide cryostat and module design(KEK, LBL, SSCL)
- Evaluate methods (eg. steel clad lead or shower weighting) to adjust e/h $\approx$ 1(KEK, LBL, SSCL)
- Continue design of modules(electrostatic transformers) with preamps outside cryostat until reliability of baseline design is demonstrated (LBL, SSCL)

Selection of Central Calorimeter Technology

- We plan to make a selection of one technology for the central calorimetry by no later than fall of 1991, in time for inclusion in the proposal

- Both additional R&D and performance assessment studies must be completed to make an informed choice

- A preliminary schedule for critical studies is shown in the enclosed table

- Adequate support of both R&D, particularly beam tests of scintillator and liquid argon, and engineering design is required to meet this schedule.

Calorimeter Performance and R&D Milestones in FY1991

			1991 J	F	M	A	M	J	J	A	S	O	N	D	1992 J
Simulation Studies of Performance Issues	pileup + trigger						X								
	e/h requirements							X							
	high luminosity requirements							X							
	electron & photon id requirements									X					
	forward calorimeter requirements									X					
Beam Tests & Engineering Design	LAr	e/h in Pb-LAr						X							
		preamps. in or out of LAr				X									
		cryostat design						X							
	Scint.	radiation hardness tests										X			
	Tile	Fe compensation test							X						
		tile uniformity tests							X						

SDC

Forward Calorimetry

- The primary function of the forward calorimetry is to provide hermeticity for missing E_T measurements, although it may also be used to "tag" forward going jets

- We have just initiated a Task Force with members from the United States, Canada and the USSR to evaluate candidate technologies, better quantify physics requirements and to develop an R&D plan. The Task Force will report next summer.

- Candidate technologies, at this time, are liquid argon, warm liquids, liquid scintillator and high pressure gas.

Pre-shower and Shower Maximum Detectors

- A simple shower-maixum detector(strips in one direction) is included in our baseline scintillator design and cost and the use of crossed strips for the liquid argon option is under study.

- The use of pre-shower and shower maximum detectors for improved electron and photon identification is under study by an SDC team in the US, France and Israel.

- A pre-shower detector would use the coil(augmented by lead) in the barrel region and stand-alone lead in the endcap region.

- Much more study of the physics requirements for either a pre-shower or shower-maximum detector must be done before a decision can be made

- The choice will coincide with the selection of the central calorimeter technology

Possible Preshower Detector Design Parameters

Fiber diameter(mm)	1.5
Fiber length(m)	2.0
Number of fibers - barrel	140,000
Number of fibers - endcaps	40,000
Weight(tons) - barrel	8
Weight(tons) - endcap	3.4
Radiation lengths(pb/coil)	2.5
Radiation lengths detector	~0.1

MUON SYSTEM

CENTRAL REGION ($|\eta| < 1.5$)

Iron toroids(1.5 m thick)+drift wires+scint. counters.

Precision momentum measurement by central tracker.

Combination of central tracker plus muon drift wires yields improved precision at high p_t, 13% at 1 TeV.

INTERMEDIATE ANGLE REGION ($1.5 < |\eta| < 2.5$)

Iron toroids (4 m thick)+drift wires+scint. & Cerenkov ctrs.

Momentum measurement from both central tracker and toroid with precision going from 17% to 40% at 1 TeV over the rapidity interval.

MUON ID

Matching of muon system tracking and central tracking information.

LAYOUT & CHANNEL COUNT FOR MUON SYSTEM

WC=Wire chamber, SC=scintillation counter, CC=Cerenkov counter

Central Region

Layer #	Radius (m)	Coor-dinate	Layers	Channels (k)
WC1	6.5	θ	6	12.1
		ϕ	4	4.0
		s	2	4.1
WC2	9.0	θ	4	11.2
SC1	9.5	θ	1	2.5
WC3	11.0	θ	6	18.6
		ϕ	4	10.0
		s	2	6.2
SC2	11.5	θ	1	2.5
Totals			28 WC 2 SC	66.2 WC 5.0 SC
Grand Total				

Intermediate Angle Region

Layer #	z (m)	Coor-dinate	Layers	Channels (k)
WC1	8.0	θ	4	4.0
WC2	10.0	θ	4	5.2
		s_1, s_2	4	5.2
SC1	13.0/16.0	θ	1	1.4
WC3	12.5/15.5	θ	4	7.2
CC1	17.0	—	1	0.5
SC2	16.0/18.0	θ	1	1.4
WC4	15.5/17.5	θ	6	12.4
		s_1, s_2	4	8.2
Totals			26 WC 2 SC 1 CC	42.2 WC 2.8 SC 0.5 CC
Grand Total				108.4 WC 7.8 SC 0.5 CC

SDC

MUON TRIGGER

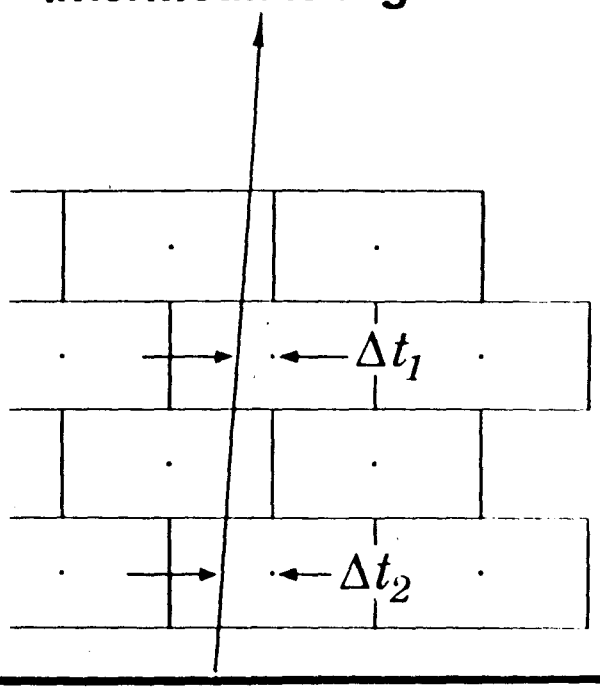
LEVEL 1

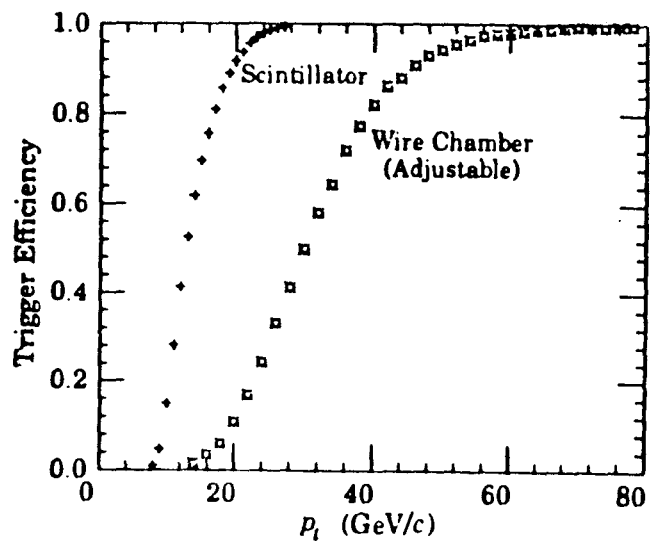
2 scintillation layers with strips aligned in θ plus combination of muon wire chamber hits also aligned in θ.

LEVEL 2

Central region: ϕ information from muon chambers combined with outer layers of central tracker.

Intermediate region: θ angle-angle measurement in forward toroid .

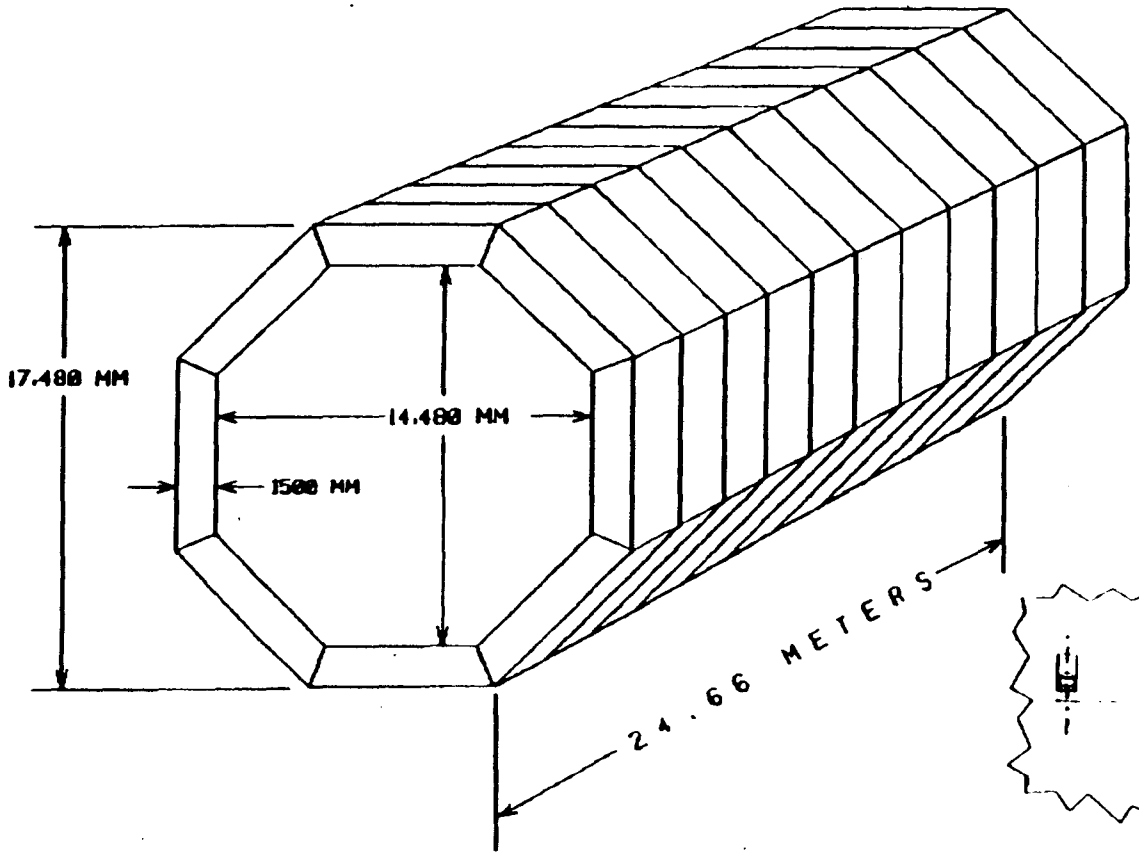


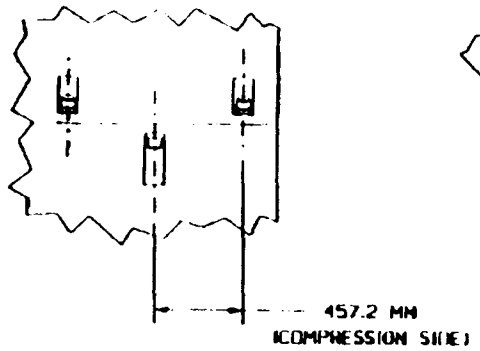


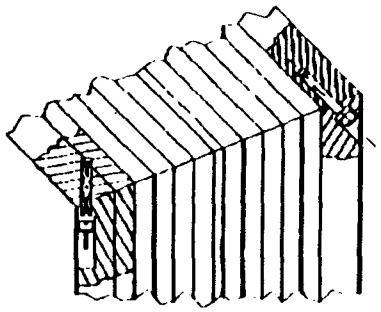
SDC

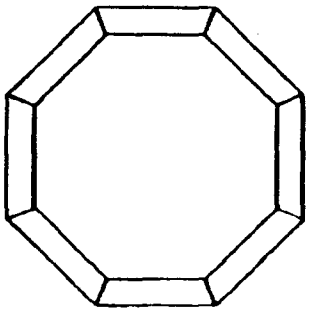
MUON BARREL STEEL

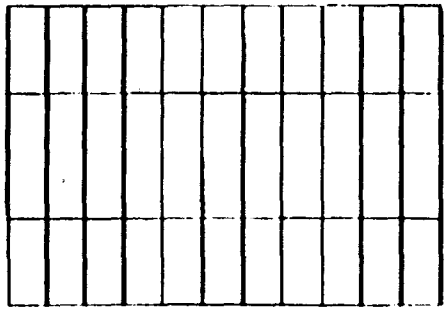
Option 1

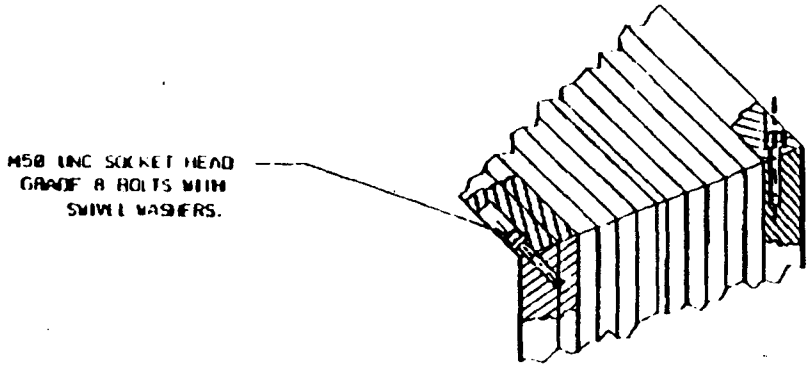








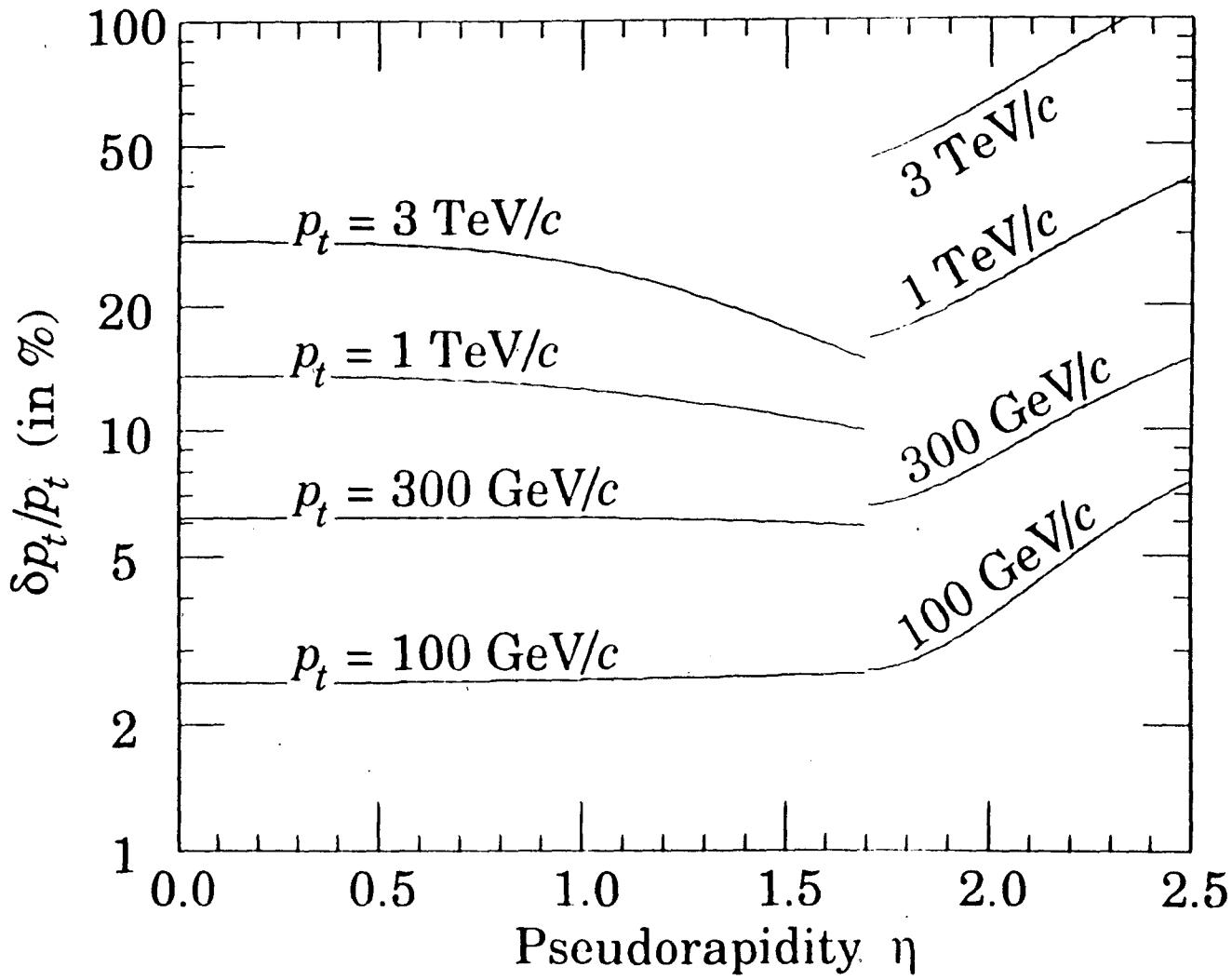




1 ASSEMBLY. 15.415 METRIC TONS

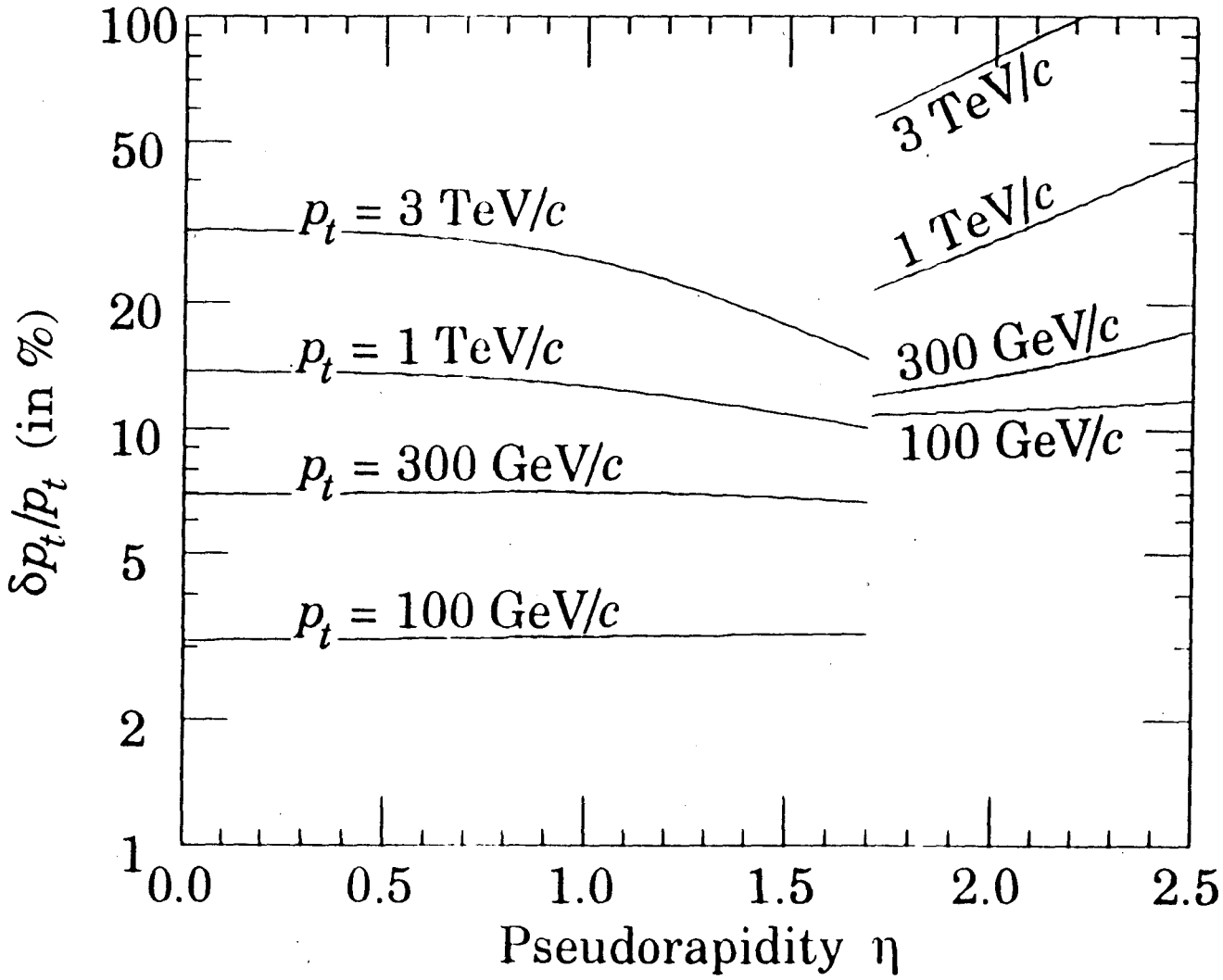
SDC

MUON SYSTEM MOMENTUM RESOLUTION



SDC

MUON SYSTEM MOMENTUM RESOLUTION
High Luminosity Performance



SDC

HIGH LUMINOSITY (~ 10^{34})

CALORIMETRY

For $|\eta| < 3$, our design goal is a calorimeter survivable for an integrated luminosity of at least a few times 10^{41}. For a scintillation calorimeter this may require the ability to replace some of the scintillator in the electromagnetic compartment for a limited range of rapidities above $|\eta| = 2$, or alternatively to design in that rapidity range a hybrid calorimeter with , for example, warm liquid in the electromagnetic section followed by the standard scintillator design in the hadronic section.

