GEM TN-93-282

Muon Group Meeting - SSCL: Muon Technology Choice Performance Comparisons

January 18-19, 1993

Abstract:

Agenda, attendees, and presentations of the GEM Muon Group Meeting held at the SSC Laboratory on January 18-19, 1993.

Muon Technology Choice
Performance Comparisions
January 18, 1993
12:30 - 7:00
Holiday Inn - Duncanville

General Remarks	Taylor	
Layout of Chambers	Nimblett	12:30-12:50
CSC Chamber Alignment	Sawicki	12:50-1:00
CSC Chamber Construction	Kiryushin	1:00-1:30
Trigger	Atiya	1:30-1:50
Test Results	Polychronakos	1:50-2:20
System Performance	Whitaker	2:20-2:50
Houston Option	Weinstein	2:50-3:30
Break		3:30-4:00
Layout of Chambers BL2A (RDT & RPC)	Miller	4:00-4:30
RDT Chamber Construction	Bromberg	4:30-5:00
RPC Chamber Construction and Tests	Bionta/Wuest	5:00-5:30
Test Results at TTR	Korytov	5:30-6:00
Trigger Schemes	Pless,/Korytov	6:00-6:30
System Performance	Bromberg	6:30-7:00

GEM
Muon Technology Choice,
Performance Comparisons
MEETING
January 18, 1993

ATTENDANCE LIST

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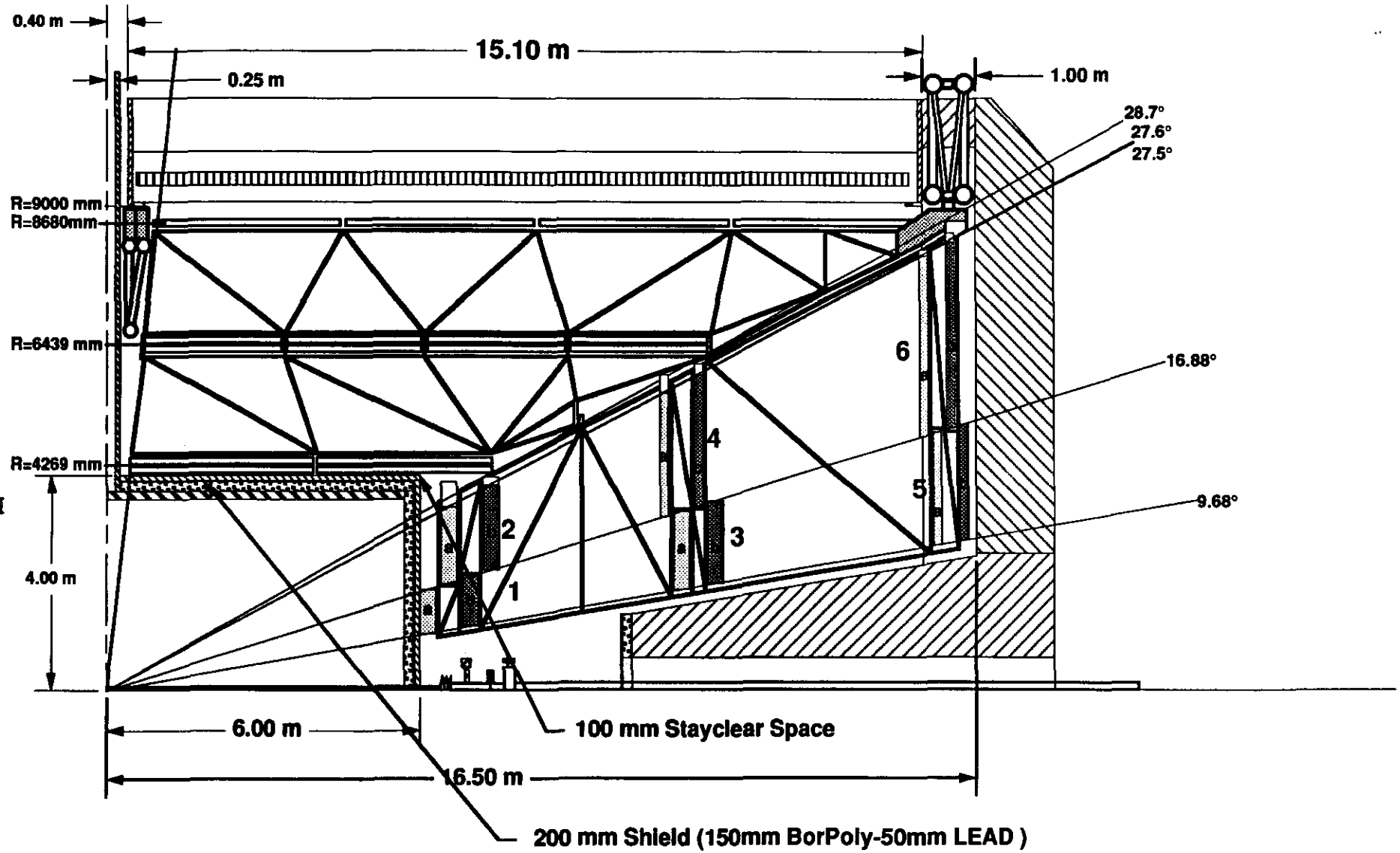
The CSC System Layout

Presentation by:

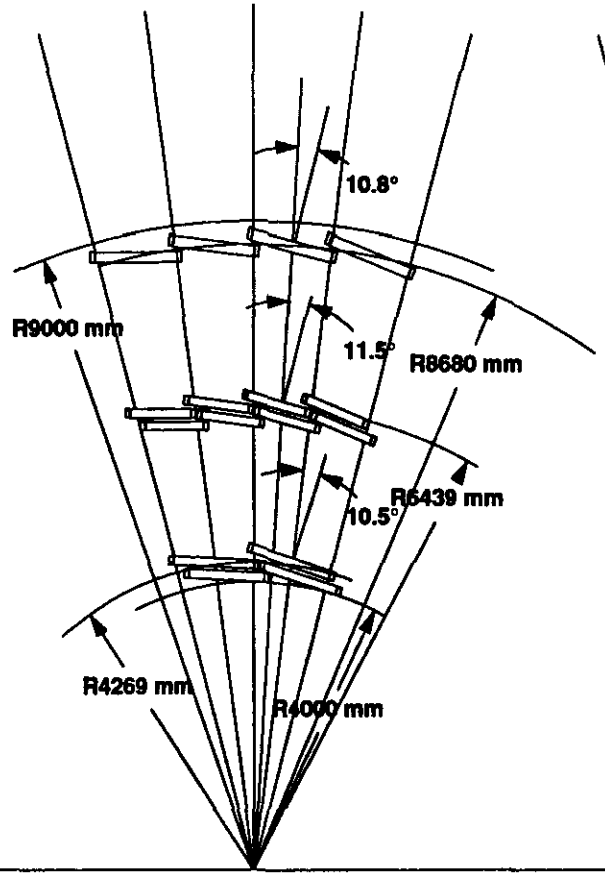
F. Nimblett



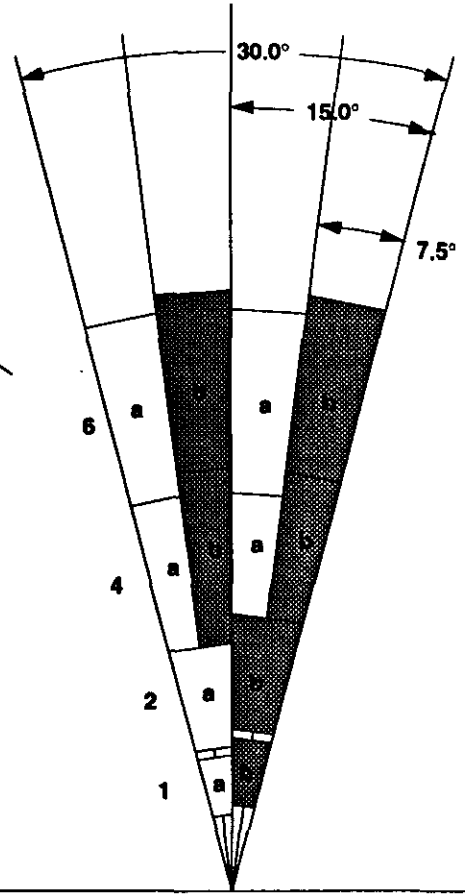
GEM CSC Muon System Layout

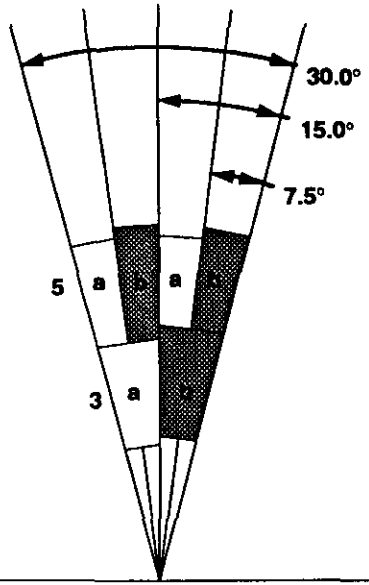
(6-6-4 Gaps per Superlayer Barrel)
(Version "h" Endcap)

Frank Nimblett
18 January '93



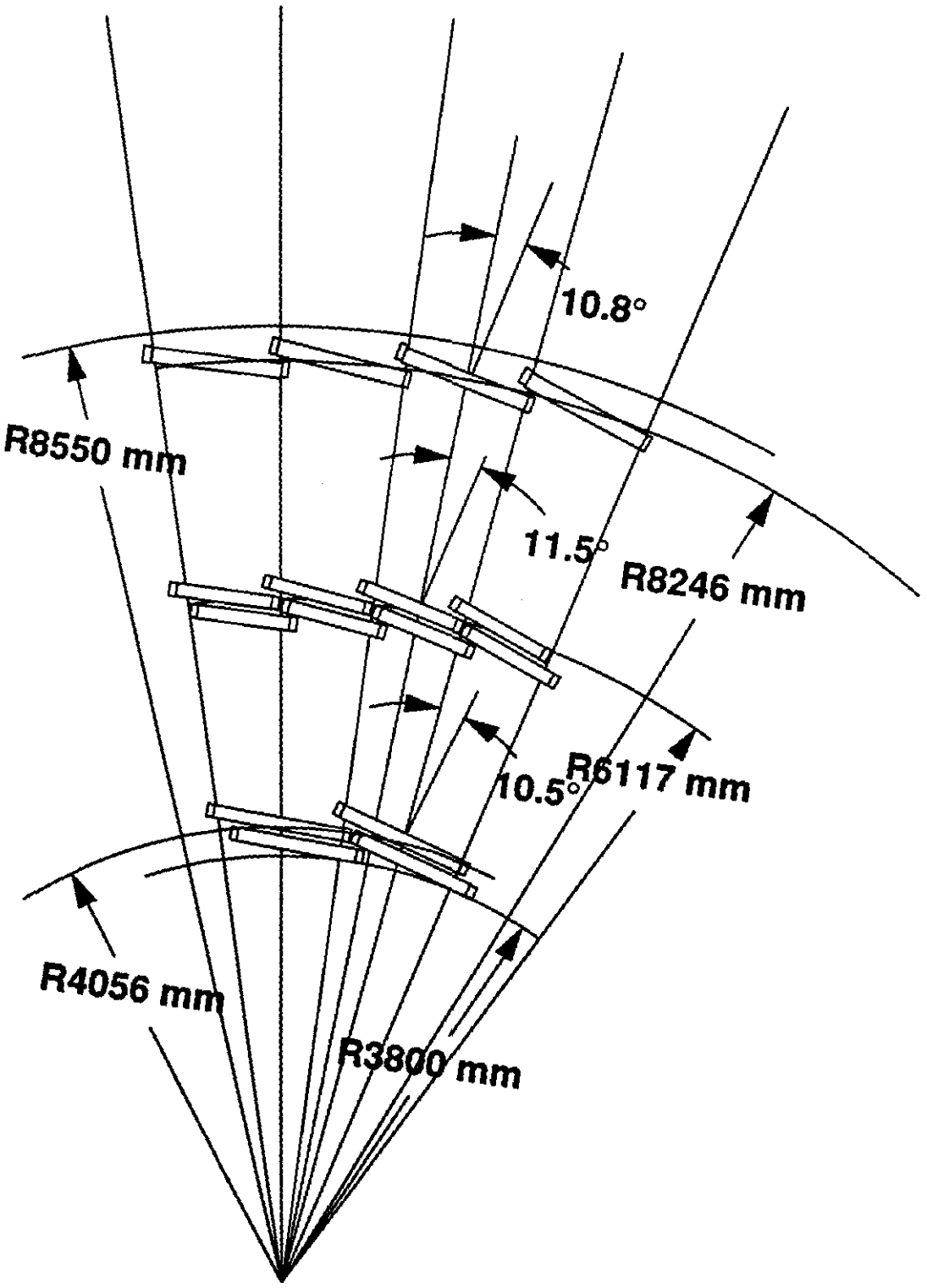
Barrel Region 100% Phi Overlap**
(6-6-4 Gaps per Superlayer)





CSC Endcap Version "h" Chamber Layout
(segmentation of each group)

Frank Nimblett
18 January '93



Barrel Region 100% Phi Overlap
(6-6-4 Gaps per Superlayer)**

φ = chamber <u>half-angle</u> (°)

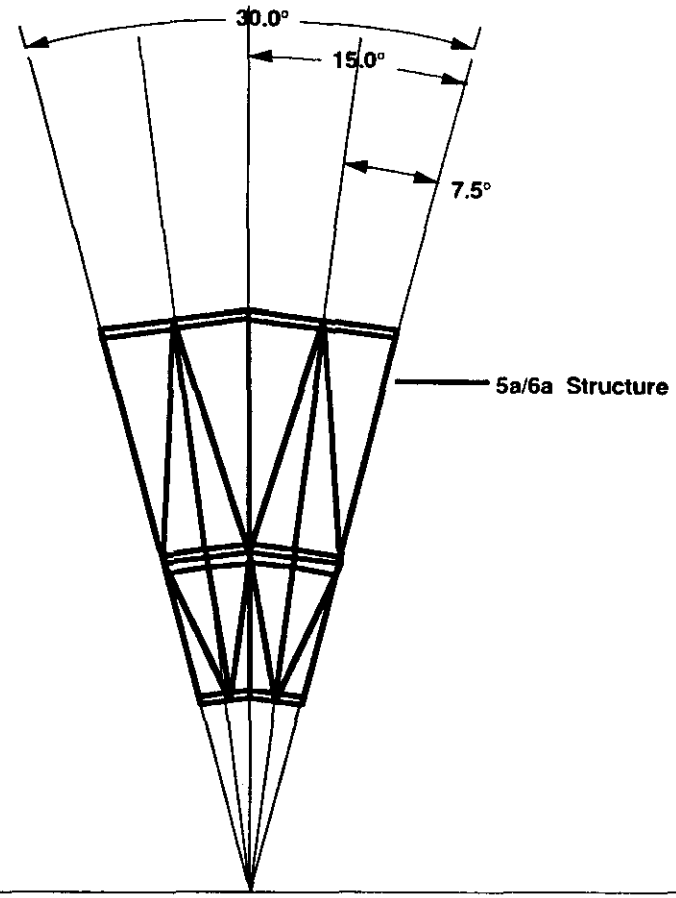
θ = Chamber tilt angle (°)

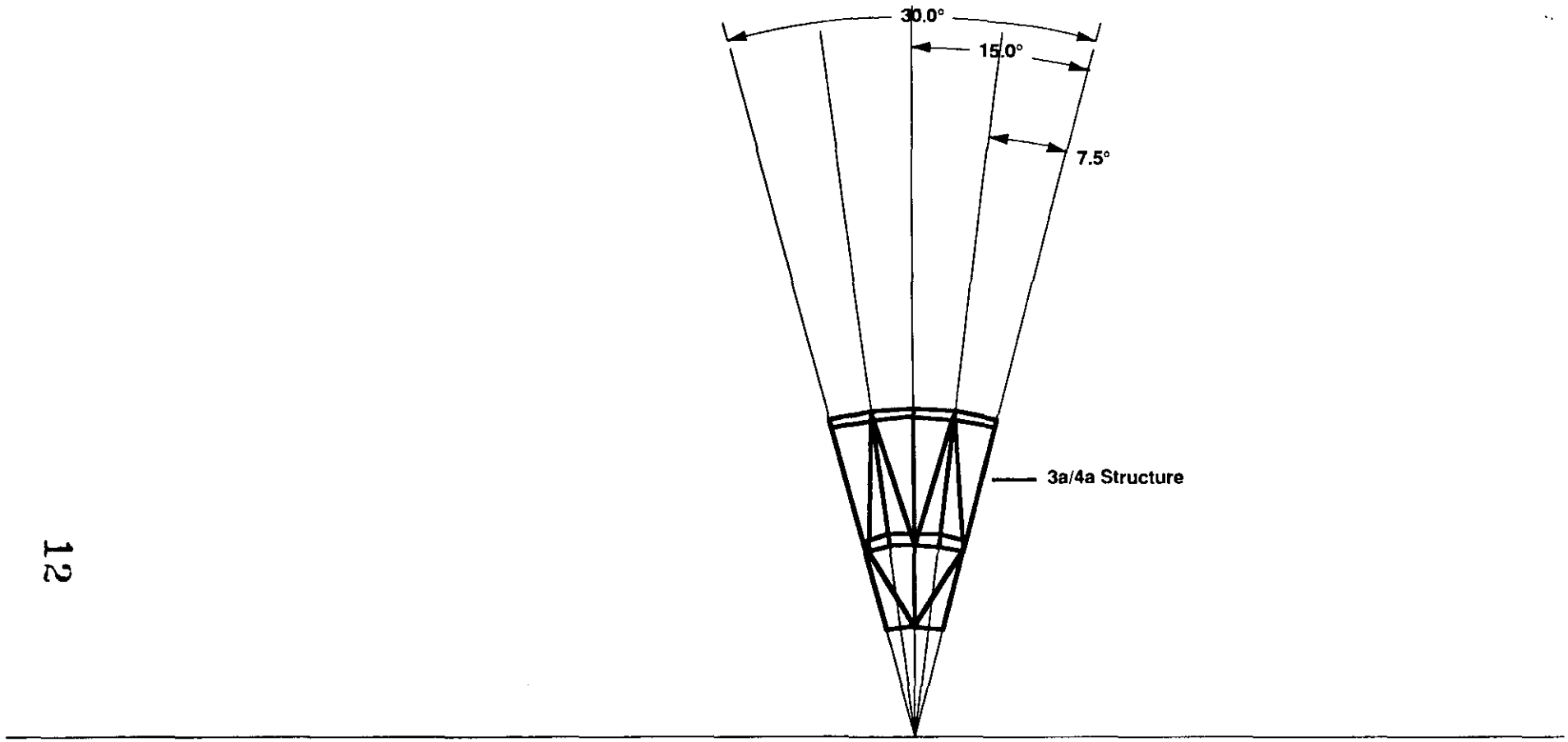
L = Lorentz angle of gas (°)

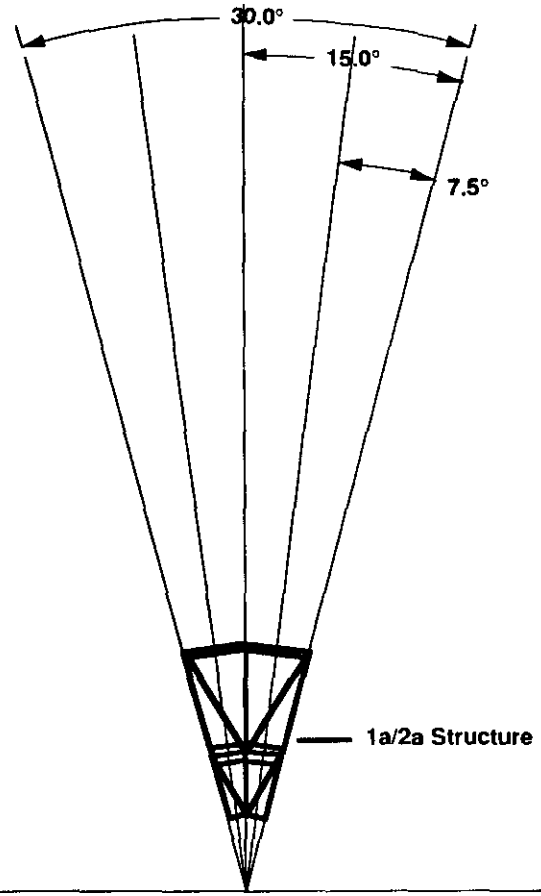
$$|L - \theta| + \varphi < 6^\circ \qquad L = 8^\circ$$

Superlayer	φ	θ	Sum
Inner	7.5°	10.5°	10°
Middle	3.75°	11.5°	7.25°
Outer	3.75°	10.8°	6.55°

F. Nimblett
18 January 1993


30.0°
15.0°
7.5°
5a/6a Structure


30.0°
15.0°
7.5°
3a/4a Structure

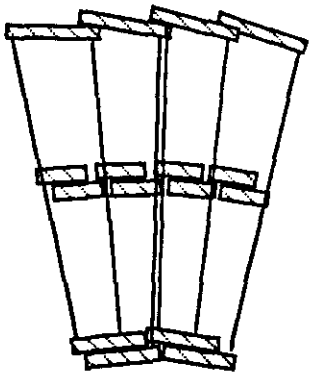

30.0°
15.0°
7.5°
1a/2a Structure

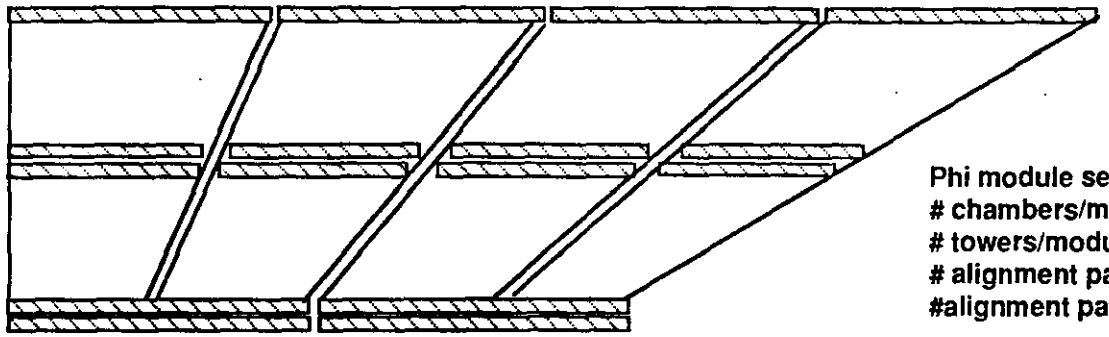
The CSC System Alignment

Presentation by:

R. Sawicki

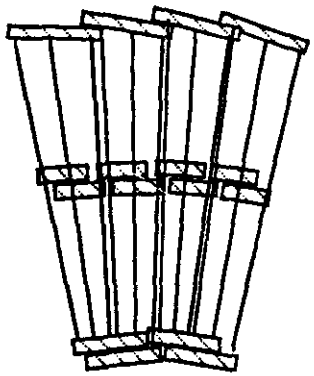
CSC barrel alignment configuration

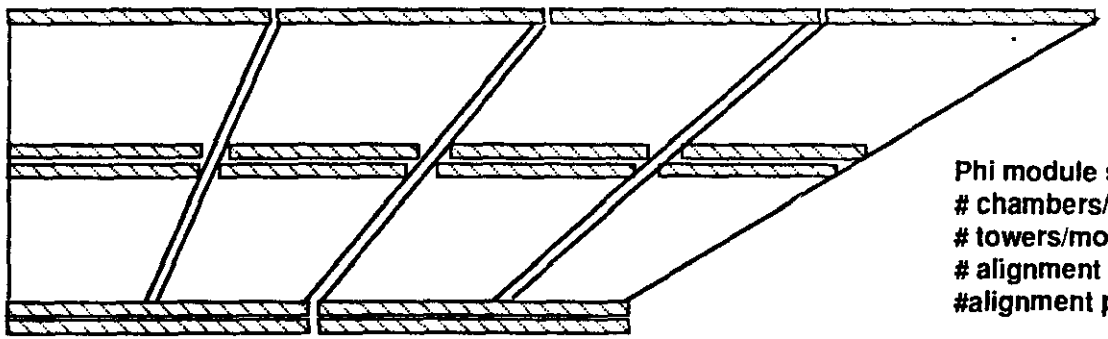




Phi module segmentation = 12
chambers/module = 56
towers/module = 8
alignment paths/module = 48
#alignment paths/GEM = 1152

Configuration with rigid chamber coupling in phi direction

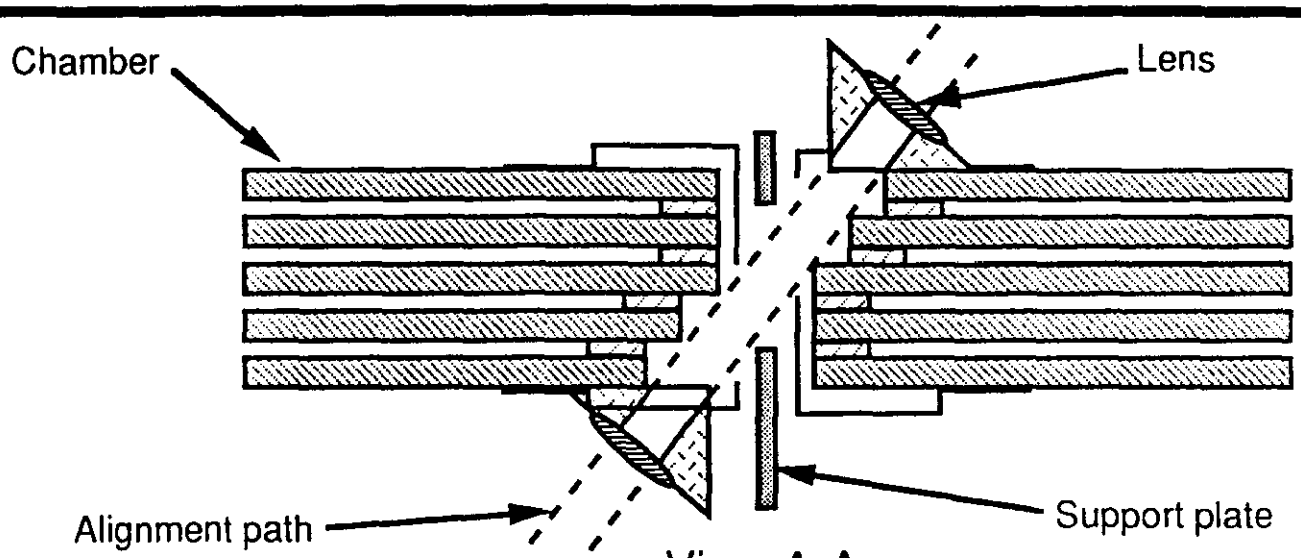




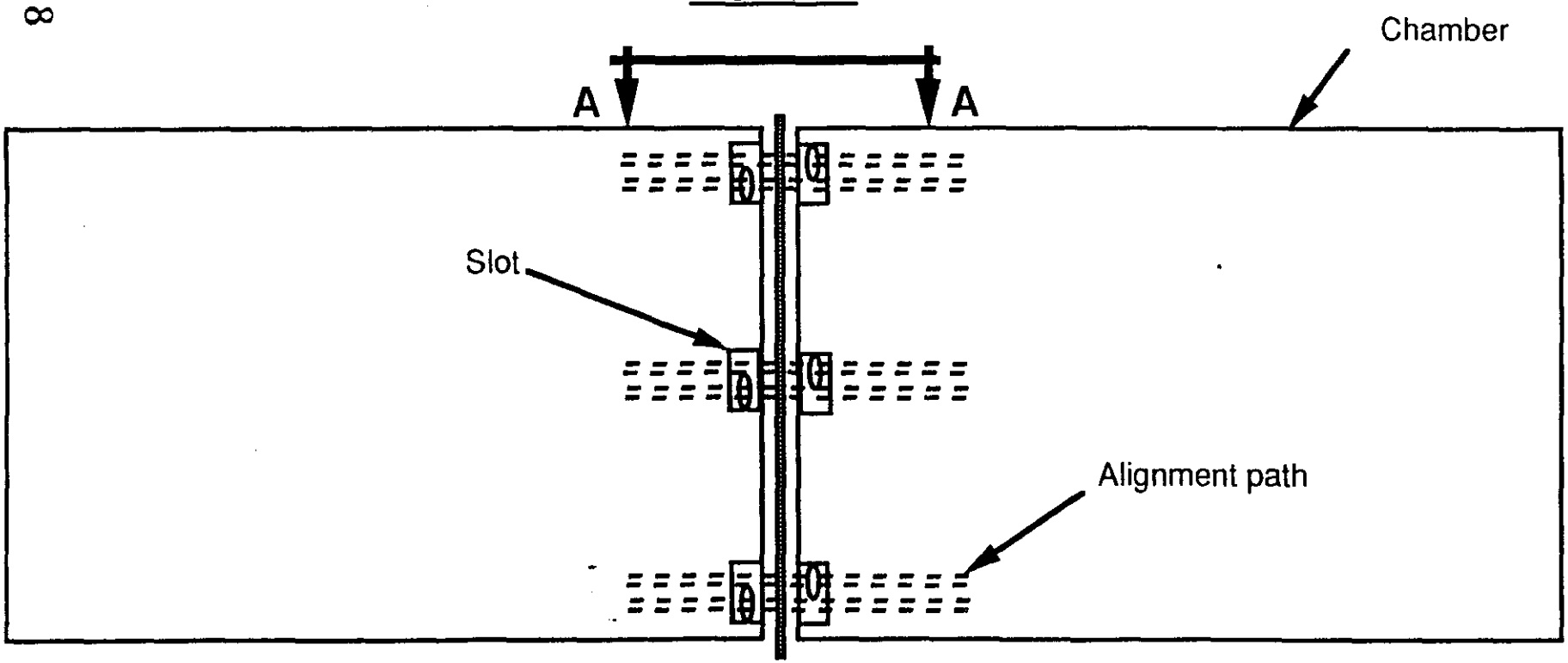
Phi module segmentation = 12
chambers/module = 56
towers/module = 16
alignment paths/module = 96
#alignment paths/GEM = 2304

Configuration with no rigid chamber coupling in phi direction

Barrel region alignment slots

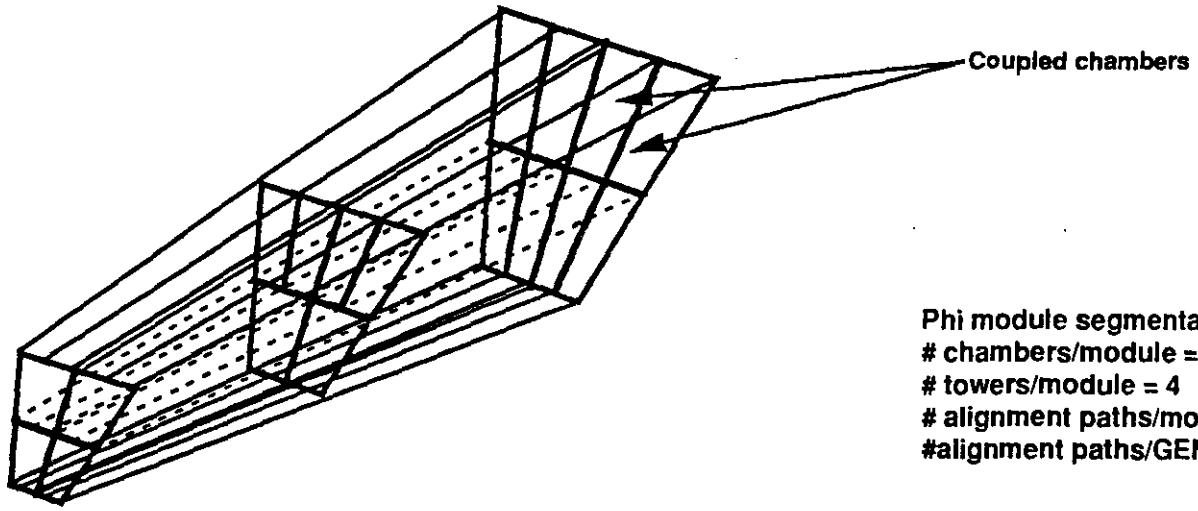


View A-A



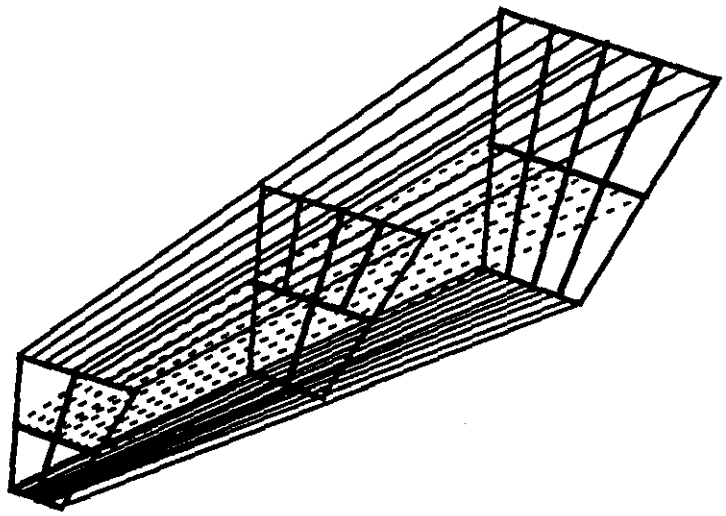
Not drawn to scale

CSC endcap alignment configuration



Phi module segmentation = 12
chambers/module = 24
towers/module = 4
alignment paths/module = 24
#alignment paths/GEM = 1152

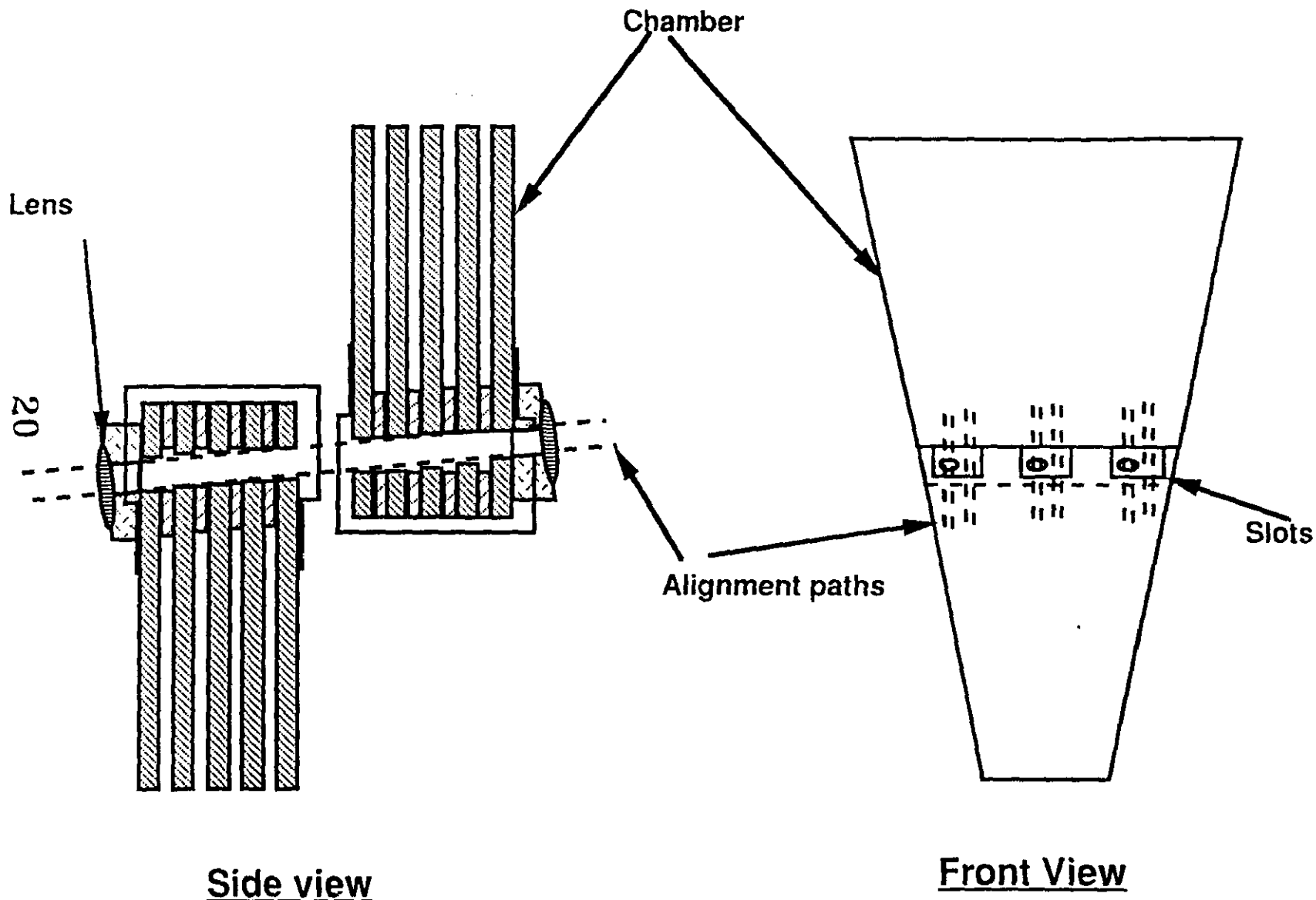
Configuration with rigid chamber coupling in phi direction



Phi module segmentation = 12
chambers/module = 24
towers/module = 8
alignment paths/module = 48
#alignment paths/GEM = 2304

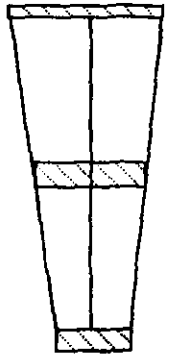
Configuration with no rigid chamber coupling in phi direction

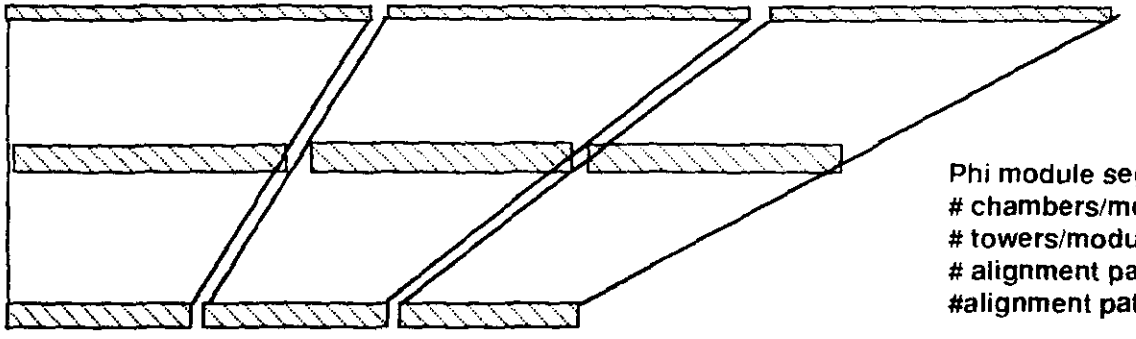
Endcap region alignment slots



Not drawn to scale

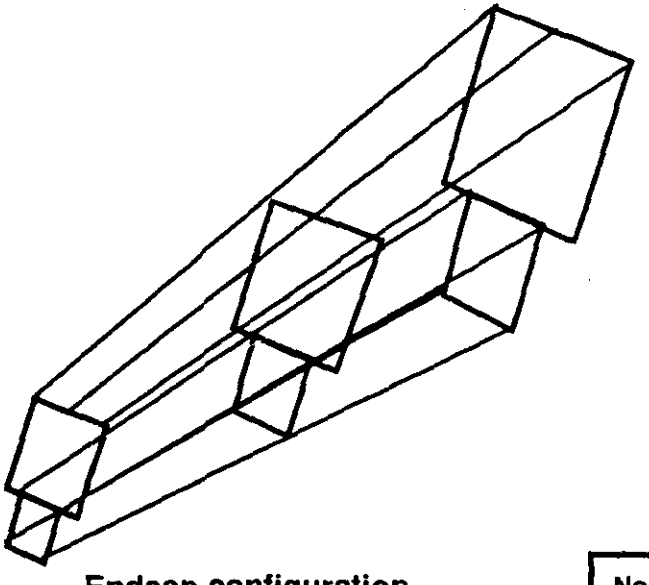
RDT alignment configurations





Phi module segmentation = 16
chambers/module = 9
towers/module = 3
alignment paths/module = 18
#alignment paths/GEM = 576

Barrel configuration with rigid chamber coupling in phi direction



Phi module segmentation = 16
chambers/module = 6
towers/module = 2
alignment paths/module = 9
#alignment paths/GEM = 288

Endcap configuration

Note: Resolution and 6 degree of freedom rigid body motion discrimination has not been verified with fewer than 6 projective alignment paths in endcap

Alignment path comparison

	#Alignment paths	Alignment channel cost - K$
CSC (no chamber coupling)	4608	2995
CSC (with chamber coupling)	2304	1497
RDT (with chamber coupling)	864	561

Notes:
1) alignment channel cost = $650
2) Endcap towers have fewer than 6 alignment paths

The CSC Chamber Construction

Presentation by:

Yu. Kiryushin

CSC construction

presented by

Yu. Kiryushin

BNL - JINR

· Structure of the chamber

For layout 6/6/4

INNER	- 3 gap
Middle	- 3 gap
Outer	- 4 gap

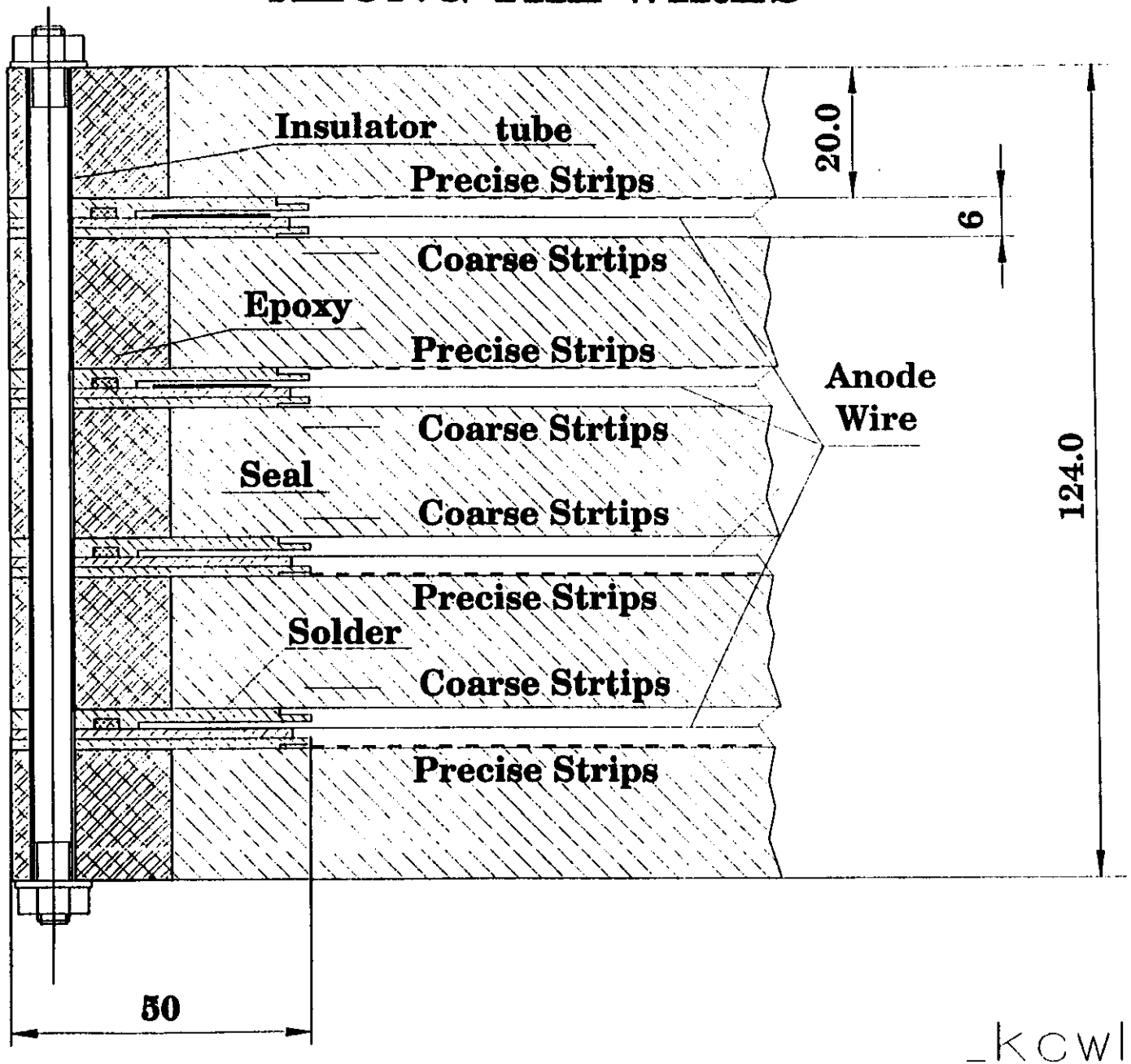
gap of the chamber

INNER	- 3 MM
MIDDLE	- 4 MM
Outer	- 5 MM

- BASE ELEMENT - HONEYCOMB PANEL

  - NOMEX CORE - 19 MM thick
  - skin layers - 0,5 MM thick G10
  - FRAMES - 25 MM width G10
  - THICKNESS TOLERANCE ±1 MM
  - FLATNESS TOLERANCE ±50 μk
  - PARALLELISM OF THE SIDES ±50 μk

CROSS SECTION ALONG THE WIRES



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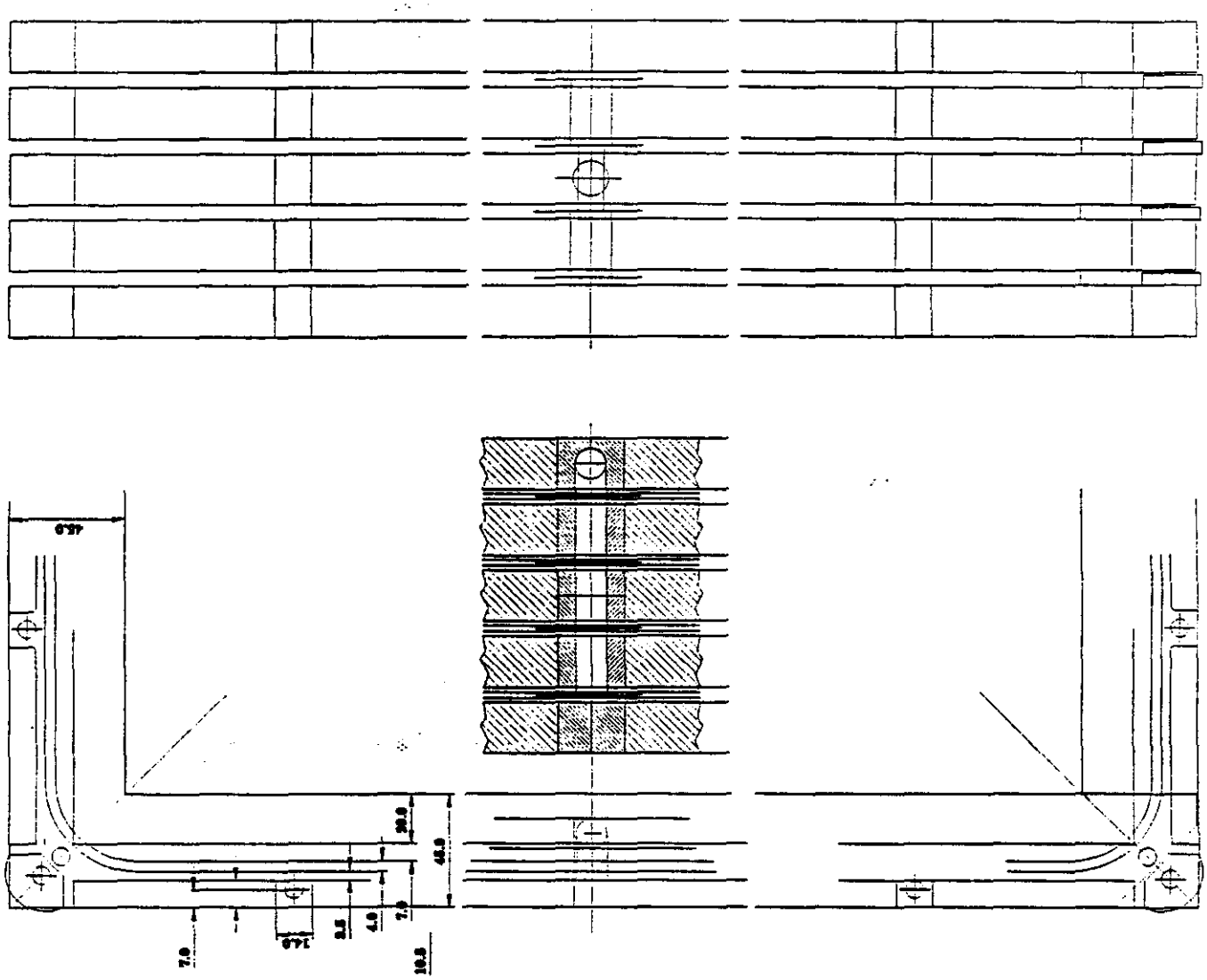


_k38.ems

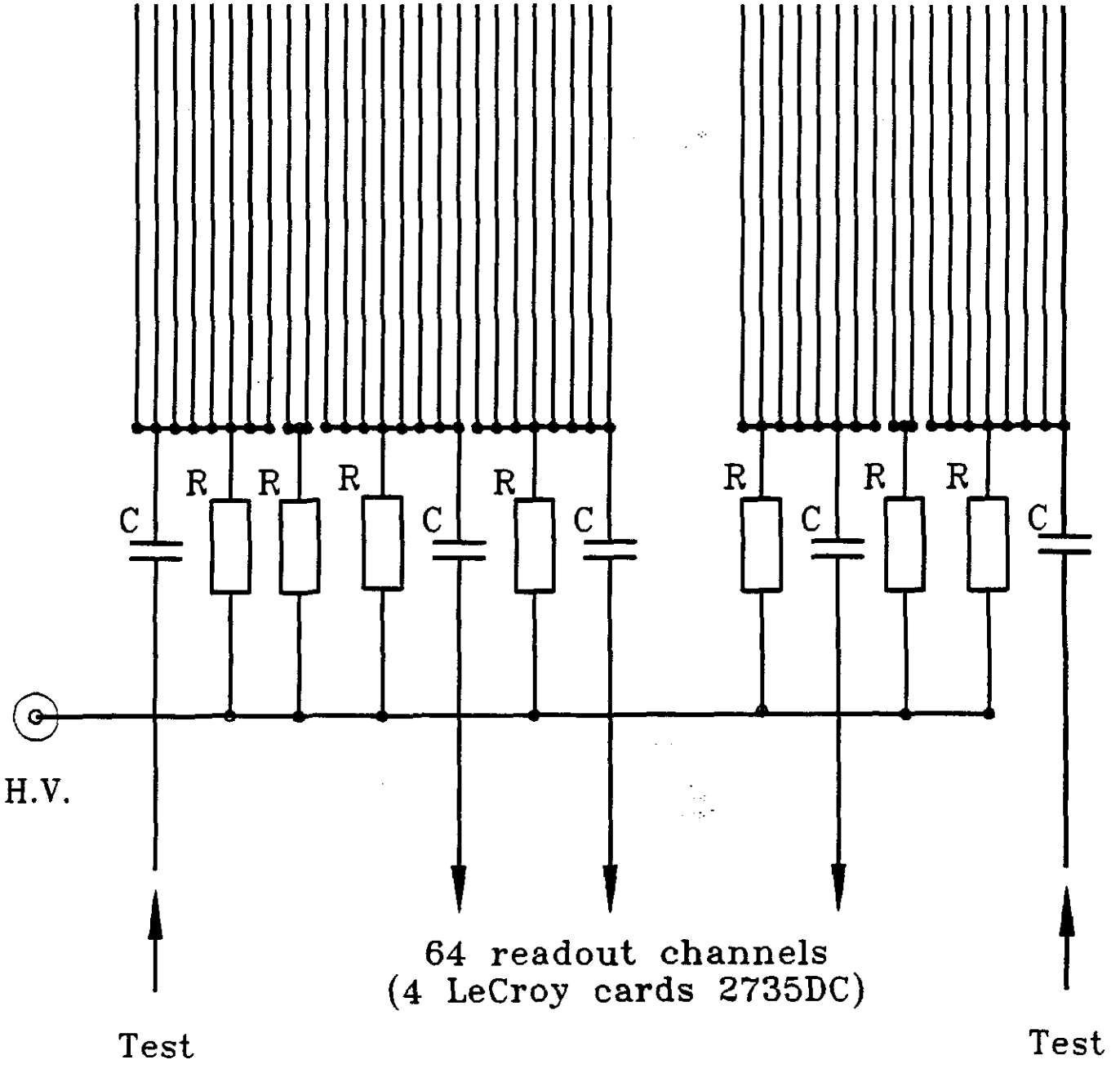
· wire plane

wire spacing	2.5 mm
wre Ø	30 μk
wire tension	≥150 g

the wires are soldered to the printed board and glued by epoxy

all the wires are grouped in groupes of 40 wires

WIRE PLANE

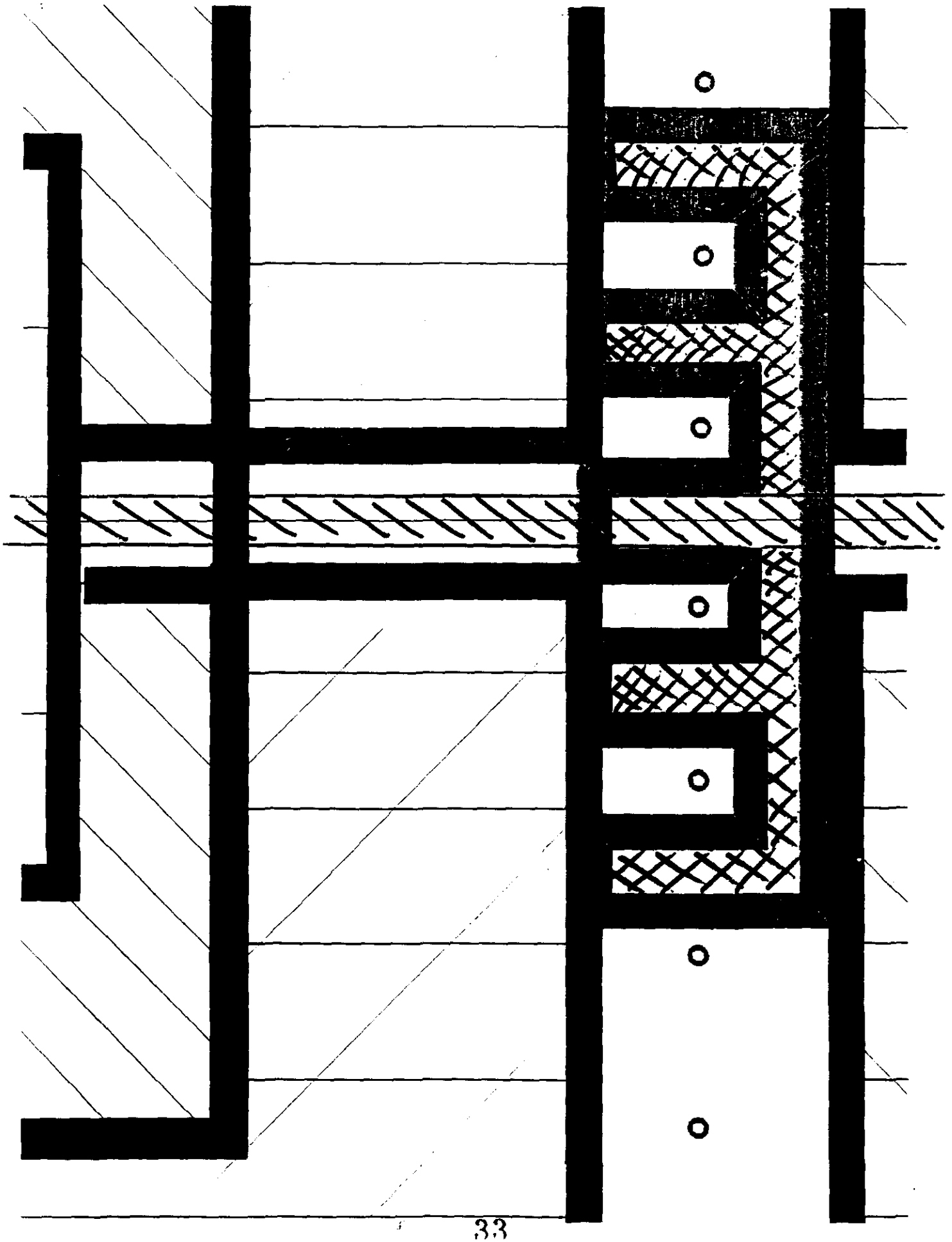

R
R
R
R
R
R
R
C
C
C
C
C
H.V.
64 readout channels
(4 LeCroy cards 2735DC)
Test
Test

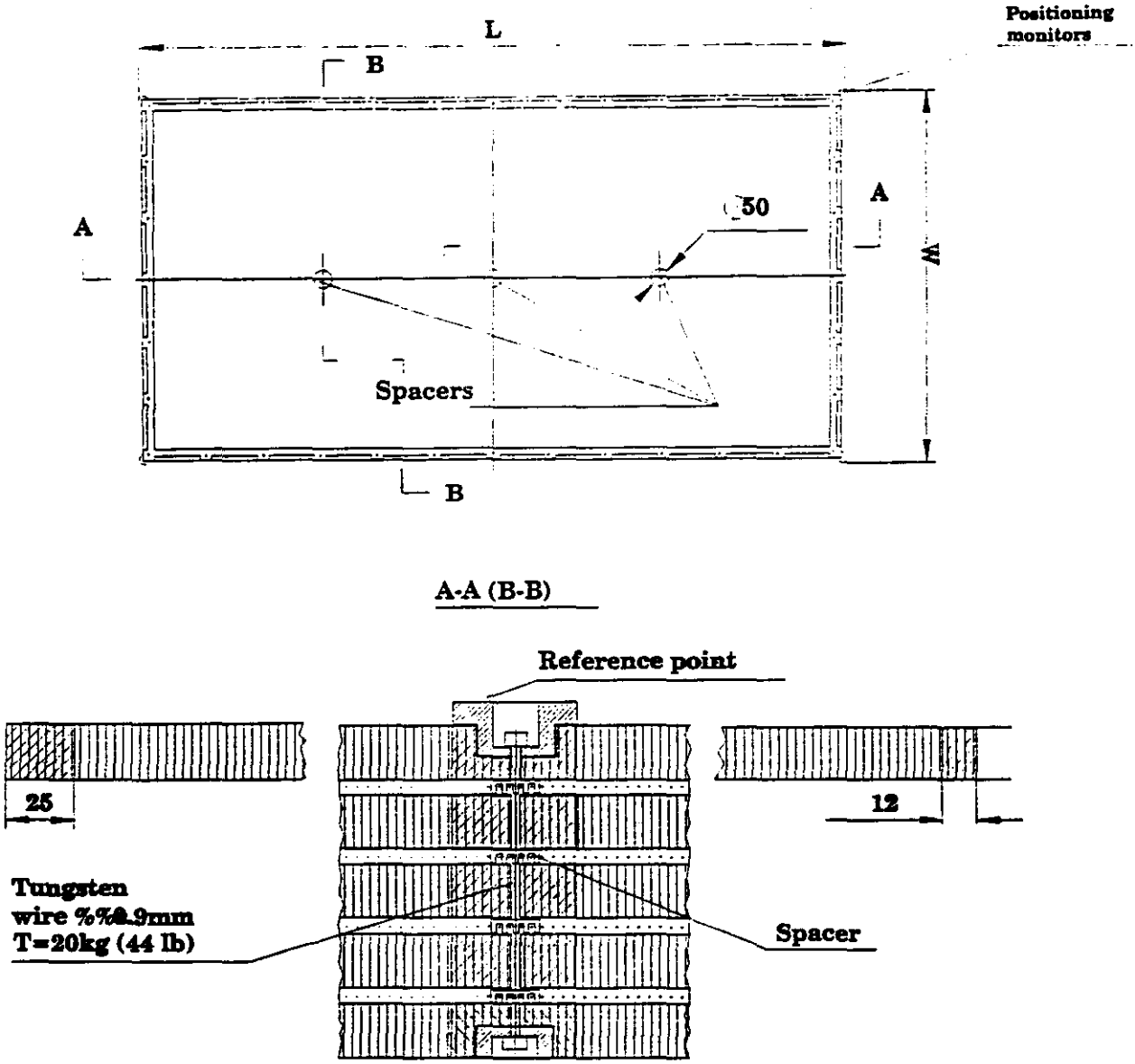
· spacer

-3 spacers should be installed in the chamber to prevent any disturbtion of the gap of the chamber

all the panels should be tighten with a force

20 ÷ 30 kg





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

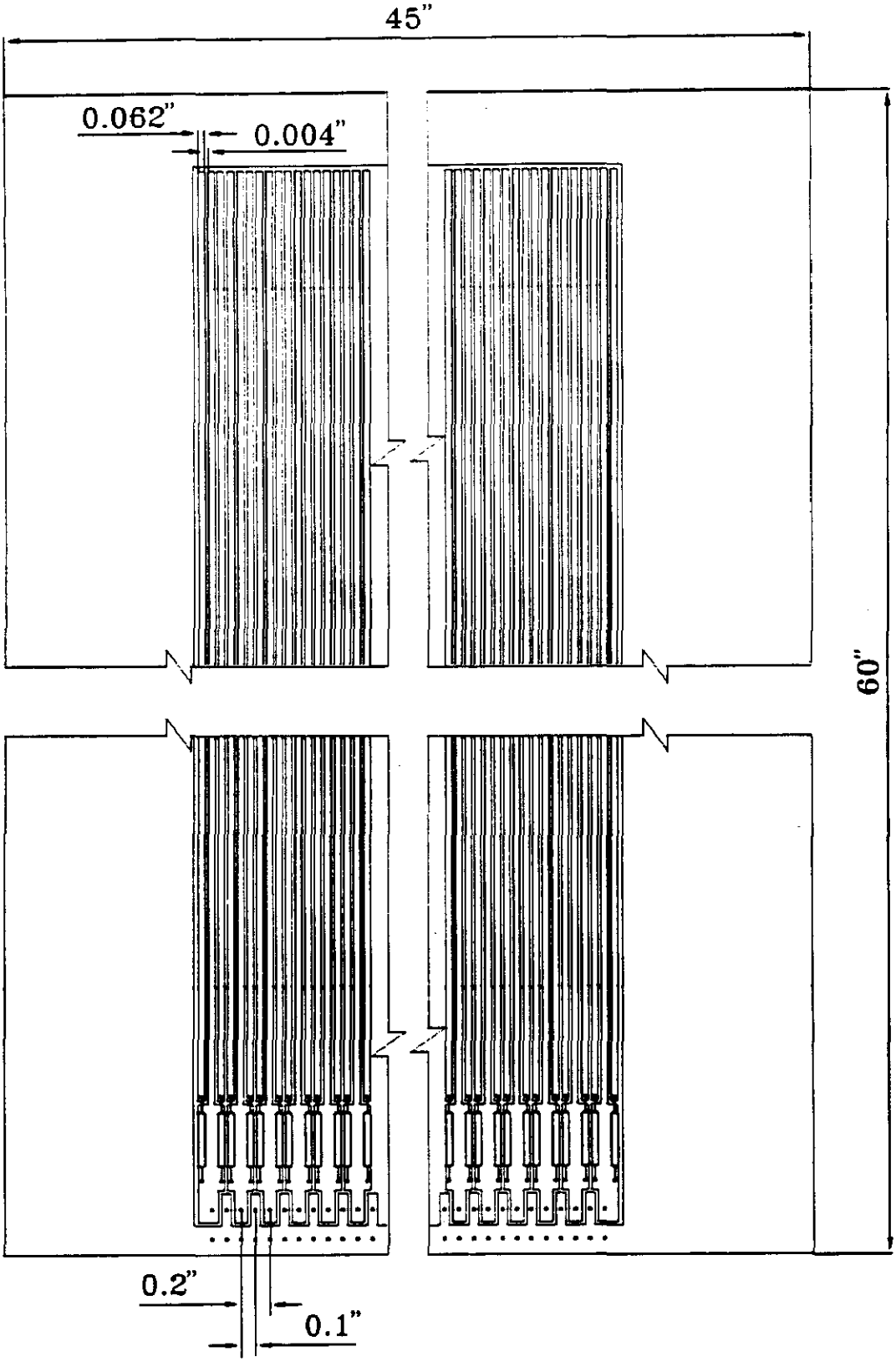
Y.Ershov
I.Golutvin
V.Vysiakov
S.Movchan

_kc7t.ems

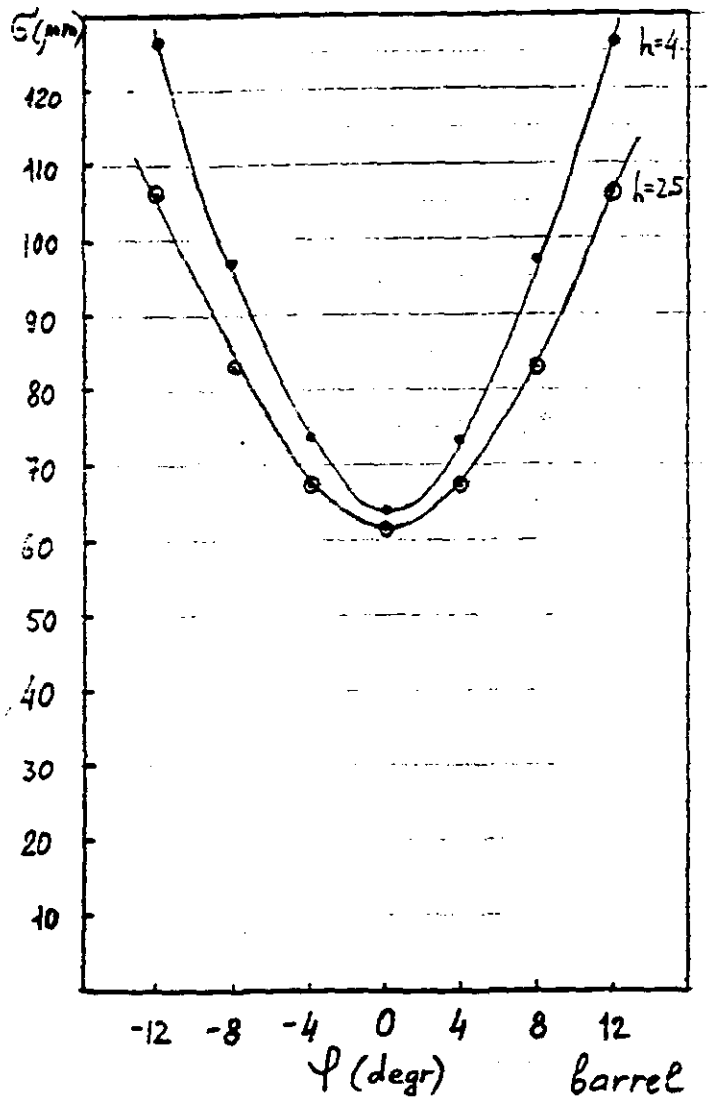
Fig. 2.8

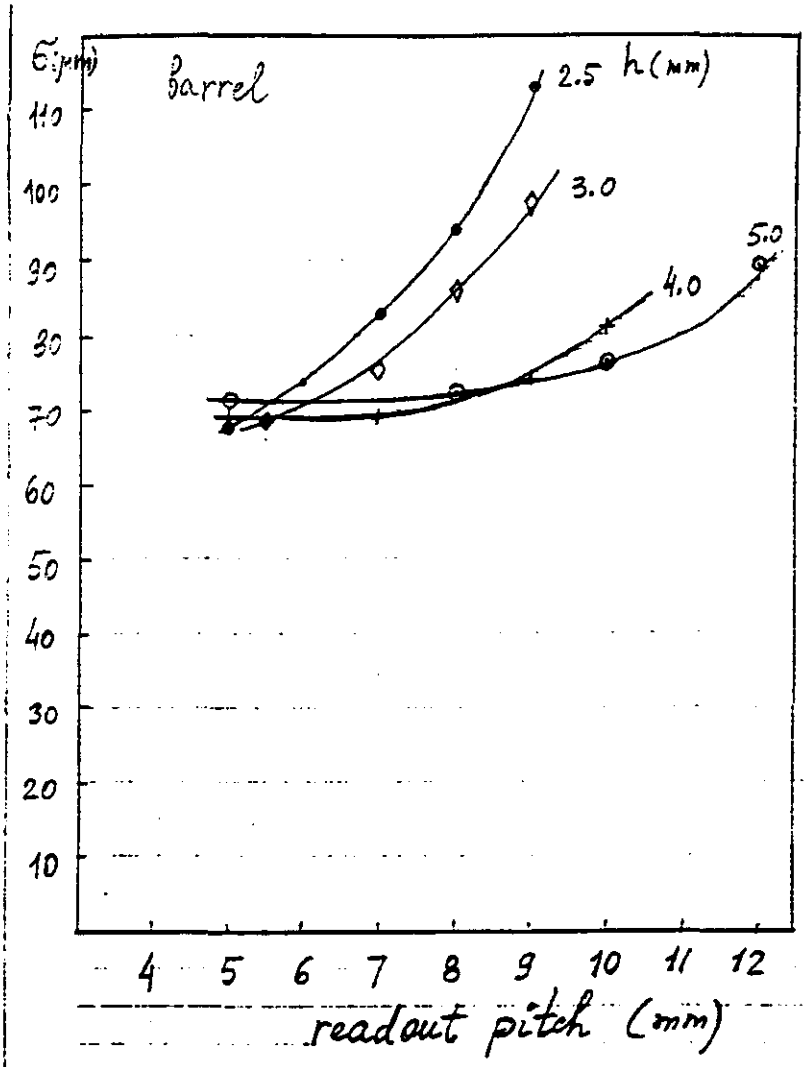
- Strip cathode
- strip readout pitch is different for layers
  - gap 3 MM - 5.5 MM
  - gap 4 MM - 8.1 MM
  - gap 5 MM - 10 MM
- Each strip channel consist of one readout and two floating strips
  - strip gap - 0.4 MM
  - cooper thickness - 17 μk

STRIP CATHODE



- All strips are grouped in groupes of 16 strips
- Each 16 strips from (4) 3 gaps of the chamber are connected to one card
- Connection of the strips to the card can be done by flat cable with ground shielding

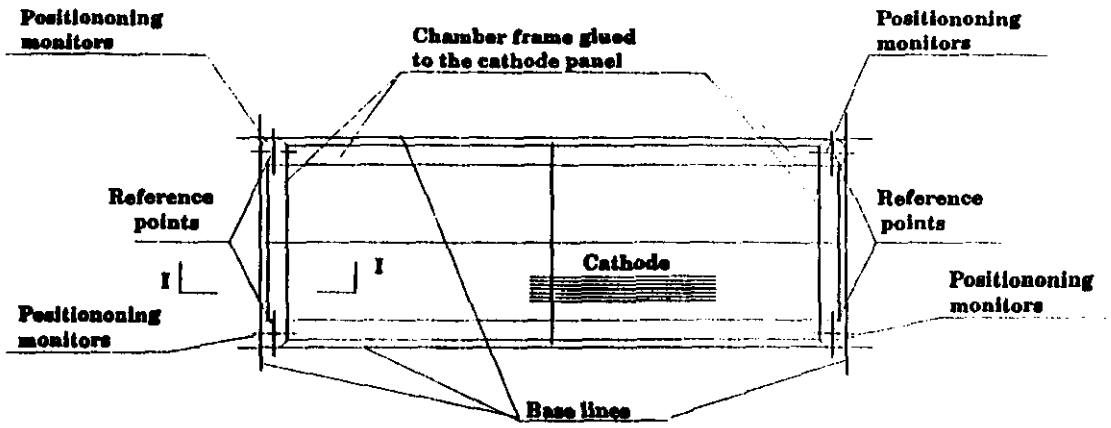

σ (μm)
120
110
100
90
80
70
60
50
40
30
20
10
h=4
h=2.5
-12
-8
-4
0
4
8
12
φ (degr)
barrel

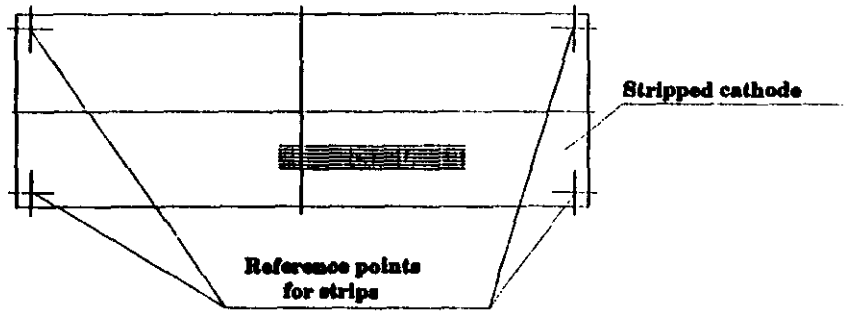

Barrel
h (мм)
2.5
3.0
4.0
5.0
110
100
90
80
70
60
50
40
30
20
10
4
5
6
7
8
9
10
11
12
readout pitch (mm)

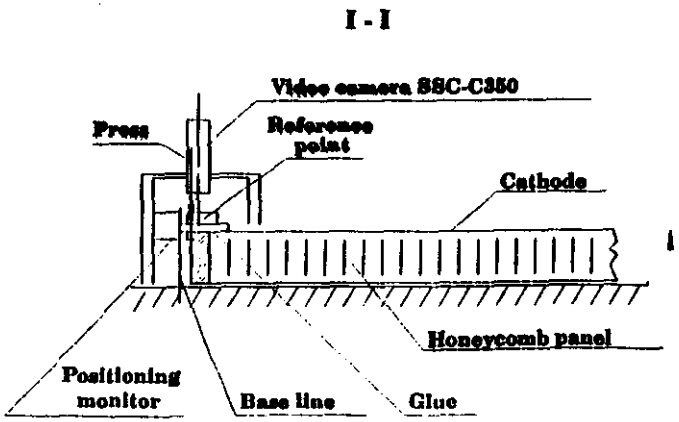
- Alignment

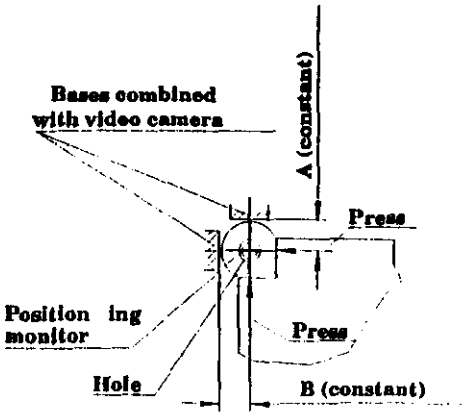
Each strip cathode panel has 4 precision washers wich overlapped the edge so as to be touchable for mechanical alignment

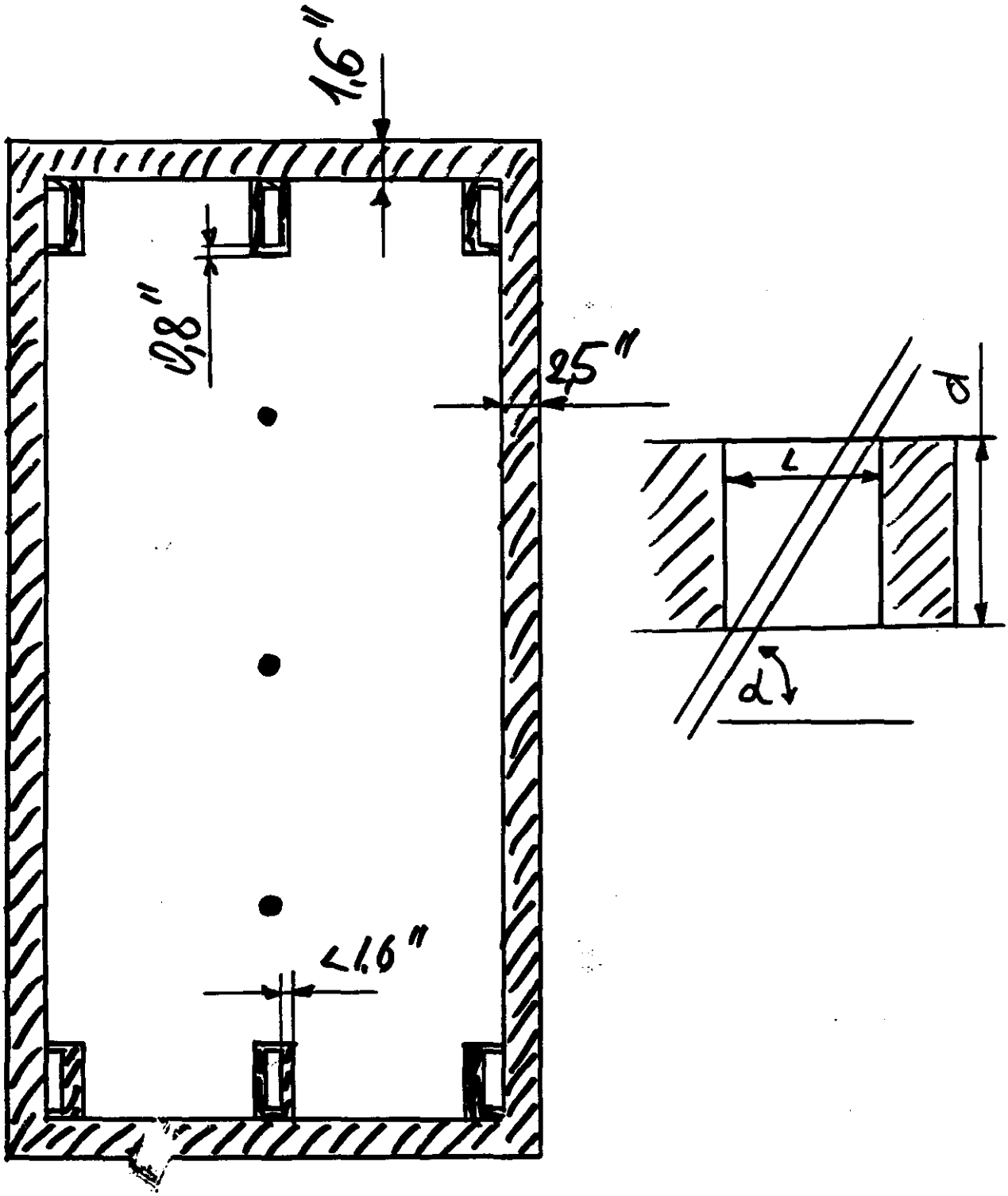
Each chamber in the middle layer has 6 slots to provide alignment in superlayers


Positiononing monitors
Chamber frame glued to the cathode panel
Positiononing monitors
Reference points
Reference points
I
I
Cathode
Positiononing monitors
Positiononing monitors
Base lines


Stripped cathode
Reference points for strips


I - I
Video camera SSC-C350
Press
Reference point
Cathode
Honeycomb panel
Positioning monitor
Base line
Glue


Bases combined with video camera
A (constant)
Press
Position ing monitor
Press
Hole
B (constant)


1,6"
0,8"
2,5"
<1,6"
L
d
α

Coverage loss for slots in mid plane CSC

6 slots per plane

1728 slots per layer

Active area in mid layer

$L = 2 \times 9524$ MM

$R = 9450$ MM

$\Delta \varepsilon = 6 \div 7\%$

Middle Layer, 3 chamber module

Area of chamber:
Length = 2.4 m
Width = 0.8 m
Total area = 1.92 m**2

Frame width = 0.050 m
Fraction of active area overlapped by frames: 0.104

component	material	density	cm/X0	thcknss (cm)	mass (Kg)	normal X0
Hexcel core	Nomex	0.14	485.7	2.0	19.74	0.0165
circuit boards	G10	1.70	19.40	0.05	13.06	0.0206
copper	copper	8.96	1.47	0.0017	2.34	0.00925
frames	G10	1.70	19.40	2.8	28.29	0.536

Total mass = 63.43 Kg
Mas per area = 33 Kg/m**2
X0's through center = 0.04635
X0's through frame = 0.536

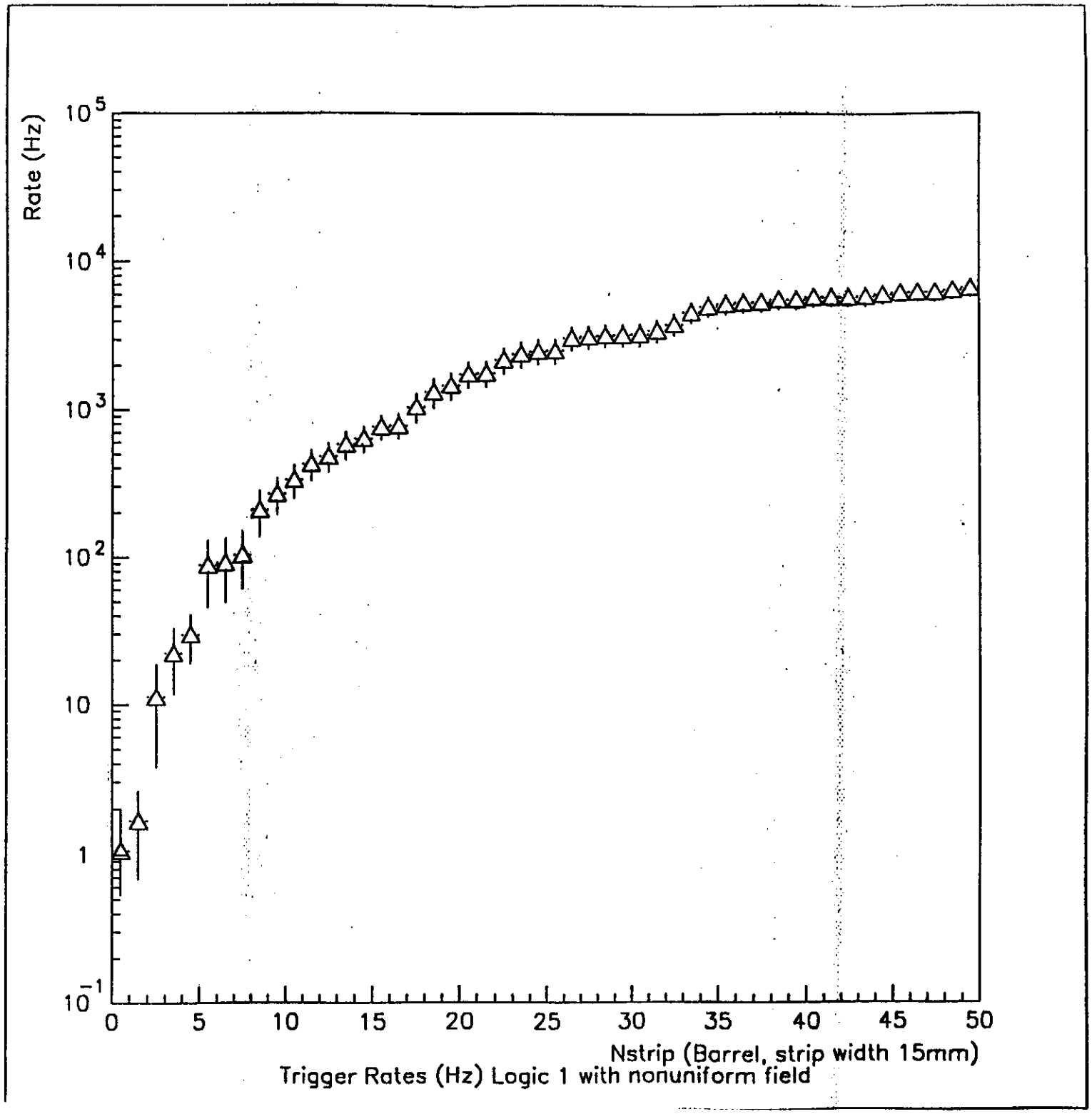
Conclusion:

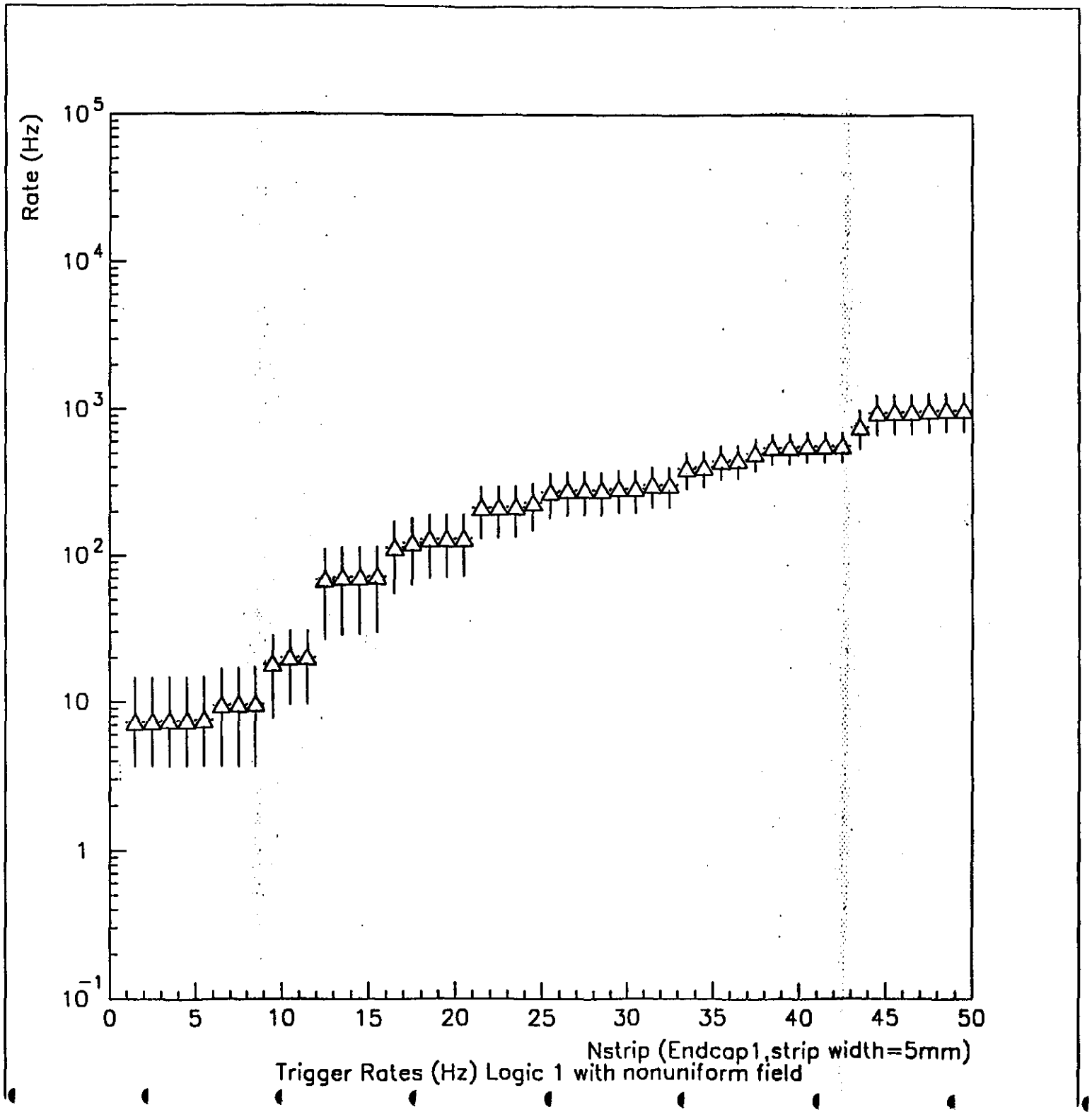
1. CSC has a rigid selfsuporting construction
2. Chamber construction techniqes USE a minimum of materials and those materials are low Z.
3. Wire placement tolerances are normal and easily achEVEd.
4. External reference to the precision strips for alignment is incorporated in the accurate cathode production by photo-lithography

The CSC Trigger

Presentation by:

M. Atiya


Rate (Hz)
10^5
10^4
10^3
10^2
10
1
10^{-1}
0
5
10
15
20
25
30
35
40
45
50
Nstrip (Barrel, strip width 15mm)
Trigger Rates (Hz) Logic 1 with nonuniform field


Rate (Hz)
10^5
10^4
10^3
10^2
10
1
10^{-1}
0
5
10
15
20
25
30
35
40
45
50
Nstrip (Endcap1,strip width=5mm)
Trigger Rates (Hz) Logic 1 with nonuniform field

Muon Trigger Components:

(1) On Chamber Trigger IC (Trigg_Loc)

(2) On Detector Trigger Board (Trigg_Board)

(3) Supervisory Function Board (Sys_Control)

Trigg_Loc IC

(1) 1 (possibly 2) per 128 channels

(2) Total of about 6,000 IC's.

(3) Area dominated by I/O pins

(4) Candidate for 0.8 micron implementation

(5) Functions:

Receive Fast Trigger Discriminator signals
Use anode to time the signals
Control the readout chain using a list of hits
Drive encoded hits out to Trigg_Board

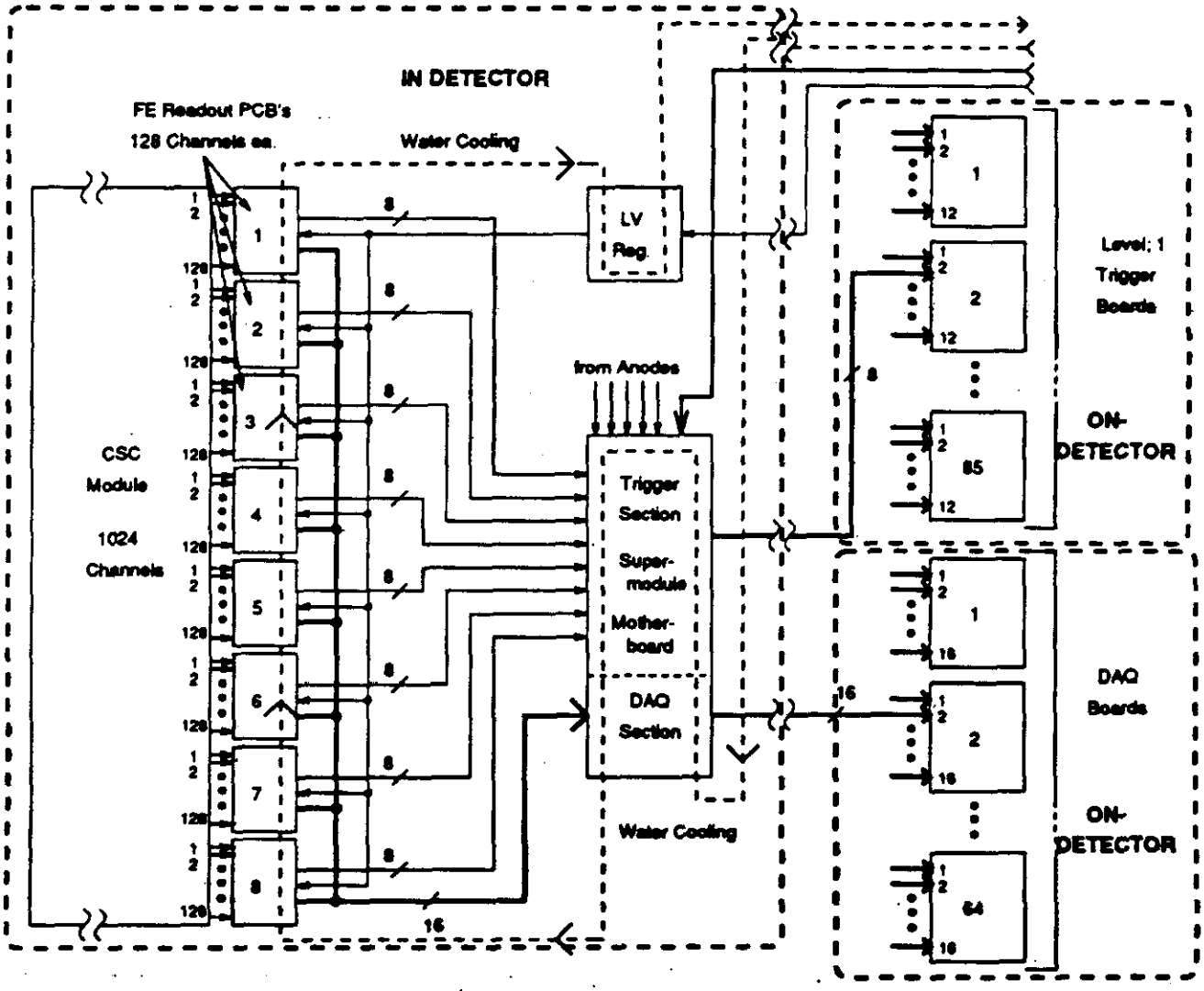
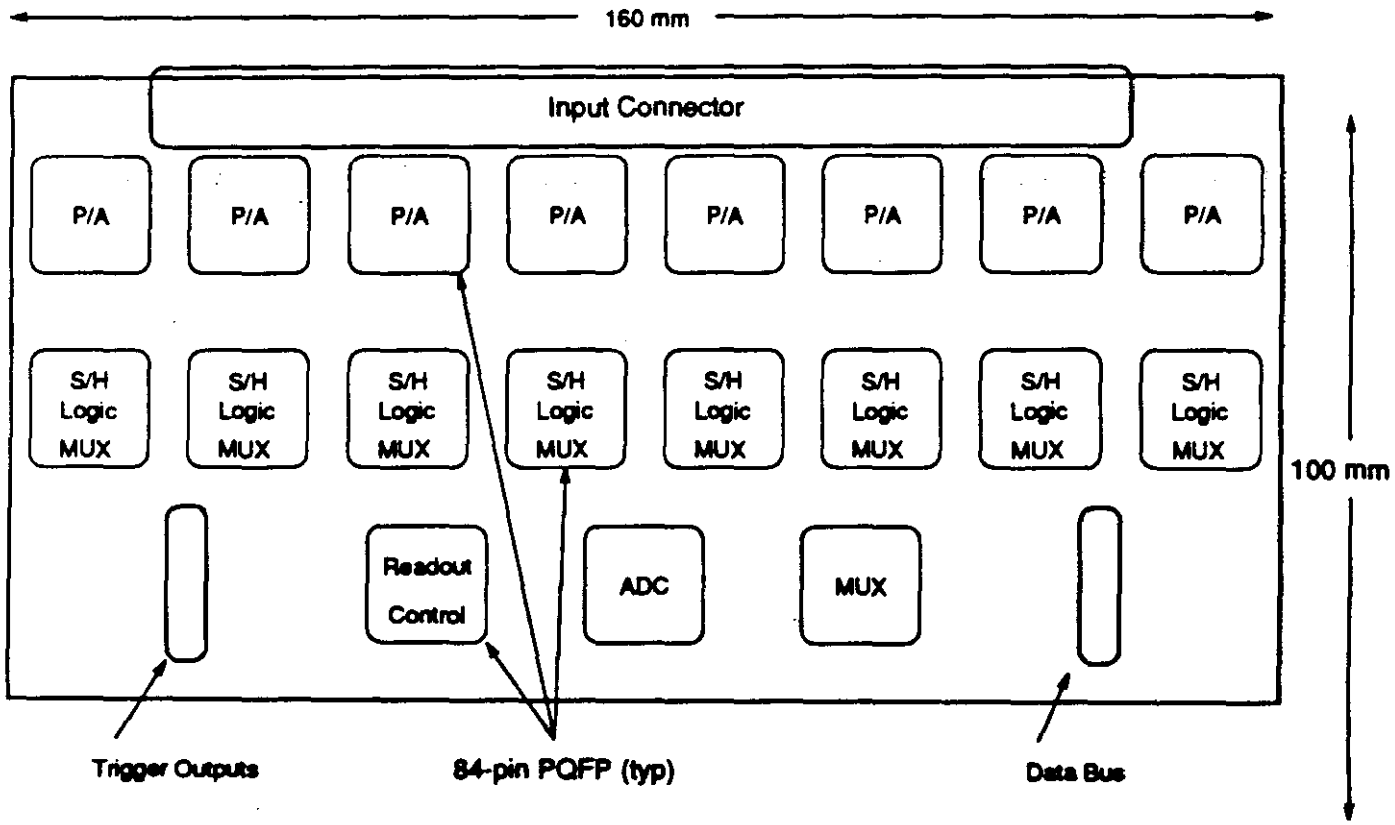


Figure 1: Schematic representation of the layer of the readout, trigger, and DAQ system for the CSC's.



CSC Chamber Board Layout
128 Channel Version

Figure 4: Physical layout of the CSC front end printed circuit board. Each 128-channel board services 32 cathode strips on the four layers that comprise a superlayer.

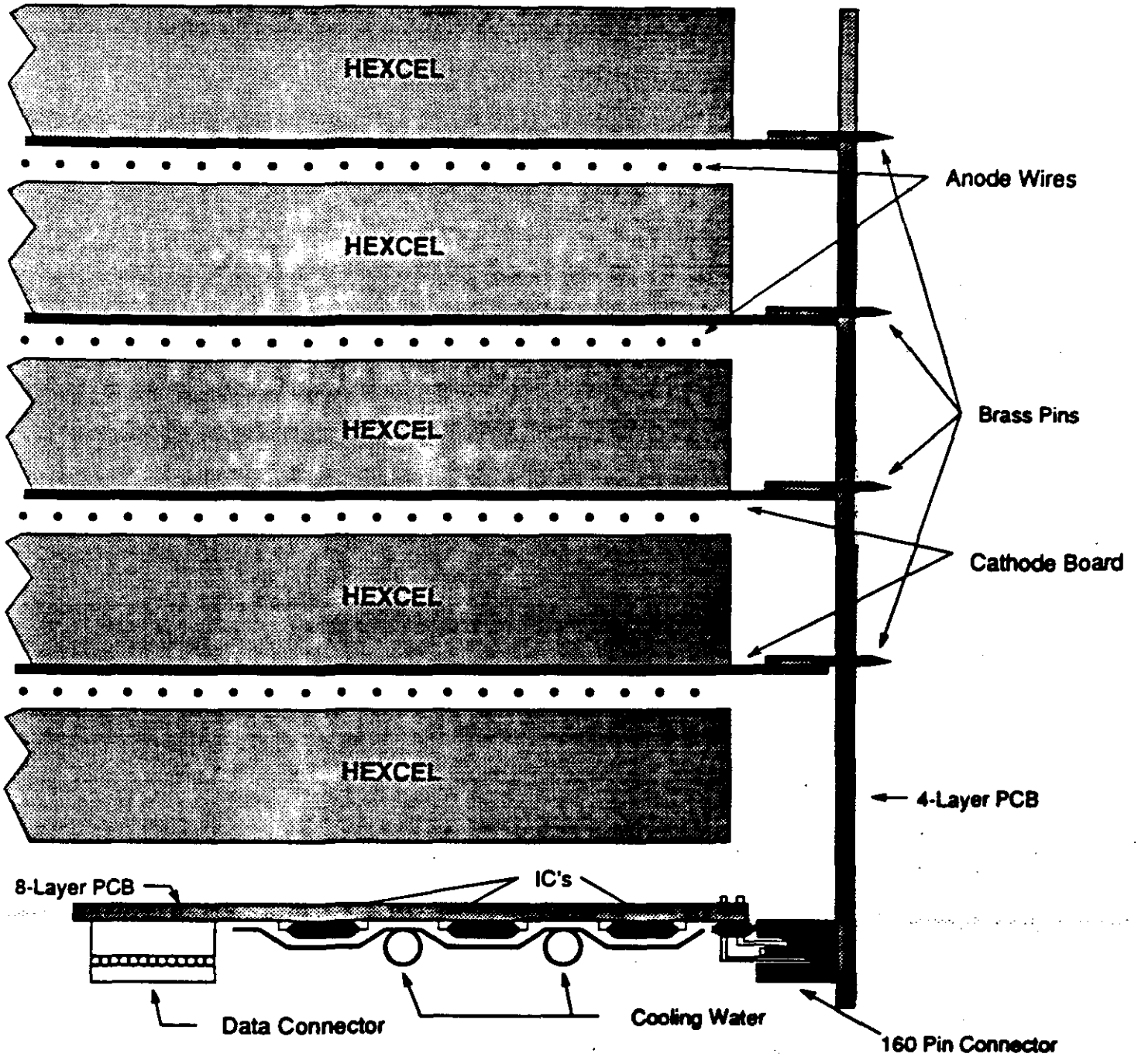


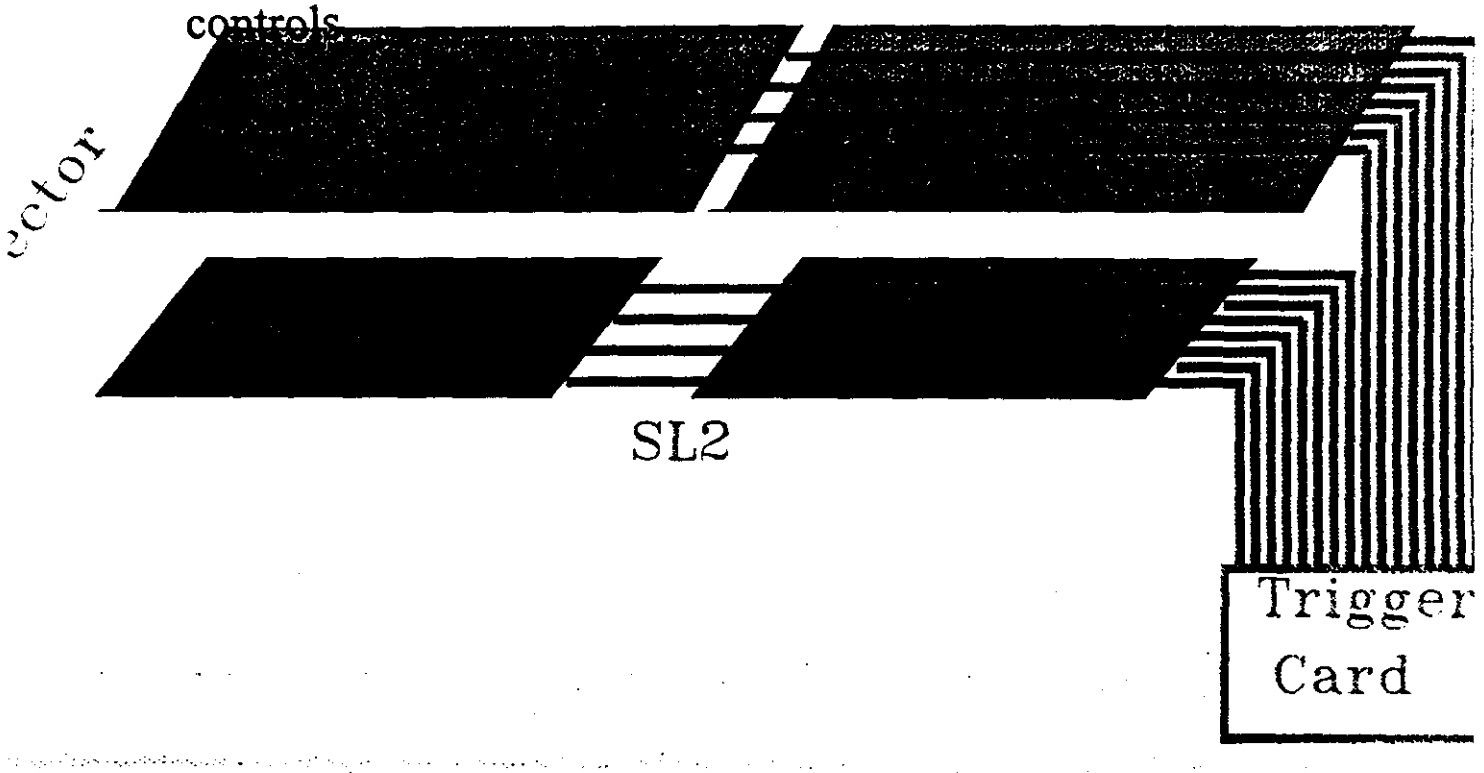
Figure 2: Mechanical mounting scheme for the CSC readout boards. One 128-channel board services 32 cathode strips on each of the four layers that comprise a superlayer.

Trigg_Board

(1) Receives signals from 2 SL2 and 2 SL3 Z chambers per sector in barrel.(similar number hold for EC)

(2) Total Number of boards
No Sectors * 4

(3) FB size, housing receivers, CAM, Interface and controls



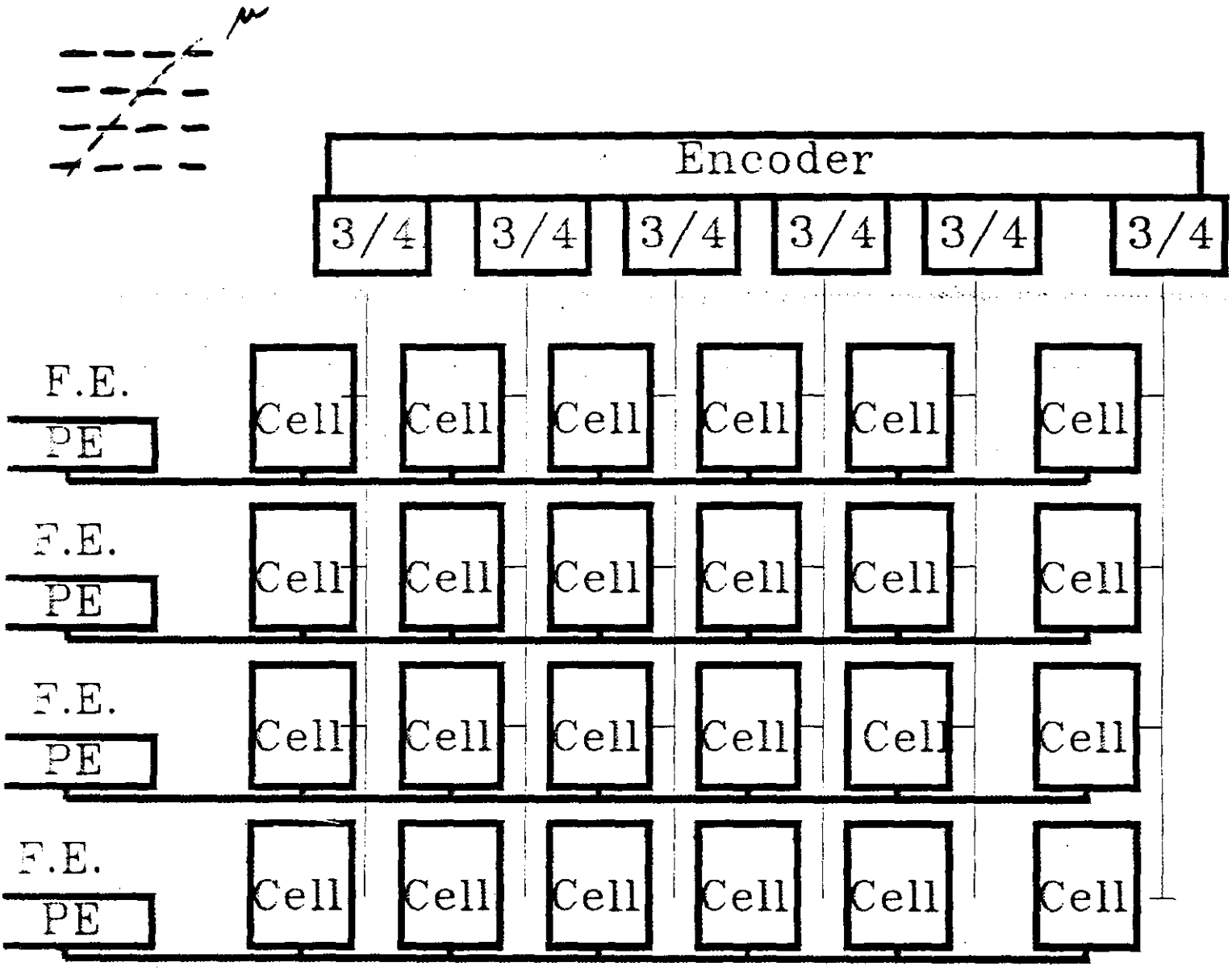
Sys_Control

(1) A small number of boards (< No sectors).

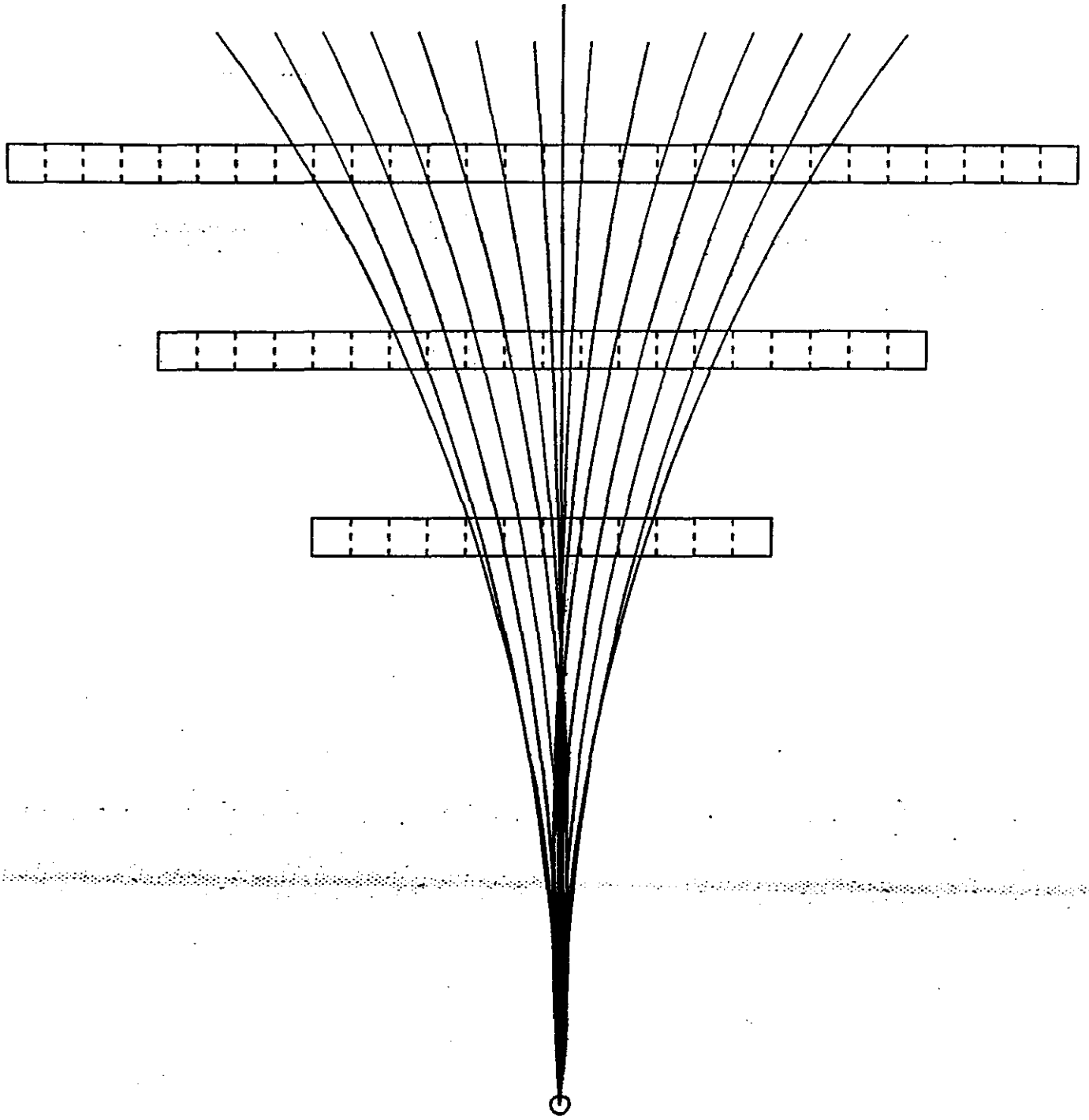
(2) Allow the overall coordination of barrel and EC and the 1 and >1 muon trigger line generation.

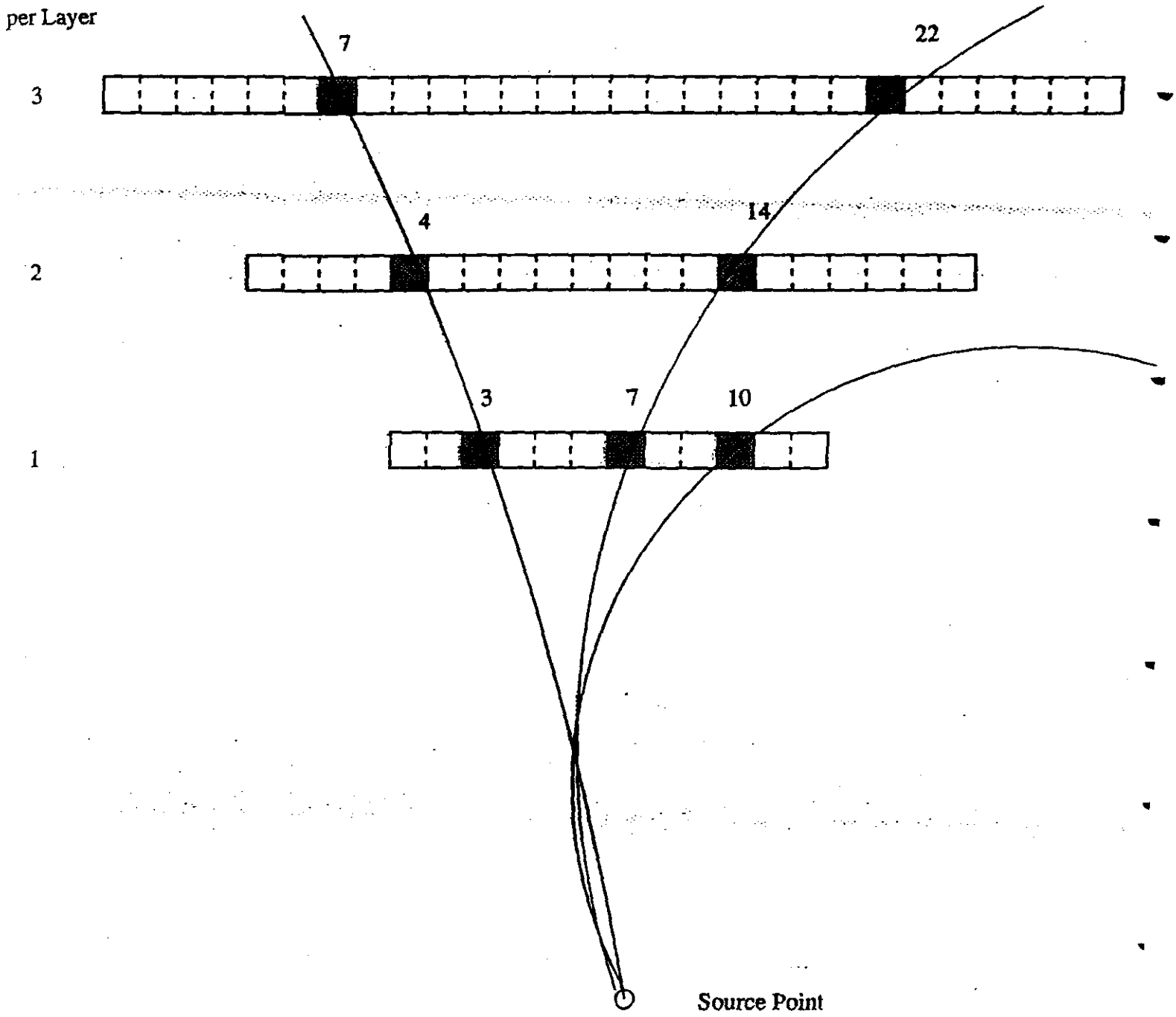
(3) If necessary it could do a modified level 1 (Level 1.1) to improve rejection.

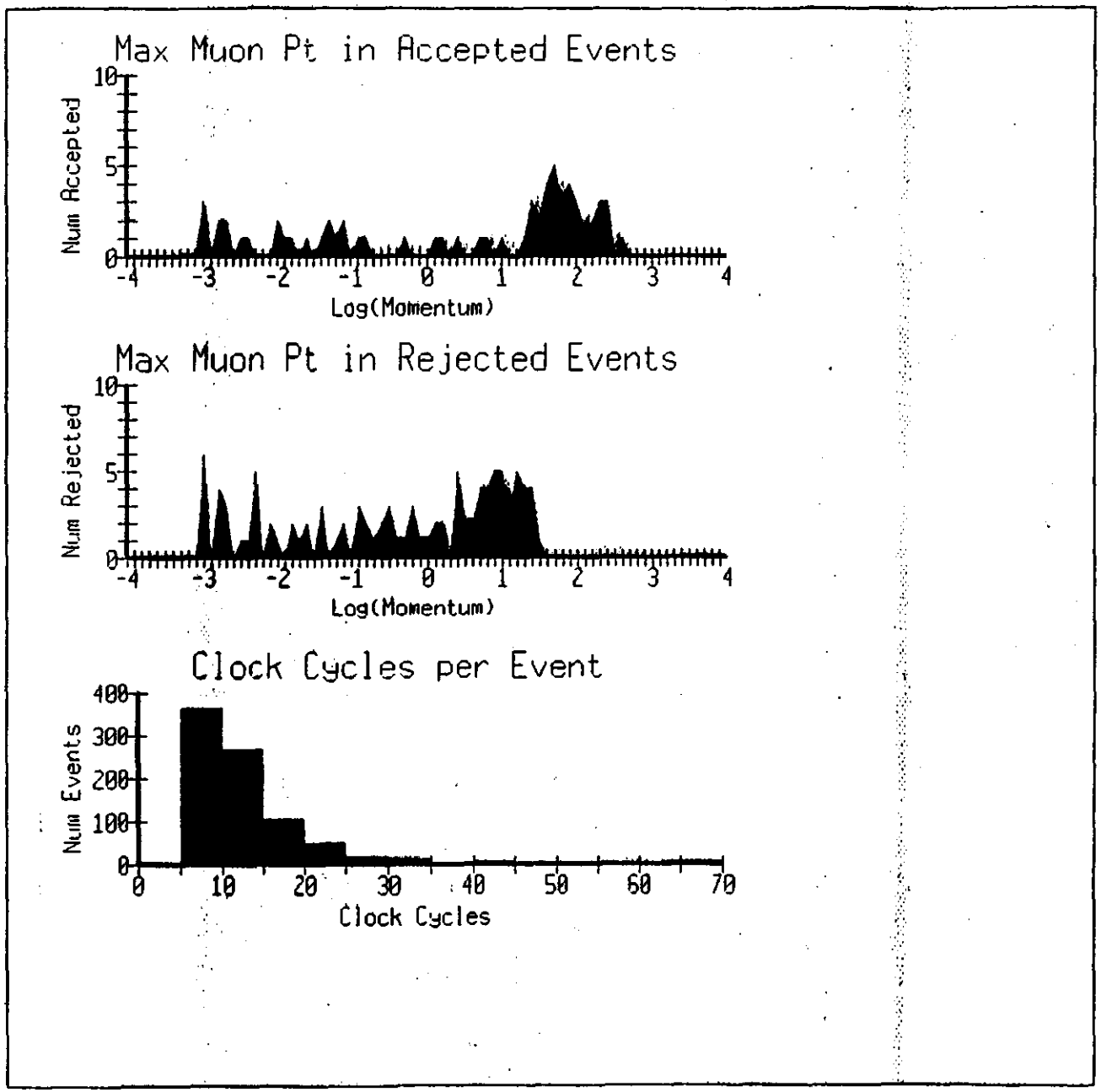
(4) Can interface to DAQ

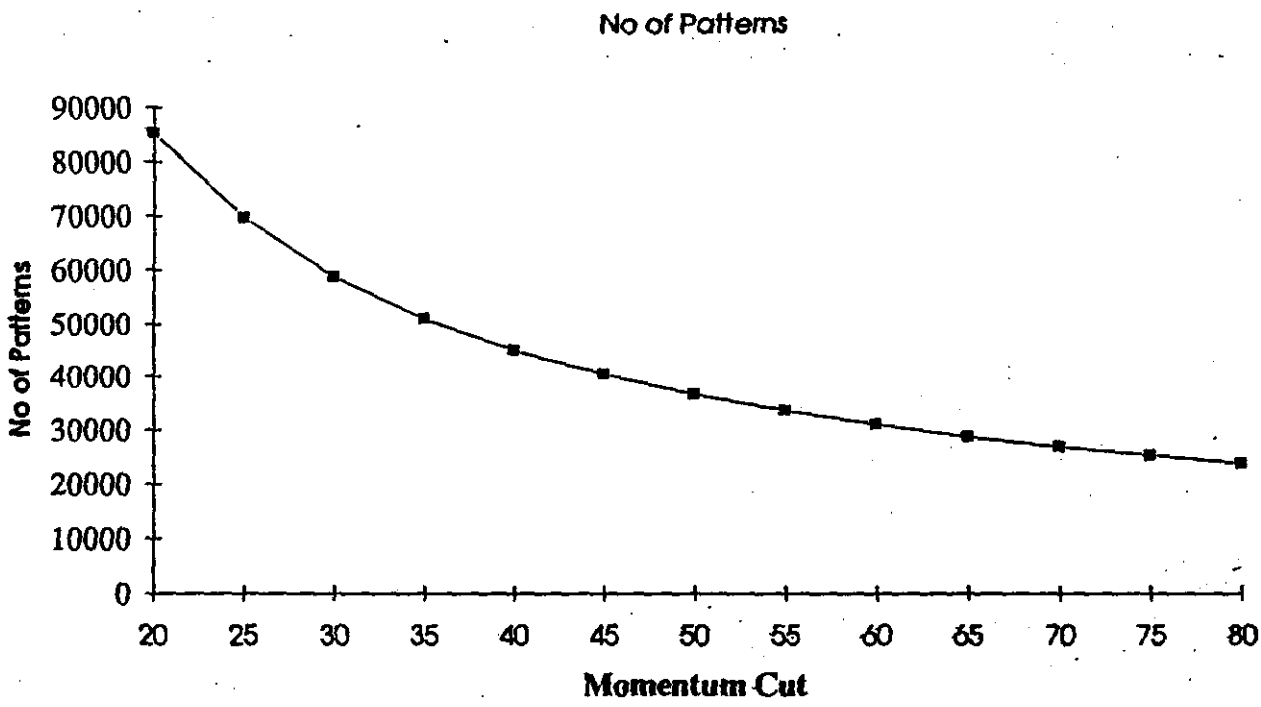


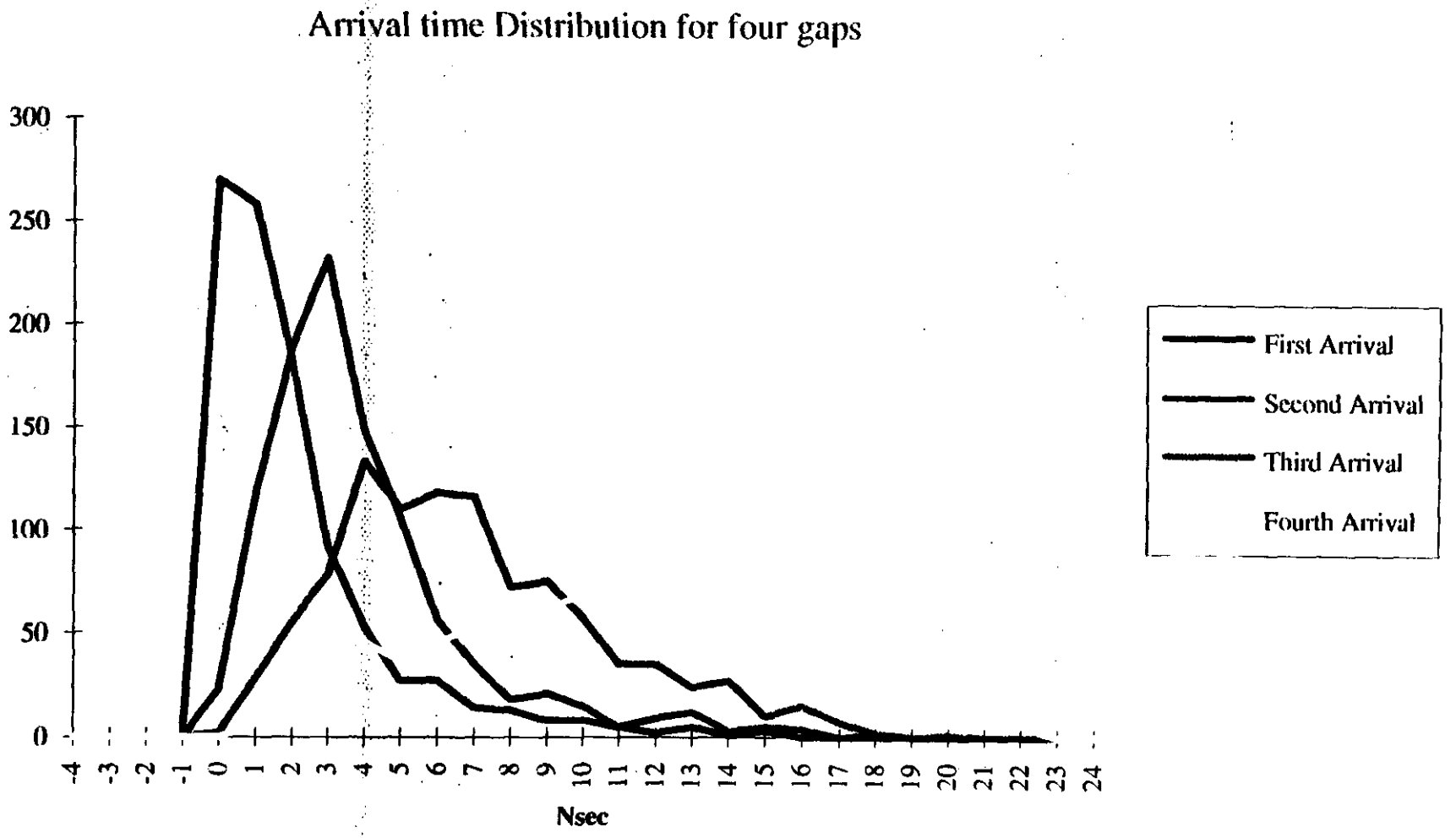
Associative Memory Scheme



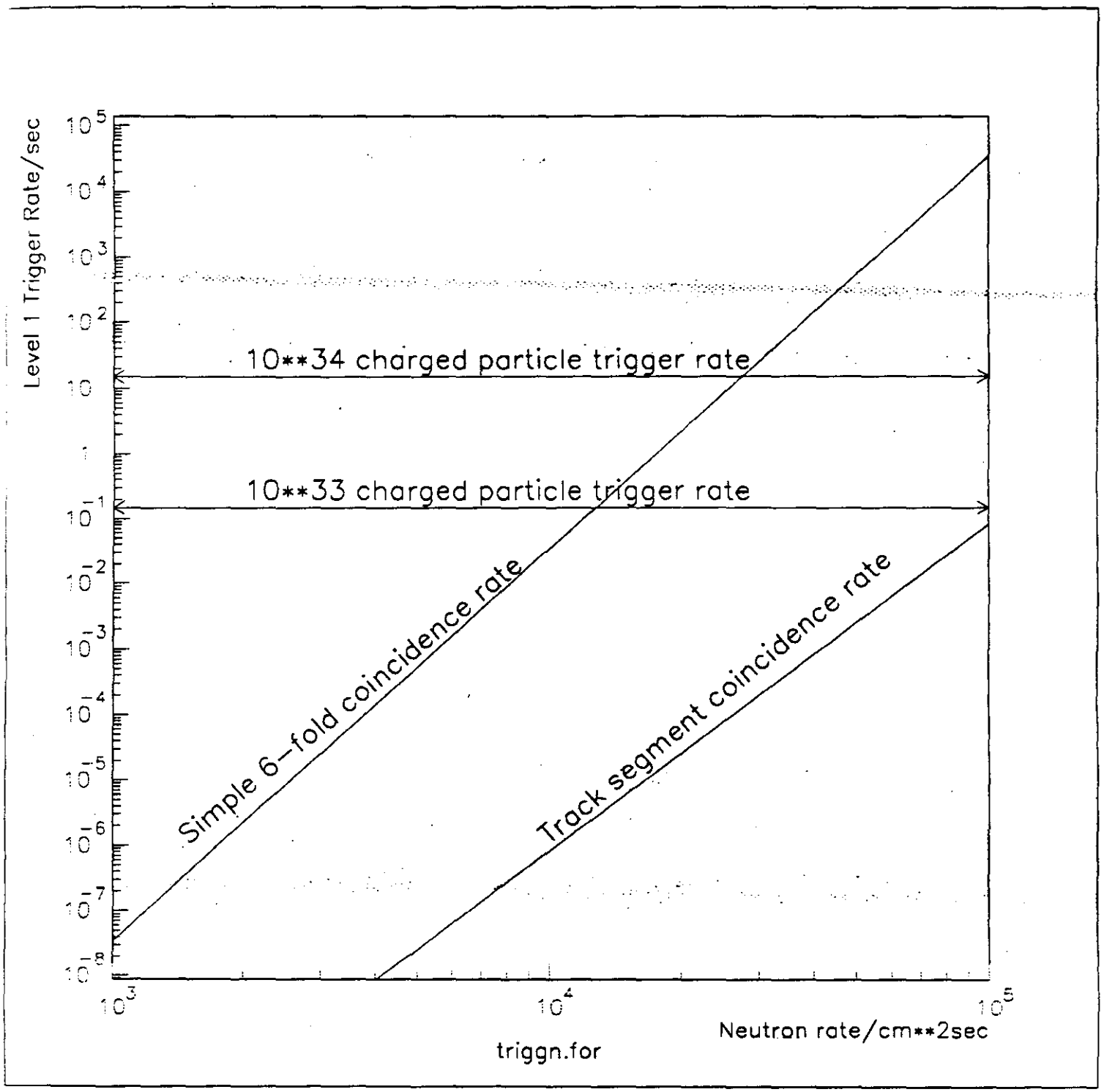

per Layer
3
2
1
7
22
4
14
3
7
10
Source Point


Max Muon Pt in Accepted Events
Num Accepted
Log(Momentum)
Max Muon Pt in Rejected Events
Num Rejected
Log(Momentum)
Clock Cycles per Event
Num Events
Clock Cycles


No of Patterns
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
No of Patterns
20
25
30
35
40
45
50
55
60
65
70
75
80
Momentum Cut


Arrival time Distribution for four gaps
300
250
200
150
100
50
0
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Nsec
First Arrival
Second Arrival
Third Arrival
Fourth Arrival

Trigger Card Cost				
Component	Number	Unit Cost	Total Parts	Comment
Receivers(single)	256	0.1	25.6	ECL
Latches(single)	256	0.1	25.6	ECL
Decoders	16	3	48	ECL
Associative Memory	32	60	1920	Custom
Timing Counter	16	10	160	ECL/Custom
Glue Logic	32	50	1600	FPGA
Connectors	12	3	36	Hi Density
Interface	2	50	100	FPGA
Board	1	400	400	12 Layer/12 wk
Debug (hrs)	8	56.32	450.56	(Sr Tech SSCL)
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	
			0	


Level 1 Trigger Rate/sec
10**34 charged particle trigger rate
10**33 charged particle trigger rate
Simple 6-fold coincidence rate
Track segment coincidence rate
Neutron rate/cm**2sec
triggn.for

The CSC Test Results from TTR

Presentation by:

V. Polychronakos

V. POLYCHRONAKOS
JAN. 18, '93

CSC Prototype Performance

Brief Description of BNL Prototypes

- TTR Tests
- Resolution
- Bunch Crossing Timing

Dubna Prototype TTR Tests

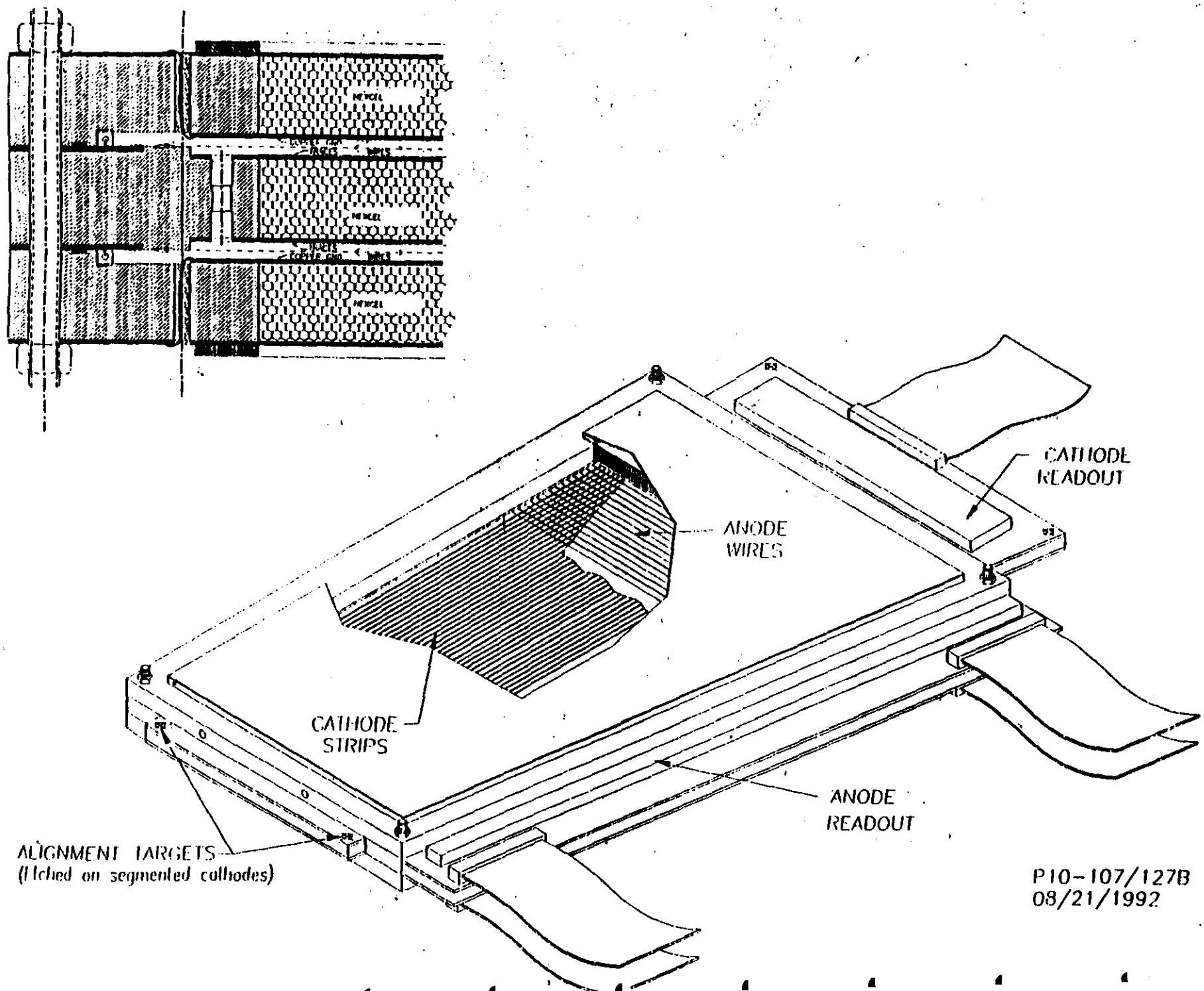
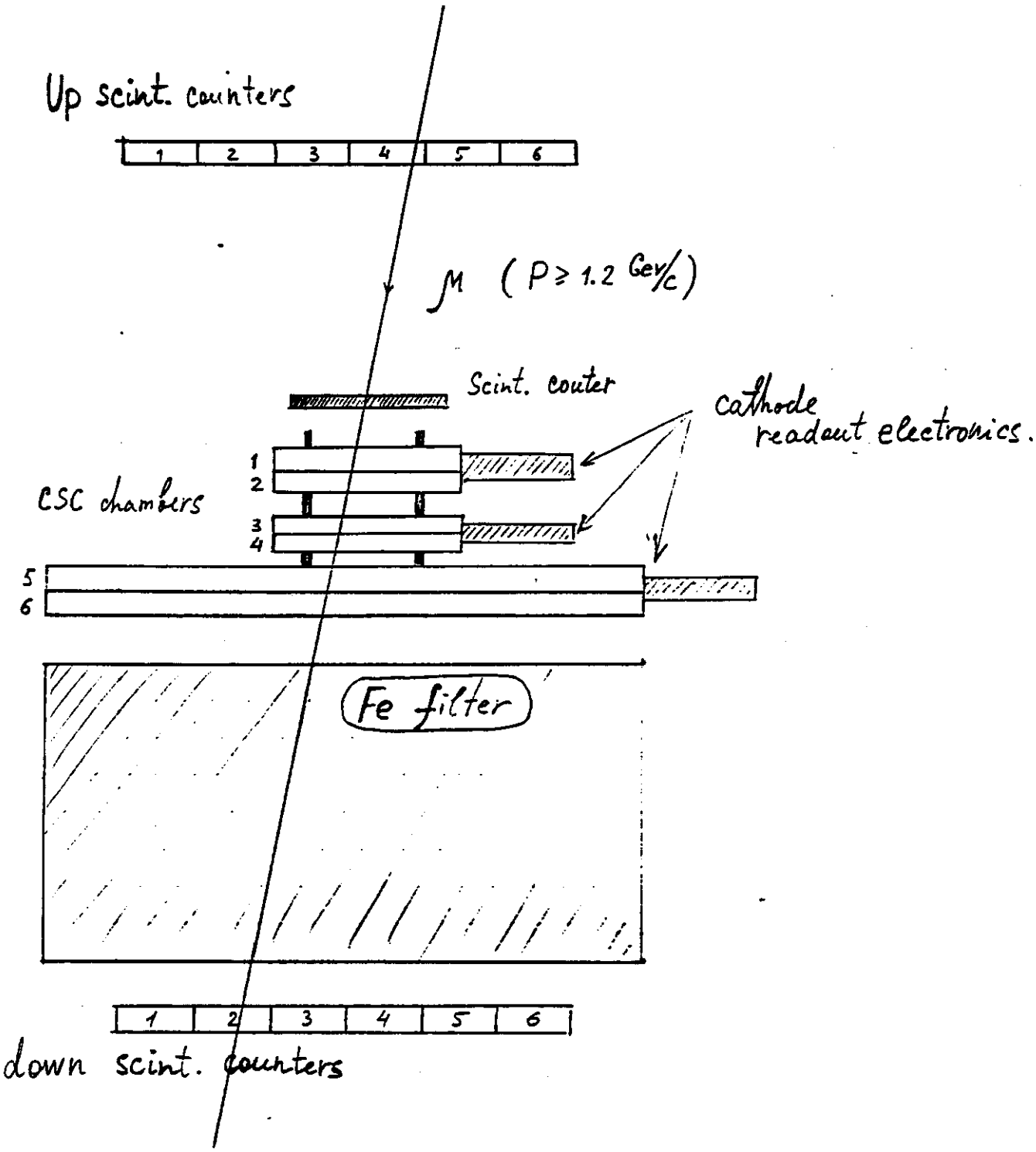
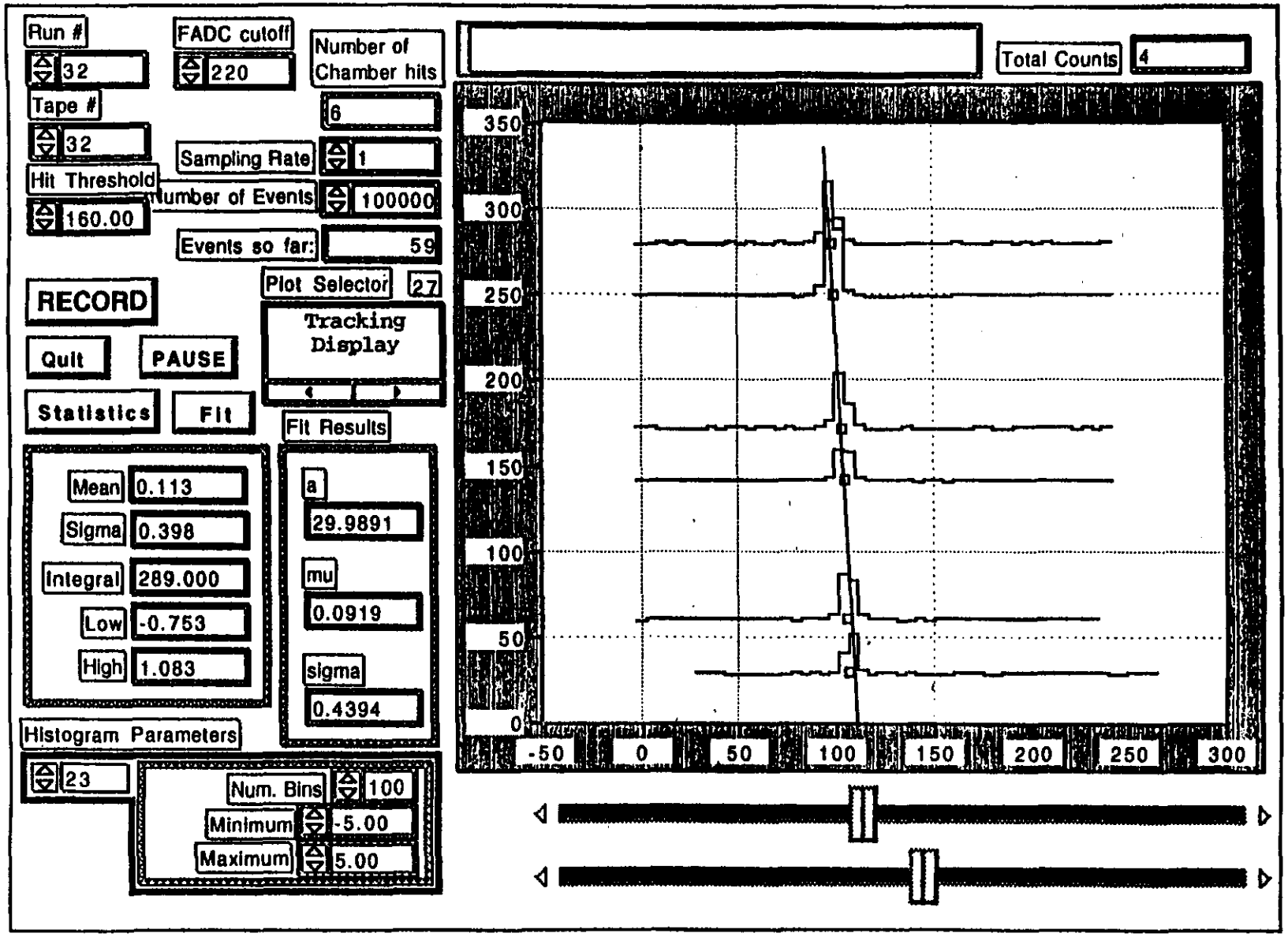

