GEM TN-92-244

PAC Review Meeting - SSCL

December 3, 1992

Abstract:

GEM Collaboration presentations to the PAC at the PAC Review Meeting held at the SSC Laboratory on December 3, 1992.

PRESENTATIONS

1)	GEM Status/Plans	(B. Barish)
2)	Calorimetry	(B. Willis)
3)	Muons	(F. Taylor)
4)	Central Tracker	(C. Baltay)

GEM Project Overview

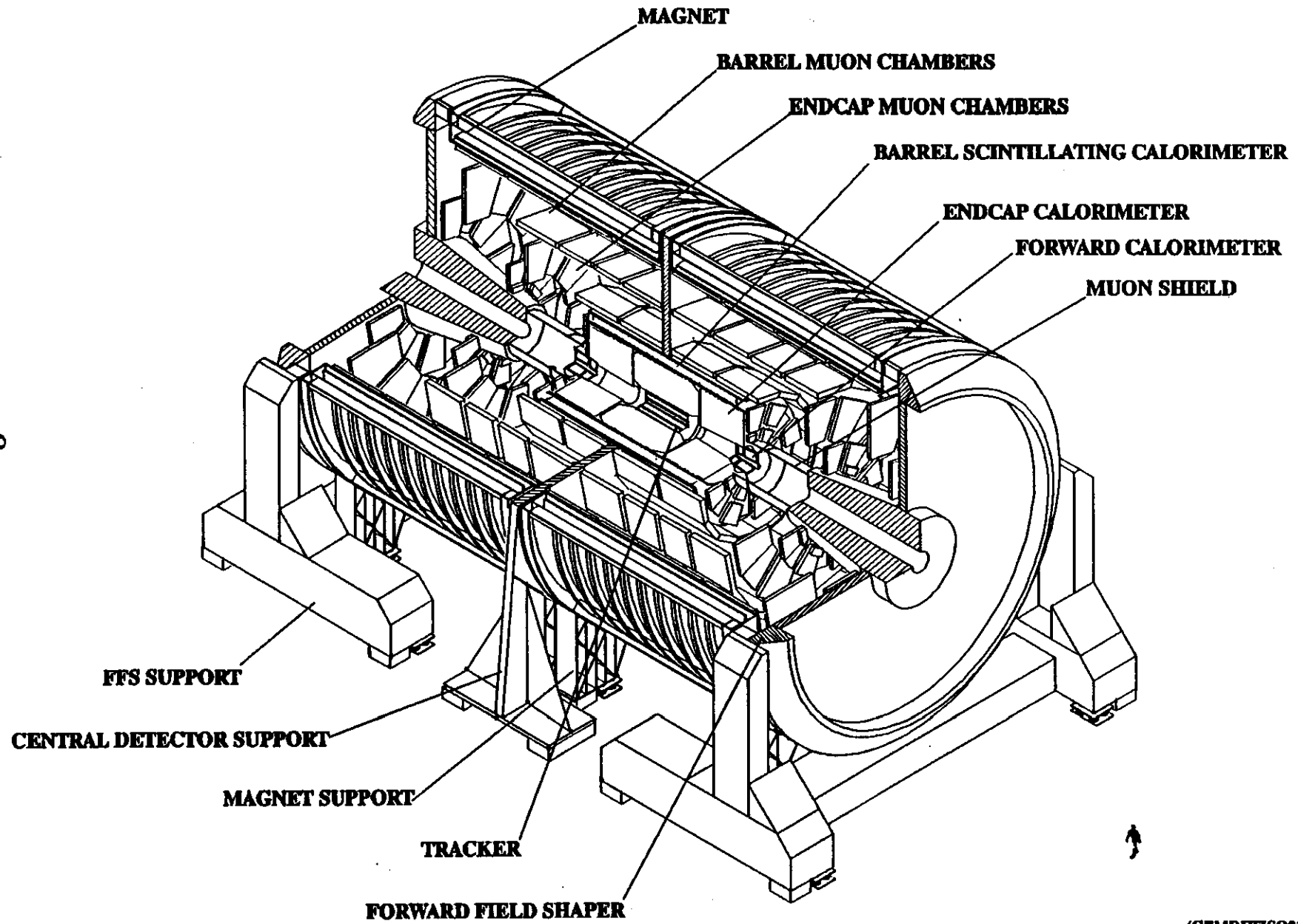
(Status of Preparation of TDR, Project Cost/Schedule and Funding Plans, Plans for Detector Engineering and Construction in FY98)

Barry Barish

EMPHASIS IN GEM

- Very precise measurement of muon momenta using only the outer muon spectrometer in an open magnetic volume
- Very precise measurement of electron and photon energies using a precision electromagnetic calorimeter with no coil in front of the calorimeter
- Hermetic calorimetry and good jet resolution
- Central tracker emphasis on ensuring clean measurement of physics signals without requiring full pattern recognition
- High luminosity

GEM DETECTOR



(GEMDETISO921118CHEN)

GEM Status

MAJOR MILESTONES

July 1991	EOI approved
December 1991	LOI approved
March 1992 (Tucson)	Established Baseline 1
November 1992 (BNL)	Established Baseline 2
March 15, 1993	Proposed TDR date

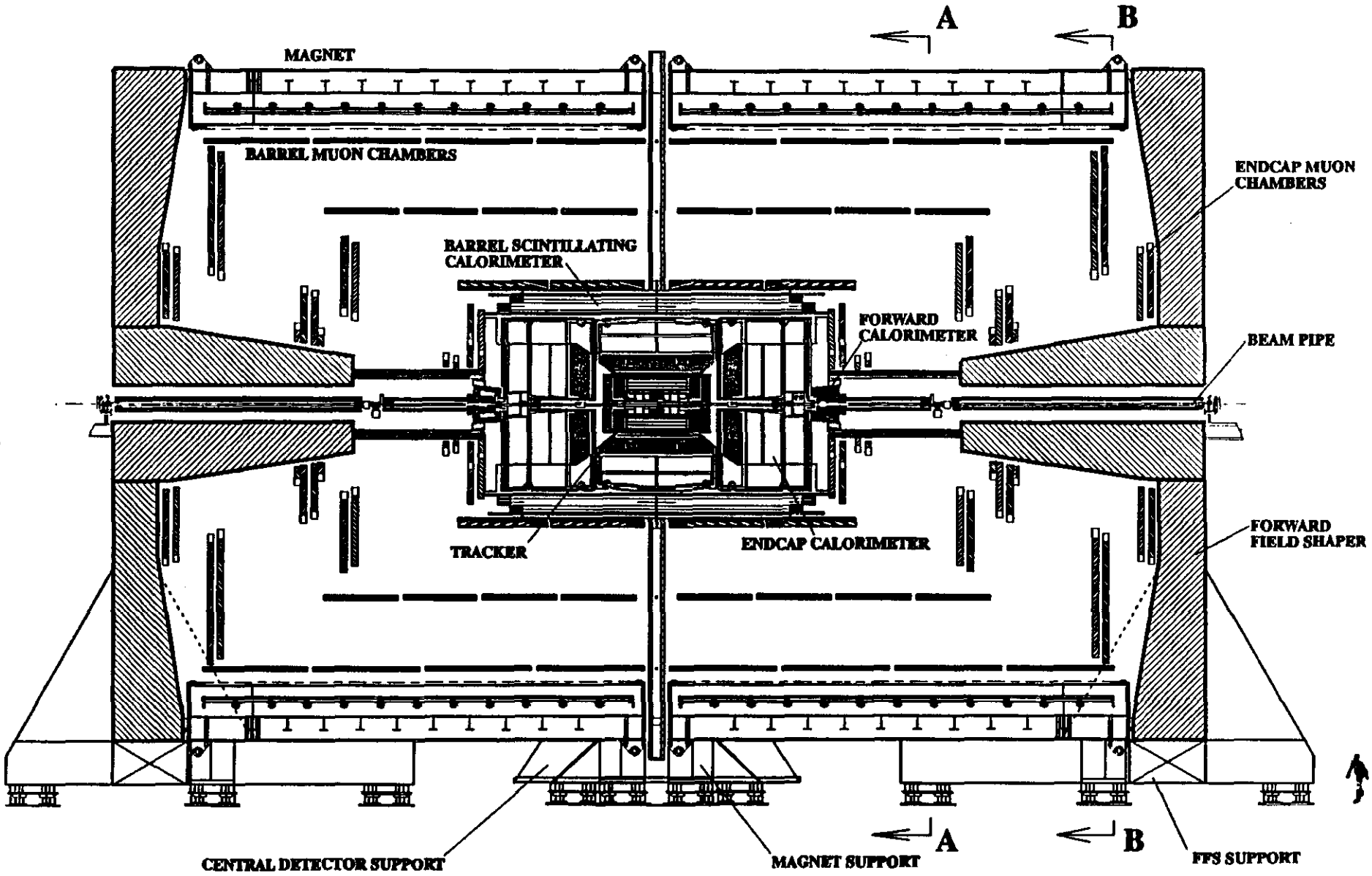
- Facilities in Title I
- Magnet Ready to Proceed
  The Critical Path Item
- Final Technology Choices
  Calorimetry
  Muons Oct/Nov
- R&D/Engineering Design Toward TDR
- Division of Responsibility/
  Manufacturing/Fiscal Plan by TDR
- Permanent Organization by TDR

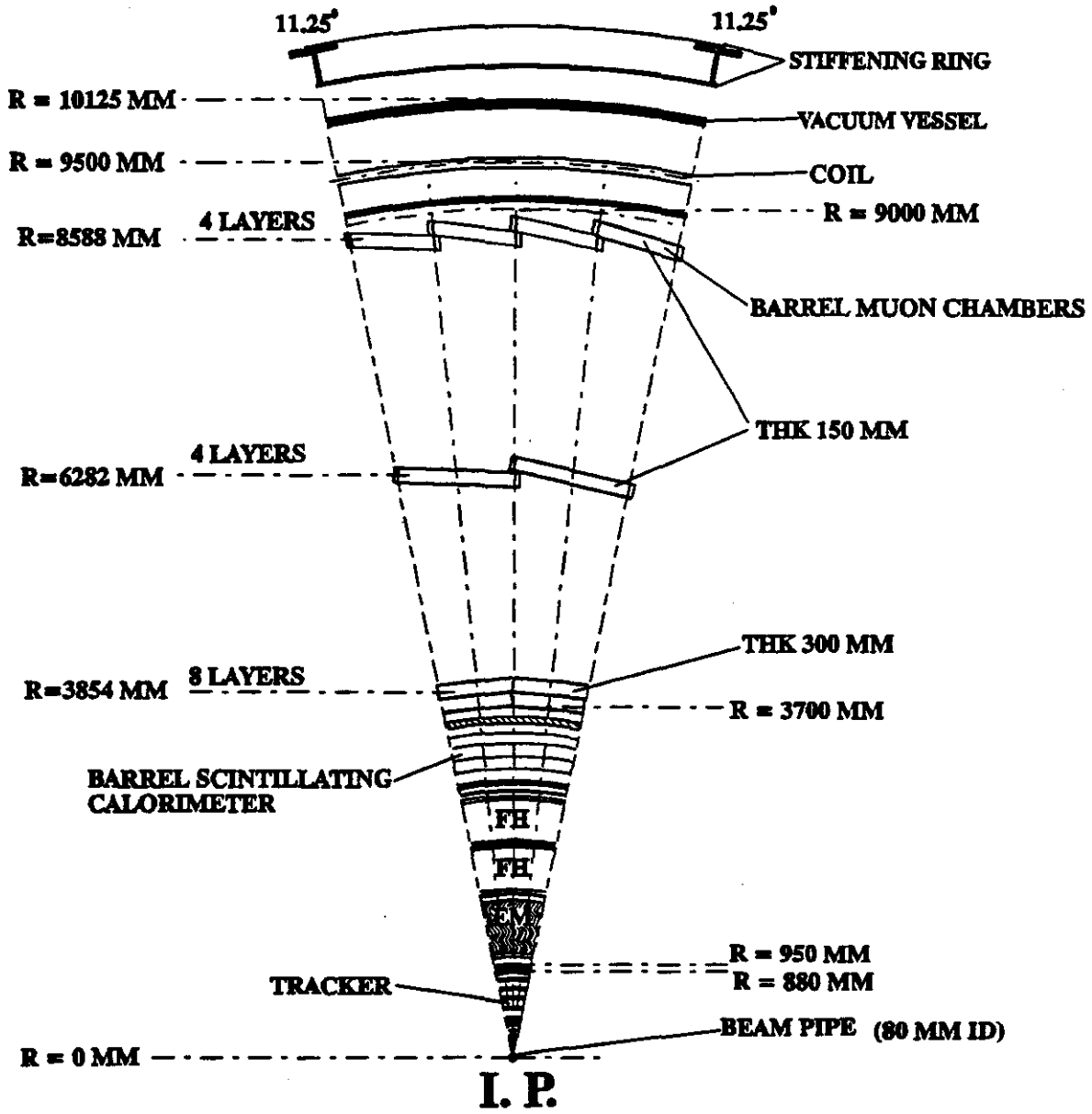
GEM Timeline

1992			1993				
October	November	December	January	February	March	April	May
Tech-nology Choices	BNL/ GEM	PAC Committee				TDR Review	Start IR5
	Baseline 2	Magnet RFP			Submit TDR		

BB/hd

GEM DETECTOR LAYOUT





TYPICAL AZIMUTHAL CUT IN BARREL REGION

GEM TIMELINE

1992			1993		
OCTOBER	NOVEMBER	DECEMBER	JANUARY	APRIL	MAY
TECHNOLOGY CHOICES	BNL/GEM	PAC COMMITTEE		TDR REVIEW	START IR5
	BASELINE 2	MAGNET RFP		SUBMIT TDR	

The GEM Collaboration

710 Collaborators

340 U.S.
370 Non - U.S.

93 Institutions

49 U.S.
44 Non - U.S.

14 Countries

Belorus, Brazil, China, Georgia,
Germany, India, Israel, Japan,
Korea, Mexico, Romania, Russia,
Taiwan, U.S.

COLLABORATION DEVELOPMENTS
(Highlights)

- **New U. S. Groups**
  - Slattery/Lobkowicz (University of Rochester)
  - McCarthy (Stony Brook)

- **New Non-U. S. Group**
  - Ecuador

- **Korea GEM Commitment**
  - Physical Society Decision
  - WY Lee/Jewan Kim

- **Taiwan GEM Commitment**
  - Central Tracker
  - Agreement Signed

- **Russia**
  - Muon Manufacturing
  - Calorimetry

- **China**
  - Muon Manufacturing
  - Accordion

GEM FACILITIES

Status: TITLE I

Coordination: M. Harris
B. Wisniewski

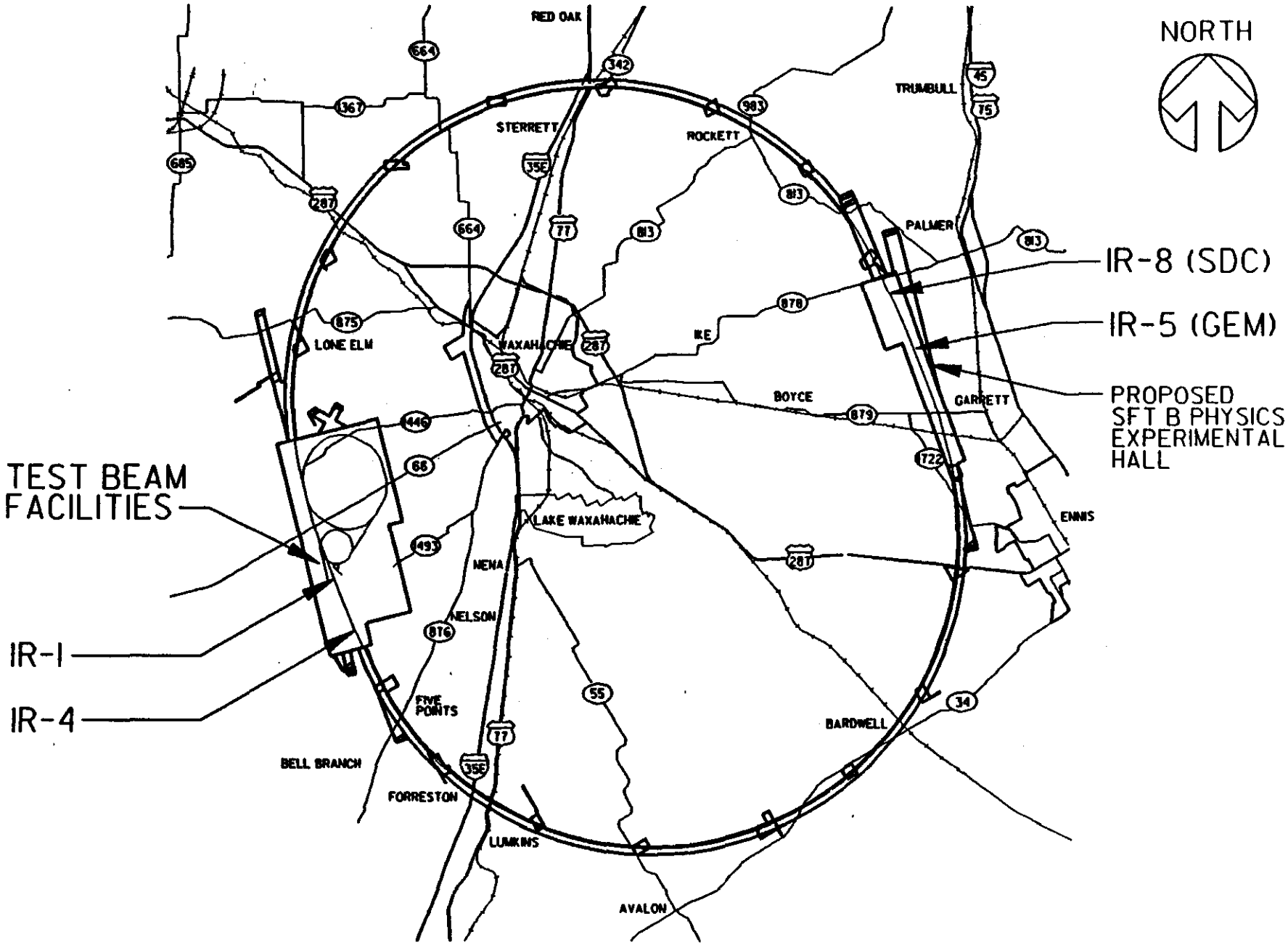
Features:

Hall	Length	100 m
	Width	30 m

Two Large Shafts

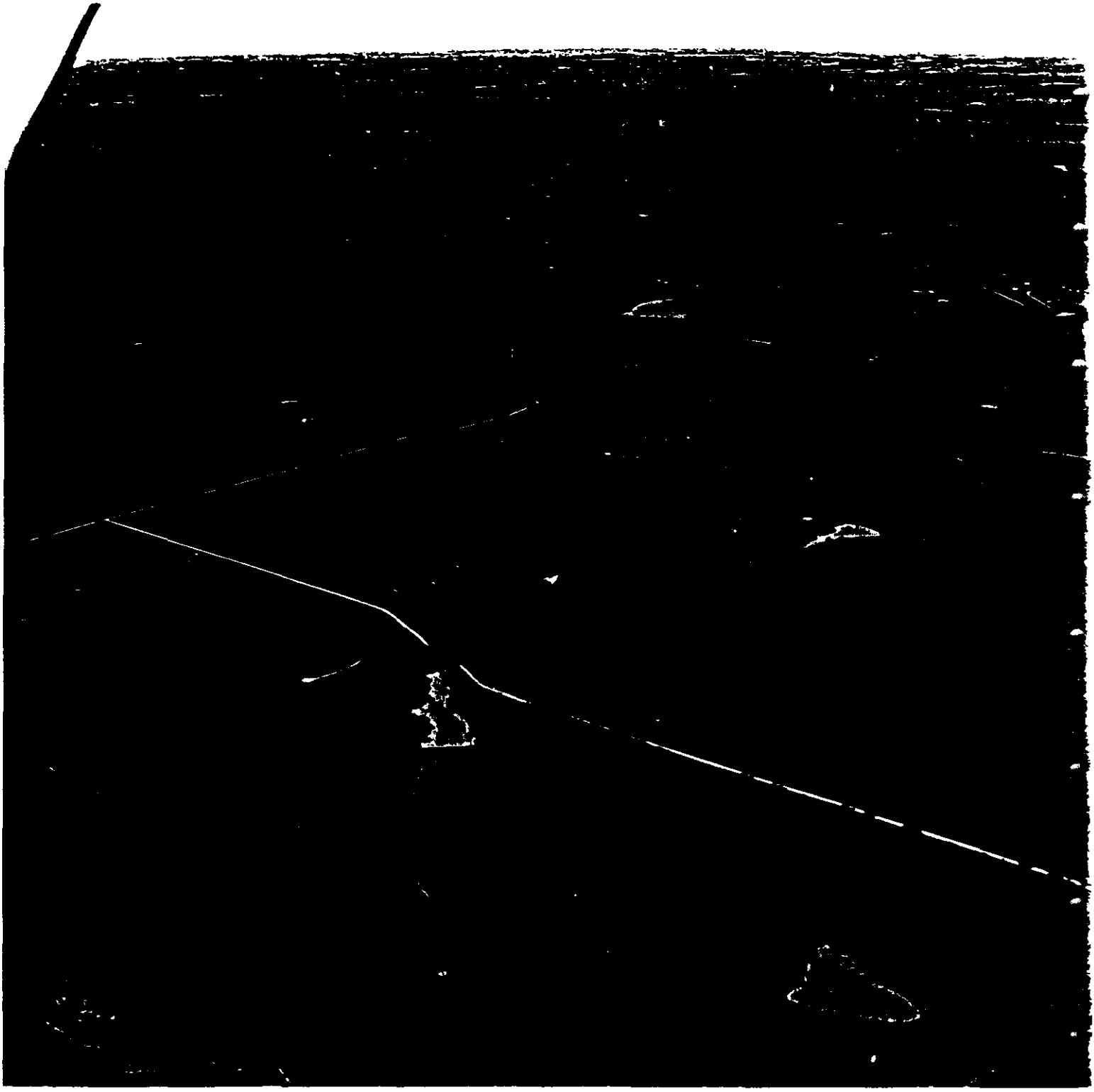
Forward Electronics Rooms

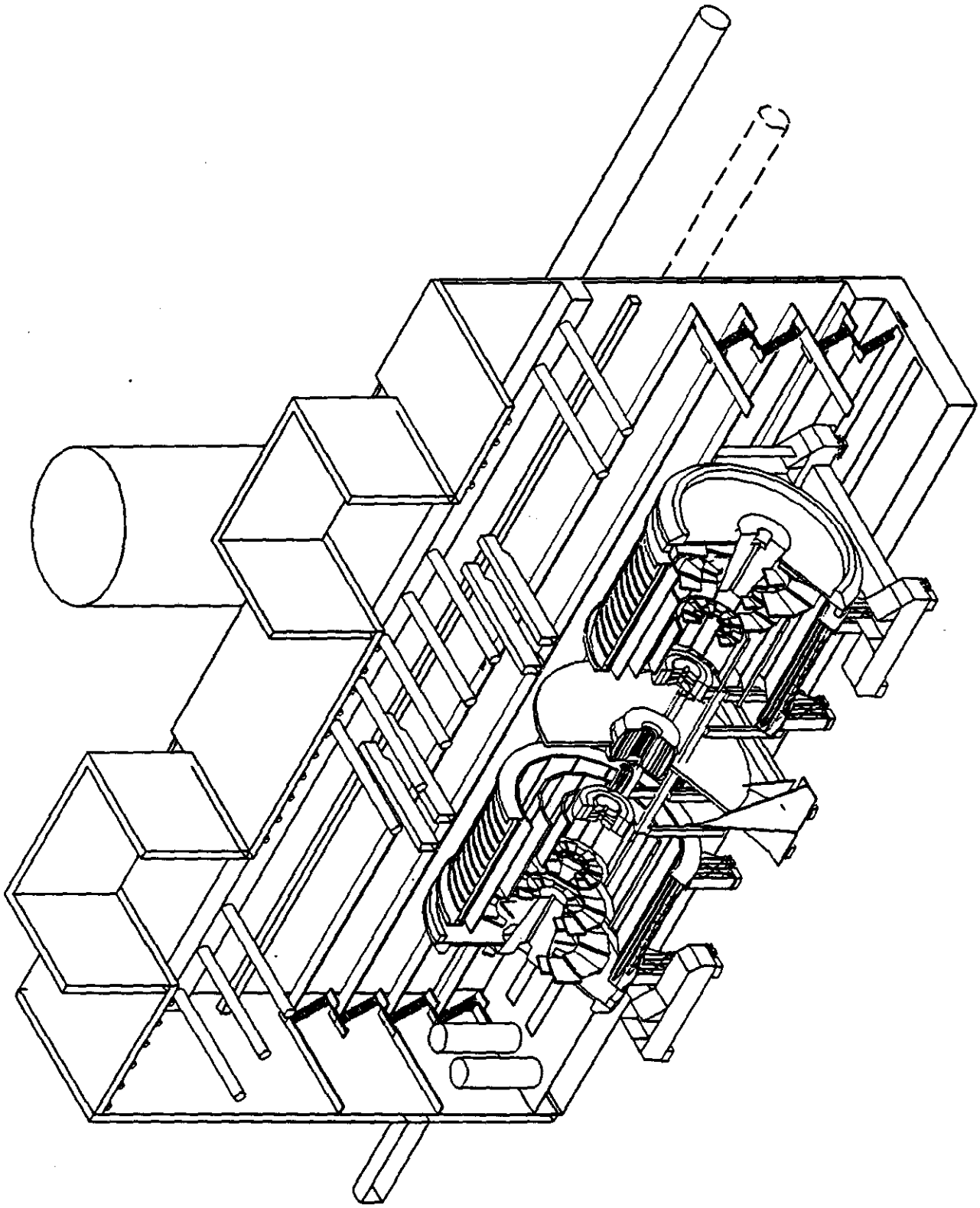
Two Large Assembly Halls
Magnet Coils and Assembly
Muon Module Construction
Etc.
Operations

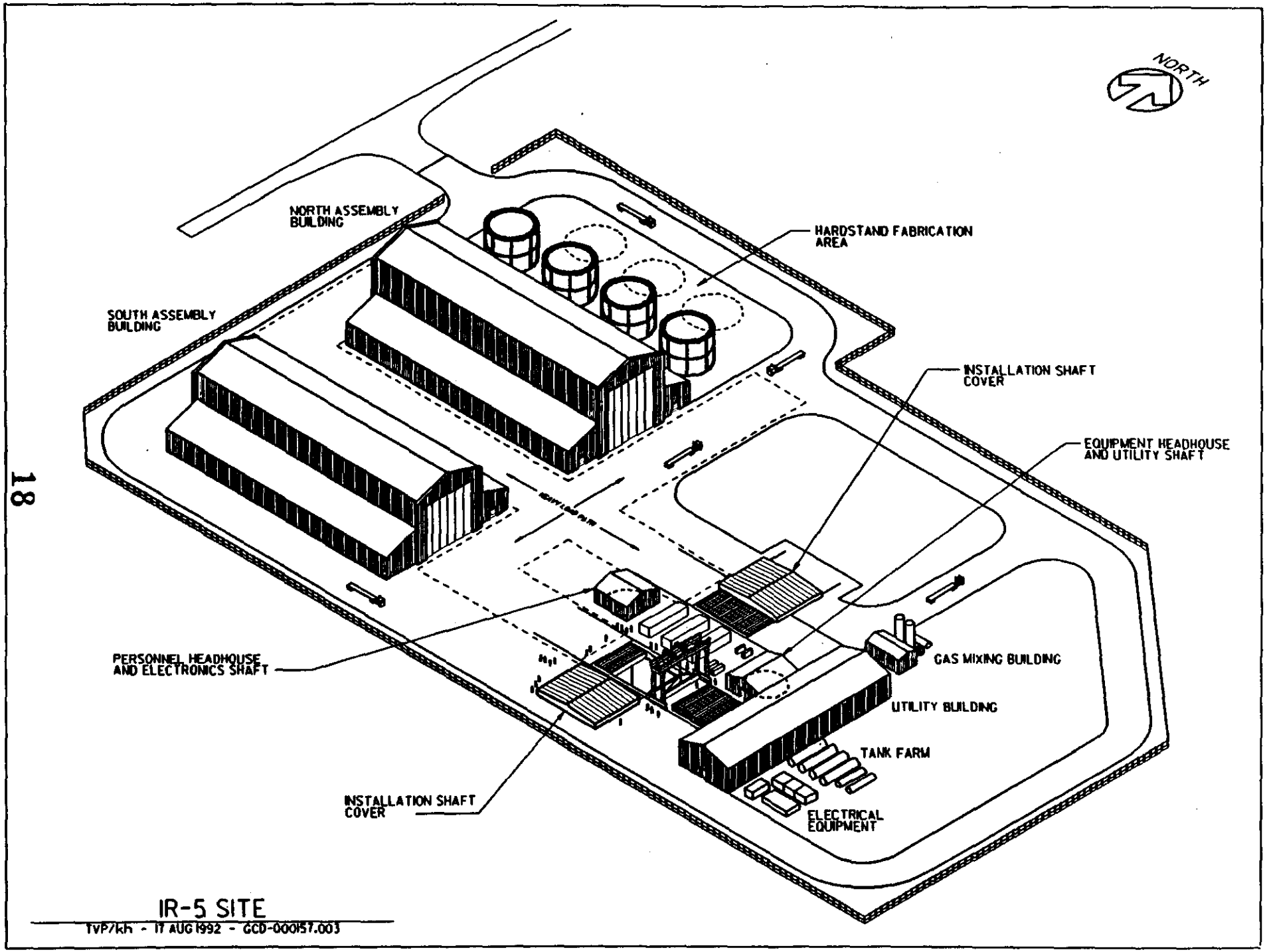


SSC EXPERIMENTAL AREA MAP

TVP/kh - 8/20/92 - R20000460 - ref. files: R20000458

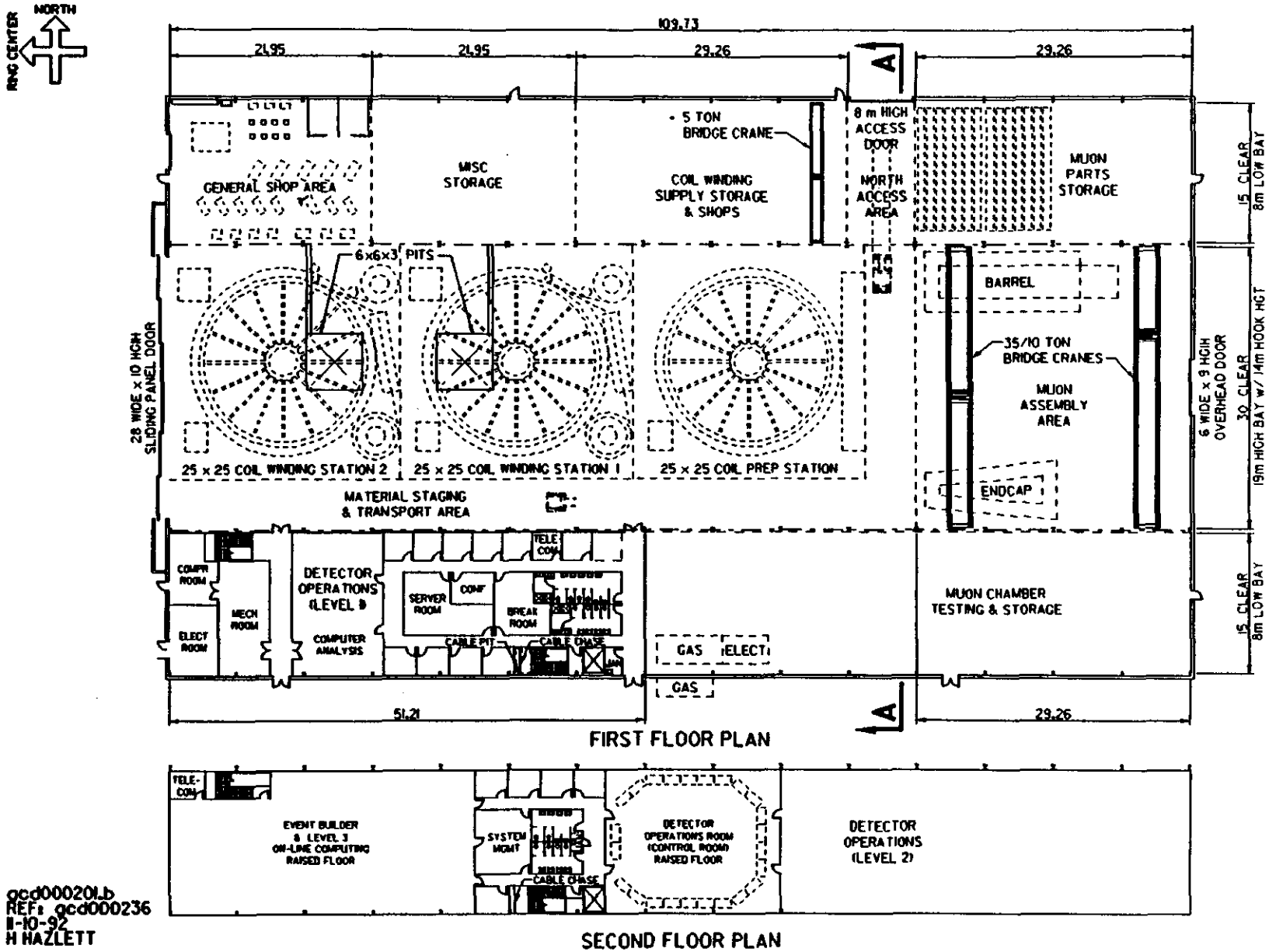






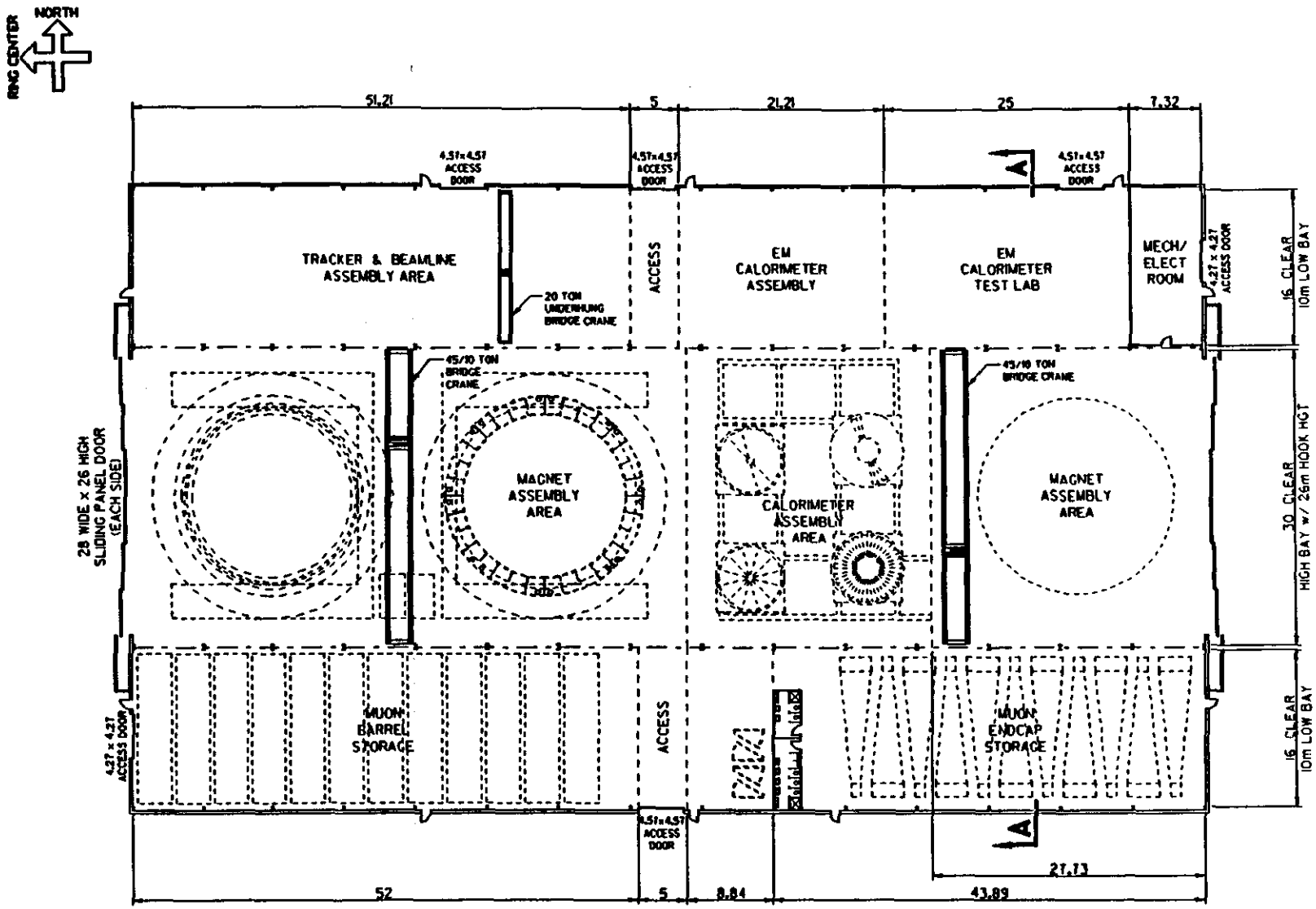
IR-5 SITE

TVP/kh - 17 AUG 1992 - GCD-000157.003



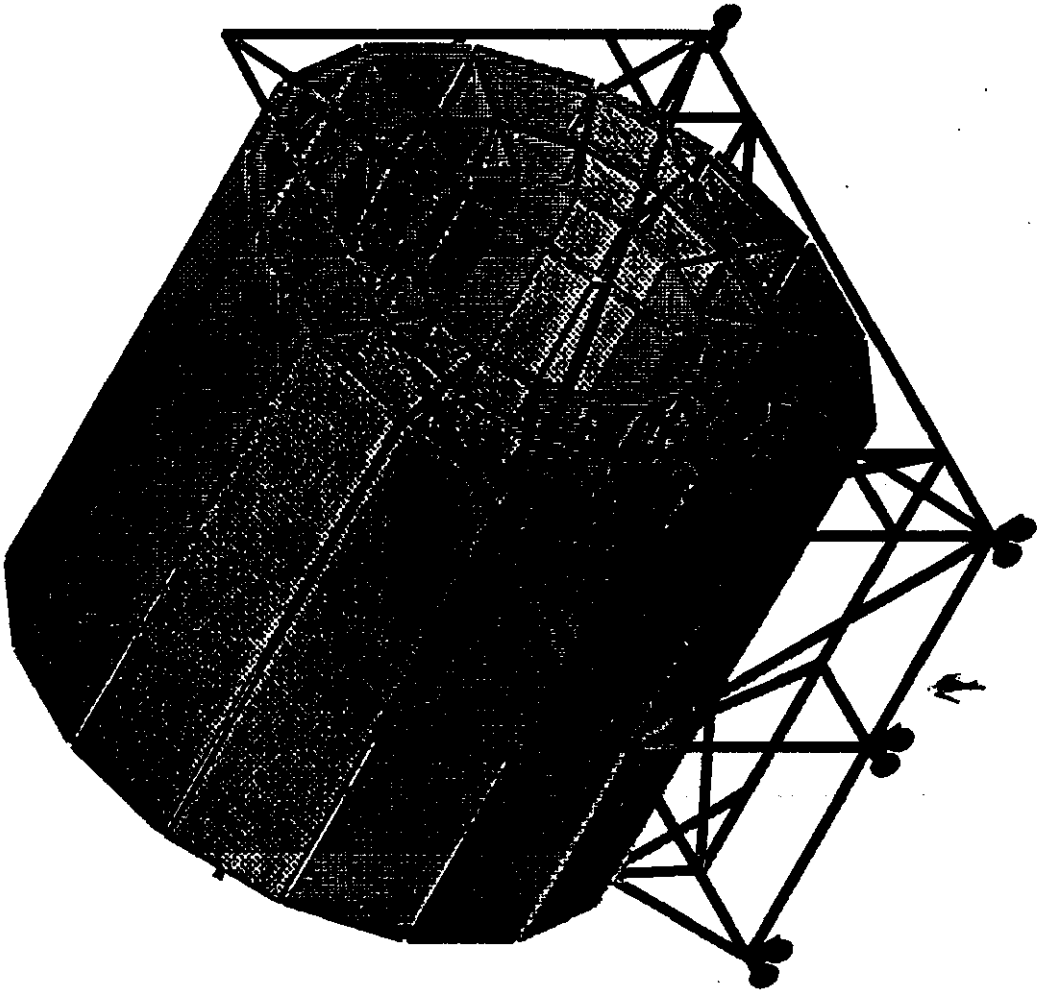
gcd000201.b
REF: gcd000236
11-10-92
H HAZLETT

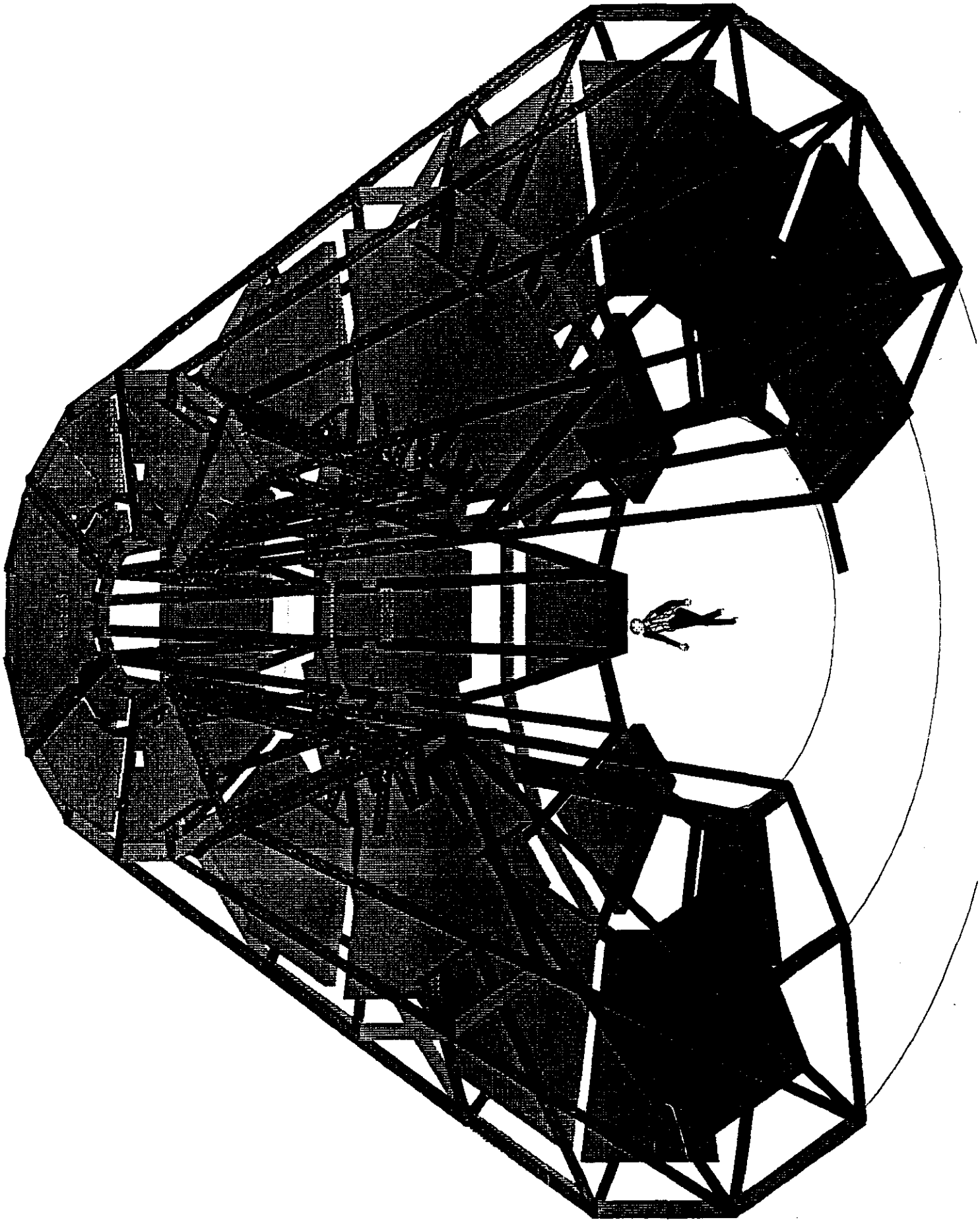
South Assembly Building Floor Plan

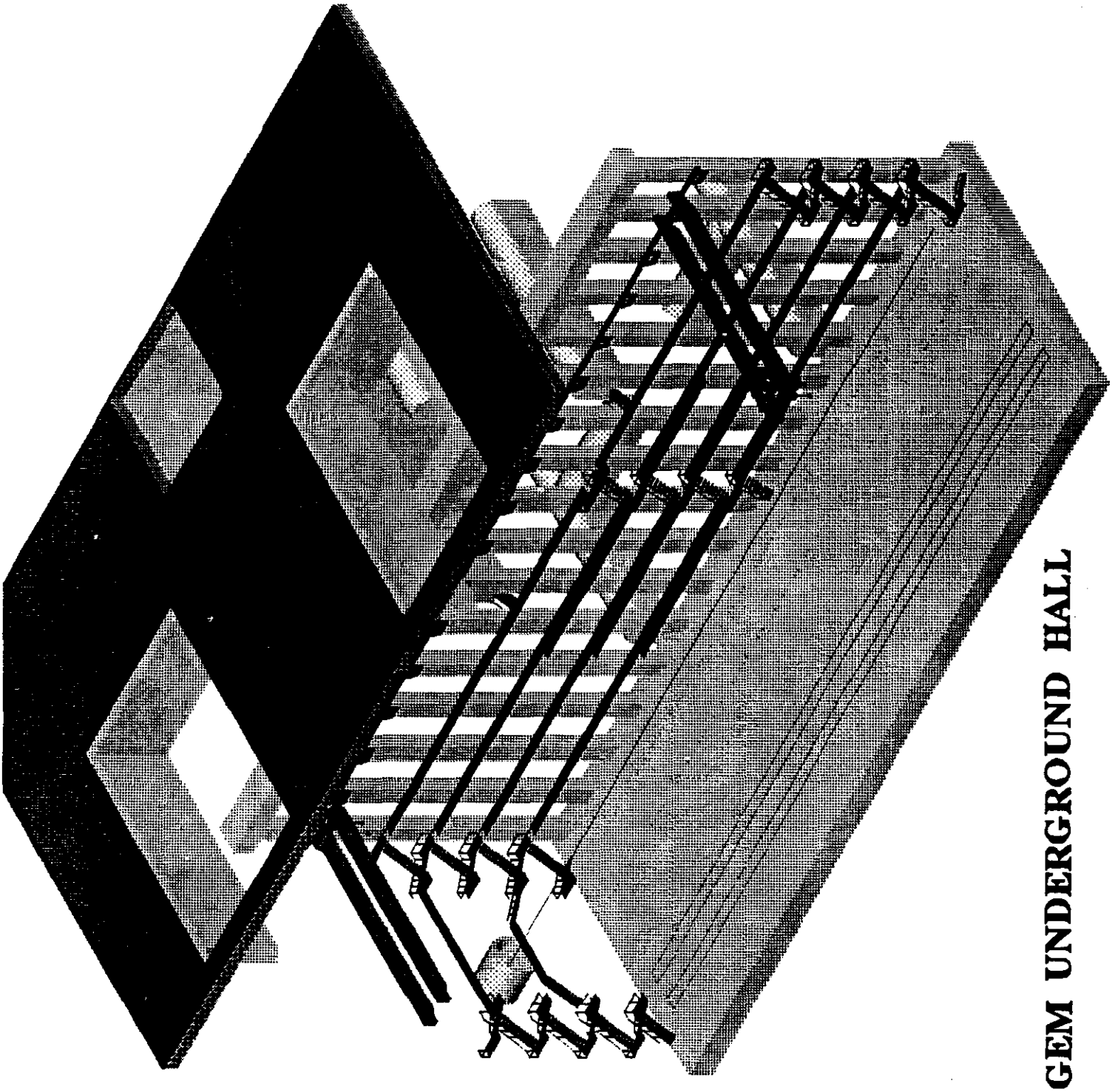


qcd000130.b
REF: qcd000240
8-12-92
H HAZLETT

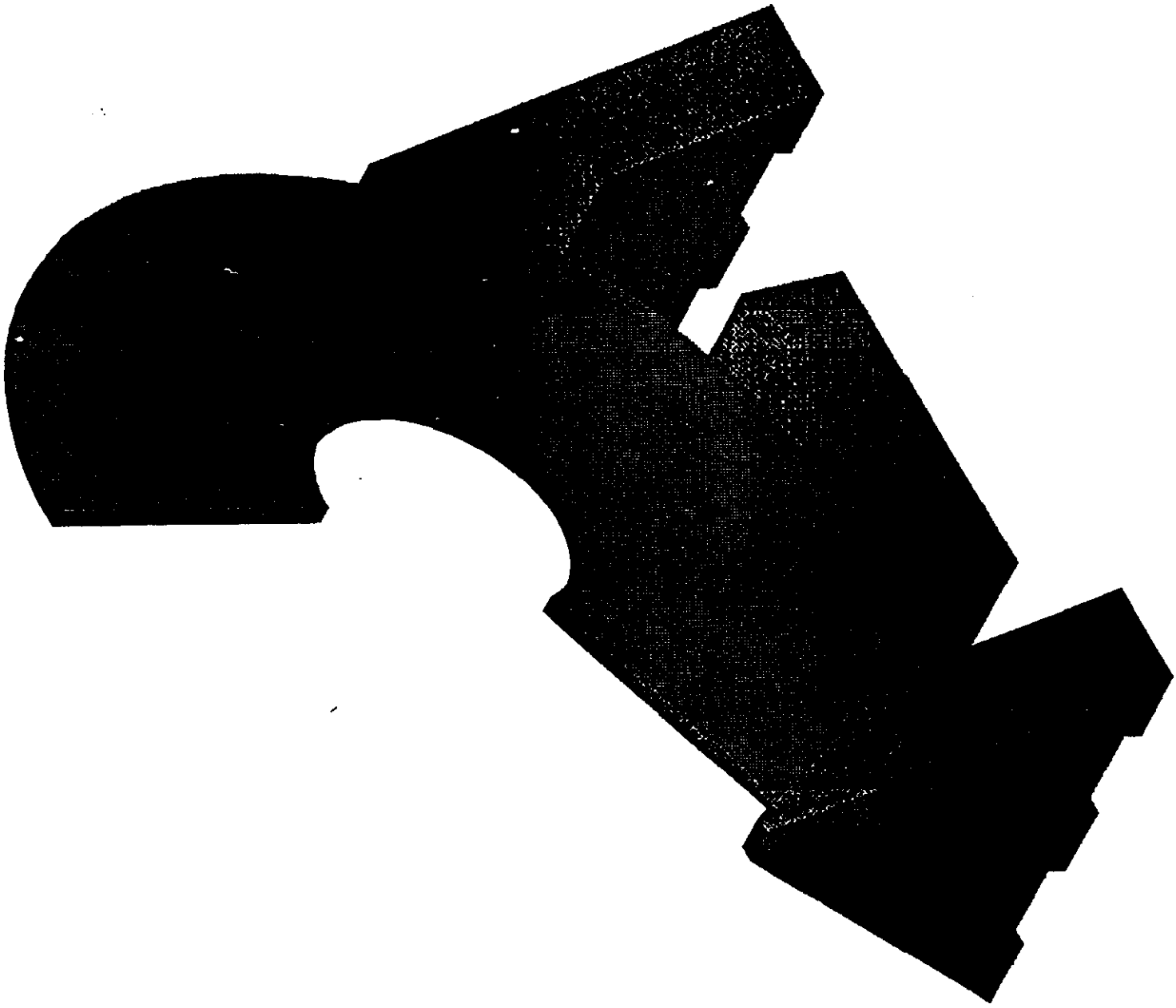
North Assembly Building Floor Plan

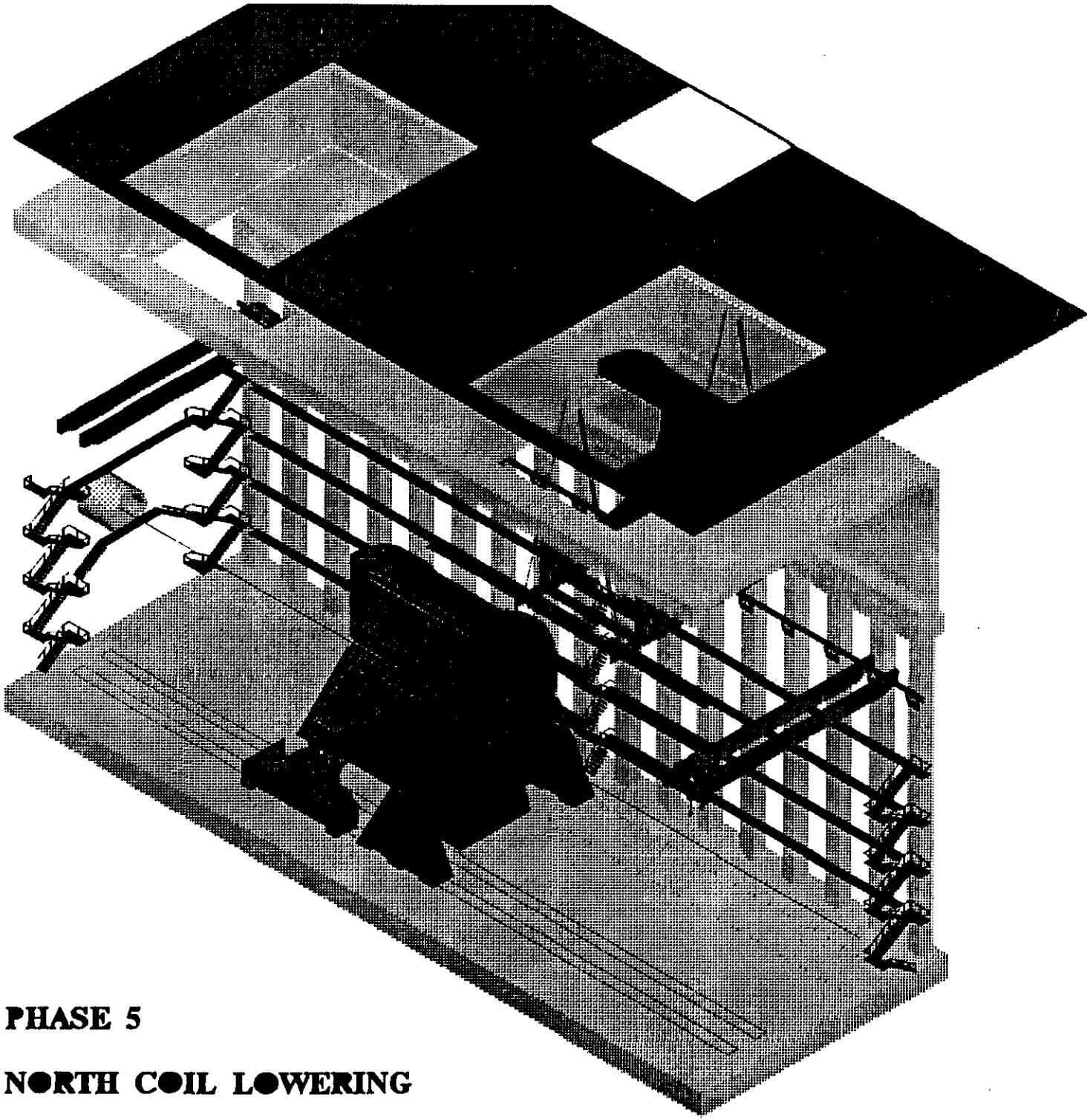






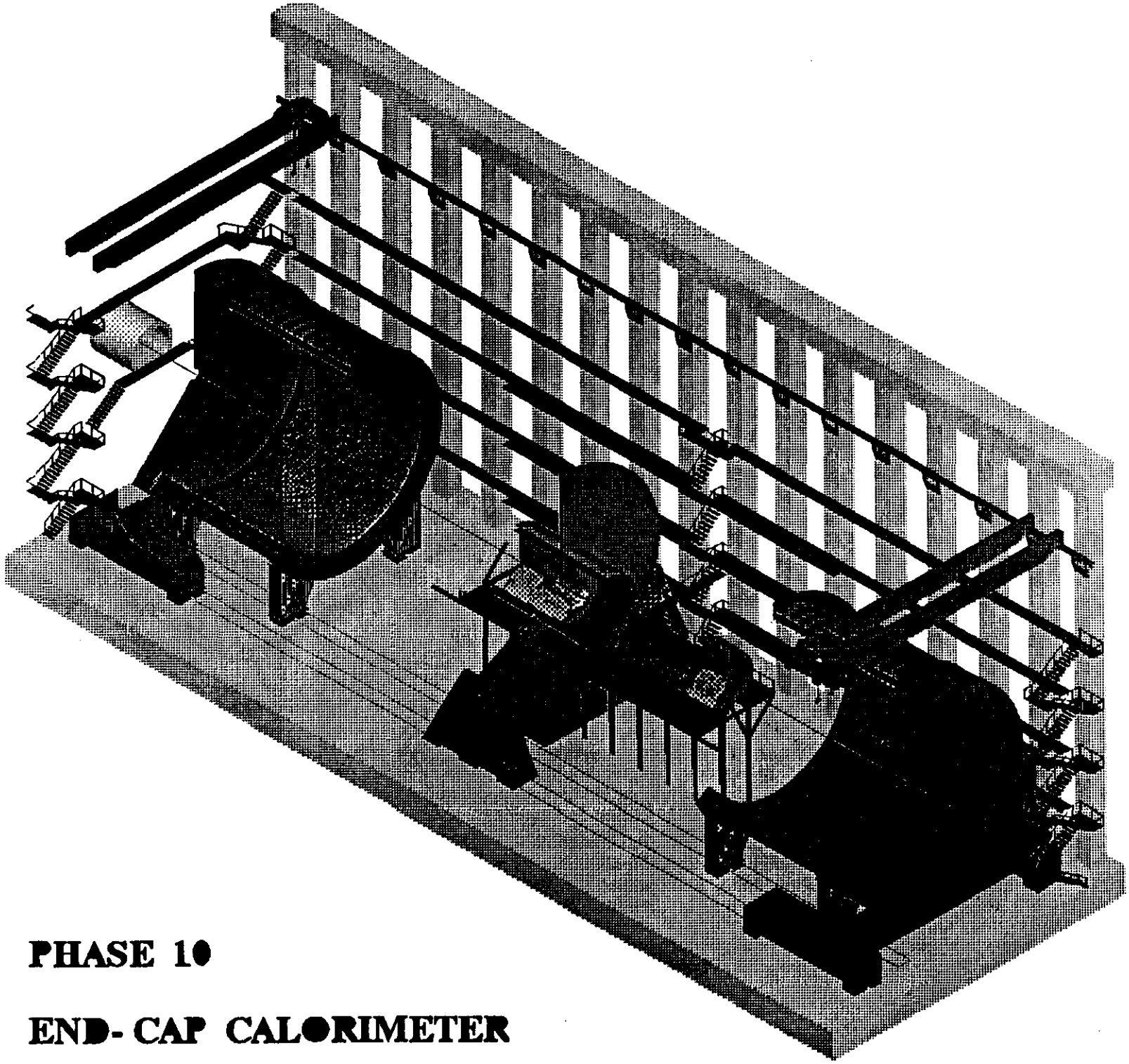
GEM UNDERGROUND HALL





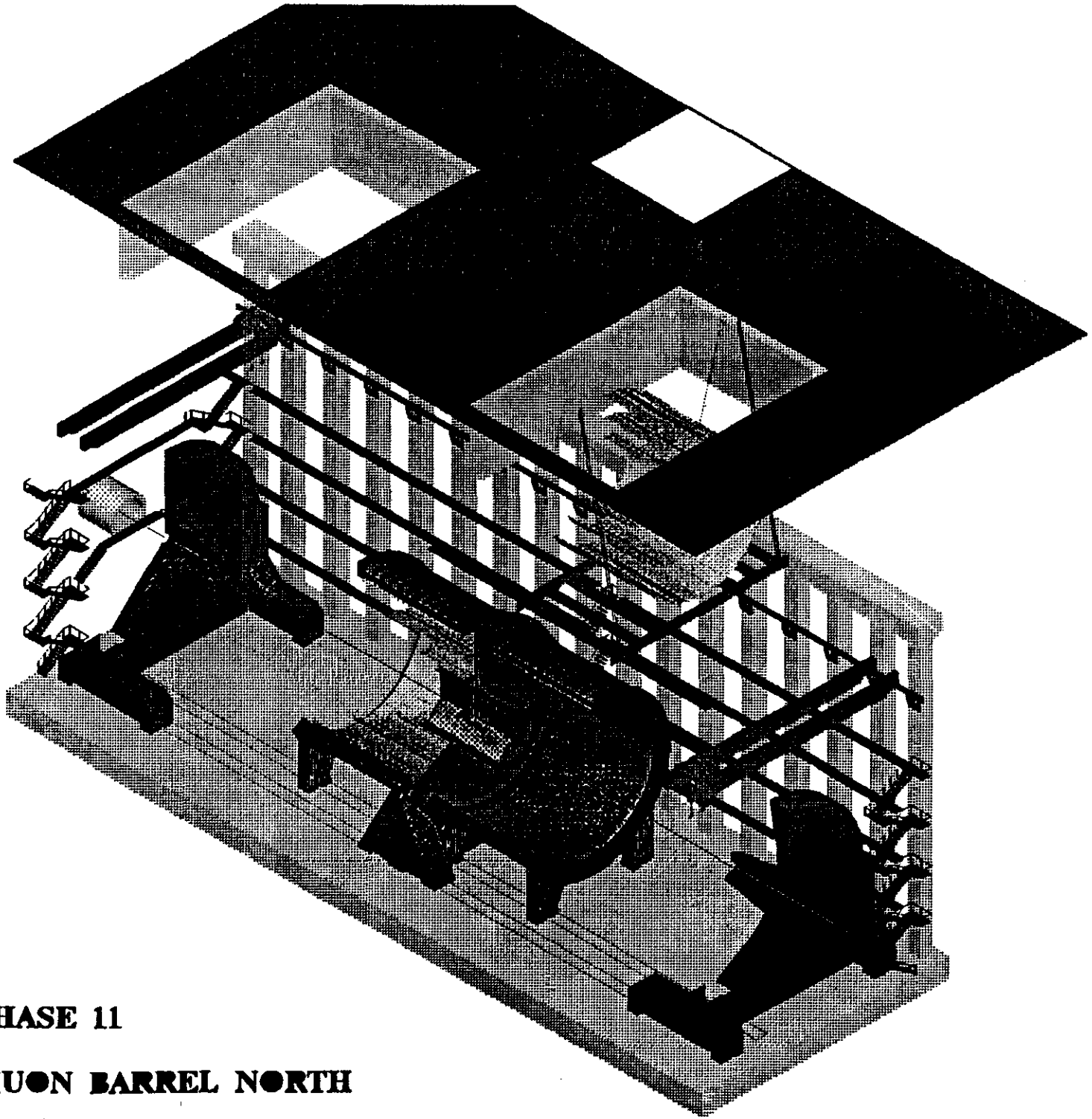
PHASE 5

NORTH COIL LOWERING



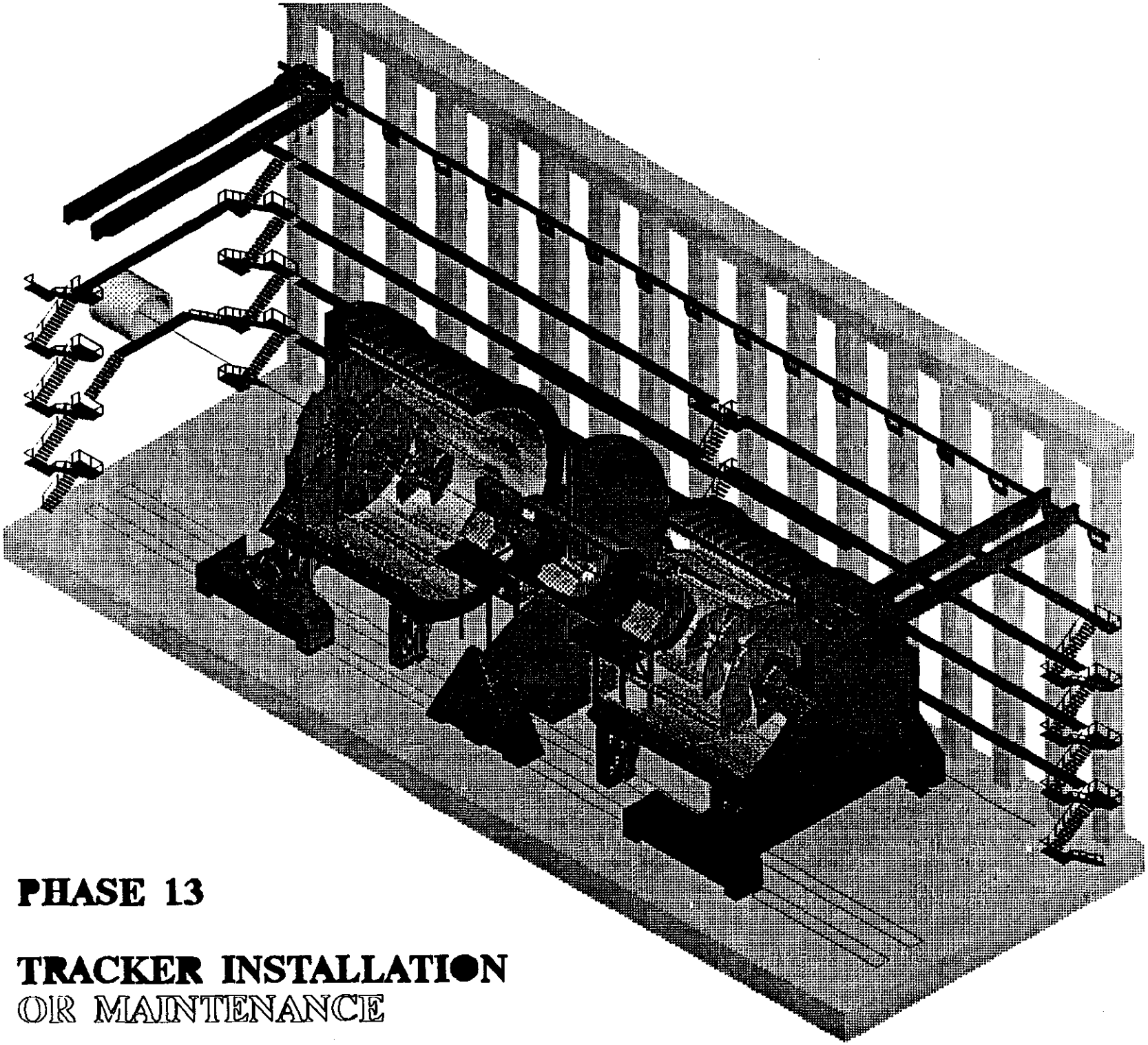
PHASE 10

END- CAP CALORIMETER



PHASE 11

MUON BARREL NORTH



PHASE 13

TRACKER INSTALLATION
OR MAINTENANCE

Schedule/Milestones

	1992	1993	1994	1995	1996	1997	1998	1999
GEM Milestones								
1. PAC Review		▼Dec						
2. Magnet RFP		▼Dec						
3. Muon Option Choice		▼Jan						
4. Technical Design Report		▼Mar						
5. Magnet Prime Contract		▼Mar						
6. PAC Review		▼Jul						
7. DOE Review		▼Sept						
8. JOD South Assembly Building			▼Apr					
9. BOD South Assembly Building			▼Jul					
10. BOD North Assembly Building			▼Oct					
11. BOD Underground Experimental Hall					▼Apr			
12. Start Detector Installation					▼Apr			
13. Complete Detector Installation								▼Jul
14. Detector Ready for Physics								▼Oct
Installation Sequence Requirements								
15. Underground Hall Ready					▼Apr			
16. Install South Forward Field Shaper					▼May			
17. Install South Magnet Half					▼Jul			
18. Install Central Detector Support					▼Aug			
19. Install North Magnet Half					▼Sept			
20. Install North Forward Field Shaper					▼Oct			
21. Close & Test Magnet & Map Field					▼Nov			
22. Install Scintillating Barrel Calorimeter						▼May		
23. Install Noble Liquid Barrel & Endcaps						▼Jul		
24. Install & Align South Muon Barrel							▼Dec	
25. Install & Align North Muon Barrel							▼Mar	
26. Install & Align South Muon Endcap							▼Jun	
27. Install & Align North Muon Endcap							▼Aug	
28. Globally Align Muon System								▼Jan
29. Install Tracker								▼Feb
30. Install Detector Beampipe								▼Jul
31. Close Magnet & Test Systems								▼Sept
32. Detector Ready for Physics								▼Oct

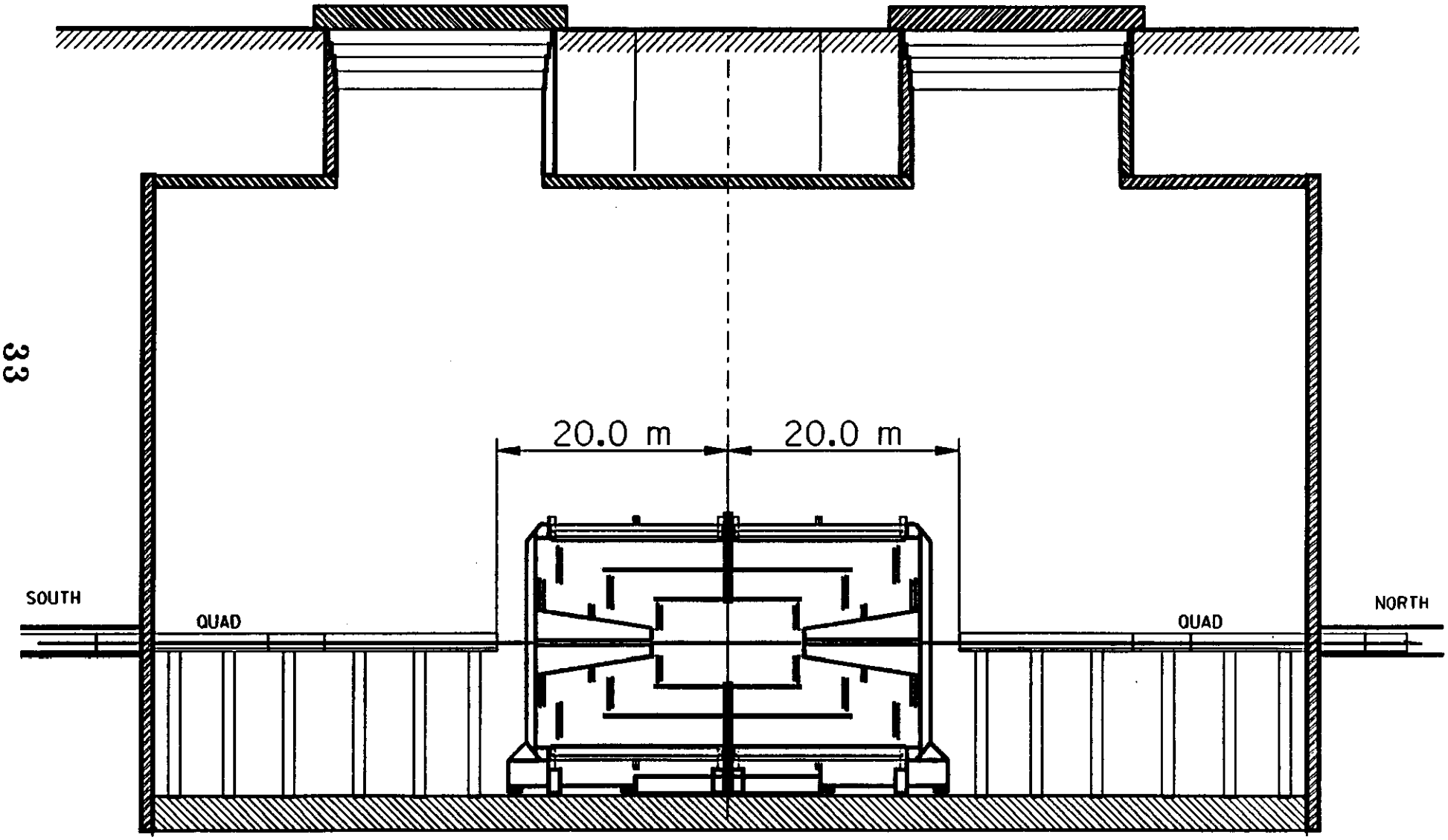
Glossary:
PAC Program Advisory Committee
RFP Request for Proposals
DOE Department of Energy
JOD Joint Occupancy Date
BOD Beneficial Occupancy Date

TIP-03522

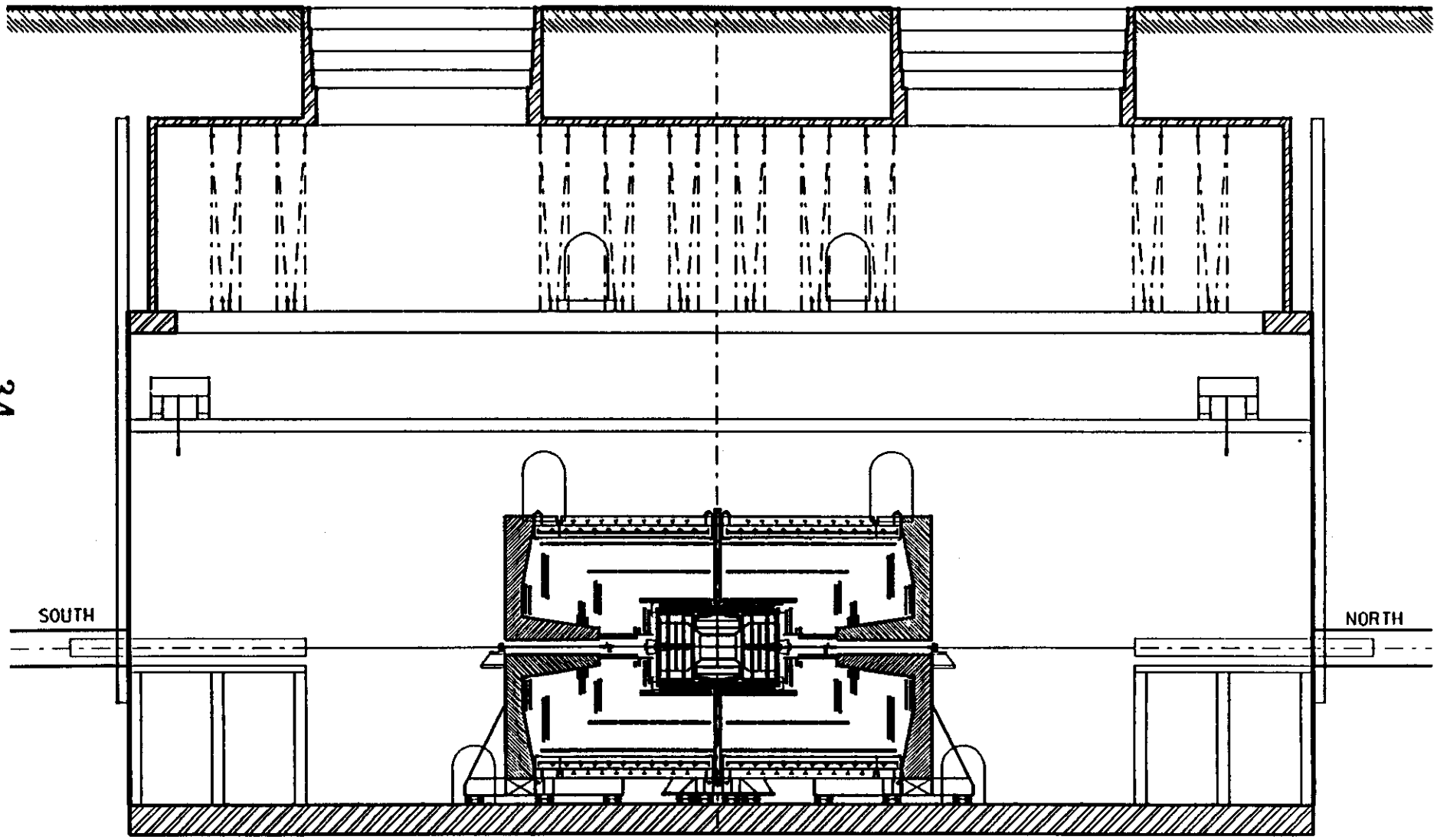
BASELINE 2

Move Quad to 35m.

POSITION QUADRUPOLE OPTION B
20 m FROM I.P.



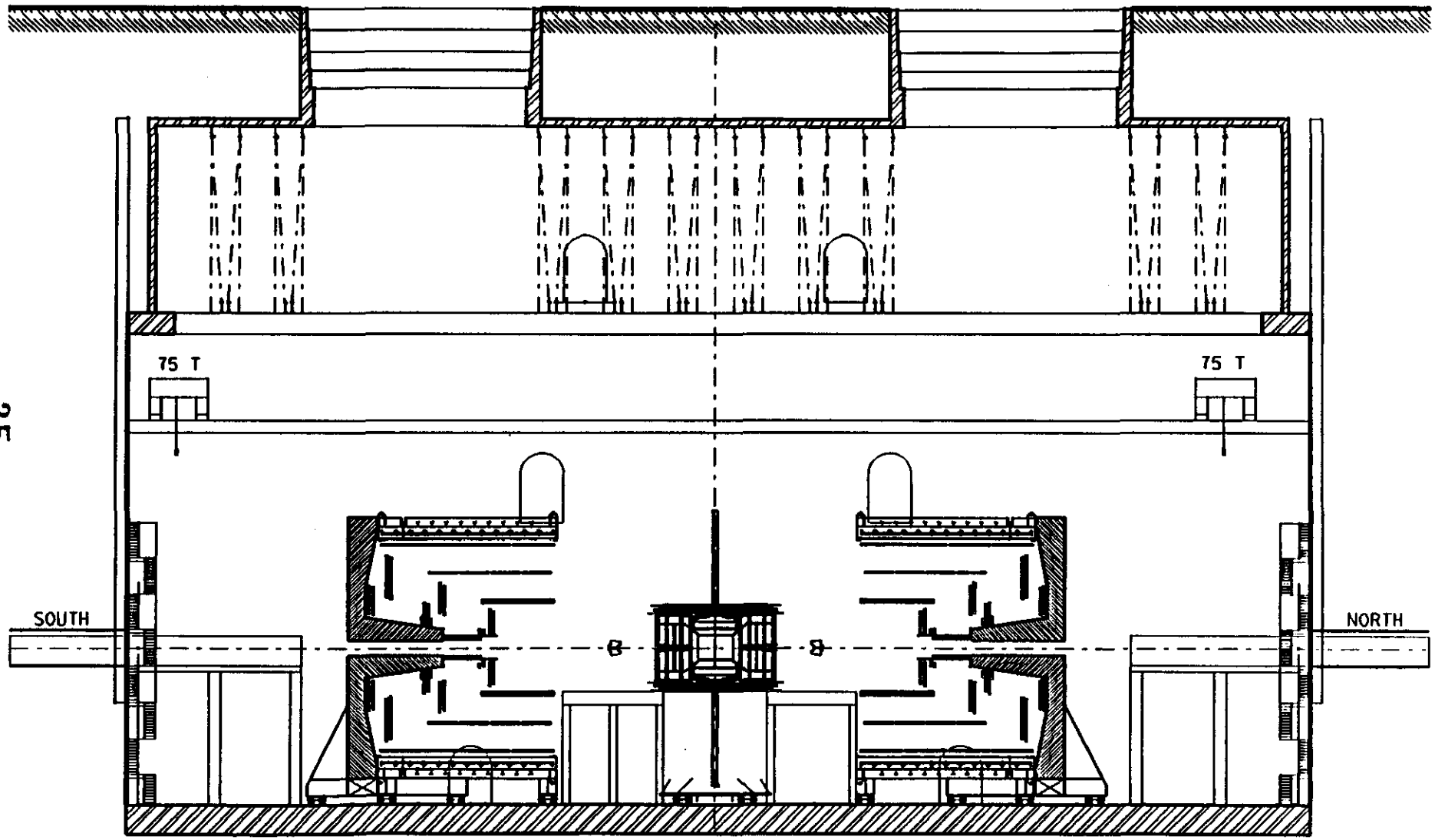
PHASE 15 - 16



COMPLETE SUBSYSTEM CONNECTIONS-LAST PART VACUUM PIPE

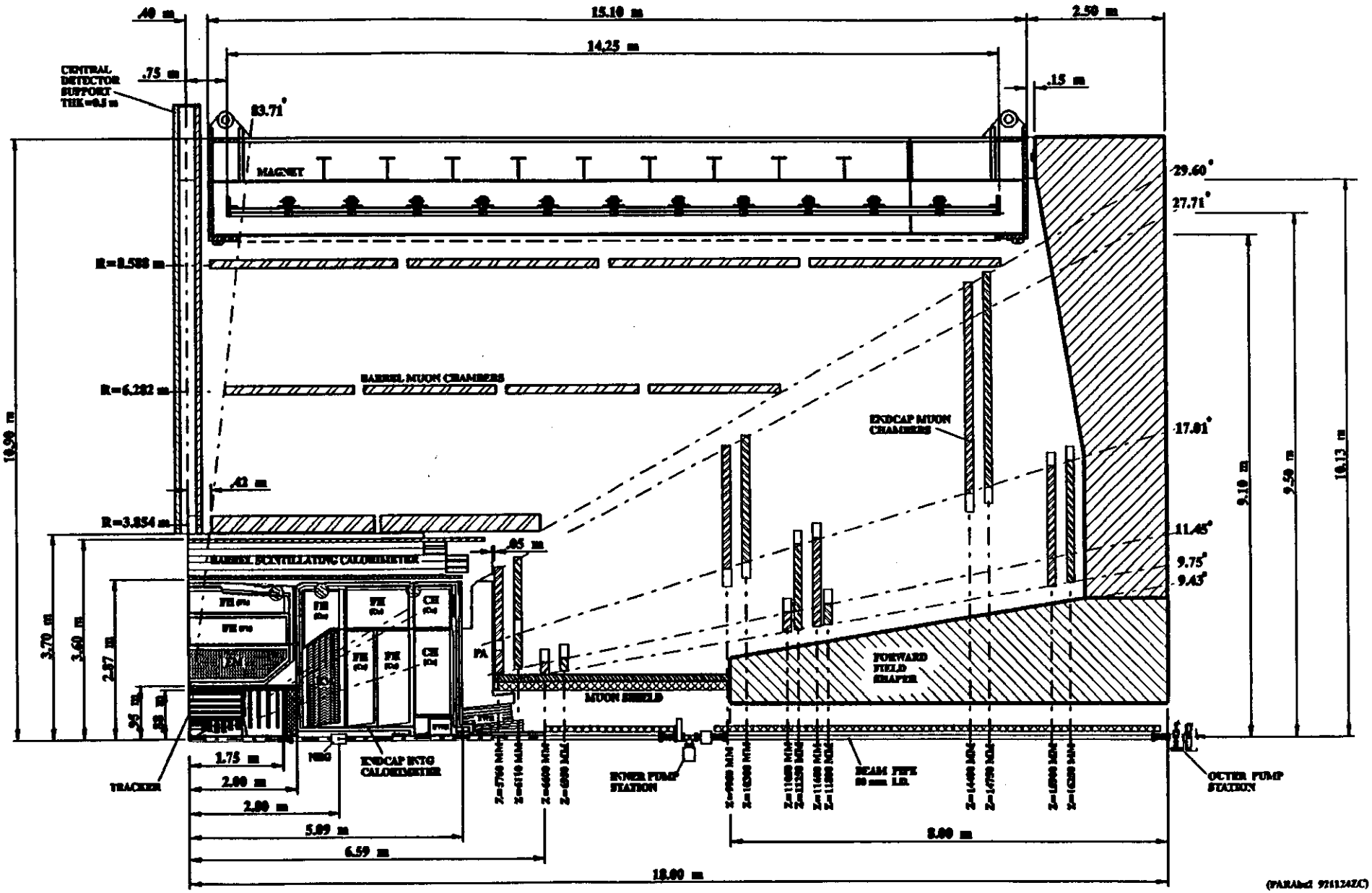
GDD-000077.A

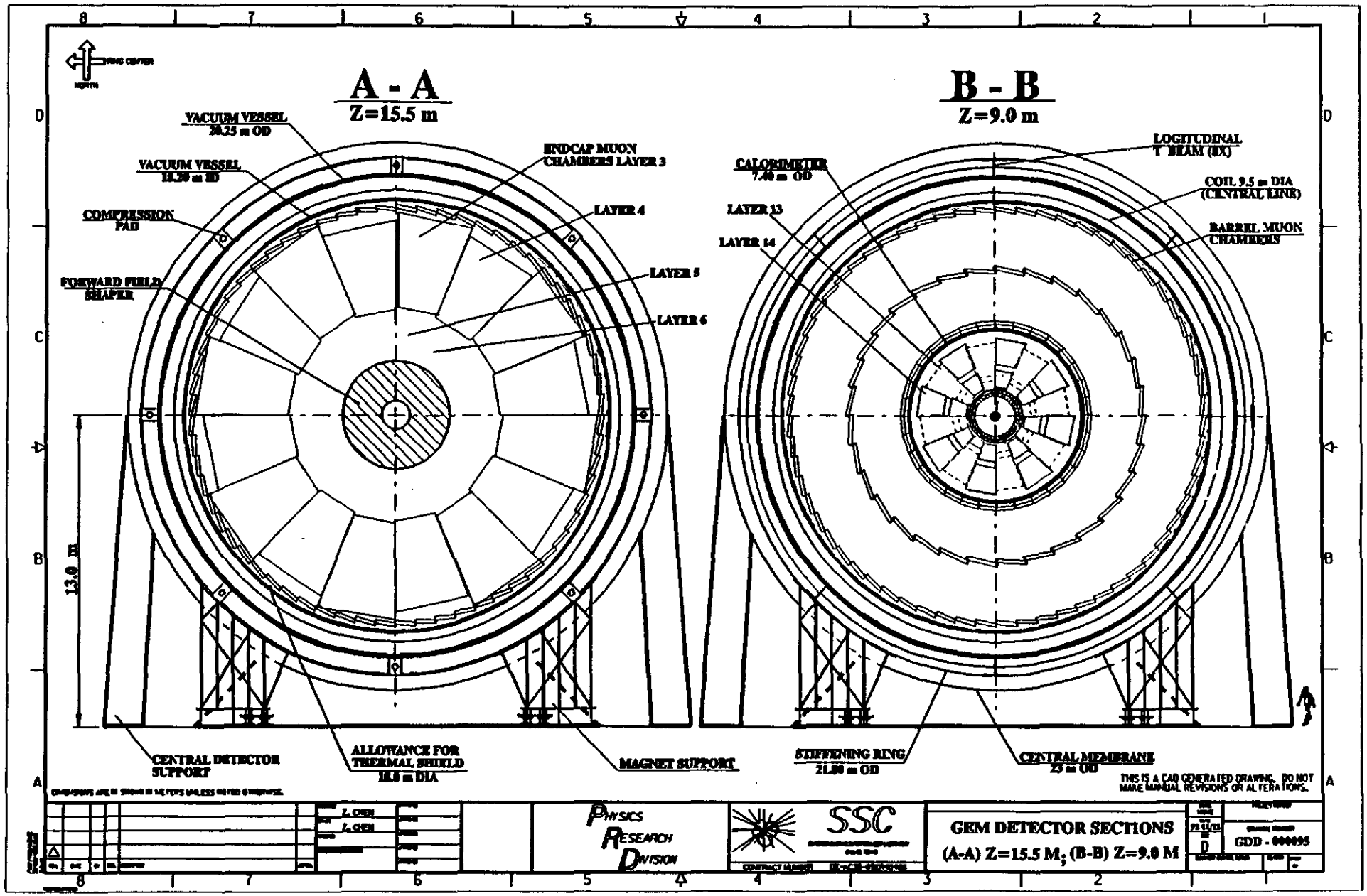
INNER DETECTOR ACCESS



GDD-000083.A

GEM DETECTOR PARAMETERS
BASELINE 2



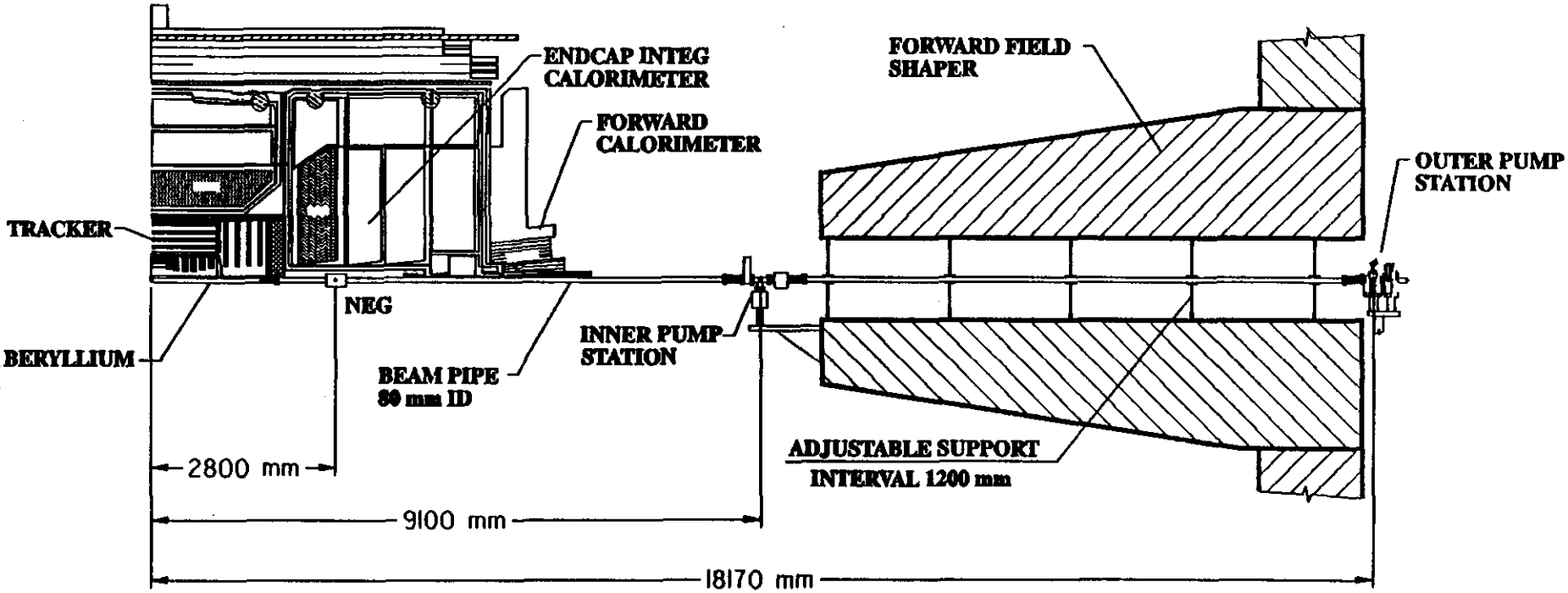

A - A
Z=15.5 m
B - B
Z=9.0 m
VACUUM VESSEL
20.25 m OD
VACUUM VESSEL
18.20 m ID
COMPRESSION PAD
FORWARD FIELD SHAPER
ENDCAP MUON CHAMBERS LAYER 3
LAYER 4
LAYER 5
LAYER 6
13.0 m
CENTRAL DETECTOR SUPPORT
ALLOWANCE FOR THERMAL SHIELD
18.0 m DIA
MAGNET SUPPORT
CALORIMETER
7.40 m OD
LAYER 13
LAYER 14
LOGITUDINAL T BEAM (BX)
COIL 9.5 m DIA (CENTRAL LINE)
BARREL MUON CHAMBERS
STIFFENING RING
21.00 m OD
CENTRAL MEMBRANE
23 m OD
THIS IS A CAD GENERATED DRAWING. DO NOT MAKE MANUAL REVISIONS OR ALTERATIONS.
PHYSICS RESEARCH DIVISION
SSC
GEM DETECTOR SECTIONS
(A-A) Z=15.5 M; (B-B) Z=9.0 M
GDD - 000095

BASELINE 2

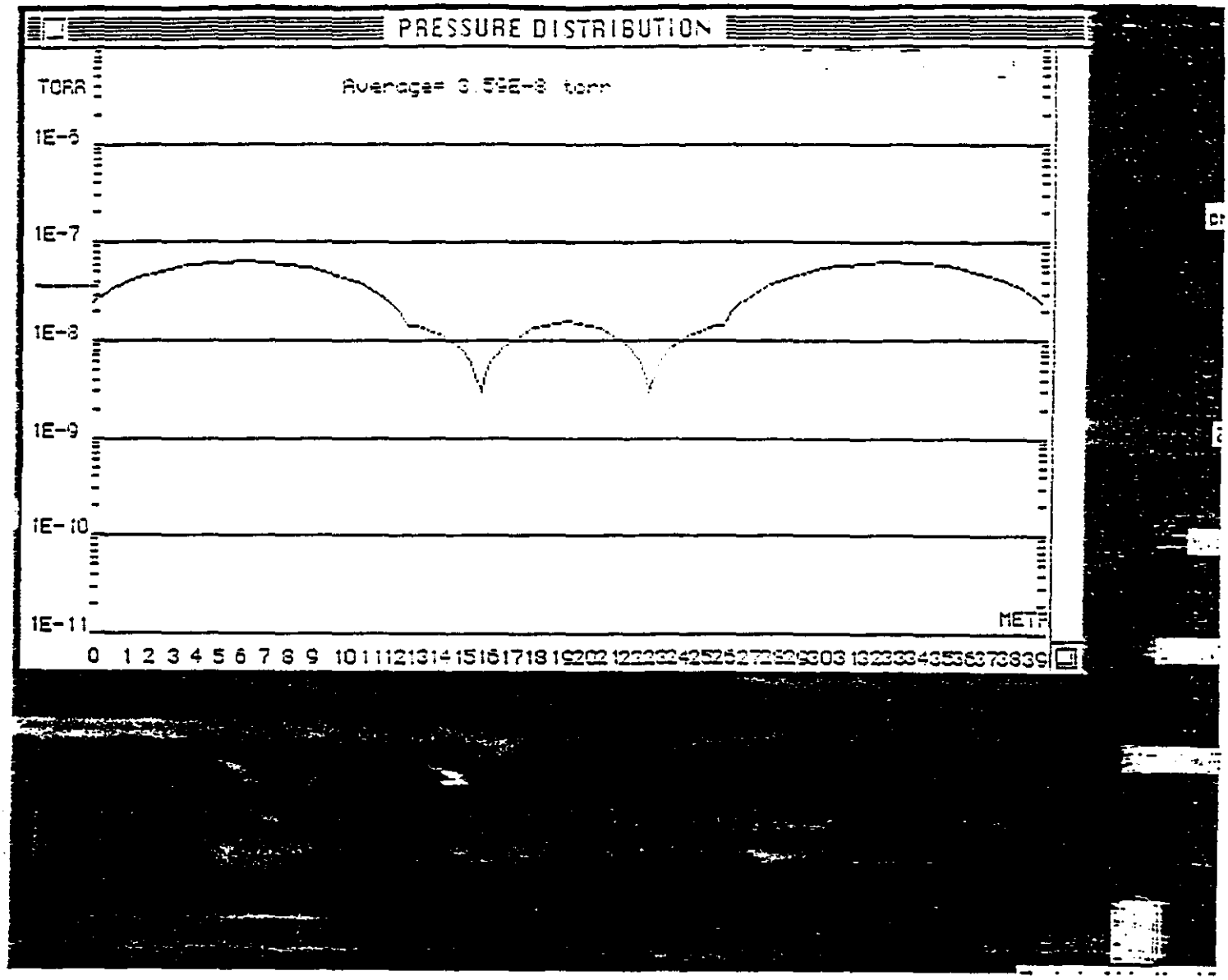
8 cm Beam Pipe

Warm
Flared ?

BEAM PIPE SUPPORT IN FFS

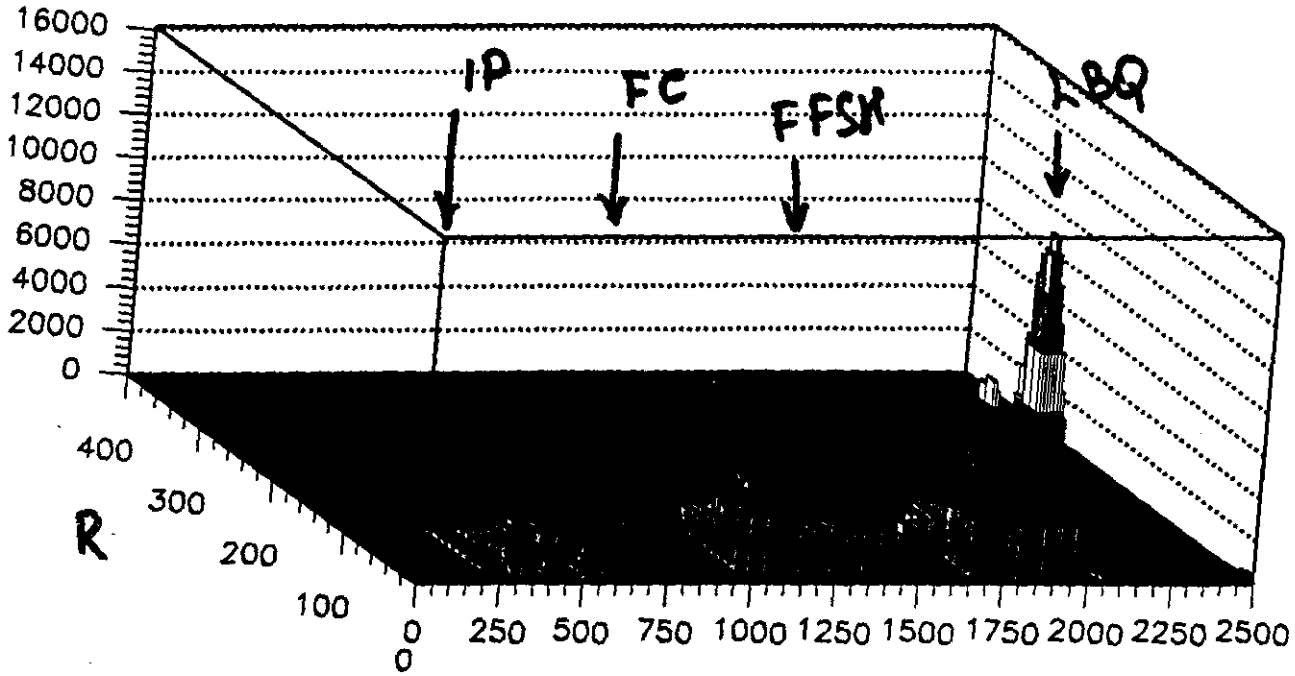


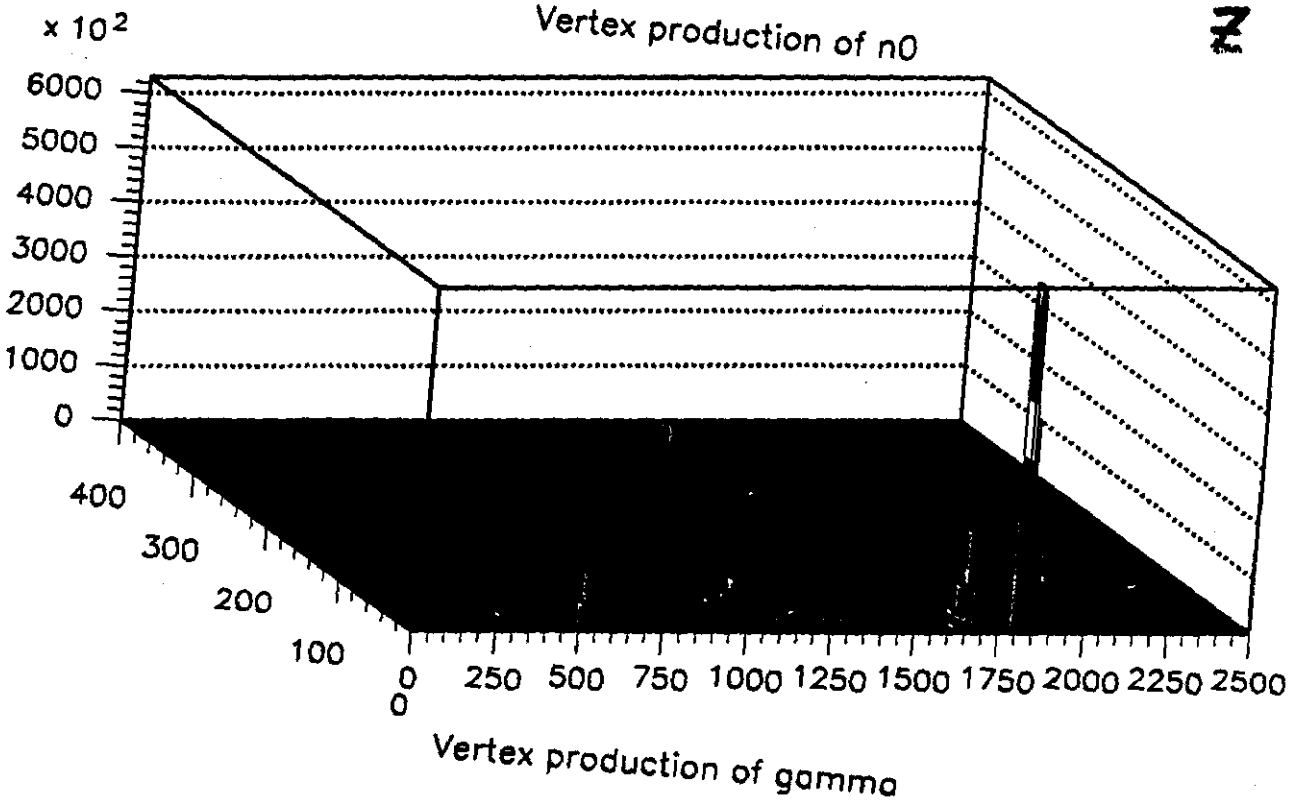
beamline
11/25/92

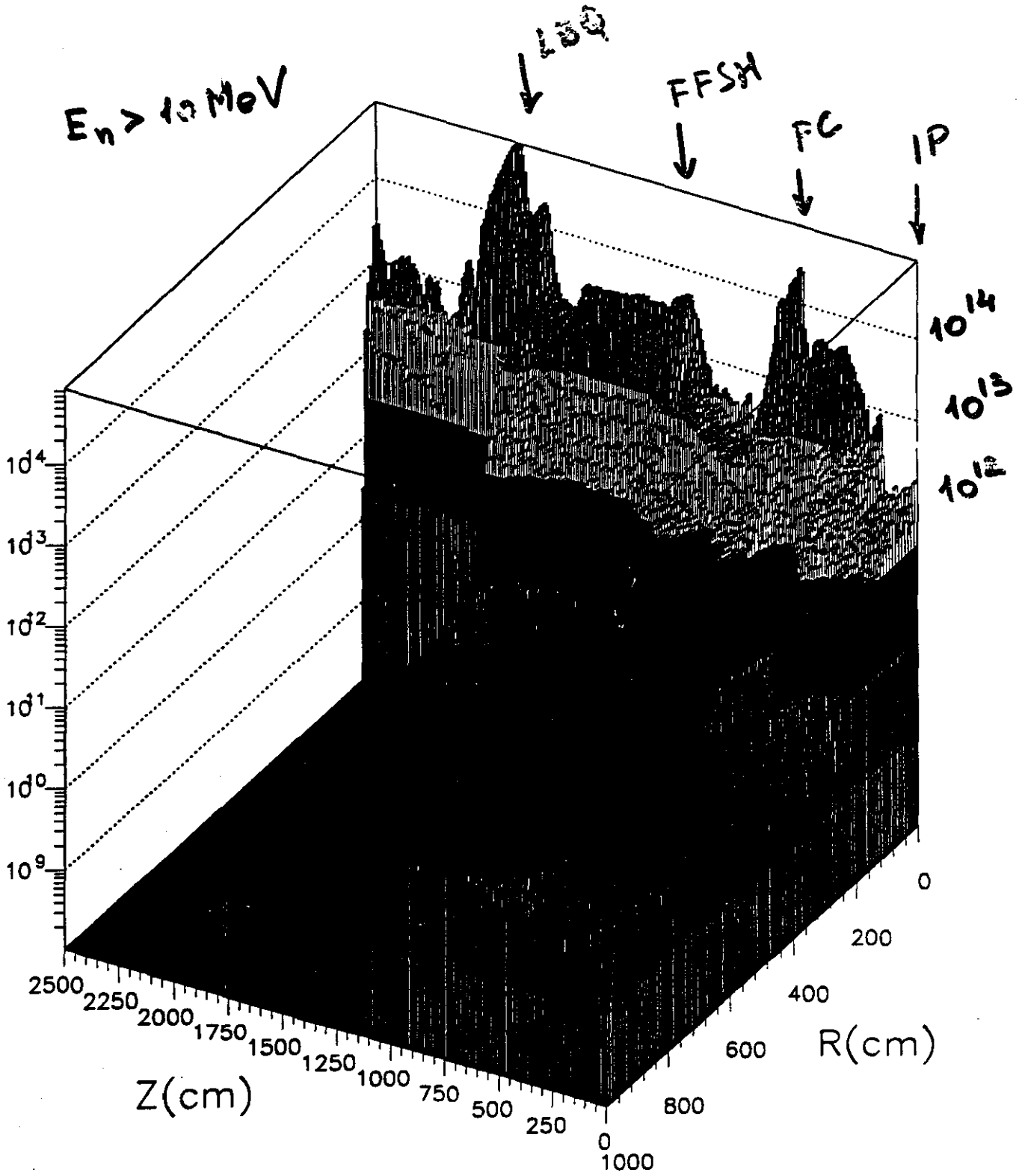


(B) 60 L/S. 60 L/S. NEG. 60 L/S. 60 L/S

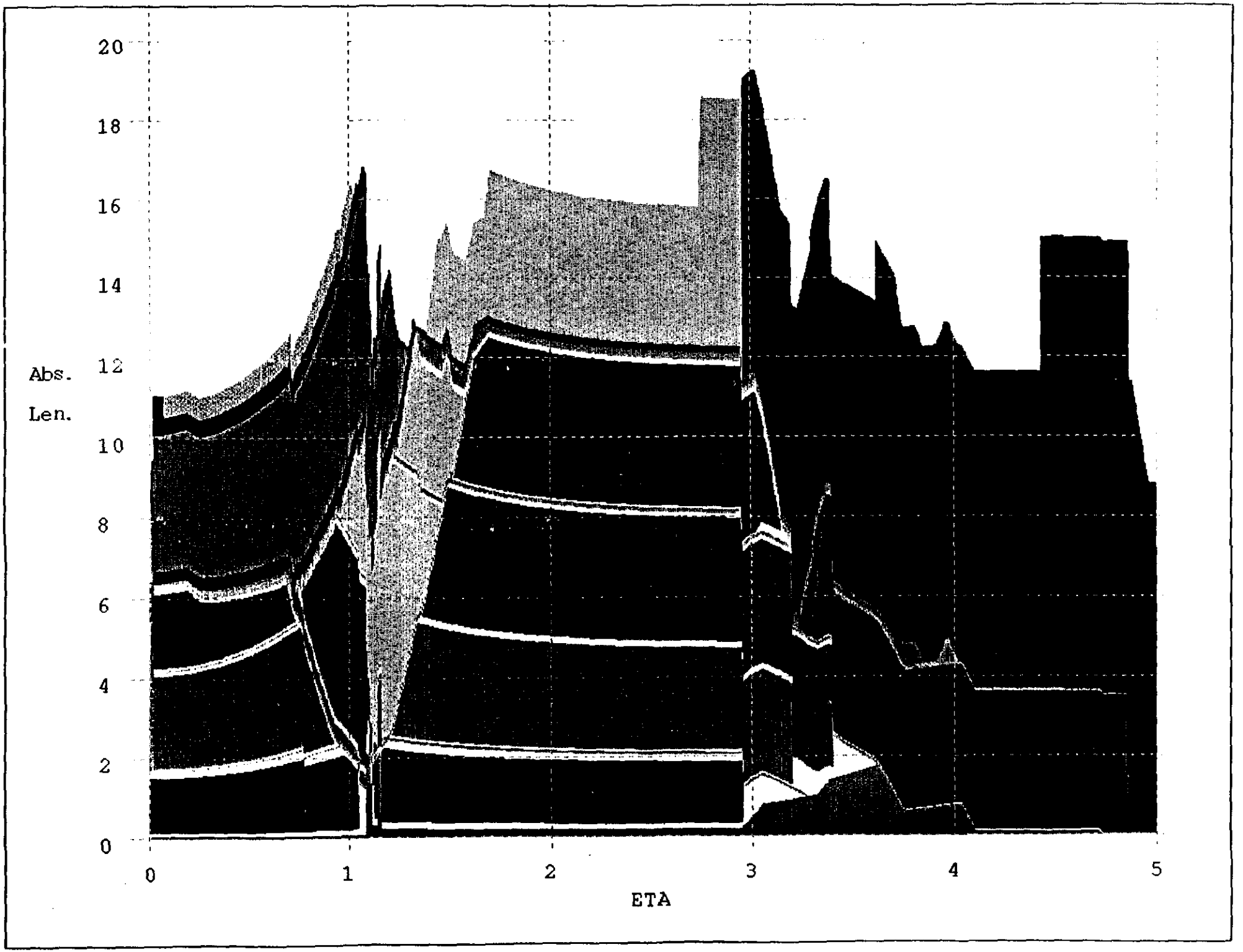
Φ 8 cm.


16000
14000
12000
10000
8000
6000
4000
2000
0
IP
FC
FFSH
FBQ
400
300
R
200
100
0
0
250 500 750 1000 1250 1500 1750 2000 2250 2500
Vertex production of n0
Z


x 10²
6000
5000
4000
3000
2000
1000
0
400
300
200
100
0
0
250 500 750 1000 1250 1500 1750 2000 2250 2500
Vertex production of gamma



Flux of neutron in (cm^{-2} $SSCy^{-1}$)


Abs.
Len.
20
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
ETA

GEM MAGNET

Top-level GEM magnet subsystem parameters are now frozen

The major parameters (overall size, shape, and performance) of the magnet subsystem have changed very little during optimization and design since July

Magnet System Parameter	7/92 Value	11/92 Value	Unit
Inner radius	9.0	9.0	m
Magnetic field at IP	0.8	0.8	T
Vacuum vessel minimum z	0.3	0.4	m
Vacuum vessel maximum z	15.5	15.5	m
Winding mean radius	9.5	9.5	m
Cold mass minimum z	0.7	0.75	m
Cold mass maximum z	15.0	15.0	m

Little Change!

We have made considerable progress in the development program

Highlights include:

100 km of SC strand will be delivered 11/30/92, to be used for conductor design verification and joint prototype tests Four joint tests (subscale) have been completed, and raw data is consistant with target resistance

Short lengths (2m) of dummy conductor have been formed to shipping-spool radii (as sm'all as 2m), and then reformed to winding radius (9.5m) without damage to sheath or conduit.

A conductor verification test, the "hairpin test" has been conceived and is in design

The magnet design continues to advance

Recent progress includes:

4th release of "magnet subsystem specification" defining requirements for performance, lifetime, etc

Completion of draft specification for conductor, ready for industry comment

Re-design of axial cold-mass support rods to reduce deflections imposed on coil

Completion of first preliminary design drawings of winding station, and beginning of detailed analysis

Completion of analysis of vacuum vessel vibration, as it affects muon system

Completion of detailed on-site fabrication and assembly plan, to be used for facilities specification and for evaluation of "prime" proposals

Development of alternate FFS support which eliminates 200 t of steel

The magnet management system has also made considerable progress

Recent progress includes:

- **An initial, complete cost/schedule package was prepared to assess division of funds and funding profiles**
- **A complete, detailed, resource-loaded schedule (compatible with SSCL PMO) is nearly complete**
- **Initial cost/schedule control system is in place and being used for FY93 activities within the magnet team**
- **Final RFP is complete (following delay). Source Evaluation Board [redacted] appointed. RFP is ready to go.**

TRACKER

Electron/photon identification

Isolation cuts

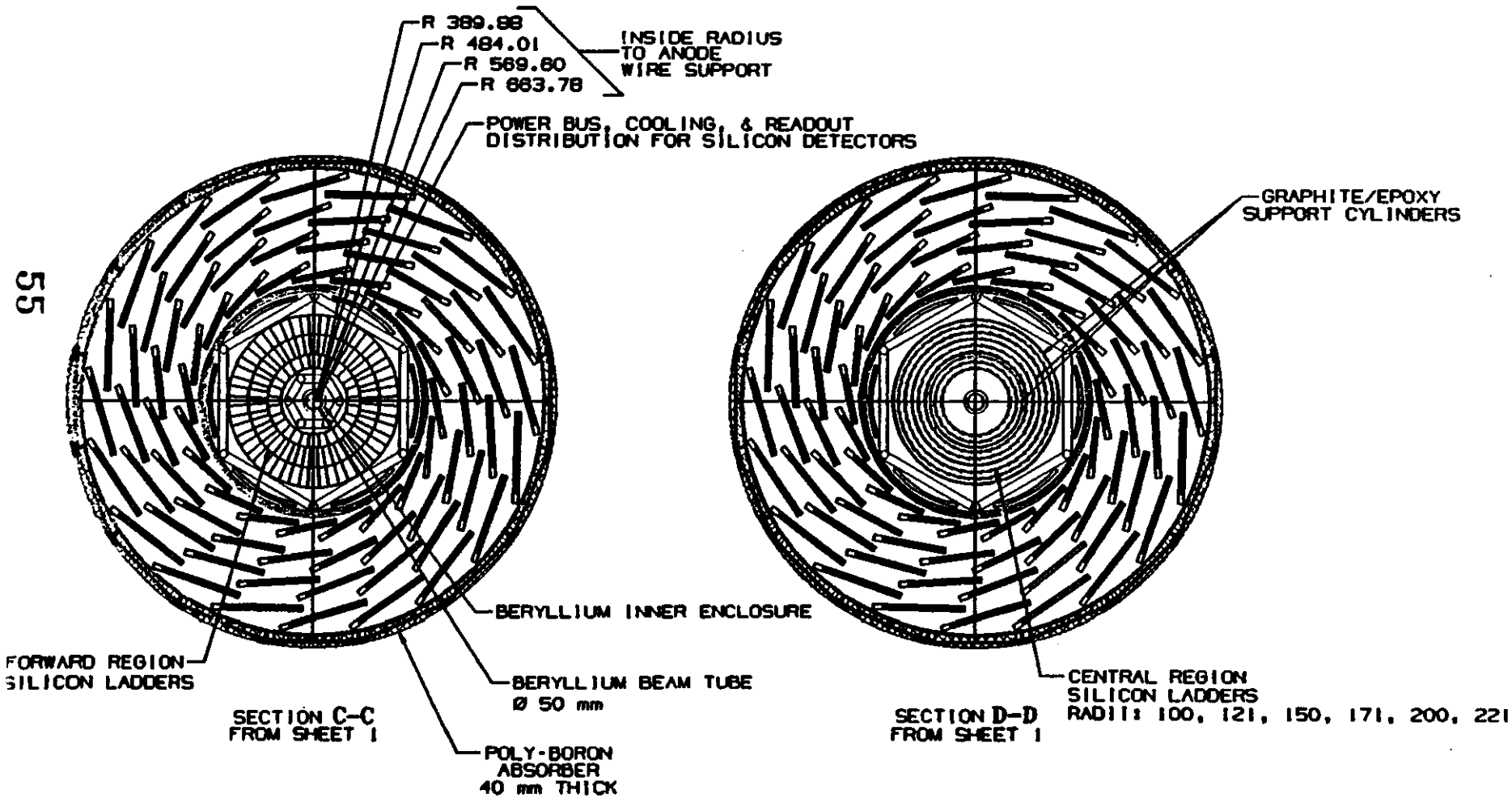
Primary vertex

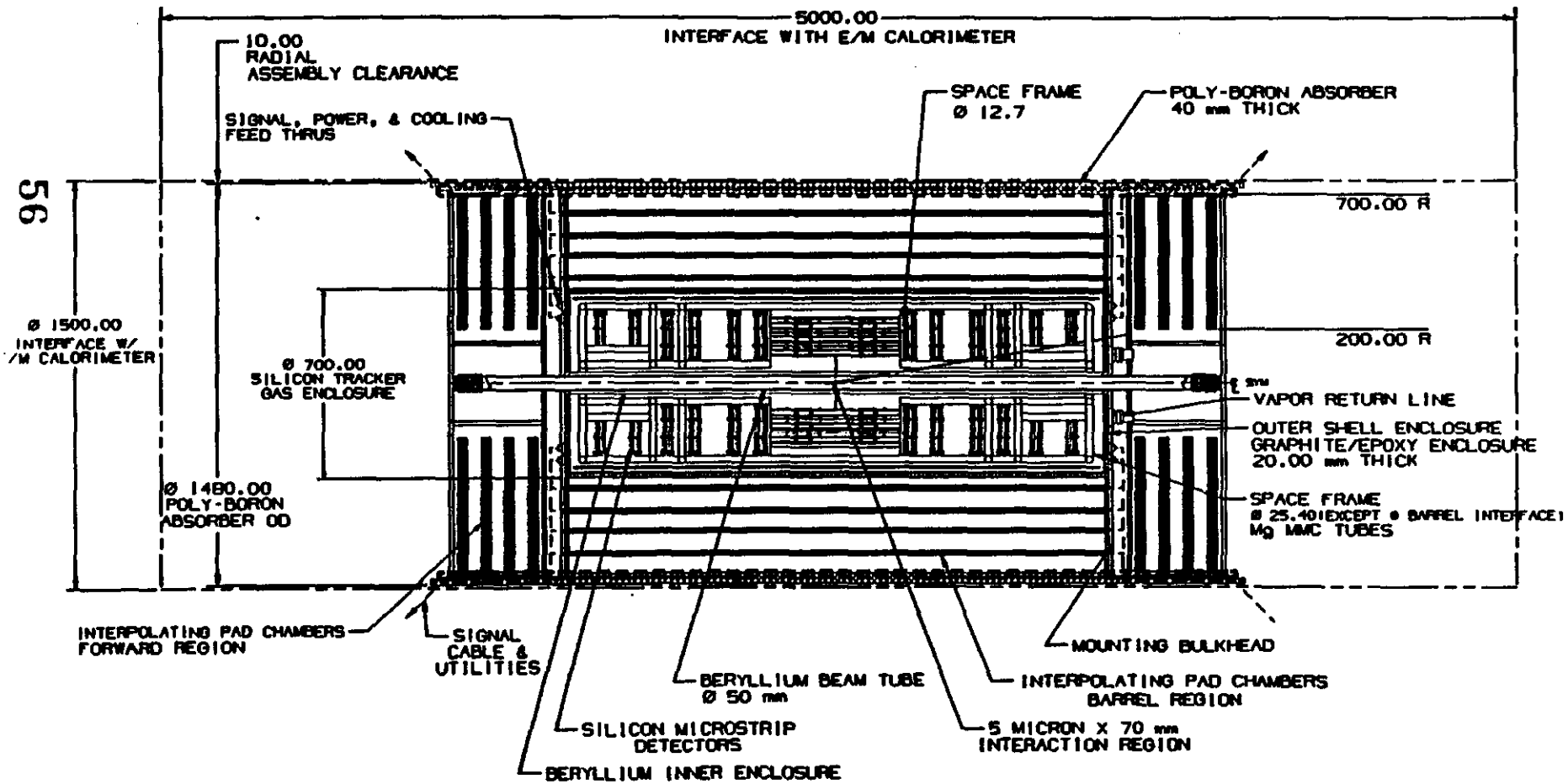
Electron/hadron identification

Electron sign

Background rejection

Silicon & IPC
— Stereo Double Layers
"Space Points"
Low Occupancy





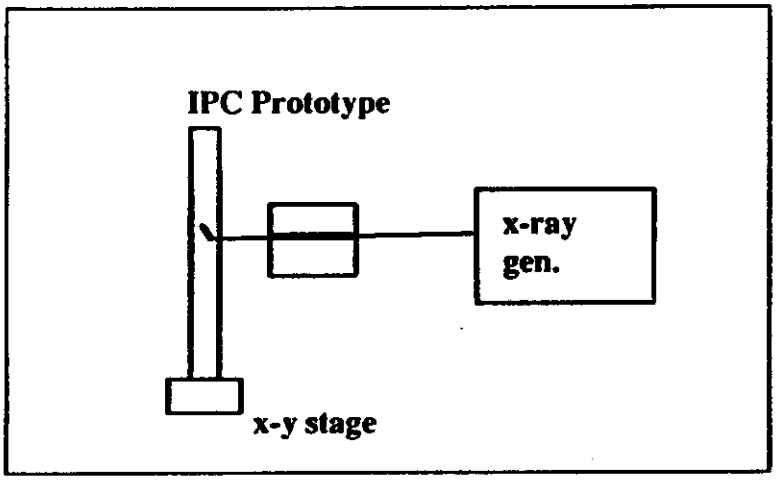
GEM CENTRAL TRACKER

GEMVG-126-JV

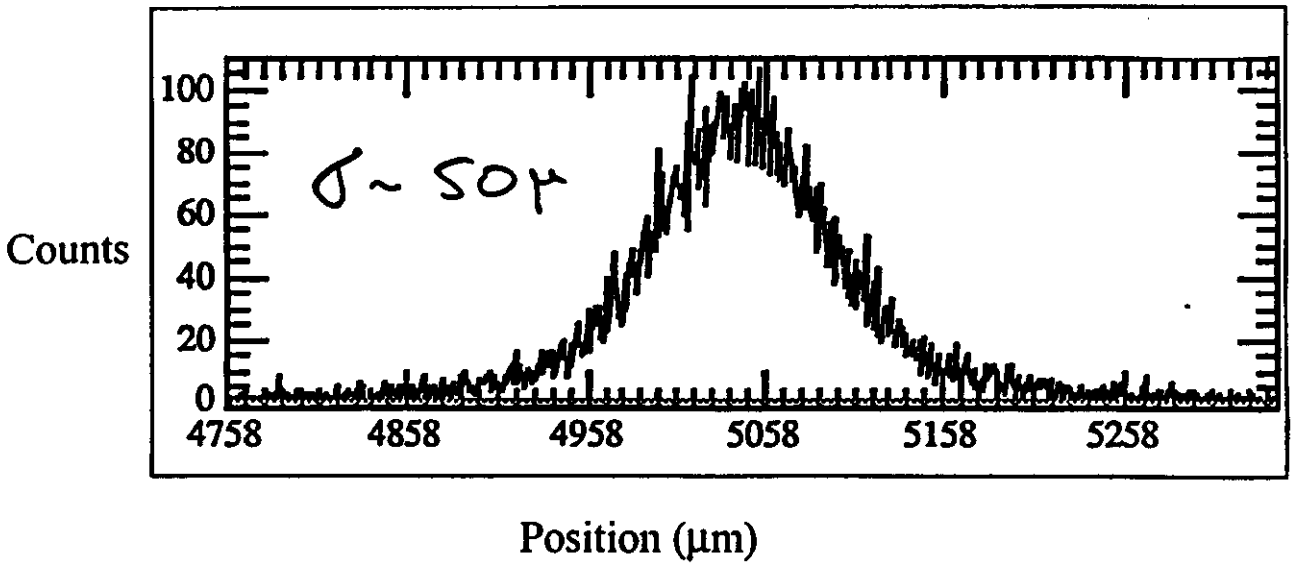
Central Tracker Status

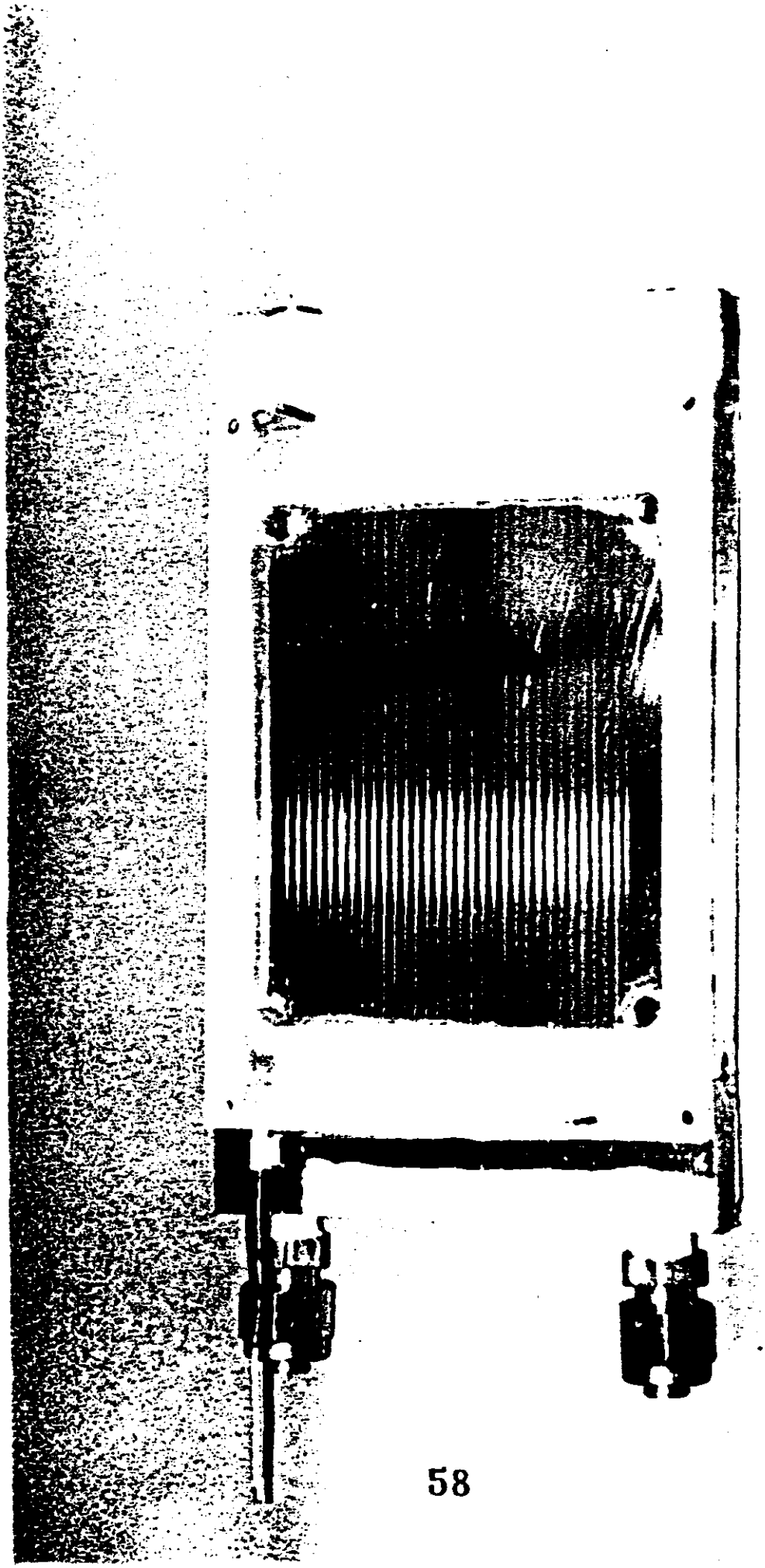
IPC Prototype Tests

<50 micron position resolution achieved in x-ray studies



100 ns peaking time
~ 20 micron resolution
from electronics noise



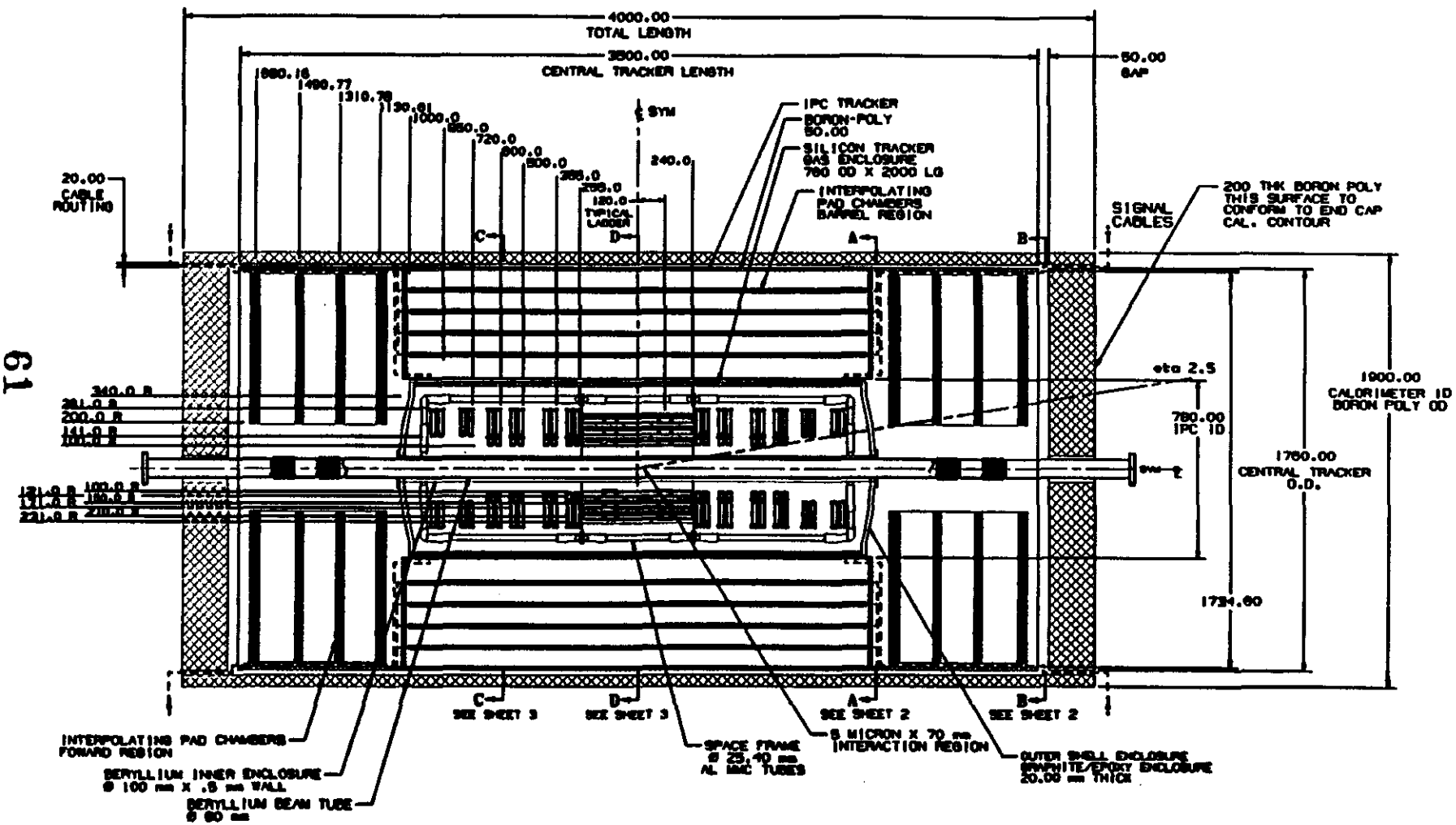


BASELINE 2

Increase Central Tracker Diameter

75cm → 95cm (radius)

(Calorimeter Front Face)


4000.00
TOTAL LENGTH
3500.00
CENTRAL TRACKER LENGTH
50.00
GAP
1680.16
1490.77
1310.78
1130.81
1000.0
850.0
720.0
600.0
500.0
385.0
255.0
120.0
TYPICAL LADDER
240.0
℄ SYM
20.00
CABLE ROUTING
IPC TRACKER
BORON-POLY
50.00
SILICON TRACKER
GAS ENCLOSURE
760 OD X 2000 LG
INTERPOLATING
PAD CHAMBERS
BARREL REGION
SIGNAL
CABLES
200 THK BORON POLY
THIS SURFACE TO
CONFORM TO END CAP
CAL. CONTOUR
eta 2.5
1900.00
CALORIMETER ID
BORON POLY OD
760.00
IPC ID
1760.00
CENTRAL TRACKER
O.D.
1734.60
340.0 R
281.0 R
200.0 R
141.0 R
100.0 R
121.0 R
131.0 R
221.0 R
100.0 R
100.0 R
200.0 R
A
B
C
D
SEE SHEET 3
SEE SHEET 3
SEE SHEET 2
SEE SHEET 2
INTERPOLATING PAD CHAMBERS
FOWARD REGION
BERYLLIUM INNER ENCLOSURE
Ø 100 mm X .5 mm WALL
BERYLLIUM BEAM TUBE
Ø 60 mm
SPACE FRAME
Ø 25.40 mm
AL MAC TUBES
5 MICRON X 70 mm
INTERACTION REGION
OUTER SHELL ENCLOSURE
GRAPHITE/EPOXY ENCLOSURE
20.00 mm THICK

GEM Central Tracker

Magnetic field		0.8 T
Length (from IP to outer faces)		±175 cm
Outer radius		88 cm
Location of neutron shield		$90 < R < 95$ cm
Occupancy	$L = 10^{33}$ cm^{-2} s^{-1}	≥ 1%
	$L = 10^{34}$ cm^{-2} s^{-1}	≥ 10%
Charge separation at 95% c.l.		≥ 600 GeV
$\Delta p/p$	High p	0.001 p_T, p_T in GeV/c
	Low p	~ 4%
Vertex	Beam direction	δz ~ 1 mm
(> 10 GeV/c)	Impact parameter	δb ~ 30 μm

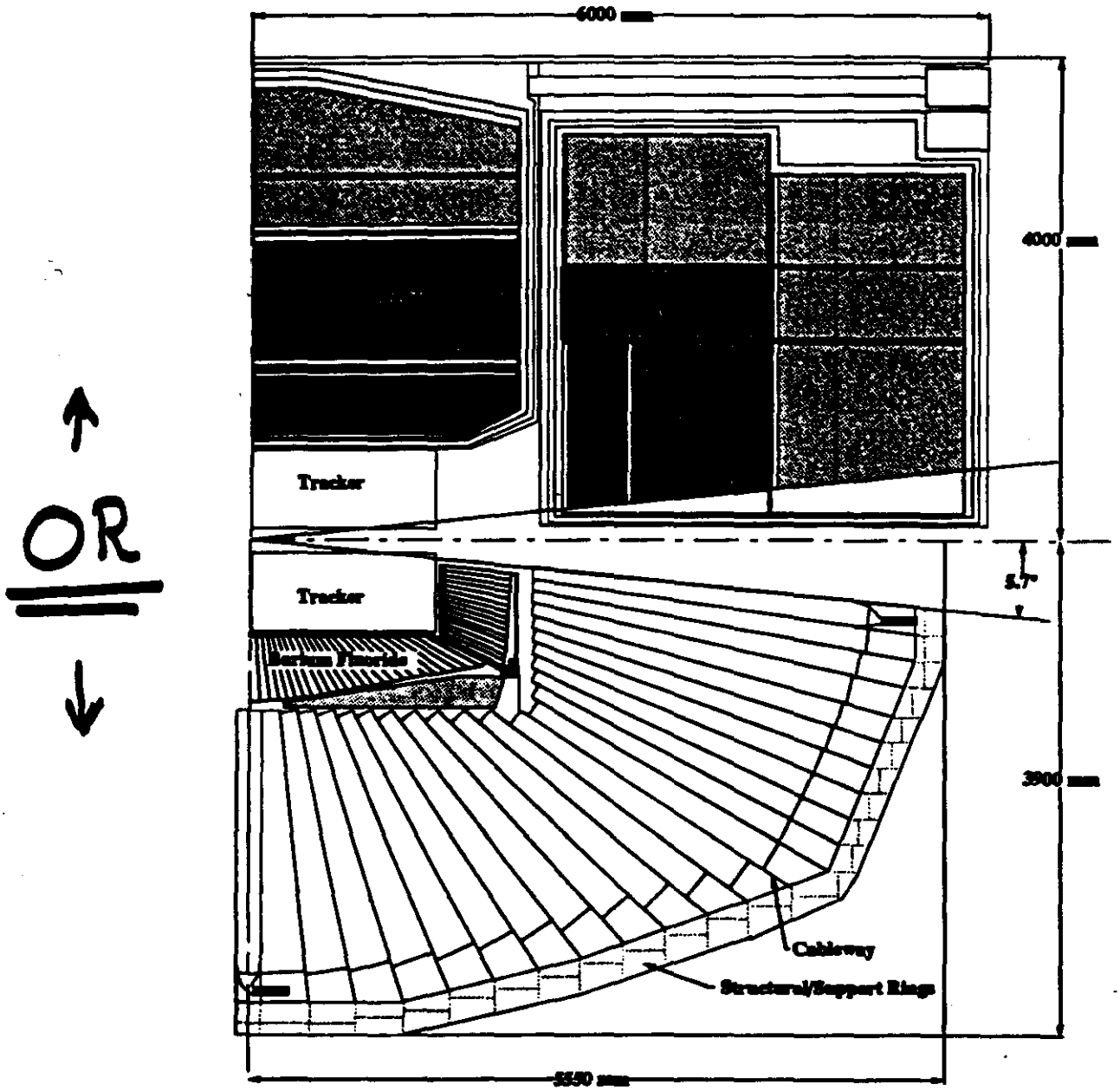
CALORIMETER

EM - Precision electron/photon energy
Electron/photon position/direction
Electron/photon identification (shape, hadron veto)
Trigger

Hadron (includes Forward) - Jet energy
Missing energy
Absorber
Muon identification, energy loss
Trigger

Liquid Argon/Krypton

Liquid Argon Calorimeter



BaF2 EM with Scintillating Fiber Hadron Calorimeter

BaF_2 + Spaghetti

$H^0 \rightarrow \gamma + \gamma$

Table 2.4-1 Effect of Energy Resolution: a and b

a =	2.0	5.0	7.5	10	15
b = .25	0.63	1.2	1.7	2.2	3.3
b = 0.5	1.0	1.4	1.8	2.3	3.4
b = .75	1.4	1.7	2.1	2.6	3.6
b = 1.0	1.8	2.1	2.4	2.9	3.7

LiArgon

BaF2

BASELINE 2

EM: Liquid Krypton Accordion

Progress of BaF_2 Crystal Study

Two Practical Approaches

Use Fast Crystal at the SSC

1. Crystals can be used after a preirradiation to a saturation, if (1) the saturated light attenuation length (LAL) is long enough to provide a uniform light response (>95 cm); and (2) the radiation damage does not recover spontaneously at application temperature.

