GEM TN-92-134

Muon Engineering Status Meeting - M.I.T.

July 13, 1992

Abstract:

Agenda, attendees, and transparencies of the GEM Muon Engineering Status Meeting held at the Massachusetts Institute of Technology on July 13, 1992. Agenda items are: Comments; Draper Overview/PAC Deliverables; Selection Criteria/Barrel Structure; CSC in the Barrel; Alignment (Local) Update; Barrel CSC Alignment; Engineering Update at Draper; Efforts at Dubna; and Discussion/Action Items.

AGENDA

GEM MUON ENGINEERING STATUS MEETING

9 JULY 1992

MIT

TIME	SUBJECT	PRESENTER
1:30	COMMENTS	F. TAYLOR
1:40	DRAPER OVERVIEW/PAC DELIVERABLES	H. BAKER
1:45	SELECTION CRITERIA/BARREL STRUCTURE	F. NIMBLETT
2:00	BARREL STRUCTURE/BIG WHEEL	J. POHLEN & J. PIER-AMORY
3:00	BREAK	
3:10	CSC IN THE BARREL	J. PIER-AMORY
3:45	ALIGNMENT (LOCAL) UPDATE	J. PARADISO
4:15	BARREL CSC ALIGNMENT	G. MITSELMAKHER
4:45	ENGINEERING UPDATE AT DRAPER	F. NIMBLETT
5:15	EFFORTS AT DUBNA	I. GOLUTVIN
5:35	DISCUSSION/ACTION ITEMS	ALL
6:00	ADJOURN	

Attendees List
Muon System Eng Meeting
9 July '92 @ MIT

NAME	ORG	Tel#	E-MAIL
Howard Baker	Draper	(617) 258-3411	hbaker@draper.com
Dick Gustavson	Draper	(617) 258-2914	REG2914@DRAPER.com
Jacques Pier-Amory	SSCL	214 708 3266.	—
Rick Sawicki	LLNL	510/423-0963	Rick Sawicki@ENGMAIL.llnl.go
Coleman Johnson	SSCL	(214) 708-1188	JohnCole@SSCVX1
Francis Taylor	MIT	617-253-7249	FET@MITLNS
Igor Golutvin	Dubna/SSCL	(214) 708 3064	IGOLUTVIN@SSCVX1
Laura S. Osborne	MIT	617-253-2396	Osborne@MITLNS
Irwin A. Pless	MIT	617-253-2367	PLESS@MITLNS
Daniel Marlow	Princeton	609-258-4383	PUPHEP::MARLOW
Gena Mitselmakher	SSC	214-708-6001	SSCVX1::MITSELMAKHER
Joe Pohlen	SSC	303 971 9584	SSCVX1::Pohlen
Joe Paradiso	Draper	617-258-2413	[illegible]@draper.com
Jim Kelsey	MIT	617-253-2069	KELSEY@MITLNS
Scott Whitaker	BU	(617) 353-8916	SCOTT@BUTHVC
Mike Gamble	SSC	(505) 665-5949	SSCVX1::GAMBLE
Martin Furey	Draper	(617) 258-4662	MJF4662@DRAPER.com

Frank Taylor/M.I.T.

F. Taylor July 9, 1992

Mechanical Engineering Issues:

(1) Chamber coverage

what to do about 30 degree region?

suggest that we adapt projective geometry in barrel

membrane interference?

gusset interference?

(2) Support structure philosophy

big wheel ?

individual sectors ?

Need a set of criteria to decide

(a) Has to be stable versus sagitta measurement.

(b) Costs, installation, staging, etc.

Decision by September so that we can focus our efforts.

Would like this meeting to discuss item (2).

Update of item (1).

Memo from Mike Harris to Frank Taylor

Superconducting Super Collider Laboratory
2550 Beckleymeade Avenue, Mail Stop 2005
Dallas TX 75237-3946
(214) 708-6325
Fax: (214) 708-6088

Physics Research Division
GEM Project Office

Memorandum

To: Frank Taylor
From: Mike Harris MH
Subject: Muon Facilities
Date: July 8, 1992

I wish to confirm the agreement reached in last Friday's muon meeting where the muon facilities requirements must be fully defined before September, 1992. This may be a difficult task because the chamber technology may not be chosen at that time but, Title 1 of the remaining surface facilities must start the beginning of September.

There are, at the moment, two structure options for supporting the chambers; modular or monolithic. The latter option may be assembled in the magnet assembly building starting April, 1996. The modular option may require additional facilities because of an earlier assembly starting late in 1995. This option also requires a large amount of storage space.

I request that you give these points some consideration and strive to obtain consensus during the next seven weeks which option is preferred by the muon group.

MH/lhb

cc: Howard Baker
Barry Barish
Michael Marx
Frank Nimblett
Joe Pohlen
Tom Prosapio
Gary Sanders

HOWARD BAKER / DRAPER

Status of Draper PAC Deliverables 7/9/92

ITEM	SUB ITEM	STATUS	COMMENT
MUON SYS DESIGN			
	A) DETAILS OF S. STRUCTURE		
	1) 3-DIMEN. DRW'S/MOD W/CHAM.	COMPLETE	INCLUDES BOTH BARREL & END CAP
	B) DETAIL OF JOINT(S)		
	1) 3-DIMEN DRW(S) OF 1 JOINT	COMPLETE	REP JOINT (BARREL) AT OUTER RADIUS
	C) DETAILS OF STRUCTURE ATTACH TO MAG		
	1) LOCAL	COMPLETE	
	2) GLOBAL	COMPLETE	END VIEW-BARREL
	D) DETAILS OF INTERFACE HDWRE-CHAM/SS		
	1) CHAM END W/ALIGN HDWRE	COMPLETE	
	2) CHAMBERS IN STRUCTURE	COMPLETE	
	3) COVERAGE IN THETA AND PHI	COMPLETE	
	4) MODULE INSTALL PROCESS	COMPLETE	BARREL AND END CAP
	E) STRUCTURAL ANALYSIS	COMPLETE	BARREL/ENDCAP
	F) INDIVIDUAL MODULE CONCEPT/BARREL	COMPLETE	
MUON SYS ALIGN/LCL			
	A) PROPOSE ALIGN SCHEME/ANALYSIS	COMPLETE	ON-GOING EFFORT
	B) IDENT. SPACERS FOR MONIT CHAM SPAC.	COMPLETE	ON-GOING EFFORT
	C) DEFINE ALIGN LOS, CLEAR,FIX LOCS, ETC	COMPLETE	ON-GOING EFFORT
COST BOOK UPDATE	REV 11 PRESENTED ON 6/23		

Frank Nimblett/Draper

Frank Nimblett
Draper Laboratory
09 July 1992

Muon MODULE vs The BIG WHEEL Concept

- Module Good Points
  - Concept of build, align, store and install proven at CERN (L3)
  - General concepts of compensation and easily applicable to Module
  - Physical Size is ONLY the size of a mobile home!
  - Access of personnel to portions of the module via simple staging, or suitable lifting devices appears best with a module concept .
  - Opportunity for consistent assembly process with compenstion for structural deformations exists.
  - Verification of alignment is accomlished by rotating module to the final orientation relative to gravity.
  - Potential for learning curve improvements for production seems high.
  - Actual mounting hardware can be used to maximize confidence in the validity of the alignment process. Fixturing appears relatively simple.
  - Use of cosmic rays for verification of operation and alignment also exists if straight-line monitors have adequate range or if adjustments can be easily made to bring them temporarily into range.(horizontal or near horizontal placement of the chambers is a benfit for this operation).
  - Cabling and Plumbing operations seem relatively easy for the module.
  - Option of removing an individual module exists for either barrel or endcap.

- Module Bad Points
  - This concept needs a special building "Muon Assy Building" plus storage space equivalent to the Magnet Assy Bldg. and the Magnet Coil Assy. Bldg.
  - Assembly schedule is currently setup to be finish as the last module is needed for installation to limit the storage capacity needs. Additional off-site storage could solve that problem.
  - Installation time appears very tight for both the barrel and endcap assemblies!
  - Endcap Installation still requires the joining of 16 modules per end into a "space-frame" structure. Unkown procedure to assure endcap alignment, but accessibility to endcap is quite good in comparison to the barrel region.
  - Chamber storage prior to installation is a problem for this system and the BIG WHEEL.

- BIG WHEEL Good Points

  - The ability to build one monolythic support structure for either the barrel or the endcap should maximize coverage of the selected region by minimizing material (no double dipping!)
  - The BIG WHEEL does only need the "Modified Magnet Assy. Building for assembly.
  - Installation time should be shorter than for the module.
  - Coordnation of installation with other subsystems should be easier due to the shorter time required.
  - Simple support system, duplicated prior to installation is a good feature, but doesn't appear better than than that offered by the individual module concept.

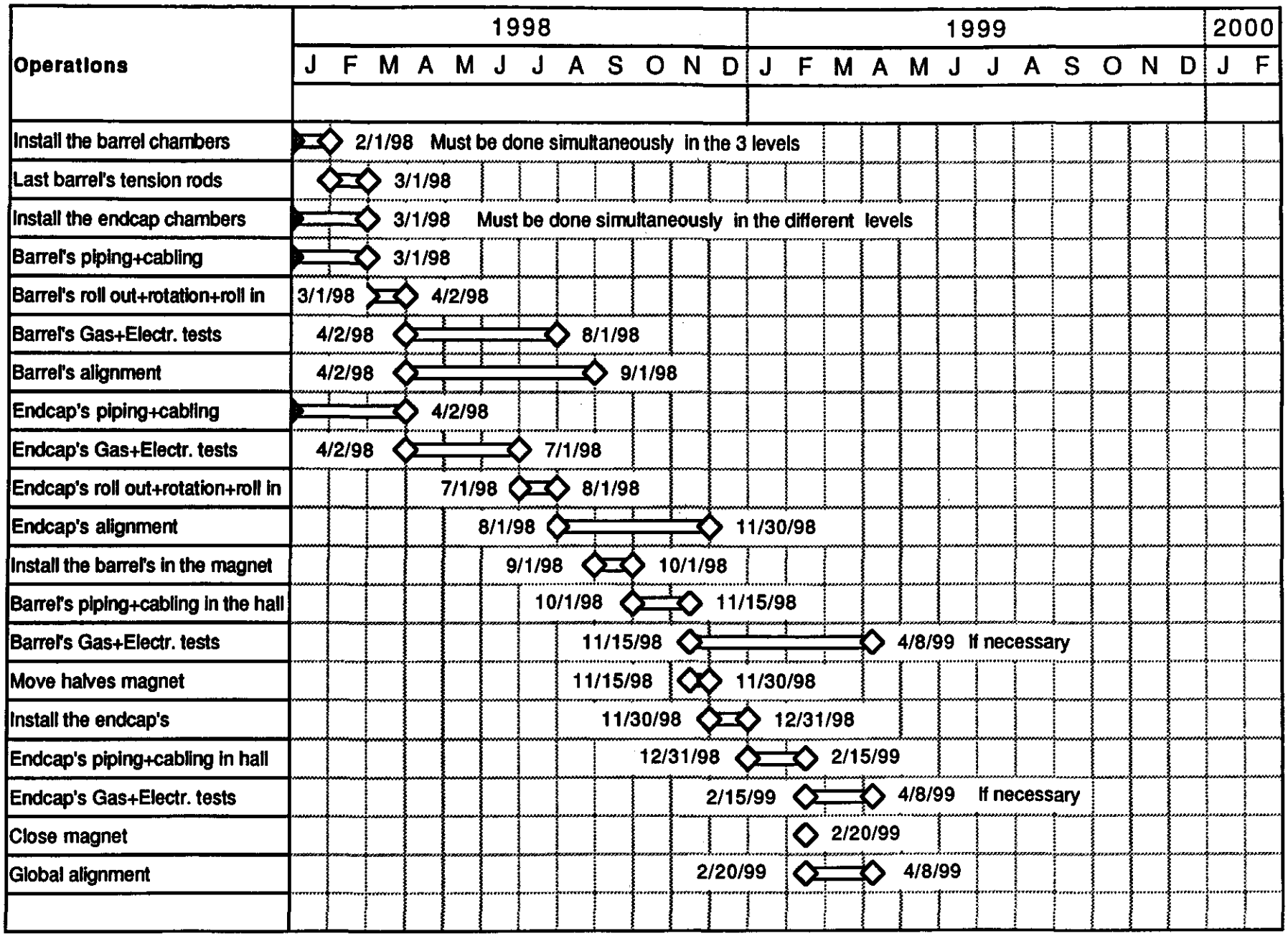
- BIG WHEEL Bad Points

  - The size of this rather delicate asssembly is that of the magnet half for the barrel region.
  - Assembly sequence of vertical installation of chambers following by the rotation of the entire assembly to axis horizontal places additional demands on chamber interface axial restraints.
  - This rotation from vertical to horizontal appears risky and will certainly require some substantial fixturing and places additional demands ont the support structure.
  - The physical act of aligning these chambers in this structure appears very difficult at best. We are talking about something the size of a five story office building.
  - Accessibility to the chambers will be difficult! Remote actuation may be required (actually not a bad idea for
  - Compensation for structural deformations will have no benefit of an assembly learning curve.
  - Verification of alignment using cosmic rays does not appear to be good option for the side mounted chambers.
  - Point Loading characteristics for the BIG WHEEL could be nearly an order of magnitude higher than for an individual module.
  - The risk to alignment or damage while moving and then lowering this large and delicate structure into the underground hall and placing onto the temporary support tube appears higher than for the module.It is done only once however!
  - Option of removing an individual module does not exist.
  - What are the real cost savings for not having Muon Assy Bldg. but having to make substantial alterations of the Magnet Assy Bldg?

Joe Pohlen/SSCL
Jacque Pier-Amory/SSCL

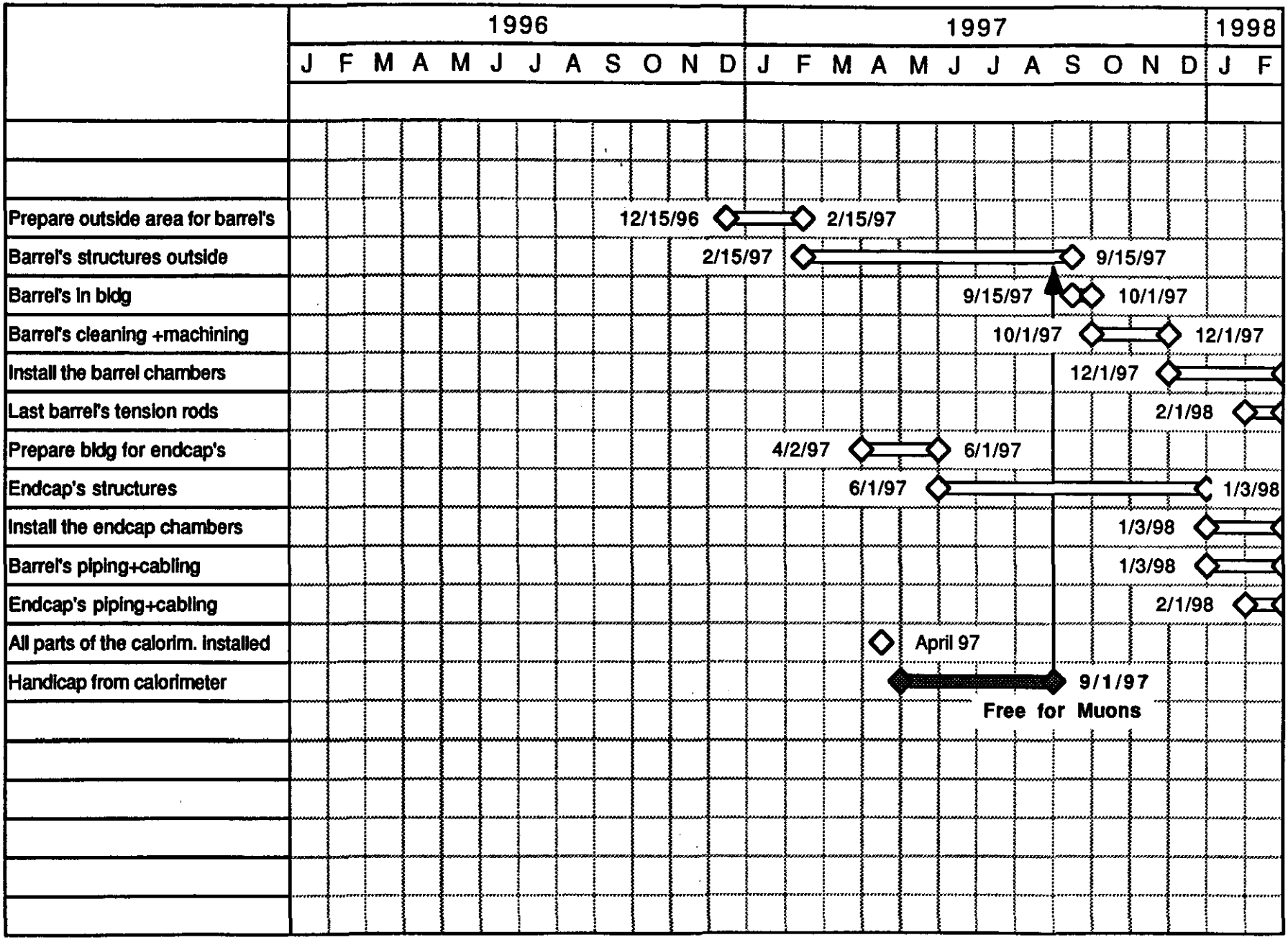
BIG WHEELS SCHEDULE

PRD/JPA



BIG WHEELS SCHEDULE

PRD/JPA



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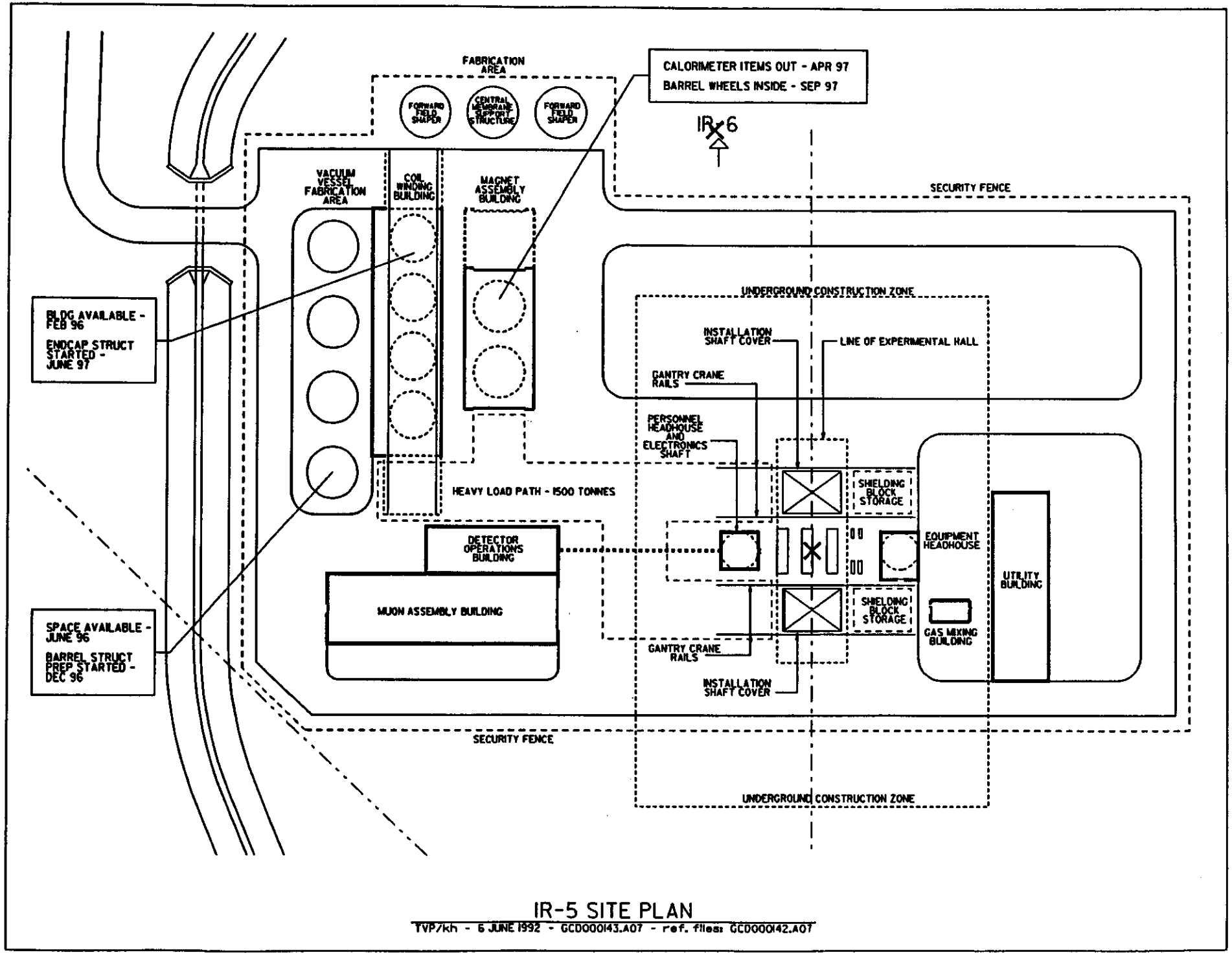
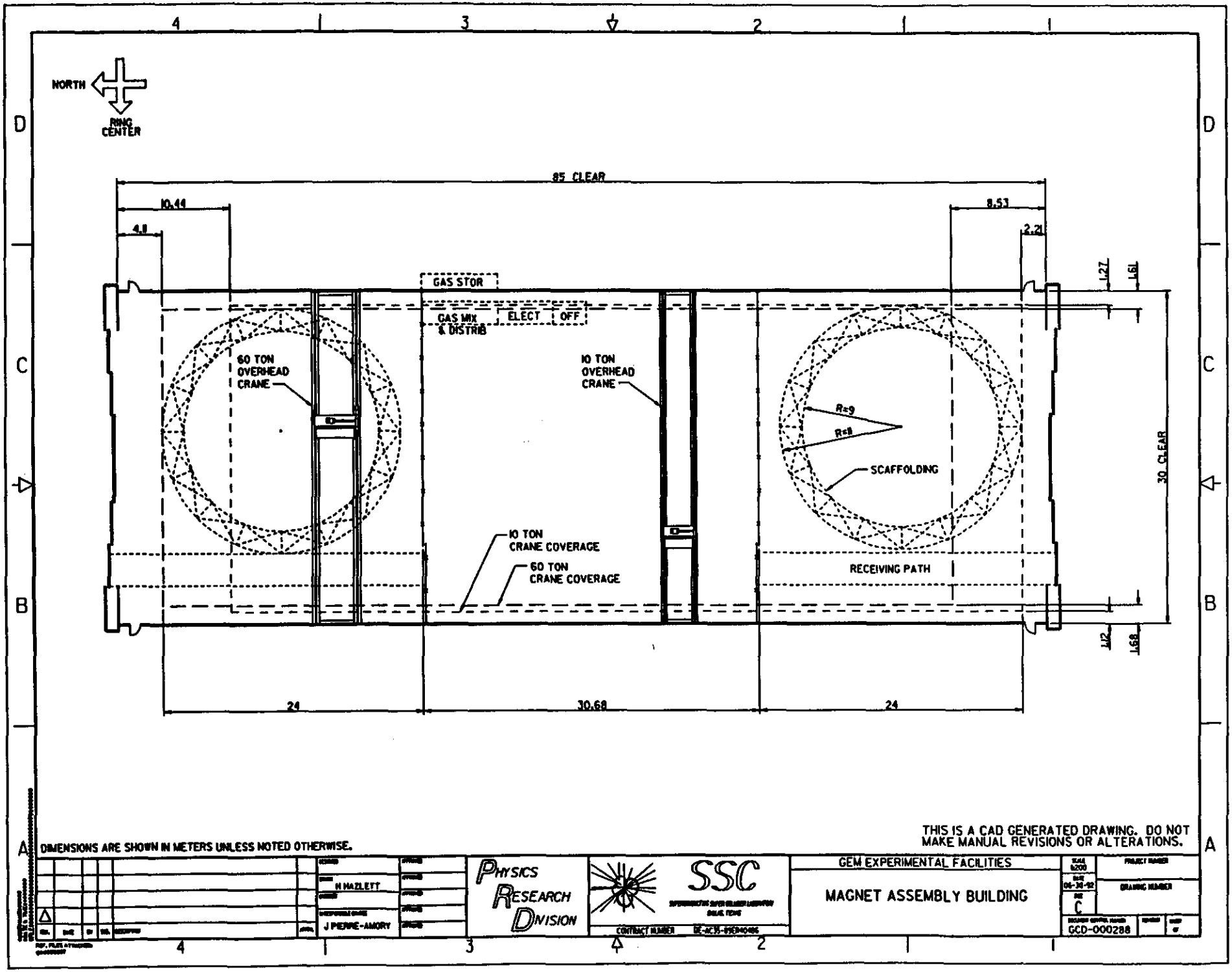


IR-5 SITE PLAN

TVP/kh - 6 JUNE 1992 - GCD000143.A07 - ref. files: GCD000142.A07


NORTH
RING CENTER
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GAS STOR
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60 TON OVERHEAD CRANE
10 TON OVERHEAD CRANE
R=9
R=11
SCAFFOLDING
10 TON CRANE COVERAGE
60 TON CRANE COVERAGE
RECEIVING PATH
1.27
1.61
30 CLEAR
1.12
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24
DIMENSIONS ARE SHOWN IN METERS UNLESS NOTED OTHERWISE.
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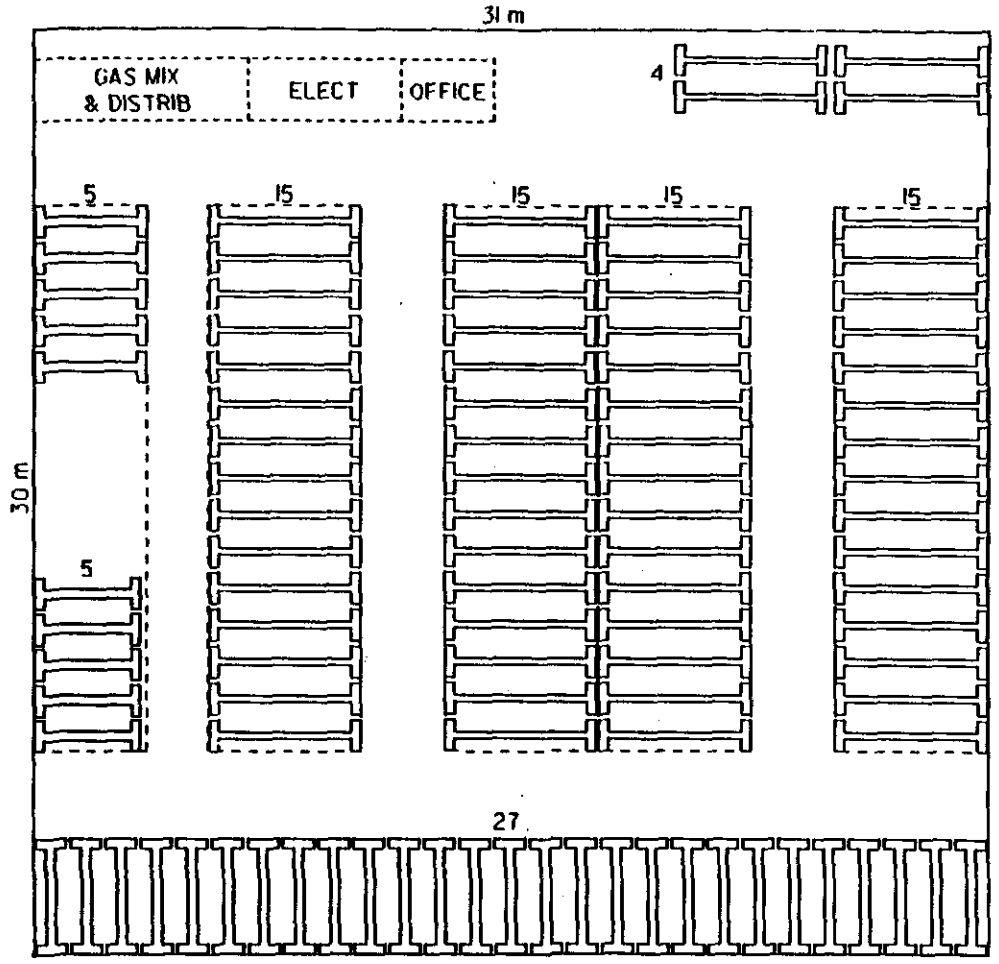
H HAZLETT
J PIERRE-AMORY
PHYSICS RESEARCH DIVISION
SSC
CONTRACT NUMBER
GEM EXPERIMENTAL FACILITIES
MAGNET ASSEMBLY BUILDING
06-30-92
C
GCD-000288

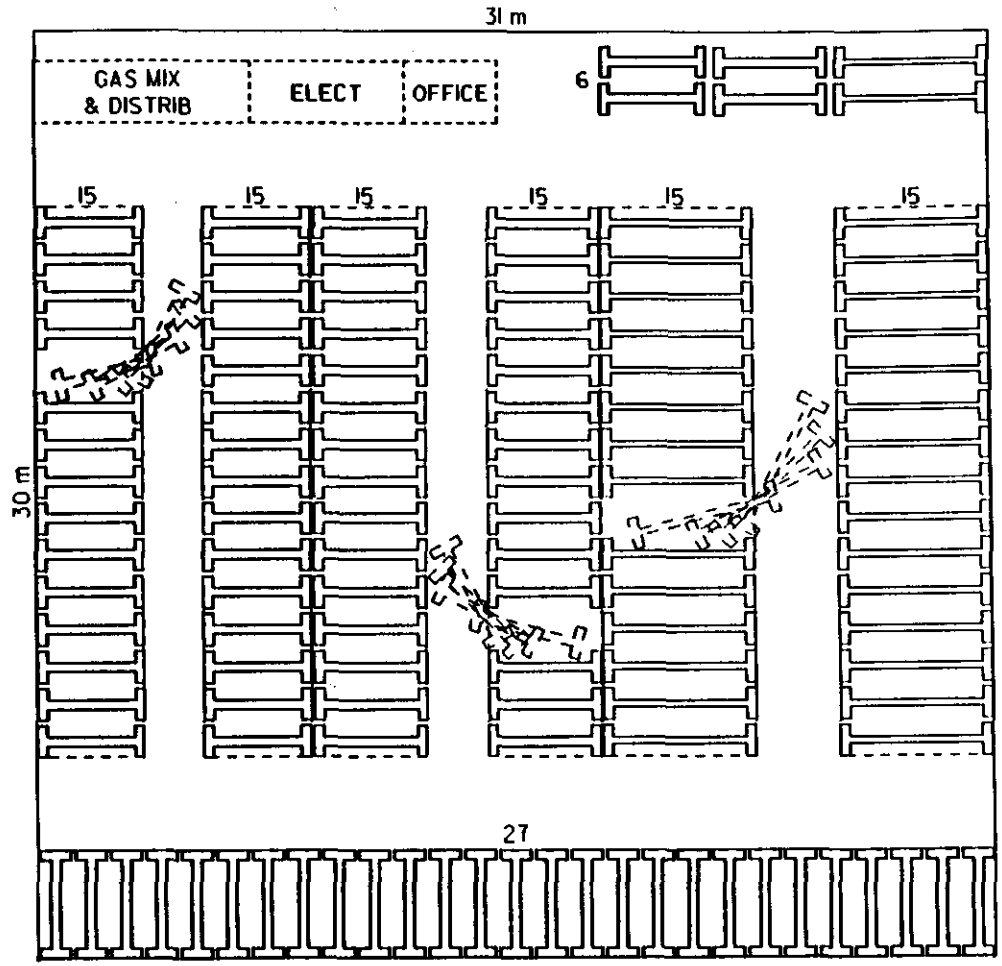


MAGNET ASSEMBLY BUILDING

CENTRAL AREA

BARREL CHAMBERS, GAS & ELECTRONIC TESTS

5	OF	64	SMALL CHAMBERS
32	OF	64	MEDIUM CHAMBERS
64	OF	96	LARGE CHAMBERS
101			REMAINING CHAMBERS

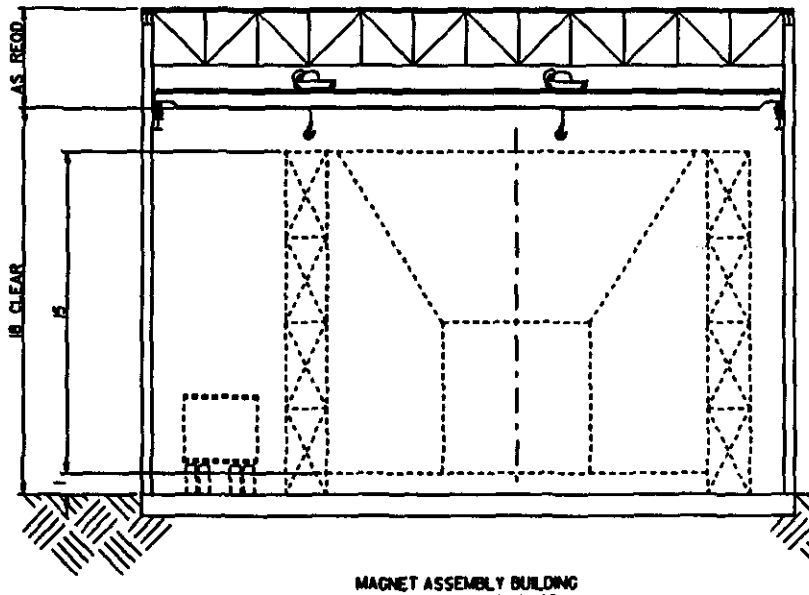


MAGNET ASSEMBLY BUILDING

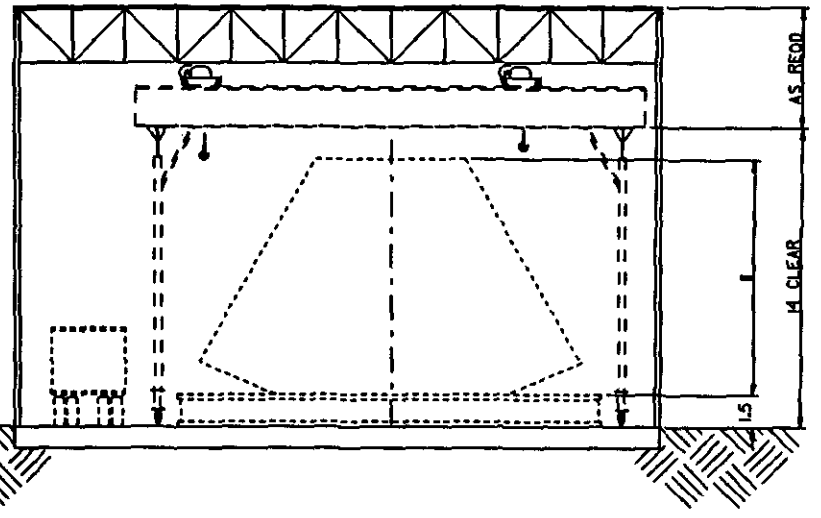
CENTRAL AREA

BARREL CHAMBERS, GAS & ELECTRONIC TESTS

59	OF	64	SMALL CHAMBERS	(92%)
32	OF	64	MEDIUM CHAMBERS	(50%)
32	OF	96	LARGE CHAMBERS	(33%)
123	OF	224	TOTAL CHAMBERS	(55%)



MAGNET ASSEMBLY BUILDING
(18 m CLEAR HEIGHT FOR
VERTICAL MAGNET ASSEMBLY)



COIL WINDING BUILDING

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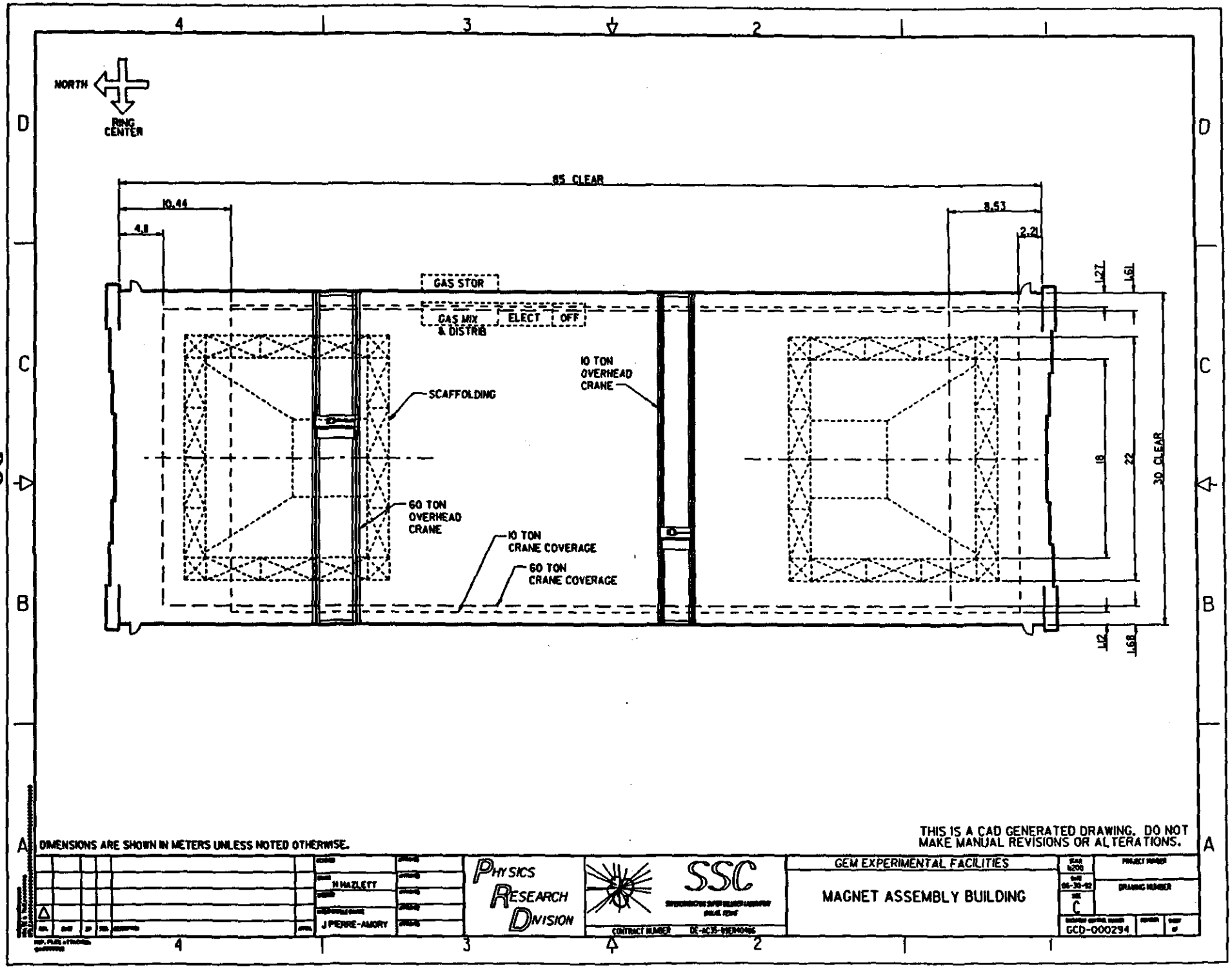
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MAGNET ASSEMBLY BUILDING
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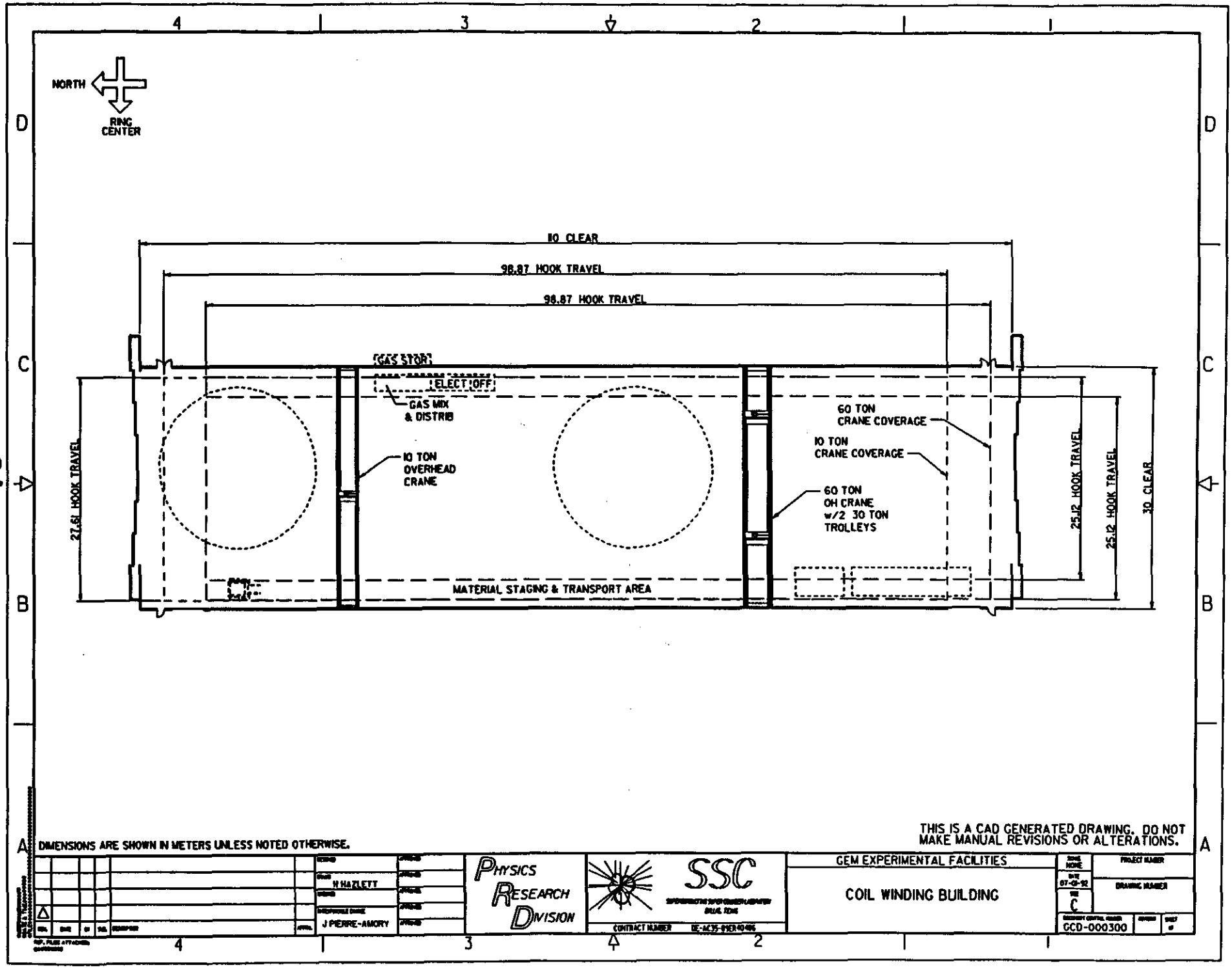
NORTH
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110 CLEAR
98.87 HOOK TRAVEL
98.87 HOOK TRAVEL
GAS STOR
ELECT OFF
GAS MIX & DISTRIB
10 TON OVERHEAD CRANE
60 TON CRANE COVERAGE
10 TON CRANE COVERAGE
60 TON OH CRANE w/2 30 TON TROLLEYS
27.61 HOOK TRAVEL
25.12 HOOK TRAVEL
25.12 HOOK TRAVEL
30 CLEAR
MATERIAL STAGING & TRANSPORT AREA
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SSC
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GEM EXPERIMENTAL FACILITIES
COIL WINDING BUILDING
NONE
07-01-92
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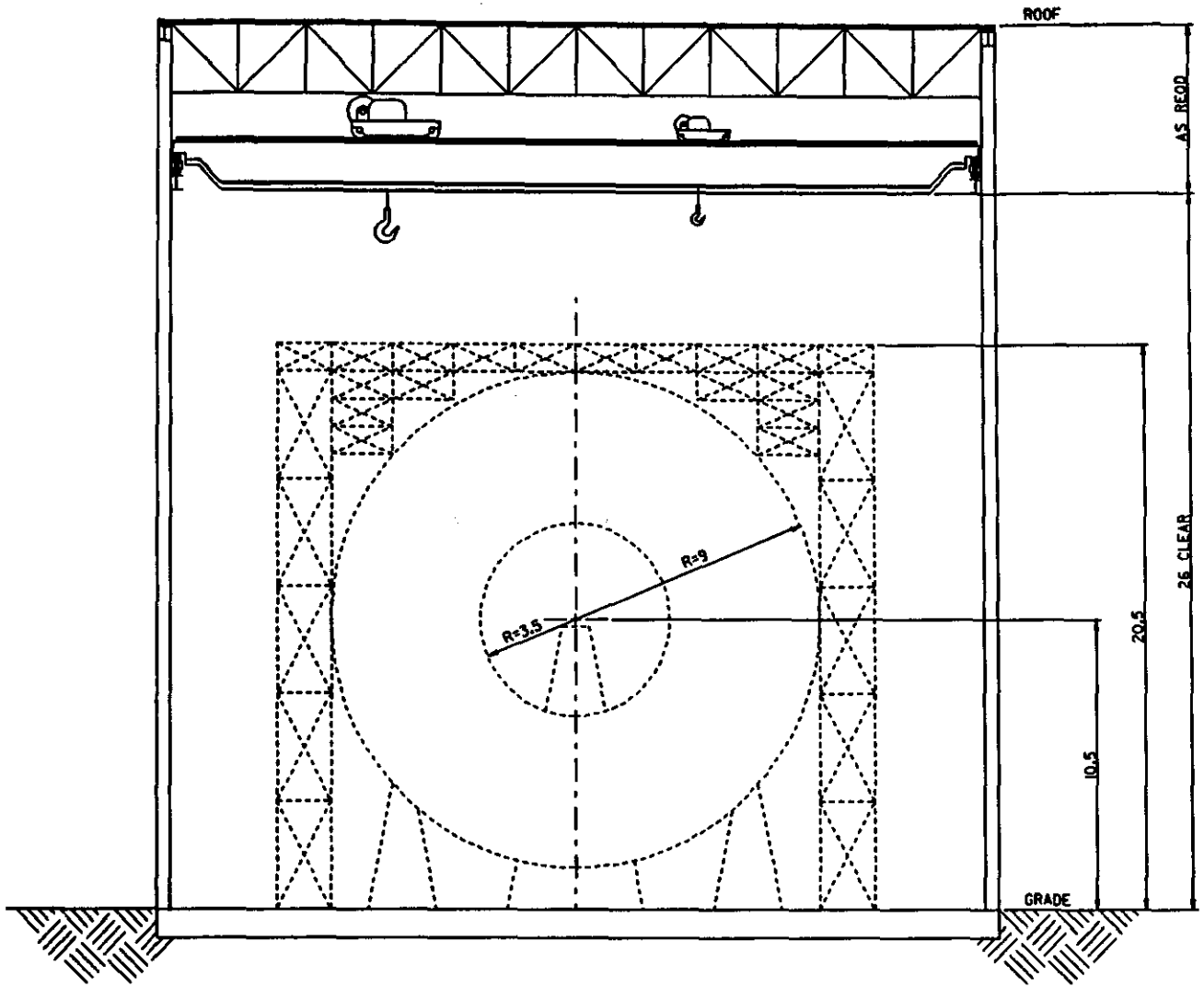
PROJECT NUMBER
DRAWING NUMBER



MAGNET ASSEMBLY BUILDING
(26 m CLEAR HEIGHT FOR
HORIZONTAL MAGNET ASSEMBLY)

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J PIERRE-AMORY		CONTRACT NUMBER	MAGNET ASSEMBLY BUILDING SECTION
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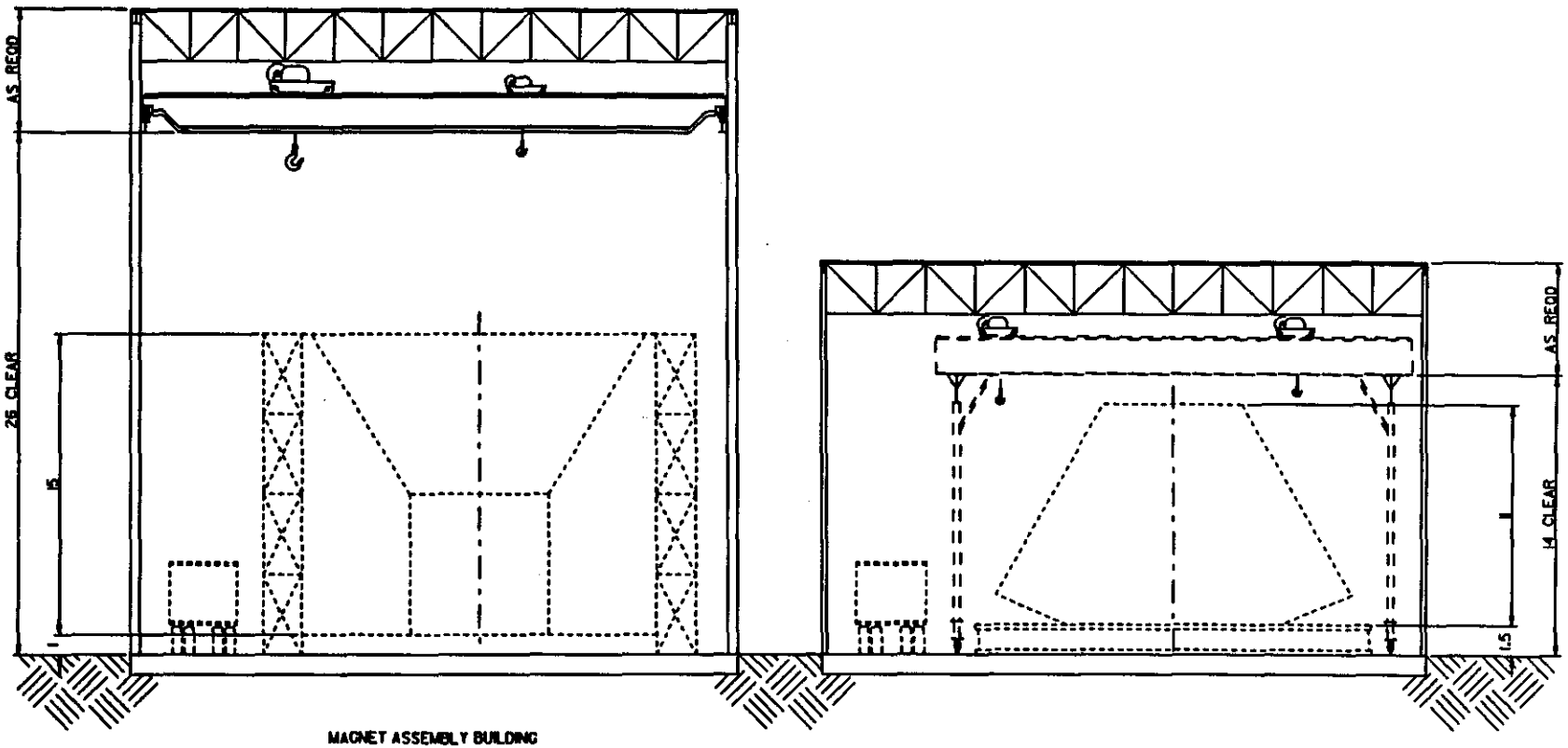

MAGNET ASSEMBLY BUILDING
(26 m CLEAR HEIGHT FOR
HORIZONTAL MAGNET ASSEMBLY)