CATHODE READOUT
ANODE WIRES
CATHODE STRIPS
ANODE READOUT
ALIGNMENT TARGETS
(Etched on segmented cathodes)
P10-107/127B
08/21/1992

Figure 3


Up scint. counters
1
2
3
4
5
6
μ (P ≥ 1.2 Gev/c)
Scint. couter
cathode readout electronics.
CSC chambers
1
2
3
4
5
6
Fe filter
1
2
3
4
5
6
down scint. counters

Front Panel


Run #
32
Tape #
32
Hit Threshold
160.00
FADC cutoff
220
Number of Chamber hits
6
Sampling Rate
1
Number of Events
100000
Events so far:
59
Plot Selector
27
RECORD
Quit
PAUSE
Tracking Display
Statistics
Fit
Fit Results
Mean
0.113
Sigma
0.398
Integral
289.000
Low
-0.753
High
1.083
a
29.9891
mu
0.0919
sigma
0.4394
Histogram Parameters
23
Num. Bins
100
Minimum
-5.00
Maximum
5.00
Total Counts
4
350
300
250
200
150
100
50
0
-50
0
50
100
150
200
250
300

Event Selection, Reconstruction Algorithm, and Corrections

Event Selection

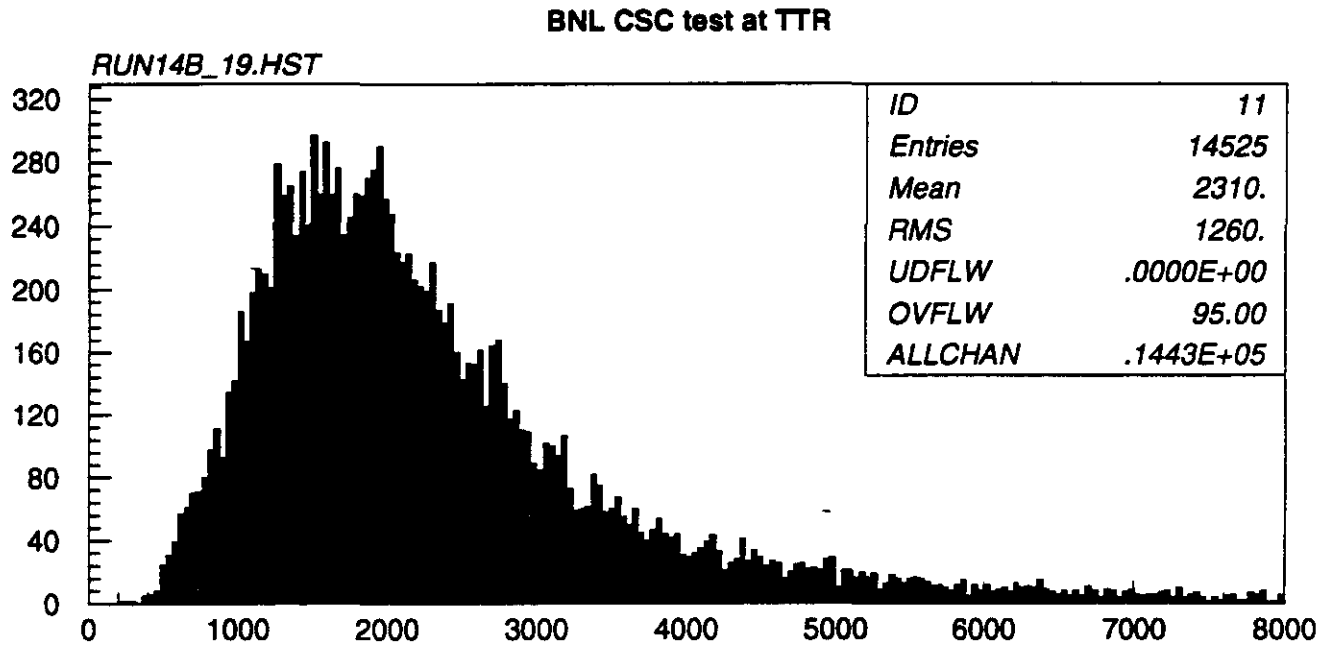
Eliminate showers
Eliminate ADC overflows
Restrict |phi| to <6 degrees
NO CUT on theta

Reconstruction Algorithm

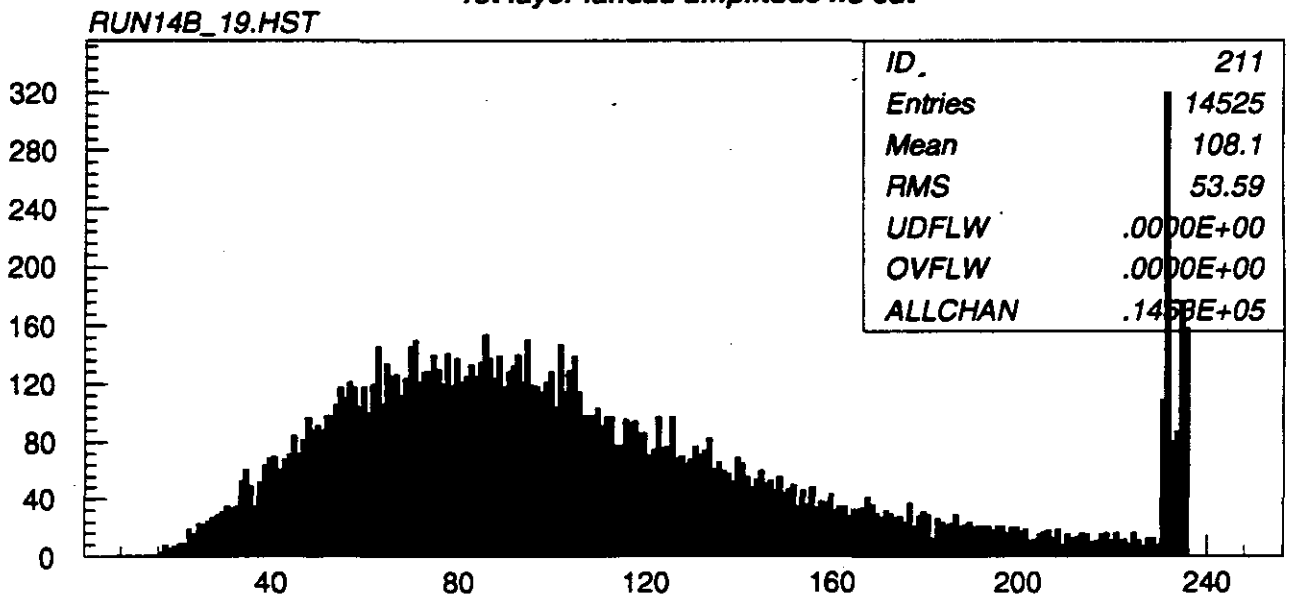
Use Calibrated Ratio of Max PH to second Max

Corrections

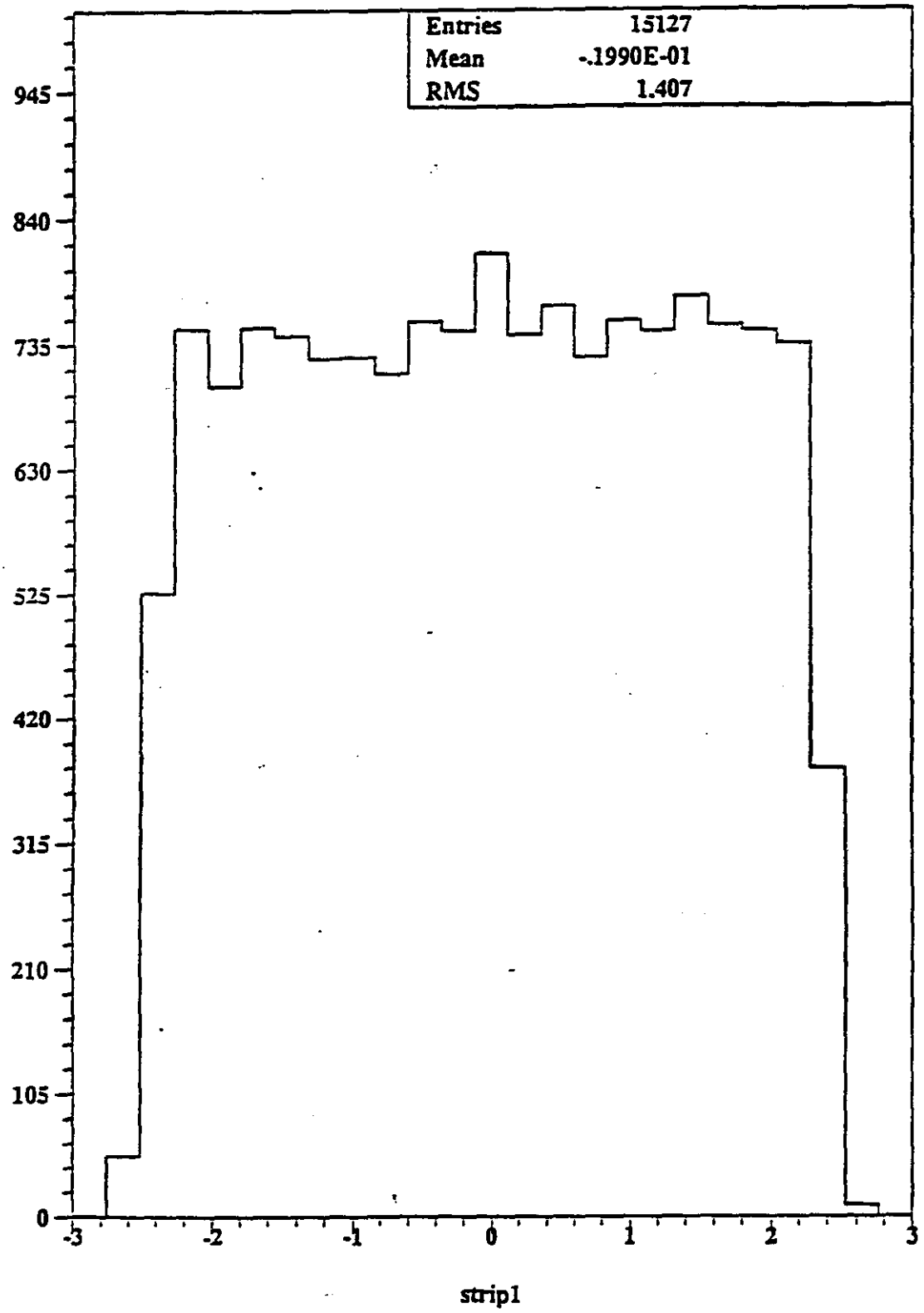
Correct for relative displacement
Correct for effect of positive ions
NO Multiple Scattering Correction
(estimated at ~30 microns)

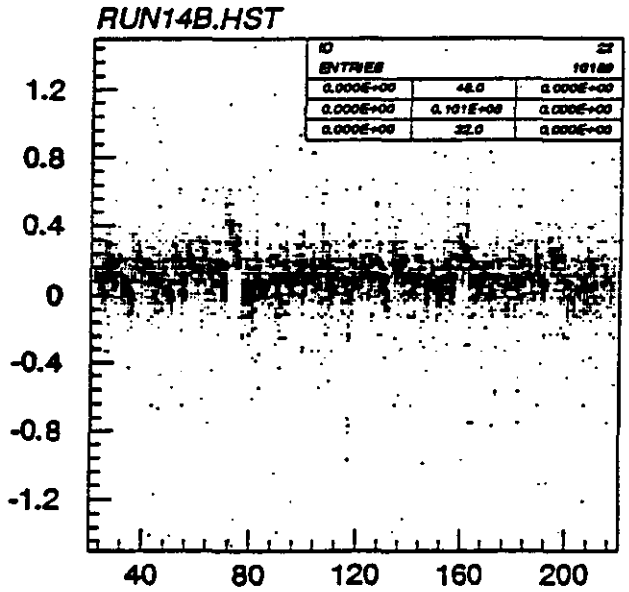


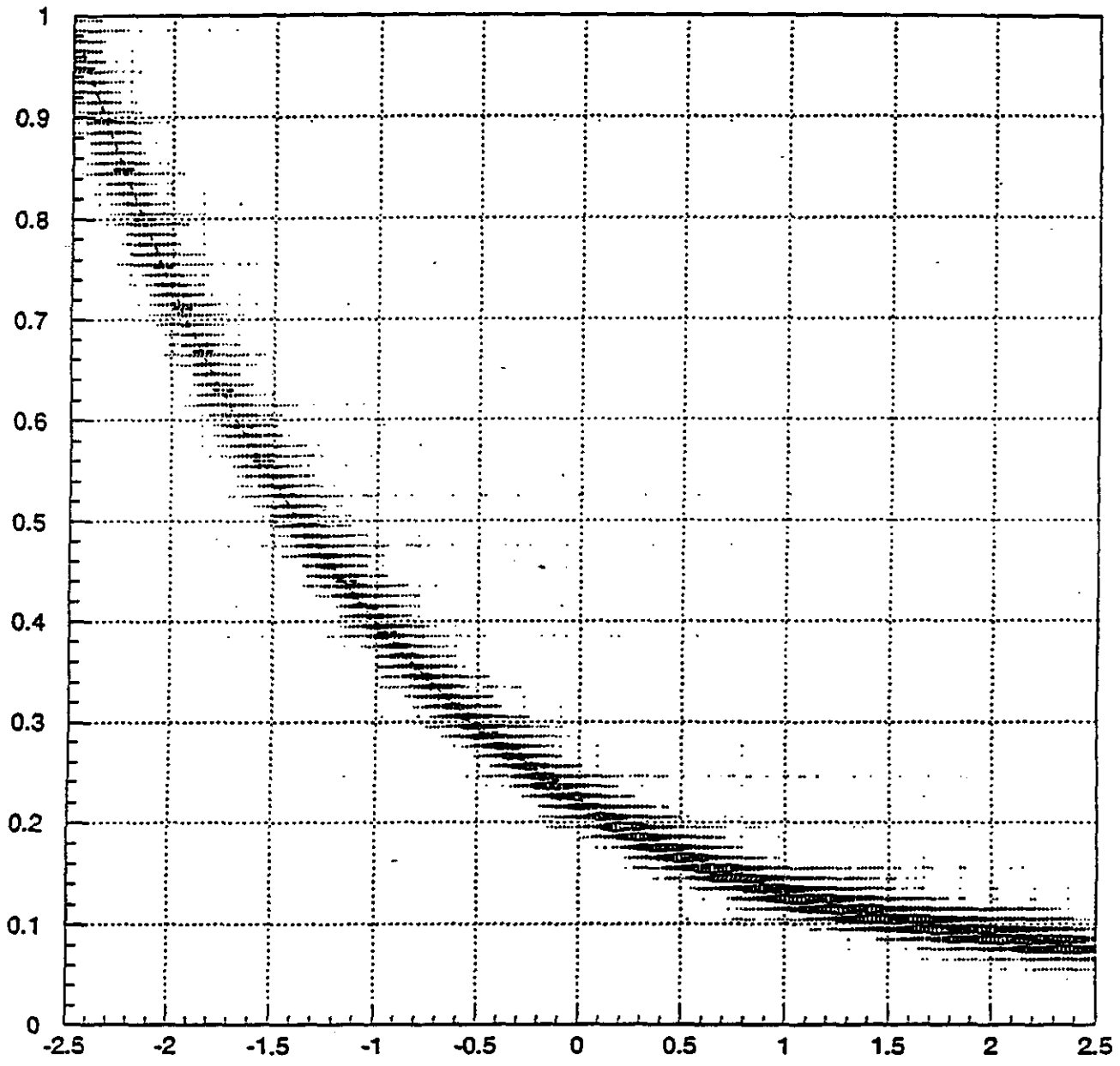
1st layer landau amplitude no cut



1st max fadc channel no cut

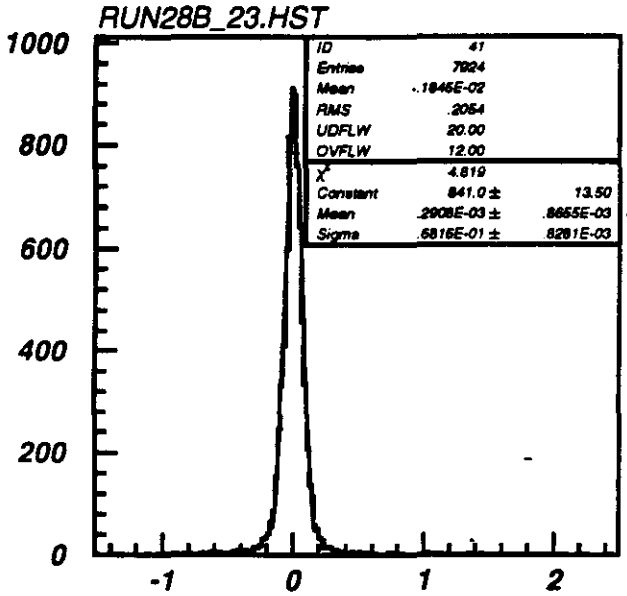

Entries 15127
Mean -.1990E-01
RMS 1.407
945
840
735
630
525
420
315
210
105
0
-3
-2
-1
0
1
2
3
strip1


RUN14B.HST
ID 22
ENTRIES 10189
0.000E+00 48.0 0.000E+00
0.000E+00 0.101E+05 0.000E+00
0.000E+00 32.0 0.000E+00
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
40
80
120
160
200

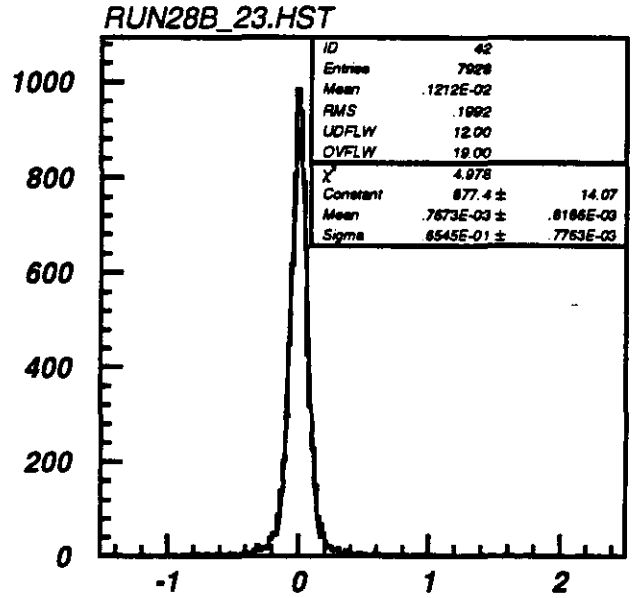


distance vs A2/A1

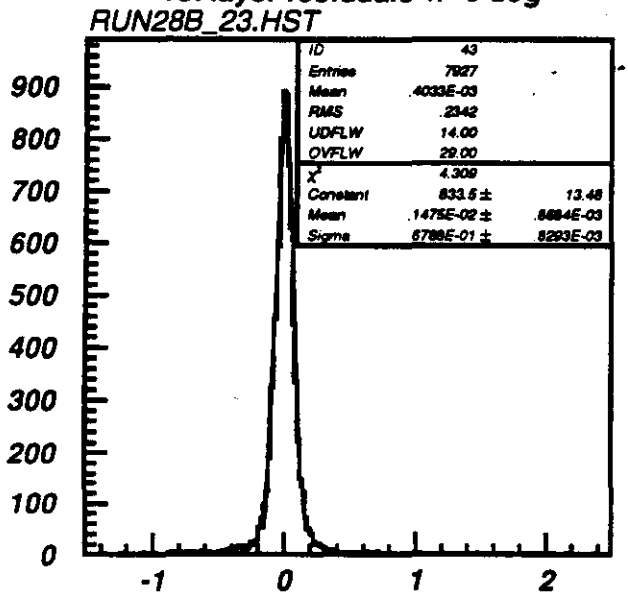
BNL CSC test at TTR



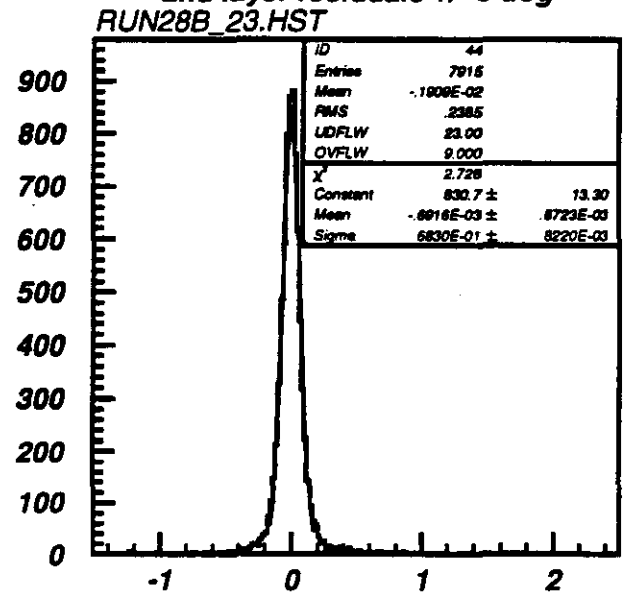
1st layer residuals +/- 6 deg



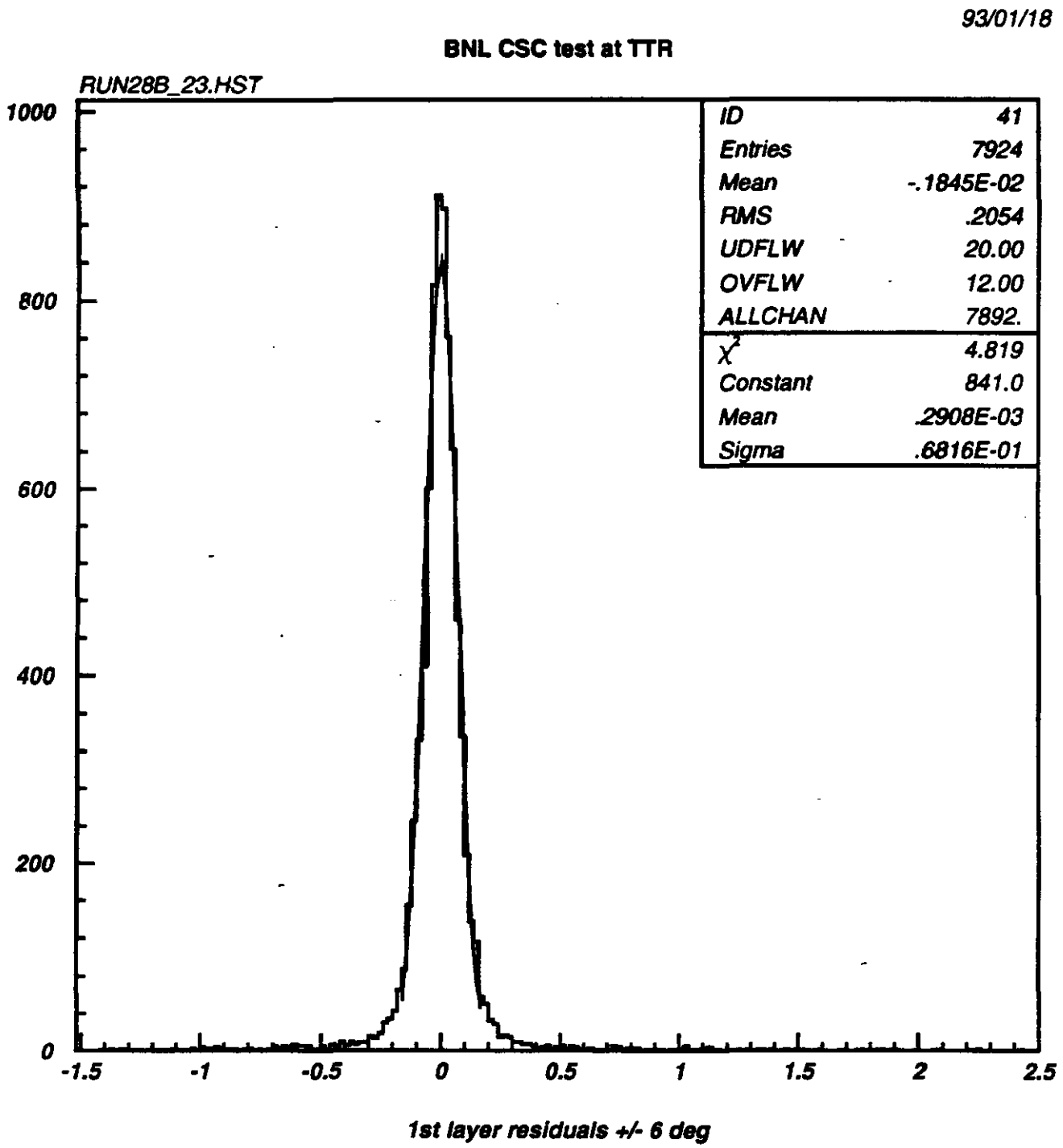
2nd layer residuals +/- 6 deg



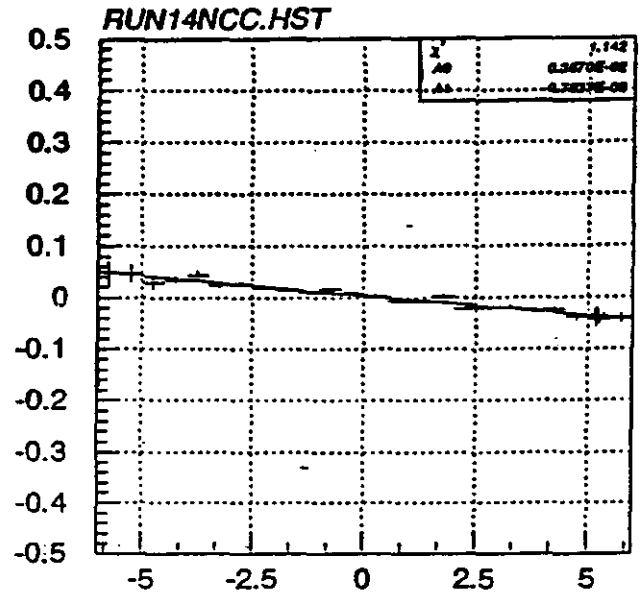
3rd layer residuals +/- 6 deg



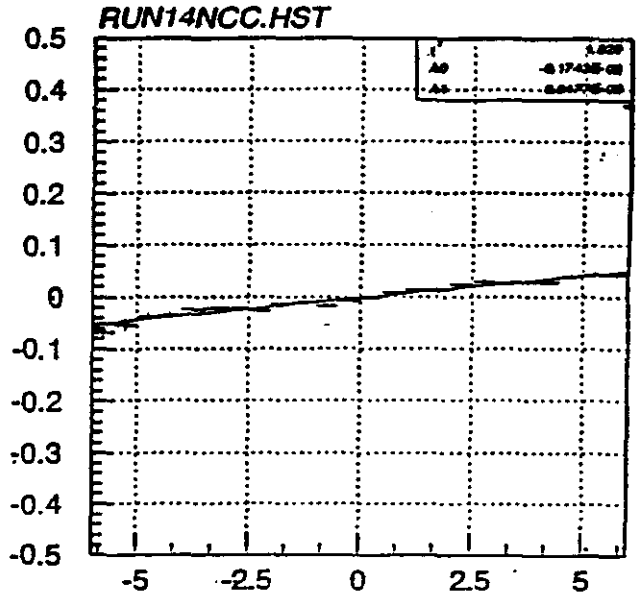
4th layer residuals +/- 6 deg


93/01/18 09.25
BNL CSC test at TTR
RUN28B_23.HST
ID 41
Entries 7924
Mean -.1845E-02
RMS .2054
UDFLW 20.00
OVFLW 12.00
ALLCHAN 7892.
χ² 4.819
Constant 841.0
Mean .2908E-03
Sigma .6816E-01
1000
800
600
400
200
0
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
1st layer residuals +/- 6 deg

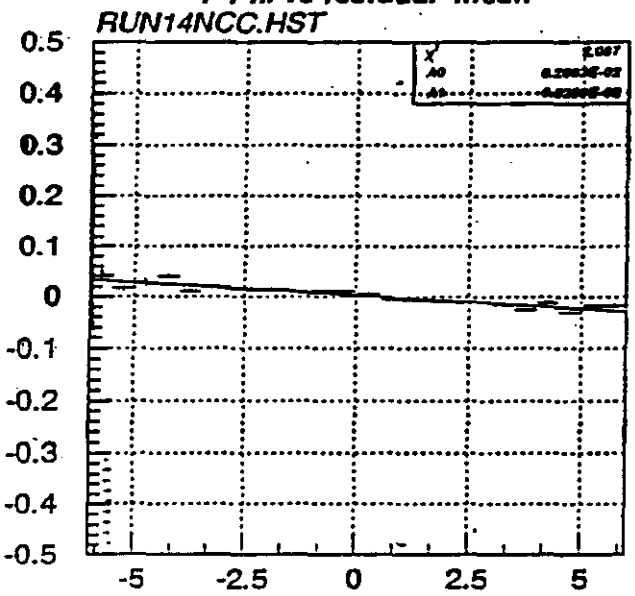
92/12/08 15.07



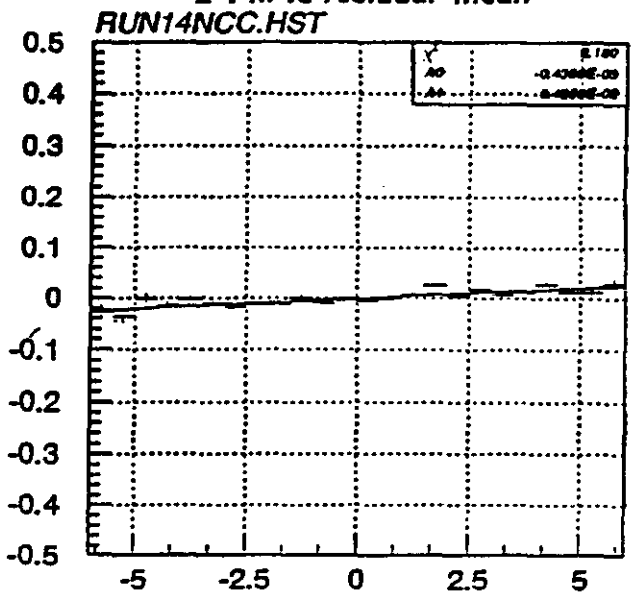
1' Phi vs residual 'mean



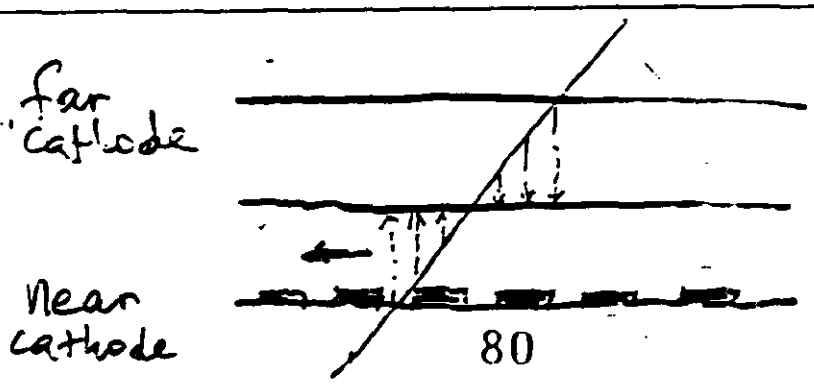
2' Phi vs residual 'mean



3' Phi vs residual 'mean

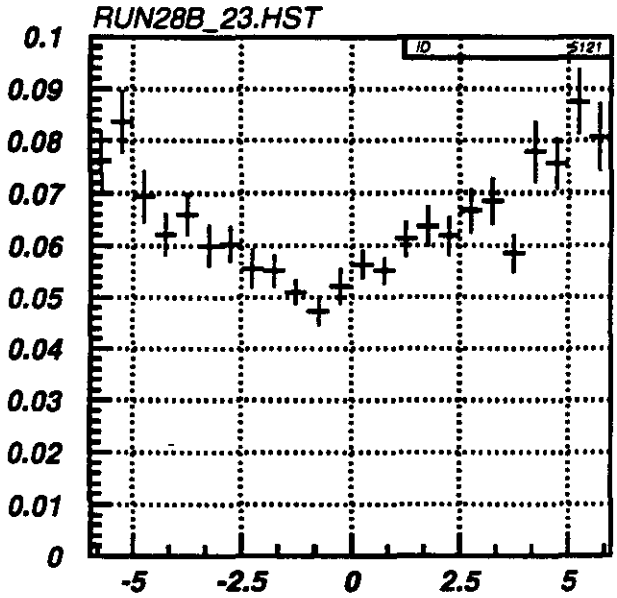


4' Phi vs residual 'mean

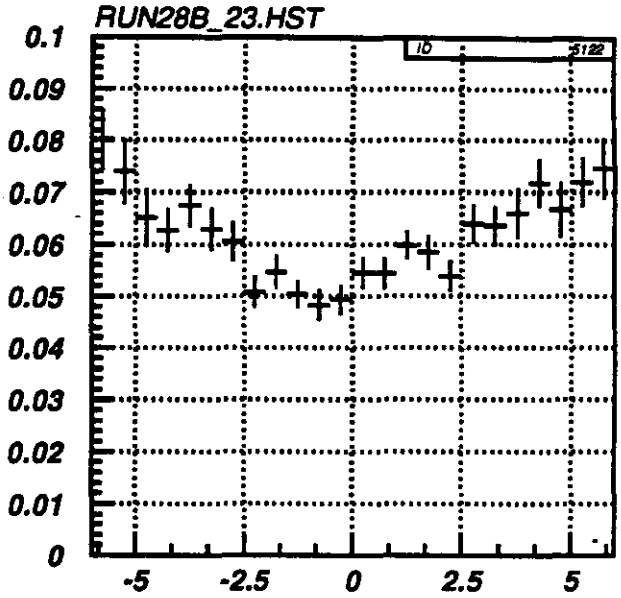


Q far < Q near

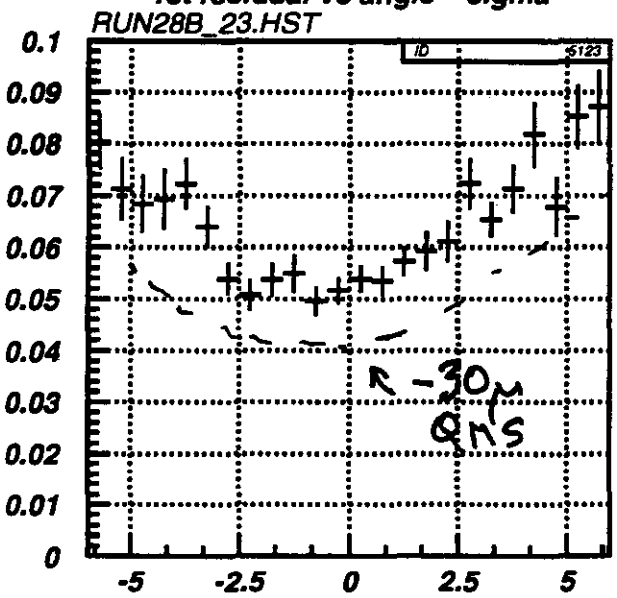
BNL CSC test at TTR



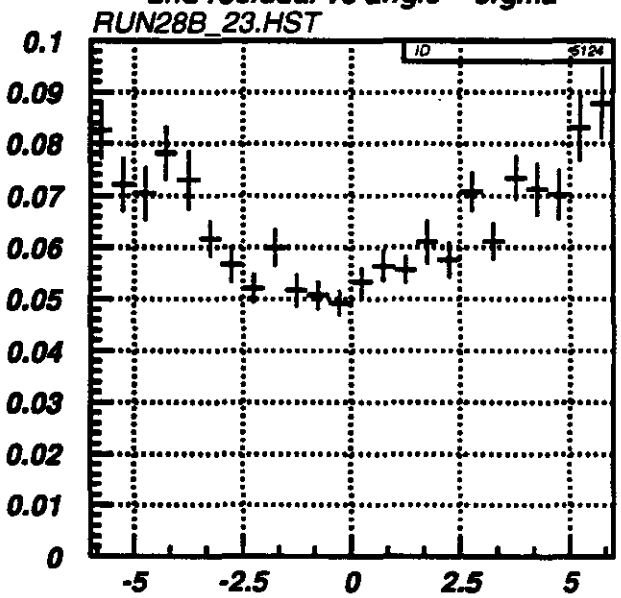
1st residual vs angle sigma



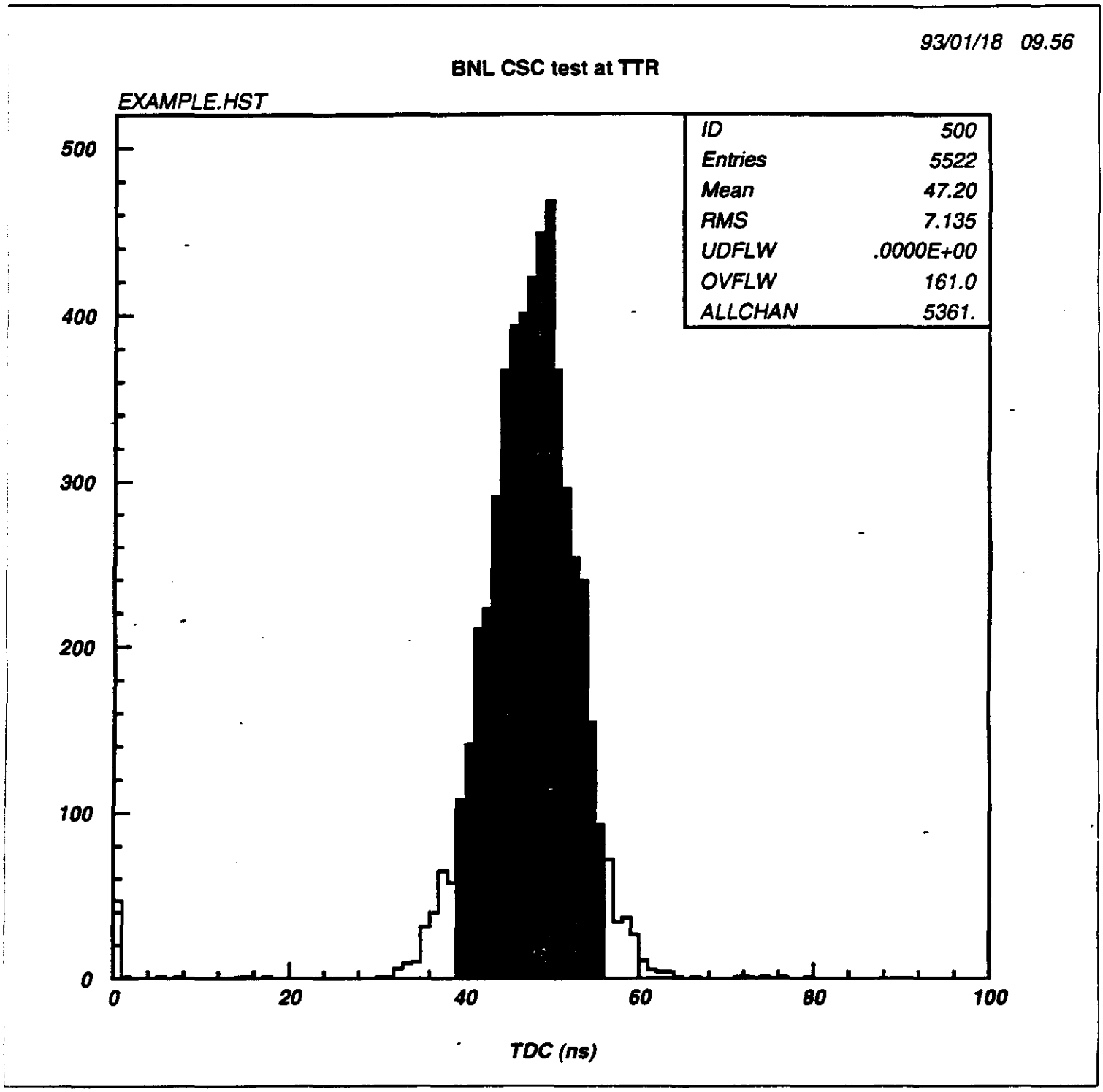
2nd residual vs angle sigma

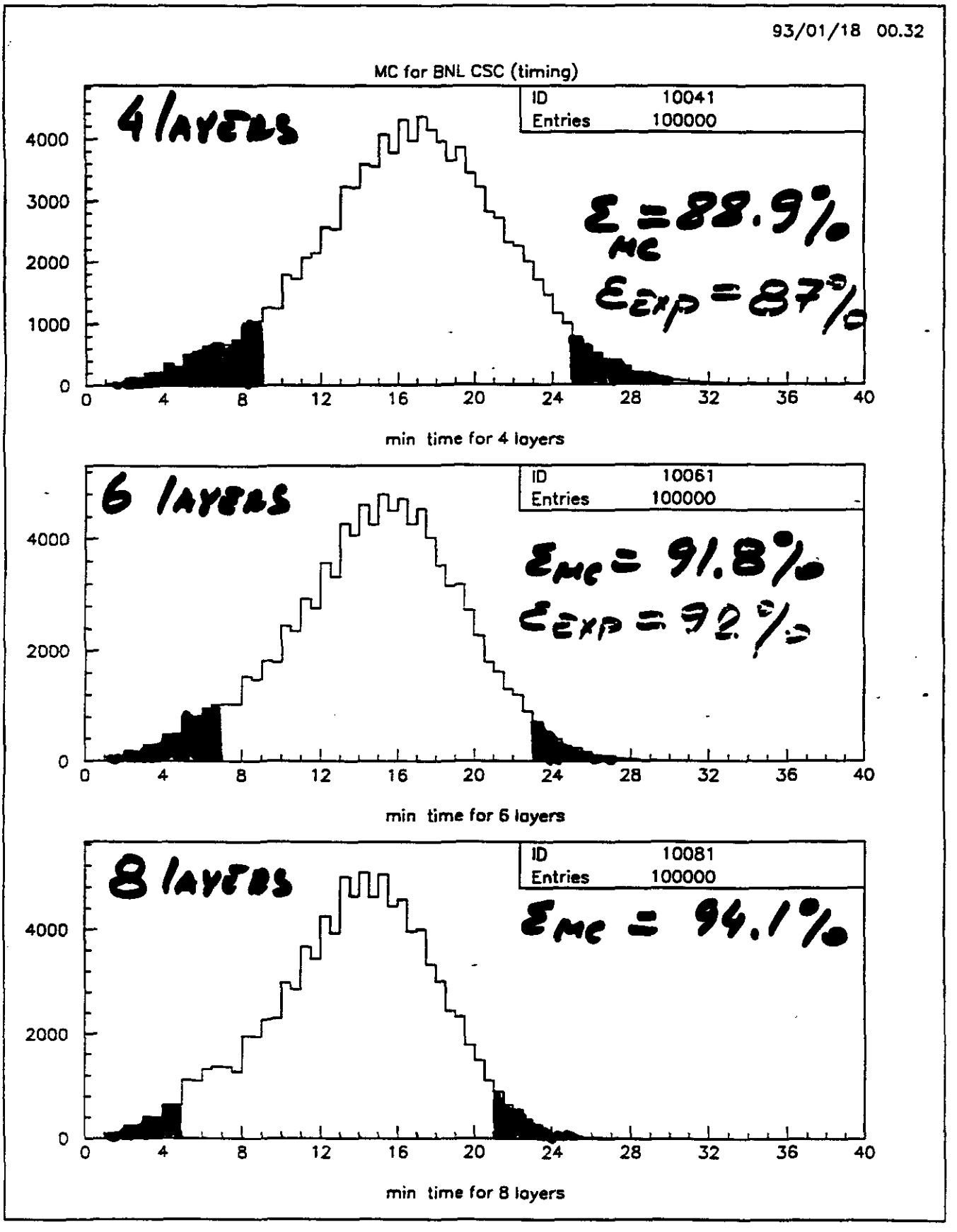


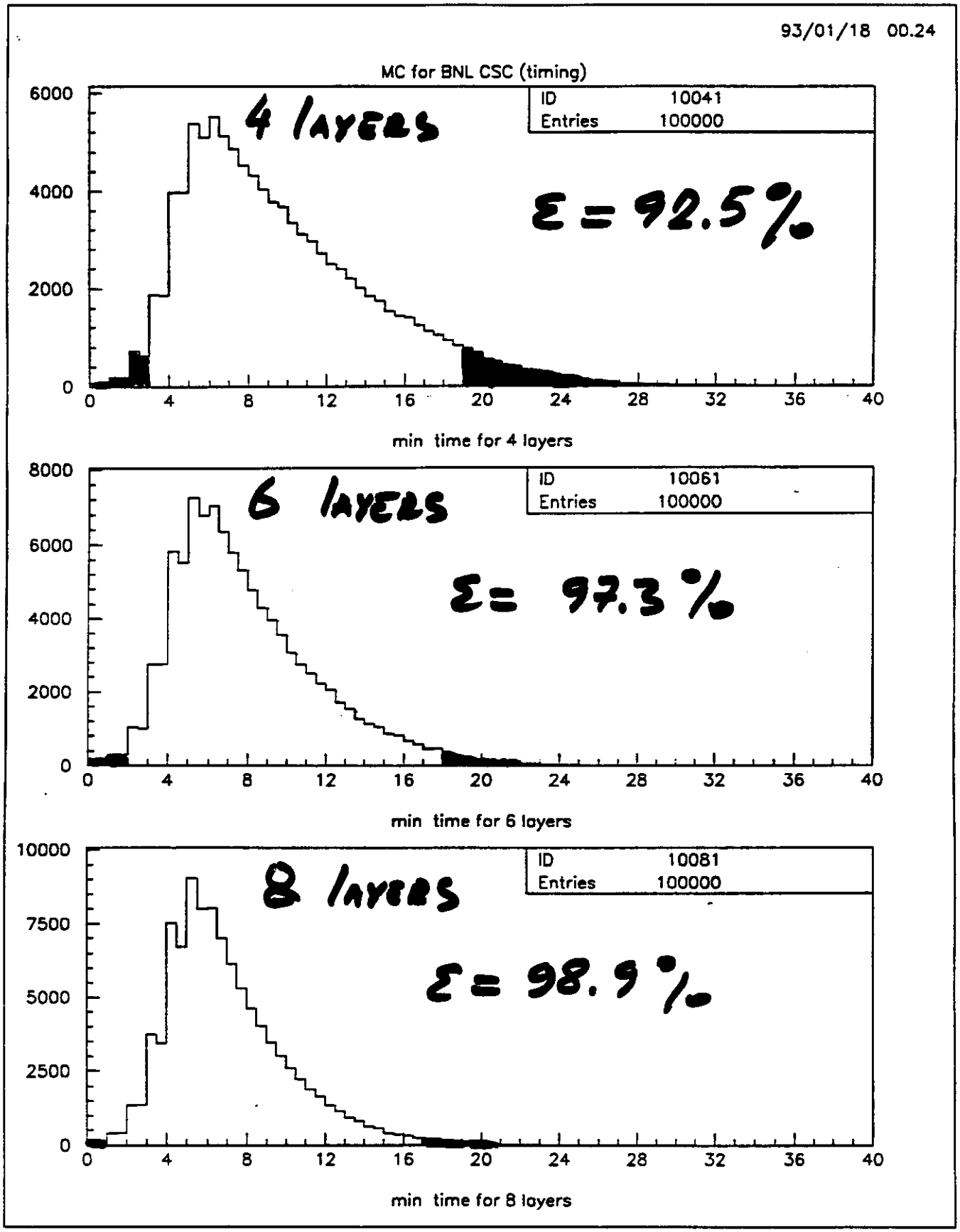
3rd residual vs angle sigma



4th residual vs angle sigma


93/01/18 09.56
BNL CSC test at TTR
EXAMPLE.HST
ID 500
Entries 5522
Mean 47.20
RMS 7.135
UDFLW .0000E+00
OVFLW 161.0
ALLCHAN 5361.
500
400
300
200
100
0
0
20
40
60
80
100
TDC (ns)

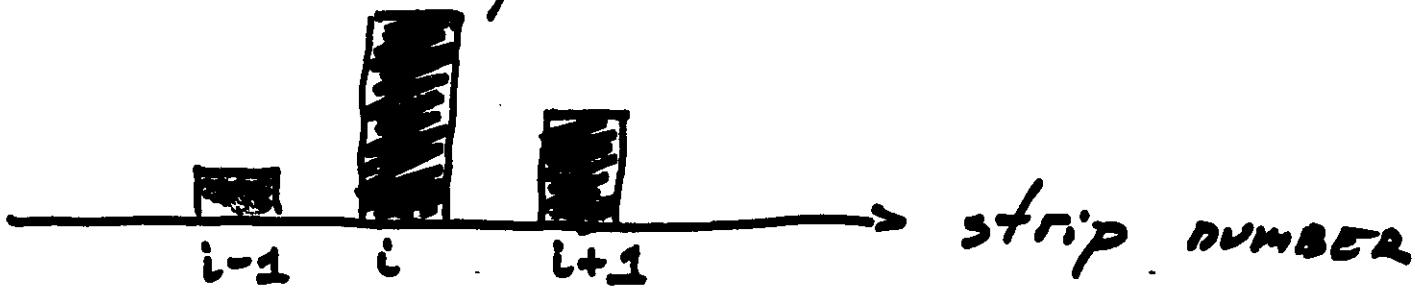

93/01/18 00.32
MC for BNL CSC (timing)
4 LAYERS
ID 10041
Entries 100000
$\varepsilon_{MC} = 88.9\%$
$\varepsilon_{EXP} = 87\%$
min time for 4 layers
6 LAYERS
ID 10061
Entries 100000
$\varepsilon_{MC} = 91.8\%$
$\varepsilon_{EXP} = 92\%$
min time for 6 layers
8 LAYERS
ID 10081
Entries 100000
$\varepsilon_{MC} = 94.1\%$
min time for 8 layers


93/01/18 00.24
MC for BNL CSC (timing)
ID 10041
Entries 100000
4 layers
ε = 92.5%
min time for 4 layers
ID 10061
Entries 100000
6 layers
ε = 97.3%
min time for 6 layers
ID 10081
Entries 100000
8 layers
ε = 98.9%
min time for 8 layers

$T_{RISE} = 7ns$

DUBNA CSC

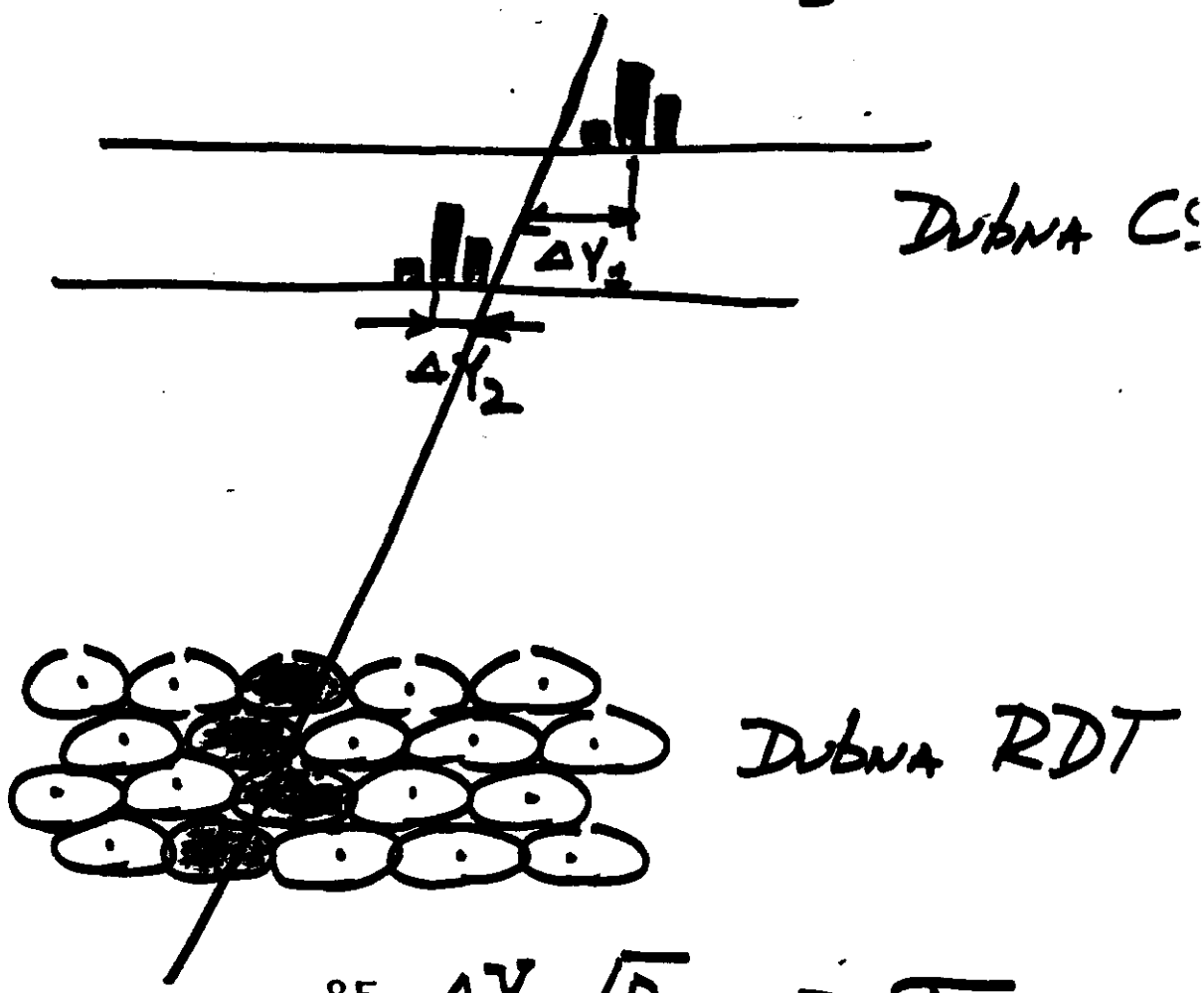
→ cluster definition



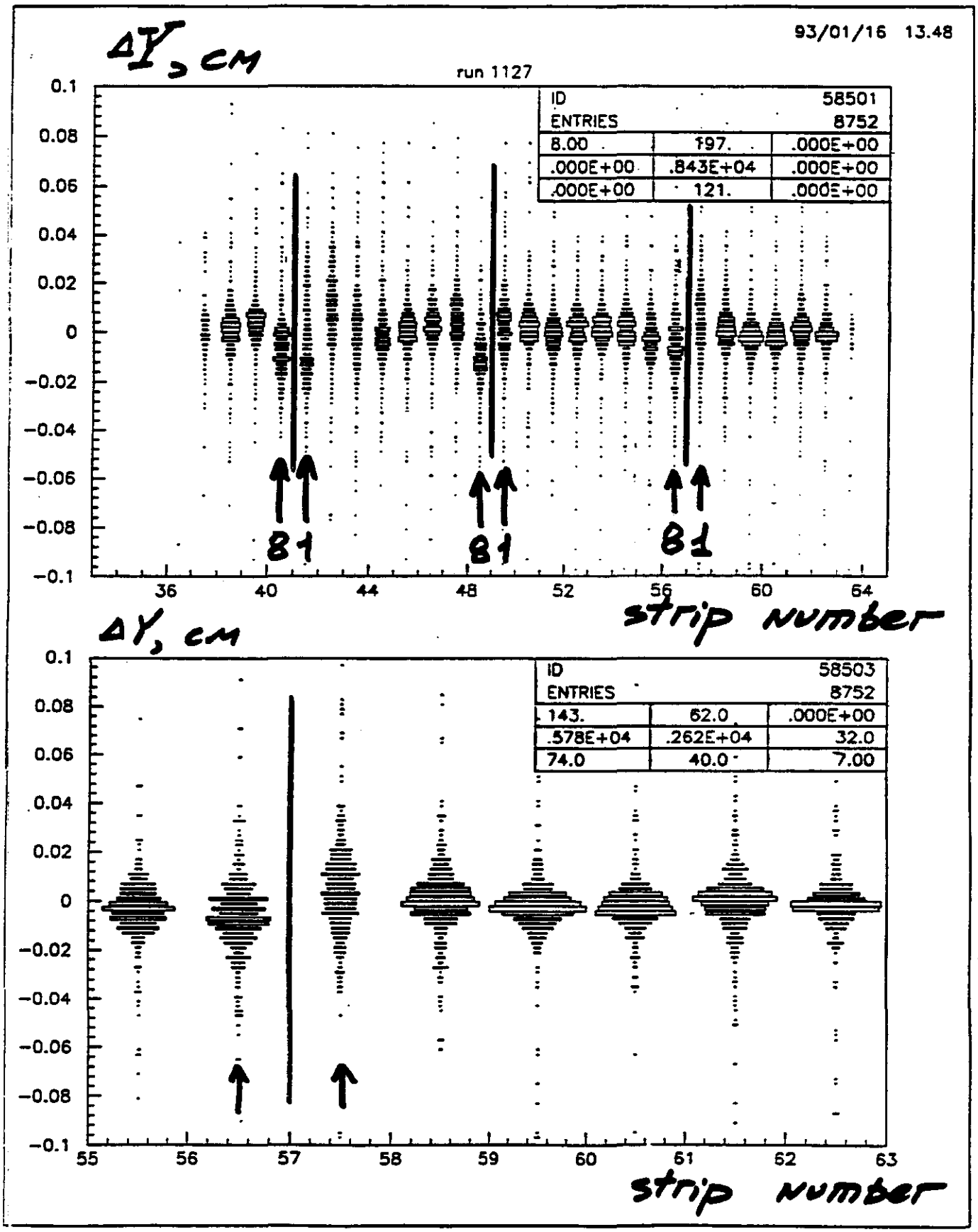
$Q_i > Q_{i-1}$; $Q_i \geq Q_{i+1}$;

$Q_i > 100$ ADC counts

→ RESOLUTION MEASUREMENTS

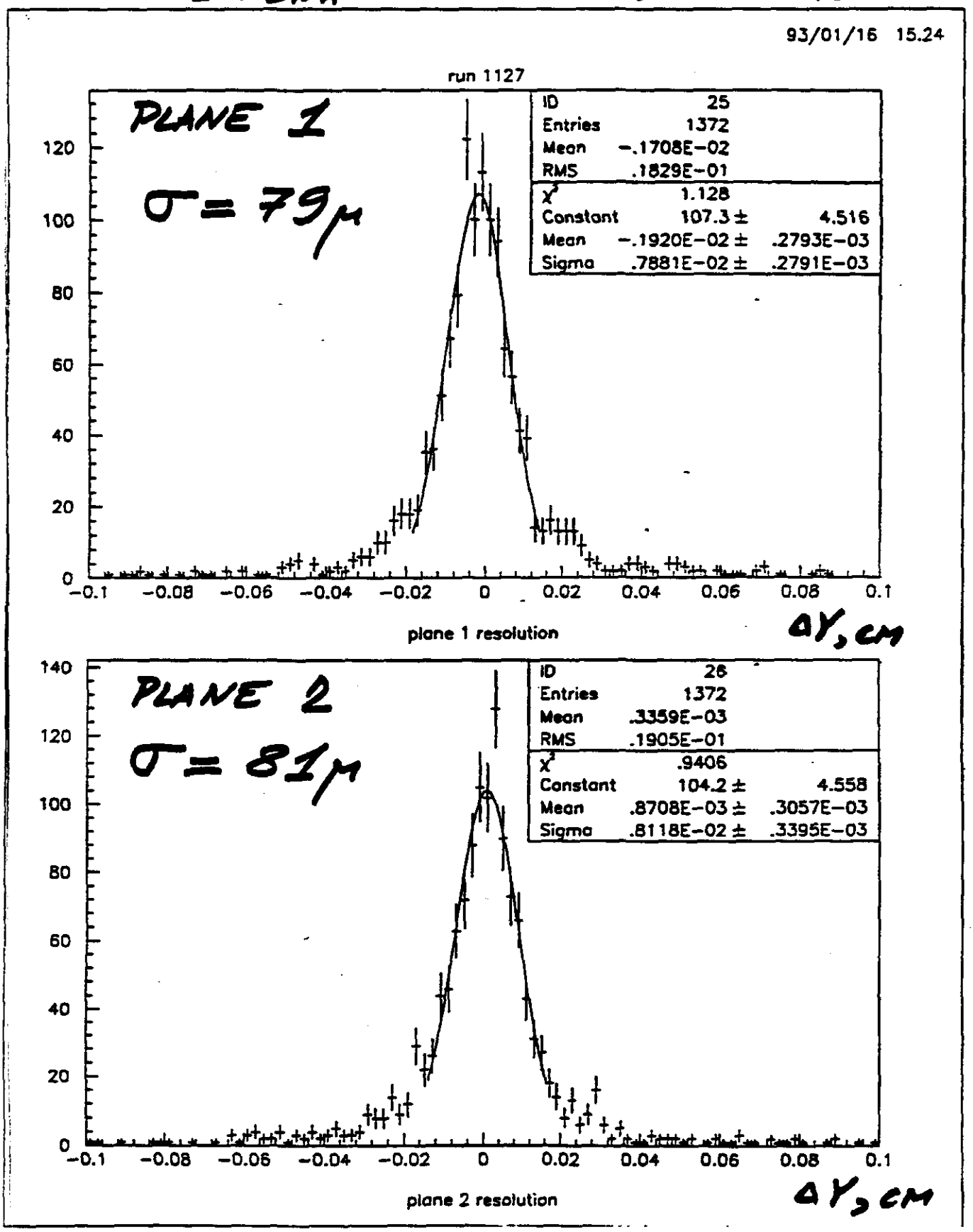


$\Delta Y \cdot \sqrt{2} \rightarrow \sigma$



RESIDUALS FOR DIFFERENT STRIPS OF DUBNA 86CSC

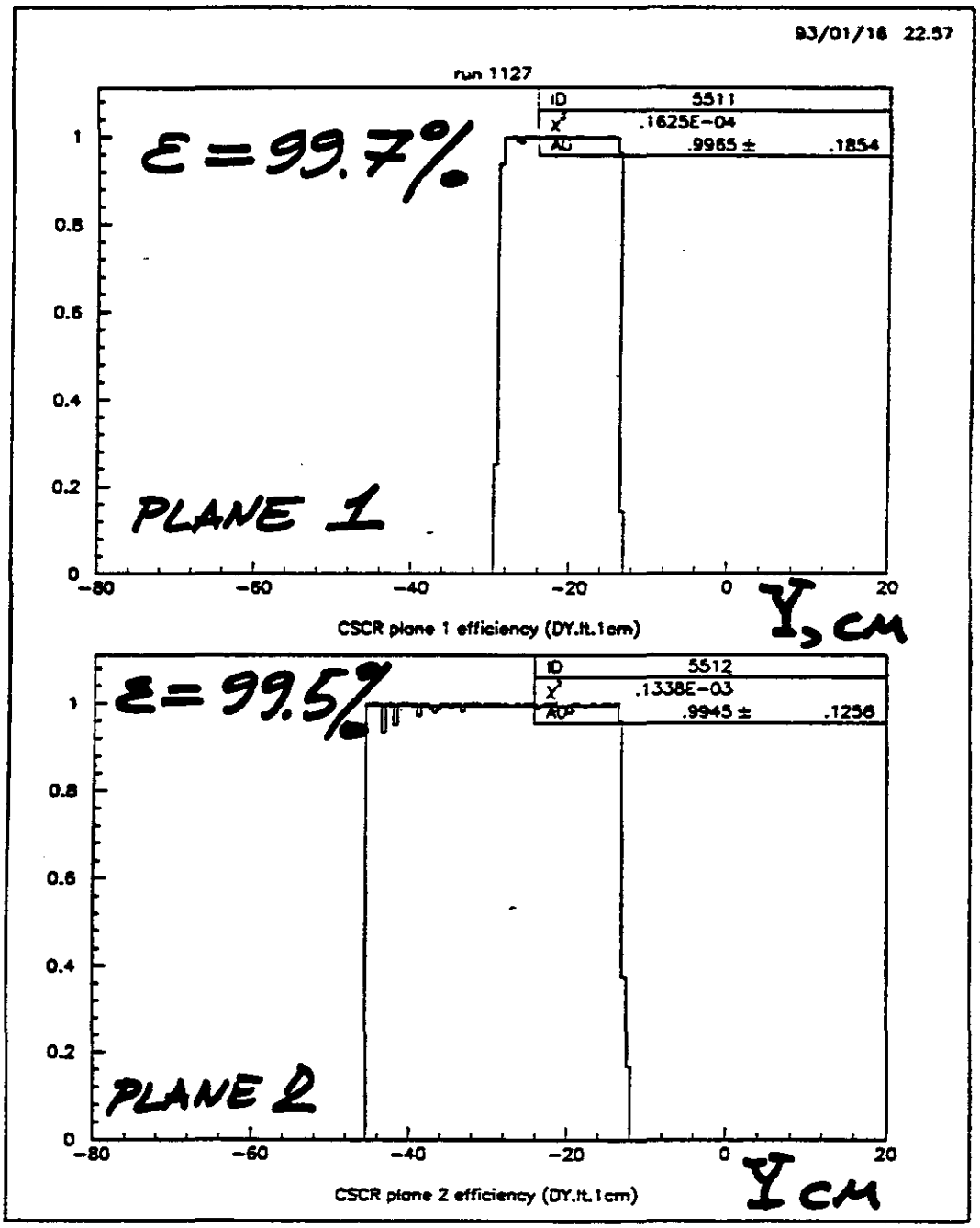
Dubna CSC resolution



4 inner channels in the same preamp 87 chip

DUBNA CSC TRACKING EFFICIENCY

$|Y_{CLUSTER} - Y_{TRACK}| < 1cm$



RDT TRACK : $N_{POINTS} = 4$

$\chi^2 < 10$

$|tg\phi| < 0.06$

Conclusions

Many Chambers of the Basic Design Now Operating

Resolution better than 75 microns demonstrated with:

- Readout utilizing monolithic IC, suitable already for large systems
- Gas that we expect to use in the Experiment

Efficiency better than 99%

Timing Performance

- 92% tagged within 16 nsec using Time-over-Threshold Didcriminators
- Fully tagged if one uses Constant Fraction Discriminators

The New Results on CSC's from Gatchina

Presentation by:

A. Vorobyov

I.

PNPI PROTOTYPE OF CSC

4 layers

380 × 440 mm² - sensitive area

5 mm gap.

2.5 mm dist. between wires

25 μm wire diam.

CSC - 380×440

CROSS SECTION
(ALONG THE WIRES)
(A-A)

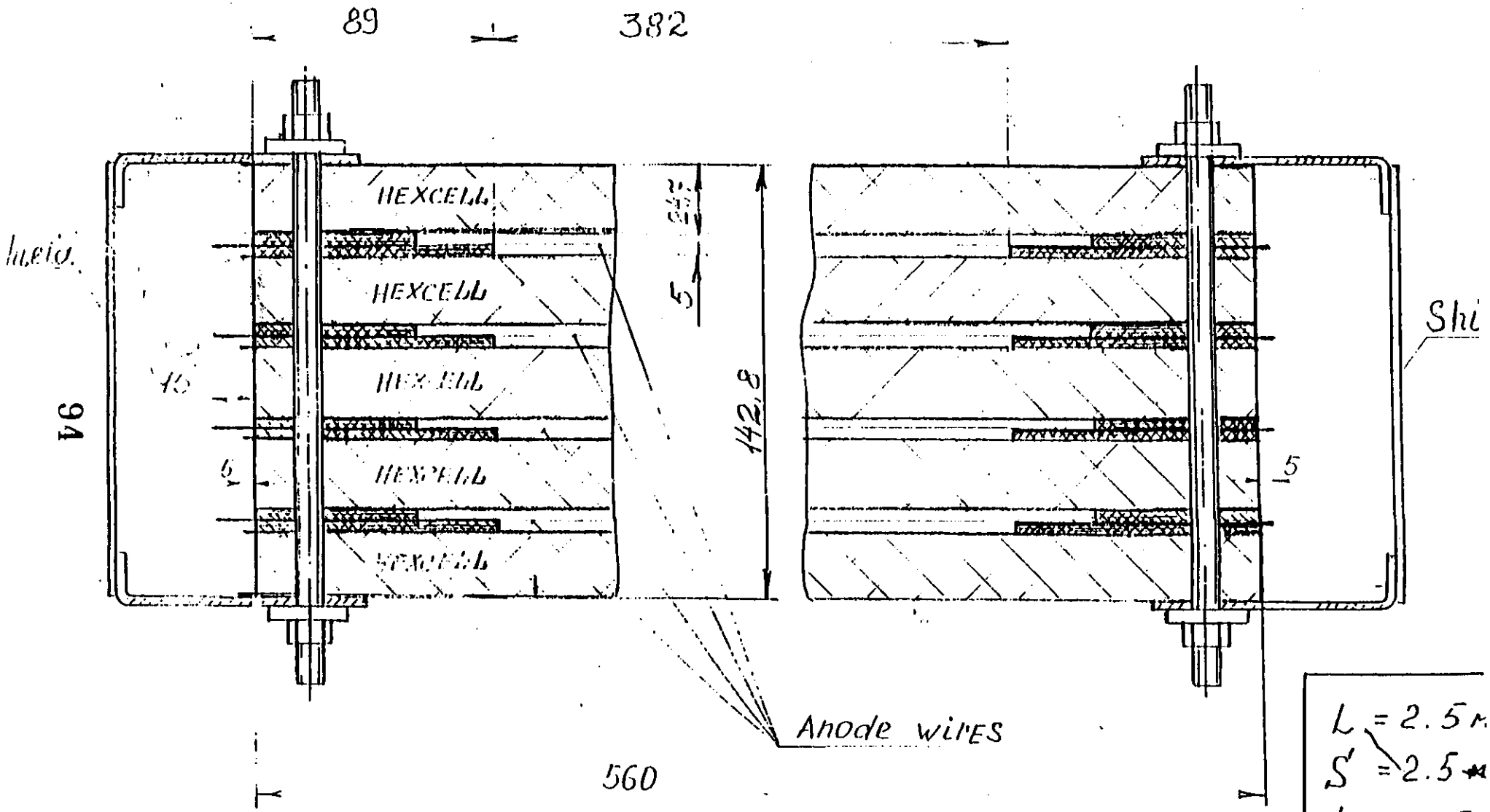
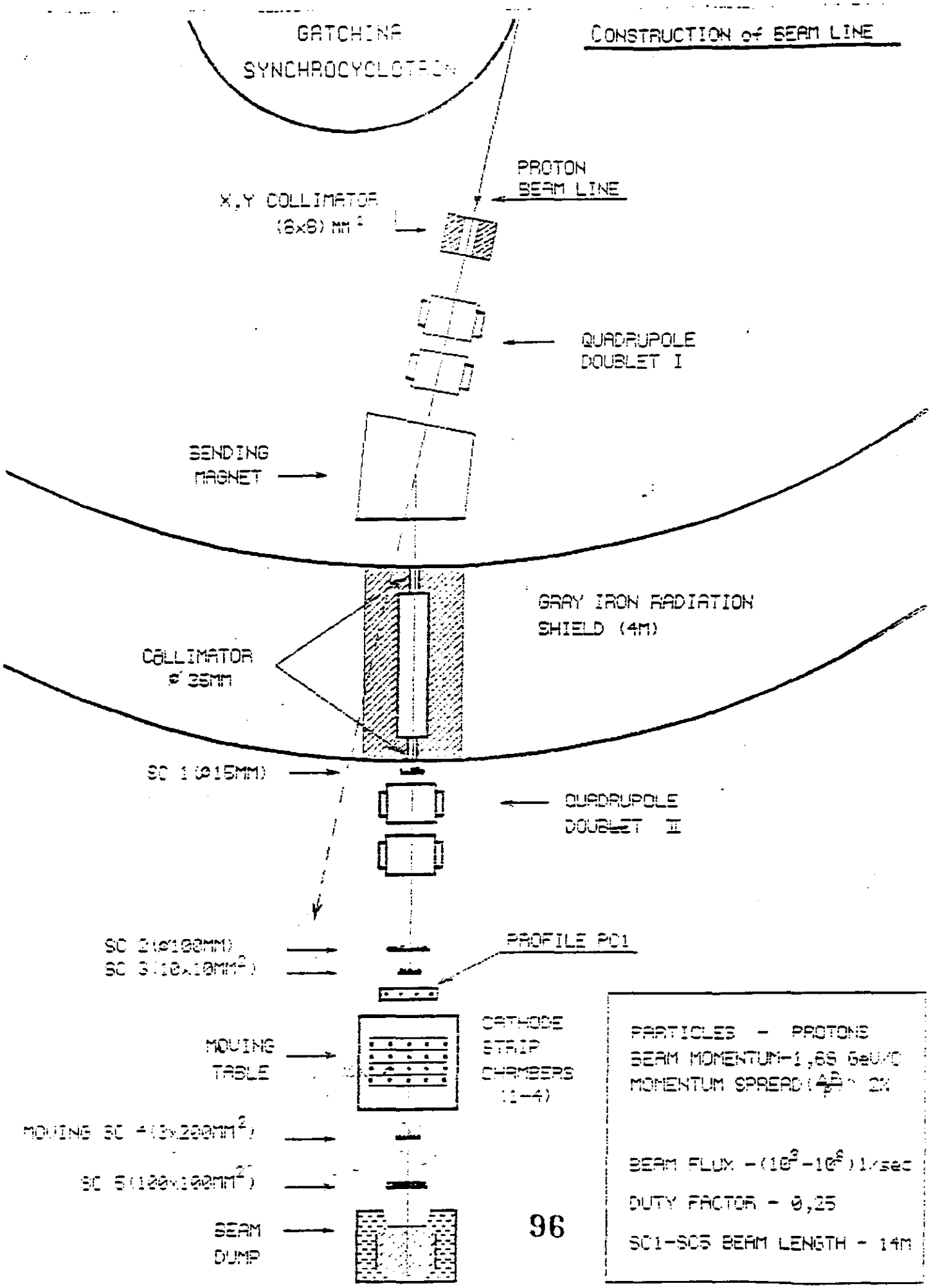


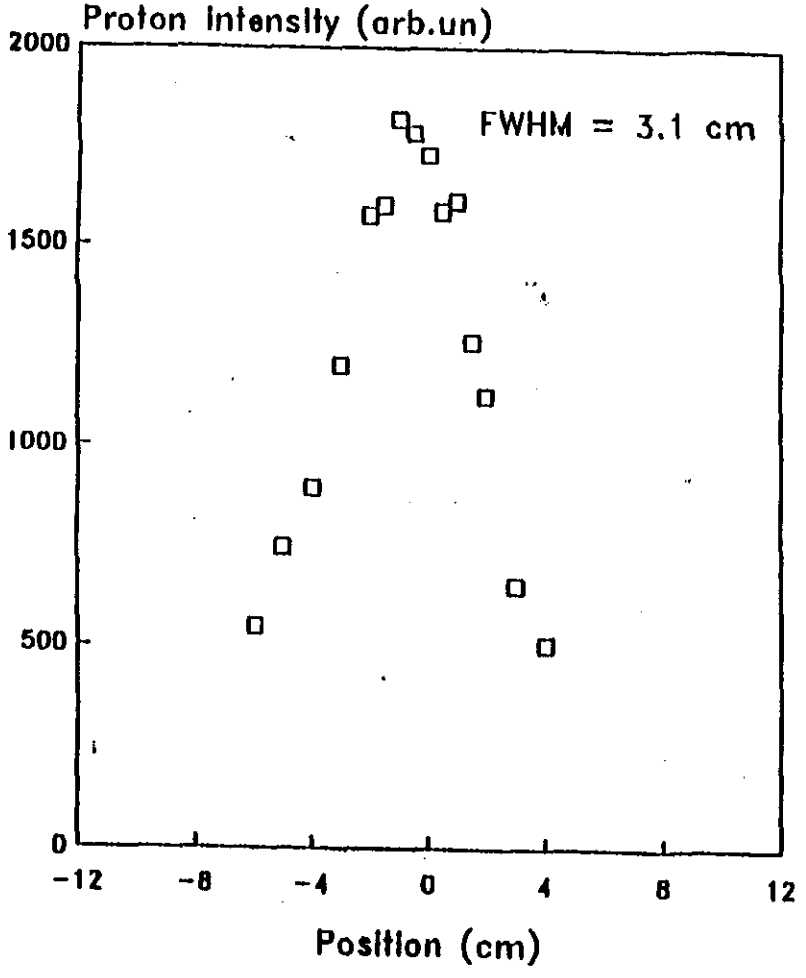
Fig. 2

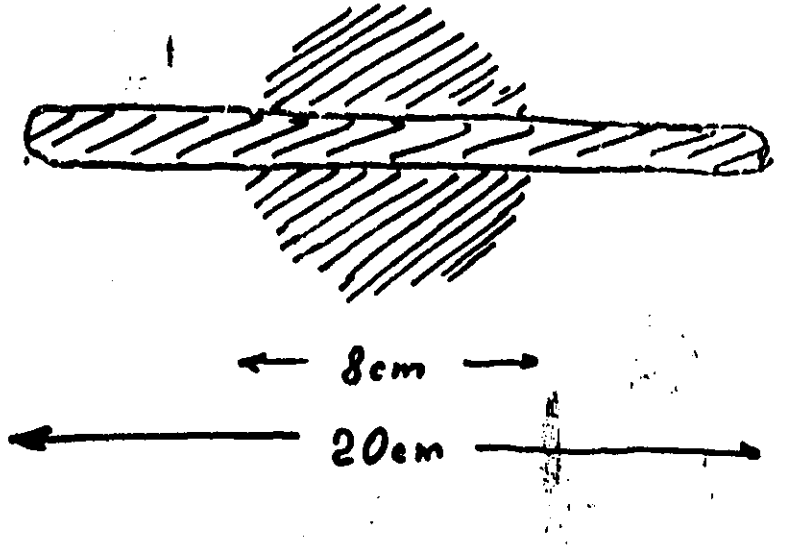
II.

1.7 GeV/c PROTON TEST BEAM


GATCHINA
SYNCHROCYCLOTRON
CONSTRUCTION of BEAM LINE
PROTON
BEAM LINE
X,Y COLLIMATOR
(6x8) mm²
QUADRUPOLE
DOUBLET I
BENDING
MAGNET
GRAY IRON RADIATION
SHIELD (4M)
COLLIMATOR
ø 35MM
SC 1 (ø15MM)
QUADRUPOLE
DOUBLET II
SC 2(ø100MM)
SC 3(10x10MM²)
PROFILE PC1
MOVING
TABLE
CATHODE
STRIP
CHAMBERS
(1-4)
MOVING SC 4(3x200MM²)
SC 5(100x100MM²)
BEAM
DUMP
PARTICLES - PROTONS
BEAM MOMENTUM-1,65 GeV/C
MOMENTUM SPREAD(ΔP/P) 2%
BEAM FLUX -(10²-10⁶)1/sec
DUTY FACTOR - 0,25
SC1-SC5 BEAM LENGTH - 14M

Beam profile





1.7 GeV/c protons

$I_p \geq 10^3\ s^{-1}$

Duty factor = 30%

III

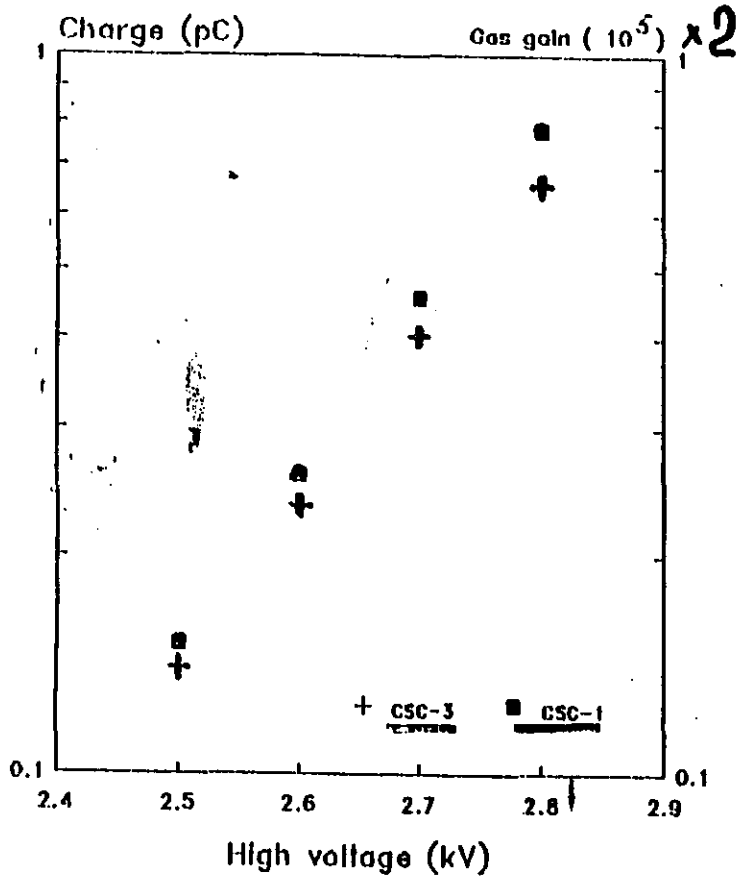
CSCs TESTS IN PROTON BEAM

$2 \cdot 10^6$ events on tapes.

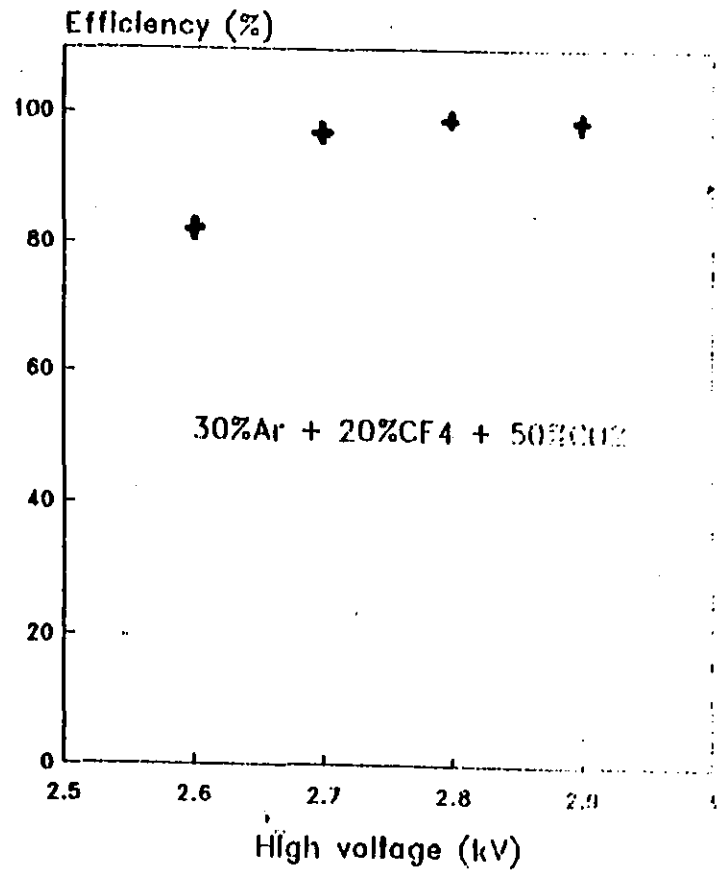
* efficiency
* time resolution
* space resolution
* angular dependence
  $\varphi = 0°, 5°, 10°$
  $\theta = 0°, 10°, 20°, 30°$
* various strip configurations
  floating strips $w = 5$ mm, 7 mm
  wide strips $w = 5$ mm, 7 mm

Fig 9

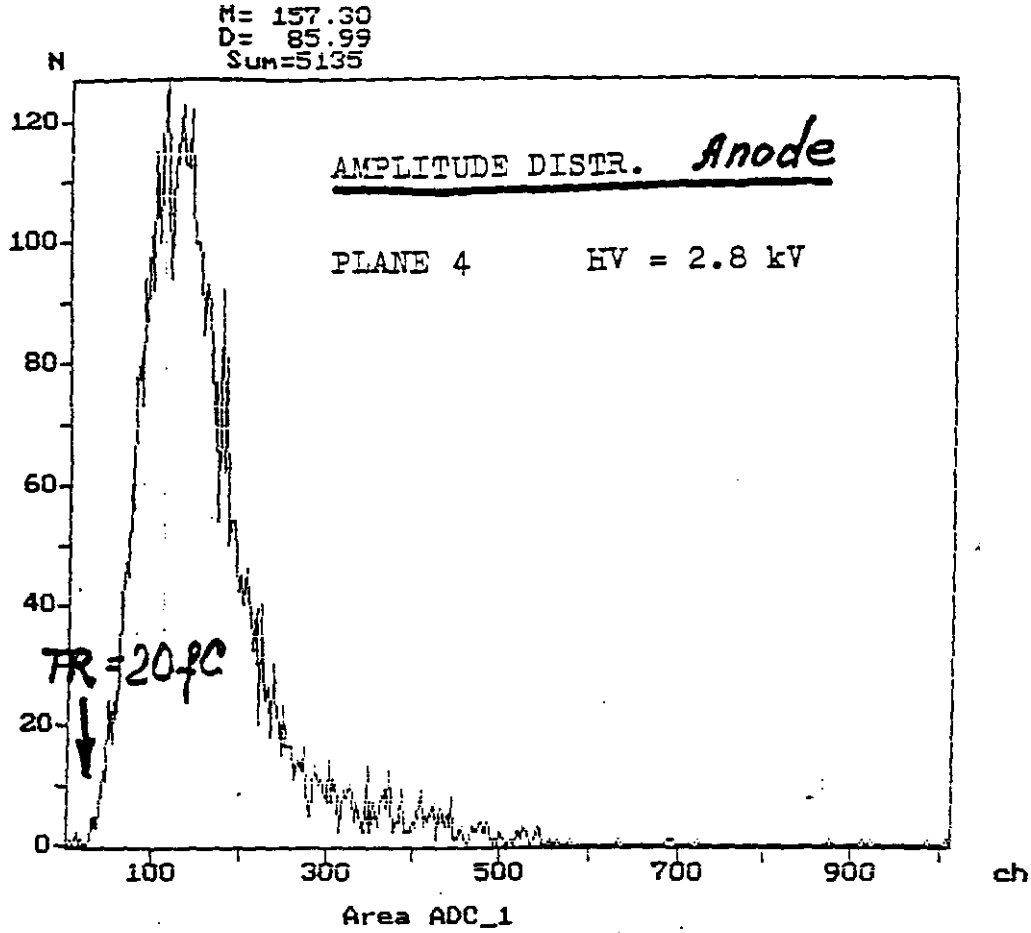
Efficiency

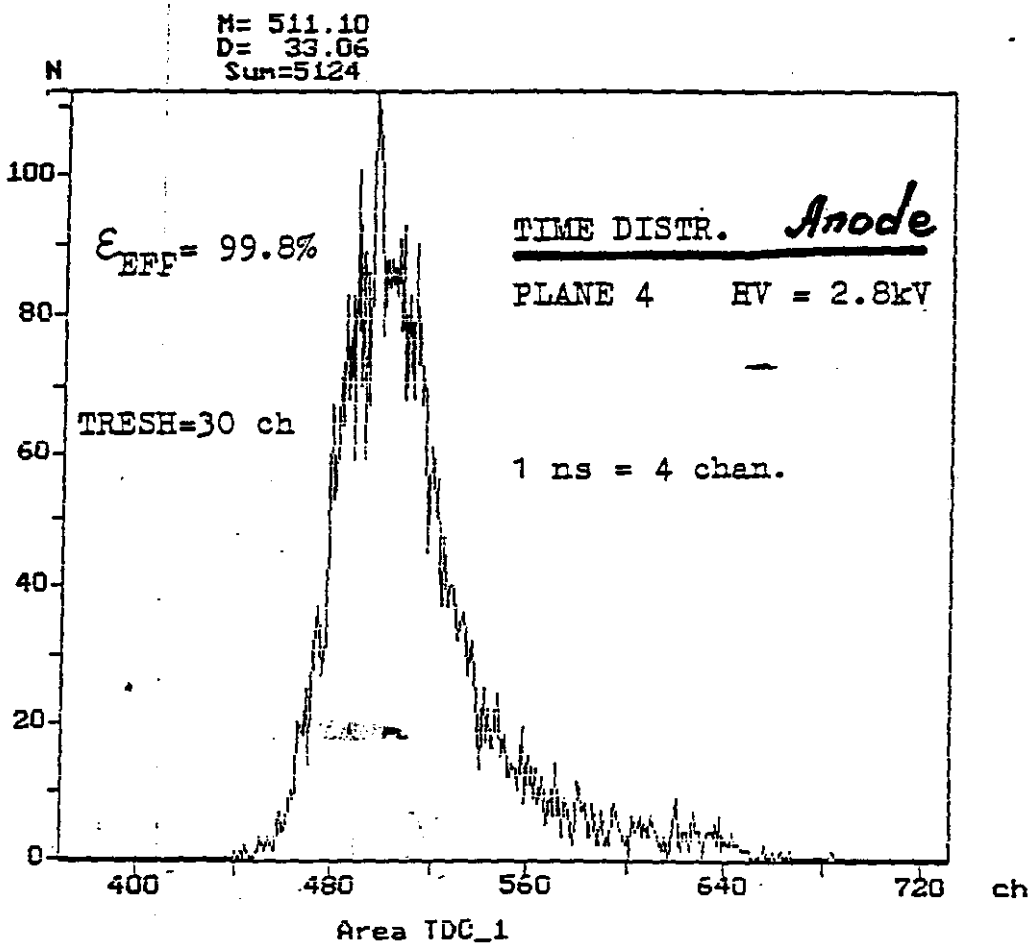


20% difference in gain



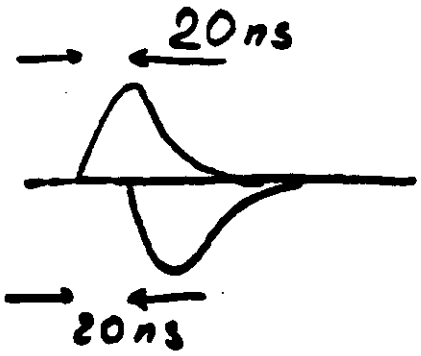
99.8% efficiency


M= 157.30
D= 85.99
Sum=5135
N
AMPLITUDE DISTR. Anode
PLANE 4
HV = 2.8 kV
TR = 20 fC
120
100
80
60
40
20
0
100
300
500
700
900
ch
Area ADC_1

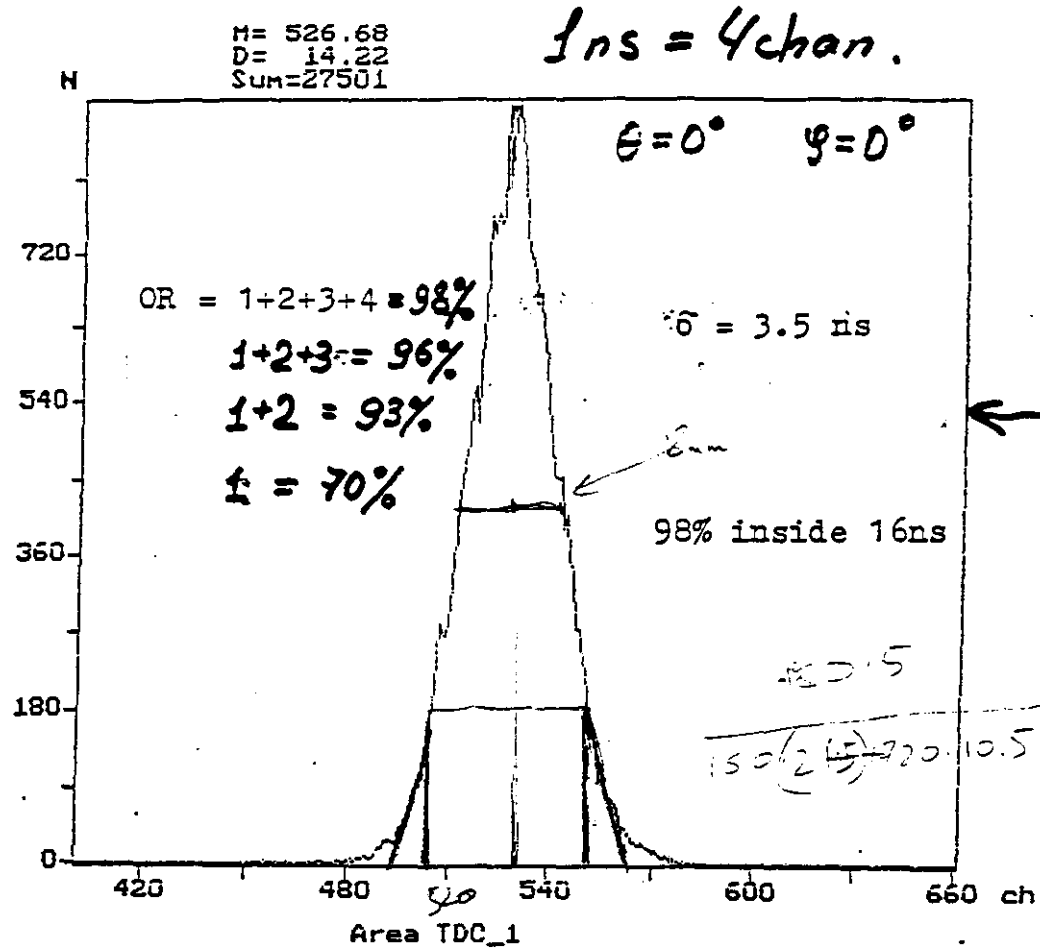

M= 511.10
D= 33.06
Sum=5124
N
ε_{EFF}= 99.8%
TIME DISTR. Anode
PLANE 4
HV = 2.8kV
TRESH=30 ch
1 ns = 4 chan.
100
80
60
40
20
0
400
480
560
640
720
ch
Area TDC_1

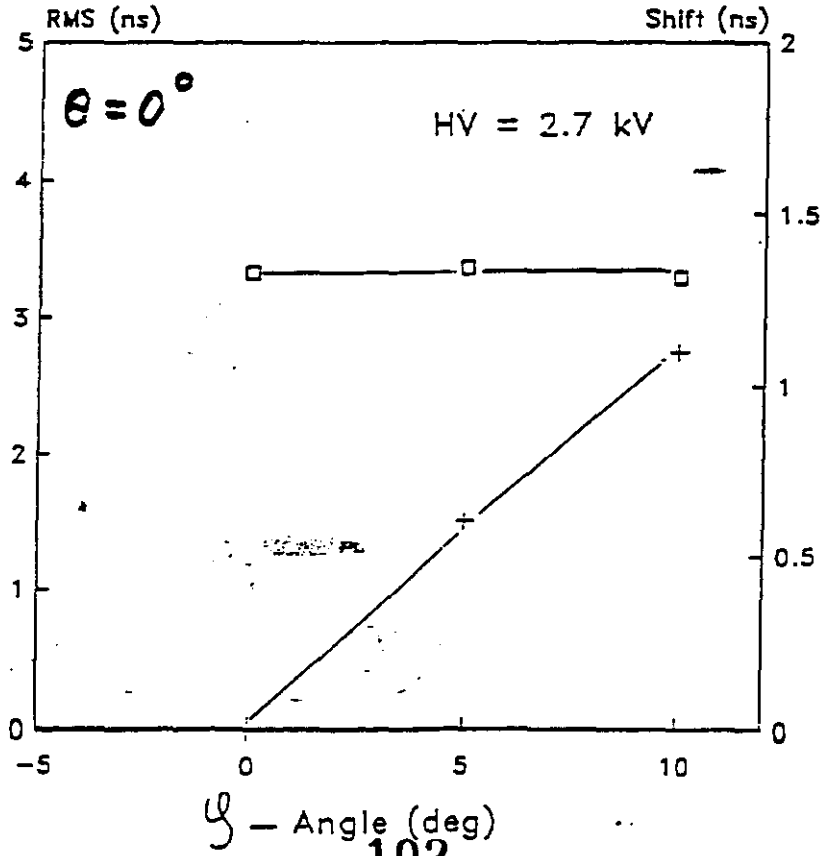
III b. TIME RESOLUTION

Zero-crossing method.

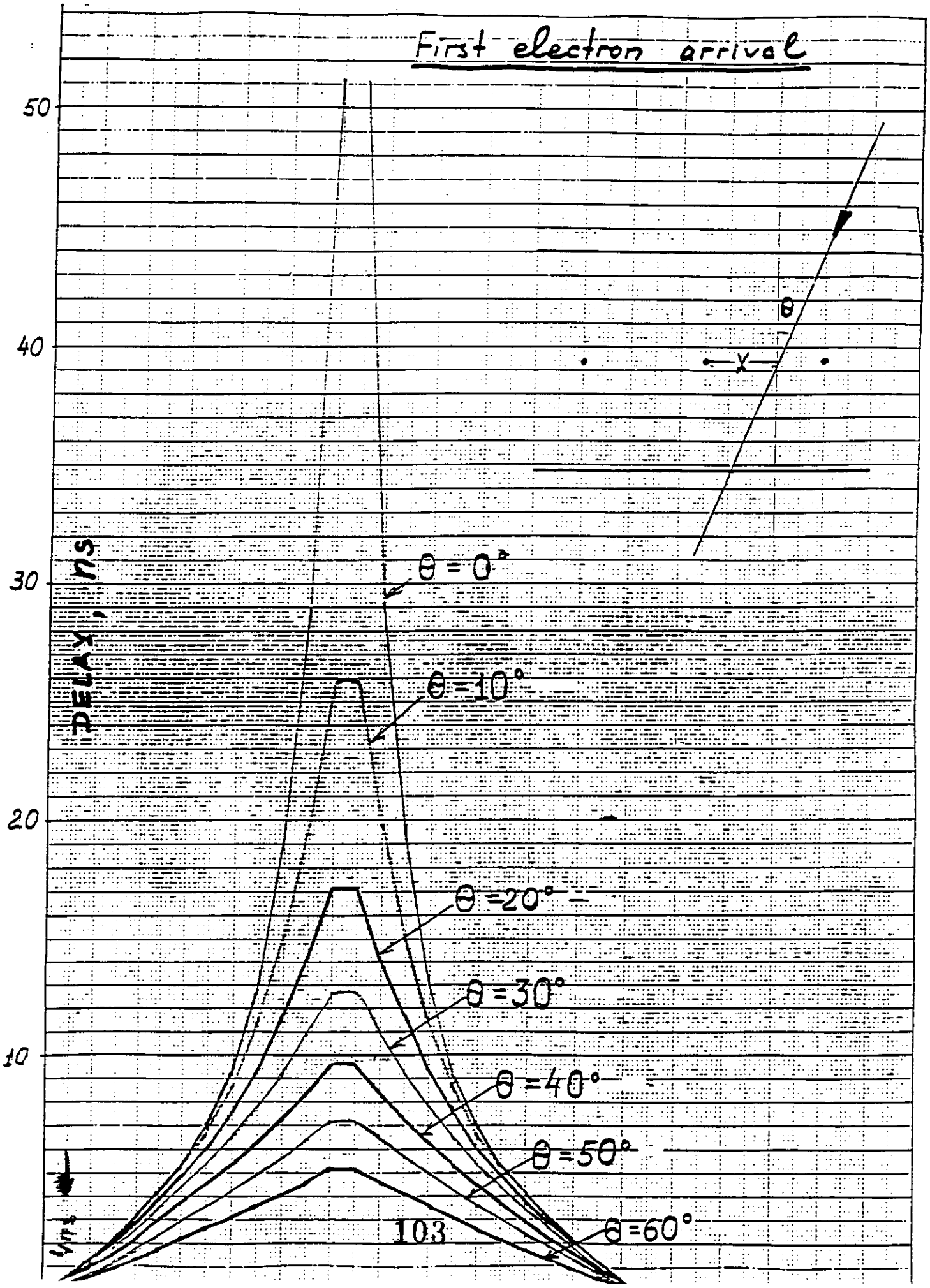


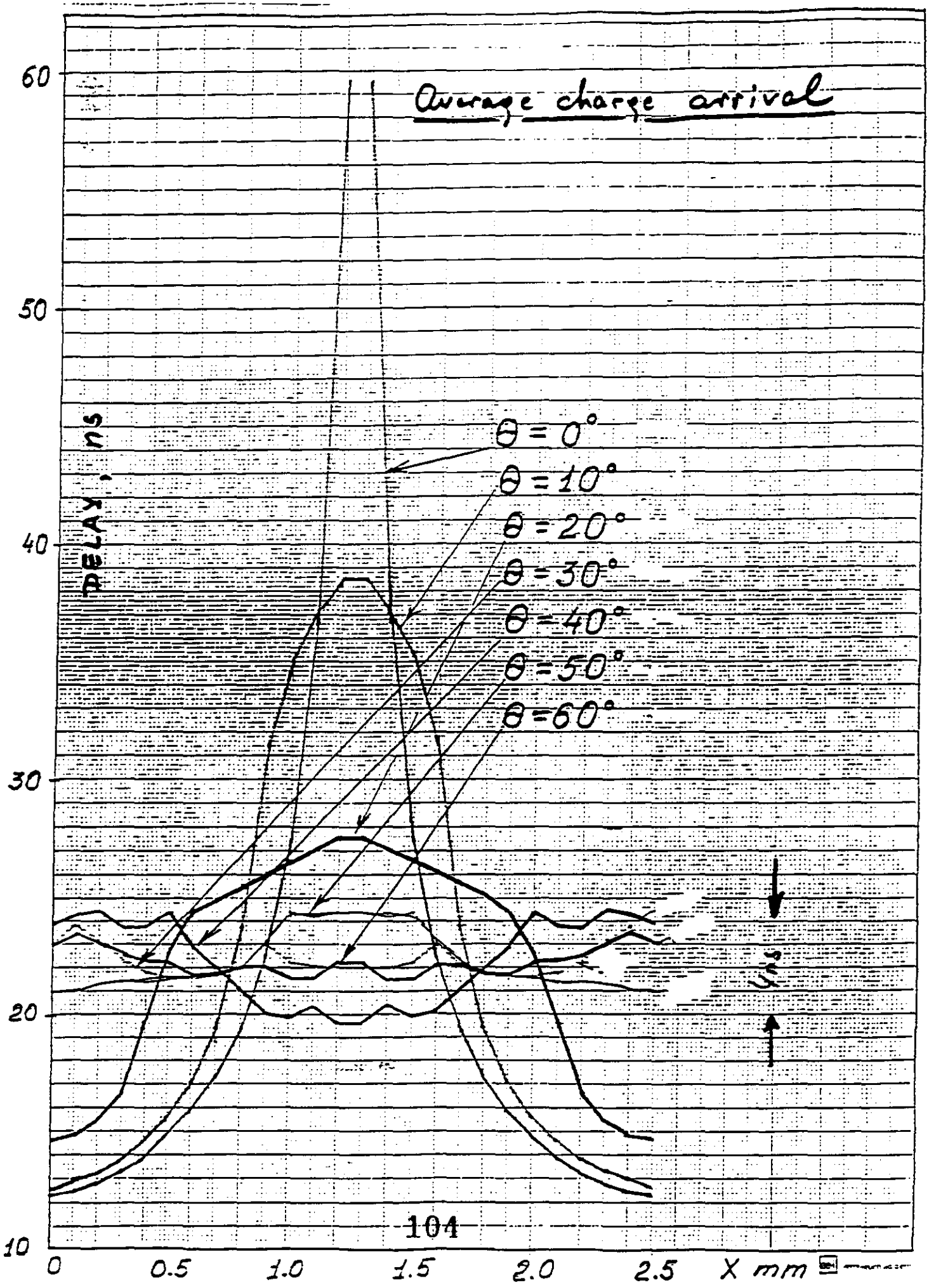
Approximately, this method measures the arrival of the average charge.

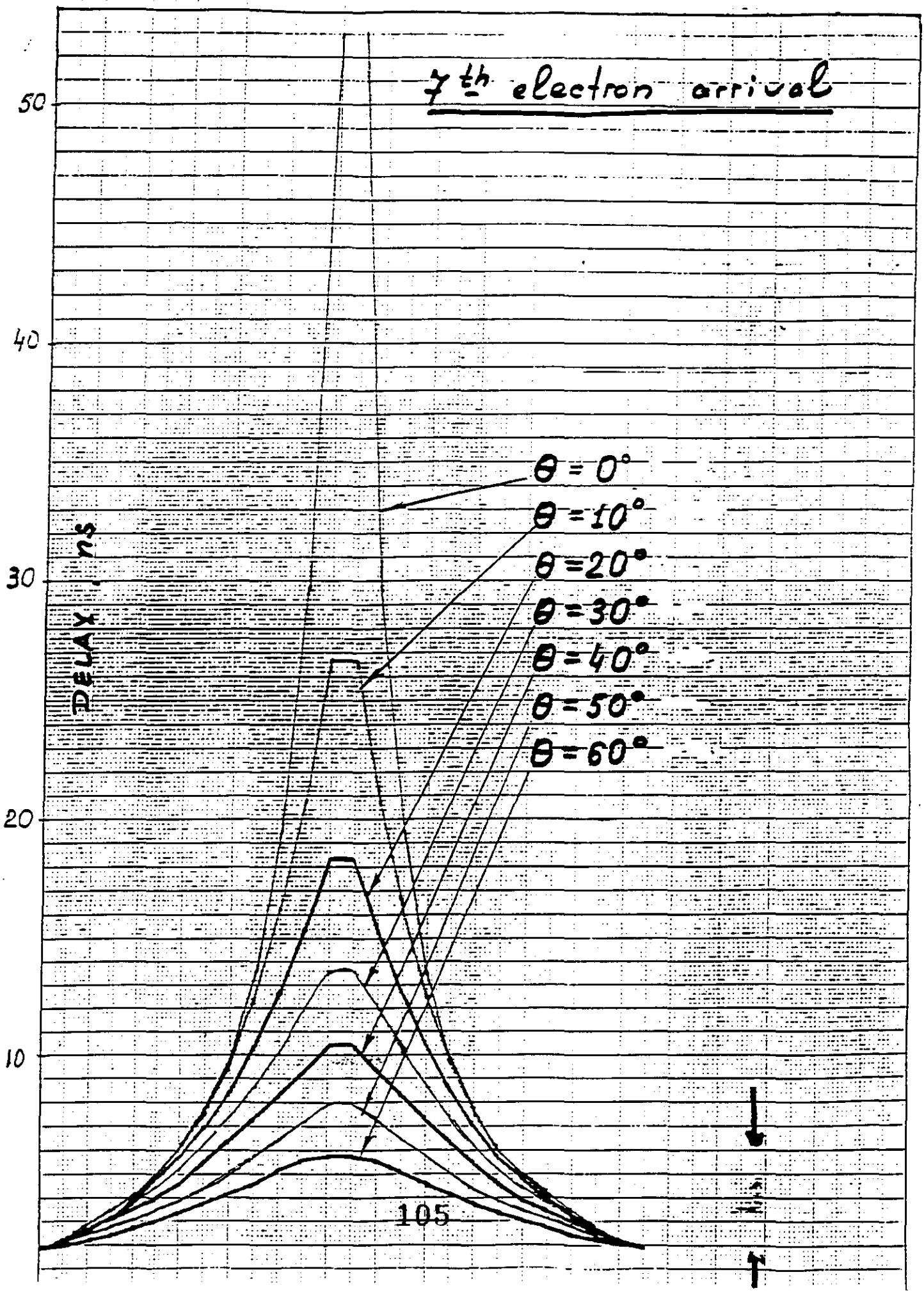




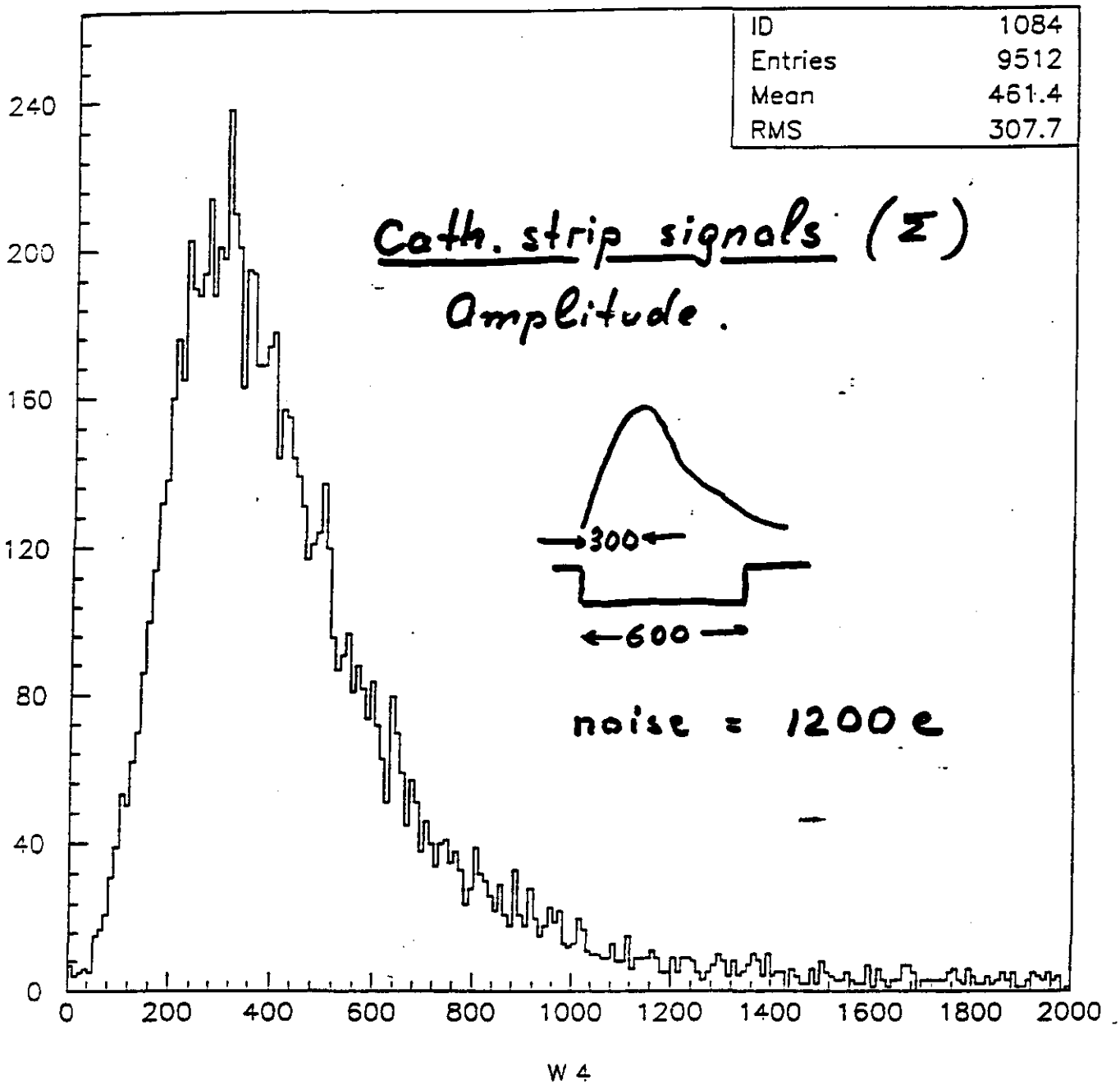
HV = 2.7 kV
σ = 3.5 ns


First electron arrival
50
40
30
20
10
DELAY, ns
θ = 0°
θ = 10°
θ = 20°
θ = 30°
θ = 40°
θ = 50°
θ = 60°
θ
X


Average charge arrival
DELAY, ns
60
50
40
30
20
10
θ = 0°
θ = 10°
θ = 20°
θ = 30°
θ = 40°
θ = 50°
θ = 60°
0
0.5
1.0
1.5
2.0
2.5
X mm

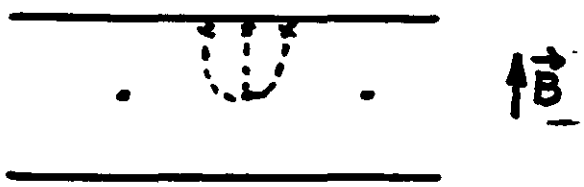

7th electron arrival
50
40
30
20
10
DELAY, ns
θ = 0°
θ = 10°
θ = 20°
θ = 30°
θ = 40°
θ = 50°
θ = 60°

Analysis of the cathode signals is just started



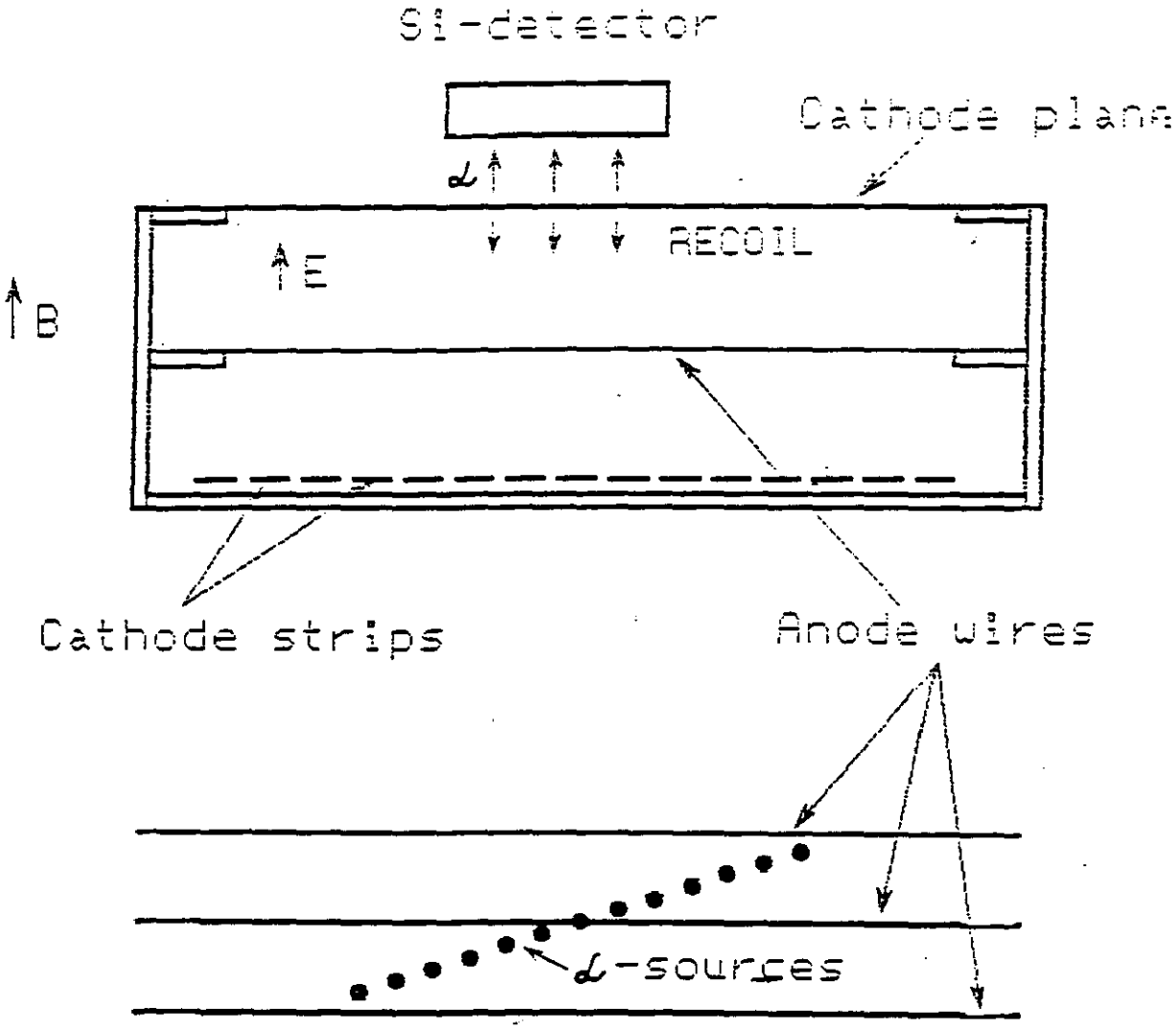
IV.

CSCs in End Caps magnetic field



shift along s-wires.
resolution!

Schematic of experimental set-up



Chamber: L=2,3mm

S=2,5mm

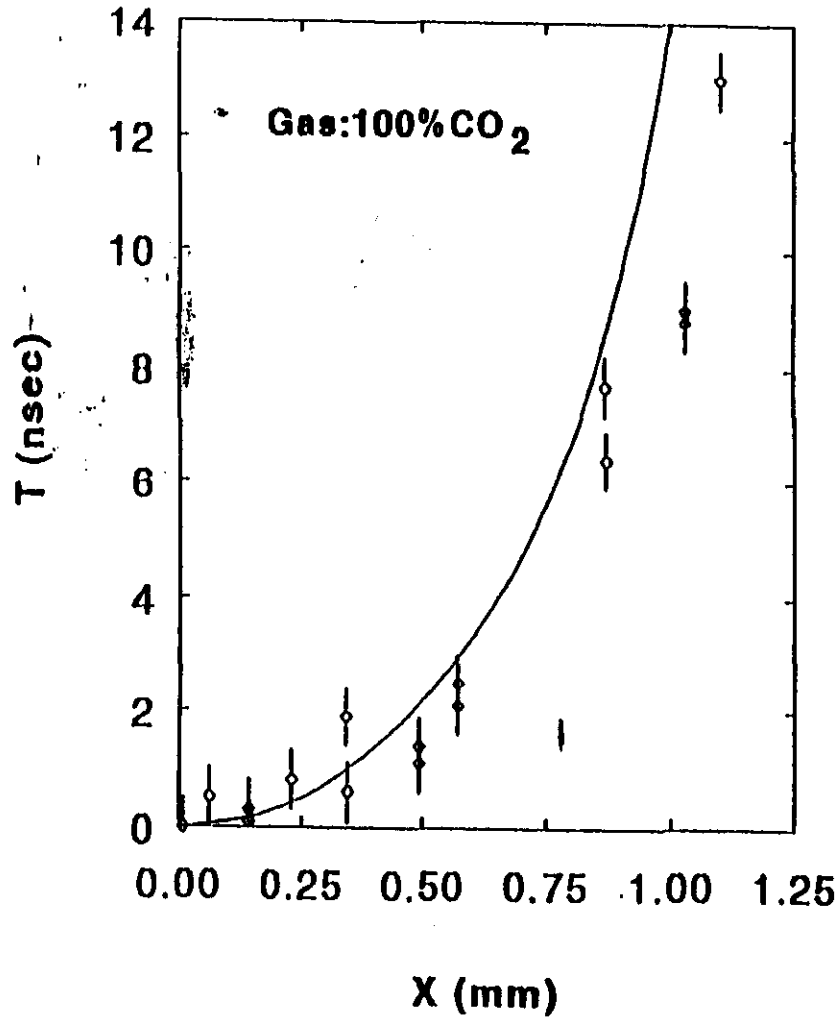
d_s=25μm

cathode strip pitch-2mm

α-source- ^{208}Po

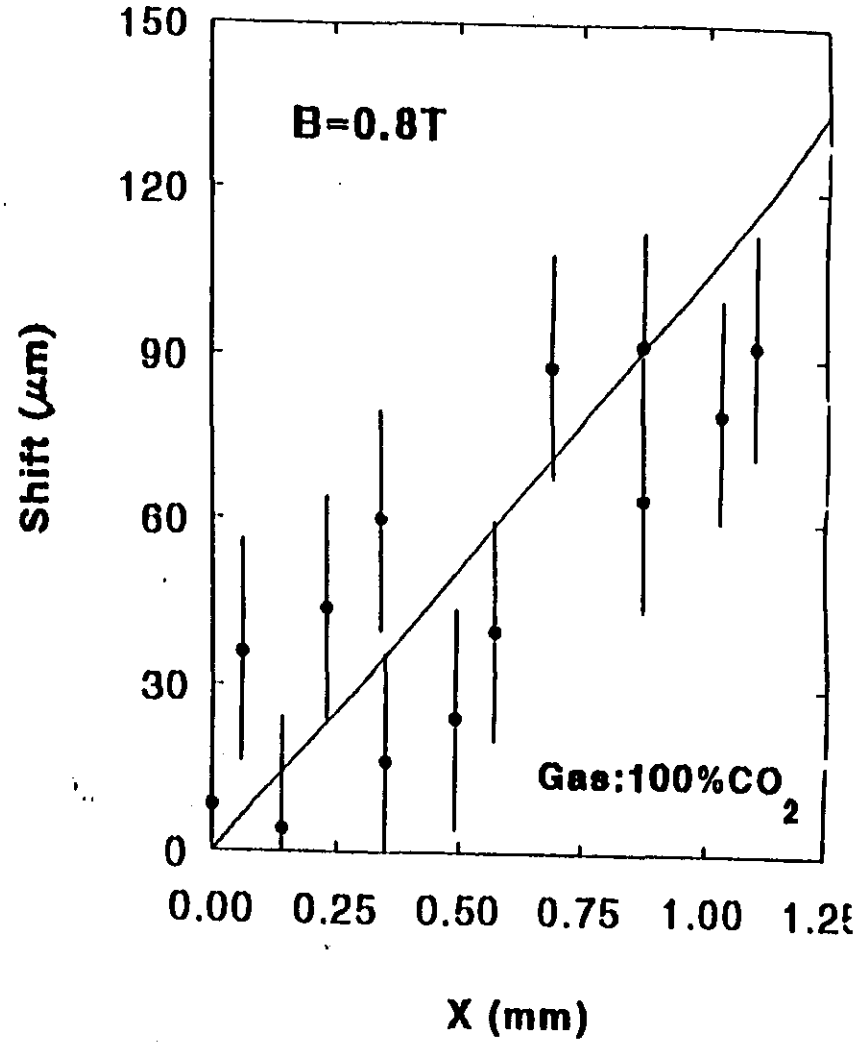
hole diameter-0,6mm

Time shift
verses the position place



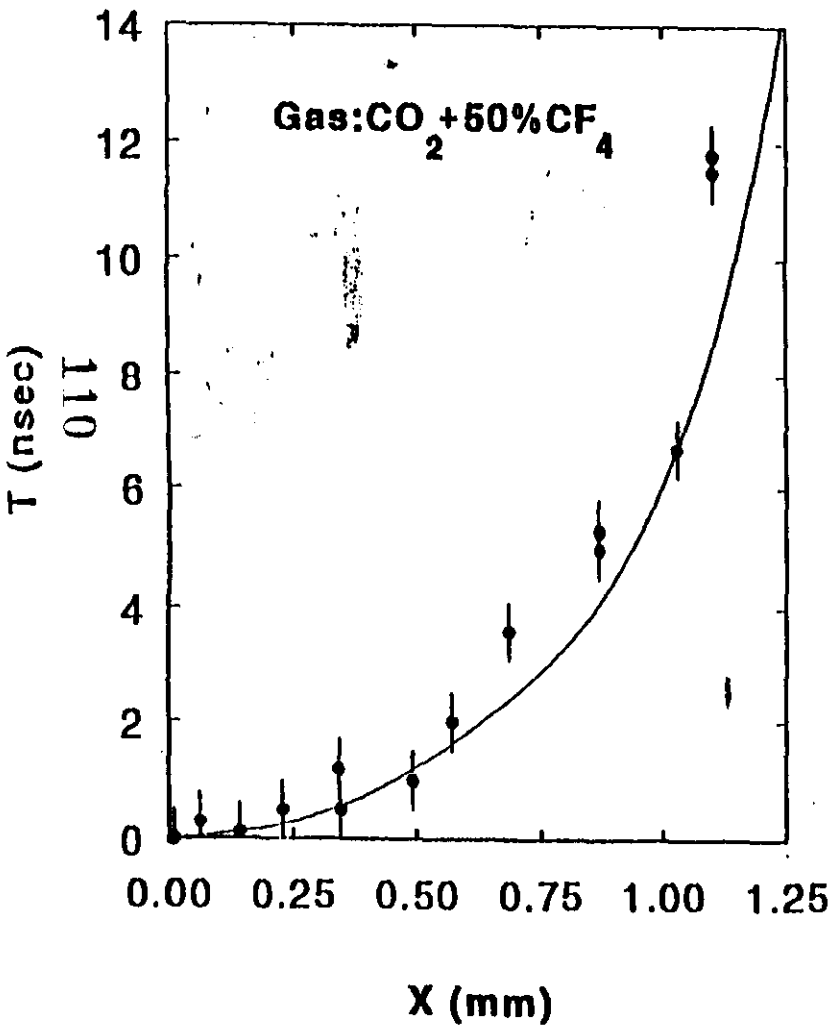
◇ PNPI measurements
— Blagl program

Coordinate shift verses
the source place in magnetic field



● PNPI measurements
— Calculations

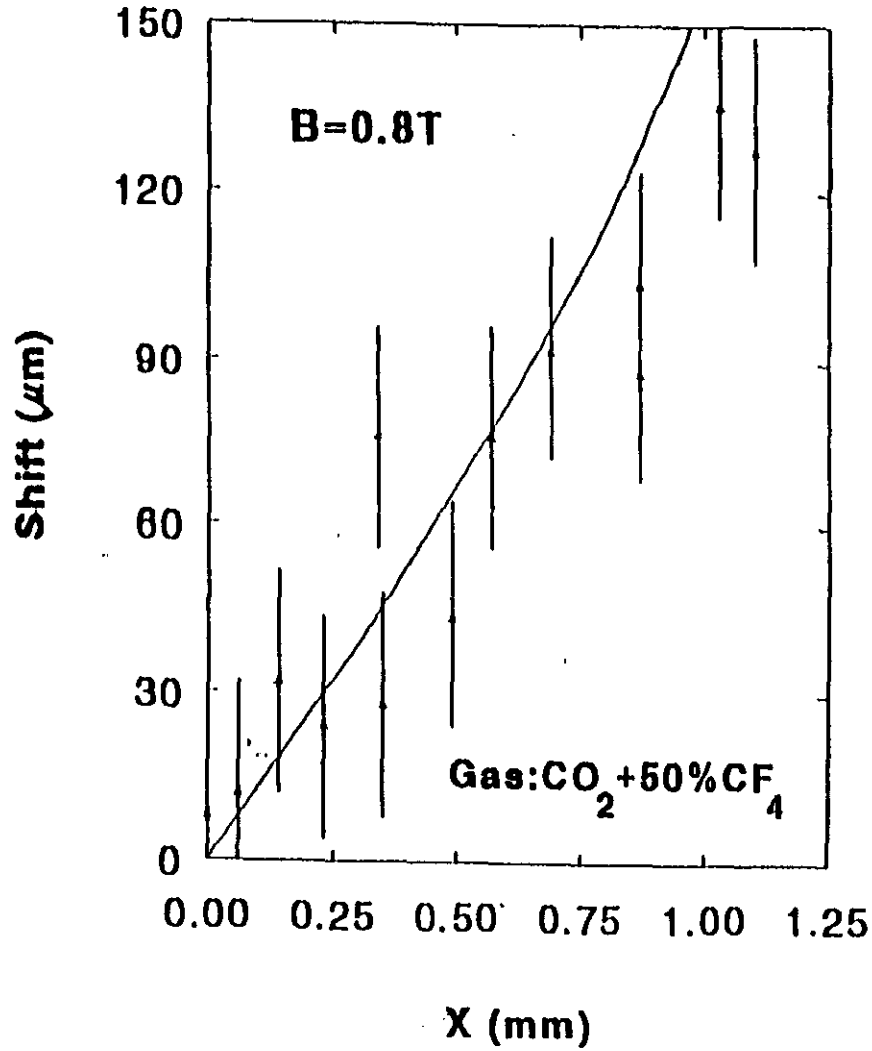
Time shift
verses the position place



● PNPI measurements

—— Blagl program

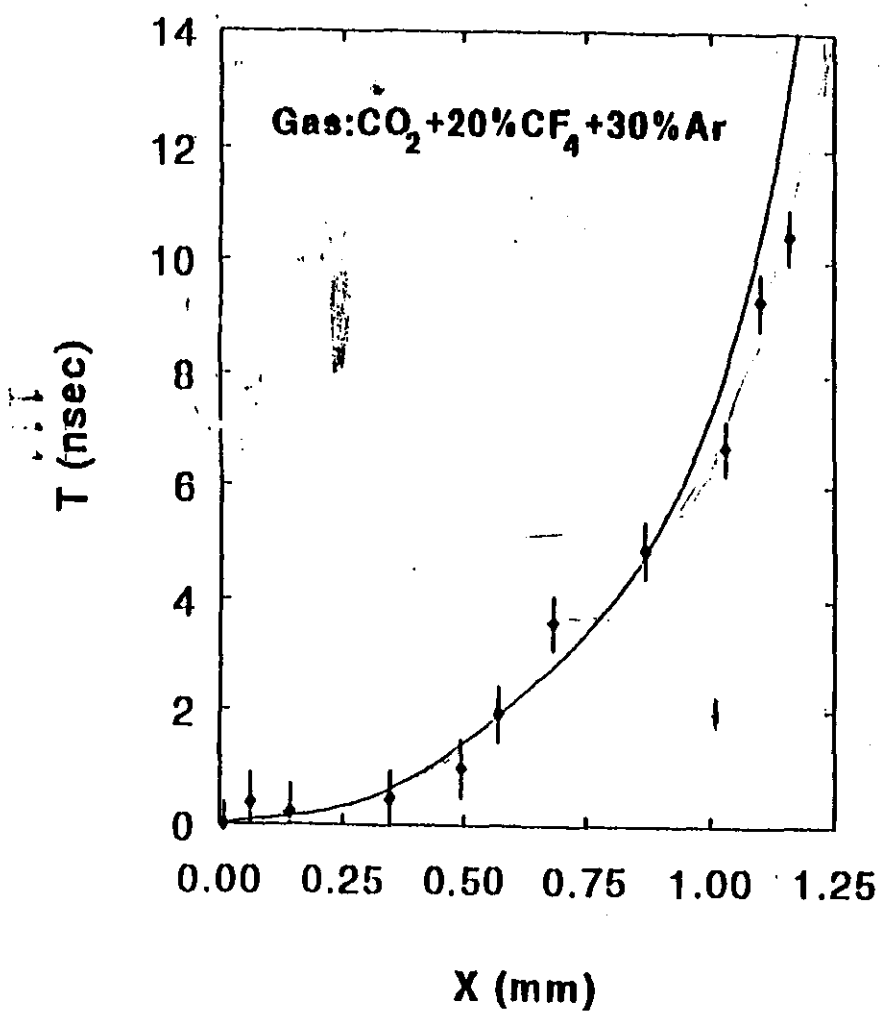
Coordinate shift verses
the source place in magnetic field



▲ PNPI measurements

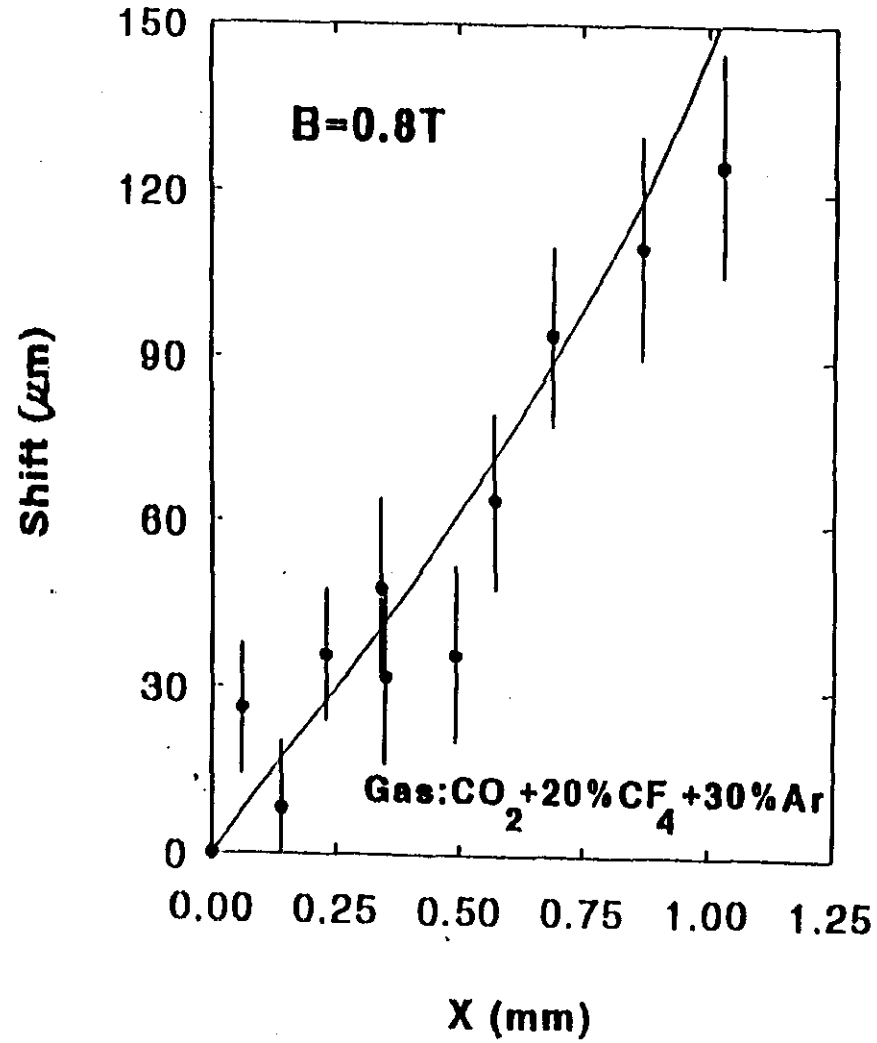
—— Calculations

Time shift
verses the position place



◆ PNPI measurements
— Blagl program

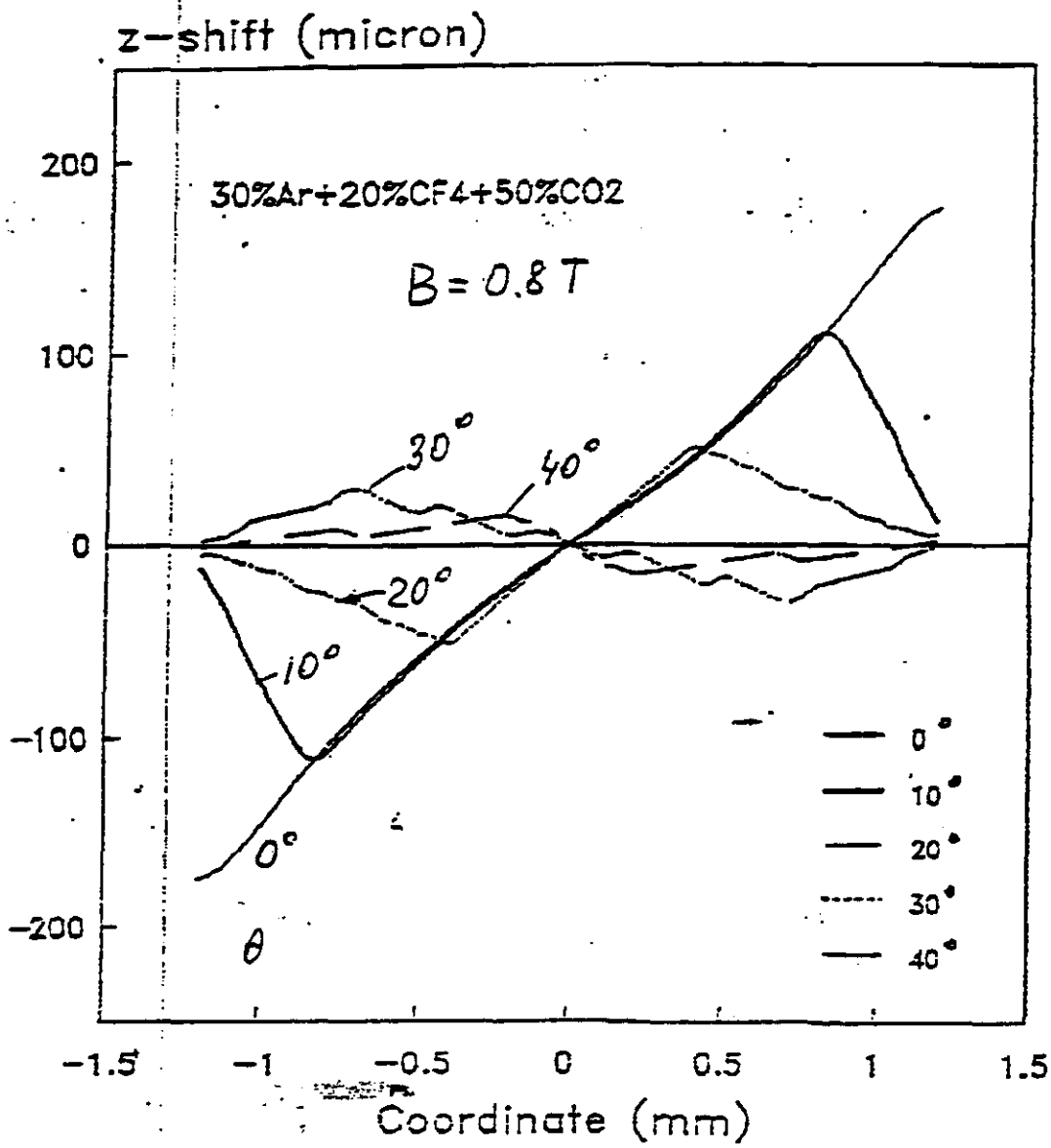
Coordinate shift verses
the source place in magnetic field



● PNPI measurements
— Calculations

③

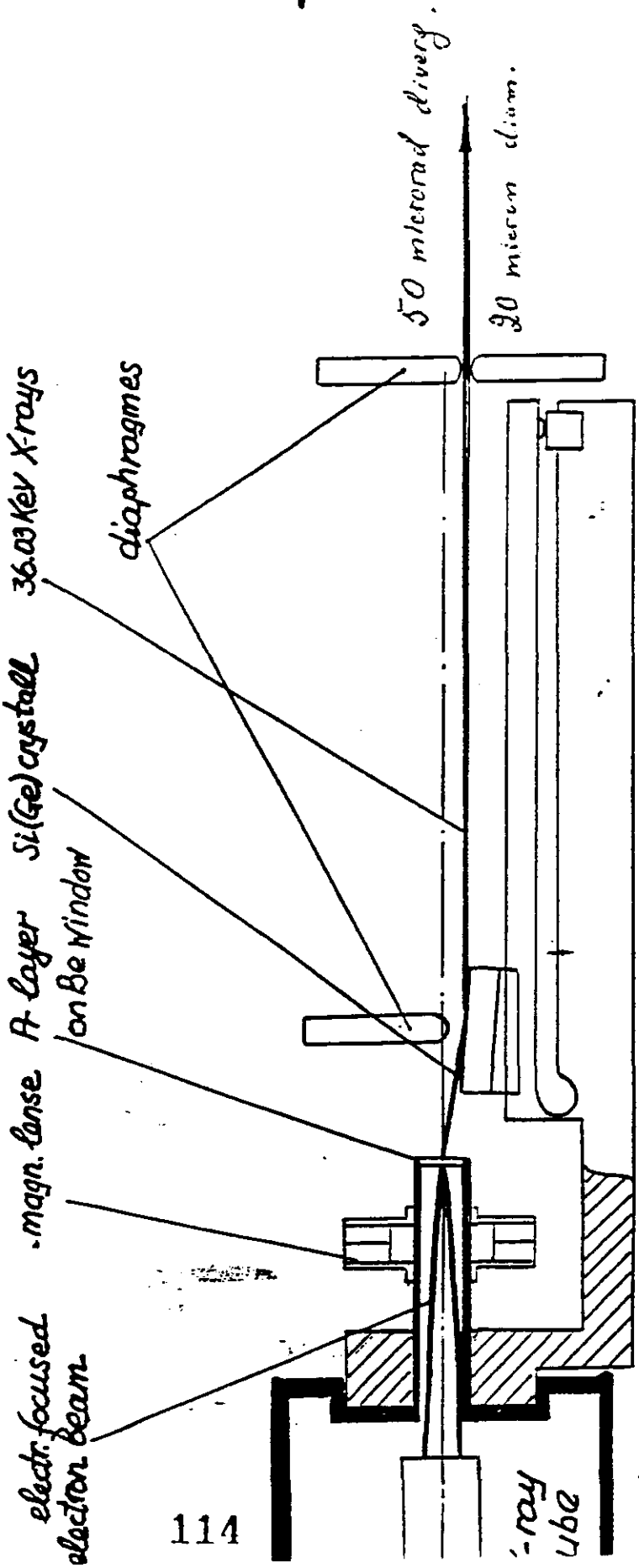
Z– shift vs position track for different entry angles



V

X - RAYS TESTS

This was proposed.