For $|\eta| > 3$, our calorimeter designs are not sufficiently far along to specify what we can hope to achieve. It is likely that missing-E_t physics will be more difficult.

TRACKING

We expect that the silicon will survive to at least a few times 10^{41}. At increased luminosity the wire system will become very marginal except at the outer layers of the barrel. A fiber system can probably retain its functionality at the increased luminosity. In either case the momentum resolution in the barrel region will only be slightly degraded. However, especially for the straw system, pattern resolution will be a greater problem. For isolated tracks, this should remain manageable, but more simulation work is needed.

HIGH LUMINOSITY (CONT.)

MUON SYSTEM

The full outer muon system will be available. If combined with the silicon and measurements from an outer superlayer, the momentum resolution is not substantially degraded. Pattern recognition is still the main issue.

CONCLUSION

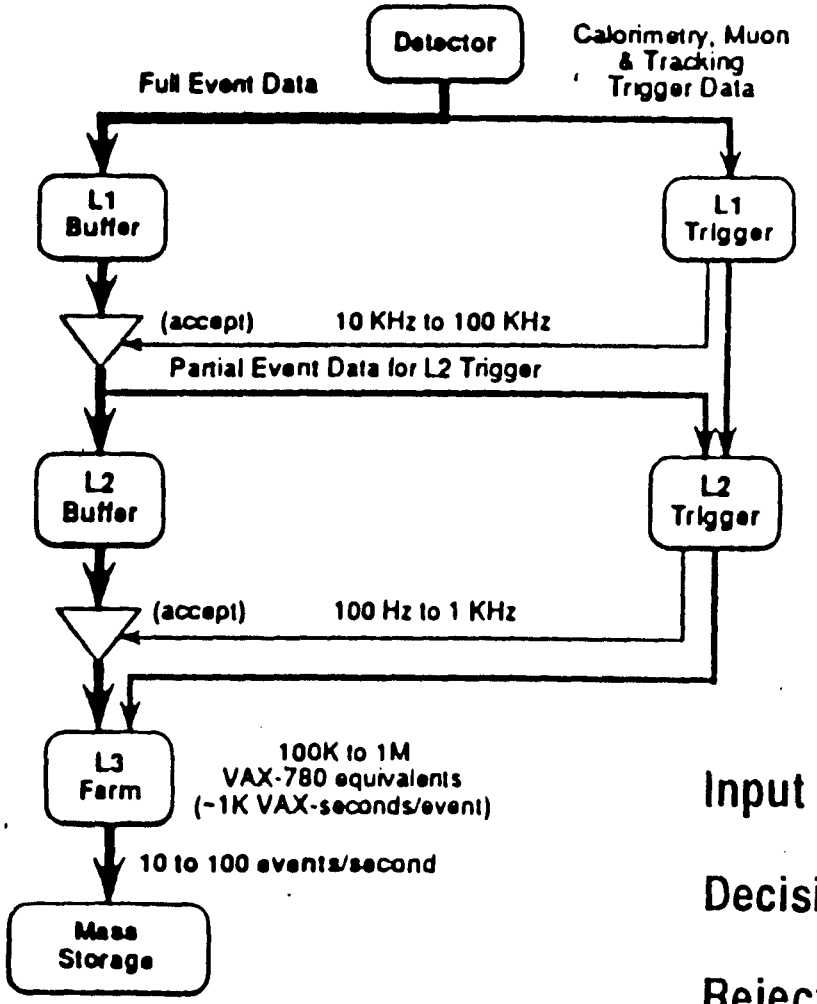
Detector should remain operable at high luminosity, and provide good measurements for many rate-limited processes.

Requirements imposed by high-luminosity survivability will be important inputs into technology choices.

Status of Electronics Development

• Silicon -strips/pixels	
KEK, RAL, Penn, UCSC, LBL, UCD, UCB, Hughes, Hawaii, Oxford	preamps, shapers, discriminators, analog/digital readout, radiation hardness
• Scintillating Fibers	
FNAL, ANL, Duke, Penn State, Rockwell	solid state PM, amplifier, discriminator, digital readout, trigger interface
• Wire Chambers	
Hiroshima/KEK, Penn, ORNL, Colorado, Toronto, Bristol, UM	TMC, TVC, trigger interface, preamp, discriminator, readout, rad. hard tests
• Calorimetry	
Harvard, LBL, Chicago, FNAL, ANL, Wisc, IBM, TxAM, Westinghse, Ames, KEK, Brandeis, Rochester	preamps, shapers, analog/digital storage, radiation hardness, flash encoders, trigger interface, transformers
• Trigger	
Chicago, FNAL, LBL, Wisconsin, Harvard, Tsukuba, KEK, UM, Oxford, Wash., Illinois, J.Hopkins, RAL	analog/digital calorimeter triggers, synchronizer, TMC, neural nets, fiber segment finder, projective cells, silicon fast trigger, global trigger
• Data Collection & Transmission	
Brown, FNAL, Illinois, KEK, LBL, Toronto, McGill, RAL, ANL, Miss, Penn, IBM, Fukui	architectual modeling & simulation, readout & control, event builder, CPU farm, data transmission

ELECTRONICS, TRIGGER AND DATA ACQUISITION



	Level 1	Level 2	Level 3
Input Rate	60 MHz	10~100 kHz	0.1~1 kHz
Decision Time	1.5 μsec	10~50 μsec	0.1~1 sec
Rejection Factor	1 k ~ 10 k	10 ~ 100	10 ~ 100

Trigger Example: Inclusive Electron Trigger

Level 1

EM tower ($\Delta\eta\Delta\phi = 0.2x0.2$) energy above threshold

Hadronic compartment energy < 20% EM energy

Level 1 or Level 2

Stiff track segment ($P_t > 5GeV$) pointing towards calorimeter cell in ϕ coordinate

Level 2

Isolation:

energy in surrounding EM+HAD towers < 20% EM energy

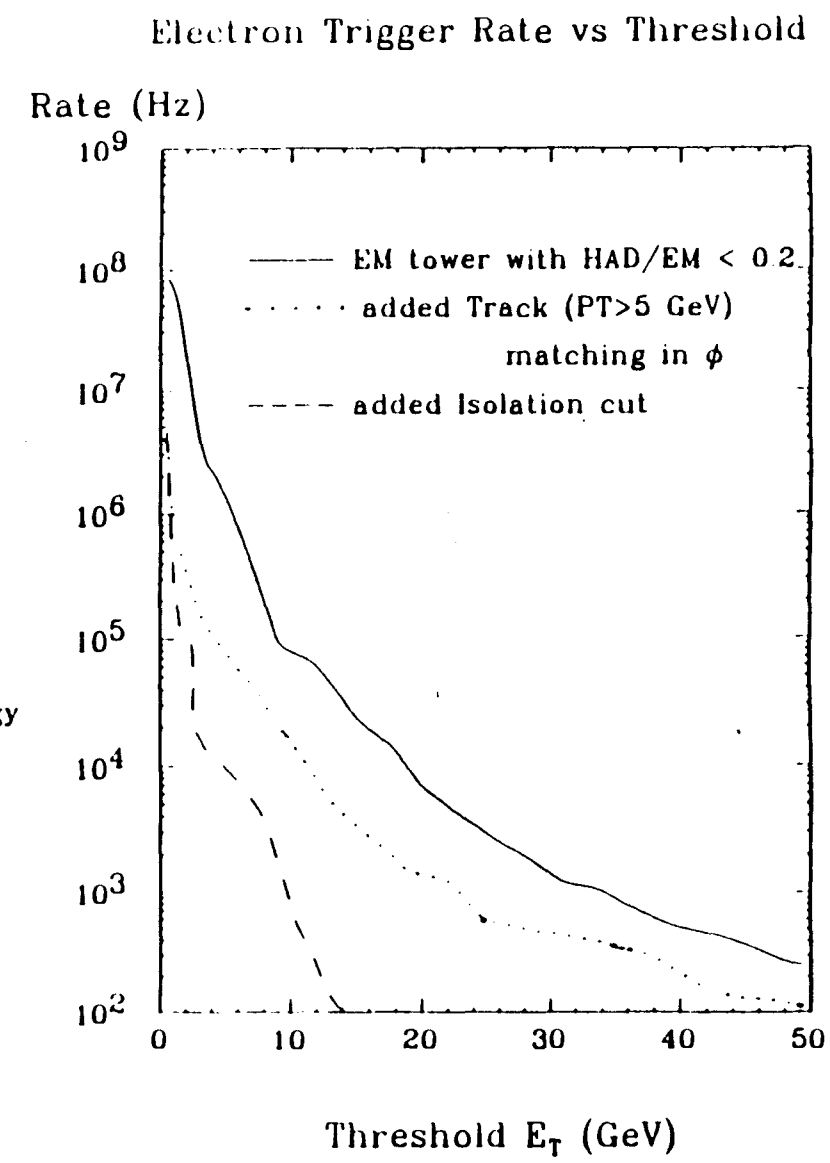
Level 3 - Further rejection via combination of:

Longitudinal and lateral shower profiles

Track matching in space and in momentum

Conversion rejection by tracking and dE/dx

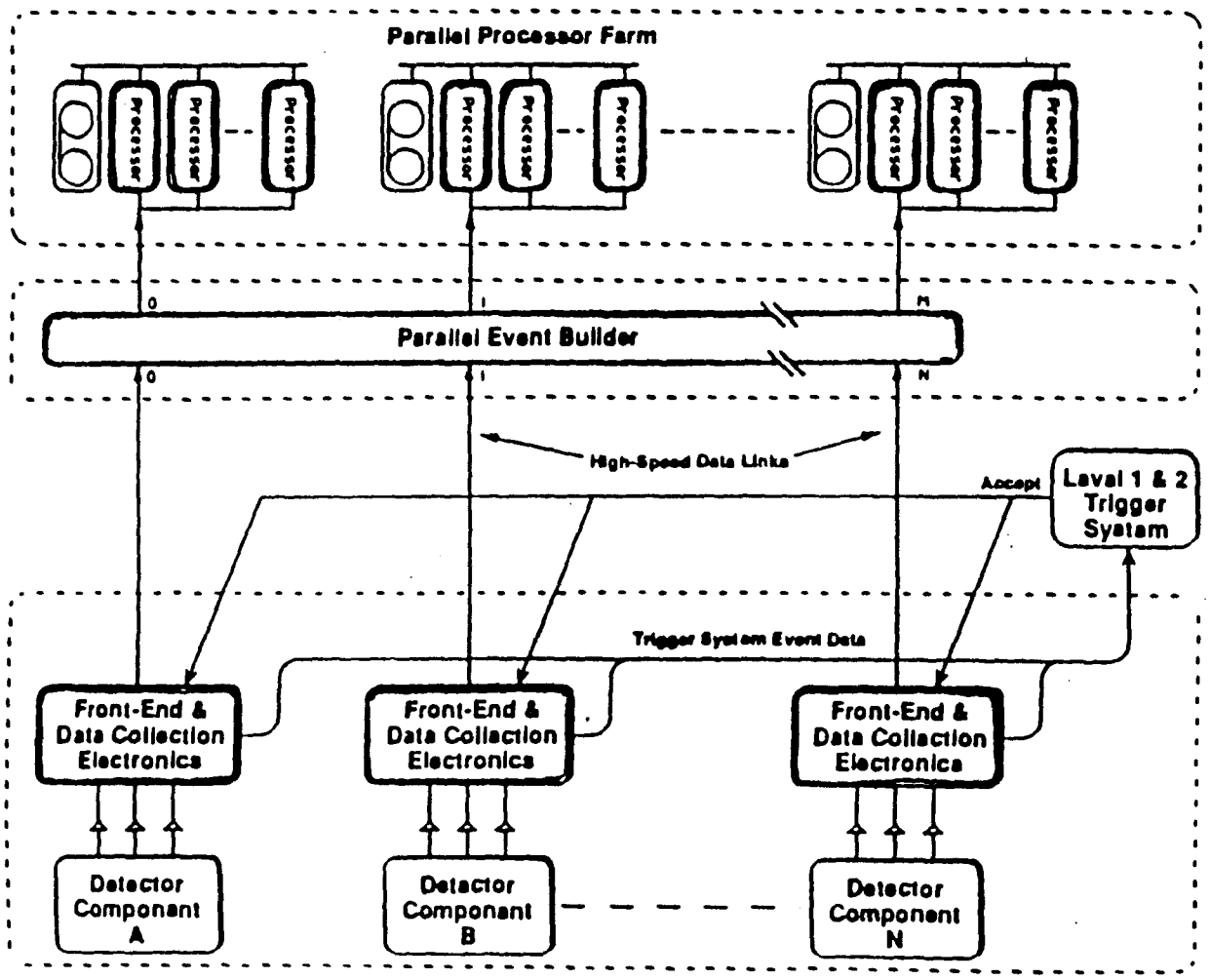
Tighter isolation cuts to reject heavy quark decays



SDC

DATA ACQUISITION SYSTEM

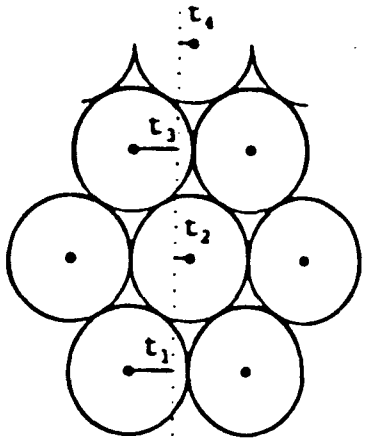
Data handling capacity ~10 Gbyte/sec and 10^5~10^6 VAX780



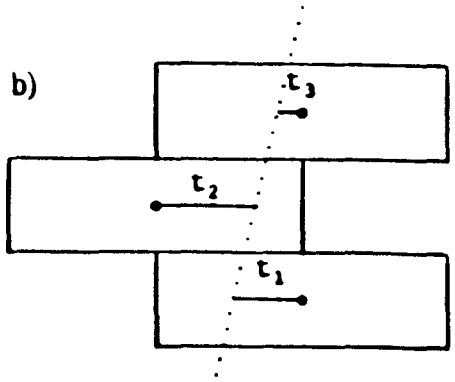
SDC

Fast Track Segment Finding

a)

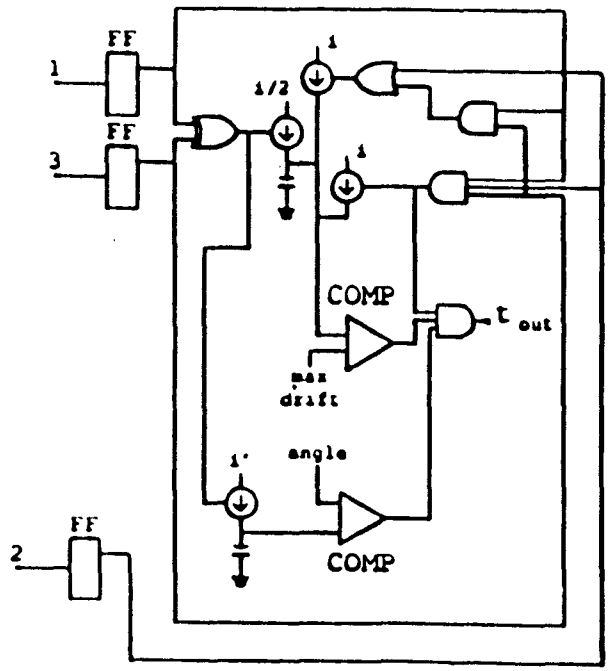


b)

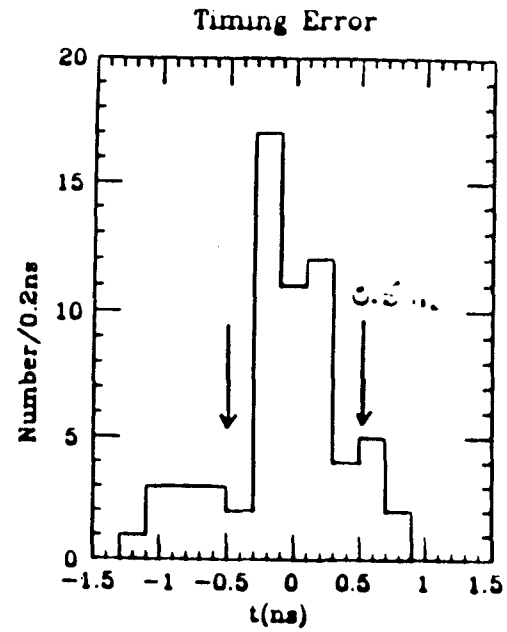


c) $$t_2 + \frac{t_1 + t_3}{2} = T$$

SUPERLAYER



SYNCHRONIZER



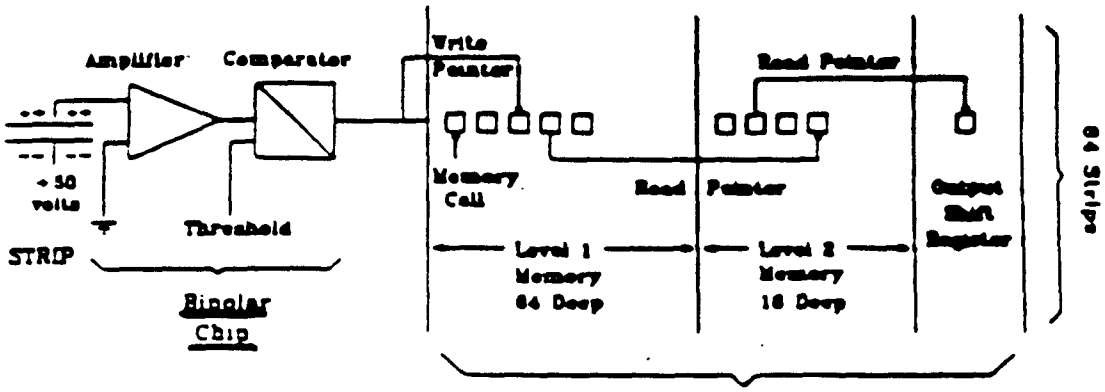
The timing uniformity of one of the first synchronizer chips.

