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GEM TN-92-143

Calorimeter Group Meeting - SSCL

August 5, 1992

Abstract:

Agenda and presentations of the GEM Calorimeter Group Meeting held at the SSC Laboratory on August 5, 1992. Agenda items were: Noble Liquid; BaF_2; $H \rightarrow 2\gamma$ Task Force; and Discussion.

August 9

GEM Calorimeter Group Meeting

8am – 11am Noble Liquid (convened by H. Gordon)

11am – 3:30pm BaF_2 (convened by H. Newman)

12 – 1:30 pm Lunch

3:30 – 4:30 pm $H \to 2\gamma$ task force (G. Mitselmakher)

4:30 – 6:30 pm Discussion

LAr / LKr GEM Calorimetry

Aug. 9, 1992

1) Review of Engineering questions and answers
H. Gordon

2) Review of accordion test beam results
D. Lissauer

~~3) Simultation update M. Leltchouk~~

4) A Scenario for Chinese Collaboration
Jiàng C.

5) Test Beam Results from parallel plate design
P. Mockett

Responses to Questions

Regarding Engineering Issues

of the

GEM Nobel Liquid Calorimetery Options

Prepared by:

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H. Gordon (BNL), M. Lajczok, L. Mason, G. Velasquez, W. Vinnedge,

5 August, 1992

SCIENCE SYSTEMS
MARTIN MARIETTA ASTRONAUTICS GROUP
DENVER, CO.

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OVERVIEW

This section describes the present baseline parameters for the liquid argon calorimeter system. We are also investigating the use of krypton as the sampling medium to improve the resolution further. For the same density, one will be able to increase the sampling ratio by reducing the plate thickness and increasing both the density and volume of the sensitive material. Krypton option parameters are provided in the attached figures.

The calorimeter is divided into three cylindrical sections: a barrel and two endcap sections including the forward calorimeters. The total weight of the barrel section is 891 Mg and each endcap is 626 Mg, including 19 Mg for each of the forward calorimeters.

Electromagnetic Calorimeter

Strict adherence to physics goals leads to an EM section design with 20 X_0 in the barrel and 28 X_0 in the endcap since the mean energy is higher there. The absorber plates are a composite of lead, prepreg and stainless steel skins. The plate thickness is kept constant in eta, but the fraction of lead is decreased at higher eta to maintain resolution. The EM calorimeter covers the region $-3 < \eta < 3$.

Electrode Structure: The EM calorimeter will utilize the accordion design with signals collected on electrodes which are transmission lines. These electrodes also sum the signal longitudinally. In the GEM design there are 4 cells per tower and the granularity in the η, ϕ directions is 0.032 x 0.032. Each tower will be segmented into two sections longitudinally: 8 and 17 X_0 at $\eta = 0$. The transverse and longitudinal segmentation allows one to get excellent position resolution at the face of the calorimeter and to be able to point back to the vertex with an angular resolution of ~6 mrad at 120 GeV. There will be ~60,000 EM channels.

Readout: The readout chain for the calorimeter will consist of a JFET pre-amp that will be placed inside the LAr calorimeter and able to survive more than 200 Mrad. The shaping amplifiers will be located in standard crates on the central membrane outside the magnet coil.

Twenty-five towers (5 x 5) are added together for an EM trigger tower (0.16 x 0.016).

Hadronic Calorimeter

The requirements on the hadronic calorimeter are less stringent than the electromagnetic calorimeter but it is still a formidable challenge to achieve them. The total number of λ at $\eta = 0$ is 12 rising to 14 at $\eta = 3$.

EST electrode structure: In order to match the director capacitance to that of the pre-amp, we are planning to use the "electrostatic transformer" configuration in the hadronic section, by adding layers in series. The absorber material will be copper tiles. The transformer ratio is 4.

Segmentation: The hadronic segmentation is determined by the size of the hadronic shower and the need to match up with the EM granularity. We have thus selected a granularity of 0.08 x 0.08 in η, and ϕ . There are three longitudinal modules with the following number of absorption lengths: λ_1=3.2, λ_2=3.2, λ_3=3.7. The middle module is divided into two readout sections to reduce the noise. Sixteen non-overlapping towers (4 x 4) will be added together for hadron veto for each EM trigger tower. Four of these veto towers will be added together for a jet trigger tower.

Readout: The readout for the hadronic section follows the EM very closely. There will be ~27,000 channels in the hadronic section.

Cryostat: The cryostat will be an aluminum alloy with a thickness 0.3 X_o at the entrance at $\eta = 0$. For the endcap, the total thickness will be 0.7 X_o. The interface between the barrel and the endcap, from $1.42 \leq \eta \leq 1.64$, will have degraded EM resolution but will have useful comparable hadronic resolution.

Installation and Assembly: The hadronic granularity leads naturally to hadronic modules. In the EM section, we envision building mini-modules consisting of about 5 towers or 9° in ϕ. The full barrel will have 200 towers in ϕ. There will be 20 modules in ϕ for the hadronic modules, while the EM in the endcap would be a monolith. The 40 EM mini-modules and hadronic modules will be assembled at the SSC Lab inside the cryostat. The cryostat itself will then be welded shut. The calorimeter will be fully assembled above ground and tested before being installed in the experimental hall.

Liquid Argon Calorimeter Physical Parameters

Number of absorption lengths	
at $\eta = 0$	12
at $\eta = 3.0$	14.0
Barrel Dimensions	
inner radius	0.76 m
outer radius	3.60 m
Lateral segmentation 0	
EM	0.032 x 0.032
HAD	0.08 x 0.08
Longitudinal segmentation	2 EM, 4 HAD

Lead Liquid Argon/EM Calorimeter

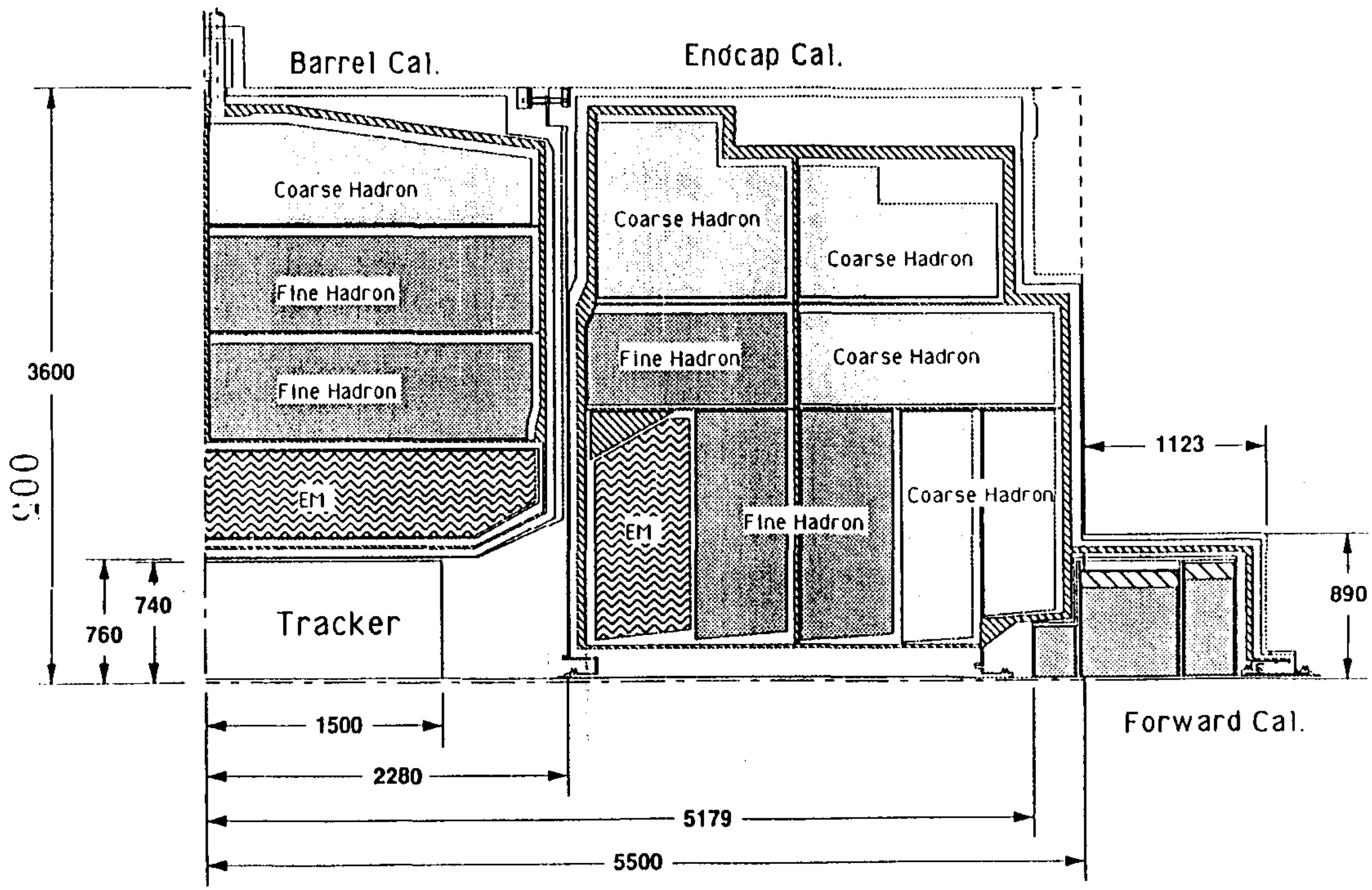
Absorber material	0.2mm SS/0.1mm prepreg/1.3mm Pb 0.1mm prepreg/0.2mm SS
Readout Board	0.4mm (kapton/Cu/kapton)
Sense Material	2 x 2 mm argon
Lateral segmentation (η, ϕ)	0.032 x 0.032
Longitudinal segmentation	2(8 X_o, 17 X_o)
Inner Radius (cryostat/accordion)	760/890 mm
Outer Radius (accordion)	1412 mm
Radiation Length	25 X_o at $\eta = 0$; 28 X_o at $\eta = 3$.
Absorption Length	1.3 λ

Number of Channels-Total	62,000	
Readout Device	JFET preamplifier (75 mW / channel)	
Weight of Barrel	59	Mg
Weight of Each End Cap	19	Mg

Liquid Argon/Copper Hadron Calorimeter

Lateral segmentation (η, ϕ)	0.08 x 0.08	
Longitudinal segmentation	4	
Dimensions		
Inner Radius (active)	1,489	mm
Outer Radius (active)	3,445	mm
Length (excluding forward)	11,000	mm
Copper Absorber Thickness (fine/coarse)	9/16	mm
Sense material: Argon	2	mm
G10 Thickness	2 x 0.5	mm
Readout Channels - total hadron	20,000	
Assemblies (including EM and vessel)	3	each
barrel Weight	891	Mg
End Cap Weight (each)	626	Mg
Forward (each)	19	Mg
Total	2,142	Mg
Liquid Volume		
Barrel	40,000	liters
End cap (each)	27,000	liters
Reserve in head vessel	3,600	liters
Reserve	6,000	liters
Total	104,000	liters
Total number of channels	87,000	

LIQUID ARGON CALORIMETER - 12 X 14 LAMBDA, FLAT ENDCAP HEAD

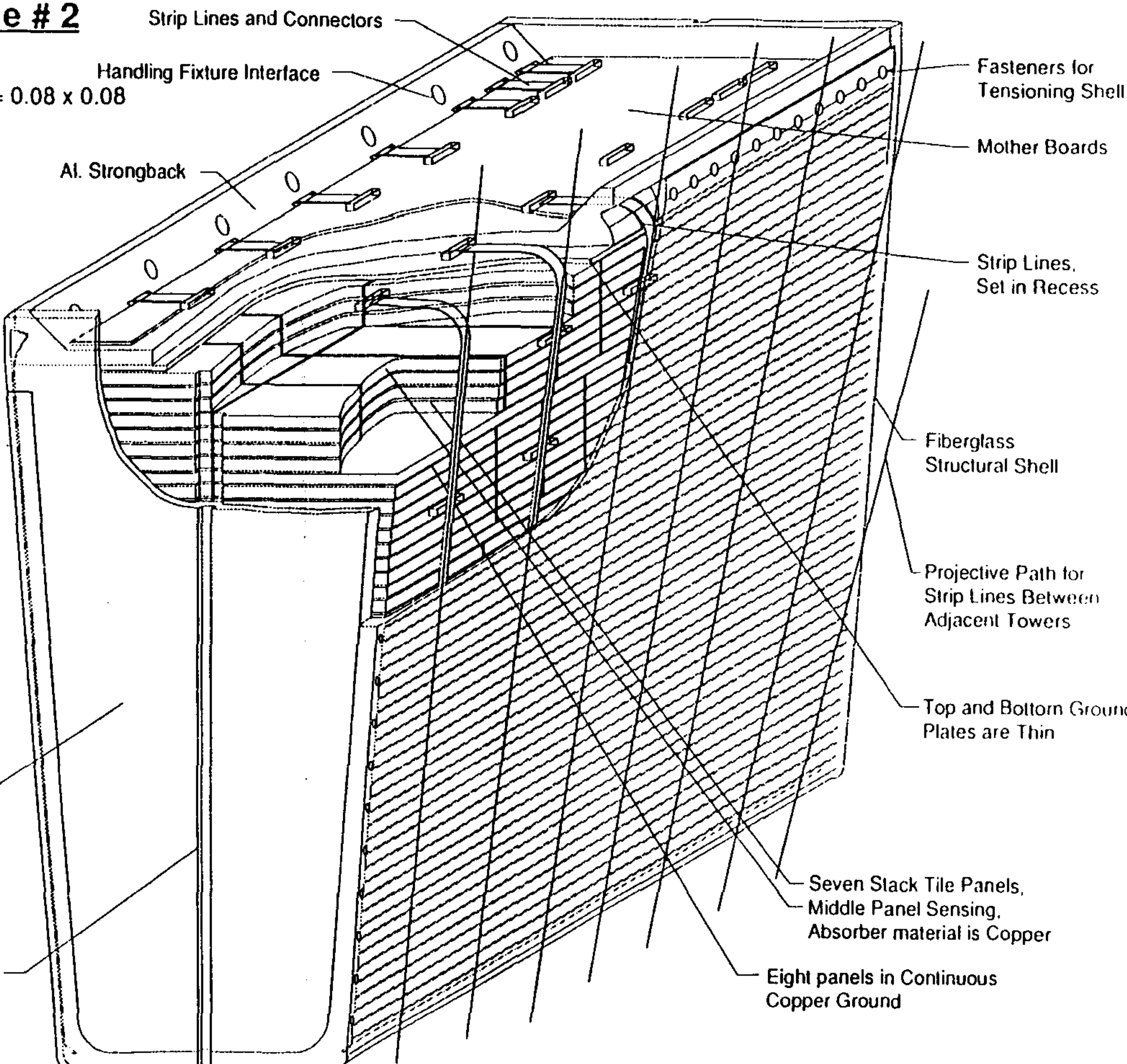


Dimensions in millimeters

Hadron Module # 2

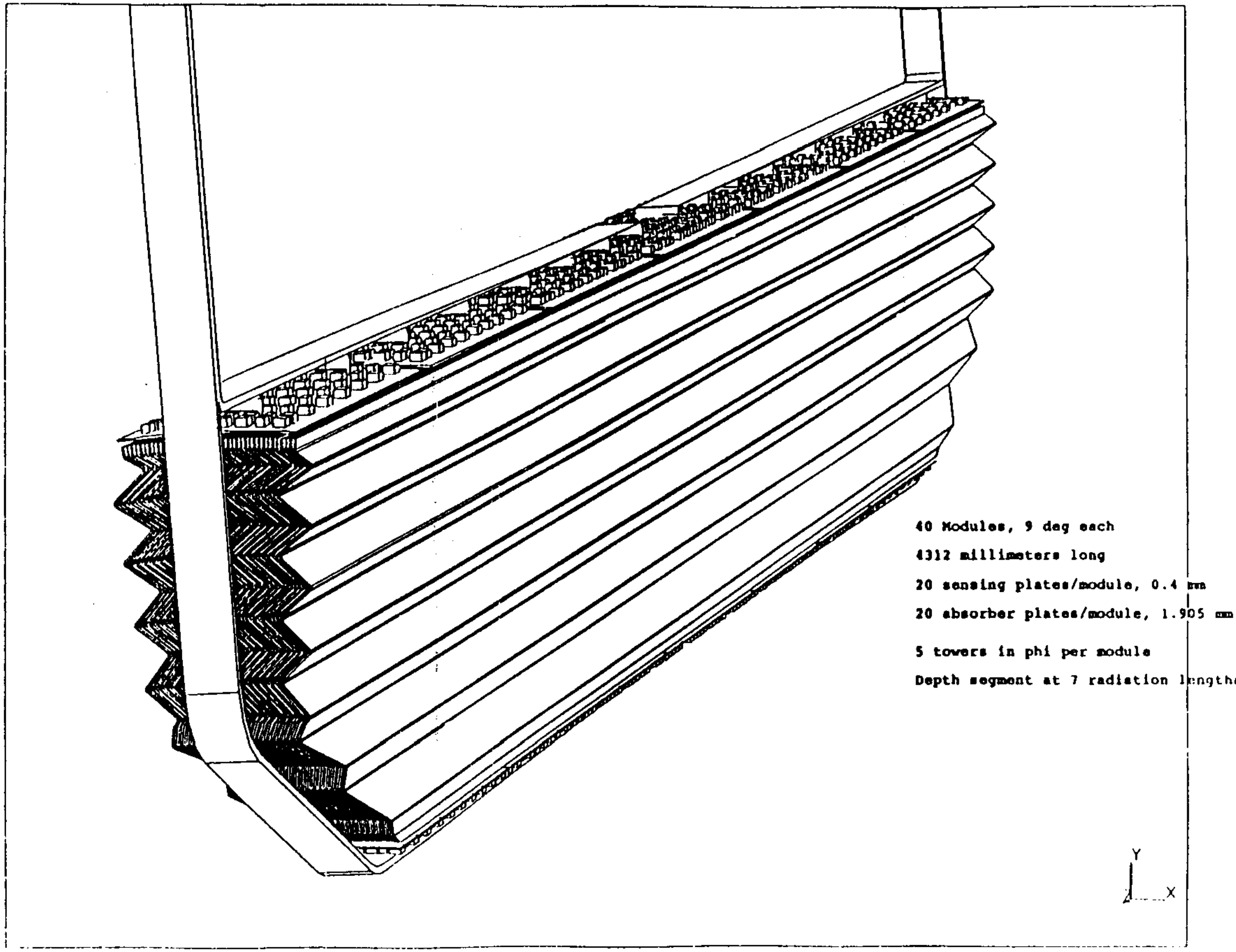
Six Cells Depth
Segmentation $\Delta\eta \times \Delta\varphi = 0.08 \times 0.08$
80 Modules Required
Wt. = 2.38 MT each
Each Module Contains the Following:

1 - Top Ground Plate
1 - Bottom Gnd Plate
5 - Included Gnd Plates
36 - Tile Plates
  Containing 948 Tile
6 - Sensing Plates
  Containing 258 Tile
1 - Strongback
1 - Structural Shell
2 - End Plates
28 - Towers with Strip Lines and Electronics
X - Mother Boards

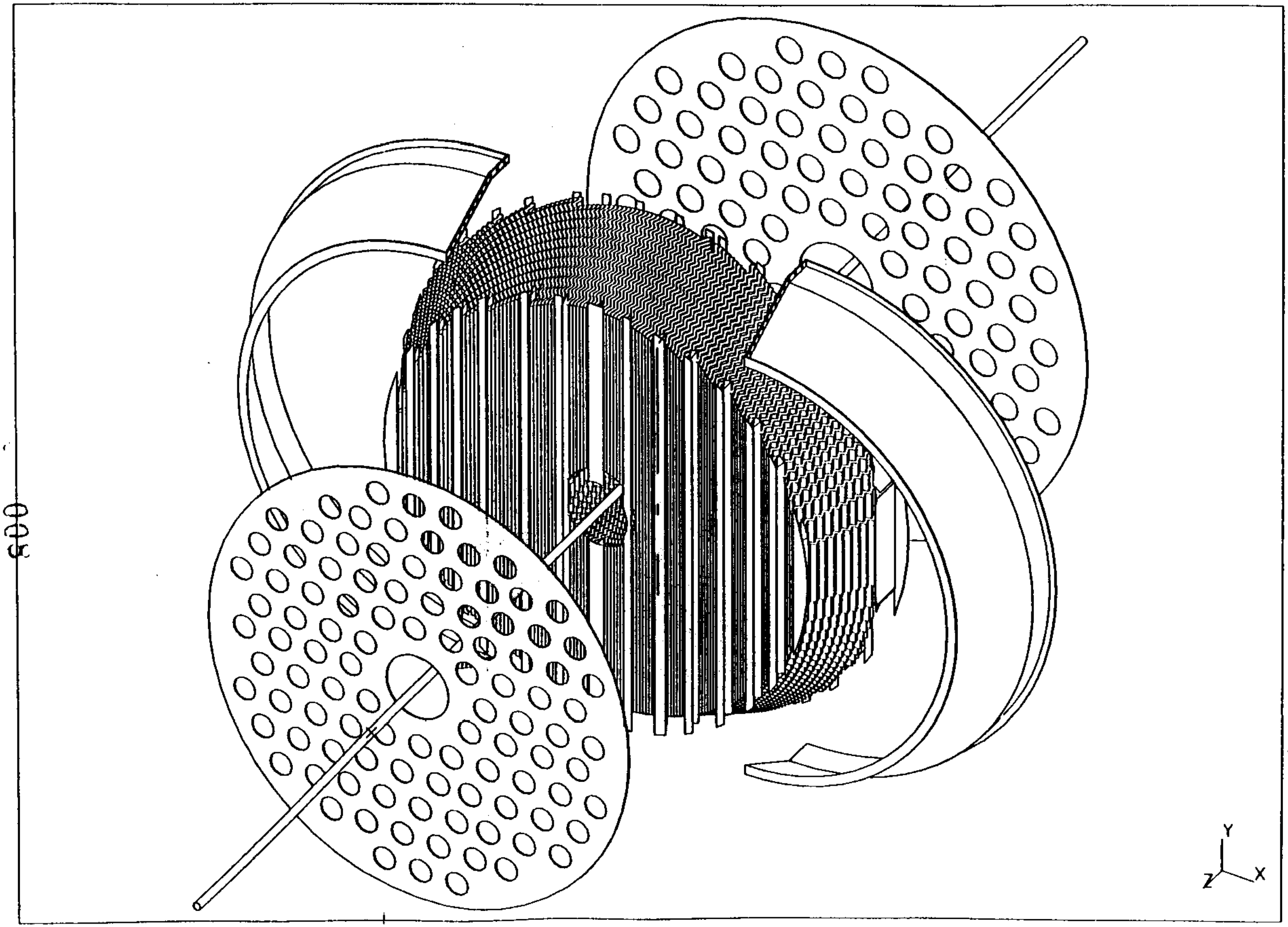


LLMason GEMLAC.HadModDetail 4/18/92

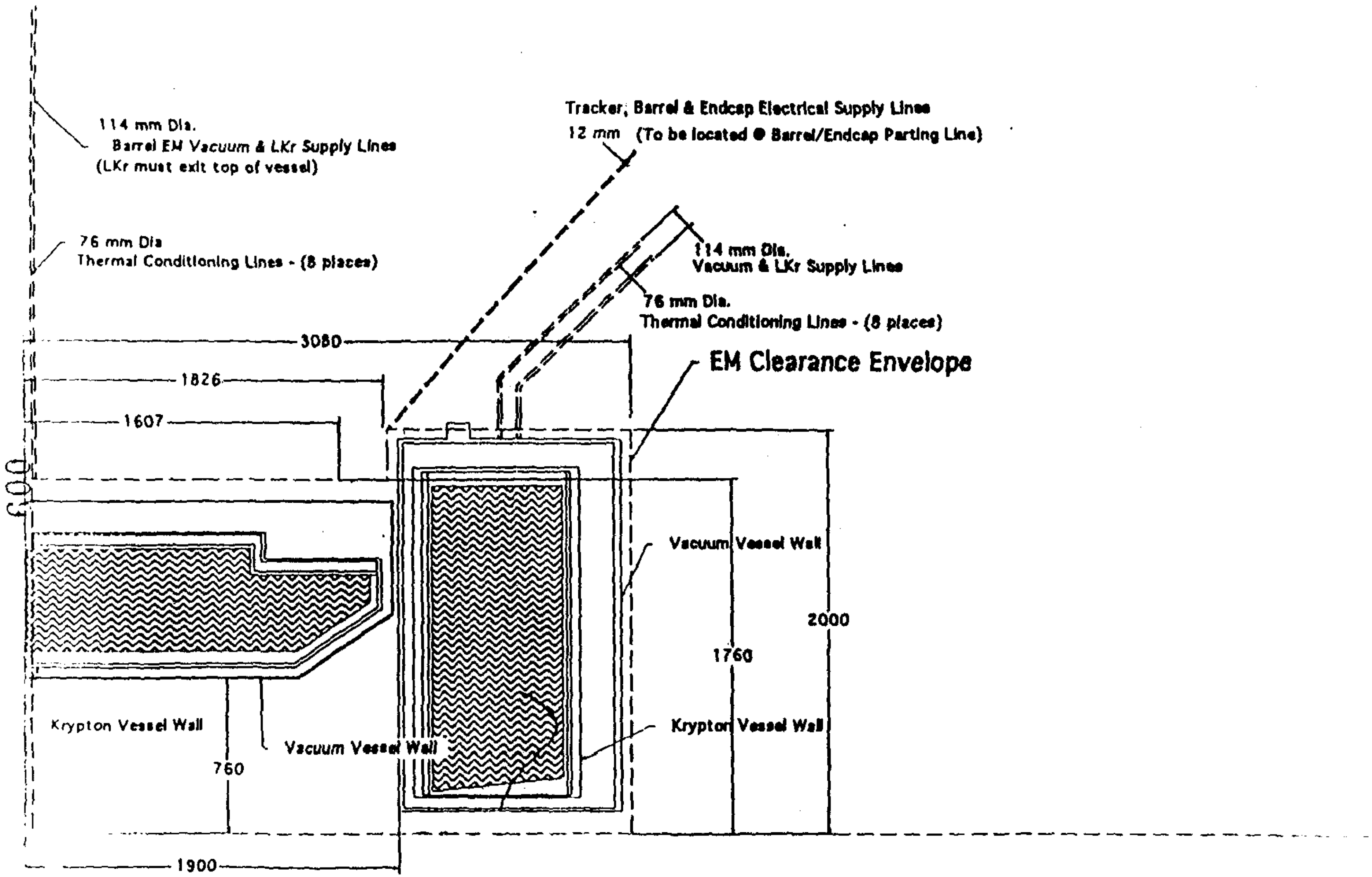
Barrel EM Module



Endcap EM Module



EM BARREL / EM ENDCAP LKr CALORIMETER



KRBarnstable LKr EM/EM 920629

EM BARREL / EM ENDCAP LKr CALORIMETER

Module Weights

Barrel Totals:
44 Megagrams EM
14 Megagrams Other Mass
58 Megagrams

Endcap Totals:
47 Megagrams EM
21 Megagrams Other Mass
68 Megagrams

Total Calorimeter Weight:
58 Megagrams Barrel
68 Megagrams Endcap
126 Megagrams Total

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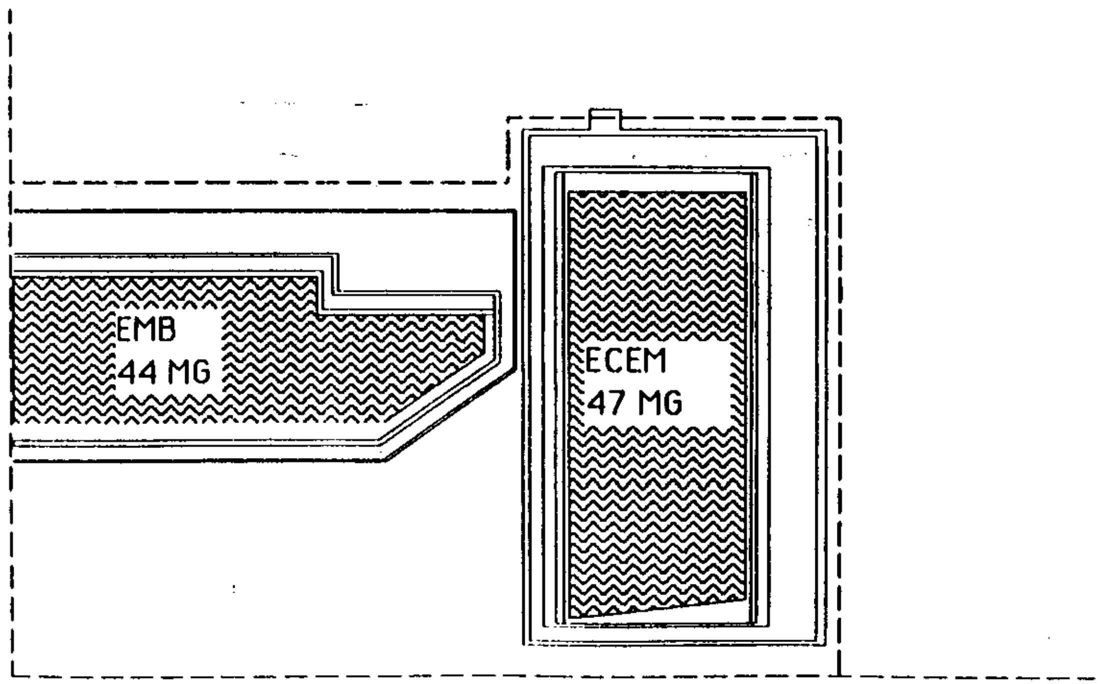
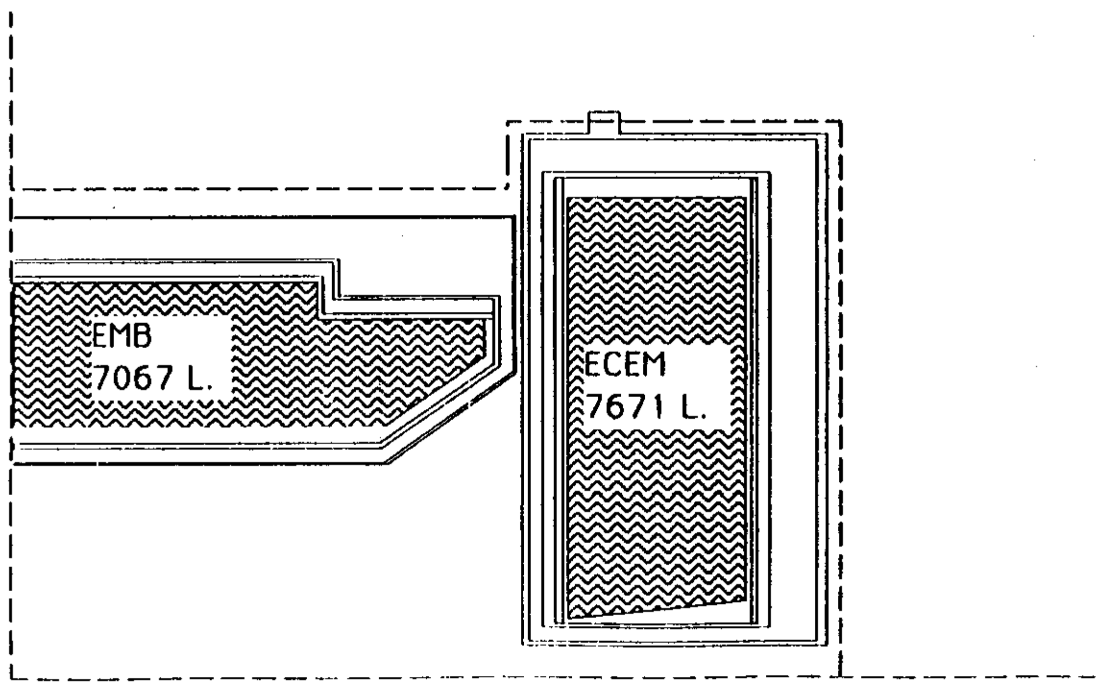


EM BARREL / EM ENDCAP LKr CALORIMETER

Liquid Volumes

Barrel - LKr Totals:	2 Endcap - LKr Totals:	EM/EM - LKr Totals:
7067 Liters EM Area	7671 Liters EM Area	10,888 Liters Barrel
3821 Liters Other Areas	3001 Liters Other Areas	10,672 Liters 2 Endcaps
10,888 Liters Total Barrel	10,672 Liters Total Endcap	21,560 Liters Total

011



Calorimeter Engineering Question

1. Liquid Krypton EM Calorimeter Support

Request: Provide proof-of-principal structural designs for the barrel and endcap accordion EM calorimeters.

Specific Concerns:
- *The load path from the barrel accordion plates to the G-10 ribs to the vessel walls is not understood.*

Answer:
- *See Attached Data.*

Specific Concerns:
- The structure of the individual barrel EM modules prior to assembly is not understood. The module structure will have to be capable of not only supporting the module during handling and shipping; but, it will be required to provide for the transfer of the load to the final assembly structure.

Answer:
- *See Attached Data.*

Data:

Barrel EM Calorimeter Modules:

- The barrel concept for the EM accordion consists of 40 modules, each module extending the full length of the barrel calorimeter. Each 9 degree module stack starts with an absorber plate and ends with a sensing plate with spacer bars at the inner and outer radii. The plate stack is pinned together at the inner and outer radii through the plates and spacer bars and held with fasteners to form a module (reference Figure 1-1).

The ends and middle of the absorber plates have composite filler strips approximately one cm long in the z direction with the thickness matching the krypton gap extending from the inner plate diameter to the outer plate diameter (reference Figures 1-2 and 2a). These filler strips form a continuous ring at eta = 0 and at the ends of the barrel EM when all the modules are assembled and also provide the structural integrity for a single module as shown in Figure 1-2b. Between the absorber and sensing plates on the flat surfaces are layers of Hexcel to control the minimum argon gap dimensions.

At the ID and OD of the module the outer and inner spacer strips are projected beyond the rest of the spacer bars to form flanges centered on the filler strips(reference Figures 1-3, 3a, and 3b). These flanges support the modules during shipping and handling and also tie adjacent modules together and provide support for the calorimeter assembly.

Barrel EM Calorimeter:

013 • Clevis fittings are installed over adjacent module flanges with fasteners inserted through them to act as stays while holding the modules together (reference Figure 1-4). The outer fittings are used to support the modules in the radial and axial direction. Only the inner fittings are guided. The fittings, filler strips, plates rings, inner and outer spacer bar and absorber plates form the structure of the module.

Figures 1-5 through 1-7 show a module assembly and a portion of two calorimeter halves prior to forming a completed assembly. Also depicted are the proposed cable bundle layouts and the electronics. The barrel EM calorimeter is supported in the X,Y and Z directions at its outer clevises. At the inner clevises the barrel EM calorimeter is supported in the hoop direction. The composite material for the spacer bars and end rings will be selected so that the thermal contraction of the barrel EM calorimeter is close the thermal contraction of the calorimeter vessel.

