GEM TN-92-218

Muon System Review Meeting - SSCL

October 6, 1992

Abstract:

Agenda, attendees, and presentations of the GEM Muon System Review Meeting held at the SSC Laboratory on October 6, 1992. Agenda items are: General Remarks; PDT Presentation - Discussion; PDT-JINR; LSDT Presentation - Discussion; CSC Presentation - Discussion; RPC Presentation - Discussion; Engineering Assessment Report; Electronics Cost Comparison Report; and External Comments and Discussion.

Technology Discussions 10/6/92

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General Remarks

F. E. Taylor

F.E.Taylor

GEM Muon System Technology Review 10/6/92

Panel of Experts
Jim Branson, Chris Fabjan, Ken Foley, Dave Nygren

Definitions:

Proponent Reports are expected to include discussion of the merits of the particular technology, R&D results, how the technology would function in the GEM Muon system, costs, feasibility, and strength of supporting group.

Discussions associated with Proponent Reports are expected to be confined to the relative merits and demerits of particular technology.

The Engineering Assessment will be a standardized comparison of mechanical aspects of each technology with a focus on alignment scheme, robustness, fabrication techniques.
R. Sawicki - Chairperson, M. Gamble, R. Humphreys, C. Johnson, F. Nimblett.

The Electronics Cost Comparison will be a comparison of the relative costs of drift technology with analog technology.

External Comments will allow those outside (or not directly involved) in the other proposals to raise strengths and weaknesses of all proposals. The request to speak can be made on 10/6/92 (in our usual free-style manner), although priority will be given to those who ask prior to the meeting. Written reports would be appreciated because of their greater impact.

October 6, 1992 AGENDA

(1) General Remarks - ground rules	8:00 - 8:30
(2) PDT presentation (Bromberg)	8:30 - 9:15
PDT discussion	9:15 - 9:45
(3) PDT-JINR (I. Golutvin)	9:45 - 10:00
(4) LSDT presentation (Osborne)	10:00 - 10:45
LSDT discussion	10:45 - 11:15
(5) CSC presentation (Whitaker)	11:15 - 12:00
CSC discussion	12:00 - 12:30
LUNCH	12:30 - 13:00
(6) RPC presentation (Wuest)	13:00 - 13:45
RPC discussion	13:45 - 14:15
(7) Engineering Assessment Report (Sawicki)	14:15 - 15:15
(8) Electronics Cost Comparison Report ((Marlow))	15:15 - 16:00
(9) External Comments and discussion (Group)	16:00 - 17:00

Calendar of Muon Chamber Technology Decision Process

Inputs:

Proponent Reports
Panel of Experts
Engineering Assessments
Electronics Cost Assessments (not received 10/2/92)
Discussion at 10/6/92 Meeting

Calendar of Events:

9/28/92	Reports are due (delivered to Expert Panel, Muon Steering Committee Members, and GEM Spokesmen).
8:00 AM 10/6/92	Presentations of Technology Proponents, Engineering, and Electronics Cost Reports.
5:00 PM 10/6/92	Expert Panel meets with Muon Steering Committee, and GEM Spokesmen.
8:00 AM 10/7/92	Expert Panel Executive Meeting
9:00 AM 10/7/92	Muon Steering Committee meets with Expert Panel and GEM Spokesmen.
11:00 AM 10/7/92	Muon Steering Committee Executive Session. Expert Panel is available for consultation.
1:00 PM 10/7/92	Recommendation presented to Muon Group for discussion.
10/8/92 12:45 PM	Recommendation presented to GEM Collaboration Council.
4:00 PM 10/8/92	Recommendation presented to GEM Executive Committee.

Expectation of this Meeting

- Challenge to Technology Proponents:

1. Show construction details of chambers (engineering drawings).
2. Describe how chambers are to be employed in muon system - their sizes, and numbers, and how they will be aligned.
3. Describe what chambers have been constructed and tested.
4. What spatial resolutions from cosmics and/or test beam data have been measured ? Discuss how corrections (geometric, L-angle) are to be made.
5. What are the rate limitations, sensitivity to backgrounds, pattern recognition capabilities of your technology ?
6. Describe trigger scheme for yourtechnology.
7. Outline costs of complete system - including electronics.

Issues for this Meeting

- Barrel Issues:

1. Which is the more attractive drift technology - PDT or LSDT ?
2. Will the RPCs perform in terms of jitter, background sensitivity, and longevity ?
3. In case RPCs are not accepted, is there an alternative trigger for the drift option ?
4. Will the CSCs perform in barrel in terms of resolution, alignment, and costs ?

- Endcap Issues:

1. Will the CSCs perform in terms of resolutions, background, and costs ?
2. Are there any alternatives to the CSCs in the Endcaps ?

Suggested Rules of Game

- Rating of technologies made on 10/6/92 defines **Baseline 2**. Thereafter engineering effort focused by leading technology(s).

- All technologies are carried until TTR tests (as defined by R&D FY92 Program) are completed.

- Final decision of Technology for TDR follows the TTR tests and completion of FY92 R&D program.

- No new Chamber R&D funds until above are finished.

Muon Chambers at the TTR

Technology	Chamber size	TTR delivery date
PDT-JINR	1 m x 4 m x 8 layers	7/28/92 (delivered)
PDT-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	(under construction)
RPC	1 m x 2 m x 2 layers	9/29/92 (delivered)
CSC-BU	0.5 m x 0.6 m x 3 x 2 layers	RD5-CERN (delivered)
CSC-BU	0.5 m x 0.6 m x 3 x 2 layers	
CSC-BNL	0.6 m x 0.6 m x 2x4 layers	
CSC-BNL	1 m x 1.8 m x 4 layers	
CSC-UH	0.5 m x 1 m x 3 layers	9/92 (delivered)
CSC-JINR	1.1 m x 1.5 m x 2 layers	(under construction)

PDT Presentation

Carl Bromberg

A Muon Tracking System for the GEM Detector Using Pressurized Drift Tubes

Discussion of the Z-Coordinate Measurement with Stereo PDT

Discussion of a High-Speed Drift Tube Trigger

Discussion of PDT for the Endcap

October 1, 1992

Prepared by C. Bromberg
for the PDT Collaboration

Pressurized Drift Tubes for the GEM Muon Detectors

Collaboration

US: Michigan State University, Boston University
Foreign: Dubna, Moscow State University, +others, ITEP and Institutions From China

Track Detector Experience

US: large MWPCs (4 and 6 m^2), 8 planes
Drift Tube Chambers (10 m^2, 1.6 cm dia. tubes), 8 planes
for Fermilab Experiment E706, 1982 to present.

Foreign: large MWPCs (4.5 m^2) 150 planes
Drift Chambers (8 m^2) 100 planes
Drift Tubes (25 m^2) 40 planes
Drift Tubes (16 m^2) 50 planes

Facilities:

US: 400 m^2 of construction space, 200 m^2 with 5-ton crane coverage.

1.6 m x 4.8 m optical flat for prototype chamber construction.

CAD Electronics Design Facility, 20 Fastbus-type designs in last 5 years.

Foreign: >2000 m^2 of construction space.

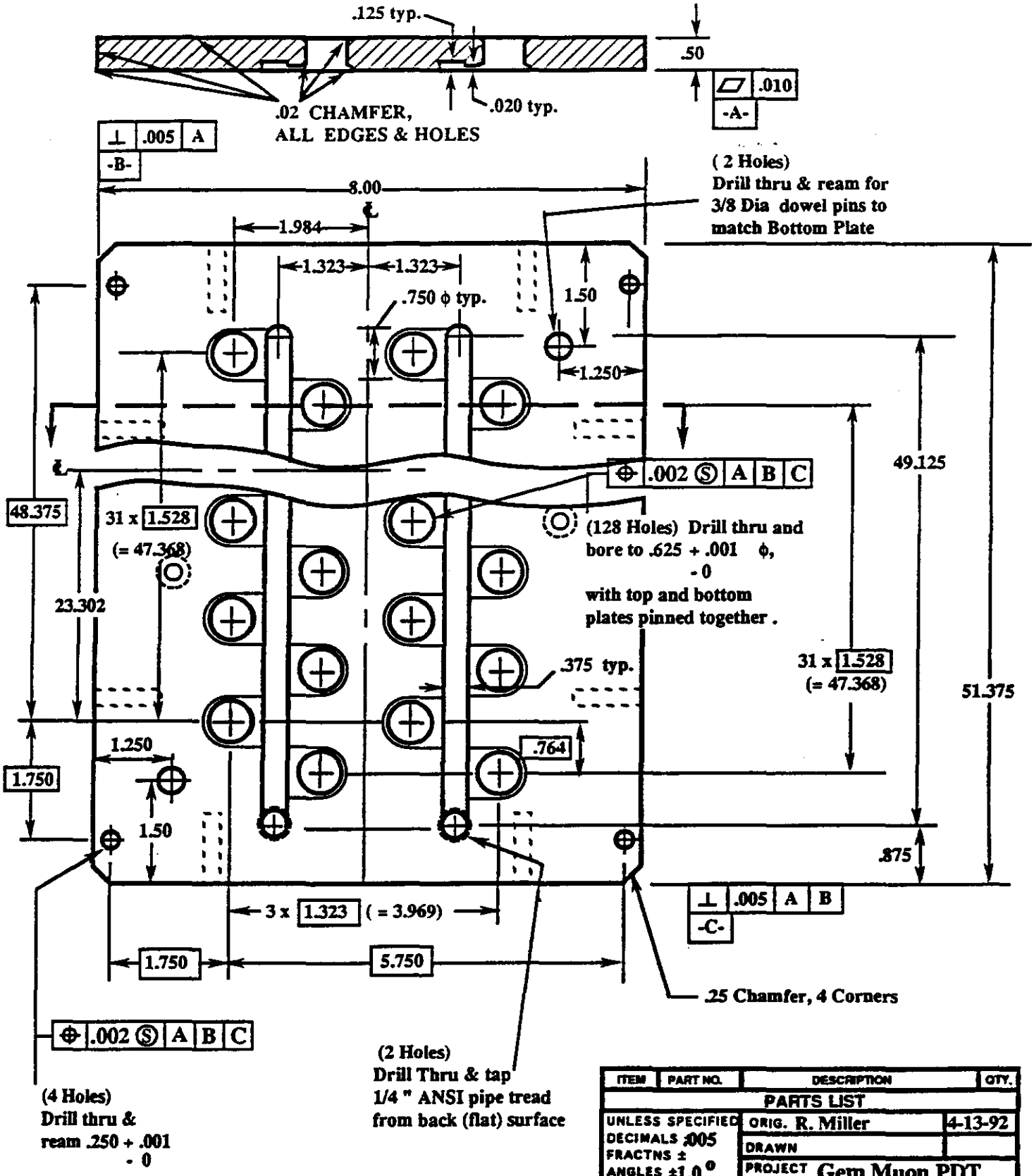
Many optical flats for assembly.

Tube washing facility.

Engineering and technical staff with 15+ years of experience in wire chamber construction and operation.

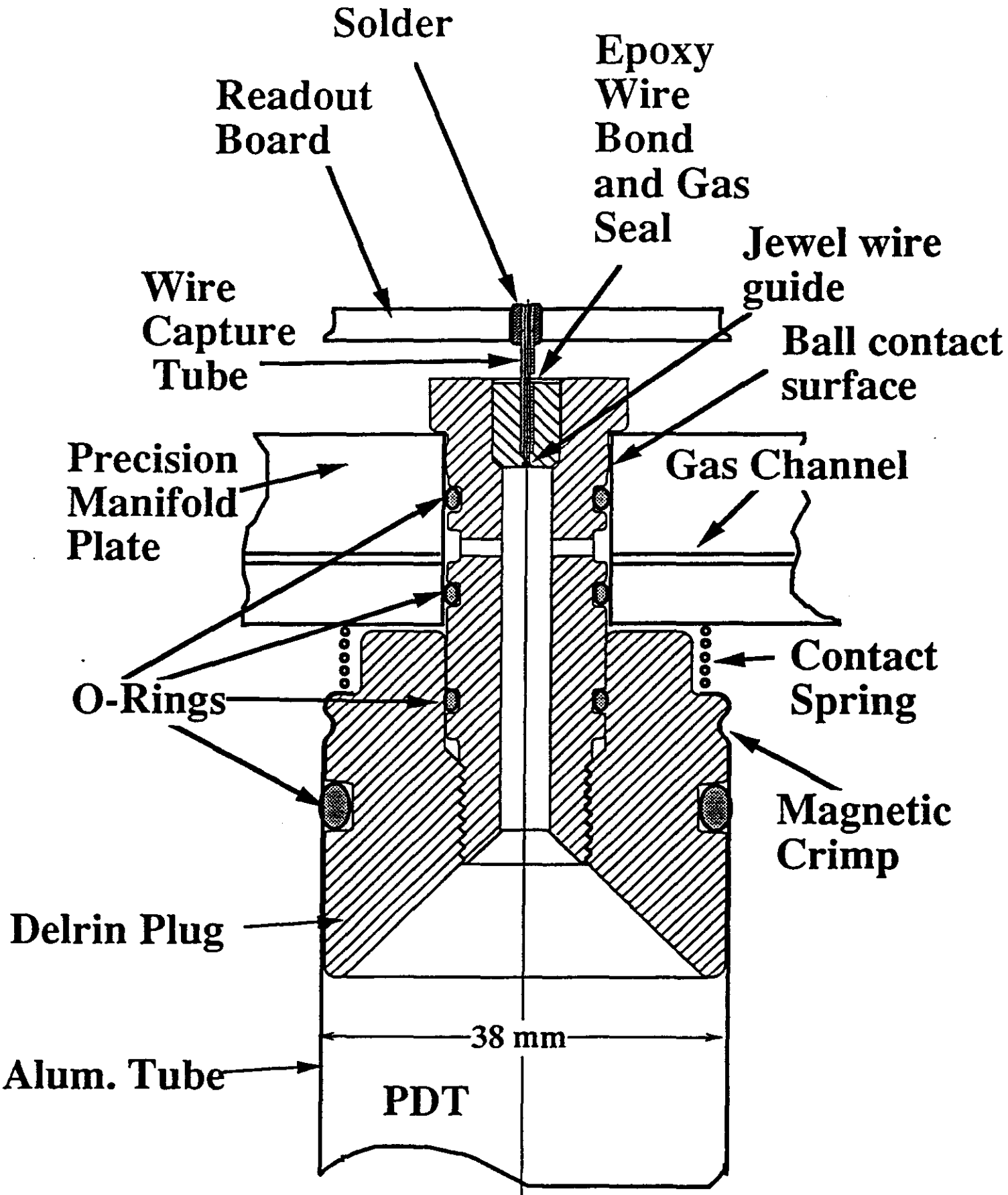
PDT Characteristics

- Proven high precision technology
- The wire tension is stable
- Non-flammable drift gas and <100μ resolution
  Less susceptible to neutron induced backgrounds • High rate capability, low gas gain
- Reliable gas tight seals, secondary gas barrier without need to compensate for atmospheric pressure changes.
- Wires are physically and electronically isolated
- Symmetry of the round tubes for ExB effects
- Laminated tube structure, very strong, very light, supported only at the ends.
- Alignment of the chamber wires is completely determined from the ends. Sides of a PDT chamber to be free from any interference
- Assembly procedure requiring a minimum of technical skill, without jigs, that will be fast.
- Very compact end treatment with a minimum of dead space
- Precision manifold plates of any size (or shape) can be fabricated by splicing smaller plates together on a dedicated jig.



ITEM	PART NO.	DESCRIPTION	QTY.
PARTS LIST			
UNLESS SPECIFIED DECIMALS ±.005 FRACTNS ± ANGLES ±1.0° BREAK ALL EDGES DO NOT SCALE DWG		ORIG. R. Miller	4-13-92
		DRAWN	
		PROJECT Gem Muon PDT	
		MATERIAL 1/2 Alum Tooling Plate MIC-6	
MICHIGAN STATE UNIVERSITY HIGH ENERGY PHYSICS			
TITLE Top Mainfold Plate-Pattern A			
DWG. NO. HEP01-022-272-A		REV. E	SCALE 1:2

Fig. 4


Solder
Epoxy
Wire
Bond
and Gas
Seal
Readout
Board
Jewel wire
guide
Wire
Capture
Tube
Ball contact
surface
Precision
Manifold
Plate
Gas Channel
Contact
Spring
O-Rings
Magnetic
Crimp
Delrin Plug
38 mm
Alum. Tube
PDT

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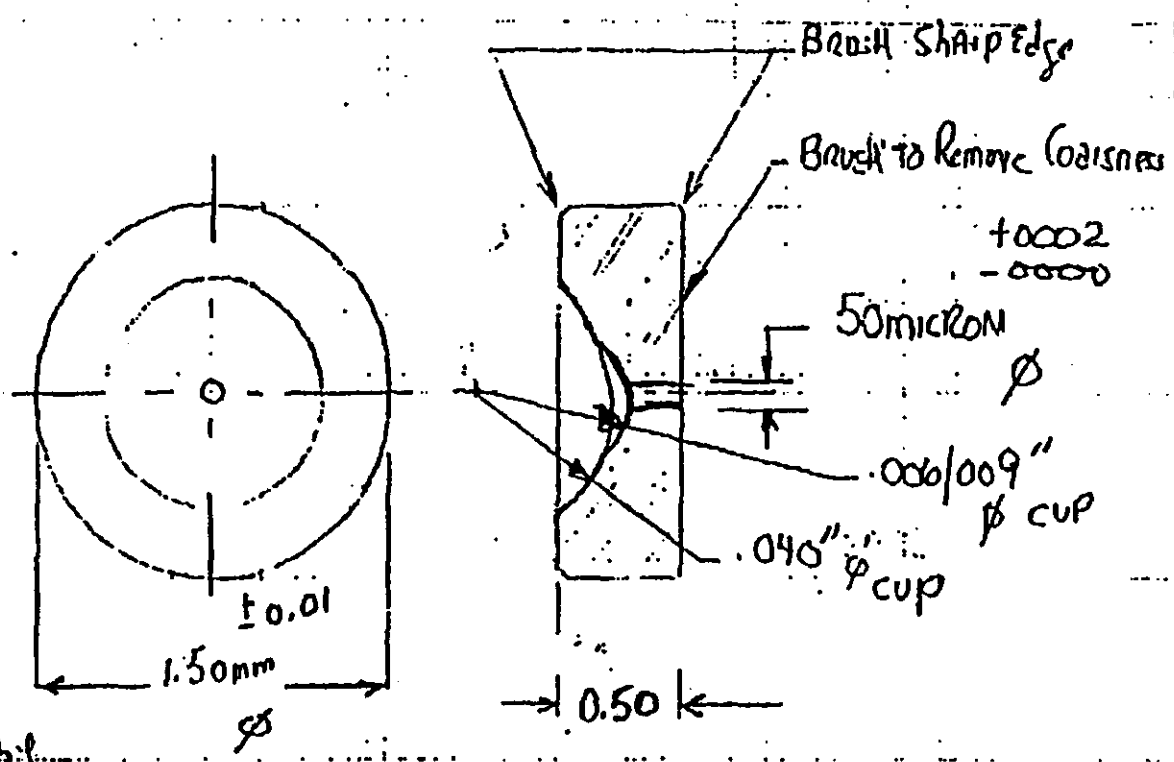


Holes:
Sapphire or Ruby
No Polish Required, Brush Face to Remove Coarsness
Id Smooth Only
Concentricity Id to O.D. within 10 microns

REVISIONS		
LTR	CHANGE	DATE

NOTATIONS UNLESS SPECIFIED

TOLERANCES:
FRACTIONS
.X
.XX
.XXX
ANGLES

CONCENTRICITY OF ID TO OD ____ TIR
____ BURR FREE 10 MAG.

DWNG: 2
DATE: 2/14/92
CK'D:
DATE: / /

MAT'L: Ruby or Sapphire
FINISH: Clear Smooth
TITLE: Orifice

BIRD PRECISION
One Spruce Street, P.O. Box 569
Waltham, MA 02254
Telephone (617) 894-0100
Fax (617) 894-5308

RB-201043 | REV:

FROM BIRD PRECISION 03/03/92 09:12 P. 2 TOTAL P. 2

Wire Positioning Accuracy

Both 20μ systematic and 20μ random errors on the wire locations have been achieved in a large PDT prototype, and are sufficient to meet or better all specifications for GEM muon detectors.

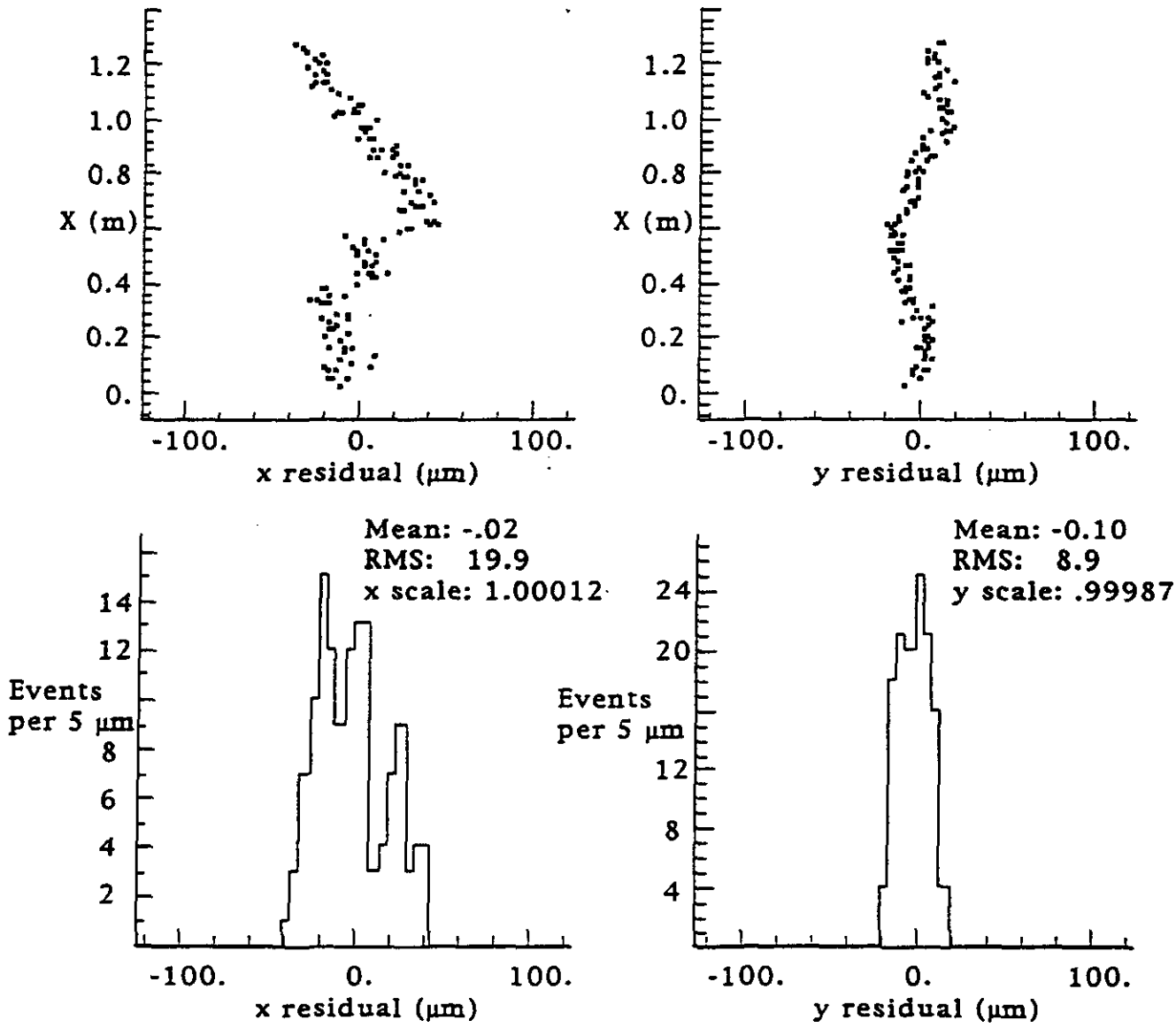
There are no other contributions to the systematic error in the wire placement.

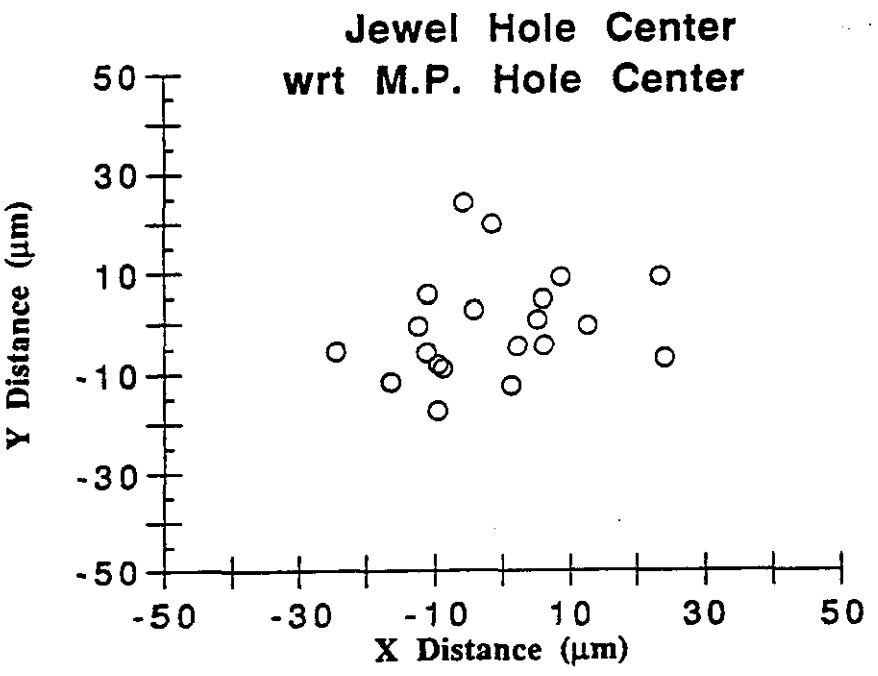
The existing plates of the MSU prototype are already within the GEM systematic error limits and they can be made better, cheaper, and larger.

No internal alignment procedures are necessary during or after assembly to achieve the stated resolutions.

Aug. 4, 92

Hole Spacings, PDT Manifold plate #1




Jewel Hole Center
wrt M.P. Hole Center
Y Distance (μm)
50
30
10
-10
-30
-50
-50
-30
-10
10
30
50
X Distance (μm)

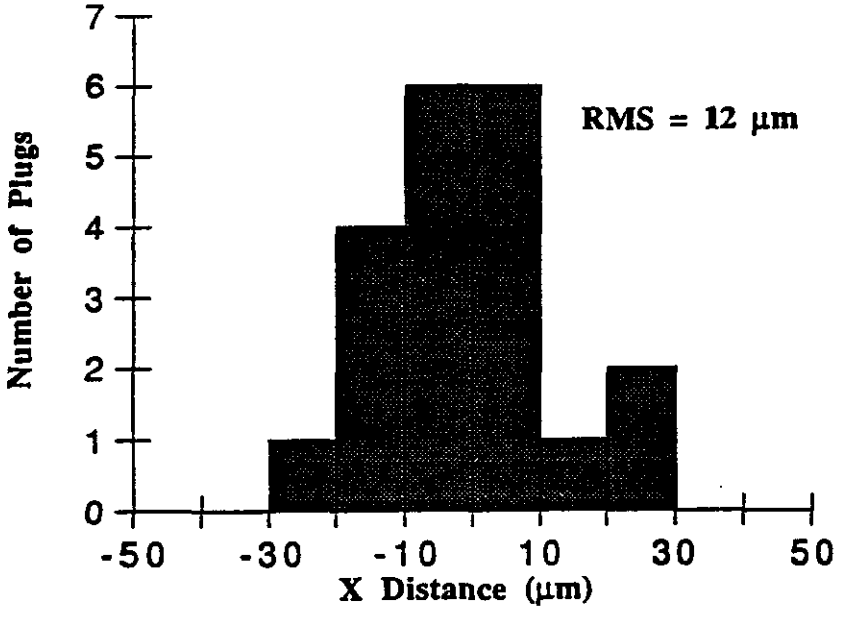

Number of Plugs
7
6
5
4
3
2
1
0
RMS = 12 μm
-50
-30
-10
10
30
50
X Distance (μm)

Fig. 14

Simple Assembly Procedures

Two part plug: Threaded End Plug and Hollow Bolt.

The Manifold plates are rigidly mounted to assembly table.

One layer a time placed between the manifold plates.

The bolts inserted through the manifold plate into plugs.

O-rings seal the bolt in the manifold plate and in the plug.

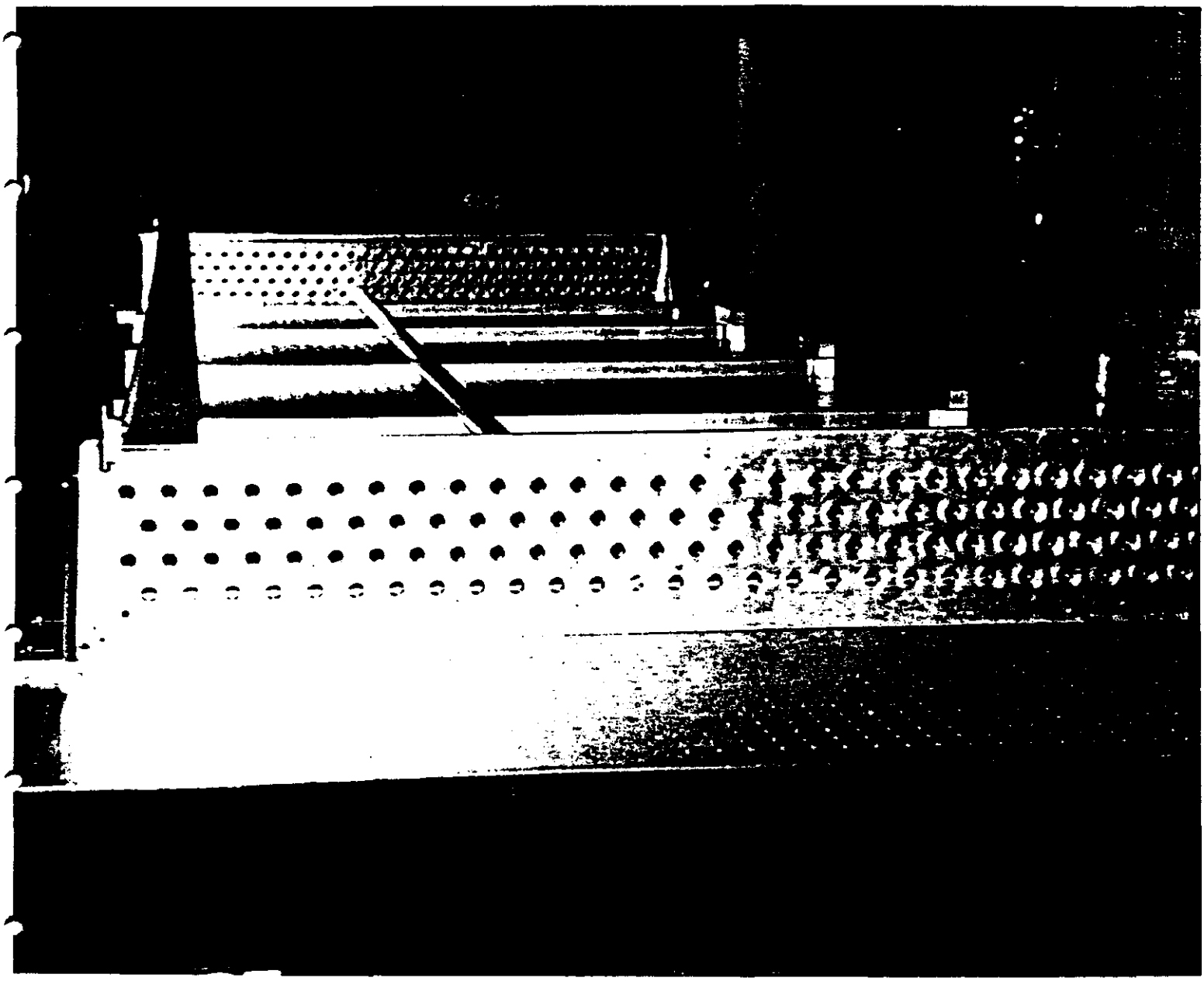
Leak Testing of Tubes

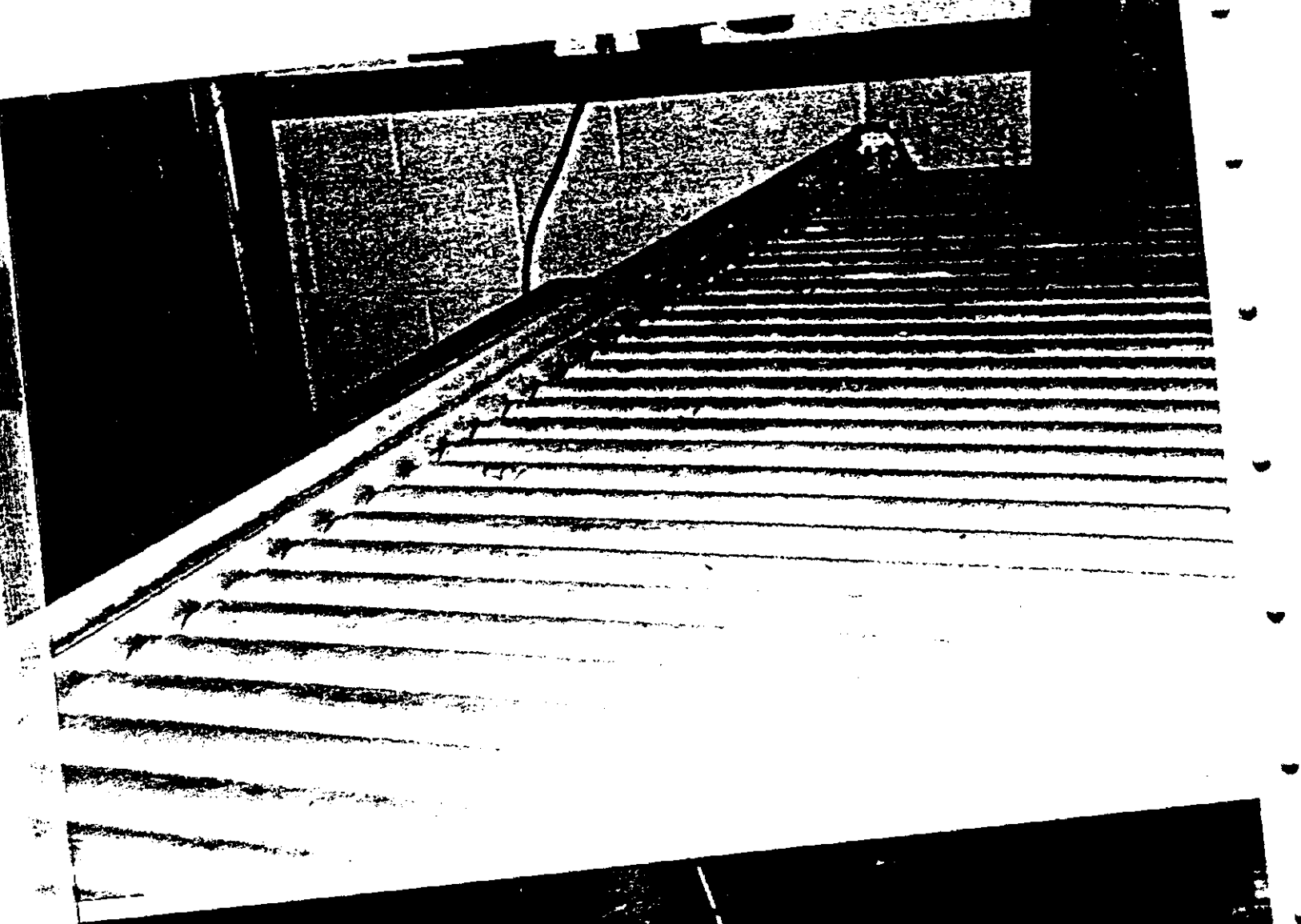
Tubes checked for leaks prior to assembly:

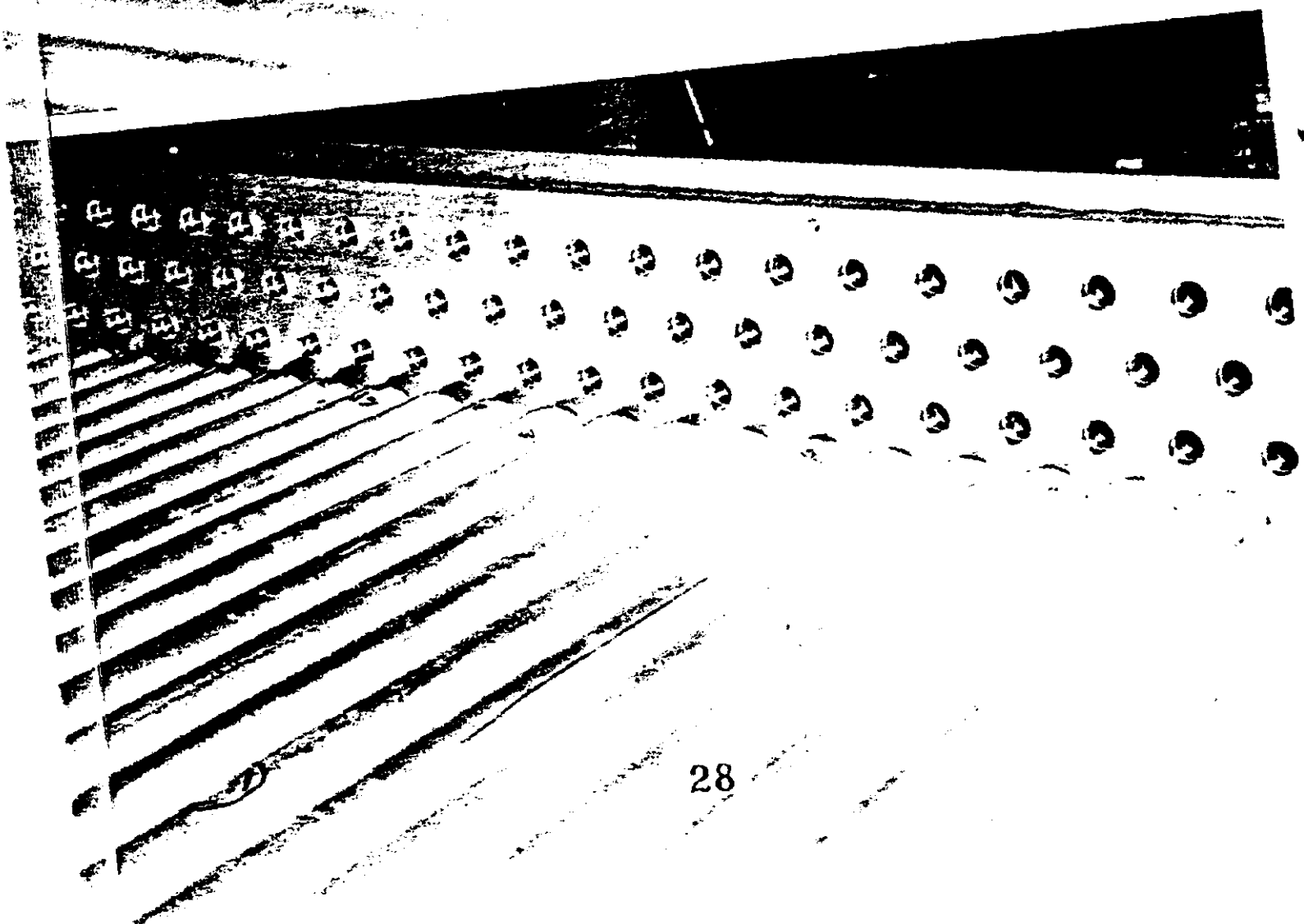
50 PSI for <u>one minute</u> and look for 0.5 PSI drop.
3 tubes out of 150 tested had cracks in the aluminum
No O-ring leaks seen.

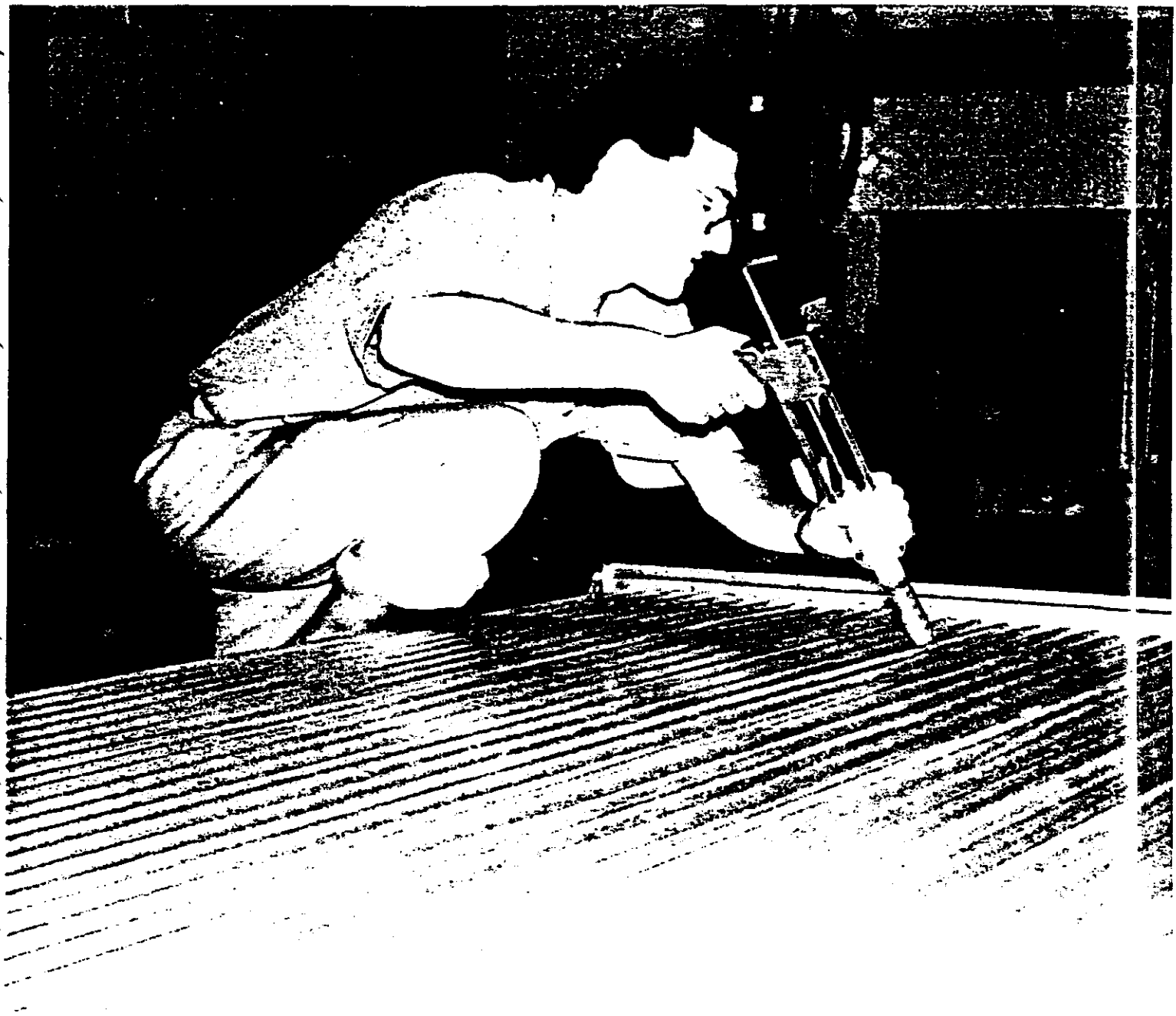
Leak test sensitivity was too low!
Only one tube leaking just below test level leads to a total leak rate of 0.5%/hour. This is what we observe.

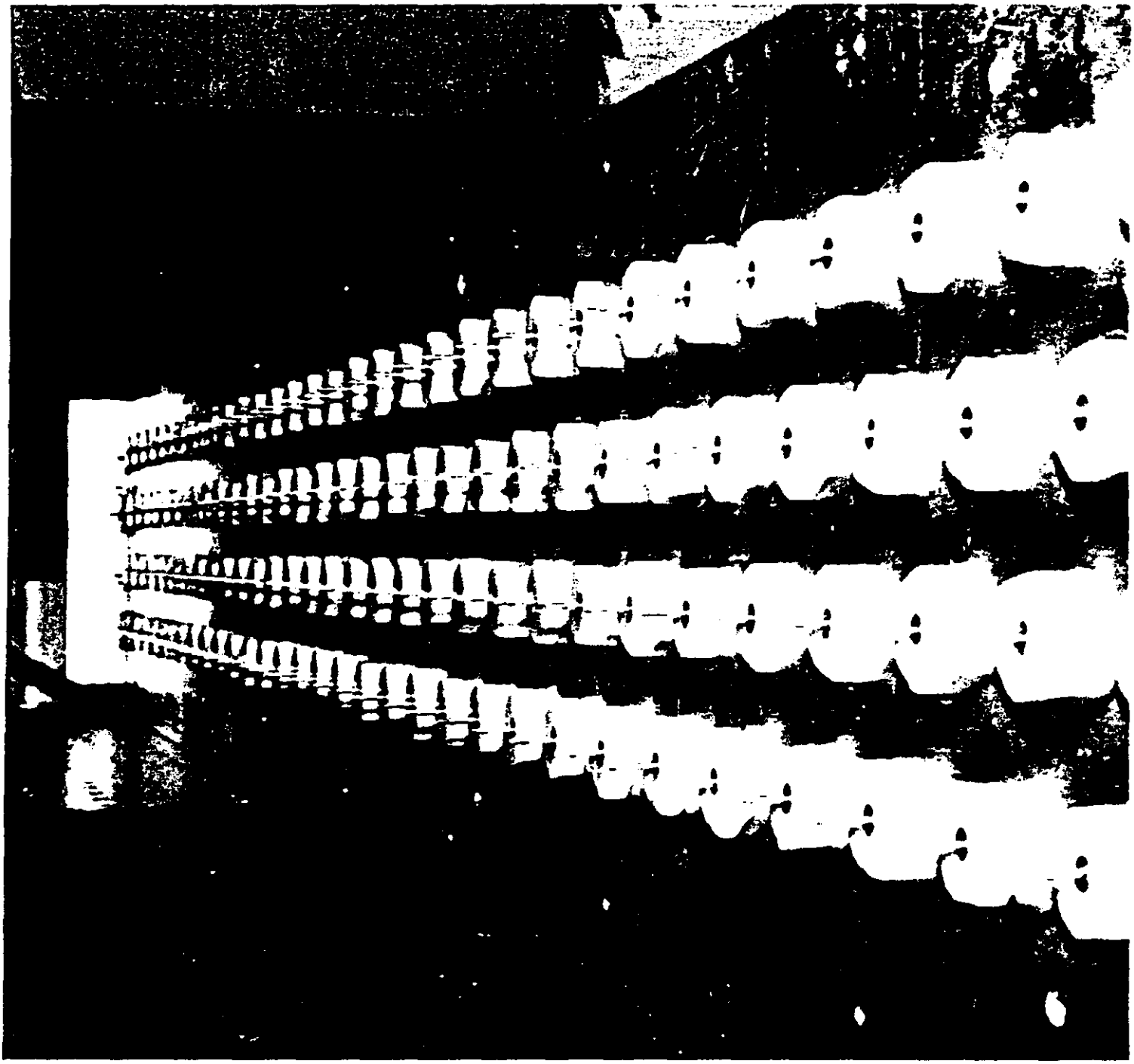
Even this rate is low, it is 2.5 liters/hr = 0.1 Cf/hr. @ 1 Atmosphere overpressure. Typical flows will be 1-2 Cf/hr. Must replace full gas volume every 5-10 days anyway to prevent buildup of toxic compounds.











Chamber Structure is Very Strong

PDT system is half the mass of any other technology
Tubes laminated together with epoxy.
Secondary Gas Barrier and Tube Protection via 1/4" Hexcell cover.

Superlayer Configuration

16 or 32 sectors are fine

8-8-4 in superlayer stacks

3-3-3 z segmentation (other arrangements possible)

Alignment

Wire tensions can be accurately (1%) set with Tungsten.

Textron, high-strength, low density fibers (wires).
2km of wire with <20% of the density

Sides of the chamber are completely free of alignment fixtures which will allow overlap of the chambers in phi without difficulty.

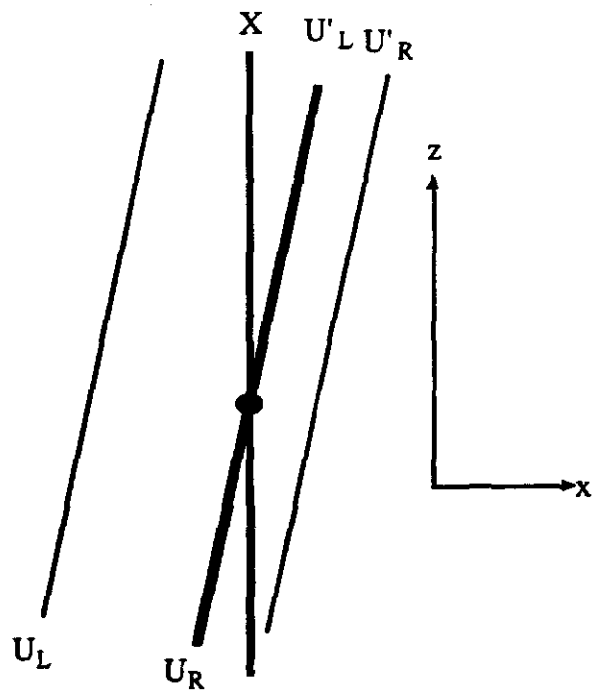
Cost

Number of Chambers	= 288 (16-Sectors)
Number of Channels	= 114,000
Component Cost	= 6.159 M$ (No Taxes)
Labor Cost	= 3.25 M$ (130,000 hrs @ 25$/hr)

Z-Coordinate Measurement with Stereo PDT

Small Stereo Angle : 10 mrad
Z- Resolution: 1 cm

X-U-U' Stereo



1. **Add 2 planes of Stereo to superlayer-I**
2. **Convert 2 planes of superlayer-II to Stereo**
3. **Add 2 planes of Stereo to superlayer-III.**

Cost

Number of channels increase by about 20%

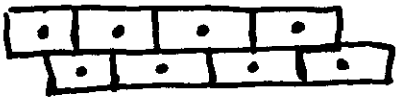
$2M in materials and labor costs and about $0.2M in amp/disc/cable costs.

Larger diameter stereo tubes in superlayer-III an option.

High-Speed Drift Tube Trigger

Provide Momentum and T0 at Level 1.

Two staggered layers of rectangular cross section (1cm × 1cm) tubes in each superlayer.



Use Methane -- <60nsec Drift Time (5 buckets)

Form coincidence pairs of staggered tubes. Coincidence narrows time uncertainty to <30nsec. (3 buckets)

Use Processor: bucket closest to Centroid of Coincidence pulse is the correct T0 bucket.

Require 2 out of 3 superlayers to agree on T0 bucket.

Notes:

1. Angle problem is minimized by 1cm layer spacing.
2. Angle is restricted to a narrow range of values for reasonable momenta at a specfic location.
3. Mechanical Tolerances are not critical, wire supports will be needed in long chambers.

System Cost

	Item	Estimated Cost ($M)
1.	Chamber Materials	2.0
2.	Chamber Assembly Labor	3.0
3.	On-Chamber Amp/Disc/Cable	1.5
4.	Trigger Processors	2.0
	Total	8.5

(5M$ Chamber Costs)

PDT for the Endcaps

Trapezoidal Chambers can be fabricated with Manifold Plate and Two Part Plug Design.

100μ resolution on the $r \cdot \phi(z)$ function

350-500μ resolution in the r(z) function.

Adjust tube diameter and segment twice in tube length to keep the Rate fairly constant in all channels.

Number of Endcap chambers will be about 2/3 of the Barrel chambers but will contain 10% more channels; 96 chambers and about 60k channels in each Endcap.

High-speed drift tube (HSDT) chambers are used here as well for triggering

Full Barrel and Endcap PDT/HSDT Cost

Item	Barrel Cost (M$)	Endcaps Est.Cost (M$)
PDT Materials and Labor	9.4	6.2
PDT Amp/Disc/Cable	1.1	1.2
HSDT Materials and Labor	5.0	3.4
HSDT Amp/Disc/Cable	1.5	0.8
HSDT Trigger Electronics	2.0	1.3
Total Cost	19.0	12.9+*

+2M$ for Stereo

* Crude Estimate

GEM- PDT END CAP CHAMBERS

INPUT PARAMETERS:

Tube Material, density:	Alum.	2.7
Tube Wall: (mm)	0.30	
M. Plate Thickness (mm), density	19.05	2.7
Case Thickness (mm), density:	6.40	0.25

VARIABLES:

Z Location (m):	5.8	6.1	10.5	11.5	14.8	16.0	Total
Inner Azimuth	17.0	9.0	17.0	9.0	17.0	9.0	
Outer Azimuth	28.0	17.0	28.0	17.0	28.0	17.0	
# of Segments:	16	16	16	16	16	16	
# of Layers:	8	8	8	8	8	8	24
Tube Dia: (mm)	20.0	10.0	30.0	15.0	40.0	20.0	

RESULTS:

Tube Length: (m)	1.3	0.9	2.4	1.7	3.3	2.4	
Tubes/Chamber:	480	592	592	736	624	768	
Chamb. width: (m)	1.23	0.74	2.22	1.40	3.13	1.95	
Chamb. thick.: (m)	0.26	0.18	0.34	0.22	0.42	0.26	
Weights (lb)							
Tubes:	70	30	236	105	467	203	
Manifold plates:	72	30	171	70	298	115	
Plugs:	47	42	73	62	94	75	
Case:	16	7	48	21	93	40	
Electronics,cable:	240	296	296	368	312	384	
Total/Chamber:	445	405	824	626	1264	816	
Weight/Half:	7126	6476	13190	10012	20220	13060	40536
Tubes/Half:	7680	9472	9472	11776	9984	12288	60672

Status of PDT - Dubna Work

Igor Golutvin

STATUS OF DUBNA PDT PROTOTYPE

PRESENTED BY I.GOLUTVIN
AT GEM MUON GROUP MEETING
OCTOBER 6, 1992

JINR /DUBNA/

ITEP /MOSCOW/

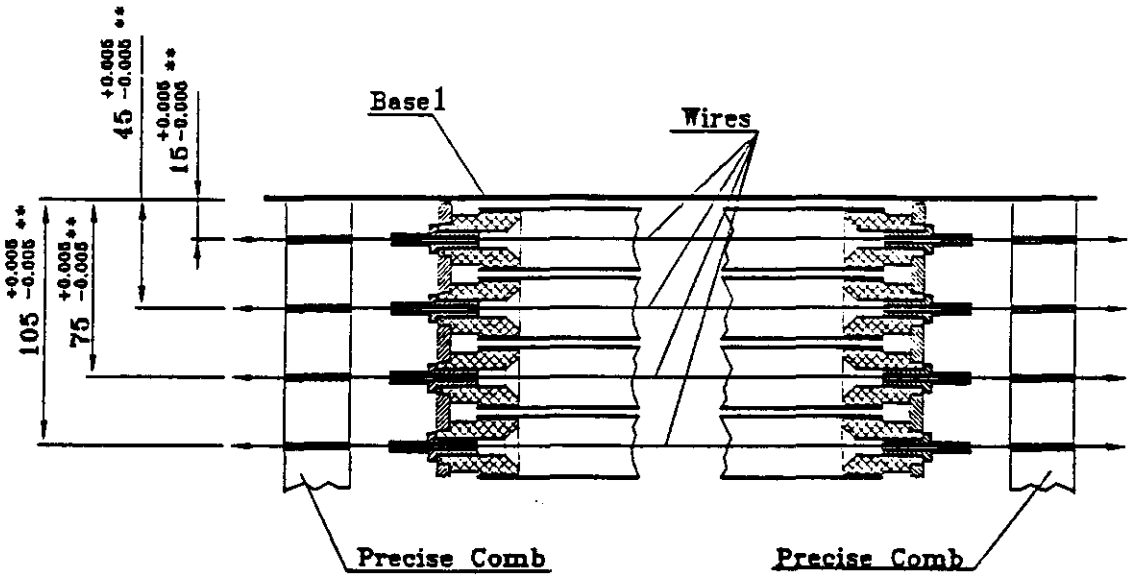
SSCL /DALLAS/

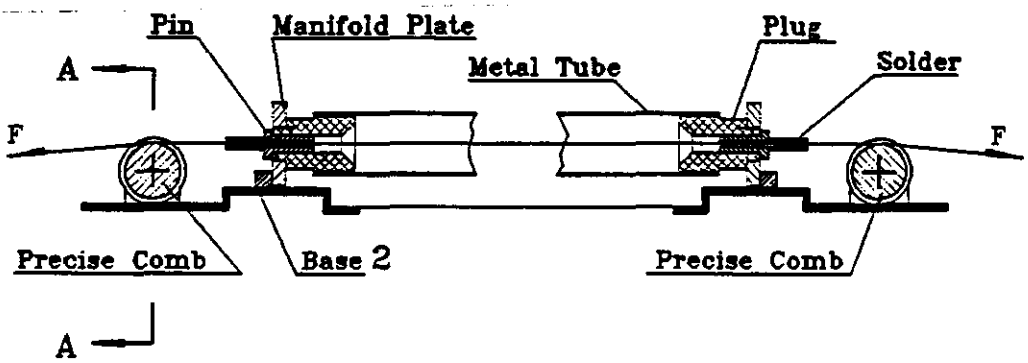
- CONCEPT
- TEST AT CERN MUON BEAM
- TEST AT SSCL

PDT PROTOTYPE DESIGN, CONSTRUCTION AND TEST SCHEDULE

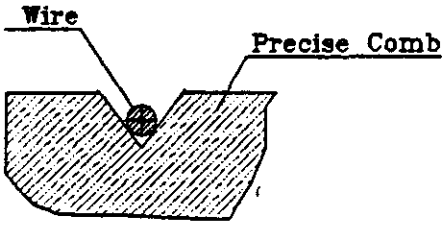
- JANUARY 92	DECISION TO DESIGN AND CONSTRUCT PDT PROTOTYPE AT DUBNA
- FEBRUARY 92	DESIGN HAS STARTED
- APRIL 92	"SMALL" PROTOTYPE CONSTRUCTED AND TESTED AT ITEP BEAM
- MAY 92	ELECTRONICS (PREAMP'S AND DISCRI'S) DESIGN COMPLETED
- JUNE 92	4m PROTOTYPE CONSTRUCTION COMPLETED
- JULY 92	4m PROTOPYPE FULLY INSTRUMENTED WITH ELECTRONICS
- 26 JULY 92	1m x 4m (2 x 0.5 x 4.0m) PROTOTYPE ARRIVED AT SSCL
- AUGUST 92	1m PROTOTYPE CONSTRUCTED
- SEPTEMBER 92	1m PROTOTYPE TESTED AT CERN MUON BEAM
-SEPTEMBER/ OCTOBER 92	4m PROTOTYPE TEST AT TTR (SSCL)

DUBNA PDT TECNOLOGY CONCEPT
(1)

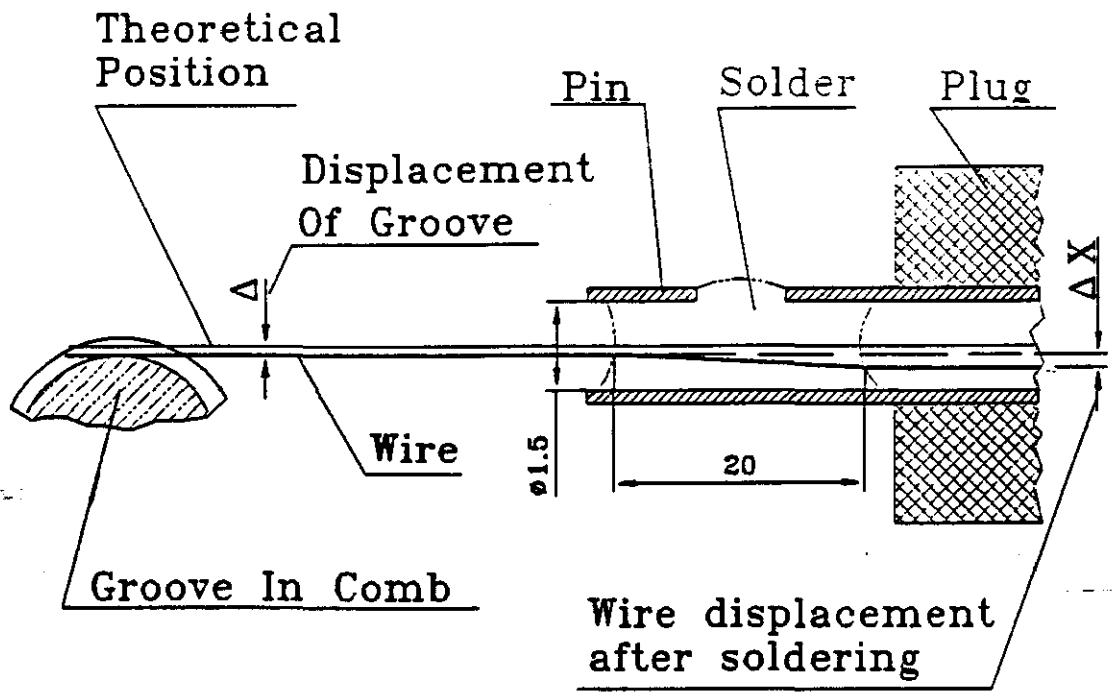


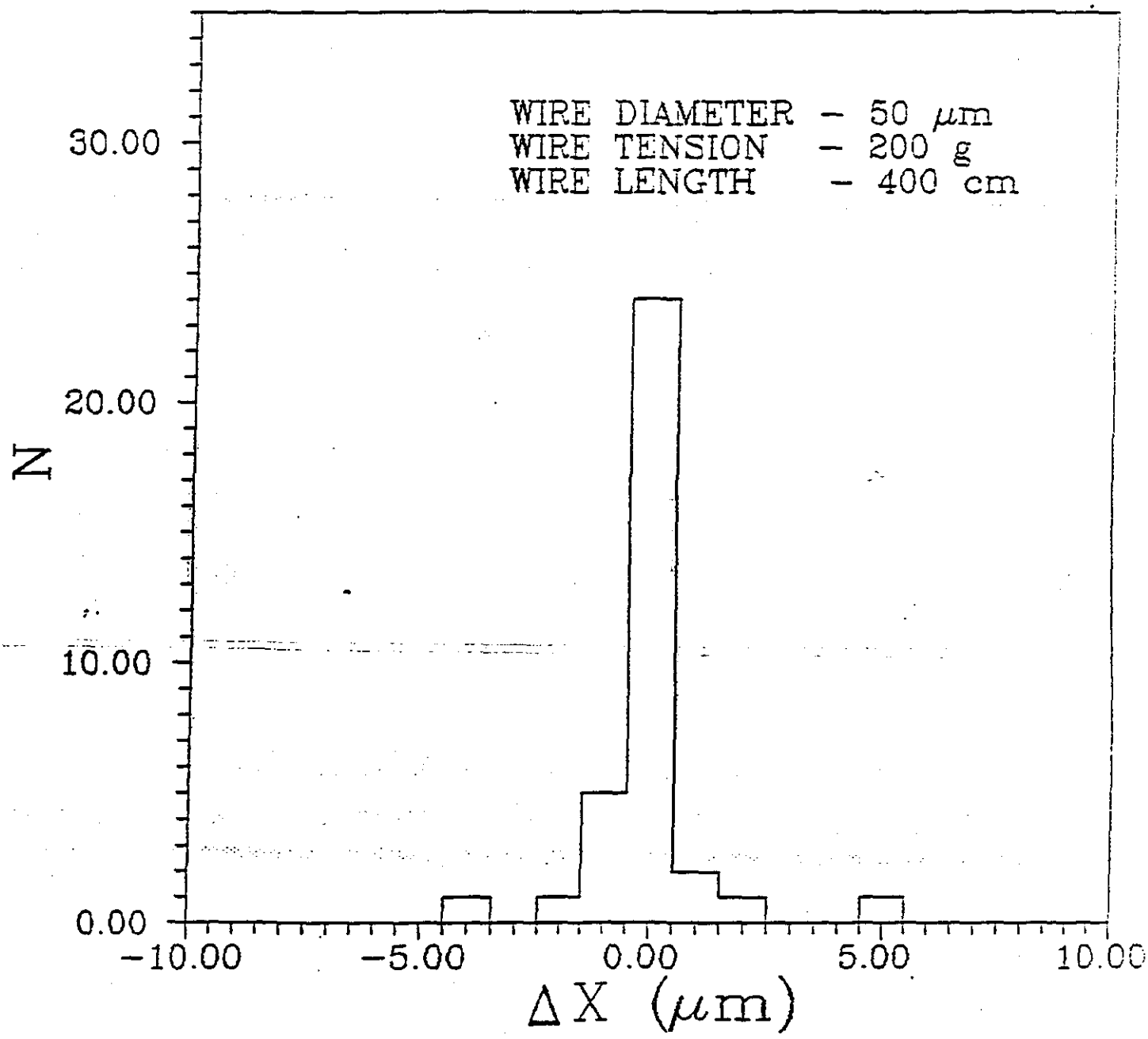


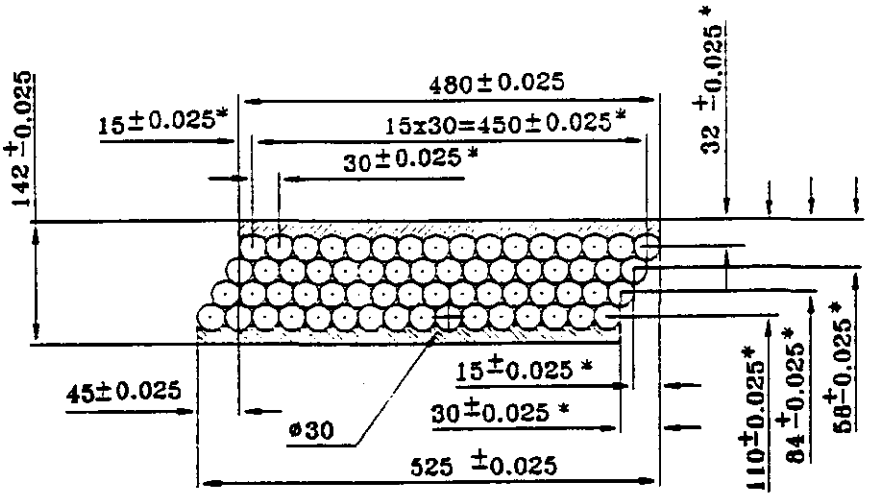
A–A

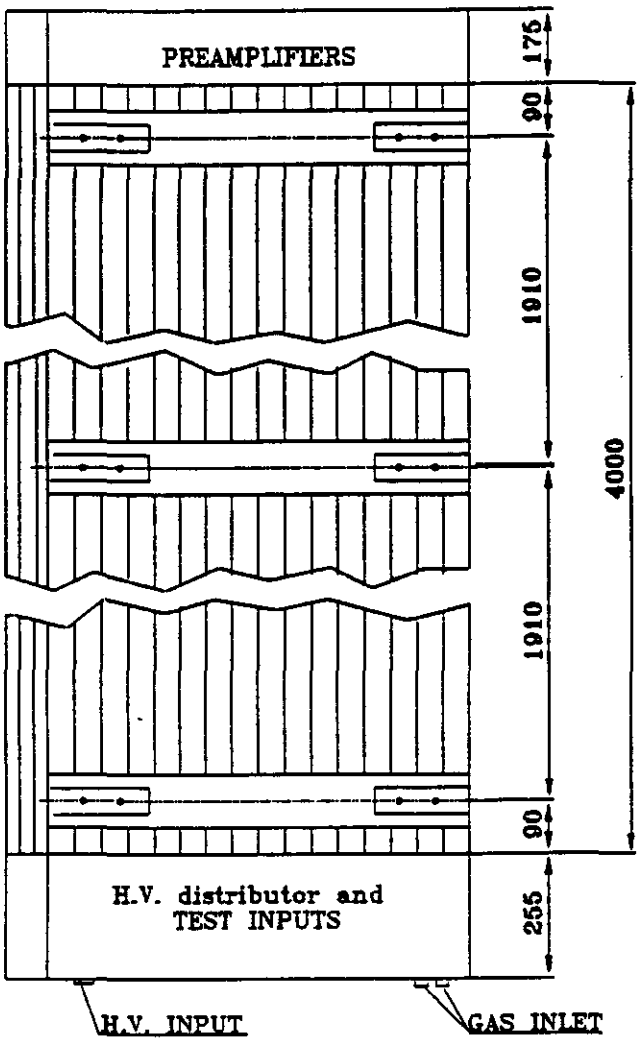


**–tolerances on grooves position

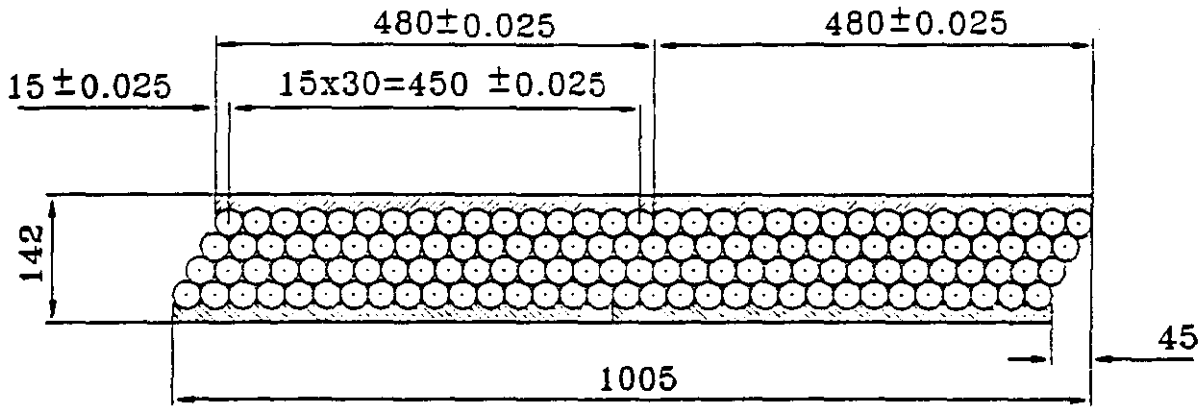

Theoretical Position
Pin
Solder
Plug
Displacement Of Groove
Δ
ΔX
Wire
ø1.5
20
Groove In Comb
Wire displacement after soldering

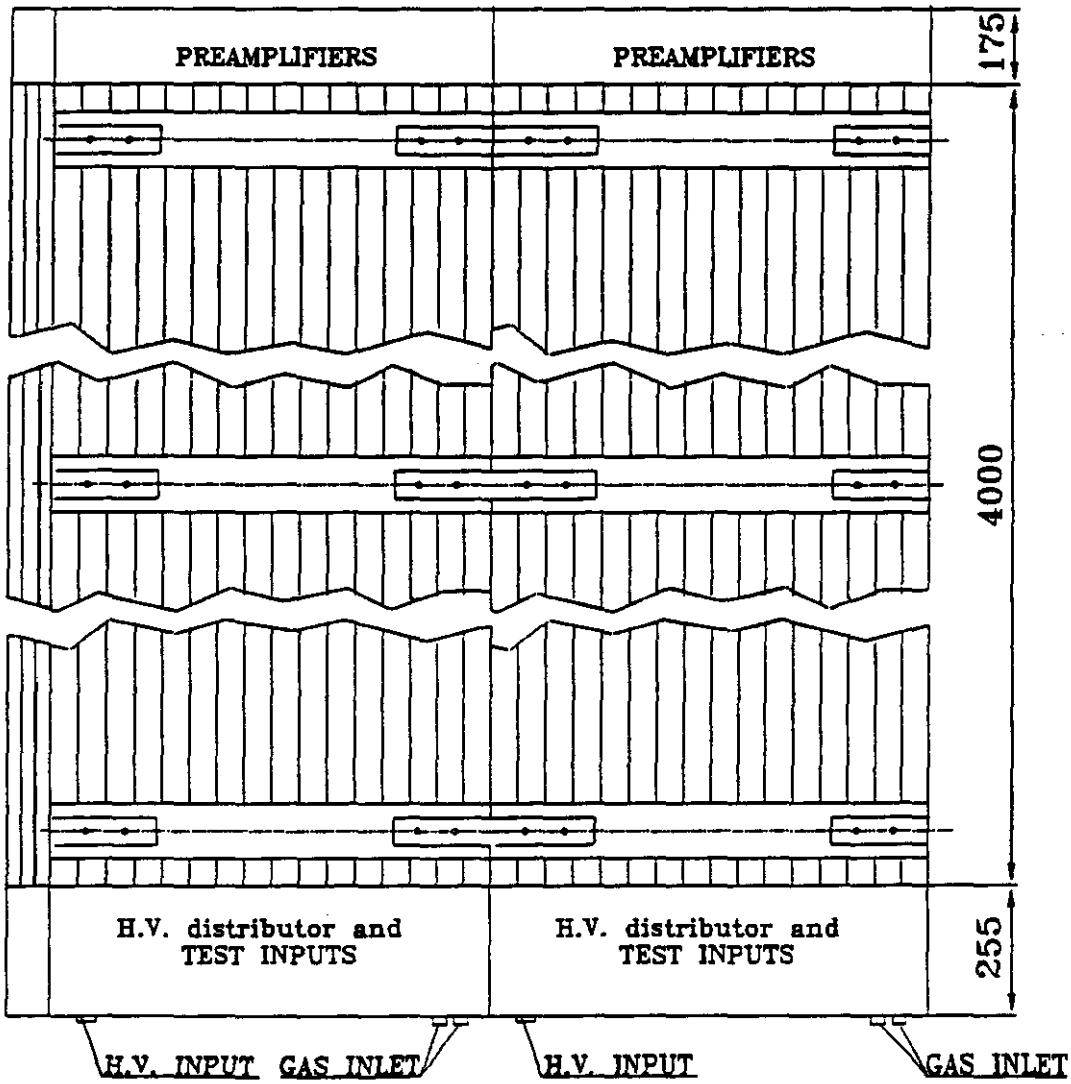

WIRE DIAMETER - 50 μm
WIRE TENSION - 200 g
WIRE LENGTH - 400 cm
30.00
20.00
10.00
0.00
N
-10.00
-5.00
0.00
5.00
10.00
ΔX (μm)





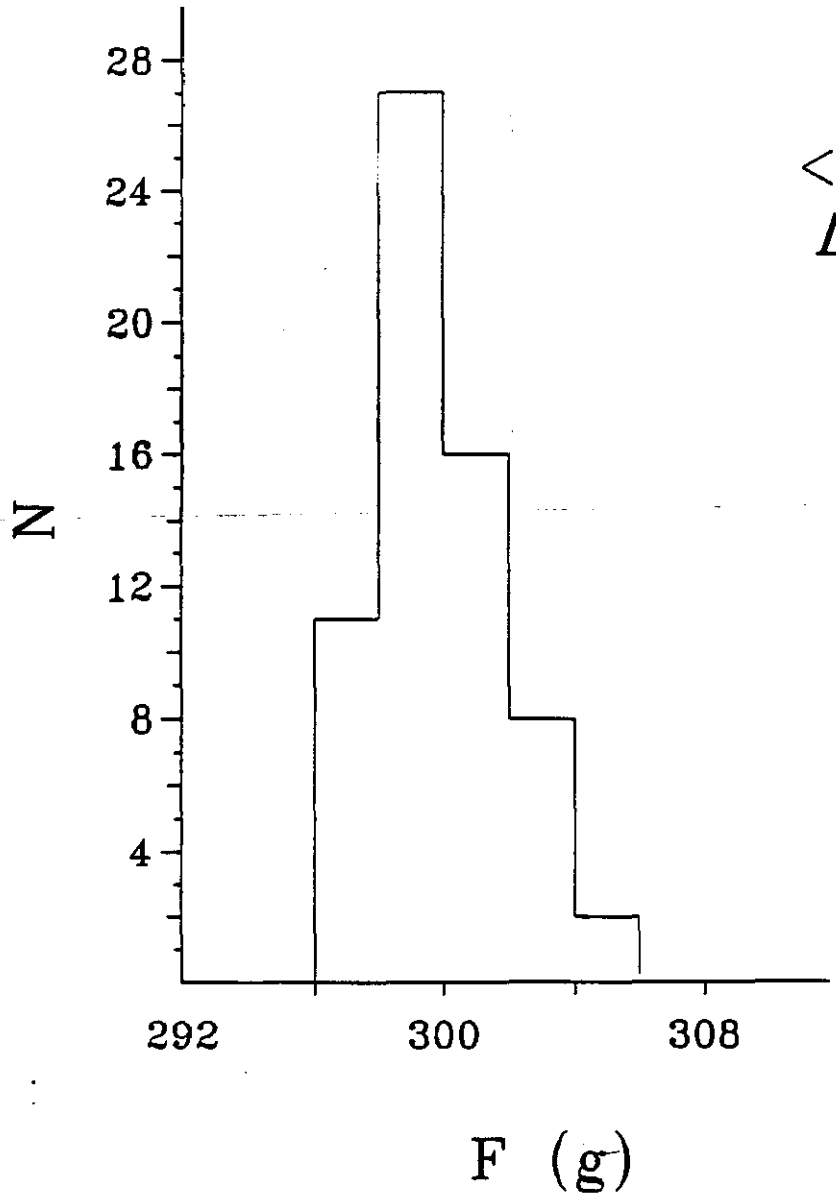
* –tolerances on wires position


480±0.025
480±0.025
15±0.025
15x30=450 ±0.025
142
45
1005

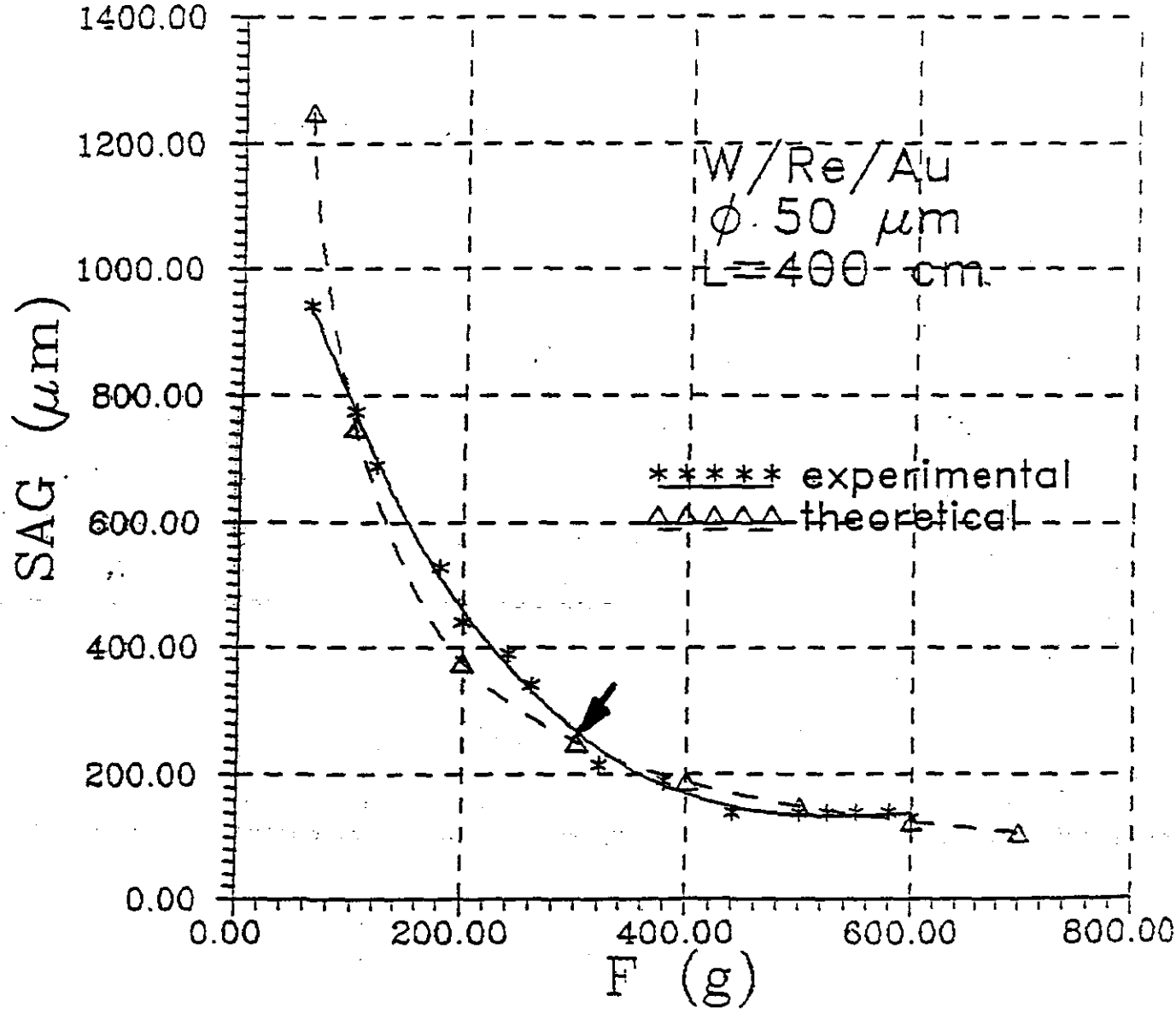

PREAMPLIFIERS
PREAMPLIFIERS
175
4000
H.V. distributor and
TEST INPUTS
H.V. distributor and
TEST INPUTS
255
H.V. INPUT
GAS INLET
H.V. INPUT
GAS INLET

DUBNA PDT PROTOTYPE

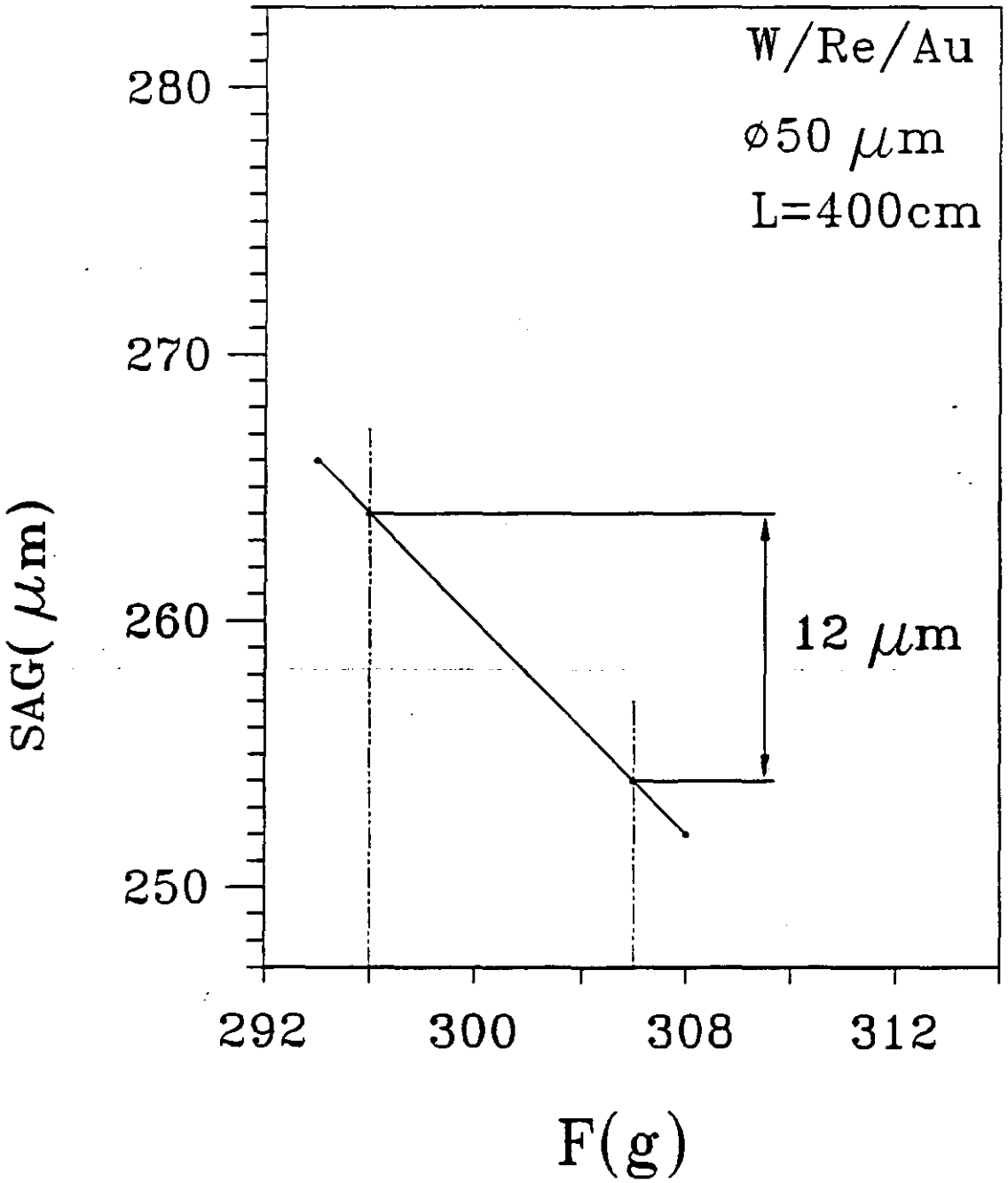
MODULE B
(64 tubes)



<F>=302,5
Δ = 3.3%


1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
SAG (μm)
0.00
200.00
400.00
600.00
800.00
F (g)
W/Re/Au
φ 50 μm
L=400 cm
***** experimental
△△△△△ theoretical