RESOLUTION

SDC

Silicon Strip Detector Readout

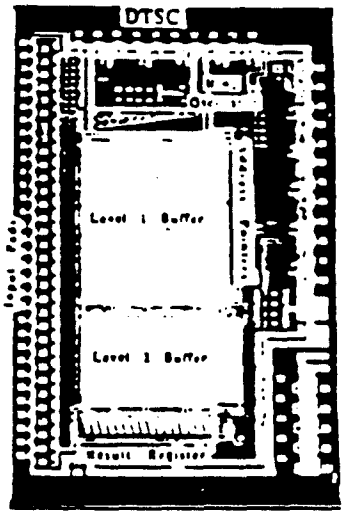
* IC Prototypes tested for:
  Preamplifier, Amplifier, Comparator (Bipolar)
  Level 1-2 Digital Storage (CMOS)



Digital Storage Chip (DTSC) in 1.2 μm Rad-Hard CMOS from UTMC

Preamp, Amp, Comparator meets noise, speed, and density requirements

Digital Time Slice Chip meets functional requirements and clocks at 30 MHz.



* Radiation Hard

  > several megarads for bipolar and CMOS
  > 10**14 n/cm**2 for bipolar chip
  > 10**15 n/cm**s for CMOS chip

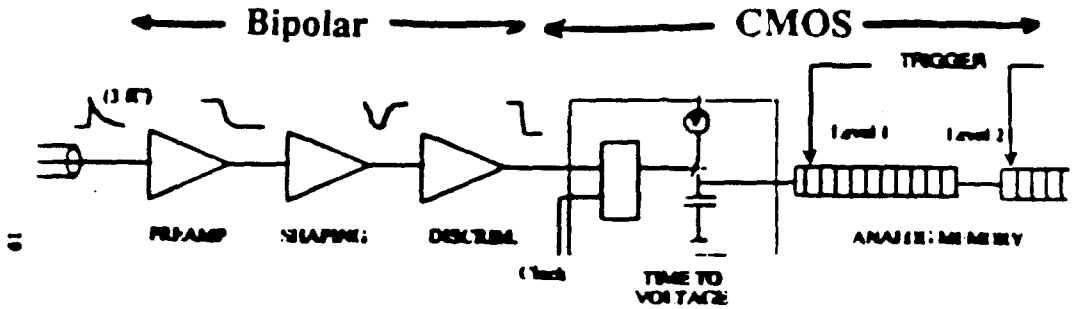
* Milestones

Lower Power preamp, shaper, comparator	Summer 91
Alternate architctures for Level 1-2 Storag	Summer 91
Prototype system for charge readout	Fall '91
Preproduction prototypes - complete system	Fall '92
Full system test: 1000 - 10000 channels	Summer '93

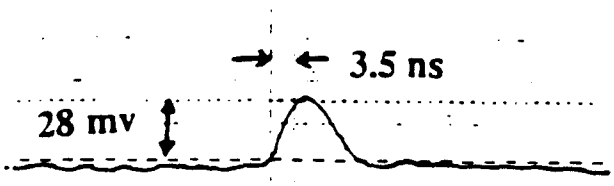
SDC

Wire Drift Chamber Readout

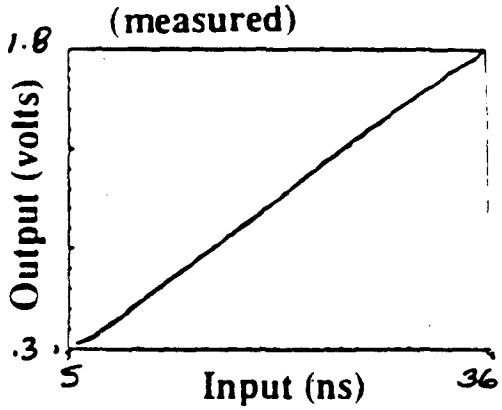
* IC Prototypes tested for Signal Detection, Time Measurement, & Level 1 Storage



Preamp/Shaper Response
Fe^{55} 2.5m Straw Tube



Time-to-Voltage Response
(measured)



* Radiation Hard

  > several megarads
  > 10**14 n/cm**2

* Detailed designs exist for:

  Level 2 storage,
  Interaction with trigger

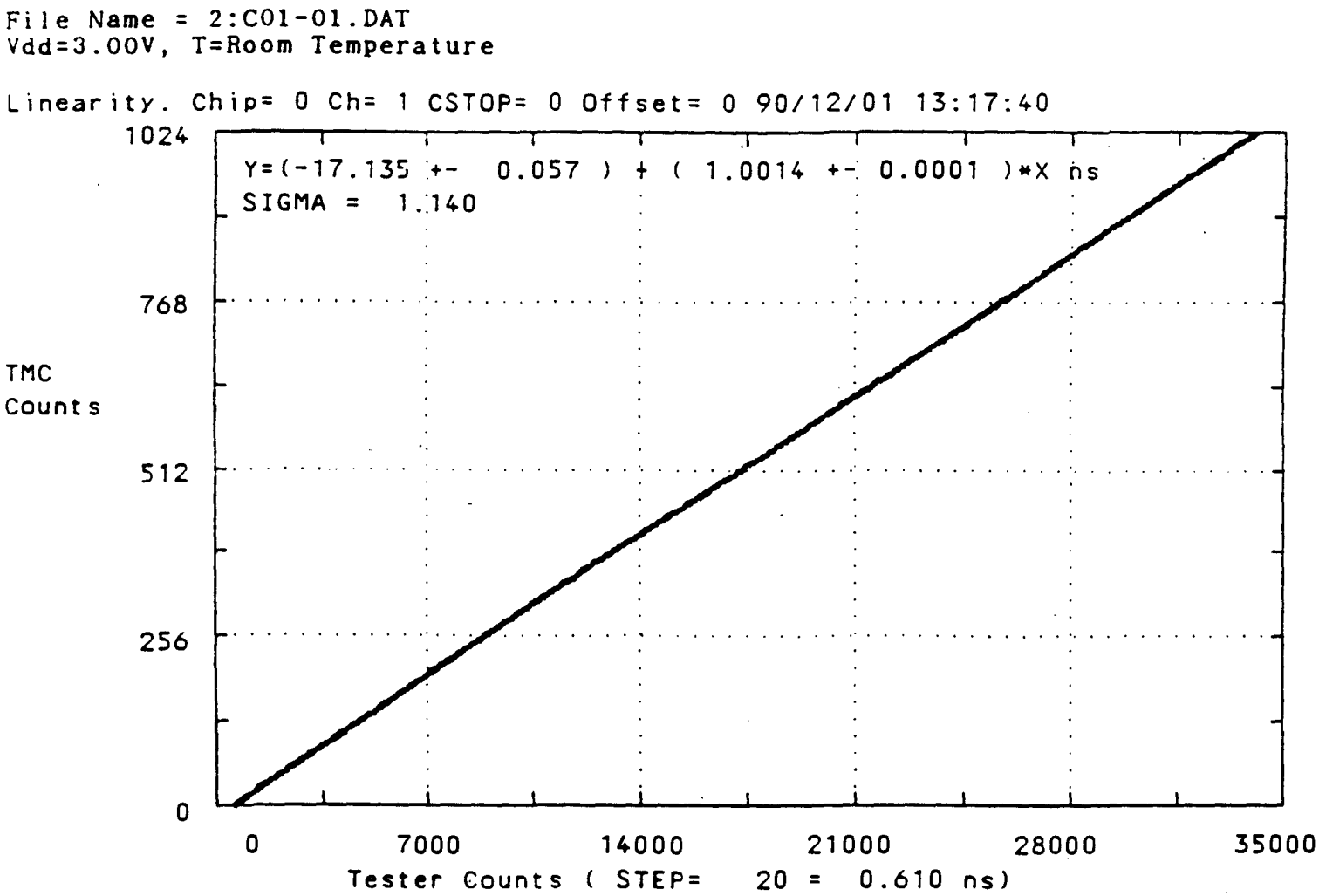
* Milestones

Prototypes including Level 2 storage and readout	Fall '91
Preproduction prototypes - complete system	Fall '92
Full system test: 100 - 1000 channels	Summer '93

SDC

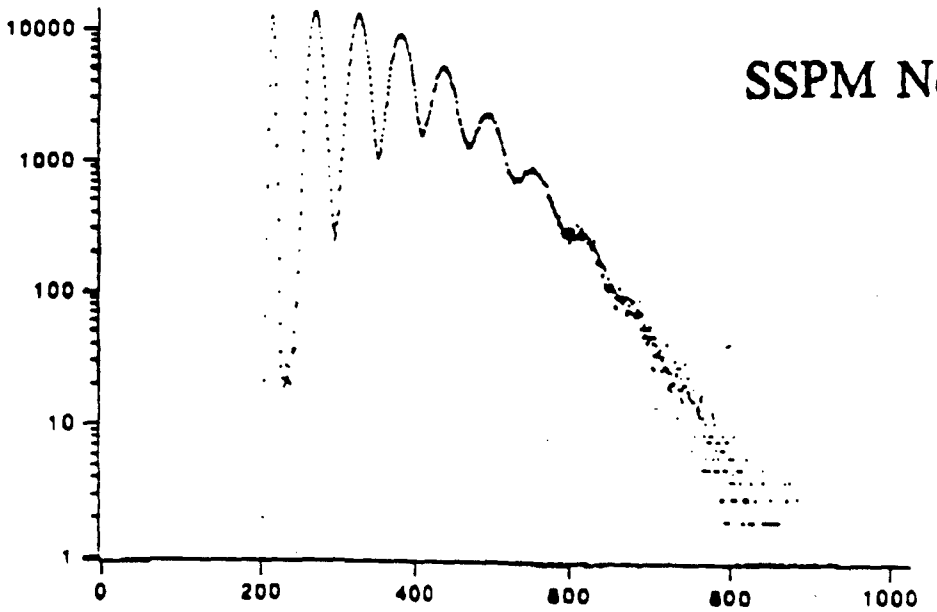
TMC (Time Memory Cell)

- a time digitizer for wire drift chambers
- using 0.8μm CMOS memory technology
- 1ns digitization, 8mW/ch
- being developed at KEK with NTT
- 4ch x 1024ns depth completed and tested

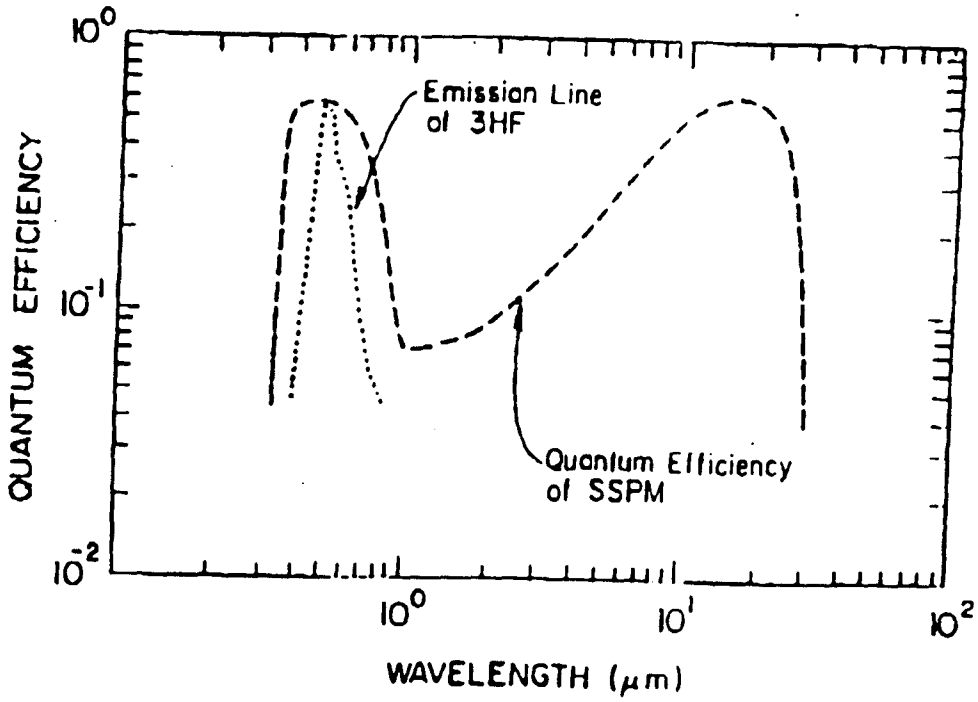


FIBER TRACKER READOUT

VLPC= Visible Light Photon Counter (Rockwell)
high-rate, infrared blind SSPM



SSPM Noise Performance

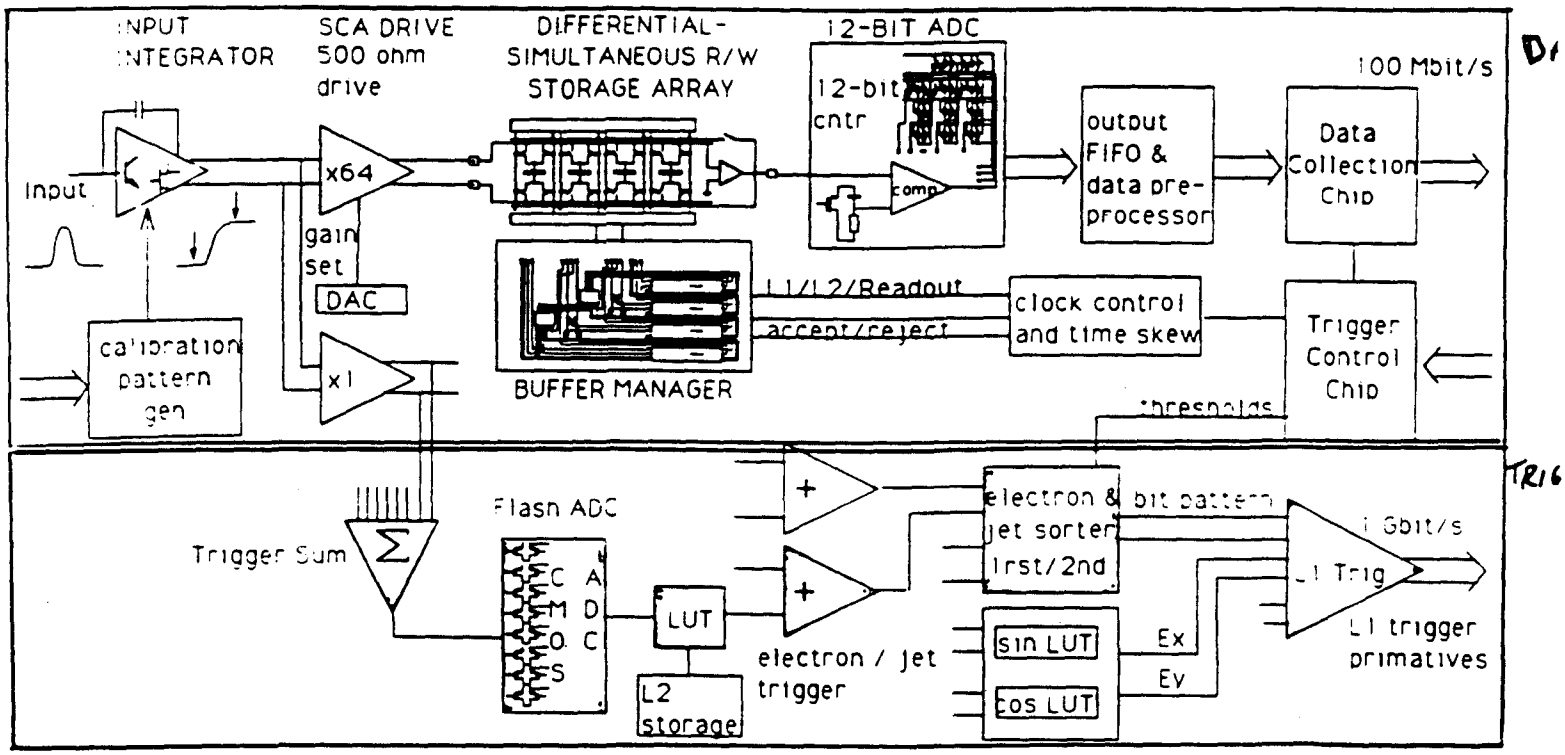


MILESTONES

VLPC Demonstration: 256 channels	Spring '91
System Test: 5000 ch, w/o cryo-elex	Summer '92
Dϕ Production:	Mid '92- End '93
Full Svstem Test: 5000 ch, w/ cryo-elex	Summer '94

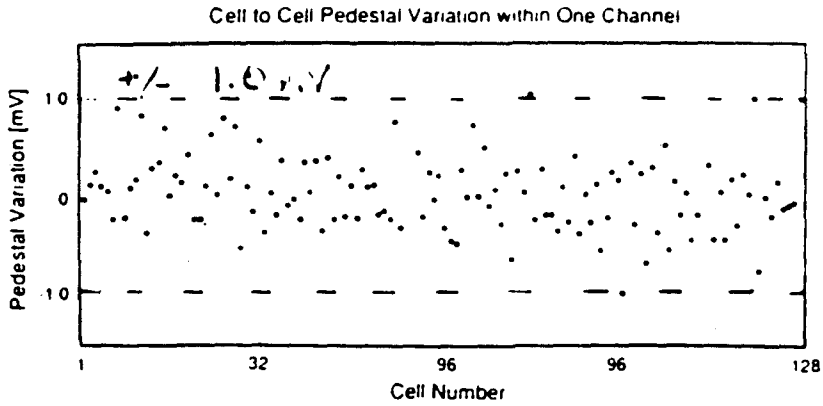
CALORIMETER READOUT

Readout Schematic:



Performance:

SCA Parameters	Achieved Performance
No. channels/chip	16
No. of elements/channel	128
Power channel	23 mW
Non-linearity	+/- 0.9%
Pedestal variation	0.3 mV rms
Charging time constant	2 ns
Channel dynamic range	4000
Maximum sample rate	90 MHz
Maximum readout rate	200 KHz
Noise floor	0.7 mV rms
Input voltage range	0.5-5.5 Volts
Capacitor droop rate	0.1 mV/msec
Output settling time	1.2 usec (to 0.02%)
Gain	1.00 +/- 0.015%



Milestones:

6/91 Test prototypes on several hundred channels
10/91 Complete prototype subsystems via subsystem R&D
10/92 Large electronics systems w/ preproduction prototypes
6/93 Full system test on order of one thousand channels

Physics Performance

PARAMETRIZATION OF PERFORMANCE

- Central tracking resolution vs η
- Muon toroid resolutions vs η
- Electron resolution
  - Lesser of calorimetry/central tracking
- Muon resolution
  - Combination of toroid/central tracking
- Calorimetry
  - Hadronic & electromagnetic resolutions
  - Degradations from structures near η=1.5
  - Non-gaussian tails on jet energies for missing E_t (CDF parametrization)
  - Segmentation: .05x.05 ($|\eta|<3$)
    .10x.10 ($3<|\eta|<5$)
  - Lepton efficiencies for isolated leptons
    - 0.85 for single lepton
    - 0.85/0.95 two leptons from same Z

SIMULATION

- For missing E_t and lepton resolutions, use parametrizatons of detector response.
- For lepton isolation and jet resolution issues, use detailed simulation including B field, shower spreading, and clustering algorithms.