Figure 1-1. Barrel EM Module Assembly

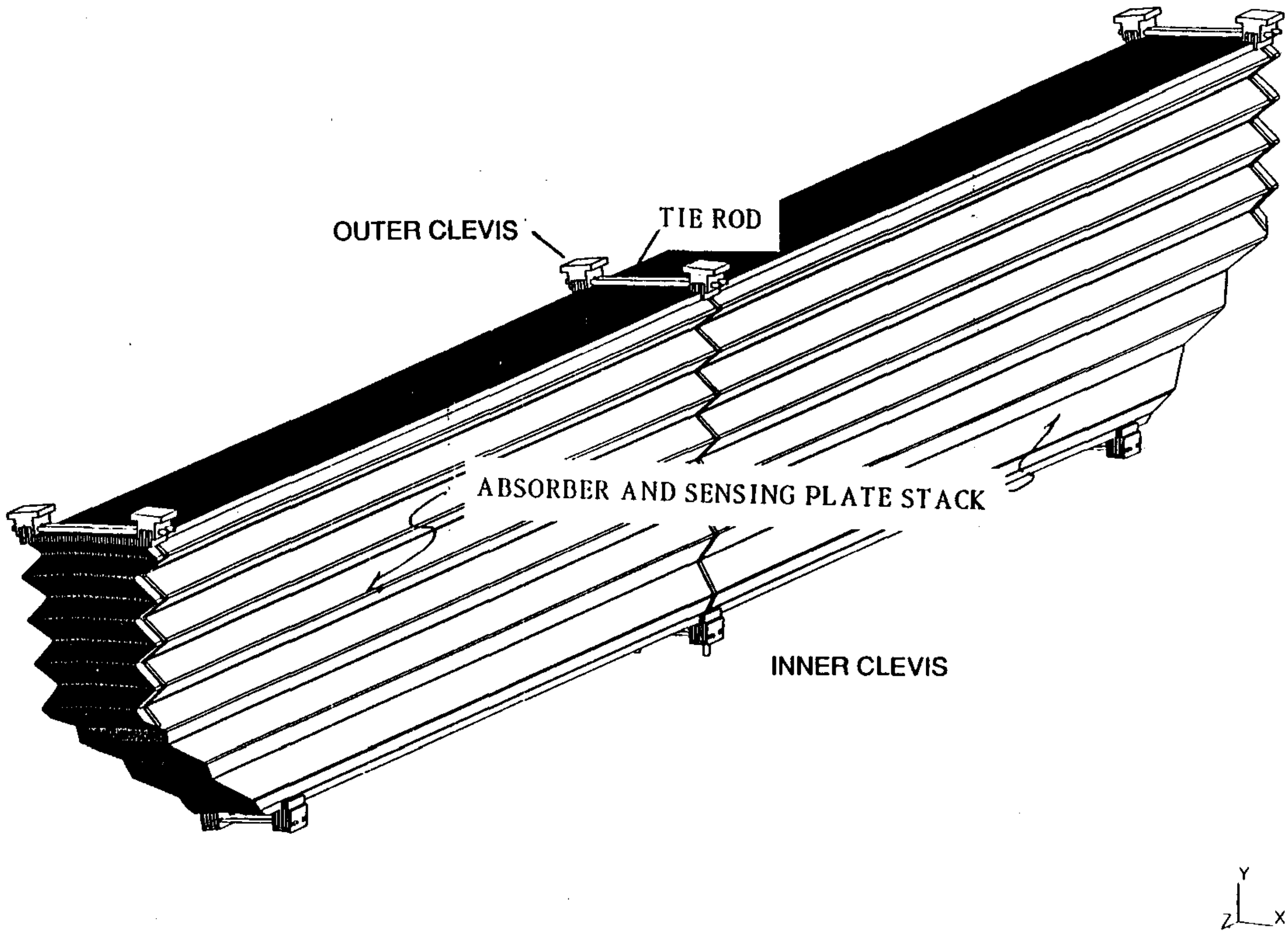


Figure 1-1 Barrel EM Module Assembly

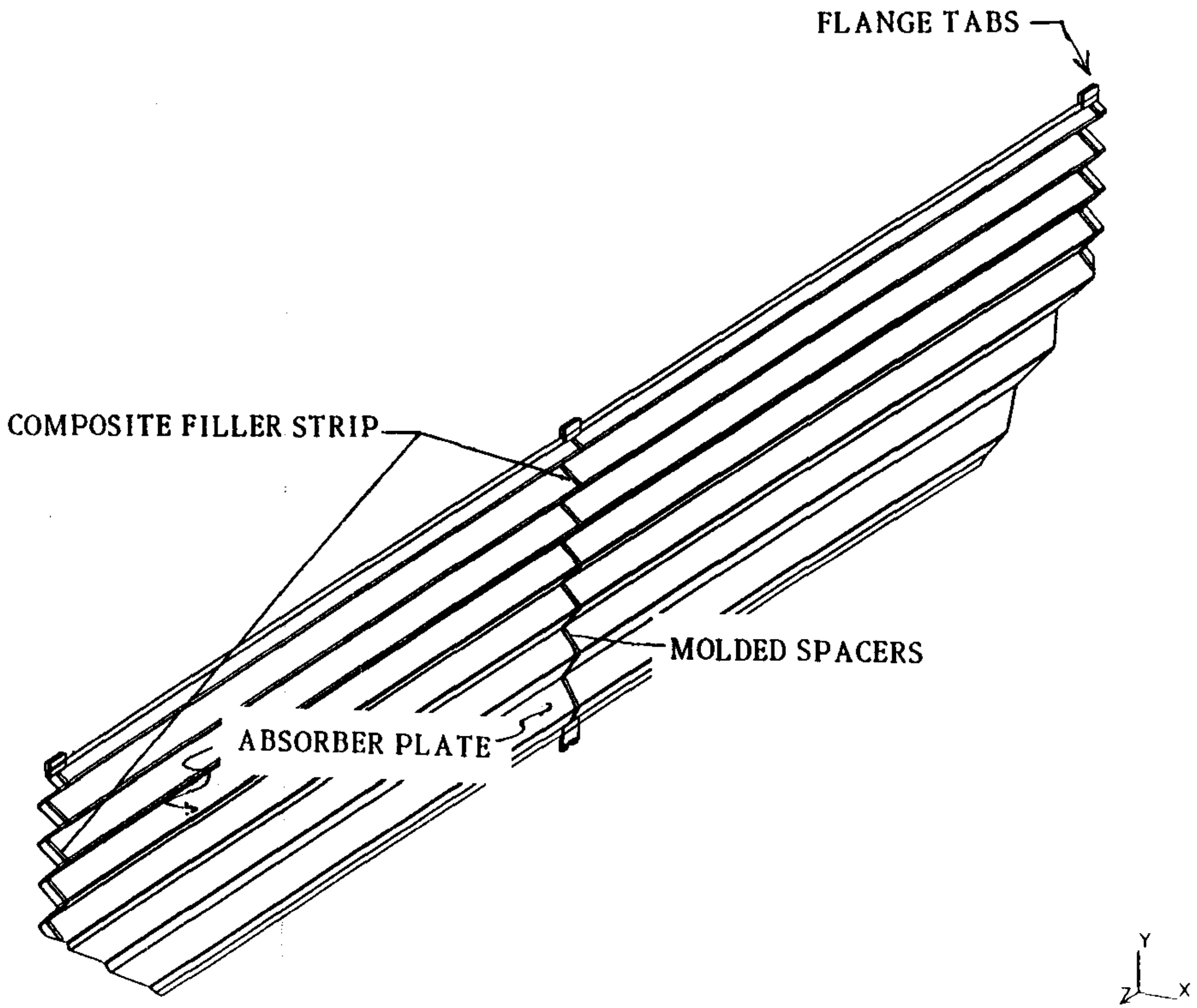


Figure 1-2 Barrel EM Module Absorber Plate

Layers of the Accordion Absorber plate

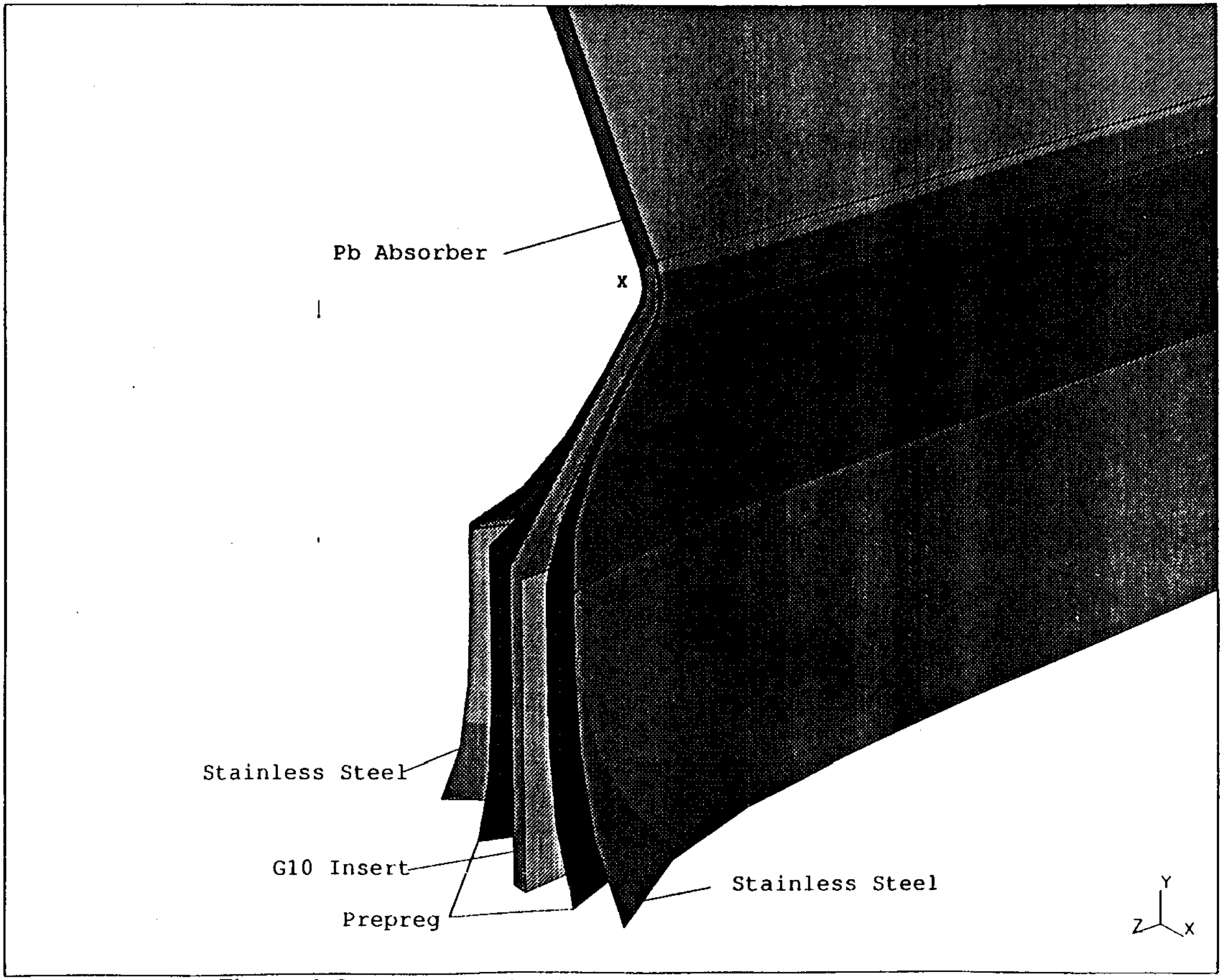


Figure 1-2a Barrel EM Module Absorber Plate Laminate

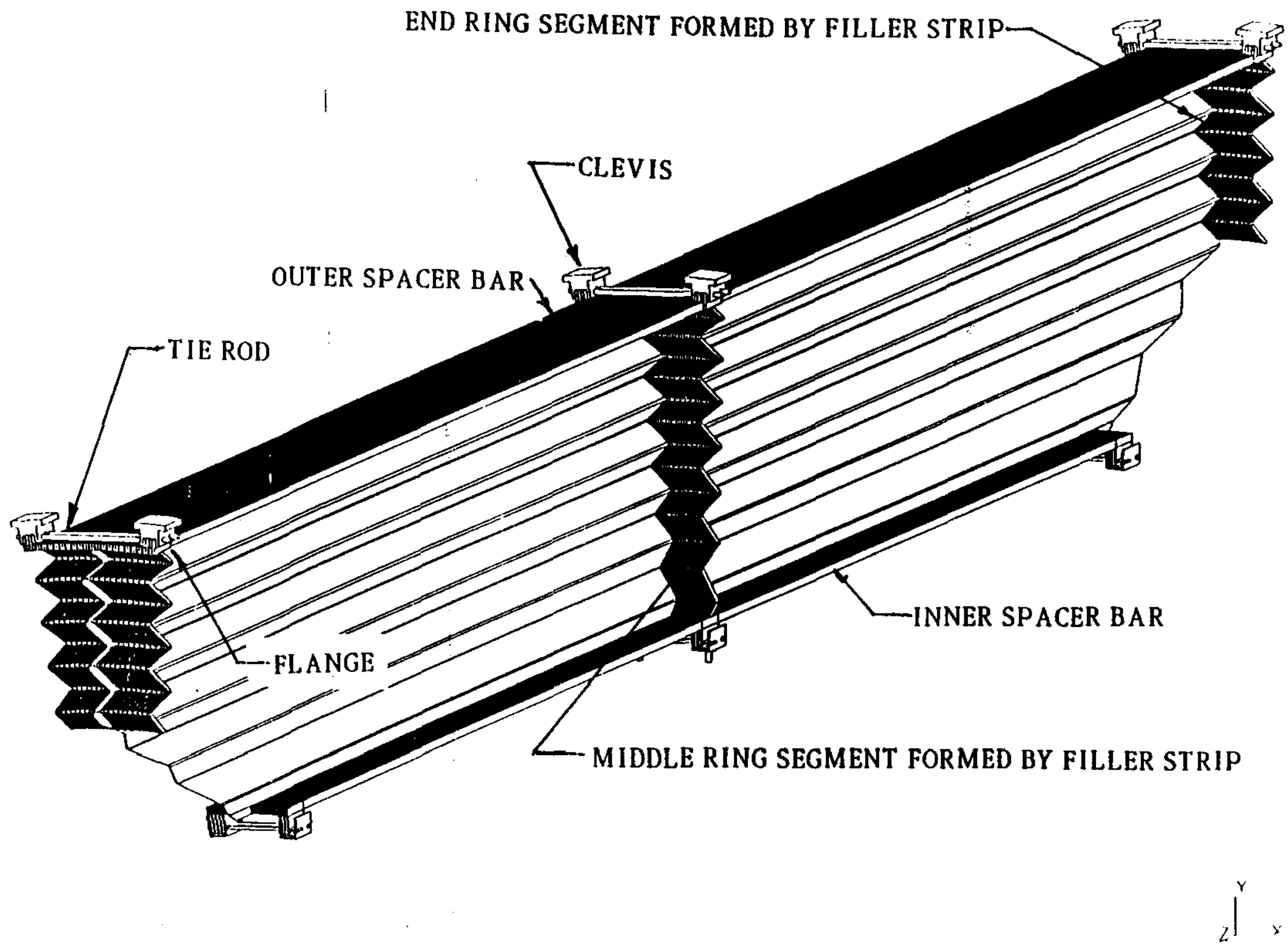


Figure 1-2b EM Module Structural Elements

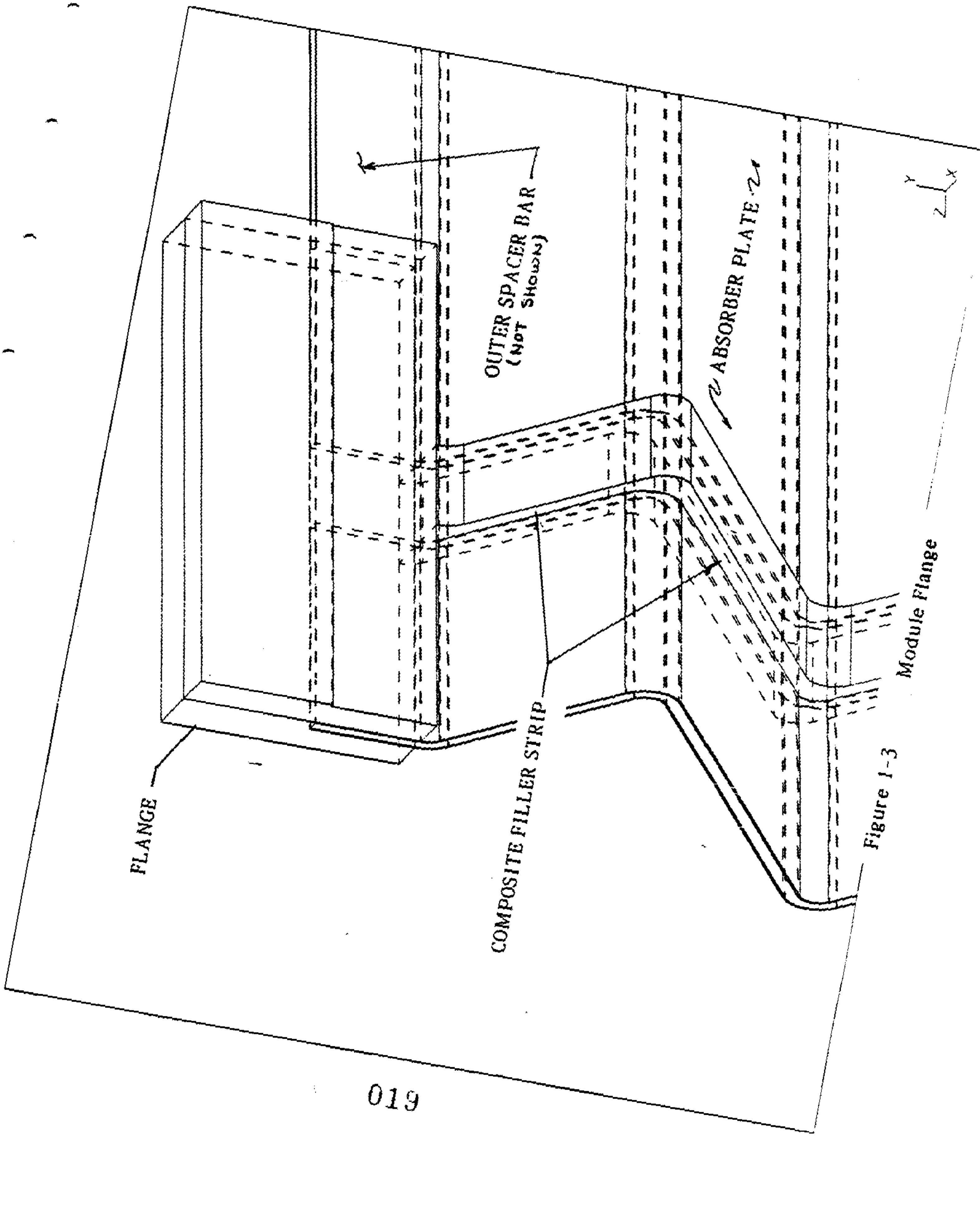

OUTER SPACER BAR
(NOT SHOWN)
ABSORBER PLATE
FLANGE
COMPOSITE FILLER STRIP
Module Flange

Figure 1-3

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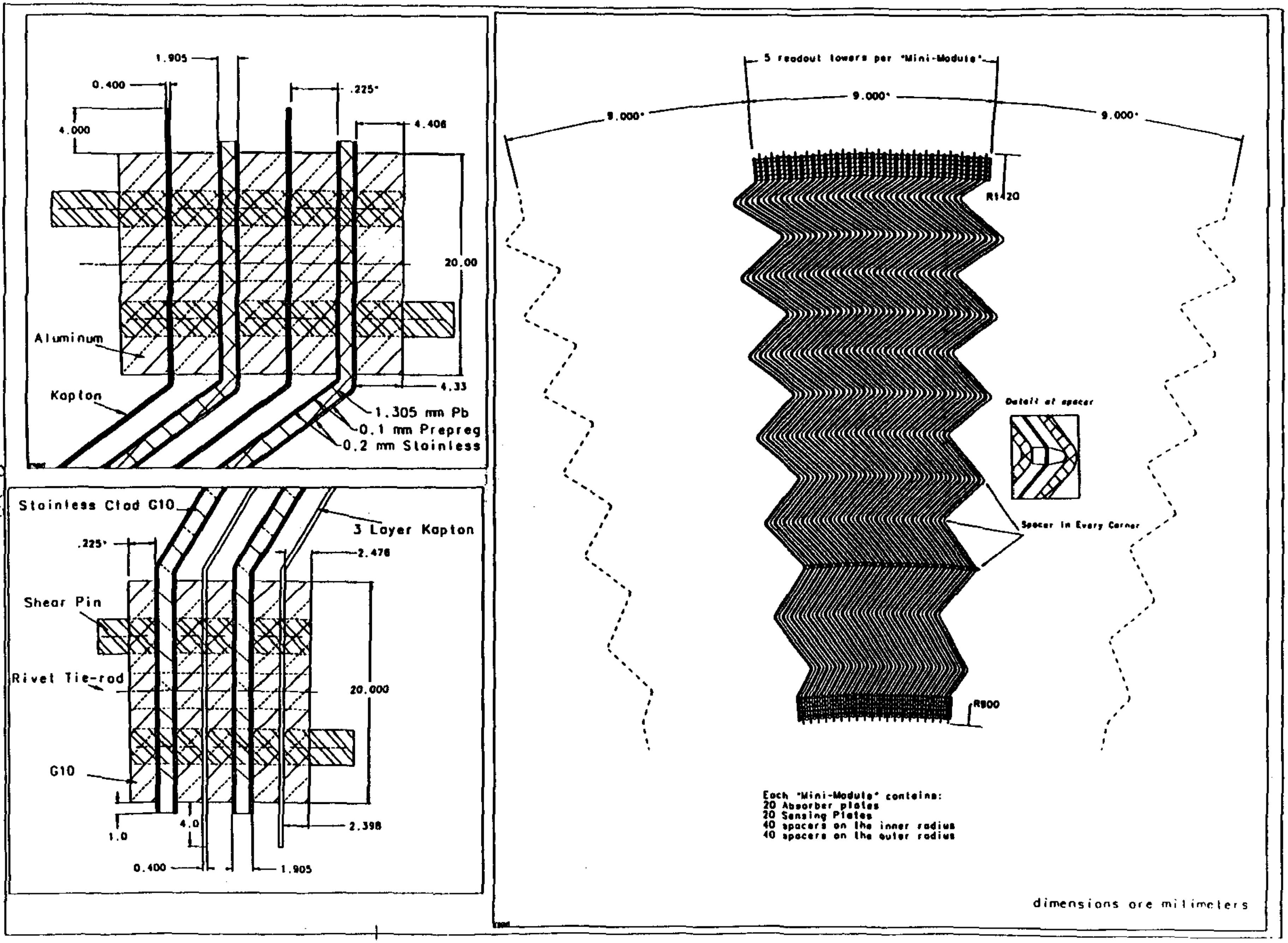


Figure 1-3a Typical Module Lay-up in Section

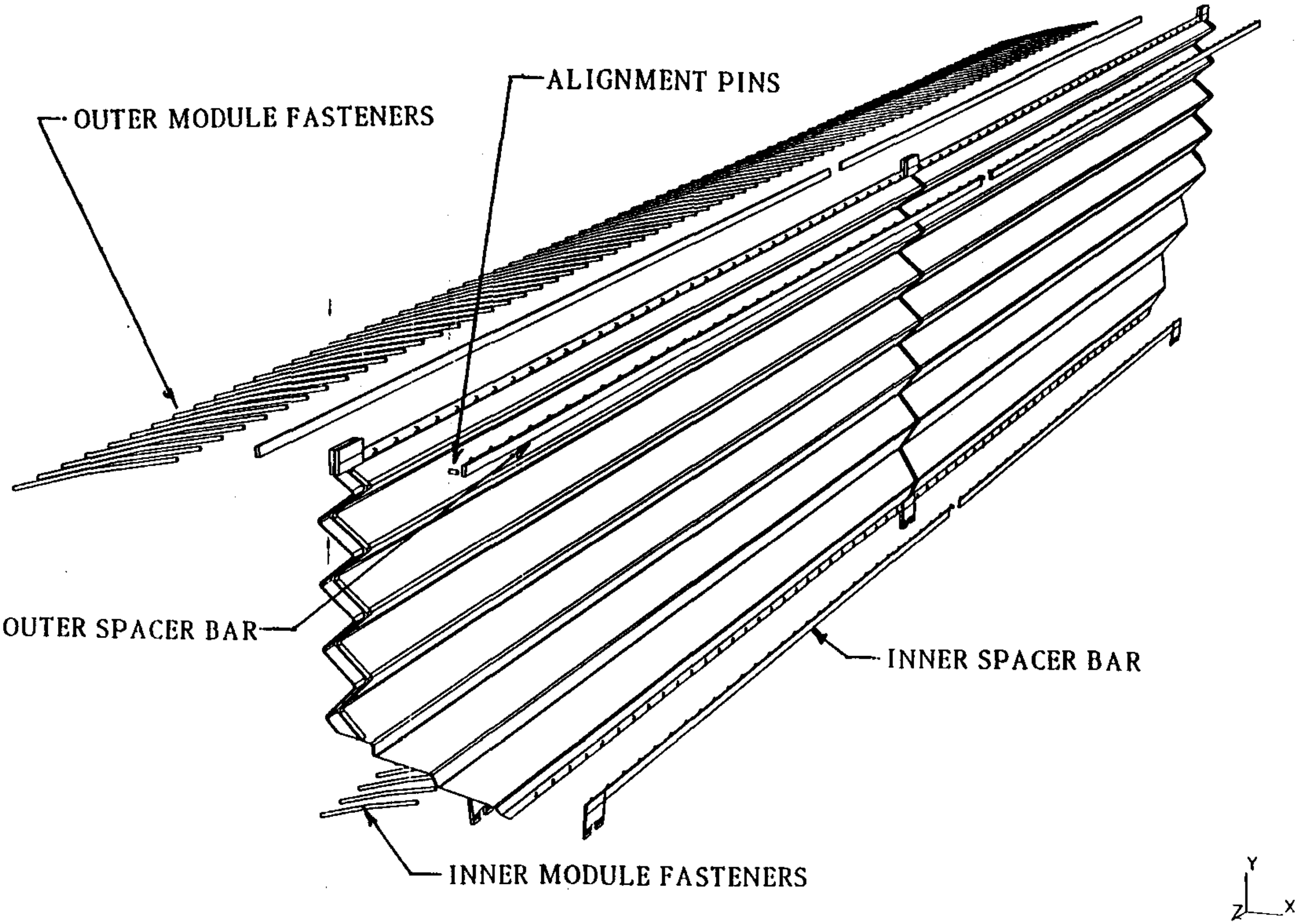


Figure 1-3b Structural and Massive Components of Module

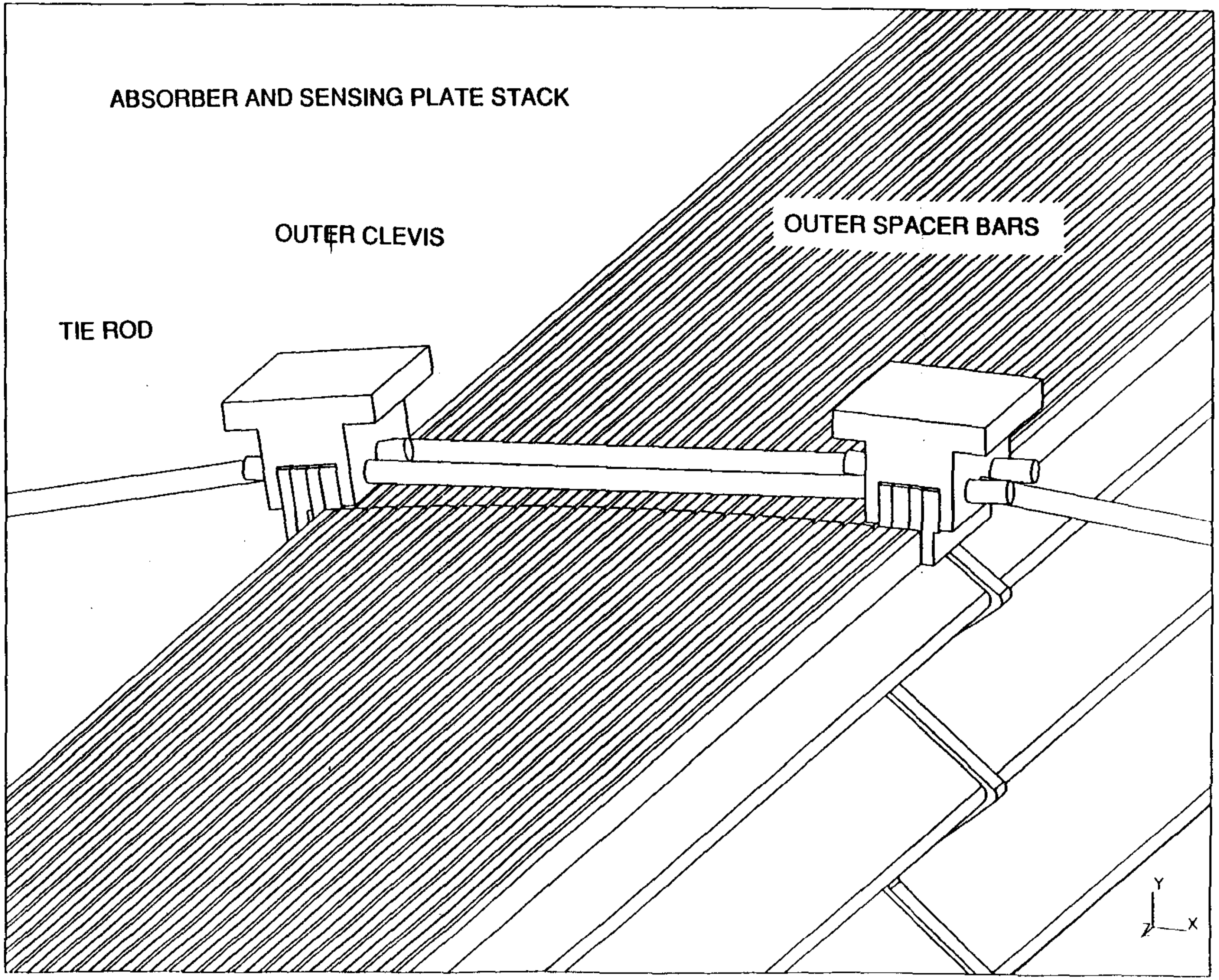


FIGURE 1-4 Plates, Spacers, Flanges, Clevis, and Tie Rod Details

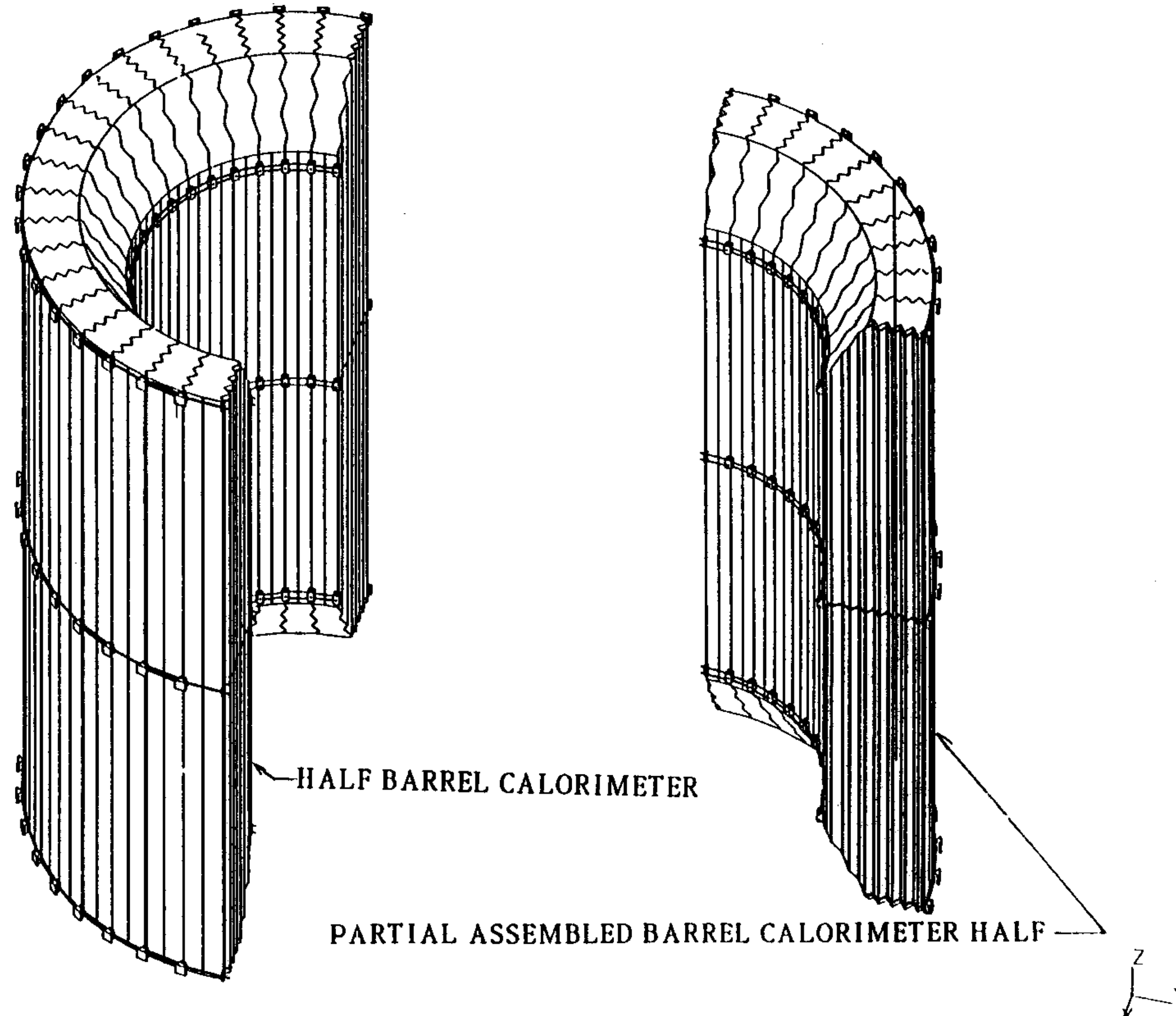


Figure 1-7 Partial View of Modules assembled in Halves

Calorimeter Engineering Question (Continued)

1. *Liquid Krypton EM Calorimeter Support*

Specific Concerns:

- *Differences in the axial thermal coefficients of expansion of the accordion plates (stainless/lead) and the cryostats (aluminum) require mechanical compensation.*

Answer:

- *Since effective axial coefficient of expansion of the accordion plate is almost identical to that of the cryostats (see Data) no mechanical compensation is required.*

Specific Concerns:

- *The radial (across the folds) thermal contraction of the accordion plates is known to be greater than the simple contraction of the material, thus increasing the difficulty of providing support at the inner and outer edges of the accordion plates.*

Answer:

- *Since the radial thermal contraction of the accordion plates is 27% more than that of the cryostats, it will require radial support. The thermal stresses induced in the plates due to radial support are currently under investigation.*

Data:

- An analysis was performed to determine the effective axial thermal coefficient of expansion of the absorber accordion plate for thermal cooldown from 296°K to 77°K. For the baseline lay-up (0.4mm stainless, 0.2mm G10 and 1.3 mm lead) the effective per cent change in length (%ΔL/L) in the axial direction is 0.35% as compared with that of aluminum of 0.37%. Therefore, the accordion plates should contract like the aluminum cryostat in the axial direction during thermal cooldown. It should be noted, however, that the plates will not be attached axially to the cryostat.

- Analysis has shown that the baseline accordion plate radial thermal contraction due to thermal cooldown to 77°K is 40% greater than the simple contraction of the material, based on plane stress assumptions. This is due to the difference in the length of the steel layer on the outside relative to the inside(reference Figure 1-8). For the baseline lay-up (0.4mm stainless, 0.2mm G10 and 1.3 mm lead) the effective per cent change in length (%ΔL/L) in the axial direction is 0.47%. Since this is much greater than that of aluminum, the accordion plates will be subject to tension if they are attached radially to the cryostat. The thermal stresses due to radial support are currently under investigation.

Figure 1-8. Baseline Absorber Accordion Lay-Up (Radial View)

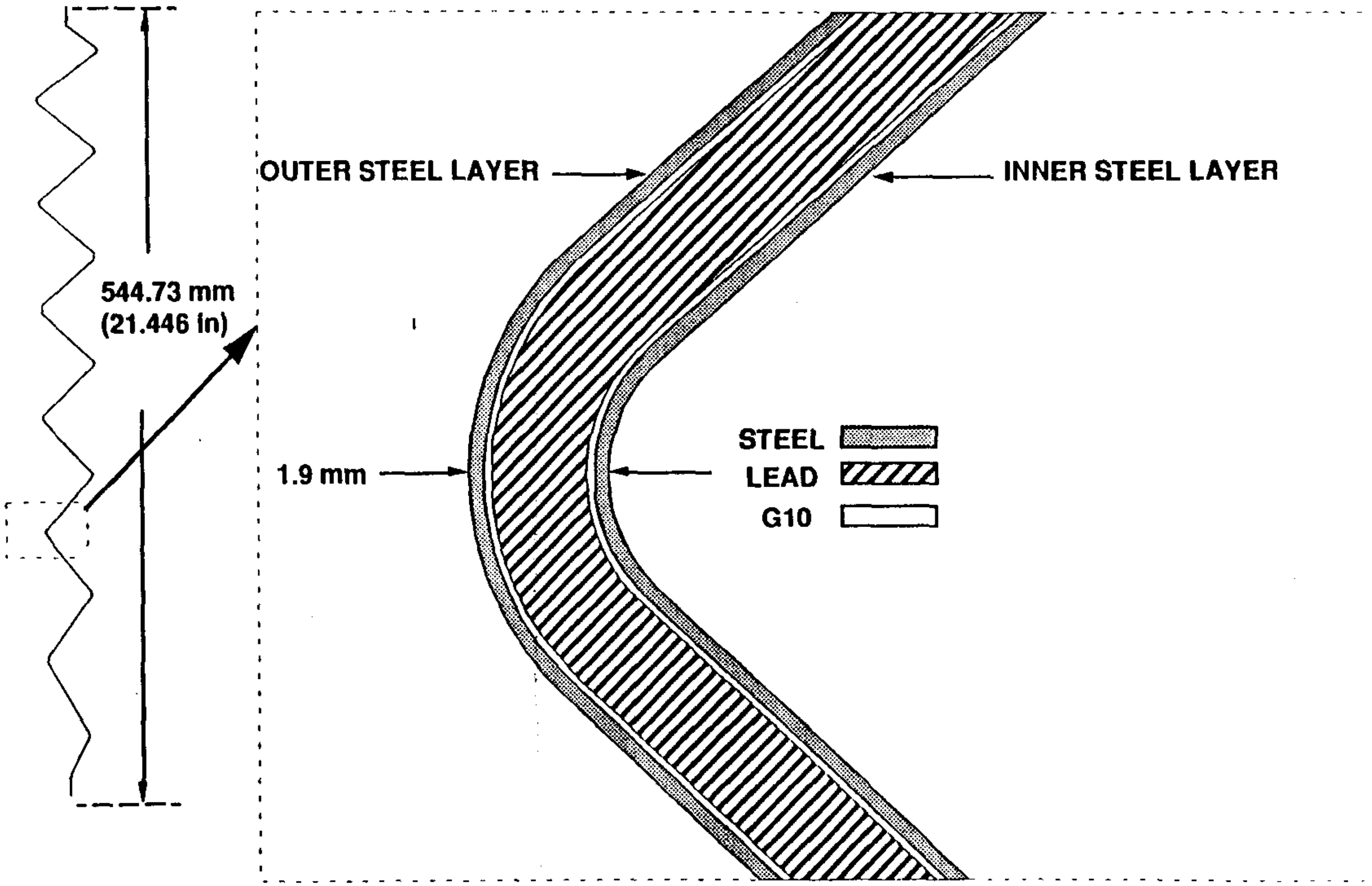


Figure 1-8 Baseline Absorber Accordion Lay-Up (Radial View)

Calorimeter Engineering Question (Continued)

1. Liquid Krypton EM Calorimeter Support

Specific Concerns:

- *Deflection of the barrel accordion plates after assembly is not understood. The plates are basically large springs which allow the inner diameter of the barrel to sag due to the mass of the assembly. In particular, the vertically oriented plates on top and bottom appear to support all the load.*

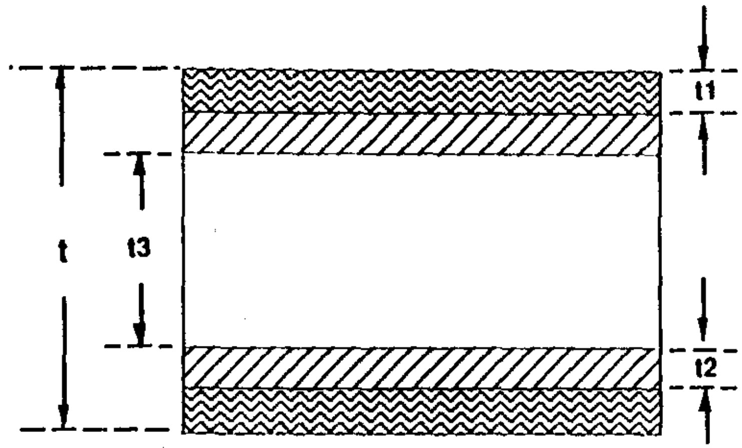
Answer:

- *The vertically oriented plates on the top and bottom do not support all the load. Analysis was performed to understand the deflections of a horizontally oriented accordion plate subject to a 1g load. This orientation causes the largest deflections to occur in the accordion plate. Several support conditions were investigated (reference Figures 1-13 through 1- 15).*

Data:

- The maximum accordion plate deflection occurs in the horizontal position.
- The baseline is assumed to be the absorber accordion plate lay-up 1 (reference Figure 1-9).
- Support case 8 was chosen because it results in less dead space and for a 1g load the maximum horizontal deflection of the absorber accordion plate is 0.973 mm in krypton (reference Figure 1-14).
- The maximum deflections and strains of the absorber plate in air and krypton are presented for several lay-ups (reference Figure 1-14).
- Interaction equations are developed to provide the capability of changing the absorber plate lay-up and determining the maximum horizontal deflections (reference Figure 1-15).