DUBNA PDT PROTOTYPE



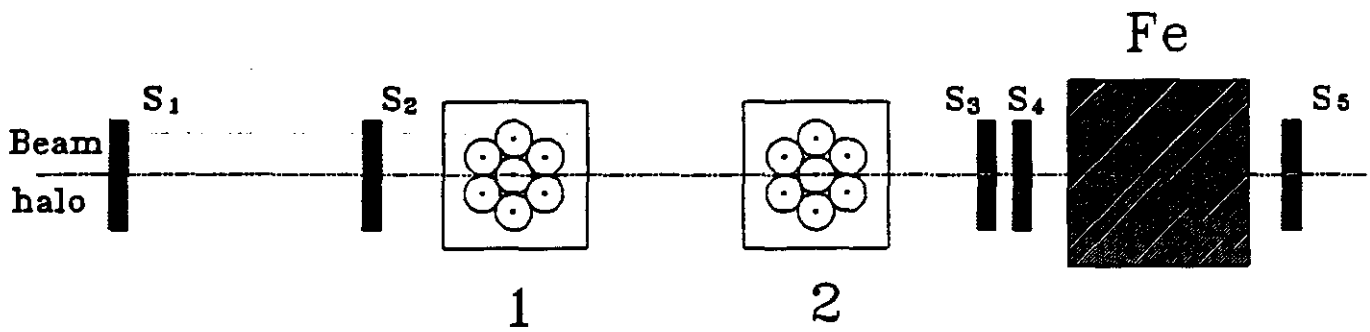
TEST SETUP

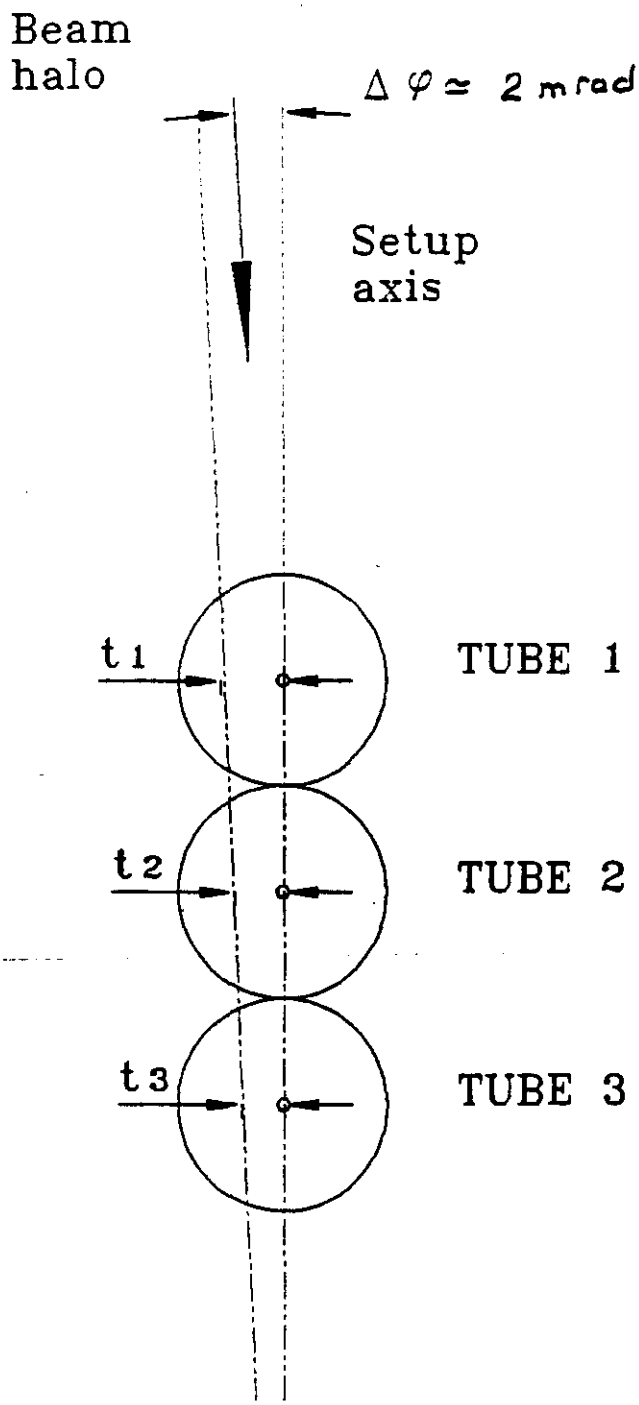
$\Delta\varphi = 2$ mrad

Rate = 20 Hz/cm^2

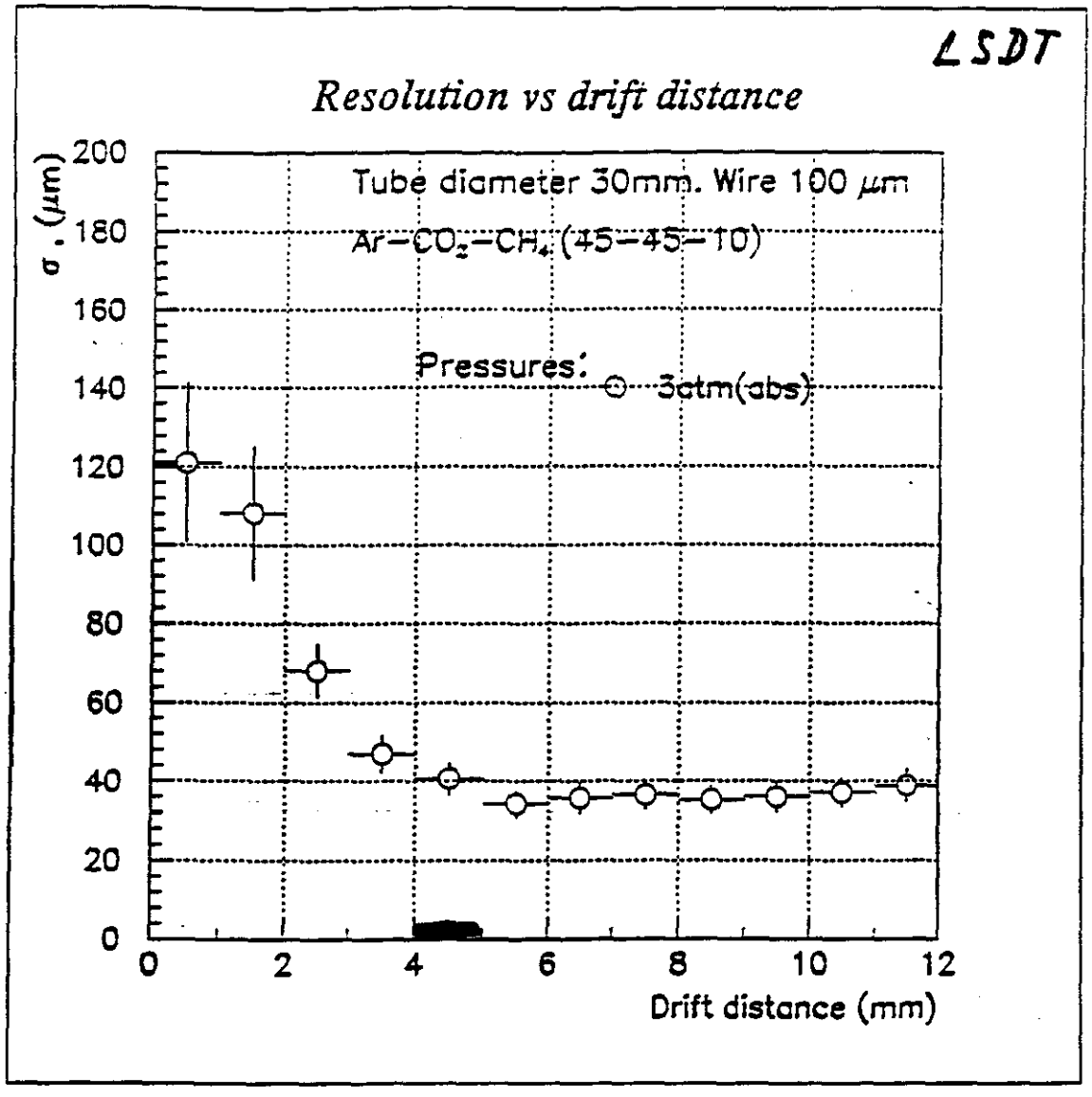
TUBE ⌀30mm

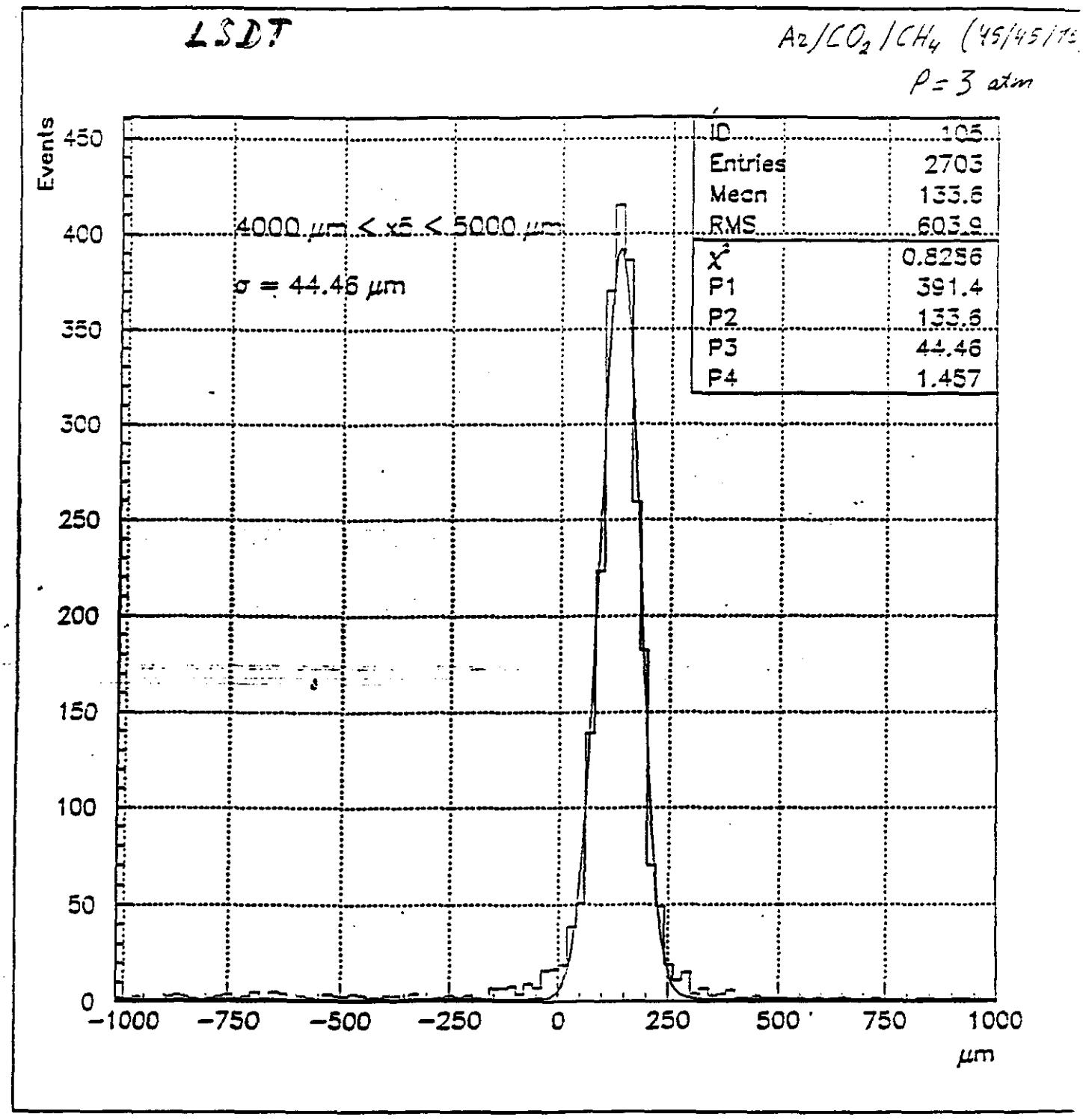
Anode ⌀100 μm



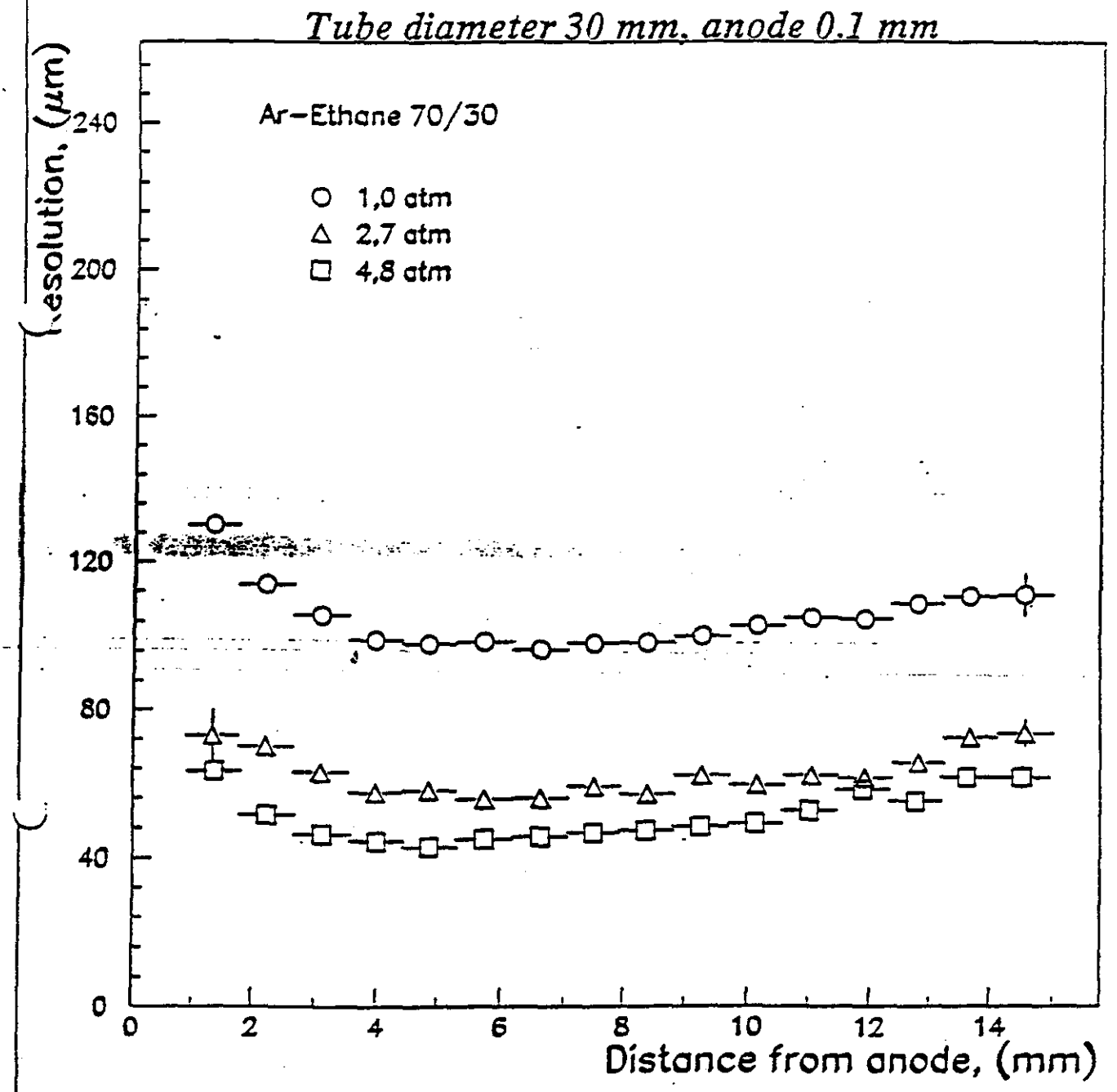


$$\sigma_{ind} = \sqrt{\frac{2}{3}} \cdot \sigma_{meas} \left[\frac{t_1 + t_3}{2} - t_2 \right]$$

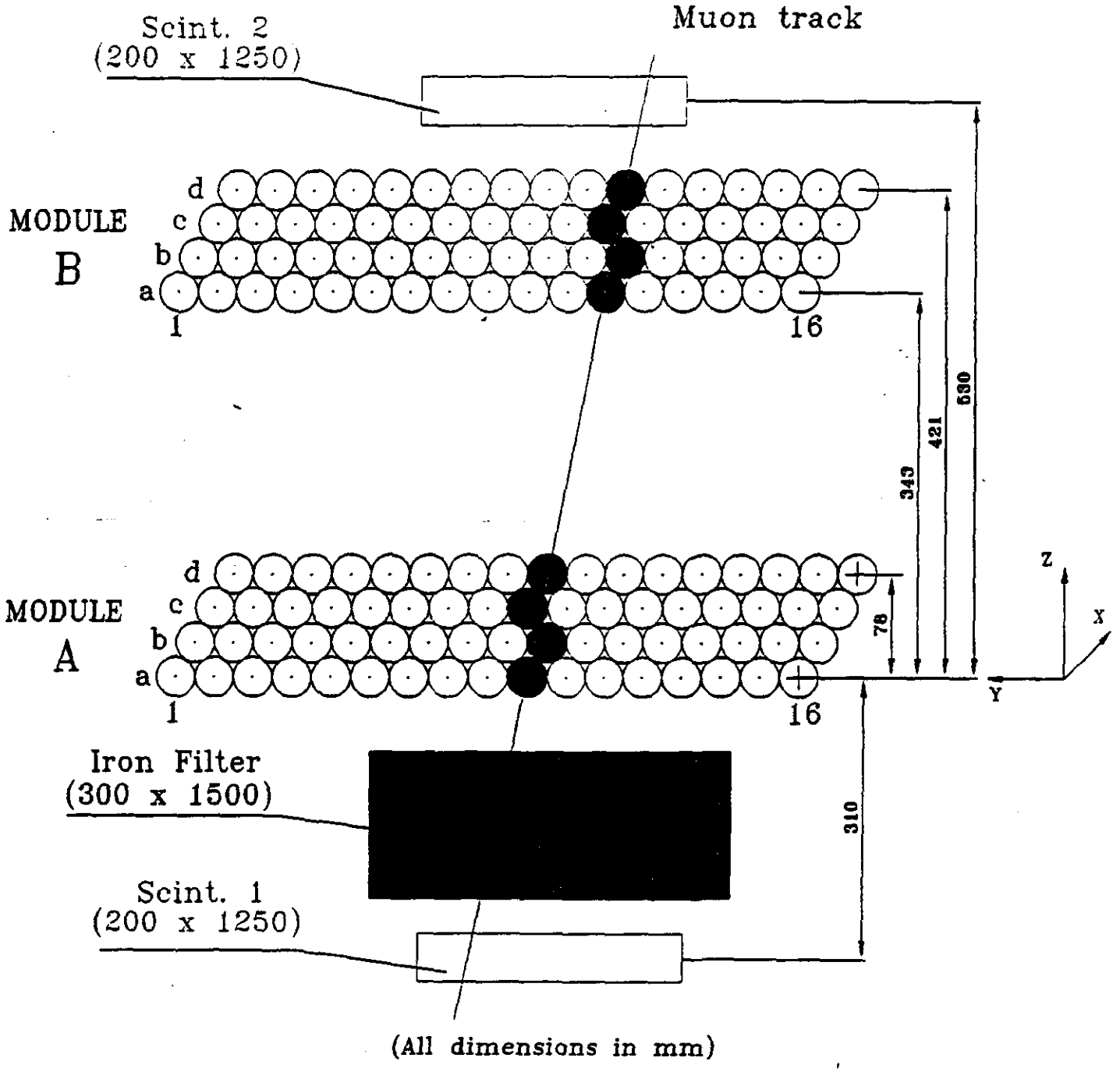

LSDT
Resolution vs drift distance
Tube diameter 30mm. Wire 100 μm
Ar–CO₂–CH₄ (45–45–10)
Pressures:
3atm(abs)
σ (μm)
200
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
Drift distance (mm)


LSDT
Ar/CO2/CH4 (45/45/10
P = 3 atm
Events
4000 μm < x5 < 5000 μm
σ = 44.46 μm
ID 105
Entries 2703
Mean 133.6
RMS 603.9
χ² 0.8256
P1 391.4
P2 133.6
P3 44.46
P4 1.457
450
400
350
300
250
200
150
100
50
0
−1000
−750
−500
−250
0
250
500
750
1000
μm

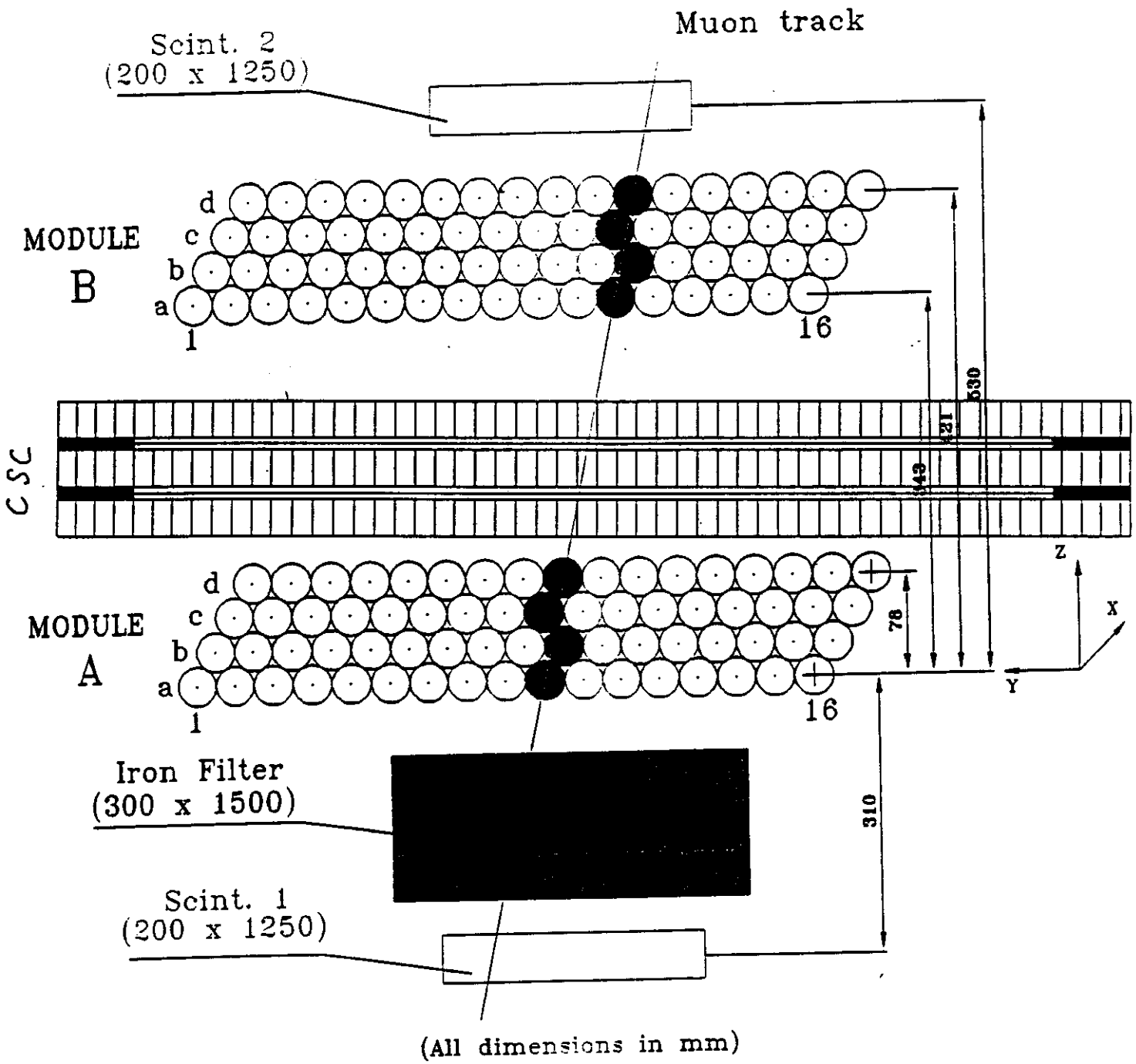
LSDT

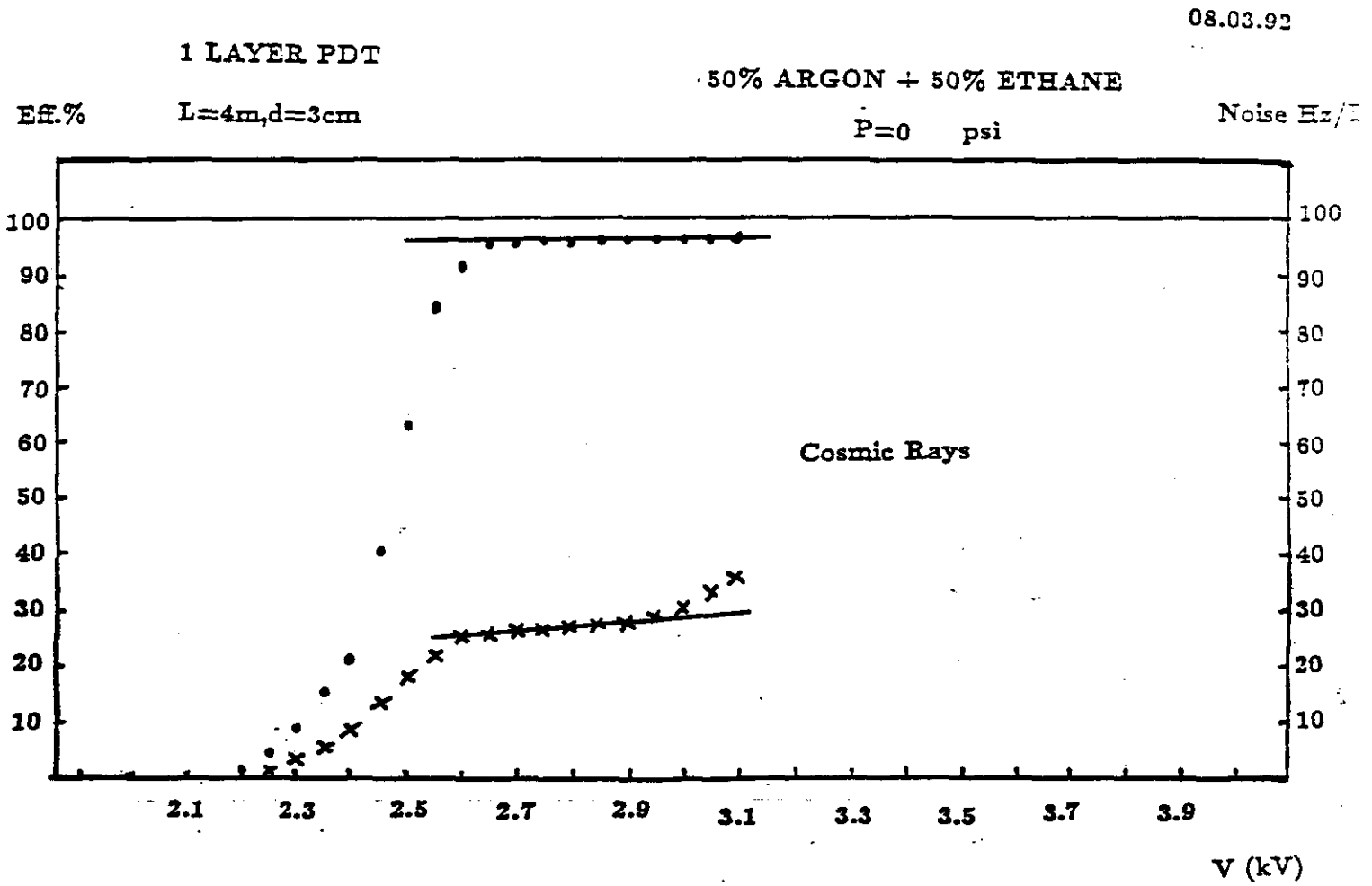

Tube diameter 30 mm, anode 0.1 mm
Ar–Ethane 70/30
1,0 atm
2,7 atm
4,8 atm
Resolution, (μm)
240
200
160
120
80
40
0
0
2
4
6
8
10
12
14
Distance from anode, (mm)

TEST SETUP

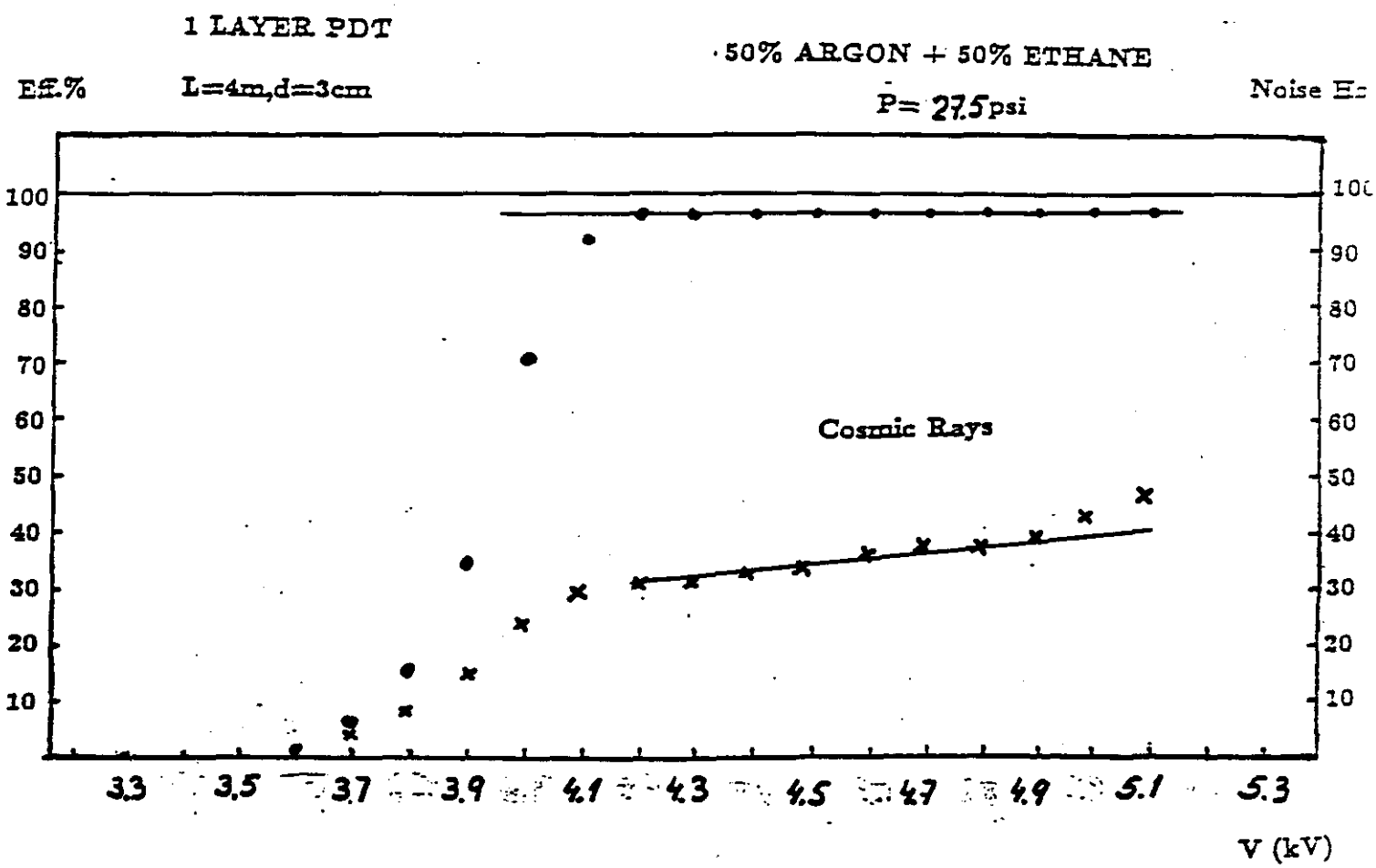

Scint. 2
(200 x 1250)
Muon track
MODULE
B
d
c
b
a
1
16
530
421
343
MODULE
A
d
c
b
a
1
16
78
Z
X
Y
Iron Filter
(300 x 1500)
310
Scint. 1
(200 x 1250)
(All dimensions in mm)

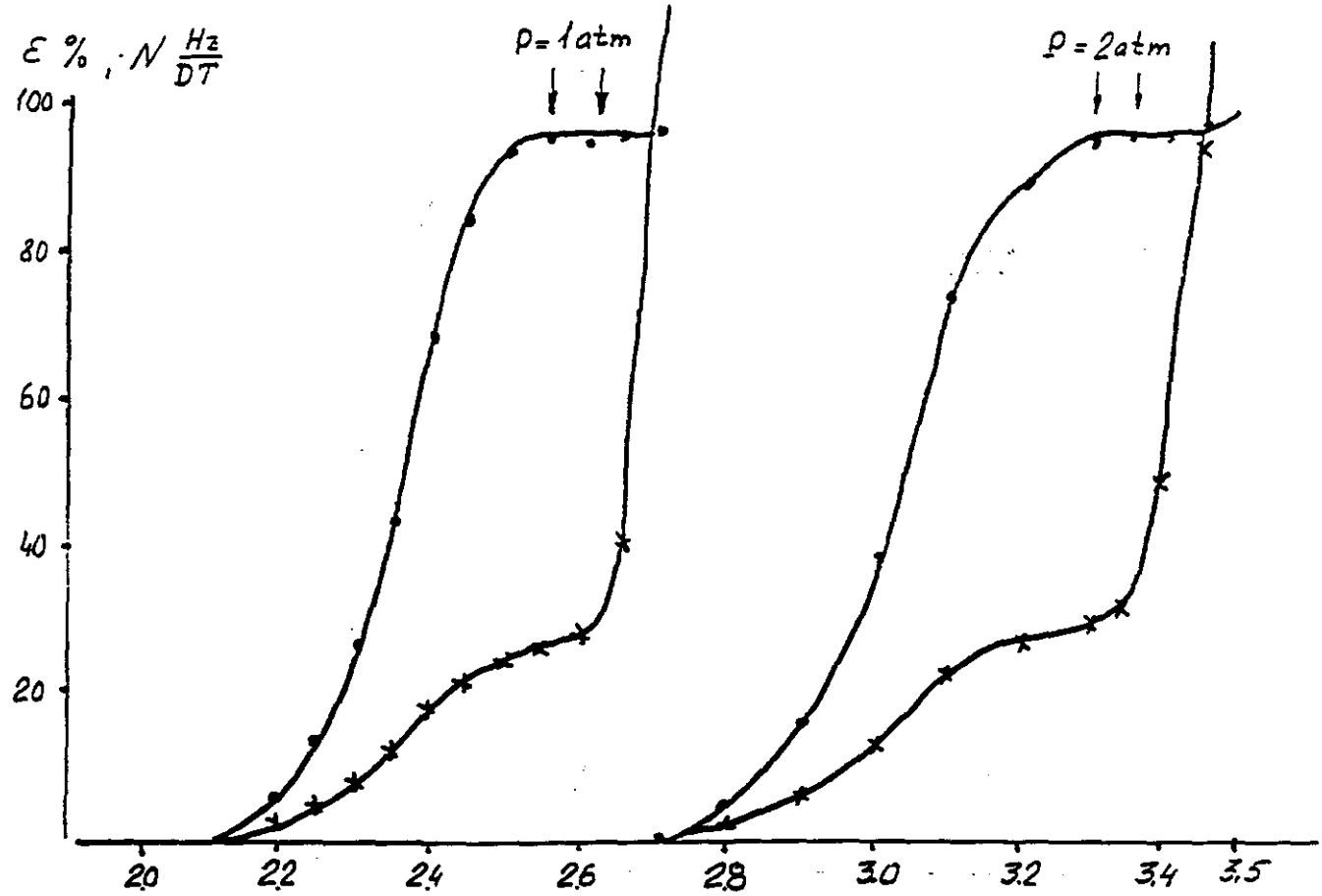
TEST SETUP

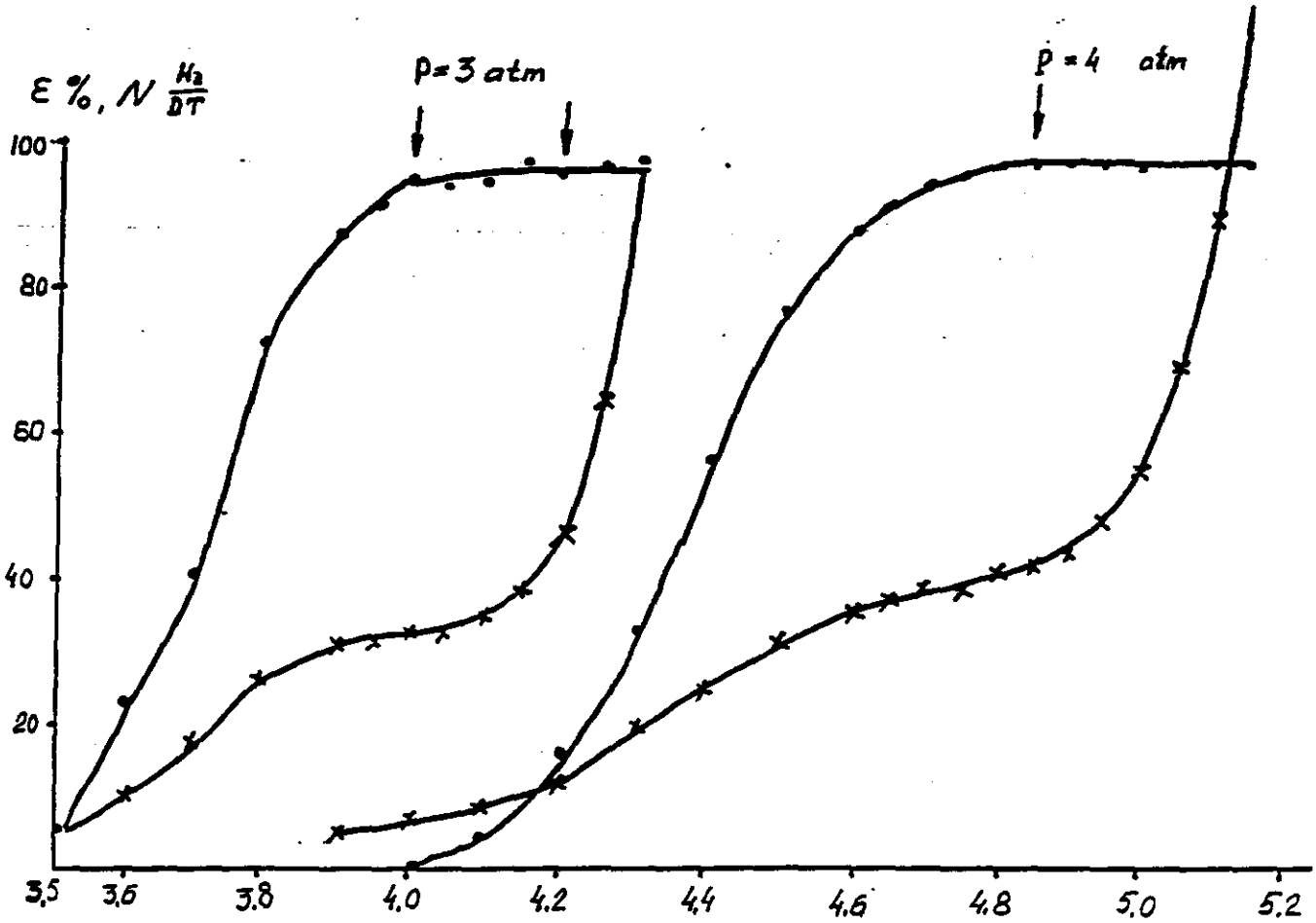

Muon track
Scint. 2
(200 x 1250)
MODULE
B
d
c
b
a
1
16
CSC
530
421
143
MODULE
A
d
c
b
a
1
16
78
Z
X
Y
Iron Filter
(300 x 1500)
310
Scint. 1
(200 x 1250)
(All dimensions in mm)


08.03.92
1 LAYER PDT
50% ARGON + 50% ETHANE
Eff.%
L=4m,d=3cm
P=0 psi
Noise Hz/
100
90
80
70
60
50
40
30
20
10
Cosmic Rays
2.1
2.3
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
V (kV)

08.04.92

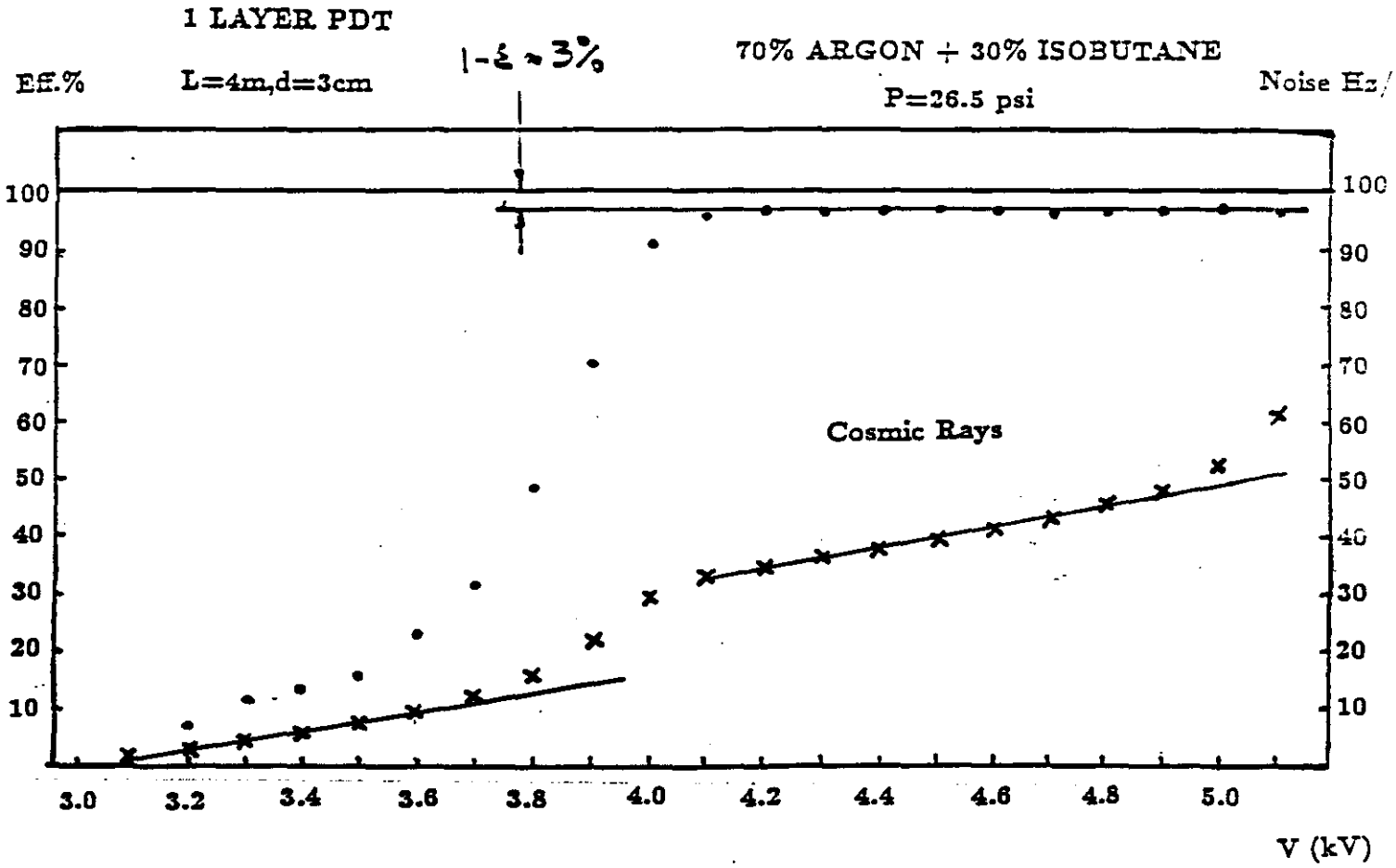

1 LAYER PDT
50% ARGON + 50% ETHANE
Eff.%
L=4m,d=3cm
P= 27.5psi
Noise Ef
Cosmic Rays
100
90
80
70
60
50
40
30
20
10
3.3
3.5
3.7
3.9
4.1
4.3
4.5
4.7
4.9
5.1
5.3
V (kV)



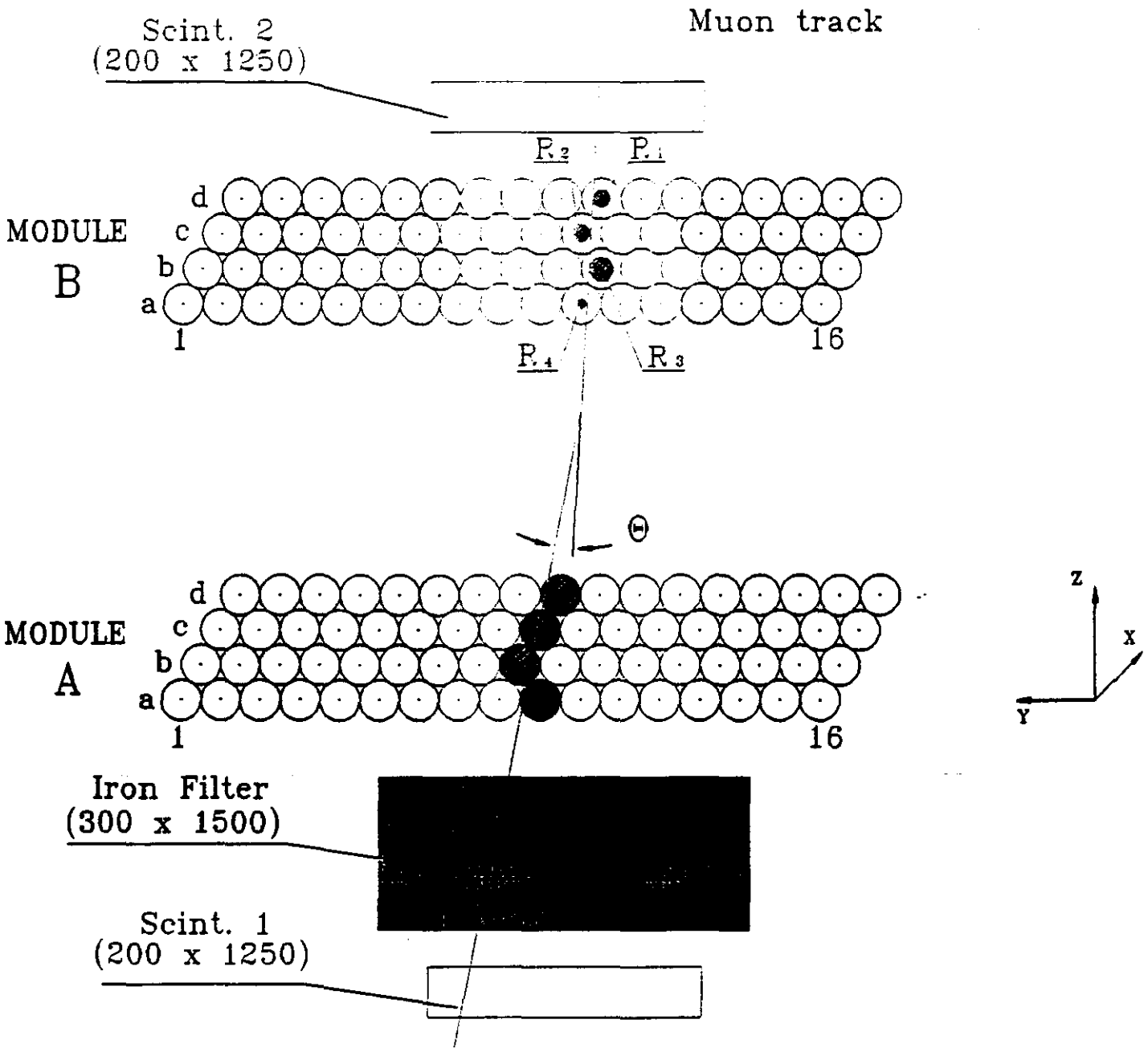


Argon 80% CO_2 20%

08.02.92


1 LAYER PDT
L=4m,d=3cm
1-ε ≈ 3%
70% ARGON + 30% ISOBUTANE
P=26.5 psi
Eff.%
Noise Hz
Cosmic Rays
100
90
80
70
60
50
40
30
20
10
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
V (kV)

METHOD A

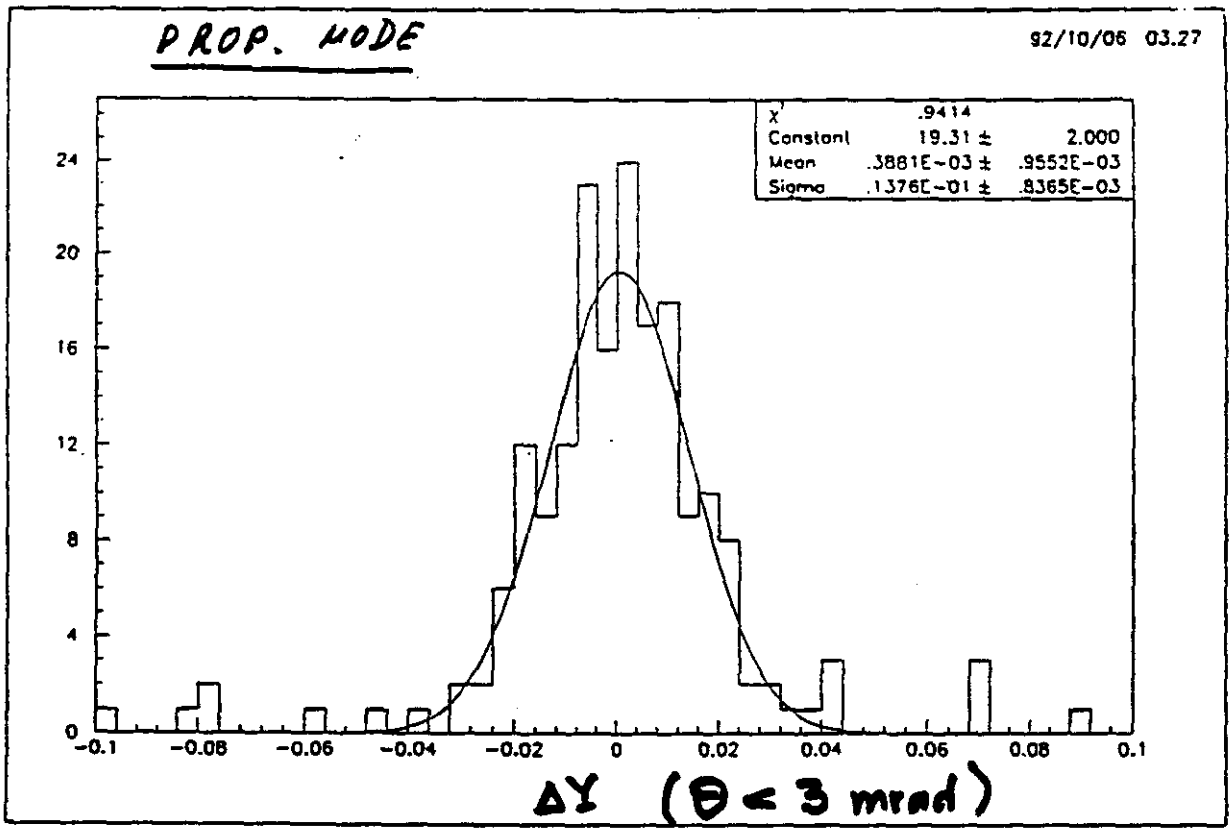


CUT: $\Theta < \Theta_{min}$

$$\Delta Y = (R_3 - R_1) - (R_4 - R_2)$$

$$\sigma = \frac{1}{2}\sigma_{\Delta Y}$$

63



$\sigma = 69\mu$

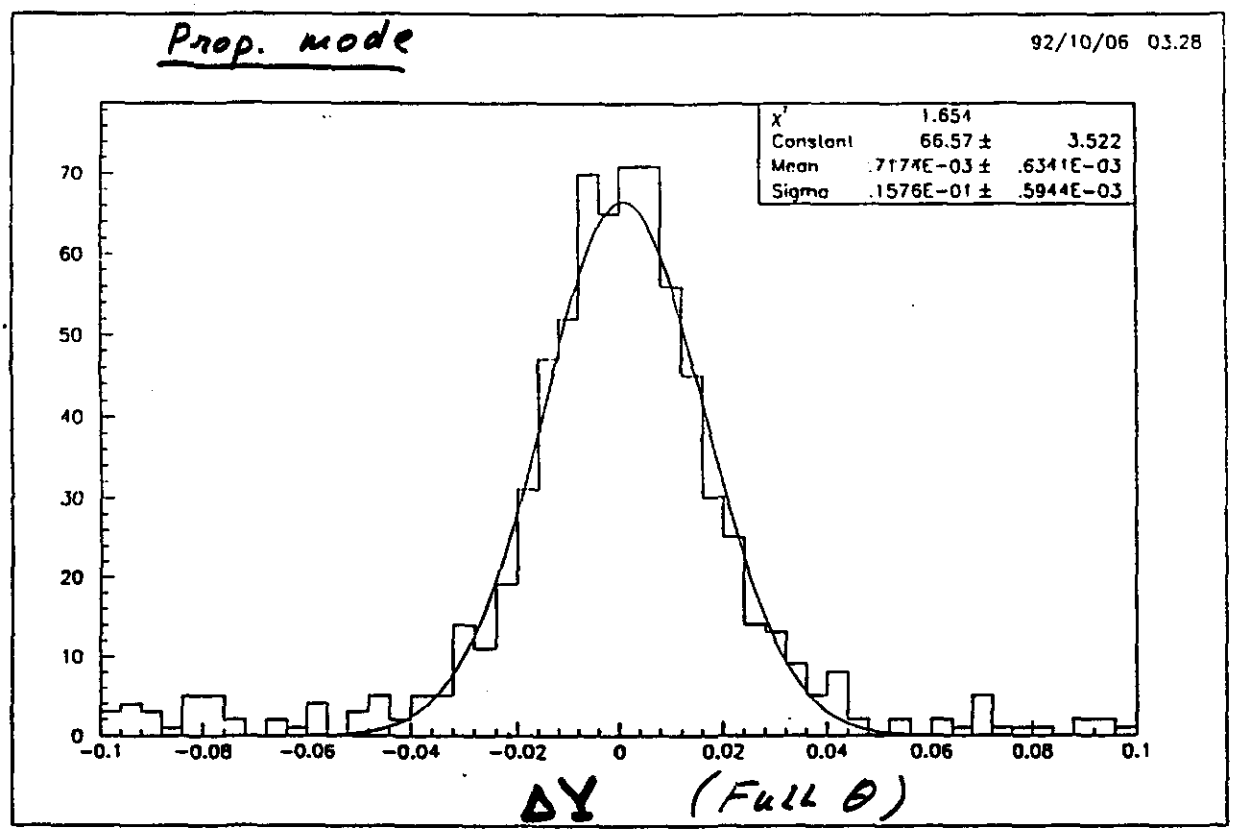
($\theta < 3$ mrad)

Ar/ethane (50:50)

$P = 3.8$ atm

$U_A = 5.9$ kv

Threshold $\simeq 2\,\mu A$



$\sigma = 79\mu$

(Full θ)

Ar/ethane (50:50)

P = 3.8 atm

$U_A = 5.9$ kv

Threshold ≈ 2 μA

A CONCLUSION (PRELIMINARY)

WE CONSIDERED TWO SOURCES OF ERROR:

(A) INTRINSIC ACCURACY OF DRIFT CELLS

(B) SYSTEMATIC DUE TO POSITIONING OF SENSE WIRES

WE SUCCEED TO ACHIEVE THE REQUIRED PERFORMANCE FOR THEM

HOWEVER WHEN WE TRY TO ATTACK 100 μ PRECISION FOR LARGE DETECTION AREAS NEW MAJOR CONTRIBUTION TO THE SYSTEMATIC ERROR HAS TO BE CONSIDERED:

(C) KNOWING OF DRIFT CHARACTERISTICS AND PRECISE TIMING CALIBRATION

NONE OF THE TESTS OF ANY DRIFT TECHNOLOGY PERFORMED SO FAR WITH LARGE AREA DETECTORS HAS SHOWN THAT THIS SOURCE DOES NOT CONTRIBUTE AT THE LEVEL BELOW 100 μ FOR THE INDIVIDUAL CELL

TO JUSTIFY THE CHOICE
OF DRIFT TECHNOLOGY
FOR GEM MUON SYSTEM
THE ACCURACY OF TRACK
LOCALISATION OVER
THE WHOLE DETECTION
AREA IS STILL TO BE
DEMONSTRATED !

LSDT Presentation

Louis Osborne

LIMITED STREAMER DRIFT TUBES FOR THE GEM MUON SYSTEM

LSDT R & D Group

R. Sumner

LeCroy Corp., Chestnut Ridge, NY

R. McNeil, W. Metcalf

Louisiana State Univ., Baton Rouge, LA

W. Busza, H. W. Kendall, A. Korytov, J. Kelsey, L. S. Osborne,
L. Rosenson, F. E. Taylor, R. Verdier, B. Wadsworth

Massachusetts Institute of Technology

Cambridge, MA

We expect that whatever technologies are chosen most of the present GEM muon group will coalesce around the chosen one(s). Many groups here who have expressed a definite interest in pursuing LSDT's were they selected. Among them:

Joint Institute for Nuclear Research, Dubna, Russia

Institute of High Energy Physics, Beijing, P. R. China

Superconducting Super Collider Lab, Dallas, Texas

University of Houston, Houston, Texas

Serendipity

For LSDT

Streamer Mode

↓

Measuring accuracy; 50 to 100 μm

+

Modern Machine Tools

Typical accuracies; 2/10,000" = 5 μm

↓

Accurate Wire Placement

Streamer Pulse

Fast: 10 nsec rise time

Large: $\sim$ 100 mv

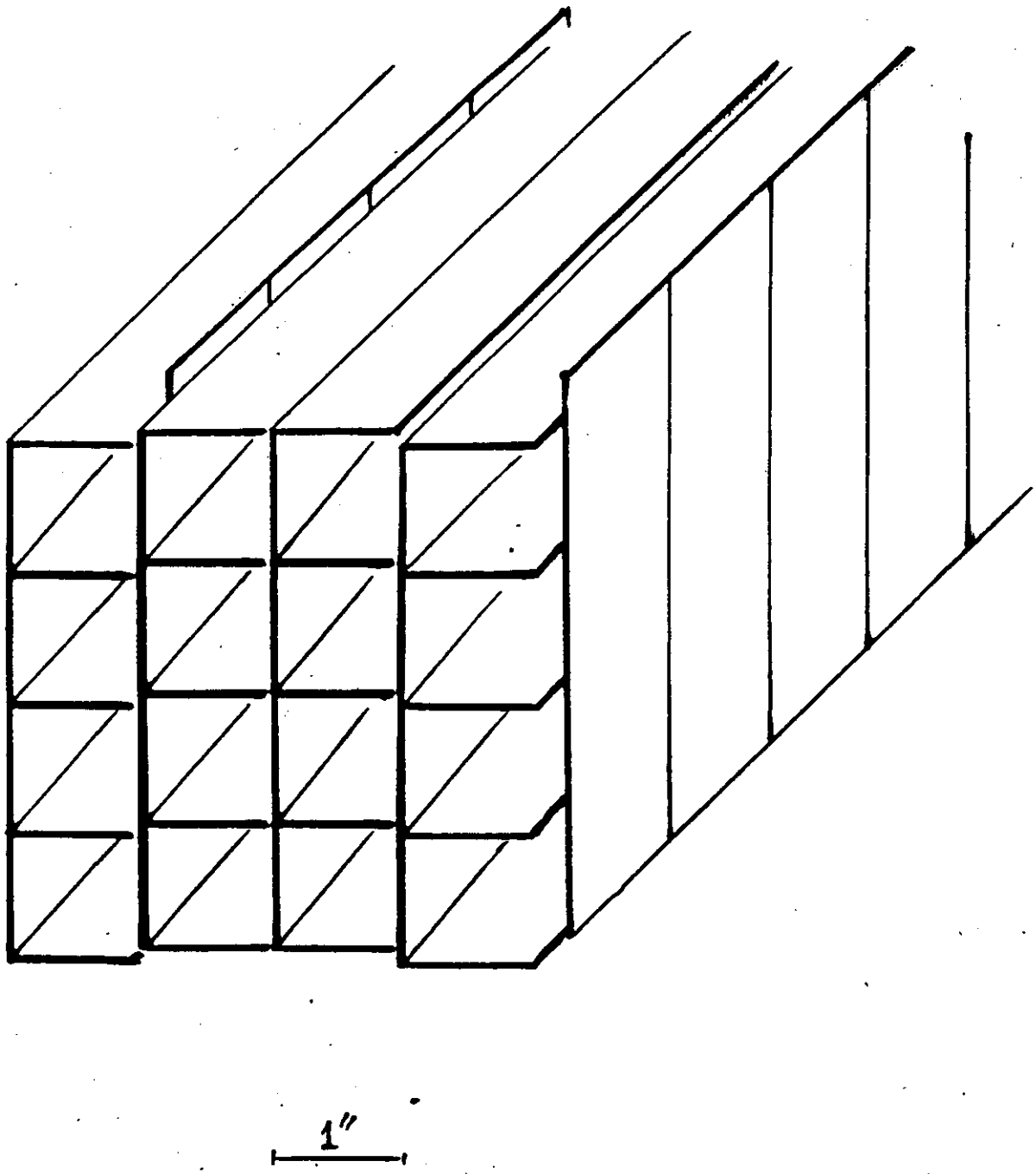
Merits of Streamer-Drift System

1. Preservation of the fast rise time in pulse transmission. ~10 nsec. ≲ 100 mV
2. Open structure for laying down wires-allows multiple wire placement and placement checking for ease of construction.
3. Precision wire positioning.
4. Minimum scattering material.
5. No restriction on chamber length.
6. Parts and assembly amenable to mass production.
7. Stiffness in the final chamber to minimize support points.
8. Single wire resolution of $\sim 100\mu$m.
9. Qne tube per one wire minimizes efficiency loss in wire breakage.

Gases Considered

Argon(A), Isobutane(IB) Safety!!
A(few %),IB(10 %), CO_2
A(few %),IB(10%),CO_2,CF_4

IB($\leq$10%)-non-flammable
CO_2-ohmic,slow,cool
CF_4-flat,fast



Fermilab Muon Telescope

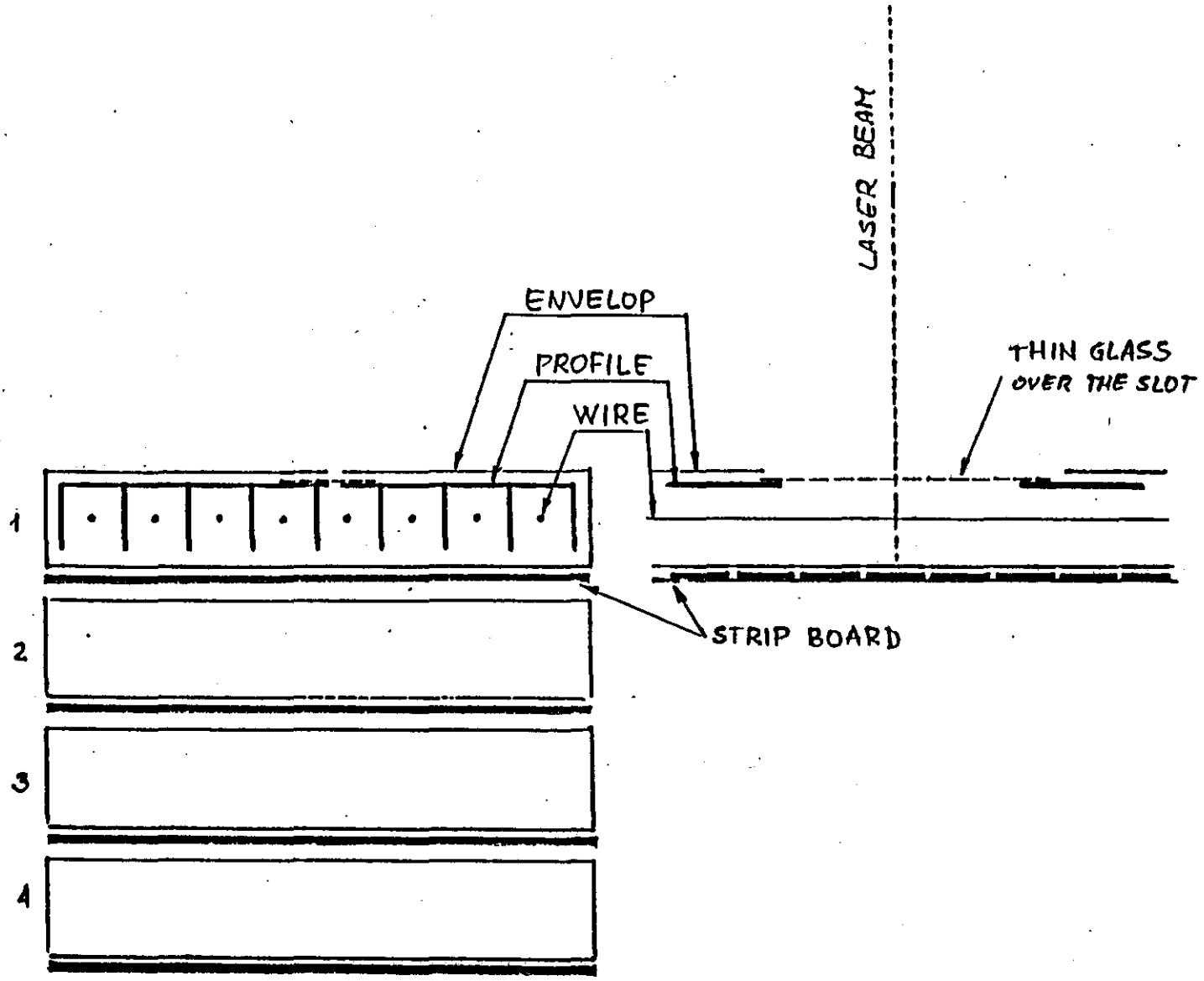

LASER BEAM
ENVELOP
PROFILE
WIRE
THIN GLASS
OVER THE SLOT
1
2
3
4
STRIP BOARD

Fig. 2.2

Table X.1: Resolution* and T_{max} for Drift Readout in 2.5 cm. cells								
Gas⟶	A-IB 25 – 75		A-IB-CO_2 2.5 – 9.5 – 88		CO_2 – CF_4 – IB 20 – 69 – 11		CO_2 – CF_4 – IB 40 – 50 – 10	
Ioniz. Source↓	σ (μm)	T_{max} (n sec)	σ (μm)	T_{max} (n sec)	σ (μm)	T_{max} (n sec)	σ (μm)	T_{max} (n sec)
Laser-no mag. field	35	260	55	830	70	280	70	460
Laser- mag. field(0.8 T)	45	278	60	835	75	295		
0.5 TeV Muons	55				95		75	

* Averaged over all drift times

Table X.2: Resolution* for Pick-up Strip Readout (1.0 cm. strips)		
GasAmpl.Mode ⟶ Ioniz.Source ↓	Proportional	Limited Streamer
Laser	45 μm	100 μm
0.5 TeV Muons	85 μm	

* Averaged over all ionization positions

Worries Over Cathode Strips

1.) Measuring to 100 μm with 1 cm strip requires a 1% measurement.
   a.) Superb amplifiers though mass produced.
   b.) Very accuratly made strips.
2.) Thermal noise requires long ($\sim$ 1 μsec integrating times.
3.) Thermal noise places upper limits on the size of the strips and, therefore the chambers.
   a.) Needs many small chambers.
   b.) Large number of electronics channels.
4.) Man made noise will be present to some extent; this will not be known quantitatively until turn on day.

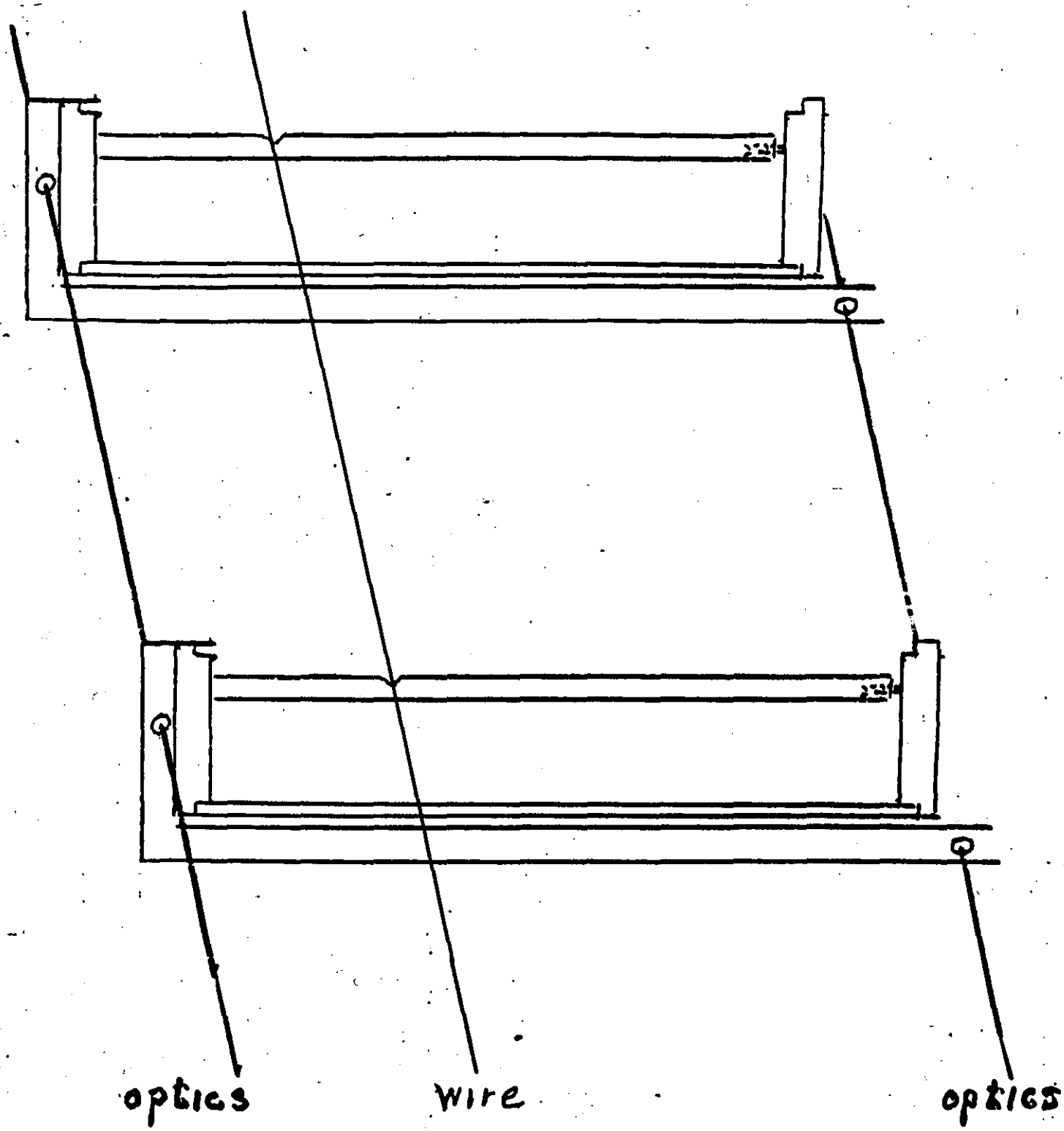
NEEDED

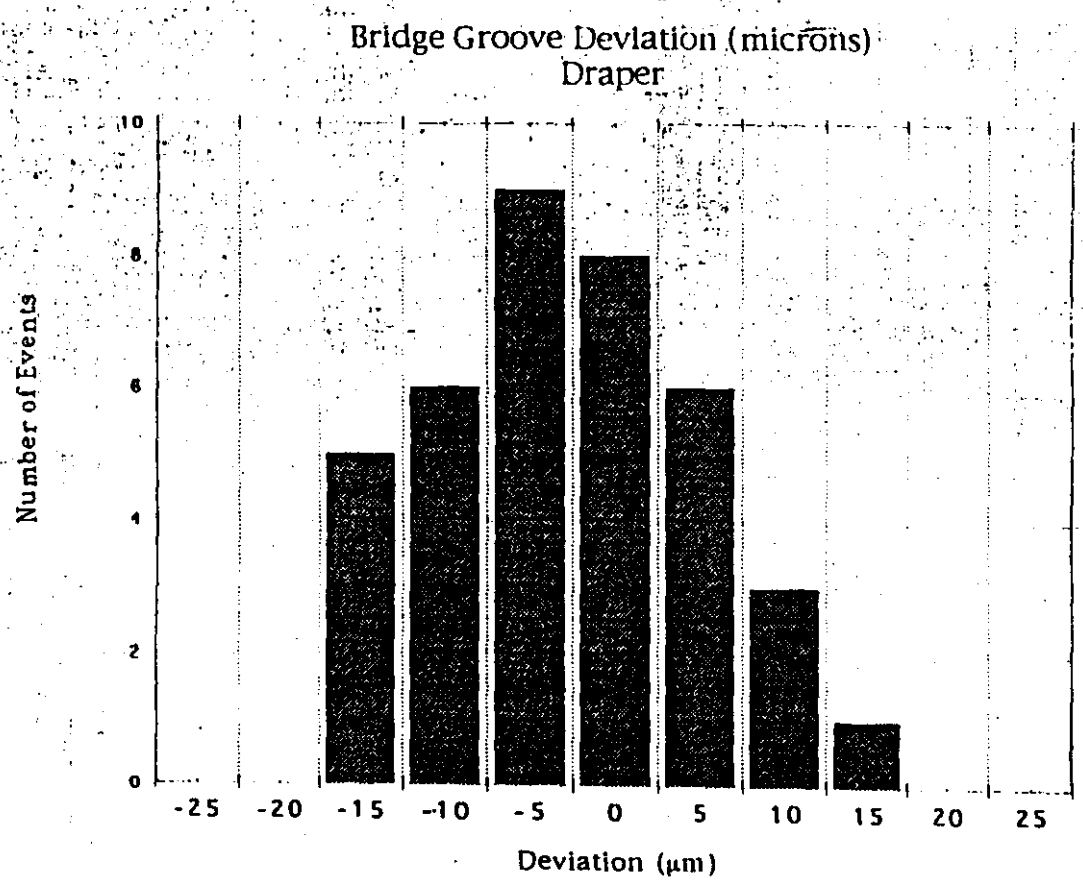
1.) A box, with precision milling but only at bridge support points.

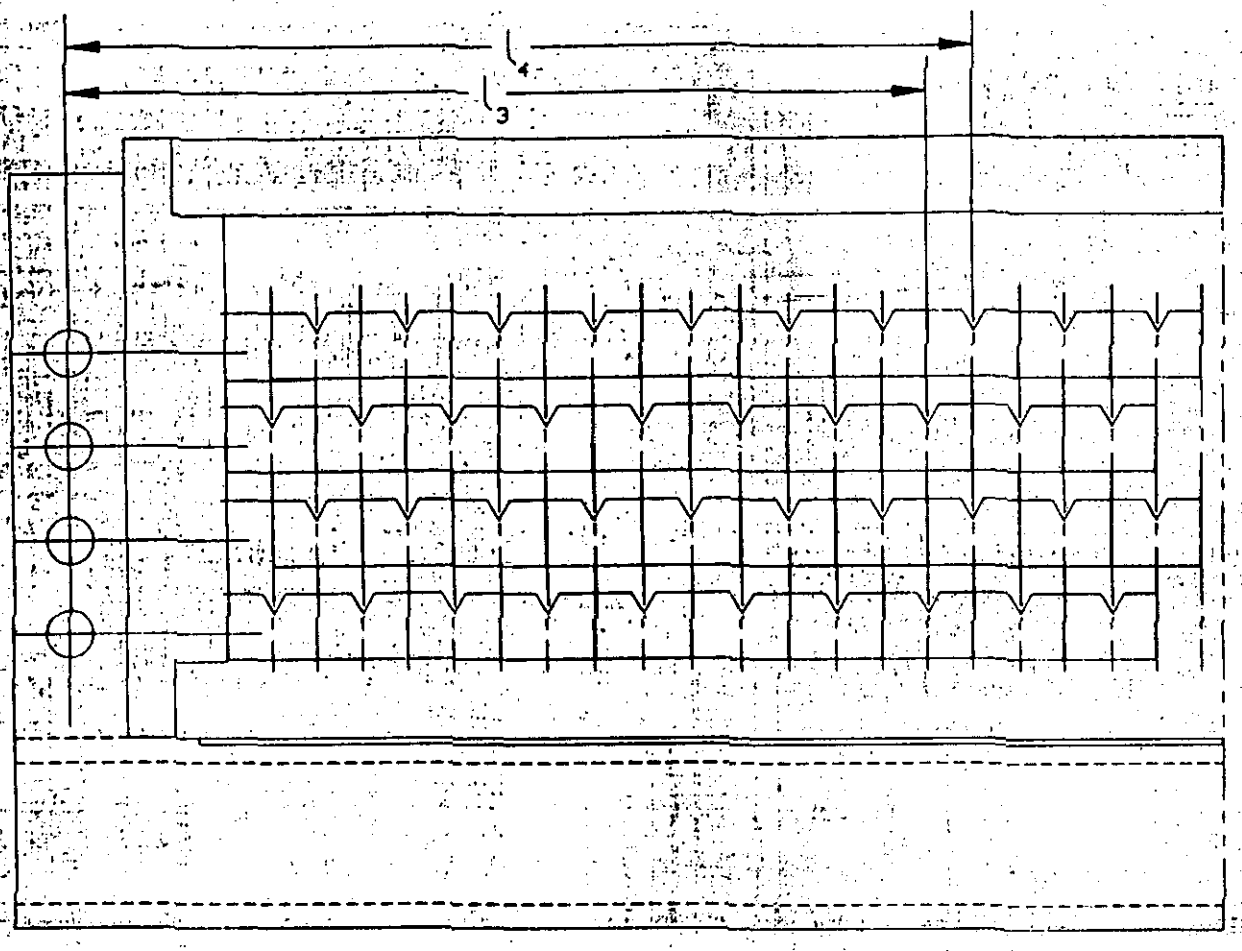
2.) Bridges: with precision grooves.

3.) U-shaped cathode planes.

4.) Z-strip planes.