SDC

STANDARD MODEL HIGGS

$M_H = 125$, 140, and 160 GeV

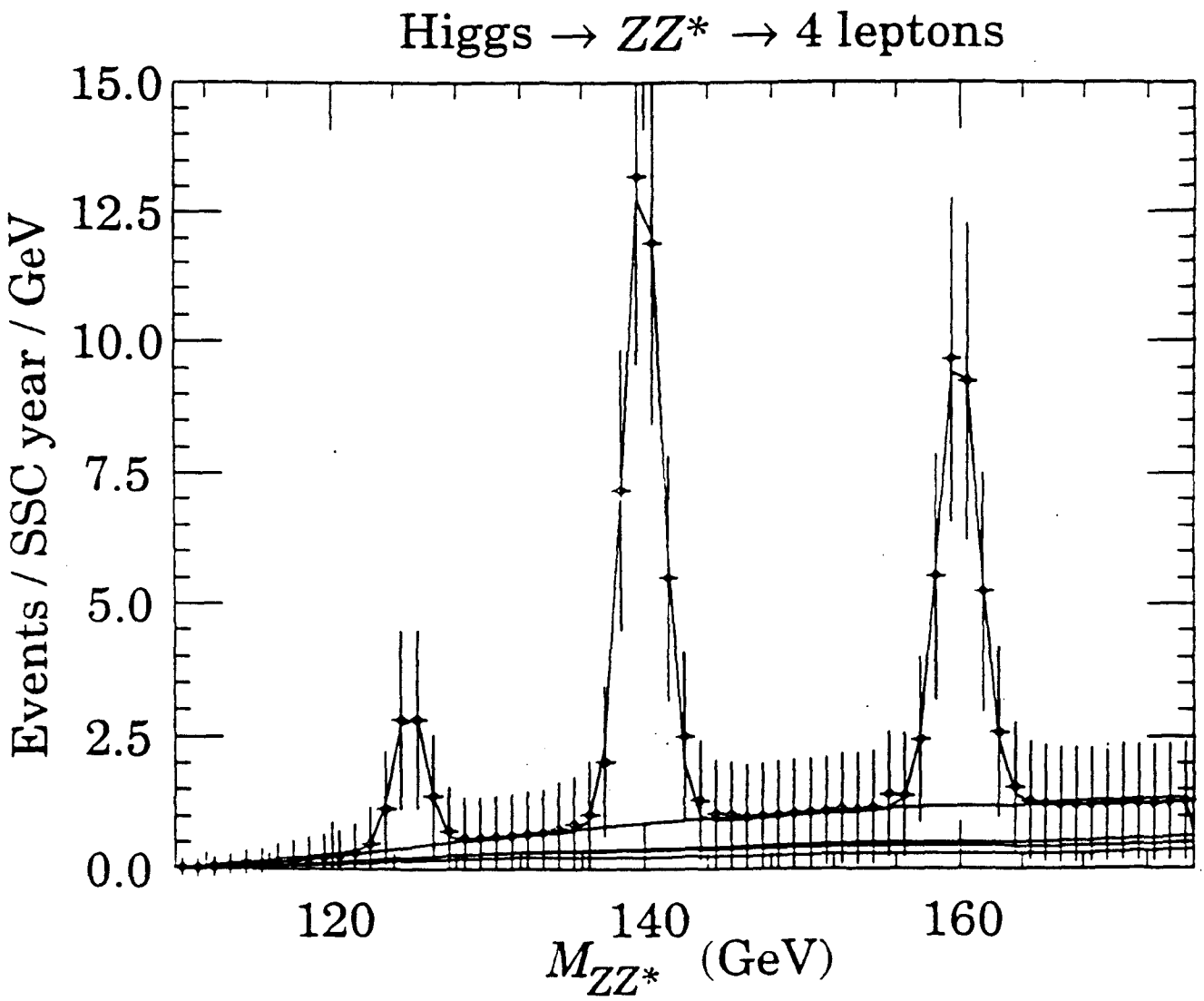
Conditions:

- Two trigger leptons with $p_t > 20$ GeV/c
- Two other leptons with $p_t > 10$ GeV/c
- Lepton isolation: $E_t < 5$ GeV in $R = 0.3$ cone after electron subtraction
- One lepton pair has $M_{\ell\ell} = M_Z \pm 10$ GeV
- Other has $M_{\ell\ell} > 20$ GeV

$M_H = 200$, 400, and 800 GeV

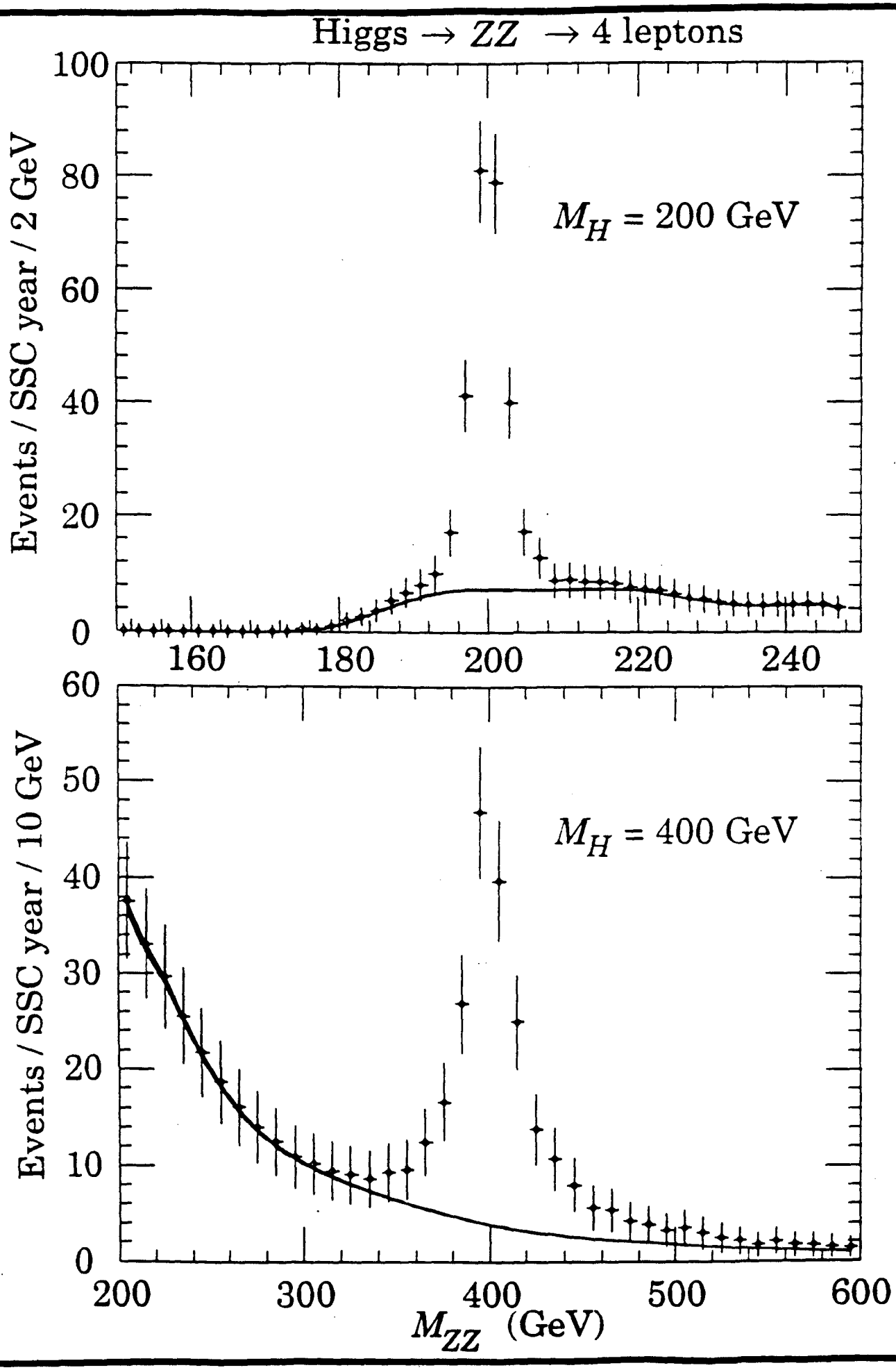
Conditions:

- Two trigger leptons with $p_t > 20$ GeV/c
- Two other leptons with $p_t > 10$ GeV/c
- Lepton isolation: $E_t < 5$ GeV in $R = 0.3$ cone after electron subtraction
- Both lepton pairs have $M_{\ell\ell} = M_Z \pm 10$ GeV

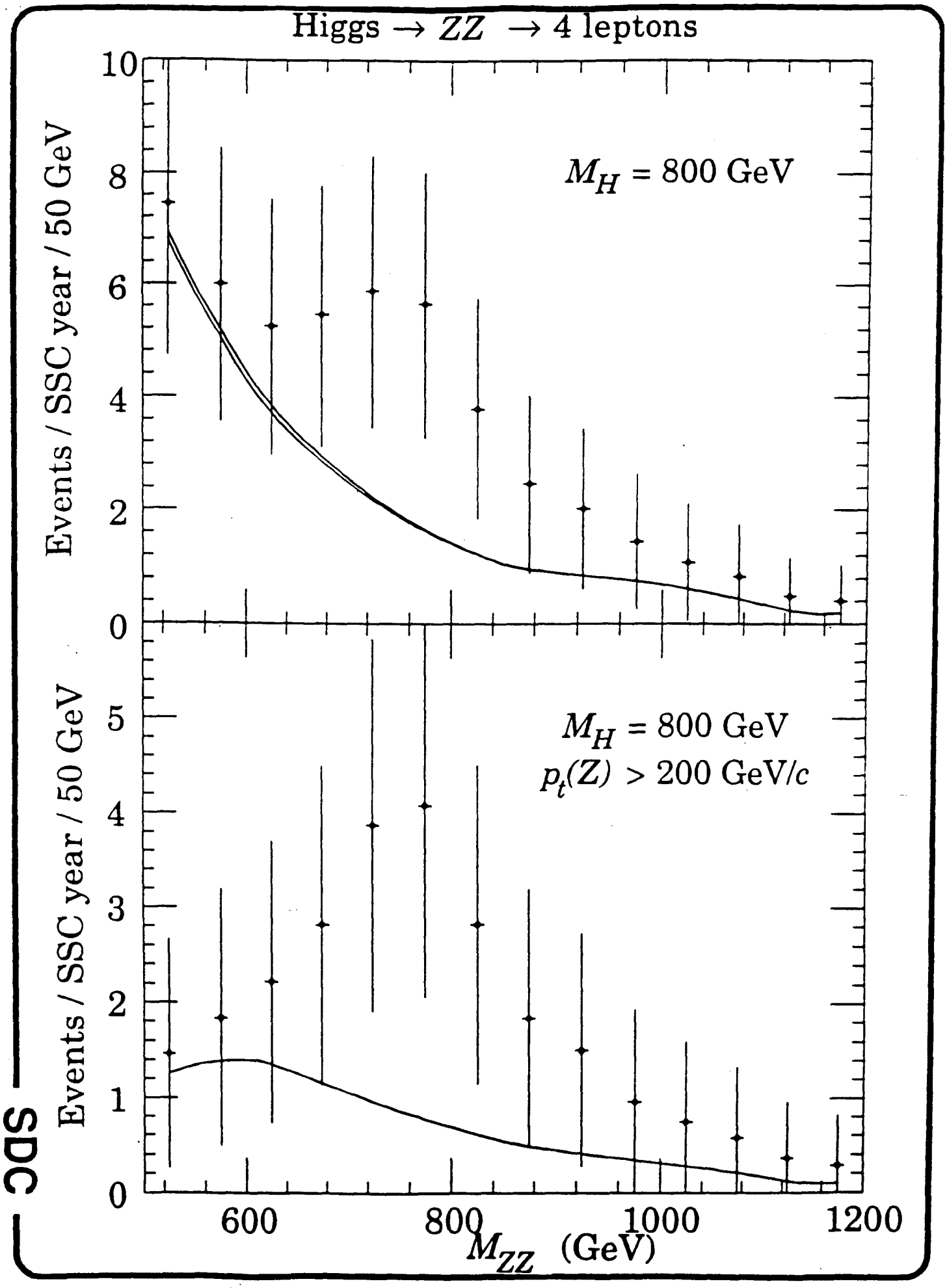


Backgrounds: 1) continuum ZZ*
2) Z + $b\bar{b}$
3) Z + $t\,\bar{t}$
4) $t\,\bar{t}$

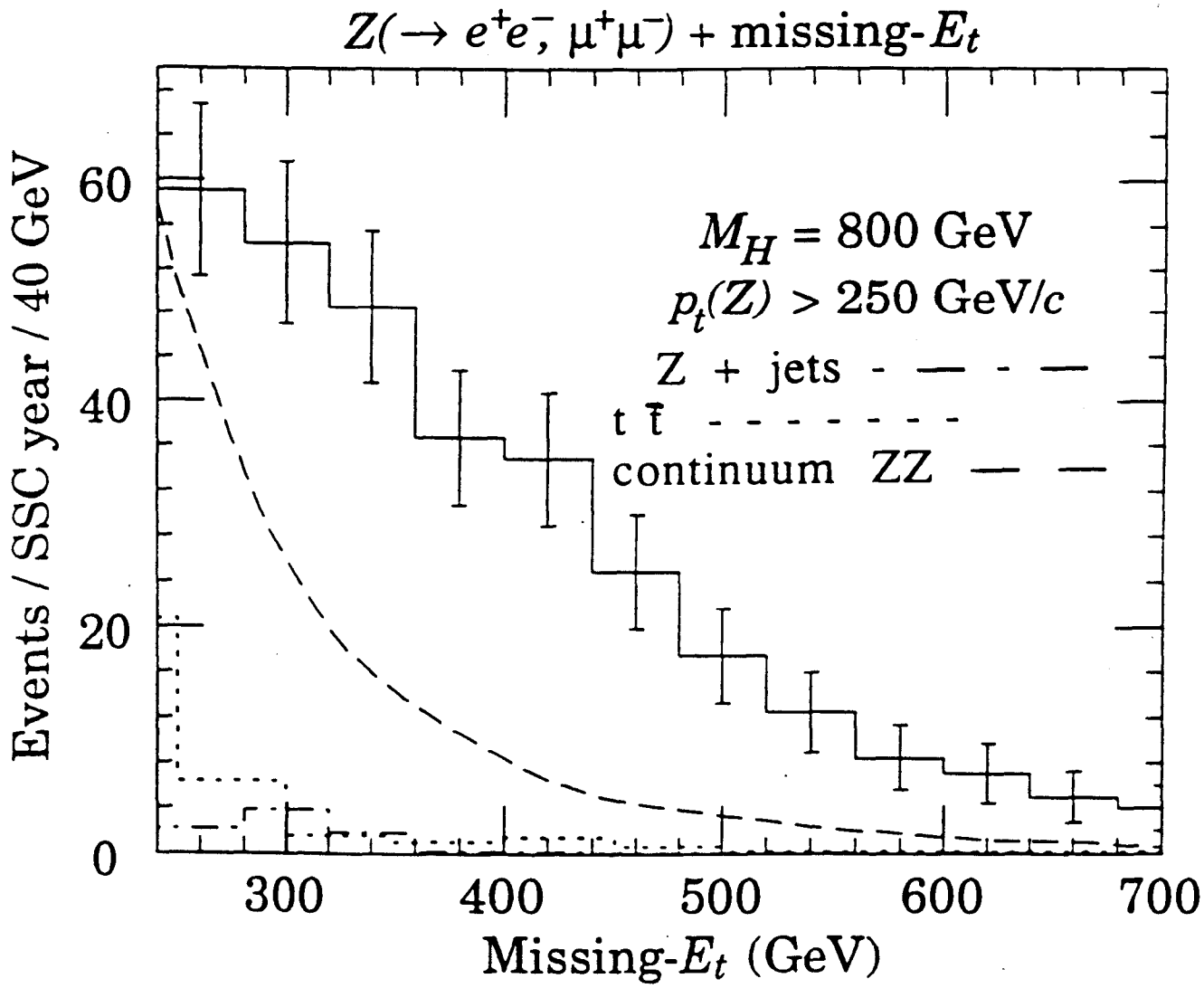
SDC


Higgs → ZZ → 4 leptons
Events / SSC year / 2 GeV
M_H = 200 GeV
Events / SSC year / 10 GeV
M_H = 400 GeV
M_{ZZ} (GeV)

SDC


Higgs → ZZ → 4 leptons
Events / SSC year / 50 GeV
M_H = 800 GeV
Events / SSC year / 50 GeV
M_H = 800 GeV
$p_t(Z)$ > 200 GeV/c
600
800
1000
1200
M_{ZZ} (GeV)

SDC



STANDARD MODEL HIGGS

Missing-E_t distribution for the final state

$$Z(\rightarrow e^+e^-,\ \mu^+\mu^-) + \text{ missing-}E_t$$

for background processes (dotted and dashed curves) plus effects of

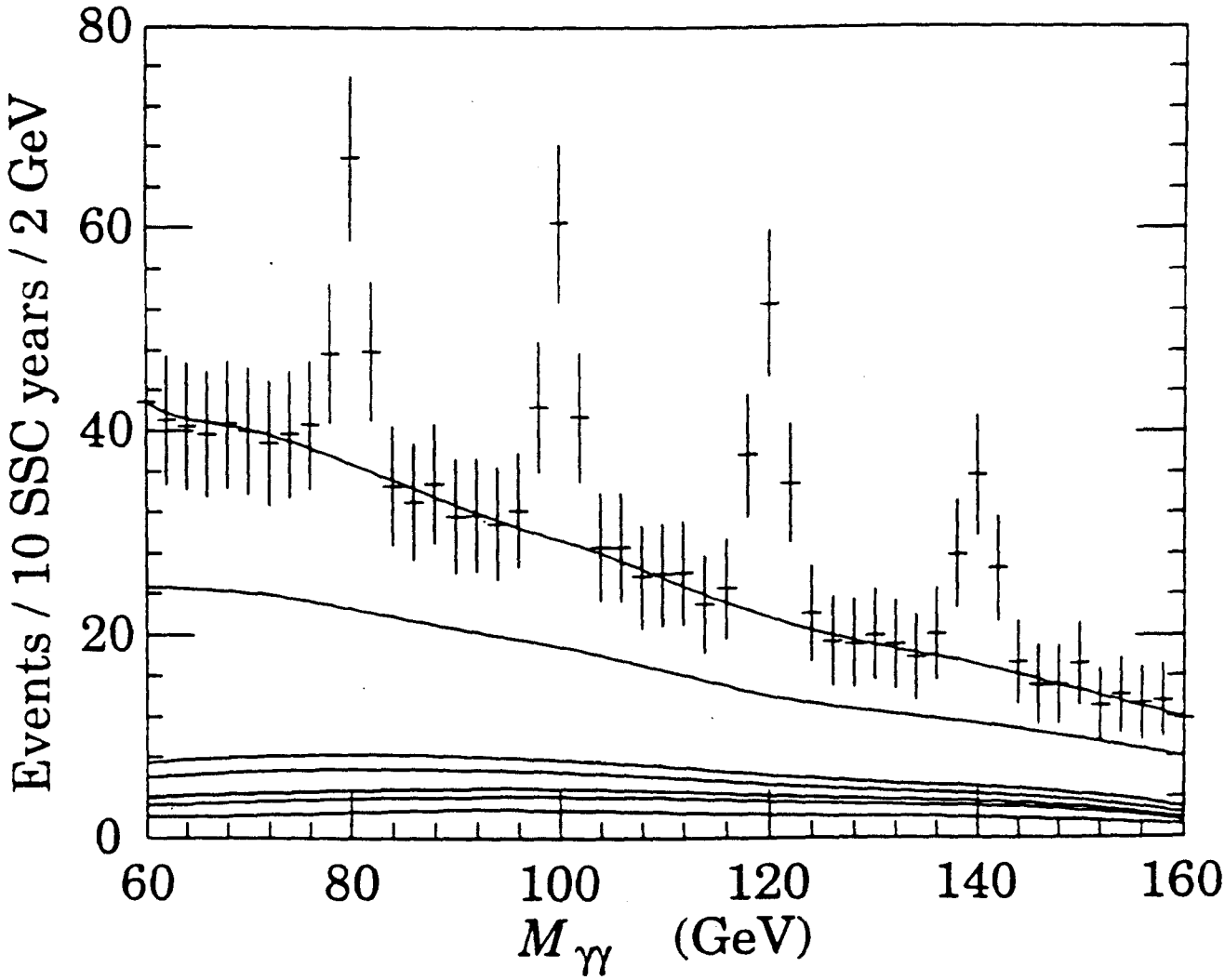
$$H \rightarrow ZZ \rightarrow \ell^+\ell^-\nu\bar{\nu}$$

- $p_t(Z) > 250$ GeV
- No jet with $E_t > 300$ GeV

SDC

$W + H$
$\hookrightarrow \gamma\gamma$
$\hookrightarrow l\,\nu$

e and γ's satisfy $p_t > 20$ GeV/c , and are separated in η–ϕ space by > 0.4



Backgrounds: 3 jet, 2jet + γ, jet + γ + γ
b+ γ + γ
b + jet + γ
b + $\bar{b}$ + γ
W + jets
W + jet + γ
W + γ + γ

SDC

Conclusions on Higgs Search

$125 < M(H) < 800$ GeV

Higgs will be discovered from $H \rightarrow Z + Z$ or $Z + Z^*$ using $eeee$, $ee\mu\mu$, $\mu\mu\mu\mu$ final states.