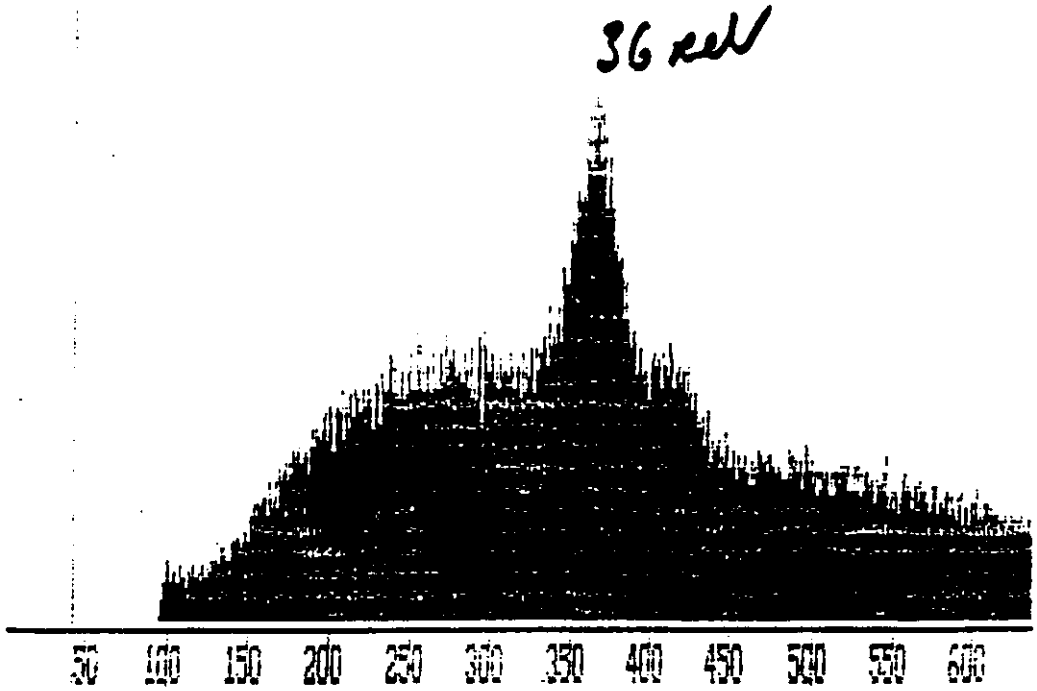


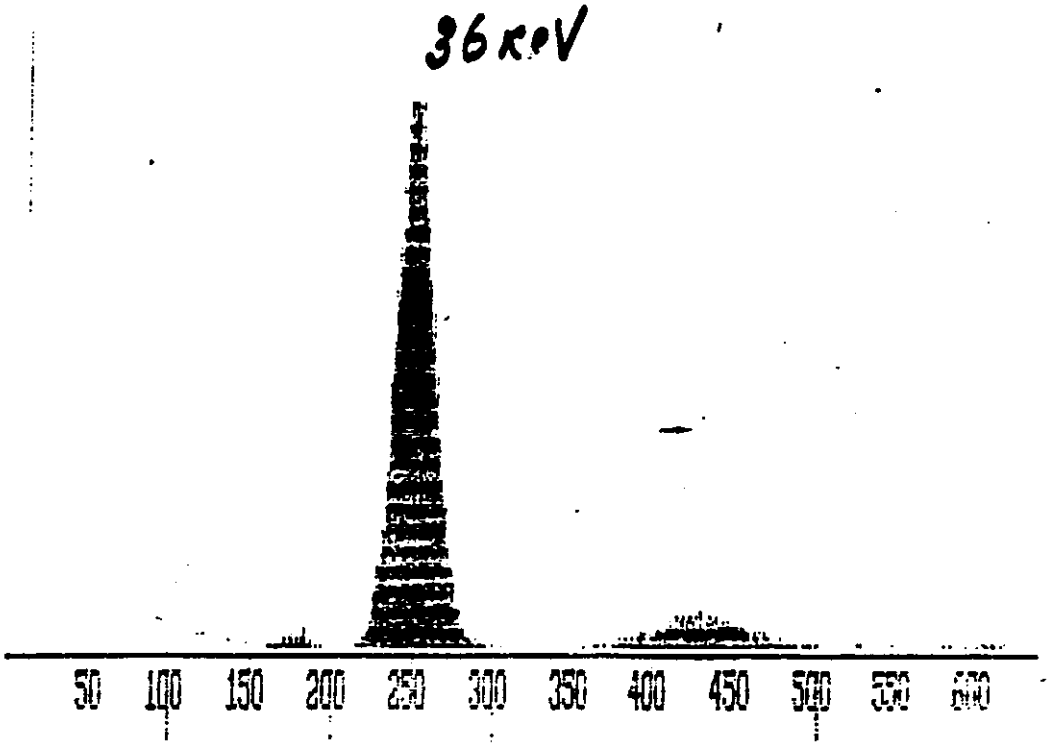
REIS - 100
X-rays tube with Pr anticathode

V = 100 kV
I = 60 μA without magn. focusing
I = 25 μA with magn. focusing

Preliminary test results
(without magn. focusing)
Monochromator Si (111) planes
Reflex width 70 mkm
Angle width < 50 mkrad
Reflex counting rate 10^3 per. sec for K_{α_1}
(for V = 95 kV I = 30 μA)

Now it is done.



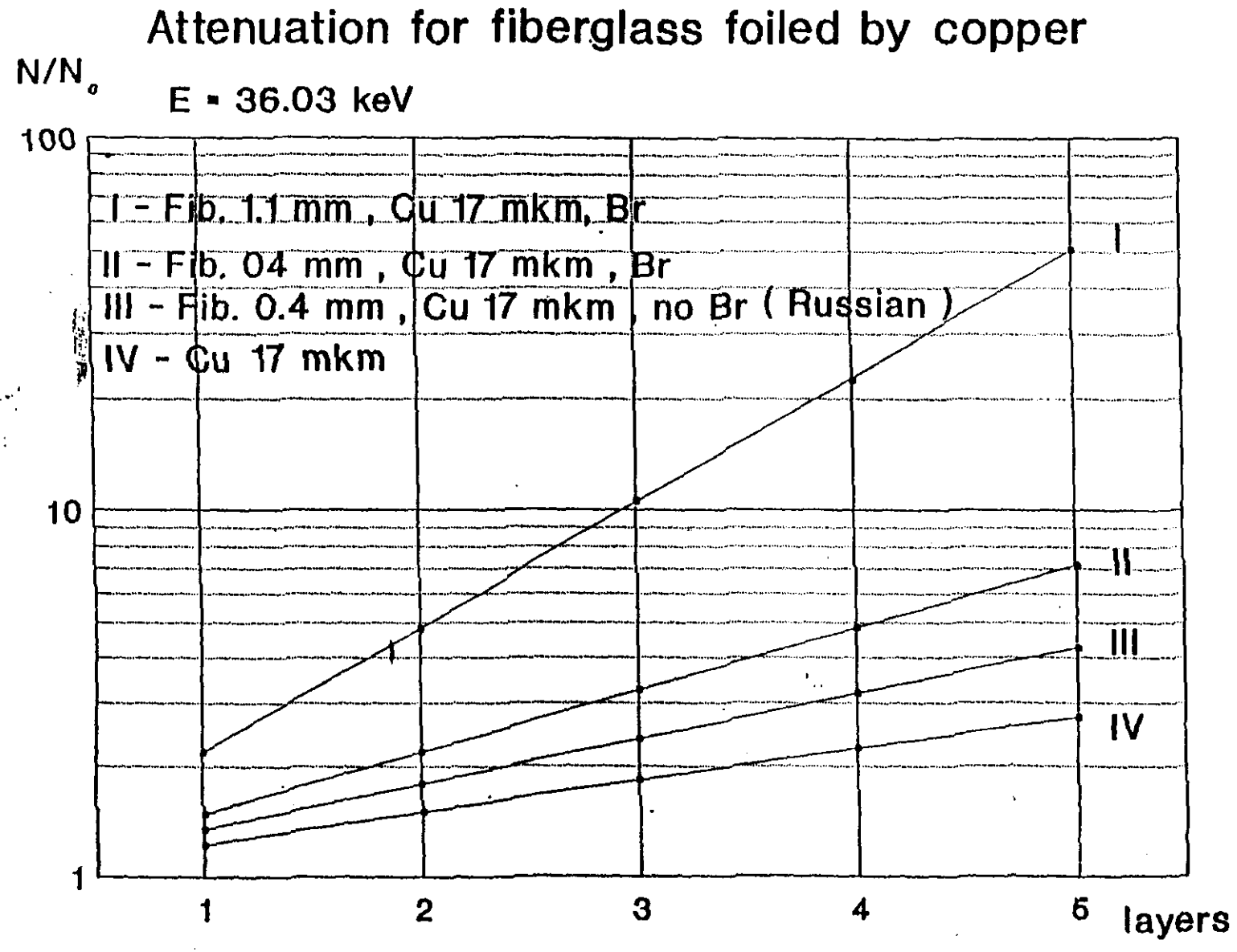


X ray spectra measured with a Ge detector.

a) without monochromator

b) with monochromator

Experimental data.



The CSC System Performance

Presentation by:

S. Whitaker

CSC System Performance

Scott Whitaker
18 January 1993

System specifications

Momentum resolution

- dPt / Pt for barrel and endcap options

Pattern recognition

- Momentum resolution dependence on # of good hits
- Probability of N' good hits from N chambers
- Two-track performance

Timing performance

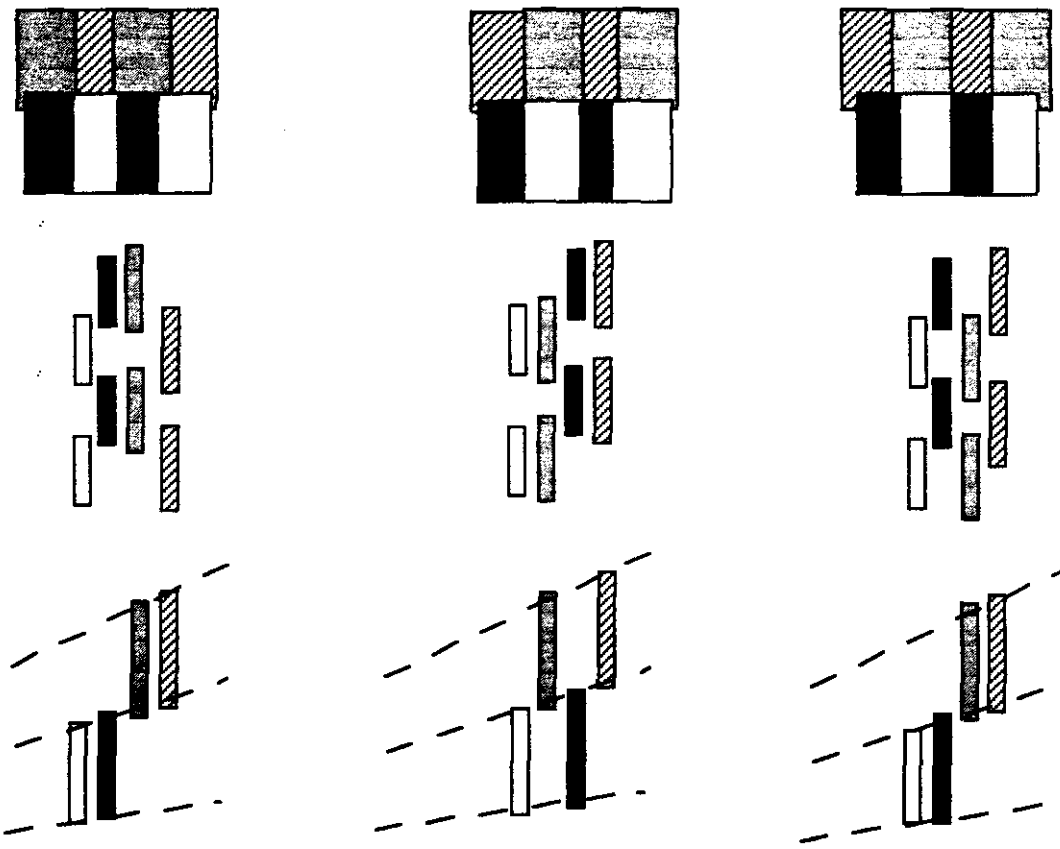
- Crossing tagging concept
- RD5 results
- Lab tests
- TTR results

ENDCAP CSC -- STAGGERING OPTIONS

FRONT VIEWS

TOP VIEWS

SIDE VIEWS



ranks

Potential access

Minimizes sector-to-sector variations; more theta variation

Alignment difficult?

towers

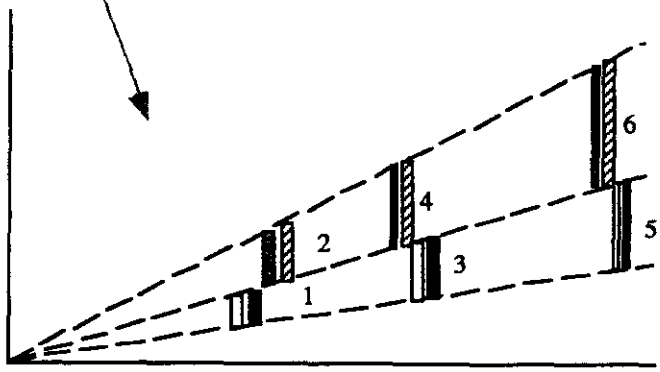
Best for alignment

Access possible?

Larger sector-to-sector variation; less theta variation

another option

any advantages?



Endcap CSC Layout -- Baseline II Version h -- Towers

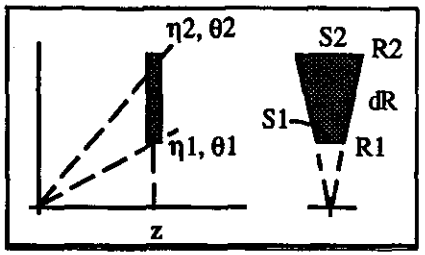
SW 12/22/1992

active coverage 9.75° to 27.71°

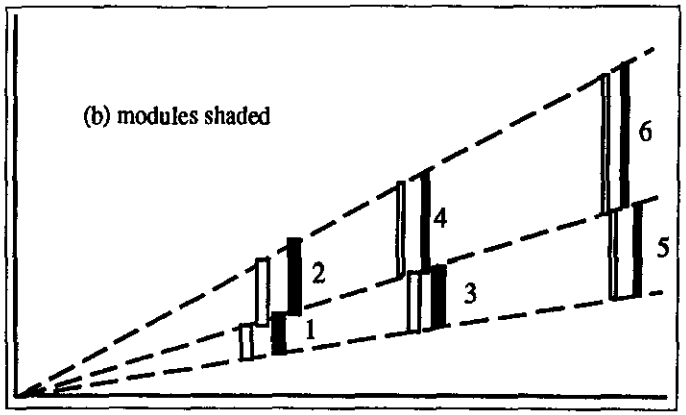
module thickness(4 gaps) = 0.15 m
intermodule space = 0.10 m

neutron flux (Hz/cm^2) = 10,000
neutron efficiency = 0.005

Nomenclature:



Layout:



Note: modules (a) occupy even-numbered sectors
modules (b) occupy odd-numbered sectors
Nsctrs/2 are type (a) and Nsctrs/2 are type (b)

	ngaps	zfr	zba	zav	Dz's	η1	θ1	η2	θ2	Nsctrs	R1	R2	dR	S2	str wid	# strips	wire gp	# r-ch	Total ch counts: # str ch	# r ch	single strip occ. ch. pt.	neut.
		m	m	m			deg		deg		m	m	m	m	mm	/pl/sctr	cm	/pl/sctr			/sec	/sec
Inner modules																						
1a)	8	5.95	6.25	6.10		2.46	9.75	1.90	17.01	24	1.05	1.87	0.82	0.49	5.00	76	5.0	16	14,607	3,144	186	2,047
1b)	8	6.75	7.05	6.90		2.46	9.75	1.90	17.01	24	1.19	2.11	0.93	0.55	5.00	86	5.0	19	16,523	3,556	211	2,315
2a)	8	6.35	6.65	6.50		1.90	17.01	1.40	27.71	24	1.99	3.41	1.42	0.89	5.00	141	5.0	28	27,077	5,470	39	3,561
2b)	8	7.15	7.45	7.30		1.90	17.01	1.40	27.71	24	2.23	3.83	1.60	1.00	5.00	158	5.0	32	30,410	6,143	43	3,999
Middle modules																						
3a)	8	10.70	11.00	10.85	4.75	2.46	9.75	1.90	17.01	24	1.86	3.32	1.46	0.87	5.00	135	5.0	29	25,982	5,592	74	3,640
3b)	8	11.35	11.65	11.50	4.60	2.46	9.75	1.90	17.01	24	1.98	3.52	1.54	0.92	5.00	143	5.0	31	27,538	5,926	79	3,858
4a)	4	10.55	10.70	10.63	4.13	1.90	17.01	1.40	27.71	48	3.25	5.58	2.33	0.73	5.00	116	5.0	47	22,178	8,941	14	5,821
4b)	4	11.10	11.25	11.18	3.88	1.90	17.01	1.40	27.71	48	3.42	5.87	2.45	0.77	5.00	121	5.0	49	23,326	9,404	15	6,122
Outer modules																						
5a)	4	15.70	15.85	15.78	4.93	2.46	9.75	1.90	17.01	48	2.71	4.83	2.12	0.63	5.00	99	5.0	42	18,928	8,130	36	5,293
5b)	4	16.20	16.35	16.28	4.78	2.46	9.75	1.90	17.01	48	2.80	4.98	2.18	0.65	5.00	102	5.0	44	19,528	8,387	37	5,460
6a)	4	15.45	15.60	15.53	4.90	1.90	17.01	1.40	27.71	48	4.75	8.15	3.40	1.07	5.00	169	5.0	68	32,406	13,065	7	8,506
6b)	4	15.95	16.10	16.03	4.85	1.90	17.01	1.40	27.71	48	4.90	8.42	3.51	1.10	5.00	174	5.0	70	33,449	13,485	7	8,779

total area of strip cathodes (m^2)	2858
total volume of chambers (m^3)	14.3
Total number of modules	432

Total => 291,951 91,242

Endcap CSC Layout -- Baseline II Version g

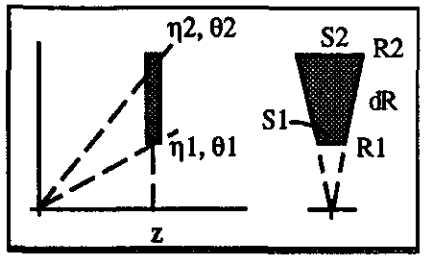
SW 12/22/1992

active coverage 9.75° to 27.71°

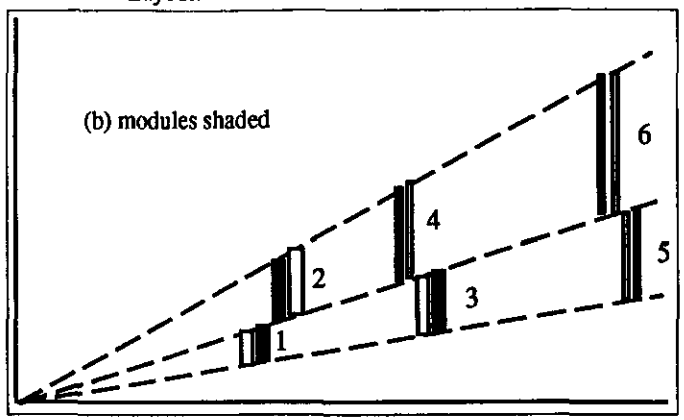
module thickness(4 gaps) = 0.15 m
intermodule space = 0.10 m

neutron flux (Hz/cm^2) = 10,000
neutron efficiency = 0.005

Nomenclature:



Layout:



Note: modules (a) occupy even-numbered sectors
modules (b) occupy odd-numbered sectors
Nsctrs/2 are type (a) and Nsctrs/2 are type (b)

	ngaps	zfr	zba	zav	Dz's	η1	θ1	η2	θ2	Nsctrs	R1	R2	dR	S2	str wid	# strips	wire gp	# r-ch	Total ch counts: # str ch	# r ch	single strip occ. ch. pt.	neut.
		m	m	m	m		deg		deg		m	m	m	m	mm	/pl/sctr	cm	/pl/sctr			/sec	/sec
Inner modules																						
1a)	8	5.95	6.25	6.10		2.46	9.75	1.90	17.01	24	1.05	1.87	0.82	0.49	5.00	76	5.0	16	14,607	3,144	186	2,047
1b)	8	6.35	6.65	6.50		2.46	9.75	1.90	17.01	24	1.12	1.99	0.87	0.52	5.00	81	5.0	17	15,565	3,350	198	2,181
2b)	8	6.75	7.05	6.90		1.90	17.01	1.40	27.71	24	2.11	3.62	1.51	0.95	5.00	150	5.0	30	28,743	5,806	41	3,780
2a)	8	7.15	7.45	7.30		1.90	17.01	1.40	27.71	24	2.23	3.83	1.60	1.00	5.00	158	5.0	32	30,410	6,143	43	3,999
Middle modules																						
3a)	8	10.70	11.00	10.85	4.75	2.46	9.75	1.90	17.01	24	1.86	3.32	1.46	0.87	5.00	135	5.0	29	25,982	5,592	74	3,640
3b)	8	11.10	11.40	11.25	4.75	2.46	9.75	1.90	17.01	24	1.93	3.44	1.51	0.90	5.00	140	5.0	30	26,940	5,798	77	3,775
4b)	4	10.20	10.35	10.28	3.38	1.90	17.01	1.40	27.71	48	3.14	5.40	2.25	0.71	5.00	112	5.0	45	21,447	8,647	14	5,629
4a)	4	10.45	10.60	10.53	3.23	1.90	17.01	1.40	27.71	48	3.22	5.53	2.31	0.72	5.00	114	5.0	46	21,969	8,857	14	5,766
Outer modules																						
5a)	4	15.95	16.10	16.03	5.18	2.46	9.75	1.90	17.01	48	2.75	4.90	2.15	0.64	5.00	100	5.0	43	19,228	8,258	37	5,377
5b)	4	16.20	16.35	16.28	5.03	2.46	9.75	1.90	17.01	48	2.80	4.98	2.18	0.65	5.00	102	5.0	44	19,528	8,387	37	5,460
6b)	4	15.45	15.60	15.53	5.25	1.90	17.01	1.40	27.71	48	4.75	8.15	3.40	1.07	5.00	169	5.0	68	32,406	13,065	7	8,506
6a)	4	15.70	15.85	15.78	5.25	1.90	17.01	1.40	27.71	48	4.83	8.28	3.46	1.08	5.00	171	5.0	69	32,927	13,275	7	8,643

total area of strip cathodes (m^2)	2809
total volume of chambers (m^3)	14.0
Total number of modules	432

Total => 289,752 90,321

Strip counting for various chamber configurations JSW 13-Jan-93

Ni = # of planes in chamber i
strw = strip width in mm

Inner modules (z = 6.6m)				Middle modules (z = 11.0m)				Outer modules (z = 15.8m)				
N1	N2	strw	totstr	N3	N4	strw	totstr	N5	N6	strw	totstr	Total strips
8	8	5	88,617	8	4	5	99,023	4	4	5	104,311	291,951
8	8	5	88,617	8	8	5	145,153	4	4	5	104,311	338,081
8	8	7	63,298	8	4	7	70,731	4	4	7	74,508	208,537
8	8	7	63,298	8	8	7	103,681	4	4	10	52,156	219,135
8	8	5	88,617	8	8	7	103,681	6	6	10	78,418	270,716
8	8	7	63,298	8	8	7	103,681	6	6	10	78,418	245,397

Endcap CSC Layout -- Baseline II Version h -- Towers

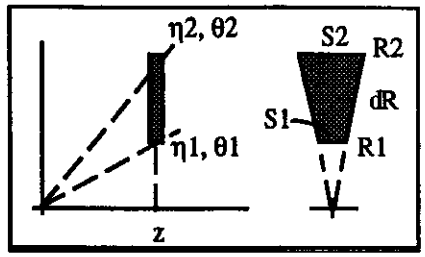
SW 12/22/1992

active coverage 9.75° to 27.71°

module thickness(4 gaps) = 0.15 m
intermodule space = 0.10 m

neutron flux (Hz/cm^2) = 10,000
neutron efficiency = 0.005

Nomenclature:



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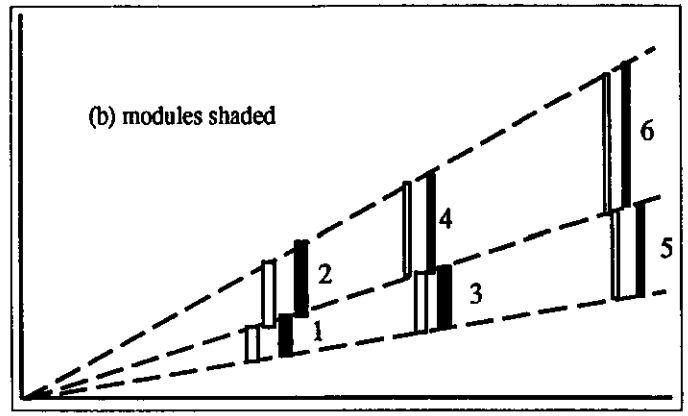


Note: modules (a) occupy even-numbered sectors
modules (b) occupy odd-numbered sectors
Nsctrs/2 are type (a) and Nsctrs/2 are type (b)

126

	ngaps	zfr	zba	zav	Dz's	η1	θ1	η2	θ2	Nsctrs	R1	R2	dR	S2	str wid	# strips	wire gp	# r-ch	Total ch counts: # str ch	# r ch	single strip occ. ch. pt.	neut.
		m	m	m			deg		deg		m	m	m	m	mm	/pl/sctr	cm	/pl/sctr			/sec	/sec
Inner modules																						
1a)	8	5.95	6.25	6.10		2.46	9.75	1.90	17.01	24	1.05	1.87	0.82	0.49	5.00	76	5.0	16	14,607	3,144	186	2,047
1b)	8	6.75	7.05	6.90		2.46	9.75	1.90	17.01	24	1.19	2.11	0.93	0.55	5.00	86	5.0	19	16,523	3,556	211	2,315
2a)	8	6.35	6.65	6.50		1.90	17.01	1.40	27.71	24	1.99	3.41	1.42	0.89	5.00	141	5.0	28	27,077	5,470	39	3,561
2b)	8	7.15	7.45	7.30		1.90	17.01	1.40	27.71	24	2.23	3.83	1.60	1.00	5.00	158	5.0	32	30,410	6,143	43	3,999
																			(88,617)			
Middle modules																						
3a)	8	10.70	11.00	10.85	4.75	2.46	9.75	1.90	17.01	24	1.86	3.32	1.46	0.87	7.00	97	5.0	29	18,558	5,592	104	5,096
3b)	8	11.35	11.65	11.50	4.60	2.46	9.75	1.90	17.01	24	1.98	3.52	1.54	0.92	7.00	102	5.0	31	19,670	5,926	111	5,402
4a)	8	10.55	10.85	10.70	4.20	1.90	17.01	1.40	27.71	48	3.27	5.62	2.34	0.73	7.00	83	5.0	47	31,906	18,008	20	8,207
4b)	8	11.10	11.40	11.25	3.95	1.90	17.01	1.40	27.71	48	3.44	5.91	2.47	0.77	7.00	87	5.0	49	33,546	18,934	21	8,629
																			(103,681)			
Outer modules																						
5a)	6	15.70	15.93	15.81	4.96	2.46	9.75	1.90	17.01	48	2.72	4.84	2.12	0.63	10.00	49	5.0	42	14,230	12,223	72	10,611
5b)	6	16.20	16.43	16.31	4.81	2.46	9.75	1.90	17.01	48	2.80	4.99	2.19	0.65	10.00	51	5.0	44	14,680	12,610	75	10,946
6a)	6	15.45	15.68	15.56	4.86	1.90	17.01	1.40	27.71	48	4.76	8.17	3.41	1.07	10.00	85	5.0	68	24,363	19,644	14	17,052
6b)	6	15.95	16.18	16.06	4.81	1.90	17.01	1.40	27.71	48	4.91	8.43	3.52	1.10	10.00	87	5.0	70	25,146	20,275	14	17,600
																			(78,418)			
																		Total =>	270,716	131,526		

total area of strip cathodes (m^2)	2873
total volume of chambers (m^3)	14.4
Total number of modules	432

Endcap CSC Layout -- Baseline II Version h -- Towers

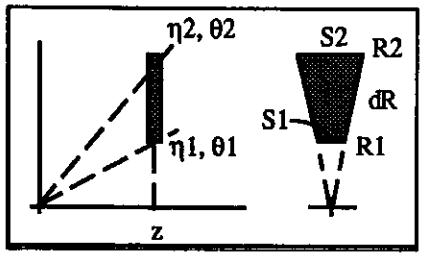
SW 12/22/1992

active coverage 9.75° to 27.71°

module thickness(4 gaps) = 0.15 m
intermodule space = 0.10 m

neutron flux (Hz/cm^2) = 10,000
neutron efficiency = 0.005

Nomenclature:



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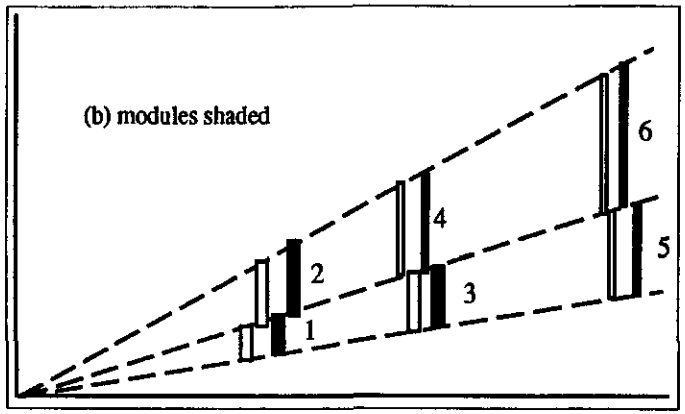


Note: modules (a) occupy even-numbered sectors
modules (b) occupy odd-numbered sectors
Nsctrs/2 are type (a) and Nsctrs/2 are type (b)

	ngaps	zfr	zba	zav	Dz's	η1	θ1	η2	θ2	Nsctrs	R1	R2	dR	S2	str wid	# strips	wire gp	# r-ch	Total ch counts: # str ch	# r ch	single strip occ. ch. pt.	neut.
		m	m	m			deg		deg		m	m	m	m	mm	/pl/sctr	cm	/pl/sctr			/sec	/sec
Inner modules																						
1a)	8	5.95	6.25	6.10		2.46	9.75	1.90	17.01	24	1.05	1.87	0.82	0.49	5.00	76	5.0	16	14,607	3,144	186	2,047
1b)	8	6.75	7.05	6.90		2.46	9.75	1.90	17.01	24	1.19	2.11	0.93	0.55	5.00	86	5.0	19	16,523	3,556	211	2,315
2a)	8	6.35	6.65	6.50		1.90	17.01	1.40	27.71	24	1.99	3.41	1.42	0.89	5.00	141	5.0	28	27,077	5,470	39	3,561
2b)	8	7.15	7.45	7.30		1.90	17.01	1.40	27.71	24	2.23	3.83	1.60	1.00	5.00	158	5.0	32	30,410	6,143	43	3,999
																			(88,617)			
Middle modules																						
3a)	8	10.70	11.00	10.85	4.75	2.46	9.75	1.90	17.01	24	1.86	3.32	1.46	0.87	7.00	97	7.0	21	18,558	3,994	104	5,096
3b)	8	11.35	11.65	11.50	4.60	2.46	9.75	1.90	17.01	24	1.98	3.52	1.54	0.92	7.00	102	7.0	22	19,670	4,233	111	5,402
4a)	8	10.55	10.85	10.70	4.20	1.90	17.01	1.40	27.71	48	3.27	5.62	2.34	0.73	7.00	83	7.0	33	31,906	12,863	20	8,207
4b)	8	11.10	11.40	11.25	3.95	1.90	17.01	1.40	27.71	48	3.44	5.91	2.47	0.77	7.00	87	7.0	35	33,546	13,524	21	8,629
																			(103,681)			
Outer modules																						
5a)	6	15.70	15.93	15.81	4.96	2.46	9.75	1.90	17.01	48	2.72	4.84	2.12	0.63	10.00	49	10.0	21	14,230	6,112	72	10,611
5b)	6	16.20	16.43	16.31	4.81	2.46	9.75	1.90	17.01	48	2.80	4.99	2.19	0.65	10.00	51	10.0	22	14,680	6,305	75	10,946
6a)	6	15.45	15.68	15.56	4.86	1.90	17.01	1.40	27.71	48	4.76	8.17	3.41	1.07	10.00	85	10.0	34	24,363	9,822	14	17,052
6b)	6	15.95	16.18	16.06	4.81	1.90	17.01	1.40	27.71	48	4.91	8.43	3.52	1.10	10.00	87	10.0	35	25,146	10,138	14	17,600
																			(78,418)			

total area of strip cathodes (m^2)	2873
total volume of chambers (m^3)	14.4
Total number of modules	432

Total => 270,716 85,303

Material Audit for Cathode Strip Chamber Module

Calculation of mass and radiation lengths for a four chamber module

Active area of chamber:

length (m) = 2.4

width (m) = 0.8

total area (m^2) = 2.1 ——(including inactive frames)

number of gaps = 3

frame material (and dead area):

width (m) = 0.025

fraction of active area overlapped by frames = 0.063 (sides only)

component	material	density	cm/X0	thcknss (cm)	mass (Kg)	normal X0
Hexcel core	Nomex	0.14	485.7	2.0	21.50	0.0165
circuit boards	.031" G10	1.7	19.4	0.050	14.16	0.0206
copper	1/2 oz.ft^2	8.96	1.43	0.0017	2.54	0.0095
frames	G10	1.7	19.4	2.8	30.94	0.5773

total mass (Kg) =	69.1	
mass/area (Kg/m^2) =	33.2	
average X0's =	0.090	
X0's through center =	0.047	
X0's, center + frames =	0.624	<- includes material of overlapping chamber
area-weighted ave X0's =	0.094	

Momentum Resolution

Results from J. Sullivan's simulation program..."Case 600"

Assumed precision:

- 75 micron random error per plane
- 50 micron internal error
- 25 micron error (module to module)

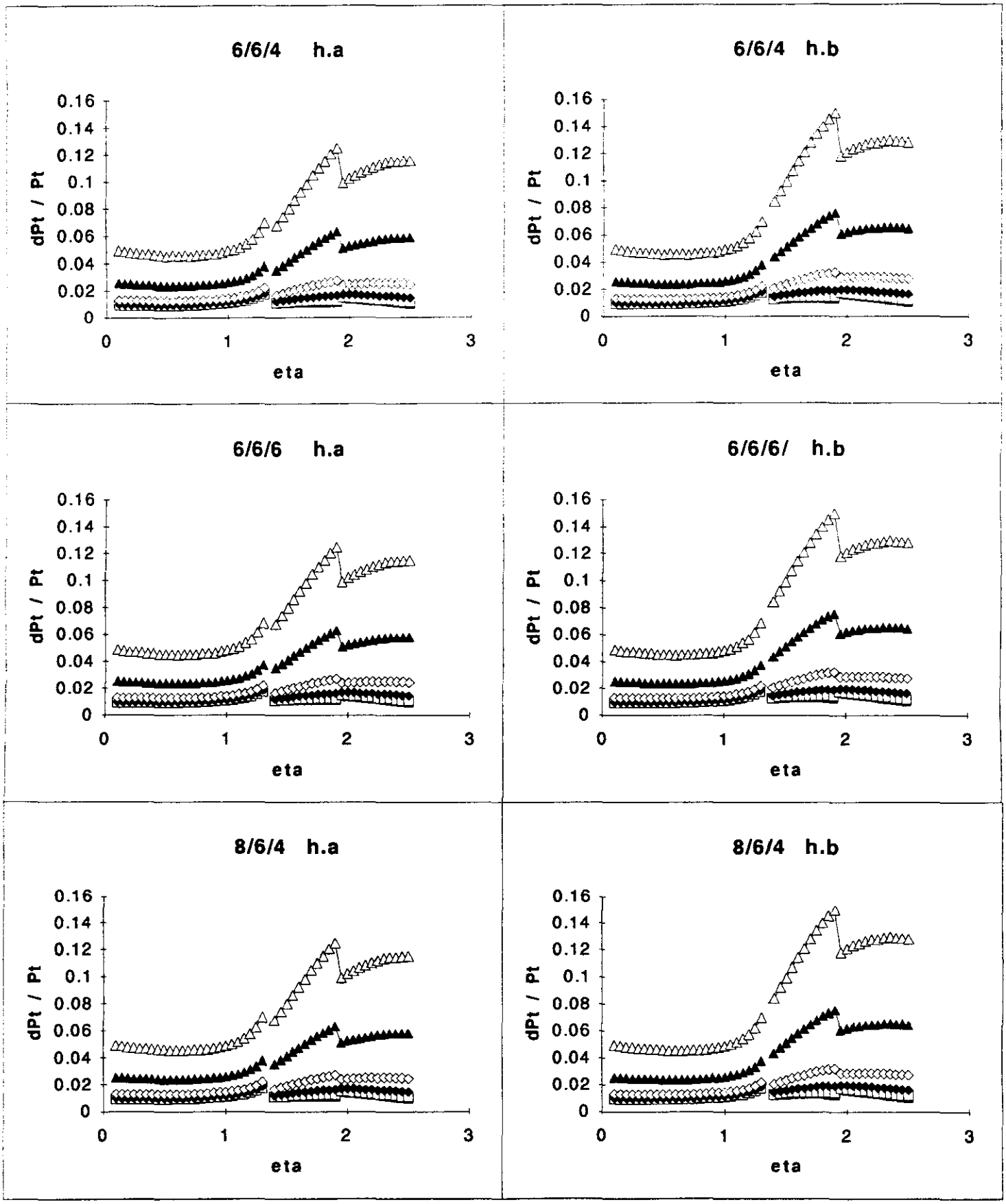
N measurements in a module improve the resolution by $\sqrt{N}$

Measurement taken to be at the module midplane

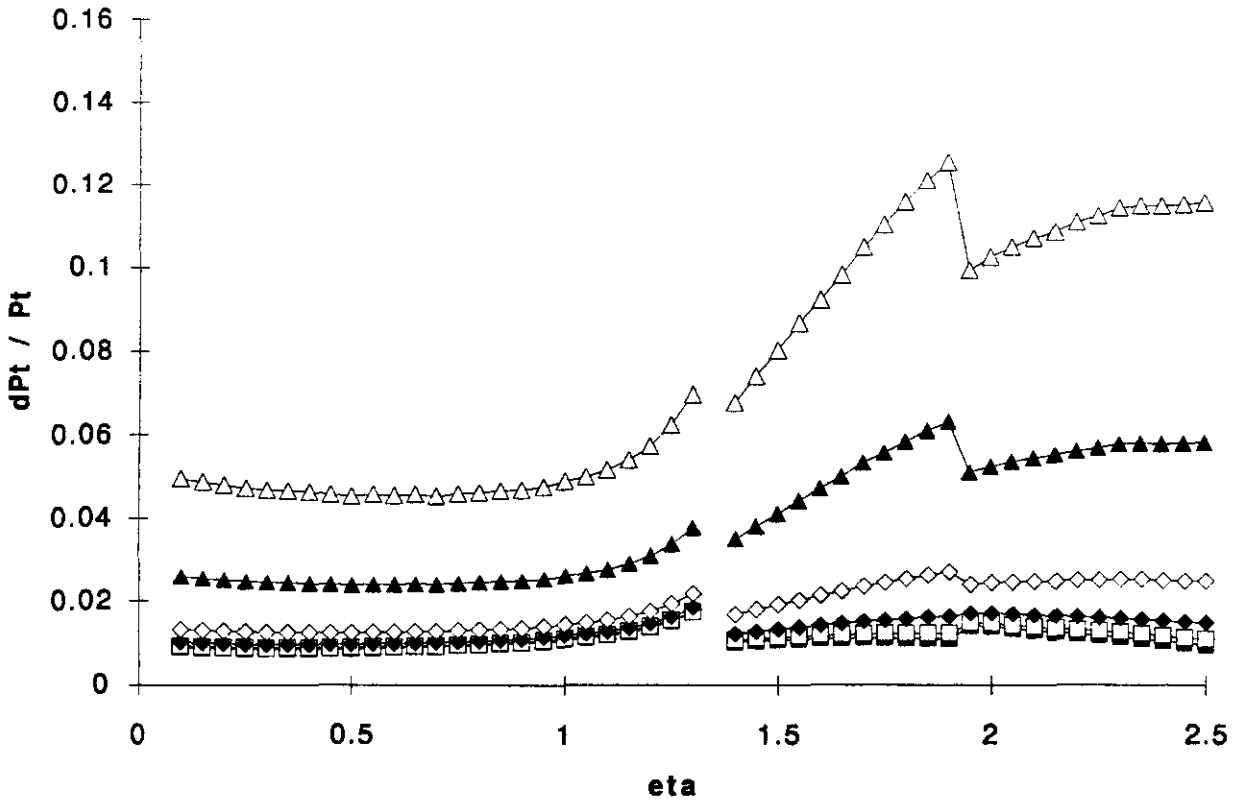
Calculation includes Gaussian multiple scattering, $\vec{B}(\vec{r})$

Thickness per plane: 1.5% X0

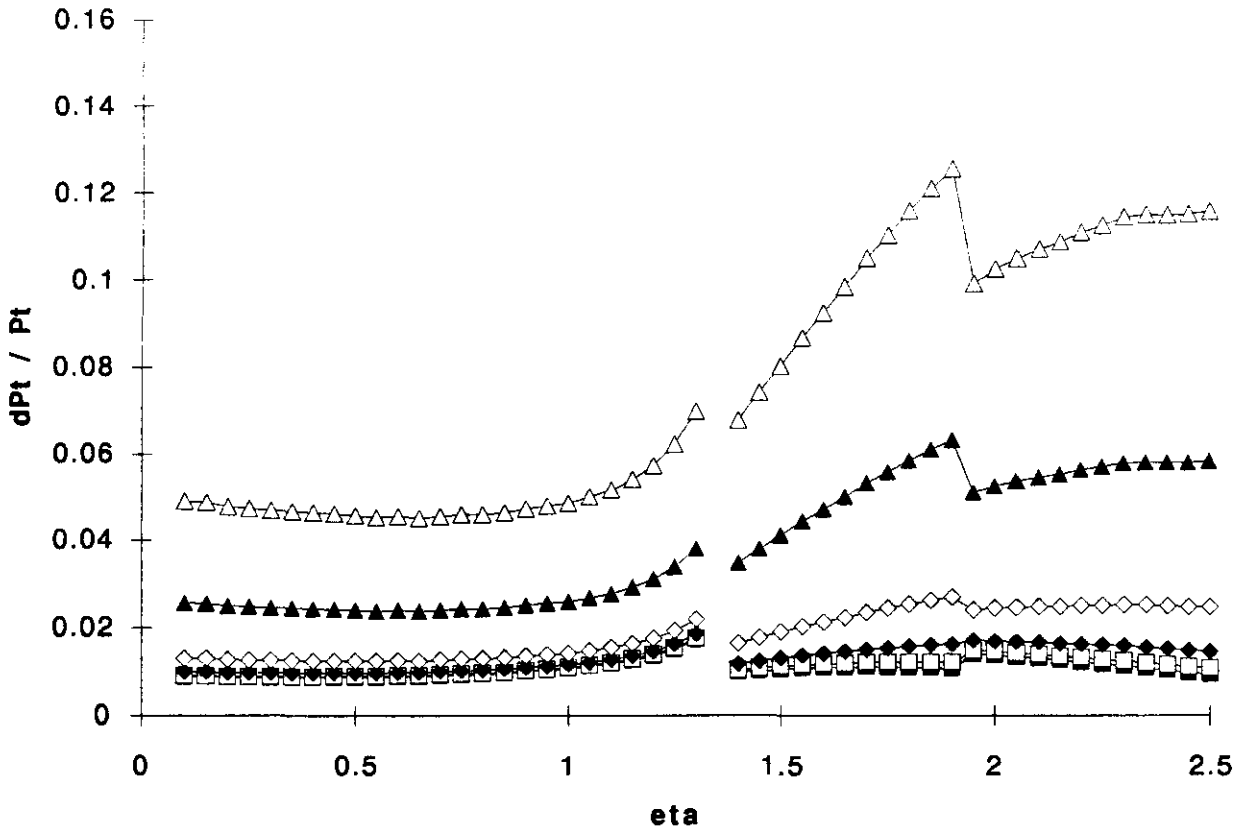
Momentum Resolution for Various CSC Configurations Pt = 10, 25, 50, 100, 250, 500 GeV/c



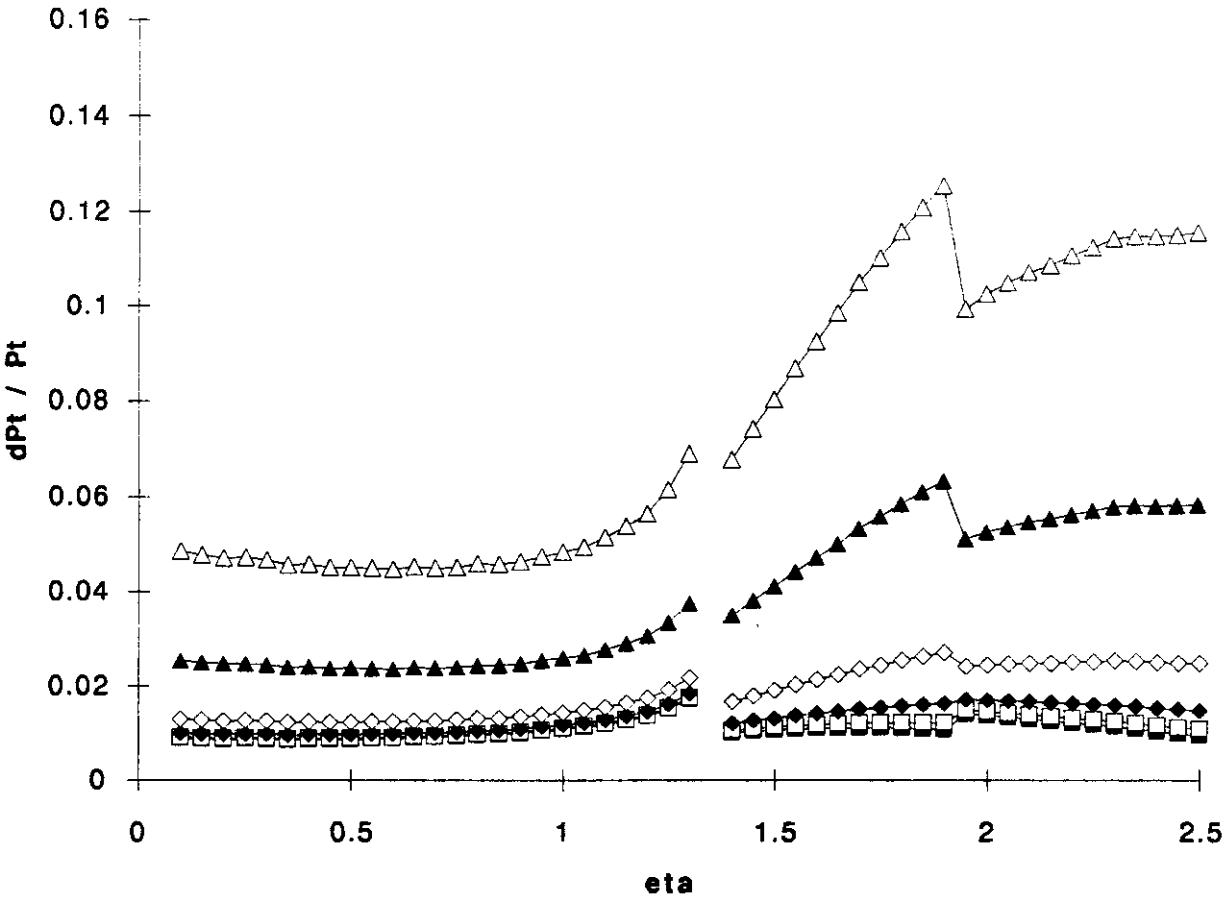
6/6/4 h.a

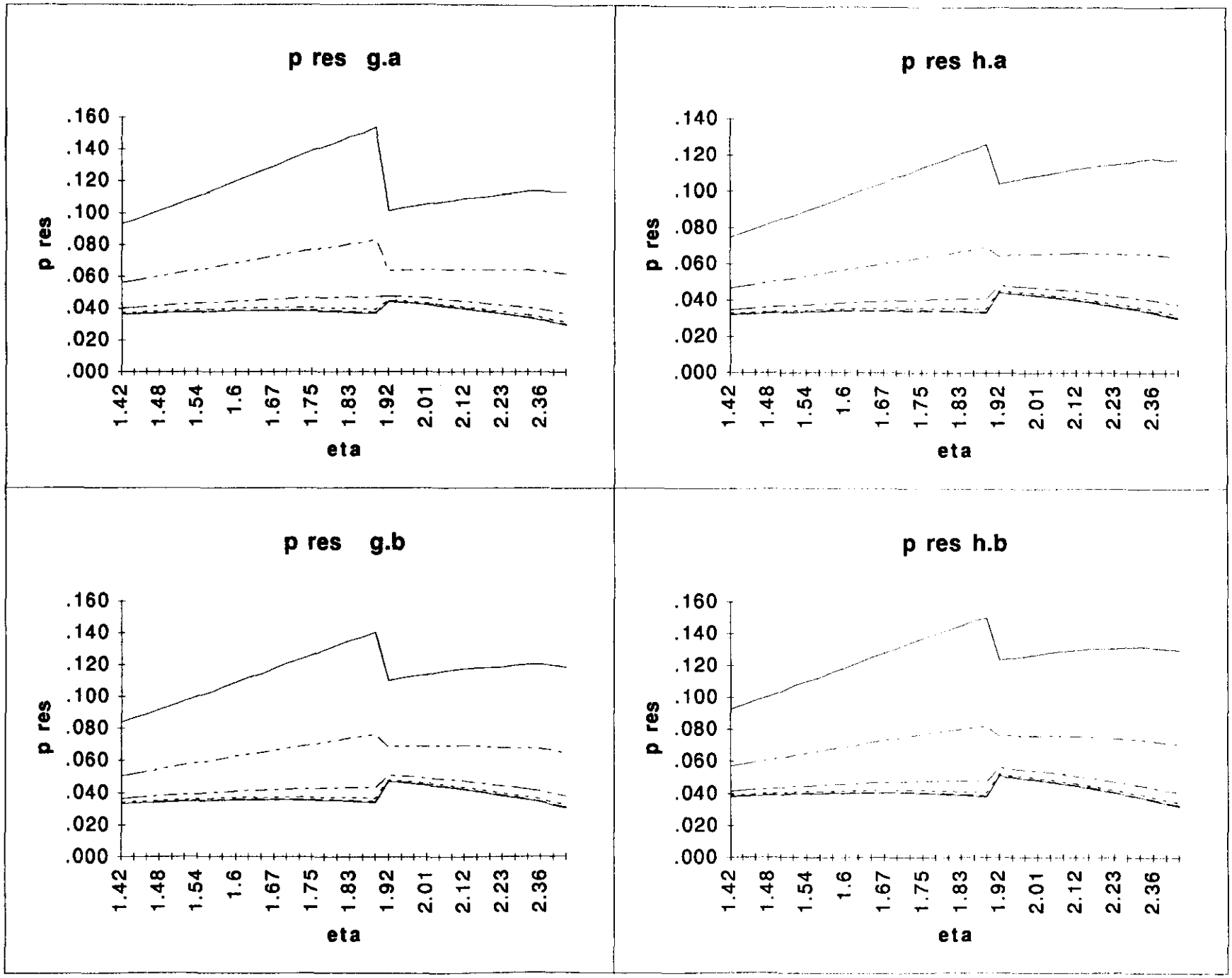


8/6/4 h.a



6/6/6 h.a

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p res g.b
p res h.b
p res
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2.36

eta	g.a	g.b	h.a	h.b
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1.44	.096	.086	.077	.095
1.46	.099	.089	.080	.098
1.48	.102	.092	.082	.101
1.5	.105	.095	.085	.104
1.52	.108	.097	.087	.107
1.54	.110	.100	.089	.110
1.56	.113	.103	.092	.113
1.58	.117	.106	.095	.116
1.6	.120	.109	.097	.119
1.63	.123	.112	.100	.122
1.65	.126	.114	.102	.125
1.67	.129	.118	.105	.128
1.7	.132	.121	.108	.131
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1.77	.141	.129	.116	.140
1.8	.144	.132	.118	.142
1.83	.148	.135	.121	.145
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1.89	.154	.140	.126	.150
1.92	.101	.110	.104	.124
1.95	.103	.112	.106	.125
1.98	.104	.113	.107	.126
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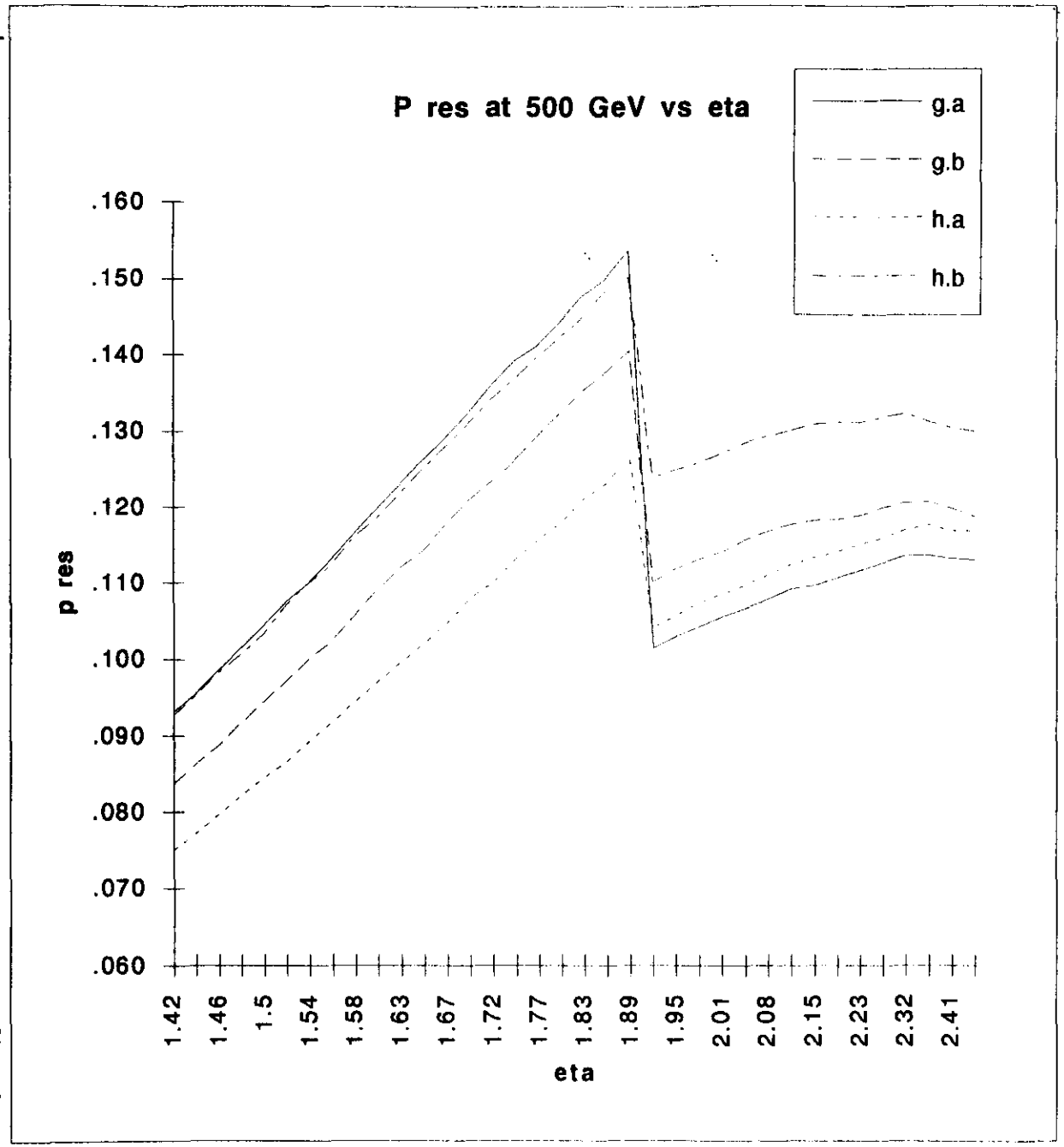

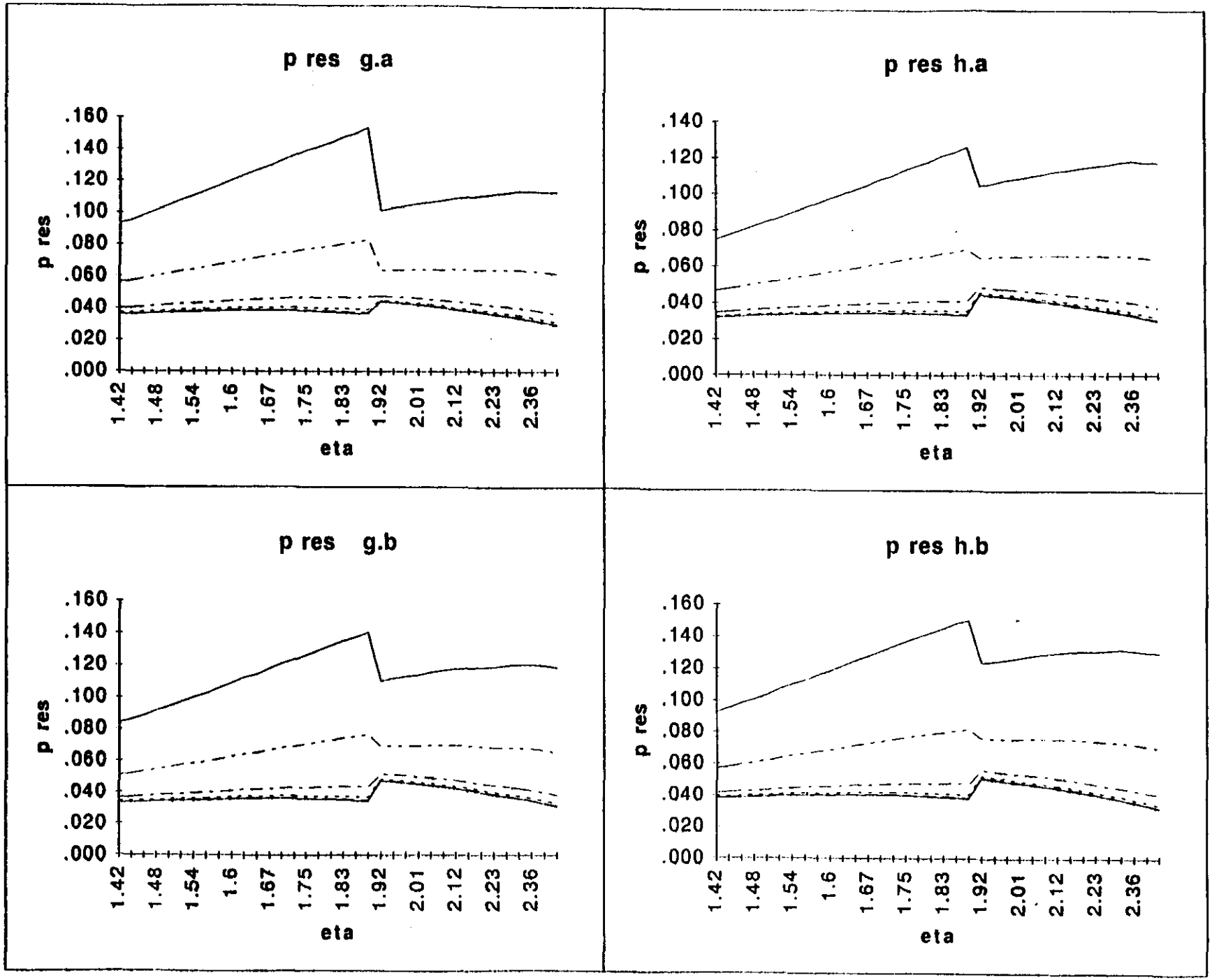
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2.23
2.36
eta

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1.44	.096	.086	.077	.095
1.46	.099	.089	.080	.098
1.48	.102	.092	.082	.101
1.5	.105	.095	.085	.104
1.52	.108	.097	.087	.107
1.54	.110	.100	.089	.110
1.56	.113	.103	.092	.113
1.58	.117	.106	.095	.116
1.6	.120	.109	.097	.119
1.63	.123	.112	.100	.122
1.65	.126	.114	.102	.125
1.67	.129	.118	.105	.128
1.7	.132	.121	.108	.131
1.72	.136	.124	.110	.134
1.75	.139	.126	.113	.137
1.77	.141	.129	.116	.140
1.8	.144	.132	.118	.142
1.83	.148	.135	.121	.145
1.86	.150	.138	.123	.148
1.89	.154	.140	.126	.150
1.92	.101	.110	.104	.124
1.95	.103	.112	.106	.125
1.98	.104	.113	.107	.126
2.01	.106	.114	.109	.127
2.04	.107	.116	.110	.128
2.08	.108	.117	.111	.129
2.12	.109	.118	.112	.130
2.15	.110	.118	.113	.131
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2.23	.112	.119	.115	.131
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2.41	.113	.120	.117	.130
2.46	.113	.119	.117	.130

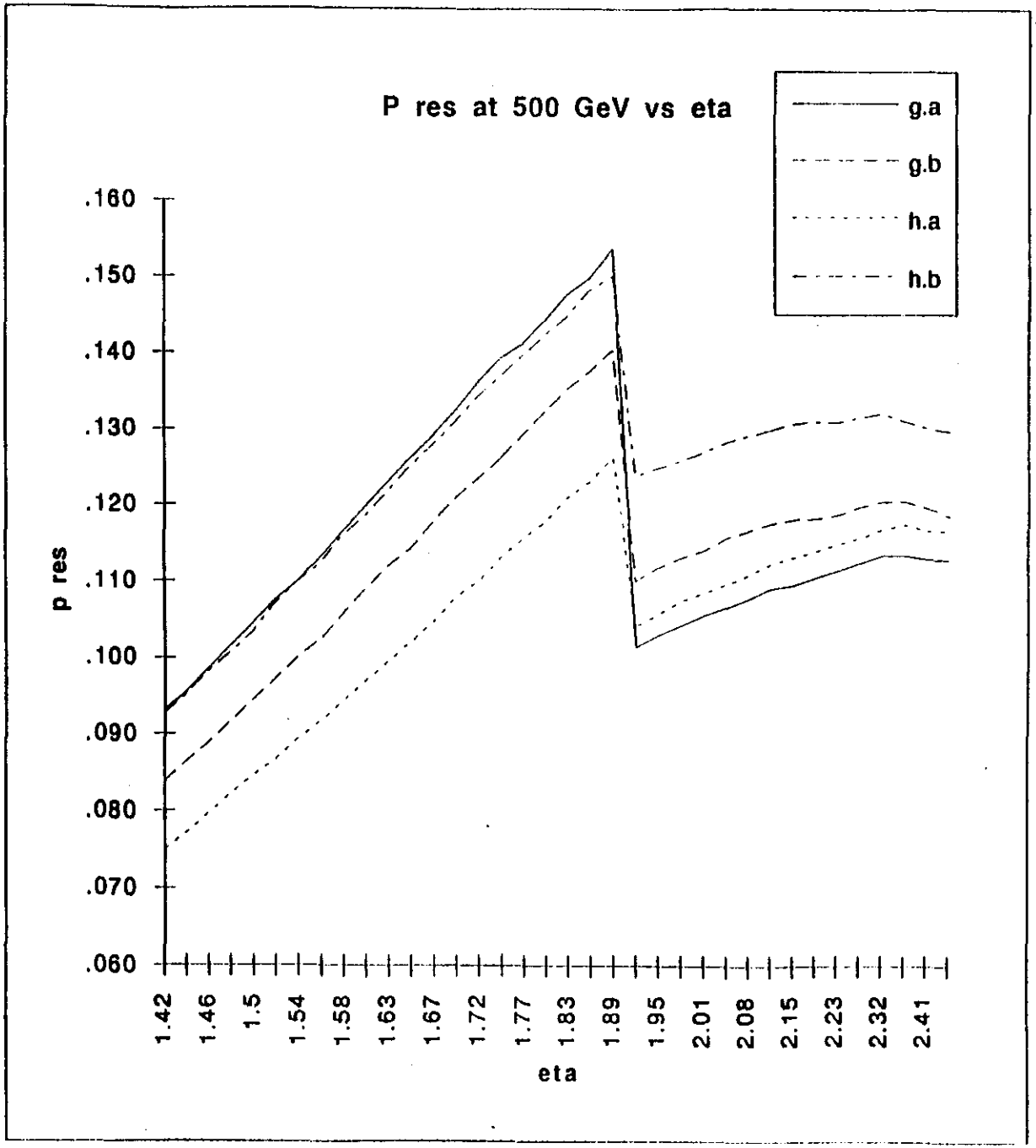


Fig. 4.1a
Momentum resolution in the GEM baseline.

Resolution vs eta for Pt:
1000 GeV
750 "
500 "
250 "
100 "
50 "
25 "
10 "

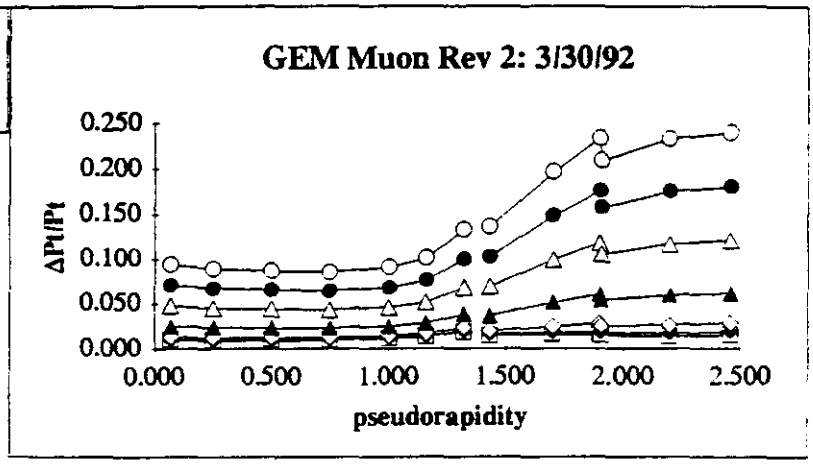


Fig. 4b
Momentum resolution for CSC's -- muons through the centers of the modules.

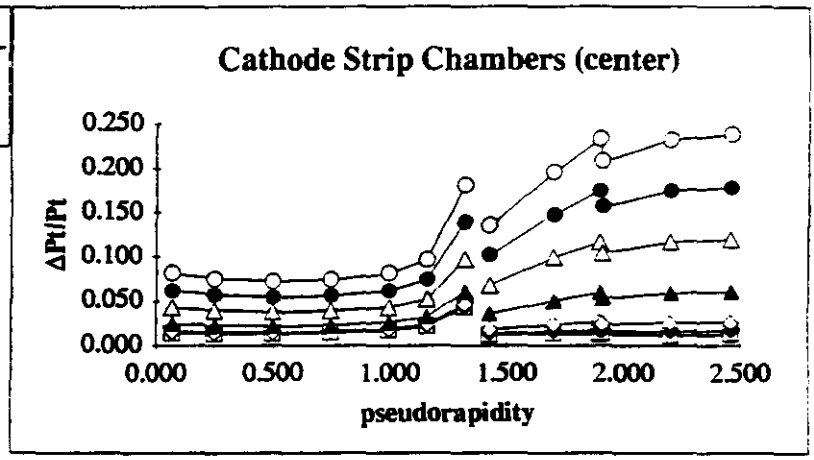


Fig. 4.1.c
Momentum resolution for CSC's -- muons through the overlap region: center of one module and frame of another.

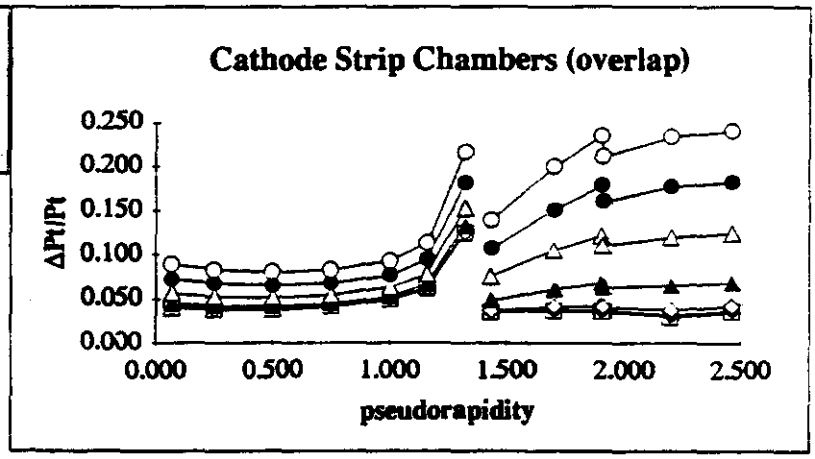


Table 4.1 ΔPt/Pt vs eta for selected Pt values and different Muon System configurations.

GEM Muon Rev 2: 3/30/92

eta	Pt values 10	25	50	100	250	500	750	1000
0.070	0.010	0.010	0.011	0.013	0.025	0.048	0.071	0.094
0.250	0.009	0.009	0.010	0.013	0.024	0.045	0.067	0.089
0.500	0.009	0.010	0.010	0.013	0.023	0.044	0.065	0.087
0.750	0.010	0.010	0.011	0.013	0.023	0.044	0.065	0.086
1.000	0.011	0.012	0.012	0.014	0.025	0.046	0.068	0.091
1.160	0.013	0.014	0.014	0.017	0.028	0.052	0.076	0.101
1.320	0.019	0.019	0.020	0.023	0.038	0.068	0.100	0.132
1.360								
1.430	0.014	0.015	0.016	0.020	0.037	0.069	0.102	0.135
1.700	0.015	0.016	0.018	0.025	0.051	0.099	0.147	0.196
1.900	0.015	0.016	0.019	0.027	0.060	0.117	0.175	0.233
1.910	0.015	0.016	0.018	0.026	0.054	0.105	0.157	0.208
2.200	0.012	0.014	0.017	0.026	0.059	0.117	0.174	0.232
2.460	0.015	0.016	0.019	0.028	0.061	0.120	0.179	0.238

CSC 8,4,4; 4,4,4; 4,4,4; 4,8,4 Centers

0.070	0.014	0.014	0.014	0.016	0.024	0.042	0.062	0.081
0.250	0.013	0.013	0.013	0.015	0.023	0.039	0.057	0.076
0.500	0.013	0.013	0.013	0.015	0.022	0.038	0.055	0.073
0.750	0.014	0.014	0.015	0.016	0.023	0.039	0.056	0.074
1.000	0.017	0.017	0.017	0.019	0.026	0.043	0.062	0.081
1.160	0.021	0.022	0.022	0.023	0.032	0.052	0.074	0.097
1.320	0.043	0.043	0.044	0.046	0.061	0.098	0.139	0.181
1.360								
1.430	0.012	0.012	0.014	0.018	0.036	0.068	0.102	0.135
1.700	0.013	0.014	0.016	0.023	0.050	0.099	0.147	0.196
1.900	0.012	0.013	0.017	0.026	0.059	0.117	0.175	0.233
1.910	0.013	0.013	0.016	0.024	0.053	0.105	0.156	0.208
2.200	0.010	0.012	0.015	0.025	0.059	0.116	0.174	0.232
2.460	0.012	0.013	0.017	0.027	0.061	0.120	0.179	0.238

"Thick" CSC 8,4,4; 4,4,4; 4,4,4; 4,8,4 Center plus overlapping frame

0.070	0.040	0.040	0.040	0.041	0.045	0.057	0.072	0.090
0.250	0.038	0.038	0.038	0.038	0.042	0.053	0.067	0.084
0.500	0.038	0.038	0.038	0.038	0.042	0.052	0.065	0.081
0.750	0.041	0.041	0.041	0.042	0.045	0.055	0.068	0.083
1.000	0.049	0.049	0.049	0.050	0.053	0.063	0.077	0.093
1.160	0.062	0.062	0.062	0.063	0.067	0.078	0.094	0.113
1.320	0.124	0.124	0.124	0.125	0.132	0.152	0.181	0.215
1.360								
1.430	0.035	0.035	0.035	0.037	0.048	0.076	0.107	0.139
1.700	0.037	0.037	0.038	0.042	0.061	0.104	0.151	0.199
1.900	0.035	0.035	0.037	0.042	0.068	0.122	0.178	0.235
1.910	0.036	0.036	0.037	0.042	0.063	0.110	0.160	0.211
2.200	0.030	0.030	0.032	0.038	0.065	0.120	0.177	0.234
2.460	0.035	0.035	0.037	0.042	0.069	0.124	0.182	0.240

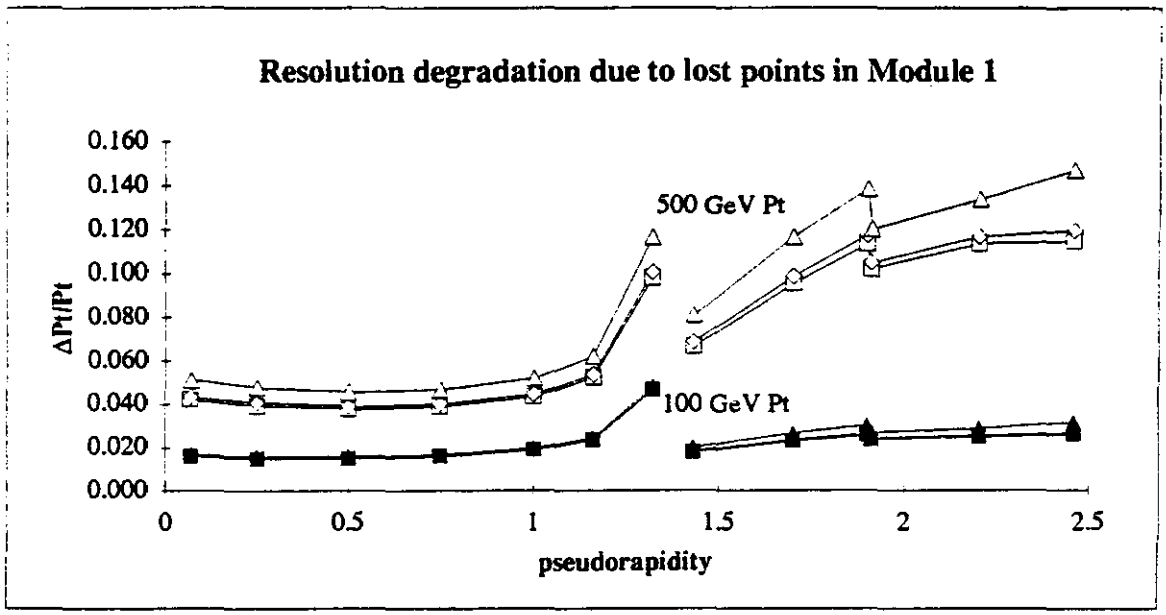


Fig 4.2.a Momentum resolution for 100 or 500 GeV Pt vs eta, for 8, 4, or 1 hits in the first module and 4 hits each in the second and third modules.

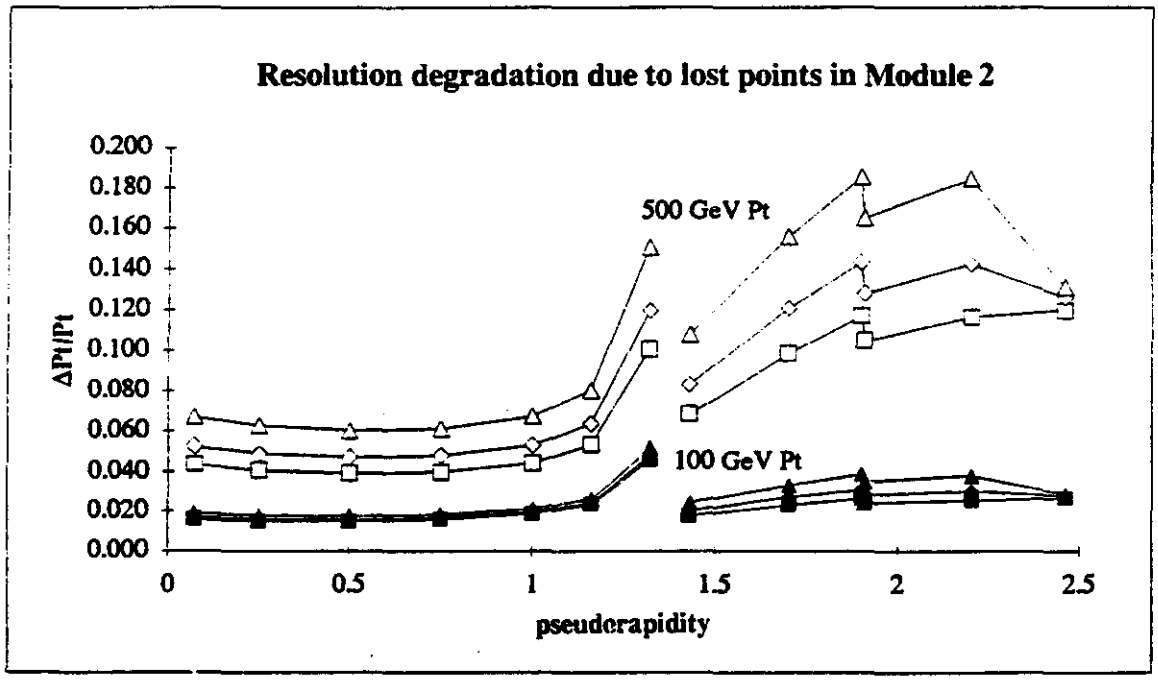
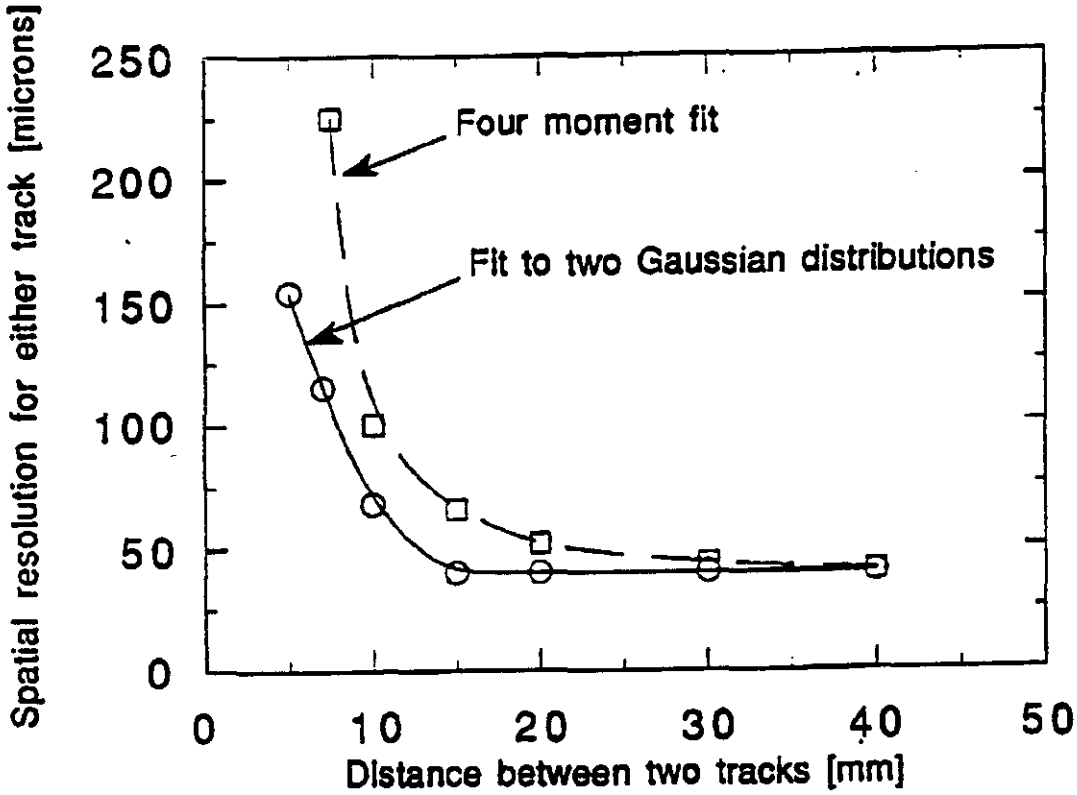


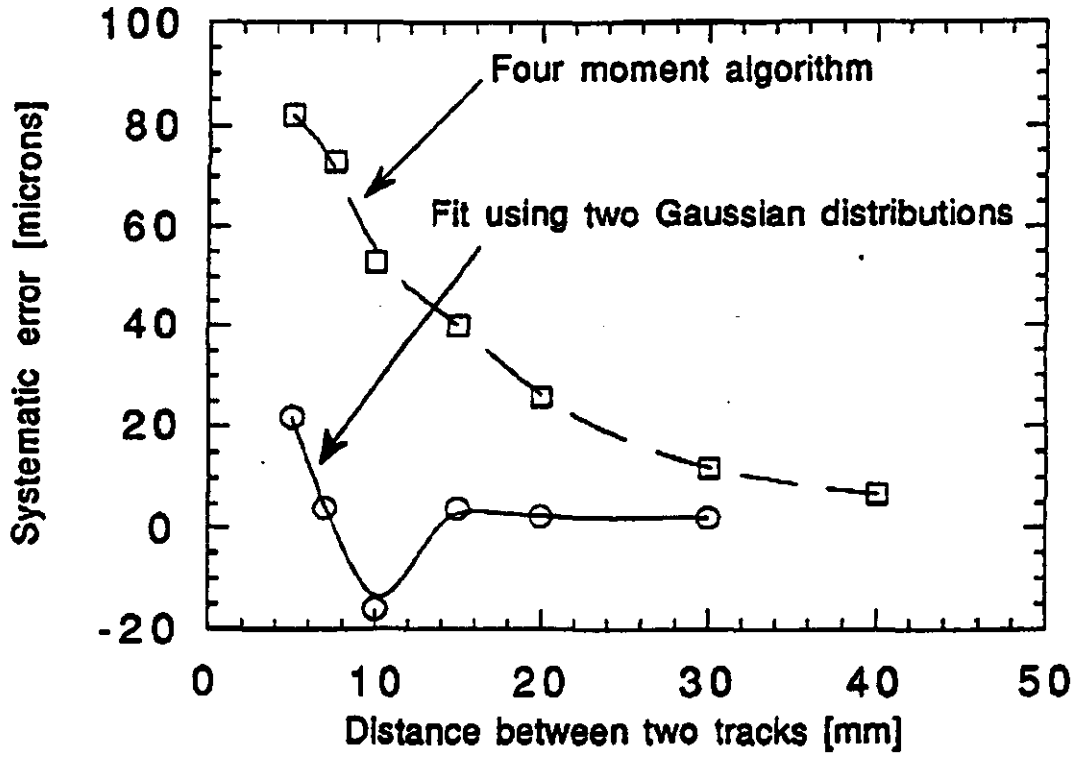
Fig 4.2b Momentum resolution for 100 or 500 GeV Pt vs eta, for 4 hits in the first and third modules and 4, 2, or 1 hits in the second module (8, 6, 5 hits below 12.45 degrees).

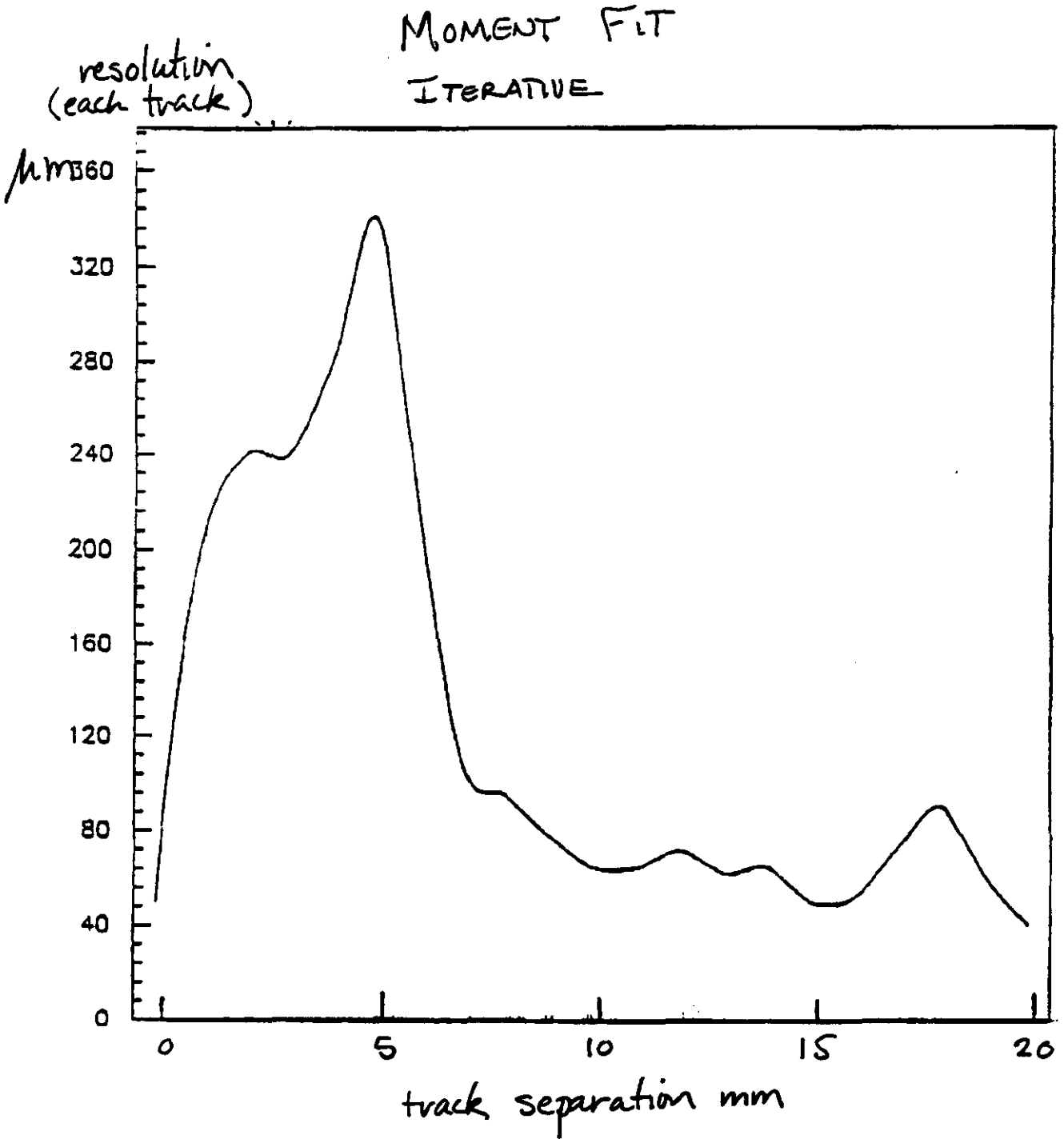
Table 4.2 Momentum resolution for Pt = 100 and 500 GeV versus pseudorapidity, varying the number of useable hits in the first and second modules from the nominal 8/4/4 (except that 8/8/4 is nominal below 12.45 degrees.)

Hits per module	844/884	844/884	444/484	444/484	144/184	144/184
eta \ Pt	100	500	100	500	100	500
0.07	0.016	0.042	0.016	0.044	0.017	0.051
0.25	0.015	0.039	0.015	0.041	0.016	0.048
0.5	0.015	0.038	0.015	0.039	0.016	0.046
0.75	0.016	0.039	0.016	0.040	0.017	0.047
1	0.019	0.043	0.019	0.044	0.019	0.052
1.16	0.023	0.052	0.024	0.053	0.024	0.062
1.32	0.046	0.098	0.046	0.101	0.048	0.116
1.36						
1.43	0.018	0.066	0.018	0.068	0.020	0.081
1.7	0.023	0.095	0.023	0.099	0.026	0.117
1.9	0.026	0.113	0.026	0.117	0.030	0.139
1.91	0.024	0.102	0.024	0.105	0.027	0.120
2.2	0.025	0.113	0.025	0.116	0.029	0.134
2.46	0.026	0.114	0.027	0.120	0.032	0.147

Hits per module	444/484	444/484	424/464	424/464	414/454	414/454
eta \ Pt	100	500	100	500	100	500
0.07	0.016	0.044	0.017	0.053	0.019	0.068
0.25	0.015	0.041	0.016	0.049	0.018	0.063
0.5	0.015	0.039	0.016	0.047	0.018	0.060
0.75	0.016	0.040	0.017	0.048	0.018	0.061
1	0.019	0.044	0.020	0.053	0.021	0.067
1.16	0.024	0.053	0.025	0.064	0.026	0.081
1.32	0.046	0.101	0.048	0.120	0.052	0.151
1.36						
1.43	0.018	0.068	0.020	0.084	0.025	0.108
1.7	0.023	0.099	0.027	0.121	0.034	0.156
1.9	0.026	0.117	0.031	0.144	0.039	0.185
1.91	0.024	0.105	0.028	0.128	0.035	0.166
2.2	0.025	0.116	0.030	0.143	0.038	0.185
2.46	0.027	0.120	0.028	0.126	0.029	0.131

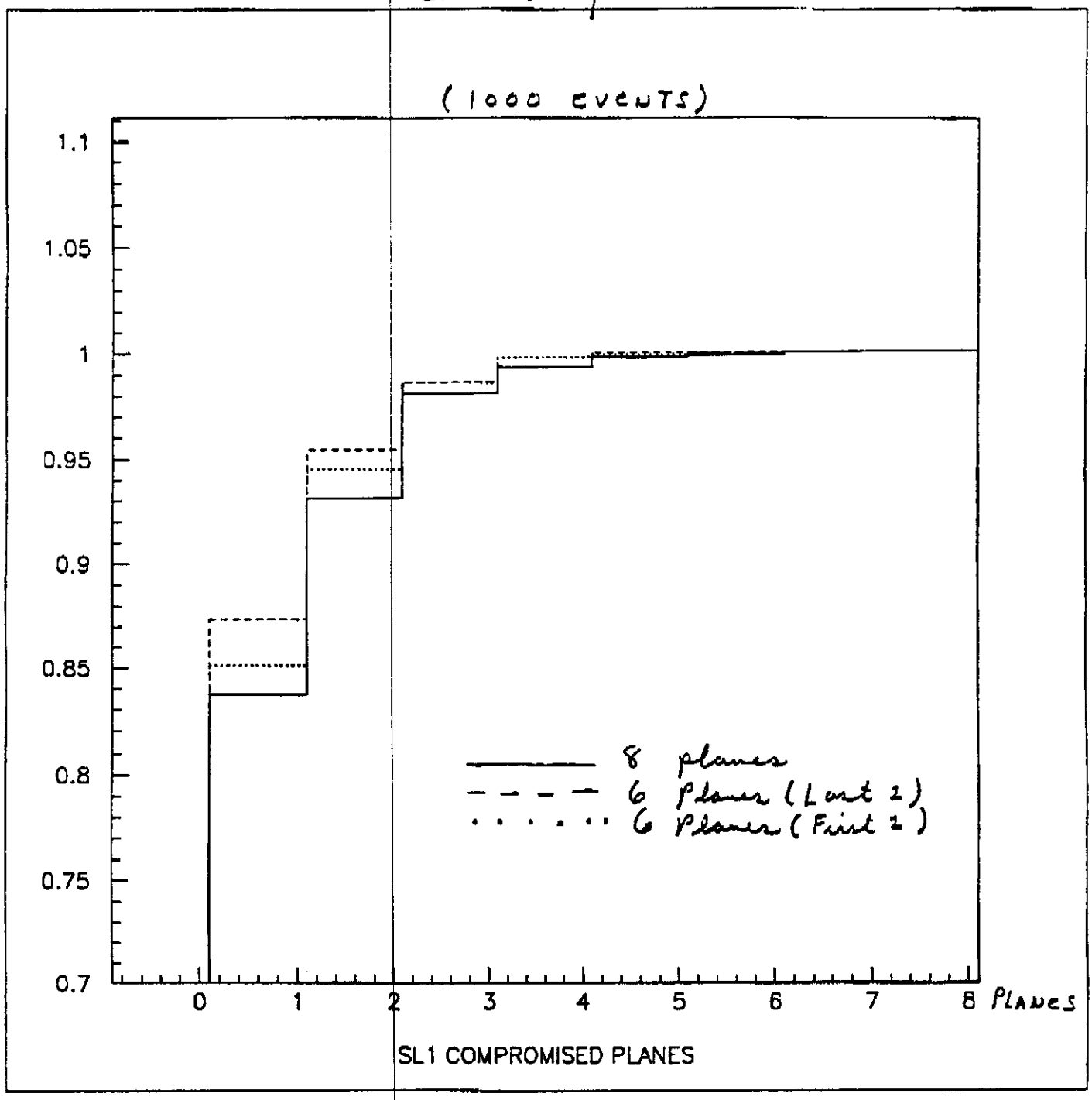

Spatial resolution for either track [microns]
250
200
150
100
50
0
Four moment fit
Fit to two Gaussian distributions
0
10
20
30
40
50
Distance between two tracks [mm]

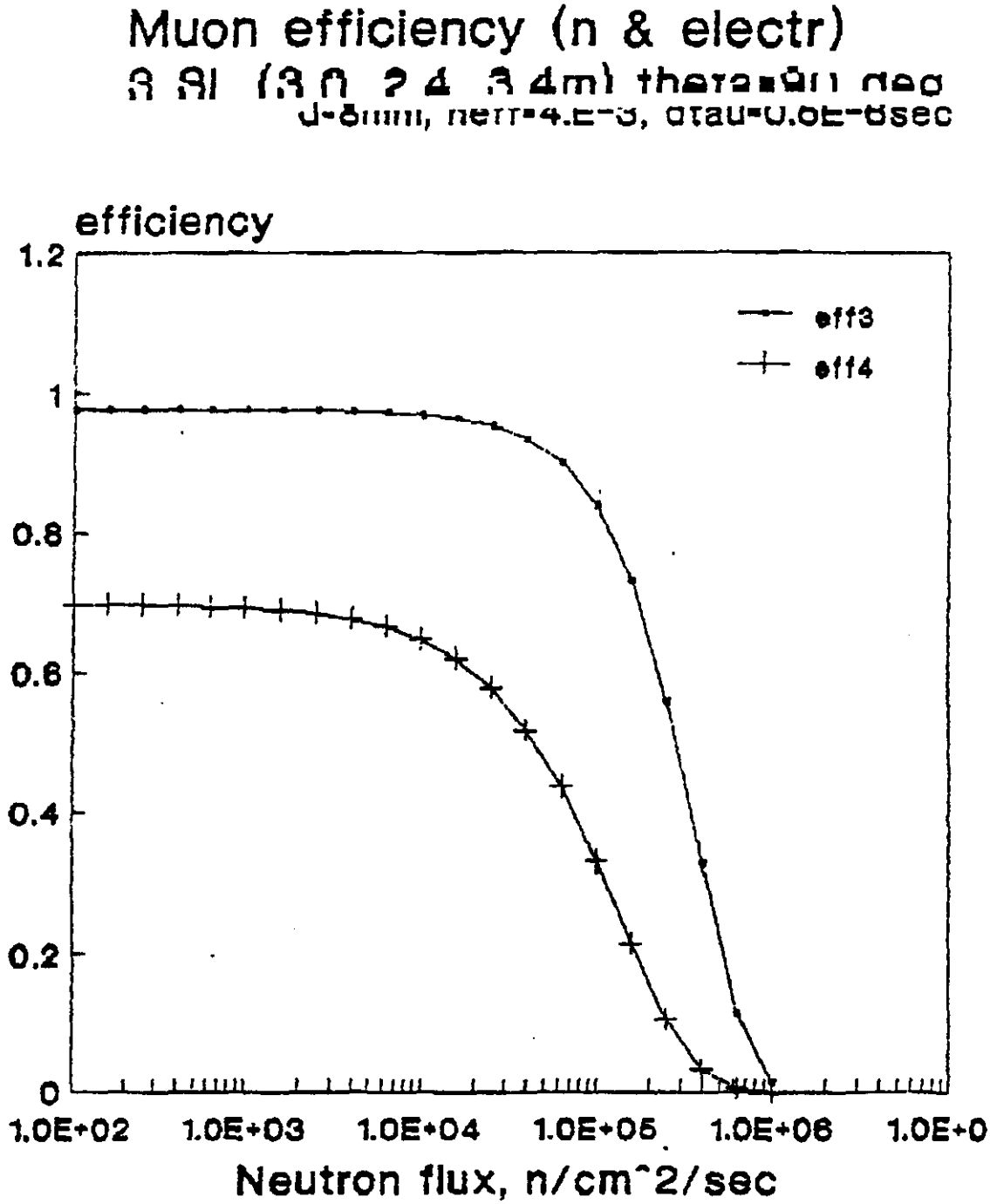

Systematic error [microns]
100
80
60
40
20
0
-20
Four moment algorithm
Fit using two Gaussian distributions
0
10
20
30
40
50
Distance between two tracks [mm]

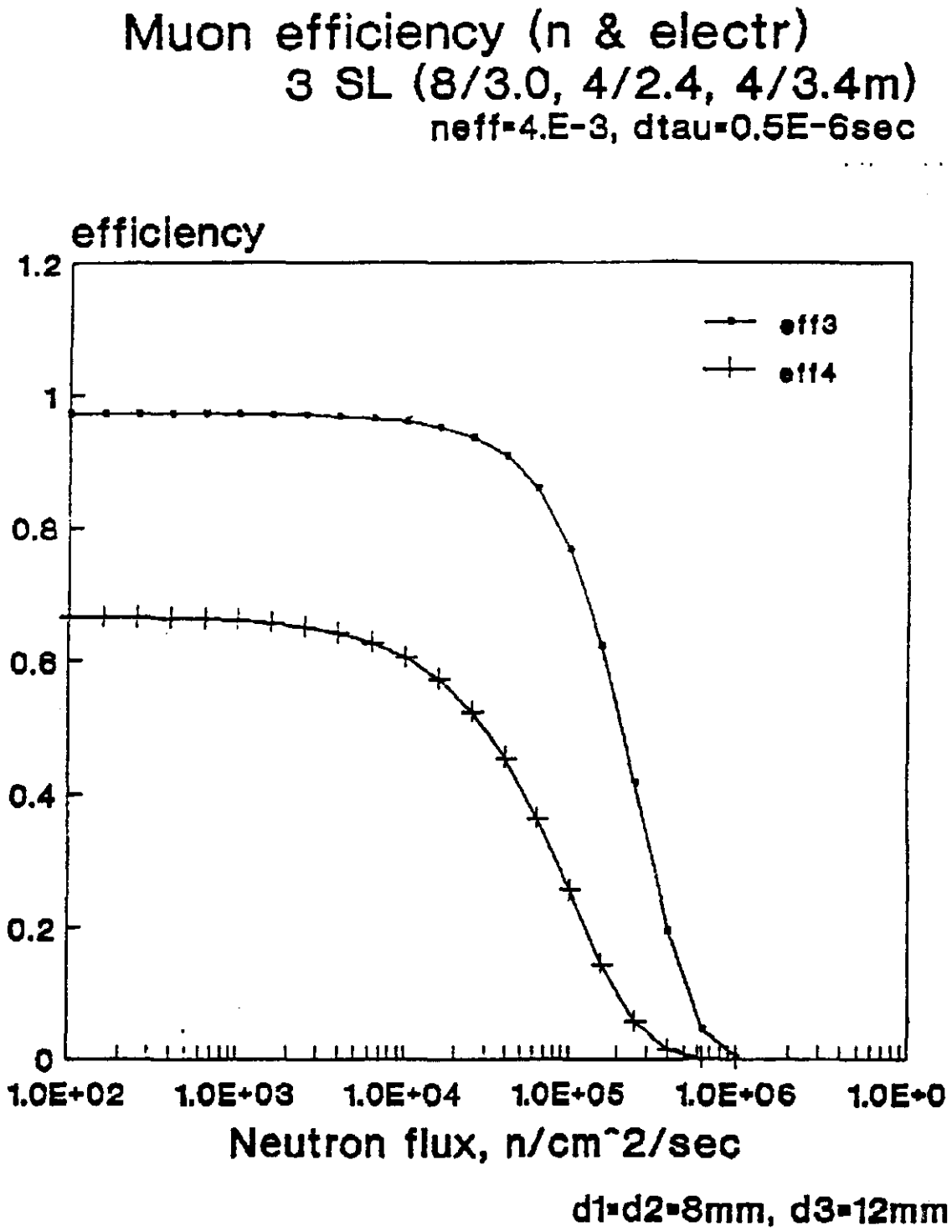

MOMENT FIT
ITERATIVE
resolution
(each track)
μm
360
320
280
240
200
160
120
80
40
0
0
5
10
15
20
track separation mm

Peter Dingus 1/15/93

1 Tev μ's




Muon efficiency (n & electr)
efficiency
1.2
1
0.8
0.6
0.4
0.2
0
eff3
eff4
1.0E+02
1.0E+03
1.0E+04
1.0E+05
1.0E+06
1.0E+0
Neutron flux, n/cm^2/sec


Muon efficiency (n & electr)
3 SL (8/3.0, 4/2.4, 4/3.4m)
neff=4.E-3, dtau=0.5E-6sec
efficiency
1.2
1
0.8
0.6
0.4
0.2
0
eff3
eff4
1.0E+02
1.0E+03
1.0E+04
1.0E+05
1.0E+06
1.0E+0
Neutron flux, n/cm^2/sec
d1=d2=8mm, d3=12mm

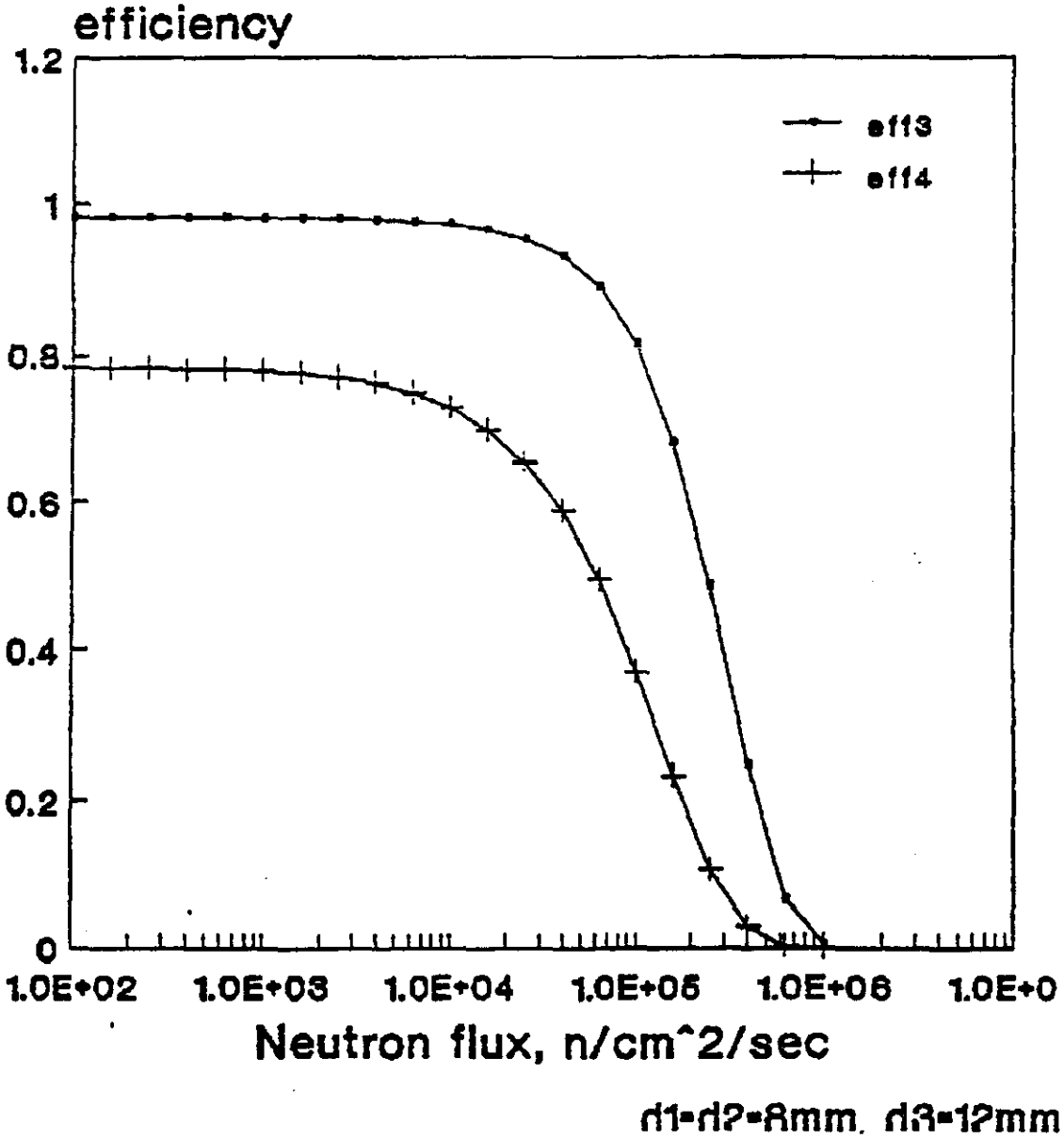

Muon efficiency (n & electr)
3 SL (8/3.0, 5/2.4, 4/3.4m)
neff=4.E-3, dtau=0.5E-6sec
efficiency
1.2
1
0.8
0.6
0.4
0.2
0
eff3
eff4
1.0E+02
1.0E+03
1.0E+04
1.0E+05
1.0E+06
1.0E+0
Neutron flux, n/cm^2/sec
d1=d2=8mm, d3=12mm

Table 5.3.1 Overlap probability for barrel of single muon events (all superlayers)

# of bad planes	double-hit resolution		
(good)	6mm	8mm	10mm
0 (16)	.188	.181	.175
1 (15)	.334	.312	.309
2 (14)	.206	.197	.182
3 (13)	.123	.117	.132
4 (12)	.083	.083	.079
5 (11)	.043	.060	.051
6 (10)	.011	.011	.020
7 (9)	.011	.013	.022
8 (8)	.007	.011	.011
> 8 (<8)	.009	.016	.020

Table 5.3.2 Overlap probability for barrel of single muon events(only superlayer1)

# of bad planes	double-hit resolution		
(good)	6mm	8mm	10mm
0 (8)	.442	435	.430
1 (7)	.294	273	.267
2 (6)	.134	143	.135
3 (5)	.067	069	.070
4 (4)	.031	036	.042
5 (3)	.018	024	.024
6 (2)	.004	007	.014
7 (1)	.002	002	.004
8 (0)	.009	013	.014

Table 5.3.3 Overlap probability for barrel of single muon events (Only superlayer1) with one or zero good plane (4-plane and 8-plane superlayer)

			????			
# of planes	θ=90 deg		θ=60 deg		θ=15 deg	
	7mm	10mm	7mm	10mm	7mm	10mm
4	0.030	0.039	0.036	0.046	0.117	0.143
8	0.013	0.013	0.018	0.021	0.030	0.038

Table 5.3.4 Overlap probability for barrel of top events (all superlayers)

# of bad planes	double-hit resolution		
(good)	6mm	8mm	10mm
0 (16)	.217	.210	.207
1 (15)	.337	.314	.301
2 (14)	.223	.230	.210
3 (13)	.133	.139	.159
4 (12)	.052	.058	.068
5 (11)	.026	.026	.032
6 (10)	.003	.003	.010
7 (9)	.007	.003	.007
8 (8)	.003	.003	.003
> 8 (<8)	.000	.003	.003

Table 5.3.5 Overlap probability for barrel of top events (only superlayer1)

# of bad planes	double-hit resolution		
(good)	6mm	8mm	10mm
0 (8)	.460	.453	.434
1 (7)	.359	.333	.343
2 (6)	.120	.146	.142
3 (5)	.042	.032	.045
4 (4)	.010	.026	.013
5 (3)	.003	.003	.010
6 (2)	.003	.000	.007
7 (1)	.000	.000	.000
8 (0)	.003	.007	.007

Table 5.3.6 Overlap probability for endcap of single muon events (all superlayers)

# of bad planes	double-hit resolution		
(good)	6mm	8mm	10mm
0 (16)	.151	.151	.151
1 (15)	.227	.211	.195
2 (14)	.205	.216	.222
3 (13)	.157	.135	.130
4 (12)	.097	.081	.092
5 (11)	.043	.070	.043
6 (10)	.011	.022	.054
7 (9)	.032	.005	.000
8 (8)	.016	.027	.027
> 8 (<8)	.060	.081	.087

Table 5.3.7 Overlap probability for endcap of single muon events(only superlayer1)

# of bad planes	double-hit resolution		
(good)	6mm	8mm	10mm
0 (8)	.297	.292	.292
1 (7)	.281	.276	.243
2 (6)	.162	.146	.178
3 (5)	.092	.097	.081
4 (4)	.049	.049	.049
5 (3)	.032	.027	.027
6 (2)	.022	.027	.038
7 (1)	.005	.016	.016
8 (0)	.060	.070	.076

Table 5.3.8 Overlap probability for endcap of top events (all superlayers)

# of bad planes	double-hit resolution		
(good)	6mm	8mm	10mm
0 (16)	.436	.427	.411
1 (15)	.191	.178	.175
2 (14)	.178	.166	.156
3 (13)	.089	.092	.102
4 (12)	.051	.061	.061
5 (11)	.035	.035	.048
6 (10)	.010	.019	.013
7 (9)	.006	.010	.013
8 (8)	.000	.010	.016
> 8 (<8)	.003	.003	.006

Table 5.3.9 Overlap probability for endcap of top events (only superlayer1)

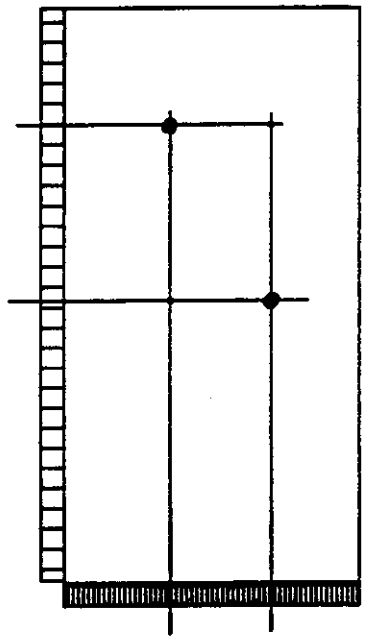
# of bad planes	double-hit resolution		
(good)	6mm	8mm	10mm
0 (8)	.567	.551	.535
1 (7)	.233	.220	.223
2 (6)	.112	.108	.092
3 (5)	.054	.064	.070
4 (4)	.019	.029	.038
5 (3)	.010	.013	.019
6 (2)	.000	.000	.006
7 (1)	.000	.006	.003
8 (0)	.006	.010	.013

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

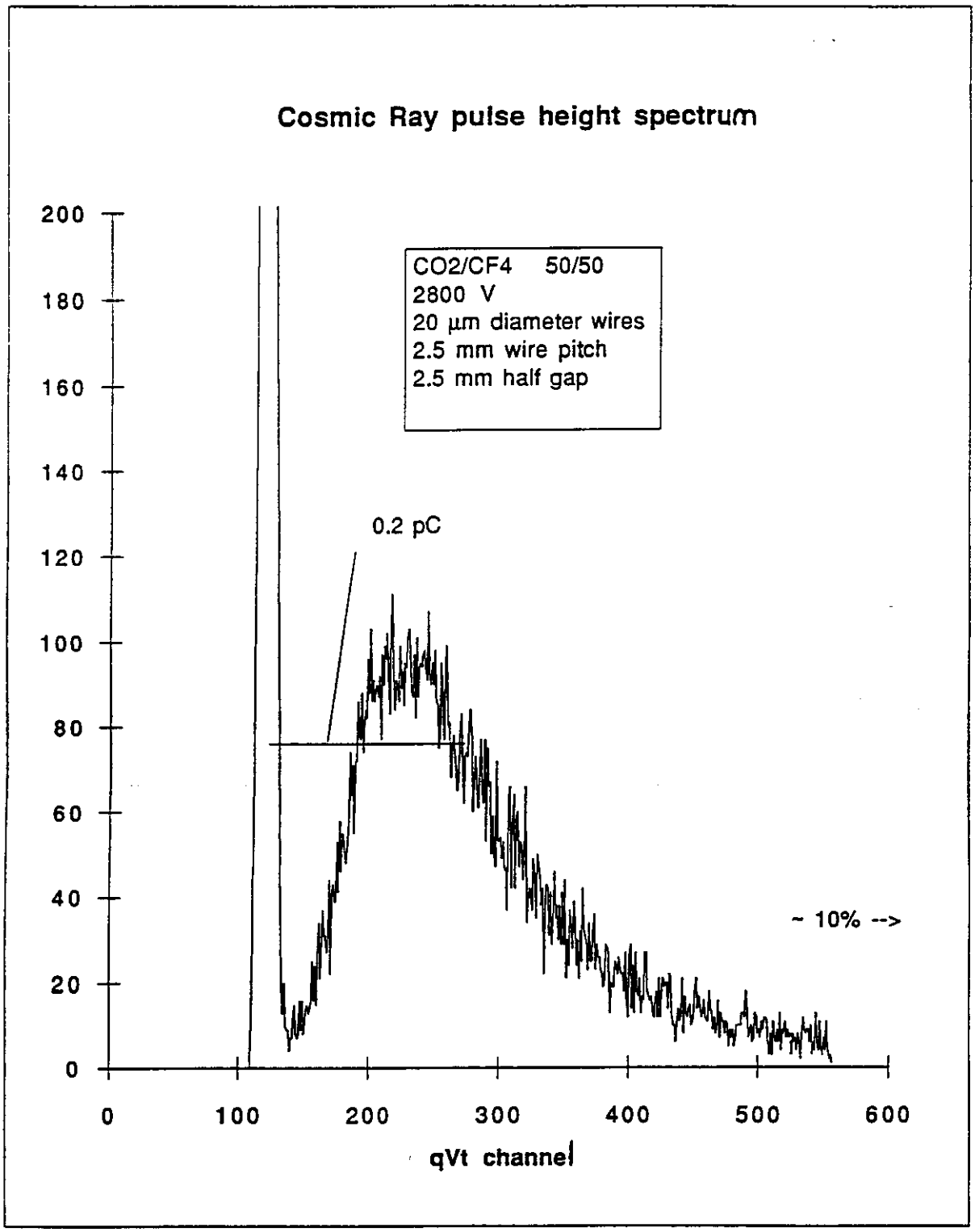
slow (300 ns -- 1 μsec peaking) output for
precision charge measurement

- track-and-hold
- Switched capacitor array

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

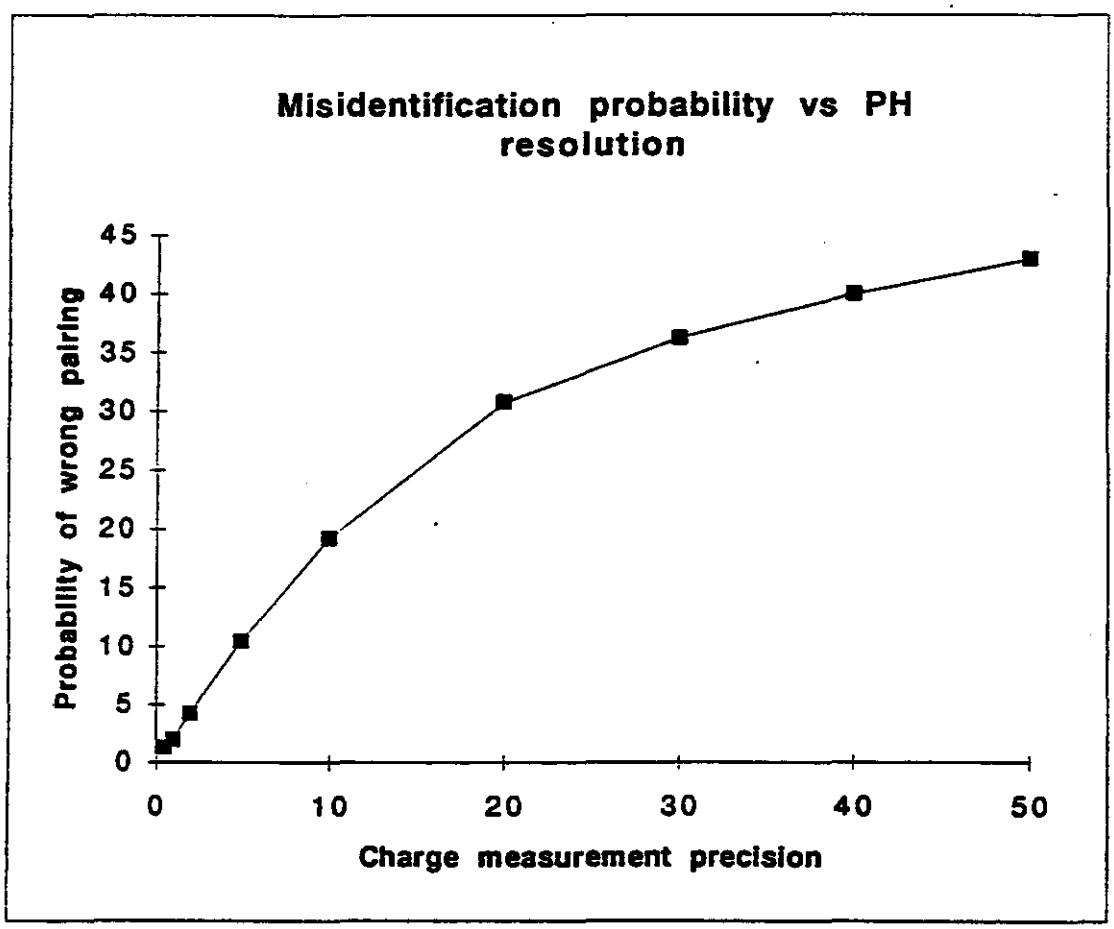
energetic Z's
Drell-Yan
decay of neutral scalars

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

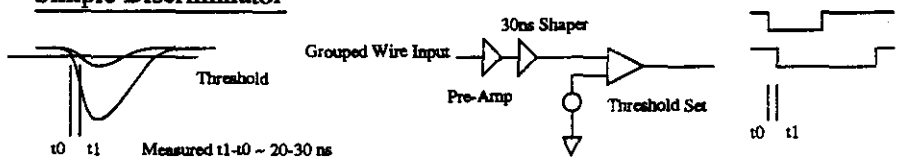
Pulse height correlation between bend and non-bend measurements can resolve ambiguities

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



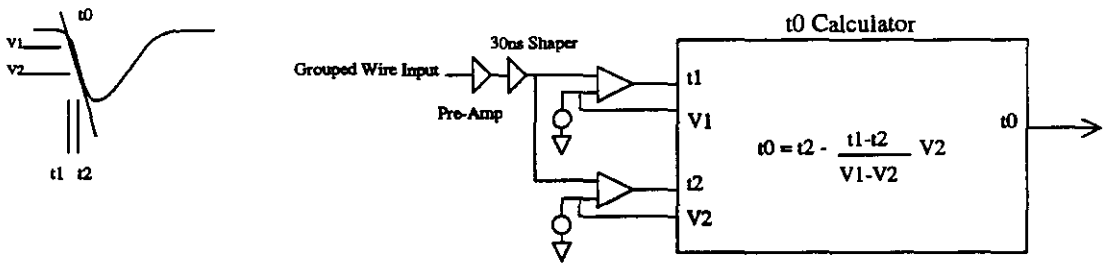
Discriminator Options

Simple Discriminator



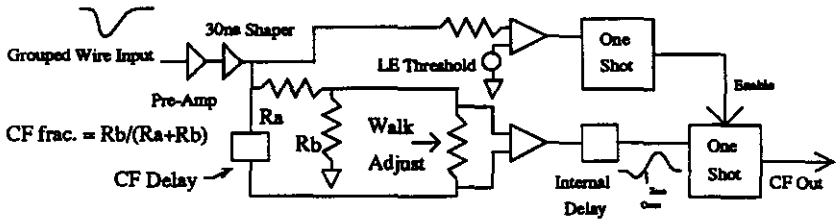
Simple and easy to implement; however suffers from unacceptable pulse height dependent time walk. Reference [1].

Two Level (LE Interp.) Discriminator



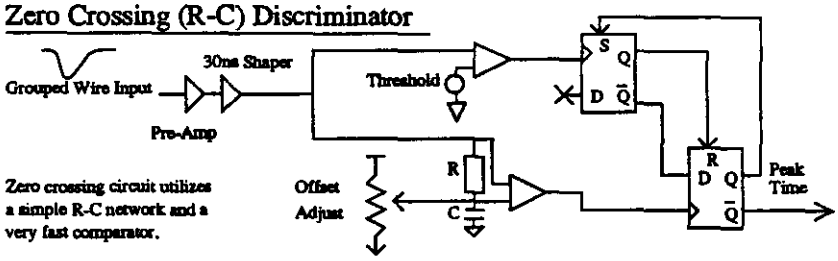
Need to implement a scheme such as the "t0 Calculator" Jitter on t0 might be excessive over a large dynamic range. Reference [2].

Constant Fraction Discriminator



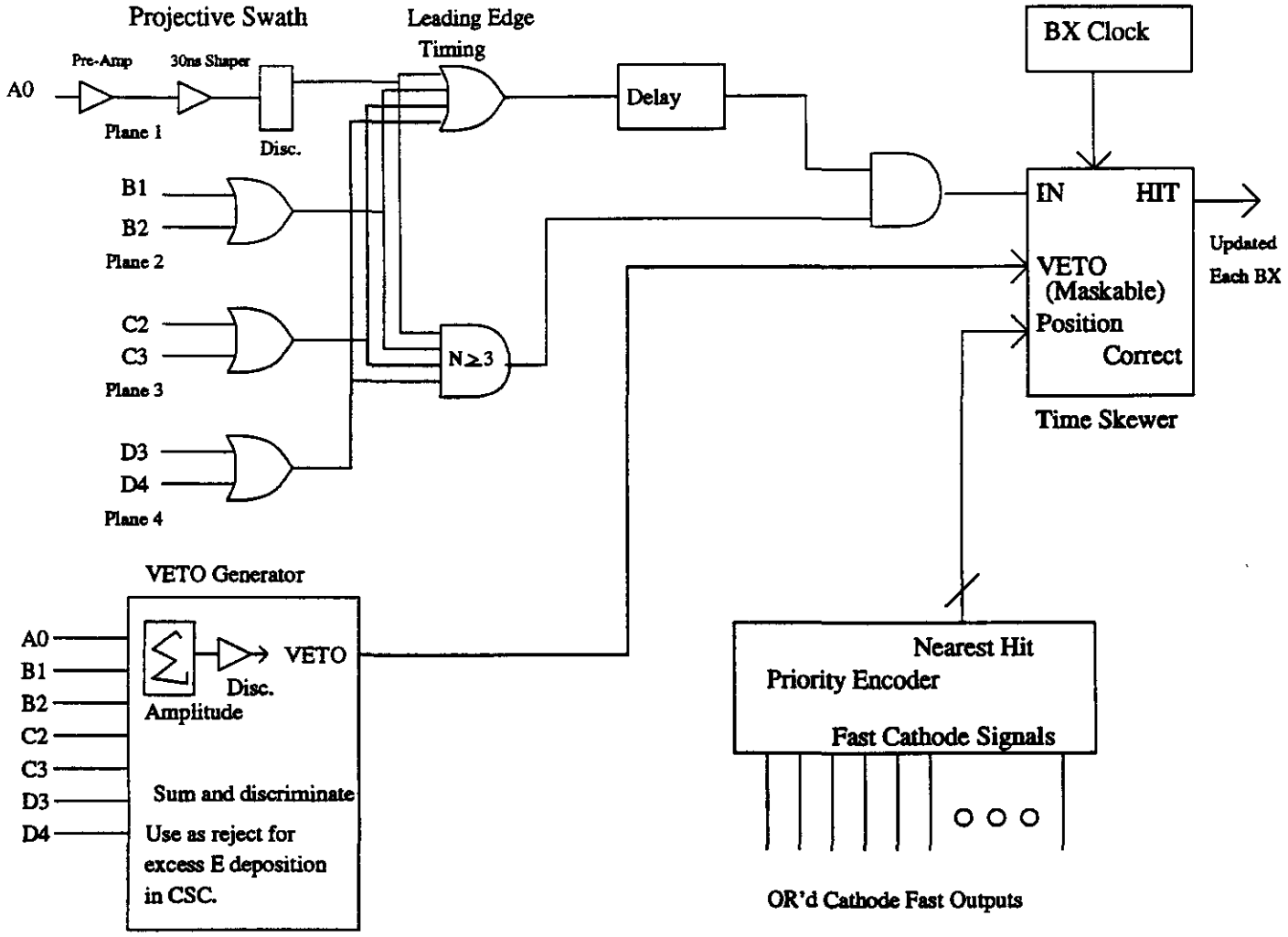
Excellent compensation for pulse height variation. Due to long shaping time, rather long delay lines required. Reference [3].

Zero Crossing (R-C) Discriminator



Able to compensate +/- 100ps over 25-30dB input variation. Easy implementation in high-density packaging. Good match to the Anode dynamic range. Reference [4].

"The Time Skewer"



RD5 CSC Analysis Status -- 18 Jan 93

Still in progress!

Problems recognized:

- HV problems during run limited gain to ~ 2×10^3

  Traced to low wire tension on two wires
  (prototype chambers were hand-wired...)

- Gain corrections were done incorrectly

  Insufficient precision on cal caps
  Resistive divider introduced to adapt to FERA system

  Full system reassembled at BU; under study

Current results:

Clean, sensible pulse height distributions

Mean pulse heights ~ 300 ADC counts

7% difference in means for 300 GeV muons compared to 100 GeV muons

Marginal noise performance

Pedestal σ ~ 3--4 counts
Pedestal stability < 3 counts

Position resolution 75--100 microns depending on run, cuts...