Figure 1-9. Accordion Lay-Up
Figure 1-10. Accordion Properties
Figure 1-11. Accordion Geometry
Figure 1-12. Support Cases 1 - 8
Figure 1-13. Absorber/Sensor Accordion Analysis Results in Air for Support Cases 1-8
Figure 1-14. Absorber Accordion Analysis Results(Air & Krypton) for Several Lay-Ups (Support Case 8)
Figure 1-15. Absorber Accordion Deflection Lay-Up Interaction Equations (Support Case 8)
Figure 1-16. Accordion Equations for Stiffness & Mass



ABSORBER PLATE LAMINA

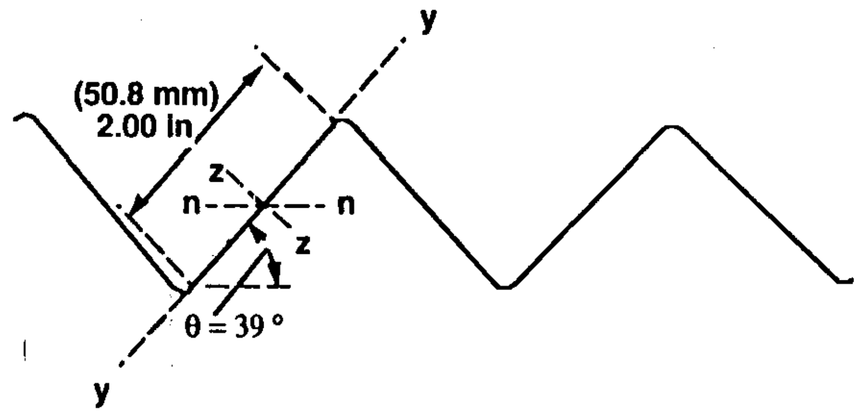
- STEEL (t1)
- G10 (t2)
- LEAD (t3)

SENSOR PLATE LAMINA

- COPPER (0.042 mm)
- KAPTON (0.218 mm)
- COPPER (0.036 mm)

PLATE LAY-UP	t1 (mm)	t2 (mm)	t3 (mm)	t (mm)
1	0.20	0.10	1.30	1.9
2	0.20	0.20	0.90	1.7
3	0.20	0.10	0.90	1.5
4	0.15	0.23	0.94	1.7
5	0.20	0.30	0.90	1.9

Figure 1-9 Accordion Lay-up



Material	(ρ) Density (g/cm³)	(E) Modulus (10^6 lbs/in²)	(ν) Poisson's Ratio	%ΔL/L (296 to 77 °K)
Steel	8.00	30.0	0.272	0.281
G10	1.70	4.40	0.187	0.638
Lead	11.3	2.60	0.400	0.577
Copper	9.10	17.0	0.345	0.304
Kapton	1.42	0.51	0.340	0.330

PLATE ID	(M_A) Mass in air (kg)	(M_K) Mass in krypton (kg)	(EI_n) Stiffness (10^6 lbs-in²)	(EI_y) Stiffness (10^3 lbs-in²)	(EI_z) Stiffness (10^6 lbs-in²)
1	27.00	20.20	0.17	1.17	0.4266
2	20.80	14.73	0.168	0.913	0.422
3	20.30	14.94	0.159	0.67	0.400
4	20.44	14.36	0.140	0.7695	0.3535
5	21.31	14.52	0.177	1.20	0.4455

(Note that mixed units are used to provide ease of use by Physicists and Engineers)

Figure 1-10 Accordion Properties

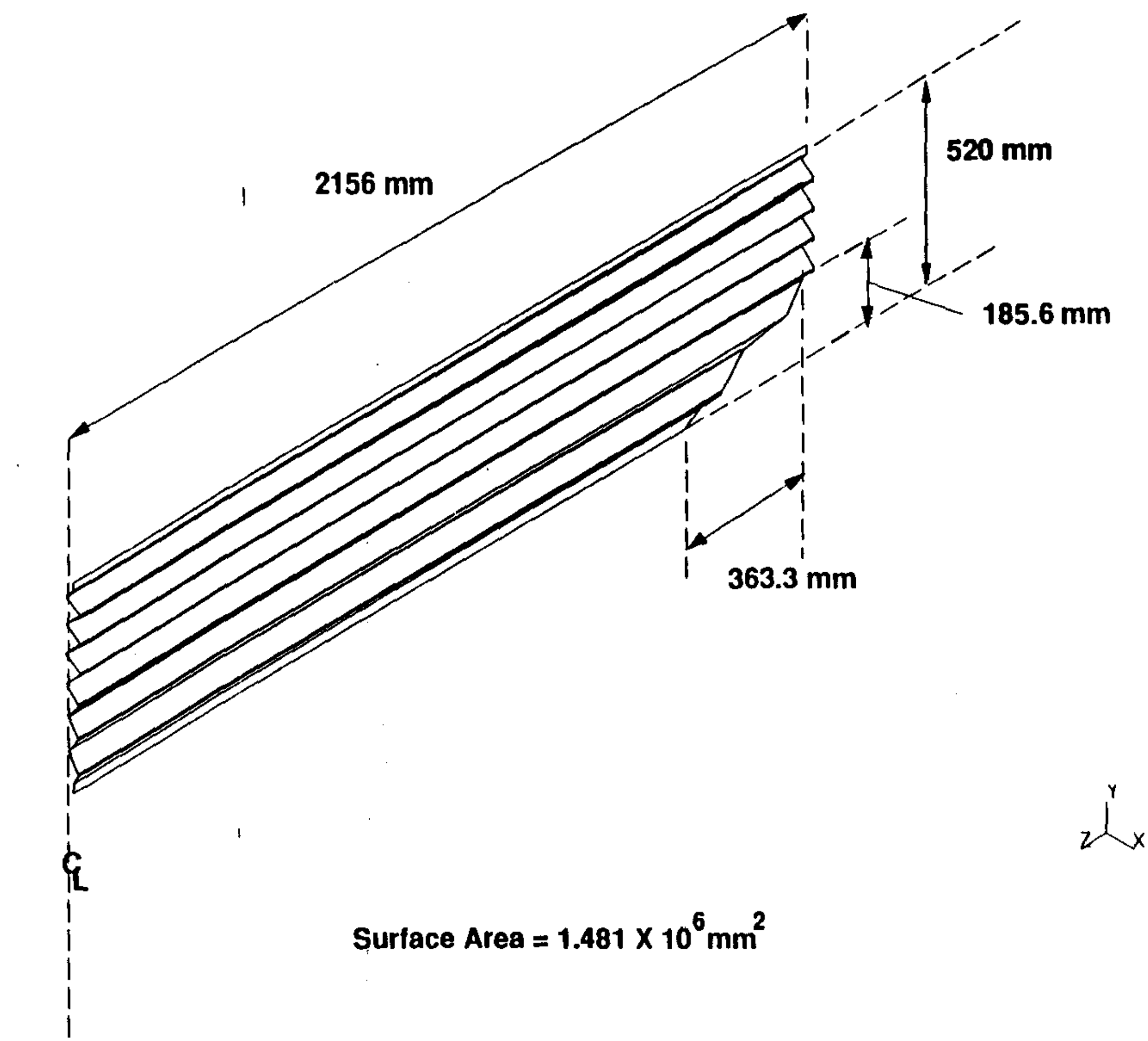
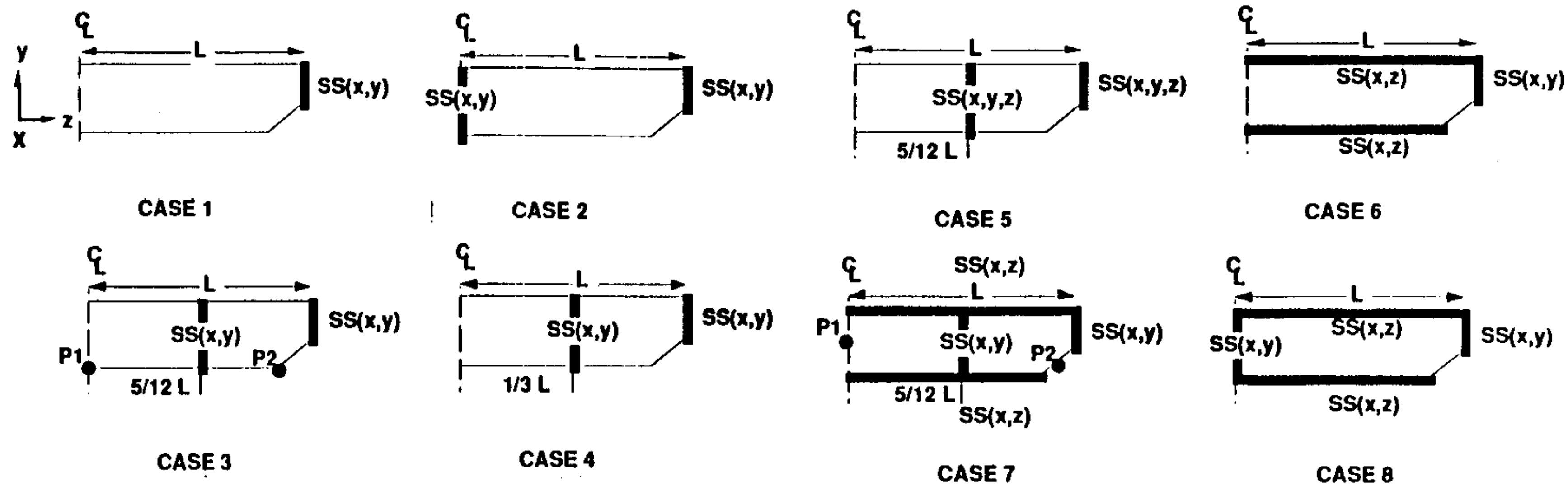


Figure 1-11 Accordion Geometry



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SS(x,y) = pinned supports in x & y directions

SS(x,z) = pinned supports in x & z directions

SS(x,y,z) = pinned supports in x, y &z directions

P1, P2 = locations for deflection measurements

L = half the length of the absorber plate

Figure 1-12 Support Cases 1-8

Absorber Analysis Results in Air

Support Case	δ_x Max Deflection x direction (mm)	δ_x Deflection at P2 x direction (mm)	ε_z % Max Strain z direction (10^{-2})
1	80.5		6.65
2	3.08		2.00
3	0.96	0.64	0.89
4	1.108		0.78
5	0.67		
6	4.9		0.75
7	0.47	0.11	0.61
8	1.3		1.24

Sensor Analysis Results in Air

Support Case	δ_x Deflection at P1 x direction (mm)	δ_x Deflection at P2 x direction (mm)	ε_z % Max Strain z direction (10^{-2})
3	2.2	0.52	0.80
7	0.35	0.33	0.43

Absorber/Sensor Relative Maximum Deflections (mm) in Air

CASE	δ_x x direction	δ_n normal to flat of plates
7	0.22	0.185

Figure 1-13 Absorber/Sensor Accordion Analysis Results in Air for Support Cases 1-8

PLATE ID	δ_x Max Deflection in Air x direction (mm)	δ_x Max Deflection in Krypton x direction (mm)	ε_z Max Strain in Air z direction (10^{-4}mm/mm)	ε_z % Max Strain in Krypton z direction (10^{-2})
1	1.30	0.973	1.24	0.928
2	1.08	0.764	1.01	0.714
3	1.17	0.861	0.999	0.735
4	1.26	0.885	1.18	0.829
5	0.99	0.674	0.944	0.643

notes:

density of krypton = 2.415 g/cm^3
deflection in krypton = deflection in air*(M_K/M_A)
stress for each layer can be computed by multiplying the strain, ε_z , by the Modulus, E

035

Figure 1-14 Absorber Accordion Analysis Results(Air & Krypton) for Several Lay-Ups (Support Case 8)

(Valid Only for This Geometry and Case 8 Support Conditions)

In air: $\alpha R_1 + \beta R_2 = \delta_x$

In krypton: $\alpha R_1 + \beta R_2 = \delta_x * (M_K/M_A)$

where

α = 6208.3351

β = 13.734216

δ_x = max vertical deflection (mm)

$R_1 = M_A/EI_n$ (kg/lbs-in^2)

$R_2 = M_A/EI_y$ (kg/lbs-in^2)

PLATE ID	R_1 (kg/lbs-in^2))	R_2 (kg/lbs-in^2))	δ_x Max Deflection in Air x direction (mm)	δ_x Max Deflection in Krypton x direction (mm)
1	0.0001591	0.023000	1.30	0.973
2	0.0001239	0.022774	1.08	0.764
3	0.0001280	0.030311	1.17	0.861
4	0.0001455	0.026571	1.26	0.885
5	0.0001203	0.017749	0.99	0.674

(Note that mixed units are used to provide ease of use by Physicists and Engineers)

Figure 1-15 Absorber Accordion Deflection Lay-Up Interaction Equations (Support Case 8)

Stiffness Equations:

$$EI_Z = \frac{1}{12} w^3 \left[2 E_1 t_1 + 2 E_2 t_2 + E_3 t_3\right]$$

$$EI_y = 2w\left[\frac{1}{12} E_1 t_1^3 + E_1 t_1 \left(\frac{t}{2} - \frac{t_1}{2}\right)^2\right] +$$

$$2w\left[\frac{1}{12} E_2 t_2^3 + E_2 t_2 \left(\frac{t}{2} - t_1 - \frac{t_2}{2}\right)^2\right] +$$

$$\frac{1}{12} w E_3 t_3^3$$

$$EI_n = \frac{1}{2}\left(EI_y + EI_z\right) + \frac{1}{2}\left(EI_y - EI_z\right)\cos(2\theta)$$

where

I_z , I_y , I_n = area moment of inertia about the z, y & n axes, respectively
E = effective modulus of elasticity of accordion plate

Accordion Mass Equations in Air & Krypton:

$$M_A = S\left(2\rho_1 t_1 + 2\rho_2 t_2 + \rho_3 t_3\right)$$

$$M_K = S\left[\left(2\rho_1 t_1 + 2\rho_2 t_2 + \rho_3 t_3\right) - \rho_k t\right]$$

where

M_A, M_K = mass of half the absorber accordion plate in air & krypton, respectively
ρ_1, ρ_2, ρ_3 = density of steel, G10 & lead, respectively
ρ_k = density of krypton
t_1, t_2, t_3 = thickness of steel, G10 & lead layers, respectively
t = total thickness of absorber accordion plate
S = surface area of half the absorber accordion plate

Figure 1-16 Accordion Equations for Stiffness & Mass

Calorimeter Engineering Question

1. Liquid Krypton EM Calorimeter Support

Request: Provide a proof-of-principal structural designs for the barrel and endcap accordion EM calorimeters.

Specific Concerns:

- *The load path from the endcap accordion plates to the endcap cryostat barrel is not understood.*

Answer:

- The load path (reference Figure 1-19) is from the plates through fasteners that hold the plates together, through stiffeners, through the face plates, through the aluminum shell and into a flange on the Endcap Calorimeter stay (not shown).

Data:

The Endcap accordion EM is constructed of 330 sensor and 331 absorber plates grouped into 110 physical "towers" (reference Figure 1-17). The first and last bend of each plate project to interaction point (reference Figure 1-18). G10 spacers are placed between the plates to provide the proper spacing of the plates. The plates are held together with fasteners. Hexcel strips are placed in the accordion region to provide a minimum high voltage gap between the sensor plate and the absorber plate. At appropriate locations the accordion is shifted one cycle to compensate for the curvature of the accordion structure. Each of these shifts contains a G10 stiffener as the structural element that supports the weight of many plates and provides a stiff support to control the effects of thermal shrinkage. The stiffeners are attached to a perforated G10 face plate. Two halves of a conical aluminum shell are joined and the face plates and stiffeners are attached to flanges on the outer edges of the aluminum shell (reference Figures 1-19, 1-20, 1-21). The flange on the rear outer edge of the aluminum shell is also used to attach the EM assembly to Endcap Calorimeter stay.

Figure 1-17 Endcap Accordion EM Without Support System
Figure 1-18 Endcap Accordion EM
Figure 1-19 Endcap EM Support System
Figure 1-20 Endcap EM Assembly
Figure 1-21 Asembled Endcap EM

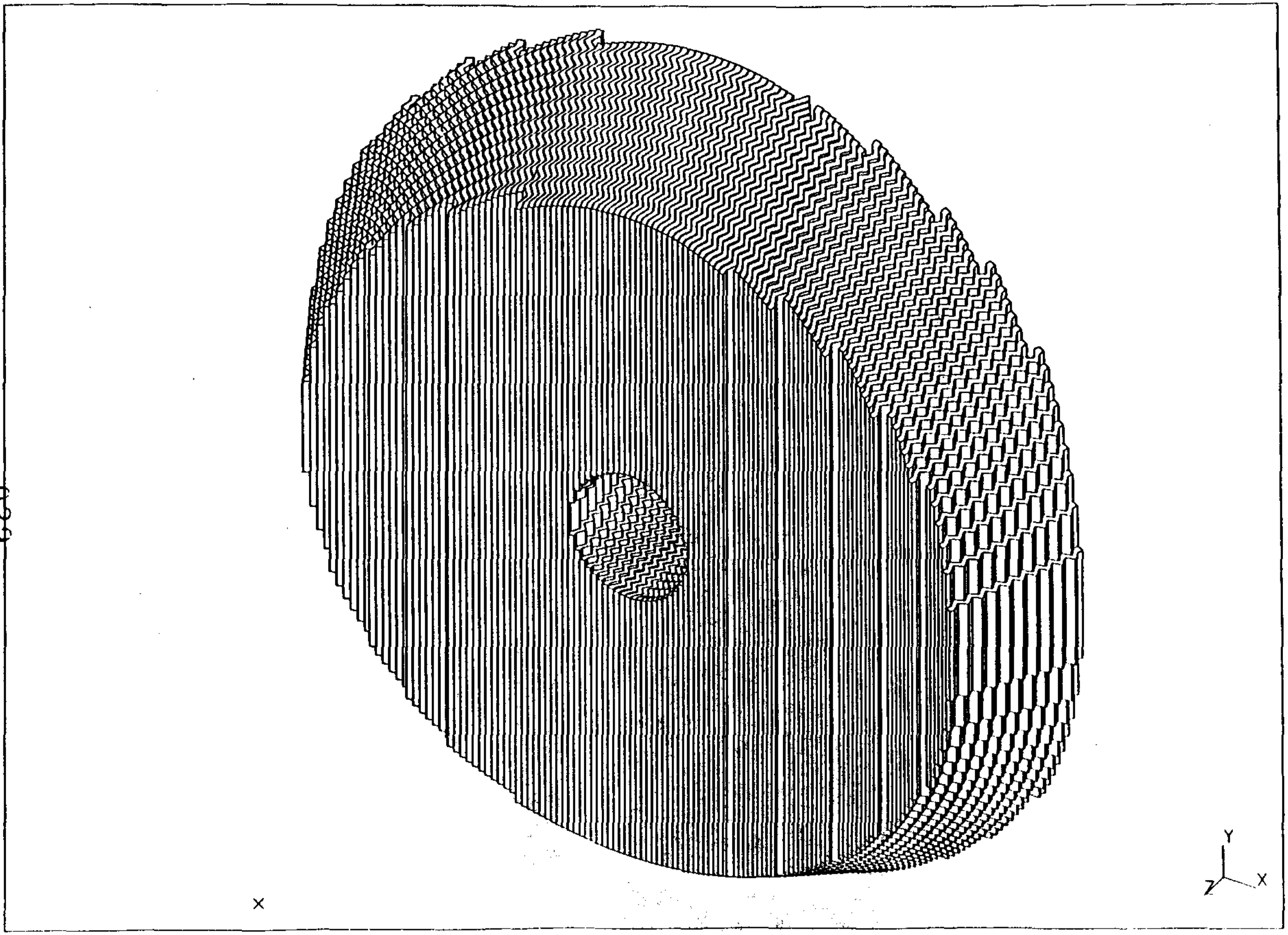

Figure 1-17 Endcap Accordion EM Without Support System

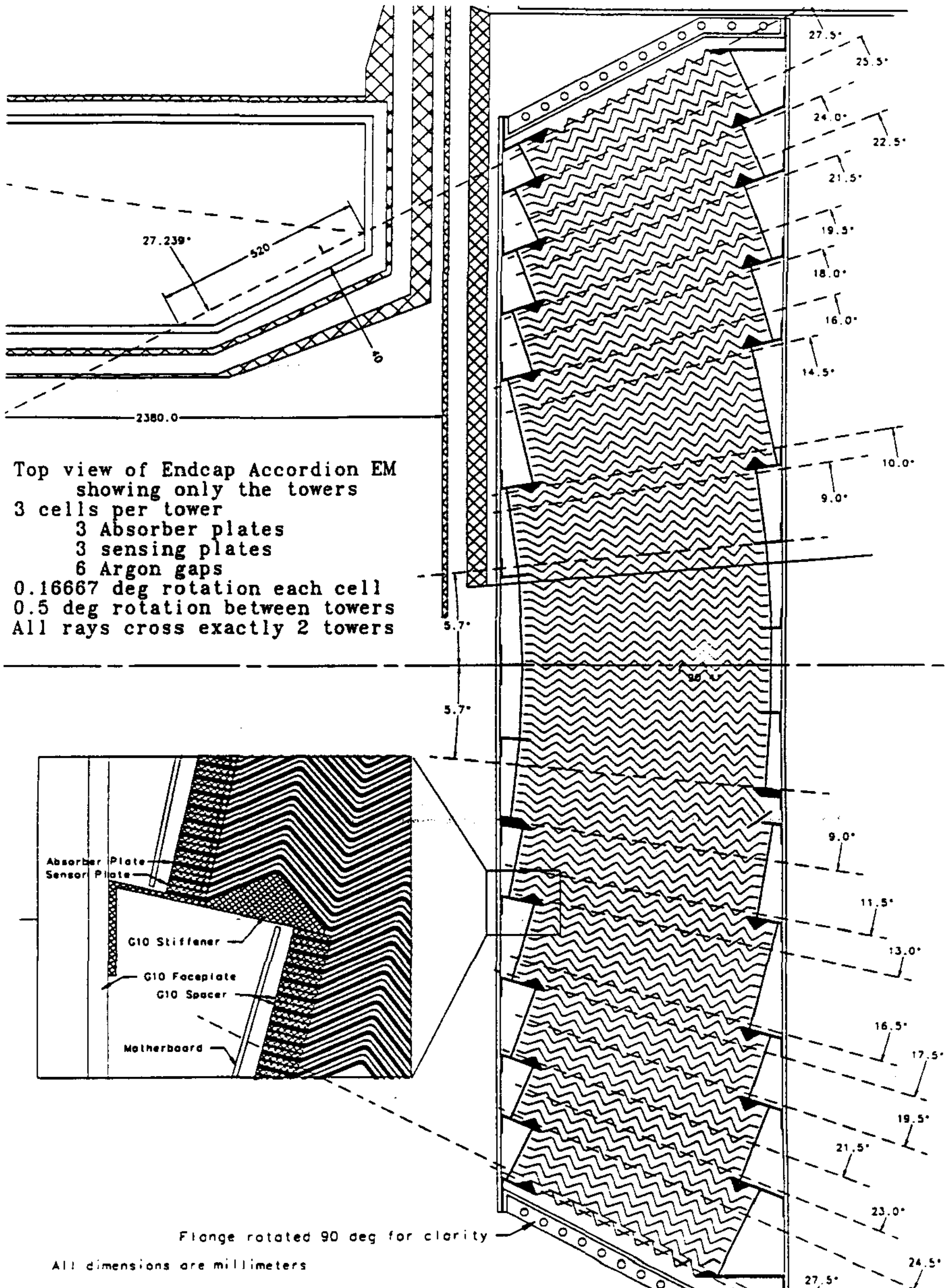

Figure 1-18 Endcap Accordion EM

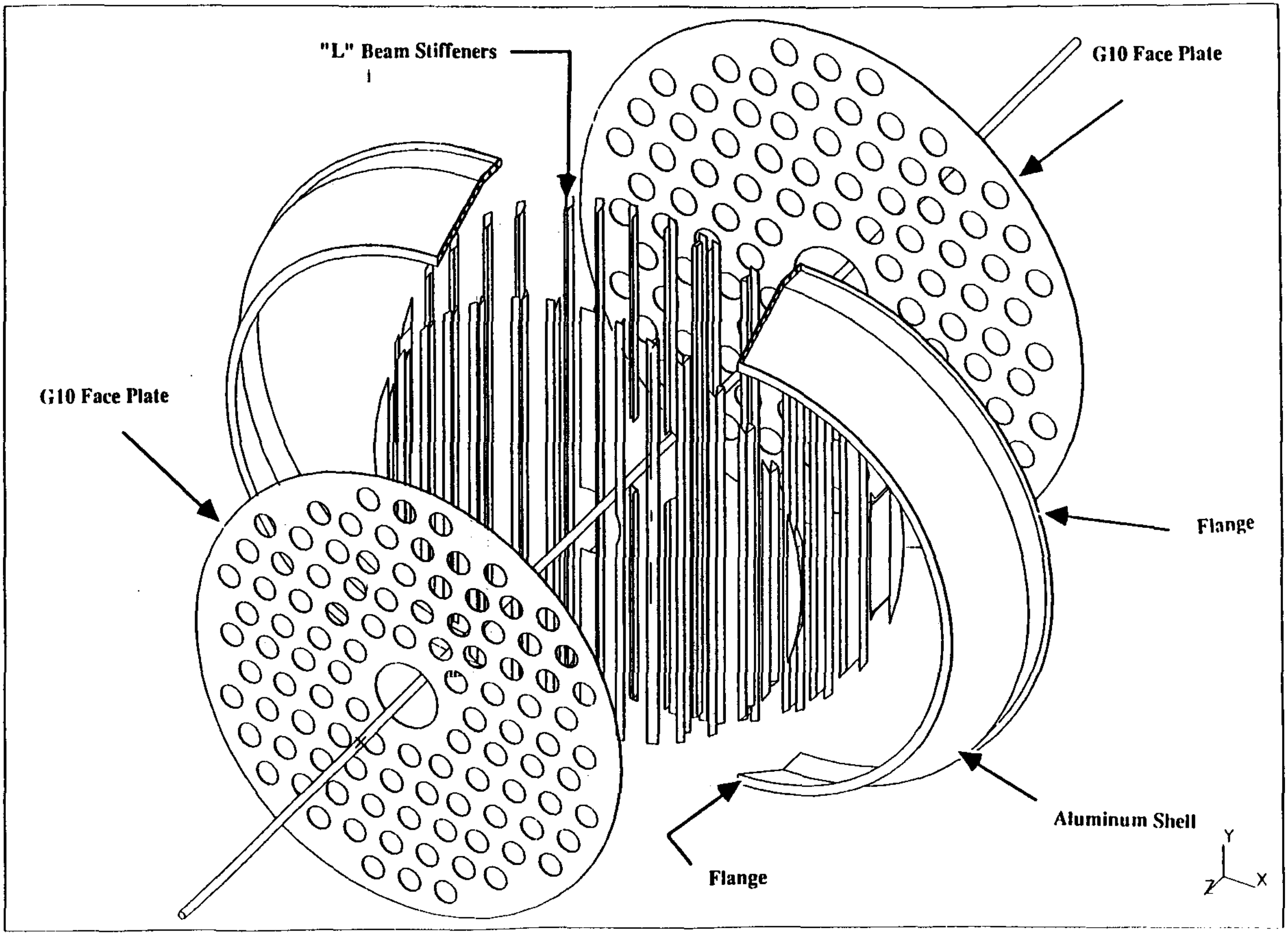

Figure 1-19 Endcap EM Support System

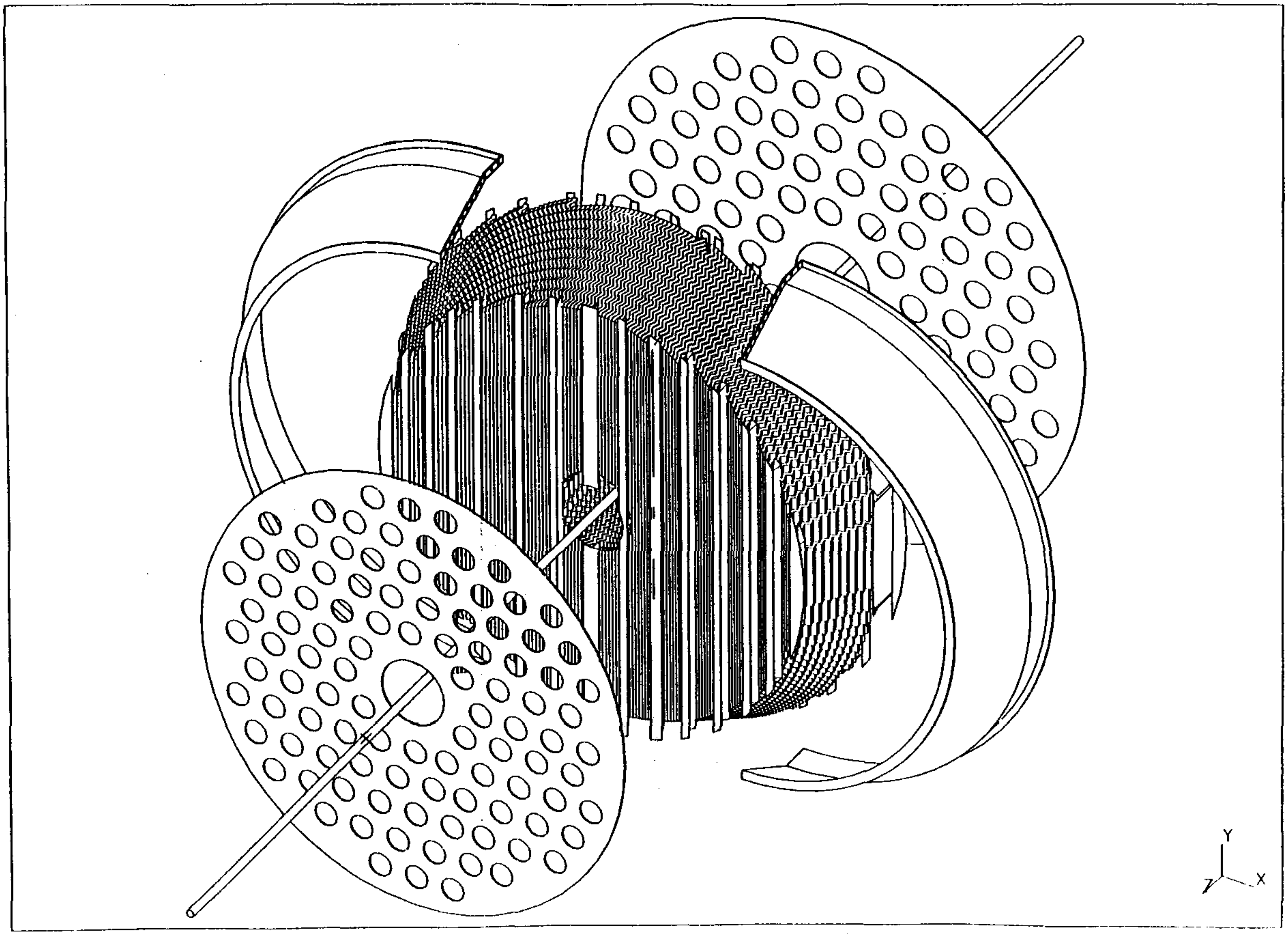

Figure 1-20 Endcap EM Assembly

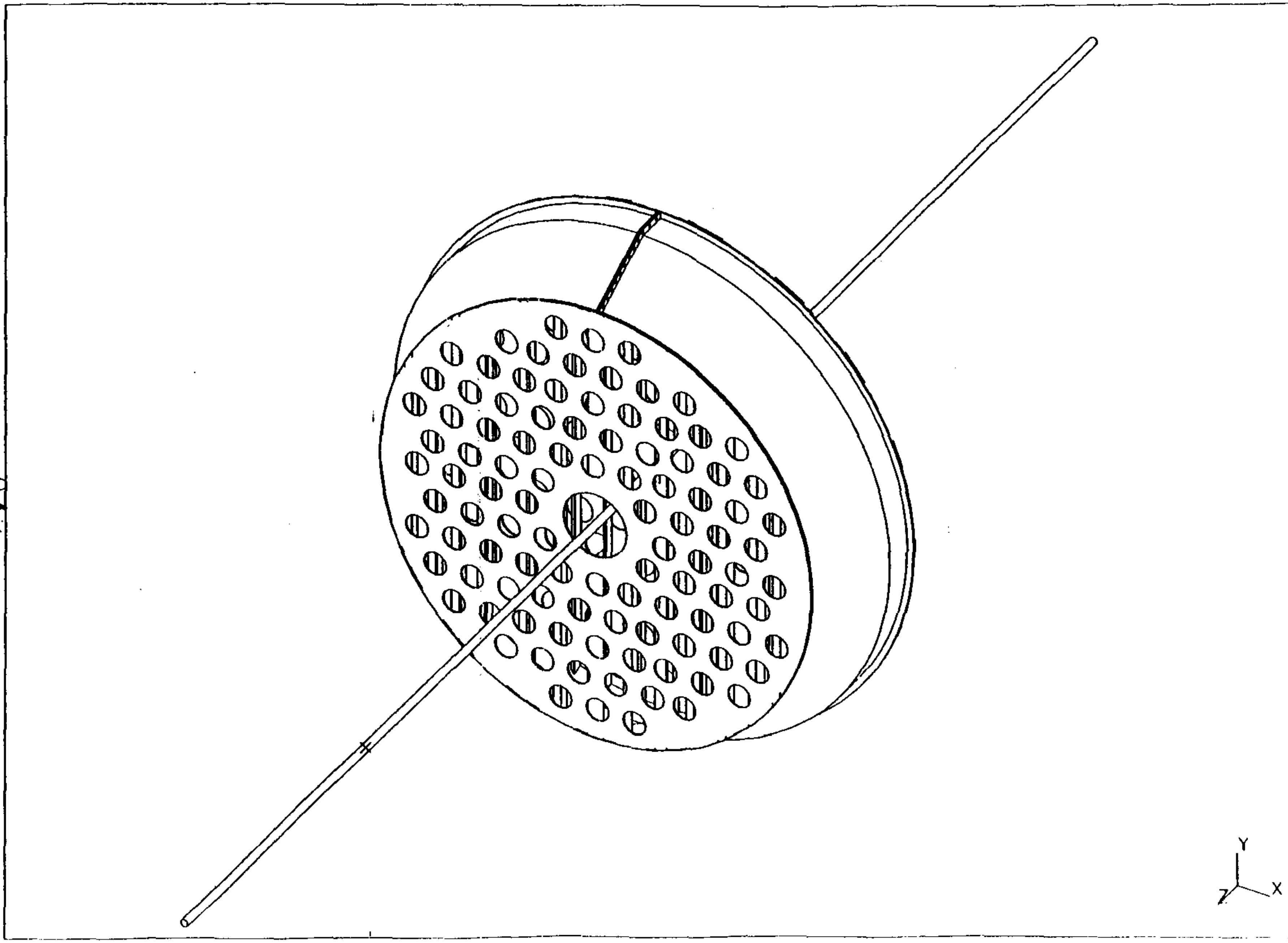

Figure 1-21 Assembled Endcap EM

Calorimeter Engineering Question

2. *Integrated Liquid Argon Calorimeter Diameter*

Request: Provide a more detailed tabulation of the diametrical stack-up of the integrated liquid argon calorimeter.

Specific Concern:

- *The stack-up should specify fabrication and assembly tolerances.*

Answer:

- *A preliminary tolerance study indicates that standard manufacturing tolerances are acceptable for both manufactured parts and procured hardware. See Figures 2-2 through 2-6.*

Specific Concern:

- *An end section at eta=0 is needed for a complete understanding of the clearances and layout of the vessel and modules.*

041

Answer:

- *See Figure 2-1.*

Data:

The actual design of the modules has not been completed in this conceptual phase but a study was performed based on the cell stacks and vessel configurations. Plate tolerances for the 9 and 15mm copper were ± 0.007 and 0.008 inches respectively. Tooling for the absorber/sensor sandwitchs are to hold a tolerance of ± 0.004 inches. The spacer buttom tolerance was ± 0.0015 inches.

Figure 2-1. Shows the nominal vessel wall and stays as fabricated. The minimal fabricate radial spaces for modules are show for comparison with the maximum module sizes. Both sets of dimensions are also shown for a temperature of 86K.

Figure 2-2 Shows the cross sectional view and tolerance stackup of the first Fine Hadronic Module.

Figure 2-3. Shows the cross sectional view and tolerance stackup of the second Fine Hadronic Module.

Figure 2-4. Shows the cross sectional view and tolerance stackup of the Coarse Hadronic Module.

Figure 2-5. Shows the maximum radial dimensions for the three hadronic modules at ambient and cold temperatures.

Figure 2-6. Work sheet for the vessel and module elements.

Figure 2-7. EM Module Diametrical Stack-up showing both ambient and cold dimensions and tolerances.

TYPICAL ARGON VESSEL TOLERANCE STACKUP

Vessels are 5083 Aluminum

All Dimensions in mm

<u>Module Max Radial Dimensions at Ambeint and Cold</u>

615.5max EM Module Ambient
631.6max EM Module Cold
624.7max 1st Fine Hadron Module Ambient
622.5max 1st Fine Hadron Module Cold
620.7max 2nd Fine Hadron Module Ambient
618.5max 2nd Fine Hadron Module Cold
649.7max Coarse Hadron Module Ambient
647.4max Coarse Hadron Module Cold

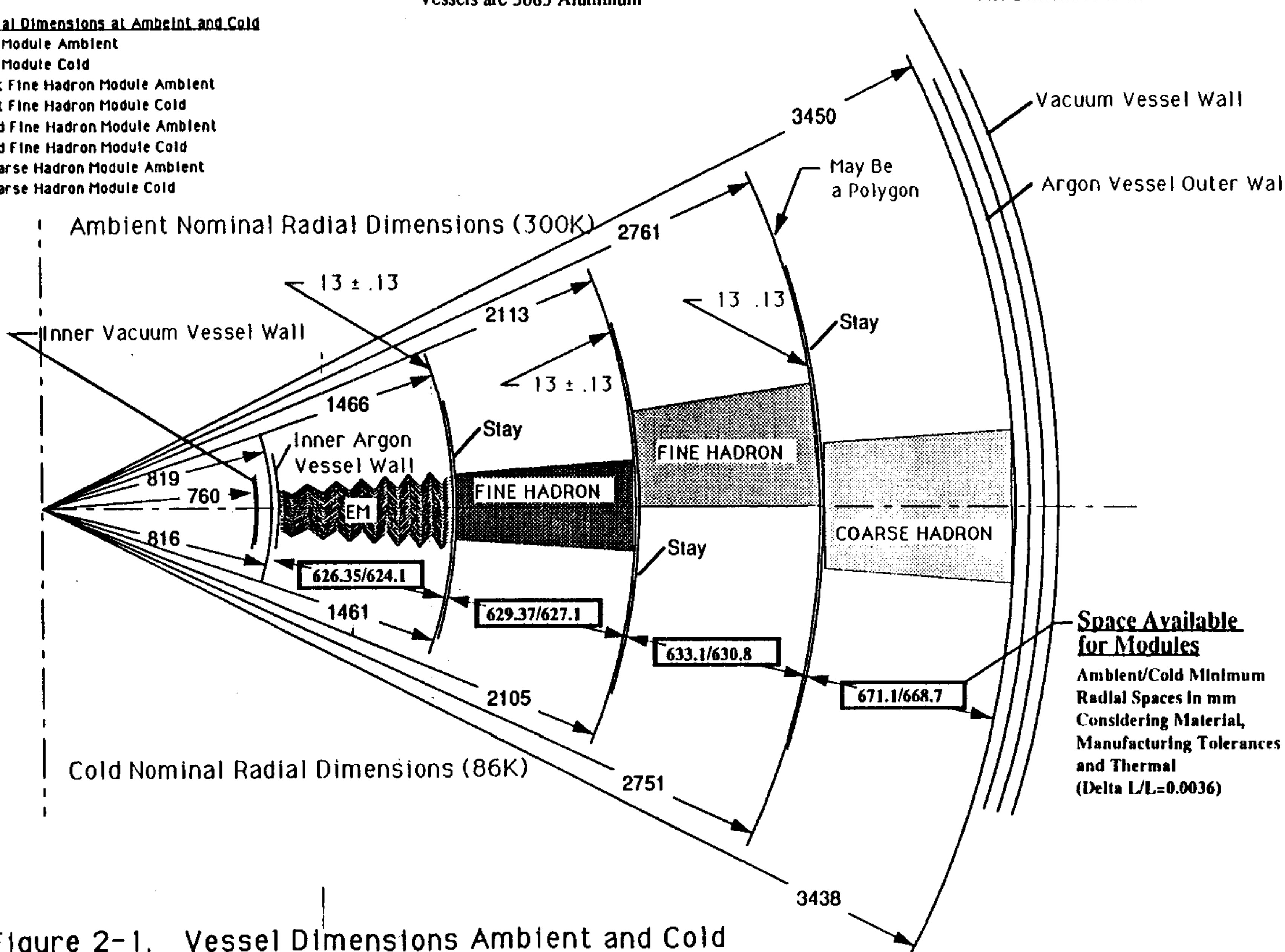

Figure 2-1. Vessel Dimensions Ambient and Cold

KRBarnstable Module Endview

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MODULE TOLERANCE STACKUP

All Dimensions in mm

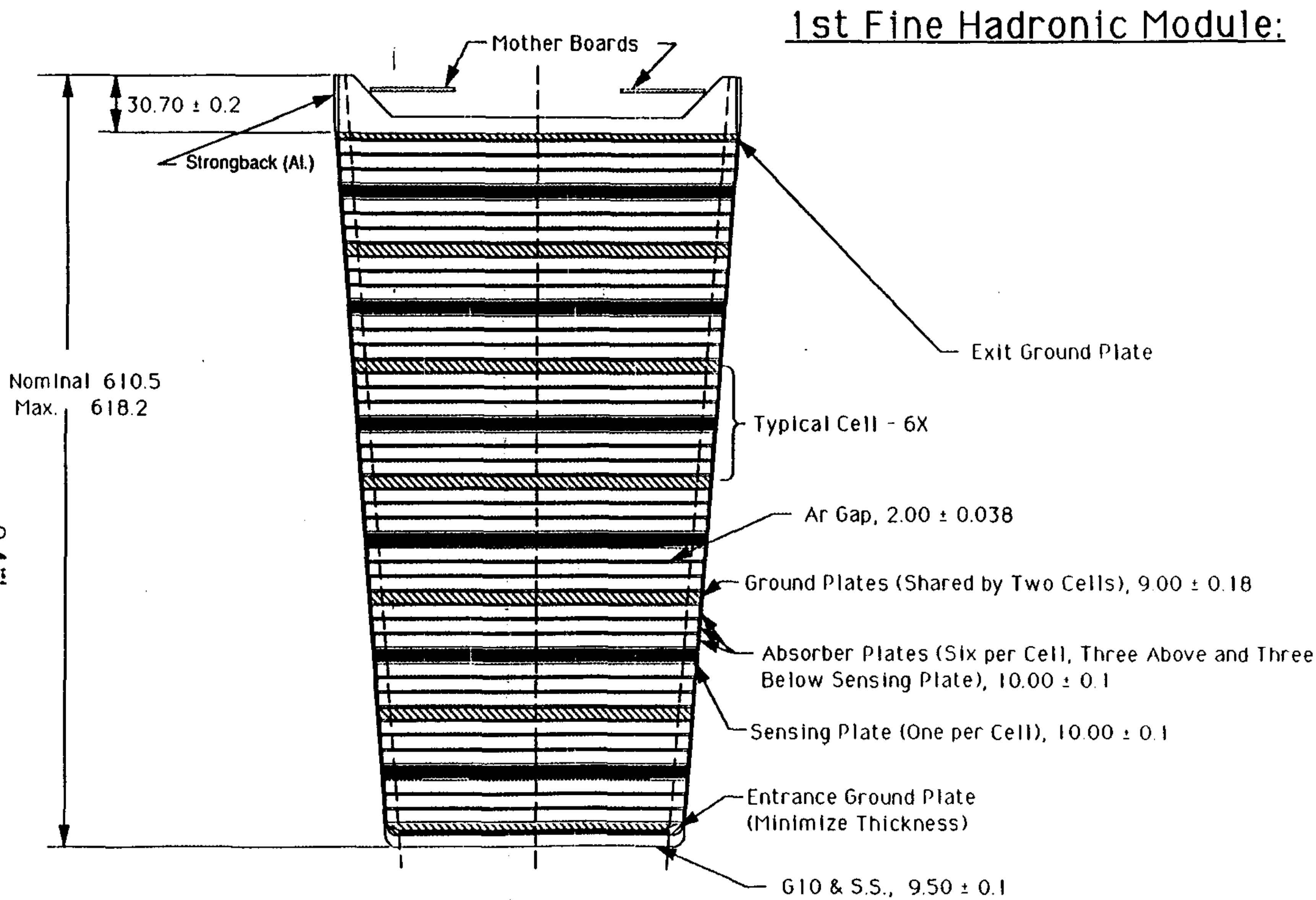

Figure 2-2. First Fine Hadron Module Showing Stack Height and Element Tolerances

KRBarnstable Module Tol F H *Fig2-2

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MODULE TOLERANCE STACKUP

All Dimensions In mm

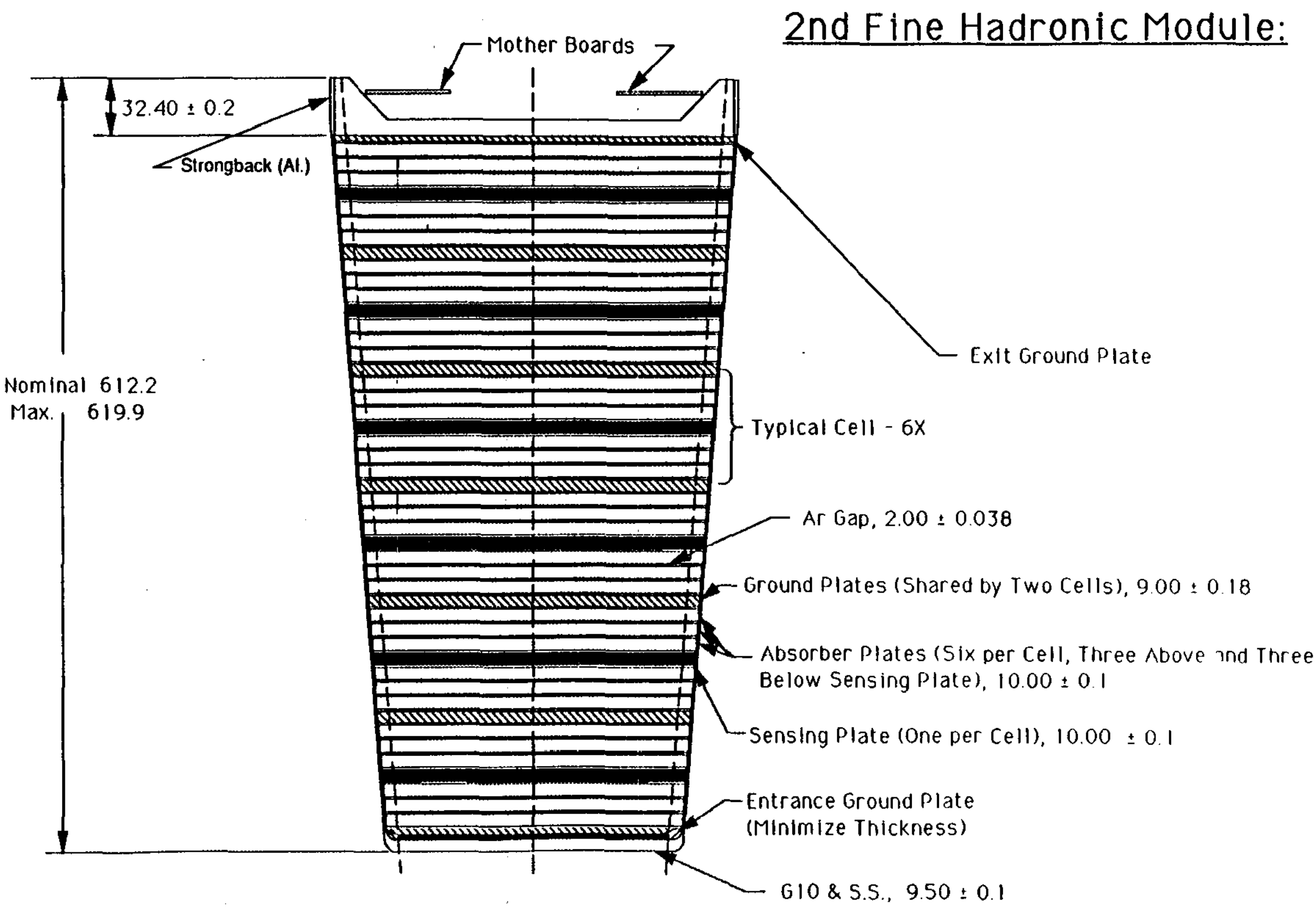

Figure 2-3. Second Fine Hadron Module Showing Stack Height and Element Tolerances