COIL WINDING BUILDING

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J PIERRE-AMORY		CONTRACT NUMBER DE-AC35-89ER40486	MAGNET ASSEMBLY & COIL WINDING BUILDINGS SECTION
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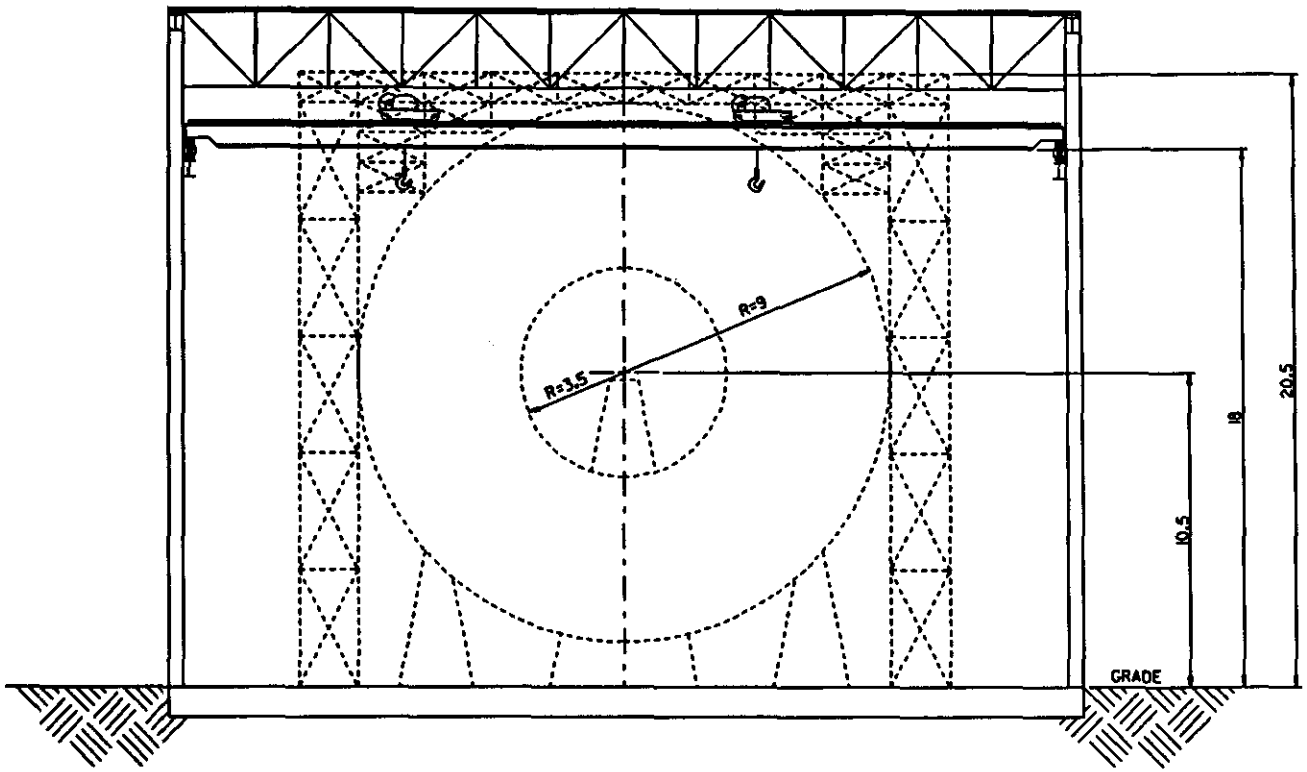

MAGNET ASSEMBLY BUILDING
(18 m CLEAR HEIGHT FOR
VERTICAL MAGNET ASSEMBLY
NOT ADEQUATE FOR
BARREL WHEEL)

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N HAZLETT	PHYSICS RESEARCH DIVISION	SSC	GEM EXPERIMENTAL FACILITIES
J PIERRE-AMORY		CONTRACT NUMBER	MAGNET ASSEMBLY BUILDING SECTION
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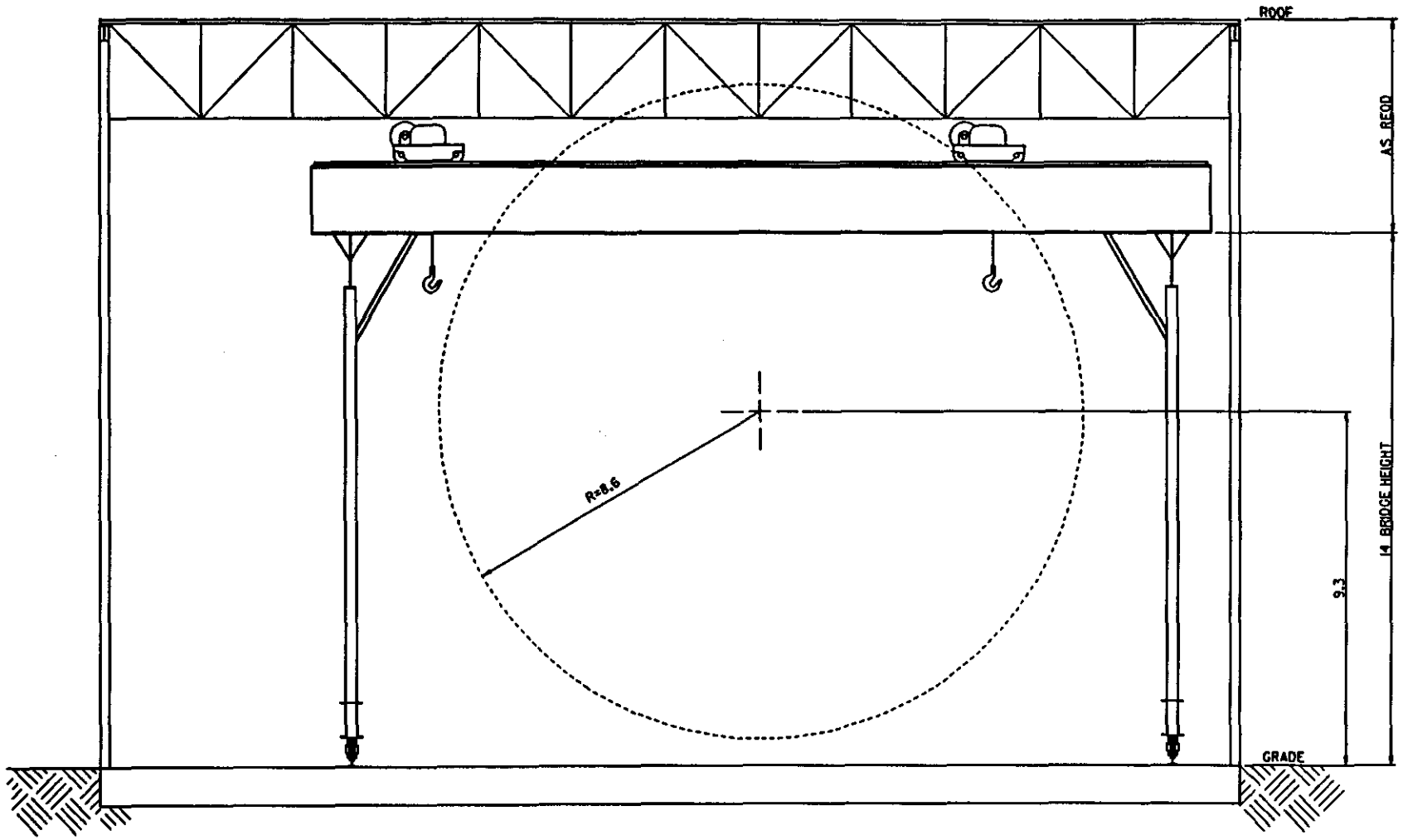

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J PIERRE-AMORY		CONTRACT NUMBER DE-AC35-89ER40486	COIL WINDING BUILDING SECTION
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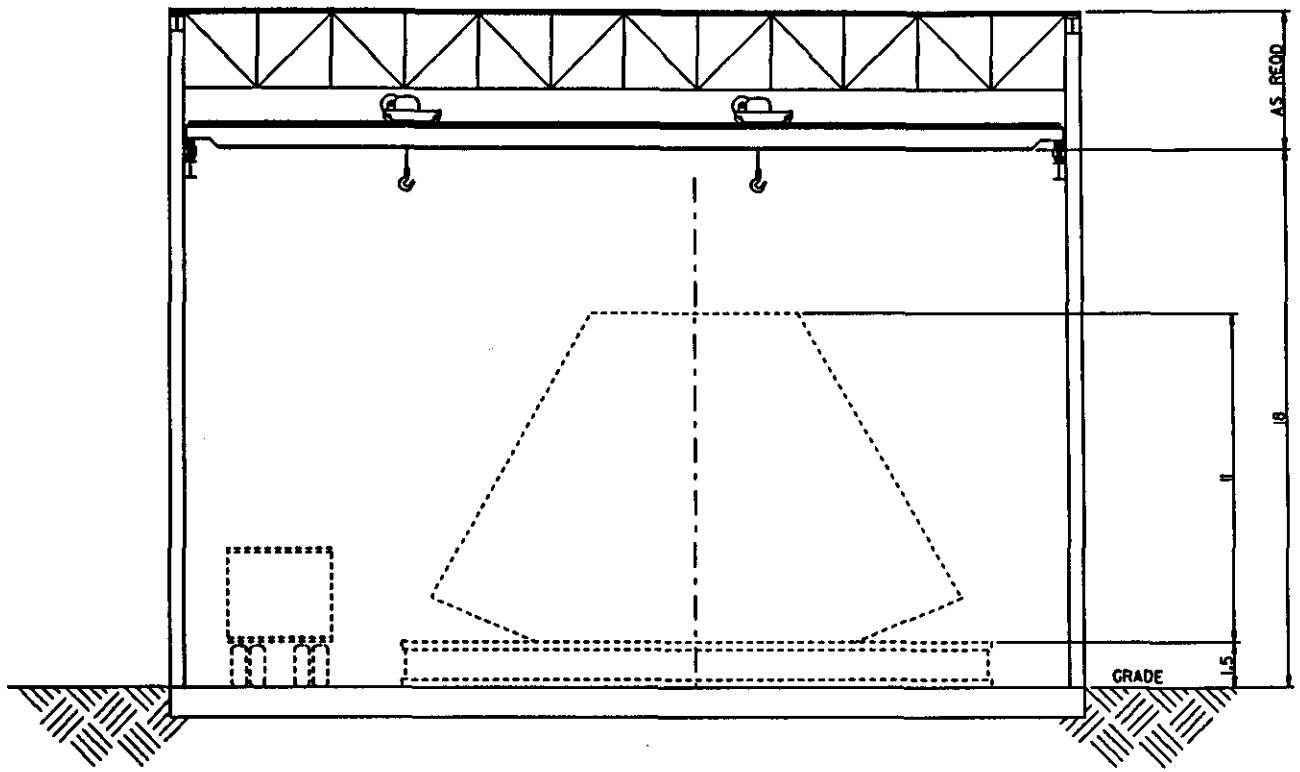

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DRAWN	H HAZLETT
RESPONSIBLE ENGR	J PIERRE-AMORY

PHYSICS RESEARCH DIVISION

SSC

CONTRACT NUMBER DE-AC35-89ER40486

GEM EXPERIMENTAL FACILITIES

MAGNET ASSEMBLY BUILDING

SECTION

SCALE NONE	PROJECT NUMBER
DATE 07-01-92	DRAWING NUMBER
SIZE C	
GCD-000302	

Big wheel structures - Manpower costs

Preparation of the outside ground	For Barrel structures only - On the vacuum vessel fabrication areas - 1 month - 2 teams of 10 men
Barrel wheel structures - Inner wheel Middle wheel Outer wheel	On the vacuum vessel fabrication areas - 7 months - 2 teams of 10 men
Preparation of the coil assy bldg	2 months - 1 team of 8 men
Endcap structures	Inside the coill assy bldg - 7 months - 2 teams of 10 men
Preparation of the Magnet assy bldg	1 month - 1 team of 8 men
Barrel wheel 1 structure inside Barrel wheel 2 structure inside	Inside the magnet assy bldg - 0.5 month 1 team 10 men - No idea about the rental cost for a trailer of 210 t capacity
Barrel structure 1 and 2 Cleaning	1 month - 2 teams of 5 men - Preparation to machine
Machining - Adjustment	1.5 month - 2 teams - 10 men - Here we are speaking about the barrel chamber fixations
Barrel wheel 1 and 2 Last tension rods	1.5 month - 2 teams of 5 men - To re-inforce the barrel wheels after the middle chambers installation

Total Manpower effort for 2 barrel + 2 endcap wheels : 384 + 10% for security = 422 Men/months **$ 3 376 000**

Big wheel structures - Material cost estimation

Weight of a barrel structure empty
In light alloy **19 t** **$ 380 000**
In stainless steel

Weight of a Endcap structure empty
In light alloy **9 t** **$ 180 000**
In stainless steel

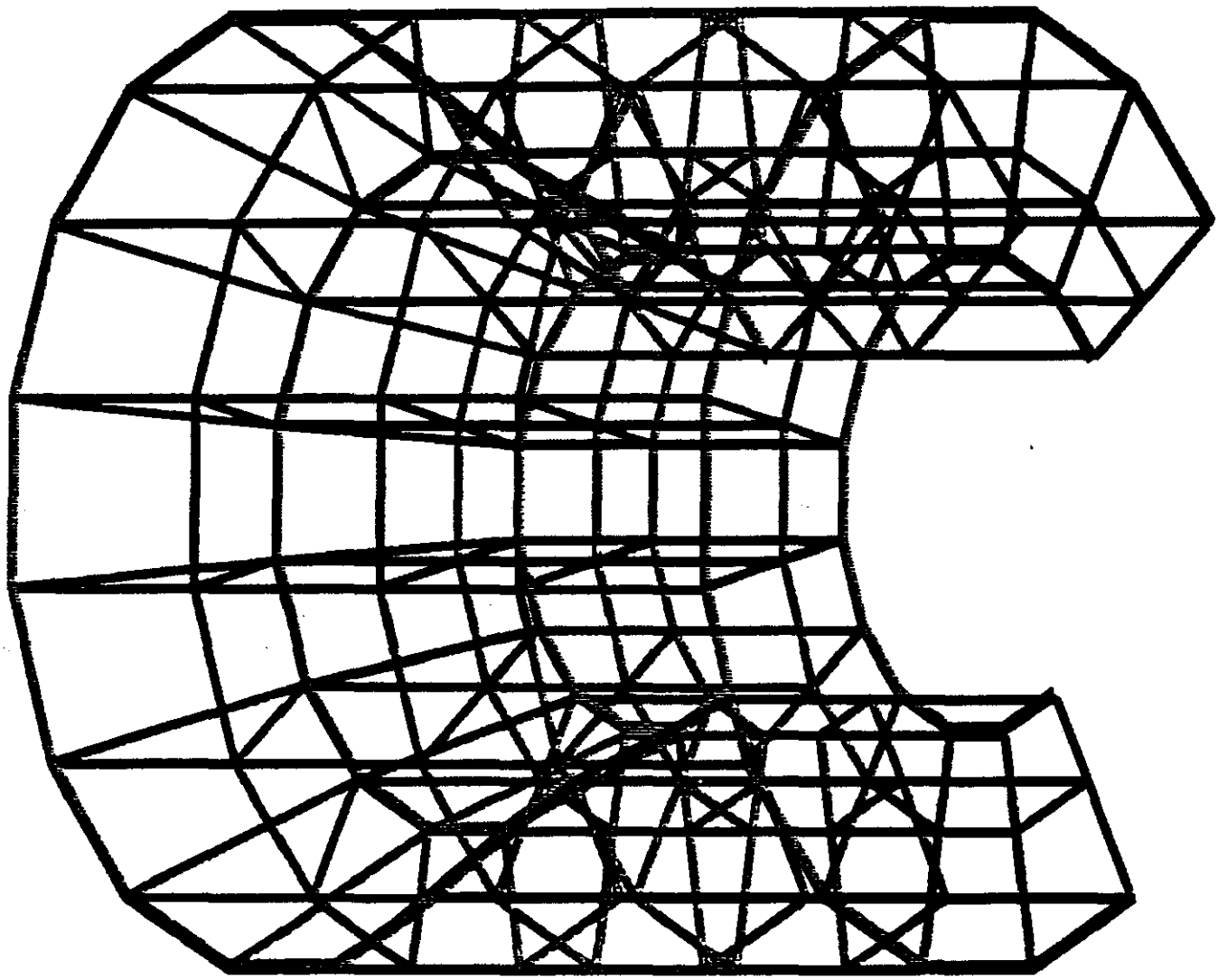
Big wheel structures - Fabrication costs

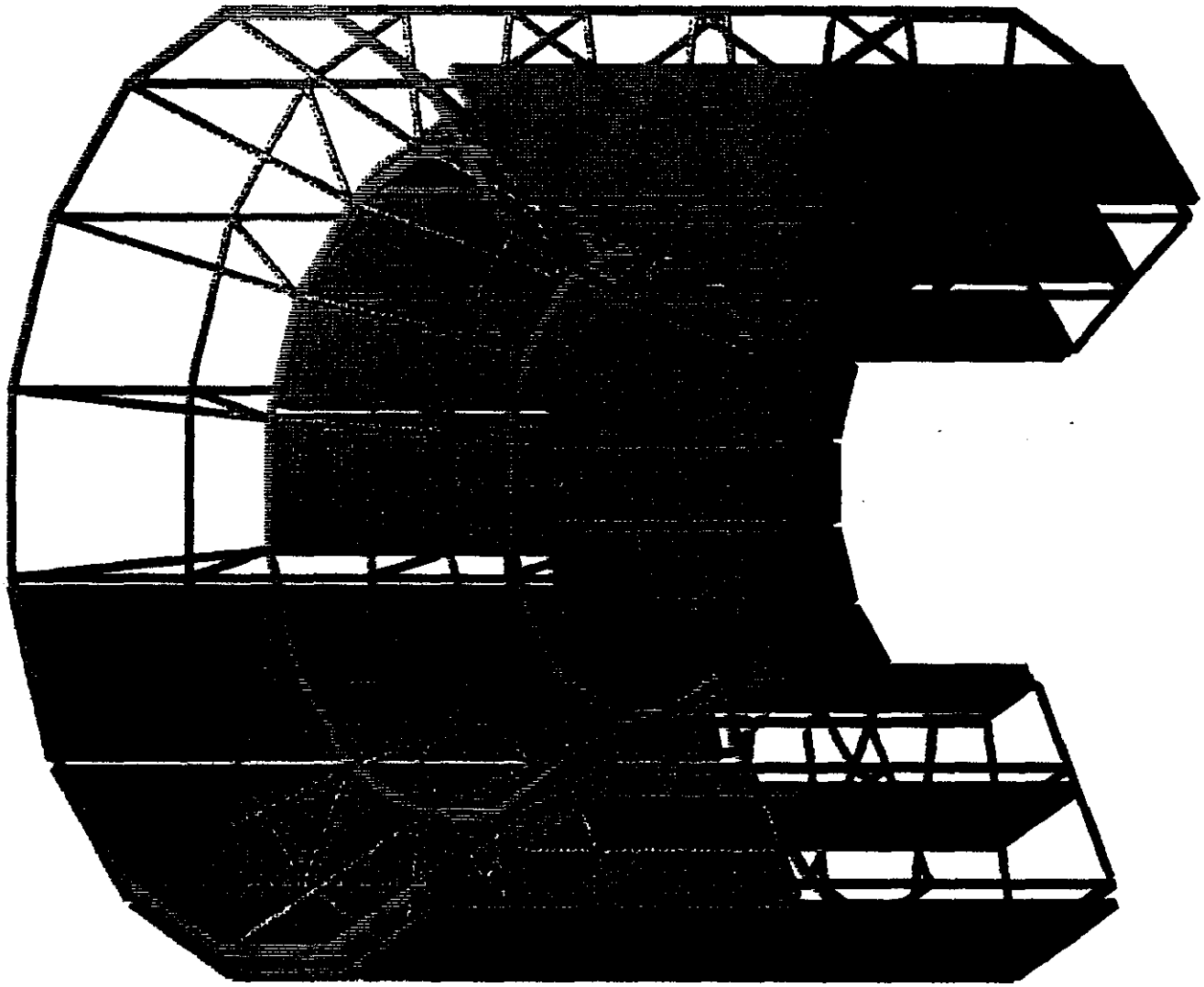
775joints per barrel structure	**$ 465 000**
388 joints per endcap structure	**$ 232 800**
Security 20% of the estimated costs	**$ 926 200**
TOTAL	**$ 5 560 000**

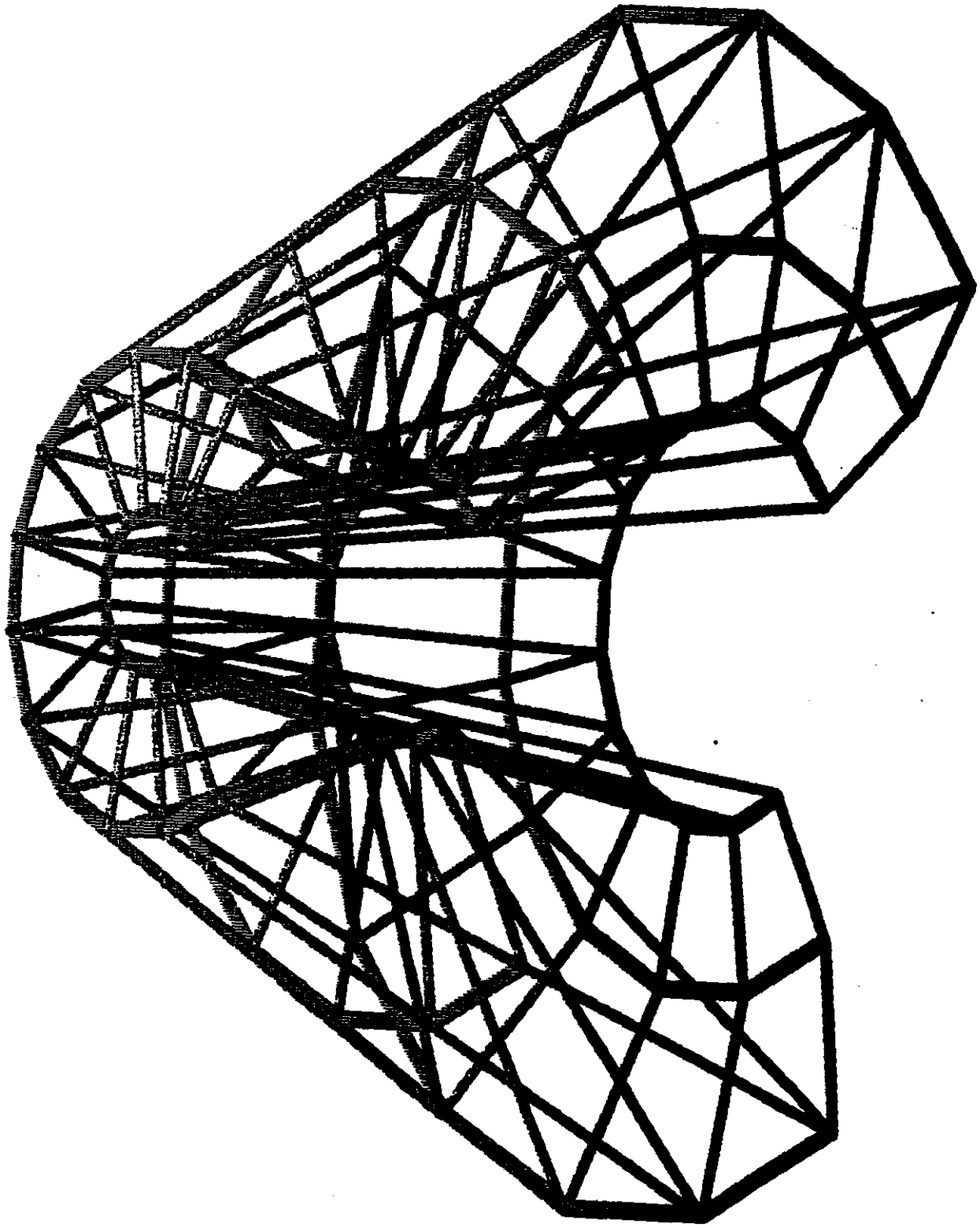
NOTE

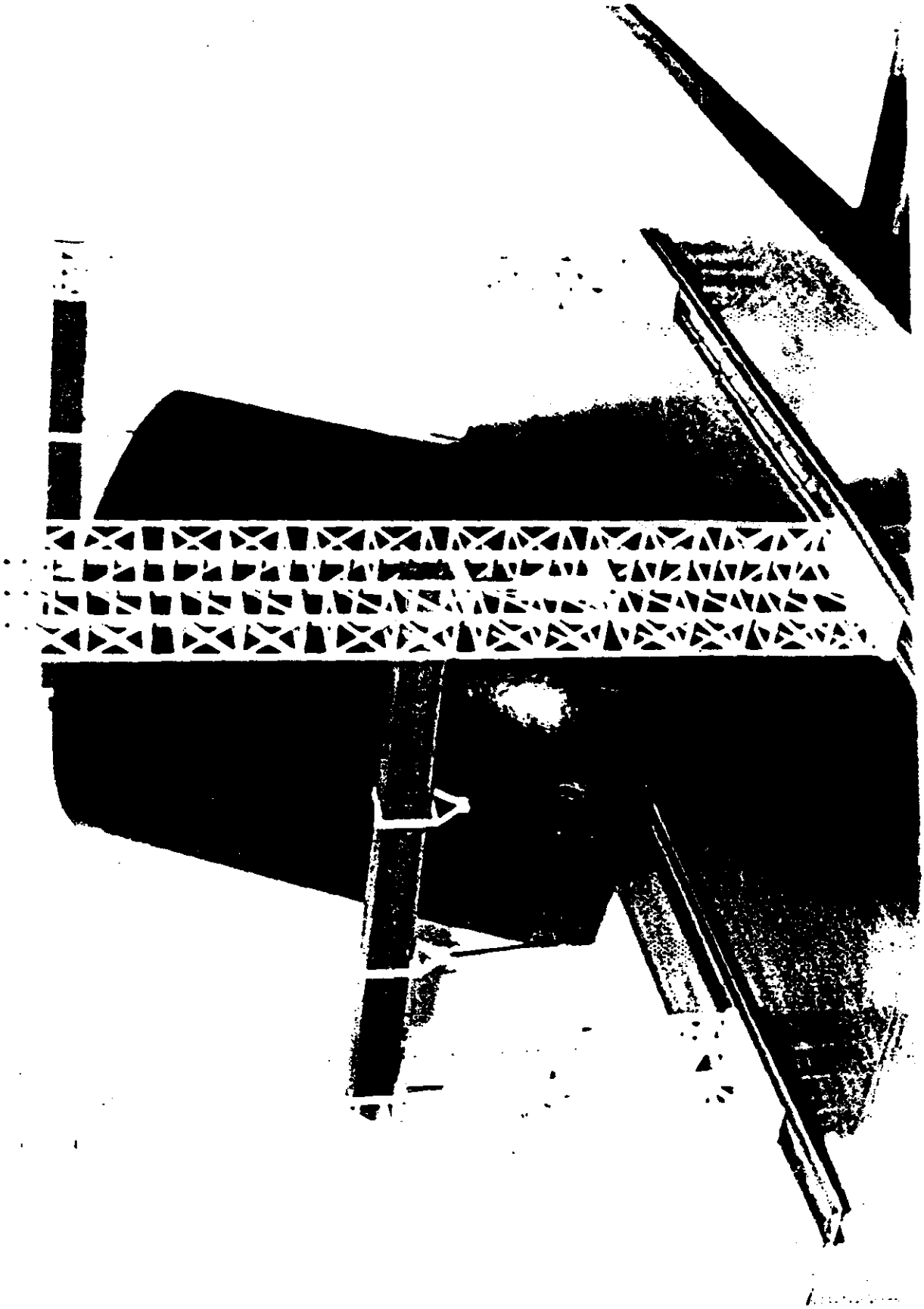
1 - This cost estimation does not included:
- Cost to install the chambers and feet to fix them on the structures
- All the components for handling (Lifting beams+Rotation devices+Special lifting jacks+ etc)
- The rental of scaffoldings+heavy trailers+eventually a tower crane

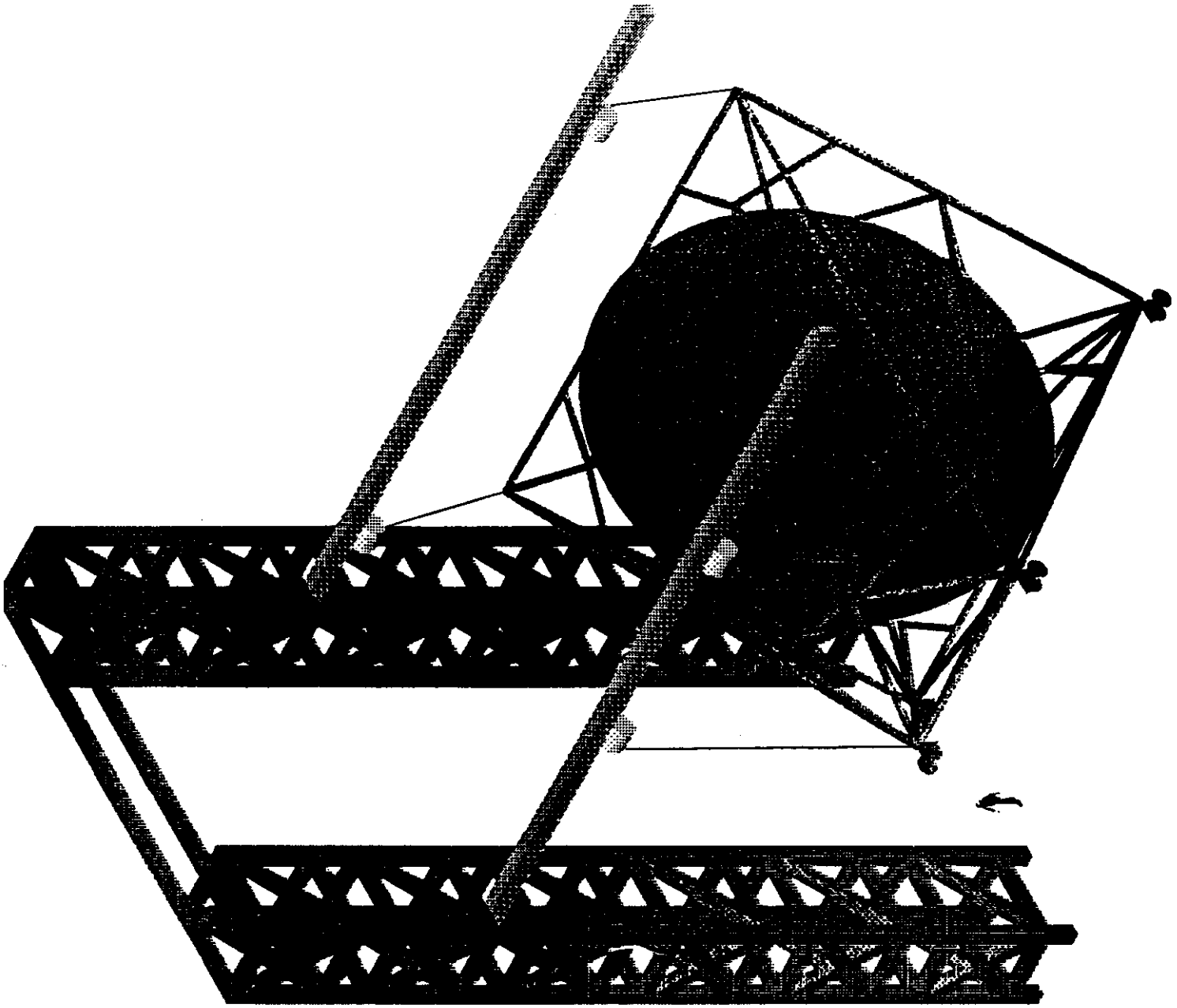
PRD/JPA
6.24.92

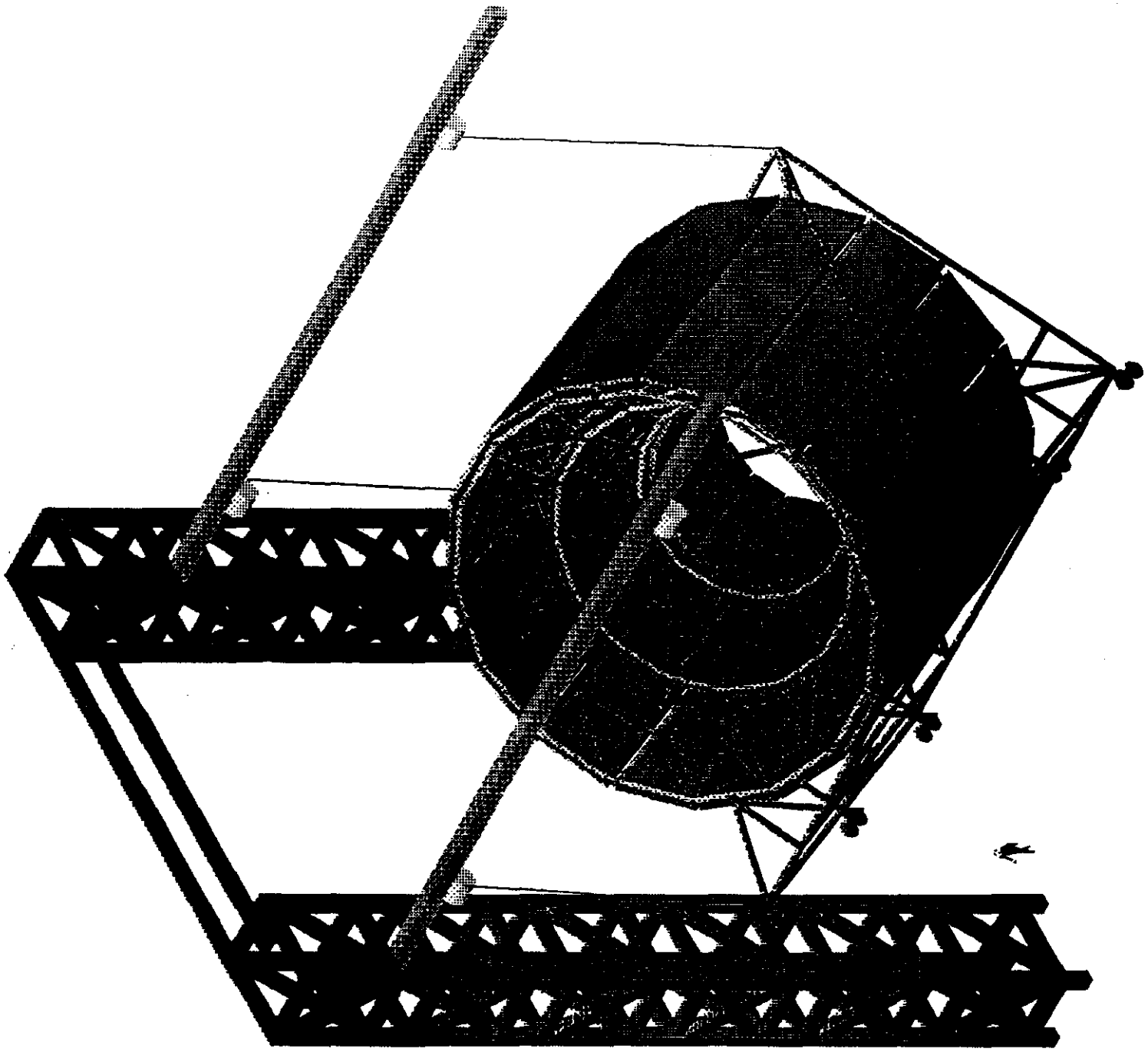




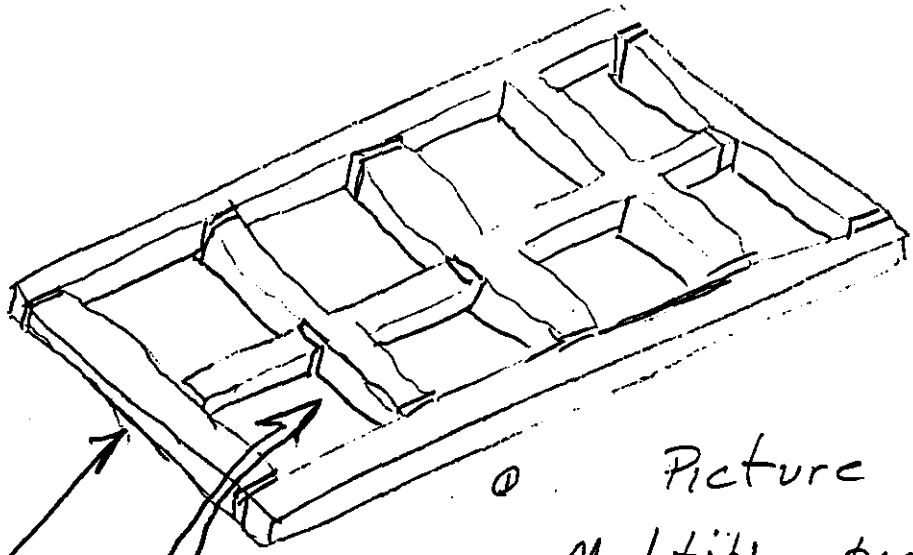








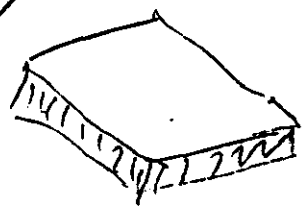
Honey Comb Panel Construction



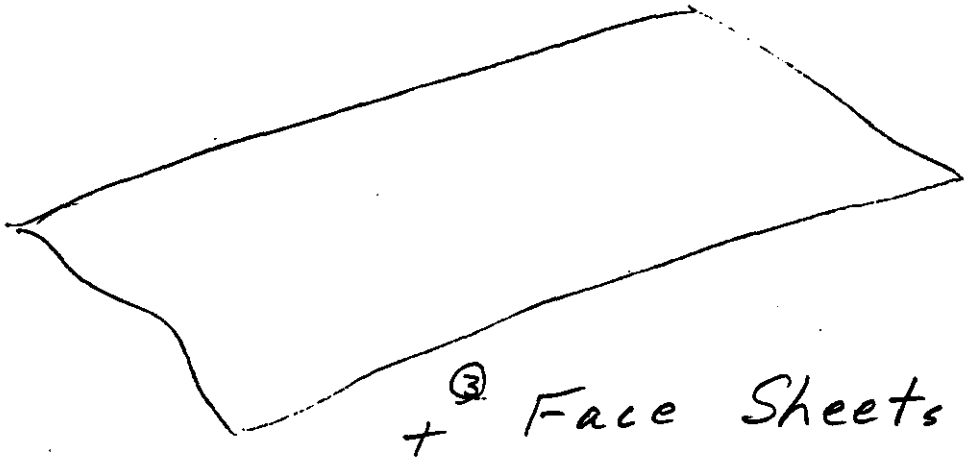
$t \leq 20$ mm

can have a 10° or 11.25° "kink" at this point

① Picture frame
Multiple pieces
- Edges precise
- thicknesses exact

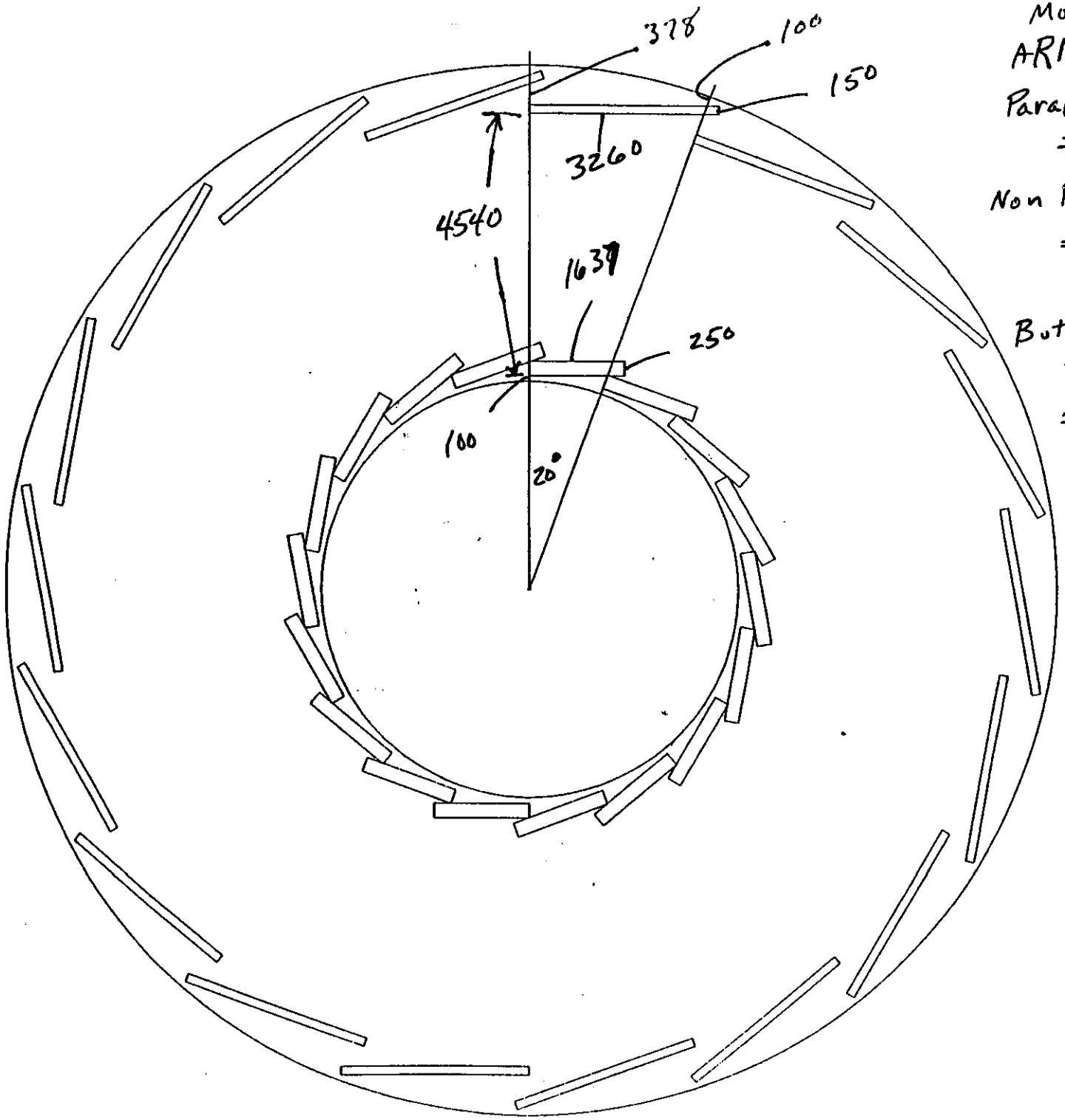


+ ② Honey Comb "call plates"
exact thickness

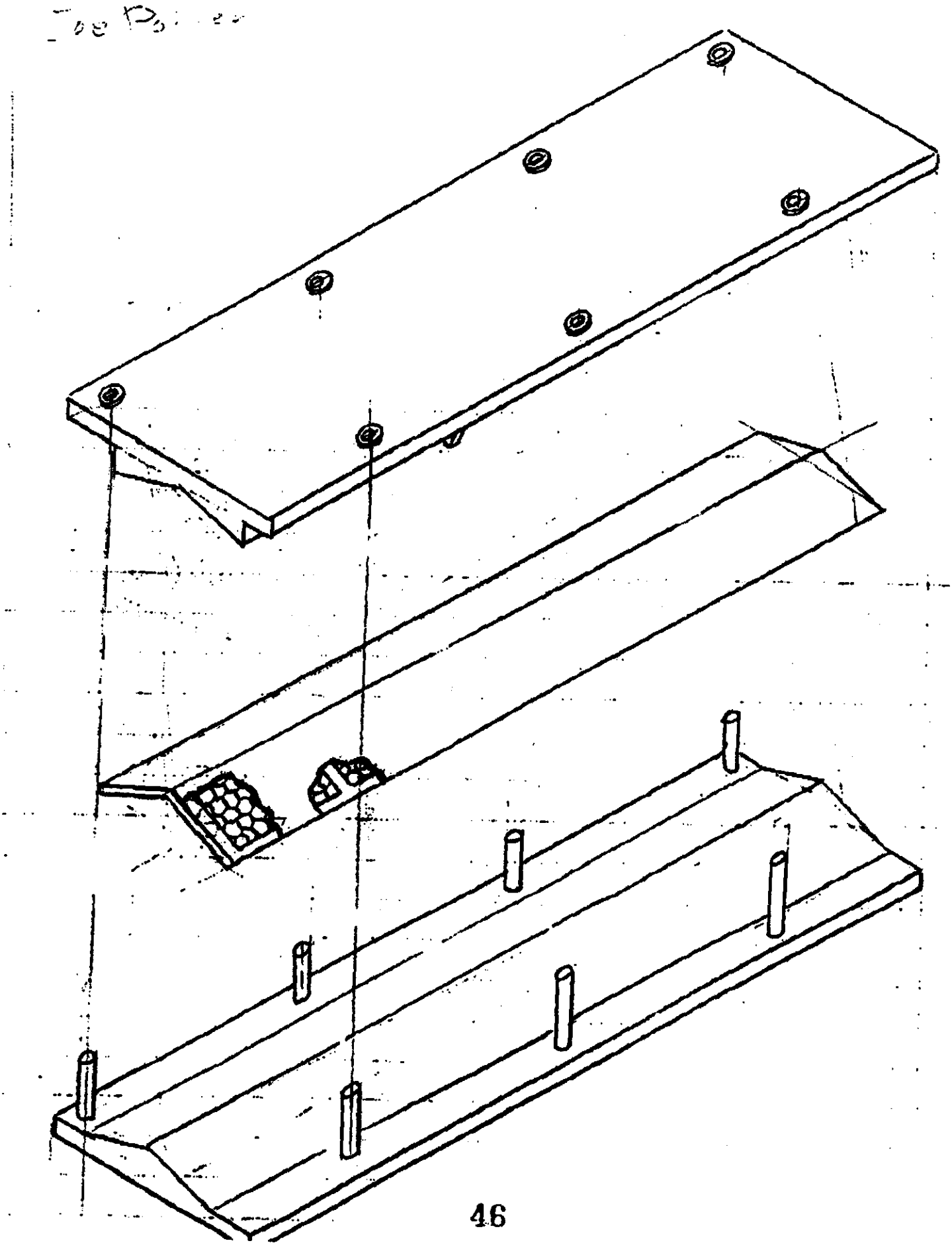


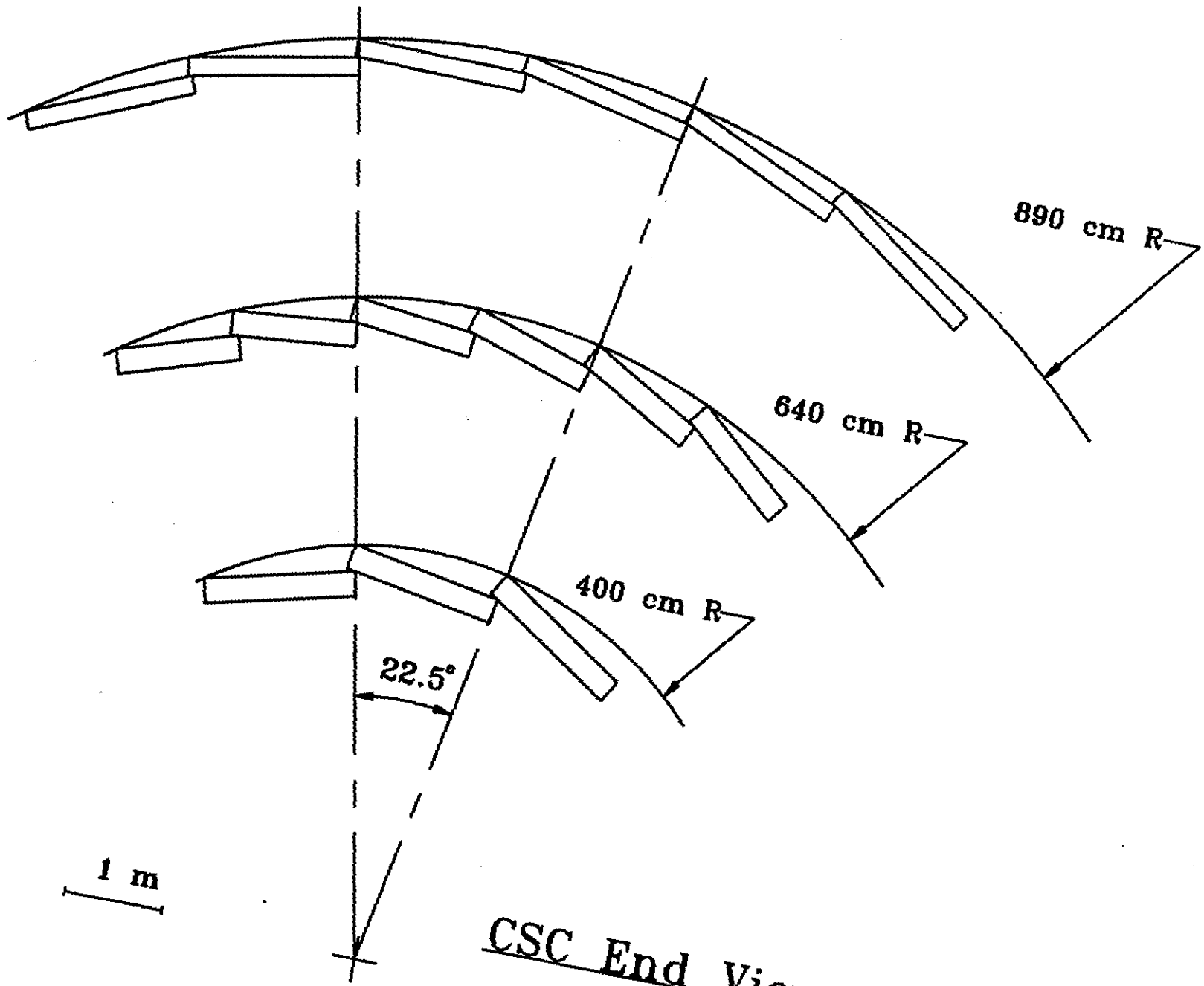
+ ③ Face Sheets
(could include "cathode" Strip G 10 Boards at this time or next Step)

④ Bag & Autoclave

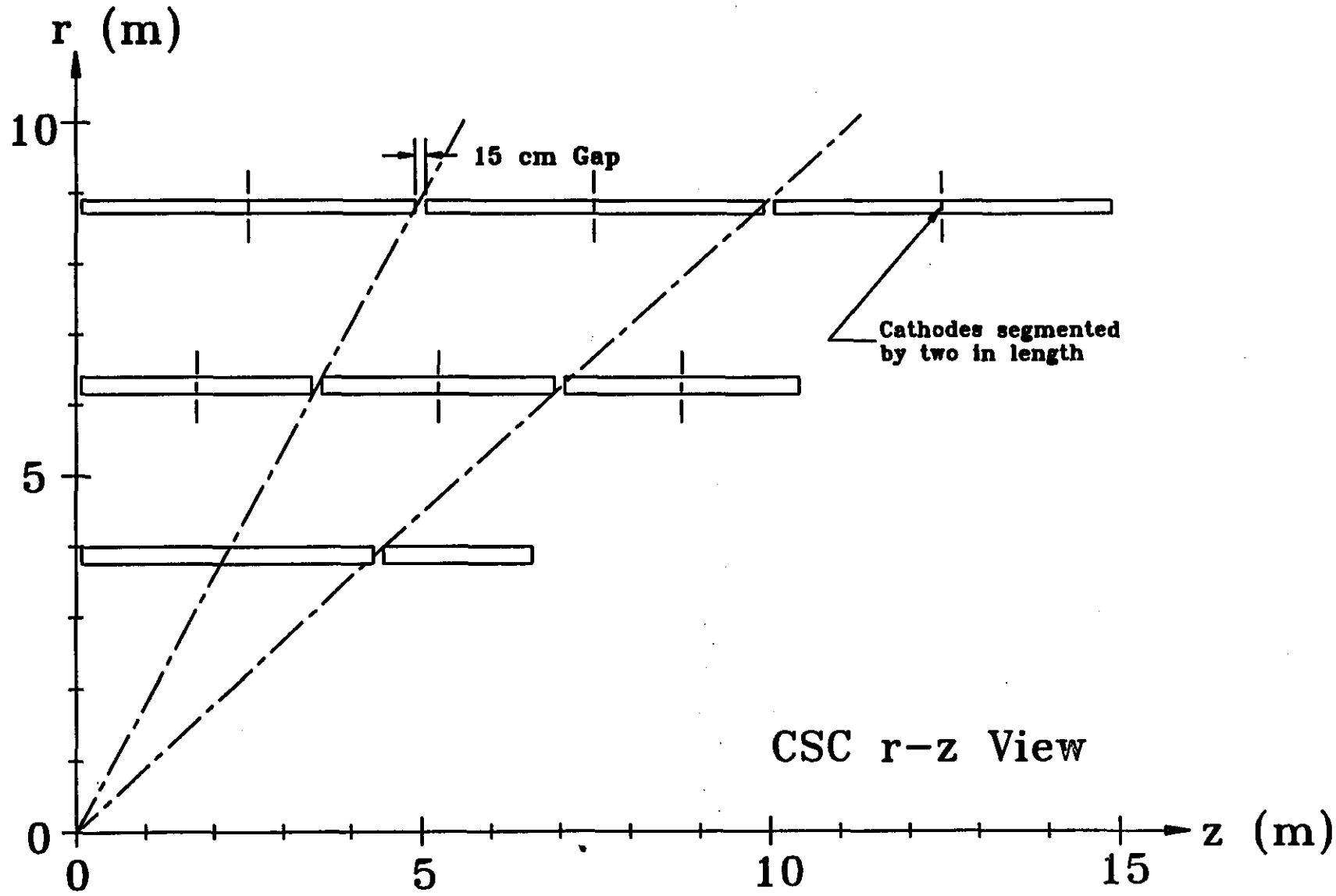


Moment
ARM
Parallel & overlap
= 4540
Non Parallel & overlap
= 4918
or + 8.3%
Butt & Parallel
No overlap
= 5068 or
+ 11.6%





CSC End View


r (m)
10
5
0
15 cm Gap
Cathodes segmented
by two in length
CSC r-z View
0
5
10
15
z (m)

Joe Paradiso/Draper

Alignment Cameos & Endeavors

- J. Paradiso 7/9/92

- Baseline/status committed to paper: "Some Alignment Concepts for the GEM Muon Array", GEM-TN-92-124
- Requirements documents drafted: "Alignment Requirements for the GEM Muon Detector", GEM-TN-92-125, and "Alignment Requirements to Muon System" (Mitselmakher & Zhukov) GEM-TN-92-120

  → Discussion has clarified discrepancies...
- Analysis of baseline alignment scheme in progress...
- New photodetectors under investigation...