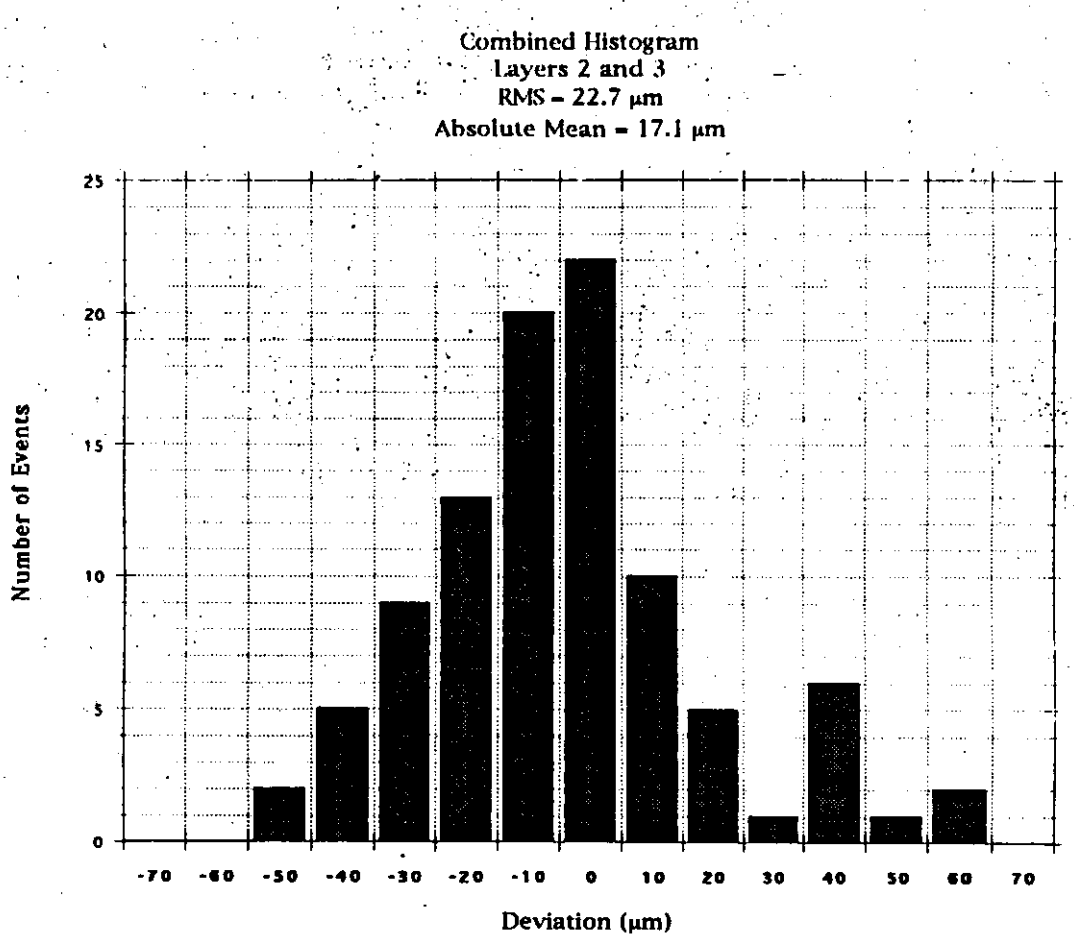

optics
wire
optics


Bridge Groove Deviation (microns)
Draper
Number of Events
0
2
4
6
8
10
-25
-20
-15
-10
-5
0
5
10
15
20
25
Deviation (μm)

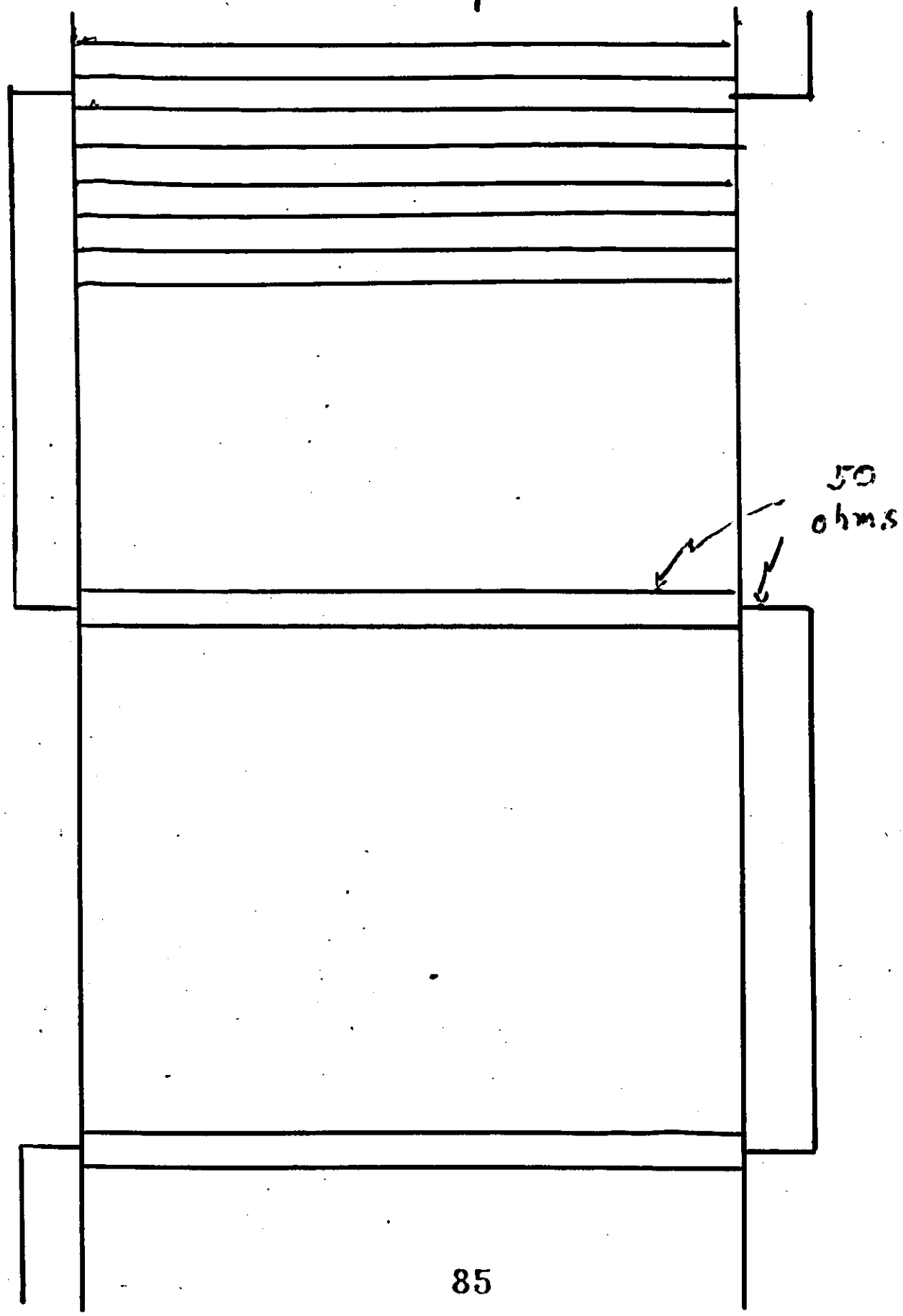


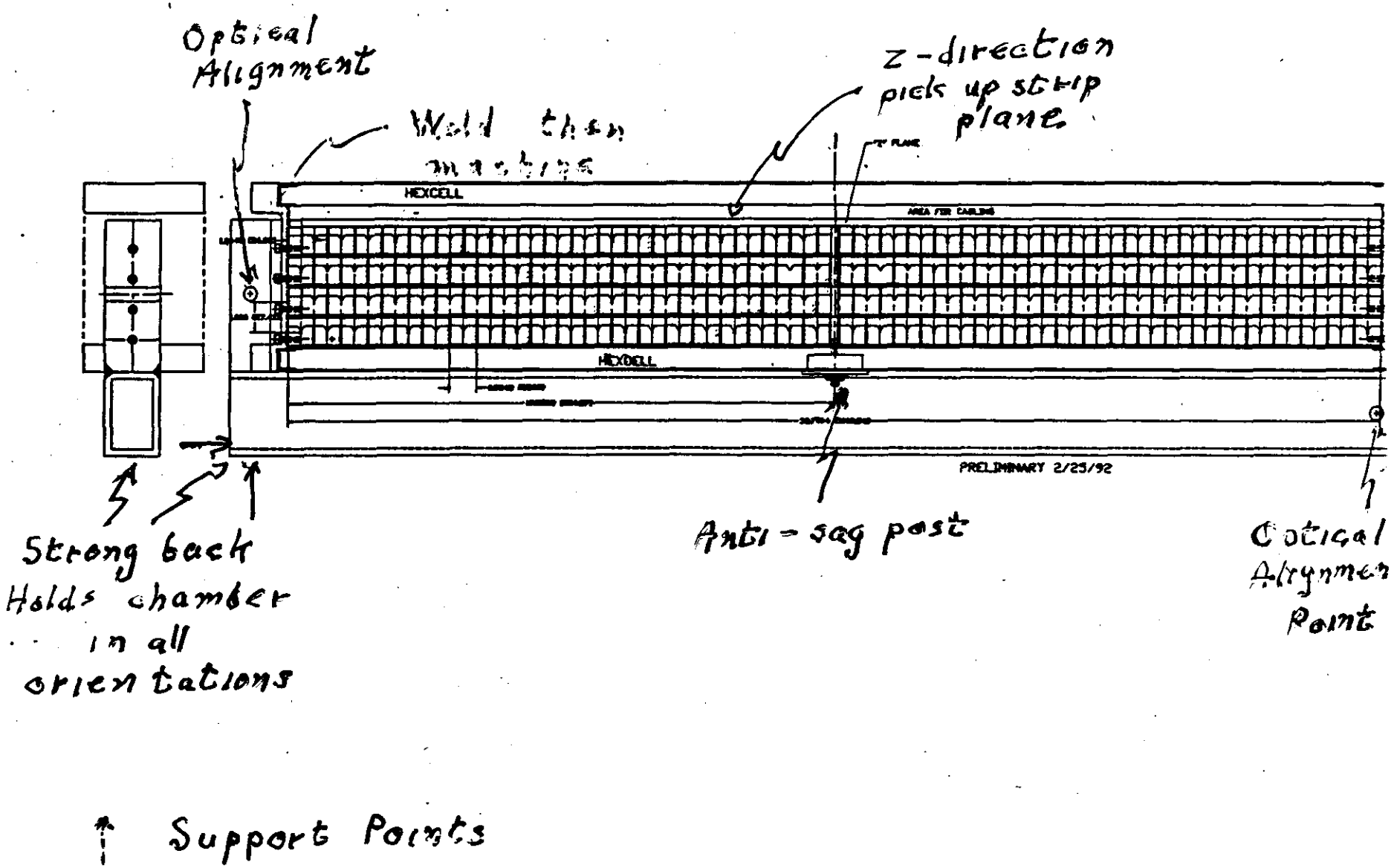
$l_3+(l_4-12.63)$ FOR 3 LAYERS, 3 BRIDGES

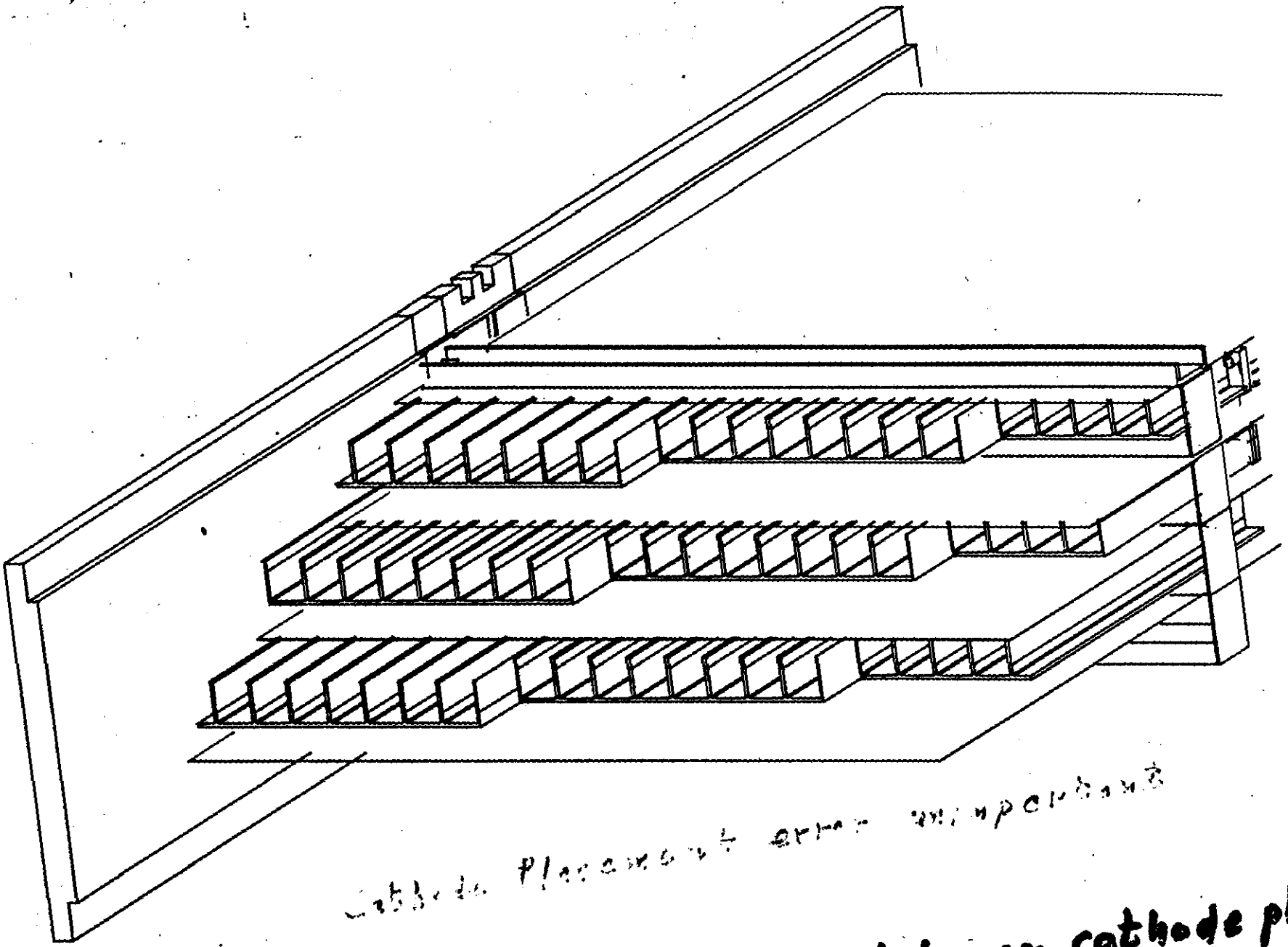
254.619
254.629
254.619
254.627
254.647
254.607
254.631
254.621
254.625


Combined Histogram
Layers 2 and 3
RMS = 22.7 μm
Absolute Mean = 17.1 μm
Number of Events
25
20
15
10
5
0
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
Deviation (μm)

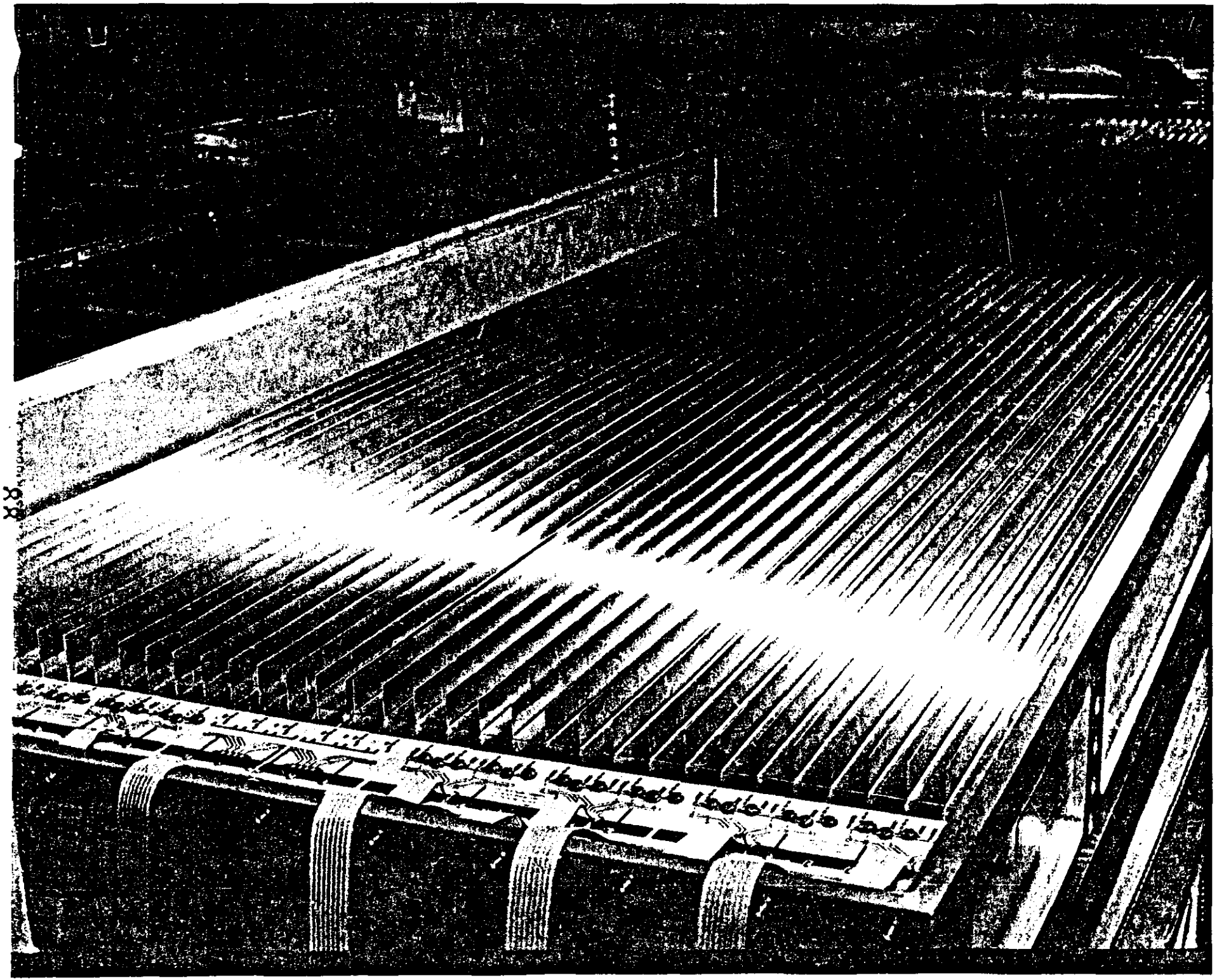
Z- strips

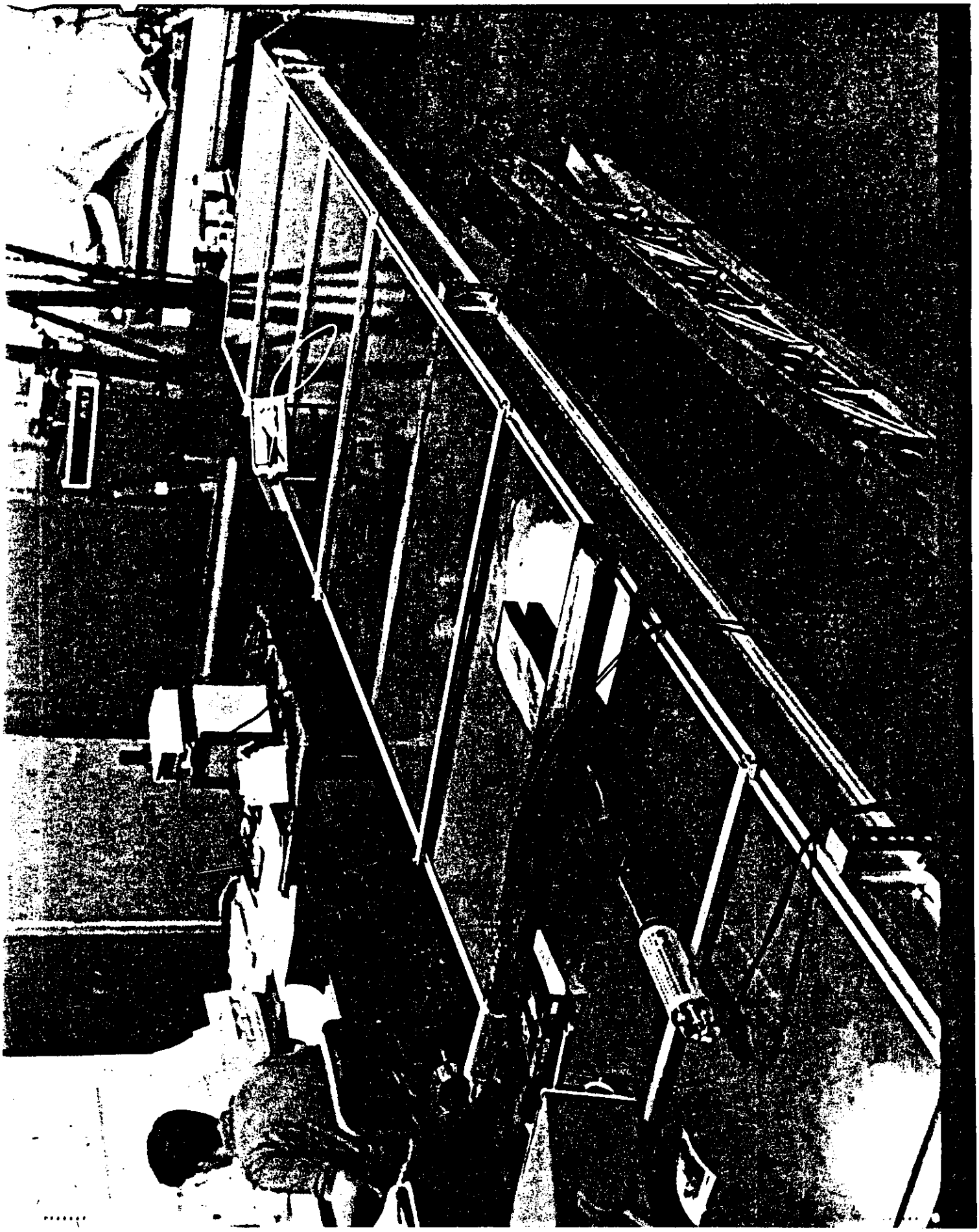



Optical Alignment
Weld then machine
z-direction pick up strip plane
HEXCELL
HEXCELL
PRELIMINARY 2/25/92
Strong back Holds chamber in all orientations
Anti-sag post
Optical Alignment Point
Support Points

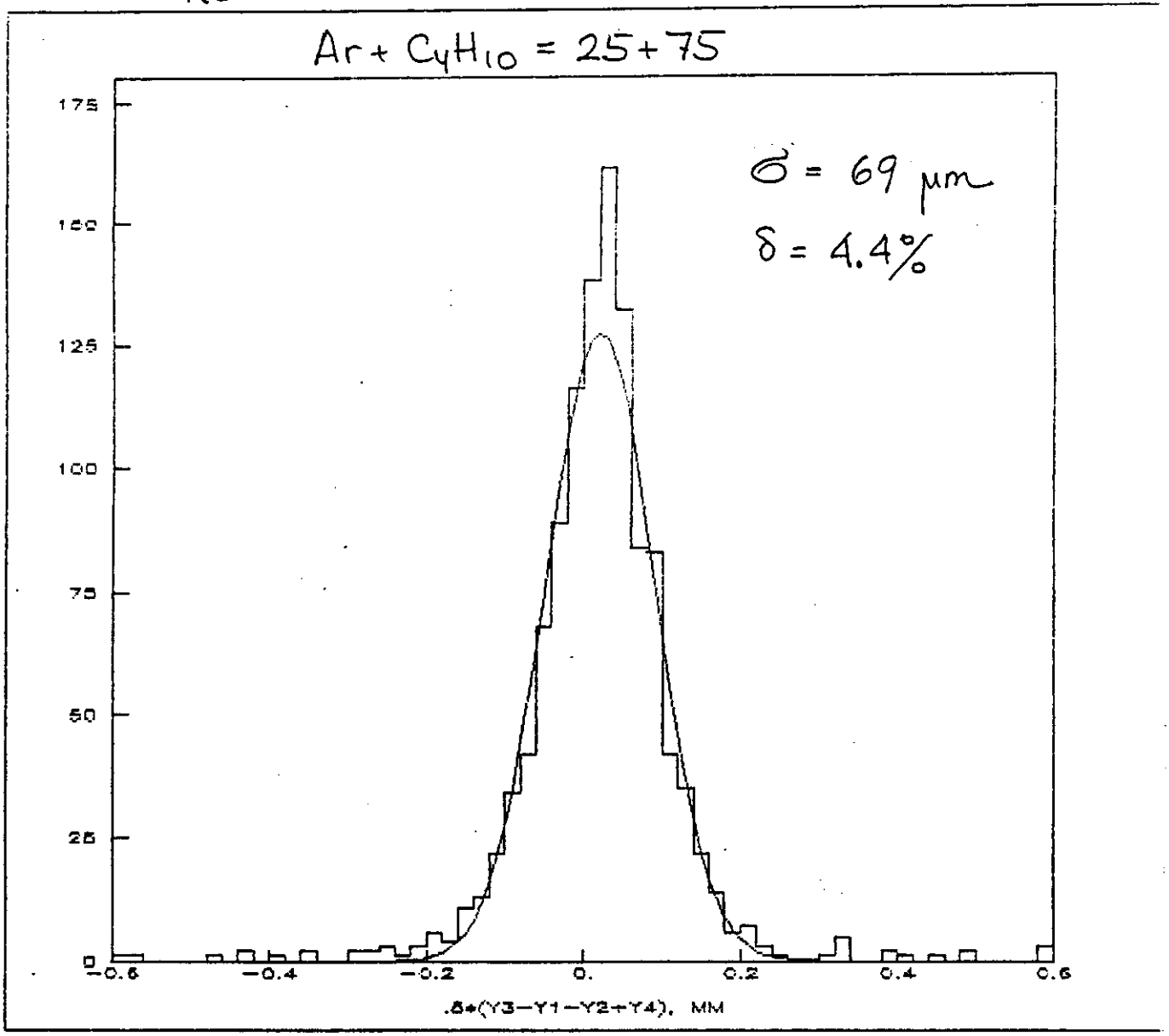


(Out of date- no gaps between cathode pl





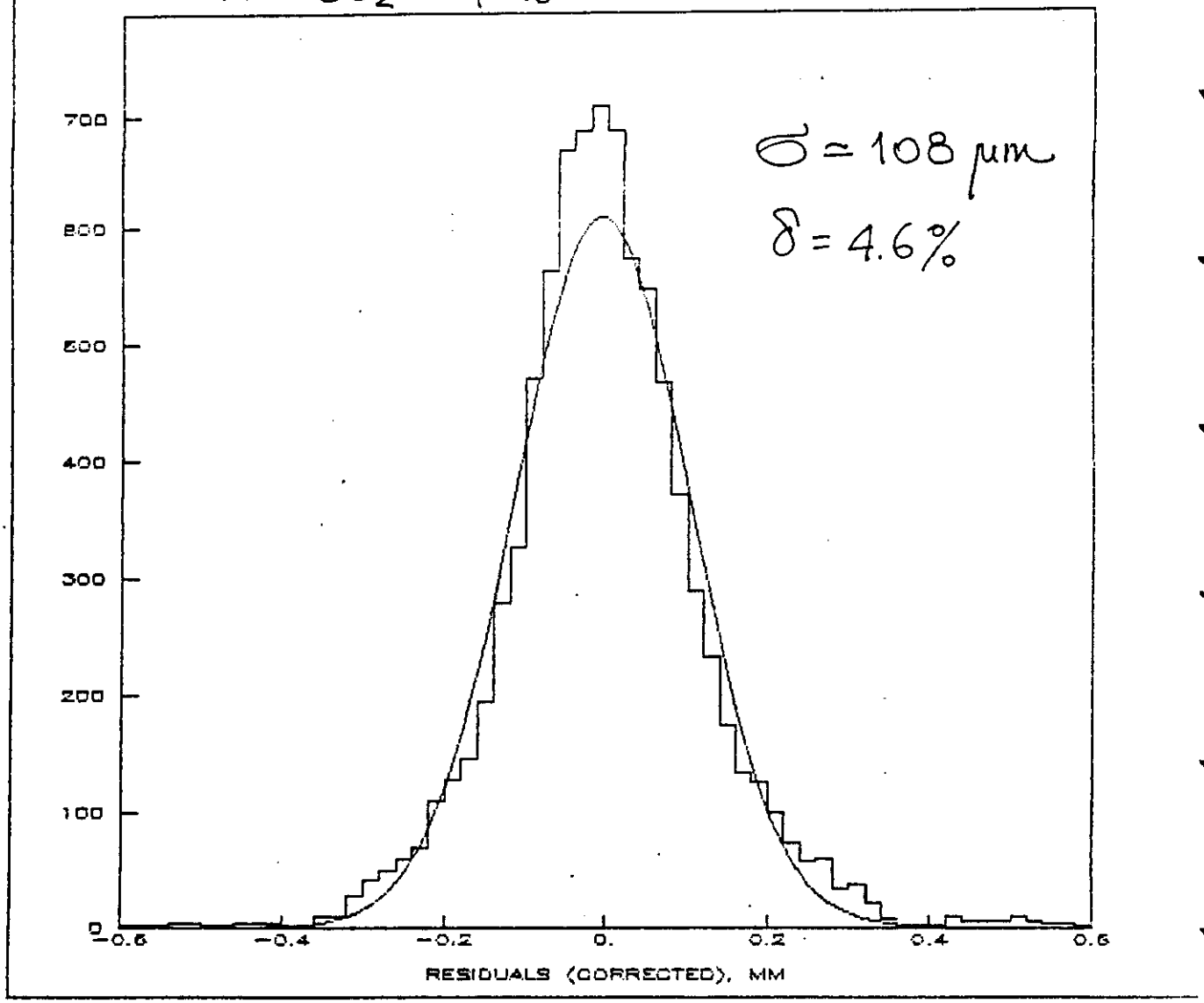
PRELIMINARY 9/20/92



ALL TRACKS GOING BETWEEN WIRES
($\sigma_\alpha \sim 4°$)

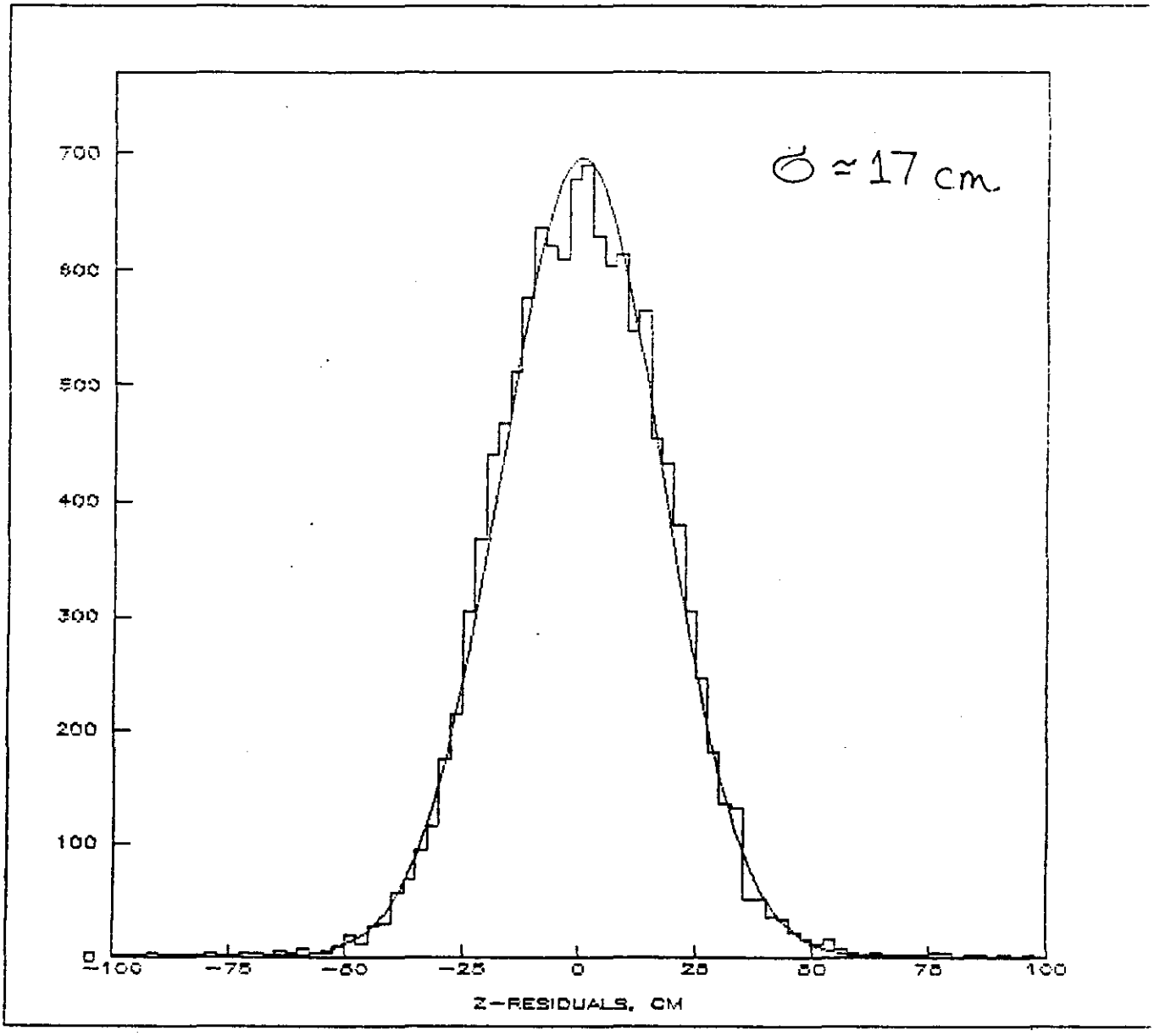
PRELIMINARY 9/18/92

$Ar + CO_2 + C_4H_{10} = 2.5 + 88 + 9.5$



#3 $|\alpha| \leq 5°$ $\sigma = 108$ μm

PRELIMINARY 9/18/92



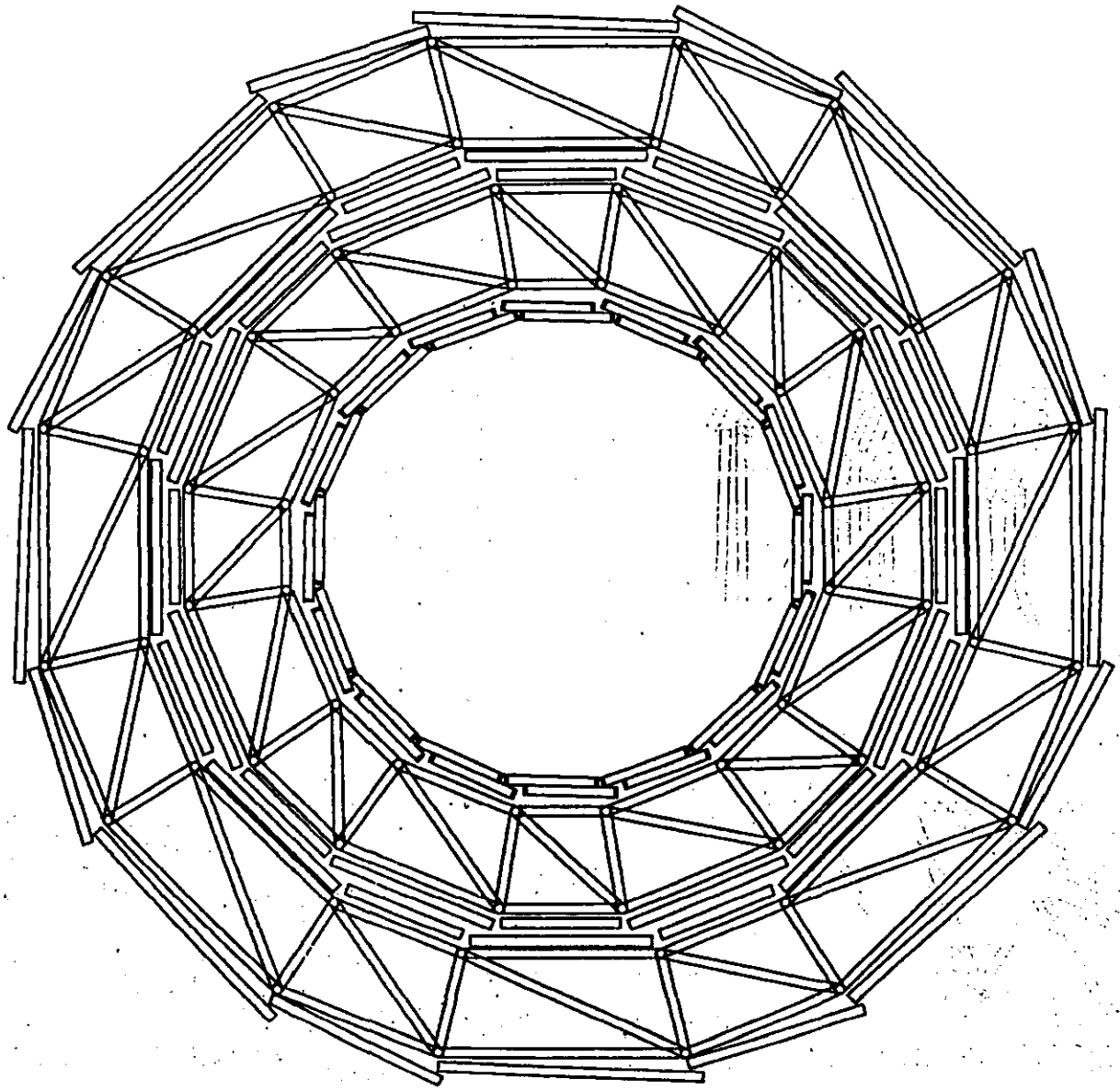
OVERLAP

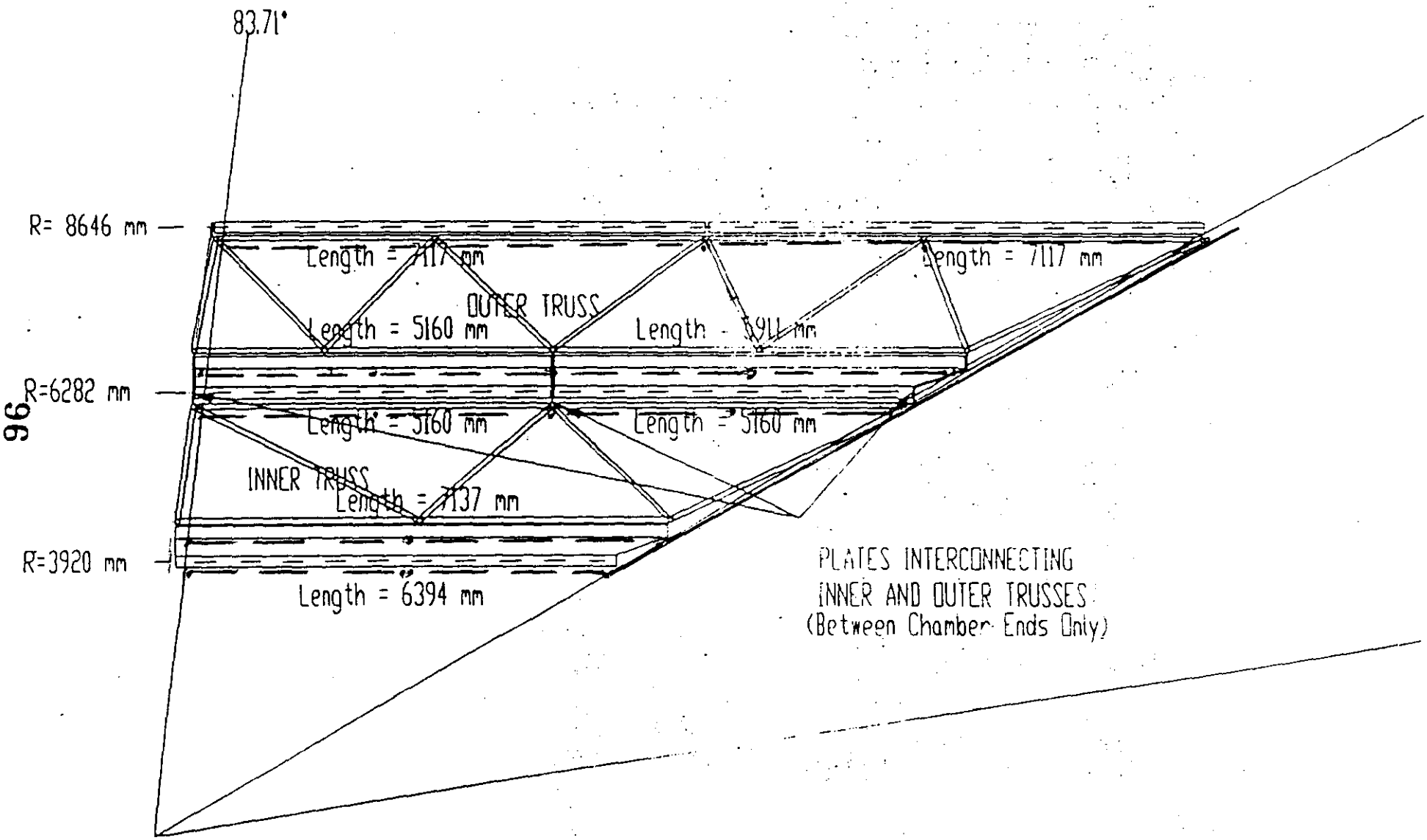
1.) Sector to Sector

2.) In Superlayers

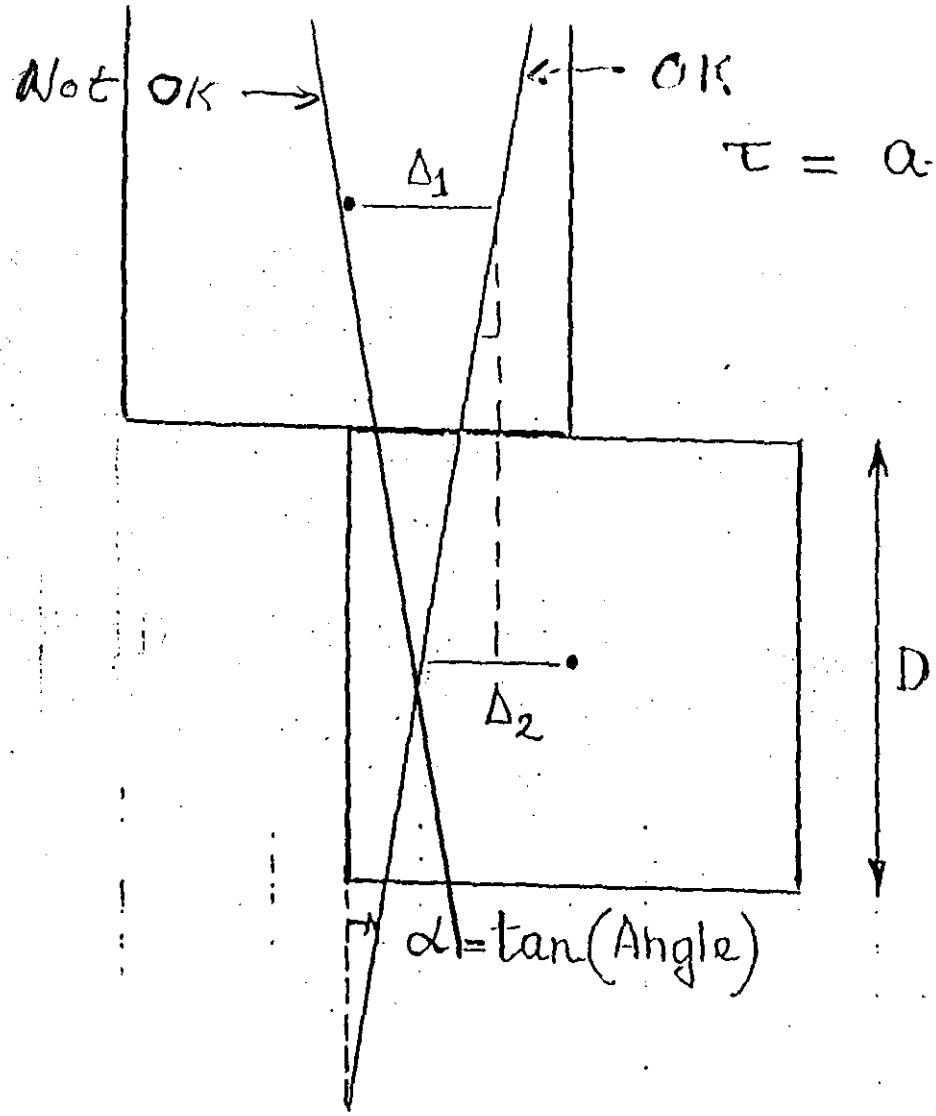
a.) along ϕ

b.) along θ





A.1.10. Side view of LSDT chamber layout.



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

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

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

Fig.A.IV.5

). GeV:	Nyes-Nno-Nwrong=	9998	0	2
). GeV:	Nyes-Nno-Nwrong=	10000	0	0
). GeV:	Nyes-Nno-Nwrong=	10000	0	0
). GeV:	Nyes-Nno-Nwrong=	9998	0	2
). GeV:	Nyes-Nno-Nwrong=	9999	0	1
). GeV:	Nyes-Nno-Nwrong=	10000	0	0

0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	796	1003	1162	1199	1239	1245
7	2293	2593	2639	2642	2656	2716
8	5104	4673	4596	4510	4449	4417
9	1640	1565	1426	1468	1444	1447
10	165	162	171	176	208	166
11	2	2	5	5	4	7
12	0	2	1	0	0	2

DINCIDENCE LEVEL

P=10 GeV/c	=20	=40	=80	=160	=320

Table 1

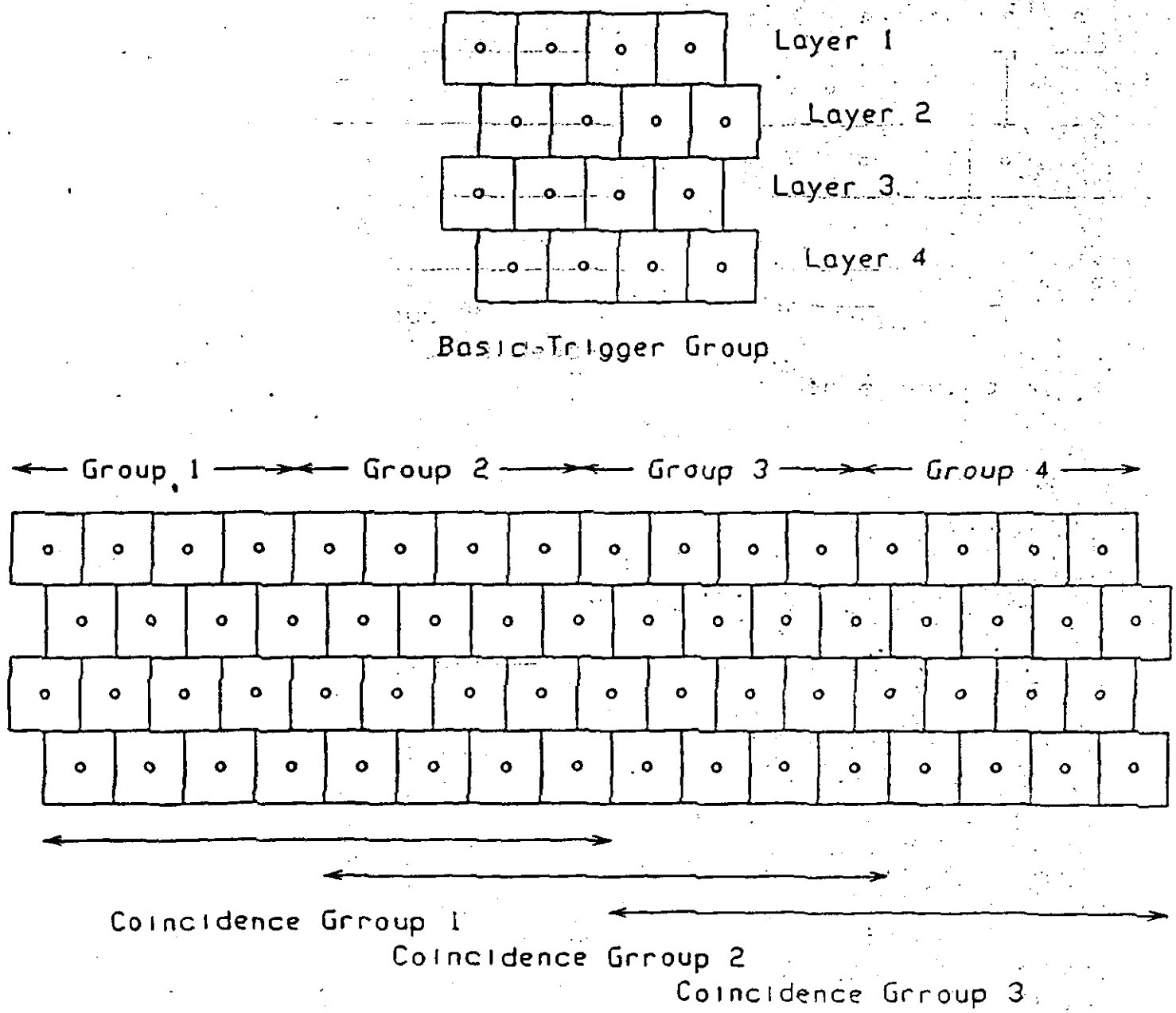
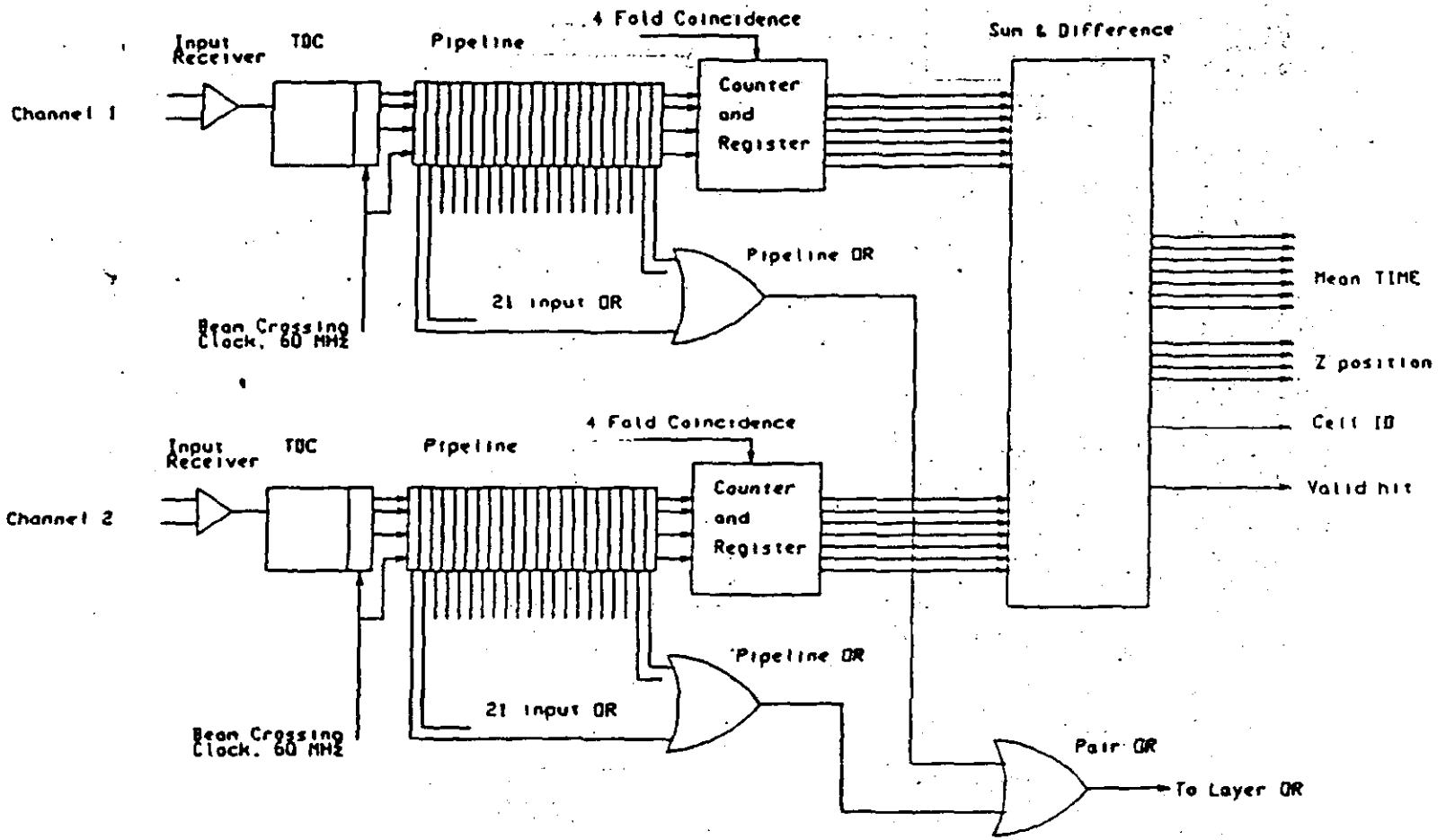

Layer 1
Layer 2
Layer 3
Layer 4
Basic Trigger Group
Group 1
Group 2
Group 3
Group 4
Coincidence Grroup 1
Coincidence Grroup 2
Coincidence Grroup 3

Fig.A.VII.1



Muon Trigger TDC

Fig.A.VII.2

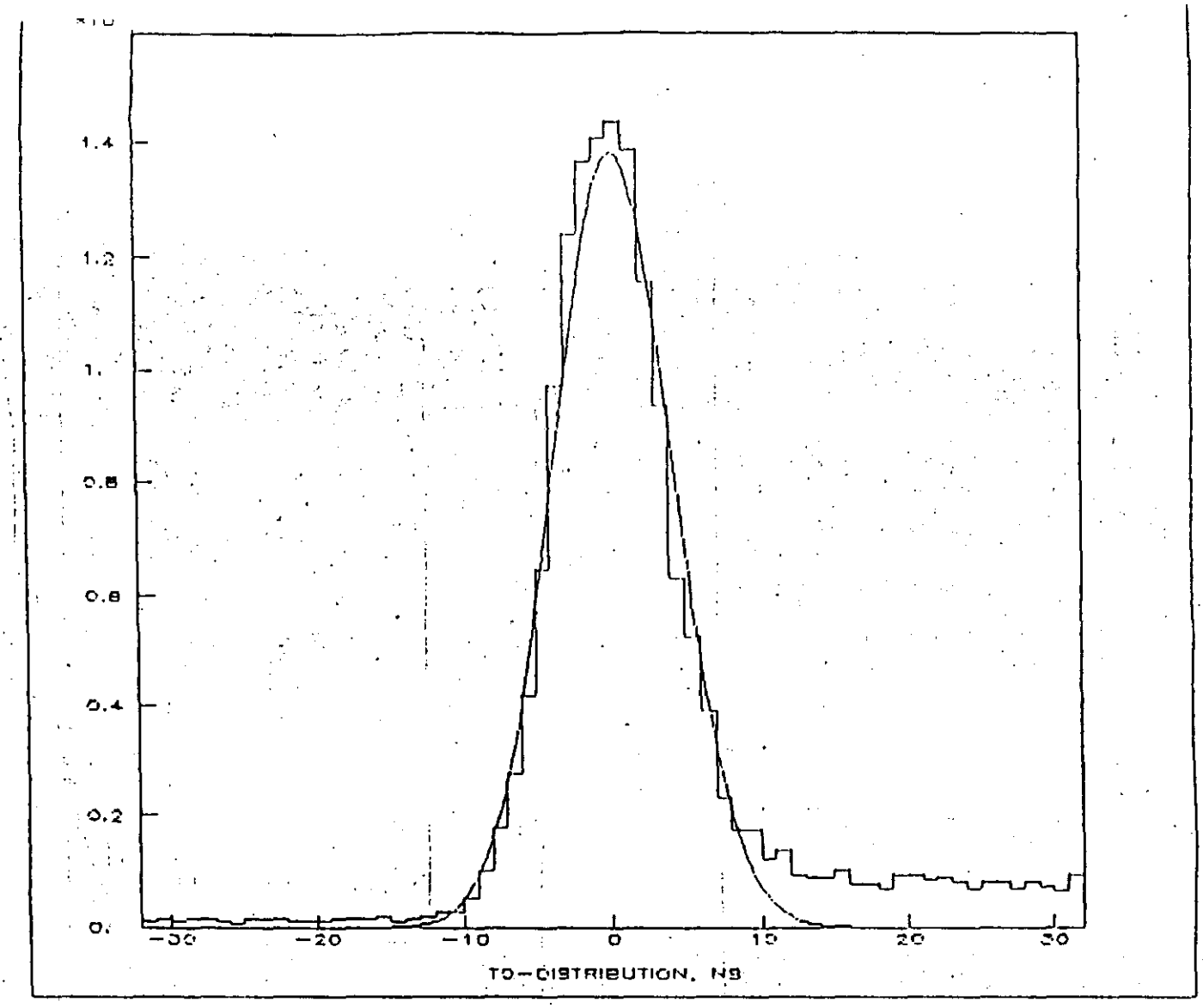
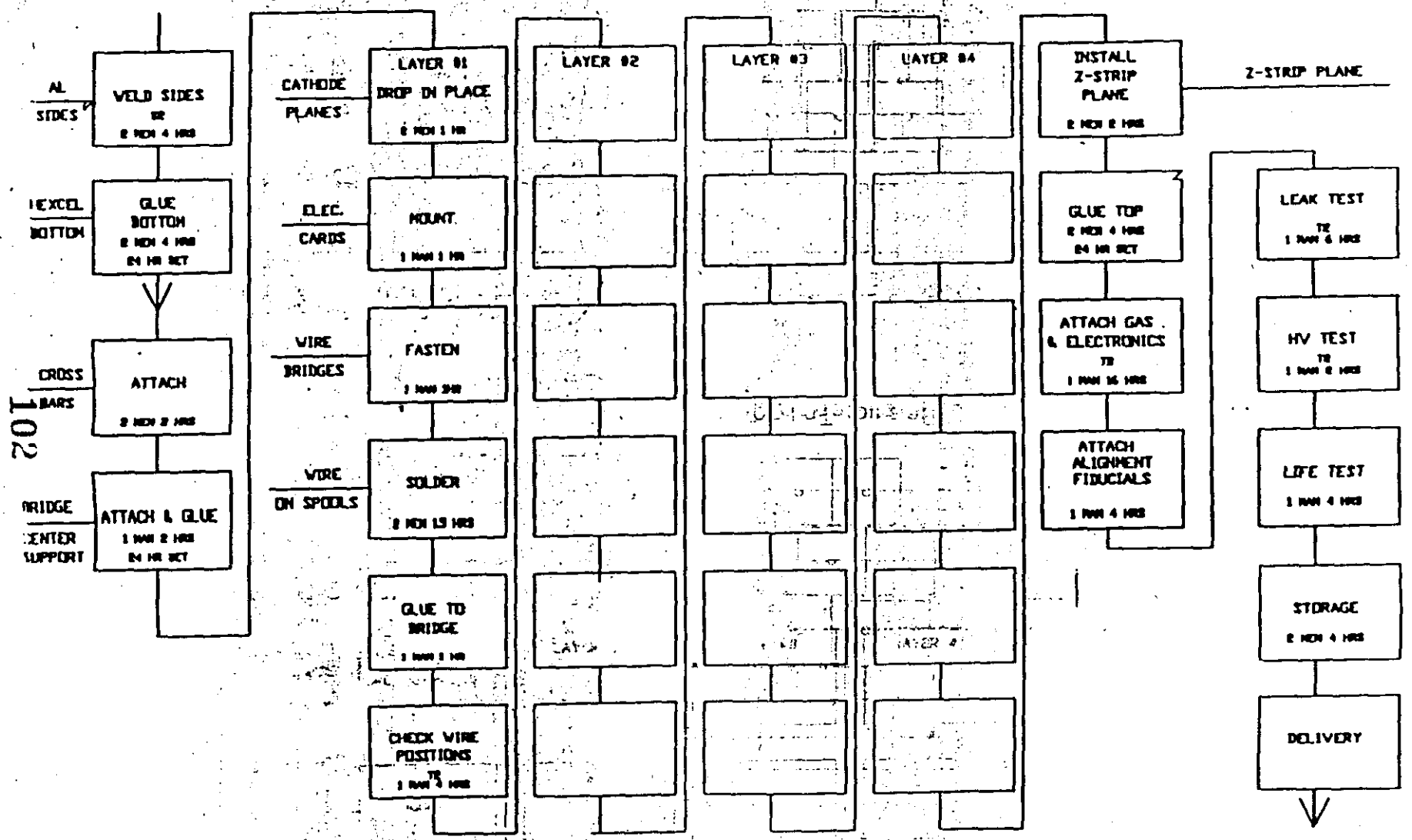


Fig.A.IV.12(a)



A.1.13. Diagrammatic flow of a chamber assembly procedure.

APPENDIX-NEUTRON BACKGROUND PROBLEMS

Given the neutron efficiency of our chamber and Laurie Waters' calculation of neutron fluxes then is the background rate disturbing?

Waters tells me by letter that the flux of neutrons after the calorimeter and 10 cm of borated polyethylene is 1.15×10^3 per cm^2 per second.

With our "efficiency" of 4×10^{-3} and typical single tube area of 2.5 cm x 1000 cm we get 11.5 kHz/wire. at the first layer.

Wire aging: Taking $\sim$ 50 picoCoulombs/pulse I get 5.75×10^{-3} Coul./cm of wire/year. It would take 174 years to get to the danger point, 1 Coul./cm. or 17.4 years at 10^{34} luminosity.

What is the chance rate to get a vector from 3 out of 4 layers firing within the drift time? I take the worst drift time , 0.5 μsec, i.e. using a CO_2 gas. I get 2.6 Hz. This does not make a level 1 trigger rate; one would require 2 such vectors in adjoining 4 layered chambers of a superlayer not to mention requiring near collinearity in the 3 superlayers.

CAVEATS:

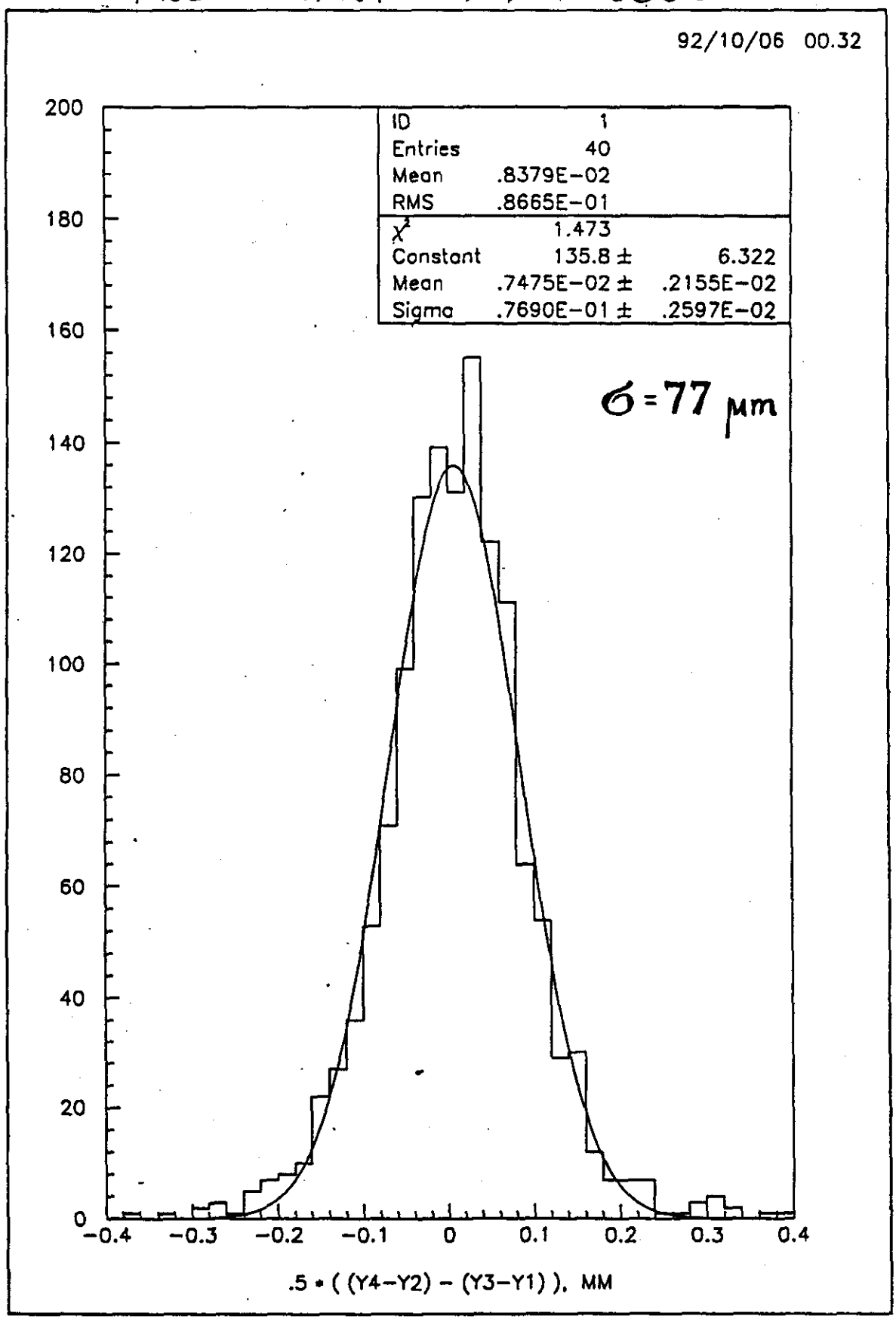
1.) The neutron flux calculation includes only the neutrons exitting from the nearby parts of the calorimeter. Reflections of the higher fluxes at smaller angles back into the barrel region are not yet calculated- the magnet acting as a bottle.

2.) There will be capture gammas associated with the neutrons, also not calculated. However these should be of the same number as the neutrons.

3.) The total amount of B-poly moderator is not decided.

4.) Can one add Boron to the copper of the calorimeter. It makes a better compensated calorimeter and captures more neutrons, although the bad and more numerous neutrons are the "high" energy ones i.e. > 5 kev.

PRELIMINARY TTR test



CSC Presentation

Scott Whitaker

THE GEM MUON SYSTEM
BASED ON CATHODE STRIP CHAMBERS

CSC Subgroup of the GEM Muon Group

Presented by

Scott Whitaker

October 6, 1992
SSCL

GEM TN-92-199

The GEM Muon System Based on Cathode Strip Chambers

Beijing Institute for High Energy Physics
Boston University
Brookhaven National Laboratory
Draper Laboratory
Hofei University
Institute for Theoretical and Experimental Physics, Moscow
Joint Institute of Nuclear Research/Dubna
Minsk Institute of Nuclear Problems
Oak Ridge National Laboratory
Princeton University
St. Petersburg Nuclear Physics Institute
SSC Laboratory, Dallas
State University of New York at Stony Brook
Tsinghua University
University of Houston

September 28, 1992

Abstract:

This document proposes to show that the Cathode Strip Chambers (CSC) Technology represents the best choice for the GEM muon system.

Beneficial Features of CSC's

Unified Technology -- One detector provides full functionality:

From the cathode strips --

- Precision measurement in the bend coordinate for momentum determination
- Fast hodoscopic measurement of bend coordinate for triggering

From the orthogonal readout (anode wires or orthogonal cathode strips) --

- Measurement of the non-bend coordinate and determination of θ
- Fast timing and bunch crossing tagging

"Simple" Technology

- A single precision element -- the strip cathode
  - Manufactured by industrial vendors, QA/QC
  - Industrializable design
  - Alignment is integrated into the chamber

Common Technology with the Endcap --

CSC's selected for the Endcaps -- only technology well suited to that geometry

Advantages of choosing CSC's also for the barrel:

- ♥ Focuses effort and resources
  - Common electronics, DAQ
  - Many common engineering issues
- ♥ Reduces system complexity -- mechanics, utilities, DAQ,...

CATHODE STRIP CHAMBERS

Proportional chambers:

- 5 mm gas gap
- 2.5 mm anode wire pitch
- CO_2 / CF_4 mixture
  - -> small Lorentz angle
  - -> adequate drift velocity max drift time ~ 25 ns
- Gas gain 10,000 -- 20,000

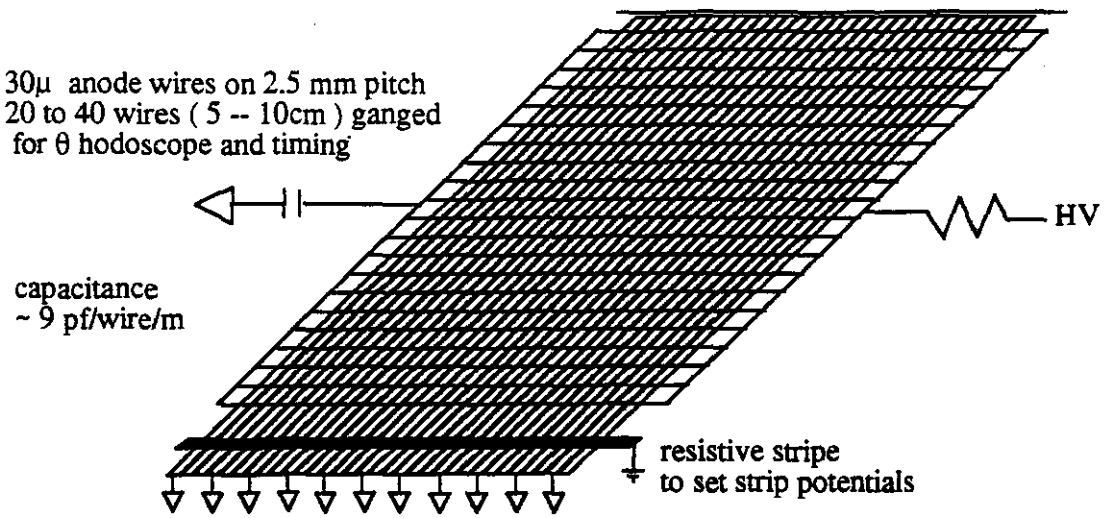
Good resolution achieved by precise measurement of image charge sharing between cathode strips

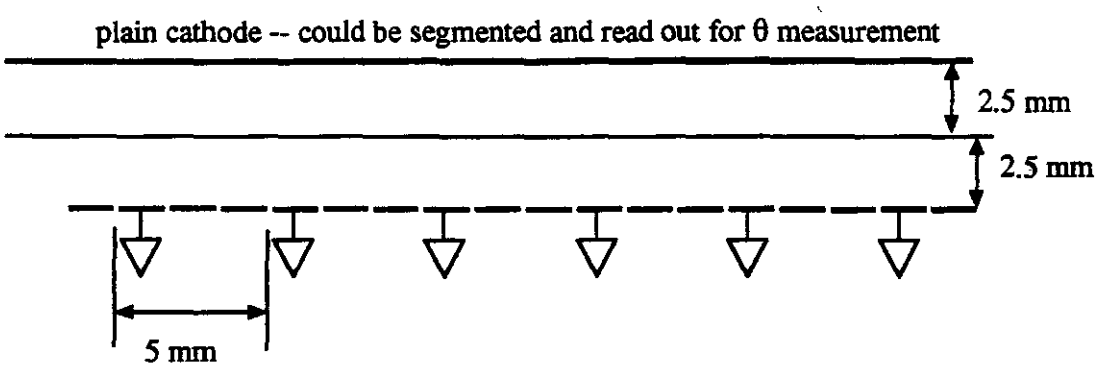
- Precise cathode structure
- Charge measurement to 1%
- Integration times 300 ns --1 μsec to reduce noise
- Precision achieved < 1% of strip width
- Space-point -- no L/R ambiguity
- Two-track resolution ~ strip width

For the present: 5 mm strip width

-> 50 -- 75 μm resolution

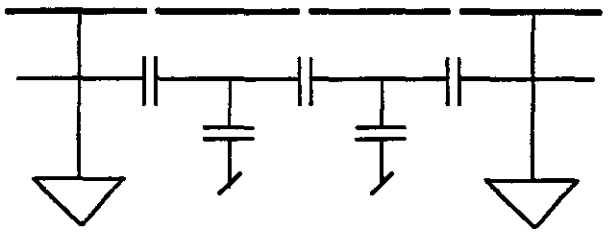
"TWO INTERMEDIATE STRIP" CATHODE DESIGN





Floating strips between readout strips act as capacitive divider
- improved linearity
- lower capacitance

capacitance seen by preamp ~ 26 pf for 1/2 m strips

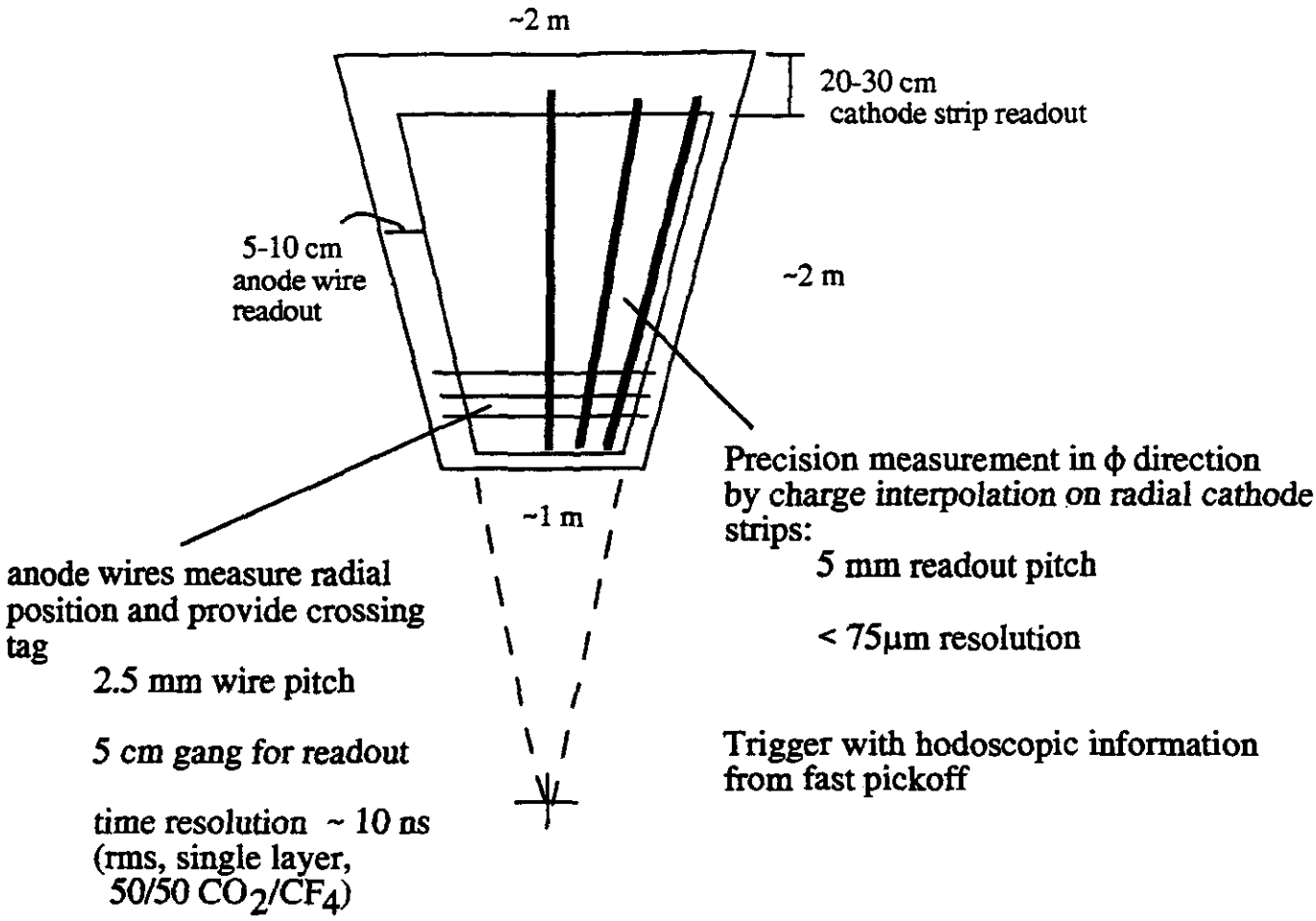


Cathode Strip Chambers for GEM Endcaps

Large area, narrow gap (5 mm) multiwire proportional chambers

Four-layer modules; light, rigid package

Alignment features integrated with precision cathodes



Chamber size limited by

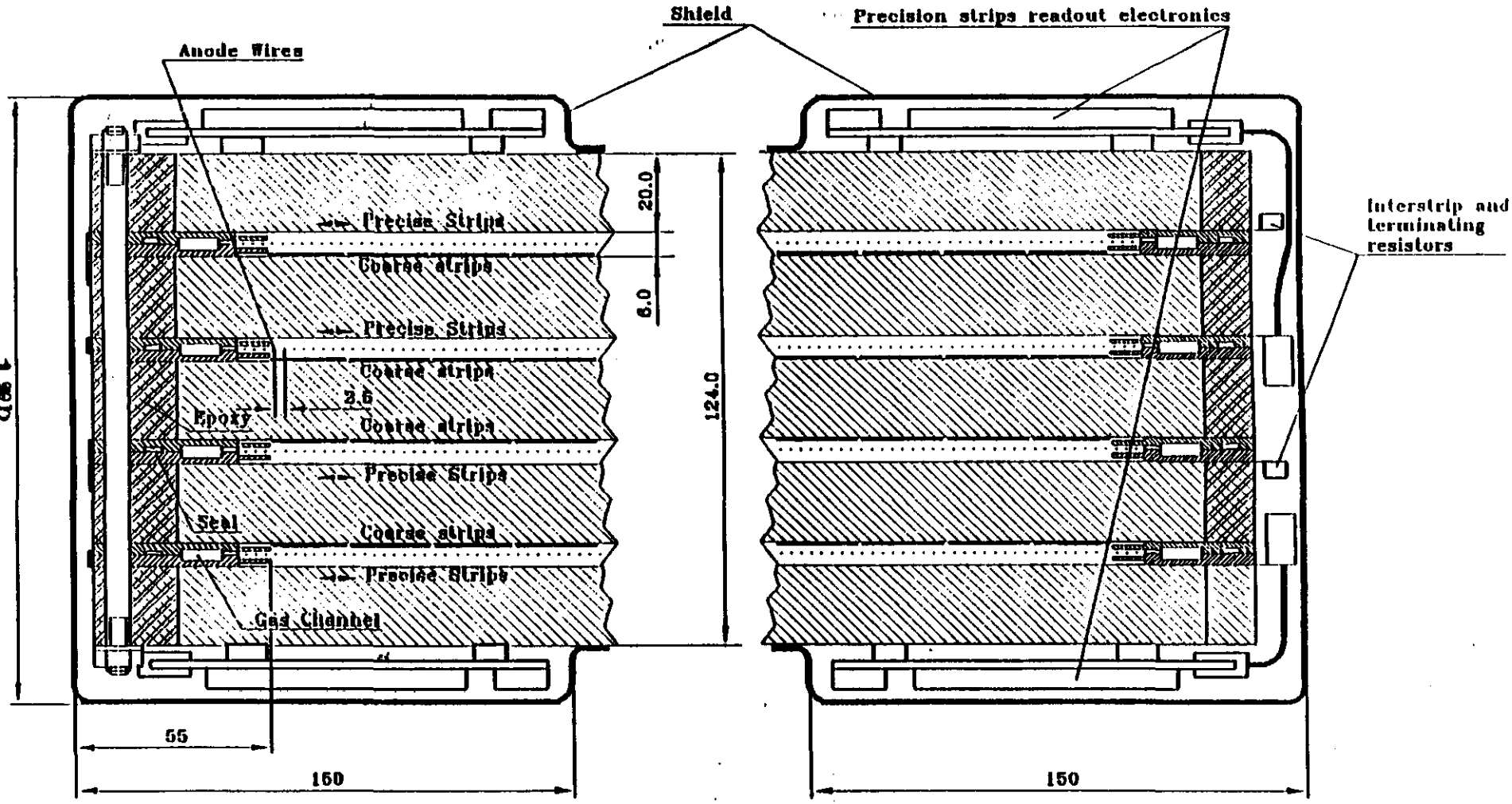
- rate
- noise contribution from strip capacitance
- capacity of circuit board houses

Need to overlap chambers to limit acceptance losses

BARREL CSC

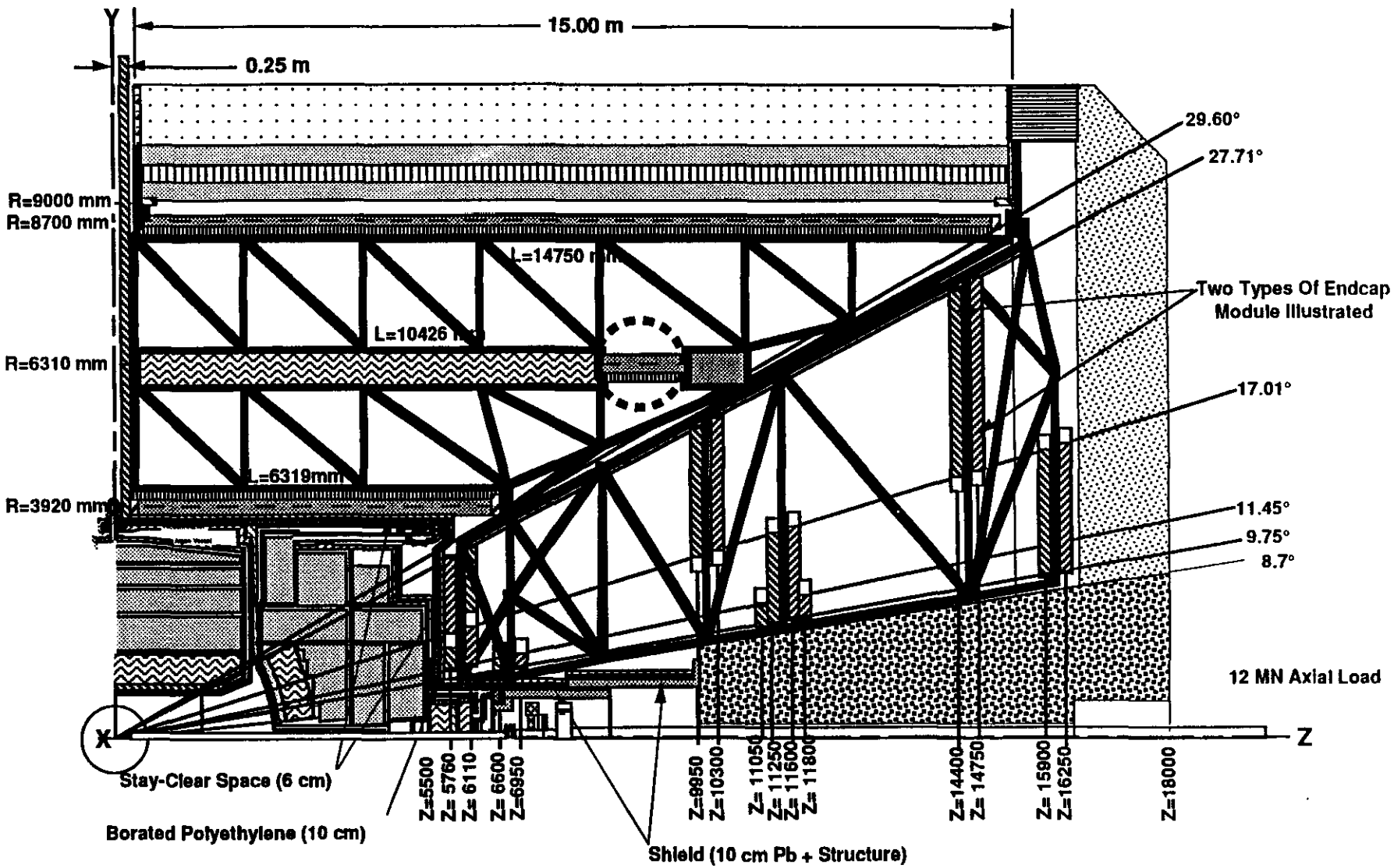
CROSS SECTION ALONG THE STRIPS

(A–A)



Y.Ershov
I.Golutvin
V.Lysiakov
S.Movchan

Fig.2.9

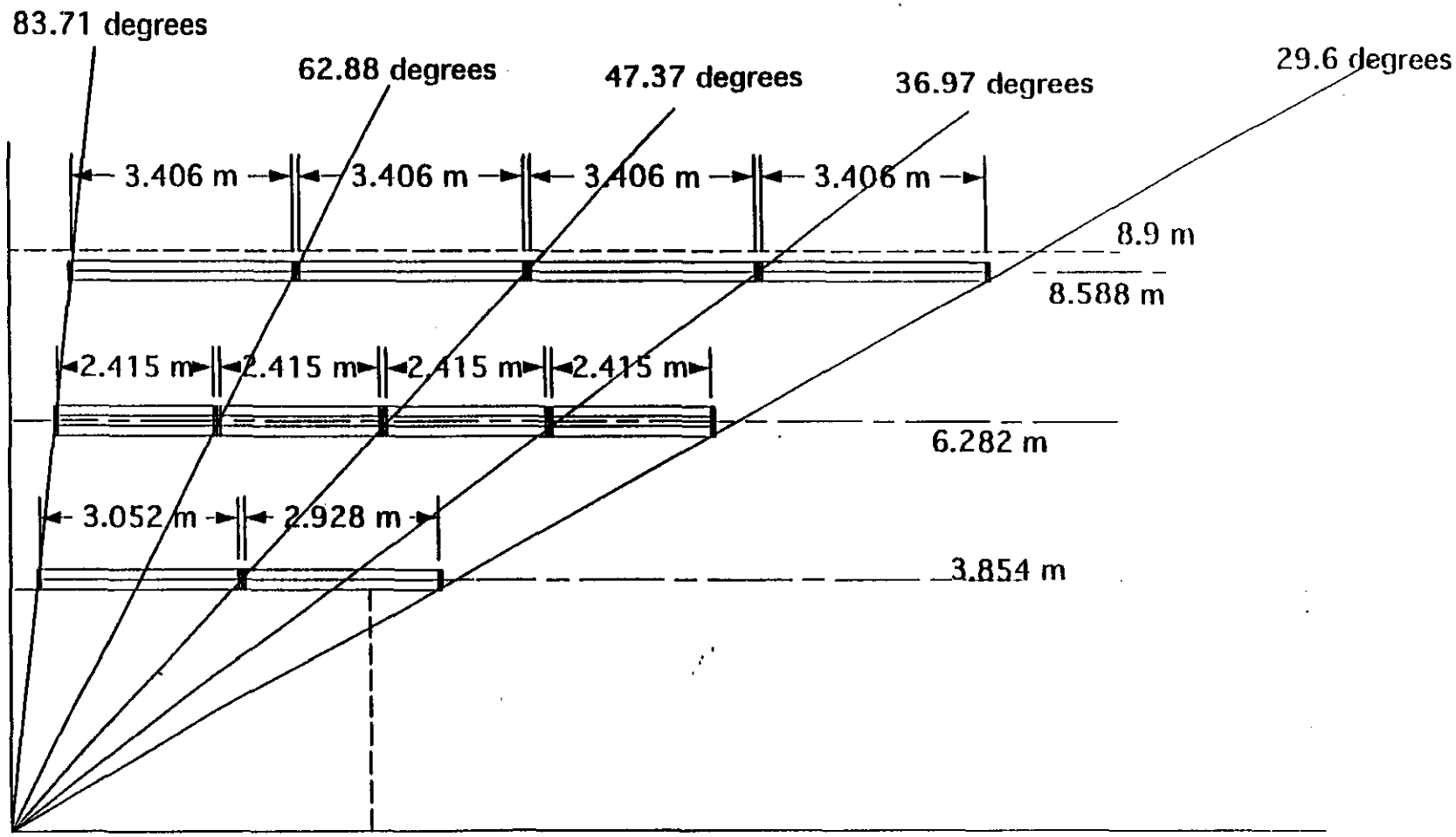


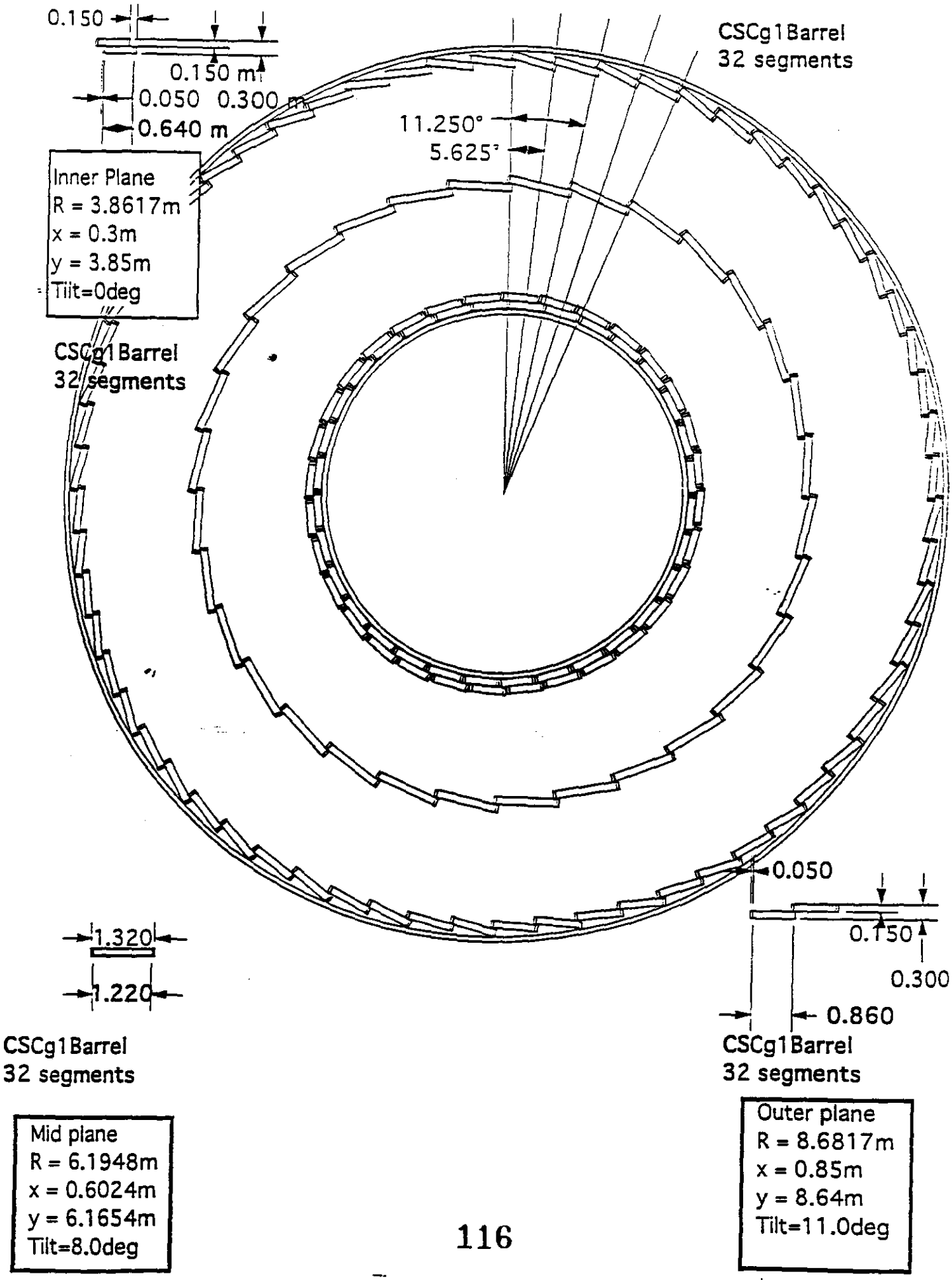
GEM MUON SYSTEM (BASELINE)

Fig. 1.3 **With Baseline LAr Calorimeter Illustrated**

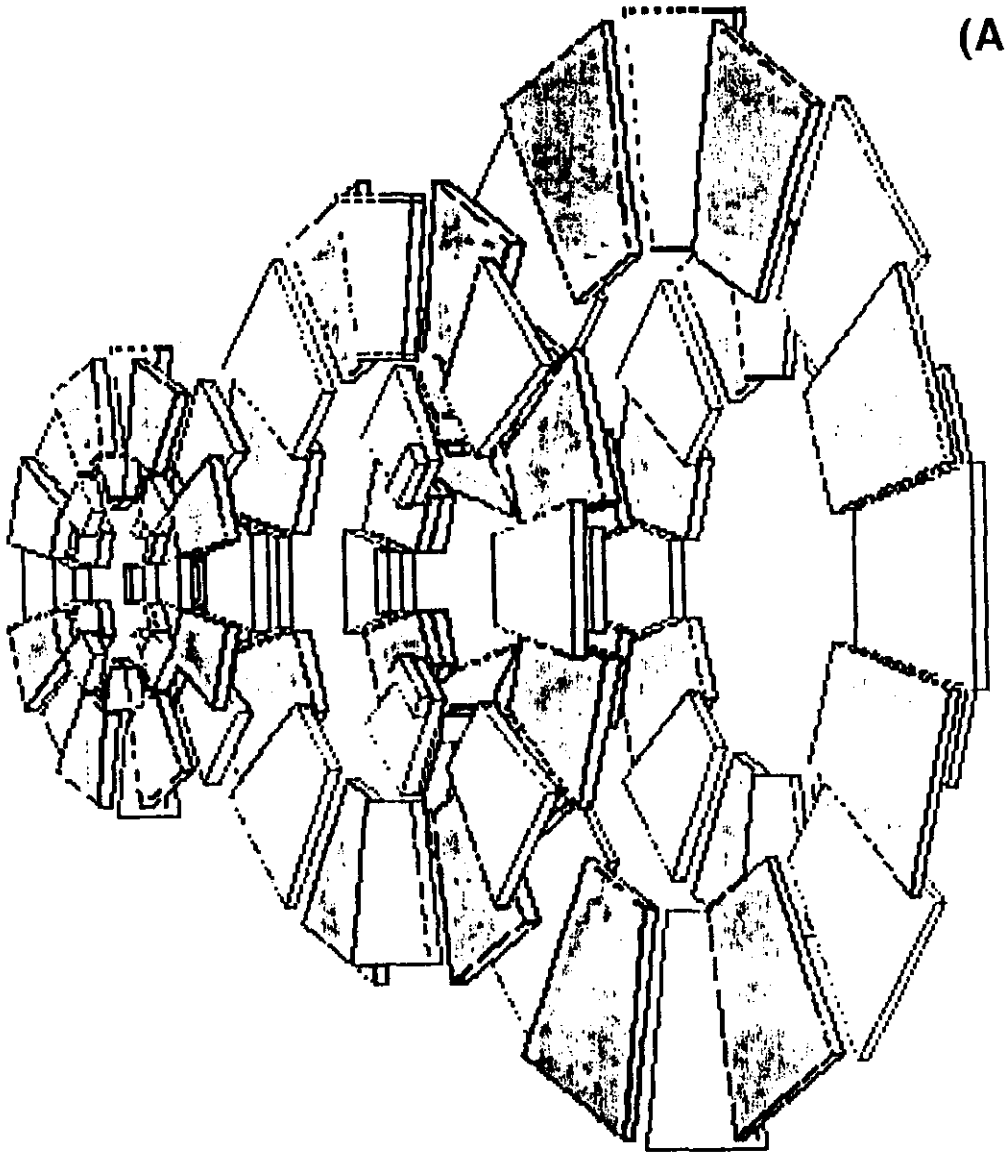
CSCf2crzBarrellayout

Lengths of active areas




0.150
0.150 m
0.050
0.300 m
0.640 m
Inner Plane
R = 3.8617m
x = 0.3m
y = 3.85m
Tilt=0deg
CSCg1Barrel
32 segments
11.250°
5.625°
CSCg1Barrel
32 segments
0.050
0.150
0.300
0.860
1.320
1.220
CSCg1Barrel
32 segments
CSCg1Barrel
32 segments
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

Cathode Strip Chambers
Baseline Array
(All Chambers Shown



F. Nimblett
Draper Lab
5/2/92

Table 1.1 Dimensional and channel count data for the barrel CSC system.