For $M(H)=800$ GeV, also use $ee\nu\nu$, $\mu\mu\nu\nu$.

About 1 SSC year is sufficient except at the lowest mass which requires ~ 2 SSC years.

$80 < M(H) < 125$ GeV

Discovery from $p + p \rightarrow W + H \ldots \rightarrow W + \gamma + \gamma$.

About 3 years at 3 x SSC luminosity are required.

TOP ANALYSIS

Three methods to detect and measure top mass:

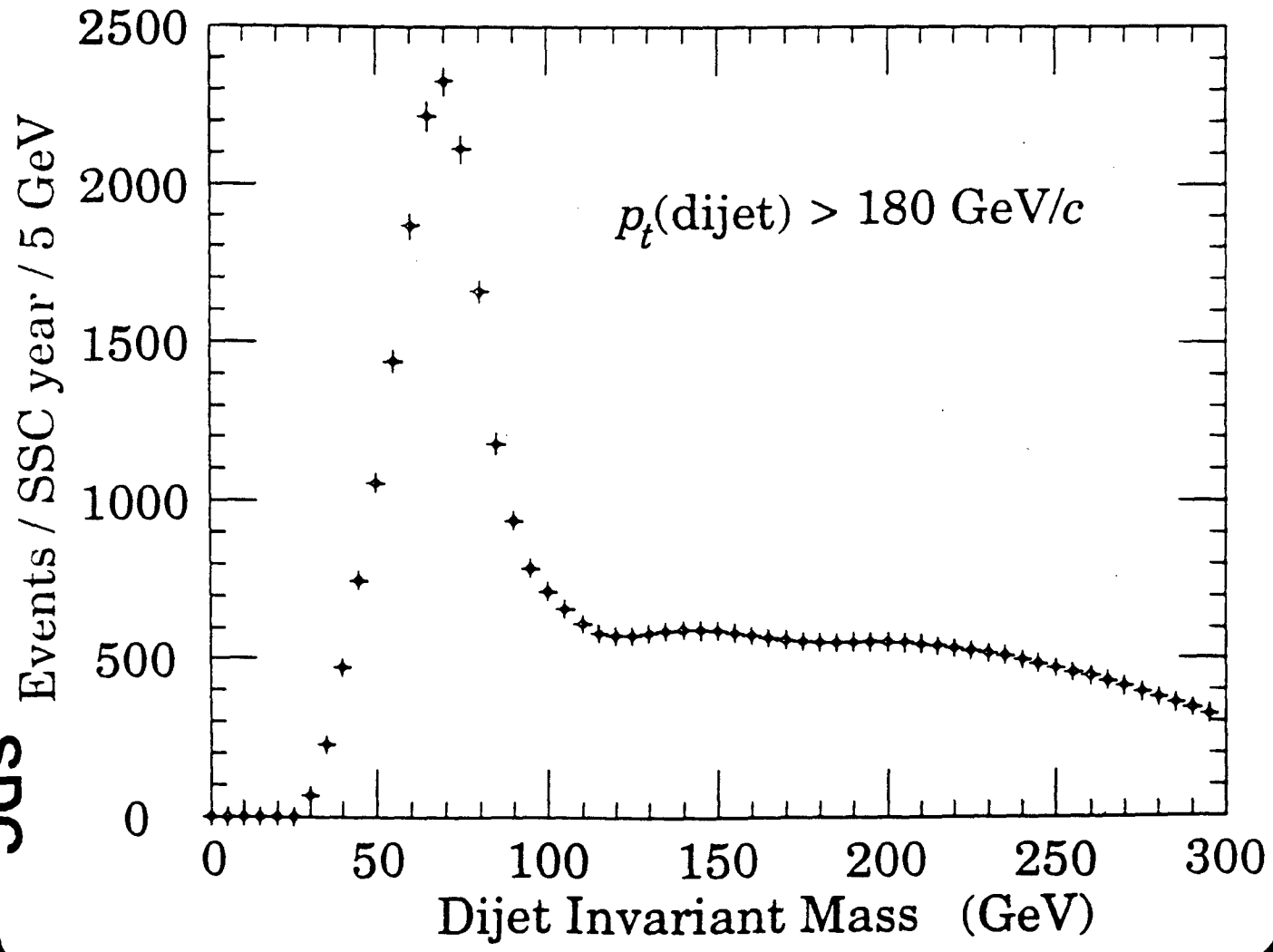
1) $t \rightarrow W^+ + b \rightarrow e/\mu^+ + \nu + b$,
   $\bar{t} \rightarrow W^- + \bar{b} \rightarrow \mu/e^- + \bar{\nu} + \bar{b}$
   Look for isolated e plus isolated μ (discussed in EoI). Good for discovery but mass determination depends on rate and is model dependent.
2) $t \rightarrow W^+ + b \rightarrow e/\mu^+ + \nu + b$,
   $\bar{t} \rightarrow W^- + \bar{b} \rightarrow$ jet + jet + b-jet
   Use b-tagging to identify b- jets. Reconstruct W from jet-jet, and top from W + b-jet. Accompanied by isolated lepton.
3) $t \rightarrow W^+ + b \rightarrow e/\mu^+ + \mu/e^- + ...$
   This is sequential decay of single t. Look for isolated electron plus non-isolated muon of opposite charge. Top mass determined from $e - \mu$ mass spectrum.

Non-standard top decay: $t \rightarrow H^+ + b$ as well as $t \rightarrow W^+ + b$.

1) If $H \rightarrow \tau + \nu$ large BR, we compare $e/\mu + \tau$ to $e/\mu + \mu/e$ (leptons isolated) to look for an excess.
2) If $H \rightarrow c + \bar{s}$ dominates, we use method 2) above to look for a separated H peak.

250 GeV t: $t\bar{t} \to WWbb \to \ell\nu\, jj\, bb$ —look at dijet invariant mass in multijet events with b's

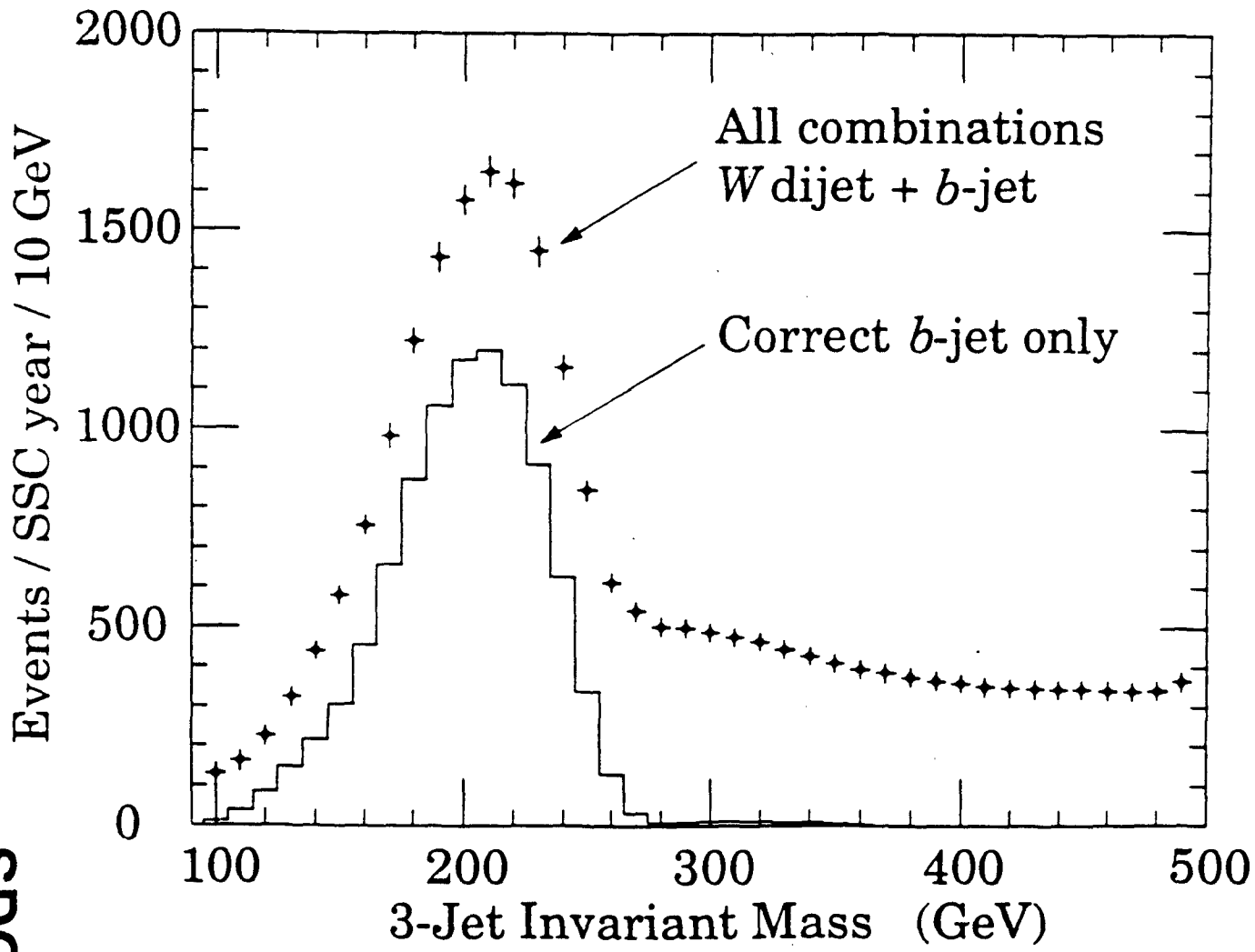
- All jet combinations included, except that tagged b jets are excluded
- p_t(dijet) > 180 GeV/c
- Electron with $p_t > 40$ GeV/c
- Missing-$E_t > 40$ GeV
- 4 jets with $p_t > 30$ GeV/c
- At least 2 tagged b jets
- Lepton isolation: $E_t < 5$ GeV in $R = 0.3$ cone after electron subtraction
- Both lepton pairs have $M_{\ell\ell} = M_Z \pm 10$ GeV



SDC

250 GeV t: $t\bar{t} \to WWbb \to \ell\nu\, jj\, b\, b$ —look at trijet consisting of W candidate dijet plus a b-tagged jet

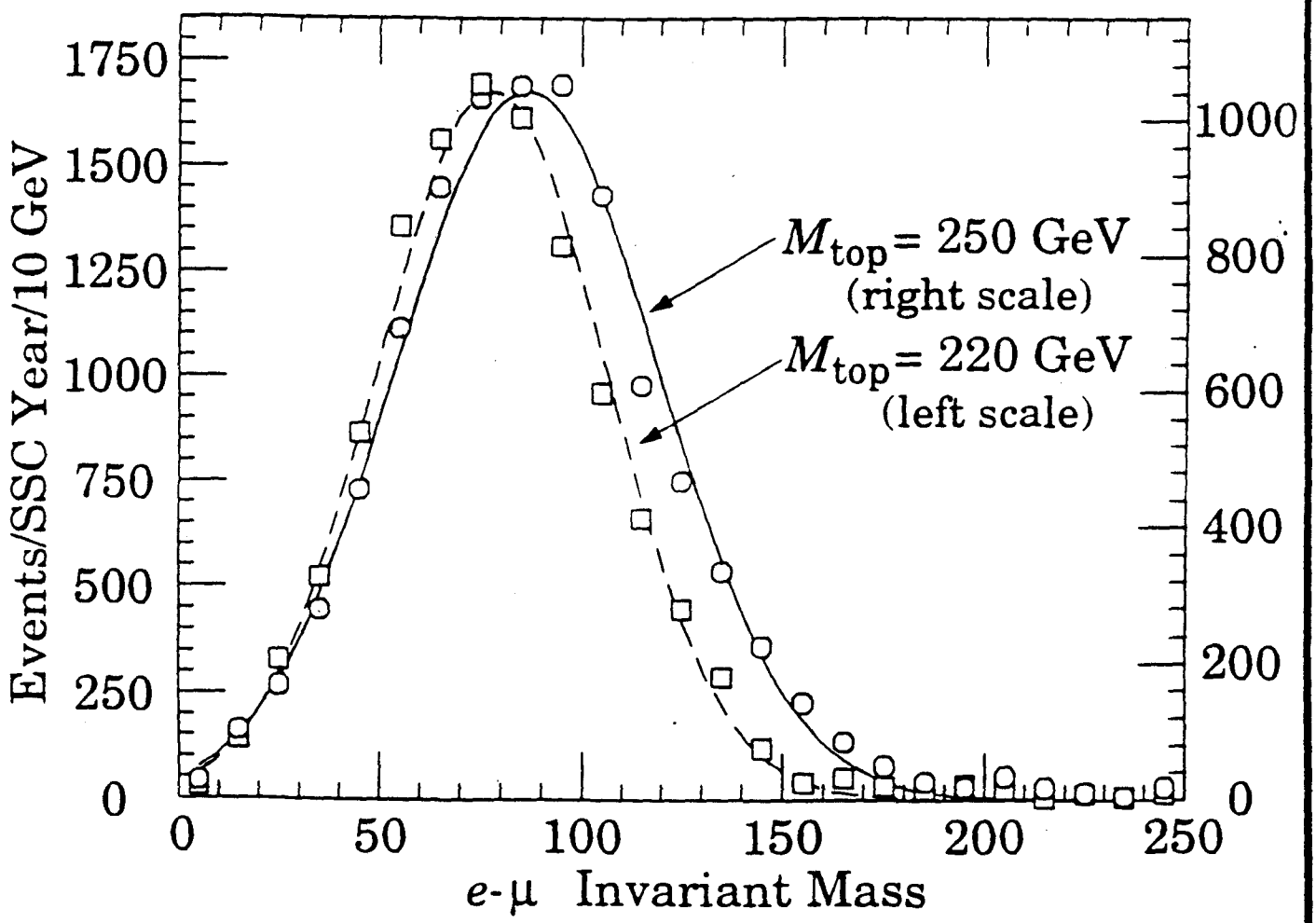
- W candidate:
  - Excluding b-tagged jets, 50 GeV $< M(\text{dijet}) <$ 95 GeV
  - $p_t(\text{dijet}) >$ 180 GeV/c



SDC

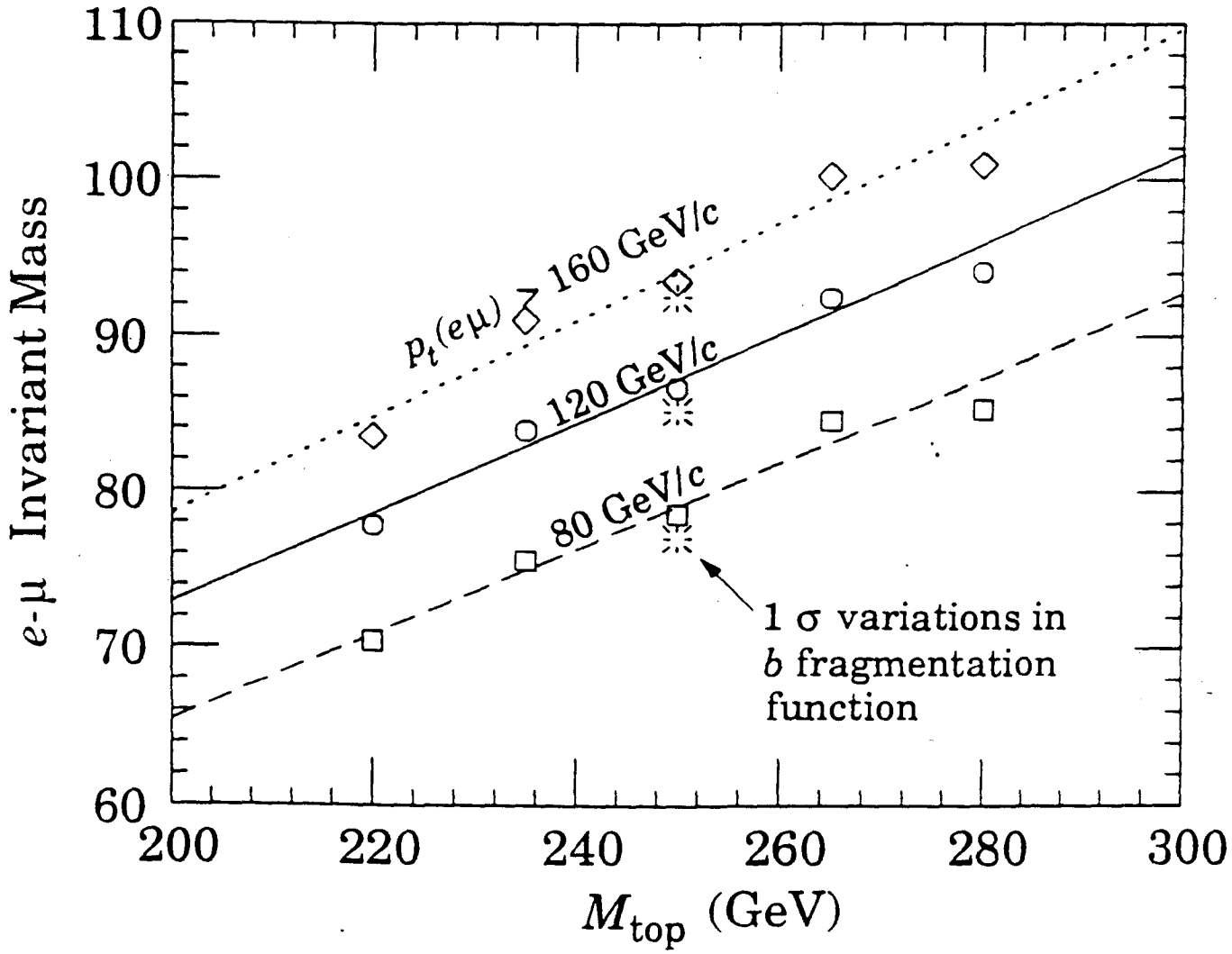
250 GeV t: $e^{\pm}$ from t decay and $\mu^{\mp}$ from sequential b decay —look at $e\mu$ invariant mass

- $p_t(e) > 40$ GeV/c and $E_t < 4$ GeV in $R = 0.2$ cone after electron subtraction
- $p_t(\mu) > 20$ GeV/c and $E_t > 20$ GeV in $R = 0.4$ cone in muon direction
- e–μ angle less than 80°
- $p_t(e\mu) > 120$ GeV/c