Muon Alignment Factors

Intrinsic Smears

- Vertex distribution along z ← *$\sigma = 7$ cm*
- Multiple scattering in calorimeter ← *50 GeV (Trigger)*, *500 GeV (Measurement)*

Needed Structural Accuracy

- Dynamic range of local alignment system ← *±1 mm assumed...*
- Alignment of trigger roads ← *1° road (barrel)*, *0.5° road (endcap)*, *Also projective in z*

Precision Measurements

- Stated momentum precision in bending plane ← *25 μm driver*
- Align to precision of detector components (muon angle)
- Extrapolate $p_{\parallel}$ from measured angle ← *Muon angle driver*
- Mass Resolution ← *Muon angle driver*

Pattern Recognition ← *??? 1 mm ???*

- Muon tracking constraints
- Track linking with central detector

Other Effects

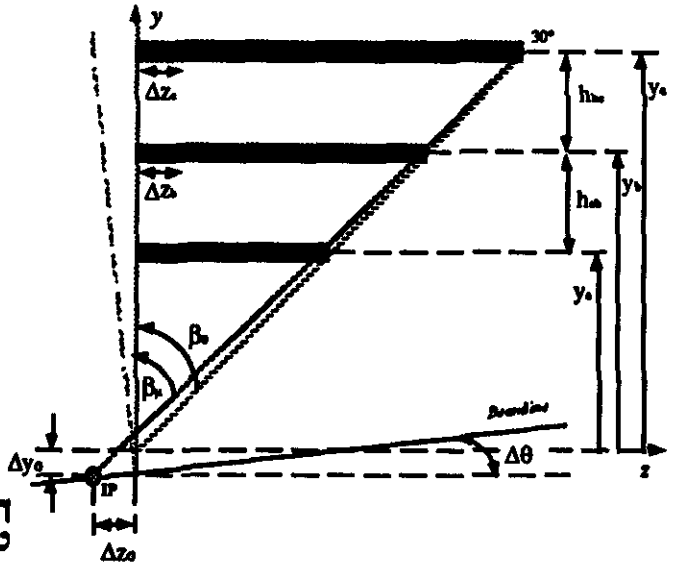
- Line-of-sight deviation from IP ← *Torque Error*

Alignment to B Field?? ← *≈ 2 mm in Endcap (Zhukov)*

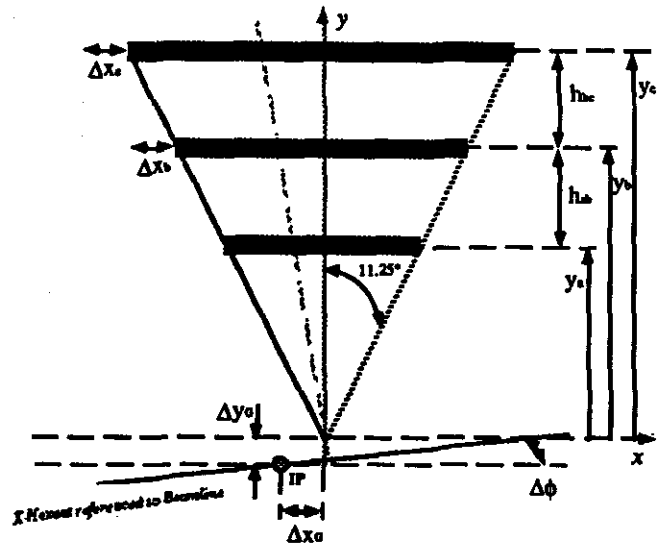
....

Alignment Definitions

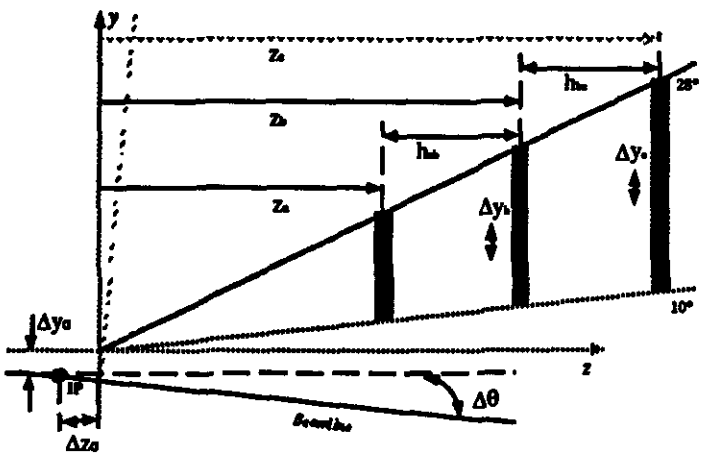
rθ plane

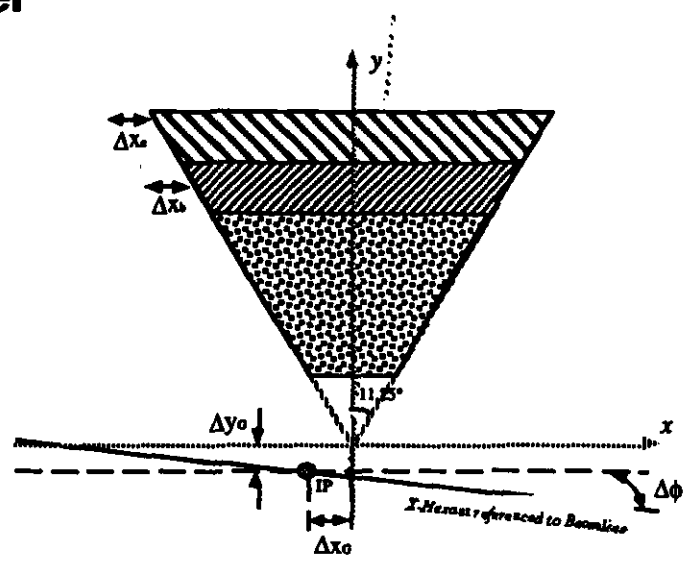


rϕ plane



Barrel





Endcap

Muon Structure Alignment Analysis

	Intrinsic Smears (+4)		Structural Accuracy		
All ±mm and ±mr	Interaction Diamond (7 cm)	Scattering in Calorimeter (50 GeV)	Dynamic Range of Local Alignment	Trigger Roads (10% Loss)	*Summary*
	+4	+4			
Barrel					
Δx(b)			1	2	1
Δx(c)			1	3.25	1
Δz(b)			1	3.25	1
Δz(c)			2	4.5	2
Δy(b)			1	1.9	1
Δy(c)			1	2.6	1
ΔX(g)		2		6.3	6.3
ΔY(g)	6.8	2		2.5	6.8
ΔZ(g)	12	4		4.5	12
Δθ	0.35	0.5			
Δφ		0.5			
Endcap					
Δx(b)			1	2	1
Δx(c)			2	3.25	2
Δy(b)			1	1.75	1
Δy(c)			2	3.5	2
Δz(b)			1.7	3	1.7
Δz(c)			3.4	6	3.4
ΔX(g)		3.3		5.6	5.6
ΔY(g)	2.1	3.3		4.1	4.1
ΔZ(g)	12	6.3		4.4	12
Δθ	0.13	0.5			
Δφ		0.5			

- ±1 mm monitor range driving most local tolerances
  - ➡ Range will extend to circa ±5 mm??
- Trigger constraints impose requirements ranging ±2 → ±5 mm
  - ➡ Simple assumptions??
- Diamond width driving global z requirement
- Radial beam location unknown to ±3 mm before startup?

Factors affecting muon angle

Project from transverse momentum: $p = \frac{p_\perp}{\sin\theta}$

$$\frac{\sigma_p}{p} = \sqrt{\left(\frac{\sigma_{p_\perp}}{p_\perp}\right)^2 + \left(\sigma_\theta \cot\theta\right)^2}$$

Invariant Mass: $m^2 = 4\, p_1\, p_2 \sin^2\left(\tfrac{1}{2}\theta_{\mu\mu}\right)$

$$\frac{\sigma_m}{m} = \sqrt{2\left(\frac{\sigma_p}{p}\right)^2 + \left[\sigma_{\mu\mu}\cot\left(\tfrac{1}{2}\theta_{\mu\mu}\right)\right]^2}$$

- **Assume momentum resolution as quoted for $p_\perp$ = 500 GeV**
- **Angle contribution down to 25% of quadrature sum (before squaring).**
- **Analyze mass error with $\theta_{\mu\mu}$ = 11.25°**

Precision Muon Alignment Requirements

		Ref. only	Precision Requirements			
All ±mm and ±mr	Scattering in Calorimeter (500 GeV)	Ultimate Detector Resolution	Precision Momentum	Momentum Vector	Mass Resolution	*Summary*
	+4					
Barrel						
Δx(b)			0.025			0.025
Δx(c)			0.05			0.05
Δz(b)						1
Δz(c)						2
Δy(b)			0.063			0.063
Δy(c)			0.125			0.125
ΔX(g)	0.2	0.33	0.2 (Goal!)		4.7	4.7
ΔY(g)	0.2	1.6		60	11	11
ΔZ(g)	0.4	13		100	4.7	4.7
Δθ	0.05	2.7		6.7	1.2	1.2
Δφ	0.05	0.13			1.2	1.2
Endcap						
Δx(b)			0.025			0.025
Δx(c)			0.05			0.05
Δy(b)						1
Δy(c)						2
Δz(b)			0.125			0.125
Δz(c)			0.25			0.25
ΔX(g)	0.33	0.13	0.2 (Goal!)		7.2	7.2
ΔY(g)	0.33	9		20	8.4	8.4
ΔZ(g)	0.63	15		100	19	19
Δθ	0.05	2.7		2.9	1.2	1.2
Δφ	0.05	1.3			1.2	1.2

- Δy local requirement comes from average induced sagitta error (≈ ½ the maximum error) held within ¼ of the 25 μm budget.

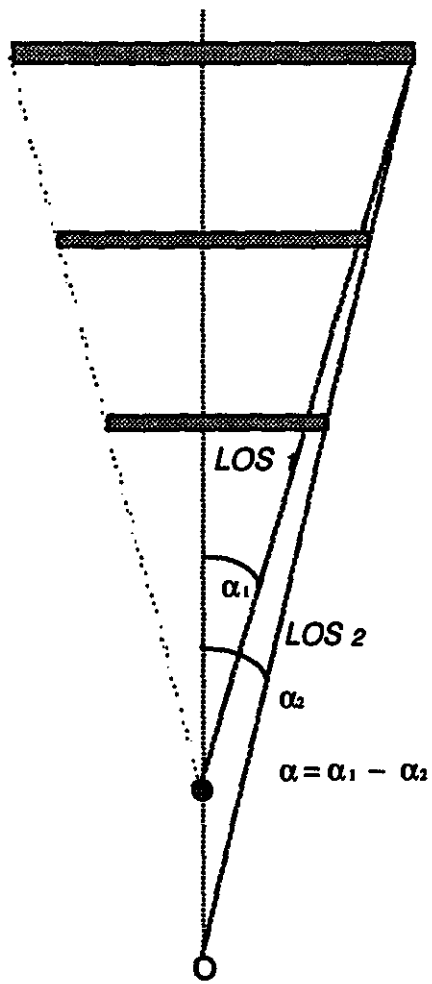
- Global requirements driven by mass resolution requirement (loose; range 5 mm → 2 cm).

  → Already restrictive?

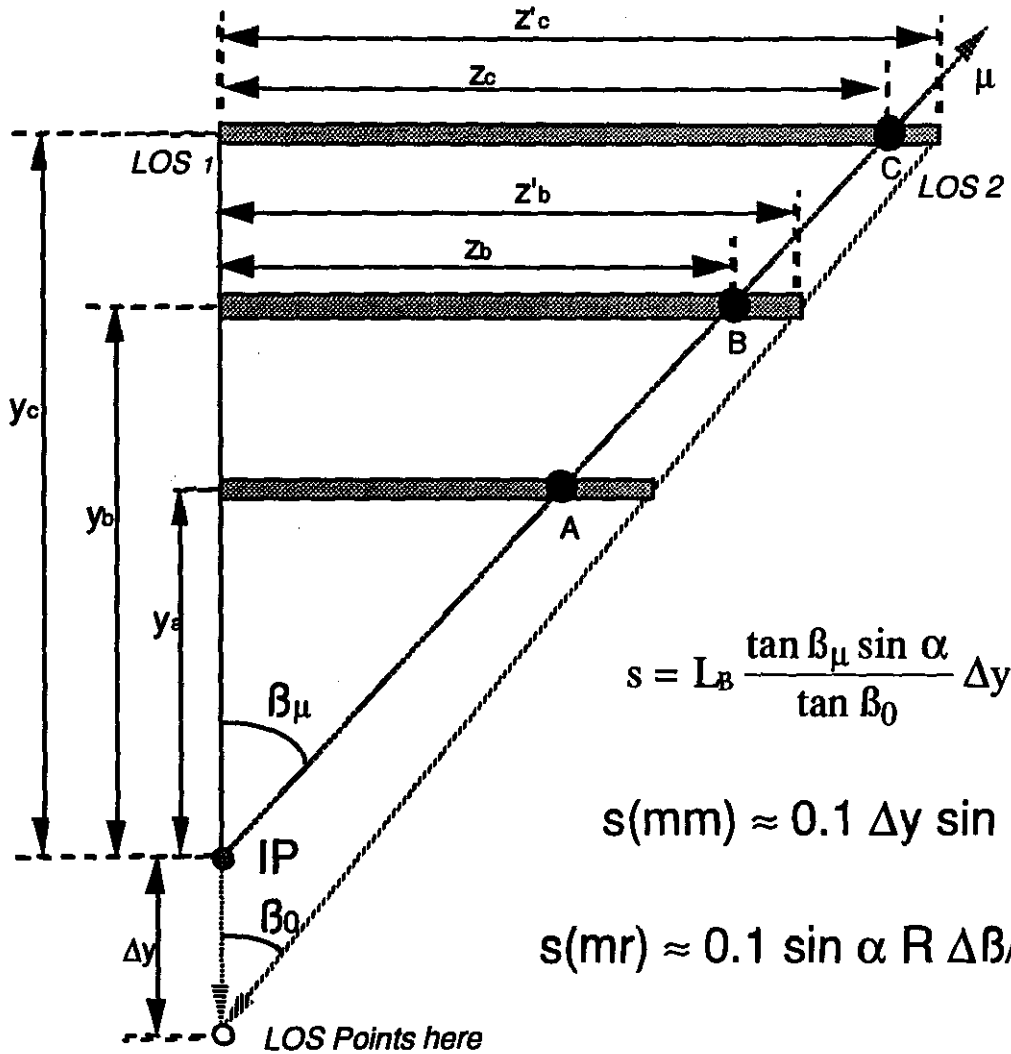
- Pattern recognition requirements not here (range ≈ ±1 mm in x, [z] per Zhukov et. al., from multiple scattering).

  → Specs. from tracker?

"Torque" Error (point LOS to IP)



rϕ View



r θ View

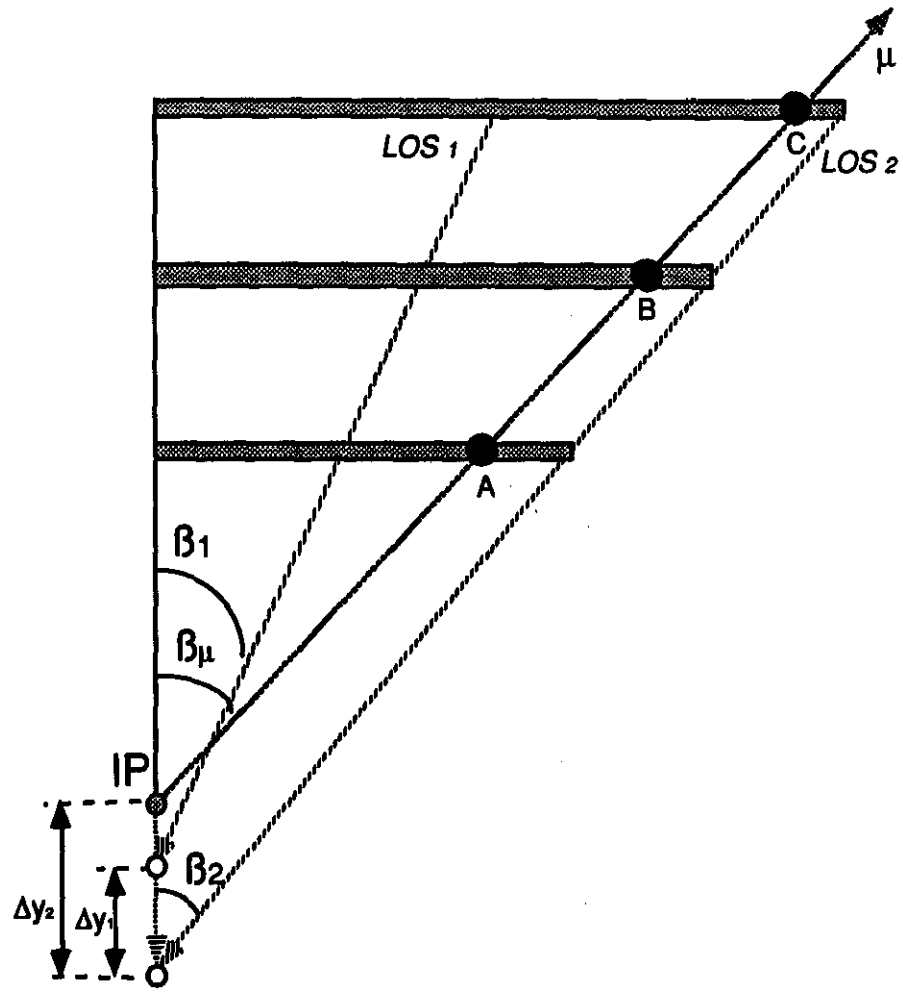
$$s = L_B \frac{\tan \beta_\mu \sin \alpha}{\tan \beta_0} \Delta y \left(\frac{1}{y_B} - \frac{1}{y_C}\right)$$

$$s(mm) \approx 0.1\ \Delta y \sin \alpha$$

$$s(mr) \approx 0.1 \sin \alpha\ R\ \Delta\beta / \sin \beta_0$$

If $\Delta\beta$, α remain less than 3 mr, s < 18 μm

Torque Error (ganged projective)

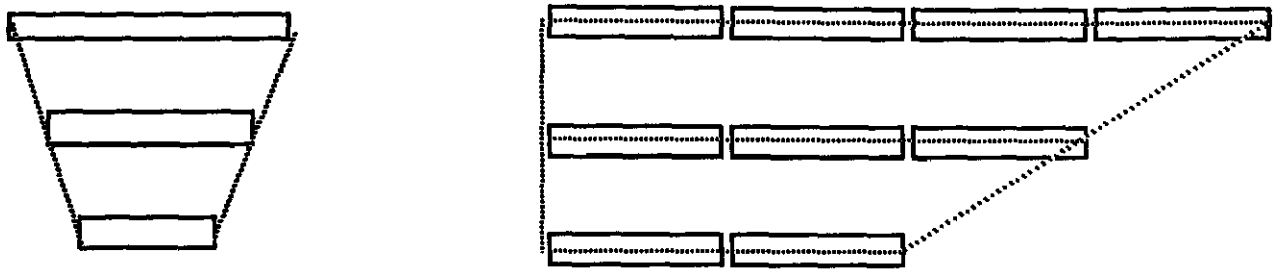


$$s = L_B \sin\alpha \left(\frac{\tan \beta_\mu y_B - \tan \beta_1 (y_B + \Delta y_1)}{\tan \beta_2 (y_B + \Delta y_2) - \tan \beta_1 (y_B + \Delta y_1)} - \frac{\tan \beta_\mu y_C - \tan \beta_1 (y_C + \Delta y_1)}{\tan \beta_2 (y_C + \Delta y_2) - \tan \beta_1 (y_C + \Delta y_1)} \right)$$

Stability

- Never exhaust dynamic range of sensors/actuators...
- Rely on taking calibration no more than once per hour
  - Would like once per run!
- Drift is in the structure, not the sensor!

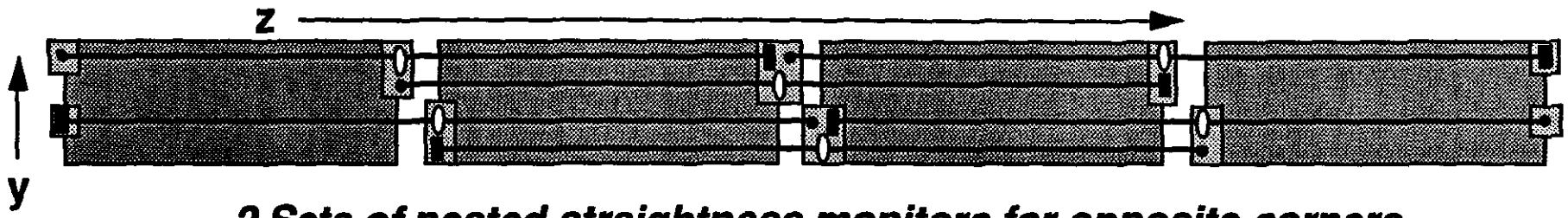
Baseline Analysis



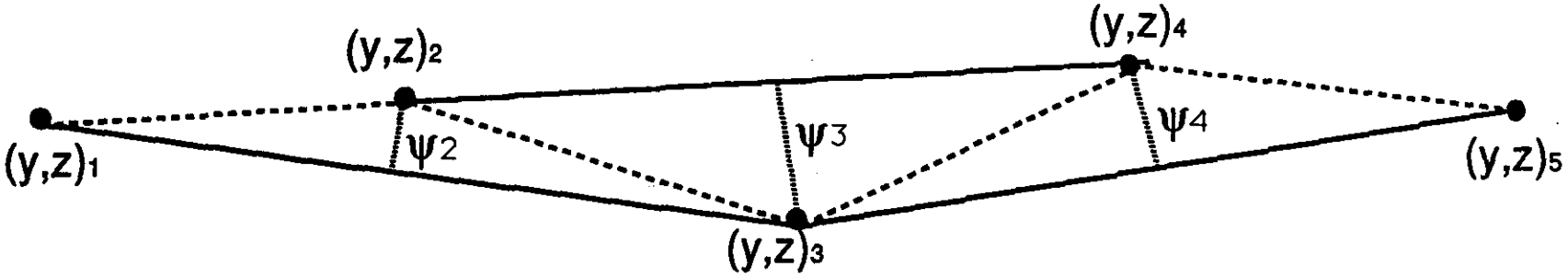
- MATLAB program nearly complete to verify alignment scheme.
- Assume four projective 3-point lines ($\phi = \pm 11.25°$, $\theta = 90°, 30°$), multipoint line along z (pick up each chamber edge relative to endpoints, where projective lines run).
- Three hierarchies of transformations implemented:
  - Rotate each chamber about its center in 3 axes, and translate.
  - Rotate each layer in 3 axes, and translate.
  - Rotate entire hexant relative to IP and translate.
- Straight lines from IP (infinite momentum muons) detected in displaced chambers.
- Alignment measurements taken (multipoint SWAT and nested SM assumed for z-axis).
- Sagitta corrected through linear interpolation of alignment data.

→ Check concept validity, "torque" mysteries, etc.
Extend to higher-order bending modes?

Nested SM's



2 Sets of nested straightness monitors for opposite corners



Measurements for one SM string

$$\mathbf{y} = \mathbf{b}\,([I] - [A])^{-1} \qquad \mathbf{b} = \begin{bmatrix} 0 \\ \psi_2 \\ \psi_3 \\ \psi_4 \\ 0 \end{bmatrix} \qquad [A] = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ \frac{z_2}{\Delta z_{13}} & 0 & -\frac{z_2}{\Delta z_{13}} & 0 & 0 \\ 0 & \frac{z_3}{\Delta z_{24}} & 0 & -\frac{z_3}{\Delta z_{24}} & 0 \\ 0 & 0 & \frac{z_4}{\Delta z_{35}} & 0 & -\frac{z_4}{\Delta z_{35}} \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

(Positioning errors add in quadrature; worst case = √3 ??)

Centroiding Receivers w. Wider Range

IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 26, NO. 12, DECEMBER 1991 1833

An Object Position and Orientation IC with Embedded Imager

David L. Standley, *Member, IEEE*

Abstract—A CMOS VLSI chip that determines the position and orientation of an object against a dark background is described. The chip operates in a continuous-time analog fashion, with a response time as short as 200 μs and power consumption under 50 mW. A self-contained phototransistor array acquires the image directly, and the output is a set of eight currents from which the position and orientation can be found. Orientation is determined to within ±2° or better for moderately sized and sufficiently elongated objects. Chip dimensions are 7900 μm × 9200 μm.

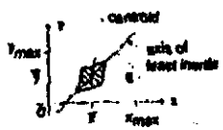
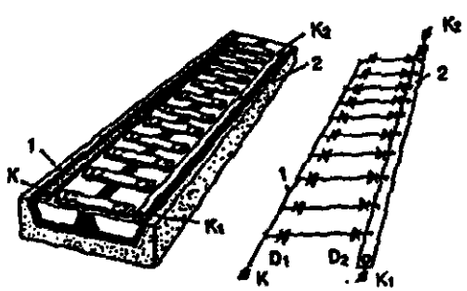


Fig. 1. Example of object centroid and axis of least inertia.

- MIT Vision project; fabricated imaging array that extracts moments & feature data (29x29 pixels, 190 μm; active area = 7.9 x 9.2 mm).
- Others; Cal Tech, Sel-Spot, etc.

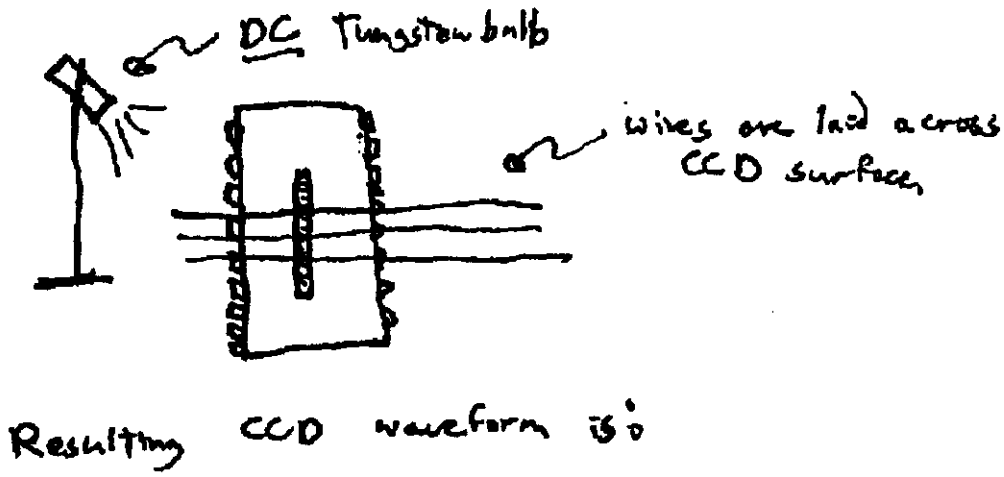
TECHNOEXAN



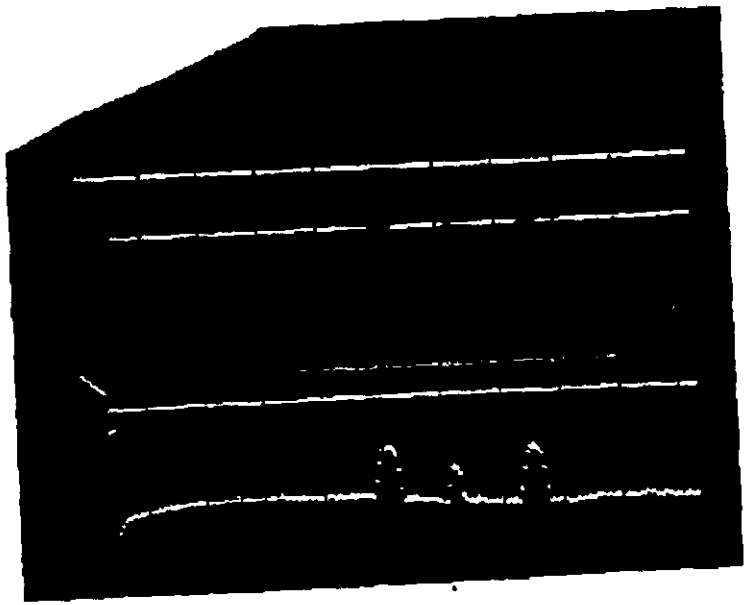
K, K₁, K₂ — electrodes
1 — common bus
2 — potentiometric resistor

- Line array that autocentriods (Soviet venture located by BNL group)

Imaging Array on a Wire Shadow



ETH, TEC Lab, 1982



Comparitor Out

CCD Output

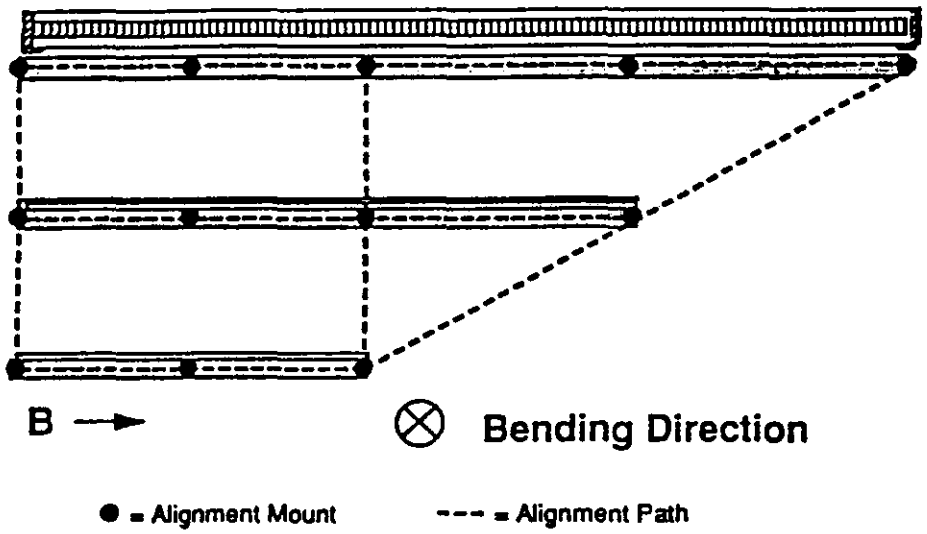
- Extend dynamic range of SWAT measurements...
- Photoresistive detector, or imaging array...

Gena Mitselmakher/SSCL

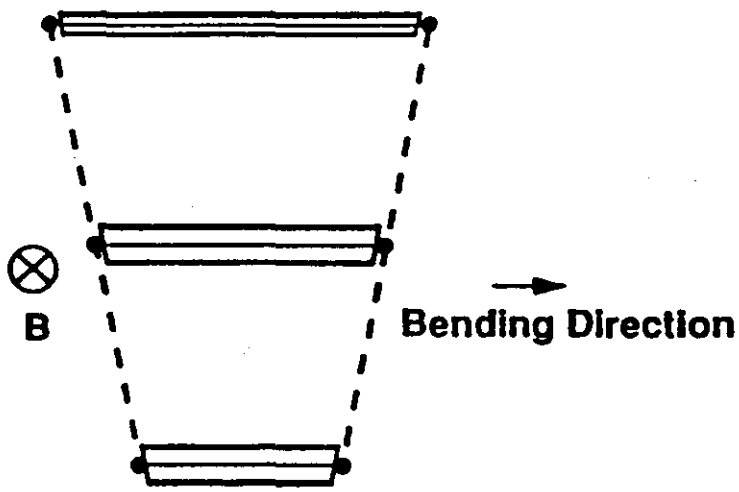
NEW MUON CHAMBERS ALIGNMENT SCHEME BASED ON INTERPOLATION AND PROJECTIVE GEOMETRY

G. MITSELMAKHER
SSCL

A. OSTAPCHUK
SSCL/ITEP



a) rθ View



b) rφ View

Figure 4.3: Straightness Monitor Paths in Muon Chamber Barrel

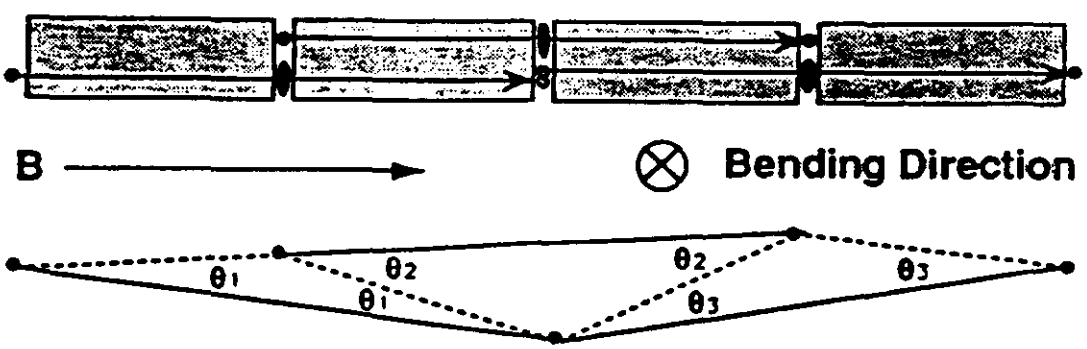


Figure 4.4: Alignment Along a Chamber Layer

Muon Alignment System

(person responsible: Joe Paradiso - Draper Labs)

In summary, the precision required by the muon alignment systems are given below:

Muon Barrel:

Bending Coordinate (Φ):	25 μm
Radial Coordinate (r):	120 μm
Beamline Coordinate (z):	1 mm

Muon Endcaps:

Bending Coordinate (Φ):	25 μm
Radial Coordinate (r):	1 mm
Beamline Coordinate (z):	120 μm

Global Alignment:

Bending Coordinates (r):	200 μm
Other Coordinates (Φ,z):	1 mm

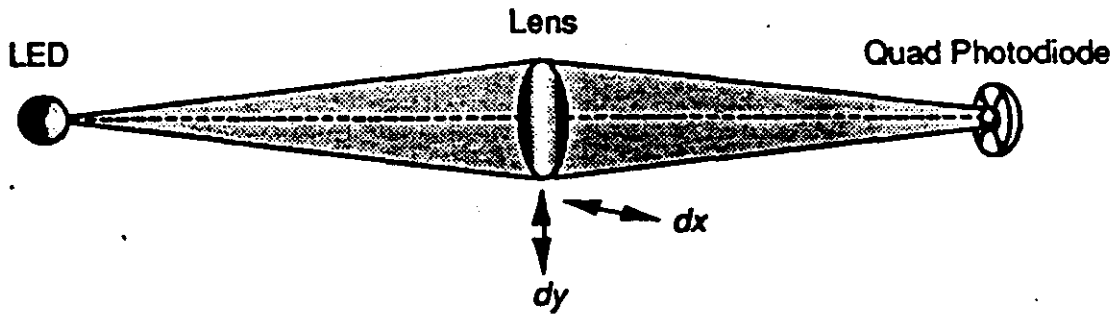


Figure 4.1: The Basic Straightness Monitor

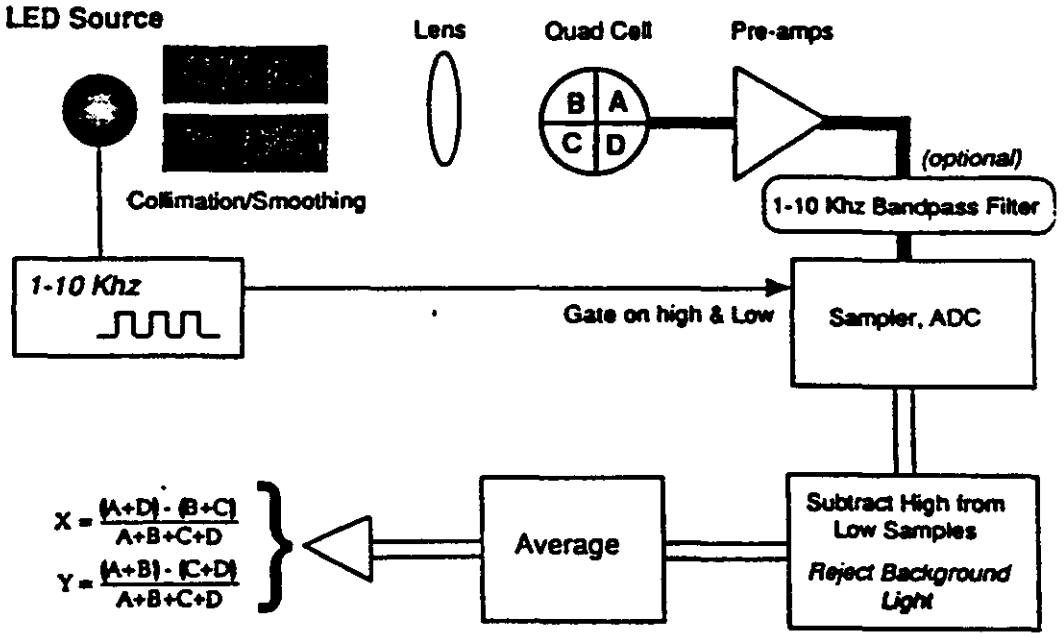
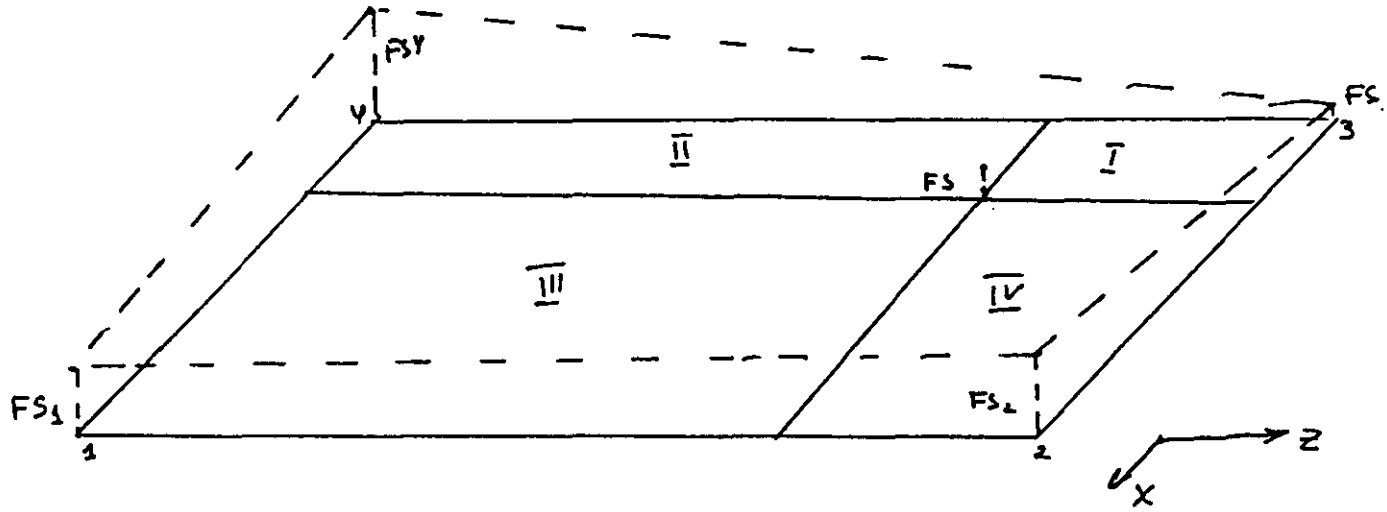


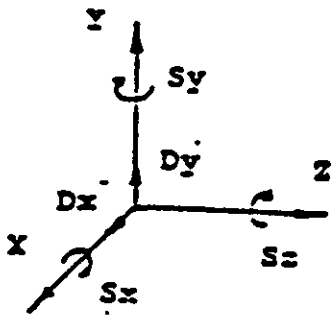
Figure 4.2: Straightness Monitor Electronics

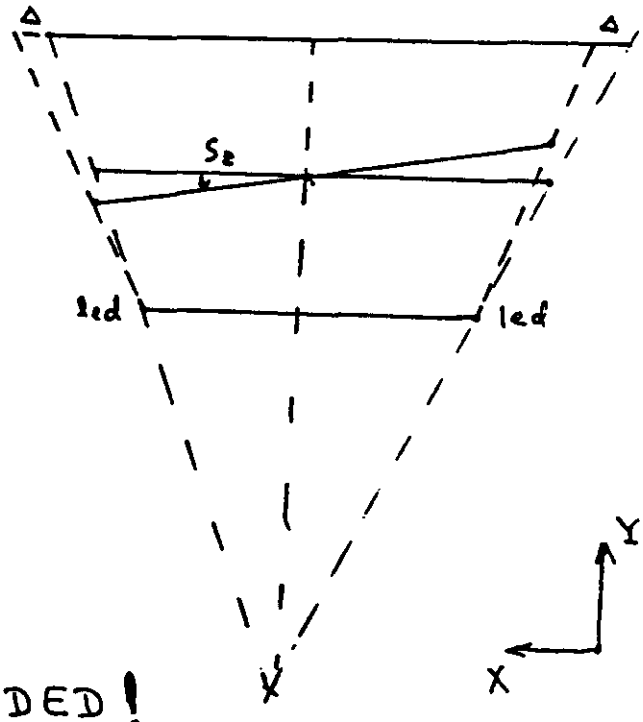
LINEAR INTERPOLATION



$$FS^{(1)} = \frac{FS_1 \times S_I + FS_2 \times S_{II} + FS_3 \times S_{III} + FS_4 \times S_{IV}}{S_{total}}$$

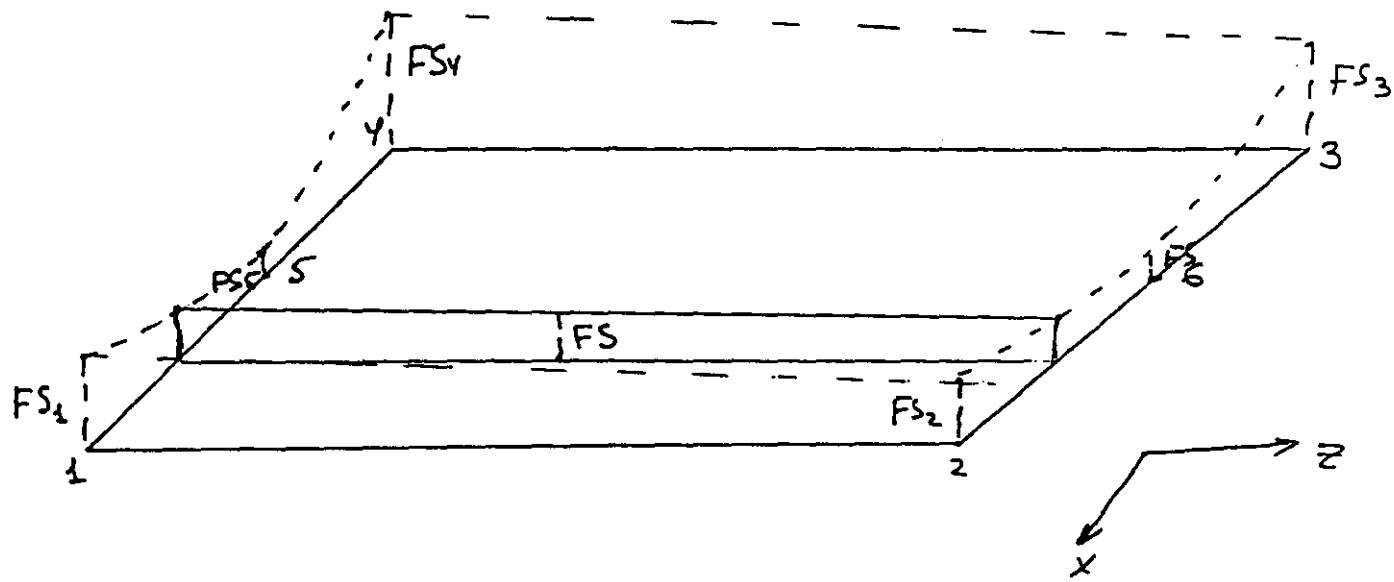
MOST SERIOUS DANGER: S_z !





FOR FOUR MONITORS
ROTATION S_z IS EQUAL
TO SHIFT Dx.
SIX MONITORS ARE NEEDED!