2. Crystals can be made to work with a defined LAL, if (1) the radiation damage is not permanent, and is optically bleachable *in situ*; and (2) the stable LAL under optical bleaching is long enough to provide a uniform light response.

The first approach is not applicable with existing production BaF_2 crystals. Following BaF_2 Expert Panel's suggestion, the second approach was pursued, and the BaF_2's radiation damage problem was solved.

Quality of Production BaF_2 Crystals

Transmittance (T) at 220 nm and corresponding Light Attenuation Length (LAL or λ) after 1 MRad ^{60}Co γ-ray Irradiation measured for 25 cm long BaF_2 crystals produced by Shanghai Institute of Ceramics.

Sample	Dimension (cm)	T_0 (%)	T_{1M} (%)	λ_{1M} (cm)
SIC102	$3^2 \times 25 \times 4^2$	84.9	16.5	15
SIC302	$3^2 \times 25 \times 4^2$	87.2	43.3	34
SIC402	$3.6^2 \times 25 \times 4.6^2$	78.0	48.6	41

!!! GEM Specification $LAL_{1M} > 95$ cm !!!

[*in situ* **Optical Bleaching**]

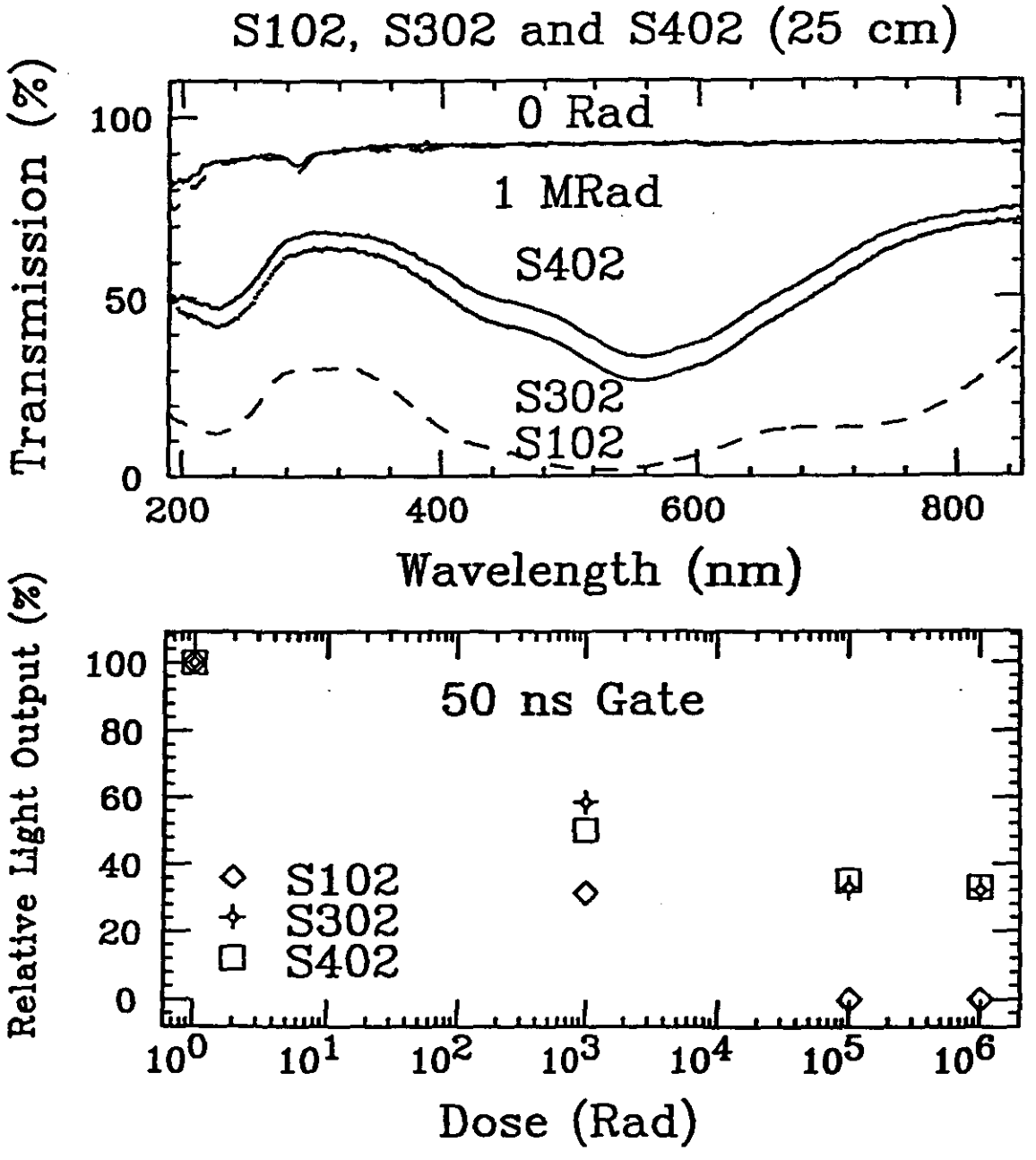


Figure 8: Transmittance before and after 1 MRad γ-ray irradiation (a) and relative light output (b) measured for three 25 cm long BaF_2 crystal produced at SIC in early 1991 (SIC102), early 1992 (SIC302) and July 1992 (SIC402).

Progress of BaF_2 Crystal Study

Optical Bleaching *in situ*

- Five independent measurements on optical bleaching by BNL, Caltech, LLNL, Tsinghua/McGill University and West Virginia University were reported in a BaF_2 Expert Group meeting, indicating BaF_2 crystals are optically bleachable.

- A quantitative study (D. Ma & R.Y. Zhu, GEM TN-92-149) shows that a blue light of 400 nm is effective in removing the radiation damage and to reset current production BaF_2 crystals to a LAL of 180 cm.

- According to GEM TN-92-149, the required light intensity to restore the LAL to a stable value of 150 cm (in dynamic equilibrium) is of an order of mW/cm^2, or a maximum of 150 W for the entire BaF_2 calorimeter at the standard SSC luminosity (10^{33} cm^{-2} s^{-1}).

The radiation damage problem of BaF_2 crystals is solved.

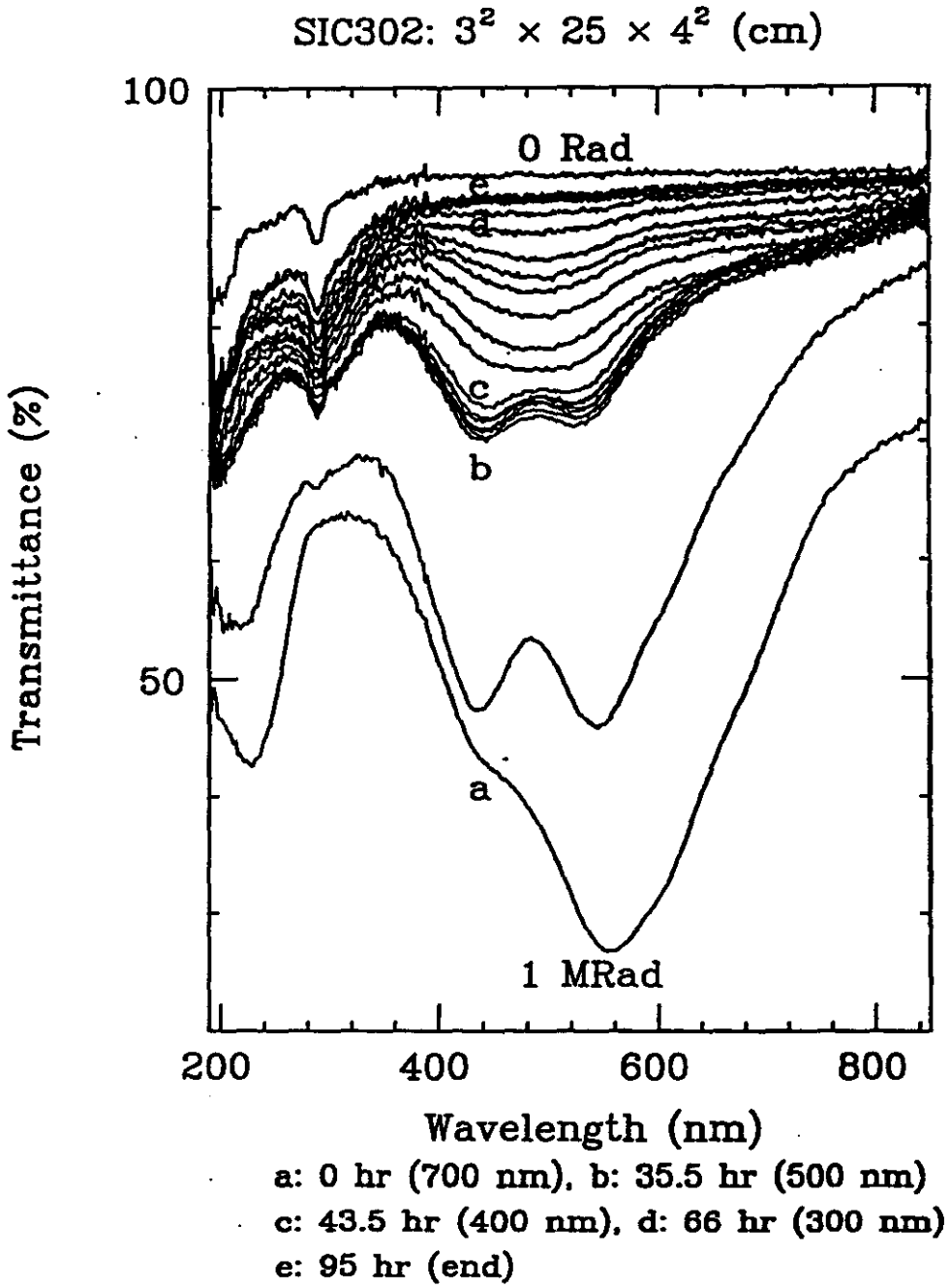


Figure 1: Transmittance of SIC302 are plotted as a function of wavelength under optical bleaching by light of different wavelengths.

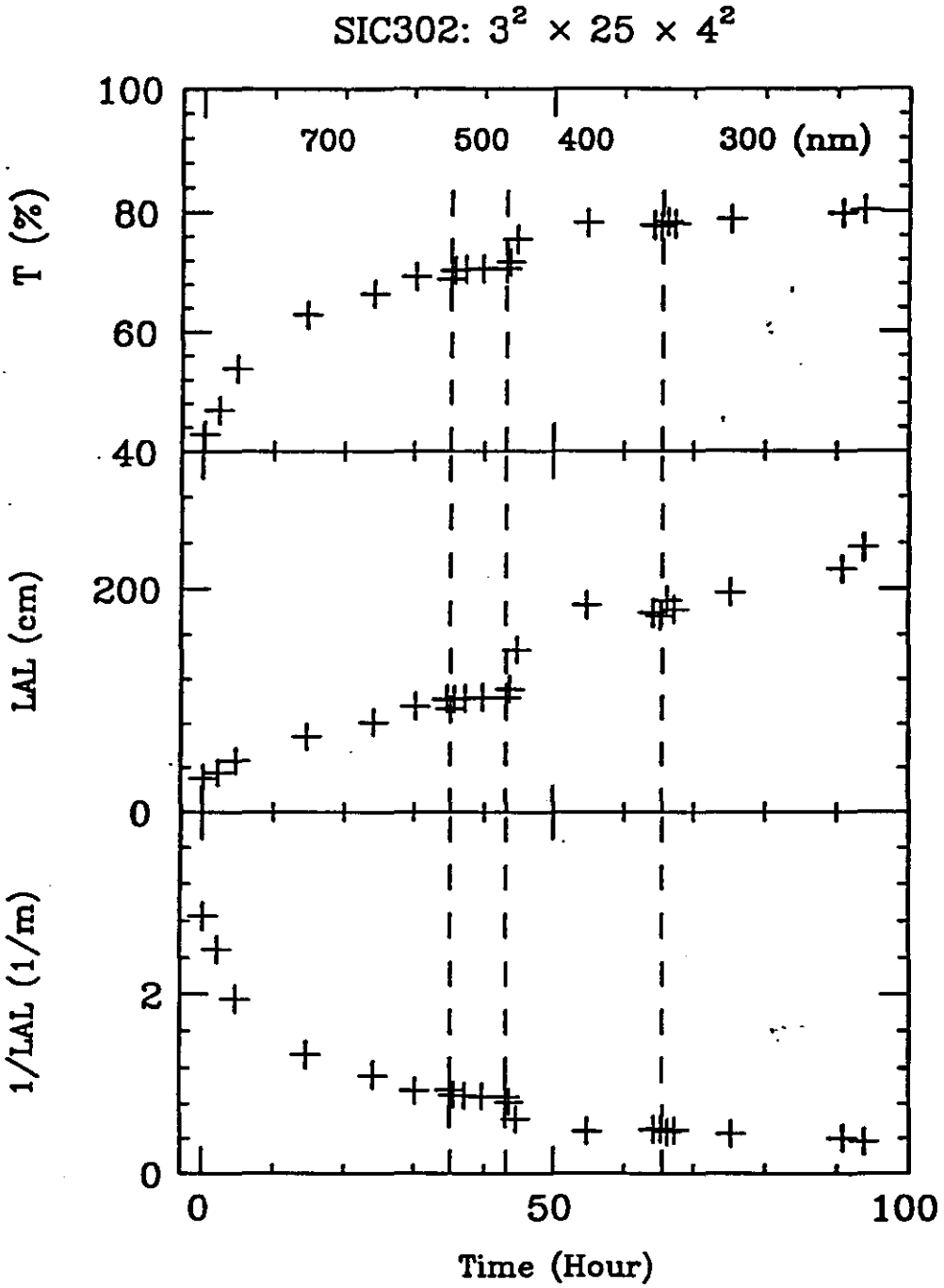


Figure 2: Transmittance (a), light attenuation length (b) and color center density (c) of SIC302 are plotted as a function of time under optical bleaching by light of different wavelengths.

The Liquid Argon Test.

Objectives:

1) EM energy resolution of $7.5\% / \sqrt{E} + 0.5\%$

1.3mm Pb Solution. Liquid Krypton. (Sampling fraction)

0.8 mm Pb in both absorber & readout electrode. (sampling frequency)

2) Position Resolution & e/π separation.

Chevron Design

3) Trigger.

Timing resolution (Bunch crossing), Trigger threshold,
Isolation efficiency.

4) Calibration.

New calibration system. 0.1-0.2 %

5) Electronic readout.

AMU – ZEUS electronics.
Track and hold.

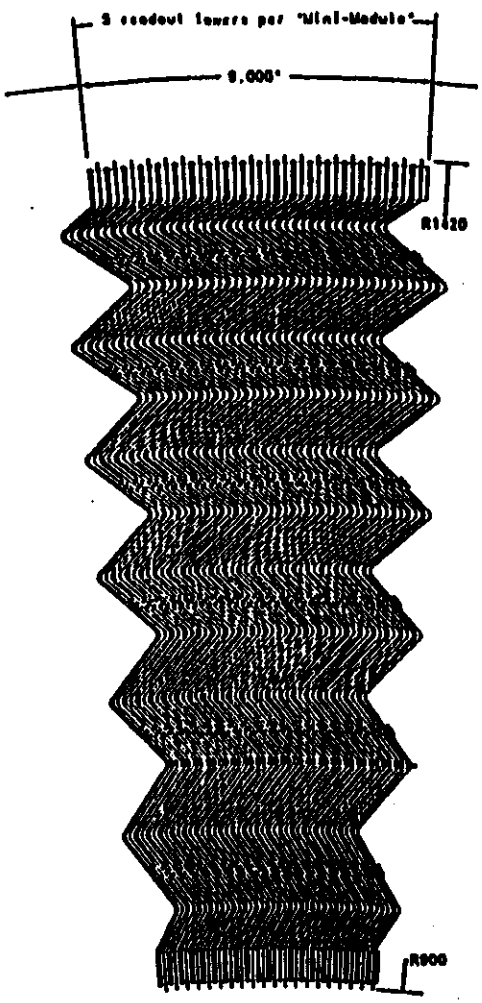
6) Simulations.

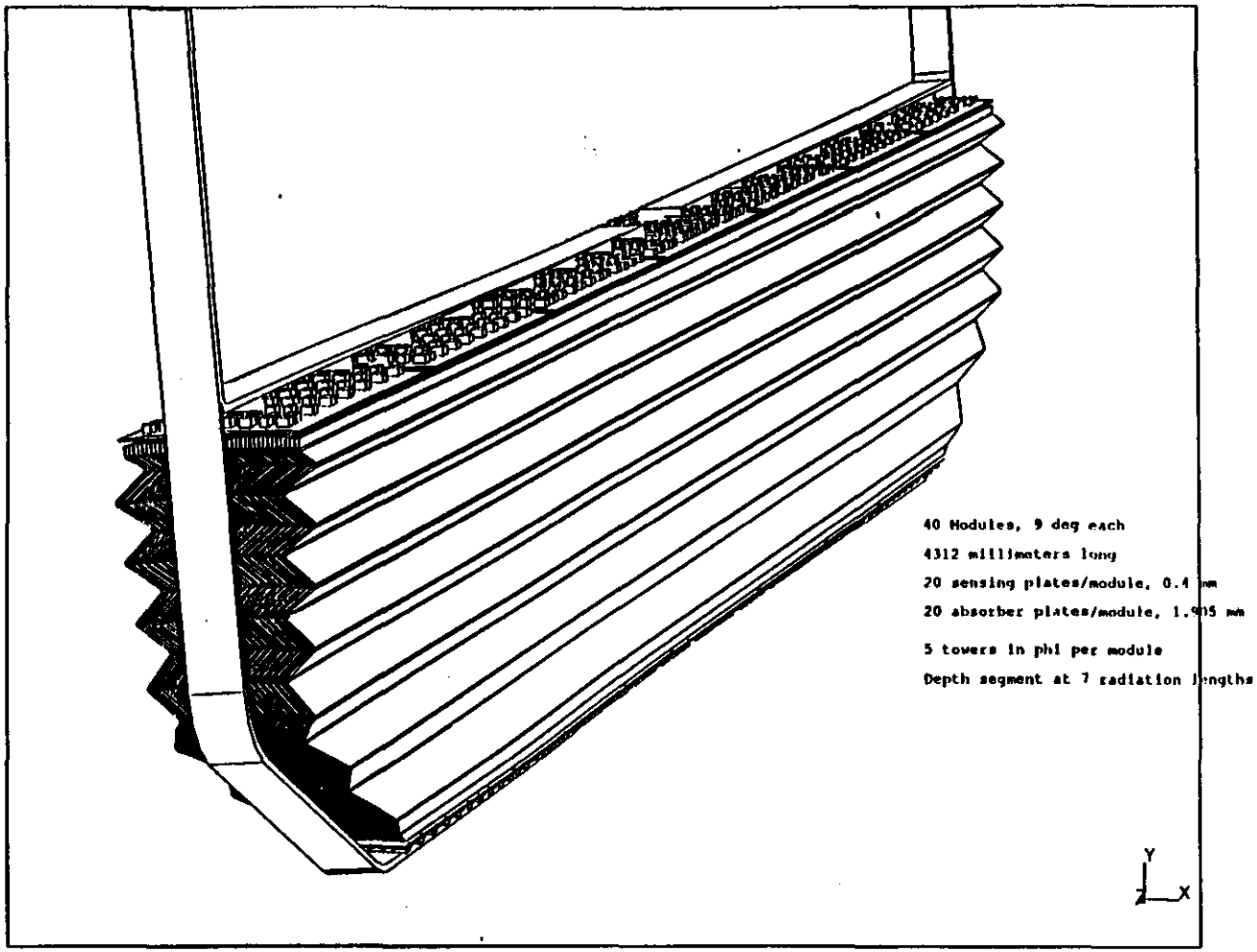
Non projective geometry
Quasi projective
Projective geometry

7) Bending machine

Bending machine for Projective Geometry.

EM BARREL MODULE with Electronics and Cables





In BNL Test Beam NOW < LAr
< LKr

Each "Mini-Module" contains:
20 Absorber plates
20 Sensing Plates
40 spacers on the inner radius
40 spacers on the outer radius

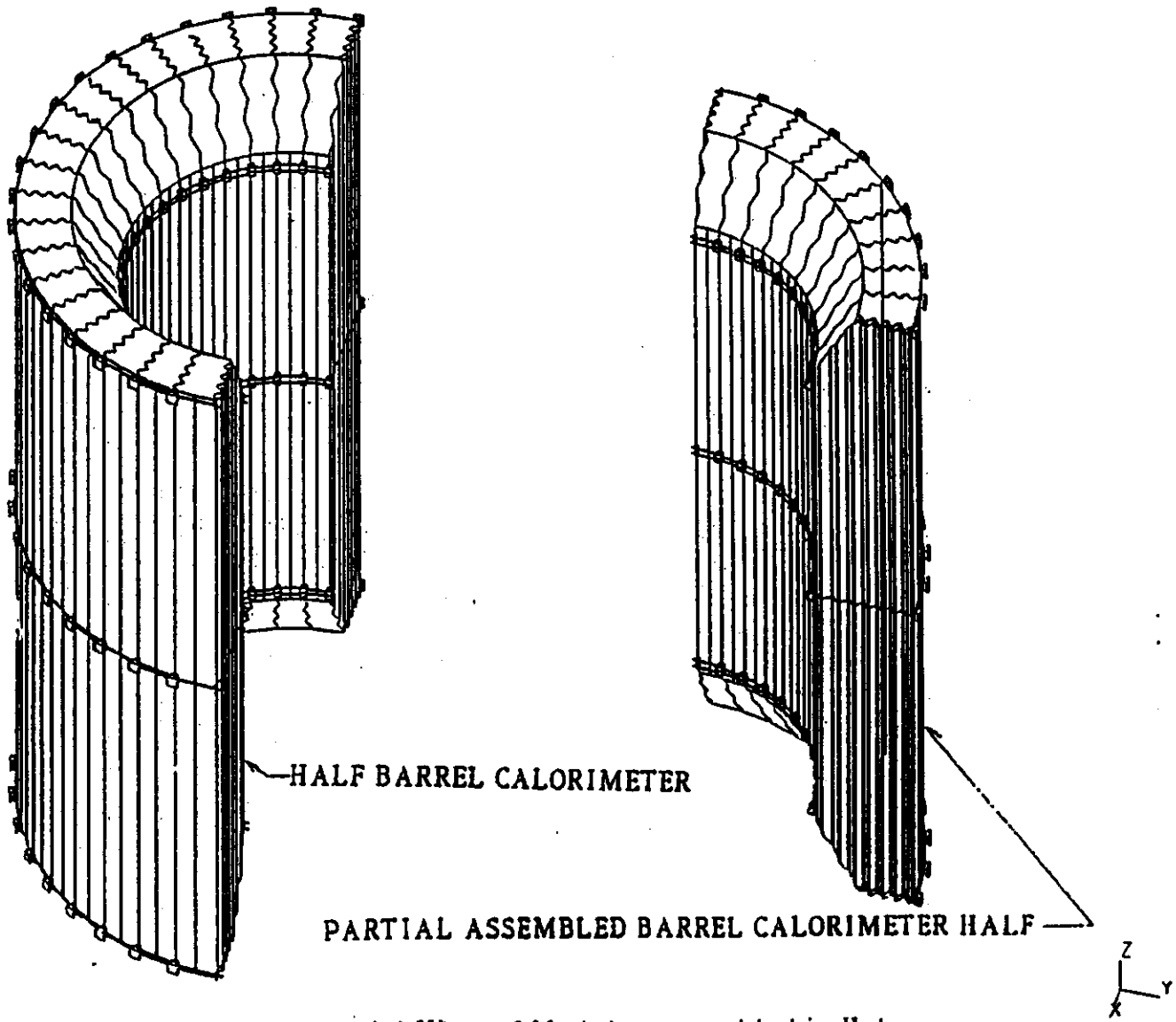
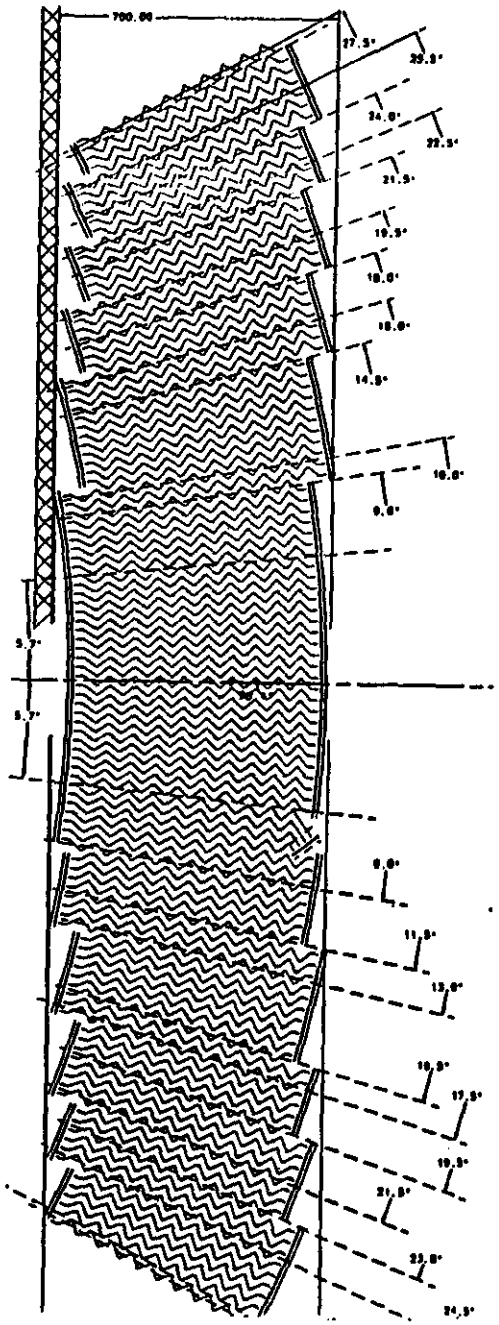
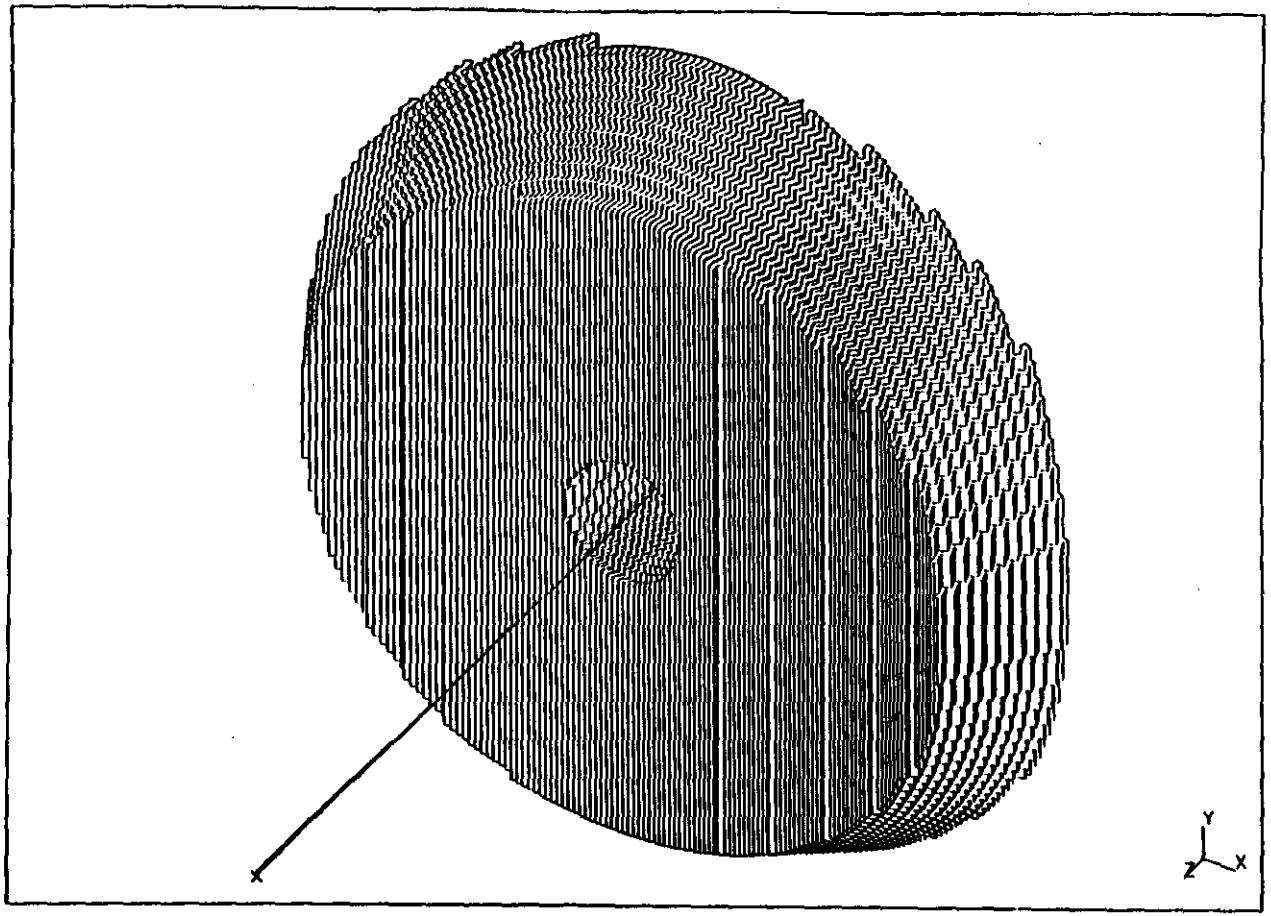


Figure 1-7 Partial View of Modules assembled in Halves

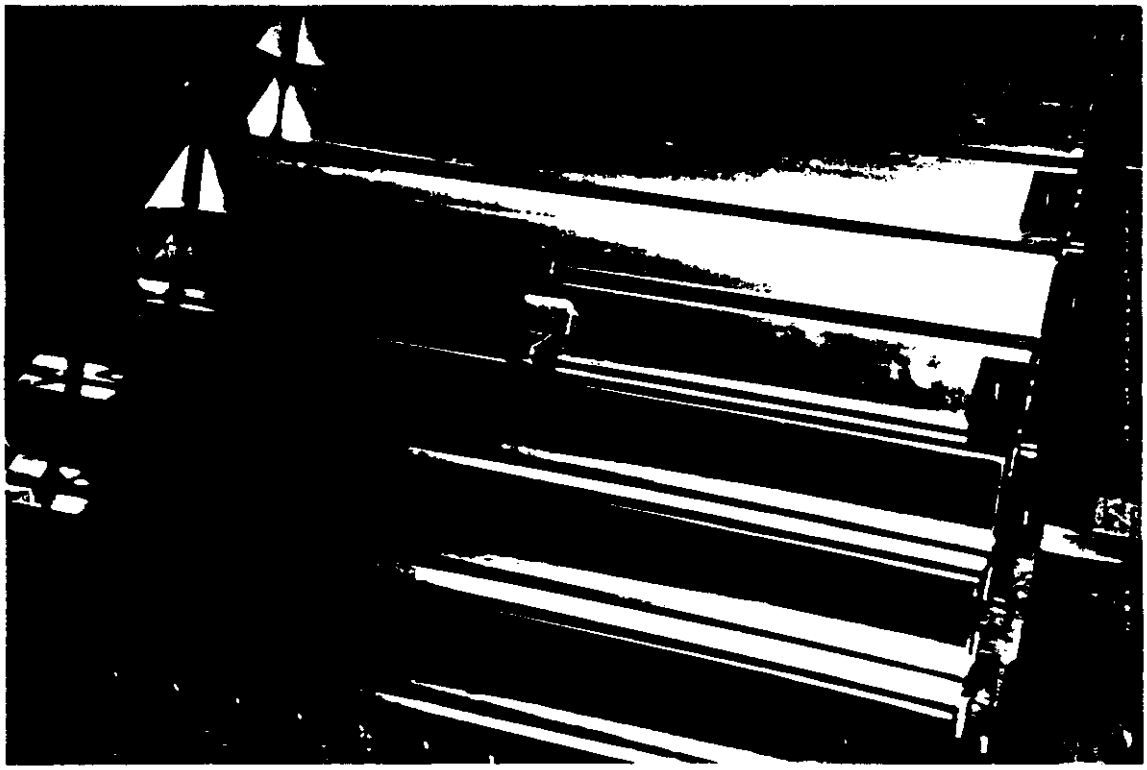
Endcap Accordion EM



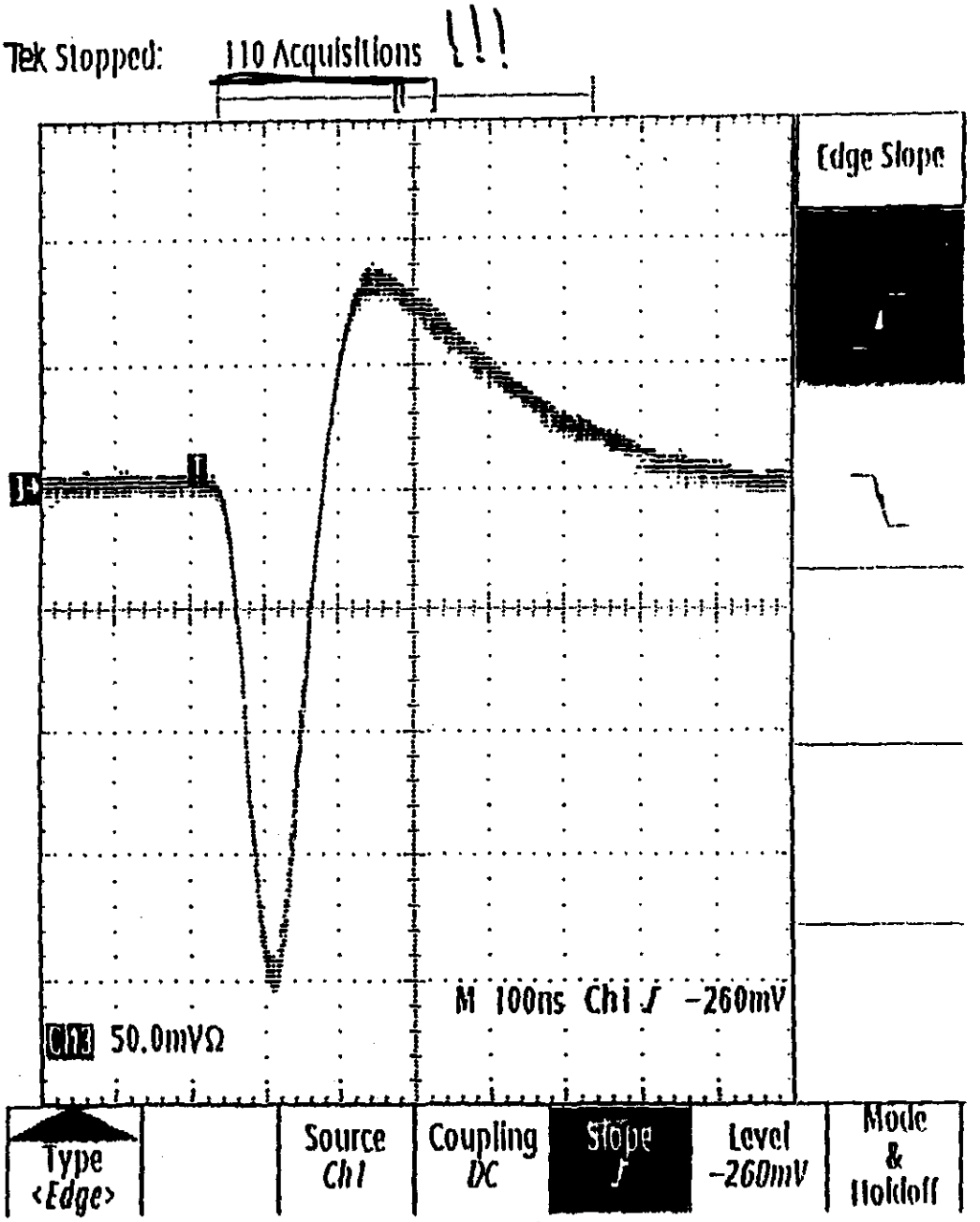


Fully Projective η, ϕ
Crackless

DUMBUS



Liquid Krypton Beam Test



LKr , 2 mm stack , 1.5 kV

206eV

Sum of ~150 channels

Multiple trace - variable persistence

Beam size : 2.5 x 5 cm^2

Energy Resolution $\sigma/\sqrt{E}$		
Stack	Measurement*	Monte Carlo
1 mm Ar	6.1 - 5.8	6.25
2 mm Ar	7.5 - 7.8	7.3
2 mm Kr	6.3 - 6.9	6.3

After
subtracting beam spread of 0.5-0.7%

BASELINE 2

EM + Hadron

HYBRID CALORIMETER

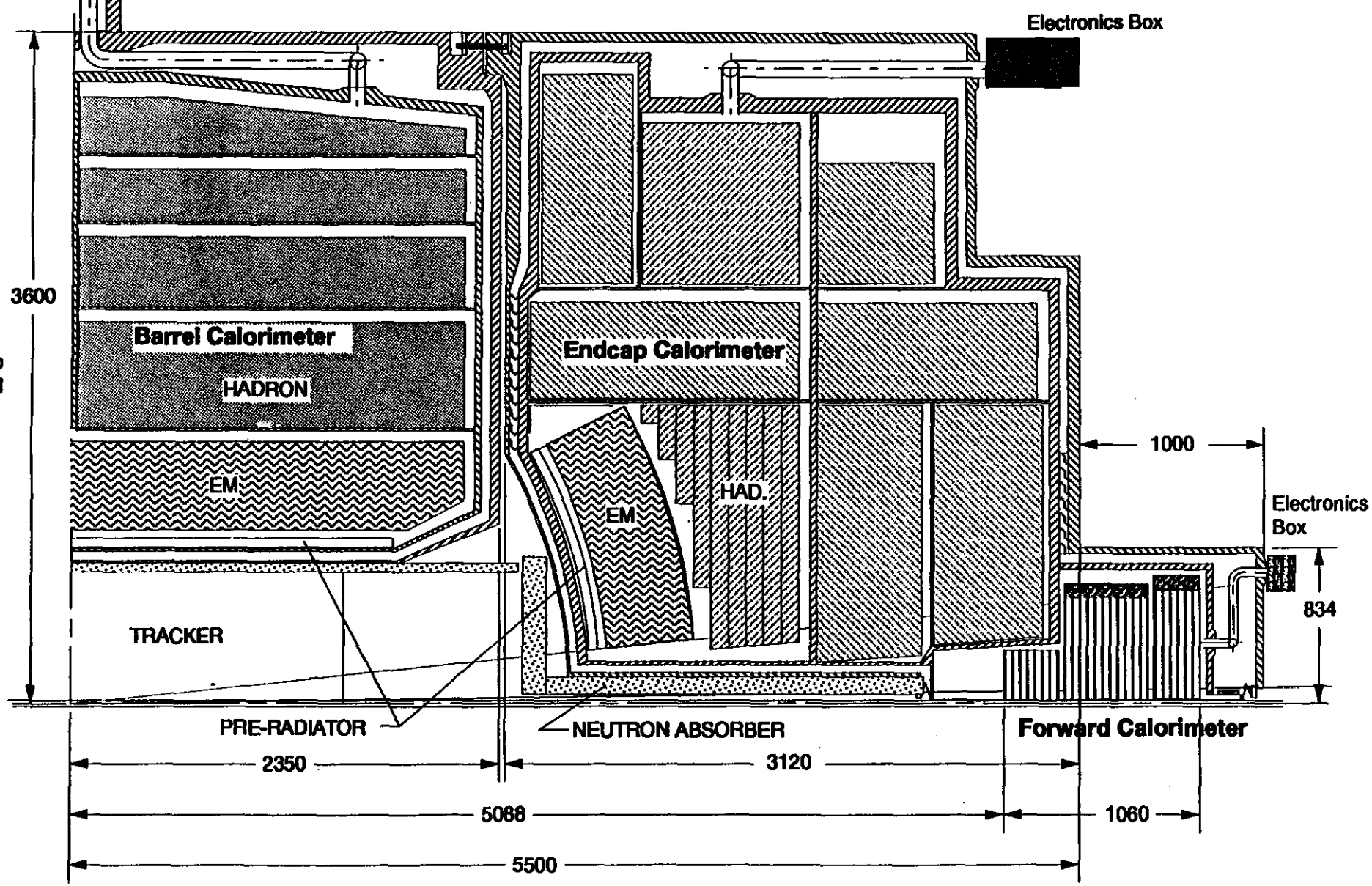
- Two Technology Calorimeter
  Liq Kr
  +
  Scint.

GEM Liquid Argon Calorimeter

1/4 Section "Off Vertical"
Copper Hadron Absorber

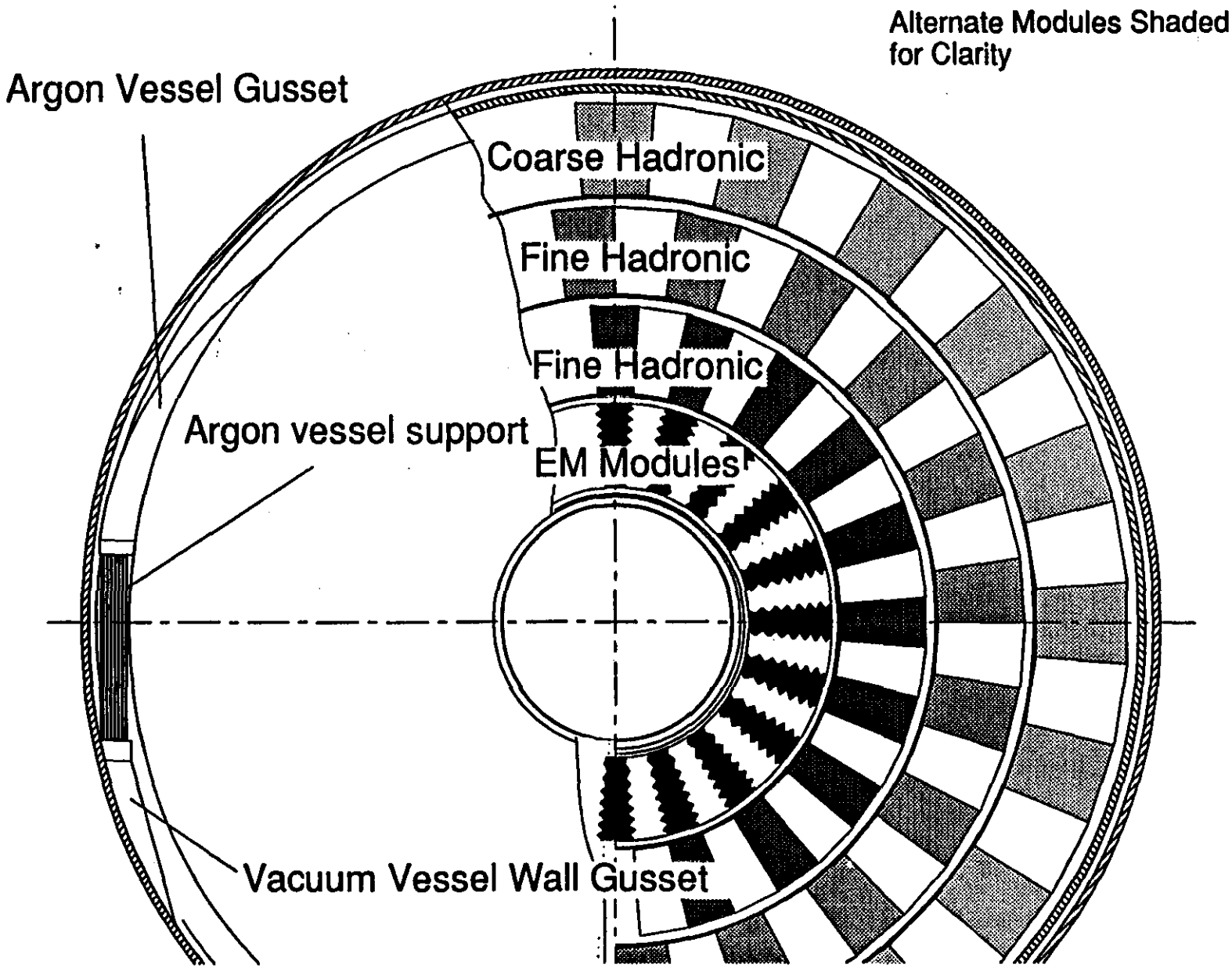
Shows General Configuration with Electronic feed throughs

In Base-line Design



LLMason 3/23/92

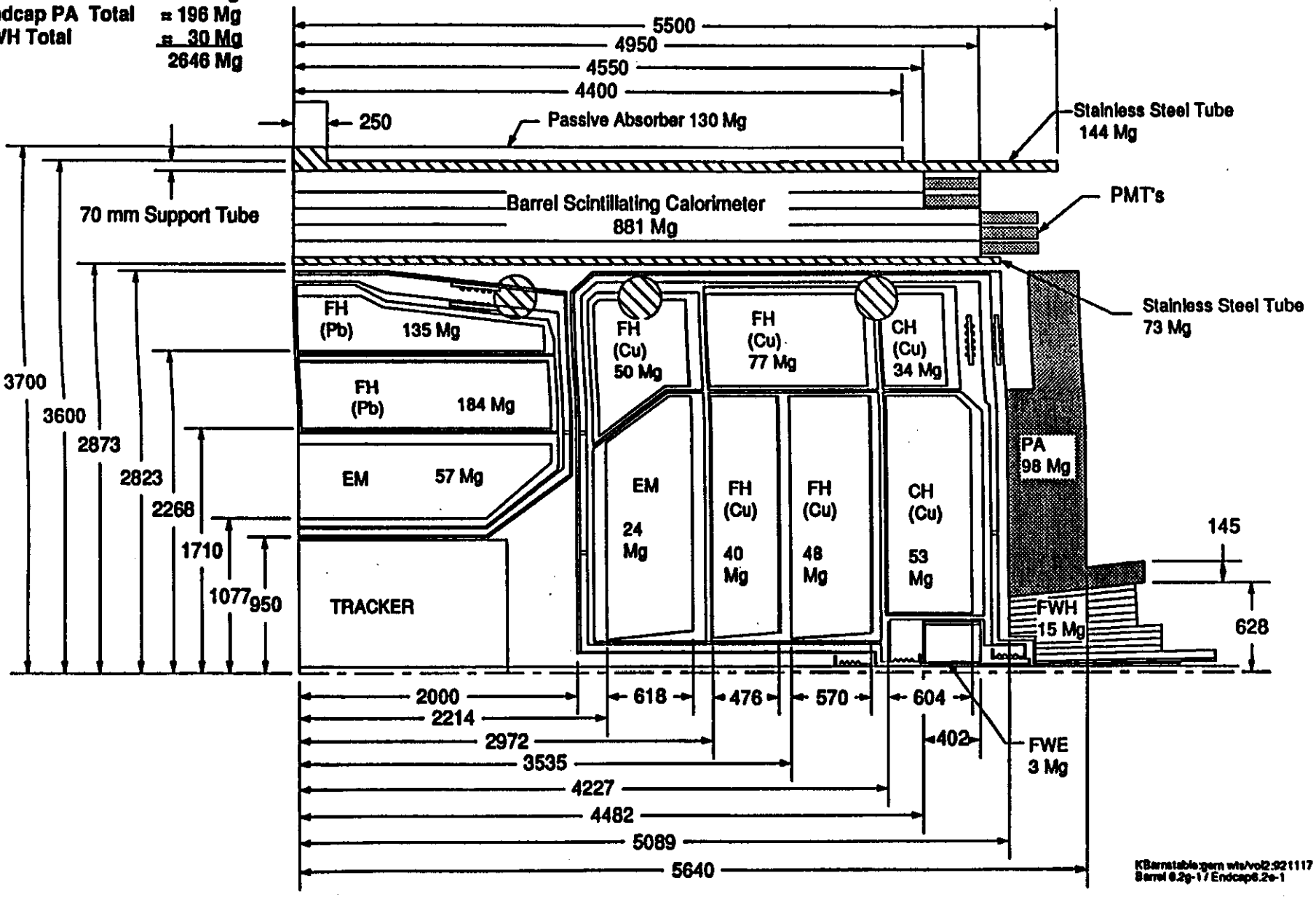
Barrel Cross-Section (looking down beam line)



GEM Calorimeter

HYBRID CALORIMETER

	Weight	Volume
Barrel Calorimeter	= 433 Mg	24135 L. LKr
2 Endcap Total	= 759 Mg	38475 L. LAr
Scint. Cal. & St. St.	= 1228 Mg	
2 Endcap PA Total	= 196 Mg	
2 FWH Total	= 30 Mg	
	2646 Mg	



Progress of GEM Physics Study and Detector Simulation

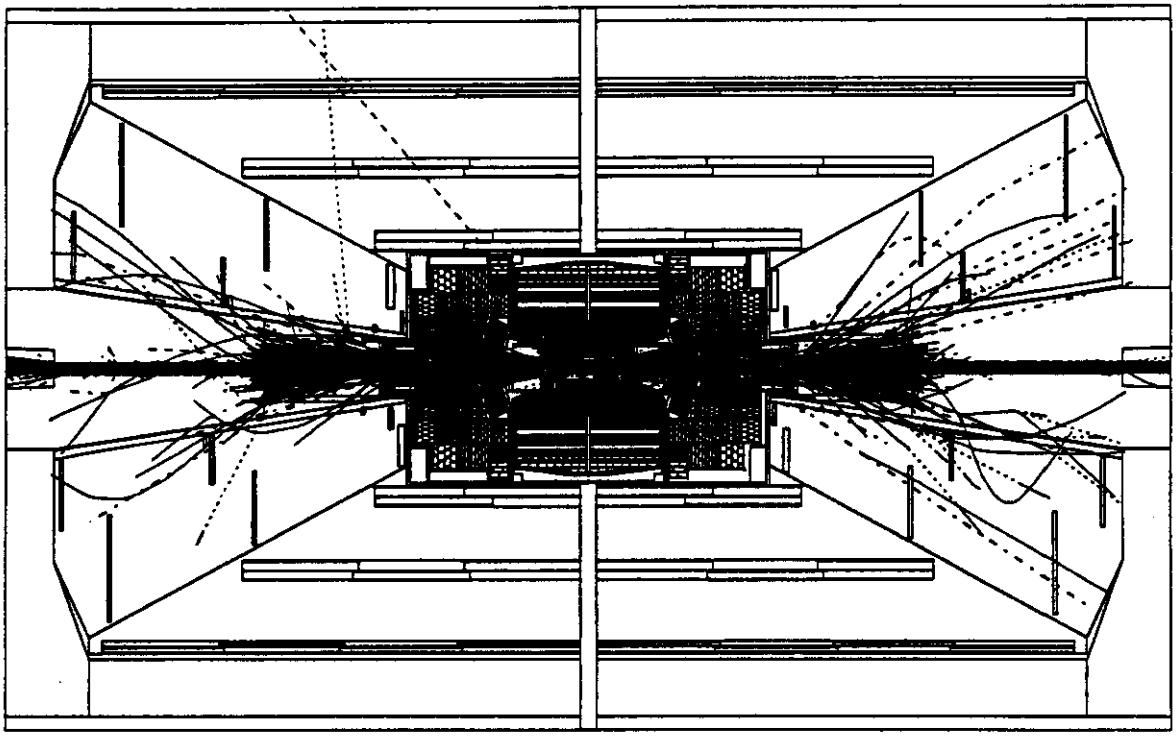
Because of decision making process, GEM's physics and detector simulation is under development. A complete study of GEM's physics capability will be presented in Technical Design Report.

- A GEMFAST program is being developed. The program implements the exact geometry of GEM detector and parametrizes its response based upon test beam data and detailed GEANT simulation. The program will be used for TDR physics studies.

- A full GEANT simulation of GEM detector has also been developed, but with slow response (1.5 hours/event in the fastest workstation).

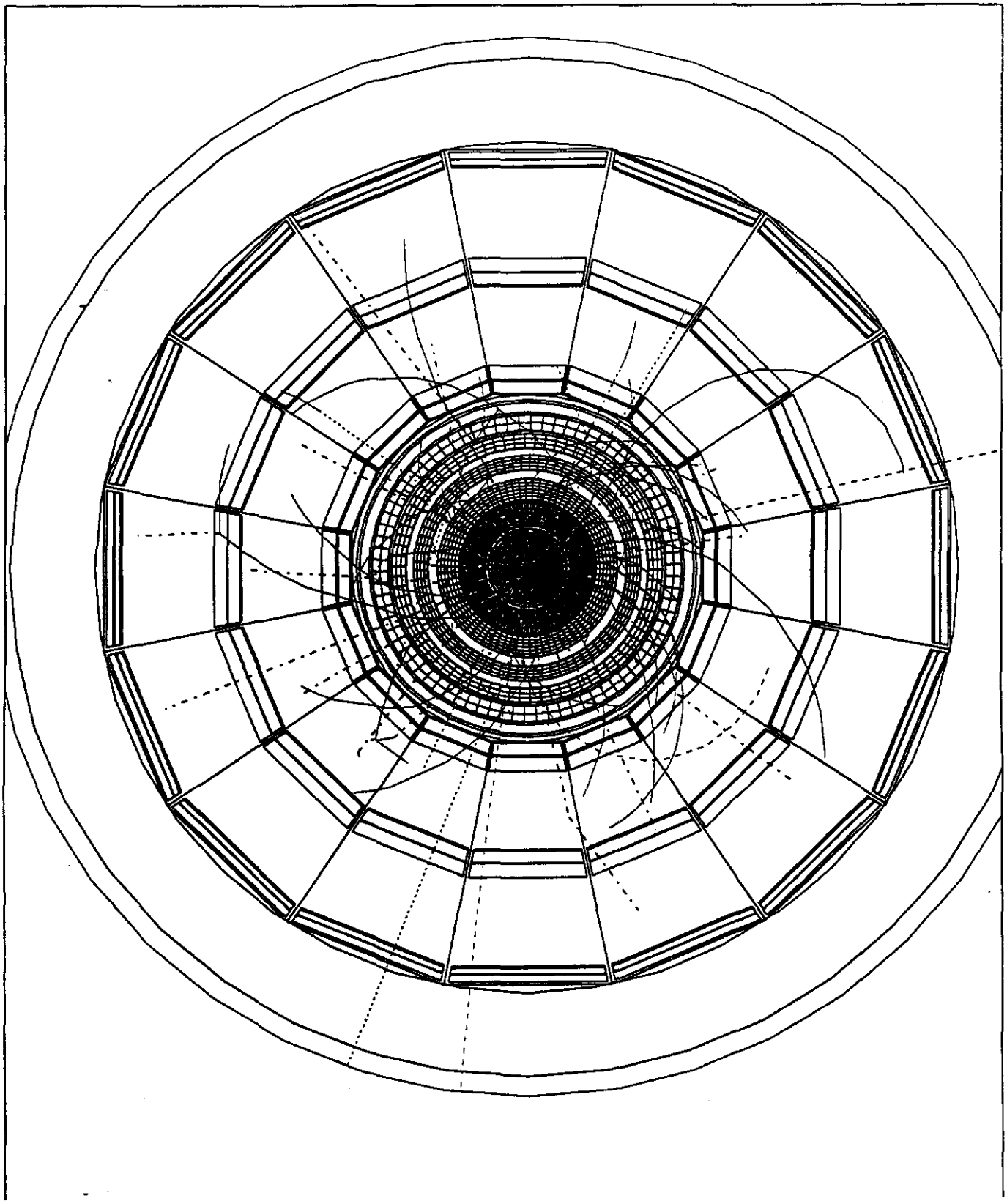
- GEM LKr EMC has 3 longitudinal segmentation (3/6/16 X_0) and 6 strips in the first segment to measure θ coordinate. It is designed to address two issues raised by the PAC:
  - Jet Background Rejection; and
  - Measurement of Photon Direction.

Event in Baseline 1 SIGEM



– $t\bar{t}$ Event –

SIGEM – cut through Baseline 1



Photon Direction Measurement

No CT, with Pointing

The most robust approach is to measure the photon direction by using **pointing** provided by longitudinally segmented calorimeter information, and determine the primary Higgs vertex by using beam constraint.

Assuming:

$$\delta\theta = c/\sqrt{E}\ mrad$$

the mass resolution (GeV) of 80 GeV Higgs($\rightarrow \gamma\gamma$) accepted in $|\eta| < 2.5$ is:

c (mrad)	0	30	40	50	60	80
a=2.0,b=0.5	0.34	0.40	0.43	0.47	0.51	0.60
a=5.5,b=0.5	0.52	0.56	0.59	0.62	0.66	0.74
a=7.5,b=0.5	0.66	0.68	0.70	0.73	0.76	0.85
a=15.,b=1.0	1.34	1.34	1.35	1.36	1.36	1.37

Works well for both SSC and LHC.

By using 3 longitudinal segments (3/6/16 X_0) and 6 θ strips in the first segment, the photon polar angle can be determined to **c = 40 mrad** for LKr EMC (H. Ma & M. Leltchouk, GEM Note), which degrades Higgs mass resolution by 14%.

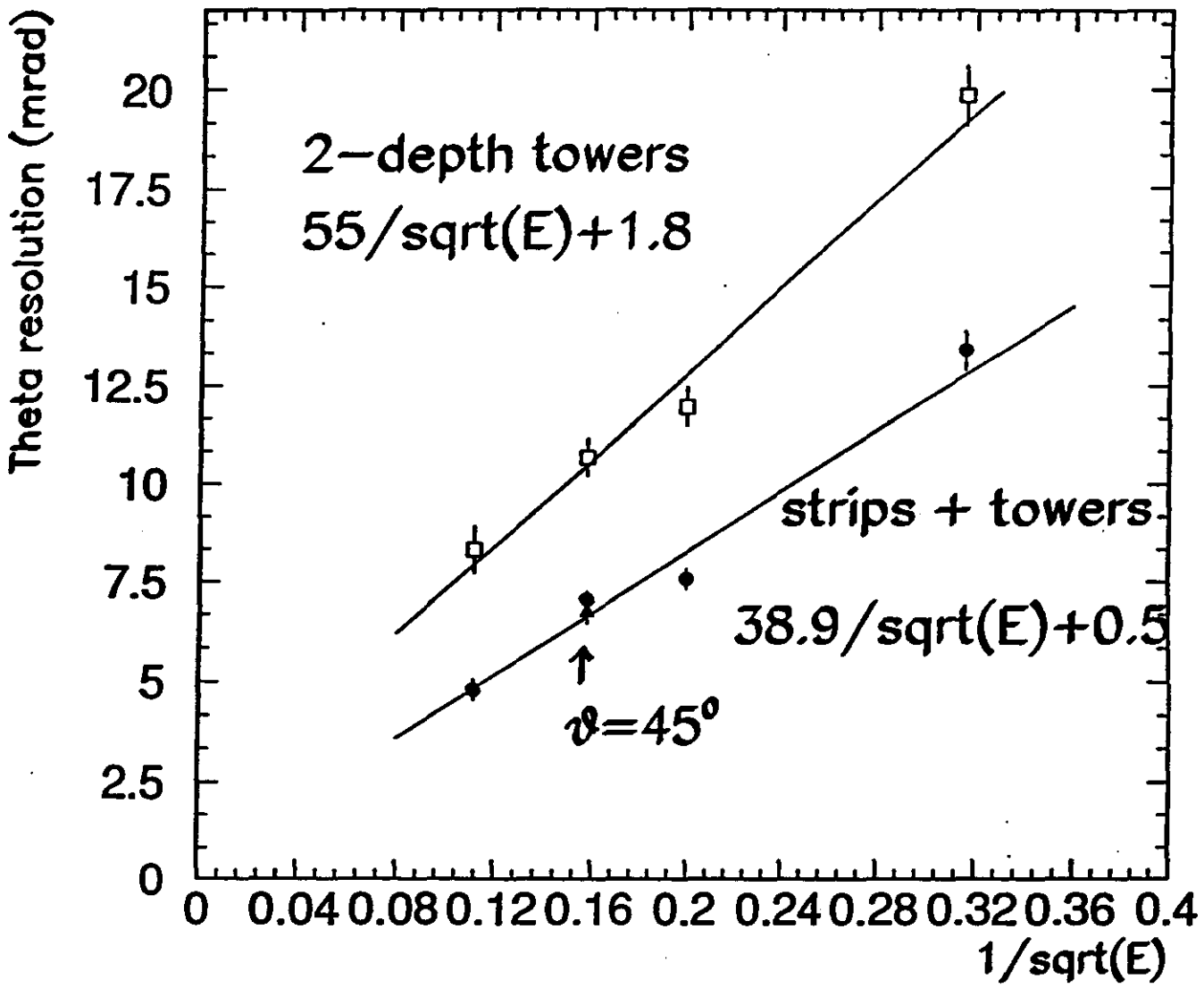


Figure 3: Angular resolution of tower and strip configuration.

Photon Direction Measurement
with both CT and Pointing

Combining pointing and vertices from CT: looking for the closest vertex to the z position reconstructed by pointing vectors.

Assuming:

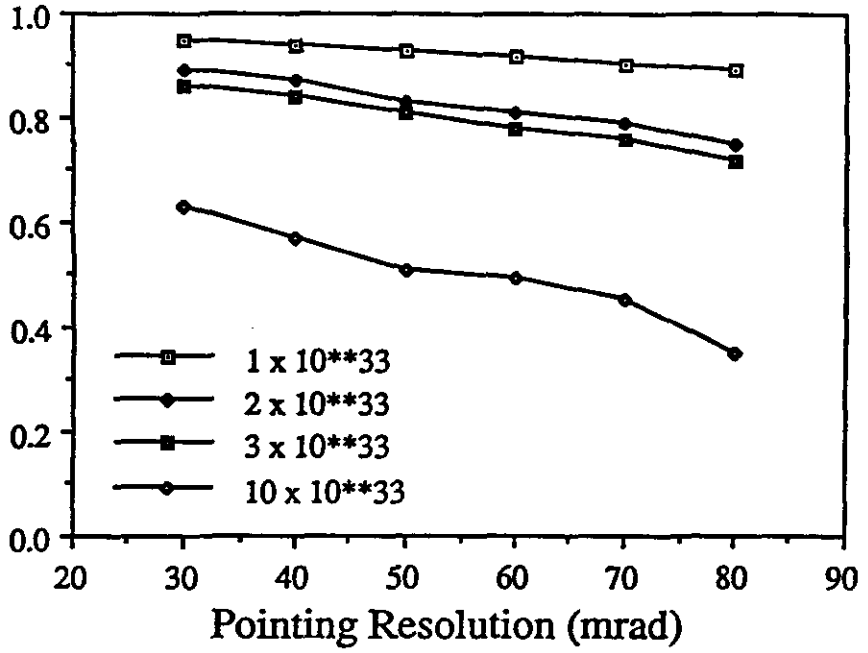
$$\delta\theta = c/\sqrt{E}\ mrad$$

the probability of finding a correct Higgs vertex ($P_{correct}$) and the z resolution of wrongly chosen vertices (δz_{wrong}) are shown as function of luminosity ($\mathcal{L}$) in $10^{33}/s/cm^2$:

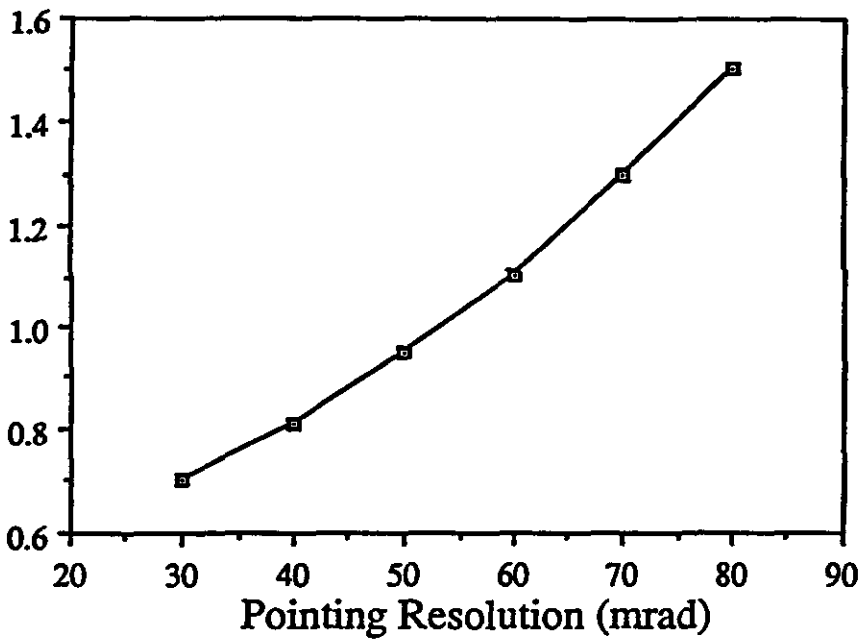
$\mathcal{L}$	c (mrad)	30	40	50	60	70	80
1	$P_{correct}$ (%)	95	94	93	92	90	89
2	$P_{correct}$ (%)	89	87	83	81	79	75
3	$P_{correct}$ (%)	86	84	81	78	76	72
10	$P_{correct}$ (%)	63	57	51	49	45	35
-	δz_{wrong} (cm)	0.70	0.81	0.95	1.1	1.3	1.5

Works well for both SSC and LHC.

Probability of finding a correct Higgs Vertex



z resolution of wrongly chosen vertices (cm)



Jet Background Rejection

6 θ strips in the first segment of GEM LKr EMC function as a preradiator which rejects multi photons and π^0's in isolated photon candidates.

By using information of

- **energy profile in strips (likelihood function),**
- **Shower size** (θ & ϕ) determined by energies in the 2nd & 3rd segments, and
- **ϕ pointing** obtained from 2nd & 3rd segments,

the π^0 can be effectively rejected, while keeping 90% acceptance for single γ's. (H. Ma & M. Leltchouk, GEM Note.)

E_{π^0} (GeV)	10	25	40	80
$R(\pi^0)$ (%)	90	85	65	42

The jet (π^0) background (12 pb) is less than 17% of total (Born + Box + Bremsstrahlung + π^0) background (70 pb), and can be further reduced by refined analysis.

Likelihood Function

$$F = \log(SYM \times ASYM \times W2 \times W3)$$

E1 = Energy in the highest energy strip — center;

E3 = Energy sum in 3 strips around the center;

E_{right} = energy sum in 3 strips right to the center;

E_{left} = energy sum in 3 strips left to the center;

$SYM = (E_{right} + E_{left})/E3$

$ASYM = |E_{right} - E_{left}|/E1$

W2 = distance between the center and the second highset energy strip, in unit of strip numbers;

W3 = distance between the center and the third highset energy strip, in unit of strip numbers.

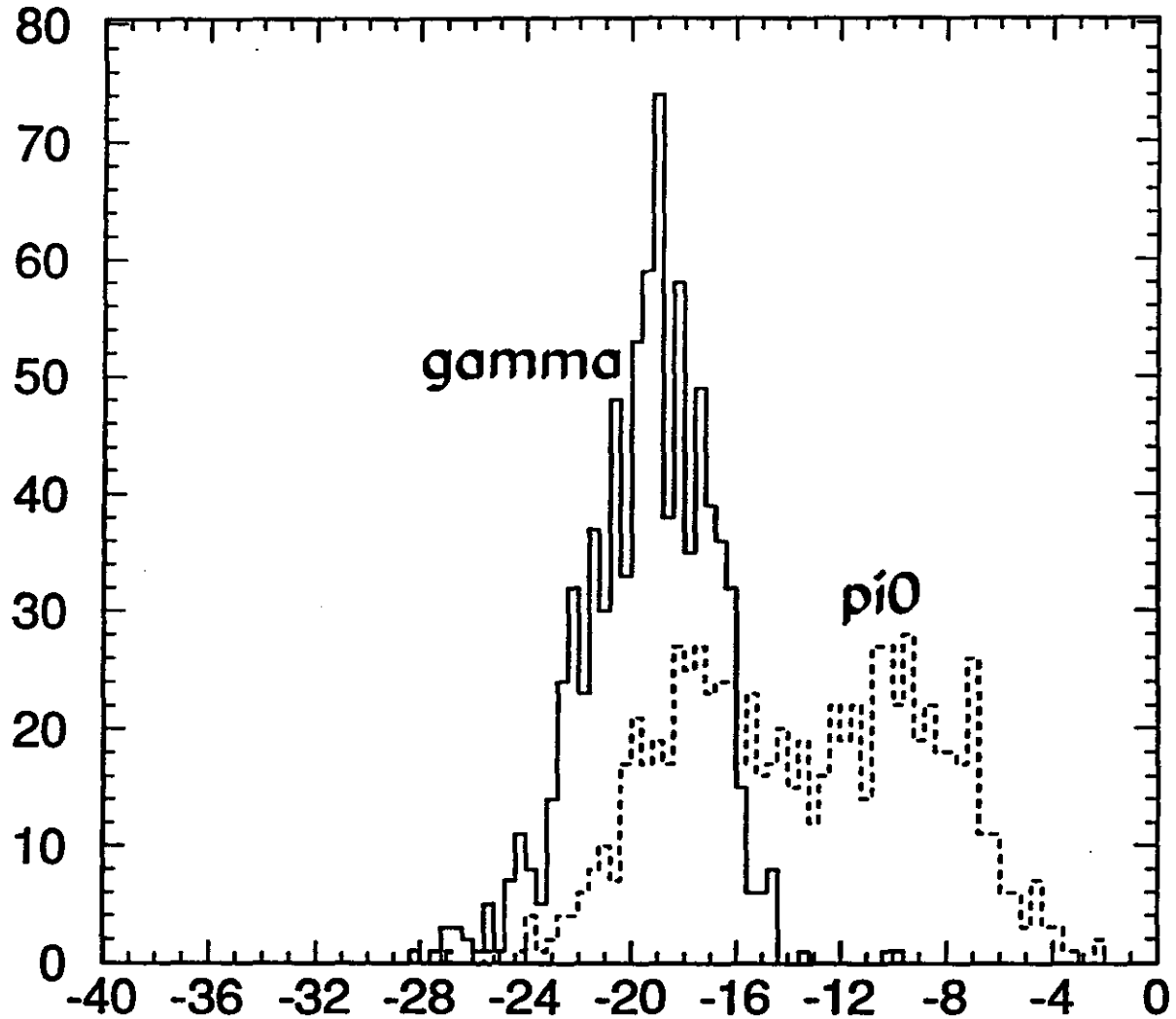


Figure 9: Separation of single photons and single π^0 of 25 GeV using strips.

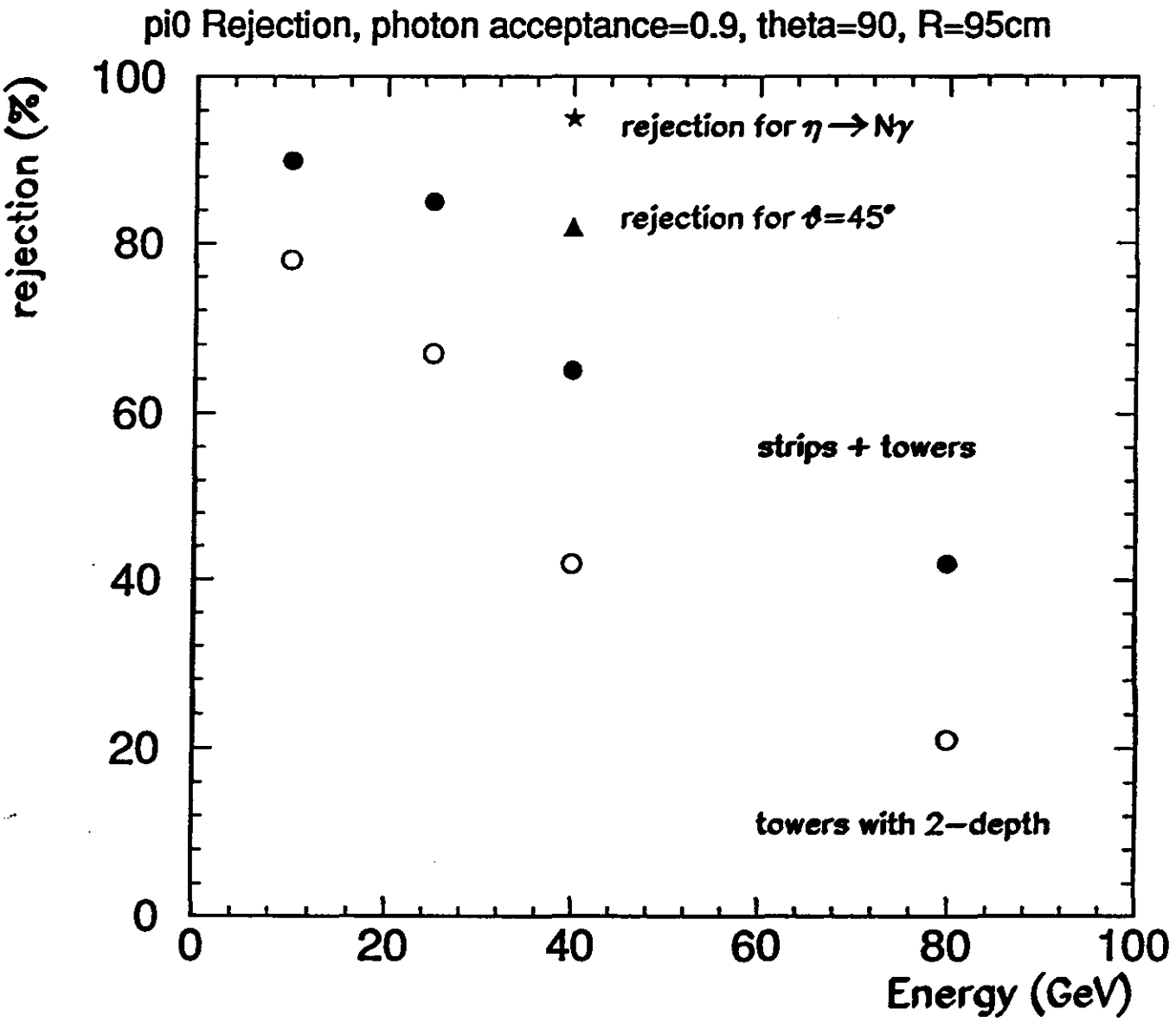
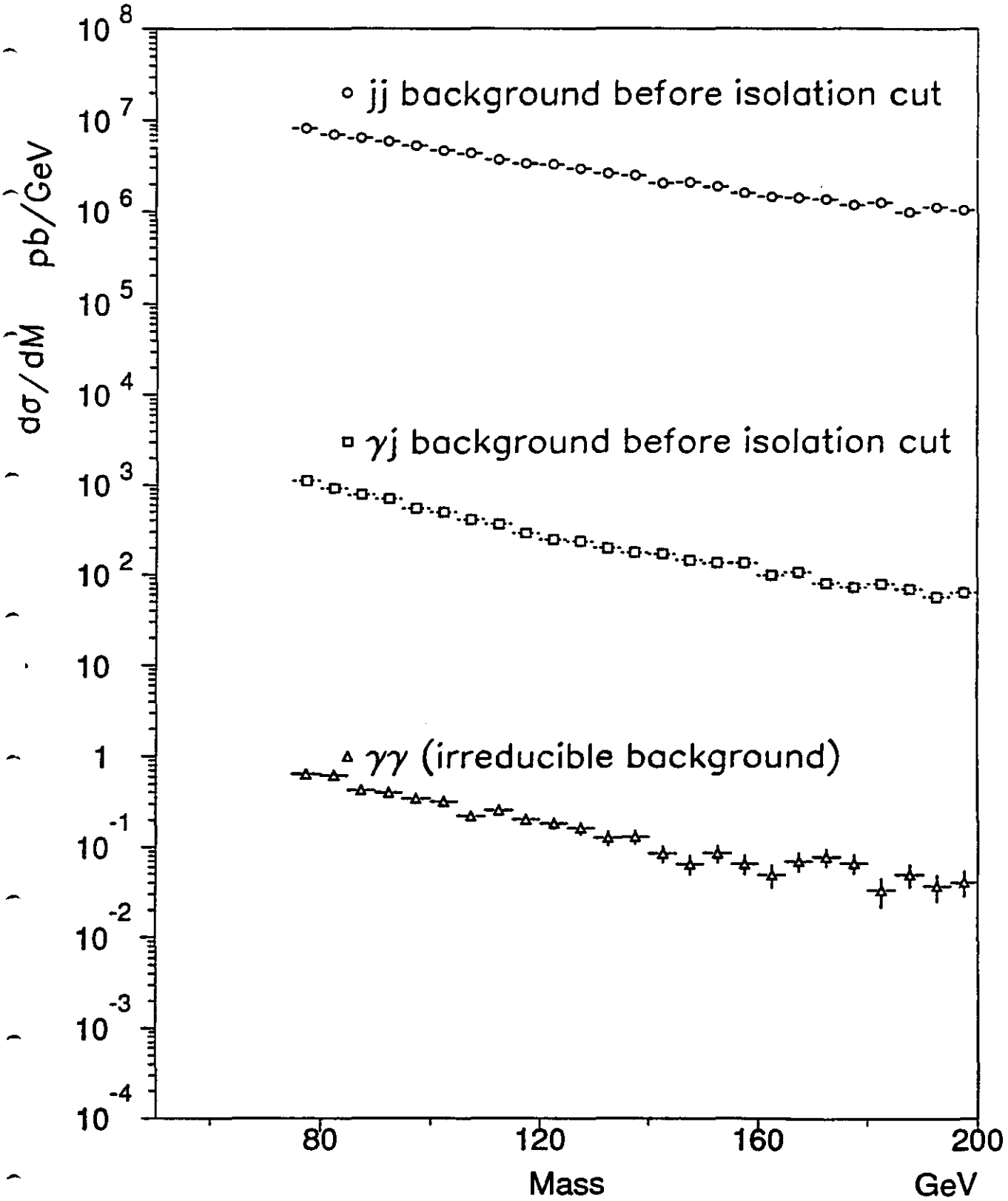


Figure 6: π^0 rejection rate as a function of energy


jj background before isolation cut
γj background before isolation cut
γγ (irreducible background)
dσ/dM pb/GeV
Mass GeV
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-4
80
120
160
200

Background X-Section

H→ $\gamma\gamma$ Searches

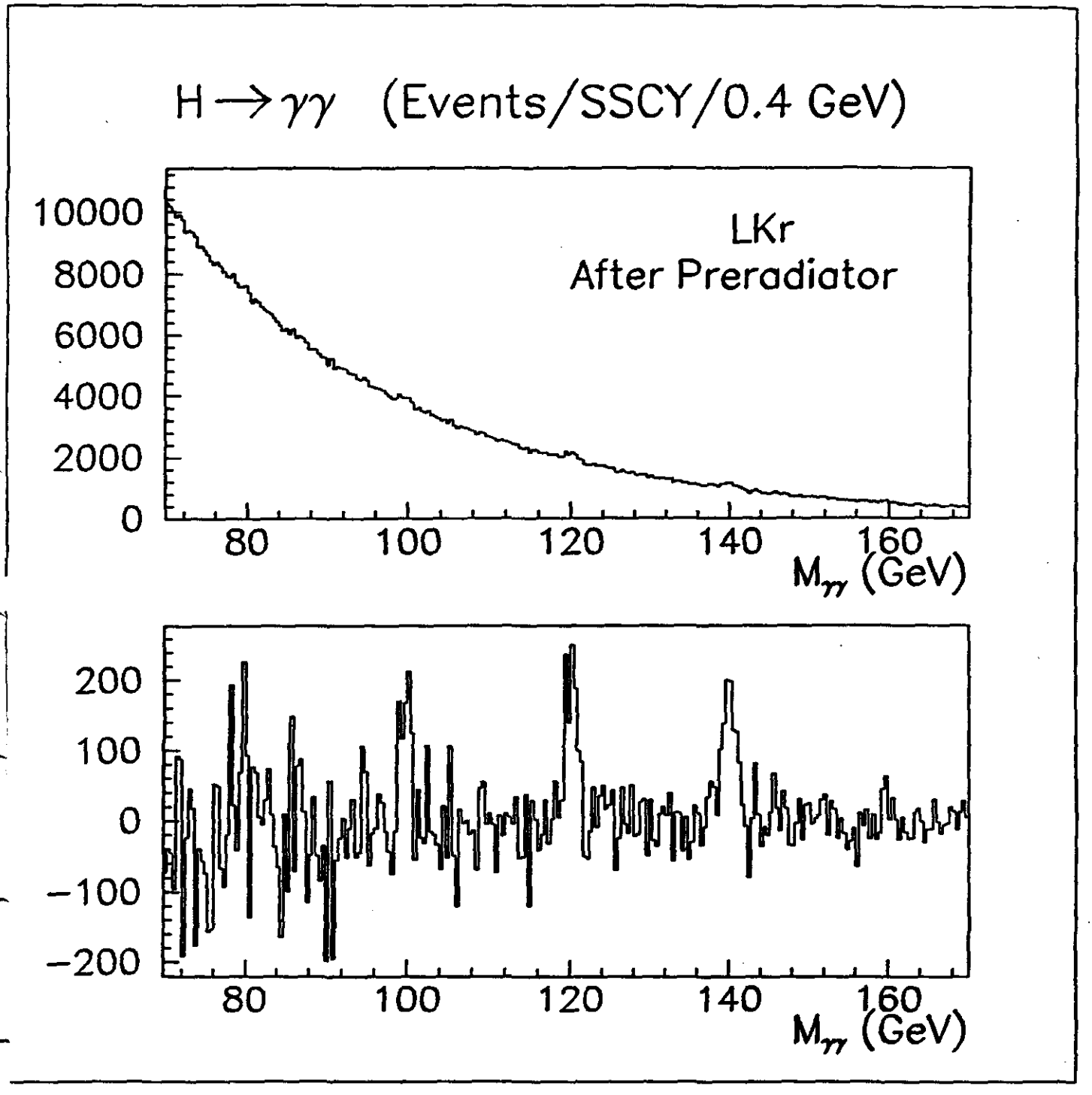
	$\gamma\gamma$	γ-jet	2jets
$\hat{p}_t > 20$ GeV	280 pb	240 nb	2.0 mb
$E_T > 20$ GeV, $\|\eta\| < 2.5$	100 pb	80 nb	530 μb
$M_{\gamma\gamma} > 75$ GeV	42 pb	34 nb	240 μb
Rejection Needed		800	6×10^6
Final Background	31 pb	19 pb	20 pb
Single Photon	31 pb	17 pb	10 pb
Jet Background		2 pb	10 pb

Note, the Jet background may be reduced by optimizing kinematics cut, such as requiring high p_T on photon.

Significance of 80 GeV Higgs

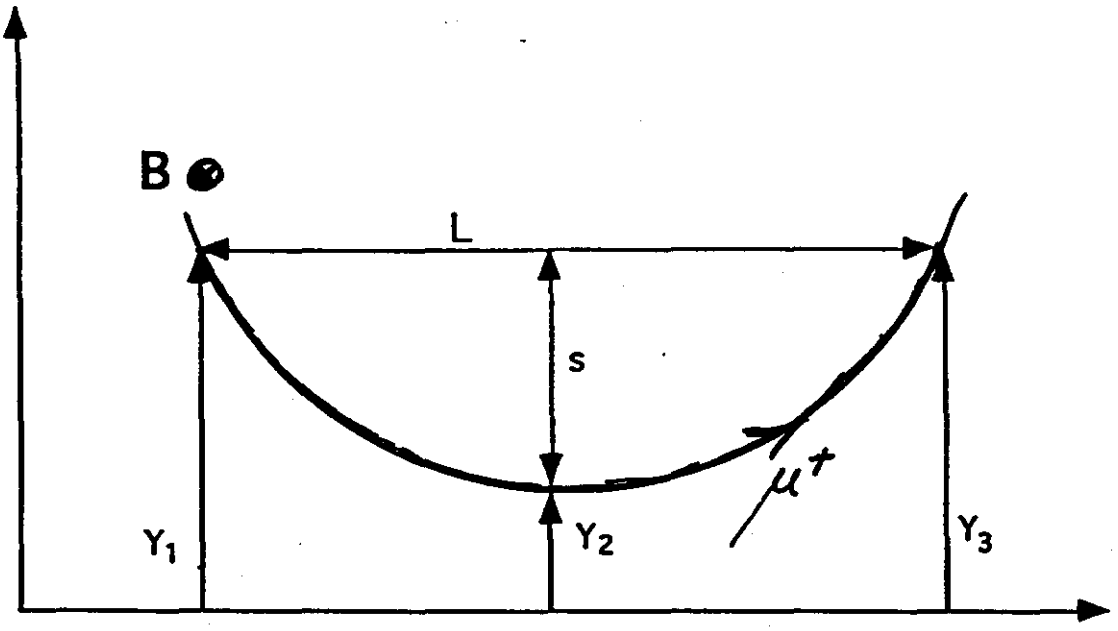
	$\gamma\gamma$ Background	All Background
	3.7	2.8
1.5 k-Factor	5.6	4.2

Note, EHLQ set 1 structure function is used.


H → γγ (Events/SSCY/0.4 GeV)
LKr
After Preradiator
10000
8000
6000
4000
2000
0
80
100
120
140
160
M_γγ (GeV)
200
100
0
−100
−200
80
100
120
140
160
M_γγ (GeV)

GEM
MUON

WE USE 3 POINT SAGITTA MEASUREMENT



$$S = \frac{y_1 + y_3}{2} - y_2 = \frac{1}{8}\frac{q\,B\,L^2}{P}$$

Optimize Magnet with large L and weak B

$S \approx 1500\ \mu m$

for:

$B \approx 0.8$ tesla

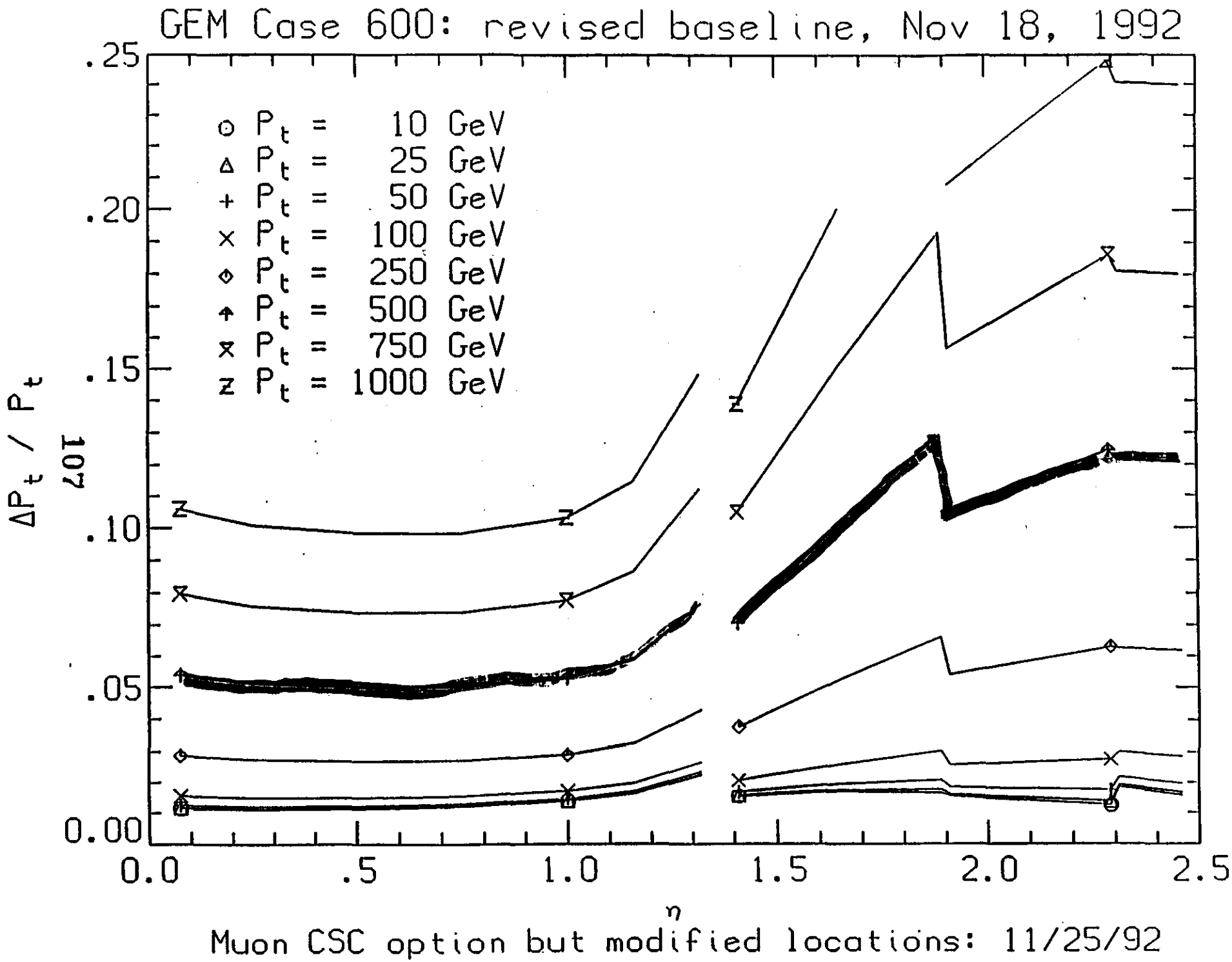
$L \approx 5$ m.

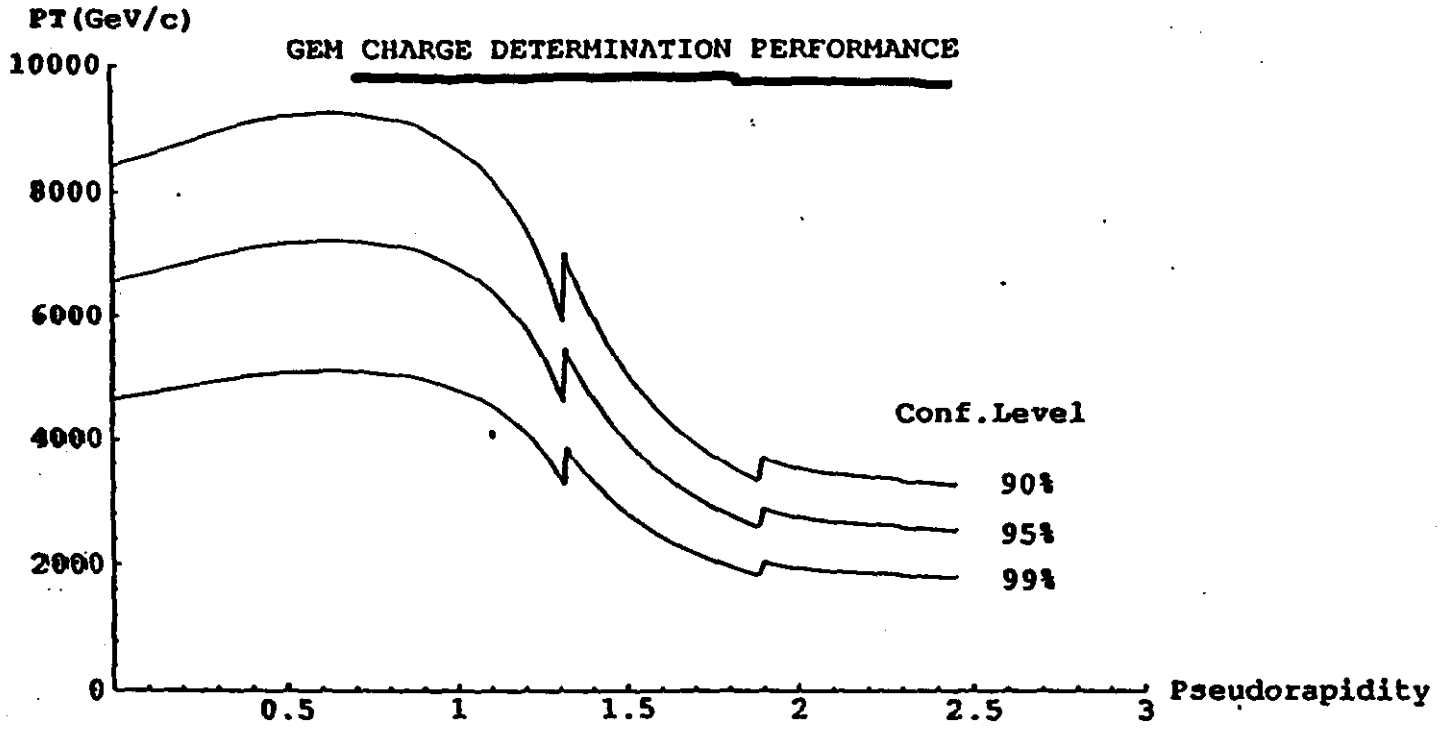
$P \approx 500$ GeV/c

To keep $\frac{\delta P}{P} \leq 0.05 \Rightarrow \delta S \leq 75\ \mu m.$

GEM Muon System

Central field	0.8 T
Length of magnet	30 m
Inner radius of magnet	9.0 m
Outer radius of calorimeter system	3.6 m
Location of neutron shield	$3.6 < R < 3.7$ m
Pseudorapidity coverage in barrel	0.074 – 1.33
Pseudorapidity coverage in endcaps	1.40 – 2.46
Intrinsic single layer resolution	100 μm
Alignment accuracy in a superlayer	50 μm
Alignment accuracy between superlayers	25 μm
Global alignment accuracy	200 μm


GEM Case 600: revised baseline, Nov 18, 1992
⊙ P_t = 10 GeV
△ P_t = 25 GeV
+ P_t = 50 GeV
× P_t = 100 GeV
◇ P_t = 250 GeV
↑ P_t = 500 GeV
⧖ P_t = 750 GeV
z P_t = 1000 GeV
$\Delta P_t / P_t$
10^7
.25
.20
.15
.10
.05
0.00
0.0
.5
1.0
1.5
2.0
2.5
η
Muon CSC option but modified locations: 11/25/92


PT(GeV/c)
GEM CHARGE DETERMINATION PERFORMANCE
10000
8000
6000
4000
2000
0
0.5
1
1.5
2
2.5
3
Pseudorapidity
Conf.Level
90%
95%
99%

Proposed Technologies for GEM Muons

ENDCAP REGION
$9.5° < \Theta < 30°$ $(1.3 < \eta < 2.5)$

Measurement	Technology
P_T (r-ϕ)	Cathode Strip Chambers
Second Coordinate (θ)	Cathode Strip Chambers
Trigger	Cathode Strip Chambers
Beam Crossing Tag	Cathode Strip Chambers

Also Under Consideration for Central Region

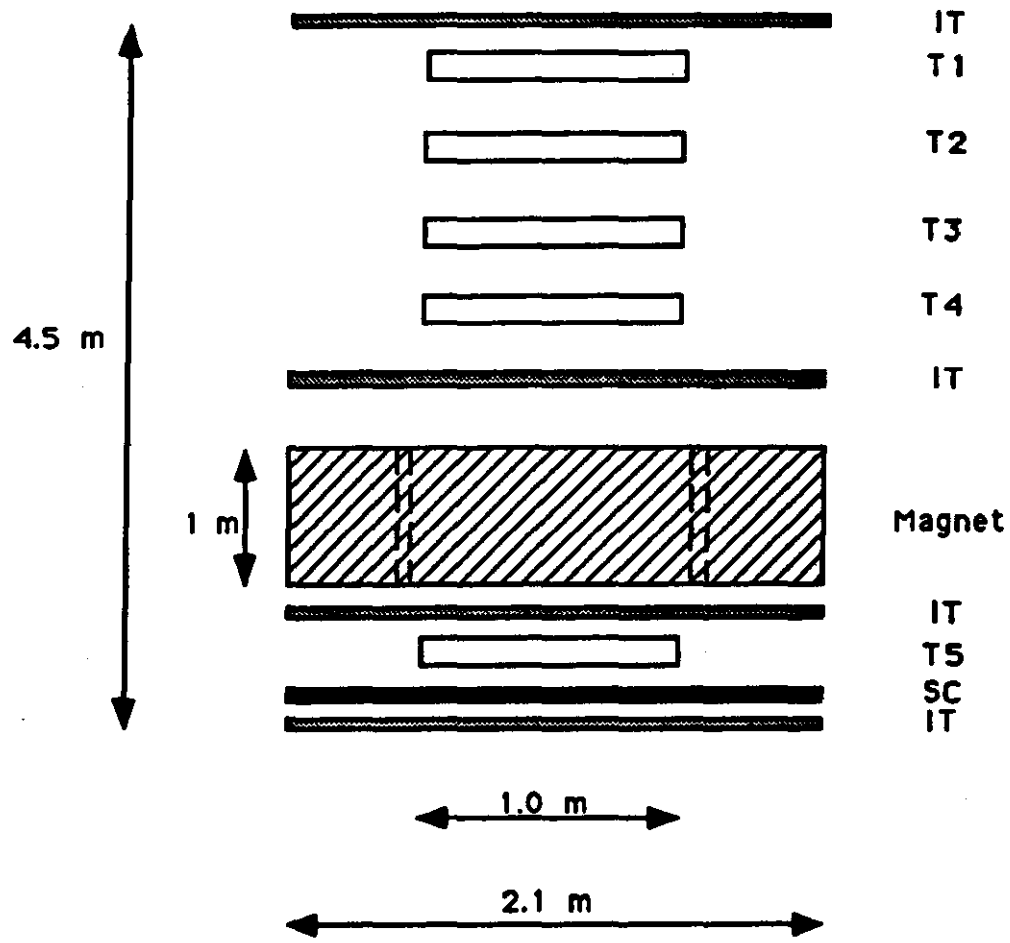
OR

CENTRAL REGION
$\Theta > 30°$ $(0.0 < \eta < 1.3)$

Measurement	Technology
P_T (r-ϕ)	Proportional Tubes or Limited Streamer Tubes in Drift Mode
Second Coordinate (θ)	Resistive Plate Chambers
Trigger	Resistive Plate Chambers
Beam Crossing Tag	Resistive Plate Chambers

TTR TEXAS TEST RIG

GEM MUON CHAMBERS EVALUATION TEST STAND

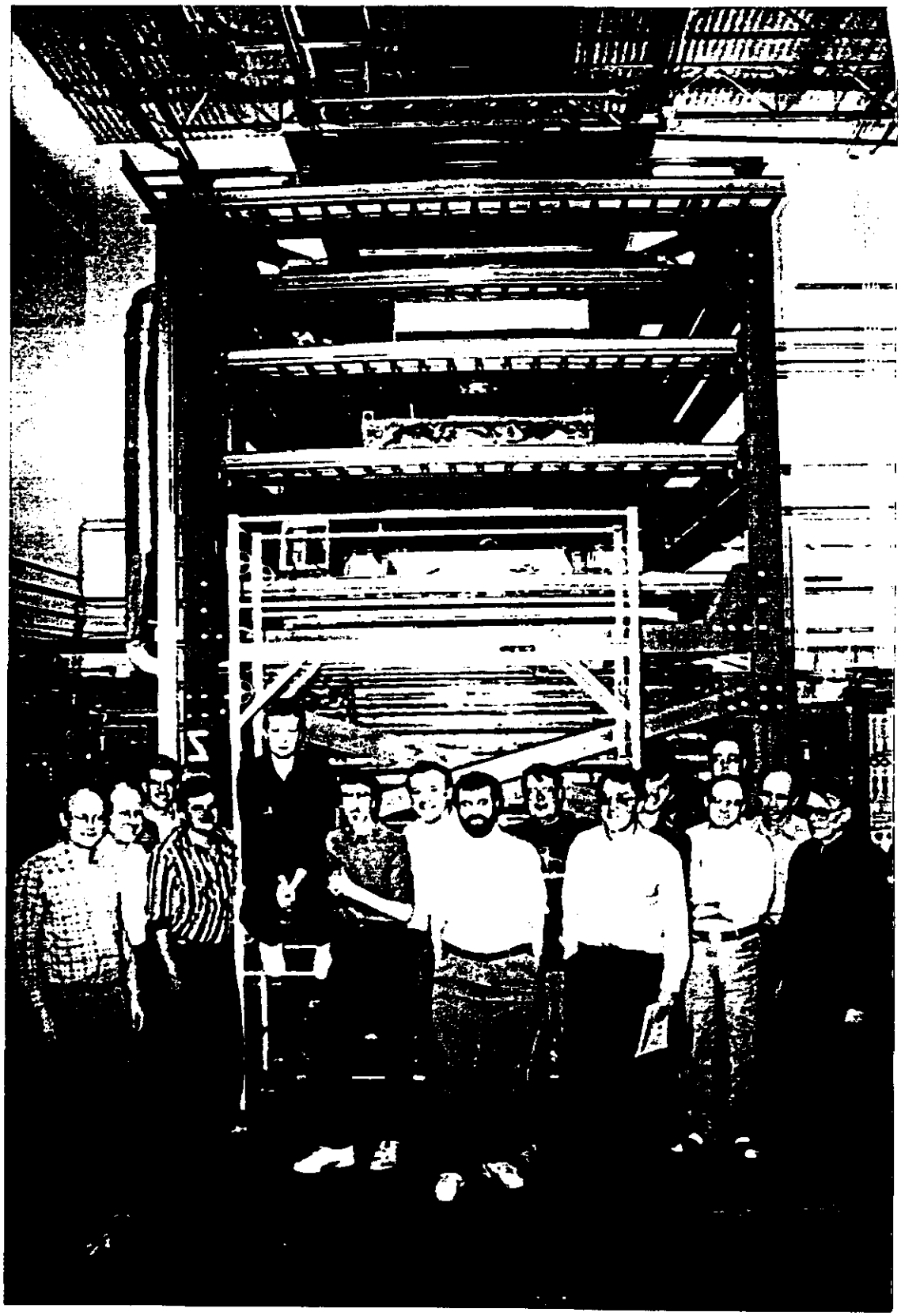


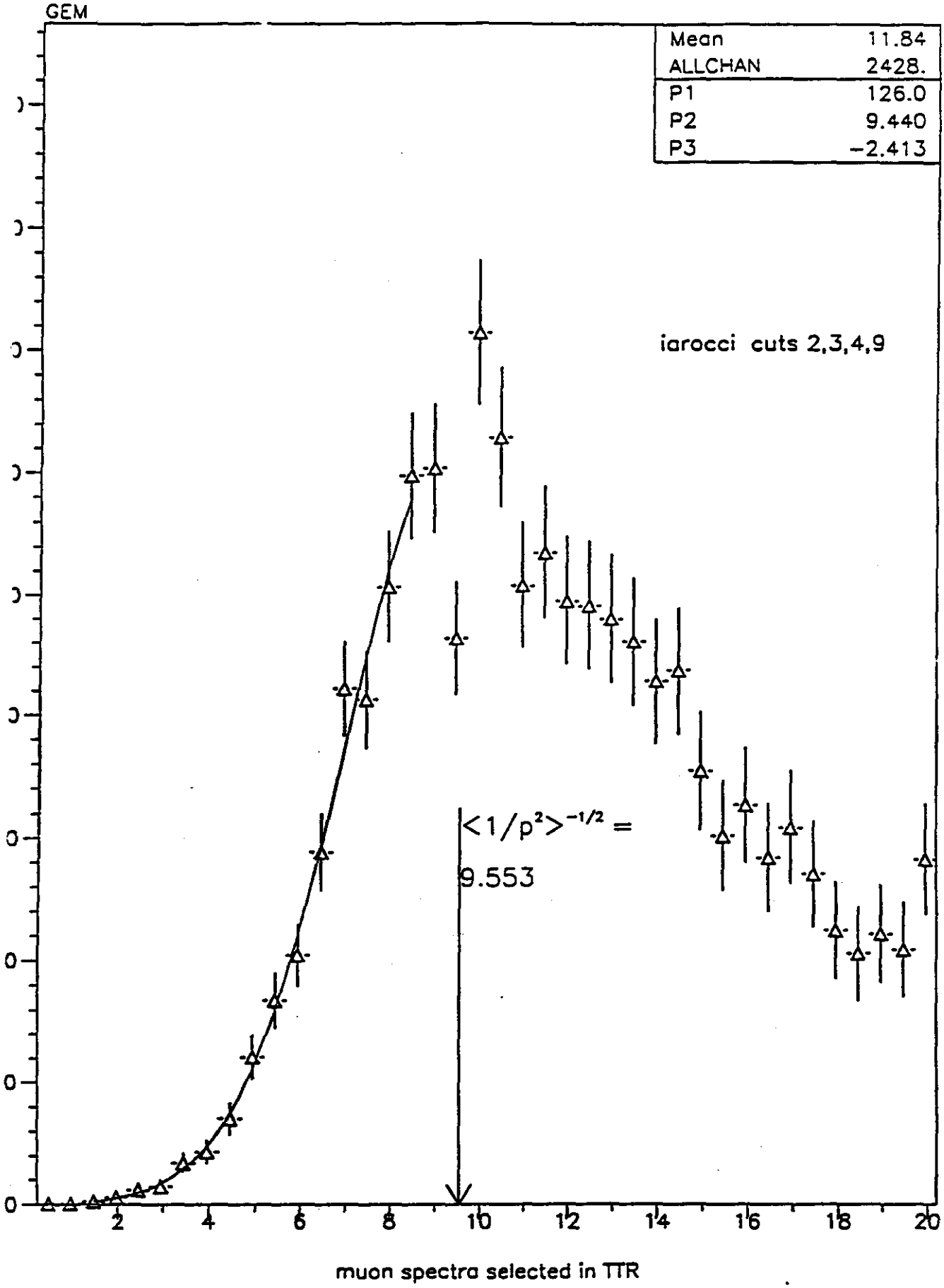
Legend:

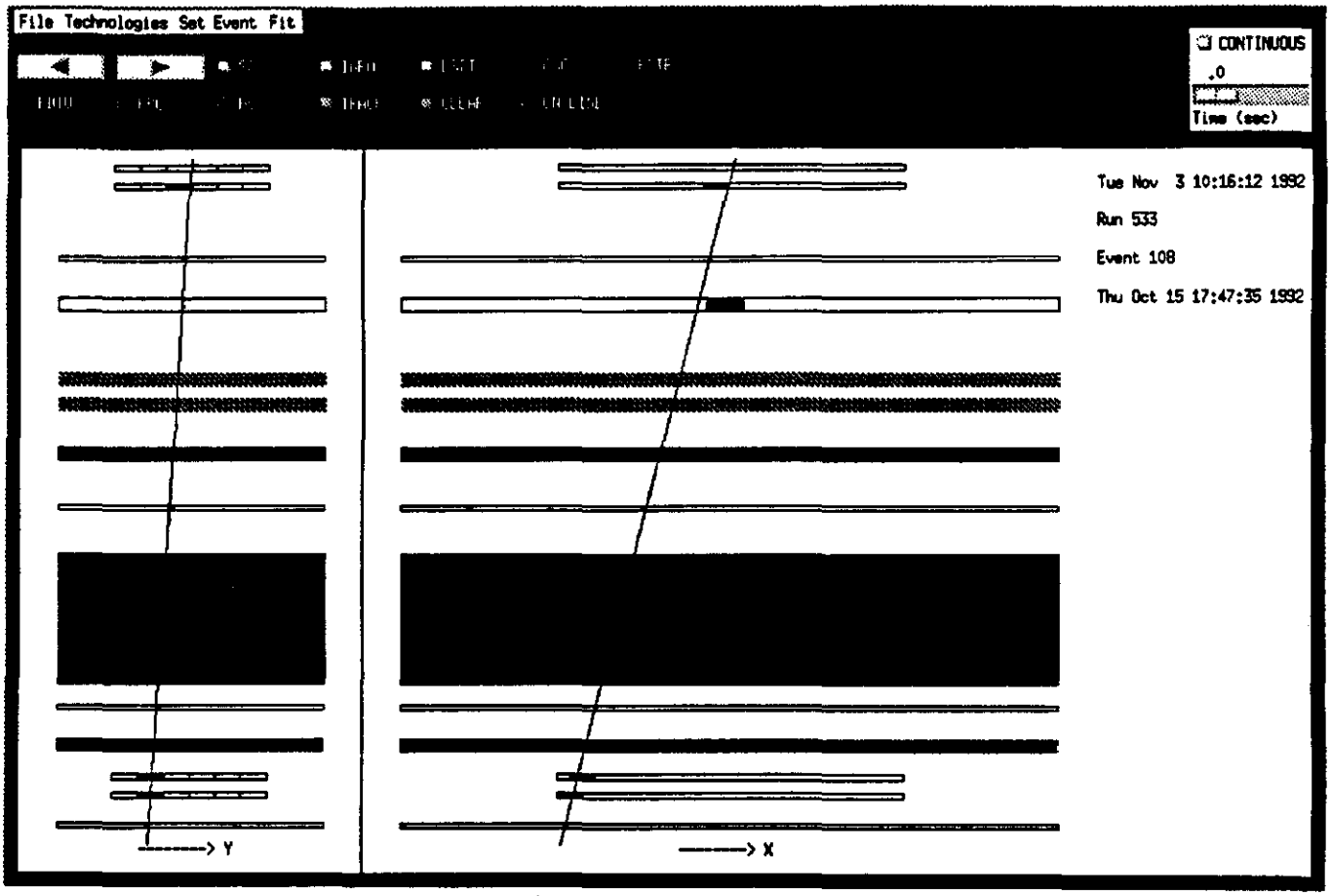
T1-T5 Technologies to be Evaluated
- T1 Pressurized Drift Tubes
- T2 Limitied Streamer Drift Tubes
- T3 Cathode Strip Chambers, Multiwire Geometry
- T4 Cathode Strip Chambers, Open Profile
- T5 Resistive Plate Chambers

SC Scintillator Counters

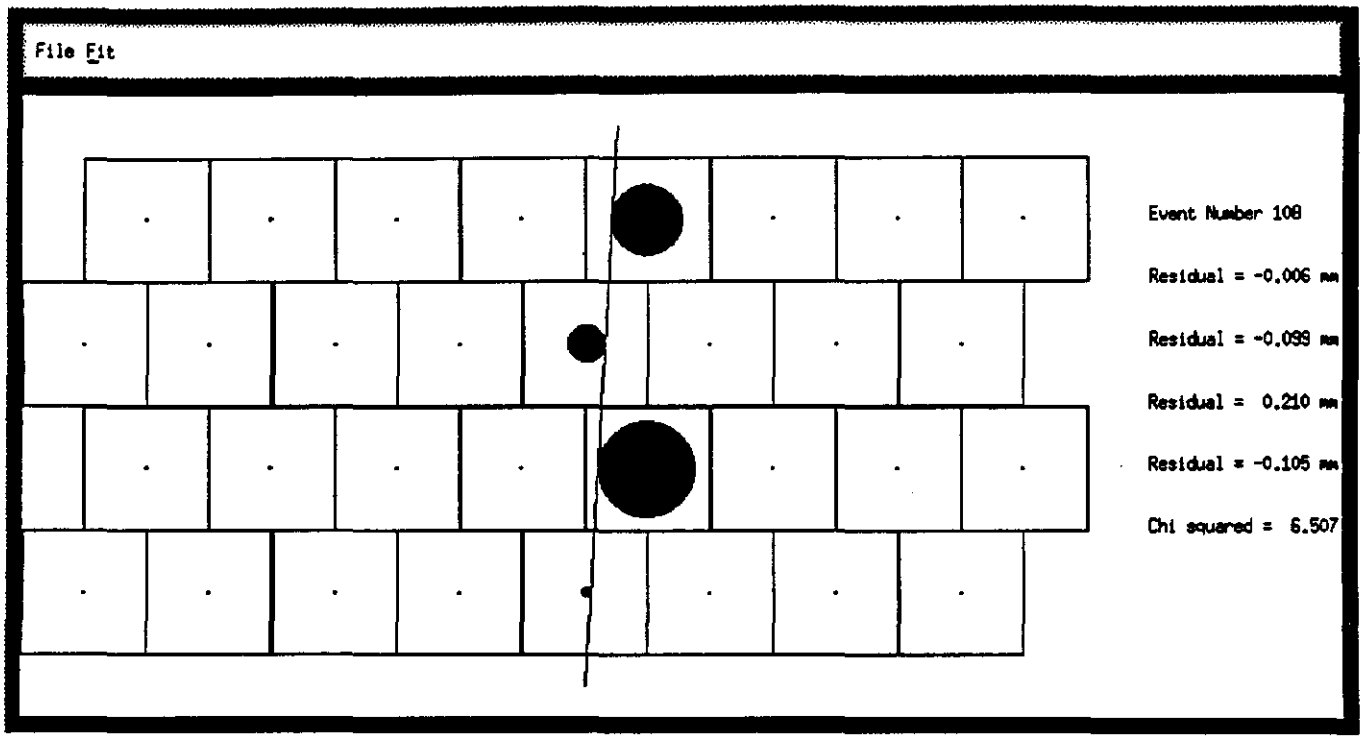
IT Iarocci-Tube Chambers for Trigger




GEM
Mean 11.84
ALLCHAN 2428.
P1 126.0
P2 9.440
P3 −2.413
iarocci cuts 2,3,4,9
$\langle 1/p^2 \rangle^{-1/2}$ =
9.553
2
4
6
8
10
12
14
16
18
20
muon spectra selected in TTR

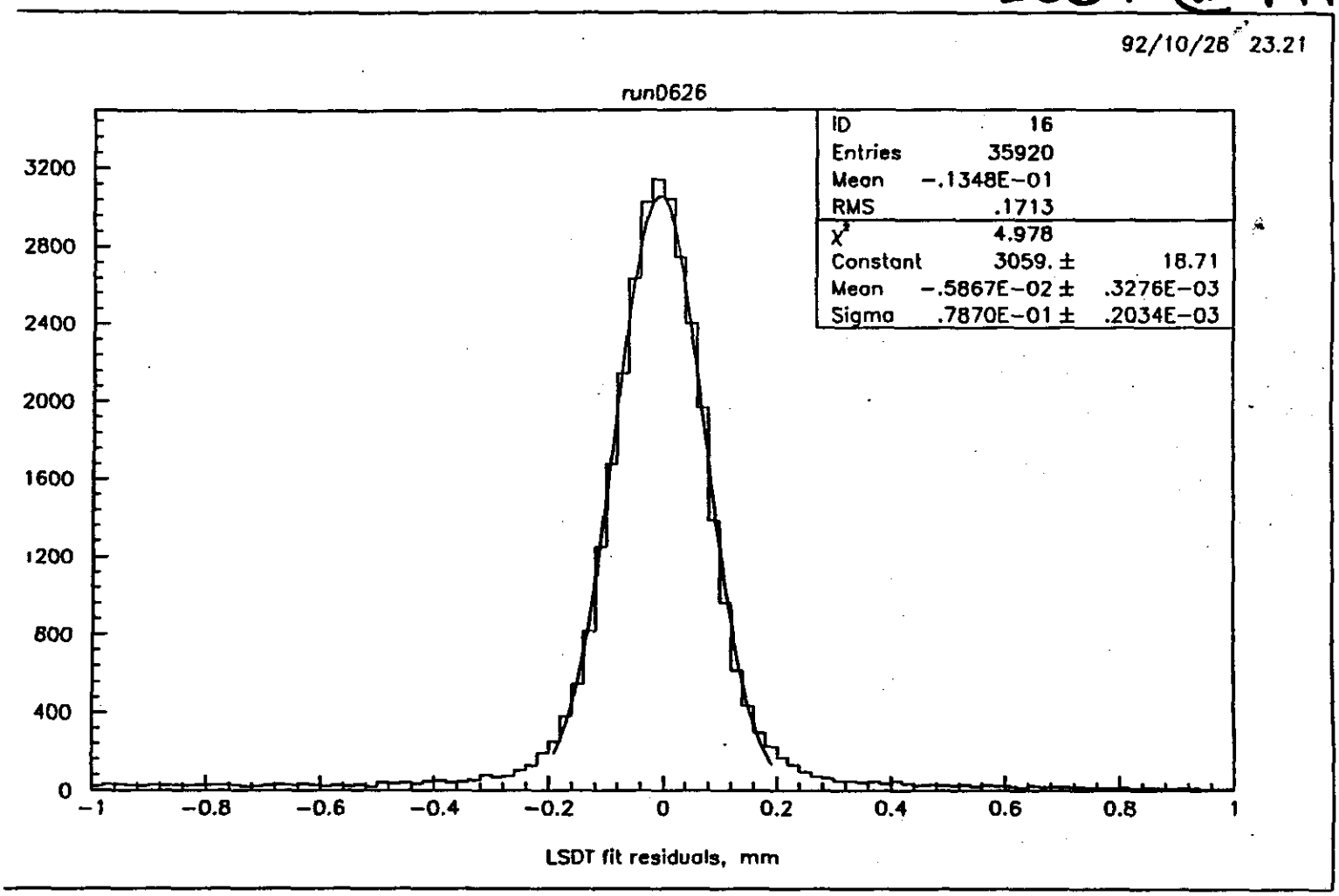

File Technologies Set Event Fit
CONTINUOUS
.0
Time (sec)
Tue Nov 3 10:16:12 1992
Run 533
Event 108
Thu Oct 15 17:47:35 1992
Y
X