Timing:

Leading edge disc with fixed threshold -- 150 mV

11 ns rms per plane

6.5 ns rms for OR of 4 planes

Not the best possible:

Improvement with higher HV

lab tests show 15% improvement
with constant fraction discrimination

anode of time

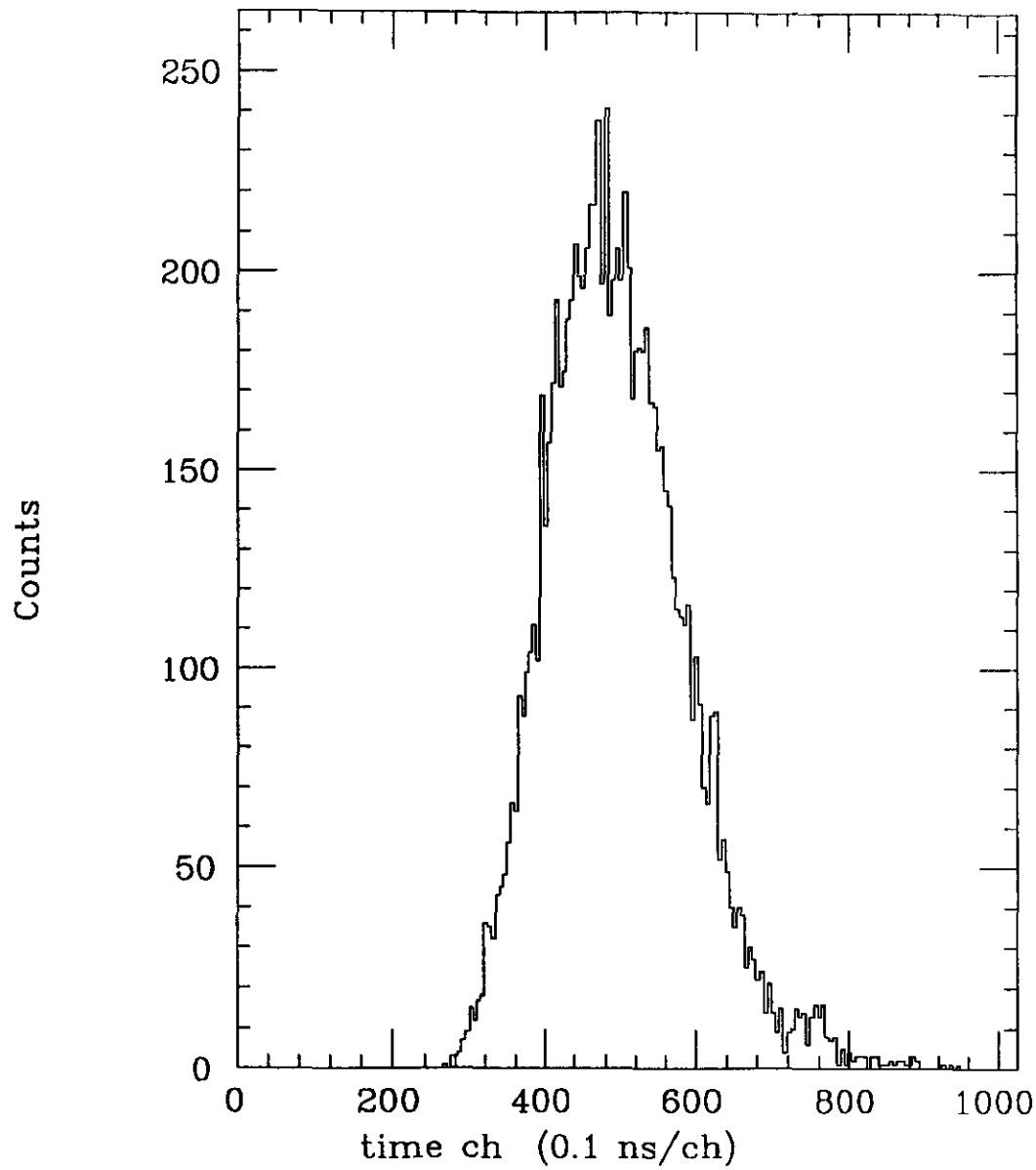
HBOOK ID = 311 DATE 16/01/93 NO = 42

```
     190                    -  -
     180                   I  **-
     170                  -I*I  *
     160                 I*-I  I*
     150                -I     I
     140               I*      I  *
     130               I       I--
     120              -*         I*
     110             I           I
     100            -*           I  *-
      90          -I             I--I
      80         I*                *
      70         I                  I
      60         *                  I*  -
      50        *I                  I-*I-
      40      *I                       I
      30     *-I                      **  -  -
      20    *-I                        I*I-I
      10 ***-I                           ***

CHANNELS  10   0         1         2         3
           1   1234567890123456789012345678 90

CONTENTS 100             1111111111
          10        124891578578722889445422 22
           1.   238465933400665182155194110602

LOW-EDGE  10        1111122222333334444455555
*{           1.   246802468024680246802468024 68
```

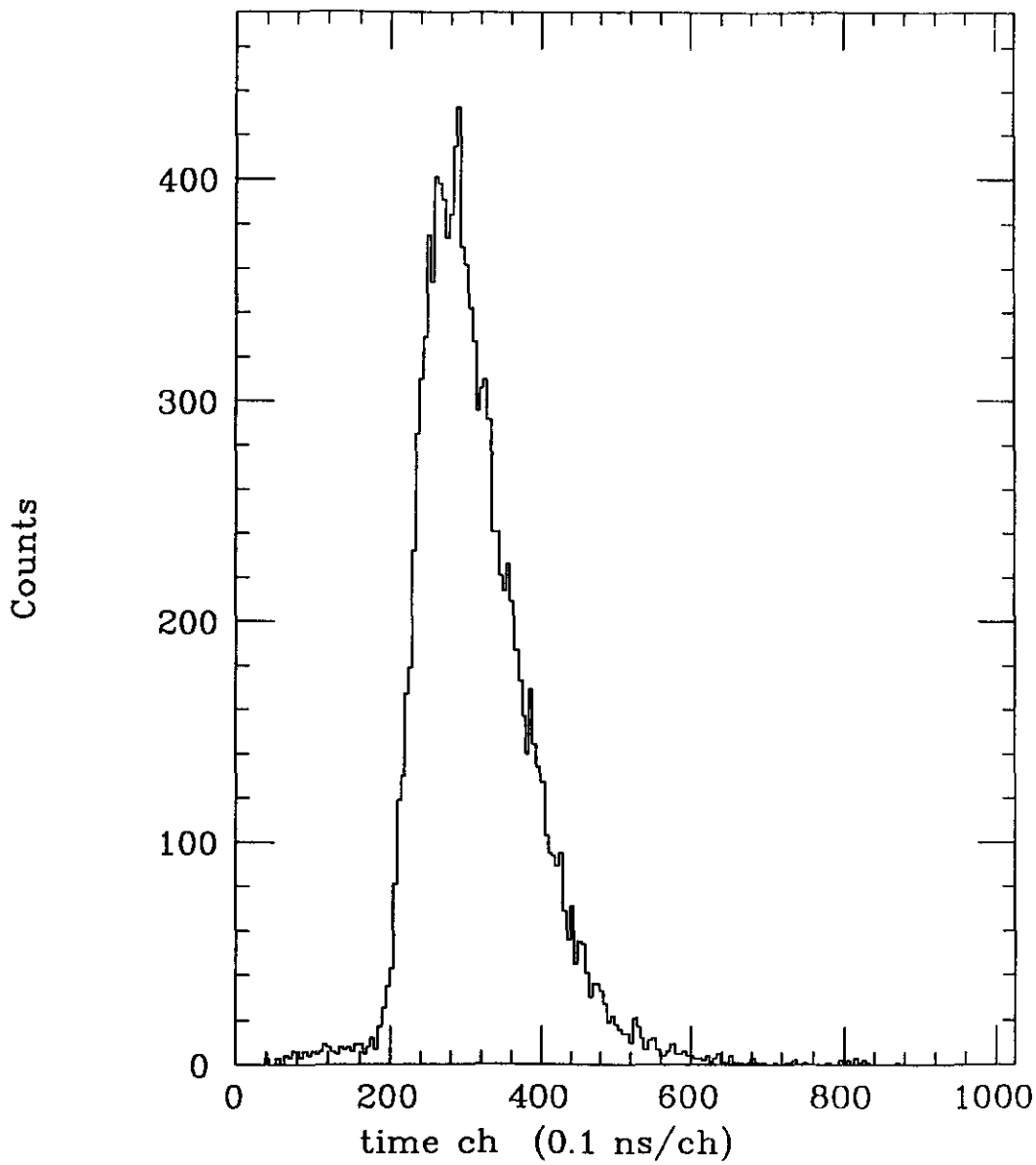
* ENTRIES = 2685 * ALL CHANNELS = 0.2370E+04 * UNDERFLOW = 0.0000E+00 * OVERFLOW = (
* BIN WID = 0.2000E+01 * MEAN VALUE = 0.3030E+02 * R . M . S = 0.1087E+02 * NEQUIVAL = (

```
 )         )         )         )         )         )         )         )         )         )         )
 min or time
HBOOK     ID =       315                                    DATE  16/01/93                NO =  46

     180                              --
     170                             I**
     160                           -**I-*-
     150                          *      *
     140                         *I      I*
     130                        - I       I*
     120                       -*-I       I-
     110                      *            I*
     100                     -I            I-*
      90                    -*              I
      80                    *               I-*
      70                   I                  I*
      60                  *I                   I*
      50                 *I                     I*
      40                *-I                     I-*-
      30              **-I                       I-*
      20           - **-I                          I**
      10        *****-I                              I****

CHANNELS  10   0         1         2         3         4
           1   12345678901234567890123456789012345678 90

CONTENTS 100                   111111111111
          10      1  122235891215577555419876532311
           1.  332289507699276555311962078058568383996 6

LOW-EDGE  10              111111111112222222223333333333
           1.   1234567890123456789012345678901234567 89

* ENTRIES =        2685      * ALL CHANNELS = 0.2666E+04      * UNDERFLOW = 0.2000E+01      * OVERFLOW = (
* BIN WID = 0.1000E+01       * MEAN VALUE   = 0.2065E+02      * R . M . S = 0.6522E+01      * NEQUIVAL = (
* CHISQUAR  =  0.3372E+02
```

Ar/CO2/CF4 20/60/20 LED 150 mV 2600V



Ar/CO2/CF4 20/60/20 CFD 65 mV 2800V



The Open Profile CSC Option

Presentation by:

K. Lau

OPEN PROFILE CSC

Advocates

Kwong Lau, Billy Mayes, Larry Pinsky
Jorg Pyrlik, and Roy Weinstein
University of Houston

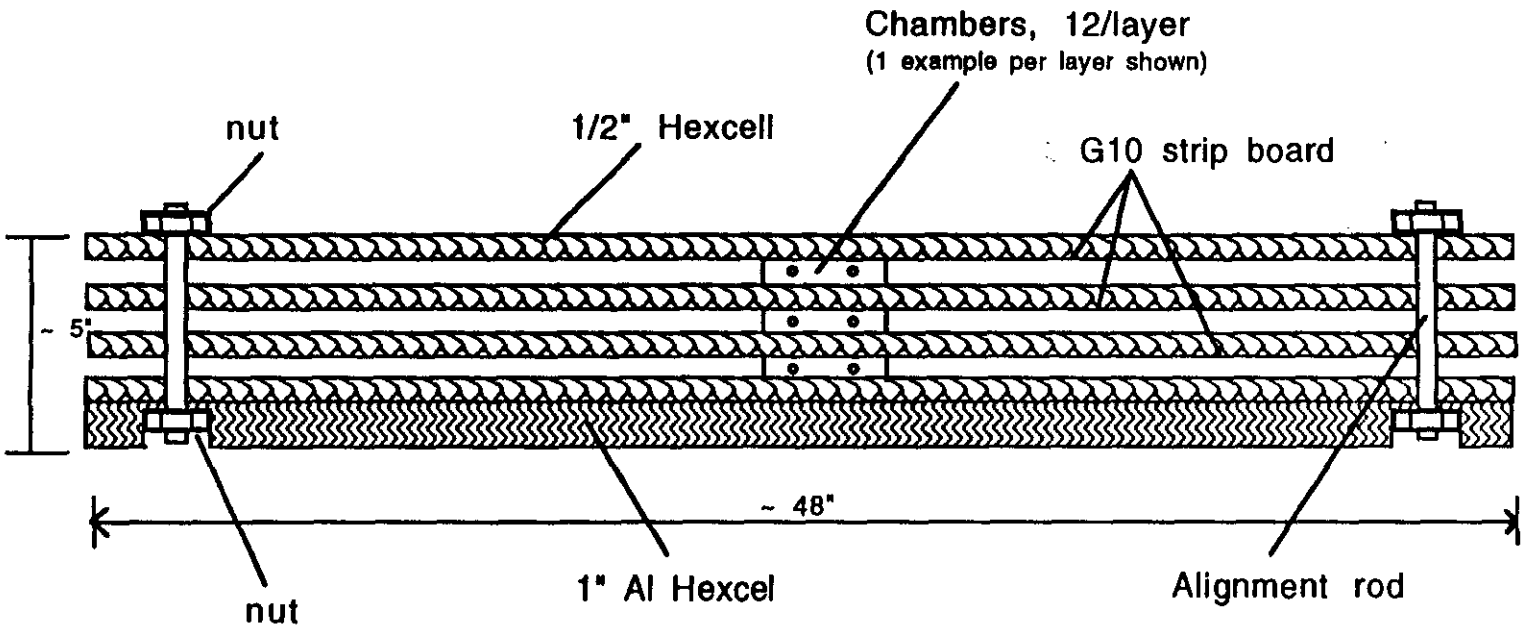
Georgii Chelkov *et al*
Dubna

Gena Mitselmakher *et al*
SSCL

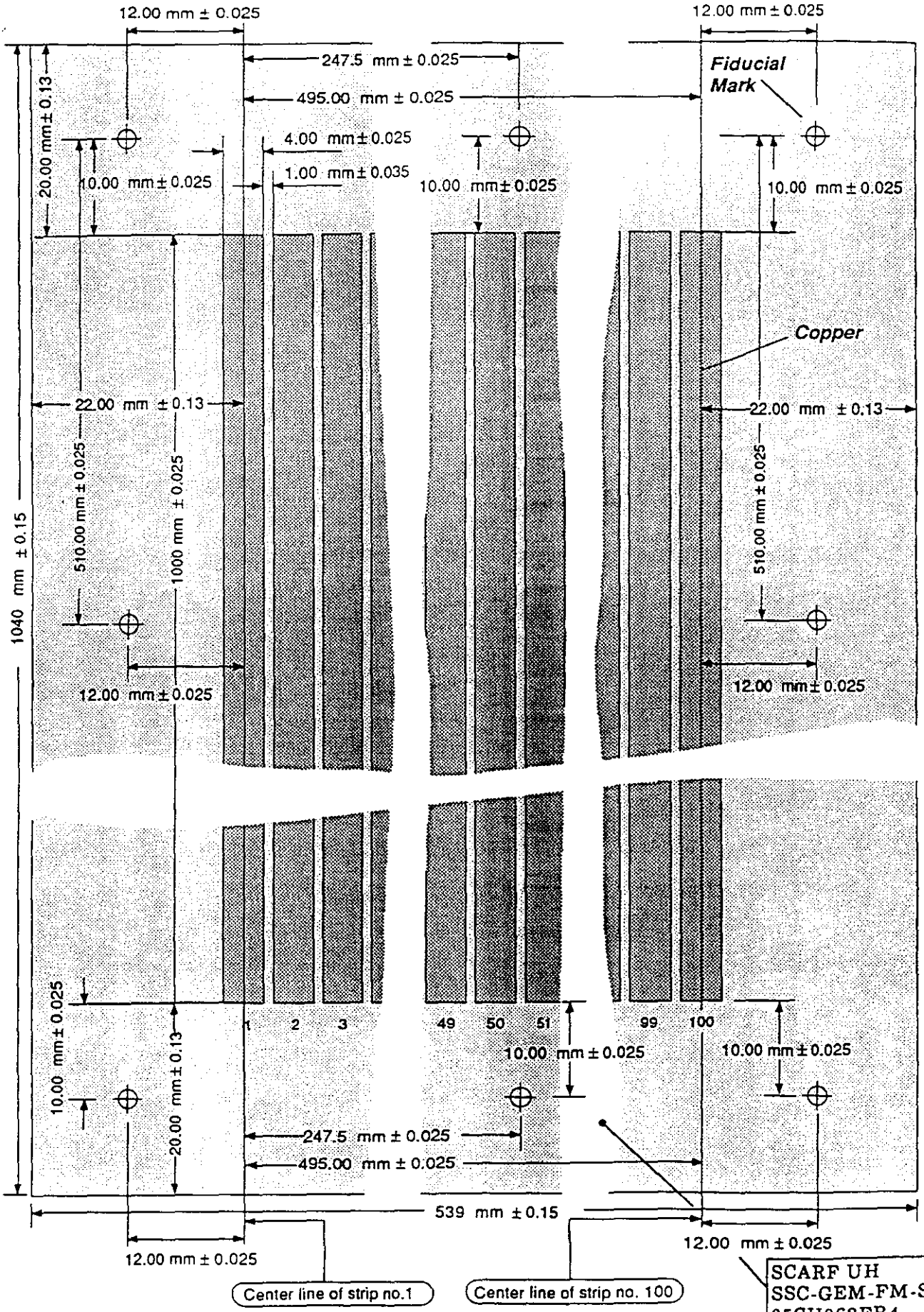
Unique Features

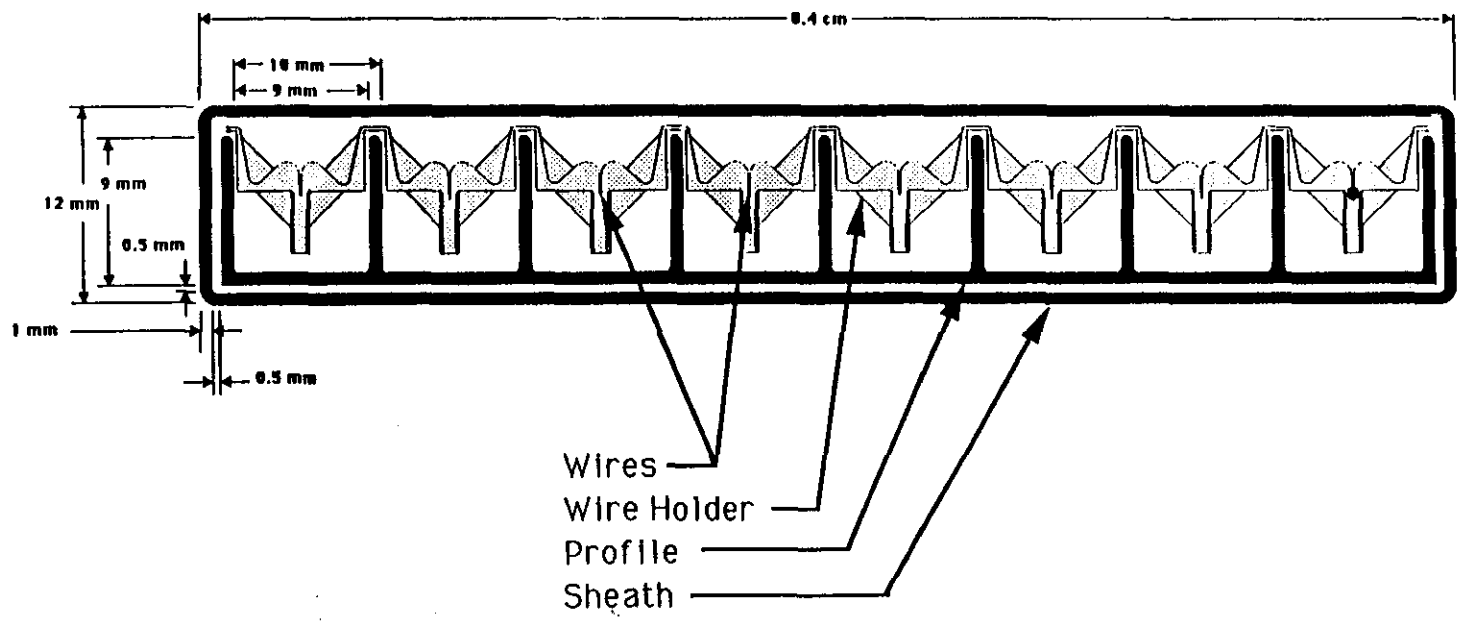
- Non-floating strips with a ground plane
- Modular chambers with conducting profiles
  - easy to repair during construction, testing, and operation
  - isolated anode wires : limits acceptance loss to 1 chamber due to broken wires
  - gas volume is not in contact with strip boards
  - uniform support for strip boards
  - anode-strip distance uncritical ($\pm$ 200 μm)

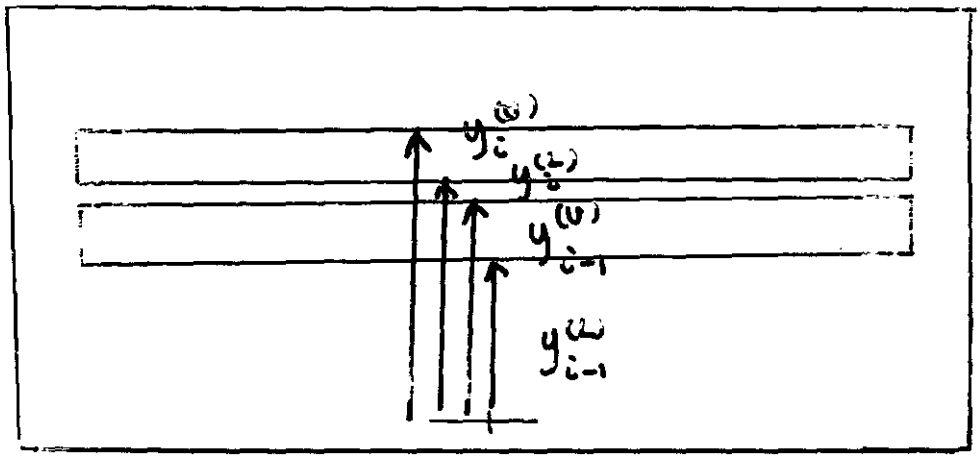
Side View of UH CSC Prototype



University of Houston


12.00 mm ± 0.025
12.00 mm ± 0.025
247.5 mm ± 0.025
495.00 mm ± 0.025
Fiducial Mark
20.00 mm ± 0.13
4.00 mm ± 0.025
1.00 mm ± 0.035
10.00 mm ± 0.025
10.00 mm ± 0.025
10.00 mm ± 0.025
Copper
22.00 mm ± 0.13
22.00 mm ± 0.13
510.00 mm ± 0.025
1000 mm ± 0.025
510.00 mm ± 0.025
1040 mm ± 0.15
12.00 mm ± 0.025
12.00 mm ± 0.025
10.00 mm ± 0.025
20.00 mm ± 0.13
1
2
3
49
50
51
99
100
10.00 mm ± 0.025
10.00 mm ± 0.025
247.5 mm ± 0.025
495.00 mm ± 0.025
539 mm ± 0.15
12.00 mm ± 0.025
12.00 mm ± 0.025
Center line of strip no.1
Center line of strip no. 100
SCARF UH
SSC-GEM-FM-SB
05CU062FR4
4/4/92 - 2


8.4 cm
10 mm
9 mm
9 mm
12 mm
0.5 mm
1 mm
0.5 mm
Wires
Wire Holder
Profile
Sheath



Strip width $w_i = y_i^{(U)} - y_i^{(L)}$

gap width $g_{i-1} = y_i^{(L)} - y_{i-1}^{(U)}$

Strip center $c_i = (y_i^{(U)} + y_i^{(L)})/2$

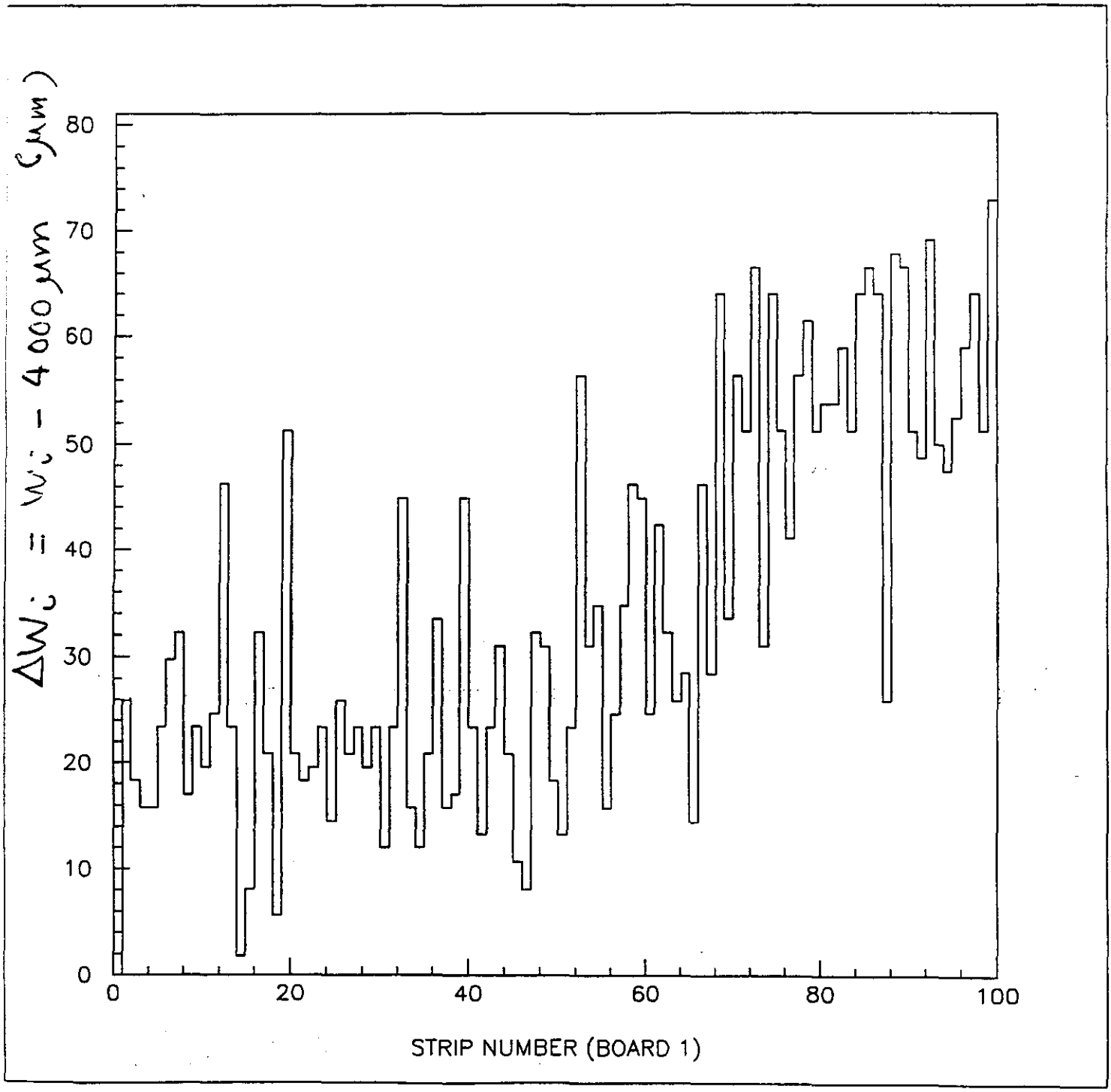
pitch $p_i = c_i - c_{i-1}$

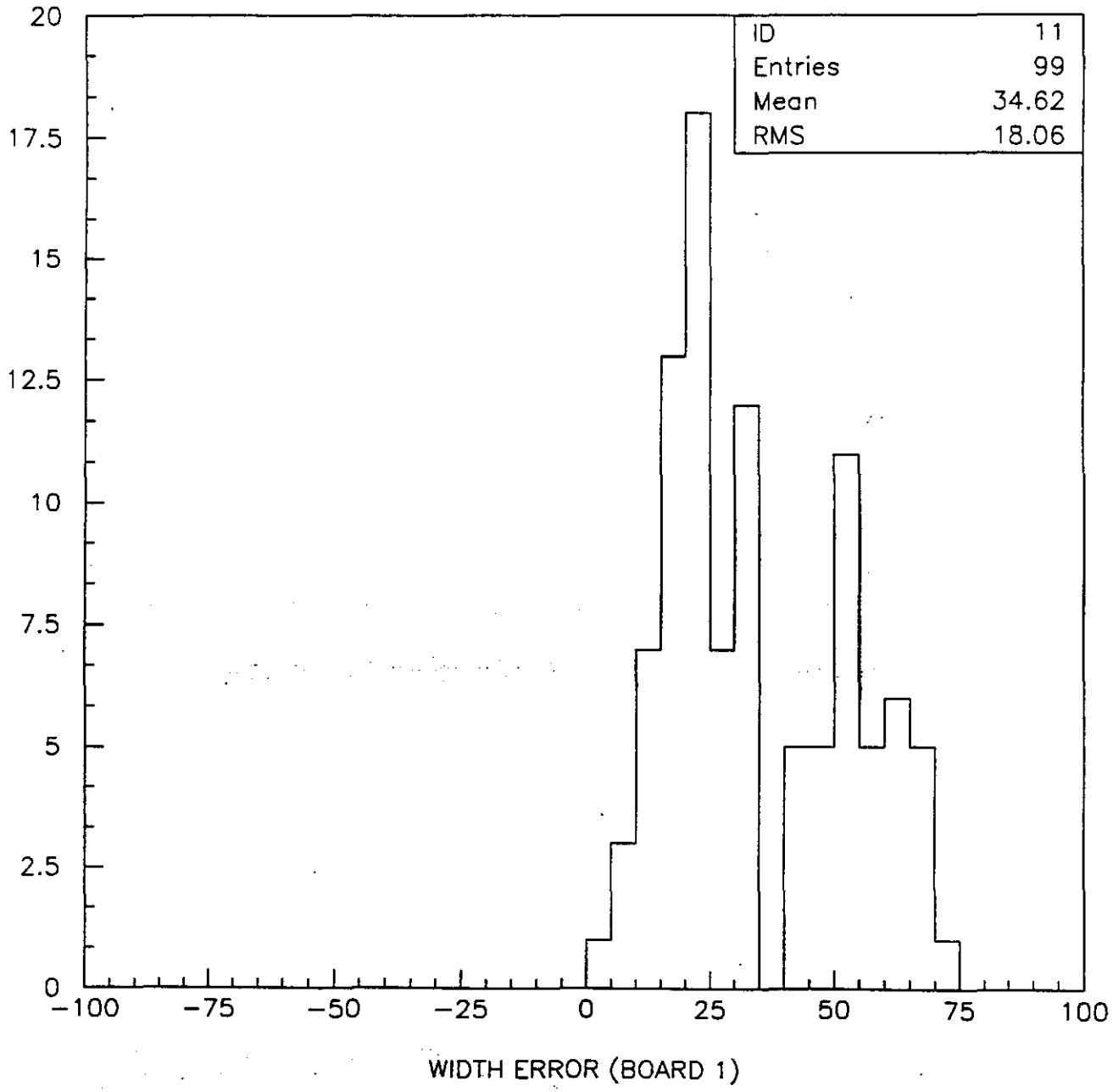
$\Delta w_i = w_i - 4000.\ \mu m$

$\Delta g_i = g_i - 1000.\ \mu m$

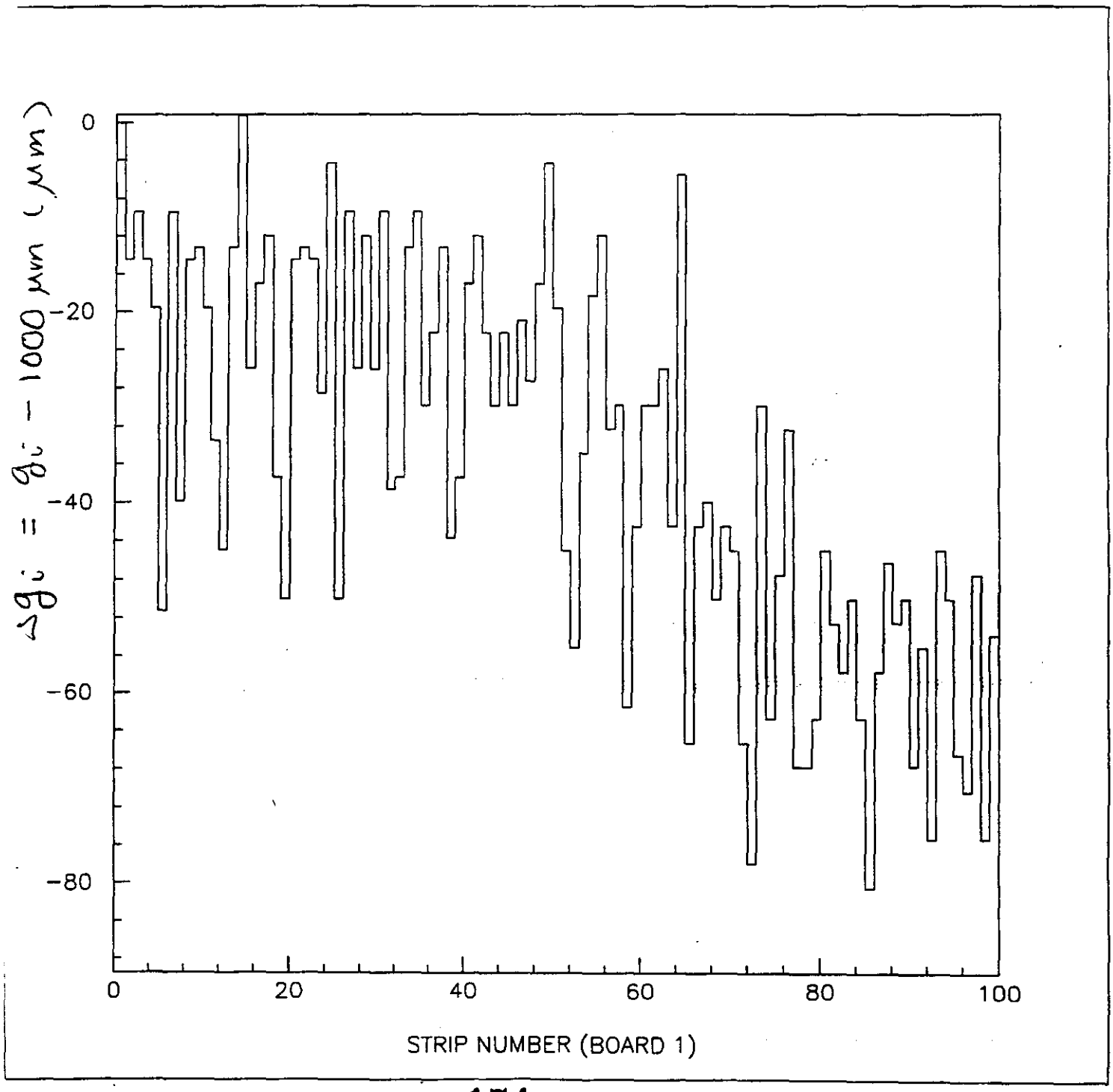
$\Delta p_i = p_i - 5000\ \mu m$

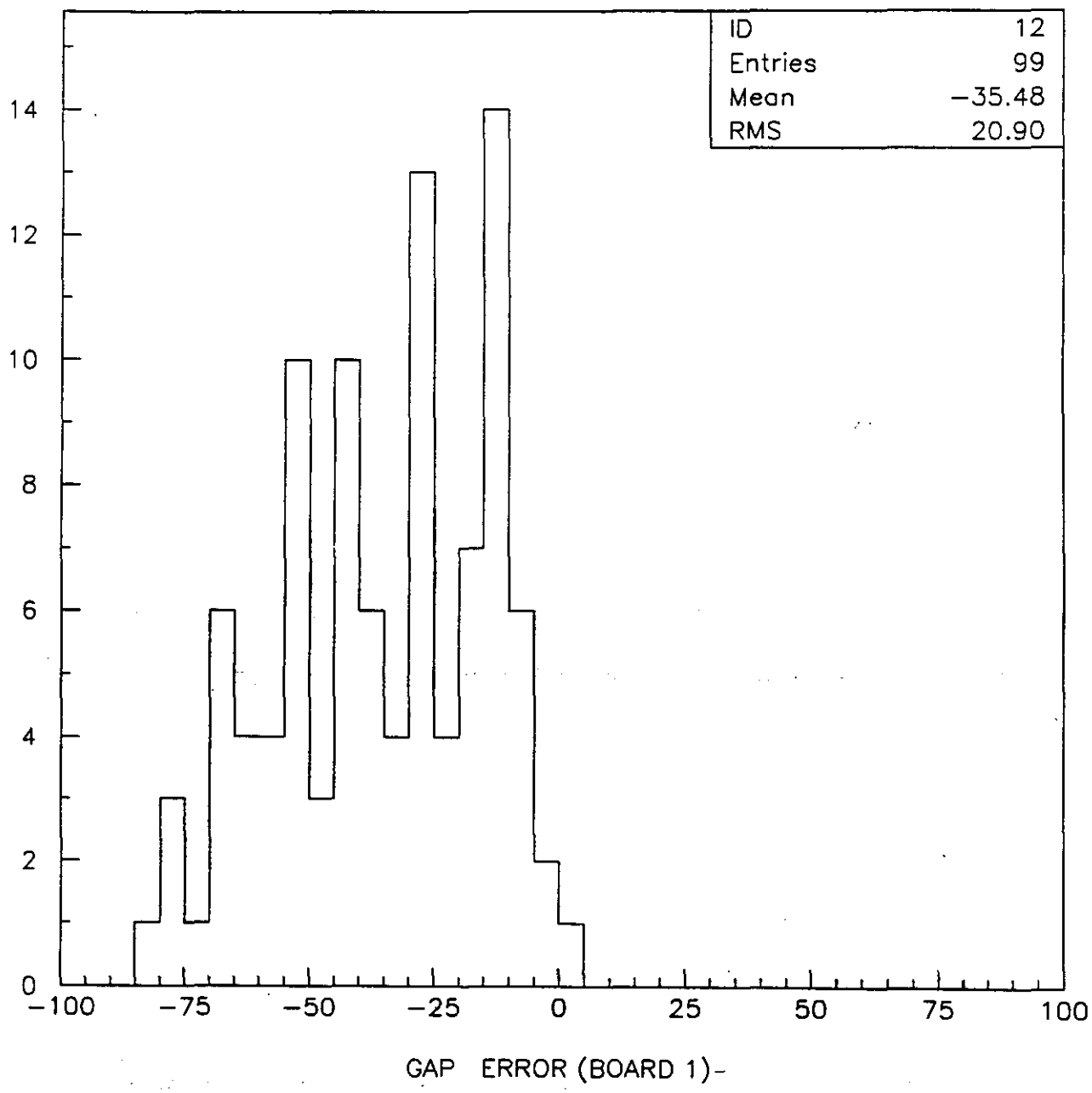
STRIP WIDTH ERROR



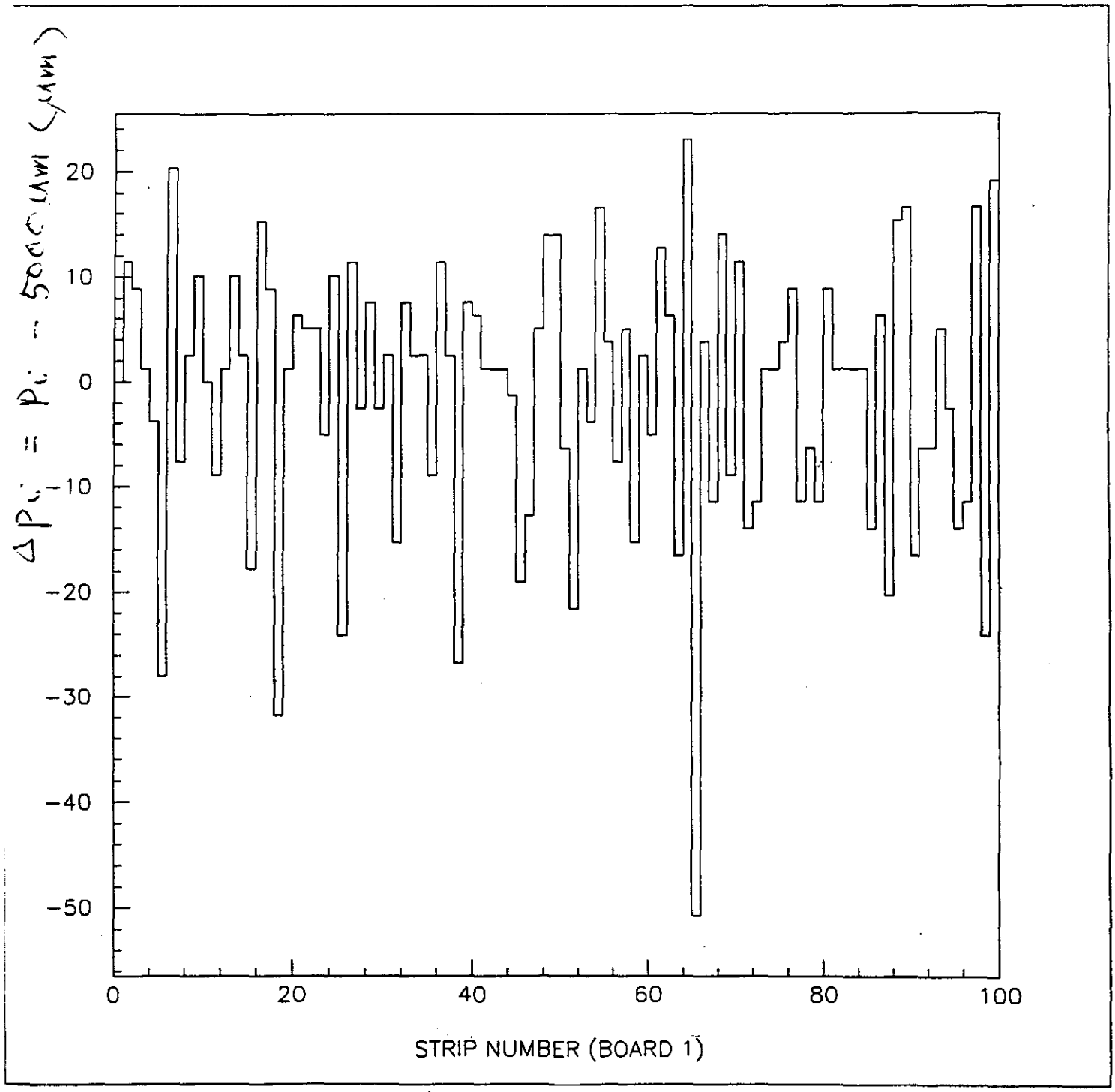

ID 11
Entries 99
Mean 34.62
RMS 18.06
20
17.5
15
12.5
10
7.5
5
2.5
0
−100
−75
−50
−25
0
25
50
75
100
WIDTH ERROR (BOARD 1)

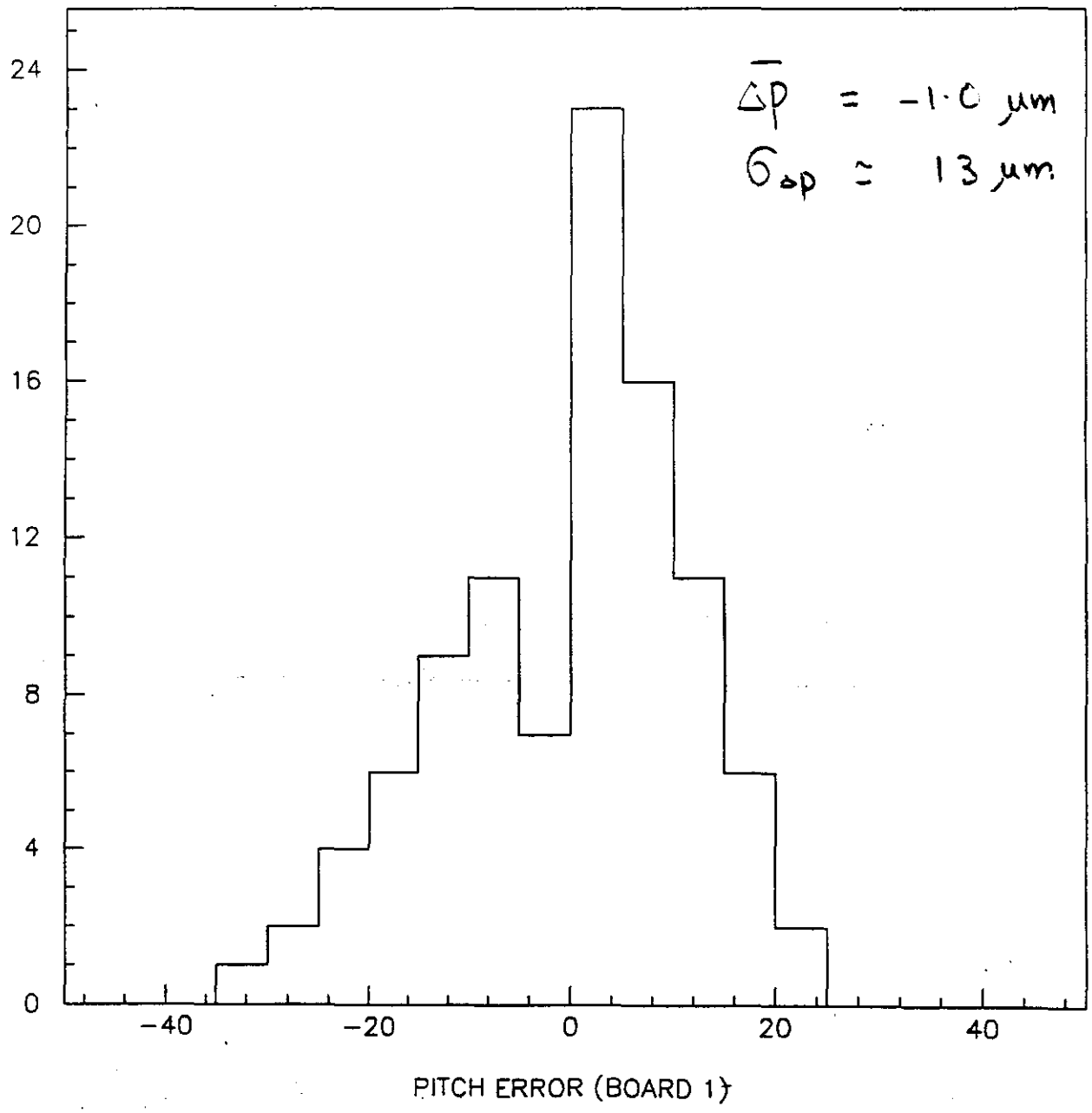
TAP WIDTH ERROR




ID 12
Entries 99
Mean −35.48
RMS 20.90
0
2
4
6
8
10
12
14
−100
−75
−50
−25
0
25
50
75
100
GAP ERROR (BOARD 1)

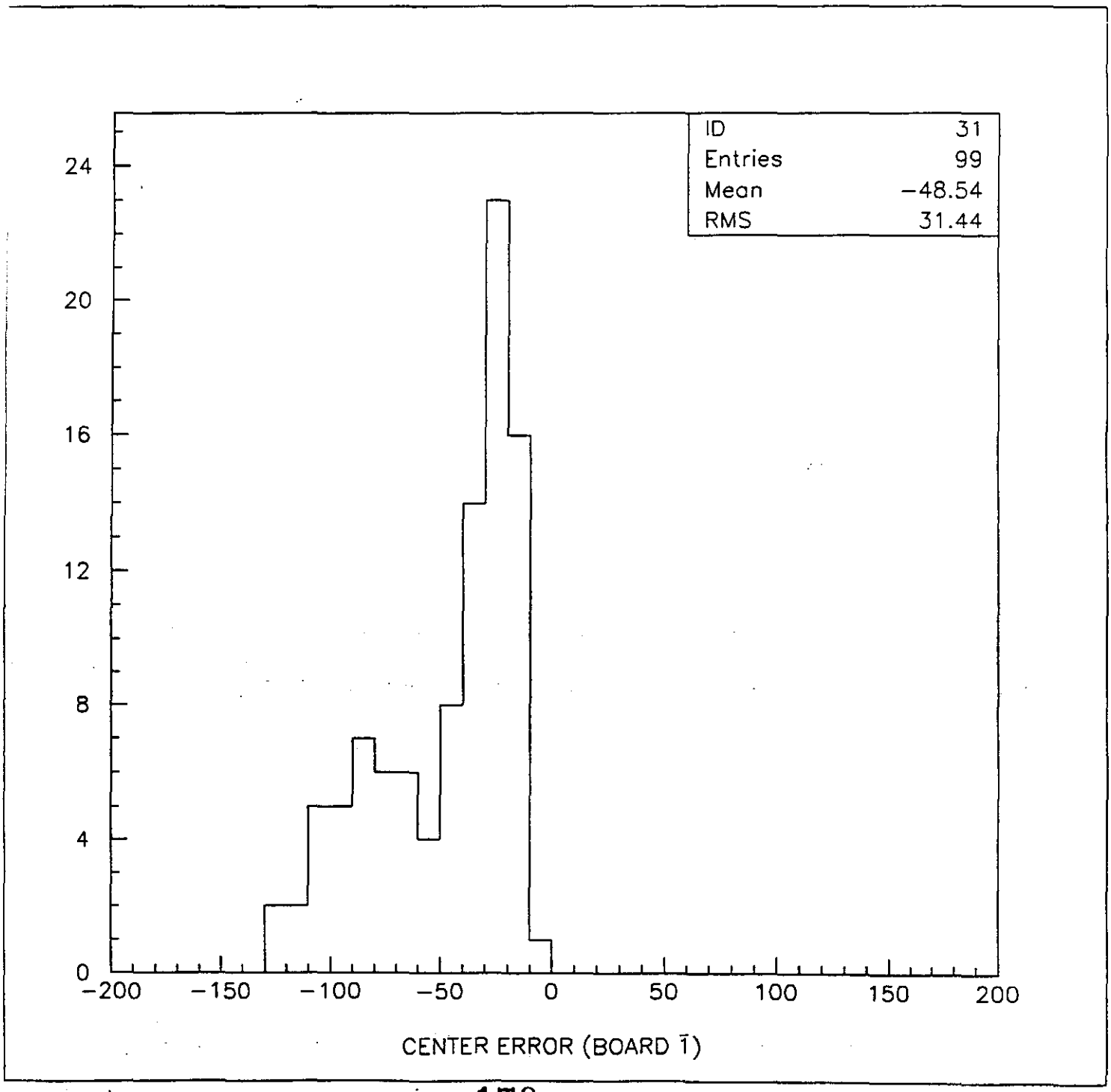
PITCH ERROR


$\Delta P_i = P_i - 5000\ \mu m\ (\mu m)$
20
10
0
−10
−20
−30
−40
−50
0
20
40
60
80
100
STRIP NUMBER (BOARD 1)


$\overline{\Delta p}$ = −1.0 μm
$\sigma_{\Delta p}$ ≃ 13 μm
24
20
16
12
8
4
0
−40
−20
0
20
40
PITCH ERROR (BOARD 1)

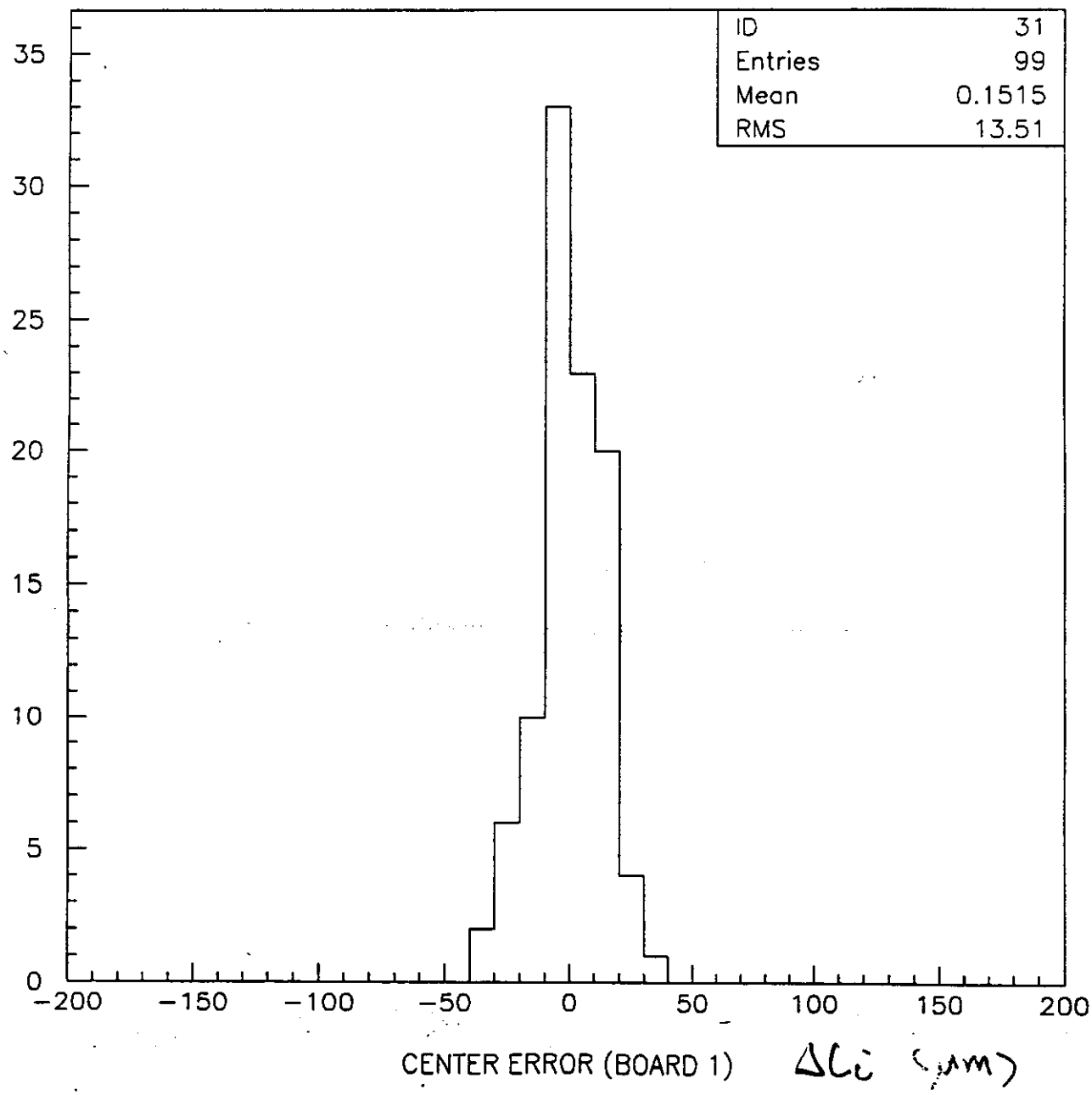
$$C_i^{th} = C_0 + i \times 5000\,\mu m$$

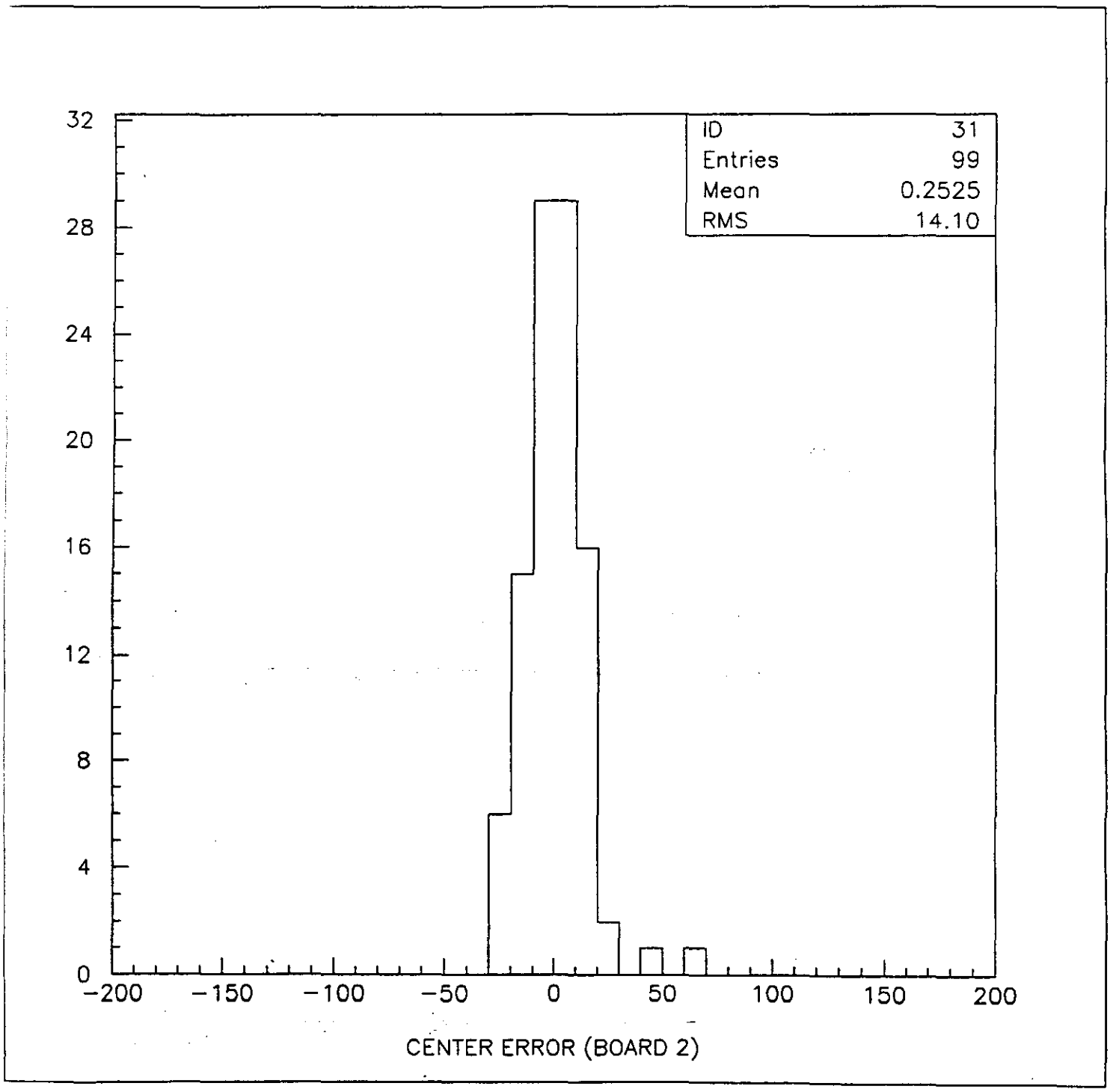
$$\Delta C_i = C_i - C_i^{th}$$



$$C_i^{th} = C_0 + i \times 4999.0\,\mu m$$

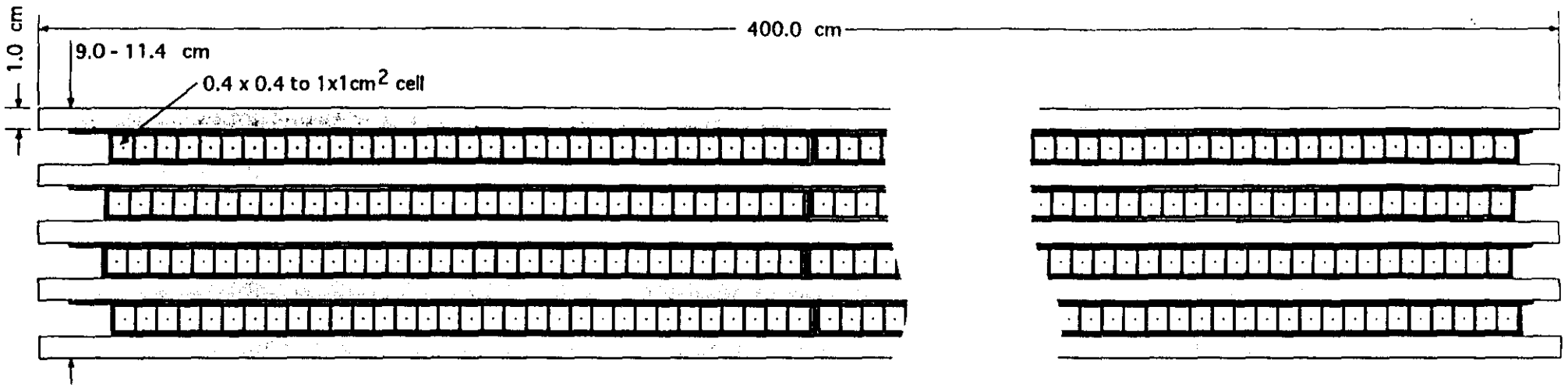
$$\Delta C_i = C_i - C_i^{th}$$

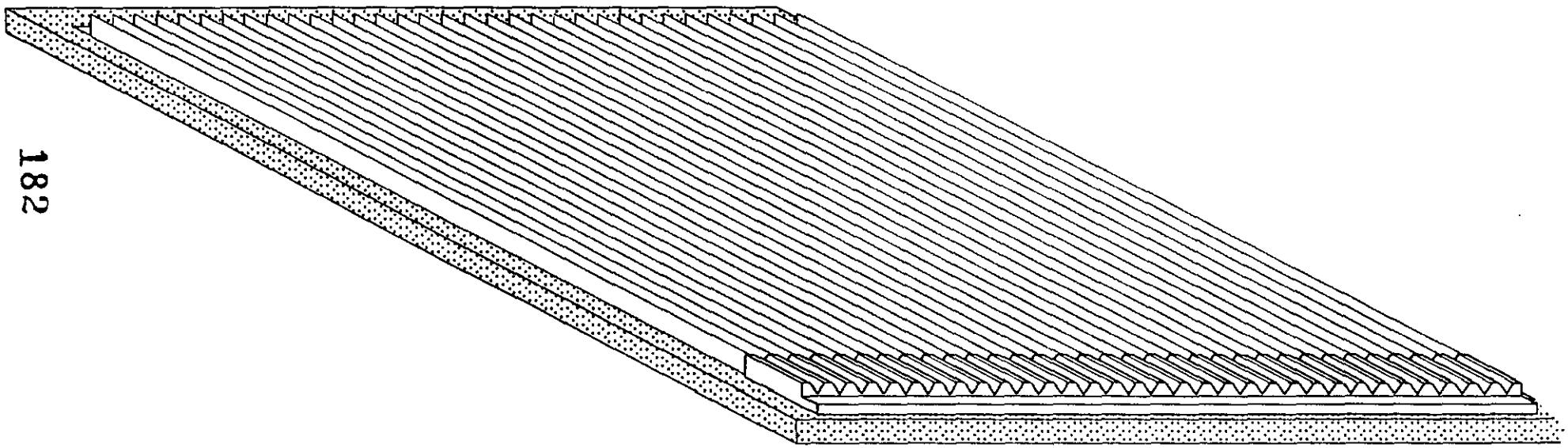



ID 31
Entries 99
Mean 0.2525
RMS 14.10
32
28
24
20
16
12
8
4
0
−200
−150
−100
−50
0
50
100
150
200
CENTER ERROR (BOARD 2)

GEM Muon System

- 8-6-6 configuration for the barrel and endcaps
- Rectangular chambers for the barrel and endcaps
  - Precision strips epoxied to honeycomb panels
  - Standard Iarocci-type PVC chambers with low-resistance ($\leq$ 4 kΩ/square) carbon-coated profiles and 50 μm wires
- Possible improvements :
  - Redesign ends to reduce dead space
  - Increase chamber width from 8 cm to 16 cm : reduce losses due to dead space between chambers by about a factor of 2
  - reduce cell size (current cell size : 9 mm x 9 mm)


400.0 cm
1.0 cm
9.0 - 11.4 cm
0.4 x 0.4 to 1x1cm^2 cell



1.4 Baseline System Layout

Figures 1.1 and 1.2 show the layout of the CSC barrel system. We have chosen a 32-fold azimuthal segmentation so as to minimize the degradation in resolution resulting from non-normal angles of incidence. The chambers of the middle and outer superlayers are tilted by 8 and 11 degrees, respectively. This reduces the Lorentz-angle effect on resolution, as discussed in GEM TN-92-137. Figure 1.3 shows a layout for the endcap region. Although figure 1.4 shows a "4/4/4" configuration—i.e. a configuration with four chambers in each superlayer—recent studies have led us to choose an 8/4/4 configuration throughout the barrel and endcap regions.

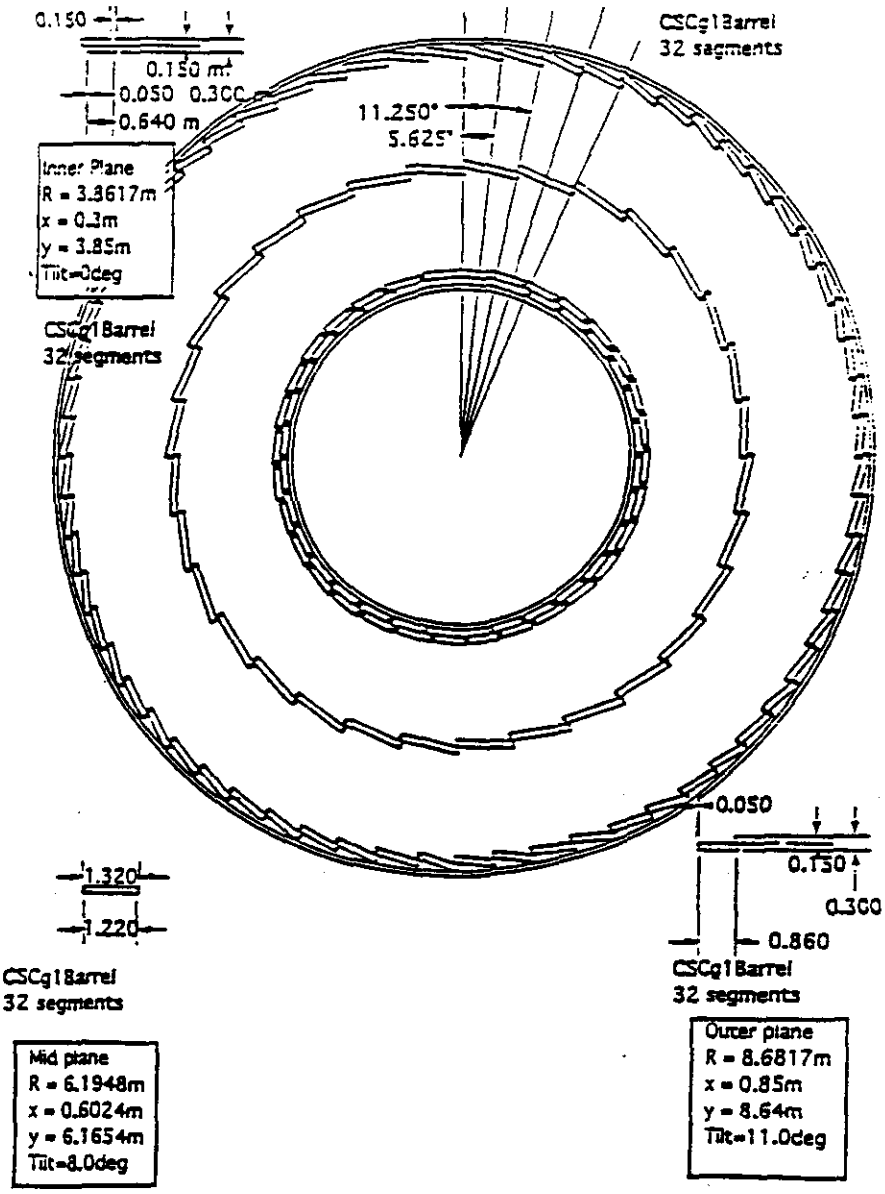


Figure 1.1 End (x-y) view of the barrel CSC system.

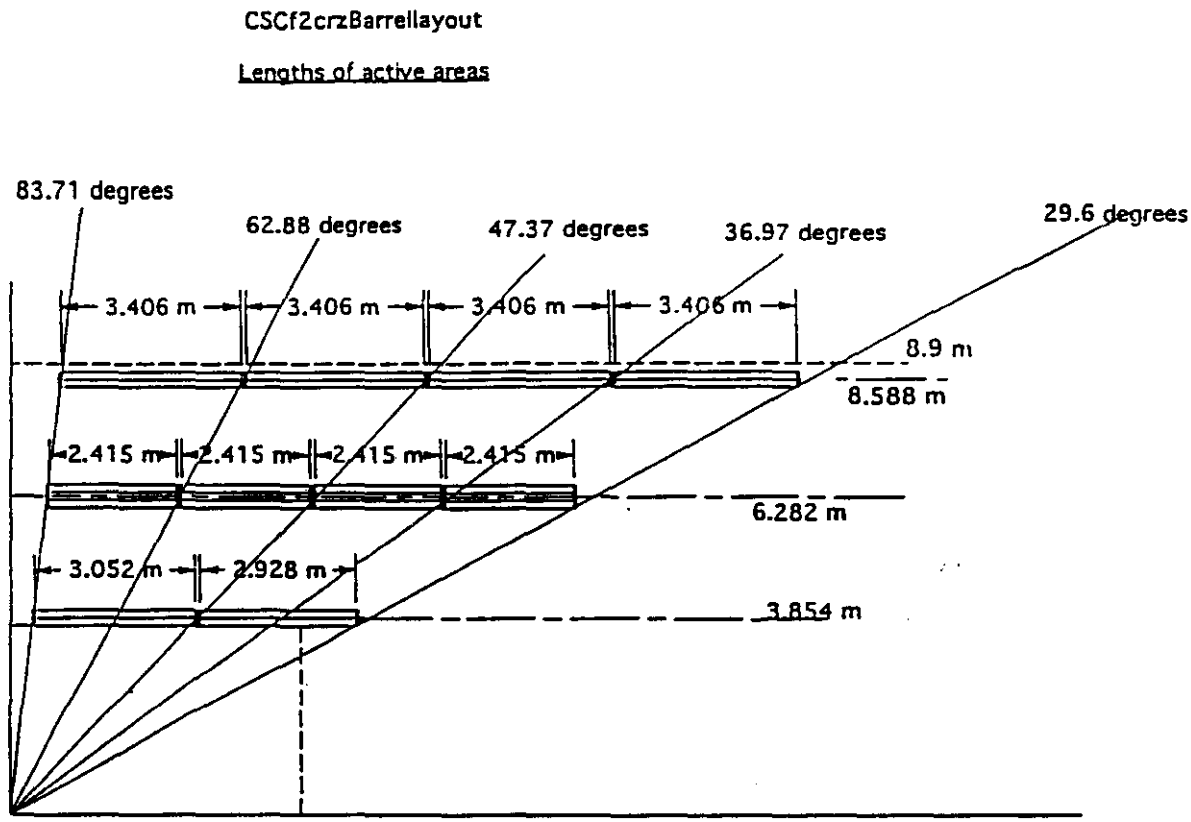


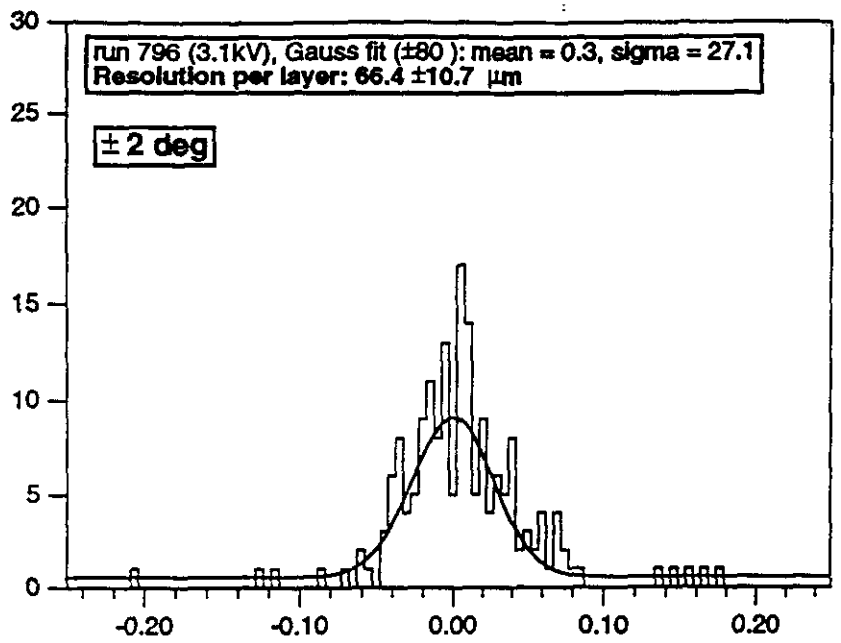
Figure 1.2 Side (r-z) view of the barrel CSC system.

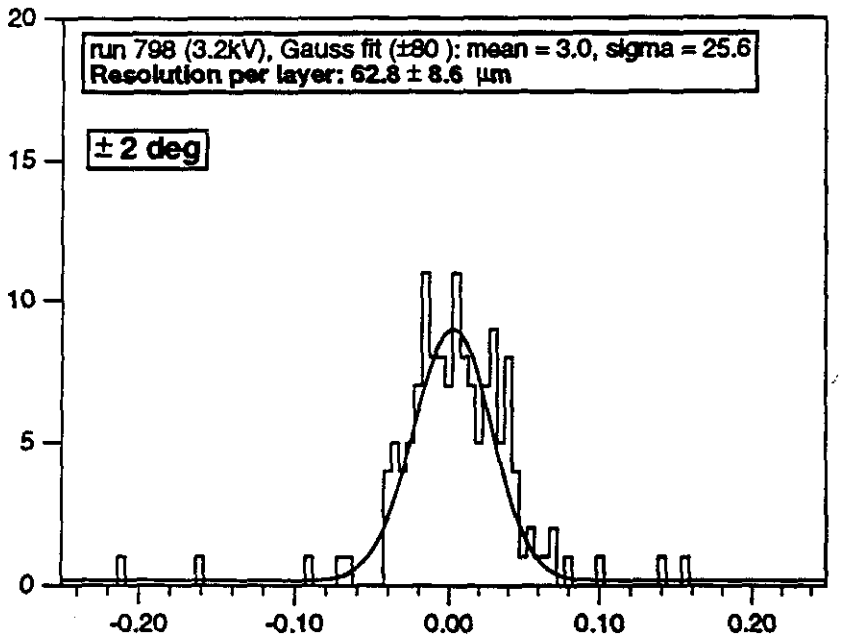
Justifications

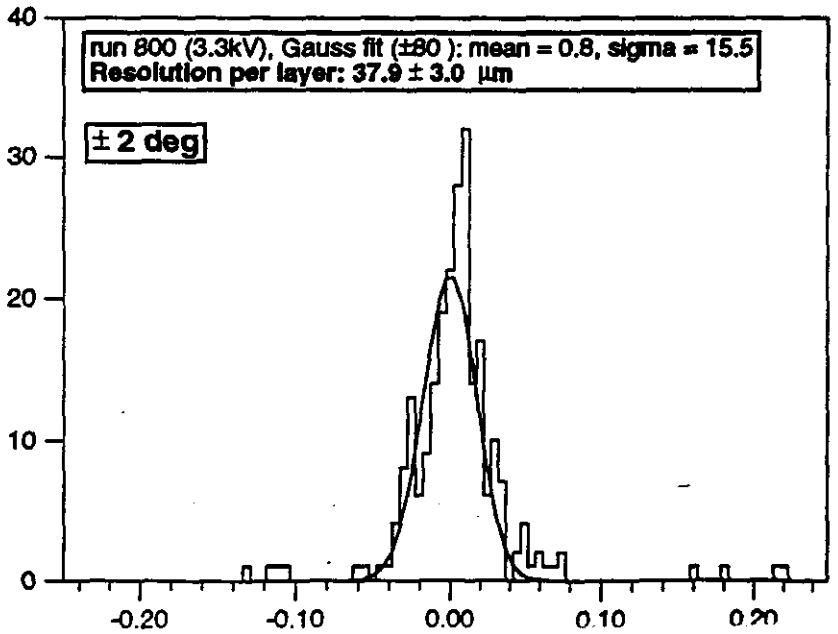
- 1.0 m x 0.5 m prototype met GEM specifications
  - $\sigma < 60\ \mu m$
  - strip centers known to within 50 μm
- All parts obtainable from industry with minimal assembly labor (25 hrs / supermodue)
- Low costs for parts and assembly labor

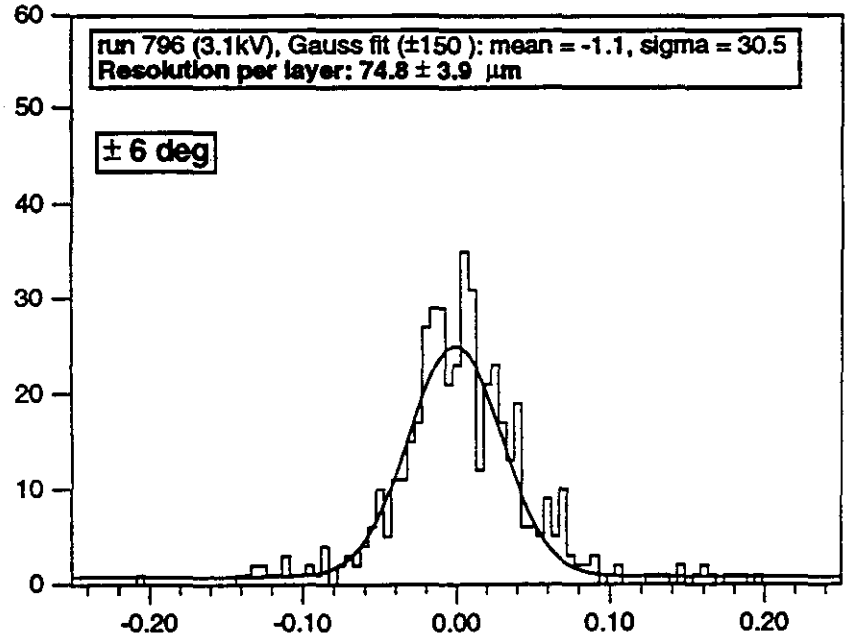
Prototype TTR Test Results

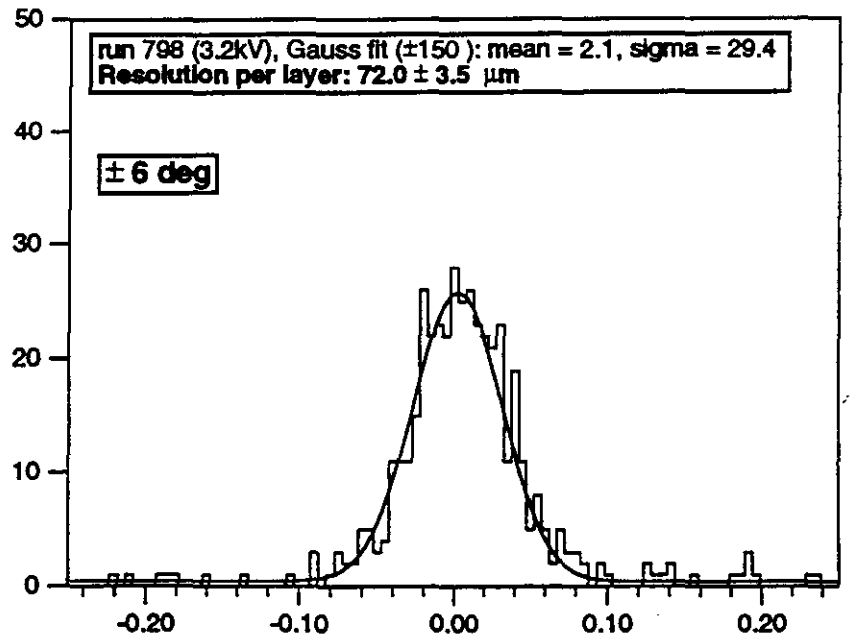
- Single layer resolution and strip alignment
  - Best $\sigma = 38 \pm 3\ \mu\text{m}$
  - Relevant $\sigma = 56 \pm 2\ \mu\text{m}$
  - Interlayer alignment $= 33 \pm 5\ \mu\text{m}$
- Losses due to chamber walls
  - Average loss $\leq 3\ \%$

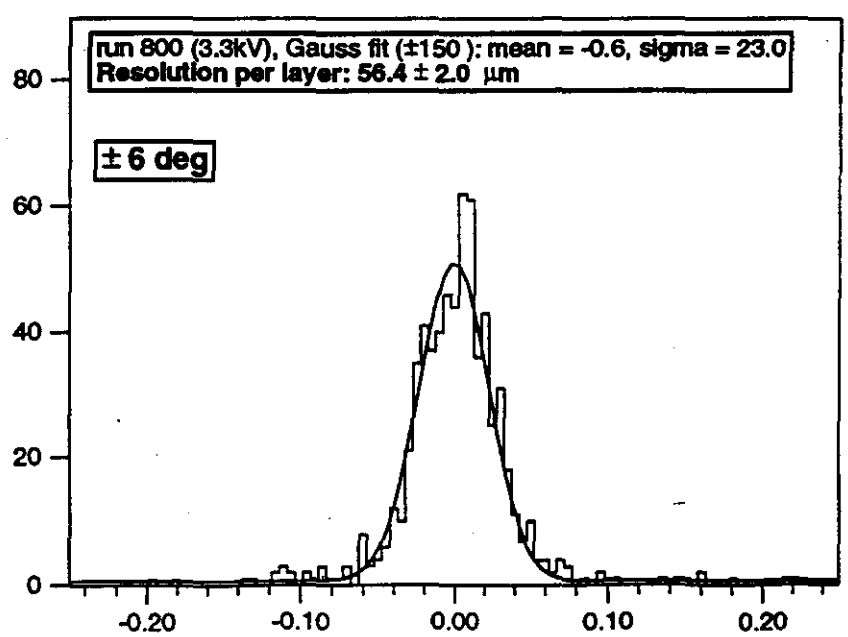

run 796 (3.1kV), Gauss fit (±80): mean = 0.3, sigma = 27.1
Resolution per layer: 66.4 ±10.7 µm
± 2 deg
30
25
20
15
10
5
0
-0.20
-0.10
0.00
0.10
0.20


run 798 (3.2kV), Gauss fit (±80): mean = 3.0, sigma = 25.6
Resolution per layer: 62.8 ± 8.6 µm
± 2 deg
20
15
10
5
0
-0.20
-0.10
0.00
0.10
0.20


run 800 (3.3kV), Gauss fit (±80): mean = 0.8, sigma = 15.5
Resolution per layer: 37.9 ± 3.0 µm
± 2 deg
40
30
20
10
0
-0.20
-0.10
0.00
0.10
0.20


run 796 (3.1kV), Gauss fit (±150): mean = -1.1, sigma = 30.5
Resolution per layer: 74.8 ± 3.9 μm
± 6 deg
60
50
40
30
20
10
0
-0.20
-0.10
0.00
0.10
0.20


run 798 (3.2kV), Gauss fit (±150): mean = 2.1, sigma = 29.4
Resolution per layer: 72.0 ± 3.5 μm
± 6 deg
50
40
30
20
10
0
-0.20
-0.10
0.00
0.10
0.20


run 800 (3.3kV), Gauss fit (±150): mean = -0.6, sigma = 23.0
Resolution per layer: 56.4 ± 2.0 μm
± 6 deg
80
60
40
20
0
-0.20
-0.10
0.00
0.10
0.20

Summary of Results (Preliminary)

- Averaged over $\pm \simeq 6°$

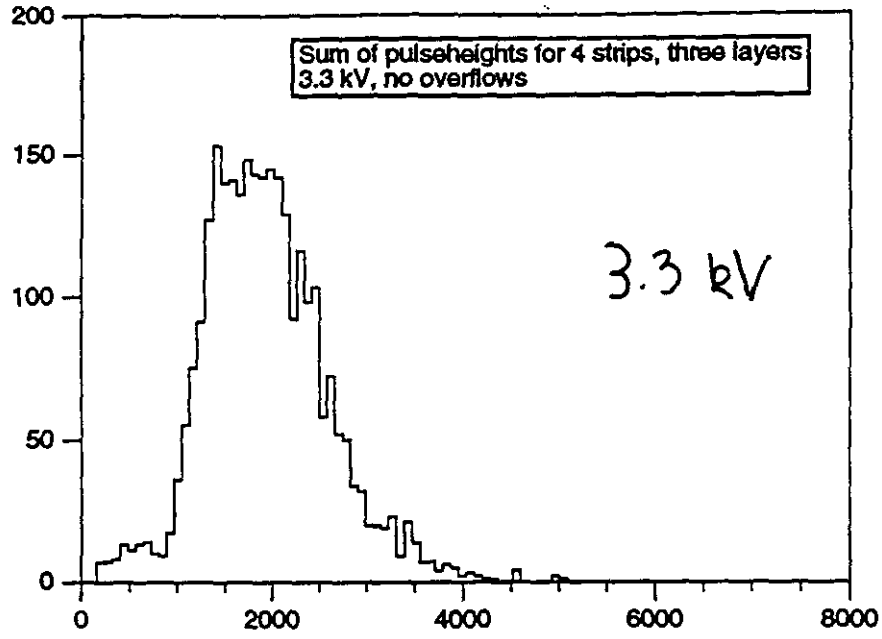
HV(kV)	$\sigma(\mu m)$
3.1	74.8 ± 3.9
3.2	72.0 ± 3.5
3.3	56.4 ± 2.0

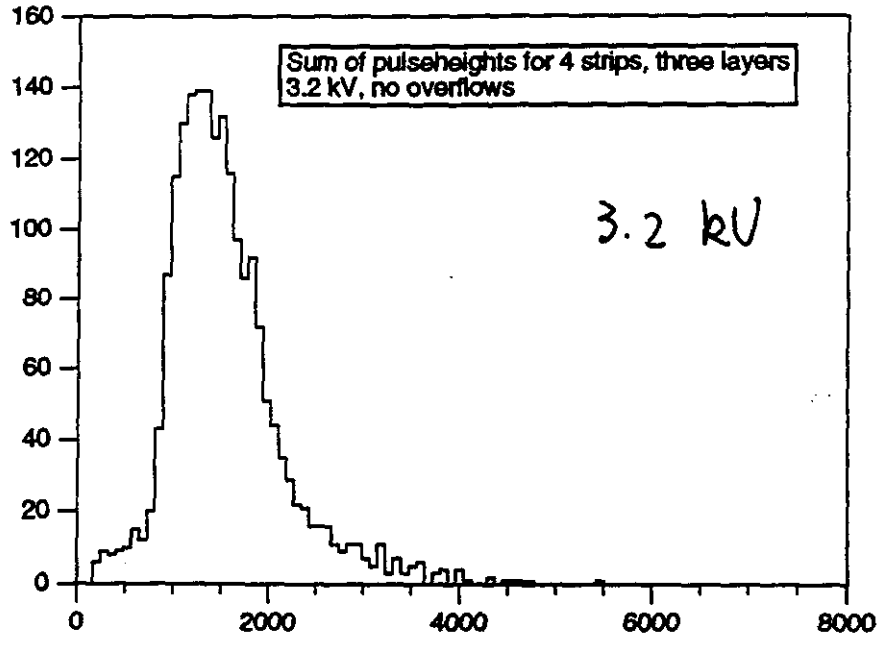
- Averaged over all angles $\pm \simeq 8°$

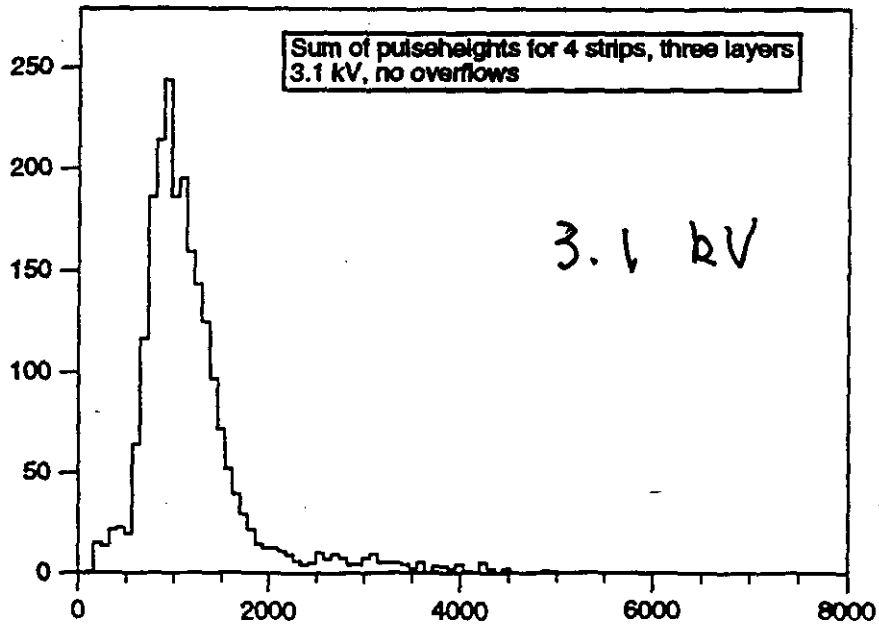
HV(kV)	$\sigma(\mu m)$
3.1	78.9 ± 3.6 (96.3)
3.2	73.2 ± 3.0
3.3	59.7 ± 1.9

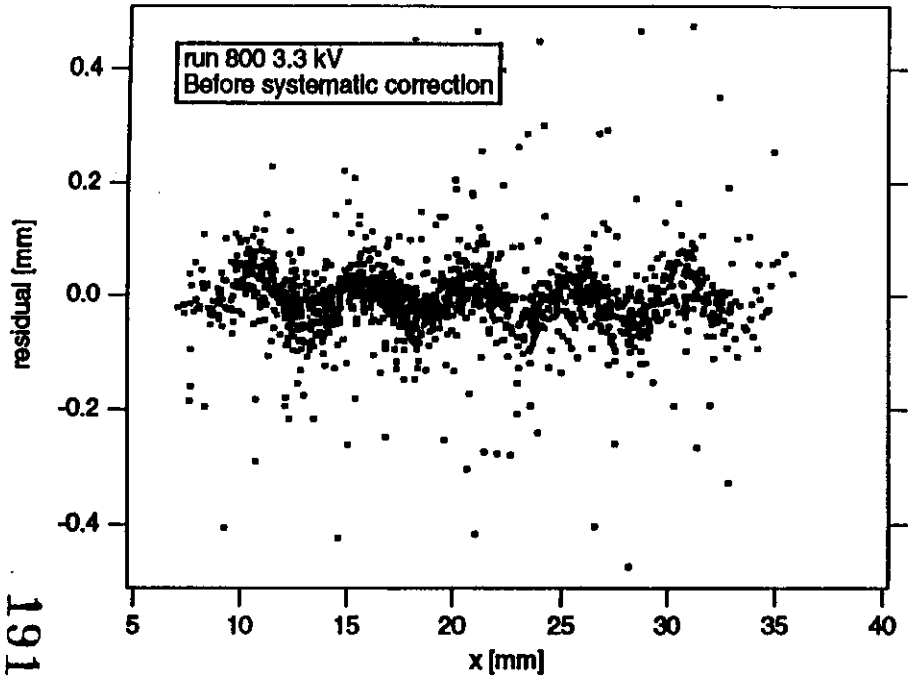
- Normal incidence $\pm$ 2.0°

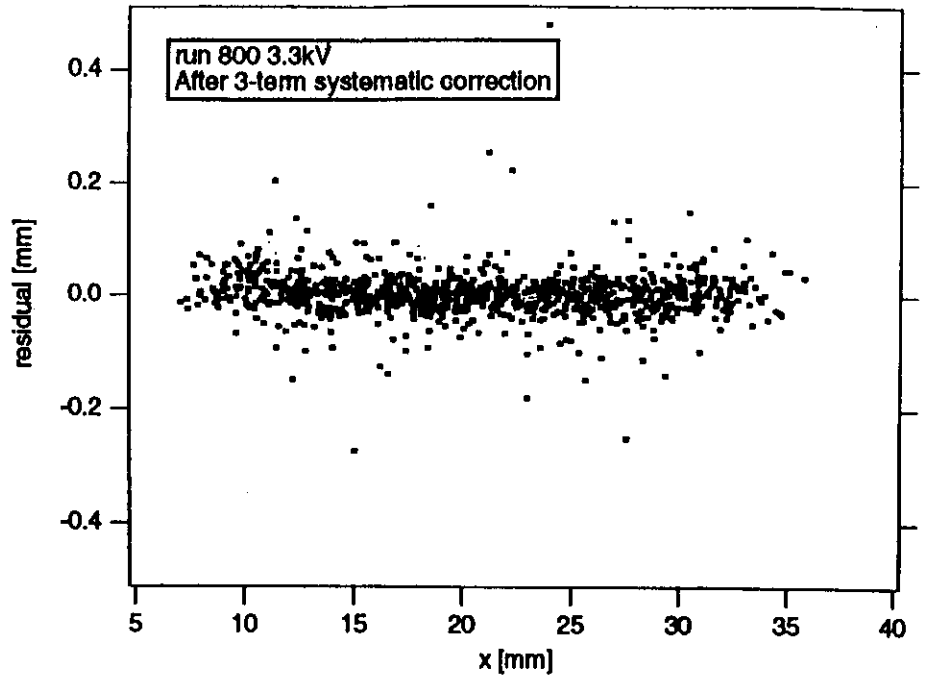
HV(kV)	$\sigma(\mu m)$
3.1	66.4 ± 10.7
3.2	62.8 ± 8.6
3.3	37.9 ± 3.0

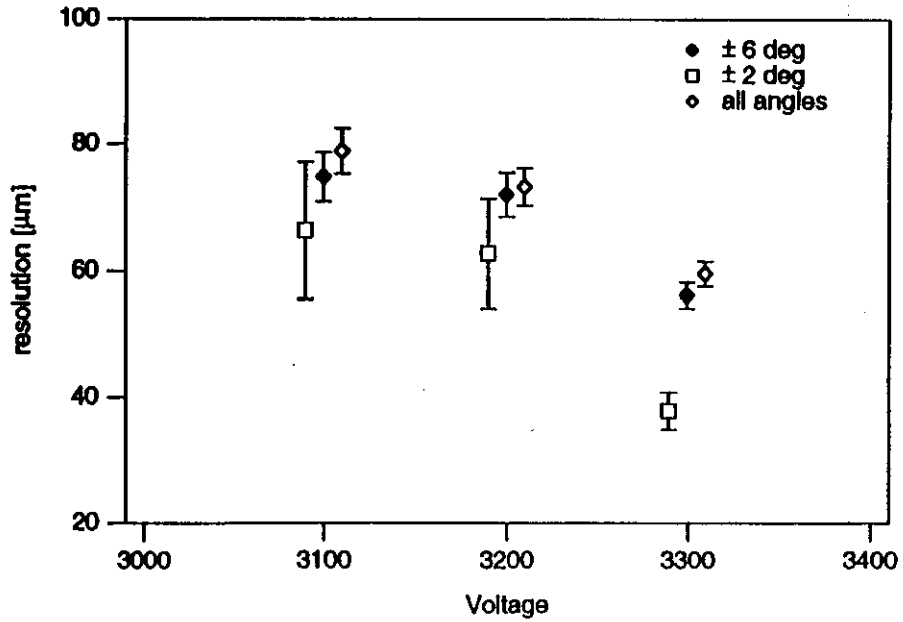

Sum of pulseheights for 4 strips, three layers
3.3 kV, no overflows
3.3 kV
200
150
100
50
0
0
2000
4000
6000
8000


Sum of pulseheights for 4 strips, three layers
3.2 kV, no overflows
3.2 kV
160
140
120
100
80
60
40
20
0
0
2000
4000
6000
8000


Sum of pulseheights for 4 strips, three layers
3.1 kV, no overflows
3.1 kV
250
200
150
100
50
0
0
2000
4000
6000
8000


run 800 3.3 kV
Before systematic correction
residual [mm]
x [mm]


run 800 3.3kV
After 3-term systematic correction
residual [mm]
x [mm]


± 6 deg
± 2 deg
all angles
resolution [μm]
Voltage

MPC, INC
Microwave Printed Circuitry
81 Old Ferry Road
Lowell, MA 01854
Phone: 508-452-9061 Fax: 508-441-0004

QUOTATION

Company: Institute for Beam Particle Dynamics
University of Houston

Attn: Kwong Lau Date: 12/17/92

PART NUMBER	QUANTITY	UNIT PRICE	NRE
Type A Board (size to be 3152 mm x 370 mm)	1024	$357.06	$525.00
Type B Board (size to be 3028 mm x 370 mm)	1024	357.06	525.00
Type C Board (size to be 2515 mm x 660 mm)	2048	387.02	575.00
Type D Board (size to be 3506 mm x 480 mm)	4096	378.04	575.00

Due to processing size restrictions, boards will be supplied in the sizes given above.

MPC to supply material.
Artwork to be supplied by the Institute as 1:1 positives.
Delivery: Initial delivery - 10 weeks ARO and artwork
Delivery rate to be mutually agreed upon.
Terms: 1-10, N30 F.O.B.: Lowell, MA
Quotation is budgetary pending review of final drawings and requirements.

If you need additional information, please contact the undersigned.

Best Regards,

Bob Deitz

Performance (extrapolated to full-sized supermodules)

- Strip precision
  - Bids with same precision for 3.0 m x 0.6 m @ \$ 250-300 /m^2 : expect comparable precision

- Spatial resolution
  - $\simeq$ 3 times increase in strip capacitance can be offset by (i) reducing the strip dielectric constant from 4 to 1.5 or/and (ii) reduce electronic noise or/and (iii) reduce the integration time from 500 ns to 300 ns or/and (iv) increase gas gain
- Timing resolution
  - monte carlo predicts $\leq$ 2 % loss for 8 layers of 1 cm cells (GEM TN-92-227)
  - calculation and measurement for 6 layers of 9 mm cells in progress

Chamber Production

- Strips from US or foreign suppliers
- Honeycomb panels from US suppliers
- Chambers from US and/or foreign Labs and/or commercial suppliers
  - Labs : SCARF (US), DUBNA(FSU), CHINA
  - Commerical : Hodotector (US), Pol Hi Tech (Italy).
- Assemble and test chambers in a 'factory' to be located near SSCL

  Procedure
  - receive and inspect strips and honeycomb panels from suppliers
  - epoxy strip boards to honeycomb panels (uncritical: $\pm$ 0.5 mm)
  - mount chambers on panels (uncritical $\pm$ 0.5 mm)
  - align all layers (critical : $\pm$ 25 μm)
  - install utilities (gas, LV, HV etc.)
  - test
  - ship to GEM

  Resources for assembly
  - Space : 10,000 sq ft
  - labor : $\simeq$ 25 hrs per supermodule
  - Special tooling for inter-layer alignment

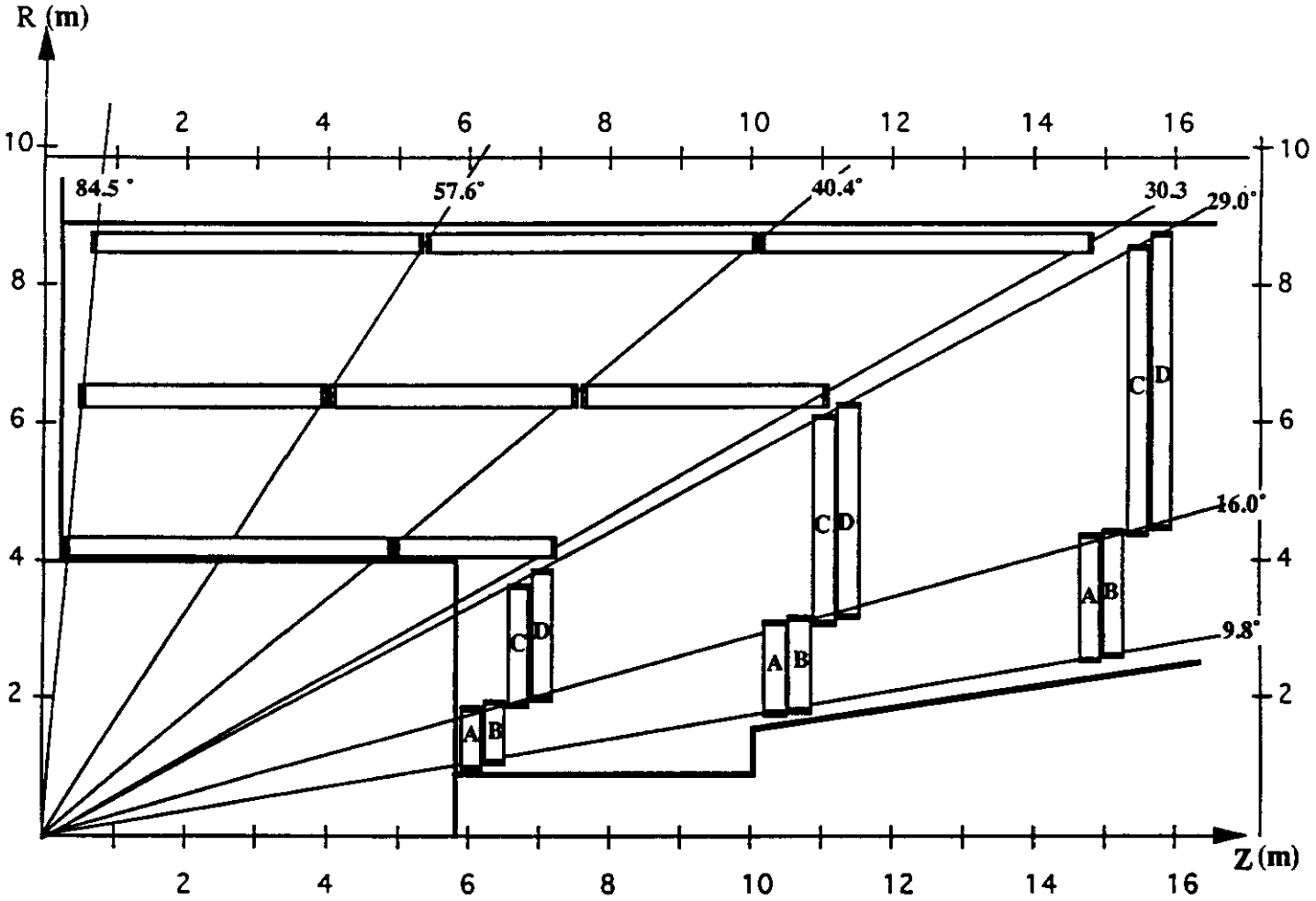
  Throughput
  - about 1 supermodule per day : parallel processing for faster production

The RDT System Layout

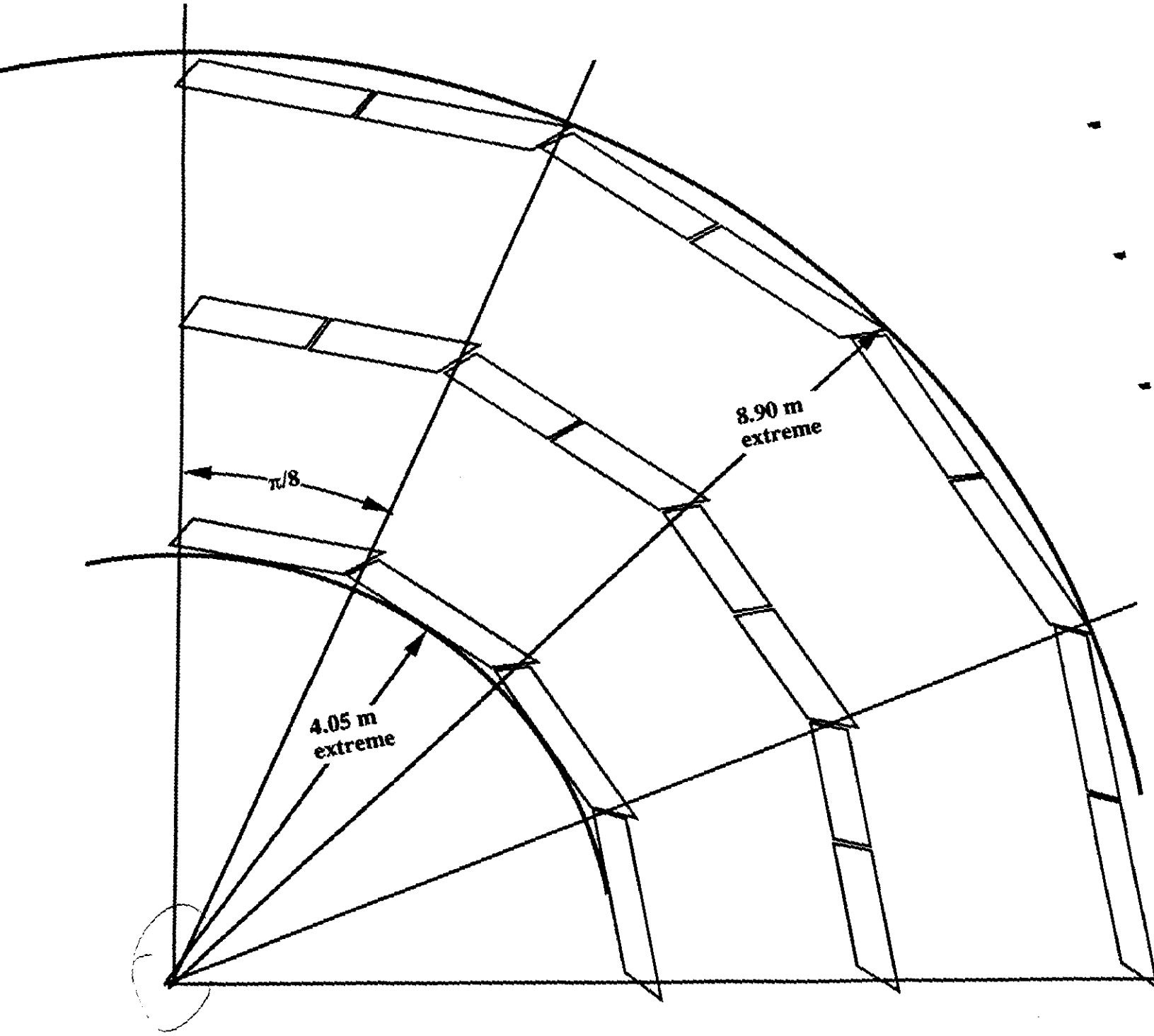
Presentation by:

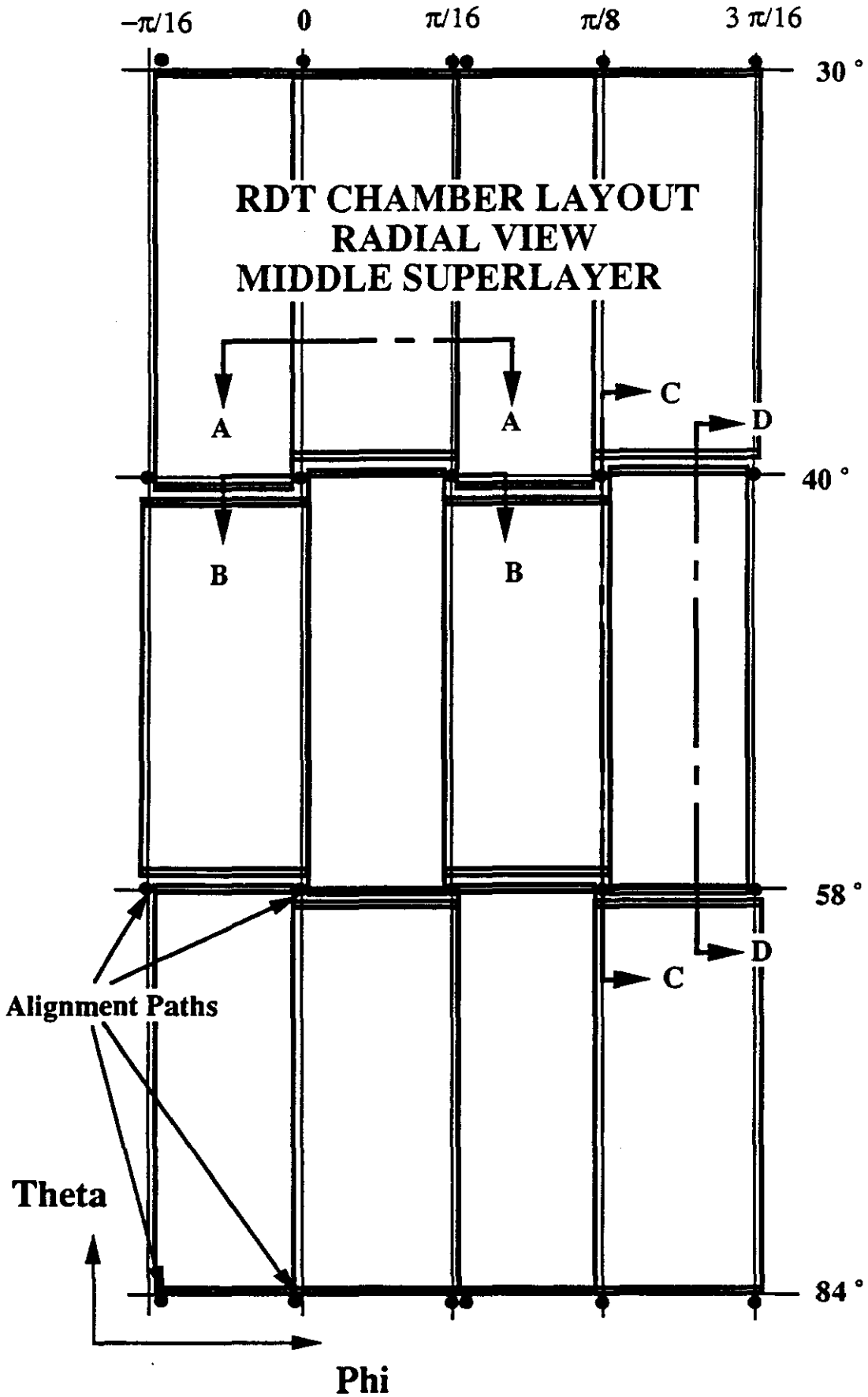
R. Miller

RDT QUADRANT LAYOUT
ELEVATION VIEW

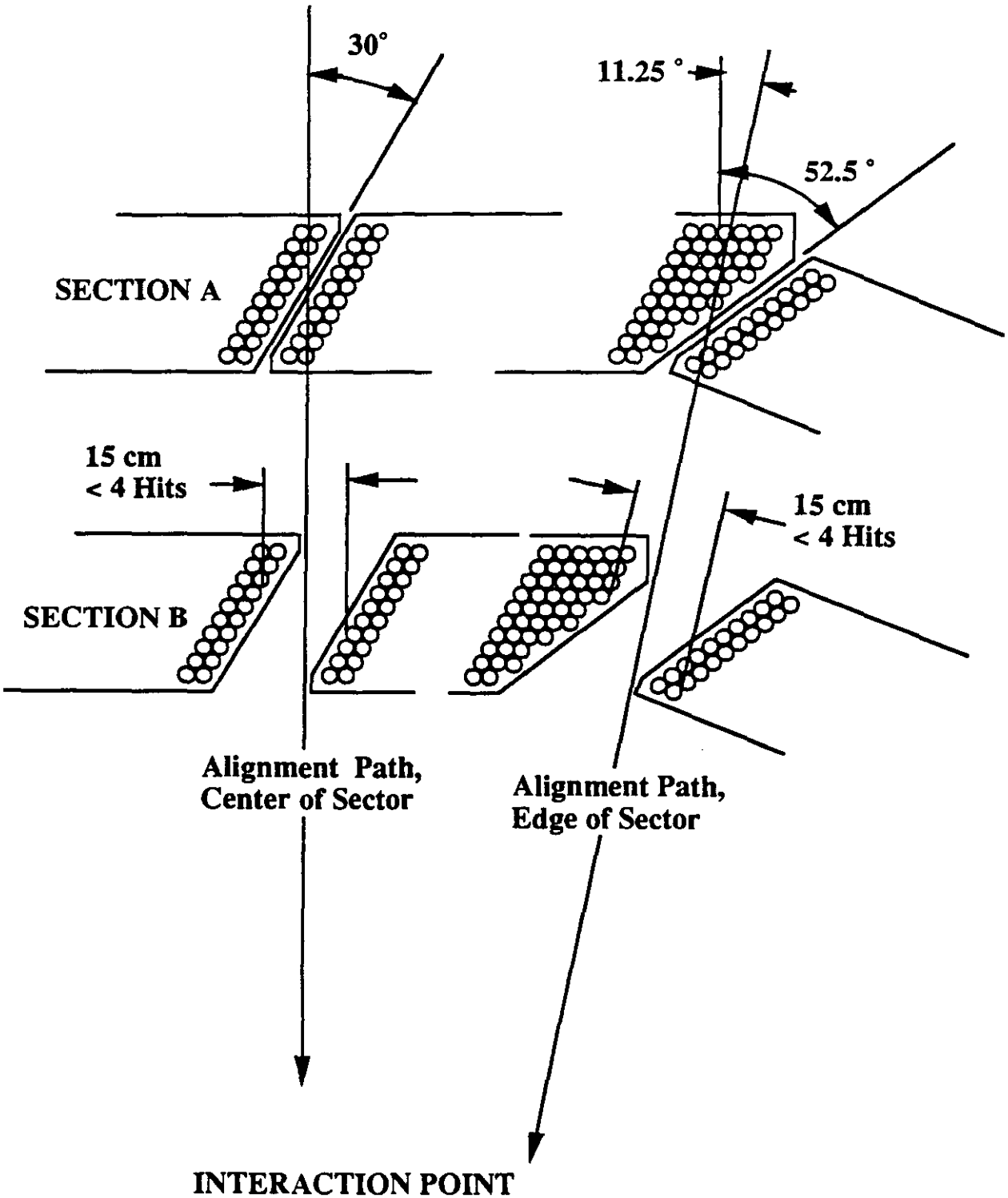


RDT BARREL QUADRANT AXIAL VIEW

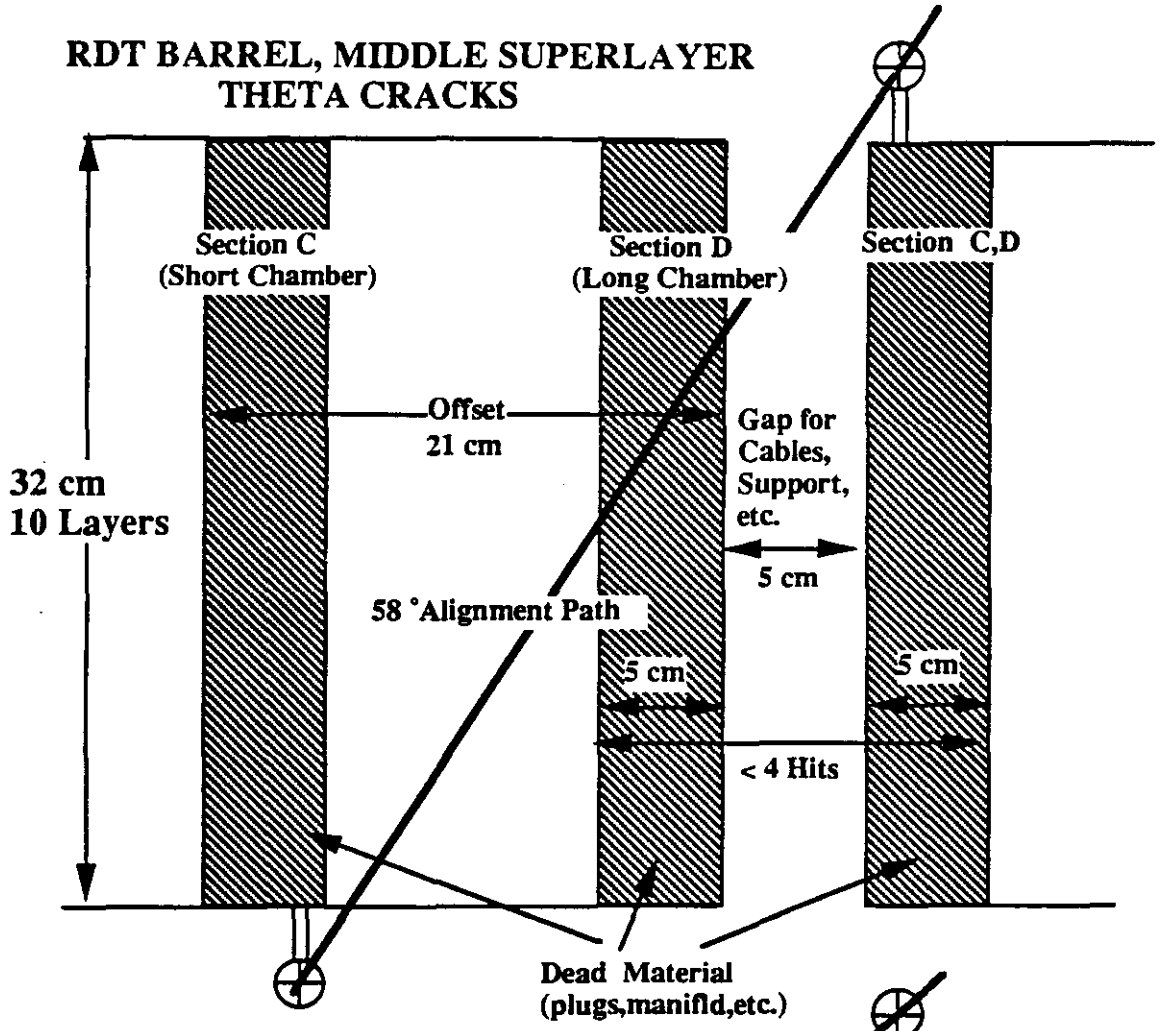


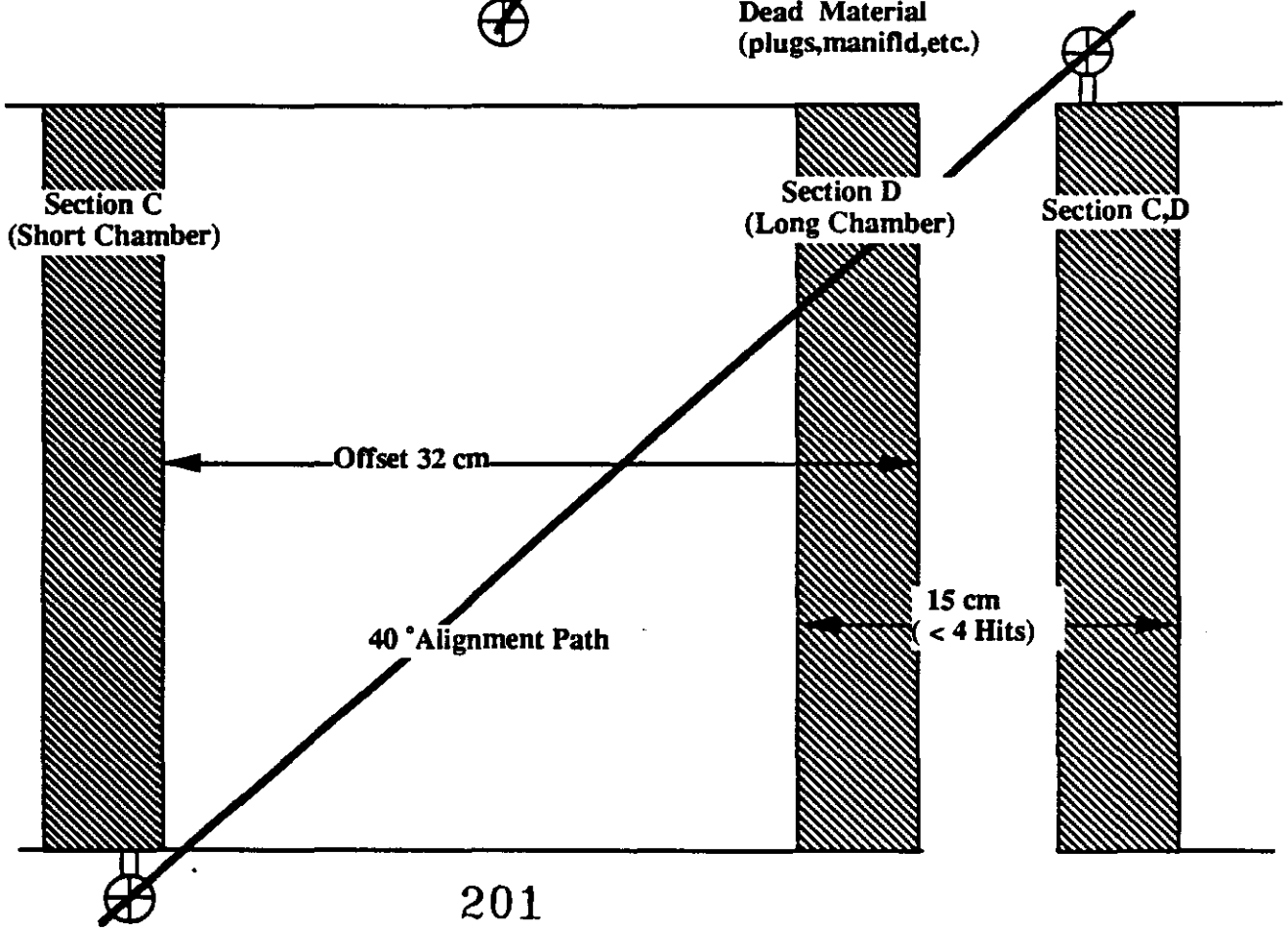

−π/16
0
π/16
π/8
3 π/16
30 °
RDT CHAMBER LAYOUT
RADIAL VIEW
MIDDLE SUPERLAYER
A
A
C
D
40 °
B
B
58 °
D
C
Alignment Paths
Theta
84 °
Phi

RDT BARREL, MIDDLE SUPERLAYER
PHI OVERLAP DETAIL

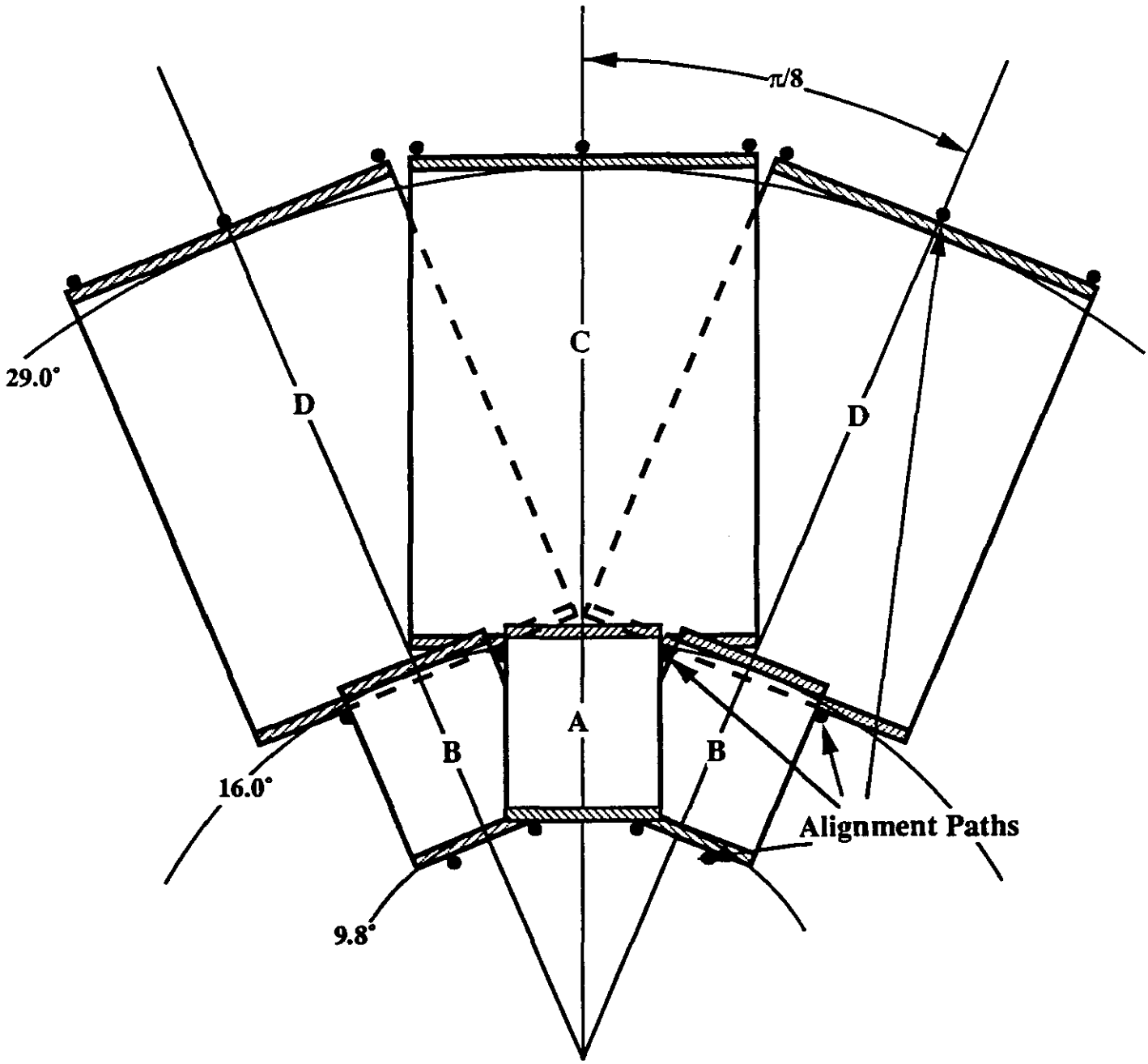


RDT BARREL, MIDDLE SUPERLAYER
THETA CRACKS





RDT ENDCAP LAYOUT
PROJECTIVE VIEW



GEM BARREL RDT CHAMBER SPECS
16 SECTORS; 8+10+8; 25 mm Dia.

INPUT PARAMETERS:

Theta angular coverage :	84.5	30.3
Tube Material, density:	Alum.	2.7
Tube Wall: (mm)	0.30	
Plate Thickness (mm), density:	19.05	2.7
Case Thickness (mm), density:	6.40	0.25
# of Segments:	16	

VARIABLES:

Radius (m):	4.2	6.4	8.6	TOTAL
Chambers/Theta	2	3	3	
Chambers/segmnt	1	2	2	
# of Layers:	8	10	8	26
Tube Dia: (mm)	25.4	25.4	25.4	

RESULTS:

Tube Length: (m)	3.4	3.4	4.6	909 km
Tubes/Chamber:	512	496	528	
Avg. width: (m)	1.67	1.26	1.69	
Chamb. thick.: (m)	0.28	0.32	0.28	
Chambers/Half:	32	96	96	224
Chambers Total	64	192	192	448
Tubes/Half:	16384	47616	50688	114688
Tubes Total	32768	95232	101376	229376

Weight/chamber (lb)

Tubes:	247	243	348	
Manifold plates:	105	92	106	
Plugs:	57	55	59	
Case:	50	41	68	
Electronics,cable:	256	248	264	
Total/Chamber:	715	679	844	
Weight/Segment:	1429	4075	5066	
Weight/Half:	22867	65208	81051	85 ton
Weight Total	45733	130415	162102	169 ton

GEM END CAP RDT CHAMBERS
16 SECTORS; 8-10-8; 25 mm Dia.

INPUT PARAMETERS:

Tube Material, density:	Alum.	2.7
Tube Wall: (mm)	0.30	
M. Plate Thickness (mm), de	19.05	2.7
Case Thickness (mm), densit	6.40	0.25
# of Sectors:	16	

VARIABLES:

Avg. Z (m):	6.25	6.85	11.20	10.60	15.60	15.00	Total
Inner Theta	9.8	16.0	16.0	9.8	16.0	9.8	
Outer Theta	16.0	29.0	29.0	16.0	29.0	16.0	
Chambers/segmnt:	1	1	1	1	1	1	
# of Layers:	8	8	10	10	8	8	26
Tube Dia: (mm)	25.4	25.4	25.4	25.4	25.4	25.4	

RESULTS:

Tube Length: (m)	0.7	1.8	3.0	1.2	4.2	1.7	314 km
Tubes/Chamber:	224	464	960	464	1072	528	
Chamb. width: (m)	0.71	1.51	2.47	1.21	3.44	1.71	
Chamb. thick.: (m)	0.28	0.28	0.32	0.32	0.28	0.28	
Chambers/Half:	16	16	16	16	16	16	96
Chambers Total	32	32	32	32	32	32	192
Tubes/Half:	3584	7424	15360	7424	17152	8448	59392
Tubes Total	7168	14848	30720	14848	34304	16896	118784

Weight/chamber (lb)							
Tubes:	23	121	409	80	636	128	
Manifold plates:	45	95	179	88	215	107	
Plugs:	25	52	107	52	120	59	
Case:	6	26	64	16	116	27	
Electronics,cable:	112	232	480	232	536	264	
Total/Chamber:	211	525	1240	467	1624	586	
Weight/Half:	3372	8407	19844	7475	25976	9374	37 ton
Weight Total	6744	16814	39689	14951	51953	18748	74 ton

RDT MUON ACCEPTANCE LOSSES

SOURCE	Crack Size (mm)	R, Z (mm)	Θ (degree)	Δ(Θ) (radian)	η	Φ/2π	LOSS (% 4π)	LOSS Δ(η)
Central Membrane	250	4000	86.4	.0623	.063	1.00	6.2%	.063
Barrel-Endcap			30.0	.0262	1.317	1.00	1.3%	.052
Forward Region			8.7	.1518	2.576	1.00	2.3%	-
					Base Loss		**9.8%**	**.115**
Chamber End	100	4000	84.5	.0248	.096	1.00	2.5%	.025
Chamber Ends	150	6000	57.6	.0178	.598	1.00	1.5%	.021
Alignment Path	360	6400	57.6	.0401	.598	0.13	0.4%	.006
Chamber Ends	150	4000	40.4	.0158	1.000	1.00	1.0%	.024
Alignment Path	470	6400	40.4	.0308	1.000	0.13	0.3%	.006
Alignment Path	125	6000	16.0	.0193	1.962	0.04	0.0%	.003
Chamber End	100	6000	9.8	.0162	2.457	1.00	0.3%	.095
					Additional Loss		**6.0%**	**.181**

The RPC Chamber Construction and Tests

Presentation by:

R. Bionta

Large Plastic RPCs

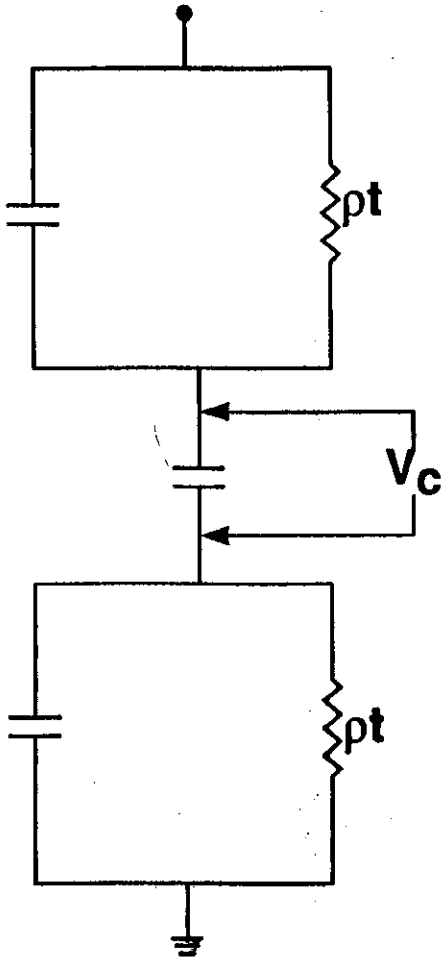
SSC Laboratory

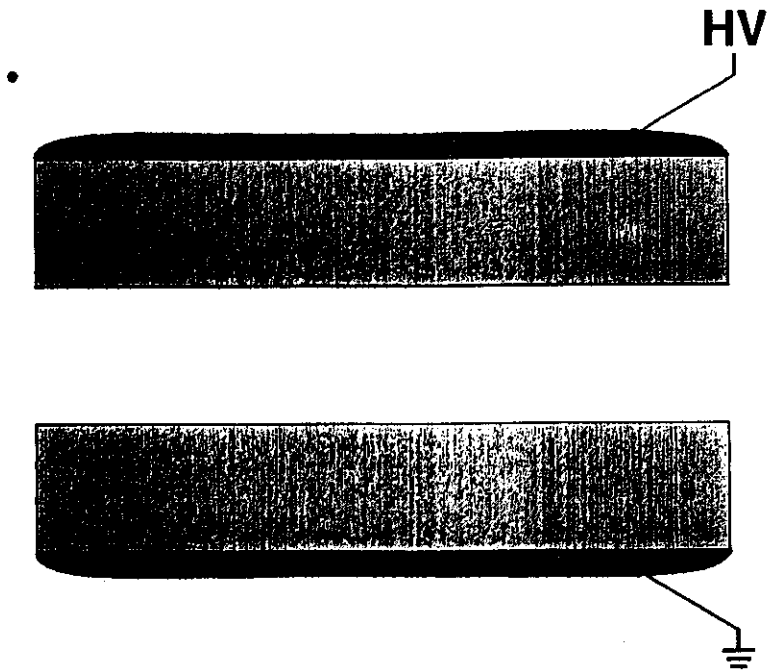
January 18-19, 1993

Lawrence Livermore National Laboratory

Presented By
Richard M. Bionta
(510) 423-4846

Spice RPC Model





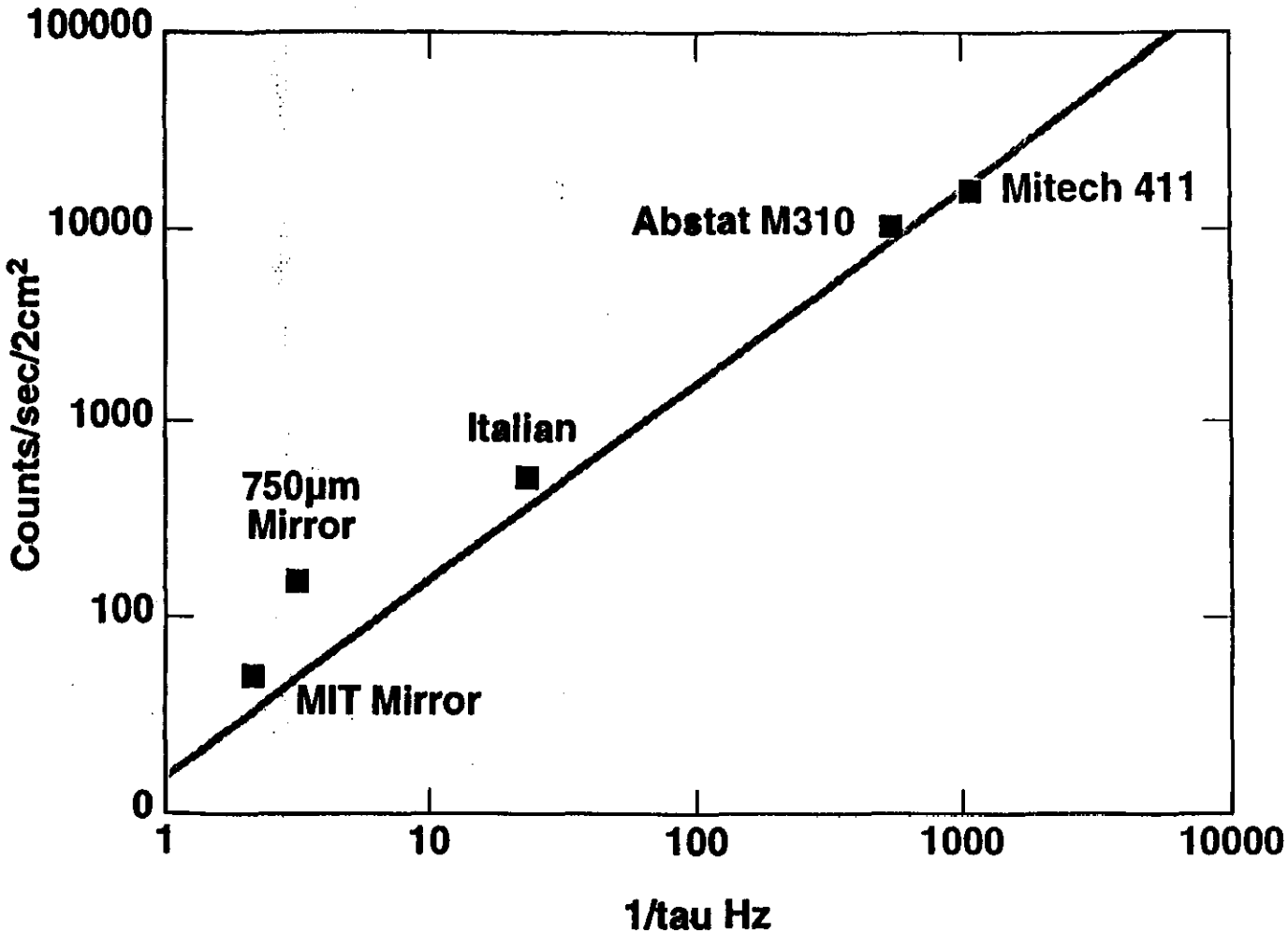
BAK.KA-01/RMB

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}

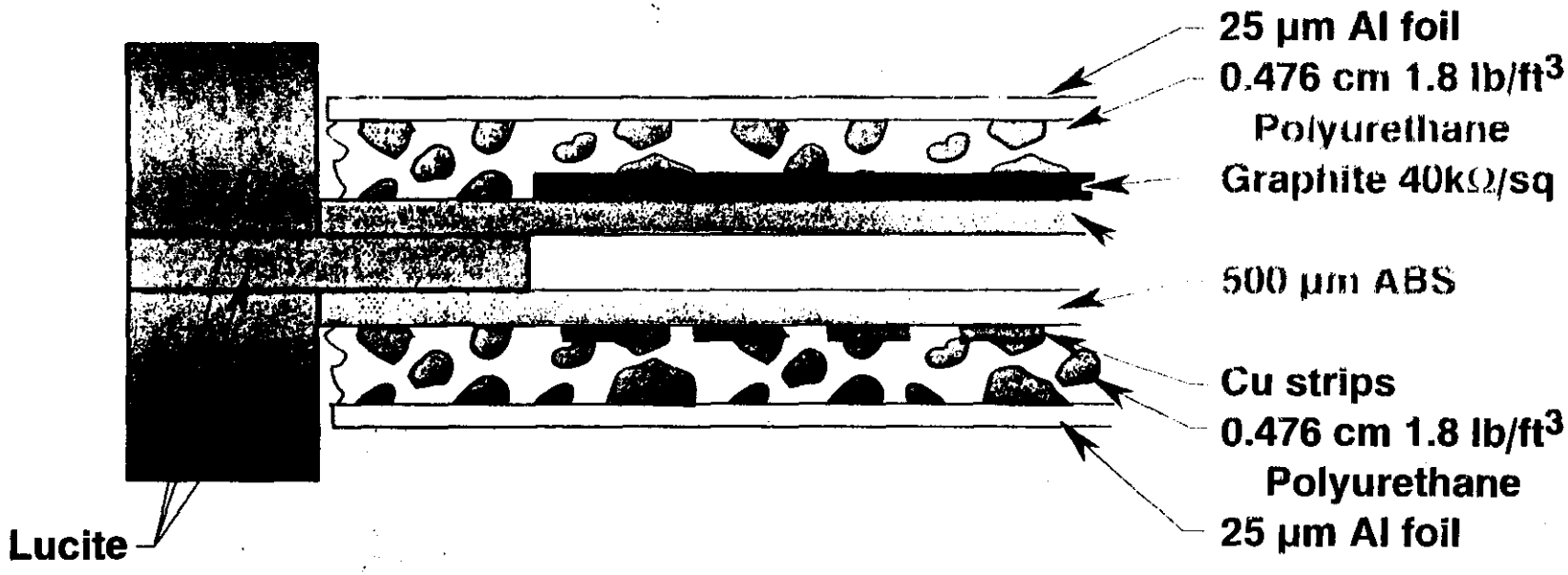
BAK.KA-14/RMB

Saturated Singles Rate vs SPICE 1/tau



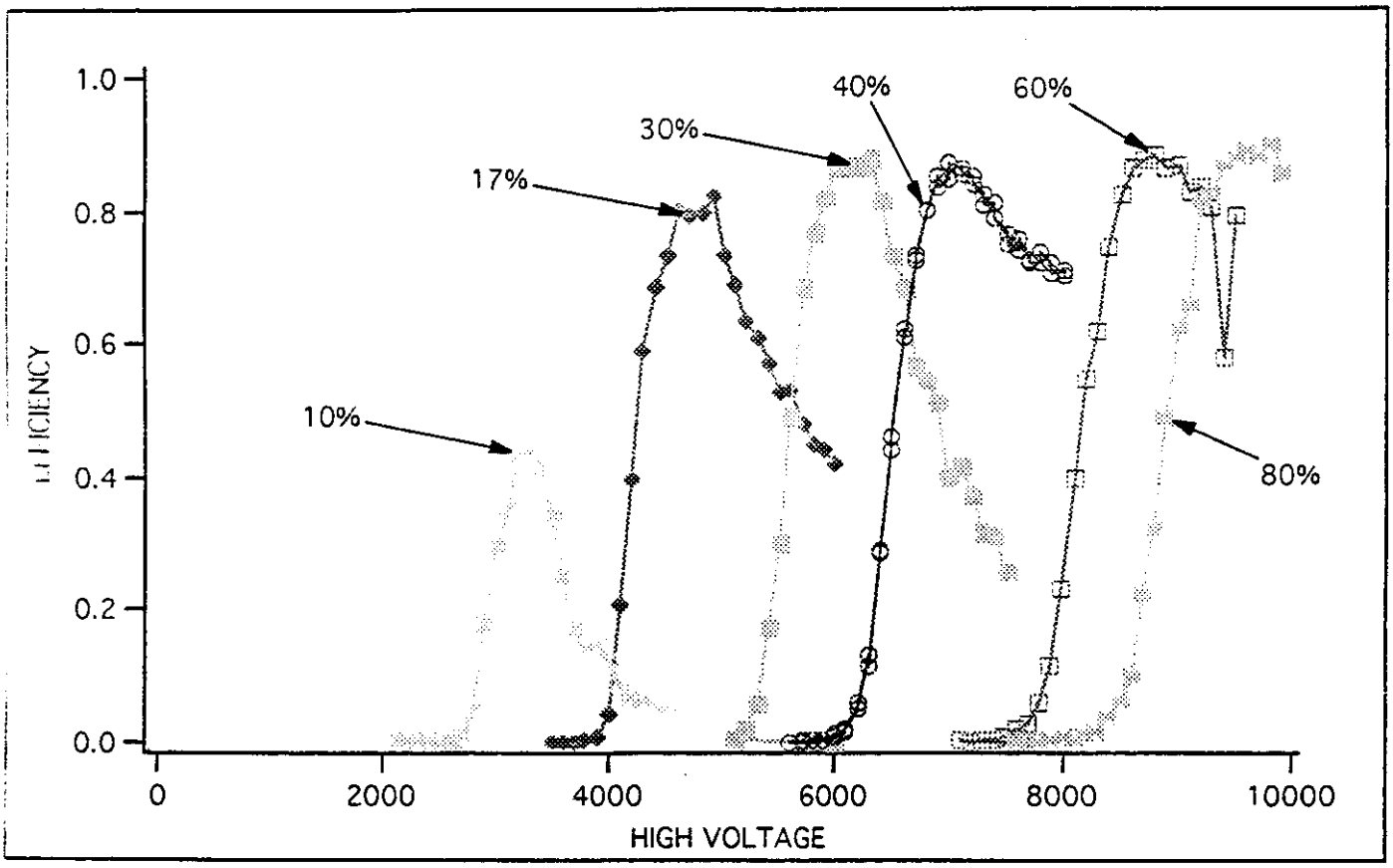
BAK.KA-17/RMB

1D RPC

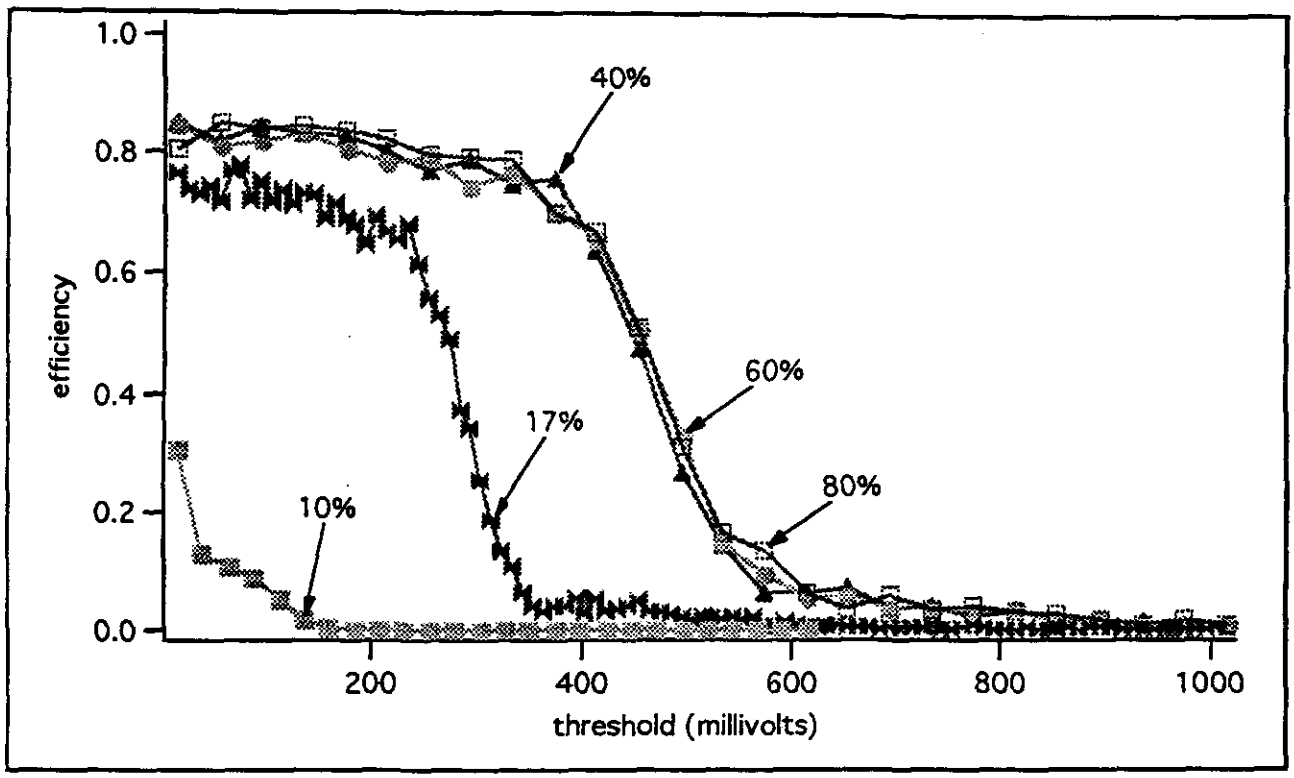


CAK.KG-01/RMB

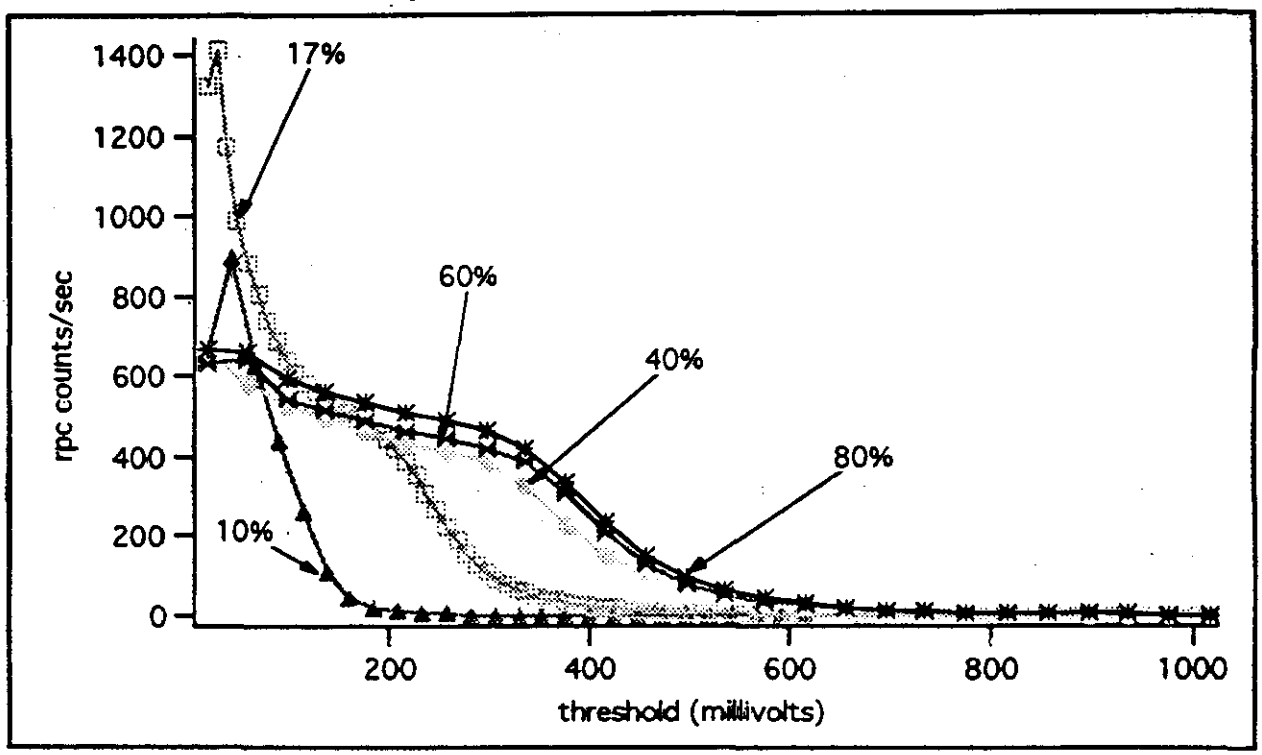
EFFICIENCY PLATEAU FOR DIFFERENT ISOBUTANE CONCENTRATIONS



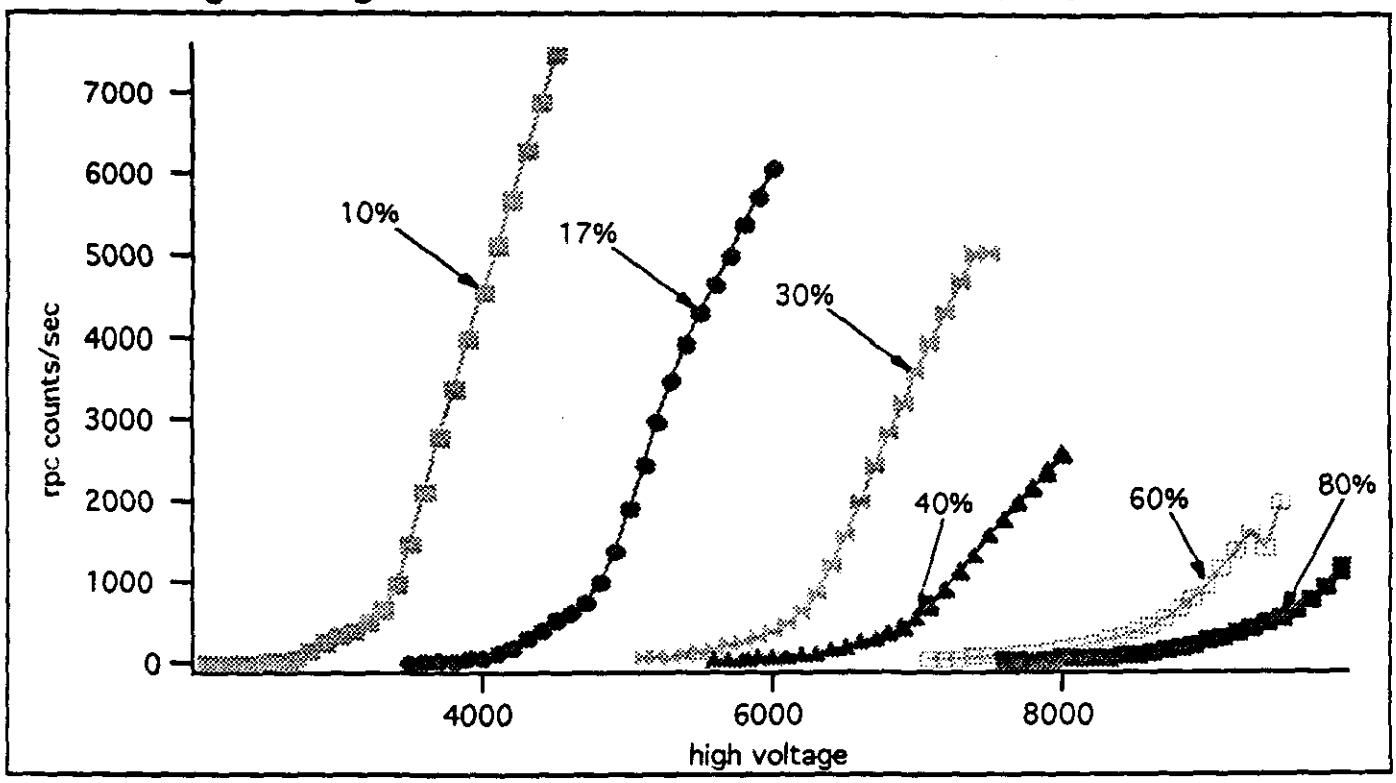
Efficiency vs threshold voltage for various isobutane concentrations