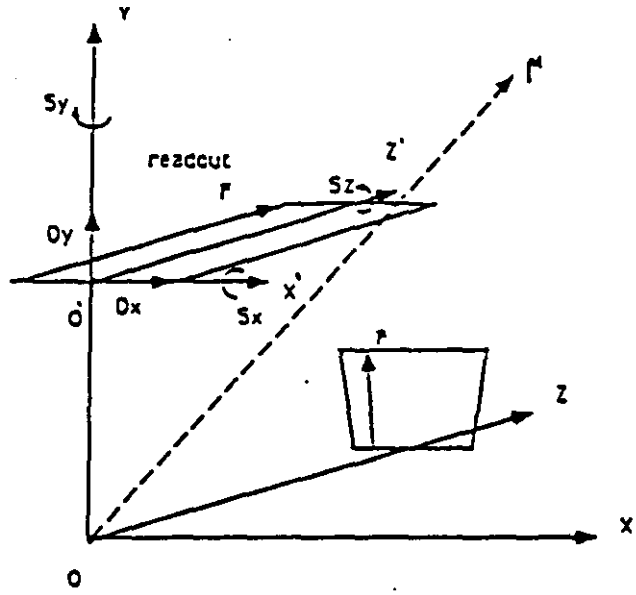
QUADRATIC INTERPOLATION



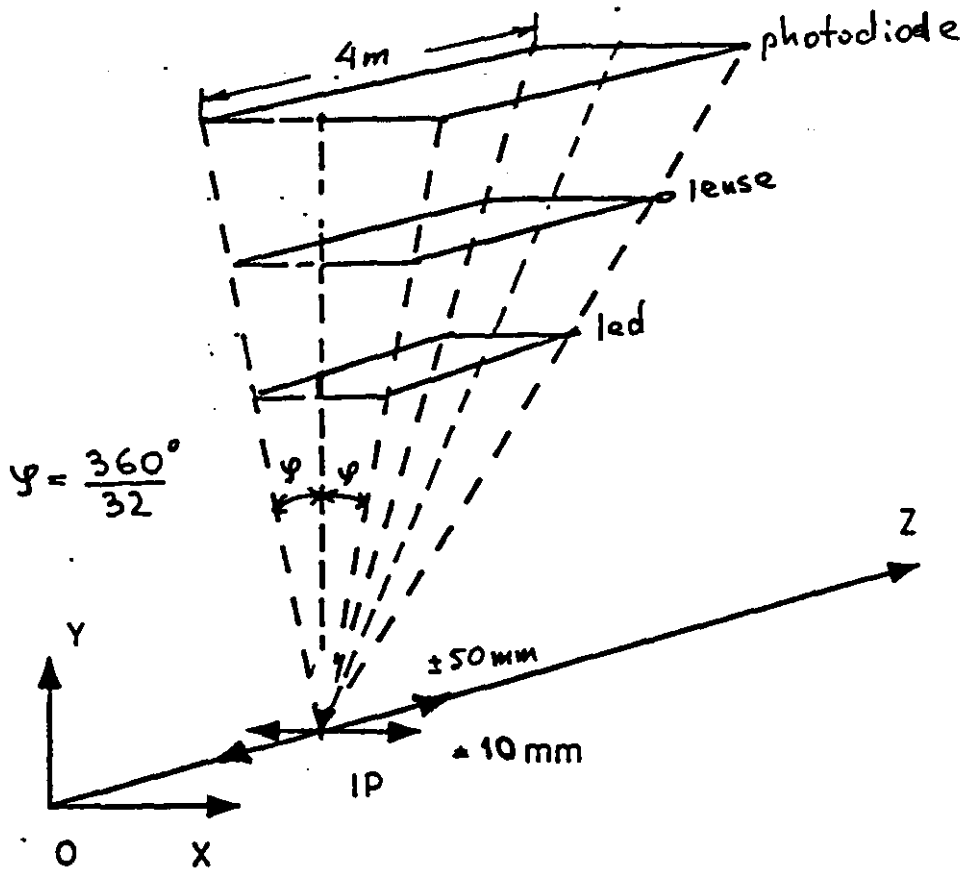
CONCLUSION

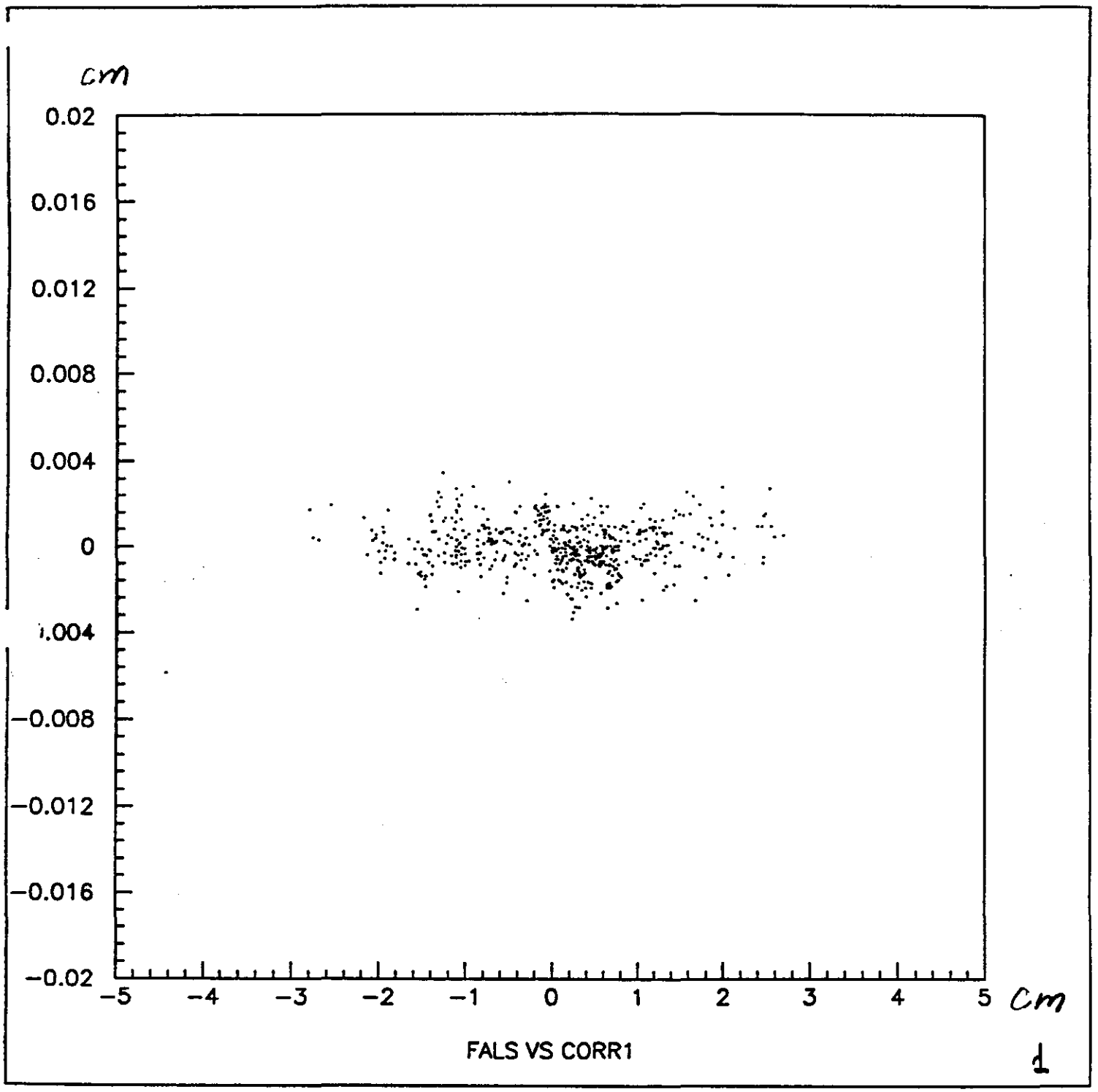
THIS SCHEME OF ALIGNMENT ALLOWS TO SOFTEN ALLIGNMENT REQUIREMENTS AS COMPARED WITH THE PREVIOUS ONE:

FOR Y-OFFSET $\times 10^1$
FOR X-OFFSET $\times 10^2$
FOR PARALLELISM $\times 10^3$

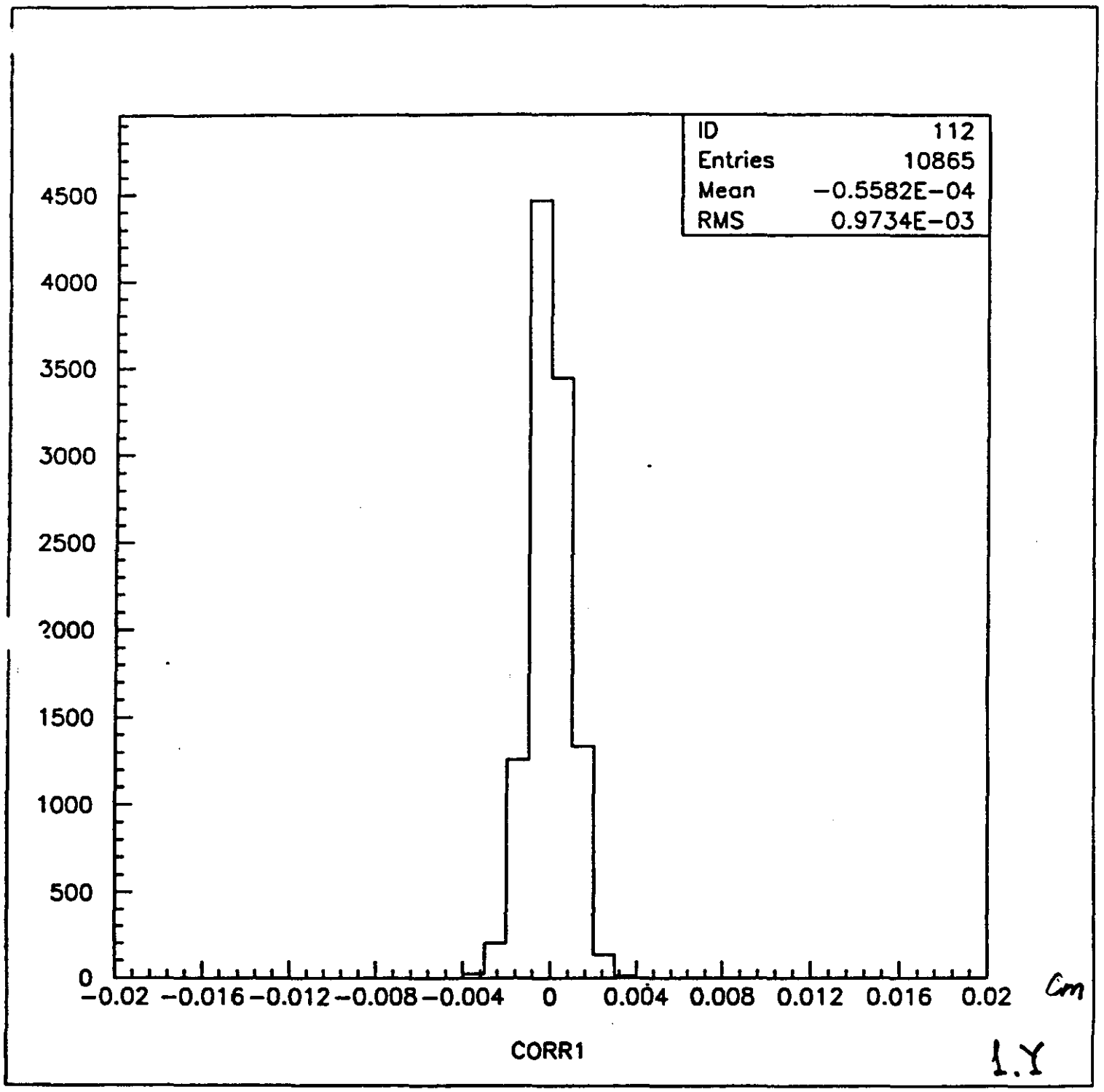


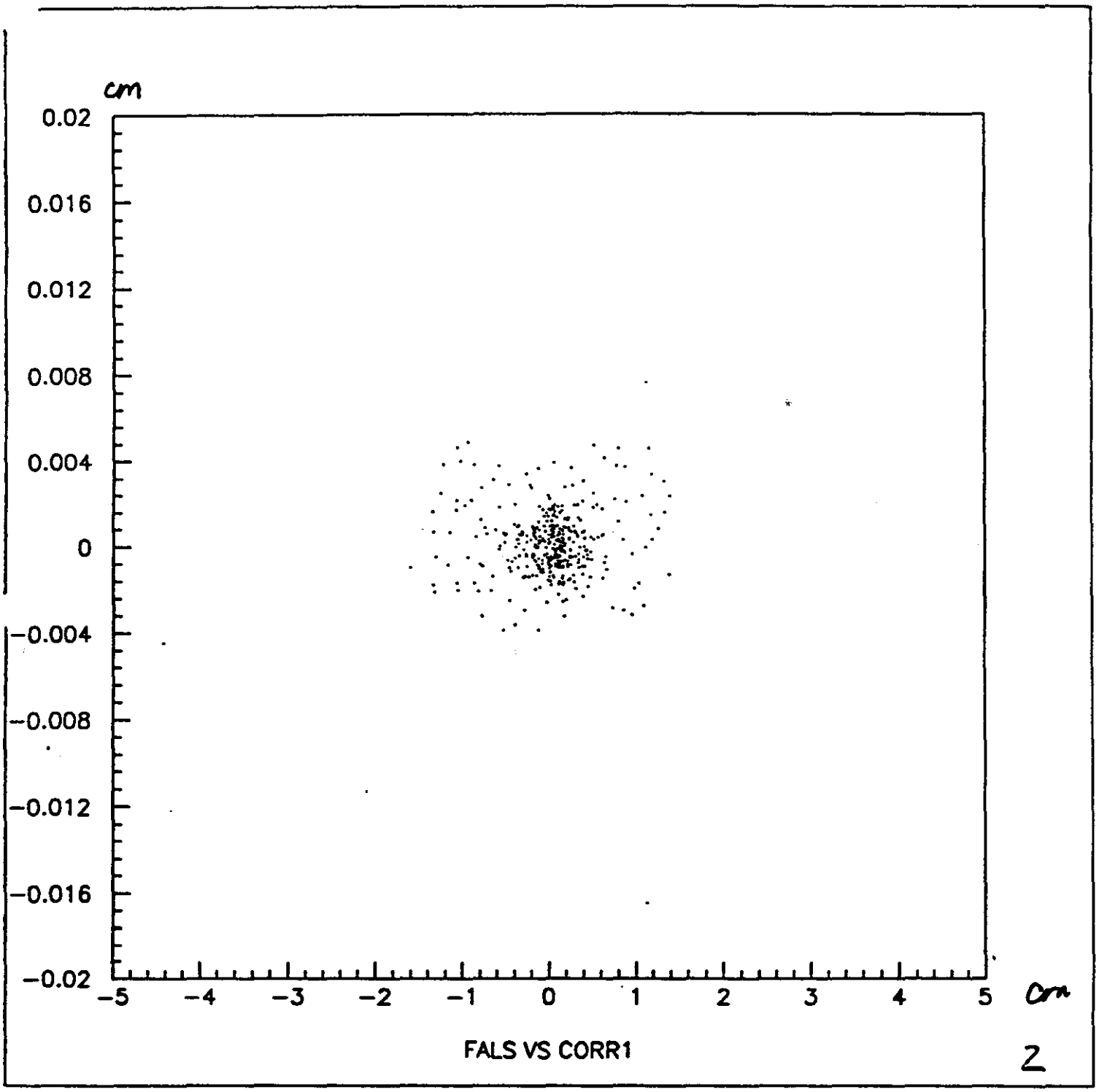
The coordinate system.



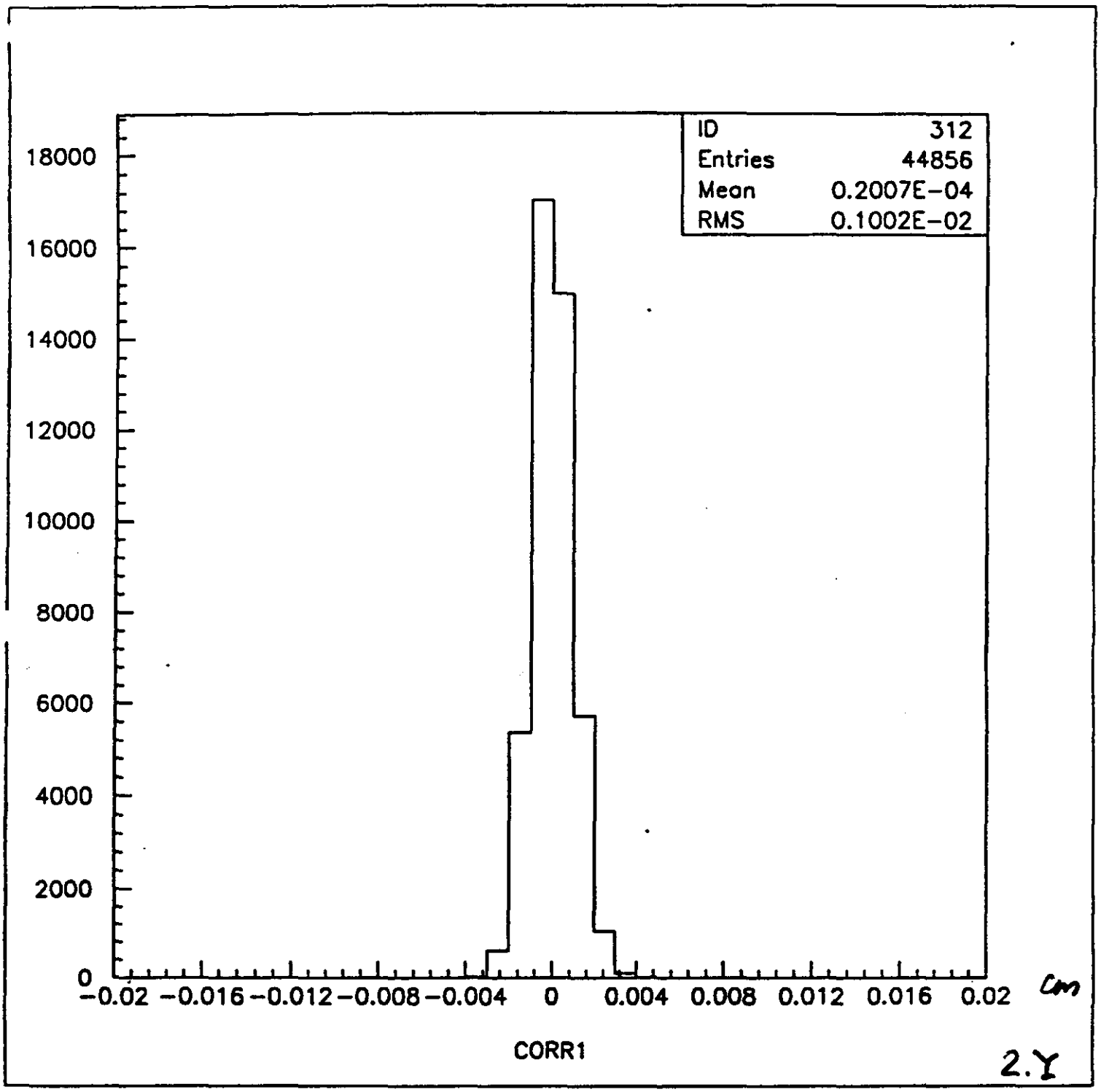


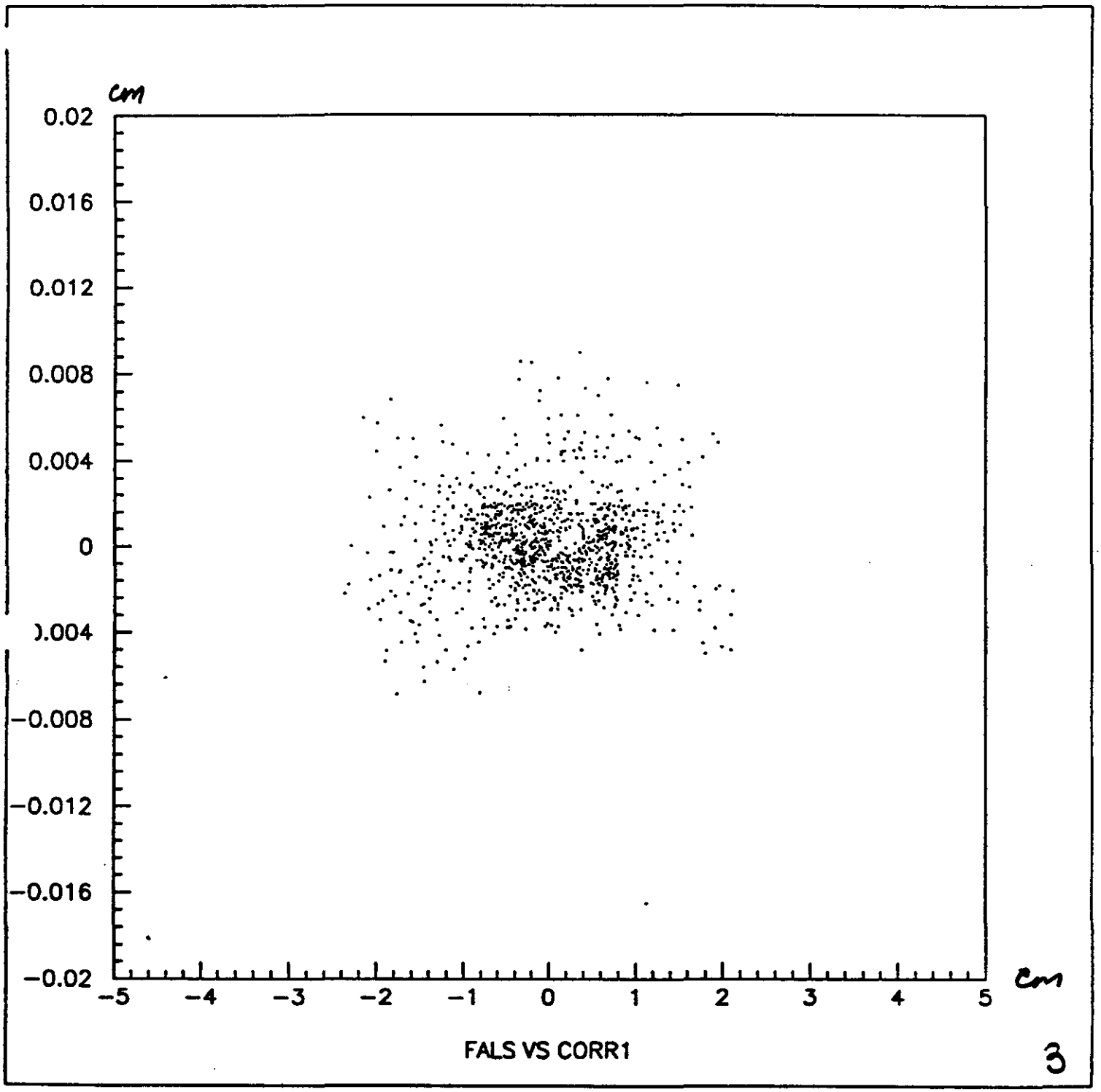
$D_x = \pm 1$ cm ; $D_y = \pm 1$ cm


ID 112
Entries 10865
Mean −0.5582E−04
RMS 0.9734E−03
4500
4000
3500
3000
2500
2000
1500
1000
500
0
−0.02 −0.016 −0.012 −0.008 −0.004 0 0.004 0.008 0.012 0.016 0.02
Cm
CORR1
1.Y

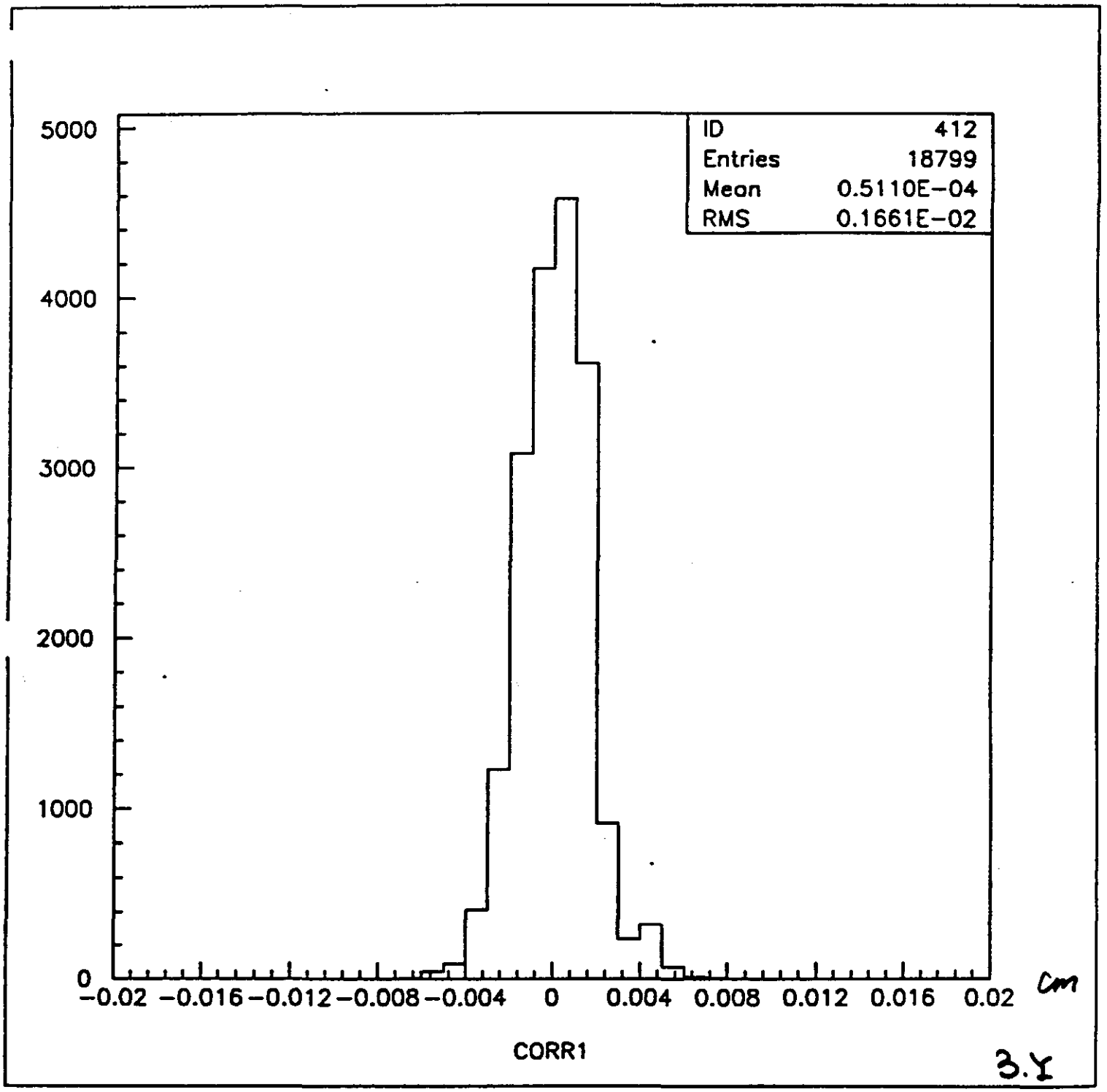

cm
0.02
0.016
0.012
0.008
0.004
0
−0.004
−0.008
−0.012
−0.016
−0.02
−5
−4
−3
−2
−1
0
1
2
3
4
5
cm
FALS VS CORR1
2

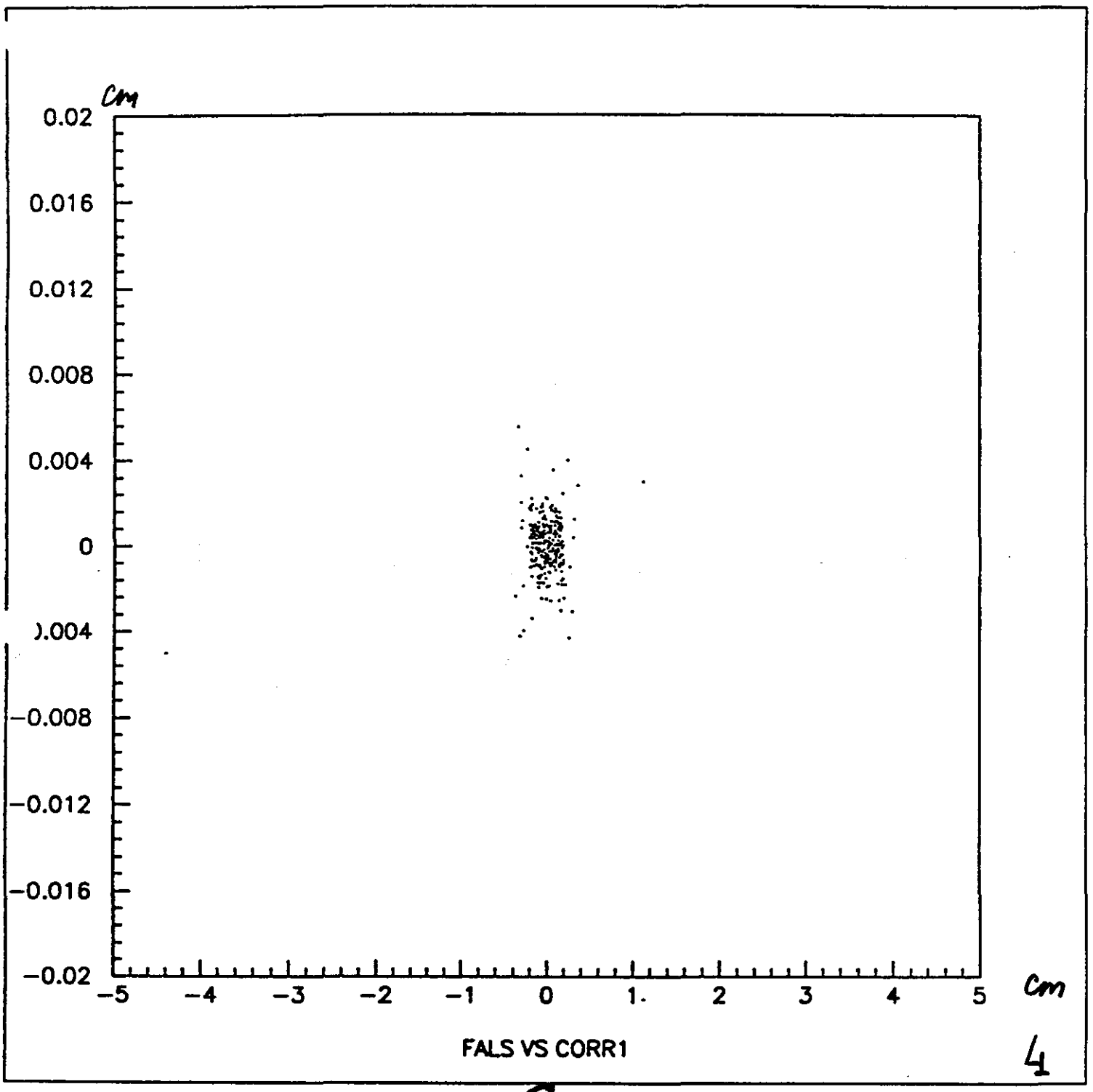
$S_y = \pm 3$ mrad


ID 312
Entries 44856
Mean 0.2007E-04
RMS 0.1002E-02
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-0.02 -0.016 -0.012 -0.008 -0.004 0 0.004 0.008 0.012 0.016 0.02
cm
CORR1
2.Y

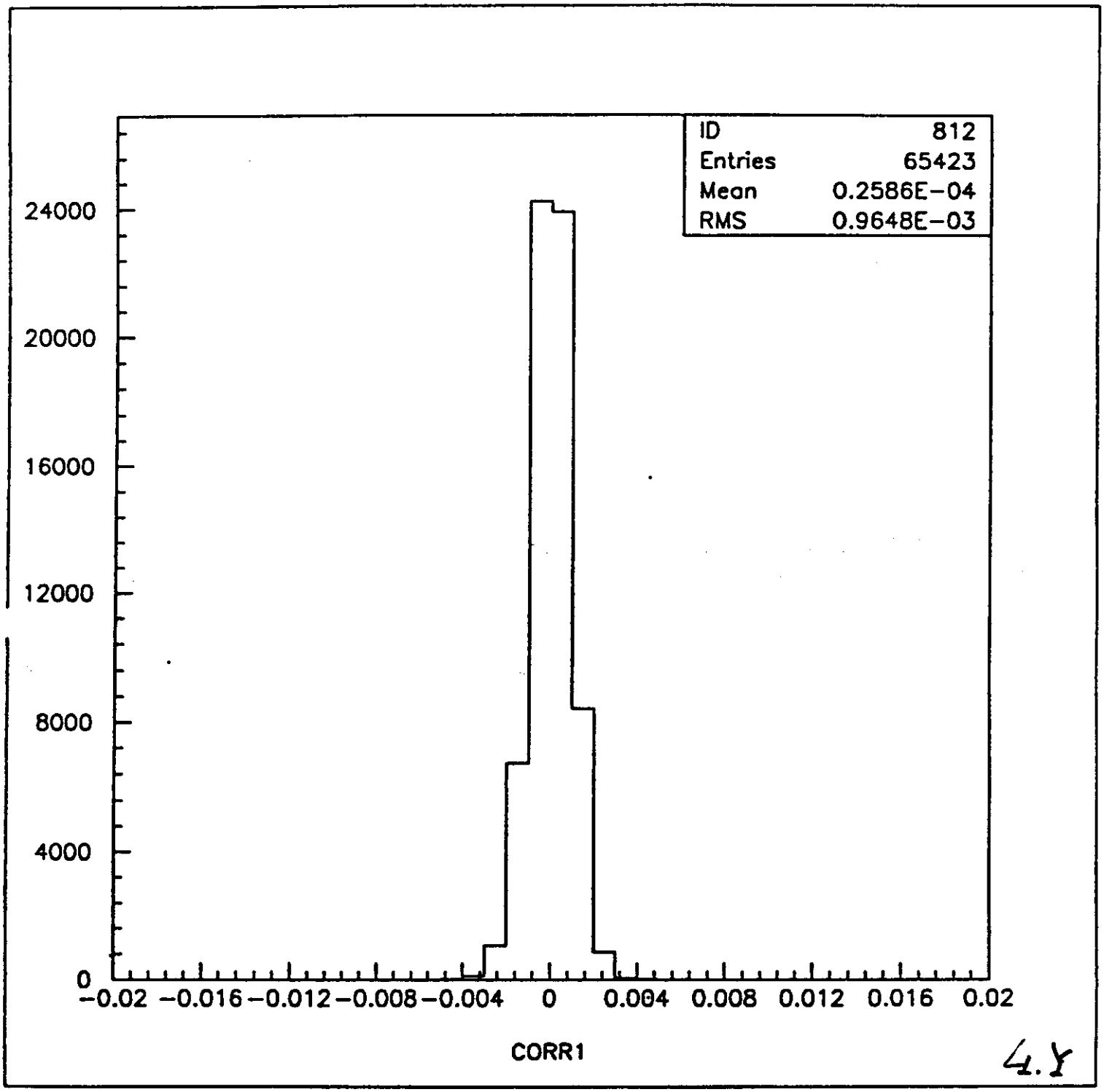


$D_x = \pm 1$ cm ; $D_z = \pm 1$ cm; $S_y = \pm 3$ mrad

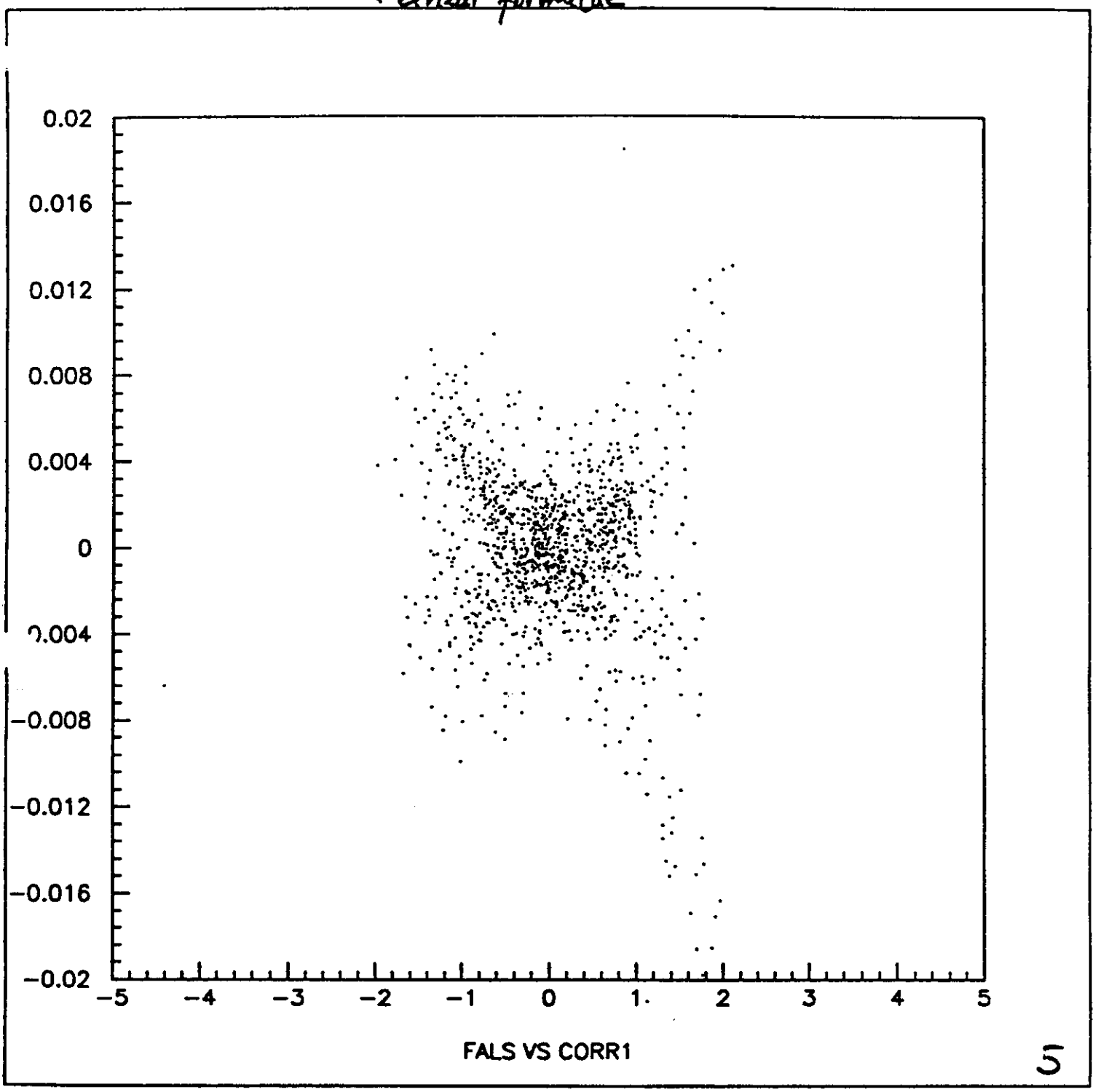

ID 412
Entries 18799
Mean 0.5110E-04
RMS 0.1661E-02
5000
4000
3000
2000
1000
0
-0.02 -0.016 -0.012 -0.008 -0.004 0 0.004 0.008 0.012 0.016 0.02
cm
CORR1
3.Y



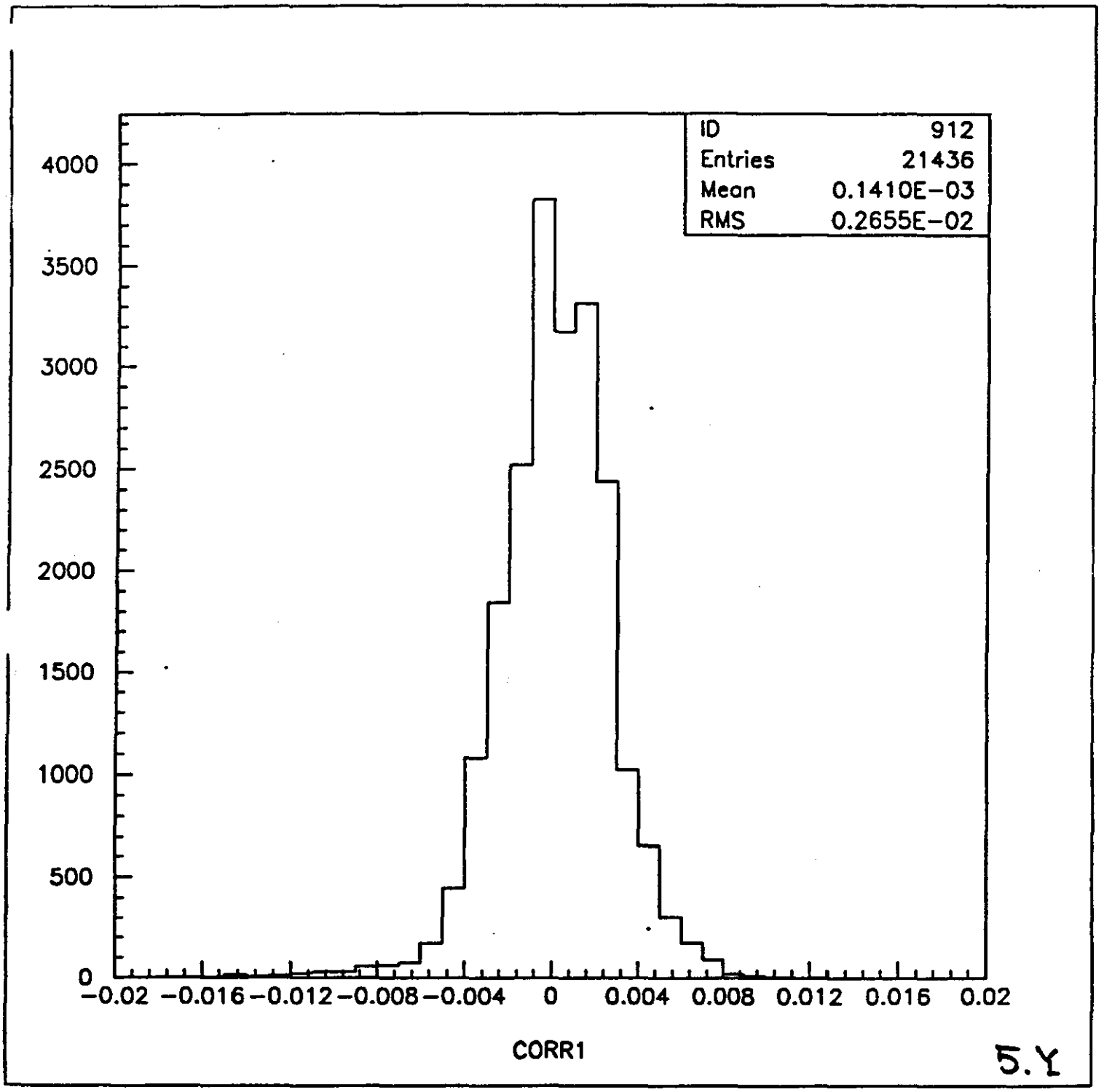
$D_Y = \pm 1\,cm$; $\Delta_X = \pm 3\,mrad$


ID 812
Entries 65423
Mean 0.2586E-04
RMS 0.9648E-03
24000
20000
16000
12000
8000
4000
0
-0.02 -0.016 -0.012 -0.008 -0.004 0 0.004 0.008 0.012 0.016 0.02
CORR1
4.Y

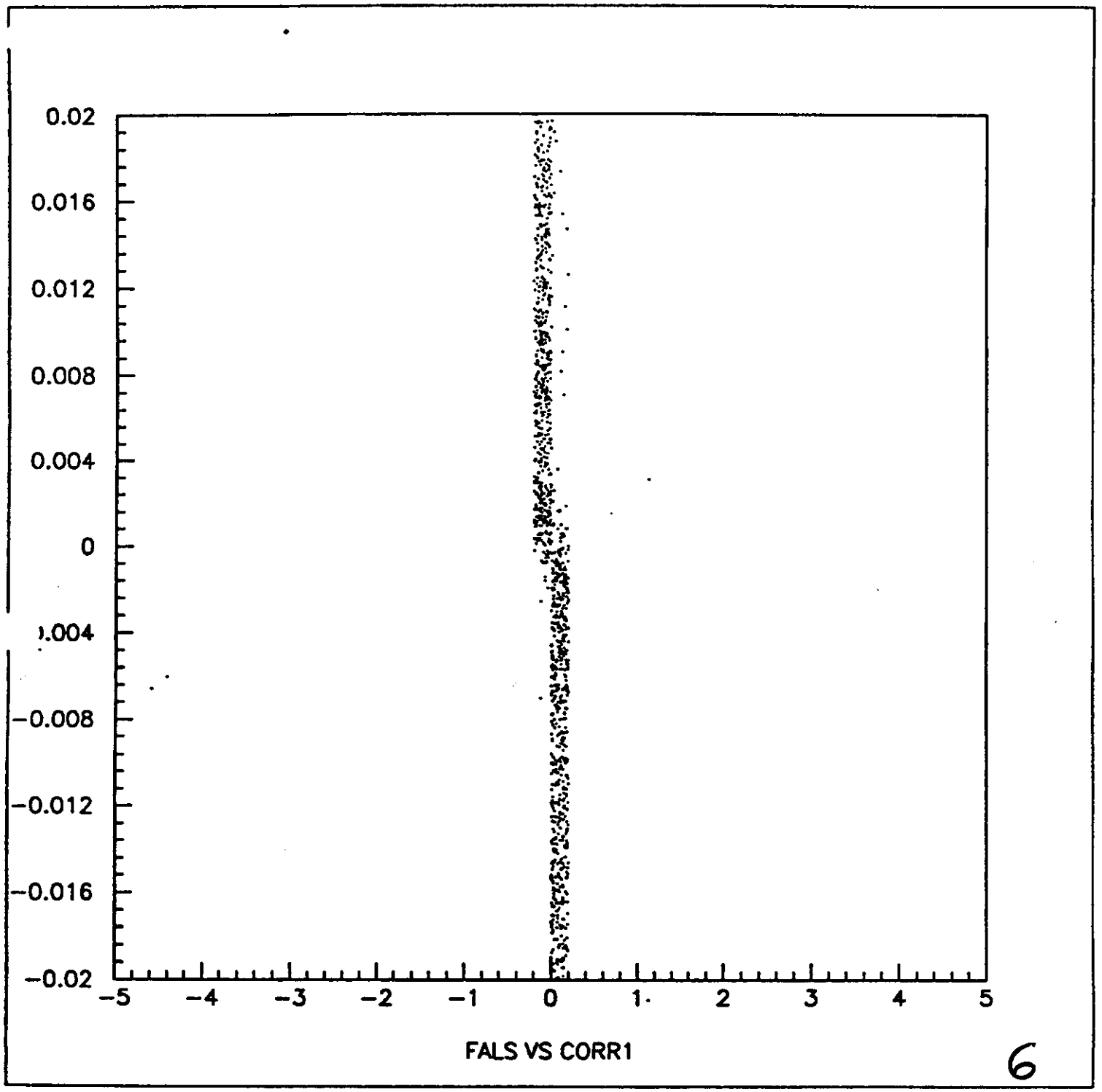
All movements and rotations exepting S_z –
– the most dangerous one
– linear formulae



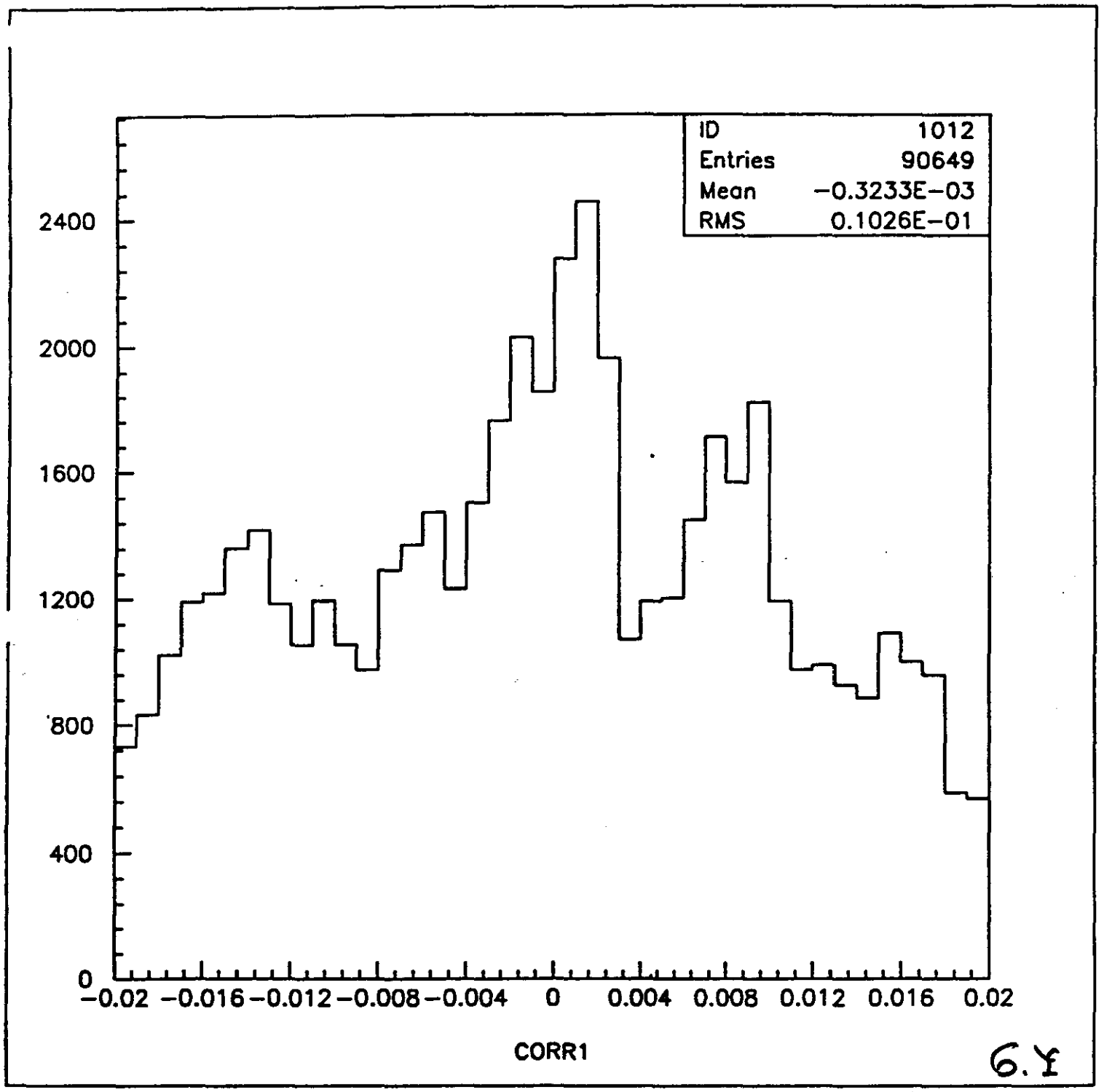
$D_x = \pm 1$ cm; $D_y = 1$ cm; $D_z = 1$ cm; $S_x = \pm 3$ mrad; $S_y = \pm 3$ mrad


ID 912
Entries 21436
Mean 0.1410E-03
RMS 0.2655E-02
4000
3500
3000
2500
2000
1500
1000
500
0
-0.02 -0.016 -0.012 -0.008 -0.004 0 0.004 0.008 0.012 0.016 0.02
CORR1
5.Y

S_z + linear formulae



$S_z = \pm 3$ mrad


ID 1012
Entries 90649
Mean −0.3233E−03
RMS 0.1026E−01
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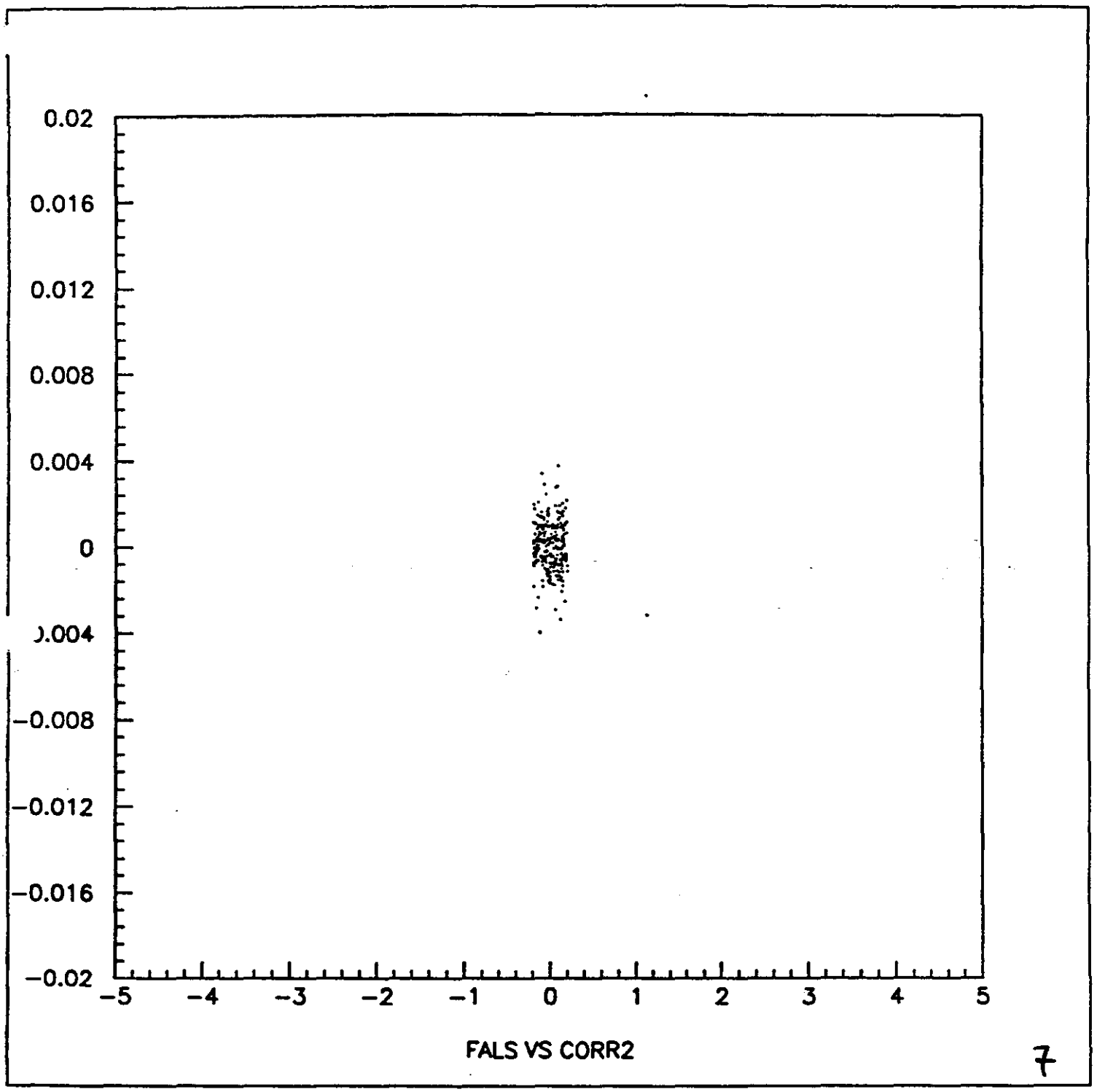
2000
1600
1200
800
400
0
−0.02 −0.016 −0.012 −0.008 −0.004 0 0.004 0.008 0.012 0.016 0.02
CORR1