KRBarnstable Module Tol F.H.*Fig2-3

MODULE TOLERANCE STACKUP

All Dimensions in mm

Coarse Hadronic Module:

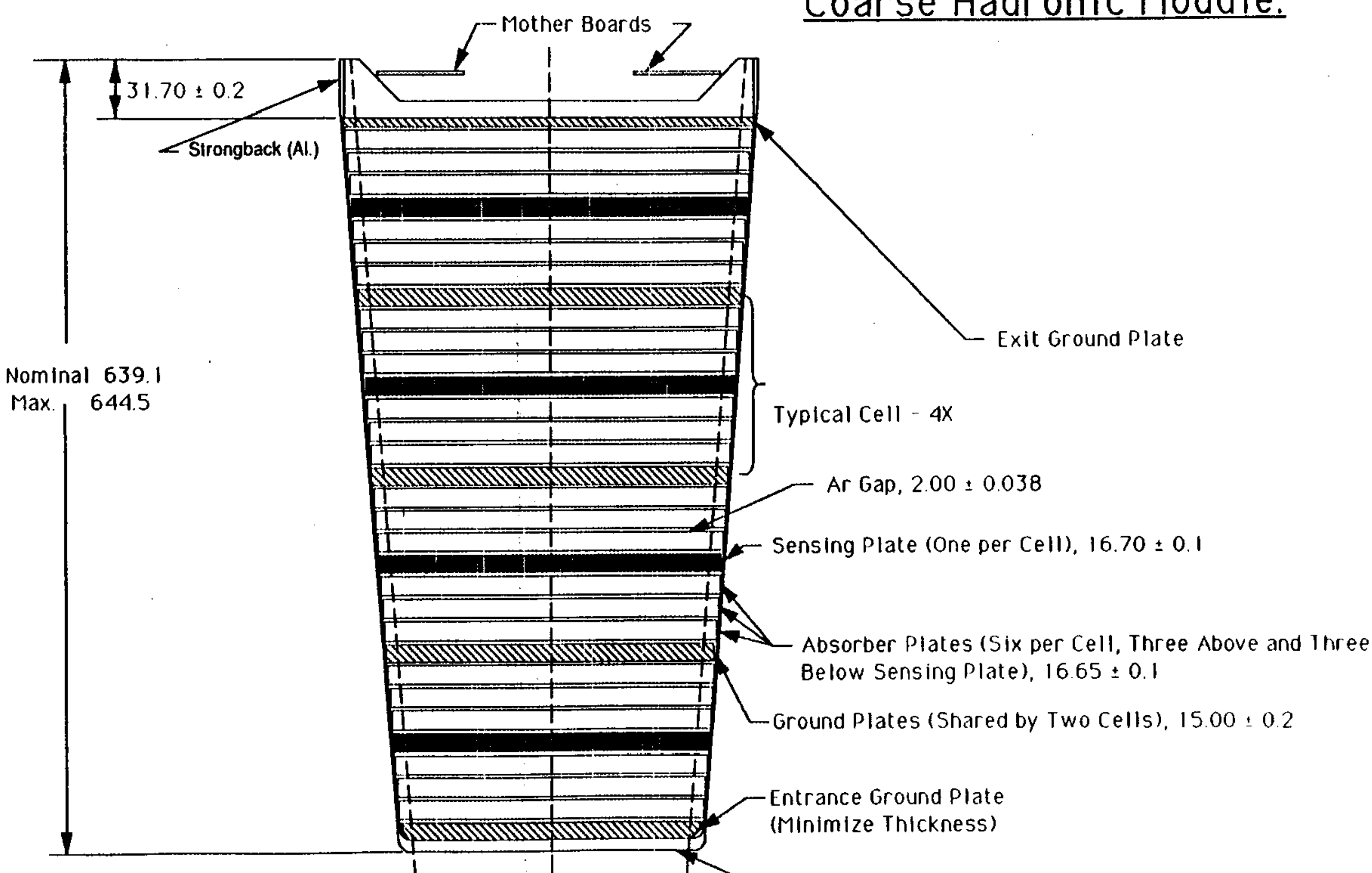

Figure 2-4. Coarse Hadron Module Showing Stack Height and Element Tolerances

KRBarnstable Module Tol C.H.#Fig2-4

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LIQUID ARGON CALORIMETER - HADRONIC MODULES

Radial dimension for confirming compatiablity with the vessel are shown.
Maximum stack heights were used to compare with minimal vessel radii in Figure 2-1.
Ambient is 300K, Cold is 86K.

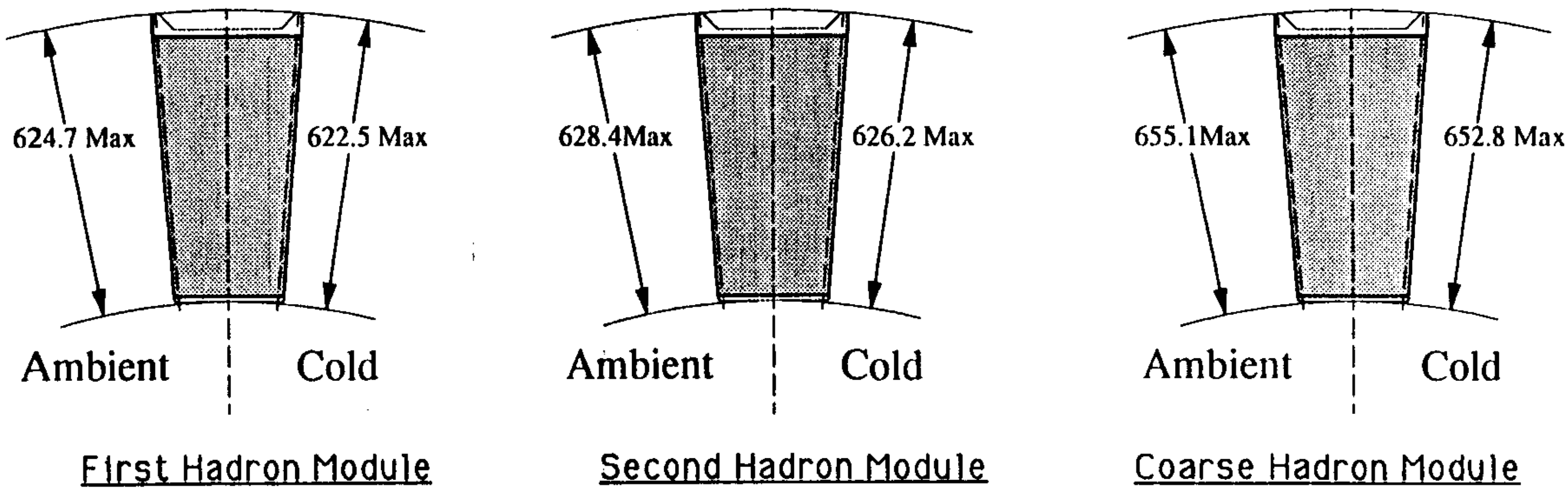

Figure 2-5. Radial Dimension - Thermal effects on Hadron Modules

All dimensions are in mm

KRBarnstable FHad#1ΔT Tol Fig 2-5

Barrel cal. Ambient Data	Qty Info	Depth, mm	Circular Stay radius, mm	Min Tol. thk mm	Max Tol. thk mm	Min Tol. radius mm	Max Tol. radius mm	Comments	Smallest Vessel Space mm	Largest Cmpnt Radi mm	Nml Amb Mod. Stck Hght mm	Max Amb Mod. Stck Hght mm	Nml Amb Mod. Stck Radi mm	Nmnl Amb Rad. Vssl Clrnc Betwn Stays
Cryostat Vessels														
Vacuum wall IR		9	760.0			2.5	2.5	Cut to 2mm, weld to 2mm two pics						
Vacuum wall OR			769.0	0.2	0.2									
Vacuum Space		50							44.80					
Argon Wall IR		16	819.0			2.5	2.5	Cut to 2mm, weld to 2mm two pics						
Argon Wall			835.0	0.2	0.2									
EM Module	Gap	10	845.0					IR Floats						
Strip Line		5	850.0	0.07	0.07			Inside of support						
Argon Gap		17.5	867.5											
G10 Board		2.5	870.0											
Argon		6.5	876.5											
Front Spacer G10		13.5	890.0			1.9	1.9	40 arcs to+-(.006)=(.24)arc						
Absorber		522							628.35	615.44	611.50		611.50	631.60
Aft Spacer G10		13.5	1425.5			1.9	1.9	40 arcs to+-(.006)=(.24)arc						
Argon Gap		6.5	1432.0											
G10 Board		2.5	1434.5											
Argon Gap		17.5	1452.0	0.07	0.07			Outside of support						
Strip line		4.5	1456.5											
	Gap	10.1	1466.6											
Stay IR		13	1466.6			2.55	2.55	Cut to 2mm, weld to 2mm two pics						
Stay OR			1479.6	0.13	0.13									
1ST Hadron Module	Gap	13	1492.6											
G 10 Interance		5.5	1498.1											
Steel Plate		4	1502.1	0.1	0.1									
Copper plates	7	9		0.18	0.18	1.26	1.26	Two of 7 are half thickness						
Absorber Plates	36	10		0.1	0.1	3.6	3.6							
Sensing Plates	6	10.05		0.1	0.1	0.6	0.6		629.07		610.50	618.18	617.00	633.00
Spacers	48	2		0.038	0.038	1.824	1.824			624.69				
Hadron depth		570.3	2072.4		Totals	7.384	7.384							
Hadron S/B Plate		12.7	2085.1											
Argon Gap		6.5	2091.6											
Circuit Board		2.5	2094.1											
To Top of Strong Back		9	2103.1											
to Corner of Module		6.503	2109.6	0.2	0.2			Delta Radius=Rad*(1/Cos(4.5/360*(2*pi()))-1)						
	Gap	3	2112.6											
Stay IR		13	2112.6	0.13	0.13	1.25	1.25							
Stay OR			2125.6											
Second Hadron Module	Gap	12	2137.6											
G 10 Interance		5.5	2143.1											
Steel Plate		4	2147.1	0.1	0.1									
Copper plates	7	9		0.18	0.18	1.26	1.26	Two of 7 are half thickness						
Absorber Plates	36	10		0.1	0.1	3.6	3.6							
Sensing Plates	6	10.05		0.1	0.1	0.6	0.6		633.07		612.20	619.88	620.70	635.70
Spacers	48	2		0.038	0.038	1.824	1.824			628.39				
Hadron depth		570.3	2717.4		Totals	7.384	7.384							
Hadron S/B		12.7	2730.1											
Argon Gap		6.5	2736.6											
Circuit Board		2.5	2739.1											
To Top of Strong Back		10.7	2749.8	0.2	0.2									
to Corner of Module		8.503	2758.3					Delta Radius=Rad*(1/Cos(4.5/360*(2*pi()))-1)						
	Gap	3	2761.3											
Stay IR		13	2761.3	0.13	0.13	1.25	1.25							
Stay OR			2774.3											
Third Hadronic Module	Gap	14	2788.3											
G 10 Interance		5.5	2793.8											
Steel Plate		4	2797.8	0.15	0.15									
Copper plates	5	15		0.2	0.2			Two of 5 are Half thickness						
Absorber Plates	24	18.85		0.1	0.1	2.4	2.4							
Sensing Plates	4	18.7		0.1	0.1	0.4	0.4							
Spacers	32	2		0.038	0.038	1.216	1.216		671.12	654.06	639.10	643.47	649.73	675.70
Hadron depth		597.9	3395.7		Totals	4.016	4.016							
Hadron S/B		12.7	3408.4											
Argon Gap		6.5	3414.9											
Circuit Board		2.5	3417.4											
To Top of Strong Back		10	3427.4	0.2	0.2									
outer radius (to corner)		10.6	3438.0					Delta Radius=Rad*(1/Cos(4.5/360*(2*pi()))-1)						
Cryostat Vessels	Gap	12	3450.0											
argon Vessel IR		50	3450.0			3.2	3.2	Cut to 5mm, weld to 5mm (two pics)						
argon Vessel OR			3500.0	1.5	1.5									
vacuum space		50												
vacuum Vessel IR		50	3550.0			3.2	3.2	Cut to 5mm, weld to 5mm (two pics)						
vacuum Vessel OR			3600.0	1.5	1.5									
Checks		3600	3600.0											

Figure 2-6. Work Sheet for Diametrical Stack-up

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Barrel cal. Ambient Data	Qty info	Depth, mm	Circular Stay radius, mm	Min Tol thk mm	Max Tol thk mm	Min Tol radius mm	Max Tol radius mm	Comments	Smallest Vessel Space mm	Largest Cmpnt Radl mm	Nnl Amb Mod Stck Hght mm	Max Amb Mod Stck Hght mm	Nml Amb Mod Stck Radl mm	Nmnl Amb Radl Vesl Circ Betwn Stays
Cryostat Vessels														
Vacuum wall IR		9	760.0			2.5	2.5	Cut to 2mm weld to 2mm two plcs						
Vacuum wall OR			769.0	0.2	0.2									
Vacuum Space		50							44.80					
Argon Wall IR		16	819.0			2.5	2.5	Cut to 2mm weld to 2mm two plcs						
Argon Wall			835.0	0.2	0.2									
EM Module	Gap	10	845.0					IR Floats						
Strip Line		5	850.0	0.07	0.07			Inside of support						
Argon Gap		17.5	867.5											
G10 Board		2.5	870.0											
Argon		6.5	876.5											
Front Spacer G10		13.5	890.0			1.9	1.9	40 arcs 10+-(.006)=(.24)arc						
Absorber		522							626.35	615.44	611.50		611.50	631.60
Aft Spacer G10		13.5	1425.5			1.9	1.9	40 arcs 10+-(.006)=(.24)arc						
Argon Gap		6.5	1432.0											
G10 Board		2.5	1434.5											
Argon Gap		17.5	1452.0	0.07	0.07			Outside of support						
Strip line		4.5	1456.5											
	Gap	10.1	1466.6											
Stay IR		13	1466.6			2.55	2.55	Cut to 2mm, weld to 2mm two plcs						
Stay OR			1479.6	0.13	0.13									
1ST Hadron Module	Gap	13	1492.6											
G 10 Interance		5.5	1498.1											
Steel Plate		4	1502.1	0.1	0.1									
Copper plates	7	9		0.18	0.18	1.26	1.26	Two of 7 are half thickness						
Absorber Plates	36	10		0.1	0.1	3.6	3.6							
Sensing Plates	6	10.05		0.1	0.1	0.6	0.6		629.07		610.50	618.18	617.00	633.00
Spacers	48	2		0.038	0.038	1.824	1.824			624.69				
Hadron depth		570.3	2072.4		Totals	7.384	7.384							
Hadron S/B Plate		12.7	2085.1											
Argon Gap		6.5	2091.6											
Circuit Board		2.5	2094.1											
To Top of Strong Back		9	2103.1											
to Corner of Module		6.503	2109.6	0.2	0.2			Delta Radius=Rad*(1/Cos(4.5/360*(2*pi()))-1)						
	Gap	3	2112.6											
Stay IR		13	2112.6	0.13	0.13	1.25	1.25							
Stay OR			2125.6											
Second Hadron Module	Gap	12	2137.6											
G 10 Interance		5.5	2143.1											
Steel Plate		4	2147.1	0.1	0.1									
Copper plates	7	9		0.18	0.18	1.26	1.26	Two of 7 are half thickness						
Absorber Plates	36	10		0.1	0.1	3.6	3.6							
Sensing Plates	6	10.05		0.1	0.1	0.6	0.6		633.07		612.20	619.88	620.70	635.70
Spacers	48	2		0.038	0.038	1.824	1.824			628.39				
Hadron depth		570.3	2717.4		Totals	7.384	7.384							
Hadron S/B		12.7	2730.1											
Argon Gap		6.5	2736.6											
Circuit Board		2.5	2739.1											
To Top of Strong Back		10.7	2749.8	0.2	0.2									
to Corner of Module		8.503	2758.3					Delta Radius=Rad*(1/Cos(4.5/360*(2*pi()))-1)						
	Gap	3	2761.3											
Stay IR		13	2761.3	0.13	0.13	1.25	1.25							
Stay OR			2774.3											
Third Hadronic Module	Gap	14	2788.3											
G 10 Interance		5.5	2793.8											
Steel Plate		4	2797.8	0.15	0.15									
Copper plates	5	15		0.2	0.2	1	1	Two of 5 are Half thickness						
Absorber Plates	24	16.65		0.1	0.1	2.4	2.4							
Sensing Plates	4	16.7		0.1	0.1	0.4	0.4							
Spacers	32	2		0.038	0.038	1.216	1.216		671.12	655.06	639.10	644.47	649.73	675.70
Hadron depth		597.9	3395.7		Totals	5.016	5.016							
Hadron S/B		12.7	3408.4											
Argon Gap		6.5	3414.9											
Circuit Board		2.5	3417.4											
To Top of Strong Back		10	3427.4	0.2	0.2									
outer radius (to corner)		10.6	3438.0					Delta Radius=Rad*(1/Cos(4.5/360*(2*pi()))-1)						
Cryostat Vessels	Gap	12	3450.0											
argon Vessel IR		50	3450.0			3.2	3.2	Cut to 5mm, weld to 5mm (two plcs)						
argon Vessel OR			3500.0	1.5	1.5									
vacuum space		50												
vacuum Vessel IR		50	3550.0			3.2	3.2	Cut to 5mm weld to 5mm (two plcs)						
vacuum Vessel OR			3600.0	1.5	1.5									
Checks		3600	3600.0											

Figure 2-6. Work Sheet for Diametrical Stack-up

Outer "ring"	R= 1421				
	Cell Thickness, mm	Delta_L/L			
G10 spacer	8.815	0.0063	0.0555		
Kapton	0.4	0.0033	0.0013		
Lead	1.3	0.00577	0.0075		
Stainless Ste	0.4	0.00281	0.0011		
Prepreg	0.2	0.0063	0.0013		
	11.115		0.0667		
	Aggregate delta_L/L =		0.0060	Delta R= 8.53	mm
Aluminum		0.00372		Delta R= 5.29	mm
				Relative Delta R= 3.25	mm

Inner "ring"	R= 877				
	Cell Thickness, mm	Delta_L/L			
G10 spacer	4.634	0.0063	0.0292		
Kapton	0.4	0.0033	0.0013		
G10 insert	1.3	0.0063	0.0082		
Stainless Ste	0.4	0.00281	0.0011		
Prepreg	0.2	0.0063	0.0013		
	6.934		0.0411		
	Aggregate delta_L/L =		0.0059	Delta R= 5.20	mm
Aluminum		0.00372		Delta R= 3.26	mm
				Relative Delta R= 1.93	mm

Figure 2-7. EM Module Diametrical Stack-up

Calorimeter Engineering Question (Continued)

2. *Integrated Liquid Argon Calorimeter Diameter*

Specific Concern:

- *A concept of the barrel feedthrus, including dimensions is needed to determine the additional diameter required as well as the interface requirements with the muon system.*

Answer:

- *Commercial pin connectors with bimetallic couplings and mounting plates can be utilized in an ASME port without impacting the radii of either the barrel or endcap calorimeter.*

Data:

The barrel feedthroughs consist of 17 sets of flange assemblies at each end of the vessel with 13 connectors in each flange, providing for 43,200 channels. The barrel feedthrough cabling requires a 50 mm clearance envelope outside the vacuum vessel from the feedthrough to the support pedestal.

Each endcap will have 2 rings of feedthroughs providing for 18 feedthroughs with 13 connectors each to accomodate 22,980 channels. The endcap feedthrough cabling requires a 40 mm clearance envelope outside of the vacuum vessel wall to the pedestal.

Figure 2-8. Shows the electronic connector installation detail in a closure plate.

Figure 2-9. Shows a typical warm and cold feedthrough flange layout and alignment.

Figure 2-10. Shows how the feedthroughs can be installed in a vessel port via the use of a pipe extension.

Figure 2-11. Shows the "Z" location of the feedthroughs in the barrel section and some radial dimensions.

Figure 2-12. An end view of the barrel calorimeter shows the feedthrough locations and Envelopes for cabling.

Figure 2-13. Shows the "Z" location for the endcap feedthroughs.

Figure 2-14. End view of the endcap showing feedthrough locations at Section A-A and the envelope required for cabling.

Figure 2-15. Shows an end view of the endcap feedthrough locations at Section B-B and the envelope required for cabling.

Figure 2-16. Shows a half section end view of the endcap feedthrough locations and the envelope reserved for the argon vesel supports.

Figure 2-17. Shows a cable management method to avoid multiple cable thicknesses.

Figure 2-18. Shows the warm and cold feedthrough cross section and cable orientation in the barrel section.

Figure 2-19. Shows the warm and cold feedthrough cross section and cable orientation in the endcap section.

LIQUID ARGON CALORIMETER

Electronic Feedthrough Cross Section - Barrel Section

Note: With proper cable orientation there will be cable bundles from only 2 connectors overlapping at any one location.

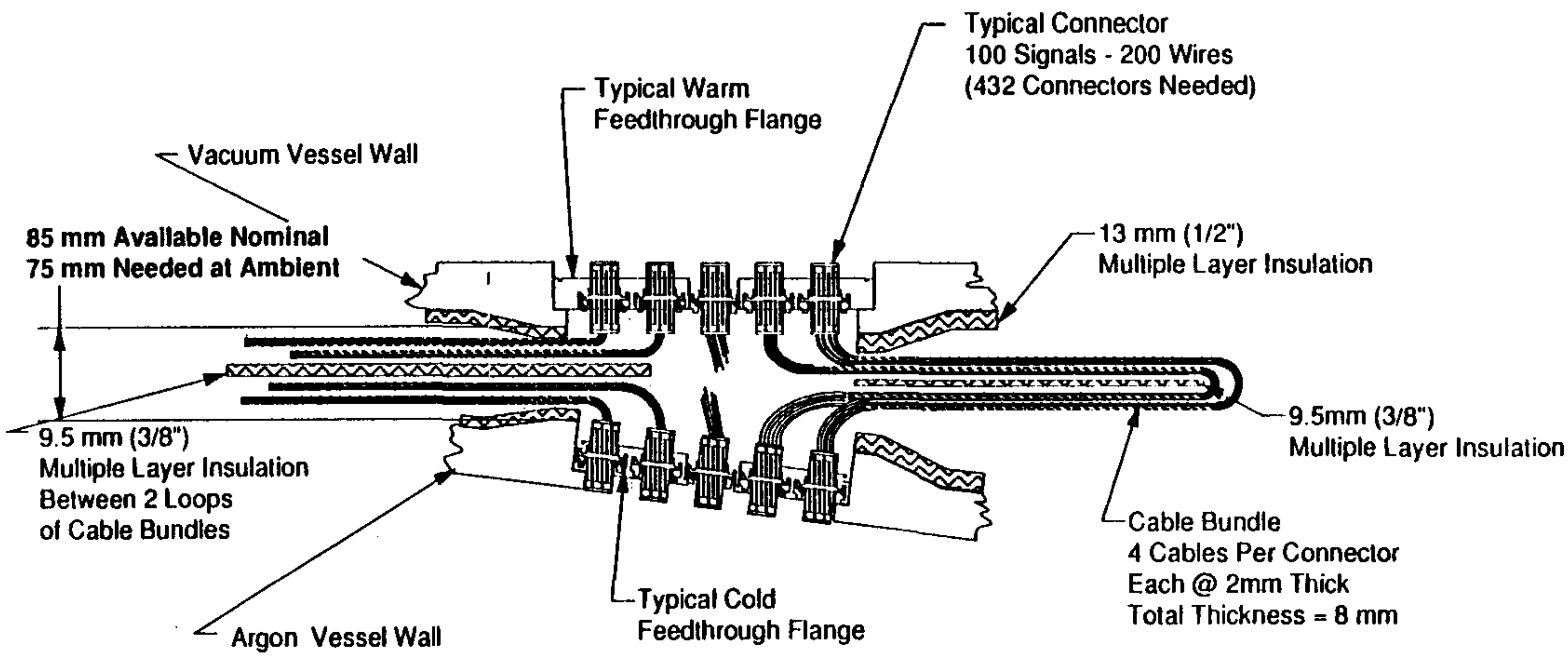


Figure 2-18. Barrel Electronic Feedthrough Section Showing Space Required for Cabling

LIQUID ARGON CALORIMETER

Electronic Feedthrough Cross Section - Endcap

Note: With proper cable orientation there will be cable bundles from only 2 connectors overlapping at any one location.

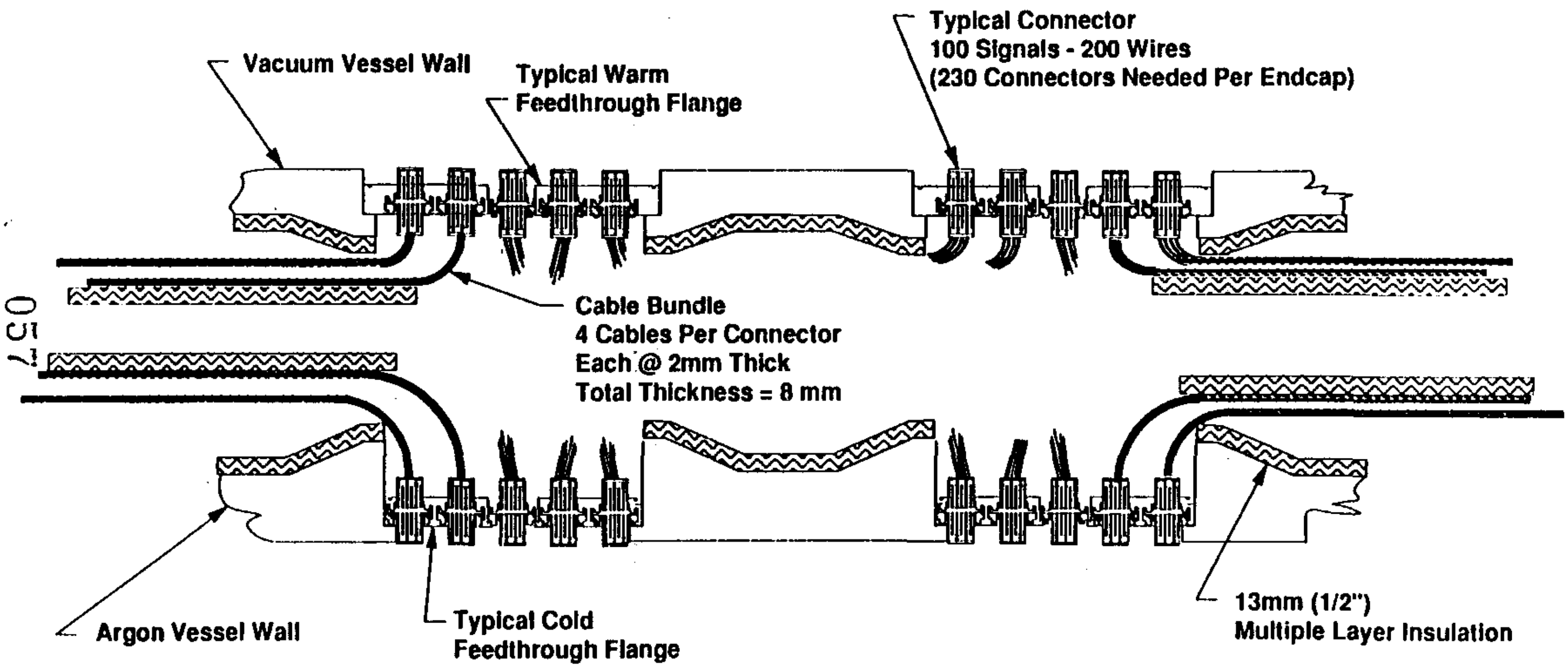


Figure 2-19. Endcap Calorimeter Feedthrough Showing Cable Clearance

LIQUID ARGON CALORIMETER

Electronic Feedthrough Detail

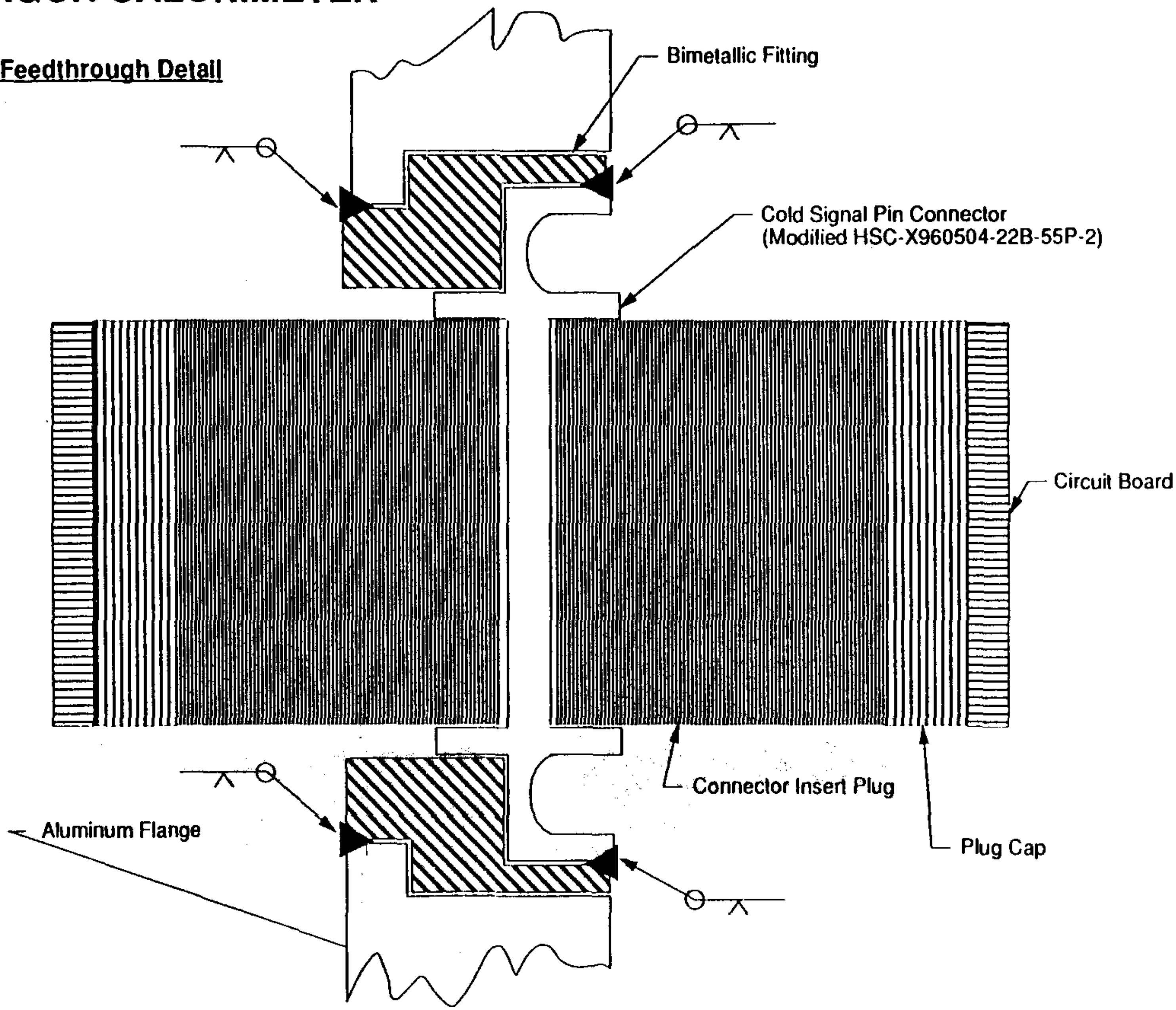
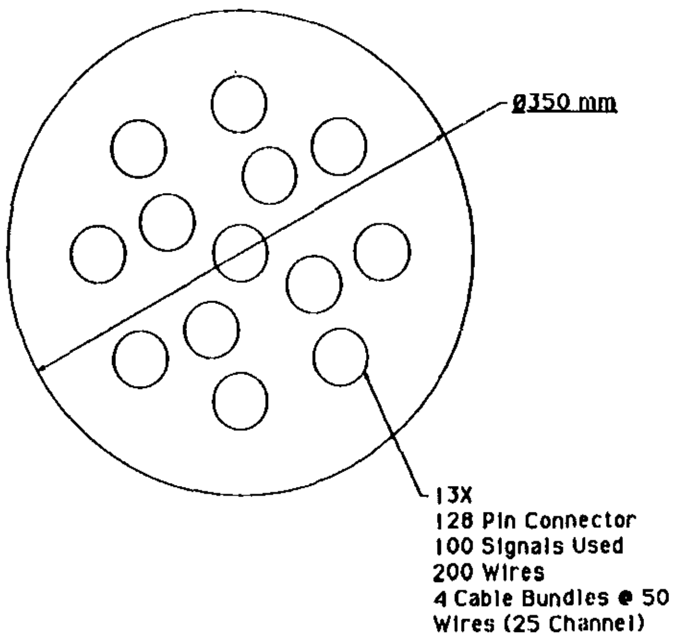


Figure 2-8. Shows Connector Attached to Flange via a Bimetallic Coupling

LIQUID ARGON CALORIMETER FEEDTHROUGHS

Note: The cold feedthrough is designed at a smaller diameter than the warm feedthrough and positioned concentric to it so that the cold feedthrough may be accessed by removal of the warm feedthrough.