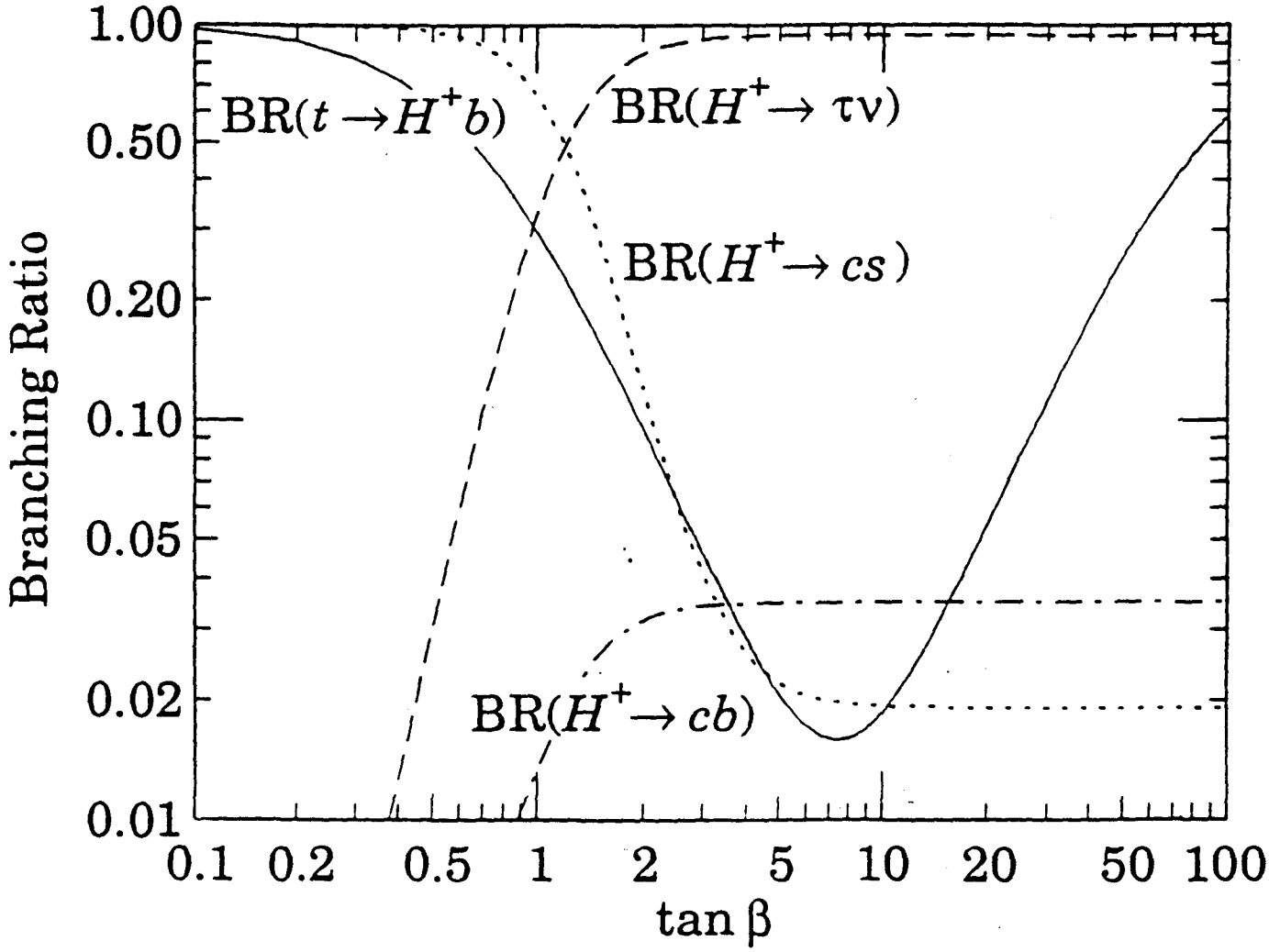
SDC

250 GeV t: $e^{\pm}$ from t decay and $\mu^{\mp}$ from sequential b decay —mean $e\mu$ invariant mass as a function of $p_t(e\mu)$ cut



SDC

Branching fractions as a function of $\tan\beta$
for $M_{\text{top}} = 250$ GeV and $M_{H^+} = 150$ GeV



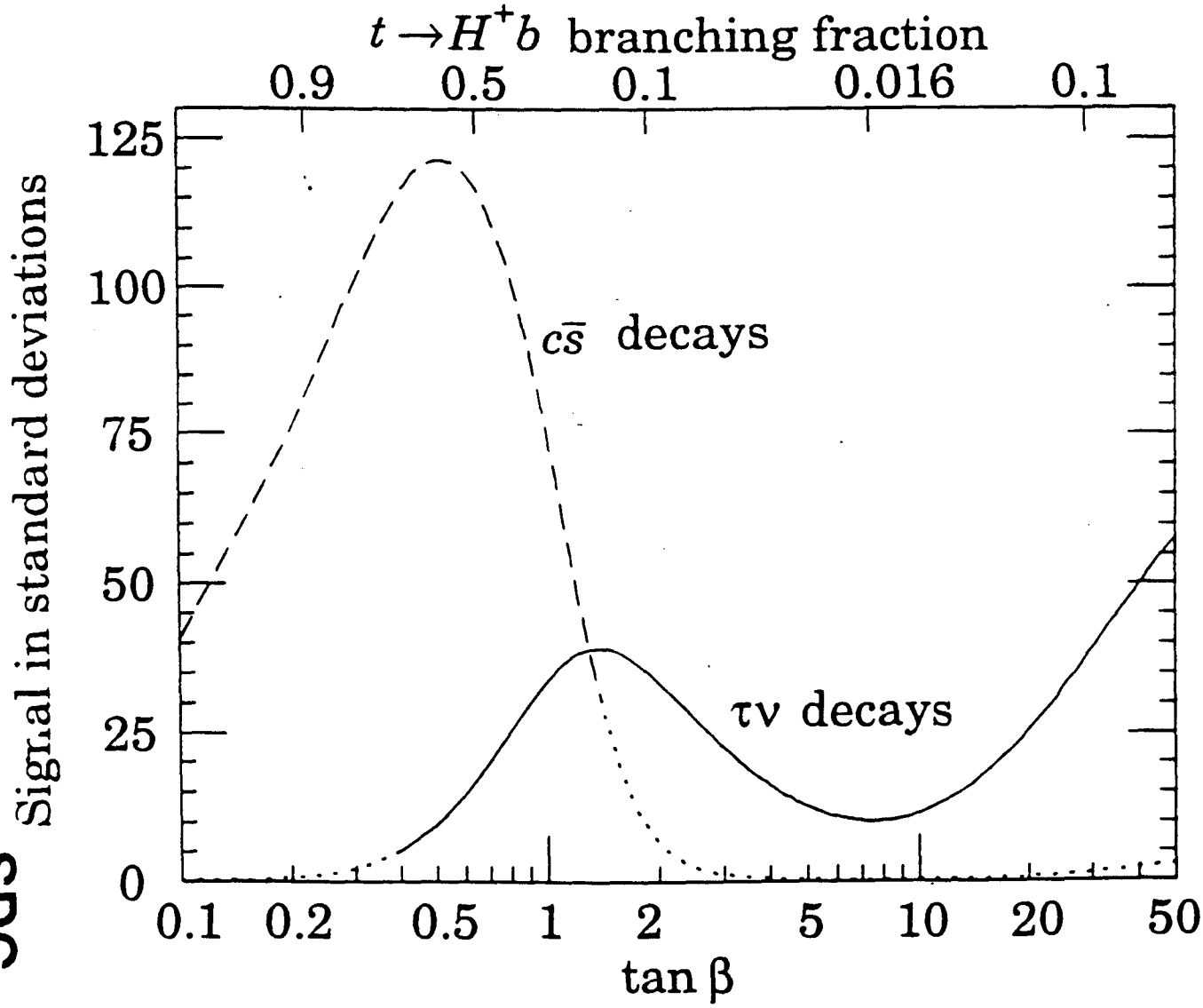
SDC

250 GeV t:

Solid curve: Statistical significance of isolated pion excess due to $t \to H^+ b$
$\hookrightarrow \tau\nu$
$\hookrightarrow \pi\nu$

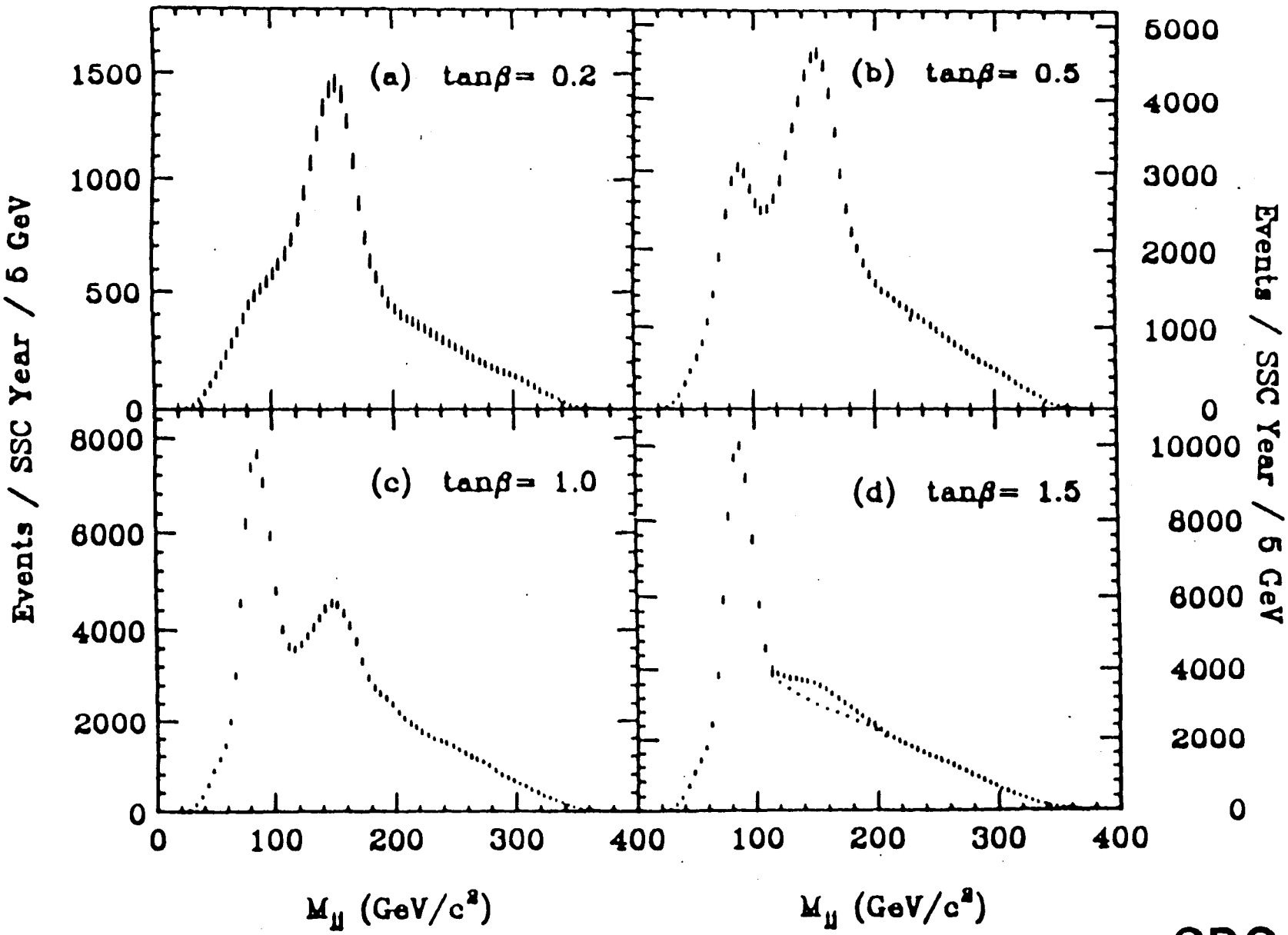
- Isolated lepton with $p_t > 40$ GeV/c
- Isolated pion with $p_t > 40$ GeV/c

(One year of running, $M_{\text{top}} = 250$ GeV and $M_{H^+} = 150$ GeV)



SDC

Dijet Mass Spectrum
t --> W/H + b, W/H --> two jets



SDC

Conclusions on Top Analysis

Three techniques studied for top discovery and mass determination :

- Isolated e + isolated μ from separate top decays
  (good for discovery, not good for precise mass)
- Isolated e + non-isolated μ from sequential decay of top
  (mass precision to about 6 GeV)
- Isolated e/μ + b-jets + W-jets from t --> b + W
  (mass precision to about 3 GeV)

t --> H^+ + b, H --> $\tau + \nu$, c + $\bar{s}$ studied in context of model
The full parameter range of that model accessible
(down to 2% t --> H^+ + b branching ratio)

These programs all require just a fraction of an SSC year.

Z/Z' DECAY TO TWO JETS

Look at two transverse momentum ranges (results depend on p_t) :

50 to 60 GeV/c and 500/600 GeV/c

Z/Z' generated via Drell-Yan using Pythia-4.9 with jet axis within $|\eta| < 1$.

Simulation tracks individual particles including effect of B-field.

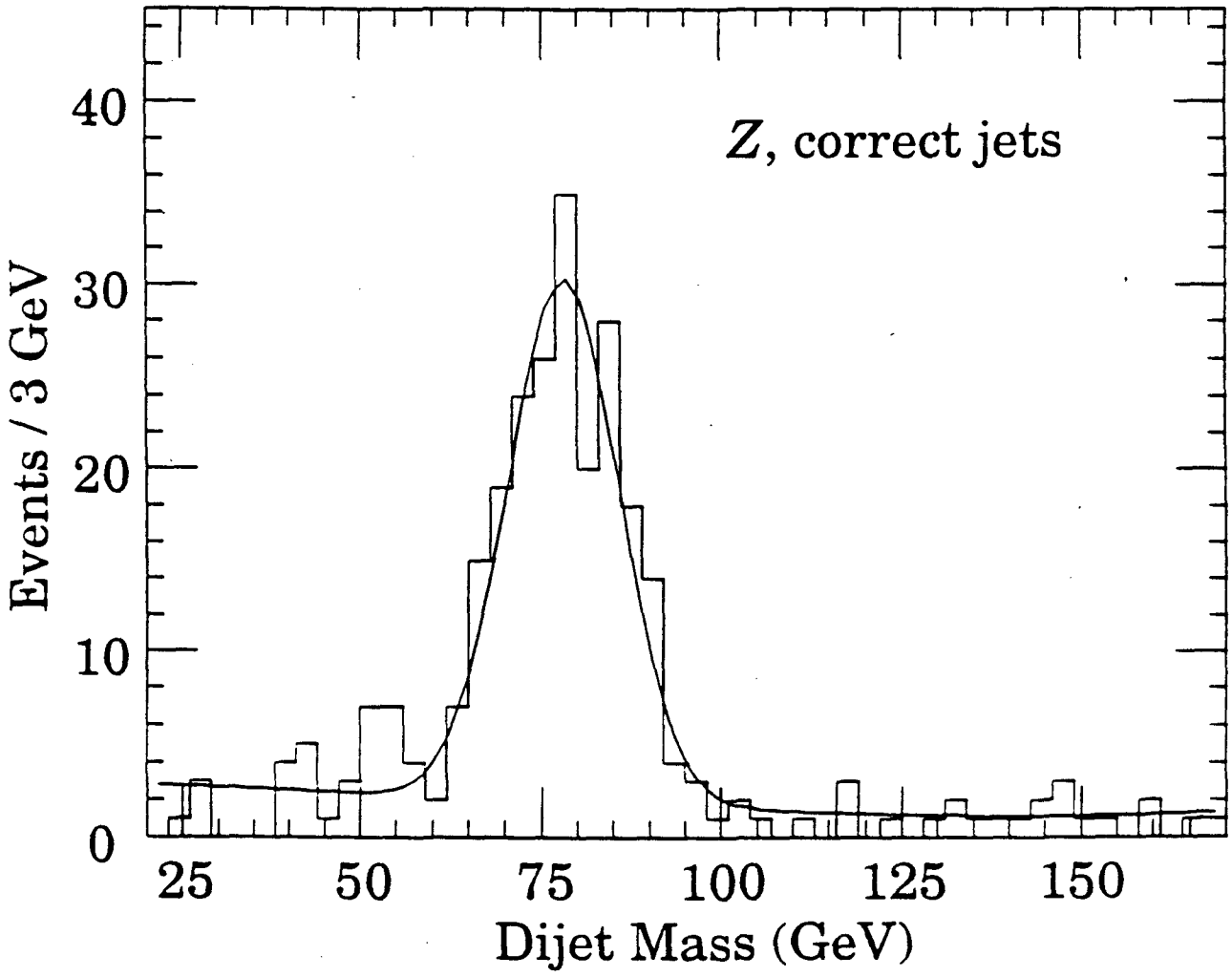
Jet clusters start from seed tower and include energy within cone of fixed radius R in $\eta - \phi$ space.

Parameters: R = 0.7, Seed threshold = 2 GeV, Tower threshold + 0.1 GeV
Tower segmentation 0.05x 0.05.

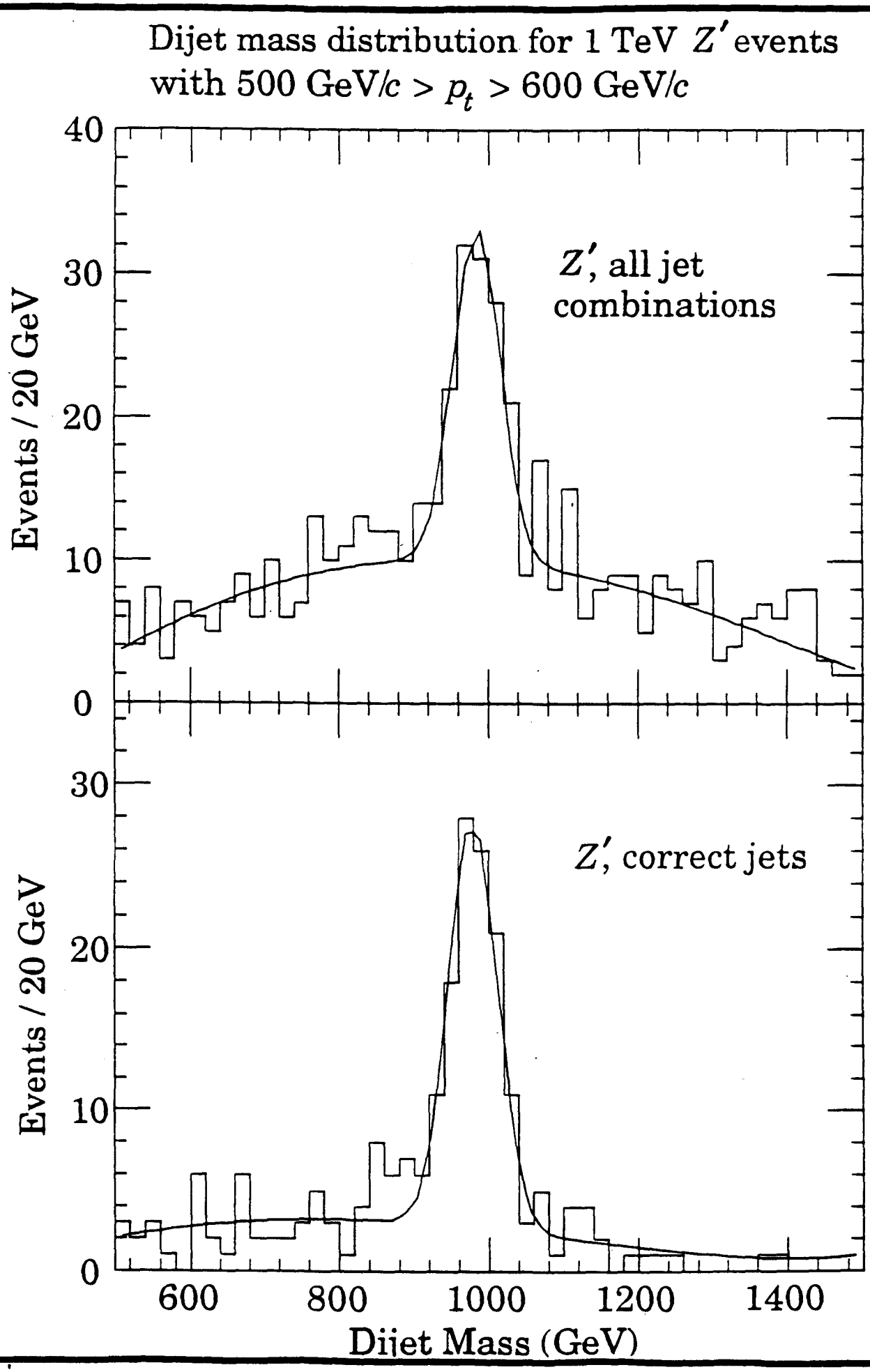
Note that detector-independent resolution effects include underlying event, clustering effects including losses out of the chosen cone, neutrinos.