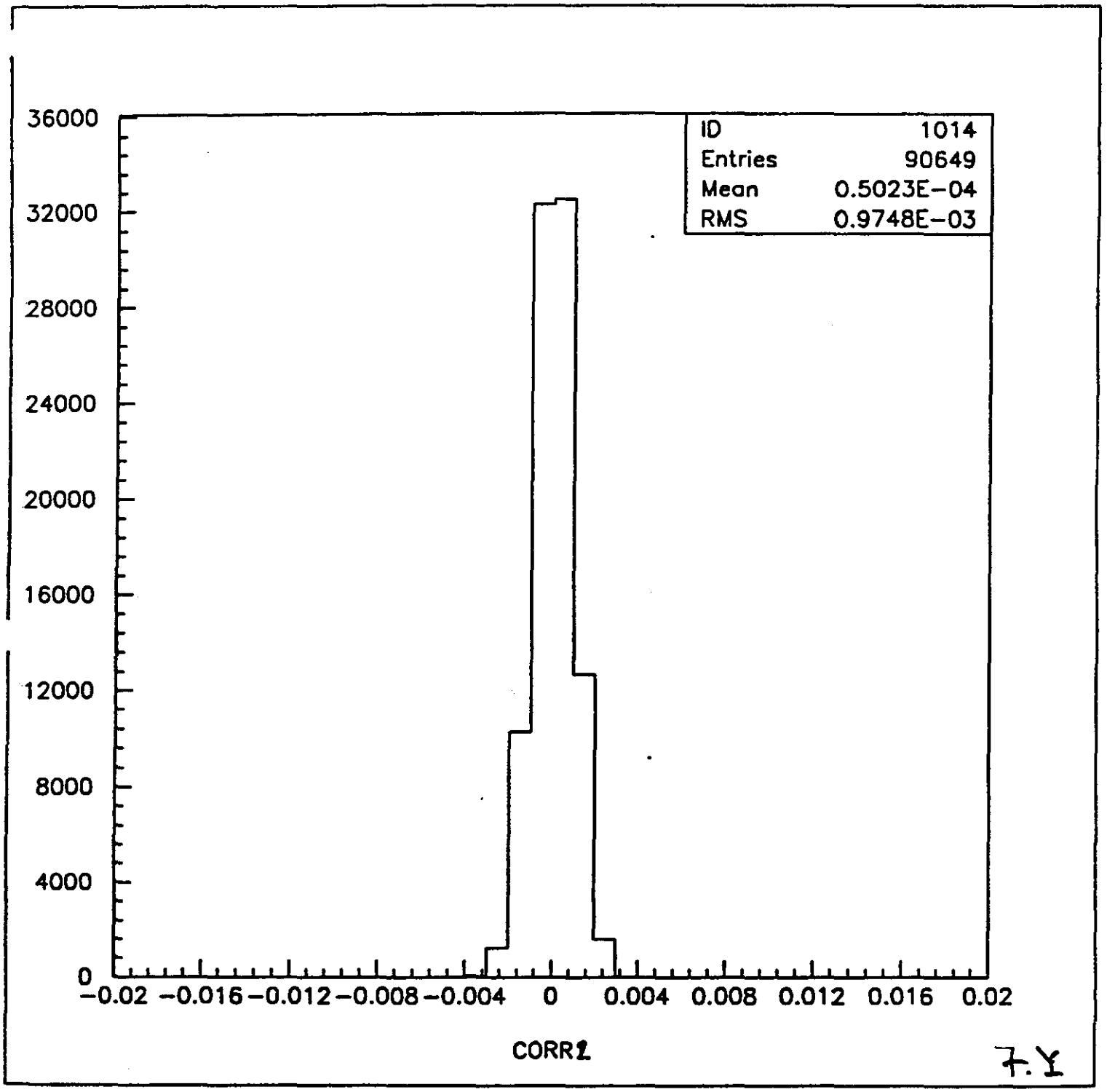
6.Y

S_z + quadratic formulae

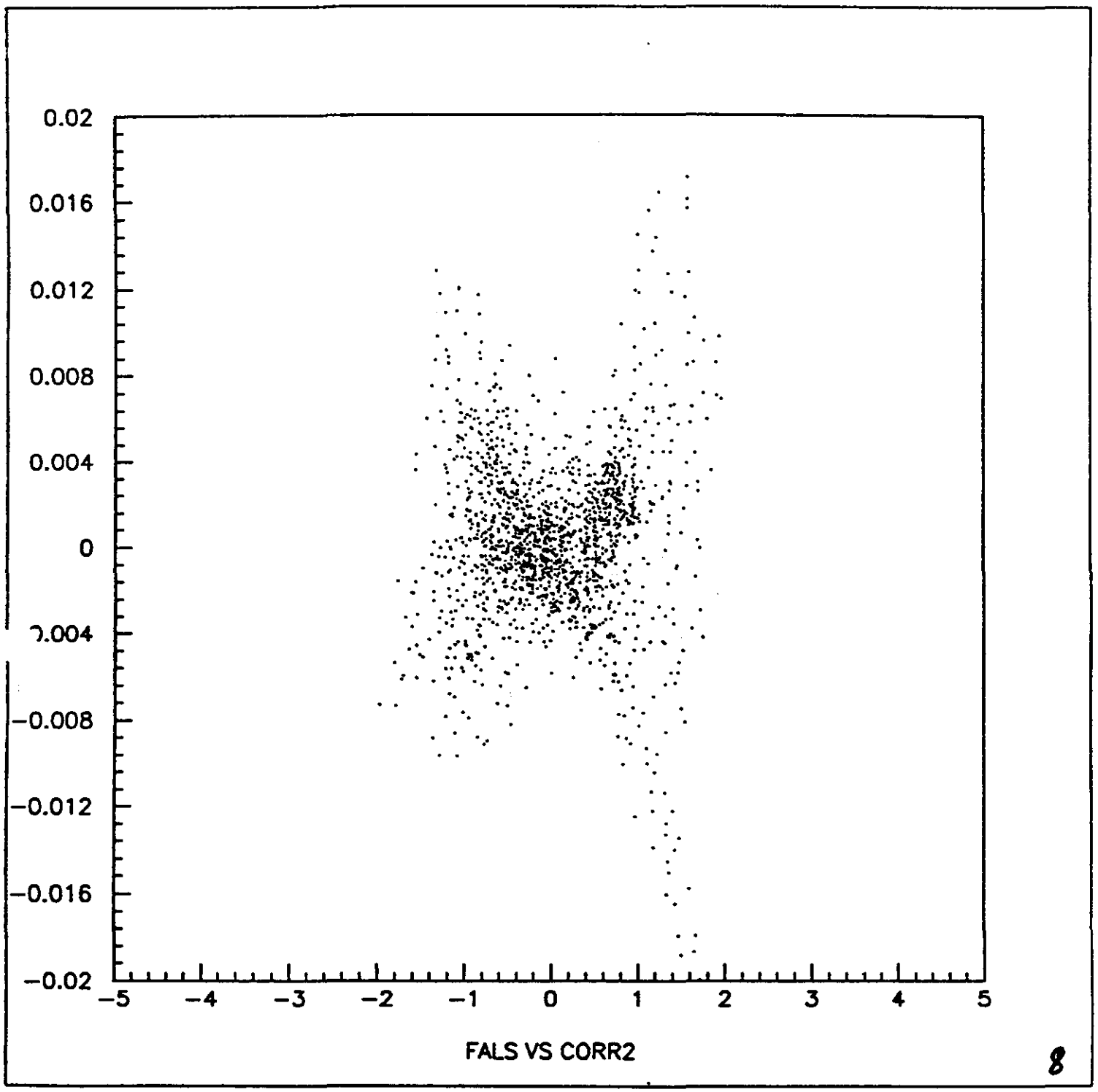


$S_z = \pm 3$ mrad

S_2 + quadratic formulae

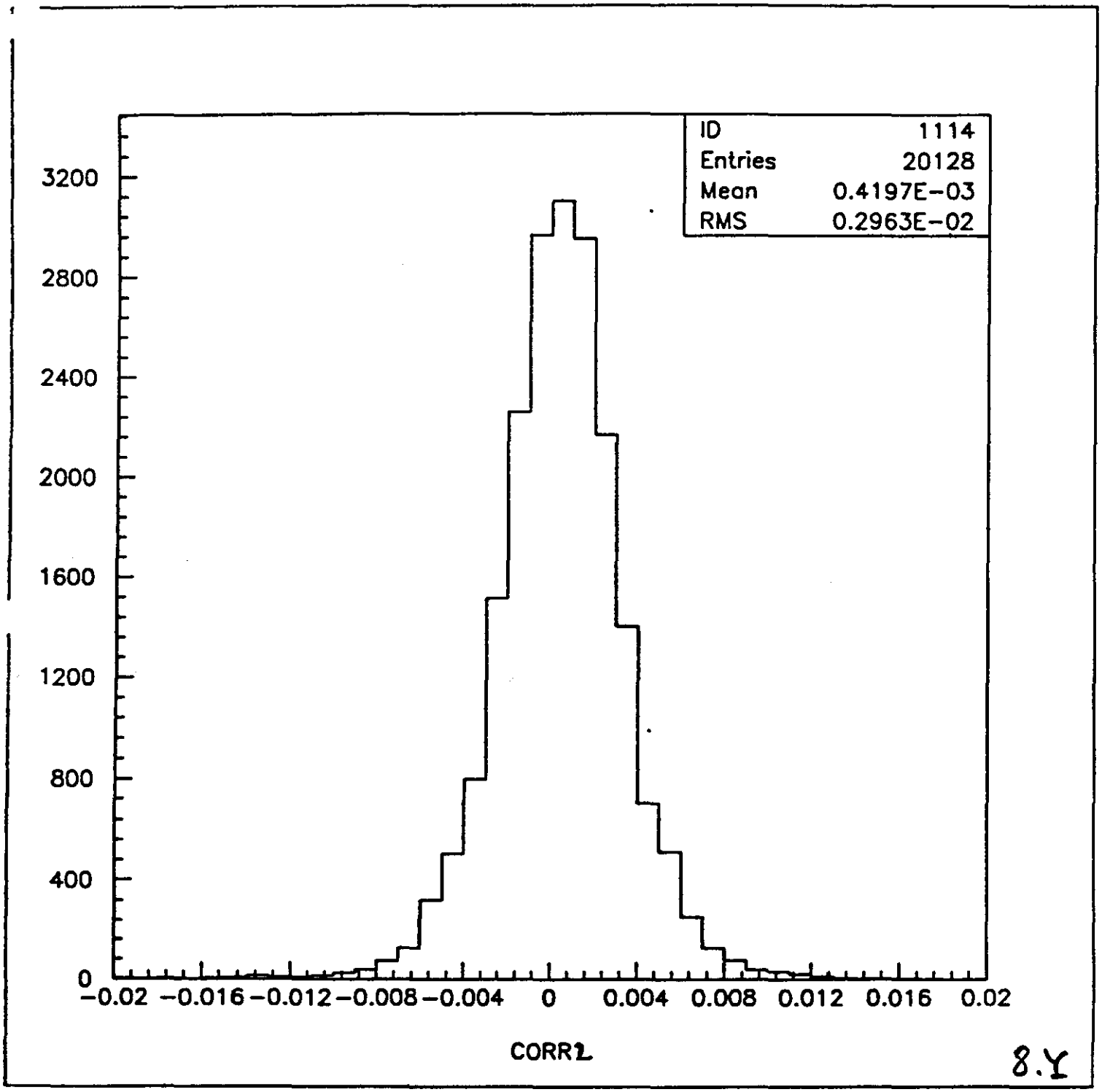


All movements and rotations of two chambers
+ quadratic interpolation

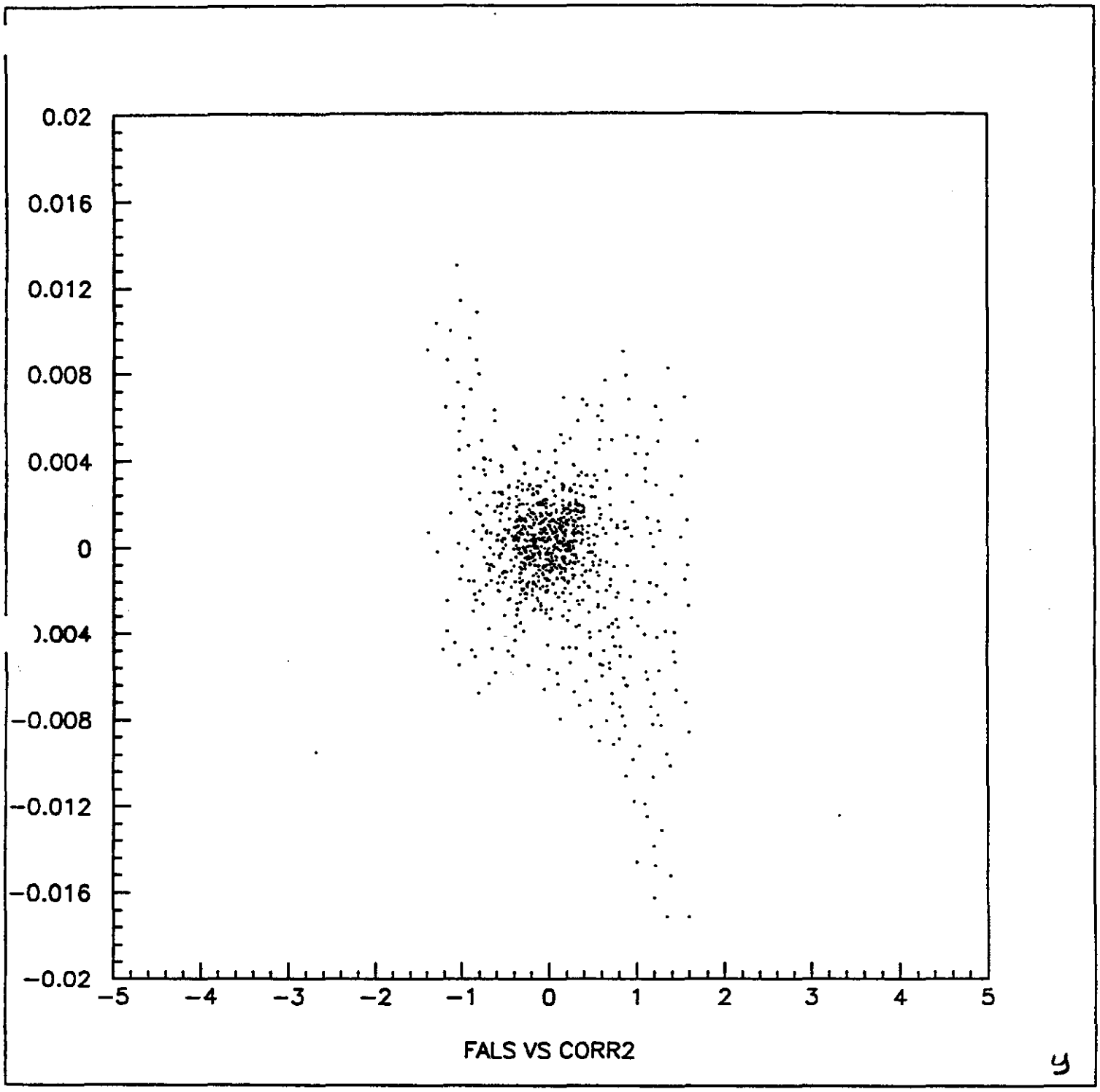


$D_x = \pm 1$ cm; $D_y = \pm 1$ cm; $D_z = \pm 1$ cm; $S_x = \pm 3$ mrad; $S_y = \pm 3$ mrad; $S_z = 3$ mra

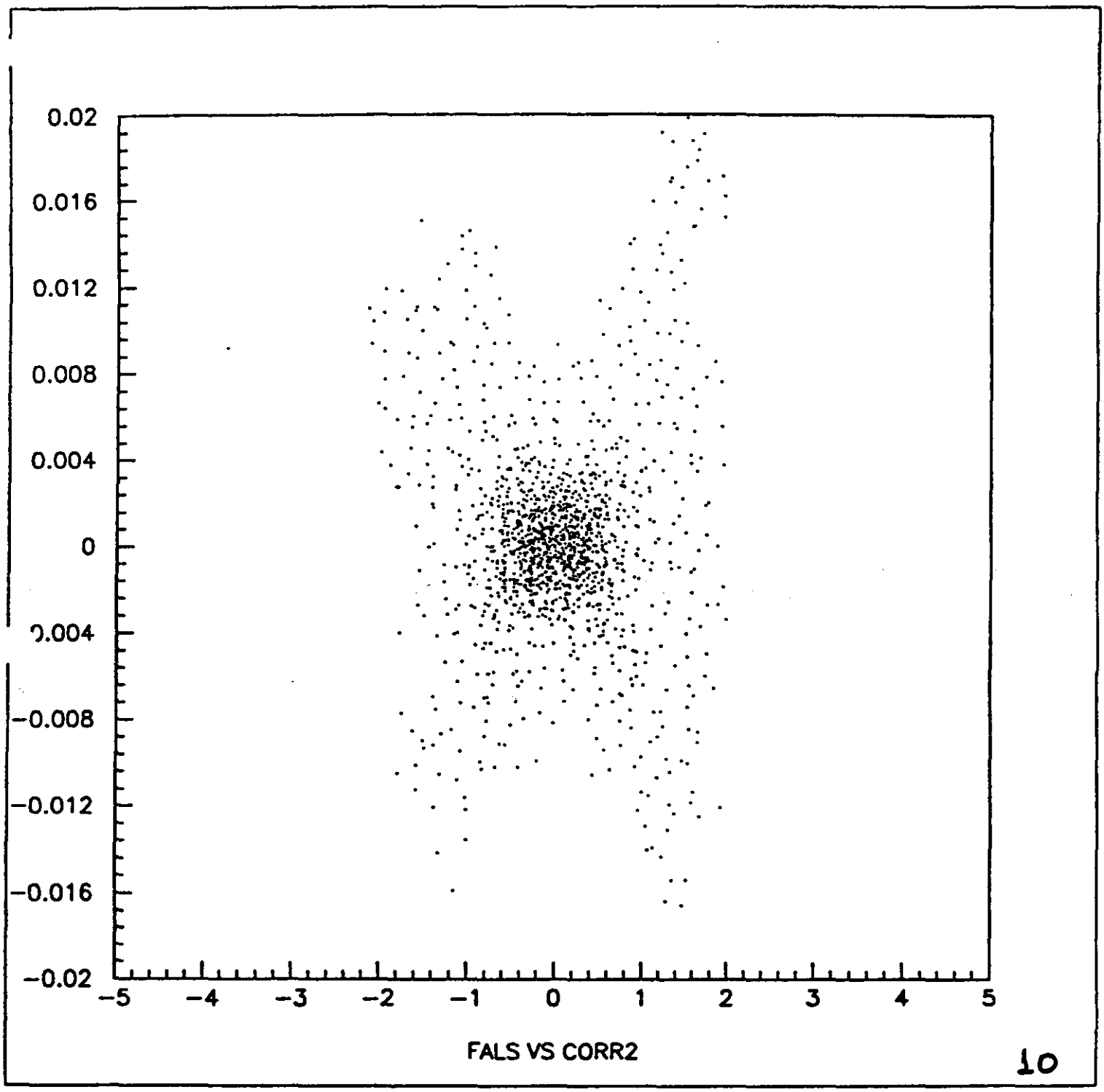
All movements and rotations 1/cm
quadratic interpolation



All movements + rotations ± 0.5cm
quadratic interpolation



$D_x = \pm 0.5$cm ; $D_y = \pm 0.5$cm ; $D_z = \pm 0.5$cm ; $S_x = \pm 3$mrad ; $S_y = \pm 3$mrad ; $S_z = \pm 3$mm



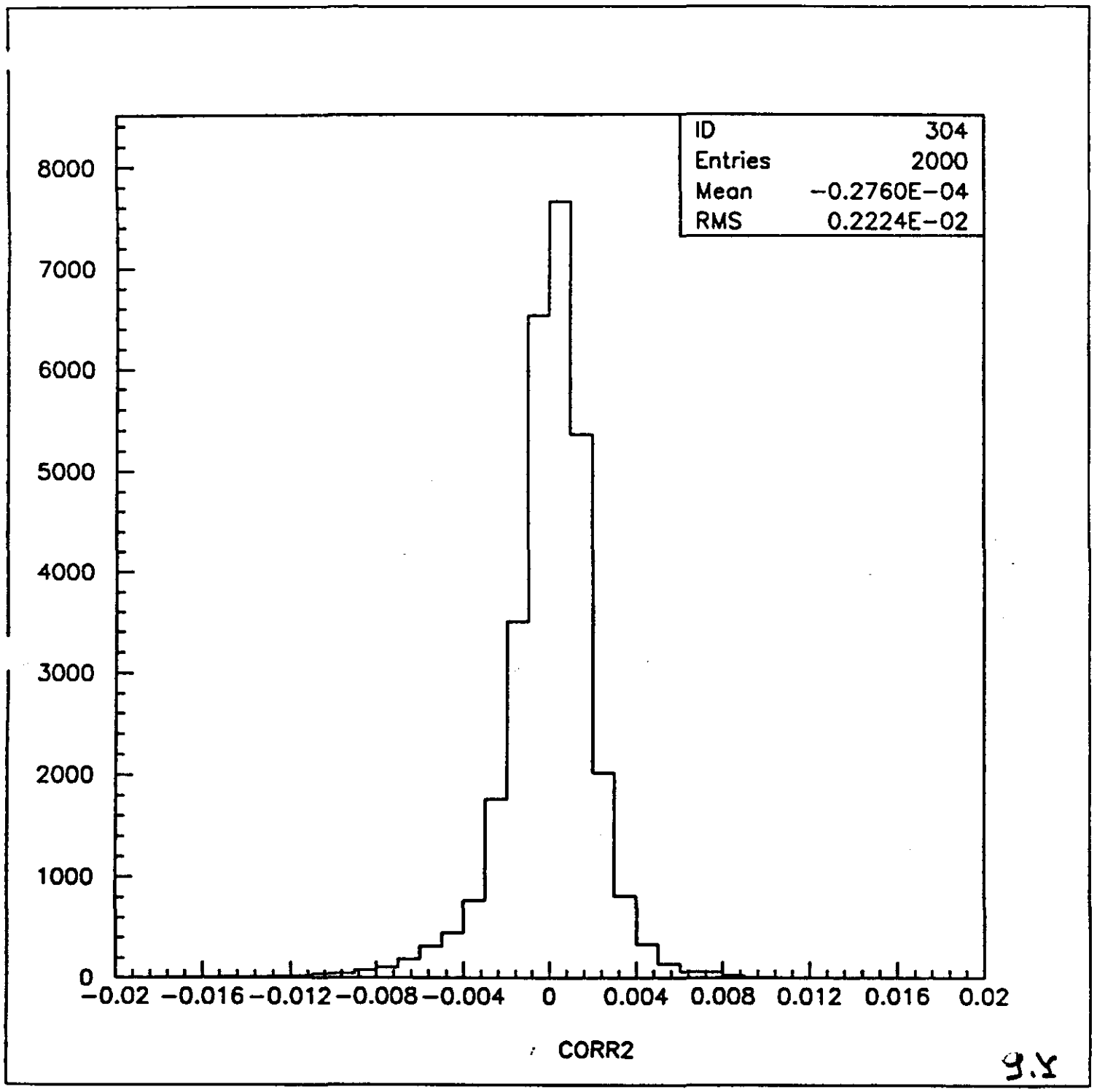
10

$D_x = \pm 0.5$ cm; $D_y = \pm 0.5$ cm; $D_z = \pm 0.5$ cm; $S_x = \pm 3$ mrad; $S_y = \pm 3$ mrad; $S_z = 23$ mm

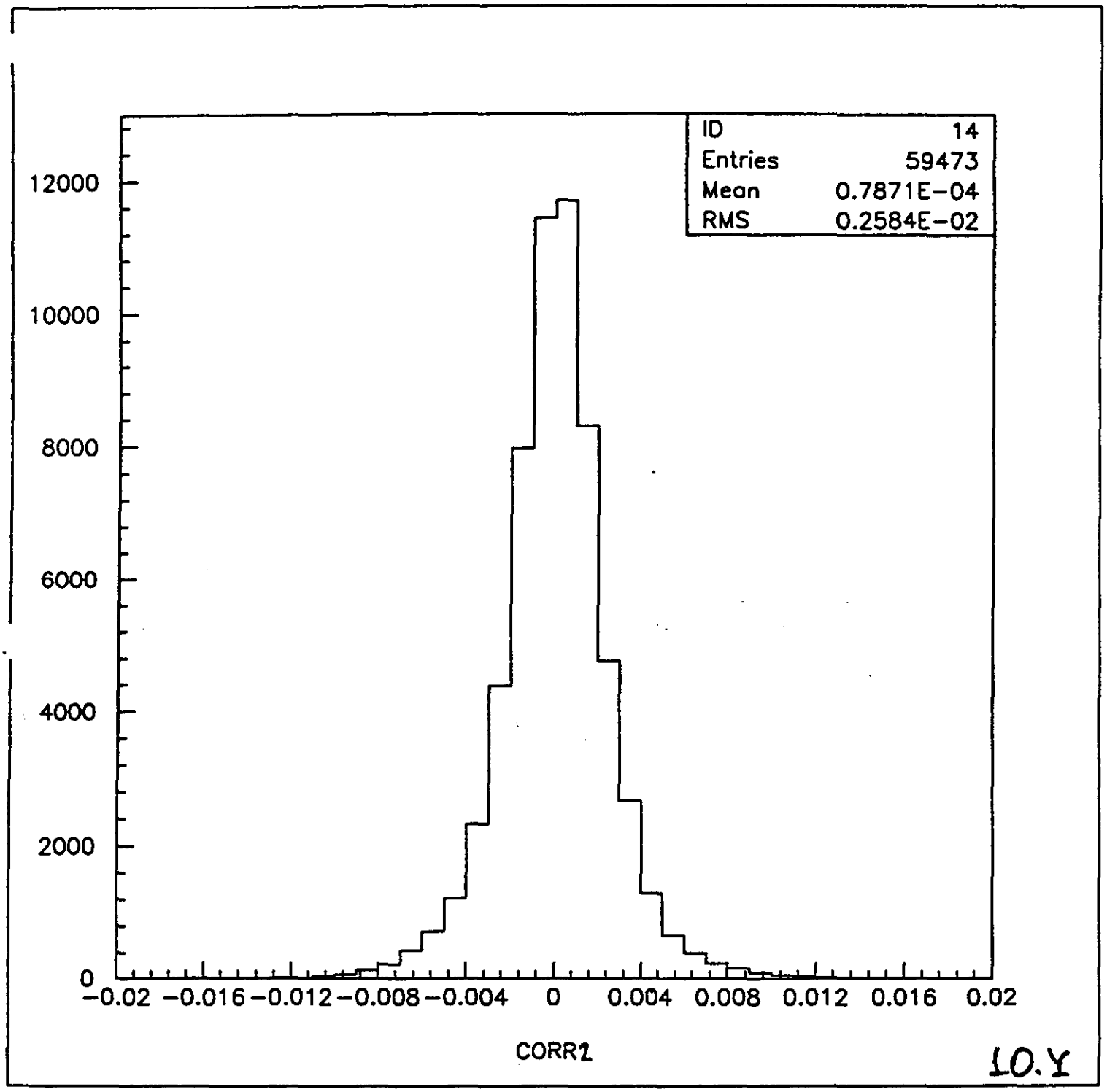
$\Delta^x_{IP} = \pm 1$ cm

$\Delta^z_{IP} = \pm 5$ cm

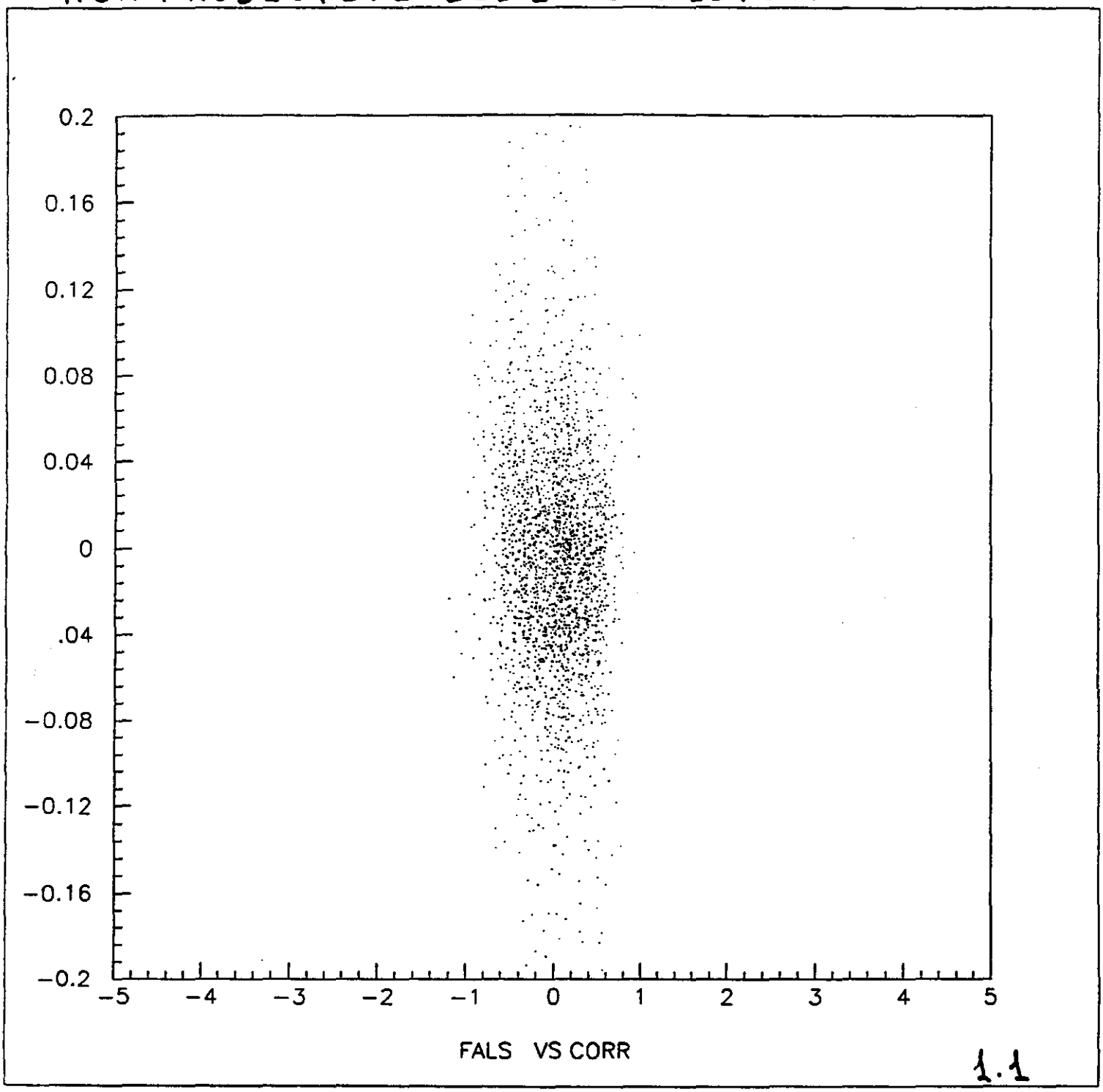
All movement and rotations ± 5mm
quadratic interpolation



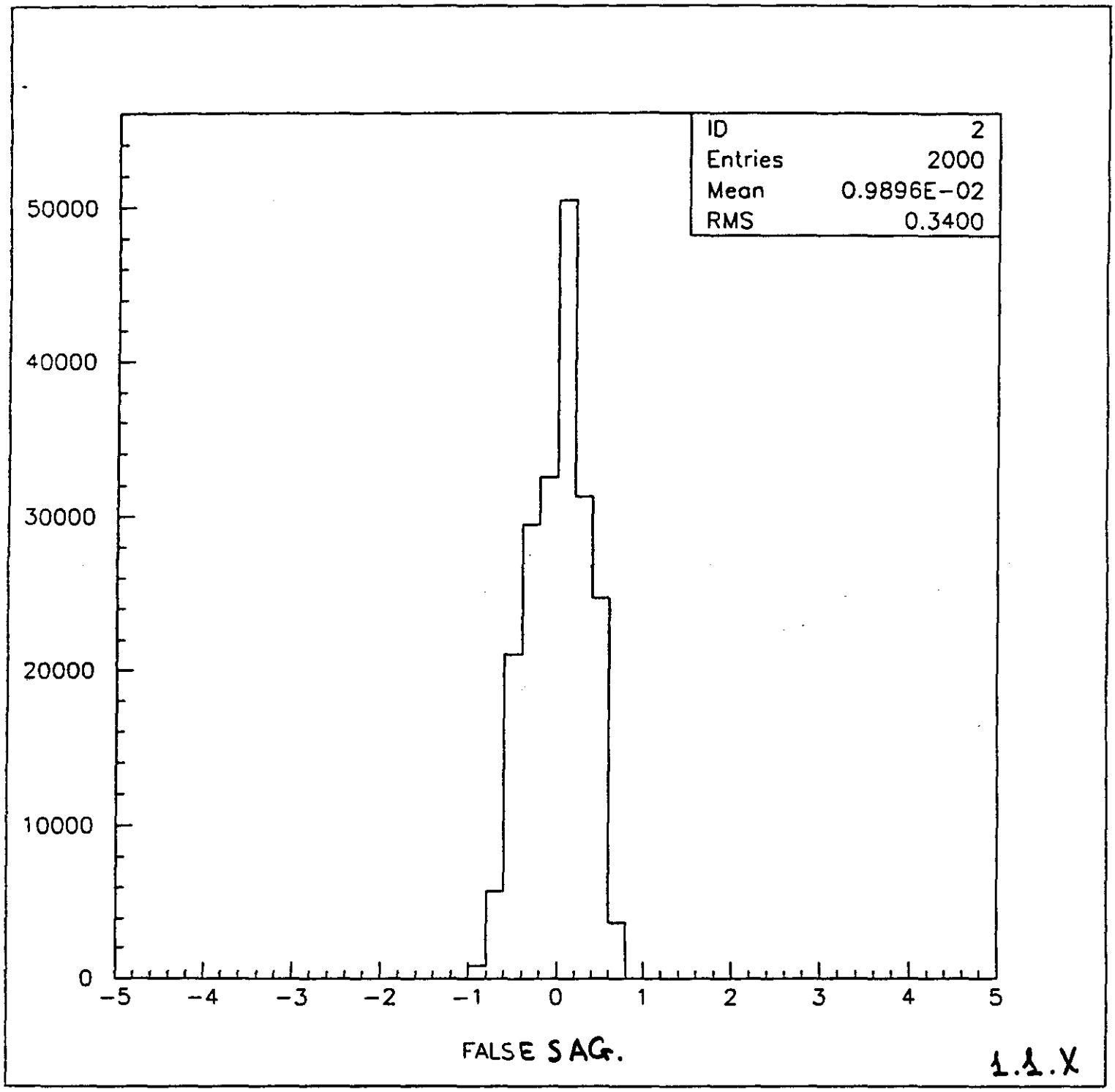
+ $\Delta Z_{IP} = \pm 50mm$, $\Delta X_{IP} = \pm 10mm$

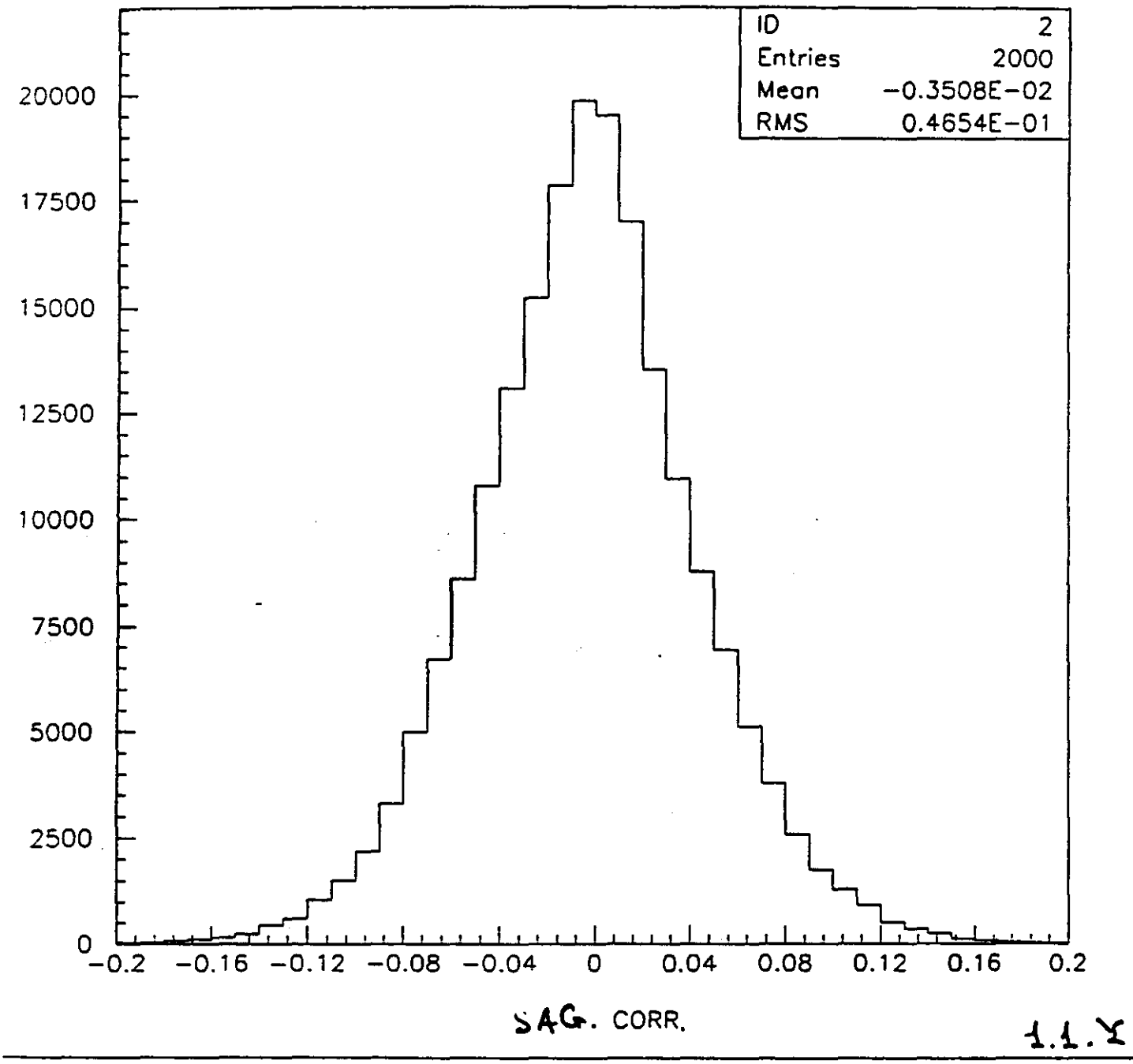


NON PROJECTIVE LEDLENS SYSTEM



$D_x = \pm 0.5$ cm ; $D_y = \pm 0.5$ cm ; $D_z = \pm 0.5$ cm ; $S_x = \pm 1$ mrad ; $S_y = \pm 1$ mrad ; $S_z = \pm 1$ mra


ID 2
Entries 2000
Mean 0.9896E-02
RMS 0.3400
50000
40000
30000
20000
10000
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
FALSE SAG.
1.1.X


ID 2
Entries 2000
Mean −0.3508E−02
RMS 0.4654E−01
20000
17500
15000
12500
10000
7500
5000
2500
0
−0.2 −0.16 −0.12 −0.08 −0.04 0 0.04 0.08 0.12 0.16 0.2
SAG. CORR.
1.1.Y

Igor Golutuin/Dubna-SSCL

EFFORTS IN DUBNA

G.E.C. MEETING, MIT, 07/03/92

THERE ARE THREE ACTIVITIES GOING ON IN DUBNA

1. THE MAJOR EFFORT IS PDT MODULE CONSTRUCTION AND TEST (IN COLLABORATION WITH ITEP/MOSCOW)

1.1. THE CONSTRUCTION HAS ALREADY BEEN COMPLETED.

MODULE WAS TESTED WITH 6 ATM.

MODULE CONSISTS OF TWO PARTS

0.5 M × 4.0 M EACH

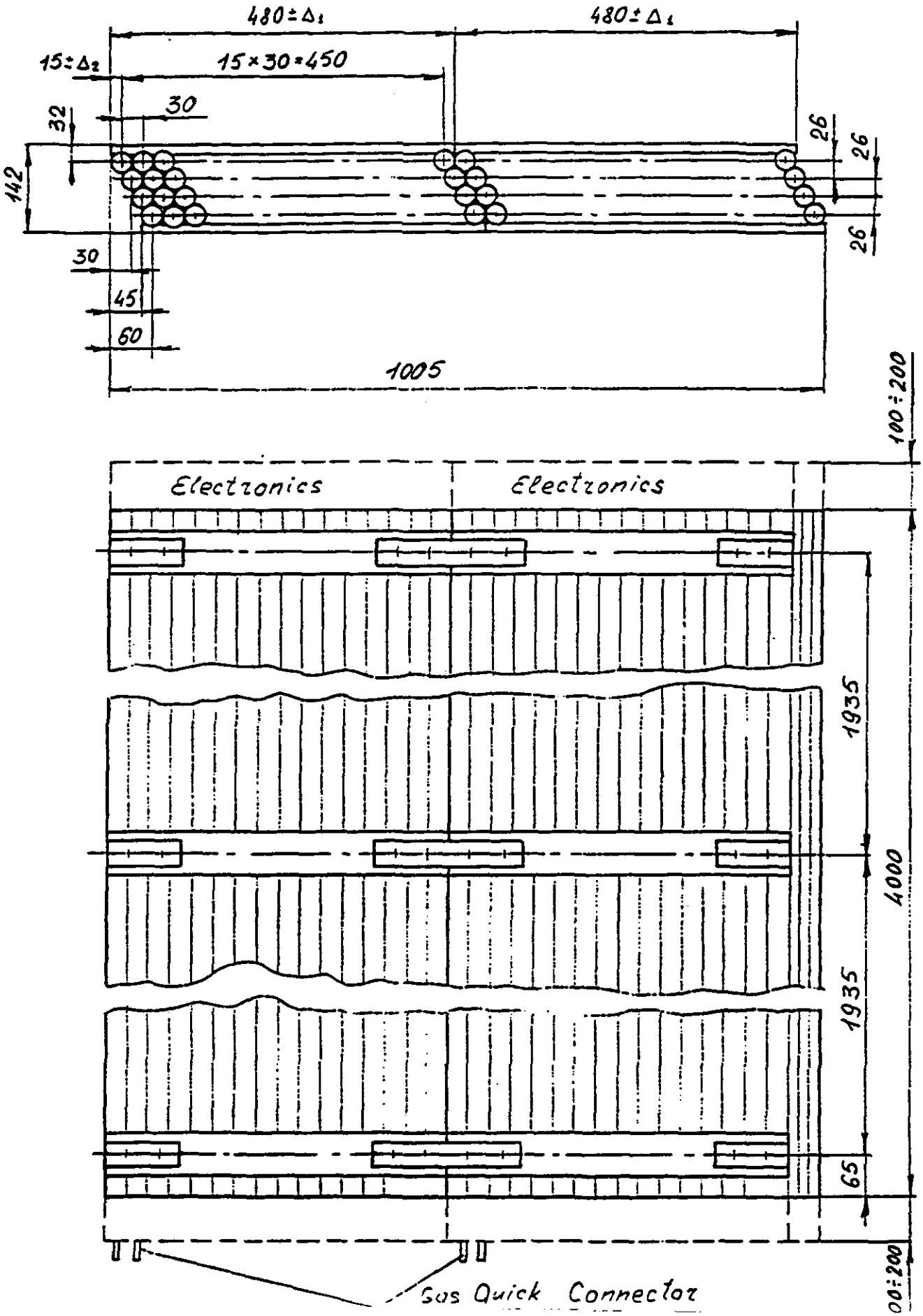
EACH PART MADE OF 64 PDT Ø 3 CM

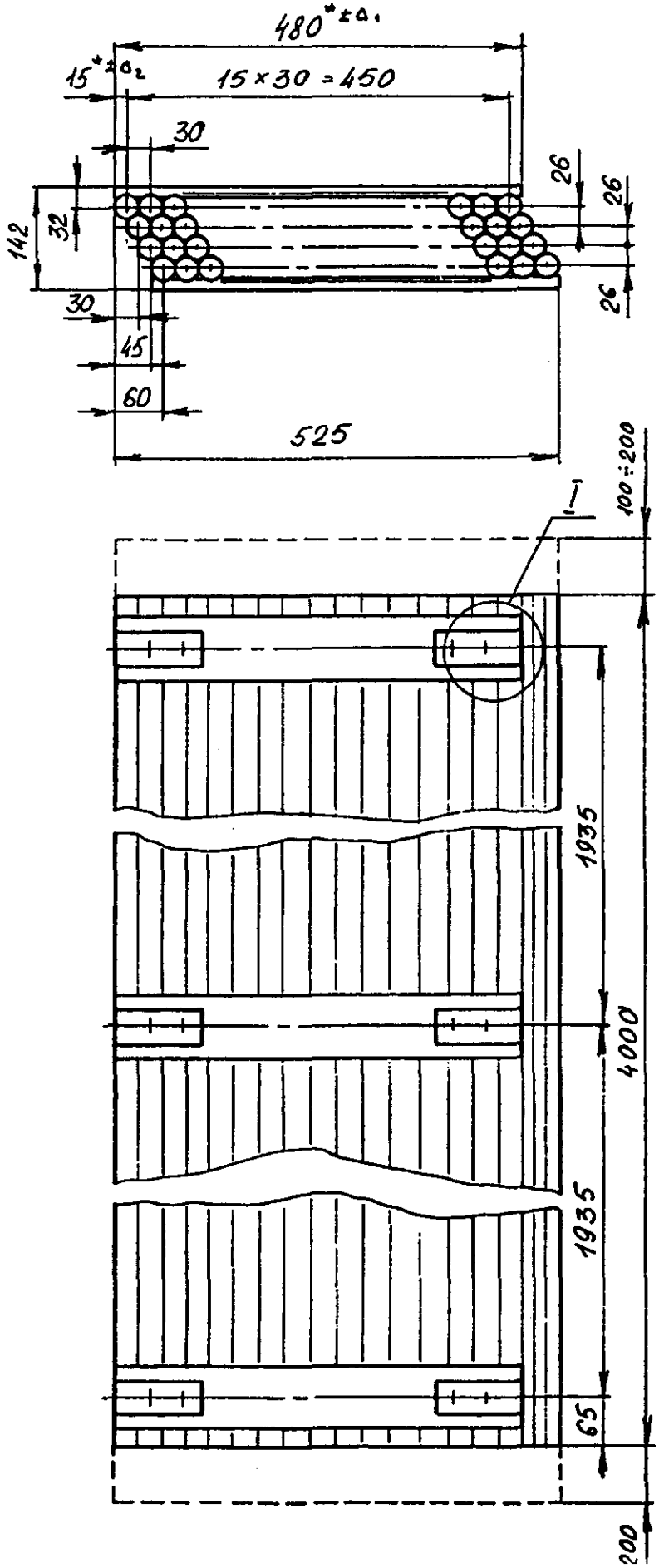
ARRANGED IN 4 LAYERS

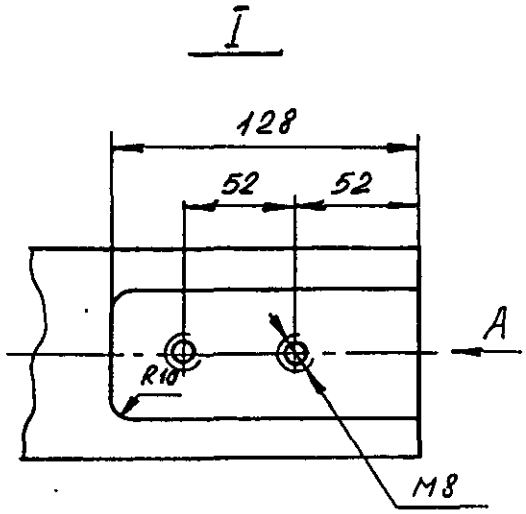
1.2. READ OUT ELECTRONICS WAS DESIGNED AND CONSTRUCTED

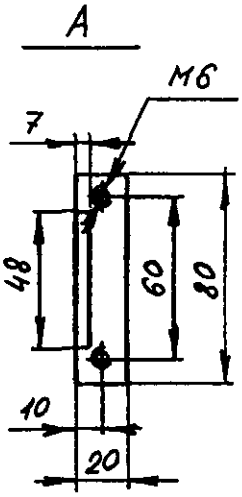
IT CONSISTS OF ON-BOARD PREAMPLIFIERS (128 INDIVIDUAL CHANNELS) AND REMOTE (10-20 M) 8 INPUT CAMAC DISCRIMINATOR UNITS (16 UNITS)

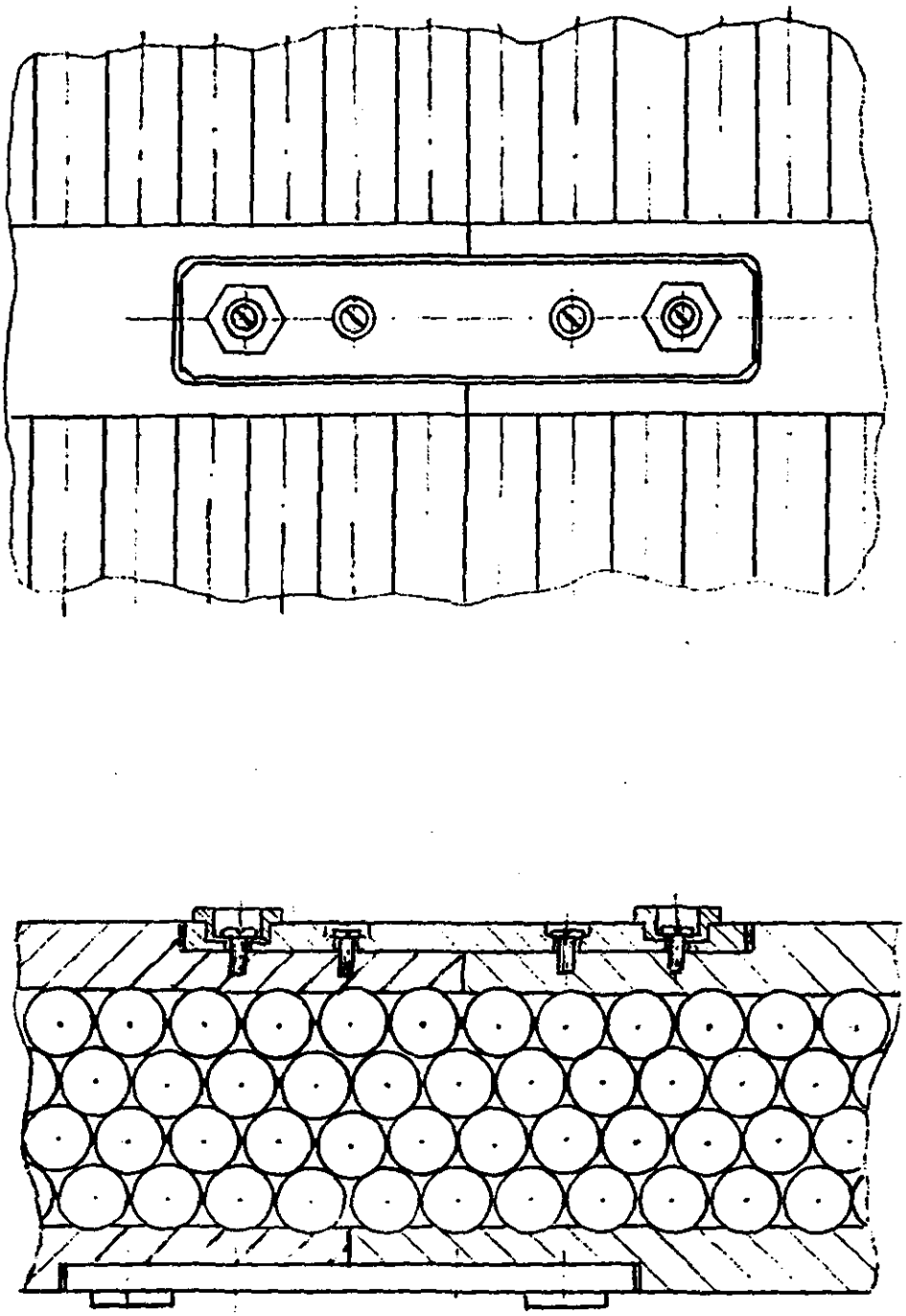
1.3. PDT MODULE FULLY INSTRUMENTED WITH ELECTRONICS WILL BE SHIPPED BY AIR ON JULY, 14.


480±Δ1
480±Δ1
15±Δ2
15×30=450
30
32
142
26
26
26
30
45
60
1005
100÷200
Electronics
Electronics
1935
4000
1935
65
100÷200
Gas Quick Connector


480*±Δ1
15*±Δ2
15×30=450
30
26
26
142
32
26
30
45
60
525
100÷200
I
1935
4000
1935
65
200


I
128
52
52
A
R10
M8


A
M6
7
48
60
80
10
20



Module stack
102

1.4. 1 HARDWARE PHYSICIST (S. MOUCHAN) AND TWO ENGENEERS (V. LYSIAKOV AND YU. ERSHOV) WILL ARRIVE ON THE MODULE TO PUT IT IN OPERATION AND CARRY OUT TESTS ON TTR.

LYSIAKOV AND ERSHOV ALSO CAN TAKE PART IN THE INTEGRATION MUON CHAMBERS IN THE DETECTOR. (NO MATTER WHICH TYPE OF MUON CHAMBER WILL BE CHOSEN BY THE GEM COLLABORATION)

2. THE SECOND PRIORITY EFFORT IS DEVELOPMENT OF FRONT-END READOUT ELECTRONICS FOR CSCs

2.1. THE LONG TERM GOAL IS TO DESIGN IN COLLABORATION WITH BYELORUSSIAN STATE UNIVERSITY (MINSK) AND BYELORUSSIAN INDUSTRY A CHEAP MONOLITICAL CIRCUIT WHICH COMPRISE A CHARGE-SENSITIVE PREAMPLIFIER, A SLOW-SHAPING AMPLIFIER FOR THE READOUT PATH, AND A FAST-SHAPING AMPLIFIER FOR THE TRIGGER PATH

2.2. PROVISIONAL TECHNICAL SPECIFICATIONS

READOUT PATH:

INPUT NOISE: 3000 e (RMS) 100 pF $\tau = \mu$sec

SHAPING TIME: 1.0 / 0.2 μsec

CROSS-TALK: < -50 db

CONVERSION GAIN: 5 mV/pC

INTEGRAL NONLINEARITY: < 0.5% AFTER CORRECTION

MAX INPUT: 200 fC

TRIGGER CHANNEL: (⇒ LRS MVL 407)

INPUT THRESHOLD: 16 fC

TIME JITTER: < 4 nsec (RMS) for Q_{in} > 10 fC

TIME WALK: < 4 nsec 2x-10x THRESH.