1/2 Barrel = 32 segments
1 precise channel (φ) = 5 mm
1 coarse channel (Z) = 100 mm

Inner Layer: Type A and Type B
Middle Layer: Type C
Outer Layer: Type D

	A	B	C	D
Sensitive Area mm × mm	640 × 3,052	640 × 2,928	1,220 × 2,415	860 × 3,406
Outside dimensions mm × mm	740 × 3,152	740 × 3.028	1,320 × 2,515	960 × 3,506
N Chambers in sector	2	2	4	8
N Chambers in barrel	128	128	256	512
Total sensitive area M^2	250	240	850	1500
N precise channels in chamber	512	512	1,024	704
N coarse channels in chamber	120	116	96	136
Total N precise channels	65,536	65,536	262,144	360,448
Total N coarse channels	15,360	14,848	24,576	69,632

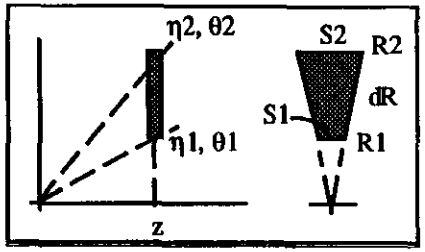
Total Number of 4-gap chambers: 1,024
Total sensitive area of 4-gap chambers: 2,840m^2
Total Number of precise channels: 753,664
Total Number of coarse channels: 124,416

Endcap CSC Layout

Open Magnet Geometry
Structure at 10.5° and 28.45°; active coverage 9.75° to 27.71°
module border (nonreadout) 10 cm; module thickness 20 cm; intermodule space 15 cm

9/27/92
SW

Nsectors= 16
wires ganged by 20 = 5.00 cm
Strip width at middle = 5.00 mm



Configuration: number of planes in 1st / 2nd / 3rd module
8 / 8 / 4 for eta > 2.3
8 / 4 / 4 elsewhere

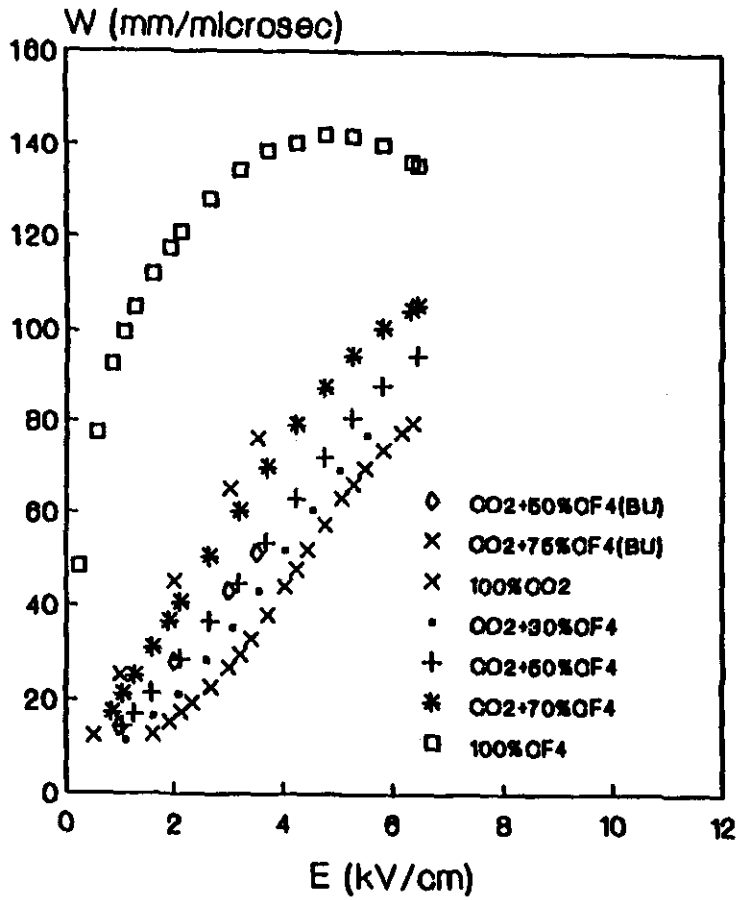
Nomenclature
Note: modules (a) occupy even-numbered sectors
modules (b) occupy odd-numbered sectors

Total channel counts:

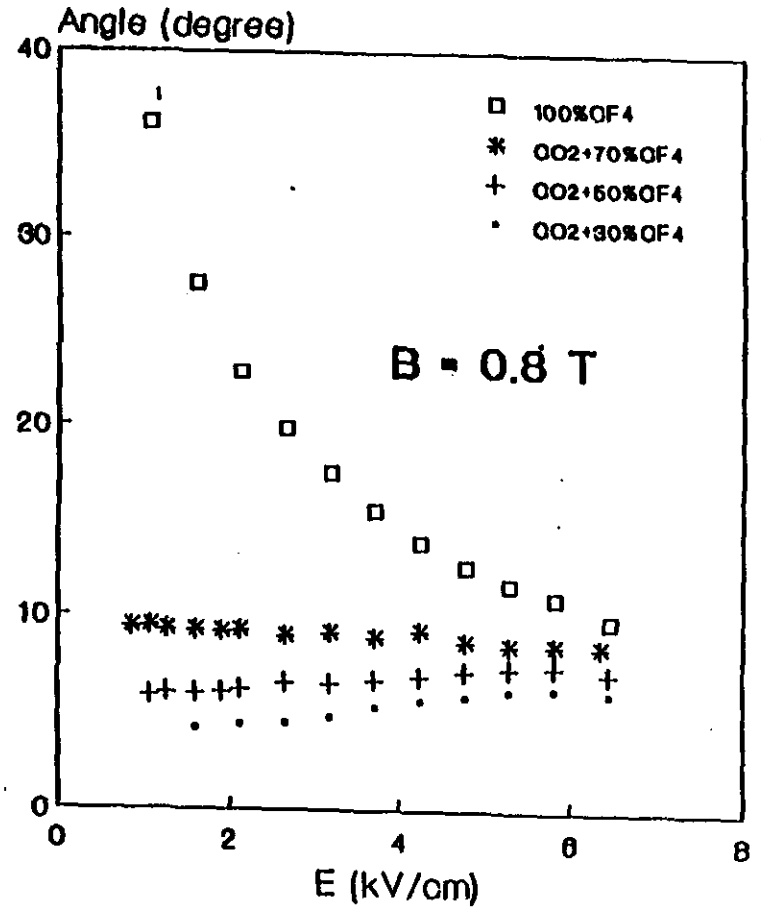
	z	η1	θ1	η2	θ2	R1	R2	dR	S1	S2	area	# strips	strip occ	# r-chans	# strip chan	# r-chan	wt/mod
	m		deg		deg	m	m	m	m	m	m^2	/pl/sctr	/sec	/pl/sctr			Kg
Inner modules																	
1a)	5.76	2.30	11.45	1.90	17.01	1.17	1.76	0.60	0.46	0.69	0.33	114	98	12	14629	1,525	25
1b)	6.11	2.30	11.45	1.90	17.01	1.24	1.87	0.63	0.48	0.73	0.38	121	104	13	15518	1,618	27
2a)	6.11	1.90	17.01	1.40	27.71	1.87	3.21	1.34	0.73	1.25	1.30	198	36	27	25361	3,428	65
2b)	5.76	1.90	17.01	1.40	27.71	1.76	3.02	1.26	0.69	1.18	1.16	187	34	25	23909	3,231	59
3a)	6.60	2.46	9.75	2.30	11.45	1.13	1.34	0.20	0.44	0.52	0.10	96	103	4	12339	520	14
3b)	6.95	2.46	9.75	2.30	11.45	1.19	1.41	0.21	0.47	0.55	0.11	102	108	4	12993	548	14
Middle modules																	
4a)	11.25	2.46	9.75	1.90	17.01	1.93	3.44	1.51	0.75	1.34	1.55	210	77	30	13422	1,933	75
4b)	11.60	2.46	9.75	1.90	17.01	1.99	3.55	1.56	0.78	1.38	1.65	216	80	31	13839	1,993	78
5a)	9.95	1.90	17.01	1.40	27.71	3.04	5.23	2.18	1.19	2.04	3.45	323	13	44	20650	2,791	144
5b)	10.30	1.90	17.01	1.40	27.71	3.15	5.41	2.26	1.23	2.11	3.70	334	14	45	21377	2,889	153
8a)	11.05	2.46	9.75	2.30	11.45	1.90	2.24	0.34	0.74	0.87	0.27	161	39	7	10329	435	23
8b)	11.80	2.46	9.75	2.30	11.45	2.03	2.39	0.36	0.79	0.93	0.31	172	41	7	11030	465	25
Outer modules																	
6a)	15.90	2.46	9.75	1.90	17.01	2.73	4.87	2.13	1.07	1.90	3.10	296	36	43	18969	2,731	132
6b)	16.25	2.46	9.75	1.90	17.01	2.79	4.97	2.18	1.09	1.94	3.24	303	37	44	19387	2,791	137
7a)	14.40	1.90	17.01	1.40	27.71	4.41	7.56	3.16	1.72	2.95	7.23	467	6	63	29886	4,039	275
7b)	14.75	1.90	17.01	1.40	27.71	4.51	7.75	3.23	1.76	3.02	7.58	478	7	65	30612	4,137	287
													Total =>		294251	35,075	24,536

total area of strip cathodes (m^2) 2484
total volume of chambers (m^3) 12.4
Total number of modules 352

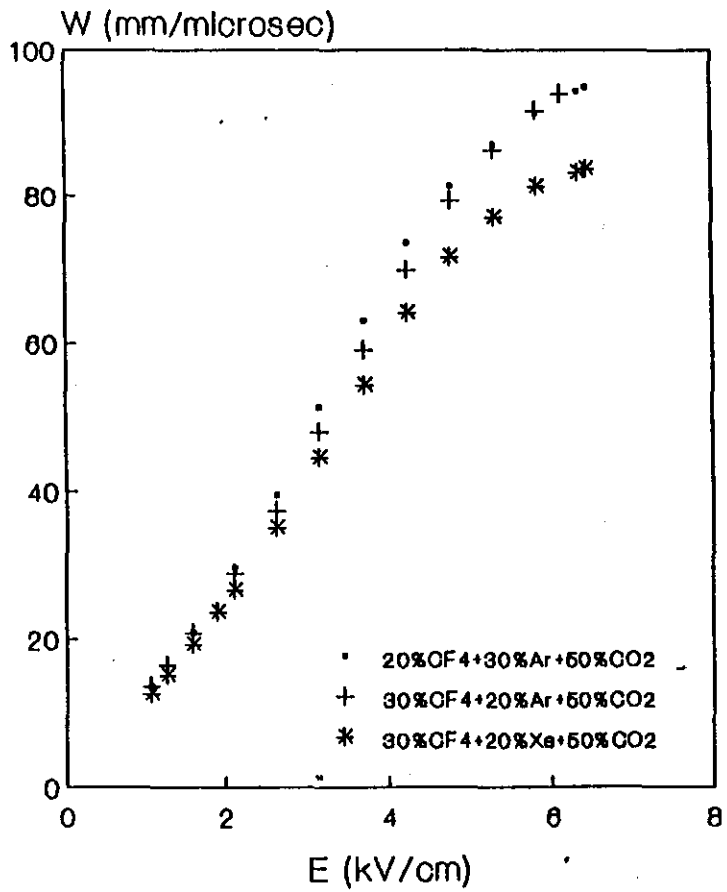
Drift velocity



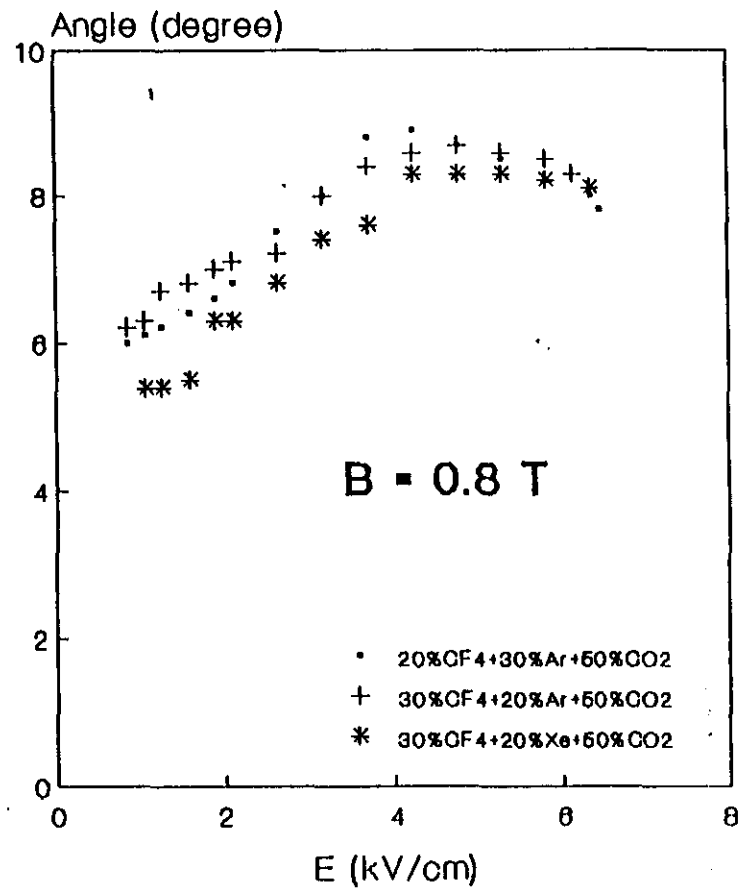
Lorentz angle



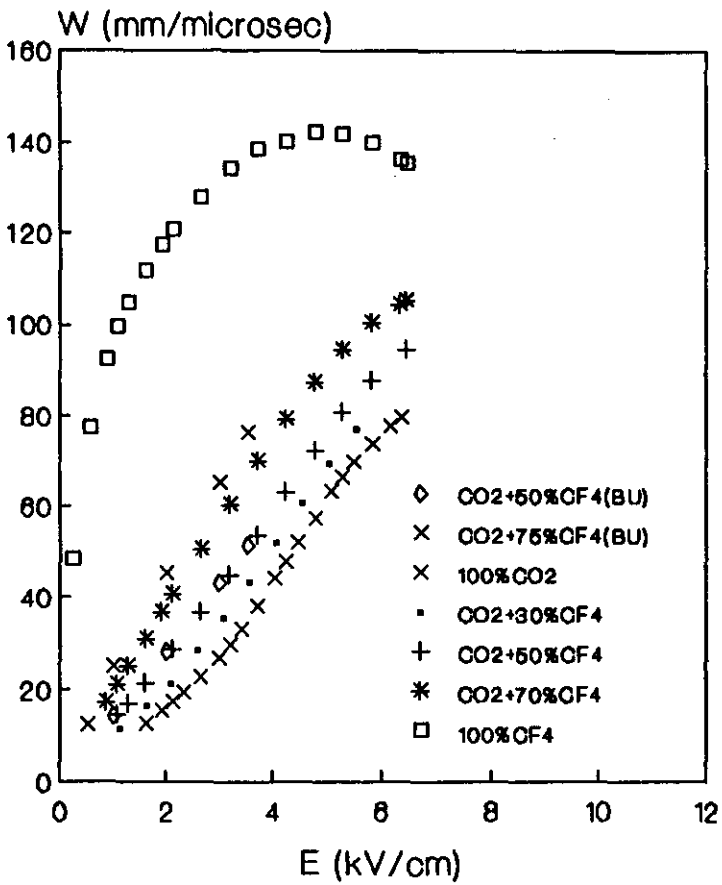
Drift velocity



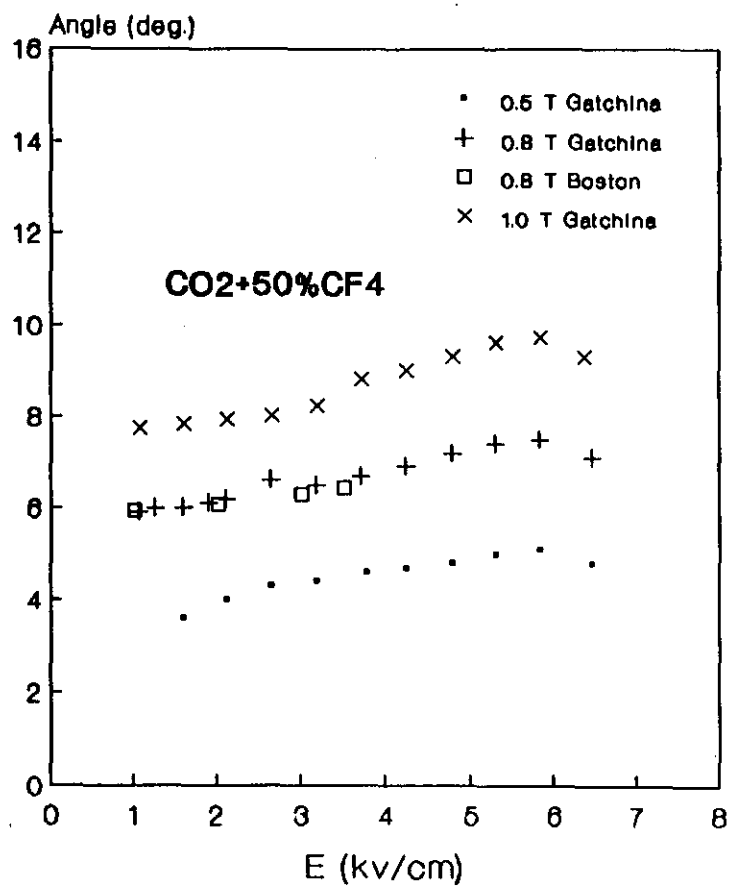
Lorentz angle



Drift velocity



Lorentz angle



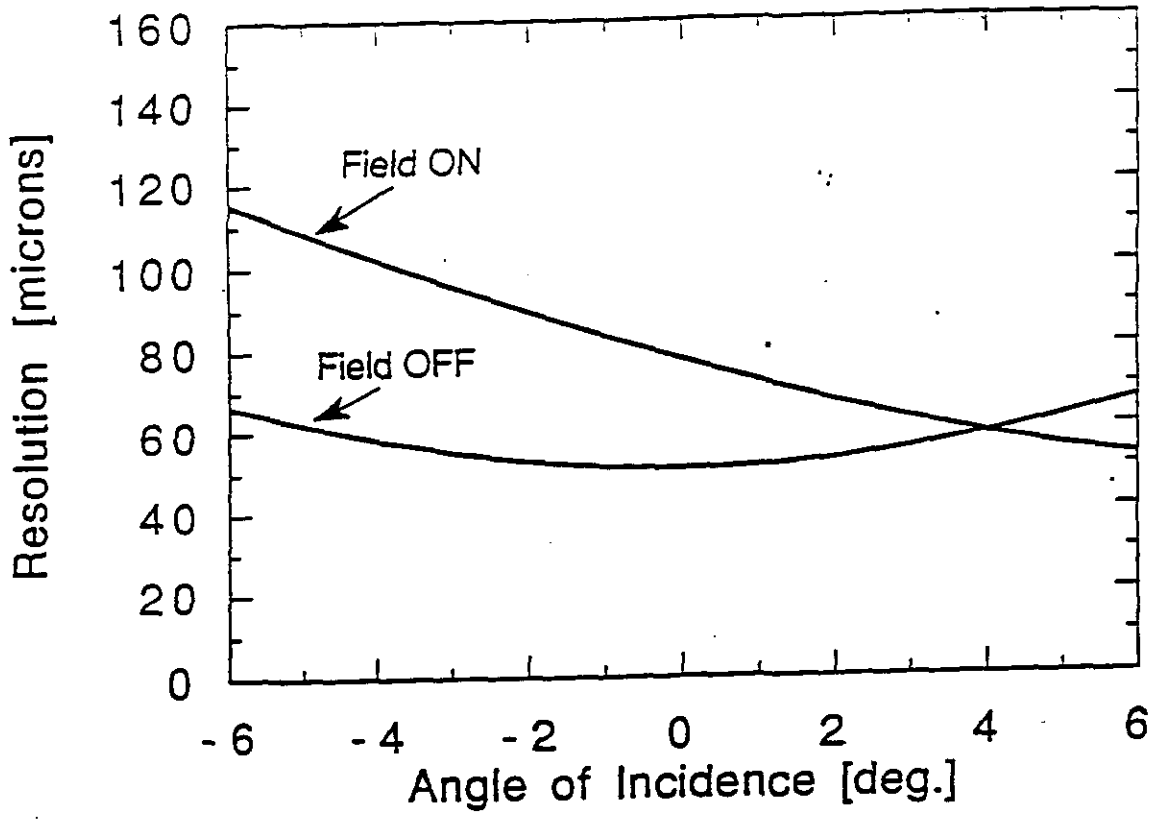


Figure 3: Resolution as a function of incident angle within a sector in a system with a 32-fold symmetry.

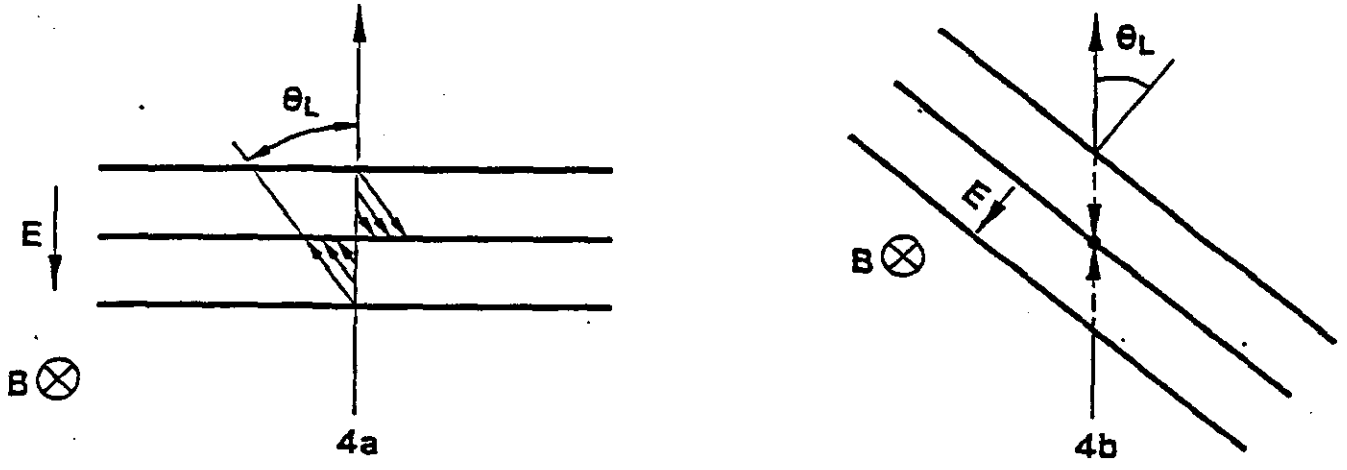
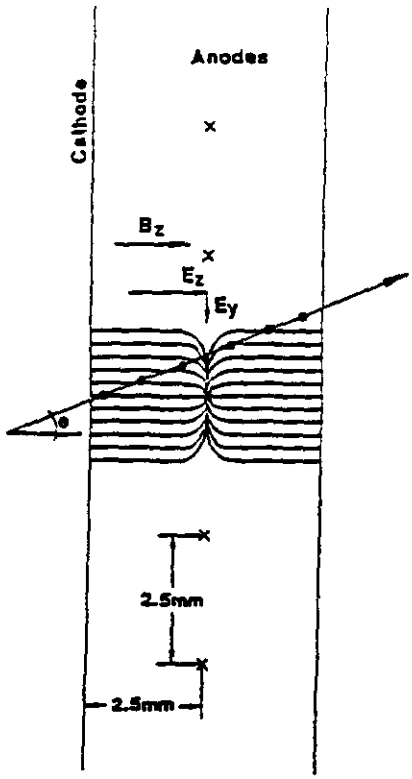
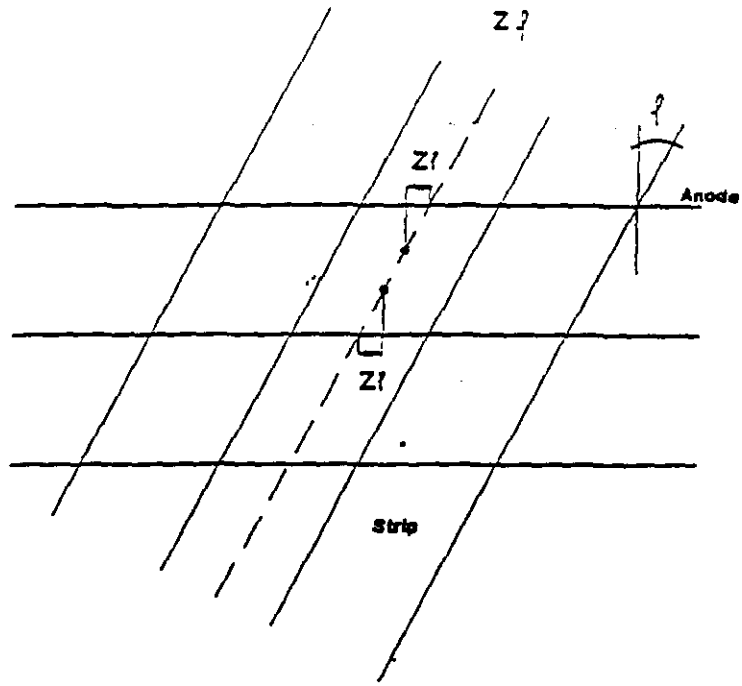
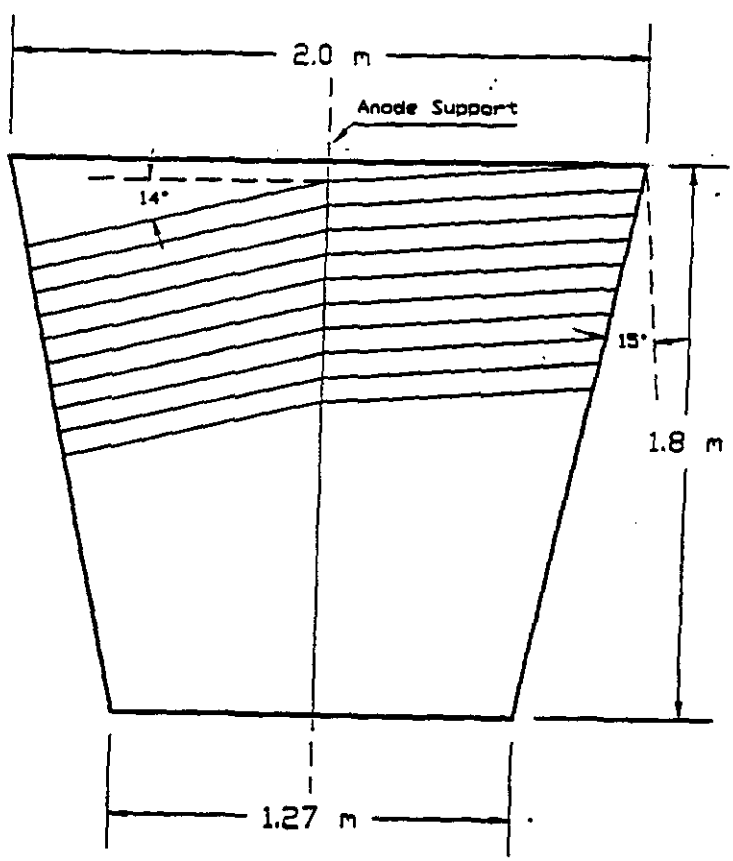
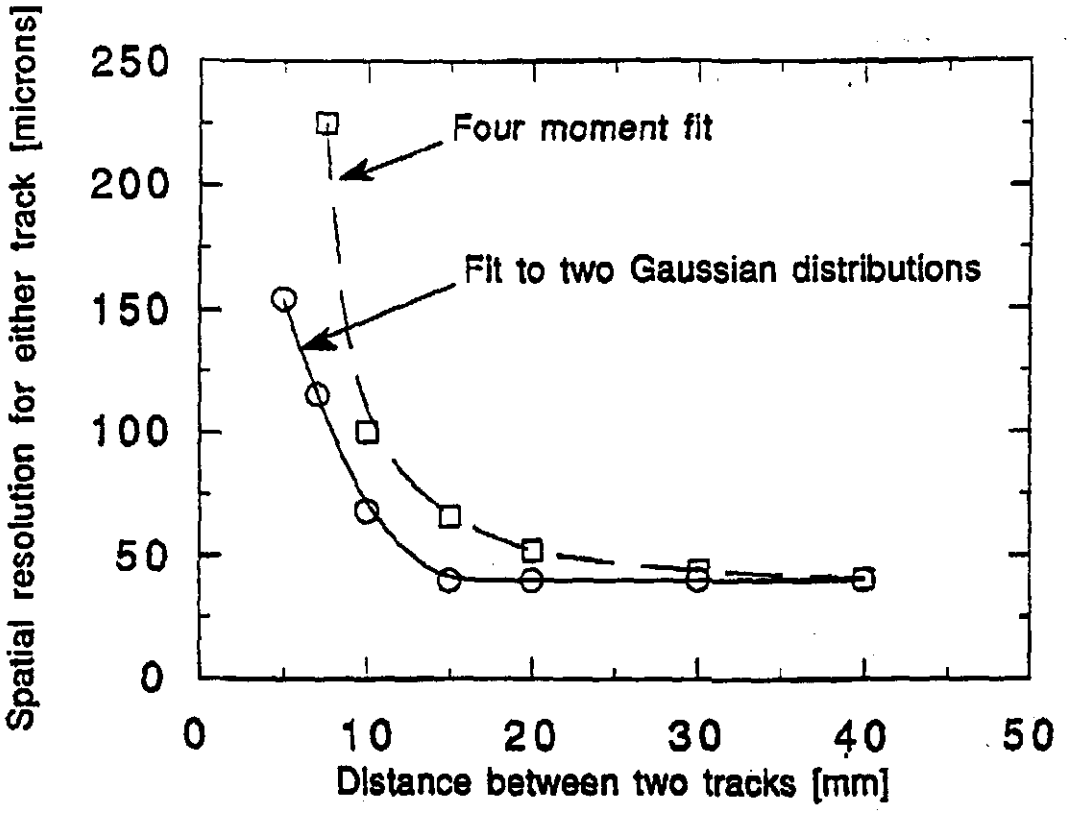


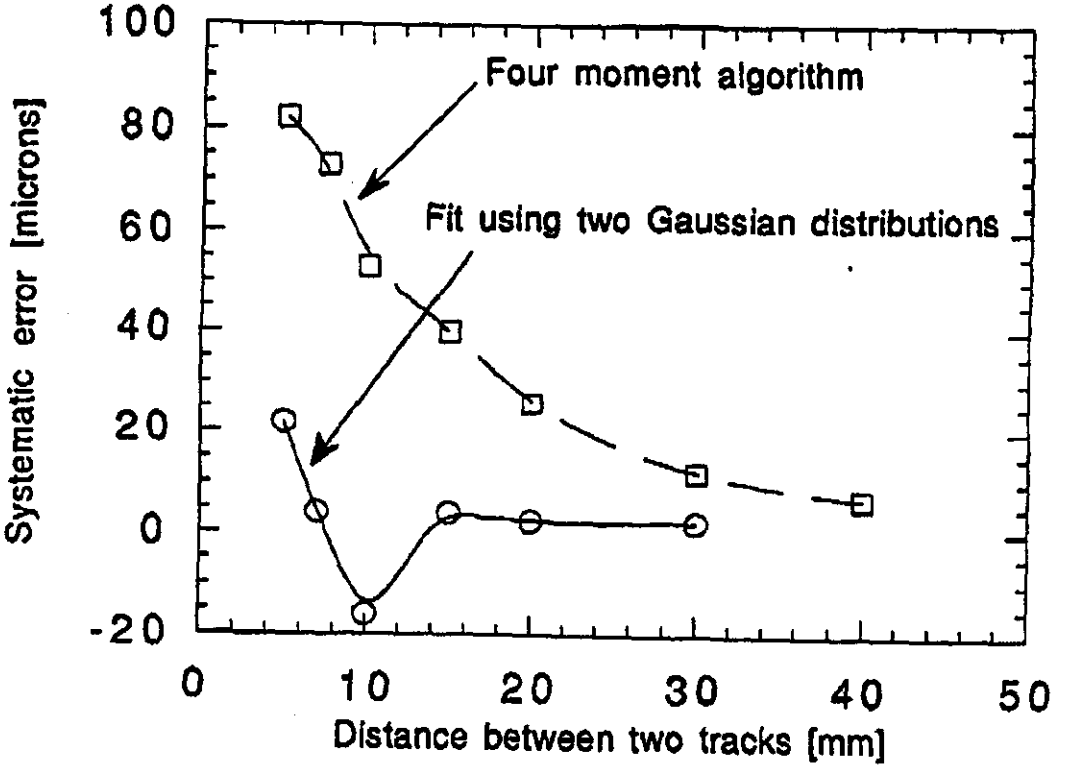
Figure 4: Normal incidence (4a) and compensation by tilting (4b)

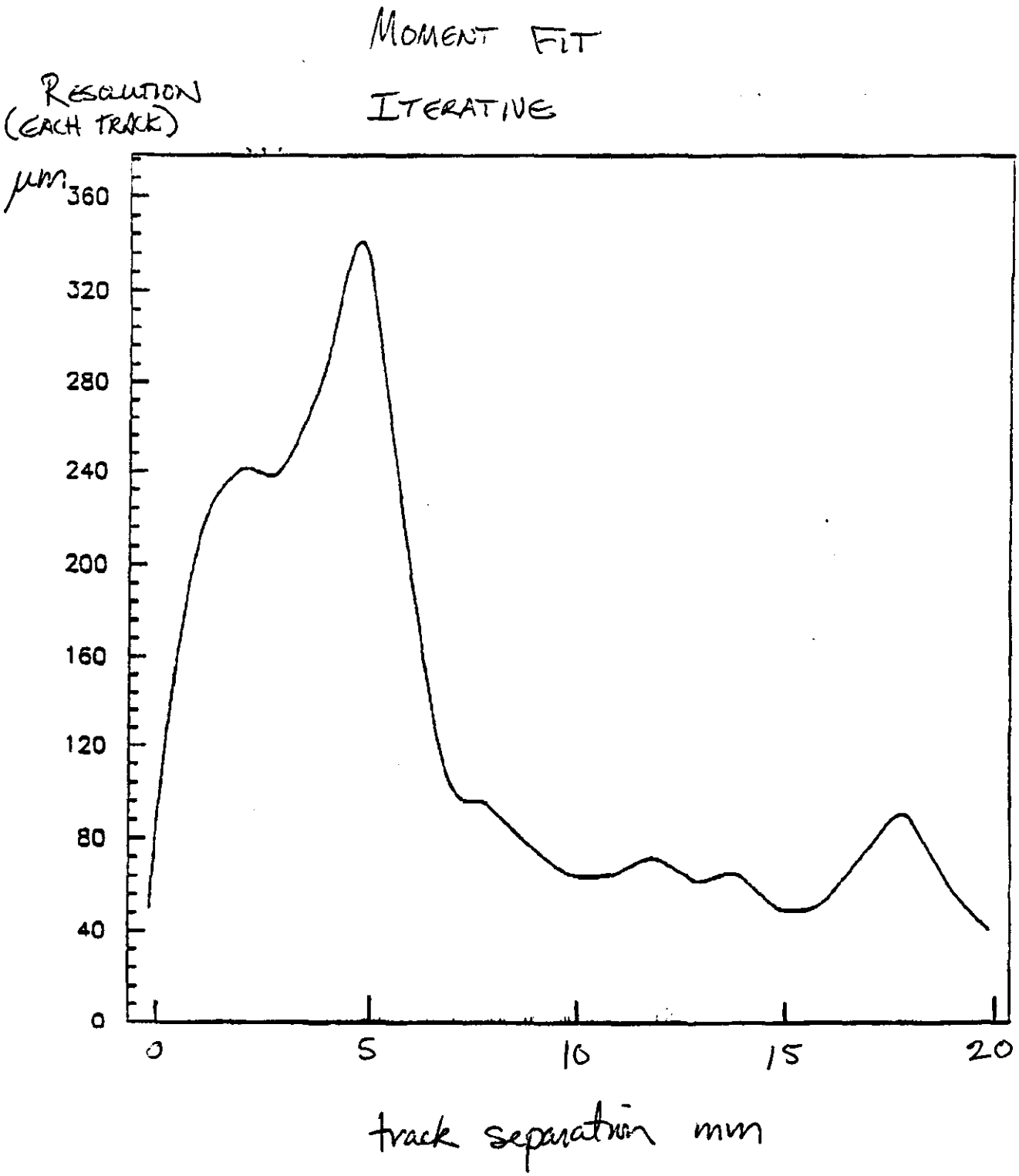

Anodes
Cathode
B_z
E_z
E_y
2.5mm
2.5mm


Anode
Strip


2.0 m
Anode Support
14°
15°
1.8 m
1.27 m


Spatial resolution for either track [microns]
250
200
150
100
50
0
0
10
20
30
40
50
Distance between two tracks [mm]
Four moment fit
Fit to two Gaussian distributions


Systematic error [microns]
100
80
60
40
20
0
-20
0
10
20
30
40
50
Distance between two tracks [mm]
Four moment algorithm
Fit using two Gaussian distributions


MOMENT FIT
ITERATIVE
RESOLUTION
(EACH TRACK)
μm
360
320
280
240
200
160
120
80
40
0
0
5
10
15
20
track separation mm

CSC Electronics Developments

Lots of work in progress at various institutions in U.S. and abroad:

Preamplifier

Designed in MOS, ENC ~ 1000 electrons for shaping time 300 -- 1000 ns
(3000 electrons for 30 ns shaping)

Shaper

Designed in CMOS, in fabrication. Variable peaking time (x2) ~ 1000ns

Readout

Track&Hold -- preamp, fast shaper, slow shaper, dual track&hold
simulated...

Switched Capacitor Array
examples in the marketplace

Timing

4-fold OR gated by 3/4 —> bunch crossing tag

Trigger

Combinational logic
Content-addressable memories

.
.
.

COST

Bottom-up cost analysis in progress --> D. Marlow

3.4 Calibration

In view of the large number of channels, it is essential that a fully automated calibration system be included as part of the initial design. The CSC readout system lends itself nicely to this since the key parameter of interest is the relative gain of a channel, which can be readily determined with a common pulser and matched capacitors for charge-injection. Experience indicates that with careful layout it will be possible match capacitors on the same chip to the 8-bit level.

The calibration system can also be used for system debugging. By downloading a digital "enable match" bit pattern containing a control bit for each channel, one can turn on arbitrary combinations of channels. The amount of interconnection will be kept to a minimum by serially loading the bit pattern.

3.5 Packaging

The large number of channels and the need to minimize noise pickup dictates that the electronics be chamber mounted. This in turn requires that the electronics be compact and reliable. For planning and costing purposes, we assume that the cathode electronics will reside on standard chamber cards of 64 channels each. A conceptual design for this card is shown in figure 3.16. Although mounted directly on the chambers the cards will be removable for repair.

The amount of cabling will depend somewhat on the trigger scheme, but in all cases will be kept to a minimum (i.e. one or two flat cables or optical fibers carrying digital data per chamber module). This will minimize cost and maximize reliability.

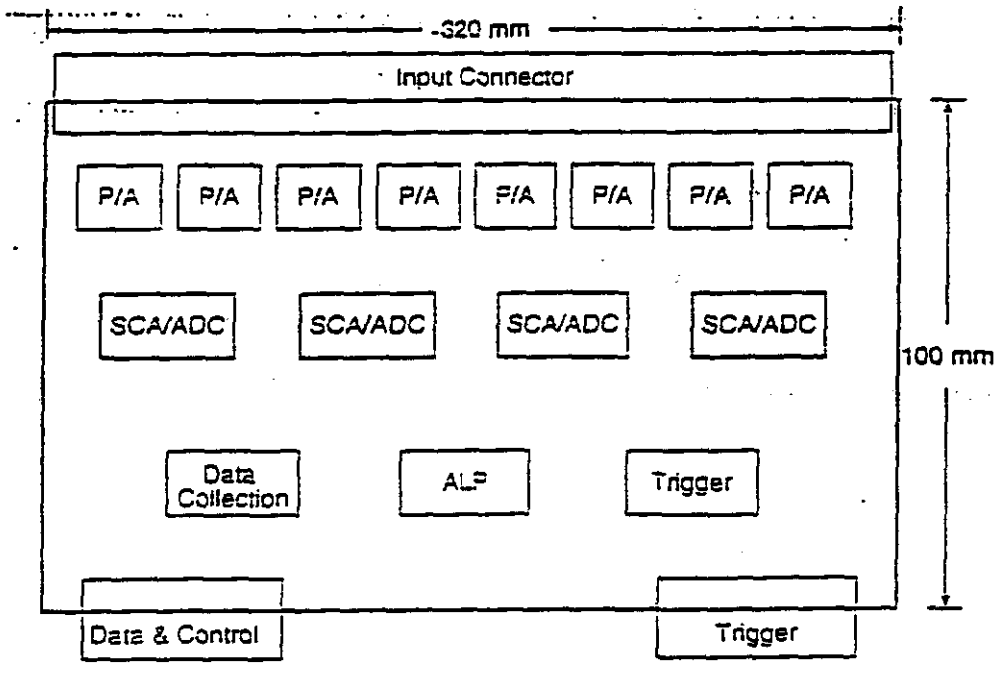


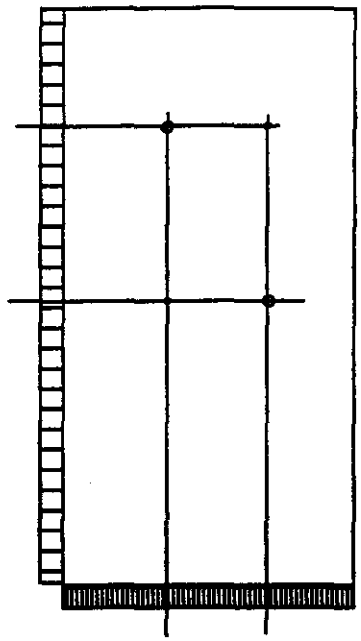
Figure 3.16: General layout of CSC cathode board

CSC Readout Concept

orthogonal readout
(wires, or dip strips)

fast (30 ns peaking) output
for timing, θ measurement

Could also measure charge to
resolve ambiguities for multimuons
by charge correlation



strip readout

fast (30 ns peaking) output for trigger, timing

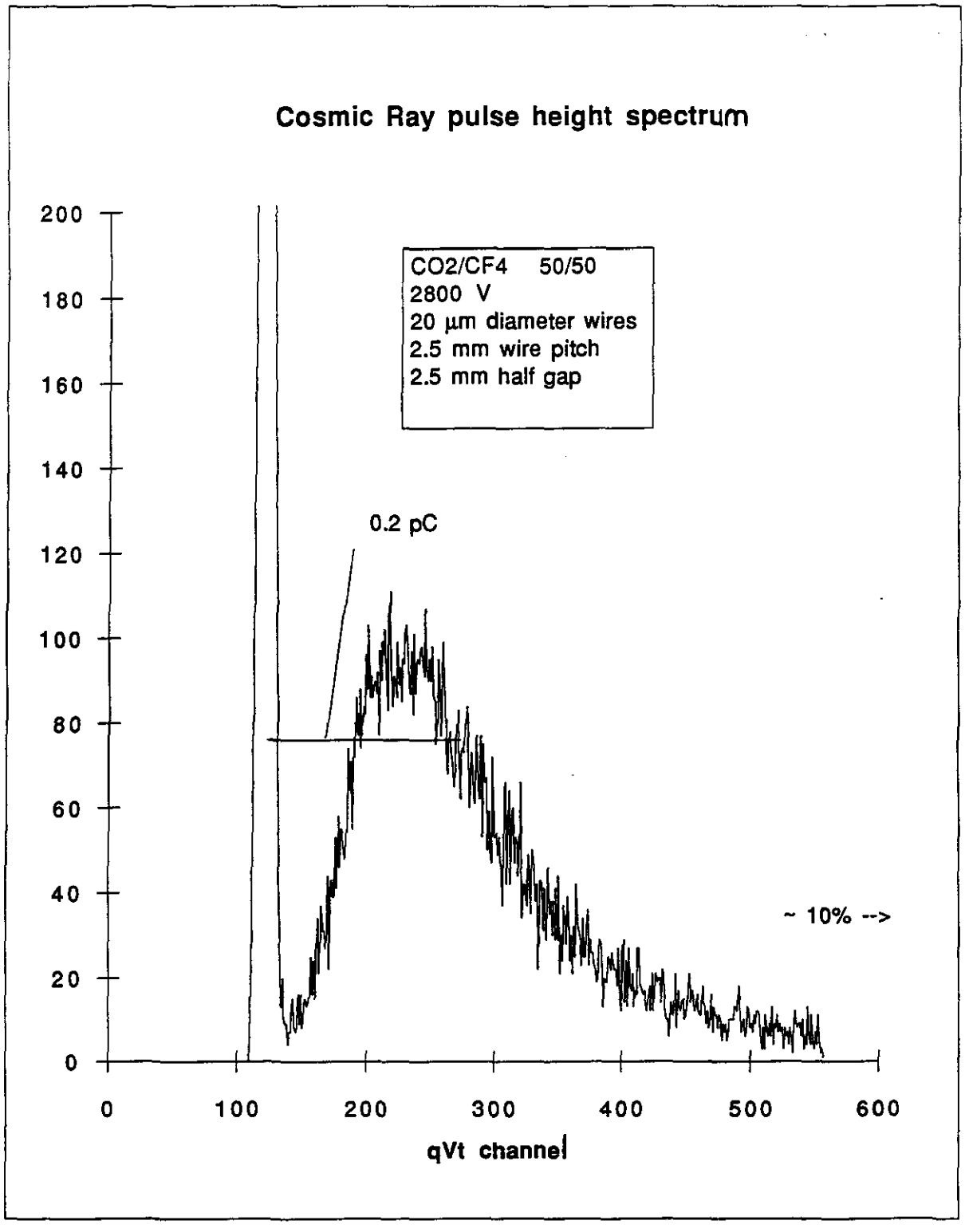
slow (300 ns -- 1 μsec peaking) output for
precision charge measurement

- track-and-hold
- Switched capacitor array

N.B. -- energetic dimuons with small opening angle could be produced by a wide range of interesting physics:

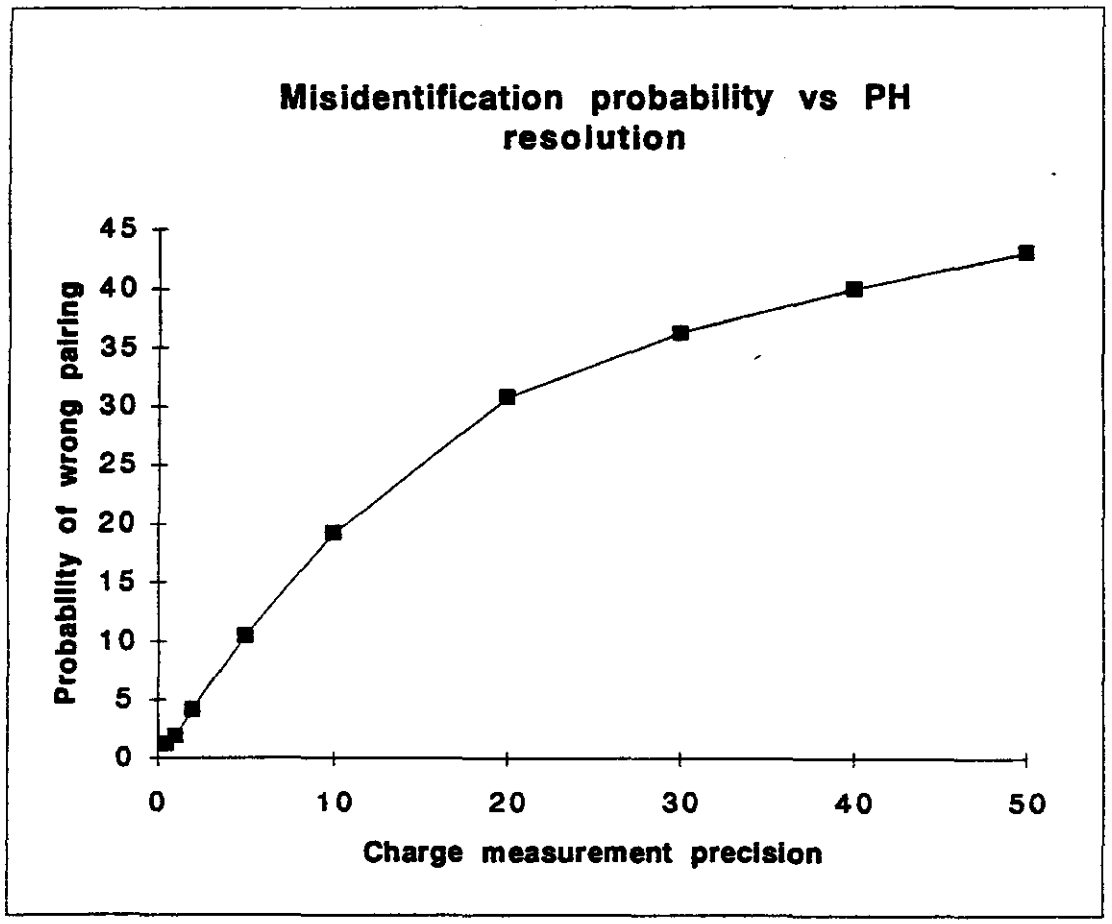
energetic Z's
Drell-Yan
decay of neutral scalars

example: a 500 GeV $Z \rightarrow \mu\mu$ has a typical opening angle between the muons of 0.19 radians, or a separation of 1.1 m at 6 m, so these muons will frequently hit the same muon detector module.


Cosmic Ray pulse height spectrum
CO2/CF4 50/50
2800 V
20 µm diameter wires
2.5 mm wire pitch
2.5 mm half gap
0.2 pC
~ 10% -->
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
qVt channel

Pulse height correlation between bend and non-bend measurements can resolve ambiguities

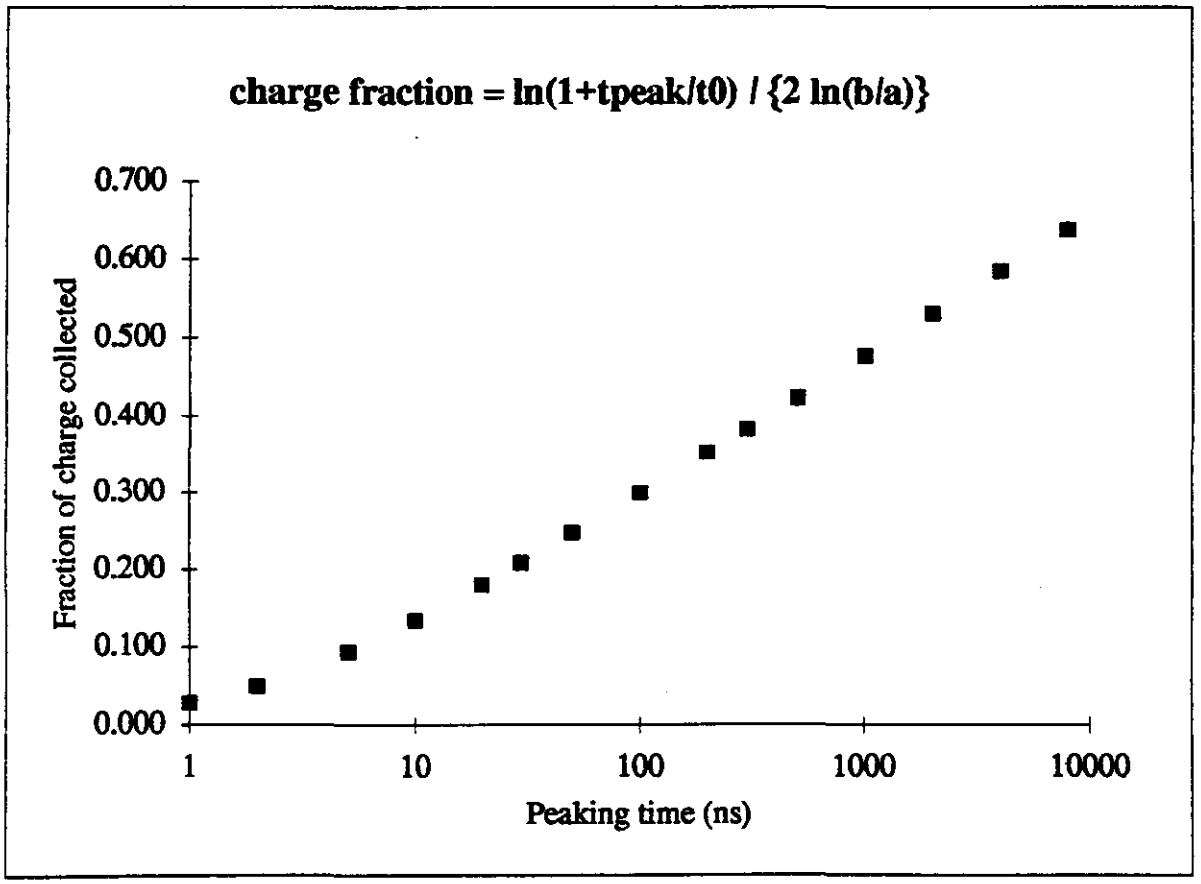
d(PH)/PH (%)	Wrong ID (%)
0.5	1.3
1	1.9
2	4.2
5	10.5
10	19.2
20	30.8
30	36.3
40	40
50	43

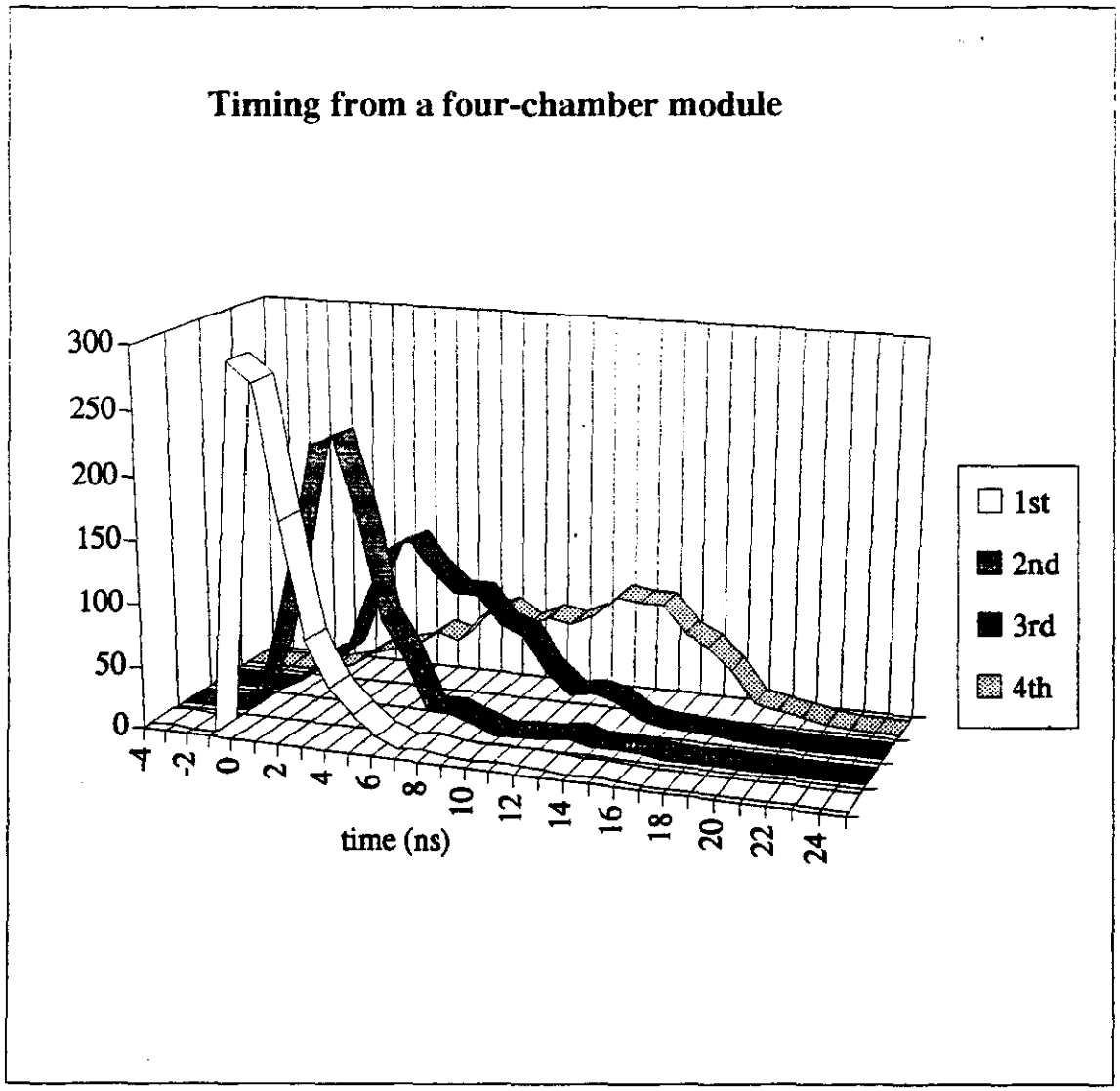


Fraction of charge collected versus integrator peaking time

tpeak (ns)	charge fraction
1	0.029
2	0.050
5	0.092
10	0.133
20	0.180
30	0.209
50	0.246
100	0.299
200	0.352
300	0.383
500	0.423
1000	0.476
2000	0.530
4000	0.584
8000	0.638
16000	0.692

anode radius	0.015	mm
wire pitch	2.5	mm
half gap	2.5	mm
eff. cathode radius	9.21	mm
CO2 mobility	1.09	cm^2/(sec V)
HV	3000	volts
characteristic time t0	2.21	ns




Timing from a four-chamber module
300
250
200
150
100
50
0
-4
-2
0
2
4
6
8
10
12
14
16
18
20
22
24
time (ns)
1st
2nd
3rd
4th

Muon Chamber Alignment

Alignment of the muon chambers is crucial for momentum resolution...

- CSC's have < 75 μm point measurement random error

  proportional response, chamber construction, low-noise electronics

For muon chambers within a sector, resolution goals require:

- 50 μm in-plane accuracy
  lithographic precision of strips on the cathodes

- 50 μm relative alignment of chambers in a module

  lithographic placement of alignment markers on the precision cathode

  single alignment transfer to external fixtures

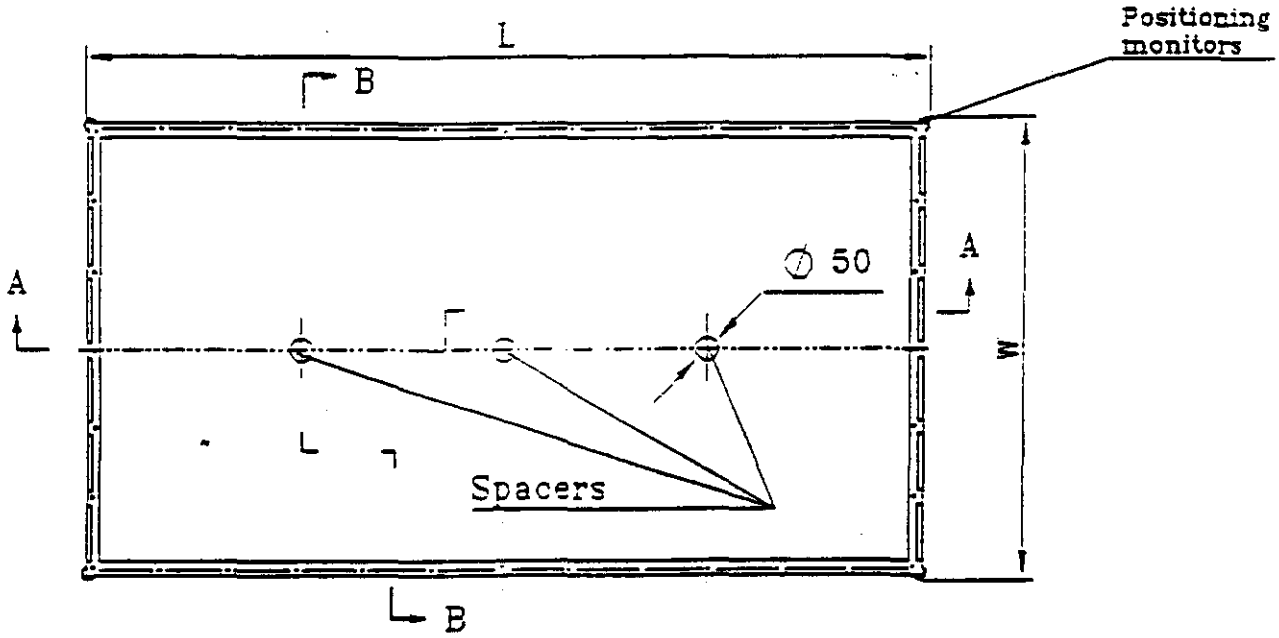
  x-ray system for verification of strip positions -- CSC measures directly the positions of the x-ray interactions

- 25 μm relative module alignment transverse to the muon trajectory

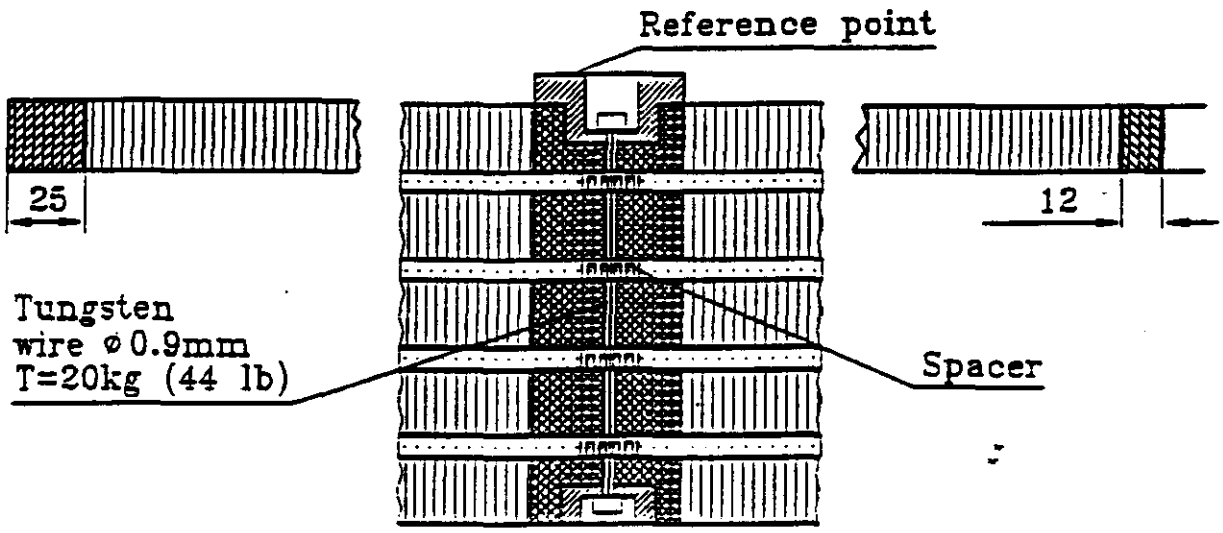
  projective straight line (LED-lens-quad cell) monitors
  GEM TN by Mitselmakher, Ostapchuk

  range measurements, bubble levels

- 250 μm position accuracy along the muon trajectory
  chamber construction, & measurement



A-A (B-B)



	Outer Layer	Middle Layer	Inner Layer
L	3.506m	2.515m	3.152/3.028m
W	0.960m	1.320m	0.740m

Fig. 2.8

Y.Ershov
I.Golutvin
V.Lysiacov
S.Movchan

BARREL CSC

CROSS SECTION ALONG THE WIRES (B–B)

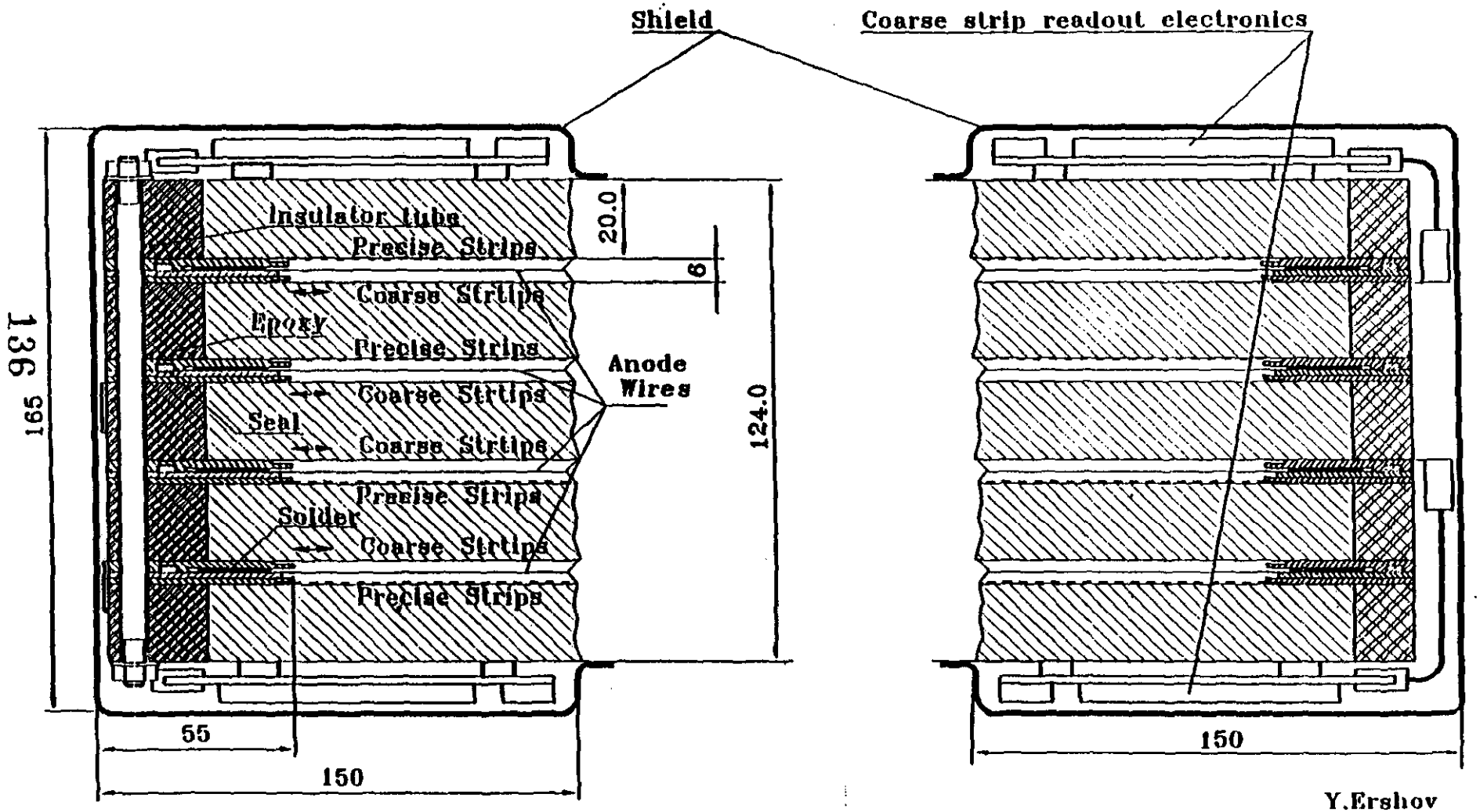


Fig.2.10

Y.Ershov
I.Golutvin
V.Lysiakov
S.Movchan

Material Audit for Cathode Strip Chamber Module

Calculation of mass and radiation lengths for a four chamber module

Active area of chamber:			frame material (and dead area):
length (m) =	3.0		width (m) = 0.050
width (m) =	1.5		
total area (m^2) =	5.0	(including inactive frames)	
		fraction of active area overlapped by frames =	0.098

Option 1: lightweight frames

component	material	density	cm/X0	thcknss (cm)	mass (Kg)	normal X0
Hexcel core	Nomex	0.14	485.7	2.5	86.80	0.0257
circuit boards	.031" G10	1.7	19.4	0.079	66.39	0.0406
copper	1/2 oz.ft^2	8.96	1.43	0.0017	7.56	0.0119
frames	~ lucite	1.2	34.4	3.0	82.80	0.4360

total mass (Kg) =	243.5	
mass/area (Kg/m^2) =	49.1	
average X0's =	0.119	
X0's through center =	0.078	
X0's, center + frames =	0.514	<- includes material of overlapping chamber
area-weighted ave X0's =	0.121	

Option 2: G10 frames

component	material	density	cm/X0	thcknss (cm)	mass (Kg)	normal X0
Hexcel core	Nomex	0.14	485.7	2.5	86.80	0.0257
circuit boards	.031" G10	1.7	19.4	0.079	66.39	0.0406
copper	1/2 oz.ft^2	8.96	1.43	0.0017	7.56	0.0119
frames	G10	1.7	19.4	3.0	117.30	0.7732

total mass (Kg) =	278.0	
mass/area (Kg/m^2) =	56.1	
average X0's =	0.150	
X0's through center =	0.078	
X0's, center + frames =	0.851	<- includes material of overlapping chamber
area-weighted ave X0's =	0.154	

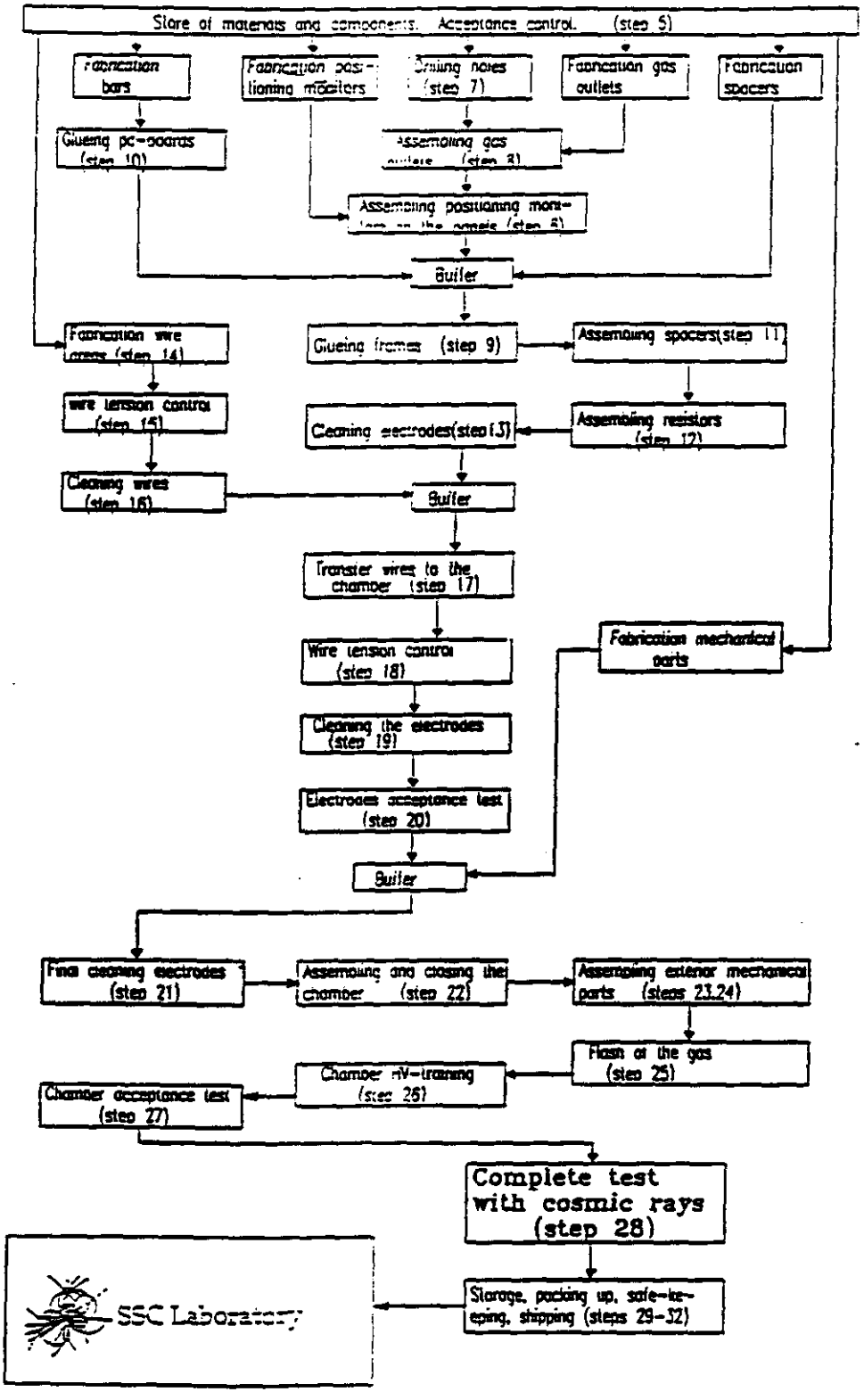
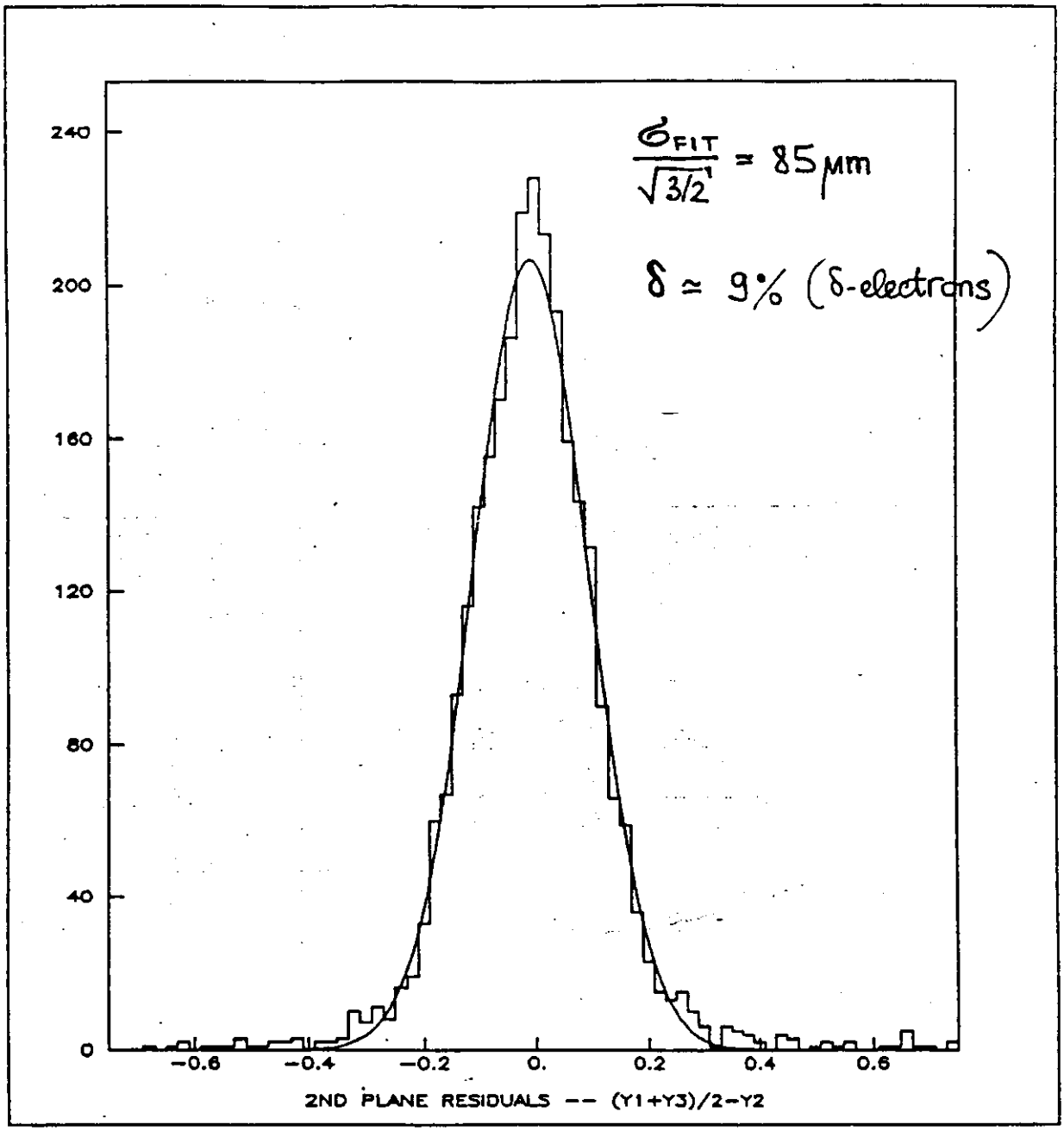


Figure 6.1 CSC Mass—Production Technological Chain

Prototype Cathode Strip Chambers

BNL/BU	-- 1m x 2m --	in construction; completion in November
BU	-- .4m x .4m	4 gaps, running in RD5 test beam at CERN
UH	-- .5m x 1m --	delivered to TTR
Dubna	-- 1m x 1.5m --	to be delivered to TTR in 10 days
BNL	-- 14" x 18" --	operating -- results from x-rays, calibration

PNPI: Gas measurements: drift velocity, Lorentz angle for different gas mixtures



STRIP READOUT (prop. mode, $Q_a \sim 1$ pC)
Ratio Method

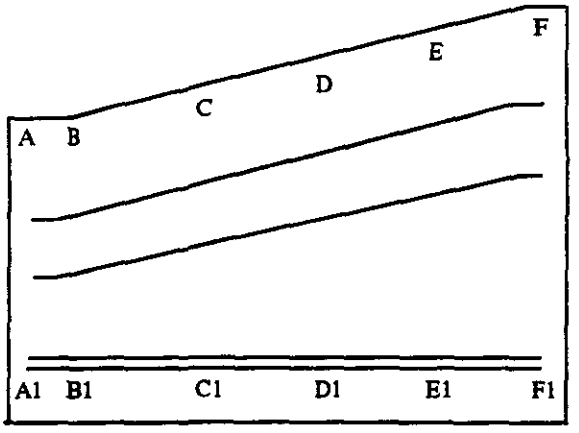
0.5 TeV/c muon beam

Measurements of Targets on Det3 Cathode

Measurements of targets etched onto precision cathodes for BU Det 3:

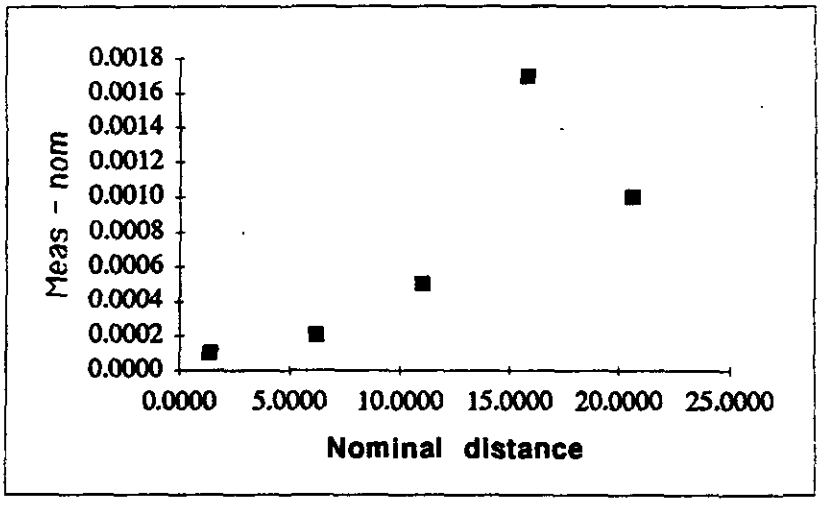
Boards from MPC (Lowell, MA)

Measured at Draper Lab



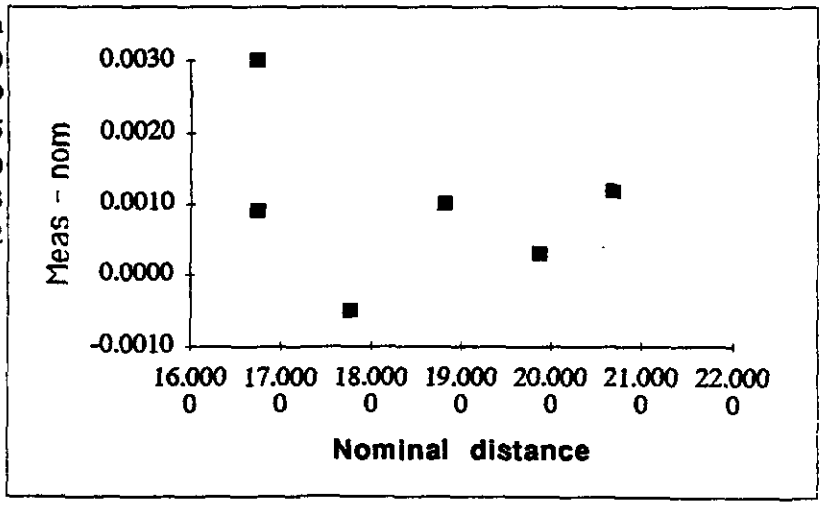
1. Along strips -- straight -- from A1

point	nominal	meas-nom
B1	1.3750	0.0001
C1	6.1880	0.0002
D1	11.0000	0.0005
E1	15.8130	0.0017
F1	20.6250	0.0010