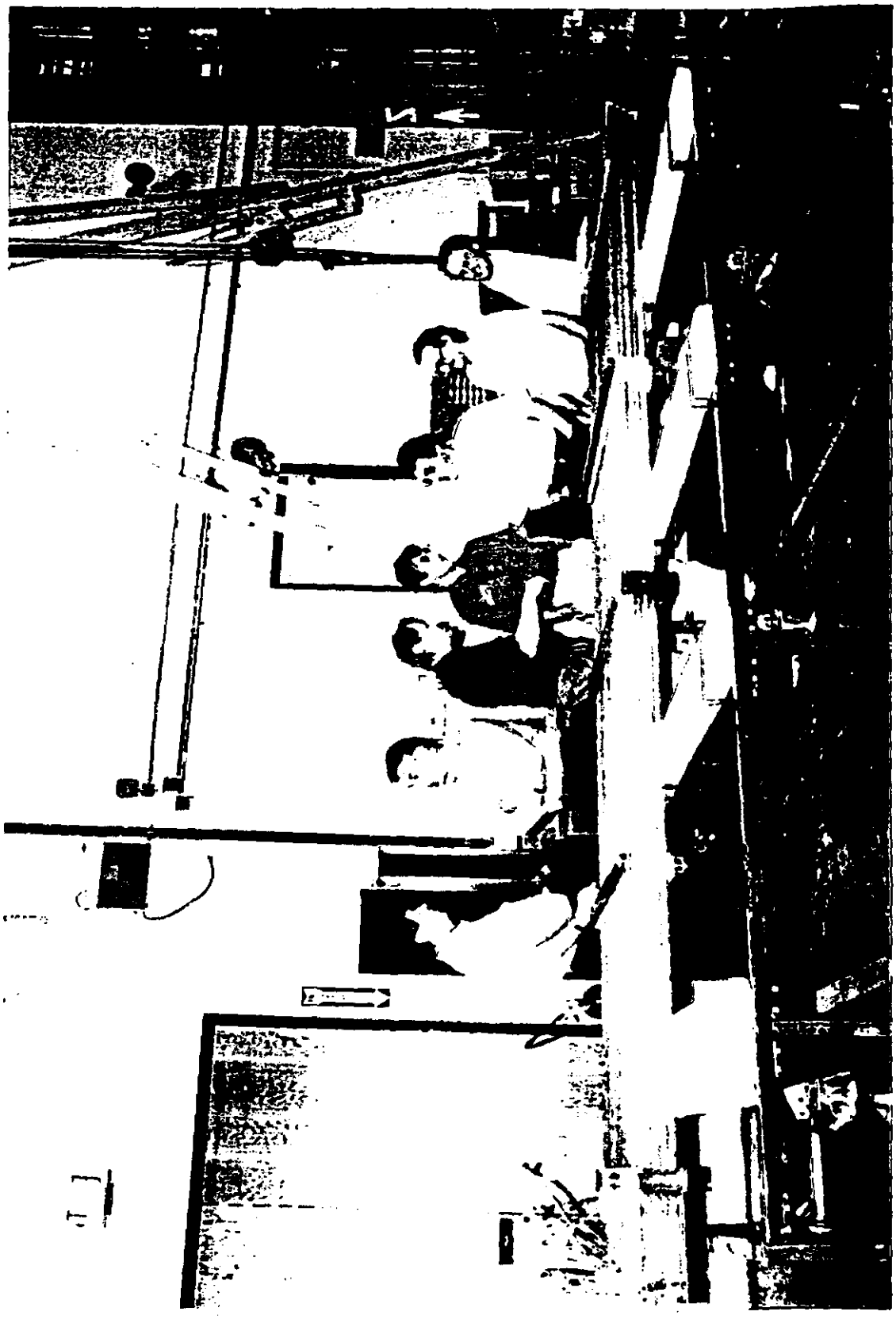
EAST


File Fit
Event Number 108
Residual = -0.006 mm
Residual = -0.099 mm
Residual = 0.210 mm
Residual = -0.105 mm
Chi squared = 6.507

$\sigma = 79\ \mu m$

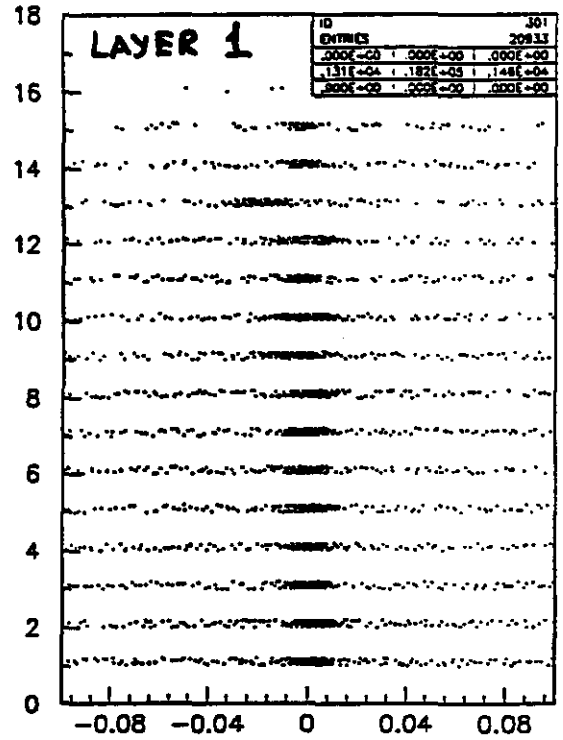
LSDT @ TTR



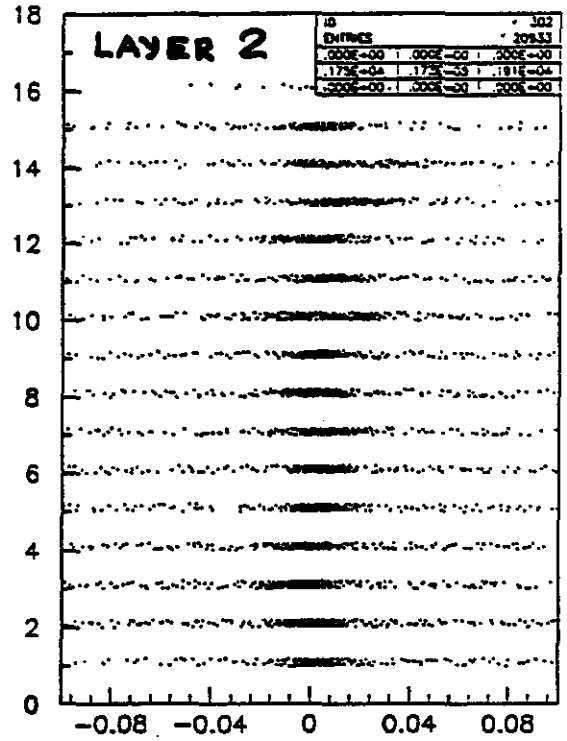


RESIDUALS VS TUBE NUMBER

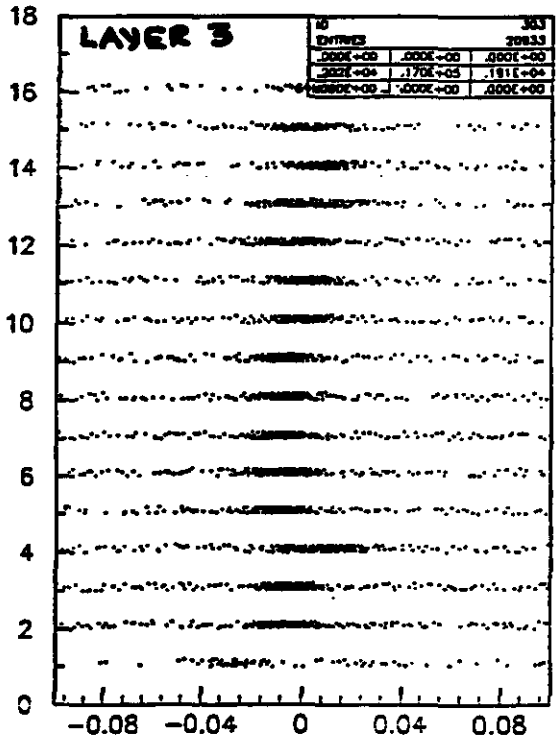
92/11/02 22.33



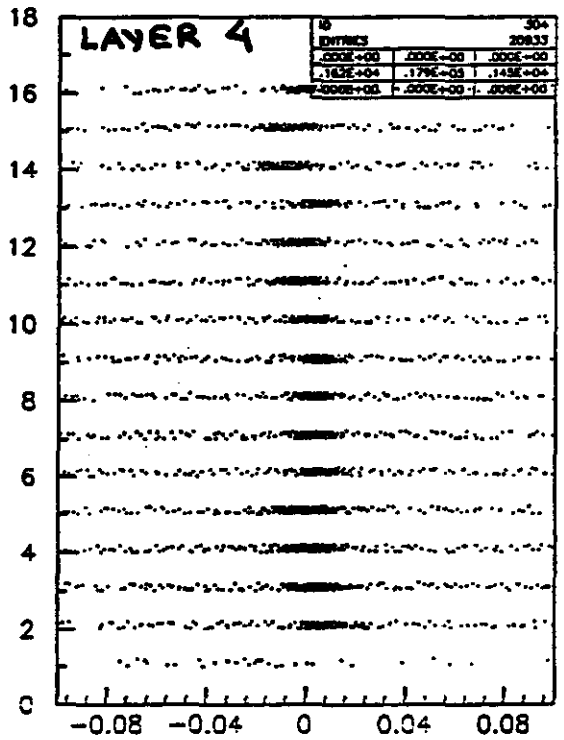
delta(Y) vs tube number for layer 1



delta(Y) vs tube number for layer 2



delta(Y) vs tube number for layer 3

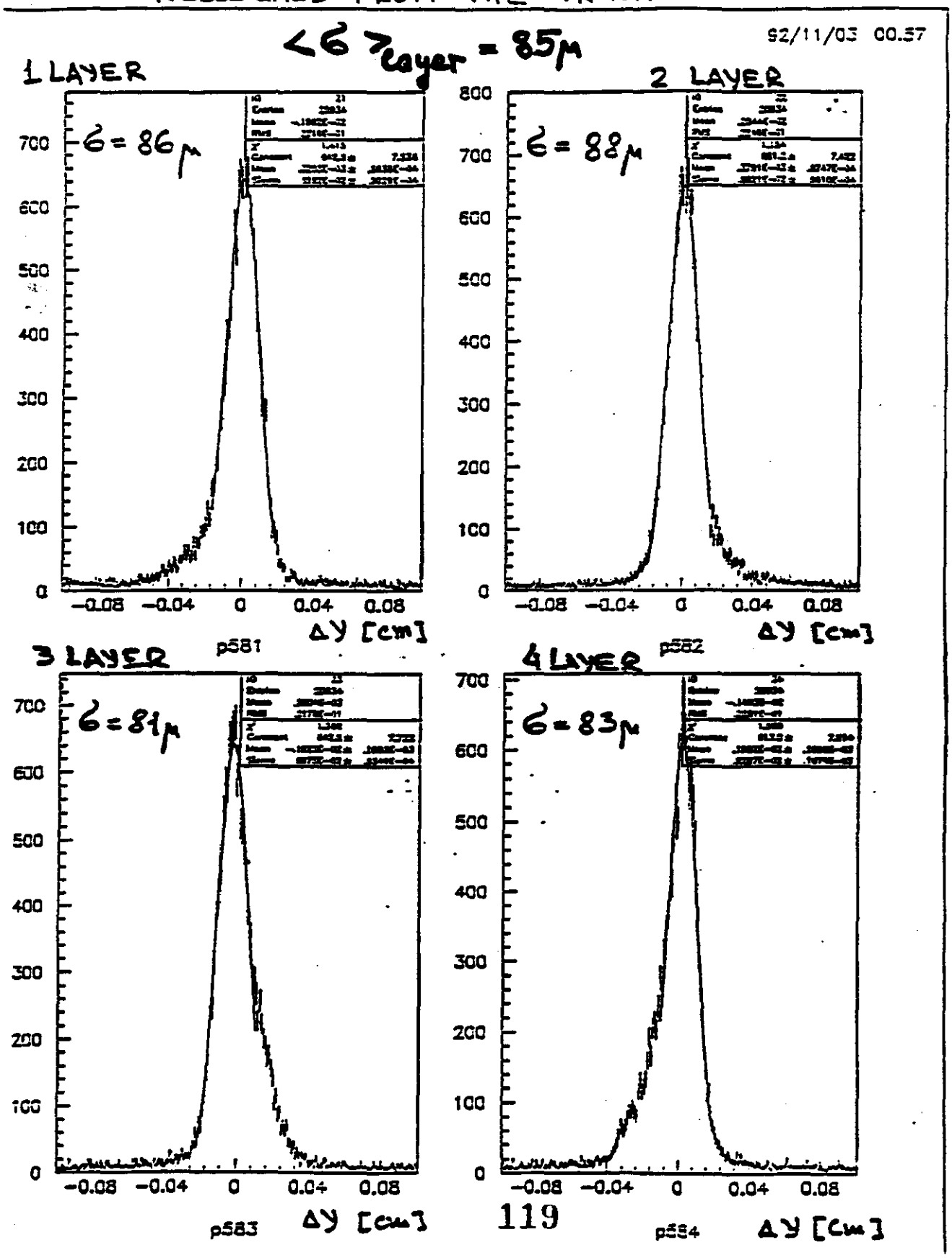


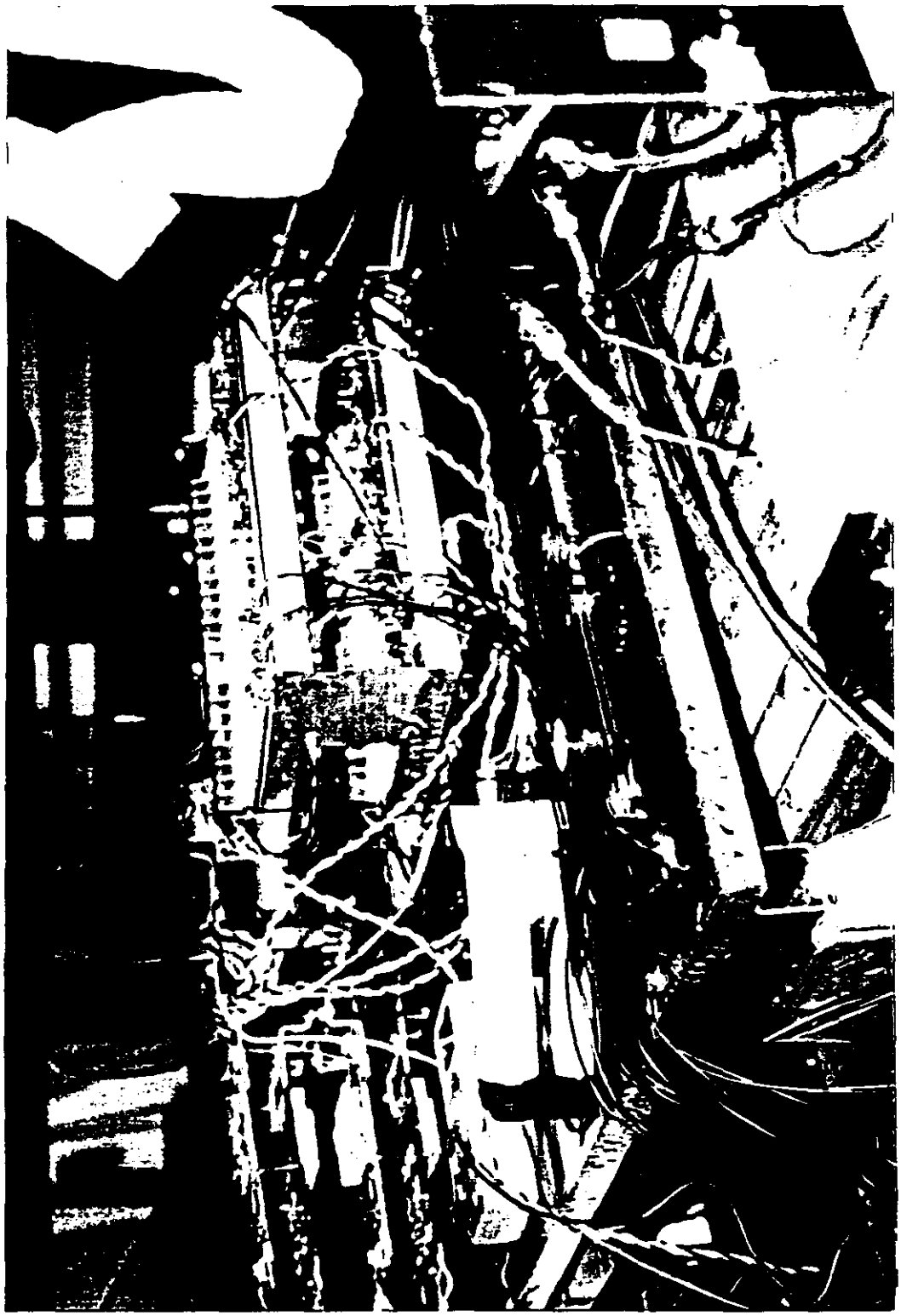
delta(Y) vs tube number for layer 4

DUBNA PDT

(Ar/C_4H_{10} (25/75) at 1 atm)

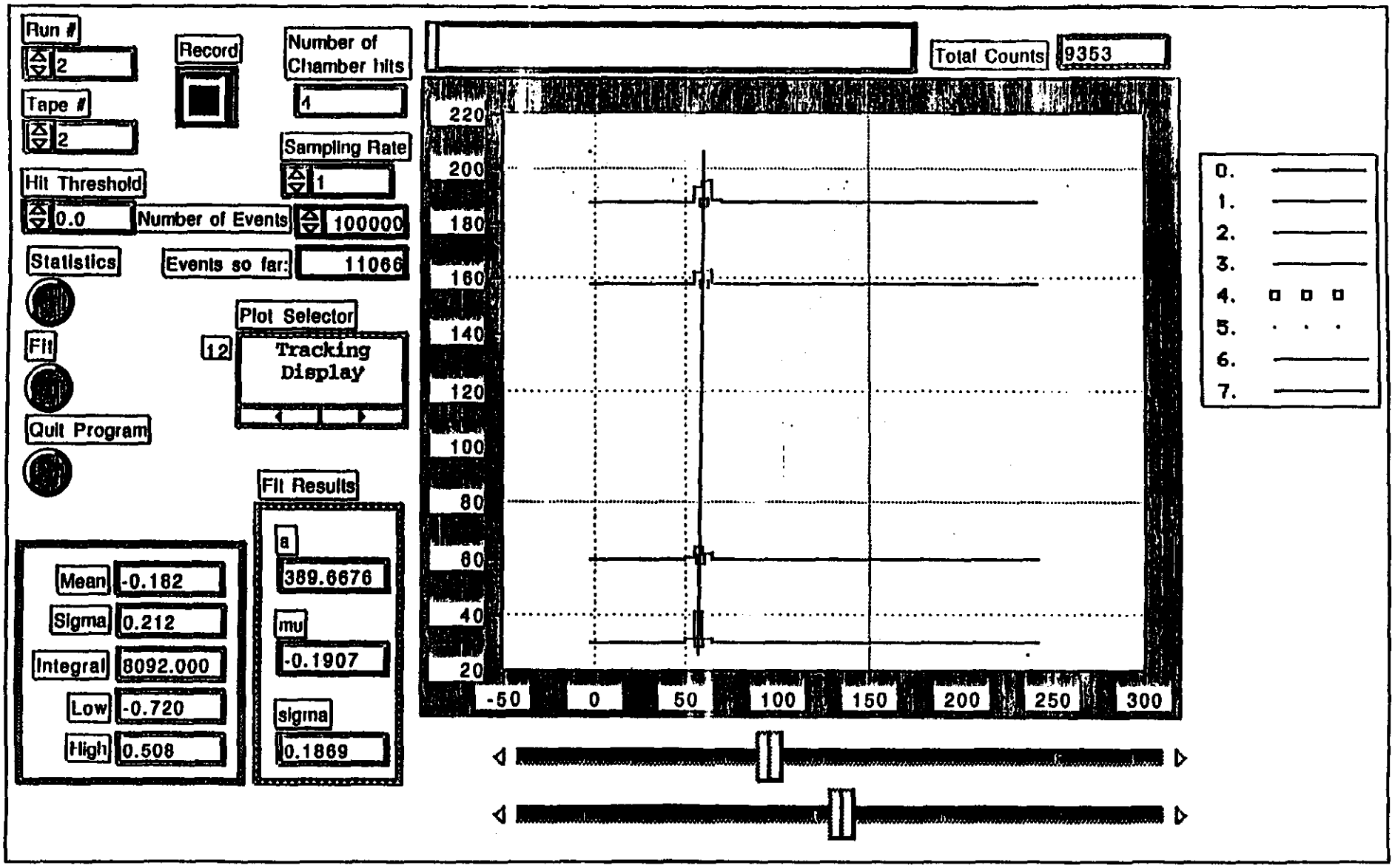
RESIDUALS FROM THE TRACK

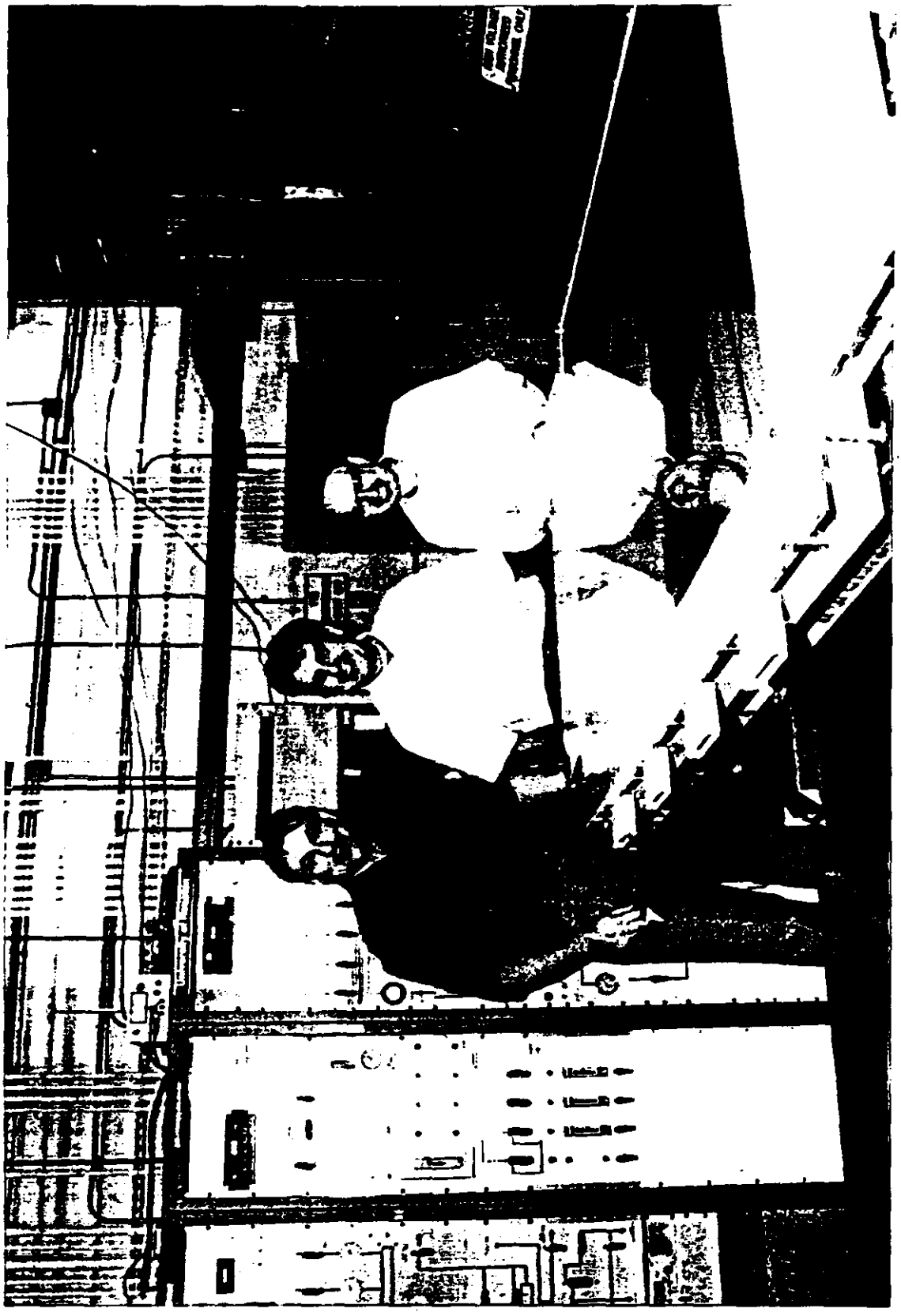




Fake Track Data (8mm)
Monday, October 19, 1992 01:43

Front Panel





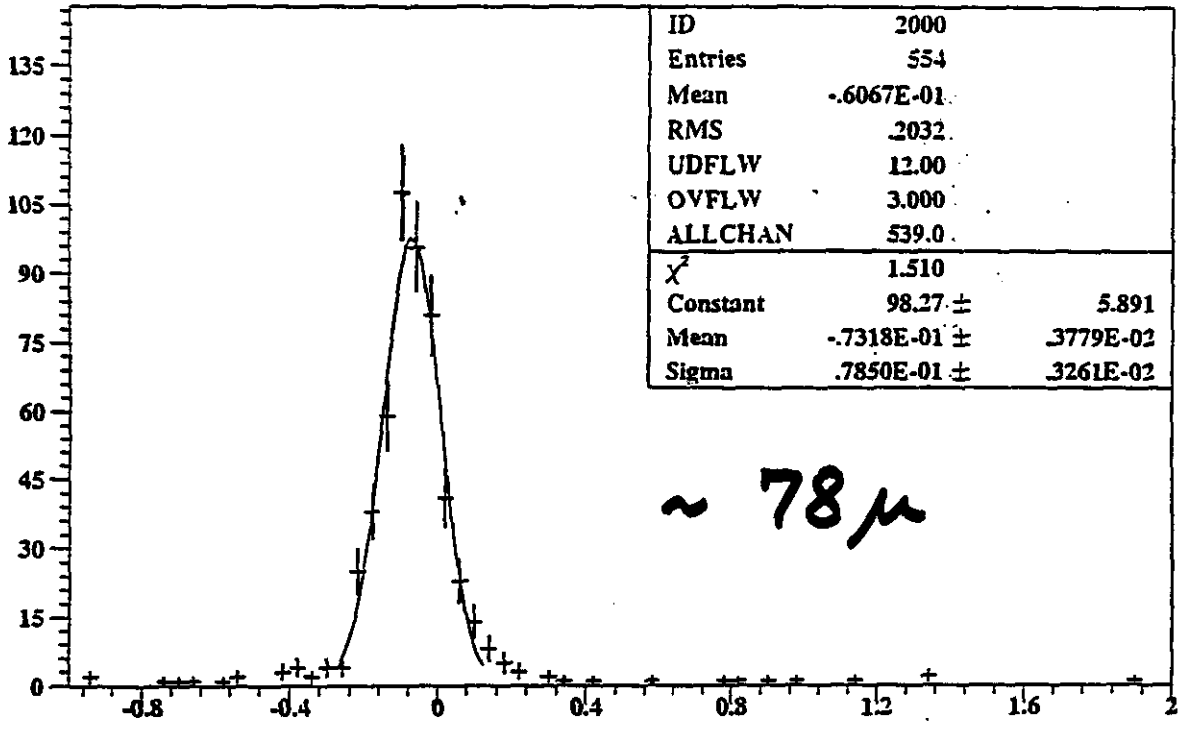
$\phi = \pm 1°$.

BNL .5x.5m

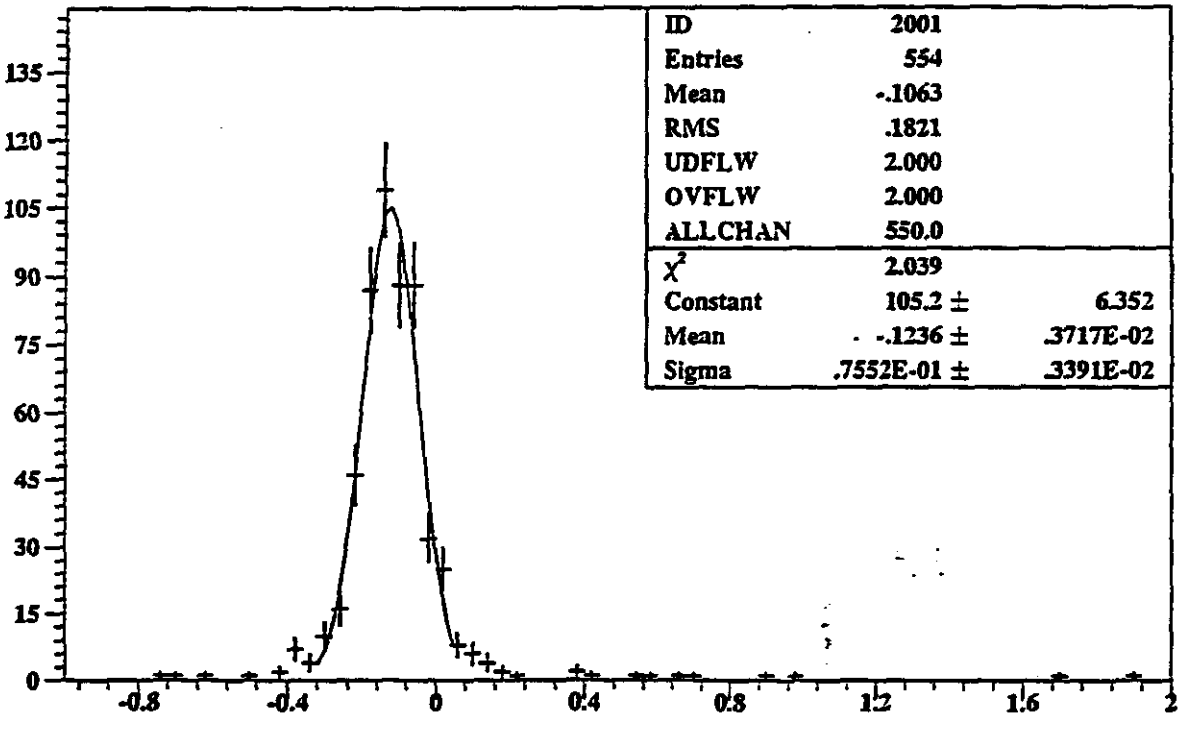
CSC

Run 12

92/11/28 00.41



Resiolution from ((x1-x2)-(x3-x4))/2



residual for plane 2,not in fit

BASELINE 2

CSC Everywhere

(Backup)
RDT's + RPC'S.

- **January Milestones.**

FY92 GEM R&D/Engineering Program

Tracker	Established microstrip and IPC configuration and requirements, conceptual design of support and cooling, construction and integration design, material selection.
Calorimetry	Conceptual design of noble liquid, scintillator and crystal options, prototype tests of all options in beams to support technology choice, crystal production and radiation resistance studies.
Muon	Chamber and support structure conceptual design, muon trigger study, Texas Test Rig construction and first tests of candidate chamber technologies, alignment design.
Magnet	Preliminary design of complete system in preparation for industry prime contract. Conductor selection. Manufacturing design.
Electronics	Conceptual design of front end system and prototype tests. Conceptual design of system architecture, data acquisition and trigger.

GEM Budget

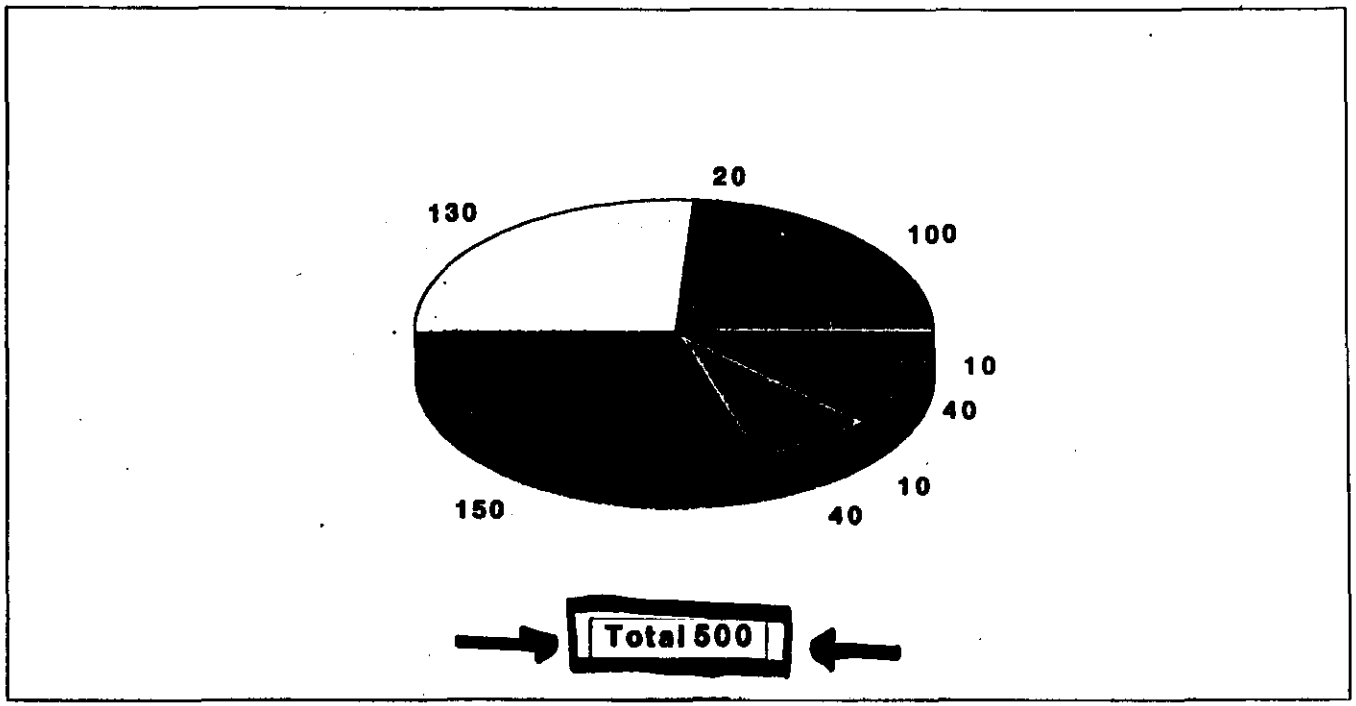
Subsystems	FY92 DOE	FY92 TNRLC	FY92 TOTAL	FY93 DOE	FY93 TNRLC	FY93 TOTAL
Tracker	1.0 M	0.0 M	1.0 M	2.0 M		2.0 M
Calorimetry	4.25 M	0.775 M	5.0 M	5.0 M		5.0 M
Muon	2.95 M	0.56 M	3.5 M	5.0 M		5.0 M
Magnet	5.1 M	0.0 M	5.1 M	13.0 M		13.0 M
Electronics	.5 M	0.515 M	1.15 M	3.3 M		3.3 M
Computing	0.0 M	0.0 M	0.0 M	0.5 M		0.5 M
Interface	0.0 M	0.0 M	0.0 M	1.0 M		1.0 M
Program Mgmt	2.1 M	0.0 M	2.1 M	3.0 M		3.0 M
Reserve	0.0 M	0.0 M	0.0 M	1.0 M		1.0 M
Total	**15.9 M**	**1.85 M**	**17.75 M**	**33.8 M**	**?**	**33.8 M**

FY93 Proposed GEM Program Objectives

Tracker	Mechanical structure, full scale IPC and microstrip prototype tests, final design, materials budget, beam tests.
Calorimetry	Engineer and begin construction of full scale prototype of noble liquid and scintillator modules. Preliminary design entire system. Beam tests of small scale prototypes. Resolve interface and integration issues. Forward calorimeter conceptual design.
Muon	Chamber and structure design. Manufacturing engineering. Full scale prototype tests. Finalize muon trigger design. Beam tests, alignment, scaled structure tests.
Magnet	Conductor and winding R&D completed. Final design with industry. Resolve all interfaces to detector.
Electronics	Final prototype tests. Complete data acquisition conceptual design.
Computing	System design. Slow control architecture completed. Magnet control design.
Interface Systems	Resolve forward, beam pipe, central detector support, and shielding issues. Complete conceptual design on all systems.

DESIGN TO COST $500M

Initial Cost Targets ($Millions)



- Magnet
- Structures
- Muon System
- Calorimeters (all)
- Tracker
- Computing
- R&D
- Trigger

GEM COST REVIEW SUMMARY
December 15, 1991
(with Liquid Argon, LSDT Option)
(Costs in millions of dollars)

Procurements/Fabrication	196	
Installation/Assembly	73	
Subtotal (Procurements and Labor)	269	
EDIA	93	(34%)*
Direct Costs	362	
Contingency	112	(31%)
Subtotal	474	
R&D	37	(14%)
Total Detector FY91 $M	510	

* % of subtotal (Procurement and Labor)

GEM COST ESTIMATE SUMMARY
June 23, 1992
(with Liquid Argon, LSDT Option)
(Costs in millions of FY90 dollars)

Procurements/Fabrication	197	
Installation/Assembly	58	
Subtotal (Procurements and Labor)	255	
EDIA	113	(44%)*
Direct Costs	368	
Contingency	97	(26%)
Subtotal	465	
R&D	25	(10%)
Total Detector FY90 $M	490	

* % of subtotal (Procurement and Labor)

Central Tracker Cost Scaling to 2 m diameter

Assumed Dimensions:

Silicon Tracker	4 cm inside radius	+ 1 cm rad.
	38 cm outside radius	+ 3 cm rad.
	200 cm long	same
IPC Tracker	39 cm inside radius	+ 3.5 cm rad.
	95 cm outside radius	+ 26 cm rad.
	300 cm long	same
Polyethylene	Barrel Section	
	97 cm inside radius	+ 26 cm rad
	102 cm outside radius	+26 cm rad
	End Sections	
	310 cm inside	same
	350 cm outside	same

Cost Scaling

Si Tracker	June 10 Cost Est. Current Design	New Design	Increment

* Note: These cost increases reflect a larger diameter that would allow for an 18 cm fwd region if the design were to evolve in that direction.

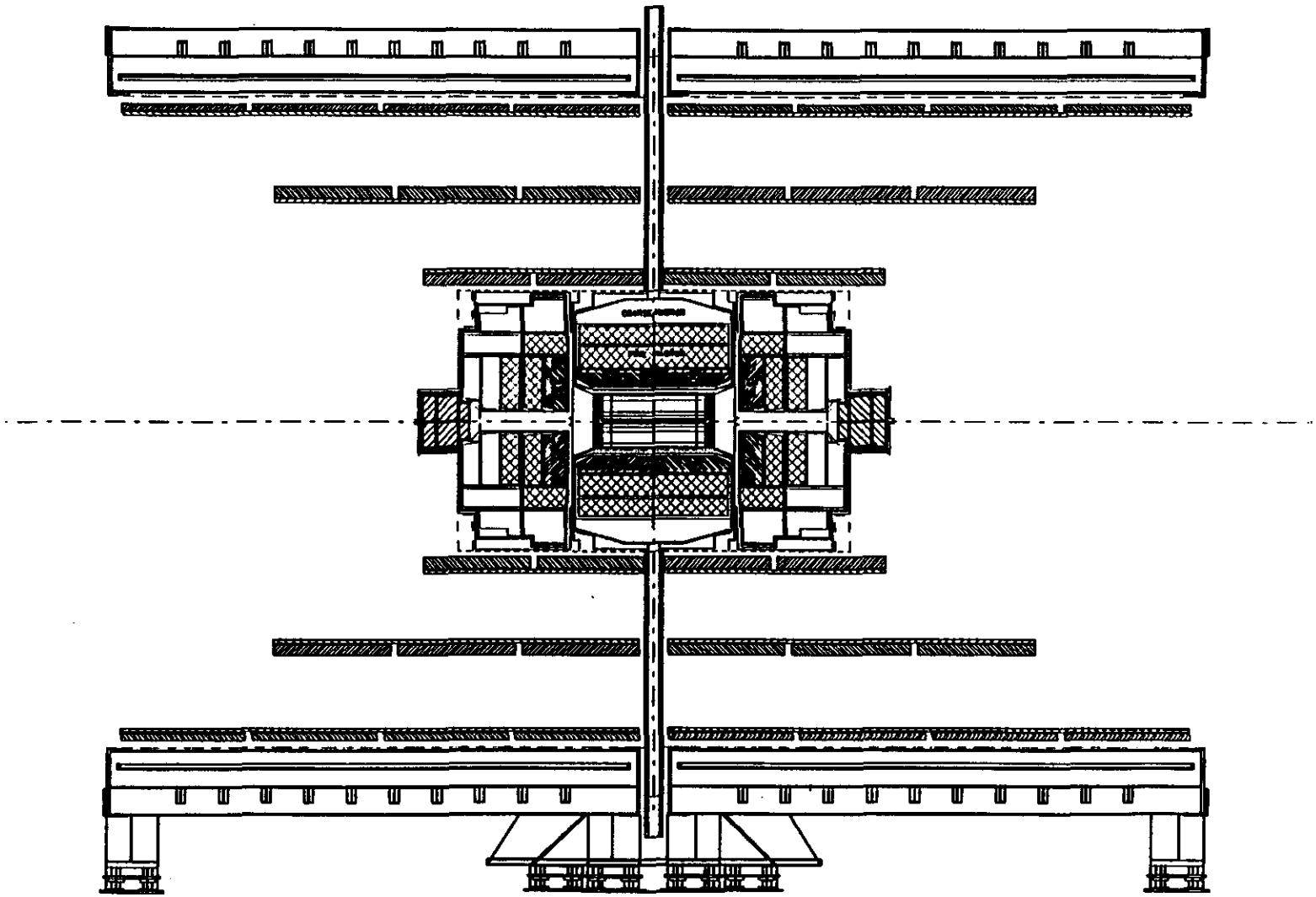
Electronics			
Power Cable & FO readout	These cost options are documented in the 12 vs 18 cm ladder cost sheet.		
Si Det. & Assy			
Cooling Rings			
Mechanical Structure*			
Support Shells	these probably don't change significantly either way		0
Outer & End Gas encl	35 cm r	38 cm r	10%
	431 k$	474 k$	43k$
Inner Gas Enclosure	8 cm r	10 cm r	25%
	60 k$	75 k$	15 k$
Space Frame	Hex. < 35 cm	Oct. < 38 cm	10 %
	New design is not yet costed, but the central spoke and complex joints may increase the cost 10%		33 k$
External Systems	No cost difference in the external cooling and safety systems is expected.		Ok$
Si Mech. Structure Total			91 k$

IPC Tracker	Current Design	New Design	Increment
Electronics			
Fwd Mod. Panels	Assume these costs increase by the ave. radius which is		30 %
	360 k$	468 k$	108 k$
Cent Mod Panels	Assume these costs increase by the ave. radius squared		68%
	204 k$	342 k$	138 k$
Cathode pads			—
Module Frames			—
Windows & Wires			—
Cooling Channels	Since the number of channels and heat load is not expected to change there would be no cost differential.		O k$
Ext Gas & Cooling Sys.	There is no expected cost increase for either one of these systems.		0 k$
Support Structure			
Bulkheads	25 sq ft	46 sq ft	84 %
	15 k$	28 k$	13 k$
Cylinders	69 cm r	95 cm r	38%
	44 k$	61 k$	17 k$
End Cap Gas Encl.			
Boron Poly.	3.7 k lbs	5.7 k lbs	54 %
	39 k$	60 k$	21 k$
IPC Total			300K w/o 3 items
Total Incremental costs			—

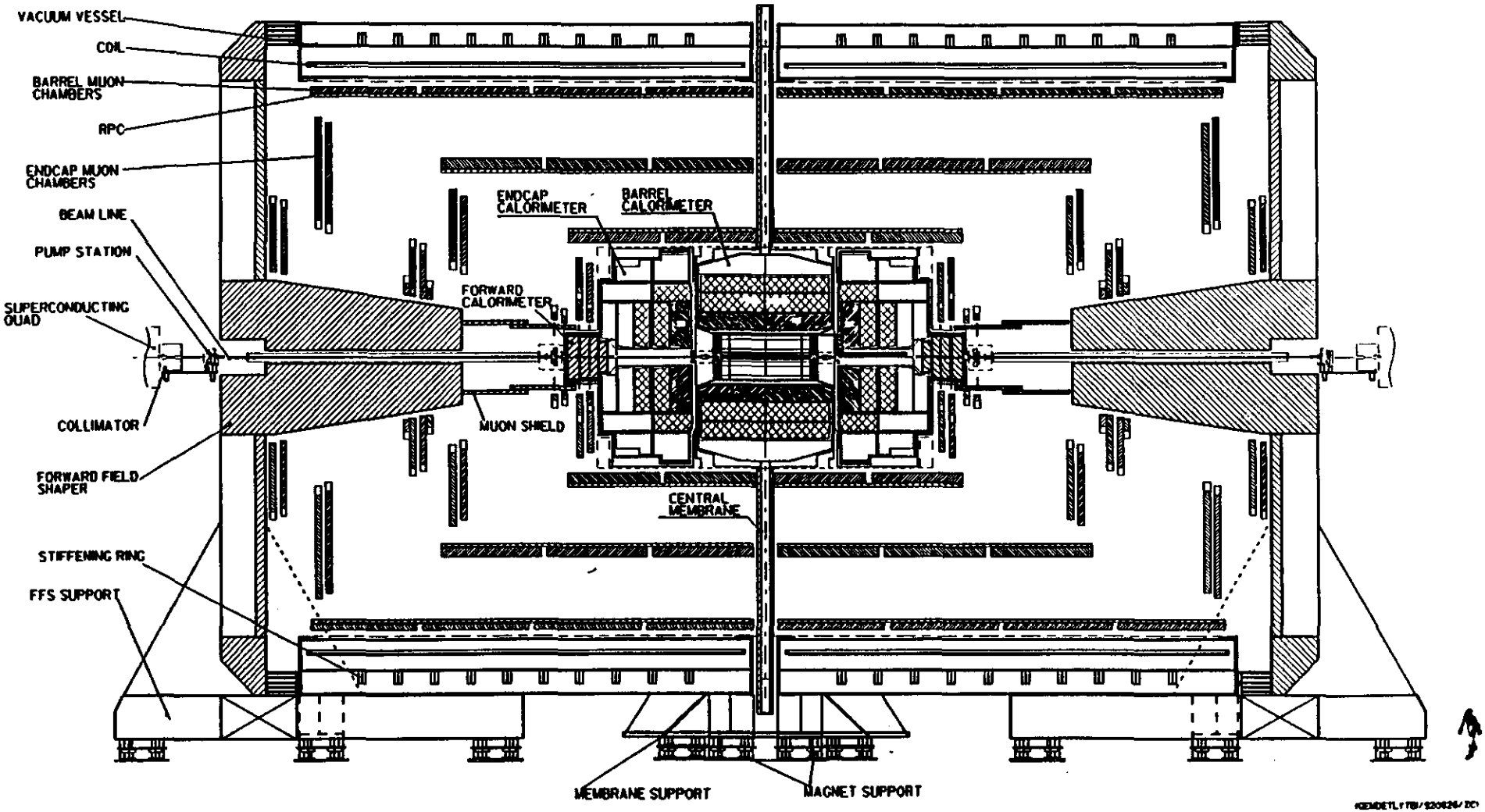
Note: there may be many small additional added costs such as increased power cable lengths, cooling distribution lines and gas manifolds lengths that should be accounted for.

STAGE : FORWARD CSC
FORWARD FIELD SHAPER

GEM DETECTOR LAYOUT



GEM DETECTOR LAYOUT



GEM Staging Scenarios

- We are considering various staging scenarious.
- If funding is short we will stage.

Model

"Stage Forward Muons"

Forward Field Shaper

• Total Cost	$17.3 M
• Design and Specify all interfaces precisely	- 0.9 M
Savings	$16.4 M

Forward Muons (CSC's)

• Forward CSC's	$29.7 M
Needed R&D/Engineer	- 2.5 M
	$27.2 M
• CSC Electronics (Developed for IPC)	$16.0 M
Savings	$43.0 M

Total Savings: $60 M

GEM TDR ORGANIZATION

TDR TEAM

- EDITORS:
  H. Newman, N. Baggett, J. Reidy, G. Yost
- PRODUCTION GROUP:
  H. Durden, L. Fowler, C. Thomas, L. Ballard

SCHEDULE: TDR SUBMISSION MARCH 15

- Final Draft To Editors March 1;
  Intermediate Drafts Due 12/15, 1/12, 2/9.

GENERAL TASKS

- Overall Document Review, Editing, Schedule
- Coordination With Lead Authors; One Author Responsible for Each Section Submission
- Centralization at SSC Lab; Coordination by Meetings, Videoconference, Network, etc.

TECHNICAL TASKS

- Text Formatting, Standardization:
  Limited Conversion from TeX, LaTeX
- Figure Conversion, Placement
- Provide Network-Accessible Versions: RTF, ASCII
- File Distribution, Local and Network Access Control

STANDARDS

- MicroSoft Word (MAC or PC)
- Fonts, Page Layout, Section Sequencing
- File Transport (RTF) Via Internet

GEM TDR OUTLINE

Due Date March 15

	Section	Pages	Lead Authors
1	Executive Summary; Detector Overview	25	Barish, Willis
2	Physics Goals, Performance, Simulations	80	Lane, Barish
3	Magnet Technical Design Report	100	Stroynowski
4	Muon Spectrometer	100	Taylor, Marx
5	Calorimeters	100	Willis, Gordon
6	Tracker	100	Baltay
7	Electronics	100	Marlow, Shaevitz
8	Computing, Controls, Networking	25	McFarlane,Cormell
9	Summary of GEFUR	25	Harris
10	Installation Plan	25	Harris
11	Summary Cost Estimate; Responsibility Matrix Funding Plan	10	Sanders, Barish, Willis
12	Summary of GEM Project Management Plan	10	Sanders, Baltay
13	Summary Safety Analysis	10	Woolley
14	Operational Plan/Upgrades	20	Barish, Willis
15	Test & Calibration Plan	20	Yost
		750	Pages

SEPARATE DOCUMENTS	
GEM Project Management Plan	Sanders, Baltay
Cost/Schedule Baseline and WBS Dictionary	Barish, Willis
GEM Conceptual Safety Analysis Report	Woolley

GEM TDR DRAFTS

DECEMBER 15

- Complete Draft of More Advanced Sections: Magnet, Tracker, Installation, etc.
- Less Advanced Sections (e.g. Calorimetry, Muons): Complete Detailed Outline, Partial Draft; Plan and Schedule for Final Draft.

JANUARY 12

- Drafts Due For All Sections
- Final Draft for More Advanced Sections
- Preliminary Drafts:
  - Complete Section Structure (3 Levels)
  - Summary of All Missing Text, In Place
  - Status Report: Plan, Schedule, Major Tasks for Final Draft

FEBRUARY 9

- Complete Draft for All Sections
- Status Report and Summary-In-Place of Planned Revisions, For Sections Not In Final Form

FEBRUARY 15 Onwards

- Majority of Sections Completed; As Many as Possible Prior to March 1
- Weekly Working and Review Group Meetings: General Status, Problem Areas, Scheduled Focus On Individual Sections

MARCH 1

- All "Final" Drafts Submitted On or Before This Date to TDR Team
- Final Section-Editing; Global Editing In Parallel
- Document Processing: Final Text and Figure Layout.
- Document Reproduction In Time for Submission

GEM TDR SUBMISSION To SSCL: MARCH 15

Calorimetry

Bill Willis

GEM CALORIMETER

BASELINE 2 FOR T.D.R.

IMPROVEMENTS WITH CONTINUITY

- LKR/Pb IN BARREL

  σ_{EM} $7.5 \rightarrow 5.7$; e/h = LA/Cu

- FINE FRONT EM

  $\sigma_\theta \Rightarrow 39\,mr/E^{1/2}$, π^0 REJECT. 2-3

  KEEP "CLEAN" E.M. ELECTRODES

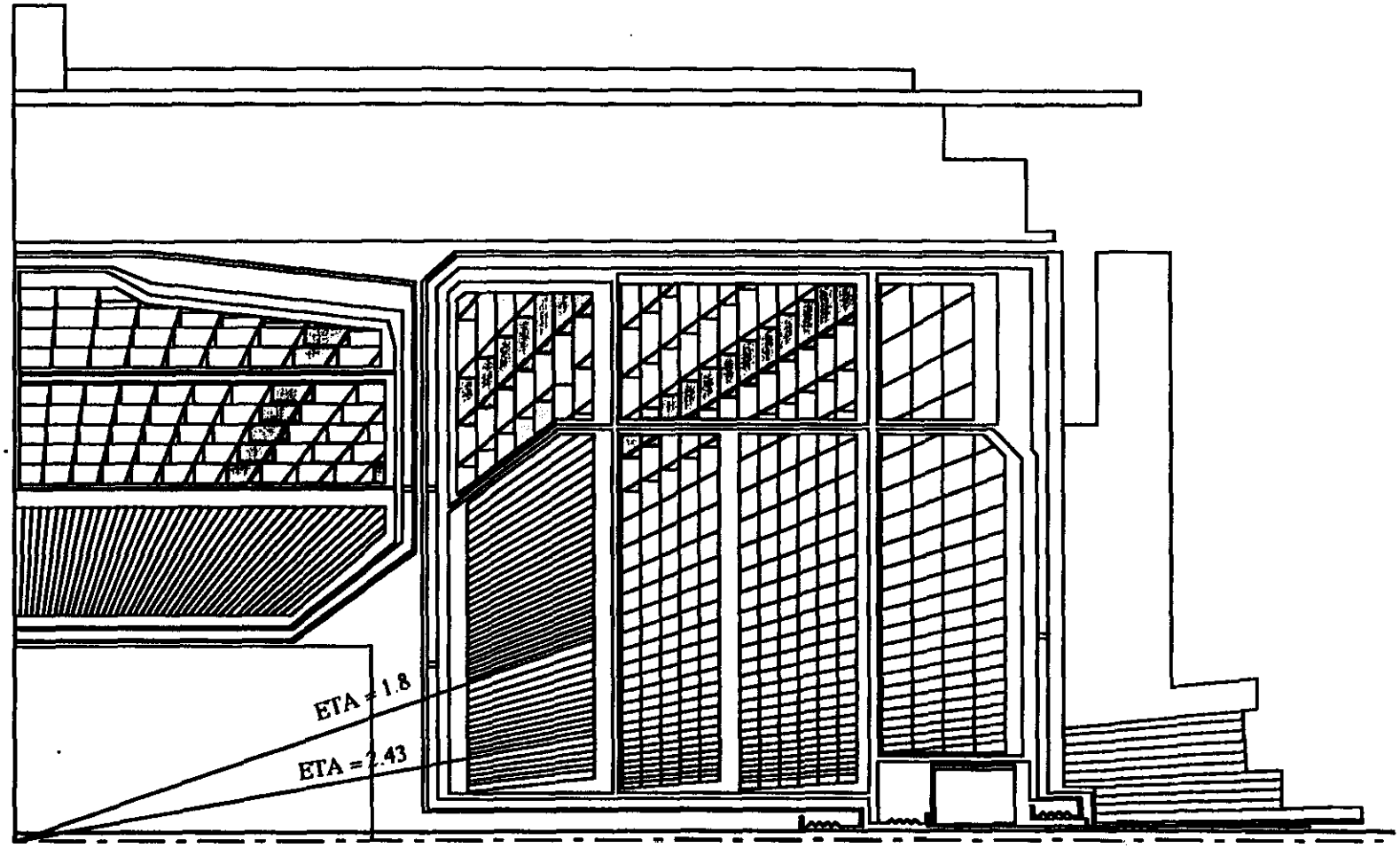
- LIQUID CALORIMETER $\lambda = 12 \rightarrow 6$

- HYBRID PERFORMANCE DESCRIPTIONS $\approx$ UNCHANGED

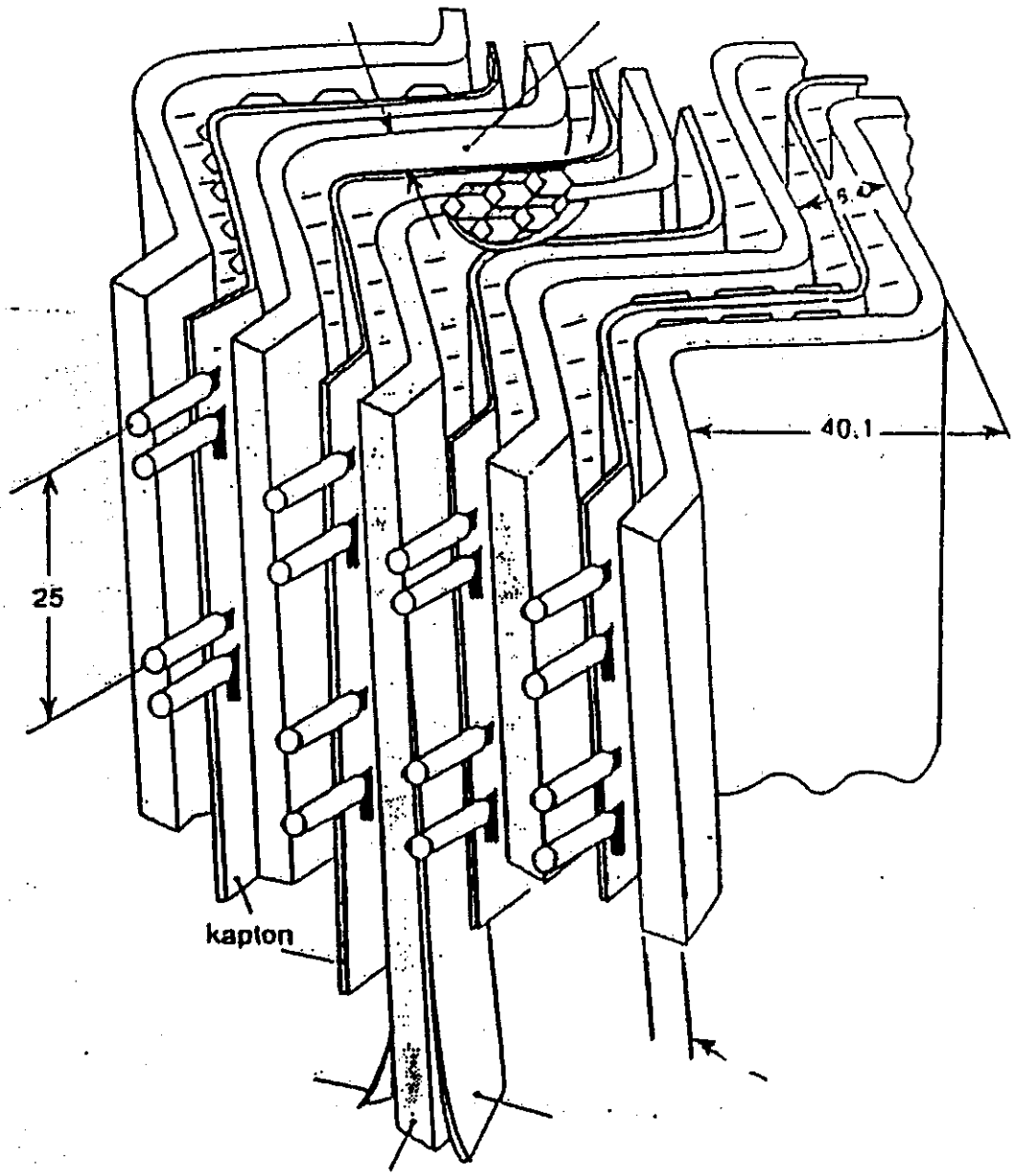
* BEAM PIPE AND NEUTRON CONSIDERATIONS REQUIRE CHANGES IN FORWARD CAL.

SEGMENTATION IN ETA: EM = .0261
HADRONIC = .08

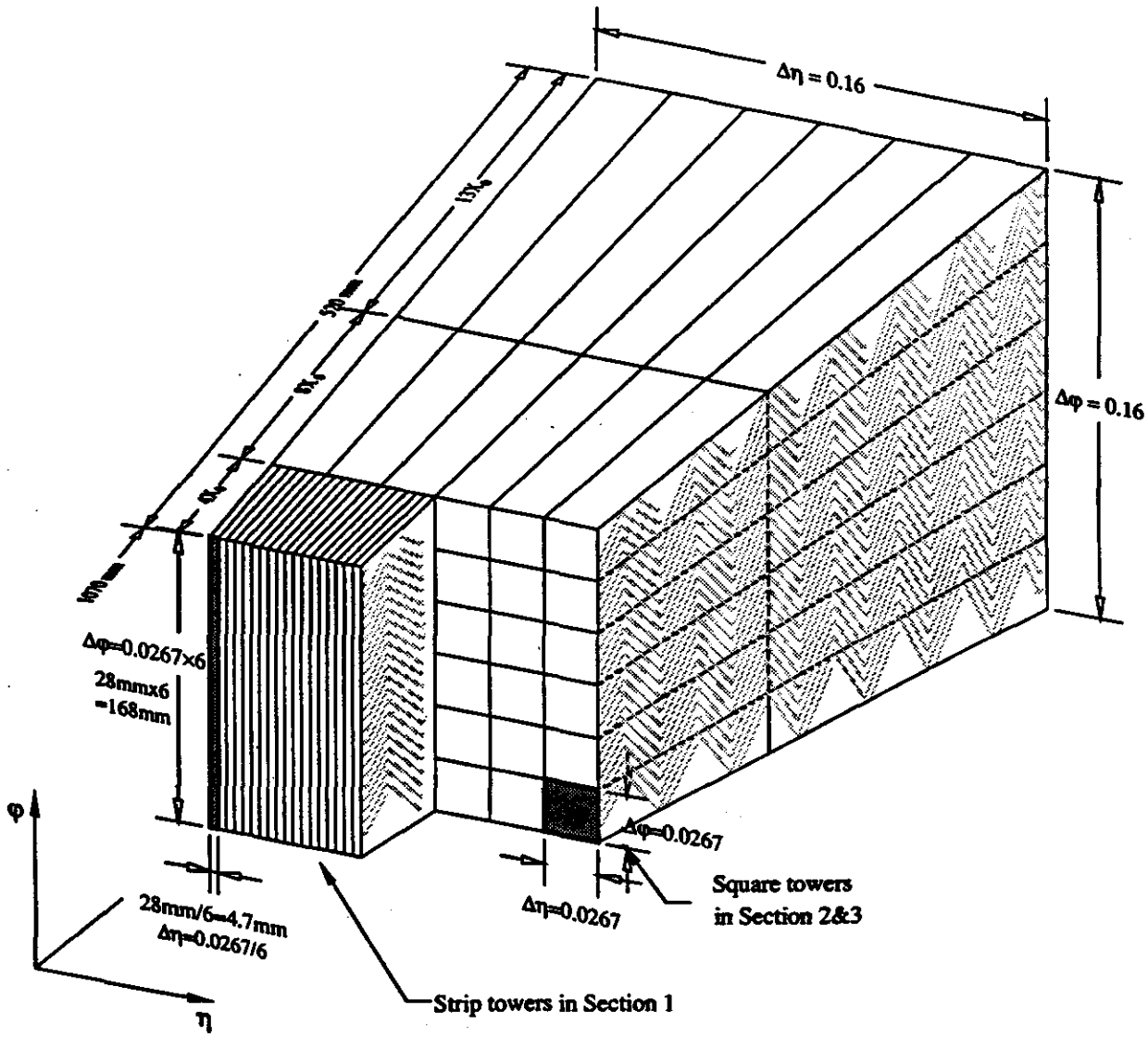
2 CM MINIMUM TOWER



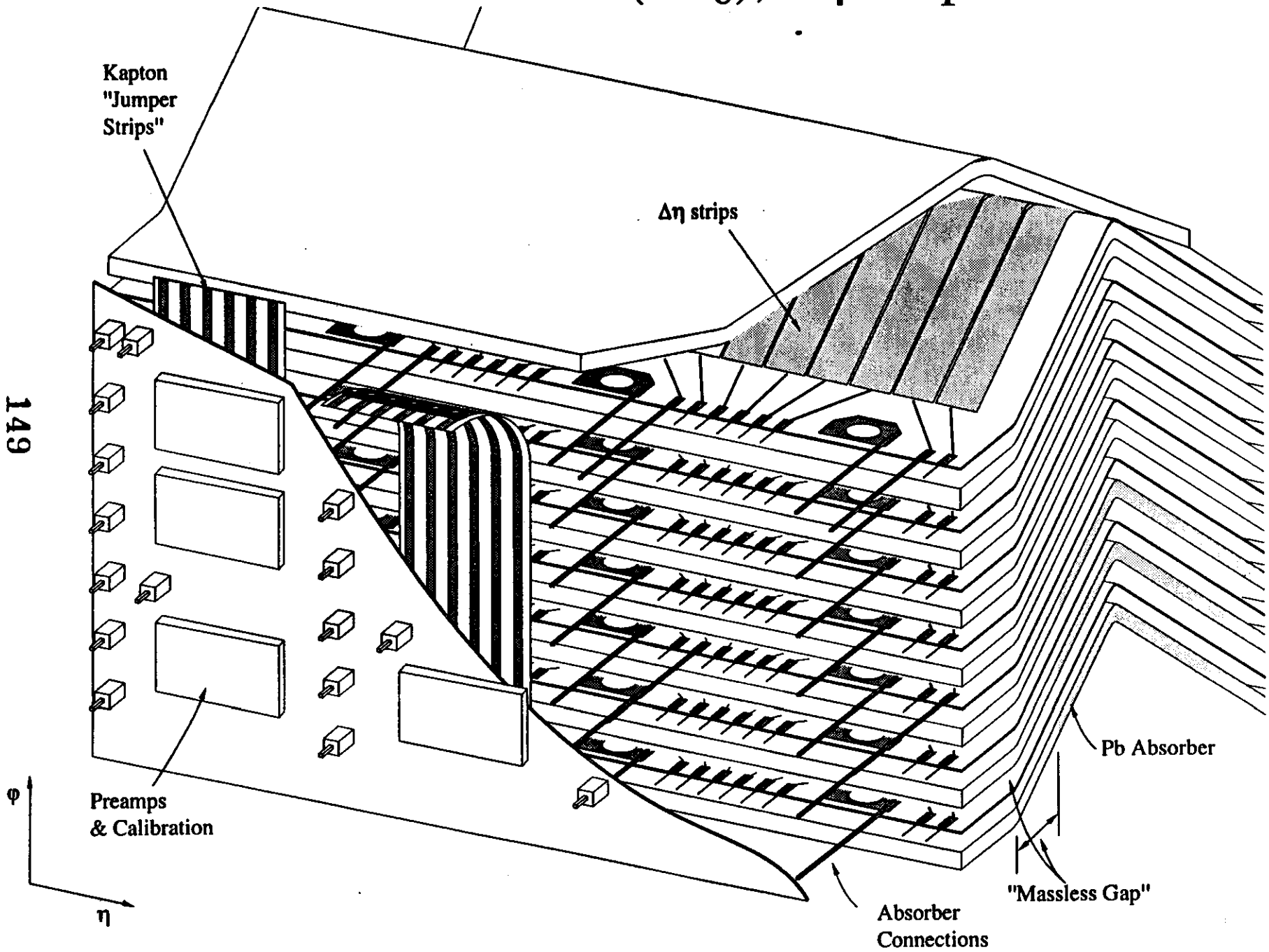
ADAMS:BL2SEG:11/30/92


40.1
25
kapton

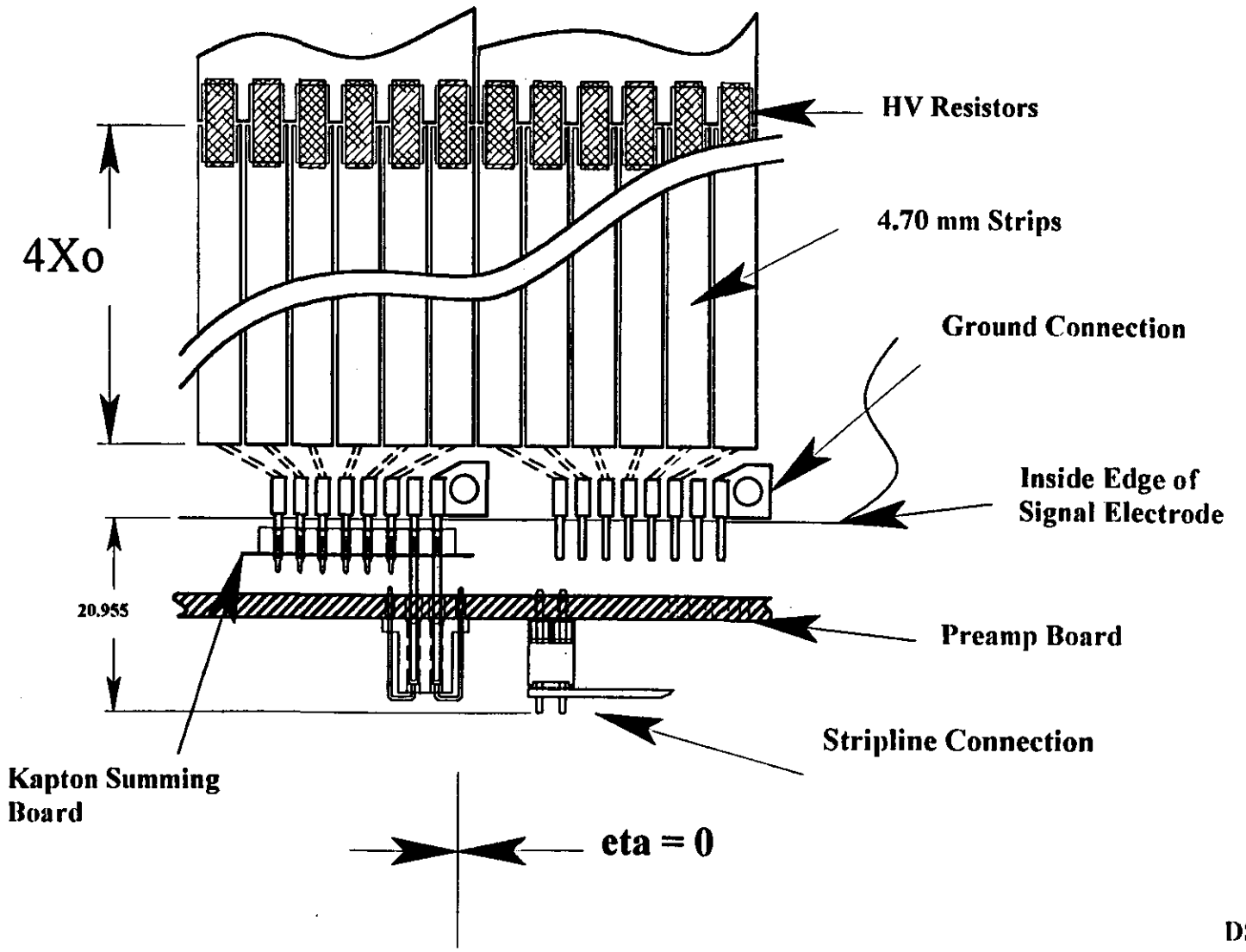
EM Accordion Segmentation



EM Accordion Electrodes
1st Section ($4X_0$), $\Delta\eta$ Strips

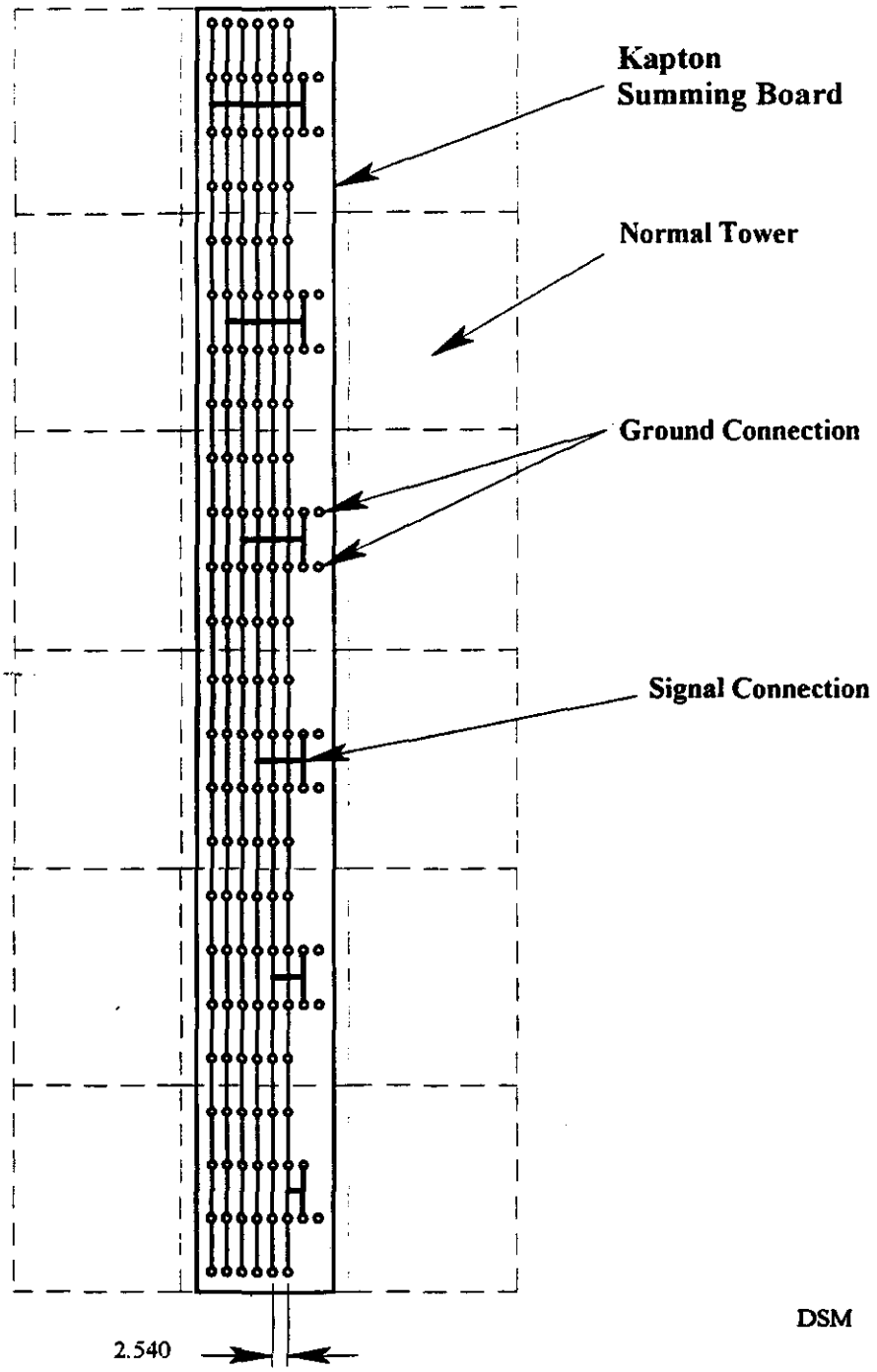


Position Detector

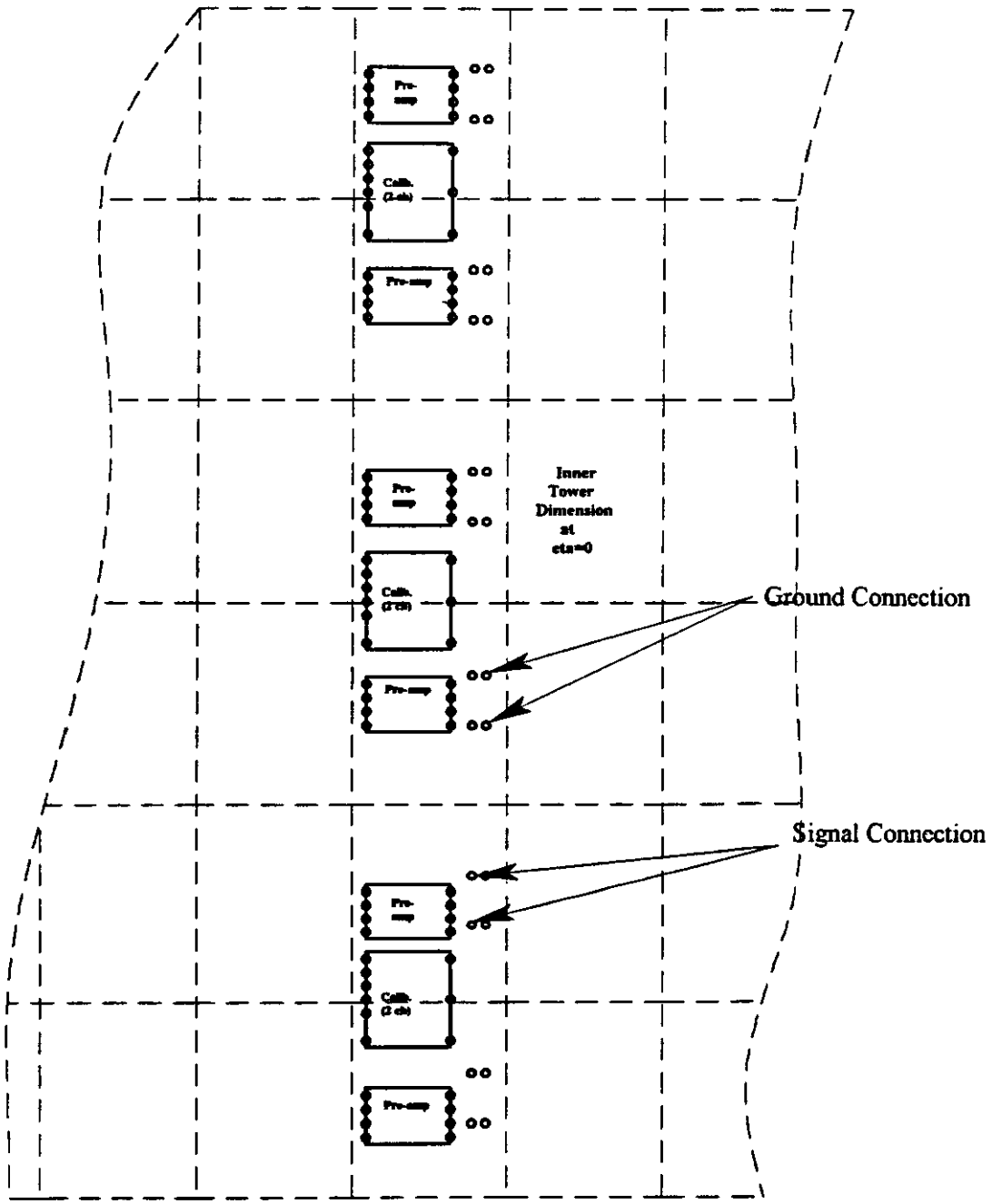


DSM

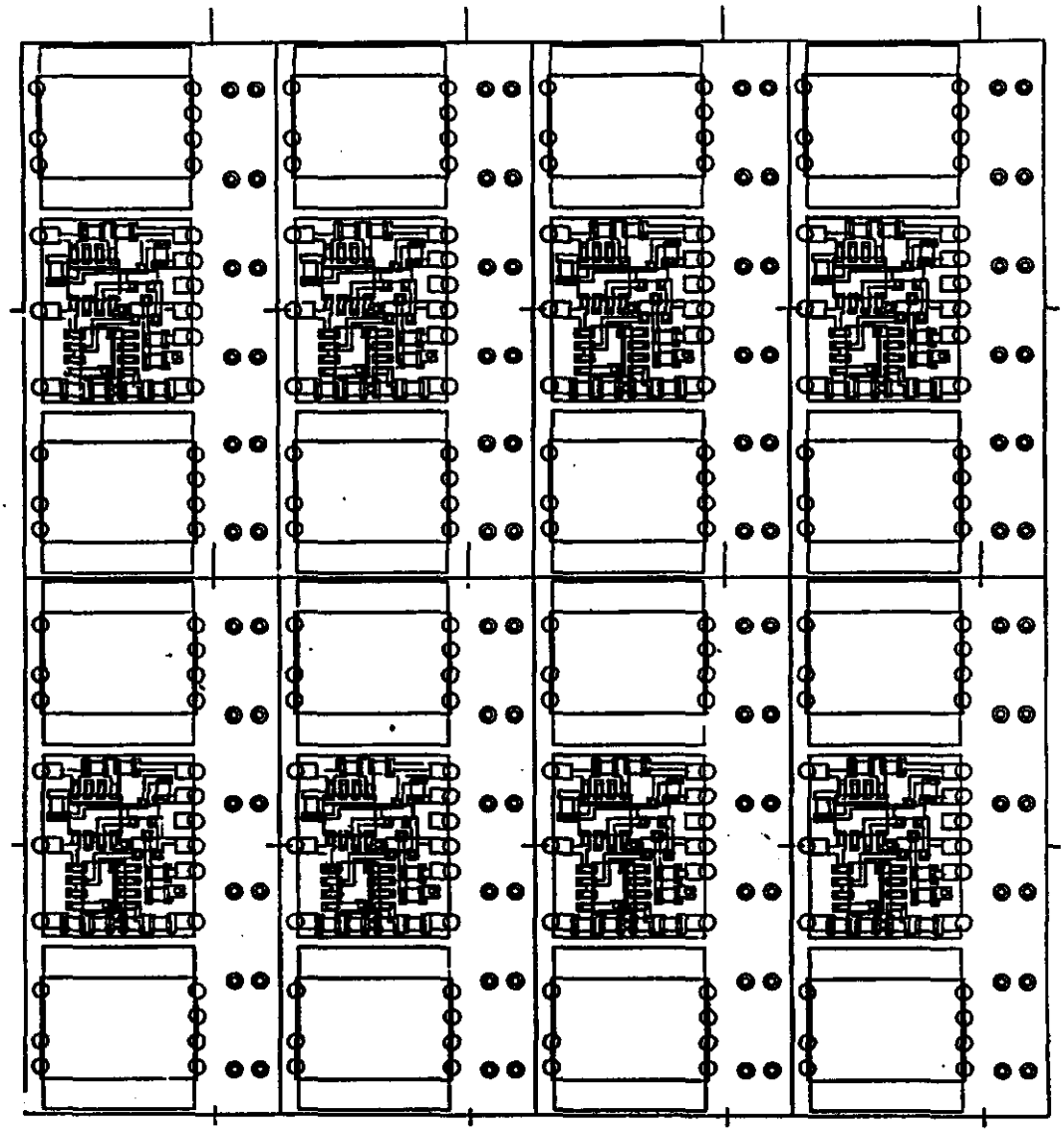
Kapton Summing Board

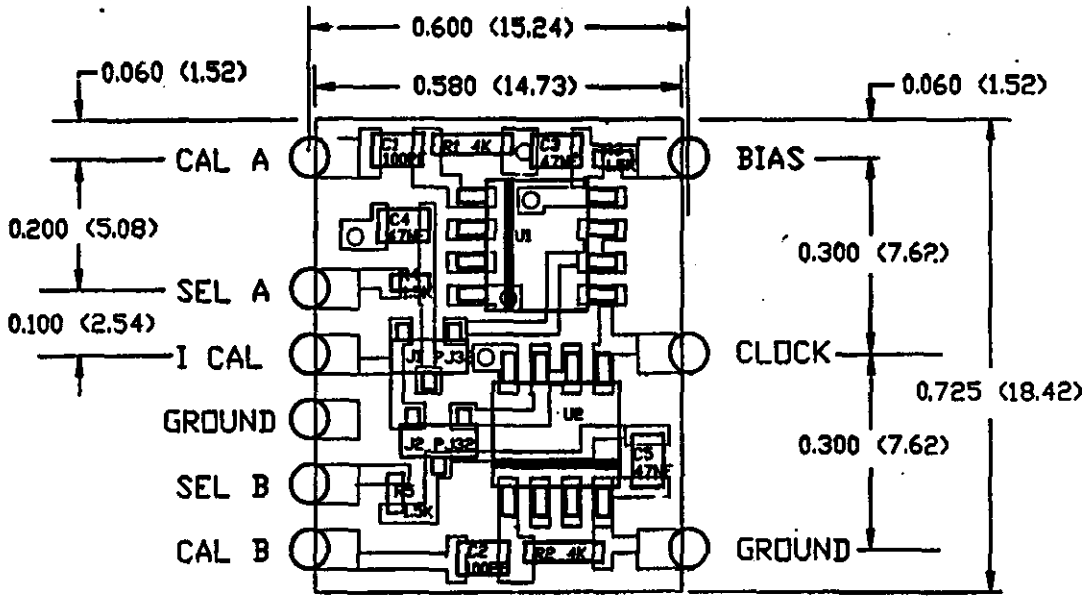


Preamplifier Board
(component layout)



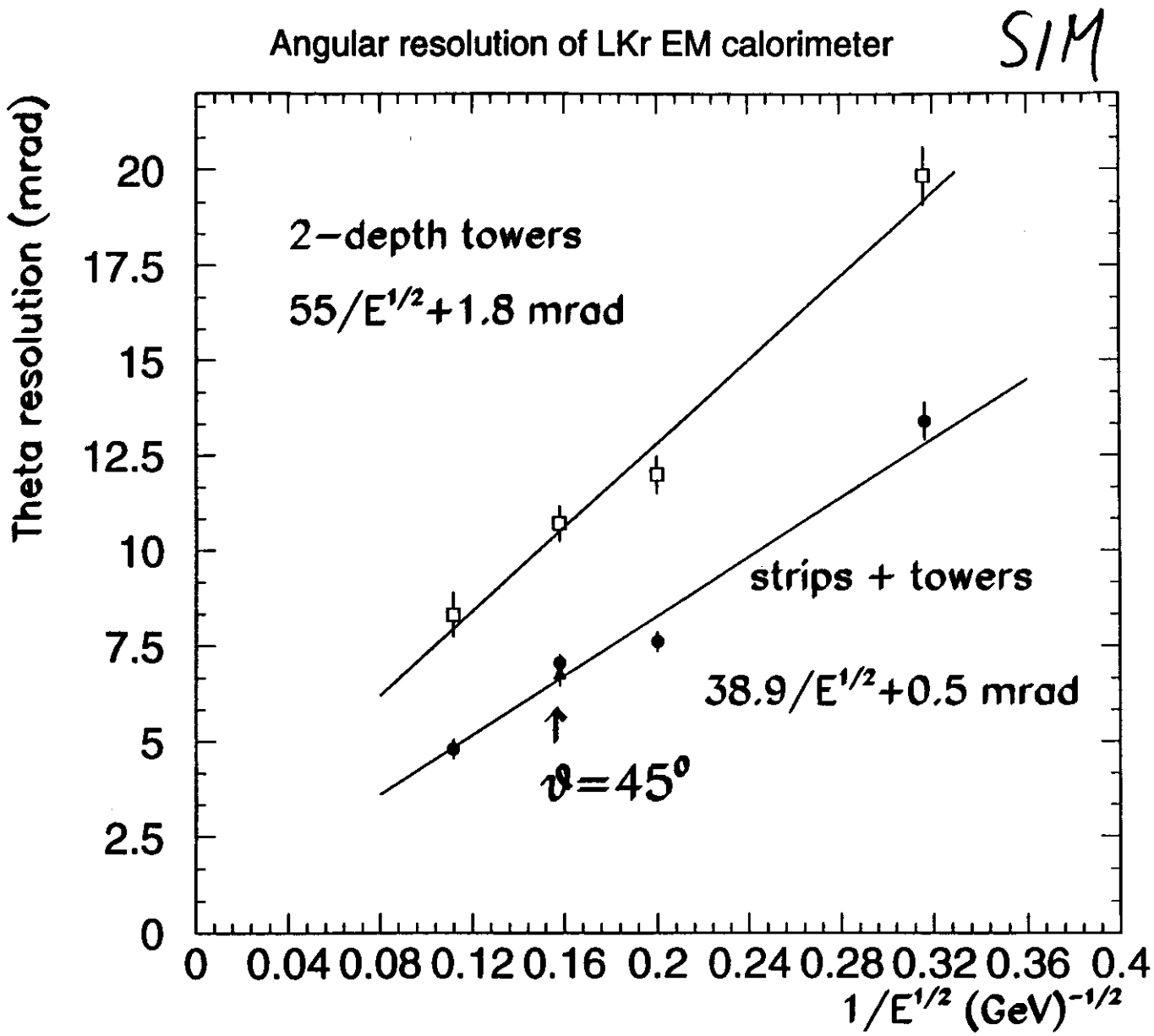
DSM



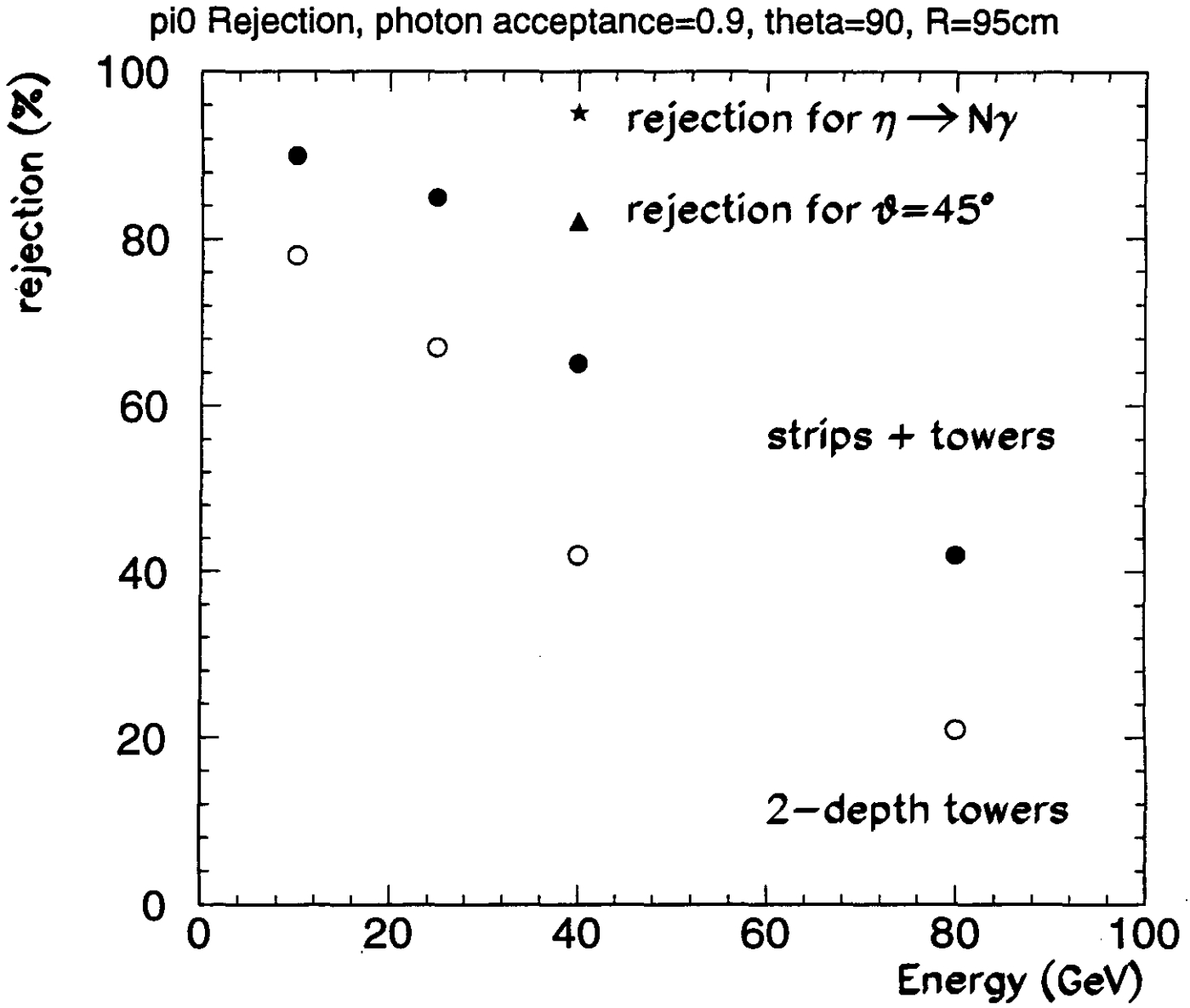


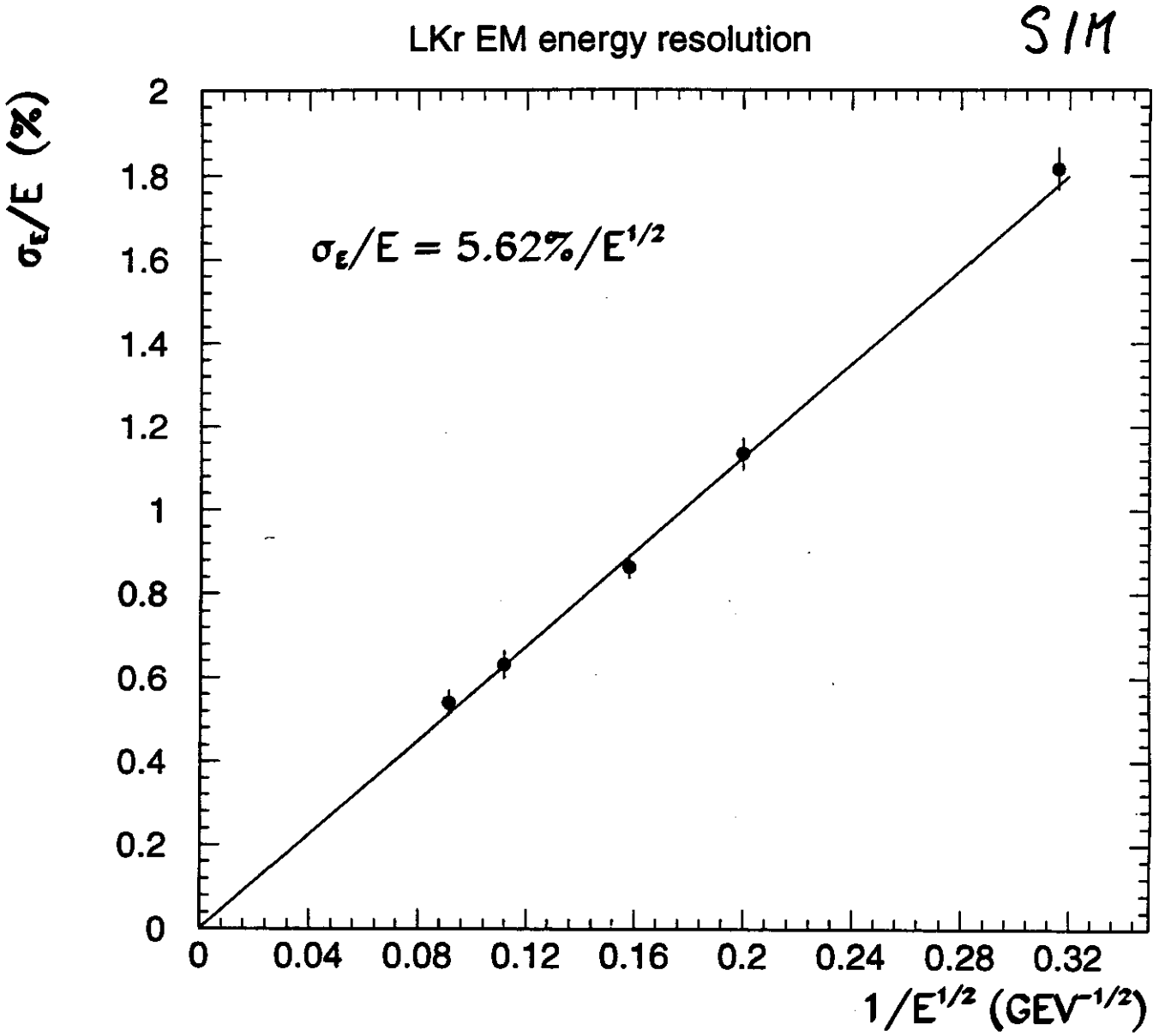
NOTE:
DIMENSIONS GIVEN IN INCHES AND (MILLIMETERS).

INSTRUMENTATION DIVISION BROOKHAVEN NATIONAL LAB. UPTON, L.I., N.Y., 11973		
TITLE: DUAL CHARGE CALIBRATION HYBRID		
B SIZE	NUMBER: 10623-1	REV:
DATE: JAN 22,1992		DWG 1 OF


Angular resolution of LKr EM calorimeter
SIM
Theta resolution (mrad)
20
17.5
15
12.5
10
7.5
5
2.5
0
2-depth towers
55/E^1/2+1.8 mrad
strips + towers
38.9/E^1/2+0.5 mrad
ϑ=45°
0
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
1/E^1/2 (GeV)^-1/2

SIM

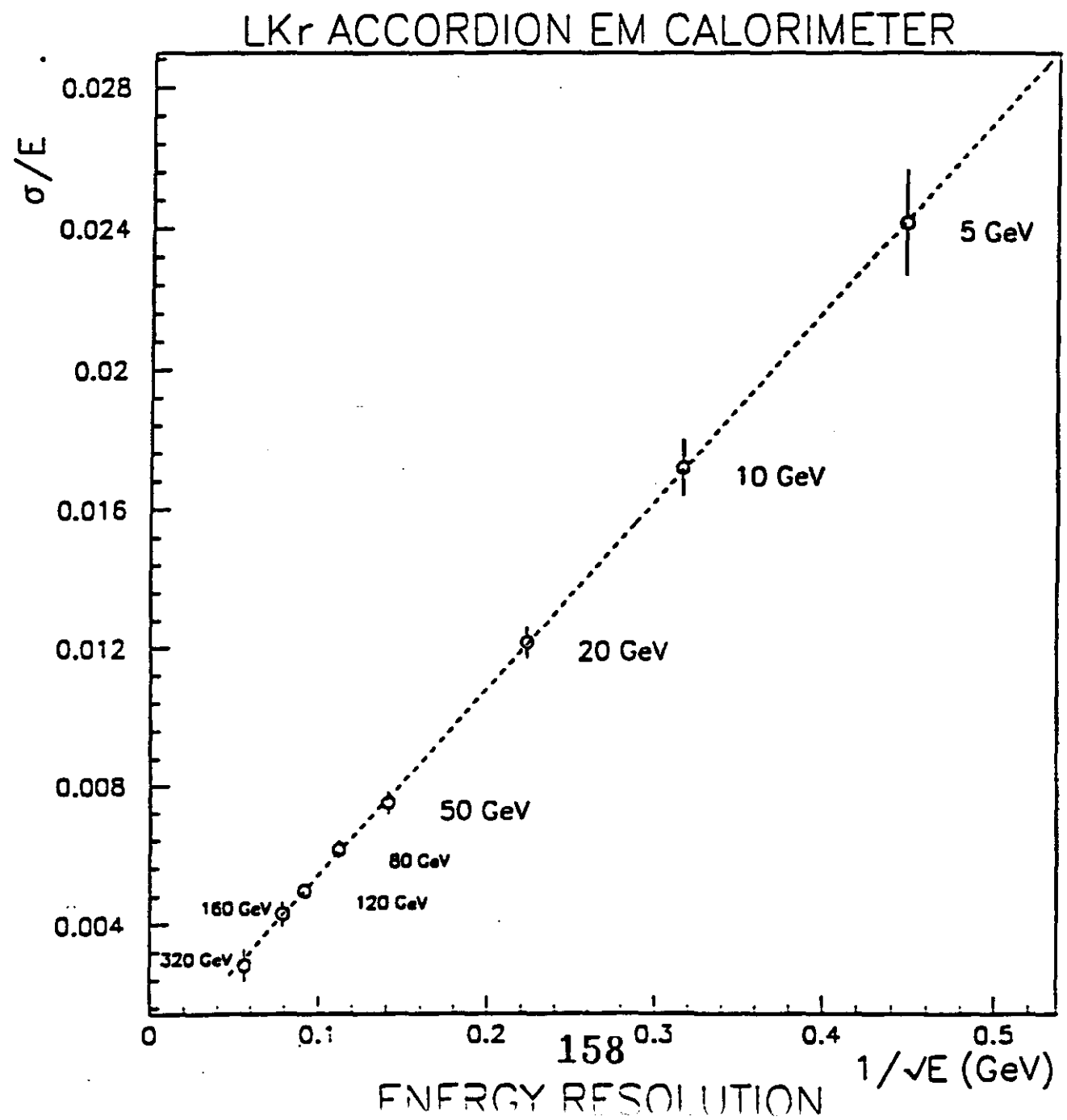

pi0 Rejection, photon acceptance=0.9, theta=90, R=95cm
rejection (%)
100
80
60
40
20
0
0
20
40
60
80
100
Energy (GeV)
rejection for $\eta \rightarrow N\gamma$
rejection for ϑ=45°
strips + towers
2−depth towers


LKr EM energy resolution
SIM
$\sigma_E/E = 5.62\%/E^{1/2}$
σ_E/E (%)
$1/E^{1/2}$ (GEV$^{-1/2}$)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32

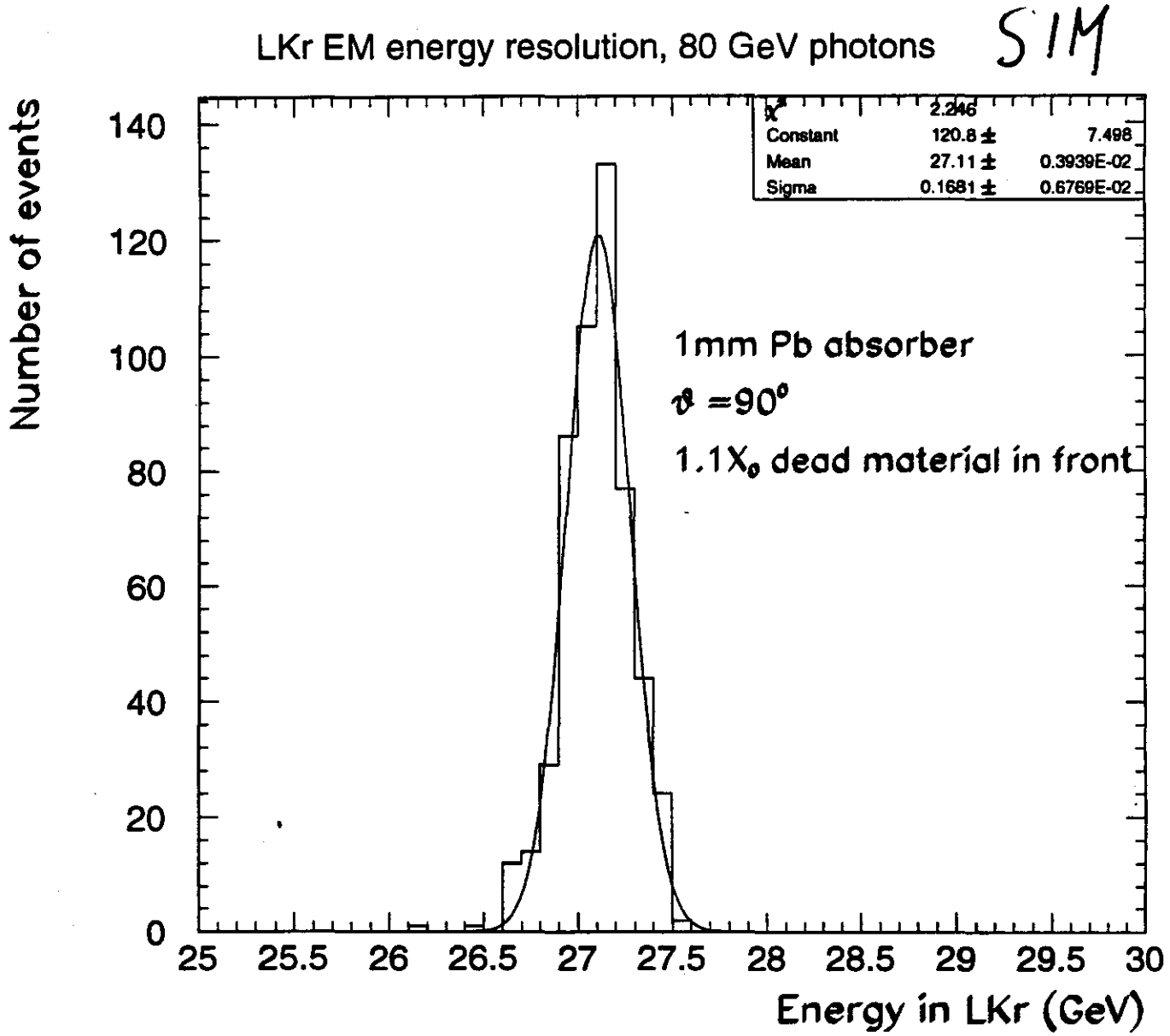
M. Seman

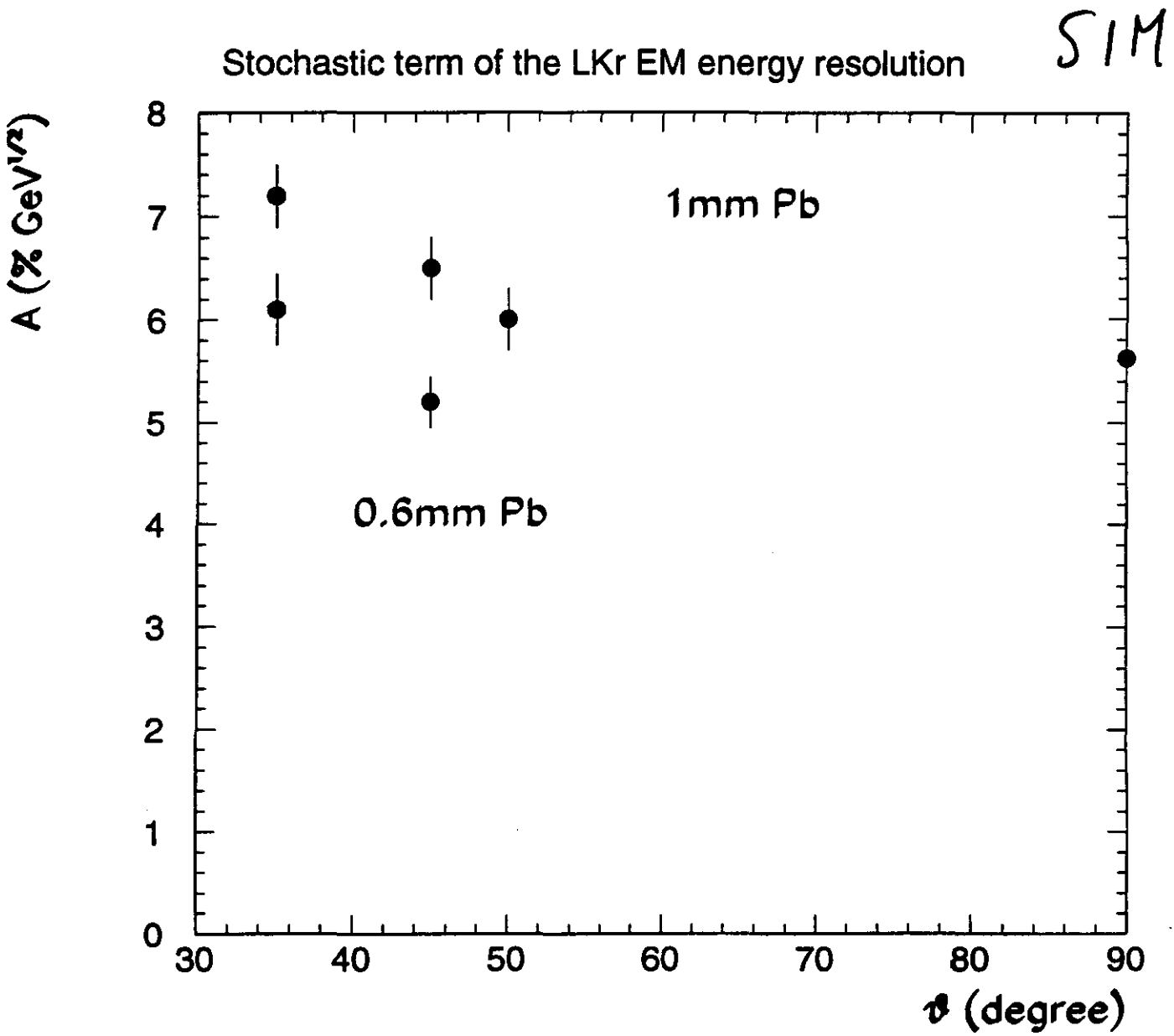
RESOLUTION AT ENERGIES ≥ 120 GeV
IS CORRECTED FOR LEAKAGE. ! ?

SIM



ENERGY RESOLUTION


LKr EM energy resolution, 80 GeV photons
SIM
χ^2 2.246
Constant 120.8 ± 7.498
Mean 27.11 ± 0.3939E-02
Sigma 0.1681 ± 0.6769E-02
1mm Pb absorber
ϑ =90°
1.1X_0 dead material in front
Number of events
Energy in LKr (GeV)
0
20
40
60
80
100
120
140
25
25.5
26
26.5
27
27.5
28
28.5
29
29.5
30


SIM
Stochastic term of the LKr EM energy resolution
A (% GeV^1/2)
1mm Pb
0.6mm Pb
ϑ (degree)
0
1
2
3
4
5
6
7
8
30
40
50
60
70
80
90

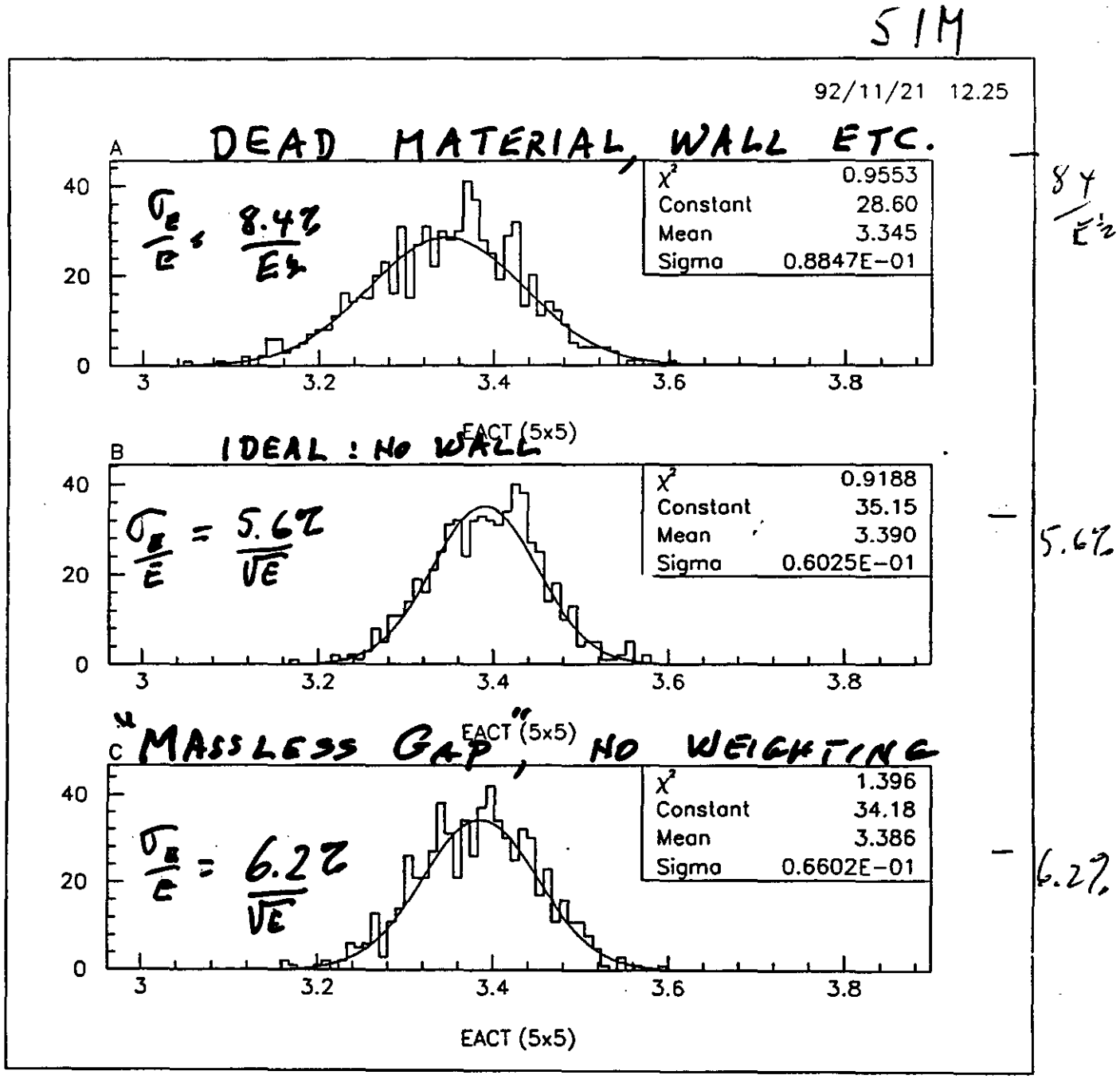


Figure 2: Energy in active medium for 10 GeV photons at $\theta = 45°$,
upper: with dead material but no massless gap;
middle: without dead material;
lower: with dead material and massless gap.

Liquid Krypton Calorimeter Test Results

O. Benary[9], S. Cannon[5], W. Cleland[7], I. Ferguson[2], C. Finley[5], A. Gordeev[6], H. Gordon[3], E. Kistenev[3], P. Kroon[3], M. Leltchouk[5], D. Lissauer[3], H. Ma[3], D. Makowiecki[3], A. Maslennikov[4], S. McCorkle[3], D. Onoprienko[6], A. Onuchin[4], Y. Oren[9], V. Panin[4], J. Parsons[5], J. Rabel[7], V. Radeka[3], L. Rogers[3], D. Rahm[3], S. Rescia[3], J. Rutherfoord[2], M. Seman[5], M. Smith[3], J. Sondericker III[3], R. Steiner[1], D. Stephani[3], E. Stern[7], I. Stumer[3], H. Takai[3], H. Themann[8], Y. Tikhonov[4]

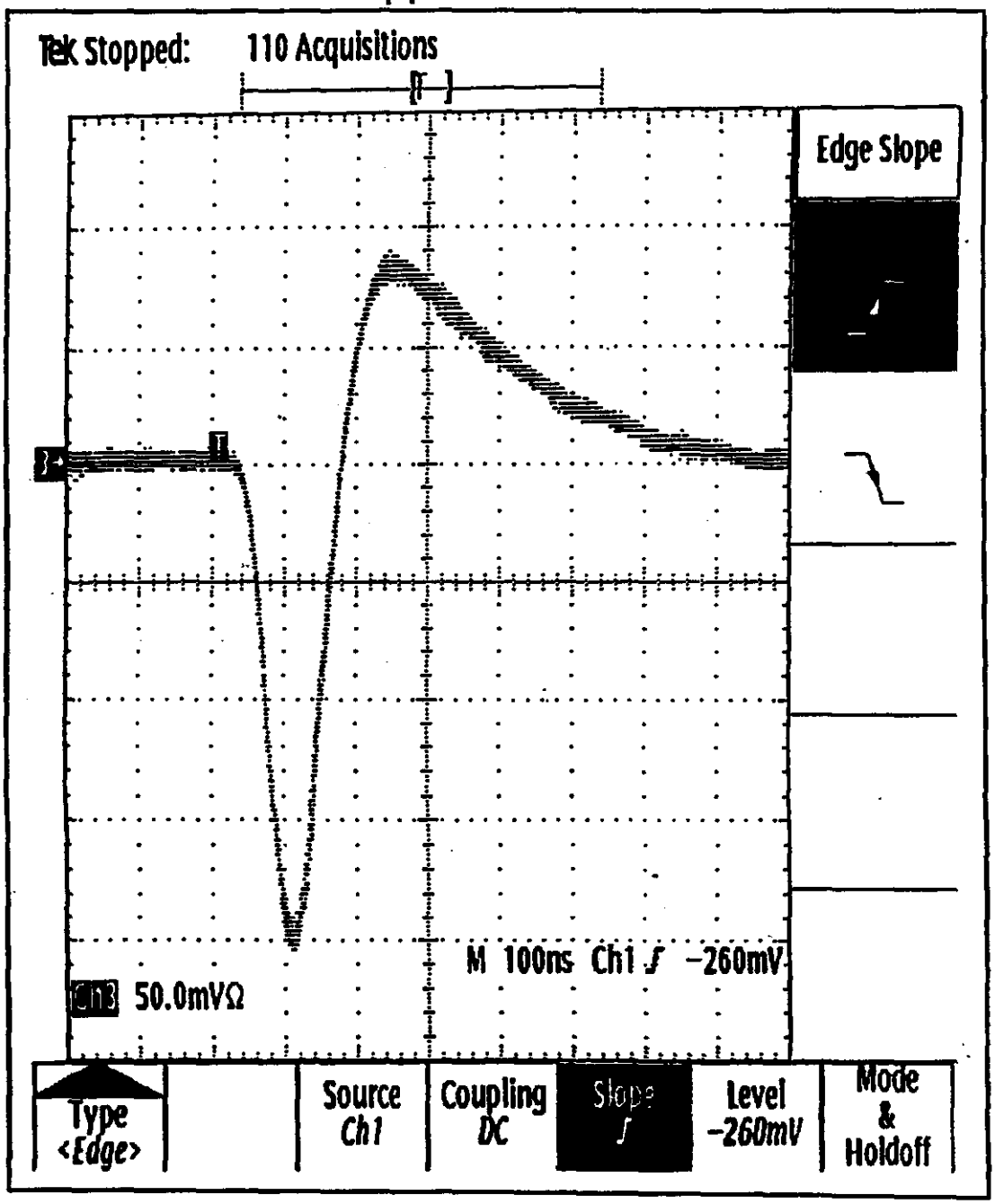
1. Adelphi University, Garden City, NY 11530
2. University of Arizona, Tucson, AZ 85721
3. Brookhaven National Laboratory, Upton, NY 11973
4. Budker Institute for Nuclear Physics, Novosibirsk, Russia
5. Columbia University, New York, NY 15633
6. Oak Ridge National Laboratory, Oak Ridge, TN 37831
7. University of Pittsburgh, Pittsburgh, PA 15260
8. SUNY at Stony Brook, Stony Brook, NY 11794
9. Tel-Aviv University, Tel-Aviv, Israel

On-line Pulse Shape

LKr, 2mm stack, 1.5kV

Beam Momentum = 20 GeV

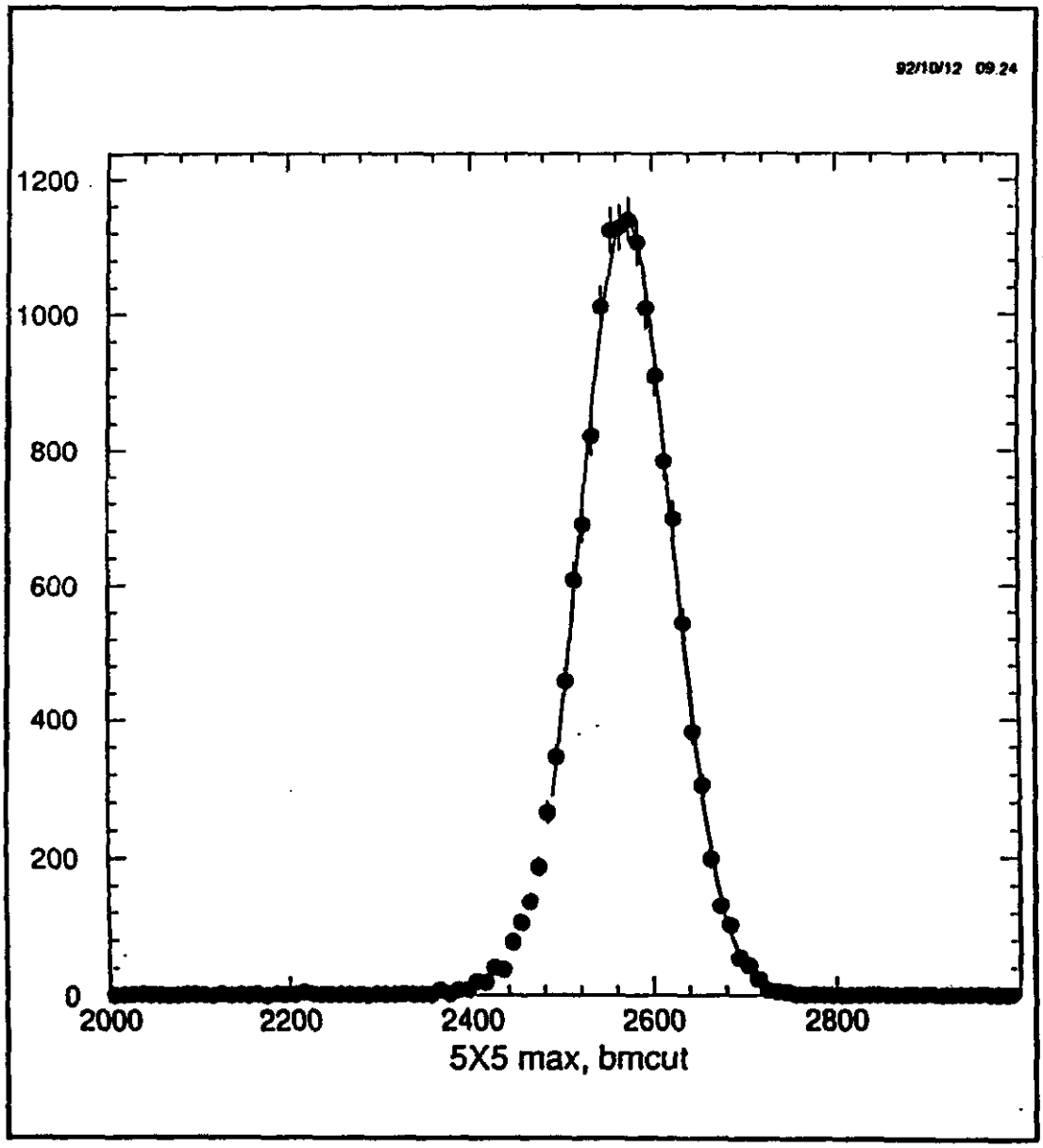
Sum of approx. 150 channels



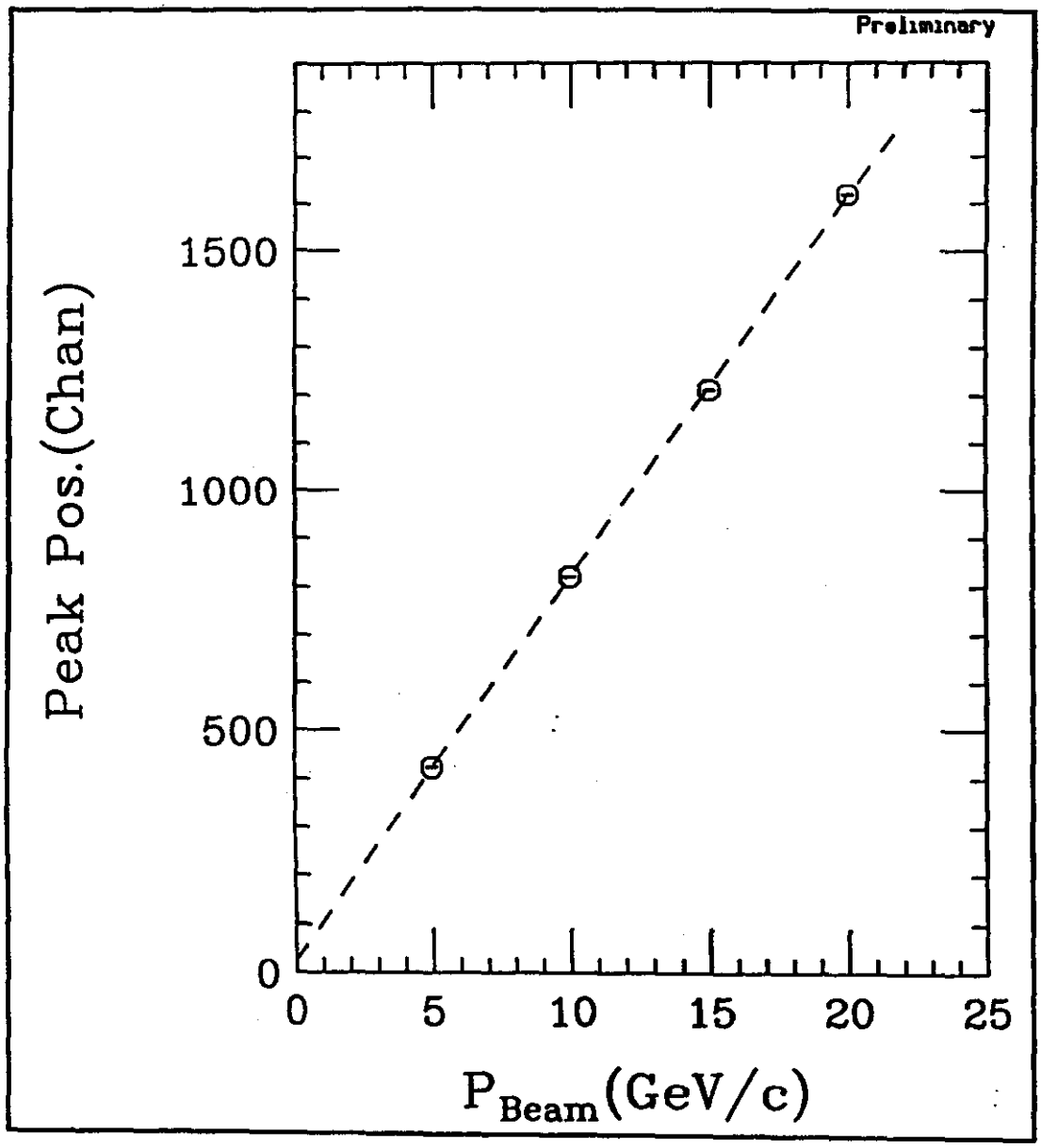
Multiple trace - variable persistence ! !