Typical Warm Feedthrough Flange:



Typical Cold Feedthrough Flange:

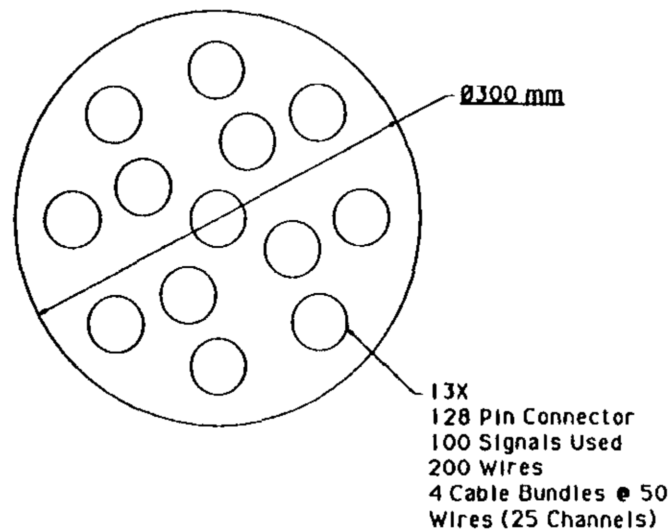


Figure 2-9. Shows the Argon and Vacuum Vessel Feethrough Flanges

Feedthrough Flange Installation

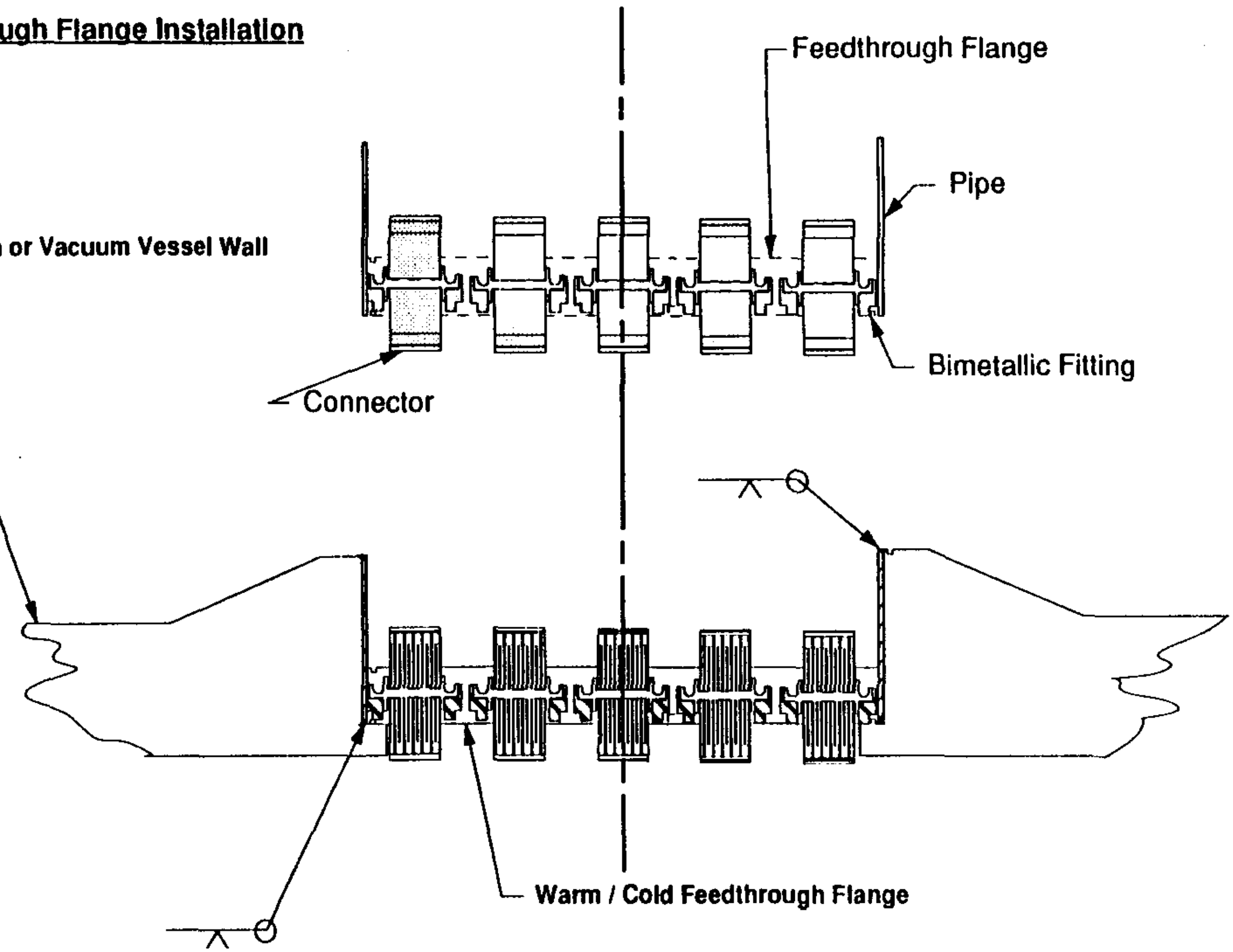


Figure 2-10. Shown Feedthrough Plate and Pipe Extension Ready for Assembly into Vessel and Assembled

KRBarnstable FT

LIQUID ARGON BARREL CALORIMETER

Barrel Feedthroughs

All Dimensions in mm

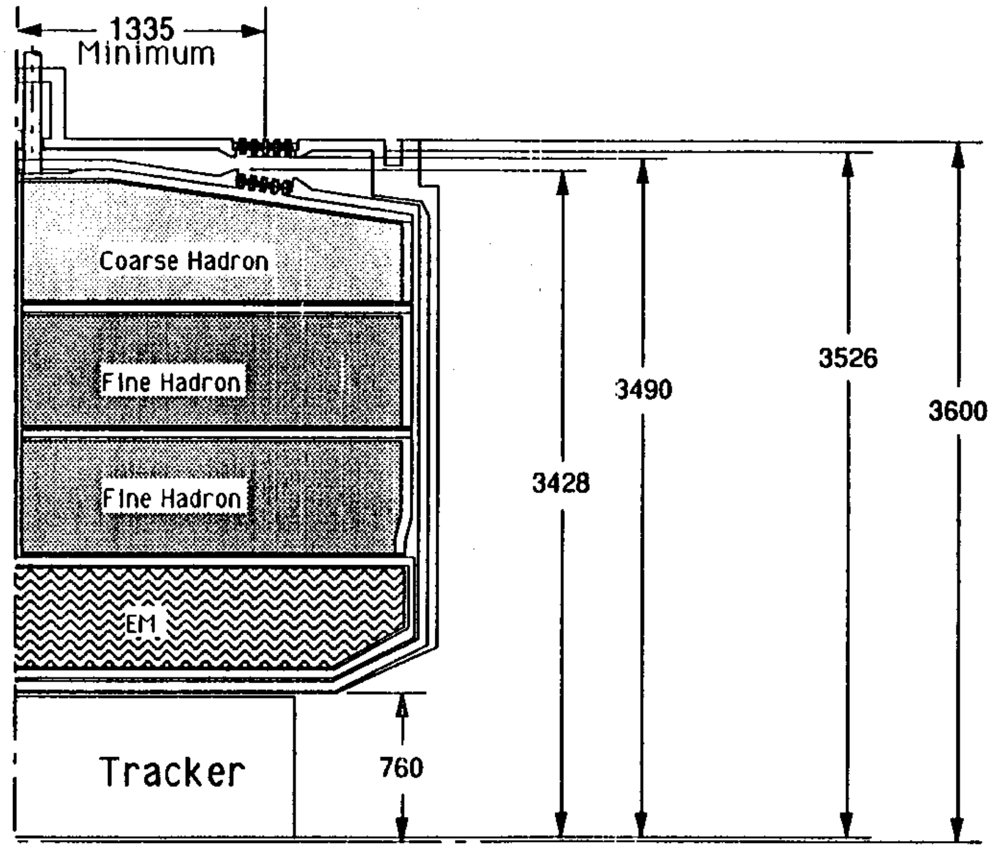


Figure 2-11. Section View Showing Location of Feedthroughs and radial dimensions

LIQUID ARGON BARREL CALORIMETER

All Dimensions in mm

Barrel Feedthroughs- End View

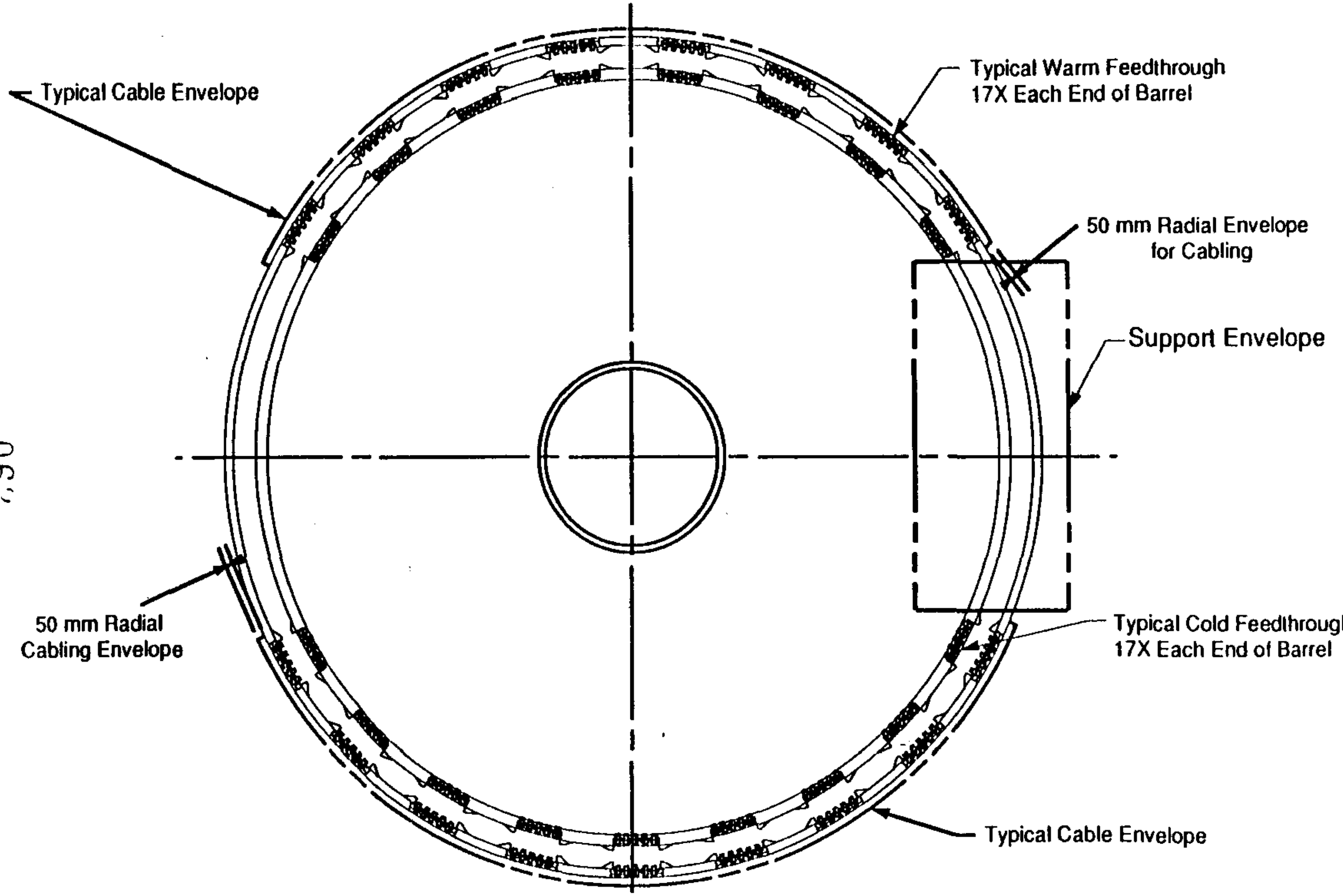


Figure 2-12. End Section View Showing Feedthrough Orientation and Cable Routing Space to Support Pedestal

KRBarnstableBL1 Barrel FT s

LIQUID ARGON ENDCAP CALORIMETER

Barrel & Endcap Feedthroughs

All Dimensions in mm

063

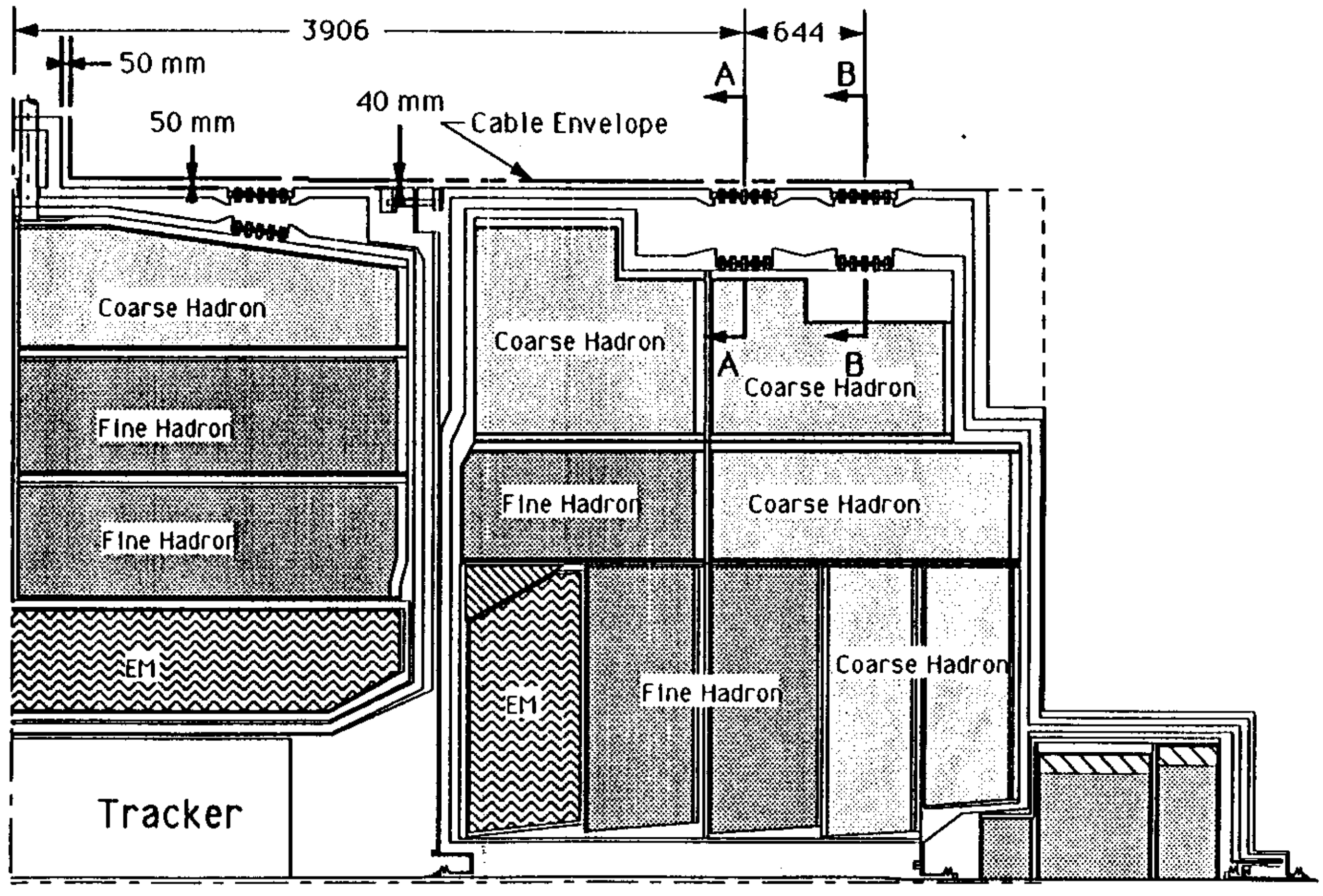


Figure 2-13. Shows the Z dimensions for the location of the Endcap Feedthrough

LIQUID ARGON ENDCAP CALORIMETER – Endview of Endcap

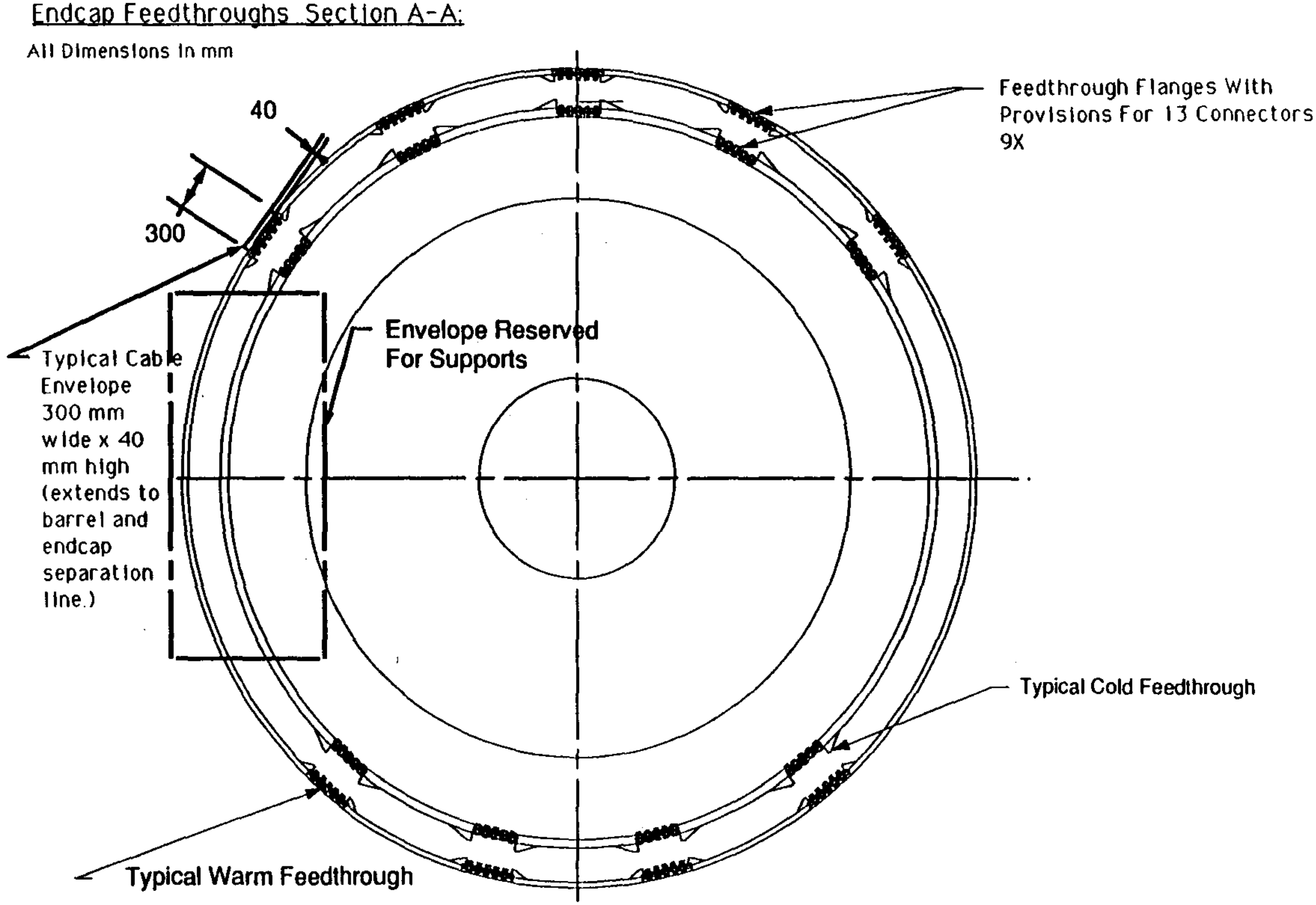


Figure 2-14. View Showing Feedthroughs at Section A-A and Envelope for Cabling

KRBarnstable BL1 E/C FT's 2-13>16

061

LIQUID ARGON ENDCAP CALORIMETER – Endview of Endcap

Endcap Feedthroughs

Section B-B:

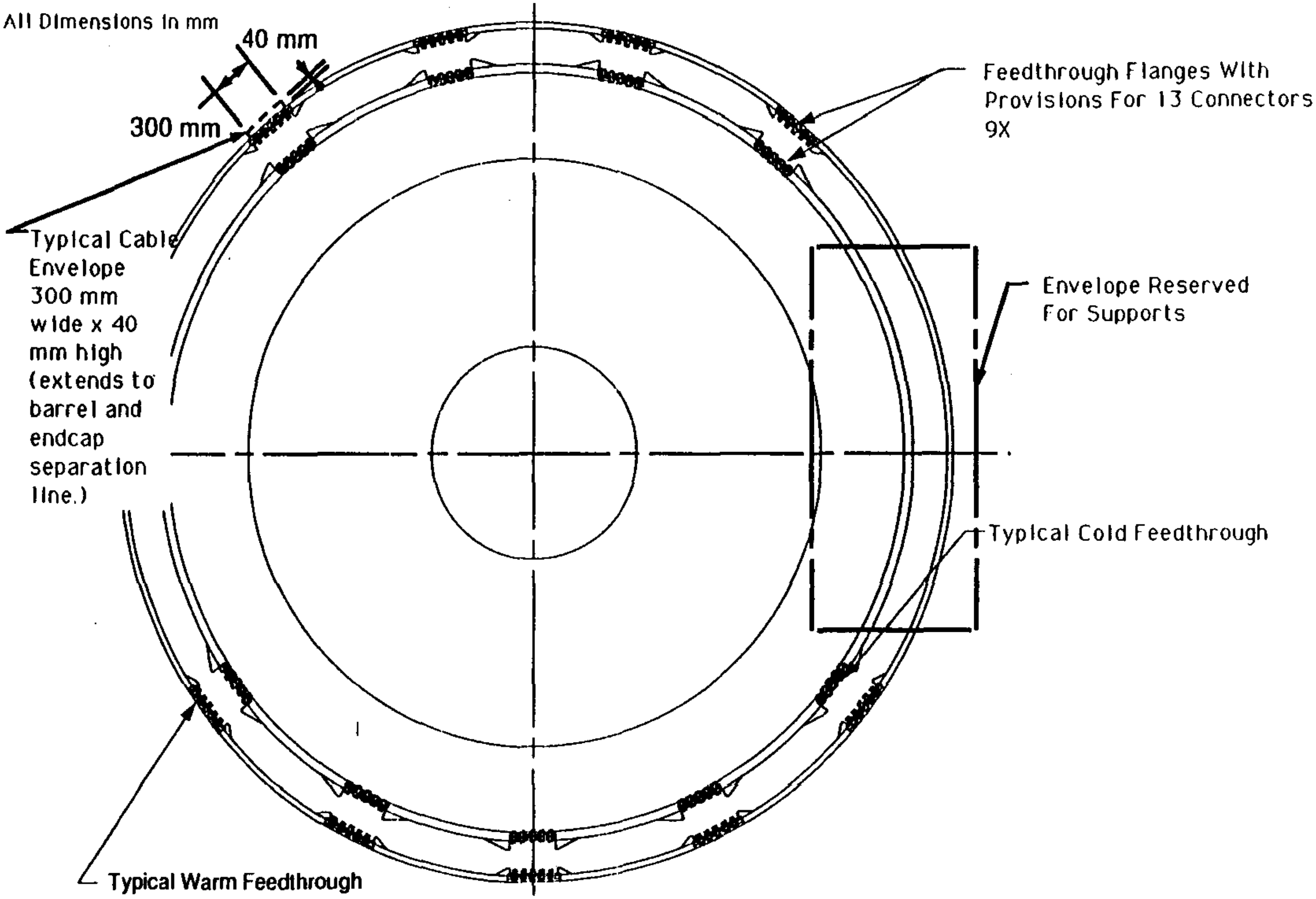


Figure 2-15. View Showing Feedthroughs at Section B-B, and Cabling Envelopes

KRBarnstable BL1 E/C FTs 2-13>16

LIQUID ARGON ENDCAP ENDCAP CALORIMETER

Endcap Feedthroughs - (Half Section End View)

All Dimensions in mm

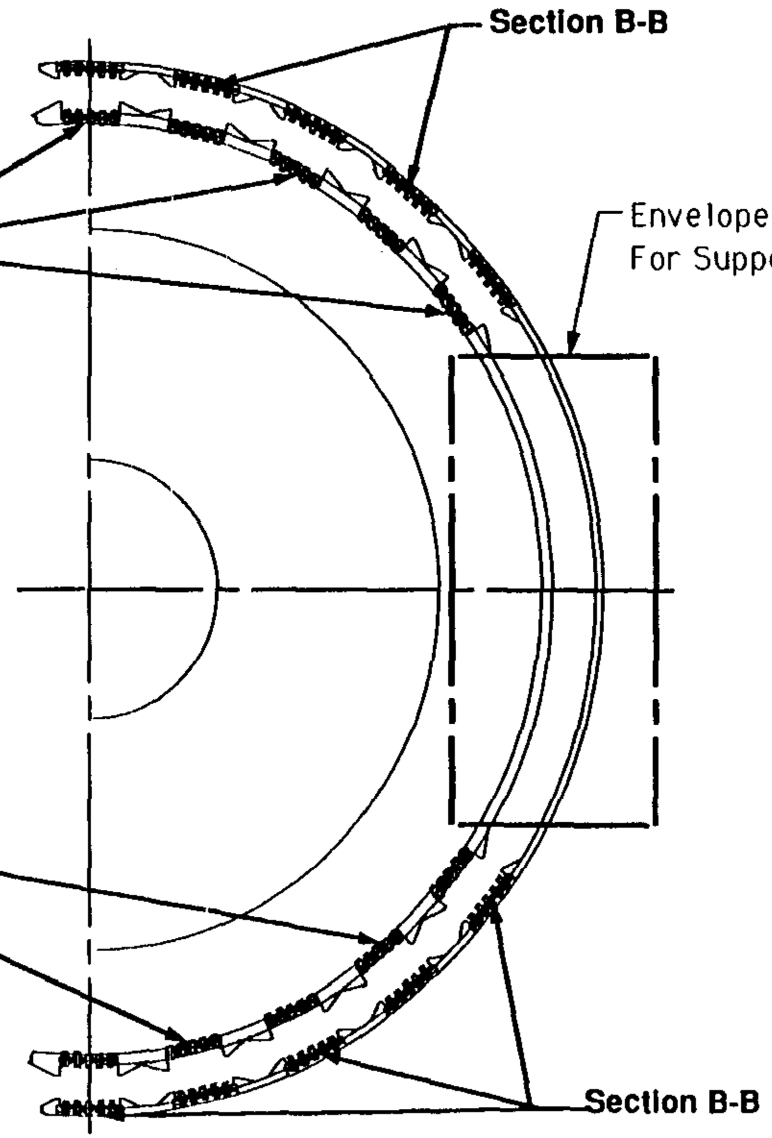


Figure 2-16. End View of Endcap Showing Super Imposed Sections A-A and B-B

KRBarnstable BL1 E/C FTs 2-13>16

LIQUID ARGON CALORIMETER - FEEDTHROUGHS

Feedthrough Twisted Pair Ribbon Cable and MLI (multilayer insulation) Detail:

Note: With proper cable orientation, there will be cable bundles from only 2 connectors overlapping at any one location.

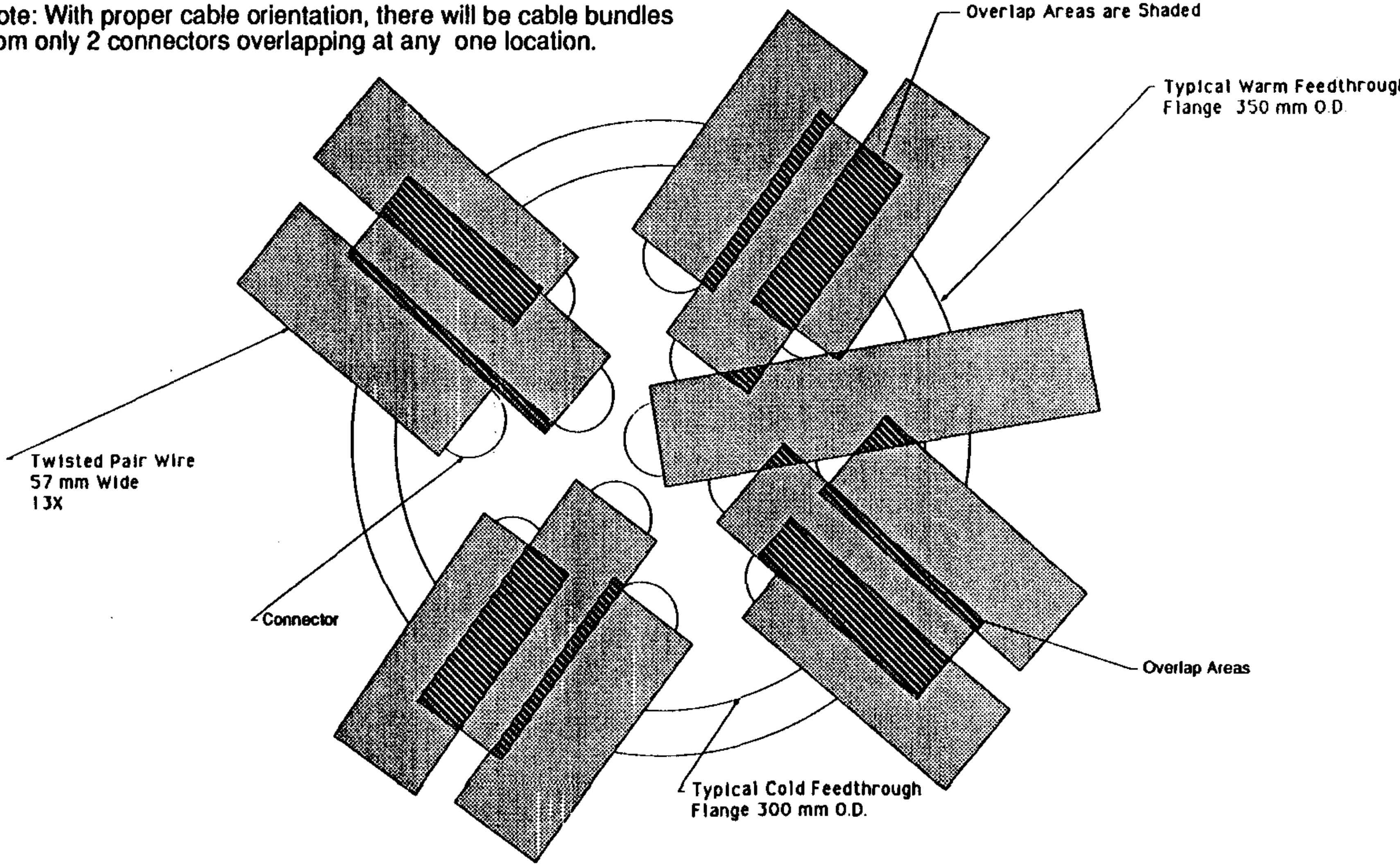


Figure 2-17. Shows the overlap of the coble bundles at the feedthrough in the space between the vessels where MLI is required

Calorimeter Engineering Question (Continued)

2. *Integrated Liquid Argon Calorimeter Diameter*

Request: Provide a more detailed tabulation of the diametrical stack-up of the integrated liquid argon calorimeter.

Specific Concerns:

- *The computation of the absorption length of the hadron layers does not appear to account for the 3-4% of absorber consumed by the tile partitions. If true this will add approximately 5 cm to the overall radius of the assembly.*

Data:

H. Gordon

Calorimeter Engineering Question

3. *Integrated Liquid Argon Calorimeter Support*

Request: Provide a scaled end section view of the liquid argon vessel cold mass supports.

Specific Concern:
•*Insufficient space is available for the cold mass support without reducing the active absorber in the hadron calorimeter.*

Answer:
•*Sufficient space has already been allocated for the cold mass supports, as shown in Figures 3-1 & 3-2, and further reduction is not required in the acitve absorber.*

Data:

- Plan and end views of the liquid argon vessel showing the locations of the stanchions (cold mass supports) are given in Figures 3-1 & 3-2, respectively.
- The Barrel Argon Vessel & Calorimetry weighs 900 MT. This weight is equally shared by four stanchions. In addition, each stanchion is subject to a lateral deflection of 15.57 mm ($0.004 \Delta L/L$ * 3892 mm) due to a thermal contraction from 296 to 86°K (reference Figures 3-1 & 3-2).
- Each Endcap Argon Vessel & Calorimetry weighs 636 MT. The front two stanchions each carry 276 MT and are subject to a lateral deflection of 14.48 mm ($0.004 \Delta L/L$ * 3619 mm) due to a thermal contraction from 296 to 86°K (reference Figures 3-1 & 3-2). The aft two stanchions each carry 42 MT and are subject to a lateral deflection of 16.60 mm ($0.004 \Delta L/L$ * 4150 mm) due to a thermal contraction from 296 to 86°K (reference Figures 3-1 & 3-2).
- The stanchions consist of plates made of Inconel (reference Figure 3-3) and are sized based on beam column analysis and subject to the guidelines of the AISC (reference Figure 3-4).

Figure 3-1.	Plan View of Liquid Argon Calorimeter Showing Stanchion Locations
Figure 3-2.	End Views of Liquid Argon Calorimeter Showing Stanchion Locations
Figure 3-3a.	Barrel Stanchion Basic Dimensions
Figure 3-3b.	Barrel Stanchion Assembly
Figure 3-4.	Loads & Analysis Results for Barrel & Endcap Stanchions

Note: All Dimensions in mm

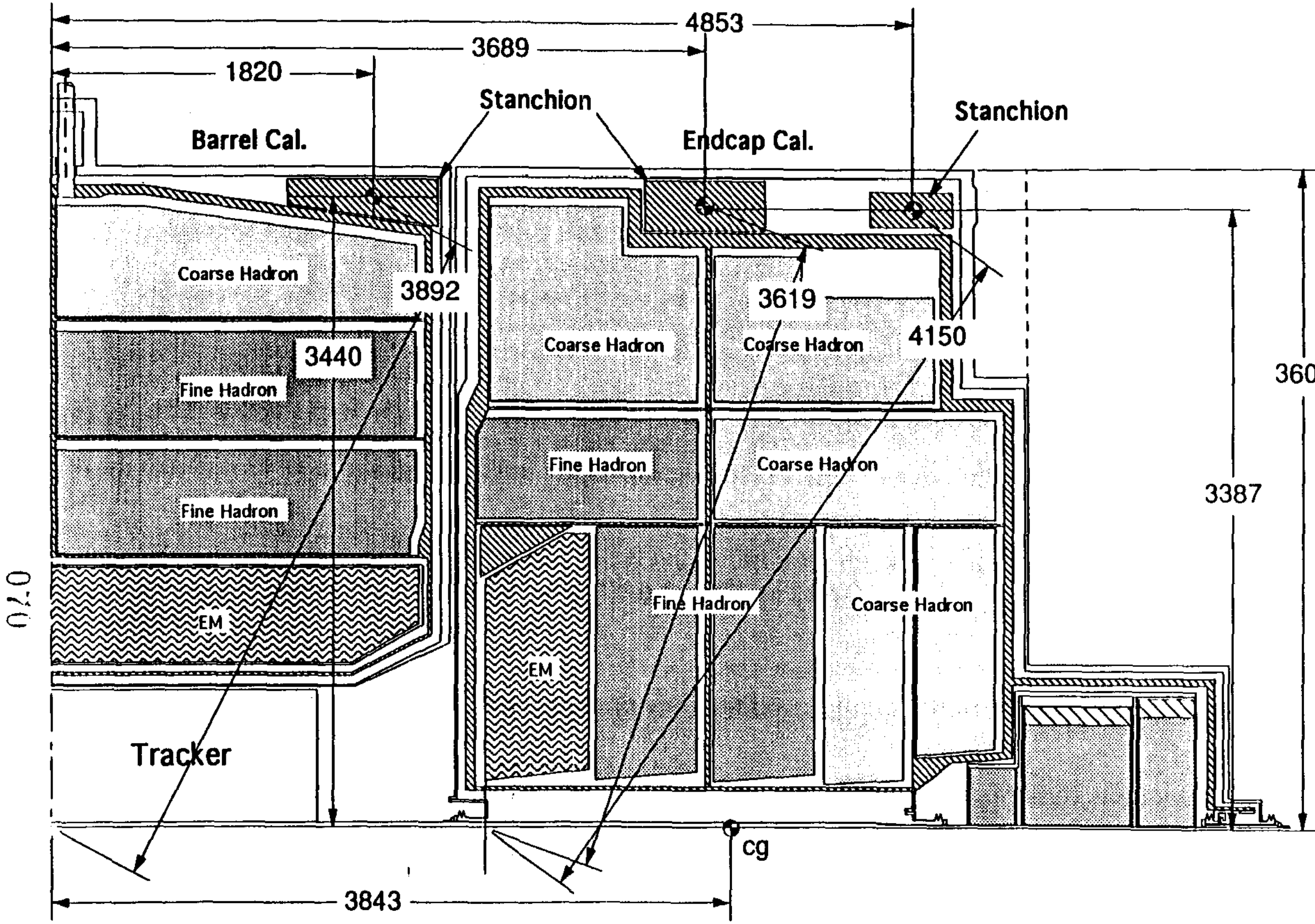


Figure 3-1 Plan View of Liquid Argon Calorimeter Showing Stanchion Locations

LLMason B/L1.Supports920620

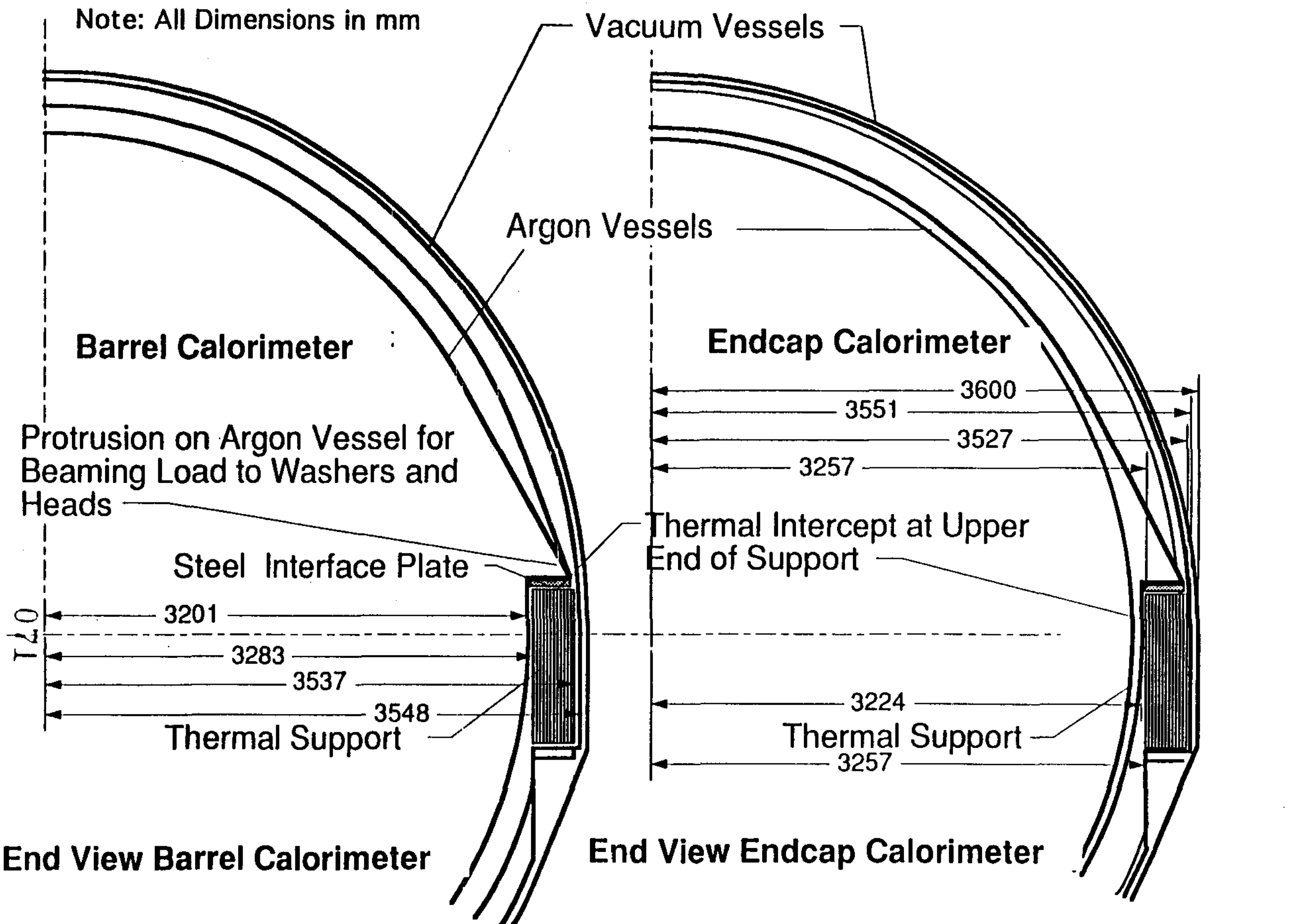


Figure 3-2 End View of Liquid Argon Calorimeter Showing Stanchion Locations

LLMason B/LI Supports920620

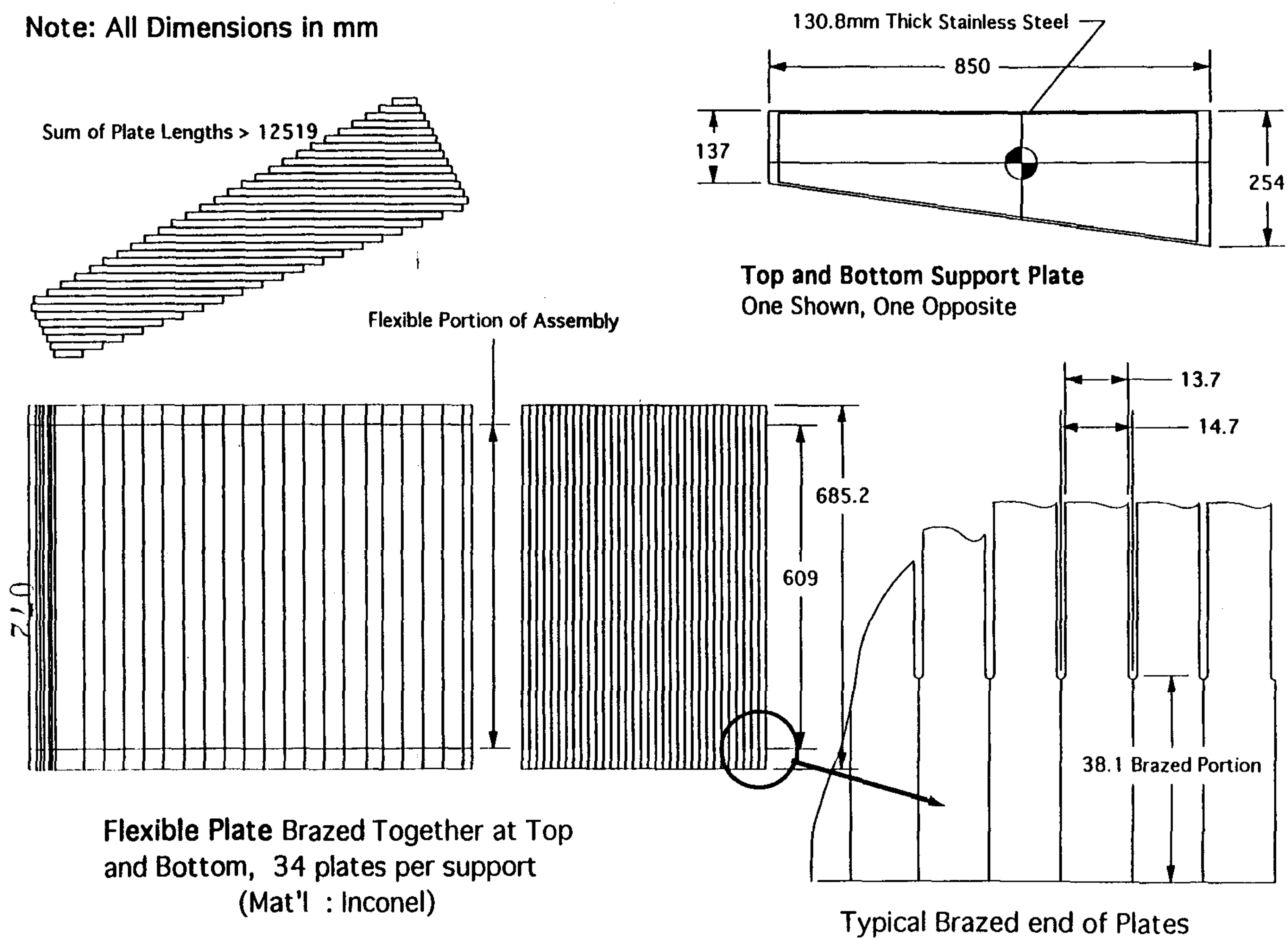
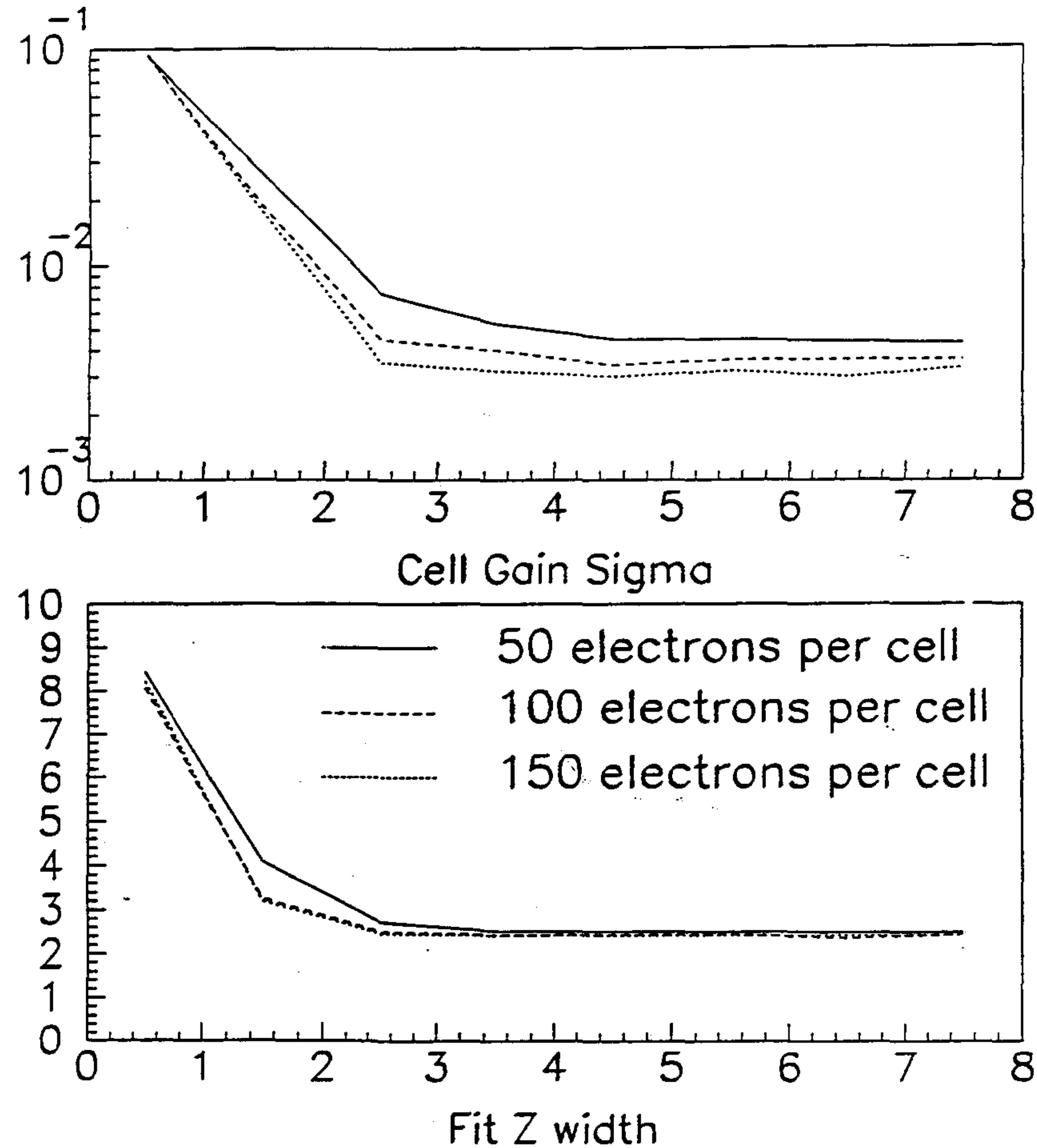