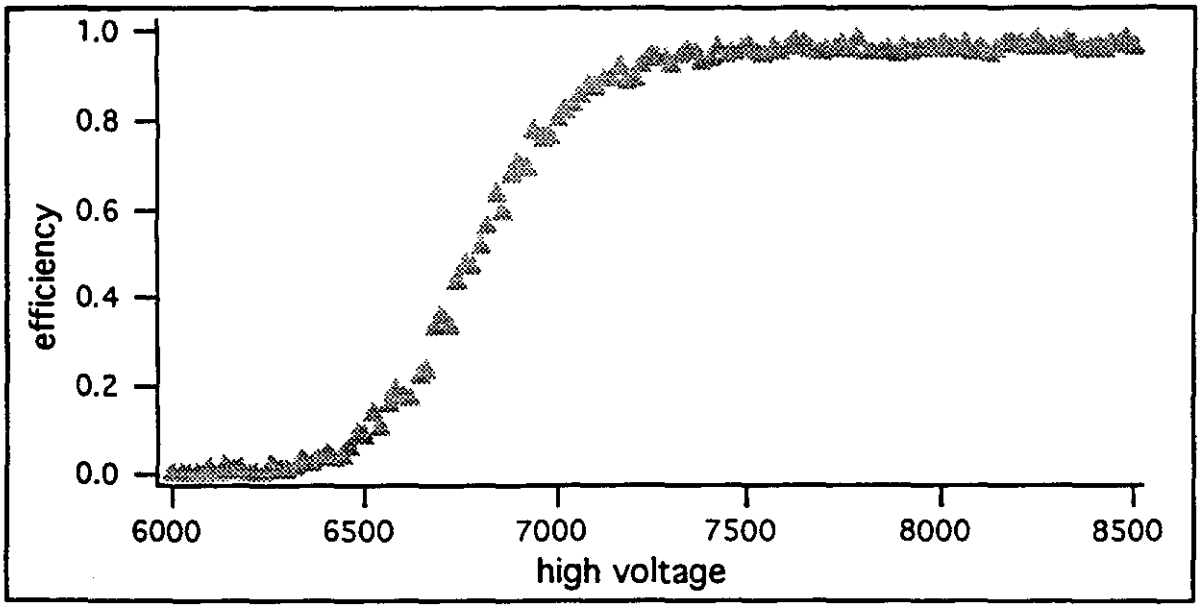
Noise vs threshold voltage for various isobutane concentrations



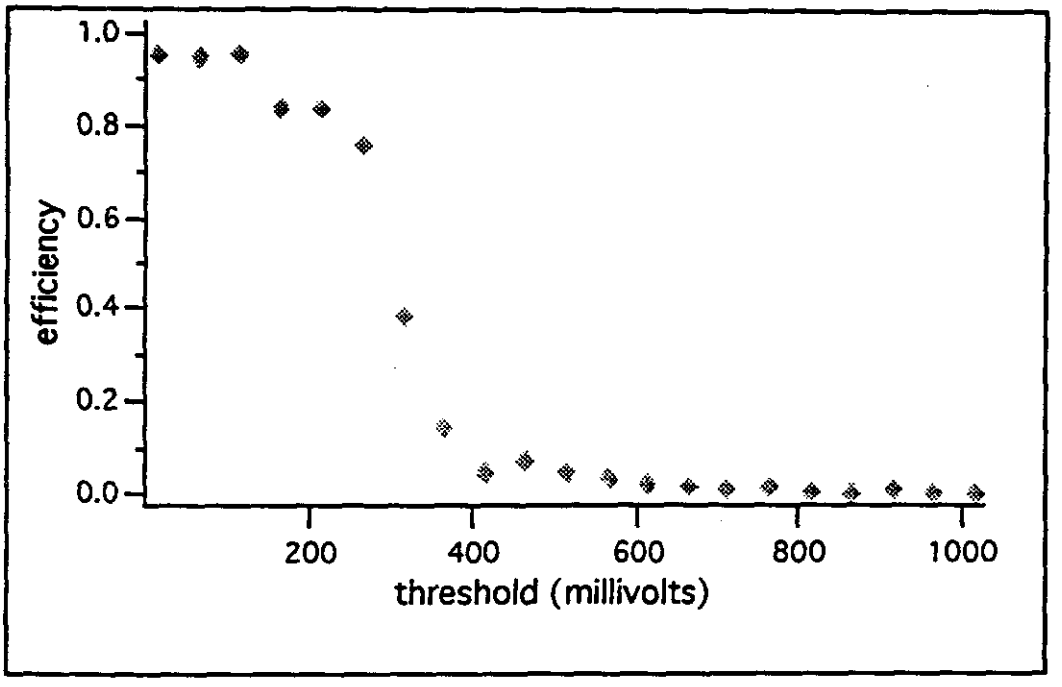
Noise vs high voltage for various isobutane concentrations

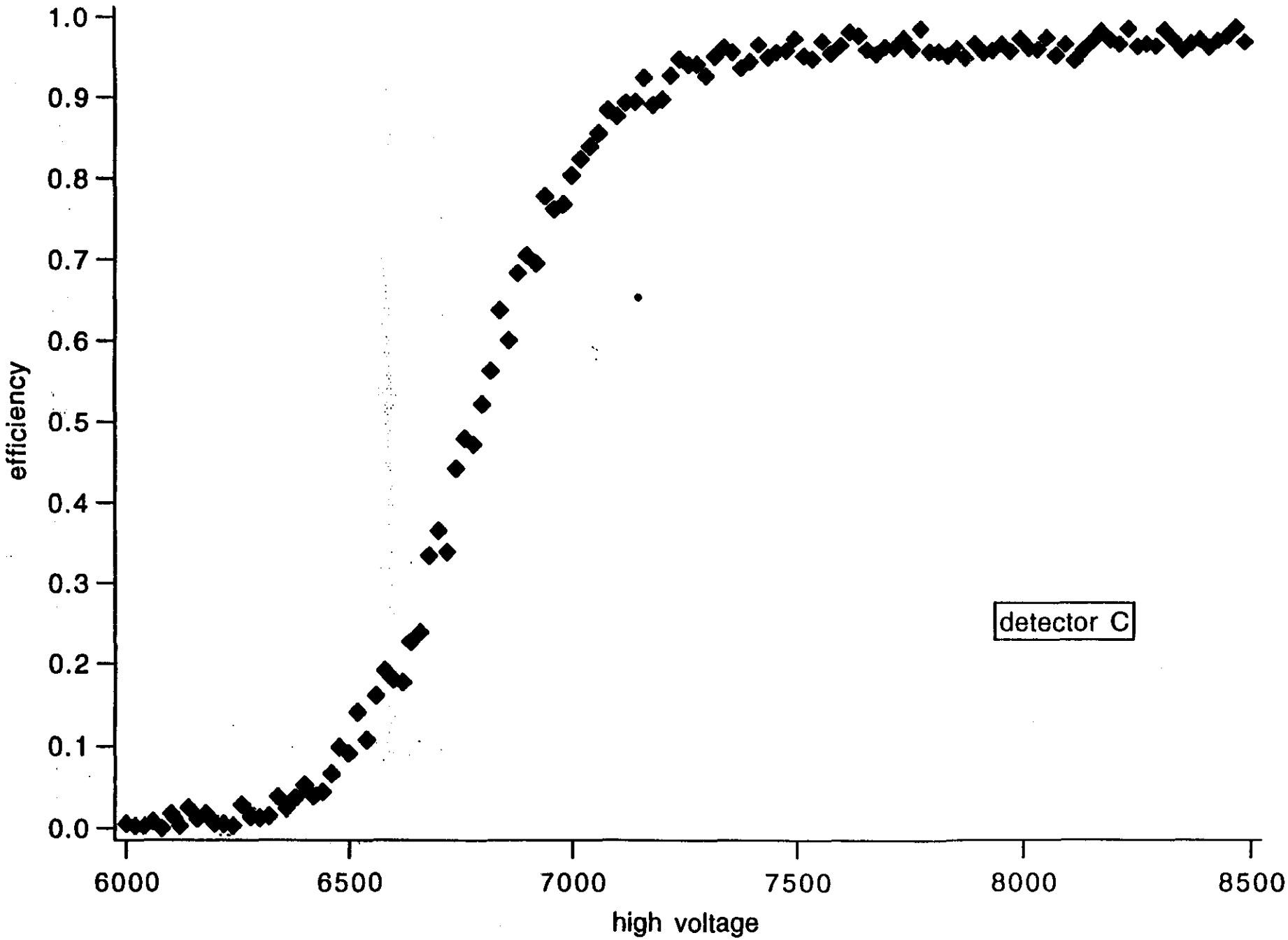


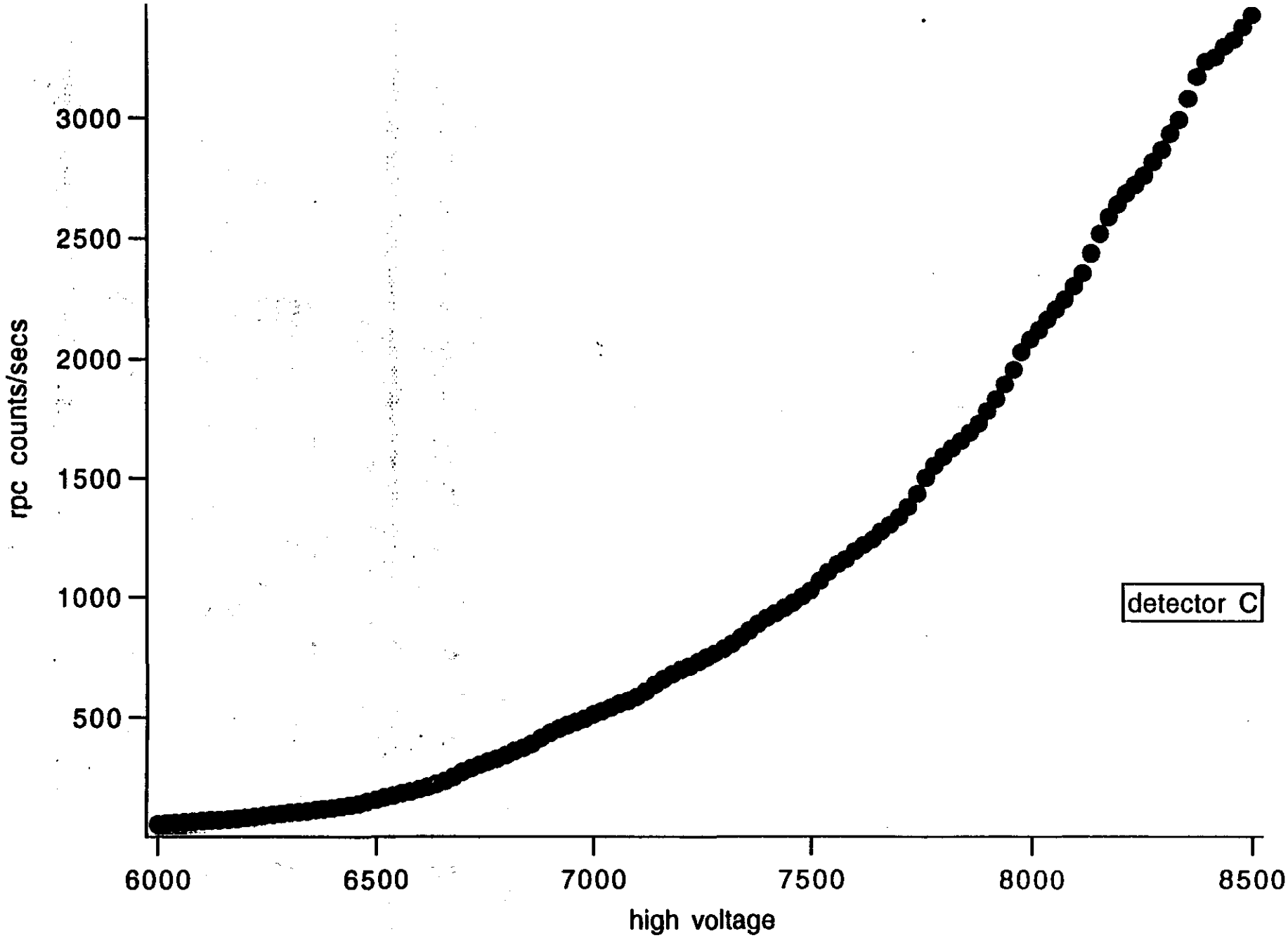
Efficiency curve for 40% isobutane, 2.5% freon 13B1

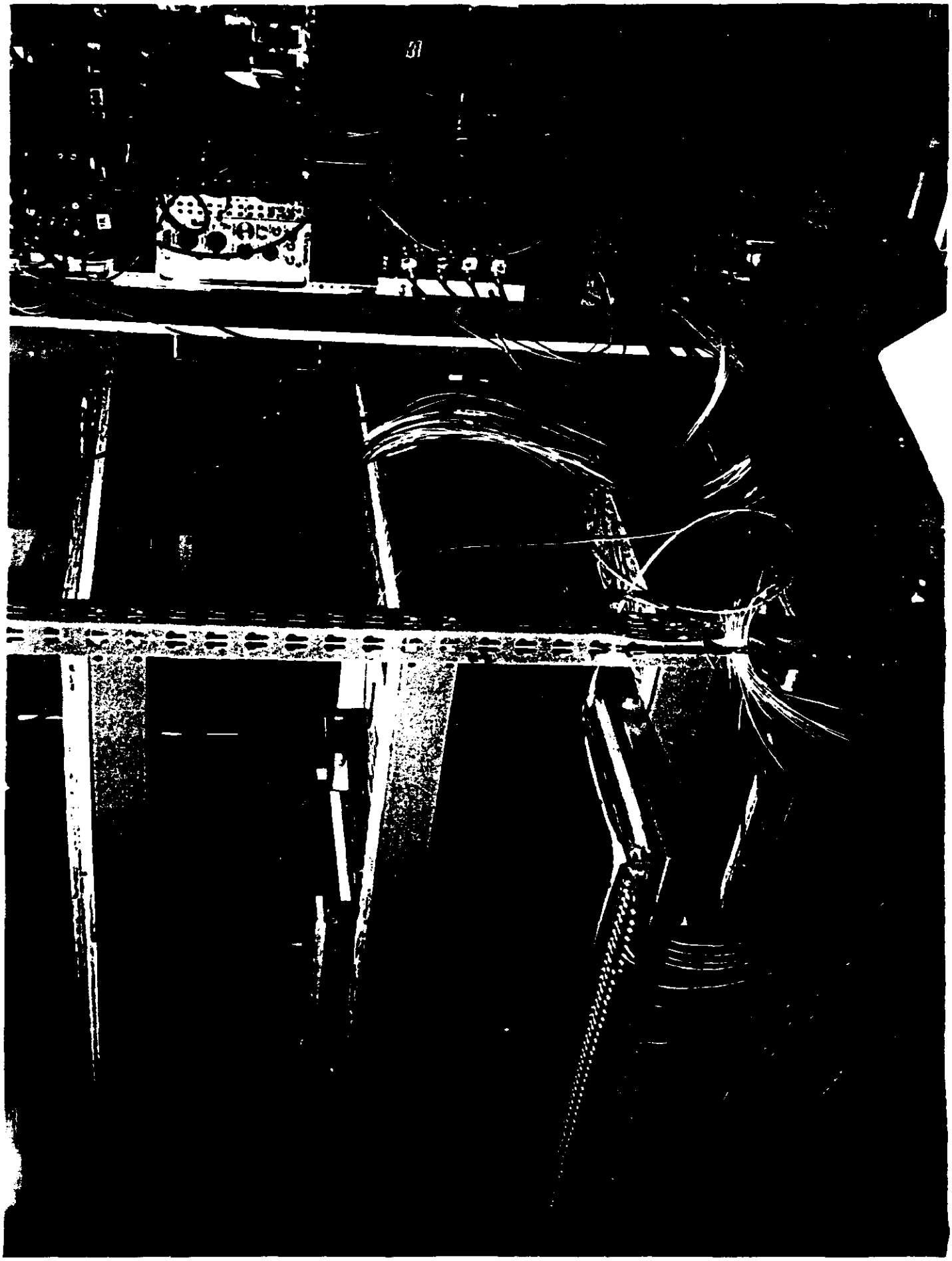


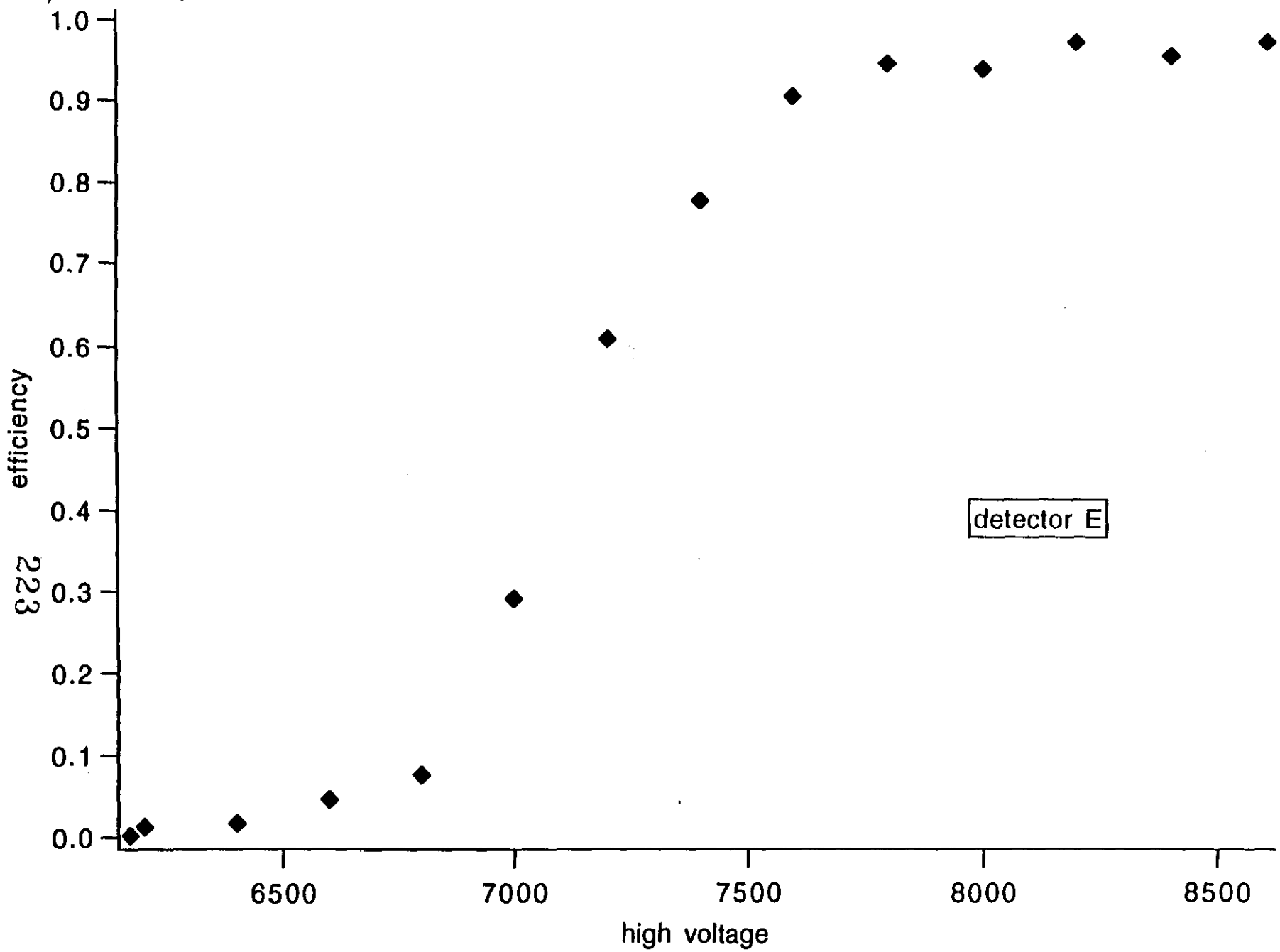
Efficiency vs threshold for 40% Isobutane, 2.5% freon 13B1

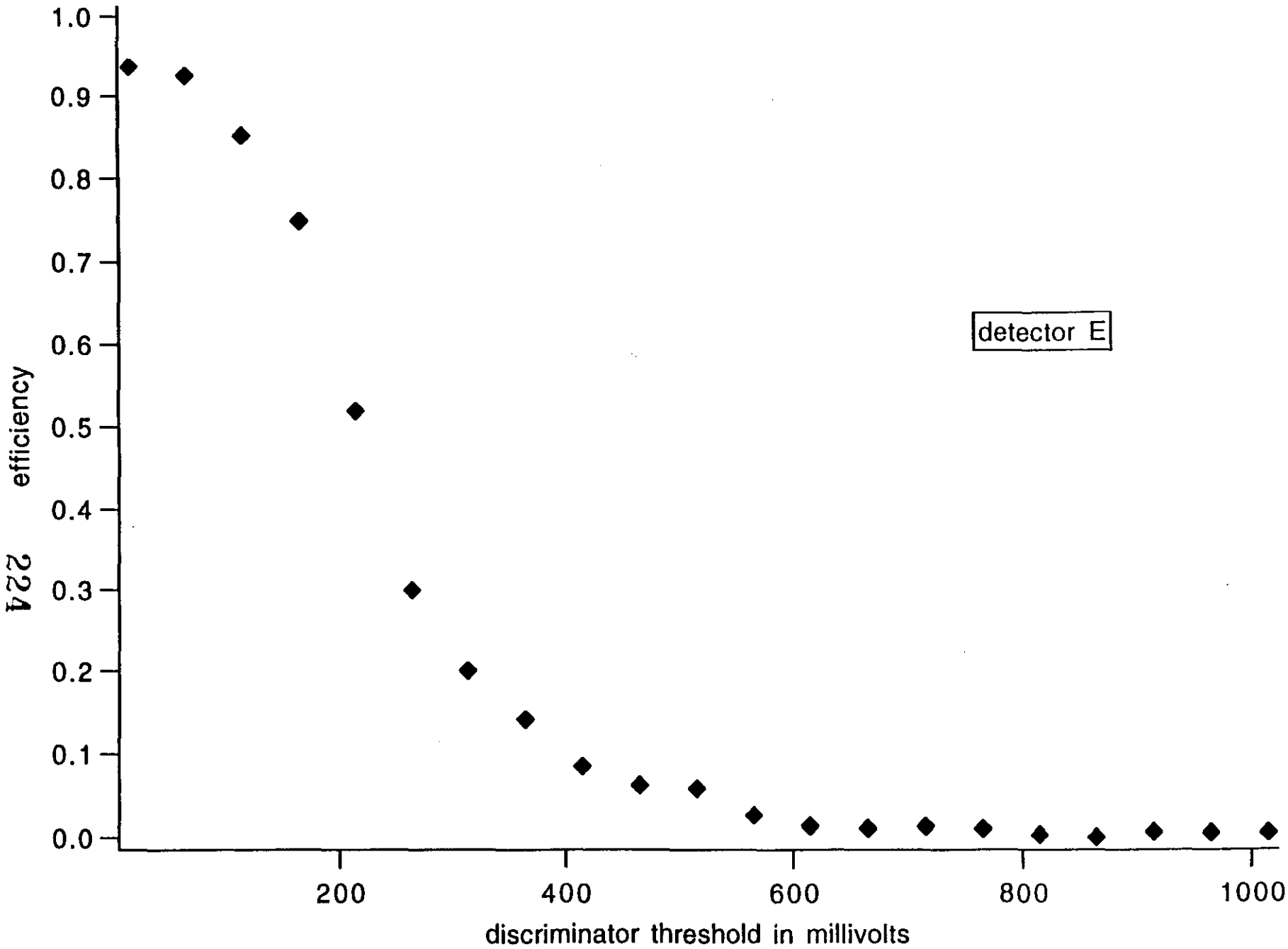



1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
efficiency
6000
6500
7000
7500
8000
8500
high voltage
detector C

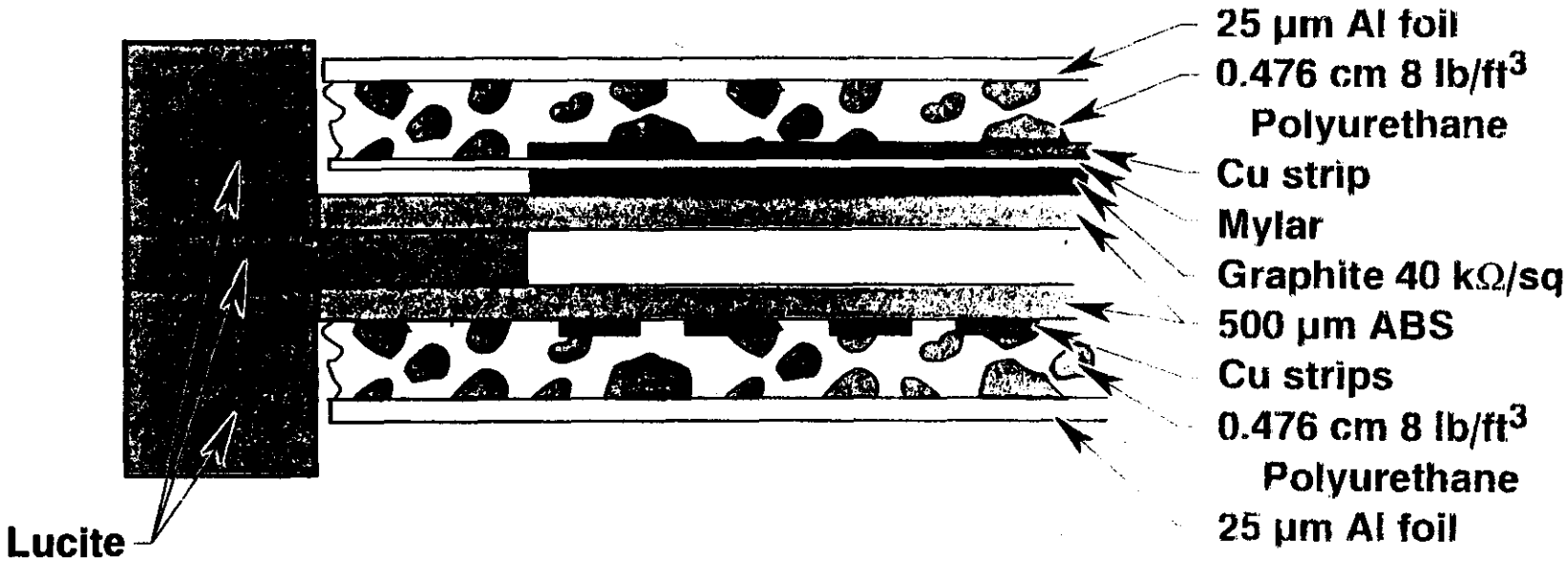

3000
2500
2000
1500
1000
500
rpc counts/secs
6000
6500
7000
7500
8000
8500
high voltage
detector C

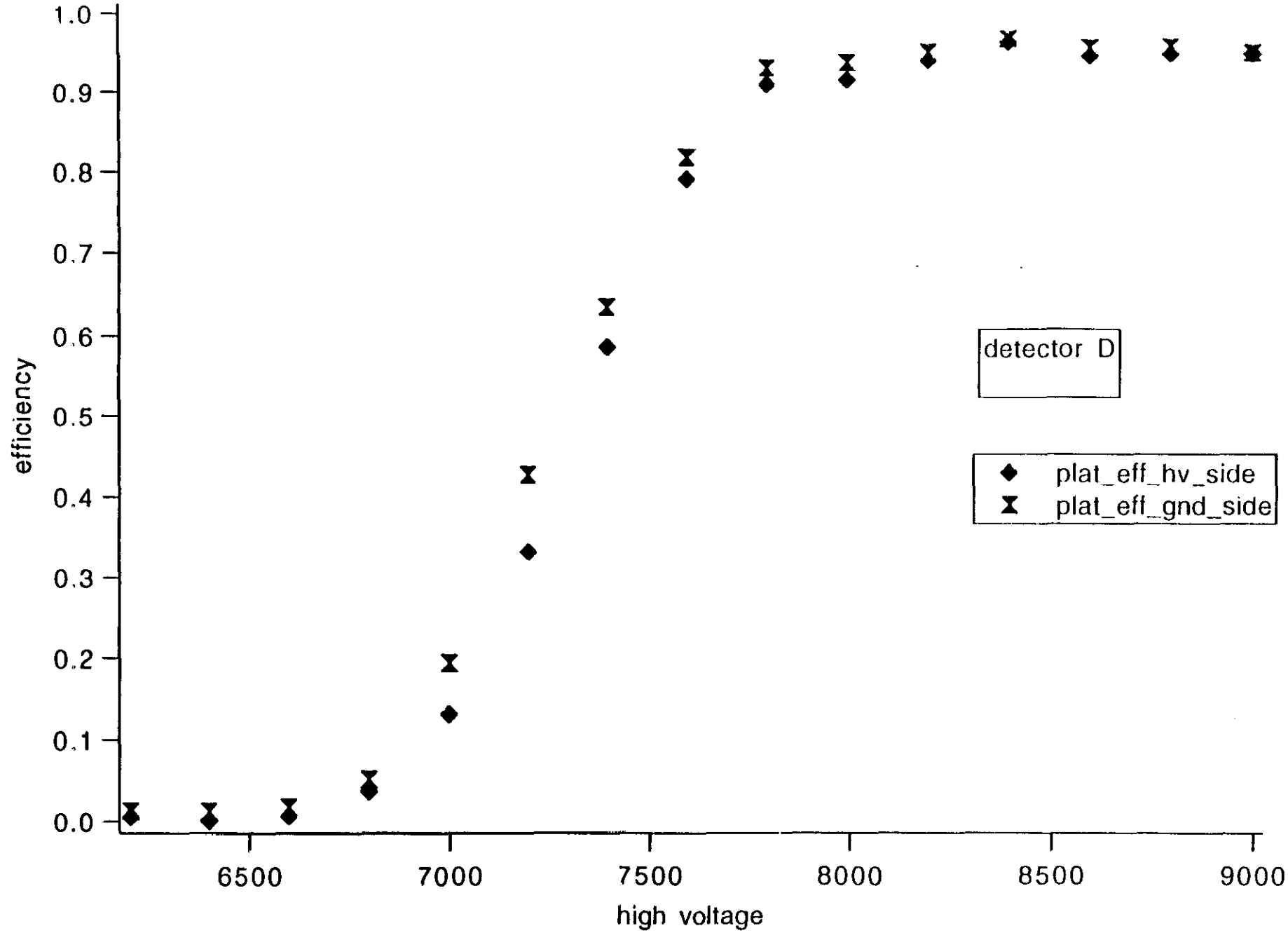



1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
efficiency
detector E
6500
7000
7500
8000
8500
high voltage


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
efficiency
detector E
200
400
600
800
1000
discriminator threshold in millivolts

2D RPC


25 μm Al foil
0.476 cm 8 lb/ft^3
Polyurethane
Cu strip
Mylar
Graphite 40 kΩ/sq
500 μm ABS
Cu strips
0.476 cm 8 lb/ft^3
Polyurethane
25 μm Al foil
Lucite


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
efficiency
6500
7000
7500
8000
8500
9000
high voltage
detector D
plat_eff_hv_side
plat_eff_gnd_side

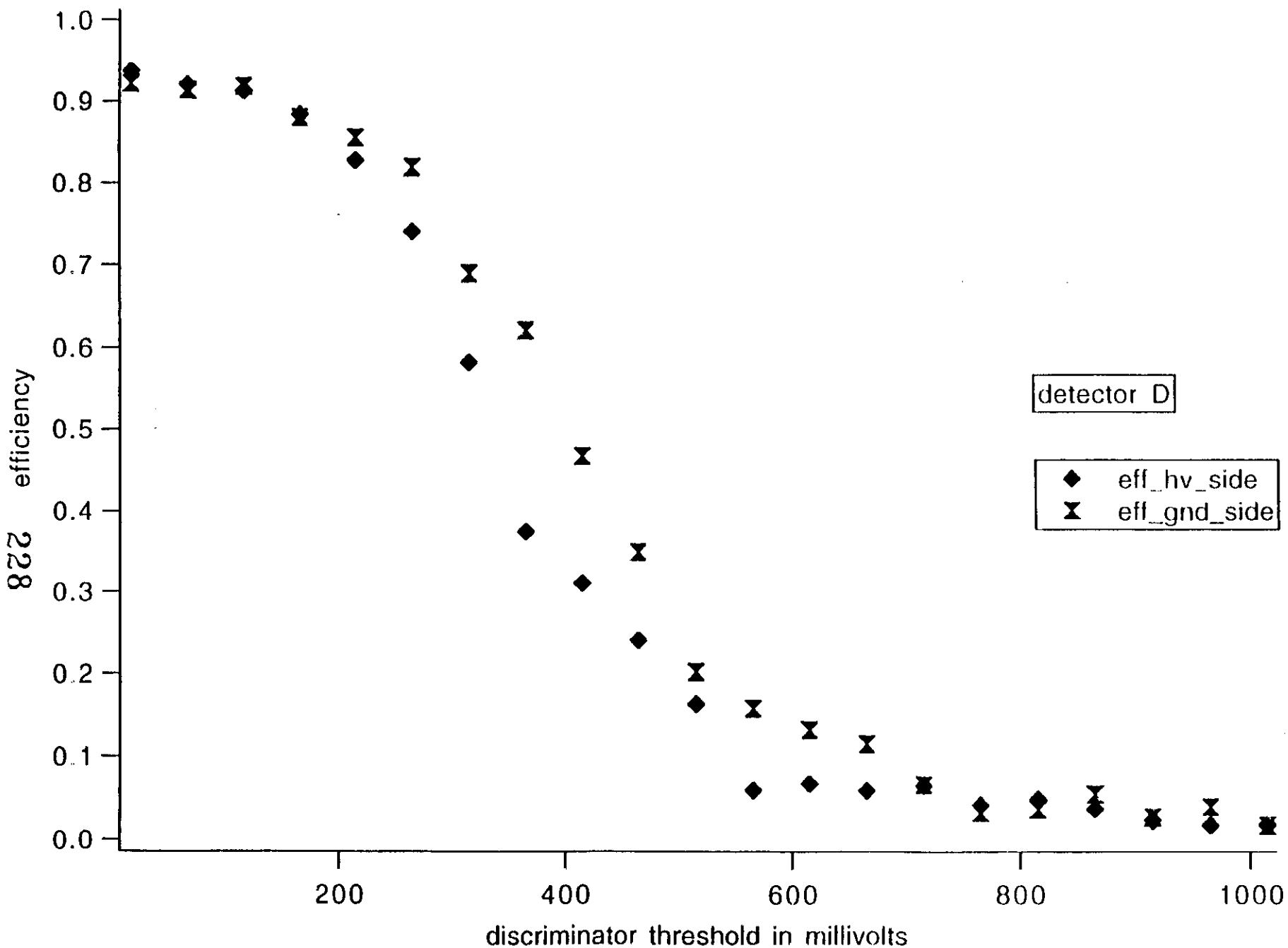
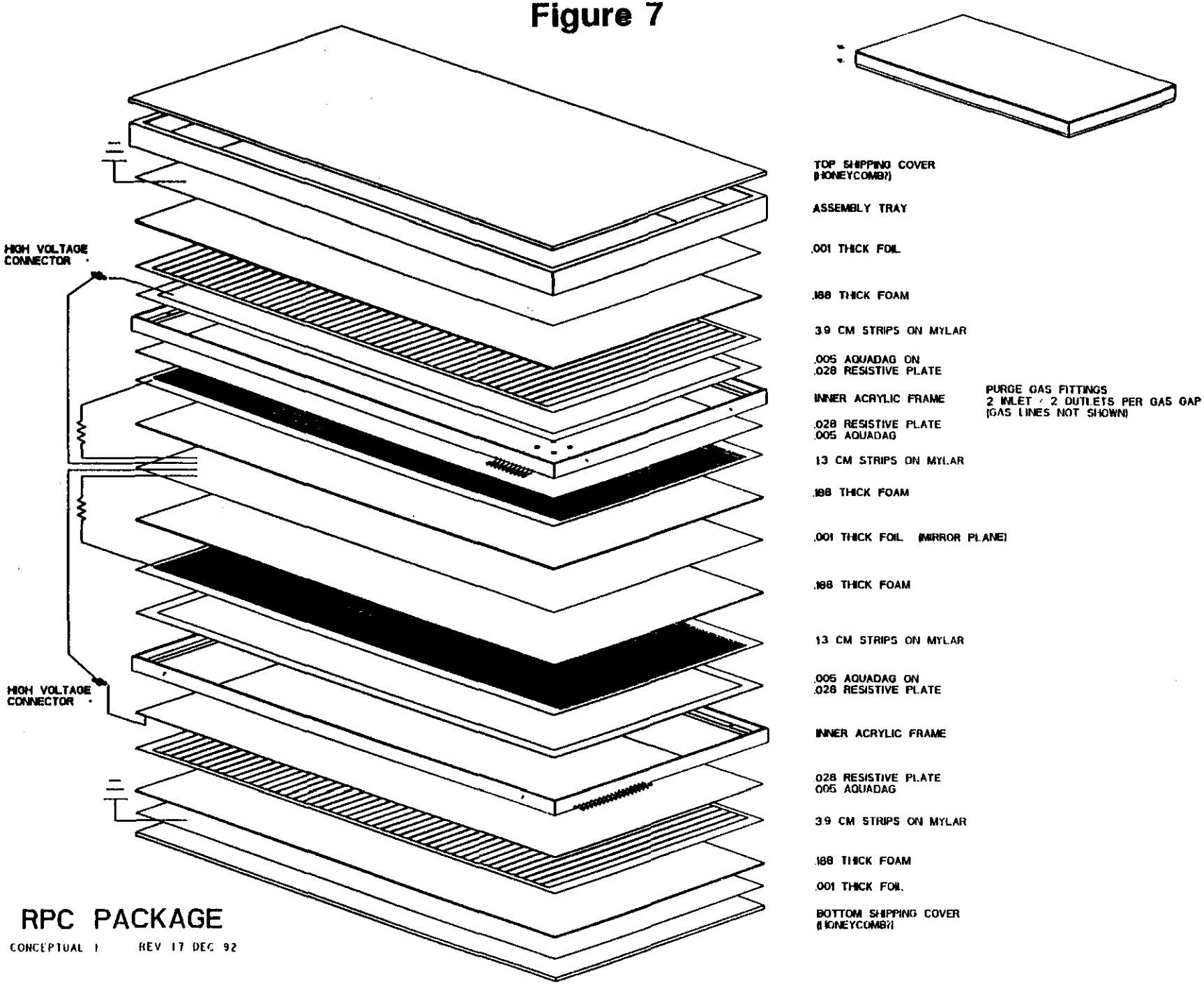
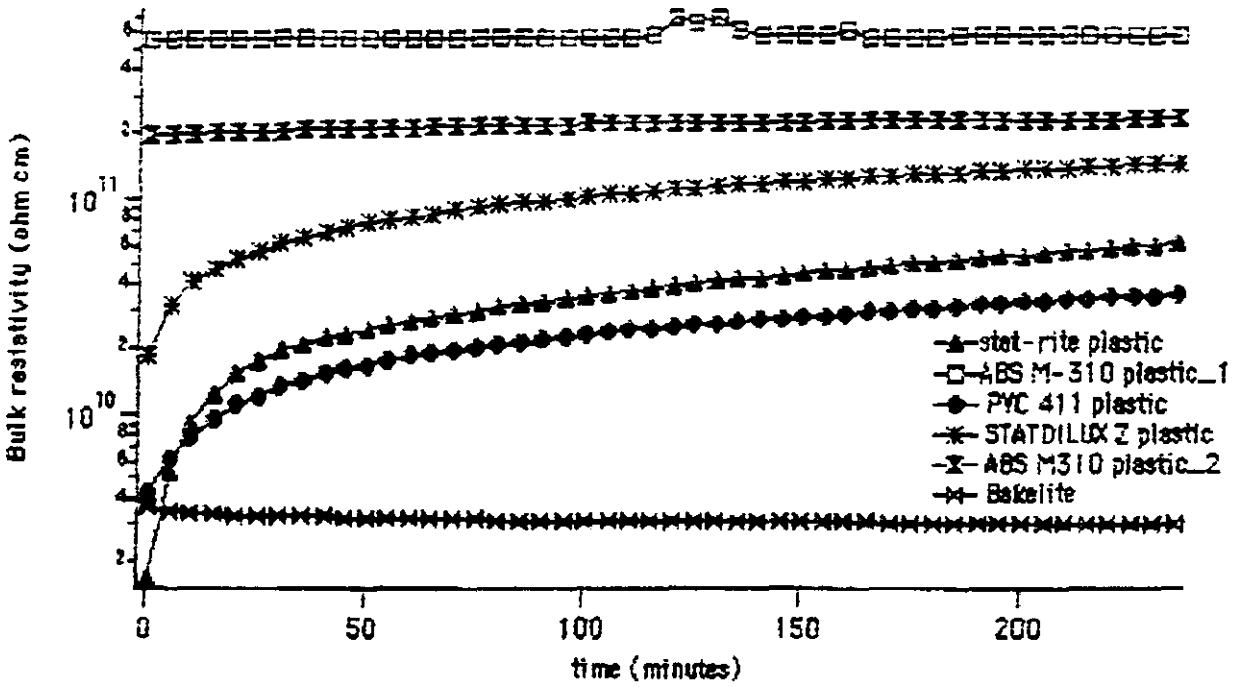
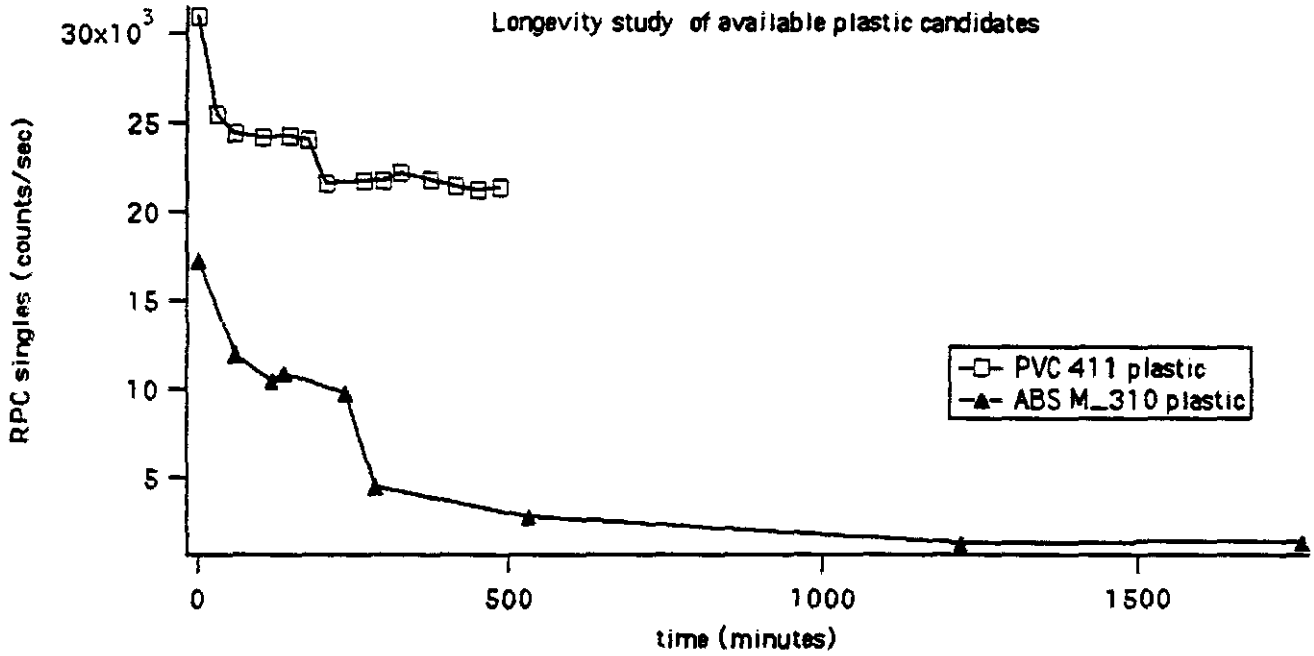

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
efficiency
200
400
600
800
1000
discriminator threshold in millivolts
detector D
eff_hv_side
eff_gnd_side

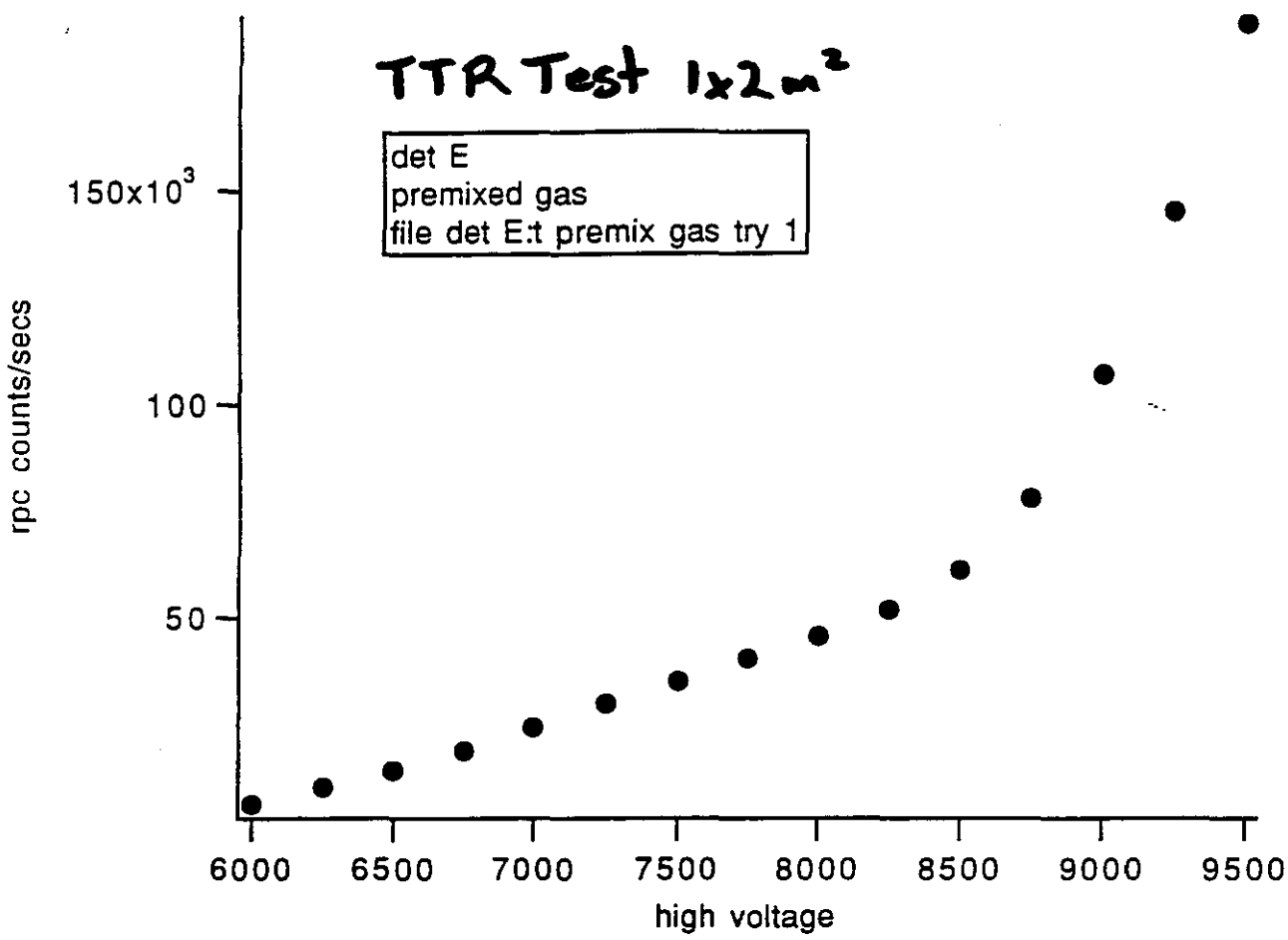
Figure 7

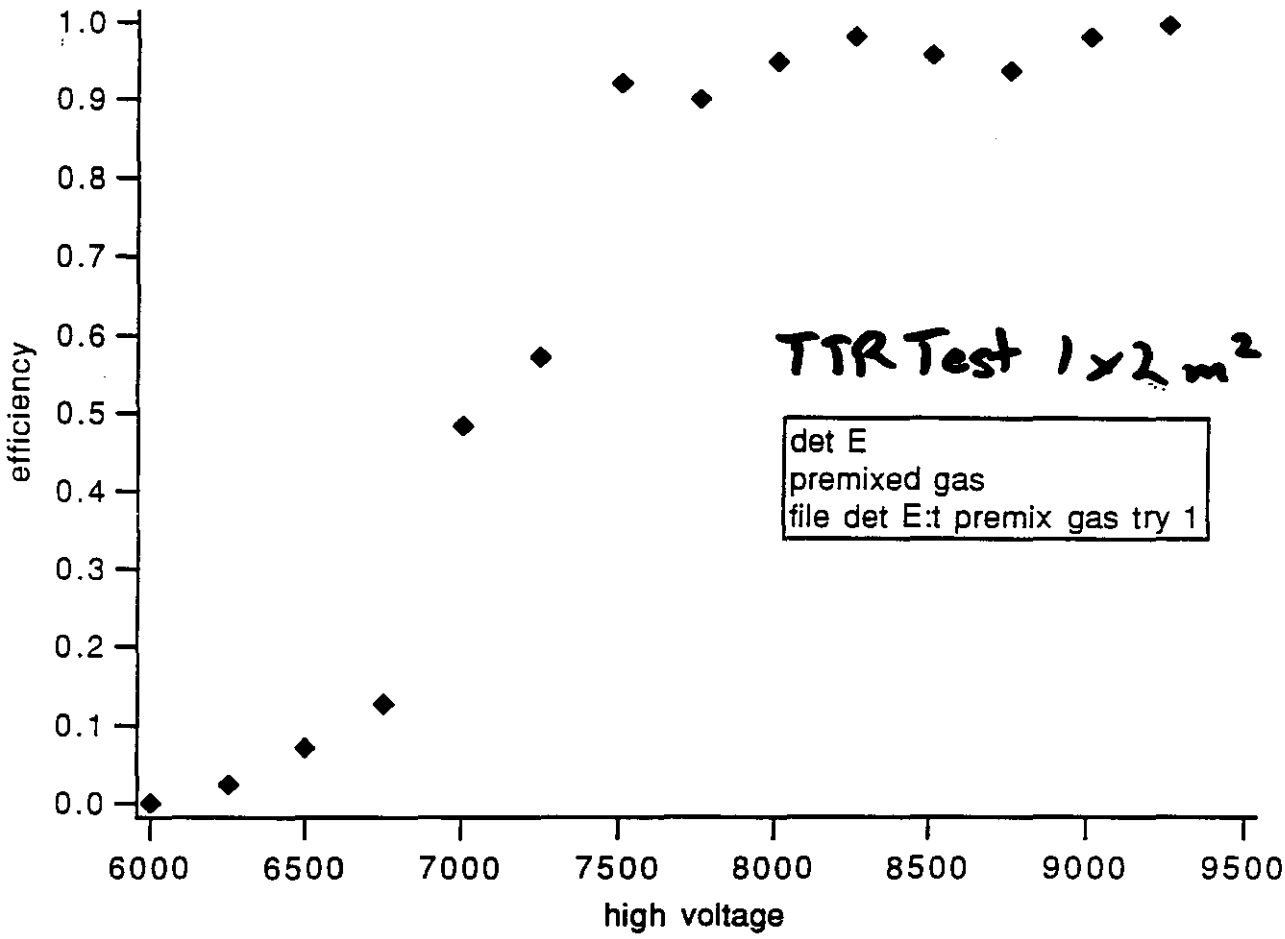

HIGH VOLTAGE CONNECTOR
HIGH VOLTAGE CONNECTOR
TOP SHIPPING COVER (HONEYCOMB?)
ASSEMBLY TRAY
.001 THICK FOIL
.188 THICK FOAM
3.9 CM STRIPS ON MYLAR
.005 AQUADAG ON .028 RESISTIVE PLATE
INNER ACRYLIC FRAME
PURGE GAS FITTINGS 2 INLET / 2 OUTLETS PER GAS GAP (GAS LINES NOT SHOWN)
.028 RESISTIVE PLATE .005 AQUADAG
1.3 CM STRIPS ON MYLAR
.188 THICK FOAM
.001 THICK FOIL (MIRROR PLANE)
.188 THICK FOAM
1.3 CM STRIPS ON MYLAR
.005 AQUADAG ON .028 RESISTIVE PLATE
INNER ACRYLIC FRAME
.028 RESISTIVE PLATE .005 AQUADAG
3.9 CM STRIPS ON MYLAR
.188 THICK FOAM
.001 THICK FOIL
BOTTOM SHIPPING COVER (HONEYCOMB?)
RPC PACKAGE
CONCEPTUAL 1 REV 17 DEC 92

Bulk resistivity of various RPC candidates




Longevity study of available plastic candidates
30x10^3
25
20
15
10
5
RPC singles (counts/sec)
0
500
1000
1500
time (minutes)
PVC 411 plastic
ABS M_310 plastic


TTR Test 1x2 m²
det E
premixed gas
file det E:t premix gas try 1
150x10³
100
50
rpc counts/secs
6000
6500
7000
7500
8000
8500
9000
9500
high voltage



100V

35 STEP.

100V/STEP

400SEC

4 HR

300

400SEC

6 min

2 33 min.

6 - 9500

3500 V

75T/cm

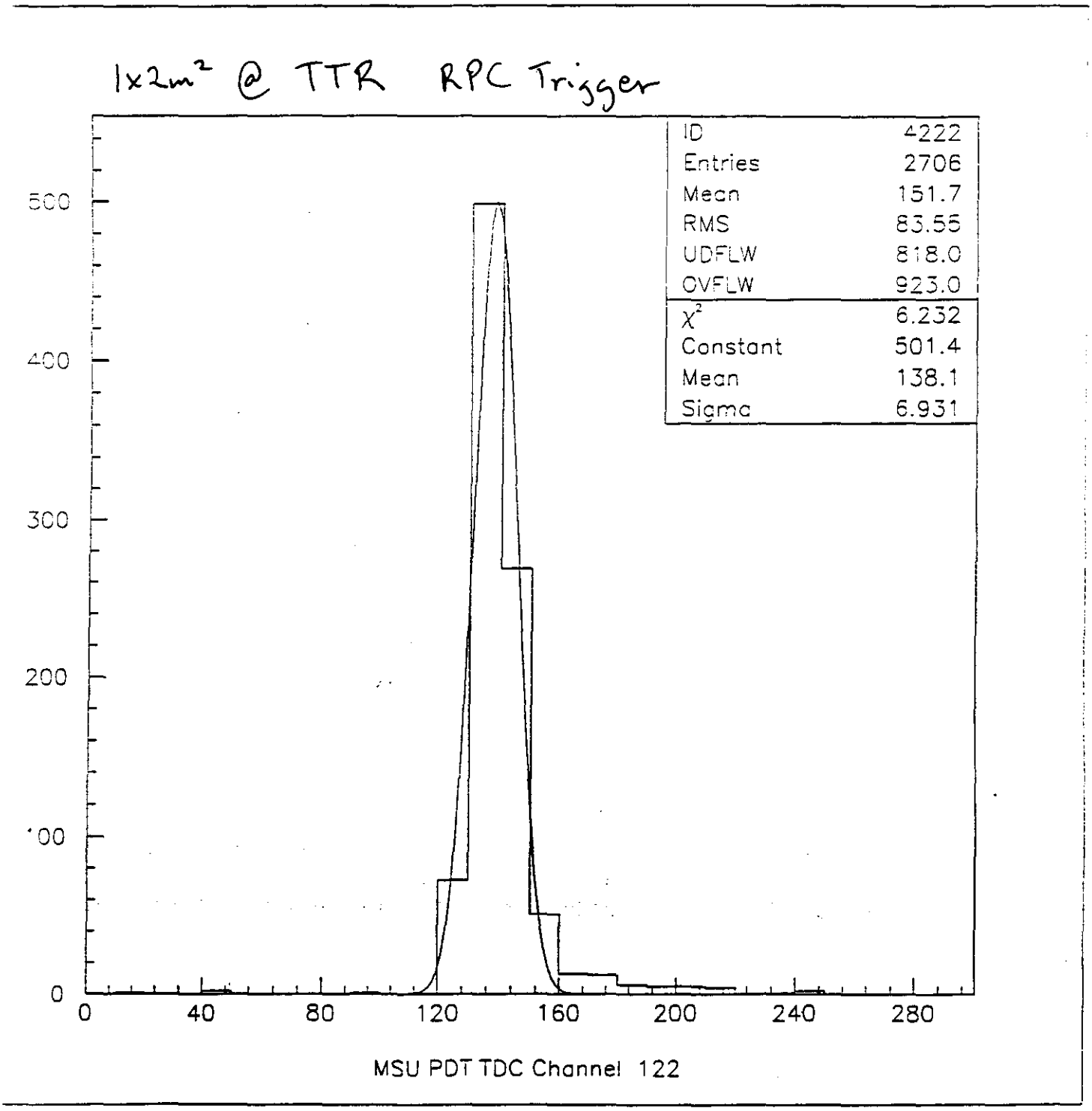
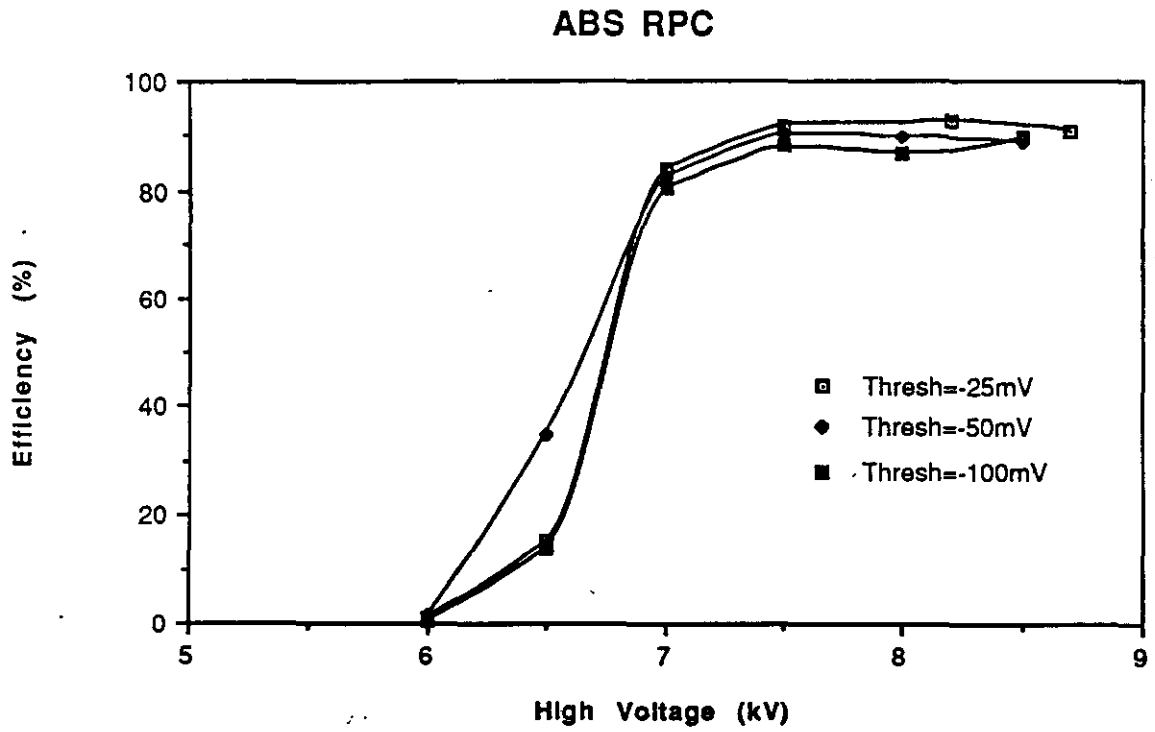
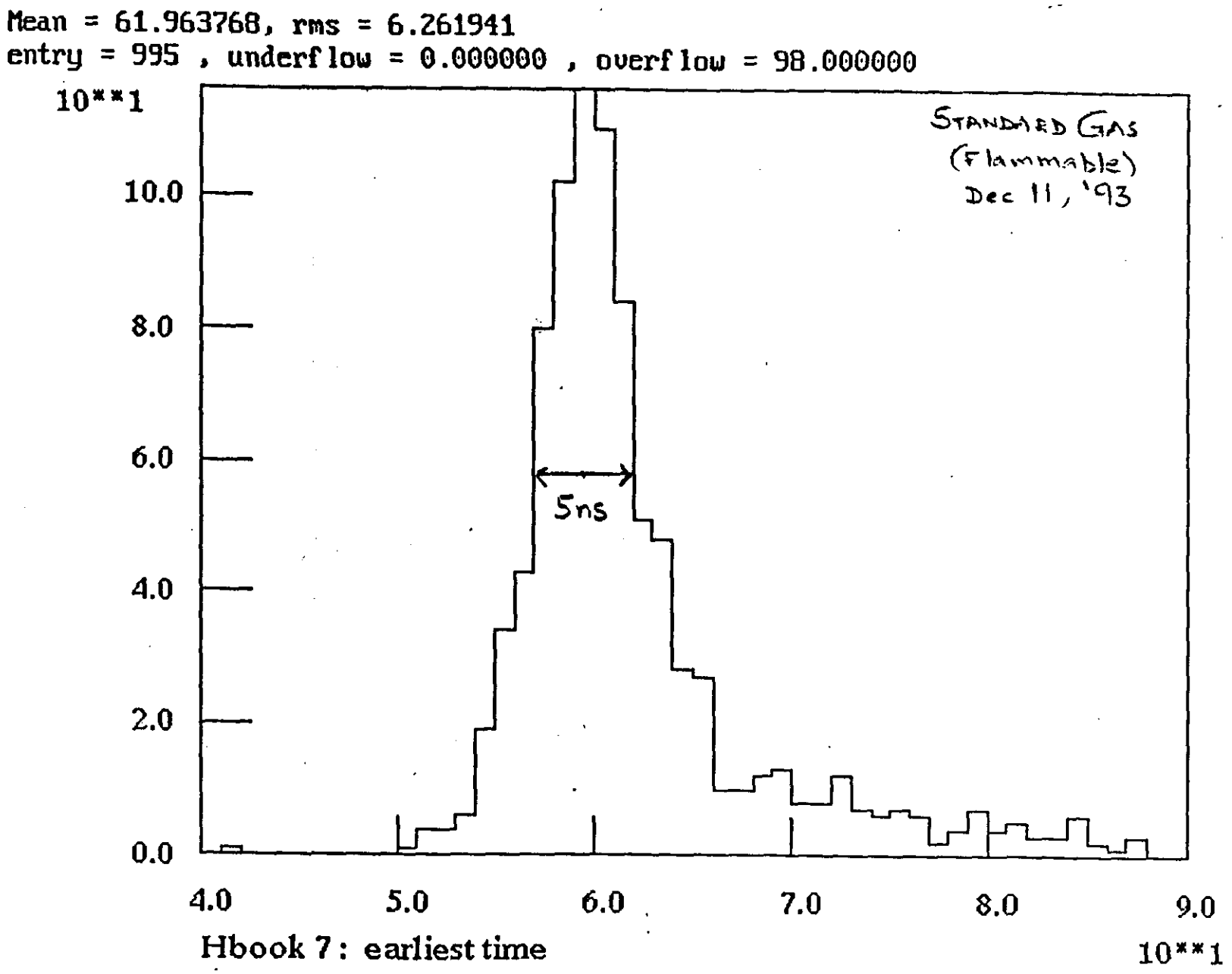
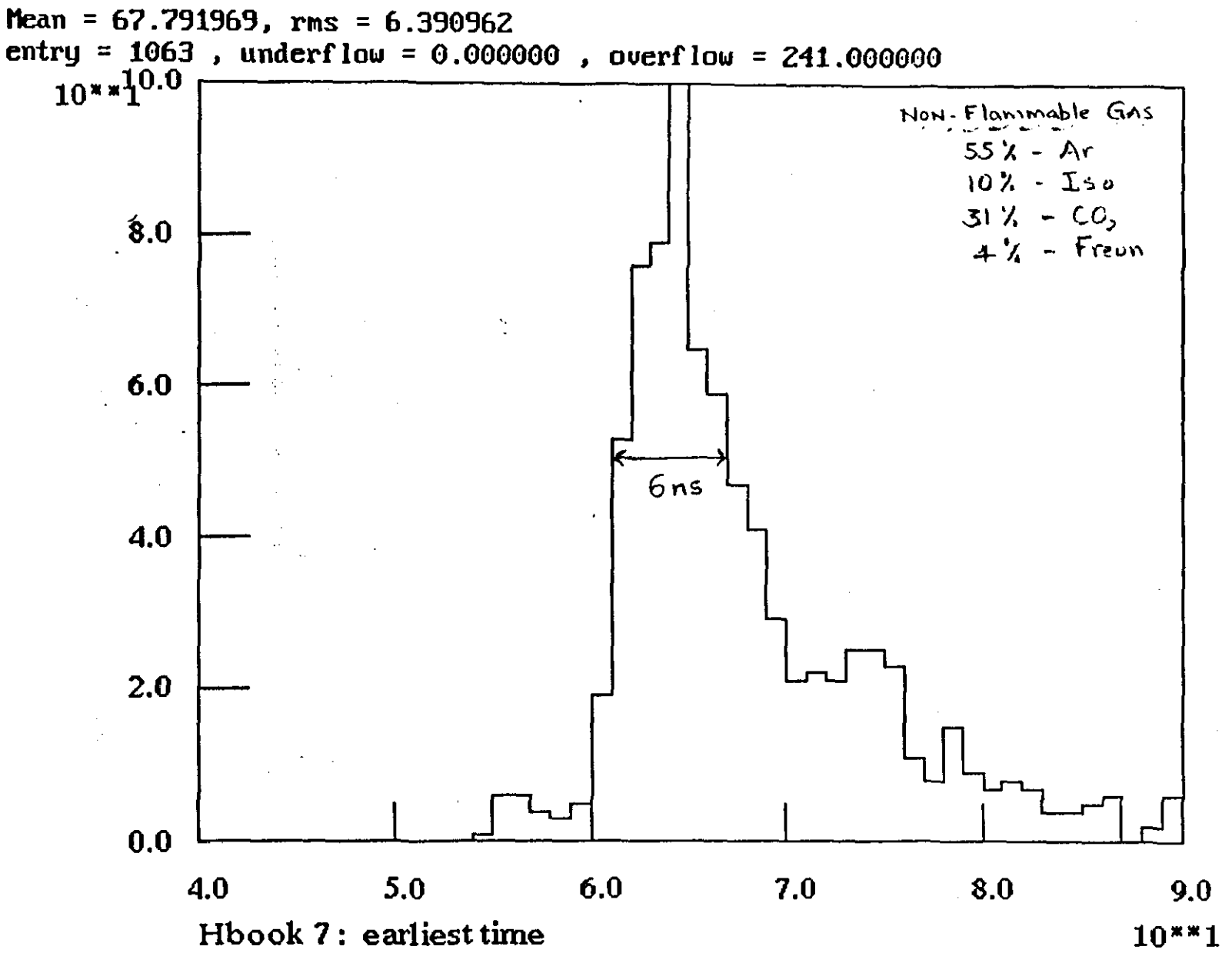

1x2m² @ TTR RPC Trigger
ID 4222
Entries 2706
Mean 151.7
RMS 83.55
UDFLW 818.0
OVFLW 923.0
χ² 6.232
Constant 501.4
Mean 138.1
Sigma 6.931
500
400
300
200
100
0
0
40
80
120
160
200
240
280
MSU PDT TDC Channel 122

Figure 17



55% Ar, 31% CO_2, 10% isobutane,
4% F13B1 - non flammable


Mean = 61.963768, rms = 6.261941
entry = 995 , underflow = 0.000000 , overflow = 98.000000
10**1
10.0
8.0
6.0
4.0
2.0
0.0
4.0
5.0
6.0
7.0
8.0
9.0
10**1
Hbook 7 : earliest time
Standard Gas
(Flammable)
Dec 11, '93
5ns

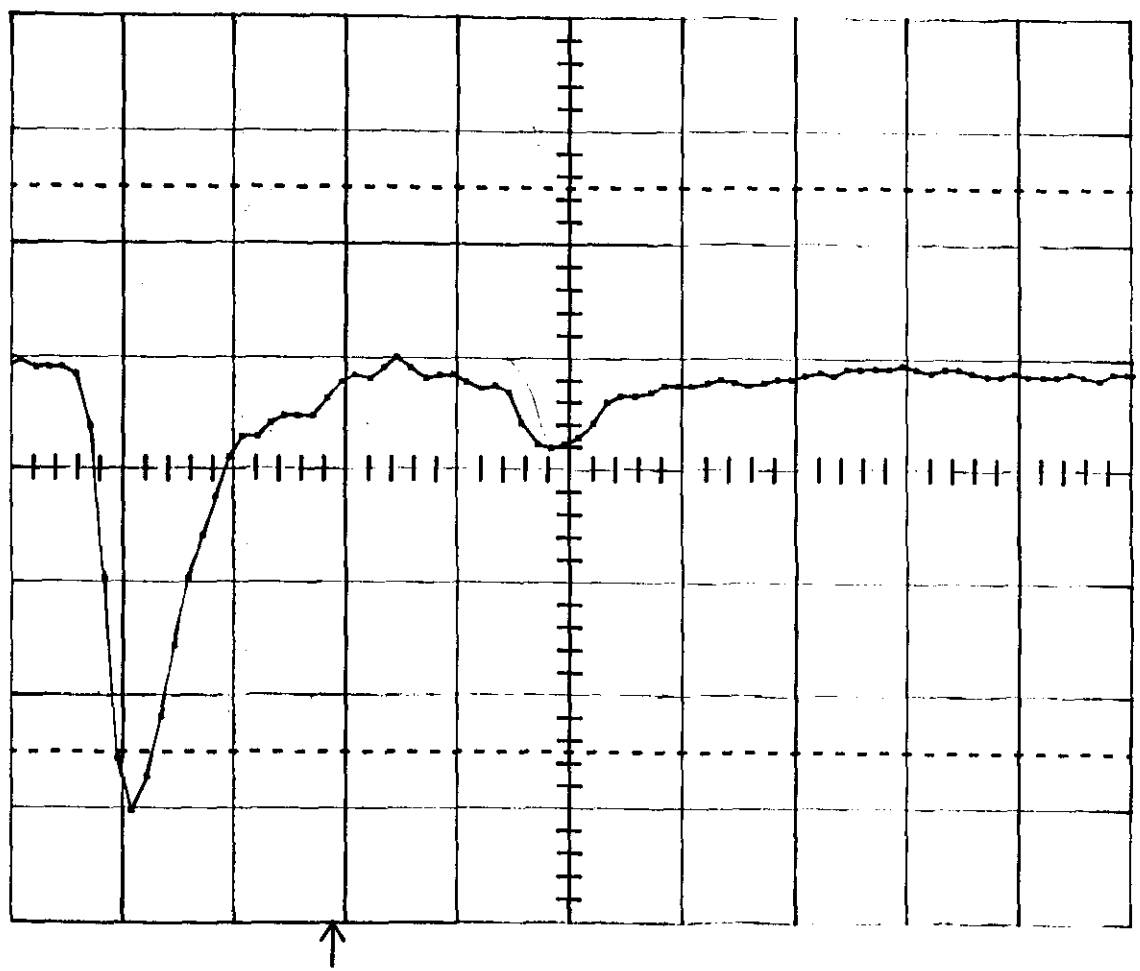

Mean = 67.791969, rms = 6.390962
entry = 1063 , underflow = 0.000000 , overflow = 241.000000
10**1
10.0
8.0
6.0
4.0
2.0
0.0
4.0
5.0
6.0
7.0
8.0
9.0
10**1
Hbook 7 : earliest time
Non-Flammable Gas
55% - Ar
10% - Iso
31% - CO2
4% - Freon
6ns

Standard Gas
66% Ar, 30% isob, 4% freon
(flammable.)

22-Dec-92
17:32:17

Main Menu

238



Chan 1
20 ns .1 V

EXT -0.15 V DC

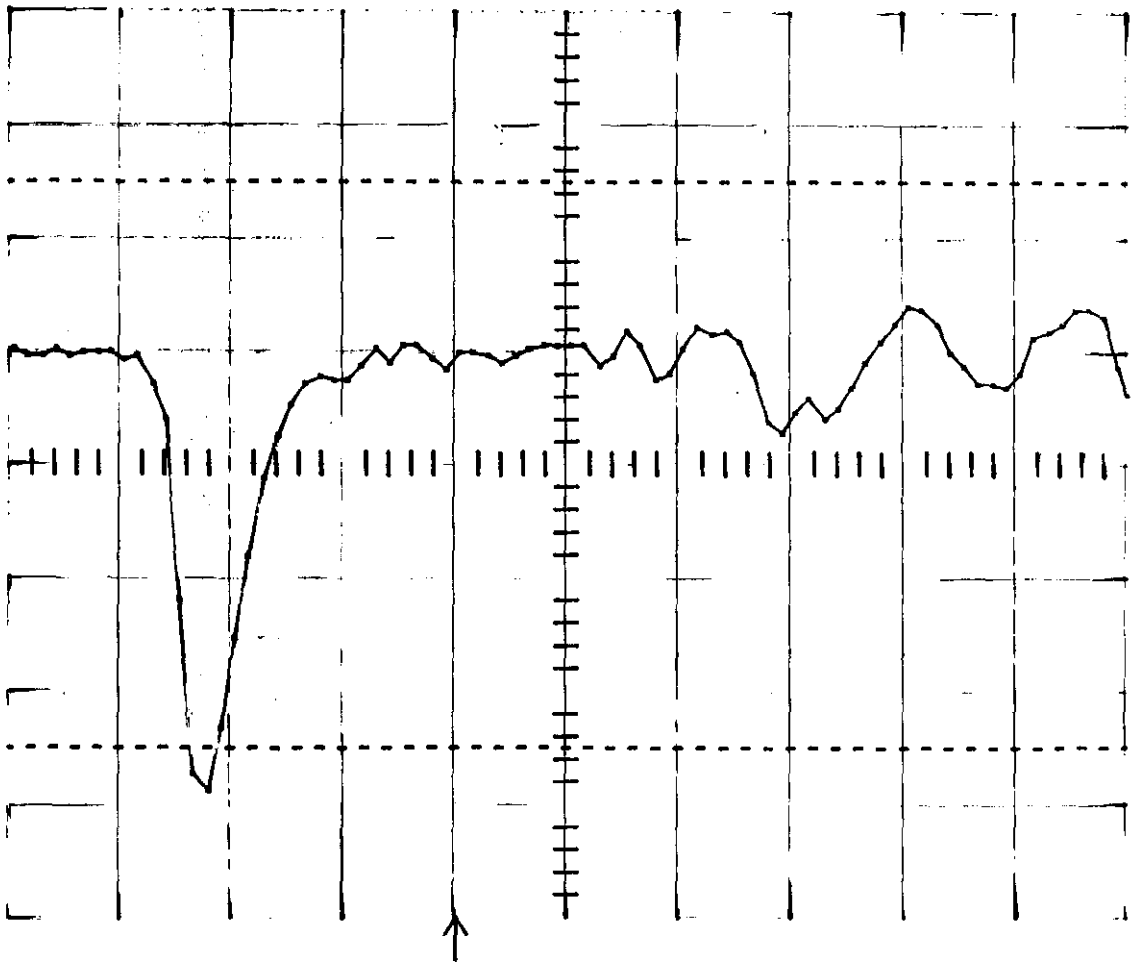
CH1 .1 V
CH2 .5 V

T/div 20 ns

Non-Flammable
GAS.

22-Dec-92
19:03:12

Main Menu



Chan 1
20 ns .1 V

EXT -0.15 V DC

CH1 .1 V
CH2 .1 V

T/div 20 ns

Future Work

- Fabricate large area RPCs with new plastic materials
- Continue study of RPC pulse height and time jitter
- Continue gas mixture studies - replacement for Freon 13B1
- 120 Ω strip line RPCs for reduced cabling volume and cost
- Fabricate 2D 1 m x 2 m RPC

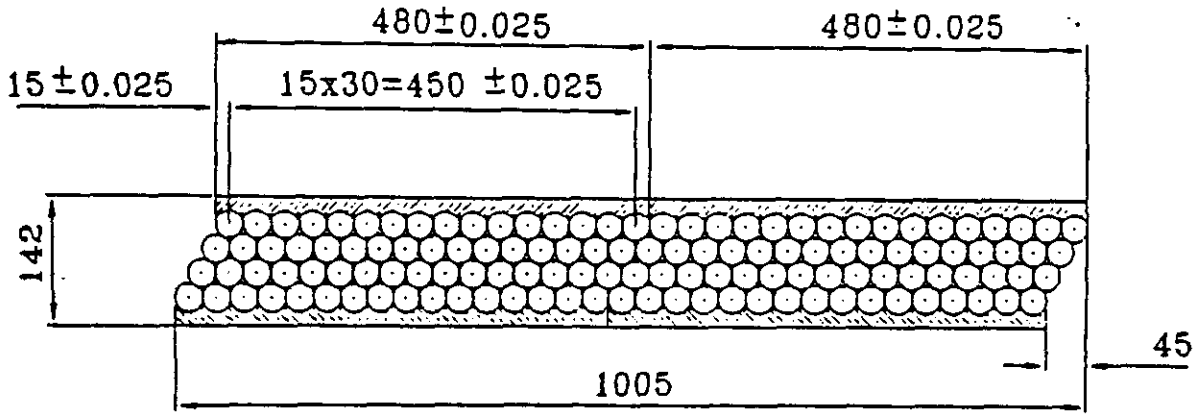
Conclusion

- Large RPCs have been built of low resistivity ABS and PVC plastics which
  - require no linseed oil for low noise operation
  - have noise rates < 1 Hz/cm
  - are light-weight and mechanically rigid
  - can be read-out in 2 dimensions
  - exhibit high rate capability up to 15 KHz/cm
  - have rise-time jitter of 2 ns
  - have geometry limited efficiencies of > 95%
- Non-flammable gas mixtures have been successfully used in plastic RPCs with no change in pulse height, efficiency and jitter
- TTR tests of RPCs show no induced noise generated on RDT and UH CSC systems
- Plastic RPC trigger of RDTs in TTR gives a total of 6.9 ns time jitter
- Higher rate RPCs can be constructed with suitable plastics

The RDT Test Results at TTR

Presentation by:

A. Korytov


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

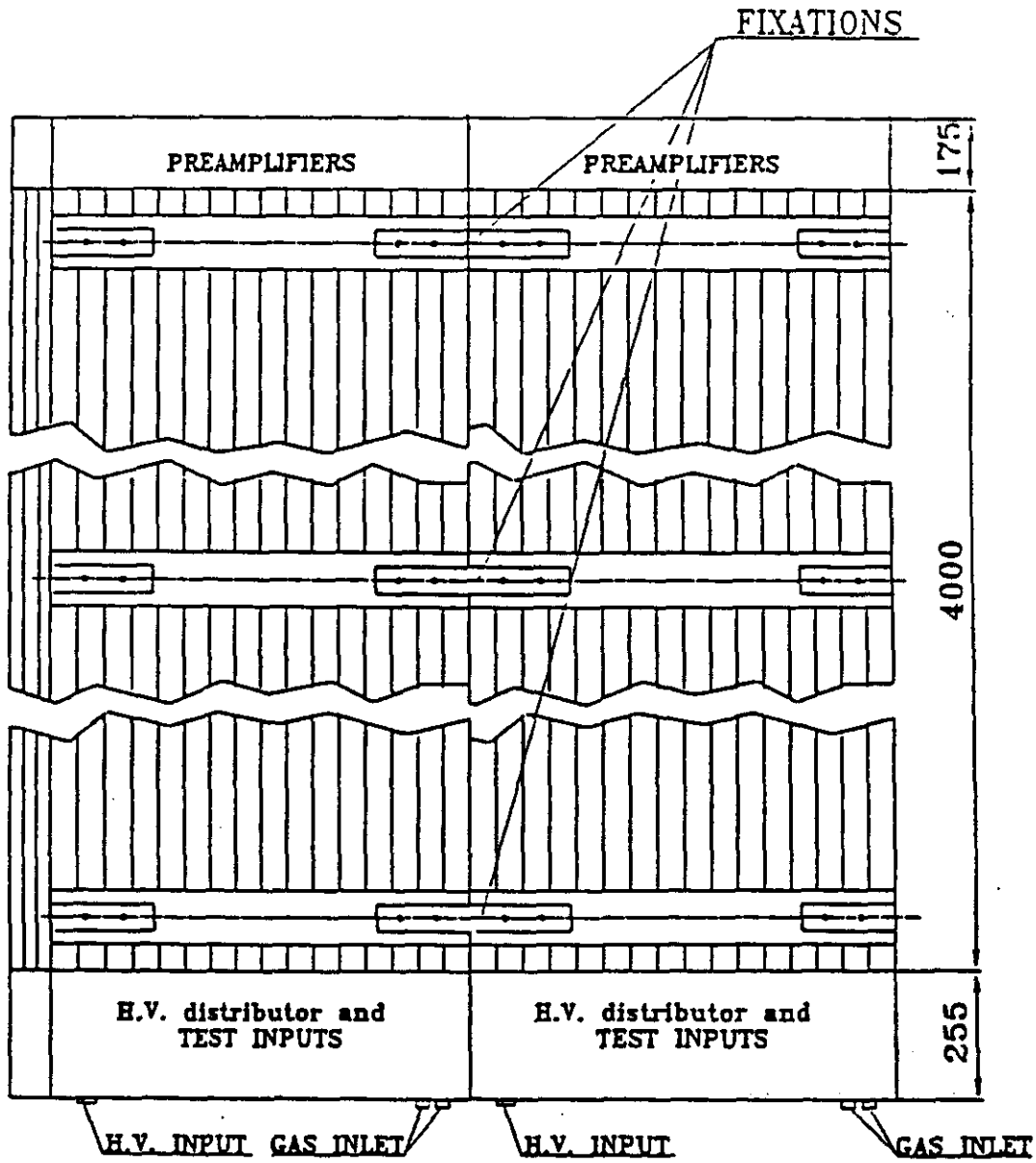
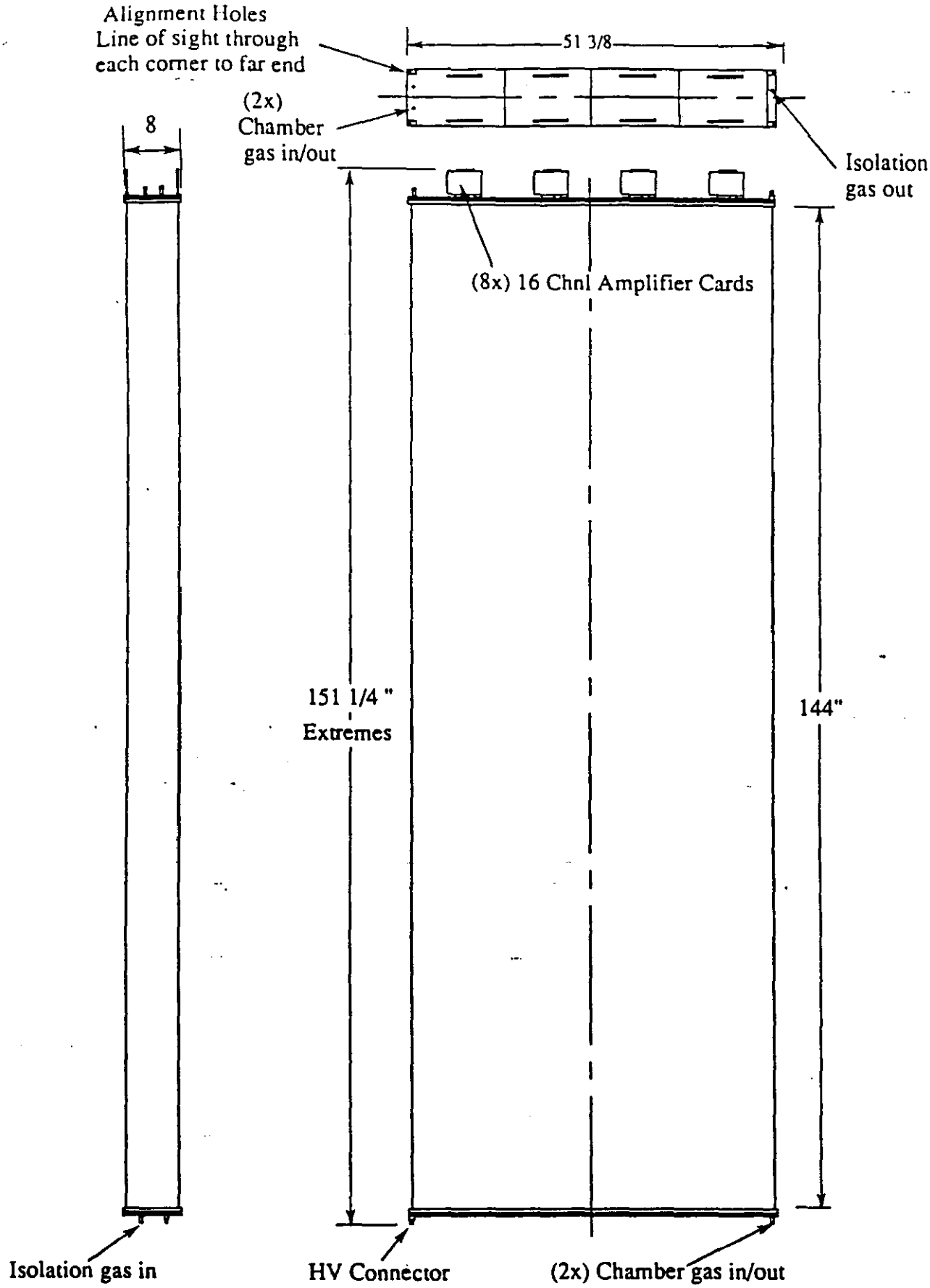

FIXATIONS
PREAMPLIFIERS
PREAMPLIFIERS
175
4000
255
H.V. distributor and TEST INPUTS
H.V. distributor and TEST INPUTS
H.V. INPUT
GAS INLET
H.V. INPUT
GAS INLET

Fig. 1(a)



GEM PDT Prototype Assembly

HEP01-022-281-D R. Miller 5-14-92

Fig. 1 (b)

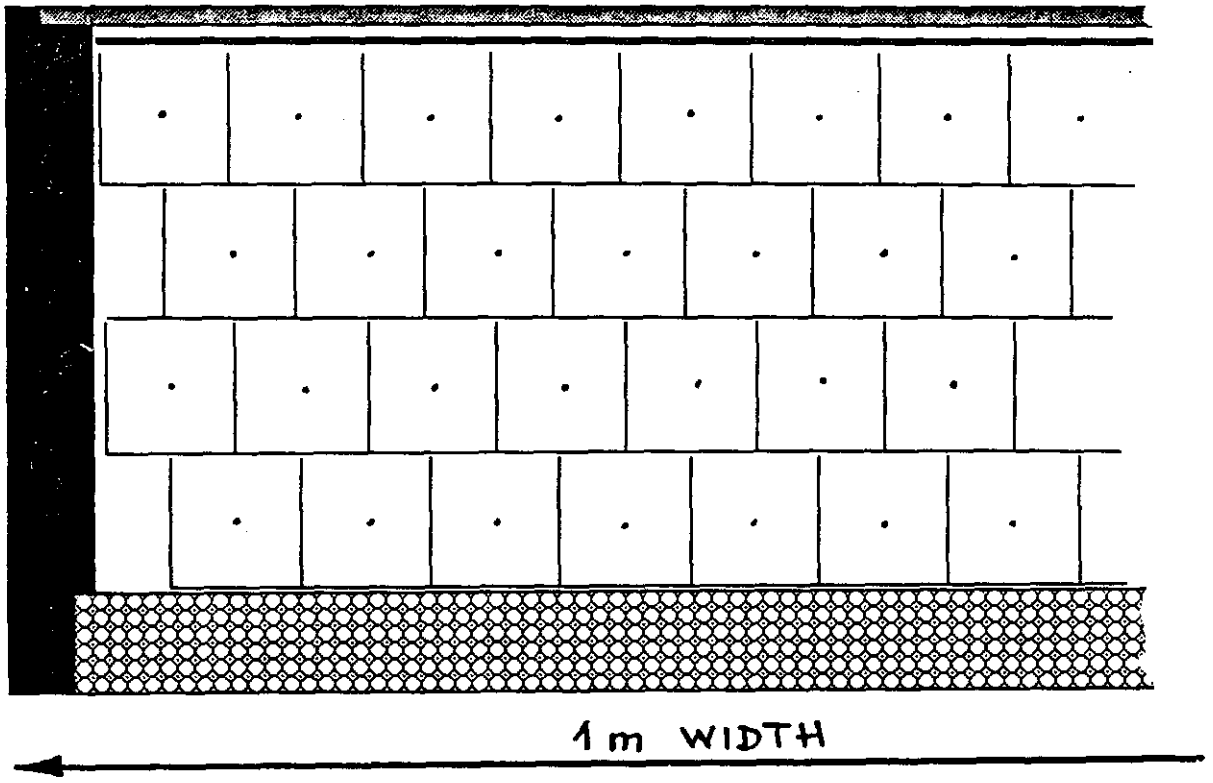


Fig 1c

DUBNA PDT TECNOLOGY CONCEPT

(2)

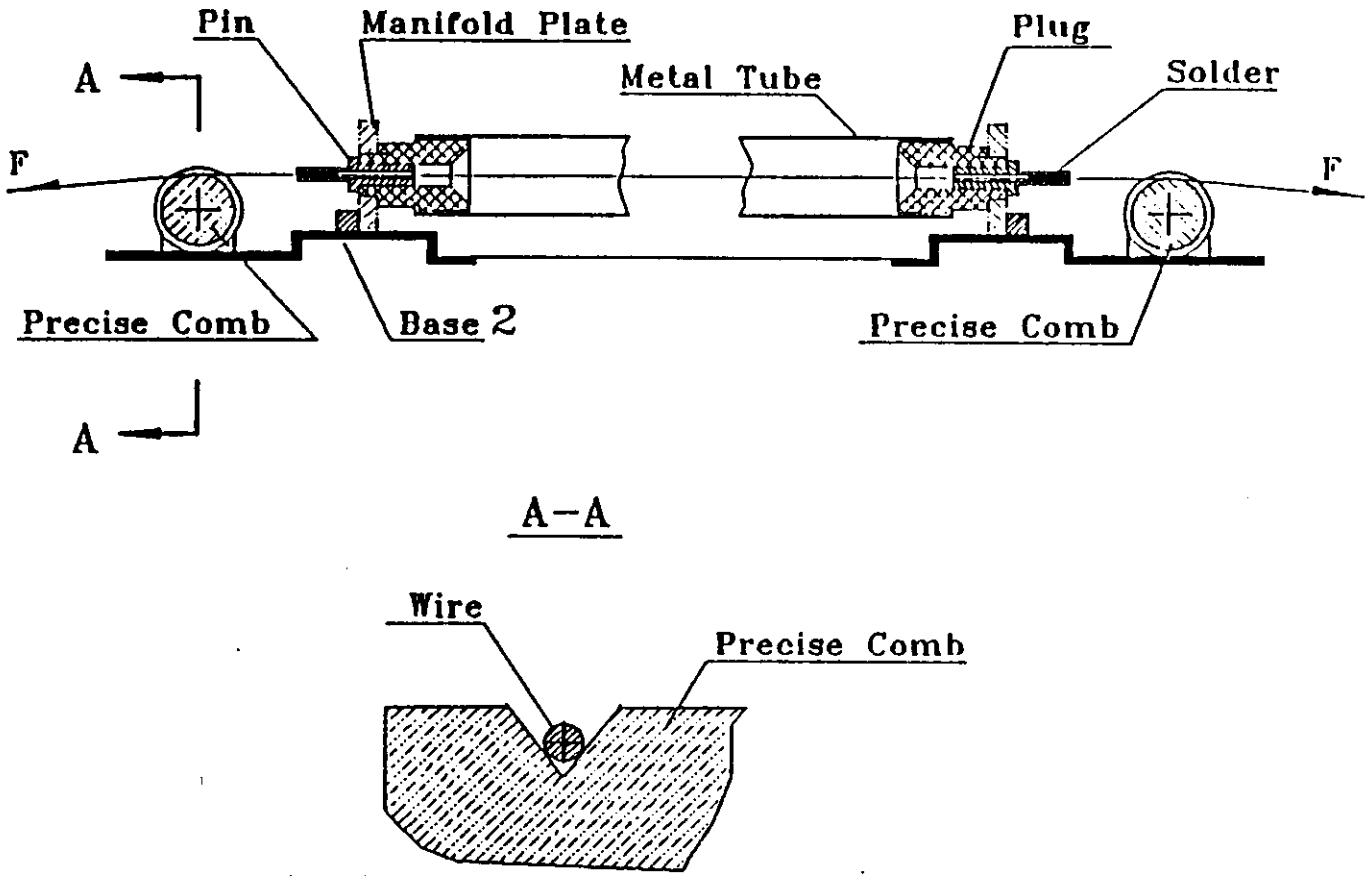


Fig. 2(a)

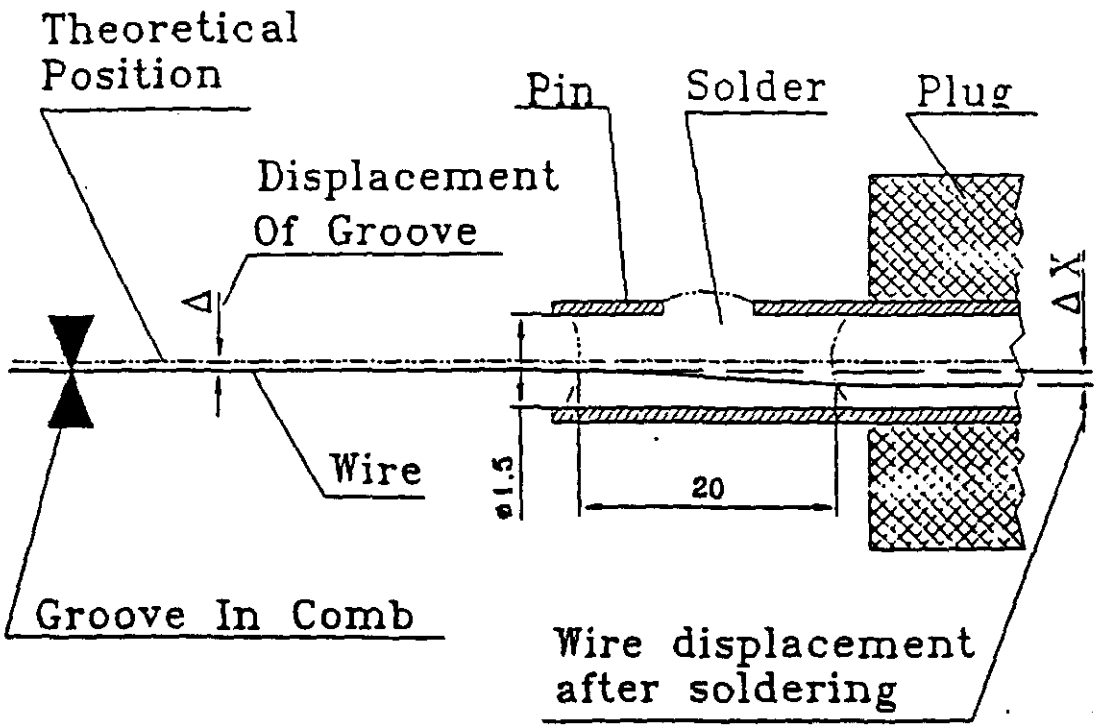

Theoretical Position
Pin
Solder
Plug
Displacement Of Groove
Δ
ΔX
Wire
ø1.5
20
Groove In Comb
Wire displacement after soldering

Fig 2(b)

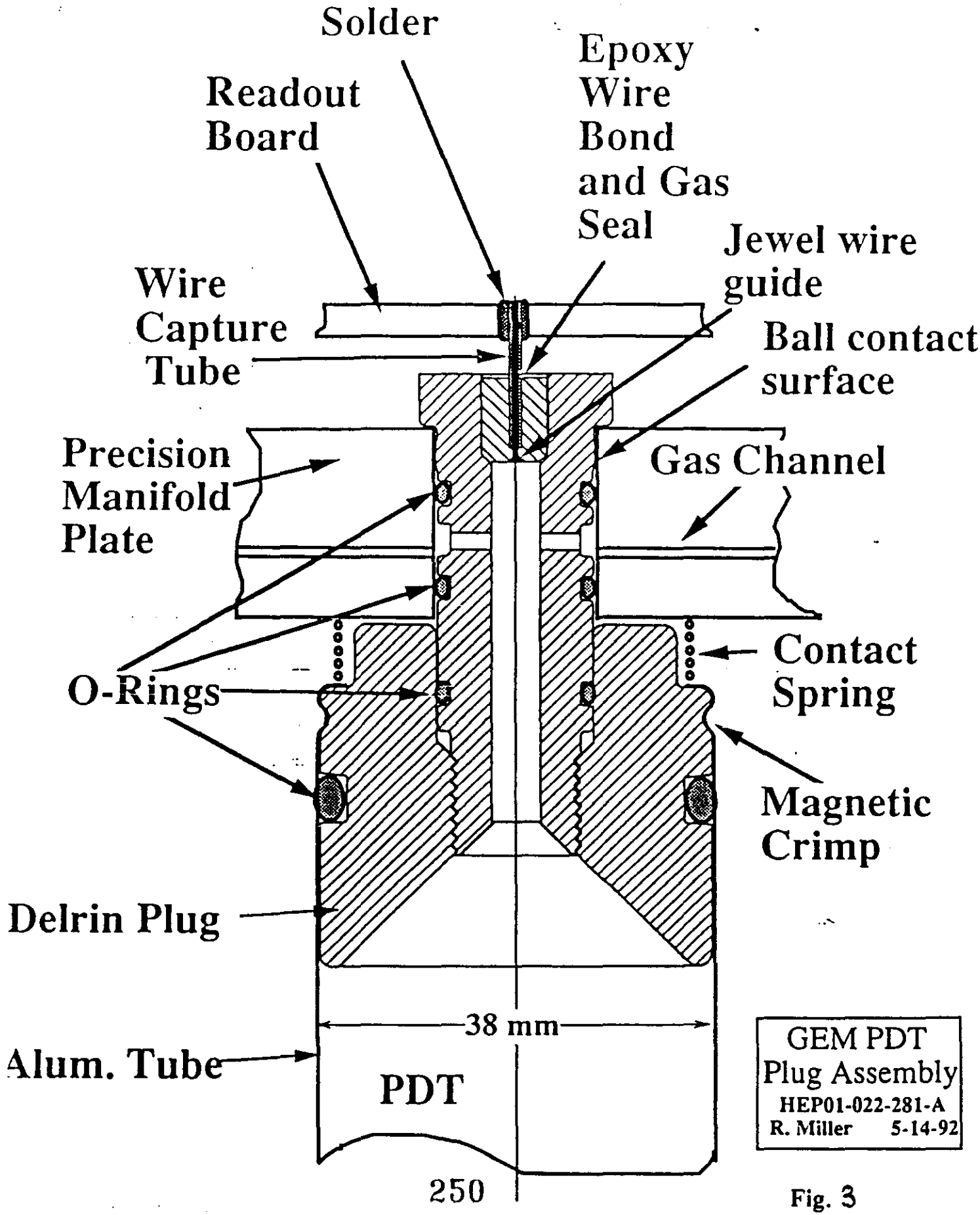

Solder
Readout Board
Epoxy Wire Bond and Gas Seal
Jewel wire guide
Wire Capture Tube
Ball contact surface
Precision Manifold Plate
Gas Channel
O-Rings
Contact Spring
Magnetic Crimp
Delrin Plug
38 mm
Alum. Tube
PDT
GEM PDT
Plug Assembly
HEP01-022-281-A
R. Miller 5-14-92

Fig. 3

Manifold Plate Hole Placement

Aug. 4, 92

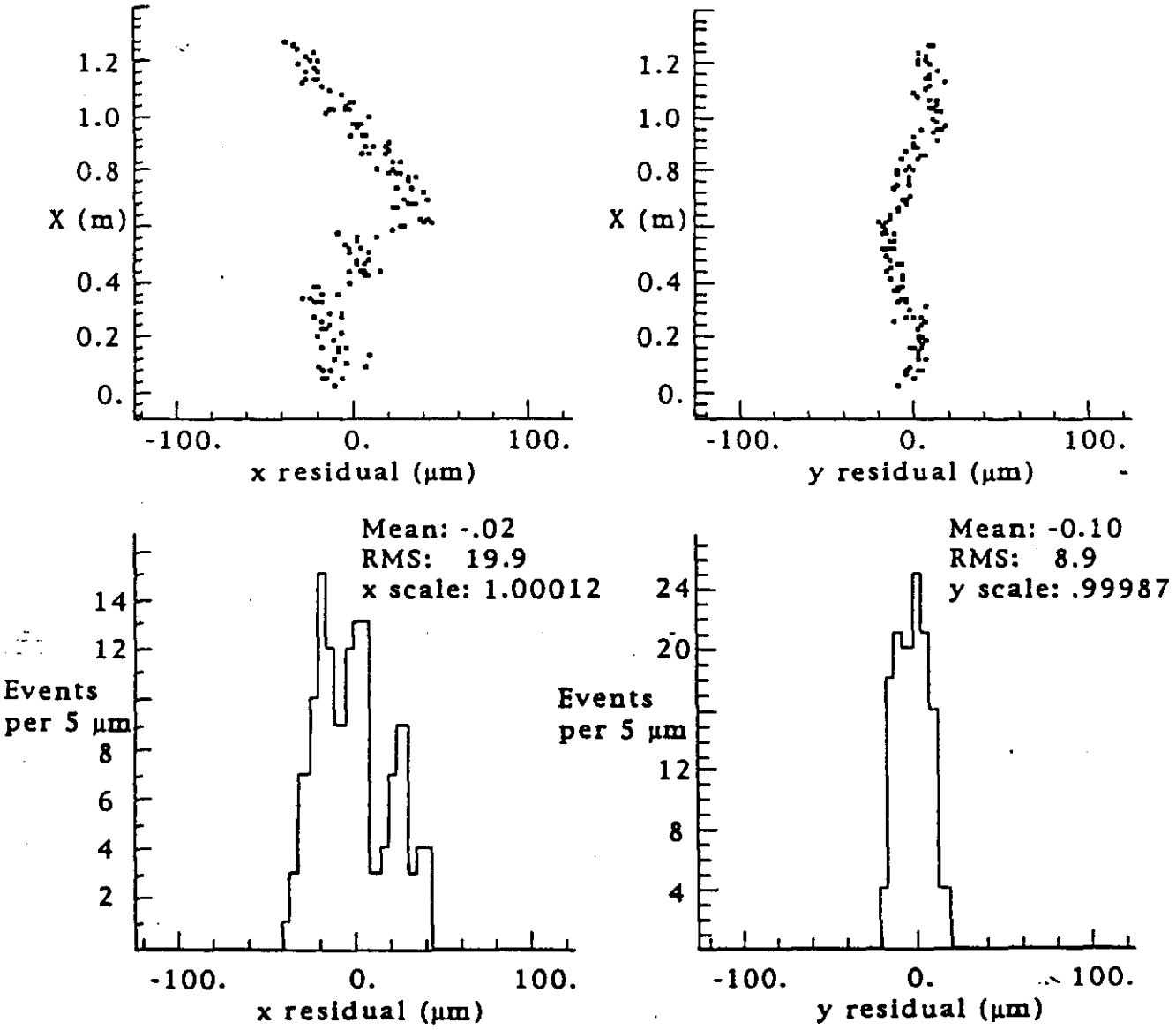


Fig. 4

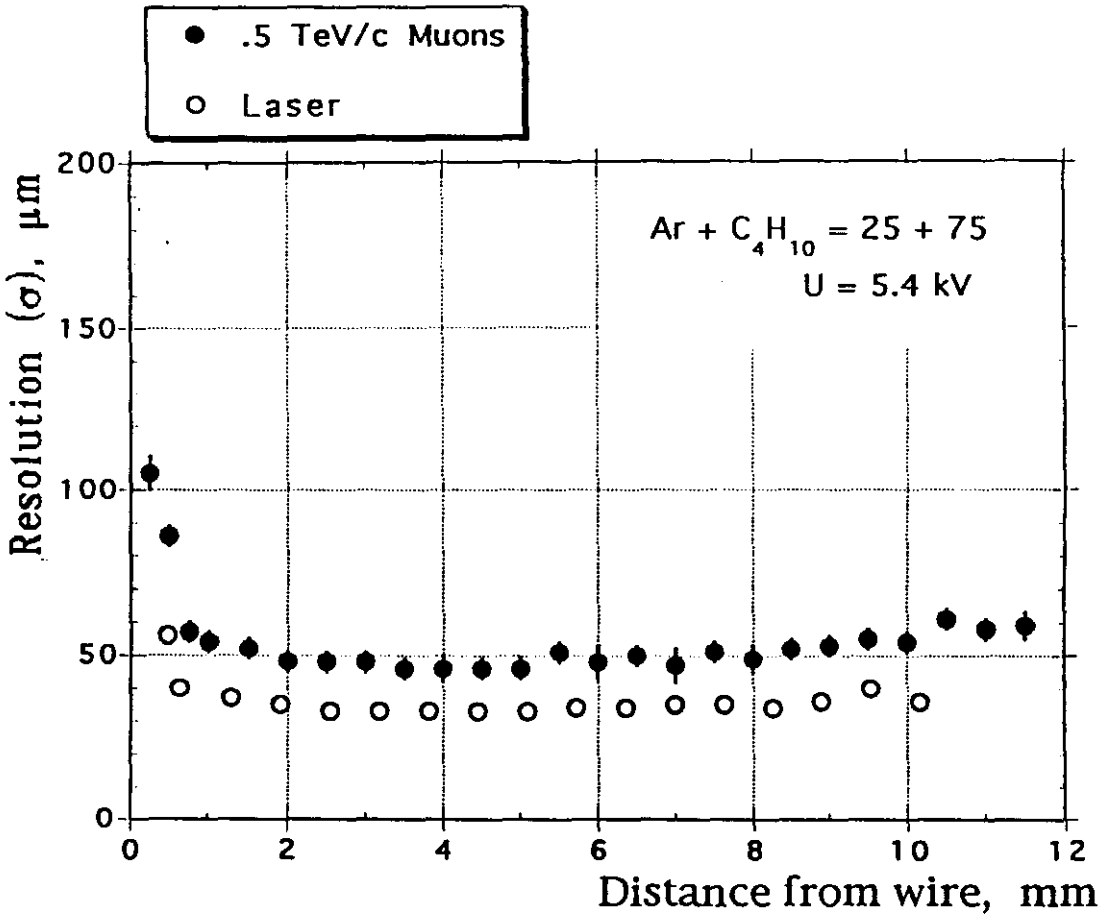

.5 TeV/c Muons
Laser
Ar + C4H10 = 25 + 75
U = 5.4 kV
Resolution (σ), μm
200
150
100
50
0
0
2
4
6
8
10
12
Distance from wire, mm

Fig 5 (a)

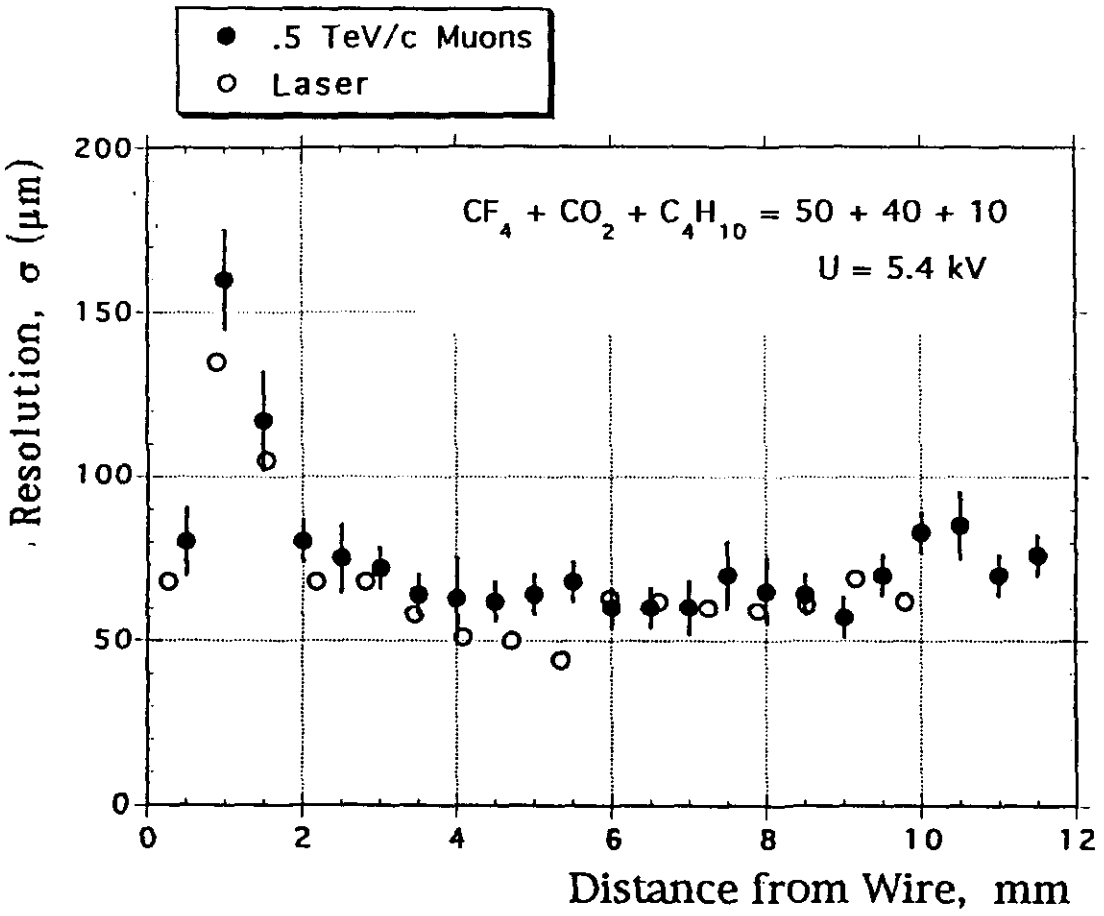

.5 TeV/c Muons
Laser
$CF_4 + CO_2 + C_4H_{10} = 50 + 40 + 10$
U = 5.4 kV
Resolution, σ (μm)
200
150
100
50
0
0
2
4
6
8
10
12
Distance from Wire, mm

Fig 5 (b)

NIM 143 (1977) 17

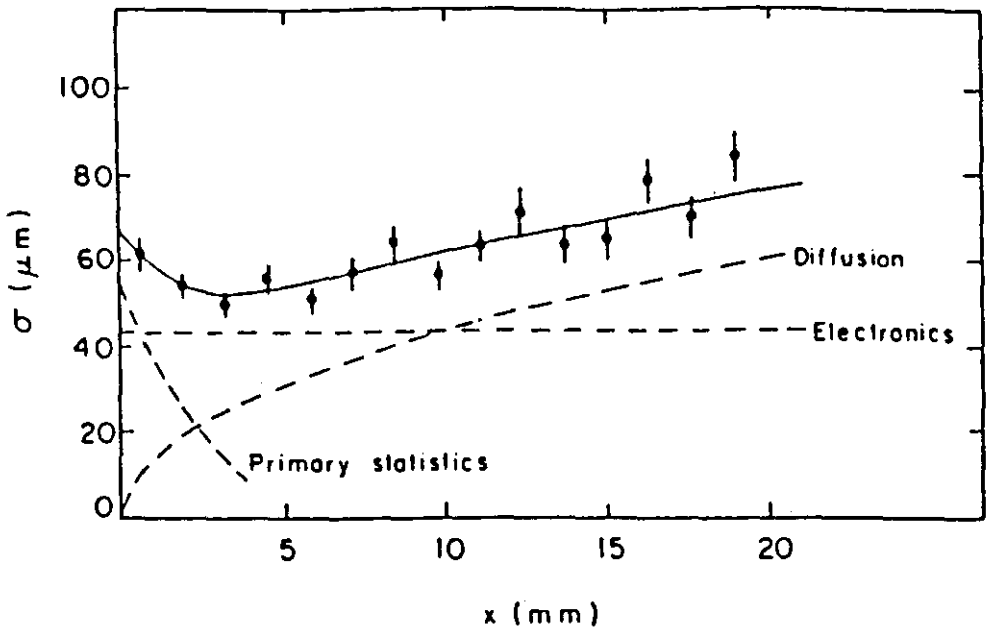


Fig 5(c)

Drift Chamber Resolution

(σ_{diff}=100 μm/(cm)$^{1/2}$; λ=250 μm)

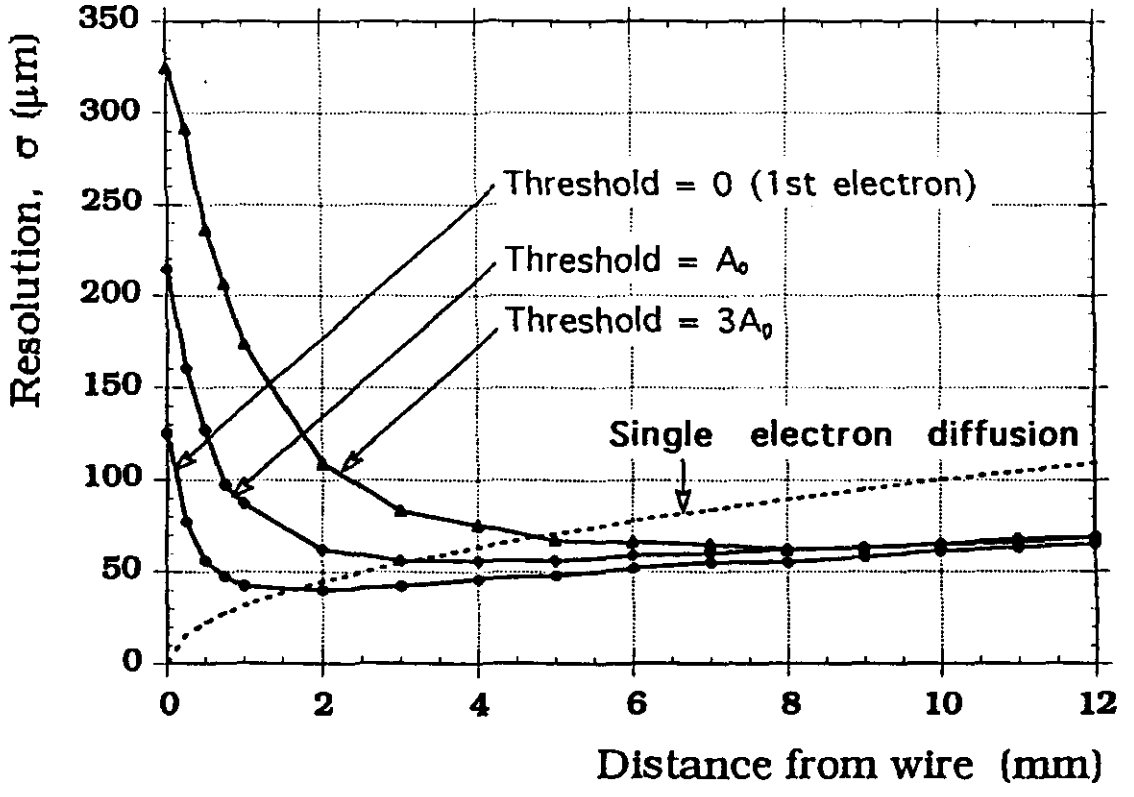


Fig 6

Ar – C_2H_6 (50/50)

PROP. MODE

U_A kV	Layer / P_{atm}	1	2	3	4	1...4
		Δ	Δ	Δ	Δ	σ
3.1	1	(+28)	(−47)	(+8)	(+10)	110
4.3	2	(+32)	(−52)	(+10)	(+10)	92
5.9	4	(+36)	(−59)	(+8)	(+10)	76

Ar – C_4H_{10} (25/75)

P = 1 atm

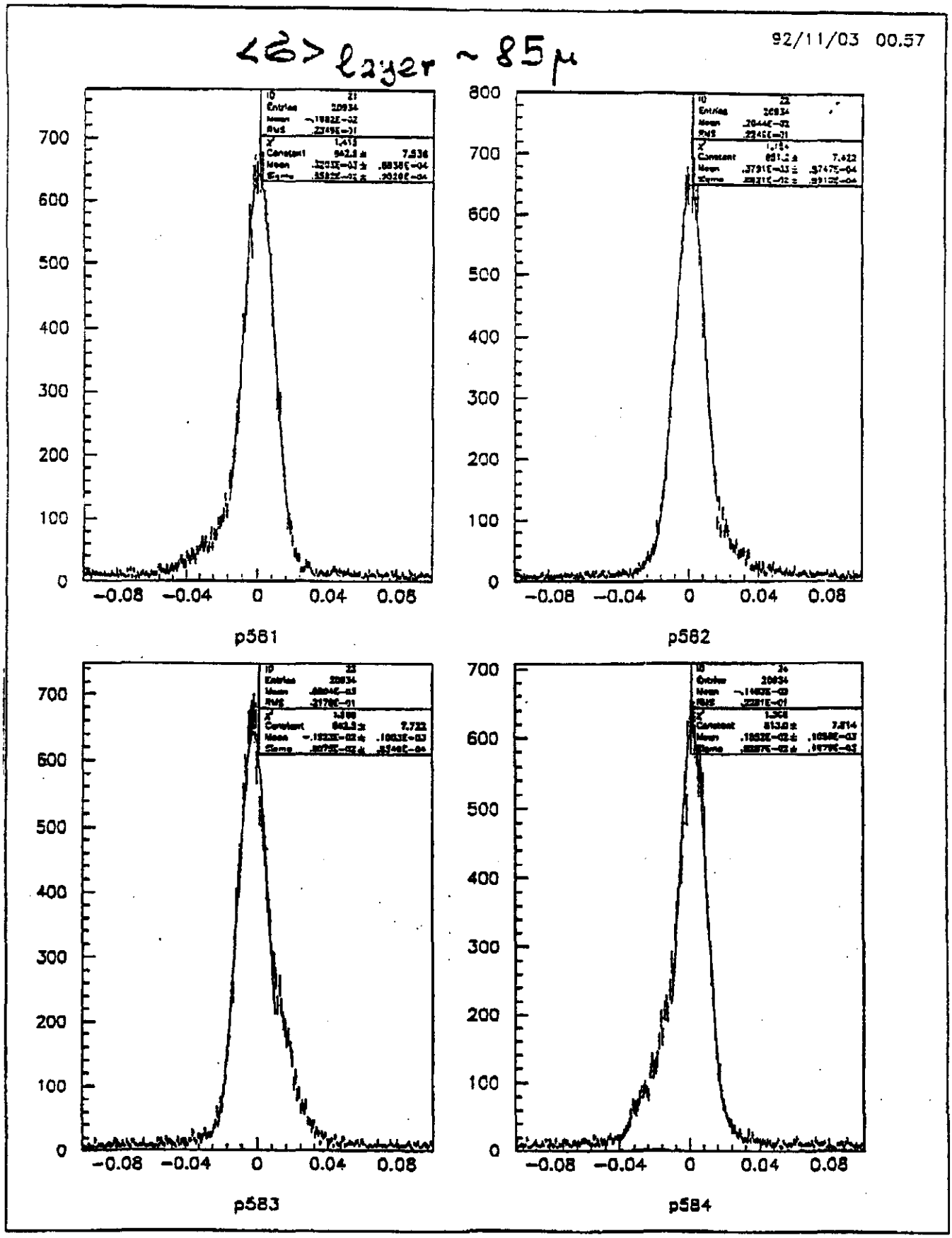
U_A kV	Layer / Mode	1	2	3	4	1...4
		Δ	Δ	Δ	Δ	σ
4.1	prop.	(+34)	(−52)	(+12)	(+10)	95
4.5	streamer	(+34)	(−57)	(+10)	(+12)	82

σ –space resolution (μm)

Δ –systematic shift (μm)

Fig. 7

DUBNA RDT: Ar-C_4H_{10} (25/75) at 1atm



ASYMMETRICAL TAILS ARE DUE TO DISPLACEMENT OF WIRES !