Calorimeter Response for 15 GeV electrons

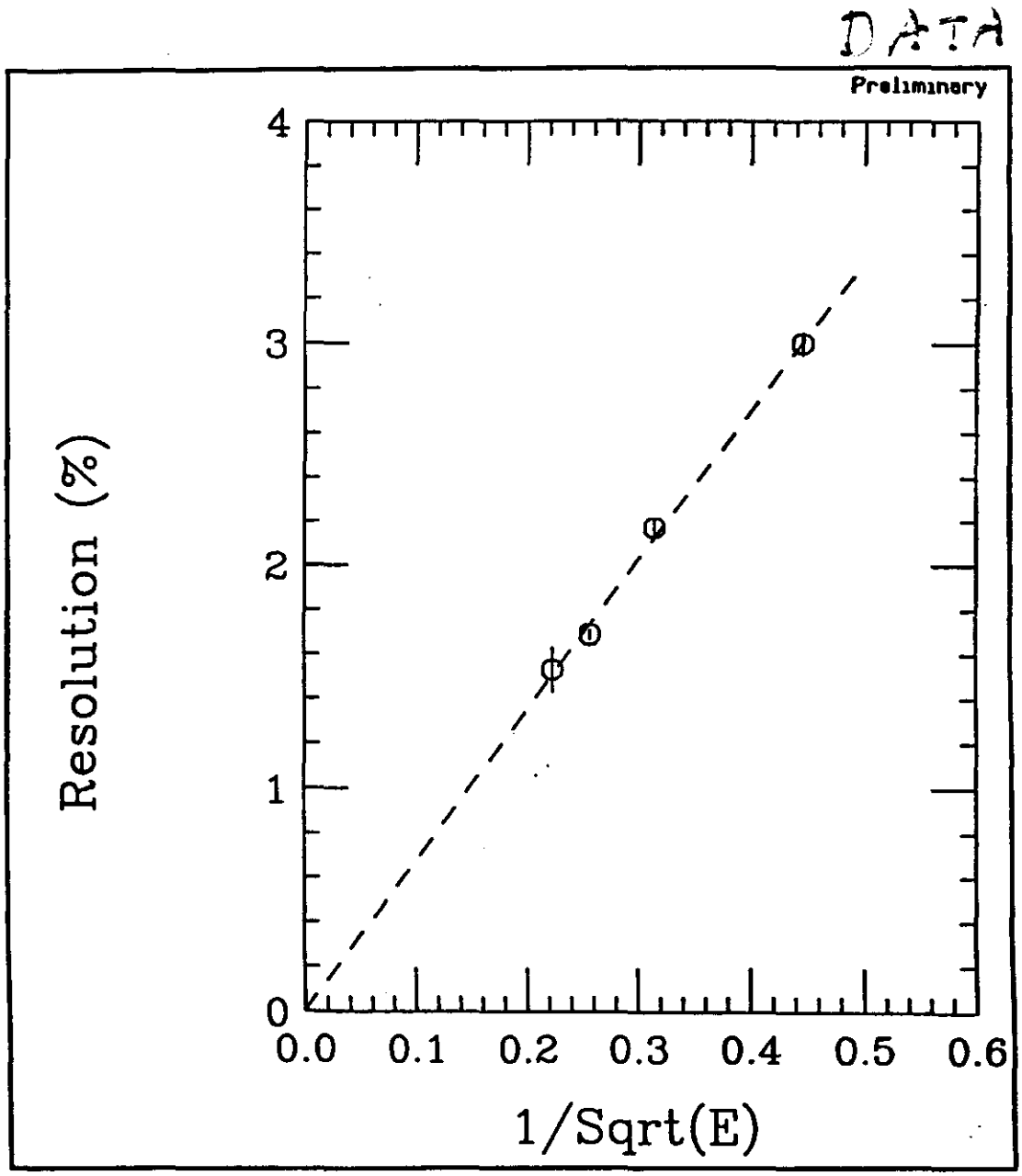
DATA



Linearity

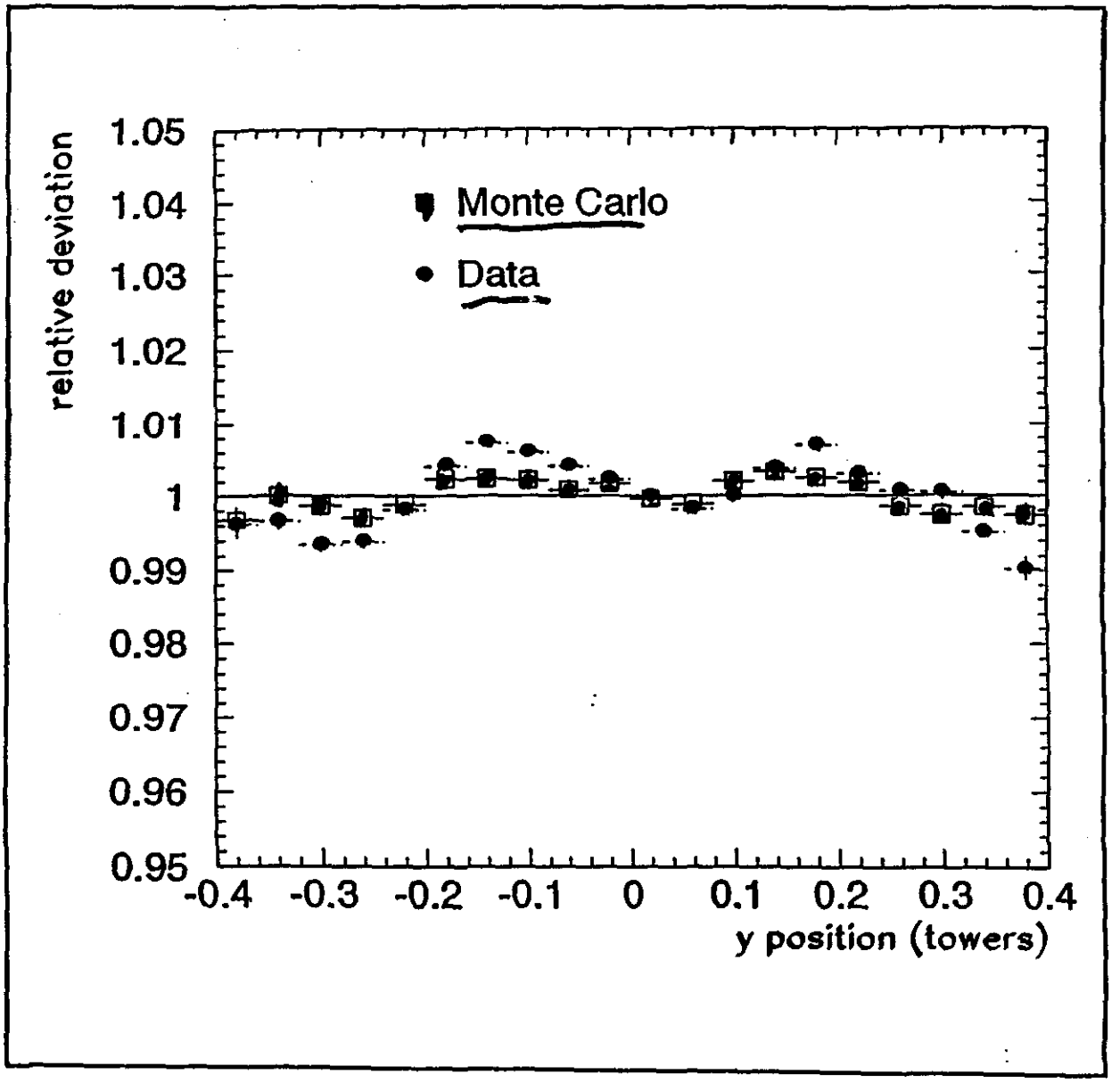

Preliminary
Peak Pos.(Chan)
1500
1000
500
0
0
5
10
15
20
25
P_{Beam}(GeV/c)

Energy Resolution



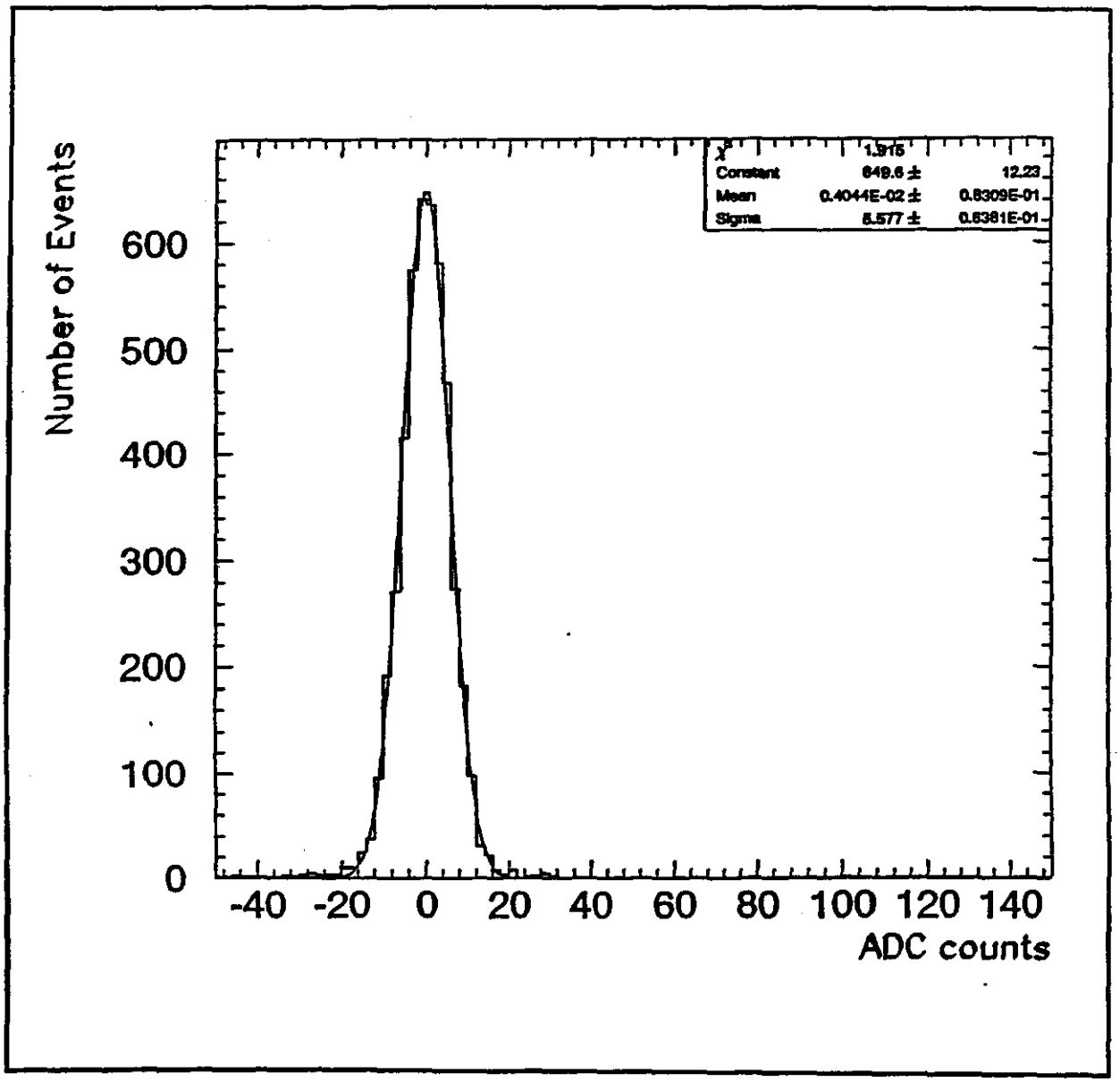
$$\frac{\Delta E}{E} = (0.0 \pm 0.2)\% \oplus \frac{(6.72 \pm 0.04)\%}{\sqrt{E}} \oplus \frac{0.080 GeV}{E}$$

y-position dependence



μ Pedestal

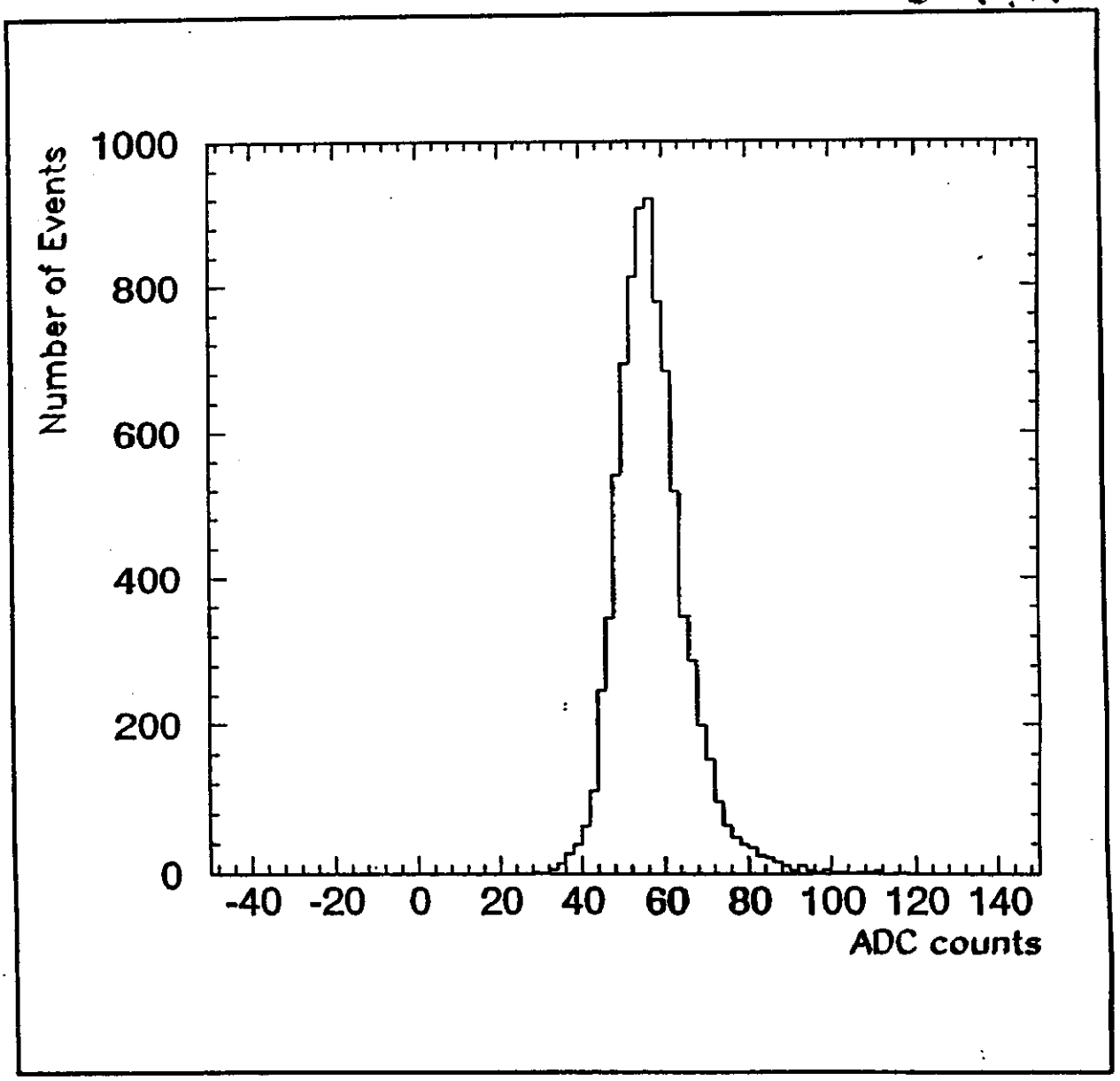
LAr - run



μ Response

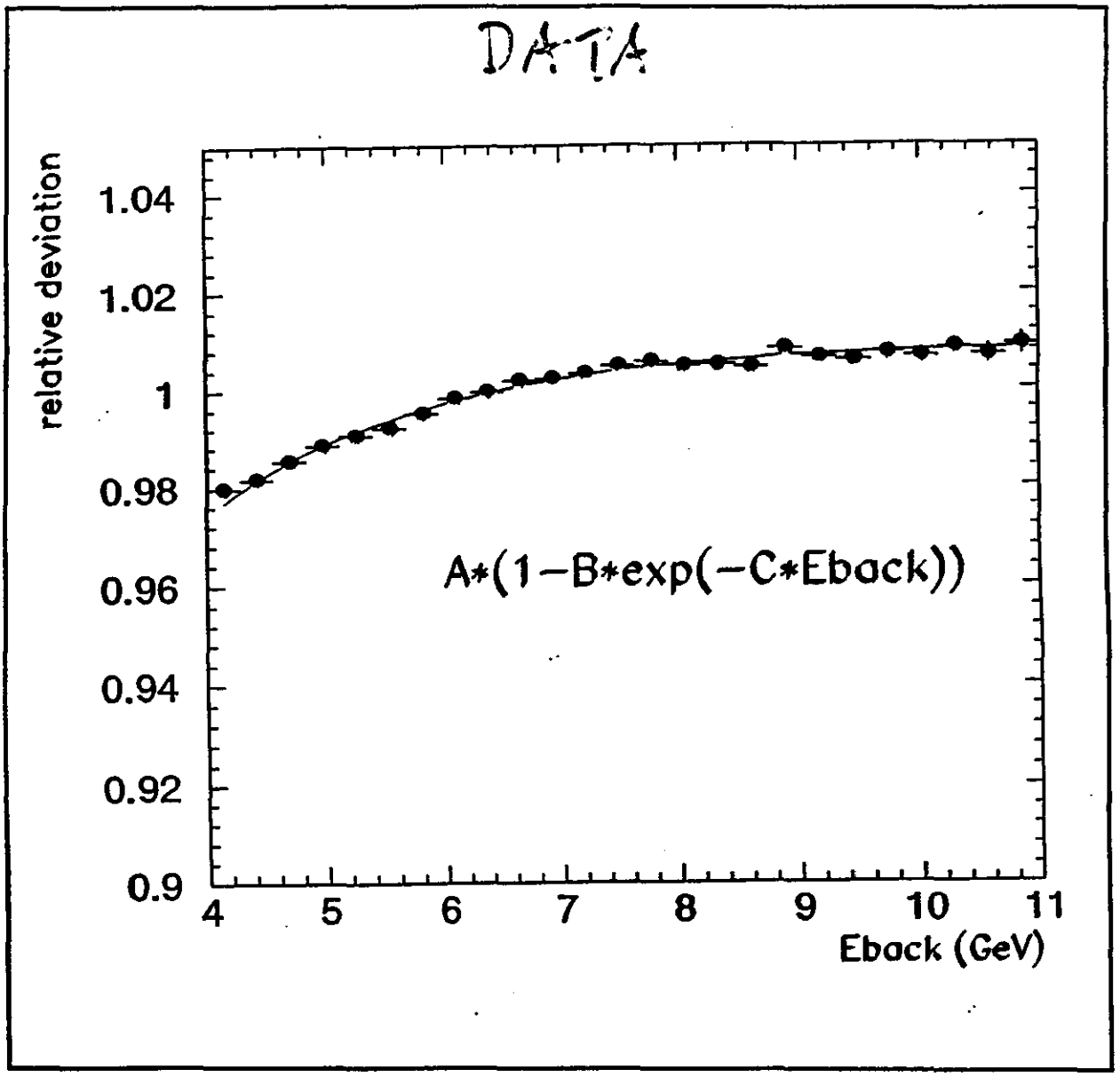
LKr - 15GeV

DATA

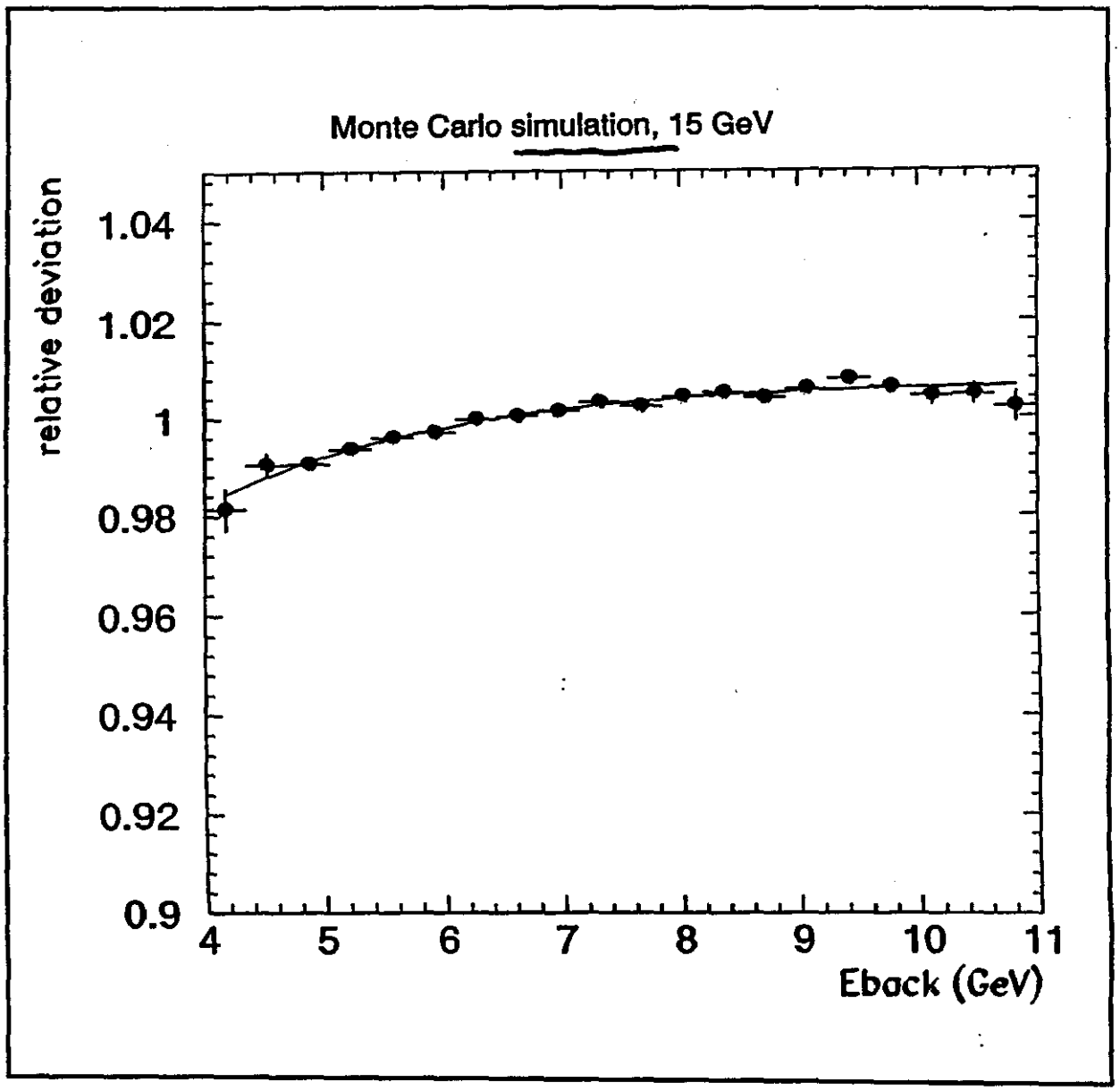


Ratio front/back

~~Simulation~~



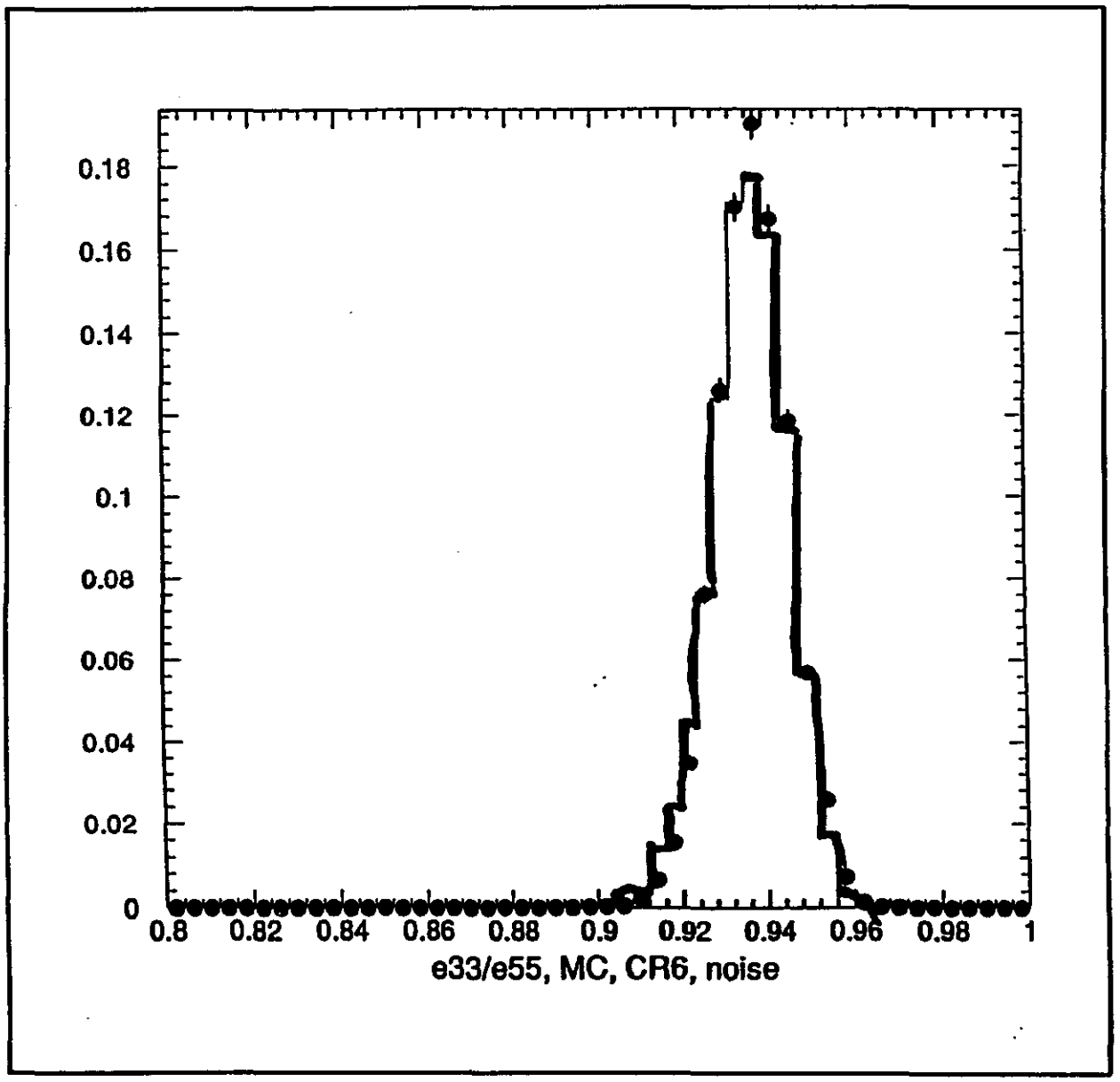
Ratio front/back

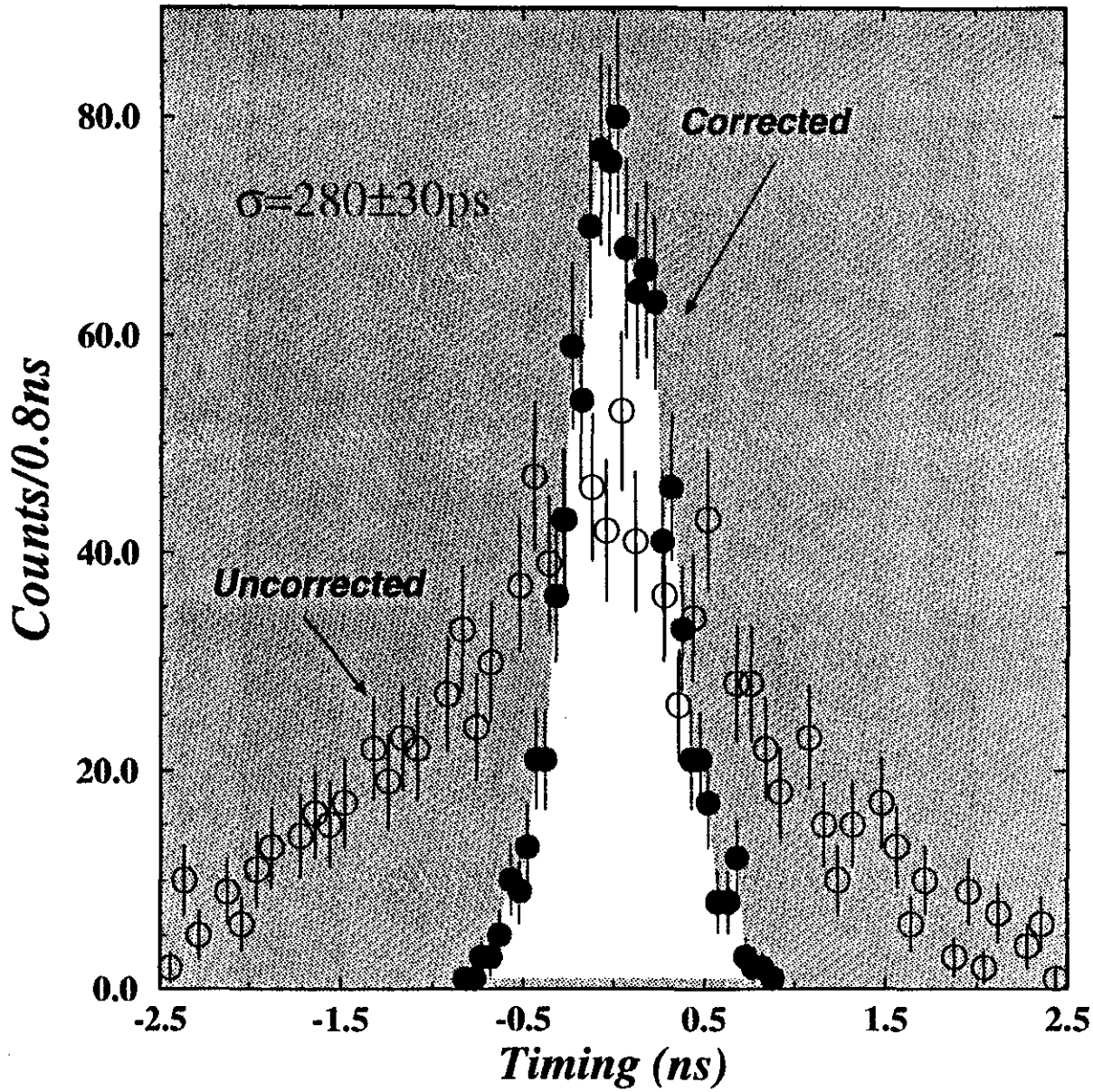


Ratio [3x3]/[5x5]

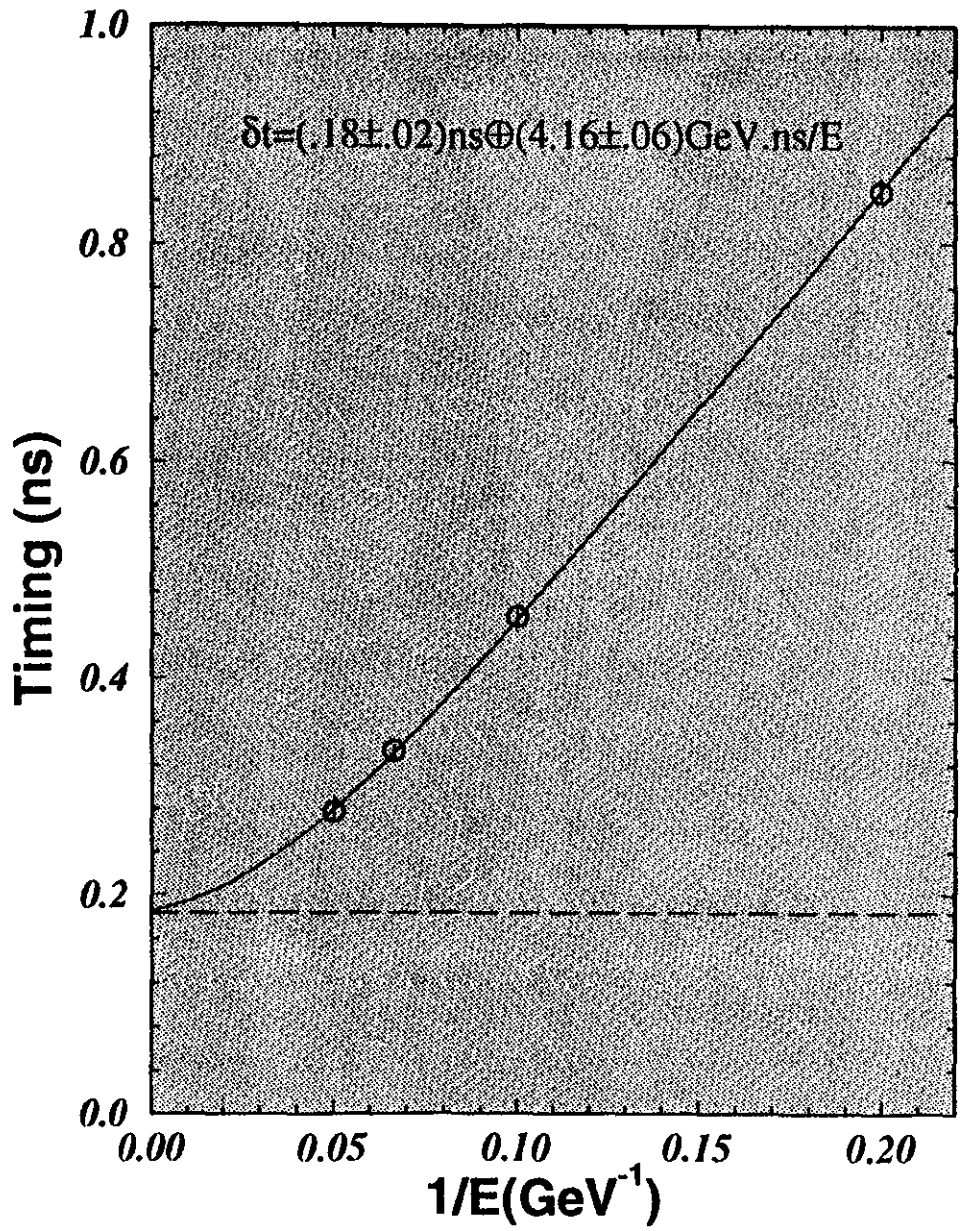
15 GeV

Data • Simulation —

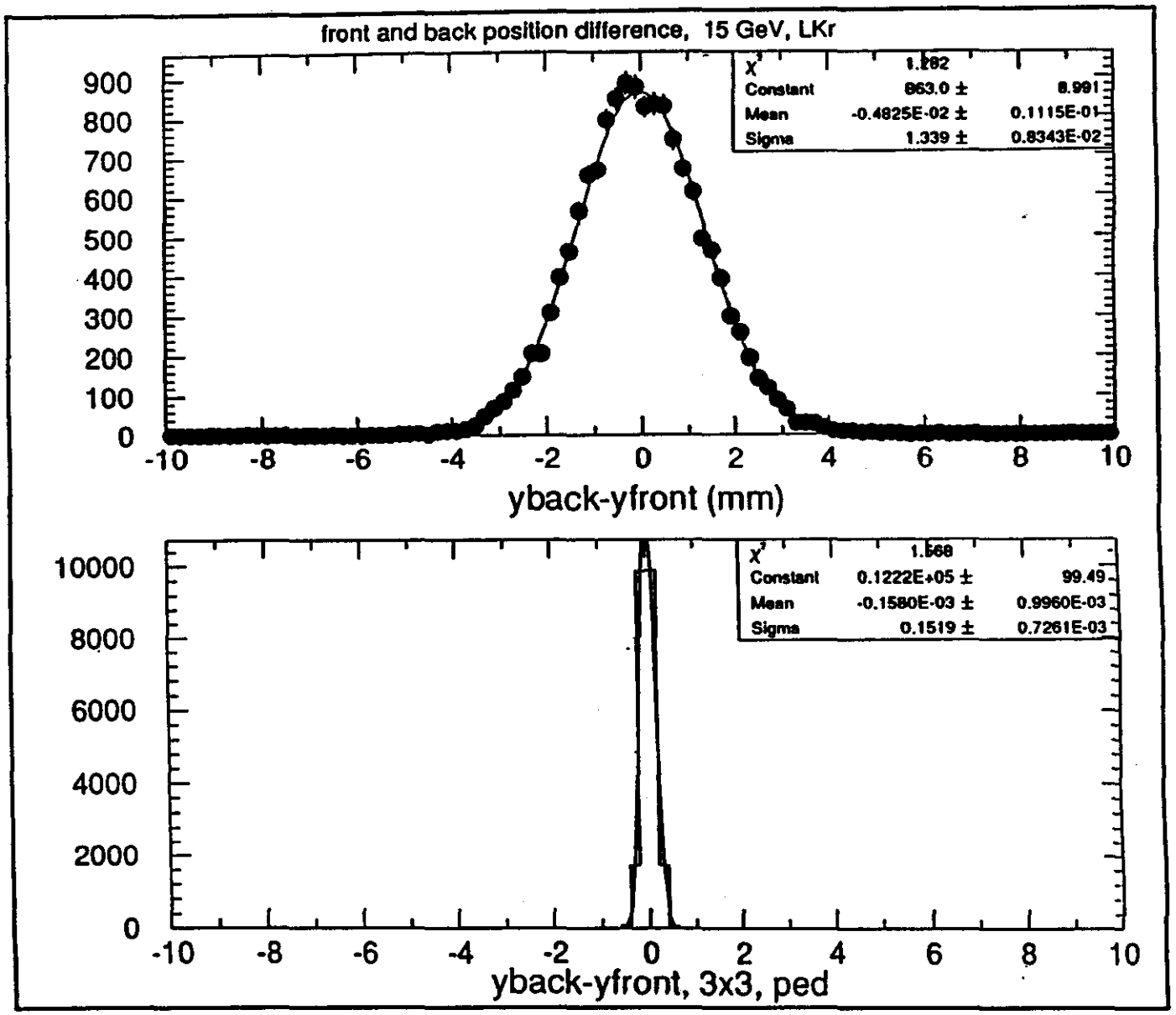


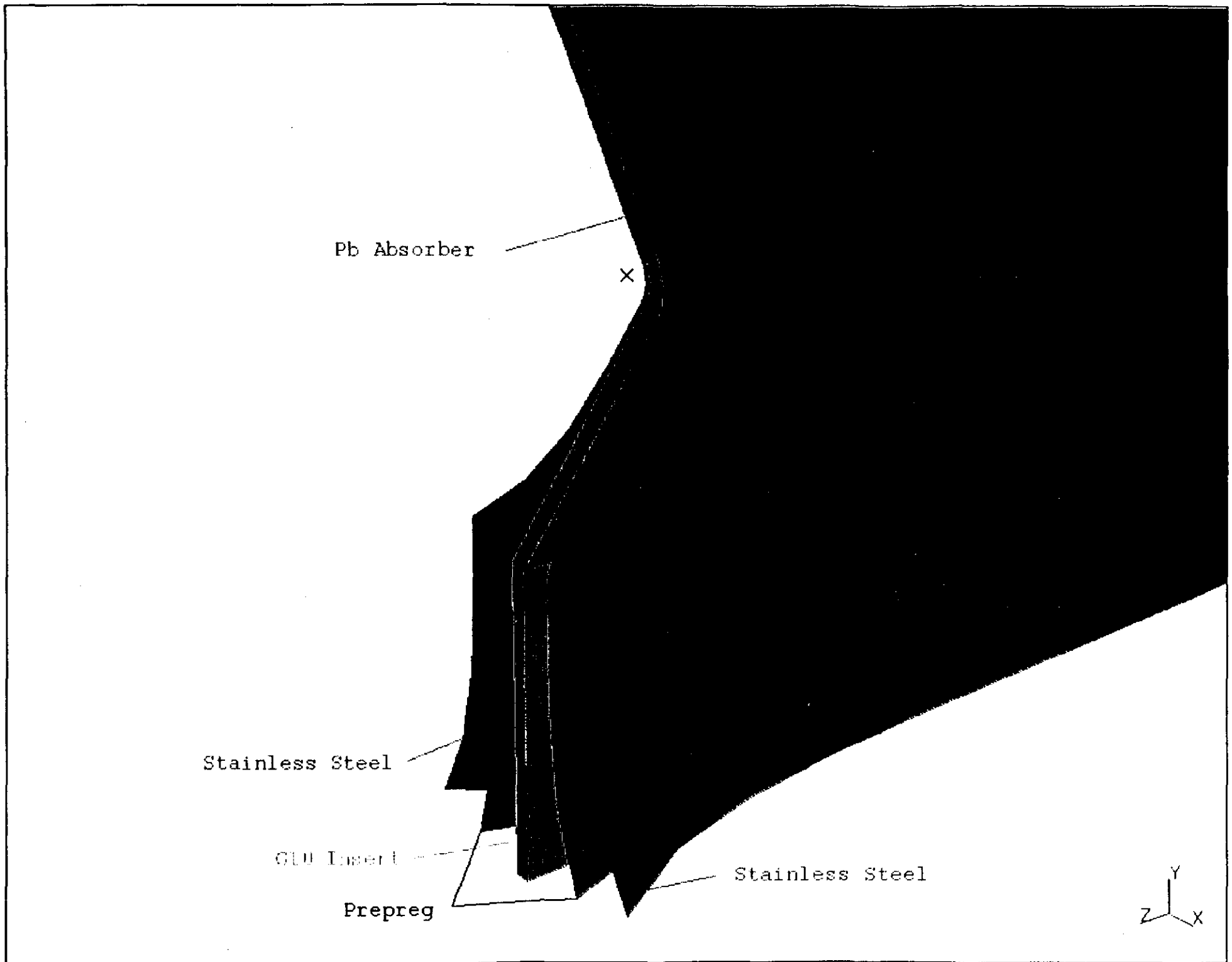

Corrected
σ=280±30ps
Uncorrected
Counts/0.8ns
80.0
60.0
40.0
20.0
0.0
-2.5
-1.5
-0.5
0.5
1.5
2.5
Timing (ns)

LKr Timing Resolution



Position Information




Pb Absorber
Stainless Steel
GLU Insert
Prepreg
Stainless Steel
Y
Z
X

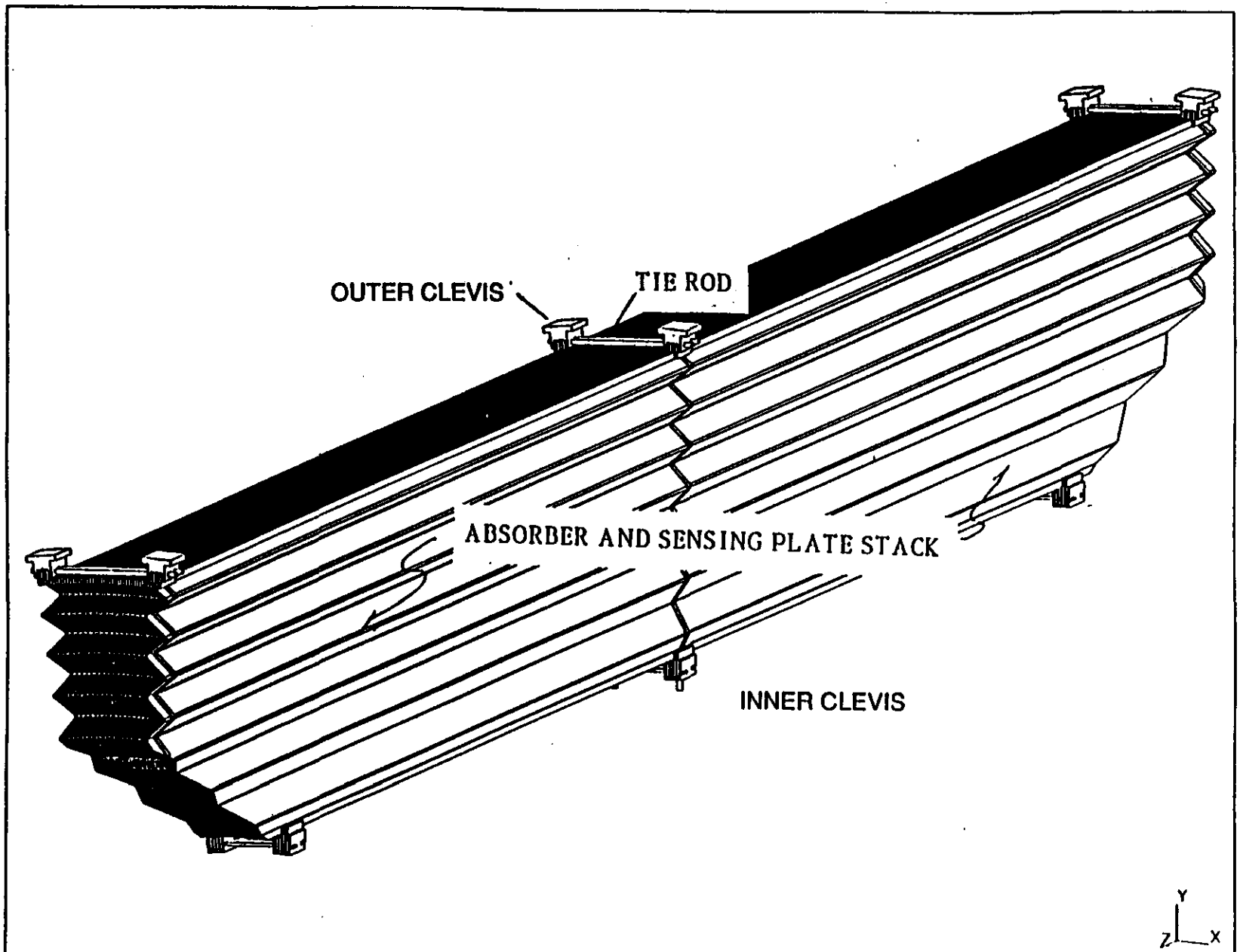
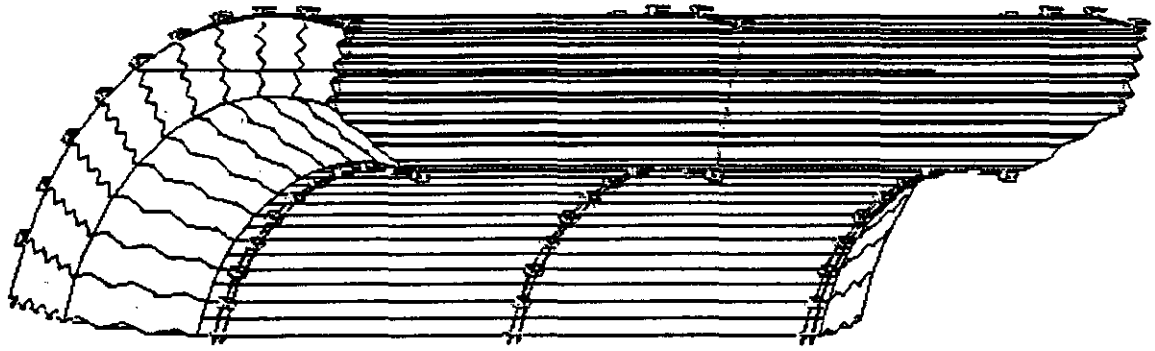
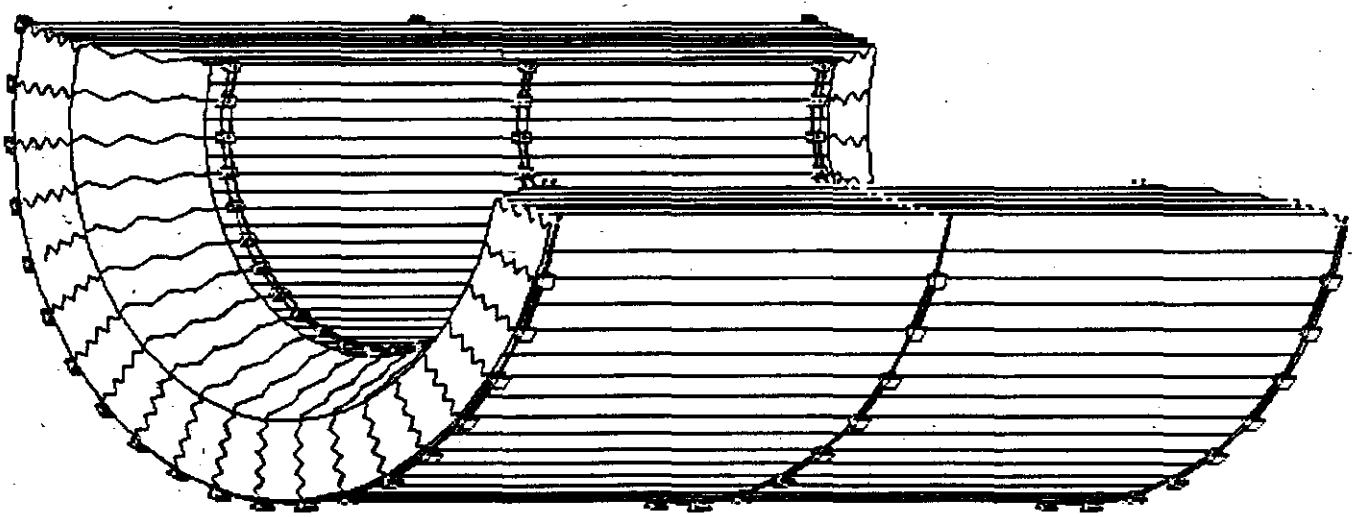


Figure 1-1 Barrel EM Module Assembly

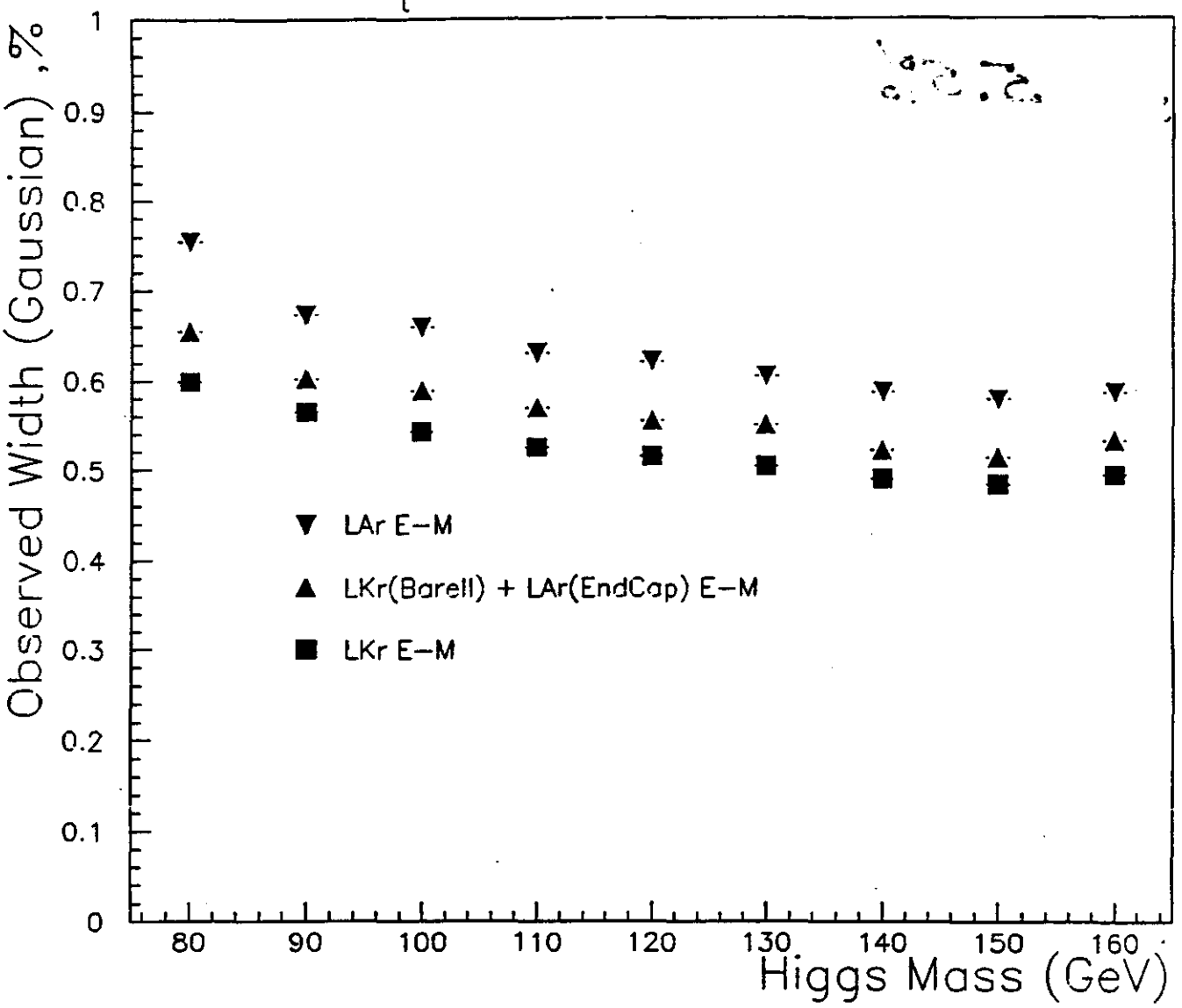




92/11/30 08.53

HIGGS MASS RECONSTRUCTION

PYTHIA5.6 m_t = 150 GeV ,perfect position resolution



A.Savin

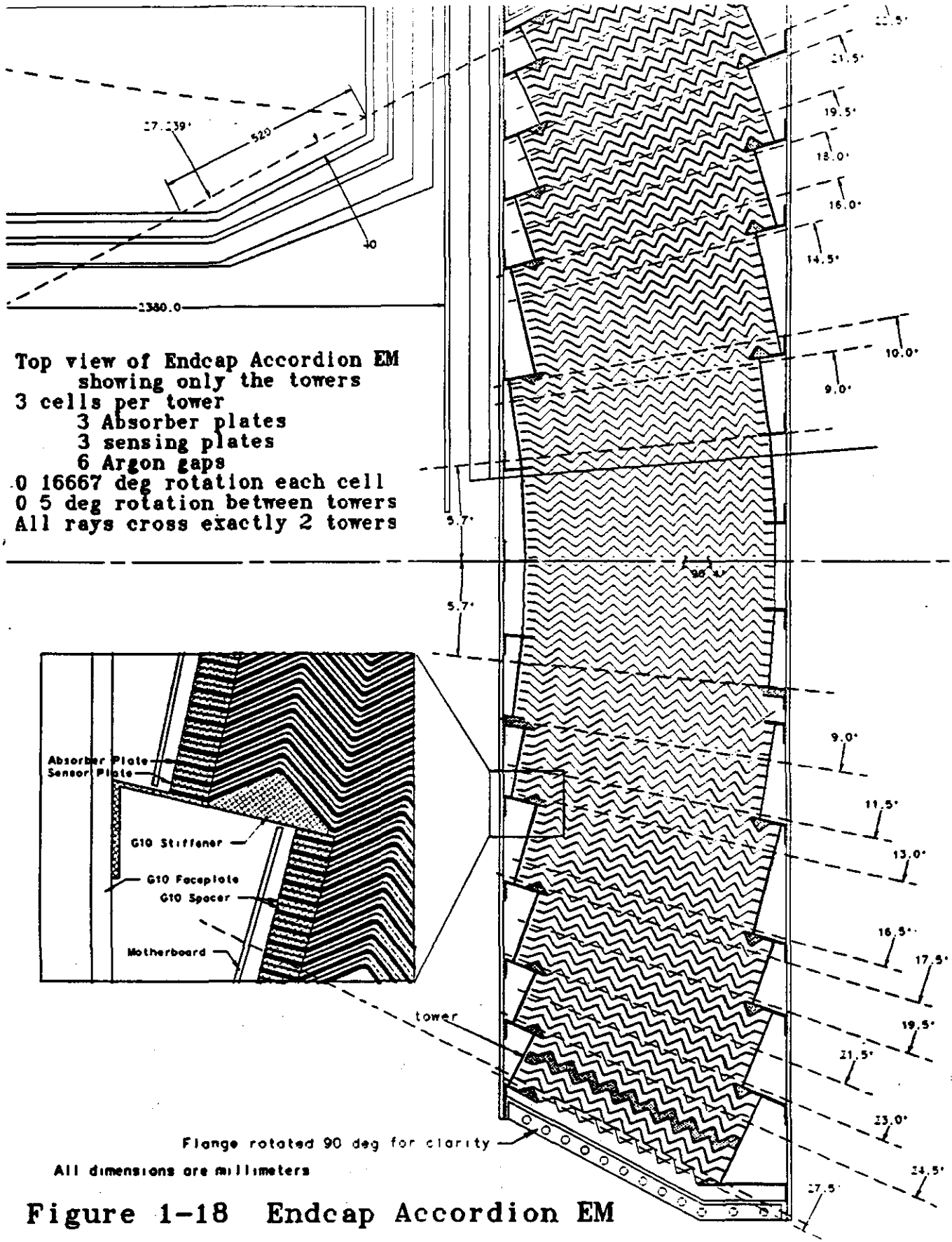
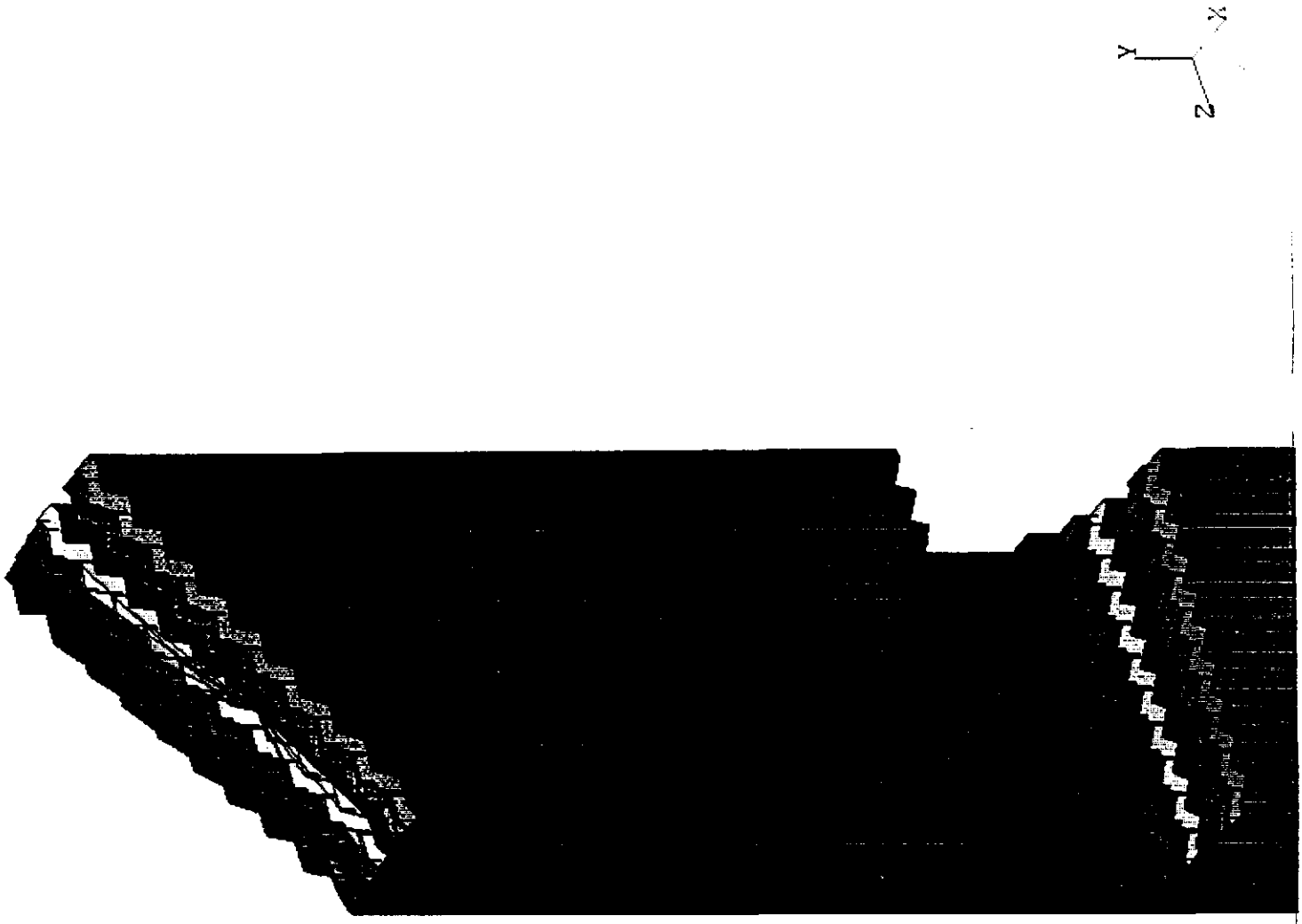
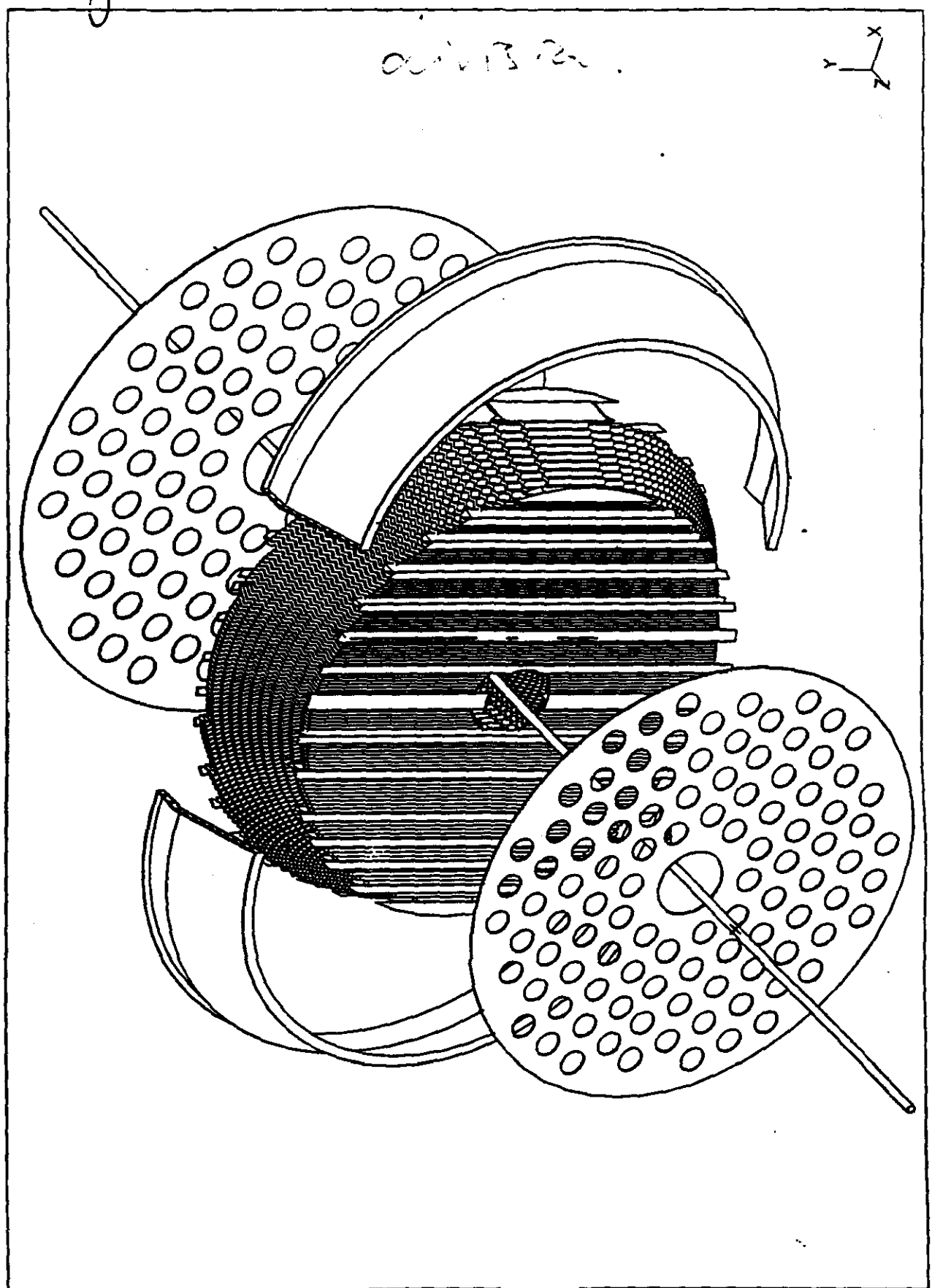


Figure 1-18 Endcap Accordion EM


X
Y
Z

optimization : possible [illegible]

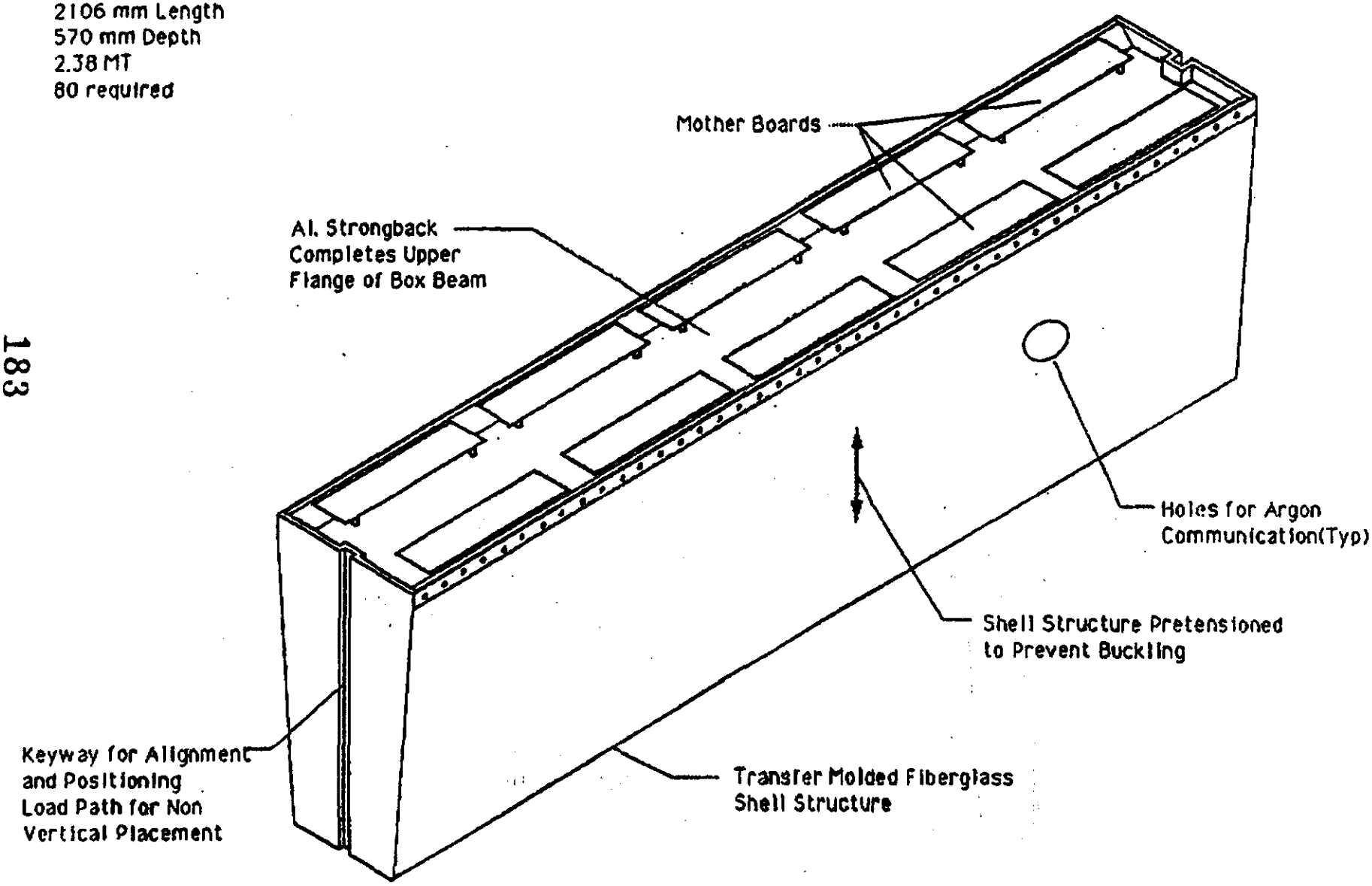
[illegible]



007

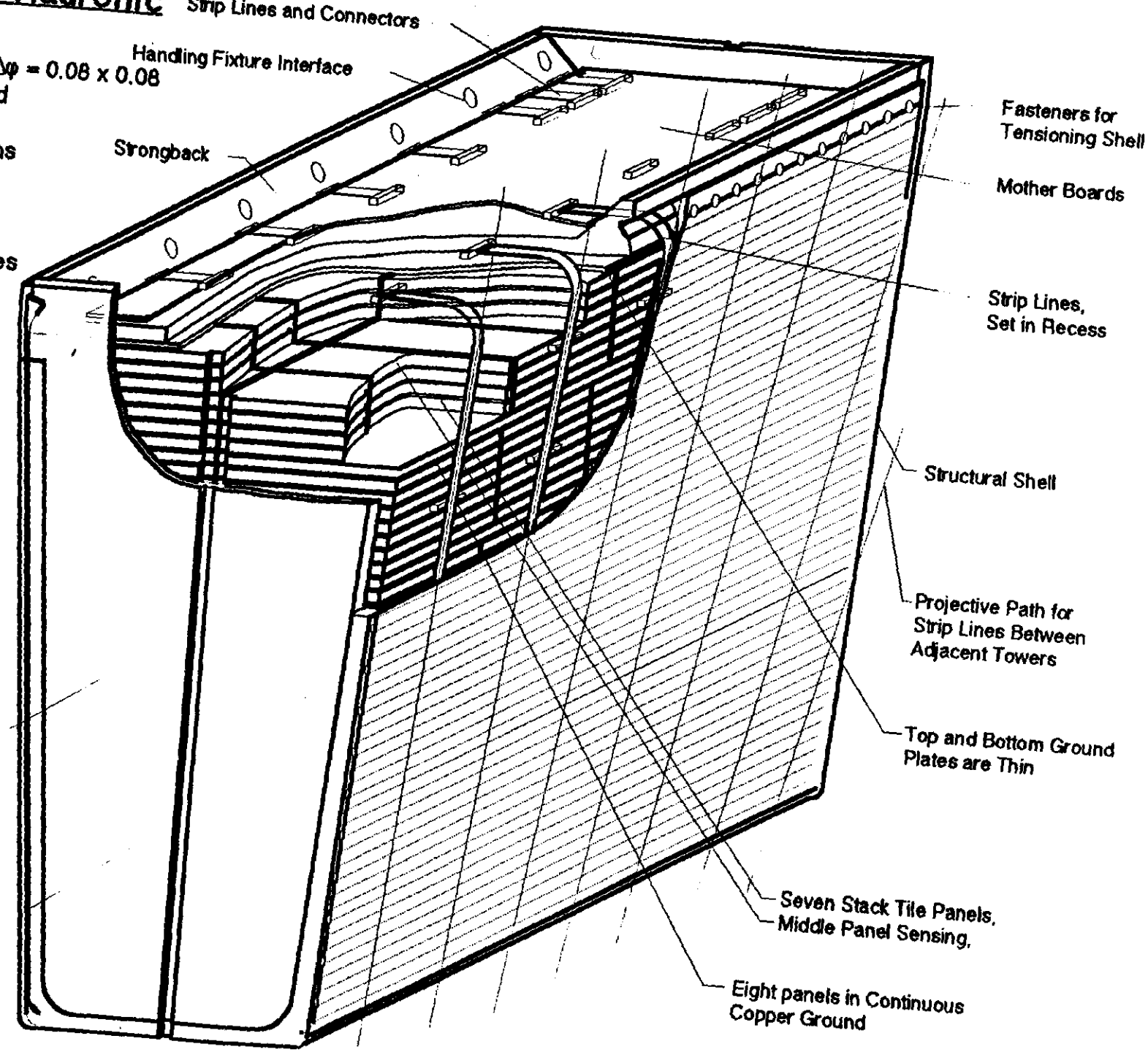
COMPOSITE SHELL MODULE CONCEPT (Module #2)

9 degree Included Angle
2106 mm Length
570 mm Depth
2.38 MT
80 required



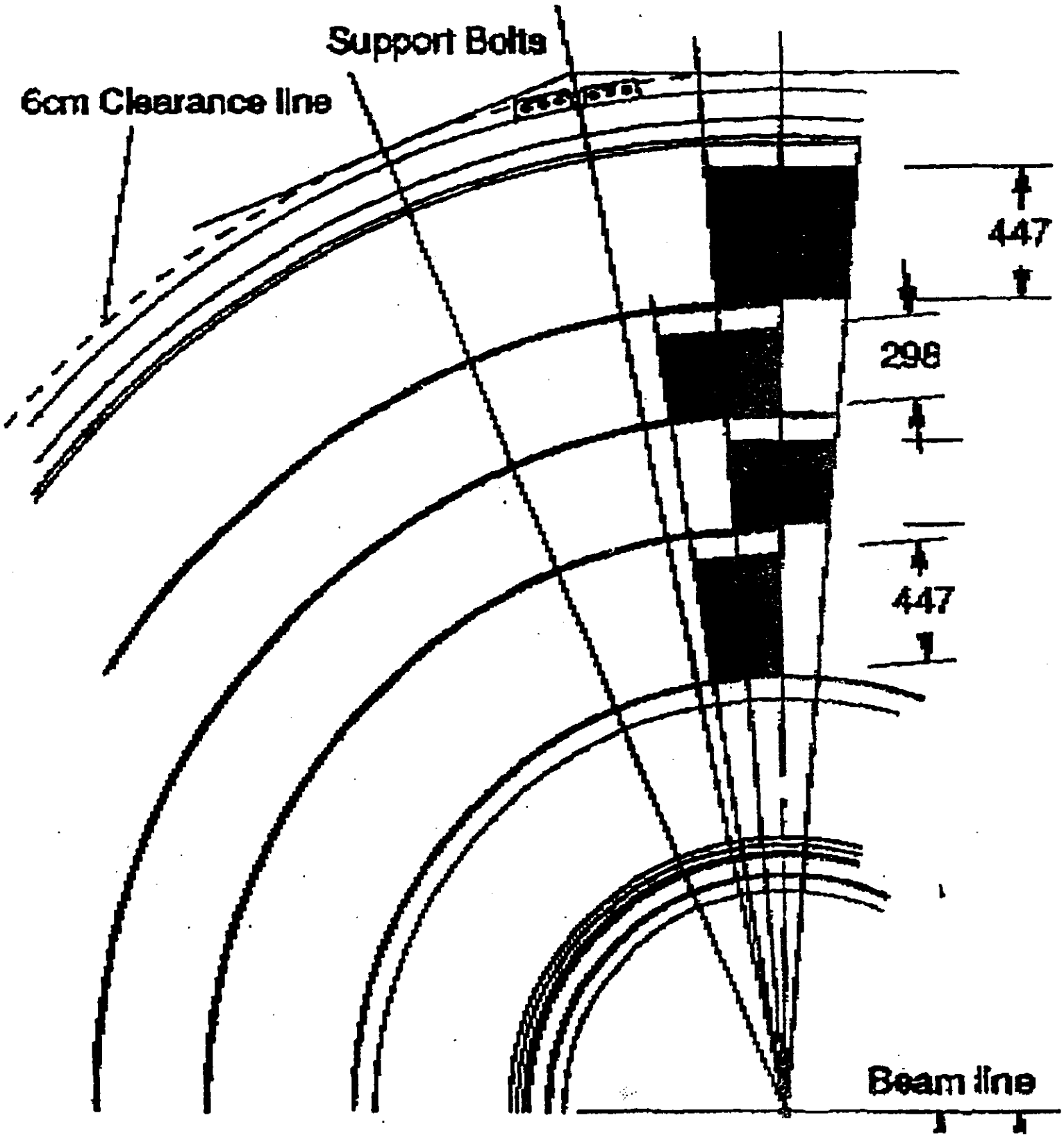
Barrel Inner Hadronic

5 Cells Depth
Segmentation $\Delta\eta \times \Delta\varphi = 0.08 \times 0.08$
80 Modules Required
Wt. = 2.38 MT each
Each Module Contains the Following:
1 - Top Ground Plate
1 - Bottom Gnd Plate
4 - Included Gnd Plates
30 - Tile Plates
5 - Sensing Plates
1 - Strongback
1 - Structural Shell
2 - End Plates
Lines and Electronics

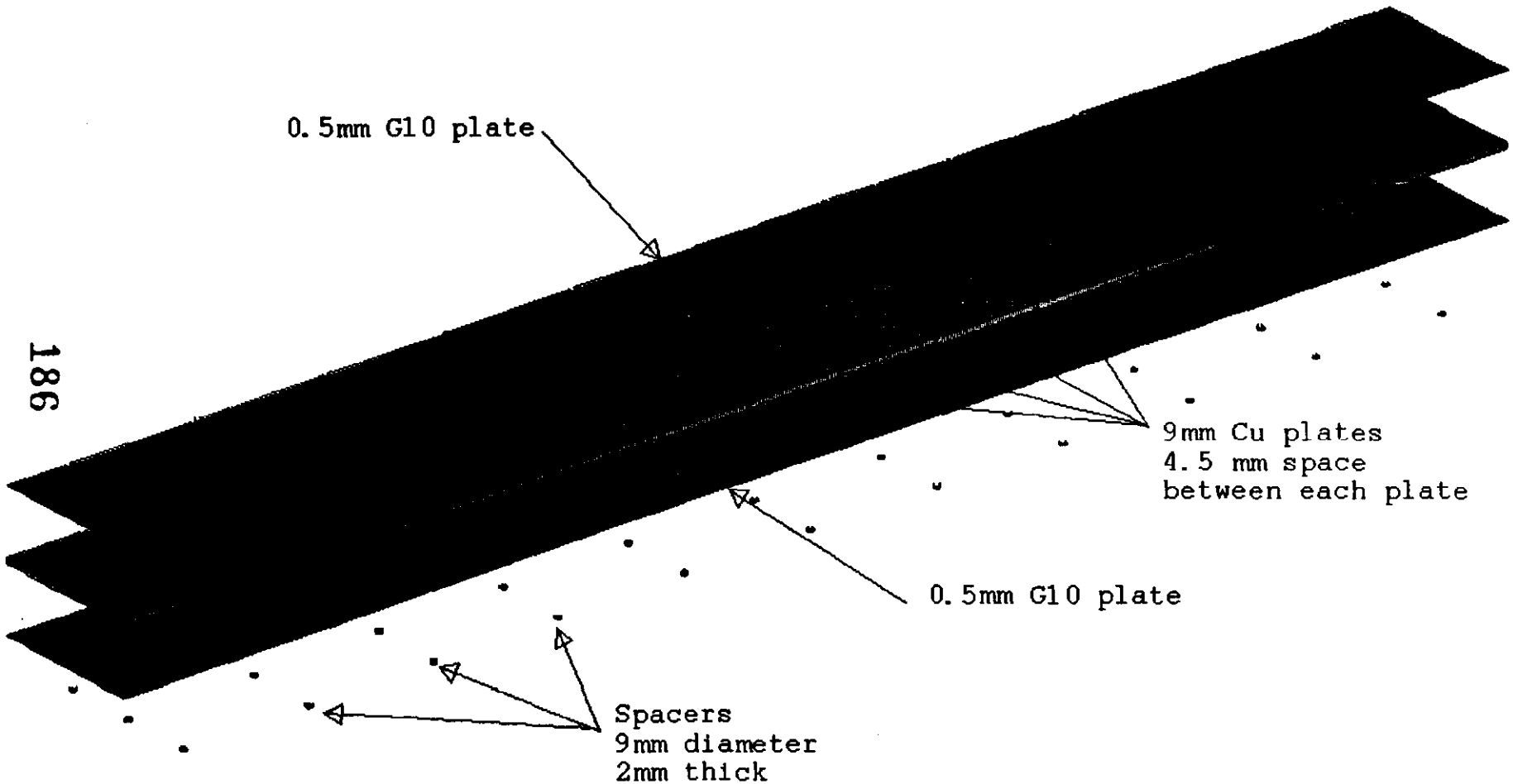


LLMason GEMLAC.HadModDetail 11/16/92

No Projective cracks.

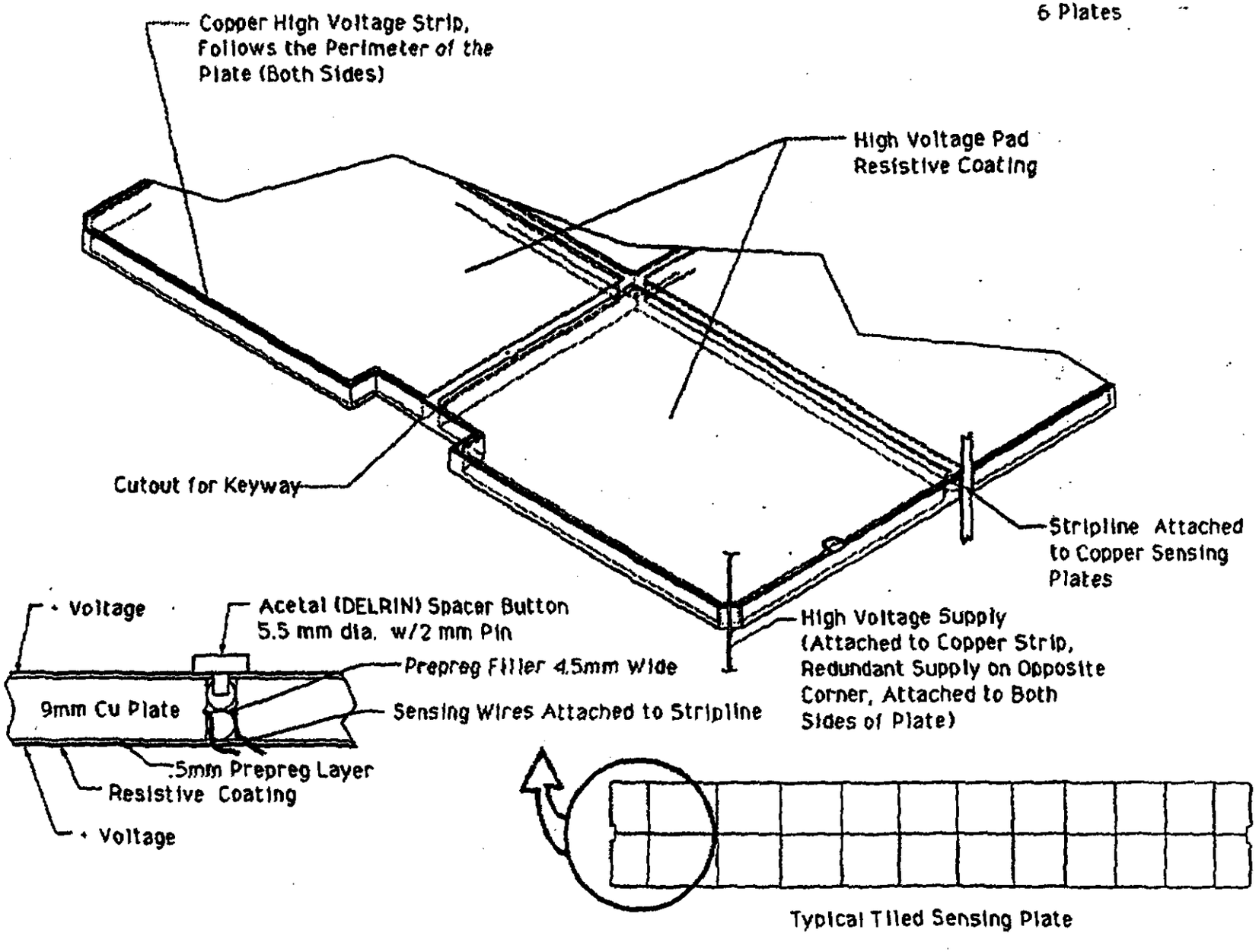


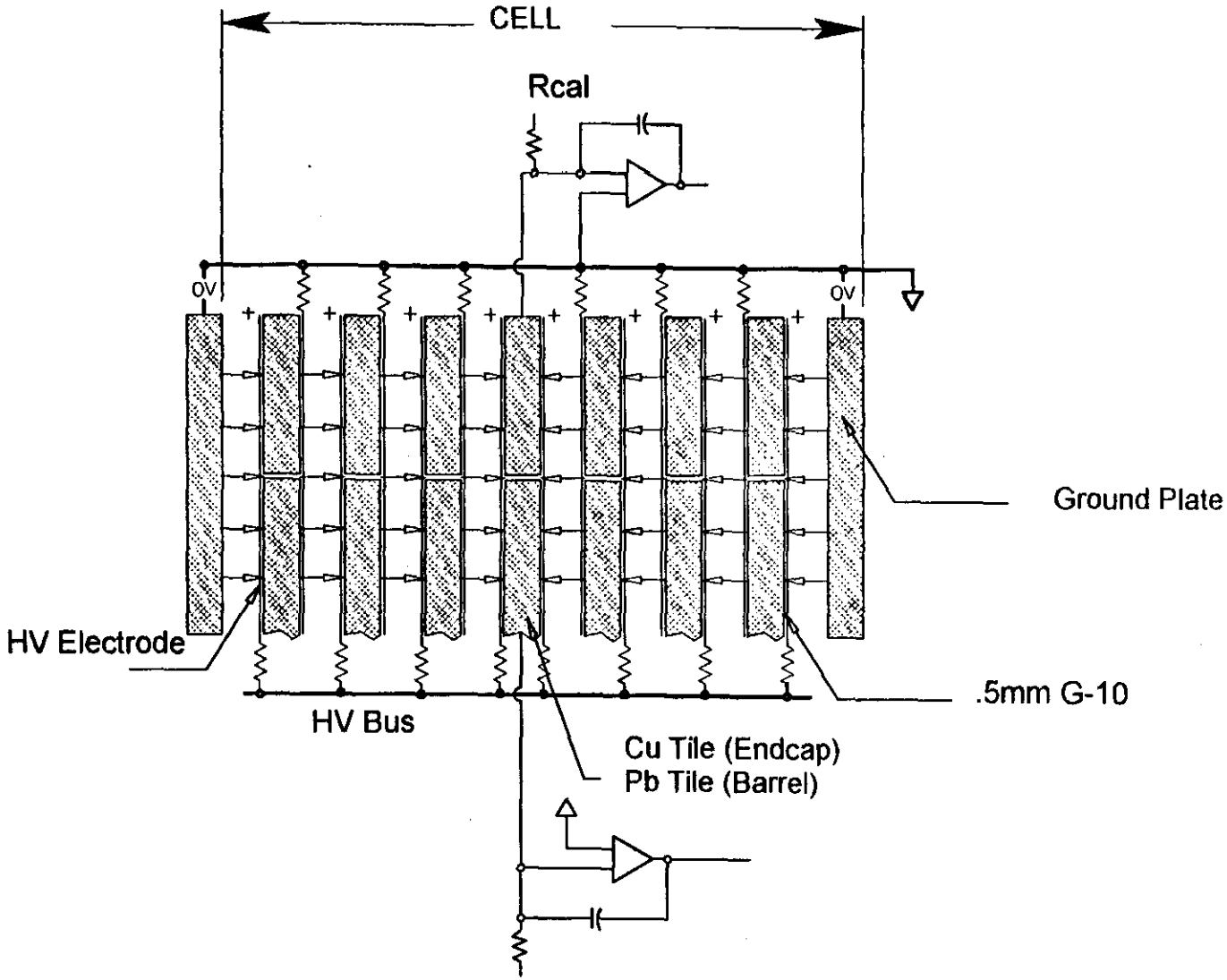
Exploded view of a Hadronic Plate



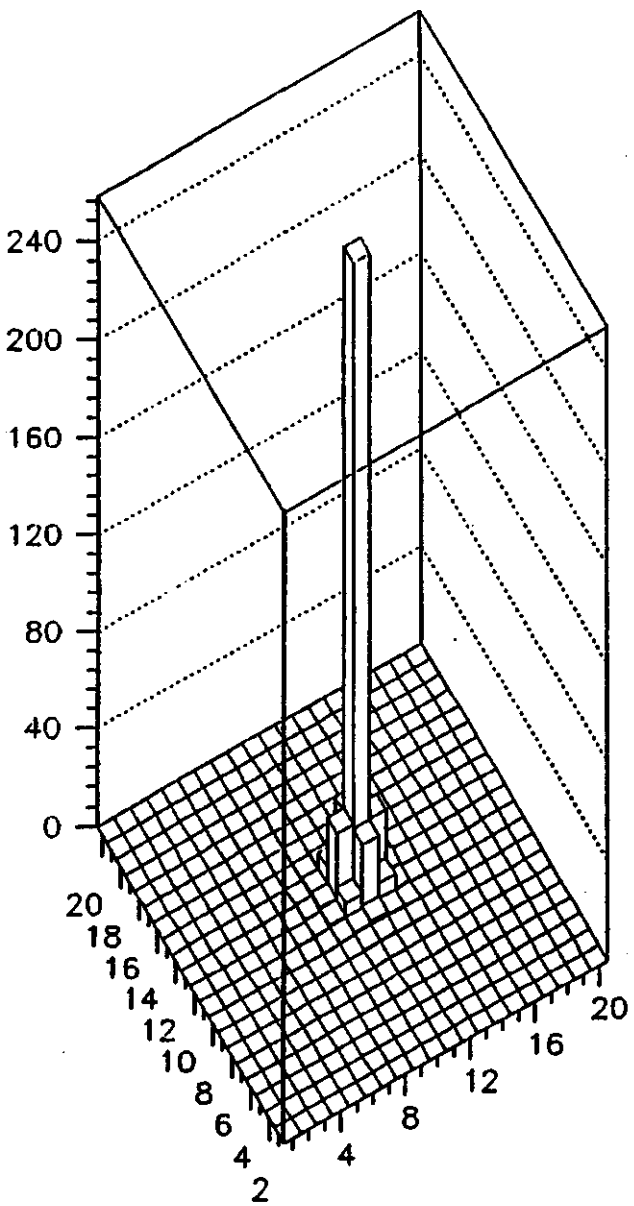
SENSING PLATE (Module #2)

6 Cell Depths
6 Resistive Coating Templates
6 Plates

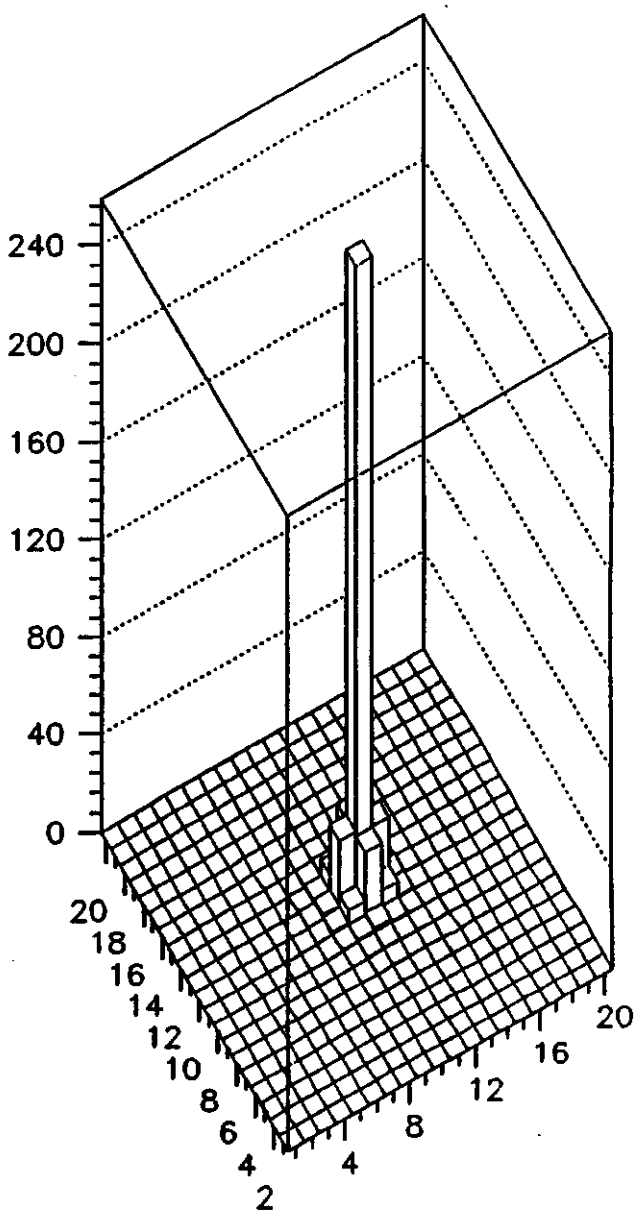




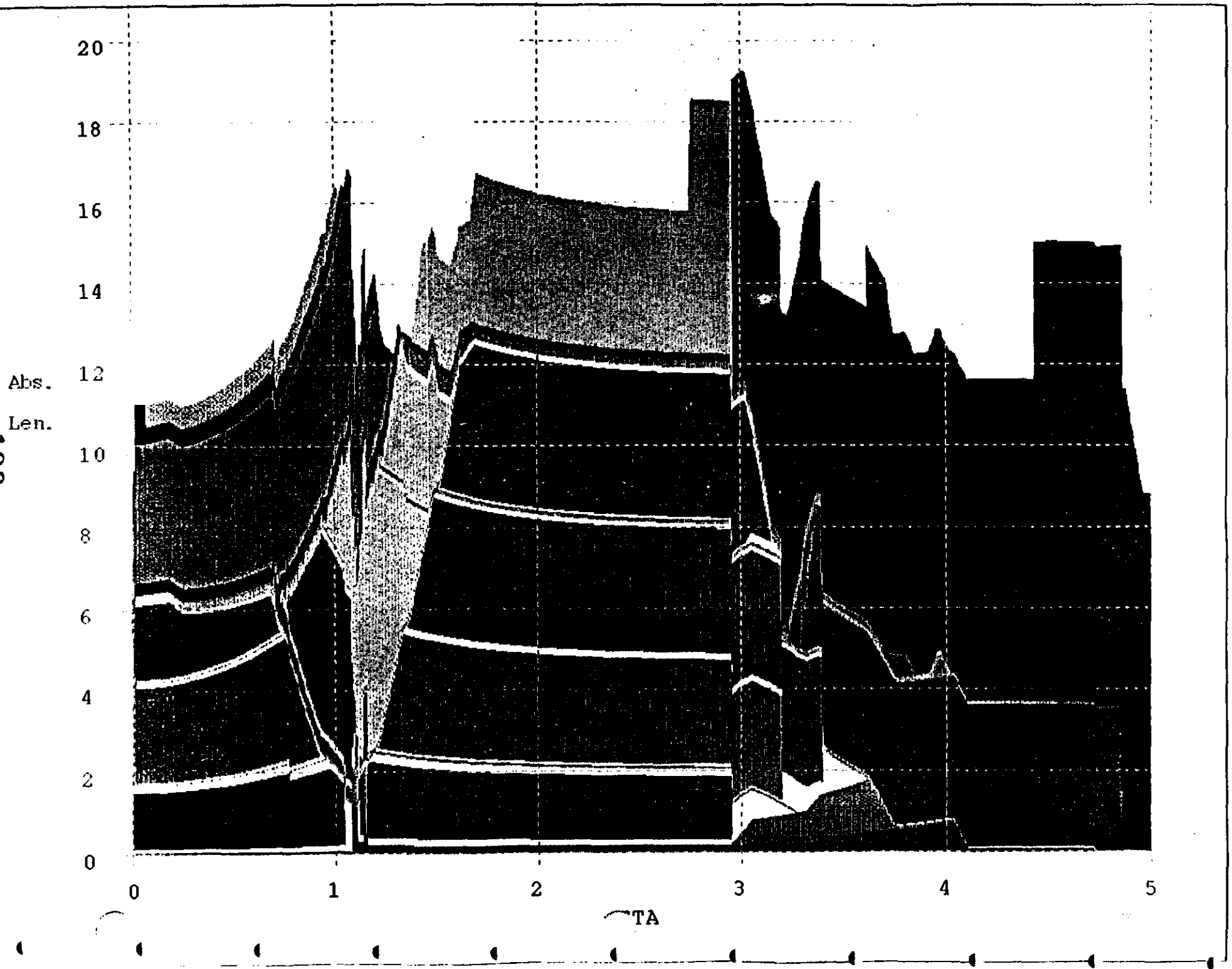
Hadronic Configuration with Electrostatic Transformer

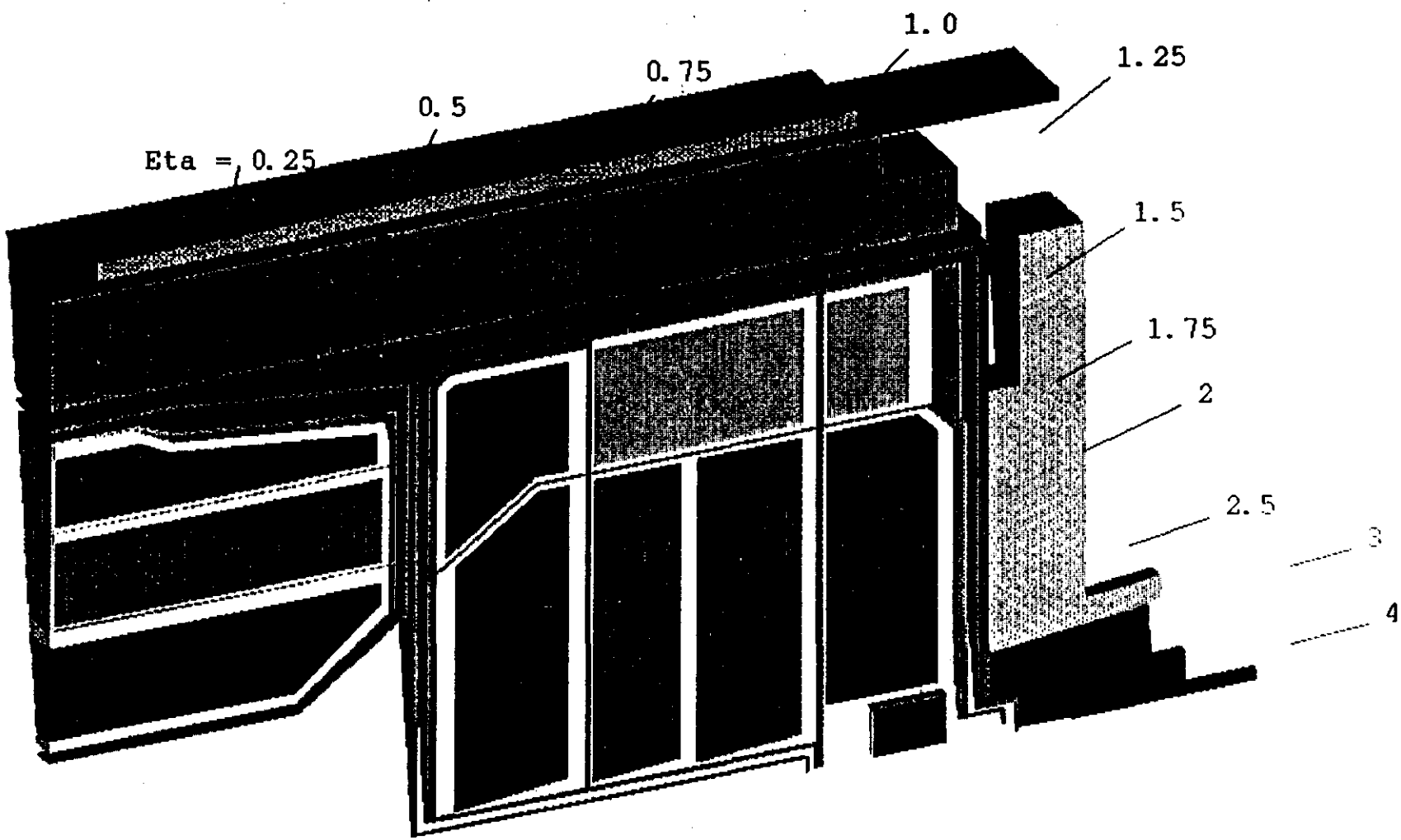


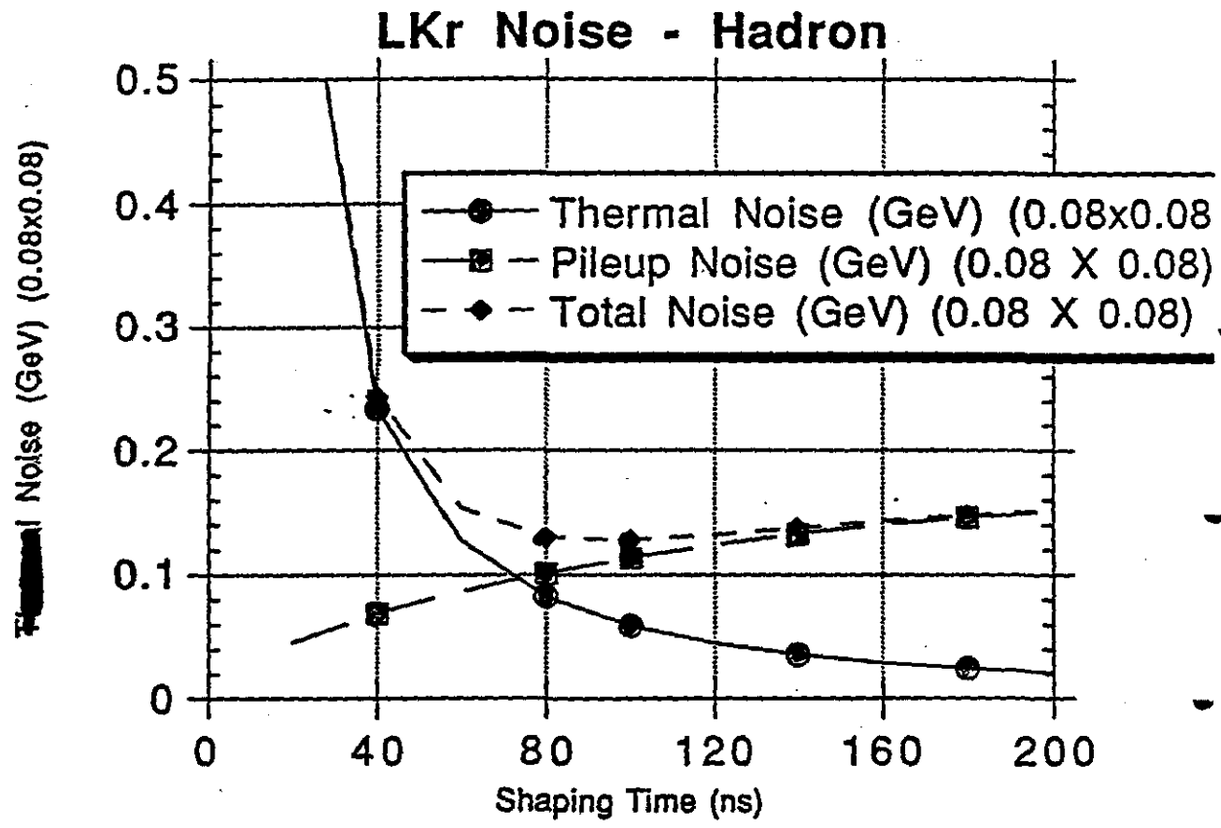
energy flow in the calorimeter



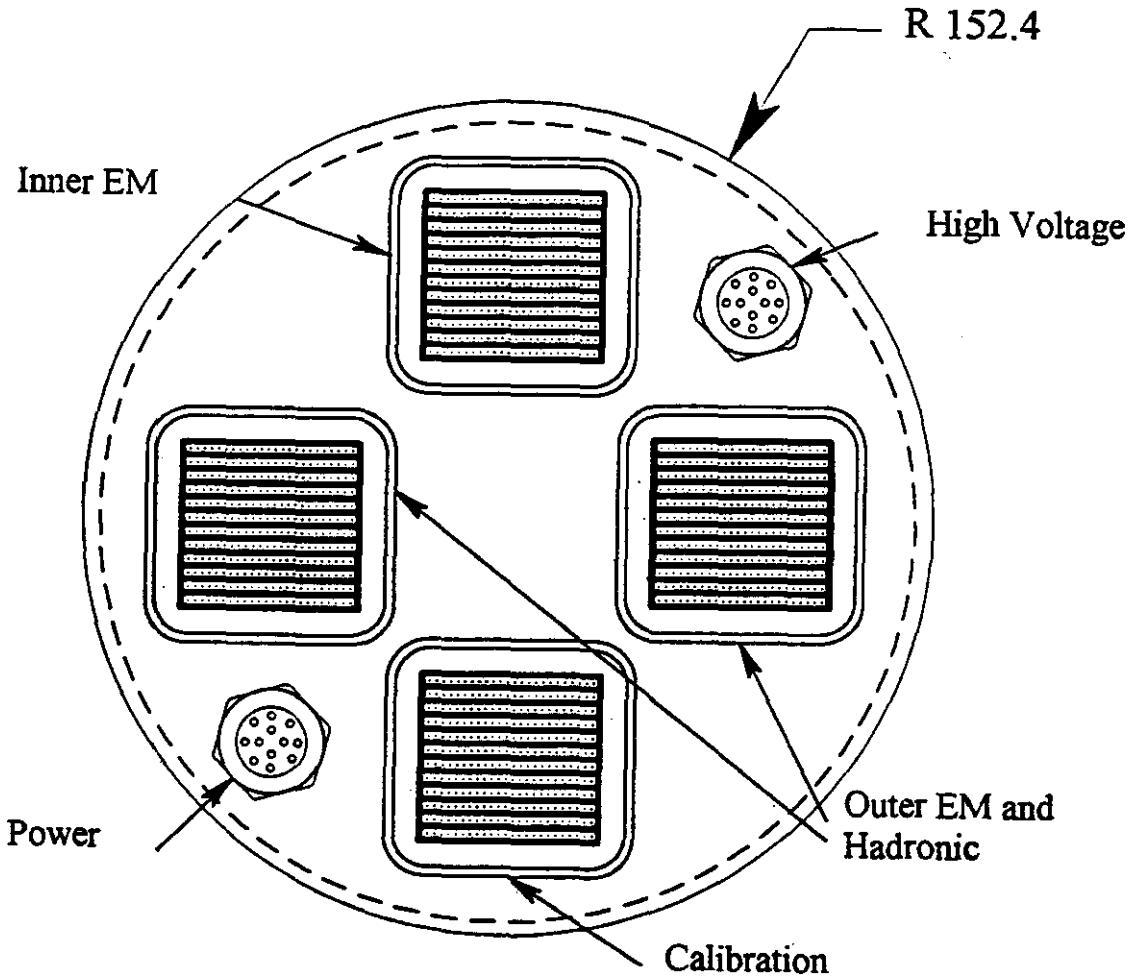
energy flow in the EST calorimeter


Abs.
Len.
20
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
TA


Eta = 0.25
0.5
0.75
1.0
1.25
1.5
1.75
2
2.5
3
4

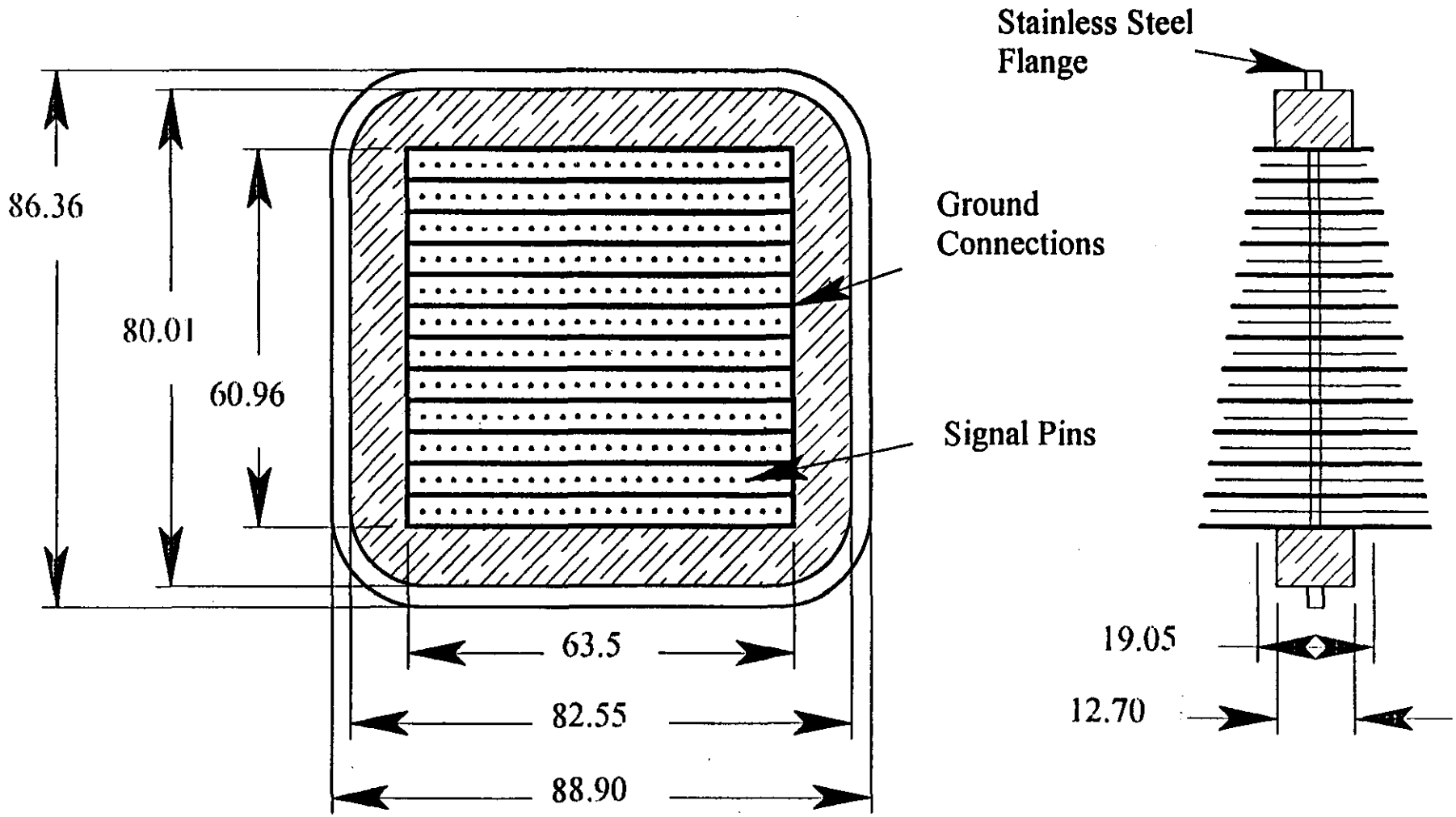

LKr Noise - Hadron
0.5
0.4
0.3
0.2
0.1
0
0
40
80
120
160
200
Shaping Time (ns)
Thermal Noise (GeV) (0.08x0.08)
Thermal Noise (GeV) (0.08x0.08
Pileup Noise (GeV) (0.08 X 0.08)
Total Noise (GeV) (0.08 X 0.08)

Feedthrough Flange
(9 deg. Sector)



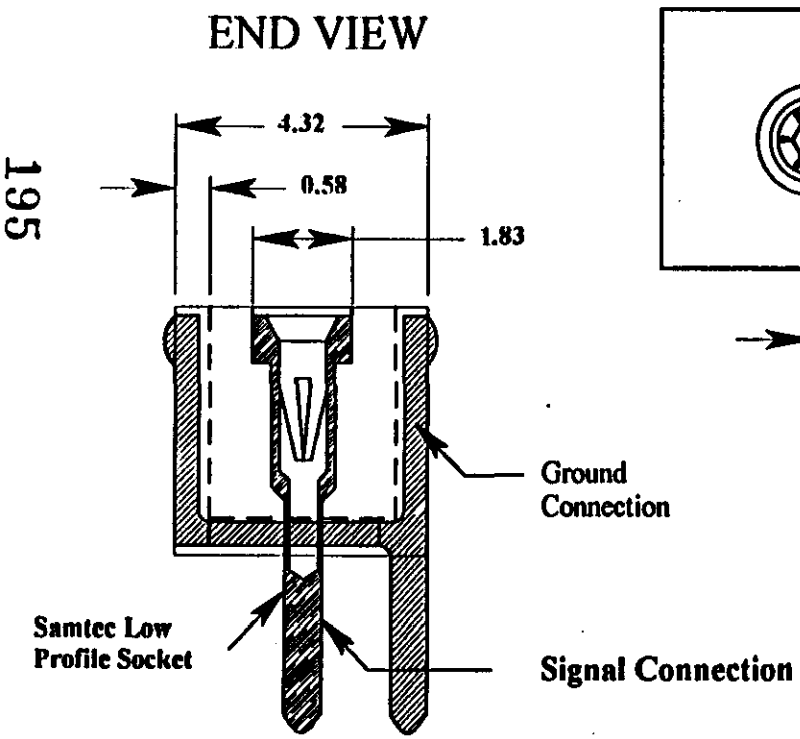
DSM

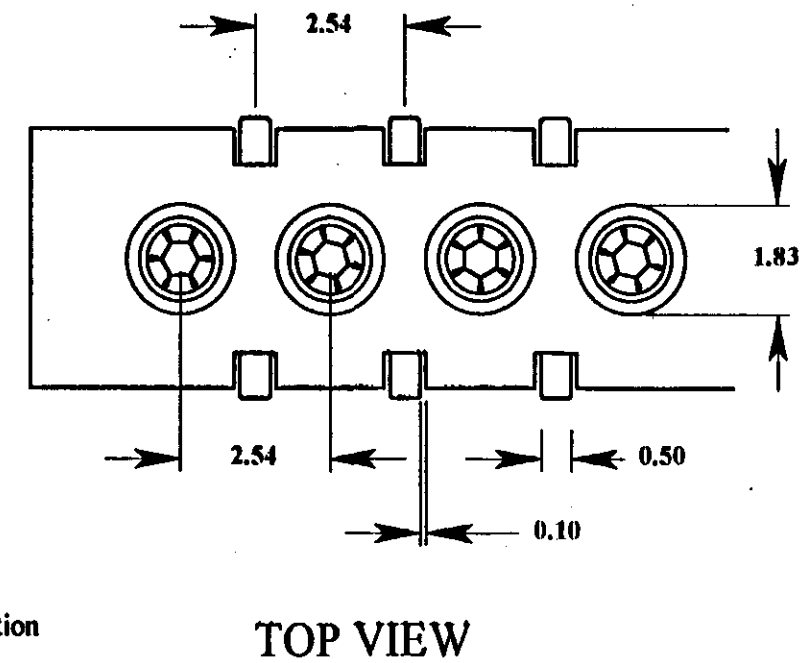
High Density Ceramic Feedthrough (288 channels)



DSM

Conceptual Drawing of Feedthrough Connector





DSM

e/π AT 10 GEV

MATERIAL	EXPERIMENT	GEANT 3.15 + FLUKA
LA/PB	1.19	1.30
LKR/PB		1.42
LA/Cu		1.41
LKR/Cu		1.69

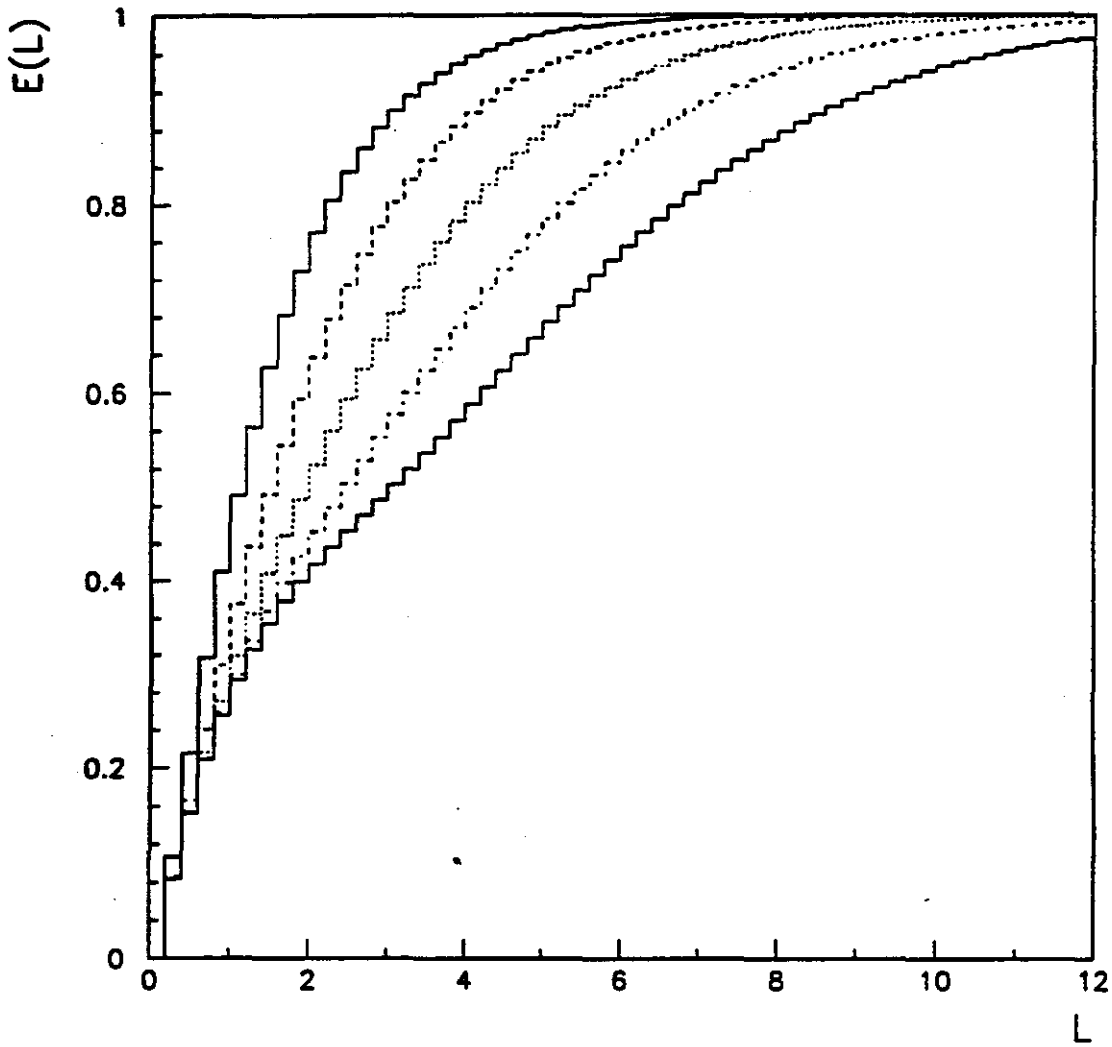


Figure 1: $\bar{E}(L)/E$ vs L for $E = 1$, 10, 100, 1000, and 10000 GeV.

Fit 8 parameters $R = 0.7$

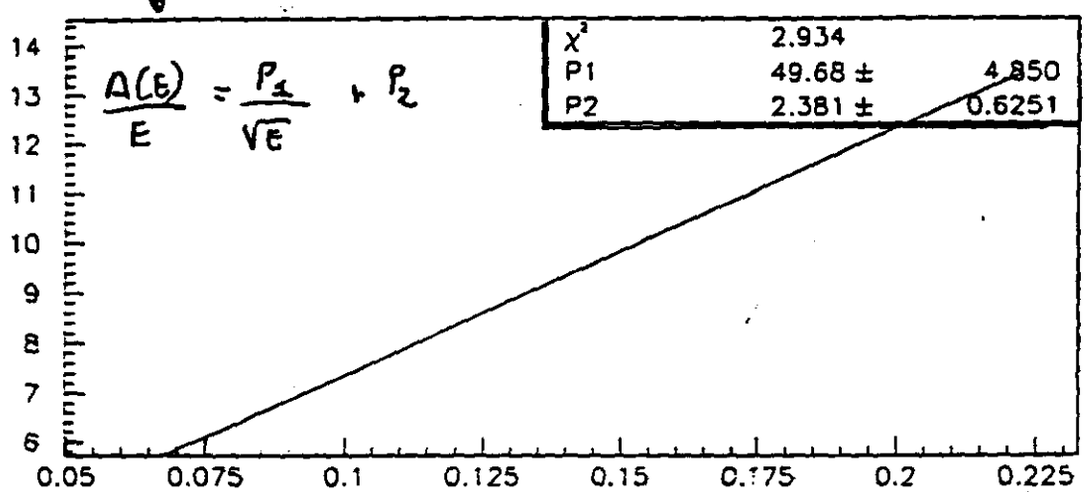
RD3 – P. Battaglia, L. Cossi, L. Perini

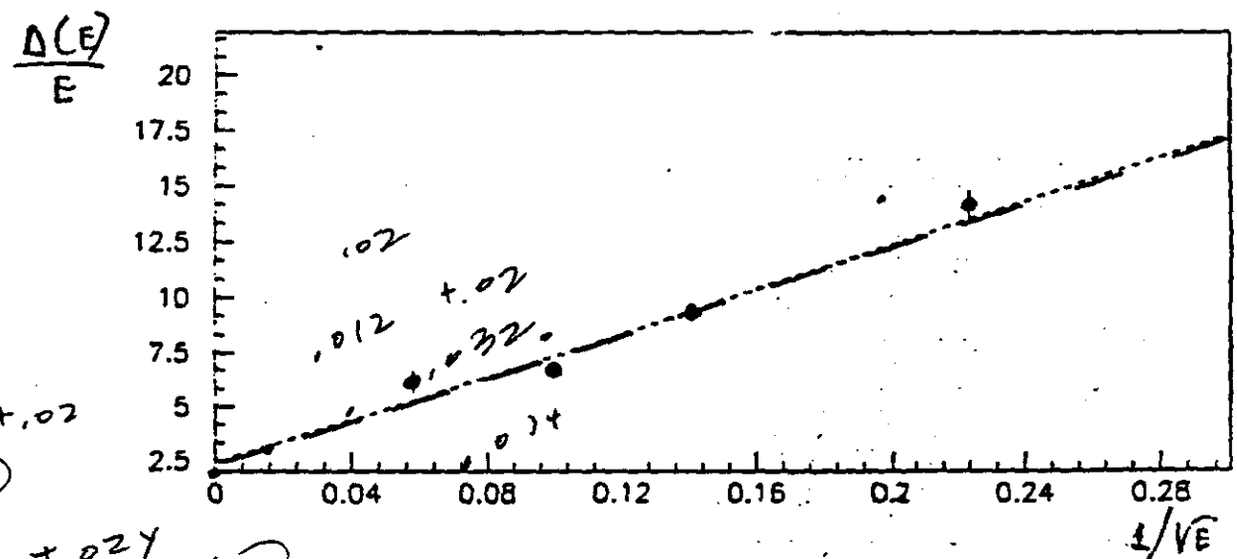
10/12/92

Accordion + Fe/LAr

Pythia Jets 20–300 GeV

GEANT 3.15 + FLUKA





eJ

1×.6 +.02

.026

01×.5 +.02Y

.005 +.02Y = .029

$$\frac{50 \pm 5\%}{\sqrt{E}} \oplus 2.4 \pm 0.6\%$$

8 parameters – 1 for each longitudinal division but NOT energy dependent

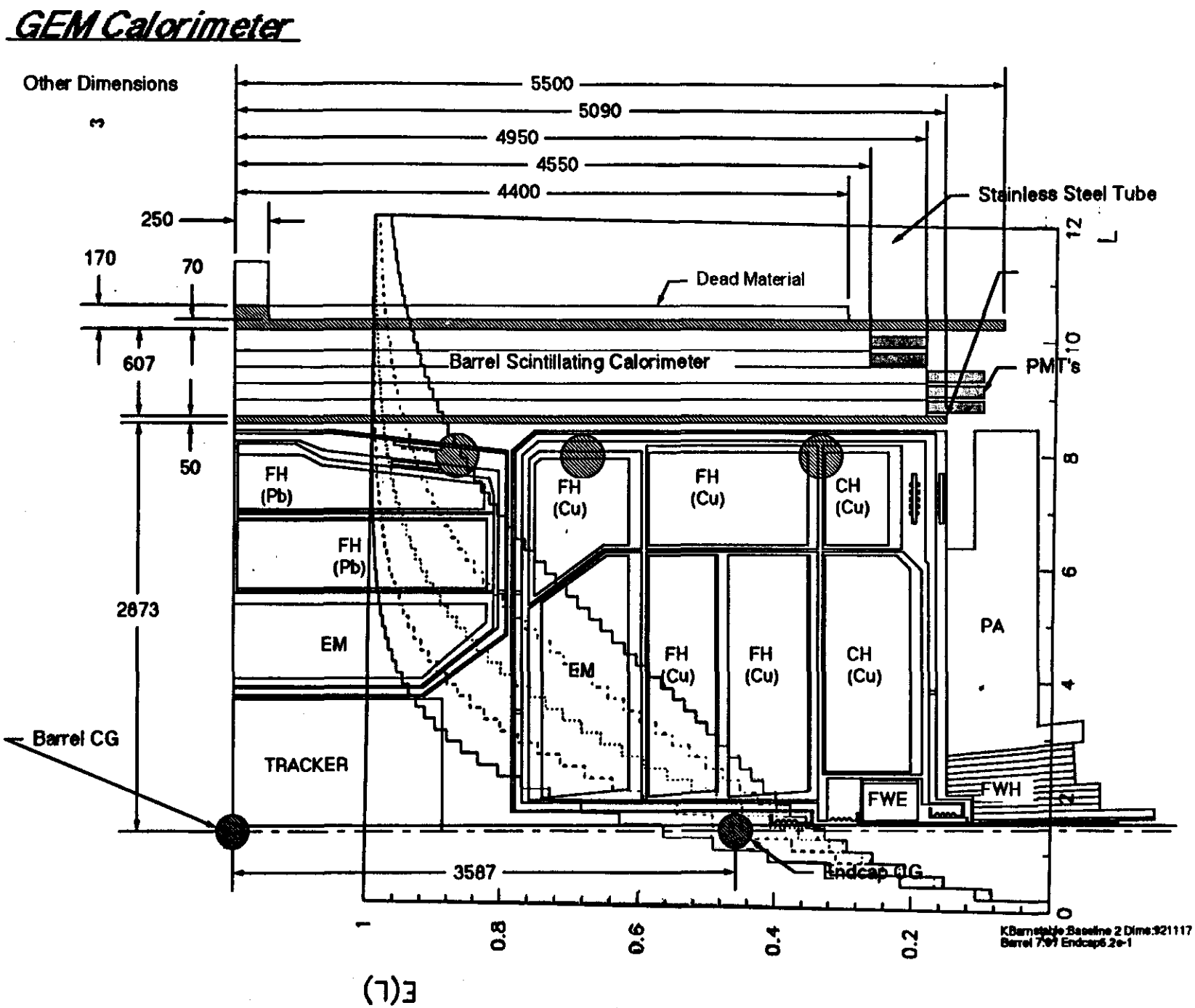


Figure 1: $\bar{E}(L)/E$ vs L for $E = 1.\ 10.\ 100.\ 1000.$ and 10000 GeV.