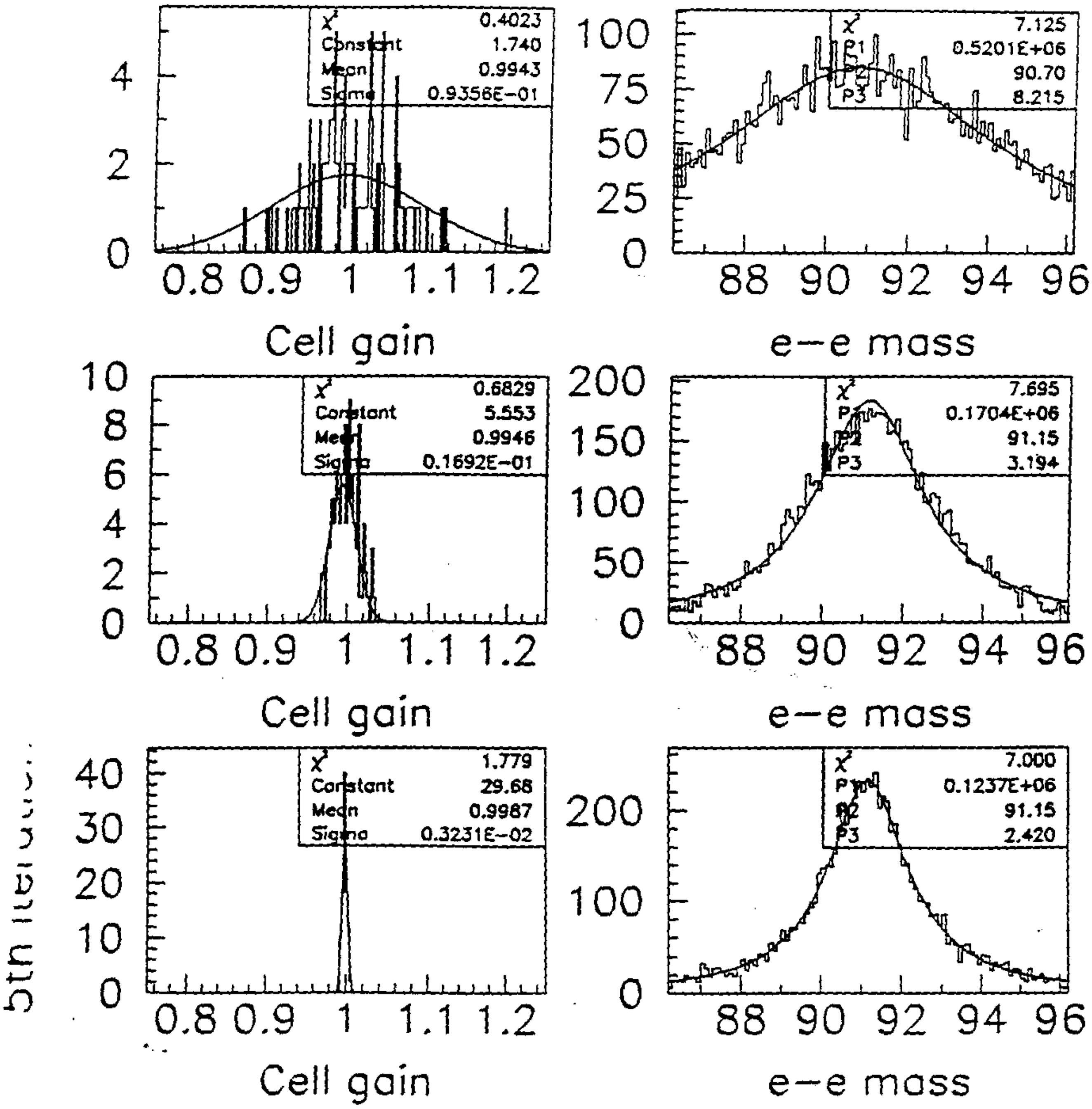
Figure 3-3a Barrel Stanchion Basic Dimensions

LLMason 920717 Column Support

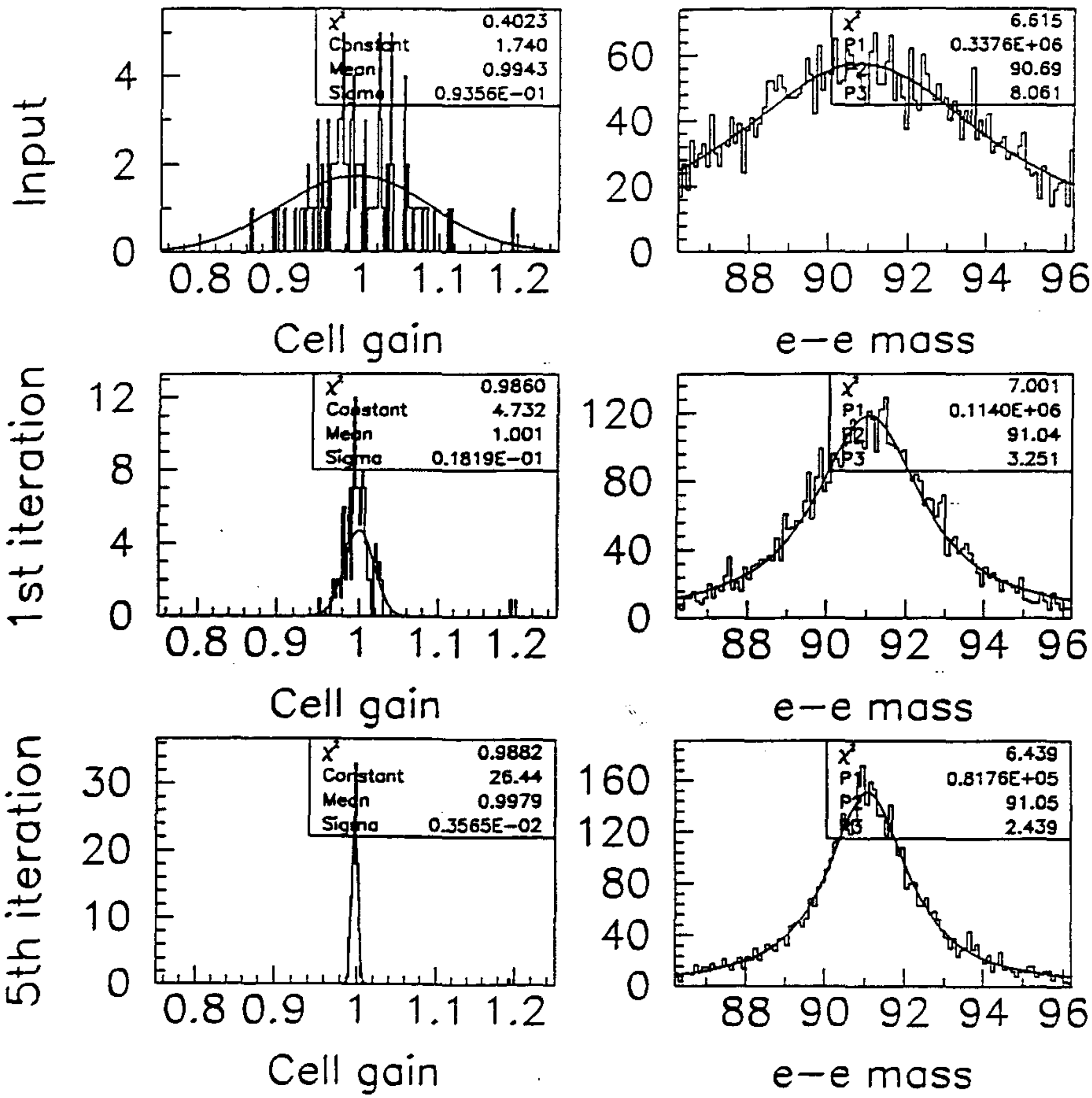


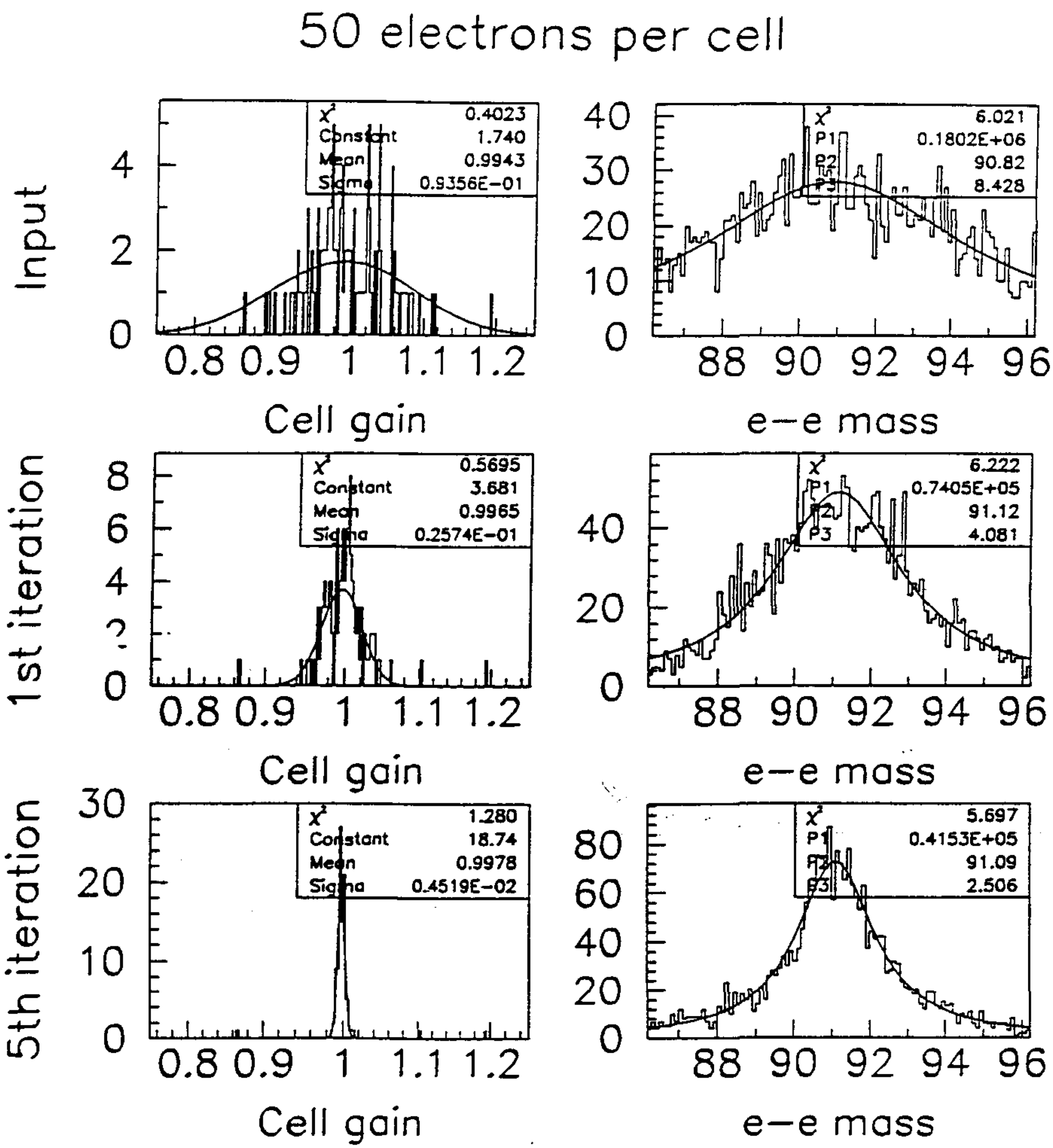
10^{-1}
10^{-2}
10^{-3}
0 1 2 3 4 5 6 7 8
Cell Gain Sigma
10 9 8 7 6 5 4 3 2 1 0
50 electrons per cell
100 electrons per cell
150 electrons per cell
0 1 2 3 4 5 6 7 8
Fit Z width

150 electrons per cell



100 electrons per cell





50 electrons per cell
Input
1st iteration
5th iteration
Cell gain
e−e mass
χ² 0.4023
Constant 1.740
Mean 0.9943
Sigma 0.9356E−01
χ² 6.021
P1 0.1802E+06
P2 90.82
P3 8.428
χ² 0.5695
Constant 3.681
Mean 0.9965
Sigma 0.2574E−01
χ² 6.222
P1 0.7405E+05
P2 91.12
P3 4.081
χ² 1.280
Constant 18.74
Mean 0.9978
Sigma 0.4519E−02
χ² 5.697
P1 0.4153E+05
P2 91.09
P3 2.506

Simulation Procedure

1. The calorimeter is composed of 21×21 crystals;

2. The opening angle between the two electrons are assumed to be measured perfectly by central tracker;

3. The mass of a Z is generated using the B-W form with the mass of 91.2 GeV and the width of 2.5 GeV;

4. For each Z decay, electrons hit the center of randomly chosen two crystals, with no overlapping in 3×3 crystals;

5. The energy of the electron is deposited in 3×3 crystals around the crystal the electron hits with the fraction measured by the test beam: i.e 95% of the total energy;

6. The measured "electron energy" is calculated by

$$E = (\sum_{3\times3} c_i \cdot E_i)/0.95$$

where c_i is the cell gain and E_i is the real energy deposit in the cell i and the summation runs over the 3×3 crystals.

Z° Calibration

Algorithm

H. Yamamoto.

1. Use all Drell-Yan $Z \rightarrow e^+e^-$ events accepted with M_{ee} within $2\Gamma_Z$ around M_z, and fit the invariant mass distribution by a B-W shape with 3 parameters: area (A_{all}), mass (M_{all}) and width (Γ_{all}).

2. Fit the same invariant mass distributions for e^+e^- pairs which has one electron hits one crystal (i), and obtain area (A_i) and mass (M_i) with fixed width (Γ_{all}).

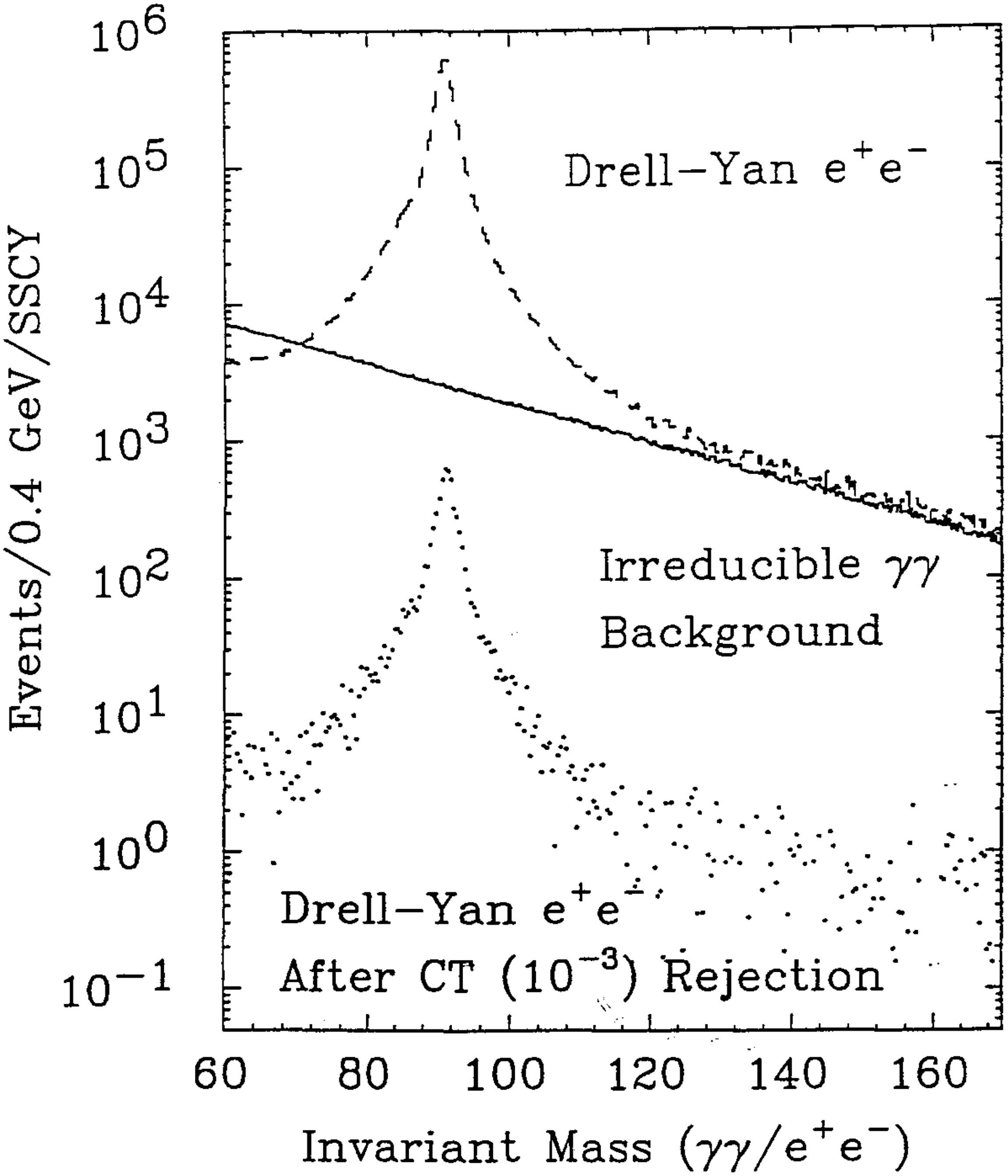
3. Repeat the second process for all crystals.

4. Multiply corrections to the gain of crystal i: $(M_{all}/M_i)^2$;

5. Repeat 1—4 until the correction factors converges to ~1.

Accuracy

- 50 e/cell (<12 SSCD): 0.42%;
- 100 e/cell (<24 SSCD): 0.35%;
- 150 e/cell (<36 SSCD): 0.32%.



10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^−1
Events/0.4 GeV/SSCY
Drell−Yan e⁺e⁻
Irreducible γγ
Background
Drell−Yan e⁺e⁻
After CT (10^−3) Rejection
60
80
100
120
140
160
Invariant Mass (γγ/e⁺e⁻)

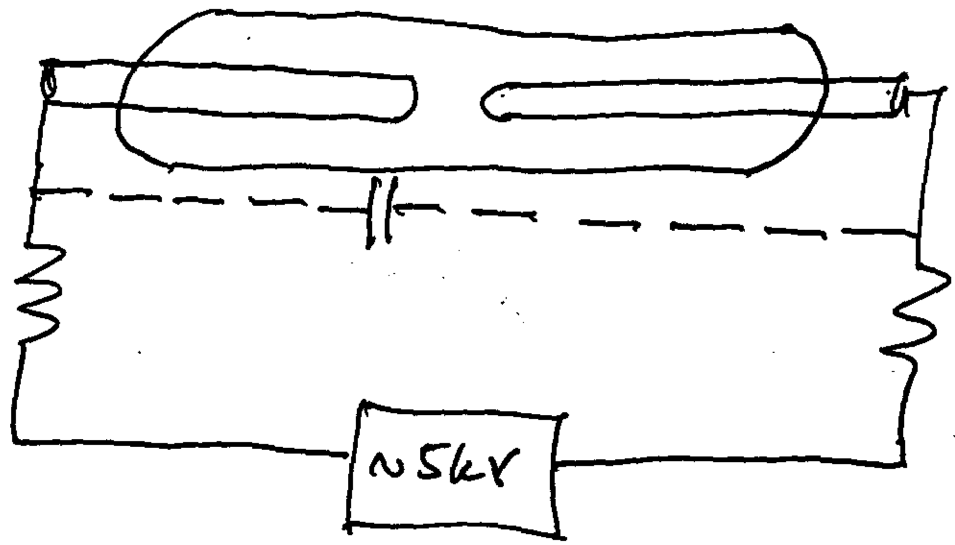
Calibration of EM Calorimeter by using $Z \rightarrow e^+e^-$ Production at SSC

Hiro Yamamoto and Renyuan Zhu
Caltech

GEM Calorimeter Meeting

Dallas, August 9, 1992

- Algorithm;
- Accuracy.


~5kV

UV Flasher System
Status as of July 1992

- Hardware
  - UV Flash Lamp .... **Complete**
  - Enclosure .... **Complete**
  - Reference Enclosure .... **Complete**
  - Fibers .... **Complete**
  - Trigger Logic .... **Complete**
  - Data Acquisition Logic .... **Complete**

- Software
  - Data Acquisition .... **Complete**
  - Analysis .... In Progress
  - Preamplifier Studies .... In Progress

- Measurements
  - First Pulse Shape .... **Complete**
  - Routine Crystal Data .... Late August
  - Matrix Monitoring Setup .... Under Design

BaF_2 MONITORING
ULTRAVIOLET FLASH LAMP

- Flash Width - 3 ns FWHM
- Wave length - 220 nm center, 25 nm FWHM
- Intensity
  - 20,000 - 60,000 p.e. after 1 m fiber
  - 150 - 300 fibers per flash lamp
- Proposal for Monitoring Relative Gain Stability
  - 1 fiber per crystal
  - 50 - 100 flashtubes for 15,000 crystals
  - 50 - 100 crystals have fibers from two flash lamps
- Proposal for Monitoring Gain and Global Linearity
  - Two sets of flash lamps
  - 2 fibers per crystal
  - 100 - 200 flash lamps for 15,000 crystals
  - 50 - 100 crystals have fibers from 4 flash lamps

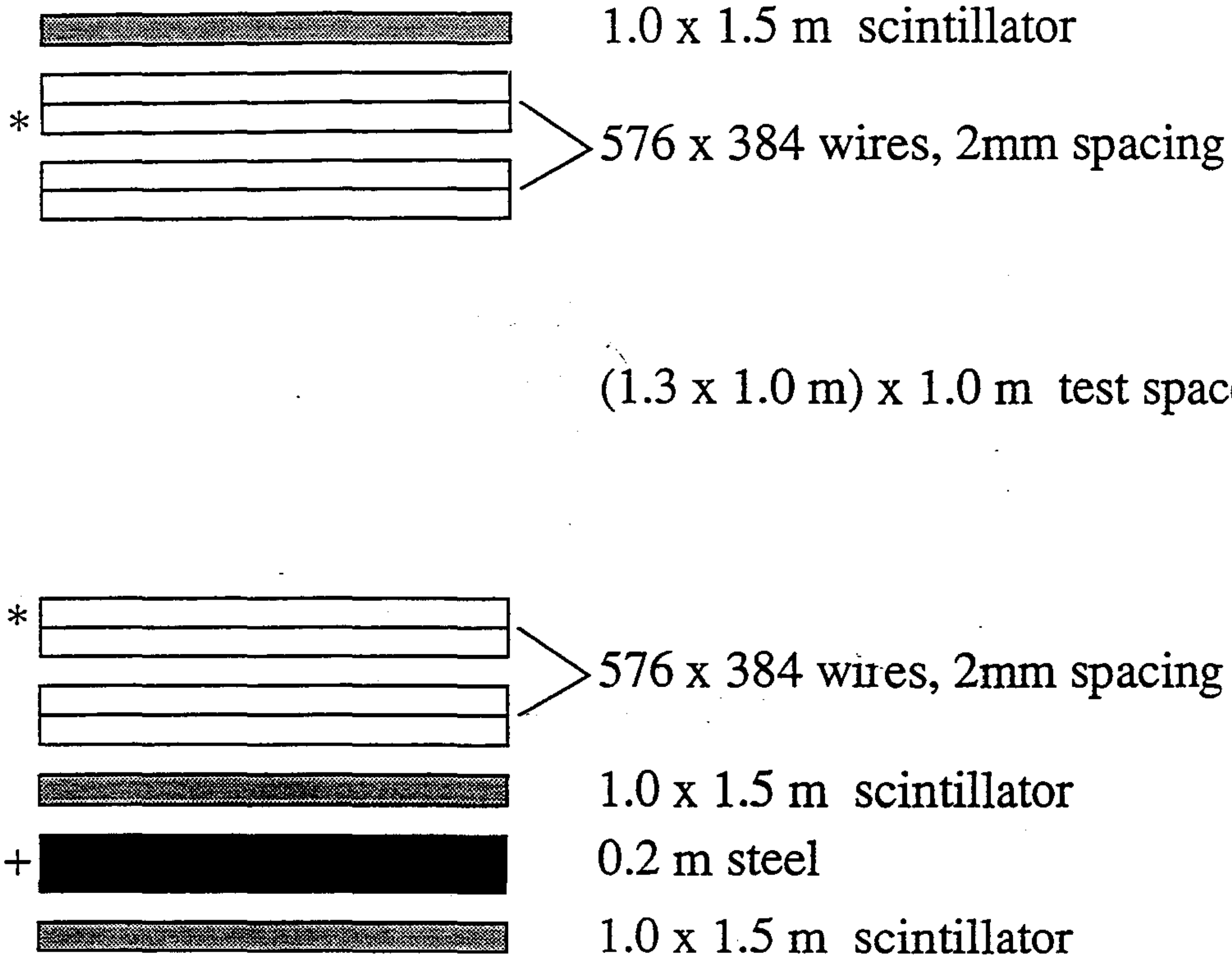
BaF_2 COSMIC RAY TEST STAND
Status as of July 1992

- Hardware
  - Mechanical Structure .... **Complete**
  - Triggering Counters.............. **Complete**
  - Defining Counters................ **Complete**
  - Trigger Logic .... **Complete**
  - Data Acquisition Logic........... **Complete**
  - PWC Mechanical (*)............. **Complete**
  - PWC Electrical.................. **Complete**
  - PWC Readout .... **Complete**
  - PWC Gas .... **Complete**

- Software
  - Data Acquisition................. **Complete**
  - Chamber Monitoring............. **Complete**
  - Tracking........................ In Progress
  - Crystal Studies (res., noise) ...... In Progress

- Near Future
  - First Crystal Data............... Mid August
  - Routine Crystal Data............ Late August

BaF_2 Cosmic Ray Test Stand



* = broken wires

\+ = not ready

\+ UV flash lamp monitoring @ 220 ± 25 nm

UCSD 30 June 92

"TEST BEAMS" → COSMIC RAY TELESCOPE

CRYSTAL UNIFORMITY

RESOLUTION (MIP = 0.3 GeV)

PREPARATION FOR HIGH E. TESTS.

LONG TIME STABILITY

MONITORING, TESTING → UV FLASH

NOW TESTING PHOTODETECTORS

LINEARITY

STABILITY

GAIN

ELECTRONICS

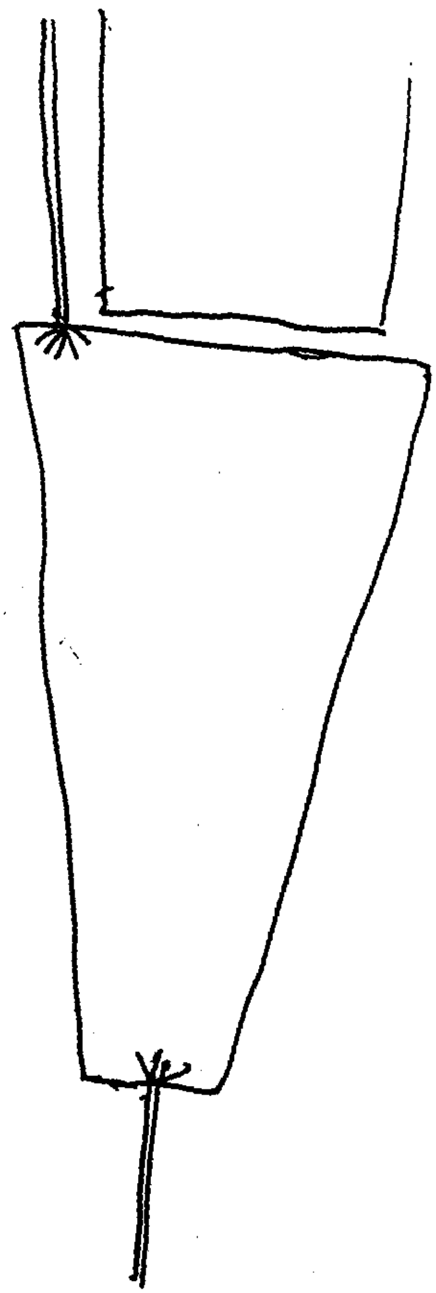
LIGHT COUPLING

TRANSMISSION

LATER ON LINE MONITORING

OVERALL TRANSMISSION /RESPONSE

LOCATE "DAMAGE"



HANS KOBRAK
PHYSICS DEPT (0319)
U. CALIF. SAN DIEGO
LA JOLLA, CA 92093

INTENTION OF IHEP

(in sequence of experience, confidence)

- μ, Electronics
- SFHC
- BaF_2
- LAr
- ~~CT~~

CHINESE INSTITUTIONS INVOLVED IN BaF_2

92.3.

Institution	people	Role
Tongji Univ.	5	Radiation Damage
Shanghai Nucl. Instit.	6	" " , Pre-rad
SIC	18	Crystal Growth
BGRI	18	" "
Zhongnan Opt. Instr.	25	" Processing – Coating
IHEP	25	Quality Control, RFQ.
USTC	23	Electronics, Assemby
Peking Univ.	4	" "
Tsinghua Univ. (7 Depts)	42	Mechanical Structure; Ti Welding – Assembly; Heat Transfer – Laser Cal. Ann.; Electronics; Crystal Inspection; General Alignment
	$\Sigma=166$	
Minister level (NanKing Univ. SAMF)		Schedule coordination

Ya-nan GUO

SSCL / IHEP (Beijing)

POINTING IN SEGMENTED BaF2 E-M CALORIMETER

(eta=0.)

50 GeV photons uniformly distributed along beam axis within +/- 60 mm

	Energy resolution, % after leakage corrections		Z pointing reconstruction accurancy, cm.	
	RMS	Sigma (Gaussian)	RMS	Sigma (Gaussian)
delta fi =0.04 delta eta =0.04				
a) 25cm+25cm BaF2	0.33	0.19 +/-0.01	1.42	1.35+/-0.07
b) 25cm+15cm BaF2	0.79	0.53 +/-0.08	1.62	1.74+/-0.22
c) 40cm BaF2+ 0.5 mm silicon dE/dx layer	1.23	1.29 +/-0.50	-	-
d) 40cm BaF2+ 3.0 cm silicon dE/dx layer	0.66	0.44 +/-0.02	3.57	3.49+/-0.20
e) 40cm BaF2+ 3.0 cm silicon dE/dx layer delta eta=0.02	-	-	2.11	2.77+/-0.42
f) 40cm BaF2+ 3.0 cm silicon dE/dx layer delta eta=0.01	-	-	3.28	2.46+/-0.23
Double Side Readout.			2.14	2.18±.11

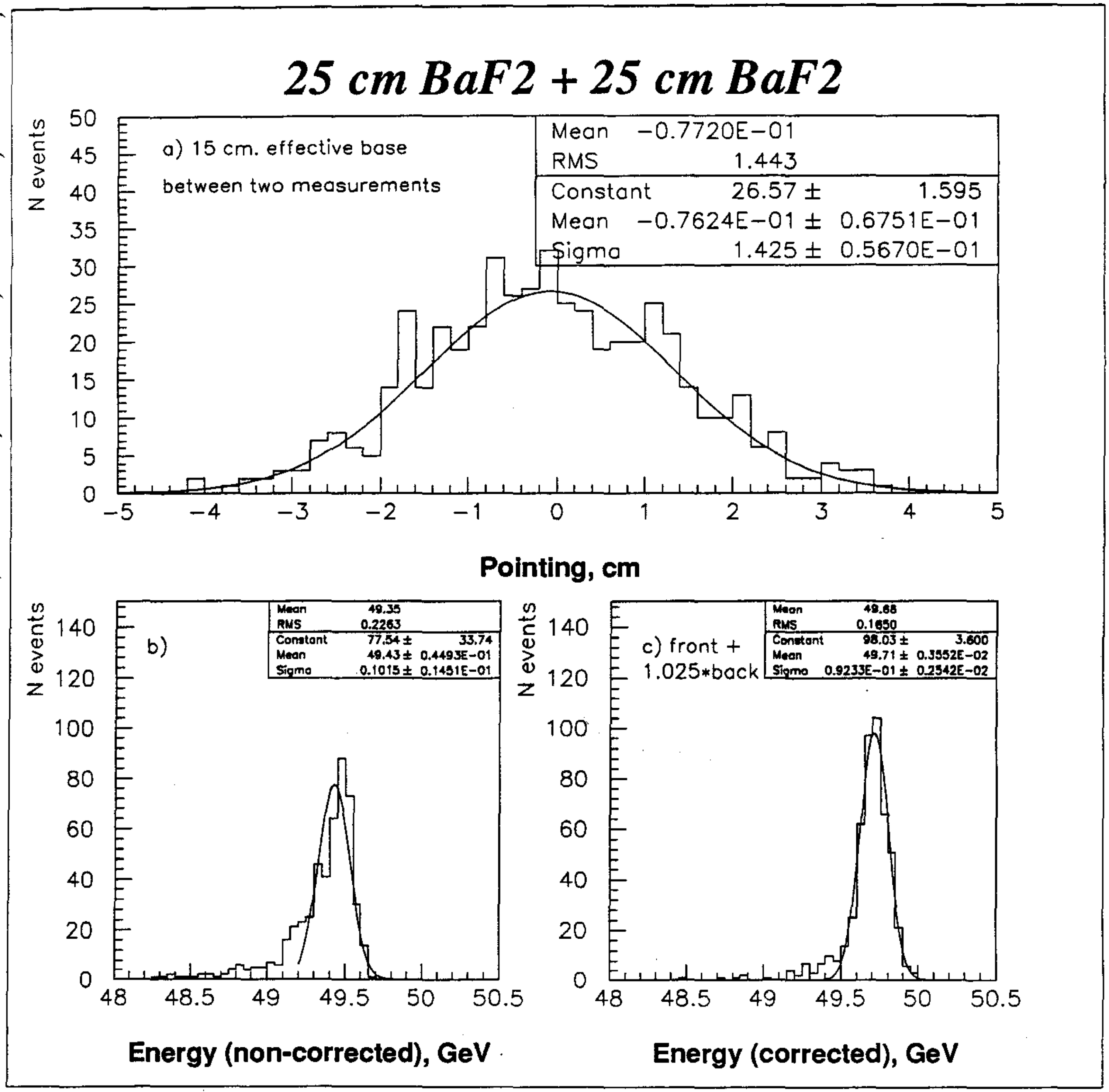

25 cm BaF2 + 25 cm BaF2
a) 15 cm. effective base
between two measurements
Mean −0.7720E−01
RMS 1.443
Constant 26.57 ± 1.595
Mean −0.7624E−01 ± 0.6751E−01
Sigma 1.425 ± 0.5670E−01
N events
Pointing, cm
b)
Mean 49.35
RMS 0.2263
Constant 77.54 ± 33.74
Mean 49.43 ± 0.4493E−01
Sigma 0.1015 ± 0.1451E−01
Energy (non-corrected), GeV
c) front +
1.025*back
Mean 49.68
RMS 0.1650
Constant 98.03 ± 3.600
Mean 49.71 ± 0.3552E−02
Sigma 0.9233E−01 ± 0.2542E−02
Energy (corrected), GeV