Residuals as a function of tube number

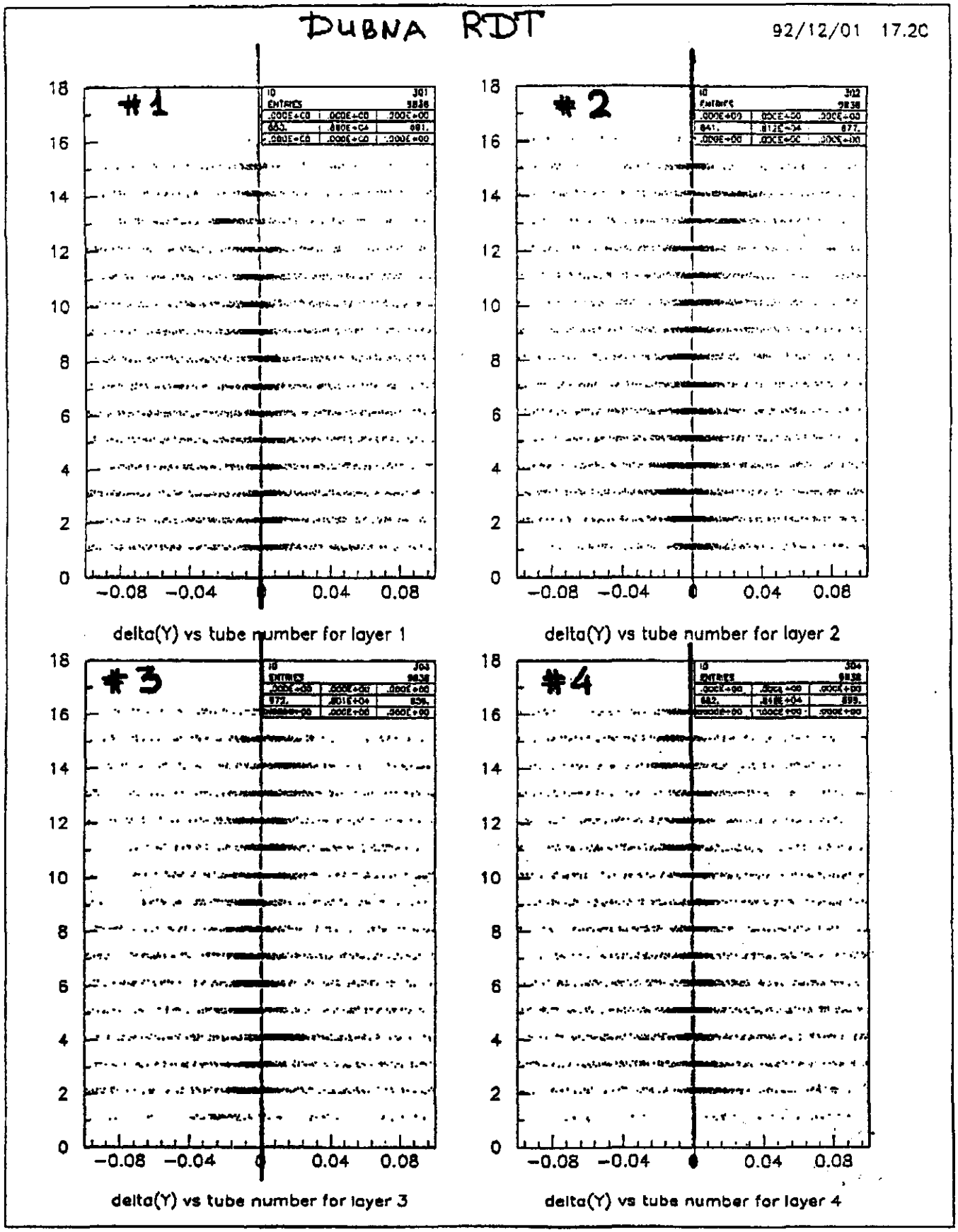


Fig. 9(a)

Residuals as a function of tube number
(after parallel shifts of wires)

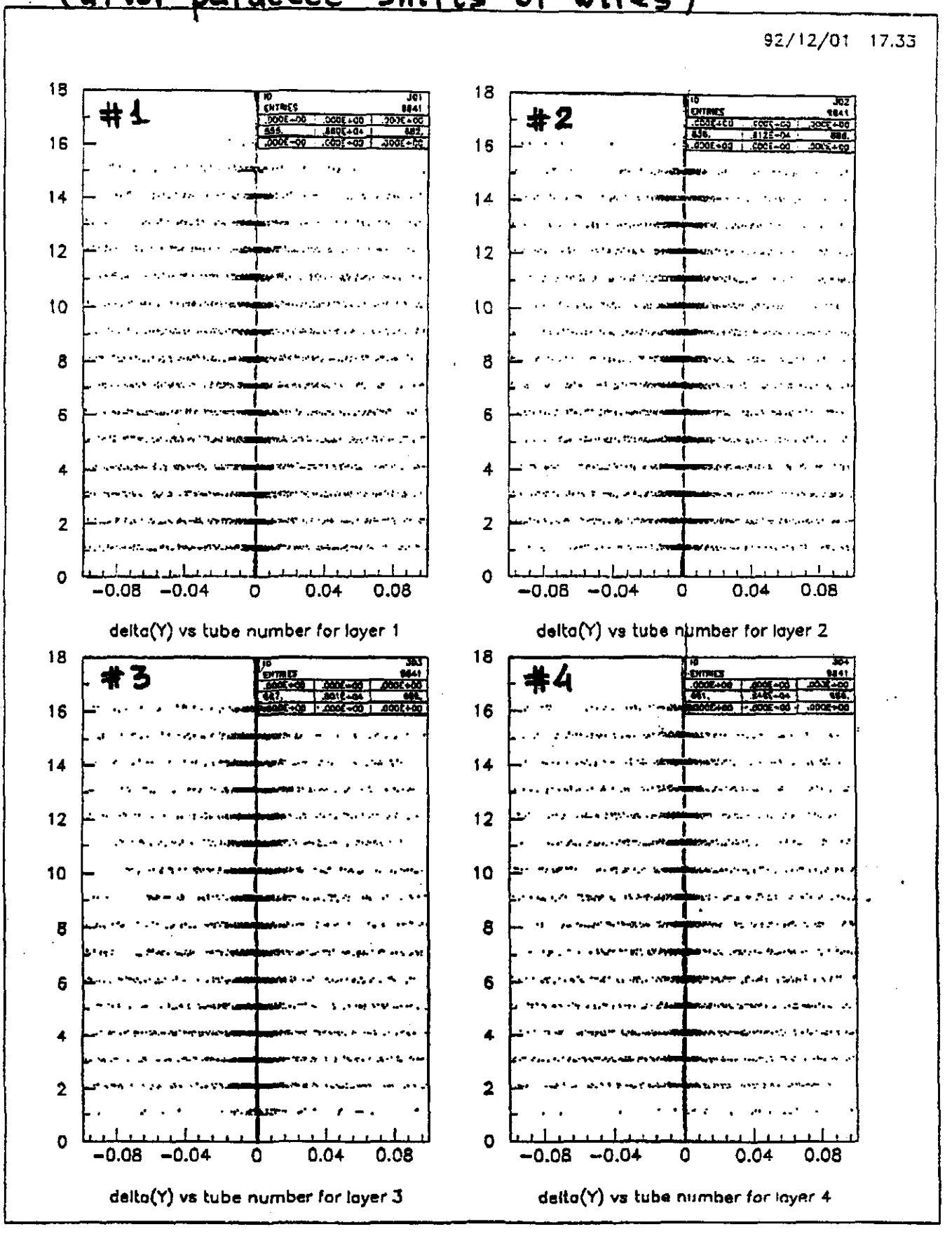


Fig. 9(b)

Rotation of layers

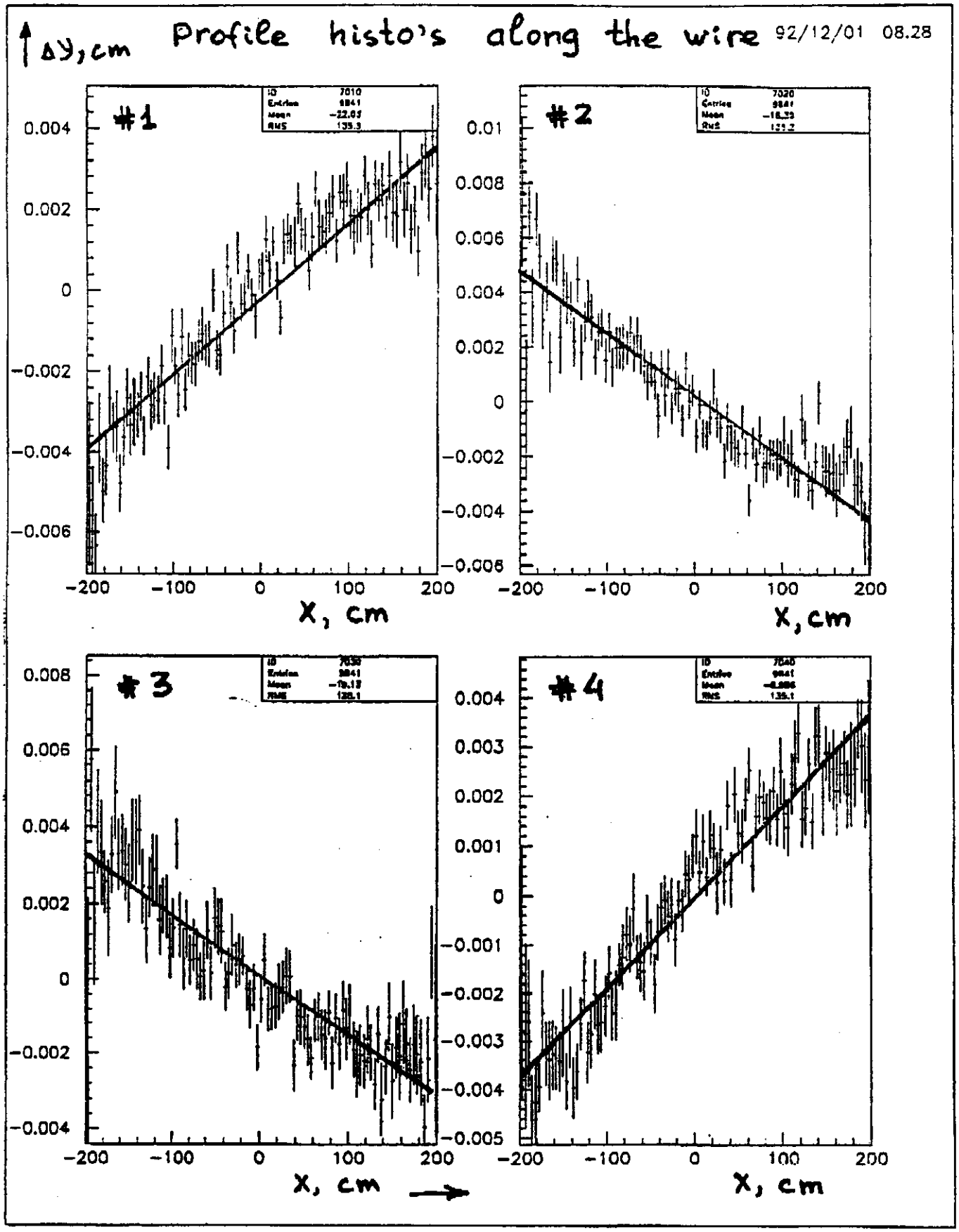
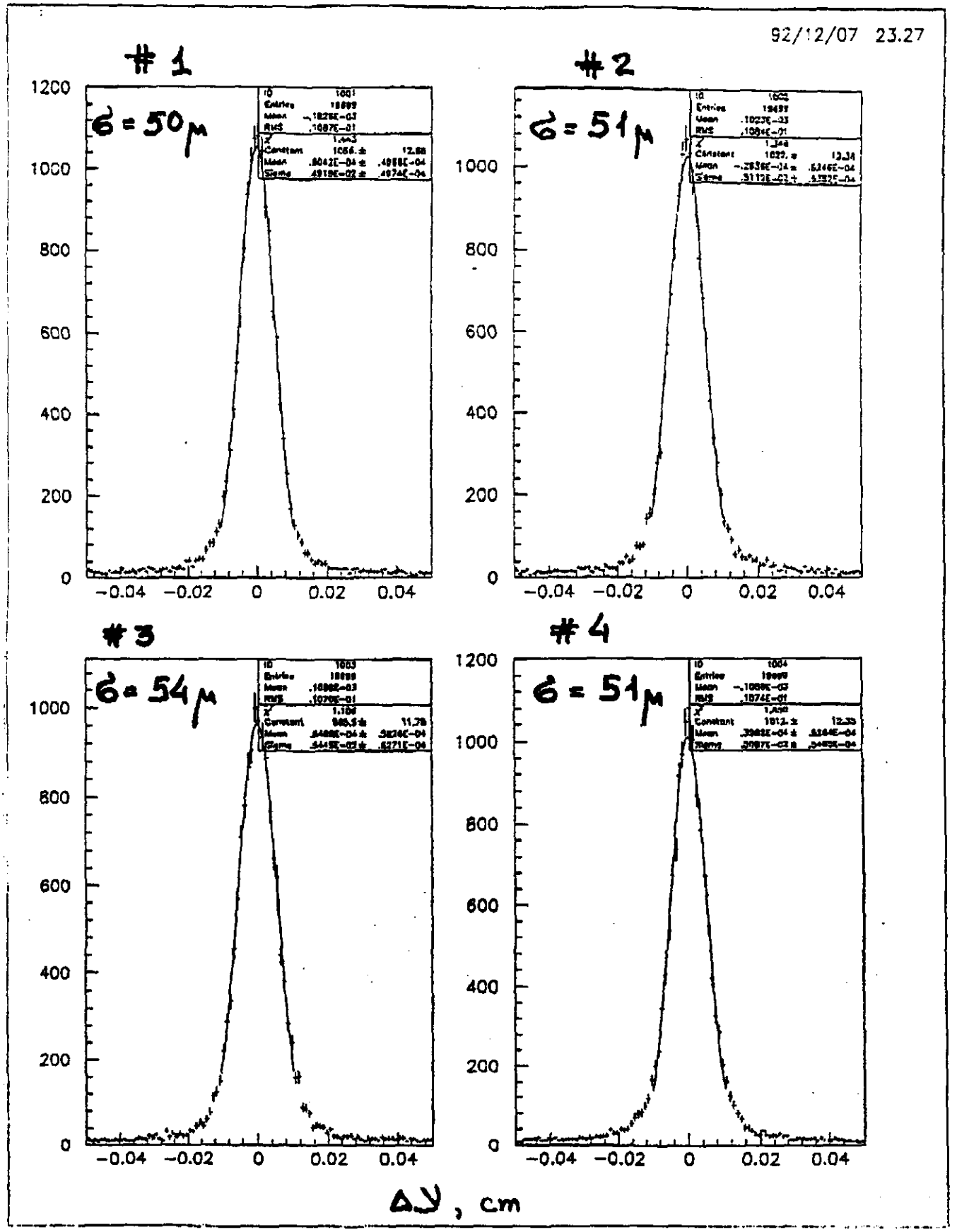


Fig. 10

RESIDUALS FOR DIFFERENT LAYERS



$Ar-C_2H_6$ at 4.8 atm

Resolution as a function of pressure

$Ar-C_2H_6$ (50/50)

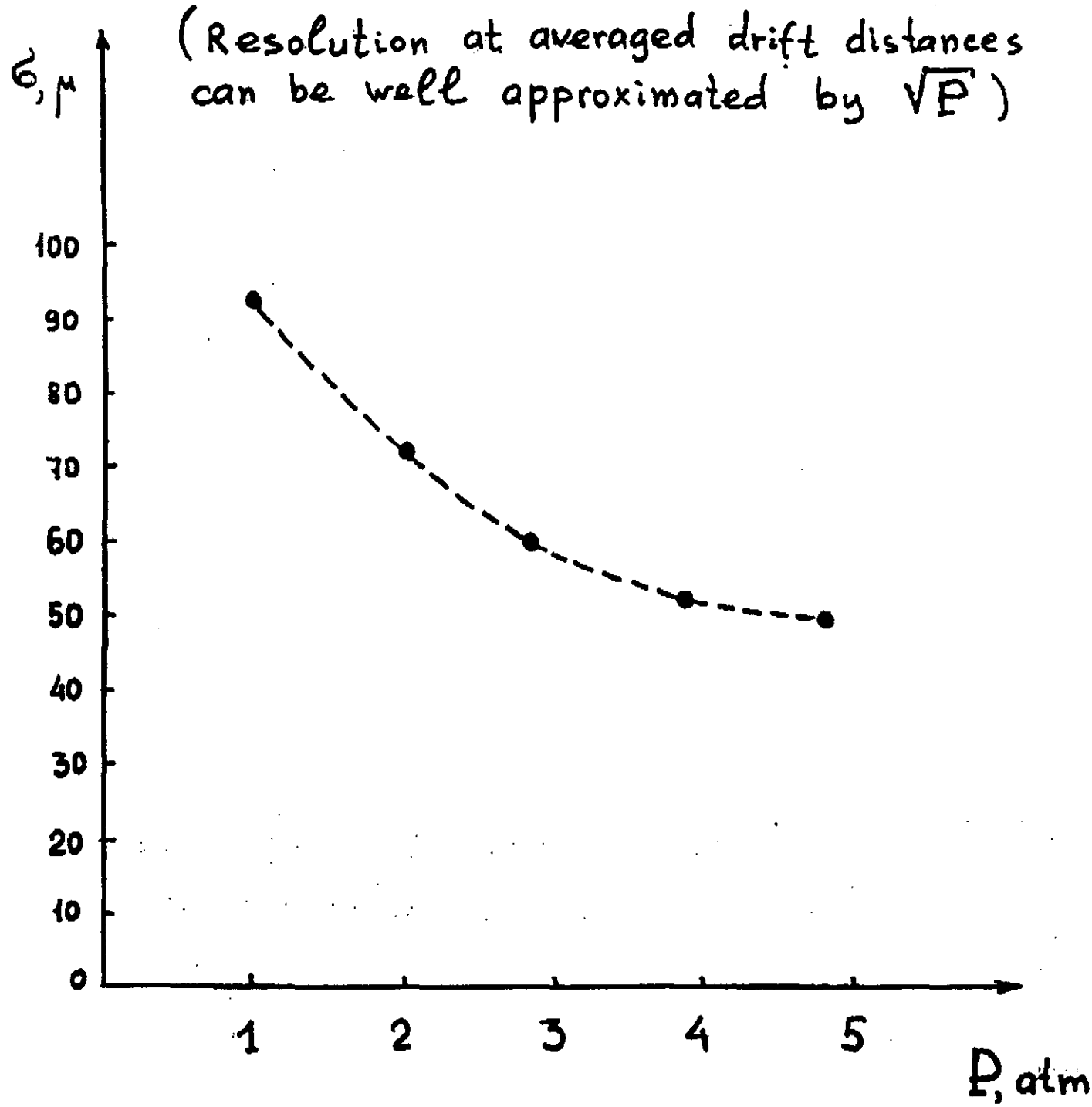
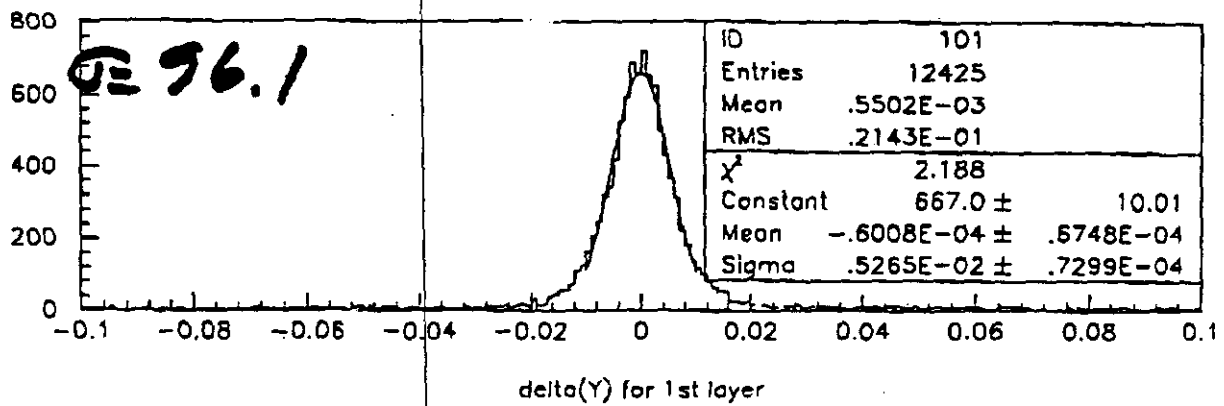


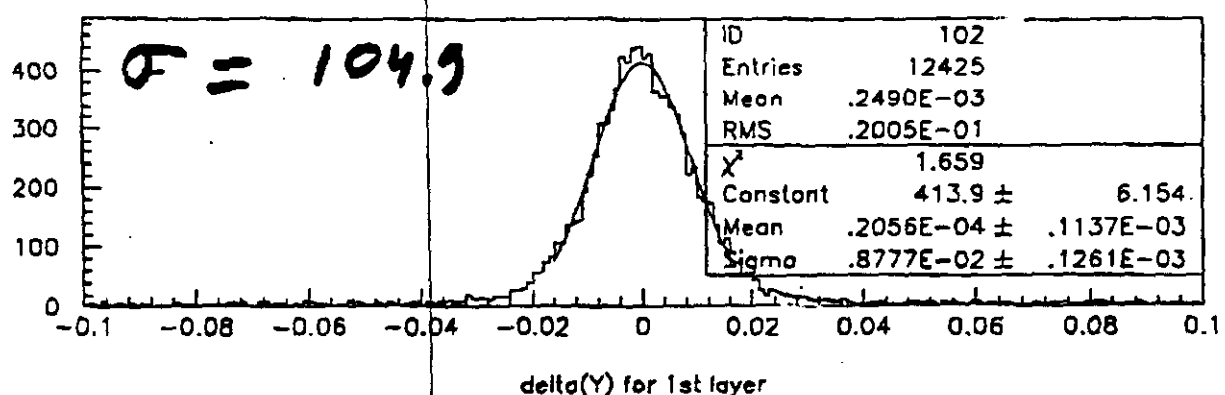
Fig. 12

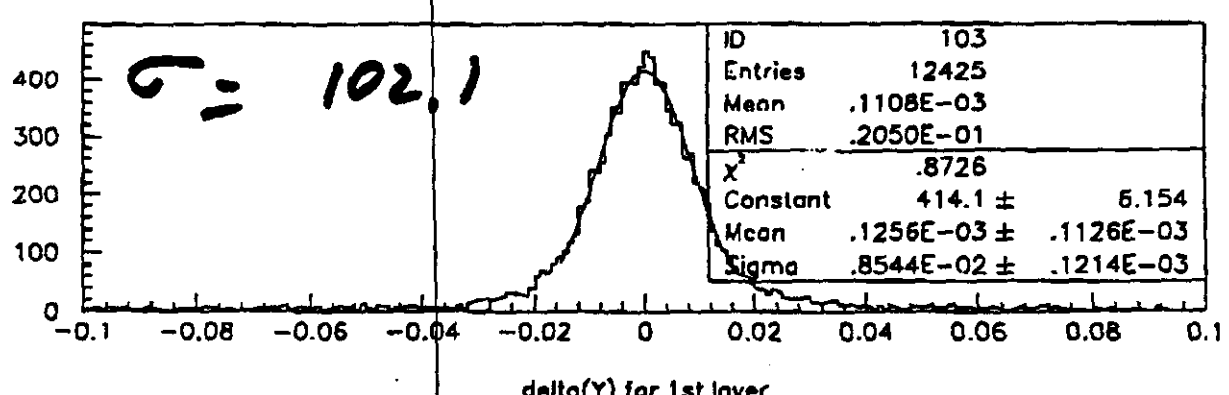
MSU PDT RUN 388

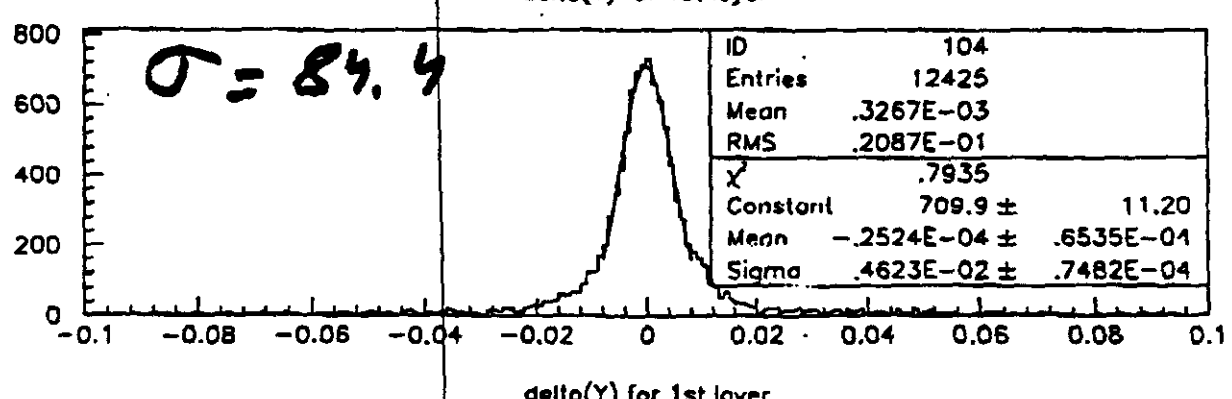
RESOLUTION

92/12/10 23.59









$\langle \sigma \rangle = 97 \pm 9\ \mu$

Fig. 13

RUN 388 Y-RESIDUALS FROM GLOBAL TRACK (PDTU)

92/12/15 15.29

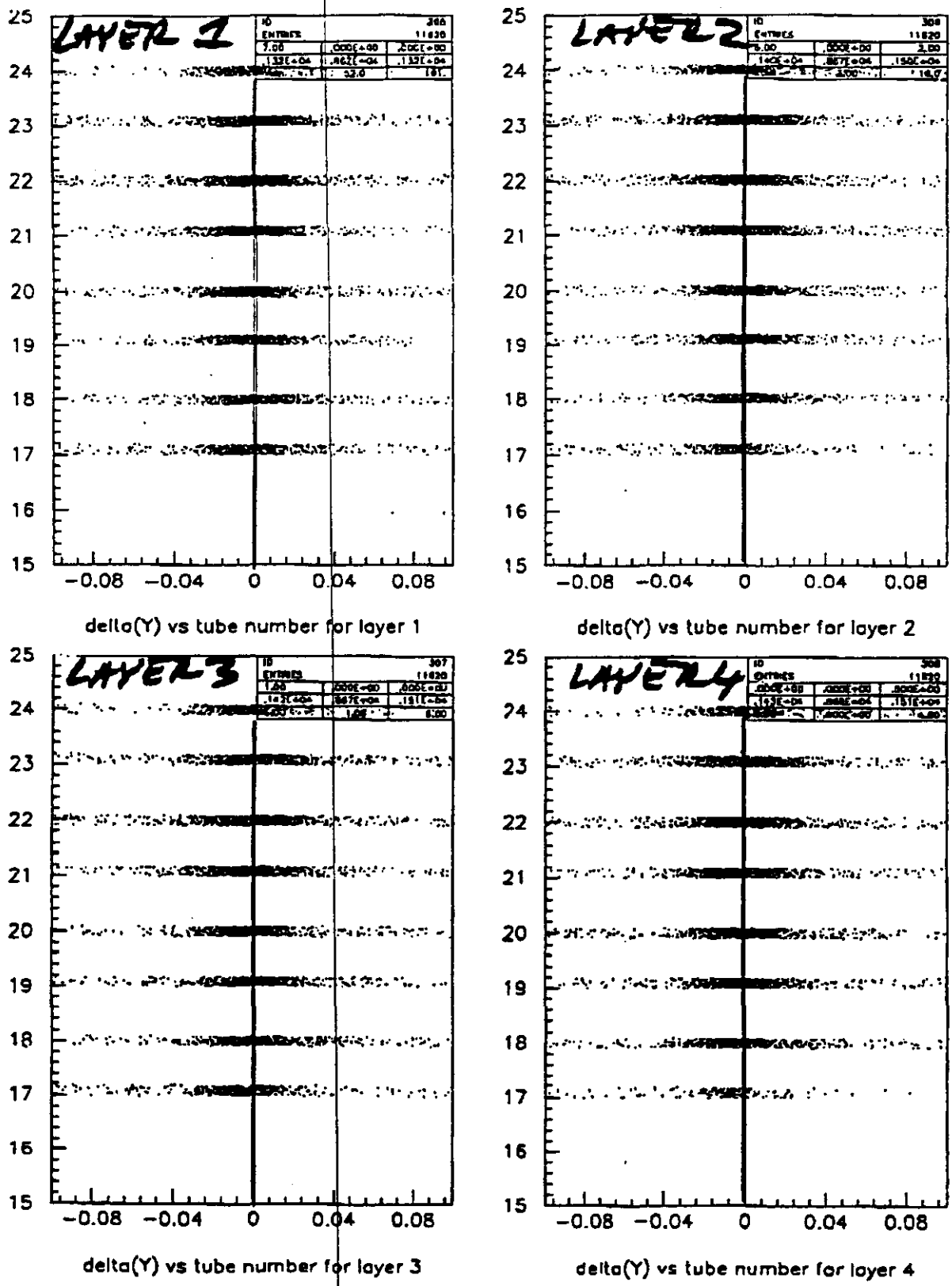


Fig. 14

MSU PROTOTYPE

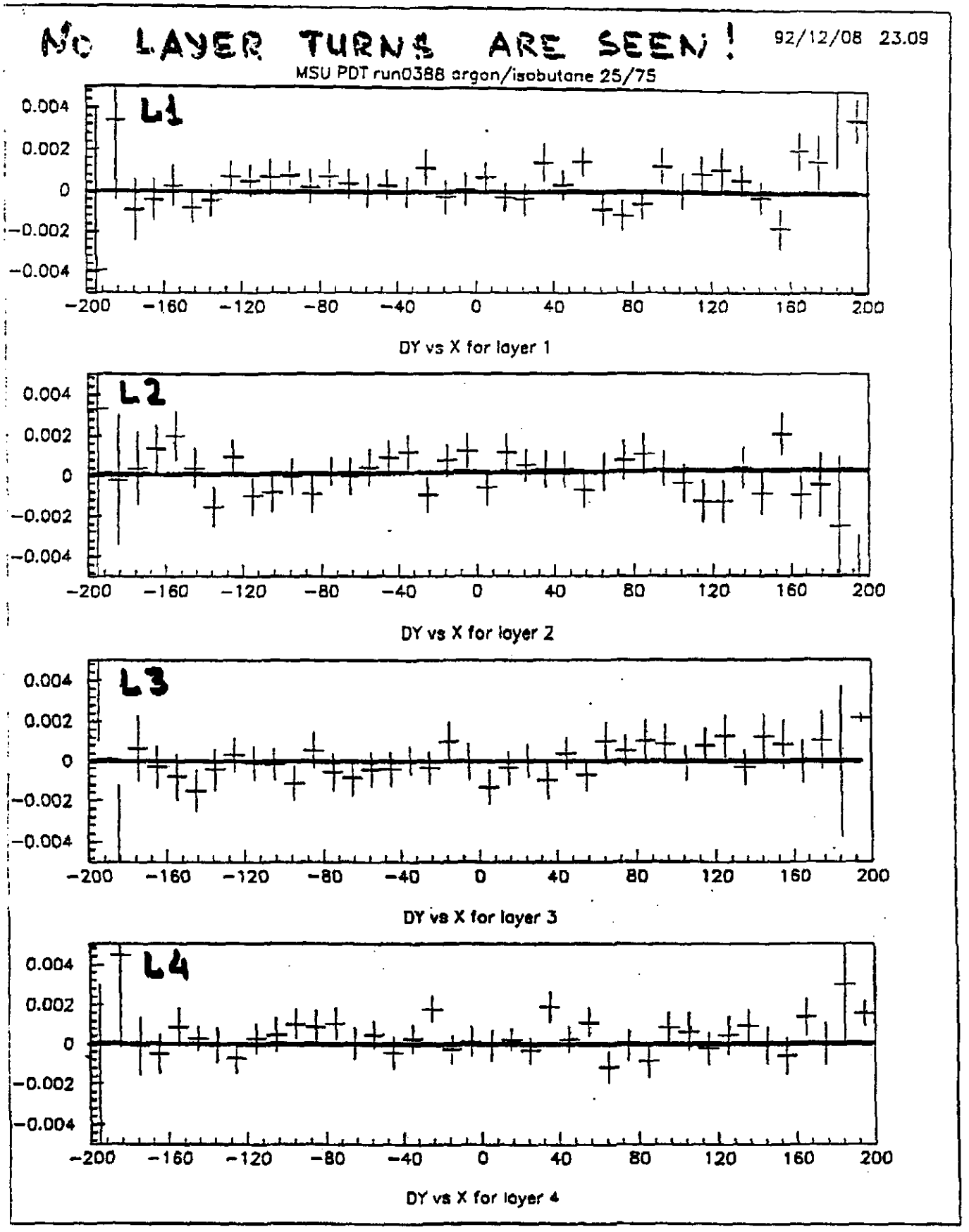


Fig. 15

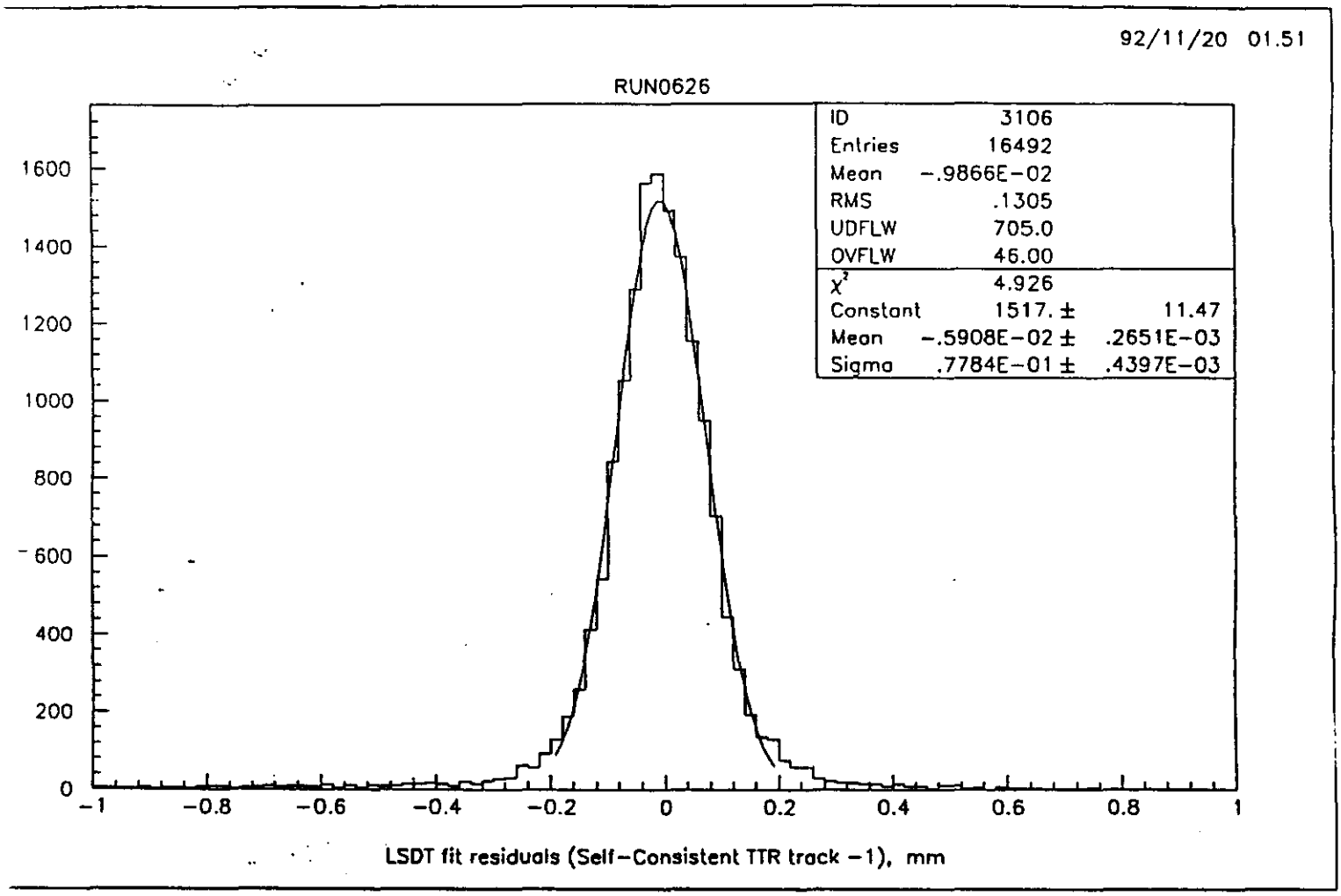

92/11/20 01.51
RUN0626
ID 3106
Entries 16492
Mean −.9866E−02
RMS .1305
UDFLW 705.0
OVFLW 46.00
χ² 4.926
Constant 1517. ± 11.47
Mean −.5908E−02 ± .2651E−03
Sigma .7784E−01 ± .4397E−03
1600
1400
1200
1000
800
600
400
200
0
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1
LSDT fit residuals (Self−Consistent TTR track −1), mm

Fig. 16

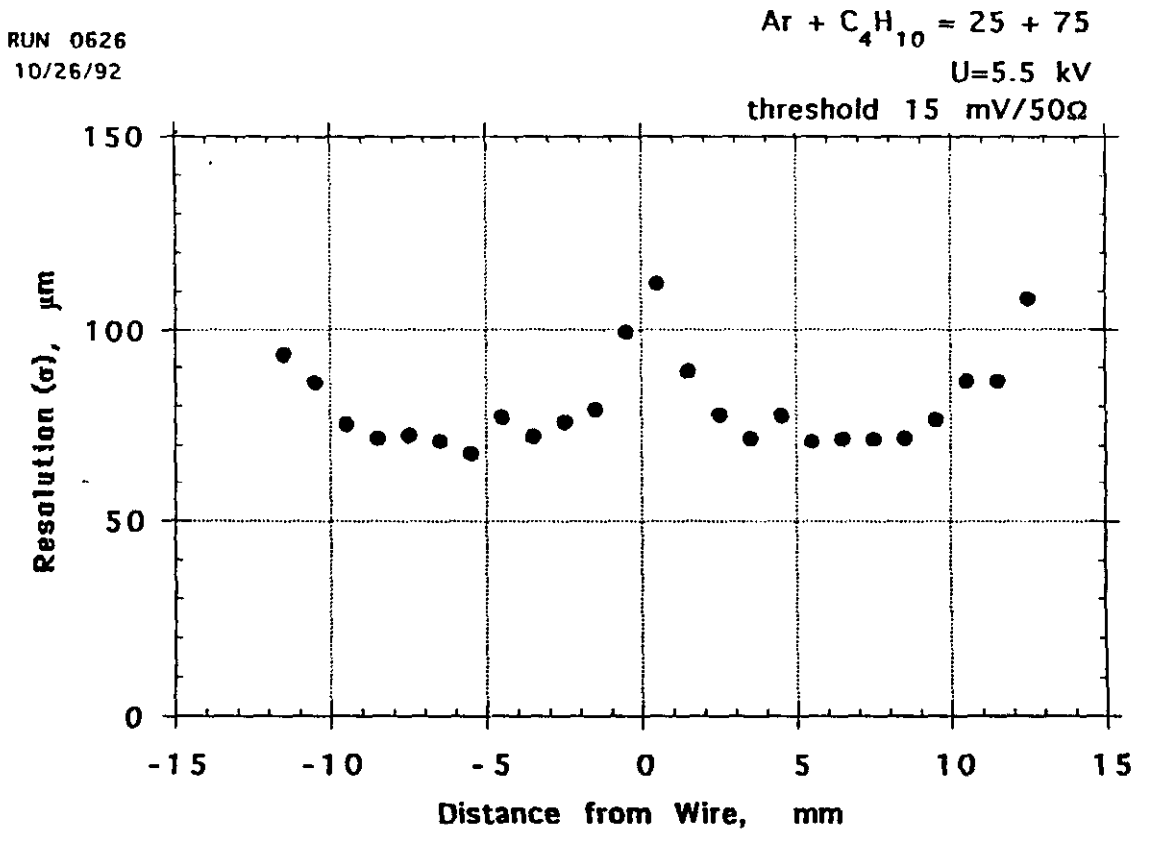

RUN 0626
10/26/92
Ar + C4H10 = 25 + 75
U=5.5 kV
threshold 15 mV/50Ω
150
100
50
0
Resolution (σ), μm
-15
-10
-5
0
5
10
15
Distance from Wire, mm

Fig. 17

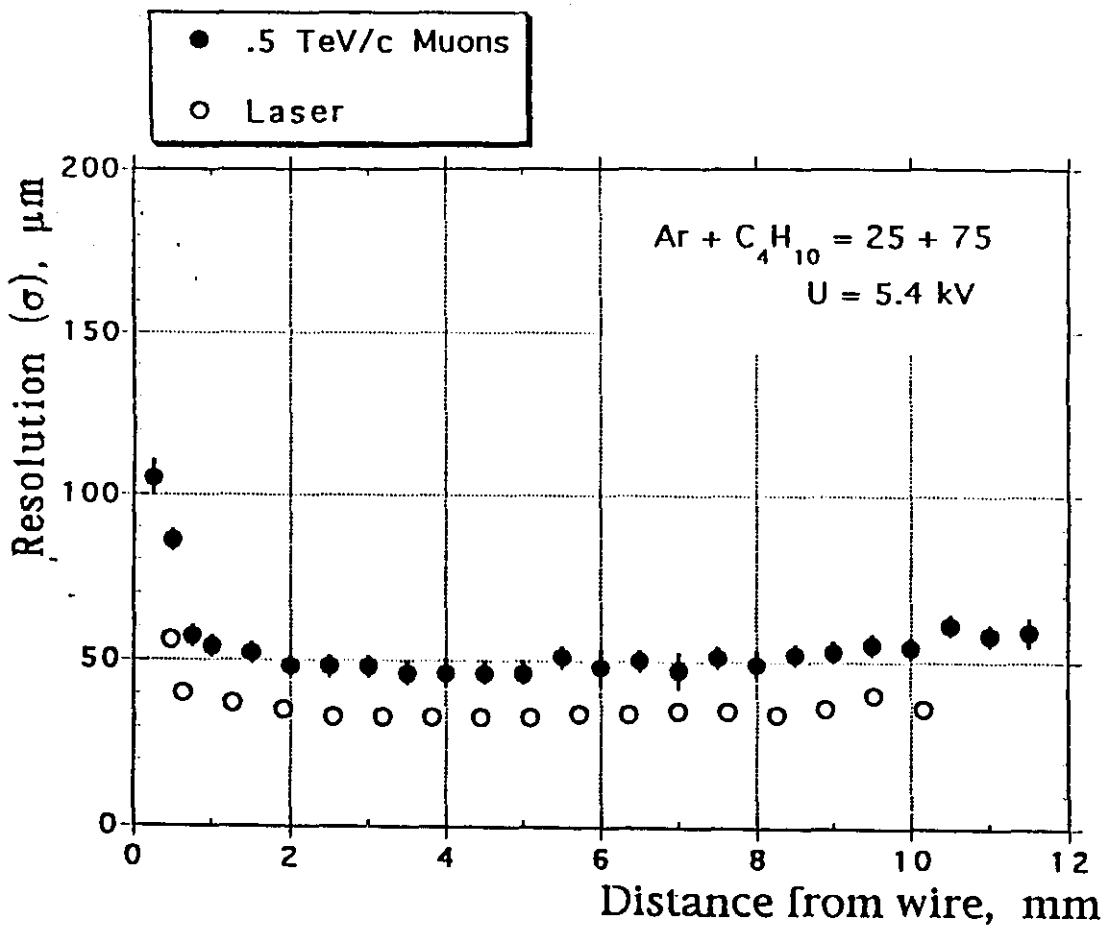

.5 TeV/c Muons
Laser
Ar + C_4H_{10} = 25 + 75
U = 5.4 kV
Resolution (σ), μm
200
150
100
50
0
0
2
4
6
8
10
12
Distance from wire, mm

Fig. 18

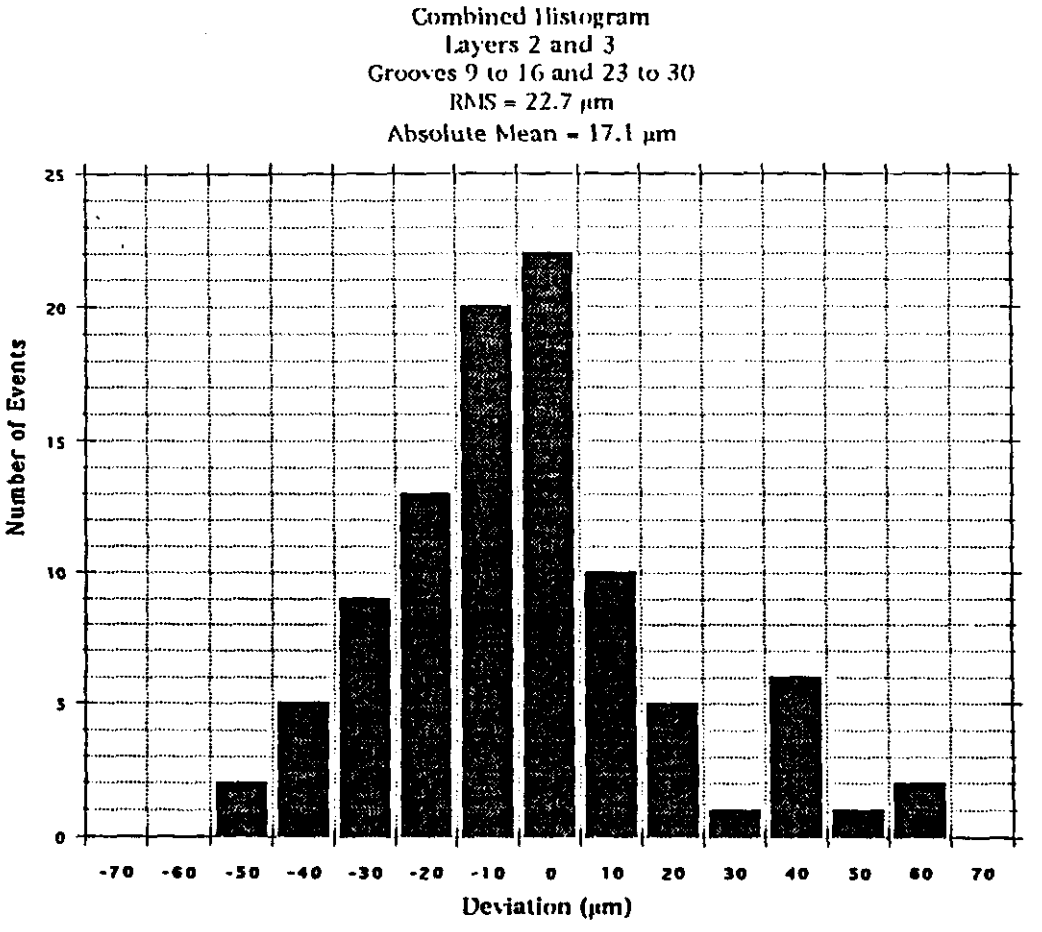

Combined Histogram
Layers 2 and 3
Grooves 9 to 16 and 23 to 30
RMS = 22.7 μm
Absolute Mean = 17.1 μm
Number of Events
0
5
10
15
20
25
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
Deviation (μm)

Fig. 19

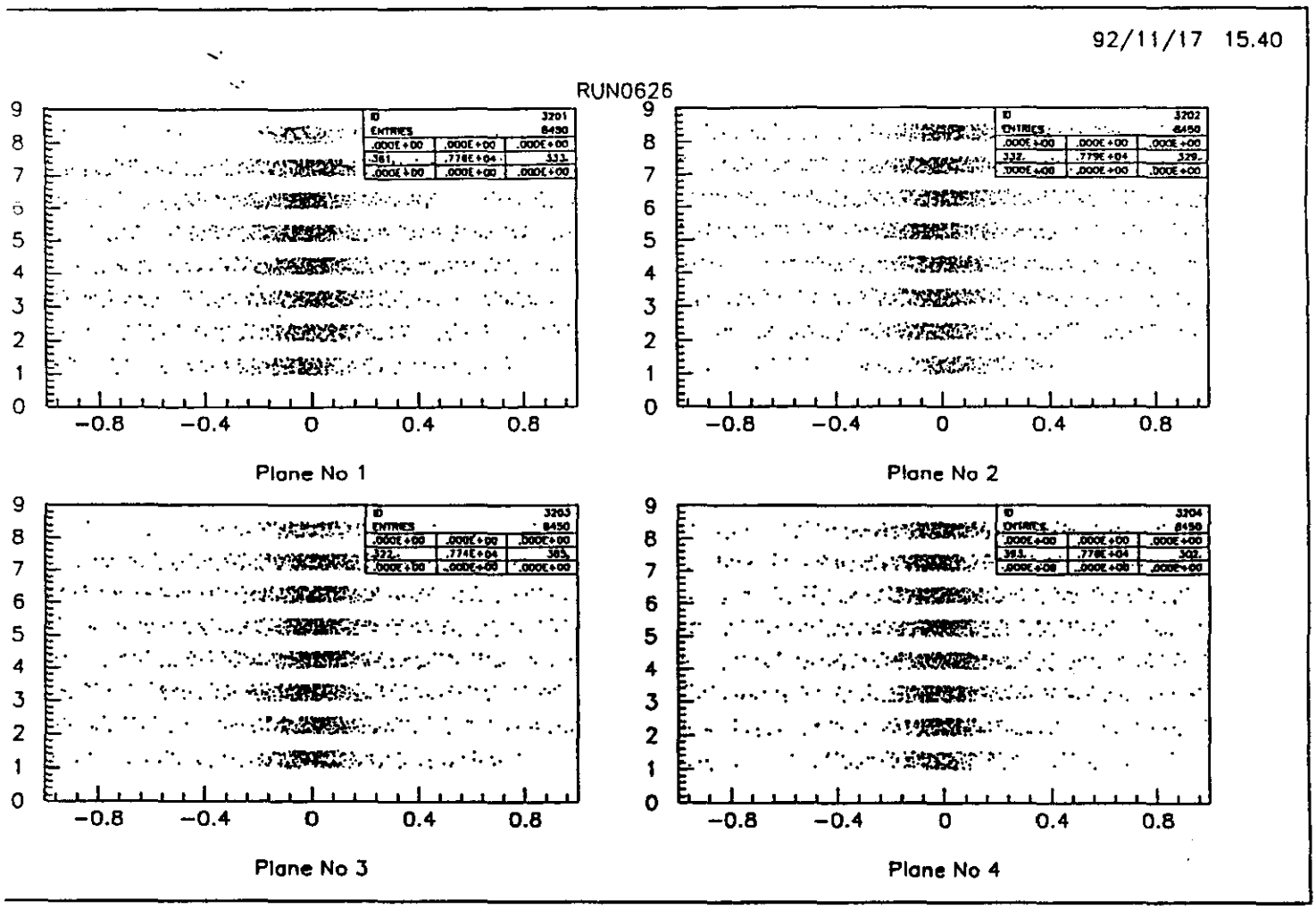


Fig 20(a)

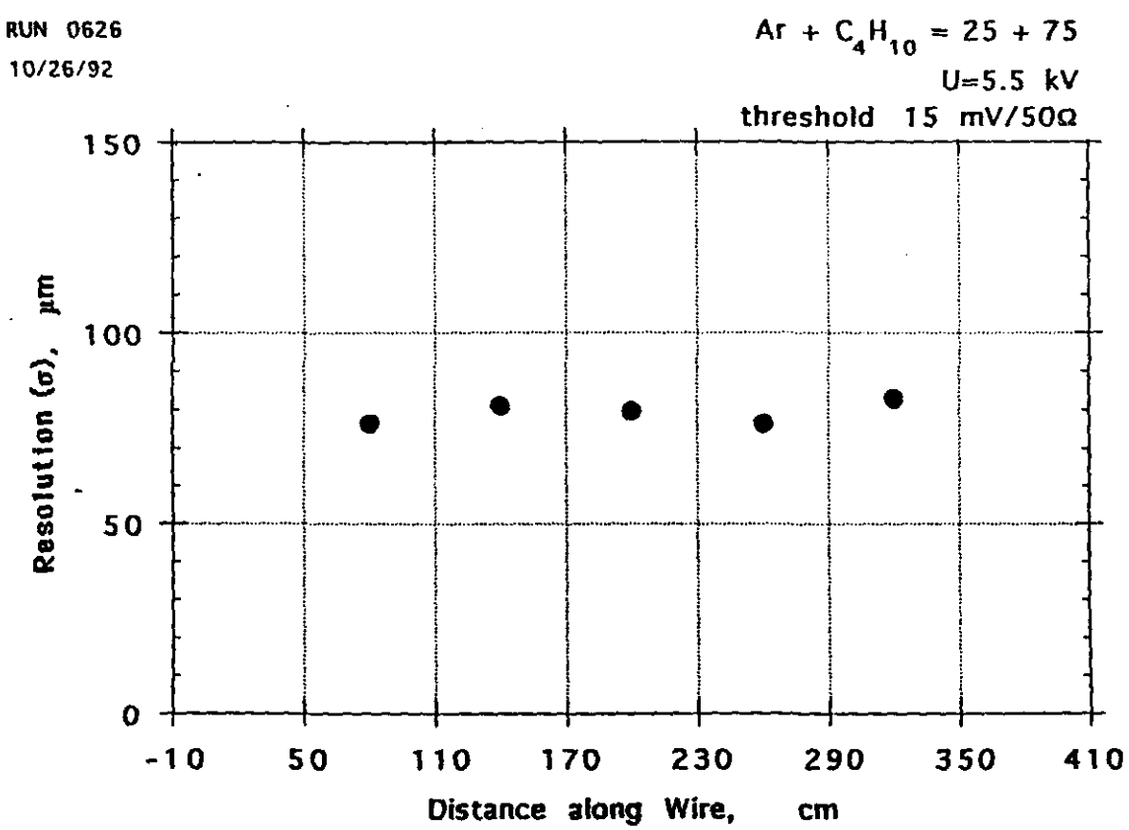

RUN 0626
10/26/92
Ar + C_4H_{10} = 25 + 75
U=5.5 kV
threshold 15 mV/50Ω
150
100
50
0
Resolution (σ), μm
-10
50
110
170
230
290
350
410
Distance along Wire, cm

Fig. 20 (b)

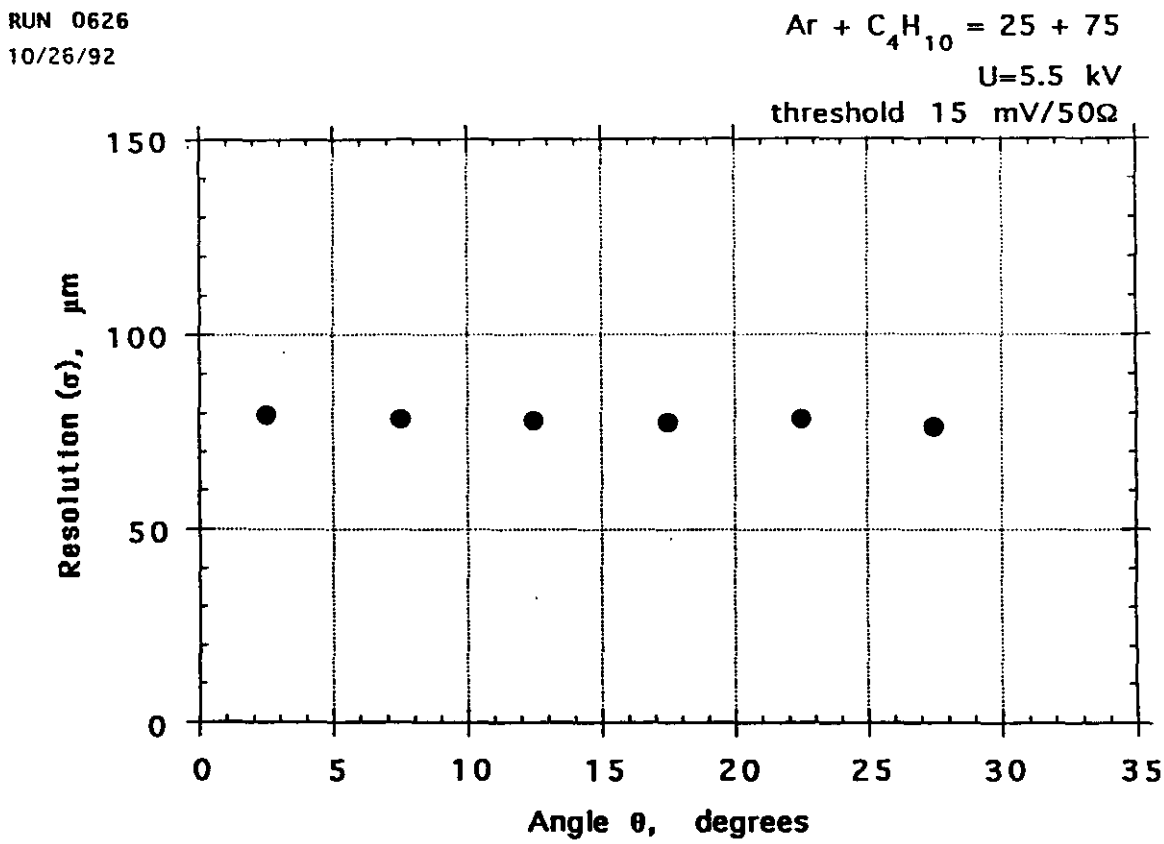

RUN 0626
10/26/92
Ar + C4H10 = 25 + 75
U=5.5 kV
threshold 15 mV/50Ω
150
100
50
0
Resolution (σ), μm
0
5
10
15
20
25
30
35
Angle θ, degrees

Fig. 20(c)

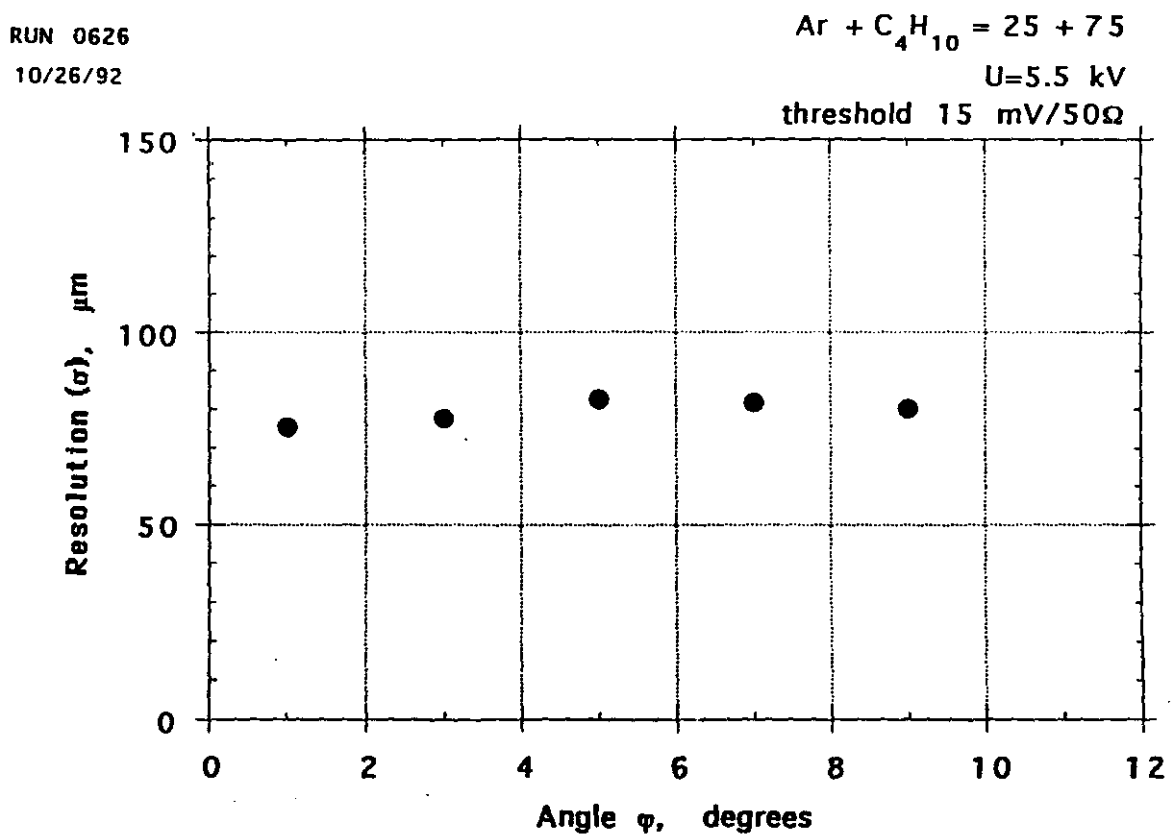

RUN 0626
10/26/92
Ar + C4H10 = 25 + 75
U=5.5 kV
threshold 15 mV/50Ω
150
100
50
0
Resolution (σ), μm
0
2
4
6
8
10
12
Angle φ, degrees

Fig. 20(d)

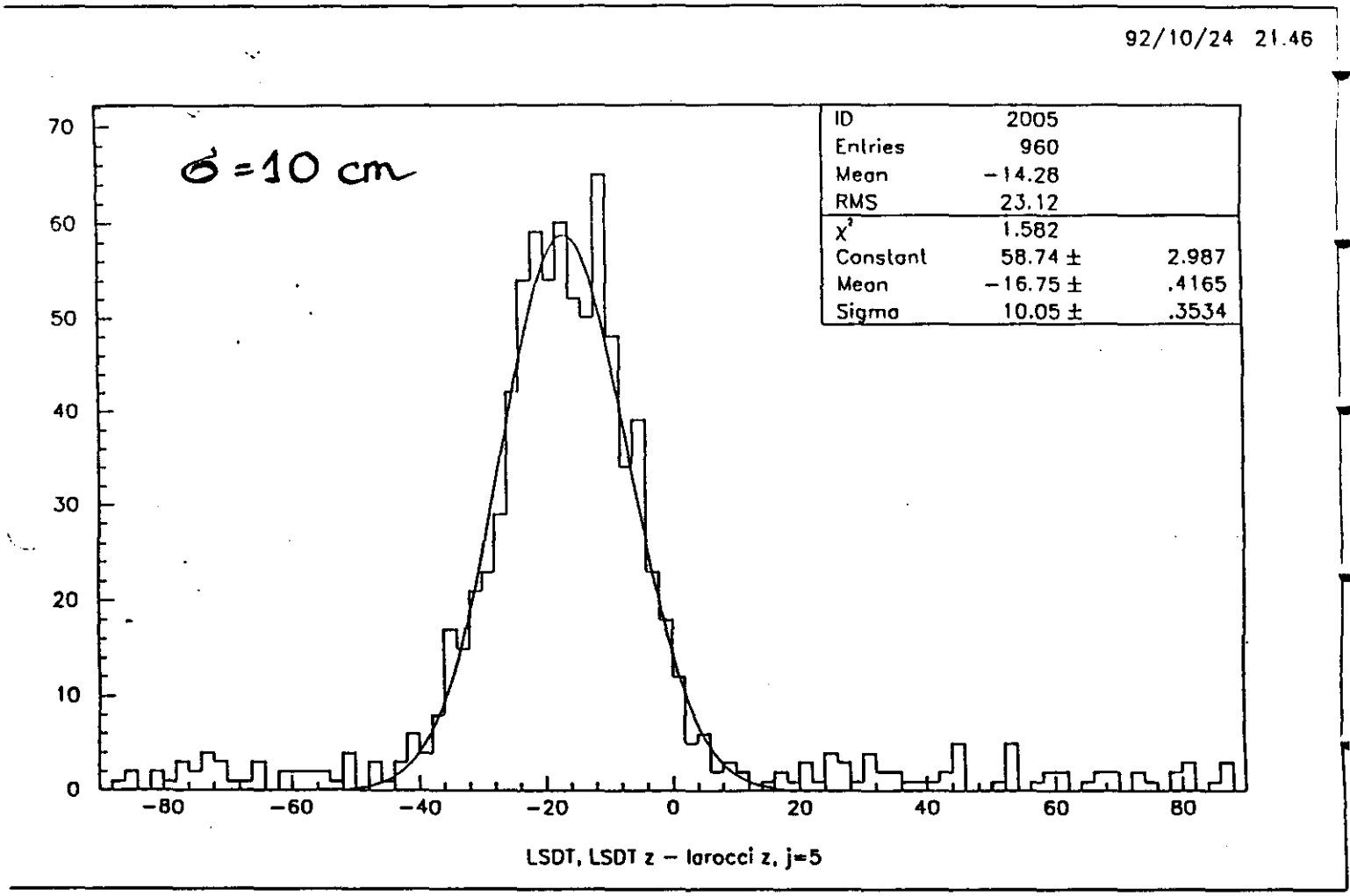

92/10/24 21.46
σ = 10 cm
ID 2005
Entries 960
Mean −14.28
RMS 23.12
χ² 1.582
Constant 58.74 ± 2.987
Mean −16.75 ± .4165
Sigma 10.05 ± .3534
70
60
50
40
30
20
10
0
−80
−60
−40
−20
0
20
40
60
80
LSDT, LSDT z − Iarocci z, j=5

Fig. 21

Conclusions:

1. A **25 μm accuracy mechanical alignment** of wires within a drift chamber is possible.

2. A **spatial resolution of 50-100 μm** is easily achievable through out the whole chamber.

3. It was demonstrated that in case of unexpected misalignment there is possibly **a way to find the geometrical corrections to restore the good resolution** (some further studies are still needed).

4. **Resolution of 10 cm along a wire** is achievable by using a time difference technique.

The RPC Trigger Schemes

Presentation by:

I. Pless

IRWIN A. PLESS
18 JANUARY 1993
SSC LAB

CONCIDERATIONS FOR A GEM MUON TRIGGER

I. COST

II. BEAM CROSSING TAG

III. TRIGGER LATENCY

IV. FALSE TRIGGER RATE
- A. SEGMENTATION

V. TRIGGER RESOLUTION
- A. STRIP WIDTH
- B. CLUSTER REMOVAL
- C. END CAP SEGMENTATION

VI. DEAD TIME

VII. PROGRAMMABLE

BEAM CROSSING TAG

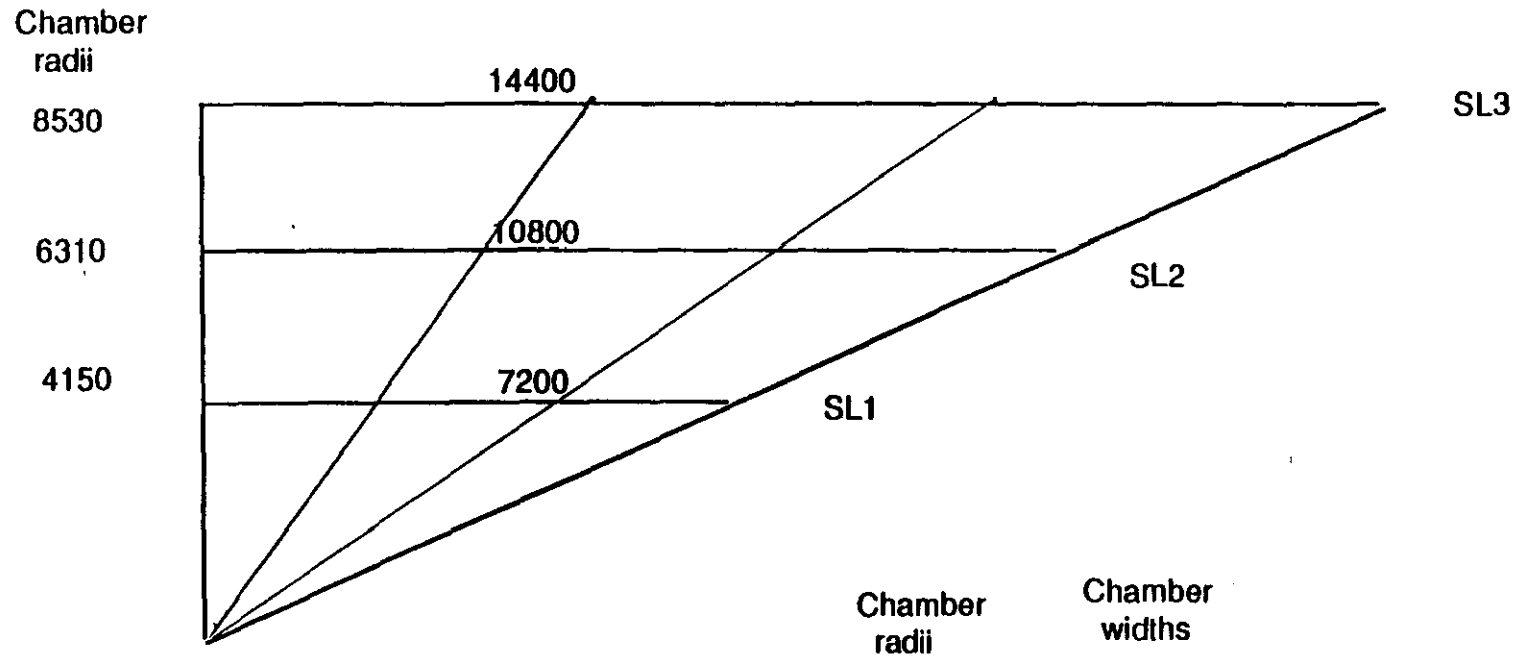
SL1	(1.4 METERS X 5)	=7 NANOSEC
CLOCK PERIOD		=4 NANOSEC
RISE TIME JITTER		=2 NANOSEC
BEND PLANE STRIP WIDTH		=1.3 CM

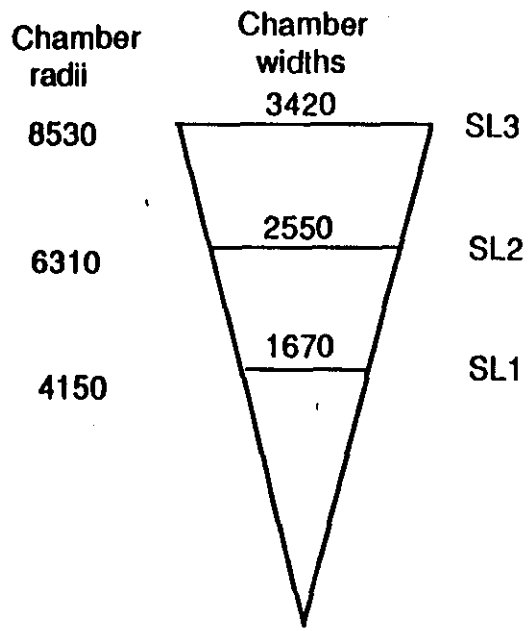
USING SL1 IN THE BEND PLANE AND SL1 IN THE NONBEND PLANE WE HAVE:

SL1 = 1.3/140 X 7 < 1 NANOSEC

WITHOUT BEND PLANE CORRECTION MAX ERROR ON CROSSING TIME =13 NANOSEC

WITH BEND PLANE CORRECTION MAX ERROR ON CROSSING TIME = 7 NANOSEC





All dimensions in millimeters

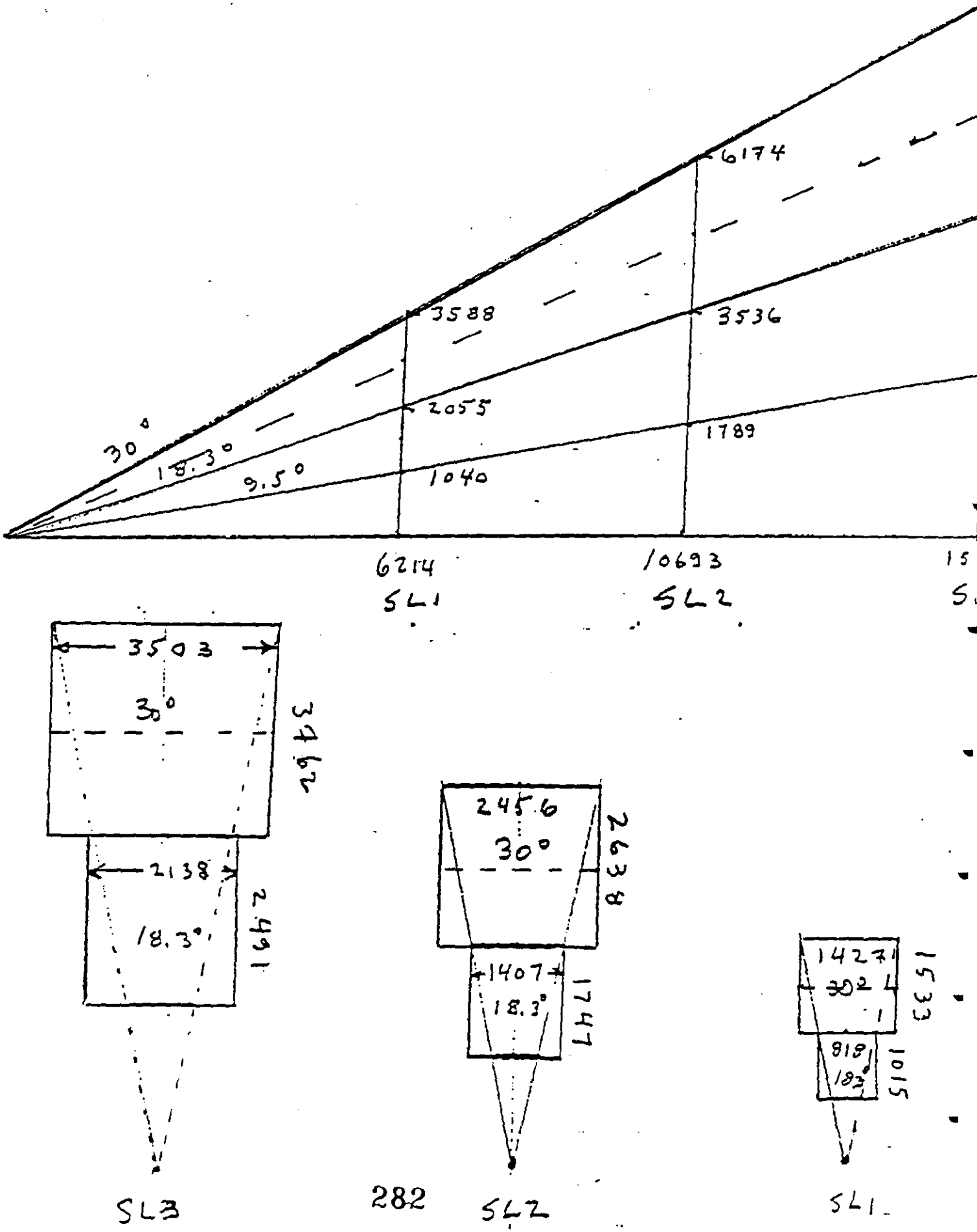
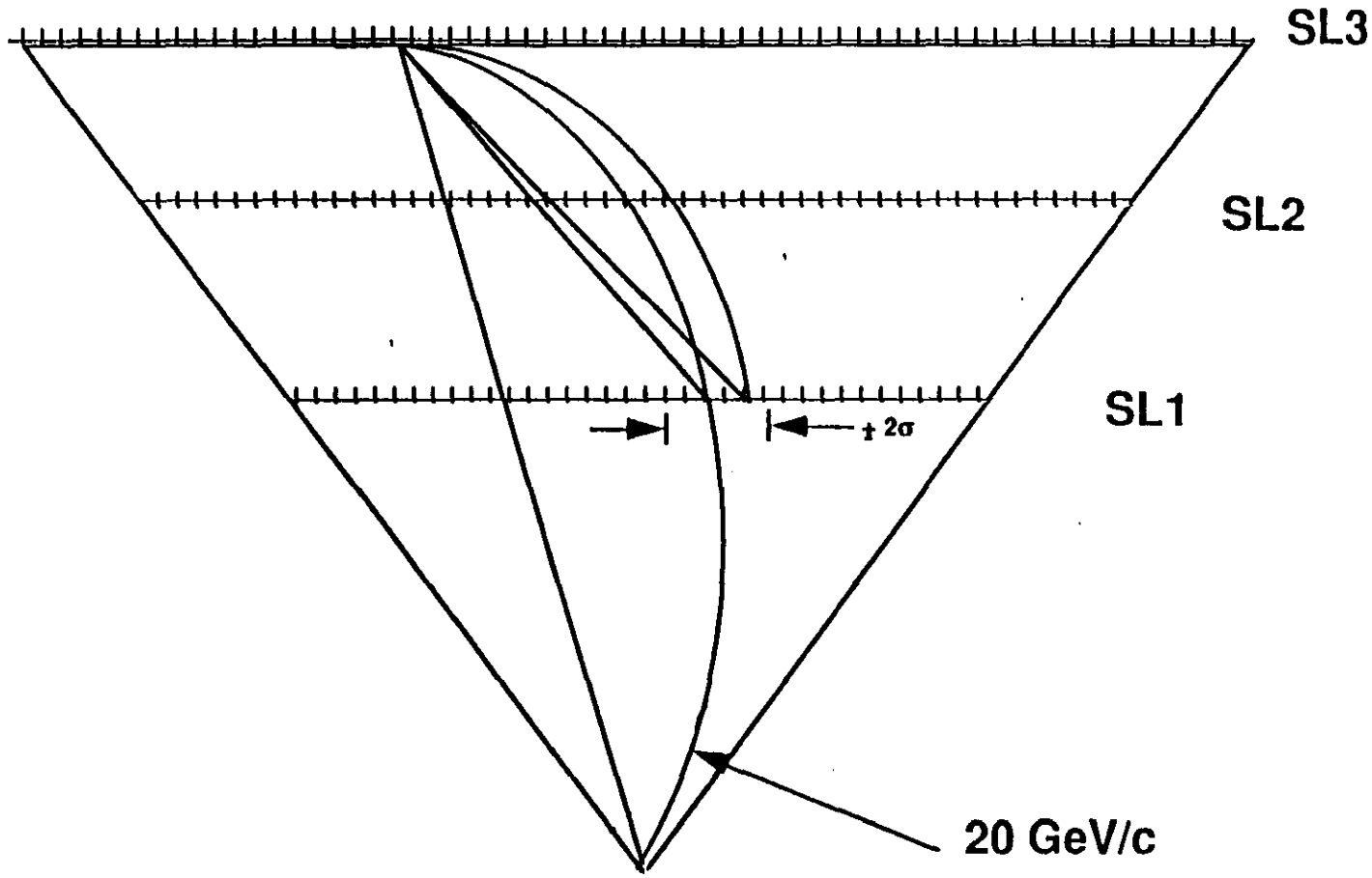
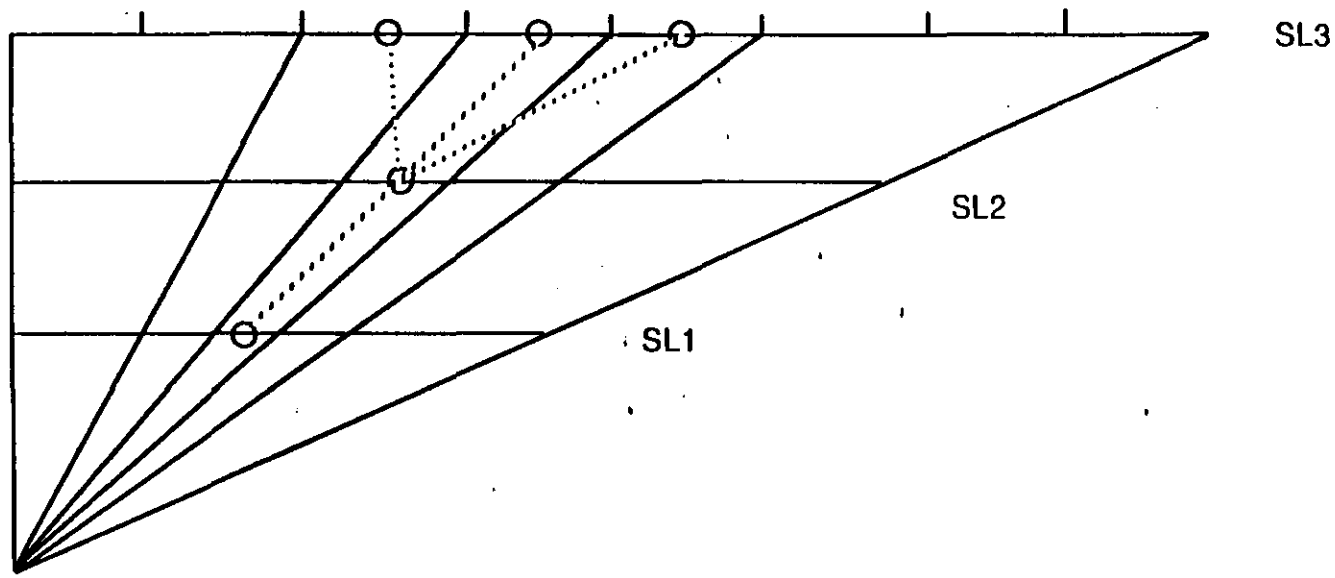

6174
3588
3536
2055
1789
1040
30°
18.3°
9.5°
6214
SL1
10693
SL2
3503
30°
3762
2138
18.3°
2491
SL3
2456
30°
2634
1407
18.3°
1747
SL2
1427
30°
1533
818
18.3°
1015
SL1

FIGURE 7

Bend Plane Trigger Geometry

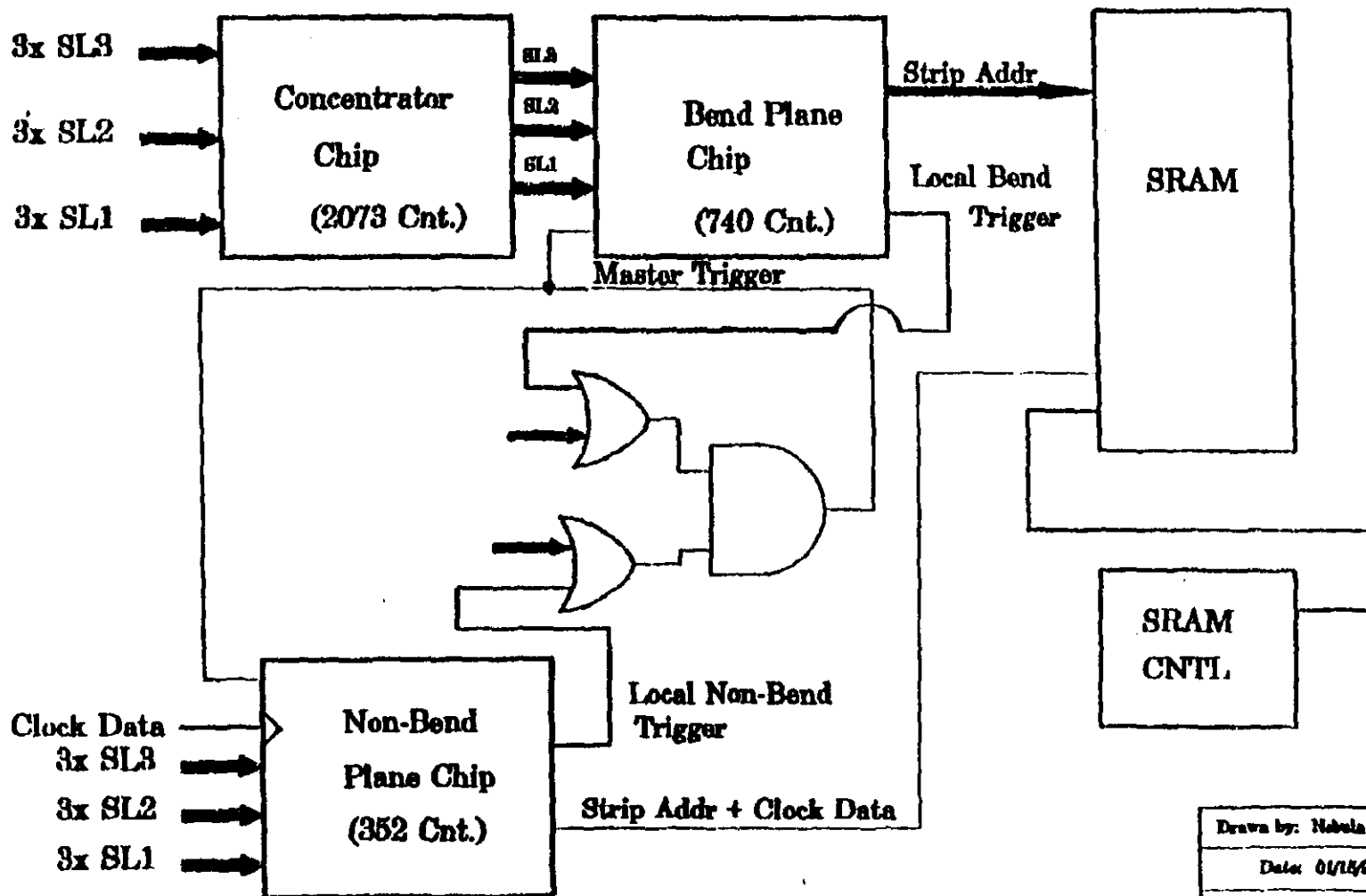



SL3
SL2
SL1

FALSE TRIGGER RATES

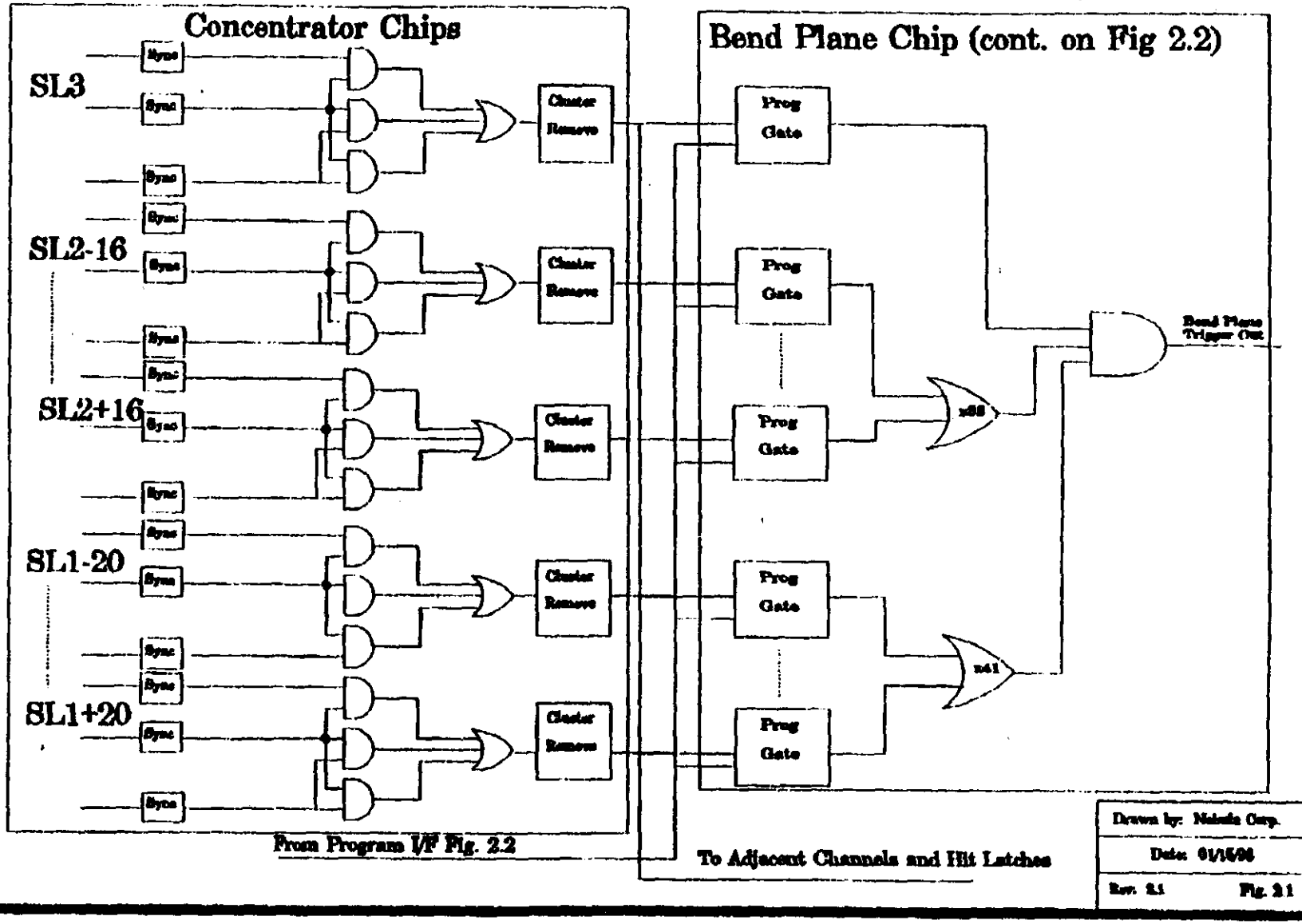
SL1	SL2	SL3	NB	TOTAL TRIGGERS	CHANNEL COUNT	COST ELECT. MILLION
1	1	1	1	$1.8X10^{4}$	100,448	$1.3
1	1	3	1	$6.0X10^{3}$	107,808	$1.3
1	3	3	1	670	112,224	$1.3
3	3	3	1	74	116,703	$1.3
1	1	1	3	372	111,072	$1.3
1	1	3	3	142	118,432	$1.3
1	3	3	3	40	122,838	$1.3
3	3	3	3	29	127,327	$1.3

SYSTEM ARCHITECTURE

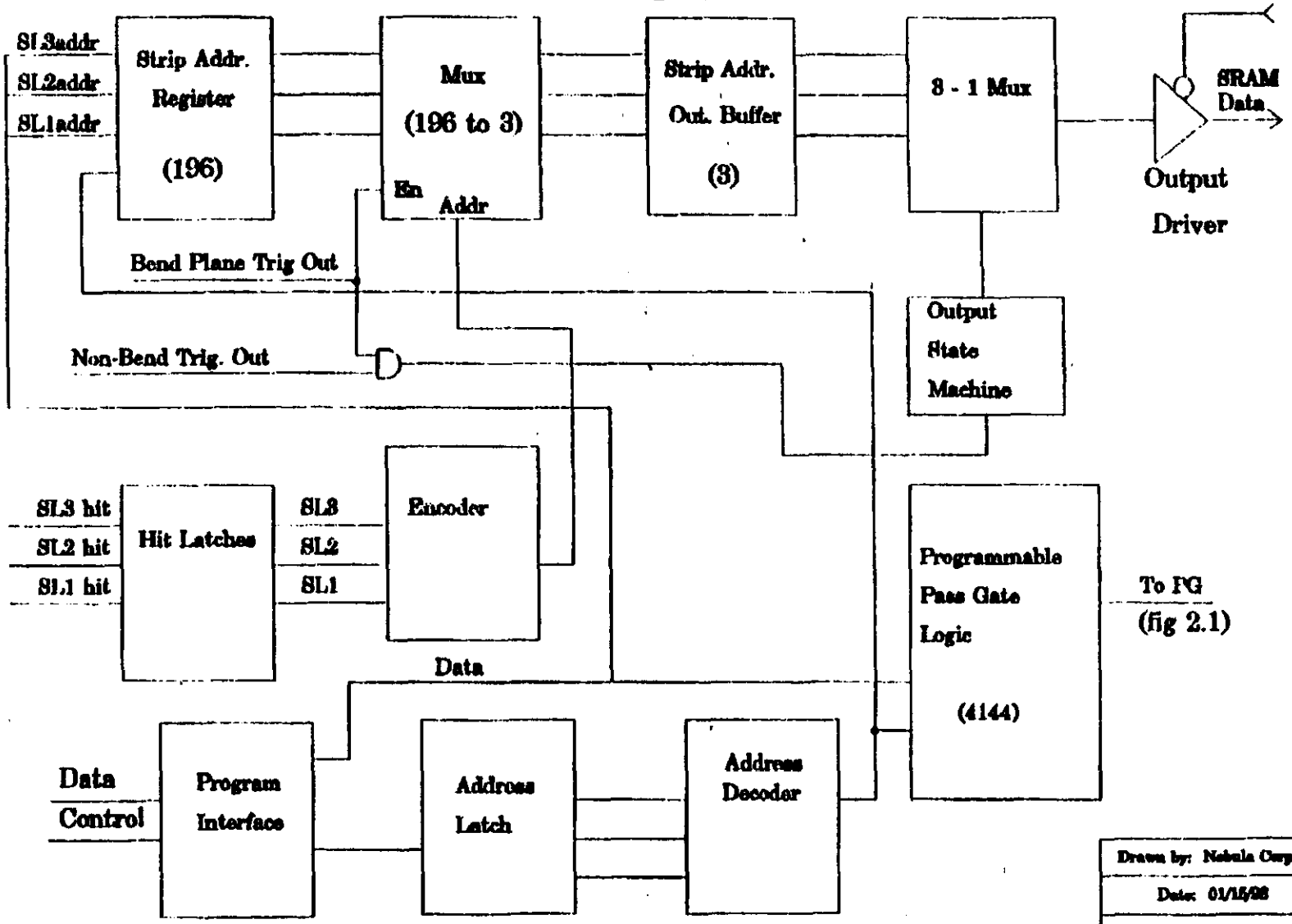


Drawn by: Nebula Corp.
Date: 01/15/96
Rev: 03 Fig. 1.0

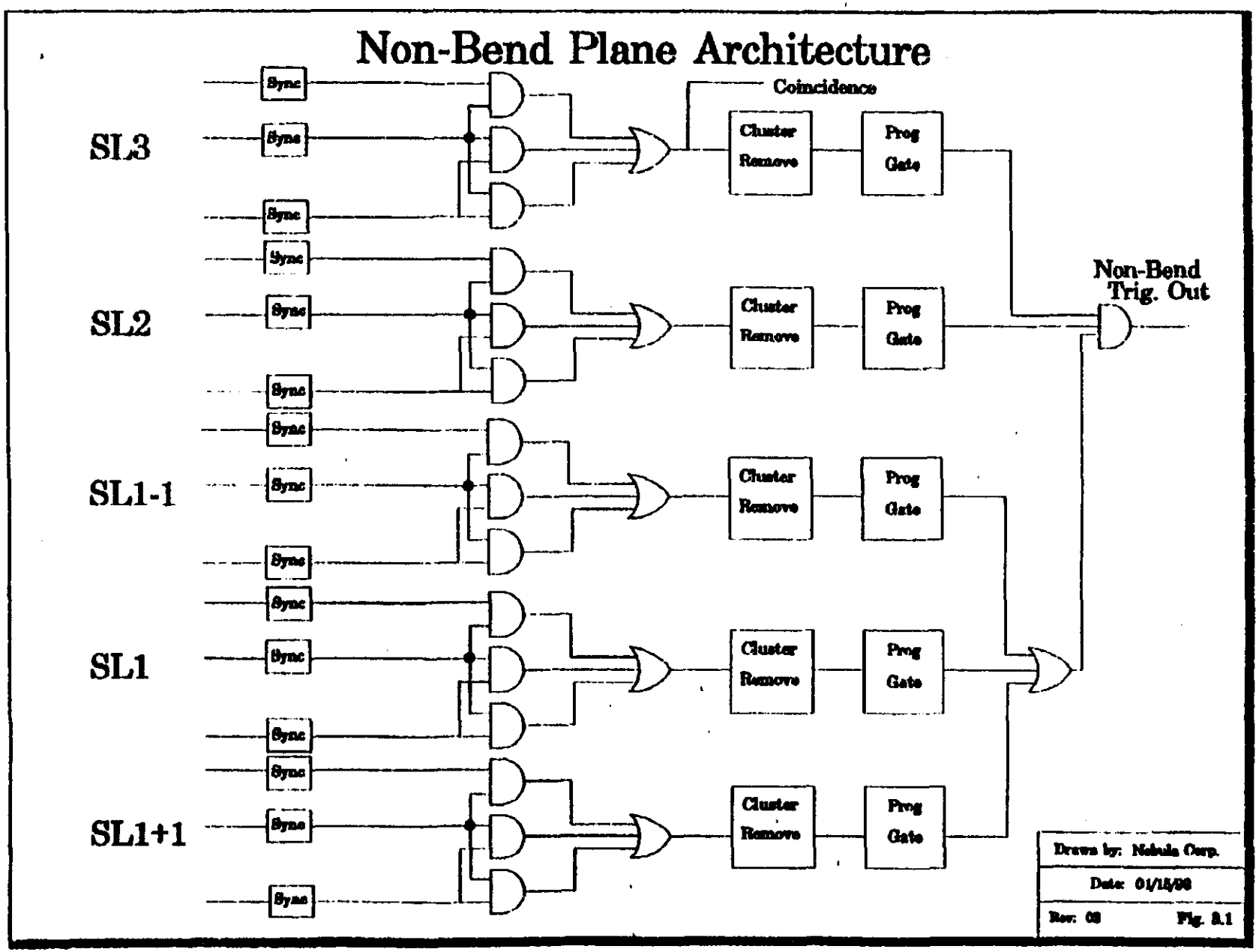
Bend Plane Architecture (1 of 56 Channels)



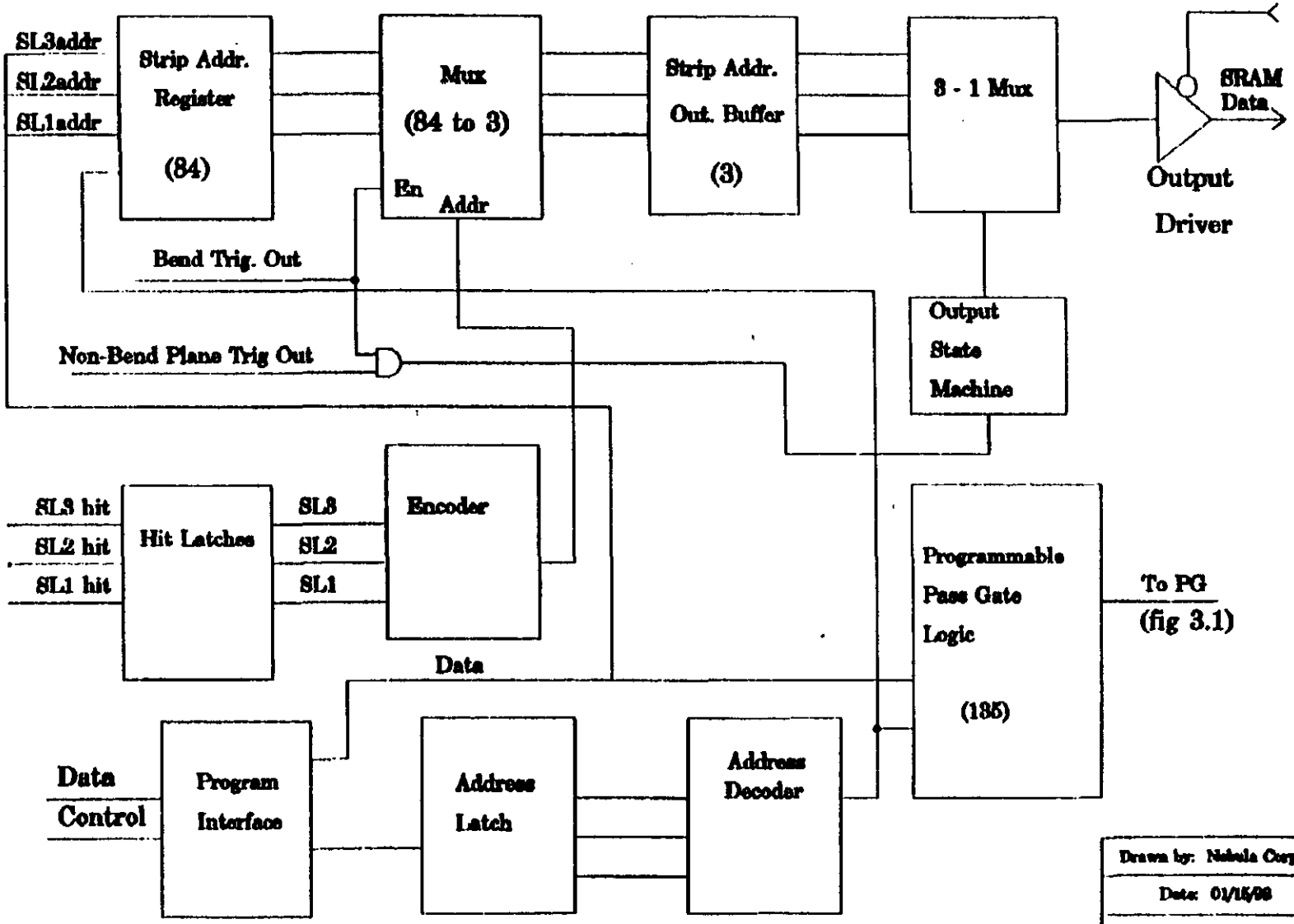
Bend Plane Chip (continued)



Drawn by: Nebula Corp.
Date: 01/15/98
Rev: 02 Fig 2.2

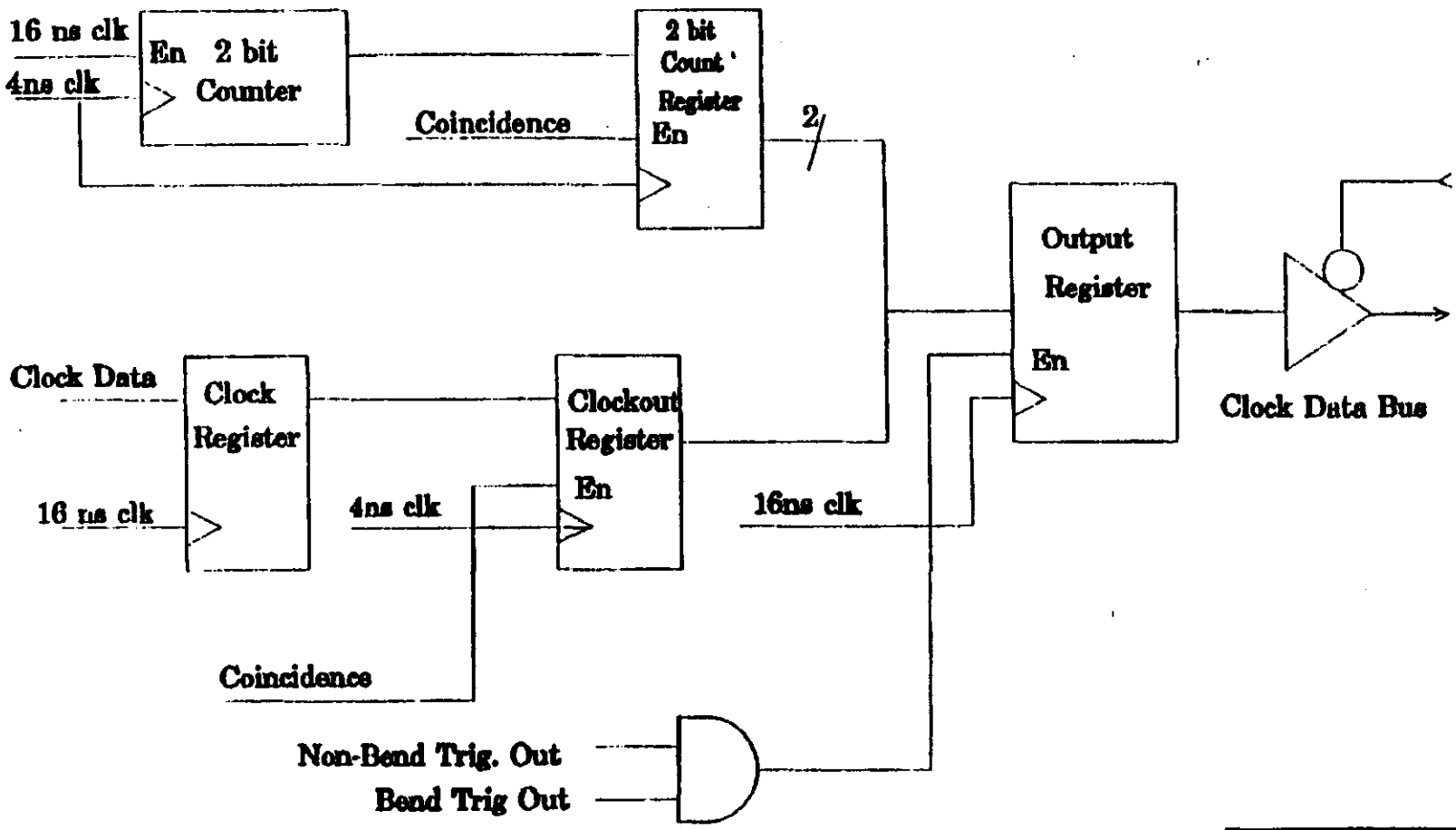

Non-Bend Plane Architecture
SL3
SL2
SL1-1
SL1
SL1+1
Sync
Coincidence
Cluster Remove
Prog Gate
Non-Bend Trig. Out
Drawn by: Nebula Corp.
Date: 01/15/00
Rev: 02
Fig. 3.1

Non-Bend Plane Chip (continued)



Drawn by: Nebula Corp.
Date: 01/15/98
Rev: 02 Fig 3.2

Non-Bend Plane Chip (continued)



Drawn by: Nebula Corp.
Date: 01/15/98
Rev: 02.1 Fig 3.3

Gem Detector Pipe Line Muon Trigger Electronics
Feasibility Study - Nebula Corp.
Preliminary Report 1/17/93

1. Overview

Nebula Corporation has studied the feasibility of integrating the electronics of the SCC Pipe Line Muon Trigger. We have created a preliminary electronic system architecture, studied potential technical risk, and estimated potential electronics costs. The study centered on the integration of the electronics into several semi-custom ASIC devices. It is anticipated that most of the system design and cost will be contained in these devices.
This is a preliminary report, and as such is meant to communicate our findings as to basic feasibility, and as to expected gross costs. Much detailed analysis remains to be performed to determine system architecture and cost more accurately.

2. Assumptions

Our analysis was performed using the following set of assumptions:

a. A basic 16 ns period, 50% duty cycle system clock is used.
Bend plane Super Layer signals will be resolved to 16 ns.
Non-bend plane Super Layer signals will be resolved to 4 ns.

b. Superlayer information from SL1,SL2,SL3 will be presented to the ASIC's as a digital logic signal pulses with standard logic levels of =5v, 0v. Bend plane pulses will have a mimimum width of 16ns. Non bend plane pulses will be a minimum width of 4ns.

c. Bend plane and non-bend plane hits are determined to be simultaneous if they occur within a 2 clock pulse 32 ns window.

d. Latency time of 300ns after detecting a "hit" before hit must be written to SRAM.

e. Operating environment will be 25C, 5v +- 5%.

3. System Architecture

3.1 Architecture

The two basic electronic system architectural issues considered in this study are:

a. How to perform relatively simple signal processing (the determination of simultaneous "hits" on the appropriate Super Layers) on a very large number of Super Layer inputs, in a cost efective manner.

Nebula determined that an ASIC implementation of the system was IO limited rather that gate limited, meaning that the system would have to be partitioned in such a way as to maximize the number of channels integrated per chip based upon the number of IO pins per channel, rather than the complexity of the logic on each chip.

b. How to resolve and determine simultaneous Super layer hits to resolutions of 4ns(non_bend plane) and 16ns(bend plane) in a cost effective manner.

We determined that it should be feasible to meet the resolution requirements by creating highly pipelined ASIC implementations using a highly pipelined architecture, and 0.8 micron CMOS technology technology.

3.2 System partition

Considering the previously discussed architectural constraints, Nebula believes that it is feasible to perform this signal processing by developing three semi-custom ASIC devices to be used as per figure 1.
The system partition separates signal processing into Bend Plane processing, and Non-Bend plane signal processing. Communication between Bend Plane processing chips and Non-Bend processing chips is required. Additionally, a Bend Plane concentrator chip is proposed. The concentrator chip takes advantage of the lower Bend-Plane processing clock speed to use a less expensive ASIC technology to concentrate the 3 redundant inputs per superlayer input into a single superlayer input. This concentration reduces the amount of inputs per channel required on the more expensive Bend Plane ASIC.

The Bend Plane/Non Bend Plane ASIC's can be packaged in a 391 pin CPGA package, with an approximate 10 to 16 square inch footprint. Further investigation is required to determine if lower cost surface mount packages or TAB packages may be available.

ASIC Characteristics:

a. Bend Plane ASIC
One 300 pin high pincount, 16ns clock, 90K gate higher density 0.8 micron ASIC to perform most of the Bend-Plane signal processing and the host processor interface. Estimated used gates 77K

b. Non-Bend Plane ASIC
One 300 pin high pincount, 4ns/16ns clock, 90K gate lower density 0.8 micron ASIC to perform Non-Bend plane signal processing. Estimated used gates 37K.

c. Bend Plane Concentrator
One 150 pin lower pincount, 16ns clocked, 10K gate 1.0 micron ASIC to be used as a concentrator chip to reduce the number of input pins . Estimated used gates 7.4K. Packaged in a 208 pin package.

As per figure 1 Nebula estimates that the complete system would require:

2073 Bend-Plane concentrator chips with 20 channels per chip
740 Bend plane ASIC's each with 57 channel/chip
352 Non-Bend plane ASIC's each with 27 channels/chip

Supporting analysis can be found in the attached appendix.

4. Estimated System Cost

The following costs are based upon recent ASIC quotations Nebula has received from ASIC vendors for the development and procurement of ASIC devices similiar to the electronic system ASIC's. These prices are estimates only.

4.1 Estimated ASIC Piece Price

Estimated unit price 0.8 micron ASIC Gate ARRAY with 300 IO pins is $350 @1K pieces
Estimated unit price 1.0 micron ASIC Gate ARRAY with 180 IO pins is $ 30 @1K pieces

Note that typical minimum device volumes are typically 1000-2000 pieces. Estimated device costs are at these volumes. Where the number of devices does not meet this volume we will assume that a minimum purchase of 1000 pieces will be required and cost the system at that total price.

ASIC TYPE	Number/System	EST Unit Cost	Total Cost	Minimum Cost
Bend Plane	740	$350	$259K	$350K
Bend Plane Conc.	2073	$ 30	$ 63K	$ 63K
Non-Bend Plane	352	$350	$124K	$350K
Total Cost			$420K	$763K

4.2 Estimated Vendor Tooling Costs

Bend Plane	$150K
Non Bend Plane	$150K
Bend Plane Conc	$ 30K

4.3 Estimated Engineering Design Costs
Total Design Cost $150K

4.4 Total ASIC Development/production Costs

Total Cost $1243K

5. Tecnical and Cost Risk Assessment

be performed to better characterize and understand these risks.

a. Power Dissipation

No power analysis has been performed. High speed CMOS devices operating at high clock rates can dissipate significant power.

b. High speed 4ns clocking/ device performance

Parts of the Non-bend plane chip run with a 4 ns clock. We believe it is possible, although difficult to operate these chips at that clock rate.

One issue is metastability in the synchronizer. We have not analyized the synchronizer MTBF due to metastability.

Another issue is the control of on chip clock skew. We have not analyized clock skew issues for these designs.

c. Gate Array Density/performance

We have made a preliminary estimate of Gate Array density, and believe that the designs are feasible at the estimated Gate Array utilizations. However, at this preliminary stage it is difficult to access the effect of internal Gate Array routing on the maximum Gate Array utilization or on the Gate Array performance. .

d. Gate Array Testability

No allowance has been made for ASIC testability or System testability. The addition of test circuitry may impact device performance, or gate array utilization.

e. System PCB

No analysis has been made of system PCB routing or density issues.

If the system can be configured such that standard 4 or 5 layer PCB (24 inch by 24 inch) can be used, Nebula estimates the cost of such a blank board to be $1K at 100 quantity.

Michael Goldman

Principal Engineer

APPENDIX

1. System Partition

1.1 Bend Plane Concentrator ASIC IO Pin Count

Based upon Prof Pless's caclulations for the number of SL1,2,3 inputs per channel.
Maximum Number of Bend Plane Channels/Bend plane Concentrator ASIC is 20.
Calculation assumes approx 185 signal pins maximum(plus additional power/ground)
See below for details:

a. IO Pin Count

As per prof Pless's calculation, on a per channel bassis there are the following IO pin considerations:

	Inputs	Outputs	@ N=20 IN	OUT
SL3	3/channel	1/channel	60	20
SL2	3*(0.75)/channel	0.75/channel	45	15
SL1	3*(0.5)/channel	0.5/channel	30	10
Overhead pins				
SL3 adjacent pins for cluster removal	4		4	
16 ns Clk In	1		1	

Number Channels/ASIC N= (185-5)/(4*2.25)= 20

1.2 Bend Plane ASIC IO Pin Count

Maximum Number of Bend Plane Channels/Bend plane ASIC is 56
Calculation assumes approx 300 signal pins maximum(plus additional power/ground)
Number of channels N= (300-170)/2.25 = 56
See below for details:

a. Sensor IO

As per prof Pless's calculation, on a per channel bassis there are the following IO pin considerations:

SL3 inputs	1/channel
SL2 inputs	0.75/channel
SL1 inputs	0.5/channel
Overhead pins	
Adjacent channel Overhead Pins	
SL2+ inputs	20
SL2- inputs	20
SL1+ inputs	15
SL1- inputs	15
SL1/2 outputs	70
Total Sensor I/O per channel	N*(2.25)+(140)

where N=number channels/chip

b. Control IO

SRAM IO:	11
8 bit SRAM SL address data bus	
2 bit WE/CS memory controls	
1 Output enable input	
System Programming/IF IO	13
1-16 ns clk input	
1-CS input	
1-Address/Data select	
1-SL Enable Data/SL Address Data	
1-SL Enable Data	
select h/l address load	
8 bit Data I/F	
use for SL address programming	
Trigger IO	2
Misc TBD	4

1.3 Non-Bend Plane ASIC IO Pin Count

Maximum Number of Bend Plane Channels/Bend plane ASIC is 56

Calculation assumes approx 300 signal pins maximum(plus additional power/ground)

Number of channels N= (300-46)/(9) = 27

See below for details:

a. Sensor IO

As per prof Pless's calculation, on a per channel bassis there are the following IO pin considerations:

SL3	3/channel
SL2	3/channel
SL1	3/channel
Overhead pins	
Adjacent channel Overhead Pins	
SL3 inputs	1
SL2 inputs	1
SL1 inputs	1
SL3 outputs	1
SL2 outputs	1
SL1 outputs	1
SL1/2/3 outputs	6

Total Sensor I/O per channel where N=number channels/chip	N*3*(2.25)+(140)

b. Control IO

SRAM IO: 8 bit SRAM SL address data bus 5 bit SRAM Clock data bus 2 bit WE/CS memory controls 1 Output enable input	19
System Programming/IF IO 1-16 ns clk input 1-CS input 1-Address/Data select 1-SL Enable Data/SL Address Data 1-SL Enable Data select h/l address load 8 bit Data I/F use for SL address programming	13
Clock Data IF	6
Trigger IO	2
Total Control IO	40

2. Gate Count

2.1 Bend plane Concentrator

	Function	Est Gate Count	Replication	Total
A.	Synchronizers	20	135	2700
B.	Coincidence Detect	19	45	855
C.	Pipelined Cluster Rem	75	45	3375
D.	Output Buffer	10	45	450
	Total Gates			7380

Conclusion: 10K (useable gates) Gate Array in 208 pin package(185 signal 23 power ground) seems feasible solution.

Technology: Must support 16ns pipelined architecture
As below 5 levels of 4 input logic can be supported.
This is consistent with the proposed design.

Typical Industry Vendor 1 micron process
Worst case process@Ta=25C; Vdd=5v:
DFf
tp = 2.7ns +0.1ns/LU
tsu/th= 0.60ns
In load = 1LU + Lwire
Lwire approx= 1.5LU/FO + 1 LU
4 In NAND(unbuffered)
tp = 0.90ns + 0.25ns/LU
In Load = 1 LU + Lwire

If FO < 3 then Lwire approx=6
and approx delay/stage =2.5ns

In a 16 ns pipeline approx td/stage=
16ns-(tpdff)-(tsdff) -(N*tdlogic/stage)>0
Therefore N=5

2.2 Bend Plane ASIC Estimates of Gate Count

	Function	Est Gate Count	Replication	Total
A.	Strip Addres Registers	80	196	15680
B.	8x56 to 1 mux			
	(8 to 1 mux)	15	64	960
C.	8x82 to 1 mux			
	(8 to 1 mux)	15	88	1320
	(4 to 1 mux)	7	8	56
	(2 to 1 mux)	5	16	80
D.	8x58 to 1 mux			
	(8 to 1 mux)	15	64	960
	(2 to 1 mux)	5	8	40
E.	Strip ADR Output Reg	80	3	240
F.	Strip ADR Hit Latch	2	196	392
G.	56 to 6 Strip ADR Piped Mux Decode			
	8 to 3 priority encode	27	8	216
	3 OR	3	7	21
H.	82 to 7 Strip ADR Piped Mux Decode			
	8 to 3 priority encode	27	13	351
	3 OR	3	13	39
I.	58 to 6 Strip ADR Piped Mux Decode			
	8 to 3 priority encode	27	8	216
	3 OR	3	7	21
J.	Program Gate Latch	5	4144	20720
H.	Program Gate Enable gate	1	4144	4144
I.	Input SL pipeline +buffer	14	196	2744
J.	Pipelined 33 OR/41OR/AND			
	33 OR/41OR	40	56	2240
	Pipeline	160	56	8960
K.	SL3 matching pipeline	10	56	560
L.	Bend Plane Trigger Out Pipe	10	56	560
M.	Misc Uncounted Gates			
	Final Number TBD			10000
Total Estimated Gate Count				76560

Note in the target 0.8 micron technology we anticipate targeting this device into an ASIC with approximately 90,000 useable gates.

Conclusion: 90K (useable gates) Gate Array in 391 pin package(305 signal, 65 power ground) seems feasible solution.

Technology: Must support 16ns pipelined architecture

As in the 1 micron case no more than 4 levels of logic with a fan out of 3 is used except in 1 critical path.

The critical path occurs at the input to the chip, where the SL2 lines drive 33 different gates or outputs, and SL1 lines drive 41 different gates/outputs.

The architecture will pipeline and buffer this path so that the critical path will be:

1 dff driving 4 buffers;

a buffer driving 8 single fo PG AND gate

the AND gate driving a single OR gate.

This is consistent with the proposed design.

Typical Industry Vendor 0.8 micron process

Worst case process@Ta=25C; Vdd=5v:

DFf

tp = 1.3ns +0.56ns/LU

tsu/th= 0.50ns

In load = 1LU + Lwire

Lwire approx= 2.4 LU/FO + 1 LU

4 In NAND(unbuffered)

tp = 0.40ns + 0.14ns/LU

In Load = 1 LU + Lwire

In a 16 ns pipeline approx td/stage=

16ns-(tpdff)-(tsdff) -(N*tdlogic/stage)>0

Therefore N=5

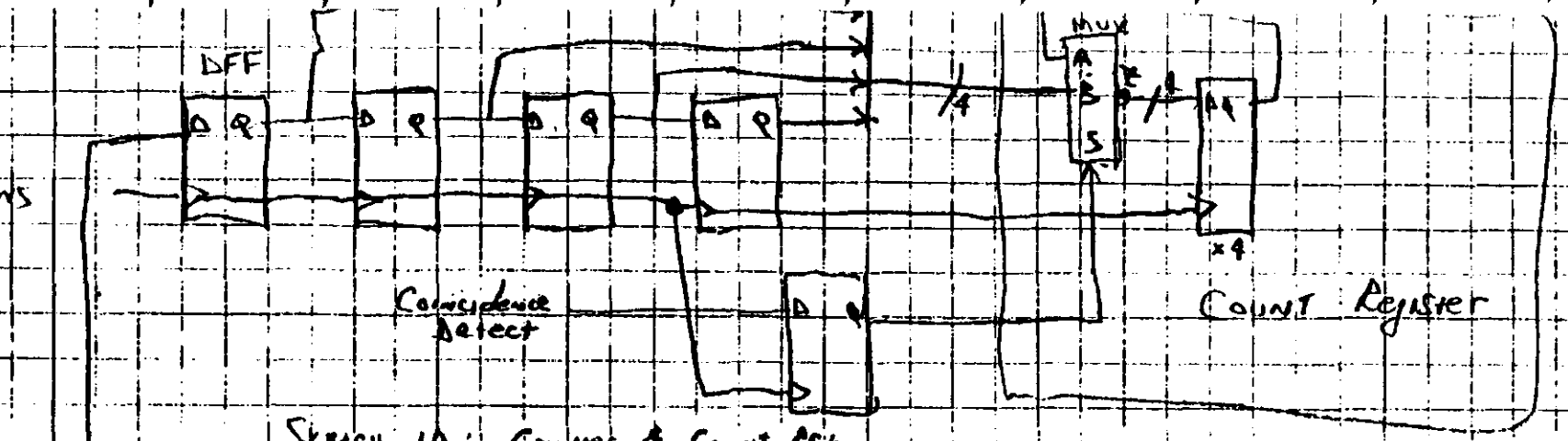
2.3 Non-Bend Plane ASIC Estimates of Gate Count

	Function	Est Gate Count	Replication	Total
A.	Synchronizer	20	243	4860
B.	Piped Coincidence Detect	24	81	1944
C.	Pipelined 4ns Ctr	132	27	3564
C.	Pipelined Cluster Rem	20	81	1620
D.	Output Buffer	10	45	450
E.	Strip Address Registers	80	84	6720
F.	(8x28 to 1 mux)x3			
	(8 to 1 mux)	15	72	1080
	(4 to 1 mux)	7	48	336
G.	Strip ADR Output Reg	80	3	240
F.	Strip ADR Hit Latch	2	84	168
G.	28 to 5 Strip ADR Piped Mux Decode			
	8 to 3 priority encode	27	18	486
	3 OR	3	9	27
H.	Program Gate Latch	5	135	675
I.	Program Gate Enable gate	1	135	135
I.	Input match pipeline +buffer	36	81	2916
J.	Pipelined 3 OR/3AND	13	27	351
K.	SL3 matching pipeline	10	27	270
L.	Non Bend Plane Trigger Out Pipe	10	27	270
M.	Input clock register	50	1	50
N.	Output clock register	70	1	70
O.	Misc Uncounted Gates			
	Final Number TBD			10000
	Total Gates			36232

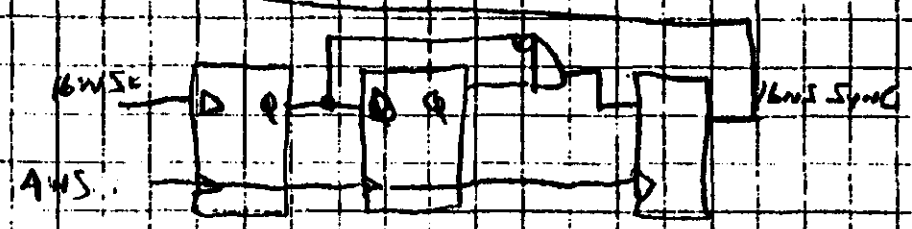
Conclusion: The proposed 90K useable Gate Array seems feasible for this design.

ASIC Technology/ performance.

The worst case speed paths for this chip are the 4ns clocked paths.
We propose to perform them in a pipelined fashion with only 1 level of logic between each pipe. The counter is performed as per sketch1. As shown there is approximately 10% margin loading the count register at 4ns clock.
This preliminary timing estimate shows that the 4ns counter timing is tight but feasible and must be carefully designed.
A similiar situation occurs when loading the external clock data into the clock data buffer.



SKETCH 1A: Counter & Count Reg



ESTIMATED WC DELAY TO LOAD COUNT REG:

T_p DFF CLK→Q = 1.4NS + 0.06NS/LD

T_p MUX S-Z = 0.6ns + 0.06NS/LD

T_p MUX A/B-Z = 0.54NS + 0.06NS/LD

T_{SU} DFF = 0.50NS

EST LD = 3.5

TOTAL WC DELAY = 3.04NS + 0.06NS×3.5

Margin (4NS − T_{WCD}) = 0.53NS

SKETCH 1 – 4NS Counter MG 1/17/92

303

per small sector = NBPA.

$$NBPA = 6 \times 10^6 / 32 \times 3 = 6.3 \times 10^4$$

Accidentals per small sector = ASS

$$ASS = (NBPA)\,(BPA)\,(\tau_1 + \tau_2)$$
$$= (6.3)\,(10^4)\,(6\,(10^2)\,(16 + 16)\,(10^{-9}) = 1.2$$

The accidental for the full sector = AFS is given by:

$$AFS = (3ASS) = 3.6$$

Total accidental for OEM = (0.0) (02) = 115 Hertz. To this we add 27 Hertz which gives the GEM accidental rate of 142 Hertz.

Dead Time

To calculate the dead time we must consider what is the probability that a track will generate a signal in all three RPC super layers. In each super layer a track goes through three pairs of bend and non-bend strips. Since we use 2 out of 3 logic we must calculate the probability that at least two pairs of bend and non-bend strips are "alive." Let this probability for any bend plane super layer $B_j = (LTP)_{Bj}$, j = 1, 2, 3.

$$(LTP)_j = [3\,D_{Bj}\,(1 - D_{Bj})^2 + (1 - D_{Bj})^3]$$

D_{Bj} = Dead time probability for bend plane strip Bj.

Total bend live time = $(LTP)_{B1}\,(LTP)_{B2}\,(LTP)_{B3} = L_B$

Total bend dead time = $1 - (LTP)_1\,(LTP)_2\,(LTP)_3 = D_B$

We will assume that after each hit on any strip the strip is "dead" for 100×10^{-9} seconds. From the previous information we calculate:

$$D_{B1} = (631.9)\,(1.3)\,(500)\,(100)\,(10^{-9}) = .041$$

01/16 16:47 7312025 #02 OF 02

$D_{NB1} = (148.5)\ (3.9)\ (500)\ (100)\ (10^{-9}) = \quad .028$

$D_{NB2} = (239)\ (6.5)\ (500)\ (100)\ (10^{-9}) = \quad .077$

$D_{NB3} = (329)\ (8.9)\ (500)\ (100)\ (10^{-9}) = \quad .147$

D_{NBj} j = 1, 2, 3 is the dead time probability for non-bend plane strip B_j

$(LTP)_{B1} = (3)\ (.04)\ (.96)^2 + (.96)^3 = .995$

$(LTP)_{B2} = (3)\ (.068)\ (.932)^2 + (.932)^3 = .987$

$(LTP)_{B3} = (3)\ (.096)\ (.904)^2 + (.904)^3 = .974$

Total bend live time = LB = (.995) (.987) (.974) = .957

Total bend dead time = 1 - LB = 1 - .957 = .043

Let $(LTP)_{NBj}$ = Live time probability of the non-bend plane j.

$(LTP)_{NB1} = (3)\ (.028)\ (.972)^2 + (.972)^3 = .998$

$(LTP)_{NB2} = (3)\ (.077)\ (.923)^2 + (.923)^3 = .983$

$(LTP)_{NB3} = (3)\ (.147)\ (.853)^2 + (.853)^3 = .942$

Let LNB = total non-bend live time.

$LNB = (LTP)_{NB1}\ (LTP)_{NB2}\ (LTP)_{NB3}$

Total non-bend dead time = 1 - LNB

LNB = (.998) (.983) (.942) = .924

Total non-bend dead time = 1 - .924 = .076

Let total GEM live time = LT

LT = (LB) (LNB) = (.957) (.924) = .88 = 88%

GEM dead time = .12 = 12%

If we assume our pulse dead time is 50 nanoseconds instead of 100 the dead time is reduced to about 6%. Both numbers are acceptable. If we assume, because of the high rates, the efficiency of the RPC degrades then there will be a different calculation for the GEM live time and dead time. Assume that the efficiency of an RPC plane is E.

GEM live time = $[(3)(1 - E)(E)^2 + E^3]^6$

E	GEM Live Time	GEM Dead Time
95%	96%	4%
90%	84%	16%
85%	69%	31%
80%	52%	48%

Obviously the dead time is sensitive to the efficiency of the individual RPC plane. A proper, by definition, high rate RPC will have an efficiency greater then 95%. It should be noted that at efficiencies greater than 95%, the previous calculation is the relevant calculation.

End Cap

The problems of the end cap are much simpler than the barrel due to the much greater segmentation. Without presenting the details, all accidentals and dead times are reduced by about two orders of magnitude. The timings are essentially as in the barrel, but all delays are reduced by about a factor two.

SUMMARY

THERE IS NOW A COMPLETE FIRST PASS DESIGN FOR THE GEM MUON SYSTEM BASED ON RESISTIVE PLATE CHAMBERS THE BASIC PROPERTIES ARE:

1. ELECTRONIC COSTS	$1.3 MILLION
2. BEAM CROSSING TAG	7 NANOSEC
3. FALSE TRIGGER RATE AT $L=10^{34}$	29 HERTZ
4. DEAD TIME- 50 NANOSEC	6%
- 90% EFF.	16%

5. PROGRAMMABLE

   A. 4 RANGES OF MOMENTUM

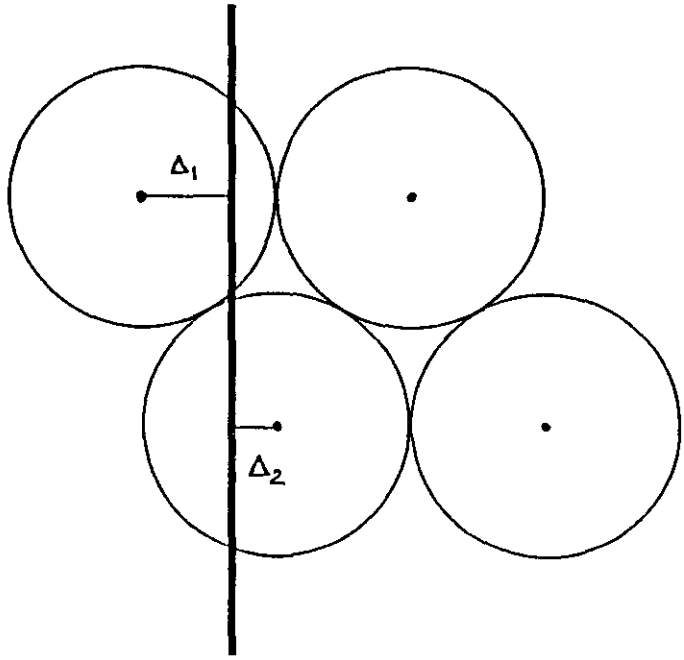
   B. RPC PLANE ALIGNMENT

   C. INTERACTION POINT ALIGNMENT

The RDT Trigger Consideration

Presentation by:

A. Korytov



Drift Times:

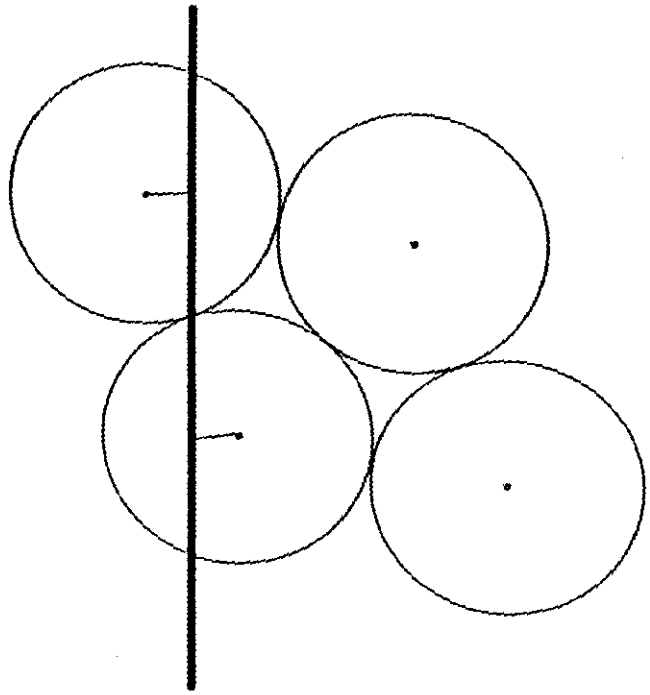
$\tau_1 = \frac{\Delta_1}{V}$ $\qquad$ $\tau_1 = T_1 - T_0$

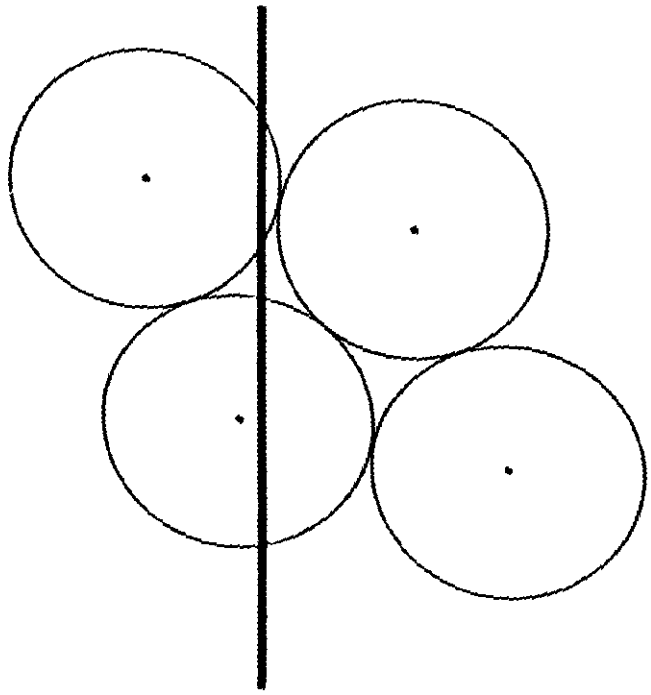
$\tau_2 = \frac{\Delta_2}{V}$ $\qquad$ $\tau_2 = T_2 - T_0$

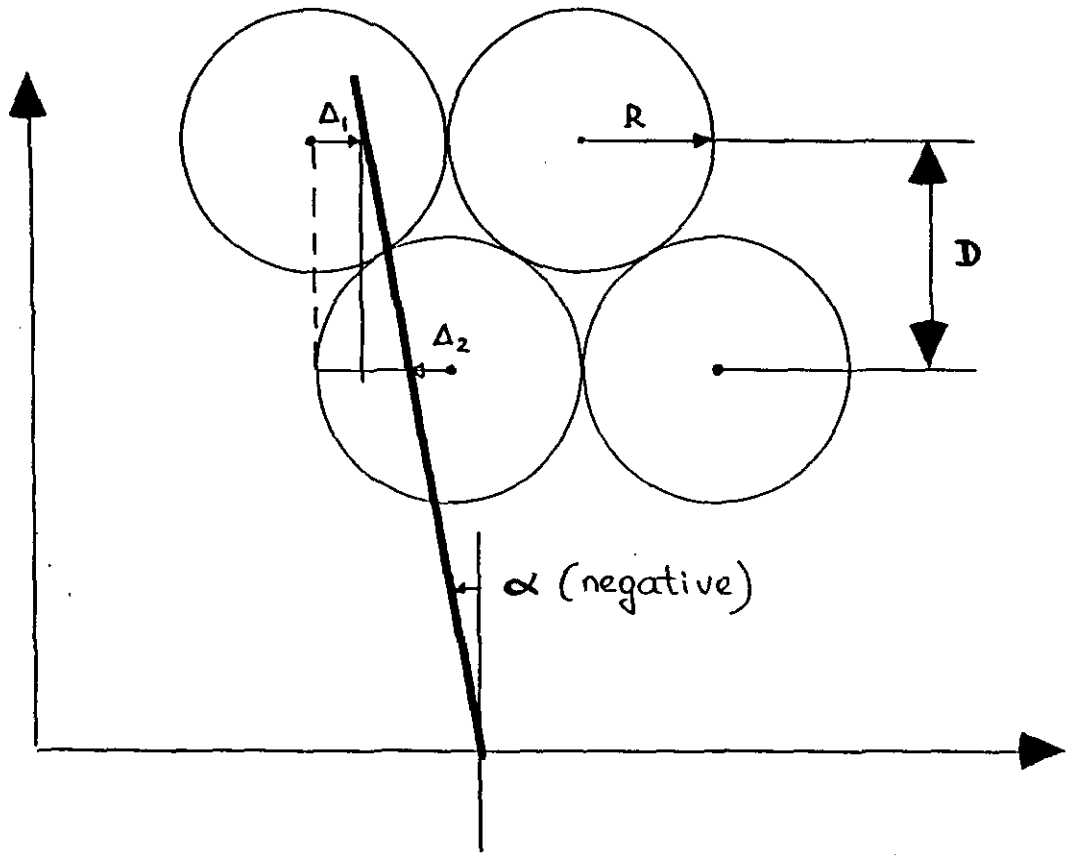
$$\boxed{T_0 = \frac{T_1 + T_2}{2} - \frac{\Delta_1 + \Delta_2}{V}\frac{1}{2} = \frac{T_1 + T_2}{2} - \frac{T_{dr}}{2}}$$

WHAT WAS USED:

1. V_{drift} = const
2. Vertical track ($\alpha = 0$) $\Rightarrow$ $\Delta_1 + \Delta_2 = R$
3. Track went between wires
4. Measurements are good (no δ-electrons, no background)







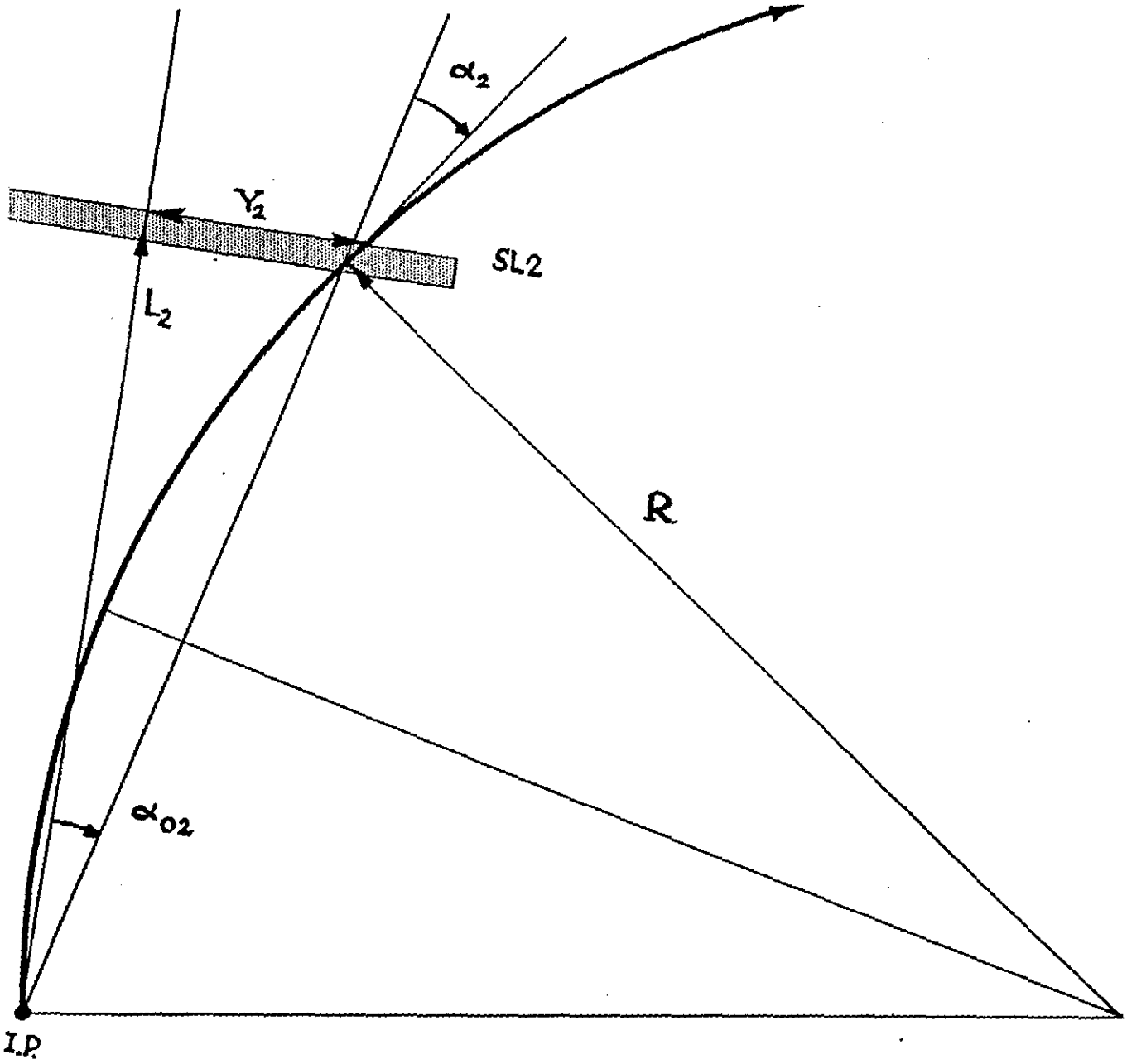
Drift Times:

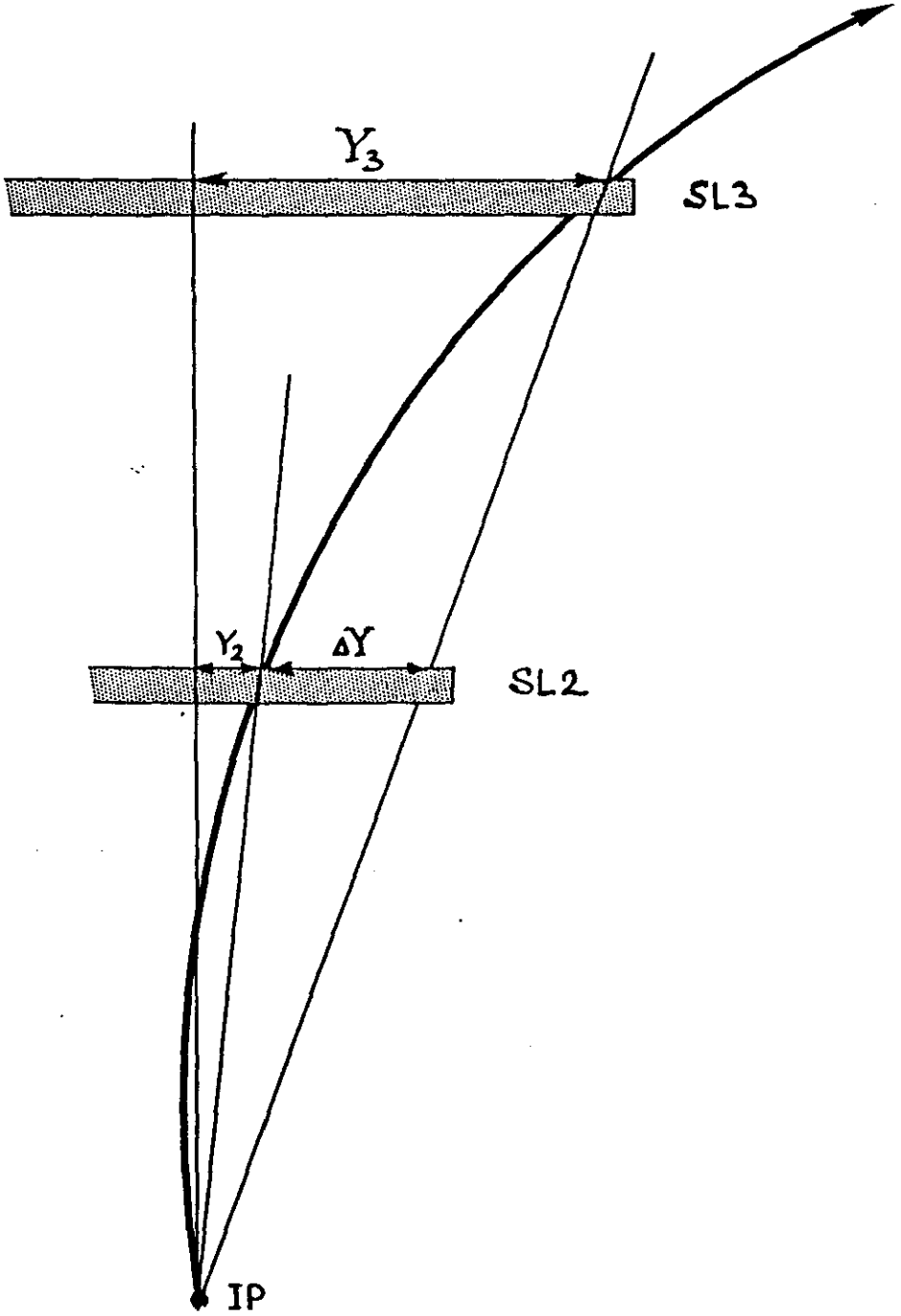
$$\tau_1 = a \cdot \Delta_1 + b \cdot \Delta_1^2 \qquad \tau_1 = T_1 - T_0$$

$$\tau_2 = a \cdot \Delta_2 + b \cdot \Delta_2^2 \qquad \tau_2 = T_2 - T_0$$

$$\Delta_2 = R + \alpha D - \Delta_1 = C_0 - \Delta_1$$

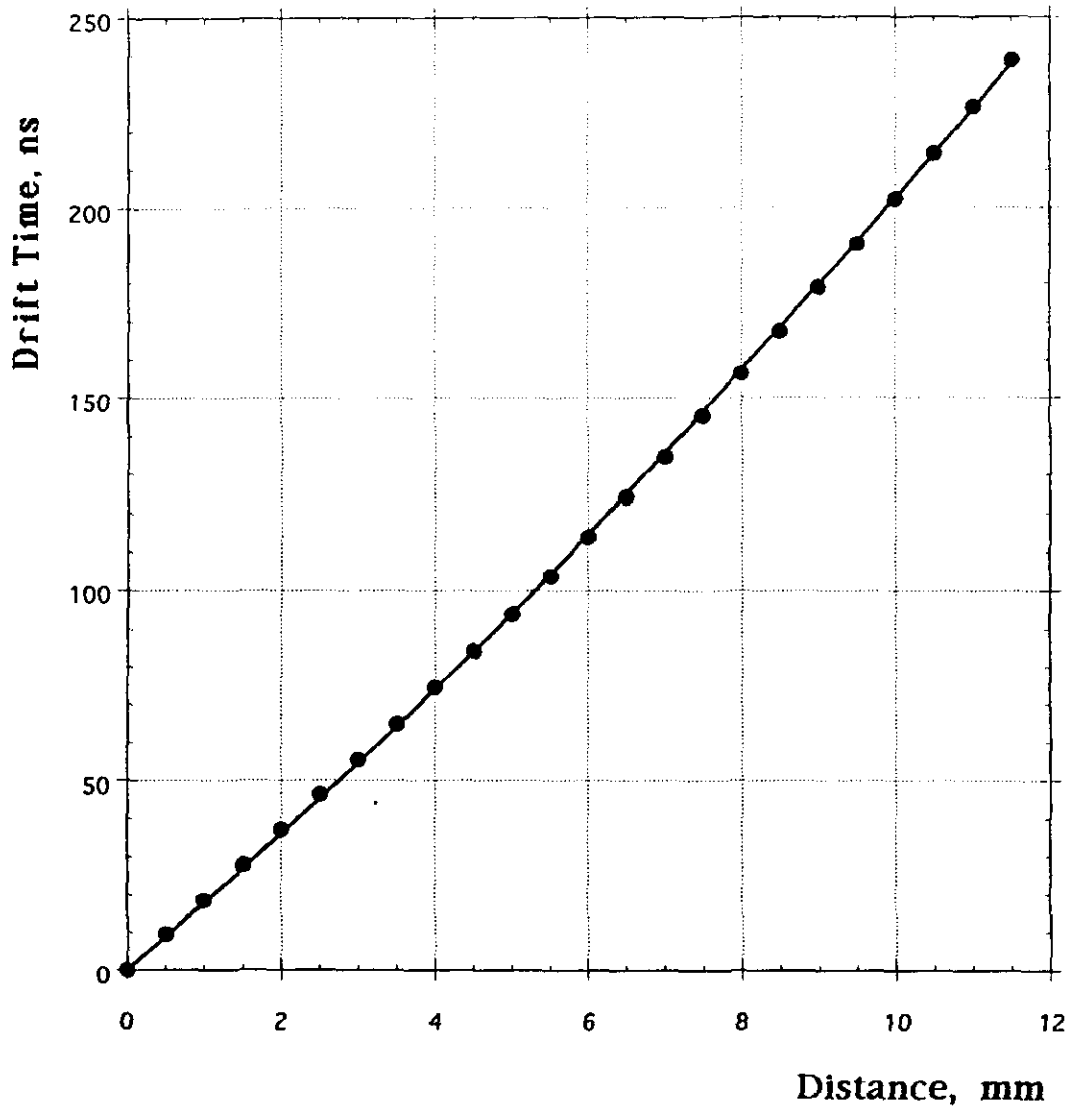
$$\boxed{\begin{gathered} T_0 = \frac{T_1 + T_2}{2} - \frac{a}{2} C_0 - \frac{b}{4}\left(C_0^2 + \frac{\Delta T^2}{(a + bC_0)^2}\right) \\ C_0 = R + \alpha D \end{gathered}}$$


α_2
Y_2
SL2
L_2
R
α_{02}
I.P.