2.3. THE DESIGNING WORK HAS ALREADY BEEN STARTED

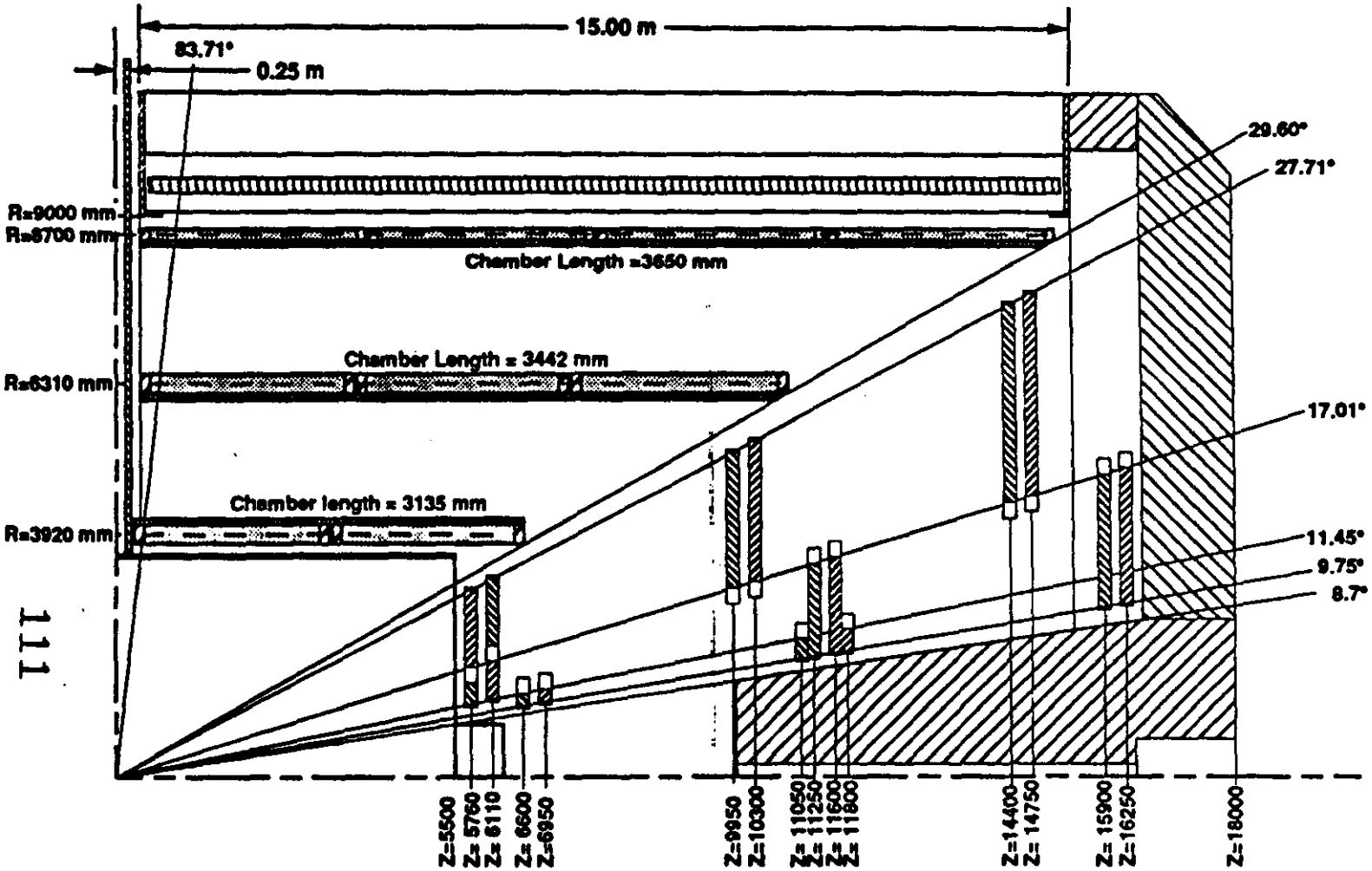
- 50 chips will be produced in Minsk by march-april 92
- 16 32 INPUT CARDS WILL BE CONSTRUCTED BY AUGUST 92 USING DESCRETE COMPONENTS

1 CARD ALREADY PRODUCED AND TESTET IN DUBNA

3. THE NEXT PRIORITY EFFORT IS DESIGN AND CONSTRUCTION OF ~1.5M × 1.0M C.S.C. PROTOTYPE

THIS PROTOTYPE WILL BE FULLY INSTRUMENTED AND SHIPPED 4-6 WEEKS AFTER RECEIVING CATHODE G-10 PLANES.

Frank Nimblett/Draper

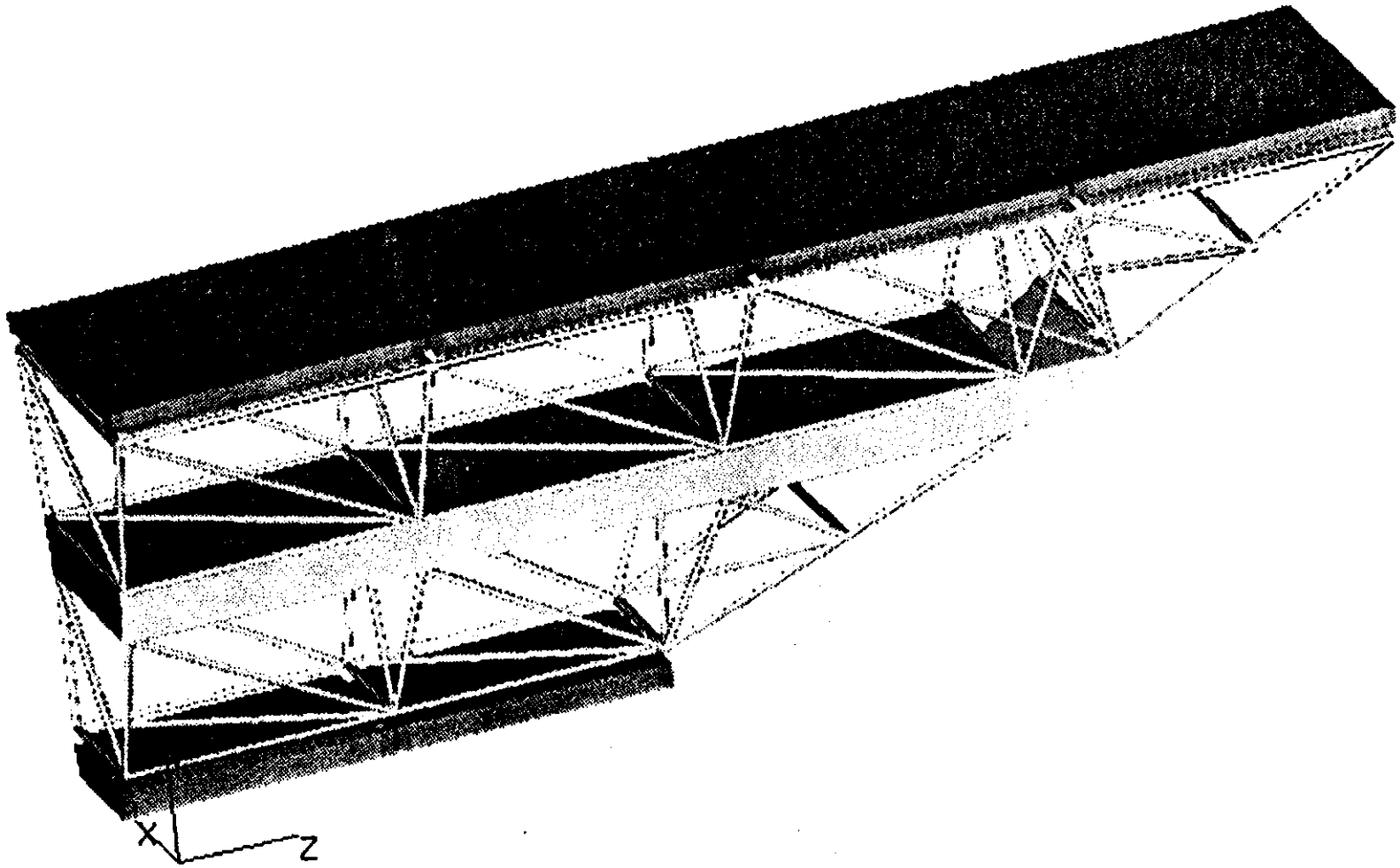


GEM MUON SYSTEM CHAMBER LAYOUT
BASELINE I
(2,3,4 PDT Chambers per Layer)

Draper Laboratory	
GEM Muon System PDT Baseline Chamber Layout	
Drawn By: F. Nimblett	Rev (-)
Dwg. No: GMU0014	6/30/92
Approved by:	

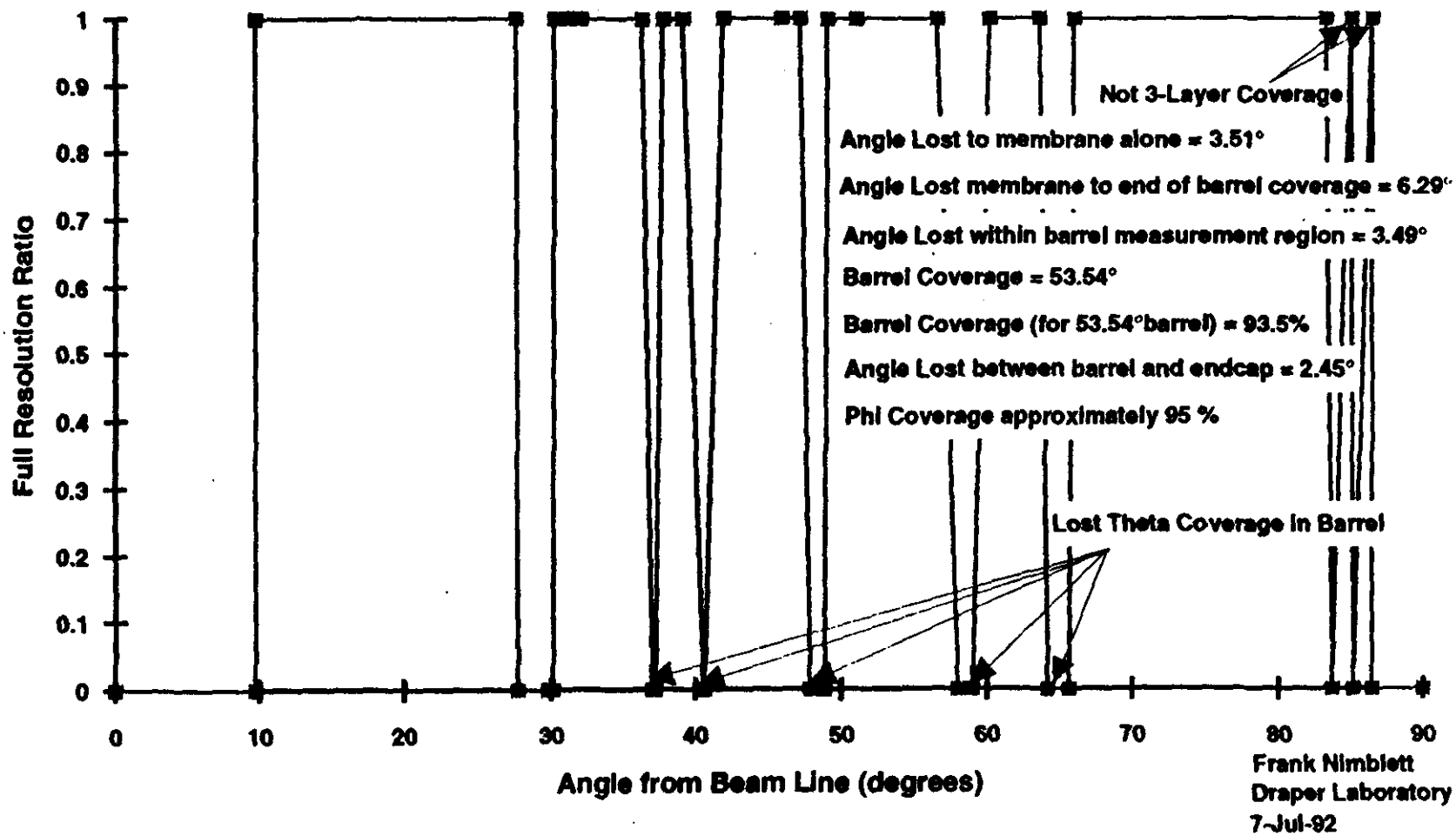
GEM BARREL REGION

MUON MODULE



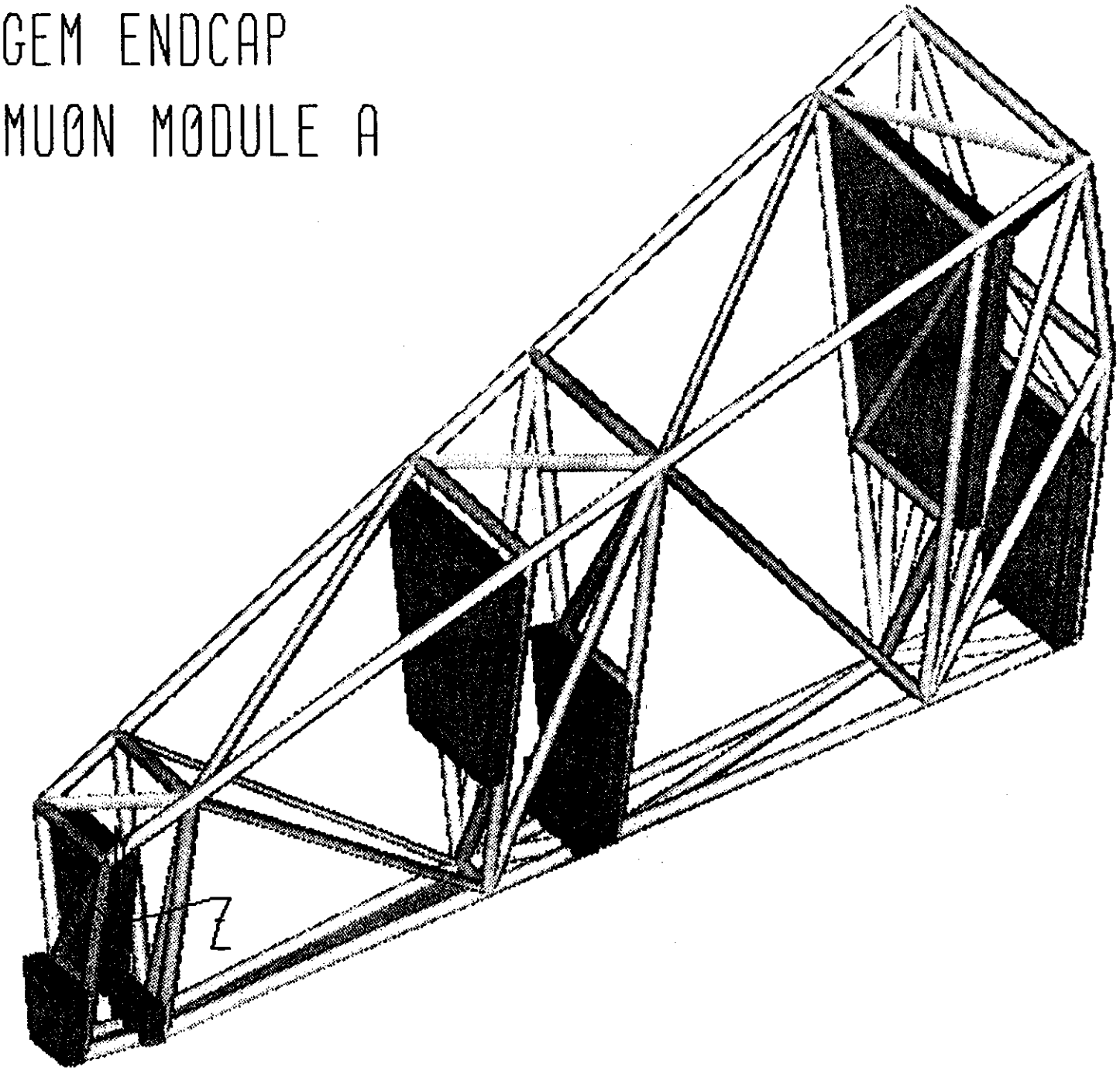
Theta Coverage for 2,3,4 PDT Chambers per Layer (Non-Projective)

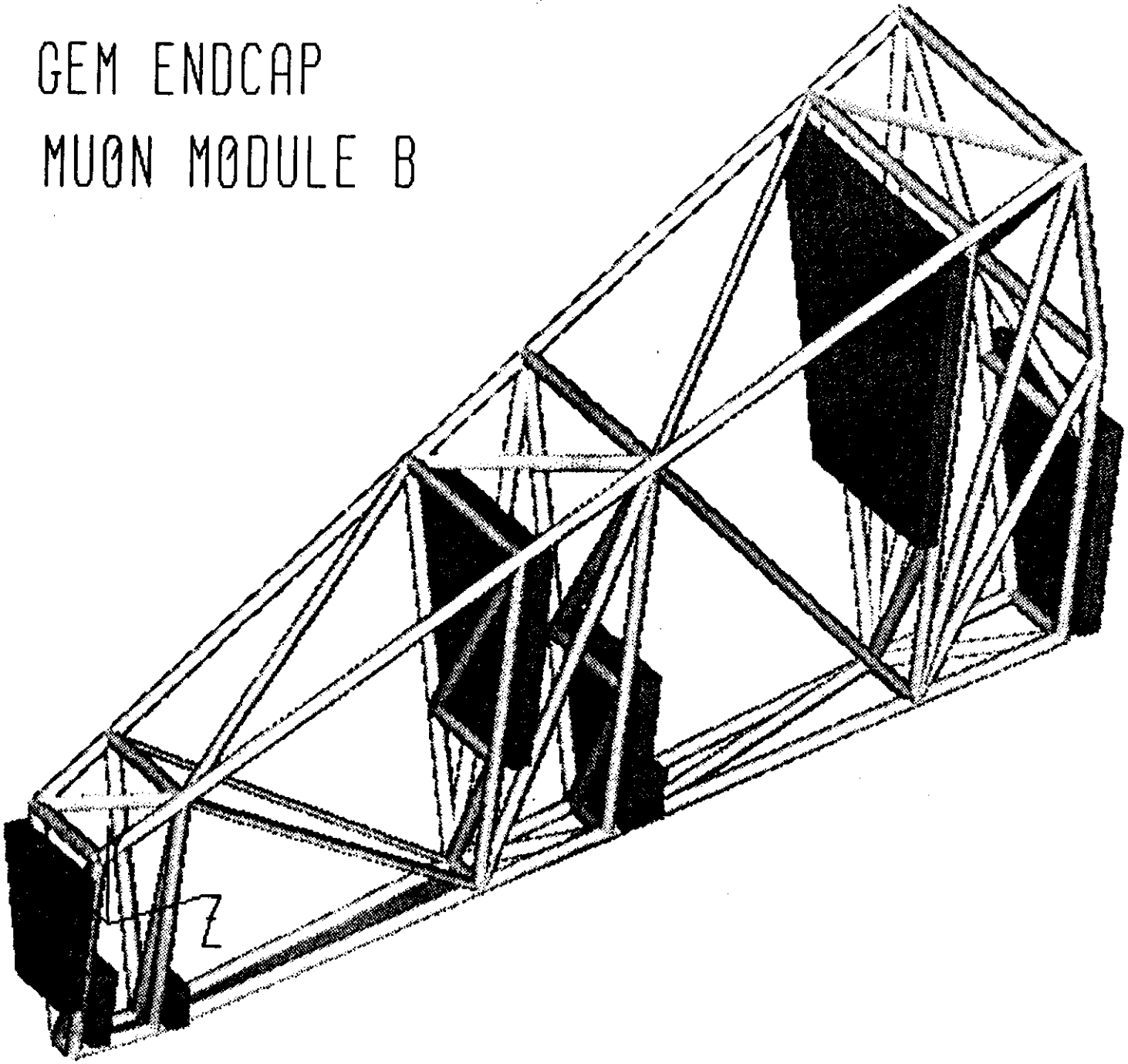
Mechanics on Chamber Ends is 150 mm and space between Chambers is 50 mm



Frank Nimblett
Draper Laboratory
7-Jul-92

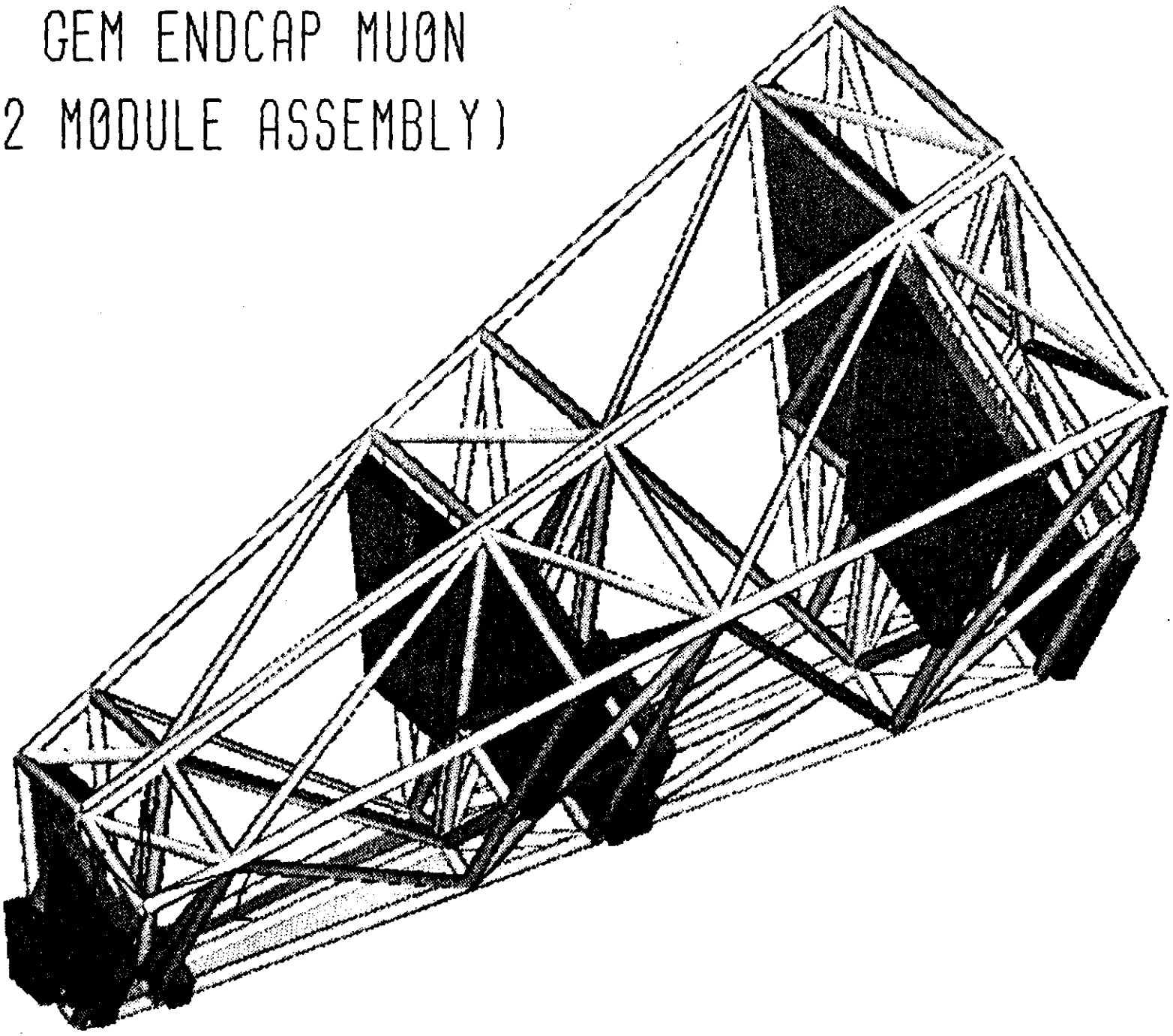
GEM ENDCAP
MUON MODULE A

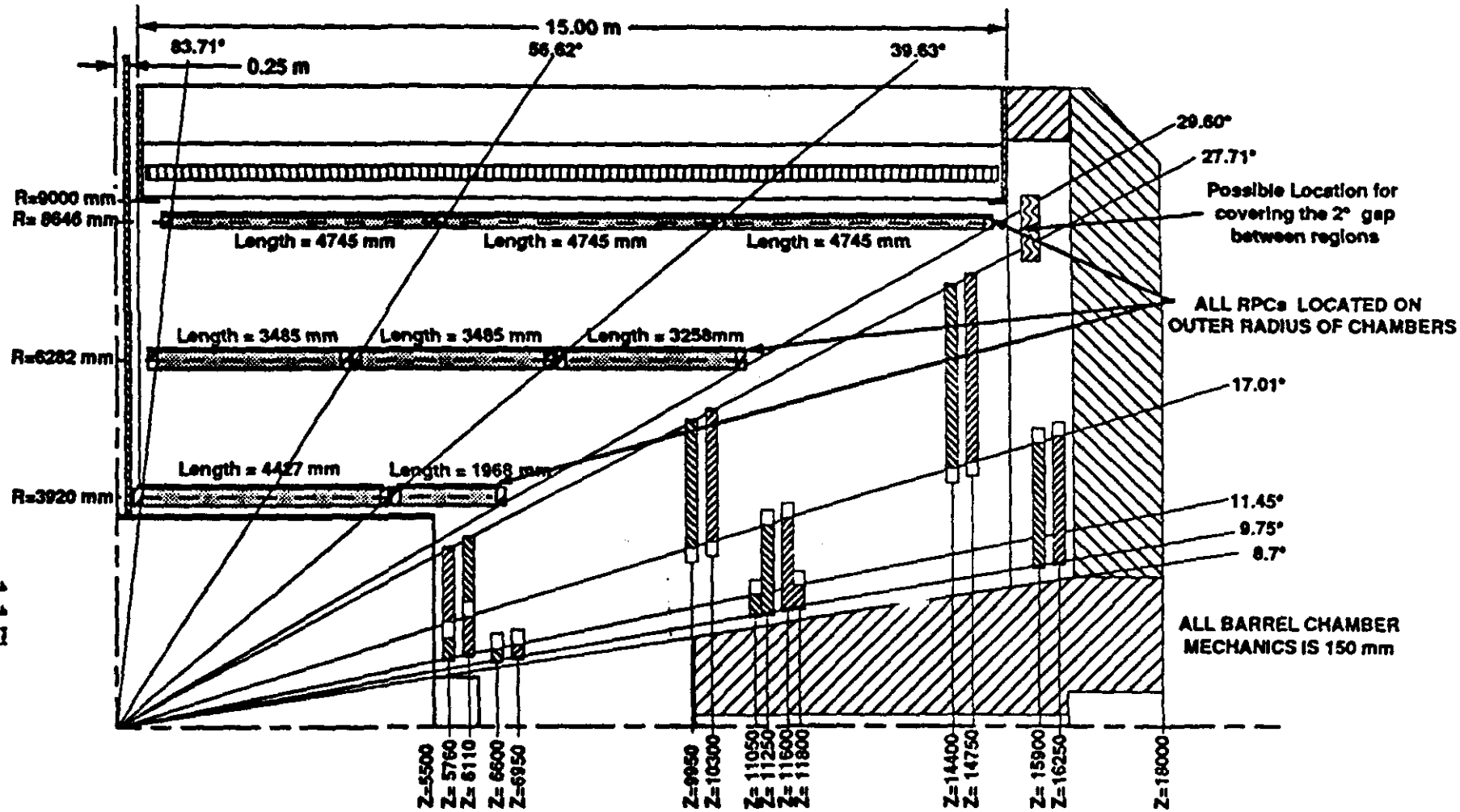



GEM ENDCAP
MUON MODULE B
Z

GEM ENDCAP MUON

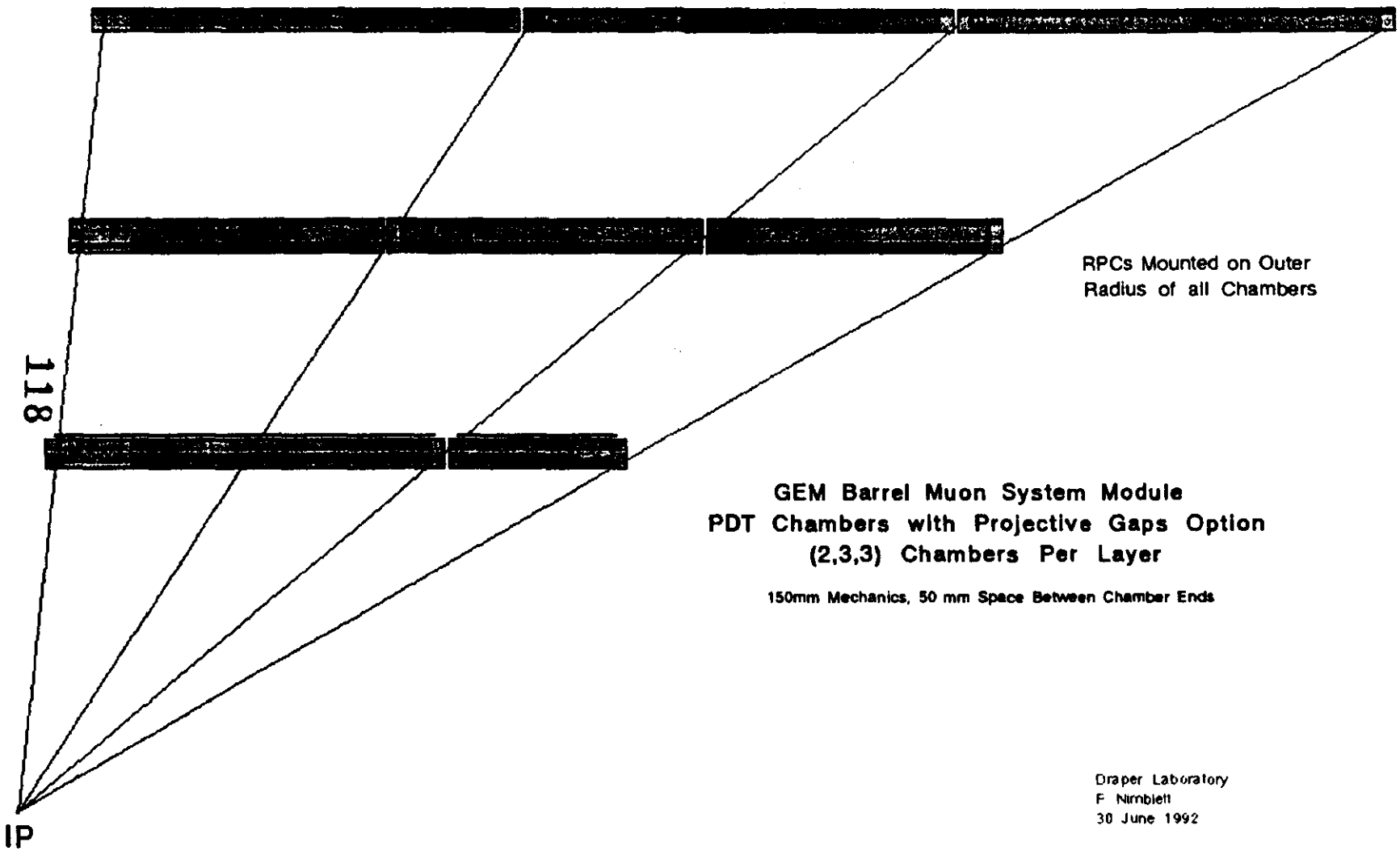
(2 MODULE ASSEMBLY)





GEM MUON SYSTEM CHAMBER LAYOUT
BASELINE II
(2,3,3 Chambers per Layer-PROJECTIVE GAPS)

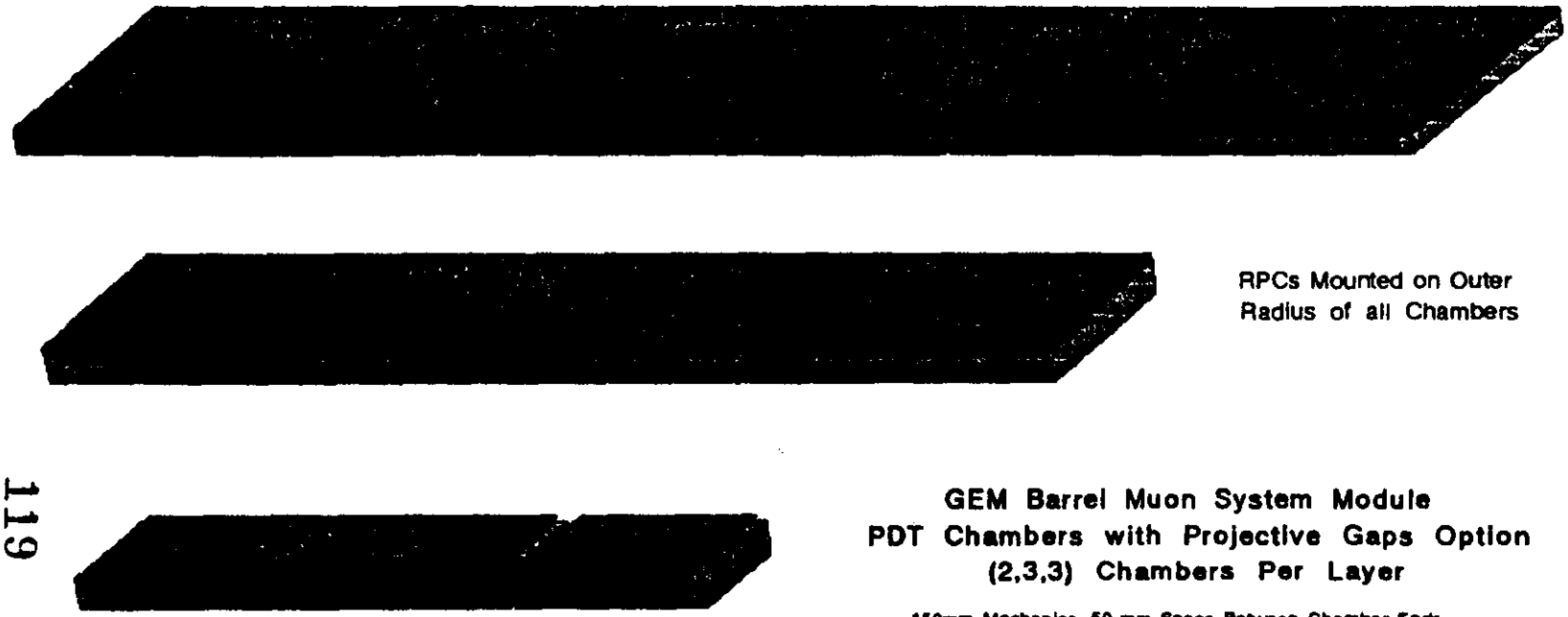
Draper Laboratory	
GEM Muon System Chamber Layout	
Drawn By: F. Nimblett	Rev (-)
Dwg. No: GMU0015	6/30/92
Approved by:	



GEM Barrel Muon System Module
PDT Chambers with Projective Gaps Option
(2,3,3) Chambers Per Layer

150mm Mechanics, 50 mm Space Between Chamber Ends

Draper Laboratory
F. Nimblett
30 June 1992



RPCs Mounted on Outer
Radius of all Chambers

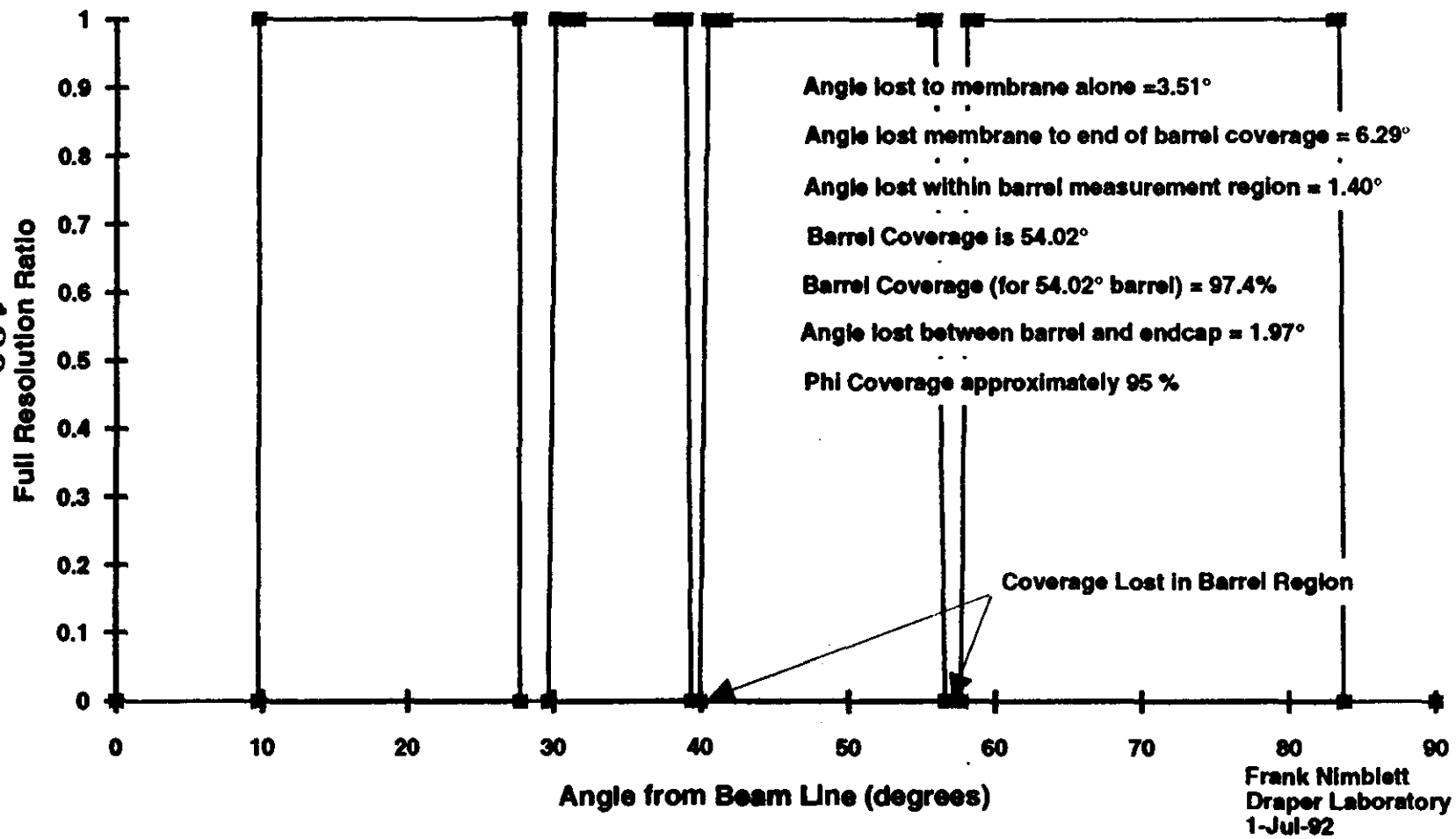
GEM Barrel Muon System Module
PDT Chambers with Projective Gaps Option
(2,3,3) Chambers Per Layer

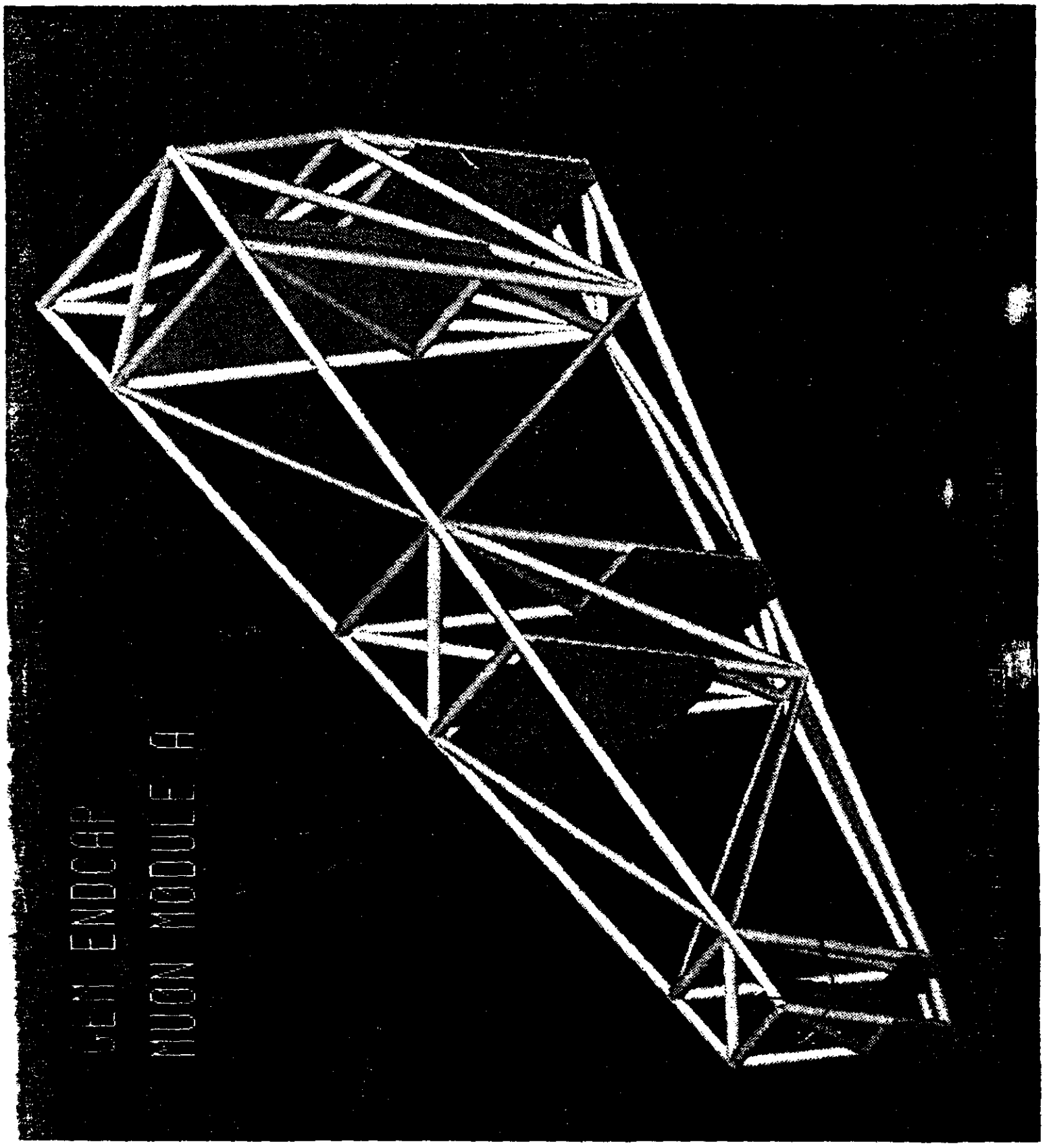
150mm Mechanics, 50 mm Space Between Chamber Ends

Draper Laboratory
F. Nimblett
30 June 1992

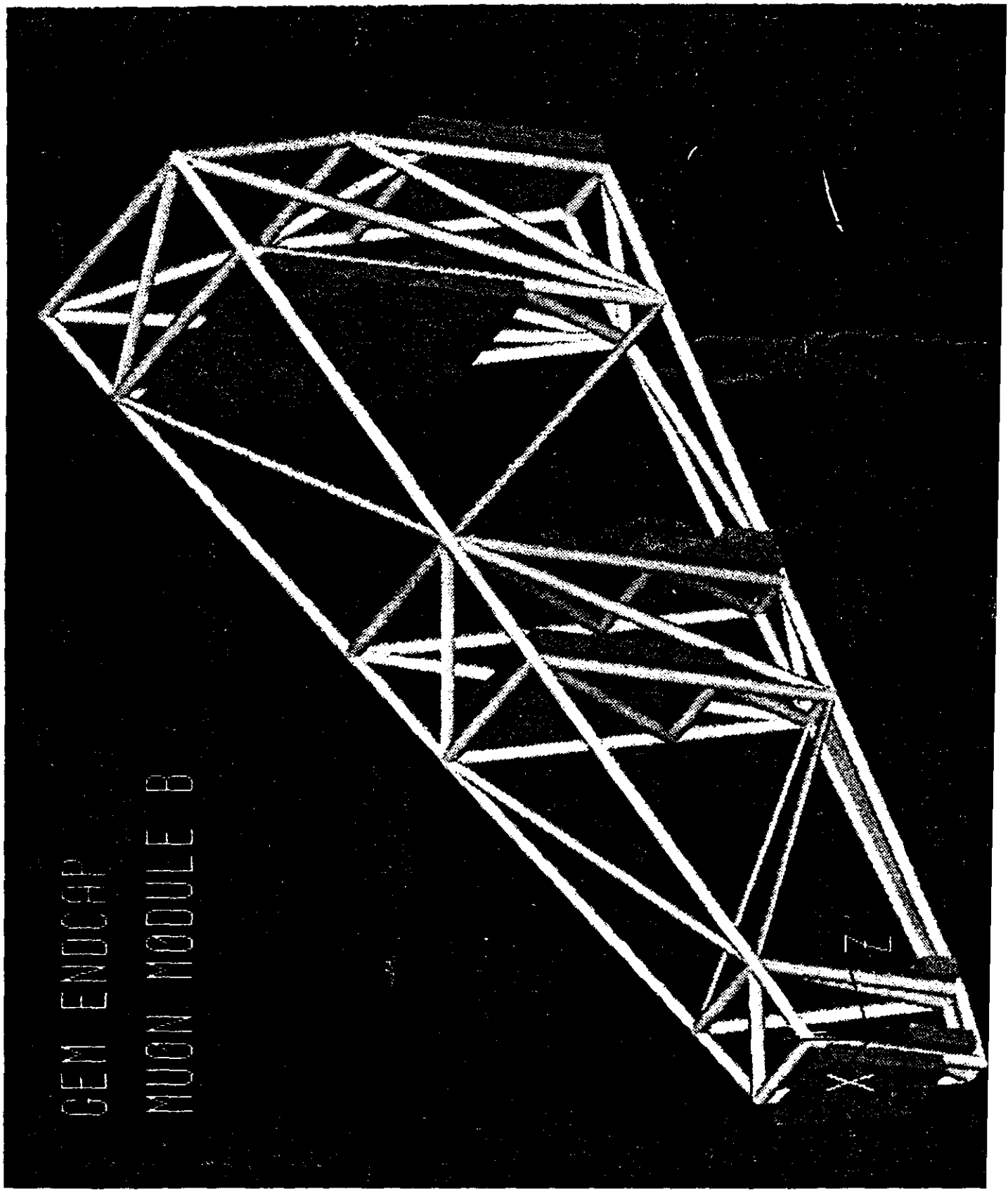
Theta Coverage for 2,3,3 PDT Chambers per Layer (Projective)

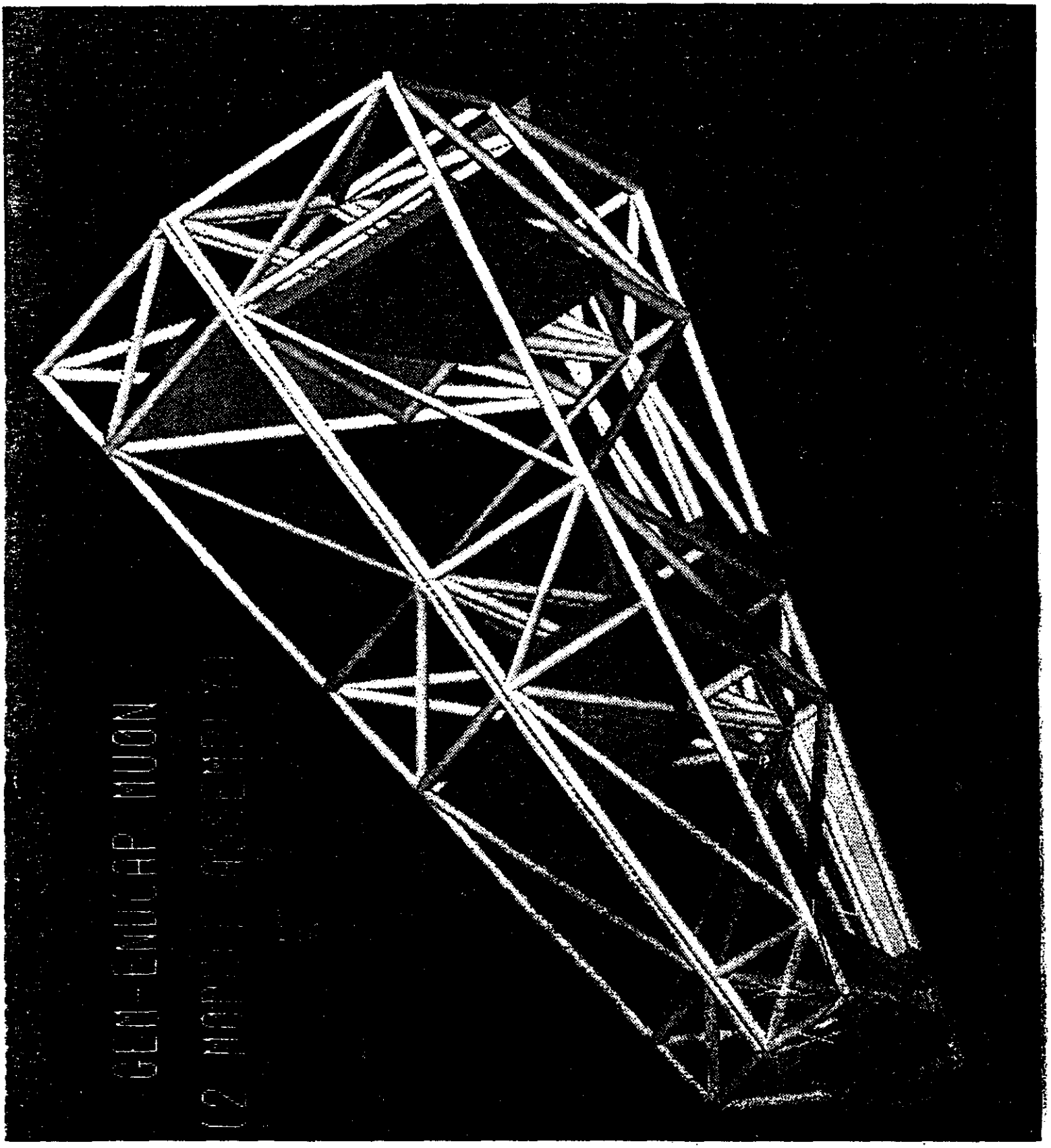
Mechanics on Chamber Ends is 150 mm and space between Chambers is 50 mm