Fig. 5-8

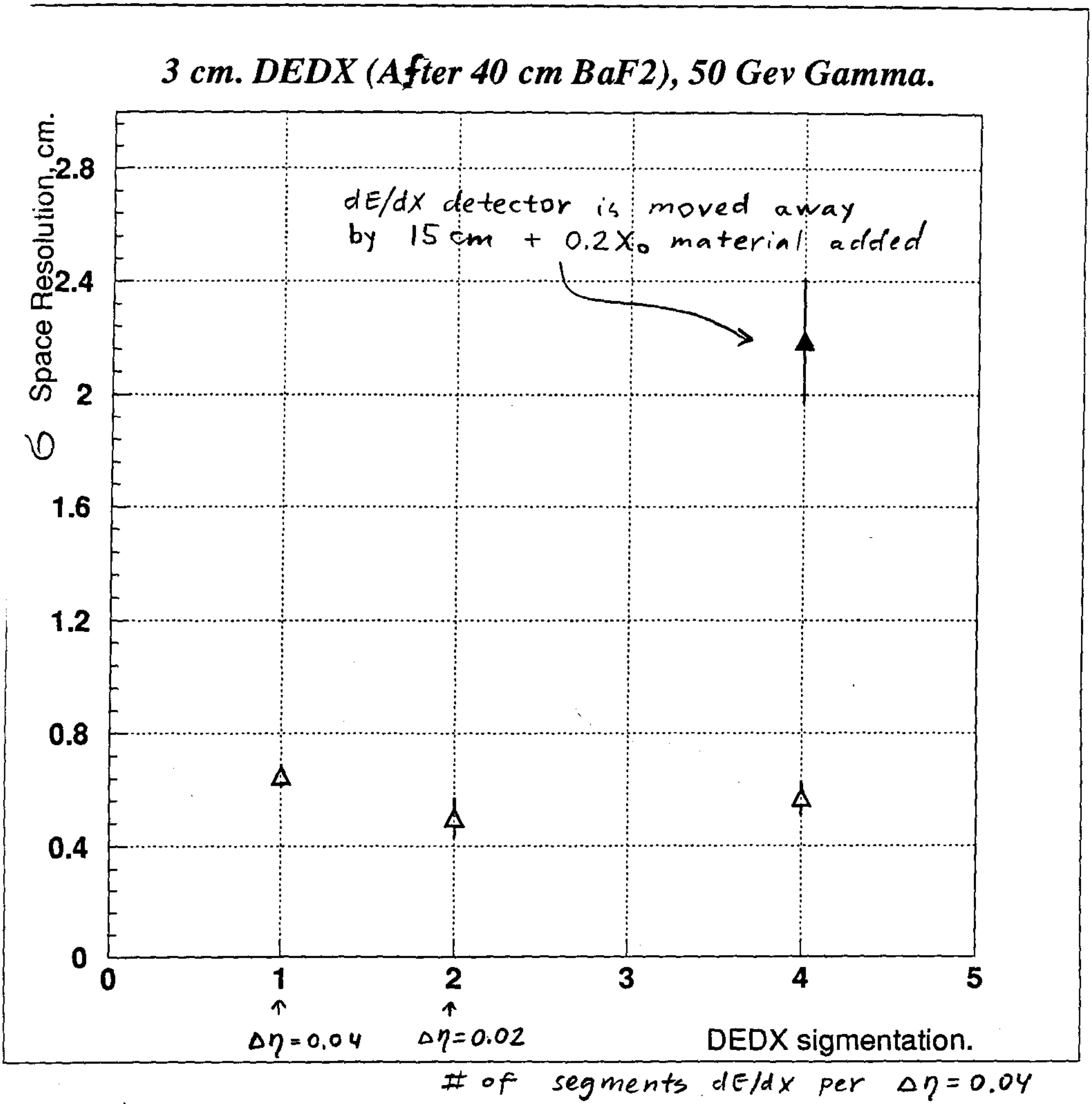
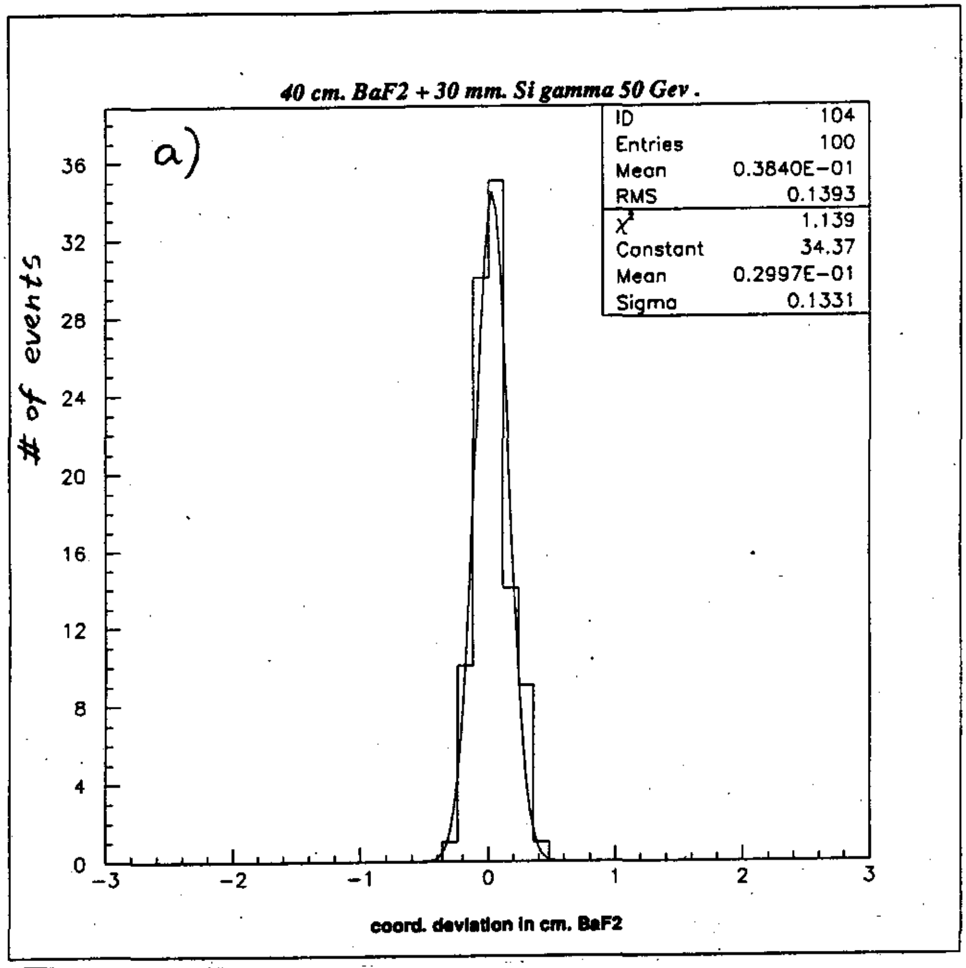

3 cm. DEDX (After 40 cm BaF2), 50 Gev Gamma.
σ Space Resolution, cm.
2.8
2.4
2
1.6
1.2
0.8
0.4
0
0
1
2
3
4
5
dE/dX detector is moved away by 15 cm + 0.2 X₀ material added
Δη = 0.04
Δη = 0.02
DEDX sigmentation.
# of segments dE/dx per Δη = 0.04

Fig. 5-7


40 cm. BaF2 + 30 mm. Si gamma 50 Gev .
a)
ID 104
Entries 100
Mean 0.3840E-01
RMS 0.1393
χ² 1.139
Constant 34.37
Mean 0.2997E-01
Sigma 0.1331
# of events
coord. deviation in cm. BaF2

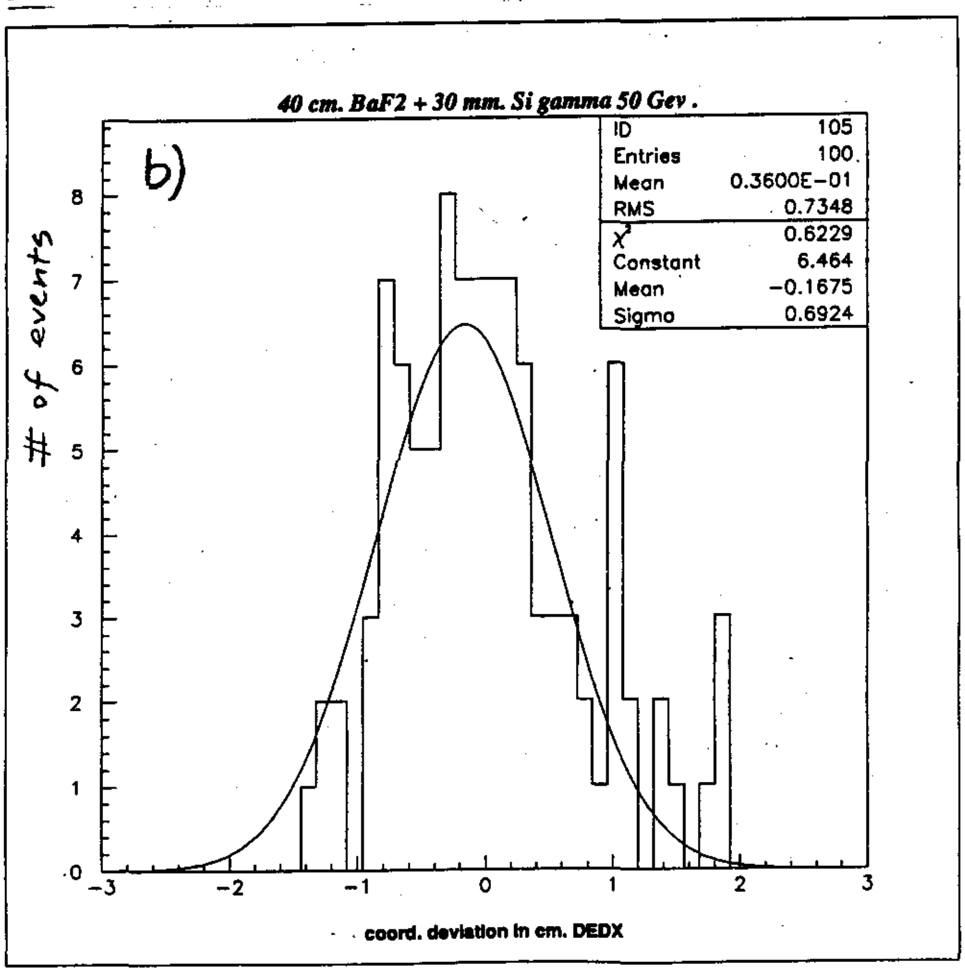

40 cm. BaF2 + 30 mm. Si gamma 50 Gev .
b)
ID 105
Entries 100
Mean 0.3600E-01
RMS 0.7348
χ² 0.6229
Constant 6.464
Mean -0.1675
Sigma 0.6924
# of events
coord. deviation in cm. DEDX

Fig 5-6

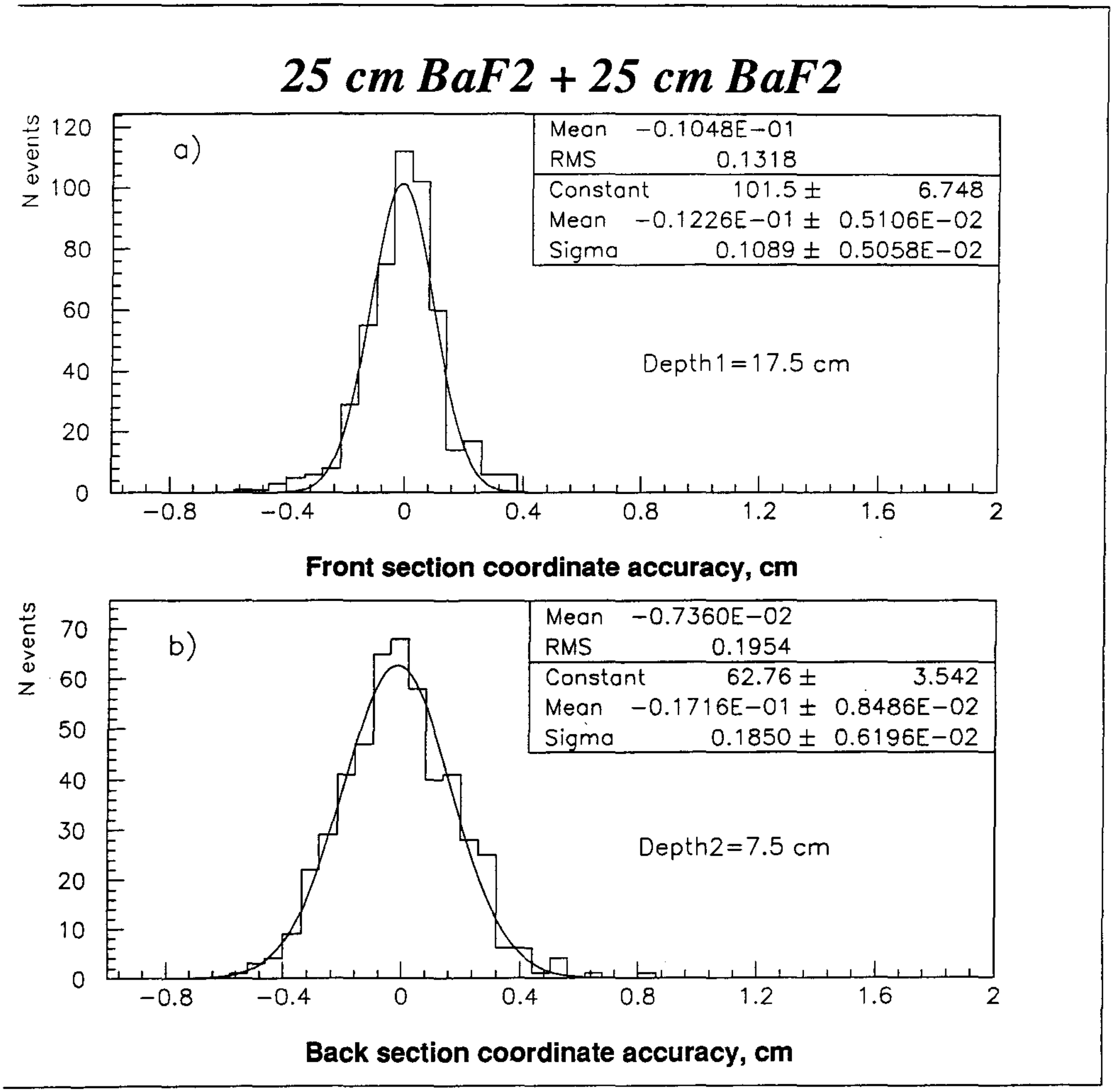
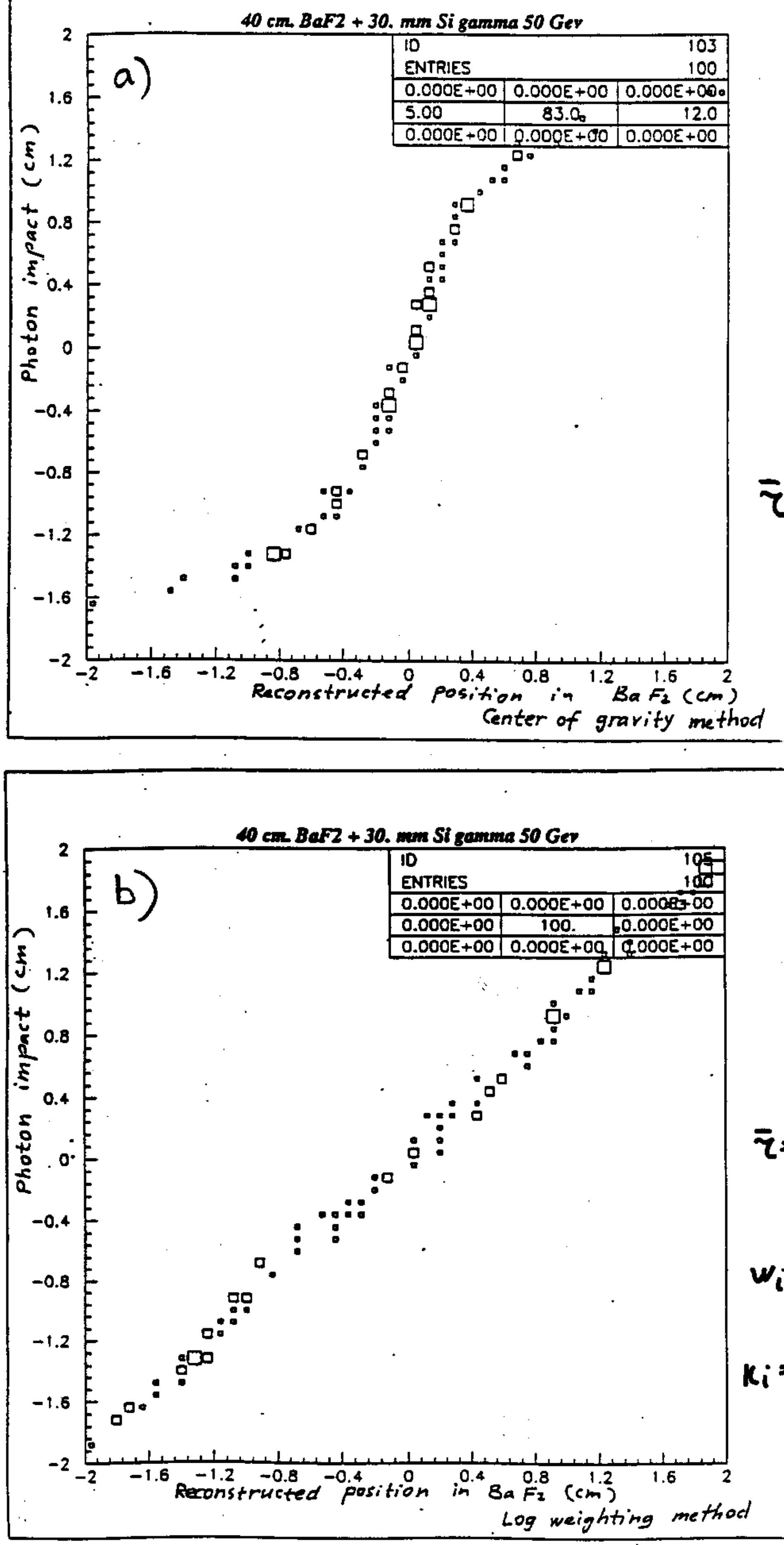

25 cm BaF2 + 25 cm BaF2
N events
a)
Mean −0.1048E−01
RMS 0.1318
Constant 101.5 ± 6.748
Mean −0.1226E−01 ± 0.5106E−02
Sigma 0.1089 ± 0.5058E−02
Depth1=17.5 cm
Front section coordinate accuracy, cm
N events
b)
Mean −0.7360E−02
RMS 0.1954
Constant 62.76 ± 3.542
Mean −0.1716E−01 ± 0.8486E−02
Sigma 0.1850 ± 0.6196E−02
Depth2=7.5 cm
Back section coordinate accuracy, cm

Fig. 5-5



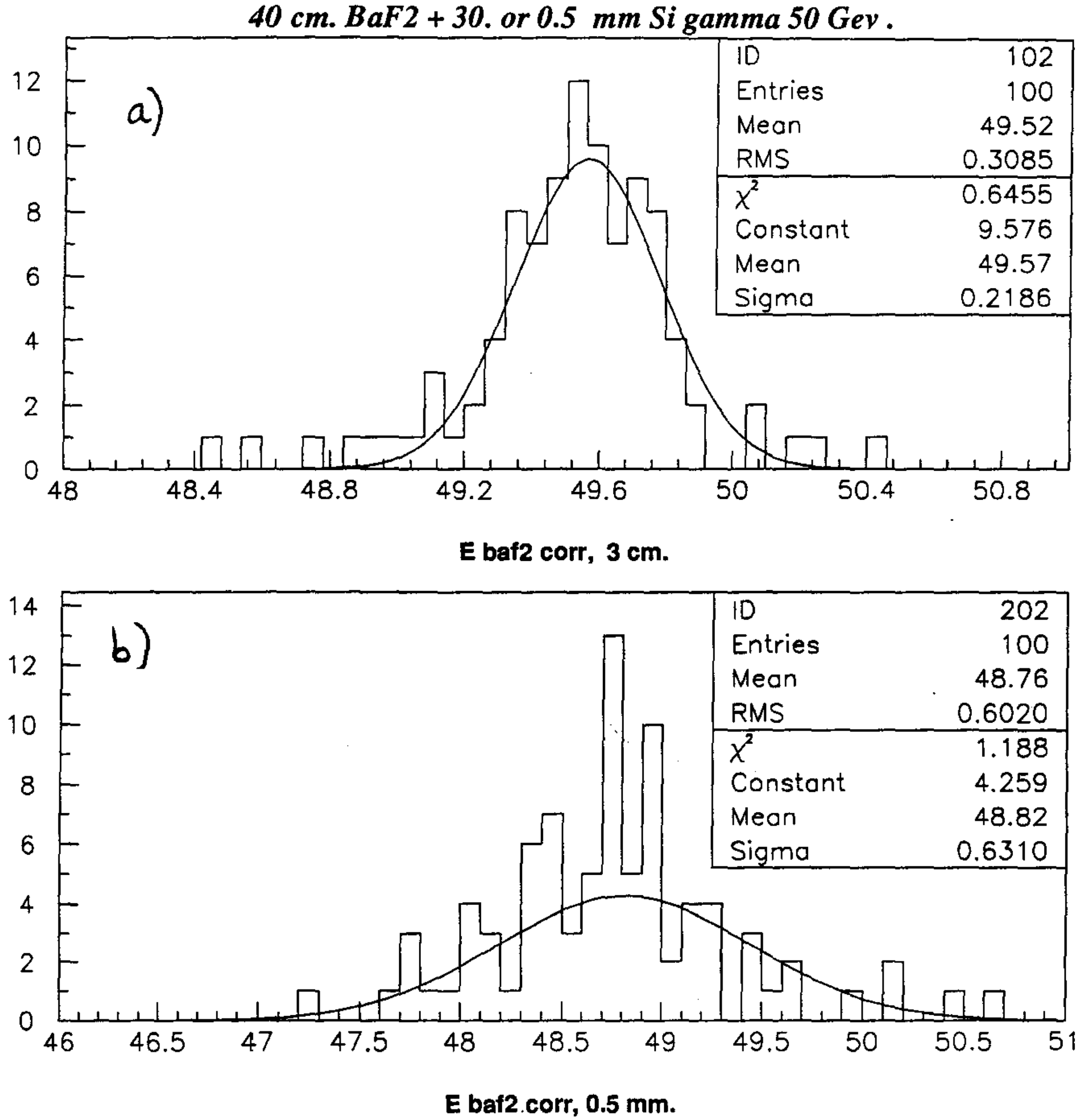
$$\bar{x} = \frac{\sum x_i E_i}{\sum E_i}$$

$$\bar{x} = \frac{\sum x_i w_i}{\sum w_i}$$

$$w_i = \max\{0, K_i\}$$

$$K_i = 4.5 + \ln(E_i/E)$$

Fig 5-4



40 cm. BaF2 + 30. or 0.5 mm Si gamma 50 Gev .
a)
ID 102
Entries 100
Mean 49.52
RMS 0.3085
χ² 0.6455
Constant 9.576
Mean 49.57
Sigma 0.2186
E baf2 corr, 3 cm.
b)
ID 202
Entries 100
Mean 48.76
RMS 0.6020
χ² 1.188
Constant 4.259
Mean 48.82
Sigma 0.6310
E baf2 corr, 0.5 mm.

Fig. 5-3

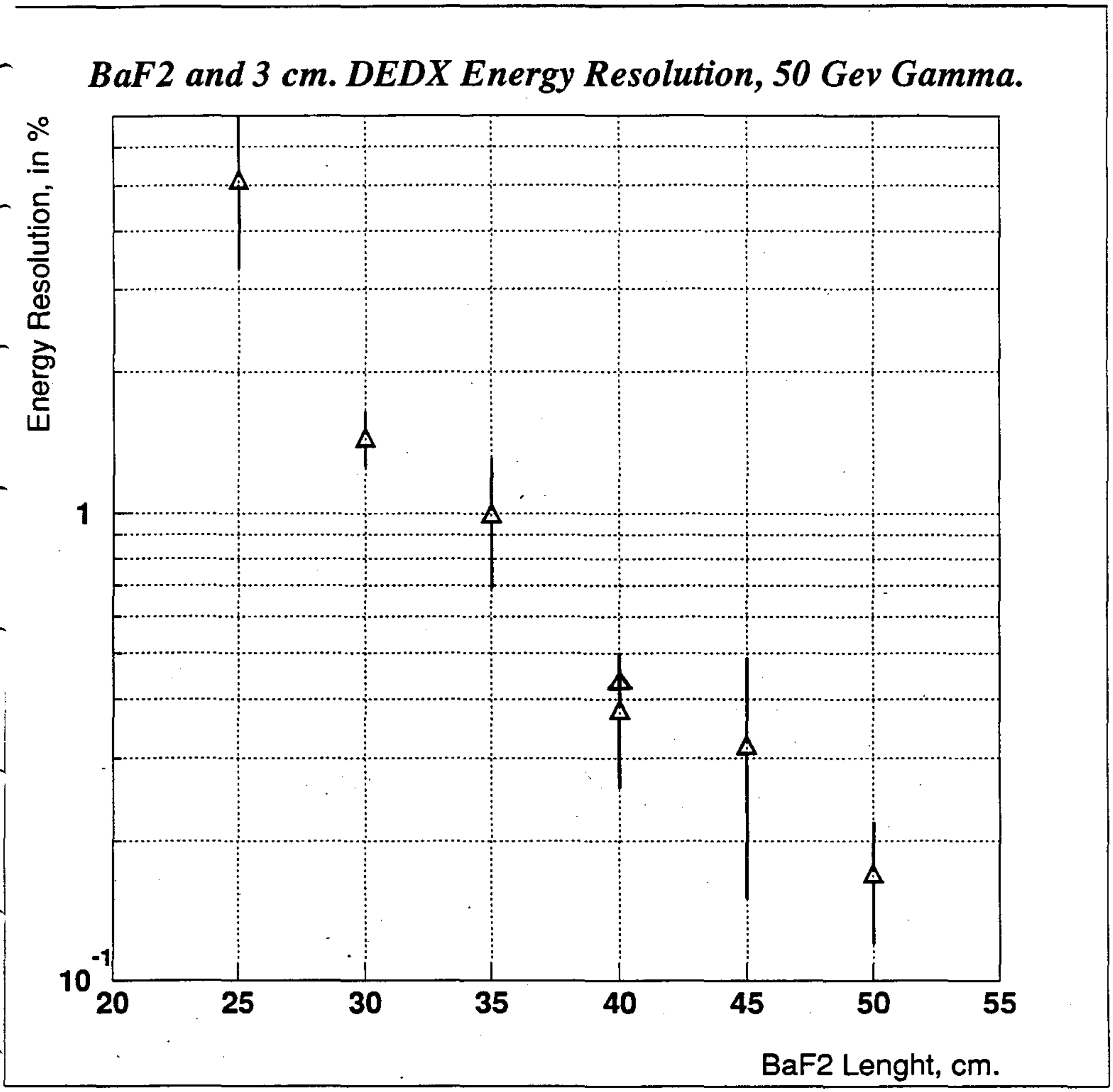

BaF2 and 3 cm. DEDX Energy Resolution, 50 Gev Gamma.
Energy Resolution, in %
1
10
-1
20
25
30
35
40
45
50
55
BaF2 Lenght, cm.

Fig. 5-2

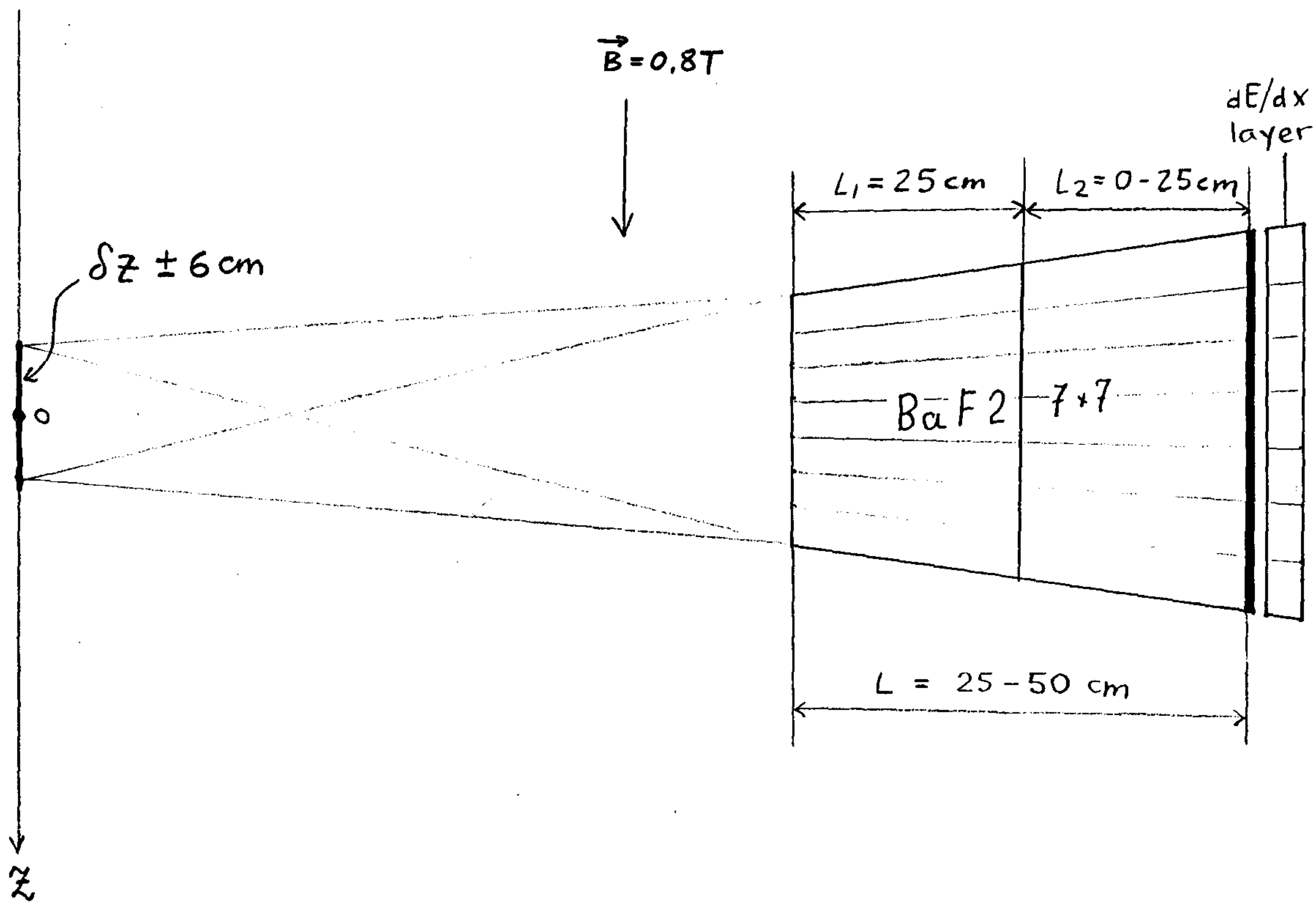


Fig. 5-1

readout).

Coordinates measured in two longitudinal sections of BaF_2 or in 40 cm long BaF_2 crystal and dE/dx detector were used to reconstruct the point of photon origin on Z-axes (pointing). The longitudinal position of the shower inside the BaF_2 was found by minimization of reconstructed Z-resolution. Figure 5-8 a) shows the accuracy of pointing reconstruction for 25 cm + 25 cm segmented BaF_2 crystals for 50 GeV photons. As it was shown in Fig. 5-5 front section has position reconstruction accuracy of 1.1 mm and back section 1.8 mm. The effective distance between two measurements is equal to 15 cm as it was found by minimization procedure. Also shown in Fig 5-8 b) is the energy measured in 25 cm + 25 cm BaF2 crystal without leakage corrections and in Fig. 5-8 c) with leakage corrections applied through longitudinal segmentation of the BaF_2 crystals.

All the results on pointing accuracy and energy resolution corrected for leakages simulated for different geometries are summarized in Table 1.

REFERENCES

- [1] "A simple method of shower localization and identification in laterally segmented calorimeters"
  T.C. Awes, F.E. Obenshain, F. Plasil et. al.,
  NIM A311 (1992)130-138

#5 POINTING IN THE LONG.SEGMENTED CRYSTALS

(Yu.Efremenko)

Simulations were done in the geometry shown in Fig 5-1. 50 GeV photons originated from vertices distributed ± 60 mm along the Z-axis were directed to the 7x7 matrix of BaF_2 crystals. Silicon photodiode readout was assumed (2.5 mm silicon dead material) followed at the back by 10 mm air gap and dE/dx detector - silicon array of 7*7 cells with thickness either a) 30 mm or b) 0.5 mm. BaF_2 crystals, if necessary, were segmented longitudinally with L_1=25 cm and L_2=0 – 25 cm. In this case the readout of the first crystals was assumed with Si-photodiodes located at the front of the crystals. All simulation was done with Magnetic field of 0.8 T in GEM configuration. Only evens with maximum enegry deposition in the central crystal were included in the analisys. Following cuts in GEANT 3.14 were used for simulations: 10 KeV for photons and 100 KeV for electrons.

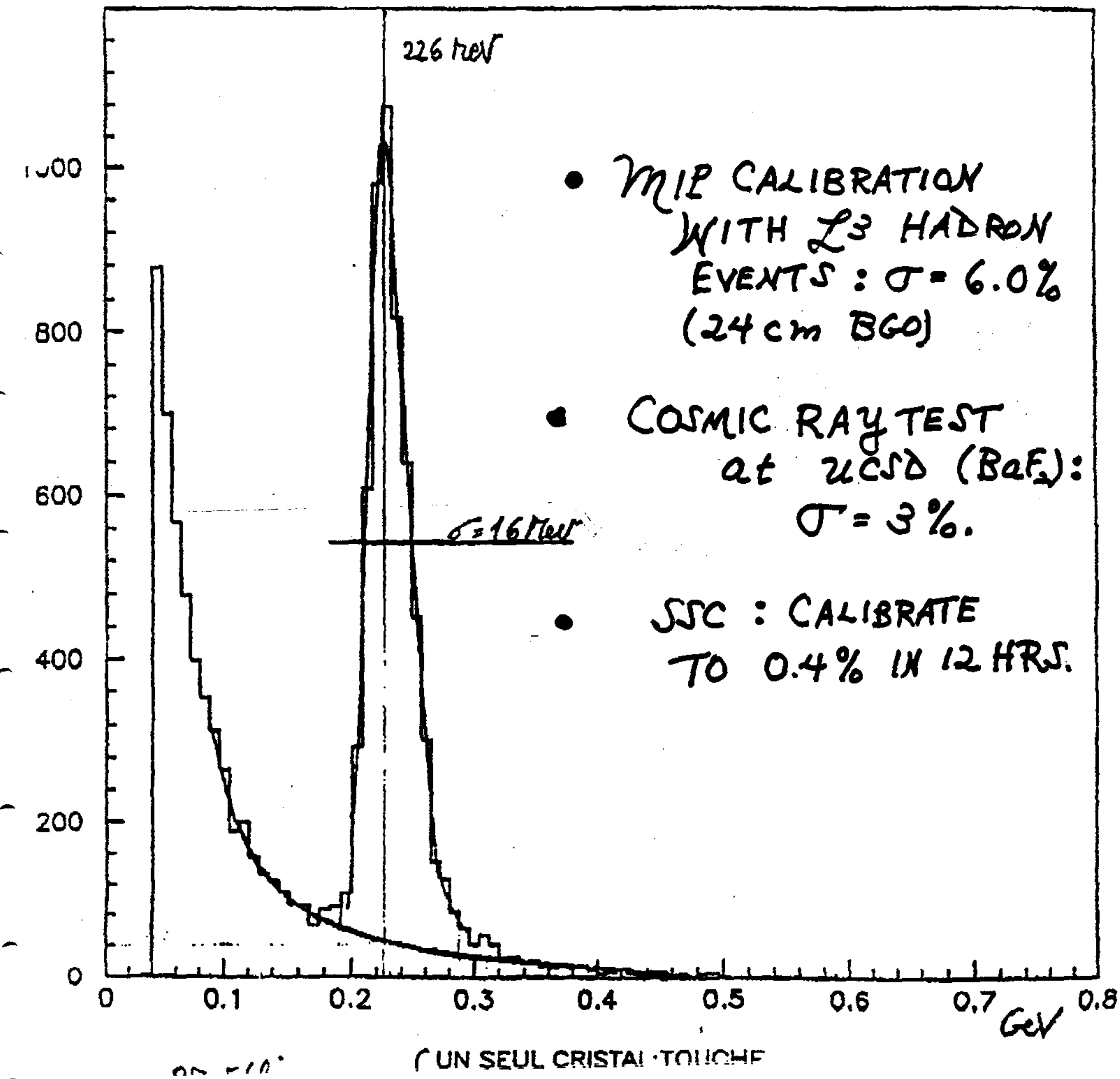
Figure 5-2 shows the optimized energy resolution for BaF_2 martix 7x7 with total variable length (from 25 to 50 cm, one readout) corrected for leakages measured in dE/dx detector. Figures 5-3a) and b) show oprimized amplitude distributions for 40 cm long BaF_2 followed by a) 3 cm thick Si-detector and b)0.5 mm thick Si-detector. With thicker dE/dx detector and 40 cm crystals initial resolution of BaF_2 is almost preserved - resolution is 0.44 ± 0.06% for 50 GeV photon. In further simulations only 3 cm dE/dx layer was used.

Figures 5-4a) and b) show reconstructed lateral position in 40 cm long BaF_2 martix vs original impact point of the photon for two reconstruction procedures : conventional center of gravity method (a) and logarithmic weigth method (b). The latter method is described in [1]. Only logarithmic method was used in the analysis. Accuracy of coordinate reconstruction in lateral direction is shown in Figures 5-5 a) and b) for segmented BaF_2 crystals (25 cm + 25 cm) for forward and backward sections respectively. Distributions shown in the figures 5-5 a) and b) were calculated for the distances $Depth_1$ and $Depth_2$ from the corresponding crystal segment face where longitudinal center of gravity of the shower in this segment is located. These distances were found from the simulated data (not from MC proper) by minimization procedure of photon origin Z-coordinate reconstruction. Similar accuracies for 40 cm long BaF_2 and for dE/dx detector are shown in Figures 5-6 a) and b) respectively. Shower width behind BaF_2 is rather broad, so that the accuracy of coordinate reconstruction by the dE/dx detector doesn't improve considerably if smaller dE/dx pads are used as shown in Fig. 5-7. Coordinate reconstruction accuracy is considerably worse (Fig 5-7 upper point) if dE/dx layer is moved back along the radius by 15cm (simulation of PM

Peak at 226 MeV ⇒ 9.42 MeV/cm
Δ ≤ 5 bin of 8 MeV ⇒ 38 MeV
σ = 16.0 MeV   σ ≈ 13.6 MeV
$\frac{\sigma}{E}$ = 7.1% $\frac{\sigma}{E}$ ≈ 6.0%

L3/BGO
JULY 90
S.Z. + D.B.