For studies of resolution, proper Z/Z'-decay jets are chosen and fits are made with sum of gaussian and polynomial.

Dijet mass distribution for Z events with
$50\ \mathrm{GeV}/c > p_t > 60\ \mathrm{GeV}/c$



SDC

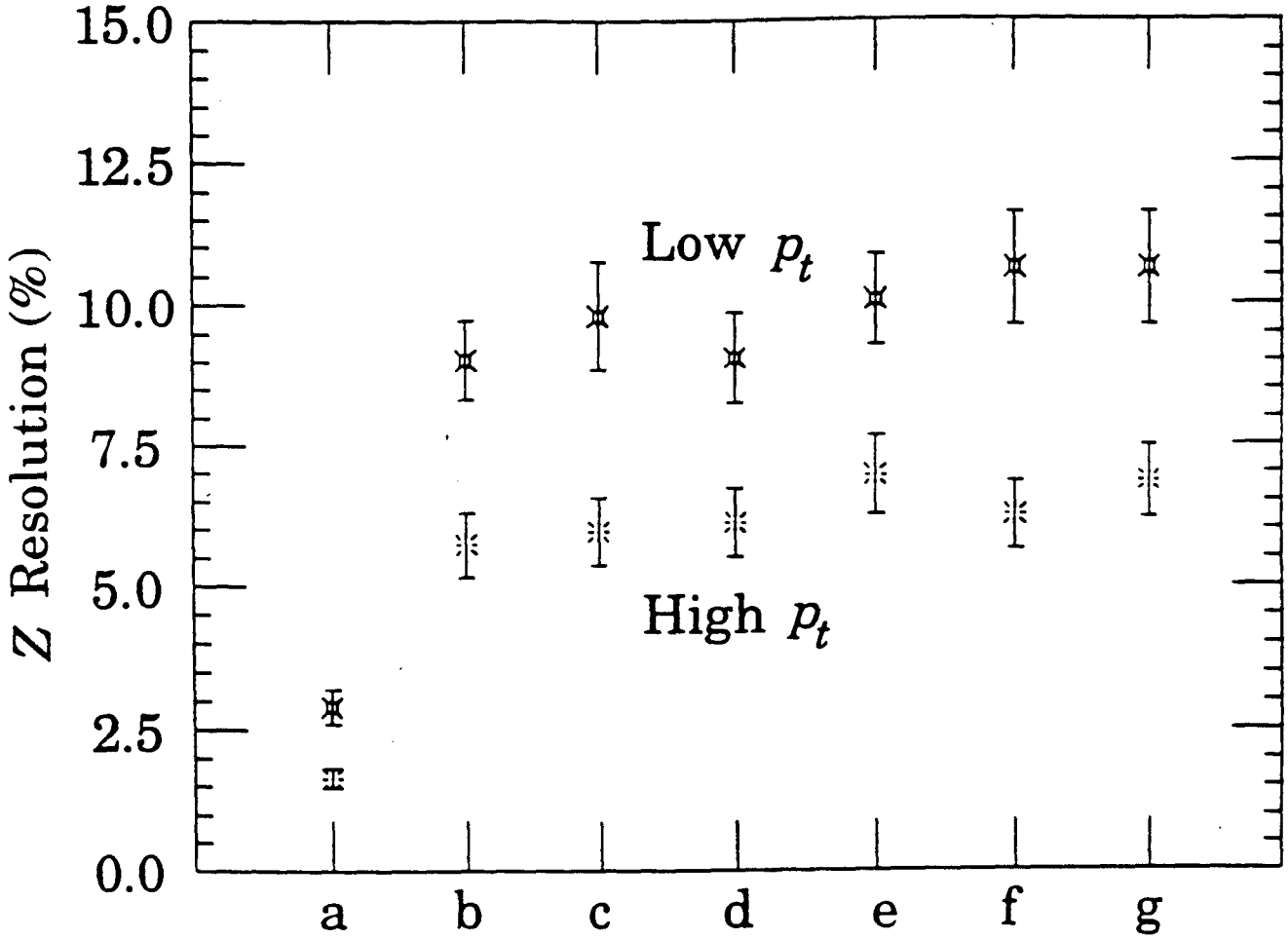

Dijet mass distribution for 1 TeV Z' events
with 500 GeV/c > p_t > 600 GeV/c
Z', all jet combinations
Z', correct jets
Events / 20 GeV
Events / 20 GeV
0
10
20
30
40
0
10
20
30
600
800
1000
1200
1400
Dijet Mass (GeV)

SDC

Resolution for reconstructed Z

Low p_t: $50\ \mathrm{GeV}/c < p_t < 60\ \mathrm{GeV}/c$

High p_t: $500\ \mathrm{GeV}/c < p_t < 600\ \mathrm{GeV}/c$



Z Resolution *vs* Conditions

(a) Losses out of $R = 0.7$ cone at 4-vector level

(b) Shower shape included, still perfect energy resolution

(c) $\sigma/E|_{\mathrm{had}} = 0.3/\sqrt{E} \oplus 0.02$ and $\sigma/E|_{\mathrm{EM}} = 0.15/\sqrt{E} \oplus$ 0.01

(d) $\sigma/E|_{\mathrm{had}} = 0.5/\sqrt{E} \oplus 0.03$

(e) $\sigma/E|_{\mathrm{had}} = 0.7/\sqrt{E} \oplus 0.04$

(f) As (d), plus $\sigma/E|_{\mathrm{EM}} = 0.25/\sqrt{E}$

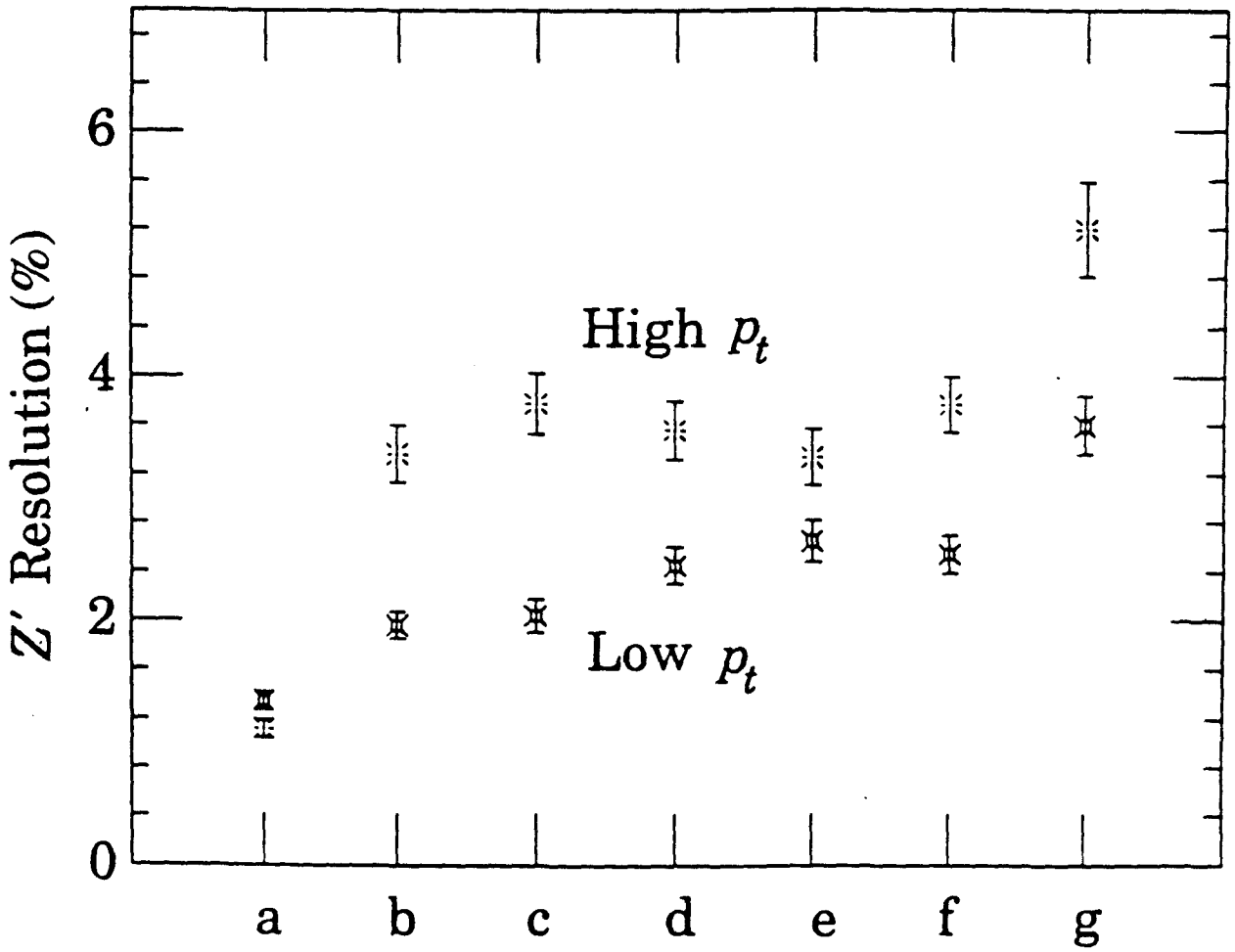
(g) As (d), with $e/h = 1.3$

SDC

Resolution for reconstructed Z'(1 TeV)

Low p_t: $50\ \mathrm{GeV}/c < p_t < 60\ \mathrm{GeV}/c$

High p_t: $500\ \mathrm{GeV}/c < p_t < 600\ \mathrm{GeV}/c$



Z' Resolution *vs* Conditions

(a) Losses out of $R = 0.7$ cone at 4-vector level

(b) Shower shape included, still perfect energy resolution

(c) $\sigma/E|_{\mathrm{had}} = 0.3/\sqrt{E} \oplus 0.02$ and $\sigma/E|_{\mathrm{EM}} = 0.15/\sqrt{E} \oplus 0.01$

(d) $\sigma/E|_{\mathrm{had}} = 0.5/\sqrt{E} \oplus 0.03$

(e) $\sigma/E|_{\mathrm{had}} = 0.7/\sqrt{E} \oplus 0.04$

(f) As (d), plus $\sigma/E|_{\mathrm{EM}} = 0.25/\sqrt{E}$

(g) As (d), with $e/h = 1.3$

SDC

Conclusions on Jet Energy Resolution

Intrinsic effects of jet clustering, jet fragmentation uncertainties and fluctuations in the underlying event dominate the jet-jet mass resolution.

The magnetic field spreads jets and modifies the direction of energy flow within the cluster cone. However relative to the detector-independent fluctuations its effects are small (no more than a 20% broadening of resolution).

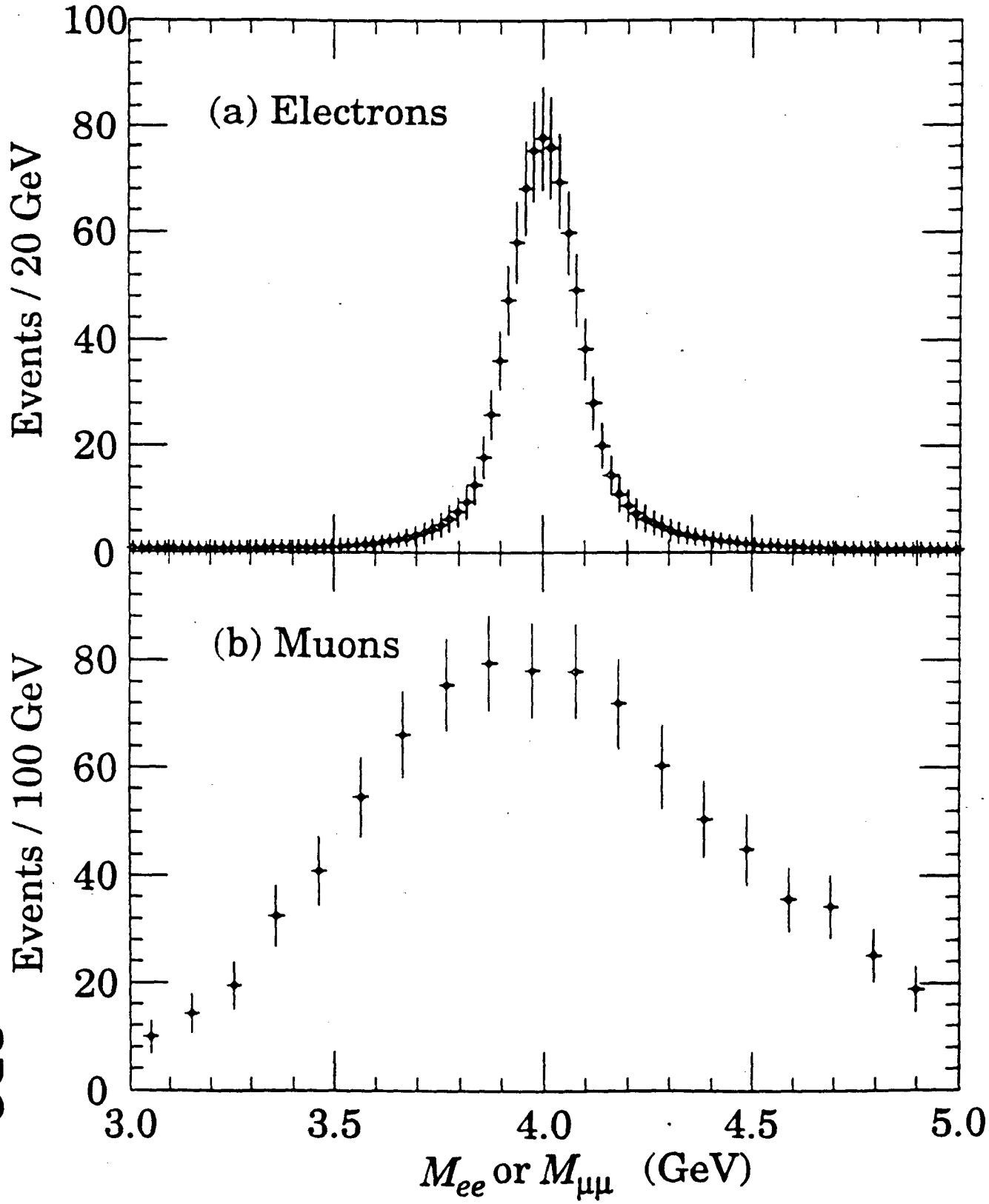
Extreme value of e/h = 1.3 instead of 1.0 worsens the Z' resolution by about a factor of 1.5, but has almost no visible effect on Z resolution (because the detector-independent resolution is worse for Z to start with).

Dilepton invariant mass distributions for

(a) $Z'(4\ \text{TeV}) \rightarrow e^+e^-$

(b) $Z'(4\ \text{TeV}) \rightarrow \mu^+\mu^-$

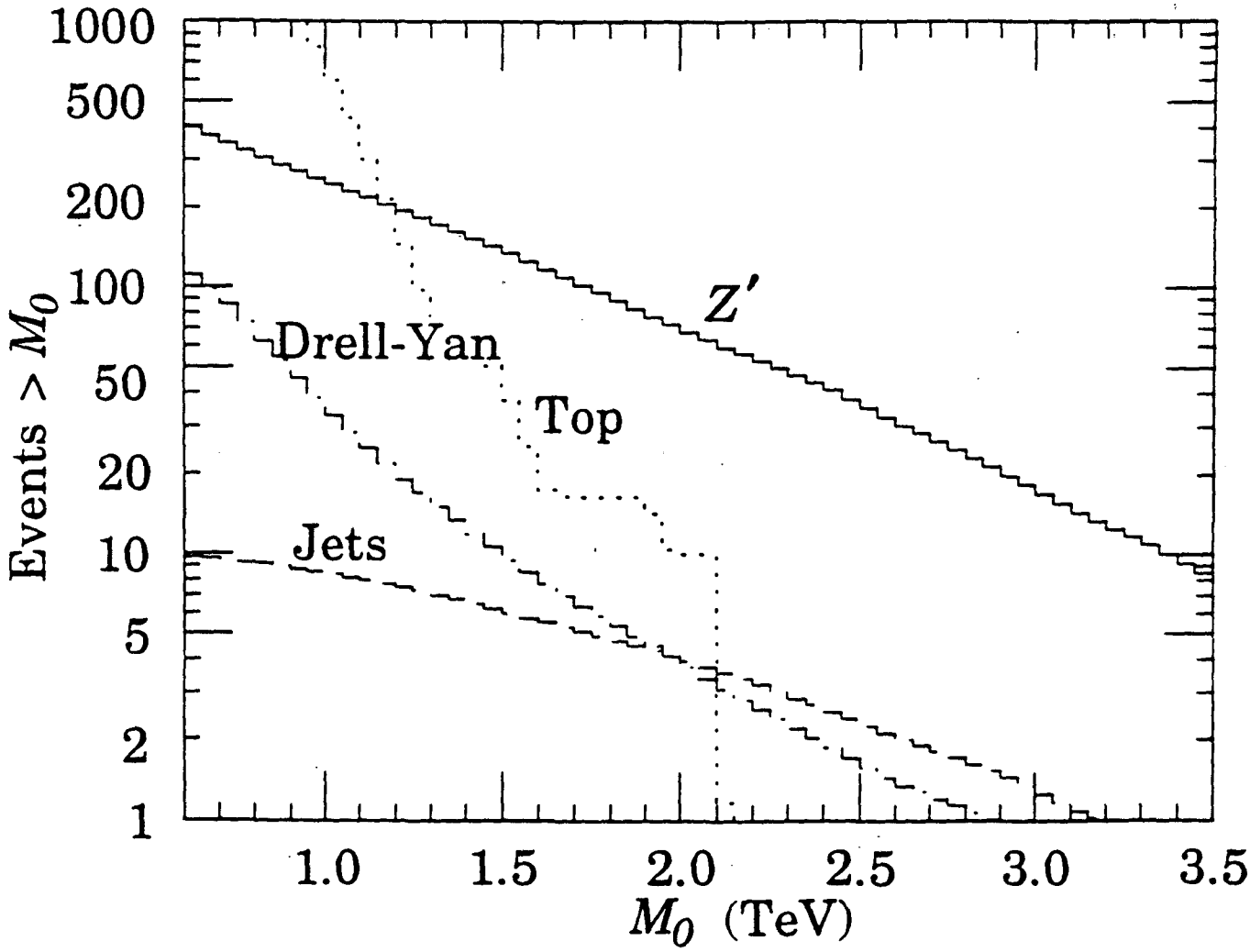
including Drell-Yan background



SDC

$Z'(4\ \text{TeV}) \rightarrow \tau^+\tau^-$

Rates for ee, $e\mu$, $e\pi$, $\mu\pi$ and $\pi\pi$ with invariant masses in excess of M_0