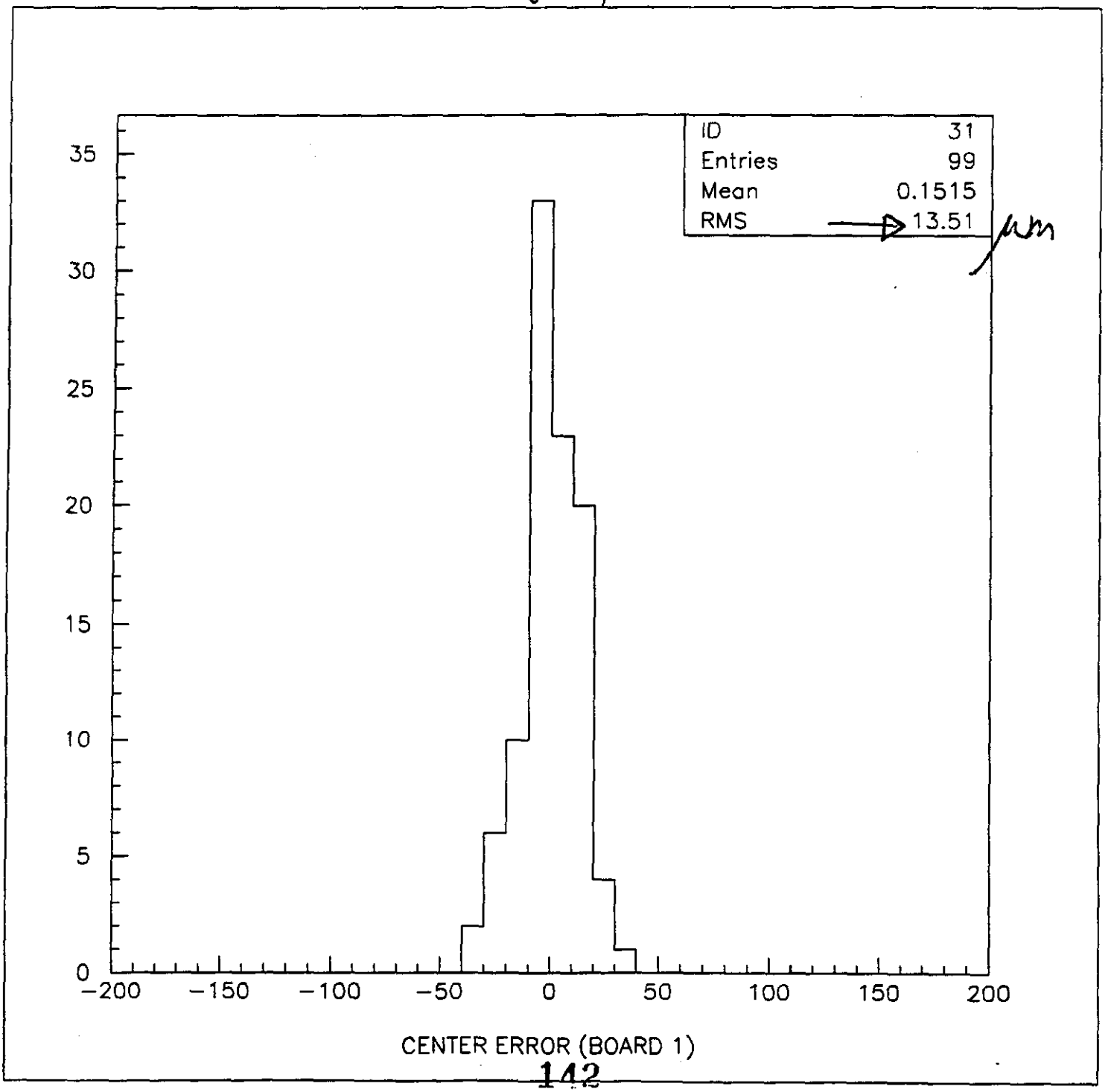


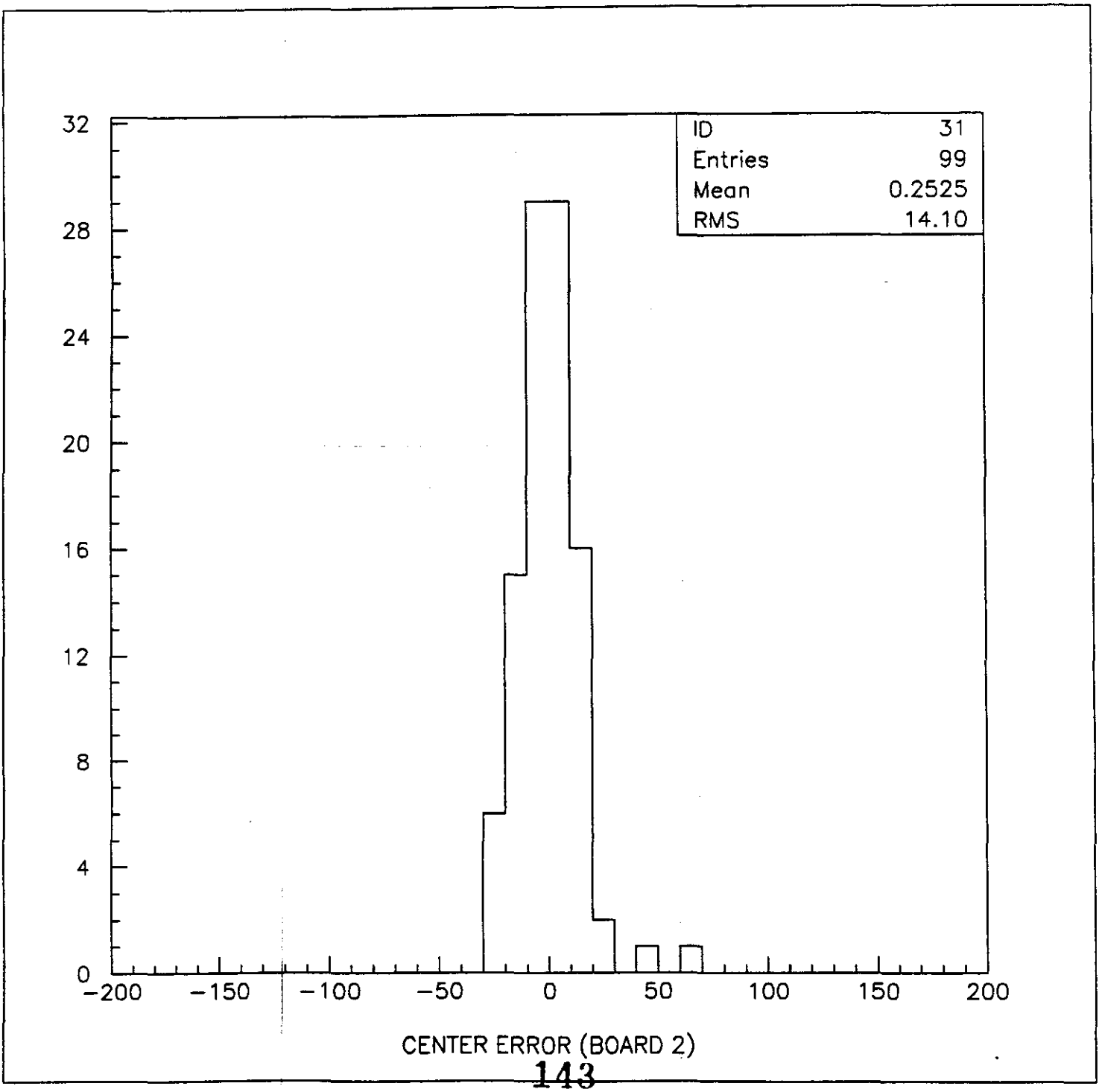
2. Across strips

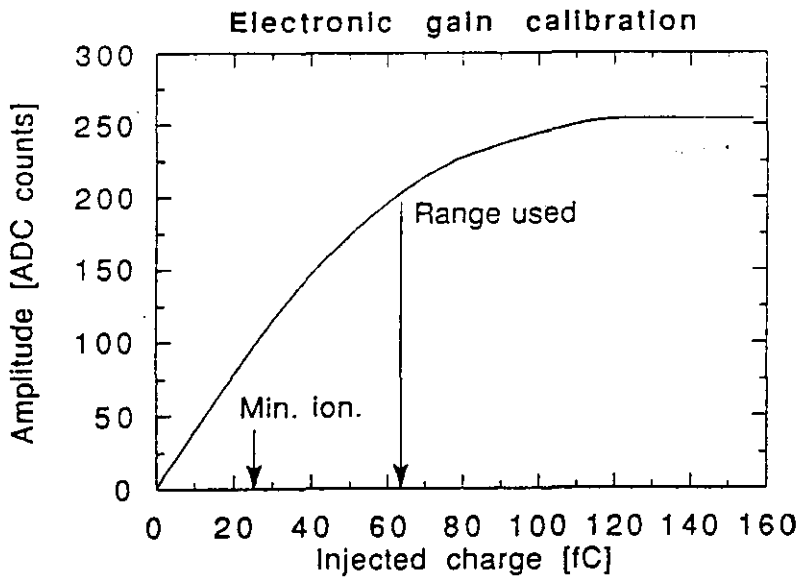
meas. path	nominal	meas-nom
A-A1	16.7420	0.0030
B-B1	16.7420	0.0009
C-C1	17.7580	-0.0005
D-D1	18.8180	0.0010
E-E1	19.8770	0.0003
F-F1	20.6890	0.0012

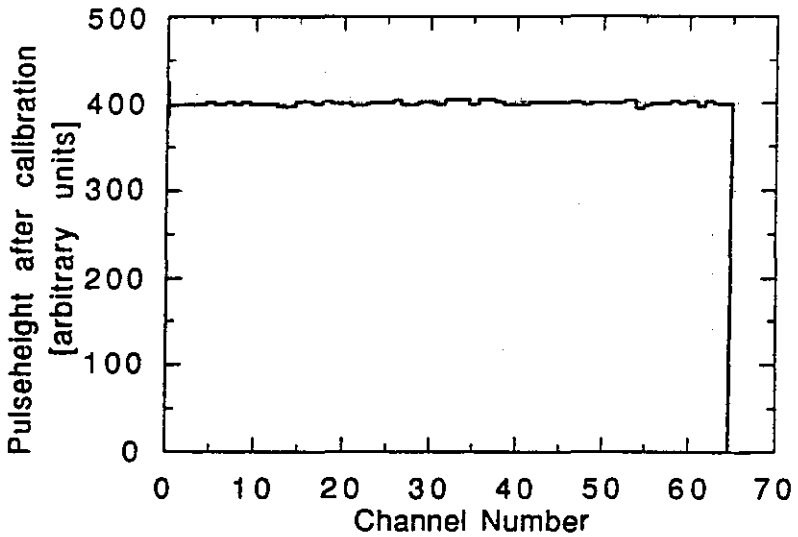


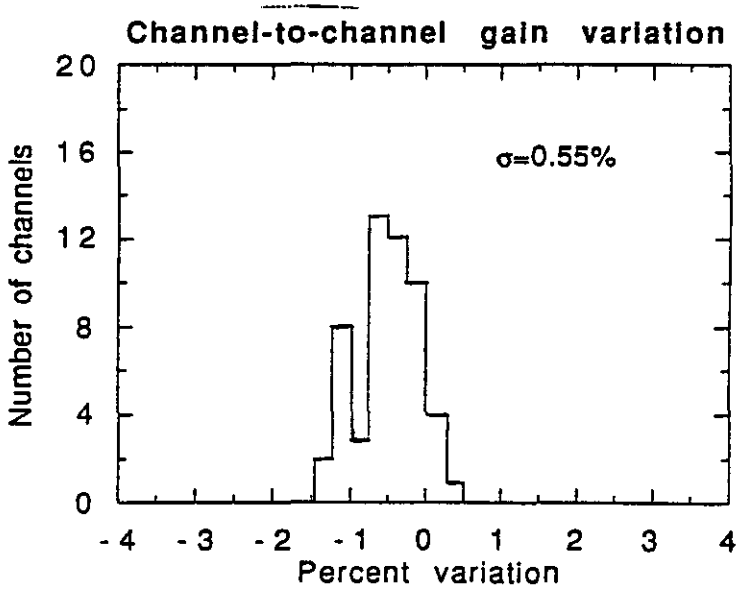
U. of Houston deviations of strip centers from design positions




ID 31
Entries 99
Mean 0.2525
RMS 14.10
32
28
24
20
16
12
8
4
0
−200
−150
−100
−50
0
50
100
150
200
CENTER ERROR (BOARD 2)

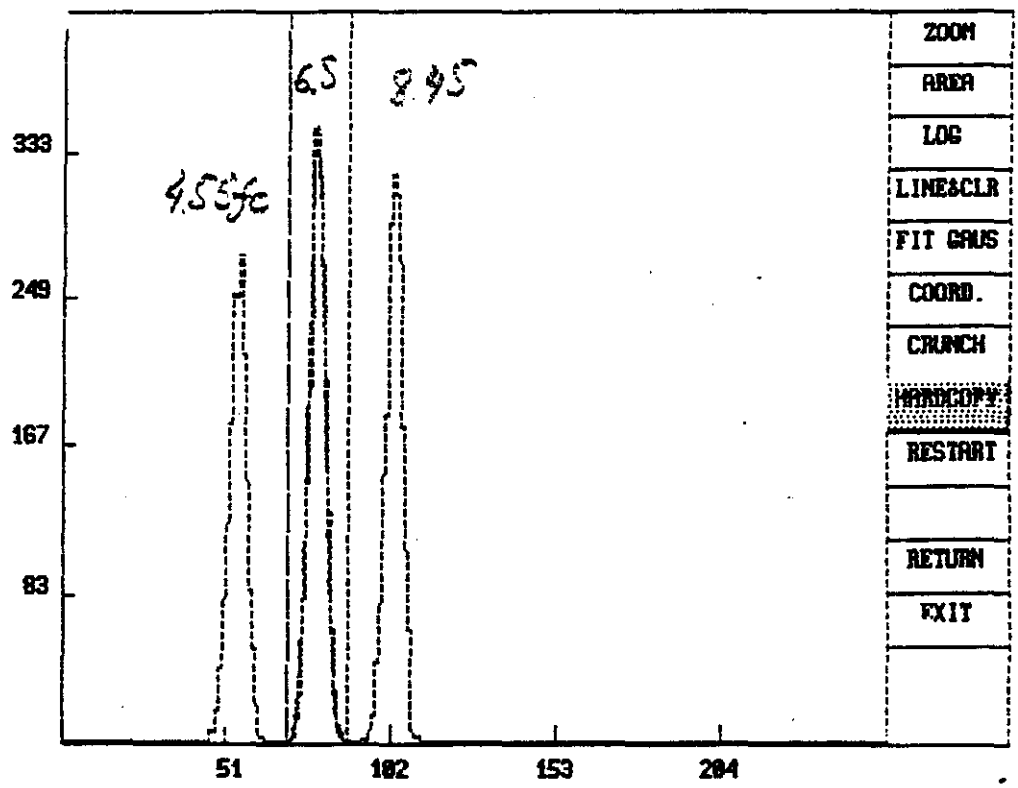

Electronic gain calibration
Amplitude [ADC counts]
300
250
200
150
100
50
0
Range used
Min. ion.
0 20 40 60 80 100 120 140 160
Injected charge [fC]


Pulseheight after calibration
[arbitrary units]
500
400
300
200
100
0
0 10 20 30 40 50 60 70
Channel Number


Channel-to-channel gain variation
Number of channels
20
16
12
8
4
0
σ=0.55%
-4 -3 -2 -1 0 1 2 3 4
Percent variation

St2 #44

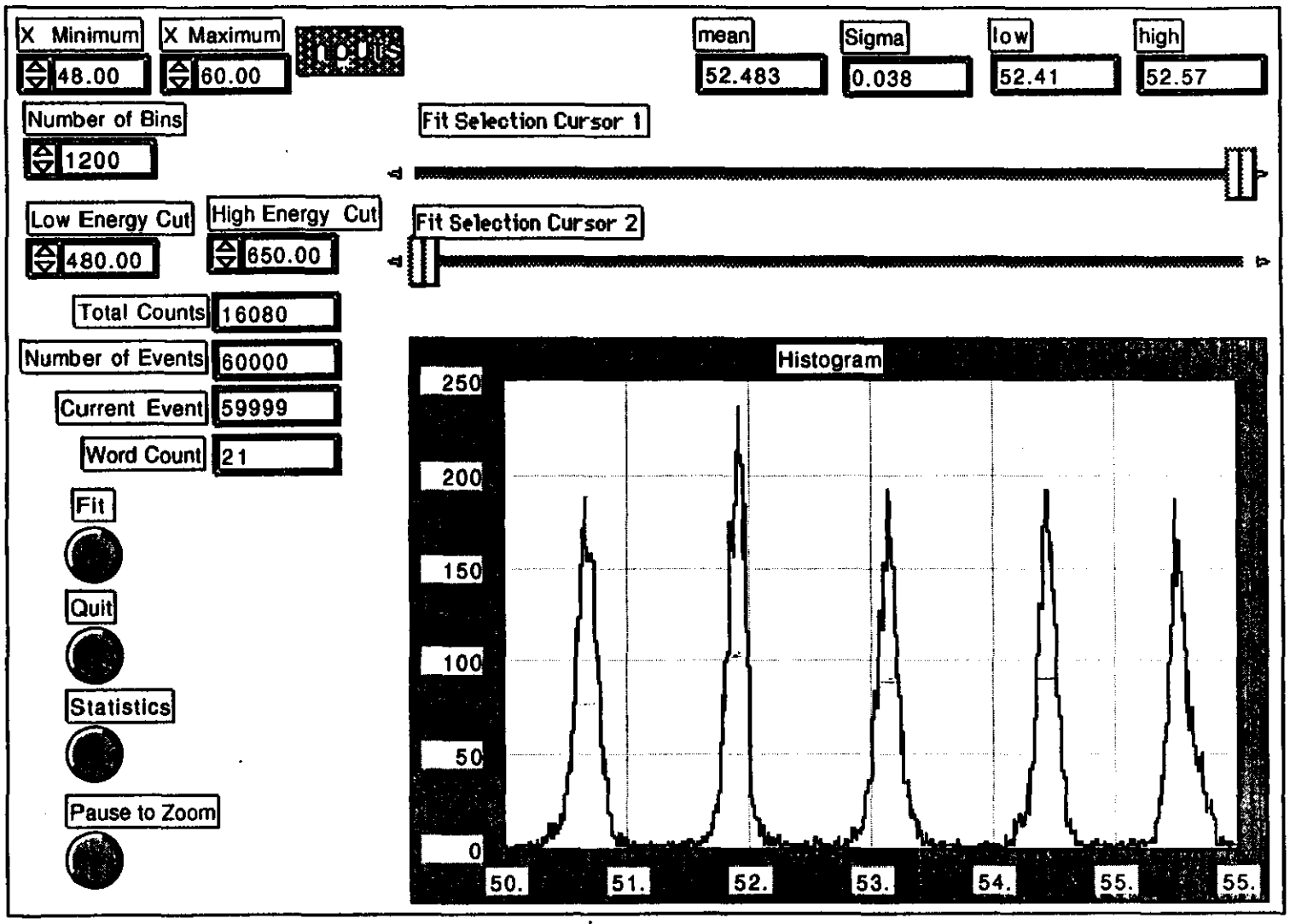
$C_{in} = 0.65 pf$ $A_{gen} = 7mv; 10mv; 13mv$



AMPLI =347.38 CENTROID = 88.39

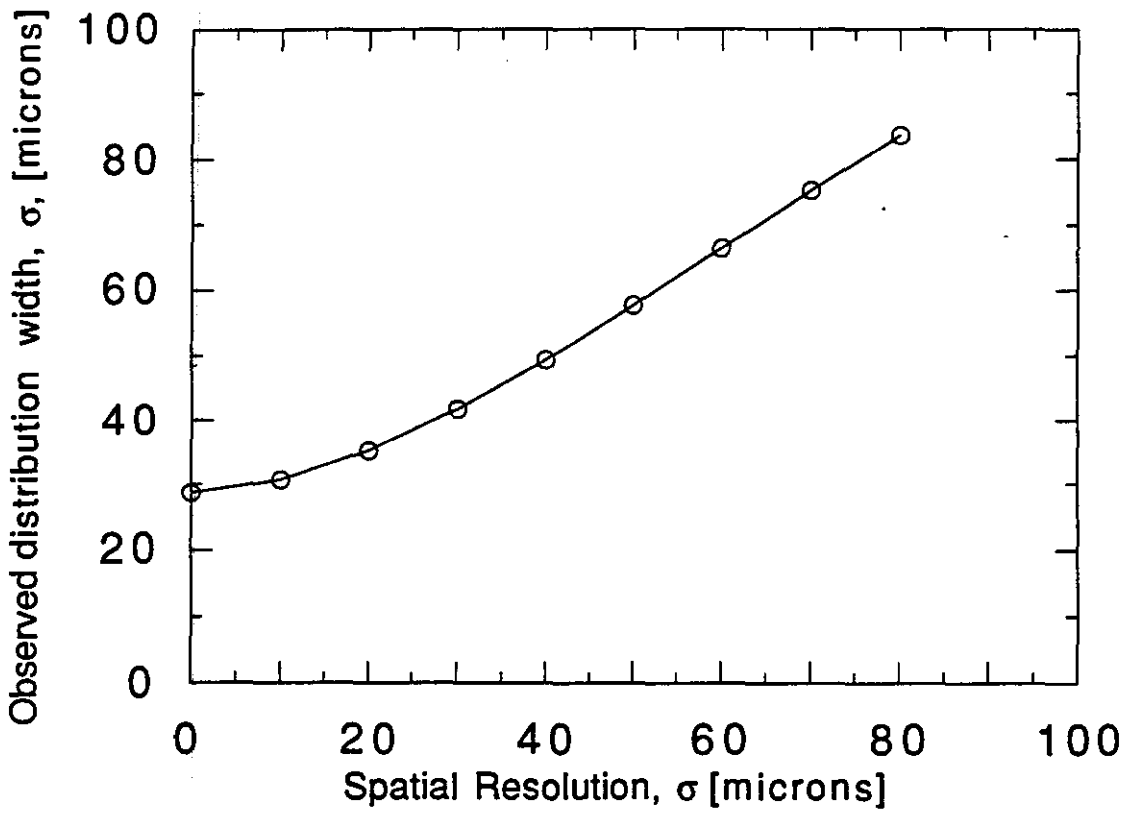
SIGMA = 2.49 SIG/CENT = .31

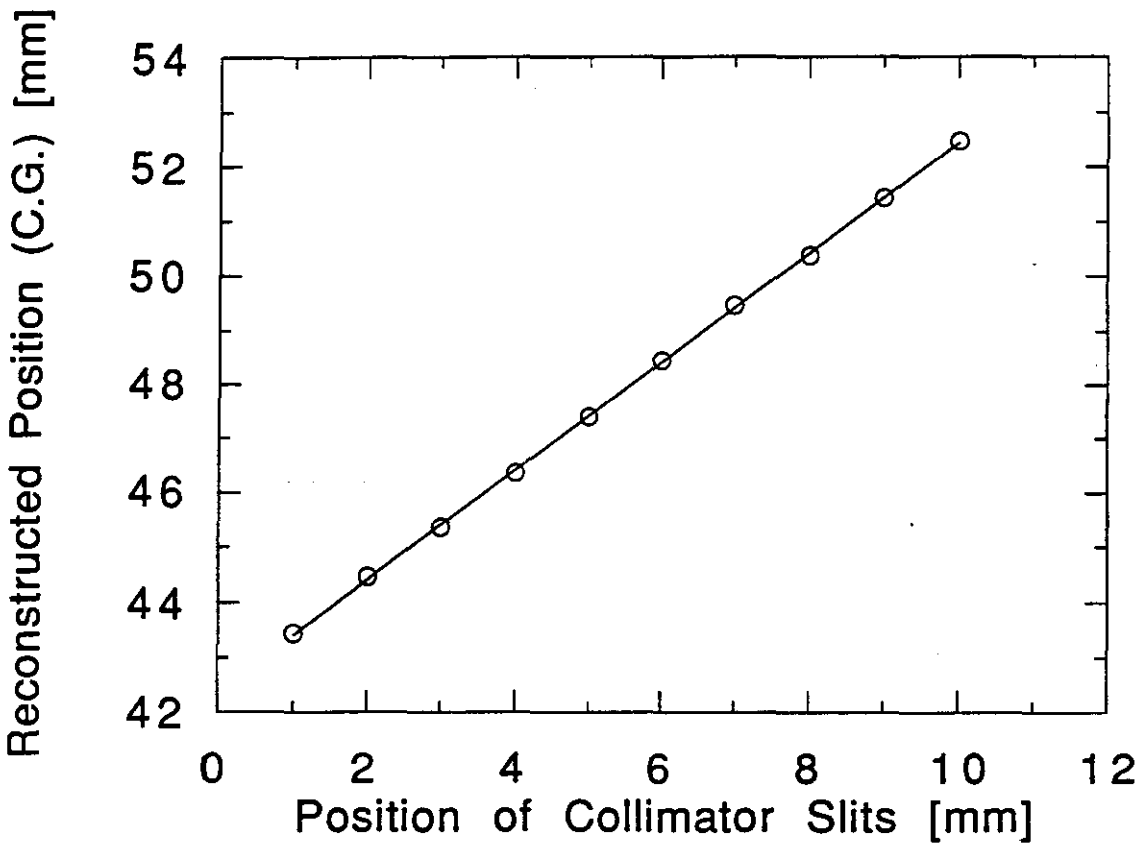
Front Panel

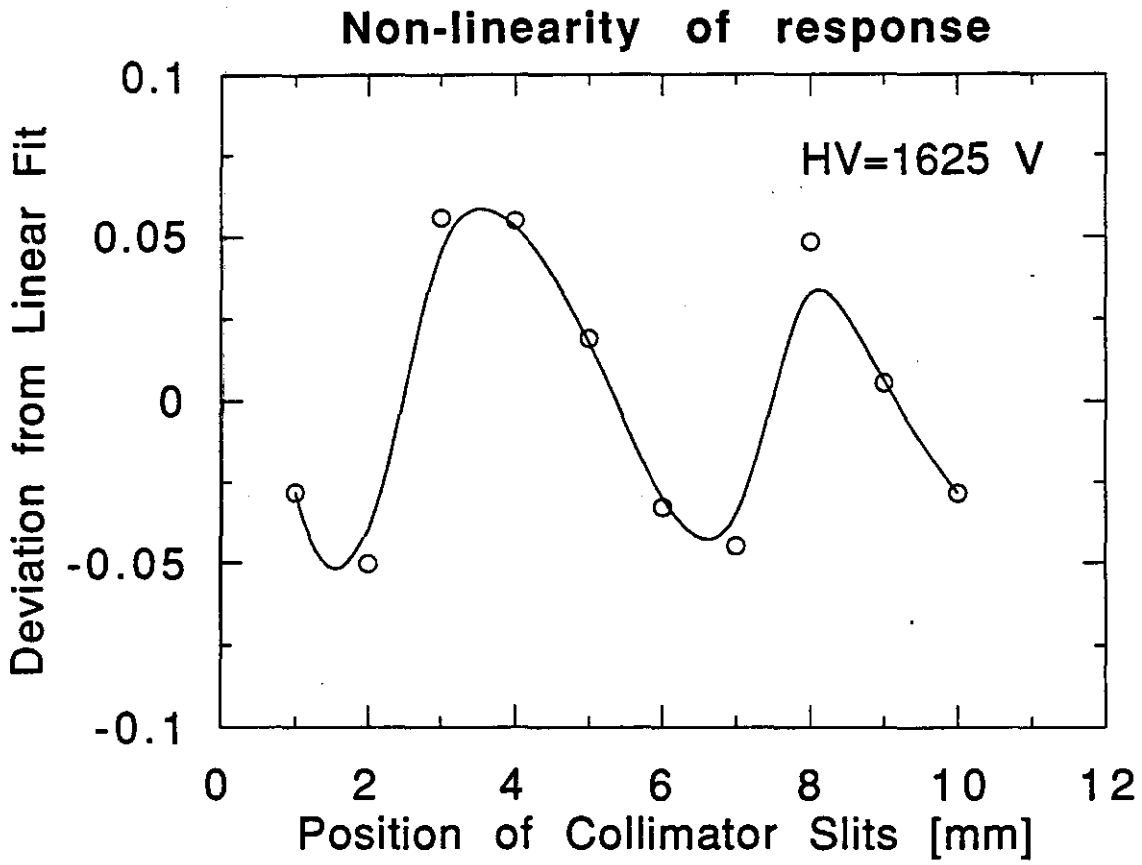


Δ=14 Δ=13 Δ=12 Δ=12

59.6 55.3 σ=51.1 σ=51.1


Observed distribution width, σ, [microns]
100
80
60
40
20
0
0
20
40
60
80
100
Spatial Resolution, σ [microns]


Reconstructed Position (C.G.) [mm]
54
52
50
48
46
44
42
0
2
4
6
8
10
12
Position of Collimator Slits [mm]


Non-linearity of response
HV=1625 V
Deviation from Linear Fit
0.1
0.05
0
-0.05
-0.1
0
2
4
6
8
10
12
Position of Collimator Slits [mm]

Beneficial Features of CSC's

Unified Technology -- One detector provides full functionality:

From the cathode strips --

- Precision measurement in the bend coordinate for momentum determination
- Fast hodoscopic measurement of bend coordinate for triggering

From the orthogonal readout (anode wires or orthogonal cathode strips) --

- Measurement of the non-bend coordinate and determination of θ
- Fast timing and bunch crossing tagging

"Simple" Technology

- A single precision element -- the strip cathode
  - Manufactured by industrial vendors, QA/QC
  - Industrializable design
  - Alignment is integrated into the chamber

Common Technology with the Endcap --

CSC's selected for the Endcaps -- only technology well suited to that geometry

Advantages of choosing CSC's also for the barrel:

- ♥ Focuses effort and resources
  - Common electronics, DAQ
  - Many common engineering issues
- ♥ Reduces system complexity -- mechanics, utilities, DAQ,...

RPC Presentation

Craig Wuest

C. Wuest

RESISTIVE PLATE CHAMBER TECHNOLOGY REVIEW

October 6, 1992

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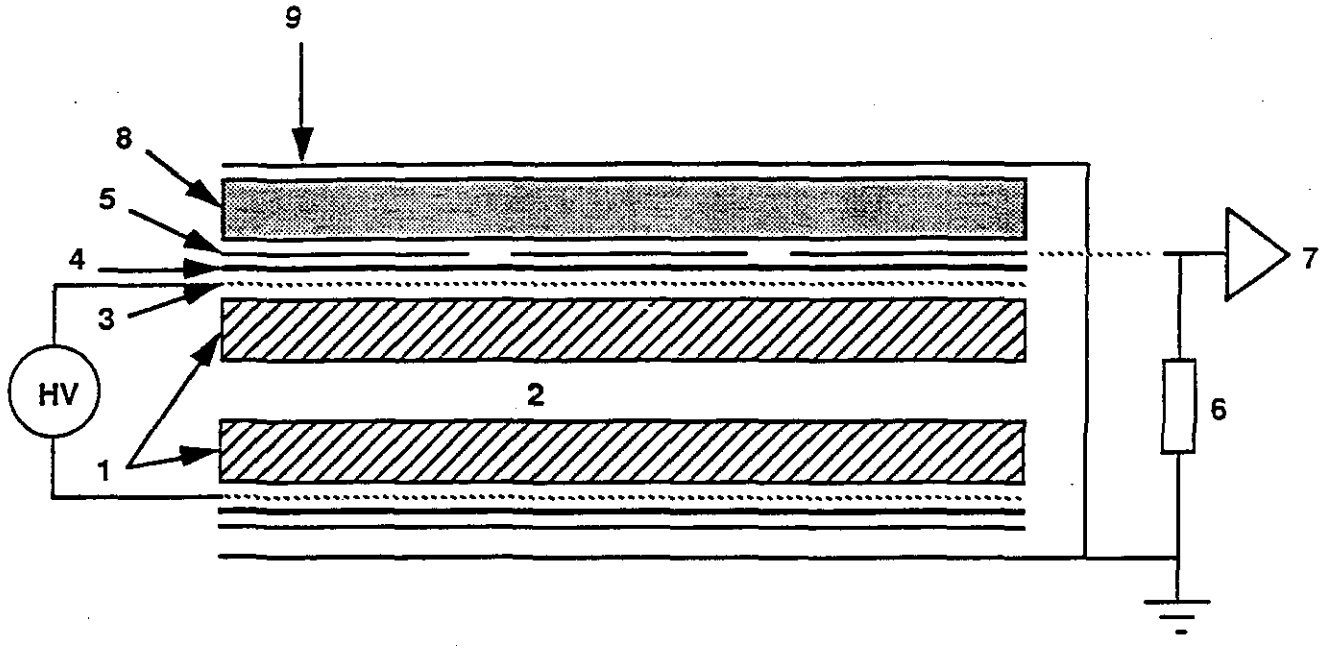
Resistive Plate Counter Design

- Resistive Plate Chambers (RPCs) have been in operation in experiments throughout the world since 1981.
- The current standard (Italian) design is two meters long by one meter wide with a sensitive gas gap of 2 millimeters.
- There are no wires or conductors anywhere in the sensitive region.
- The walls of the chamber - in contact with the gas of the sensitive volume - consists of a semi-conductor (Bakelite, for example) with a bulk resistance of about 10**11 ohm-centimeters.
- An ioniz ing particle passing through the sensitive volume (2 m x 1 m x 2 mm) breaks down the gap and creates an electrical discharge.
- This discharge is very fast (a few nanoseconds).
- The discharge is capacitively coupled to pick-up strips which are located outside the semiconductor walls of the gas cell.

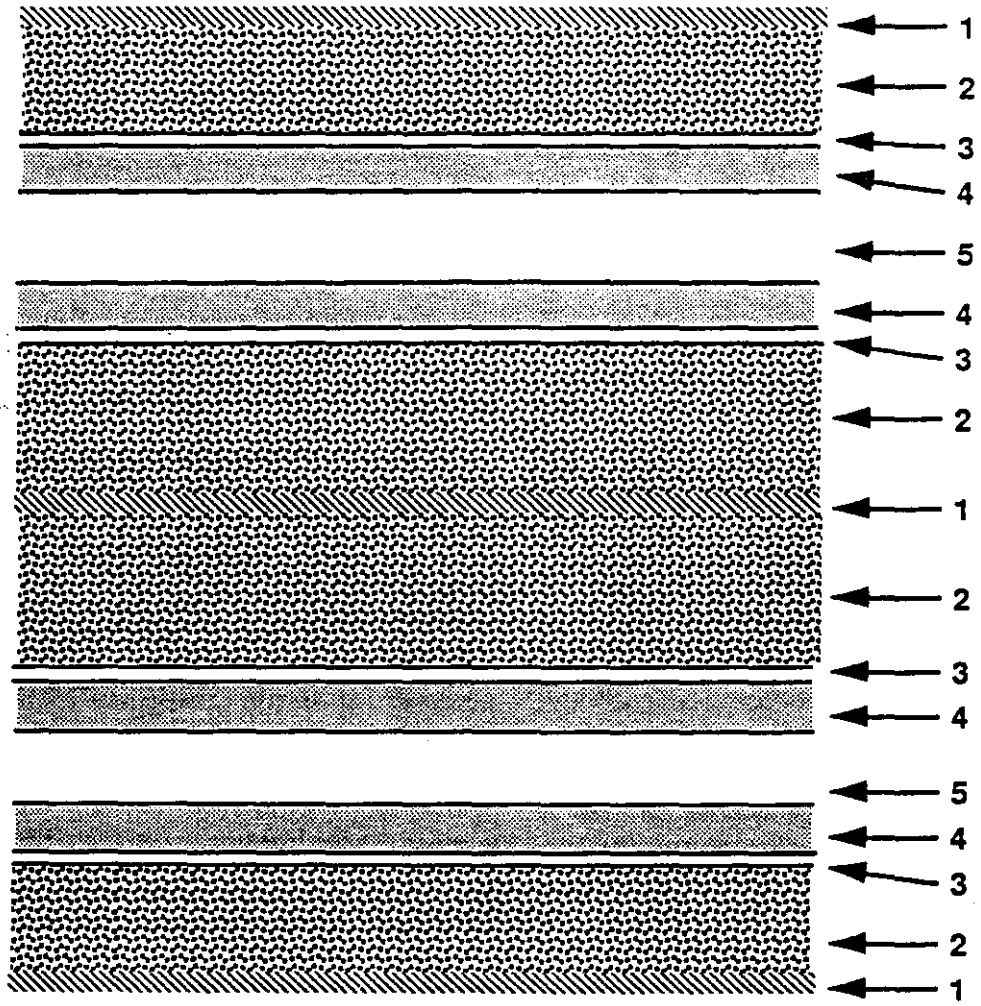
Resistive Plate Counter Design

- Hundreds of these chambers have been produced and are operating in experiments all over the world.
- A set of these chambers have operated at Frascati for 7 years.
- Such chambers are currently being used in E-771 at Fermilab.
- Recently L3 at CERN has ordered 400 of these chambers from General Technica, Colli, Italy, a company that is a commercial supplier of RPCs.
- Not a new technology, but rather a mature technology which is well understood and for which the manufacturing technology has already been transferred to industry.



1 Bakelite plate
2 gas
3 graphite coating
4 insulating foil
5 aluminum strips
6 line termination
7 discriminator
8 foam
9 aluminum ground plane

Figure 1



1. 0.010" aluminum
2. 4 mm foam
3. 0.005" al. mylar
4. 0.015" Bakelite(aquadag coating)
5. 2 mm gas gap

scale ~ 10:1

Figure 2

Nuclear Instruments and Methods in Physics Research A263 (1988) 20–25
North-Holland, Amsterdam

PROGRESS IN RESISTIVE PLATE COUNTERS

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Results of experimental tests on resistive plate counters of 6×0.5 m^2 area are reported. The results show that this technique is suitable for time of flight measurements over large areas with a resolution of the order of 1 ns.

Dc operated gaseous detectors of ionizing particles such as wire or drift chambers and streamer tubes have successfully replaced, in the course of the last 15 years or so, the older technique of the scintillation counter coupled to photomultipliers in experiments requiring a high spatial resolution. Conversely the scintillator is still the most commonly utilized technique to obtain high time resolution in current apparatus for subnuclear research.

The above mentioned detectors are indeed not competitive with the scintillator as far as time resolution is concerned. This is due to the fluctuations of the time needed by the electrons liberated in the gas by an ionizing particle, to drift up to the multiplication region, very close to the wire, where avalanches and eventually streamers are produced. A higher time resolution is clearly achievable if a uniform and intense electric field is used instead of that produced by a charged wire. In this case indeed the sequence of transitions:

free electron → avalanche → streamer

can occur in a very short time and with minimal fluctuations. This possibility was first studied by Keufell [1] and others [2]. More recently it has been shown that substantial advantages can be obtained if high resistivity electrode plates are used to create the field and that time resolutions better than 0.1 ns are achievable in small counters working with high pressure gas [3].

The resistive plate counters (RPC) [4] described in this paper are dc operated particle detectors whose sensitive element is a 2 mm thick gas layer of argon, butane and Freon at normal pressure, under a uniform steady electric field of 4–4.5 kV/mm generated by two parallel electrode plates of phenolic polymers with a volume resistivity of $10^{11 \pm 1}$ Ω cm.

When the gas layer is crossed by an ionizing particle an electric discharge is suddenly initiated by the liberated electrons. This discharge is quenched by the following mechanisms:

1) prompt switching off of the field around the discharge point, due to the large electrode resistivity;
2) UV photon absorption by the butane preventing secondary discharges from gas photoionization;
3) capture of outer electrons of the discharge due to the Freon electron affinity, which reduces the size of the discharge and possibly its transversal dimensions.

The duration of the discharge is typically ~ 10 ns. The relaxation time of the resistive electrode plates is of the order of $\rho\epsilon = \tau \approx 10^{-2}$ s. The large difference between these two characteristic times insures that during the discharge the electrode plates behave like insulators, so that only a limited area of ~ 0.1 cm^2 around the discharge point remains inactive for a dead time of the order of τ.

Fig. 1 shows the sketch of a "double layer" RPC consisting of two independent counters superimposed on each other in the same mechanical structure. In each counter the 2 mm gap between two resistive plates of phenolic polymers is filled with a gas mixture of argon (2/3 in volume), butane (1/3) and a small amount of Freon at atmospheric pressure. Graphite painted high-voltage electrodes of surface resistivity 200–300 k$\Omega/\square$, transparent to the electric pulses originated in the gas, allow a capacitive readout through external pickup electrodes. These are aluminum strips 3 cm wide, facing the grounded copper electrode also shown in fig. 1. These behave as transmission lines of ~ 50 Ω characteristic impedance. Standard double layer RPC moduli have been made with a useful area of 1.92×0.48 m^2. Several moduli can be assembled in a supermodulus as sketched in fig. 2, where a detector of 5.8×0.48 m^2 sensitive area made of three moduli is represented. The gas flows serially from one modulus to the next, and a set of 16 pickup strips on each of the sensitive planes constitut-

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Nuclear Instruments and Methods in Physics Research A270 (1988) 190–193
North-Holland, Amsterdam

PLASTIC SPARK COUNTERS WITH PVC ELECTRODES

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Received 16 September 1987 and in revised form 4 January 1988

The performance of a spark counter based on plasticized PVC is described. The relevant features of this detector match the requirements of surface and underground cosmic ray experiments. Its technological characteristics allow large area detector construction.

1. Introduction

In the framework of the study of new apparatus for extensive air showers of cosmic rays, we have considered the application of spark counters. For this purpose a time accuracy of the order of only a few nanoseconds is required [1]. Low cost, reliability and easy monitoring are of relevant importance.

So far the development of plate spark counters [2] with resistive electrodes has shown the possibility of reaching high time accuracies and good space resolution at the same time, but their use has been limited by the strict technological requirements due to the high gas pressure and to the degree of mechanical tolerances needed for gaps of 0.1–0.2 mm. They require electrode materials with volume resistivity in the range 10^9–10^{11} Ω cm, with a sufficient degree of homogeneity; for this purpose some resistive glasses have been successfully proposed, but they are rather expensive and not easily available. In practice all these limitations become prohibitive for large area counters.

In order to reduce the technological difficulties a new type of resistive plate counter (RPC) [3] has been developed, to be employed whenever a time resolution of the order of hundreds of picoseconds is sufficient. In this detector the resistive electrodes are made out of a phenolic thermosetting resin denominated Bakelite. The counter gap is of the order of 1.5–2 mm, and the gas circulation is at atmospheric pressure. Anyway, the RPCs, as the other spark counters, exhibit a noisy operation, i.e. the production of spurious sparks, and the use of thermosetting materials is restrictive as far as the construction technology is concerned.

We describe here a new plastic spark counter based on plasticized PVC. While rigid (unplasticized) PVC has a volume resistivity of the order of 10^{15} Ω cm, the addition of plasticizers to obtain the standard commercial soft PVC, lowers resistivity down to 10^{11}–10^{12} Ω cm [4]; by doping with ionic compounds, a volume resistivity around 10^{8} cm can be easily achieved [5]. We show that the use of commercial plasticized PVC allows the construction of spark counters with noiseless operation and time resolution of the order of 1 ns. Furthermore the use of a material such as PVC makes it possible to exploit the thermoplastic material technology which allows easy construction procedures for large area counters.

2. Prototype description

Fig. 1 shows the cross section of one prototype. The active volume containing the gas mixture is delimited by two parallel plate electrodes made of plasticized PVC, 1 mm thick. The volume resistivity is $\sim 10^{11}$ Ω cm. High voltage is supplied to the PVC electrodes by means of a graphite coating on the surface not in contact with the gas. The varnish is a commercial solution of graphite in methyl-isobutyl-ketone, and the surface resistivity is ~ 10 k$\Omega/\square$. A copper strip provides the electrical contact with the high voltage. The graphite-coated surface

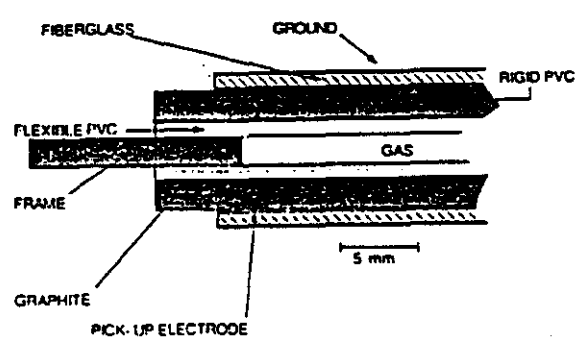

Fig. 1. Cross section of a spark counter prototype.

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(North-Holland Physics Publishing Division)

Preprint ROM2F/91/18
22 July 1991

Muon tracking and hadron punchthrough measurements using Resistive Plate Chambers

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talk delivered by A.Di Ciaccio at the "5th Pisa Meeting on Advanced Detectors", La Biodola, Isola d'Elba, 26-31 May 1991

Abstract

Study of high energy muon tracking and measurements of punchthrough probability for showers of charged hadrons with momenta 40, 70, 80 and 150 GeV/c have been performed at the CERN SPS test-beams using resistive electrode plate chambers. The results are compared with Montecarlo predictions and with measurements from other experiments.

1. Introduction

Resistive Plate Chambers (RPCs) are gaseous detectors that combine good space resolution with a time response of a nsec[1]. They are easy to build, stable and reliable over long periods of operation and therefore well suited for detectors with large area coverage in regions of limited access. These characteristics make the RPCs a good candidate for a fast muon tracking trigger at the future hadron colliders (LHC, SSC)[2]. The main limitation comes from the efficiency reduction of these detectors under high particle fluxes[3]. Charged particle punchthrough measurements as a function of the absorber thickness are crucial to evaluate the expected background rates and therefore the possibility of operating RPCs for muon detection under the high particle fluxes expected from pp interactions at 16-40 TeV centre of mass energy[4].

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN/DRDC/90-36
DRDC/P7
August 30th, 1990

Study of muon triggers and momentum reconstruction in a strong magnetic field for a muon detector at LHC

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CERN/DRDC/91-53
RD-5 / Status Report
January 13th, 1992

Status report of the RD5 Experiment

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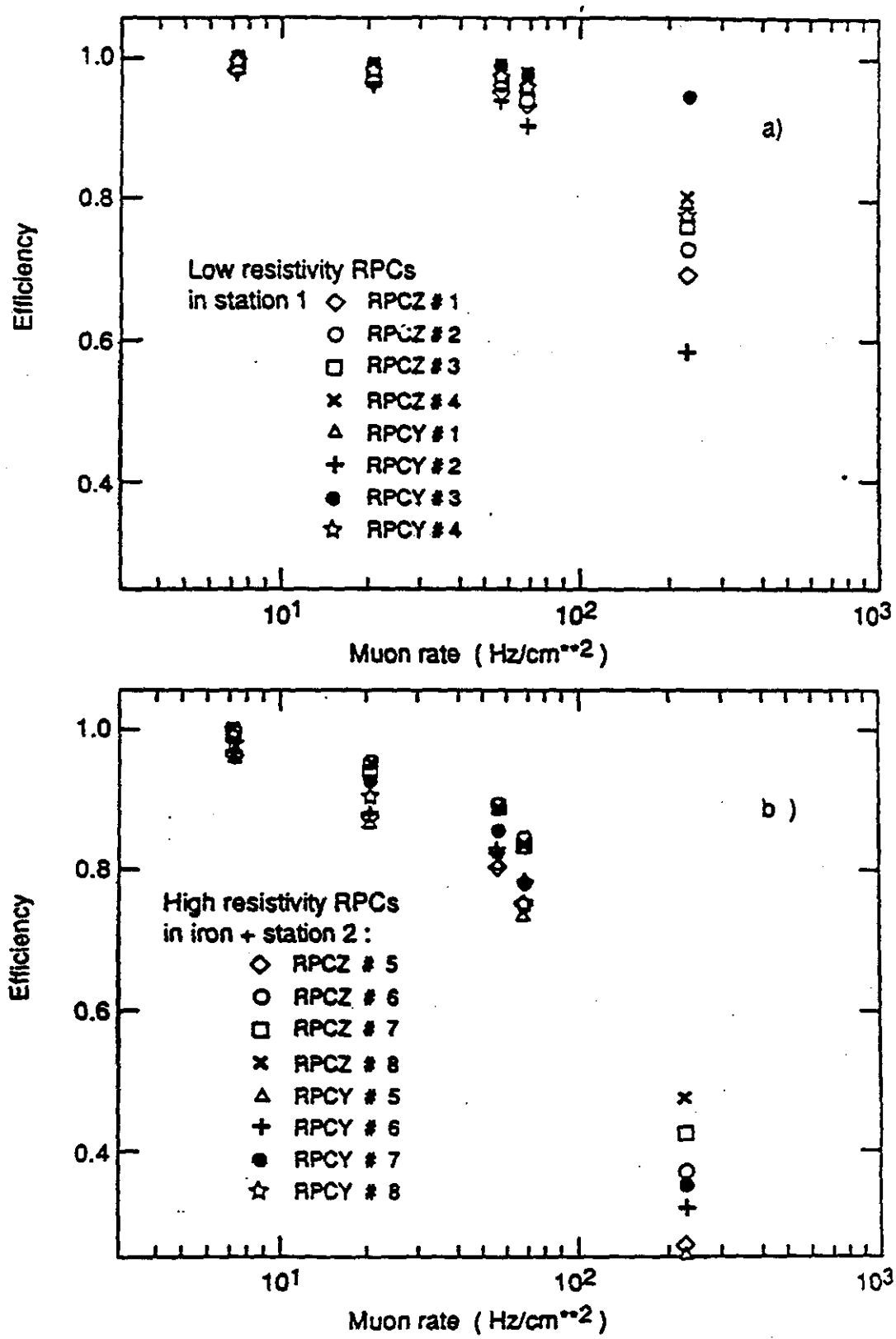
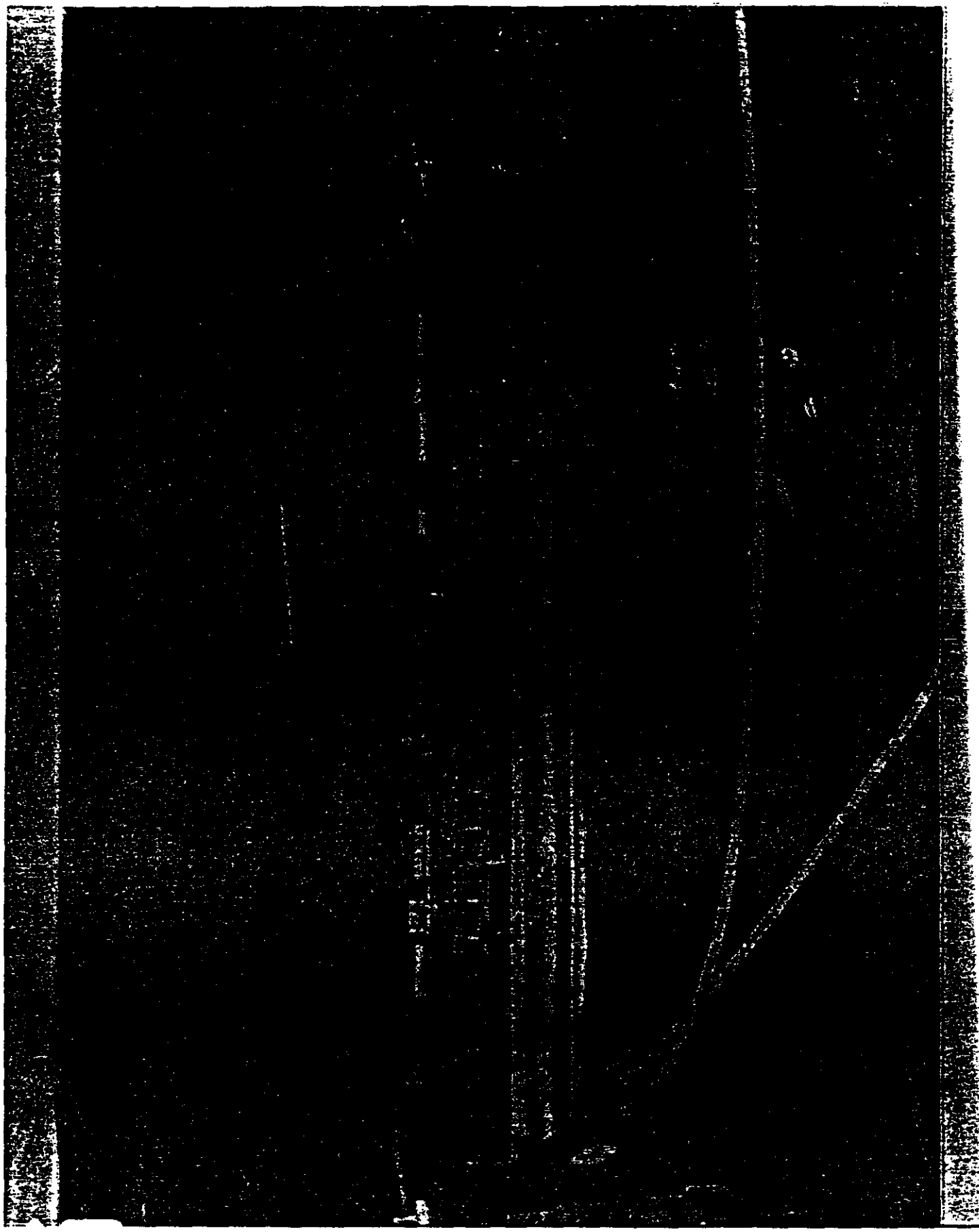
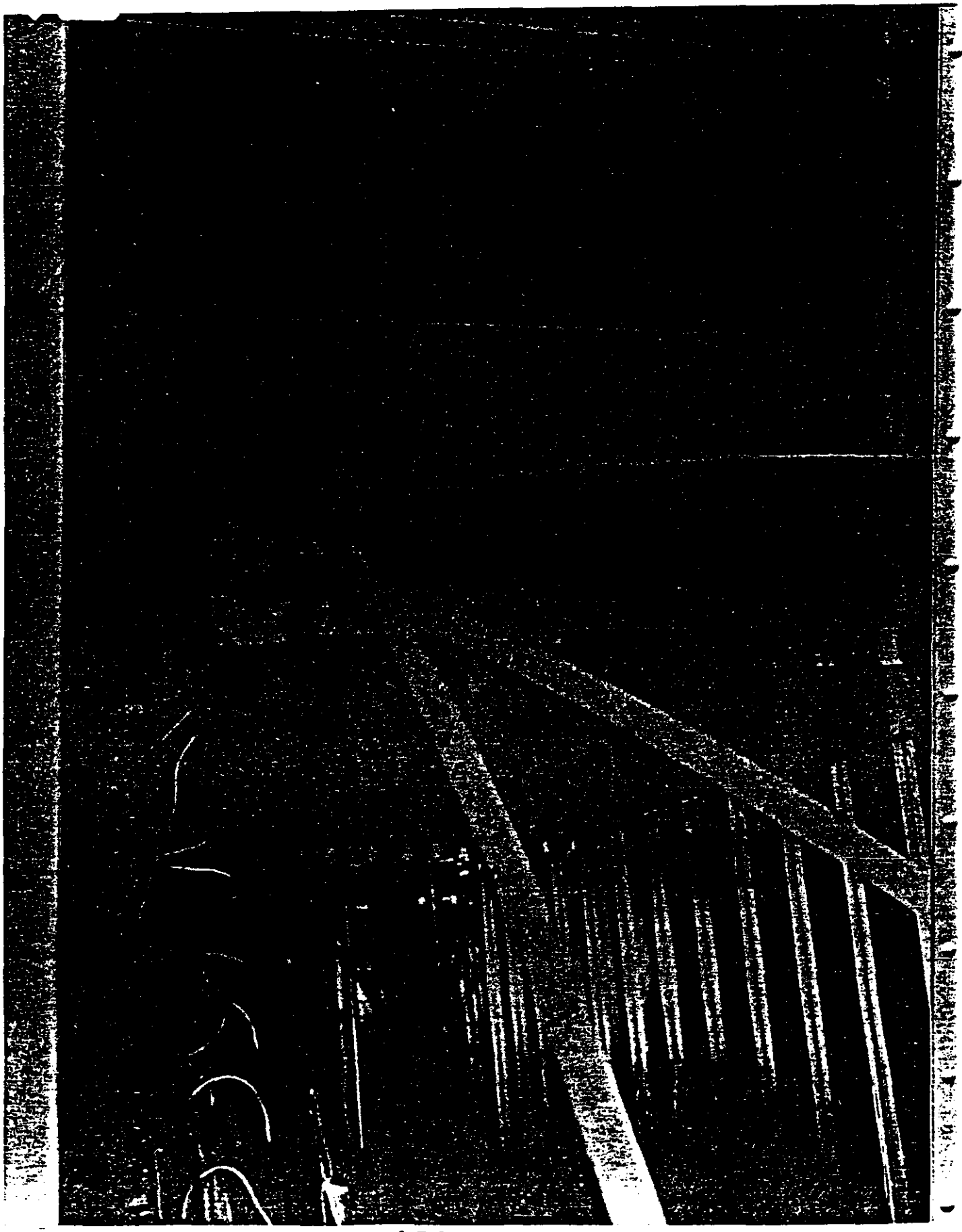
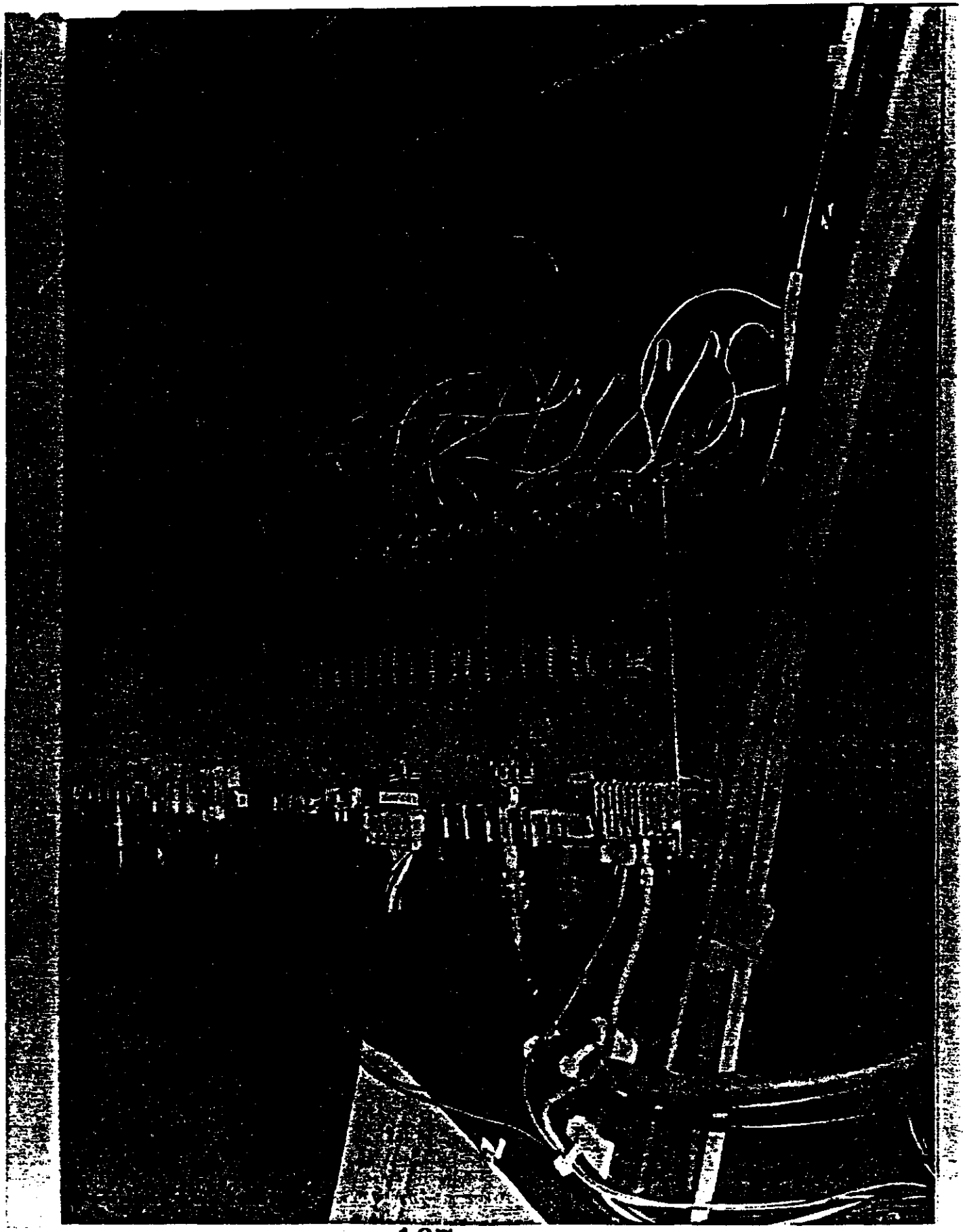
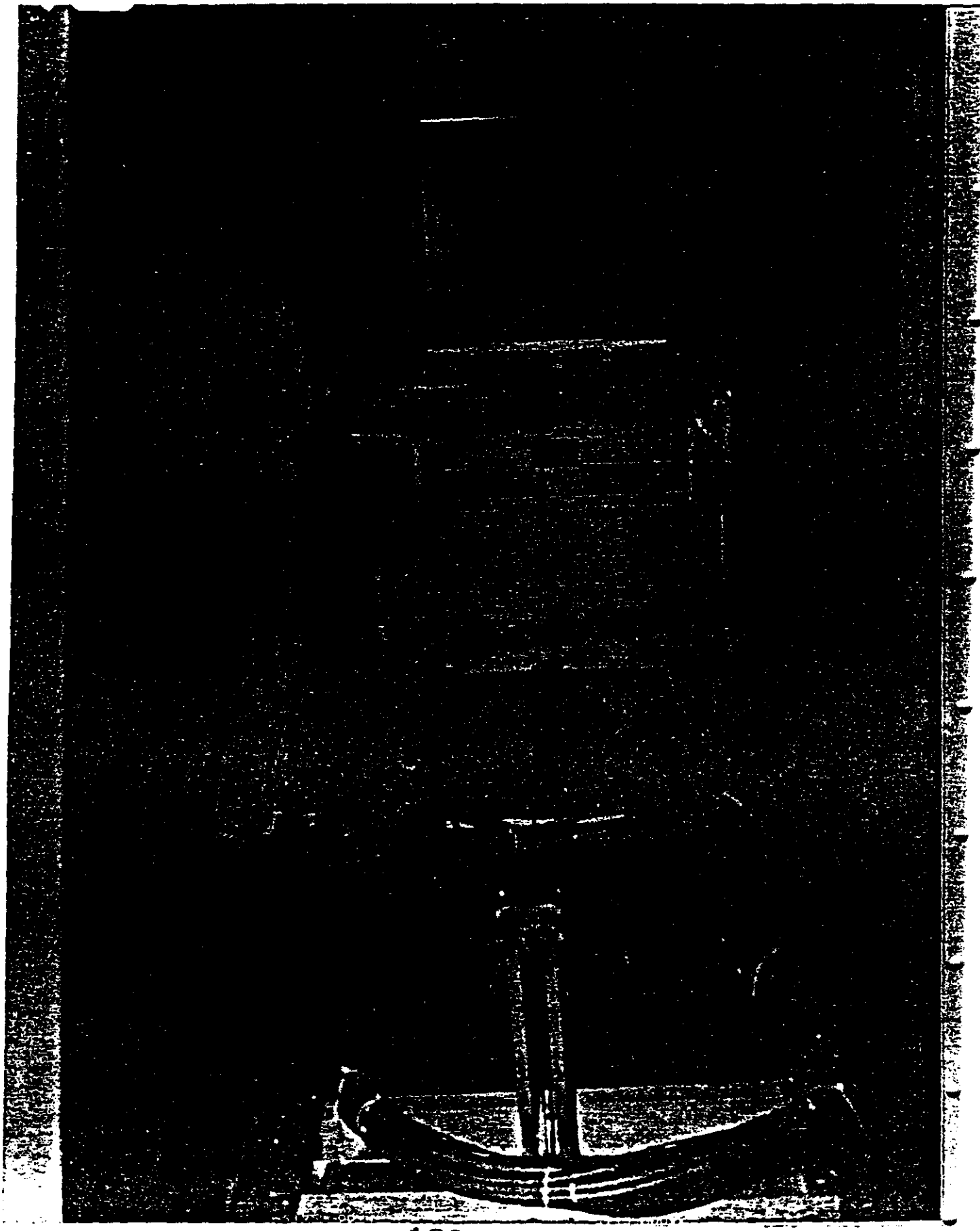

1.0
0.8
0.6
0.4
Efficiency
a)
Low resistivity RPCs
in station 1
RPCZ # 1
RPCZ # 2
RPCZ # 3
RPCZ # 4
RPCY # 1
RPCY # 2
RPCY # 3
RPCY # 4
10^1
10^2
10^3
Muon rate (Hz/cm**2)
b)
High resistivity RPCs
in iron + station 2 :
RPCZ # 5
RPCZ # 6
RPCZ # 7
RPCZ # 8
RPCY # 5
RPCY # 6
RPCY # 7
RPCY # 8

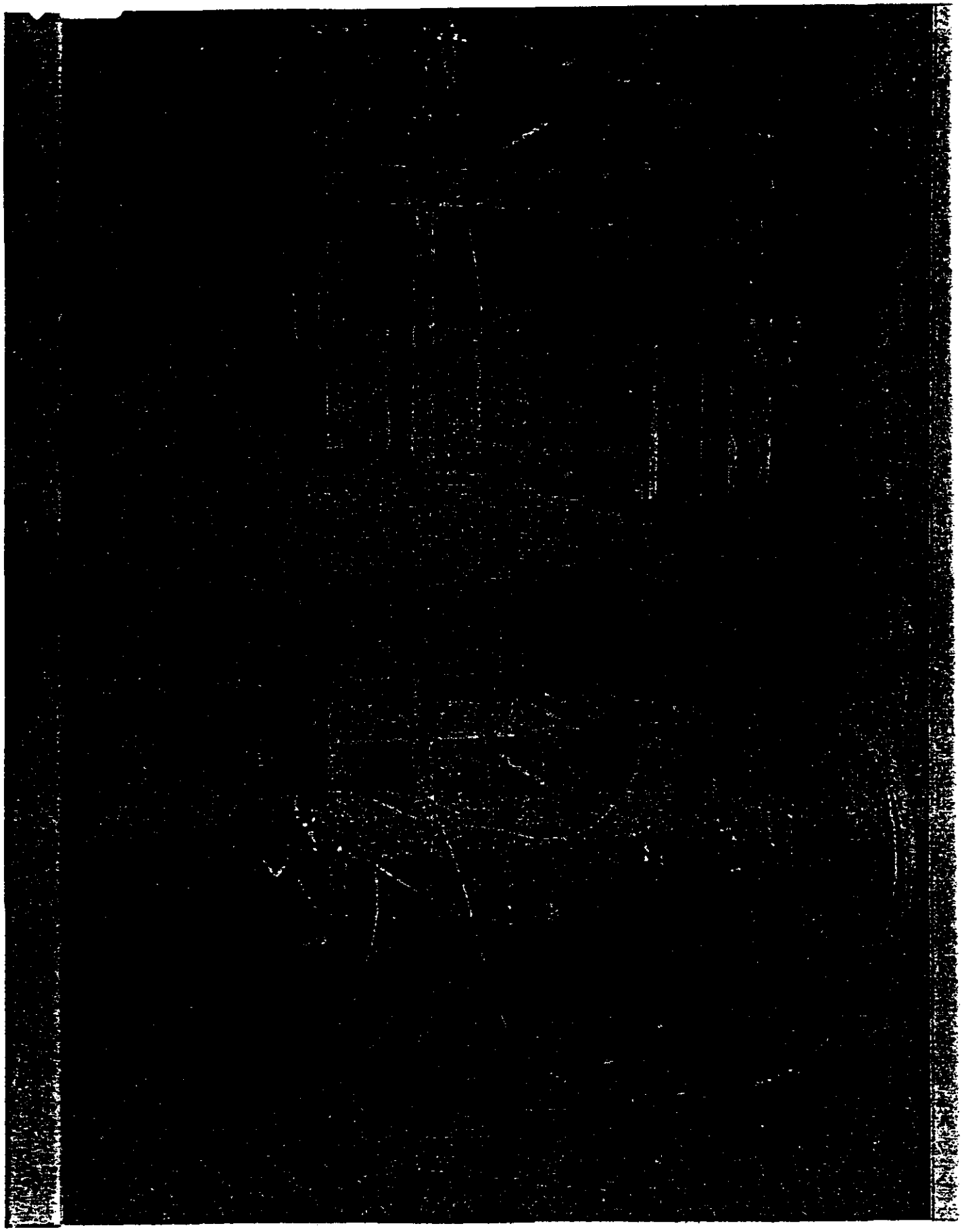
FIG. 20

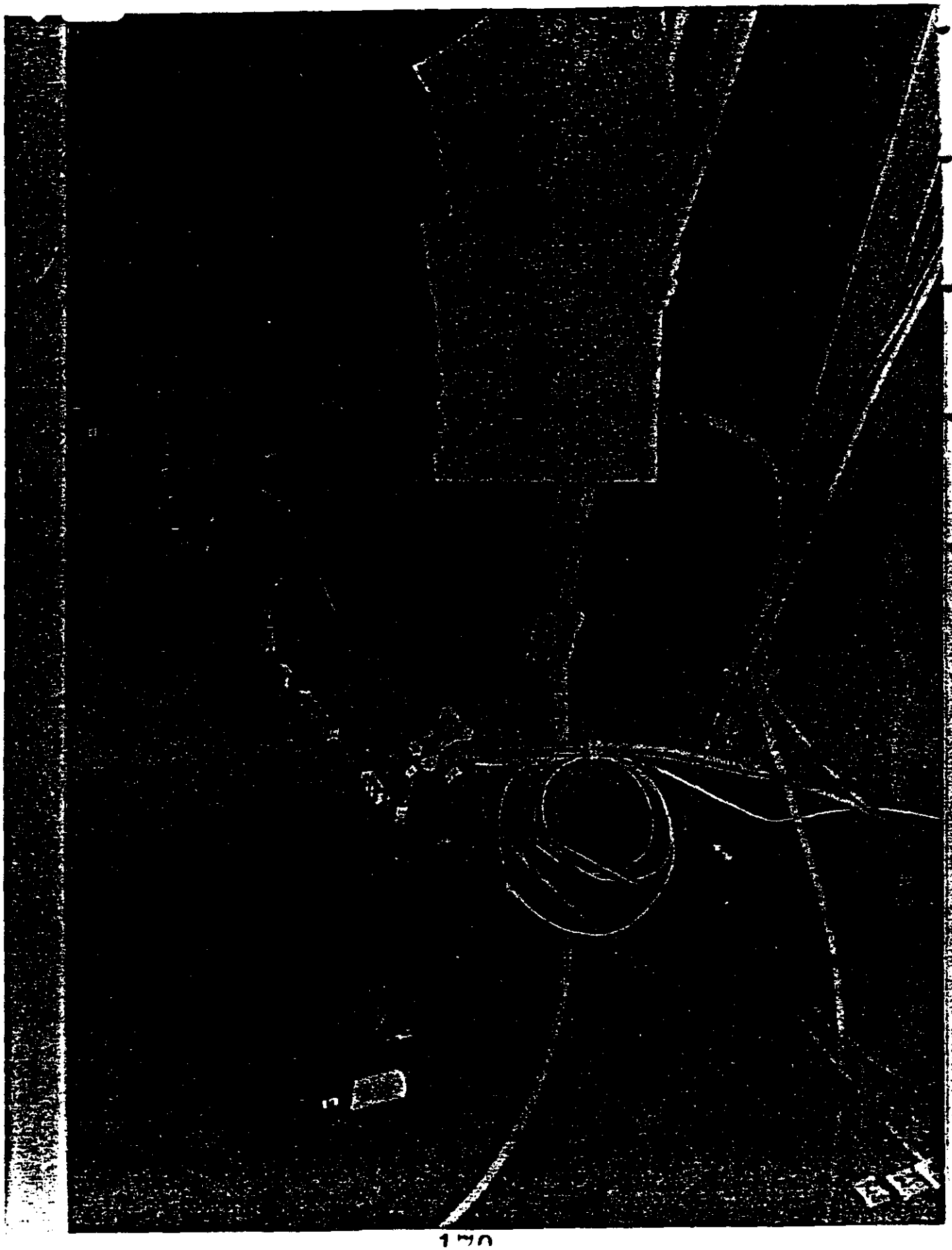












- In November 1991, the RPC Collaboration submitted its R&D program for the GEM Muon Beam Tagging Trigger and Z-coordinate Measuring System using Resistive Plate Counters.

- Properties of RPCs that have been measured include:

  - Pulse rise-time jitter
  - Maximum counting rate
  - Efficiency
  - Lifetime
  - Noise
  - Response to neutrons and gammas

- A number of RPC prototypes have been fabricated using new materials:

  - Glasses
  - Cermets
  - Plastics

- Results from the RPC R&D program:
  - Pulse rise-time jitter measured on 1m x 2 m Italian RPC - 1.4 ns
  - Pulse rise-time -2.5 ns
  - Pulse width - 50 ns
  - Pulse height - 200-500 mV into 50 ohms without amplification.
  - Saturated counting rate -
    - Glasses - 50-75 Hz/cm^2
    - Bakelite - 560 Hz/cm^2
    - Static-dispersive plastics - 15 KHz/cm^2
  - Efficiency – 95% using cosmic ray scintillator telescope.
  - Lifetime – 1% decrease in efficiency measured for 8.2 SSC years exposure.
  - Noise – 10 x cosmic rays.
  - Neutron sensitivity (1-10 MeV) – 4.8 x 10^-3, same as other technologies.
  - Photon sensitivity (1-10 MeV) – 6.6 x 10^-3.

- Conclusions:
  - The R&D program has successfully addressed the major concerns of RPC counting rate, aging/lifetime, neutron sensitivity, and noise.

Resistive Plate Chamber R&D

- Two RPC prototypes have been constructed at LLNL:
  - 30 cm x 30 cm RPC test stand to study cermet thin films.
  - 30 cm x 50 cm test stand to study bakelite RPCs.
- Cr/SiO cermet thin film RPCs may suffer from damage due to spark interaction. Also, bulk resistivity is measured to be too small for proper operation.
- However, boron thin films may be more robust. Boron films are being deposited now. Bulk resistivity can be controlled by film thickness - e.g. 10 μm boron film = 1MΩ-cm.
- New materials are being tested:
  - static dispersive polymers - bulk resistivity ~ 10^9 - 10^{10} Ω-cm
  - Westinghouse low resistivity phenolic - bulk resistivity ~ 10^5 - 10^{10} Ω-cm.
- SPICE modeling of RPCs provides insight into rate capability.
- Measurements being made of cross talk on adjacent strips in small test stand with 750 μm glass plates (10^{10} Ω-cm).
- One FTE effort till end of fiscal year to design full-scale gas system for GEM RPC system.

DRAFT

SSC GEM NOTE 1
(92-1)

BEHAVIOR OF LARGE RESISTIVE PLATE COUNTERS

SEPTEMBER 1992

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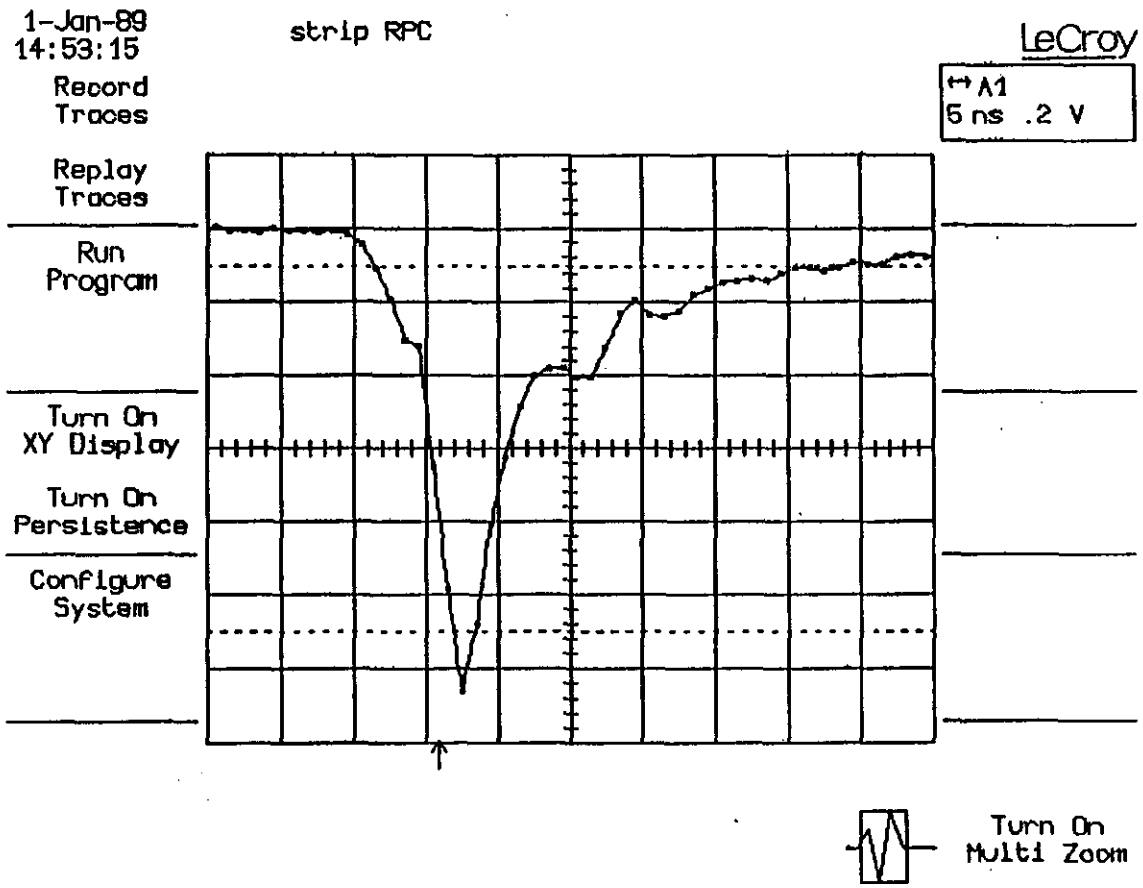
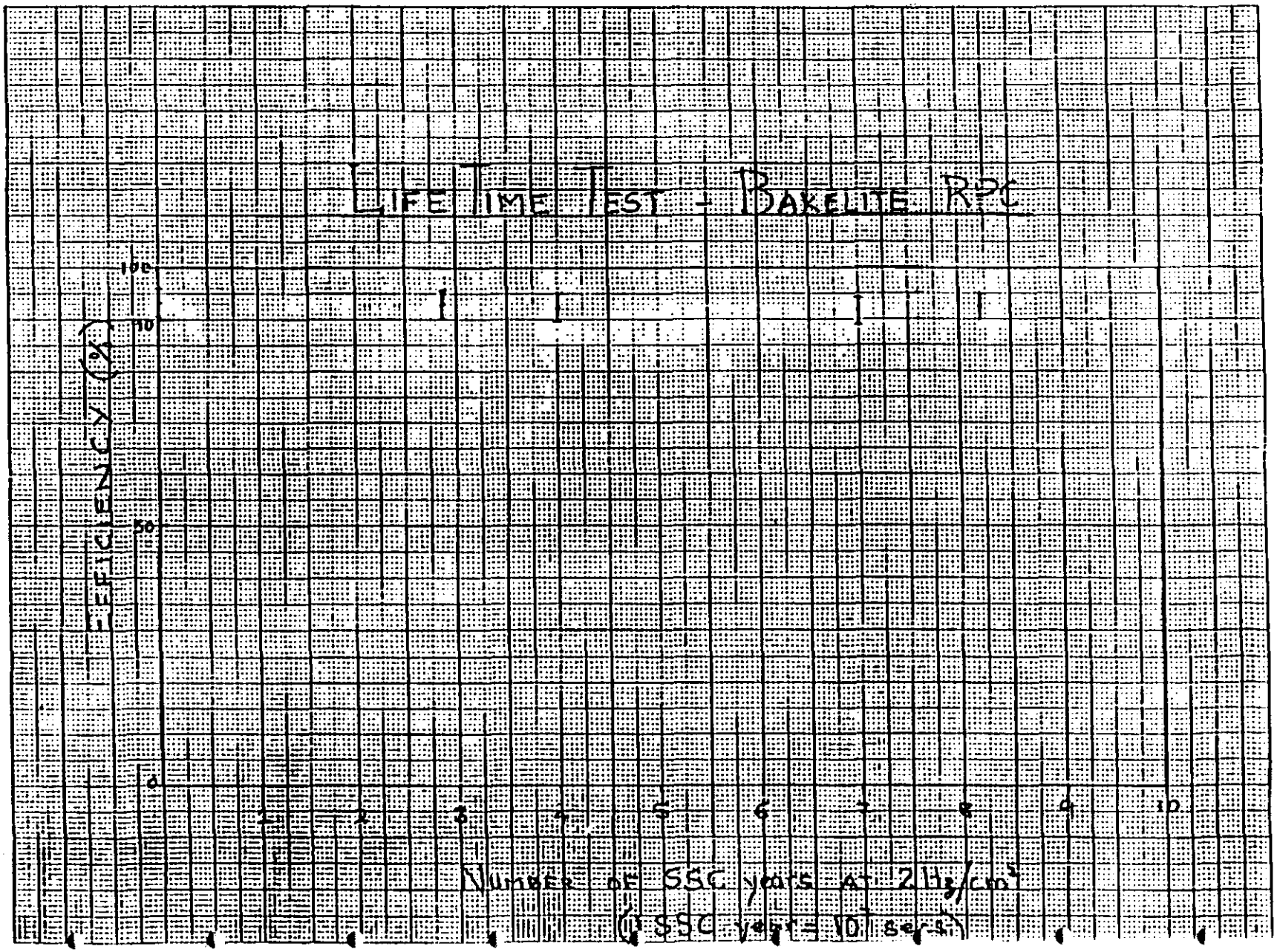
09/16 16:36 7312025 #02

Typical glass RPC signal



K+E 10 X 10 TO THE CENTIMETER KEUFFEL & ESSER CO. 461510

Figure 16



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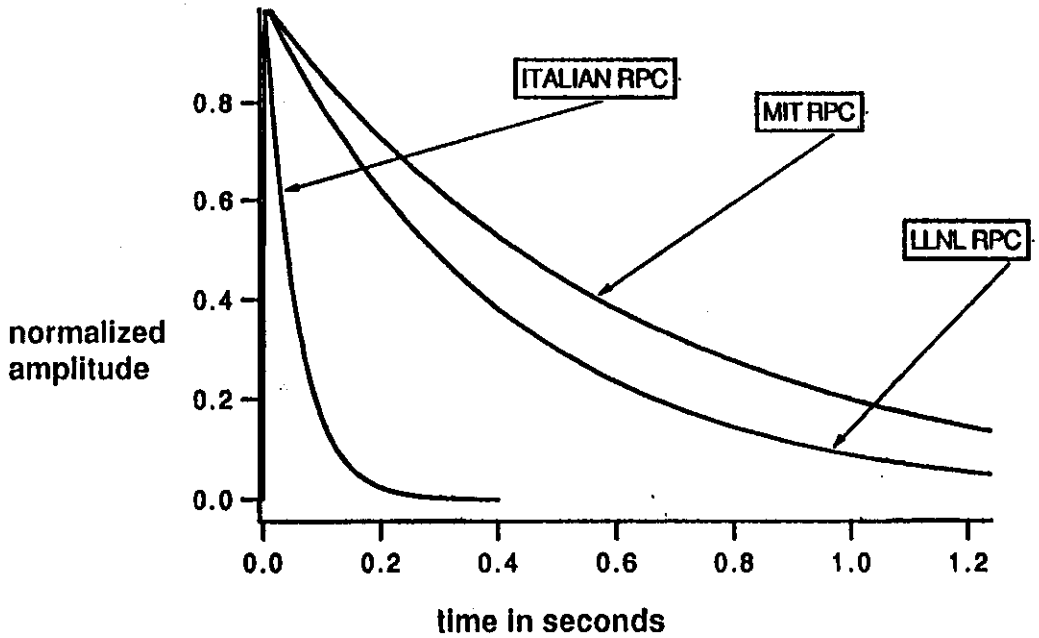
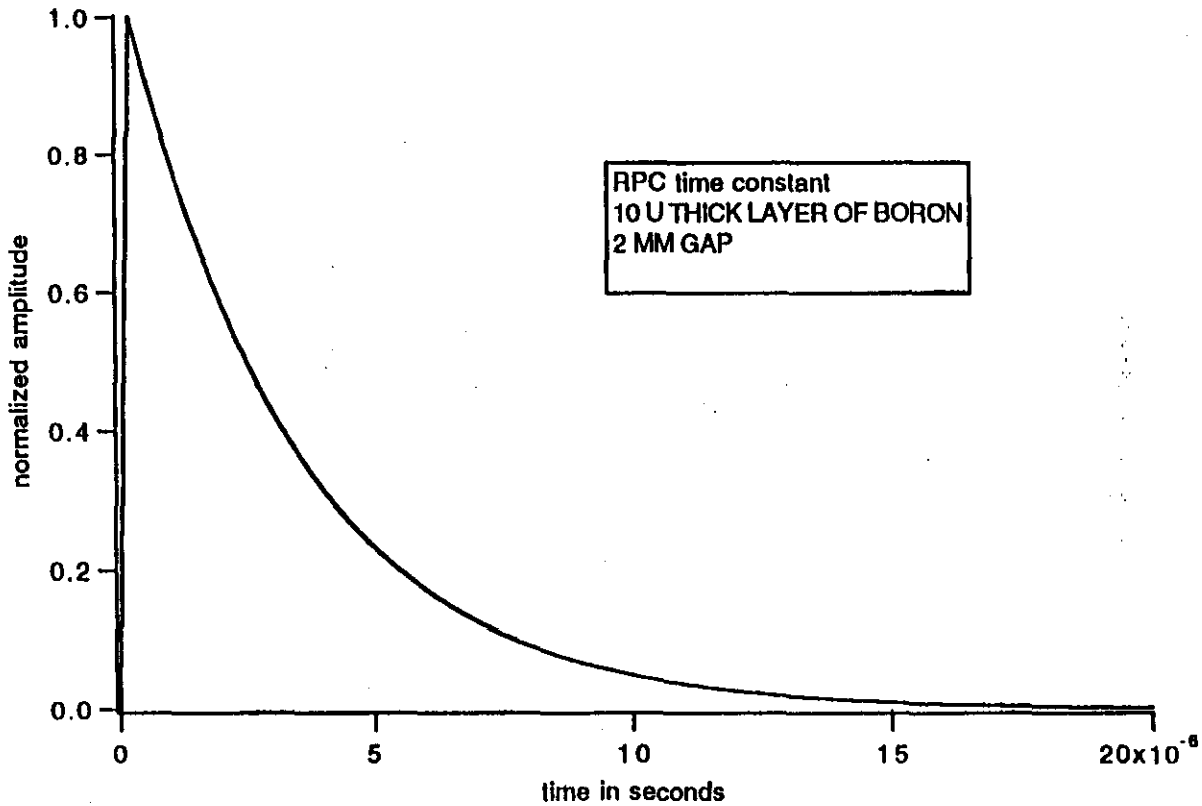
Resistive Plate Chamber R&D

SPICE calculation of different RPC recovery times based on bulk resistivity of materials: bakelite for Italian RPC, glasses for LLNL and MIT RPCs
- note time scale is seconds



SPICE calculation of boron RPC recovery time - note time scale is microseconds



Resistive Plate Counter Technology Review

- Three Cost Reviews have been completed for RPCs:
  - Complete cost with material and assembly labor – $5.7M
  - "the RPC system is clearly the lowest cost technology..."

- Engineering Review of RPC Technology has been completed:
  - "The RPC engineering design is the simplest and most risk free of any of the technologies."
  - "Assembly tolerances are large in comparison with the other technologies .... production processes can be quite simple and rapid."
  - "only the RPC technology presented a design for a gas system."
  - "RPC internal alignment requirements are quite modest in comparison to the other technologies.
  - "Each of the proposed designs, except for the RPCs require high structural stability in order to meet the precision alignment tolerances.