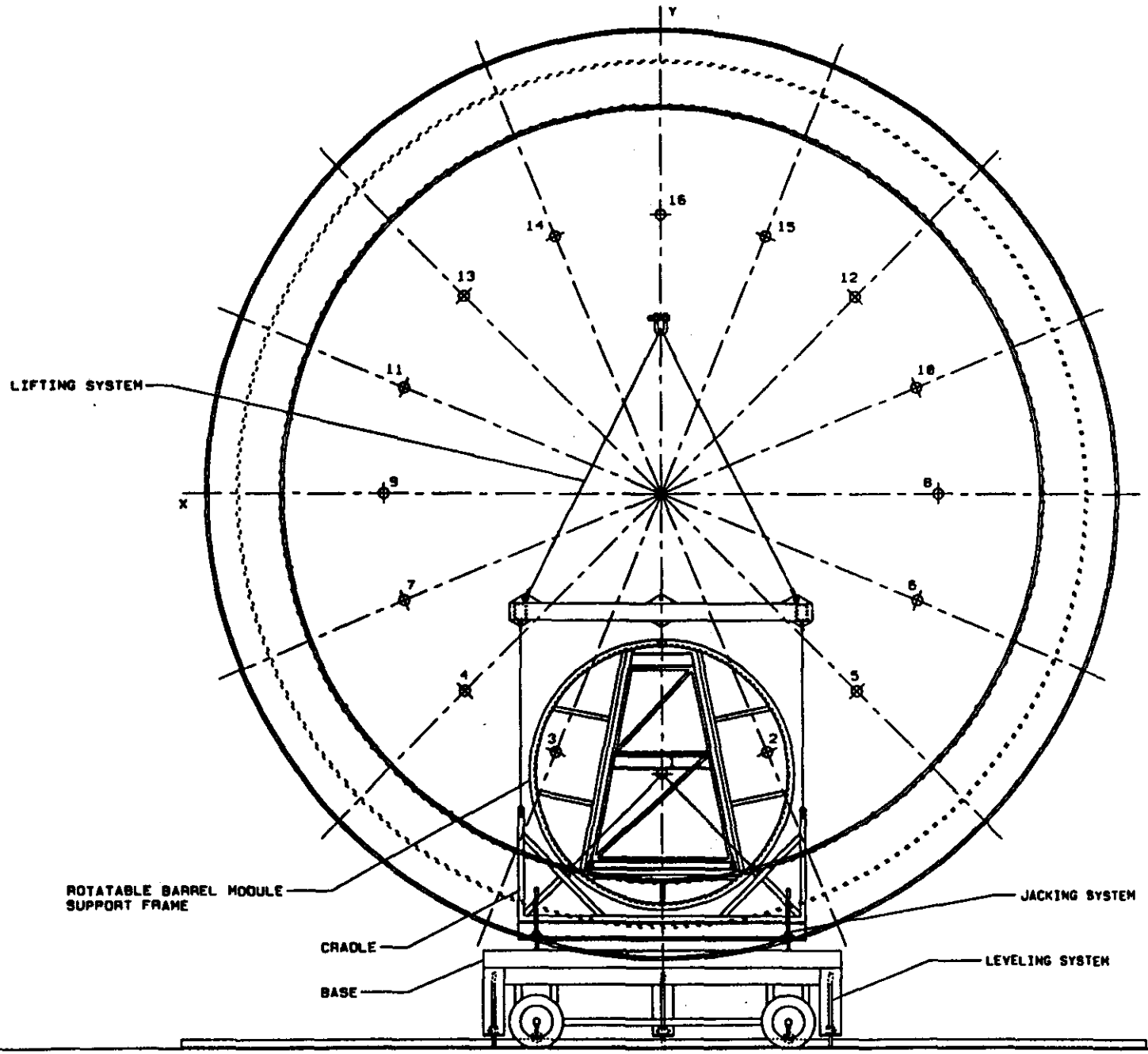

GEM ENDCAP
MOON MODULE A

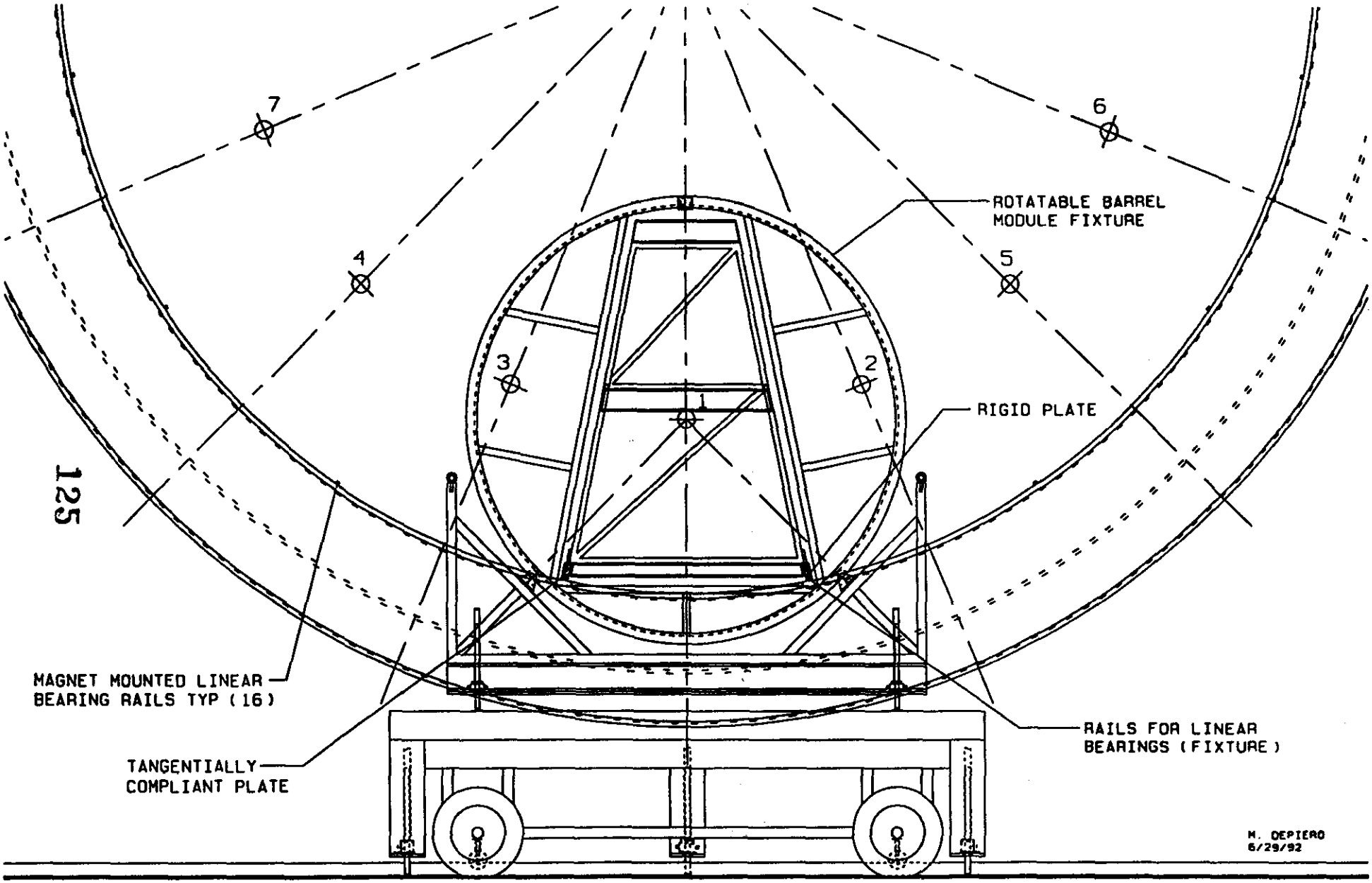
C-LINE # 62000




GEM-EMULAP MUON

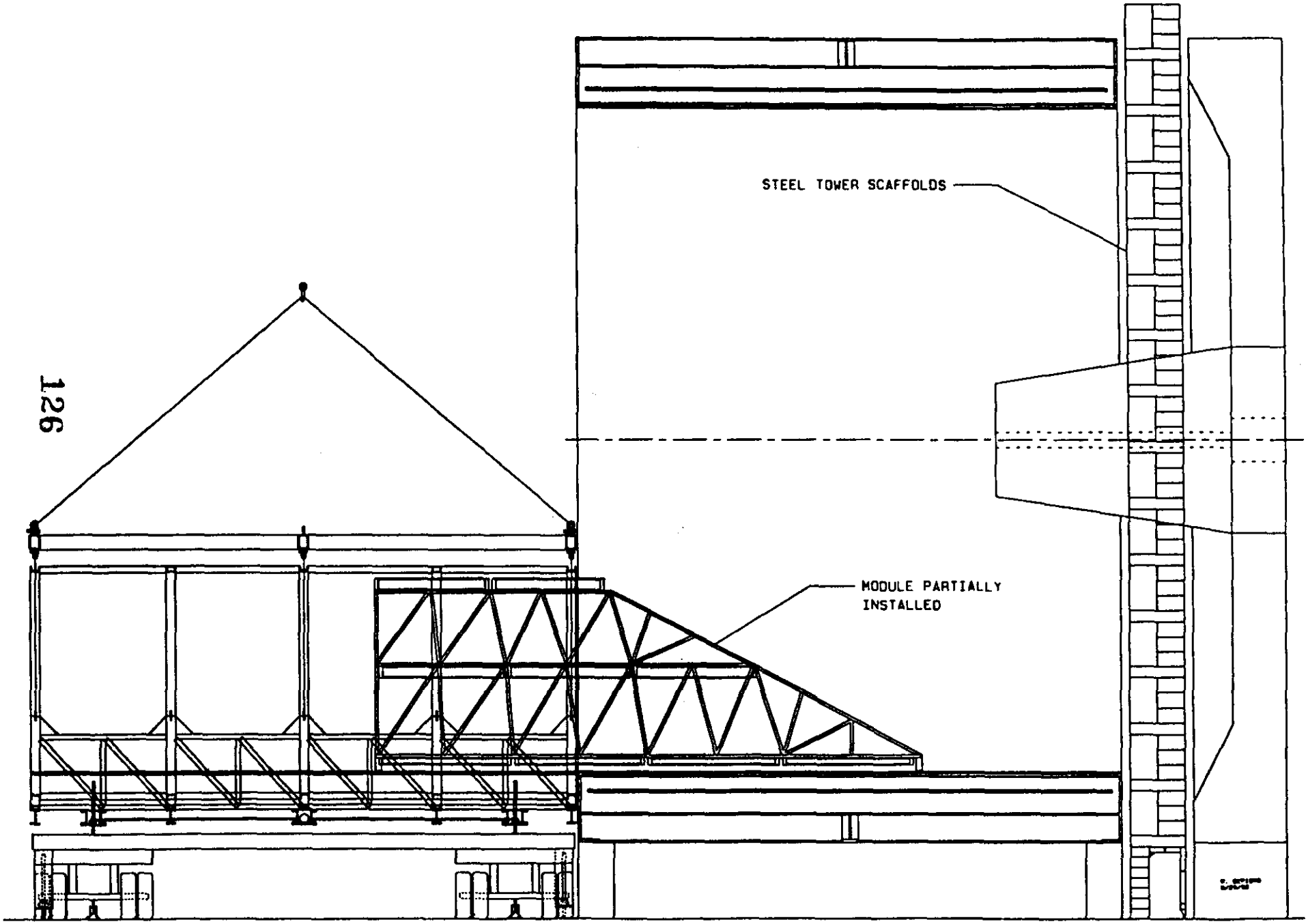
BARREL REGION INSTALLATION
(MODULE IN FRAME LOWERED ONTO INSTALLATION FIXTURE)



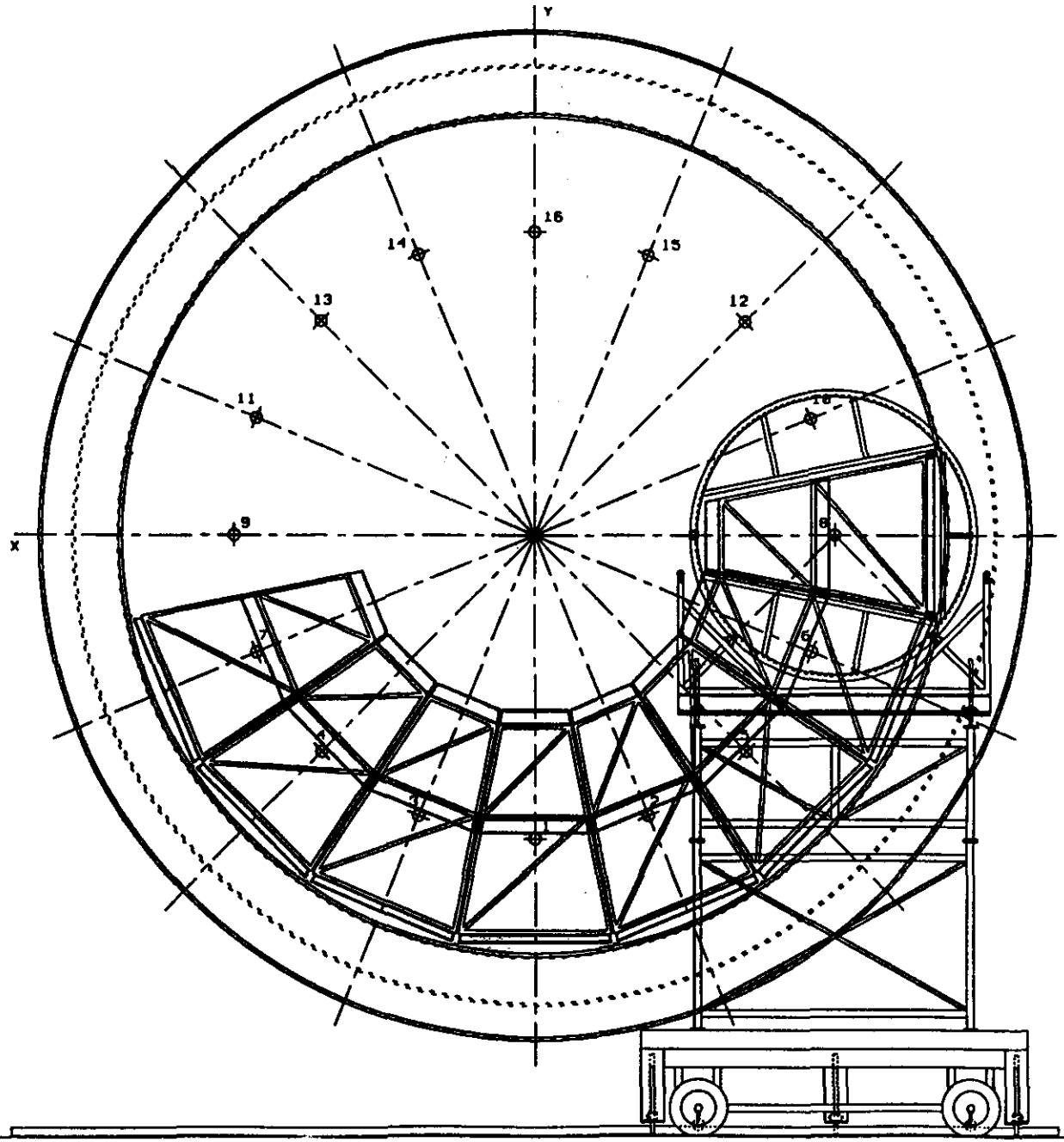


BARREL REGION INSTALLATION
(END VIEW)

BARREL REGION INSTALLATION
(ELEVATION VIEW)



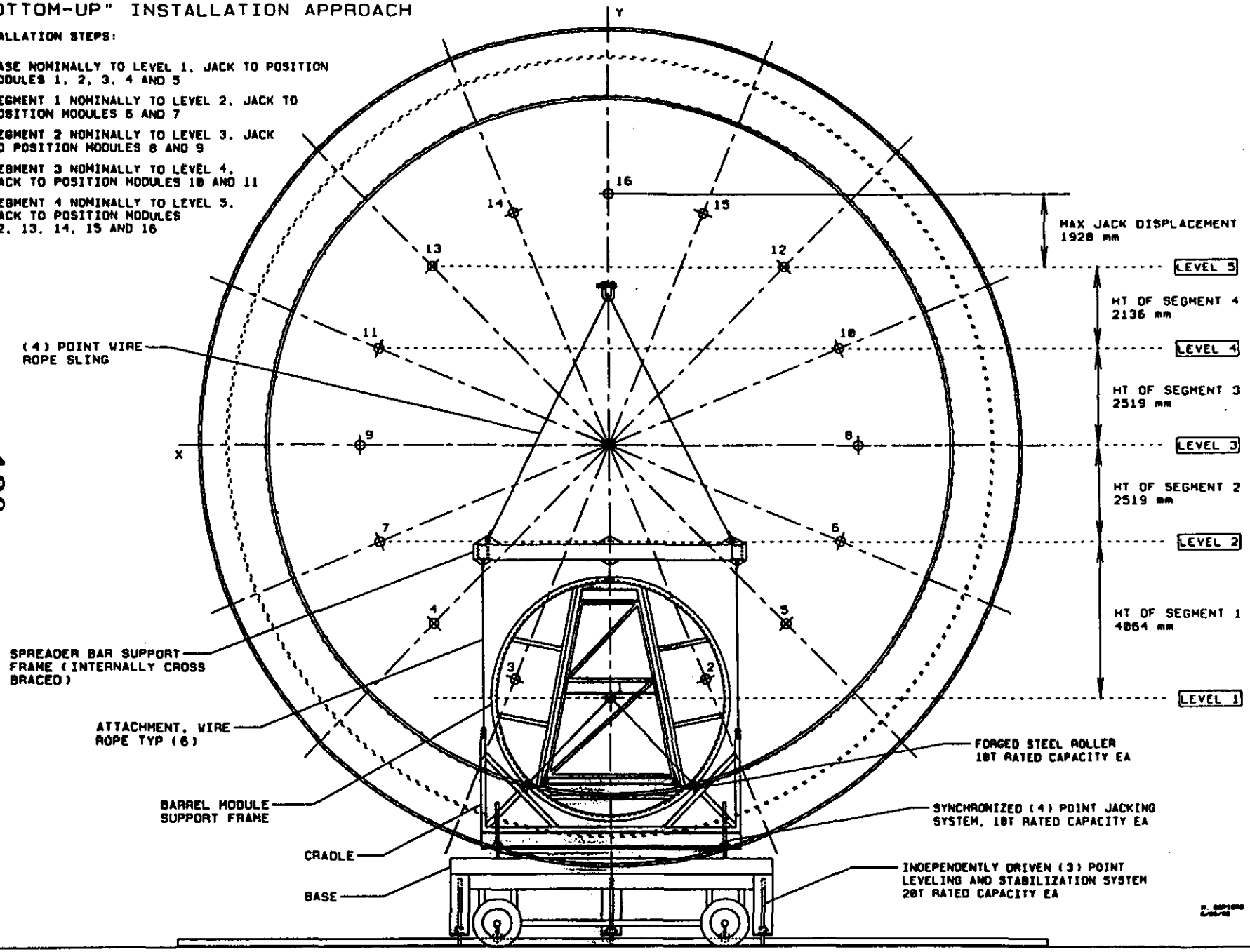
BARREL REGION INSTALLATION
(3-O'CLOCK POSITION)



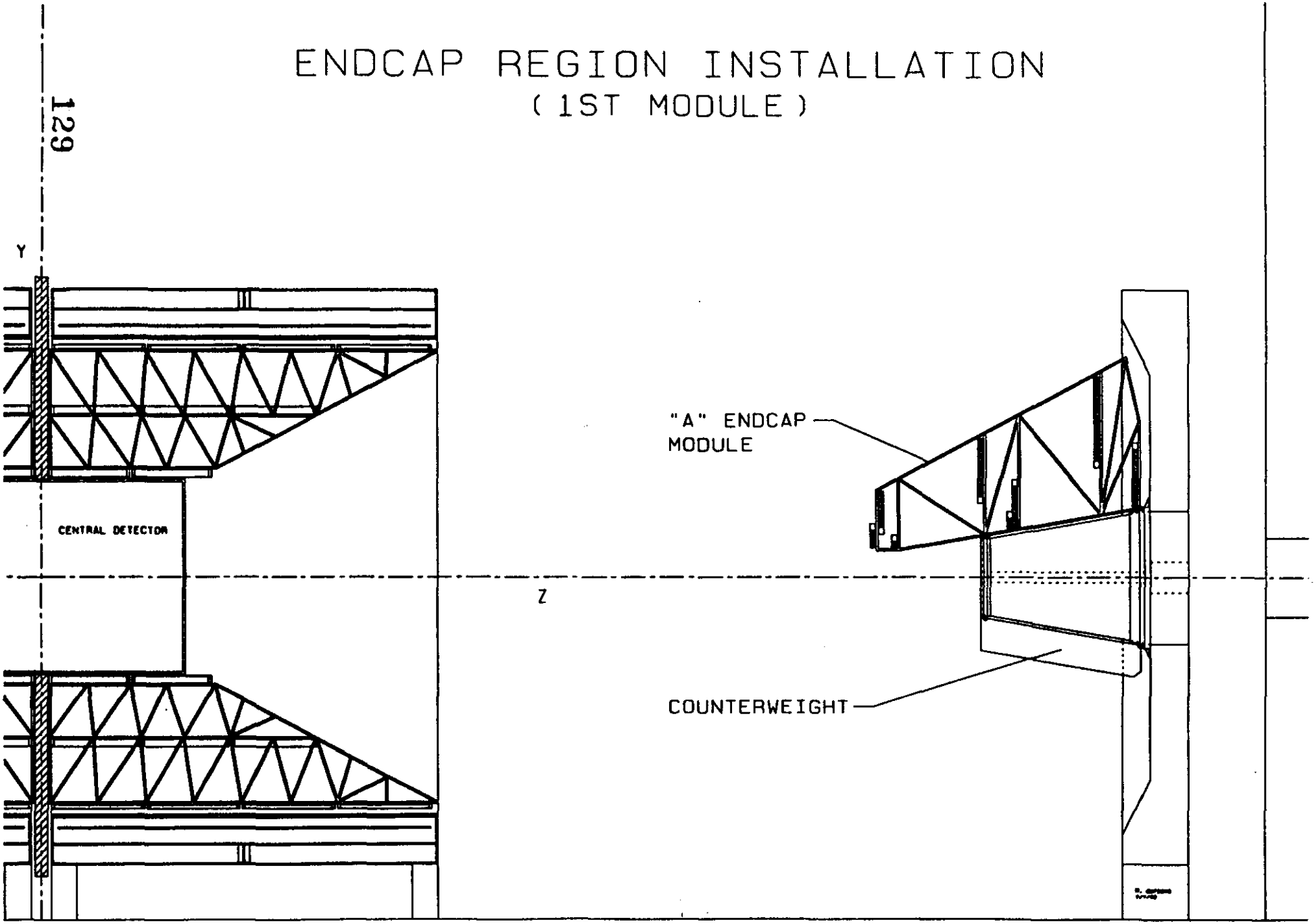
"BOTTOM-UP" INSTALLATION APPROACH

INSTALLATION STEPS:

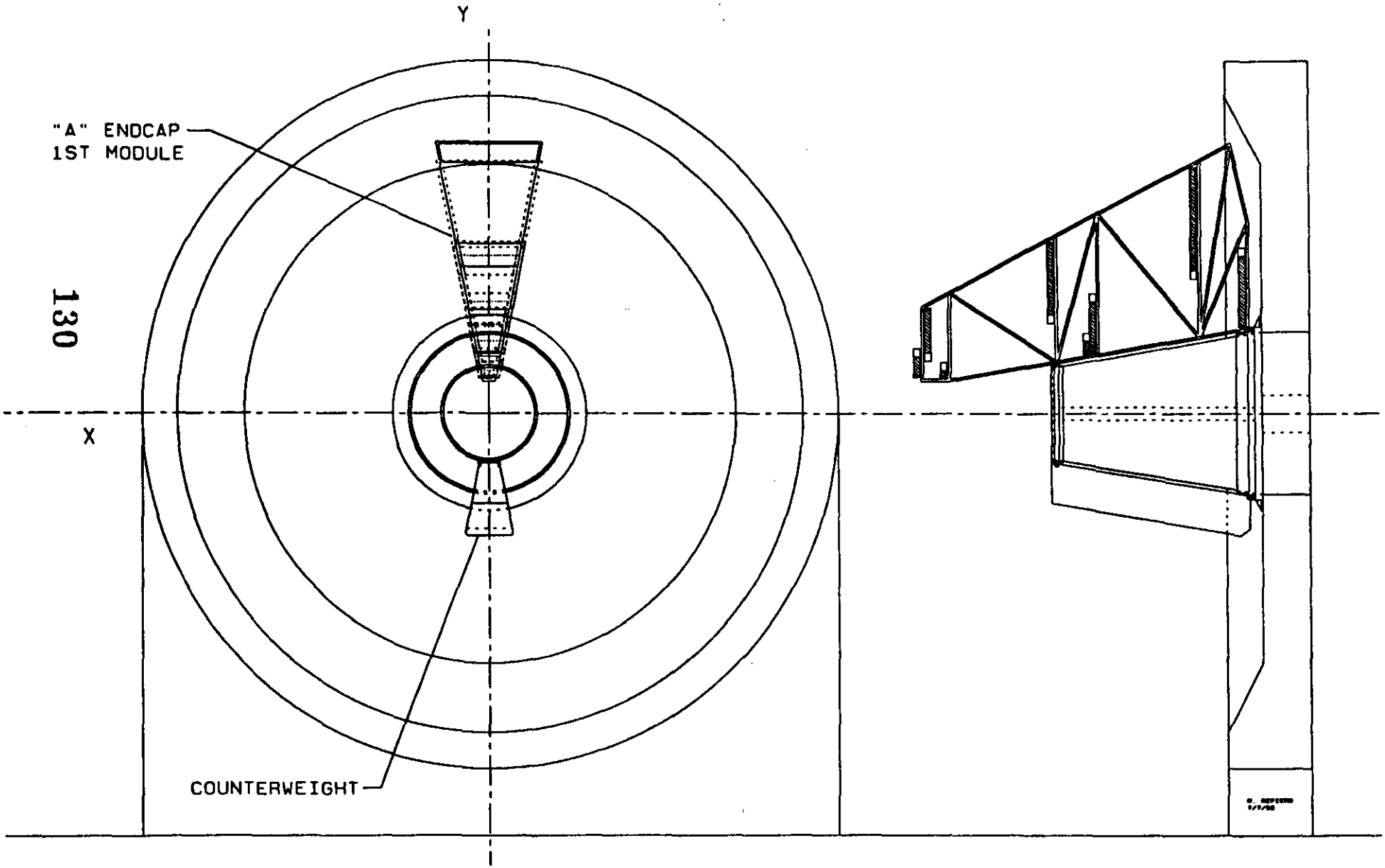
1. BASE NOMINALLY TO LEVEL 1, JACK TO POSITION MODULES 1, 2, 3, 4 AND 5
2. SEGMENT 1 NOMINALLY TO LEVEL 2, JACK TO POSITION MODULES 6 AND 7
3. SEGMENT 2 NOMINALLY TO LEVEL 3, JACK TO POSITION MODULES 8 AND 9
4. SEGMENT 3 NOMINALLY TO LEVEL 4, JACK TO POSITION MODULES 10 AND 11
5. SEGMENT 4 NOMINALLY TO LEVEL 5, JACK TO POSITION MODULES 12, 13, 14, 15 AND 16



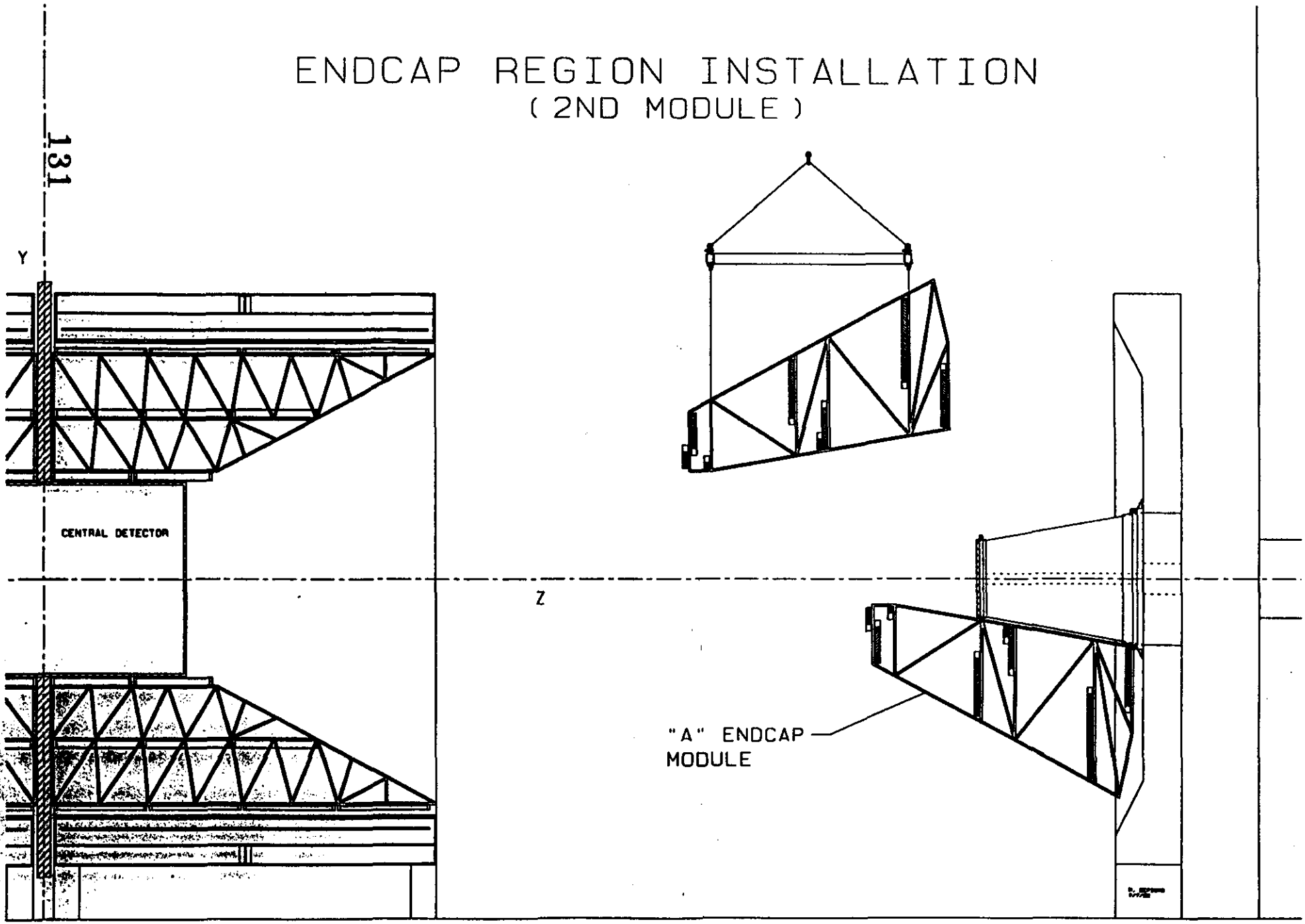
ENDCAP REGION INSTALLATION
(1ST MODULE)



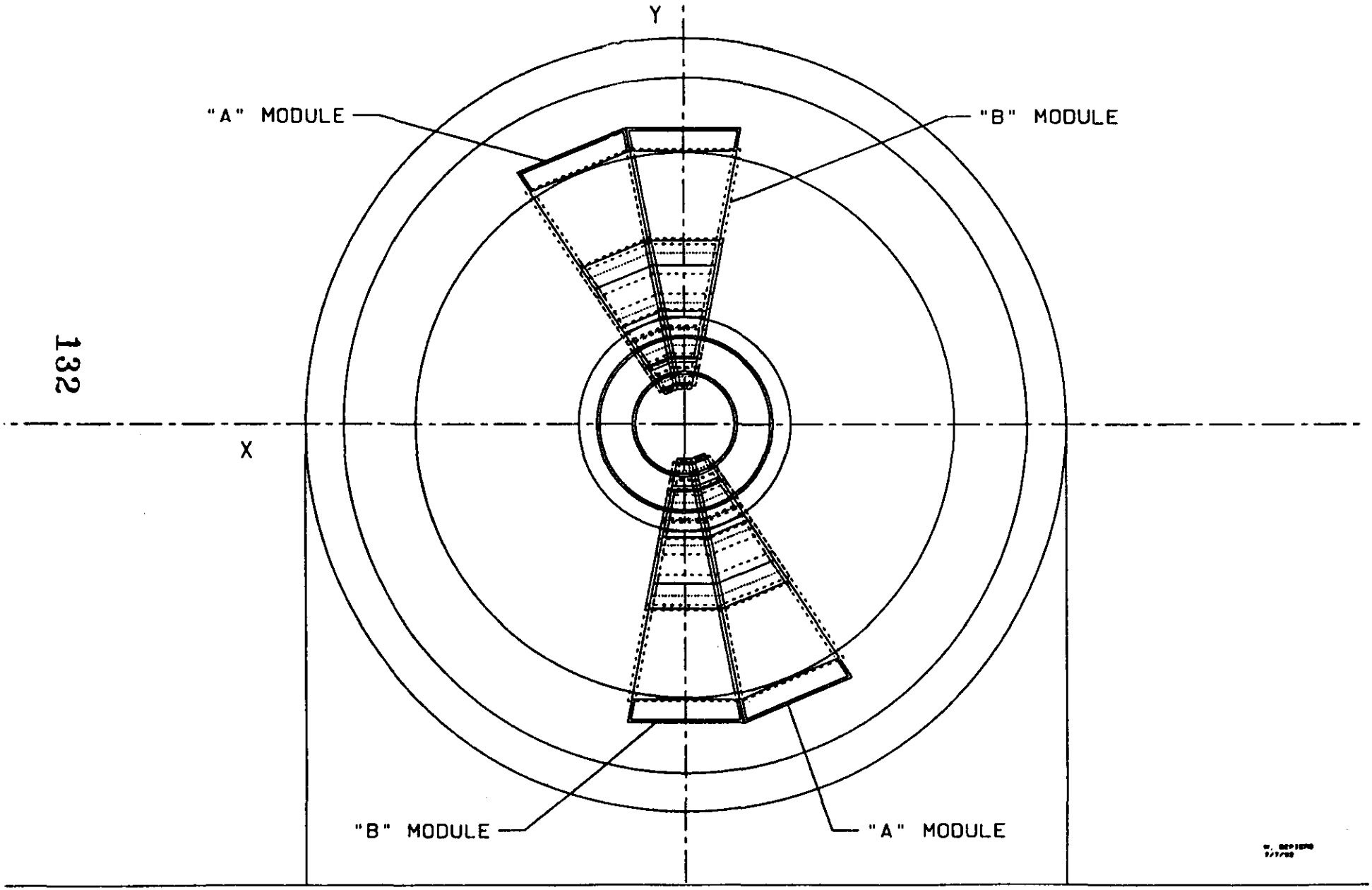
ENDCAP REGION INSTALLATION
(1ST MODULE)



ENDCAP REGION INSTALLATION
(2ND MODULE)



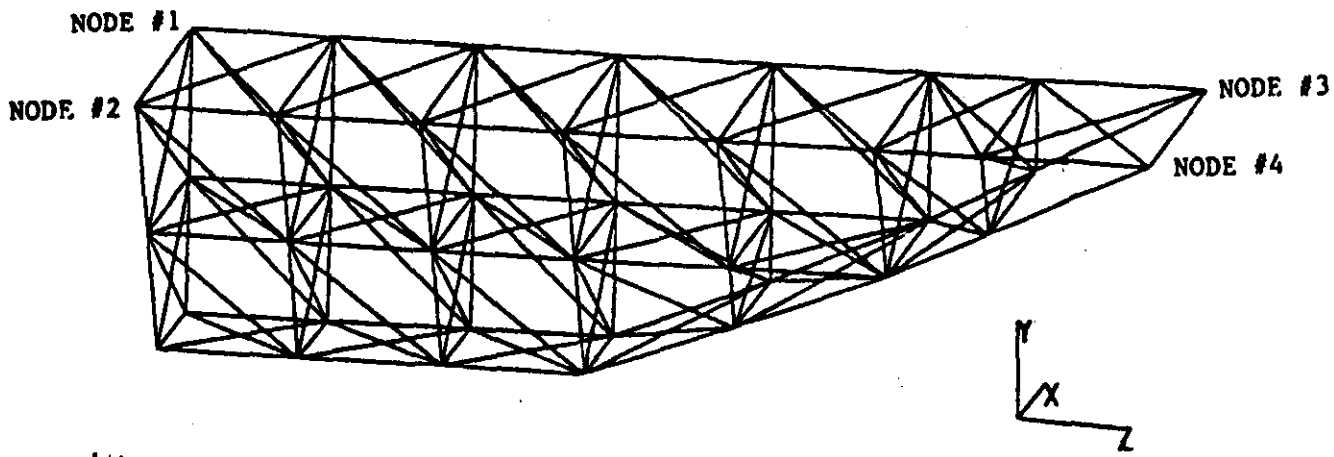
ENDCAP REGION INSTALLATION
(4TH MODULE)



BARREL REGION

G.E.M.

01 July 1992



NODE #1 X,Y,Z CONSTRAINED
NODE #2 Y,Z CONSTRAINED
NODE #3 X,Y CONSTRAINED
NODE #4 Y CONSTRAINED

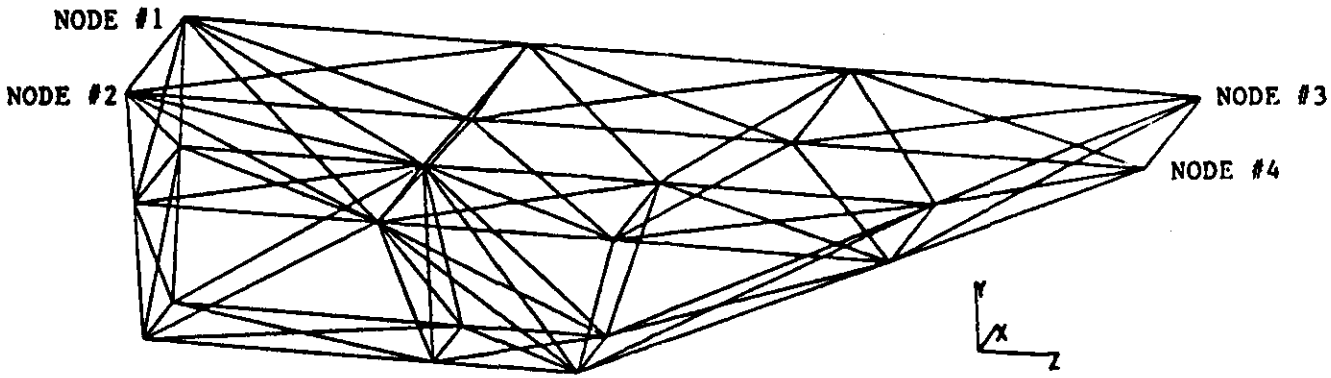
- Results Summary
  - maximum deflection 5.0 mm
  - minimum stress safety factor of 13.5 relative to yield
  - maximum force ≈ 2.48E4 N
  - buckling safety factor design criterion minimum of 5
  - global fn > 7 Hz
  - lowest member fn ≈ 12 Hz

F. Taylor

DRAPER LABORATORY

BARREL REGION
PROJECTIVE GAP OPTION

G.E.M. 01 July 1992



NODE #1 X,Y,Z CONSTRAINED
NODE #2 Y,Z CONSTRAINED
NODE #3 X,Y CONSTRAINED
NODE #4 Y CONSTRAINED

- Results Summary
  - 2,3,3 chambers/layer
  - structure has 22 joints vs. 40 for present baseline design and is 55% lighter
  - maximum deflection 4.2 mm
  - minimum stress safety factor of 15.5 relative to yield
  - maximum force ≈ 1.99E4 N
  - buckling safety factor design criterion minimum of 5
  - global fn > 7.6 Hz
  - lowest member fn ≈ 7 Hz

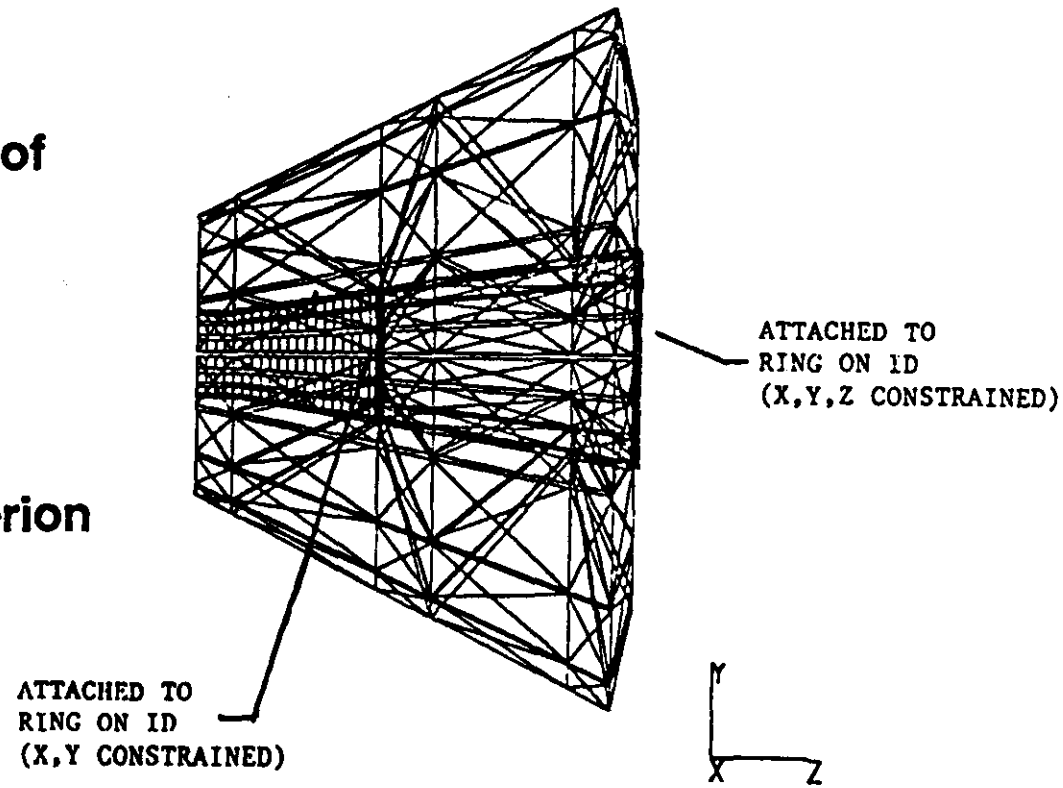
F. Taylor

DRAPER LABORATORY

END CAP FFS MOUNT

G.E.M. — 01 July 1992

- Results Summary
  - maximum deflection 1.5 mm
  - minimum stress safety factor of 12.5 relative to yield
  - maximum force ≈ 1.17E4 N
  - buckling safety factor design criterion minimum of 5
    - members not meeting criterion to be reinforced
  - global fn > 13 Hz
  - lowest member fn ≈ 8 Hz



F. Taylor

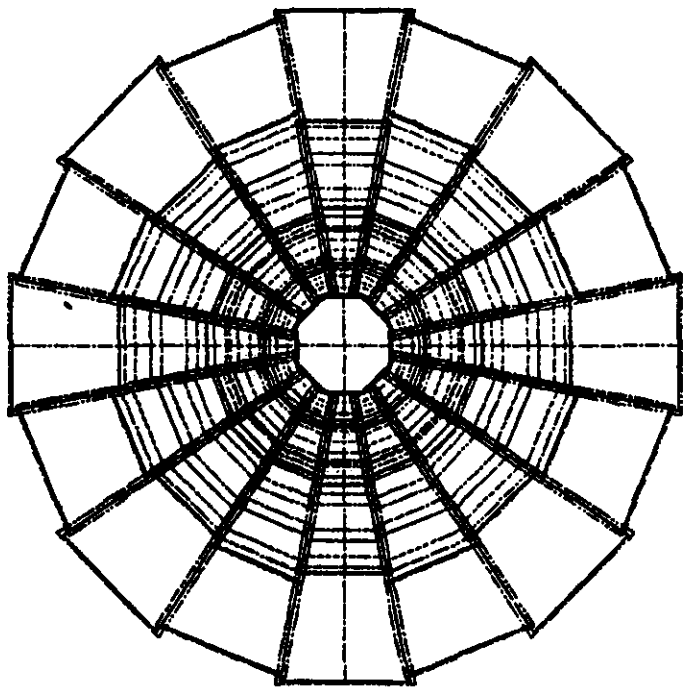
DRAPER LABORATORY

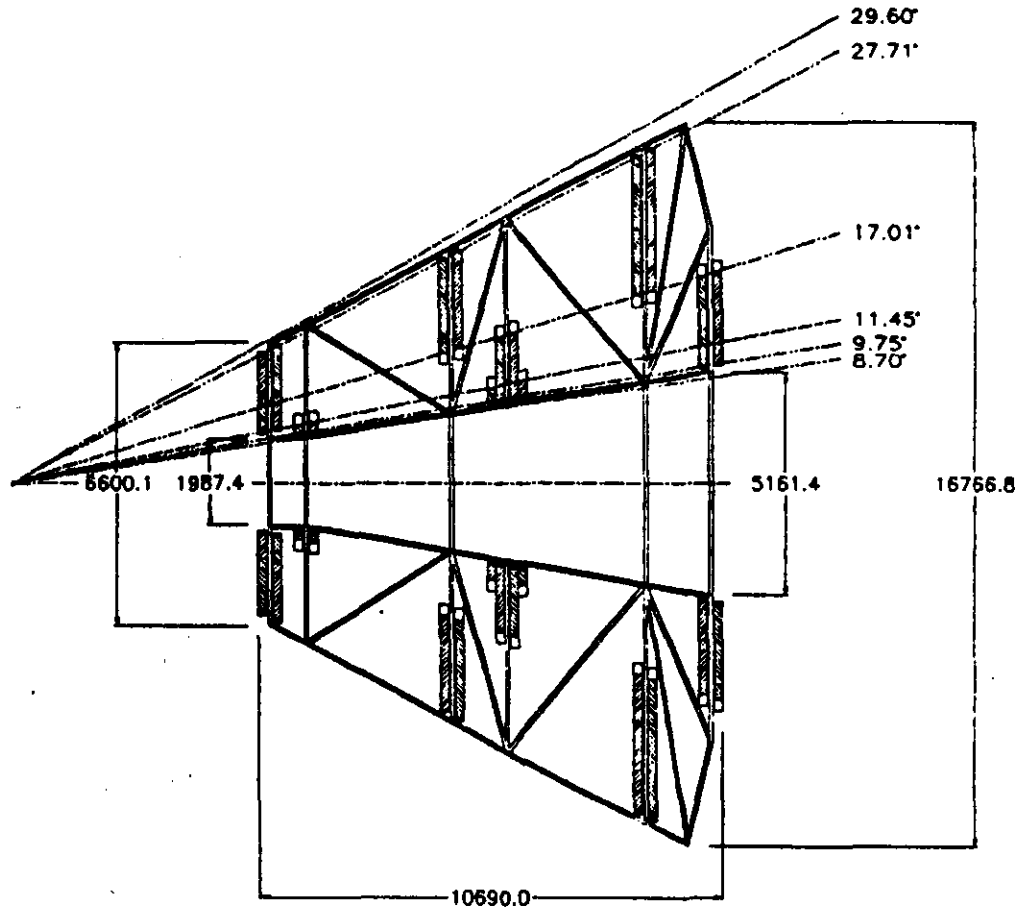
ANALYSIS ASSUMPTIONS

G.E.M. — 01 JULY 1992

- Linear material properties
- Small displacement theory (consistent with linear assumption)
- Material: 6061-T6 Al
  - Properties taken from MIL-HDBK-5C
- Element cross-section properties taken from Structural Aluminum Design, Reynolds Co., 1966
- Support structures modeled as space frames
  - Joints capable of resisting bending moments
- Truss tubes checked for buckling:
  - Design safety factor chosen as 5
  - Member end conditions assumed to be pinned-pinned (conservative)
- Assembly first mode natural frequencies estimated as greater than:
  - $fn = (1/2\pi)(G/\delta max)^{0.5}$
- Member natural frequencies calculated assuming pinned-pinned end conditions

F. Taylor — DRAPER LABORATORY



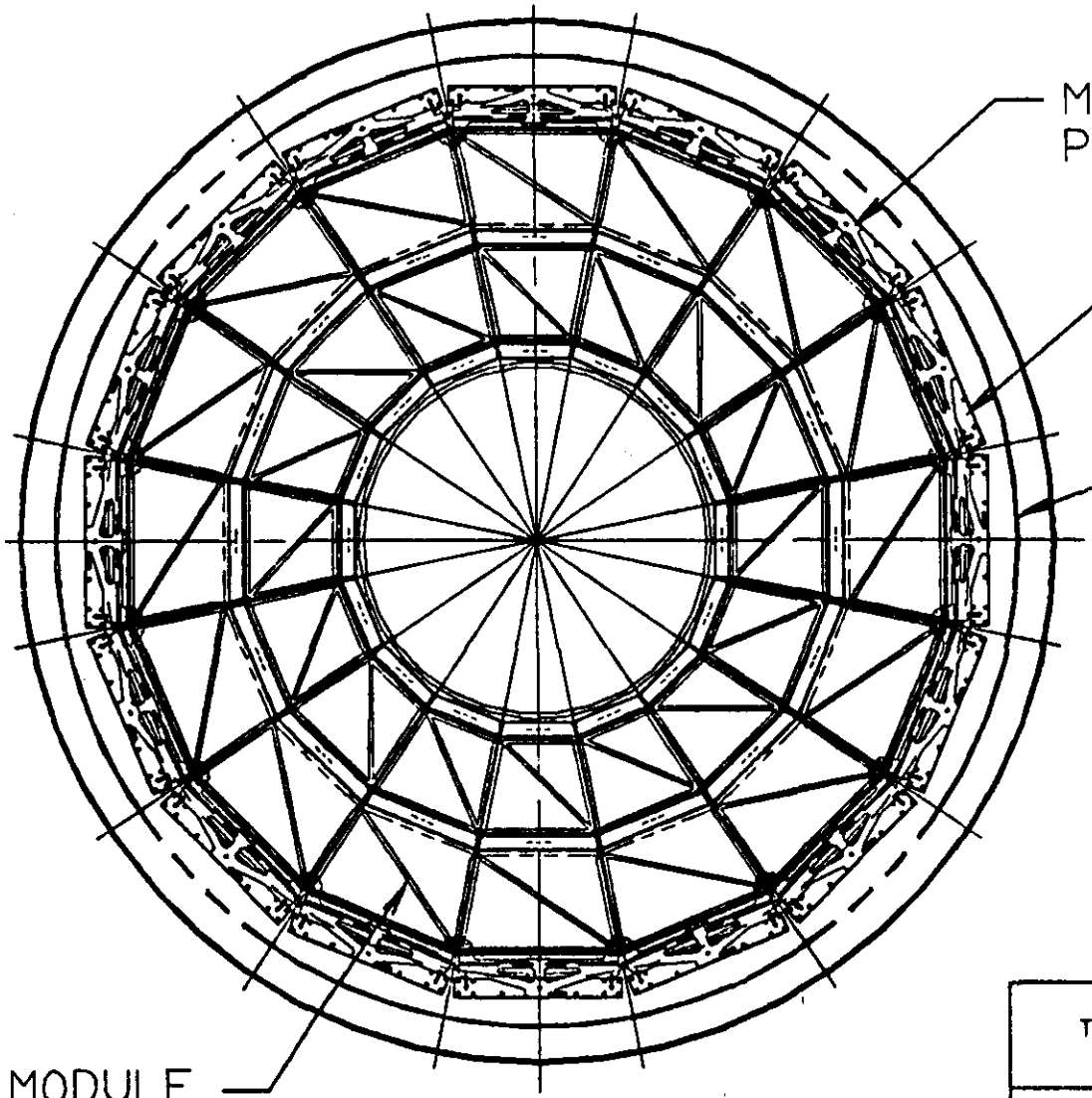


PART NO.
SEE PL

GEM ENDCAP MUON SYSTEM ASSEMBLY

E 51993 292933

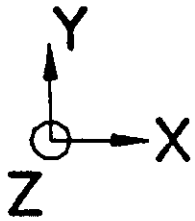
C-LINE # 62000



MODULE ATTACHMENT PLATE

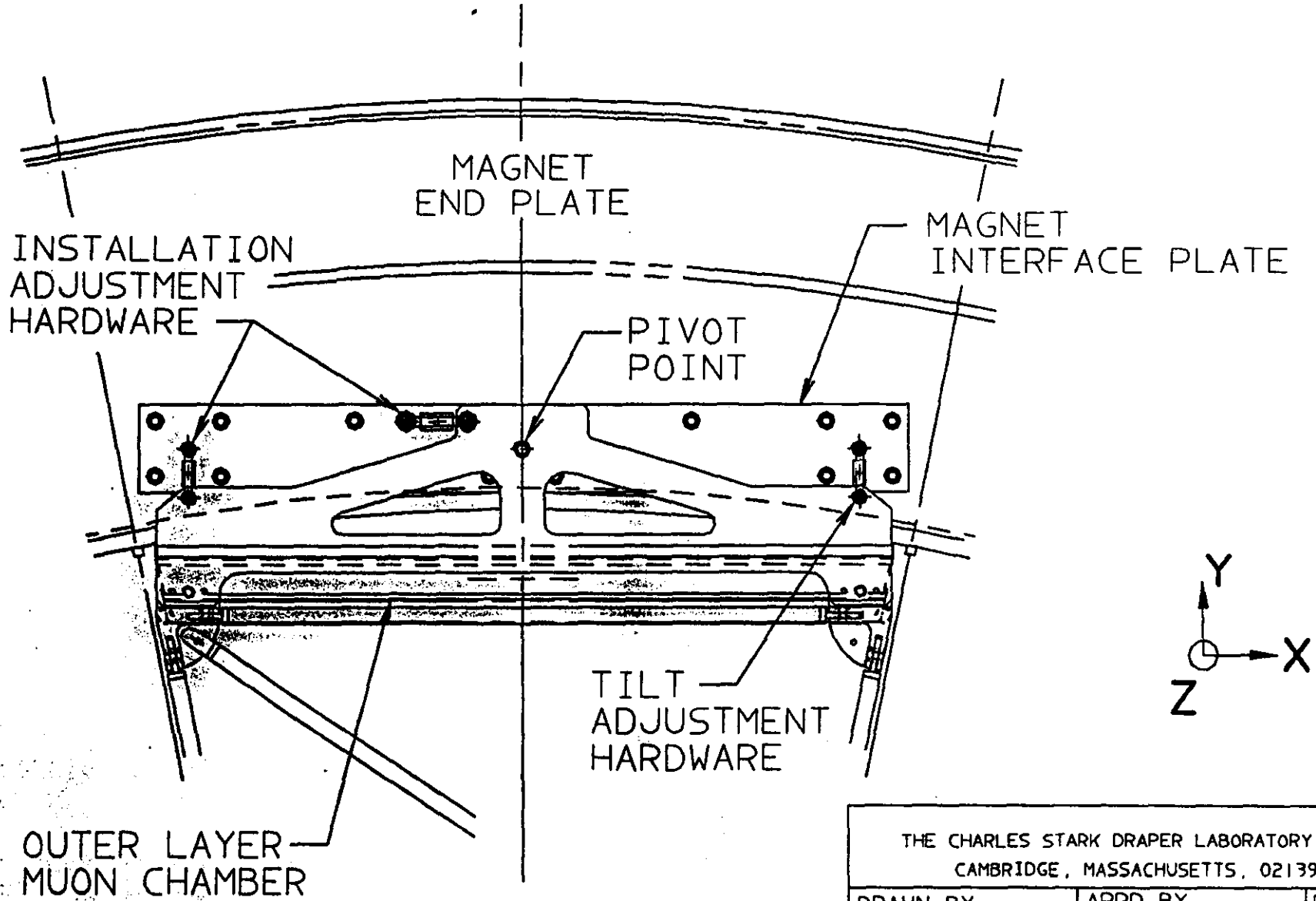
MAGNET INTERFACE PLATE

MAGNET END PLATE

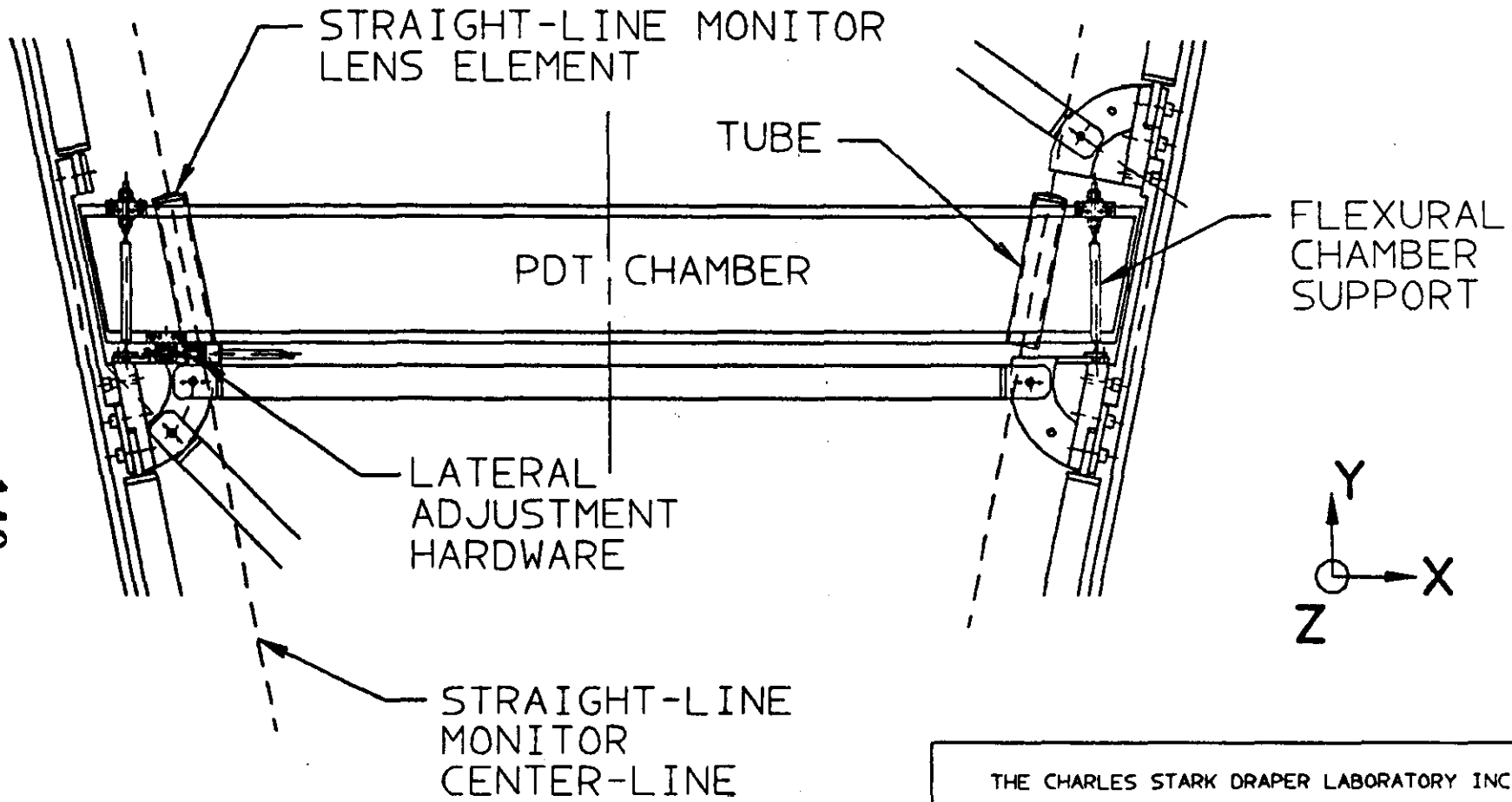


MUON MODULE (ONE OF 16) INDEPENDENTLY MOUNTED TO MAGNET END PLATES

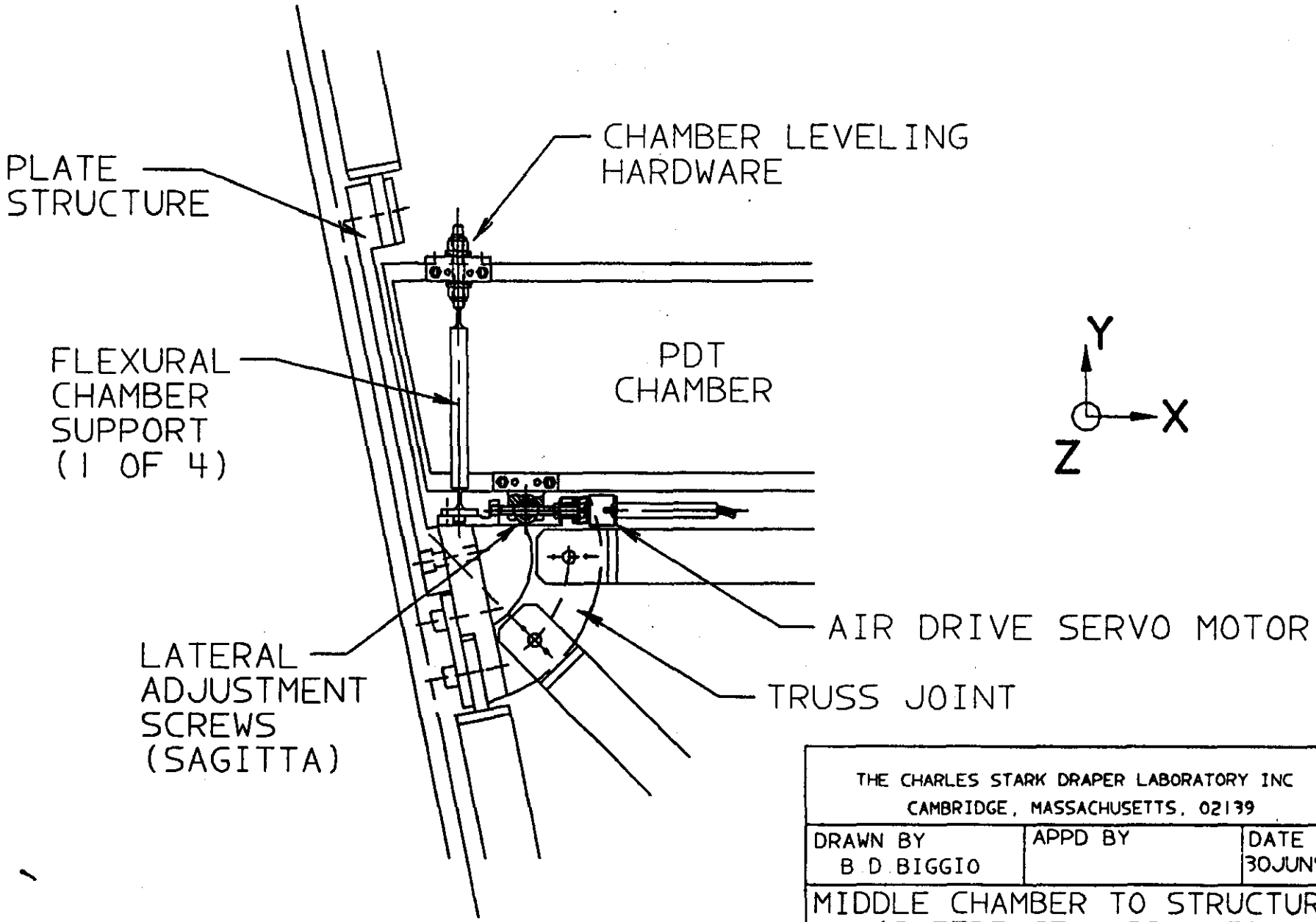
THE CHARLES STARK DRAPER LABORATORY INC. CAMBRIDGE, MASSACHUSETTS, 02139		
DRAWN BY B.D.BIGGIO	APPD BY	DATE 30JUN92
GEM BARREL REGION MUON SYSTEM (END VIEW)		
SIZE FSCM NO	DRAWING NO	REV