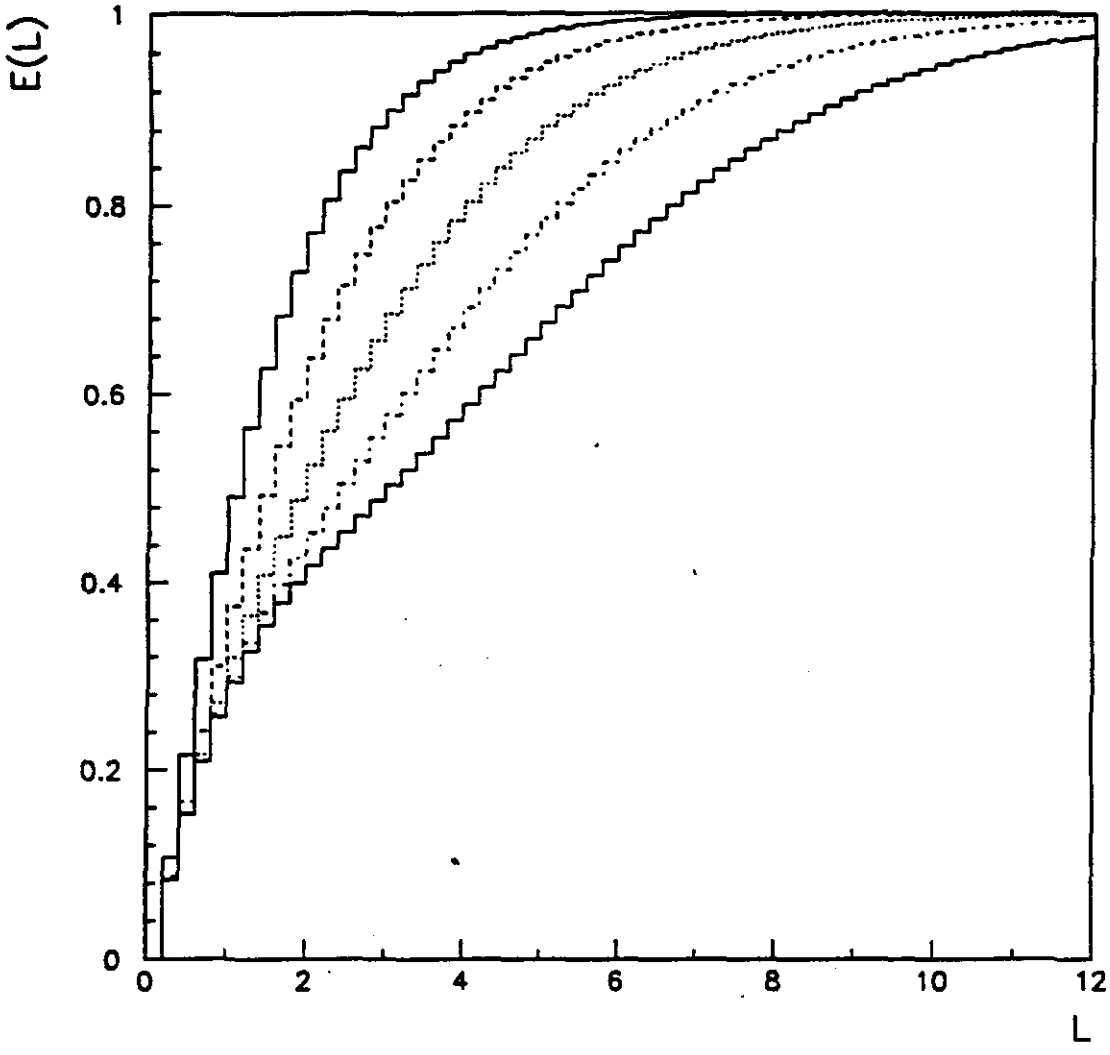
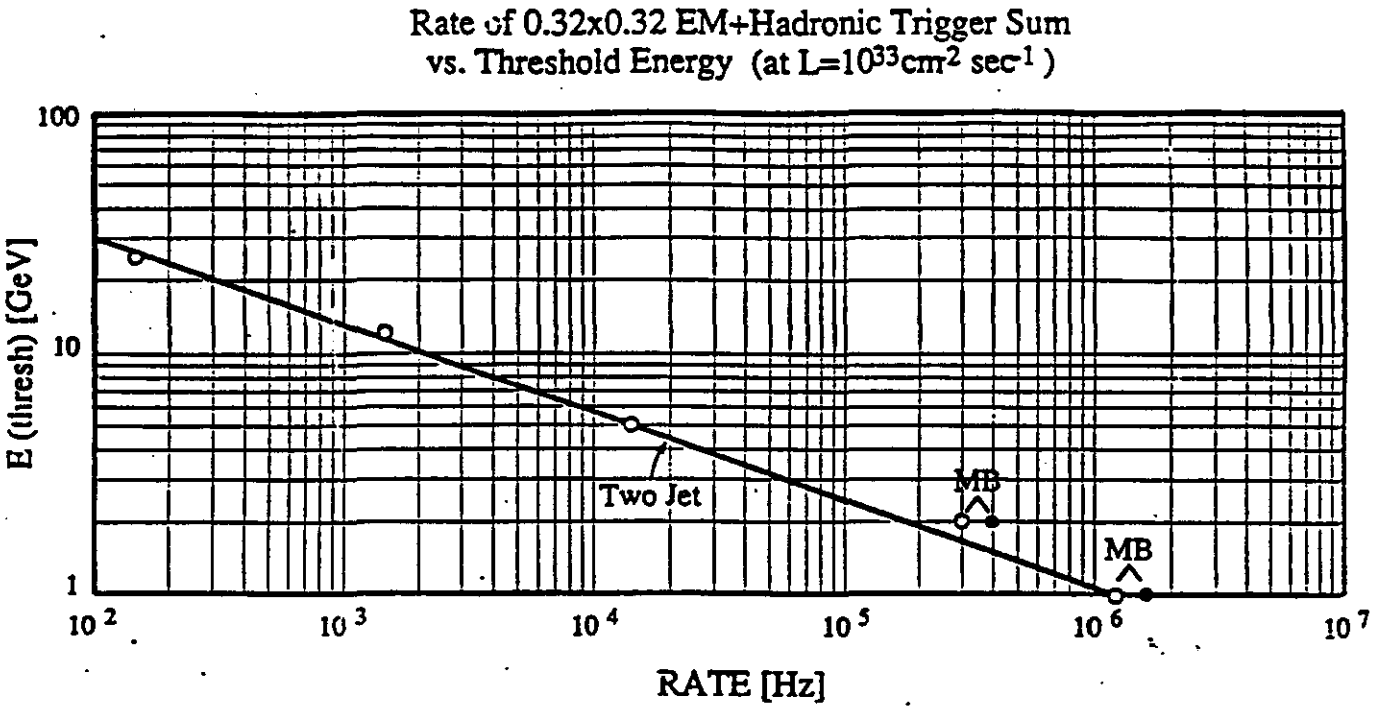


Figure 1: $\bar{E}(L)/E$ vs L for $E = 1$, 10, 100, 1000, and 10000 GeV.

BACKGROUND AND PHYSICS RATES



- Bunch crossing 16ns
- Interactions/b.c. 1.6 @ $L=10^{33}$ cm^{-2} s^{-1}
- Highly selective trigger necessary (rejection factor of 1000–10000). Level 1 decision latency≈ 2–3 μsec.
- Very low physics rate:
  Higgs-->4 leptons (M=500MeV) 10^{-5} s^{-1}
- Signal path of all calorimeter channels has a storage element to accomodate for Level 1 decision time.
- Level 1 trigger will tag all signals pertaining to the corresponding bunch crossing for further storage (Virtual Level 2) or for transfer/digitization.

Even at LHC, consensus is that LAr is an excellent choice for calorimetry.

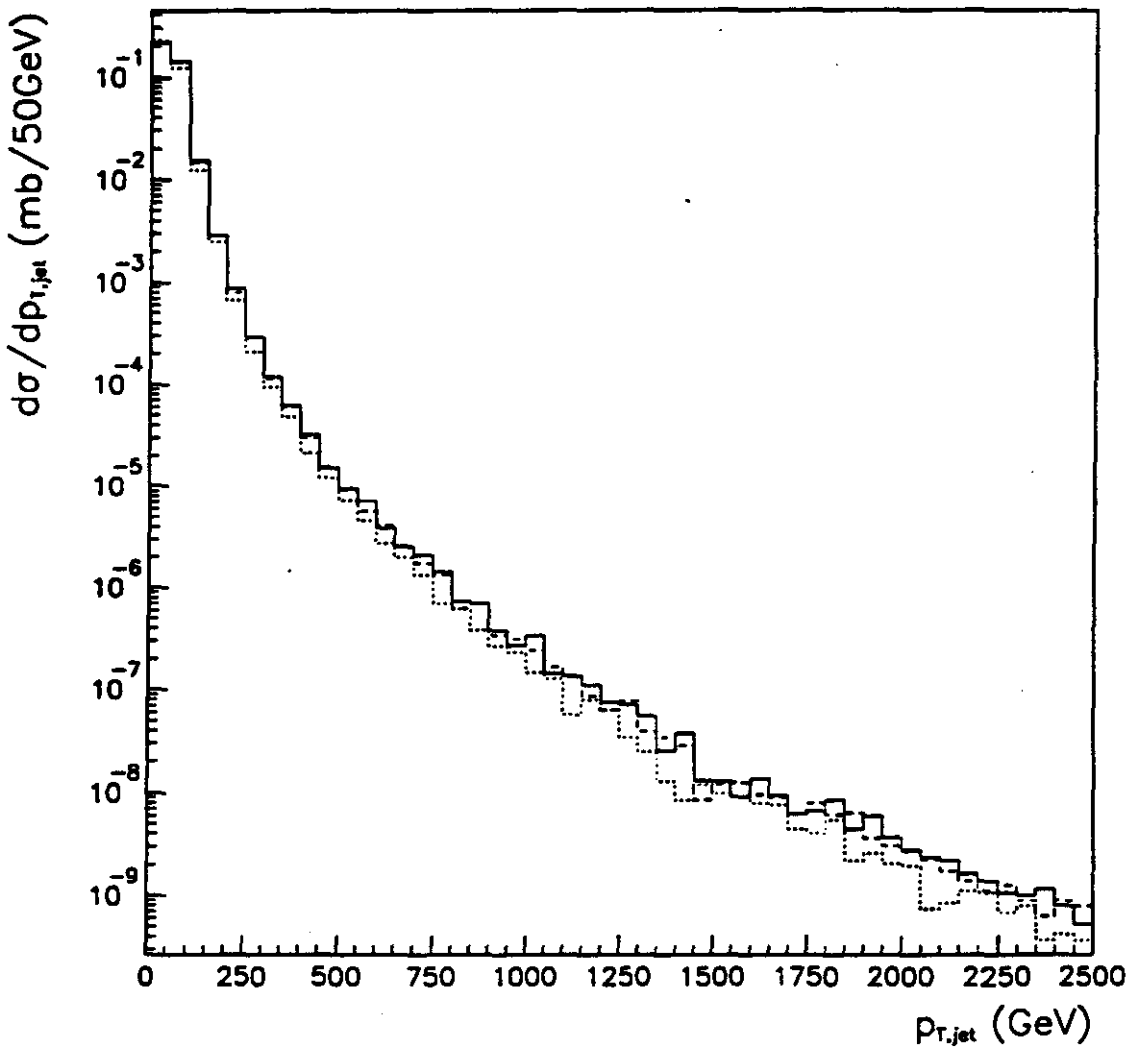


Figure 5: Inclusive jet cross section. Solid: Full calorimeter. Dash: 6λ calorimeter. Dot: 3λ calorimeter.

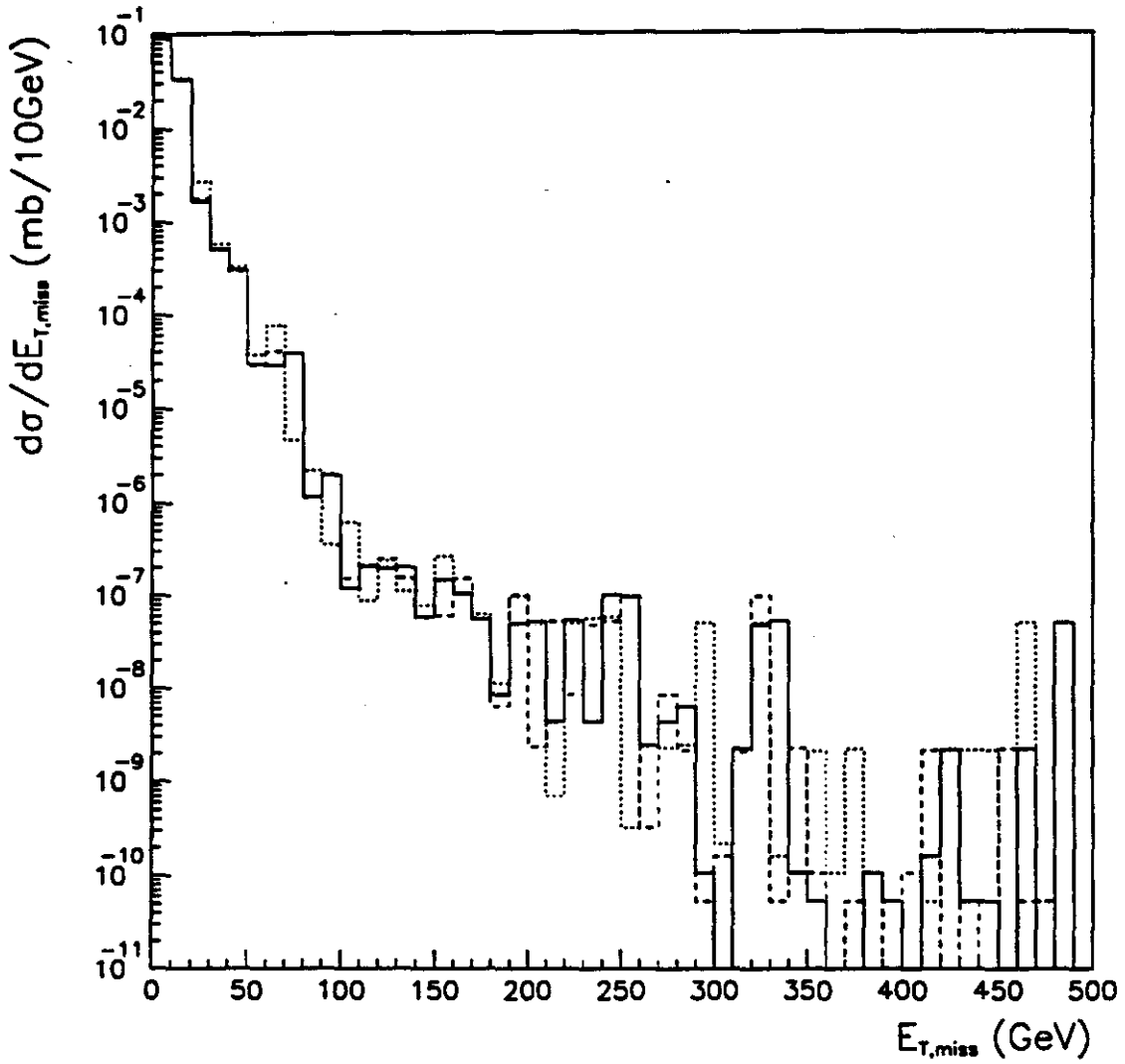


Figure 2: Inclusive $\not\!\!E_T$ cross section. Solid: Full calorimeter. Dash: 6λ calorimeter. Dot: 3λ calorimeter.

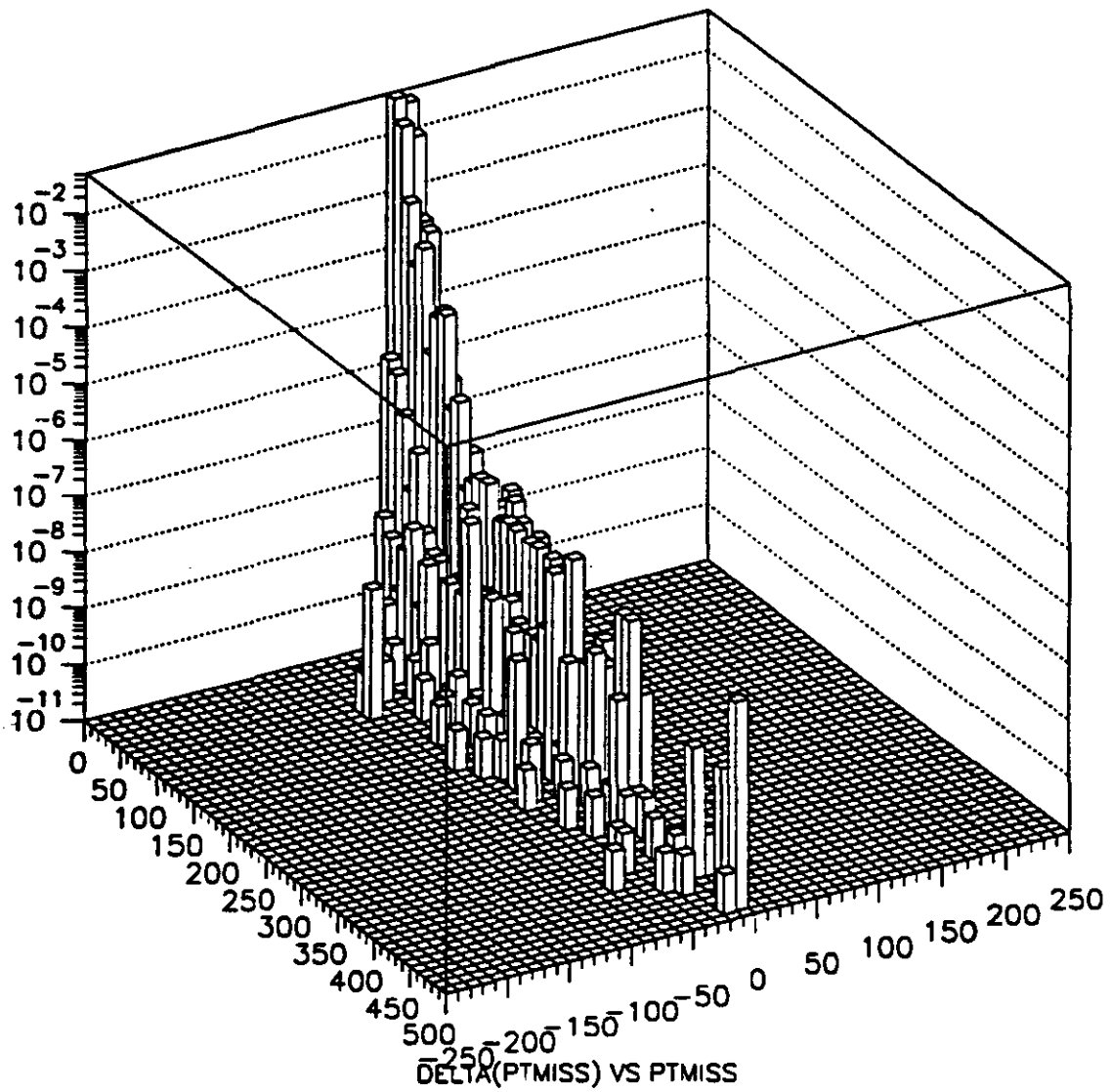
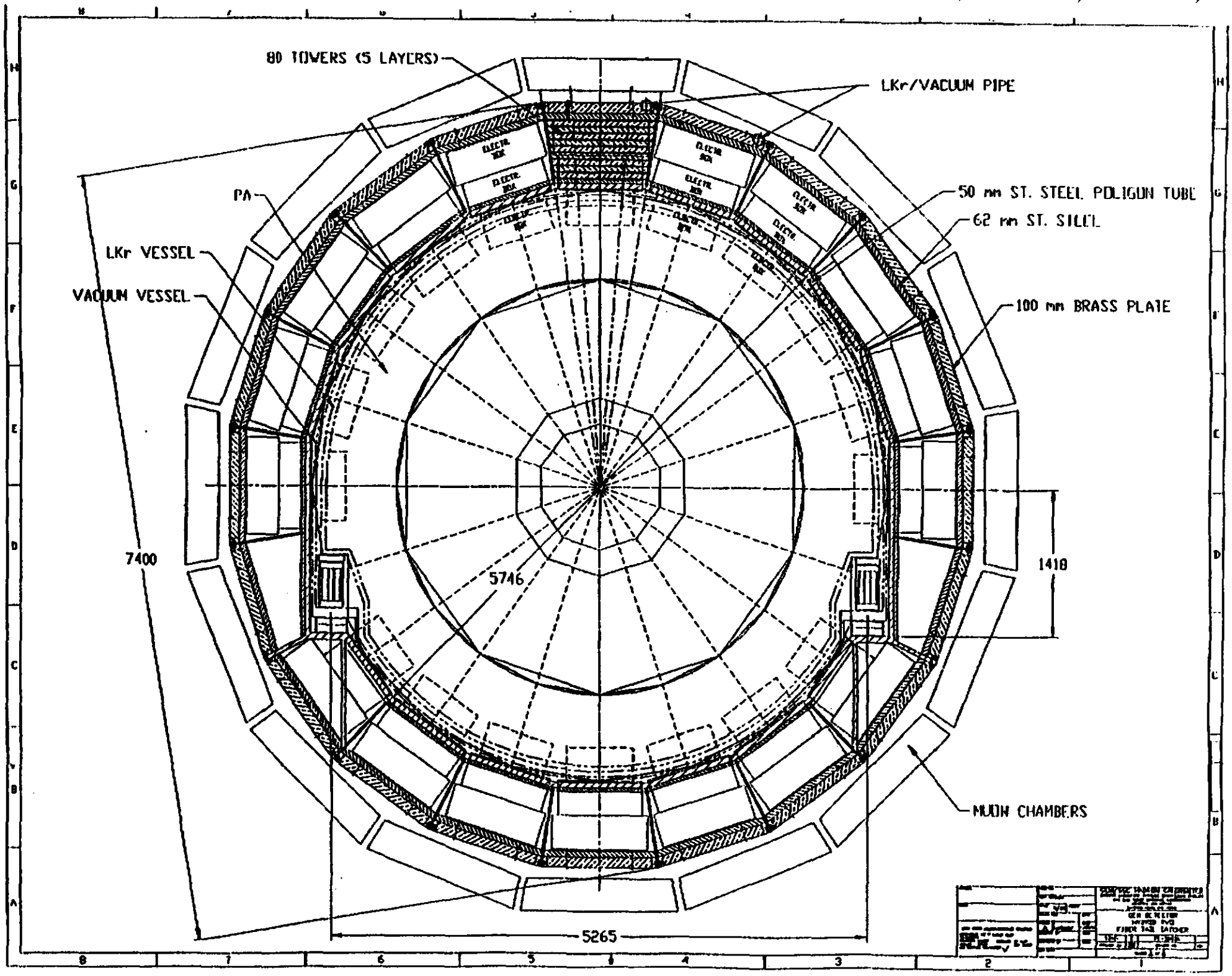
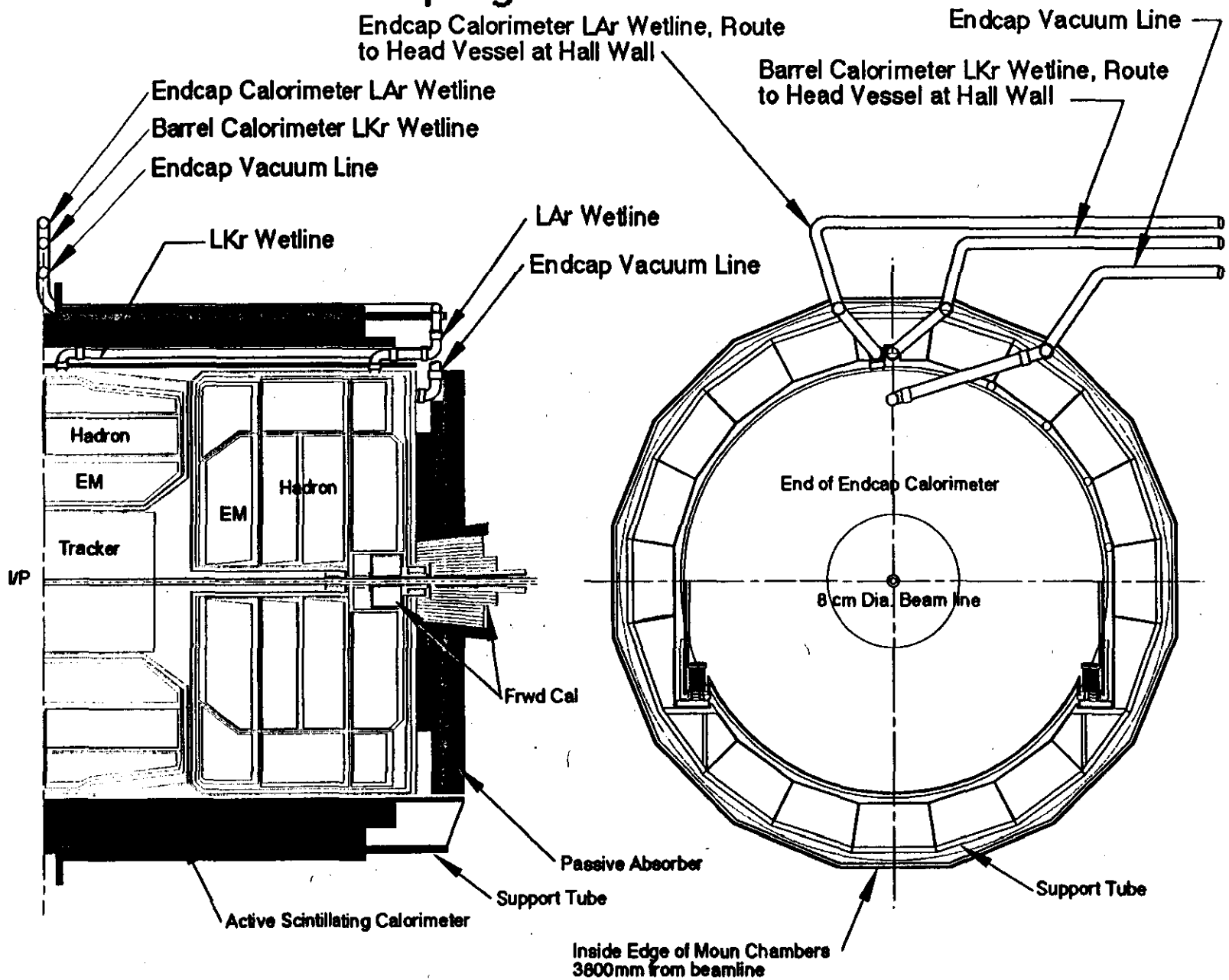


Figure 3: Lego plot of $\not{E}_{T,6\lambda} - \not{E}_{T,\mathrm{full}}$ vs. $\not{E}_{T,\mathrm{full}}$.


80 TOWERS (5 LAYERS)
LKr/VACUUM PIPE
PA
50 mm ST. STEEL POLIGON TUBE
62 mm ST. STEEL
LKr VESSEL
VACUUM VESSEL
100 mm BRASS PLATE
7400
5746
1418
MUON CHAMBERS
5265

GEM Calorimeter Piping Plan



Half Section - GEM Calorimeter

End View - Gem Calorimeter

LLMason:Calorimeter Piping:11/16/92

SDRC I-DEAS V: FE_Modeling_&_Analysis 13-NOV-92 09:01:05

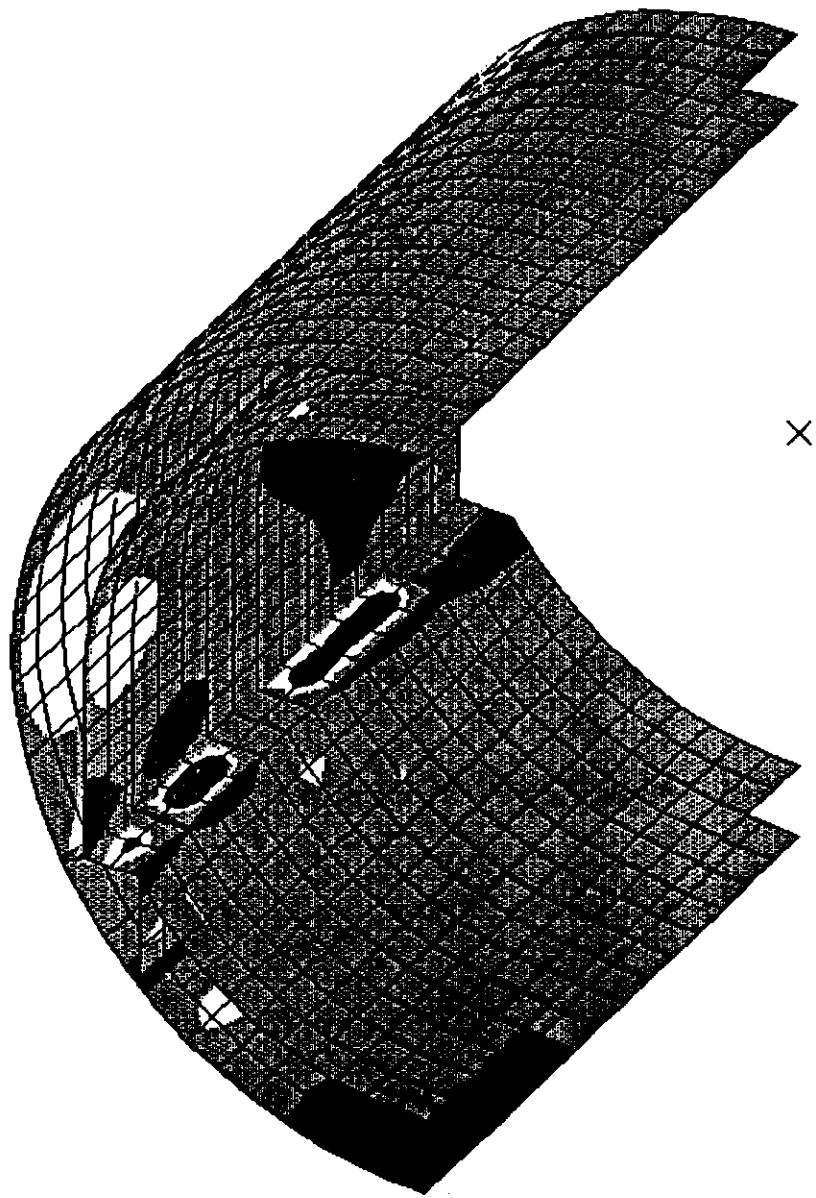
Database: scintube
View : No stored View
Task: Post Processing
Model: 2-MODEL2

Units : IN
Display : No stored Option
Model Bin: 1-MAIN
Associated Workset: 3-WORKING SET3

scintube

LOADCASE: 1
FRAME OF REF: LOCAL 1
STRESS - MAX PRIN MIN: -10151.01 MAX: 7263.13

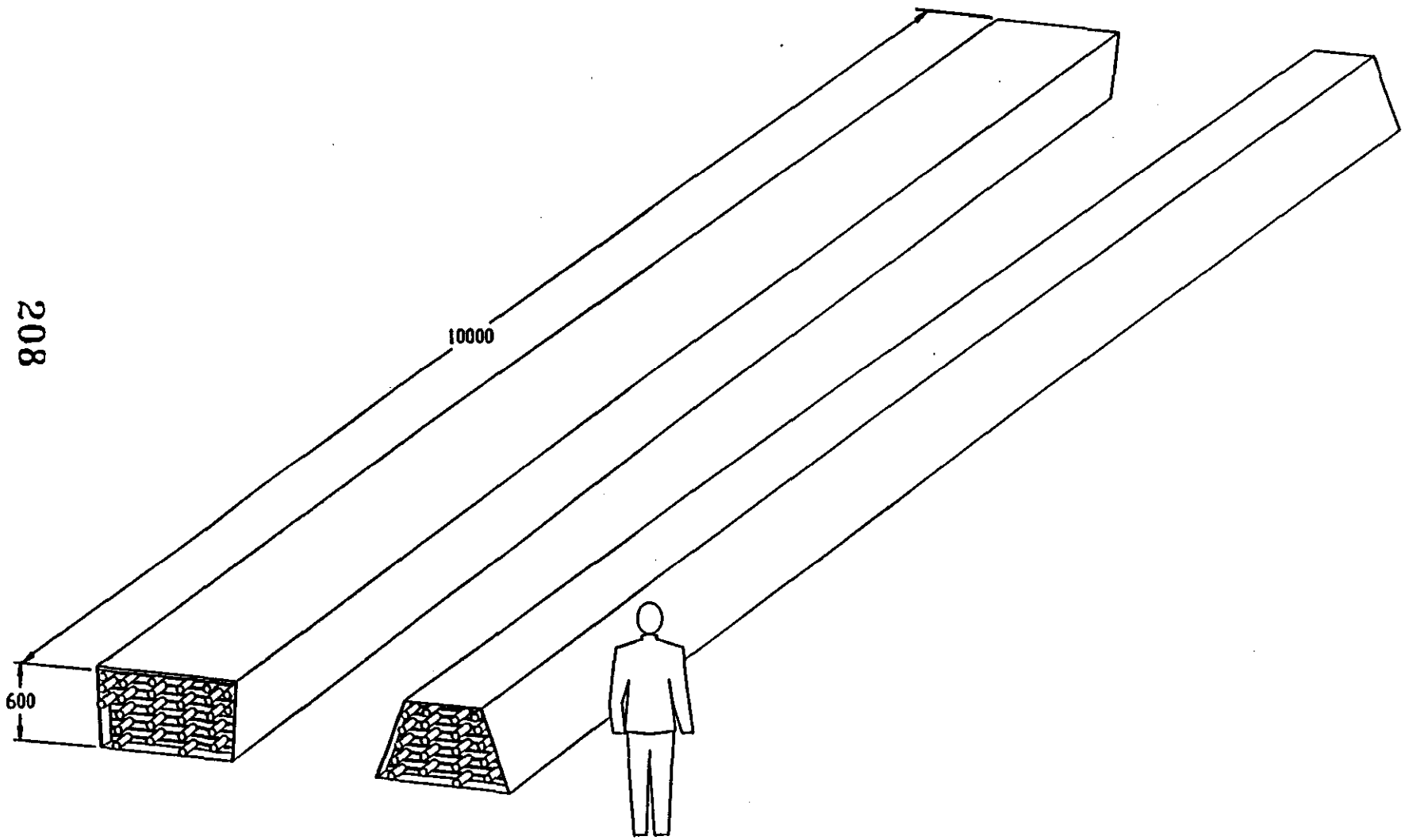
SHELL SURFACE: BOTTOM



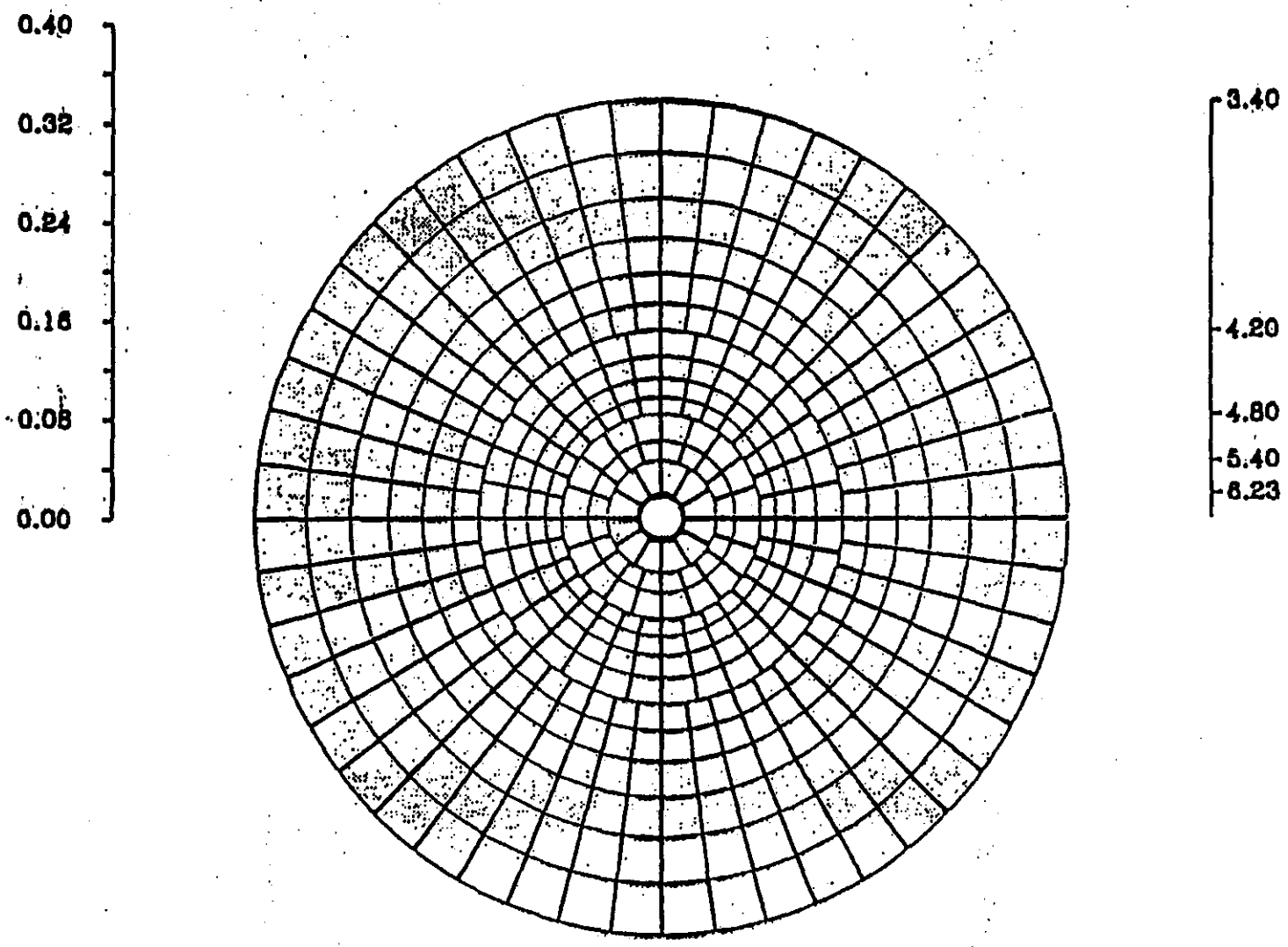
7263.13
4775.39
2287.66
-200.08
-2687.81
-5175.55
-7663.28
-10151.01

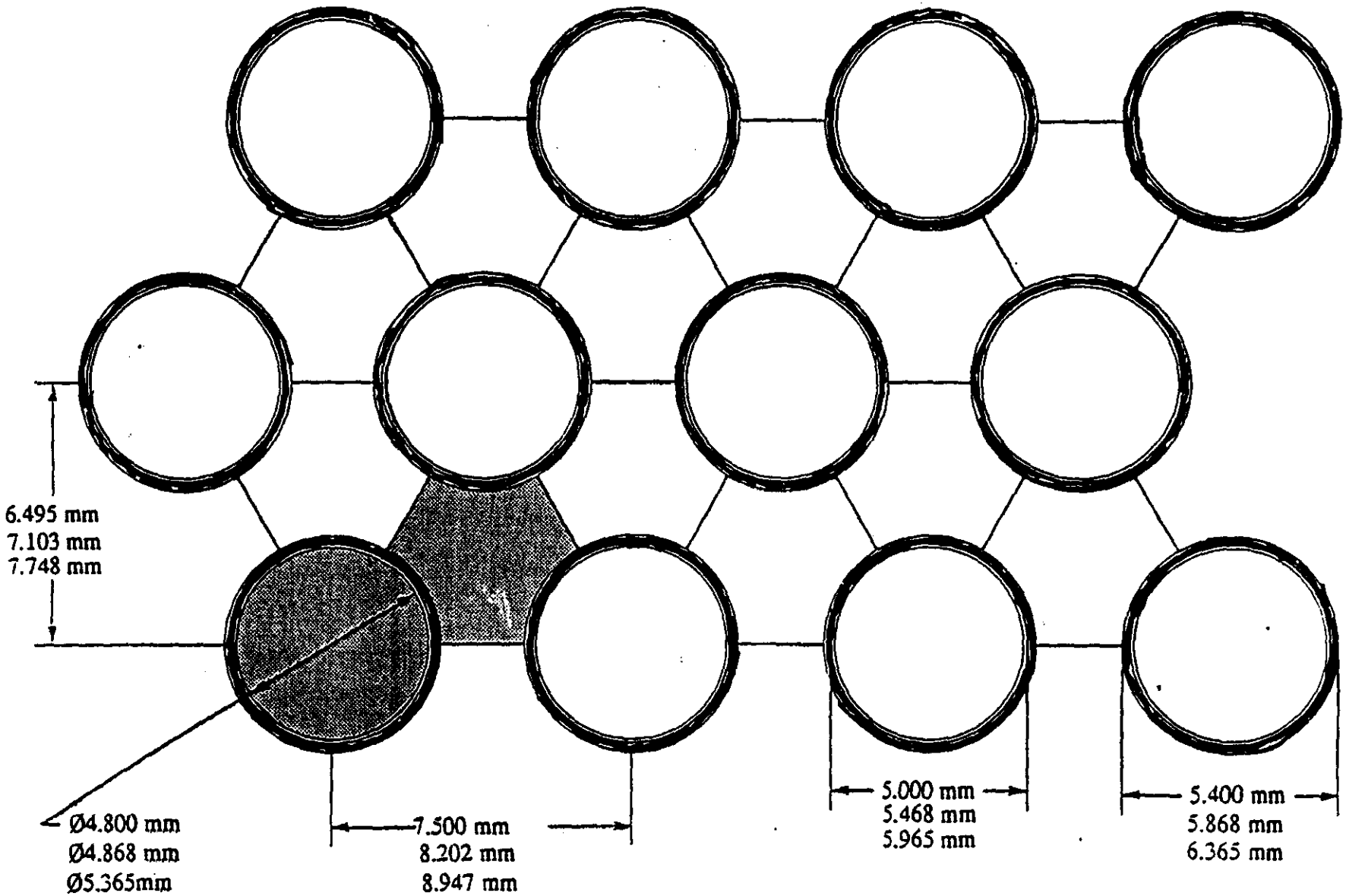
Y
X
Z

208



GEN DETECTOR
FIXED TAIL CARRIER
ISOMETRIC VIEW

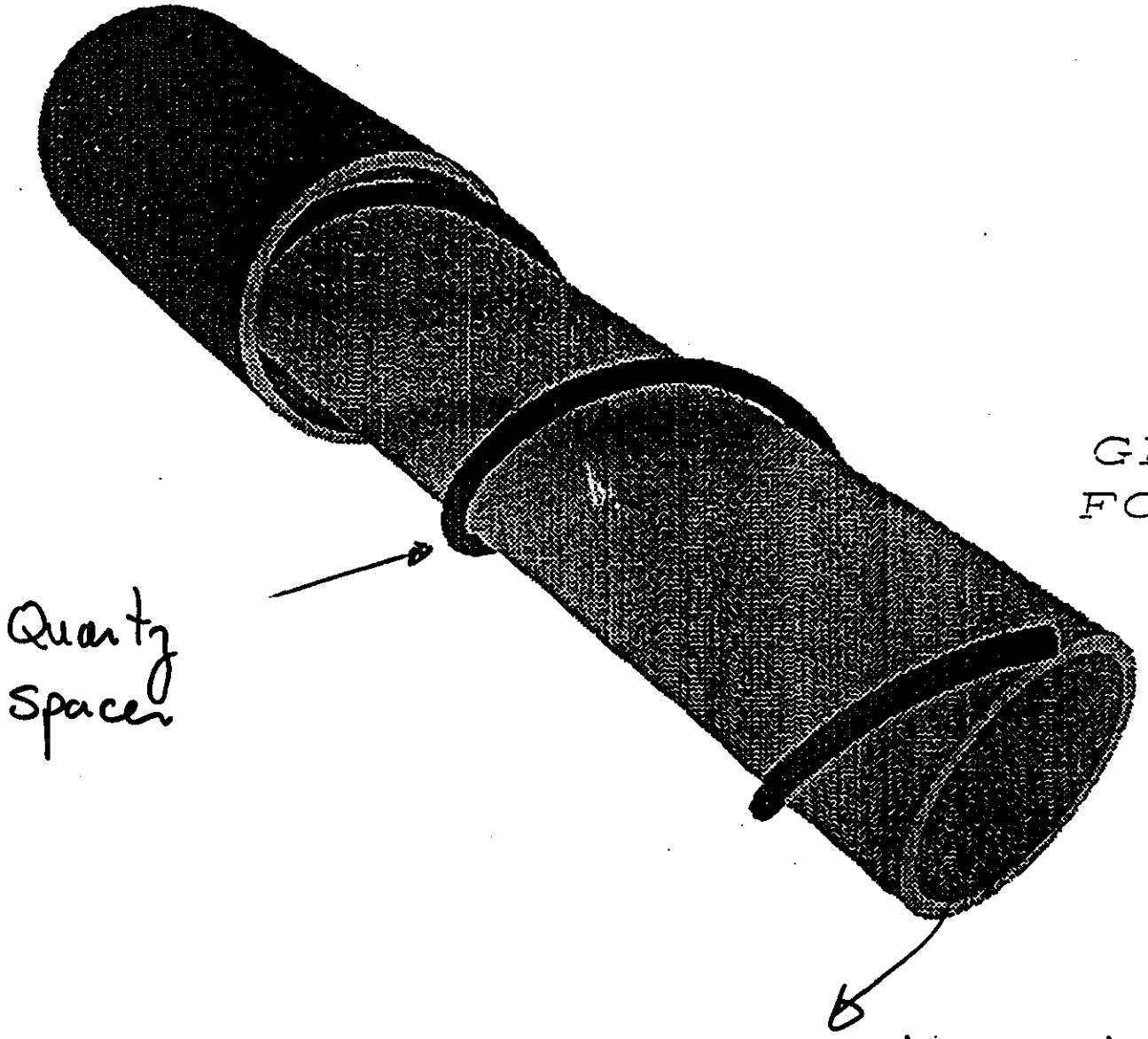

0.40
0.32
0.24
0.16
0.08
0.00
3.40
4.20
4.80
5.40
6.23



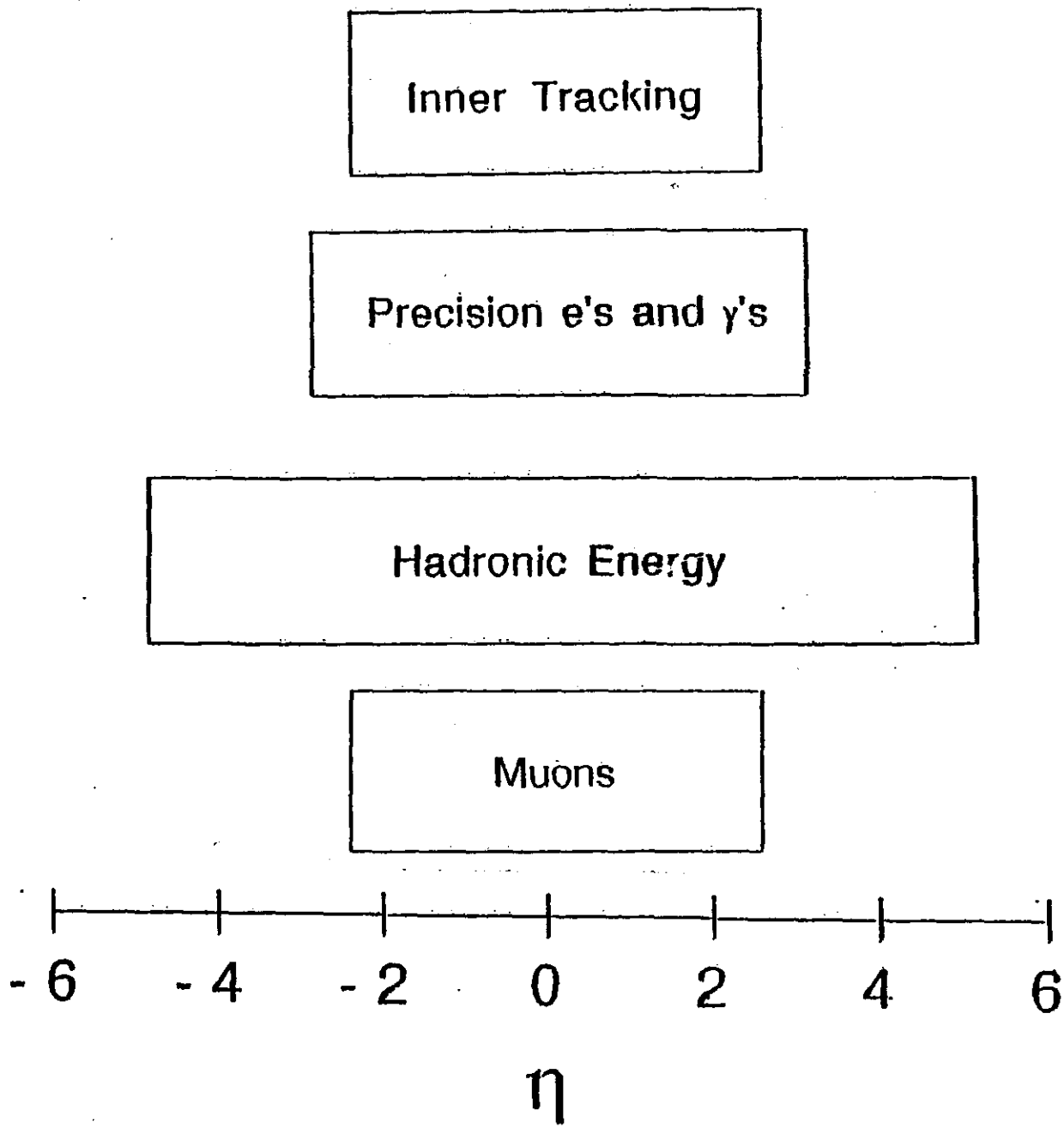
FCAL MODULE - TUNGSTEN ARRAGEMENT

LAR MODULE-DEFORM

SM CHAE


GEM LAC
FCal Tube
Quartz
Spacer
Tungsten Rod.

GEM Coverage



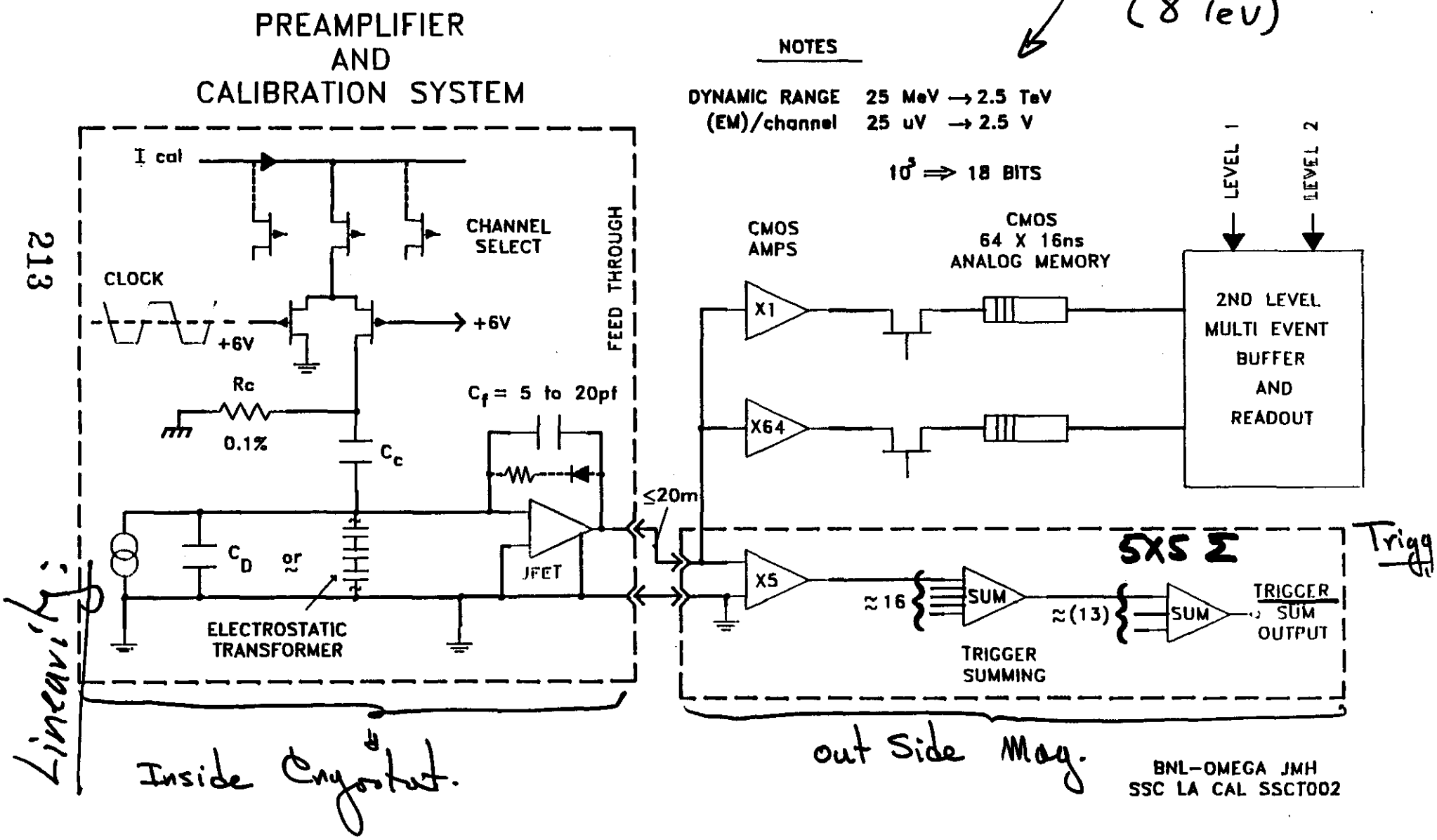
* 0.1 - 0.2% Calibration.

$\simeq 10^{14}$ n/cm²

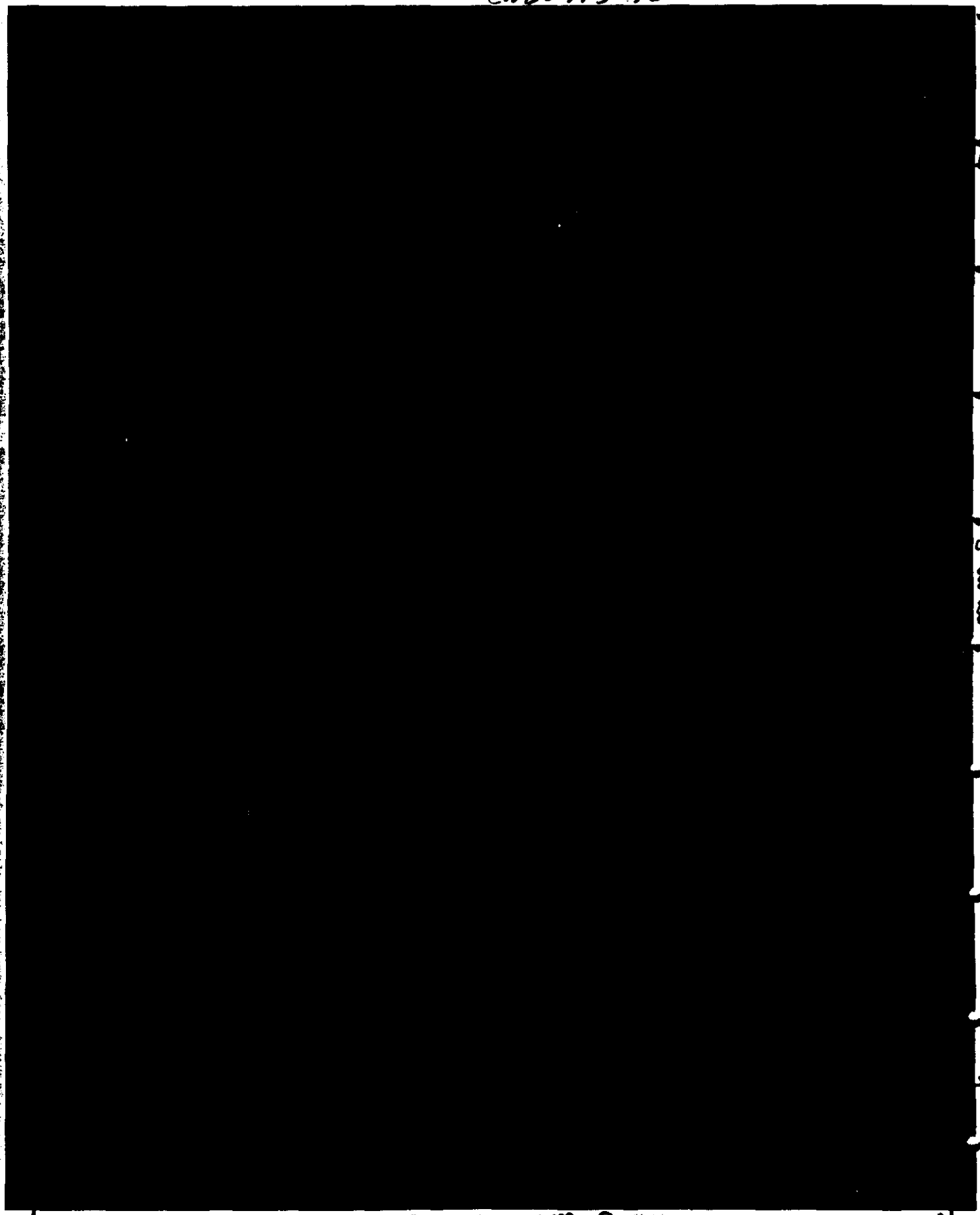
$\simeq$ 10 - 30 Mrad.

Tested to: 5×10^{14} n/cm²
100 Mrad.

Dynamic Range set by $Z' \to ee$ (8 TeV)

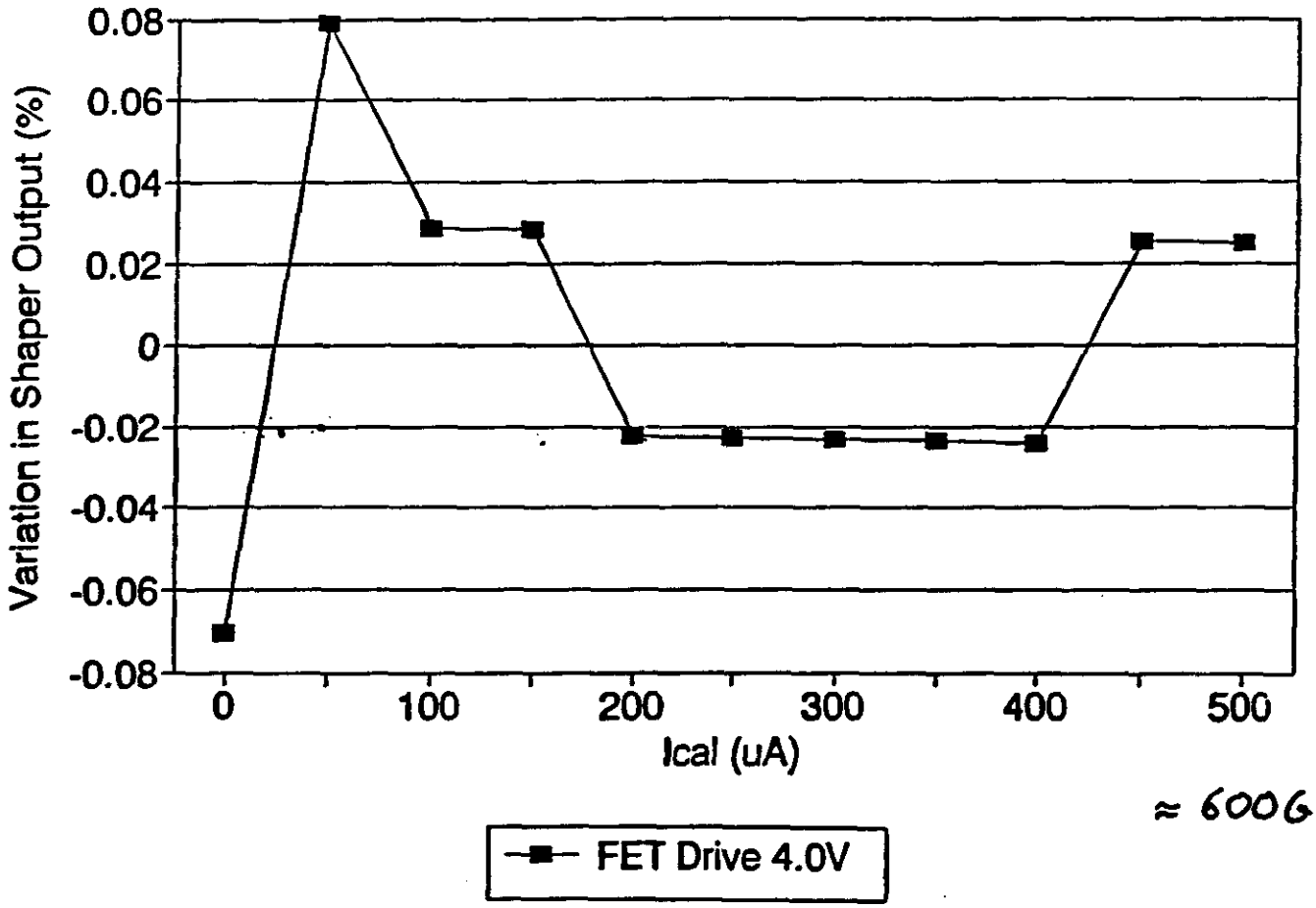


CNL-173-90 589 KODAK



LA Calibration - "IT" method

P Channel FET , $t_m = 25$ nsec



≈ 600 GeV

Fig. 5

Calorimeter Trigger Information

The calorimeter system has to provide a major part of the information that is needed by the trigger system. This imposes a number of constrains on the design .

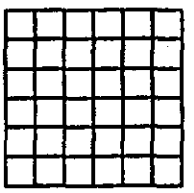
The information we need:

- isolated em shower : $P_T > 15$ Gev/c. 1,2 or 3 candidates.
- isolated em shower : $P_T > 35$ Gev/c. 1 or 2 candidates.
- Jet : $P_T > 100$, 200 , 500 , 1000Gev/c 4 Levels for Jet trigger.
- E_T^{total} : $E_T > 200$, 500 , 1000 Gev/c 3 Levels for the E_T trigger
- E_T^{em}: $E_T > 35$ Gev/c.
- SPT- Single Particle trigger : $E_T > 50$, 100 , 500 Gev/c. 3 levels for the Single particle trigger.
- Missing E_t: $E_T^{miss} > 100$ GeV.

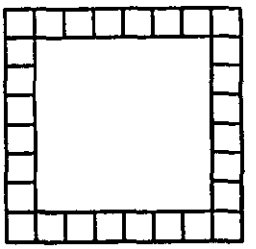
Trigger Sums

EM cell
(.027x.027)

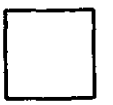
EMF=6x6 EM
(.16x.16)



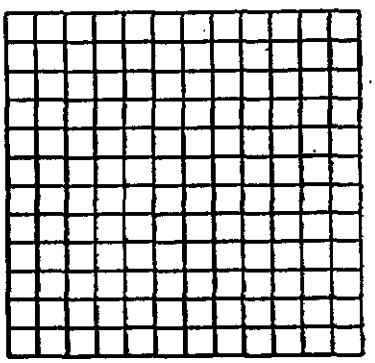
EMB (border)
(.21x.21)



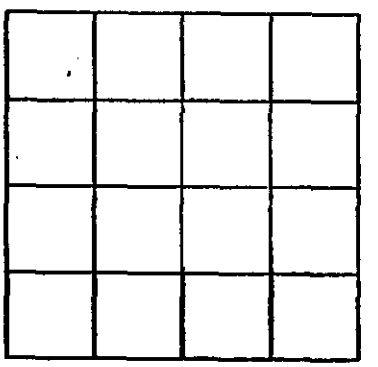
HAD cell
(.08x.08)



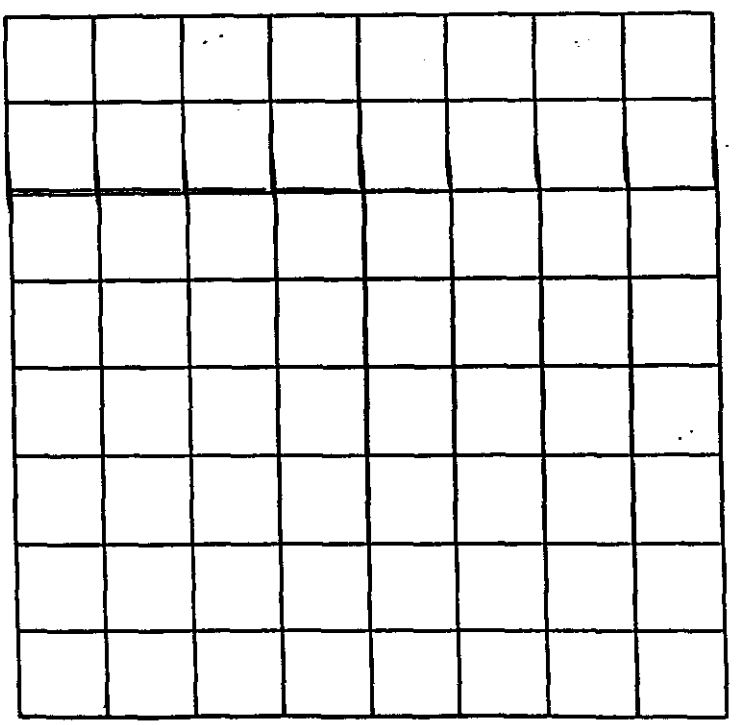
SPEM=2x2 EMF (.32x.32)



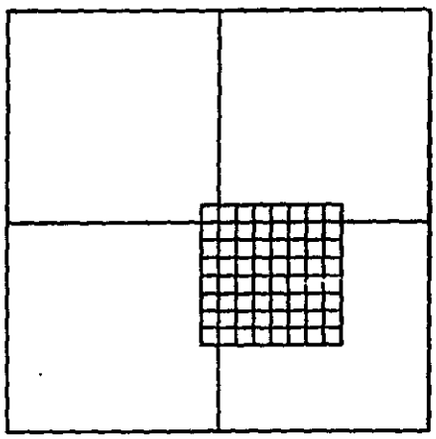
SP=4x4 HAD (.32x.32)



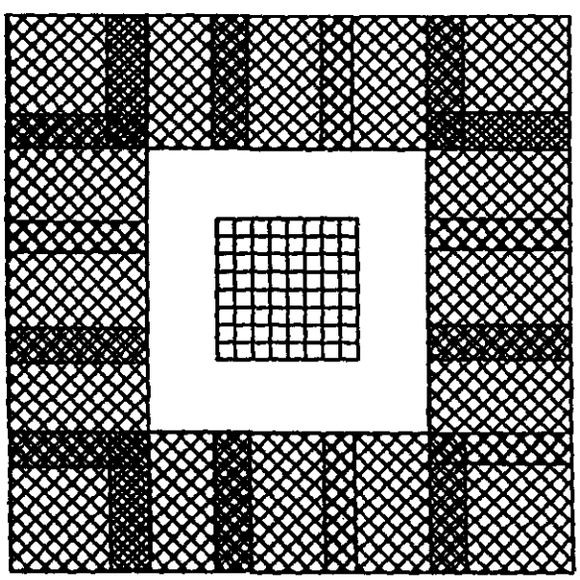
Jet Sum=2x2 SP
(.64x.64)



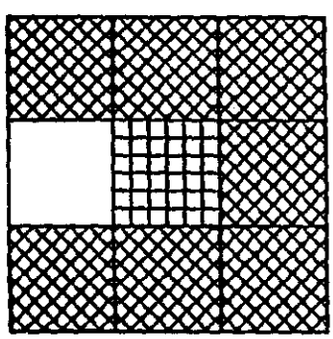
GEM Isolated γ – trigger



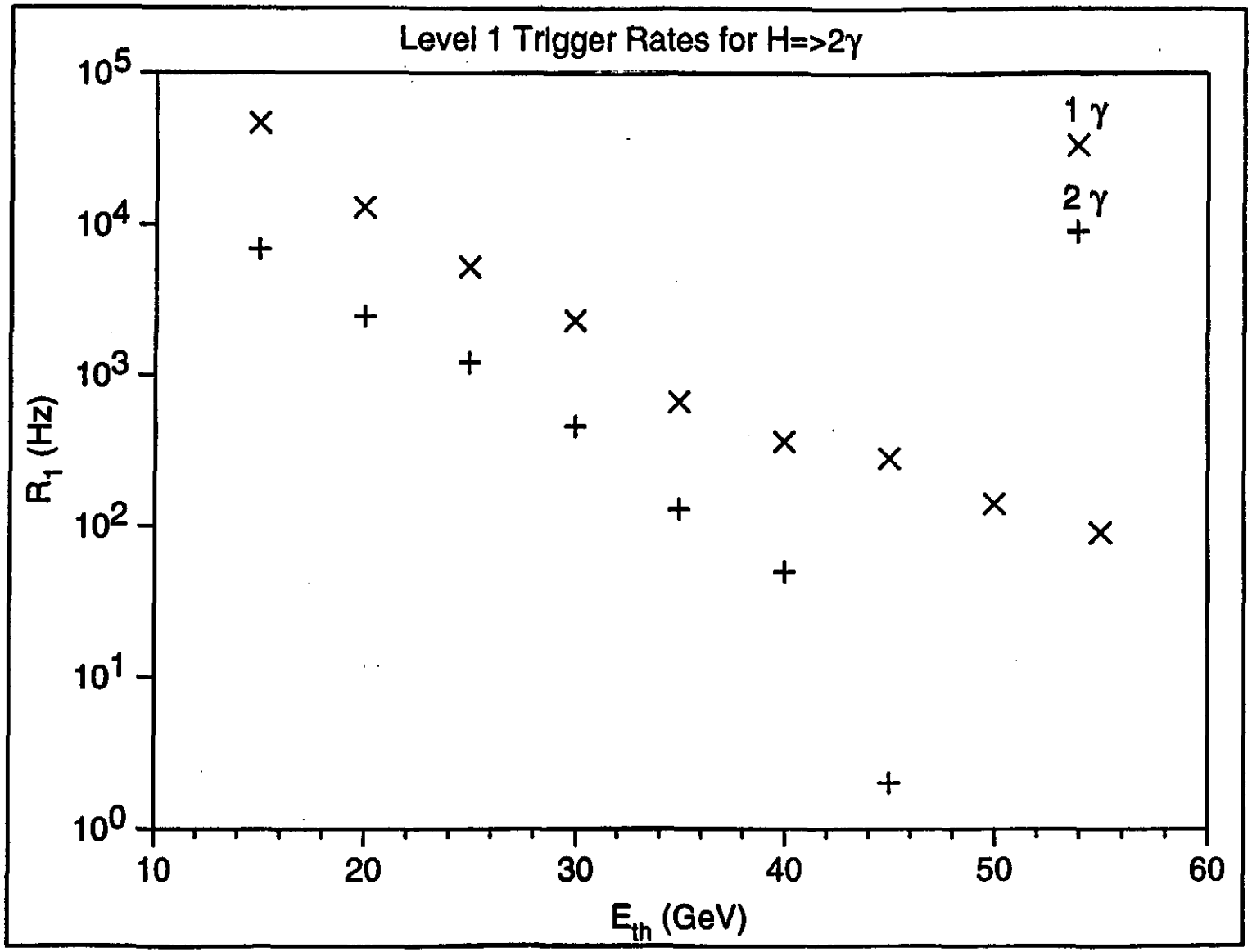
EM with hadronic veto
(Level 1)

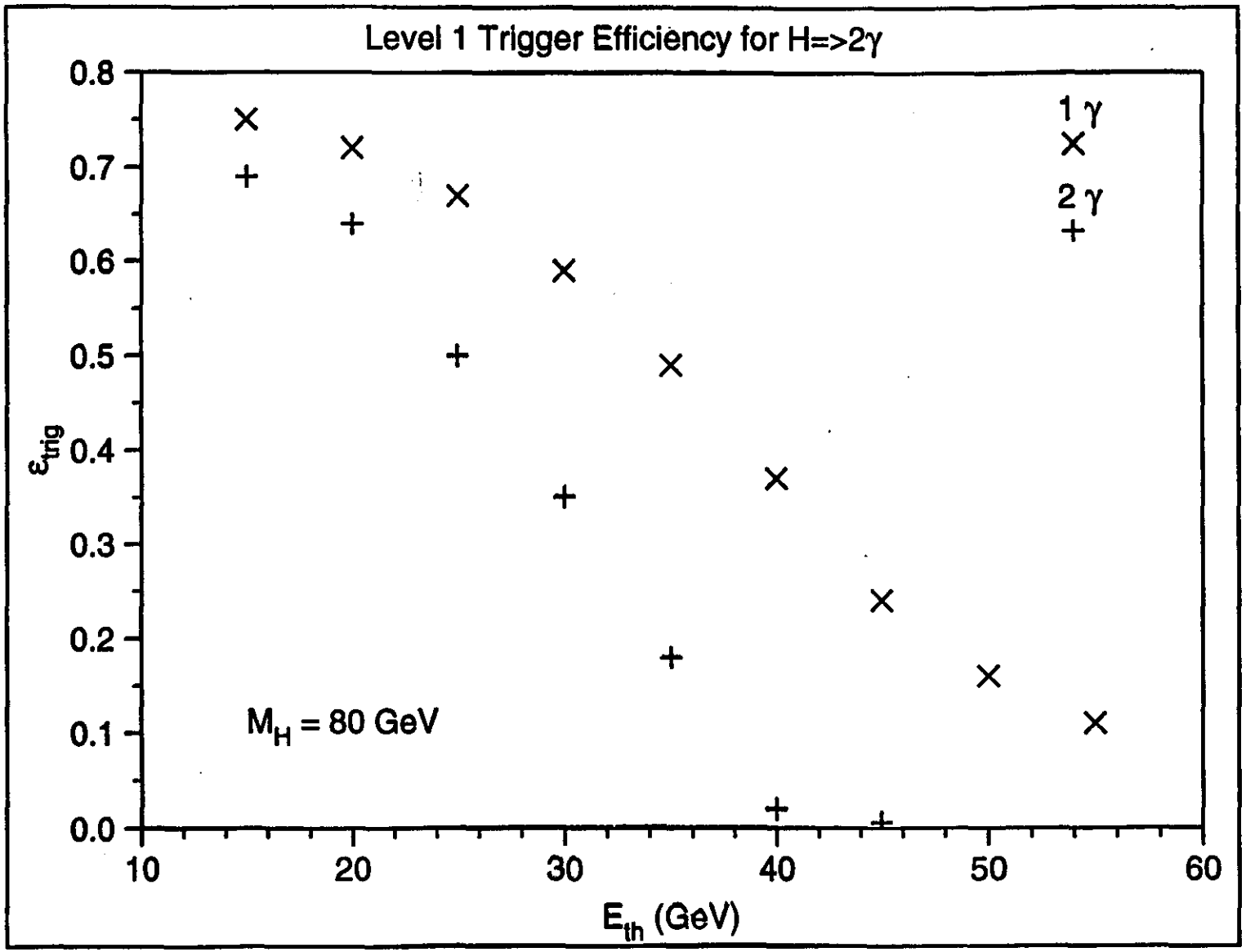


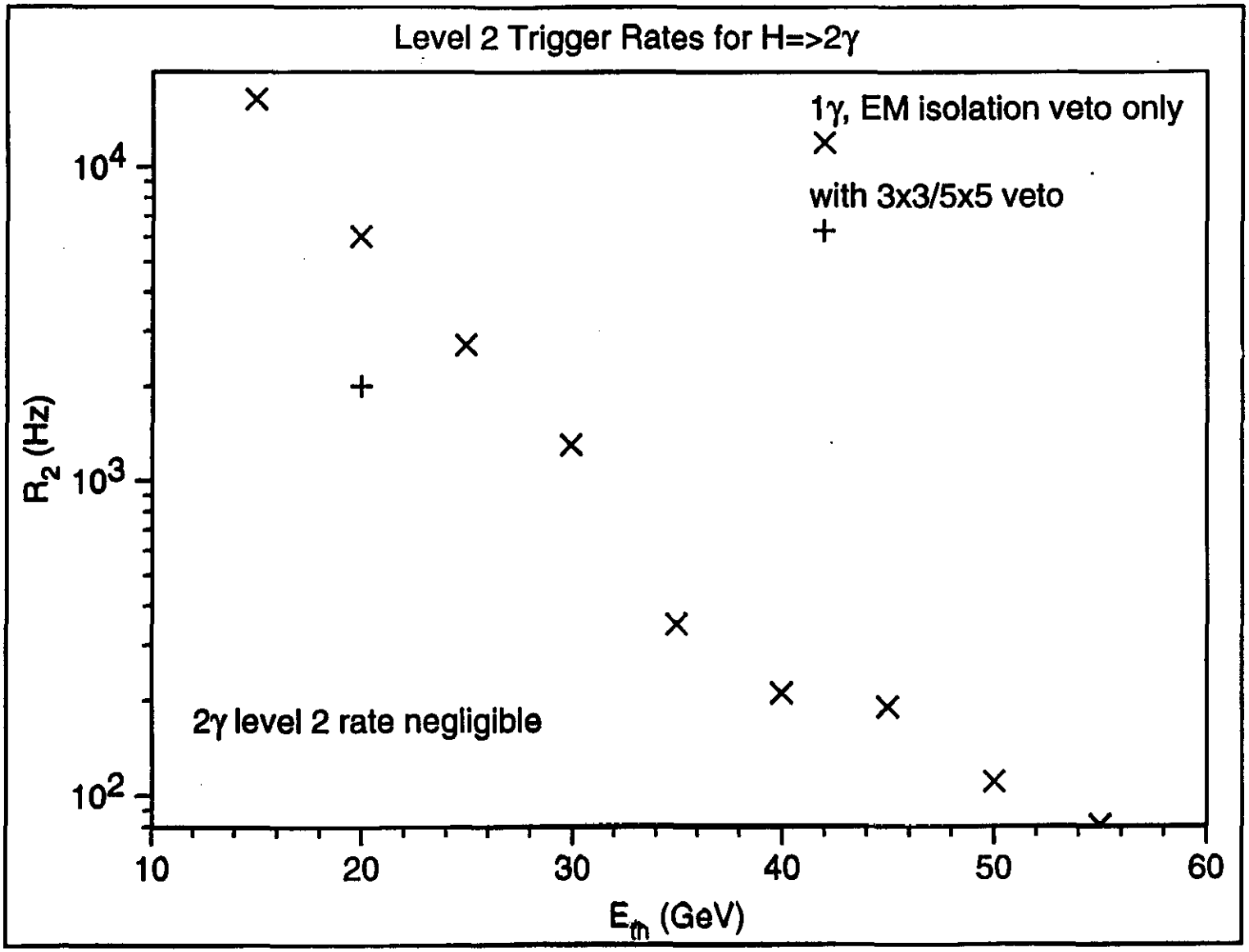
EM with EM veto
(Level 1)



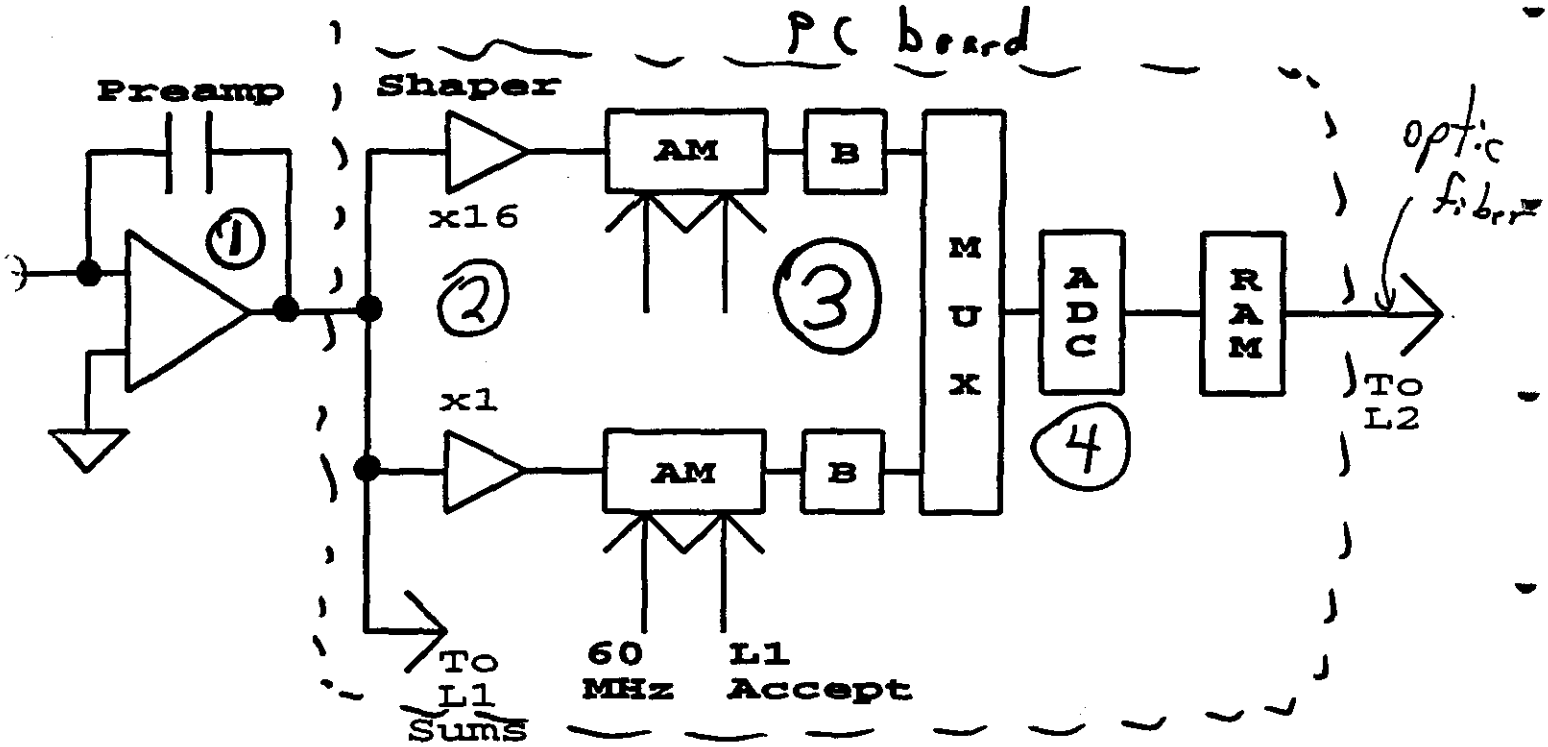
EMF with EMF veto
(Level 2a)


Level 1 Trigger Rates for H=>2γ
1 γ
2 γ
R_1 (Hz)
10^5
10^4
10^3
10^2
10^1
10^0
10
20
30
40
50
60
E_{th} (GeV)


Level 1 Trigger Efficiency for H=>2γ
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
ε_{trig}
1 γ
2 γ
M_H = 80 GeV
10
20
30
40
50
60
E_{th} (GeV)


Level 2 Trigger Rates for H=>2γ
1γ, EM isolation veto only
with 3x3/5x5 veto
2γ level 2 rate negligible
R_2 (Hz)
10^4
10^3
10^2
10
20
30
40
50
60
E_{th} (GeV)

Schematic of LKr/LAr Readout



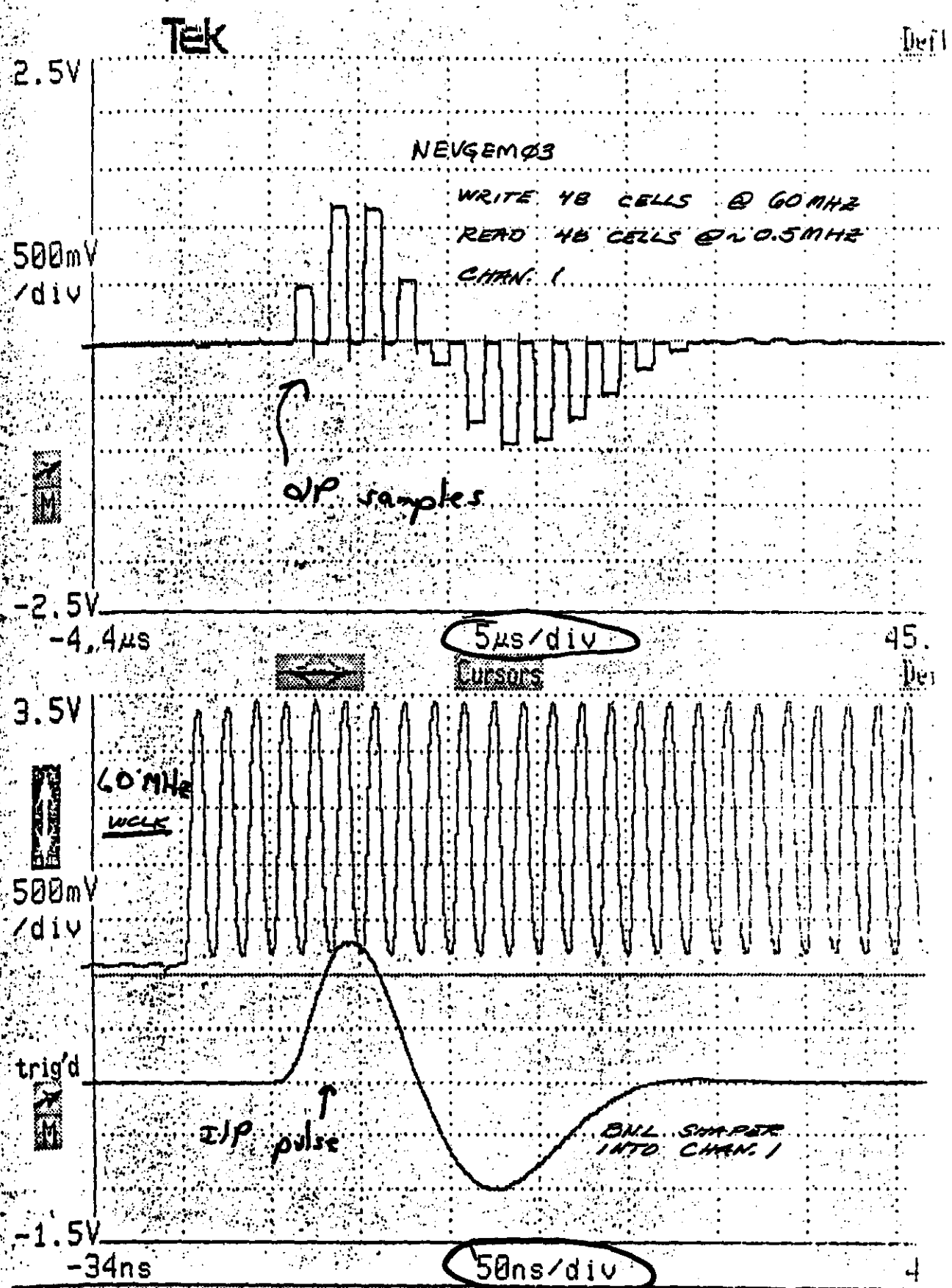
① JFET pre-amp – inside cryostat
(along with calib. circuit)

② Bipolar shapers → 2 gain scales
→ 40ns peaking time (impulse respons
for EMC

③ 60MHz analog memory + derandomizing
buffer + MUX
(digital pipeline also being investigated)

④ ADC – 12 bit?
– commercial?

11402 DIGITIZING OSCILLOSCOPE [exp:3.7,dig:3.91,asy:3.3]
date: 2-SEP-92 time: 7:47:17 Instrument ID# B010270



gem

Calorimeter – PM
G. Sanders

Calorimeter – Eng
M. Harris

Subsystem Leader
B. Mills

Calorimetry – PM

Calorimetry – Engineer

Integration – Phys
B. Wasserman

Integration – Eng
D. Richied

Semi-Active Calorimeter
Physics
Y. Kamyshkov
L. Sulak

Elastic Calorimeter
Physics
V. Radeka

Semi-Active Calorimeter
Engineer
M. Bernfeld

Elastic Calorimeter
Engineer
L. Mason

Fast Calorimeter
THE TEAM

WORKING GROUPS

GEM Full Scale Barrel Calorimeter Prototype

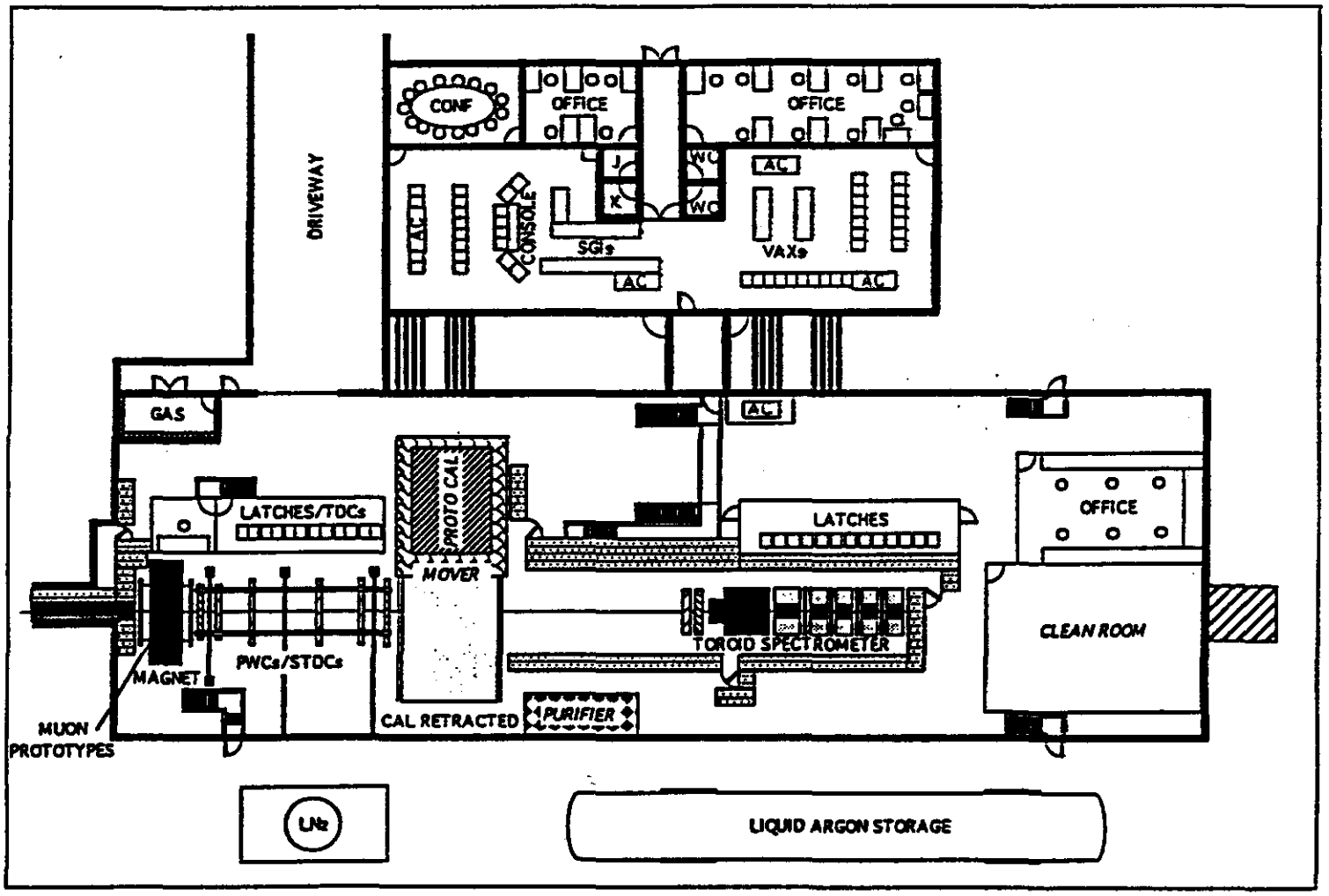
- Full Shower Containment
  [~5% Azimuthal Coverage]
  - EM Accordion Calorimetry
    2 – 3 Full-Length 9° Sectors
  - Parallel Plate Hadronic Calorimetry
    3 – 4 Half-Length 9° Sectors
  - Limited End Cap Calorimetry
    [Hadronic Portion of 1st Layer]
  - External Scintillating Calorimetry
- Cylindrical Aluminum Cryostat
  [5.5 m long; Liquid Krypton Fill]
- Versatile Calorimeter Transporter
  [Horizontal; Vertical; Rotation; Tilt]

GEM Barrel Calorimeter 1994-95 FNAL Beam Test

- Goals
  - Full Scale Engineering Studies [Mechanical; Electrical; Cryogenic]
  - Achieve System Integration [EM; Hadronic; External]
  - System Test of Readout Electronics
  - Resolution Studies at High Energies
  - Detailed Studies of Cracks & Gaps
  - Investigation of Barrel to End Cap Transition [Extending into 1996]

MWEST at FNAL

- Layout for GEM Muon Studies – Phase I



For Schematic Purposes Only – Not Drawn to Scale

The Chinese "Leading Committee"

—Vice Premier Zhu Rongji
(Economic Development)

—President, China Shipbuilding Co.
Yang Shou

—President, Academy of Sciences,
Zou Chongzhao

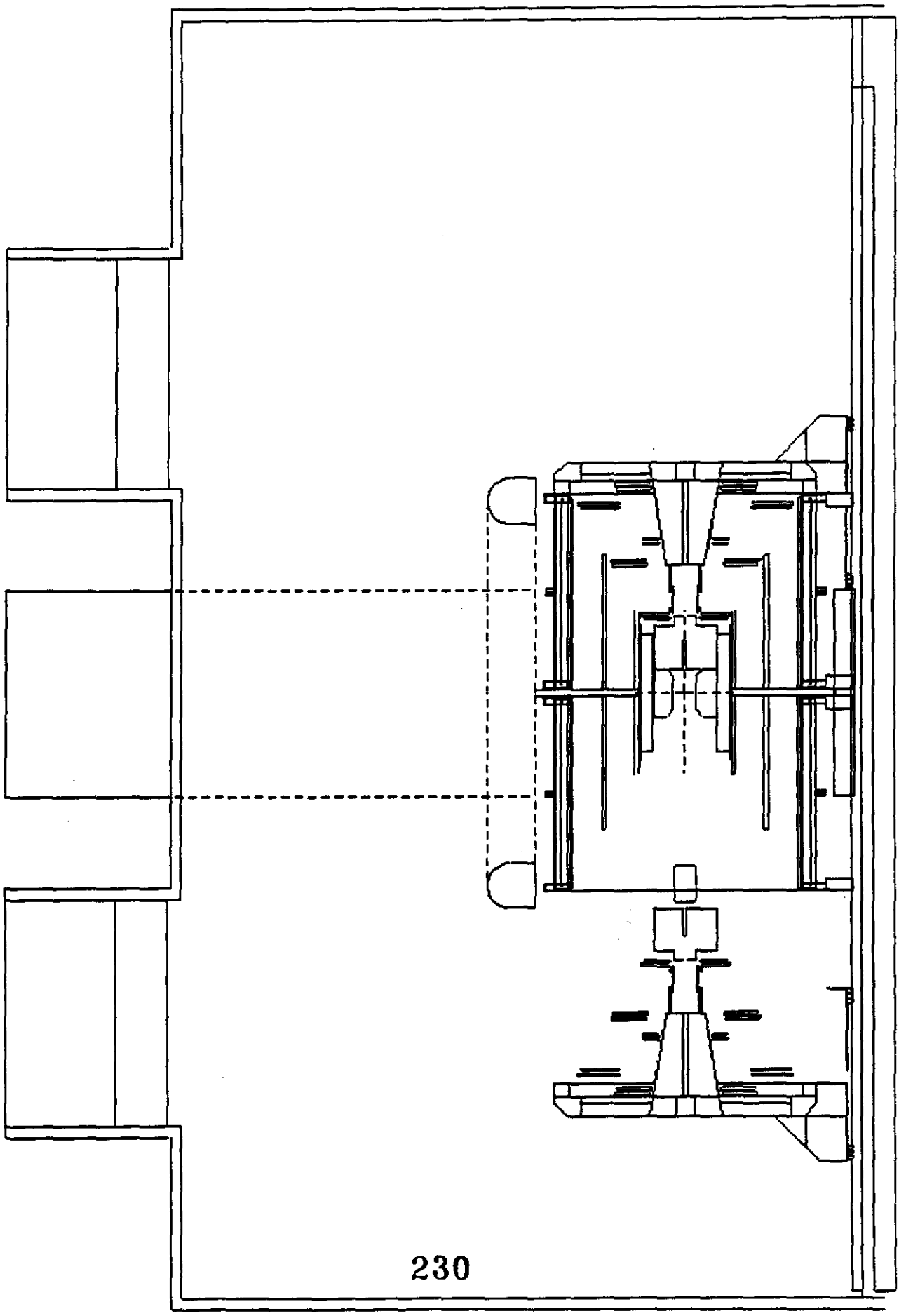
—Chairman, State Council on
Science and Technology
Song Jian

—Minister of Aerospace,
Liu Jieyang-Contract

"We are [illegible] the Chinese Program is scientific and [illegible] profit is secondary."

OUR CALORIMETER HAS BEEN OPTIMIZED BY VERY MANY STUDIES AND COMPETITION.

WE THINK THE E.M. PERFORMANCE IS THE BEST WHICH CAN PRESENTLY BE ACHIEVED.



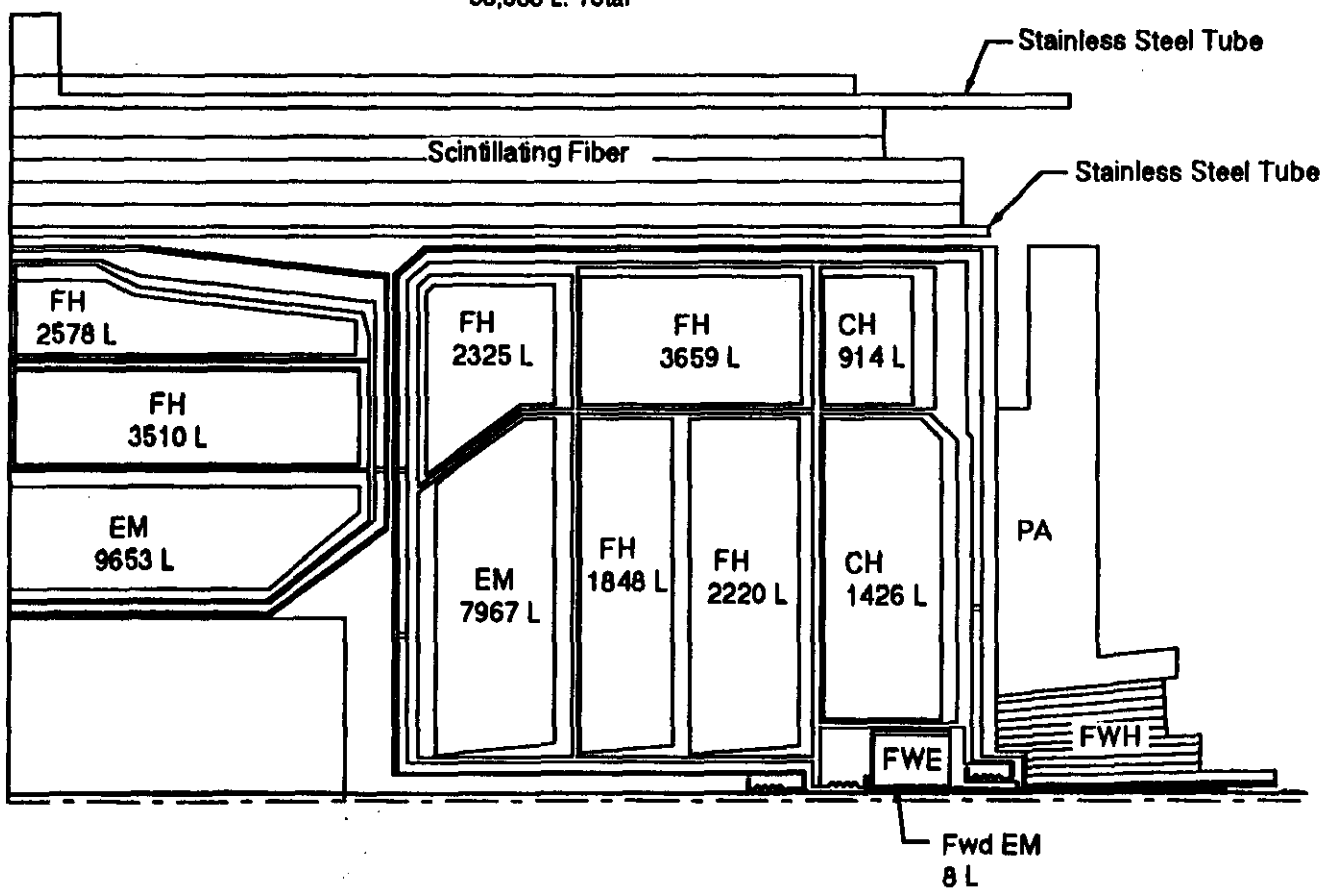
GEM Calorimeter - Volumes

Each Endcap Total:

7967 L. EM
1848 L. FH
2220 L. FH
3659 L. FH
2325 L. FH
1426 L. CH
914 L.CH
8 L. FWE
20,367 L. LAr
18,521 L. Other
38,888 L. Total

Barrel Totals:

9653 L. EM
3510 L. FH
2578 L. FH
15,741 L. LKr
8,395 L. Other
24,136 L. Total



Barrstable gemcalbl2:921123
Barrel 7.0/ Endcap7.0 -Cu

GEM Calorimeter - Weights

Each Endcap Total:
24 Mg EM
40 Mg FH
48 Mg FH
77 Mg FH
50 Mg FH
53 Mg CH
34 Mg CH
5 Mg FWE
331 Mg
50 Mg Other
381 Mg Total

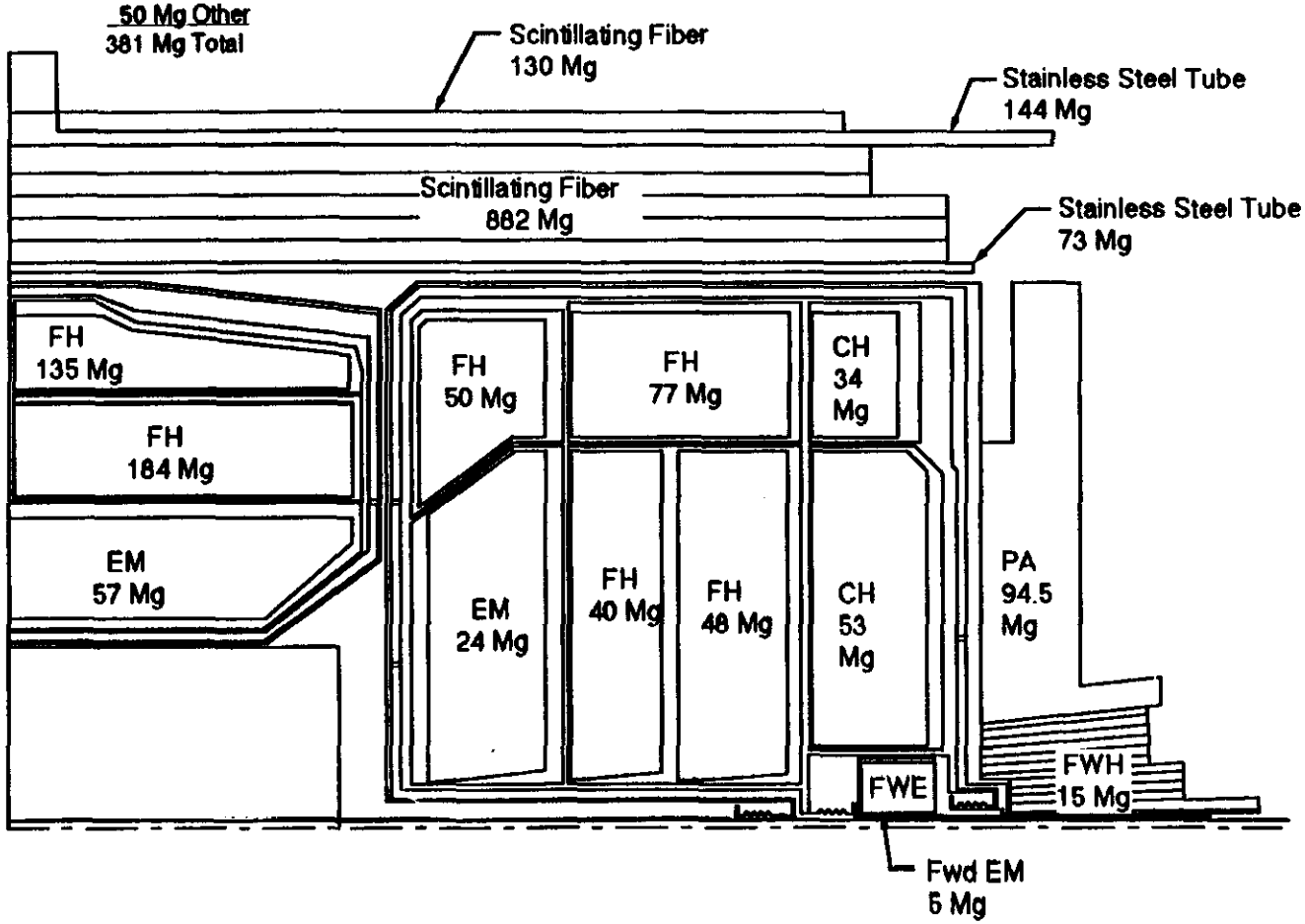
Barrel Totals:
57 Mg EM
184 Mg FH
135 Mg FH
376 Mg
57 Mg Other
433 Mg Total

Other Totals:
217 Mg S.S. Tubes
1012 Mg Sc. Fiber
1229 Mg total

Forward Total:
15 Mg FWH

PA Total:
94.5 Mg

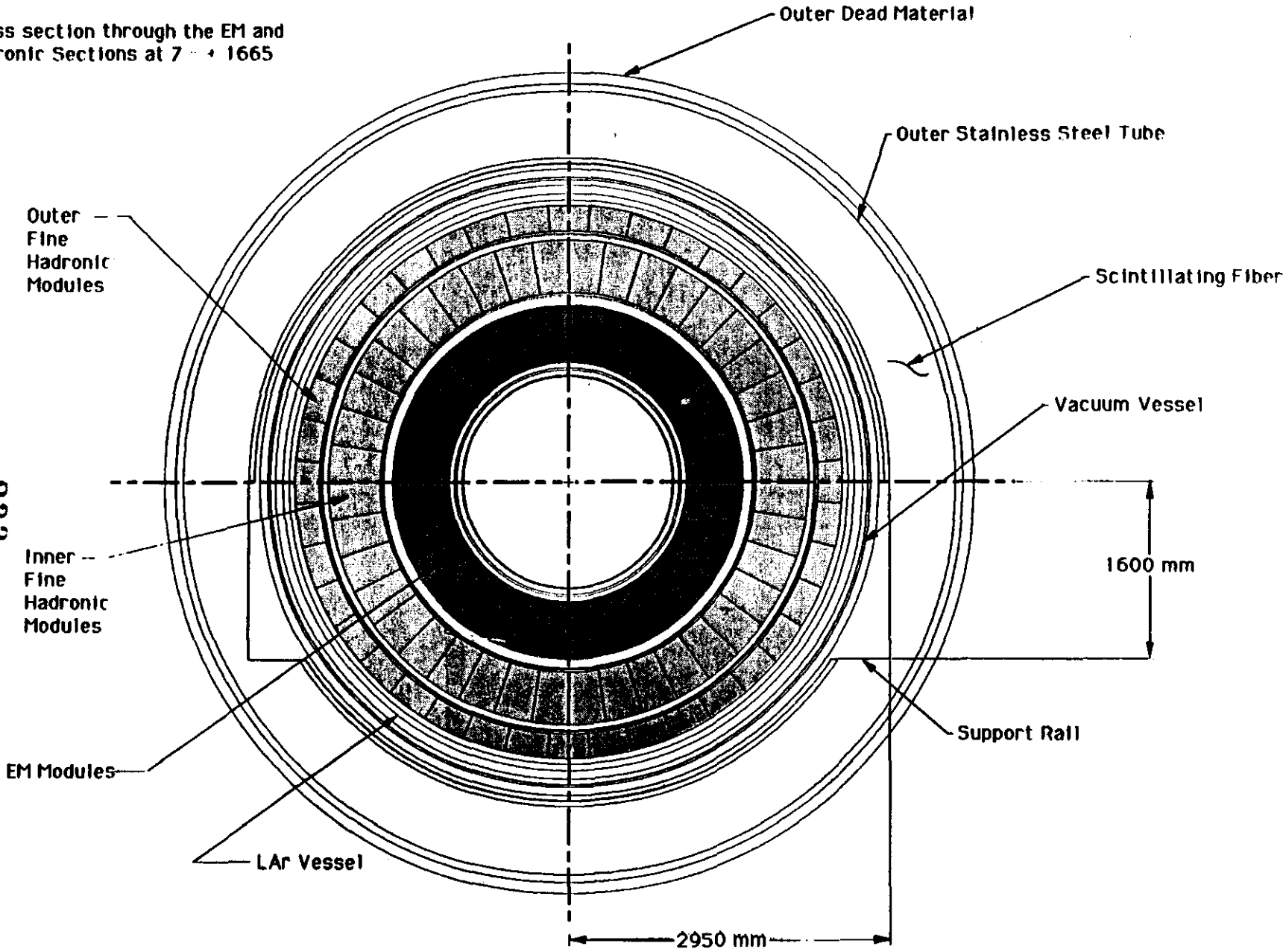
Total Calorimeter:
381 Mg Endcap
381Mg Endcap
433 Mg Barrel
1229 Mg Other
15 Mg Fwd
15 Mg Fwd
94.5 Mg PA
94.5 Mg PA
2643 Mg total

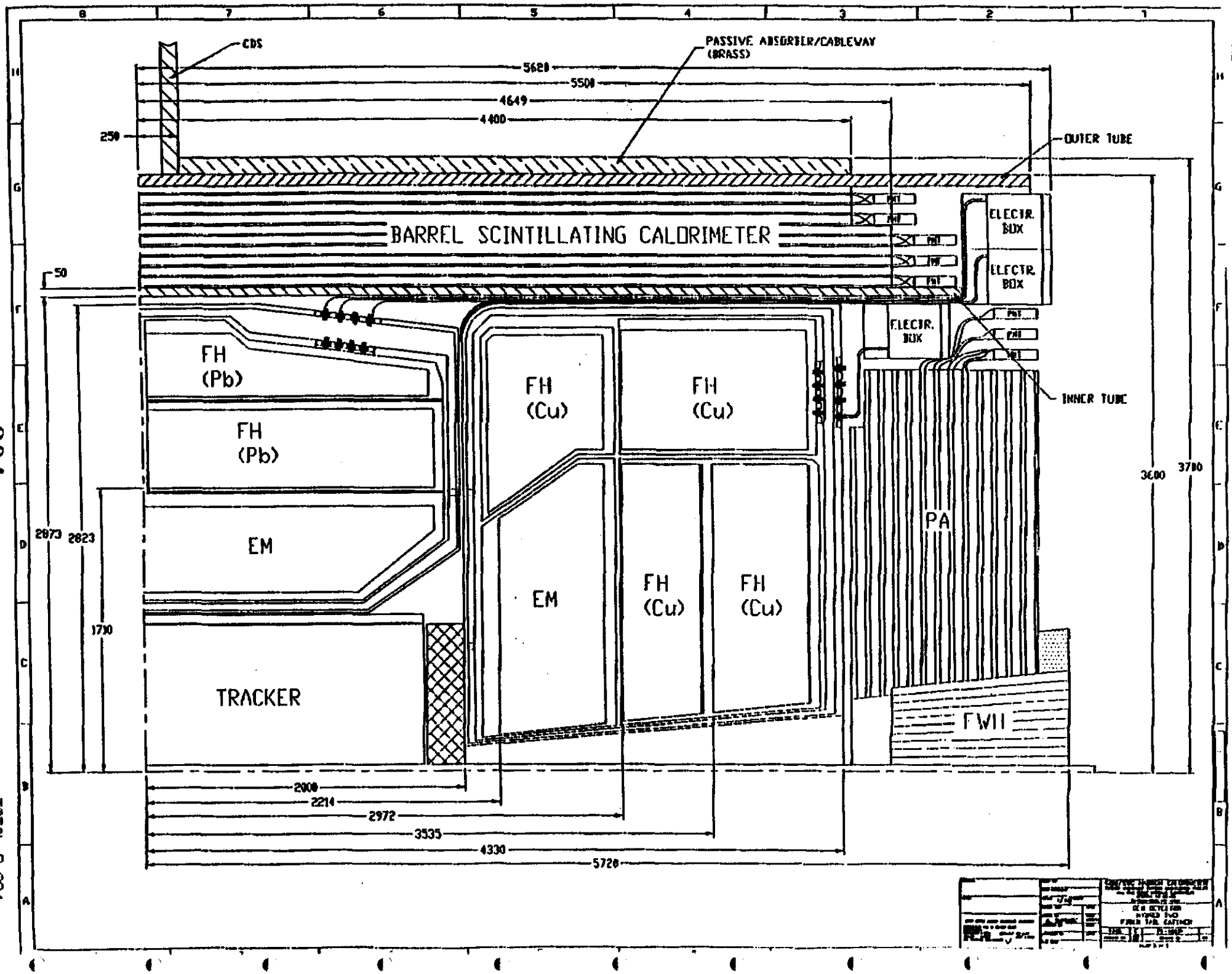


Barrstable:gemcalbl2:921123
Barrel 7.0/ Endcap7.0 -Cu

GEM Calorimeter - Barrel Crossection

Cross section through the EM and Hadronic Sections at Z = 1665 mm




CDS
PASSIVE ABSORBER/CABLEWAY
(BRASS)
5620
5500
4649
4400
250
OUTER TUBE
BARREL SCINTILLATING CALORIMETER
ELECTR. BOX
ELECTR. BOX
ELECTR. BOX
PMT
50
INNER TUBE
FH (Pb)
FH (Pb)
EM
FH (Cu)
FH (Cu)
EM
FH (Cu)
FH (Cu)
PA
FWH
TRACKER
2873
2823
1710
3600
3780
2000
2214
2972
3535
4330
5720

Dec. 2, 1992
F.E. Taylor

Status of GEM Muon System

Overview of system

Progress on support structure concept

Progress on chamber technology: BASELINE 2

Game plan for TDR

GEM Muon Group

List of Personnel at Institutions:

Boston University:
Bing Zhou, Alex Marin, Steve Ahlen, Jianguo Xu, Robert Chivas, Scott Whitaker, J. Shank, E. Hazen, G. Varner, F.S.U. visitor
contact person: Scott Whitaker

Brookhaven National Laboratory:
Michael J. Murtagh, M. Atiya, V. Polychronakos, V. Radeka
contact person: M. J. Murtagh

Brown University:
Mildred Widgoff
contact person: Mildred Widgoff

BSU-MINSK
N.Shumeiko, M.Baturitsky, V.Shuliak, .Dvornikov, V.Stepanets, S.Degtiarev, V.Mikhailov, I.Emelianchik
contact person:Nikolai Shumeiko

Draper Laboratory:
Howard Baker, Frank Nimblett, Joe Paradiso, Martin Furry, Richard Gustavson
contact person: H. Baker

IHEP-Beijing
Yigang Xie, Yuanbo Chen, Ya-nan Guo
contact person: Yigang Xie

ITEP-Moscow
V. Akimov, V. Balagura, S. Bojarinov, M. Danilov, A. Droutskoi, V. Gavrilov, A. Golutvin, I. Korolko, S. Kuleshov, L. Laptin, P. Murat, V. Nagovitsin, A. Nepejpivo, A. Ostapchuk, P. Pakhlov, V. Popov, F. Ratnikov, V. Shibaev, V. Stolin, I. Tikhohirov, V. Tchistilin, Z. Zhokin
contact person: M. Danilov

JINR-Dubna
I. Golutvin, Yu. Kiryushin, A. Makhankov, I. Melnichenko, V .Kalagin, V. Lysiakov, V.Rashevsky, A.Dergunov, Yu.Viktorov, V.Khabarov, Yu.Ershov L.Smirnov, V.Peshekhov, V.Zhiltsov, A.Vishnevsky, D.Smolin, S.Sergeev, V.Kondrashev, V.Perelygin, N.Gorbunov, S.Movchan, I.Ivanov, T.Preda, G.Alexeev, N.Khovansky, Z.Krumstein, G.Chelkov, A.Volodko, E.Ladygin, V.Obudovsky, D.Pose,V.Karzhavin, S.Khabarov, S.Selunin, A.Lyubin, D.Belosludtsev
contact person:Igor Golutvin

Lawerance Livermore National Laboratory:
Craig Wuest, Orrin Fackler, Richard Bionta, Dan Makowiecki, Torre Wenaus, Rick Sawicki, Coleman Johnson, Allen House, Elden Ables, Joe Mauger, Owen Alford, Harlan Olson, Otis Clamp, Kerry Miller, Curt Cochran, Rich Coombs, Phil Ramsey, Mark McKernan, Max Haro, Karl Van Bibber
contact person: Craig Wuest

LeCroy Corporation:
R. Sumner
contact person: R. Sumner

Louisana State University:
Roger McNeil, C. Lydon, Graduate Student
contact person: Roger McNeil

Massachusetts Institute of Technology:
J. Kelsey, D. McCurry, A. Korytov, L. S. Osborne, L. Rosenson, D. Ross, J. Sullivan, F.E. Taylor, I. Pless, E.S. Hafen, P. Haridas
contact person: L.S. Osborne

Michigan State University:
M. Abolins, R. Brock, C. Bromberg, J. Huston, J. Linnemann, R. Miller, D. Owen, B. Pope, H. Weerts, D. Edmunds, S. Gross, P. Laurens, S. Joy, E. Skup, R. Richards, B. Tigner, 4 Research Associates, 10 Graduate Students, 40,000 Undergraduate Students.
contact person: C. Bromberg

Moscow State University
Yu. Fissiak, N. Sotmkova, V. Zhukov
contact person: Yu. Fissiak

Oak Rige National Laboratory:
R. A. Todd, engl
contact person: R. A. Todd

PNPI - St. Petersburg:
A. Krivshich, G. Gavrilov, Maleev, O. Prokofiev, V. Grachev, N. Bondar, V. Mylnikov, S. Patrichev, O. Kiselev, V. Andreev, A. Smirnov, P. Levchenko, An. Vorobyov, L. Lapina, O. Kiselev, A. Tsaregorodzev, A. Dobrovolsky, V. Grachev, A. Khanzadeev, G. Velichko, G. Korolev, N. Sagidova, I. Tkach, N. Abrosimov, G. Ryabov
contact person: A. Vorobyov

Superconducting Super Collider Laboratory:
G. Mitselmakher, M. Marx, G. Yost, K. McFarlane, C. Milner, Yu. Bonushkin, F. Stoker, M. Harris, P. Dingus, R. Shypit, L. Villasenor, V. Glebov, J. Pier-Amory, C. Johnson, E. Zimmer-Nixdorf, A. Gonzalez, M. Gamble, Yu. Fisyak, A. Vanyashin, + 6 guest scientists and engineers.
contact person: G. Mitselmakher

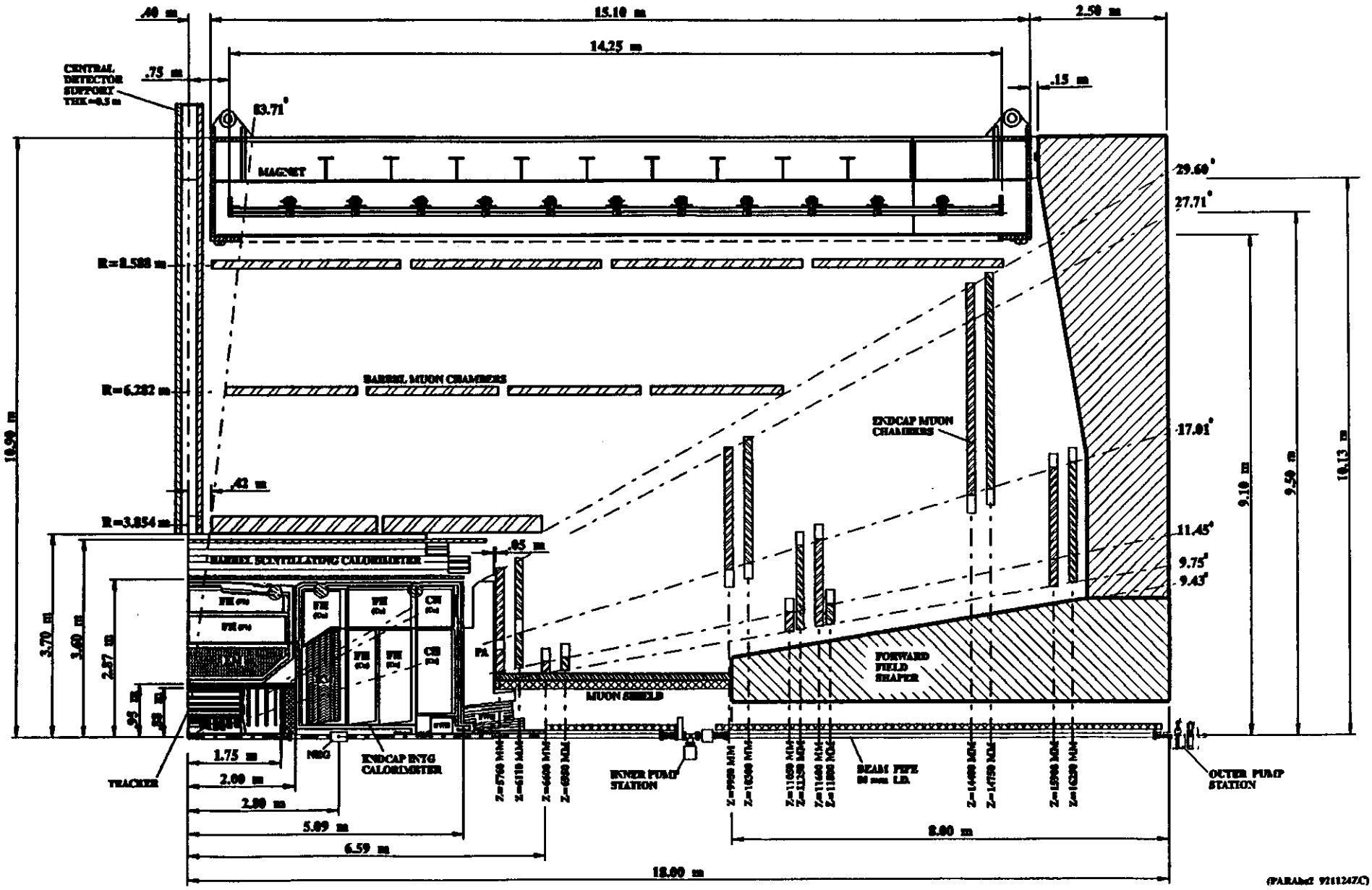
Stony Brook:
M. Mohammadi, A. Sanjari, M. Rijssenbeek, C. Yanagisawa
contact person: M. Mohammadi

Tsinghua University-Beijing:
Ni Weidou, Rencheng Shang, Keren Shi
contact person: Ni Weidou

University of Arizona:
K. Johns, J. Steinberg, L. Shaver
contact person: Ken Johns

University of Houston-SCARF:
K. Lau, B. Mayes, L. Pinsky, J. Pyrlik, R. Weinstein, D. Hungerford, D. Parks
contact person: K. Lau

GEM DETECTOR PARAMETERS
BASELINE 2



(PARAbnl 9211247C)

Chamber Support Structure

- Stable platform for chambers

  specification:

  $\sigma \approx 25\ \mu m$ inter - superlayer alignment - systematic
  $\sigma \approx 50\ \mu m$ intra - superlayer alignment - random
  $\sigma \approx 75\ (100)\ \mu m$ single layer resolution - random

- Evaluated two designs and variants:

  individual sectors (L3 philosophy)
  monolithic structure

- Considered:

  performance (stability to vibrations)
  cost
  fabrication
  schedule impact on GEM construction

- Results:

  sectors:
  + practical (smaller, prototype, etc.)
  + alignment partitioned
  - vibration stability (< 20 Hz) not conservative

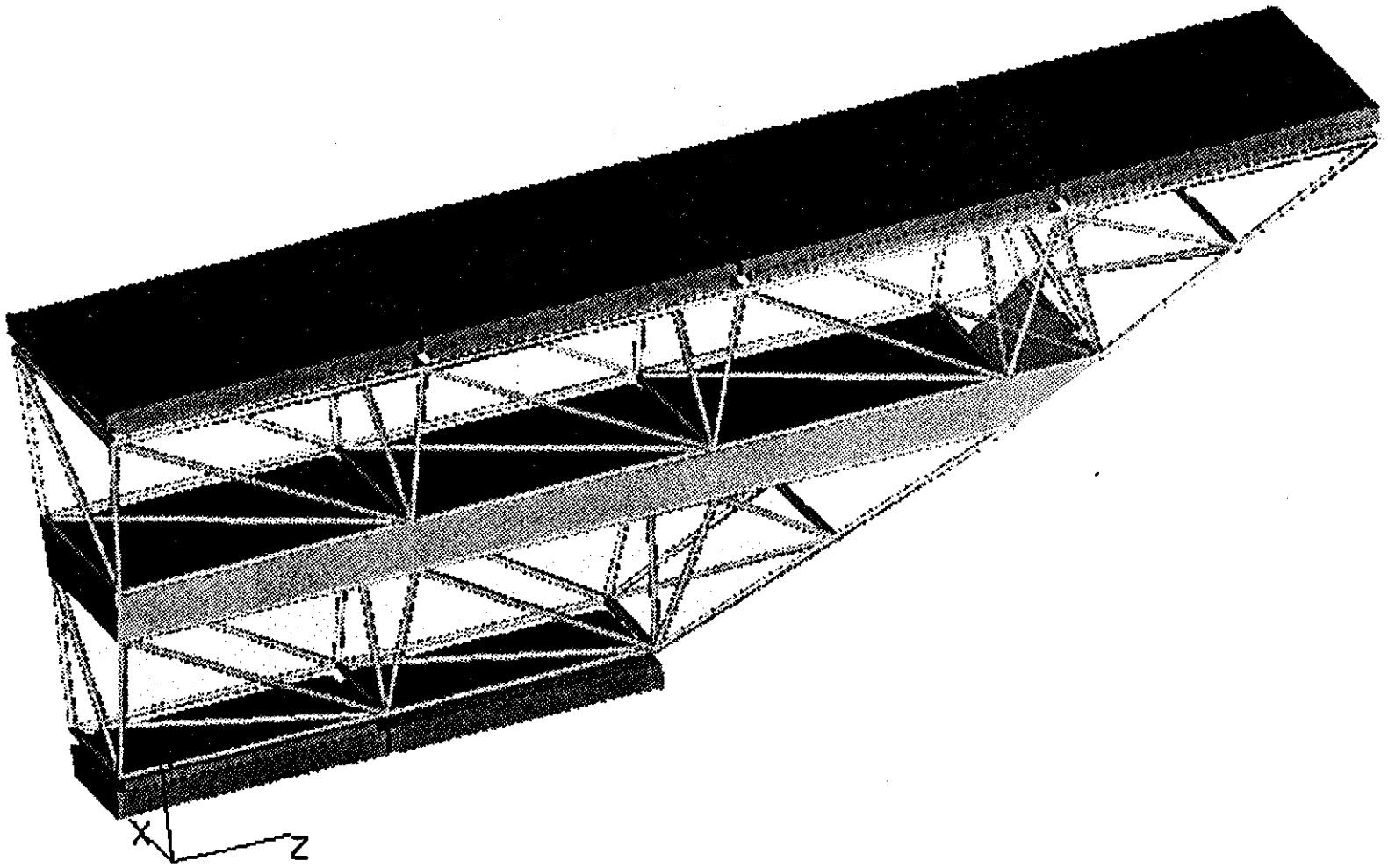
  monolith(s):
  + better vibration performance
  + better decoupling from magnet
  - harder to build but easier to install
  - alignment not completely partitioned

- Propose to build:

  sectors tied together as a monolith barrel and endcaps

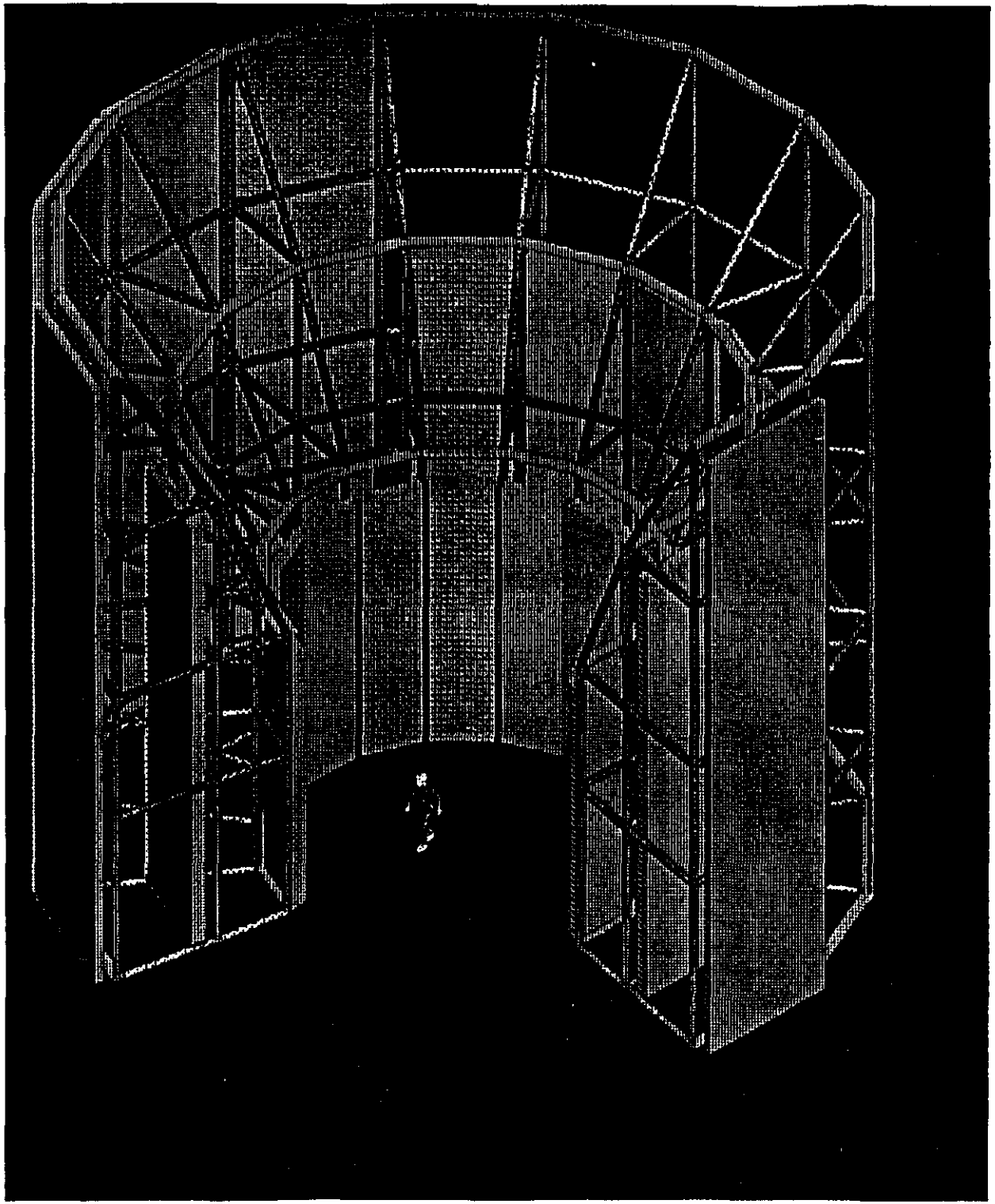
GEM BARREL REGION

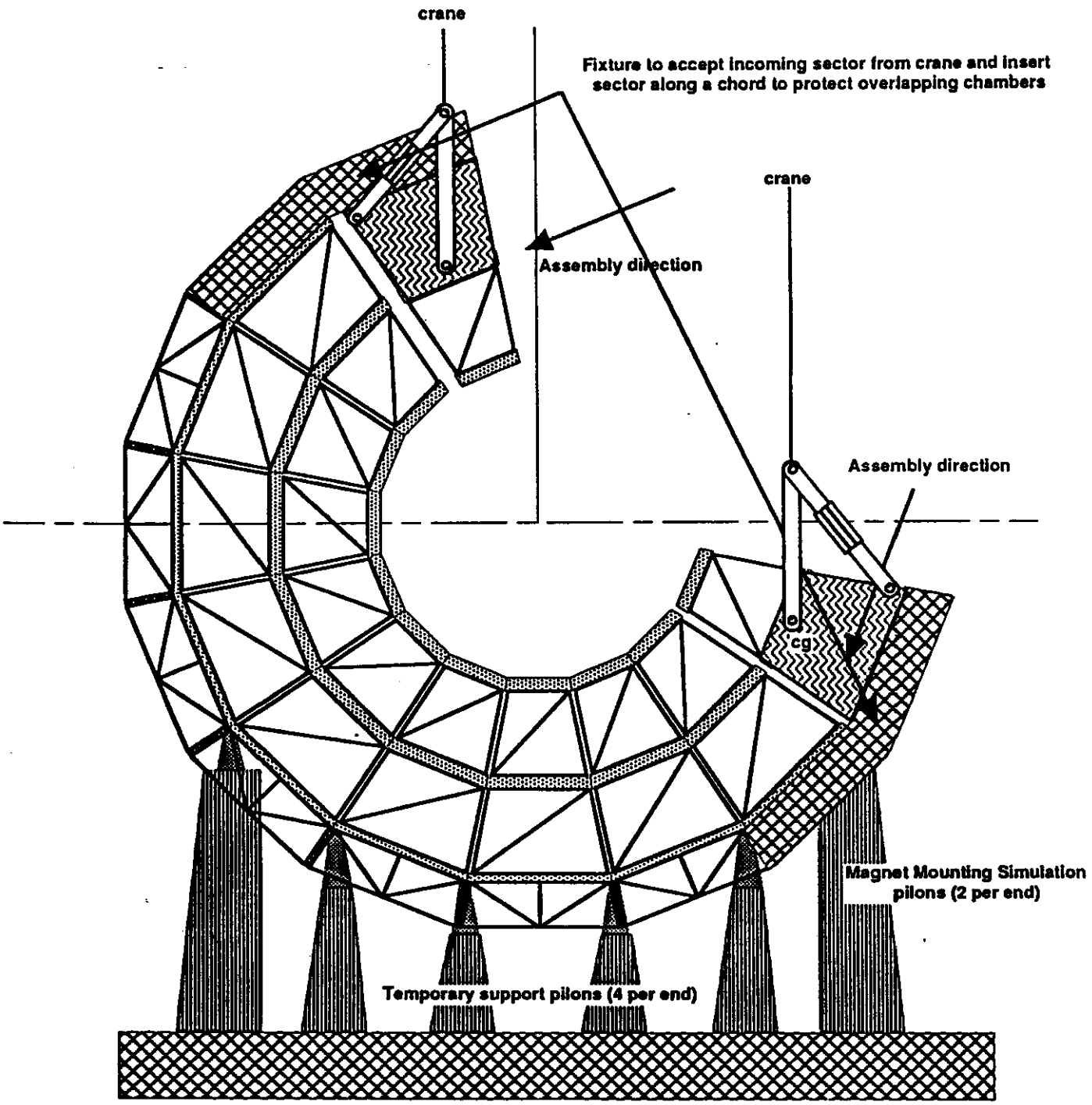
MUON MODULE



"Big Wheel"
Pre-Assembled &
Aligned on
Surface

(Also for Ends)



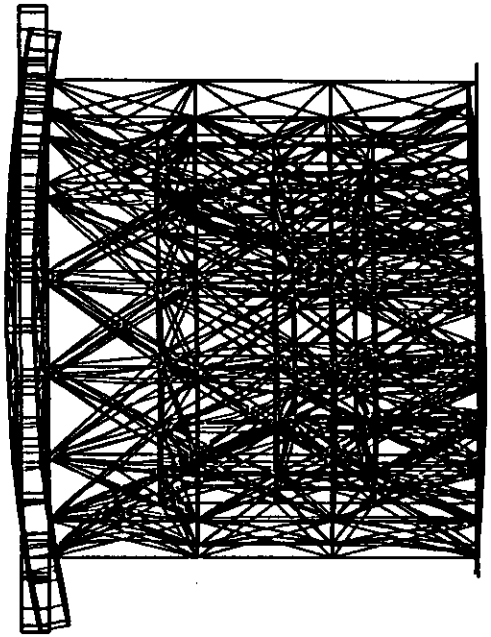


GEM MUON SYSTEM BARREL ASSY
(Sectors With Integral Structural Ring

END VIEW OF BARREL

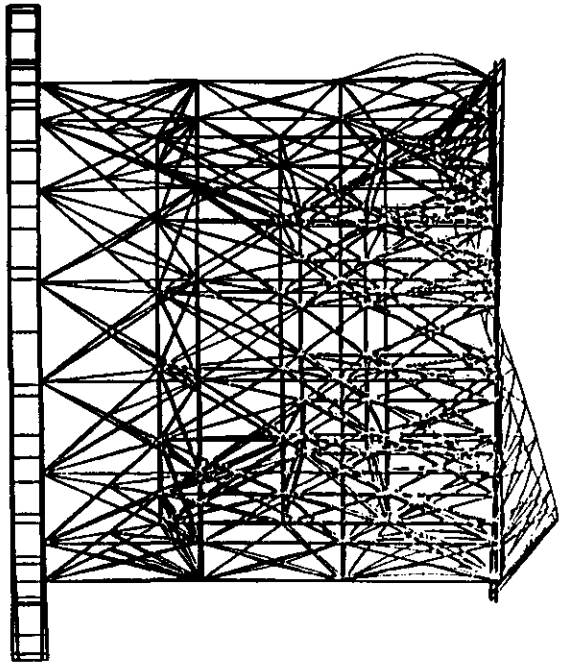
Draper Laboratory	
GEM Muon System Assy (end view, barrel)	
Drawn By: F. Nimblett	Rev (-)
Dwg. No: GMU0023	11/18/92
Approved by:	

Displacement Mag
Deformed Original Model
Max Disp +1.3106E-01
Scale 6.5618E+02
Mode 5, +6.7627E+00 Hz.