Y_3
SL3
Y_2
ΔY
SL2
IP

y = m1*M0 + m2*M0*M0		
	Value	Error
m1	17.357073062	0.094725
m2	0.28546071821	0.0104131
Chisq	13.306709135	NA
R	0.99994534341	NA

T=a*X + b*X^2
(Points are calculated
from accurate fit of LASER DATA),
Ar+IB =25+75

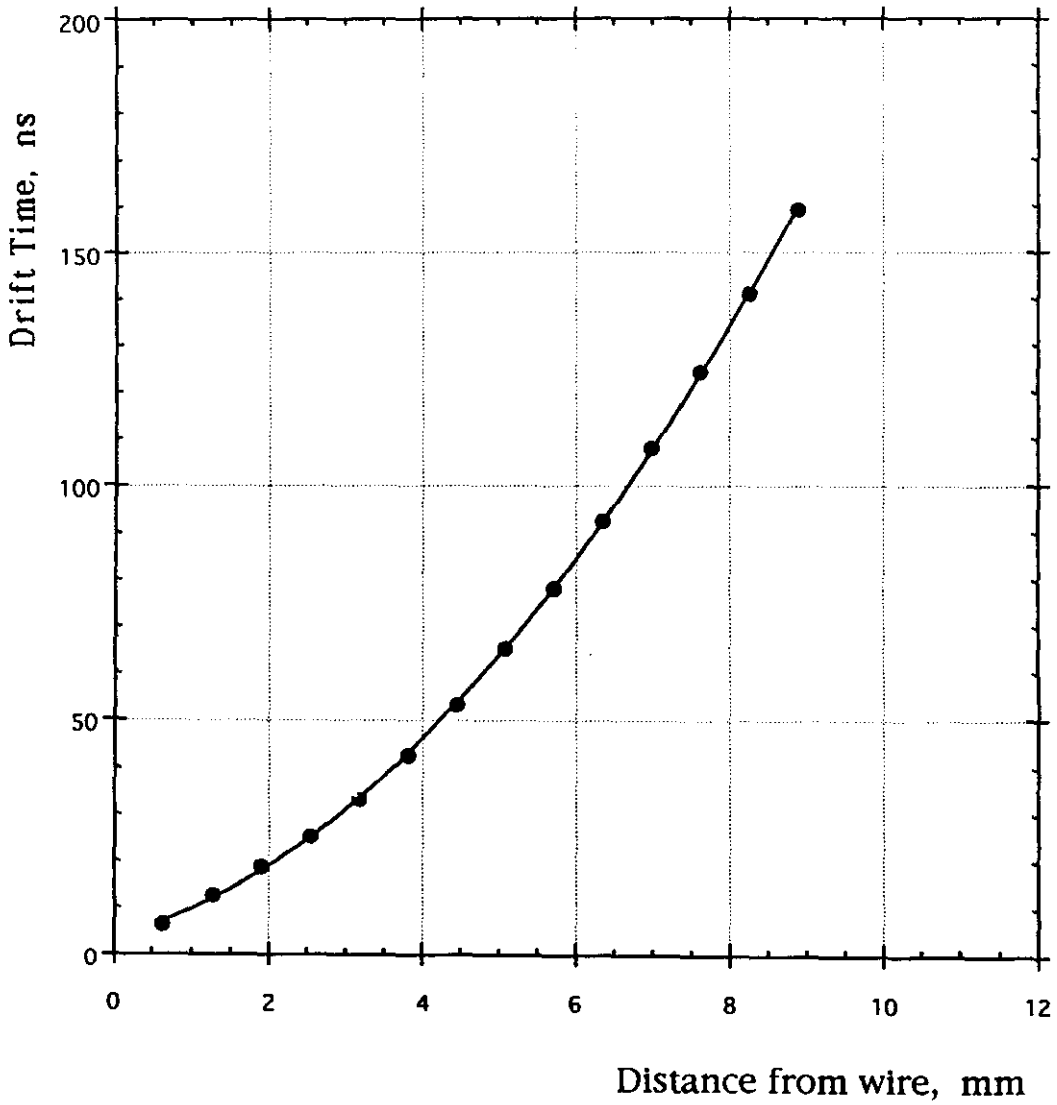


y = m1+m2*M0 + m3*M0*M0		
	Value	Error
m1	3.3417585497	0.484641
m2	5.031063318	0.23408
m3	1.4116950994	0.0239047
Chisq	2.9760939244	NA
R	0.99995388072	NA

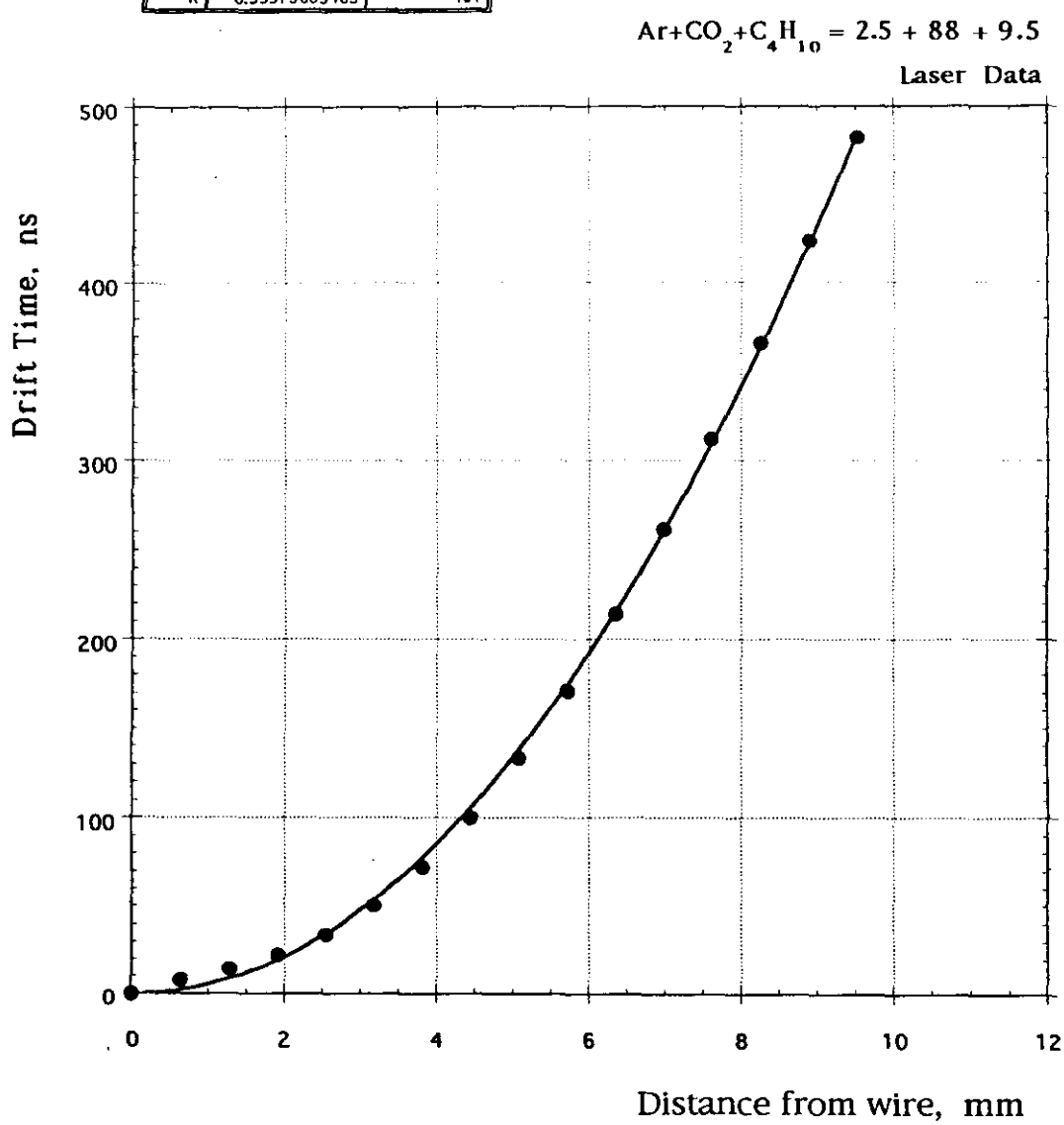
$CF_4 + CO_2 + C_4H_{10} = 69 + 20 + 11$

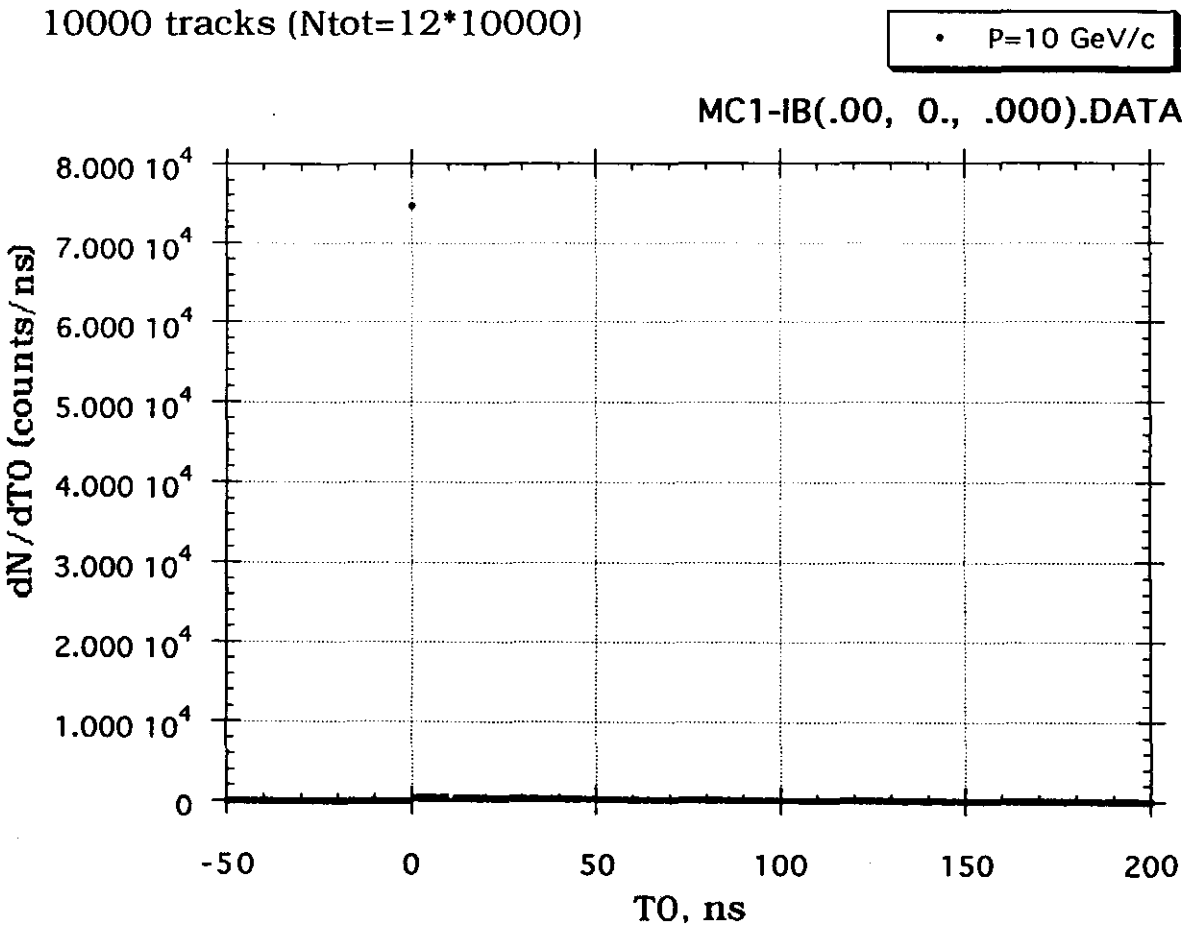
U = 5.4 kV

Laser Data



T=b*x^2		
	Value	Error
b	5.3277617937	0.0214464
Chisq	199.89911477	NA
R	0.99973685403	NA

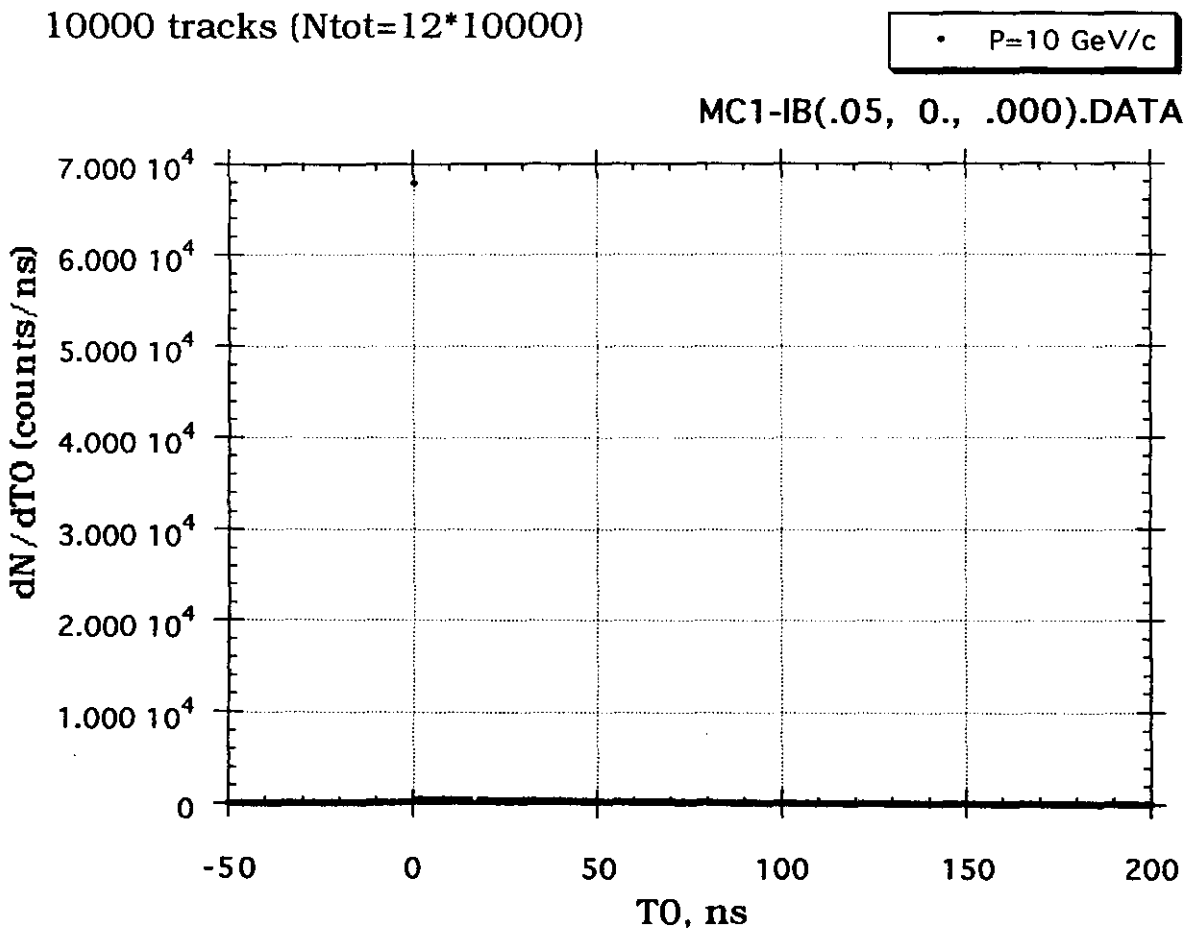


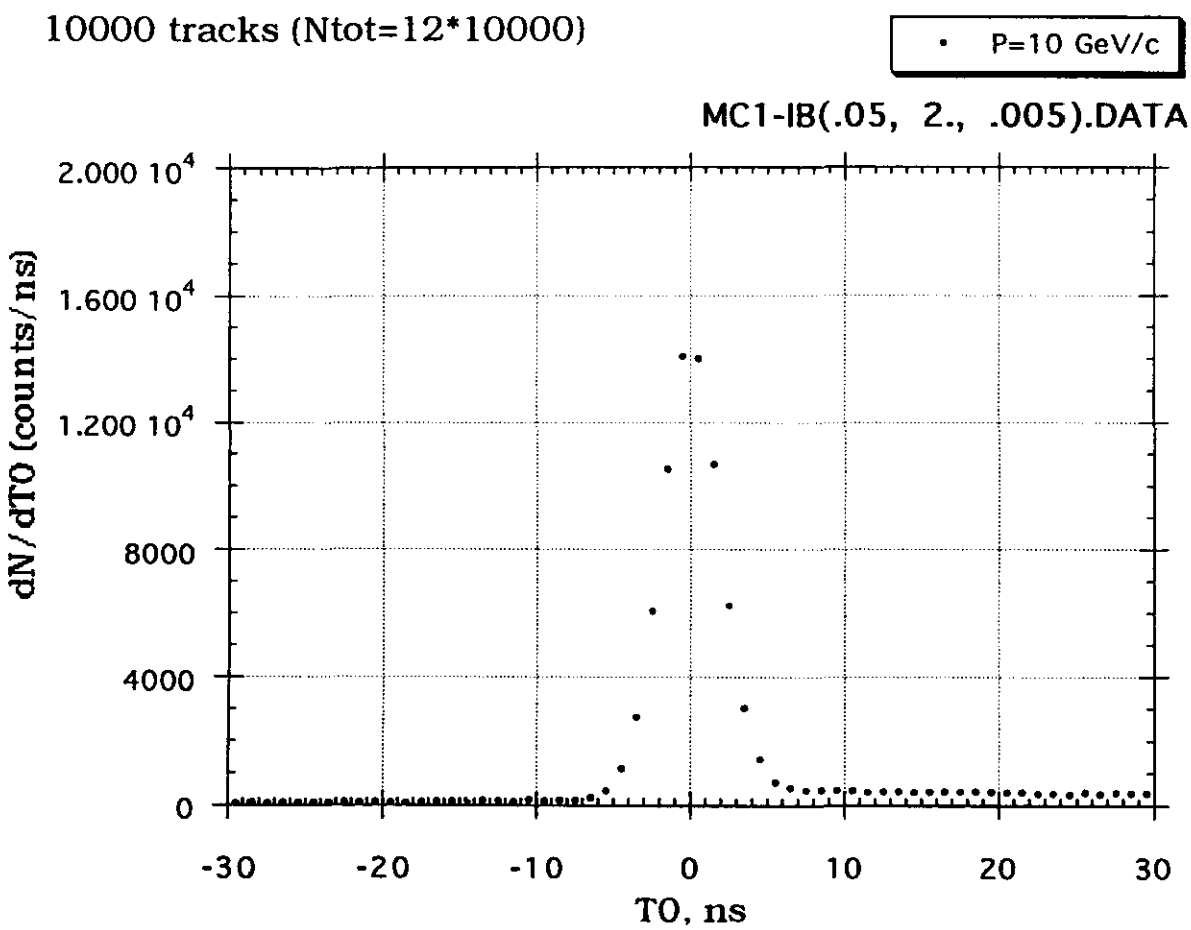

10000 tracks (Ntot=12*10000)
P=10 GeV/c
MC1-IB(.00, 0., .000).DATA
8.000 10^4
7.000 10^4
6.000 10^4
5.000 10^4
4.000 10^4
3.000 10^4
2.000 10^4
1.000 10^4
0
dN/dT0 (counts/ns)
-50
0
50
100
150
200
T0, ns

(= 5.031063 b= 1.411695
:EY=1
ps=.000 Terror(ns)=0.0 Aerror(rad)=.000

20. GeV: Nyes-Nno-Nwrong= 9999 0 1

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	0	664	0	0	0	0
7	0	1602	0	0	0	0
8	0	4161	0	0	0	0
9	0	2764	0	0	0	0
10	0	764	0	0	0	0
11	0	42	0	0	0	0
12	0	3	0	0	0	0

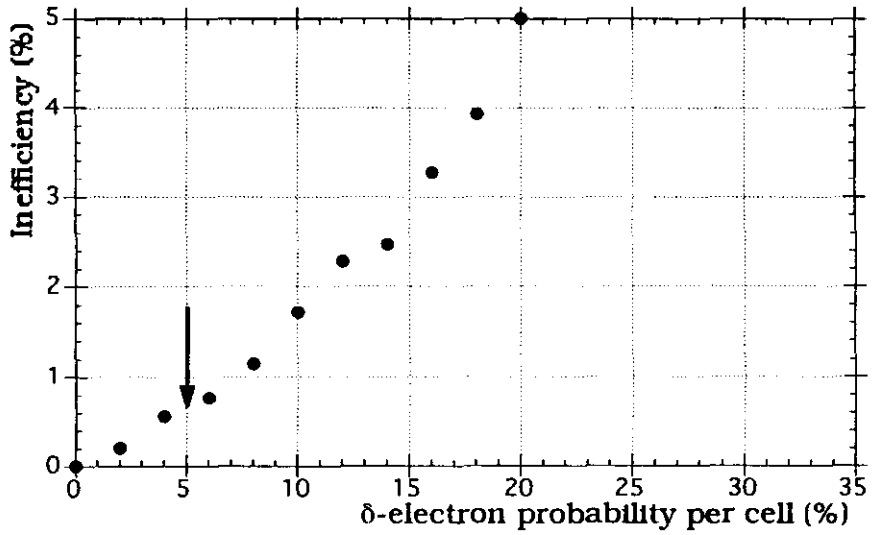

10000 tracks (Ntot=12*10000)
P=10 GeV/c
MC1-IB(.05, 0., .000).DATA
7.000 10^4
6.000 10^4
5.000 10^4
4.000 10^4
3.000 10^4
2.000 10^4
1.000 10^4
0
dN/dT0 (counts/ns)
-50
0
50
100
150
200
T0, ns

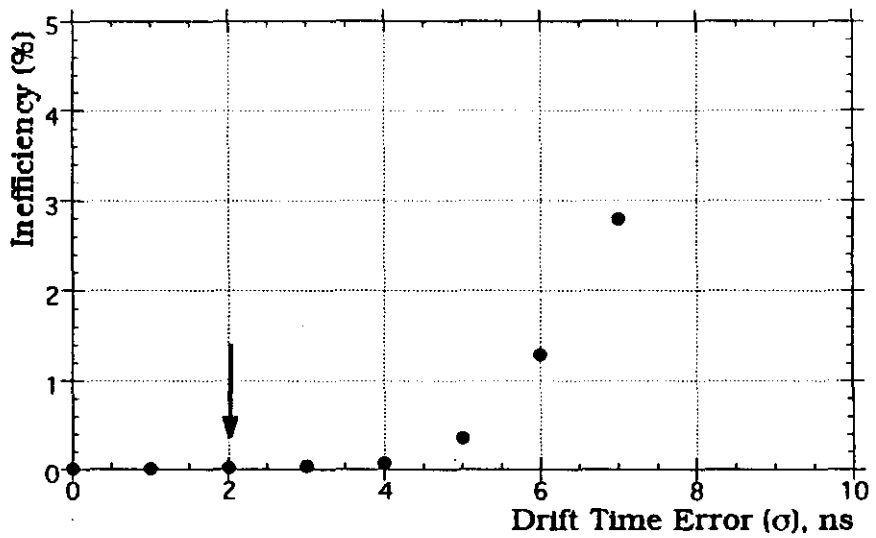

10000 tracks (Ntot=12*10000)
P=10 GeV/c
MC1-IB(.05, 2., .005).DATA
2.000 10^4
1.600 10^4
1.200 10^4
8000
4000
0
dN/dT0 (counts/ns)
-30
-20
-10
0
10
20
30
T0, ns

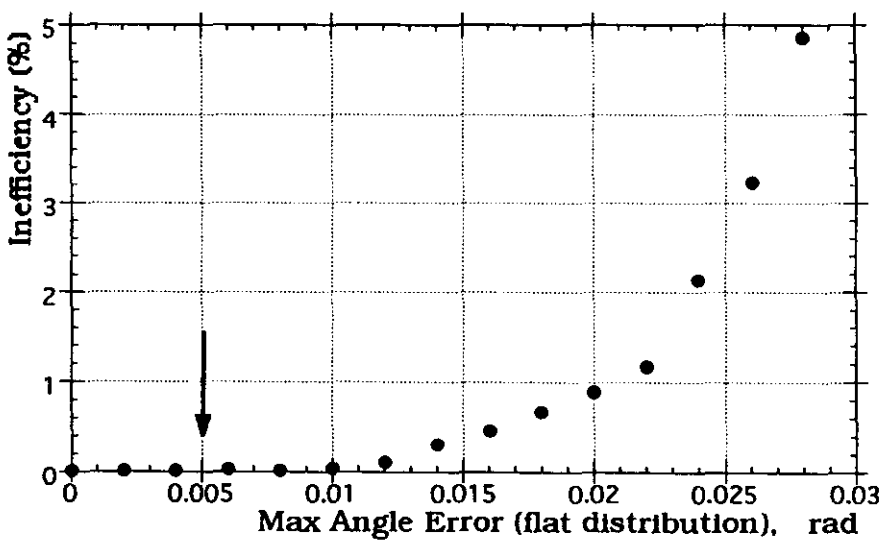
SL2

Time Trigger Inefficiency

$CF_4+CO_2+C_4H_{10}$ = 69+20+11



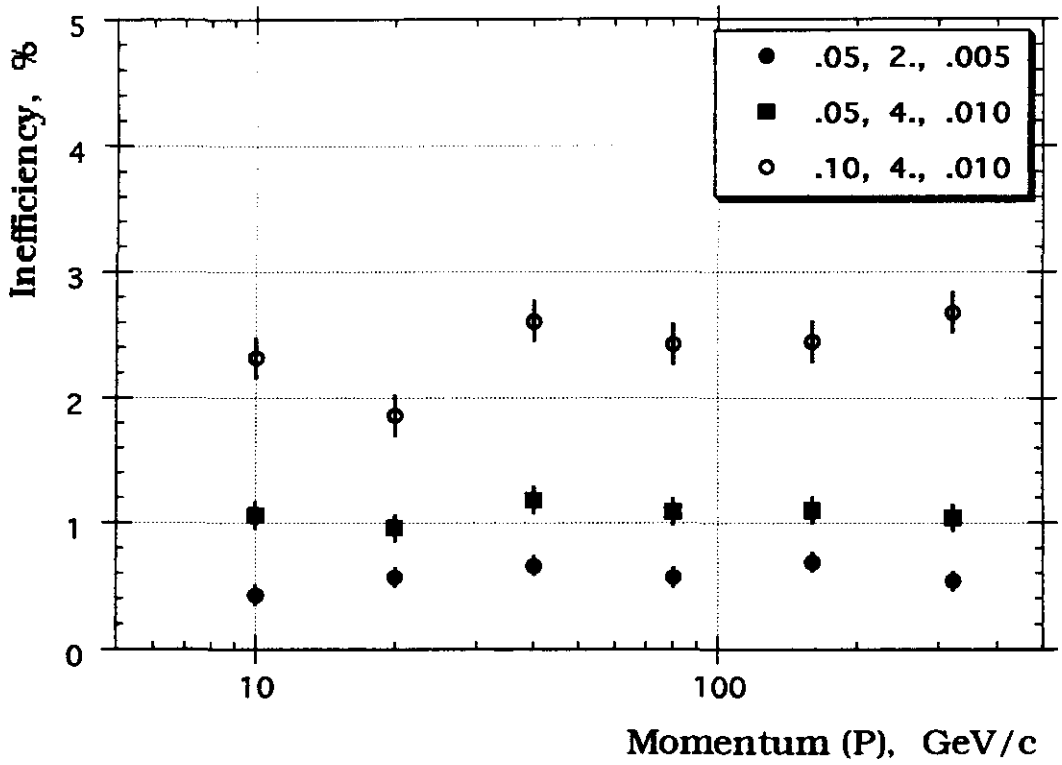




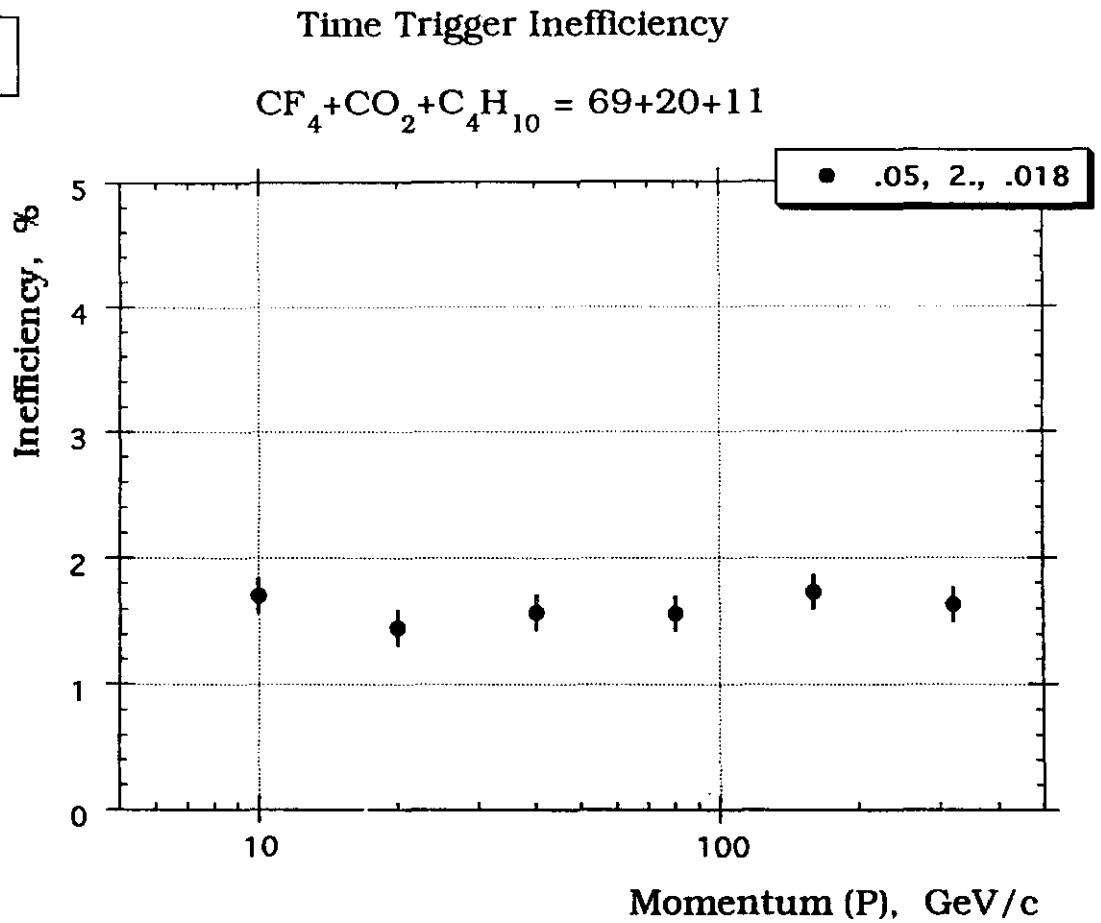
SL2

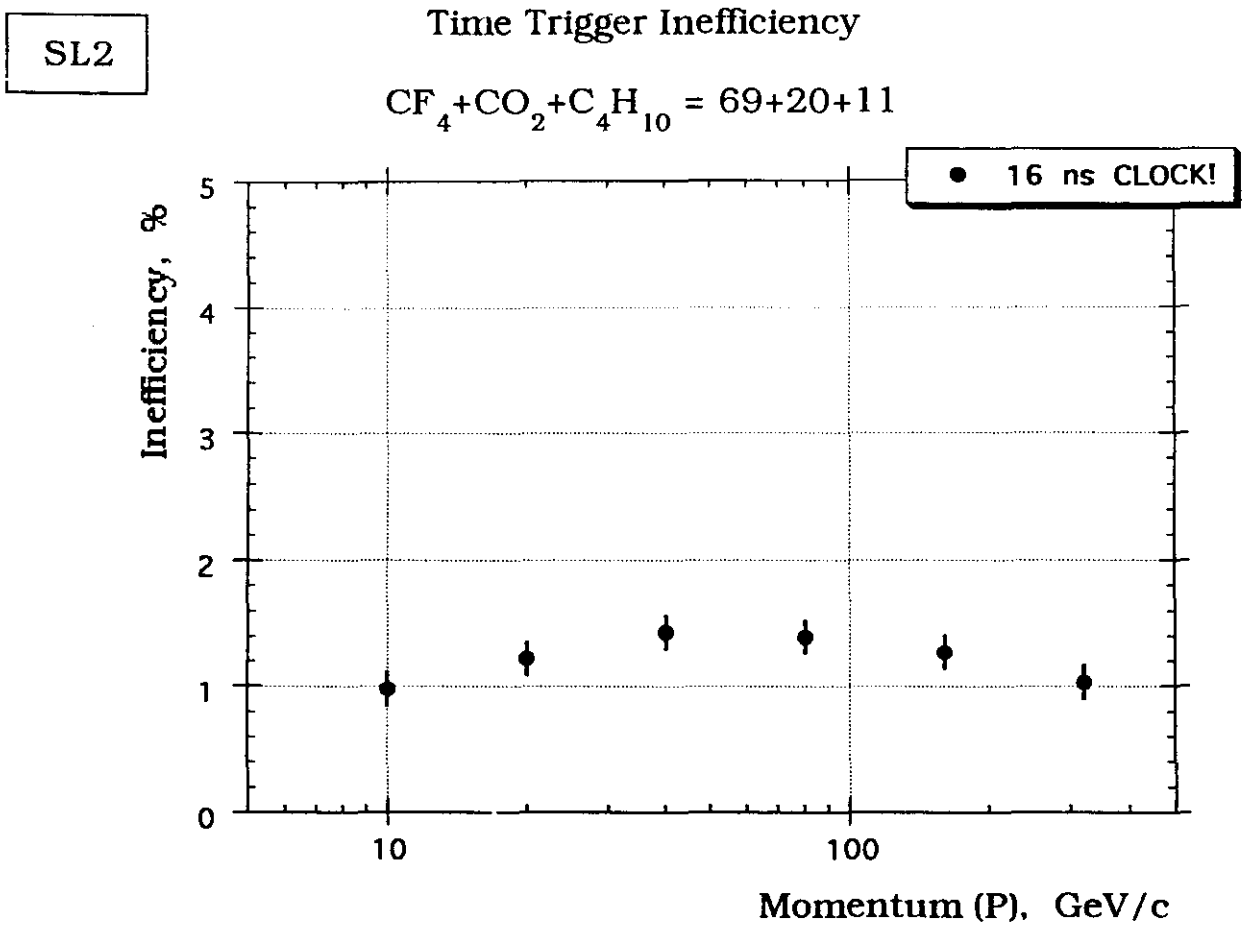
Time Trigger Inefficiency

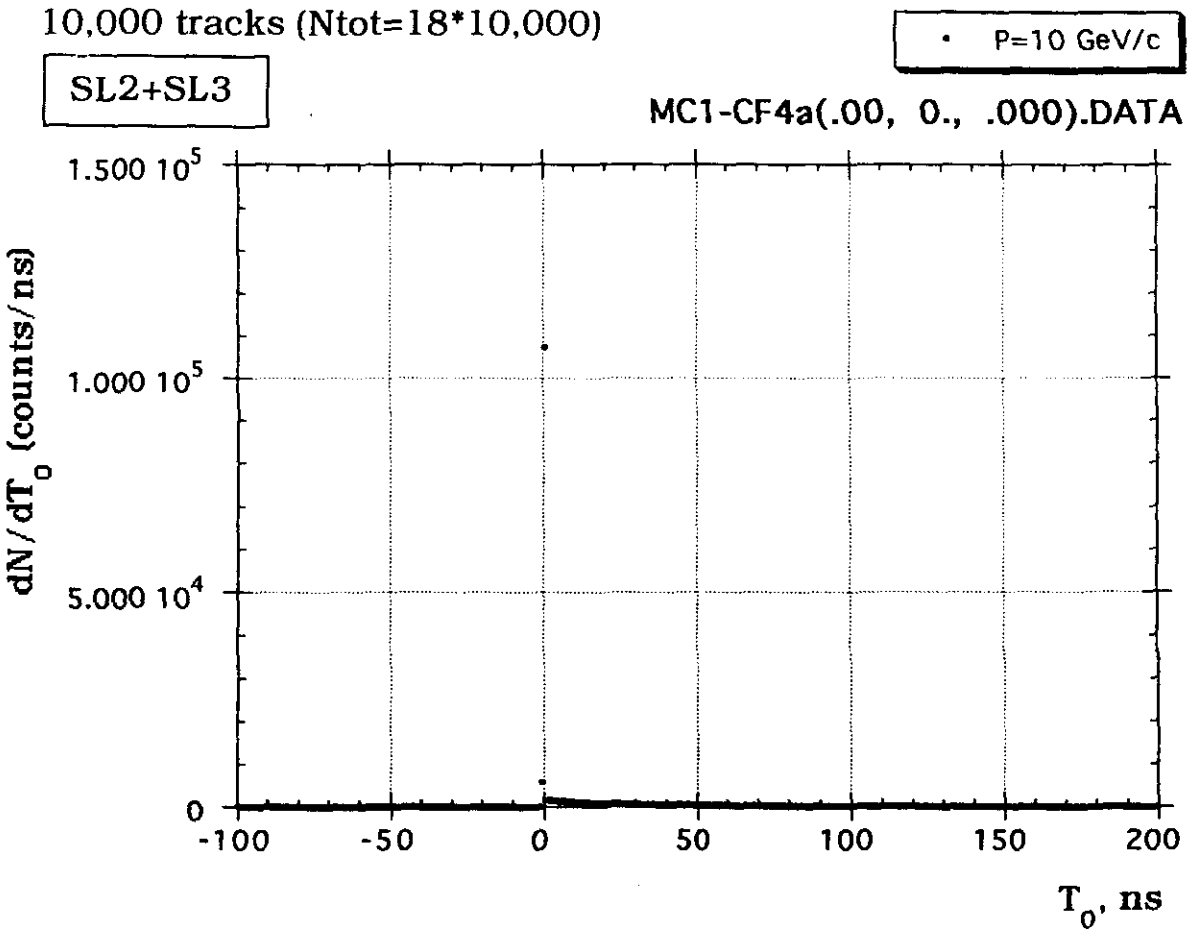
$CF_4+CO_2+C_4H_{10}$ = 69+20+11



SL2


Time Trigger Inefficiency
$CF_4+CO_2+C_4H_{10}$ = 69+20+11
.05, 2., .018
Inefficiency, %
5
4
3
2
1
0
10
100
Momentum (P), GeV/c

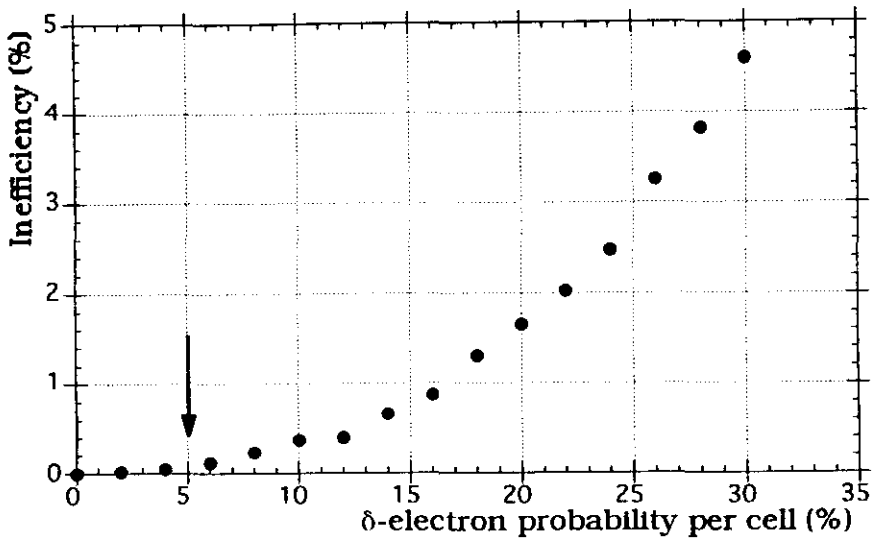

SL2
Time Trigger Inefficiency
$CF_4+CO_2+C_4H_{10}$ = 69+20+11
16 ns CLOCK!
Inefficiency, %
0
1
2
3
4
5
10
100
Momentum (P), GeV/c

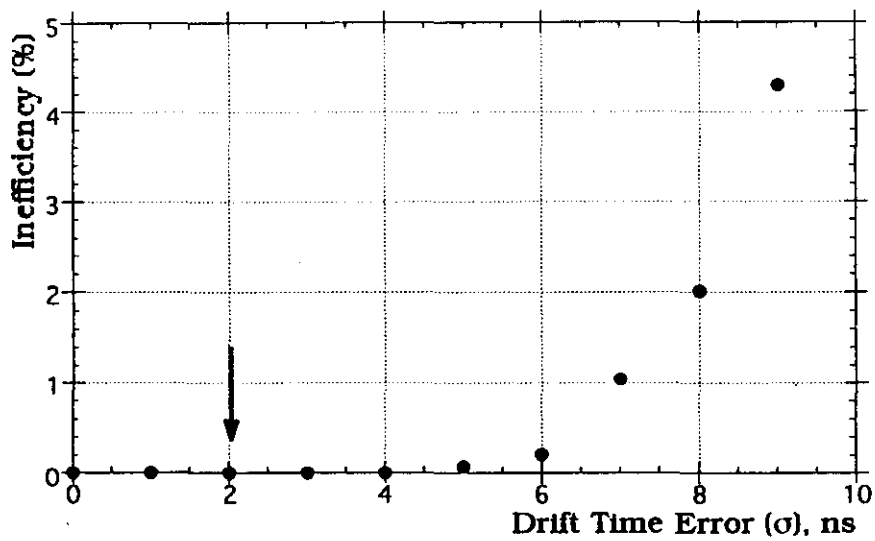

10,000 tracks (Ntot=18*10,000)
SL2+SL3
P=10 GeV/c
MC1-CF4a(.00, 0., .000).DATA
1.500 10^5
1.000 10^5
5.000 10^4
0
-100
-50
0
50
100
150
200
dN/dT_0 (counts/ns)
T_0, ns

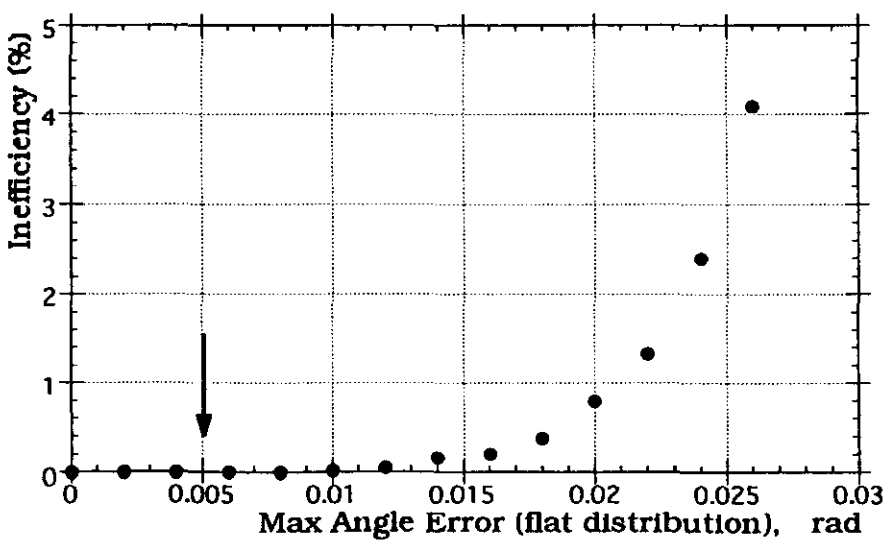
SL2+SL3

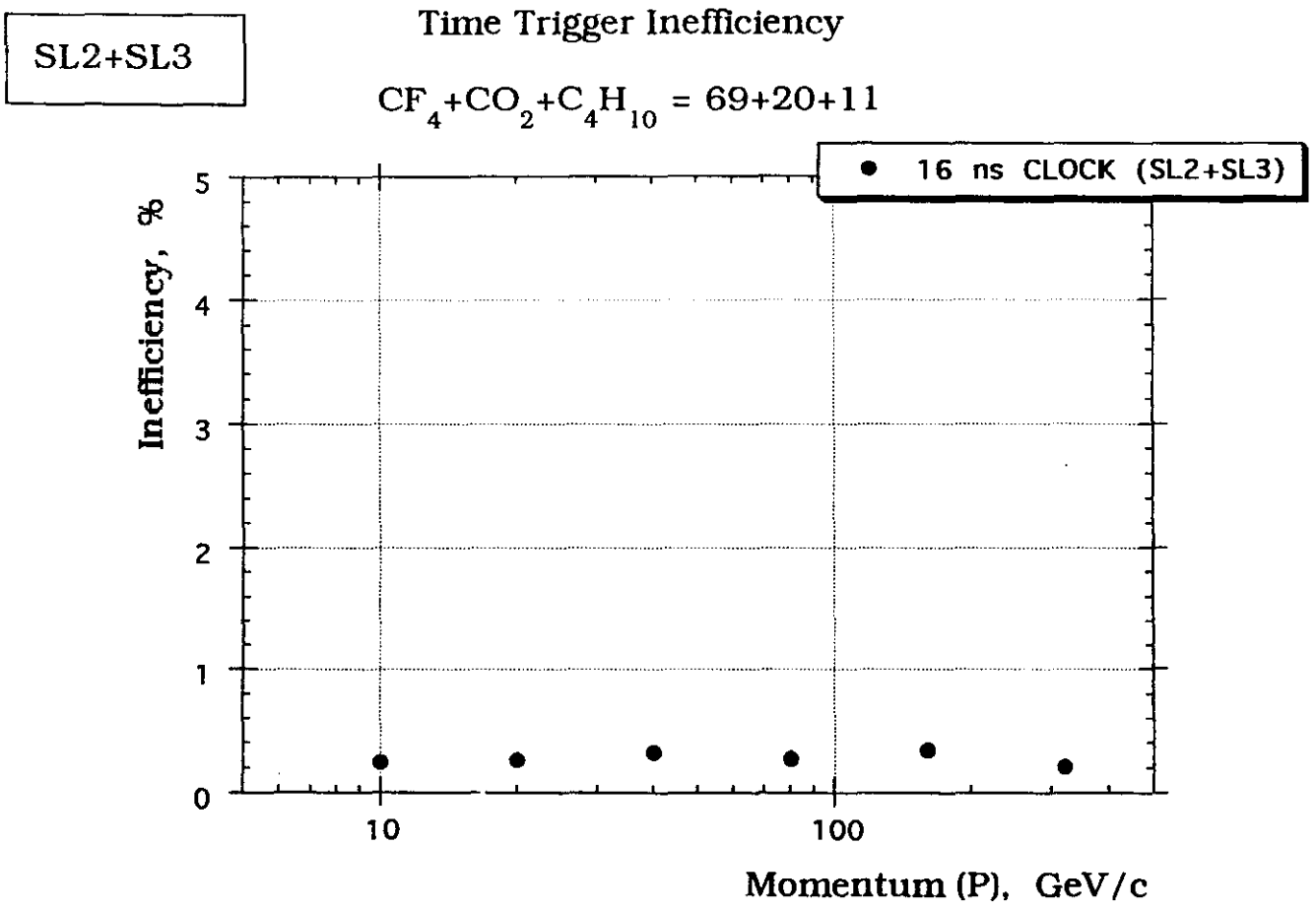
Time Trigger Inefficiency

$CF_4+CO_2+C_4H_{10} = 69+20+11$



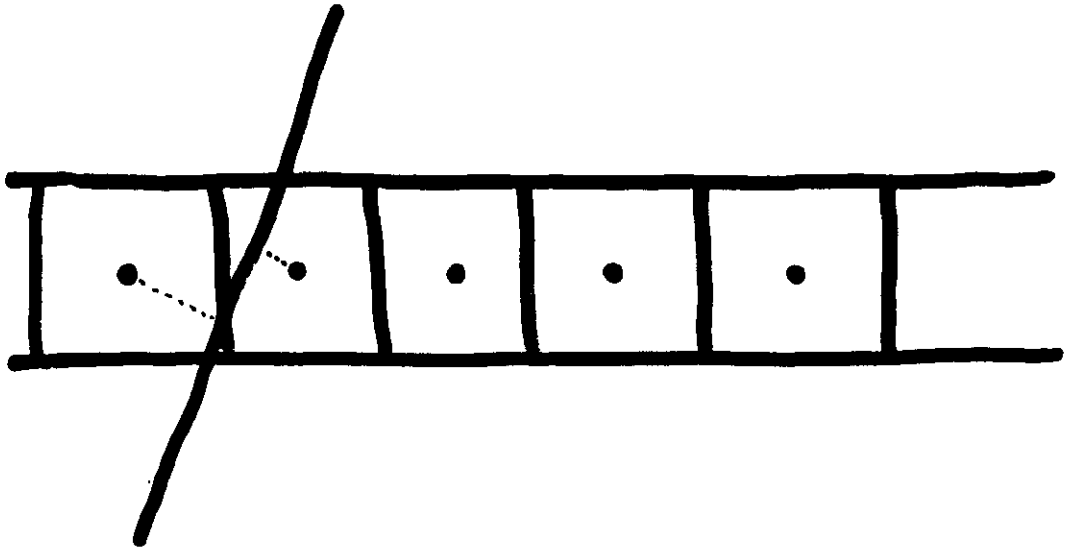





SL2+SL3
Time Trigger Inefficiency
$CF_4+CO_2+C_4H_{10}$ = 69+20+11
16 ns CLOCK (SL2+SL3)
Inefficiency, %
5
4
3
2
1
0
10
100
Momentum (P), GeV/c

DATA CUTS (!):

TTR:	* TTR data consistency (?) * 2 TOP Iarocci Planes (both projections) * X-STRIPS: nhits(1) × nhits(2) ≤ 1 * 2 BOTTOM Iarocci Planes (Just φ-projection) * x within 2 M
LSDT:	* one hit in the top plane. * at least one hit per plane. * nhits (LSDT) ≤ 6
TTR/LSDT: TOP PLANE	* $\lvert x(LSDT) - x(TTR) \rvert \leq 30$ cm. * $\lvert y(LSDT) - y(TTR) \rvert \leq 1.8$ cm. TUBE #



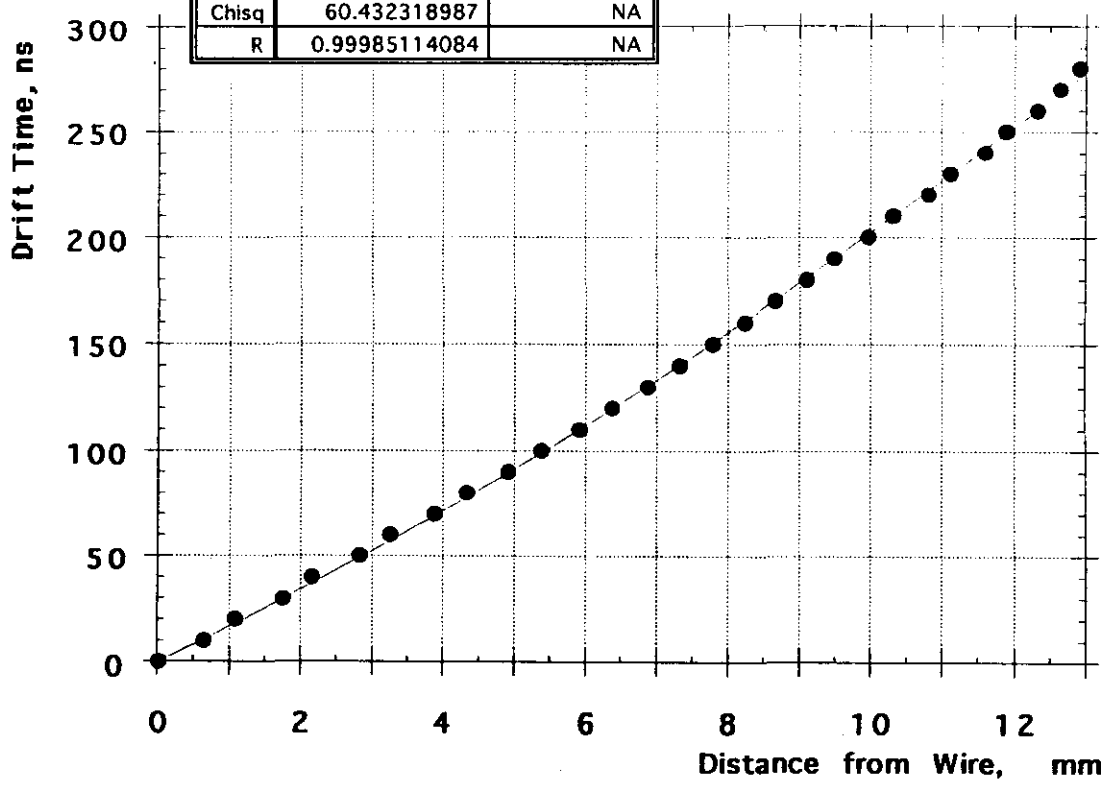
1. TUBE WITH THE SHORTEST TIME in the plane

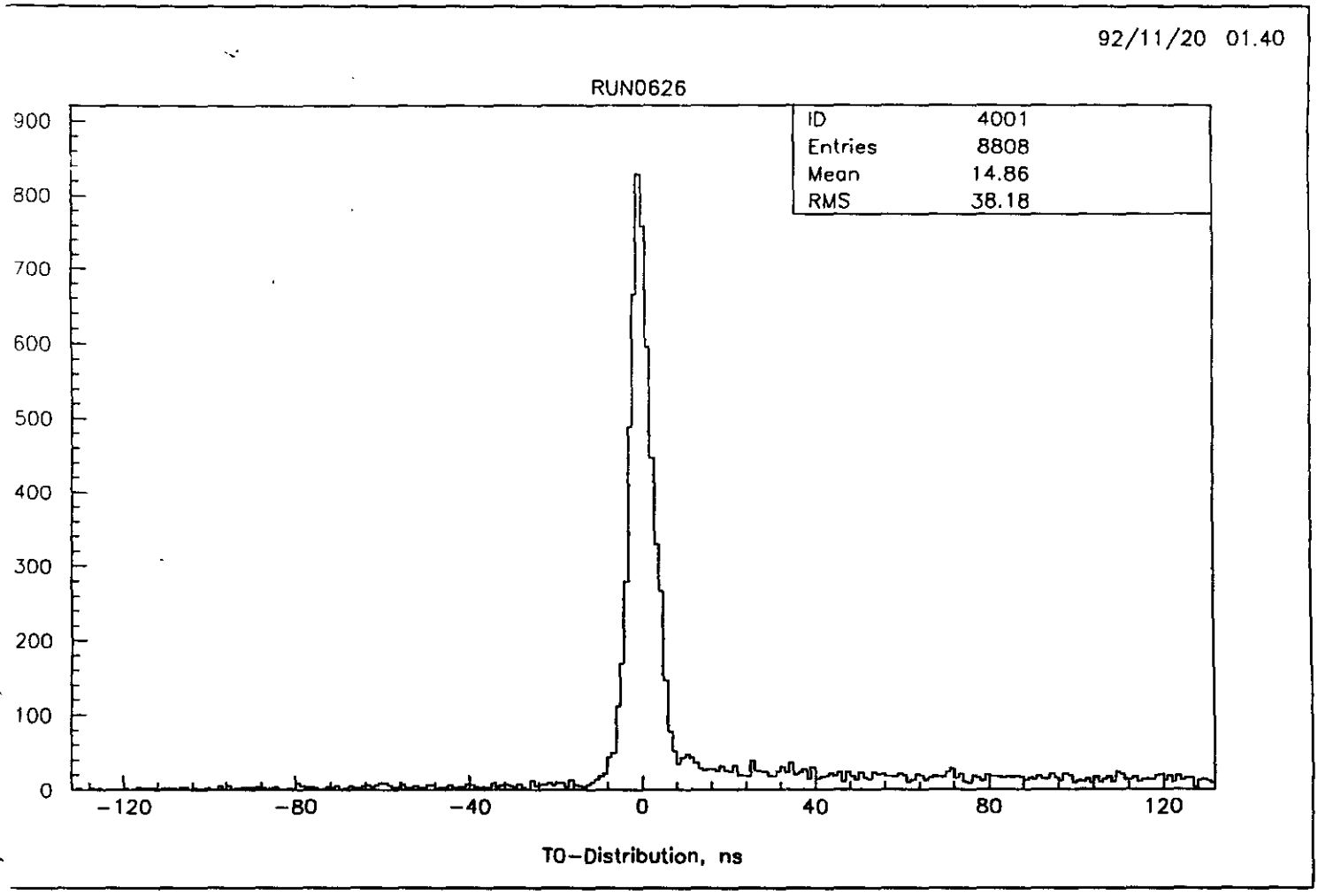
⇓

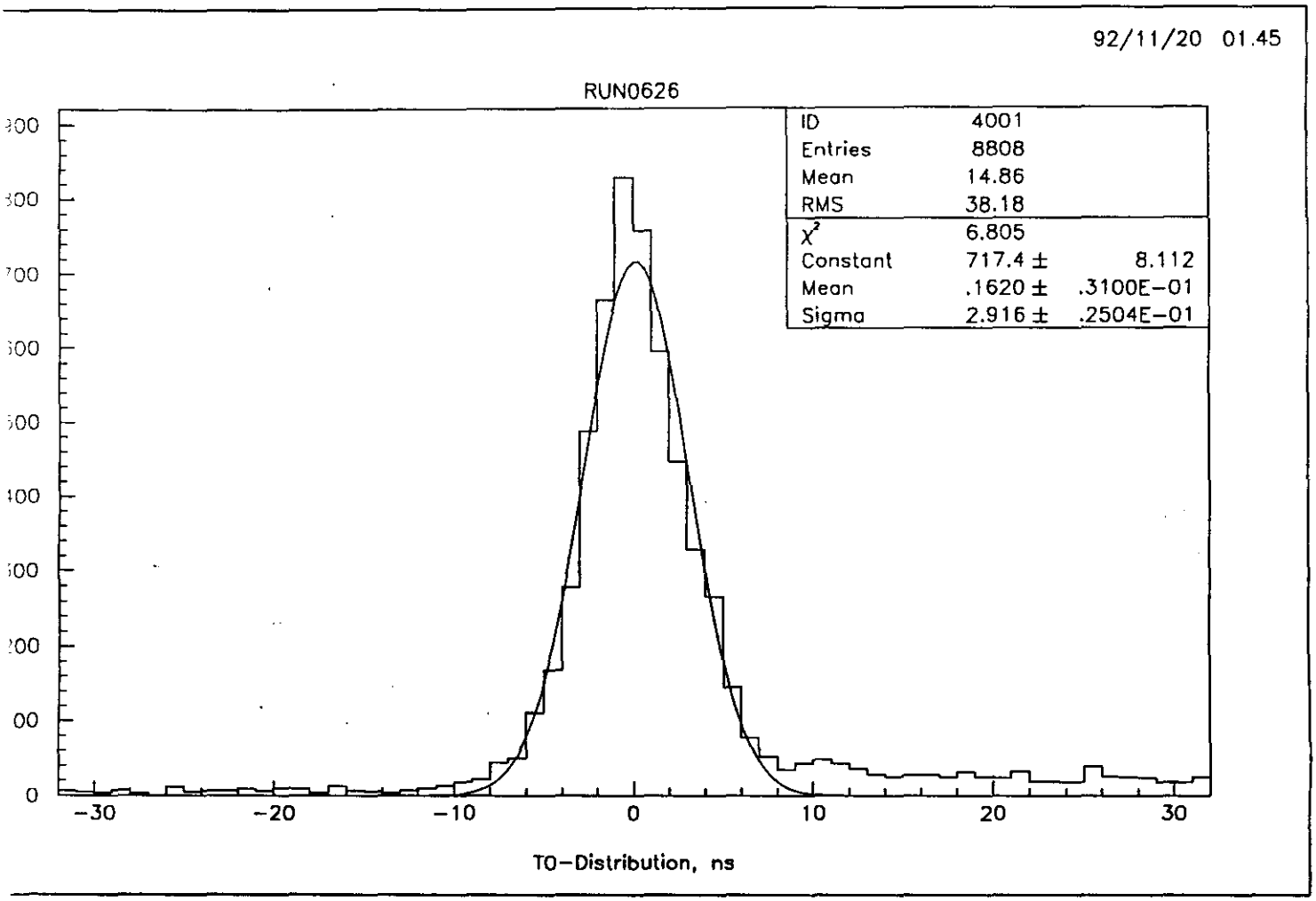
0.8 %
GAVE INCONSISTENT PATTERNS

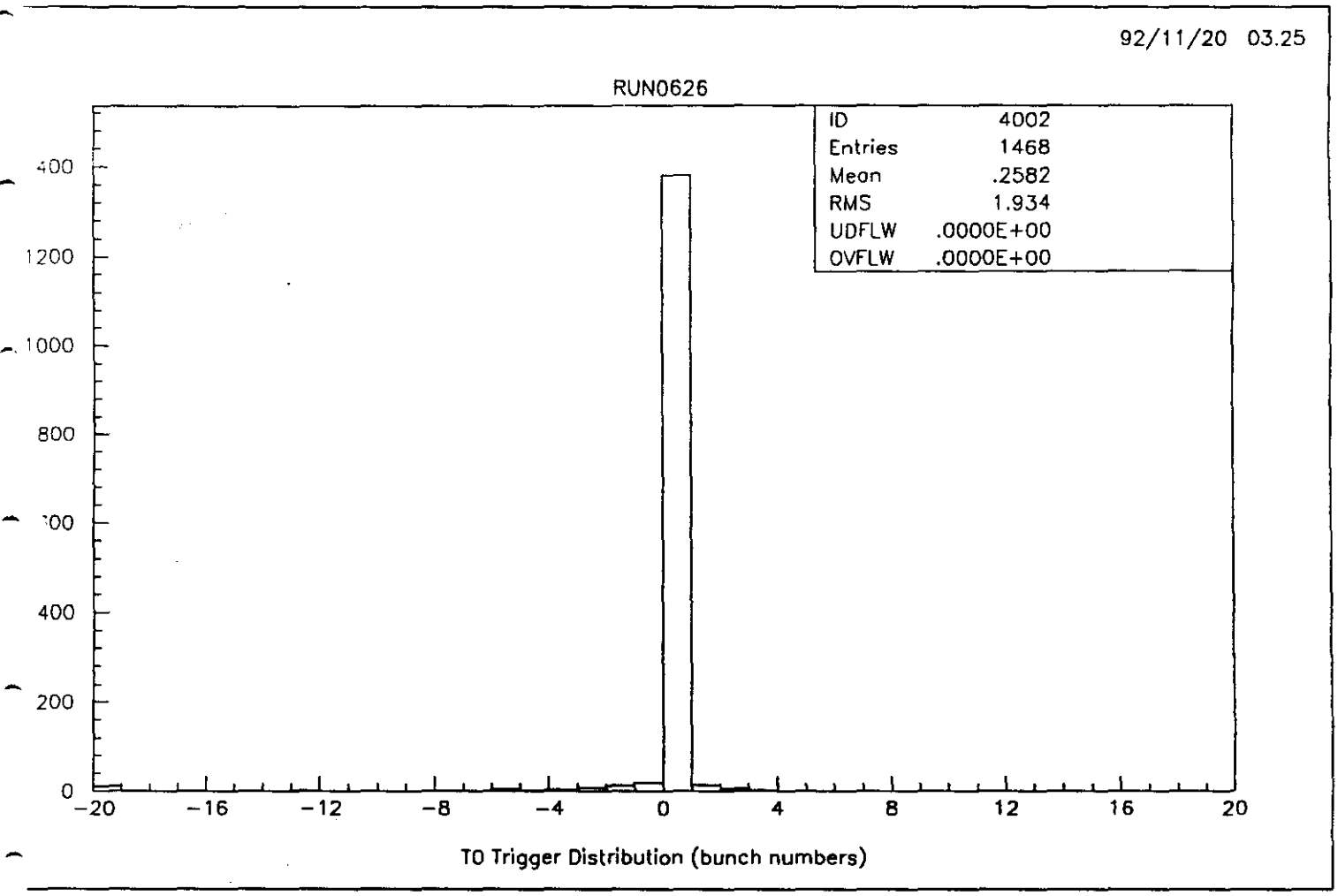
RUN 0626

T = a*X + b*X^2		
	Value	Error
a	16.357749129	0.148809
b	0.38743023349	0.0142478
Chisq	60.432318987	NA
R	0.99985114084	NA

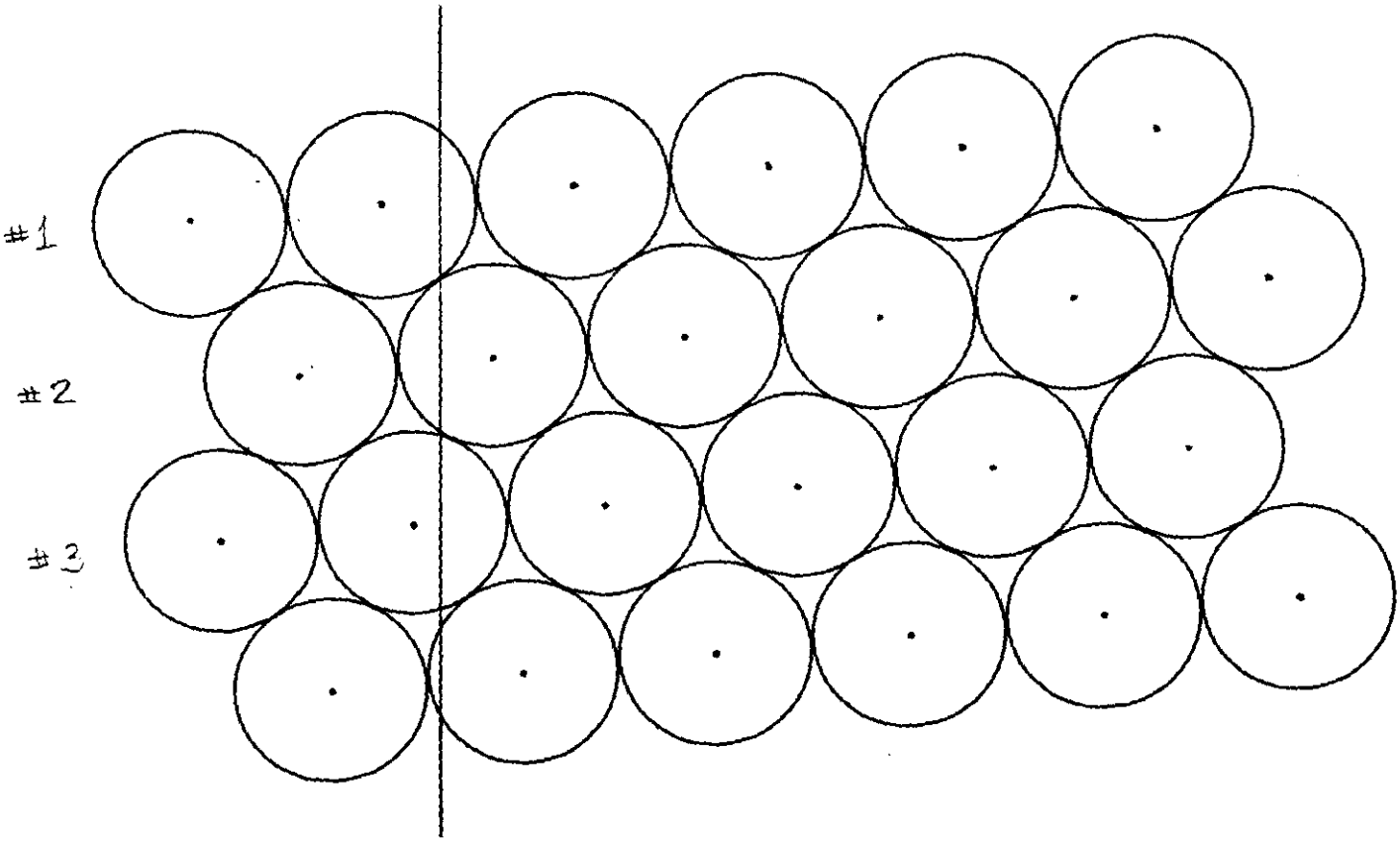



92/11/20 01.40
RUN0626
ID 4001
Entries 8808
Mean 14.86
RMS 38.18
900
800
700
600
500
400
300
200
100
0
-120
-80
-40
0
40
80
120
T0-Distribution, ns


92/11/20 01.45
RUN0626
ID 4001
Entries 8808
Mean 14.86
RMS 38.18
χ² 6.805
Constant 717.4 ± 8.112
Mean .1620 ± .3100E−01
Sigma 2.916 ± .2504E−01
0
−30
−20
−10
0
10
20
30
T0−Distribution, ns

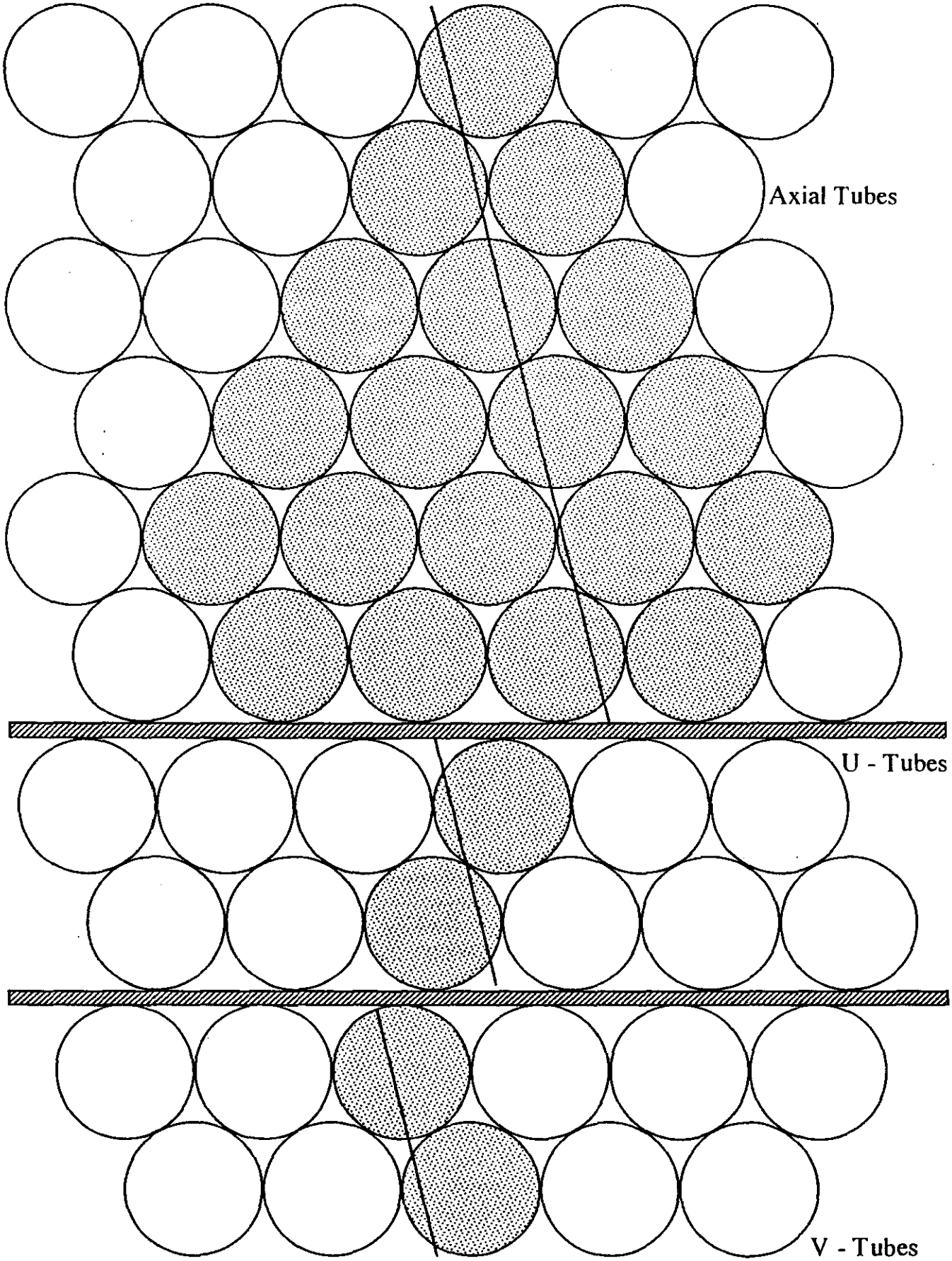


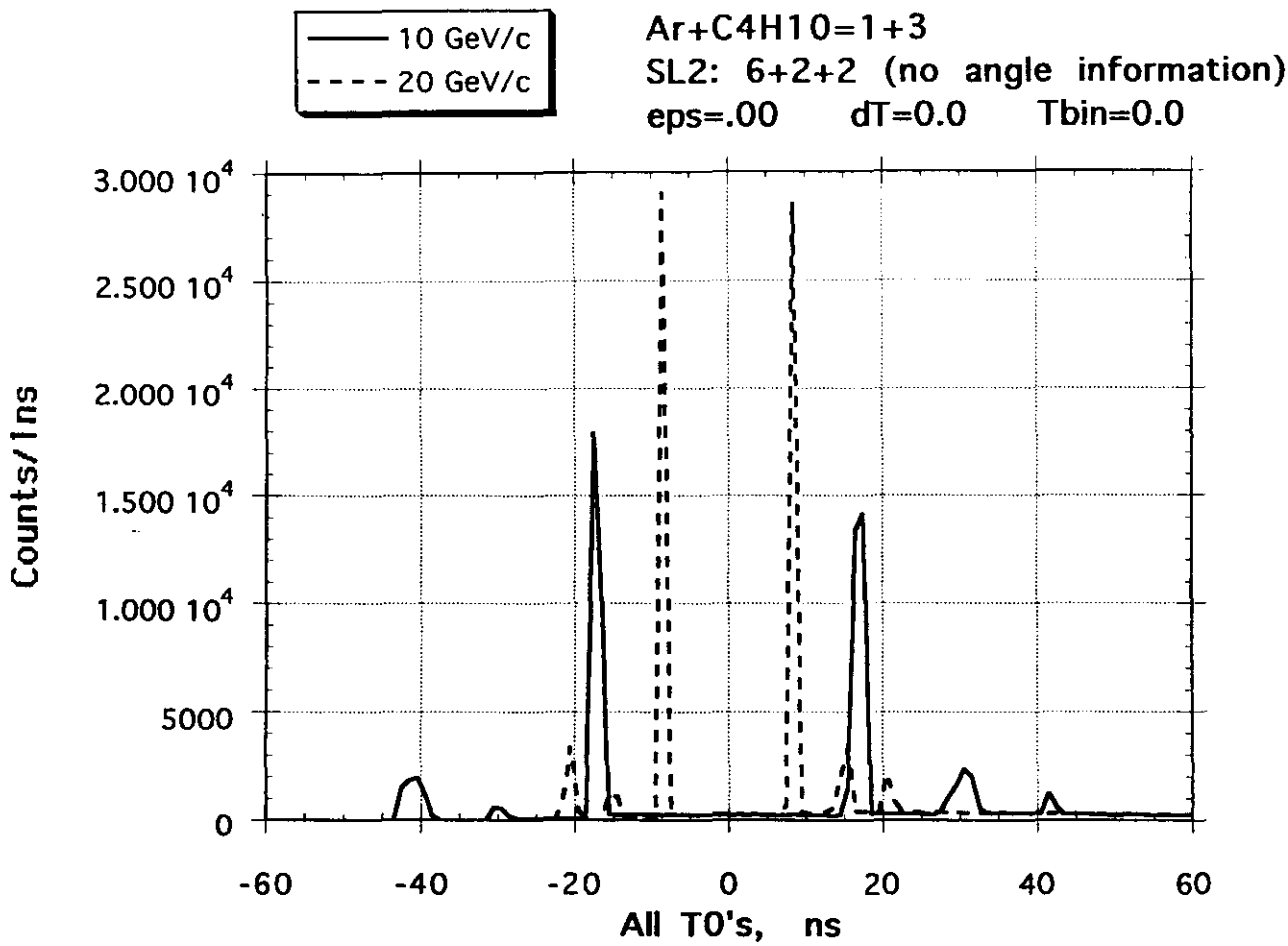
	TTR	MC
RIGHT T_0	94%	93.6%
WRONG T_0	5%	6.1%
NO T_0	1%	0.3%

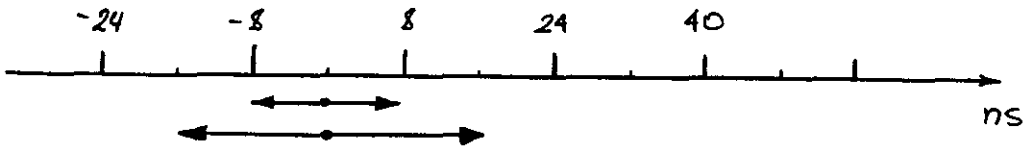


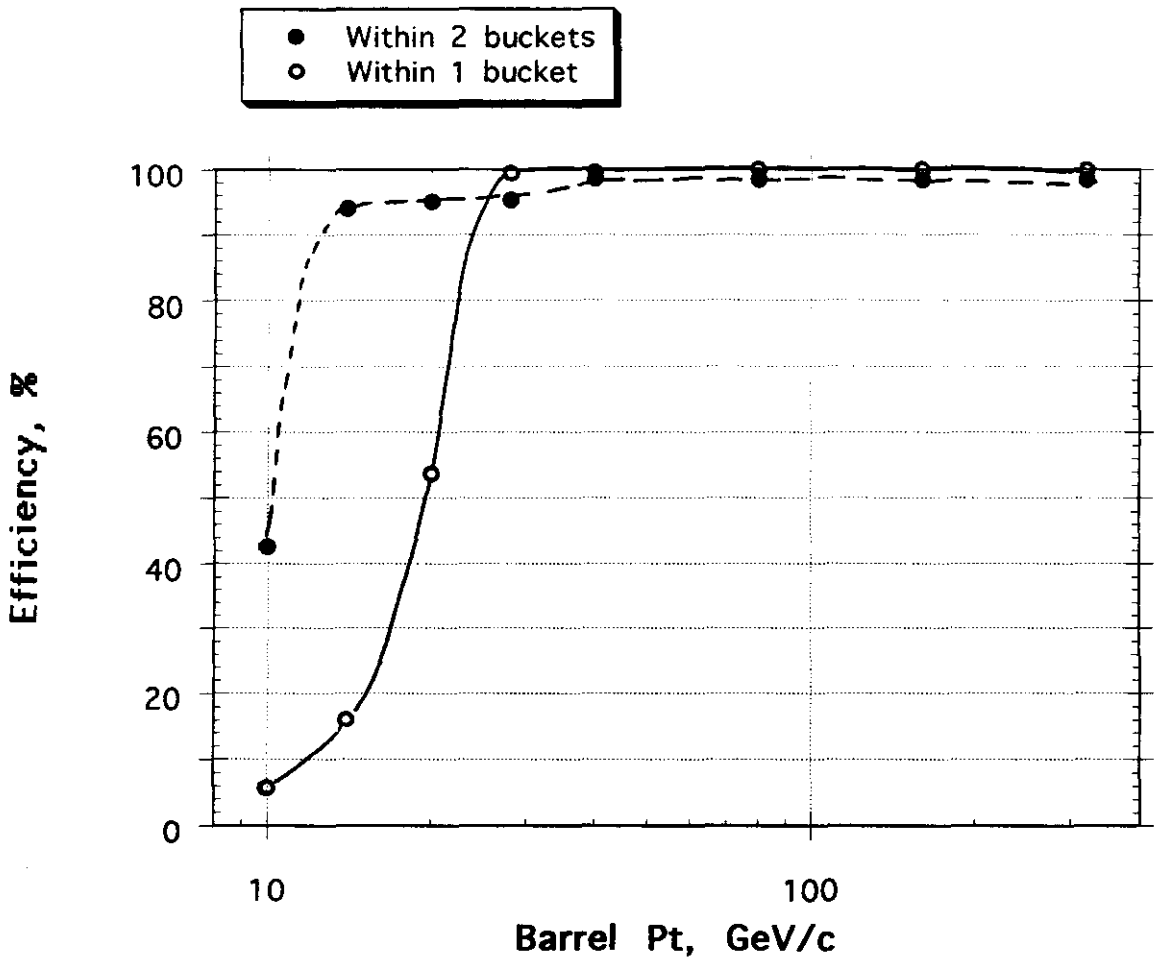
$$T_0 = \frac{T_1 + T_2}{2} - \frac{a}{2}\left(d - \alpha \cdot D\right)$$

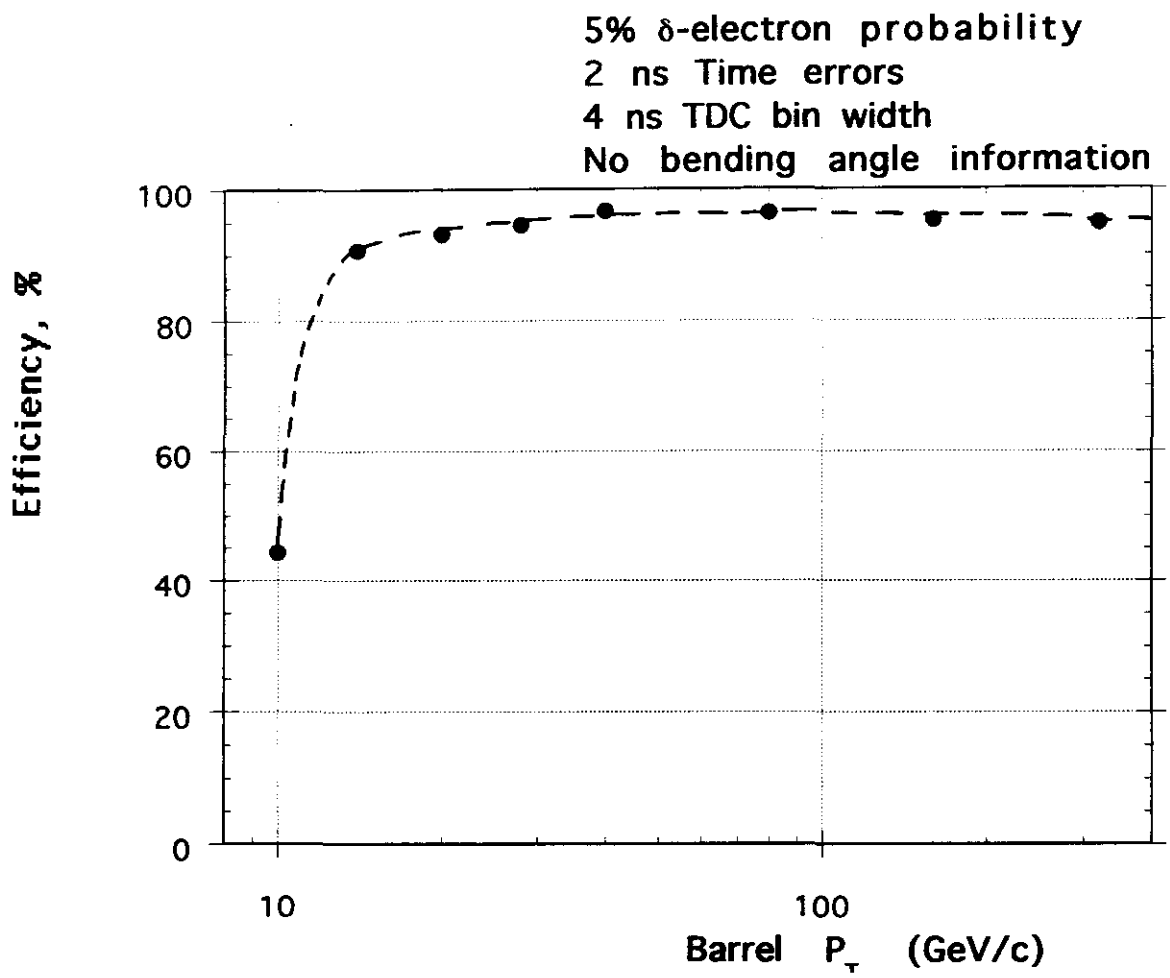
$$T_0 = \frac{T_1 + T_2}{2} - \frac{a}{2}\left(d + \alpha \cdot D\right)$$

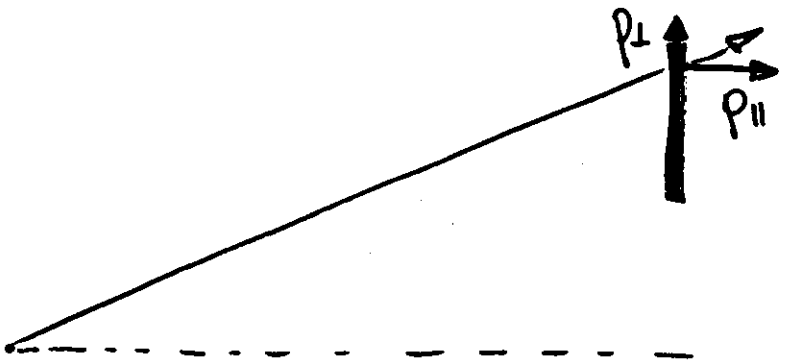

Axial Tubes
U - Tubes
V - Tubes


10 GeV/c
20 GeV/c
Ar+C4H10=1+3
SL2: 6+2+2 (no angle information)
eps=.00 dT=0.0 Tbin=0.0
3.000 10^4
2.500 10^4
2.000 10^4
1.500 10^4
1.000 10^4
5000
0
Counts/1ns
-60
-40
-20
0
20
40
60
All T0's, ns


-24
-8
8
24
40
ns


Within 2 buckets
Within 1 bucket
100
80
60
40
20
0
Efficiency, %
10
100
Barrel Pt, GeV/c


5% δ-electron probability
2 ns Time errors
4 ns TDC bin width
No bending angle information
Efficiency, %
100
80
60
40
20
0
10
100
Barrel P_T (GeV/c)



$$\alpha \sim \frac{eBL^2}{p_\perp}$$

$$L = z \cdot \theta$$

$$\beta \sim \frac{p_\perp \cdot \alpha}{p_\parallel} \sim \frac{eBL^2}{p_\parallel} \sim \frac{eBz^2\theta^2}{p_\perp/\theta} \sim$$

$z\theta_{max} = L_{BARREL}$

$$\sim \frac{eBz^2\theta^3}{p_\perp} \sim \frac{1}{2}\beta_{BAR} \cdot \frac{\theta^3}{\theta_{max}^3}$$

$$\beta \sim \frac{\beta_{BARREL}}{2} \cdot \left(\frac{\theta}{\theta_{max}}\right)^3$$

Simulation of Muon Background: CSC vs RDT

Presentation by:

A. Ostapchuk

CSC vs RDT and muon background

A. Ostapchuk
1.19.93

Two kinds of background:

- <u>correlated</u> ($e^{\pm}, \gamma$ produced by muon in calorimeter and in muon system).
  It could be simulated with GEANT

- <u>uncorrelated</u> (soup from n and γ)
  Too many uncertainties.

We will characterize the performance of muon system by the value $\underline{P}^{<3}$ - probability to have <u>less than 3 "good" hits</u> for one SL.

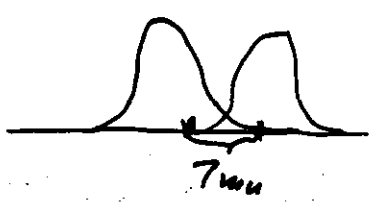
<u>Good hit for CSC</u> - there are no extra hits closer to the muon hit than <u>7 mm</u>, and there are no 2 extra hits closer to muon hit than <u>20 mm</u>.

<u>Good hit for RDT</u> - there are no extra hits <u>closer to wire</u>, than muon hit ($\phi_{tube} = 25$ mm)

$\underline{p_{\mu}^{tot} = 1 \text{ TeV/c}}$ for all calculations

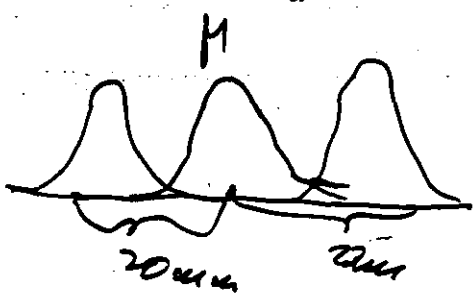
Correlated Background

Em-debris from calorimeter (8 layers)				$e^{\pm}$ produced by muon in muon system	
Barrel		EndCaps		Barrel ≈ Endcaps	
CSC	RDT	CSC	RDT	CSC	RDT
$R^{<3} \sim 1.5\%$	$R^{<3} \sim .8\%$	$R^{<3} \sim 10\%$	$R^{<3} \sim 5\%$	Probability of bad hit ~ 4-5%	Probability of bad hit ~ 3-4%
Effect is small		For CSC loss of accuracy, not loss of track		For 6 layers $R^{<3} << 1\%$	For 8 layers $R^{<3} << .1\%$

1) 

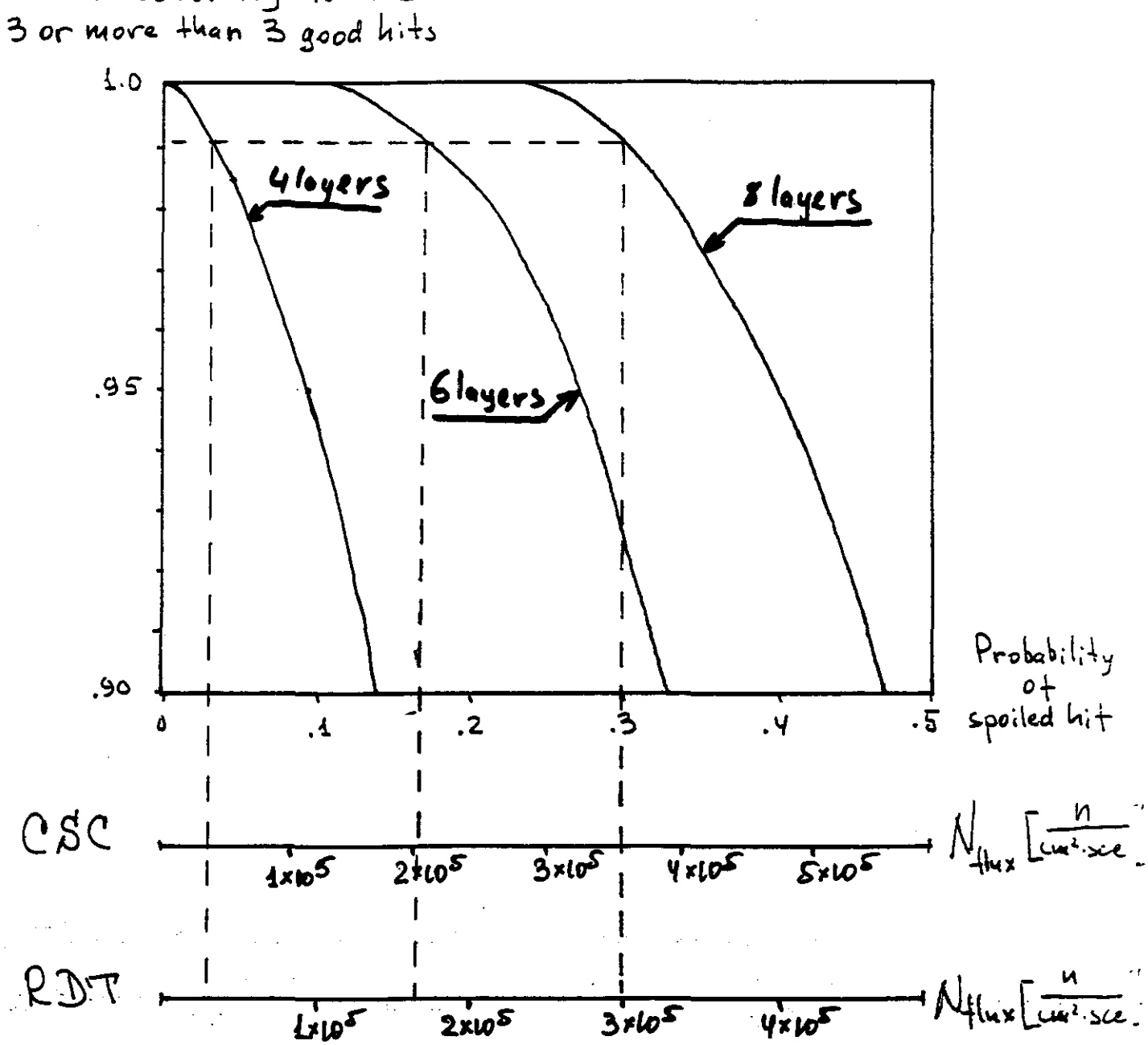
6%

Or → 10%

2) 

6%

Uncorrelated background

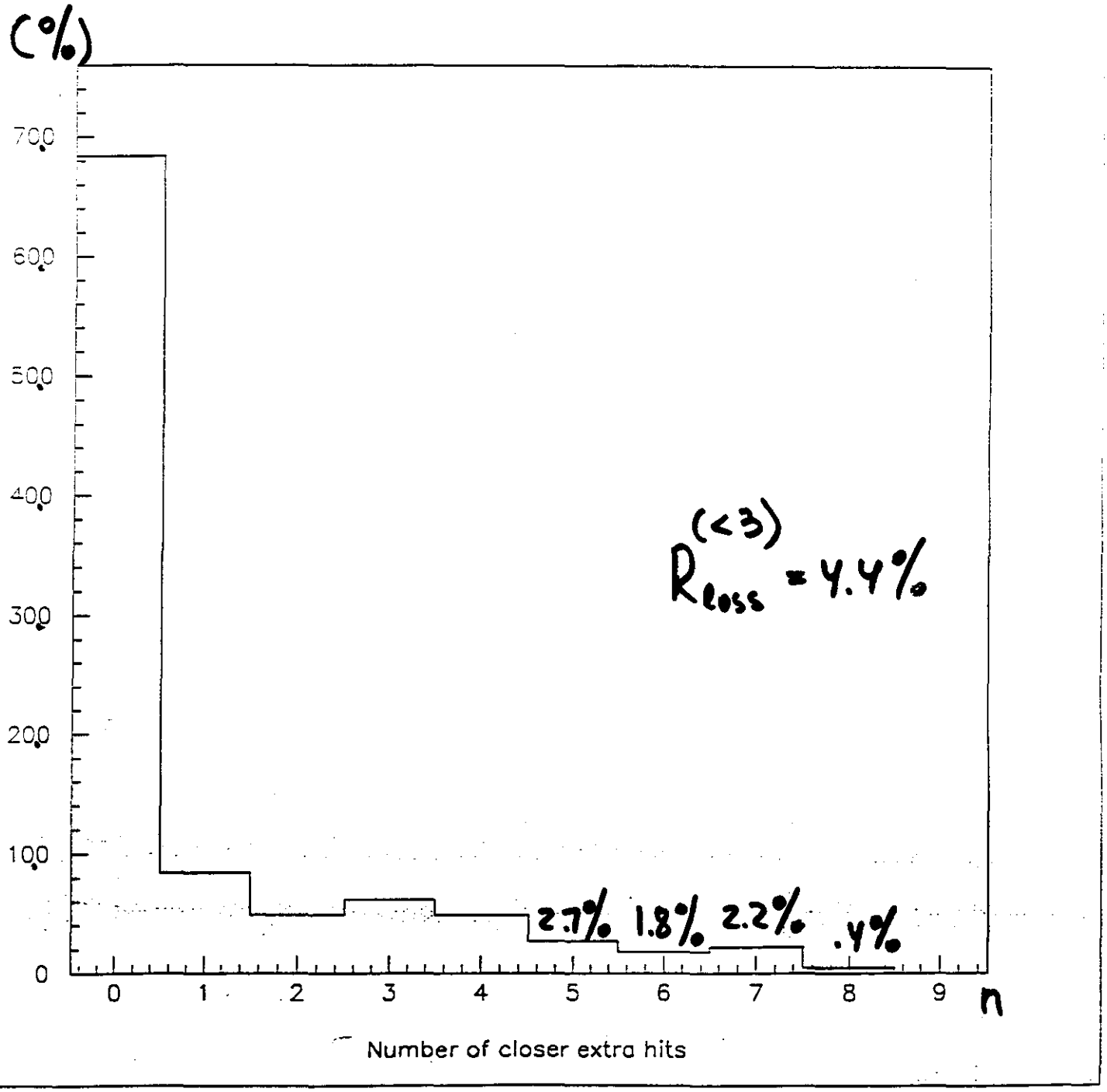


Probability of spoiled hit (P_{spoil})

CSC	RDT
$P_{spoil} = Area \times Time \times \varepsilon_{sens} \times N_{flux} =$	$P_{spoie} = \frac{1}{2} \times Area \times Time \times \varepsilon_{sens} \times N_{flux} =$
$= (2 \times \Delta_{res}^{2hit}) \times l_{strip} \times t_{int} \times \varepsilon_{sens} \times N_{flux} =$	$= \frac{1}{2} \times D_{tube} \times L_{tube} \times t_{drift} \times \varepsilon_{sens} \times N_{flux} =$
$= 2 \cdot 0.7cm \cdot 300cm \cdot 5 \cdot 10^{-7} sec \cdot 4 \cdot 10^{-3} \cdot N_{flux} =$	$= \frac{1}{2} \cdot 2.5cm \cdot 400cm \cdot 5 \cdot 10^{-7} sec \cdot 4 \cdot 10^{-3} \cdot N_{flux} =$
$= 8.4 \times 10^{-7} cm^2 \cdot sec \cdot N_{flux}$	$= 1.0 \times 10^{-6} cm^2 \cdot sec \cdot N_{flux}$

Part of events with n bad hits

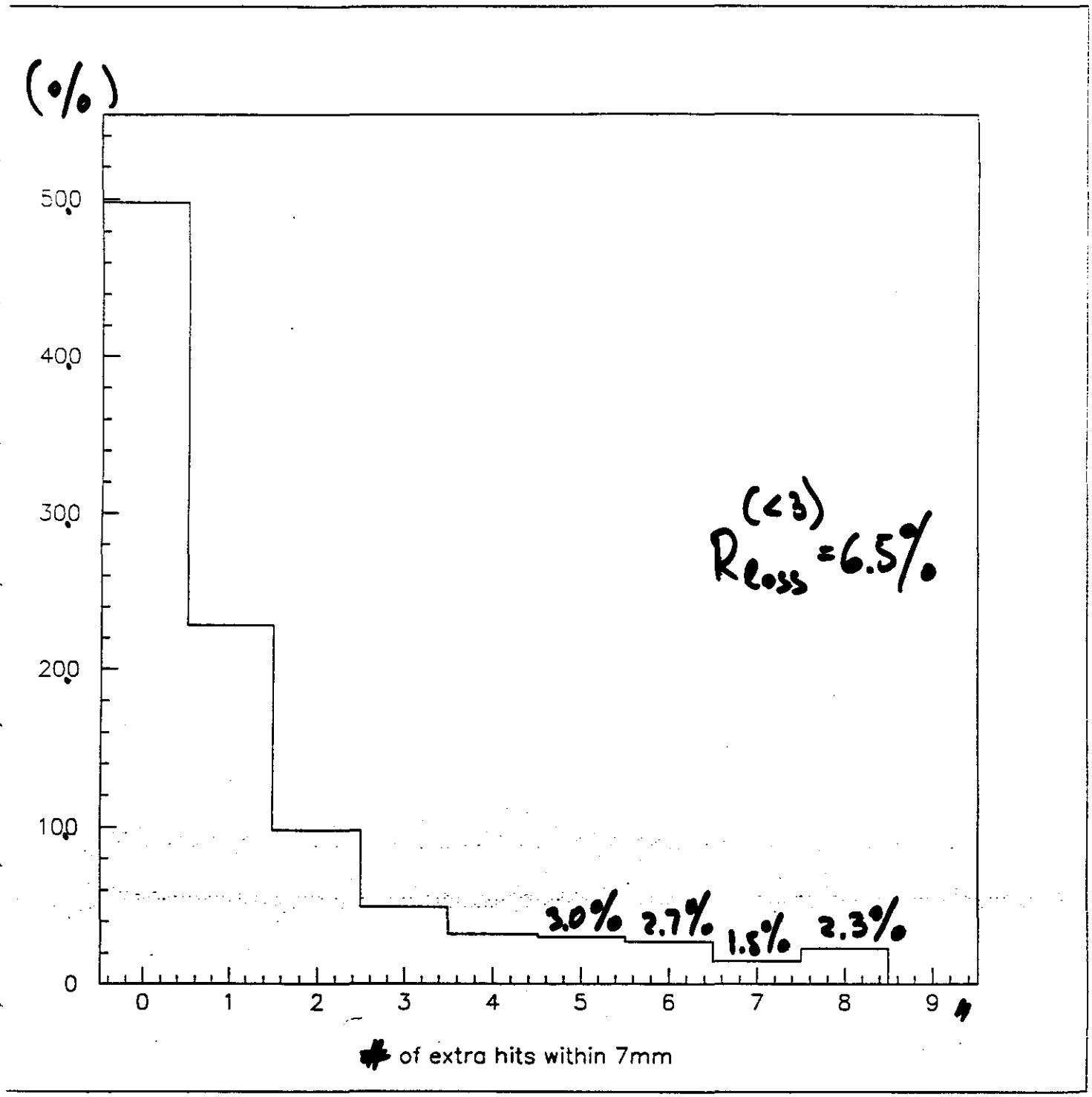
RDT



$P_{\mu}^{tot} = 1$ TeV/c ; $\theta = 15°$; 1-st SL ; $D_{tube} = 2.5$ c

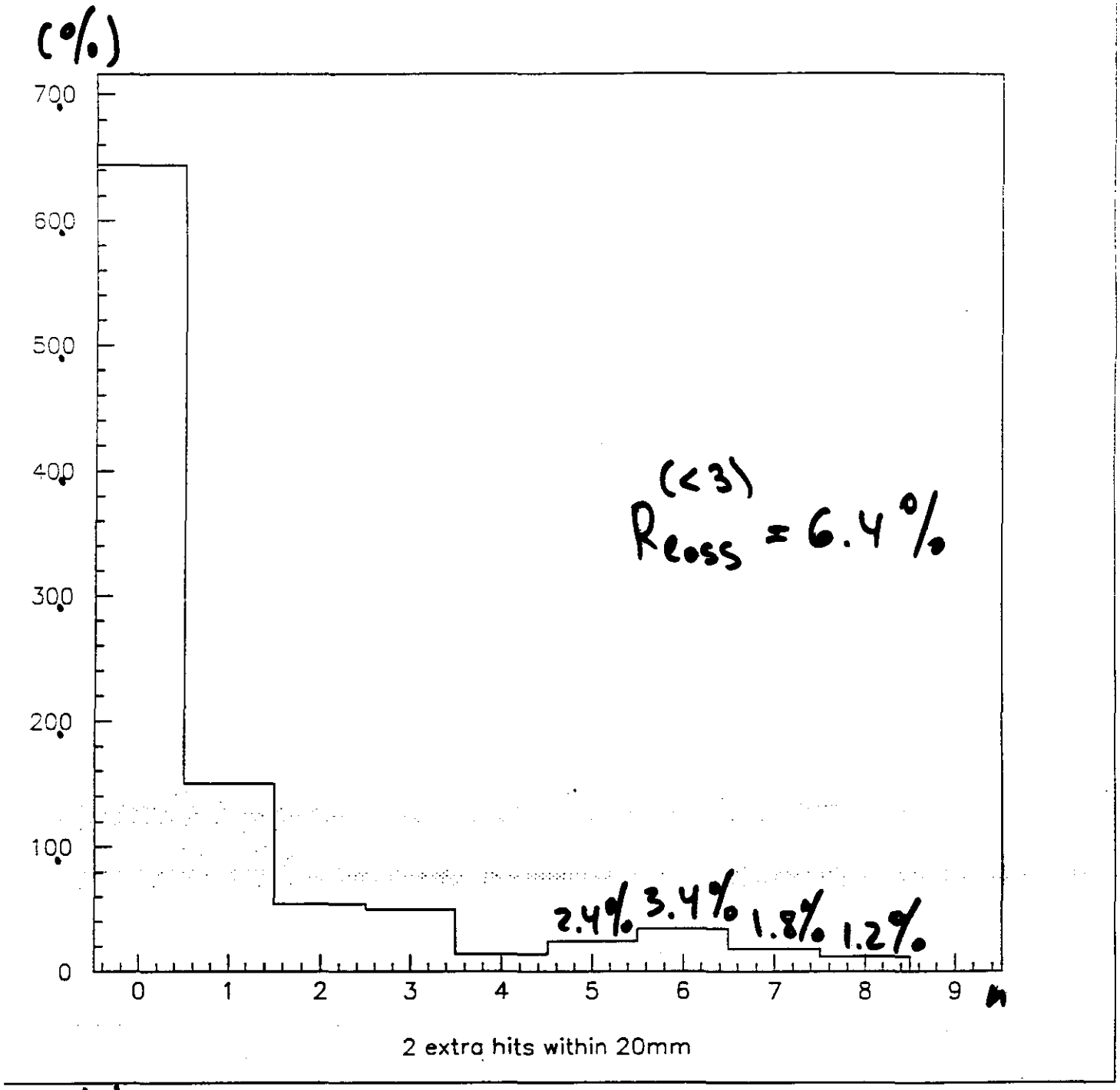
Part of event with n bad hits

CSC



$P_\mu^{tot} = 1$ TeV/c; $\theta = 15°$; 1-st Sh (8 layers)

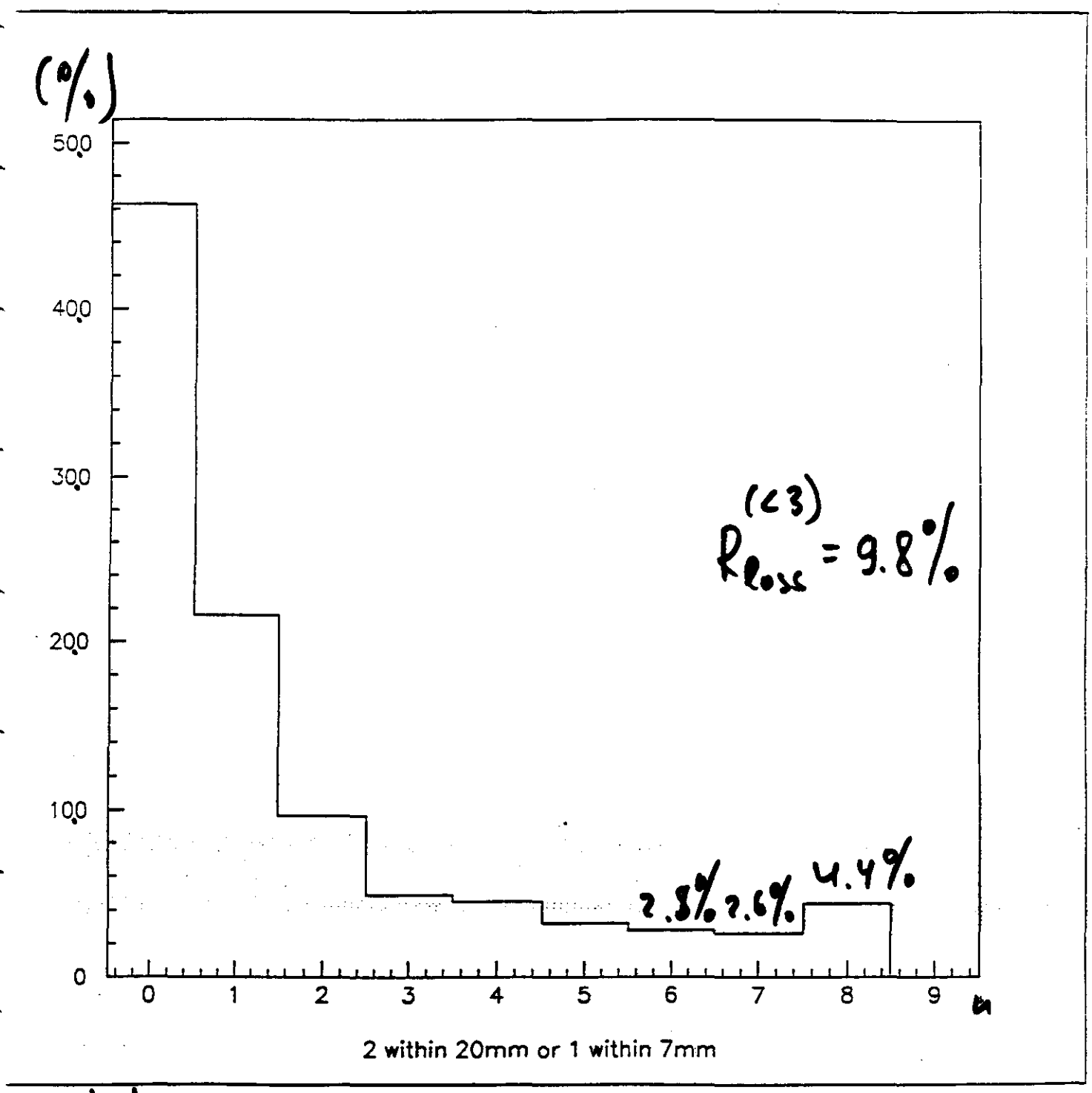
Part of events with n bad hits



$P_\mu^{tot} = 1$ TeV/c ; $\theta = 15°$; 1-st SL (8 layers)

Part of events with n bad hits

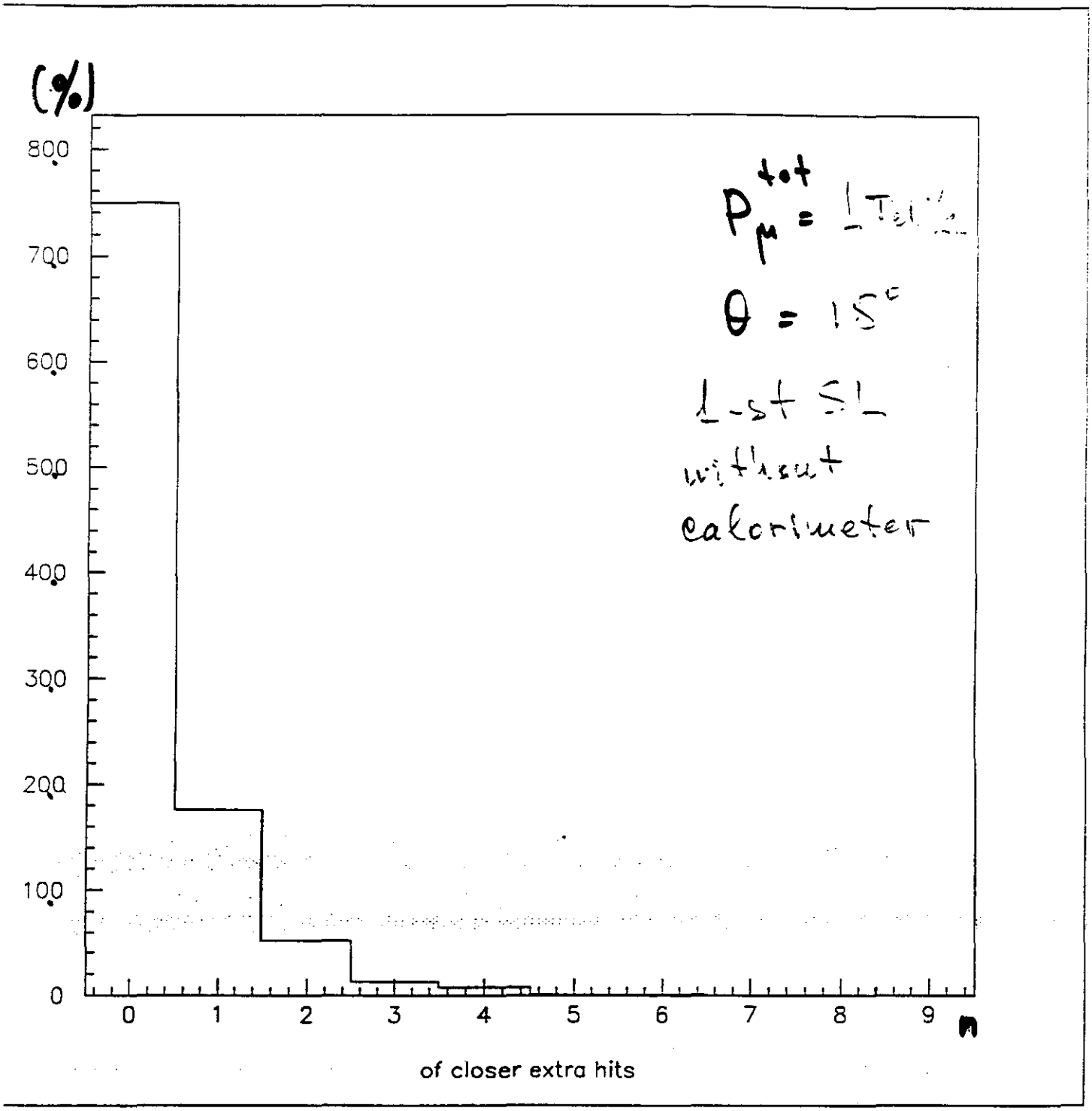
CSC



$P_\mu^{tot} = 1$ TeV/c ; $\theta = 15°$; 1-st SL (8 layers)

Part of events with n bad hits

RDT

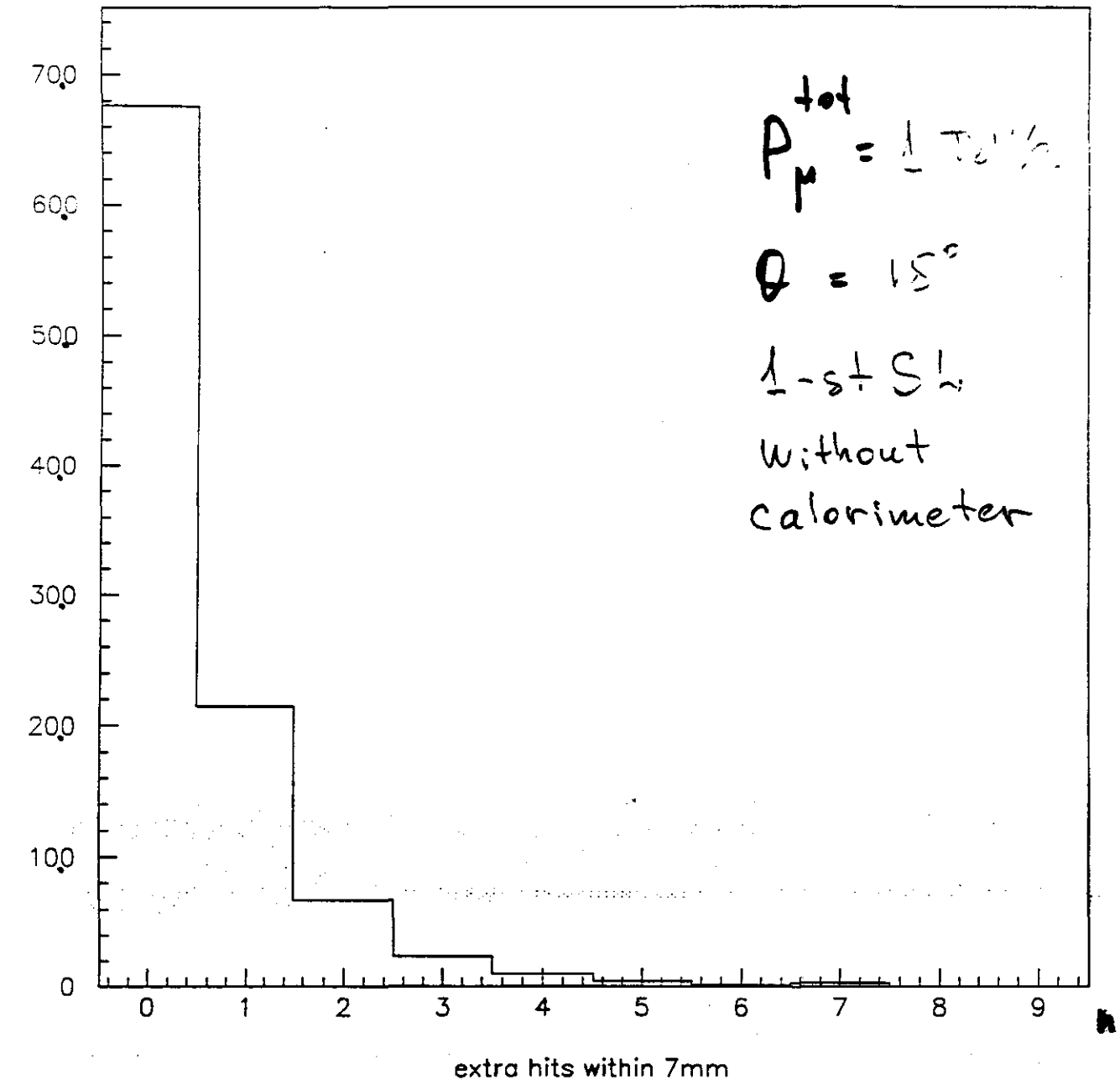


Approximately binomial distribution

with $Pr_{spoiled\ hit} \simeq 0.035$

Part of events with n bad hits

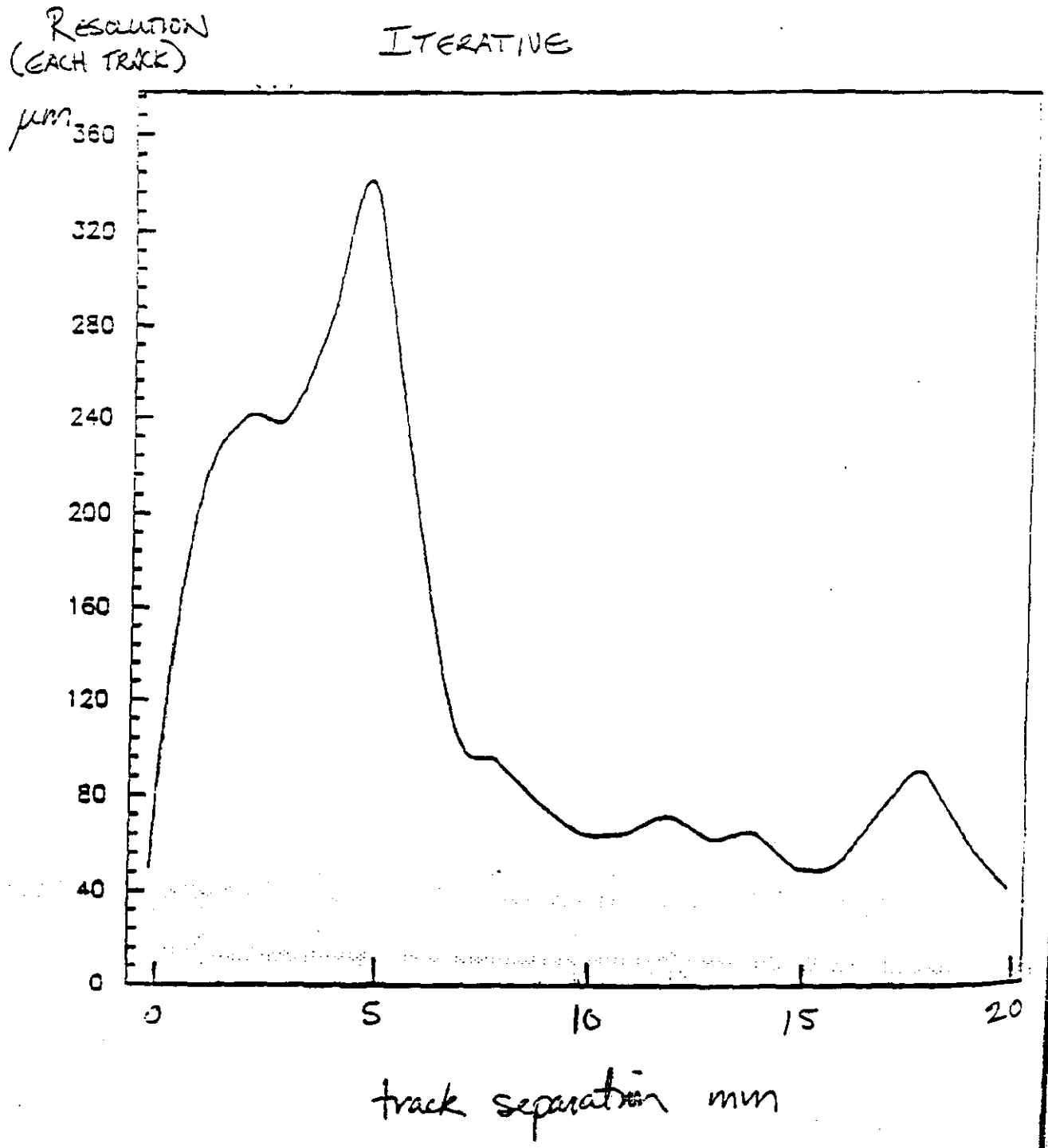
CSC



Approximately binomial distribution with $Pr_{spoiled\ hit} \simeq 0.048$

MOMENT FIT

ITERATIVE



The GEM Muon Subsystem Cost Matrix

Presentation by:

R. Gustavson

GEM

Muon Subsystem Cost Matrix

Revision 15

15 January 1993

DRAPER LABORATORY

MUON SYSTEM
COST ESTIMATION WORKSHEET BACK-UP

WBS ELEMENT DESCRIPTION: Barrel Region; RPCs; Off-Site; RPC & Assy Fixturing, Final Design

WBS ELEMENT NUMBER: 30.02.2.1.6"
DATE: 16 June 92 REV: 0 ESTIMATOR: T. Hamilton

ENGINEERING/DESIGN
Organization: MIT

LABOR	PY	Rate ($K/PY)	$K
engineer, nat'l lab	0.00	161	0
designer, nat'l lab	0.00	118	0
draftsman, nat'l lab	0.00	77	0
engineer, nat'l avg	1.25	133	166
designer, nat'l avg	0.00	107	0
draftsman, nat'l avg	2.00	82	164
Total, w/ Comp Rate	3.25	102	330

M&S: ENG/DESIGN and INSPECT/ADMIN	$K
office supplies ($2.4K/PY)	8
PC/Mac/workstation operating charges ($3.6K/PY)	12
travel	0
office/engineering service equipment	0
	0
	0
ww	0
xx	0
yy	0
zz	0
Total	20

INSPECTION/ADMINISTRATION
Organization: MIT

LABOR	PY	Rate ($K/PY)	$K
engineer, nat'l lab	0.00	161	0
sr. tech, nat'l lab	0.00	118	0
jr. tech, nat'l lab	0.00	108	0
engineer, nat'l avg	0.13	133	17
sr. tech nat'l avg	0.00	107	0
jr. tech nat'l avg	0.00	82	0
engineer, SSCL	0.00	69	0
sr. tech, SSCL	0.00	44	0
sr. tech, job shop	0.00	48	0
jr tech, job shop	0.00	34	0
Total, w/ Comp Rate	0.13	133	17

CONTINGENCY

	Factor	Percentage	Total
technical	8	2	16%
cost	6	1	6%
schedule	8	1	8%
Total Contingency			30%

INSTALLATION/ASSEMBLY
Organization: none

LABOR	PY	Rate ($K/PY)	$K
engineer, nat'l lab	0.00	161	0
sr. tech, nat'l lab	0.00	118	0
jr. tech, nat'l lab	0.00	108	
engineer, nat'l avg	0.00	133	0
sr. tech, nat'l avg	0.00	107	0
jr. tech, nat'l avg	0.00	82	0
engineer, SSCL	0.00	69	0
sr. tech, SSCL	0.00	44	0
machinist, job shop	0.00	57	0
sr. tech, job shop	0.00	48	0
jr tech, job shop	0.00	34	0
rigger, welder	0.00	46	0
pipefitter, electrician	0.00	57	0
Total, w/ Comp Rate	0.00	0	0

PROCUREMENT and FABRICATION MATERIAL	$K
component stock	0
fabrication equip	0
assembly/test equip	0
materials and supplies (nuts, bolts, etc)	0
inspection equipment	0
support tubes	0
end plugs	0
tt	0
uu	0
vv	0
ww	0
xx	0
yy	0
zz	0
Total	0

MATERIAL: INSTALLATION/ASSEMBLY	$K
office supplies ($1.2K/PY)	0
travel	0
office/engineering service equipment	0
equipment operating charges	0
uu	0
vv	0
ww	0
Total	0

COMMENTS

Barrel Region Structure
(Aluminum)

Portion	Size	Length	Cost/ft *	Total (k$)	
CDS Ring	10" O.D., $\frac{1}{2}$" wall	607 ft	$ 28.11	17.0	
	6" O.D., $\frac{1}{2}$" wall	672 ft	$ 10.15	6.8	23.8
FFS Ring	10" O.D., $\frac{1}{2}$" wall	1702 ft	$ 28.11	47.8	
	6" O.D., $\frac{1}{2}$" wall	1390 ft	$ 10.15	14.1	61.9
Modules	4" O.D., $\frac{1}{4}$" wall	20138 ft	$ 6.37	128.3	
	Plates (2" thick)	2300 ft^2	$ 56.99 (/ft^2)	131.1	259.4

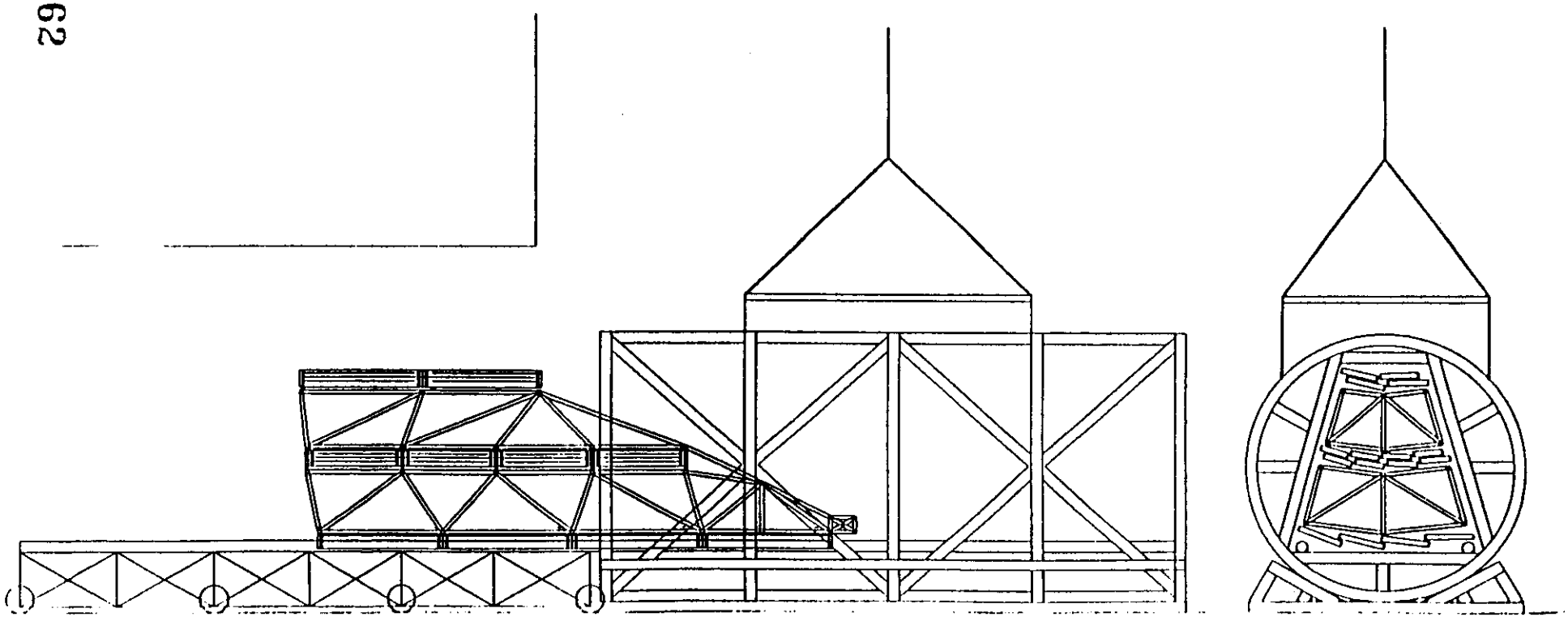
* "rough" estimate from Ryerson (Boston)

R.E. Gustavson
15 Jan. 1993

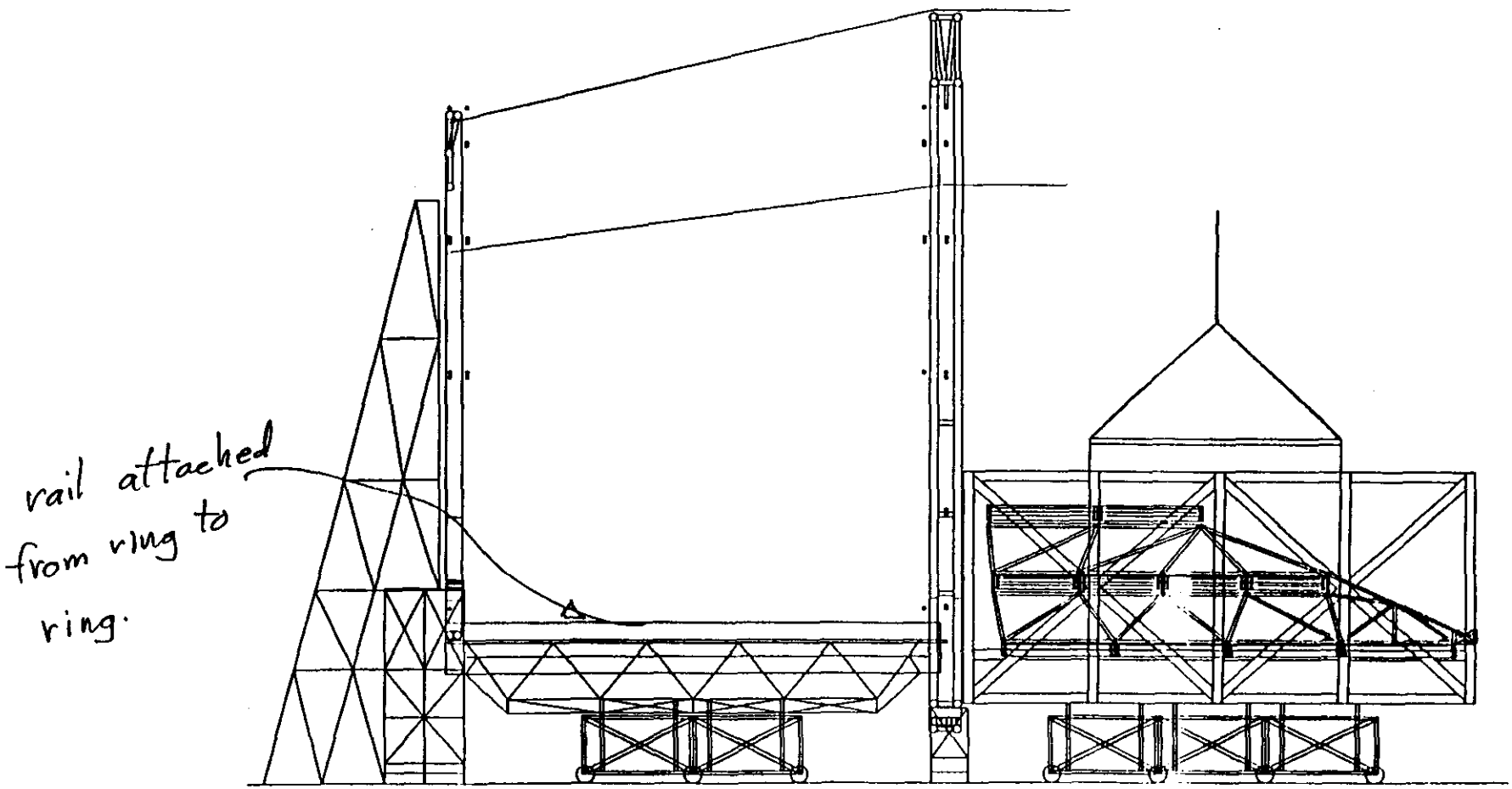
#	Operation	Description	Equip.required	Quantity	Mat'l.	Unit weight	Total Wt. (lb)
9	Barometer	very fine calibration		1	n/a		
10	Interferometers	range up to 3.5 M	High precision	2	n/a		
11	Thermometers	32 deg,F. - 120 deg.F.	0.1 deg. C. precision	10	n/a		
12	Distance references		Reference bar	15	n/a		
			Measuring stick	20	n/a		
			Survey plug	50	n/a		
			Micrometer digital set(0 to 4)	3	n/a		
			Micrometer digital set(4 to 8)	1	n/a		
13	Tool boxes		Complete tool set wrenches, drivers, digital caliber, files, hammers, precision square, sockets, rachet wrench, etc.	50	n/a		
			Hand drill with drills	10			
14	Gas System	receiving chamber test	Supply	2	n/a		
		module test of group	mixing	2	n/a		
			distribution	2	n/a		
15	Electrical test system	goes with gas system	rack	2	n/a		
			test programs	1	n/a		
16	Scintillators / counters		4M long x 0.25M x 1 in.	220	n/a		
17	Electronic Bubble Levels	calibration of structure	((18X4)+4)*1.1 = 80	80	n/a		
18	Alignment laser	calibration of modules		4	n/a		

#	Estimated unit cost	Design Labor hours	Fabrication Labor hours	Assembly Labor hours	Minimum people	Labor Cost	Materials Cost	Purchased Cost	Total Cost
9	1000					0		1000	1000
10	150000					0		300000	300000
11	500					0		5000	5000
12	300					0		4500	4500
	300					0		6000	6000
	200					0		10000	10000
	760					0		2280	2280
	1065					0		1065	1065
13	500					0		25000	25000
	300					0		3000	3000
14	200000					0		400000	400000
15	200000					0		400000	400000
			240			6216		0	6216
16	2310					0		508200	508200
17	1500					0		120000	120000
18	15000					0		60000	60000

Loading Module into transport

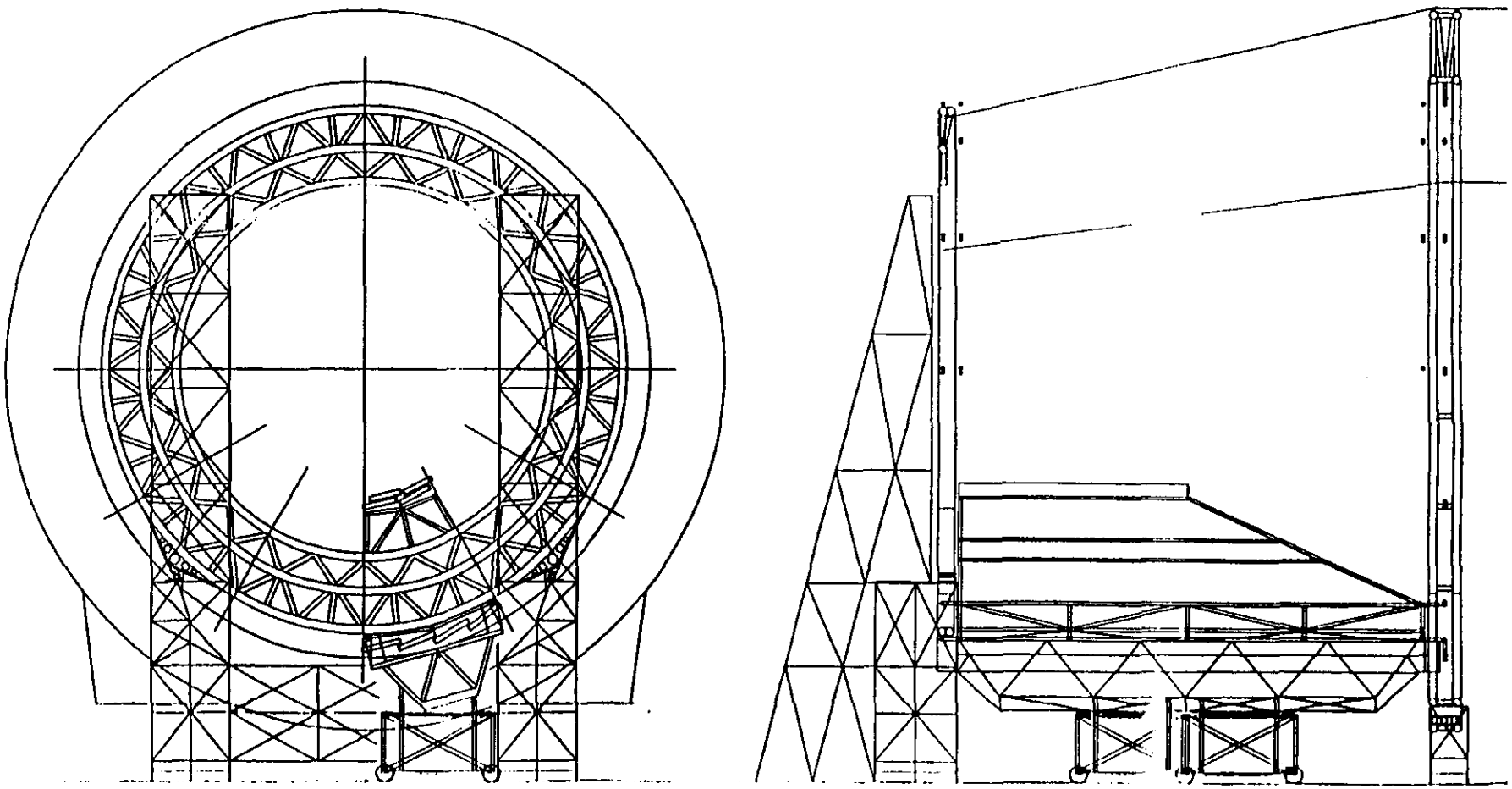


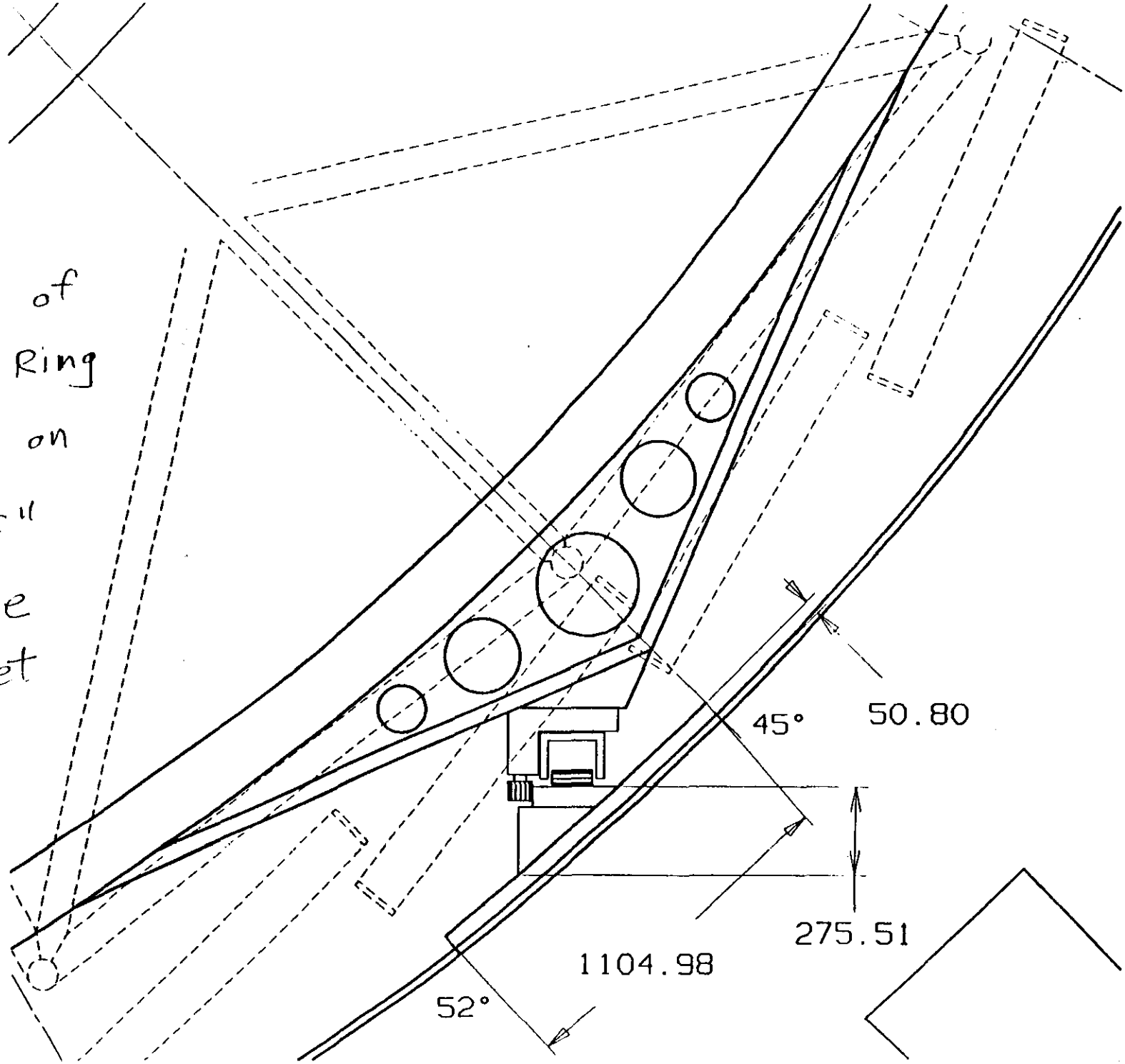
Module ready for assembly into monolith.



Assy of Module into Monolith

exhibits need for rotatable & elevatable fixture (crane not usable)




Detail of
CDS Ring
riding on
"shelf"
inside
magnet
45°
50.80
275.51
1104.98
52°

A Minimization Method for Determining Product Costs

1. Establish the manufacturing tasks required. Specify (or estimate) the cycle time for each.

2. Specify (or estimate) the cost of equipment required to perform each task.

3. Use task/resource matrix (steps 1 and 2) as input for the ASDP-FPR general solution.

4. Determine the "most desirable" system based upon unit cost and number of stations required.

5. Use ASDP specific solution to establish the expected costs and steady-state behavior for the system(s).

6. Use PIB program to develop scenarios for increasing yield and reducing cycle time. Include replacement costs and inflation factors, as appropriate.