- Concerns included:
  - Gas choice and effects of contamination.
  - Details of the assembly – non-standard sized chambers.
  - Details of the alignment – local and global, strip dimensional tolerances

Resistive Plate Counter Cost Estimate

- Two RPC designs have been costed:
  - Two layer Bakelite RPC - Italian design using existing technology.
  - Two layer Cermet RPC - still in R&D. Promise of reduced mass and cost.
- Materials costs have been estimated in the following manner:
  - direct estimate from vendor - written and oral for quantities needed, e.g. Hexcel
  - LLNL Stores catalogs - quantity discounts not taken into account, e.g. mylar sheet
- Design assumptions based on Baseline I document as much as possible.
- Design of structure based on estimates for other muon technologies.
- LLNL has one designer/draftsman and is hiring one engineer for structure work.
- Design is still evolving as R&D progresses, e.g. RPC readout schemes, etc.

Standard Bakelite RPC design

	Item	Cost ($/m^2)	Total Cost ($K)
1.	Aluminum U-channel	4.3	11.8
2.	Bakelite sheet or Cermet coated plastic film	27.0	74.1
3.	Foam (e.g. polyurethane sheet)	1.2	3.2
4.	Aquadag	16.9	46.4
5.	Aluminized Mylar sheet	15.4	42.2
7.	Spacers , glue	0.36	1.0
	Total Materials	65.16	178.7

	Cost ($/m^2)	Total Cost ($K)
Total Materials (x.25 for mach'g and waste):	**81.45**	**223.4**

	Item	Cost ($/m^2)	Total Cost ($K)
8.	Fabrication cost estimate: $60/hr @ 1m^2/hr	60.0	164.6
9.	Gas fittings edge x 2 for gas manifold)	4.6	12.6
10.	Steel tubing (1/4" diameter, 10.4 km long)	11.52	31.6
11.	RG-174 coaxial cabling (67.5 km)	5.18	14.2
12.	LEMO connectors (2 x 33,184 channels)	80.0	219.4
13.	Gas (Recirculator)	91.14	250.0
Total Miscellaneous		**252.4**	**692.4**

Subtotal:

	Cost ($/m^2)	Total Cost ($K)
Materials, Fab., Gas system, Elect. system:	**333.9**	**915.8**

	Cost ($/m^2)	Total Cost ($K)
RPC Materials, Fab., Gas system	333.9	915.8
Structural supports and integration with drift tubes	300.0	823
Materials contingency (5%)	15.85	43.5
Labor contingency (100%)	60.00	164.4
	Cost ($/m^2)	Total Cost ($K)
TOTAL	709.8	1,947

DRAFT

Mechanical Engineering Evaluation of the Muon Chamber Technology Options

R. Sawicki, chairperson
M. Gamble
R. Humphreys
C. Johnson
F. Nimblett

October 1, 1992

Abstract:

This report summarizes an engineering evaluation of the technologies that are being proposed for the muon subsystem of the GEM detector. A summary of the status of each option is presented along with a comparison of the relative strengths and weaknesses of each design.

Table 1. GEM RPC Specifications

Coverage: 100% - Z, 95% Phi
Areal Mass: projected thickness = 0.7% X_0/layer

Material	Thickness	Rad. Length	% Rad. Length
Al	0.005"	8.9	0.14
Foam	4 mm	424	0.09
Mylar	0.005"	28.7	0.04
Bakelite	0.015"	34.4	0.11
Gas	2 mm	Large	0
Bakelite	0.015"	34.4	0.11
Mylar	0.005"	28.7	0.04
Foam	4 mm	424	0.09
Al	0.005"	8.9	0.14
Foam	4 mm	424	0.09
Mylar	0.005"	28.7	0.04
Bakelite	0.015"	34.4	0.11
Gas	2 mm	Large	0
Bakelite	0.015"	34.4	0.11
Mylar	0.005"	28.7	0.04
Foam	4 mm	424	0.09
Al	0.005"	8.9	0.14
Total:			**1.38**

Nominal Radius (M):	4.0	6.0	8.0
# of chambers	64	96	128
Width (cm)	148.5	239.0	329.6
Length (cm)	330.0	360.0	380.0
Total Length	631.9	1042.1	1475.0
# Bend-plane strips:	114	183	253
# Non-bend-plane strips:	166	166	166
Width of bend-plane strips (cm):	1.3	1.3	1.3
Width of non-bend-plane strips (cm):	3.9	6.5	8.9
Weights (lbs):			
Bakelite:	1877	4943	9593
Aluminum perimeter frame:	1049	1472	2304
Cable:	385	641	963
Connectors, brackets:	1160	2855	5795
TOTAL/Super-layer	4471	9911	18655

TOTAL WEIGHT (TONS) 16.5 TONS

Resistive Plate Counter Design

- There are no sense wires in this technology.
- The pick-up strips are formed on an aluminized mylar substrate.
- The simplest method utilizes a shadow mask as the mylar is aluminized.
- In addition, etching, grinding, and sand-blasting are all viable techniques for creating the strips.
- The required precision for the strips is $\pm$ 500 microns.
- Once the mylar is glued into the RPC stack, the strip positions need to be known with respect to an outside fiducial with a precision of $\pm$ 2 mm.

Resistive Plate Counter Design

- There are no precision requirements necessary for the RPC assembly.
- Standard toler ances on thicknesses of Bakelite and other commercially available laminate materials are sufficient for the proper operation of the RPCs.
- The PVC disk spacers can be turned out using computerized machining with the necessary height tolerance of $\pm$ 100 microns ($\pm$ 4 mils) without difficulty.
- Pick up strips can be laid out by masking aluminized mylar sheet or by machining with fine cutting tools. Either method is capable of providing the necessary dimensional tolerance of $\pm$ 0.5 mm.

Resistive Plate Counter Design

- The chamber will be made up of various layers glued together to form a single self-supporting laminated plate.

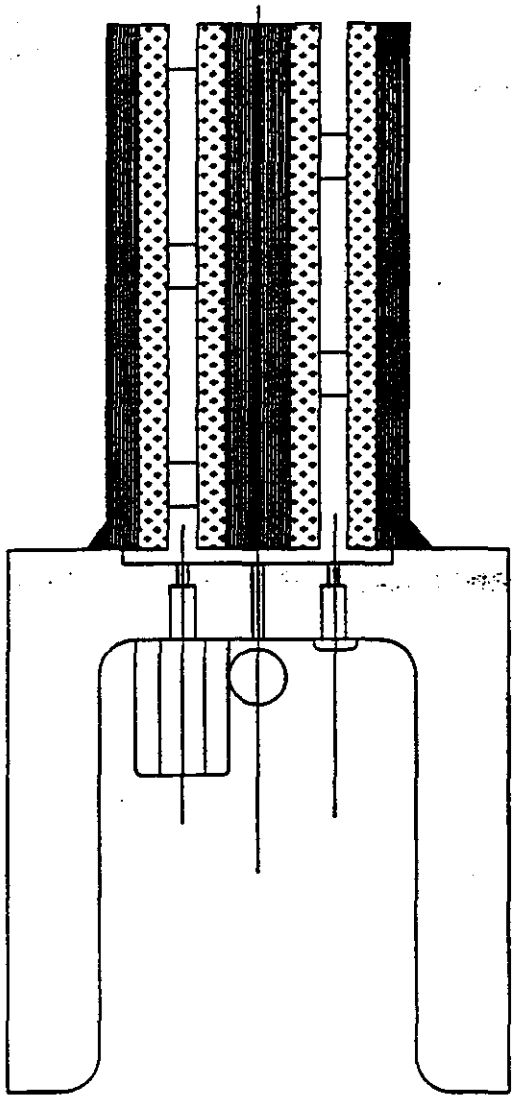
- Spacers are used, consisting of 2 mm thick, 10 mm diameter PVC disks

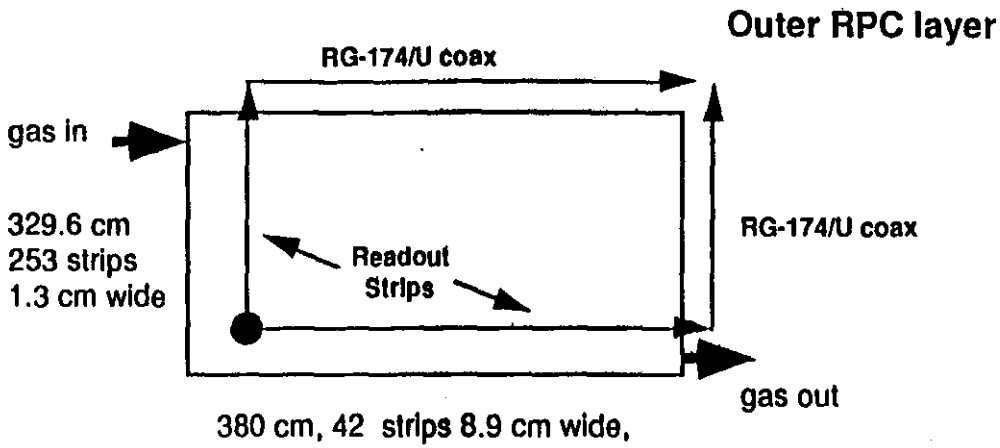
  - Spacers mechanically separate the two Bakelite plates and keep the plates flat with respect to one another by being placed on a 10 cm square grid.
  - They insulate the resistive plates from each other.
  - They transmit the mechanical stresses from one side of the plate to the other.

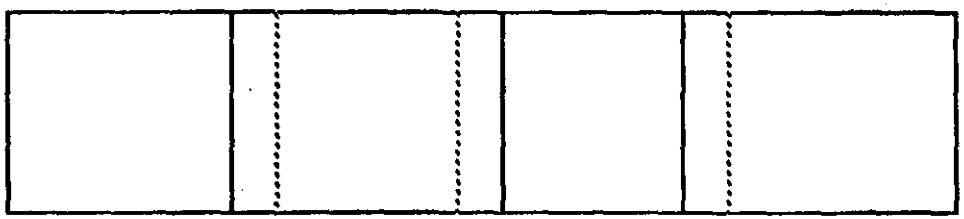
- The edges of the RPCs will be sealed by gluing 1 cm wide, 2 mm thick PVC strips between the Bakelite plates. This stiffens the edges mechanically so that the plate is self-supporting.

- Aluminum U-channel frame will encompass the chamber on all four sides.

  - Protect the edges of the RPC dur ing shipping, handling and installation
  - Stiffen the edges so that the RPC can be mounted by four corners (if necessary)
  - Furnish the base to mount the high voltage connectors, the gas connectors and the LEMO signal connectors.







4 overlayed RPC layers
3 strips overlap, don't use first and last strips on upper RPC s. Longitudinal strips are or'd together.

Cable length and weight (RG-174/U):

(168 x 10 cm) + 6 x (253 x 17 cm) + (253 x 10 cm) - layer interconnects

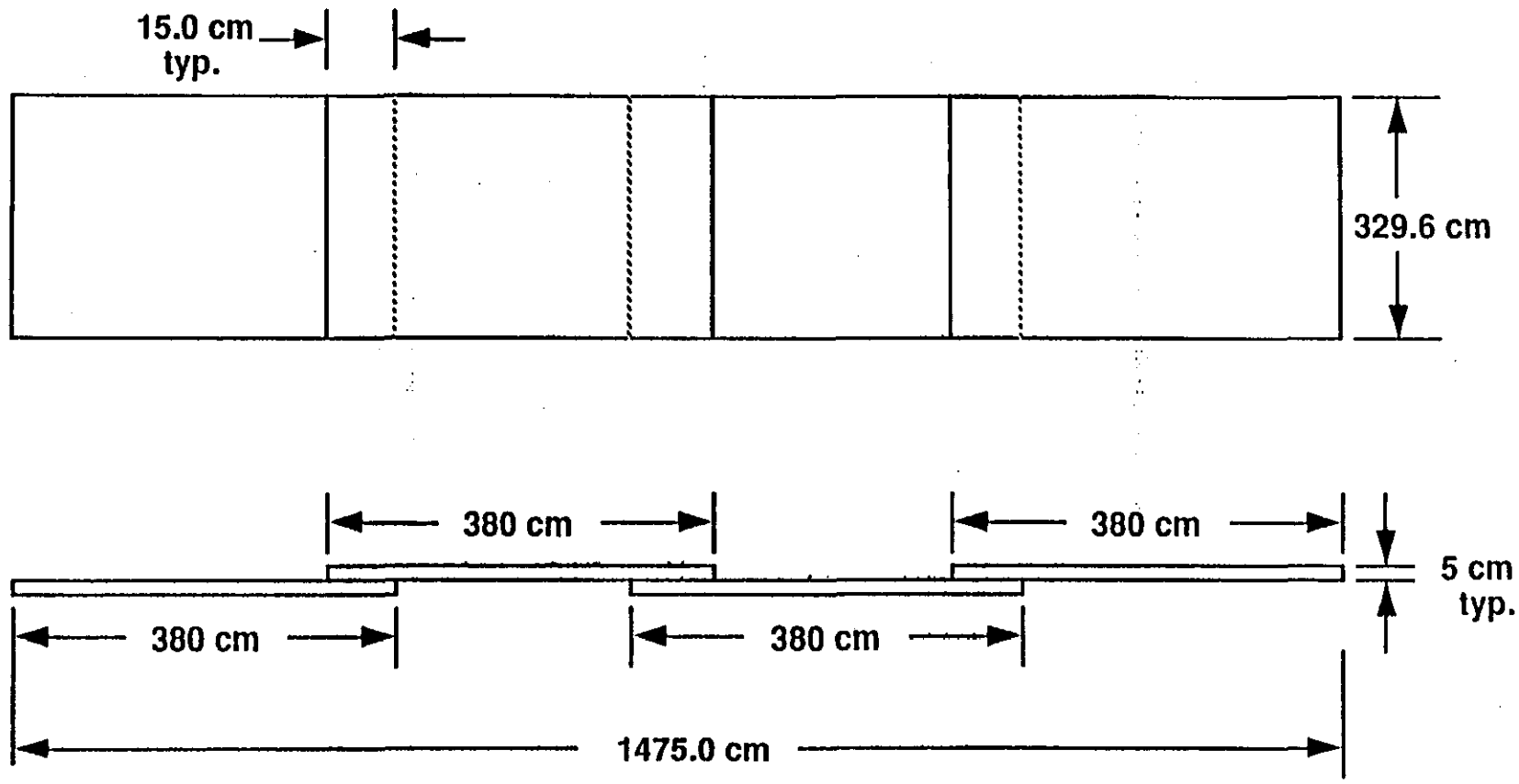
+ (380/2 cm) x 42
+ (350/2 cm) x 40 - non-bend plane strips
+ (380/2 cm) x 42
+ (365/2 cm) x 41

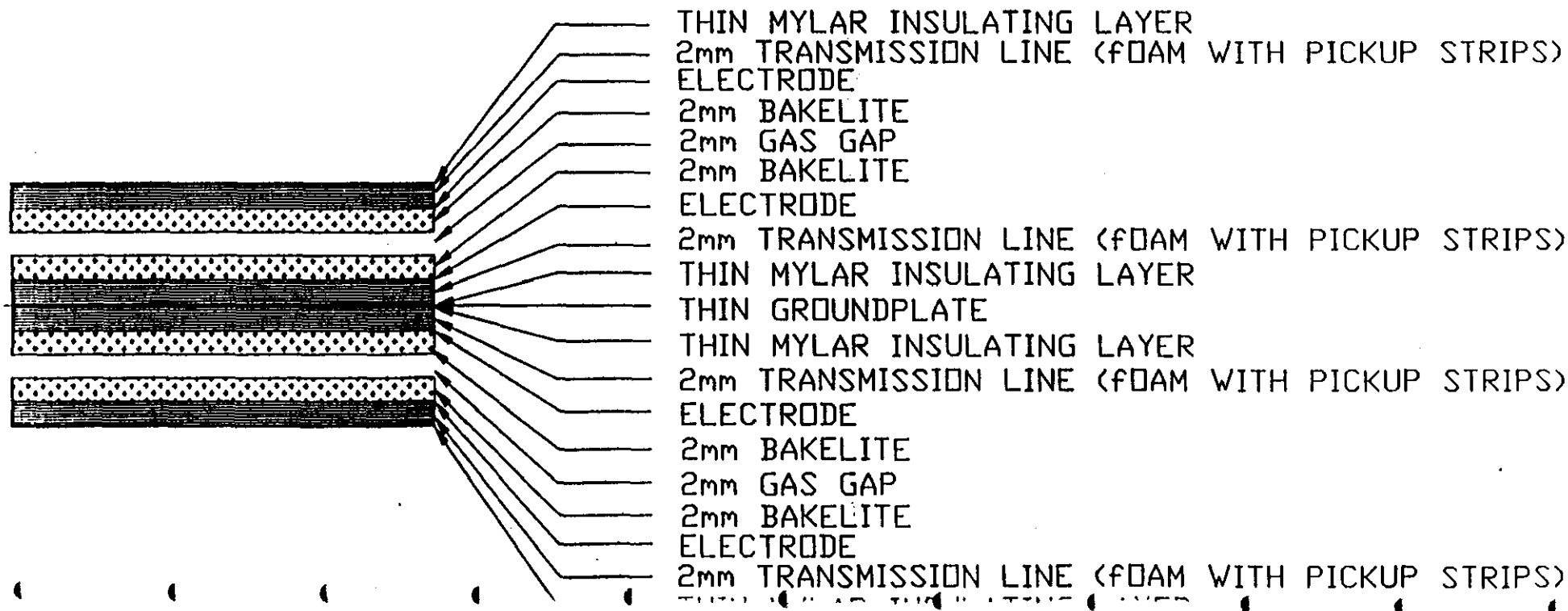
+ (329.6/2 cm) x 253 - bend plane strips

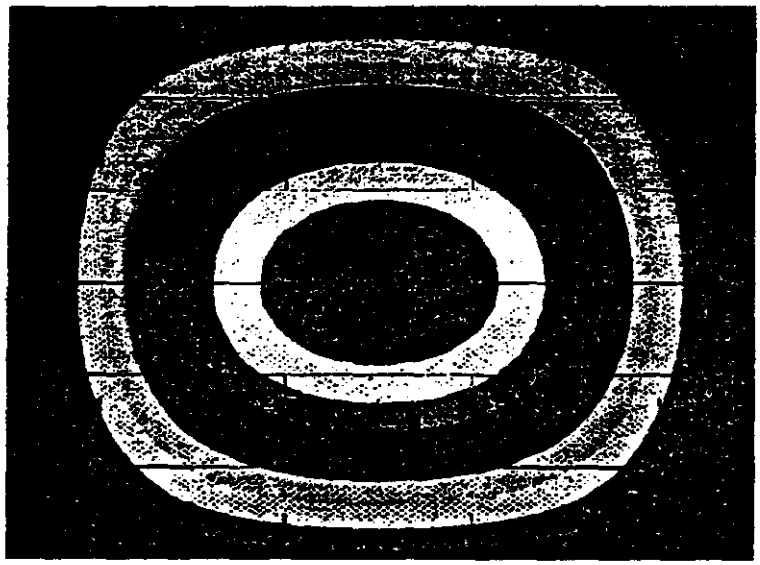
= 1.02 x 10**5 cm x 2.95 x 10**-4 lb/cm = <u>30.1 lb</u>

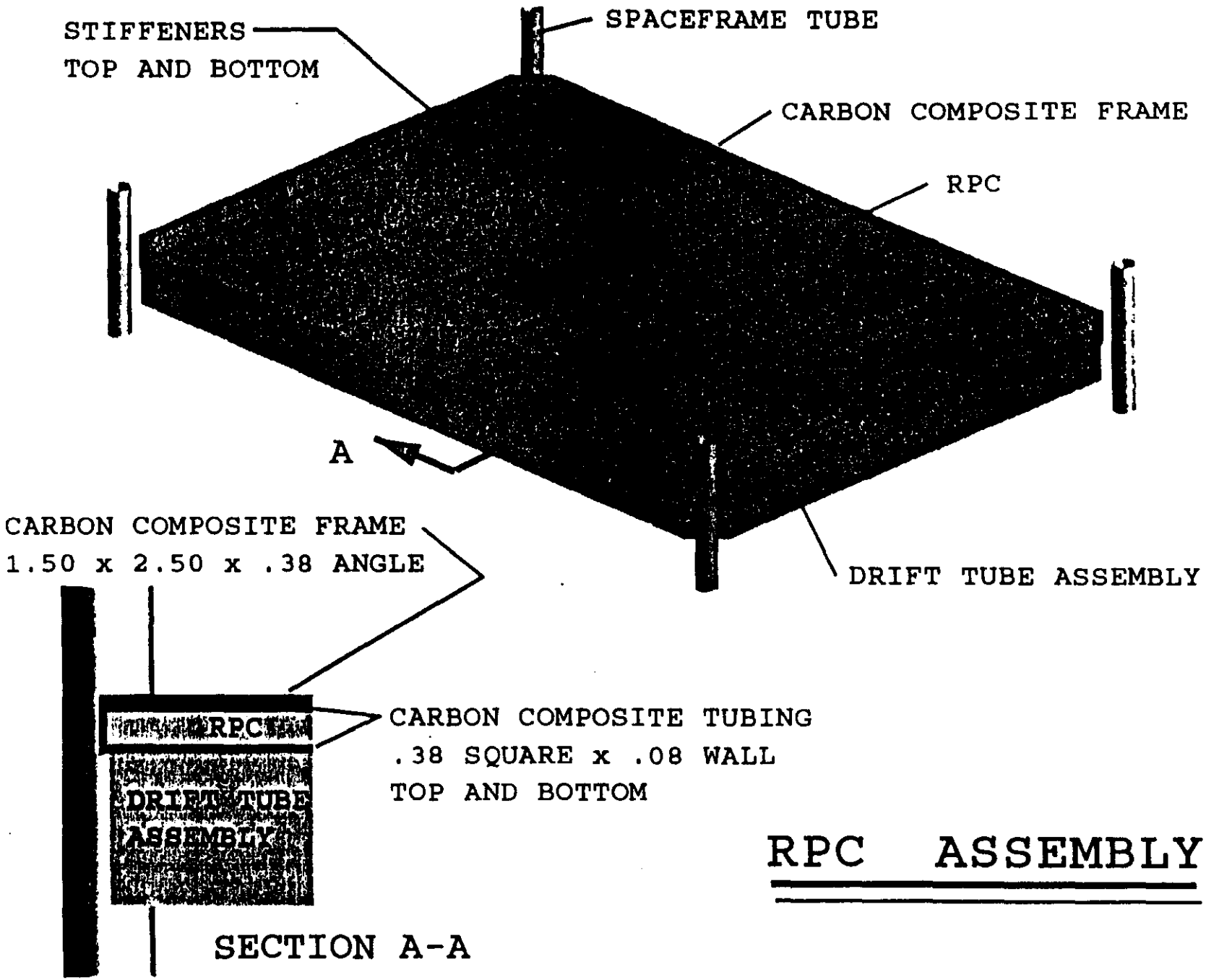
Outer RPC box layout - 4 chambers overlap per sector
x 16 sectors x 2 halves = 128 chambers

- 15.0 cm overlap

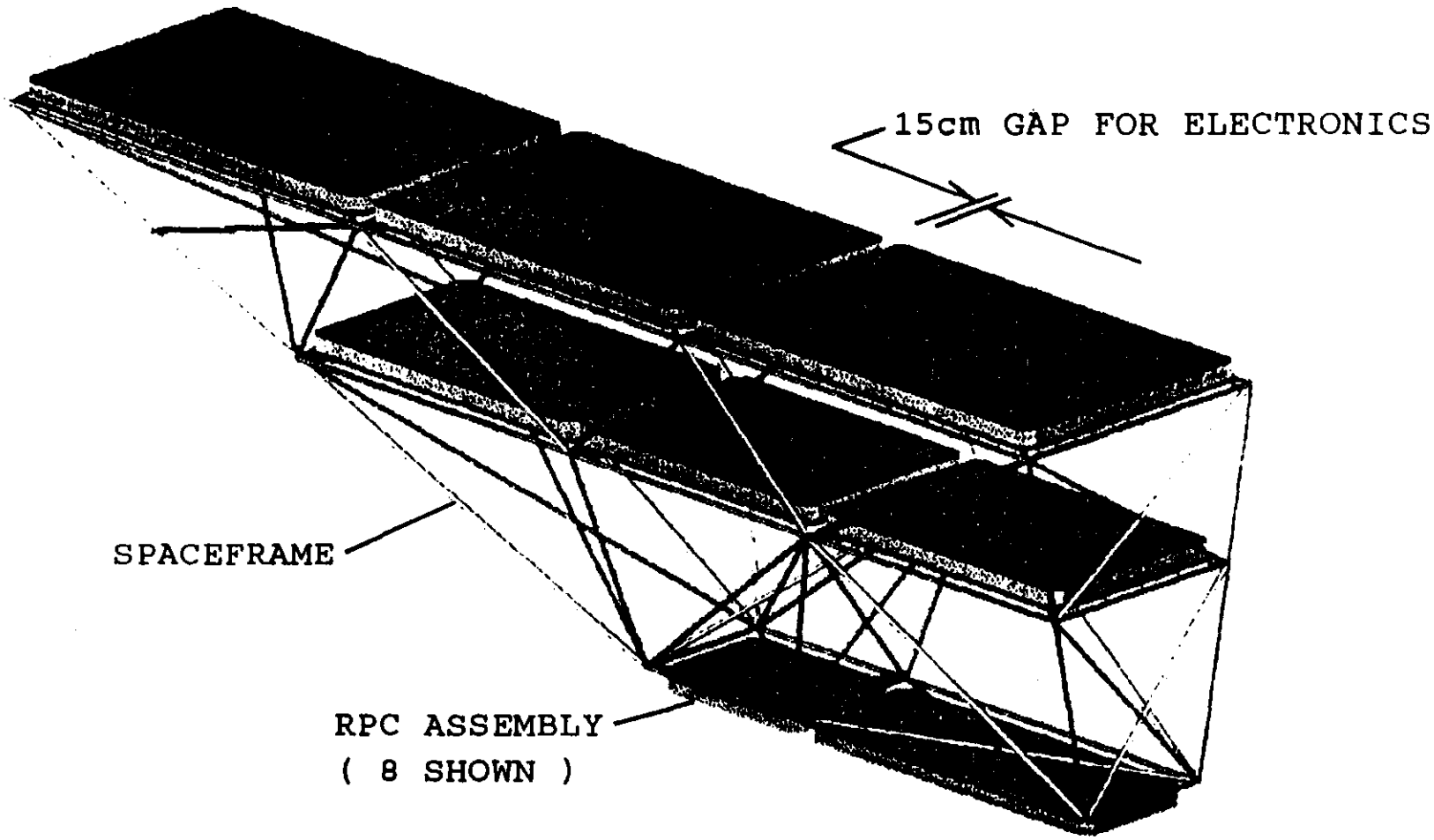



THIN MYLAR INSULATING LAYER
2mm TRANSMISSION LINE (FOAM WITH PICKUP STRIPS)
ELECTRODE
2mm BAKELITE
2mm GAS GAP
2mm BAKELITE
ELECTRODE
2mm TRANSMISSION LINE (FOAM WITH PICKUP STRIPS)
THIN MYLAR INSULATING LAYER
THIN GROUNDPLATE
THIN MYLAR INSULATING LAYER
2mm TRANSMISSION LINE (FOAM WITH PICKUP STRIPS)
ELECTRODE
2mm BAKELITE
2mm GAS GAP
2mm BAKELITE
ELECTRODE
2mm TRANSMISSION LINE (FOAM WITH PICKUP STRIPS)





RPC ASSEMBLY



MUON SEGMENT

Resistive Plate Counter Design

- RPCs, as a Level 1 trigger, do not require precision alignment.
- The RPCs can be mounted either separately from the precision drift tube technology, or co-located with the drift tubes.
- Sufficient care in fabrication will allow strips to be located with an accuracy of about $\pm$ 1 mm with respect to a fiducial placed on the edge of the RPC.
- Sag in the RPC will be within the limits imposed for proper muon timing and momentum determination so that monitoring of the sag will not be necessary.
- In-situ RPC alignment can be performed using cosmic rays or physics events..
- In addition, if the RPC system is incorporated into the drift tube structure, alignment will be coupled to the drift tube alignment system without added cost. This is because the RPC strip readout is referenced to a fiducial that can be referenced to the drift tube align ment system.
- In any event, RPC location to ~2 mm in Z and Φ is sufficient and to ~1cm in R to insure proper operation for Level 1 triggering.

Resistive Plate Counter Design

- The RPC is a very rugged reliable device without sense wires or regions of high fields.
- In case of a failure one half of the double RPC would fail.
- Each RPC gap as a separate chamber. The loss of one RPC gap means a decrease of efficiency of 1%.
- The RPC system is, for practical purposes, 100% redundant.
- Any single failure has a negligible effect on the practical efficiency of the system.
- If one gap fails per year (two orders of magnitude higher failure rate than is indicated by our current experience), then the probability of two gaps failing in the same RPC chamber in ten years of operation is less than 10%.

Resistive Plate Counter Design

- All material and components are off-the-shelf stock items.
- Once the items have been identified, all items and materials can be at the RPC Factory within 120 days of receipt of purchase orders.
- We estimate that construction can proceed at a rate of about 160 square meters per week. Our average chamber has an area of 10 square me ters.
- Hence, we can estimate that this assembly team can assemble about 16 chambers per week or about three chamber per day.
- The total of 288 chambers will therefore take, under this assumption, 18 weeks. A factor of two contingency gives a 36 week estimate for fabrication time.

Resistive Plate Counter Design

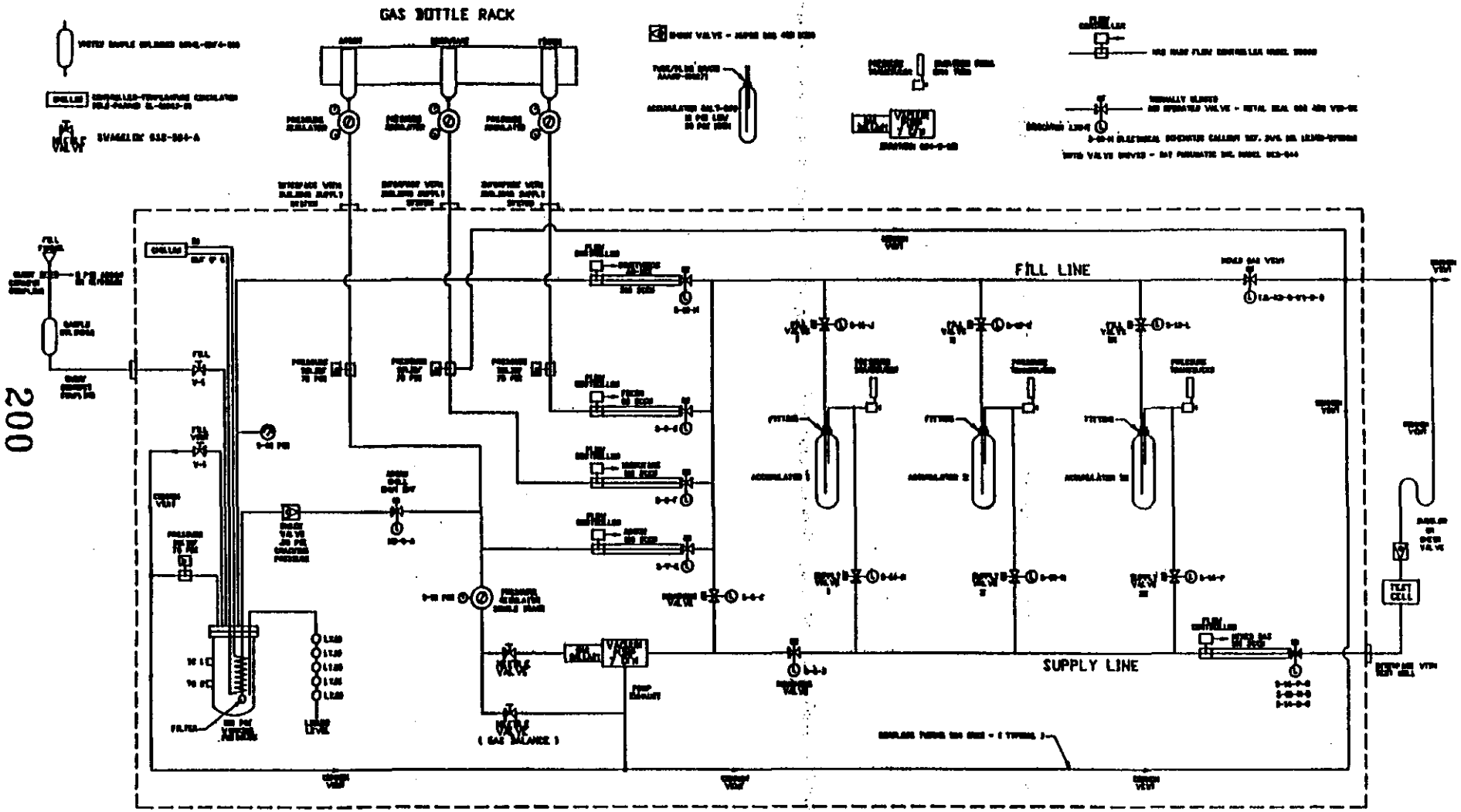
- RPCs have been manufactured in large quantities by Italian University groups for many years - R&D on an Italian RPC with dimensions 1 m x 2 m at MIT.
- A factory to build these RPCs is already in place and is capable of building RPCs to our specifications with minor modifications to their manufacturing process to take into account our new materials.
- If the need arises the manufacturing of RPCs could be carried out in the US at LLNL or MIT or also in China.

Resistive Plate Counter Design

- One year final R&D effort to construct the largest prototype RPC chamber.
- This chamber would be constructed by the members of the RPC Collaboration.
- Second R&D year to set up a proper factory including special jigs and handing tools, and to work out the assembly line bugs.
- Given the appropriate R&D funding for those two years, the first production RPC chamber would appear in January, 1996.

Resistive Plate Counter Design

- LLNL is designing the RPC gas system.
- The envisioned system is a low-flow, simple state-of-the-art recirculating system using standard technology
- All components are standard, off-the-shelf items.
- 2743 square meters of surface area in the three muon super-layers contain 0.4 cm total thickness of gas layers - total gas volume of 10.9 cubic meters.
- Typical RPCs operate with a gas flow rate of about 10% of their volume per hour or about 1.1 cubic meters per hour (18.3 liters per minute).
- The RPC gas system is designed to provide this flow rate for an accurately mixed combination of gases.
- Previous RPC systems have run successfully using a gas mixture consisting of 66% Argon, 32% isobutane and 2% freon. It is unlikely that this mixture of gases will be allowed at the SSC because of its flammable nature.
- Alternative gas mixtures are being explored in R&D. One candidate gas is a non-flammable mixture of 49% CO_2, 49% CF_4, and 2% freon.



GAS MIXING CONTROL

TA HAGGERY - LOUAYER - XD-7000
GMCSYSTM

200

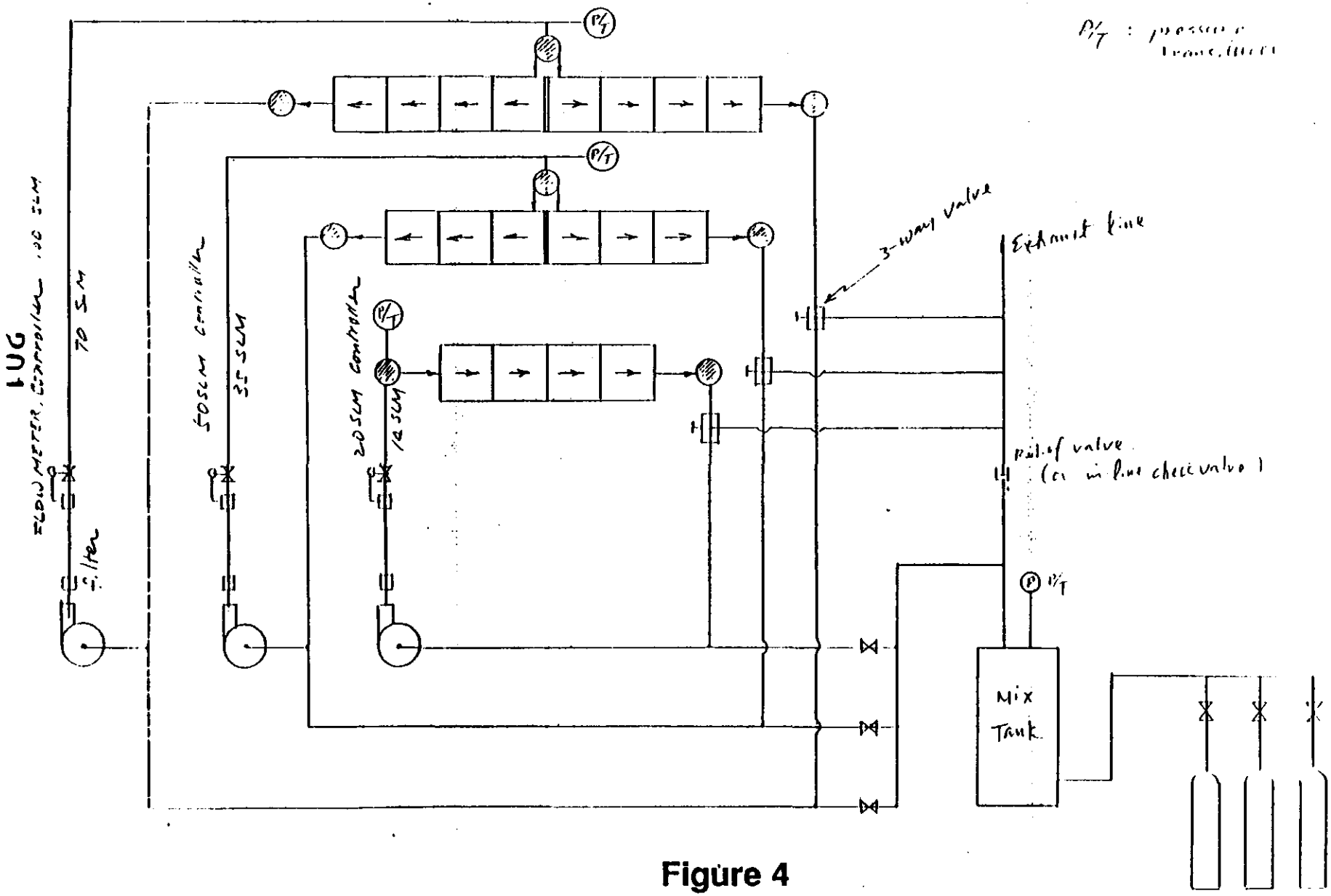

P/T : pressure transducer
3-way valve
Exhaust line
pilot valve
(or in line check valve)
Mix Tank
P/T
50SLM controller
20SLM controller
70 SLM
35 SLM
20 SLM
10 SLM
filter

Figure 4

PRESENTATION TO THE MUON TRIGGER MEETING AT THE SSC LABORATORY 22 JANUARY 1992

IRWIN A. PLESS

BARREL RPC TRIGGER

I. INTRODUCTION

II. RATES

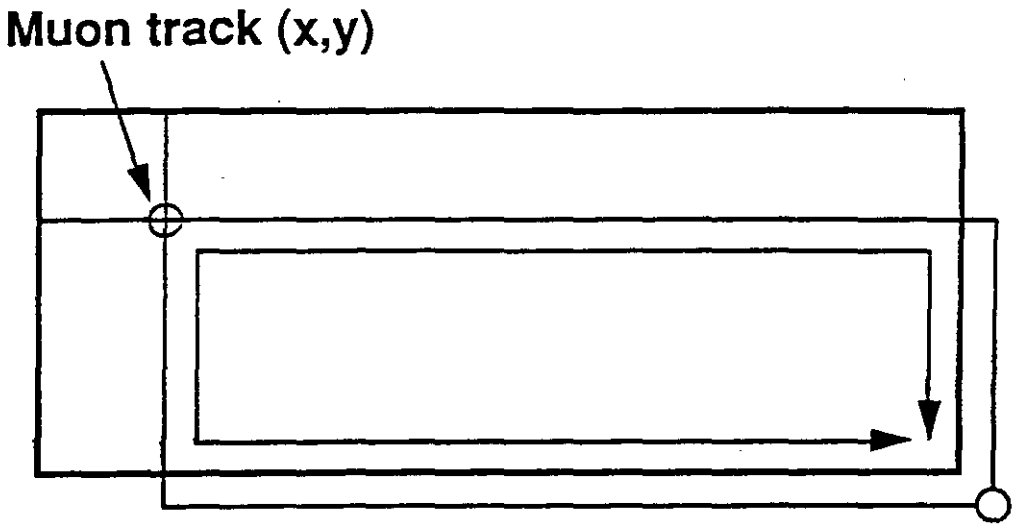
III. TIMING AND TRIGGER WIDTHS

IV. TRIGGER STRATEGY

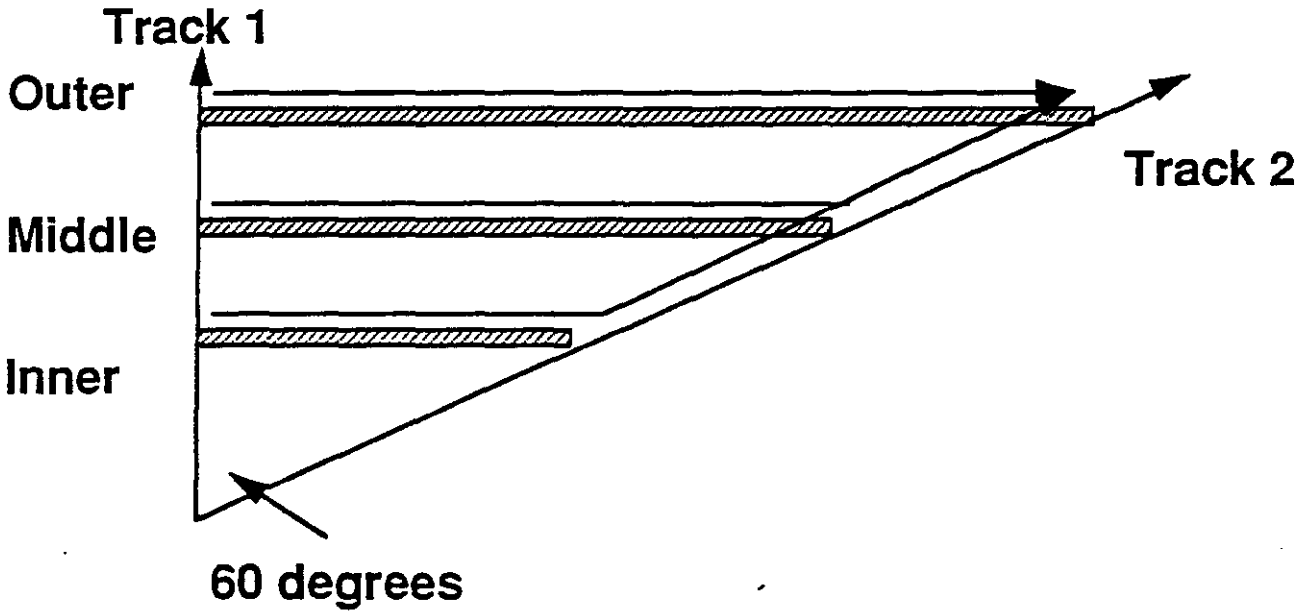
V. HARDWIRE IMPLEMENTATION

VI. ASSOCIATIVE MEMORY IMPLEMENTATION

VII. SUMMARY

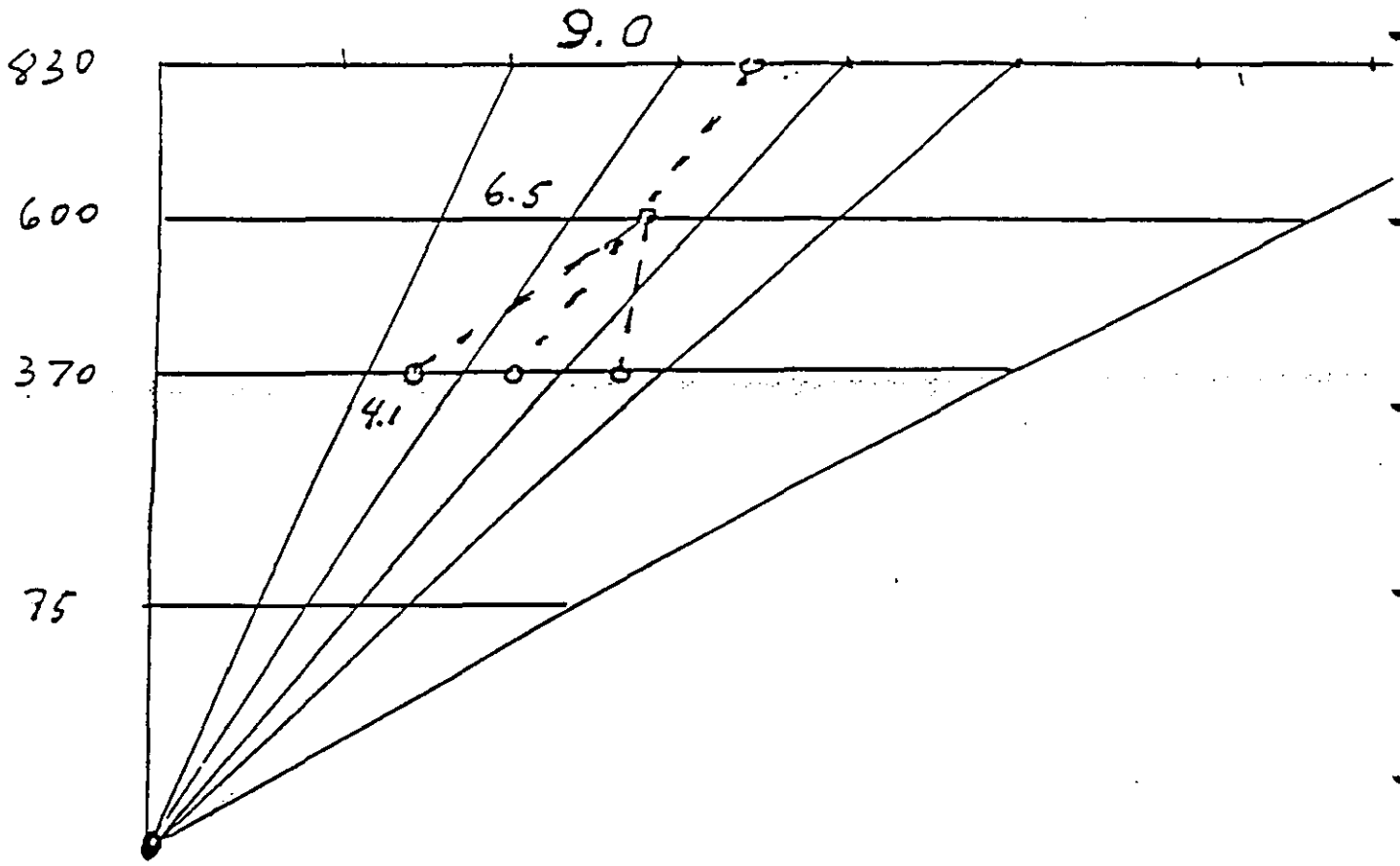


(a)



(b)

Figure 11



For each outer strip there are three, three fold coincidence circuits. Any triple coincidence generates a non-bend trigger.

Tower geometry.

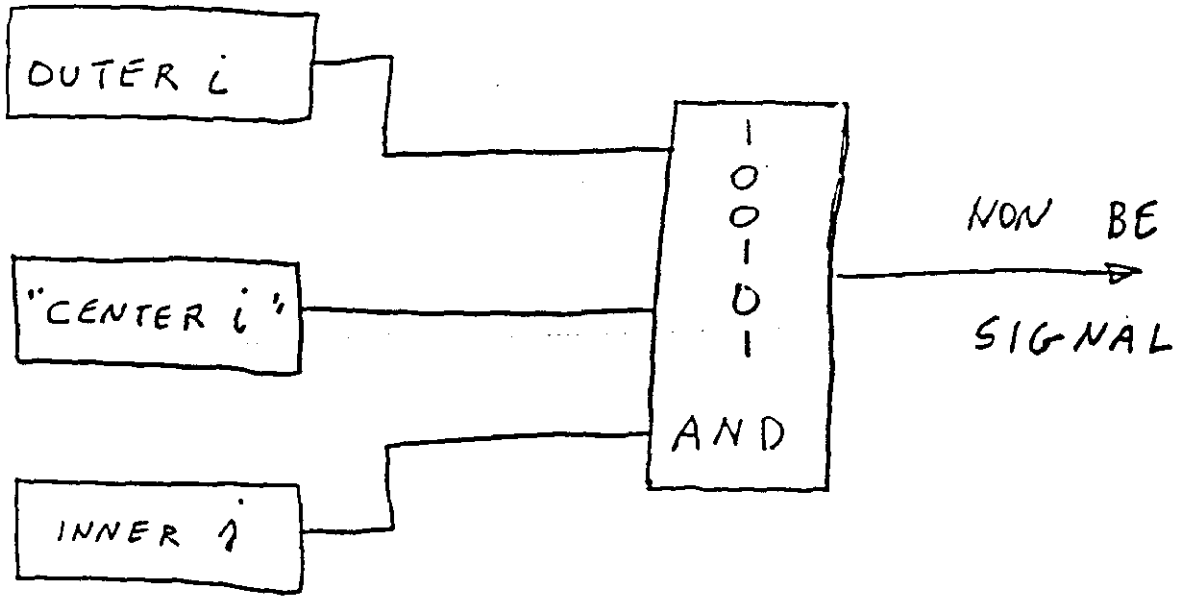
Each plane is divided into 161 strips.

Outer	= 9.0 cm
Center	= "6.5" cm
Inner	= 4.1 cm

Center is really 5 strips OR'd together, each strip is 1.3 cm wide to furnish the z coordinate of the track.

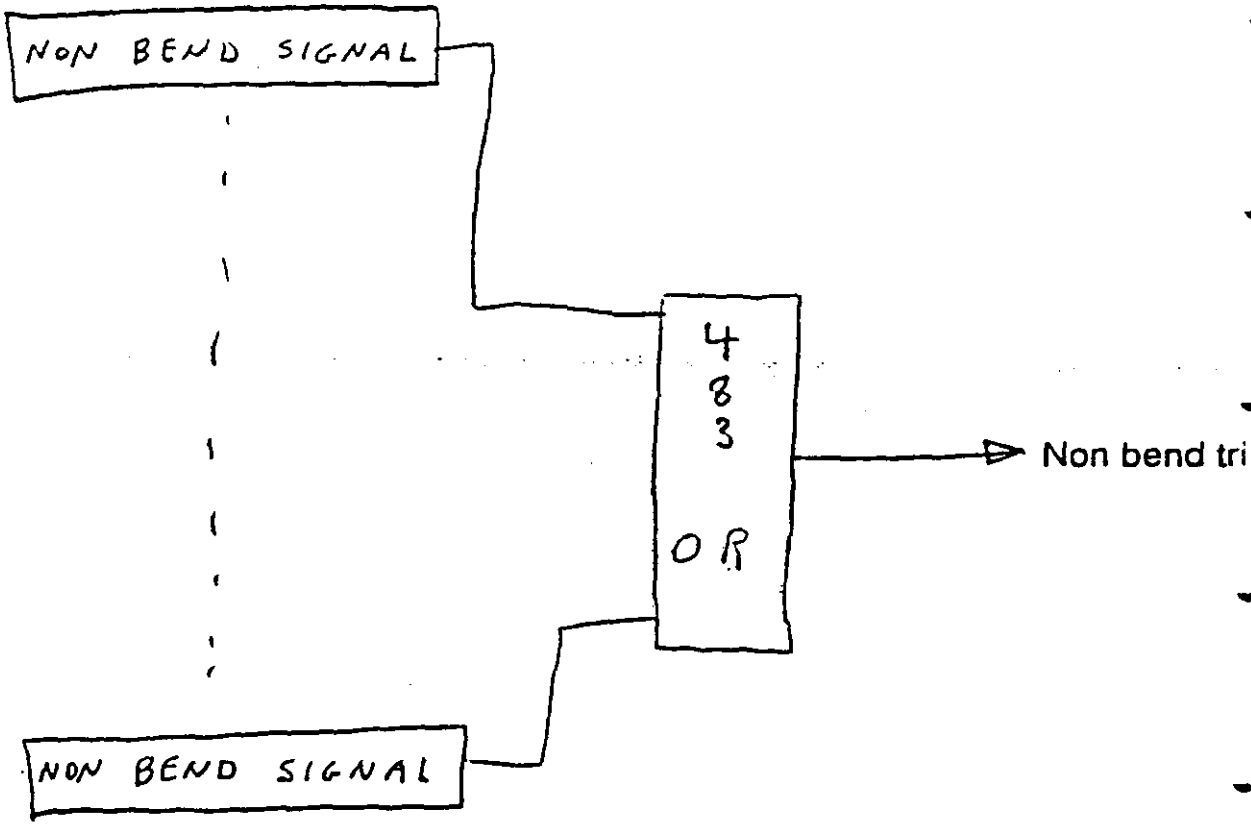
For each outer strip there are three coincidence circuits to account for multiple scattering.

This implies there are 3 x 161 = 483 circuits per sector. Each circuit is as follows:



$j = i-1,\ i,\ i+1$

NON BEND CIRCUIT



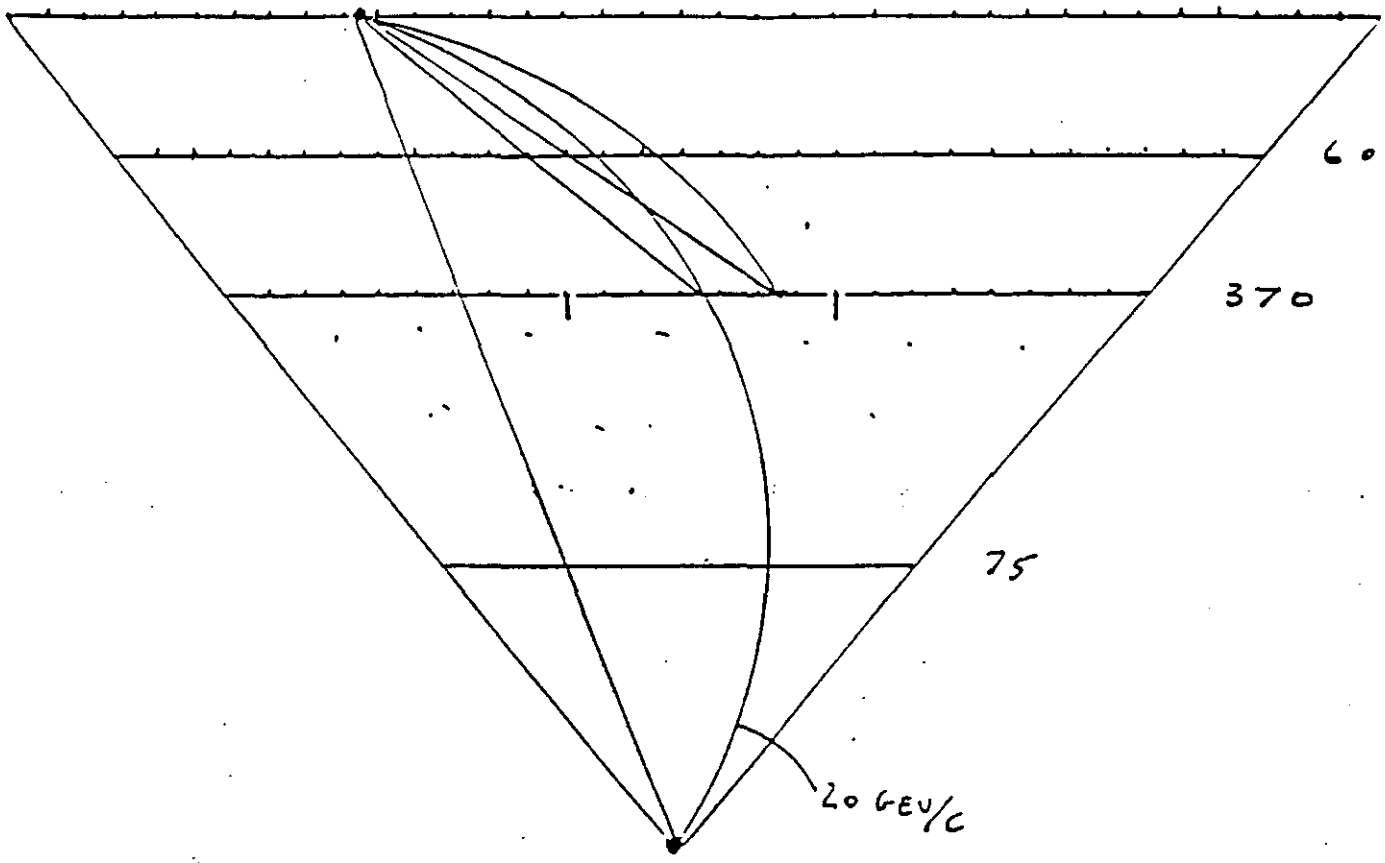
This has 100% acceptance for $P_t > 30$ GeV/c.

This has about 70% acceptance for $P_t = 10$ GeV/c

Acceptance falls rapidly for $P_t < 10$ GeV/c

We have	161 strips	4.1 cm (inr
	161 strips	9.0 cm (out
	805 strips	1.2 cm (cen

Hence a total of 1127 strips => 1127 discriminators per sector. Trigger box must accommodate 1127 connectors or about 2254 cm linear length.



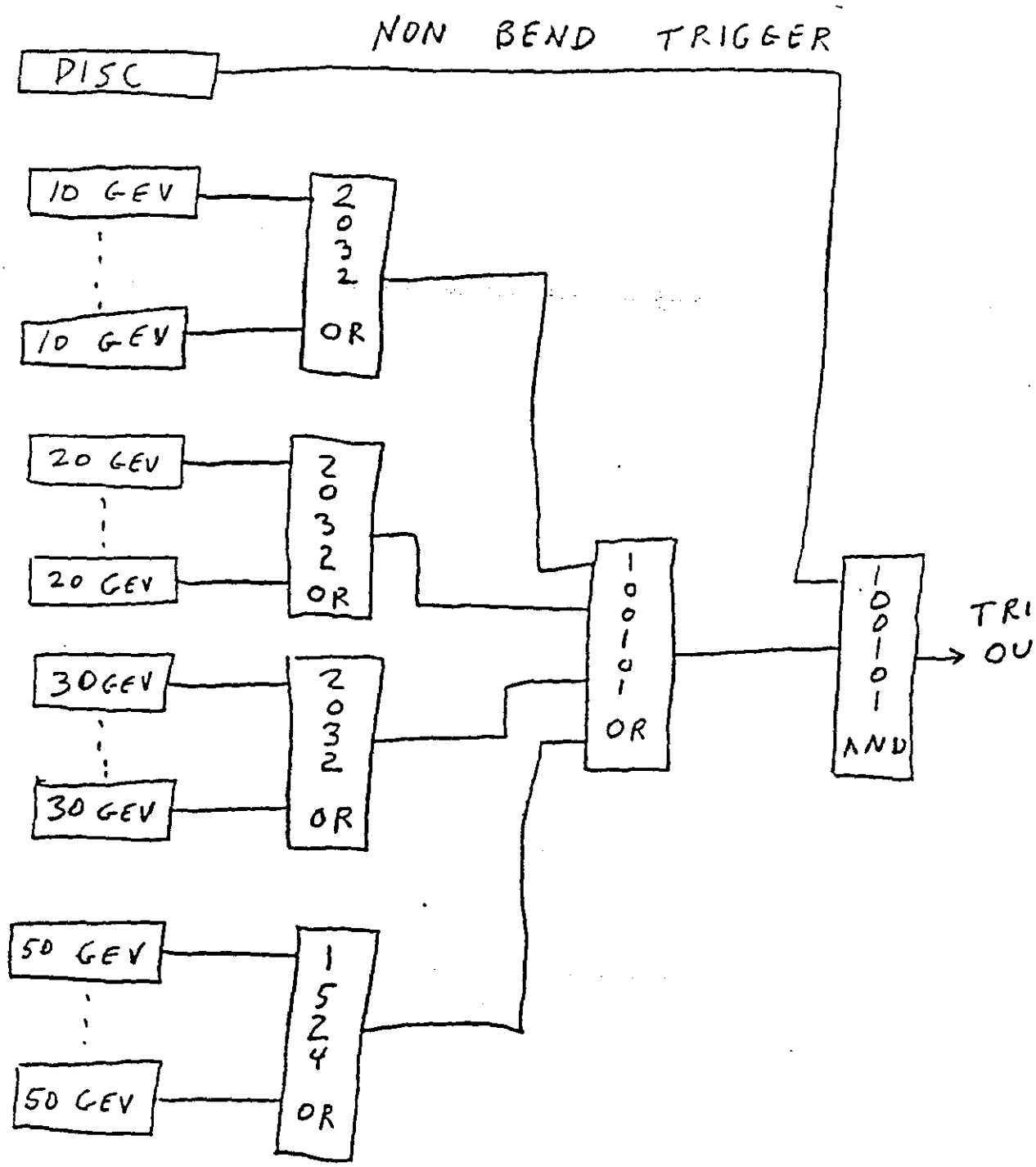
A 20 GeV/c track has a sigma of 2 strips around the ideal intersection point at R = 370 due to multiple scattering. In order to have a 95% acceptance we have to be able to handle ± 4 strips around the ideal (no multiple scattering) intersection point.

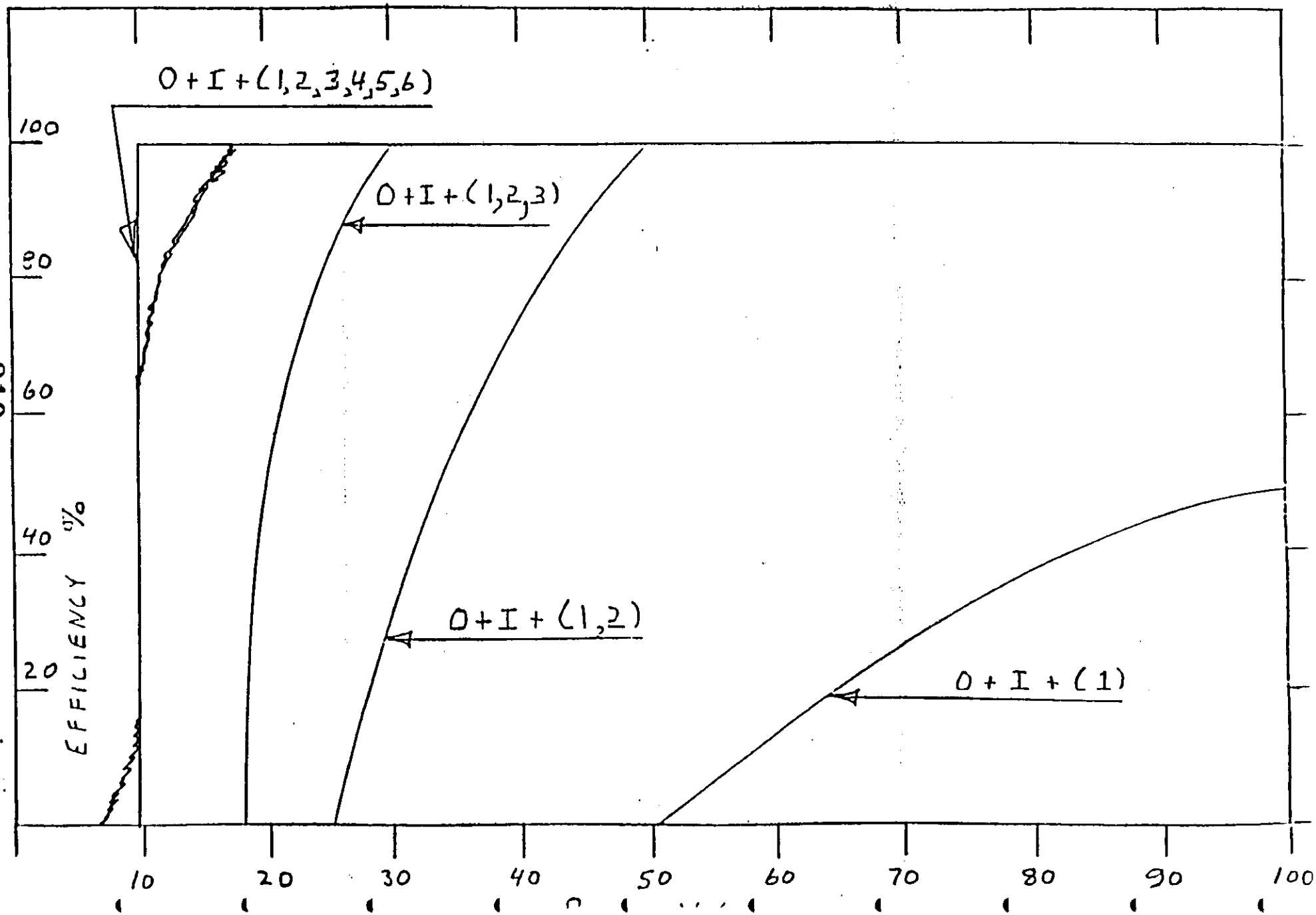
P	S R = 370	S R = 600	σ R = 370	# σ	# STRIPS/2 R = 370	# STRIPS R = 370	# STRIPS S = 600	# STRIPS S = 370
	CM	CM	CM					
10	20.5	6.4	5.0	1	4	8	5	15.8
20	10.2	3.2	2.5	2	4	8	4	7.8
30	6.8	2.1	1.7	3	4	8	3	5.2
40	5.1	1.6	1.3	3	4	8	3	3.9
50	4.1	1.3	1.0	3	3	6	2	3.2

† 30 AND 40 CANNOT BE SEPERATED

POSITIVE MUON

Trigger > 10 GeV




O + I + (1,2,3,4,5,6)
O + I + (1,2,3)
O + I + (1,2)
O + I + (1)
EFFICIENCY %
100
80
60
40
20
10
20
30
40
50
60
70
80
90
100

VII. SUMMARY

WE FIND THE FOLLOWING TRIGGER RATES FOR THE BARREL:

$P_t > 0$ GeV/c	1.3×10^6 HERTZ
$P_t > 10$ GeV/c	2,000 HERTZ
$P_t > 20$ GeV/c	400 HERTZ
$P_t > 30$ GeV/c	75 HERTZ

WE CONCLUDE THAT IN ORDER TO OPERATE AT A LUMINOSITY OF 10^{34} WE SHOULD HAVE FOUR TRIGGER LEVELS:

$P_t > 10$ GeV/c

$P_t > 20$ GeV/c

$P_t > 30$ GeV/c

$P_t > 50$ GeV/c

USING OUR PROPOSED WIRING GEOMETRY, WE HAVE THE POSSIBILITY AT THE FIRST LEVEL TRIGGER OF CALCULATING THE EVENT TIME TO THE LEVEL OF THE RISE TIME JITTER OF THE RPC. IF TH RPC RISE TIME JITTER IS LESS THAN 4 NANO-SECONDS, THEN THE BEAM CROSSING IS UNIQUELY IDENTIFIED AT THE FIRST LEVEL TRIGGEF

WE FIND WE CAN DO COINCIDENCES OF THE VARIOUS STRIPS WITH GATE WIDTHS OF 13, 9, AN 6.5 NANO-SECONDS. THIS WILL REDUCE SINGLE RANDOM NOISE HITS BY A FACTOR 7.

WE HAVE SHOWN A TRIGGER STRATEGY THAT CAN BE IMPLEMENTED IN FIXED HARDWARE OR BY USING ASSOCIATIVE MEMORIES. IT WILL TAKE MORE STUDY TO DETERMINE WHICH IS THE OPTIMA WAY TO GO FOR THE GEM DETECTOR.

Daniel Marlow
June 9, 1992

A Simple Circuit for Time-Deskewing in the GEM RPC's

Introduction

The baseline option for the barrel muon trigger system in GEM is the Resistive Plate Chamber (RPC). The good timing resolution ($\sigma_t \simeq 1-2$ ns) of these devices makes realtime bunch-cross tagging possible. This feature helps to simplify many other aspects of the trigger and DAQ system design. Practical complications arise, however, because of the large size of the GEM muon system, which produces considerable variations in arrival times and pulse transit times along the readout strips.

As an example, consider the simple sketch of Figure 1, which approximately corresponds to an outer-layer RPC in the GEM barrel. Muons leaving the vertex at right angles to the beam (trajectory A) travel about nine meters and reach the RPC after roughly 27 ns (to keep the numbers simple, we assume muon flight times 3 ns/m). Although the RPC avalanche develops quickly, the resulting current pulse must propagate to the readout electronics located at the end of the strip, as shown. The total delay is then $27+75 = 102$ ns. In constrast, muons leaving the vertex at the most forward angles (trajectory D) must travel $\sqrt{9^2+15^2} = 17.5$ meters, resulting in a pulse-arrival time of 53 ns. The 50 ns difference in arrival times corresponds to three bunch crossing intervals, which is unacceptable.

Possible Solutions

Perhaps the most straightforward way to address this problem would be to segment each strip in z into lengths short enough to reduce the time variations to less than 16 ns. In practice this would require segmenting the 15-meter-long strip shown into four pieces. Unfortunately, this simple expedient raises the channel count and the attendant electronics costs by a corresponding factor. Other schemes, where the z strips are used to dynamically generate time corrections, have also been proposed, but these are complex and involve 250 MHz logic.

Meantimers for Long Scintillators

A similar problem arises in the readout of long scintillators, where transit time variations produce significant timing jitter if only one PMT is used. However, the average time of arrival of pulses from a pair of phototubes arranged so as to view each end of a long scintillator (see top part of figure 2) is independent of the particle's impact position. In practice, the average arrival time can be generated in real time using either analog or digital circuits, called "meantimers" or "chronotrons". A classic digital approach employing tapped delay lines is shown in the lower portion of figure 2. If the total length of each delay line is chosen to be the same as the time required for light to propagate the length of the counter (ΔT), the output marked "MT" will fire after a fixed delay time ΔT, independent of the position of incidence. The spacing between taps is constant and the number of taps (and the number of AND gates) can be adjusted to give the desired resolution. A tap spacing of δt limits the single-measurement error to $\pm\delta t/2$.