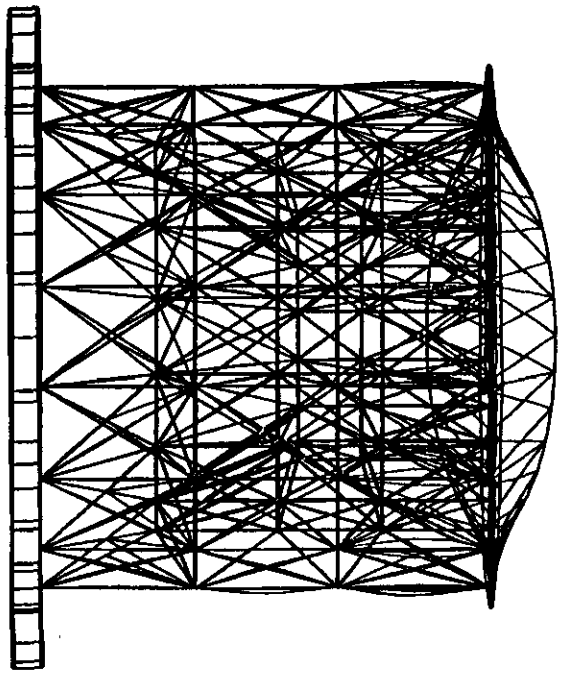
mode 5

Displacement Mag
Deformed Original Model
Max Disp +5.4679E-01
Scale 1.5728E+02
Mode 6, +6.8574E+00 Hz.



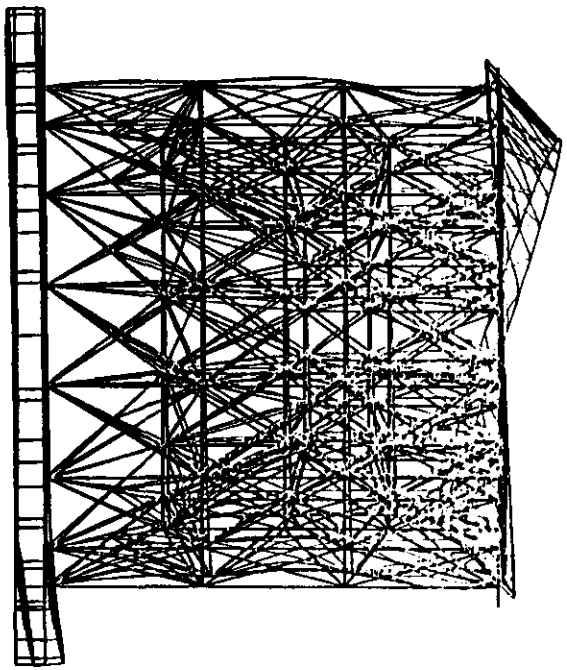
mode 6

Displacement Mag
Deformed Original Model
Max Disp +6.0556E-01
Scale 1.6202E+02
Mode 7, +7.1636E+00 Hz

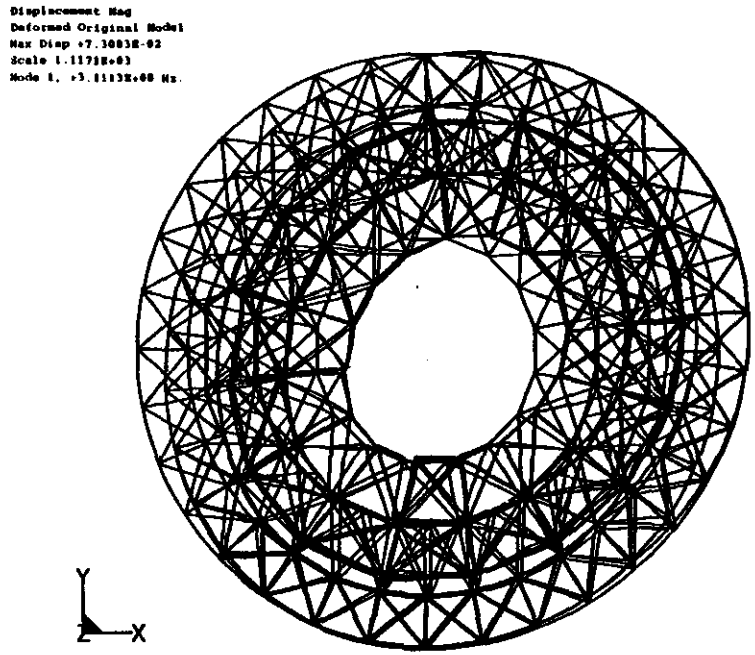


mode 7

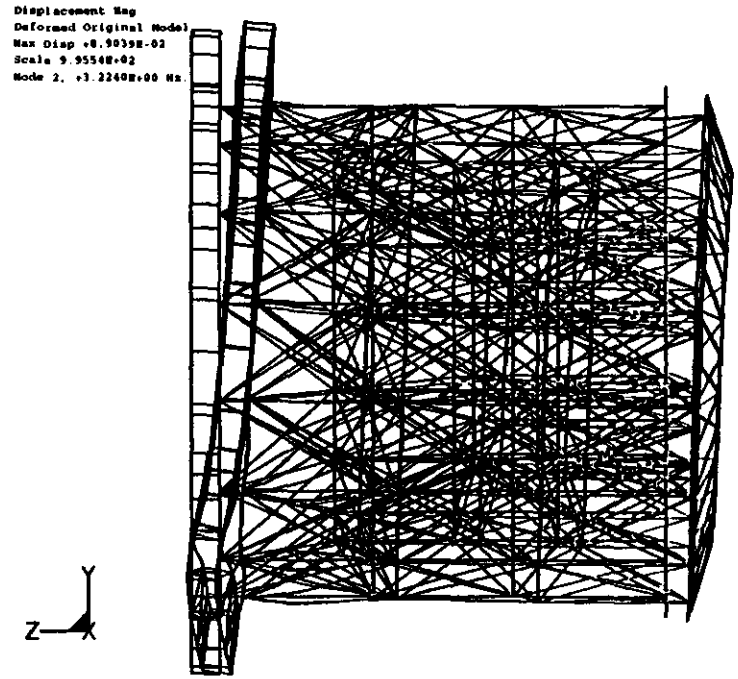
Displacement Mag
Deformed Original Model
Max Disp +3.0439E-01
Scale 2.8253E+02
Mode 8, +7.3539E+00 Hz



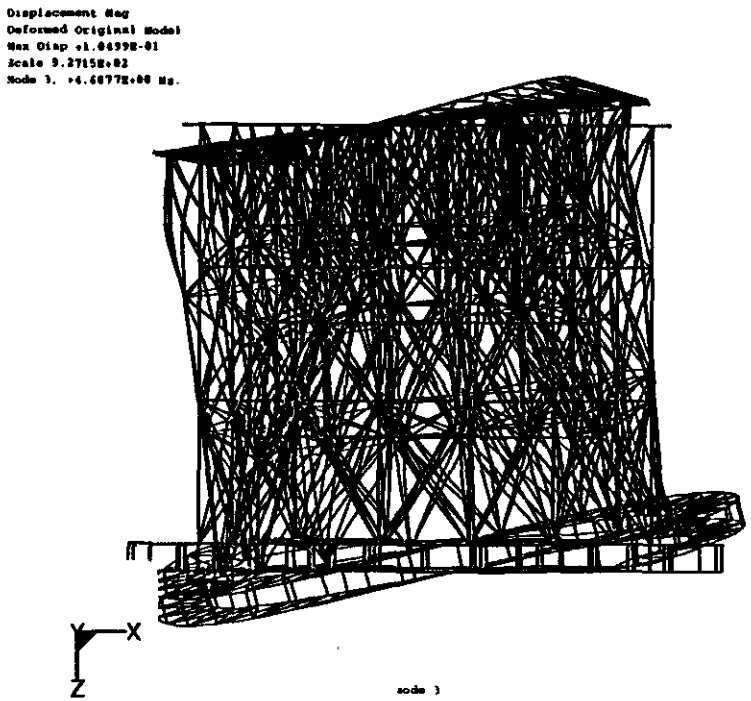
mode 8



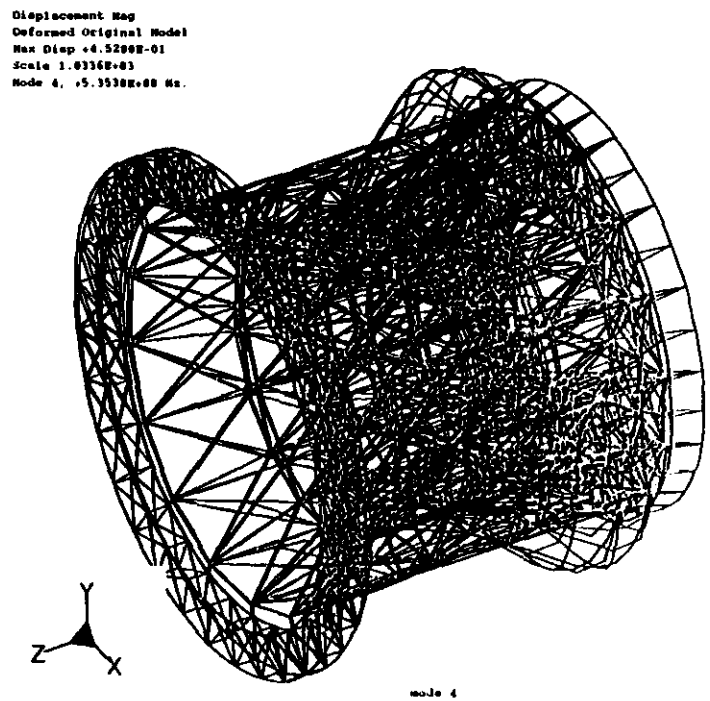
mode 1



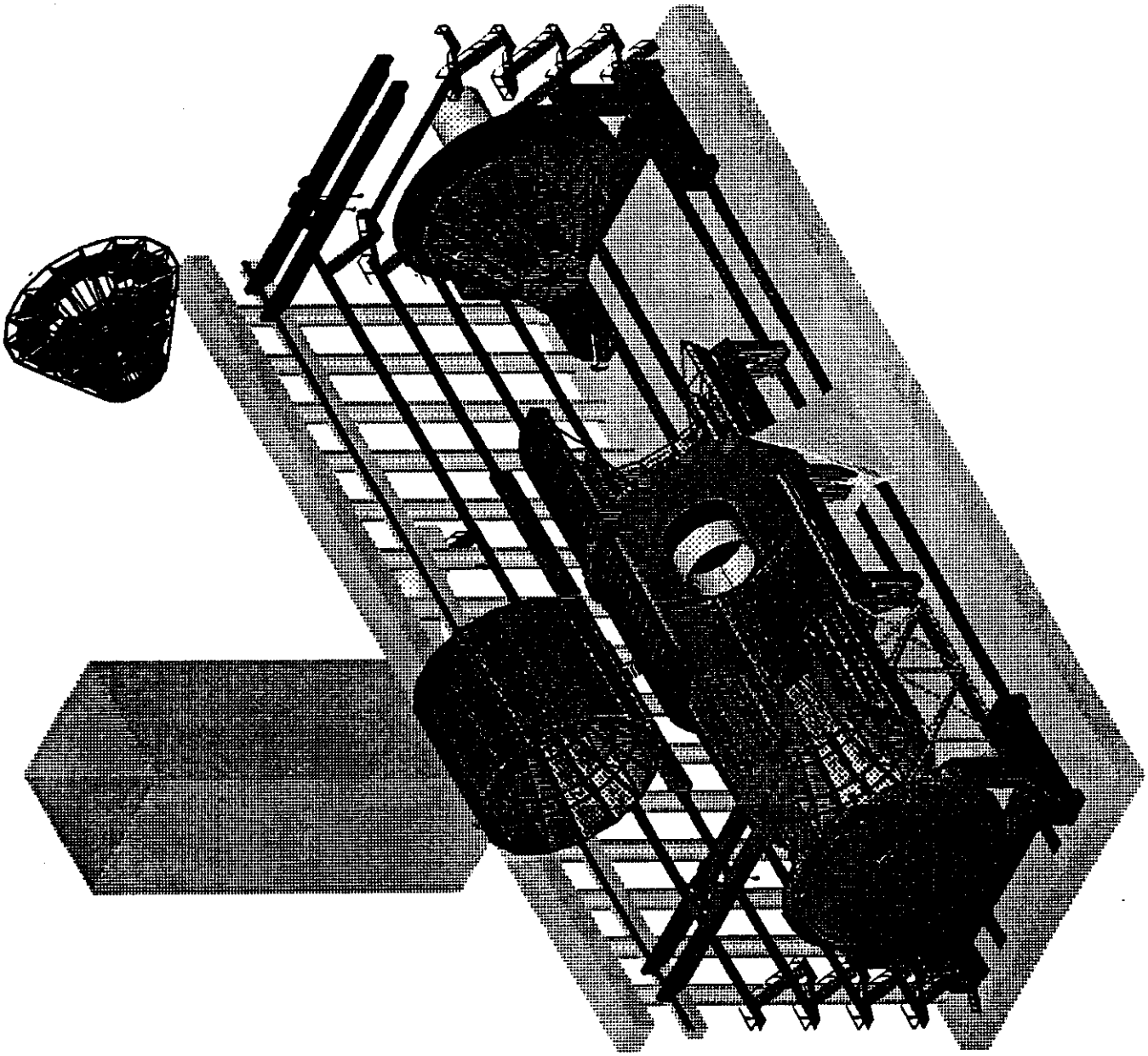
mode 2



mode 3



mode 4



Technologies considered in FY92

Acronyms:

CSC = Cathode Strip Chambers (anolog readout)

LSDT = Limited Streamer Drift Tubes

PDT = Pressurized Drift Tubes (now called Round Drift Tubes RDT)
RDT = PDT

RPC = Resistive Plate Counter

To test chambers (and get something "real" at the SSCL)

TTR = Texas Test Rig (Cosmic ray muon laboratory at SSCL)

Cathode Strip Chamber

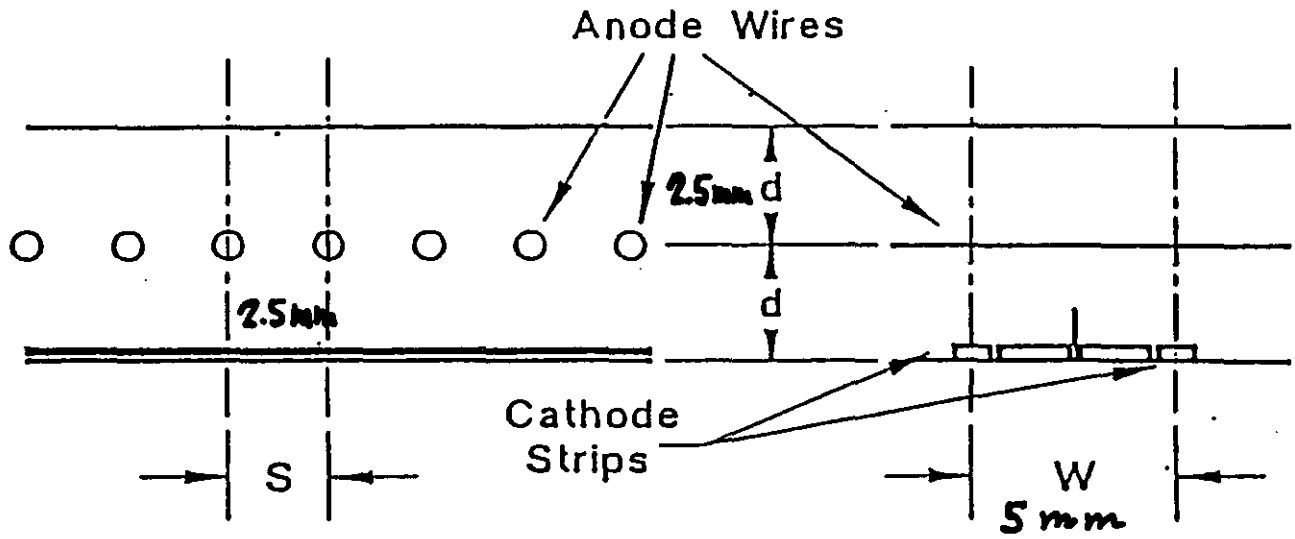
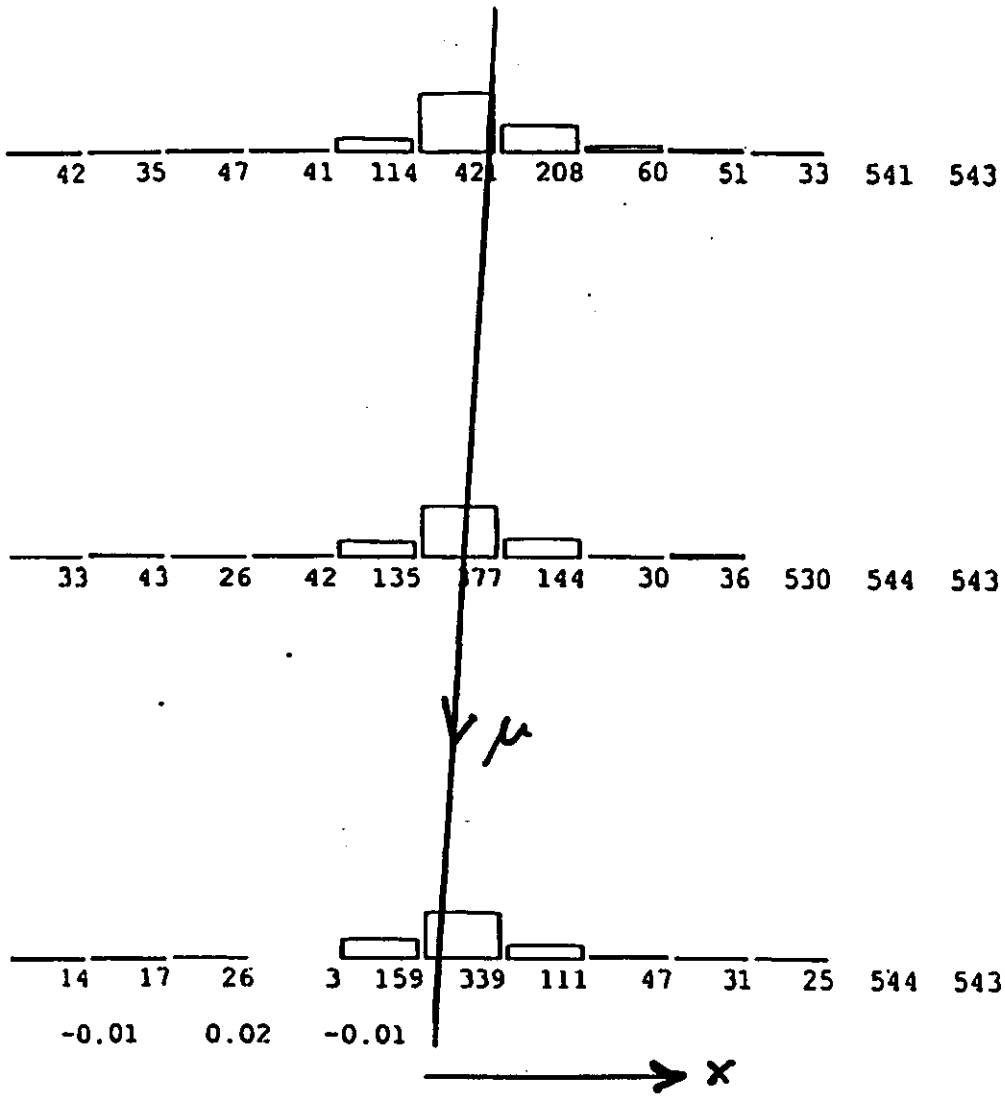


Figure 1: Geometry of the basic cell of the CSC

Run#: 666 Events on File: 45442 groups on file: 2
Event#: 4200 Fri, Oct 23, 1992 17:45

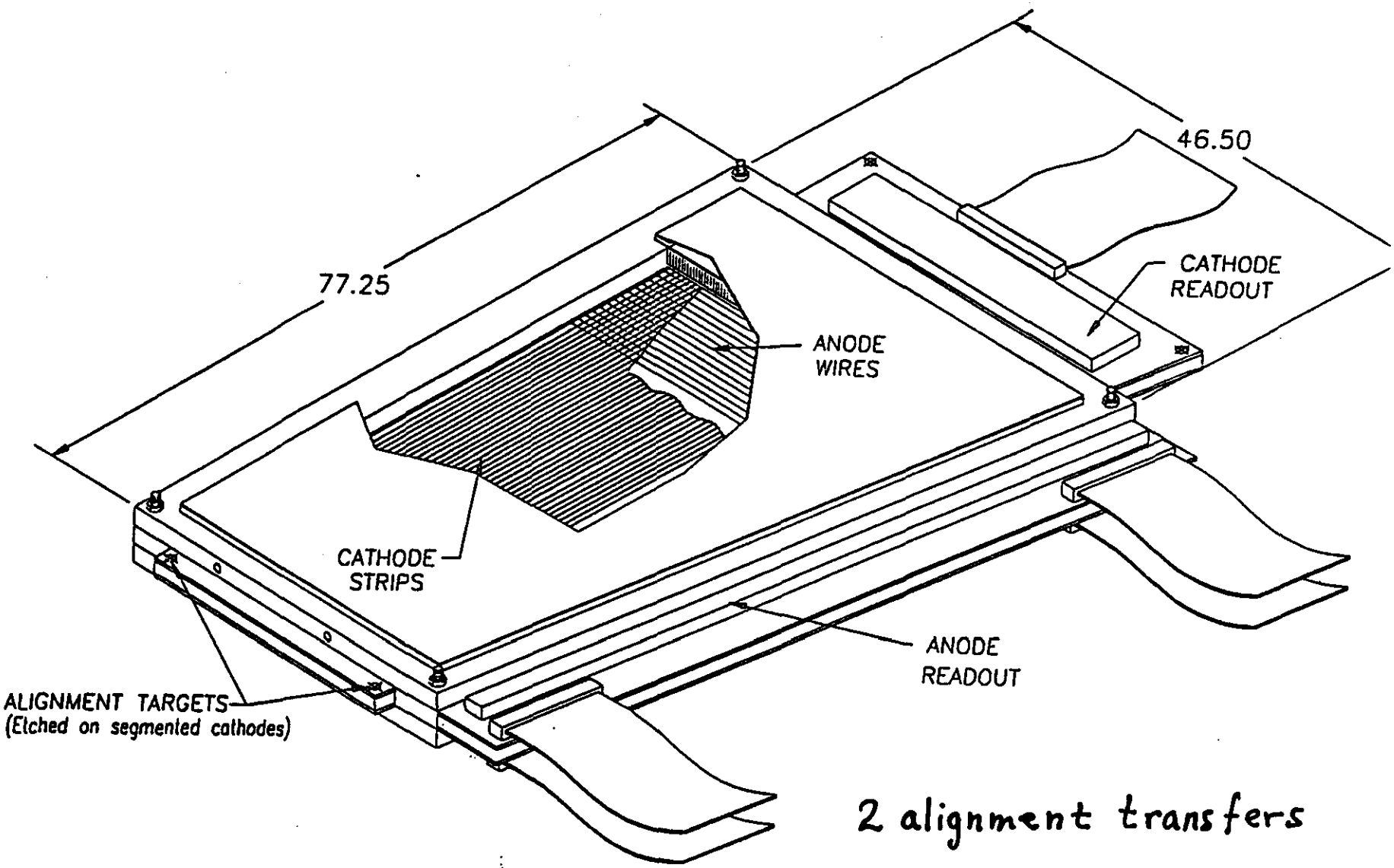
UH prototype



position: $x_{cg} = \frac{\sum x_i q_i}{\sum q_i}$ $\quad x_i = (l)\, l_a$

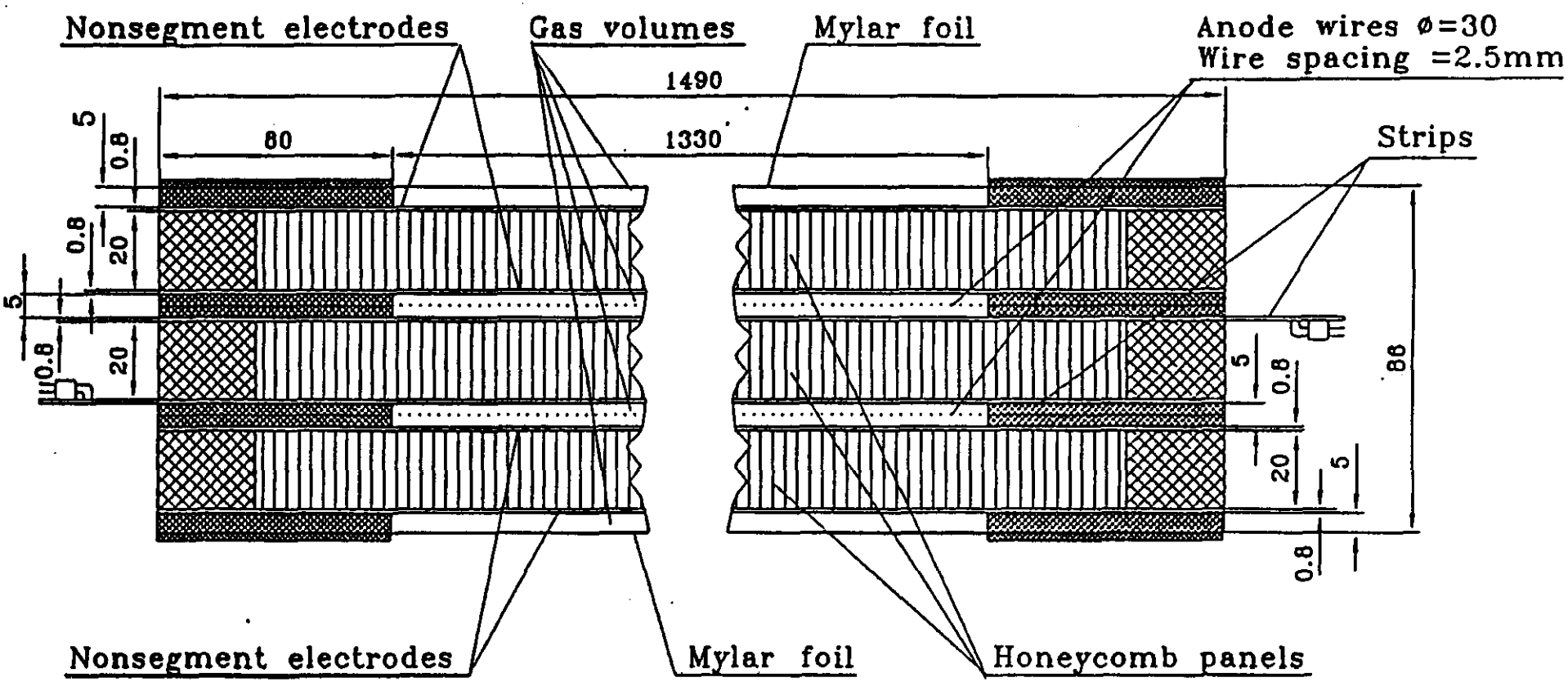
resolution: $\sigma_{cg} = l_a \frac{\sigma_{noise}}{Q} \sqrt{2}$ for 3 strips

Prototype Cathode Strip Chamber



2 alignment transfers

DUBNA CSC PROTOTYPE



Cross-section of MWPC perpendicular to the wires

(All dimensions in mm)

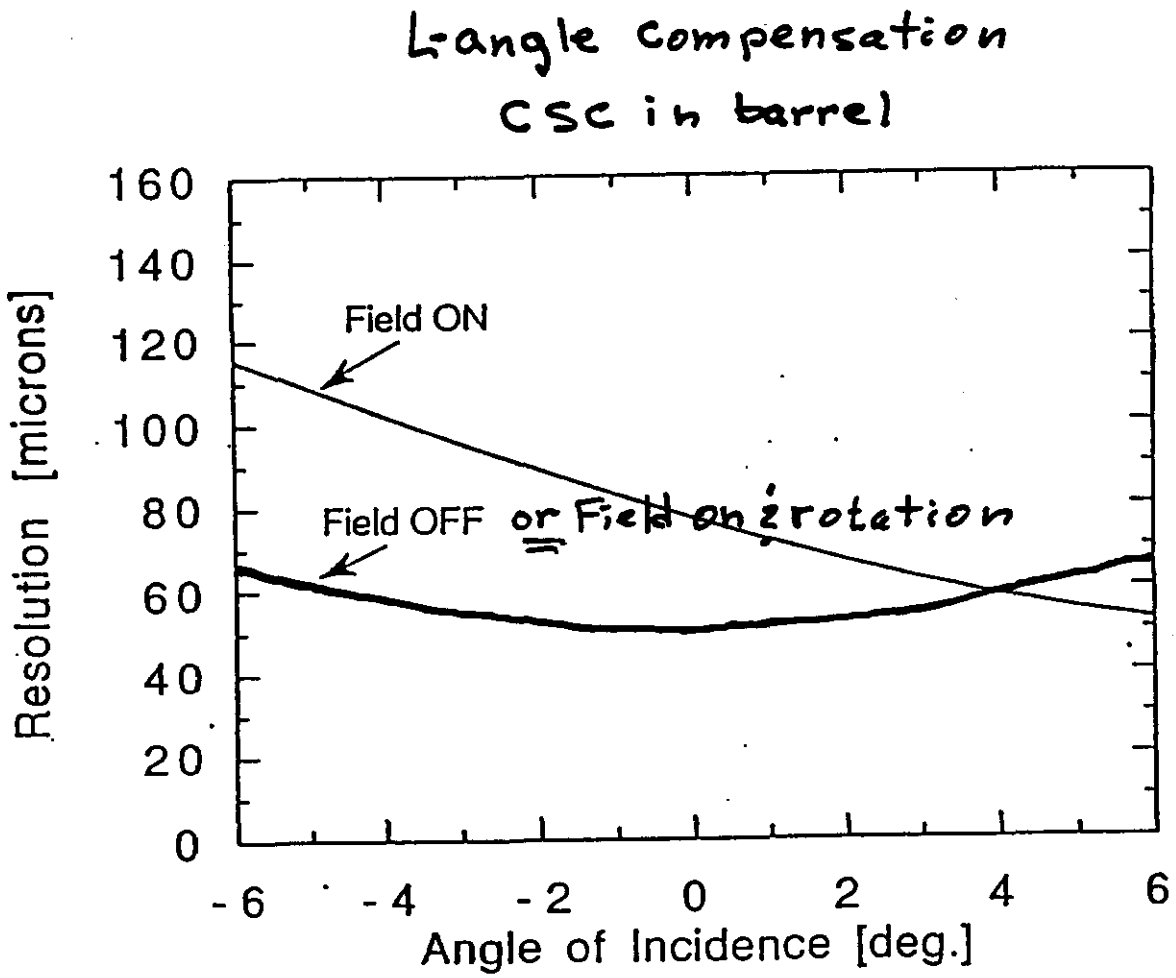


Figure 3: Resolution as a function of incident angle within a sector in a system with a 32-fold symmetry.

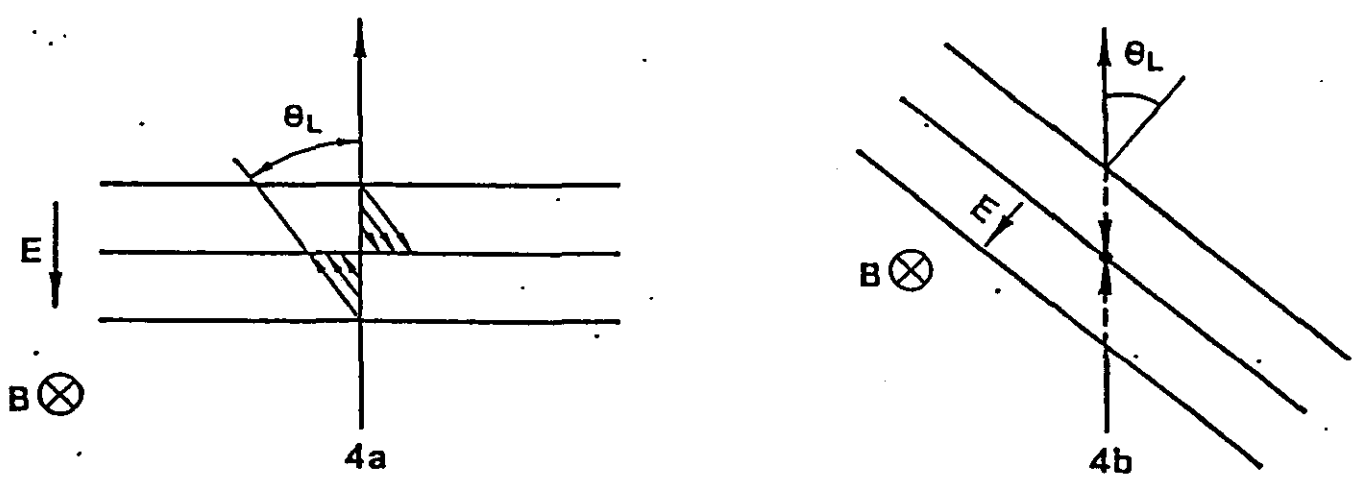


Figure 4: Normal incidence (4a) and compensation by tilting (4b)

CSC Endcap Design

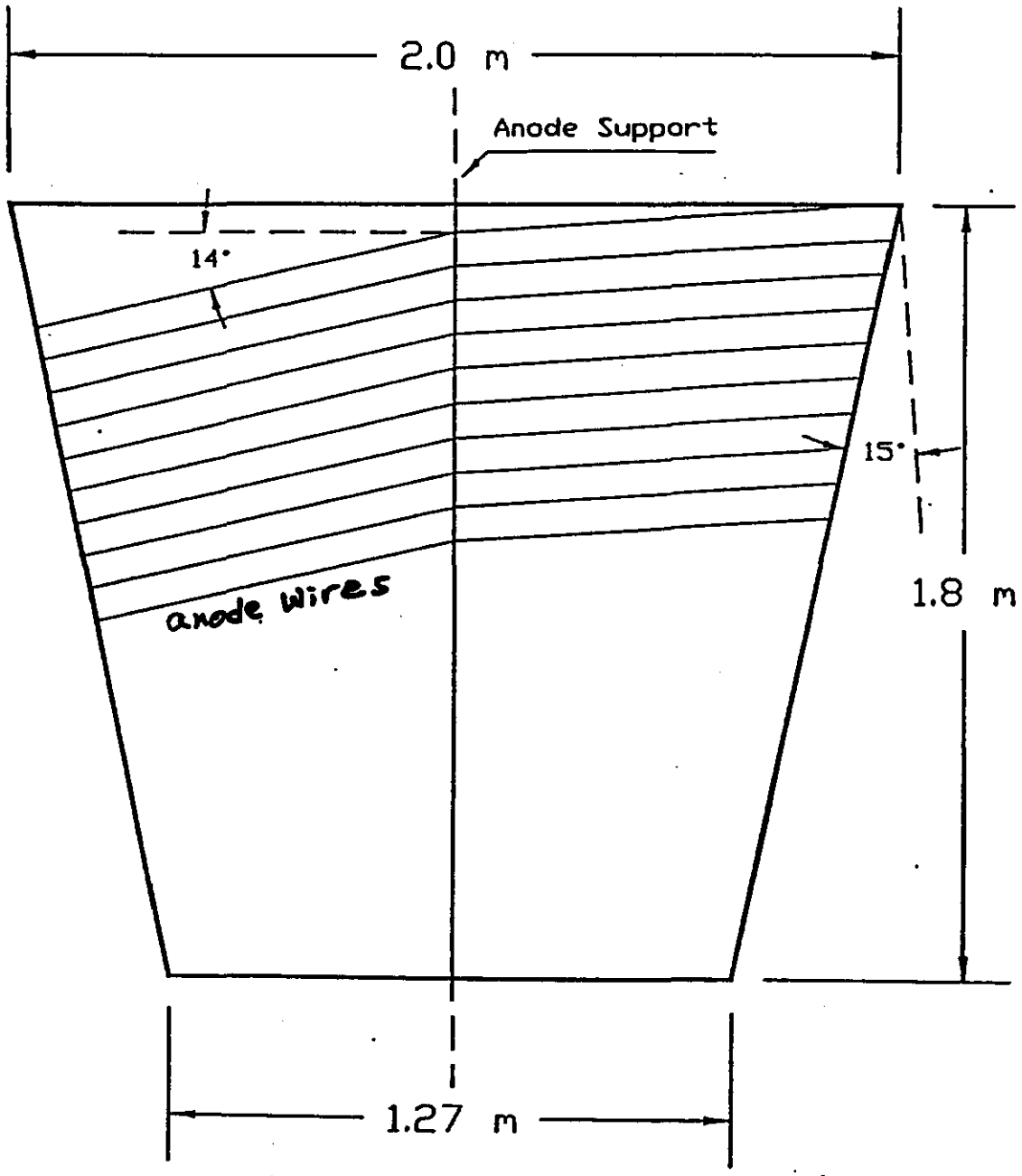
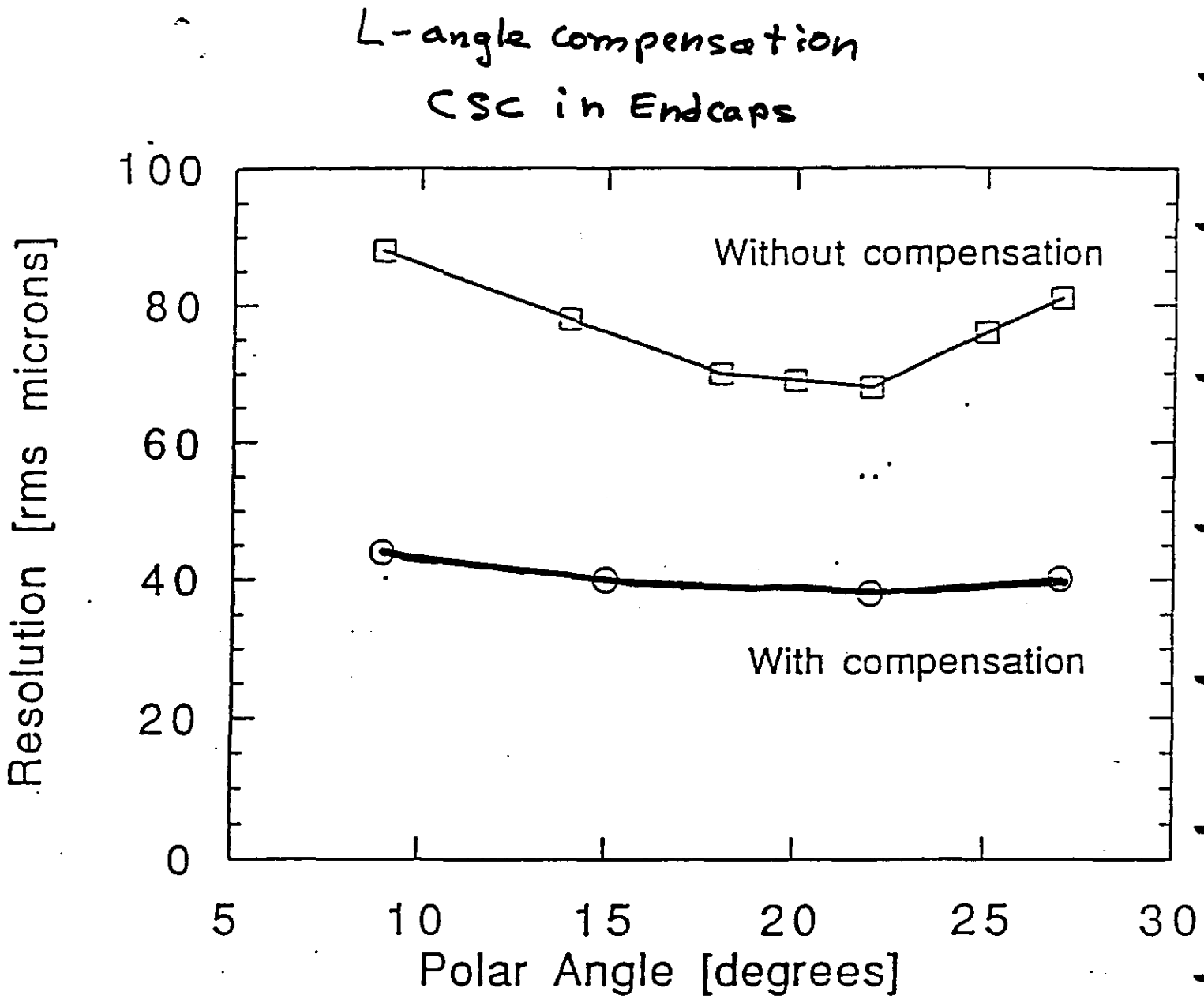


Figure 7: Wire placement to minimize effect of the angle between the anode wires and radial strips and the effect of the magnetic field.

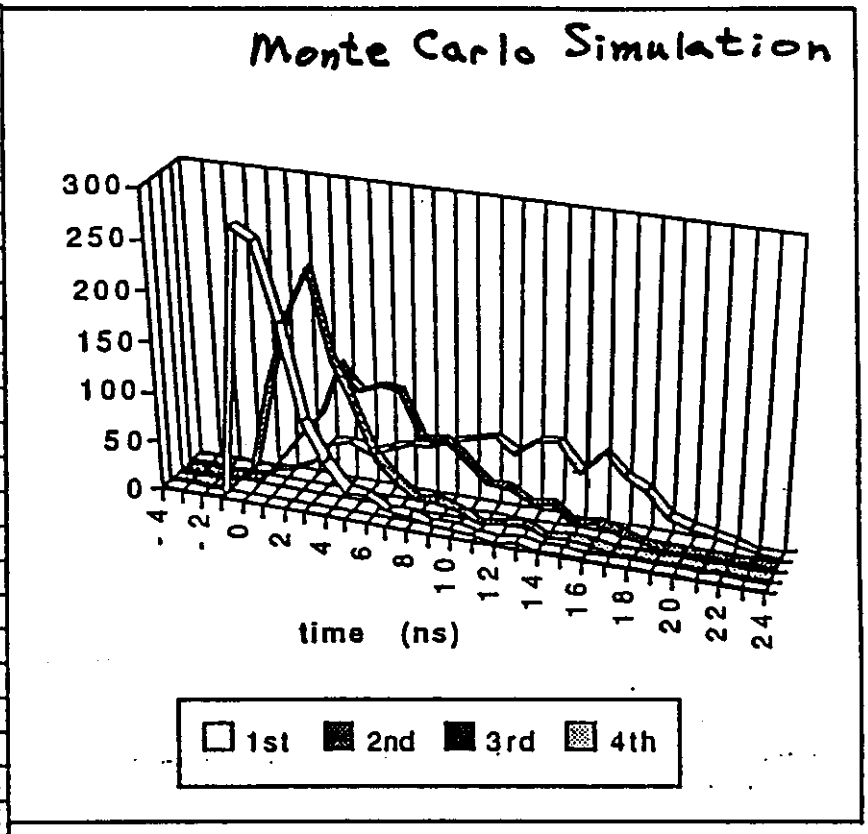
P: y z L-angle cup.

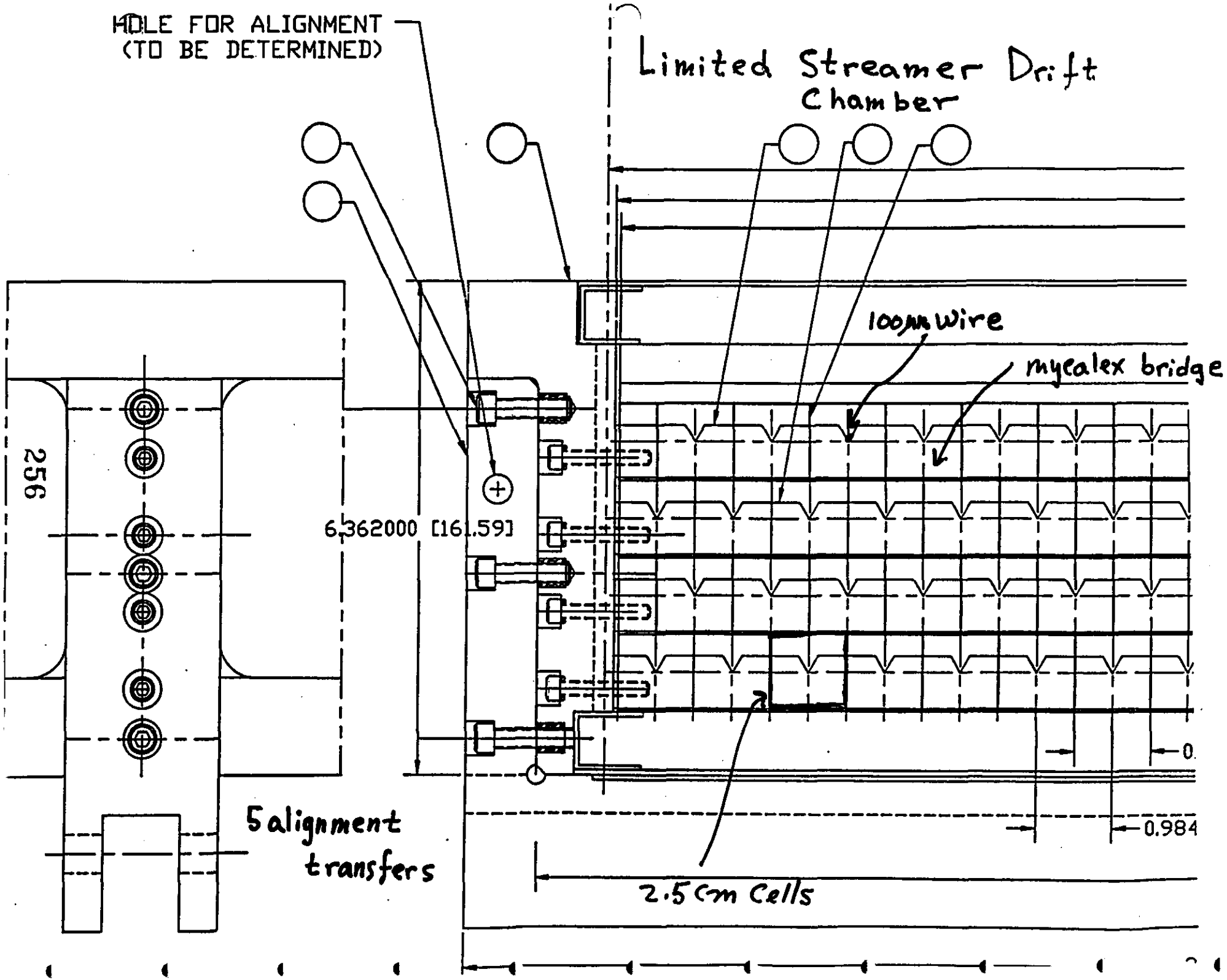

L-angle compensation
CSC in Endcaps
Without compensation
With compensation
Resolution [rms microns]
Polar Angle [degrees]
100
80
60
40
20
0
5
10
15
20
25
30

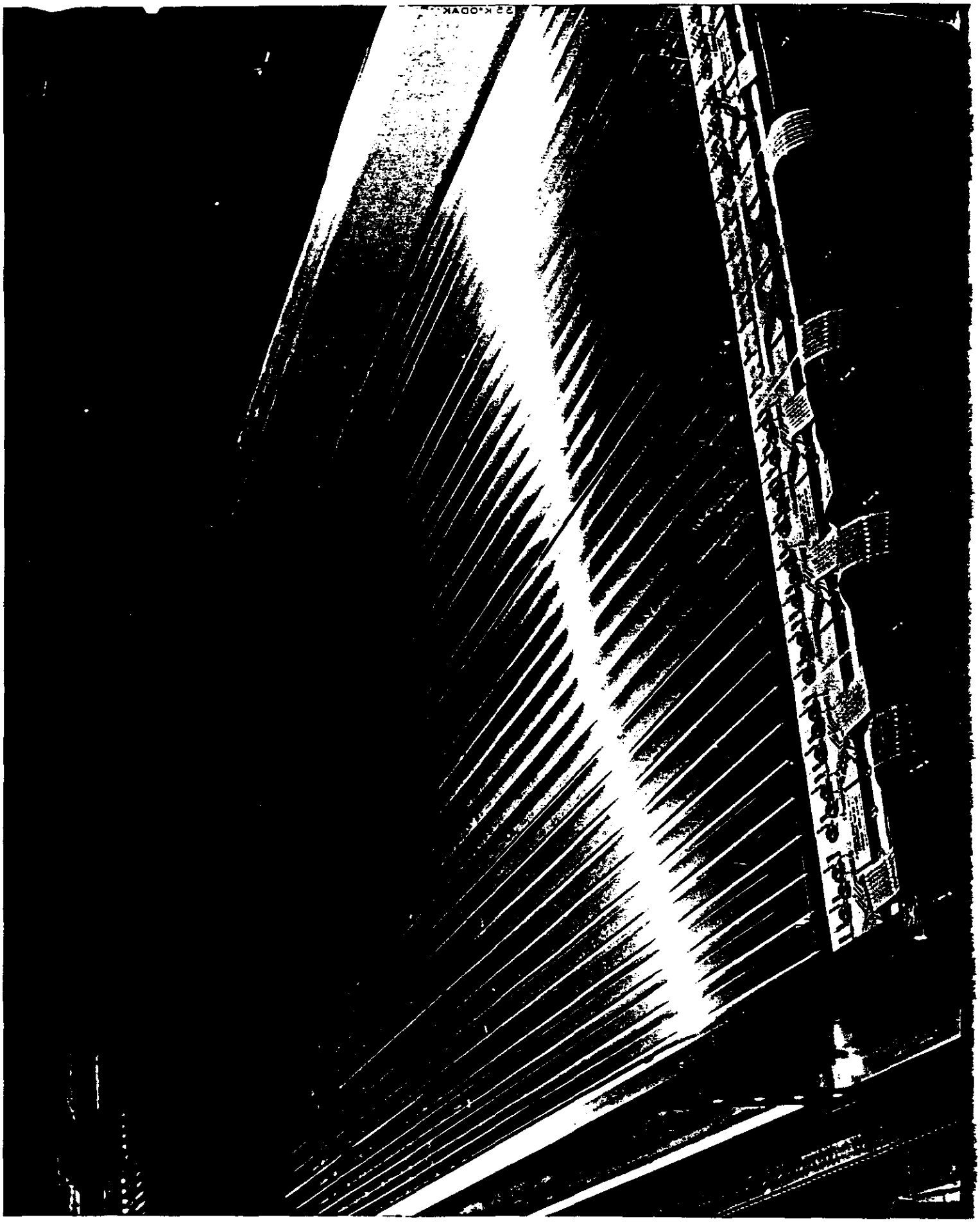
CSC beam crossing tag

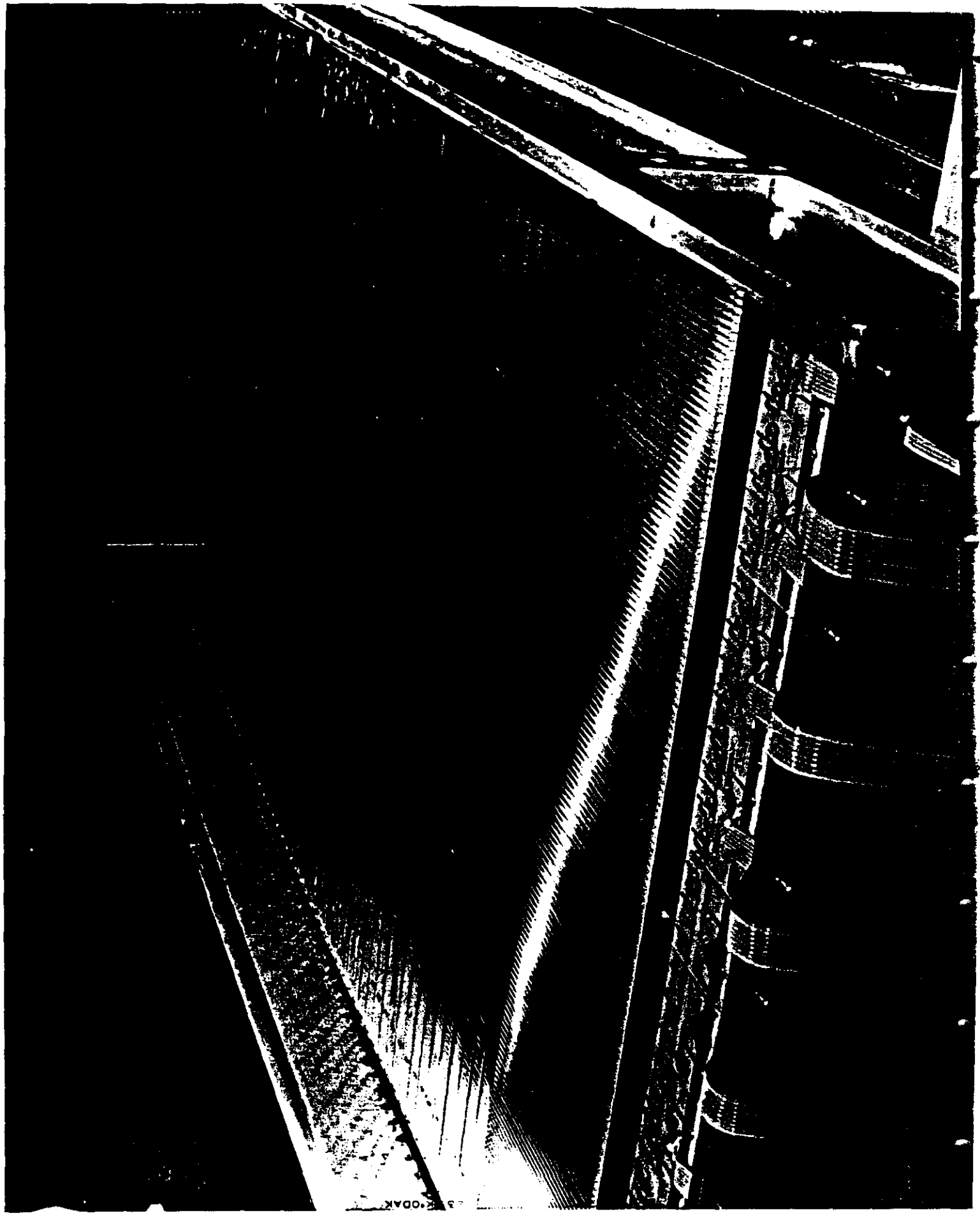
reliable: 99% ≤ 12 ns

time (ns)	1st	2nd	3rd	4th
-4	0	0	0	0
-3	0	0	0	0
-2	0	0	0	0
-1	0	0	0	0
0	270	23	2	0
1	258	118	28	7
2	183	189	55	15
3	92	232	78	40
4	53	148	133	46
5	27	106	110	36
6	27	56	118	45
7	14	35	116	53
8	13	18	72	53
9	8	21	75	62
10	8	15	57	68
11	5	5	35	75
12	2	9	35	61
13	5	12	24	77
14	1	3	27	80
15	3	5	10	53
16	0	4	15	76
17	0	0	7	56
18	1	0	2	45
19	0	0	0	21
20	0	1	1	15
21	0	0	0	10
22	0	0	0	6
23	0	0	0	0
24	0	0	0	0

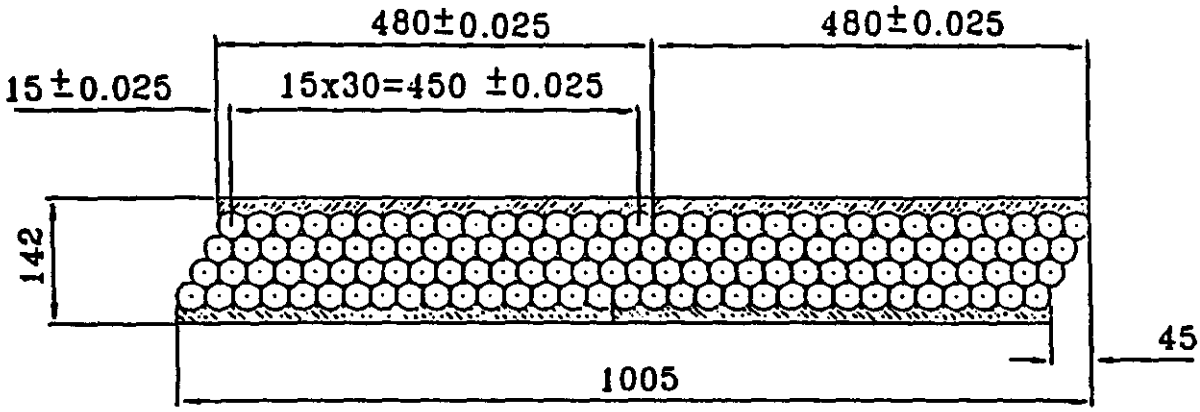



HOLE FOR ALIGNMENT
(TO BE DETERMINED)
Limited Streamer Drift
Chamber
100μm wire
mycalex bridge
256
6.362000 [161.59]
5 alignment
transfers
2.5 cm Cells
0.984

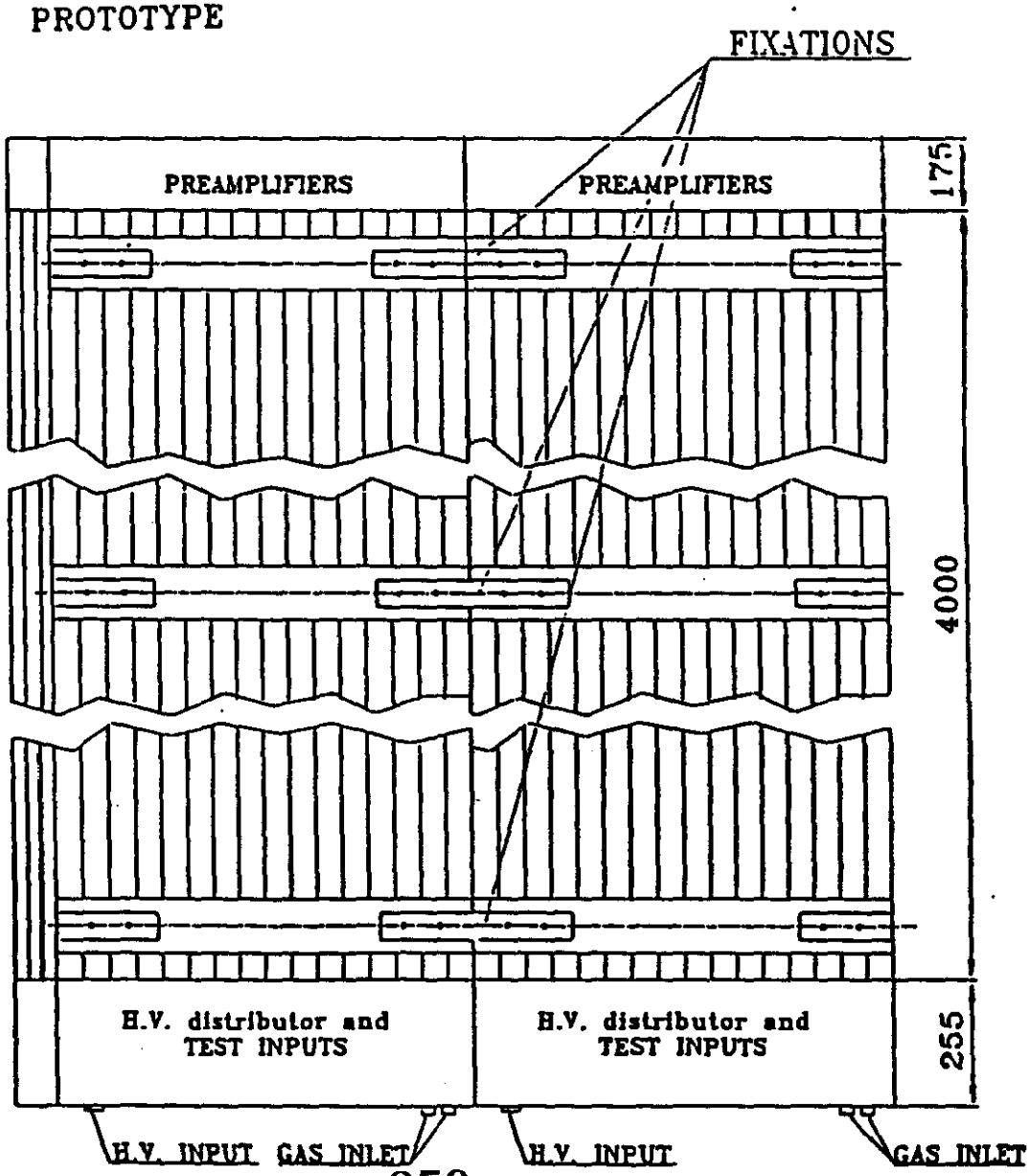


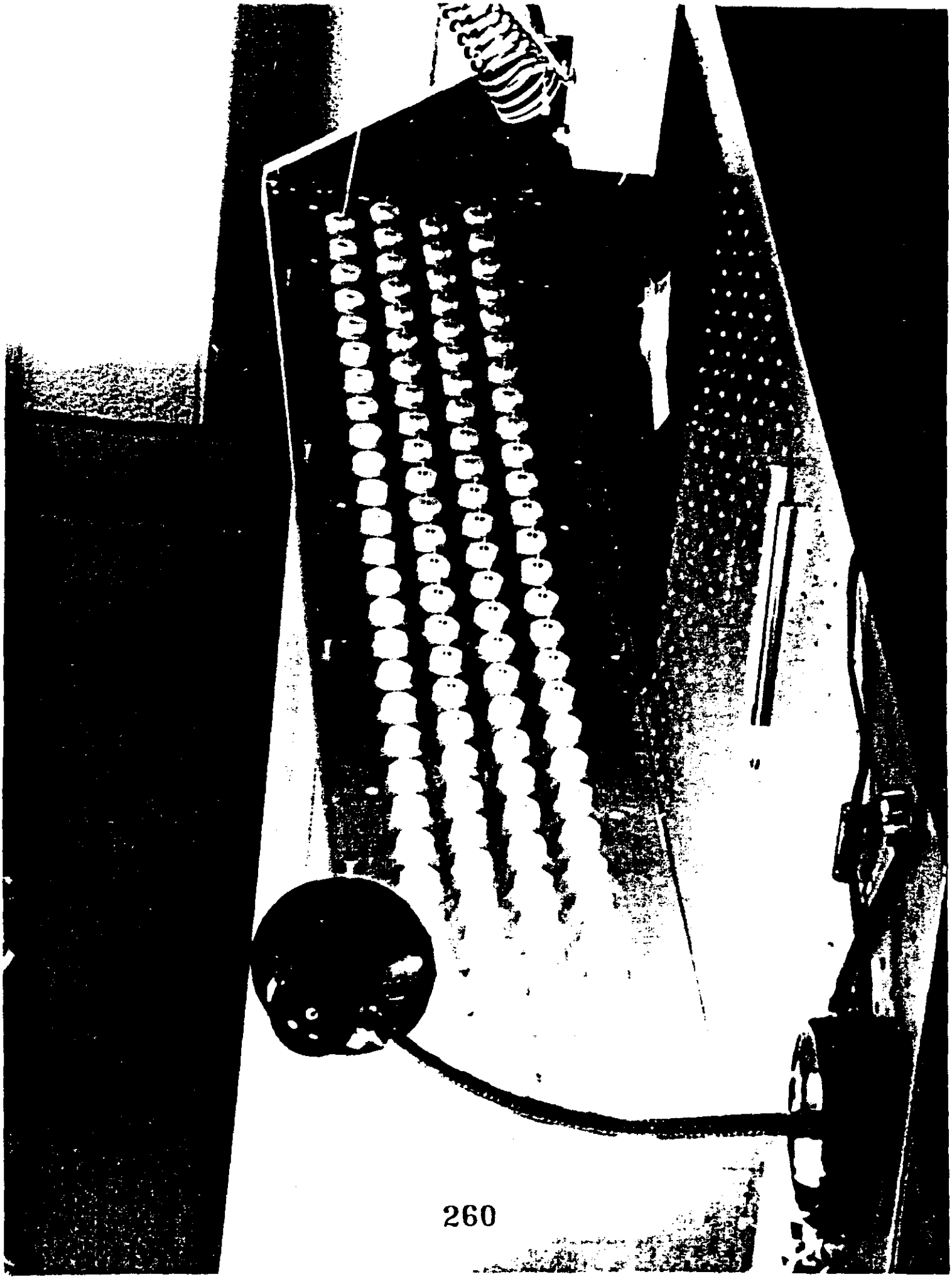


Round Drift Tube



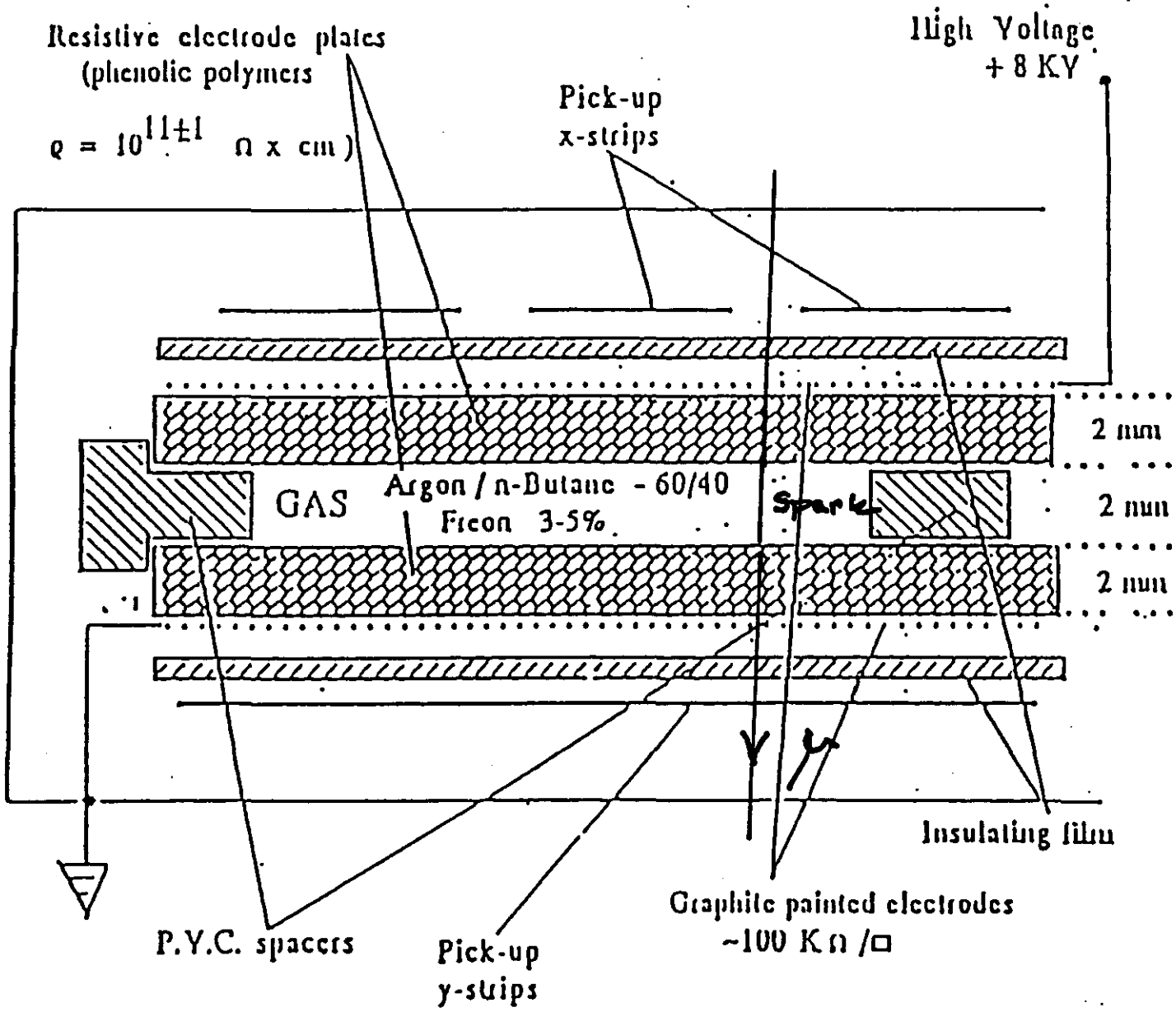
DUBNA PDT PROTOTYPE



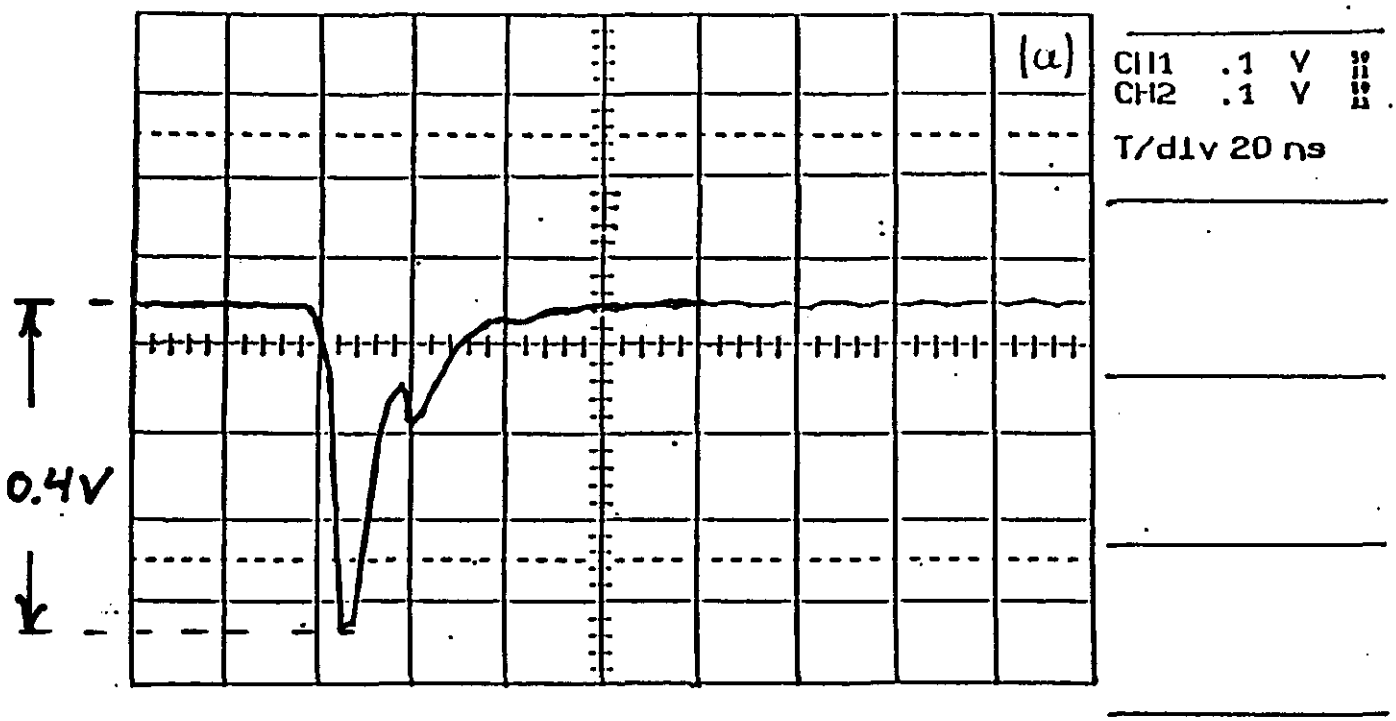


Resistive Plate Counter

Bakelite RPC



Bakelite RPC



jitter $\lesssim$ 1.5 ns

$r \leq 50\ Hz/cm^2$ Bakelite

Baseline 1: (10/91 - 11/92)

	Barrel	Endcaps
L-1 Triggering:	RPC	CSC
Tracking:	PDT or LSDT	CSC

Requirements to meet performance

<u>Cathode Strips:</u>

Configuration (SL1:SL2:Sl3)	8:4:4 8:8:4 forward angles
Single layer resolution	75 μm RMS
Alignment (internal random)	50 μm RMS
Alignment (external SL-to-SL)	25 μm RMS

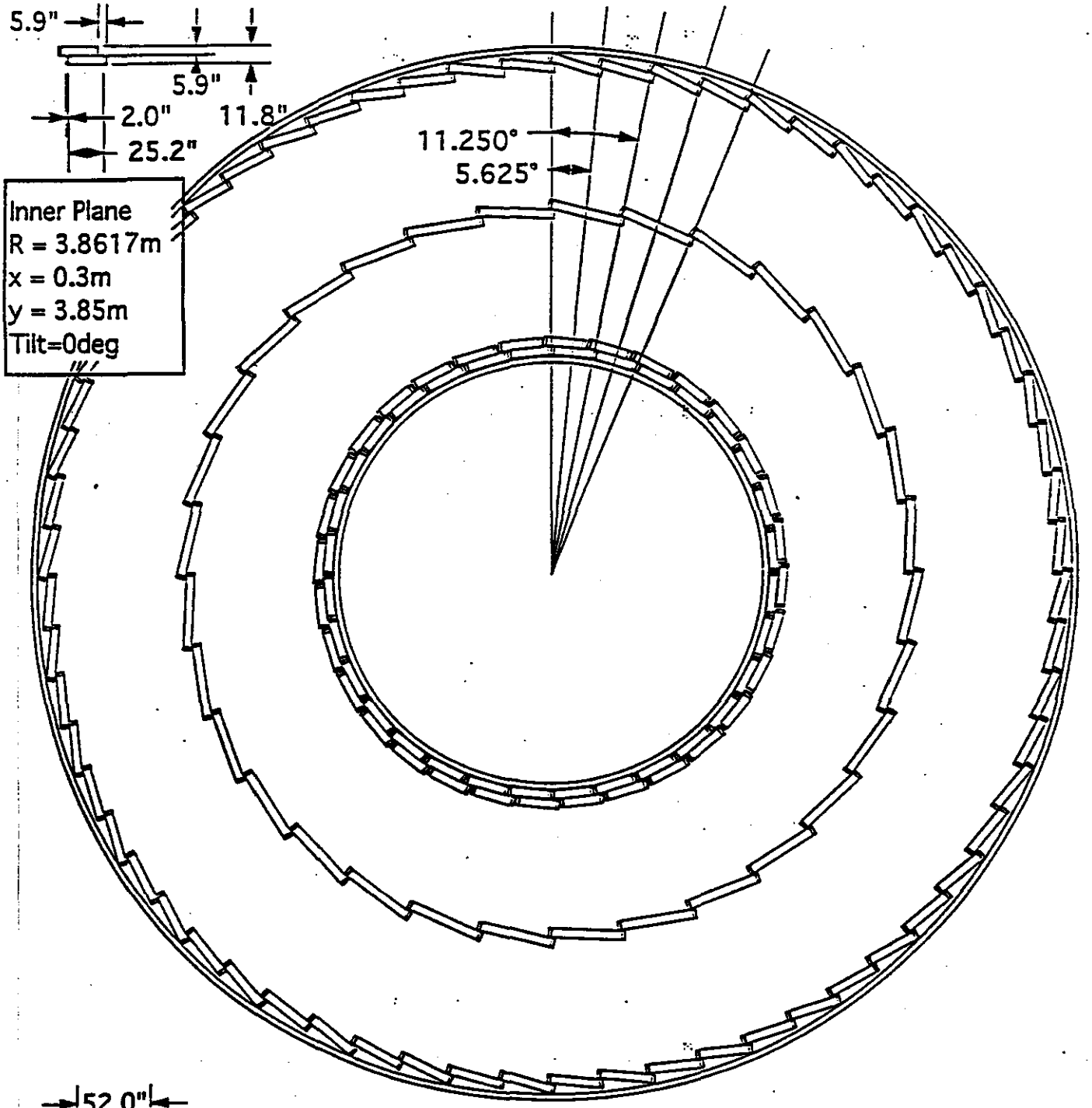
<u>Drift:</u>

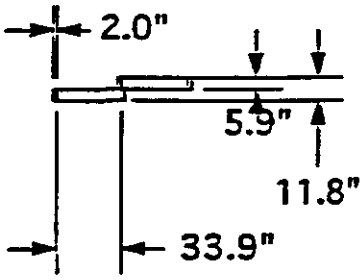
Configuration (SL1:SL2:Sl3)	8:8:4
Single layer resolution	100 μm RMS
Alignment (internal random)	50 μm RMS
Alignment (external SL-to-SL)	25 μm RMS

Baseline 2: (>11/92)

	Barrel	Endcaps
L-1 Triggering*:	CSC	CSC
Tracking**:	CSC	CSC
Backups		
* Trigger:	RPC	RPC
** Tracking:	RDT	RDT

Deployment of CSC in Barrel





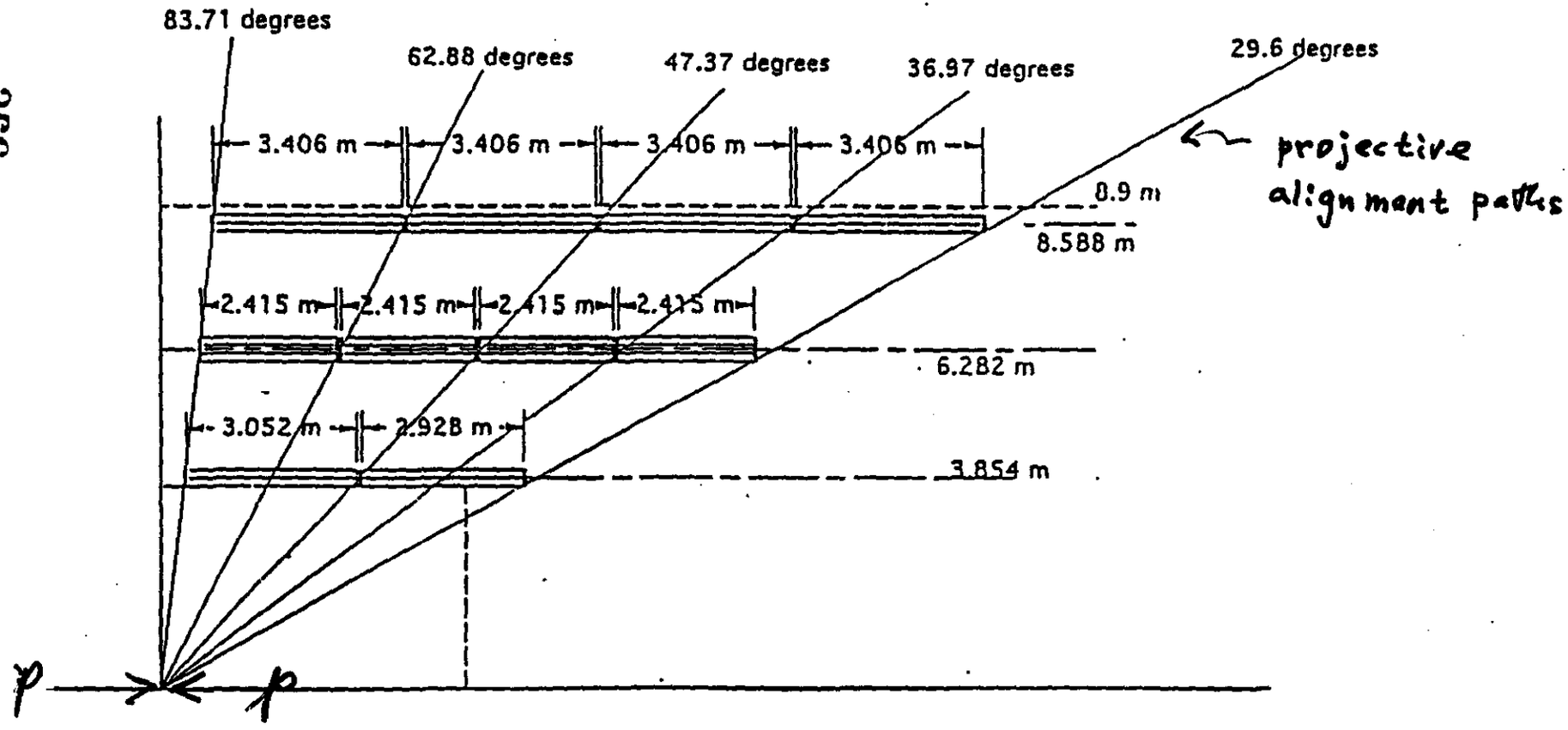
Mid plane
R = 6.1948m
x = 0.6024m
y = 6.1654m
Tilt=8.0deg

Outer plane
R = 8.6817m
x = 0.85m
y = 8.64m
Tilt=11.0deg

CSCg1ftBarrel
32 segments

CSCf2crzBarrellayout

Lengths of active areas



BASELINE - 2 Parameters

Parameter*	Barrel value	Endcap value	Total
Bend-plane segment width	5 mm	5 mm (in middle)	
Bend-plane channel count	754,000	294,000	1,048,000
Nonbend-plane segment width	10 cm	5 cm	
Nonbend-plane channel count	124,000	35,000	159,000
Number of chambers (4-gap)	1024	352	1376
Number of wires	3.6 M	0.7 M	4.3 M
Number of alignment paths	1536	384 approx.	1920 approx.

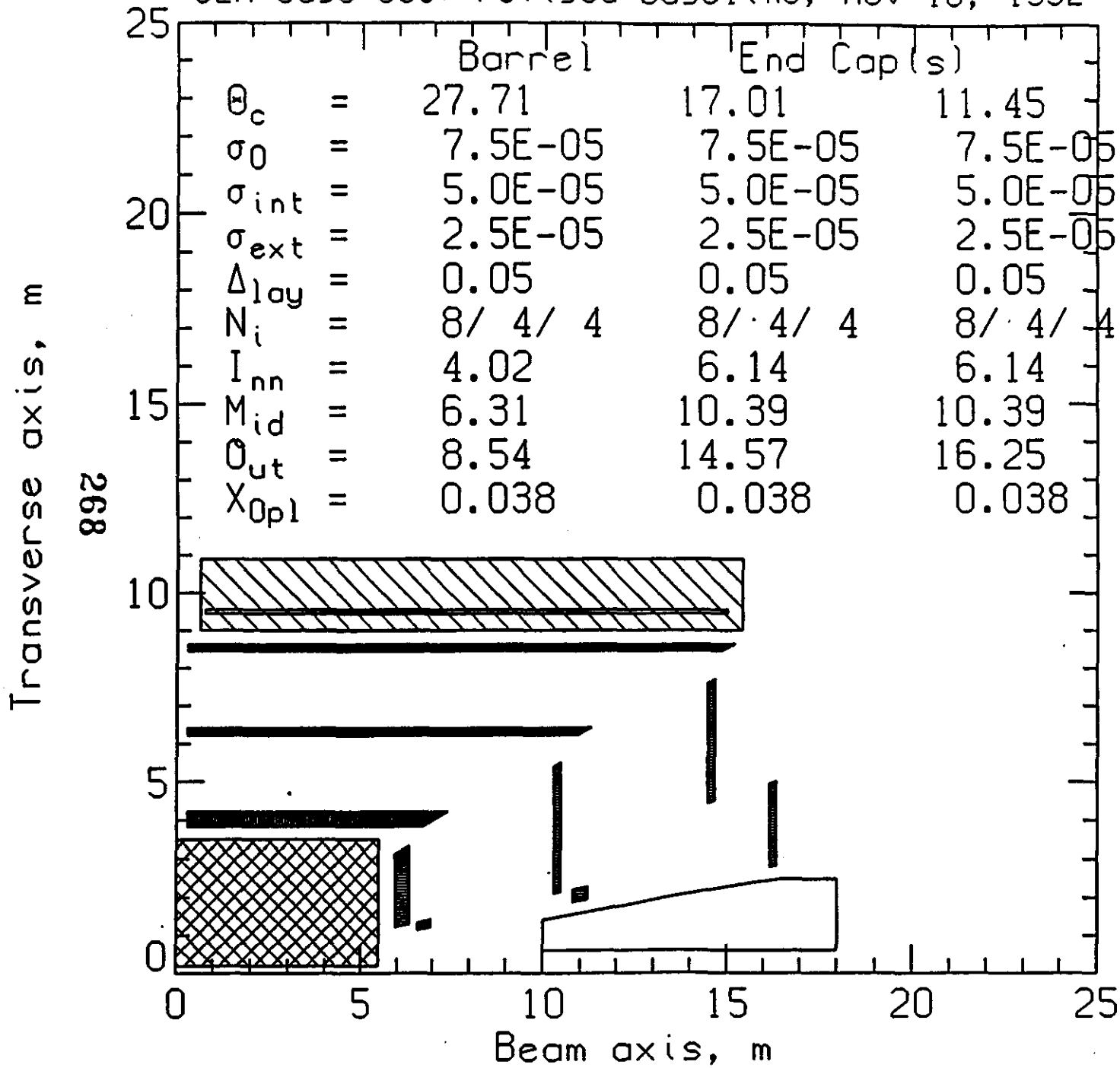
* All values preliminary and not optimized.

Performance model

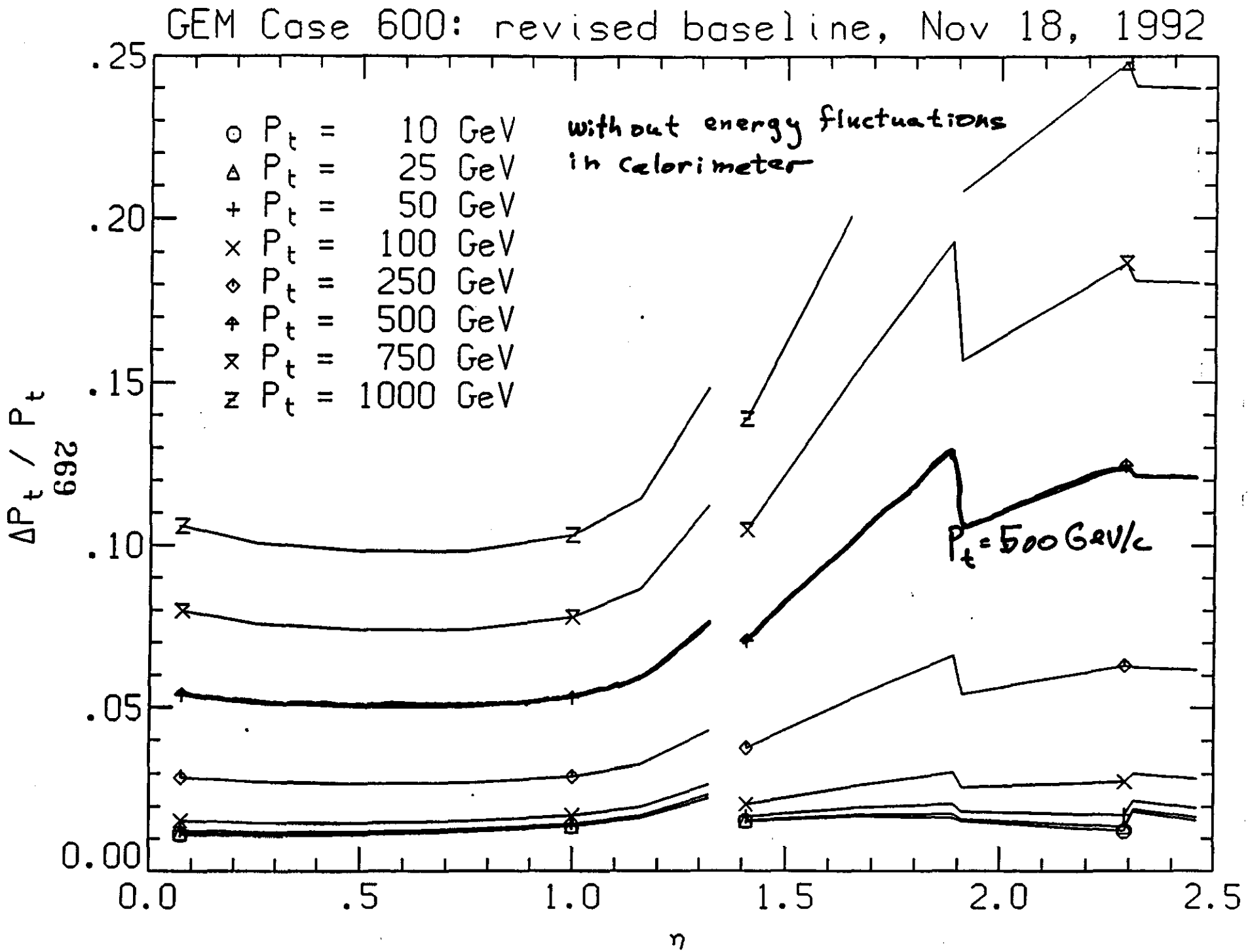
J. Sullivan / L. Rosenson

GEM Case 600: revised baseline, Nov 18, 1992

		Barrel	End Cap(s)		
θ_c	=	27.71	17.01	11.45	9.75
σ_0	=	7.5E-05	7.5E-05	7.5E-05	7.5E-05
σ_{int}	=	5.0E-05	5.0E-05	5.0E-05	5.0E-05
σ_{ext}	=	2.5E-05	2.5E-05	2.5E-05	2.5E-05
Δ_{lay}	=	0.05	0.05	0.05	0.05
N_i	=	8/ 4/ 4	8/ 4/ 4	8/ 4/ 4	8/ 8/ 4
I_{nn}	=	4.02	6.14	6.14	6.75
M_{id}	=	6.31	10.39	10.39	11.00
O_{ut}	=	8.54	14.57	16.25	16.25
X_{0pl}	=	0.038	0.038	0.038	0.038



Muon CSC option but modified locations: 11/25/92


GEM Case 600: revised baseline, Nov 18, 1992
○ P_t = 10 GeV
△ P_t = 25 GeV
+ P_t = 50 GeV
× P_t = 100 GeV
◇ P_t = 250 GeV
P_t = 500 GeV
P_t = 750 GeV
z P_t = 1000 GeV
without energy fluctuations in calorimeter
P_t = 500 GeV/c
$\Delta P_t / P_t$
.25
.20
.15
.10
.05
0.00
0.0
.5
1.0
1.5
2.0
2.5
η
Muon CSC option but modified locations: 11/25/92

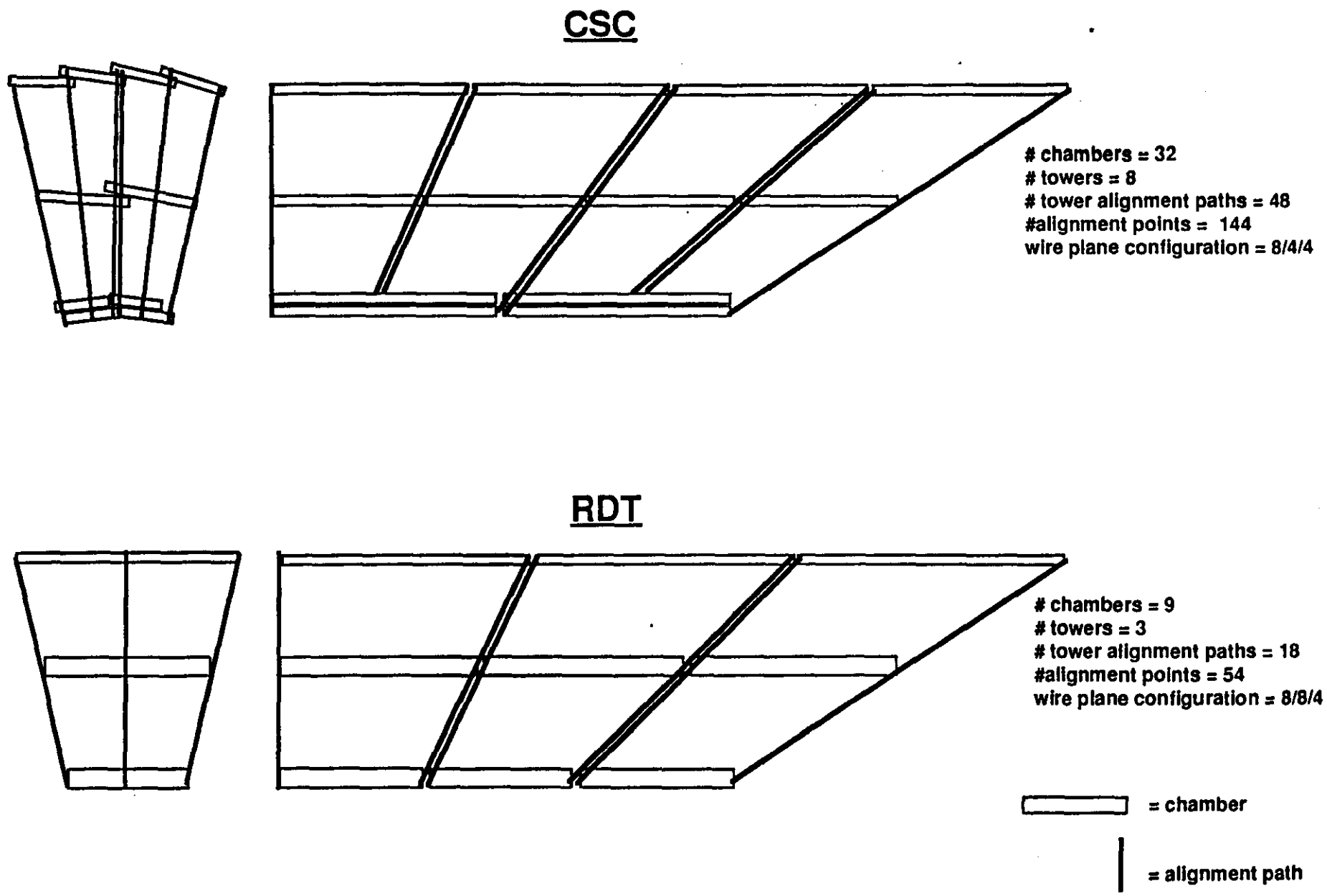


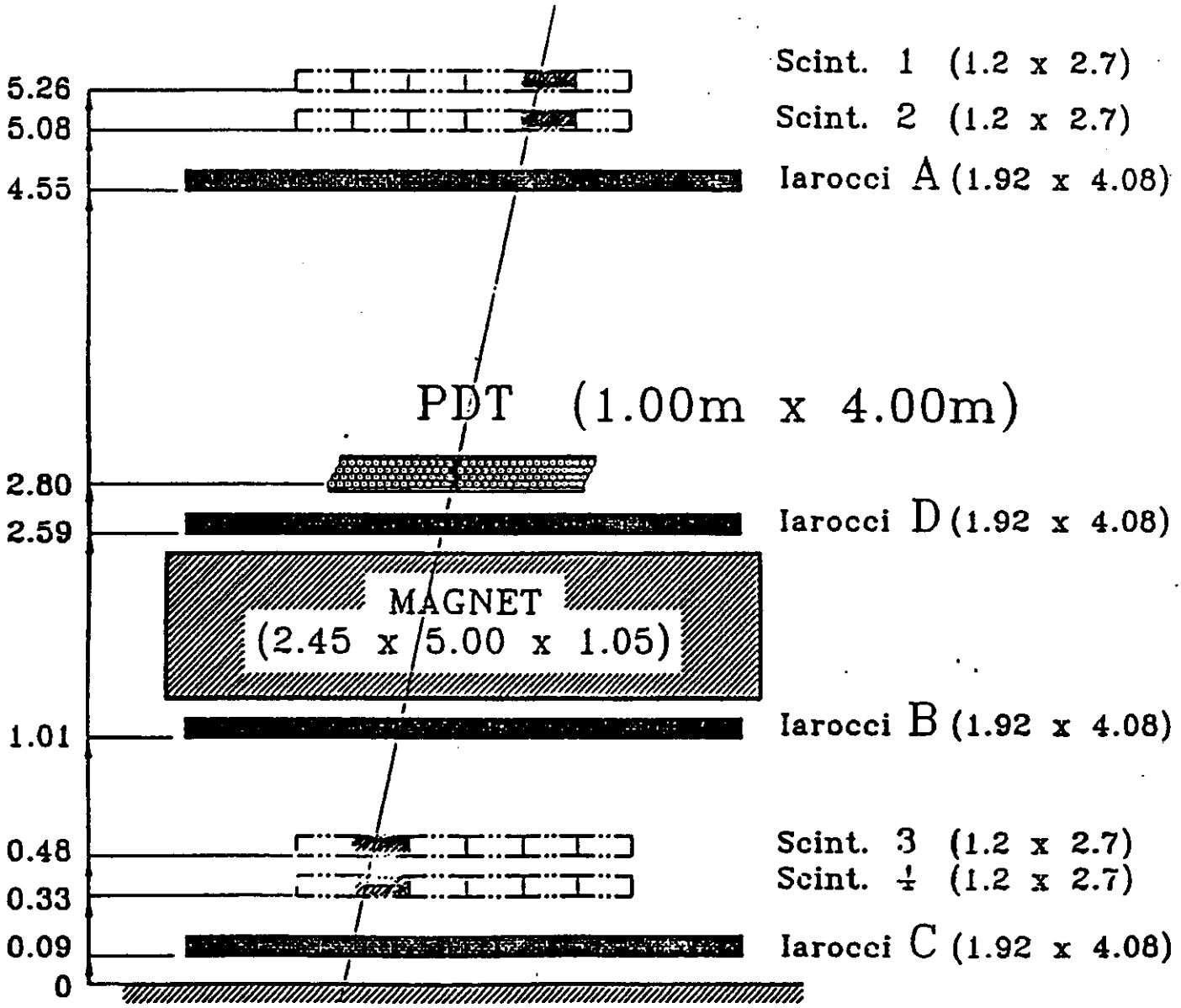
Figure 3. Local alignment schemes for muon barrel

How did we get here ?

Chambers of R&D92 Program

Technology	Chamber size	TTR delivery date
RDT-JINR	1 m x 4 m x 8 layers	7/28/92 (delivered)
RDT-MSU	1.3 m x 3.8 m x 4 layers	9/29/92 (delivered)
LSDT	1 m x 4 m x 4 layers	9/22/92 (delivered)
LSDT	1 m x 4 m x 4 layers	10/23/92 (delivered) 10/28/92 (sent back)
RPC-INFN	1 m x 2 m x 2 layers	9/29/92 (delivered)
CSC-BU	0.3 m x 0.4 m x (2x2) layers	RD5-CERN (delivered)
CSC-BNL	0.5 m x 0.5 m x (2x2) layers	10/20/92(delivered)
CSC-BNL	1 m x 1.8 m x 4 layers	(under construction)
CSC-UH	0.5 m x 1 m x 3 layers	9/92 (delivered)
CSC-JINR	1.2 m x 1.5 m x 2 layers	10/10/92 (delivered)

TTR TEST SETUP



All dimensions in m

EAST

Process:

(I) Muon Review SSCL 10/6/92

Input:

- Proponent Reports
- Engineering Assessment
- Panel of Experts
- Muon Steering Committee
- Chamber Tests at TTR

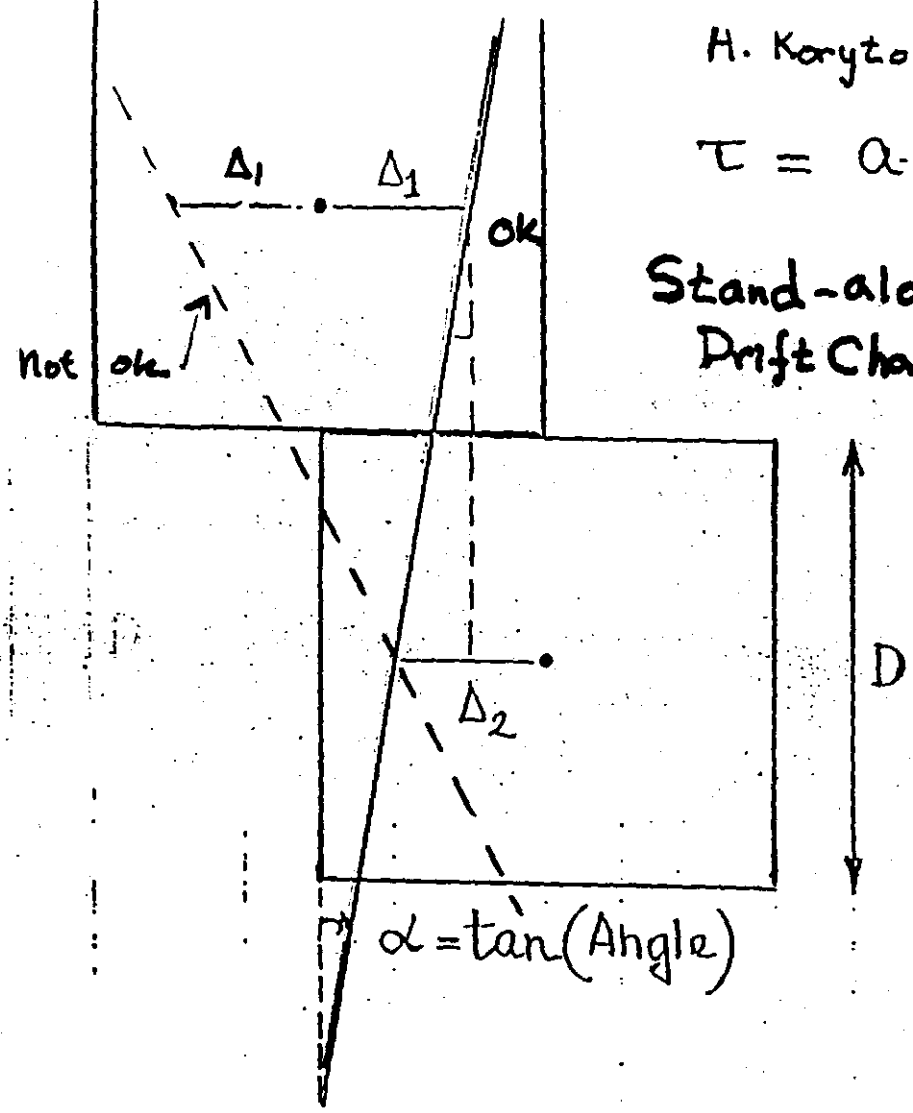
Conclusions - barrel system only:

- LSDT with stand-alone trigger (no RPC needed) looked most attractive for barrel application.
- PDT operated in LS mode and LSDT with RPC trigger same. (The PDT became the "RDT".).
- RPC with low resistivity plastic attractive (high rate possible).
- No rating of CSC barrel application.

H. Korytov – MIT

$$\tau = a \cdot \Delta + b \cdot \Delta^2$$

Stand-alone Trigger Drift Chamber



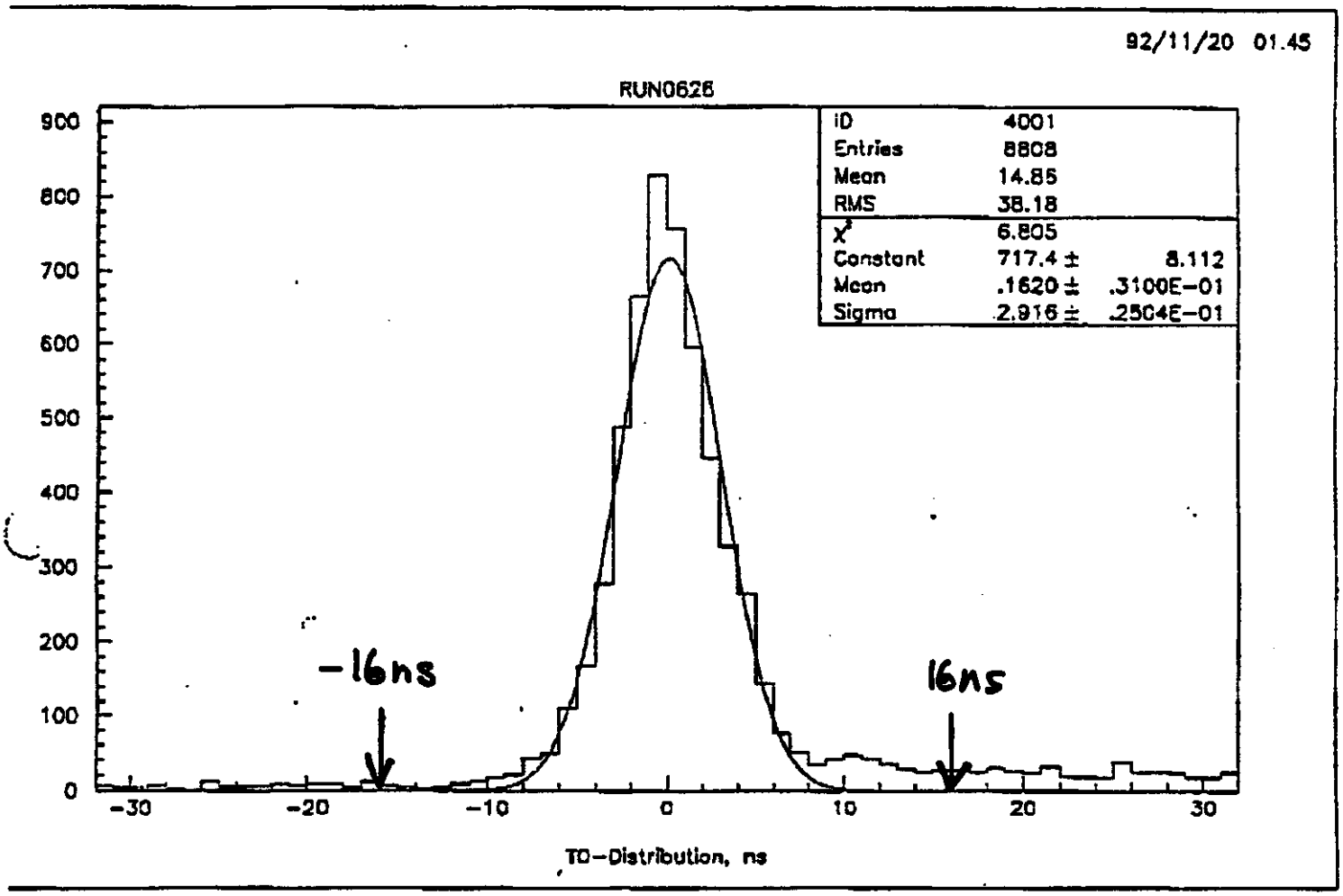
$$T_0 = \frac{T_1 + T_2}{2} - \frac{a \cdot C_0}{2} - \frac{b}{4}\left(C_0^2 + \frac{(\Delta T)^2}{(a + bC_0)^2}\right)$$

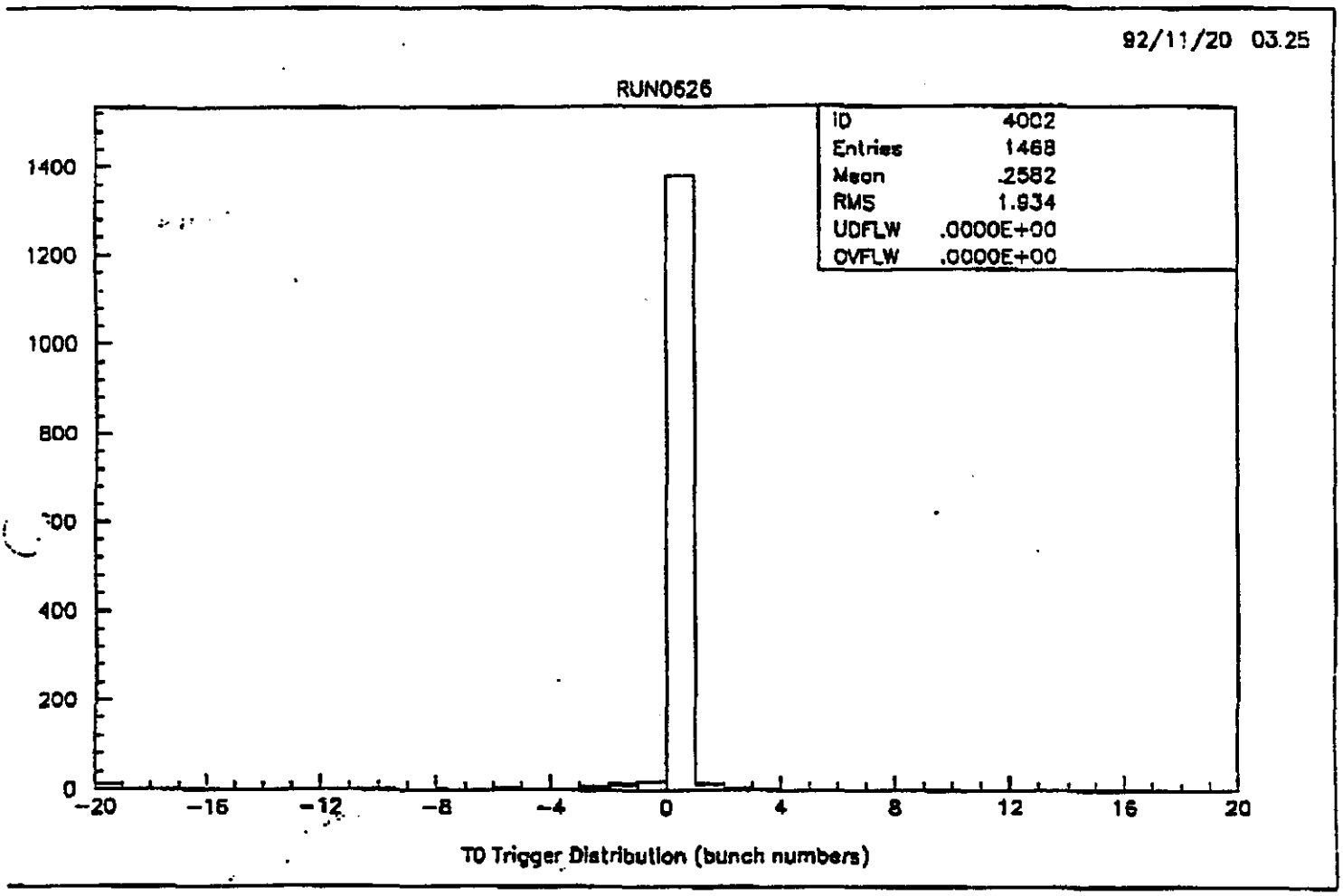
$$C_0 = \frac{D}{2} + \alpha \cdot D$$

Can determine T_0 (beam crossing) & P_T

Fig.A.IV.5

With LSDT use real data to Simulate trigger





	TTR	MC
RIGHT T_0	94%	93.6%
WRONG T_0	5%	6.1%
NO T_0	1%	0.3%

(II) BNL 11/5/92 & Duncanville 11/19/92

All technologies have results:

- Analog: (resol'n required σ layer = 75 μm)
  - CSC (BNL) σ layer = 109 μm
  - CSC (UH) σ layer = 96 μm

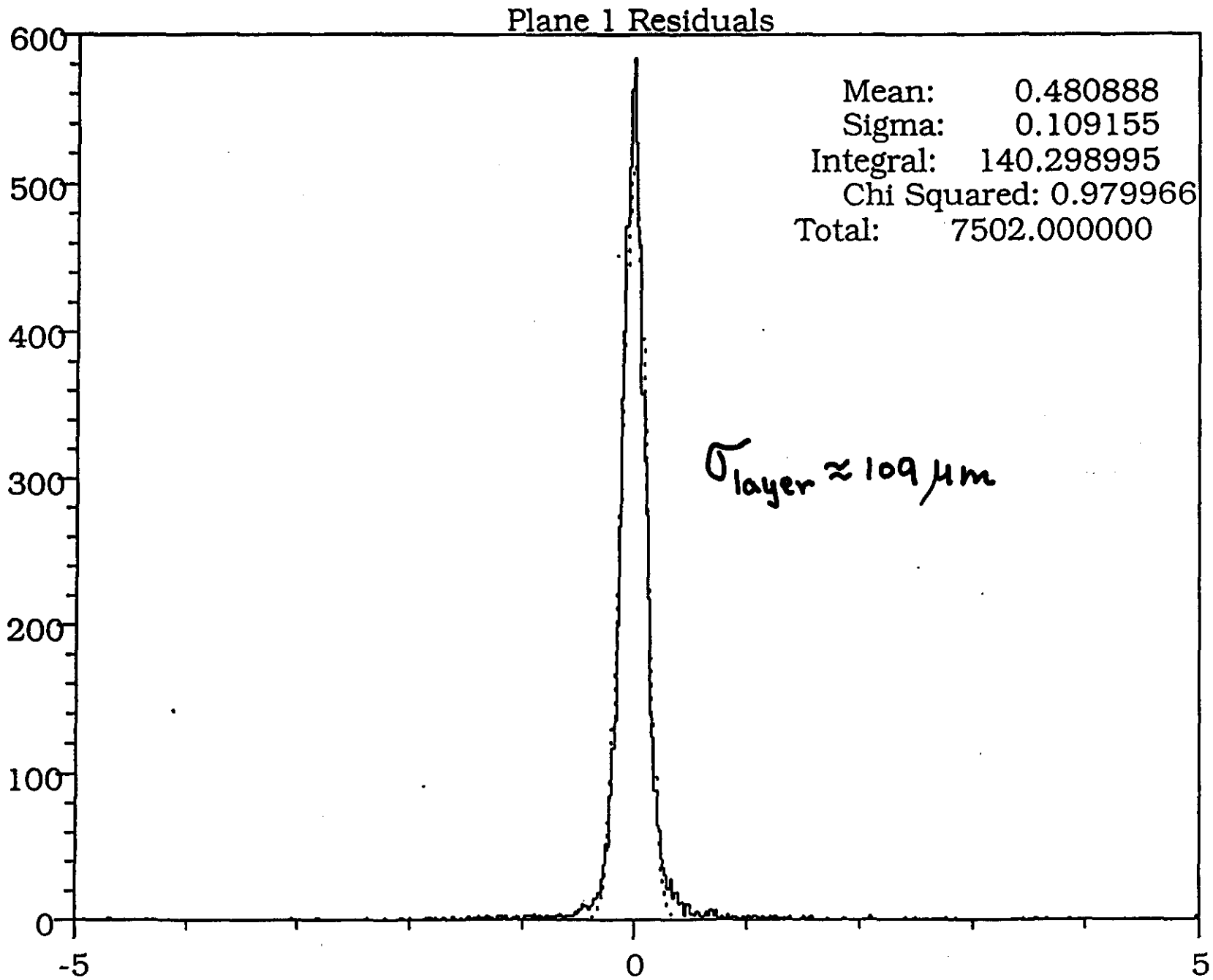
All CSC results are preliminary, but promising.

- Drift: (resol'n required σ layer = 100 μm)
  - LSDT σ layer = 80 μm (only 32 wires strung)
  - RDT (Dubna) σ layer = 85 μm
  - RDT (MSU) σ layer = 86μm (To fitted)

All are full-size chambers (≈1 m x 4 m). Flammable gas used.

- RPC: (1 m x 2 m chamber)
  - trigger jitter 1.4 ns
  - (- saturated counting rate 15 kHz /cm^2 measured new plastic)

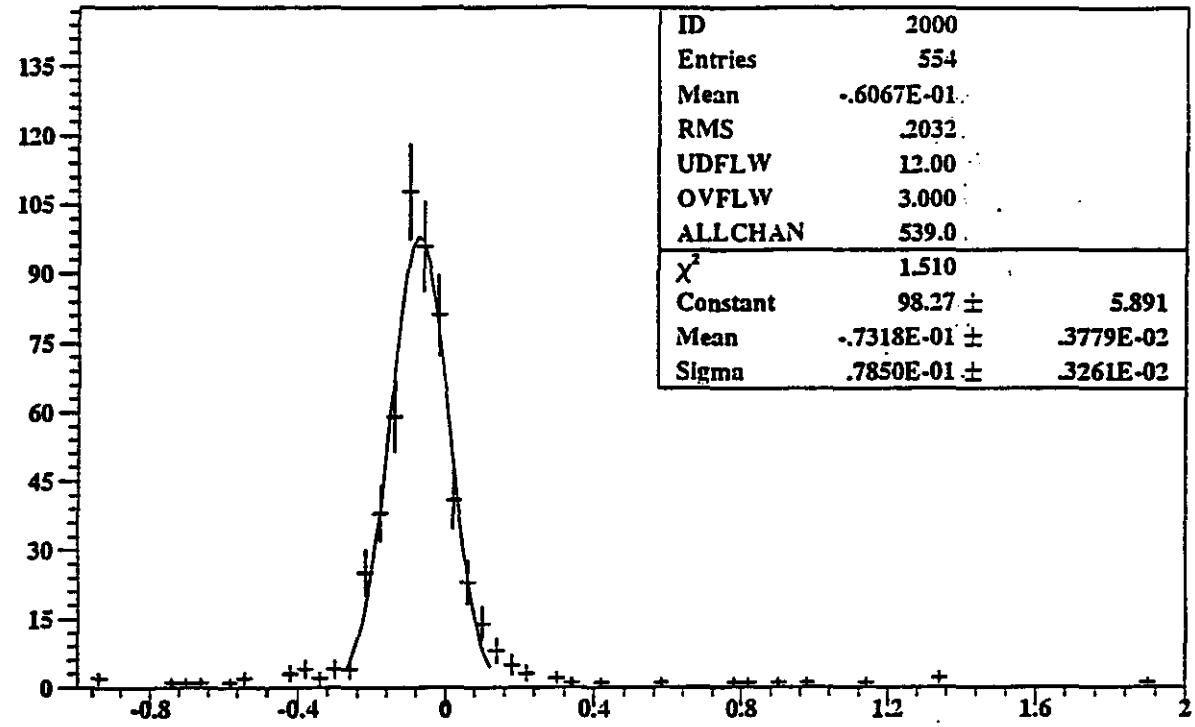
CSC-BNL Chamber Performance



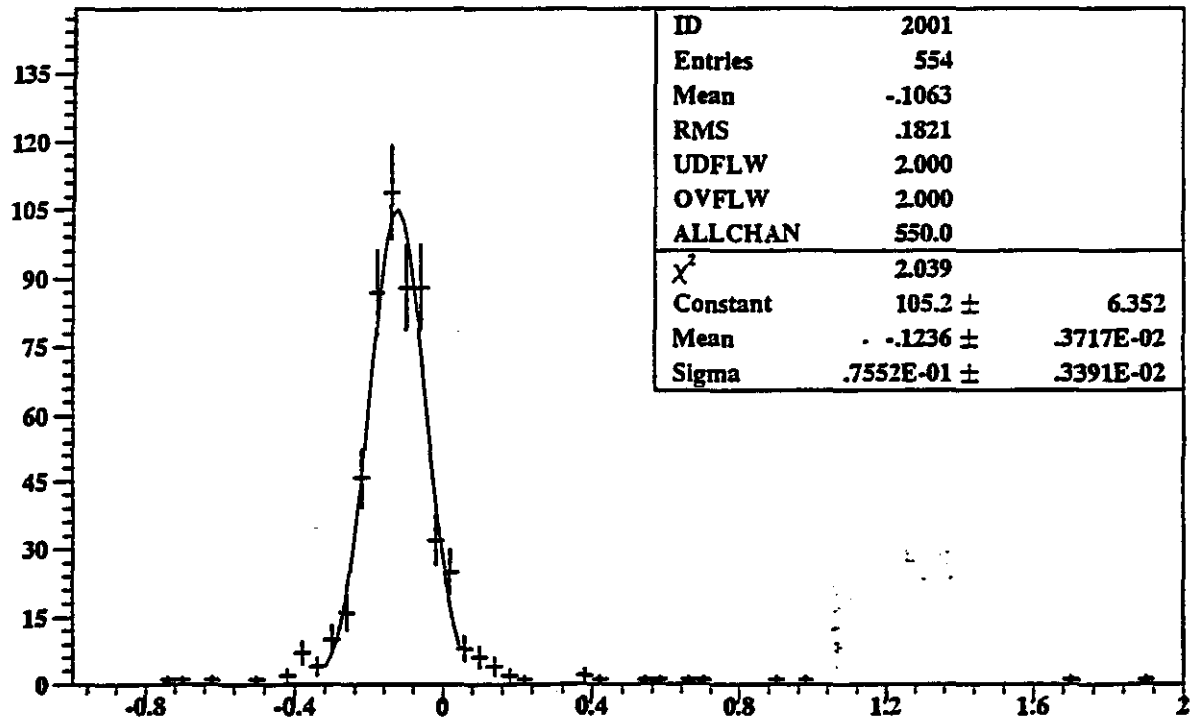
$\varphi = \pm 1^\circ$.