DRAPER LABORATORY

RPC Assembly Process

Aggregate task	Description	Time
1	Incoming inspection	10 hr
2	Layout and clean resistiveplastic (6 sheets)	6 hr
3	Apply Aquadag high voltage coating to resistive plastic sheets (1 hour per sheet plus 8 hours drying time).	14 hr
4	Glue mylar with pick-up strips to 6 resistive plastic sheet (1 hour per sheet plus 8 hours drying time). Glue metal foil to 6 dielectric foam sheets (1 hour per sheet plus 8 hours drying time). Glue foam/metal to resistive plastic/ mylar/pick-up strips (1 hour per sheet plus 8 hours drying time).	26 hr
5	Install termination resistor pack on strips.	6 hr
6	Install cabling on strips	18 hr
7	Cut, machine, drill Lucite for frame	4 hr
8	Assemble frame	1 hr
9	Glue one laminate into Lucite frame and install and glue spacers onto resistive plastic sheet (4 hours to install spacers plus 8 hours to allow glue to dry).	12 hr
10	Glue second laminate onto previously installed spacers and frame (1 hour to apply glue to previously installed spacers 8 hours to allow glue to dry). Glue third laminate onto second laminate Install spacers on third laminate (1 hour to glue third laminate, 4 hours to install spacers, 8 hours to dry).	14 hr
11	Glue fourth laminate to previously installed spacers (1 hour to apply glue and 8 hours to dry). Glue fifth laminate onto fourth laminate Install spacers on fifth laminate (1 hour	14 hr

APPLICABLE TECHNOLOGY CHART

Title: RPC Chambers Assy/Test Date: 11 Jan. 93

224	Working Days per Year	.01 %	Min. Attractive Rate of Return
1	Shifts Available	3 yr	Capital Recovery Period
0 s	Station-to-Station Move Time	59.71	Average Loaded Labor Rate ($/h)

	Units	~~Days required~~
Production Batch Data	288	Barrel
	192	End Cap

RESOURCE Data Set Name: RPCRES TASK Data Set Name: RPCTSK

For each resource:

- C Hardware cost ($)
- ρ Installed cost / Hardware cost - rho Factor
- ε Up-time expected (%)
- v Operating / Maintenance rate ($/hr)
- t_c Tool change time (sec)
- m_s Maximum stations per worker

when a resource can be used on a task:

Operation time (sec) | Tool number
Hardware cost ($)

TASK Number \ RESOURCE	MSR (C: 200, ρ: 2, ε: 100, v: 1, t_c: 60, m_s: .54)	MJR (C: 200, ρ: 2, ε: 100, v: 1, t_c: 60, m_s: 1.23)	MTS (C: 200, ρ: 2, ε: 100, v: 1, t_c: 120, m_s: 0.76)	CUR (C: 0, ρ: 1.2, ε: 100, v: .25, t_c: 0, m_s: 20)	(C: , ρ: , ε: , v: , t_c: , m_s:)	(C: , ρ: , ε: , v: , t_c: , m_s:)
1. Incoming Inspection			36000 301 2000			
2. Layout & clean resistive plastic		14400 201 2000				
3. Apply aquadag		14400 202 5000				
4. Dry				28800 401 15000		
5. Glue mylar P.U.s to res. sheet	14400 101 2000					
6. Dry				28800 401 15000		
7. Glue metal foil to dielectric foam	14400 102 2000					
8. Dry				28800 401 15000		
9. Glue foam/metal to plastic/mylar	14400 103 4000					
10. Dry				28800 401 15000		
11. Install term. res. pack on strips	14400 104 3000					

Note: 16 hrs off-line

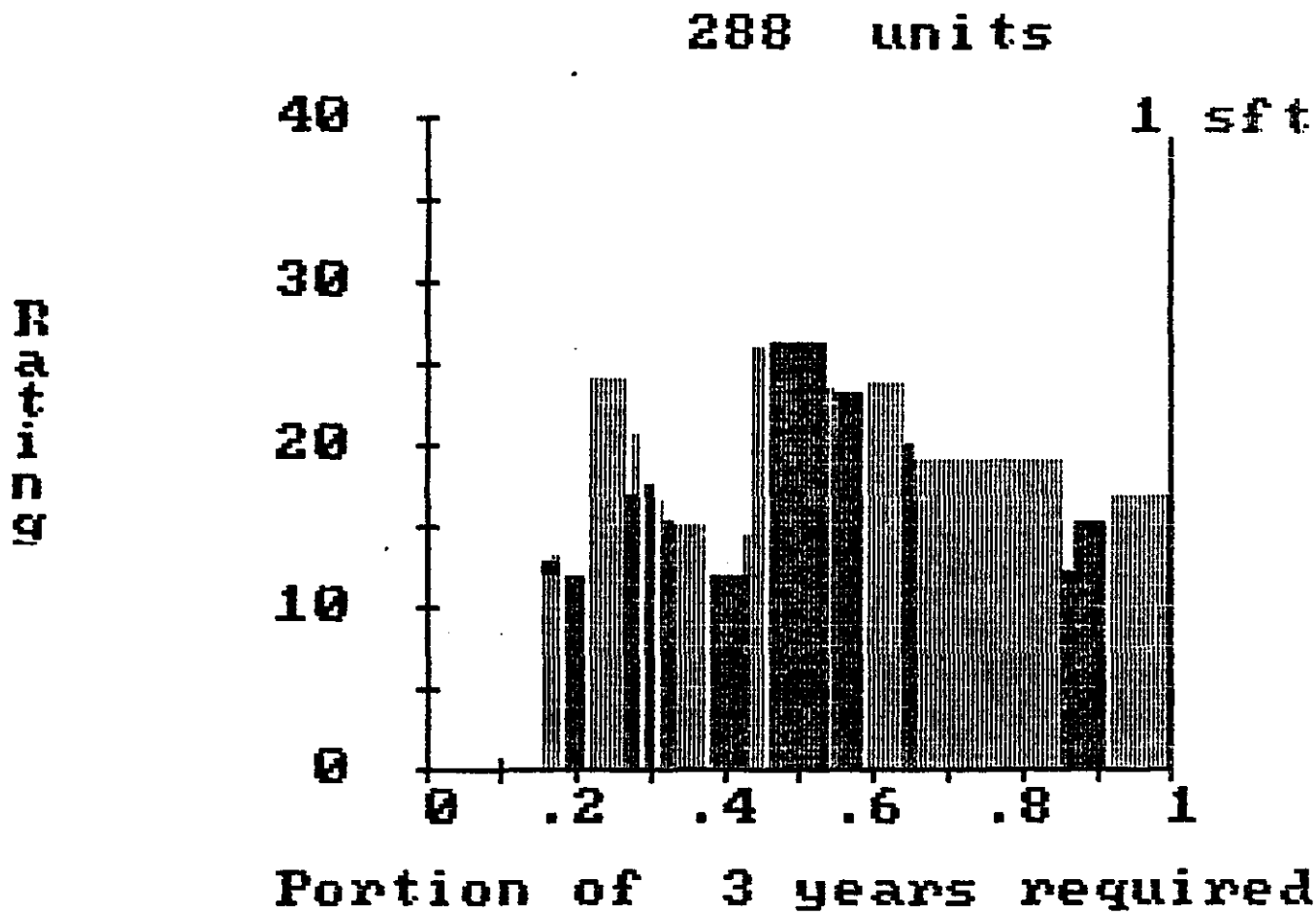
Prepared by: REG Sheet 1 of

RPC Barrel Chambers Assembly / Test

ASSEMBLY SYSTEM DESIGN 01-11-1993 12:52:25

A. S. D. P. Version 7.0

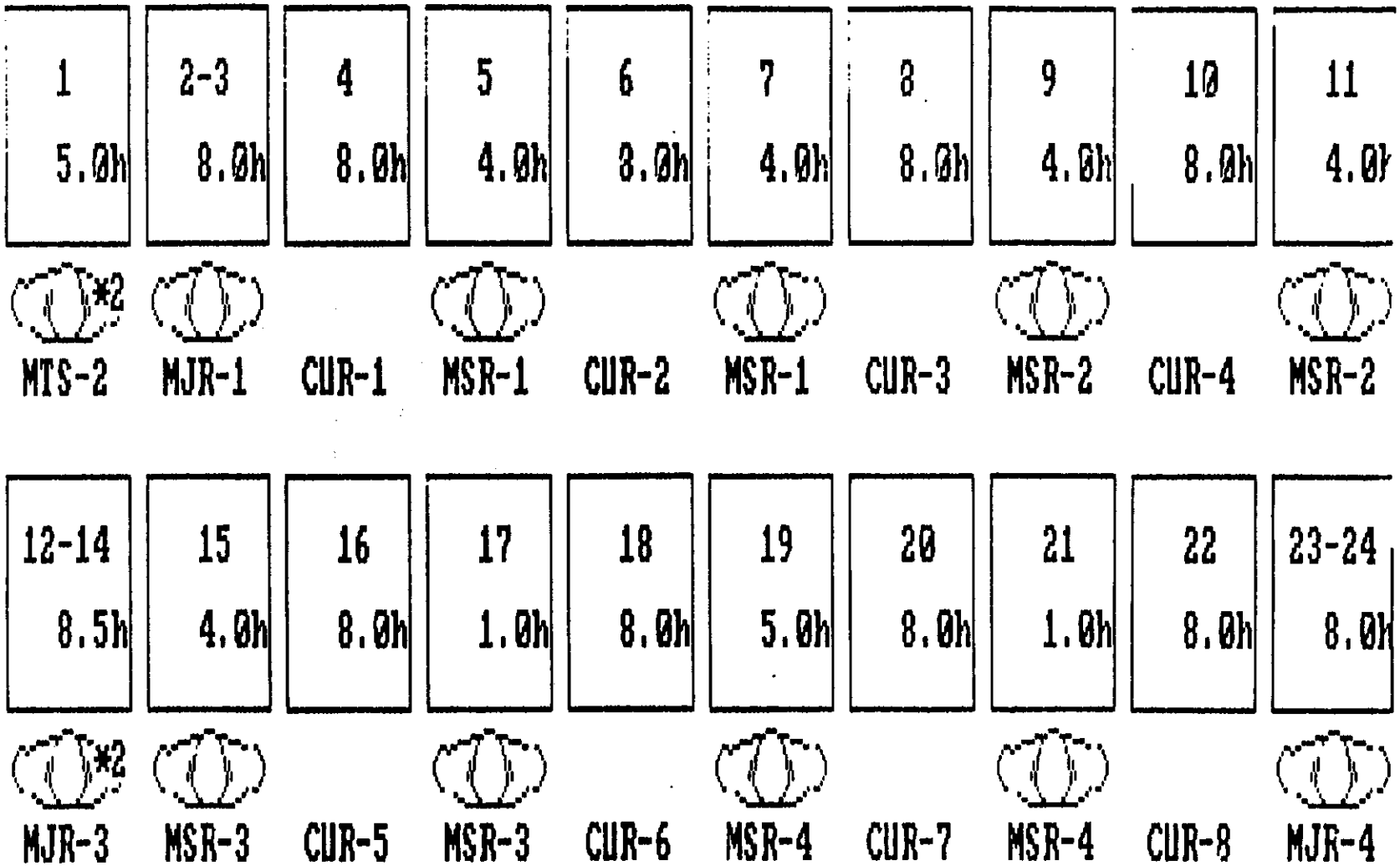
Weighting factors:	Unit Cost	85.00%
	Investment	0.00%
	Stations	15.00%



0.6454	7.17	10	13832.40	388400	4	5	2	7
149	20.10		9229.82			^		
0.6428	7.04	11	13931.81	402400	4	5	2	9
162	23.72		8649.57		^			
0.5901	5.53	10	15177.10	422800	5	5	2	9
178	23.12		8662.69		^			
0.5365	5.53	11	15177.12	422800	5	5	2	9
179	23.41		8620.03				^	
0.5356	4.27	11	16656.46	427200	5	5	3	9
210	26.13		8189.43			^		
0.4561	3.68	11	17534.47	417600	5	6	3	9
223	25.97		8145.24		^			
0.4303	1.96	12	21810.20	449200	7	8	3	9
223	14.10		10061.39			^		
0.4291	1.97	10	21751.73	429200	7	8	3	9
224	14.43		9968.65				^	
0.4285	1.29	9	24313.57	651600	7	8	4	18
254	11.87		10179.75			^		
0.3776	1.16	7	25220.81	652000	7	9	4	18
297	15.06		9228.88		^			
0.3222	1.01	7	26466.08	672400	8	9	4	18
298	15.17		9162.14			^		
0.3213	1.00	8	26653.19	736400	8	9	4	18
315	16.51		8861.76			^		
0.3040	0.91	8	27501.97	716800	8	10	4	18
335	17.46		8631.07			^		
0.2860	0.92	7	27385.03	676800	8	10	4	18
356	20.47		8109.28			^		
0.2695	0.74	7	29537.52	697600	9	11	4	18
358	16.82		8684.69		^			
0.2678	0.65	8	31016.88	702000	9	11	5	18
448	24.17		7501.54		^			
0.2142	0.22	9	44155.48	1060400	13	17	6	27
537	11.86		9271.70				^	
0.1785	0.20	10	45634.82	1064800	13	17	7	27
590	13.26		8849.32			^		
0.1624	0.19	10	46542.04	1065200	13	18	7	27
595	12.83		8939.98		^			
0.1611	0.18	10	47787.31	1085600	14	18	7	27
597	12.00		9152.37			^		

RPC Barrel Chambers Assembly / Test

210 Units $7677.965 Each 8.5h Cycle Time 1.0 Shifts 1.000 9F



RPC Barrel Assembly / Test

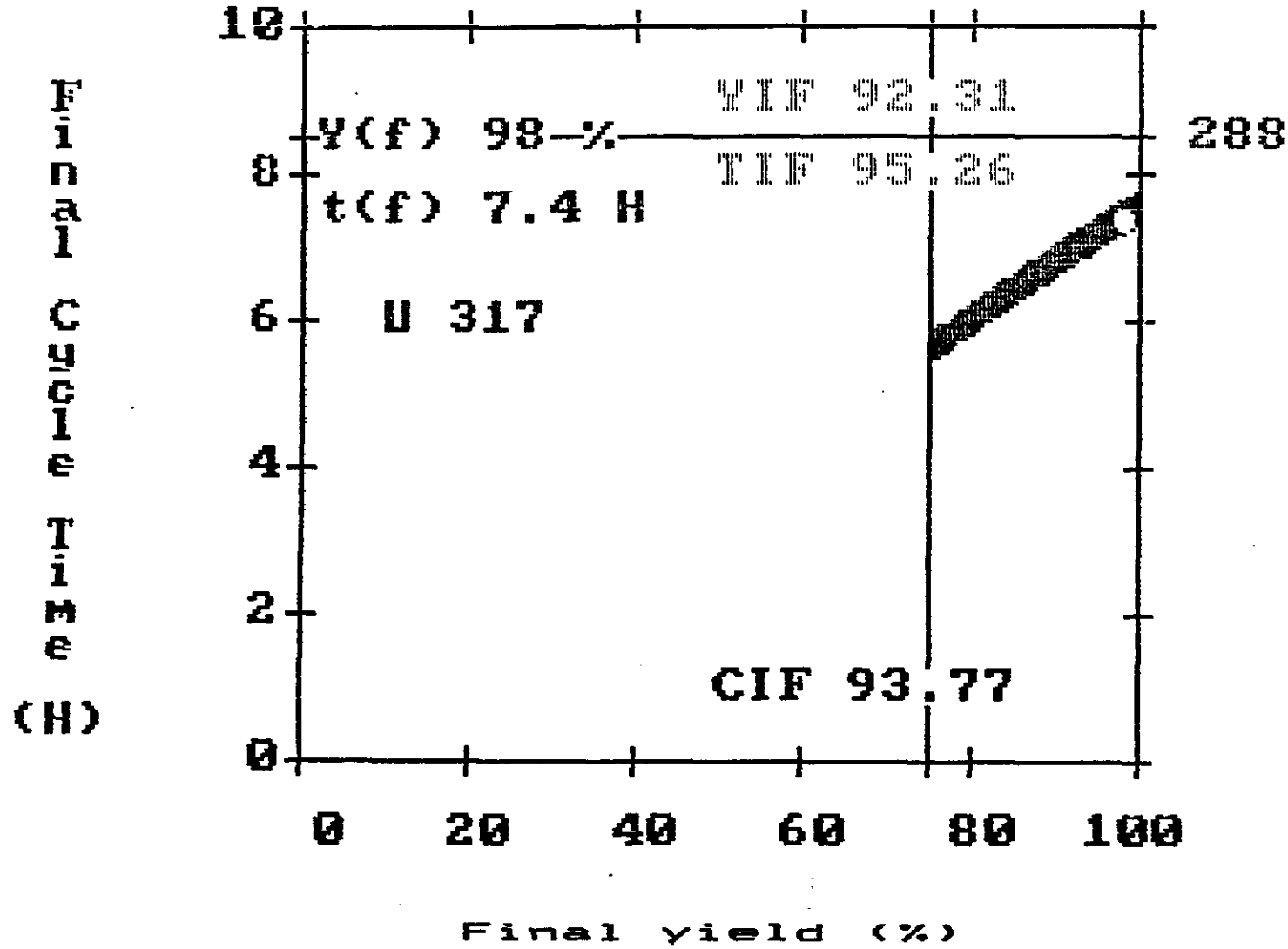
Production Improvement Behavior 01-14-1993 11:10:19

Total time available : 2453 H

Cycle time for first unit : 8.5 H

Yield for first unit : 75 %

Output units : 217 min. 829 max.



processed units =	1.425	-0.405 sqr[1 - [(output -	288.000)/	294.724]^2]
cycle time =	10.639	-3.239 sqr[1 - [(units -	317.000)/	420.841]^2]

RPC Barrel Assembly / Test

Production Improvement Behavior 01-14-1993 11:16:36

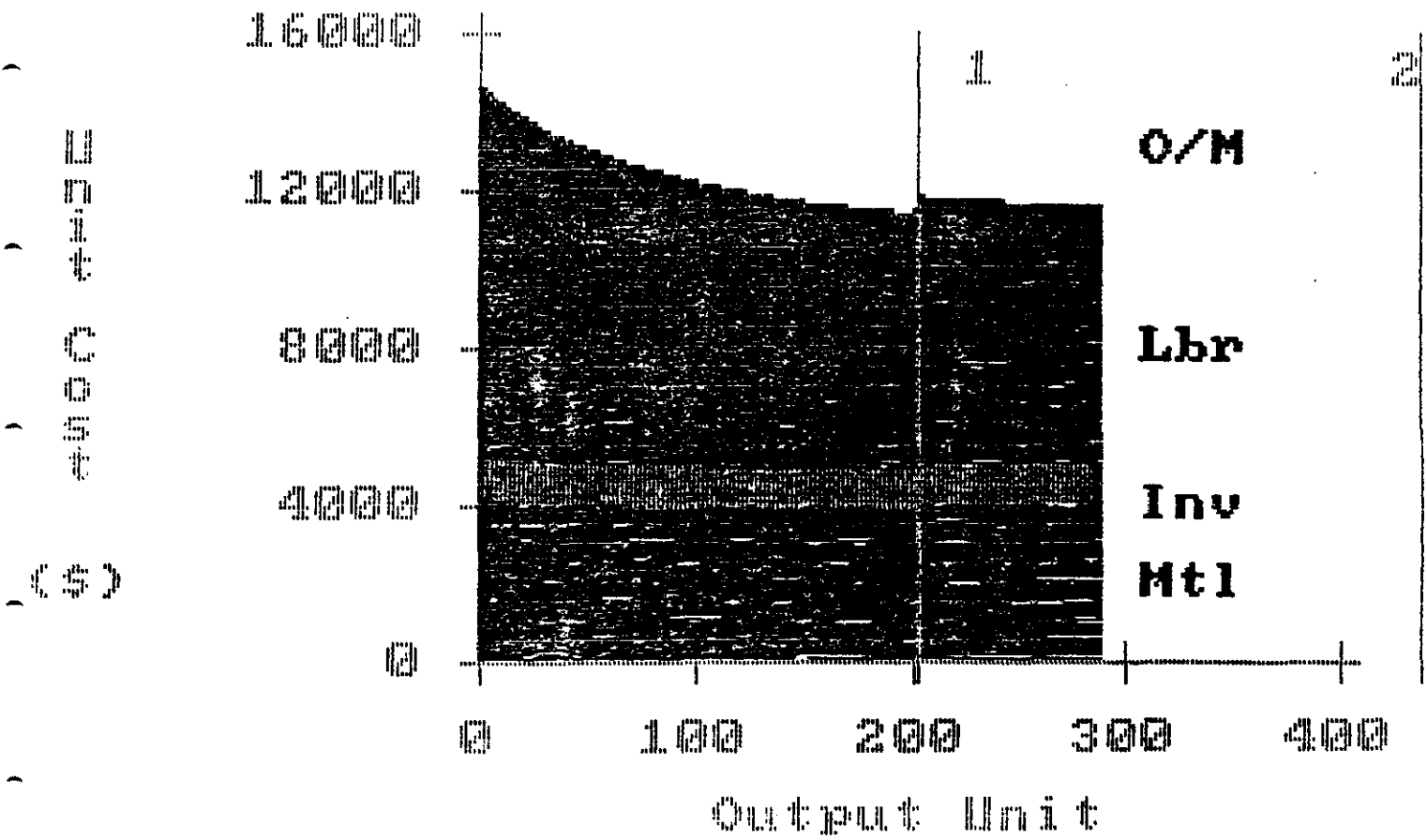
224 Working days per year, 1 shift per day

13.78 Workers required at 59.71 $/hr (4.0% inflation)

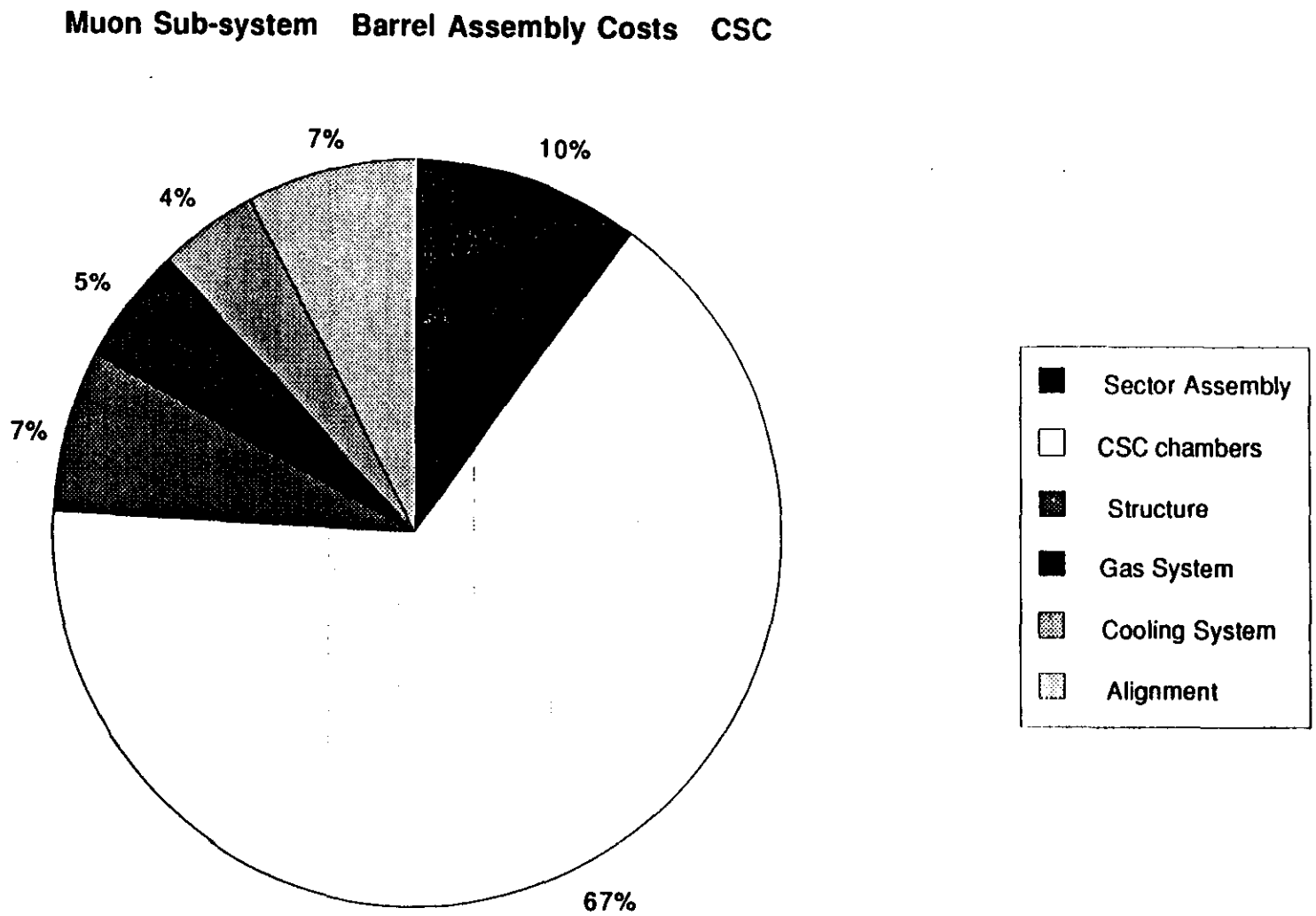
15.3 $/hr operating/maintenance rate (3.0% inflation)

$3792.00 initial Materials Unit Cost (5.0% inflation)
25.00% of current cost for replacement

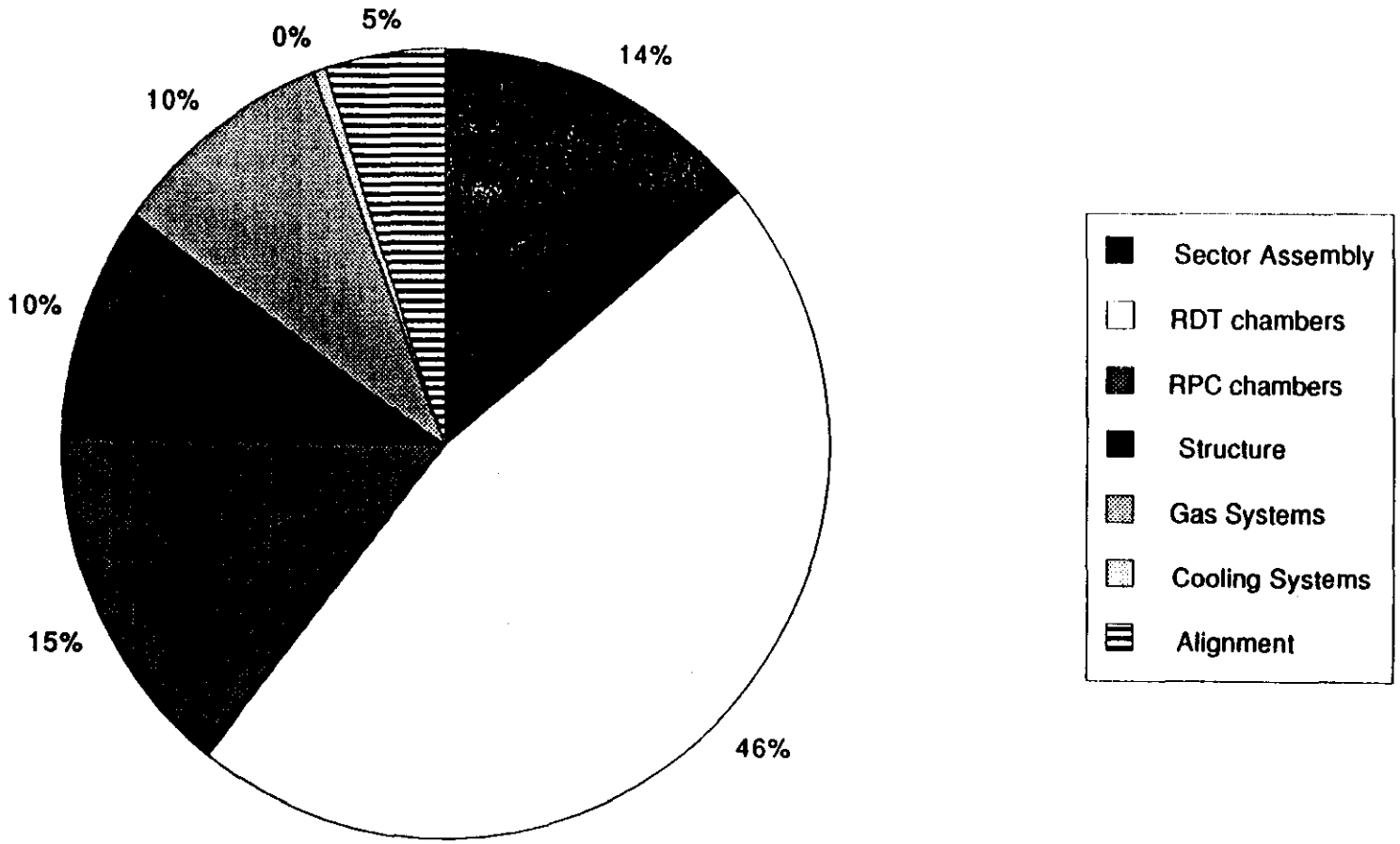
$177021 Capital Equipment Cost $90579 Tooling Cost
2.000 (Total Cost)/(Hardware Cost) 0.0% MARR 3 yr Capital Recovery

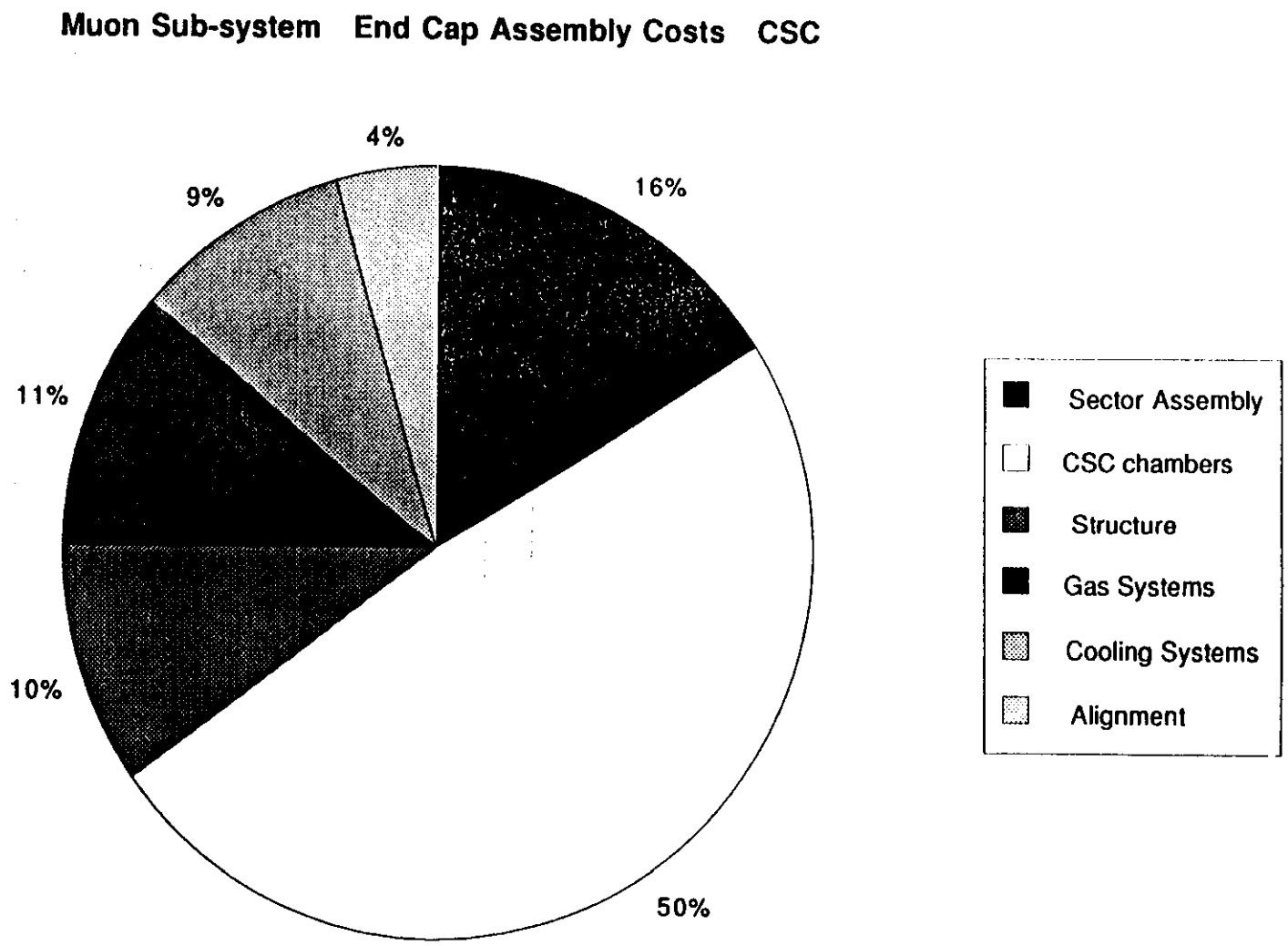


Year	Units Output	Units Processed	Materials Unit Cost	Investment Unit Cost	Labor Unit Cost	Oper/Main. Unit Cost	Total Cost
1	201.2	228.0	3918	1044	7327	136	2500395
2	86.8	89.0	4008	1044	6519	120	1014325
totals	288.0	317.0	1136145	300774	2040090	37711	3514720

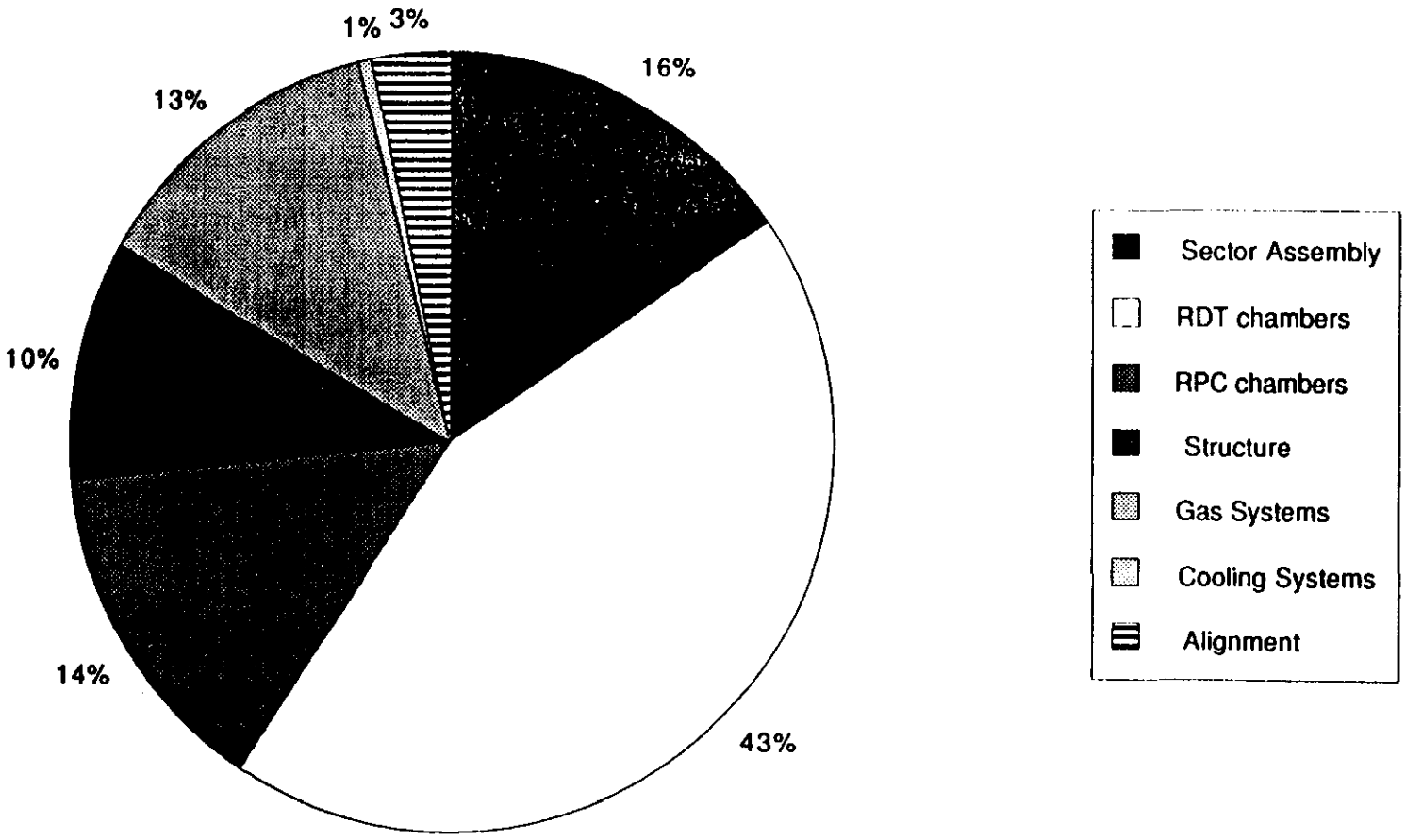

Muon Sub-system Barrel Assembly Costs CSC
7%
10%
4%
5%
7%
67%
Sector Assembly
CSC chambers
Structure
Gas System
Cooling System
Alignment

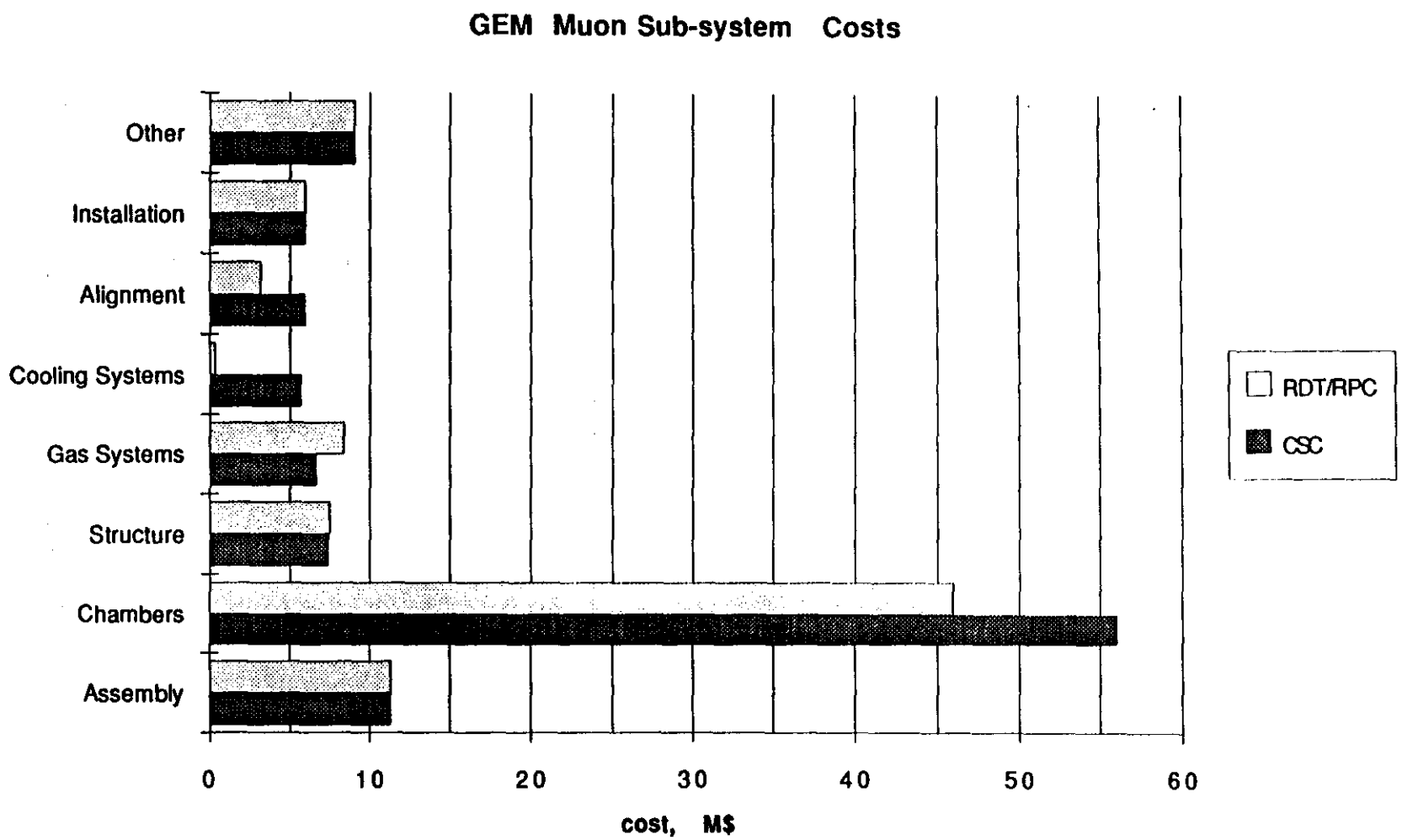
Muon Sub-system Barrel Assembly Costs RDT/RPC




Muon Sub-system End Cap Assembly Costs CSC
4%
16%
9%
11%
10%
50%
Sector Assembly
CSC chambers
Structure
Gas Systems
Cooling Systems
Alignment

Muon Sub-system End Cap Assembly Costs RDT/RPC




GEM Muon Sub-system Costs
Other
Installation
Alignment
Cooling Systems
Gas Systems
Structure
Chambers
Assembly
0
10
20
30
40
50
60
cost, M$
RDT/RPC
CSC

Muon Subsystem Cost Summary - Rev. 15 1/15/93

WBS No.	Item	Engrg/Design	M&S	Insp/Admin	Materials	Assembly	Installation	Equipment	Sub-total	Des Gr Allow	Total
30	Totals - CSC	9.259	1.691	8.420	25.032	25.690	1.361	10.836	82.289	25.806	108.095
30'	Totals - RDT/RPC	9.846	2.051	8.498	16.263	21.963	1.361	11.545	71.525	20.298	91.823
30.01	R&D	2.313	0.110	0	0	0	0		2.423	0.485	2.908
30.02	Central Region - CSC	2.097	0.370	2.575	18.988	16.853	0	5.567	46.450	15.631	62.081
30.02.1	Sector Assembly	0.297	0.032	0.155	0.075	0.509	0	3.768	4.836	1.451	6.287
30.02.2	CSC chambers	0.332	0.079	1.129	14.552	13.378	0	0.643	30.113	10.841	40.954
30.02.3	Structure	0.555	0.087	0.410	0.498	0.810	0	0.856	3.216	1.079	4.295
30.02.5	Gas System	0.550	0.124	0.655	0.481	0.808	0	0.000	2.618	0.578	3.196
30.02.6	Cooling System	0.226	0.031	0.067	1.517	0.279	0	0.000	2.120	0.636	2.756
30.02.7	Alignment	0.137	0.017	0.159	1.865	1.069	0	0.300	3.547	1.046	4.593
30.02'	Central Region - RDT/RPC	2.378	0.547	2.475	10.946	12.232	0	6.026	34.604	10.127	44.731
30.02.1	Sector Assembly	0.297	0.032	0.155	0.075	0.509	0	3.768	4.836	1.451	6.287
30.02.2'	RDT chambers	0.332	0.055	0.593	7.851	6.611	0	0.651	16.093	4.786	20.879
30.02.2"	RPC chambers	0.332	0.043	0.343	1.092	3.020	0	0.269	5.099	1.496	6.595
30.02.3'	Structure	0.555	0.087	0.410	0.498	0.810	0	0.856	3.216	1.079	4.295
30.02.5'	Gas Systems	0.774	0.283	0.867	0.640	0.756	0	0.182	3.502	0.77	4.272
30.02.6'	Cooling Systems	0.011	0.032	0.014	0.050	0.036	0	0	0.143	0.043	0.186
30.02.7'	Alignment	0.077	0.015	0.093	0.74	0.490	0	0.300	1.715	0.502	2.217
30.03	End Cap Region - CSC	2.132	0.353	2.084	5.866	8.837	0	3.879	23.151	7.843	30.994
30.03.1	Sector Assembly	0.297	0.032	0.155	0.075	0.446	0	2.900	3.905	1.172	5.077
30.03.2	CSC chambers	0.332	0.057	0.628	3.004	6.704	0	0.381	11.106	3.998	15.104
30.03.3	Structure	0.555	0.089	0.422	0.104	0.716	0	0.450	2.336	0.769	3.105
30.03.5	Gas Systems	0.585	0.126	0.662	0.506	0.582	0	0.148	2.609	0.827	3.436
30.03.6	Cooling Systems	0.226	0.031	0.069	1.517	0.279	0	0	2.122	0.804	2.926
30.03.7	Alignment	0.137	0.018	0.148	0.660	0.110	0	0	1.073	0.273	1.346
30.03'	End Cap Region - RDT/RPC	2.438	0.536	2.260	5.139	9.731	0	4.129	24.233	7.839	32.072
30.03.1	Sector Assembly	0.297	0.032	0.155	0.075	0.446	0	2.900	3.905	1.172	5.077
30.03.2'	RDT chambers	0.332	0.051	0.499	3.450	5.501	0	0.397	10.230	3.682	13.912
30.03.2"	RPC chambers	0.332	0.039	0.230	0.429	2.074	0	0.263	3.367	1.212	4.579
30.03.3'	Structure	0.555	0.089	0.422	0.183	0.716	0	0.450	2.415	0.796	3.211
30.03.5'	Gas Systems	0.774	0.275	0.792	0.640	0.756	0	0.119	3.356	0.738	4.094
30.03.6'	Cooling Systems	0.011	0.032	0.014	0.050	0.043	0	0	0.150	0.045	0.195
30.03.7'	Alignment	0.137	0.018	0.148	0.312	0.195	0	0	0.810	0.194	1.004
30.04	Installation	1.325	0.123	0.465	0.178	0	1.361	1.39	4.842	1.136	5.978
30.04.1	Barrel Region	0.891	0.075	0.221	0.100	0	0.693	0.910	2.89	0.687	3.577
30.04.2	End Cap Region	0.297	0.034	0.162	0.028	0	0.473	0.480	1.474	0.356	1.83
30.04.3	Global Alignment	0.137	0.014	0.082	0.050	0	0.195	0	0.478	0.093	0.571
30.05	Project Mgmt.	0	0.435	3.296	0	0	0	0	3.731	0.373	4.104
30.06	Concept Design	1.392	0.300	0	0	0	0	0	1.692	0.338	2.030

		Engineering/Design			M&S	Inspection/Admin			Proc/Fab	Assembly				
		Labor	Rate	Total		Labor	Rate	Total	Material	Labor	Rate	Subtotal	Captl. Eqpt.	Tooling
WBS no.	Item	py	k$/py	k$	k$	py	k$/py	k$	k$	py	k$/py	k$	k$	k$
30	Muon Sub-system (CSC)	83.9	110	9256	1691	71.4	118	8419	25032	272.9	87	23825	8849	597
30'	Muon Sub-system (RDT/RPC)	89.6	110	9842	2051	72.7	117	8495	16263	237.5	86	20088	9185	970
30.01	Muon Subsystem R&D	18.77	123	2313	110									
30.01.1	Develop Chamber Technologies	6.26	119	743	38									
30.01.2	Chamber Performance Evaluation	1.56	161	251	9									
30.01.3	Muon Trigger	0.48	140	67	3									
30.01.4	Alignment Technology	1.68	119	200	10									
30.01.5	Electronics evaluation	1.52	119	180	9									
30.01.6	Simulations	0.20	161	32	1									
30.01.7	Ind. Chamber Des. & Factory layout	0.00	154	0	0									
30.01.8	Engineering (structures, costs, etc.)	7.07	119	839	42									
30.02	BARREL REGION	19.77	106	2096	370	23.40	110	2575	18988	174.92	89	15632	5300	267
30.02.1	Barrel Region Module Assembly	3.00	99	297	32	2.32	67	155	75	9.29	48	447	3768	0
30.02.1.1	On-Site	0.00		0	9	1.44		99	75	9.29	48	447	3768	0
30.02.1.1.1	Module Storage			0	0	0.00		0	0			0		
30.02.1.1.2	Test			0	3	0.56	69	39	25	1.25	52	65	100	
30.02.1.1.3	Assembly			0	4	0.63	69	43	50	7.29	47	343	3668	0
30.02.1.1.4	Fac Prep			0	2	0.25	69	17	0	0.75	52	39		
30.02.1.2	Off-Site	3.00		297	23	0.88		55	0	0.00		0	0	0
30.02.1.2.1	Assy Fixt Final Dsgn: Mach, Assy	3.00	99	297	23	0.88	63	55						
30.02.2	Cathode Strip Chambers	3.25	102	332	79	8.49	133	1129	14552	123.83	103	12738	521	122
30.02.2.1	Off-Site	3.25		332	79	8.49		1129	14552	123.83		12738	521	122
30.02.2.1.1	Shipping			0	0	0.00	133	0	0	1.00	82	82	0	0
30.02.2.1.2	Test			0	8	1.32	133	176	0	20.61	133	2741	266	0
30.02.2.1.3	Assembly			0	38	6.29	133	837	0	98.47	97	9552	255	122
30.02.2.1.4	Facility Prep			0	5	0.75	133	100	0	3.75	97	364	0	0
30.02.2.1.5	Machining, Inspection			0	8	0.00	133	0	14552	0.00	57	0	0	0
30.02.2.1.6	Final Design, Drwg/Spec Mods	3.25	102	332	20	0.13	133	17						

		Engineering/Design			M&S	Inspection/Admin			Proc/Fab	Assembly				
		Labor	Rate	Total		Labor	Rate	Total	Material	Labor	Rate	Subtotal	Captl. Eqpt.	Tooling
WBS no.	Item	py	k$/py	k$	k$	py	k$/py	k$	k$	py	k$/py	k$	k$	k$
30.02.3	**Module Support Structures**	5.00	111	555	87	4.77	86	410	498	12.00	58	697	711	145
30.02.3.1	Off-Site	5.00		555	87	4.77		410	498	12.00		697	711	145
30.02.3.1.1	Shipping			0	2	0.25	69	17	20	0.50	82	41		
30.02.3.1.2	Machining, Inspection			0	46	3.77	76	287	478	11.50	57	656	711	145
30.02.3.1.3	Final Design, Drwg/Spec Mods	5.00	111	555	39	0.75	142	107	0	0	0	0		
30.02.4	**Electronics/Electrical Hardware**	0.00		0	0	0.00		0	0	0.00		0	0	0
30.02.5	**Gas System**	5.02	110	550	124	6.06	108	655	481	11.10	48	533	0	0
30.02.5.1	Off-Site	3.20	121	387	75	3.50	137	480	0	0.00	0	0	0	0
30.02.5.1.1	Design and Development	3.20	121	387	75	3.50	137	480	0	0.00	0	0		
30.02.5.2	On-Site	1.82	347	163	49	2.56	68	175	481	11.10	48	533	0	0
30.02.5.2.1	Design and drawings	0.20	82	16	4	0.50	82	41	0	0.00	0	0		
30.02.5.2.2	Test Procedure development	0.46	57	26	8	0.12	73	9	0	0.00	0	0		
30.02.5.2.3	Safety Procedure development	0.58	104	60	10	0.12	133	16	0	0.00	0	0		
30.02.5.2.4	Maintenance Procedure development	0.58	104	60	10	0.12	133	16	0	0.00	0	0		
30.02.5.2.5	Assembly and Test	0.00		0	7	0.65	53	34	337	11.10	48	533	0	0
30.02.5.2.6	Procurement - Surface System	0.00		0	4	0.42	52	22	25	0.00		0		0
30.02.5.2.7	Procurement - Hall System	0.00		0	6	0.63	59	37	119	0.00		0		0
30.02.6	**Cooling System**	2.00	113	226	31	0.48	140	67	1517	2.30	94	217	0	0
30.02.6.1	Off-Site	2.00	113	226	31	0.48	140	67	1517	2.30	94	217	0	0
30.02.6.1.1	Shipping				4	0.05	133	7		0.10	82	8		
30.02.6.1.2	Subassembly, Test				5	0.13	133	17		1.00	95	95		
30.02.6.1.3	Machining, Inspection				5	0.13	133	17	1467	1.00	95	95		
30.02.6.1.4	Procurement				2	0.05	133	7	50	0.20	95	19		
30.02.6.1.5	Final Design, Drwg/Spec Mods	2.00	113	226	15	0.13	161	20						
30.02.7	**Local Alignment**	1.50	91	137	17	1.28	124	159	1865	16.40	61	1000	300	0
30.02.7.1	Off-Site	1.50	91	137	17	1.28	124	159	1865	16.40	61	1000	300	0
30.02.7.1.1	Shipping				1	0.20	69	14	0	0.50	82	41		
30.02.7.1.2	Test				3	0.43	133	57		8.55	59	504	300	
30.02.7.1.3	Assembly				2	0.35	133	47		6.85	59	404		
30.02.7.1.4	Facility Prep				2	0.25	133	33	25	0.25	107	27		
30.02.7.1.5	Machining, Inspection				0	0.05	161	8	1840	0.25	95	24	0	0
30.02.7.1.6	Final Design, Drwg/Spec Mods	1.50	91	137	9									

		Engineering/Design			M&S	Inspection/Admin			Proc/Fab	Assembly				
		Labor	Rate	Total		Labor	Rate	Total	Material	Labor	Rate	Subtotal	Captl. Eqpt.	Tooling
WBS no.	Item	py	k$/py	k$	k$	py	k$/py	k$	k$	py	k$/py	k$	k$	k$
30.02'	BARREL REGION RDT/RPC	22.24	107	2376	547	22.94	108	2476	10946	133.01	85	11267	5505	521
30.02.2'	Round Drift Tubes (RDT)	3.25	102	332	55	4.46	133	593	7851	60.75	103	6235	508	143
30.02.2.1'	Off-Site	3.25	102	332	55	4.46	133	593	7851	60.75	103	6235	508	143
30.02.2.1.1'	Shipping				0	0.00	133	0	0	1.00	82	82	0	0
30.02.2.1.2'	Test				6	0.96	133	128	0	15.00	121	1815	211	0
30.02.2.1.3'	Assembly				14	2.30	133	306	25	36.00	99	3564	297	143
30.02.2.1.4'	Facility Prep				5	0.75	133	100	0	3.75	97	364		
30.02.2.1.5'	Machining, Inspection				10	0.32	133	43	7826	5.00	82	410	0	0
30.02.2.1.6'	Final Design, Drwg/Spec Mods	3.25	102	332	20	0.13	133	17						
30.02.2"	Resistive Plate Counters (RPC)	3.25	102	332	43	2.58	133	343	1092	31.54	89	2805	190	79
30.02.2.1"	Off-Site	3.25		332	43	2.58		343	1092	31.54		2805	190	79
30.02.2.1.1"	Shipping				0	0.00	133	0	0	1.00	82	82	0	0
30.02.2.1.2"	Test				2	0.26	133	35	0	4.11	133	547	34	0
30.02.2.1.3"	Assembly				5	0.87	133	116	0	13.68	95	1300	156	79
30.02.2.1.4"	Facility Prep				5	0.75	133	100	0	3.75	97	364		
30.02.2.1.5"	Machining, Inspection				11	0.57	133	76	1092	9.00	57	513	0	0
30.02.2.1.6"	Final Design, Drwg/Spec Mods	3.25	102	332	20	0.13	133	17						
30.02.3'	Module Support Structures RDT/RPC	5.00	111	555	87	4.77	86	410	498	12.00	58	697	711	145
30.02.3.1'	Off-Site	5.00		555	87	4.77		410	498	12.00		697	711	145
30.02.3.1.1'	Shipping				2	0.25	69	17	20	0.50	82	41		
30.02.3.1.2'	Machining, Inspection				46	3.77	76	287	478	11.50	57	656	711	145
30.02.3.1.3'	Final Design, Drwg/Spec Mods	5.00	111	555	39	0.75	142	107	0	0	0	0		
30.02.5'	Gas Systems - RDT/RPC	6.98	111	774	283	7.92	110	867	640	12.50	51	638	28	154
30.02.5.1'	Off-Site, RDT	1.60	121	194	56	1.95	134	261	0	0.00	0	0	0	0
30.02.5.1.1'	Design and Development	1.60	121	194	56	1.95	134	261	0	0.00		0		
30.02.5.2'	On-Site, RDT	1.89	102	193	85	2.01	86	172	320	6.25	51	319	14	77
30.02.5.2.1'	Design and drawings	0.15	82	12	41	0.25	69	17	0	0.00		0		
30.02.5.2.2'	Test Procedure development	0.58	104	60	10	0.12	133	16	0	0.00		0		
30.02.5.2.3'	Safety Procedure development	0.58	104	60	10	0.12	133	16	0	0.00		0		
30.02.5.2.4'	Maintenance Procedure development	0.58	104	60	10	0.12	133	16	0	0.00		0		
30.02.5.2.5'	Assembly and Test	0.00		0	4	0.40	48	19	212	6.25	51	319		0
30.02.5.2.6'	Procurement - Surface System	0.00		0	5	0.50	88	44	16	0.00		0		14
30.02.5.2.7'	Procurement - Hall System	0.00		0	5	0.50	88	44	92	0.00		0	14	63
30.02.5.1"	Off-Site, RPC	1.60	121	194	56	1.95	134	261	0	0.00	0	0	0	0
30.02.5.1.1"	Design and Development	1.60	121	194	56	1.95	134	261	0	0.00	0	0		
30.02.5.2"	On-Site, RPC	1.89	102	193	86	2.01	86	172	320	6.25	51	319	14	77
30.02.5.2.1"	Design and drawings	0.15	82	12	41	0.25	69	17	0	0.00	0	0		
30.02.5.2.2"	Test Procedure development	0.58	104	60	10	0.12	133	16	0	0.00	0	0		
30.02.5.2.3"	Safety Procedure development	0.58	104	60	10	0.12	133	16	0	0.00	0	0		

		Engineering/Design			M&S	Inspection/Admin			Proc/Fab	Assembly				
		Labor	Rate	Total		Labor	Rate	Total	Material	Labor	Rate	Subtotal	Capit. Eqpt.	Tooling
WBS no.	Item	py	k$/py	k$	k$	py	k$/py	k$	k$	py	k$/py	k$	k$	k$
30.02.5.2.4"	Maintenance Procedure development	0.58	104	60	10	0.12	133	16	0	0.00	0	0		
30.02.5.2.5"	Assembly and Test	0.00		0	4	0.40	48	19	212	6.25	51	319		0
30.02.5.2.6"	Procurement - Surface System	0.00		0	5	0.50	88	44	16	0.00		0		14
30.02.5.2.7"	Procurement - Hall System	0.00		0	6	0.50	88	44	92	0.00		0	14	63
30.02.6'	Cooling Systems - RDT/RPC	0.10	110	11	32	0.10	118	14	50	0.16	92	15	0	0
30.02.6.1'	Off-Site, RDT	0.05		6	16	0.05		7	25	0.08		7	0	0
30.02.6.1.1'	Shipping				4	0.01	133	1	0	0.02	82	2		
30.02.6.1.2'	Subassembly, Test				4	0.01	133	1		0.02	95	2		
30.02.6.1.3'	Machining, Inspection				4	0.01	133	1	25	0.02	95	2		
30.02.6.1.4'	Procurement				2	0.01	133	1	0	0.02	95	2		
30.02.6.1.5'	Final Design, Drwg/Spec Mods	0.05	110	6	2	0.01	161	2						
30.02.6.1"	Off-Site, RPC	0.05		6	16	0.05	154	7	25	0.08	95	7	0	0
30.02.6.1.1"	Shipping				4	0.01	133	1	0	0.02	82	2		
30.02.6.1.2"	Subassembly, Test				4	0.01	133	1		0.02	95	2		
30.02.6.1.3"	Machining, Inspection				4	0.01	133	1	25	0.02	95	2		
30.02.6.1.4"	Procurement				2	0.01	133	1	0	0.02	95	2		
30.02.6.1.5"	Final Design, Drwg/Spec Mods	0.05	110	6	2	0.01	161	2						
30.02.7.1'	Local Alignment RDT/RPC	0.66		77	15	0.79		93	740	6.77		432	300	0
30.02.7.1.1'	Off-Site	0.66		77	15	0.79		93	740	6.77		432	300	0
30.02.7.1.1.1'	Shipping				1	0.20	69	14	0	0.50	82	41		
30.02.7.1.1.2'	Test				1	0.16	133	21		3.20	59	189	300	
30.02.7.1.1.3'	Assembly				1	0.13	133	17		2.57	59	152		
30.02.7.1.1.4'	Facility Prep				2	0.25	133	33	0	0.25	107	27		
30.02.7.1.1.5'	Machining, Inspection				0	0.05	161	8	740	0.25	95	24	0	0
30.02.7.1.1.6'	Final Design, Drwg/Spec Mods	0.66	116	77	10									
30.03	END CAP REGION	19.89	107	2131	353	19.79	105	2083	5866	98.01	84	8193	3549	330
30.03.1	End Cap Region Module Assy	3.00	0	297	32	2.32	0	155	75	8.14	47	386	2900	0
30.03.1.1	On-Site	0.00		0	9	1.44		99	75	8.14	47	386	2900	0
30.03.1.1.1	Sector Storage					0.00		0	0			0		
30.03.1.1.2	Test				3	0.56	69	39	25	1.25	52	65	100	
30.03.1.1.3	Assembly				4	0.63	69	43	50	6.14	46	282	2800	0
30.03.1.1.4	Facility Prep				2	0.25	69	17	0	0.75	52	39		
30.03.1.2	Off-Site	3.00		297	23	0.88		55	0	0.00		0	0	0
30.03.1.2.1	Assy Fixt Fnl Dsgn: Mach, Assy	3.00	99	297	23	0.88	63	55			0	0		

		Engineering/Design			M&S	Inspection/Admin			Proc/Fab	Assembly				
		Labor	Rate	Total		Labor	Rate	Total	Material	Labor	Rate	Subtotal	Captl. Eqpt.	Tooling
WBS no.	Item	py	k$/py	k$	k$	py	k$/py	k$	k$	py	k$/py	k$	k$	k$
30.03.2	Cathode Strip Chambers	3.25	102	332	57	4.72	133	628	3004	64.97	98	6351	301	80
30.03.2.1	Off-Site	3.25		332	57	4.72		628	3004	64.97		6351	301	80
30.03.2.1.1	Shipping				1	0.00	133	0	42	1.00	82	82	0	0
30.03.2.1.2	Test				4	0.62	133	82	0	9.68	133	1287	134	0
30.03.2.1.3	Assembly				17	2.84	133	378	20	44.54	96	4276	167	80
30.03.2.1.4	Facility Prep				5	0.75	133	100	0	3.75	97	364		
30.03.2.1.5	Machining, Inspection				10	0.38	133	51	2942	6.00	57	342		
30.03.2.1.6	Final Design, Drwg/Spec Mods	3.25	102	332	20	0.13	133	17						
30.03.3	Module Support Structures	5.00	111	555	89	4.97	85	422	104	10.50	139	611	300	150
30.03.3.1	Off-Site	5.00	111	555	89	4.97	85	422	104	11	139	611	300	150
30.03.3.1.1	Shipping				2	0.25	69	17	20	0.50	82	41		
30.03.3.1.2	Machining, Inspection				48	3.97	75	298	84	10.00	57	570	300	150
30.03.3.1.3	Final Design, Drwg/Spec Mods	5.00	111	555	39	0.75	142	107				0		
30.03.4	Electronics/Electrical Hardware	0.00		0	0	0.00		0	0	0.00		0	0	0
30.03.5	Gas System	5.14	114	585	126	6.06	109	662	506	11.10	48	533	48	100
30.03.5.1	Off-Site	3.20	121	387	75	3.50	137	480	0	0.00	0	0	0	0
30.03.5.1.1	Design and Development	3.20	121	387	75	3.50	137	480	0	0.00	0	0		
30.03.5.2	On-Site	1.94	102	197	51	2.56	71	182	506	11.10	48	533	48	100
30.03.5.2.1	Design and drawings	0.20	82	16	4	0.50	82	41	0	0.00	0	0		
30.03.5.2.2	Test Procedure development	0.58	104	60	10	0.12	133	16	0	0.00	0	0		
30.03.5.2.3	Safety Procedure development	0.58	104	60	10	0.12	133	16	0	0.00	0	0		
30.03.5.2.4	Maintenance Procedure development	0.58	104	60	10	0.12	133	16	0	0.00	0	0		
30.03.5.2.5	Assembly and Test	0.00		0	7	0.65	53	34	337	11.10	48	533		
30.03.5.2.6	Procurement - Surface System	0.00		0	4	0.42	52	22	25	0.00		0	25	0
30.03.5.2.7	Procurement - Hall System	0.00		0	6	0.63	59	37	144	0.00		0	23	100
30.03.6	Cooling System	2.00	113	226	31	0.49	140	69	1517	2.30	94	217	0	0
30.03.6.1	Off-Site	2.00	113	226	31	0.49	140	69	1517	2.30	94	217	0	0
30.03.6.1.1	Shipping				4	0.05	133	7	0	0.10	82	8		
30.03.6.1.2	Subassembly, Test				5	0.13	133	17	0	1.00	95	95	0	0
30.03.6.1.3	Machining, Inspection				5	0.13	133	17	1467	1.00	95	95	0	0
30.03.6.1.4	Procurement				2	0.05	133	7	50	0.20	95	19		
30.03.6.1.5	Final Design, Drwg/Spec Mods	2.00	113	226	15	0.13	161	21				0		

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		Engineering/Design			M&S	Inspection/Admin			Proc/Fab	Assembly				
		Labor	Rate	Total		Labor	Rate	Total	Material	Labor	Rate	Subtotal	Capit. Eqpt	Tooling
WBS no.	Item	py	k$/py	k$	k$	py	k$/py	k$	k$	py	k$/py	k$	k$	k$
30.03.7	Local Alignment	1.50		137	18	1.23		148	660	1.00		95	0	0
30.03.7.1	Off-Site	1.50		137	18	1.23		148	660	1.00		95	0	0
30.03.7.1.1	Shipping				1	0.23	69	16		0.00	0	0		
30.03.7.1.2	Test				2	0.25	133	33		0.25	95	24		
30.03.7.1.3	Assembly				2	0.25	133	33		0.25	95	24		
30.03.7.1.4	Facility Prep				2	0.25	133	33		0.25	95	24		
30.03.7.1.5	Machining, Inspection				2	0.25	129	32	660	0.25	95	24		
30.03.7.1.6	Final Design, Drwg/Spec Mods	1.50	91	137	9	0.00	133	0						
30.03'	END CAP REGION RDT/RPC	23	106	2436	536	21.54	105	2259	5139	104.51	84	8821	3680	449
30.03.2'	Round Drift Tubes (RDT)	3.25	102	332	51	3.88	129	499	3450	51.42	100	5159	267	130
30.03.2.1'	Off-Site	3.25		332	51	3.88		499	3450	51.42		5159	267	130
30.03.2.1.1'	Shipping				0	0.00	133	0	0	0.67	82	55		
30.03.2.1.2'	Test				3	0.57	133	76	0	9.00	120	1080	82	39
30.03.2.1.3'	Assembly				13	2.17	133	289	25	34.00	98	3332	185	91
30.03.2.1.4'	Facility Prep				5	0.75	133	100	0	3.75	97	364		
30.03.2.1.5'	Machining, Inspection				10	0.26	133	35	3425	4.00	82	328		
30.03.2.1.6'	Final Design, Drwg/Spec Mods	3.25	102	332	20	0.13	133							
30.03.2"	Resistive Plate Counters (RPC)	3.25	102	332	39	1.86	124	230	429	20.29	92	1868	185	78
30.03.2.1"	Off-Site	3.25		332	39	1.86		230	429	20.29		1868	185	78
30.03.2.1.1"	Shipping				0	0.00	133	0	0	1.00	82	82	0	0
30.03.2.1.2"	Test				1	0.16	133	21	0	2.58	133	343	34	0
30.03.2.1.3"	Assembly				4	0.60	133	80	0	9.46	93	880	151	78
30.03.2.1.4"	Facility Prep				5	0.75	133	100	0	3.75	97	364		
30.03.2.1.5"	Machining, Inspection				9	0.22	133	29	429	3.50	57	200	0	0
30.03.2.1.6"	Final Design, Drwg/Spec Mods	3.25	102	332	20	0.13	133							
30.03.3'	Module Support Structures RDT/RPC	5.00	111	555	89	4.97	85	422	183	10.50	139	611	300	150
30.03.3.1'	Off-Site	5.00	111	555	89	4.97	85	422	183	11	139	611	300	150
30.03.3.1.1'	Shipping				2	0.25	69	17	20	0.50	82	41		
30.03.3.1.2'	Machining, Inspection				48	3.97	75	298	163	10.00	57	570	300	150
30.03.3.1.3'	Final Design, Drwg/Spec Mods	5.00	111	555	39	0.75	142	107				0		
30.03.5'	Gas Systems - RDT/RPC	6.98	111	774	275	7.18	110	792	640	12.50	51	638	28	91
30.03.5.1'	Off-Site, RDT	1.60	121	194	56	1.95	134	261	0	0.00	0	0	0	0
30.03.5.1.1'	Design and Development	1.60	121	194	56	1.95	134	261	0	0.00		0		
30.03.5.2'	On-Site, RDT	1.89	102	193	81	1.64	82	135	320	6.25	51	319	28	63

		Engineering/Design			M&S	Inspection/Admin			Proc/Fab	Assembly				
		Labor	Rate	Total		Labor	Rate	Total	Material	Labor	Rate	Subtotal	Capit. Eqpt.	Tooling
WBS no.	Item	py	k$/py	k$	k$	py	k$/py	k$	k$	py	k$/py	k$	k$	k$
30.03.5.2.1'	Design and drawings	0.15	82	12	41	0.25	69	17	0	0.00		0		
30.03.5.2.2'	Test Procedure development	0.58	104	60	10	0.12	133	16	0	0.00		0		
30.03.5.2.3'	Safety Procedure development	0.58	104	60	10	0.12	133	16	0	0.00		0		
30.03.5.2.4'	Maintenance Procedure development	0.58	104	60	10	0.12	133	16	0	0.00		0		
30.03.5.2.5'	Assembly and Test	0.00		0	4	0.40	48	19	212	6.25	51	319		0
30.03.5.2.6'	Procurement - Surface System	0.00		0	1	0.13	48	6	16	0.00		0	14	0
30.03.5.2.7'	Procurement - Hall System	0.00		0	5	0.50	88	44	92	0.00		0	14	63
30.03.5.1"	Off-Site, RPC	1.60	121	194	56	1.95	134	261	0	0.00	0	0	0	0
30.03.5.1.1"	Design and Development	1.60	121	194	56	1.95	134	261	0	0.00	0	0		
30.03.5.2"	On-Site, RPC	1.89	102	193	82	1.64	82	135	320	6.25	51	319	0	28
30.03.5.2.1"	Design and drawings	0.15	82	12	41	0.25	69	17	0	0.00	0	0		
30.03.5.2.2"	Test Procedure development	0.58	104	60	10	0.12	133	16	0	0.00	0	0		
30.03.5.2.3"	Safety Procedure development	0.58	104	60	10	0.12	133	16	0	0.00	0	0		
30.03.5.2.4"	Maintenance Procedure development	0.58	104	60	10	0.12	133	16	0	0.00	0	0		
30.03.5.2.5"	Assembly and Test	0.00		0	4	0.40	48	19	212	6.25	51	319		0
30.03.5.2.6"	Procurement - Surface System	0.00		0	1	0.13	48	6	16	0.00		0		14
30.03.5.2.7"	Procurement - Hall System	0.00		0	6	0.50	88	44	92	0.00		0		14
30.03.6'	Cooling Systems - RDT/RPC	0.10	110	11	32	0.10	120	14	50	0.16	92	15	0	0
30.03.6.1'	Off-Site, RDT	0.05		6	16	0.05		7	25	0.08		7	0	0
30.03.6.1.1'	Shipping				4	0.01	133	1	0	0.02	82	2		
30.03.6.1.2'	Subassembly, Test				4	0.01	133	1		0.02	95	2		
30.03.6.1.3'	Machining, Inspection				4	0.01	133	1	25	0.02	95	2		
30.03.6.1.4'	Procurement				2	0.01	133	1	0	0.02	95	2		
30.03.6.1.5'	Final Design, Drwg/Spec Mods	0.05	110	6	2	0.01	161	2						
30.03.6.1"	Off-Site, RPC	0.05		6	16	0.05	154	7	25	0.08	95	7	0	0
30.03.6.1.1"	Shipping				4	0.01	133	1	0	0.02	82	2		
30.03.6.1.2"	Subassembly, Test				4	0.01	133	1		0.02	95	2		
30.03.6.1.3"	Machining, Inspection				4	0.01	133	1	25	0.02	95	2		
30.03.6.1.4"	Procurement				2	0.01	133	1	0	0.02	95	2		
30.03.6.1.5"	Final Design, Drwg/Spec Mods	0.05	110	6	2	0.01	161	2						
30.03.7'	Local Alignment RDT/RPC	1.50		137	18	1.23		148	312	1.50		145	0	0
30.03.7.1'	Off-Site	1.50		137	18	1.23		148	312	1.50		145	0	0
30.03.7.1.1'	Shipping				1	0.23	69	16		0.50	82	41		
30.03.7.1.2'	Test				2	0.25	133	33		0.25	107	27		
30.03.7.1.3'	Assembly				2	0.25	133	33		0.25	107	27		
30.03.7.1.4'	Facility Prep				2	0.25	133	33	0	0.25	107	27		
30.03.7.1.5'	Machining, Inspection				2	0.25	129	32	312	0.25	95	24		
30.03.7.1.6'	Final Design, Drwg/Spec Mods	1.50	91	137	9									

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		Engineering/Design			M&S	Inspection/Admin			Proc/Fab	Assembly				
		Labor	Rate	Total		Labor	Rate	Total	Material	Labor	Rate	Subtotal	Capit. Eqpt.	Tooling
WBS no.	Item	py	k$/py	k$	k$	py	k$/py	k$	k$	py	k$/py	k$	k$	k$
30.04	INSTALLATION	13.50	98	1325	123	6.83	68	466	178					
30.04.1	Barrel Region	9.00	99	891	75	3.51	63	221	100					
30.04.1.1	On-Site	0.00		0	8	1.38		95	100					
30.04.1.1.1	Test				0	0.00		0	0					
30.04.1.1.2	Mechanical Assembly				3	0.50	69	35	25					
30.04.1.1.3	Electrical/Electronics Assy				2	0.38	69	26	75					
30.04.1.1.4	Fac Prep				3	0.50	69	35	0					
30.04.1.2	Off-Site	9.00		891	67	2.13		126	0					
30.04.1.2.1	Install. Tool Fnl Dsgn: Mach, Assy	9.00	99	891	67	2.13	59	126	0					
30.04.2	End Cap Region	3.00	99	297	34	2.59	63	162	28					
30.04.2.1	On-Site	0.00		0	6	0.96		66	28					
30.04.2.1.1	Test				0	0.00	0	0	10					
30.04.2.1.2	Mechanical Assembly				2	0.33	69	23	18					
30.04.2.1.3	Electrical/Electronics Assembly				2	0.38	69	26	0					
30.04.2.1.4	Fac Prep				2	0.25	69	17	0					
30.04.2.2	Off-Site	3.00		297	28	1.63		96	0					
30.04.2.2.1	Install. Tool Final Dsgn: Mach, Assy	3.00	99	297	28	1.63	59	96	0					
30.04.3	Global Alignment	1.50	91	137	14	0.73	113	82	50					
30.04.3.1	Off-Site	2		137	14	0.73		82	50					
30.04.3.1.1	Shipping				1	0.23	69	16	50					
30.04.3.1.2	Test				2	0.25	133	33	0					
30.04.3.1.3	Assembly				2	0.25	133	33	0					
30.04.3.1.4	Final Design, Drwg/Spec Mods	1.50	91	137	9									
30.05	PROJECT MANAGEMENT				435	21.40	154	3296						
30.05.1	Administration/Oversight				150	9.50	154	1463						
30.05.2	Resource Management				45	1.19	154	183						
30.05.3	ES&H Assurance				90	2.38	154	367						
30.05.4	Quality Assurance Program				90	3.57	154	550						
30.05.5	Systems Integration				30	2.38	154	367						
30.05.6	Subsystem Cost/Schedule Monitor				30	2.38	154	367						
30.06	CONCEPTUAL / PRELIMINARY DESIGN	12.00	116	1392	300									

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		Assembly		Installation							Summary			
		Material	Total	Labor	Rate	Subtotal	Captl. Eqpt	Tooling	Material	Total	Labor	Material	Captl. Eqpt	Tooling
WBS no.	Item	k$	k$	py	k$/py	k$	k$	k$	k$	k$	k$	k$	k$	k$
30	Muon Sub-system (CSC)	1865	35136	18.4	59	1095	1265	125	265	2750	42596	28853	10114	722
30'	Muon Sub-system (RDT/RPC)	1872	32115	18.4	59	1095	1265	125	265	2750	39521	20451	10450	1095
30.01	Muon Subsystem R&D										2313	110	0	0
30.01.1	Develop Chamber Technologies										743	38	0	0
30.01.2	Chamber Performance Evaluation										251	9	0	0
30.01.3	Muon Trigger										67	3	0	0
30.01.4	Alignment Technology										200	10	0	0
30.01.5	Electronics evaluation										180	9	0	0
30.01.6	Simulations										32	1	0	0
30.01.7	Ind. Chamber Des. & Factory layout										0	0	0	0
30.01.8	Engineering (structures, costs, etc.)										839	42	0	0
30.02	BARREL REGION	1221	22420								20303	20579	5300	267
30.02.1	Barrel Region Module Assembly	62	4277								898	169	3768	0
30.02.1.1	On-Site	62	4277								546	146	3768	0
30.02.1.1.1	Module Storage	50	50								0	50	0	0
30.02.1.1.2	Test	2	167								104	30	100	0
30.02.1.1.3	Assembly	9	4020								386	63	3668	0
30.02.1.1.4	Fac Prep	1	40								56	3	0	0
30.02.1.2	Off-Site	0	0								352	23	0	0
30.02.1.2.1	Assy Fixt Final Dsgn: Mach, Assy		0								352	23	0	0
30.02.2	Cathode Strip Chambers	640	14021								14199	15271	521	122
30.02.2.1	Off-Site	640	14021								14199	15271	521	122
30.02.2.1.1	Shipping	372	454								82	372	0	0
30.02.2.1.2	Test	25	3032								2917	33	266	0
30.02.2.1.3	Assembly	118	10047								10388	156	255	122
30.02.2.1.4	Facility Prep	125	489								464	130	0	0
30.02.2.1.5	Machining, Inspection	0	0								0	14560	0	0
30.02.2.1.6	Final Design, Drwg/Spec Mods										349	20	0	0

		Assembly		Installation							Summary			
		Material	Total	Labor	Rate	Subtotal	Capt. Eqpt	Tooling	Material	Total	Labor	Material	Capt. Eqpt	Tooling
WBS no.	Item	k$	k$	py	k$/py	k$	k$	k$	k$	k$	k$	k$	k$	k$
30.02.3	Module Support Structures	113	1666								1662	698	711	145
30.02.3.1	Off-Site	113	1666								1662	698	711	145
30.02.3.1.1	Shipping	51	92								58	73	0	0
30.02.3.1.2	Machining, Inspection	62	1574								942	586	711	145
30.02.3.1.3	Final Design, Drwg/Spec Mods	0	0								662	39	0	0
30.02.4	Electronics/Electrical Hardware	0	0							0	0	0	0	0
30.02.5	Gas System	275	808	0	0	0	0	0	0	0	1738	880	0	0
30.02.5.1	Off-Site	0	0	0	0	0			0	0	867	75	0	0
30.02.5.1.1	Design and Development	0	0	0	0	0			0	0	867	75	0	0
30.02.5.2	On-Site	275	808	0	0	0			0	0	871	805	0	0
30.02.5.2.1	Design and drawings	0	0	0	0	0			0	0	57	4	0	0
30.02.5.2.2	Test Procedure development	0	0	0	0	0			0	0	35	8	0	0
30.02.5.2.3	Safety Procedure development	0	0	0	0	0			0	0	76	10	0	0
30.02.5.2.4	Maintenance Procedure development	0	0	0	0	0			0	0	76	10	0	0
30.02.5.2.5	Assembly and Test	102	635	0	0	0			0	0	567	446	0	0
30.02.5.2.6	Procurement - Surface System	25	25	0		0			0	0	22	54	0	0
30.02.5.2.7	Procurement - Hall System	148	148	0		0			0	0	37	273	0	0
30.02.6	Cooling System	62	279								511	1610	0	0
30.02.6.1	Off-Site	62	279								511	1610	0	0
30.02.6.1.1	Shipping	25	33								15	29	0	0
30.02.6.1.2	Subassembly, Test	10	105								112	15	0	0
30.02.6.1.3	Machining, Inspection	25	120								112	1497	0	0
30.02.6.1.4	Procurement	2	21								26	54	0	0
30.02.6.1.5	Final Design, Drwg/Spec Mods										246	15	0	0
30.02.7	Local Alignment	69	1369								1295	1951	300	0
30.02.7.1	Off-Site	69	1369								1295	1951	300	0
30.02.7.1.1	Shipping	26	67								55	27	0	0
30.02.7.1.2	Test	10	814								562	13	300	0
30.02.7.1.3	Assembly	8	412								451	10	0	0
30.02.7.1.4	Facility Prep	25	52								60	52	0	0
30.02.7.1.5	Machining, Inspection	0	24								32	1840	0	0
30.02.7.1.6	Final Design, Drwg/Spec Mods		0								137	9	0	0

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		Assembly		Installation							Summary			
		Material	Total	Labor	Rate	Subtotal	Captl. Eqpt	Tooling	Material	Total	Labor	Material	Captl. Eqpt	Tooling
WBS no.	Item	k$	k$	py	k$/py	k$	k$	k$	k$	k$	k$	k$	k$	k$
30.02'	BARREL REGION RDT/RPC	963	18256							0	16119	12456	5505	521
30.02.2'	Round Drift Tubes (RDT)	376	7262								7159	8282	508	143
30.02.2.1'	Off-Site	376	7262								7159	8282	508	143
30.02.2.1.1'	Shipping	188	270								82	188	0	0
30.02.2.1.2'	Test	18	2044								1943	24	211	0
30.02.2.1.3'	Assembly	43	4047								3870	82	297	143
30.02.2.1.4'	Facility Prep	125	489								464	130	0	0
30.02.2.1.5'	Machining, Inspection	2	412								453	7838	0	0
30.02.2.1.6'	Final Design, Drwg/Spec Mods		0								349	20	0	0
30.02.2"	Resistive Plate Counters (RPC)	215	3289								3480	1350	190	79
30.02.2.1"	Off-Site	215	3289								3480	1350	190	79
30.02.2.1.1"	Shipping	188	270								82	188	0	0
30.02.2.1.2"	Test	5	586								581	7	34	0
30.02.2.1.3"	Assembly	6	1541								1415	11	156	79
30.02.2.1.4"	Facility Prep	5	369								464	10	0	0
30.02.2.1.5"	Machining, Inspection	11	524								589	1114	0	0
30.02.2.1.6"	Final Design, Drwg/Spec Mods										349	20	0	0
30.02.3'	Module Support Structures RDT/RPC	113	1666								1662	698	711	145
30.02.3.1'	Off-Site	113	1666								1662	698	711	145
30.02.3.1.1'	Shipping	51	92								58	73	0	0
30.02.3.1.2'	Machining, Inspection	62	1574								942	586	711	145
30.02.3.1.3'	Final Design, Drwg/Spec Mods	0	0								662	39	0	0
30.02.5'	Gas Systems - RDT/RPC	118	938								2278	1041	28	154
30.02.5.1'	Off-Site, RDT	0	0	0	0	0			0	0	455	56	0	0
30.02.5.1.1'	Design and Development	0	0	0		0			0	0	455	56	0	0
30.02.5.2'	On-Site, RDT	59	469	0	0	0			0	0	684	464	14	77
30.02.5.2.1'	Design and drawings	0	0	0		0			0	0	30	41	0	0
30.02.5.2.2'	Test Procedure development	0	0	0		0			0	0	76	10	0	0
30.02.5.2.3'	Safety Procedure development	0	0	0		0			0	0	76	10	0	0
30.02.5.2.4'	Maintenance Procedure development	0	0	0		0			0	0	76	10	0	0
30.02.5.2.5'	Assembly and Test	59	378	0		0			0	0	338	275	0	0
30.02.5.2.6'	Procurement - Surface System	0	14	0		0			0	0	44	21	0	14
30.02.5.2.7'	Procurement - Hall System	0	77	0		0			0	0	44	97	14	63
30.02.5.1"	Off-Site, RPC	0	0	0	0	0			0	0	455	56	0	0
30.02.5.1.1"	Design and Development	0	0	0	0	0			0	0	455	56	0	0
30.02.5.2"	On-Site, RPC	59	469	0	0	0			0	0	684	465	14	77
30.02.5.2.1"	Design and drawings	0	0	0	0	0			0	0	30	41	0	0
30.02.5.2.2"	Test Procedure development	0	0	0	0	0			0	0	76	10	0	0
30.02.5.2.3"	Safety Procedure development	0	0	0	0	0			0	0	76	10	0	0

		Assembly		Installation							Summary			
		Material	Total	Labor	Rate	Subtotal	Capit. Eqpt	Tooling	Material	Total	Labor	Material	Capit. Eqpt	Tooling
WBS no.	Item	k$	k$	py	k$/py	k$	k$	k$	k$	k$	k$	k$	k$	k$
30.02.5.2.4"	Maintenance Procedure development	0	0	0	0	0			0	0	76	10	0	0
30.02.5.2.5"	Assembly and Test	59	378	0	0	0			0	0	338	275	0	0
30.02.5.2.6"	Procurement - Surface System	0	14	0		0			0	0	44	21	0	14
30.02.5.2.7"	Procurement - Hall System	0	77	0		0			0	0	44	98	14	63
30.02.6'	Cooling Systems - RDT/RPC	21	36								40	103	0	0
30.02.6.1'	Off-Site, RDT	14	21								20	55	0	0
30.02.6.1.1'	Shipping	2	4								3	6	0	0
30.02.6.1.2'	Subassembly, Test	1	3								3	5	0	0
30.02.6.1.3'	Machining, Inspection	2	4								3	31	0	0
30.02.6.1.4'	Procurement	9	11								3	11	0	0
30.02.6.1.5'	Final Design, Drwg/Spec Mods										7	2	0	0
30.02.6.1"	Off-Site, RPC	7	14								20	48	0	0
30.02.6.1.1"	Shipping	2	4								3	6	0	0
30.02.6.1.2"	Subassembly, Test	1	3								3	5	0	0
30.02.6.1.3"	Machining, Inspection	2	4								3	31	0	0
30.02.6.1.4"	Procurement	2	4								3	4	0	0
30.02.6.1.5"	Final Design, Drwg/Spec Mods										7	2	0	0
30.02.7.1'	Local Alignment RDT/RPC	58	790								601	813	300	0
30.02.7.1.1'	Off-Site	58	790								601	813	300	0
30.02.7.1.1.1'	Shipping	26	67								55	27	0	0
30.02.7.1.1.2'	Test	4	493								210	5	300	0
30.02.7.1.1.3'	Assembly	3	155								168	4	0	0
30.02.7.1.1.4'	Facility Prep	25	52								60	27	0	0
30.02.7.1.1.5'	Machining, Inspection	0	24								32	740	0	0
30.02.7.1.1.6'	Final Design, Drwg/Spec Mods		0								77	10	0	0
30.03	END CAP REGION	644	12716	0	0	0	0	0	0	0	12407	6863	3549	330
30.03.1	End Cap Region Module Assy	60	3346	0	0	0	0	0	0	0	838	167	2900	0
30.03.1.1	On-Site	60	3346								486	144	2900	0
30.03.1.1.1	Sector Storage	50	50								0	50	0	0
30.03.1.1.2	Test	2	167								104	30	100	0
30.03.1.1.3	Assembly	7	3089								326	61	2800	0
30.03.1.1.4	Facility Prep	1	40								56	3	0	0
30.03.1.2	Off-Site	0	0								352	23	0	0
30.03.1.2.1	Assy Fixt Fnl Dsgn: Mach, Assy		0								352	23	0	0

		Assembly		Installation							Summary			
		Material	Total	Labor	Rate	Subtotal	Captl. Eqpt	Tooling	Material	Total	Labor	Material	Captl. Eqpt.	Tooling
WBS no.	Item	k$	k$	py	k$/py	k$	k$	k$	k$	k$	k$	k$	k$	k$
30.03.2	Cathode Strip Chambers	353	7085								7310	3414	301	80
30.03.2.1	Off-Site	353	7085								7310	3414	301	80
30.03.2.1.1	Shipping	156	238								82	199	0	0
30.03.2.1.2	Test	12	1433								1370	16	134	0
30.03.2.1.3	Assembly	53	4576								4654	90	167	80
30.03.2.1.4	Facility Prep	125	489								464	130	0	0
30.03.2.1.5	Machining, Inspection	7	349								393	2959	0	0
30.03.2.1.6	Final Design, Drwg/Spec Mods										349	20	0	0
30.03.3	Module Support Structures	105	1166	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1588	298	300	150
30.03.3.1	Off-Site	105	1166	0	0	0	0	0	0	0	1588	298	300	150
30.03.3.1.1	Shipping	51	92								58	73	0	0
30.03.3.1.2	Machining, Inspection	54	1074								868	186	300	150
30.03.3.1.3	Final Design, Drwg/Spec Mods										662	39	0	0
30.03.4	Electronics/Electrical Hardware	0	0								0	0	0	0
30.03.5	Gas System	49	730	0	0	0	0	0	0	0	1779	681	48	100
30.03.5.1	Off-Site	0	0	0	0	0			0	0	867	75	0	0
30.03.5.1.1	Design and Development	0	0	0	0	0			0	0	867	75	0	0
30.03.5.2	On-Site	49	730	0	0	0			0	0	913	606	48	100
30.03.5.2.1	Design and drawings	0	0	0	0	0			0	0	57	4	0	0
30.03.5.2.2	Test Procedure development	0	0	0	0	0			0	0	76	10	0	0
30.03.5.2.3	Safety Procedure development	0	0	0	0	0			0	0	76	10	0	0
30.03.5.2.4	Maintenance Procedure development	0	0	0	0	0			0	0	76	10	0	0
30.03.5.2.5	Assembly and Test	49	582	0	0	0			0	0	567	393	0	0
30.03.5.2.6	Procurement - Surface System	0	25	0		0			0	0	22	29	25	0
30.03.5.2.7	Procurement - Hall System	0	123	0		0			0	0	37	150	23	100
30.03.6	Cooling System	62	279								512	1610	0	0
30.03.6.1	Off-Site	62	279								512	1610	0	0
30.03.6.1.1	Shipping	25	33								15	29	0	0
30.03.6.1.2	Subassembly, Test	10	105								112	15	0	0
30.03.6.1.3	Machining, Inspection	25	120								112	1497	0	0
30.03.6.1.4	Procurement	2	21								26	54	0	0
30.03.6.1.5	Final Design, Drwg/Spec Mods										247	15	0	0

		Assembly		Installation							Summary			
		Material	Total	Labor	Rate	Subtotal	Capit. Eqpt	Tooling	Material	Total	Labor	Material	Capit. Eqpt	Tooling
WBS no.	Item	k$	k$	py	k$/py	k$	k$	k$	k$	k$	k$	k$	k$	k$
30.03.7	Local Alignment	15	110								379	693	0	0
30.03.7.1	Off-Site	15	110								379	693	0	0
30.03.7.1.1	Shipping	15	15								16	16	0	0
30.03.7.1.2	Test		24								57	2	0	0
30.03.7.1.3	Assembly		24								57	2	0	0
30.03.7.1.4	Facility Prep		24								57	2	0	0
30.03.7.1.5	Machining, Inspection		24								56	662	0	0
30.03.7.1.6	Final Design, Drwg/Spec Mods		0								137	9	0	0
30.03'	END CAP REGION RDT/RPC	909	13859	0		0	0	0	0	0	13516	6584	3680	449
30.03.2'	Round Drift Tubes (RDT)	342	5898								5989	3843	267	130
30.03.2.1'	Off-Site	342	5898								5989	3843	267	130
30.03.2.1.1'	Shipping	164	219								55	164	0	0
30.03.2.1.2'	Test	11	1212								1156	14	82	39
30.03.2.1.3'	Assembly	41	3649								3621	79	185	91
30.03.2.1.4'	Facility Prep	125	489								464	130	0	0
30.03.2.1.5'	Machining, Inspection	1	329								363	3436	0	0
30.03.2.1.6'	Final Design, Drwg/Spec Mods										332	20	0	0
30.03.2"	Resistive Plate Counters (RPC)	206	2337								2430	674	185	78
30.03.2.1"	Off-Site	206	2337								2430	674	185	78
30.03.2.1.1"	Shipping	188	270								82	188	0	0
30.03.2.1.2"	Test	3	380								364	4	34	0
30.03.2.1.3"	Assembly	6	1115								960	10	151	78
30.03.2.1.4"	Facility Prep	5	369								464	10	0	0
30.03.2.1.5"	Machining, Inspection	4	204								229	442	0	0
30.03.2.1.6"	Final Design, Drwg/Spec Mods										332	20	0	0
30.03.3'	Module Support Structures RDT/RPC	105	1166	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1588	377	300	150
30.03.3.1'	Off-Site	105	1166	0	0	0	0	0	0	0	1588	377	300	150
30.03.3.1.1'	Shipping	51	92								58	73	0	0
30.03.3.1.2'	Machining, Inspection	54	1074								868	265	300	150
30.03.3.1.3'	Final Design, Drwg/Spec Mods										662	39	0	0
30.03.5'	Gas Systems - RDT/RPC	118	875								2203	1033	28	91
30.03.5.1'	Off-Site, RDT	0	0	0	0	0			0	0	455	56	0	0
30.03.5.1.1'	Design and Development	0	0	0		0			0	0	455	56	0	0
30.03.5.2'	On-Site, RDT	59	459	0	0	0			0	0	647	460	28	63

		Assembly		Installation							Summary			
		Material	Total	Labor	Rate	Subtotal	Captl. Eqpt	Tooling	Material	Total	Labor	Material	Captl. Eqpt.	Tooling
WBS no.	Item	k$	k$	py	k$/py	k$	k$	k$	k$	k$	k$	k$	k$	k$
30.03.5.2.1'	Design and drawings	0	0	0		0			0	0	30	41	0	0
30.03.5.2.2'	Test Procedure development	0	0	0		0			0	0	76	10	0	0
30.03.5.2.3'	Safety Procedure development	0	0	0		0			0	0	76	10	0	0
30.03.5.2.4'	Maintenance Procedure development	0	0	0		0			0	0	76	10	0	0
30.03.5.2.5'	Assembly and Test	59	378	0		0			0	0	338	275	0	0
30.03.5.2.6'	Procurement - Surface System	0	14	0		0			0	0	6	17	14	0
30.03.5.2.7'	Procurement - Hall System	0	77	0		0			0	0	44	97	14	63
30.03.5.1"	Off-Site, RPC	0	0	0	0	0			0	0	455	56	0	0
30.03.5.1.1"	Design and Development	0	0	0	0	0			0	0	455	56	0	0
30.03.5.2"	On-Site, RPC	59	406	0	0	0			0	0	647	461	0	28
30.03.5.2.1"	Design and drawings	0	0	0	0	0			0	0	30	41	0	0
30.03.5.2.2"	Test Procedure development	0	0	0	0	0			0	0	76	10	0	0
30.03.5.2.3"	Safety Procedure development	0	0	0	0	0			0	0	76	10	0	0
30.03.5.2.4"	Maintenance Procedure development	0	0	0	0	0			0	0	76	10	0	0
30.03.5.2.5"	Assembly and Test	59	378	0	0	0			0	0	338	275	0	0
30.03.5.2.6"	Procurement - Surface System	0	14	0		0			0	0	6	17	0	14
30.03.5.2.7"	Procurement - Hall System	0	14	0		0			0	0	44	98	0	14
30.03.6'	Cooling Systems - RDT/RPC	28	43								40	110	0	0
30.03.6.1'	Off-Site, RDT	14	21								20	55	0	0
30.03.6.1.1'	Shipping	2	4								3	6	0	0
30.03.6.1.2'	Subassembly, Test	1	3								3	5	0	0
30.03.6.1.3'	Machining, Inspection	2	4								3	31	0	0
30.03.6.1.4'	Procurement	9	11								3	11	0	0
30.03.6.1.5'	Final Design, Drwg/Spec Mods										7	2	0	0
30.03.6.1"	Off-Site, RPC	14	21								20	55	0	0
30.03.6.1.1"	Shipping	2	4								3	6	0	0
30.03.6.1.2"	Subassembly, Test	1	3								3	5	0	0
30.03.6.1.3"	Machining, Inspection	2	4								3	31	0	0
30.03.6.1.4"	Procurement	9	11								3	11	0	0
30.03.6.1.5"	Final Design, Drwg/Spec Mods										7	2	0	0
30.03.7'	Local Alignment RDT/RPC	50	195								429	380	0	0
30.03.7.1'	Off-Site	50	195								429	380	0	0
30.03.7.1.1'	Shipping	25	66								57	26	0	0
30.03.7.1.2'	Test		27								60	2	0	0
30.03.7.1.3'	Assembly		27								60	2	0	0
30.03.7.1.4'	Facility Prep	25	52								60	27	0	0
30.03.7.1.5'	Machining, Inspection		24								56	314	0	0
30.03.7.1.6'	Final Design, Drwg/Spec Mods		0								137	9	0	0

		Assembly		Installation							Summary			
		Material	Total	Labor	Rate	Subtotal	Capt. Eqpt	Tooling	Material	Total	Labor	Material	Capt. Eqpt.	Tooling
WBS no.	Item	k$	k$	py	k$/py	k$	k$	k$	k$	k$	k$	k$	k$	k$
30.04	INSTALLATION			18.44	59	1095	1265	125	265	2750	2886	566	1265	125
30.04.1	Barrel Region			10.91	56	608	785	125	85	1603	1720	260	785	125
30.04.1.1	On-Site			10.91		608	785	125	85	1603	703	193	785	125
30.04.1.1.1	Test			3.00	71	213	60	0	76	349	213	76	60	0
30.04.1.1.2	Mechanical Assembly			0.41	47	19	600	0	0	619	54	28	600	0
30.04.1.1.3	Electrical/Electronics Assy			1.00	57	57	125	125	1	308	83	78	125	125
30.04.1.1.4	Fac Prep			6.50	49	319			8	327	353	11	0	0
30.04.1.2	Off-Site			0.00		0	0	0	0	0	1017	67	0	0
30.04.1.2.1	Install. Tool Fnl Dsgn: Mach, Assy			0.00	0	0			0	0	1017	67	0	0
30.04.2	End Cap Region			6.53	60	393	480	0	80	953	853	142	480	0
30.04.2.1	On-Site			6.53	60	393	480	0	80	953	459	114	480	0
30.04.2.1.1	Test			3.00	71	213	60	0	76	349	213	86	60	0
30.04.2.1.2	Mechanical Assembly			0.28	46	13	420	0	0	433	36	20	420	0
30.04.2.1.3	Electrical/Electronics Assembly			1.00	57	57			1	58	83	3	0	0
30.04.2.1.4	Fac Prep			2.25	49	110			3	113	128	5	0	0
30.04.2.2	Off-Site			0.00		0	0	0	0	0	393	28	0	0
30.04.2.2.1	Install. Tool Final Dsgn: Mach, Assy			0.00	0	0			0	0	393	28	0	0
30.04.3	Global Alignment			1.00	95	95	0	0	100	195	313	164	0	0
30.04.3.1	Off-Site			1.00		95	0	0	100	195	313	164	0	0
30.04.3.1.1	Shipping			0.50	82	41			100	141	57	151	0	0
30.04.3.1.2	Test			0.25	107	27				27	60	2	0	0
30.04.3.1.3	Assembly			0.25	107	27				27	60	2	0	0
30.04.3.1.4	Final Design, Drwg/Spec Mods									0	137	9	0	0
30.05	PROJECT MANAGEMENT										3296	435	0	0
30.05.1	Administration/Oversight										1463	150	0	0
30.05.2	Resource Management										183	45	0	0
30.05.3	ES&H Assurance										367	90	0	0
30.05.4	Quality Assurance Program										550	90	0	0
30.05.5	Systems Integration										367	30	0	0
30.05.6	Subsystem Cost/Schedule Monitor										367	30	0	0
30.06	CONCEPTUAL / PRELIMINARY DESIGN										1392	300	0	0

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WBS no.	Item	Summary Subtotal k$	Dsgn Growth Allwnce Rate	Dsgn Growth Allwnce Amount, k$	Total k$	Number Required	"unit" cost, K$	Area M^2	area "unit" cost, K$	Last modified
30	Muon Sub-system (CSC)	82285	31%	25803	108088	1	108088			15-Jan-93
30'	Muon Sub-system (RDT/RPC)	71517	28%	20299	91816	1	91816			15-Jan-93
30.01	Muon Subsystem R&D	2423	20%	485	2907					
30.01.1	Develop Chamber Technologies	780	20%	156	937					21-Dec-92
30.01.2	Chamber Performance Evaluation	260	20%	52	312					21-Dec-92
30.01.3	Muon Trigger	70	20%	14	84					21-Dec-92
30.01.4	Alignment Technology	209	20%	42	251					21-Dec-92
30.01.5	Electronics evaluation	189	20%	38	227					21-Dec-92
30.01.6	Simulations	33	20%	7	40					21-Dec-92
30.01.7	Ind. Chamber Des. & Factory layout	0	0%	0	0					21-Dec-92
30.01.8	Engineering (structures, costs, etc.)	880	20%	176	1057					21-Dec-92
30.02	BARREL REGION	46449	34%	15628	62078	2	31039			15-Jan-93
30.02.1	Barrel Region Module Assembly	4835	30%	1451	6286	2	3143			15-Jan-93
30.02.1.1	On-Site	4460	30%	1338	5798					
30.02.1.1.1	Module Storage	50	30%	15	65					13-Jan-92
30.02.1.1.2	Test	234	30%	70	304					2-May-92
30.02.1.1.3	Assembly	4117	30%	1235	5352					15-Jan-93
30.02.1.1.4	Fac Prep	59	30%	18	77					10-Jan-92
30.02.1.2	Off-Site	375	30%	113	488					
30.02.1.2.1	Assy Fixt Final Dsgn: Mach, Assy	375	30%	113	488					16-Jun-92
30.02.2	Cathode Strip Chambers	30113	36%	10841	40954	1024	40	4000	10.24	4-Jan-93
30.02.2.1	Off-Site	30113	36%	10841	40954					
30.02.2.1.1	Shipping	454	36%	163	617					4-Jan-93
30.02.2.1.2	Test	3216	36%	1158	4373					4-Jan-93
30.02.2.1.3	Assembly	10921	36%	3932	14853					4-Jan-93
30.02.2.1.4	Facility Prep	594	36%	214	807					23-Oct-92
30.02.2.1.5	Machining, Inspection	14560	36%	5242	19802					4-Jan-93
30.02.2.1.6	Final Design, Drwg/Spec Mods	369	36%	133	502					23-Oct-92

		Summary								
		Subtotal	Dsgn Growth Allwnce		Total	Number	"unit"	Area	area "unit"	Last
WBS no.	Item	k$	Rate	Amount, k$	k$	Required	cost, K$	M^2	cost, K$	modified
30.02.3	Module Support Structures	3216	34%	1079	4295	24	179			15-Jan-93
30.02.3.1	Off-Site	3216	34%	1079	4295					
30.02.3.1.1	Shipping	131	23%	30	161					26-Oct-92
30.02.3.1.2	Machining, Inspection	2384	34%	811	3195					15-Jan-93
30.02.3.1.3	Final Design, Drwg/Spec Mods	701	34%	238	939					16-Jun-92
30.02.4	Electronics/Electrical Hardware	0		0	0					
30.02.5	Gas System	2618	22%	576	3194	2	1597			4-Jan-93
30.02.5.1	Off-Site	942	22%	207	1149					
30.02.5.1.1	Design and Development	942	22%	207	1149					4-Jan-93
30.02.5.2	On-Site	1676	22%	369	2045					
30.02.5.2.1	Design and drawings	61	22%	14	75					4-Jan-93
30.02.5.2.2	Test Procedure development	43	22%	9	52					21-Oct-92
30.02.5.2.3	Safety Procedure development	86	22%	19	105					21-Oct-92
30.02.5.2.4	Maintenance Procedure development	86	22%	19	105					21-Oct-92
30.02.5.2.5	Assembly and Test	1013	22%	223	1236					4-Jan-93
30.02.5.2.6	Procurement - Surface System	76	22%	17	93					4-Jan-93
30.02.5.2.7	Procurement - Hall System	310	22%	68	378					4-Jan-93
30.02.6	Cooling System	2121	30%	636	2757	2	1378			4-Jan-93
30.02.6.1	Off-Site	2121	30%	636	2757					
30.02.6.1.1	Shipping	44	30%	13	57					4-Jan-93
30.02.6.1.2	Subassembly, Test	127	30%	38	165					4-Jan-93
30.02.6.1.3	Machining, Inspection	1609	30%	483	2091					4-Jan-93
30.02.6.1.4	Procurement	80	30%	24	104					4-Jan-93
30.02.6.1.5	Final Design, Drwg/Spec Mods	261	30%	78	339					4-Jan-93
30.02.7	Local Alignment	3546	29%	1046	4592	2	2296			13-Jan-93
30.02.7.1	Off-Site	3546	29%	1046	4592					
30.02.7.1.1	Shipping	82	30%	25	106					13-Jan-93
30.02.7.1.2	Test	875	30%	262	1137					13-Jan-93
30.02.7.1.3	Assembly	461	30%	138	599					13-Jan-93
30.02.7.1.4	Facility Prep	112	23%	26	138					31-Jan-92
30.02.7.1.5	Machining, Inspection	1872	30%	562	2433					13-Jan-93
30.02.7.1.6	Final Design, Drwg/Spec Mods	146	23%	33	179					31-Jan-92

WBS no.	Item	Summary: Subtotal k$	Degn Growth Allwnce Rate	Degn Growth Allwnce Amount, k$	Total k$	Number Required	"unit" cost, K$	Area M^2	area "unit" cost, K$	Last modified
30.02'	BARREL REGION RDT/RPC	34601	29%	10127	44728	2	22364			8-Jan-93
30.02.2'	Round Drift Tubes (RDT)	16092	30%	4786	20879	288	72	4000	5.22	8-Jan-93
30.02.2.1'	Off-Site	16092	30%	4786	20879					
30.02.2.1.1'	Shipping	270	30%	81	351					4-Jan-93
30.02.2.1.2'	Test	2178	30%	653	2831					8-Jan-93
30.02.2.1.3'	Assembly	4392	30%	1318	5709					8-Jan-93
30.02.2.1.4'	Facility Prep	594	23%	137	730					24-Jan-92
30.02.2.1.5'	Machining, Inspecion	8291	30%	2487	10778					8-Jan-93
30.02.2.1.6'	Final Design, Drwg/Spec Mods	369	30%	111	479					16-Jun-92
30.02.2"	Resistive Plate Counters (RPC)	5099	29%	1496	6595	288	23	7821	0.84	13-Jan-93
30.02.2.1"	Off-Site	5099	29%	1496	6595					
30.02.2.1.1"	Shipping	270	30%	81	351					13-Jan-93
30.02.2.1.2"	Test	622	30%	187	809					13-Jan-93
30.02.2.1.3"	Assembly	1661	30%	498	2160					13-Jan-93
30.02.2.1.4"	Facility Prep	474	23%	109	582					24-Jan-92
30.02.2.1.5"	Machining, Inspecion	1703	30%	511	2214					13-Jan-93
30.02.2.1.6"	Final Design, Drwg/Spec Mods	369	30%	111	479					16-Jun-92
30.02.3'	Module Support Structures RDT/RPC	3216	34%	1079	4295	32	134			15-Jan-93
30.02.3.1'	Off-Site	3216	34%	1079	4295					
30.02.3.1.1'	Shipping	131	23%	30	161					12-Jan-92
30.02.3.1.2'	Machining, Inspecion	2384	34%	811	3195					15-Jan-93
30.02.3.1.3'	Final Design, Drwg/Spec Mods	701	34%	238	939					16-Jun-92
30.02.5'	Gas Systems - RDT/RPC	3501	22%	770	4272	2	2136			4-Jan-93
30.02.5.1'	Off-Site, RDT	511	22%	112	623					
30.02.5.1.1'	Design and Development	511	22%	112	623					4-Jan-93
30.02.5.2'	On-Site, RDT	1239	22%	273	1512					
30.02.5.2.1'	Design and drawings	71	22%	16	86					4-Jan-93
30.02.5.2.2'	Test Procedure development	86	22%	19	105					21-Oct-92
30.02.5.2.3'	Safety Procedure development	86	22%	19	105					21-Oct-92
30.02.5.2.4'	Maintenance Procedure development	86	22%	19	105					21-Oct-92
30.02.5.2.5'	Assembly and Test	613	22%	135	748					4-Jan-93
30.02.5.2.6'	Procurement - Surface System	79	22%	17	96					4-Jan-93
30.02.5.2.7'	Procurement - Hall System	218	22%	48	266					4-Jan-93
30.02.5.1"	Off-Site, RPC	511	22%	112	623					
30.02.5.1.1"	Design and Development	511	22%	112	623					4-Jan-93
30.02.5.2"	On-Site, RPC	1240	22%	273	1513					
30.02.5.2.1"	Design and drawings	71	22%	16	86					4-Jan-93
30.02.5.2.2"	Test Procedure development	86	22%	19	105					21-Oct-92
30.02.5.2.3"	Safety Procedure development	86	22%	19	105					21-Oct-92

WBS no.	Item	Summary: Subtotal k$	Dsgn Growth Allwnce Rate	Dsgn Growth Allwnce Amount, k$	Total k$	Number Required	"unit" cost, K$	Area M^2	area "unit" cost, K$	Last modified
30.02.5.2.4"	Maintenance Procedure development	86	22%	19	105					21-Oct-92
30.02.5.2.5"	Assembly and Test	613	22%	135	748					4-Jan-93
30.02.5.2.6"	Procurement - Surface System	79	22%	17	96					4-Jan-93
30.02.5.2.7"	Procurement - Hall System	219	22%	48	267					4-Jan-93
30.02.6'	Cooling Systems - RDT/RPC	143	30%	43	185	2	93			
30.02.6.1'	Off-Site, RDT	75	30%	22	97					
30.02.6.1.1'	Shipping	9	30%	3	12					4-Jan-93
30.02.6.1.2'	Subassembly, Test	8	30%	2	11					4-Jan-93
30.02.6.1.3'	Machining, Inspection	34	30%	10	44					4-Jan-93
30.02.6.1.4'	Procurement	14	30%	4	18					4-Jan-93
30.02.6.1.5'	Final Design, Drwg/Spec Mods	9	30%	3	12					4-Jan-93
30.02.6.1"	Off-Site, RPC	69	30%	20	88					
30.02.6.1.1"	Shipping	9	30%	3	12					4-Jan-93
30.02.6.1.2"	Subassembly, Test	8	30%	2	11					4-Jan-93
30.02.6.1.3"	Machining, Inspection	34	30%	10	44					4-Jan-93
30.02.6.1.4"	Procurement	7	30%	2	9					4-Jan-93
30.02.6.1.5"	Final Design, Drwg/Spec Mods	9	30%	3	12					4-Jan-93
30.02.7.1'	Local Alignment RDT/RPC	1714	29%	502	2217					13-Jan-93
30.02.7.1.1'	Off-Site	1714	29%	502	2217					
30.02.7.1.1.1'	Shipping	82	30%	25	106					13-Jan-93
30.02.7.1.1.2'	Test	515	30%	155	670					13-Jan-93
30.02.7.1.1.3'	Assembly	172	30%	52	224					13-Jan-93
30.02.7.1.1.4'	Facility Prep	87	23%	20	107					31-Jan-92
30.02.7.1.1.5'	Machining, Inspection	772	30%	232	1003					13-Jan-93
30.02.7.1.1.6'	Final Design, Drwg/Spec Mods	87	23%	20	106					31-Jan-92
30.03	END CAP REGION	23149	34%	7842	30991	2	15495			15-Jan-93
30.03.1	End Cap Region Module Assy	3905	30%	1172	5077	2	2538			15-Jan-93
30.03.1.1	On-Site	3530	30%	1059	4589					
30.03.1.1.1	Sector Storage	50	30%	15	65					13-Jan-92
30.03.1.1.2	Test	234	30%	70	304					2-May-92
30.03.1.1.3	Assembly	3187	30%	956	4143					15-Jan-93
30.03.1.1.4	Facility Prep	59	30%	18	77					10-Jan-92
30.03.1.2	Off-Site	375	30%	113	488					
30.03.1.2.1	Assy Fbd Fnl Dsgn: Mach, Assy	375	30%	113	488					16-Jun-92

WBS no.	Item	Summary: Subtotal k$	Design Growth Allwnce Rate	Design Growth Allwnce Amount, k$	Total k$	Number Required	"unit" cost, K$	Area M^2	area "unit" cost, K$	Last modified
30.03.2	Cathode Strip Chambers	11105	36%	3998	15103	256	59	2847	5.30	13-Jan-93
30.03.2.1	Off-Site	11105	36%	3998	15103					
30.03.2.1.1	Shipping	281	36%	101	382					12-Jan-93
30.03.2.1.2	Test	1520	36%	547	2067					13-Jan-93
30.03.2.1.3	Assembly	4991	36%	1797	6787					13-Jan-93
30.03.2.1.4	Facility Prep	594	36%	214	807					16-Jun-92
30.03.2.1.5	Machining, Inspection	3352	36%	1207	4558					13-Jan-93
30.03.2.1.6	Final Design, Drwg/Spec Mods	369	36%	133	502					16-Jun-92
30.03.3	Module Support Structures	2336	33%	769	3105	32	97			15-Jan-93
30.03.3.1	Off-Site	2336	33%	769	3105					
30.03.3.1.1	Shipping	131	15%	20	151					31-Jan-92
30.03.3.1.2	Machining, Inspection	1504	34%	511	2015					15-Jan-93
30.03.3.1.3	Final Design, Drwg/Spec Mods	701	34%	238	939					16-Jun-92
30.03.4	Electronics/Electrical Hardware	0		0	0					5-Jan-93
30.03.5	Gas System	2608	32%	827	3435	2	1717			13-Jan-93
30.03.5.1	Off-Site	942	28%	264	1205					
30.03.5.1.1	Design and Development	942	28%	264	1205					13-Jan-93
30.03.5.2	On-Site	1667	34%	563	2229					
30.03.5.2.1	Design and drawings	61	28%	17	79					13-Jan-93
30.03.5.2.2	Test Procedure development	86	34%	29	116					16-Jun-92
30.03.5.2.3	Safety Procedure development	86	34%	29	116					16-Jun-92
30.03.5.2.4	Maintenance Procedure development	86	34%	29	116					16-Jun-92
30.03.5.2.5	Assembly and Test	960	34%	326	1287					13-Jan-93
30.03.5.2.6	Procurement - Surface System	76	34%	26	102					13-Jan-93
30.03.5.2.7	Procurement - Hall System	310	34%	105	416					13-Jan-93
30.03.6	Cooling System	2122	38%	804	2926	2	1463			5-Jan-93
30.03.6.1	Off-Site	2122	38%	804	2926					
30.03.6.1.1	Shipping	44	40%	18	61					5-Jan-93
30.03.6.1.2	Subassembly, Test	127	40%	51	178					5-Jan-93
30.03.6.1.3	Machining, Inspection	1609	40%	644	2253					5-Jan-93
30.03.6.1.4	Procurement	80	40%	32	112					5-Jan-93
30.03.6.1.5	Final Design, Drwg/Spec Mods	262	23%	60	322					5-Jan-93

		Summary								
		Subtotal	Degn Growth Allwnce		Total	Number	"unit"	Area	area "unit"	Last
WBS no.	Item	k$	Rate	Amount, k$	k$	Required	cost, K$	M^2	cost, K$	modified
30.03.7	Local Alignment	1072	25%	273	1345	2	673			14-Jan-93
30.03.7.1	Off-Site	1072	25%	273	1345					
30.03.7.1.1	Shipping	32	15%	5	37					14-Jan-93
30.03.7.1.2	Test	59	23%	14	73					14-Jan-93
30.03.7.1.3	Assembly	59	23%	14	73					14-Jan-93
30.03.7.1.4	Facility Prep	59	23%	14	73					31-Jan-92
30.03.7.1.5	Machining, Inspection	718	27%	194	912					14-Jan-93
30.03.7.1.6	Final Design, Drwg/Spec Mods	146	23%	33	179					31-Jan-92
30.03'	END CAP REGION RDT/RPC	24229	32%	7839	32069	2	16034			12-Jan-93
30.03.2'	Round Drift Tubes (RDT)	10229	36%	3682	13911	192	72	2847	4.89	12-Jan-93
30.03.2.1'	Off-Site	10229	36%	3682	13911					
30.03.2.1.1'	Shipping	219	36%	79	298					12-Jan-93
30.03.2.1.2'	Test	1291	36%	465	1756					8-Jan-93
30.03.2.1.3'	Assembly	3976	36%	1431	5407					8-Jan-93
30.03.2.1.4'	Facility Prep	594	36%	214	807					16-Jun-92
30.03.2.1.5'	Machining, Inspection	3799	36%	1367	5166					8-Jan-93
30.03.2.1.6'	Final Design, Drwg/Spec Mods	352	36%	127	478					16-Jun-92
30.03.2"	Resistive Plate Counters (RPC)	3367	36%	1212	4579	192	24	1077	4.25	13-Jan-93
30.03.2.1"	Off-Site	3367	36%	1212	4579					
30.03.2.1.1"	Shipping	270	36%	97	367					13-Jan-93
30.03.2.1.2"	Test	402	36%	145	547					13-Jan-93
30.03.2.1.3"	Assembly	1199	36%	431	1630					13-Jan-93
30.03.2.1.4"	Facility Prep	474	36%	170	644					16-Jun-92
30.03.2.1.5"	Machining, Inspection	671	36%	241	912					13-Jan-93
30.03.2.1.6"	Final Design, Drwg/Spec Mods	352	36%	127	478					16-Jun-92
30.03.3'	Module Support Structures RDT/RPC	2415	33%	796	3210	32	100			15-Jan-93
30.03.3.1'	Off-Site	2415	33%	796	3210					
30.03.3.1.1'	Shipping	131	15%	20	151					31-Jan-92
30.03.3.1.2'	Machining, Inspection	1583	34%	538	2121					15-Jan-93
30.03.3.1.3'	Final Design, Drwg/Spec Mods	701	34%	238	939					16-Jun-92
30.03.5'	Gas Systems - RDT/RPC	3355	22%	738	4093	2	2047			13-Jan-93
30.03.5.1'	Off-Site, RDT	511	22%	112	623					
30.03.5.1.1'	Design and Development	511	22%	112	623					13-Jan-93
30.03.5.2'	On-Site, RDT	1198	22%	263	1461					

		Summary								
		Subtotal	Dsgn Growth Allwnce		Total	Number	"unit"	Area	area "unit"	Last
WBS no.	Item	k$	Rate	Amount, k$	k$	Required	cost, K$	M^2	cost, K$	modified
30.03.5.2.1'	Design and drawings	71	22%	16	86					13-Jan-93
30.03.5.2.2'	Test Procedure development	86	22%	19	105					16-Jun-92
30.03.5.2.3'	Safety Procedure development	86	22%	19	105					16-Jun-92
30.03.5.2.4'	Maintenance Procedure development	86	22%	19	105					16-Jun-92
30.03.5.2.5'	Assembly and Test	613	22%	135	748					13-Jan-93
30.03.5.2.6'	Procurement - Surface System	37	22%	8	45					13-Jan-93
30.03.5.2.7'	Procurement - Hall System	218	22%	48	266					13-Jan-93
30.03.5.1"	Off-Site, RPC	511	22%	112	623					
30.03.5.1.1"	Design and Development	511	22%	112	623					13-Jan-93
30.03.5.2"	On-Site, RPC	1136	22%	250	1385					
30.03.5.2.1"	Design and drawings	71	22%	16	86					13-Jan-93
30.03.5.2.2"	Test Procedure development	86	22%	19	105					16-Jun-92
30.03.5.2.3"	Safety Procedure development	86	22%	19	105					16-Jun-92
30.03.5.2.4"	Maintenance Procedure development	86	22%	19	105					16-Jun-92
30.03.5.2.5"	Assembly and Test	613	22%	135	748					13-Jan-93
30.03.5.2.6"	Procurement - Surface System	37	22%	8	45					13-Jan-93
30.03.5.2.7"	Procurement - Hall System	156	22%	34	190					13-Jan-93
30.03.6'	Cooling Systems - RDT/RPC	150	30%	45	194	2	97			5-Jan-93
30.03.6.1'	Off-Site, RDT	75	30%	22	97					
30.03.6.1.1'	Shipping	9	30%	3	12					5-Jan-93
30.03.6.1.2'	Subassembly, Test	8	30%	2	11					5-Jan-93
30.03.6.1.3'	Machining, Inspection	34	30%	10	44					5-Jan-93
30.03.6.1.4'	Procurement	14	30%	4	18					5-Jan-93
30.03.6.1.5'	Final Design, Drwg/Spec Mods	9	30%	3	12					5-Jan-93
30.03.6.1"	Off-Site, RPC	75	30%	22	97					
30.03.6.1.1"	Shipping	9	30%	3	12					5-Jan-93
30.03.6.1.2"	Subassembly, Test	8	30%	2	11					5-Jan-93
30.03.6.1.3"	Machining, Inspection	34	30%	10	44					5-Jan-93
30.03.6.1.4"	Procurement	14	30%	4	18					5-Jan-93
30.03.6.1.5"	Final Design, Drwg/Spec Mods	9	30%	3	12					5-Jan-93
30.03.7'	Local Alignment RDT/RPC	809	24%	194	1004	2	502			14-Jan-93
30.03.7.1'	Off-Site	809	24%	194	1004					
30.03.7.1.1'	Shipping	83	15%	12	95					14-Jan-93
30.03.7.1.2'	Test	62	23%	14	76					14-Jan-93
30.03.7.1.3'	Assembly	62	23%	14	76					14-Jan-93
30.03.7.1.4'	Facility Prep	87	23%	20	107					31-Jan-92
30.03.7.1.5'	Machining, Inspection	370	27%	100	470					14-Jan-93
30.03.7.1.6'	Final Design, Drwg/Spec Mods	146	23%	33	179					31-Jan-92

		Summary								
		Subtotal	Dsgn Growth Allwnce		Total	Number	"unit"	Area	area "unit"	Last
WBS no.	Item	k$	Rate	Amount, k$	k$	Required	cost, K$	M^2	cost, K$	modified
30.04	INSTALLATION	4842	23%	1136	5978	2	2989			15-Jan-93
30.04.1	Barrel Region	2890	24%	687	3577					15-Jan-93
30.04.1.1	On-Site	1806	22%	394	2200					
30.04.1.1.1	Test	349	17%	59	408					2-May-92
30.04.1.1.2	Mechanical Assembly	682	23%	157	839					15-Jan-93
30.04.1.1.3	Electrical/Electronics Assy	411	23%	95	506					2-May-92
30.04.1.1.4	Fac Prep	364	23%	84	448					6-Jan-92
30.04.1.2	Off-Site	1084	27%	293	1376					
30.04.1.2.1	Install. Tool Fnl Dsgn: Mach, Assy	1084	27%	293	1376					16-Jun-92
30.04.2	End Cap Region	1475	24%	356	1831					15-Jan-93
30.04.2.1	On-Site	1053	23%	242	1296					
30.04.2.1.1	Test	359	23%	83	442					27-Jan-92
30.04.2.1.2	Mechanical Assembly	476	23%	109	585					15-Jan-93
30.04.2.1.3	Electrical/Electronics Assembly	86	23%	20	106					27-Jan-92
30.04.2.1.4	Fac Prep	133	23%	30	163					27-Jan-92
30.04.2.2	Off-Site	421	27%	114	535					
30.04.2.2.1	Install. Tool Final Dsgn: Mach, Assy	421	27%	114	535					27-Jan-92
30.04.3	Global Alignment	477	20%	93	571	1	571			
30.04.3.1	Off-Site	477	20%	93	571					
30.04.3.1.1	Shipping	208	15%	31	239					31-Jan-92
30.04.3.1.2	Test	62	23%	14	76					31-Jan-92
30.04.3.1.3	Assembly	62	23%	14	76					31-Jan-92
30.04.3.1.4	Final Design, Drwg/Spec Mods	146	23%	33	179					31-Jan-92
30.05	PROJECT MANAGEMENT	3731	10%	373	4104					
30.05.1	Administration/Oversight	1613	10%	161	1774					9-Jun-92
30.05.2	Resource Management	228	10%	23	251					9-Jun-92
30.05.3	ES&H Assurance	457	10%	46	502					9-Jun-92
30.05.4	Quality Assurance Program	640	10%	64	704					9-Jun-92
30.05.5	Systems Integration	397	10%	40	436					9-Jun-92
30.05.6	Subsystem Cost/Schedule Monitor	397	10%	40	436					9-Jun-92
30.06	CONCEPTUAL / PRELIMINARY DESIGN	1692	20%	338	2030					31-Jan-92

The GEM Muon Subsystem Cost Estimation

Presentation by:

R. Sawicki

Cost parameterization objectives

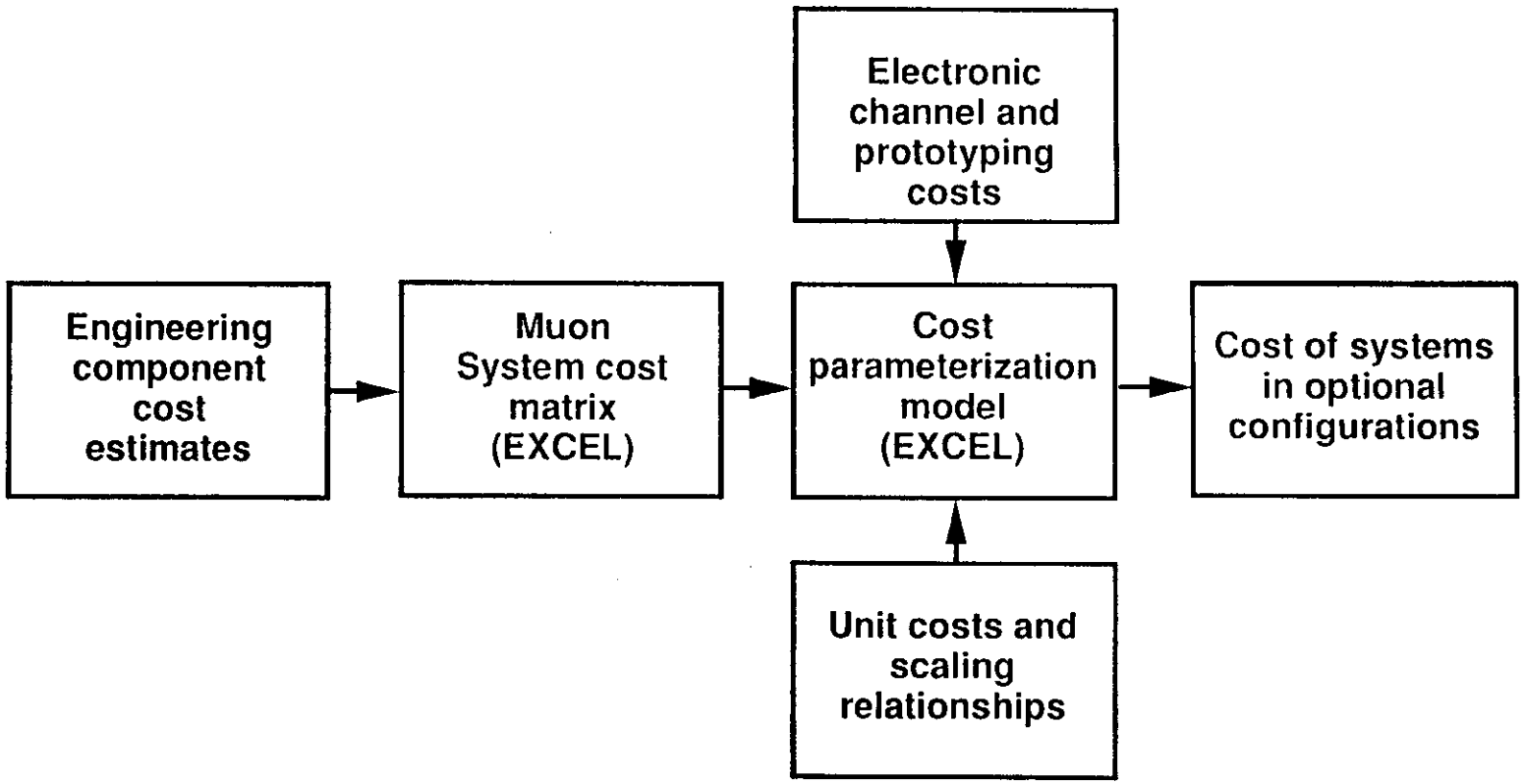
- Develop a system capable of assessing the cost impacts of different design options for the CSC technology

- Integrate model with Muon System cost matrix
  - consistent cost "story"
  - enable rapid updating for future cost refinements
  - EXCEL spreadsheet

- Permit variability of a broad range of fundamental system parameters
  - system size, configuration, unit costs

- Include parametrization of barrel and endcap
  - initial barrel model complete
  - endcap model not yet implemented
    - -- totals assume baseline configuration and costs

Cost model data flow



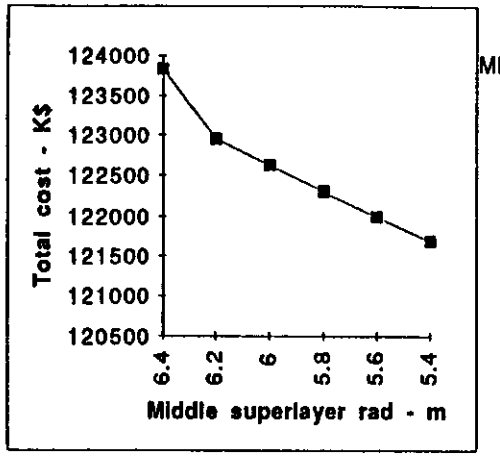
REVIS, 6/4/4

	A	B	C	D	E	F	G	H	I	J
1										
2										
3		**Barrel Region**						**Endcap Region**		
4										
5										
6		Input quantities:						Input quantities:		
7										
8		Parameter	Units	Value	Value	Value		Parameter	Units	Value
9				Inner	Middle	Outer				
10		Detector layout						Detector layout		
11										
12		Average radius	m	4.2	6.4	8.7				
13		Minimum theta of barrel	degrees	29.6						
14		Maximum theta of barrel	degrees	83.7						
15		Baseline volume	m3	4037						
16		Baseline # chambers	#	1024						
17										
18		Chamber configuration						Chamber configuration		
19										
20		Axial space between chambers	cm	2.5	10	2.5				
21		Axial segmentation	#	2	4	4				
22		Phi segmentation	#	24	48	48				
23		Tilt angle	degrees	6	10.77	10.54				
24		Module segmentation	#	12						
25		Baseline module segmentation	#	12	Channel	559104				
26		Baseline # of alignment towers	#	384	Measure	36				
27		Baseline manufactured panel area	m2	15161.62	Cost	123833				
28										
29		Chamber details						Chamber details		
30										
31		Desired pitch	mm	5	8	10				
32		Honeycomb thickness	mm	20						
33		#Planes/superlayer	#	6	6	4				
34		Max number of planes/chamber	#	3	3	4				
35		Wire pitch	mm	2.5	2.5	2.5				
36		Axial dead space	mm	65	65	65				
37		Phi dead space	mm	50	50	50				
38		Baseline number of channels	#	815371						
39		Layer/layer placement error	micron	50	50	50				
40		Superlr/superlr/measurement error	micron	25	25	25				
41		# wires/coarse channel	#	40	40	40				
42										
43										
44		Unit costs								
45										
46		Plain cathode cost	$/m2	5				Electronic channel prototype developm	K$	2246
47		Strip cathode cost	$/m2	258				Number of fine electronic channels	#	292000
48		Manufactured panel cost - a paramete	K$	686				Number of coarse electronic channels	#	90000
49		Manufactured panel cost - b paramete	K$/m2	0.19366						
50		Wire cost	$/m	0.29						
51		Circuit board cost	$/m2	50						
52		Spacer cost	K$/GEM	631						
53		Cost/fine electronic channel	$/channel	11						
54		Cost/coarse electronic channel	$/channel	11						
55		Assembly labor cost	K$/yr	100						
56		Contingency	%	30						
57		R&D costs	K$	2423						
58		Conceptual/preliminary design	K$	3731						
59		Project management	K$	1692						
60		Chamber assembly cost	Manhrs/gap	50						
61		Chamber assembly labor rate	K$/yr	96						
62										
63		Miscellaneous								
64										
65		#hours to assemble ave. chamber	hrs	200						
66										
67										
68		Baseline costs:						Base costs:		
69										
70		Parameter	Units	Value	Value	Value		Parameter	Units	Value
71				Inner	Middle	Outer				
72		Fixed costs								
73										
74		Sector assembly	K$	484				Sector assembly	K$	3905
75		Chambers	K$	3268				Chambers	K$	11105
76		Support structure	K$	1052				Support structure	K$	2336
77		Electronics	K$	0				Electronics	K$	2246
78		Gas system	K$	1604				Gas system	K$	2608
79		Cooling system	K$	386				Cooling system	K$	2122
80		Alignment system	K$	1159				Alignment system	K$	1072
81		Installation	K$	1287				Installation	K$	1475
82										
83										
84		Fixed base cost subtotal	K$	9241				Fixed base cost subtotal	K$	26869
85										
86		Variable costs								
87										
88		Sector assembly	K$	4352				Sector assembly	K$	0
89		Chambers	K$	26845				Chambers	K$	0
90		Support structure	K$	2164				Support structure	K$	0
91		Electronics	K$	8969				Electronics	K$	4202

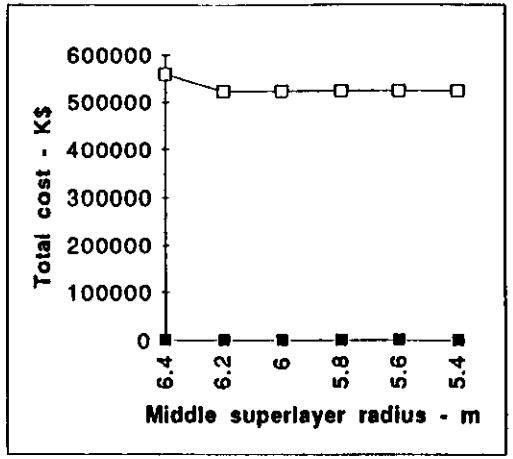
	A	B	C	D	E	F	H	I	J
92		Gas system	K$	1014			Gas system	K$	0
93		Cooling system	K$	1734			Cooling system	K$	0
94		Alignment system	K$	2865			Alignment system	K$	0
95		Installation	K$	1603			Installation	K$	0
96									
97		Variable base cost subtotal	K$	49545			Variable base cost subtotal	K$	4202
98									
99		WBS totals							
100									
101		Sector assembly		4835					
102		Chambers		30113					
103		Support structure		3216					
104		Electronics		8969					
105		Gas system		2618					
106		Cooling system		2121					
107		Alignment system		4024					
108		Installation		2890					
109									
110		Subtotal		58785					
111									
112		Baseline totals							
113									
114		Barrel Fixed+Variable costs	K$	58785			Endcap Fixed+Variable costs	K$	31071
115		Endcap Fixed+Variable costs	K$	31071					
116		R&D cost	K$	2423					
117		Project Management	K$	3731					
118		Conceptual/preliminary design	K$	1692					
119									
120		Subtotal	K$	97702					
121									
122		Contingency (30%)	K$	29311					
123									
124		Total base cost with contingency	K$	127012					
125									
126									
127									
128		Output quantities:					Output quantities:		
129									
130		Parameter	Units	Value	Value	Value	Parameter	Units	Value
131				Inner	Middle	Outer			
132									
133		Superlayer resolution	microns						
134		Superlayer length	m	6.93	10.56	14.36			
135		Average chamber length	m	3.45	2.57	3.57			
136		Average active chamber area	m	3.67	2.08	3.98			
137		Active length	m	3.32	2.44	3.44			
138		Total strip cathode area/GEM	m2	2115.53	4783.48	6119.60			
139		Total plain cathode area/GEM	m2	3525.88	7972.47	9179.41			
140		Total manufactured panel area/GEM	m2	2820.70	6377.98	7649.51			
141		Total # manufactured panels/GEM	#	768	3072	1920			
142		Total wire length/GEM superlayer	m	564141	1275595	1223921			
143		Total wire length/GEM	m	3063657					
144		Total GEM barrel region volume	m3	4037.43					
145		Segmentation width	m	1.10	0.84	1.14			
146		Real width	m	1.21	0.95	1.26			
147		Active width	m	1.11	0.85	1.16			
148		Calculated pitch	mm	4.93	7.61	10.34			
149		Gas gap	mm	2.47	3.81	5.17			
150		Number of card widths/chamber	#	14.00	7.00	7.00			
151		# fine channels/chamber plane	#	224	112	112			
152		# fine channels/GEM superlayer	#	129024	258048	172032			
153		Total number of fine channels/GEM	#	559104					
154		# coarse channels/GEM superlayer	#	6379	18701	13210			
155		# coarse channels/GEM	#	38291					
156		# chamber through thickness	#	2.00	2.00	1.00			
157		Total no. GEM chambers/superlayer	#	192	768	384			
158		Total number of GEM chambers	#	1344					
159		Number of GEM alignment towers	#	384					
160		Single layer error	microns	57.34	64.03	70.85			
161		Superlayer error	microns	23.41	26.14	35.43			
162		Error weighting factor	-	0.51	1.00	0.49			
163		Bsig2	microns2	785.77	808.33	1095.00			
164		Total error	microns	35.71					
165									
166		Output costs:					Output costs:		
167									
168		Parameter	Units	Value	Value	Value	Parameter	Units	Value
169				Inner	Middle	Outer			
170		Fixed costs							
171									
172		Sector assembly	K$	484					
173		Chambers	K$	3268					
174		Support structure	K$	1052					
175		Electronics	K$	0					
176		Gas system	K$	1604					
177		Cooling system	K$	386					
178		Alignment system	K$	1159					
179		Installation	K$	1287					
180									
181		Fixed cost subtotal	K$	9241					
182									

	A	B	C	D	E	F	G	H	I	J
183		Variable costs								
184										
185		Sector assembly	K$	4352						
186		Chambers		26623						
187		Chamber material cost		14661						
188		Plain cathodes		103						
189		cost/area	$/m2	5						
190		area	m2	20678						
191		Strip cathodes		3359						
192		cost/area	$/m2	258						
193		area	m2	13019						
194		Manufactured panel		9009						
195		fixed cost - a parameter	$	686						
196		cost/area - b parameter	$/in2	0.19366						
197		area	m2	16848						
198		Wires		888						
199		cost/length	K$/m	0.29						
200		total length	m	3063657						
201		Circuit boards		651						
202		cost/area	K$/m2	50						
203		area	m2	13019						
204		Spacers		651						
205		Chamber assembly labor	K$	11962						
206		number of gaps	#	2208						
207		cost per gap	$/gap	50						
208		labor rate	K$/yr	96						
209		Support structure	K$	2164						
210		Electronics	K$	6571						
211		fine channel total	K$	6150						
212		cost/finechannel	$/channel	11						
213		# channels	#	559104						
214		coarse channel total		421						
215		cost/coarse channel	$/channel	11						
216		#coarse channels	#	38291						
217		Gas system	K$	1077						
218		Cooling system	K$	1843						
219		Alignment system	K$	2865						
220		Installation	K$	1603						
221										
222										
223		Variable cost subtotal	K$	47098						
224										
225		Total cost	K$	56339						18995
226										
227		Contingency	K$	16902						
228										
229		Total cost with contingency	K$	73240						
230										
231		Total cost								
232										
233		Sector assembly	K$	4836						
234		Chambers	K$	29892						
235		Support structure	K$	3216						
236		Electronics	K$	6571						
237		Gas system	K$	2681						
238		Cooling system	K$	2229						
239		Alignment system	K$	4024						
240		Installation	K$	2890						
241										
242		Total cost		56339						
243										
244										
245		Summary								
246										
247		Barrel cost	K$	56339						
248		Endcap cost	K$	31071						
249		R&D	K$	2423						
250		Conceptual/preliminary design		3731						
251		Project management		1692						
252		Subtotal	K$	95256						
253										
254		Total contingency	K$	28577						
255										
256		Grand total	K$	123833						
257										
258										
259										
260										

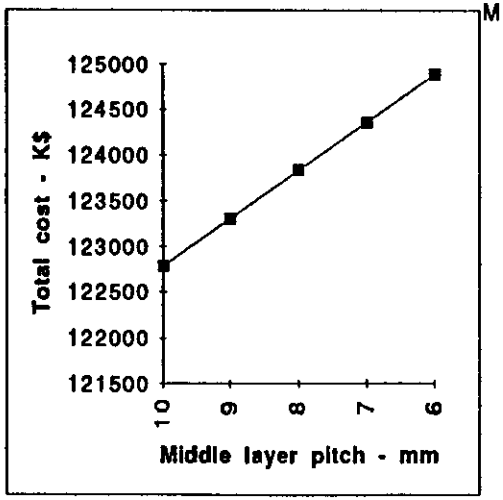
Middle radius	Total cost
	123833
6.4	123833
6.2	122960
6	122626
5.8	122303
5.6	121991
5.4	121690



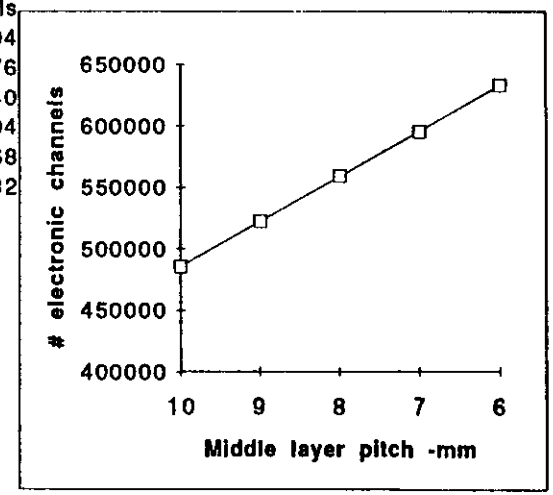
Middle radius	# channels
	559104
6.4	559104
6.2	522240
6	522240
5.8	522240
5.6	522240
5.4	522240



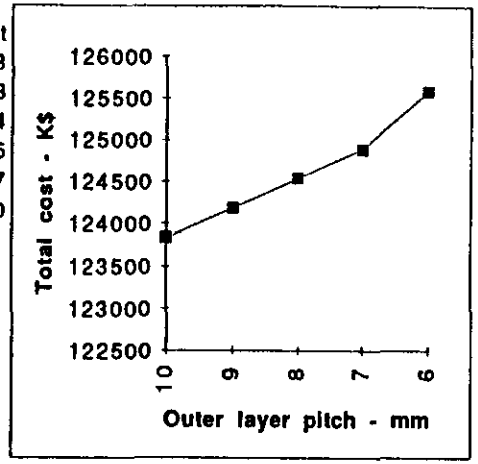
M layer pitch	Total cost
	123833
10	122778
9	123305
8	123833
7	124360
6	124887



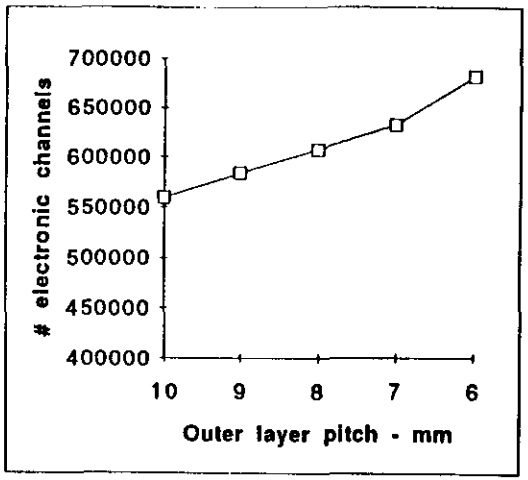
M layer pitch	#channels
	559104
10	485376
9	522240
8	559104
7	595968
6	632832



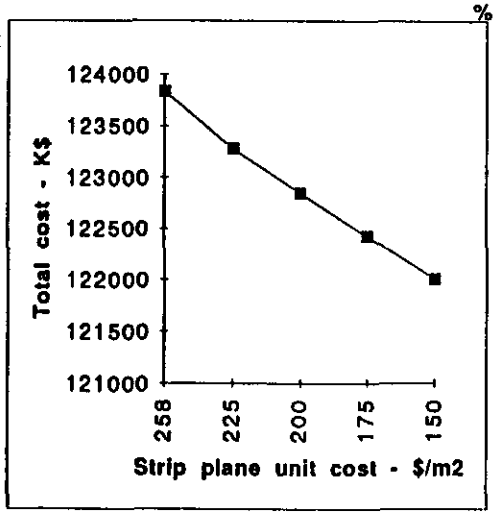
O layer pitch	Total cost
	123833
10	123833
9	124184
8	124535
7	124887
6	125590



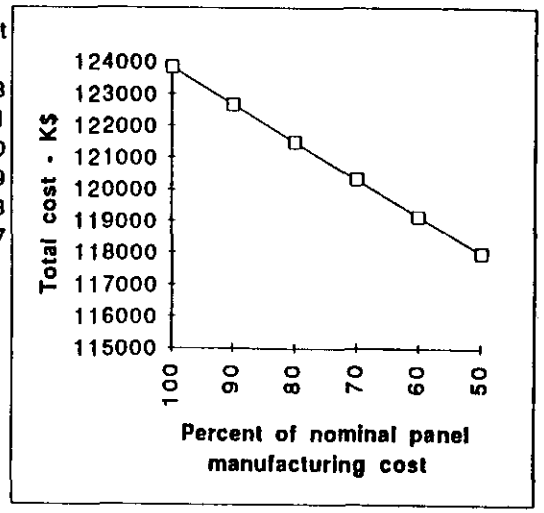
O layer pitch	# channels
	559104
10	559104
9	583680
8	608256
7	632832
6	681984



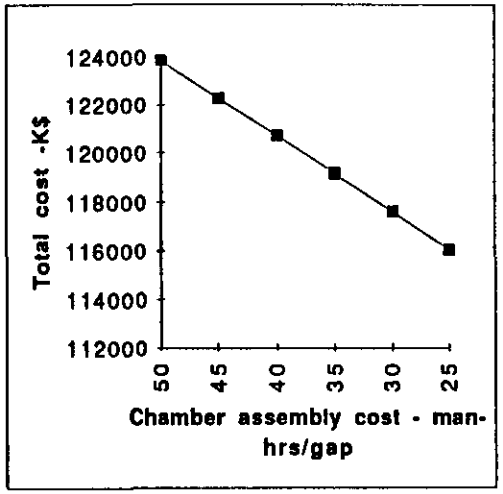
strip plane cost $/m2	Total cost
	123833
258	123833
225	123274
200	122851
175	122428
150	122005



% of panel fab cost	Total cost
100	123833
90	122661
80	121490
70	120319
60	119148
50	117977



Ch assy rate Man-hr/gap	Total Cost
	123833
50	123833
45	122277
40	120722
35	119167
30	117612
25	116057



Preliminary cost parameterization results

# Phi segments	#planes/ superlayer			pitch (mm)			# Barrel E/channels	Measure. error (microns)	Cost (K$)
	I	M	O	I	M	O			
12	8	4	4	5	5	5	786432	38	122469
12	6	6	4	5	8	10	559104	36	123833
12	6	6	6	5	8	10	645120	35	132967
12	8	6	4	5	8	10	602112	35	125903
12	8	6	6	5	8	10	688128	35	135038
12	8	8	4	5	8	10	688128	34	131897

= Baseline 8/4/4, 12 fold segmentation, 5mm/5mm/5mm pitch

= new proposals

CSC/RDT Cost Comparison

	CSC (6/6/4)			RDT/RPC		
	Barrel	Endcap	Total	Barrel	Endcap	Total
Sector assembly	4836	3905	8741	4835	3905	8741
Chambers	29892	11105	40997	21191	13596	34787
Support structure	3216	2336	5552	3216	2415	5630
Gas systems	2681	2608	5289	3501	3355	6856
Cooling systems	2229	2122	4351	143	150	292
Alignment	4024	1072	5096	2192	809	3001
Installation	2890	1475	4365	2890	1475	4364
Mechanical subtotal	49768	24623	74391	37968	25704	63672
Electronics subtotal	6571	4202	10773	1309	2519	3828
Subtotal	56339	28825	85164	39277	28223	67500
R&D	2423	2246	4669	2423	2246	4669
Conceptual/prelimnary	1692		1692	1692		1692
Project management	3731		3731	3731		3731
Subtotal	64184	31071	95256	47122	30469	77591
Contingency (30% CSC, 28%RDT)	19255	9321	28577	13373	8647	22020
Grand total	83440	40392	123832	60495	39116	99611

Notes:

1) CSC costs were developed from cost parameterization model
2) RDT cost are from Gustavson"s cost matrix with electronic channel cost added
3) Same electronic unit costs used for CSC and RDT
   a) channel cost = $11/channel plus contingency
   b) Electronic prototype development cost=2246K$
   c) # channels (fine and coarse, barrel and endcap)
      =979,395 CSC
      = 348,000 RDT (no RPC channel costs included)

Muon Technology Choice

Discussion led by:

F. Taylor

Elements to Consider

T.E.I.
1/18/93

1) System Performance
   a) Pattern recognition
   b) $P_\perp$ resol'n
   c) θ & φ resol'n
   d) Trigger resol'n ($P_\perp$ & T_0)
   e) Intrinsic rate capability
   f) Robustness
2) Technical Risk of System
   a) How well has R&D validated design?
   b) Any major risks w/o feasible backup?
   c) Complexity of System (no. channels, etc.)
   d) Construction req'rd (chambers, S.S.)
3) Cost of System
   a) Cost of chambers & risk
   b) Cost of electronics & risk
   c) Cost of Sup. Structure & alignment
   d) Foreign contributions & interests
4) Strength of R&D Effort
   a) Short term ($T < TDR$)
      Program strong enough to answer crucial Questions for TDR?
   b) Enough effort invested in backups?
5) Strength of TDR Case
   If backups needed, what % of design will change?

Technology Review Questions
- from BNL meeting -

1) The existing CSC prototypes must show resol'ns consistent with 75 μm
   - Dubna chamber
   - Large BNL chamber
   - BNL chamber
   - BU/RD5 chamber
   - UH chamber

Added:

2) The jitter of CSC should be measured
   - BU/RD5 chamber
   - BNL chamber
   - PNPI $\sigma = 3.4$ ns 98% $\tau \leq 16$ ns

3) must demonstrate a large RPC operation consistent with EC application
   - jitter
   - operation with RDT
   - rate capability

4) Credible design of RDTs in EC & RPCs
   - trigger
   - resol'n
   - layout & alignment

5) nonflammable gas for RDT
   - resol'ns
   - mitigation