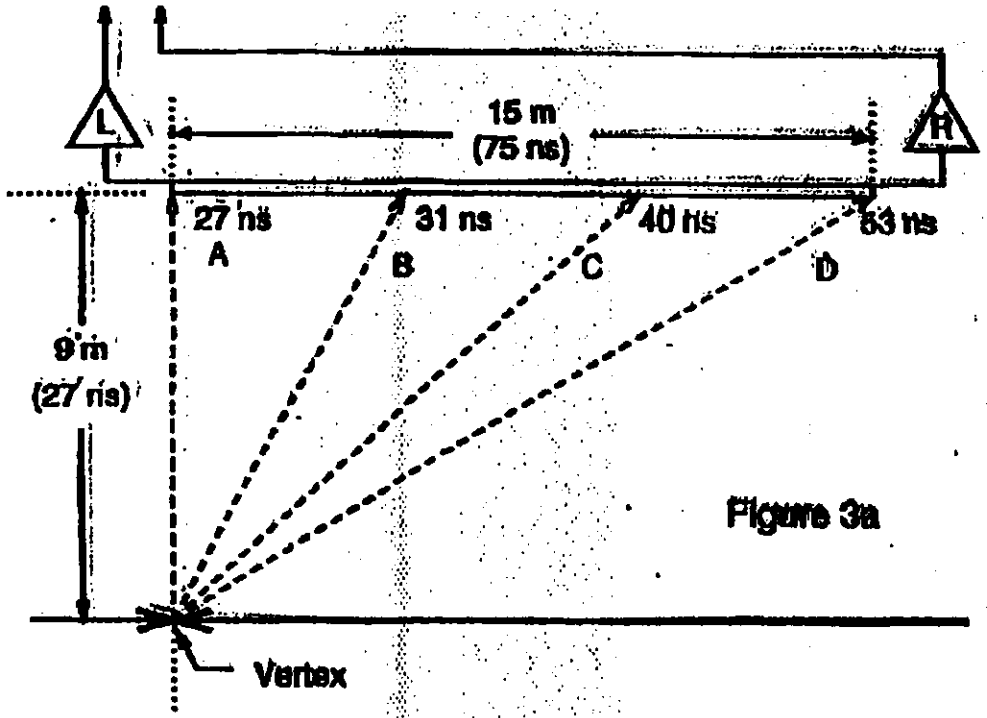


Figure 3a

Arrival Time in ns		
Case	T_L	T_R
A	27	102
B	56	81
C	90	65
D	128	53

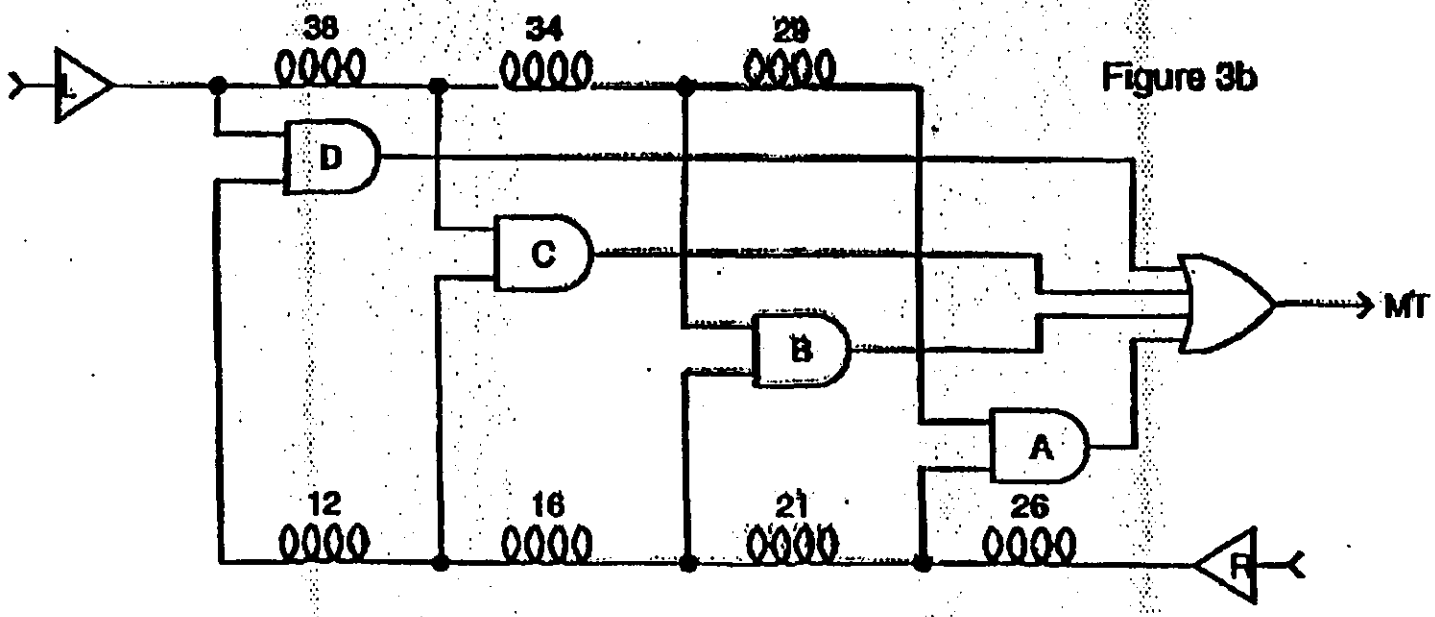


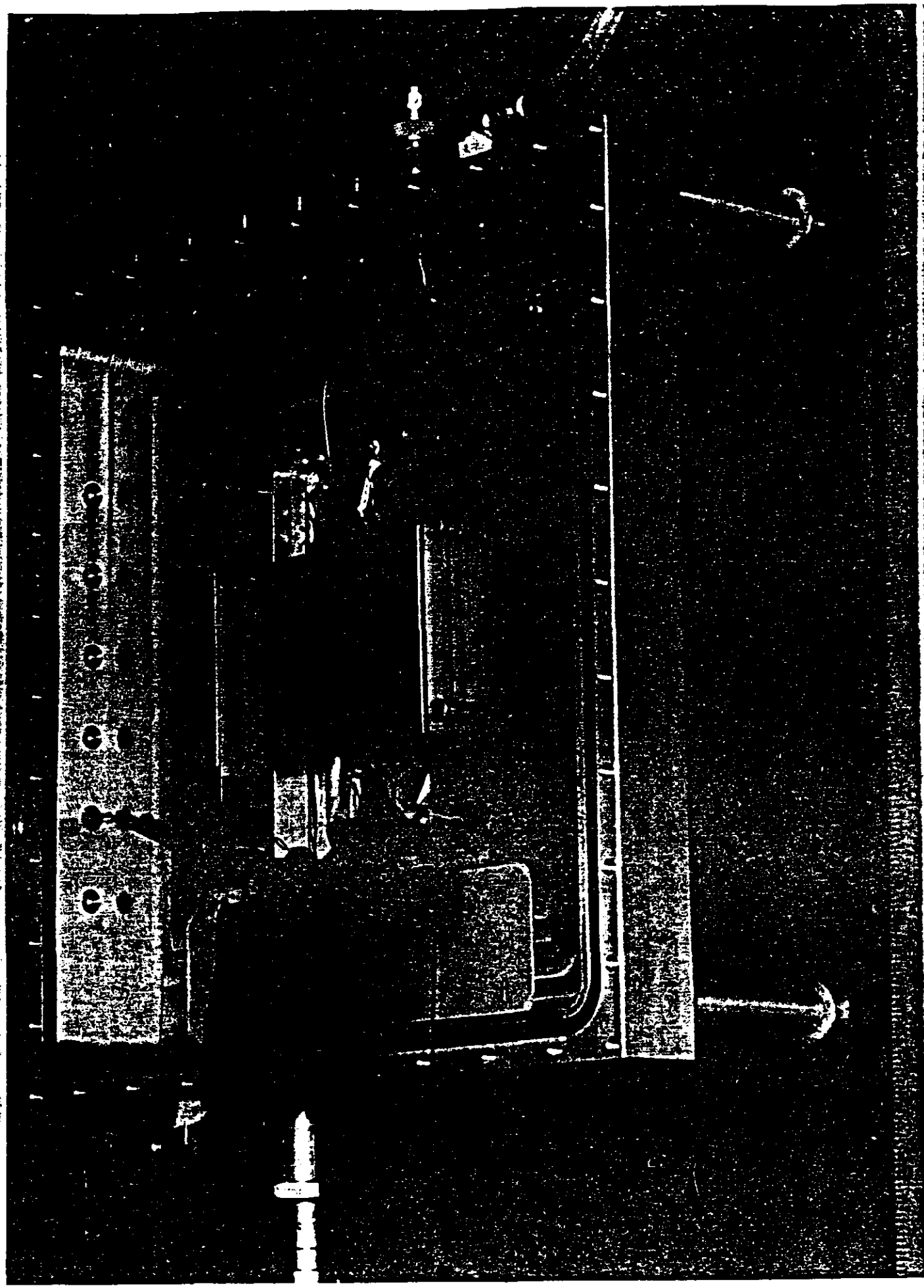
Figure 3b

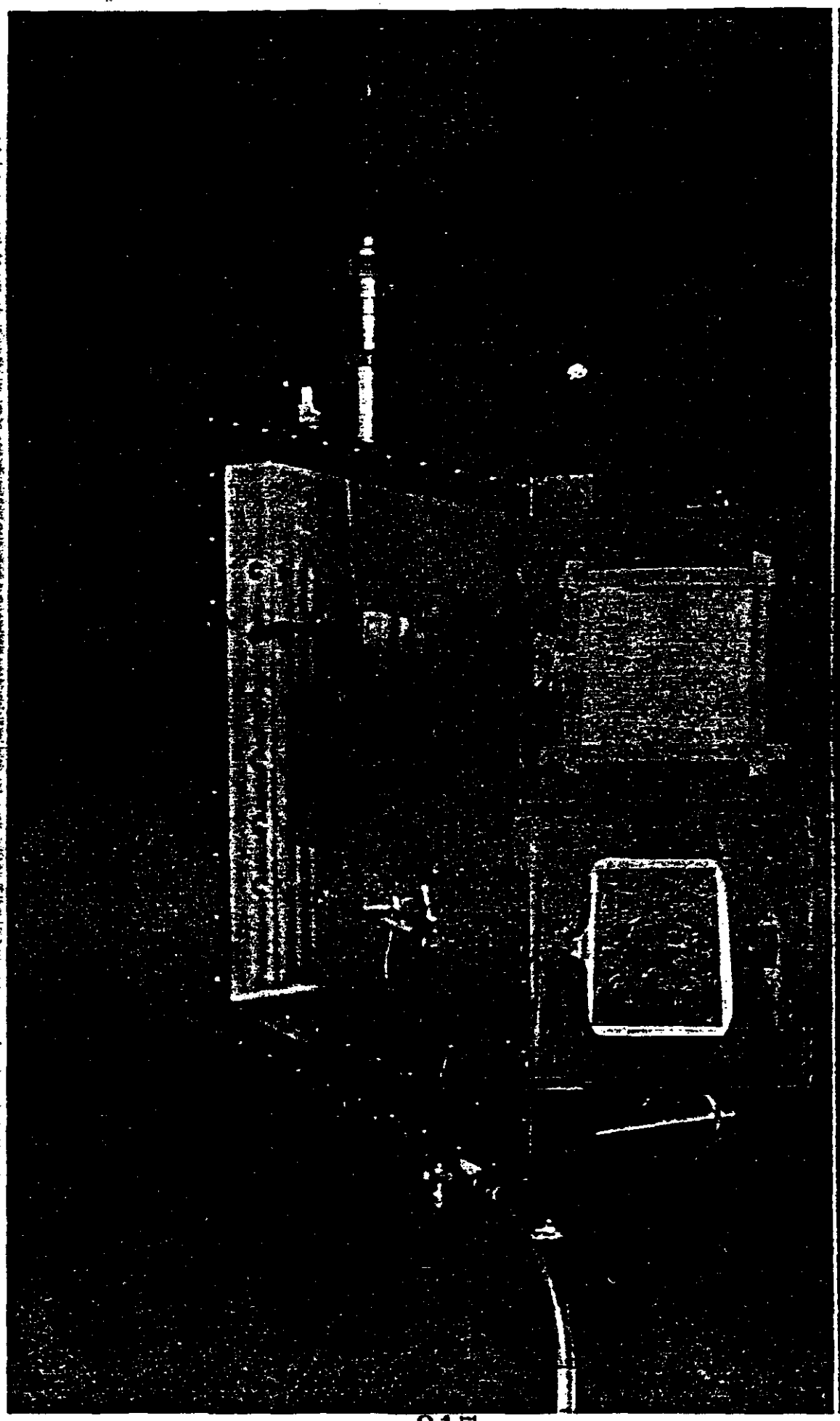
C. Wuest

High Rate RPC Materials

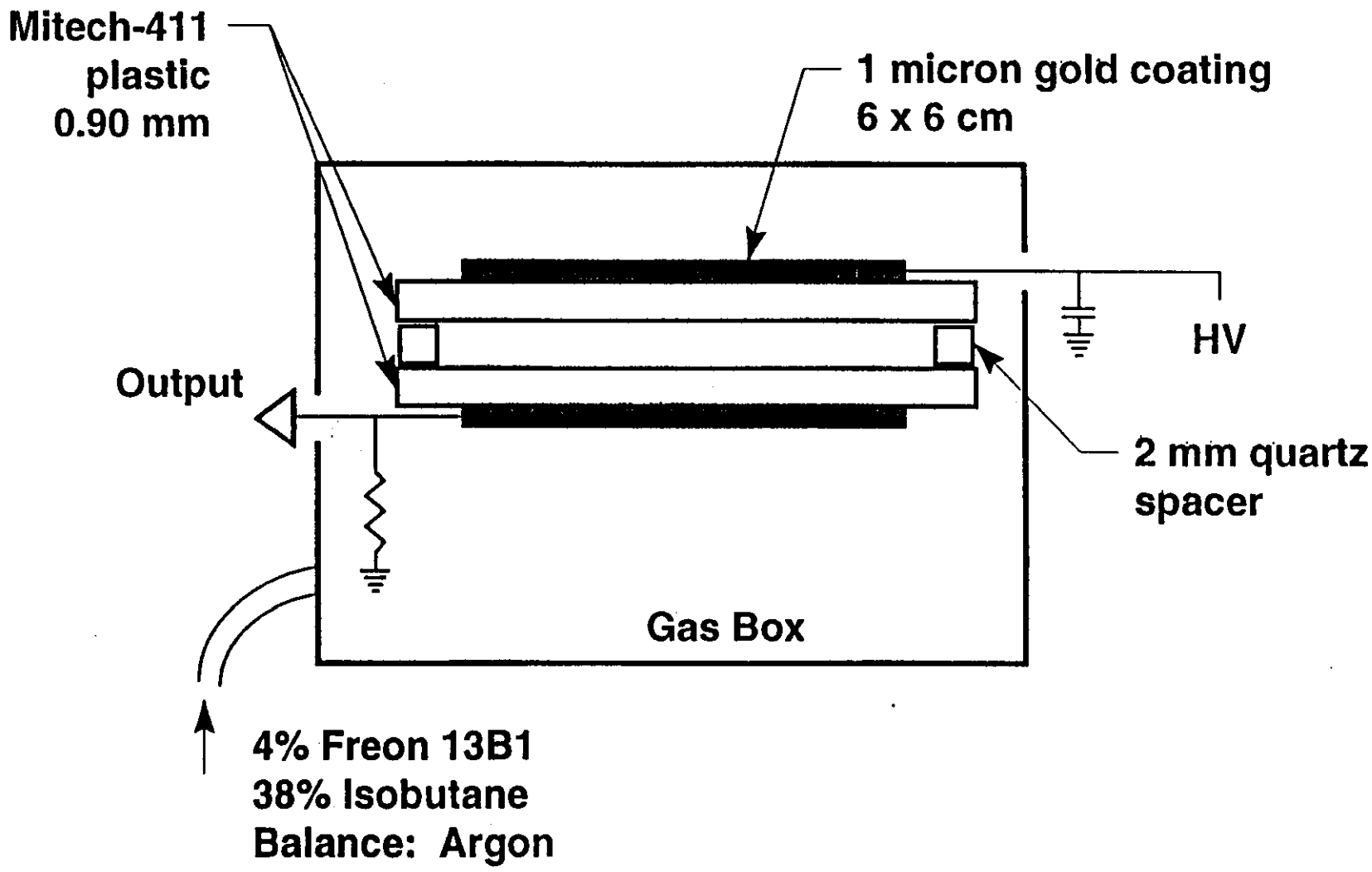
October 6-7, 1992

Presented by:
Richard M. Bionta
Lawrence Livermore
National Laboratories

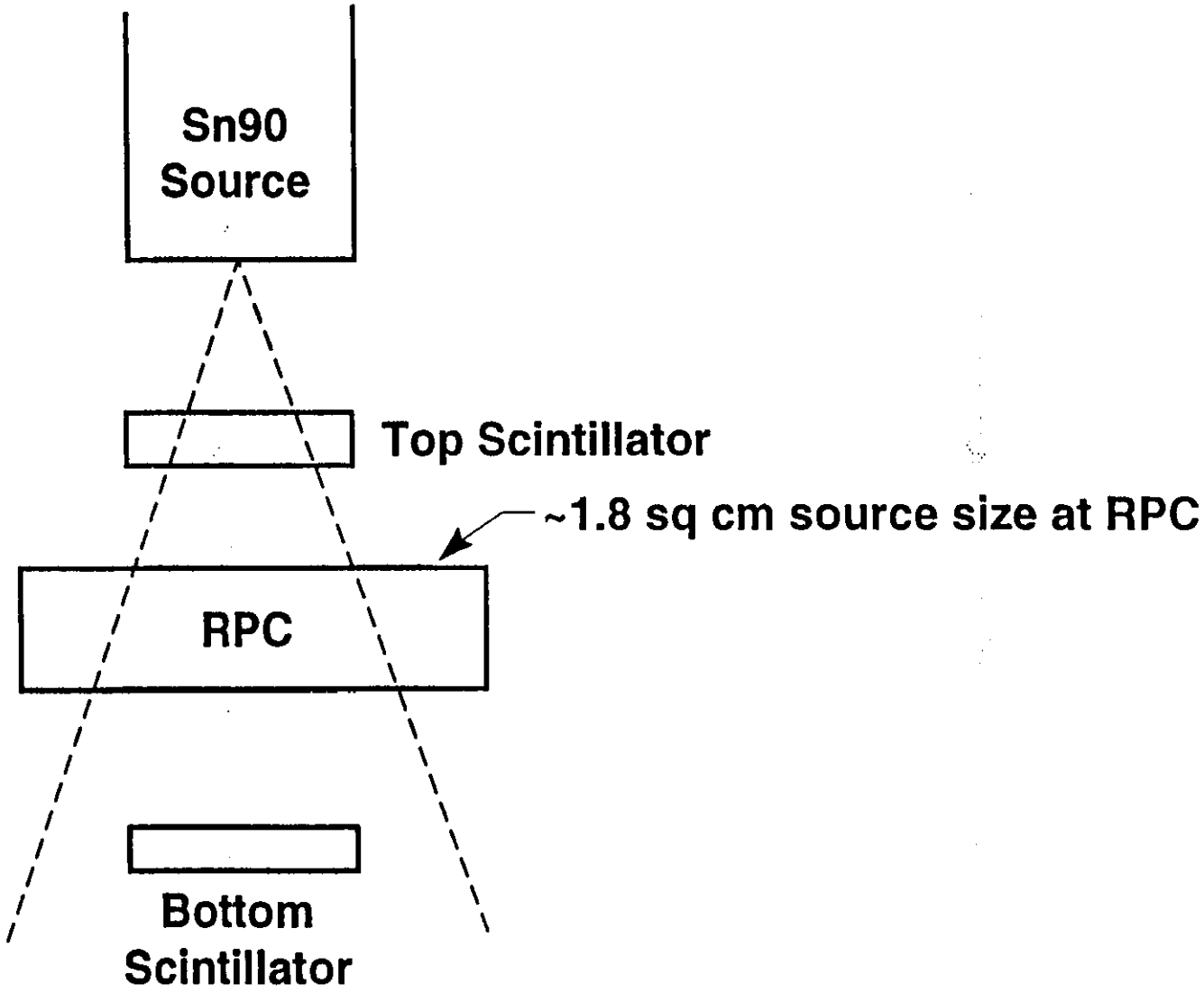




Materials Test Detector

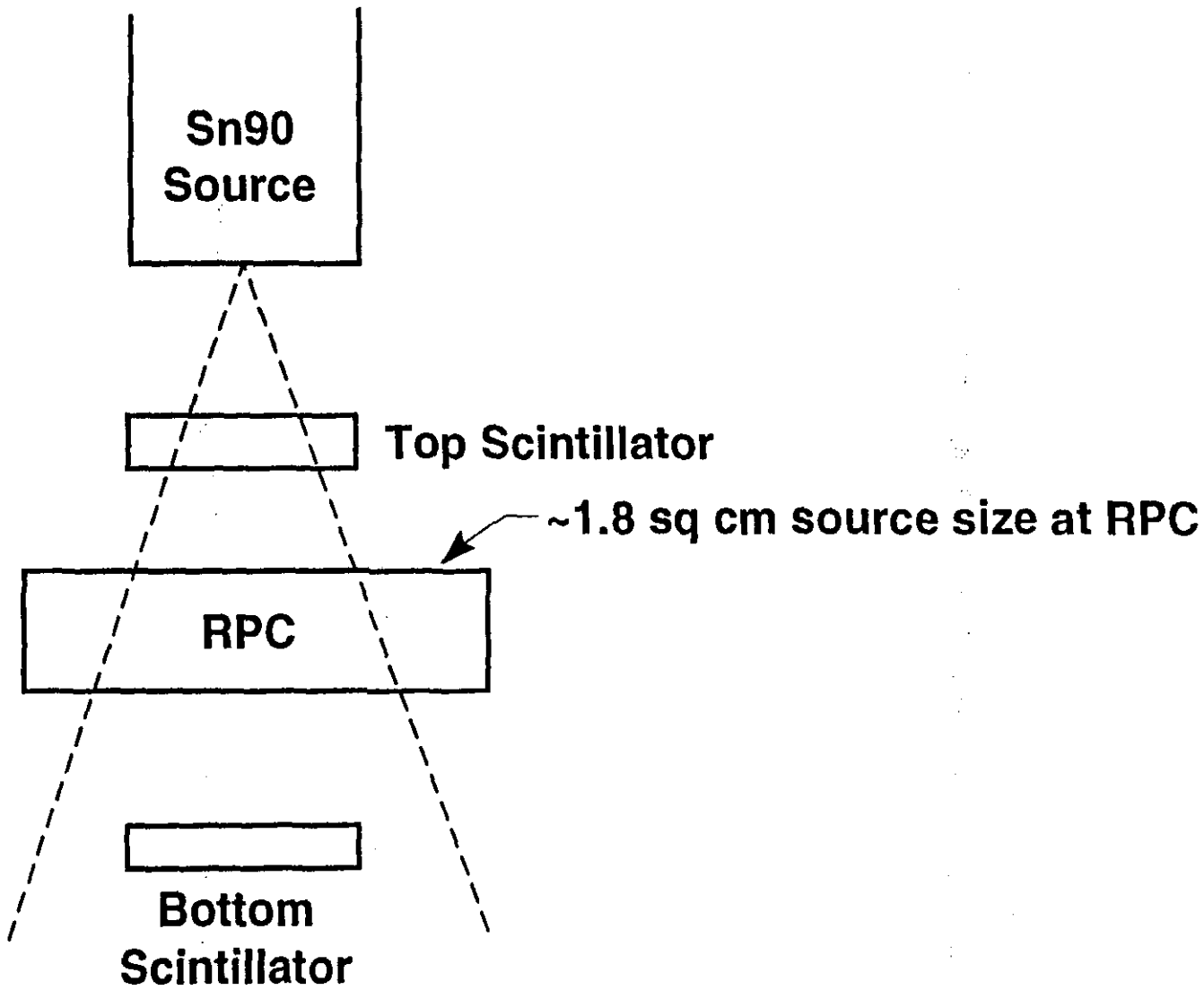


RPC Source Test



BAK.KA-02/RMB

RPC Source Test



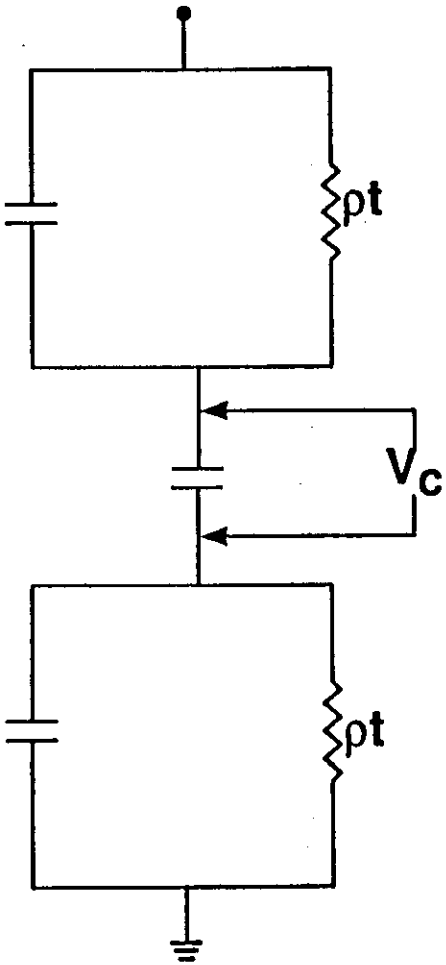
BAK.KA-02/RMB

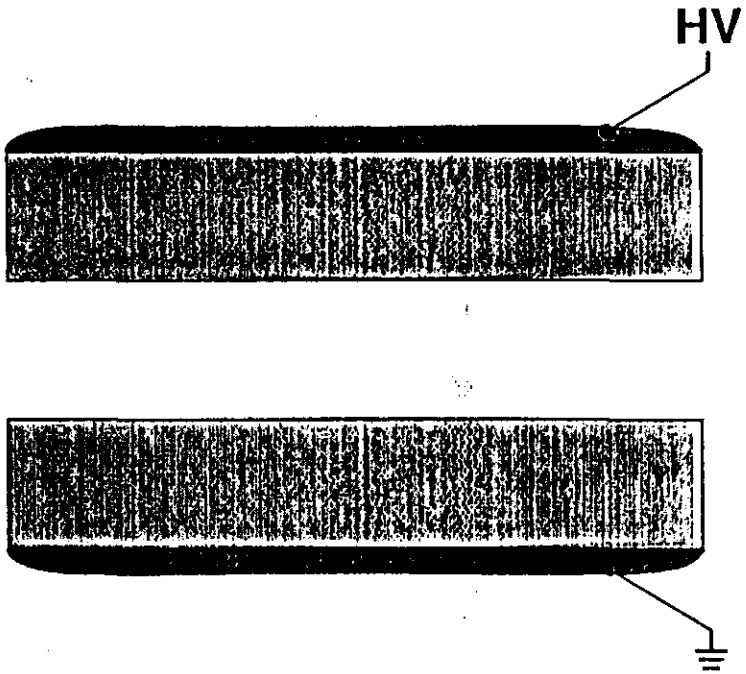
RPC Candidate Material

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}

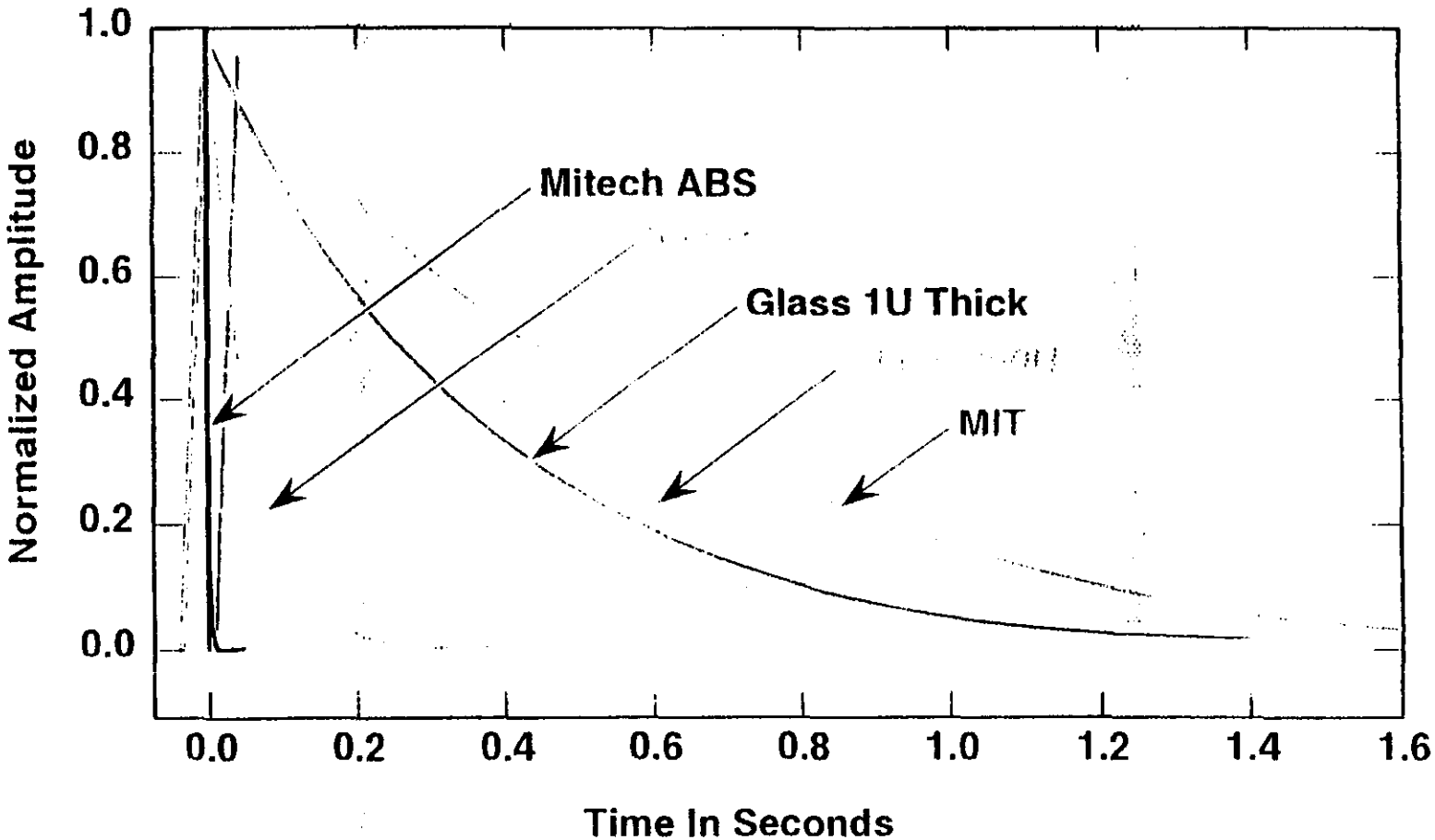
OAK KA-14/BMB

Spice RPC Model

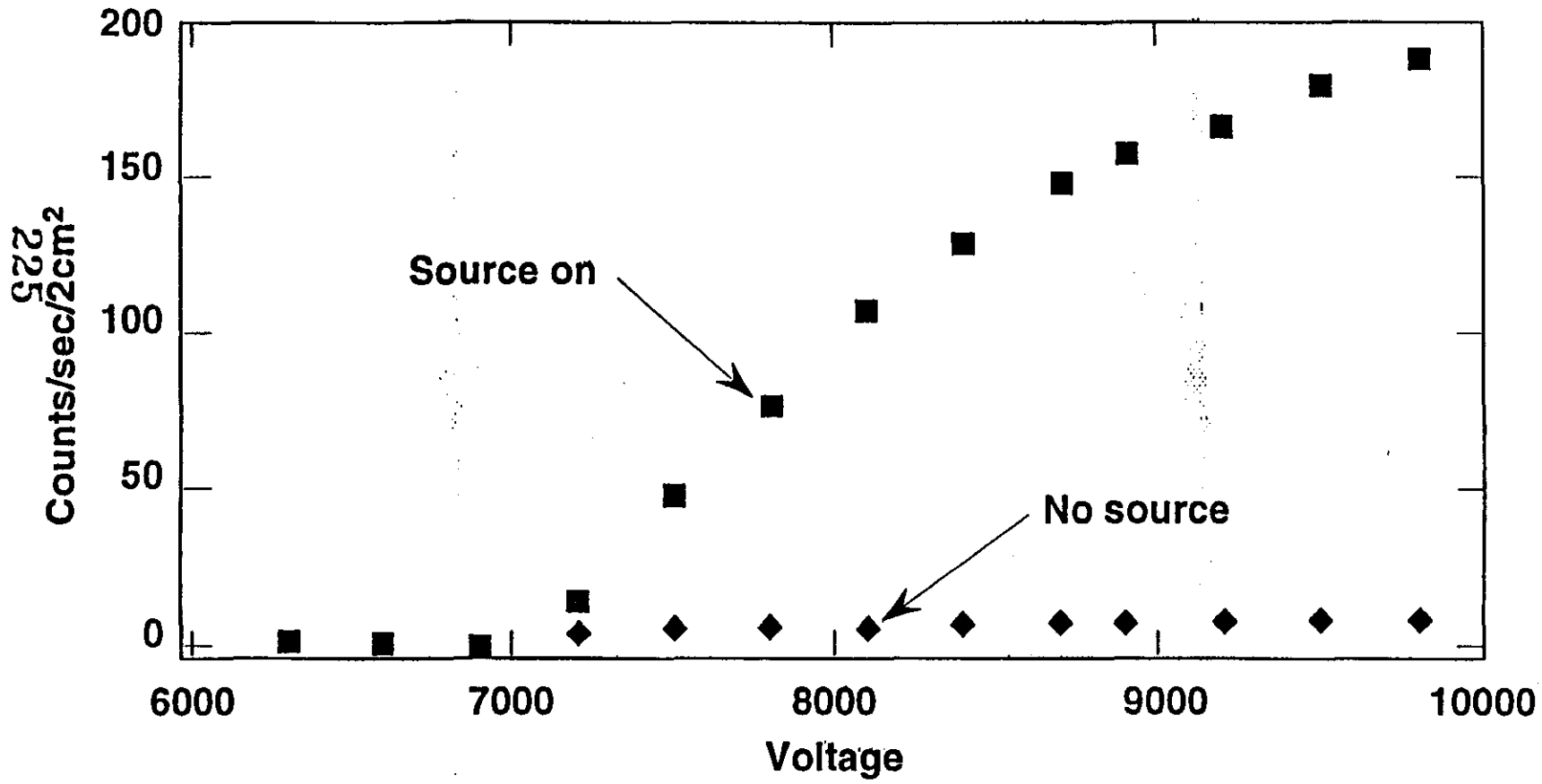




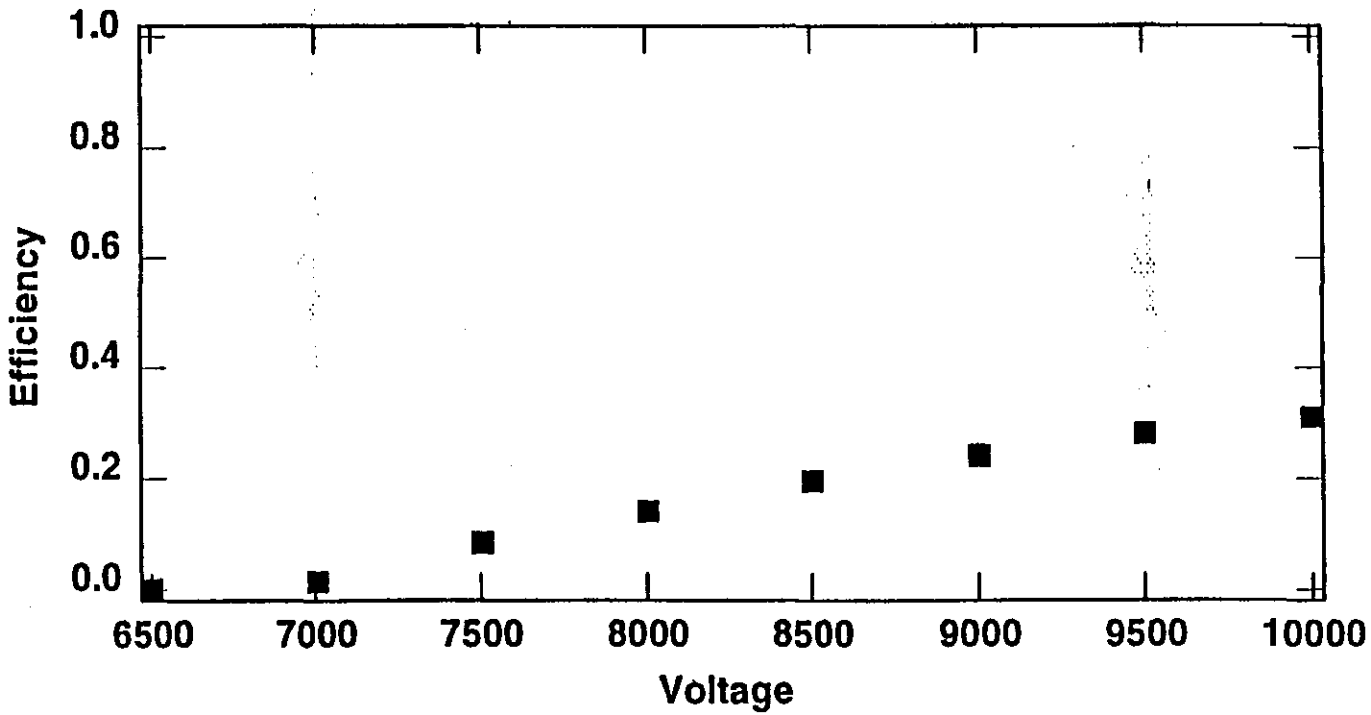
Spice Calculations of Recharge



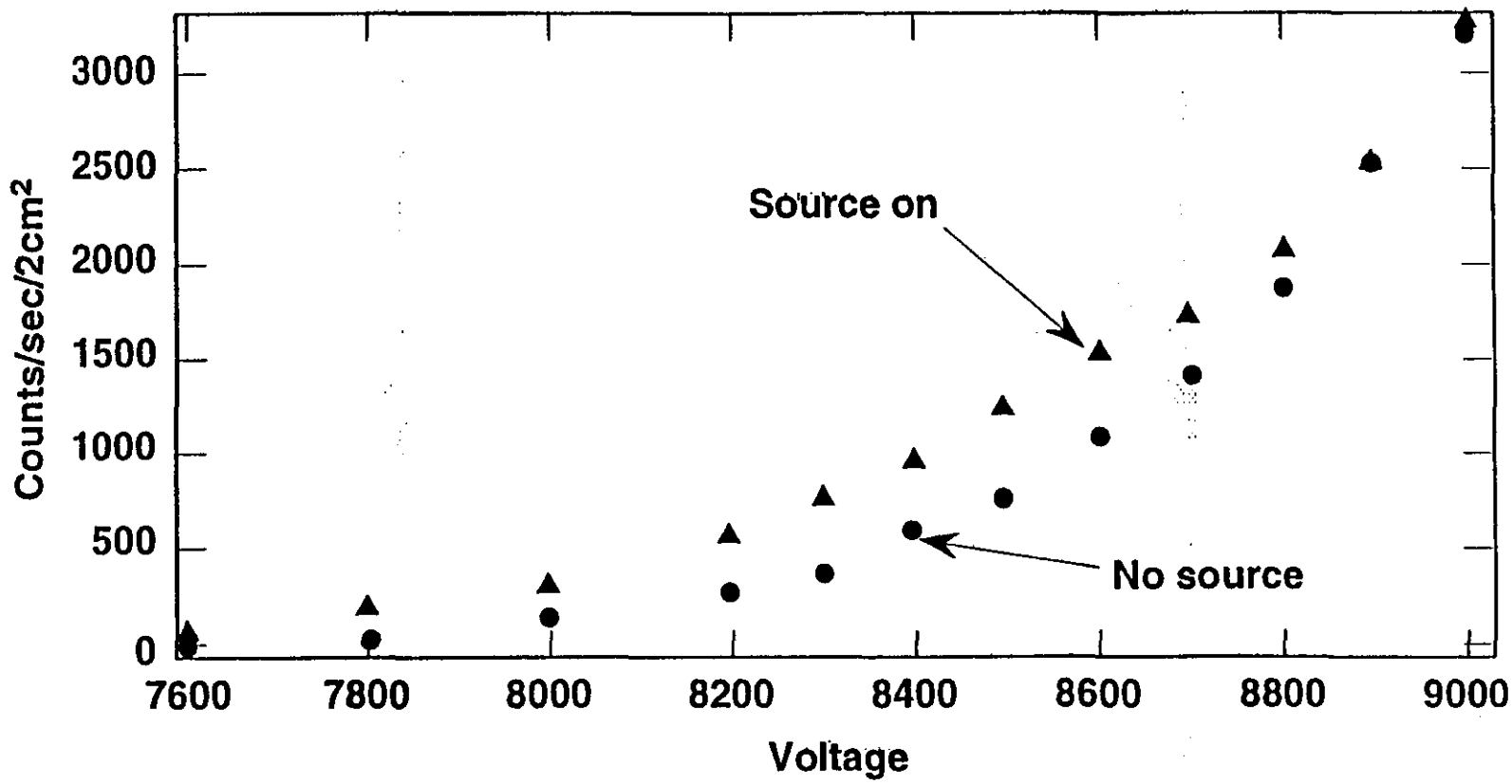
750 Micron Mirror Glass Detector Singles



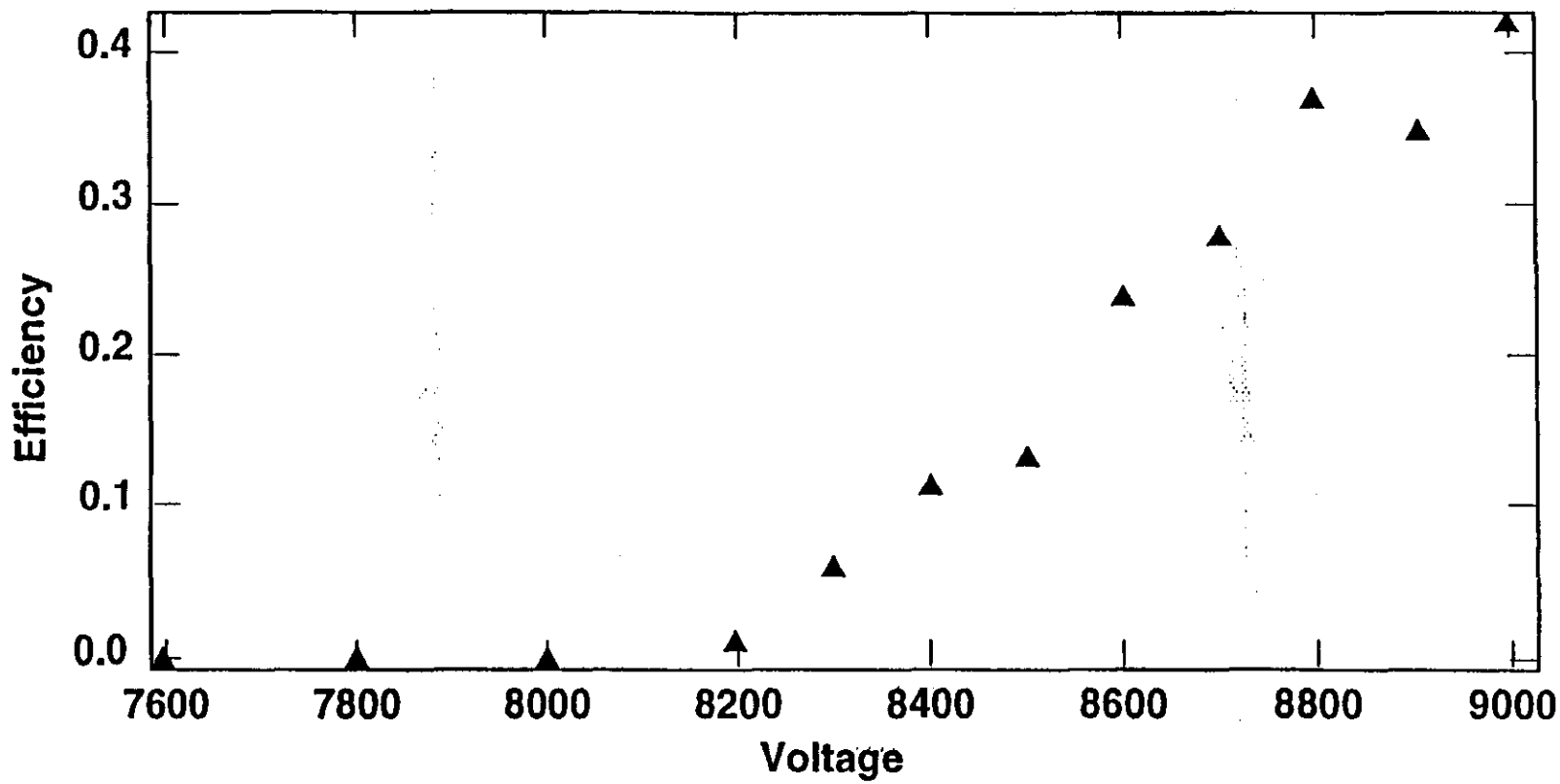
750 Micron Mirror Glass Plateau



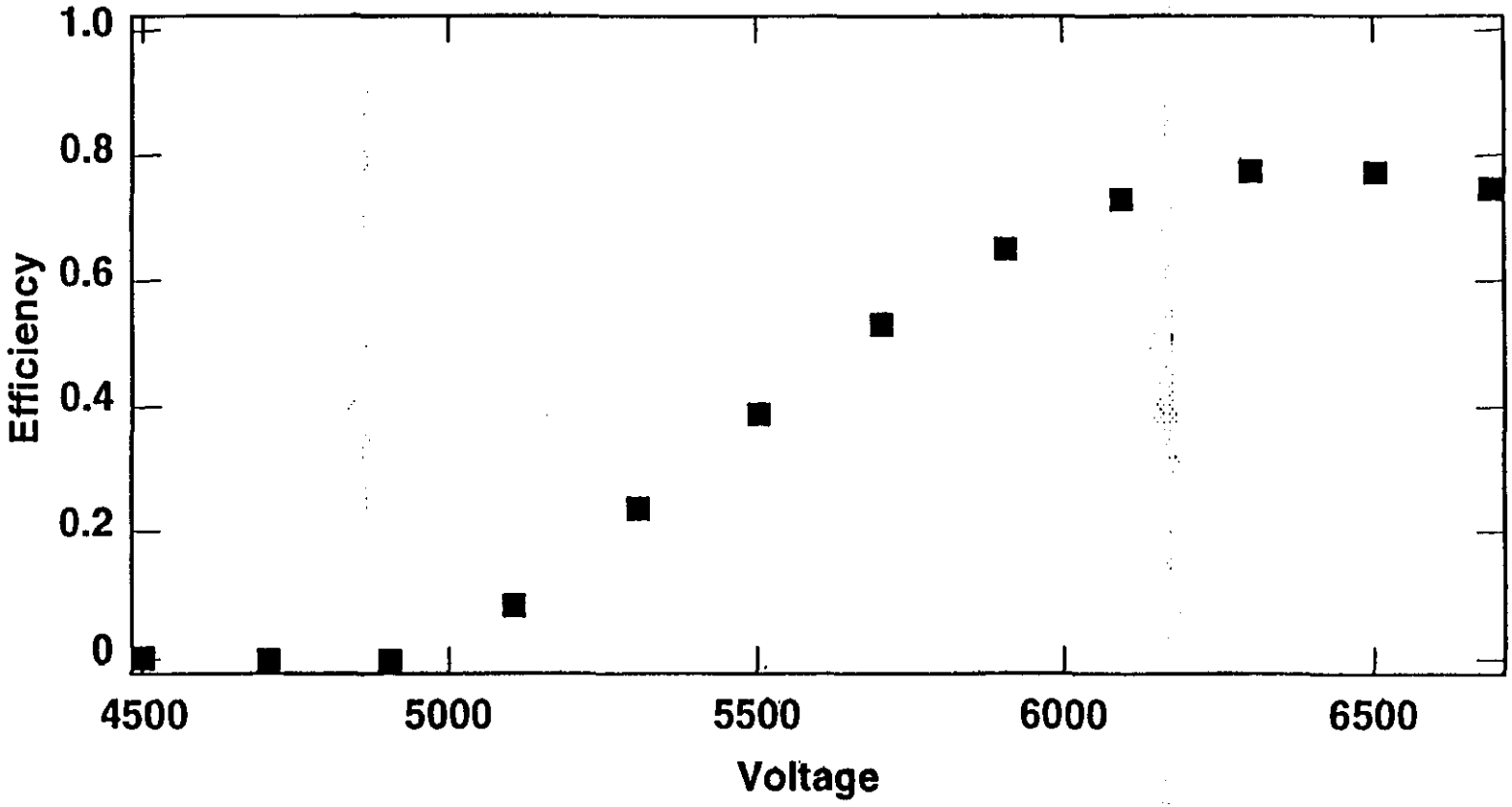
Bakelite/linseed Oil Detector Singles

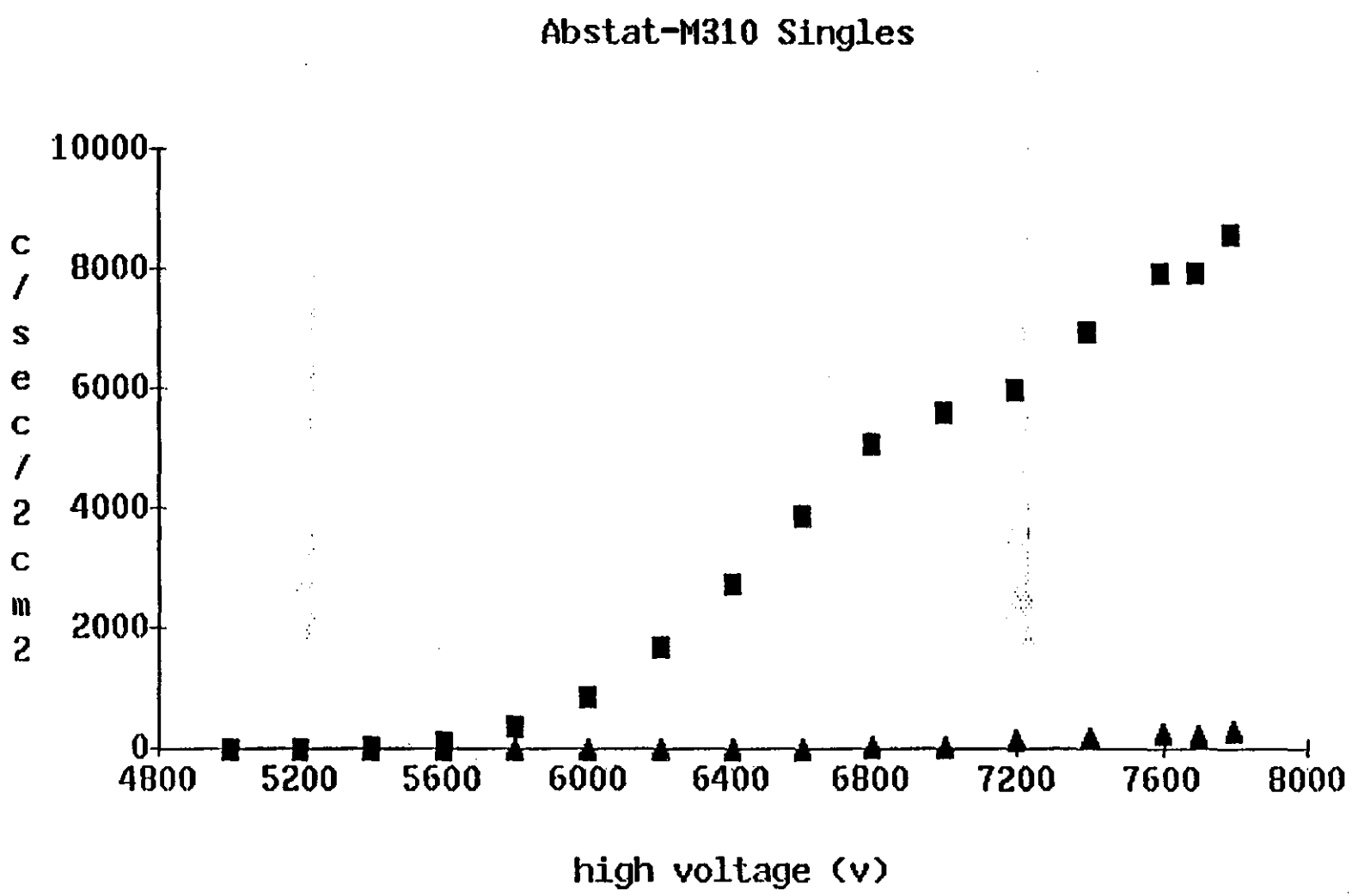


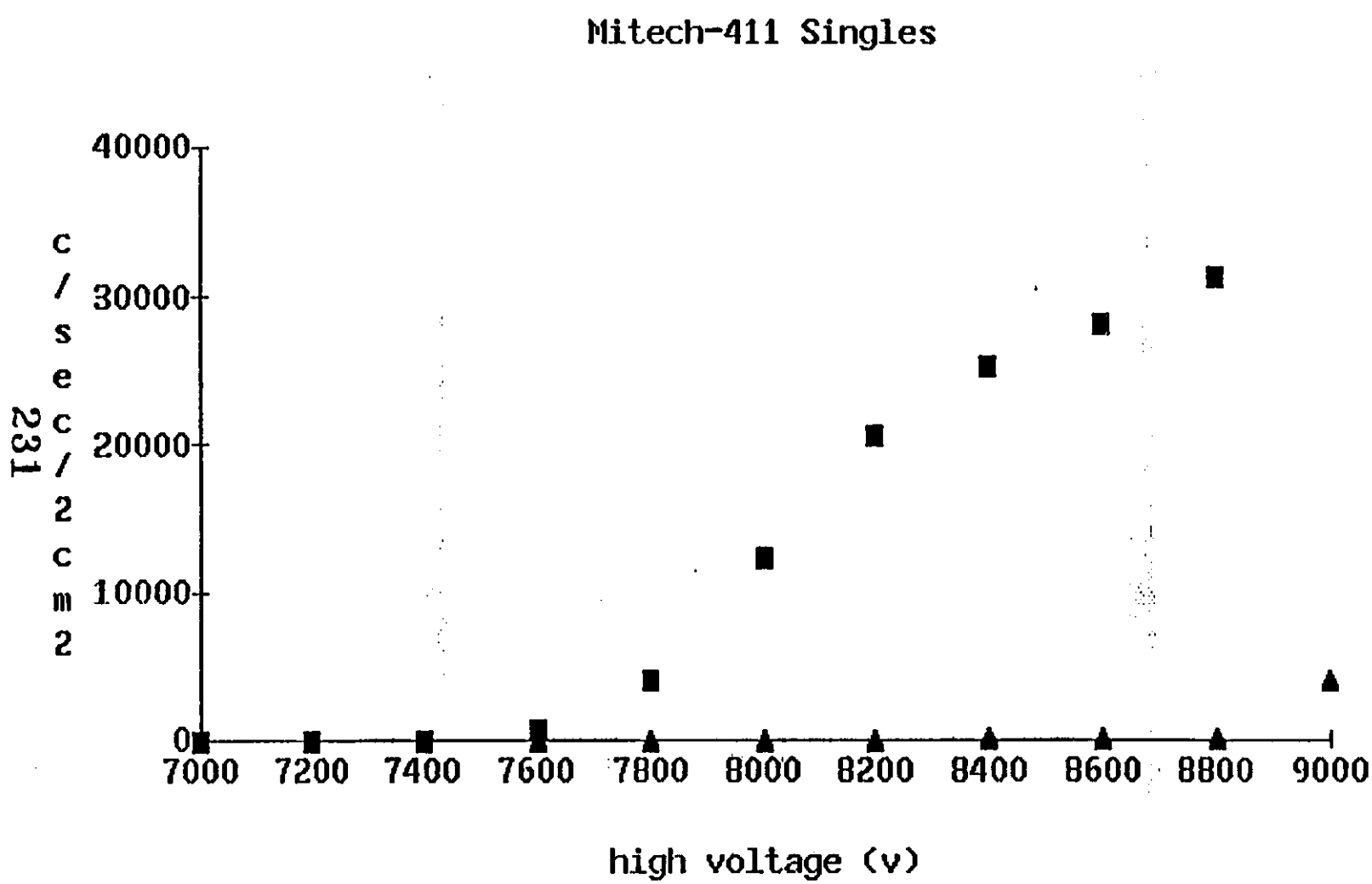
Bakelite/Linseed Oil Detector Plateau



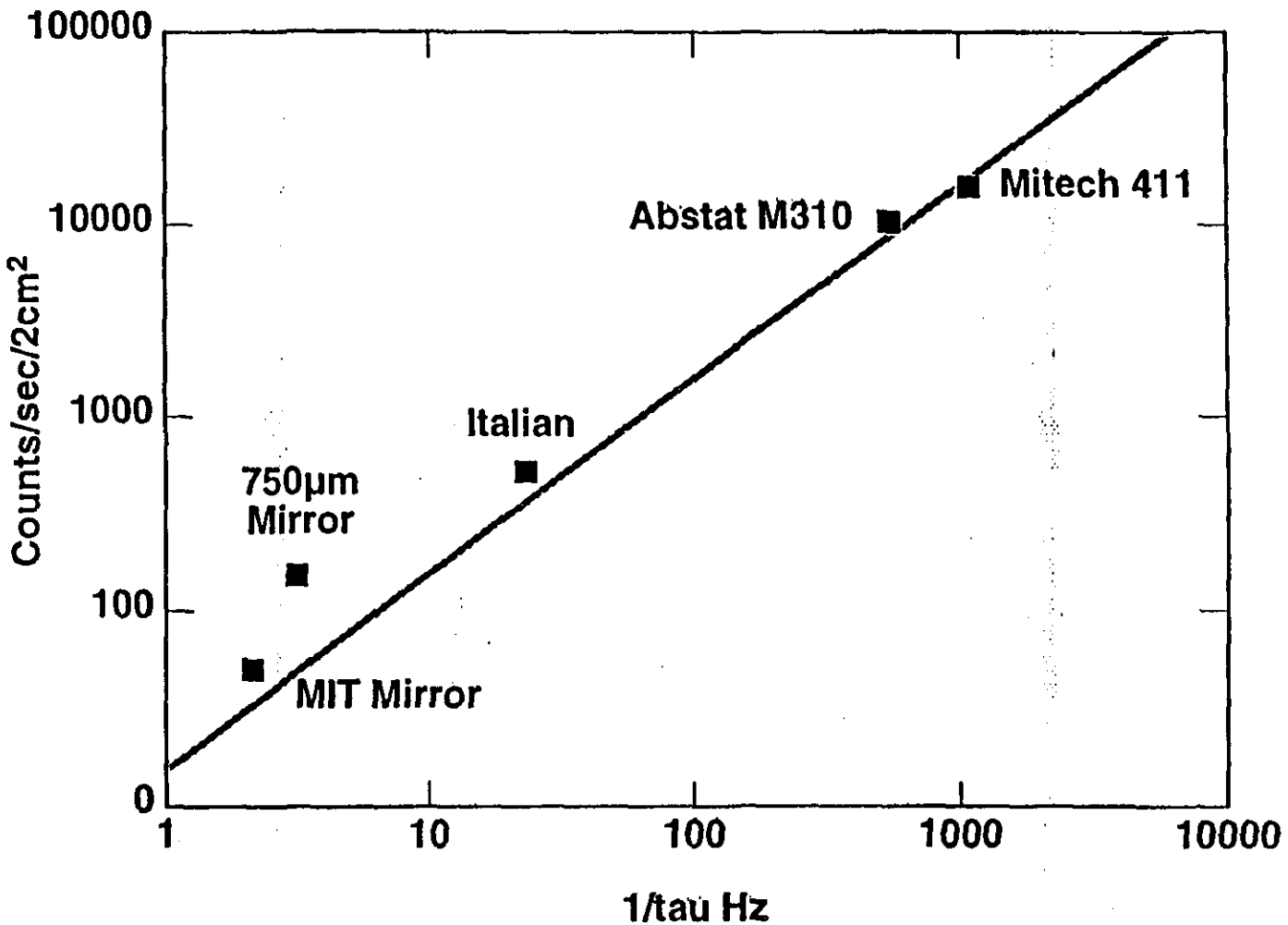
ABSTAT–M310 Lucite Frame Second Build Plateau




Abstat-M310 Singles
c/sec/2cm2
10000
8000
6000
4000
2000
0
4800
5200
5600
6000
6400
6800
7200
7600
8000
high voltage (v)


Mitech-411 Singles
c/sec/2cm2
40000
30000
20000
10000
0
7000
7200
7400
7600
7800
8000
8200
8400
8600
8800
9000
high voltage (v)

Saturated Singles Rate vs SPICE 1/tau



BAK.KA-17/RMB

Conclusions

- SPICE model can be used to predict rate handling capability of candidate RPC materials
- RPC performance depends mainly on bulk resistivity
- RPC's built of ABSTAT M310 will be an excellent choice for GEM offering an order of magnitude improvement in rate handling capability and ease of fabrication
- Large multi-channel M310 RPC to be built in FY93'
- Precision measurements of efficiency vs. rate will require test beam time

Engineering Assessment Report

Rick Sawicki

Rich Sawicki

Mechanical Engineering Evaluation of the Muon Chamber Technology Options

237

October 6, 1992

Scope

- From a mechanical engineering perspective, review all four barrel muon technology options
  - cathode strip chambers
  - limited streamer drift tubes
  - pressurized drift tubes
  - resistive plate chambers
- Compile as detailed information as is available on all aspects of the design
- Compare relative strengths of each design
- Identify issues and concerns

Review process

- Charter established on Sept 1, 1992
  - M. Gamble
  - R. Humphreys
  - C. Johnson
  - F. Nimblett
  - R. Sawicki, chairperson

- Convened four oral reviews with Technology leaders
  - CSC - V. Polychronakis
  - LSDT - L. Osborne
  - PDT - Carl Bromberg
  - RPC - C. Wuest

- Each technology leader submitted a written summary which is contained in appendix of report
  - CSC report received too late for review and comment
    - -- CSC vugraphs included in appendix

- Evaluation of each technology written by a single panel member but reviewed and approved by the panel as a whole

Review topics

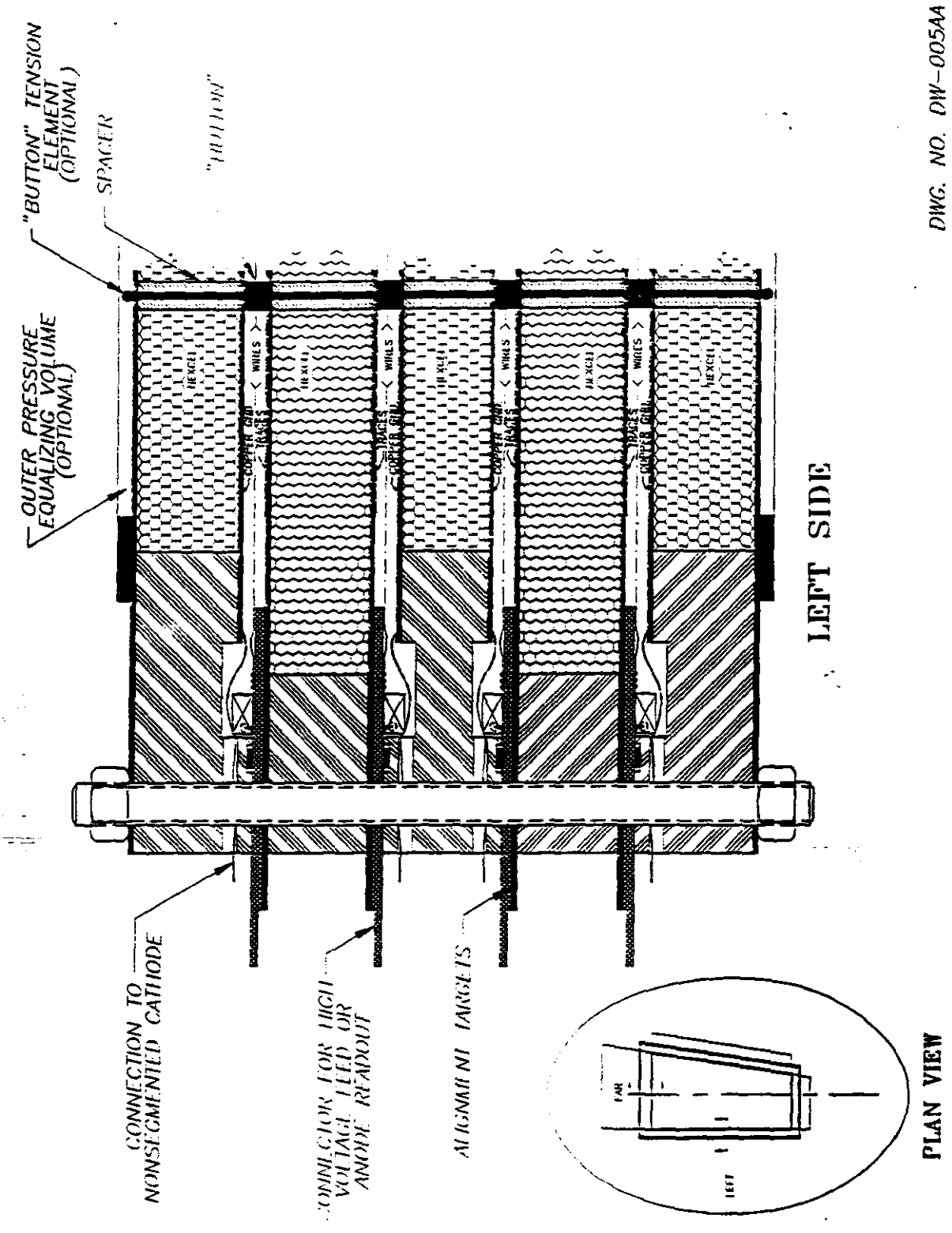
- Design
  - general design concept
  - weight
  - wire or strip support
  - gas systems
  - chamber structure
  - impact on truss structure design
  - superlayer configuration
  - electronic packaging requirements
  - size limitations
  - utility routing
  - failure tolerance
- Manufacture/assembly
  - approach/philosophy
  - component fabrication
  - precision requirements
  - development requirements
  - vendor availability
  - assembly procedures
  - fixturing requirements
- Alignment
  - internal - wire/wire,plane/plane
  - external - superlayer/superlayer
  - fiducialization
- Structural
  - stiffness requirements
  - dimensional stability
- Coverage
  - acceptance - phi and theta
  - phi overlap potential
- Cost
  - assumptions
  - equipment, material and labor
  - cost uncertainties
- Schedule
  - long lead components
  - component fabrication time
  - assembly time
  - installation time
  - first availability

CSC design concept

- Each chamber consists of a four gap stackup of
  - G10 cathode planes
  - honeycomb stiffening panels
  - glass filled polyester edge frame
  - spacers
  - clamping bolts
  - wire anode planes

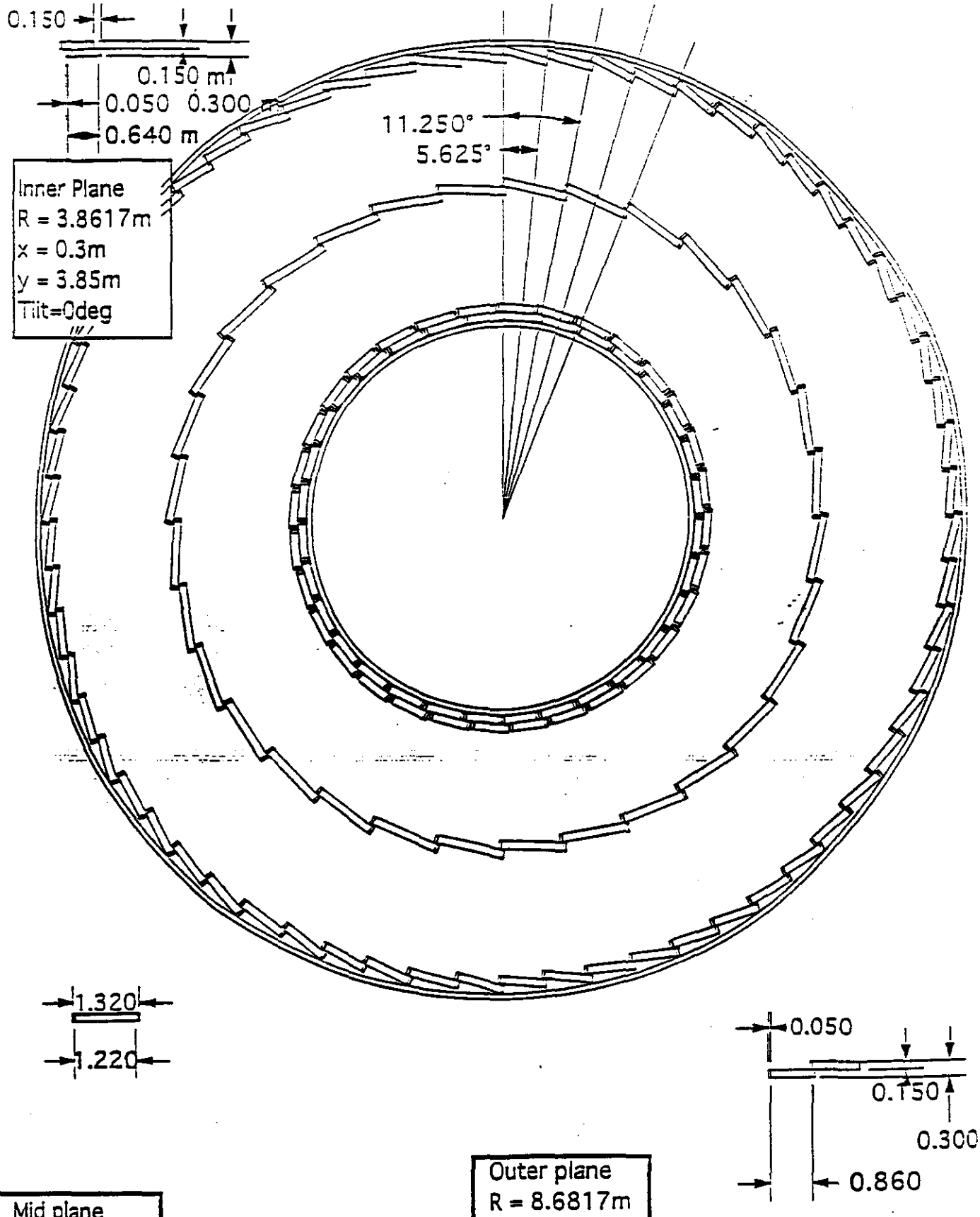
- Superlayer composition
  - outer layer -- 4 chambers (coupled in pairs, phi direction), 4 chambers lengthwise
  - middle layer - 2 chambers (phi), 4 chambers lengthwise
  - inner layer - 2 layer stack of 4 chambers (phi), 2 chambers lengthwise

- Sector (1/16) composition
  - 8-4-4 sense layers configuration
  - 32 chamber per sector
  - 8 towers per sector



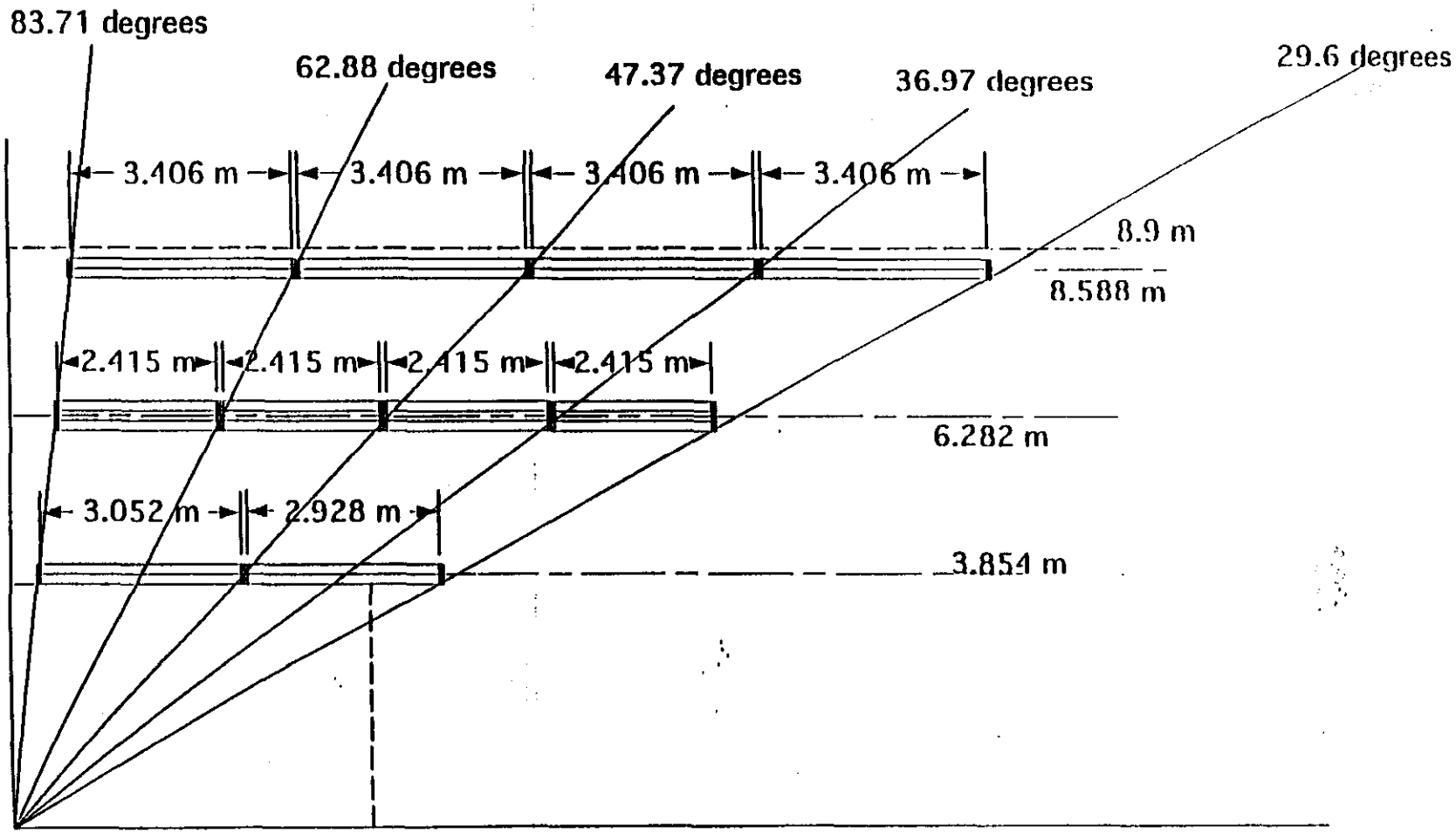
DWG. NO. DW-005AA

Fig. 2.11 An alternative CSC design concept


0.150
0.150 m
0.050
0.300 m
0.640 m
11.250°
5.625°
Inner Plane
R = 3.8617m
x = 0.3m
y = 3.85m
Tilt=0deg
1.320
1.220
0.050
0.150
0.300
0.860
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
CSCg1Barrel
32 segments

CSCf2crzBarrellayout

Lengths of active areas



CSC alignment requirements

Strip-to-strip placement accuracy	50 microns
Strip parallelism (layer to layer)	50 microns
Strip flatness over 1 meter length	50 microns
Wire to strip placement accuracy	50 microns
Knowledge of strip sag	100 microns

CSC alignment strategy

- Strip to strip tolerances are controlled by photolithographic mask
  - commercial vendors have been approached and believe tolerances can be achieved without any process development effort

- Cathode flatness is established by precision of vacuum platen during bonding of G10 to Hexcel panel
  - platen accuracy is achievable
  - results should be highly reproducable

- Strip parallelism is maintained by precision spacers

- Wire to strip placement accuracy is achieved by straightness of edge frame and precision of spacers
  - edge frame precision not yet demonstrated in full lengths
  - machining may be required
  - stackup of tolerances not presented

- Knowledge of sag (lengthwise) of cathode planes may require real time measurement if sag exceeds 100 microns
  - detailed calculations need to be performed

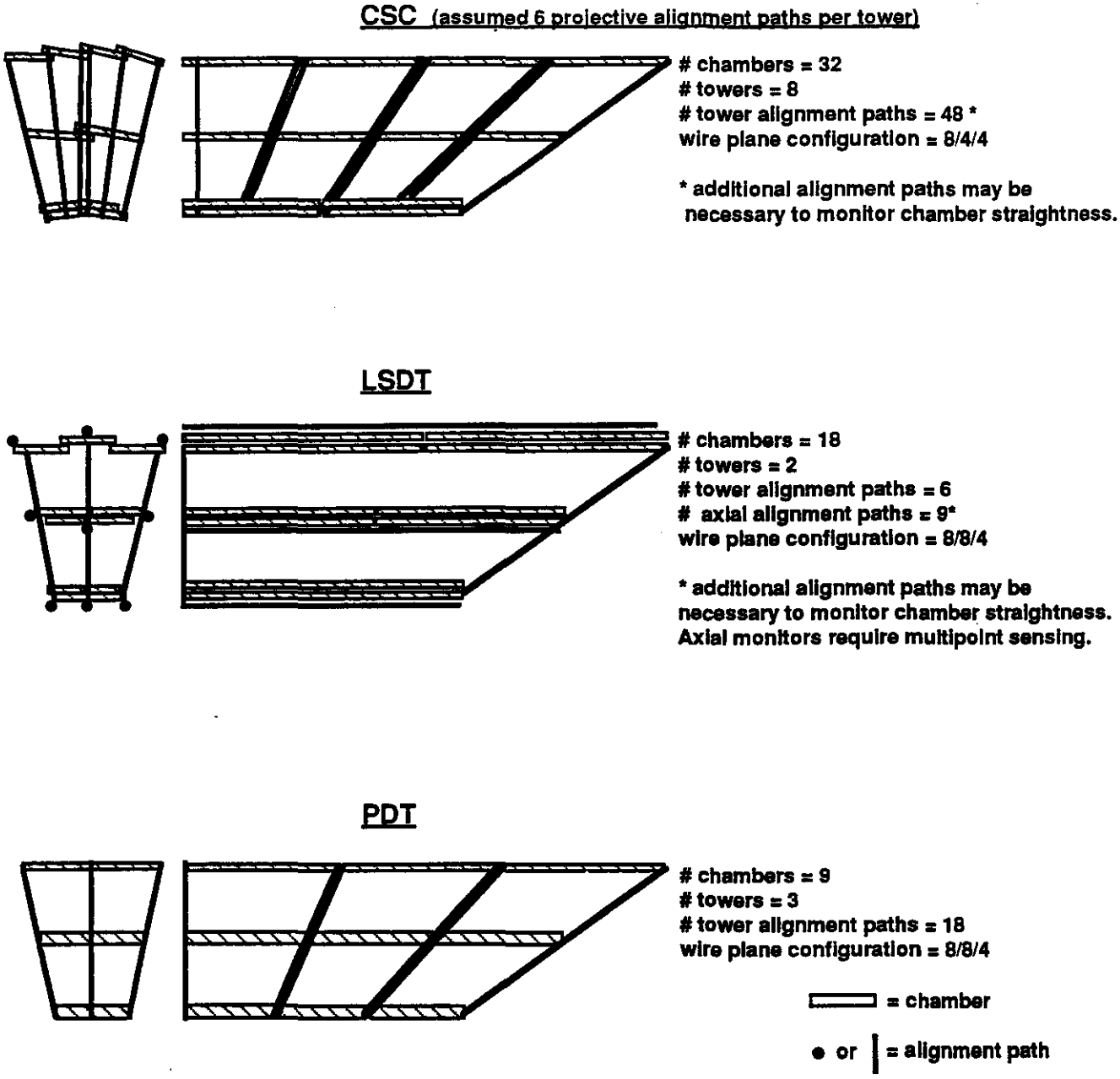


Figure 7.2.1-1. Sector configuration comparison

CSC issues and concerns

- Impact of coupling chambers (phi direction) on alignment
  - details not yet developed
  - must maintain accurate strip to strip placement
    - -- thermal distortion and interaction with truss structure requires evaluation

- Precision requirements of integrated chamber not yet demonstrated at full scale
  - accuracy of lithography
  - pultrusion precision
  - sag
  - pressure distortion (outer barrier not part of baseline)

- 8 towers per sector may require 48 alignment paths
  - includes coupled chambers

- Gas contamination at low pressure
  - need gas system design

- Power dissipation = 100 kw
  - design may be straightforward but no design presented

- Wire breakage can cause loss of full wire plane

- Management of about 900,000 electrical channels

LSDT design concept

- Each chamber consists of a 4 wire plane stackup of
  - precision machined mycalex bridges
  - aluminum frame
  - steel L-bracket stiffeners
  - Hexcell honeycomb stiffening panels
  - spacers
  - aluminum sheet metal cathodes
  - tungsten wires

- Superlayer composition
  - outer layer
    - -- 3 coupled chambers (phi), 2 chambers lengthwise
  - middle layer
    - -- 2 layers of 2 chambers (phi), 2 chambers lengthwise
  - inner layer
    - -- 2 layers of 2 chambers (phi), 1 chmaber lengthwise

- Sector composition
  - 8-4-4 sense layer configuration
  - 18 chambers per sector
  - 2 complex towers per chamber

LSDT alignment strategy

- Wire placement accuracy (phi direction) maintained by precision mycalex bridges
  - accuracy demonstrated on 1 m long prototypes

- Radial placement (layer-to-layer within a superlayer) is maintained by pinning bridges to a common frame structure
  - on one side registration is maintained by precision holes and pins
  - midspan support required to minimize sag
    - -- requires adjustment and must maintain adjustment in dynamic environment
  - sliding pin on opposite end permits expansion
    - -- requires stable "square" frame

- Fiducials, located on L-bracket, are closely coupled to side wall
  - several transfers are required but can be controlled

- Multiple support points to truss structure lengthwise along chamber require additional chamber straightness monitors
  - one proposed for each superlayer
  - adequacy of a single monitor to represent all chambers in a superlayer layer requires evaluation

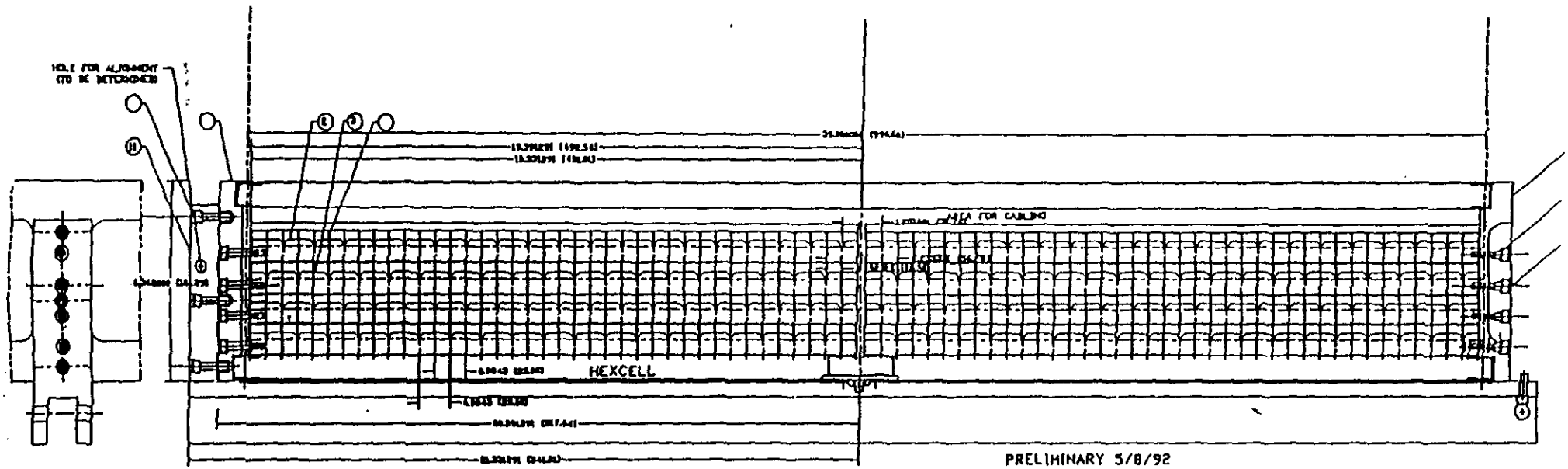
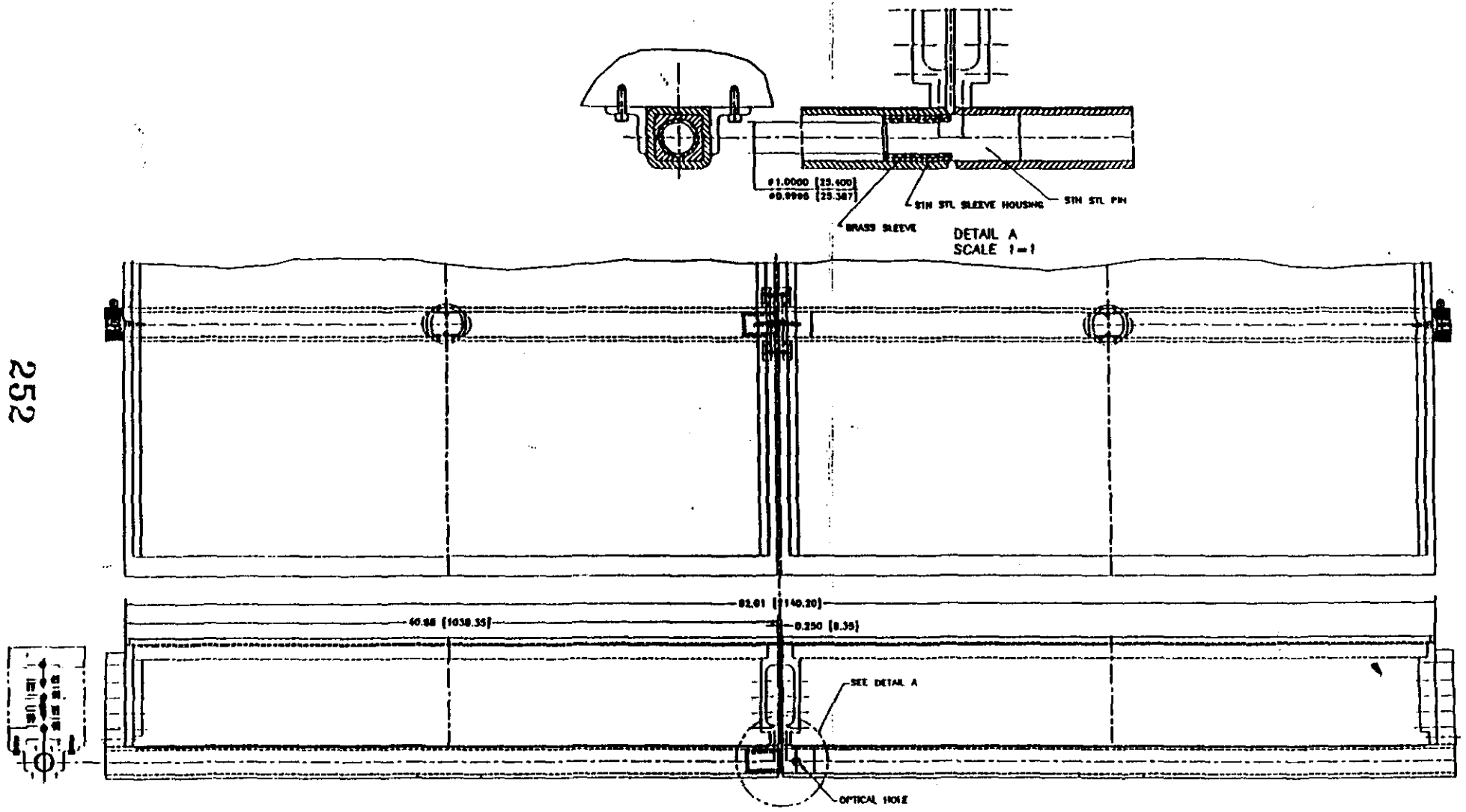
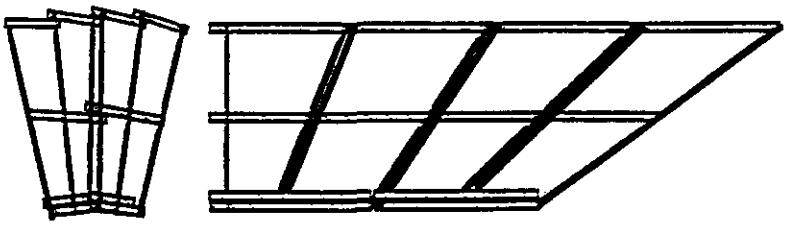


Fig. X.2 Cross sectional view of a typical full sized chamber



A.1.12. Fastening of two chambers to form a layer.

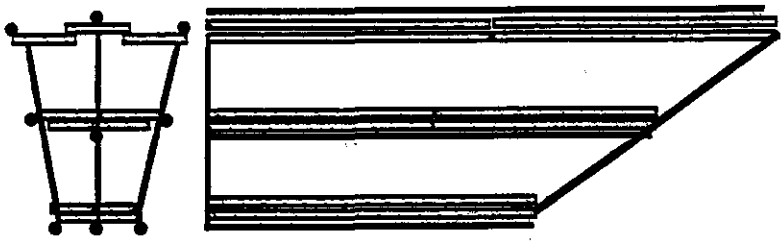
CSC (assumed 6 projective alignment paths per tower)



chambers = 32
towers = 8
tower alignment paths = 48 *
wire plane configuration = 8/4/4

* additional alignment paths may be necessary to monitor chamber straightness.

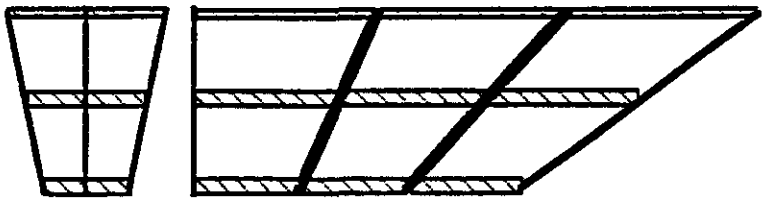
LSDT



chambers = 18
towers = 2
tower alignment paths = 6
axial alignment paths = 9*
wire plane configuration = 8/8/4

* additional alignment paths may be necessary to monitor chamber straightness. Axial monitors require multipoint sensing.

PDT



chambers = 9
towers = 3
tower alignment paths = 18
wire plane configuration = 8/8/4

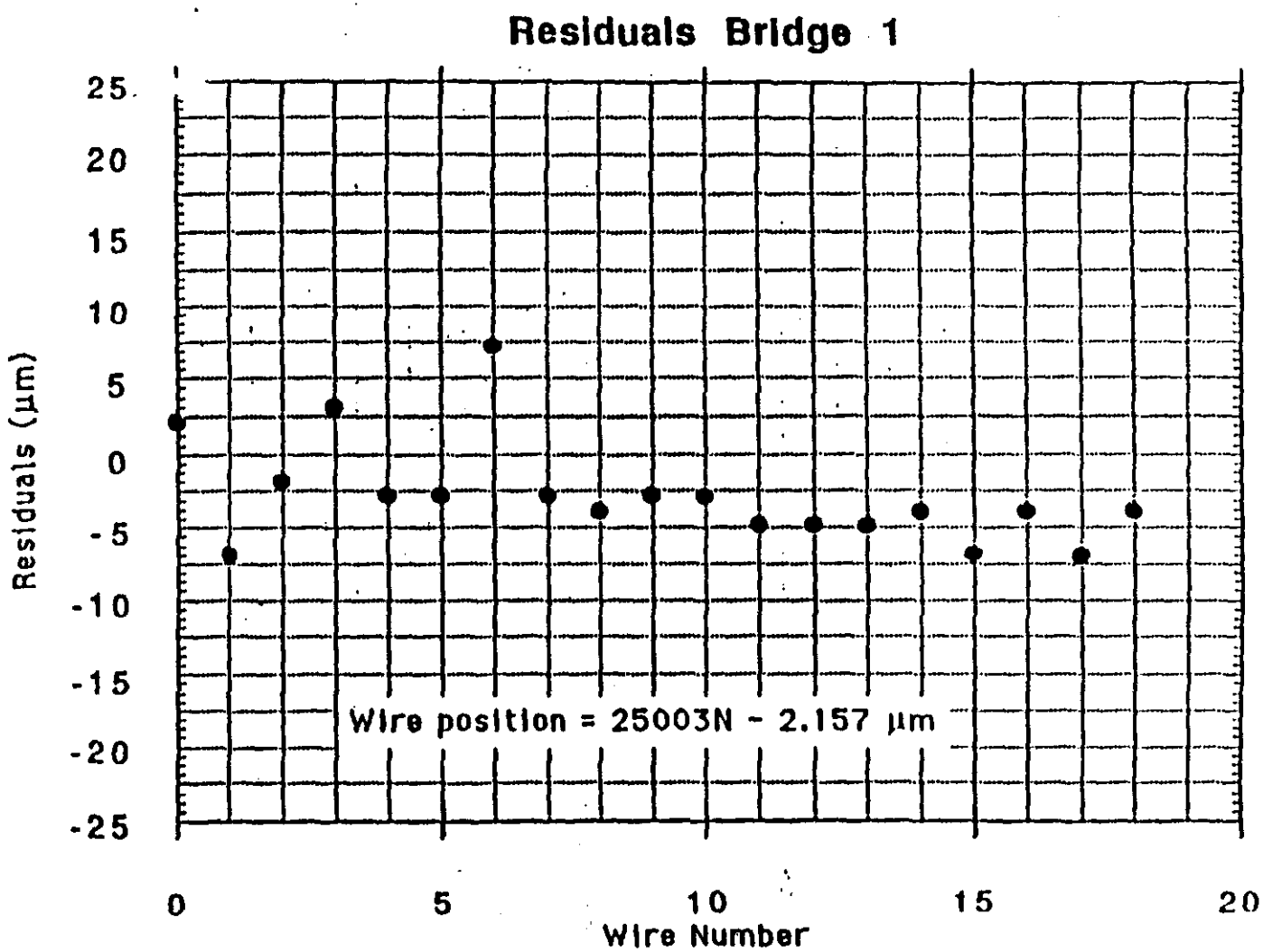
▭ = chamber

● or | = alignment path

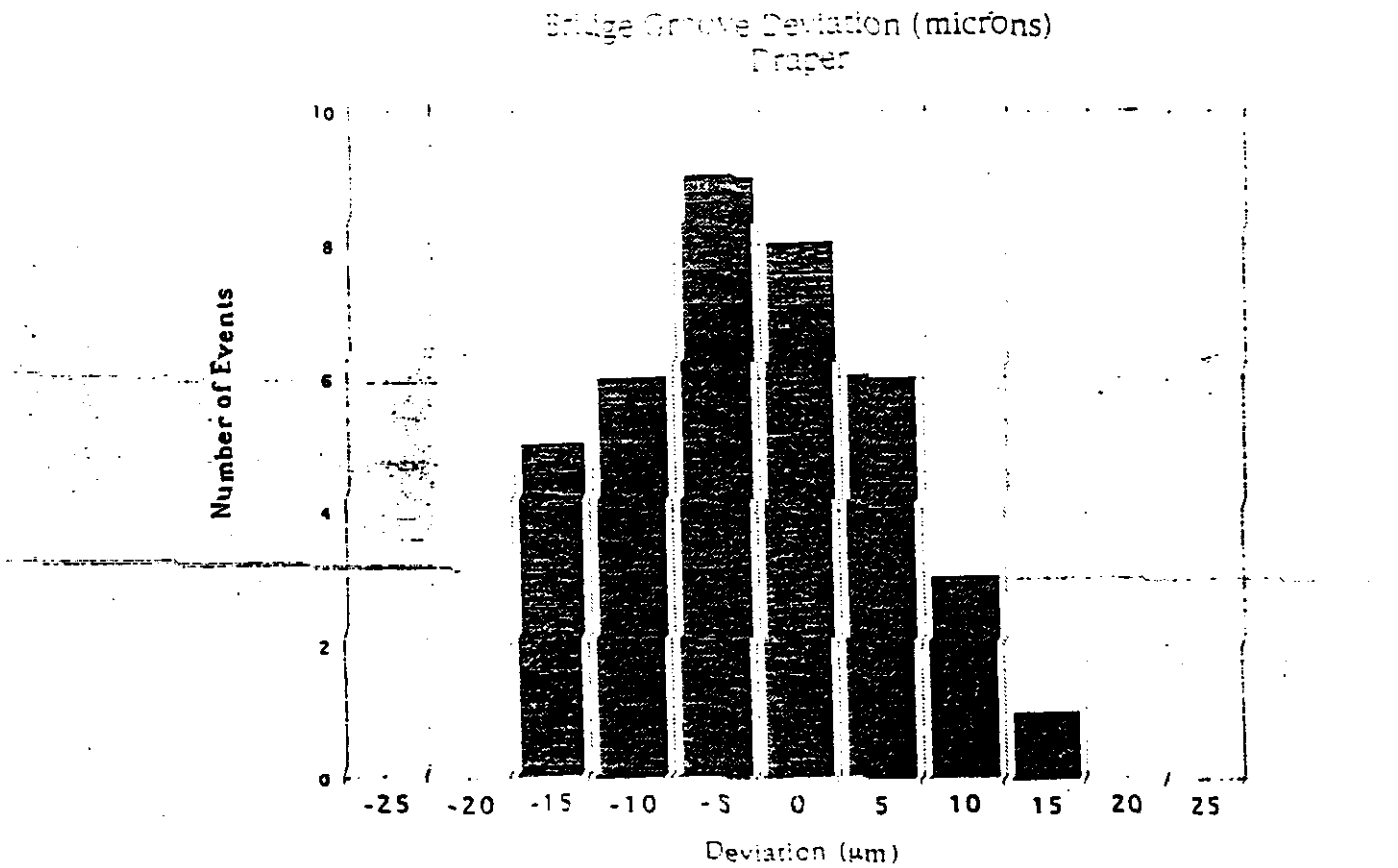
Figure 7.2.1-1. Sector configuration comparison

LSDT alignment requirements

Wire to wire placement accuracy	25 microns (systematic)
Wire to wire placement accuracy	50 microns (random)
Wire plane placement accuracy (layer to layer)	125 microns (radial)



A.I.4. Scatter in deviation of bridge groove position.(0.5 m bridge)



A.I.5. Scatter in deviation of bridge groove position (1.0 m bridge).