Run 12

92/11/28 00.41

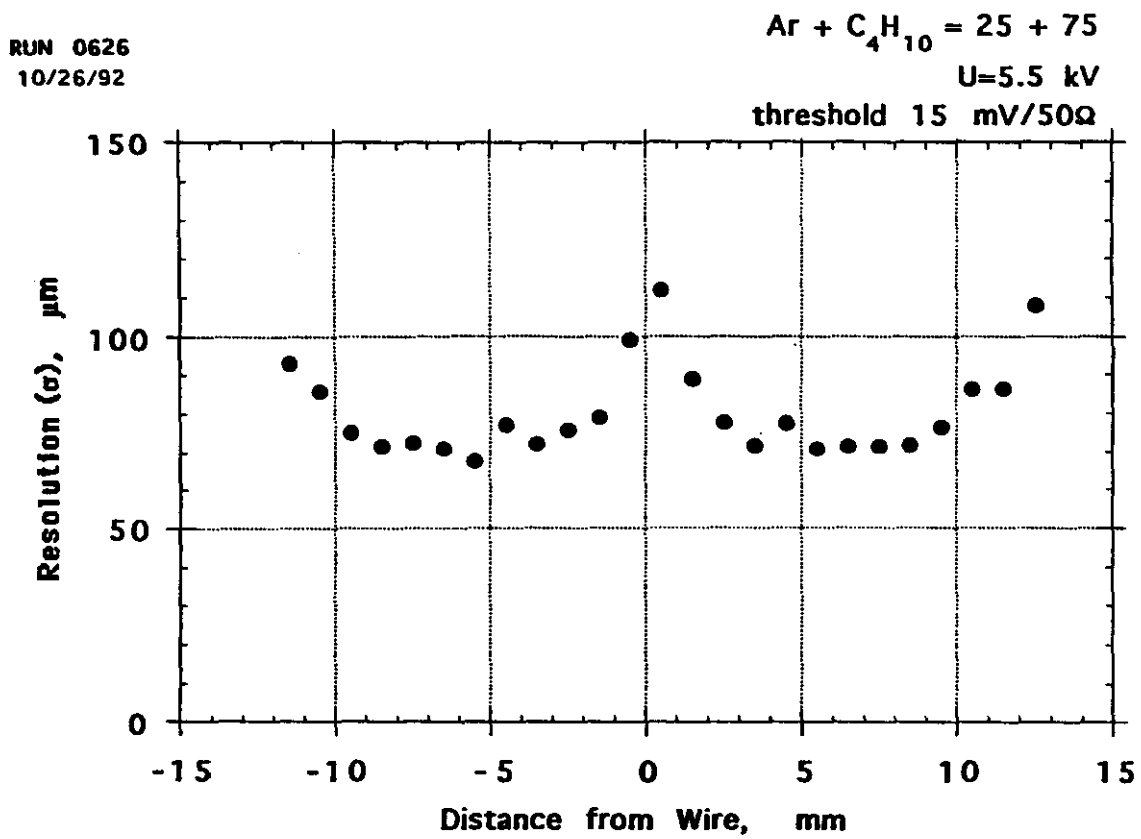


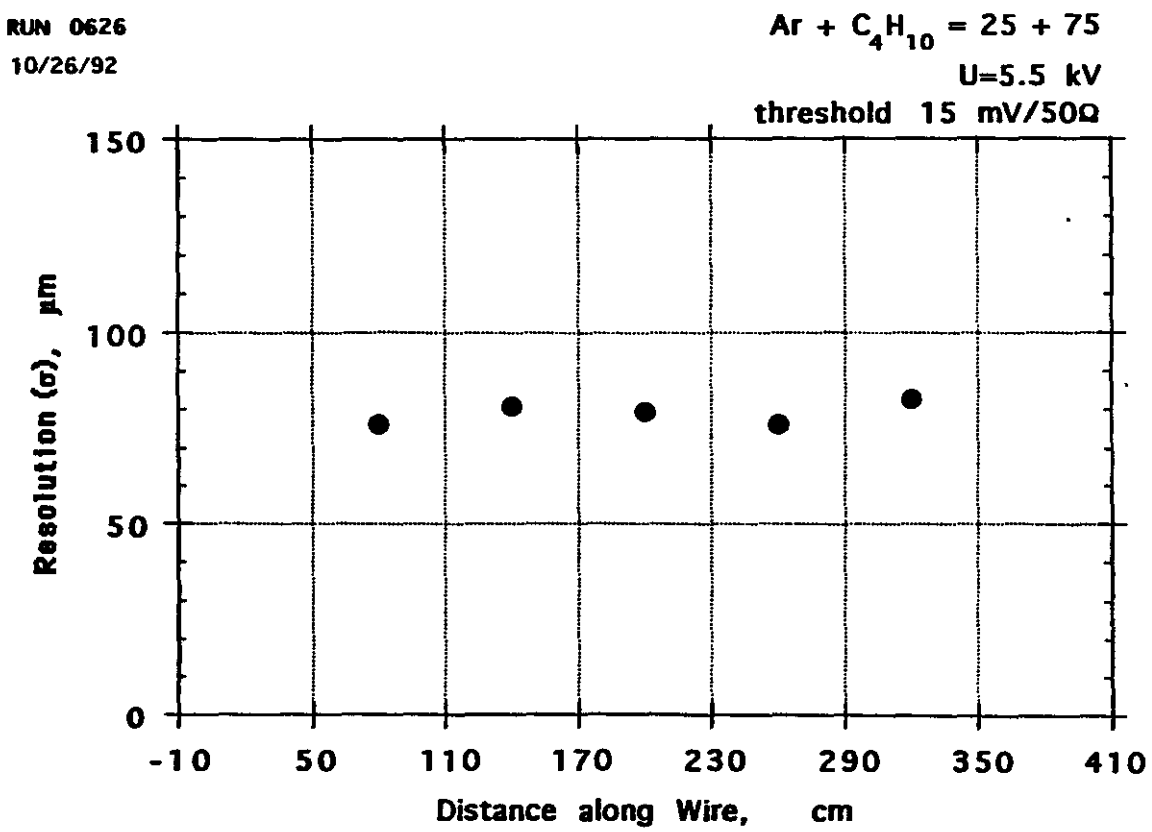
Reslolution from ((x1-x2)-(x3-x4))/2

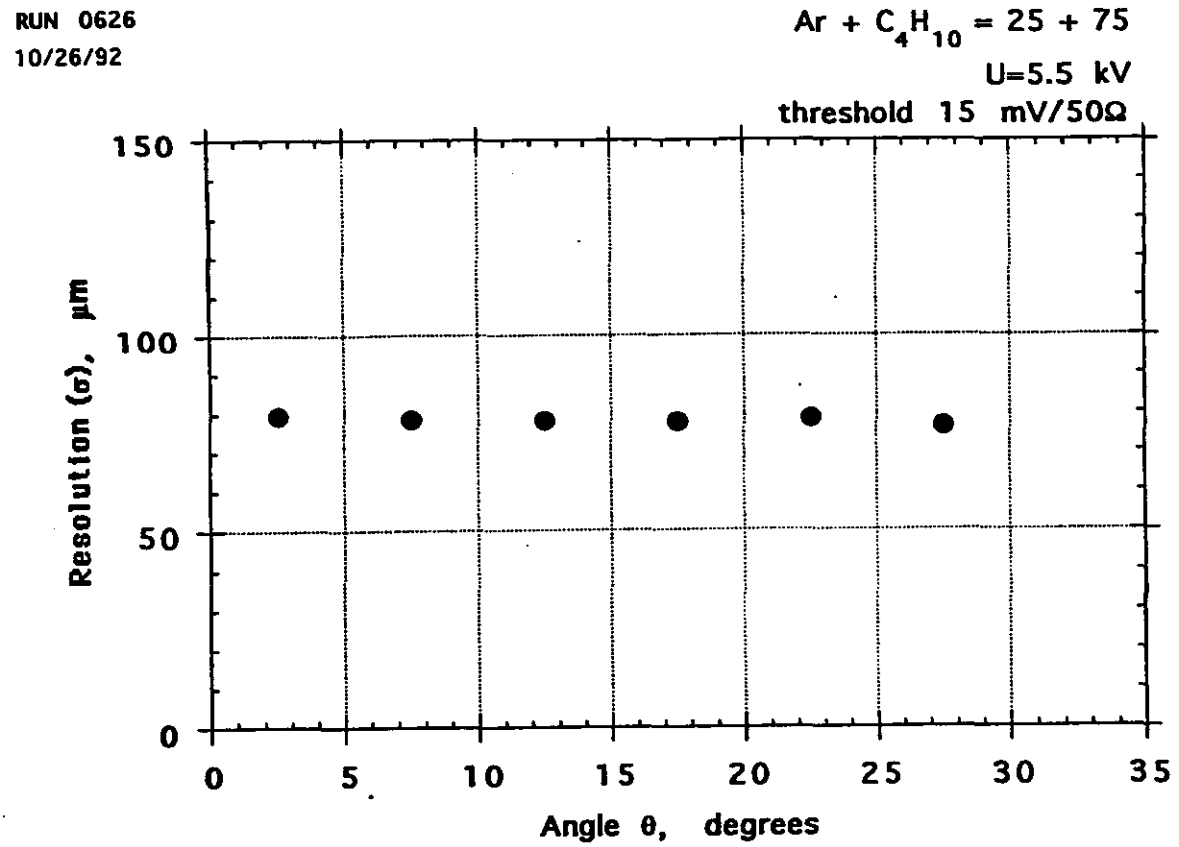


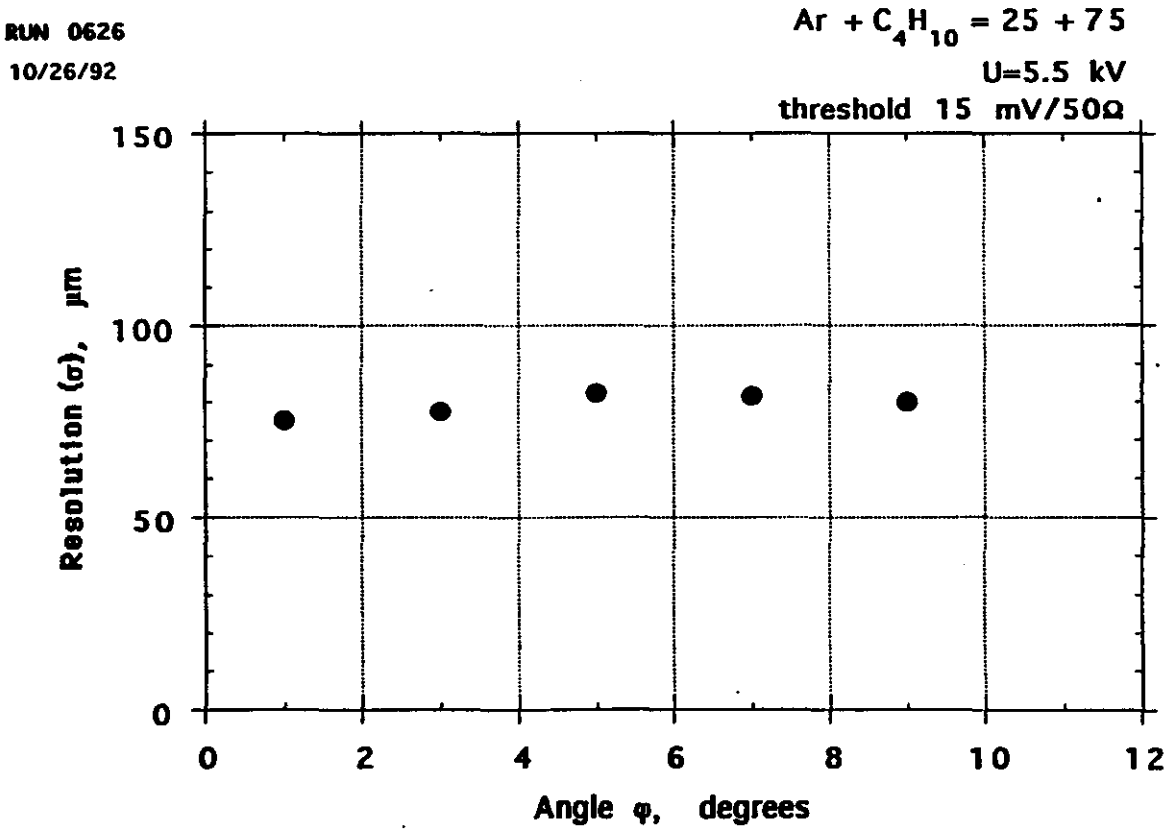
residual for plane 2,not in fit

LSDT test results

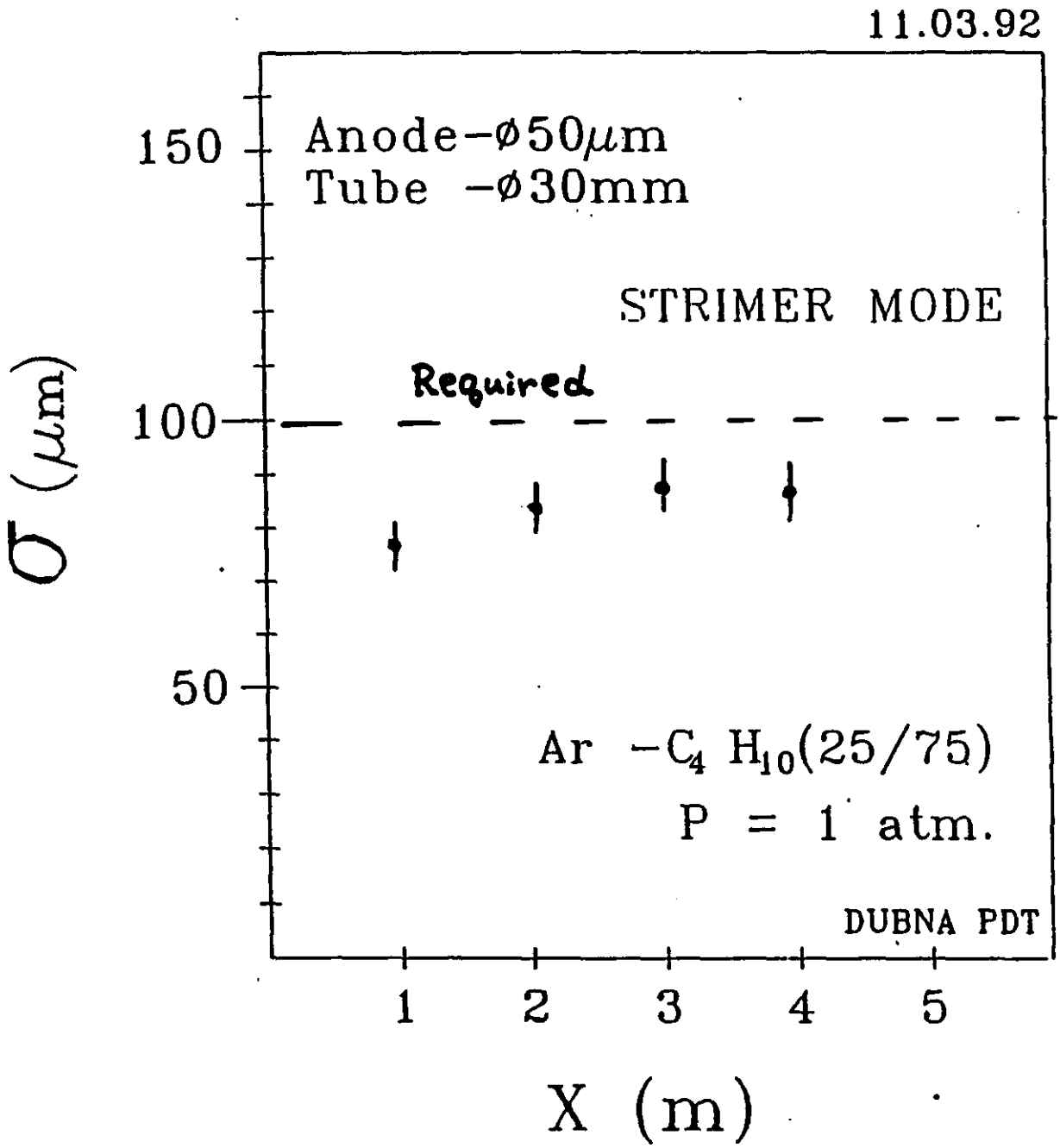





RUN 0626
10/26/92
Ar + C4H10 = 25 + 75
U=5.5 kV
threshold 15 mV/50Ω
Resolution (σ), μm
150
100
50
0
0
5
10
15
20
25
30
35
Angle θ, degrees


RUN 0626
10/26/92
Ar + C4H10 = 25 + 75
U=5.5 kV
threshold 15 mV/50Ω
Resolution (σ), μm
150
100
50
0
0
2
4
6
8
10
12
Angle φ, degrees

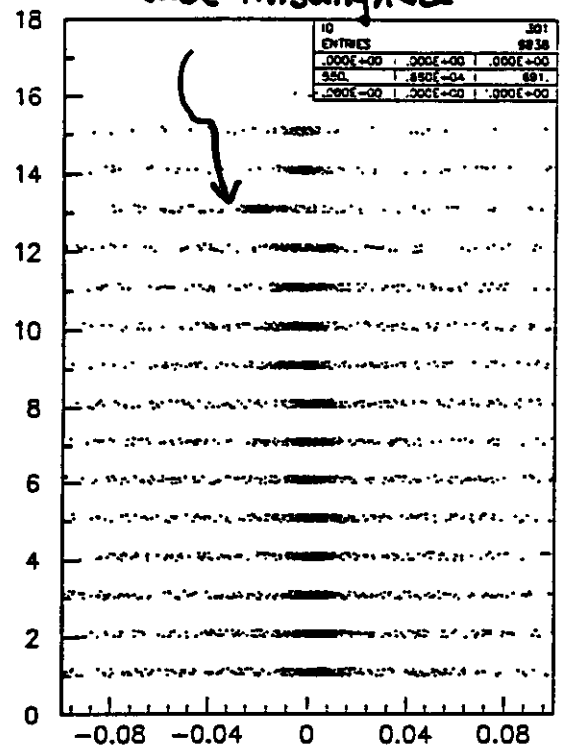
Cosmic Ray test Dubna PDT



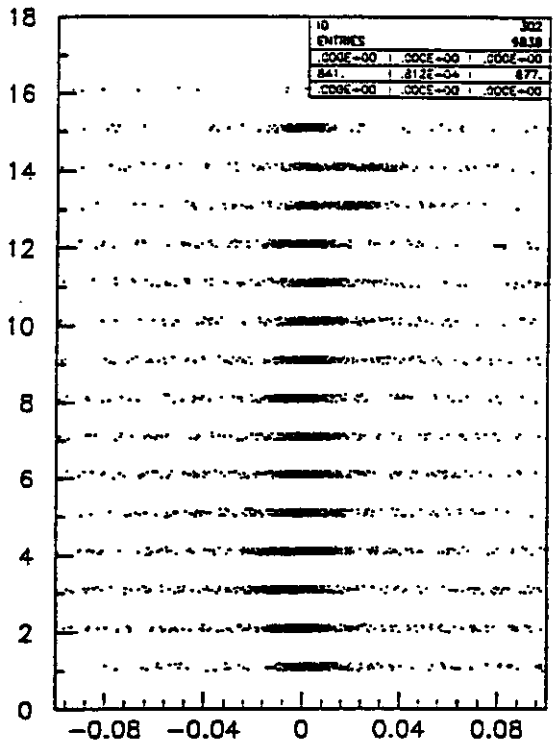
Analysis by ITEP Collaboration

92/12/01 17.20

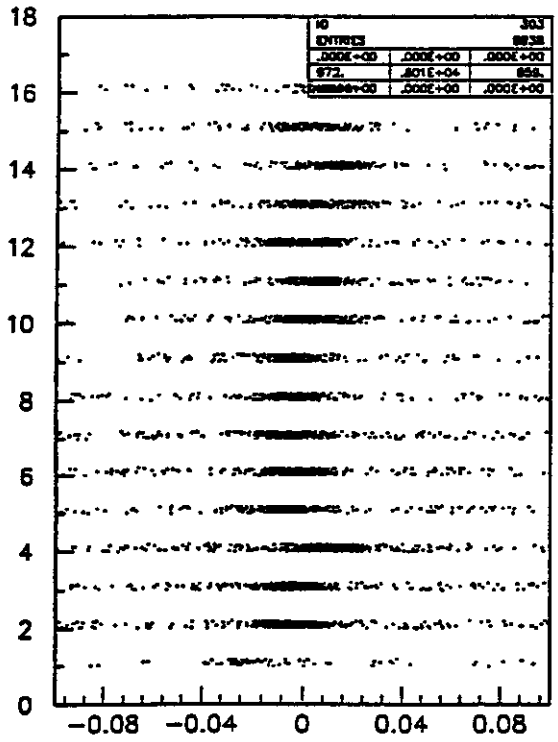
tube misaligned



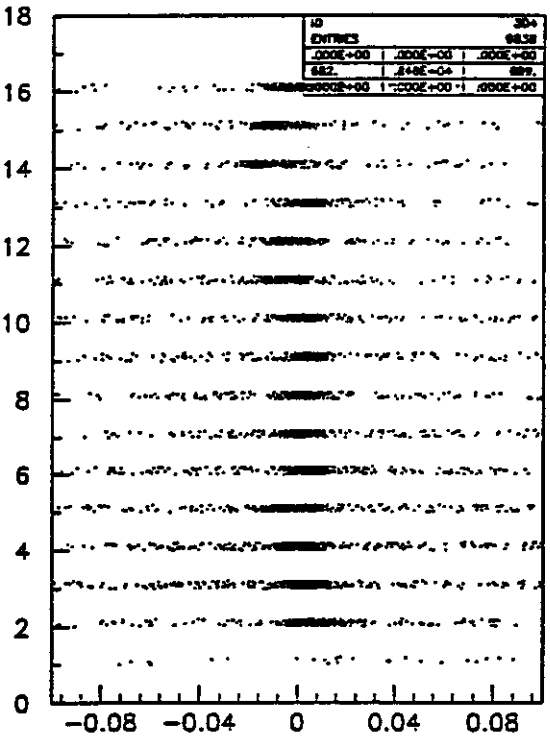
delta(Y) vs tube number for layer 1



delta(Y) vs tube number for layer 2



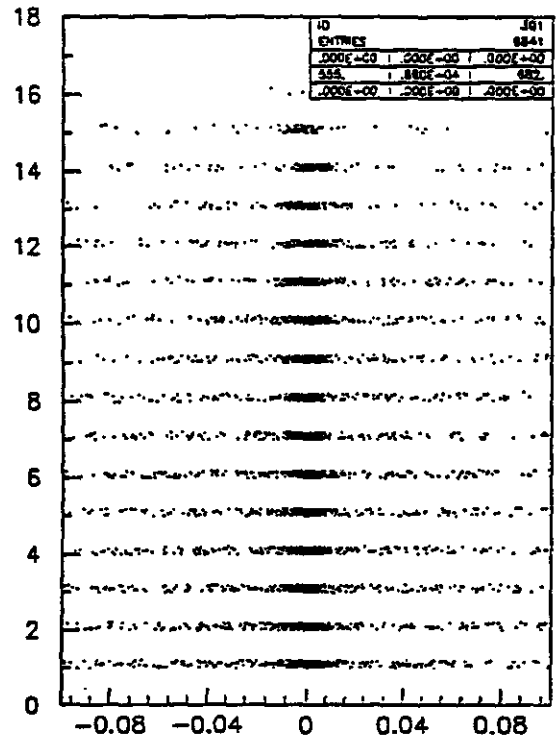
delta(Y) vs tube number for layer 3



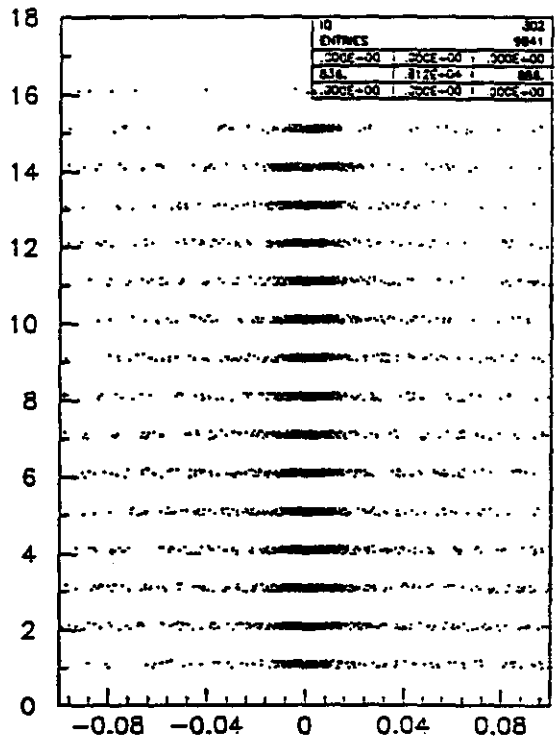
delta(Y) vs tube number for layer 4

Tubes now aligned

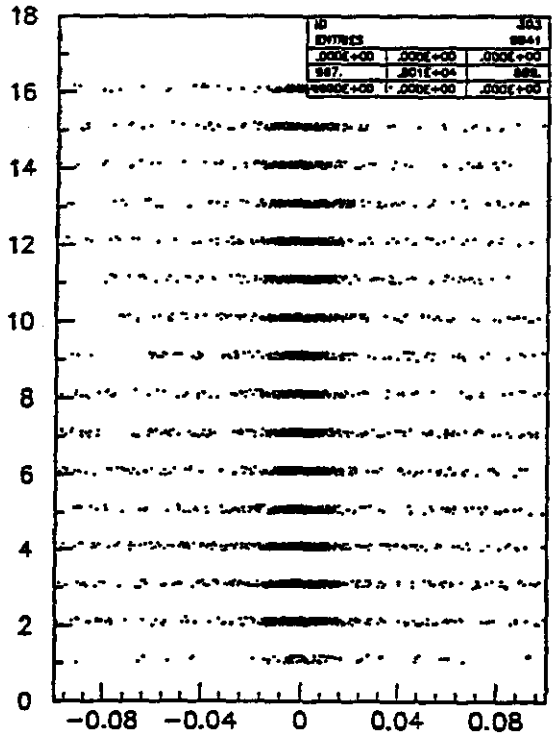
92/12/01 17.33



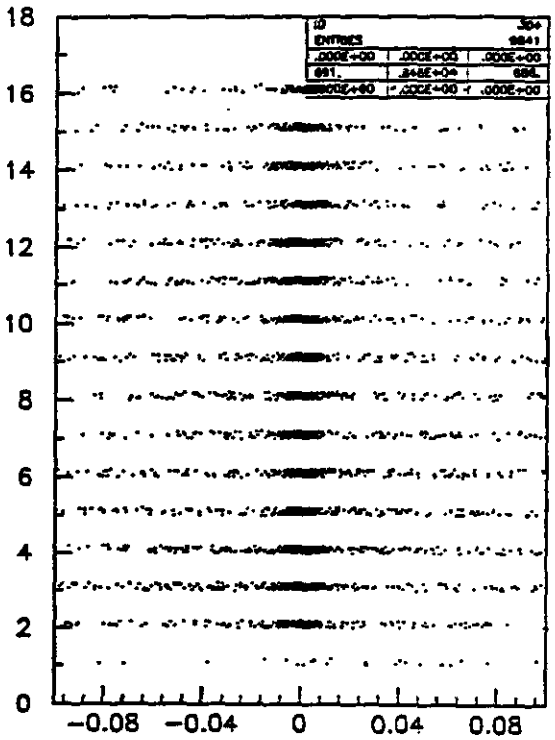
delta(Y) vs tube number for layer 1



delta(Y) vs tube number for layer 2

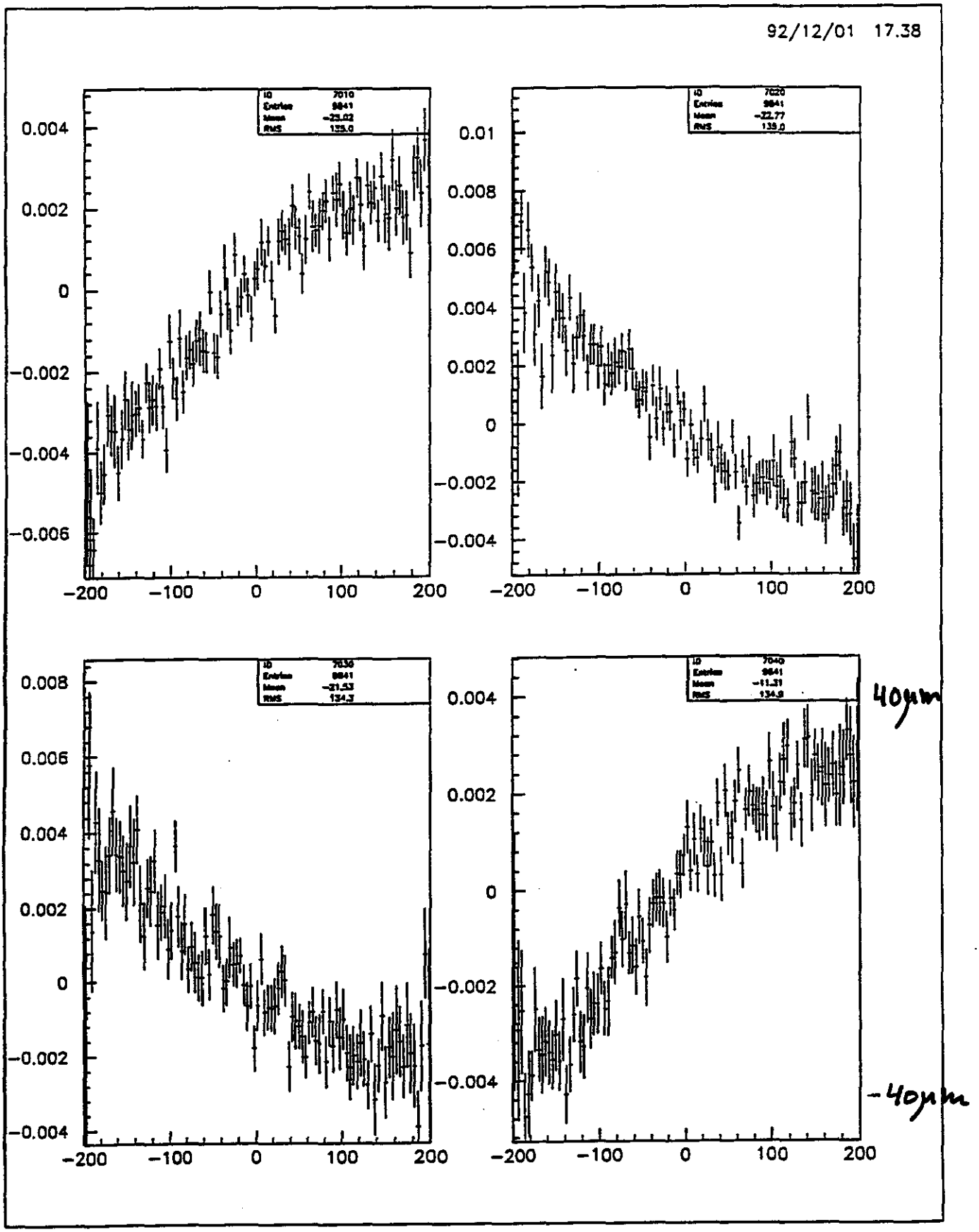


delta(Y) vs tube number for layer 3

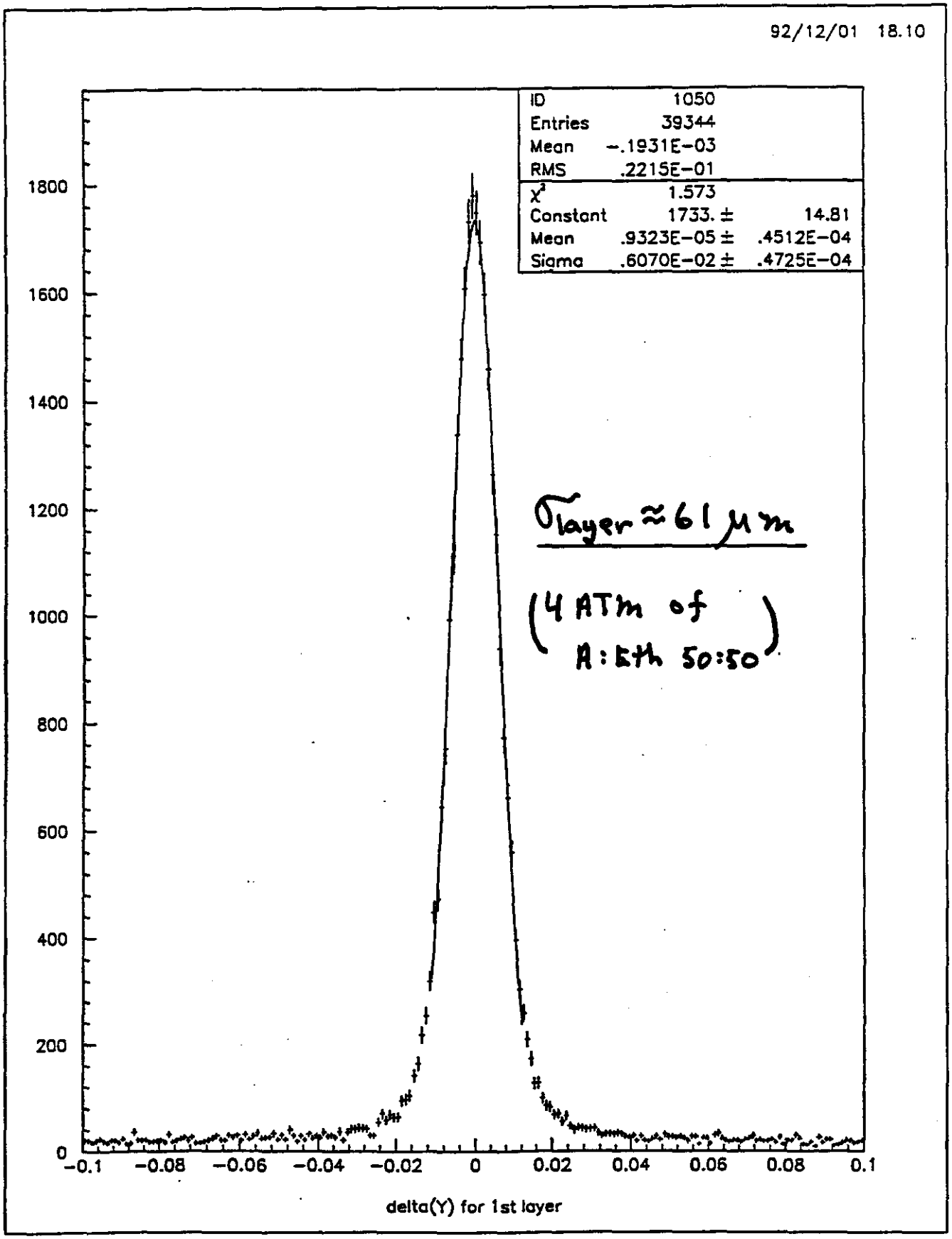


delta(Y) vs tube number for layer 4

Tubes have "Crossed" misalignments



RDT Resolution - all corrections

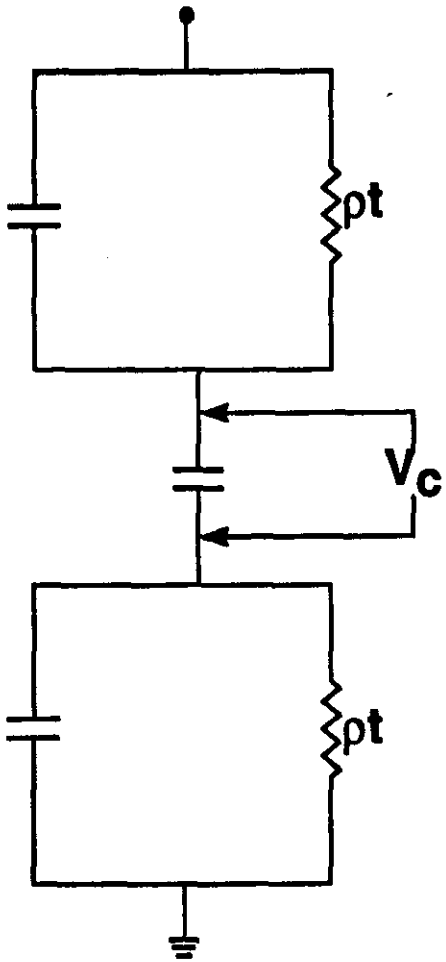


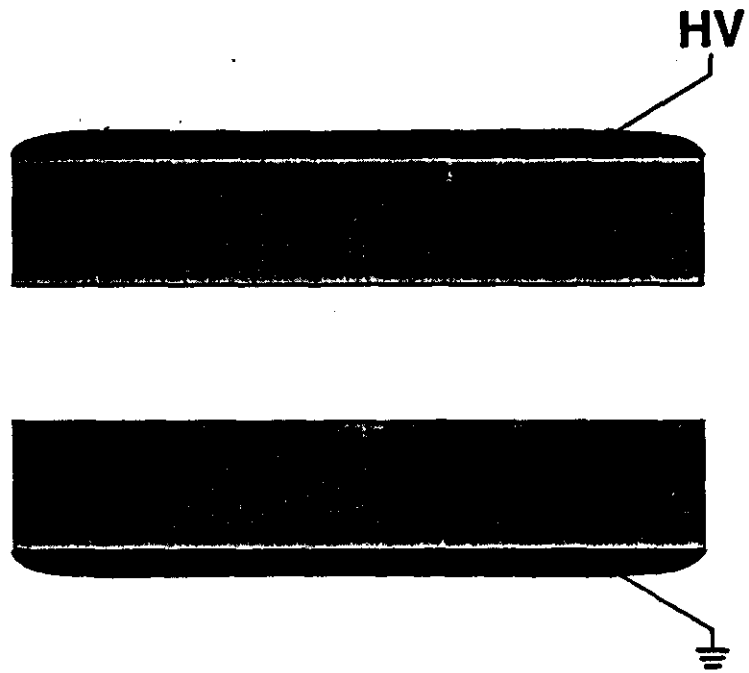
RPC Candidate Material

Material	Thickness (cm)	Bulk Resistivity (Ωcm)	Arc Resistivity (Ωcm^2)
MIT mirror	.300	5.0×10^{12}	1.5×10^{12}
750 micron mirror	.066	4.9×10^{12}	3.23×10^{11}
Kodak projector glass	.123	6.42×10^{11}	7.89×10^{10}
Italian RPC	.200	1.0×10^{11}	2×10^{10}
Bakelite	.161	4.5×10^{9}	7.24×10^{8}
ABSTAT–M310	.072	5.78×10^{9}	4.16×10^{8}
ABSTAT–M310	.060	5.78×10^{9}	3.47×10^{8}
Mitech–410	.090	2.03×10^{9}	1.83×10^{8}
Mitech–410	.030	2.03×10^{9}	6.19×10^{7}
Corning 0211 glass	.056	6.7×10^{7}	3.75×10^{6}
Boron	.0001	1×10^{6}	1×10^{2}

BAK.KA-14/RMB

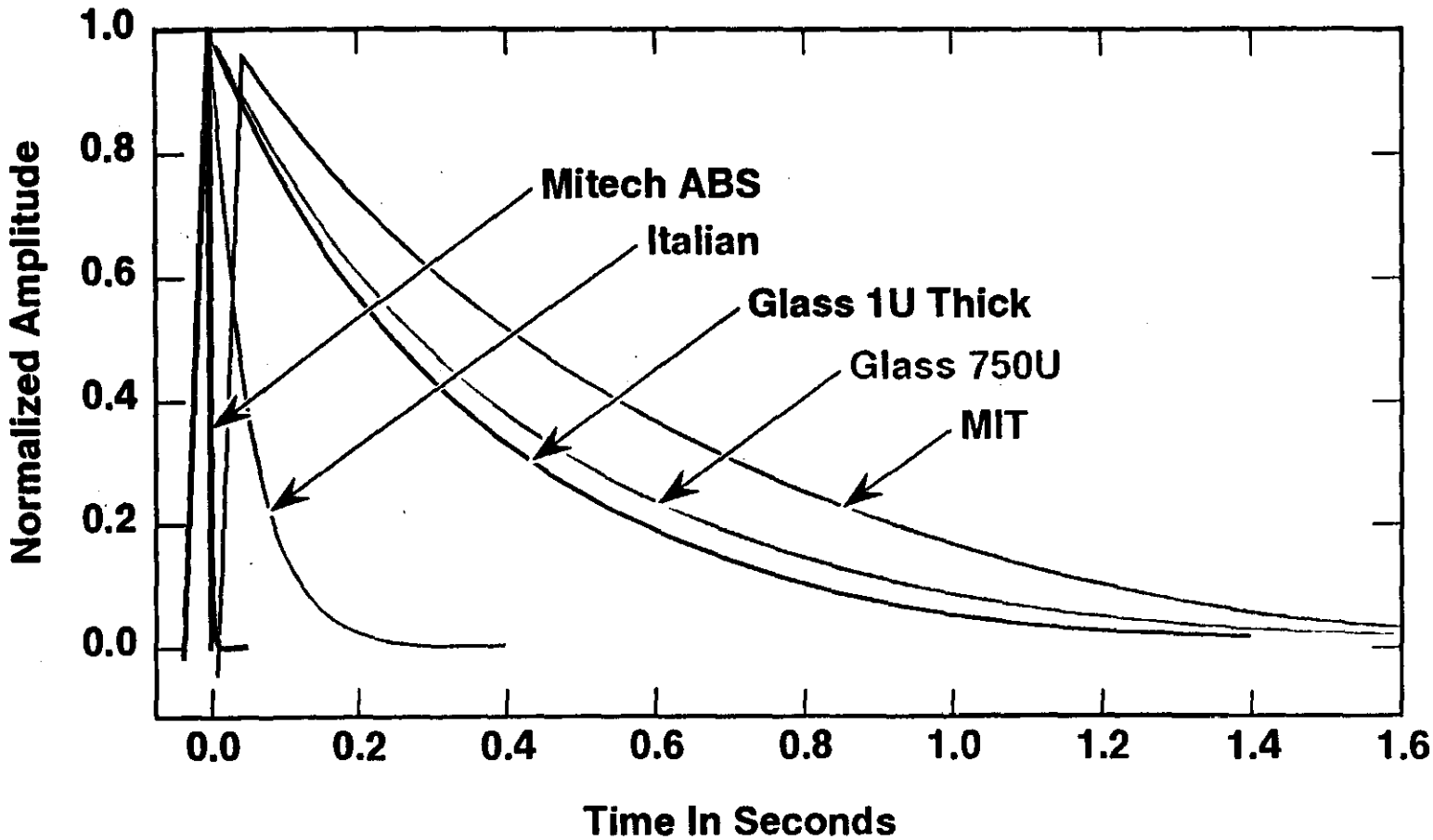
Spice RPC Model





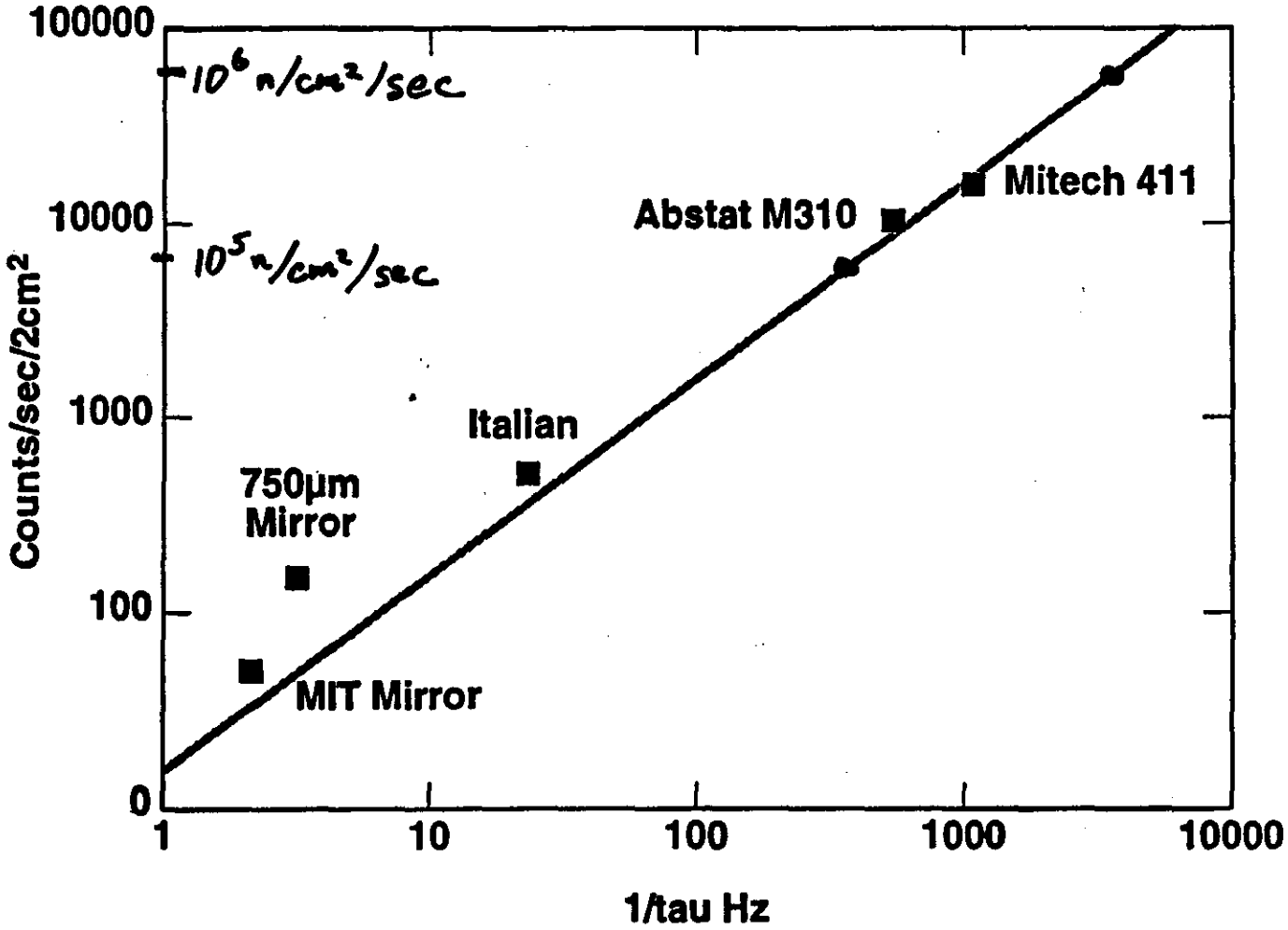
BAK.KA-01/RMB

Spice Calculations of Recharge



BAK KA-16/RMB

Saturated Singles Rate vs SPICE 1/tau



BAK.KA-17/RMB

CSCs for both Barrel and Endcaps:

- intrinsically fast
  (< 24 ns drift time in 2.5 mm gap)
- highly partitioned
  (small strips => flexible response to bkg.)
- performs both triggering and tracking functions
- good single layer resolution
- alignment of chamber involves few elements
- X and Y coordinate measurements in one chamber plane

However:

- need to demonstrate resolution
  (require $\sigma = 75\ \mu m$)
- trigger timing to be measured
  (expect $\tau < 12$ ns 99 % of time)
- gain experience with large scale prototype
  (noise, resol'n, wire stability, ..)

Backup Option:

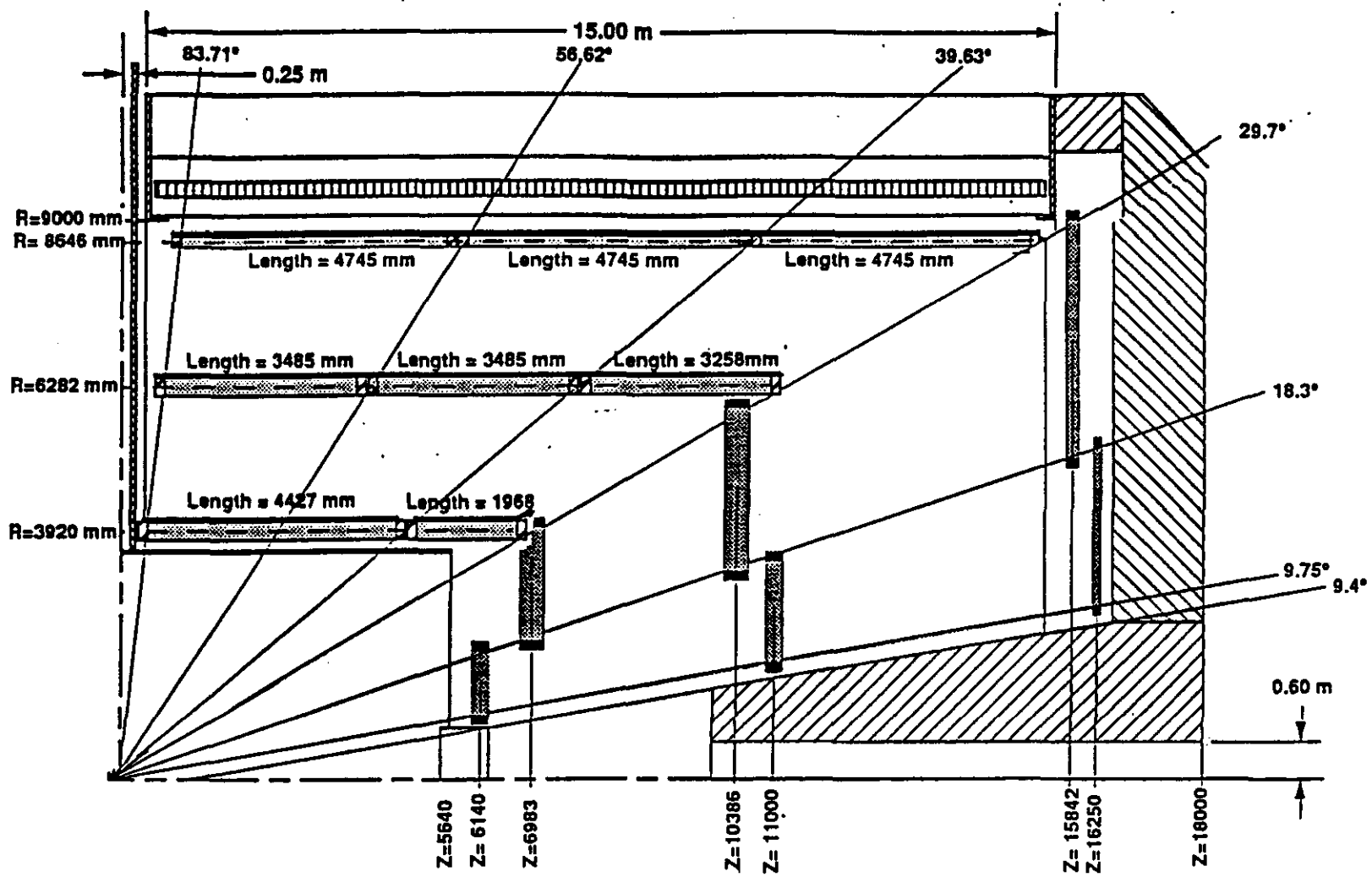
- RDT and RPC everywhere

Several issues must be resolved:

- need design for EC (trigger - RPC in neutron bkg.)
- nonflammable gas
- chamber lifetime -especially in EC
- wire sag - alignment etc.

Decided that RDT was more attractive than LSDT

- better mechanical design (light and rigid)
- easier to align (but have to measure wire sag)
- both can be operated in the LS mode
- stand-alone trigger would work in both
- pressurization another freedom

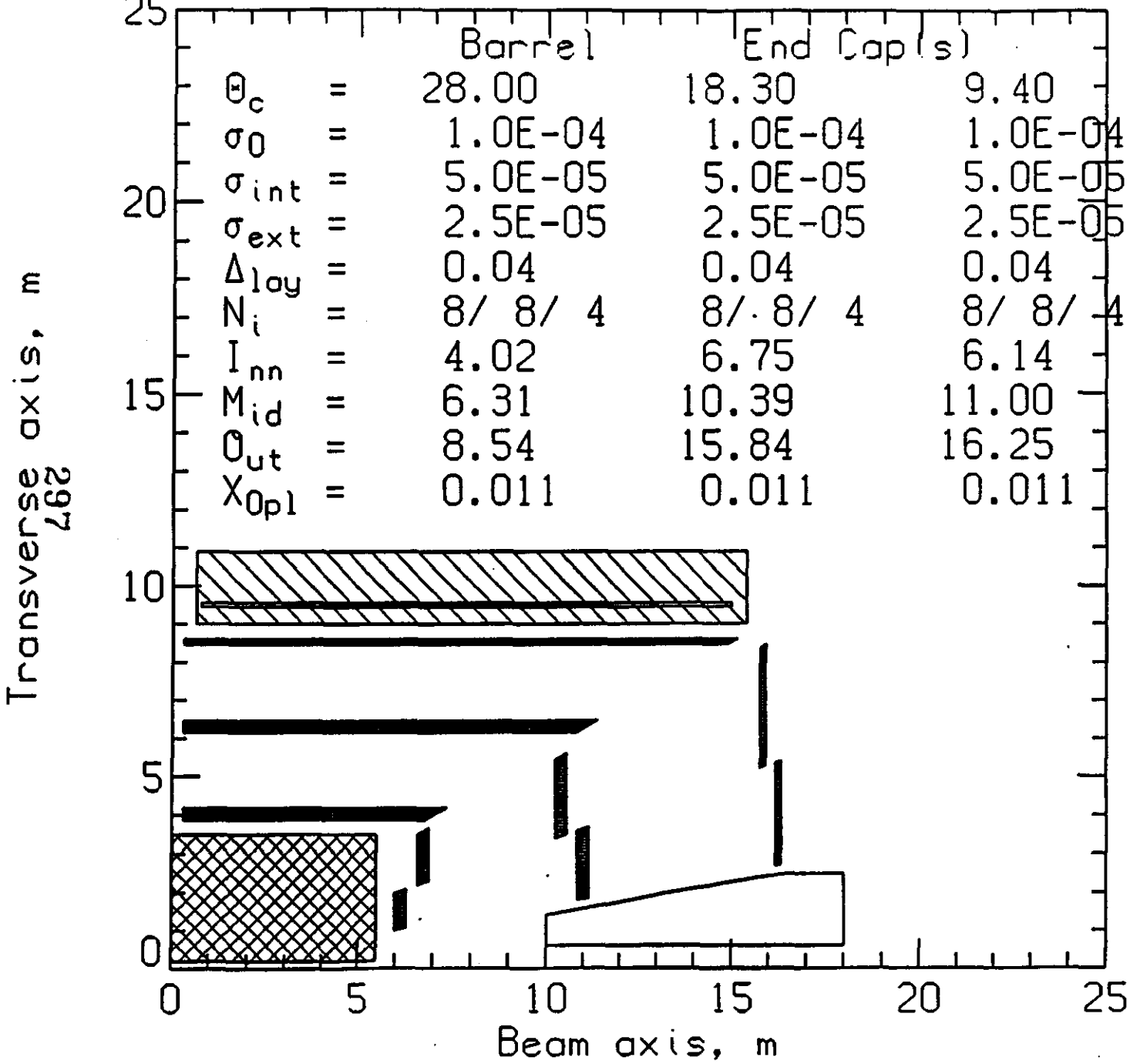


GEM MUON SYSTEM RDT CHAMBER LAYOUT
(Barrel and Endcap 8,8,4 RDT Layers per Superlayer)

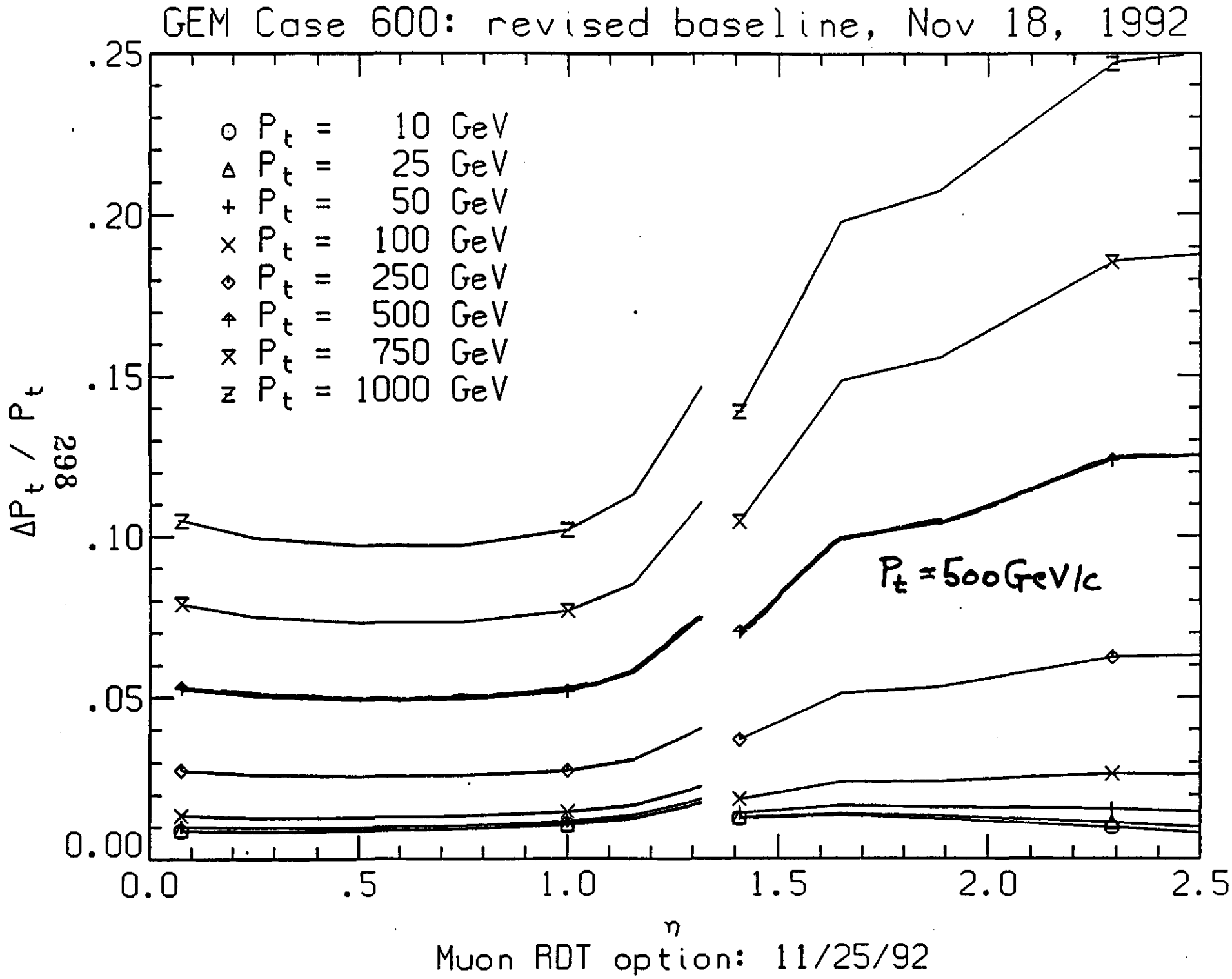
"PRELIMINARY"

Draper Laboratory	
GEM Muon System RDT Chamber Layout	
Drawn By: F. Nimblett	Rev (-)
Dwg. No: GMU0024	11/30/92
Approved by:	

GEM Case 600: revised baseline, Nov 18, 1992



Muon RDT option: 11/25/92


GEM Case 600: revised baseline, Nov 18, 1992
○ P_t = 10 GeV
△ P_t = 25 GeV
+ P_t = 50 GeV
× P_t = 100 GeV
◇ P_t = 250 GeV
↑ P_t = 500 GeV
⊠ P_t = 750 GeV
z P_t = 1000 GeV
P_t = 500 GeV/c
$\Delta P_t / P_t$
.25
.20
.15
.10
.05
0.00
0.0
.5
1.0
1.5
2.0
2.5
η
Muon RDT option: 11/25/92

End Game for TDR

Review of Baseline 2 and Backup 1/15/93

For Baseline to be viable

- CSC must show:

  single layer resolution ($\sigma = 75\mu m$)

  RD5 results ($\sigma = 75\mu m$ and timing jitter)

  larger prototype (JINR and BNL) operational

  practical design for chambers in structure with alignment

For Backup Option to be viable

- RDT/RPC must show:

  RDT credible design for EC

    rates, pattern recognition, lifetime, resol'n

  RPC trigger design for EC

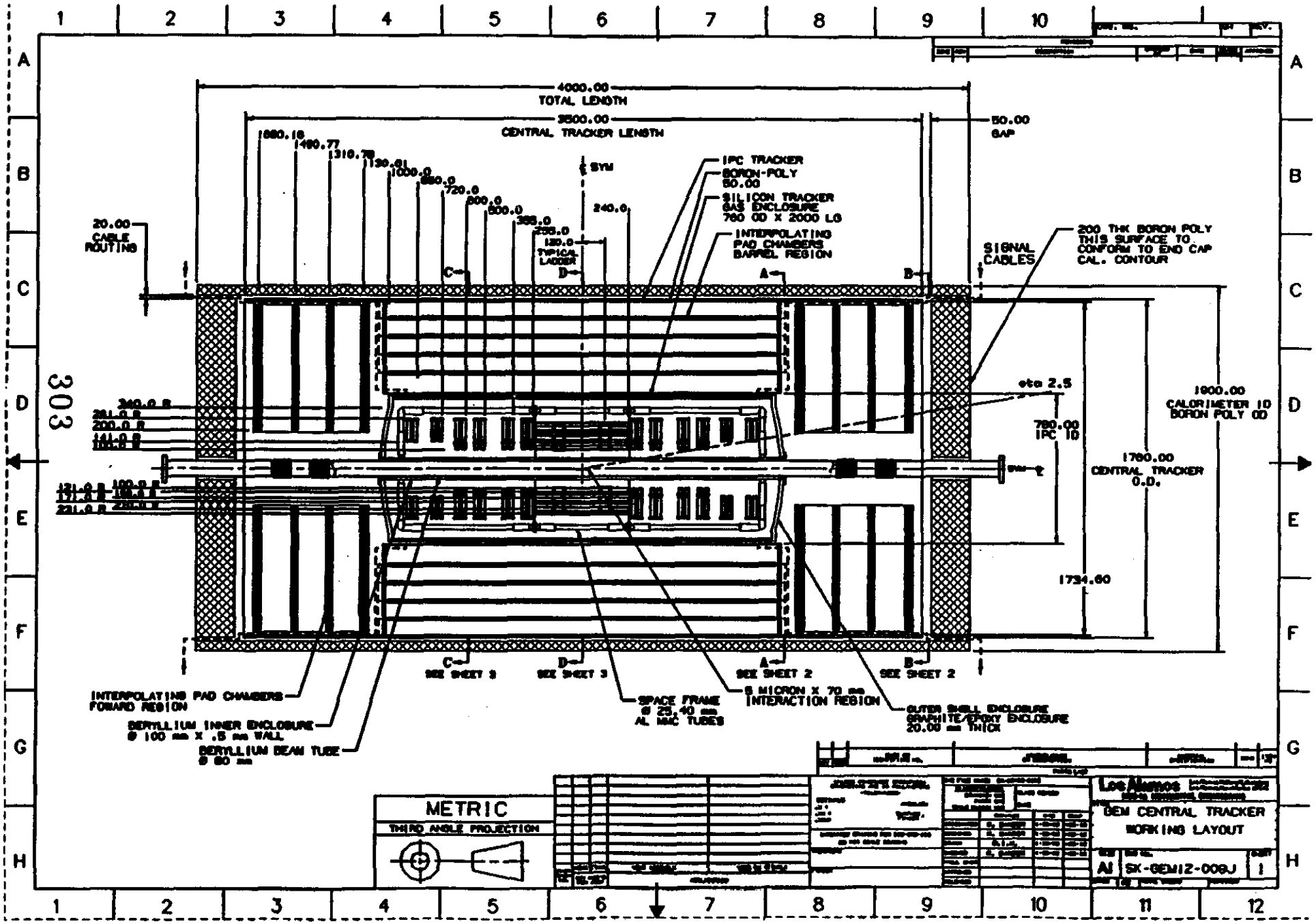
    rates, lifetime, slewing, neutron bkg.

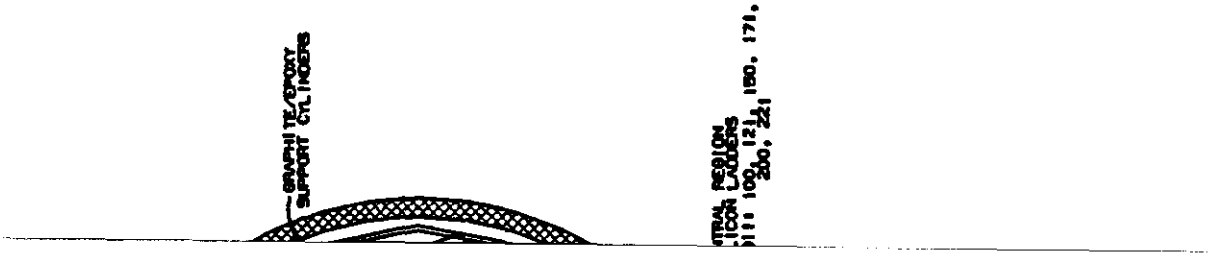
R&D program is focused on TDR

gem cell

Training System

Charge Battery


4000.00
TOTAL LENGTH
3500.00
CENTRAL TRACKER LENGTH
50.00
GAP
1880.18
1480.77
1310.78
1130.61
1000.0
880.0
720.0
600.0
500.0
388.0
255.0
120.0
TYPICAL LADDER
240.0
℄ SYM
IPC TRACKER
BORON-POLY
50.00
SILICON TRACKER
GAS ENCLOSURE
760 OD X 2000 LG
INTERPOLATING
PAD CHAMBERS
BARREL REGION
20.00
CABLE ROUTING
SIGNAL CABLES
200 THK BORON POLY
THIS SURFACE TO
CONFORM TO END CAP
CAL. CONTOUR
eta 2.5
1900.00
CALORIMETER ID
BORON POLY OD
760.00
IPC ID
1760.00
CENTRAL TRACKER
O.D.
1734.60
340.0 R
281.0 R
200.0 R
141.0 R
121.0 R
171.0 R
221.0 R
100.0 R
150.0 R
200.0 R
SEE SHEET 3
SEE SHEET 3
SEE SHEET 2
SEE SHEET 2
INTERPOLATING PAD CHAMBERS
FORWARD REGION
BERYLLIUM INNER ENCLOSURE
Ø 100 mm X .5 mm WALL
BERYLLIUM BEAM TUBE
Ø 80 mm
SPACE FRAME
Ø 25.40 mm
AL MMC TUBES
5 MICRON X 70 mm
INTERACTION REGION
OUTER SHELL ENCLOSURE
GRAPHITE/EPOXY ENCLOSURE
20.00 mm THICK
METRIC
THIRD ANGLE PROJECTION
Los Alamos
GEM CENTRAL TRACKER
WORKING LAYOUT
A1
SX-GEM12-009J
1



At the SSC there are 16 nsec between beam crossings, so that a response time (memory time) of 16 nsec would be appropriate. (62 Megahertz !!)

- So we expect within memory time of det.

  5×10^{10} tracks/sec $\times$ 16 nsec $\sim 10^3$ tracks

- Tracks per unit area of detector

Inside $r = 10$ cm $A \sim 10^3$ cm^2 $\Rightarrow \sim 1$ track/cm^2/mem-time

Outside $r = 35$ cm $A \sim 10^4$ cm^2 $\Rightarrow \sim 1/10$ tracks/cm^2/mem-time

- To keep occupancy below 10%, we need to have cell sizes of

  $\lesssim 0.1$ cm^2 inside

  $\lesssim 1$ cm^2 outside

- The very high segmentation for each

Layers 1x - 3 each

50μ × 12cm strips

10μ resolution, 10μ aligu. stability

Digital Read out

~3×10^6 strips

~5000 channels

~7 m² of silicon if double sided

~9000 chips 3cm×6cm

GEM SILICON INNER TRACKER

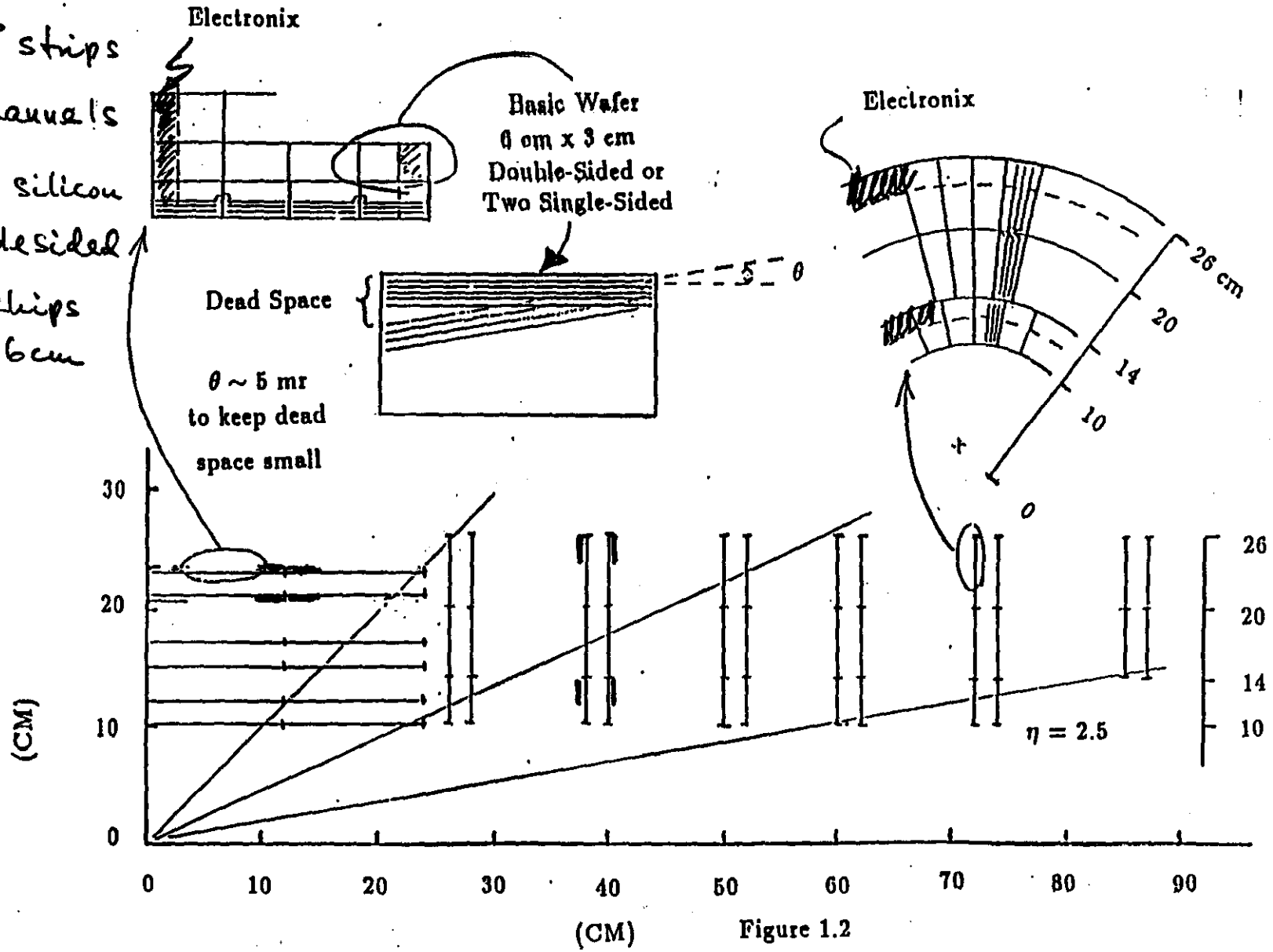
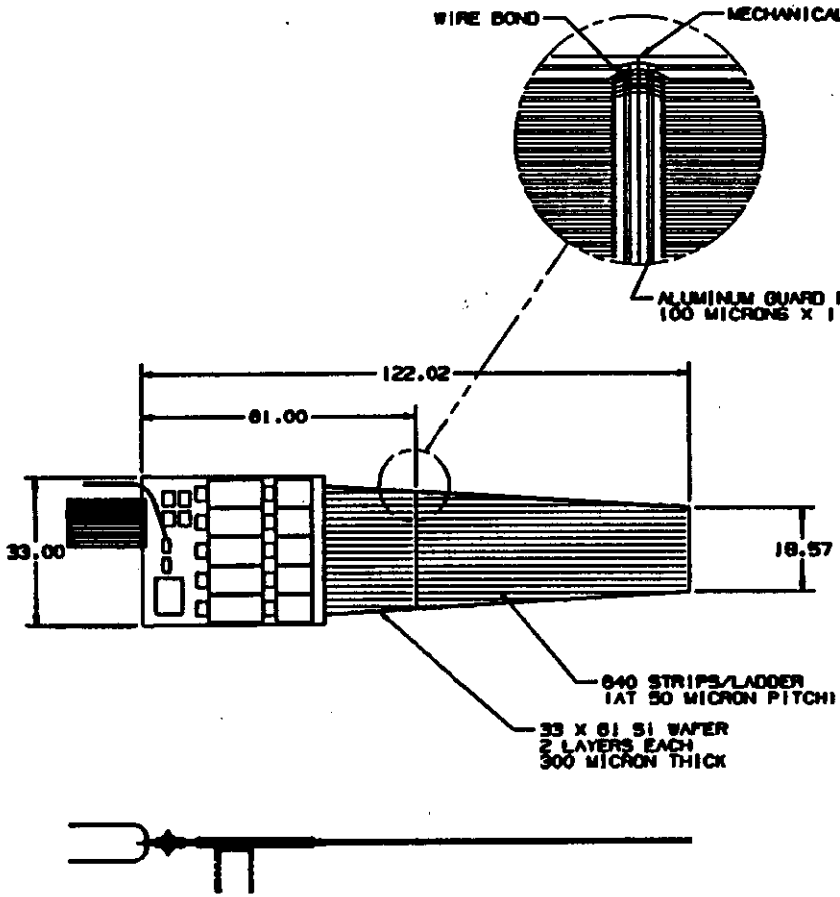


Figure 1.2



ITEM 1 2#	1.243g	(.0027 lbs)	=2.486g (.0054 lbs)
ITEM 2 2#	.915g	(.002 lbs)	=1.83g (.004 lbs)
MCM 2#	.932g	(.0021 lbs)	=1.864g (.0041 lbs)
TOTAL WEIGHT PER LADDER			=6.18g (.0135 lbs)

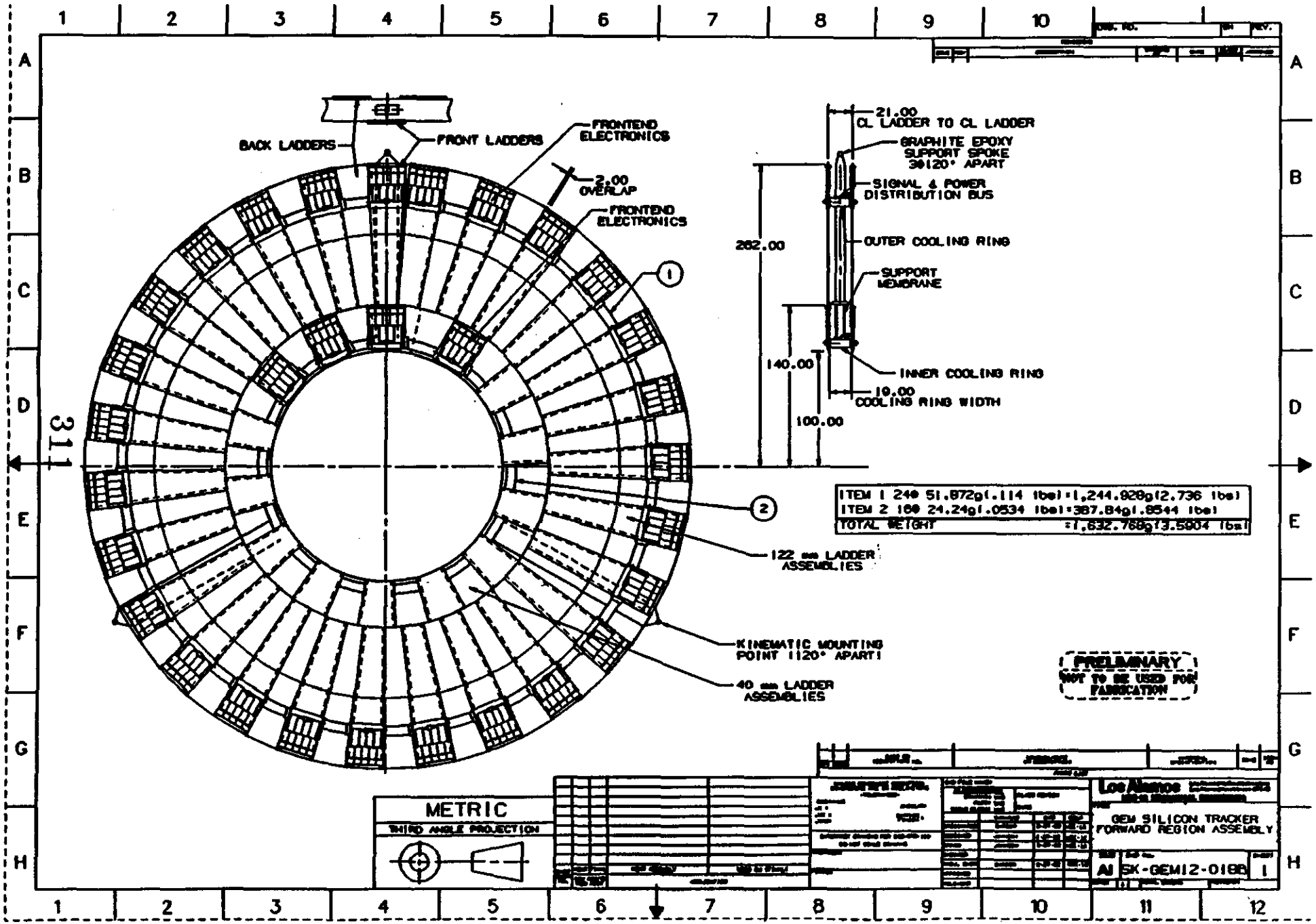
PRELIMINARY
NOT TO BE USED FOR FABRICATION

METRIC
THIRD ANGLE PROJECTION

Los Alamos

GEM SILICON TRACKER
FORWARD LADDER ASSEMBLY
DETAIL

A1 SK-GEM12-030C 1

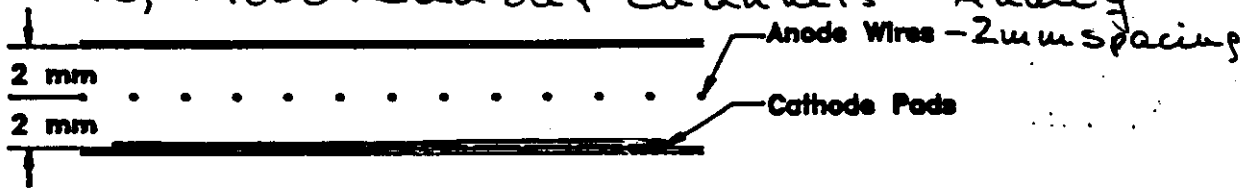

BACK LADDERS
FRONT LADDERS
FRONTEND ELECTRONICS
2.00 OVERLAP
FRONTEND ELECTRONICS
1
2
122 mm LADDER ASSEMBLIES
KINEMATIC MOUNTING POINT (120° APART)
40 mm LADDER ASSEMBLIES
21.00 CL LADDER TO CL LADDER
GRAPHITE EPOXY SUPPORT SPOKE 3@120° APART
SIGNAL & POWER DISTRIBUTION BUS
OUTER COOLING RING
SUPPORT MEMBRANE
INNER COOLING RING
10.00 COOLING RING WIDTH
262.00
140.00
100.00
ITEM 1 24@ 51.872g(.114 lbs)=1,244.928g(2.736 lbs)
ITEM 2 16@ 24.24g(.0534 lbs)=387.84g(.8544 lbs)
TOTAL WEIGHT =1,632.768g(3.5904 lbs)
PRELIMINARY
NOT TO BE USED FOR FABRICATION
METRIC
THIRD ANGLE PROJECTION
Los Alamos
GEM SILICON TRACKER
FORWARD REGION ASSEMBLY
AI
SK-GEM12-0188
1

Pad size $\Delta\eta \times \Delta\phi = 0.0007$ or 2.5 mm x a few cm

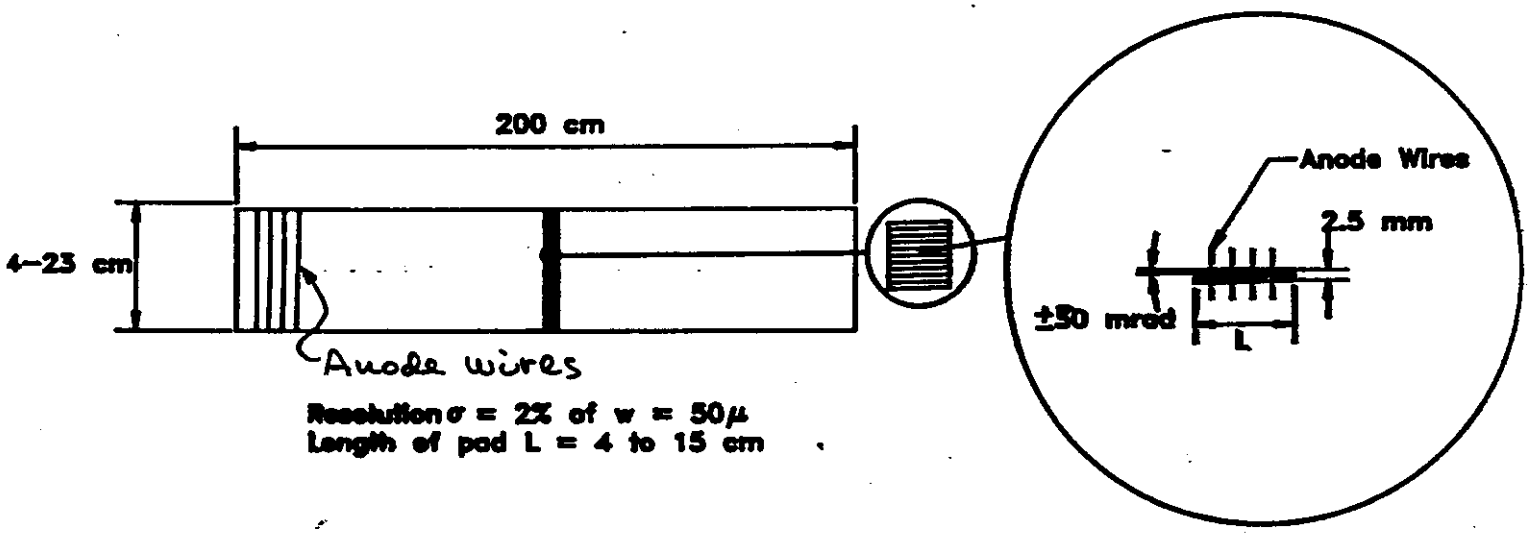
50μ resolution, 25μ alignement stability

±50 mrad stereo to get z resolution of ~ 600μ

400,000 Pads, ~1600 read out channels - Analog

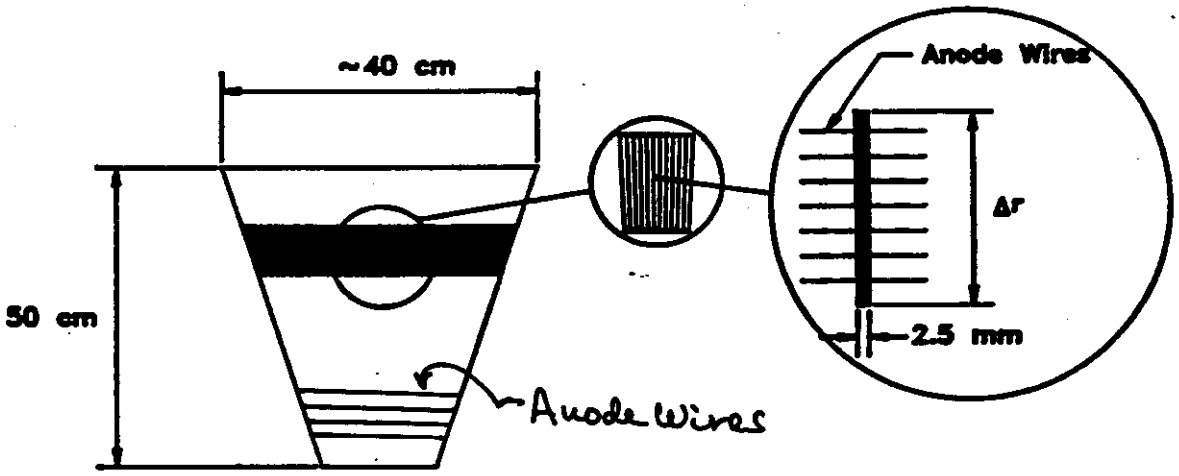


a) Cell Geometry Viewed Along the Anode Wires



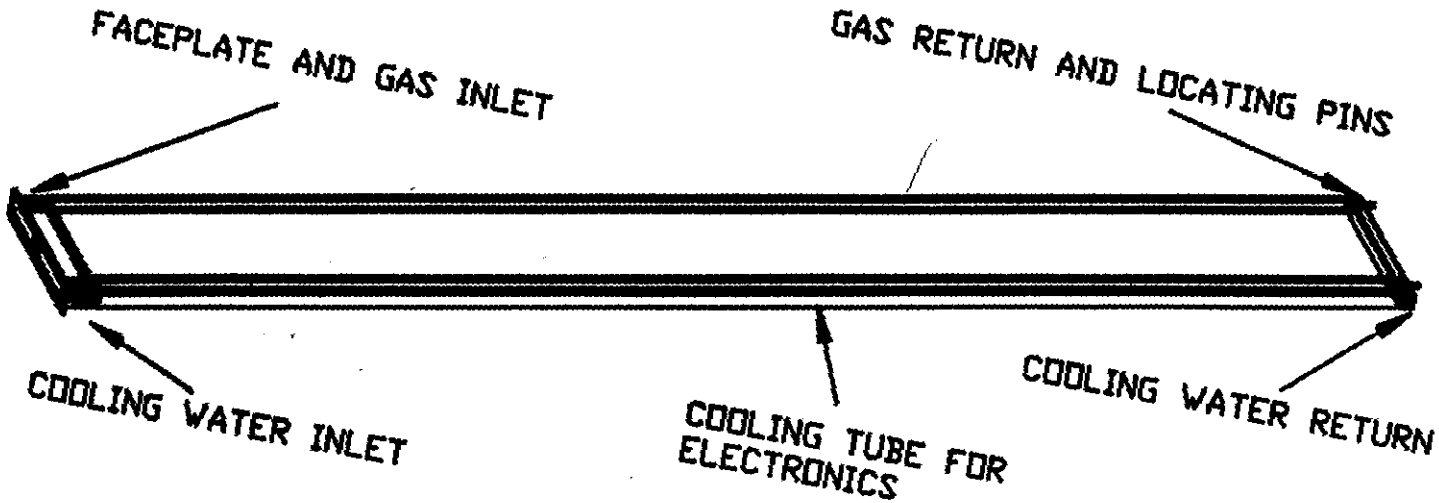
Resolution σ = 2% of w = 50μ
Length of pad L = 4 to 15 cm

b) Pad Arrangement in the Barrel Chambers (80 chambers total)

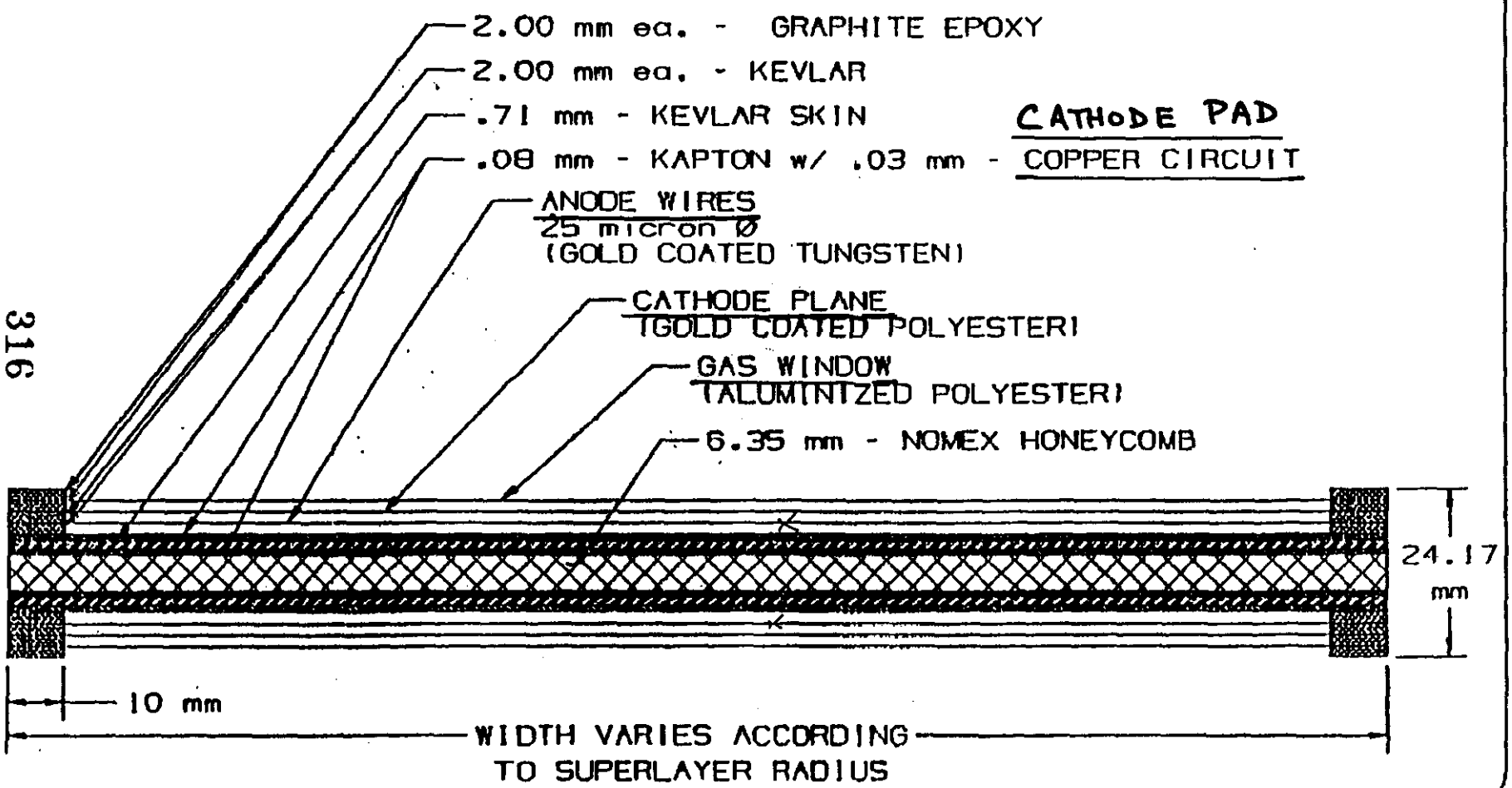


Resolution σ = 2% of w = 50μ

IPC SUPERLAYER



GEM IPC SUPERLAYER

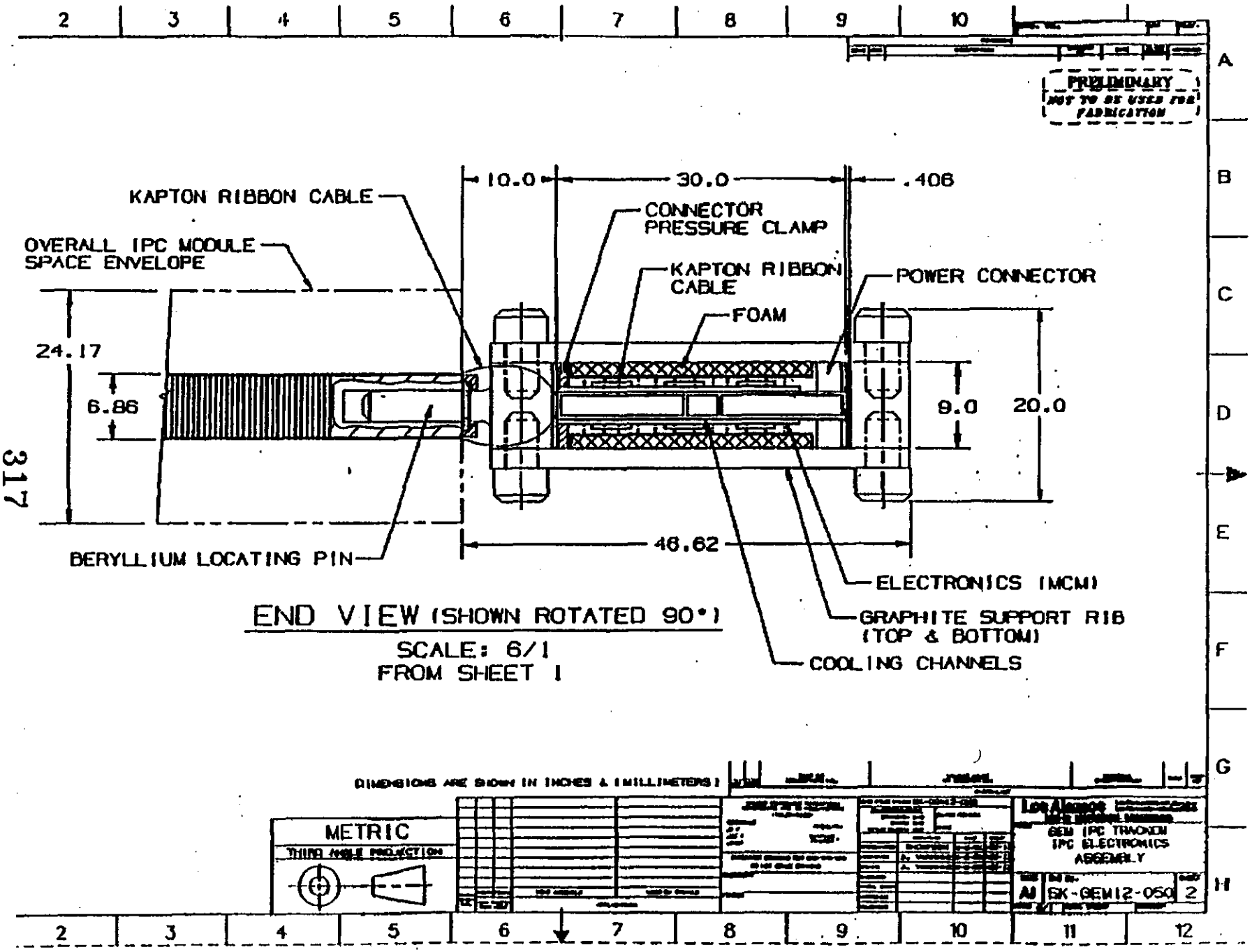


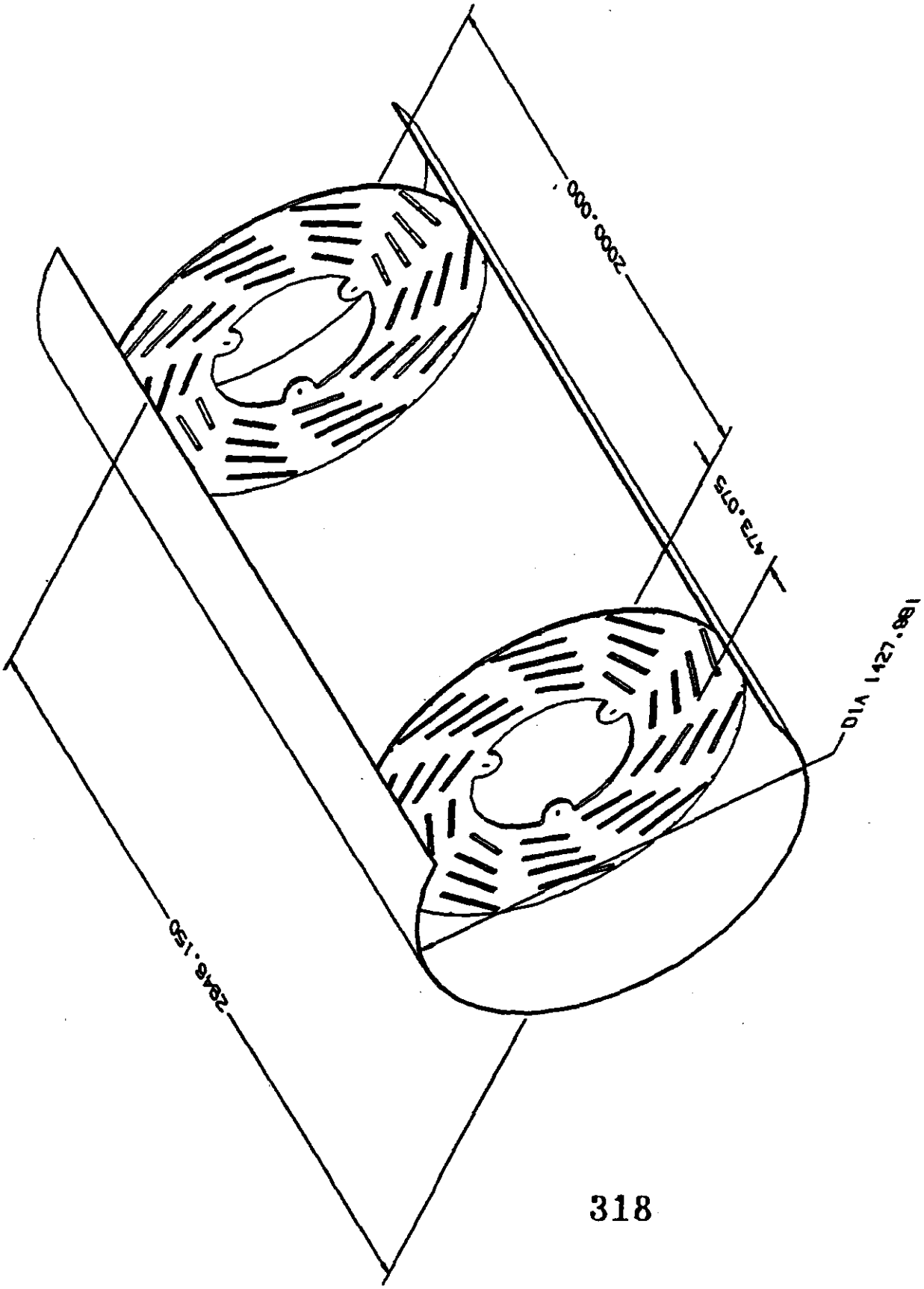
ALL DIMENSIONS ARE IN mm

GEMVG-IPC-SUPERLAYER

gem

LANL


PRELIMINARY
NOT TO BE USED FOR FABRICATION
KAPTON RIBBON CABLE
OVERALL IPC MODULE SPACE ENVELOPE
10.0
30.0
.406
CONNECTOR PRESSURE CLAMP
KAPTON RIBBON CABLE
FOAM
POWER CONNECTOR
24.17
6.86
9.0
20.0
46.62
BERYLLIUM LOCATING PIN
ELECTRONICS (MCM)
GRAPHITE SUPPORT RIB (TOP & BOTTOM)
COOLING CHANNELS
END VIEW (SHOWN ROTATED 90°)
SCALE: 6/1
FROM SHEET 1
DIMENSIONS ARE SHOWN IN INCHES & (MILLIMETERS)
METRIC
THIRD ANGLE PROJECTION
Los Alamos
GEM IPC TRAXION
IPC ELECTRONICS
ASSEMBLY
A1
SK-GEM12-050
2


2848.150
2000.000
473.075
DIA 1427.881

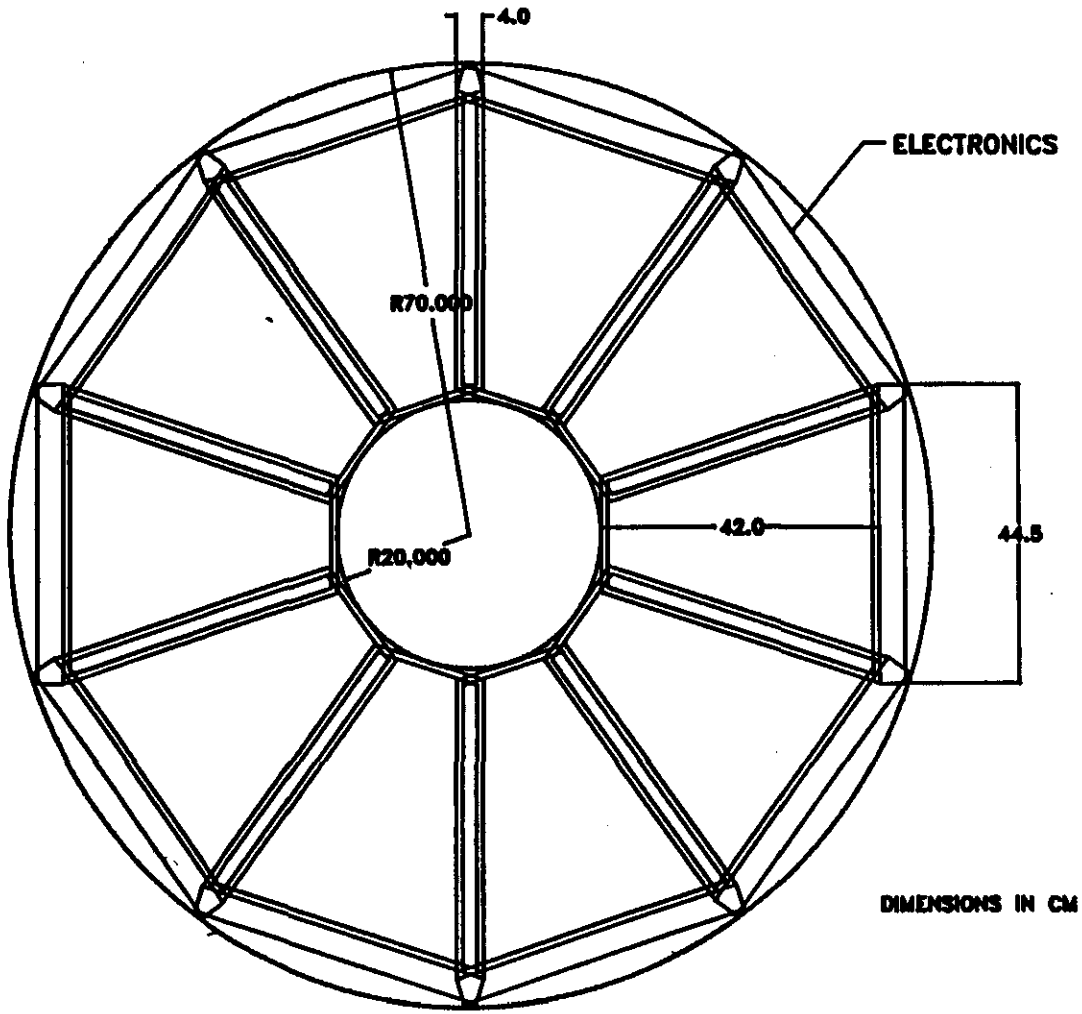


FIGURE 3: GEM IPC TRACKER–FRONTAL VIEW OF ENDCAP
(FIRST OF FOUR SUPERLAYERS SHOWN)

Radiation Hardness of Central Tracker

1. Charged particles, including secondary interactions, γ conversions, Delta rays, loopers, etc

	Yearly Radiation Dose		Design for Lifetime Dose
	$\mathcal{L} = 10^{33}$	$\mathcal{L} = 10^{34}$	
Silicon R=10cm	0.4 Mrad/yr	4 Mrad/yr	4 Mrads
Pads R=40cm	0.025 Mrad/yr	0.25 Mrad/yr	2½ Mrads

2. Neutron Flux with Polyethelene Shield

	Yearly Neutron Flux		Design for Lifetime Dose
	$\mathcal{L} = 10^{33}$	$\mathcal{L} = 10^{34}$	
Silicon	$5\times10^{12}/cm^2/yr$	$5\times10^{13}/cm^2/yr$	$5\times10^{13}/cm^2$
Pads	$5\times10^{12}/cm^2/yr$	$5\times10^{13}/cm^2/yr$	$5\times10^{14}/cm^2$

3. Silicon should be good for 10 years at 10^{33}

Pads should be good for 10 years at 10^{34}

GEM CENTRAL TRACKER BUDGET [illegible]

GEMCENTJ (ver 1a)

LEVEL II REPORT

WBS No.	Item	Engineering & Design			EDI&A	Inspection Q/A			Proc/Fab	Assembly					Installation					Totals				
		Labor	Rate	Total	M&S	Labor	Rate	Total	Material	Labor	Rate	Subtot.	Mat.	Total	Labor	Rate	Subtot.	Mat.	Total	Labor	Material	Subtotal	Contin.	Total K$
		myr	k$/myr	k$	k$	myr	k$/myr	k$	k$	myr	k$/myr	k$	k$	k$	myr	k$/myr	k$	k$	k$	k$	k$	k$	k$	k$
x.1	CENTRAL TRACKER	39.8	97	3869	801	23.7	92	2173	8386	33.2	54	1783	683	2466	5.3	62	327	114	441	8152	9983	18136	5834	23969
1.1	Silicon Tracker	22.3	100	2232	466	4.8	98	468	5956	13.0	65	841	603	1444	1.2	44	54	15	69	3595	7041	10636	3184	13820
1.2	Interpolating Pad Tracker	11.7	90	1055	179	1.9	61	116	2124	10.7	39	417	4	421	0.0	0	0	0	0	1598	2306	3894	1452	5347
1.3	Support Structure	2.8	105	295	56	0.1	97	13	184	0.2	0	8	0	8	0.0	0	0	0	0	316	240	556	128	684
1.4	Beam Pipe	0.0	0	0	0	0.0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0
1.5	Assembly at SSCL (uphole)	2.0	93	182	52	4.9	87	426	122	9.4	55	517	76	593	0.0	0	0	0	0	1125	249	1374	461	[illegible]
1.6	Detector Installation (downhole)	1.0	102	104	48	1.0	99	100	0	0.0	0	0	0	0	4.0	68	273	99	372	476	147	625	188	[illegible]
1.7	Detector Project Management	0.0	0	0	0	11.0	95	1050	0	0.0	0	0	0	0	0.0	0	0	0	0	1050	0	1050	420	[illegible]
5.1	Electronics	34.0	81	2764	612	5.0	108	538	13335	11.0	53	583	0	583						3895	13947	17832	6673	24505

Total 48 M 92 $

REV. 1 (2/13/1992)

GEM CENTRAL TRACKER SCHEDULE

ACTIVITY	91	92	93	94	95	96	97	98	99
Expression of Intent	Δ								
Conceptual Design/R&D Effort	├	─	─	┤	- - -	- - -			
Letter of Intent	Δ								
Choice of Technologies		Δ							
Detailed Engineering Design		├	─	┤	- - -	- - -	┤		
DESIGN REPORT		Δ							
Build Prototypes		├	─	┤					
Test Prototypes		├	─	┤					
Construction (off-site)				├	─	─	┤		
Assembly (at SSCL)						├	─	┤	
Installation in GEM								Δ	
Commissioning								├	┤
Ready for Data									Δ

Progress on Central Tracker

1. First Draft of Technical Design Report written July 31, 1992

2. Design Optimization & Fine Tuning

   a) No showstoppers or major changes sofar

   b) Overall Tracker Dimensions

      Radius 70 cm → 88 cm

      Length 300 cm → 350 cm

   c) Stereo angles

      Silicon 0, +5 mr → ± 5 mr

      Pads ± 30 mr → ± 50 mr

   d) Silicon "Lorentz Angle"

      9° → 1½°

      pinwheel to staggered geometry

   e) We are considering longer Si strip length

      12 cm → 18 cm (?)

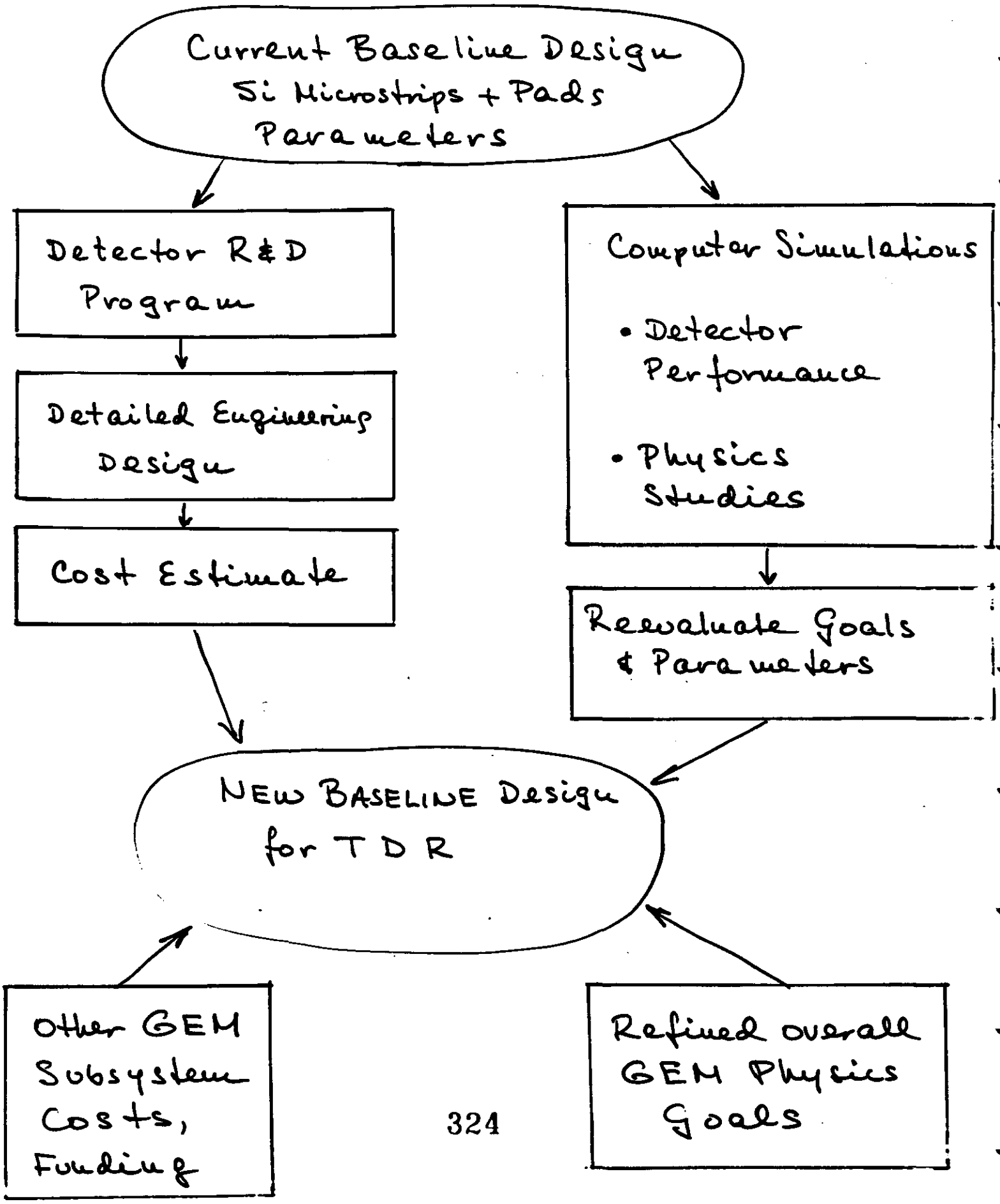
3. Continued detector & physics simulations

4. Prototype work

5. Taiwanese Collaboration

6. Organization and R&D Plan

PLANNING FOR THE TECHNICAL DESIGN REPORT



Overall Tracker Dimensions

1. Choice of Calorimeter allows a somewhat larger volume for Tracker

   Radius 70cm → 88cm
   Length 300cm → 350cm

2. Keep Silicon Detector unchanged

   Keep number of Pad chambers the same

   Keep pads the same $\Delta\eta\,\Delta\phi$ but 2.5mm wide

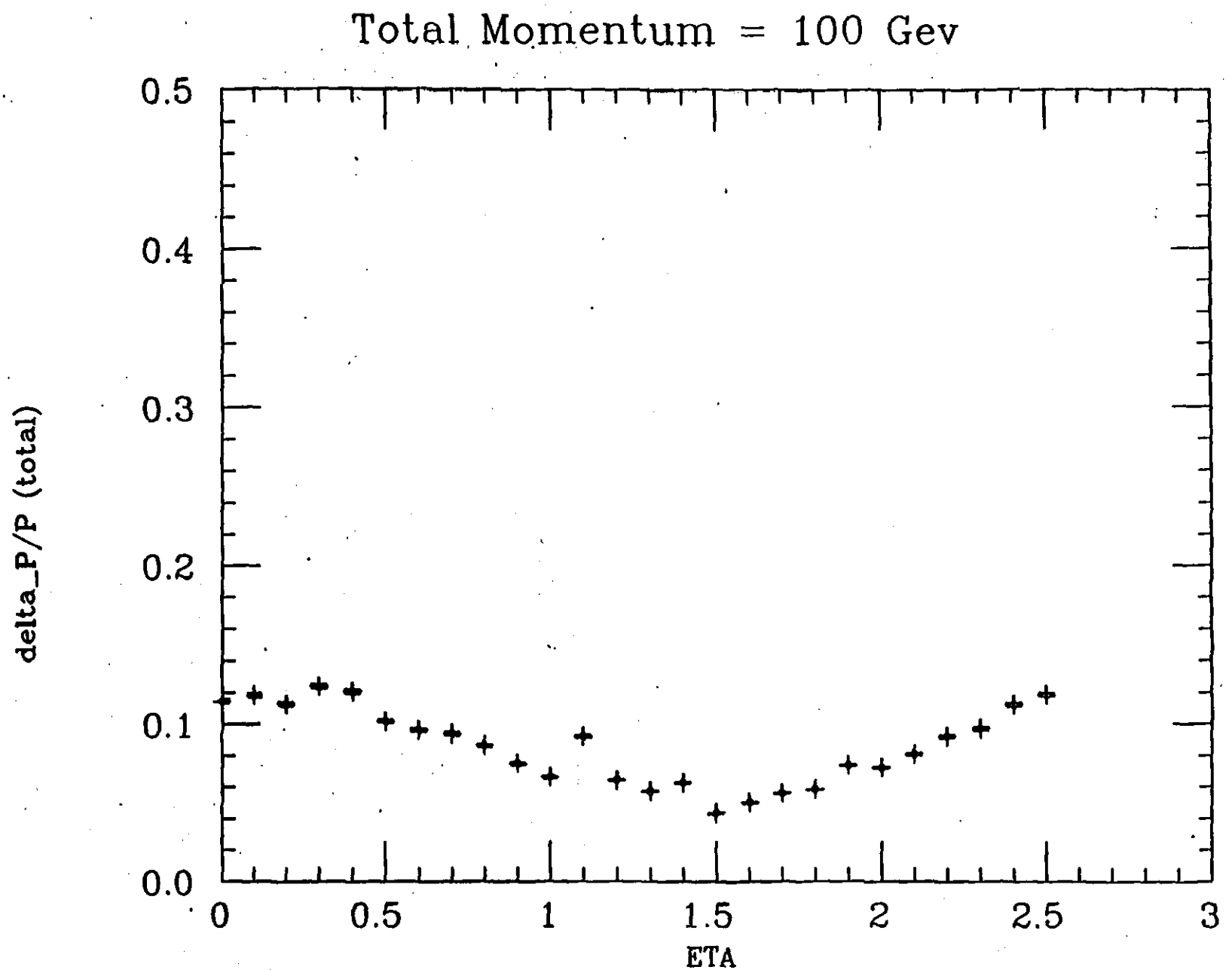
   ∴ same channel count

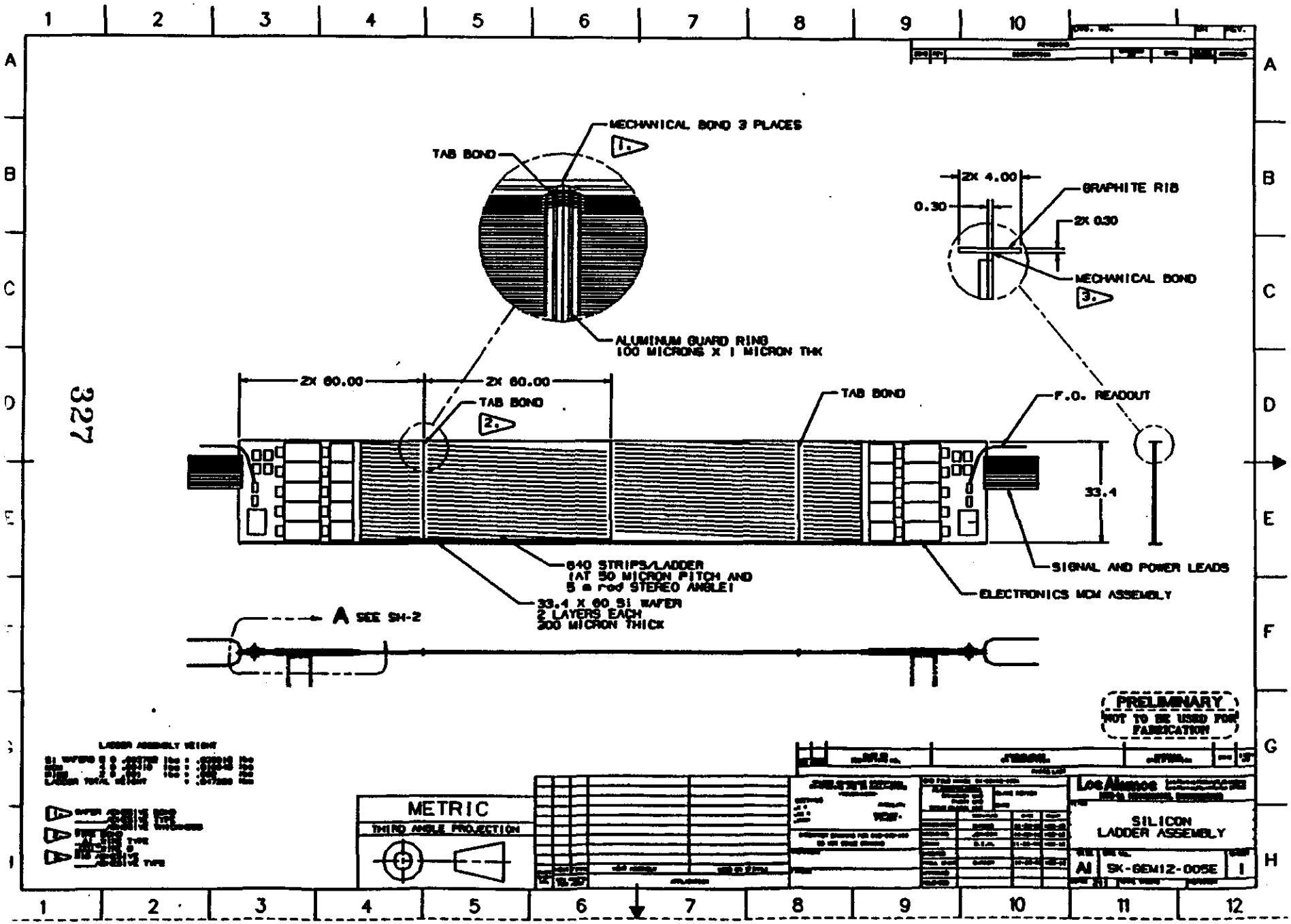
   Move Pad chambers: expand spacing to fill volume

3. Cost increase to Tracker negligible (~ 1% of Tracker cost)

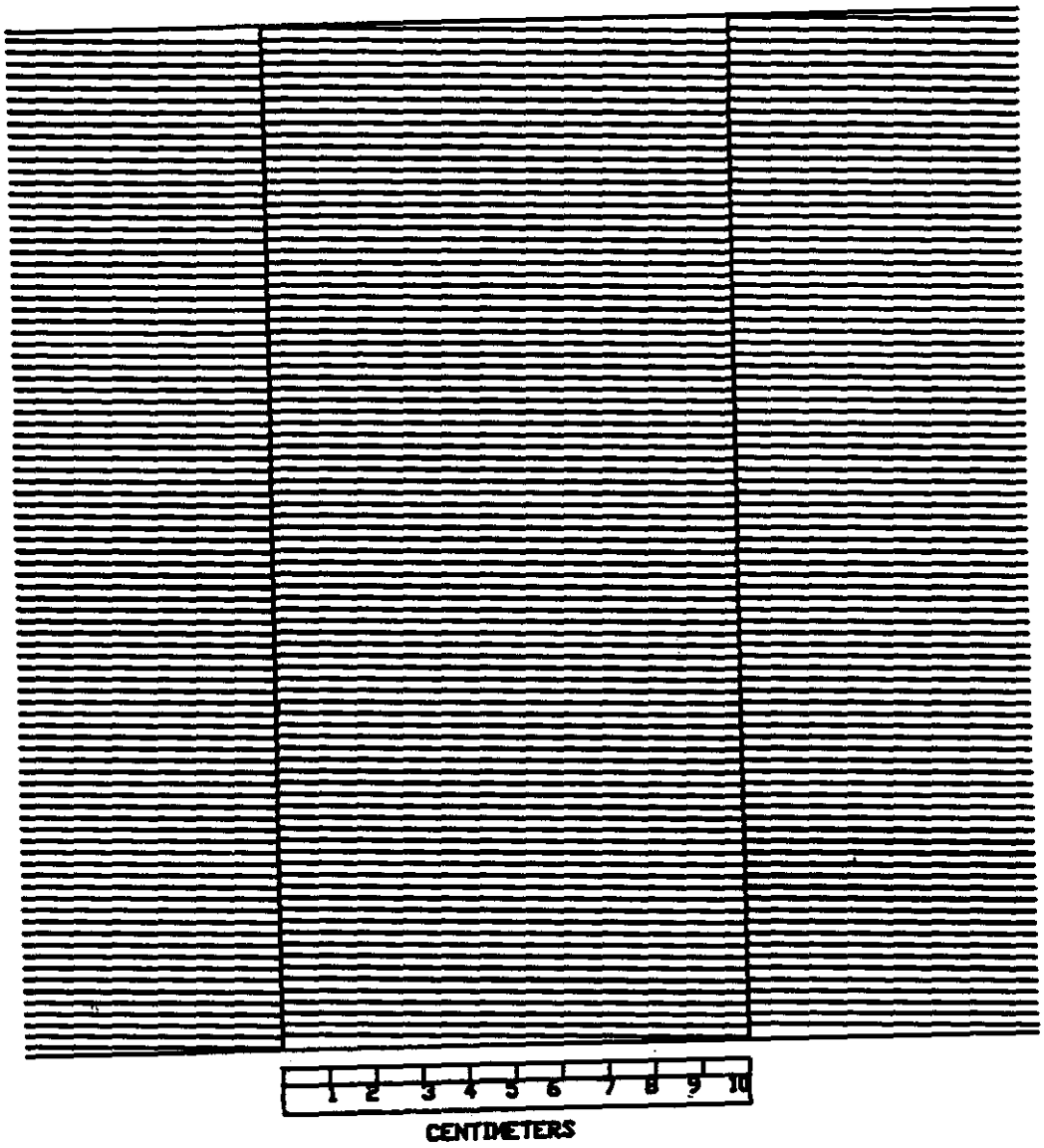
4. Improve momentum resolution for large p by $\sim \left(\frac{88}{70}\right)^2 \sim 1.6$

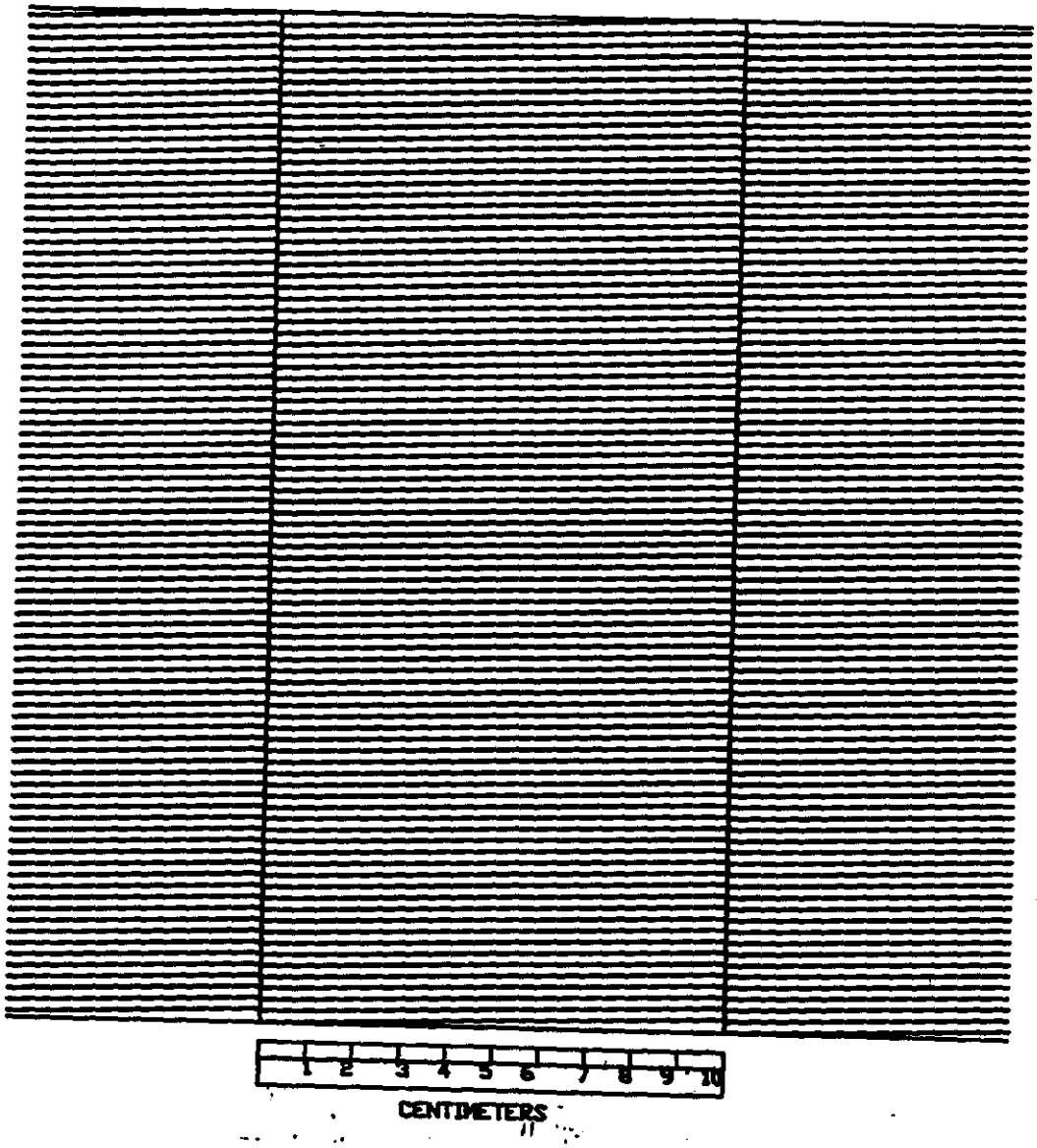
   Improve vertex z resolution


Total Momentum = 100 Gev
delta_P/P (total)
0.0
0.1
0.2
0.3
0.4
0.5
0
0.5
1
1.5
2
2.5
3
ETA