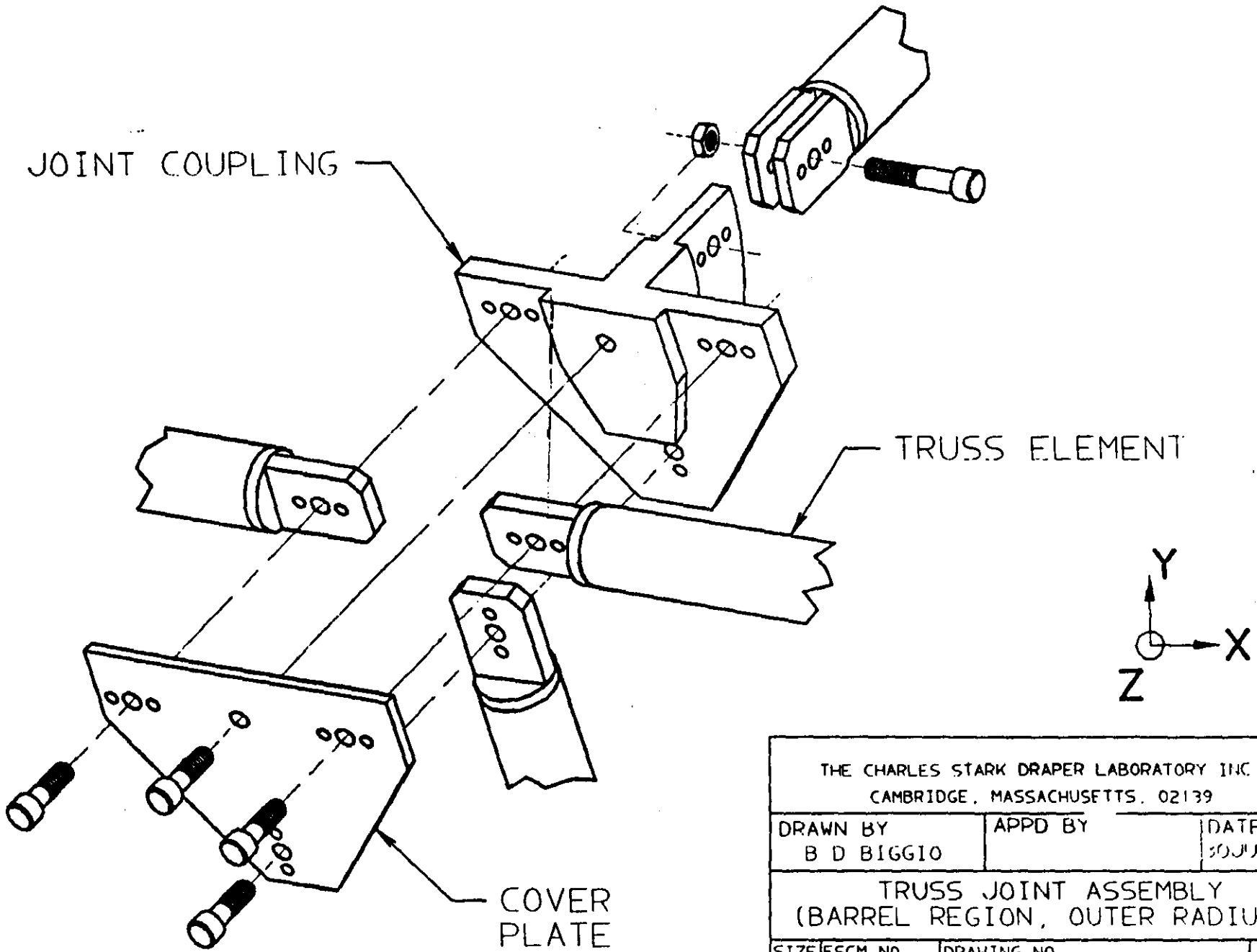
THE CHARLES STARK DRAPER LABORATORY INC CAMBRIDGE, MASSACHUSETTS, 02139		
DRAWN BY B D BIGGIO	APPD BY	DATE 30JUN92
INTERFACE HARDWARE (MAGNET/BARREL MUON MODULE)		
SIZE A / FSCM NO. 51993	DRAWING NO. 292932-02	REV –
SCALE NONE		SHEET 1 OF



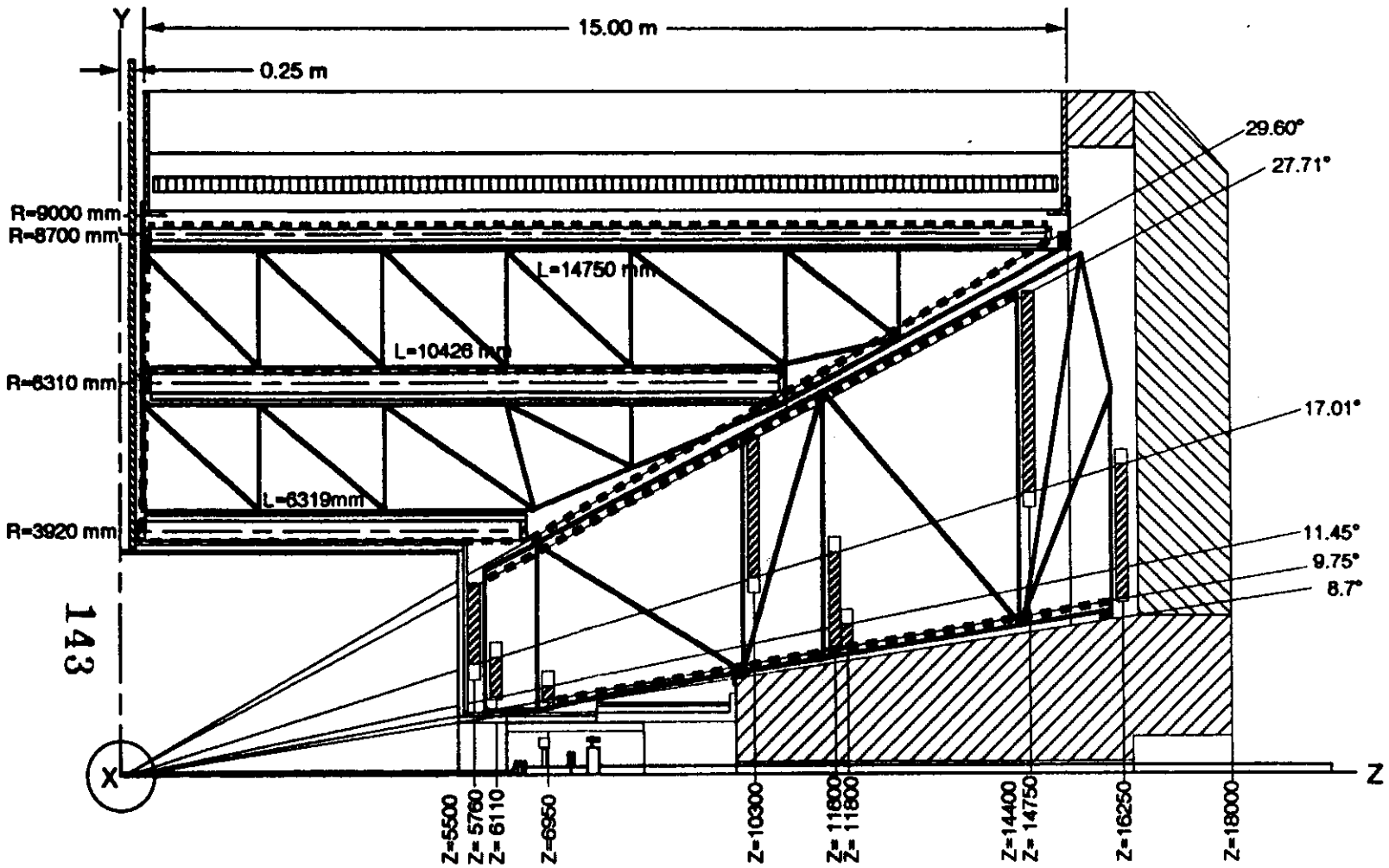
THE CHARLES STARK DRAPER LABORATORY INC. CAMBRIDGE, MASSACHUSETTS, 02139		
DRAWN BY B.D.BIGGIO	APPD BY	DATE 30JUN92
MIDDLE CHAMBER/STRUCTURE ASSY (BARREL REGION-PDT CHAMBERS) ALIGNMENT LINES ON MEMBRANE END		
SIZE A / FSCM NO. 51993	DRAWING NO 292929-02	REV -
SCALE NONE		SHEET 1 OF



THE CHARLES STARK DRAPER LABORATORY INC CAMBRIDGE, MASSACHUSETTS, 02139		
DRAWN BY B D BIGGIO	APPD BY	DATE 30JUN92
MIDDLE CHAMBER TO STRUCTURE (INTERFACE HARDWARE)		
SIZE A / FSCM NO 51993	DRAWING NO 292929-01	REV –
SCALE NONE		SHEET 1 OF



THE CHARLES STARK DRAPER LABORATORY INC. CAMBRIDGE, MASSACHUSETTS, 02139		
DRAWN BY B D BIGGIO	APPD BY	DATE [illegible]
TRUSS JOINT ASSEMBLY (BARREL REGION, OUTER RADIUS)		
SIZE A / FSCM NO 51993	DRAWING NO 292929-03	REV -
SCALE NONE		SHEET 1 OF

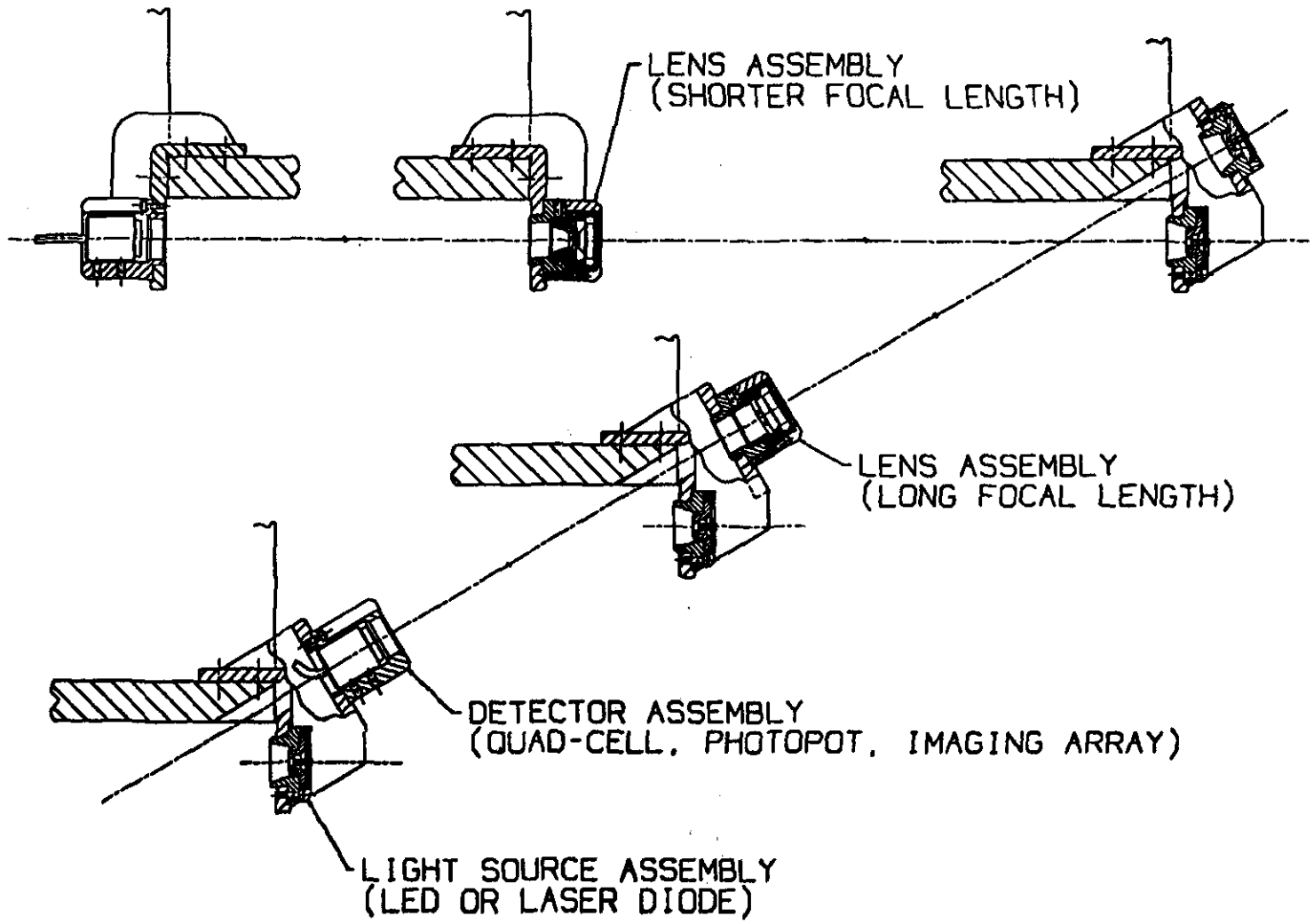


GEM MUON SYSTEM (BASELINE I)
(Alignment Line Layout)

Projective Lines ▪▪▪▪▪

Barrel Parallel to Beam Line ▪▪▪▪▪

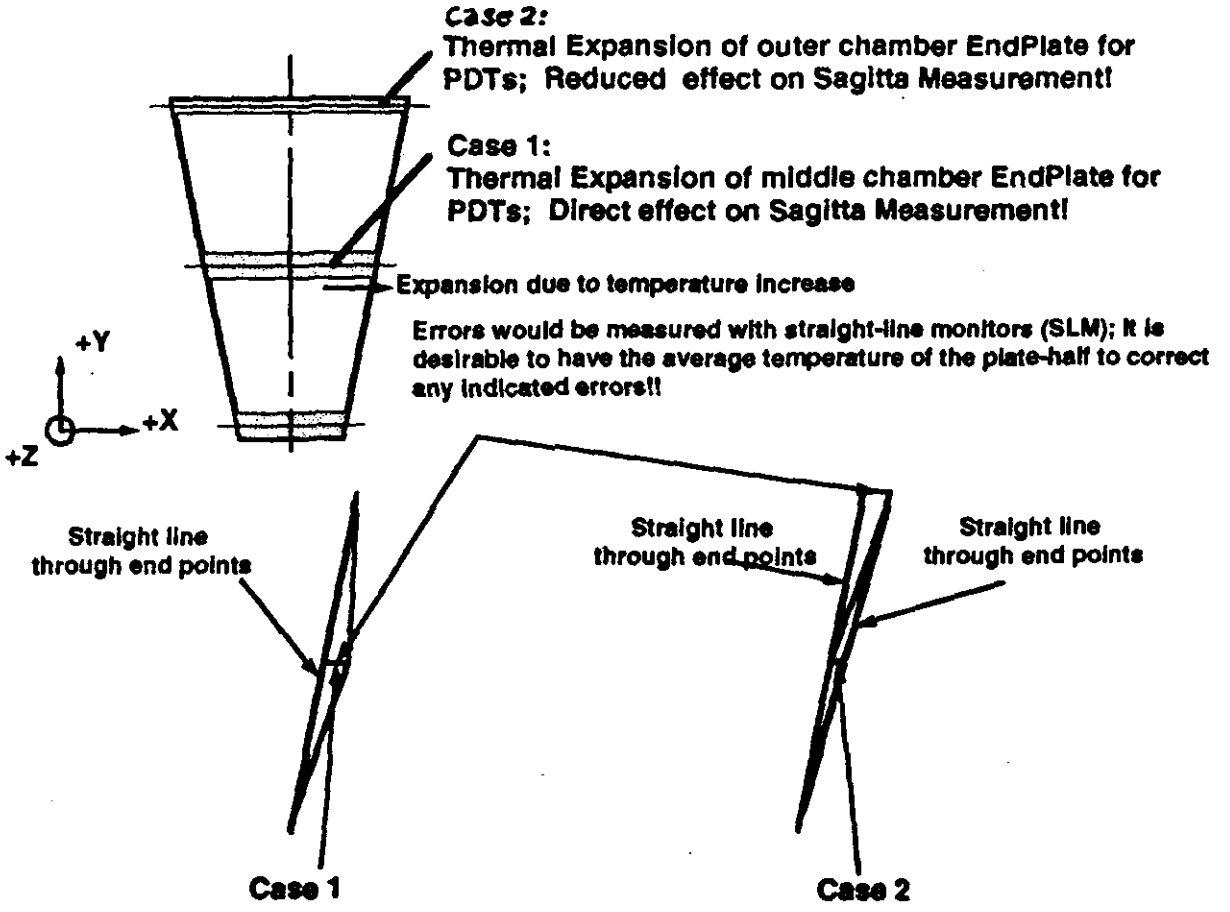
GEM Muon System (BASELINE) (Alignment Line Layout)		
Drawn By:	F. Nimblett	Rev (-)
Dwg. No:	GMU0013	6/30/92
Approved by:		



PART NO. 292934-001
SEE PL

ALIGNMENT HARDWARE
(GEM BARREL
MUON SYSTEM)

E 51983 292934



Sagitta Measurement Error due to ΔT in the middle chamber layer

Sagitta Measurement Error due to ΔT in the Outer chamber layer

Case 1: For a 10μ contribution to the sagitta error, knowledge of the average temperature to 0.3° C is necessary.

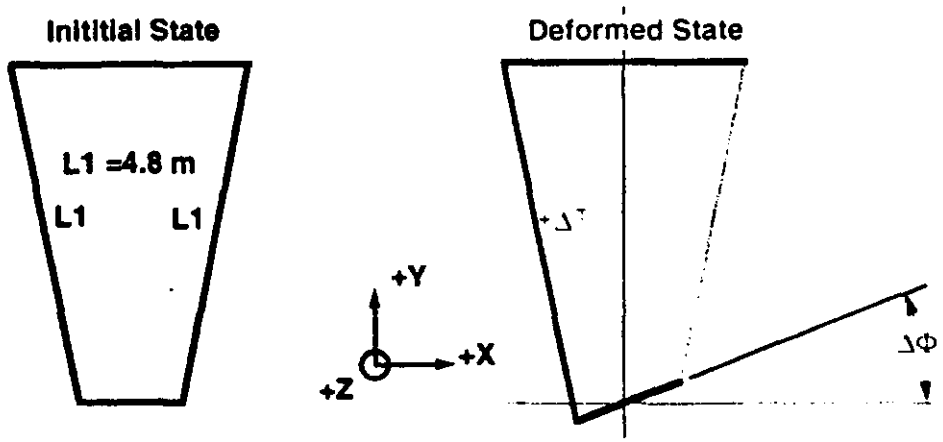
Case 2: For a 10μ contribution to the sagitta error, knowledge of the average temperature to 0.5° C is necessary.

Case N: Combinations of these options can worsen the indicated sagitta error but do not change the measuerement accuracy needs.

Cathode Strip Chambers (CSCs): Similar effects occur for the CSCs in the endcap region; however the temperature requirements are less stringent due to the lower Coefficient of Thermal Expansion (CTE) of the Epoxy board sturcture. α = 10 to 13 μ/ m-°c versus 23 m/m-°C for Aluminum. Thus for the same error budget, the termperature tolerance is 1° and 1.5° C for Case 1 and Case 2 respectively.

Barrel and Endcap Region Chamber Thermal Deformation (Due to temperature changes of chambers)

Frank Nimblett
Draper Laboratory
8 July 1992



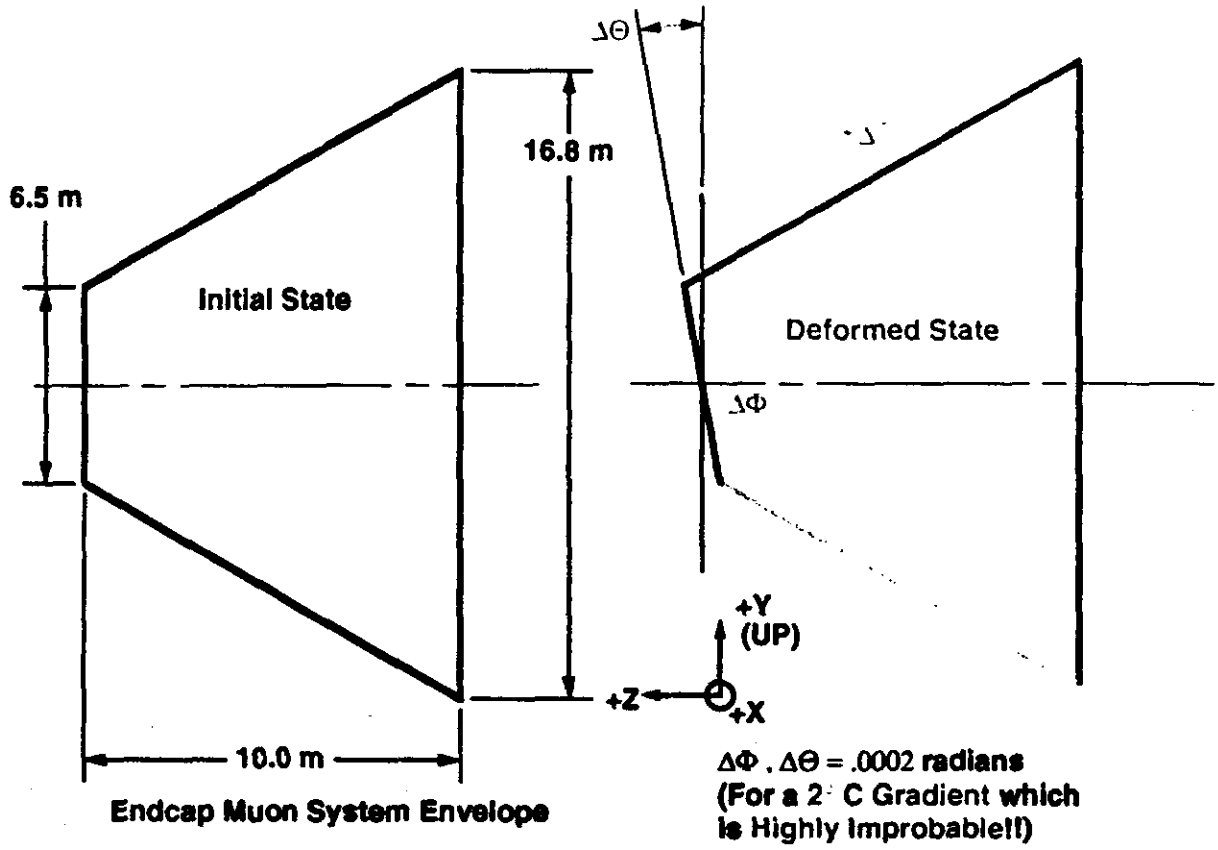
α = 23 μ / m -°C
(6061-T6 Alum)

ΔΦ = .00014 radians
(for a 2° C Gradient which
is Highly Improbable!!)

Target Φ stability is .0001 radians
1.4 C gradient is acceptable

BARREL REGION THERMAL DEFORMATIONS
Due to Thermal Gradients

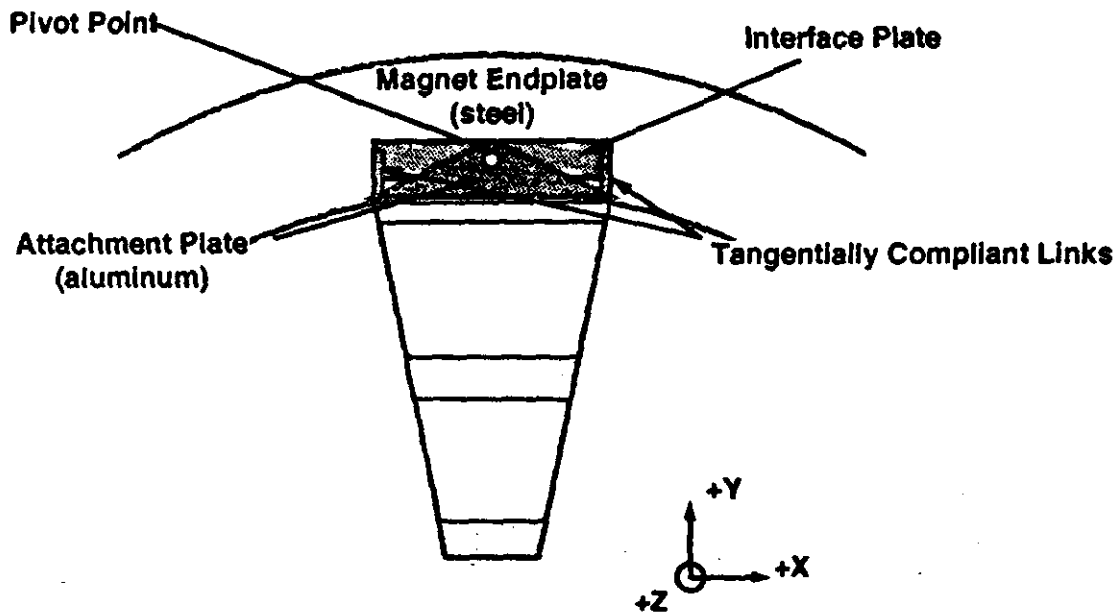
Frank Nimblett
Draper Laboratory
8 July 1992



(1 C Gradient required to meet .0001 radian ΔΦ budget)
(Probably within spec.. easily monitored if necessary!)

ENDCAP THERMAL DEFORMATIONS
Due to Thermal Gradients

Frank Nimblett
Draper Laboratory
8 July 1992



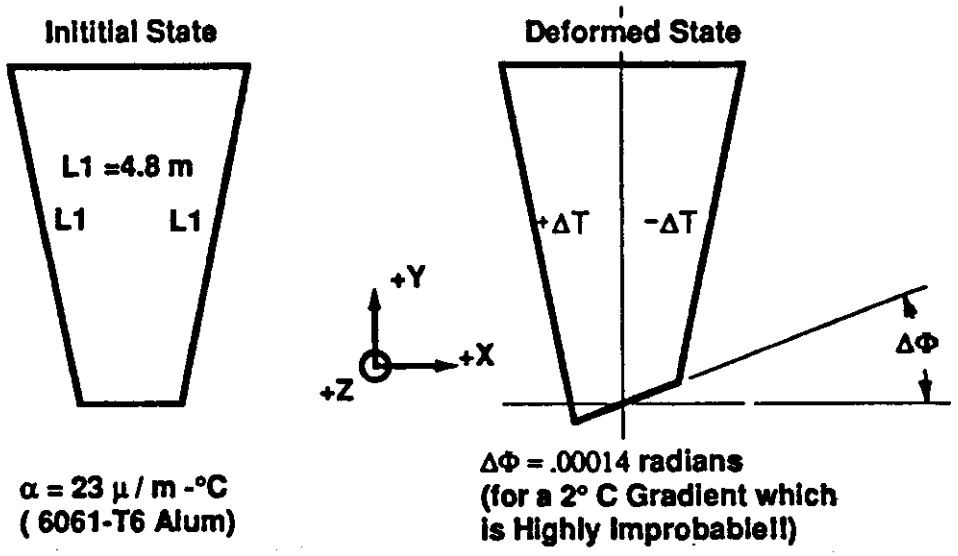
Temperature Differences between the Magnet Endplate and the Interface plate cause no first-order deformations of the attachment plate due to isolation by the tangentially compliant links!

A two-point mounting system (one pivot and one tangentially compliant) with attachment points near the side truss members would also be an appropriate solution to this problem!

Radially, the muon module goes where the magnet endplate goes !!

THERMAL EFFECTS OF THE MAGNET ATTACHMENT HARDWARE

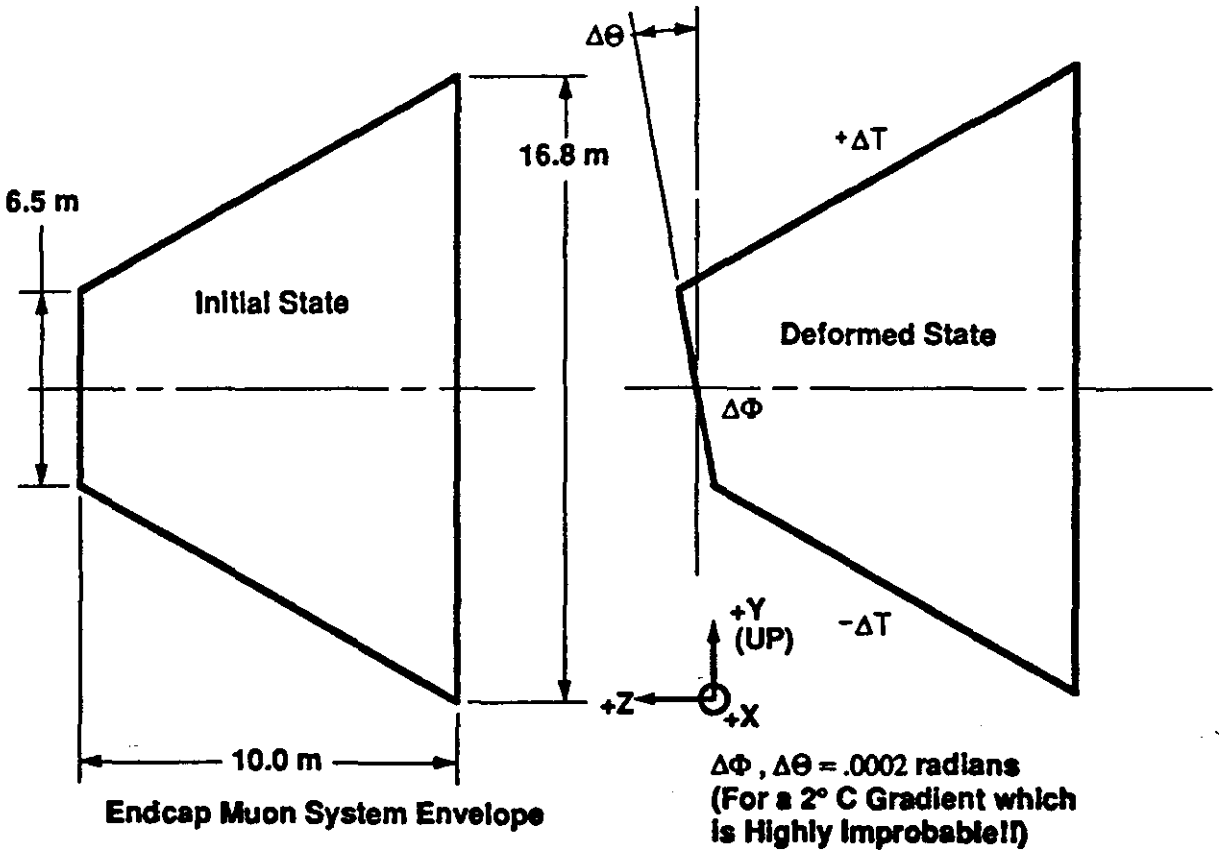
Frank Nimblett
Draper Laboratory
8 July 1992



Target Φ stability is .0001 radians
therfore 1.4° C gradient is acceptable

BARREL REGION THERMAL DEFORMATIONS
Due to Thermal Gradients

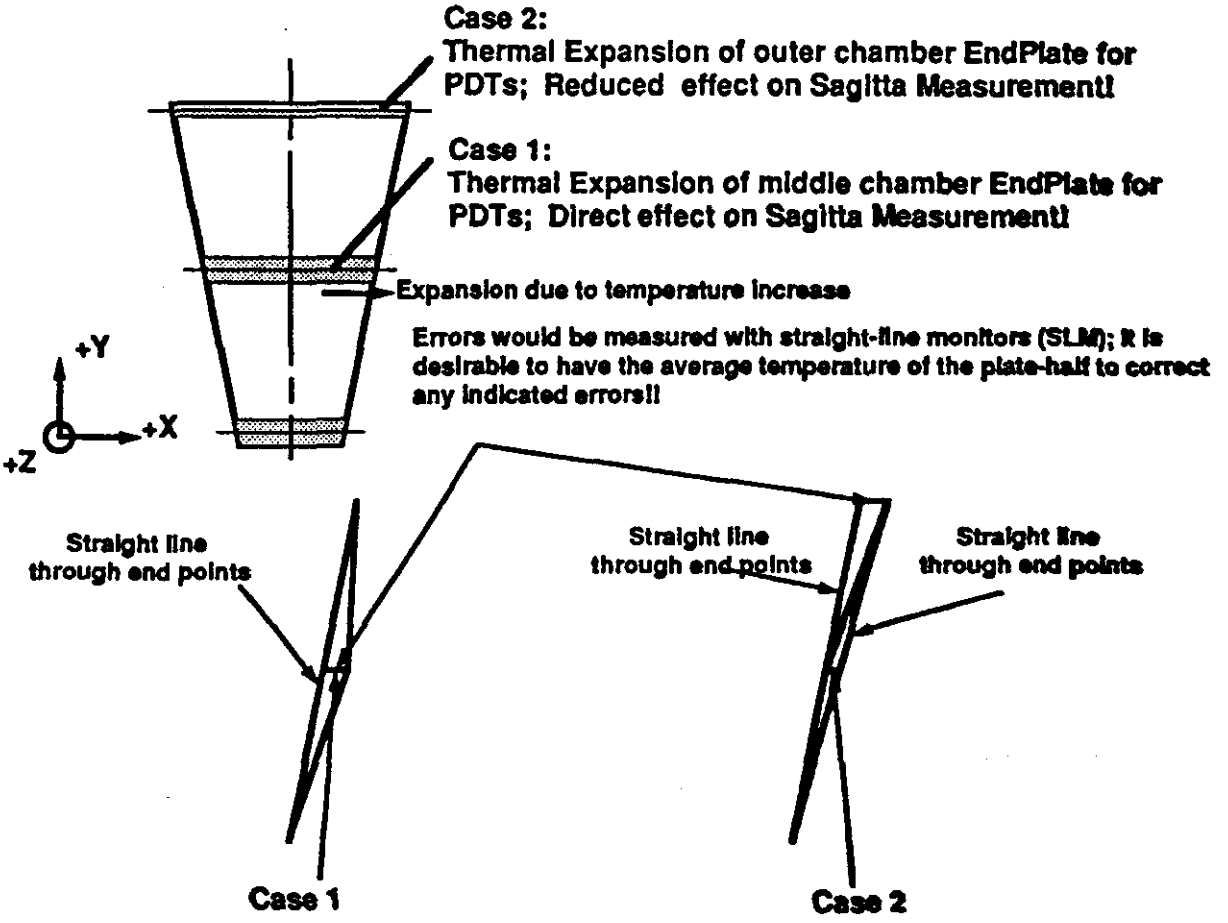
Frank Nimblett
Draper Laboratory
8 July 1992



(1° C Gradient required to meet .0001 radian ΔΦ budget)
(Probably within spec., easily monitored if necessary!)

ENDCAP THERMAL DEFORMATIONS
Due to Thermal Gradients

Frank Nimblett
Draper Laboratory
8 July 1992



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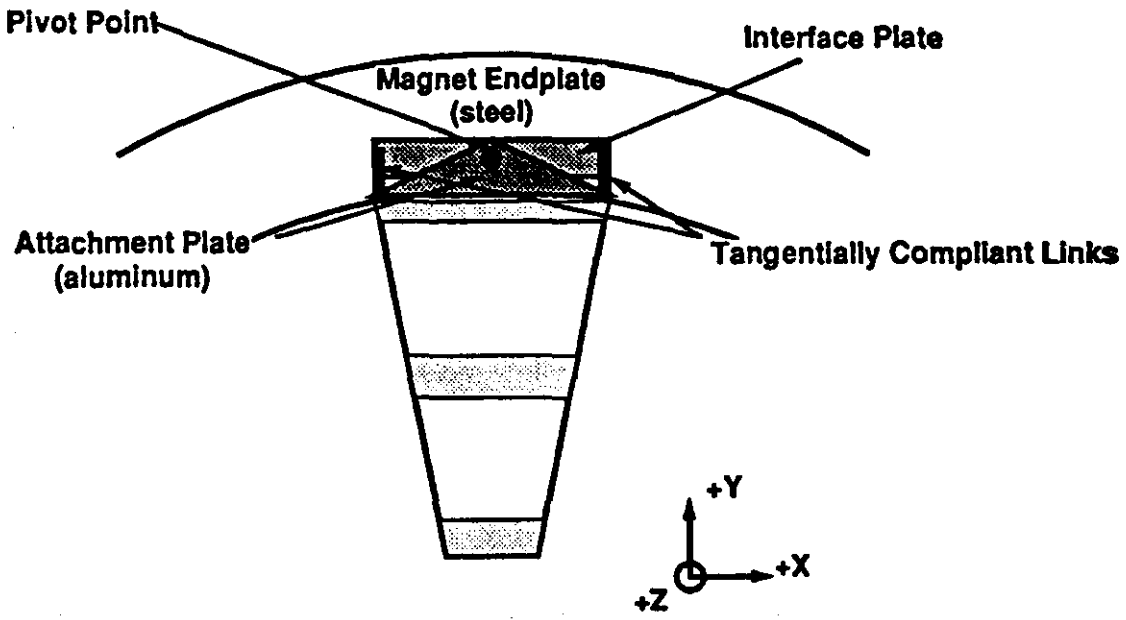
Frank Nimblett
Draper Laboratory
8 July 1992



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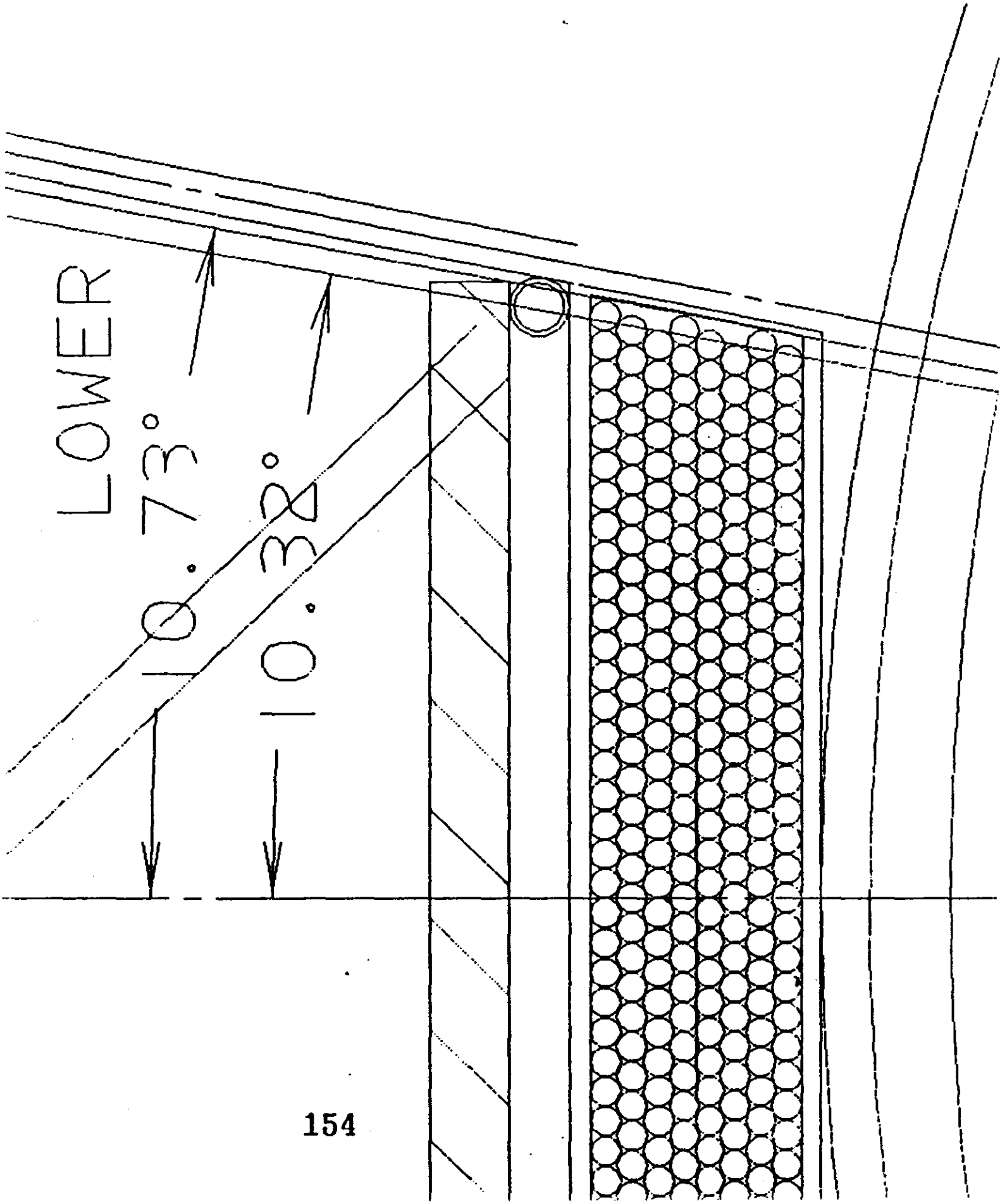
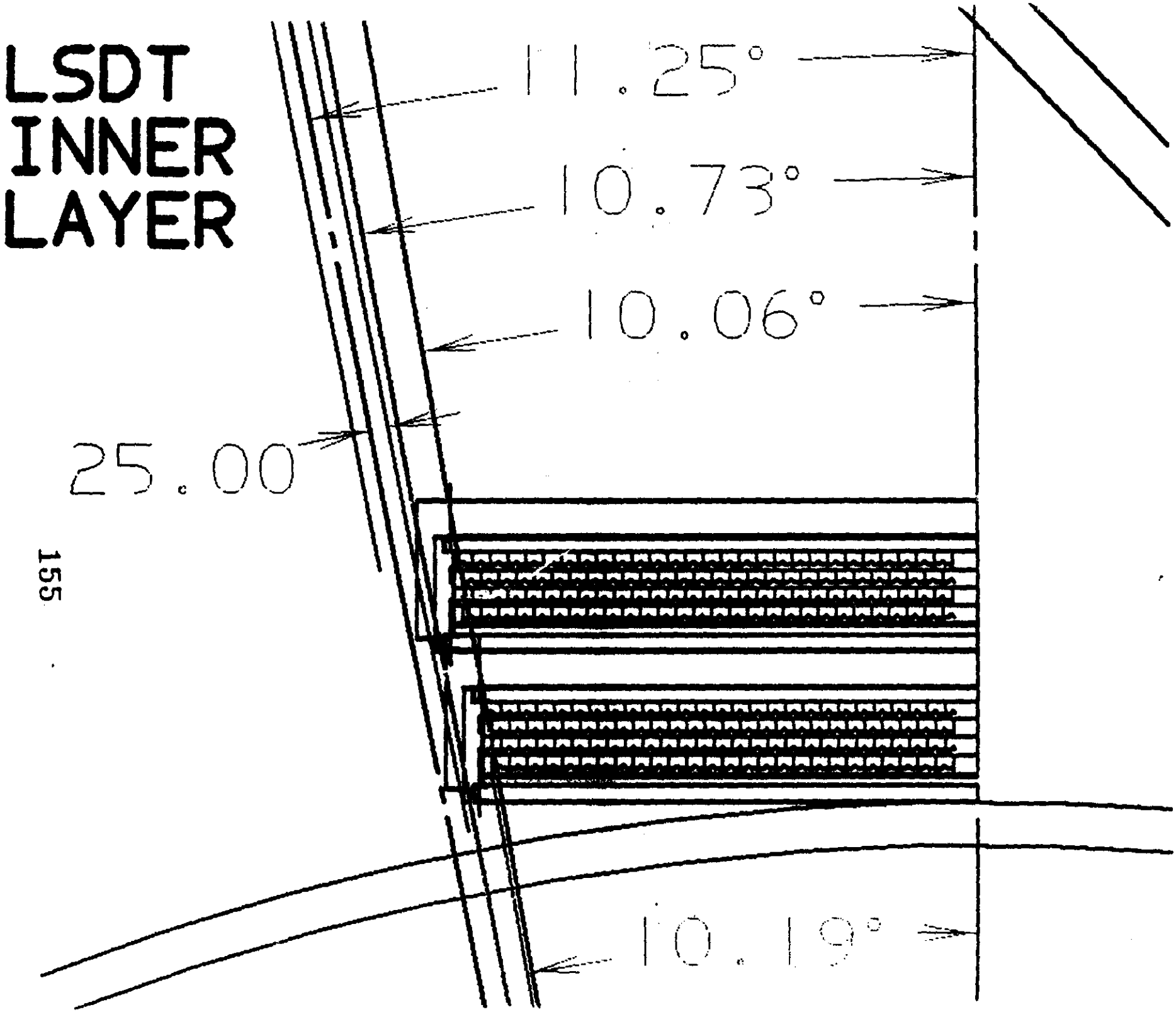
Radially, the muon module goes where the magnet endplate goes !!

THERMAL EFFECTS OF THE MAGNET ATTACHMENT HARDWARE

Frank Nimblett
Draper Laboratory
8 July 1992

IDDLE PLATE
JOINT


LOWER
10.73°
10.32°


LSDT
INNER
LAYER
11.25°
10.73°
10.06°
25.00
10.19°