LSDT issues and concerns

- Impacts of chamber coupling in a sector have not yet been evaluated from an alignment perspective
  - relative motion between chambers
  - straightness monitor location

- Non-projective alignment monitors needs to be proven consistent with new (Mitselmahker) alignment approach

- Distortions of chambers caused by indeterminant, multipoint supports on truss structure requires evaluation

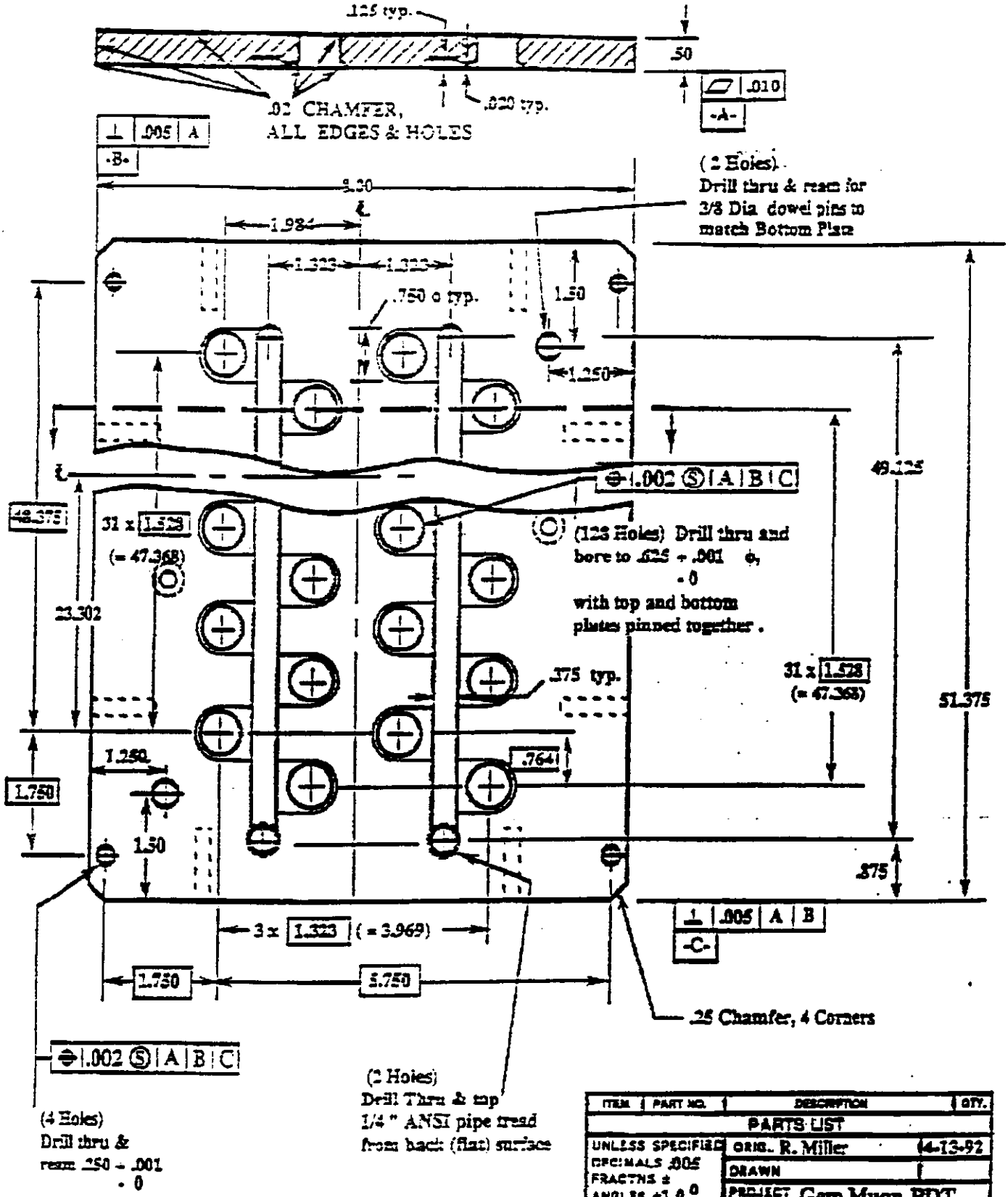
- Non-flammability of gas must be confirmed by GEM safety
  - 9.5% isobutane

PDT design concept

- Each chamber consists of up to 8 wire planes
  - thin walled aluminum tubes
  - tungsten wire
  - segmented aluminum endplates
  - glass filled delrin wire supports
  - jewel (sapphire) wire holder

- Superlayer composition
  - all three layers
    - -- 1 chamber (phi), 3 chambers lengthwise

- Sector composition
  - 8-8-4 sense layer configuration
  - 9 chambers per sector
  - 3 towers per chamber



ITEM	PART NO.	DESCRIPTION	QTY.
PARTS LIST			

UNLESS SPECIFIED DECIMALS .005 FRACTNS ± ANGLES ±1.0° BREAK ALL EDGES DO NOT SCALE DWG	ORIG. R. Miller	4-13-92
	DRAWN	
	PROJECT Gem Muon PDT	
	MATERIAL 1/2 Alum Tooling Plate MIC-6	
MICHIGAN STATE UNIVERSITY HIGH ENERGY PHYSICS		
TITLE Top Mainfold Plate-Pattern A		
DWG. NO. HEP01-022-272-A	REV. E	SCALE 1:2

Fig. 4

SEP-23-1992 15:10 FROM HIGH ENERGY PHYSICS TO 8121472855088 P.21

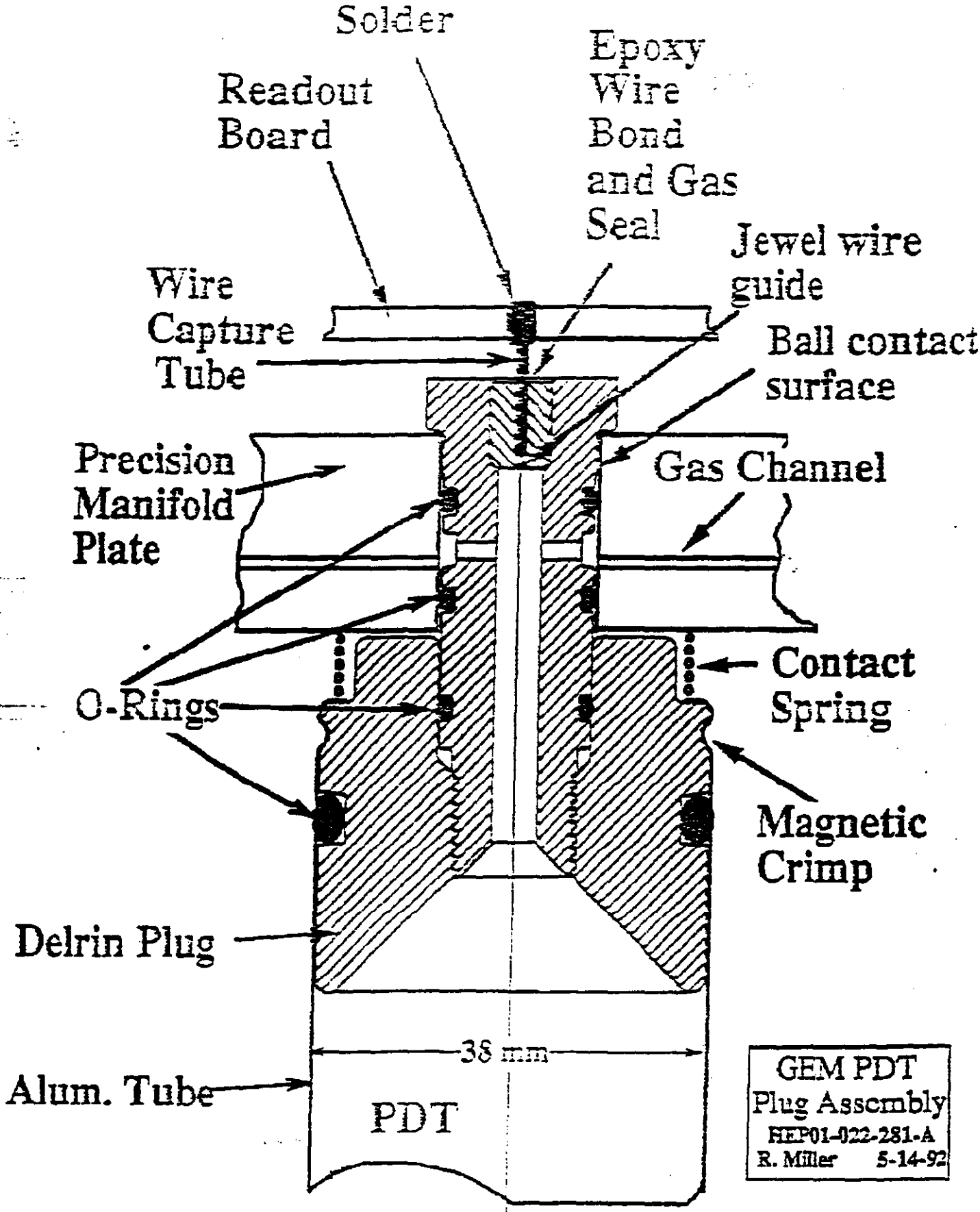


Fig. 6

SEP-25-1992 16:10 FROM HIGH ENERGY P- 8105 TO 8121472650B6 P.23

PDT alignment requirements

Wire to wire placement accuracy	25 microns (systematic)
Wire placement accuracy	40 microns (random)
Wire plane placement accuracy (layer to layer)	50 microns (radial)
Wire/tube concentricity	500 microns

PDT alignment strategy

- Wire to wire placement accuracy (phi and radial directions)is determined by
  - precision machining of endplates
    - -- achieved in 1 m prototypes
  - coupling of endplate segments on precision fixture
    - -- not yet demonstated
  - dimensional accuracy of wire support components
    - -- accuracy measured on prototype parts
  - quality control and parts inspection important in production environment

- Tension of wire must be maintained to within 5%
  - not demonstrated to be a problem in other (L3...) designs
  - stretch of wire is large (cm's) so very large deflections are needed to make a significant tension difference

- Thermal growth of endplate needs to be compensated
  - temperature monitors
  - alignment monitors with appropriate interpolation functions

- Lack of any intermediate supports eliminates need for additional straightness monitors

Manifold Plate Hole Placement

Aug. 4, 92

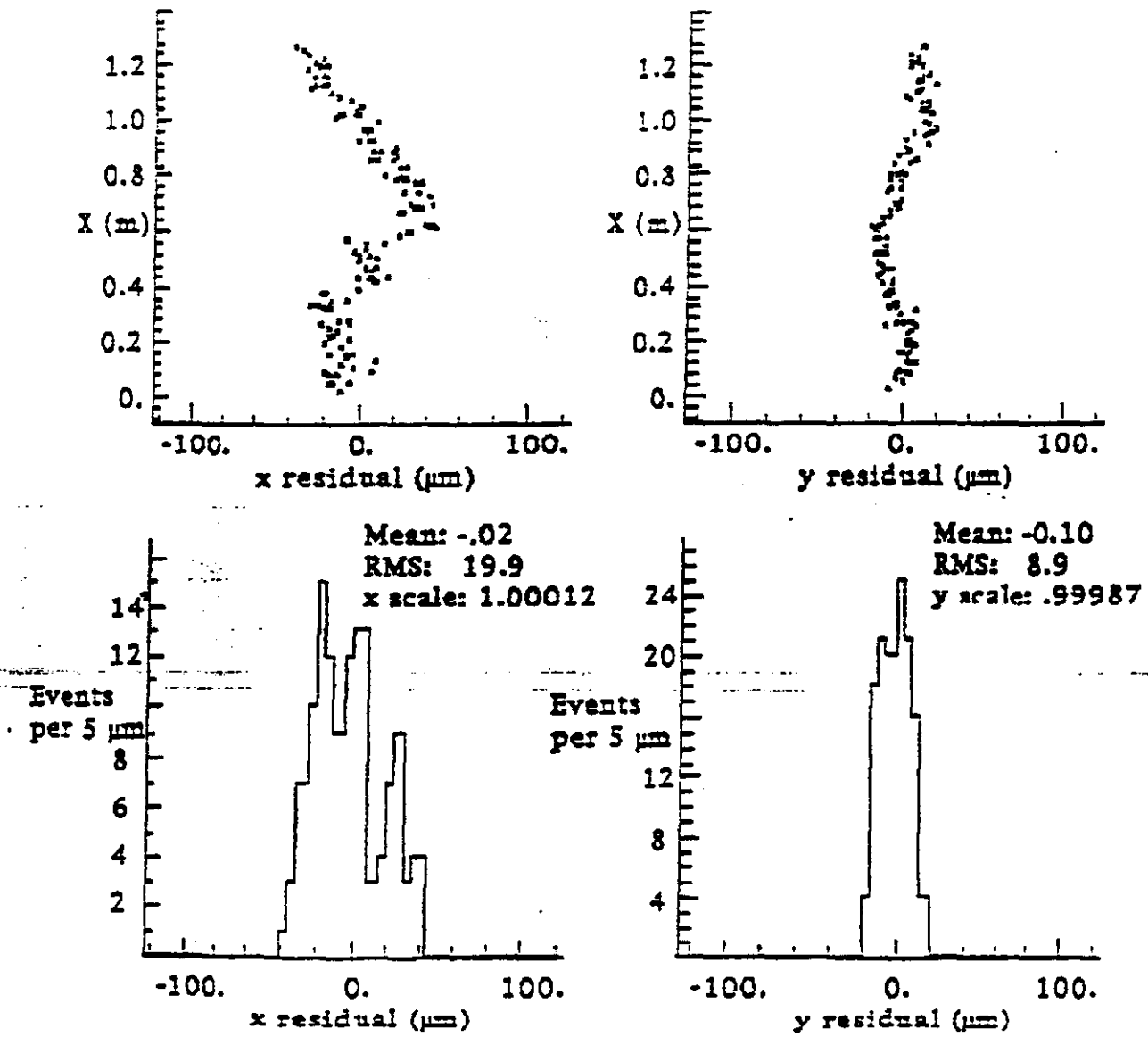


Fig. 5

SEP-23-1992 16:10 FROM HIGH ENERGY PHYSICS TO 81214708503B P.22

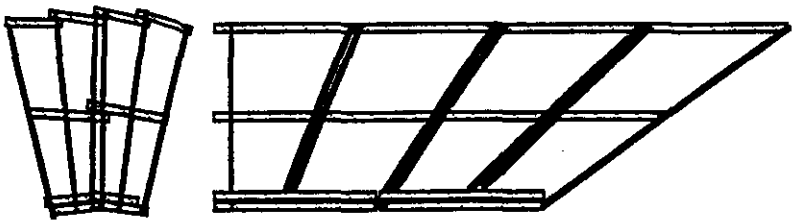
TABLE V

Error Budget

Source	Status	± Limits (μm)	Random RMS(μm)	Systematic RMS(μm)
Wire - Jewel	Calc.	5	3	0
Jewel - Bushing Bushing - Plug Plug- M.P. Hole	Meas.	25	12	0
M.P. Hole - Alignment	Meas.	50	15	20
Total			**20**	**20**

SEP-23-1992 15:08 FROM HIGH ENERGY PHYSICS TO 8121470850B8 P.17

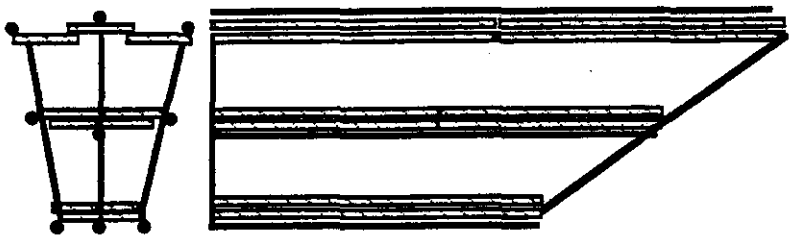
CSC (assumed 6 projective alignment paths per tower)



chambers = 32
towers = 8
tower alignment paths = 48 *
wire plane configuration = 8/4/4

* additional alignment paths may be necessary to monitor chamber straightness.

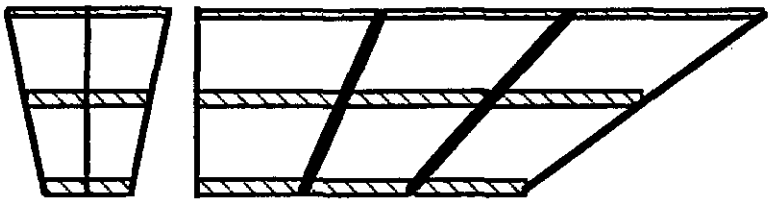
LSDT



chambers = 18
towers = 2
tower alignment paths = 6
axial alignment paths = 9*
wire plane configuration = 8/8/4

* additional alignment paths may be necessary to monitor chamber straightness. Axial monitors require multipoint sensing.

PDT



chambers = 9
towers = 3
tower alignment paths = 18
wire plane configuration = 8/8/4

= chamber

● or | = alignment path

Figure 7.2.1-1. Sector configuration comparison

PDT issues and concerns

- Wire placement accuracy has not yet been demonstrated at full width
  - precision fixture for endplate mating key to success
  - precision "comb" technique is a good backup strategy

- Gas leakage is expected to be 0.5% per hour
  - secondary containment sweeps away lost gas
  - gas replacement due to contamination expected to cause refills at a more rapid rate
  - concept needs a clearly defined gas system design, gas tightness checkout procedure and gas system management strategy

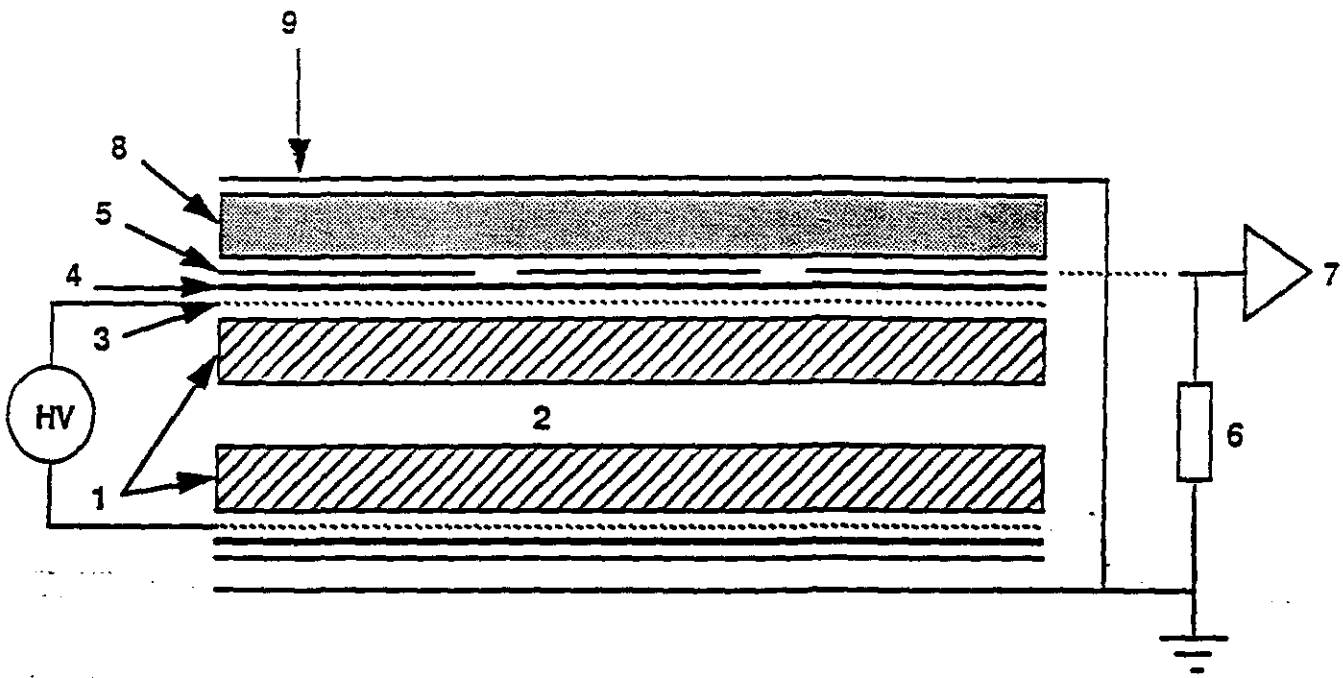
- Although wire/tube concentricity requirement is loose, 500 microns, no stackup of tolerances was presented
  - assembly tolerances
  - tube straightness

- Wire placment error caused by thermal distortion of the aluminum endplates has not been evaluated
  - 1 degree C can cause in excess of 50 micron growth

RPC design concept

- Each chamber consists of a stackup of
  - .015" Bakelite panels (10^11 ohm centimeters)
  - .005" aluminized mylar
  - 4mm rigidized foam
  - .010" aluminum ground plane
  - spacers

- Superlayer composition
  - outer layer -- 4 chambers lengthwise
  - middle layer -- 3 chambers lengthwise
  - inner layer -- 2 chambers lengthwise



1 Bakelite plate
2 gas
3 graphite coating
4 insulating foil
5 aluminum strips
6 line termination
7 discriminator
8 foam
9 aluminum ground plane

Figure 1

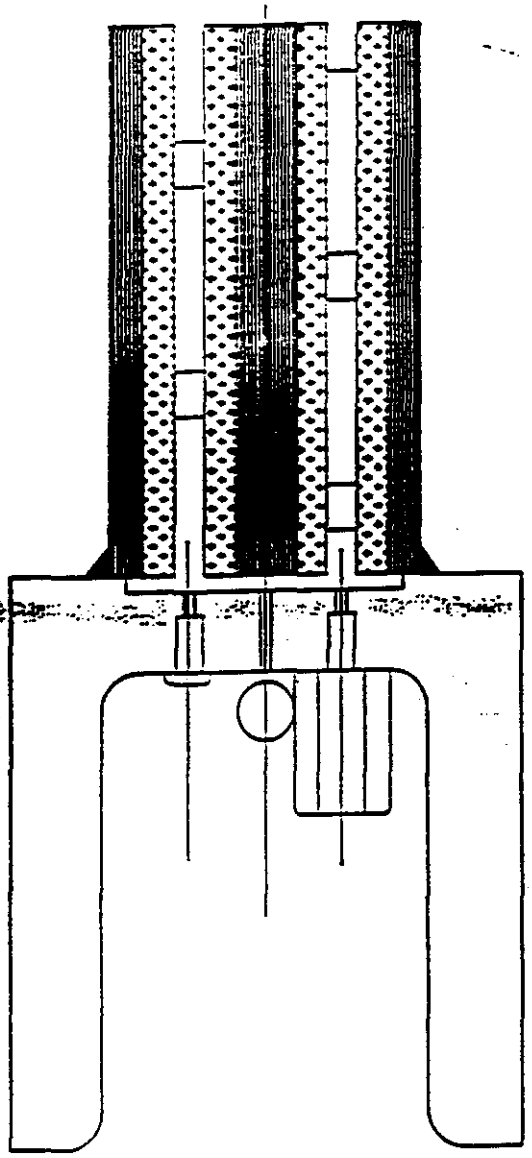


Figure 13

RPC alignment requirements

Parallelism of gap walls	200 microns
Strip straightness	100 - 500 microns

RPC alignment strategy

- Parallelism of gap walls will be maintained by precision PVC spacers located every 10 cm
  - spacers staggered between layers to achieve 100% coverage

- Strip straightness, 500 microns, can be achieved with shadow masks during aluminizing process

- RPC's are attached directly to drift chambers for structural support
  - cross-stiffeners provides additional stiffness as required

RPC issues and concerns

- Joining of thin Bakelite sheets to achieve full sector width
  - several concepts have been suggested
  - strength of glue and impact on overall stiffness has not been quantified but stiffness requirements are quite lax

- Gas mixture contains 32% isobutane and and 2% freon
  - safety issues regarding flammability needs to be addressed
  - contamination with O2 and N2 in low pressure system

- Aging of linseed oil coated bakelite
  - preliminary accelerated aging tests show satisfactory lifetimes

- Initial testing of static dispersive plastics, which can be used as a replacement for the bakelite, shows promise
  - may reduce concern for joining requirement and need for oil coating

7.1 Table summary

	CSC	LSDT	PDT	RPC
Max. chamber weight - kg	100	250	470	.92
Total chamber weight - kg	117,000	126,400	55,000	20,560
Maximum chamber width - m	1.32	1.2	3.46	3.3
Maximum chamber length m	3.506	7.65	5.0	3.8
Maximum chamber thickness - m	.124	.22	.40	.03
# chambers/sector (1/16)	32	18	9	9
Total # chamber	1024	576	288	288
Inactive chamber edge zone - m	not defined	.065		.04
Phi overlap capable	Yes	Yes	Yes	Yes
Inactive chamber end zone (not including alignment)- m	0.01	0.015		.04
Projected wire-to-wire (strip-to-strip) placement accuracy (random) - microns	50	20	20	1000
Total power dissipation(internal to magnet)- W	100,000	10,000	30,000	NA
Proven performance with non-flammable gas	yes	yes (9.5% isobutane)	yes	no
Operating gas pressure - inches of water	0.1	0.1	30 - 60 (psig)	.25
Total gas volume - m^3	60	456	576	10.9
Total # electronic channels	1,000,000 (with multiplexing	110,000	114,000	33,000
Total material cost - K$	14,800**	3663**	5959	954
Total assembly labor cost - K$	1228***	3607	3450	1796
Total engineering and development cost - K$				1355
Total cost - K$	16028	7270	9409	5742
Total assembly time - person years*	25.6	38.1	62.7	24.7

* Based on 1920 worked hours per year and
1) CSC = 48 hr/chamber
2) LSDT = 127 hr/chamber
3) PDT = 418 hr/chamber

** no electronic costs included
*** based on $25/hr and 25.6 person years

Table 7.1-1. Engineering parameter table

Electronics Cost Comparison

Dan Marlow

CSC Readout Electronics Design & Cost

Presented at the

GEM Muon Technology Selection Meeting

Daniel R. Marlow
Princeton University

October 6, 1992

GEM CSC Readout Design Goals

- Equivalent noise charge ($\sim 3000\ e^-$) rms (for $\tau = 300$ ns)
- Dynamic Range
  - — 50 μm measurement for strip width $w = 5$ mm

$$\frac{\sigma_s}{w} \simeq \sqrt{2}\frac{\sigma_q}{Q} \Longrightarrow \frac{Q}{\sigma_q} \simeq \sqrt{2}\frac{w}{\sigma_s} = 140$$

$\Longrightarrow$ 7.1 bits

  - — Landau tail $\varepsilon \simeq 95\% \Longrightarrow 40 - 230\ e^-$

$\Longrightarrow$ 2.5 bits

  - — $\times 2$ Design margin $\Longrightarrow$ 1.0 bits
  - — Total $\Longrightarrow$ 10.6 bits
- $< 10\ \mu$s conversion time
- Time resolution $\sim$ BX (for rejection of neutron hits)
- Low cost ($\sim$ \$10. – \$20. per channel)
- Radiation hard? $F_n \simeq 10^{13}$ cm^{-2} 10 SSC-yr^{-1} ?

Neutron Rates

- Currently very uncertain
- Product of three factors

$$R = \varepsilon_n F_n A \equiv r_n A$$

where

$$\varepsilon_n = \text{detection efficiency}$$
$$F_n = \text{fluence}$$
$$A = \text{strip area}$$

The efficiency

measured

calculated $\longrightarrow$ $2 \times 10^{-4} < \varepsilon_n < 5 \times 10^{-3}$

the fluence (TN 92-91)

$z = 575$cm

$z = 235$cm $\longrightarrow$ $10^3 < F_n < 10^5 \text{ cm}^{-2}\text{s}^{-1}$

the area

$$A = \ell w \simeq 300 \times 0.5 = 150 \text{ cm}^2$$

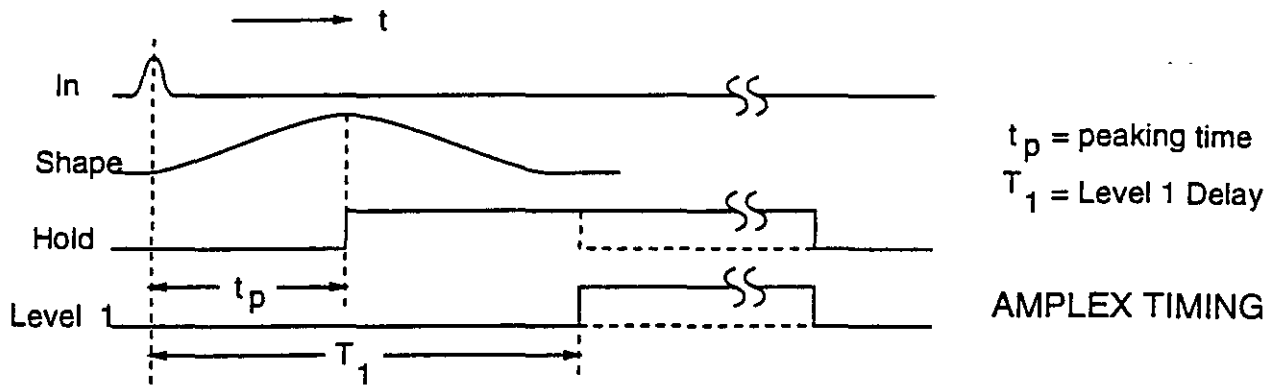
yielding a rate per strip (assuming $\varepsilon_n = 0.5\%$ of

$$0.75 < R < 75 \text{ kHz}$$

note that the corresponding rates per unit area are

$$5 < r_n < 500 \text{ cm}^{-2}\text{s}^{-1}$$

AMPLEX Option

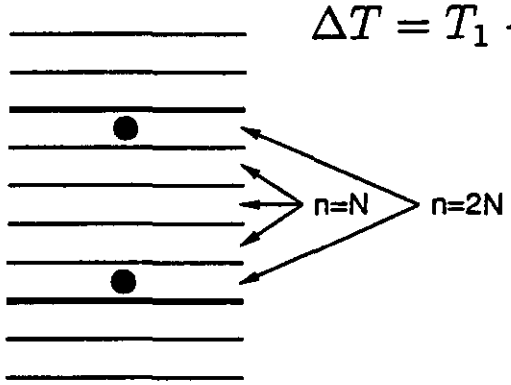


Spoilage Scenarios:

1) Accidental pulse comes early by $\Delta t \leq T_1 - t_p$, causing the hold to be issued too early.
2) Accidental pulse comes late by $\Delta t \leq t_p$, possibly overlapping with the true signal.

Thus the effective total time aperture for spoilage is

$$\Delta T = T_1 - t_p + t_p = T_1 = 2\ \mu\text{s}$$



N = # strips in readout group. (Currently $N = 16$)

$$N_{\text{eff}} = \frac{(N-2)}{N}N + \frac{2}{N}2N = N + 2$$

If we allow

$$p_{\text{max}} = \text{maximum hit spoilage} = 10\%$$

then

$$R_{\text{max}} = \frac{p_{\text{max}}}{N_{\text{eff}}\Delta T} = \begin{cases} 2.8\ \text{kHz}, & N = 16 \\ 5.0\ \text{kHz}, & N = 8 \\ 8.3\ \text{kHz}, & N = 4 \end{cases}$$

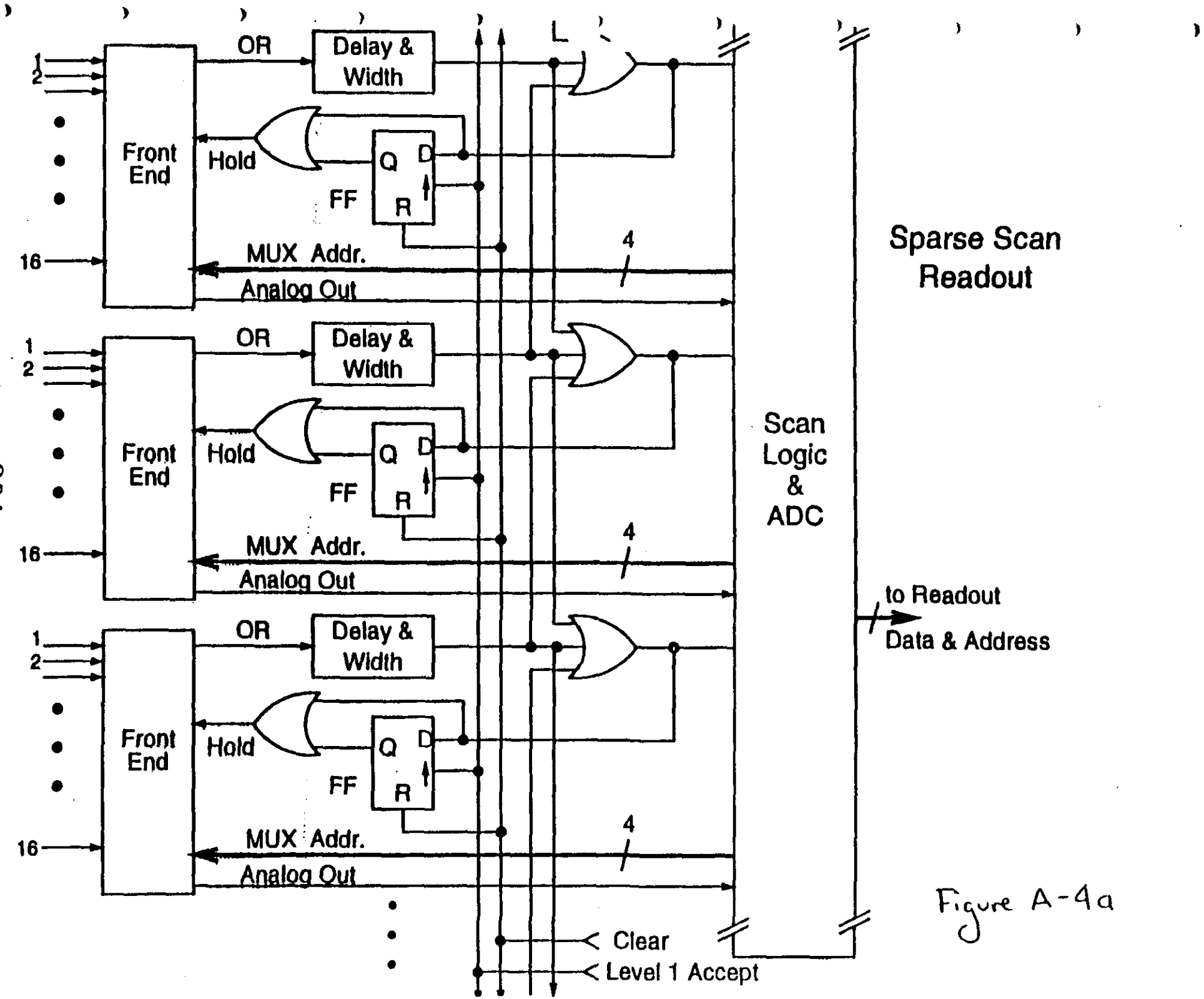
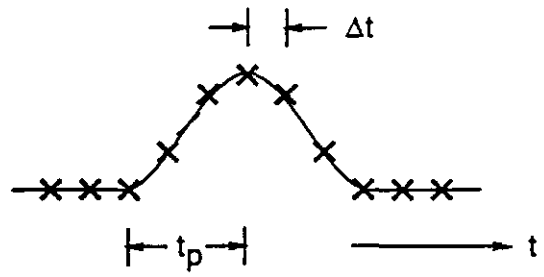

Sparse Scan Readout
Front End
OR
Delay & Width
Hold
FF
Q
D
R
MUX Addr.
Analog Out
1
2
16
4
Scan Logic & ADC
to Readout
Data & Address
Clear
Level 1 Accept

Figure A-4a

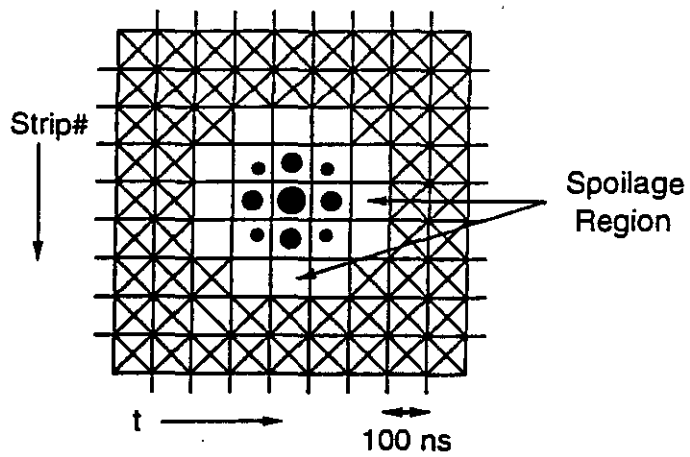
Analog Pipeline (SCA) Option



Assume

$$t_p = \text{pulse peaking time} = 300 \text{ ns}$$

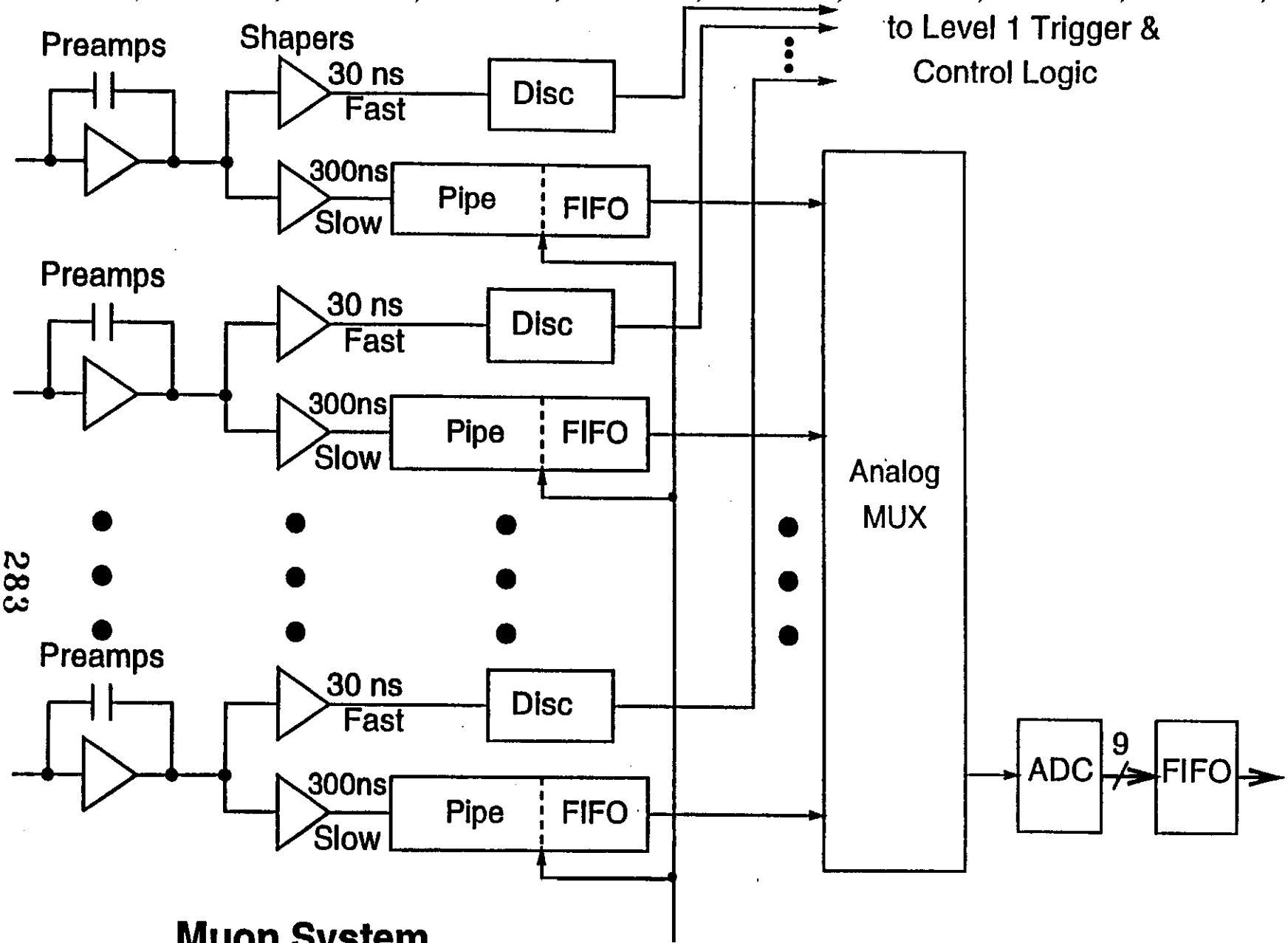
$$\Delta t = \text{sample clock period} = 100 \text{ ns}$$



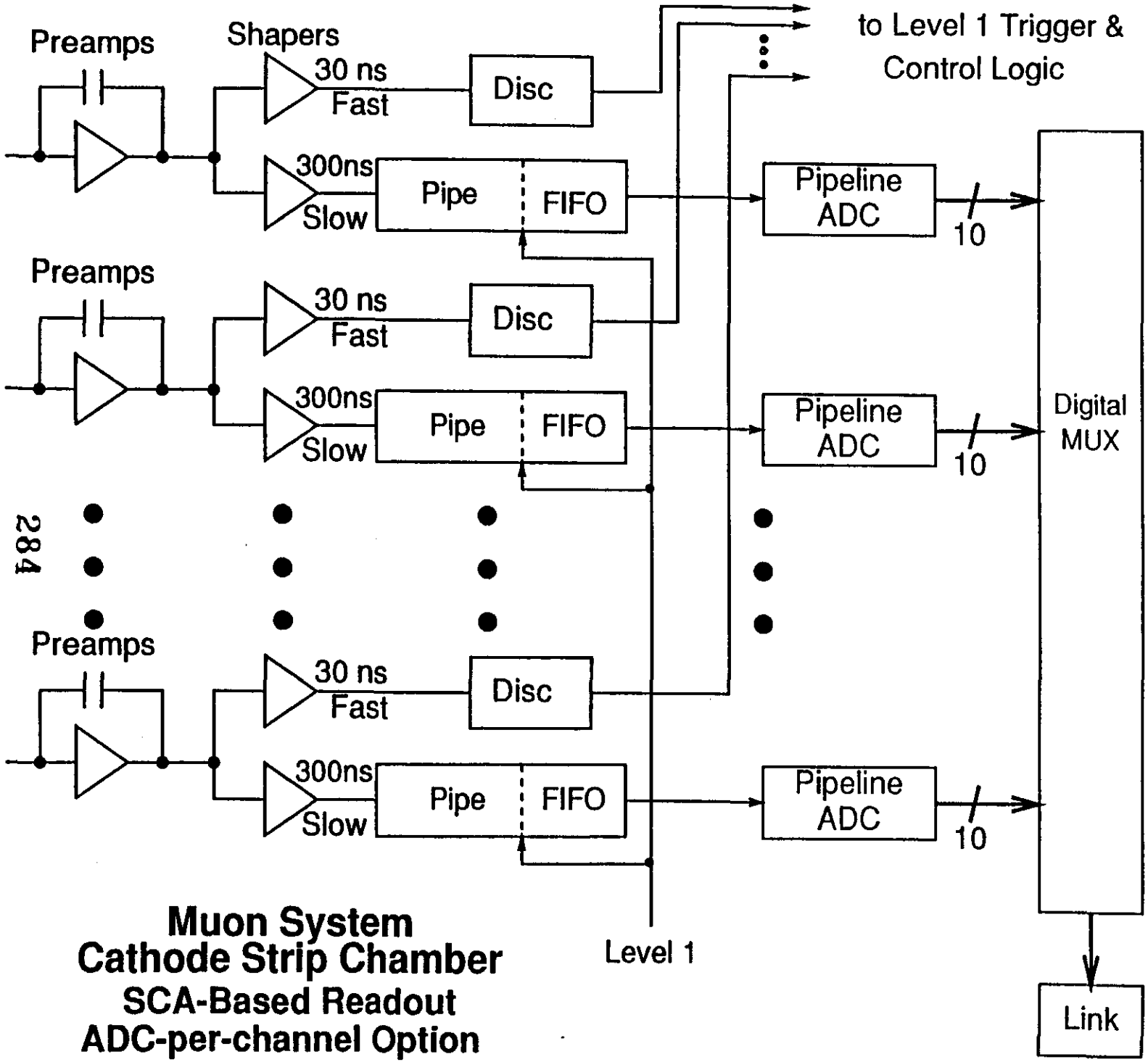
If accidental pulses falling within the indicated region in the space-time grid shown above are considered to spoil the signal pulse, the maximum unspoiled rate is given by

$$R_{\max} = \frac{p_{\max}}{21\Delta t} = \frac{0.1}{21 \times 10^{-7}} = 48 \text{ kHz}$$

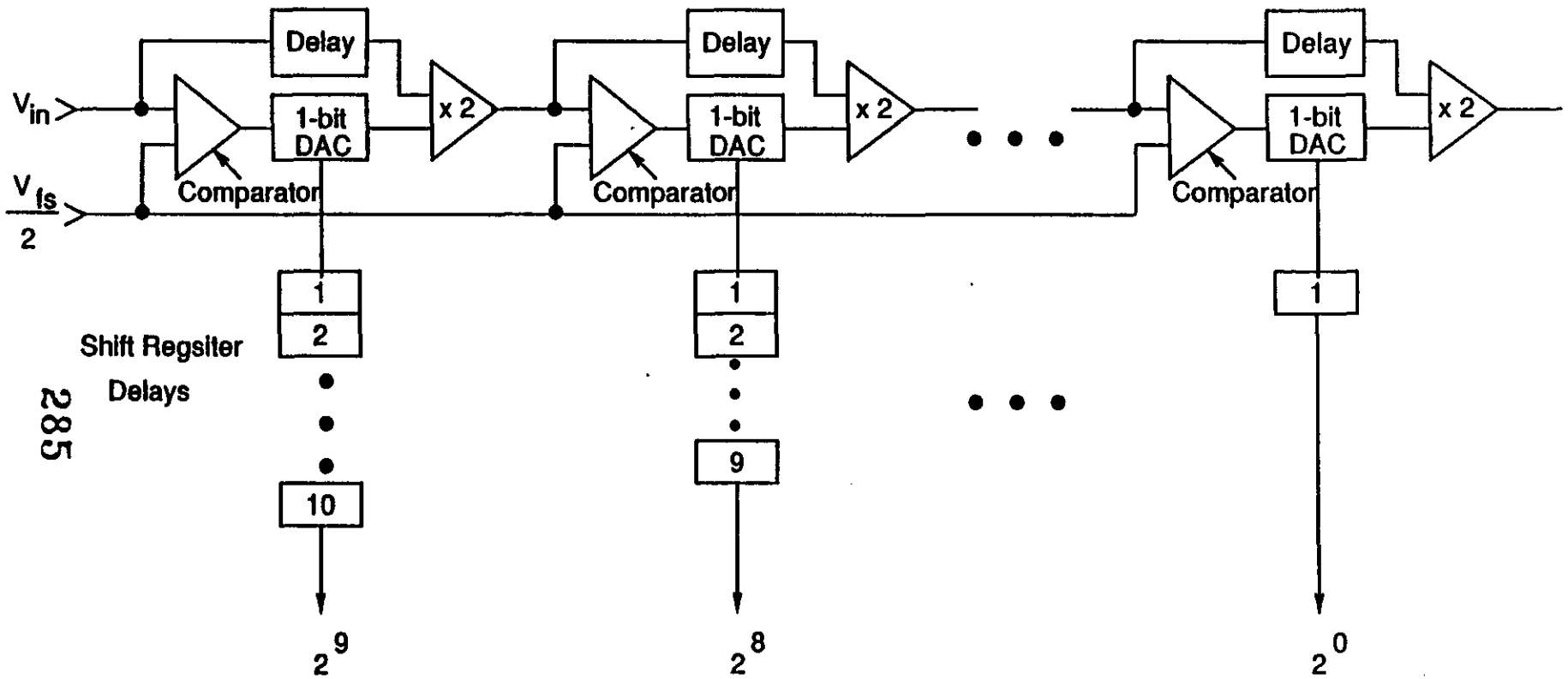
(corresponding to $r = 320 \text{ cm}^{-2}\text{s}^{-1}$)



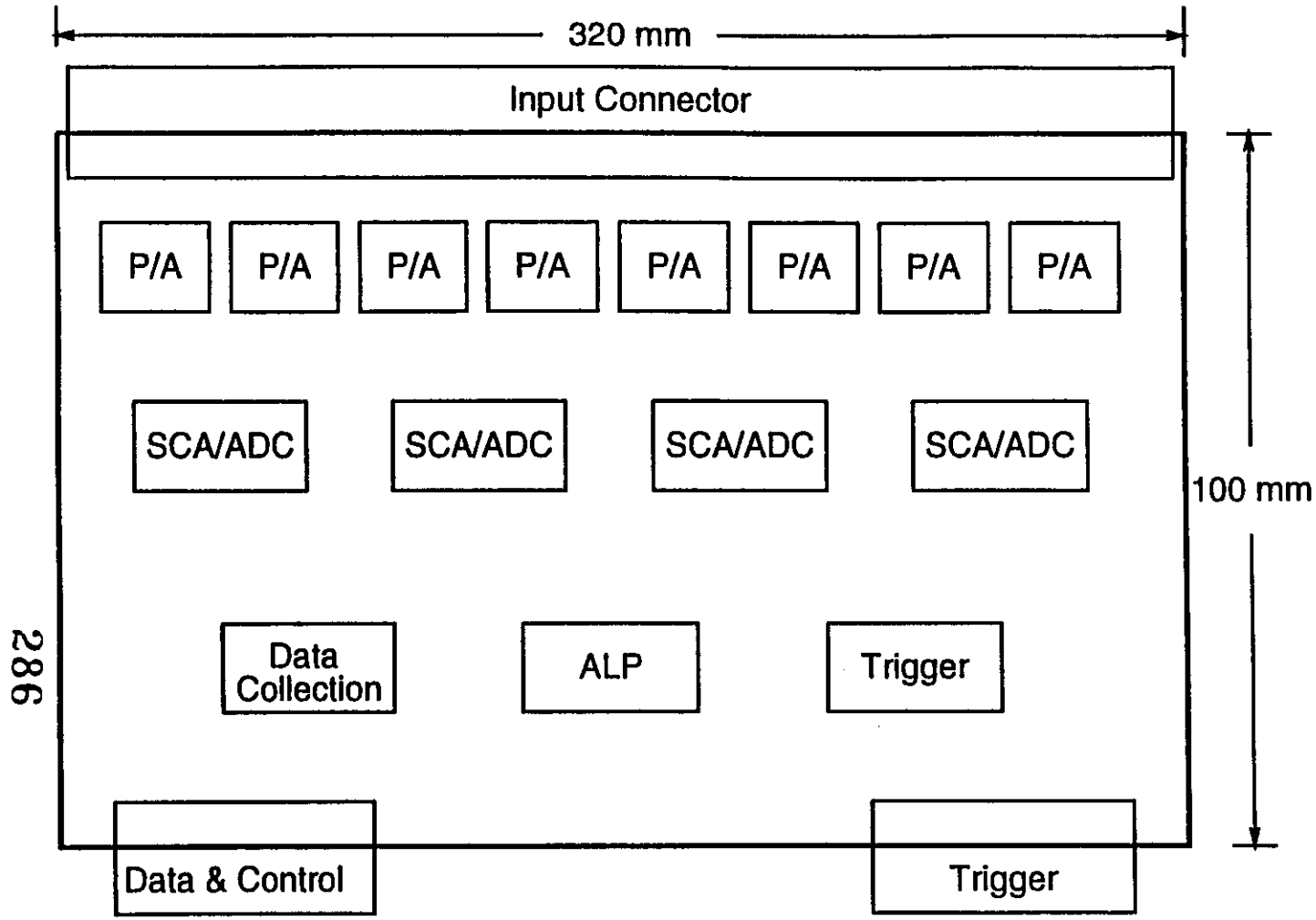
Muon System
Cathode Strip Chamber
SCA-Based Readout



Muon System
Cathode Strip Chamber
SCA-Based Readout
ADC-per-channel Option



Pipeline ADC Concept



CSC Chamber Board Layout

IC Cost Summary

SDC IC Costing Rules						
Size	Area	Yield	Fab.	Pkg	Test	Total
Tiny	6.8 mm^2	70%	$ 2.05	$ 1.00	$ 7.50	$ 10.55
Small	35 mm^2	65%	$ 11.17	$ 1.50	$ 8.00	$ 20.67
Medium	50 mm^2	60%	$ 17.65	$ 2.00	$ 8.50	$ 28.15

Non-recurring expenses (NRE):
— $ 25K per design for masks
— $ 5K per design for testing setup

CSC IC's			
Description	Type	Chans/Pkg	$/Chan
P/A Shaper	Tiny	8	$ 1.32
SCA/ADC	Medium	16	$ 1.75
ALP	Medium	64	$ 0.44
DCC	Medium	64	$ 0.44
Trig	Medium	64	$ 0.44
Total			$ 4.39

Electronics Cost Estimate

Item	$/Board	$/Chan
IC's (see summary table)	$ 281	$ 4.39
PCB Fab. (0.15 $/cm^2)	$ 48	$ 0.75
Connectors (Male & Female)	$ 64	$ 1.00
Misc. Parts (W.A.G.)	$ 20	$ 0.32
Assy (1500 leads at $ 0.06/lead)	$ 90	$ 1.41
Q/A (20 min)	$ 10	$ 0.16
Test (1 man-hour)	$ 30	$ 0.47
Rework (20% at 2 hrs/ea)	$ 12	$ 0.19
LVPS (200 mW/chan at $ 5.00/W)	$ 64	$ 1.00
Mounting Hardware (W.A.G)	$ 20	$ 0.31
Packing & Shipping	$ 20	$ 0.31
Subtotal	$ 659	$ 10.30
Contingency (30%)	$ 198	$ 3.08
Grand Total	$ 857	$ 13.40

- Assumptions
  - — 64 channel board of area 32 × 10 cm^2 (8 layers)
  - — Includes P/A shaper, SCA/ADC, DCC, & 1st Level Trigger
  - — SDC chip costing rules
  - — PC costs based on discussions with U.S. & Canadian vendors
  - — Assume SMT for automated assembly
  - — Fixed costs of R&D, EDIA, & NRE not included

CSC System Cost Summary

- Additional Front End WBS Elements (added cost per 1000-channel-module)

— HVPS & Cable	\$ 200
— Fiber Data Links	\$ 370
— Trigger Cable	\$ 120
— Total add'l per chan. (incl. 30% cont.)	\$ 0.90

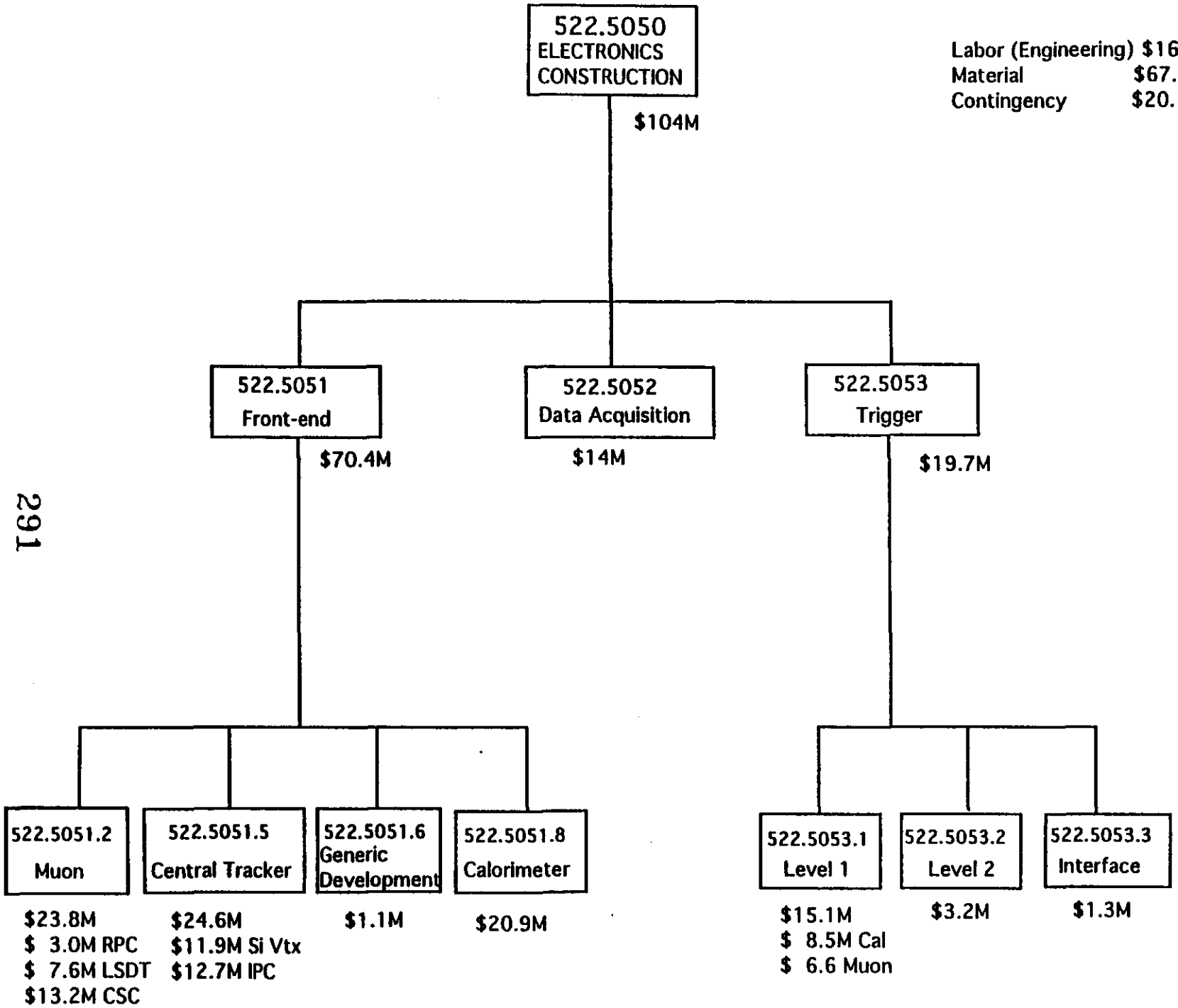
- Grand total per channel: \$13.40 + \$0.90 = \$14.30
- Channel Count
  - — 1050 K fine cathodes
  - — 160 K anodes (or coarse cathodes)
  - — 1210 K total
- Fixed cost of R&D, prototypes, etc. \$ 2760 K (from LRS report)
- Total Front End Cost

$$\$2760\ \mathrm{K} + 1210\ \mathrm{K} \times \$14.30 = \$20.1\ \mathrm{M}$$

- There is an additional \$ 6.6 M in the LRS report for the Level 1 trigger.

Overall Cost Comparison for GEM Electronics

		Production				
System	Proto.	Cost/Chan	Cont	# Chan	Subtotal	Total
Si Vtx	$ 3,010 K	$ 2.13	30.6%	3200 K	$ 8,922 K	$ 11,933 K
IPC	$ 3,230 K	$ 16.11	36.4%	400 K	$ 8,791 K	$ 12,021 K
Calor.	$ 4,016 K	$ 141.80	30.5%	86 K	$ 15,290 K	$ 19,936 K
RPC	$ 560 K	$ 53.67	23.4%	33 K	$ 2,186 K	$ 2,745 K
DC Wire	$ 1,686 K	$ 37.40	35.6%	110 K	$ 5,578 K	$ 7,264 K
CSC Pad	$ 2,761 K	$ 19.48	40.8%	242 K	$ 6,642 K	$ 9,403 K
CSC Wire	$ 2,027 K	$ 34.35	25.0%	29 K	$ 1,245 K	$ 3,272 K
Muon Front End Subtotal						$ 22,684 K
CSC Pad'	$ 2,761 K	$ 11.00	30.0%	1210 K	$ 17,303 K	$ 20,064 K



6/16/92(gem/wbs2)

Daniel Marlow
Revised 10/7/92

Overall Cost Comparison for GEM Electronics

		Production				
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Calor.	$ 4,016 K	$ 141.80	30.5%	86 K	$ 15,290 K	$ 19,936 K
RPC	$ 560 K	$ 53.67	23.4%	33 K	$ 2,186 K	$ 2,745 K
DC Wire	$ 1,686 K	$ 37.40	35.6%	110 K	$ 5,578 K	$ 7,264 K
CSC Pad	$ 2,761 K	$ 19.48	40.8%	242 K	$ 6,642 K	$ 9,403 K
CSC Wire	$ 334 K	$ 34.35	25.0%	29 K	$ 1,245 K	$ 1,579 K
Hybrid Muon Front End Subtotal						$ 20,991 K
CSC Pad'	$ 2,761 K	$ 11.00	30.0%	1210 K	$ 17,303 K	$ 20,064 K

Comments

1.) As noted yesterday, the CSC wire development (prototype) costs in the hybrid muon approach have been overestimated due to a bookkeeping error. The correct number is approximately $ 334 K. The table above has been revised to reflect this correction.

2. A bottom-up (BU) cost estimate of the drift-wire readout has not been done. **Thus it is not possible to make a dependable systematic comparison on the time scale of a few hours.** In comparing costs one might be tempted to perform a simple "scaling", by the ratio of the bottom-up estimate to the LRS estimate for the CSC's—i.e. by scaling the production costs according to

$$F = \frac{\$11.00 \times 1.300}{\$19.48 \times 1.408} = 52\%$$

It is far from clear, however, that this is valid. In particular, the mix of integrated circuits versus cables and connectors is different for the two systems—the drift-wire schemes have on-chamber preamplifier/discriminators that drive cables to magnet-mounted rack electronics. The CSC electronics are almost entirely chamber-mounted.

Open Presentations

J.E. Taylor
10/6/92

Comparison of Drift vs. CSC Resolutions

Drift:

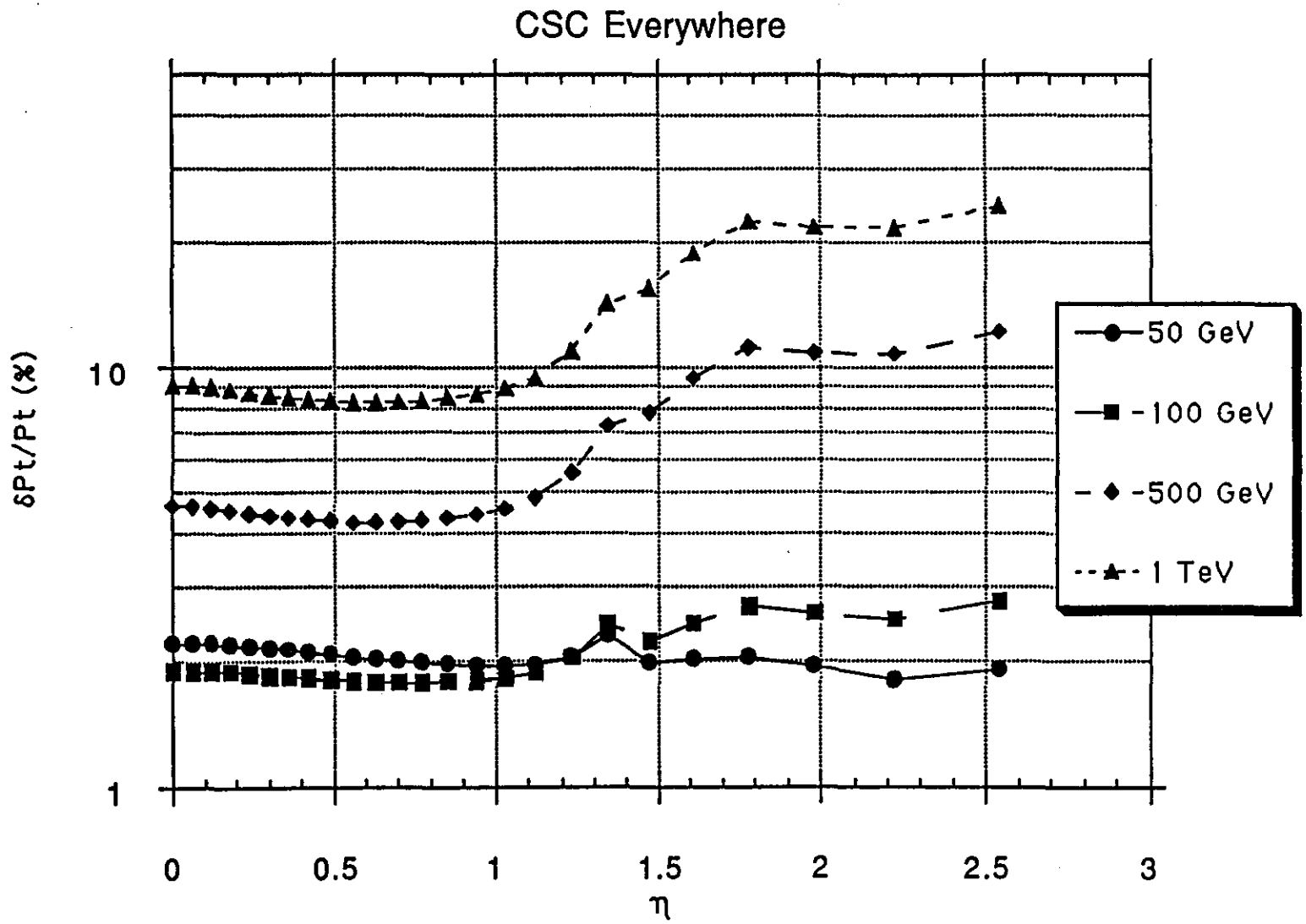
Configuration (SL1:SL2:Sl3)	8:8:4
Single layer resolution	100 μm RMS
Alignment (internal random)	50 μm RMS
Alignment (external SL-to-SL)	25 μm RMS

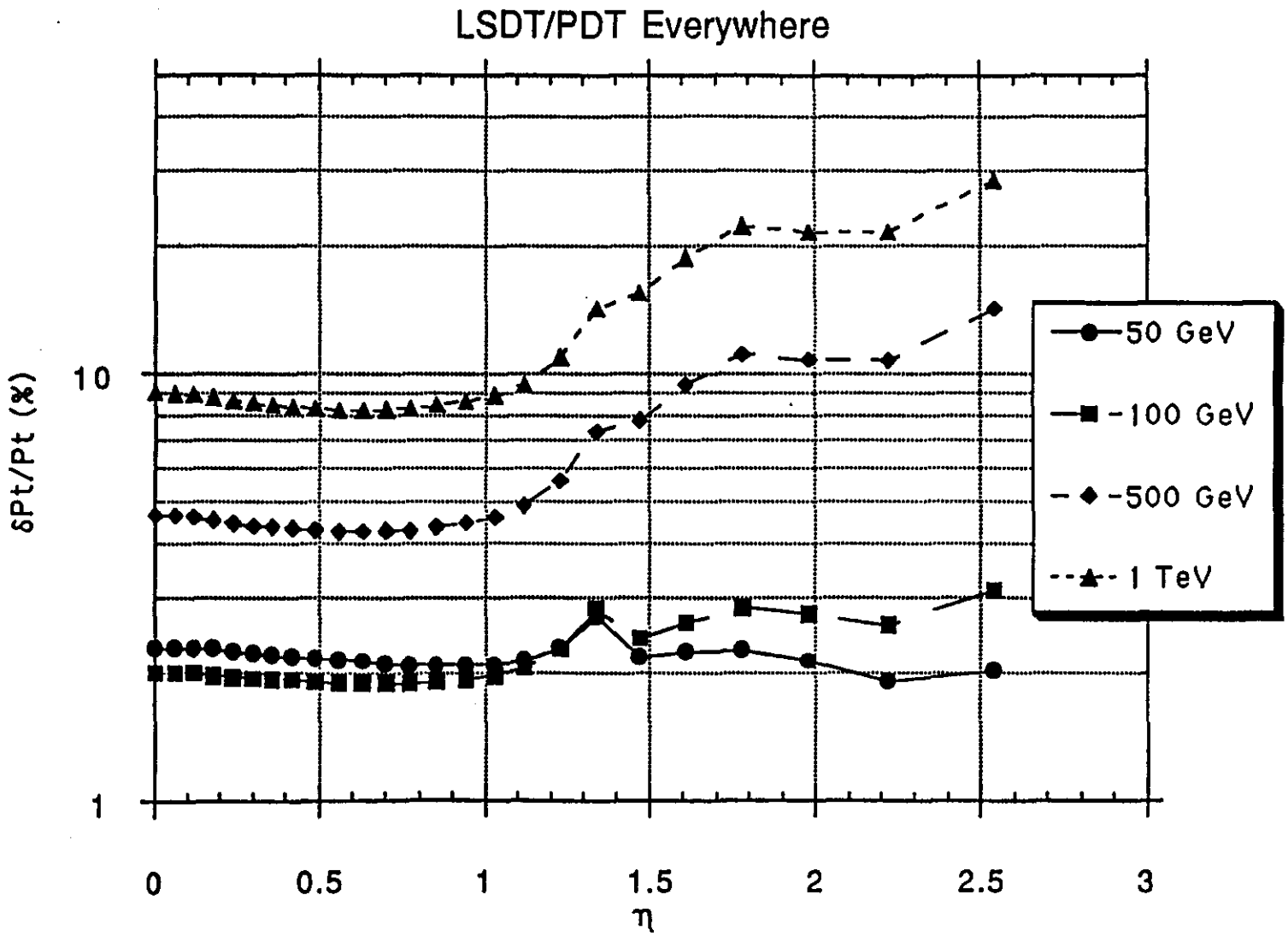
Cathode Strips:

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

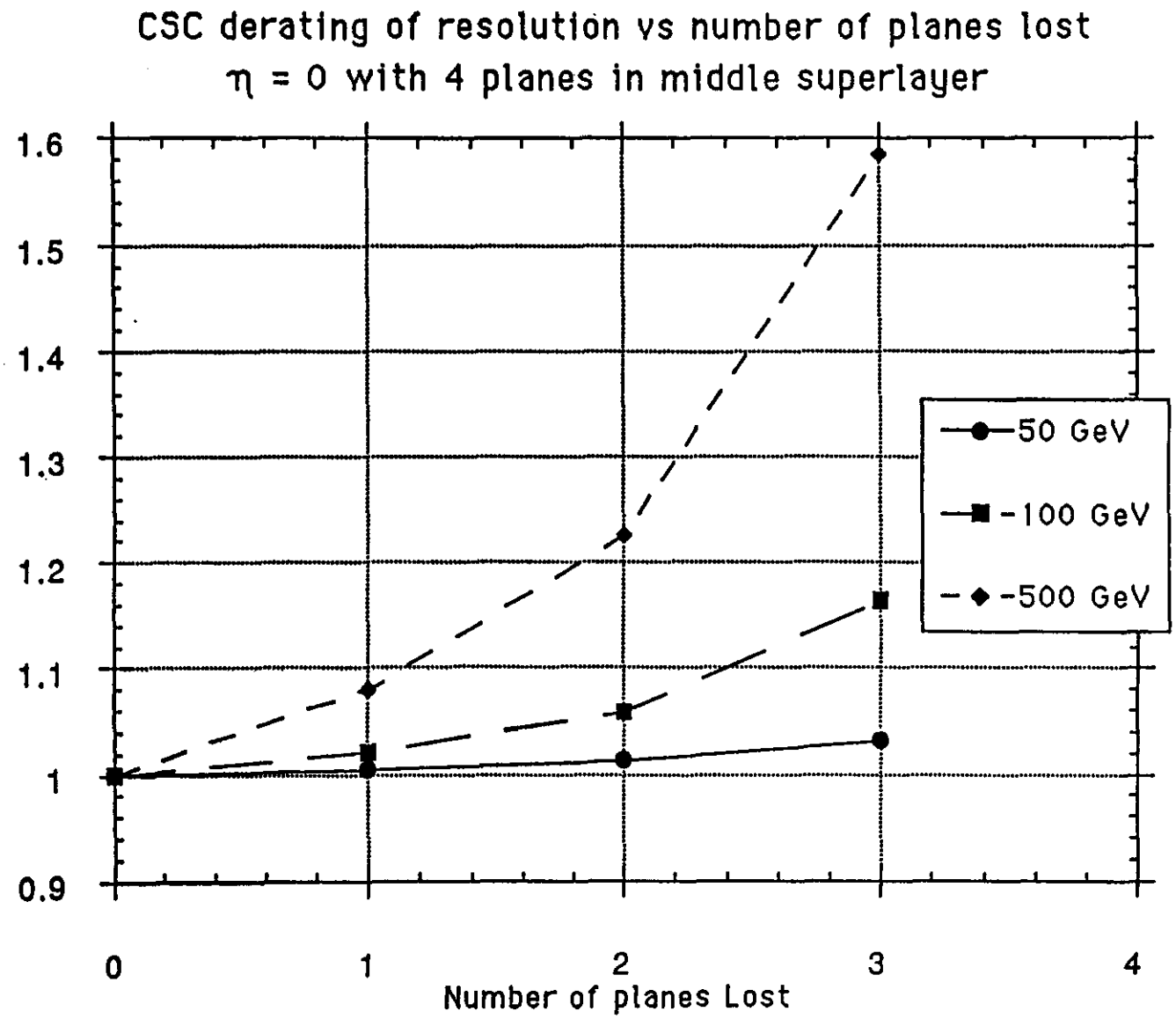
Questions:

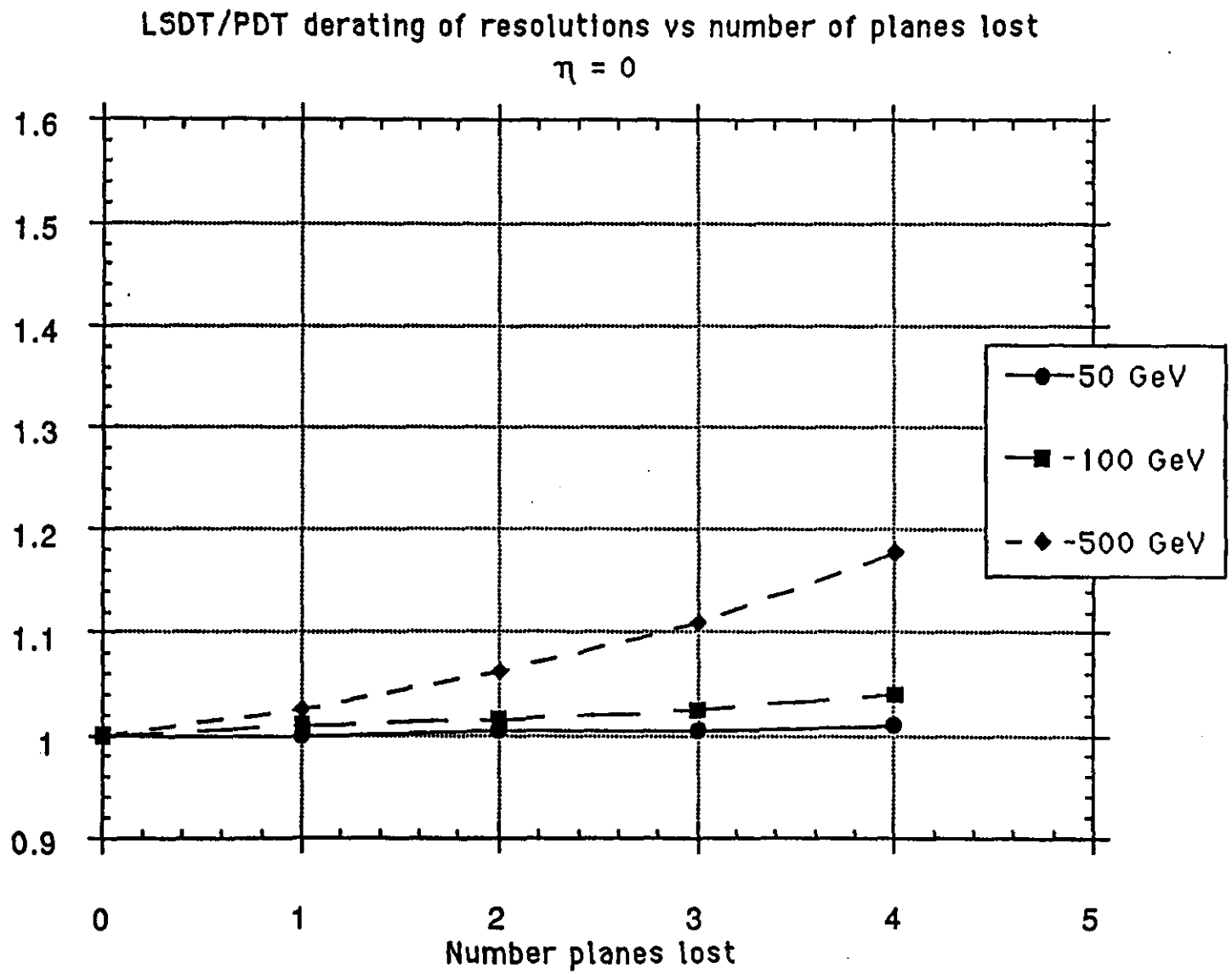
- How do baseline resolutions compare ?
- How do resolutions derate under loss of planes in middle superlayer ?

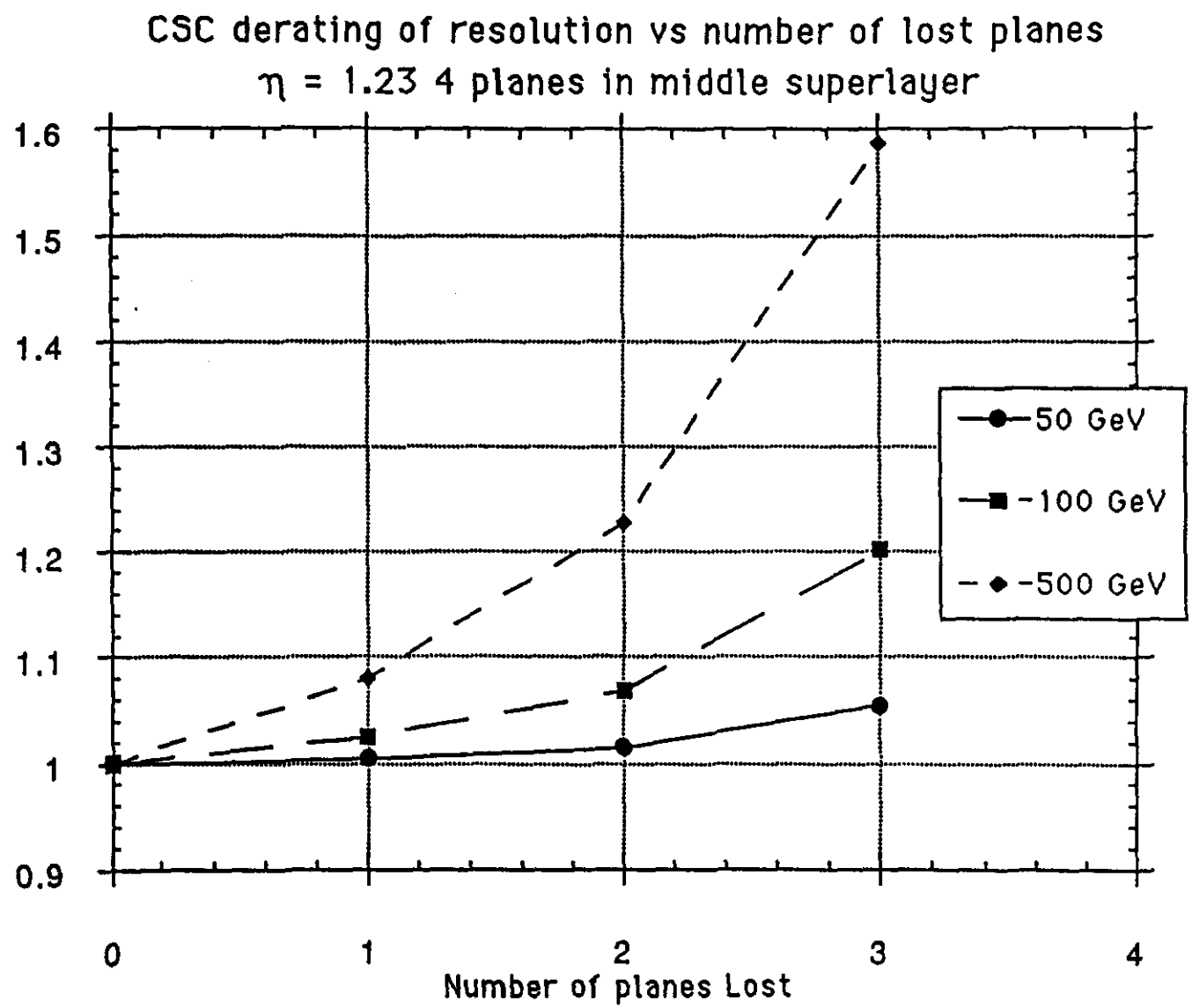

CSC Everywhere
δPt/Pt (%)
10
1
0
0.5
1
1.5
2
2.5
3
η
50 GeV
100 GeV
500 GeV
1 TeV

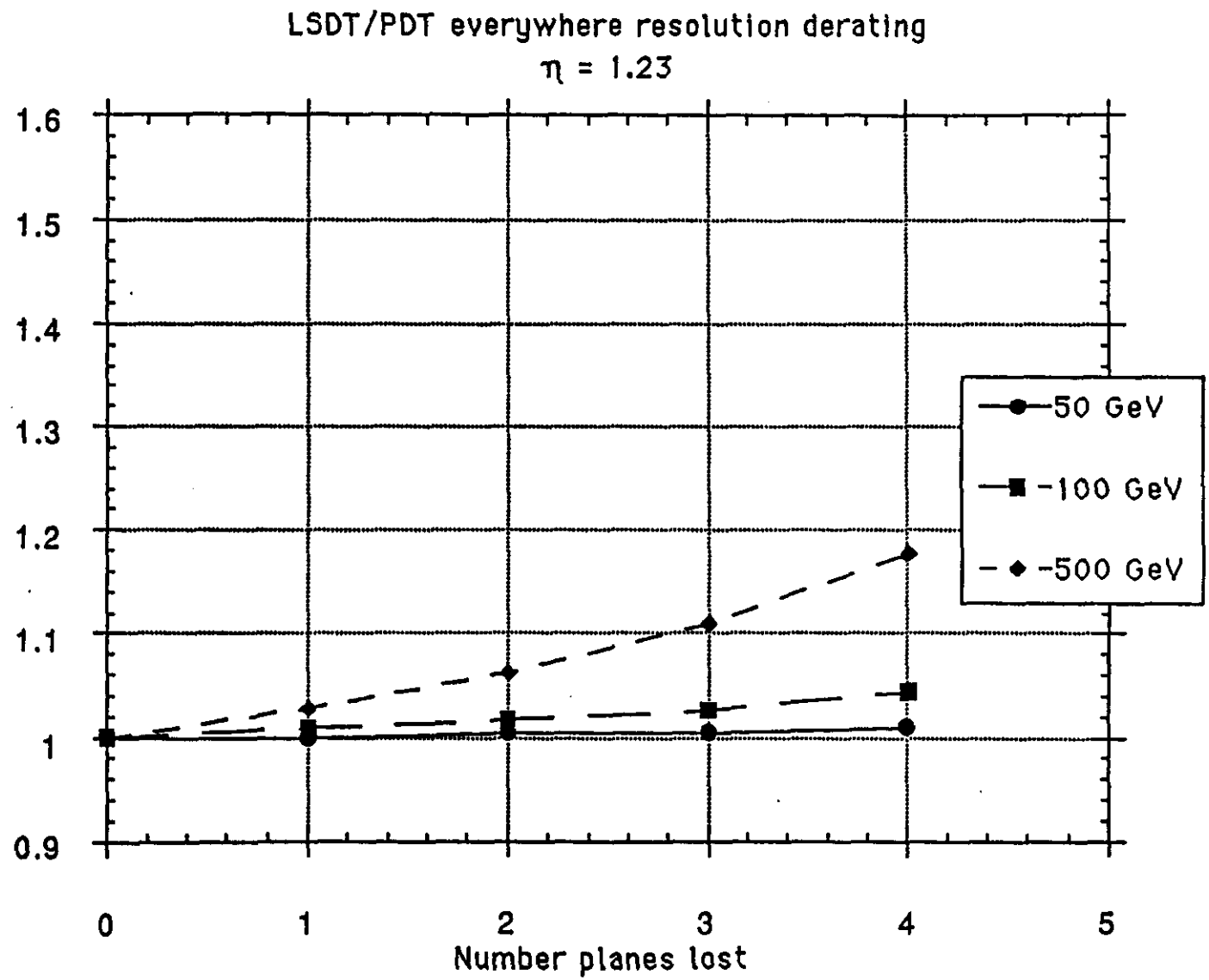

LSDT/PDT Everywhere
δPt/Pt (%)
10
1
0
0.5
1
1.5
2
2.5
3
η
50 GeV
100 GeV
500 GeV
1 TeV

C-LINE #62037
CLEAR TOPPER

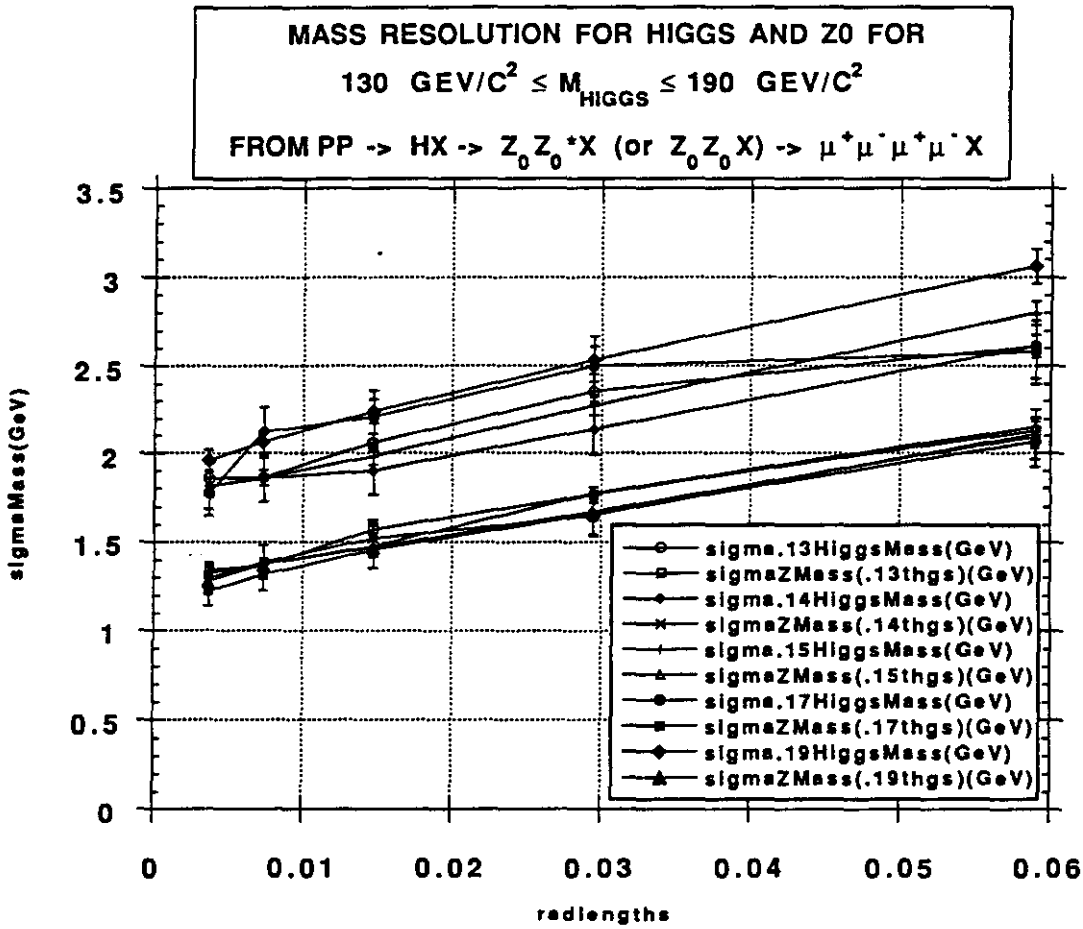



LSDT/PDT derating of resolutions vs number of planes lost
η = 0
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0
1
2
3
4
5
Number planes lost
50 GeV
-100 GeV
-500 GeV


CSC derating of resolution vs number of lost planes
η = 1.23 4 planes in middle superlayer
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0
1
2
3
4
Number of planes Lost
50 GeV
100 GeV
500 GeV


LSDT/PDT everywhere resolution derating
η = 1.23
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0
1
2
3
4
5
Number planes lost
50 GeV
-100 GeV
-500 GeV

L. Rosenson


MASS RESOLUTION FOR HIGGS AND Z0 FOR
130 GEV/C² ≤ M_HIGGS ≤ 190 GEV/C²
FROM PP -> HX -> Z0Z0*X (or Z0Z0X) -> μ+μ-μ+μ-X
sigmaMass(GeV)
radiengths
sigma.13HiggsMass(GeV)
sigmaZMass(.13thgs)(GeV)
sigma.14HiggsMass(GeV)
sigmaZMass(.14thgs)(GeV)
sigma.15HiggsMass(GeV)
sigmaZMass(.15thgs)(GeV)
sigma.17HiggsMass(GeV)
sigmaZMass(.17thgs)(GeV)
sigma.19HiggsMass(GeV)
sigmaZMass(.19thgs)(GeV)