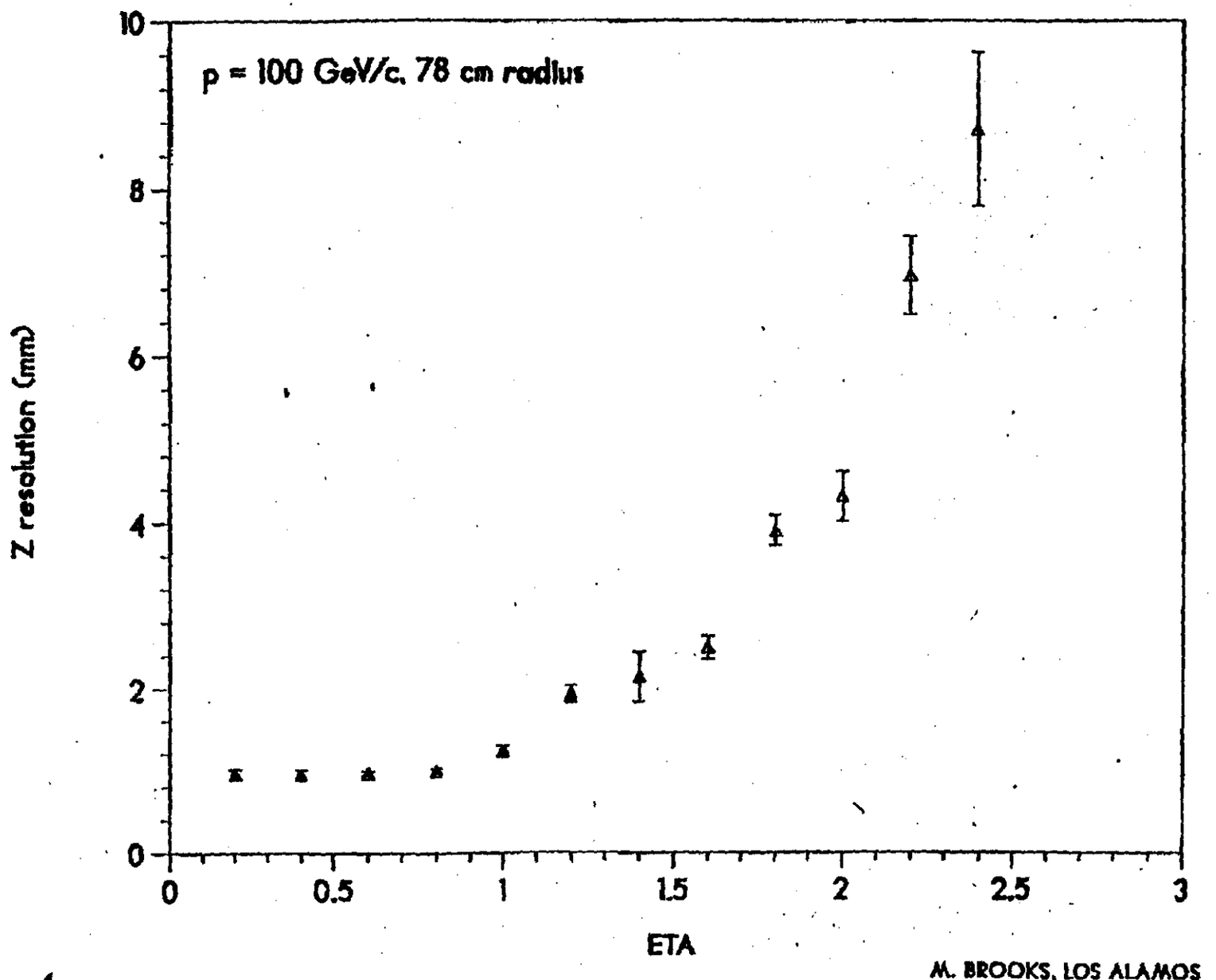

MECHANICAL BOND 3 PLACES
TAB BOND
ALUMINUM GUARD RING
100 MICRONS X 1 MICRON THK
2X 4.00
0.30
GRAPHITE RIB
2X 0.30
MECHANICAL BOND
2X 60.00
2X 60.00
TAB BOND
TAB BOND
F.O. READOUT
33.4
640 STRIPS/LADDER
(AT 50 MICRON PITCH AND
5 m rad STEREO ANGLE)
33.4 X 60 Si WAFER
2 LAYERS EACH
300 MICRON THICK
SIGNAL AND POWER LEADS
ELECTRONICS MCM ASSEMBLY
A SEE SH-2
PRELIMINARY
NOT TO BE USED FOR FABRICATION
METRIC
THIRD ANGLE PROJECTION
Los Alamos
SILICON
LADDER ASSEMBLY
A1
SK-GEM12-005E
1

327


1 2 3 4 5 6 7 8 9 10
CENTIMETERS

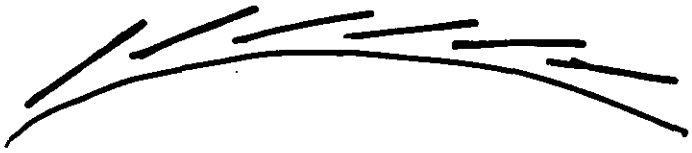

1 2 3 4 5 6 7 8 9 10
CENTIMETERS

SENT BY:Xerox Telecopier



Silicon Geometry

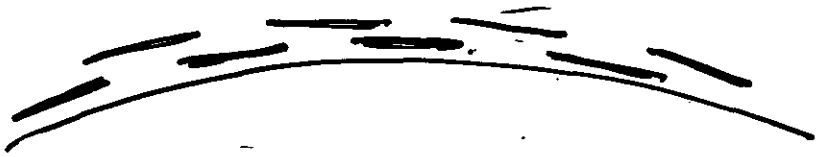
1. Present Design
   9° tilt angle, pinwheel geometry



looking along beam

2. Relevant Lorentz angle in Silicon Microstrips is ~ 1½°

3. New design with 1½° tilt angle and staggered geometry



looking along beam

1½° tilt angle reduces charge spreading to neighbouring strips

∴ improves signal to noise

Silicon Detector Strip Length

.. Present Design

Barrel – 48 cm long i.e. 4 × 12 cm

Forward – 16 cm radially 12 cm + 4 cm

.. Modified Design under consideration

Barrel – 36 cm long 2 × 18 cm

Forward – 18 cm radially 18 cm

.. Advantages of 18 cm strip length Design

a) Mechanically much simpler

b) All Electronics on end of barrel, outer edge of Forward discs

- No buried cooling rings
- Easier and reduced cable plant
- Easier access to electronics
- Reduced Radiation Length

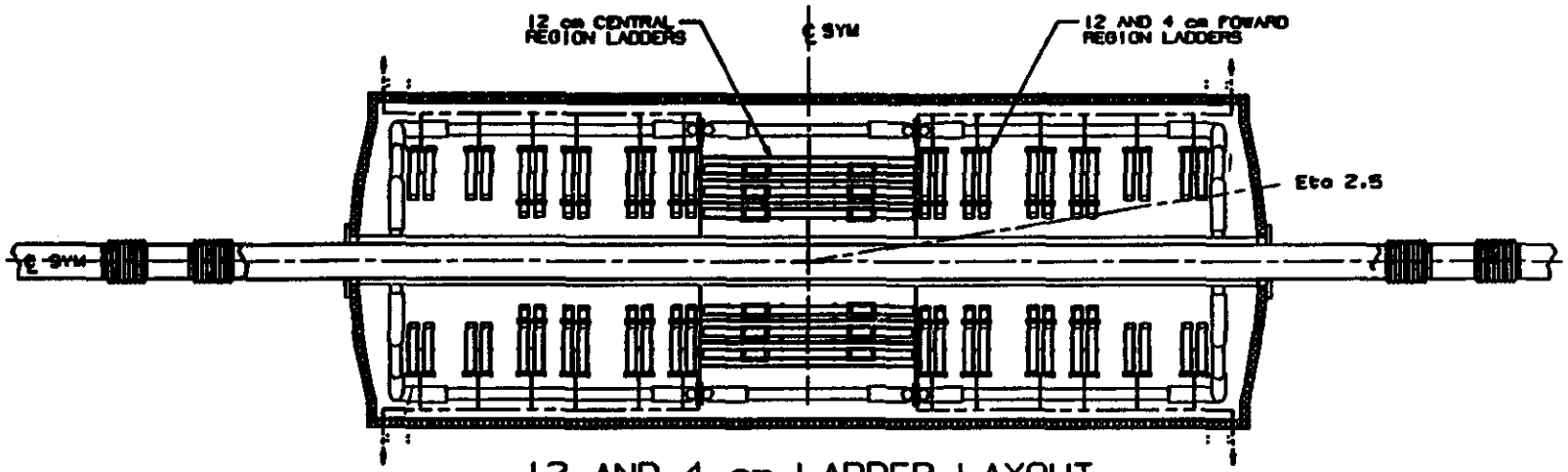
c) Channel count reduced by ~ 25%

- Cost saving
- Less total power dissipated

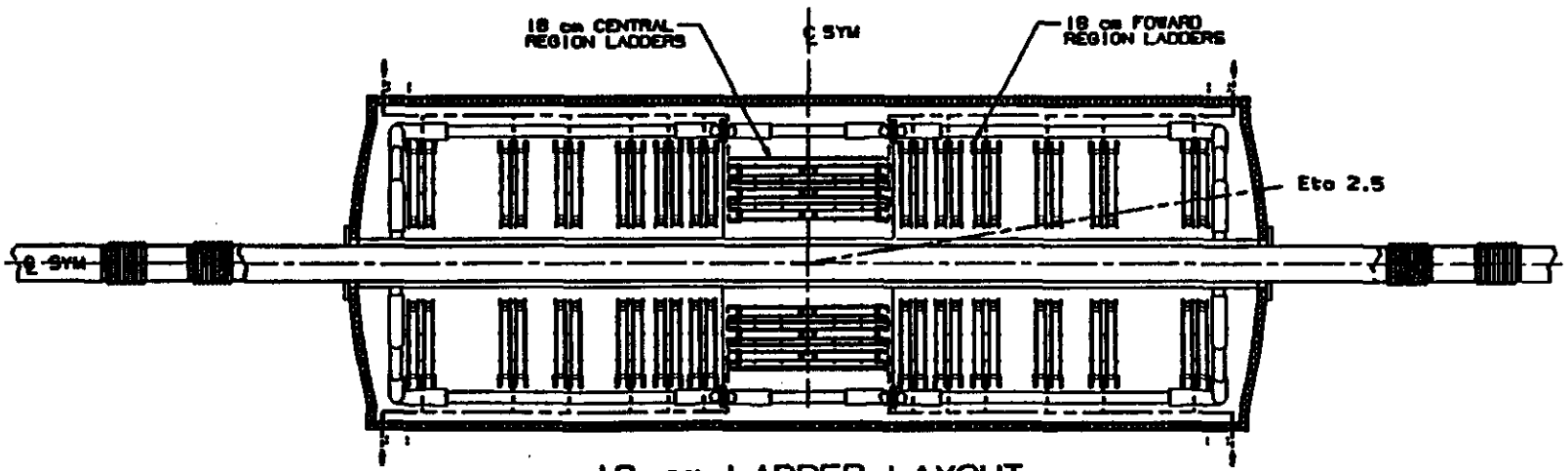
1. Concerns about 18 cm long strips

Signal to Noise

Will make decision after actual measurements on prototypes



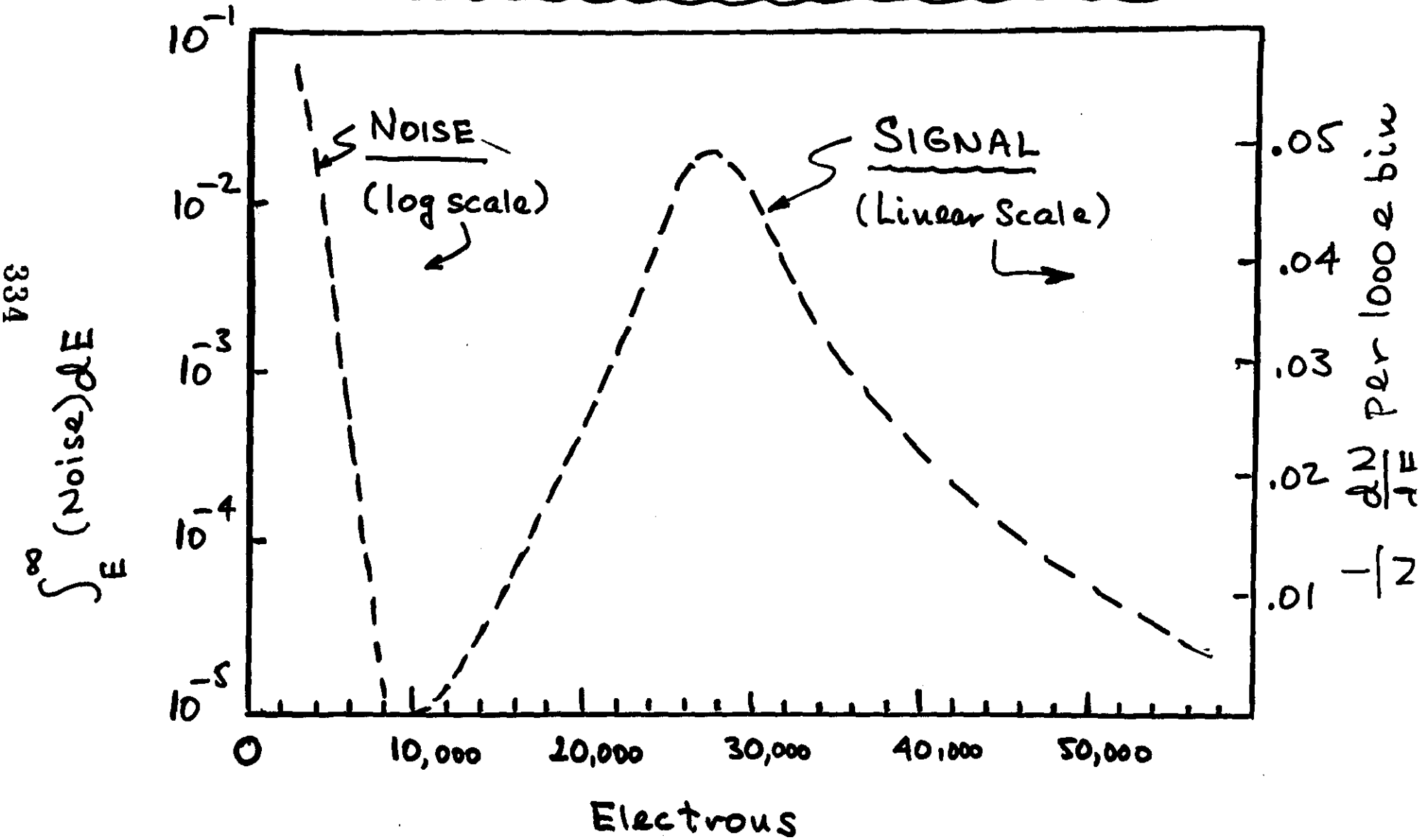
12 AND 4 cm LADDER LAYOUT

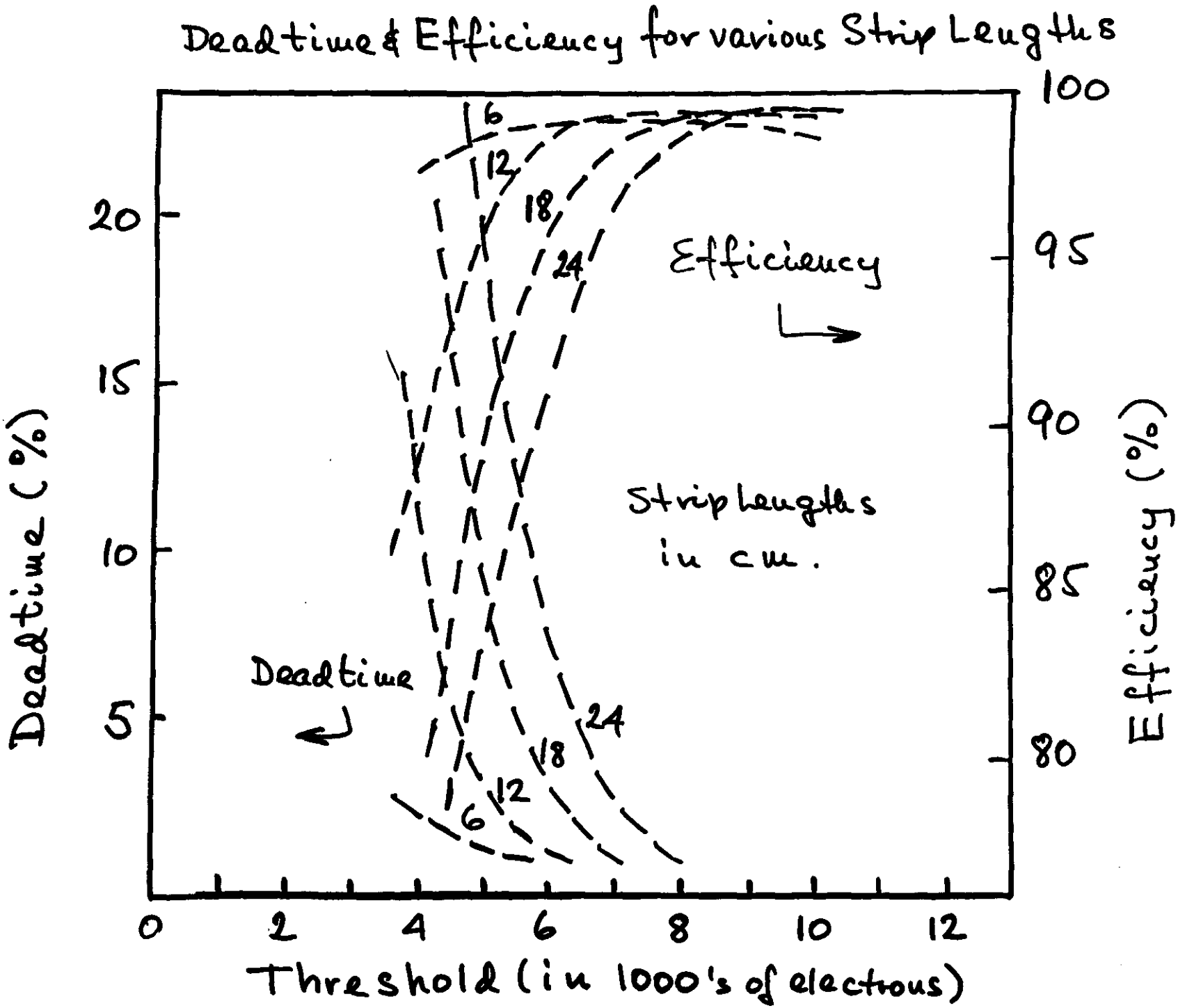


18 cm LADDER LAYOUT

JIM BRAU, Univ. of Oregon

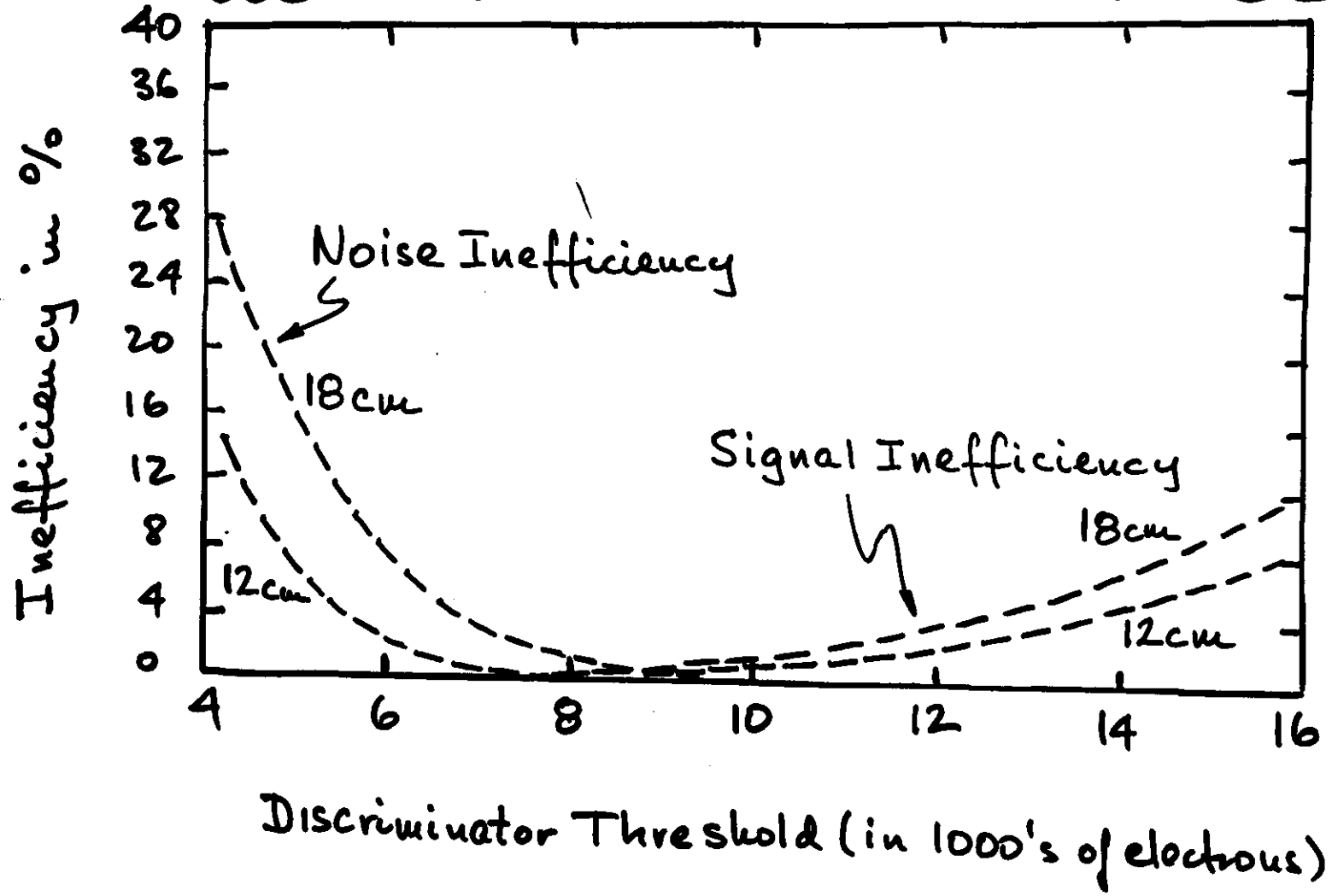
Signal to Noise in Silicon Microstrips




Deadtime & Efficiency for various Strip Lengths
Deadtime (%)
Efficiency (%)
Threshold (in 1000's of electrons)
Efficiency
Deadtime
Strip Lengths in cm.
6
12
18
24
0
2
4
6
8
10
12
5
10
15
20
80
85
90
95
100

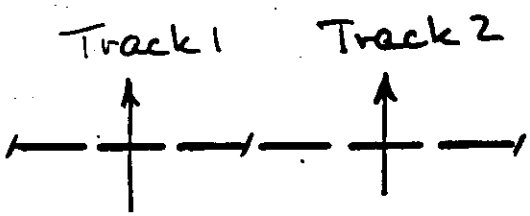
G. Mills & S. Hahn, Los Alamos

Inefficiencies for 12 and 18 cm long strips



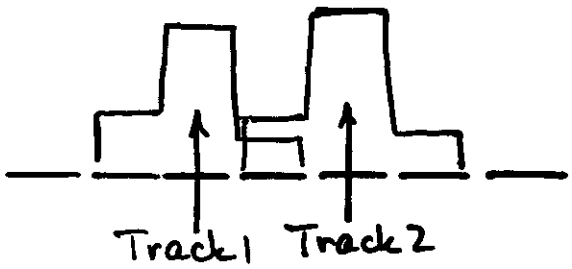
TWO TRACK RESOLUTION

- Second track 3 pads away



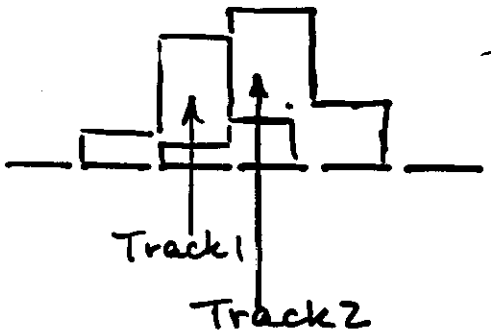
No problem – occupancy per cell of 3 pads relevant as discussed above

- Second track 2 pads away



Should be able to get close to full precision on both tracks

- Second track in adjacent pad



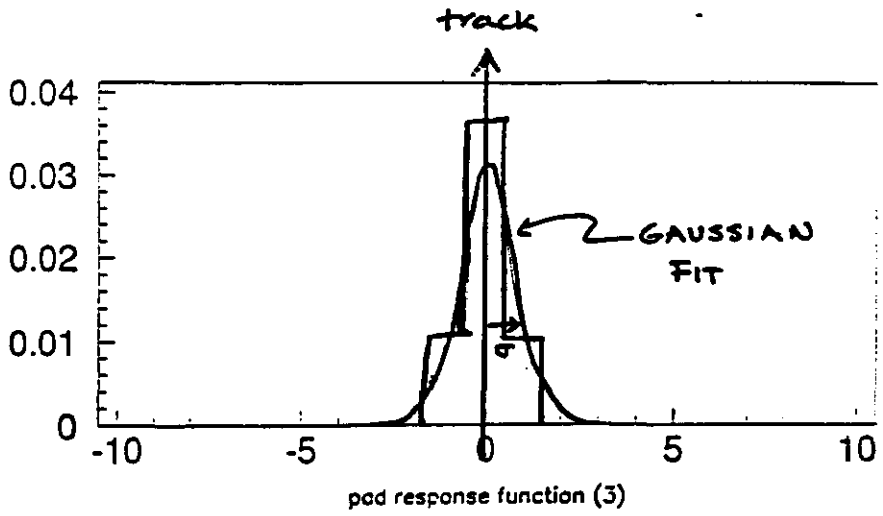
Charge on 4 pads measured
4 unknowns (total charge and position of each track)
Not clear how well we can do in this case

- Second track in same pad

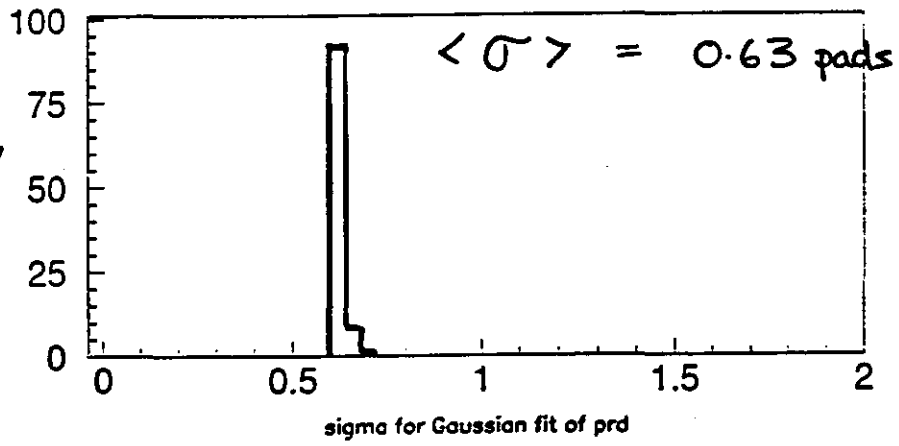
No hope for precision meas. of position of either track. However should be able to tell that more than one track hit pad. This may be the basis of τ recognition since τ decay often has several charged tracks close together.

• PROCEDURE TO MEASURE RESOLUTION

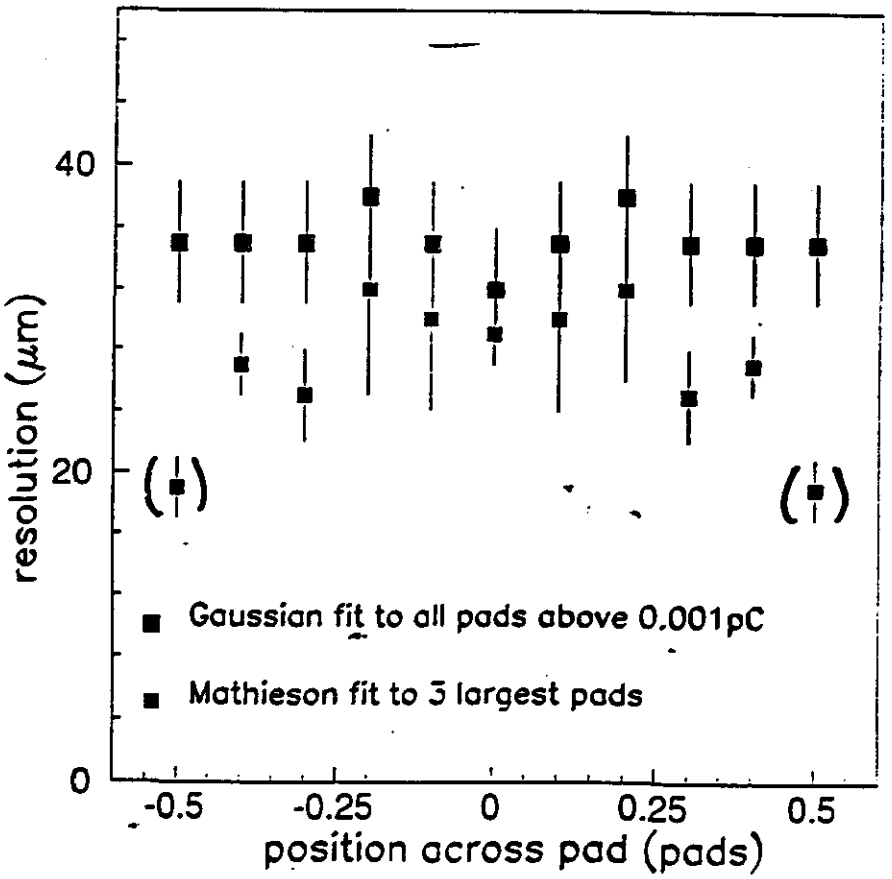
FIT GAUSSIAN TO CHARGE ON 3 PADS



MEASURE σ FOR MANY TRACKS

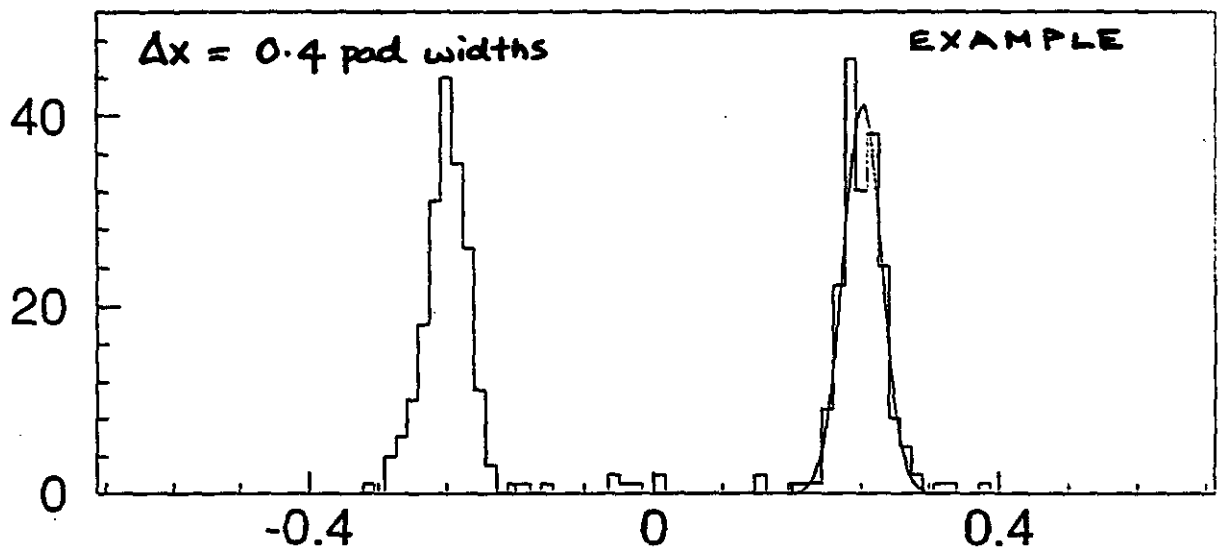


SINGLE TRACK RESOLUTION USING KNOWN σ

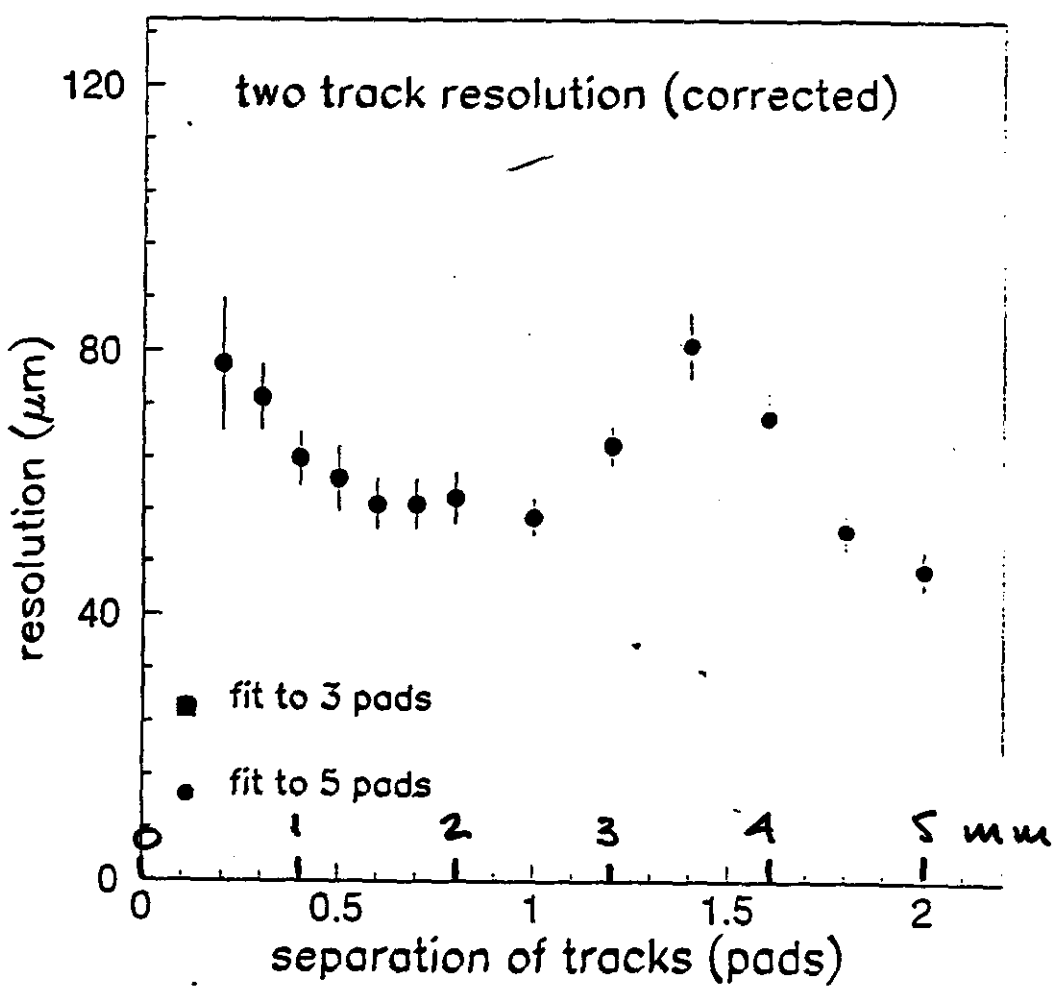


- USING KNOWN WIDTH FOR CHARGE DISTRIBUTION

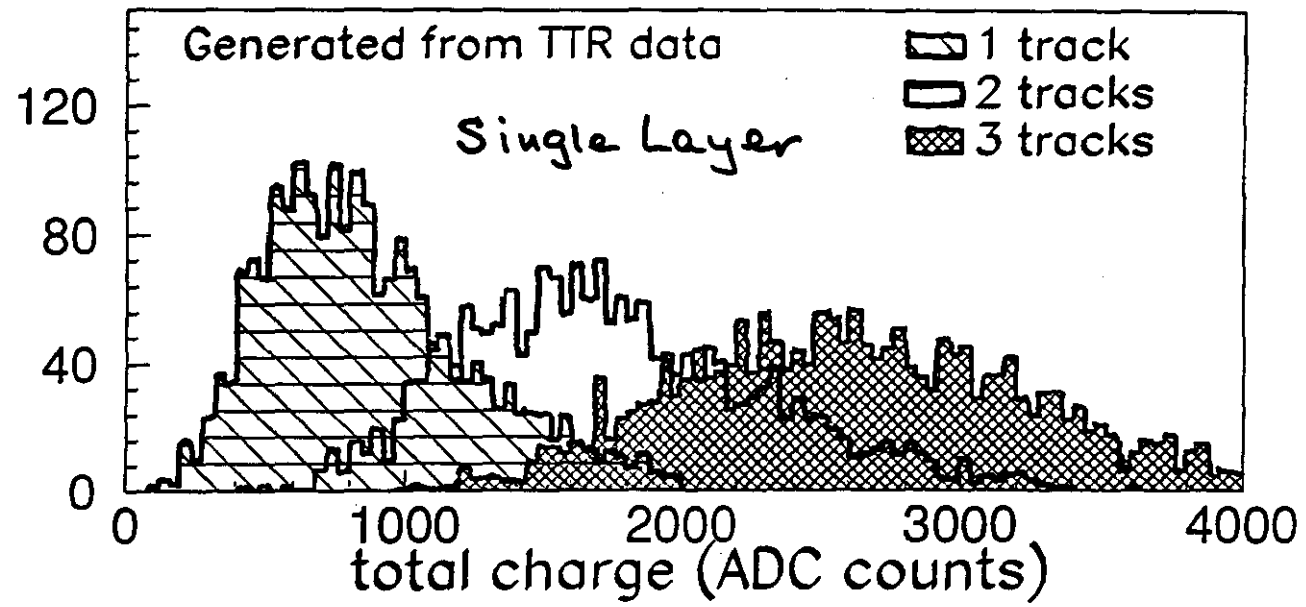
- TWO TRACKS CAN BE RESOLVED UP TO $\Delta x = 0.2$ pads $= 0.5$ mm

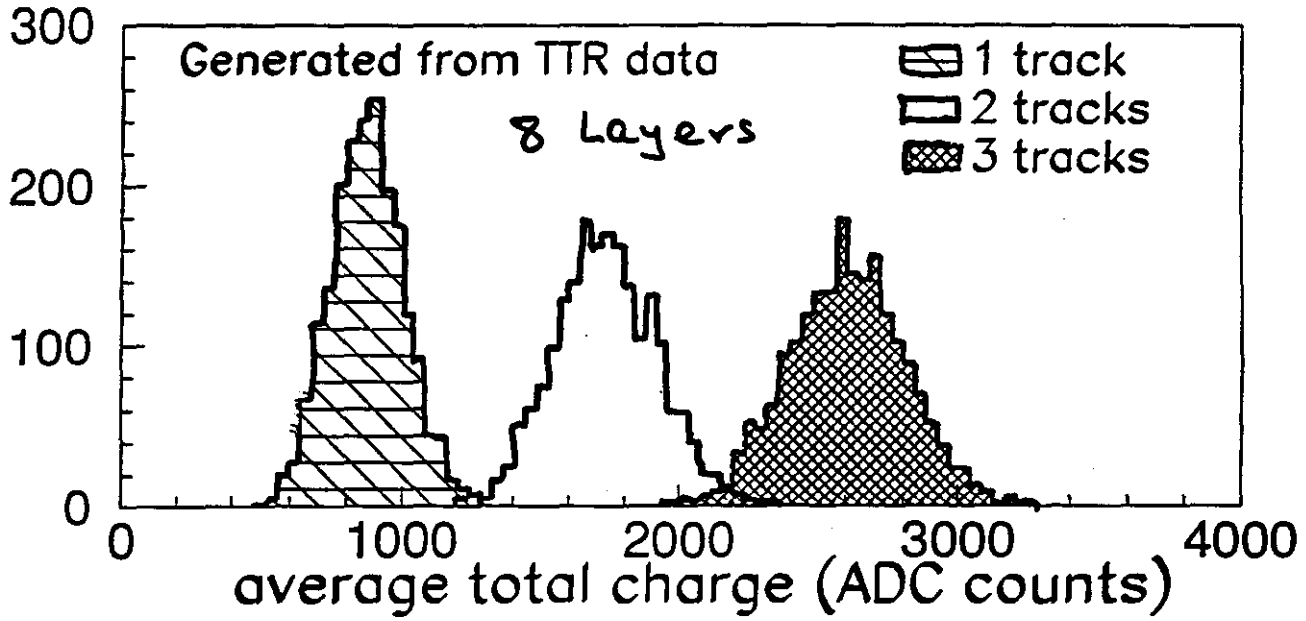


gaussian fit to position using known prf



- 3 TRACKS CAN BE IDENTIFIED USING AVERAGE OF CHARGE OVER EIGHT LAYERS





R & D Prototype Program

1. Silicon Tracker

a) 18 cm Barrel Ladder	J. Brau	U. of Oregon
b) Forward Disc	D. Lee	Los Alamos

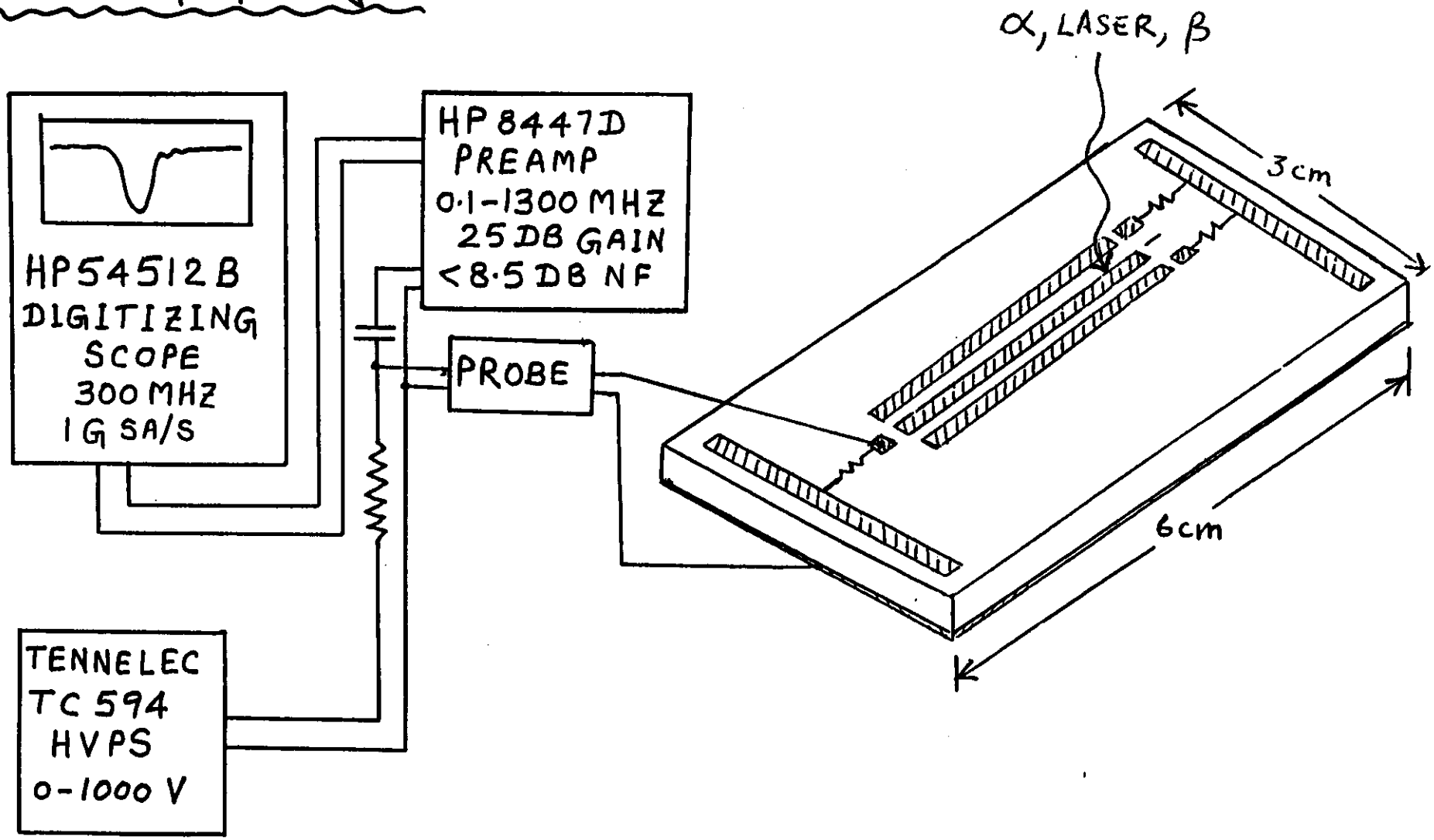
2. IPC Tracker

a) Reduced size prototype with final working parameters	C. Bowers	Indiana U.
b) Fullsize Barrel Chamber	C. Baltay	Yale U.
c) Fullsize Endcap Chamber		Taiwan

3. Test Beam Setups

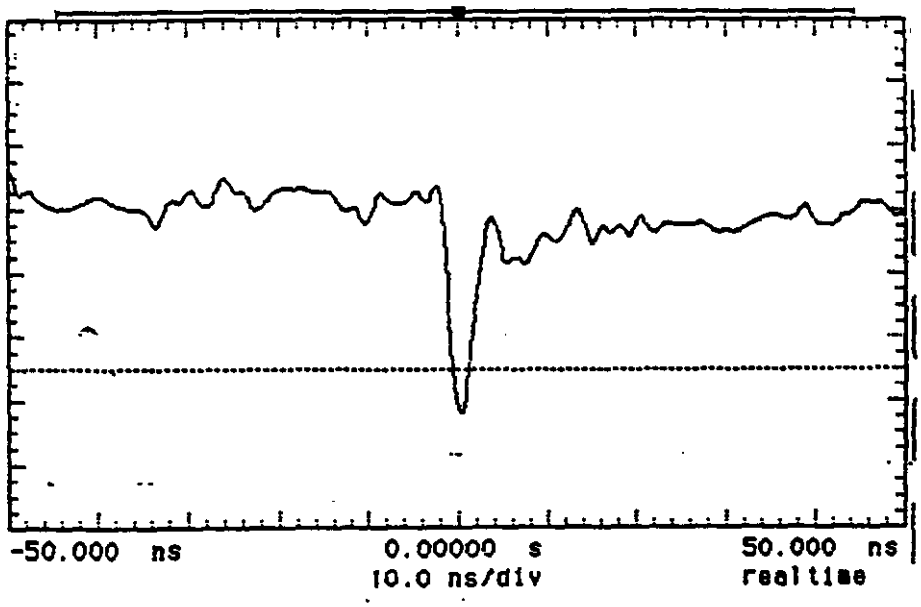
a) Silicon Ladders	G. Mills, R. Frey	Los Alamos, U. of Oregon
b) IPC Chambers	K. Morgan	SSCL

University of Oregon

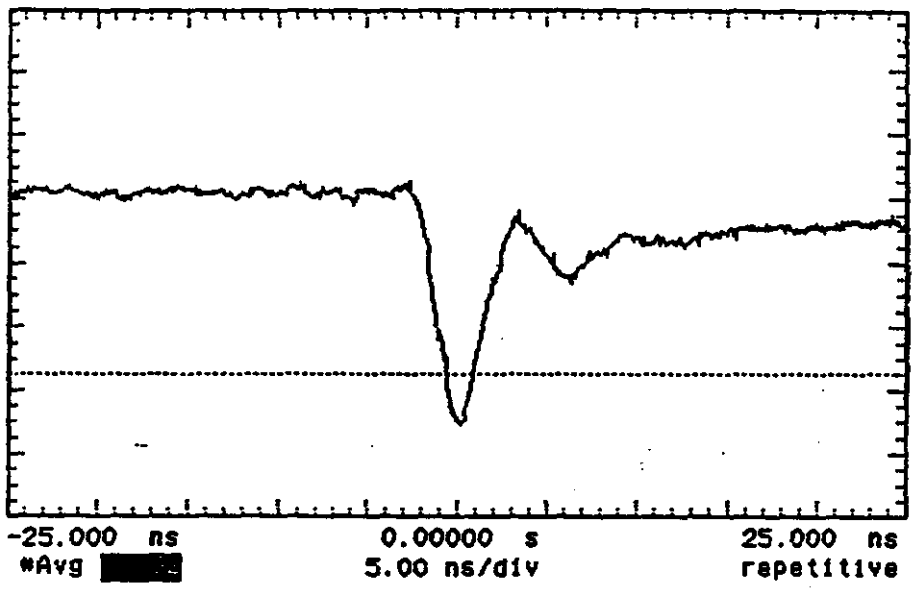


MOSCOW DETECTORS

PITCH	50 μm	COUPLING	AC
P^+ STRIP WIDTH	8 μm	OXIDE THICKNESS	225 nm
Al STRIP WIDTH	16 μm	POLY SI RESISTOR	2±.2 MΩ
Al THICKNESS	1 μm	ρ_{SUB}	8 KΩ-cm

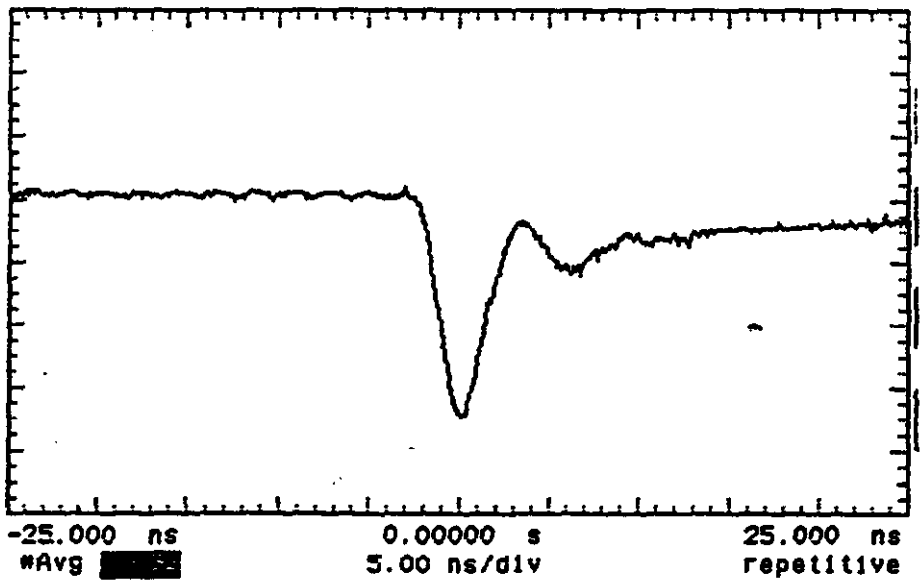


2 mV/div



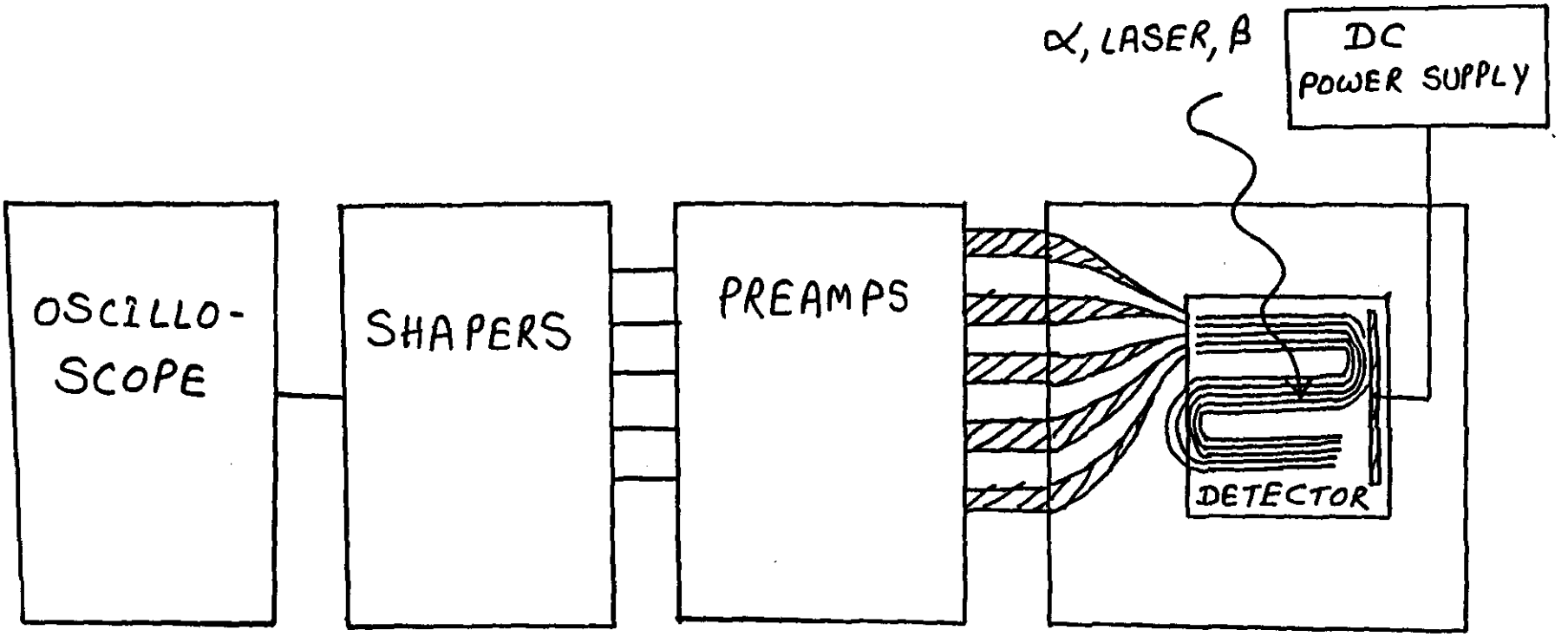
2 mV/div

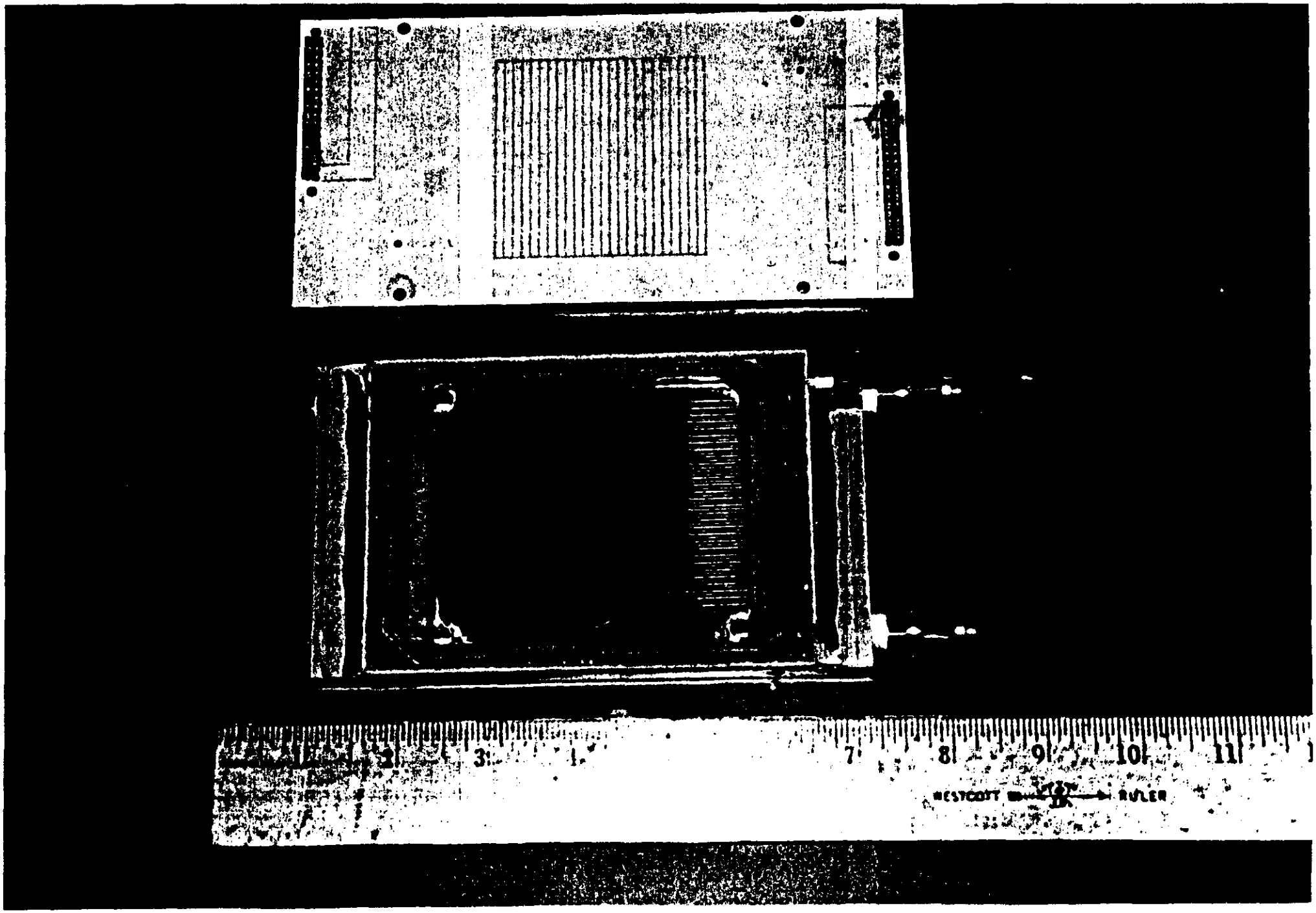
α-SOURCE CLOSE TO THE PROBE TIP



2 mV/DIV

α-SOURCE AT 6 CM AWAY FROM THE PROBE TIP

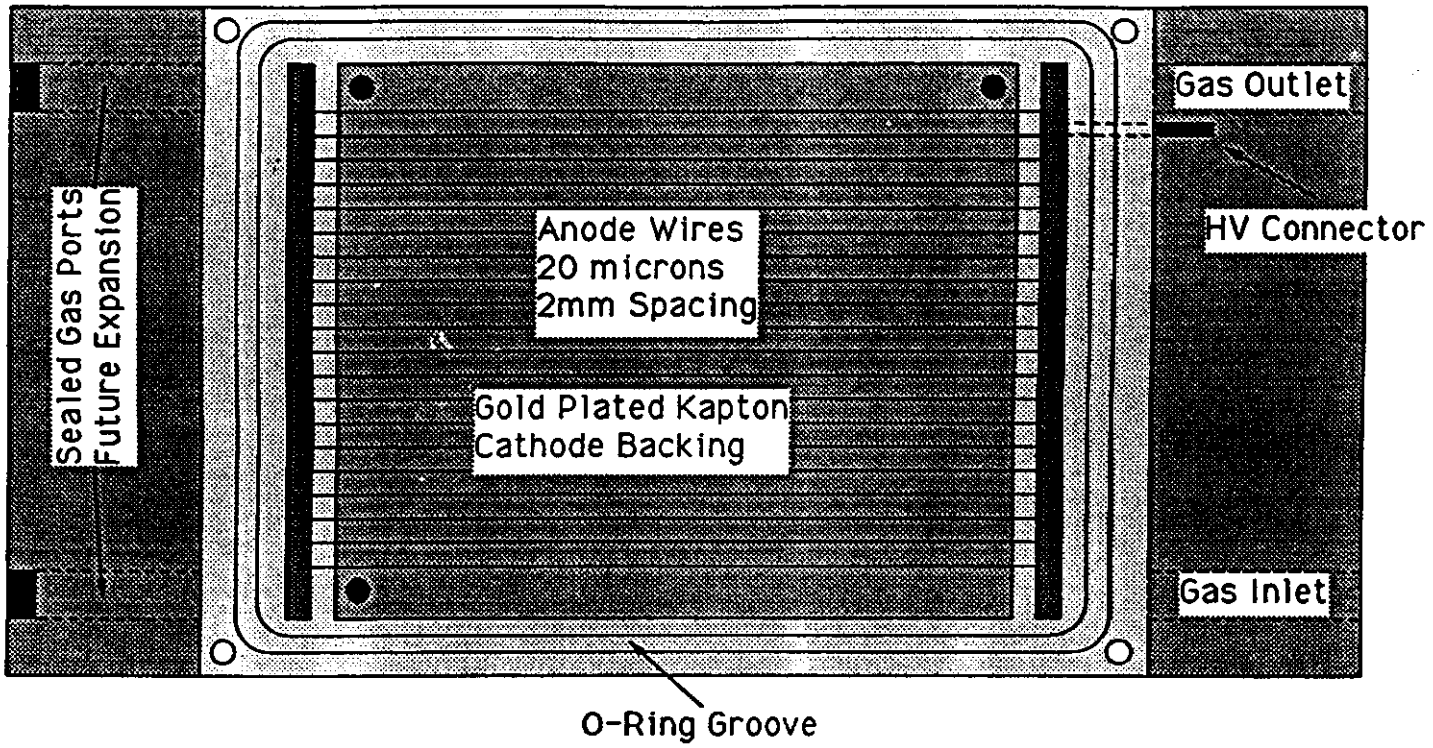

OSCILLO-
SCOPE
SHAPERS
PREAMPS
α, LASER, β
DC
POWER SUPPLY
DETECTOR


WESTCOTT
RULER

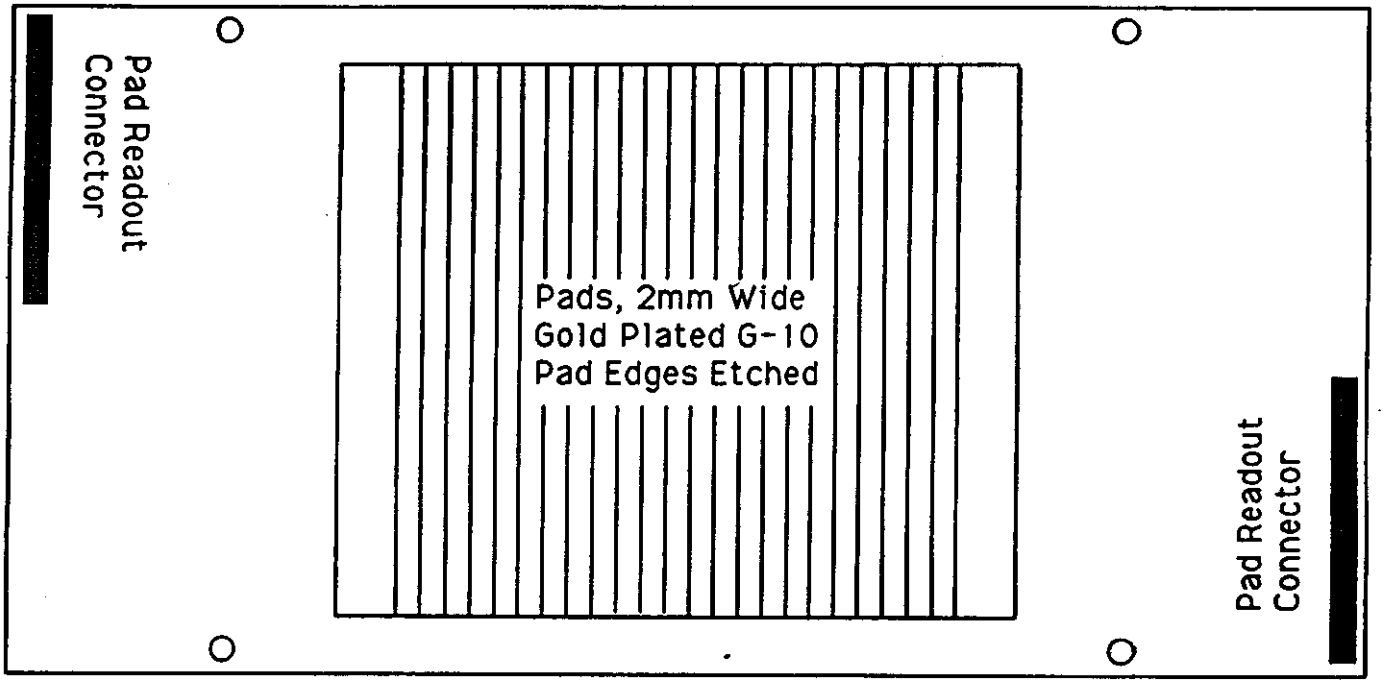
Interpolating Pad Chamber Parameters

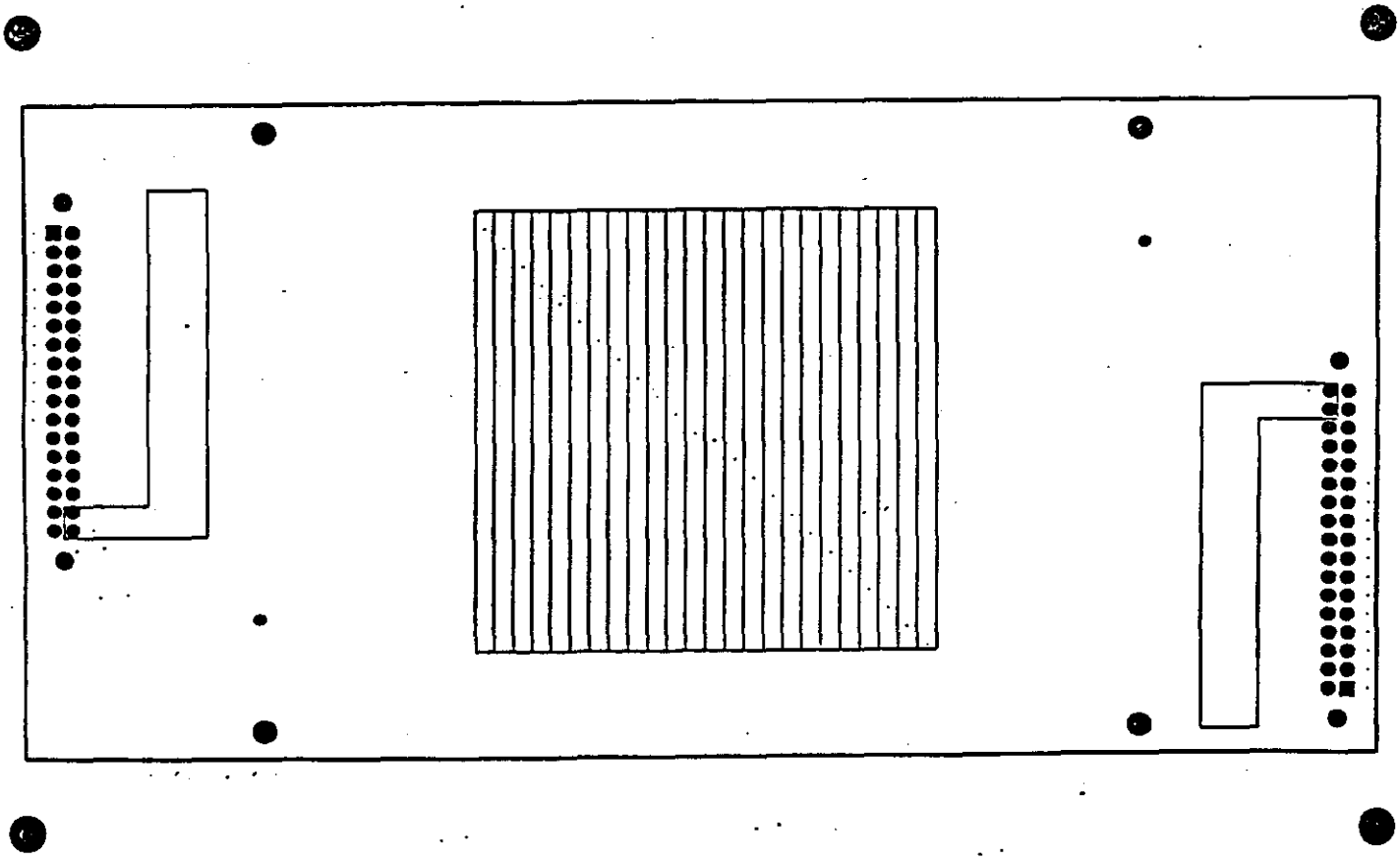
Anode to cathode distance	2 mm
Anode wire diameter	40 μ
Anode wire spacing	2 mm
Anode wire voltage	3000 Volts
Gas gain	5×10^4
Pad size	2.5 mm × a few cm
Input Capacitance to Preamp	5 – 35 pF
Shaping time	20 nsec
Typical signal on pad	2×10^5 e
Typical noise on pad	1000 e
Signal to noise	200:1
Accumulated charge on wire	1.4 Coul/cm/yr at 10^{34}
Chamber gas	$CO_2 - CF_4$ (50:50)

Anode Board

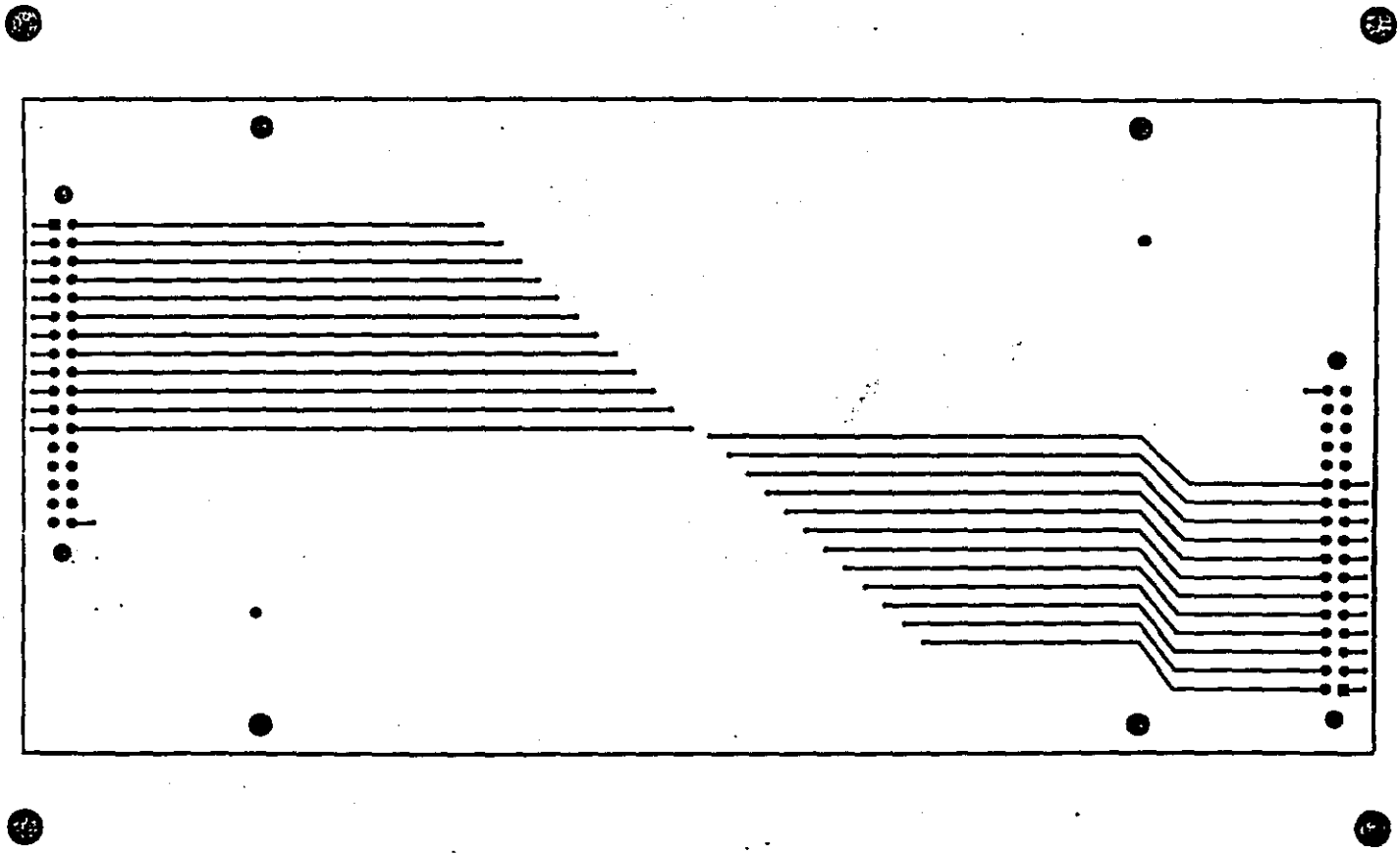


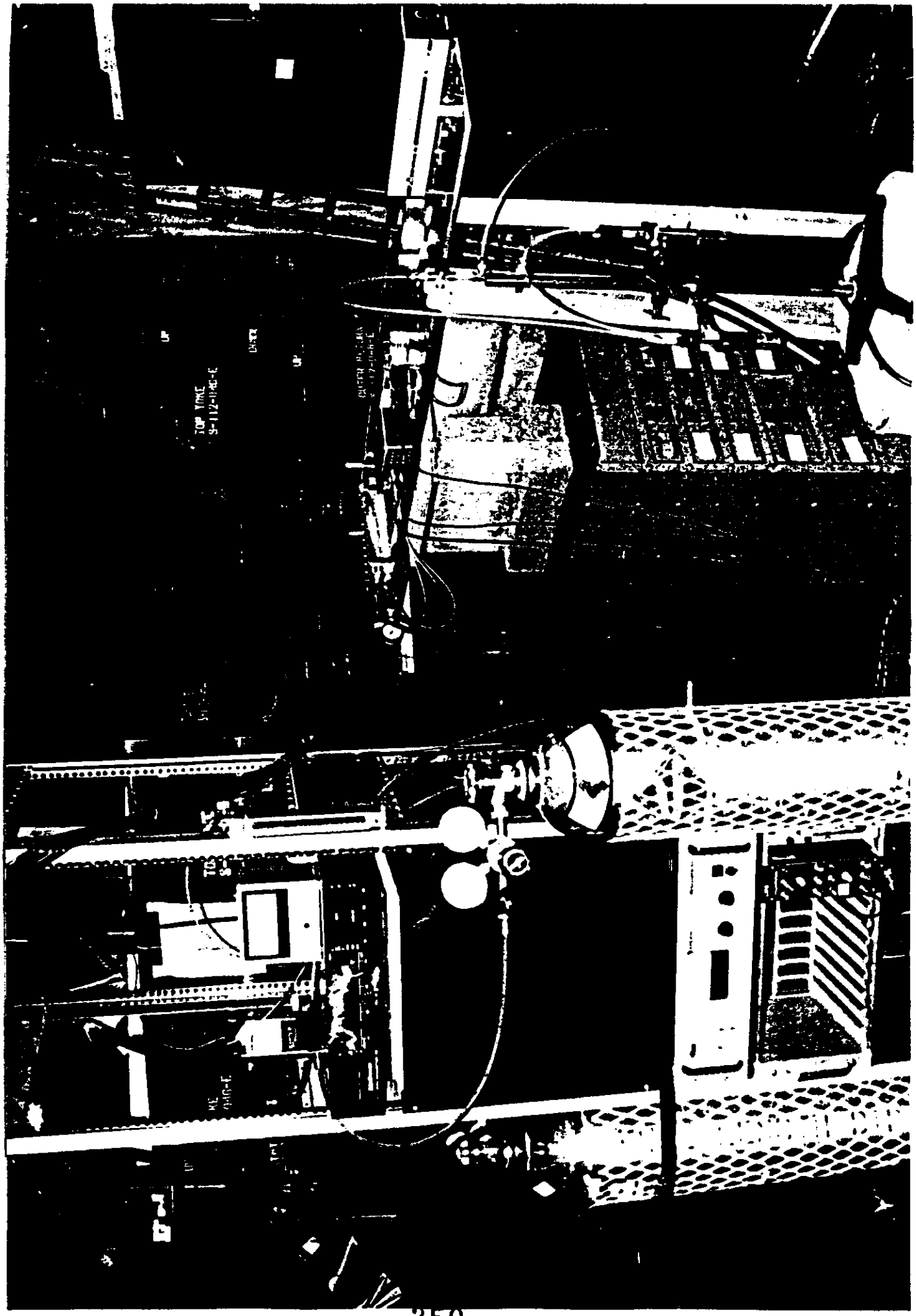
Pad Board

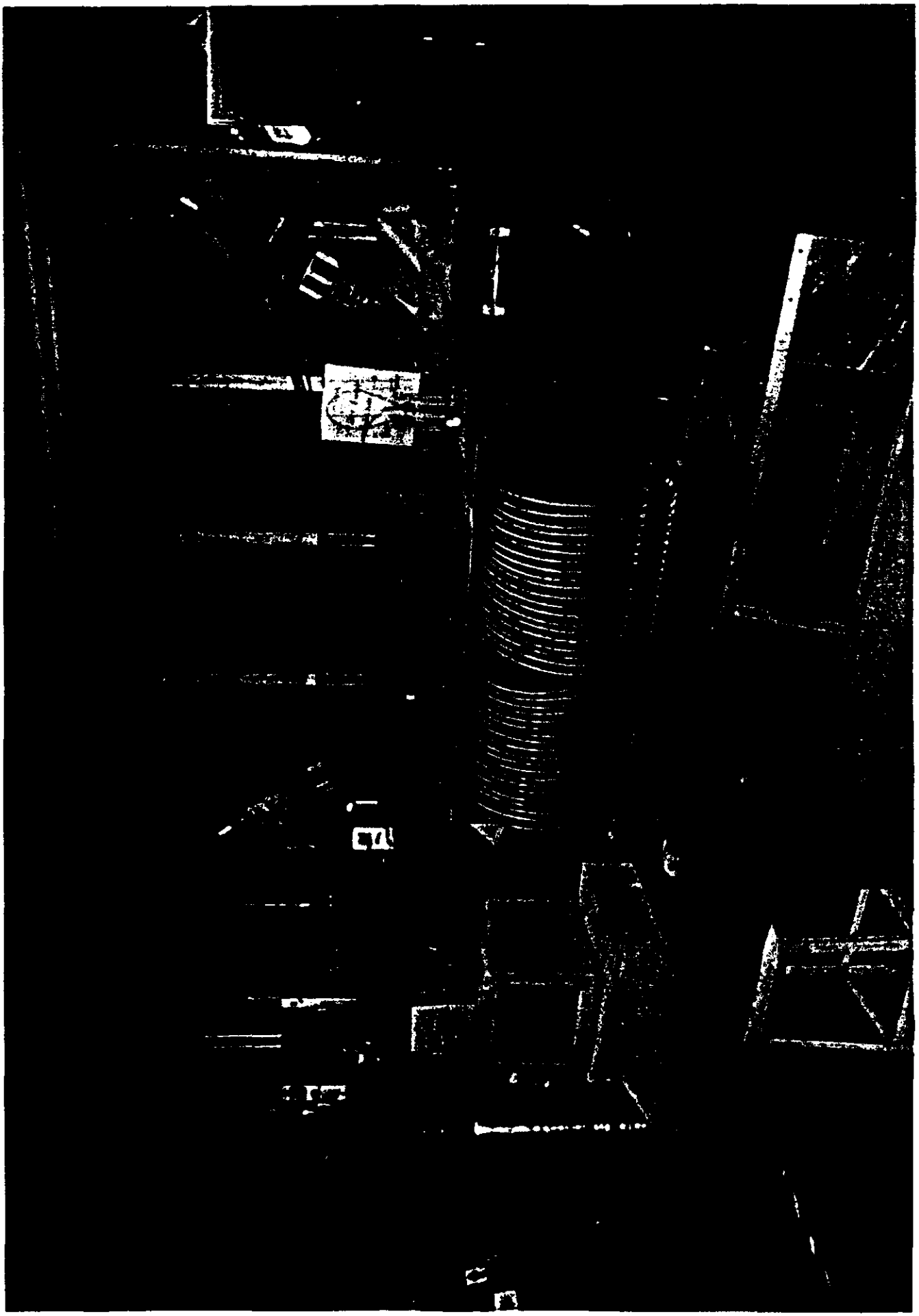


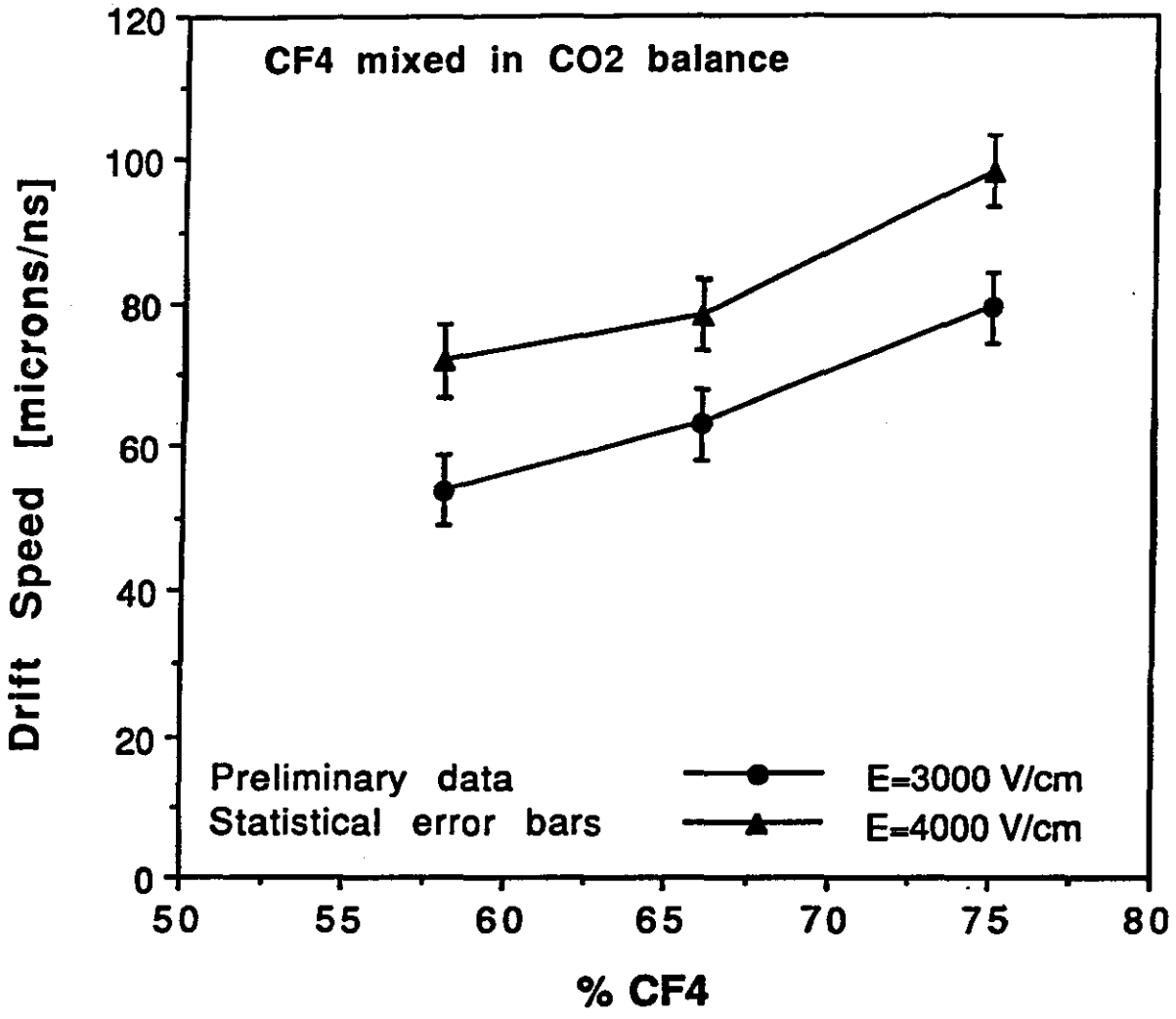


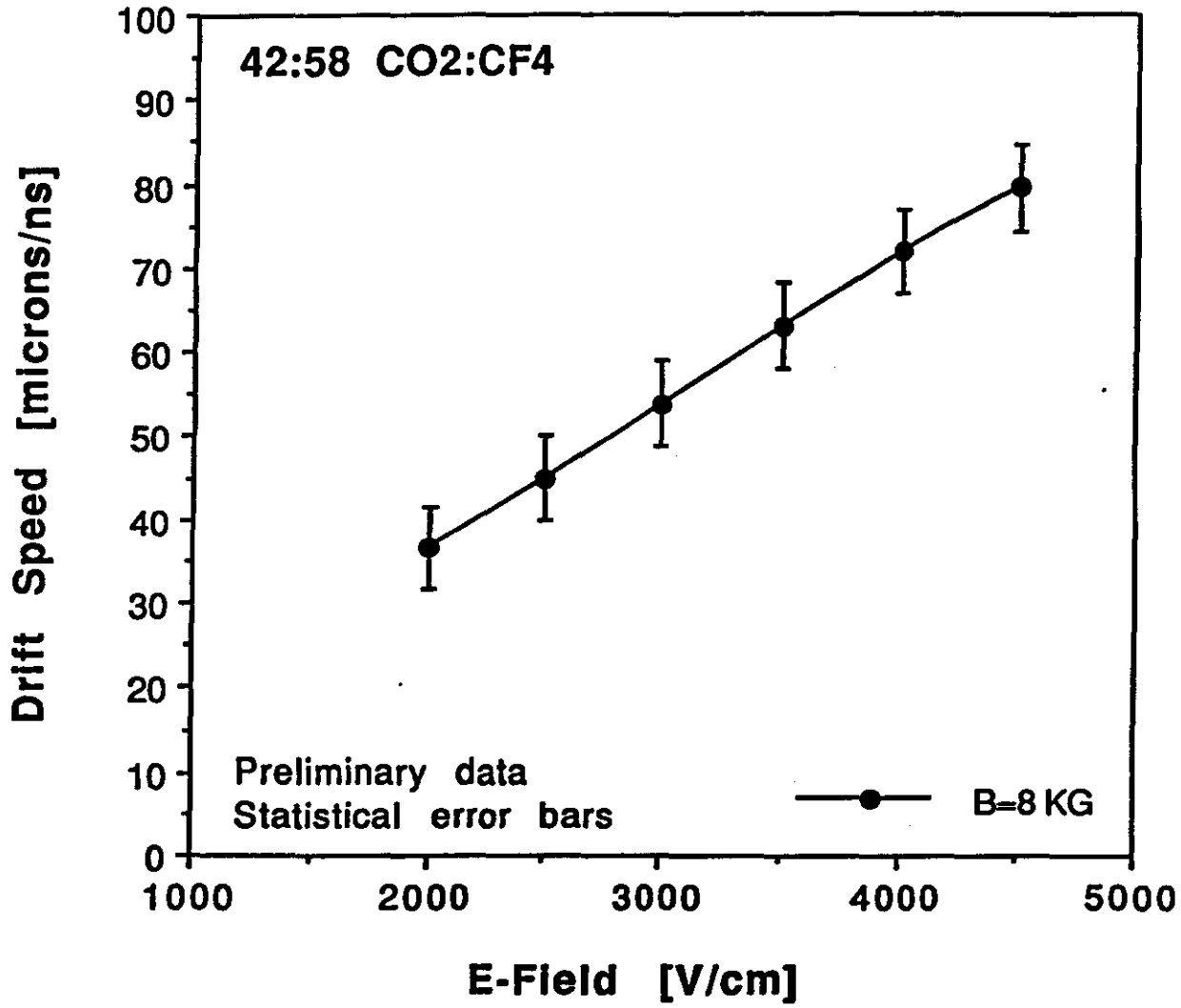
pad1.job - Fri Apr 03 16:22:29 1992

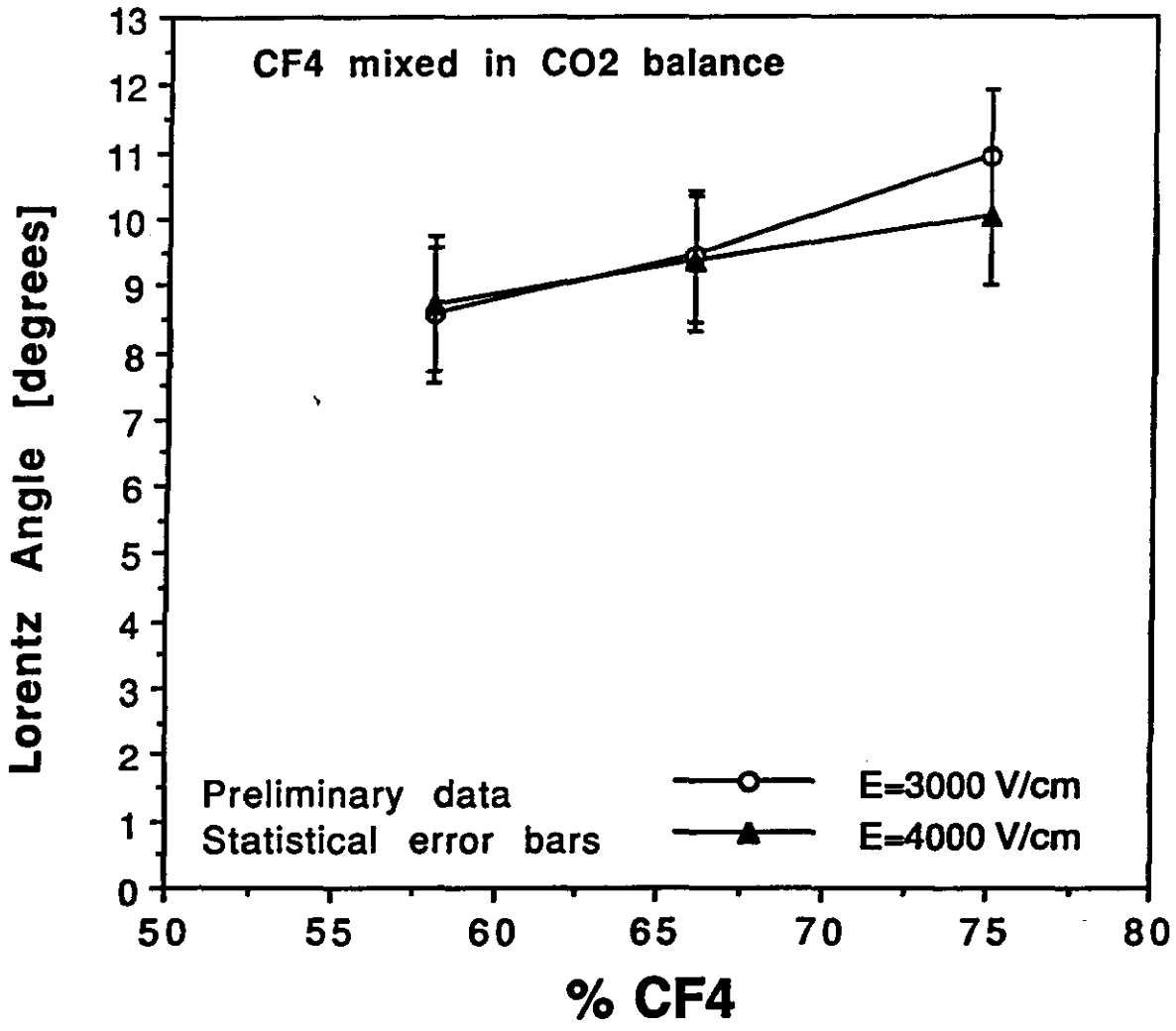


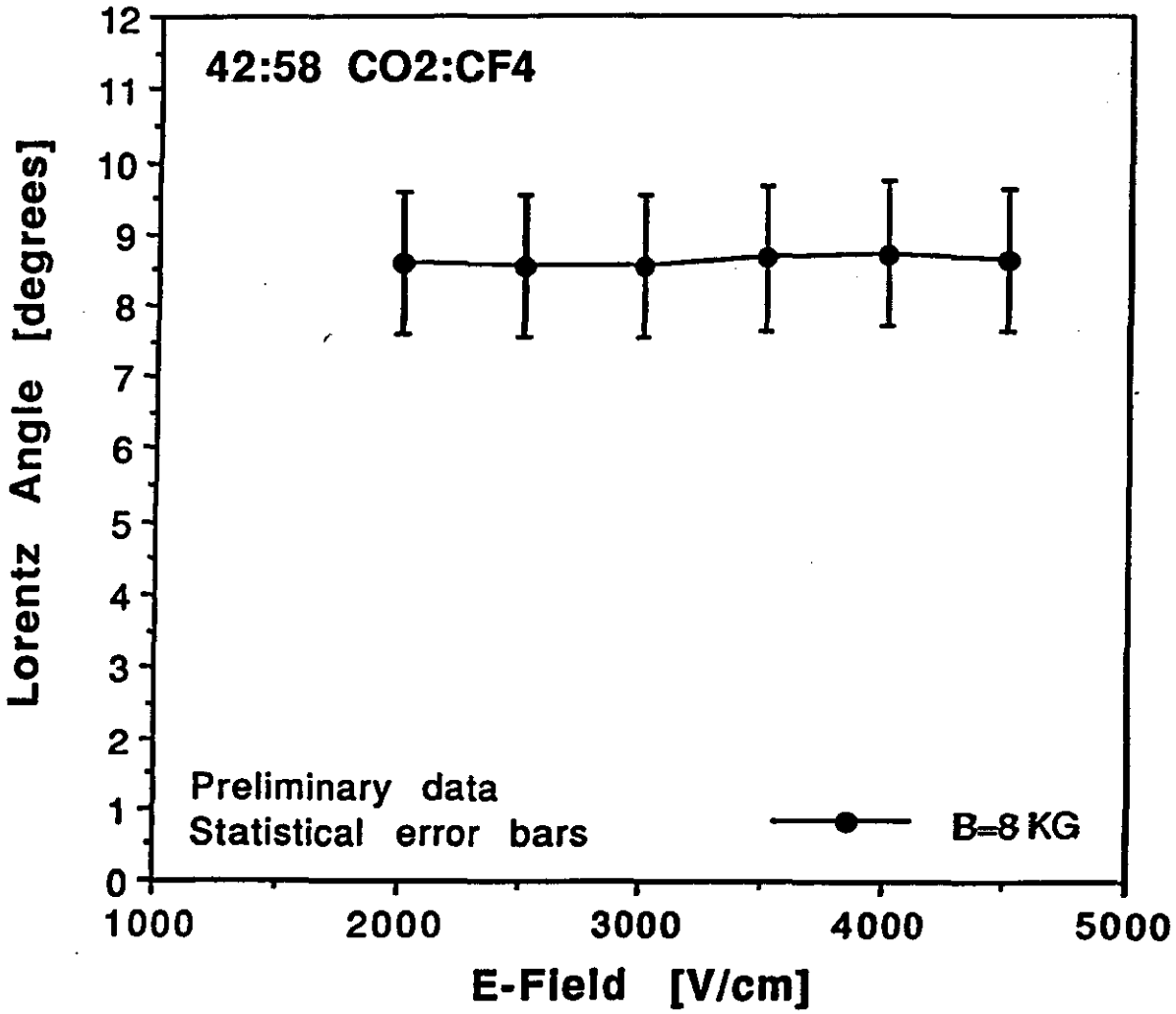

TOP VIEW
S-112-HMC-E
OUTER MOTOR
TOP

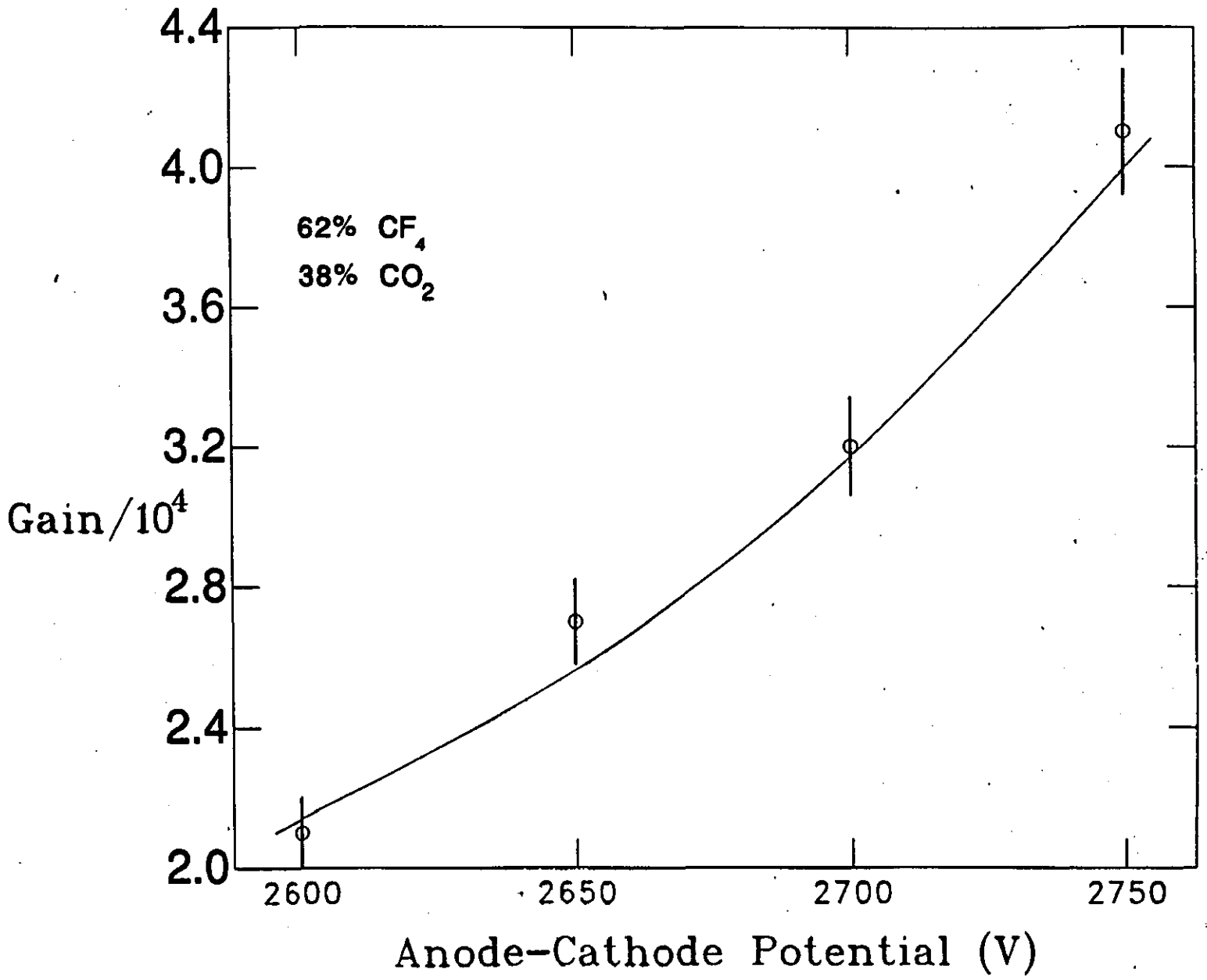


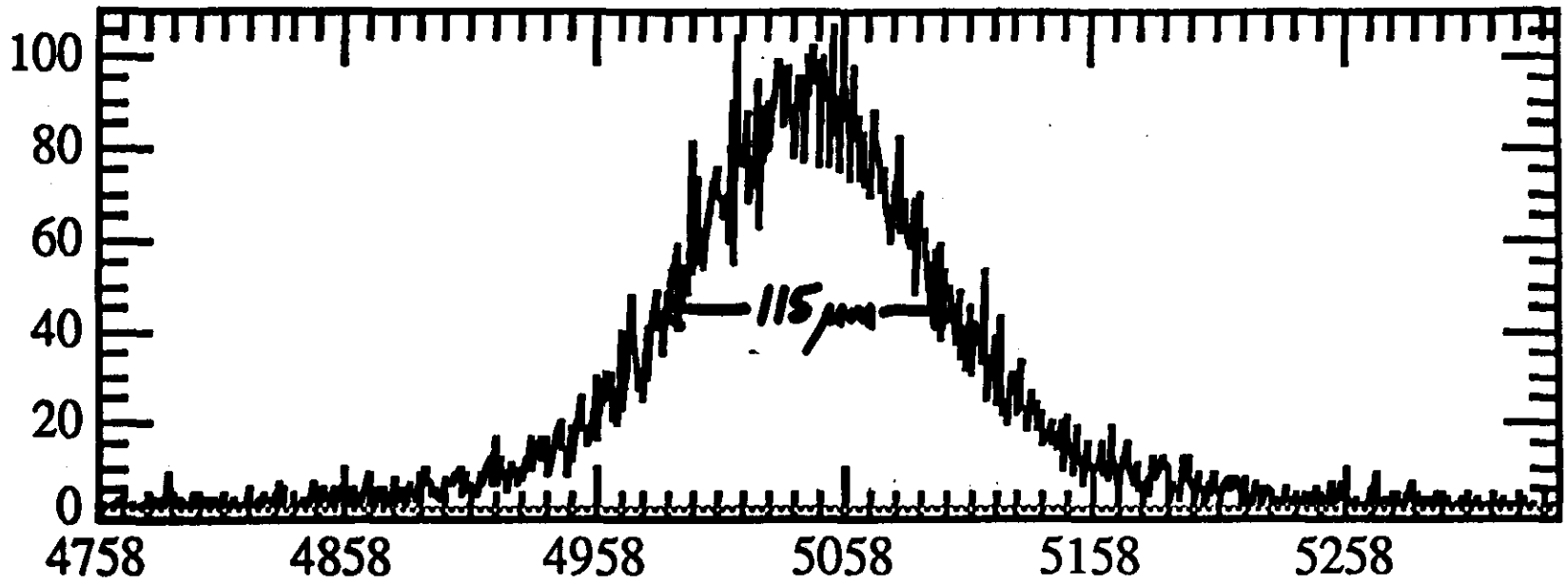

CF4 mixed in CO2 balance
Drift Speed [microns/ns]
% CF4
Preliminary data
Statistical error bars
E=3000 V/cm
E=4000 V/cm
0
20
40
60
80
100
120
50
55
60
65
70
75
80


42:58 CO2:CF4
Drift Speed [microns/ns]
E-Field [V/cm]
Preliminary data
Statistical error bars
B=8 KG
0
10
20
30
40
50
60
70
80
90
100
1000
2000
3000
4000
5000


CF4 mixed in CO2 balance
Lorentz Angle [degrees]
% CF4
Preliminary data
Statistical error bars
E=3000 V/cm
E=4000 V/cm
0
1
2
3
4
5
6
7
8
9
10
11
12
13
50
55
60
65
70
75
80


42:58 CO2:CF4
Lorentz Angle [degrees]
E-Field [V/cm]
Preliminary data
Statistical error bars
B=8 KG
0
1
2
3
4
5
6
7
8
9
10
11
12
1000
2000
3000
4000
5000


4.4
4.0
3.6
3.2
2.8
2.4
2.0
Gain/10^4
62% CF_4
38% CO_2
2600
2650
2700
2750
Anode–Cathode Potential (V)



$\frac{FWHM}{2.355} = 50\mu m$

Centroid (μm)-Va

4.95 keV X-Rays
<25μm wide collimator
beam centered on pad
3 pads used in CM

Collaboration with Taiwan

ACADEMIA SINICA

Research group of S.C. Lee et al

ITRI Industrial & Technical Research Institute
5500 Employees, ~300M$ Annual Budget
Has 11 Labs or Institutes

ERSO - Electronics Research Service Org.
MRL - Material Science Research Lab
MIRL - Precision Machining etc.
⋮

NSC National Science Council (Funding Agency)

TAIWANESE UNIVERSITIES

Students, research groups

SCOPE - We are proposing ~50M U.S.$ collaboration

HELP from T.D. Lee crucial at this time

Letter of Understanding

We, the National Science Council on behalf of the Academia Sinica, the Universities and the Industrial Technology Research Institute, and the Superconducting Super Collider, express definite intention to proceed in accordance with the Cooperative Agreement (as attached).

1. Upon the signing of this letter, the following will start immediately (with all terms defined in the attached document).

a) A start of the scientific exchange program

b) The startup of the strengthening of the research groups and their infrastructure in Taiwan

c) A start of the R&D (Research and Development) program and the collaboration on the engineering design of the GEM Central Tracker

2. Formal agreement will be signed upon the completion of due review process and approval from the relevant agencies of both parties. We expect this completion should not be later than February 1993.

Executed by the parties this 6TH day of NOVEMBER, 1992.

For Superconducting Super Collider Laboratory

R. Schwitters

For National Science Council

Yii Der Chuang

INTERLABORATORY COOPERATIVE AGREEMENT

BETWEEN

THE SUPERCONDUCTING SUPER COLLIDER LABORATORY
TEXAS, U.S.A.

AND

THE NATIONAL SCIENCE COUNCIL
TAIPEI, TAIWAN, REPUBLIC OF CHINA

A PROGRAM OF COLLABORATION ON THE SUPERCONDUCTING SUPER COLLIDER

Preamble

The Superconducting Super Collider Laboratory (SSCL) of the United States of America (USA) operated by the Universities Research Association, Inc.(SSCL/URA) and the Academia Sinica (AS), the Universities and the Industrial Technology Research Institute (ITRI) of Taiwan, R.O.C., hereinafter referred to as the parties, with the National Science Council (NSC) acting as the representative of the collaborating Chinese institutions in Taiwan.

Because of the importance that the AS/Universities/ITRI and the SSC Laboratory attach to the science and technology expected to come from the SSC Laboratory;

Because of desire of scientists in concerned institutions to share in the construction and utilization of the SSC Laboratory;

Because the AS/Universities/ITRI and the SSC Laboratory are developing a special agreement to facilitate and support Taiwanese collaboration at the SSC Laboratory;

Because the AS/Universities/ITRI and the SSC Laboratory would like to establish close and long-term cooperation on the SSC project;

The concerned institutions agree to the following:

Article I
Objective

The objective of the Interlaboratory Collaborative Agreement (Agreement) is to establish an arrangement for collaboration on the SSC scientific program, to advance the design and construction of the GEM detector, and to ensure the full exploitation of the scientific capabilities.

Tasks to be performed by the AS/Universities/ITRI and the SSC Laboratory under this agreement are subject to favorable review and approval of the individual proposals by concerned parties, the U.S. Department of Energy and the National Science Council in the R.O.C.

Article II
The Superconducting Super Collider

The Superconducting Super Collider (SSC) is an accelerator complex and laboratory which the United States Department of Energy (DOE), through its Management and Operating Contractor, Universities Research Association, Inc. (SSCL/URA), will build and operate in Ellis County, Texas, USA. The SSC is to provide access to interactions at a luminosity of $10^{33}cm^{-2}sec^{-1}$ of two colliding proton beams, each at the energy of 20 TeV, at up to four interaction regions in the collider ring to support physics research into the fundamental nature of matter and energy. The accelerator complex is to consist of five cascaded accelerators including a 600 MeV linear accelerator, an 11 GeV Low Energy Booster (LEB) synchrotron; a 200 GeV Medium Energy Booster (MEB)

synchrotron; a 2 TeV High Energy Booster (HEB) synchrotron; and the collider itself, which is two synchrotrons located in a common tunnel. Detectors are to be located in underground experimental halls at four primary interaction points. Present plans envision two large major detectors GEM and SDC, to be ready for data taking at the first operation of the SSC. The SSC Laboratory is to include the accelerator complex and offices, laboratories, work space, and technical support facilities for an estimated staff of 2200, including an estimated 500 visiting scientists from throughout the world.

Article III
Collaborating Taiwanese Institutions

The Academia Sinica (AS) is responsible for conducting basic science research in Taiwan, R.O.C.

The Industrial Technology Research Institute (ITRI) is responsible for conducting research and development relating to the construction of GEM/Central Tracker of the program.

The universities in Taiwan with strong interest in a program in physics shall join this collaborative agreement for training of Chinese physicists.

Article IV
Scope

This Agreement addresses the SSCL/URA collaborative tasks with the AS/Universities/ITRI during the period of design and construction of the SSC and the GEM detector and its utilization for the purposes of scientific research at the SSC.

The GEM detector is designed to measure all aspects of SSC collisions and in particular has the best performance possible on high energy photons, electrons and muons (the "Gammas", Electrons and Muons in the GEM acronym). These particles play a particularly important role in SSC physics. It consists of the Central Tracker where all charged particles are measured, a calorimeter, or energy measuring total absorption device, and the Muon Detector, which measures the penetrating charged particles in an array of tracking chambers, all in the magnetic field created by a very large superconducting solenoid. The electronics is designed to handle the flux of over 10^9 particles per second.

The Central Tracker is located at the center of the whole detector, immediately outside the vacuum pipe in which the collisions occur. It comprises a very high precision array of silicon detectors with strip electrodes and a gas tracking detector of fine granularity.

The scope of the effort covered by this agreement can be divided into three categories:

a) A program of scientific exchange between the institutions and universities in Taiwan and the U.S.. This program will include the exchange and training of graduate students, and an exchange of post doctoral and senior scientists and engineers.

b) Strengthening the experimental particle physics research groups at the Academia Sinica and selected universities in Taiwan and the building up of infrastructure at these institutions to support the effective operation of these groups.

c) A collaboration between the institutions and universities in Taiwan and the U.S. to design, construct and operate the Central Tracker of the GEM detector for the SSC. The physics goals and the conceptual design of the GEM detector are described in the "GEM Letter of Intent", November 30, 1991 and the Central Tracker is described in "The GEM Central Tracker", July 21, 1992.

Article V
Description

This agreement will cover approximately an eight-year period starting in 1993 and would consist of the full program outlined in "Article IV, Scope".

At the present time we envision the following financial arrangement to carry out this Collaboration:

a) The costs, including salaries, travel, tuition, etc. of Chinese graduate students and scientists from Taiwan visiting U.S. institutions and universities will be borne by Taiwan. It is anticipated that these costs will be of the order of the equivalent of US$2M over the duration of the agreement.

b) The costs of the build up of the research teams in Taiwan and their operating costs will be borne by Taiwan, and is expected to be of the order of the equivalent of US$6M.

c) The general principle relevant to the R & D, design, and construction of the GEM Central Tracker is anticipated to be that expenses incurred in or by Taiwan will be covered by Taiwanese funds and the effort at the U.S. institutions and universities will be supported by U.S. funds. The present estimate is that the amount of Taiwanese funds required for the Taiwanese part of the effort will be approximately the equivalent of US$56M, while the U.S. effort will be US$6M for the R & D effort and US$15M for the detector construction effort at the U.S. institutions and universities.

d) The entire Central Tracker will be assembled in Taiwan.

Actual budgets and schedules will be specified in future addenda to this agreement when such information becomes available and relevant.

Article VI
Termination

Once a Task is initiated, it is the intention of all of the institutions involved to complete the effort. In the event that this is not possible, either SSCL/URA or the AS/Universities/ITRI may terminate this Agreement, in whole or in part, upon six months advance written notice to the other.

Article VII
Force Majeure

The AS/Universities/ITRI and the SSC Laboratory shall be excused from any failure to perform which is beyond their control including but not limited to, delays in delivery relating to war and to causes such as fires, floods, or natural disasters.

Article VIII
General Provisions

1. Activities under this Agreement, including the provision of financial support, are subject to applicable national laws and regulations, and shall be subject to the availability of appropriated funds.

2. The management structure for carrying out this collaboration will be specified in a future addendum to this agreement.

3. All questions relating to the interpretation or application of the Agreement that arise during the period it is in force shall be settled by mutual agreement. Failure to reach agreement shall be referred to the Director of the SSC Laboratory and the Chairman of the NSC and Presidents of the AS/ITRI.

GEM Central Tracker Engineering Responsibilities
Mechanical--Group A
Overall Coordination: R. Barber/C. Hsu (CMS)

TASK	U.S.A.	TAIWAN
1) Silicon Tracker	T. Thompson	C.L. Wu
a) Support & cooling rings, ladders, etc.	T. Thompson, R. Barber	Chung-Lin Wu, Larry C.C. Tang
b) Support frame	T. Thompson	Y.C. Chen
c) Cooling & gas flow	R. Barber	Chung-Lin Wu, Larry Tang, Ping-Ho Sam Shih
d) Alignment & monitoring	J. Hanlon	Li-Shing Lee
e) Cabling	R. Barber, B. Cooke	Jong-Ming Liu
2) IPC Tracker	W. Emmet	L.S. Lee
a) Chamber modules	W. Emmet, D. Pilon	Chung-Lin Wu, Jau-Liang Chen, Larry Tang
b) Support structure	D. Pilon, T. Thompson	Chung-Lin Wu
c) Cooling and gas flow	R. Martin	Ping-Ho Sam Shih
d) Alignment & monitoring	J. Hanlon	Li-Shing Lee
e) Cabling	W. Emmet	Jong-Ming Liu

Totals: (6) U.S. Engineers, (7) Taiwanese Engineers

GEM Central Tracker Engineering Responsibilites
Electronics--Group B
Overall Coordination: Jim Musser/Julia Fu-Su

TASK	U.S.A.	TAIWAN
1) Silicon Detector	S. Hahn	Julia Fu-Su
a) Detectors	R.T. Kollipara	W.C. Tsai
b) Front end amplifiers	S. Hahn	S.W. Chang, Sebastian Liau
c) Digital pipeline (CMOS1)	B. Cooke	Steven Yang, Peter Chou
d) Readout controller (CMOS2)	B. Cooke, R.T. Kollipara	
e) Multichip module (MCM)	B. Cooke	Fang-Lin Chao, H.C. Chang, Mei-Ling Chou
f) Fiber optics/Power Dist.	B. Cooke	W.S. Chan
2) IPC Electronics	(Jim Musser)	S.K. Peter Chou
a) Front end amplifiers	P. O'Connor	S.W. Chang, Sebastian Liau
b) Switched capacitor array	C. Britton	Peter Chou
c) ADC, Multiplexer	J. Mann	Steven Yang
d) Readout controller	C. Bender	
e) Fiber optics/Power Dist.	C. Bender	W.S. Chan

Totals: (7) U.S. Engineers, (11) Taiwanese Engineers

GEM Central Tracker
Proposed Plan for Collaboration on R&D and Engineering Design

Approximately two-year period - 1993 & 1994

1. **Sign Agreement to formalize Phase I collaboration on R&D effort and engineering design.**

2. **Consolidate project-oriented working groups to start collaboration**

   a) Identify U.S. and Chinese group leaders
   b) Group members

3. **Each working group (in coordination with overall Central Tracker Management) should start in November 1992 to**

   a) Set up schedule of short and long visits back and forth
   b) Develop work plan of activities
   c) Propose a schedule for the work plan
   d) Define milestones for "Deliverables" i.e. measureable signs of progress such as specific designs, prototypes, test results, etc.

4. **Define Subsystem Prototype program**

   a) Identify person in charge
   b) Institutional responsibilities
   c) Develop schedules & milestones

5. **Sign Phase II of the Agreement**

6. **Develop Fabrication Plan for the Central Tracker**

   a) Define subsystems or tasks
   b) Identify persons in charge of each subsystem
   c) Propose institutional responsibility for each subsystem
   d) Develop fabrication schedule for each subsystem
   e) Define milestones to measure progress

Silicon Microstrip Detectors
R&D Schedule and Milestones

J. Drau
Oct 26, 92

Proposed ERSO GEM Silicon Microstrip R&D Plan

Fabricate 1st Microstrips based on 7.93 x 4.01 cm2 design (minimize strip resitance)	8/92-12/92
Develop back-to-back 2 chip bonding with 5 micron precision	12/92-3/93
Develop rad-hard poly resitance of 500kOhm	1/93-4/93
Study effects of edge defects on wafer yield and strip reliability	1/93-4/93
Fabricate 1st GEM specific microstrip prototype	3/93-5/93
Study microstrip characteristics (leak current, depletion voltage, breakdown voltage, poly resist, etc) vs. radiation exposure and develop hardening procedures	4/93-9-93
Fabricate 2nd GEM specific microstrip prototype	9/93-11/93
Study microstrip characteristics (leak current, depletion voltage, breakdown voltage, poly resist, etc) vs. radiation exposure and develop hardening procedures	11/93-4-94
Fabricate Final GEM specific microstrip prototype	4/94- 6/94

MILESTONES

Deliver 7.93 x 4.01 cm2 microstrip detector to Oregon (goal: strip res: 10 ohm/cm)	Jan 15, 1993
Define GEM silicon detector design	Feb 31, 1993
Deliver 1st GEM specific prototype	May 1, 1993
Define revised GEM detector design	Oct 15, 1993
Deliver 2nd GEM microstrip prototype	Jan 1, 1994
Define Final GEM detector design	June 15, 1994
Deliver Final GEM Prototypes	Aug 1, 1994

10-24-92
S. Hahn

R&D Milestones for Si-Tracker Electronics Development

Item	Milestone Date	Notes
Bipolar VLSI	Jan 1993	Fabrication of semi-custom (single-channel) chips
	Mar 1993	Complete test for semi-custom chip, including radiation-hardness
	June 1993	Test of semi-custom chips with Si-strip detectors
	Aug 1993	Complete prototype chip design with simulation results and layout
		Place order for a prototype quantity of wafers
	Nov 1993	Complete wafer and Si-strip combination test plan and test setup
	Dec 1993	Prototype wafer ready for test
	Mar 1994	Prototype test with Si-strip detector done, including radiation hardness
		Final VLSI design released for production fabrication
CMOS-1 VLSI	Apr 1993	Finalize chip architecture with complete simulation results
	Aug 1993	FPGA implementation of subcircuits
	Oct 1993	Complete Test of FPGA implementations with Si-detector+bipolar combination
	Jan 1994	Complete prototype VLSI design with simulation results and layout
		Release of prototype design for fabrication
	Apr 1994	Complete wafer test plan and setup
		Prototype wafer ready for test
	July 1994	Complete prototype wafer test including radiation hardness
	Sep 1994	Release final design for fabrication
CMOS-2 VLSI:	Similar to CMOS-1 Chip milestones, but with 2-month approximate delay.	

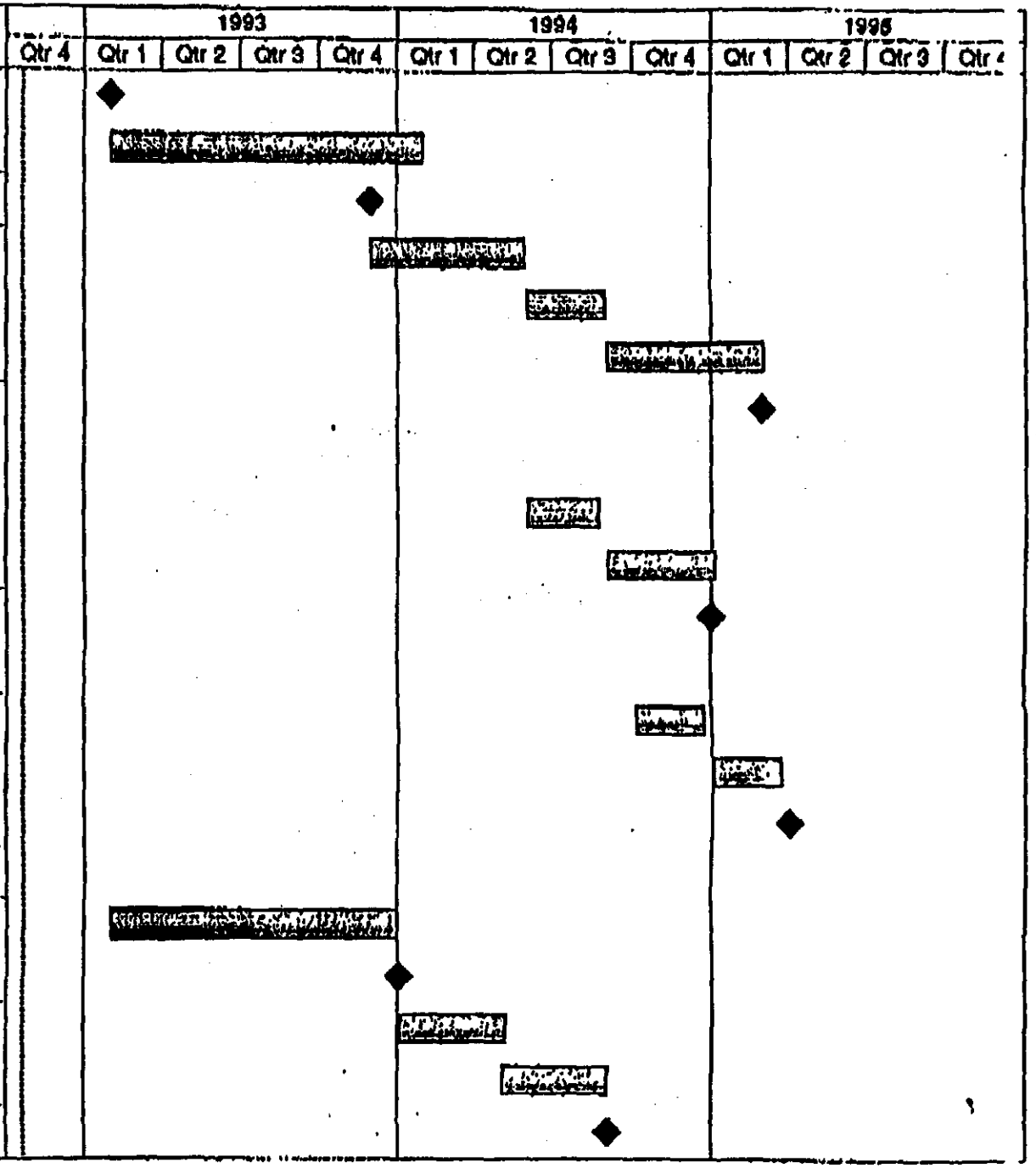
MCM:	Design of the prototype MCM is to start as soon as the prototype chip designs for bipolar and CMOS are reasonably settled. It is, however, necessary to produce some technology demonstration MCMs of dummy lines and blank chips by July 1993 to ensure the availability of the services for the final design. The demo MCM should contain representative number of connections, components and power dissipation. The prototype MCMs should be ready for test by June 1994 to receive the prototype VLSIs	
Fiber Optic Links	Mar 1993	Prototype design complete
	July 1993	Prototype fabrication complete
	Dec 1993	Prototype test complete connected with FPGA , including radiation-hardness Release final design for fabrication
Clock Distributor:	Similar to Fiber Optics Schedule	

Note: A *prototype* is an item which is as close to the final product as the designer can produce within budget, is synonymous with *pre-production unit*, and is used to determine any performance and manufacturability issues prior to final production commitment.

IPC Electronics - [illegible]

J. Hussey Oct 26 '92

ID	Name	Duration
1	Start Rad-Hard CMOS Develc	0d
2	Develop Rad-Hard CMOS	261d
3	Design Rules Available	0d
4	Simulate/Layout Rdout IOs	130d
5	Fab Rdout ICs - prototypes	66d
6	Test Rdout IC prototypes	191d
7	Ready Final IO Design Phase	0d
8		
9	Design/Layout MCM	60d
10	Fab Prototype MCM	90d
11	Prototype MCM Available	0d
12		
13	Design/Layout Rdout Board	60d
14	Fab Prototype Rdout Board	60d
15	Rdout Board Prototype Avail.	0d
16		
17	Study Rdout Link Options	240d
18	Define Rdout link Protocol	0d
19	Design Reciever Card	90d
20	Fab Reciever Card	90d
21	Prototype Reciever Card Aval	0d



The Central Tracking Group

Academia Sinica, Taiwan, R.O.C.
A. Antos, Y.C. Chen, T.L. Chu, M. Huang, S.C. Lee, A. Sumarokov, P.K. Teng, M.J. Wang, P. Yeh

Brookhaven
P.O'Connor, V. Radeka, G. Smith, B. Yu

Indiana University
C. Bender, C. Bower, M. Gebhard, R. Heinz, S. Mufson, J. Musser, J. Pitts

Industrial Technical Research Institute, Taiwan, R.O.C.
W.S. Chan, H.C. Chang, S.W. Chang, F.L. Chao, J.L. Chen, Y.C. Chen, M.L. Chou, S.K. Chou, J. Fu-Su, D. Hsing, C. Hsu, L.S. Lee, S. Liau, J.M. Liu, P.H. Shih, C.C. Tang, W.C. Tsai, C.L. Wu, S. Yang

Los Alamos
R. Barber, J.G. Boissevain, M. Brooks, D. Brown, M. Cafferty, B. Cooke, K. Fuller,, S.F. Hahn, J. Hanlow, C. Johnson, J. Kapustinsky, W.W. Kinnison, D.M. Lee, R. Martin, G.B. Mills, R. Prael, G.H. Sanders, W.E. Sondheim, T. Thompson, J. VanAnne, L. Waters, B. Weinstein,

Moscow State University
G. Bashindzhagyan, Y. Fisyak, D. Karmanov, E. Kuznetsov, A. Larichev, M. Merkin, A. Savin, A. Voronin, V. Zhukov

Nanjing University
E. Chen, D. Gao, M. Qi, D.X. Xie, N.G. Yao, Z.W. Zhang

Rutgers University
P. Jacques, M. Kalelkar, R.J. Plano, P. Stamer, G.B. Word

SSCL
K. Morgan, I. Sheer, J. Thomas

University of Albany
M.S. Alam, I.J. Kim, B. Neman, J. O'Neill, H. Severini, C.R. Sun, L. Zhichao

University of Michigan
D Kouba, D. Levin, J. Mann, S. McKee, G. Tarle

University of Oregon
A. Arodzero, J. Brau, R. Frey, K. Furuno, R.T. Kollipara, D. Strom

Yale University
C. Baltay, M.B. Barakat, R. Ben-David, , W. Emmet, S. Manly, D. Pilon, S. Sen, John Sinnott, J. Turk, E. Wolin

Central Tracker Steering Committee

C. Baltay, J. Brau, D. Hsing, D. Lee, S.C. Lee, K. Morgan, J. Musser
Chairman: C. Baltay

Total of 111 scientists

Institutional & Personal Responsibility Matrix

Area of Effort	Person Responsible	Institution Involved
Silicon Detector	D. Lee, J. Brau	Los Alamos Nat. Lab. U. of Oregon Taiwan Moscow State
-Mechanical	T. Thompson	
-Electronics	S. Hahn	
Pad Chambers	J. Musser, C. Baltay	Brookhaven Nat. Lab. Los Alamos Nat. Lab. Yale U. Indiana U. U. of Michigan Rutgers U. Taiwan
-Mechanical	W. Emmet	
-Electronics	J. Musser, P. O'Connor	
Integration into GEM	K. Morgan R. Barber	All
Simulations	S. McKee	All
Beam Tests	K. Morgan	All
Budgets	H. Pretty	All

R & D Requests for FY93

GEM Central Tracker

October 6, 1992

GEM Central Tracking - FY93 R & D Request
(in thousands of dollars)

	Contact	Engineering Design	R&D M&S	Total
1. Central Tracker (Not including Electronics)				
a) Silicon Tracker				
Los Alamos	D. Lee	476	417	893
Univ. of Oregon	J. Brau	85	115	200
Moscow State Univ.	G. Bashind-zhagyan.	0	20	20
b) Pad Chambers				
Los Alamos	R. Barber	140	0	140
Yale University	C. Baltay	94	104	198
Univ. of Michigan	G. Tarle	55	55	110
SUNY Albany	M.S. Alam	0	40	40
c) Test Beam Work				
SSC	K. Morgan	0	155	155
SUNY Albany	M.S. Alam	0	40	40
		850	946	1,796
2. Central Tracking Electronics				
a) Silicon Tracker				
Los Alamos	S. Hahn	560	570	1,130
Univ. of Oregon	J. Brau	50	50	100
b) Pad Chambers				
Brookhaven	P. O'Connor	120	25	145
Indiana Univ.	J. Musser	85	110	195
Oak Ridge	C. Britton	120	105	225
SLAC	G. Haller	120	30	150
Univ. of Michigan	G. Tarle	84	20	104
		1,139	910	2,049