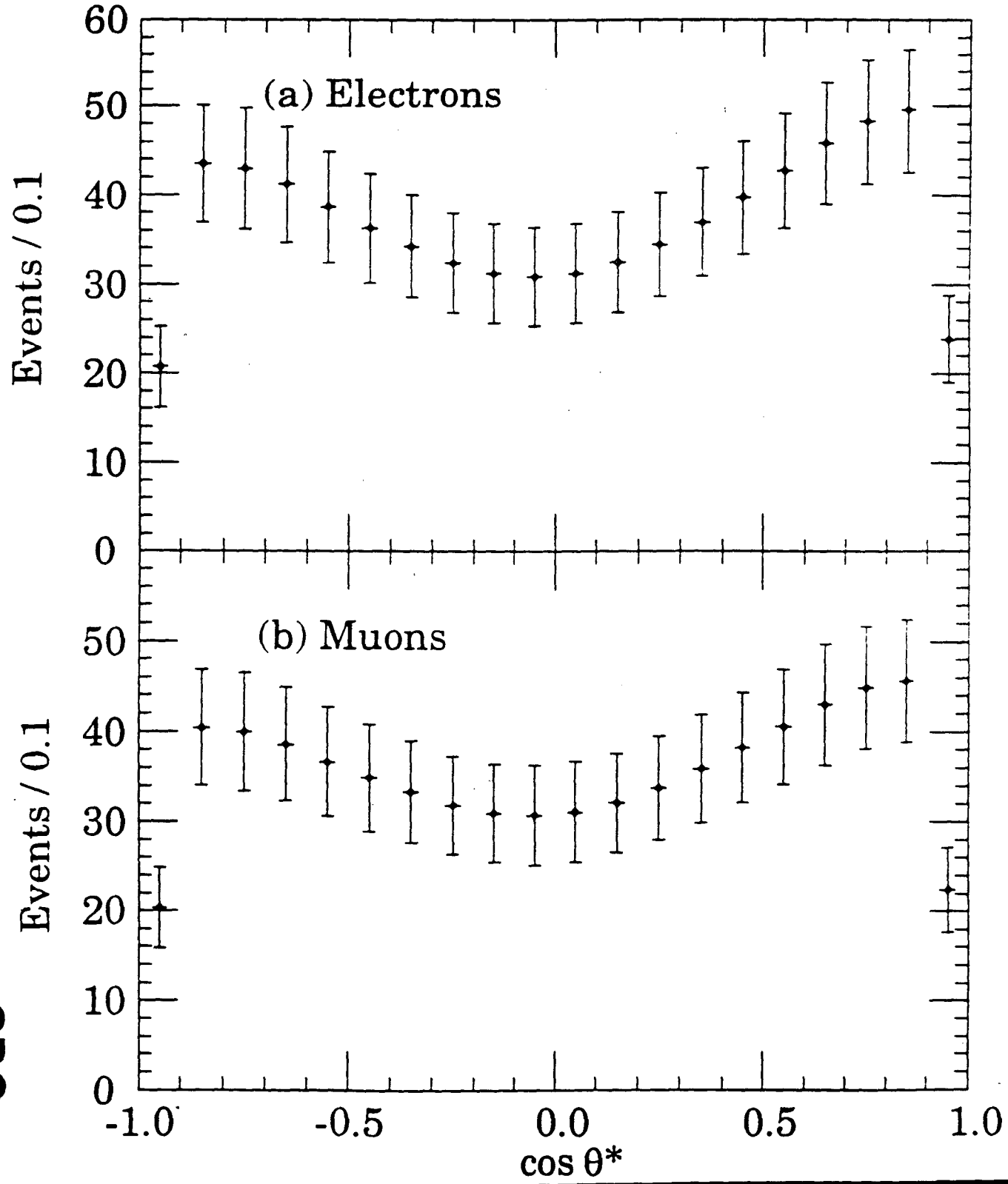
SDC

Angular distributions of

(a) e^- from $Z'(4\ \mathrm{TeV}) \to e^+e^-$

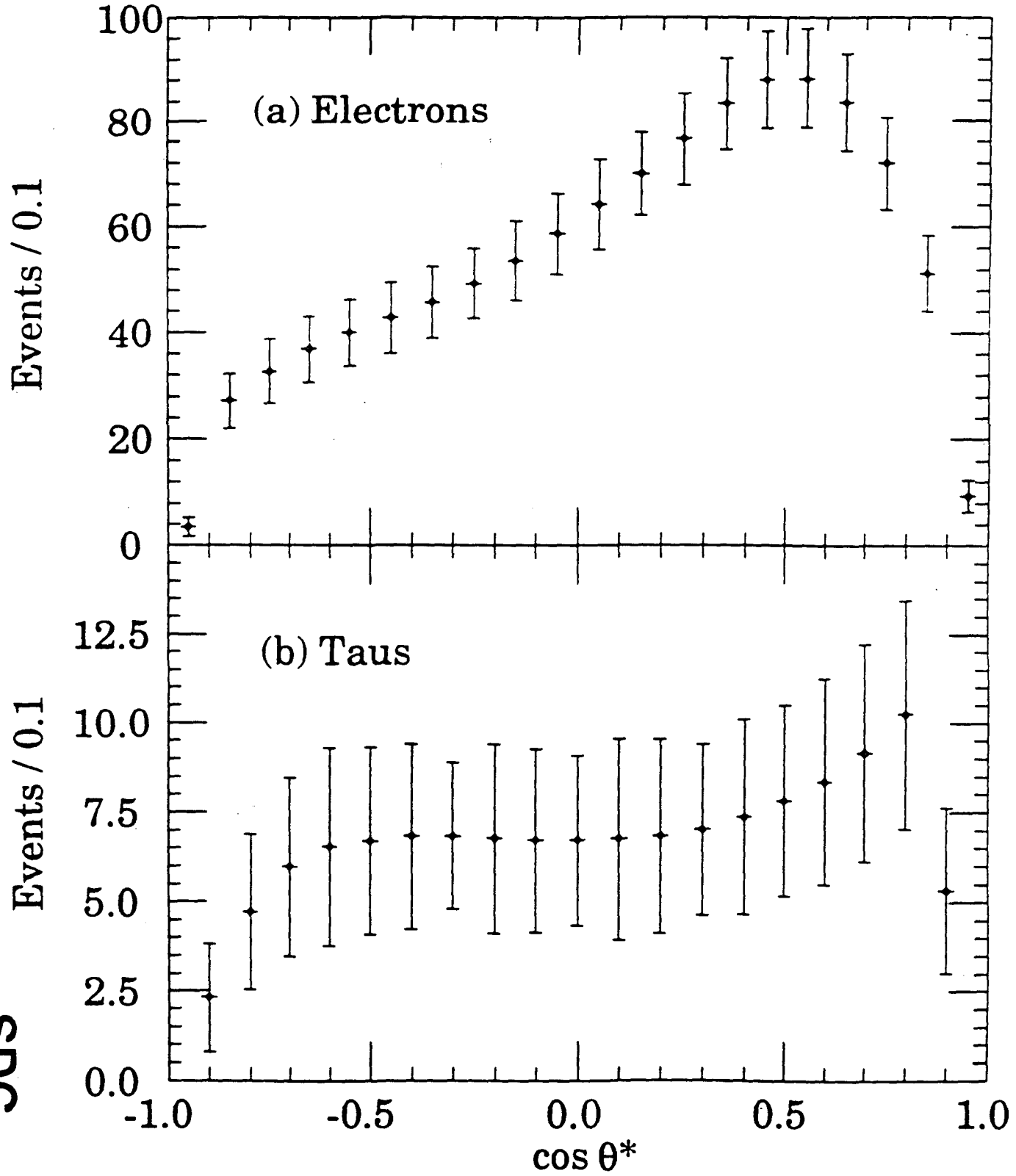
(b) μ^- from $Z'(4\ \mathrm{TeV}) \to \mu^+\mu^-$

(dilepton invariant mass between 3 and 5 TeV



SDC

Z'(4 TeV): Angular distributions of
(a) e^-, for 1 TeV < $M_{e^+e^-}$ < 2 TeV
(b) Negative track of ee, $e\mu$, $e\pi$, $\mu\pi$, or $\pi\pi$
with two-track mass > 1.4 TeV



SDC

Conclusions on Z'(4 TeV) Studies

For 1000 decays of each dilepton variety, the SDC can:

Measure the mass in ee channel with σ = 3 GeV.
Measure the mass in $\mu\mu$ channel with σ = 10 GeV.
Measure the width in ee channel with σ = 7 GeV.
Measure asymmetries in both ee and $\mu\mu$ to 5%.
For $\tau\tau$ channel the rate relative to ee can be measured to about 8%. An asymmetry can be measured to about 10%, but it is averaged over a broad range of $\tau\tau$ masses.

Construction Cost Estimate

- The construction cost of the detector with scintillator/lead/iron calorimetry is estimated to be $509M(FY90) dollars - see table.

- The estimate is based, primarily, on a "bottoms-up" evaluation of costs for all of the major subsystems

- The estimate is based on US-estimating methods and reflects the cost as if the entire detector were to be built from SSC funds in the US.

- However, we expect in-kind contributions from non-US countries to account for about 40% of the equivalent cost, as shown in the table.

- Negotiations within the collaboration and within the participating countries have begun. These will lead to definite commitments of equipment and personnel

SDC Detector Cost Estimate (FY90 $M)

	BASE	EDIA	% EDIA	BASE + EDIA	CONT	% CONT	SUB TOTAL	APPROX NON-US CONTR.
1 TRACKING SYSTEMS							94.8	40
1.1 SILICON TRACKING SYSTEM	24.9	8.1	25%	33	6.6	20%	39.6	
1.2 CENTRAL TRACKER	26.3	9.3	26%	35.6	8.3	23%	43.9	
1.3 INTERMEDIATE TRACKER	6.7	2	23%	8.7	2.6	30%	11.3	
2 CALORIMETRY							138.6	50
2.1 CENTRAL CALORIMETER	55.3	9.1	14%	64.4	15.8	25%	80.2	
2.2 INTERMEDIATE CALORIMETER	25.5	4.8	16%	30.3	7.5	25%	37.8	
2.3 FORWARD CALORIMETER	14	2.5	15%	16.5	4.1	25%	20.6	
3 MUON SYSTEM							103.2	55
3.1 IRON TOROIDS	41.7	1.5	3%	43.2	6.5	15%	49.7	
3.2 MUON CHAMBERS	28.6	2.6	8%	31.2	7.8	25%	39	
3.3 MUON TRIGGER COUNTERS	11.8	0.8	6%	12.6	1.9	15%	14.5	
4 SUPERCONDUCTING MAGNETS							29.8	25
4.1 SC SOLENOID	22.7	2.1	8%	24.8	5	20%	29.8	
5 DATA ACQUISITION & TRIGGER							69.3	25
5.1 DATA ACQUISITION SYSTEMS	12.5	4.2	25%	16.7	4.2	25%	20.9	
5.2 TRIGGER SYSTEMS	18.9	19.8	51%	38.7	9.7	25%	48.4	
6 COMPUTING							11.9	0
6.1 ON-LINE COMPUTING	4.4	5.5	56%	9.9	2	20%	11.9	
7 CONVENTIONAL SYSTEMS							20.6	0
7.1 UTILITIES	1.1	0.5	31%	1.6	0.3	19%	1.9	
7.2 CONTROLS	2.3	2.1	48%	4.4	1.3	30%	5.7	
7.3 SAFETY SYSTEMS	1.9	2	51%	3.9	1.2	31%	5.1	
7.4 CRYOGENIC SYSTEMS	3	0.8	21%	3.8	1	26%	4.8	
7.5 STRUCTURAL SUPPORT SYSTEMS	1.1	1.4	56%	2.5	0.6	24%	3.1	
8 INSTALLATION AND TEST							28.1	5
8.1 TEST BEAM PROGRAM	6	1.5	20%	7.5	1.5	20%	9	
8.2 SUBSYSTEM INSTALL. AND TEST	10	5.3	35%	15.3	3.8	25%	19.1	
9 PROJECT MANAGEMENT							13.2	0
9.1 PROJECT PLANNING	0.4	0.9	69%	1.3	0.2	15%	1.5	
9.2 PROJECT TRACKING	0.4	1	71%	1.4	0.2	14%	1.6	
9.3 DOCUMENT DIST. AND CONTROL	0.7	0.5	42%	1.2	0.2	17%	1.4	
9.4 SUBSYSTEMS INTEGRATION	1.8	5.8	76%	7.6	1.1	14%	8.7	
TOTALS	322	94.1	23%	416.1	93.4	22%	509.5	200

TOTAL US CONTRIBUTION	309
TOTAL NON-US CONTRIBUTION	200
TOTAL CONSTRUCTION COST	509

Cost Estimate - Options

- The primary options under consideration are (1) liquid argon calorimetry and (2) scintillating fibers for tracking

- Our preliminary estimate is that the use of liquid argon calorimetry would raise the total cost of the detector by $25-40M. More engineering work is needed to improve the estimate.

- Our preliminary estimate is that a complete fiber tracker would raise the cost by $10 - 20M. The major uncertainty is the cost per channel of the readout system

Cost Estimate - Off-line Computing

- This element does not appear in the detector construction cost roll-up, since it will be funded outside SSC WBS 5.2
- Our request is for 50% of the funds from SSC WBS 5.3 available for hardware purchases for experiments ie. > $20M(FY90)
- In addition, the SDC will need "operating" support in the form of programmers from SSC WBS 5.3
- We plan to work with the SSCL to develop a detailed computing plan for the SDC, taking into account not only SSCL resources but resources internal to the collaboration
- This can start seriously at our Jan. 10-12 collaboration meeting at the SSCL

		SUB TOTALS ($K)	PRIORITY
Integration of tracking systems		765	1
Pixel and silicon trackers(LANL, LBL)	275		
Modular straw tracker(ORNL, WSTC)	245		
Fiber, hybrid and overall outer tracker(ORNL)	245		
Superconducting solenoid design		300	1
Design and integration with other systems(FNAL)	300		
Integration of calorimeter systems		975	1
Scintillating-tile(ANL, FNAL, WSTC)	650		
Liquid ionization(LBL)	325		
Integration of muon systems		285	1
Chamber support design(FNAL)	65		
Iron toroid design, chamber design and integration with other systems(U. of Wisconsin - PSL)	220		
Integration of electronics systems		790	1
Trigger systems(U. of Chicago, Harvard, U. of Michigan, U. of Wisconsin)	275		
Data acquisition systems(FNAL, IBM)	100		
Silicon and wire chamber rad-hard processing development(U. of Pennsylvania, UC Santa Cruz, IBM)	75		
Straw tube front-end system integration (Colorado, ORNL, U. of Pennsylvania)	75		
Calorimeter front-end system integration (FNAL, LBL, WSTC)	165		
Overall electronics system integration(WSTC)	100		
Computing and software engineering		495	1
Software engineers(ANL, FNAL, LBL)	300		
Workstations and other hardware(ANL, FNAL, LBL)	95		
Software packages and licenses(ANL, FNAL, LBL)	100		
Overall integration and coordination		800	1
Overall detector systems integration(LBL, RTK)	600		
Project coordination and management(LBL)	200		
Project reserve - contingency		400	2
LBL	400		
Project reserve - R&D		400	2
SSCL	400		

GRAND TOTAL 5210

Budget Request cont.

- Further we are requesting funds for
  - R&D not covered under the major subsystems program, to be determined when funding is finalized for this program
  - Project reserve
- Substantial pre-construction funding will also be required in FY92 to support engineering design, systems integration and critical R&D.
- We will present a detailed budget request for FY92 by the summer of 1991
- Our preliminary budget request (US only) for FY92 is $24.8M

	FY91($M)	FY92($M)
1 TRACKING SYSTEMS	**0.89**	**5.8**
1.1 SILICON TRACKING SYSTEM	0.31	3
1.2 CENTRAL TRACKER	0.48	2.5
1.3 INTERMEDIATE TRACKER	0.10	0.3
2 CALORIMETRY	**1.05**	**6.5**
2.1 CENTRAL CALORIMETER	0.53	4
2.2 INTERMEDIATE CALORIMETER	0.42	2
2.3 FORWARD CALORIMETER	0.10	0.5
3 MUON SYSTEM	**0.30**	**1**
3.1 IRON TOROIDS	0.15	0.4
3.2 MUON CHAMBERS	0.15	0.5
3.3 MUON SCINTILLATORS		0.1
4 SUPERCONDUCTING MAGNETS	**0.30**	**0.6**
4.1 SC SOLENOID	0.30	0.6
5 DATA ACQUISITION & TRIGGER	**0.70**	**3**
5.1 DATA ACQUISITION SYSTEMS	0.35	1.5
5.2 TRIGGER SYSTEMS	0.35	1.5
6 COMPUTING	**0.50**	**1**
6.1 ON-LINE COMPUTING		0.2
6.2 OFFLINE COMPUTING	0.50	0.8
7 CONVENTIONAL SYSTEMS	**0.15**	**0.6**
7.1 UTILITIES	0.05	0.1
7.2 CONTROLS		0.1
7.3 SAFETY SYSTEMS		0.2
7.4 CRYOGENIC SYSTEMS	0.05	0.1
7.5 STRUCTURAL SUPPORT SYSTEMS	0.05	0.1
8 INSTALLATION AND TEST	**0.40**	**3.2**
8.1 TEST BEAM PROGRAM	0.20	2.5
8.2 SUBSYSTEM INSTALLATION AND TEST	0.20	0.7
9 PROJECT MANAGEMENT	**0.93**	**3.1**
9.1 PROJECT PLANNING	0.18	0.2
9.2 PROJECT TRACKING	0.00	0.2
9.3 DOCUMENT DISTRIBUTION AND CONTROL	0.05	0.2
9.4 SUBSYSTEMS INTEGRATION	0.70	2.5
TOTALS	**5.21**	**24.8**

Table 12. Preconstruction funding request for FY91 and FY92 by WBS element. Only the US part of the SDC preconstruction budget request is given in this Table. The budget request for FY91 assumes that almost all of the R&D for the SDC is supported by the major subsystems program or by other means. In FY92 it is assumed that most of the research and development will be supported under the auspices of the SDC. This budget request would also support susbsystem engineering design and systems integration.

Table 10

Management of the Solenoidal Detector Collaboration

SPOKESPERSON:
G. Trilling (LBL)

DEPUTY SPOKESPERSONS:
G. Bellettini (University of Pisa)
D. Green (FNAL)
T. Kondo (KEK)

TECHNICAL MANAGER:
M. Gilchriese (LBL)

CHAIRPERSON OF INSTITUTIONAL BOARD:
T. Kirk (ANL)

CHAIRPERSONS OF TECHNICAL STEERING COMMITTEES:

Calorimetry
A. Maki (KEK)
L. Nodulman (ANL)
J. Siegrist (SSCL)

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K. Amako (KEK)
A. Baden (Univ. Maryland)
L. Price (ANL)

Detector integration and experimental facilities
J. Cooper (FNAL)
R. Kadel (LBL)

Electronics, data acquisition, and trigger
M. Campbell (Univ. Michigan)
A. Lankford (Univ. Calif. Irvine)
W. Smith (Univ. Wisconsin)
Y. Watase (KEK)
H. H. Williams (Univ. Pennsylvania)

OTHER MEMBERS OF TECHNICAL BOARD:
R. Hubbard (CEN Saclay)

EXECUTIVE BOARD:
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G. Feldman (Harvard Univ.)
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K. Kondo (Tsukuba Univ.)
S. Mori (Tsukuba Univ.)
Y. Nagashima (Osaka Univ.)
T. Ohsugi (Hiroshima Univ.)
L. Price (ANL)
R. Ruchti (Univ. Notre Dame)
A. Seiden (Univ. Calif. Santa Cruz)
R. Thun (Univ. Michigan)

Muon systems
G. Feldman (Harvard Univ.)
S. Mori (Tsukuba Univ.)
R. Thun (Univ. Michigan)

Physics and detector performance
K. Einsweiler (LBL)
L. Price (ANL)
Y. Takaiwa (KEK)

Superconducting magnets
R. Kephart (FNAL)
A. Yamamoto (KEK)

Tracking
J. Elias (FNAL)
W. Ford (Univ. Colorado)
T. Ohsugi (Hiroshima Univ.)

SUMMARY

Through this LoI, the SDC expresses its intent to design and build a general purpose detector with broad capabilities for exploring a wide range of physics issues. Redundancy and in-situ calibration capability are also strong features, important in the search for new phenomena.

Substantial progress has been made in the detector design since the EoI. Magnet and calorimeter technological options have been reduced, and the muon system has been refined. Scope reduction to meet SSCL guidelines has been accomplished without excessive loss in physics capability.

This detector will retain a substantial part of its functionality at luminosities well above SSC design value, and be matched to those physics issues whose elucidation requires increased rates.

A preliminary "bottoms-up" cost estimate has been made and amounts to $509M using U.S. costing practices. It is anticipated that about $200M in in-kind contributions will come from the foreign collaborators in SDC.

The proposal preparation will require a large engineering effort. Timely and adequate funding are essential to meet the goal of having a proposal in about a year.

The SDC plans to have its detector in place and operational in time to take advantage of the first physics opportunuties provided by SSC operation.