~ 30 000 qq̄ Events
~ 1/4 of 1990
~ 5100 MIP



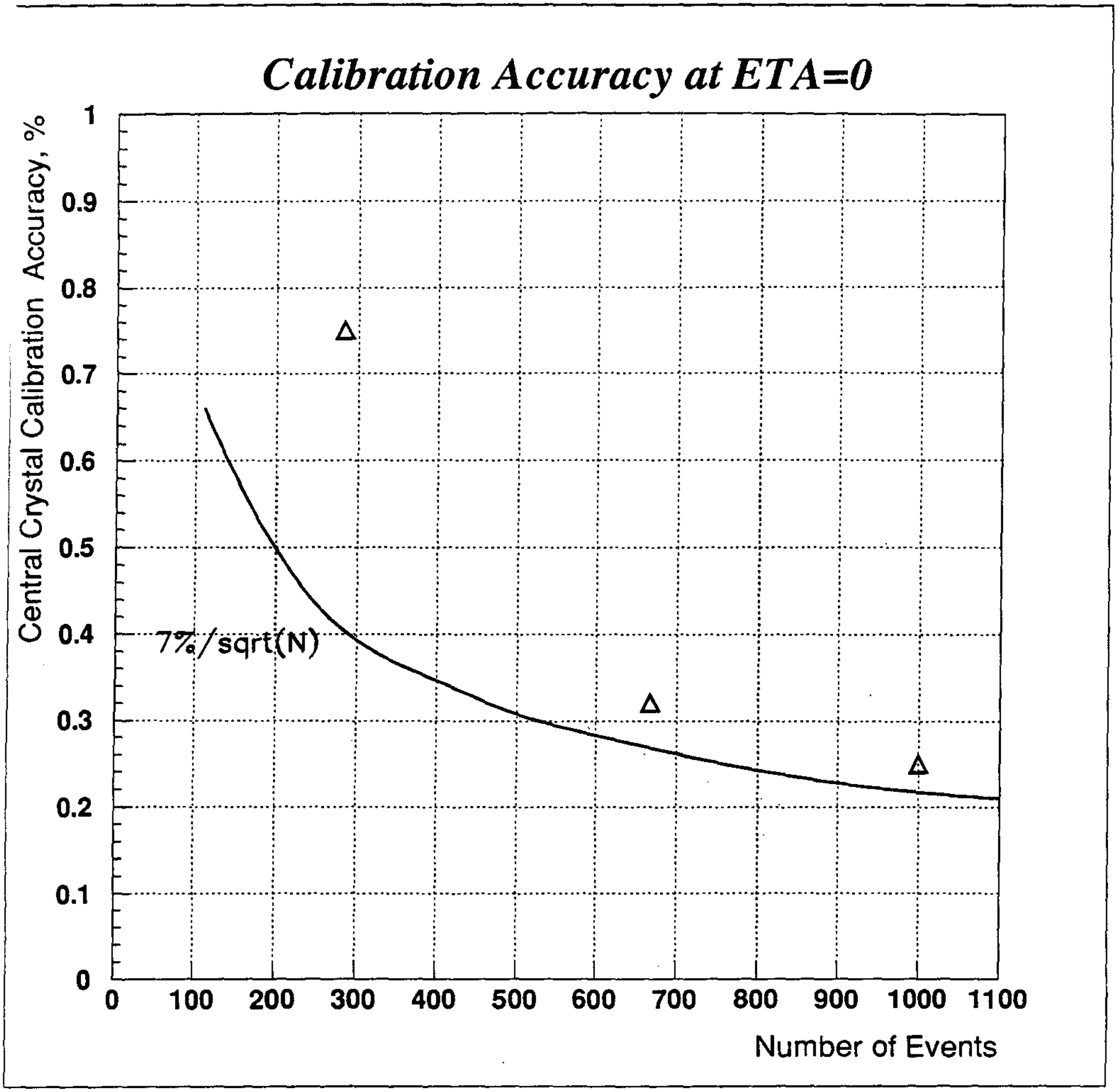
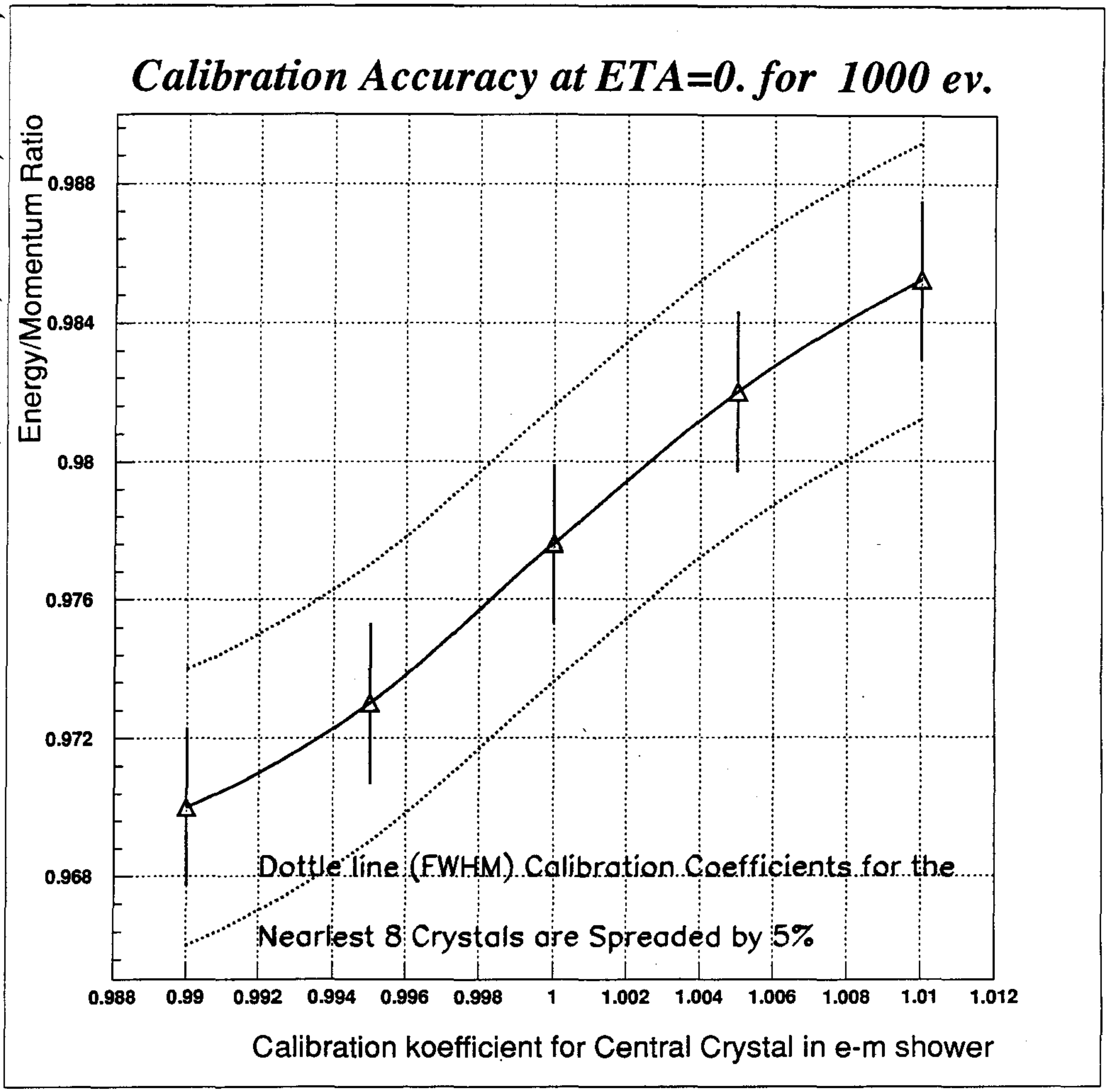

Calibration Accuracy at ETA=0
Central Crystal Calibration Accuracy, %
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7%/sqrt(N)
0 100 200 300 400 500 600 700 800 900 1000 1100
Number of Events

Fig. 4-6



Calibration Accuracy at ETA=0. for 1000 ev.
Energy/Momentum Ratio
0.988
0.984
0.98
0.976
0.972
0.968
Dottle line (FWHM) Calibration Coefficients for the
Nearlest 8 Crystals are Spreaded by 5%
0.988
0.99
0.992
0.994
0.996
0.998
1
1.002
1.004
1.006
1.008
1.01
1.012
Calibration koefficient for Central Crystal in e-m shower

Fig. 4-5

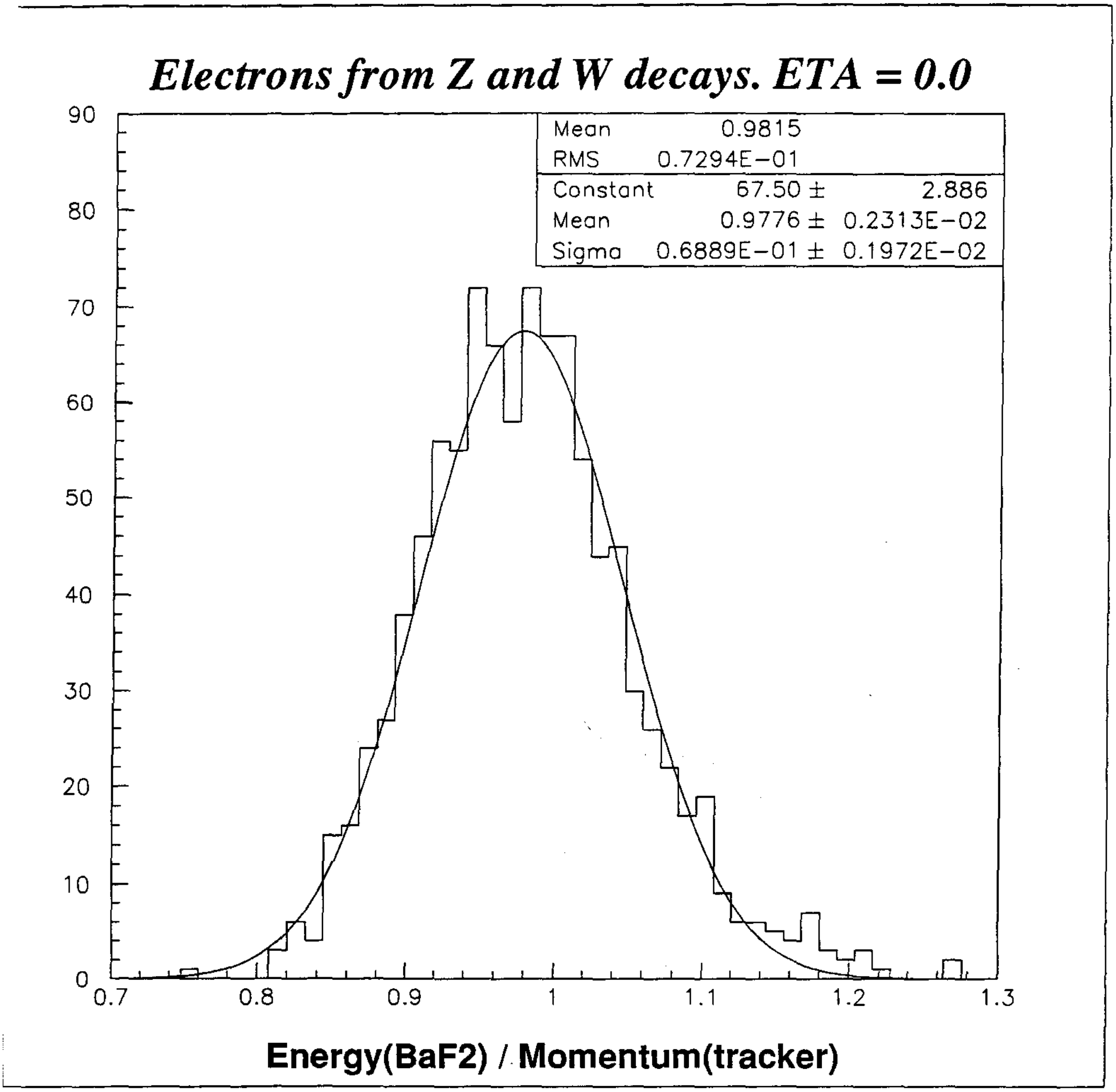
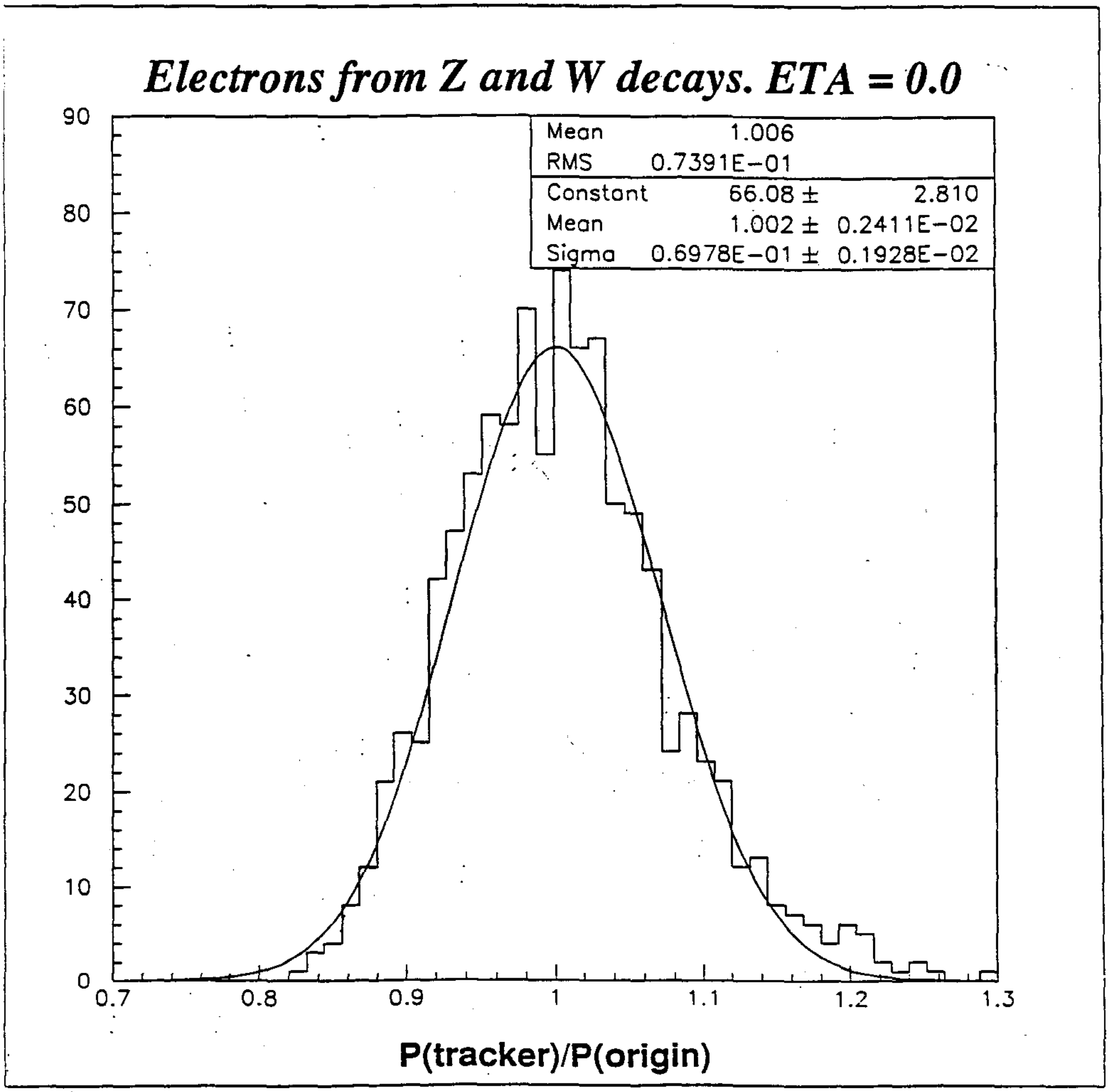

Electrons from Z and W decays. ETA = 0.0
Mean 0.9815
RMS 0.7294E-01
Constant 67.50 ± 2.886
Mean 0.9776 ± 0.2313E-02
Sigma 0.6889E-01 ± 0.1972E-02
90
80
70
60
50
40
30
20
10
0
0.7
0.8
0.9
1
1.1
1.2
1.3
Energy(BaF2) / Momentum(tracker)

Fig. 4-4



$\delta p/p = 4\% \oplus (0.15 \cdot p)\%$ GEM TN-92-76 REV. C

Fig. 4-2

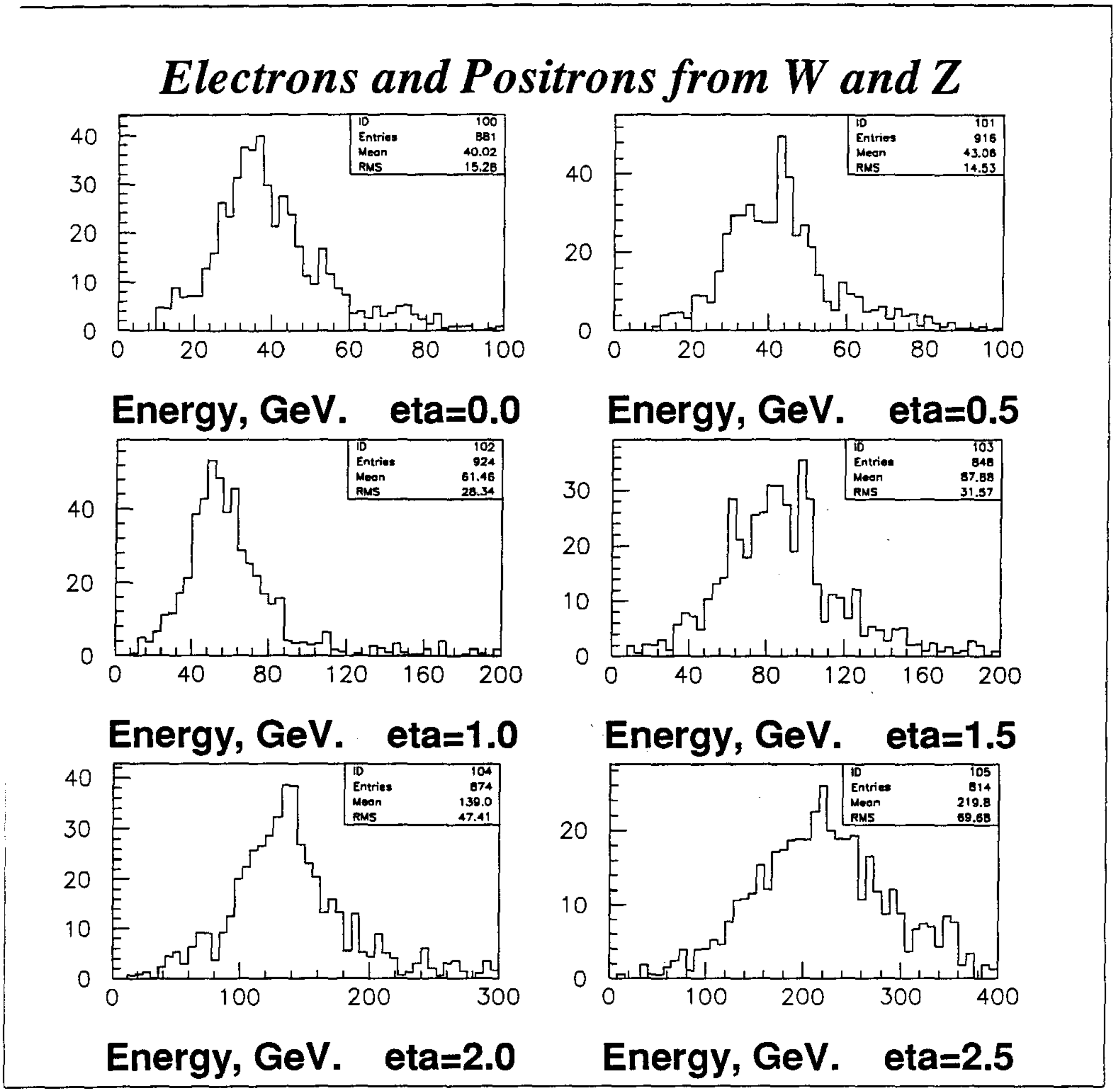
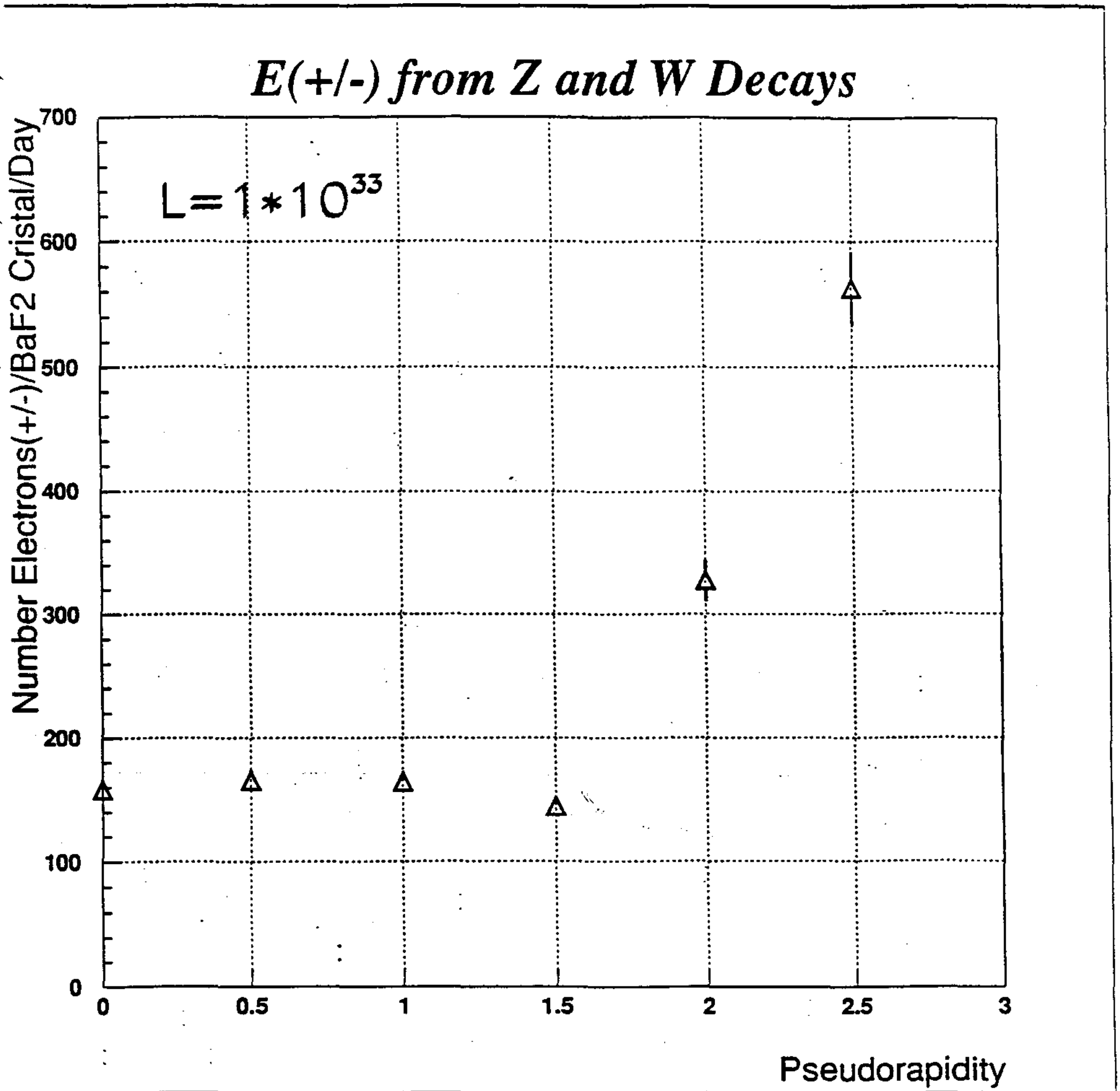

Electrons and Positrons from W and Z
ID 100
Entries 881
Mean 40.02
RMS 15.28
Energy, GeV. eta=0.0
ID 101
Entries 916
Mean 43.06
RMS 14.53
Energy, GeV. eta=0.5
ID 102
Entries 924
Mean 61.46
RMS 28.34
Energy, GeV. eta=1.0
ID 103
Entries 848
Mean 87.88
RMS 31.57
Energy, GeV. eta=1.5
ID 104
Entries 874
Mean 139.0
RMS 47.41
Energy, GeV. eta=2.0
ID 105
Entries 814
Mean 219.8
RMS 69.68
Energy, GeV. eta=2.5

Fig. 4-2



USEFULL

- Fssective running time 0.7
- Trigger / DAQ 0.85
- Electron/tracker reconstruction cuts 0.8
- Electrons without Bremstrahlung 0.7

TOTAL 0.33

Fig 7-1

So for $\eta = 0.0$ for accuracy 0.4% 15 day is O-K.

Table 1

SOURCES OF ISOLATED ELECTRONS

(Pythia 5.6 , M(top)= 150 GeV , Pt > 25 GeV)

Process	Sigma nb	N e(+/-) per sec in full solid angle	Comments
Z Production	85	5.44	
W Production	233	23.3	
t (150 GeV) Production	10	1.0	Included in W-decays
Beauty Production	500000	many	Isolation has to be proven

day. Not all the electrons can be used for calibration. Following considerations given in [1] (p.196) we can assume following reduction factors:

- Effective running time 0.7
- Trigger/DAQ 0.85
- Electron/tracker reconstruction cuts 0.8
- Useful electrons (little or no bremstrahlung) 0.7
- Product 0.33

These factors are rather conservative and will be elaborated for GEM/SSC conditions and DAQ system in the further study. If we assume that only 33 % of electrons can be used for calibration and we need 1000 events per crystal to assure the accuracy of calibration of 0.3crystals at $\eta = 0$ one will require 20 days.

Accuracy at larger η in GEM tracker is worse than at η=0 and eaverage momenta of particles are getting larger with η (Fig. 4-2). To achieve calibration accuracy of 0.3 % by this method at $\eta = 2.5$ one will need correspondingly 415 days of SSC running at luminosity 10^{33}.

At $\eta = 2.5$ where no tracker information is available this method can not be applied and BaF_2 crystals should be calibrated by another method.

REFERENCES

- [1] Expression of Interest. CMS : a compact solenoidal detector for LHC, M.Della Negra & H.Desportes Proceedings of the General Meeting on LHC Physics & Detectors, Evian-les-Bains, March 1992

#4 IN-SITU CALIBRATION WITH ISOLATED ELECTRONS
(Yu.Efremenko)

Z and W production cross sections are very big at SSC energies, so it is very attractive to use their electron decay modes for calibration of BaF2 crystal e-m calorimeter in GEM. CMS Collaboration proposed [1] to use isolated electrons from Z decays to calibrate their CeF_3 e-m detector. Electron momentum P has to be measured in the tracker and then compared with the energy E measured in e-m calorimeter - calibration constant can be found from the requirement E/P=1 for each crystal. Although the tracker momentum resolution is order of magnitude worse in GEM than in CMS, this method can be applied to GEM tracker-e-m calorimeter too.

Since Z^o mass constraint is not used in this method, any single isolated electrons can be used for calibaration purpose. Table 1 give cross sections for high Pt electrons from different sources as simulated in Pythia 5.6. The largest source is electrons from beauty decays but separate simulations are necessary to understand with what efficiency these electron can be isolated at the level necessary for calibration. In present simulations we are using only W and Z decays as sorce of isolated electrons. Figure 4-1 shows the number of electrons in one BaF_2 crystal per day at luminosity 10^{33} as function of pseudorapidity. Figure 4-2 shows spectra of electrons at different values of pseudorapidity. Figure 4-3 shows the momentum resolution (parametrization for the momentum resolution in the tracker is taken from GEM TN-92-76 REV C) for electrons from W and Z decay at $\eta = 0.$ averaged over the spectrum of electrons shown in Fig. 4-2. Average accuracy of momentum reconstruction from the tracker for choosen types of events at $\eta = 0.$ is 7 %. E/P distribution for these events at η=0 is shown in Figure 4-4. The mean value of the distribution is below 1 because of the rear leakages in e-m calorimeter. Figure 4-5 shows how the ratio E/P changes with variation of calibration coefficient in the central crystal (with maximum deposition of shower energy). Error bars represent the accuracy of E/P determination by fitting E/P distribution with given statistics (1000 events per crystal in this Figure) with Gaussian curve. Two dotted curves represent variations of this dependence (rms level) if nearest 8 crystals in the matrix 3x3 has randomly distributed gains within $\pm$ 5% (electron impact point covers total front area of the central crystal). We can envisage that some itterative procedure will be required to find calibration coefficients for all crystals in the calorimeter. Point in Figure 4-6 represent the accuracy of calibration coefficient reconstruction for central cristal vs numbers of electrons hitting this crystal. Accuracy of 0.3 % can be achieved with 1000 isolated electrons per crystal.

As it is seen from Figure 4-1 at $\eta = 0$ each crystal will receive about 150 electrons per

Punch Through Calibration MBE

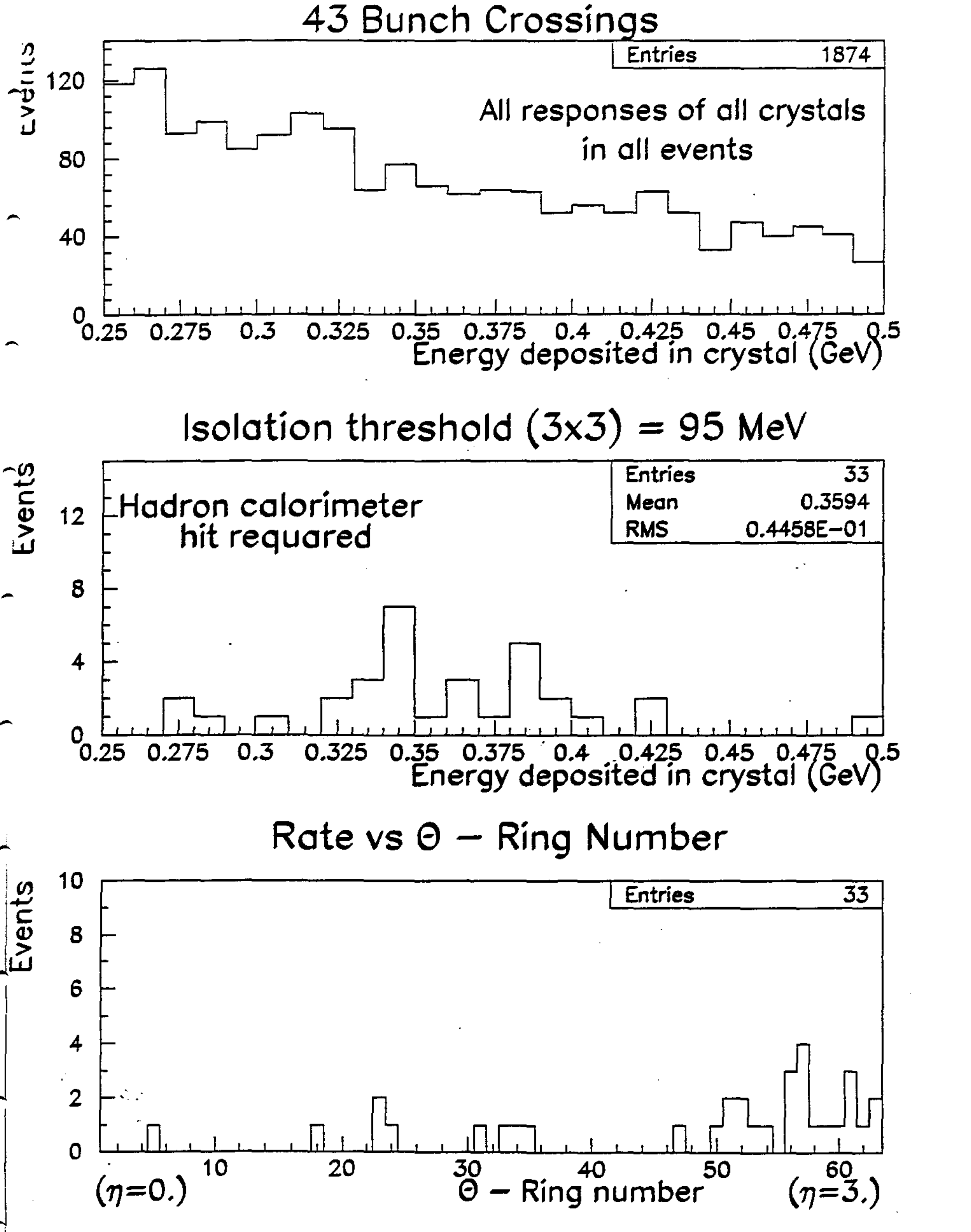


Table 1.

Accuracy of BaF2 calibration with MIPs from MBE

(Results of Gaussian fit [.25,.5] GeV interval)

Statistics events	fit	14%/srqt(N) dependence
200	1.05 %	0.99%
500	0.63 %	0.63%
700	0.52 %	0.53%
1000	0.44 %	0.44%

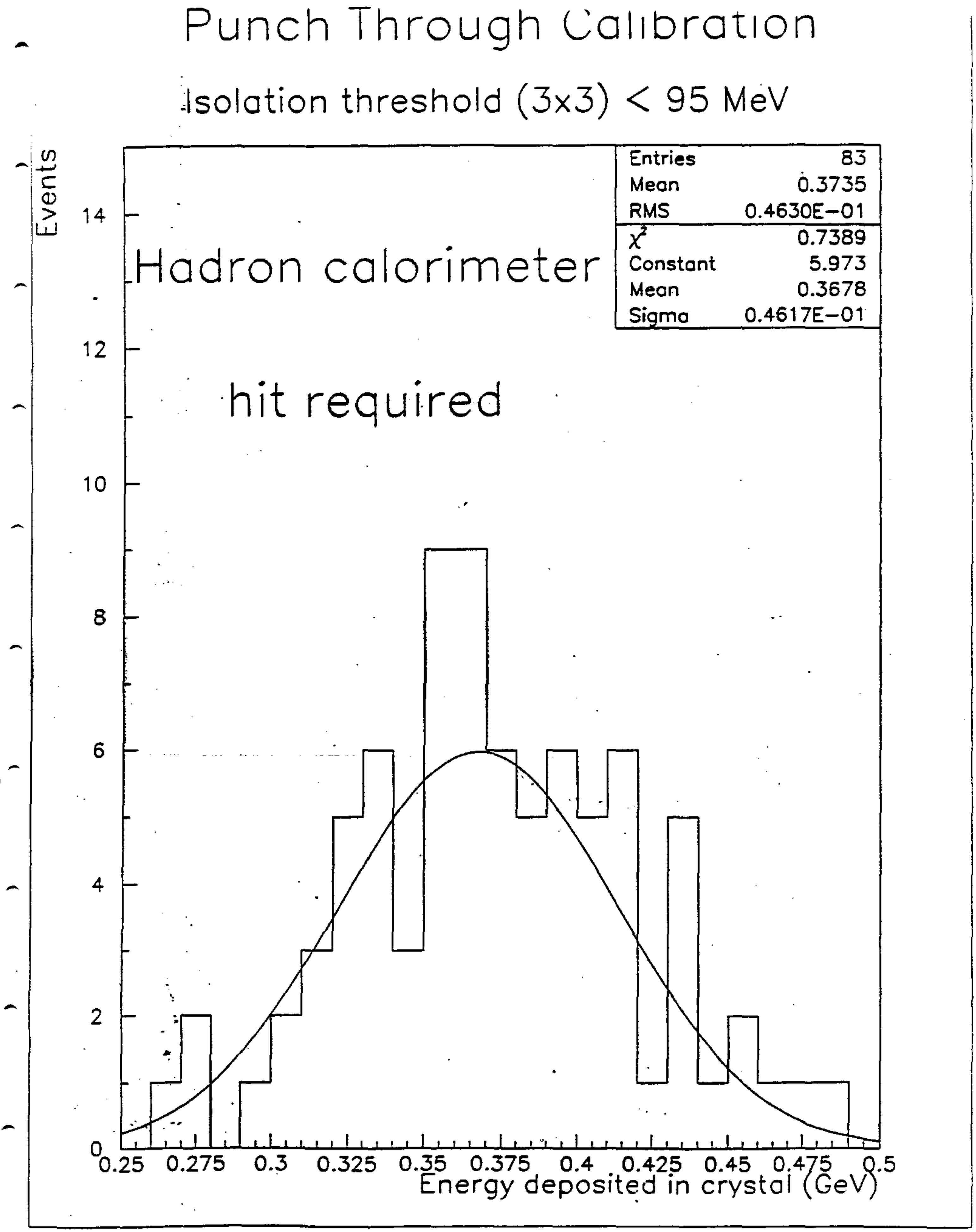
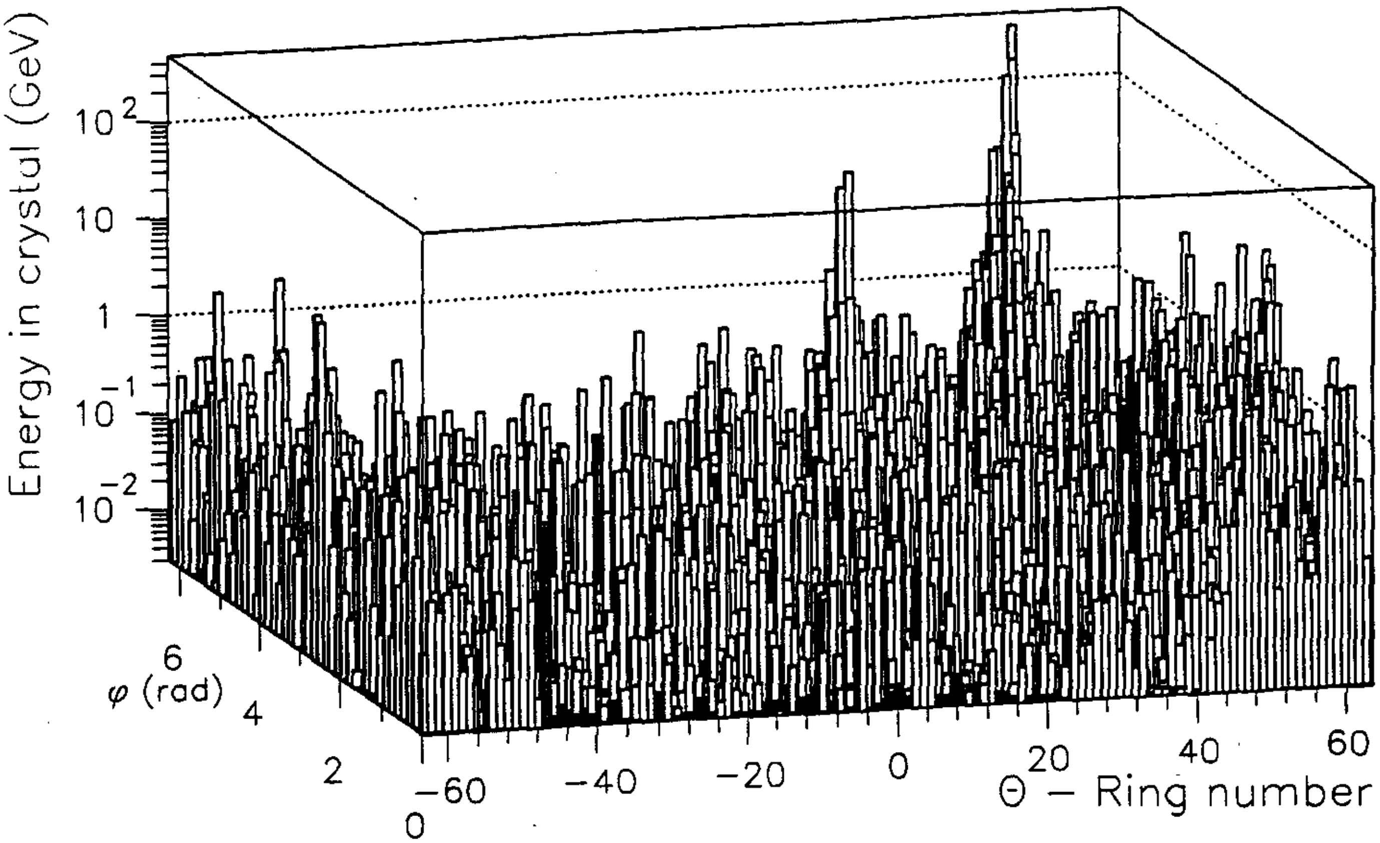

Punch Through Calibration
Isolation threshold (3x3) < 95 MeV
Events
Entries 83
Mean 0.3735
RMS 0.4630E-01
χ² 0.7389
Constant 5.973
Mean 0.3678
Sigma 0.4617E-01
Hadron calorimeter
hit required
0
2
4
6
8
10
12
14
0.25
0.275
0.3
0.325
0.35
0.375
0.4
0.425
0.45
0.475
0.5
Energy deposited in crystal (GeV)

Fig. 3-3

High Pt Event at L=10**33/cm/sec



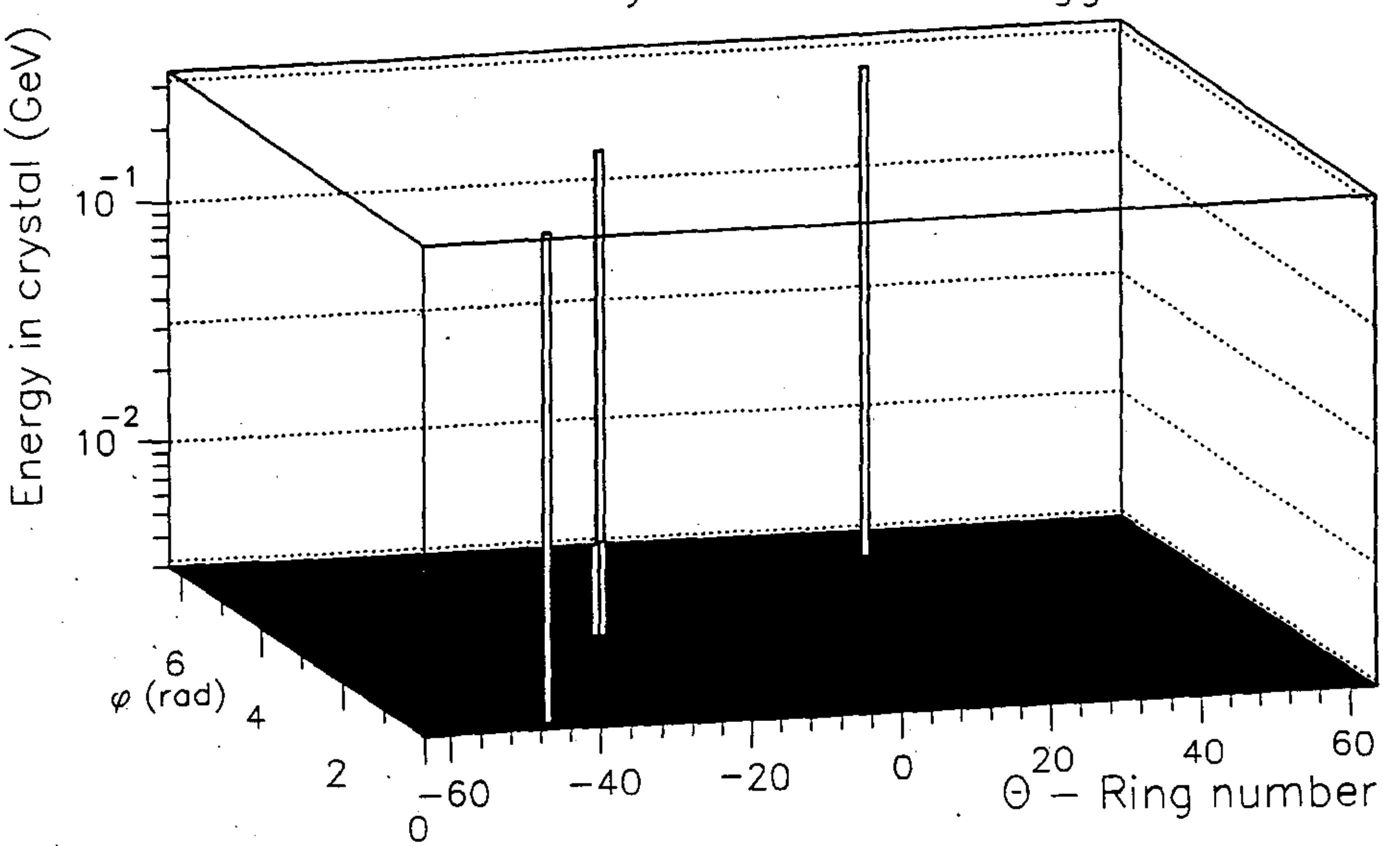


Fig 3-2

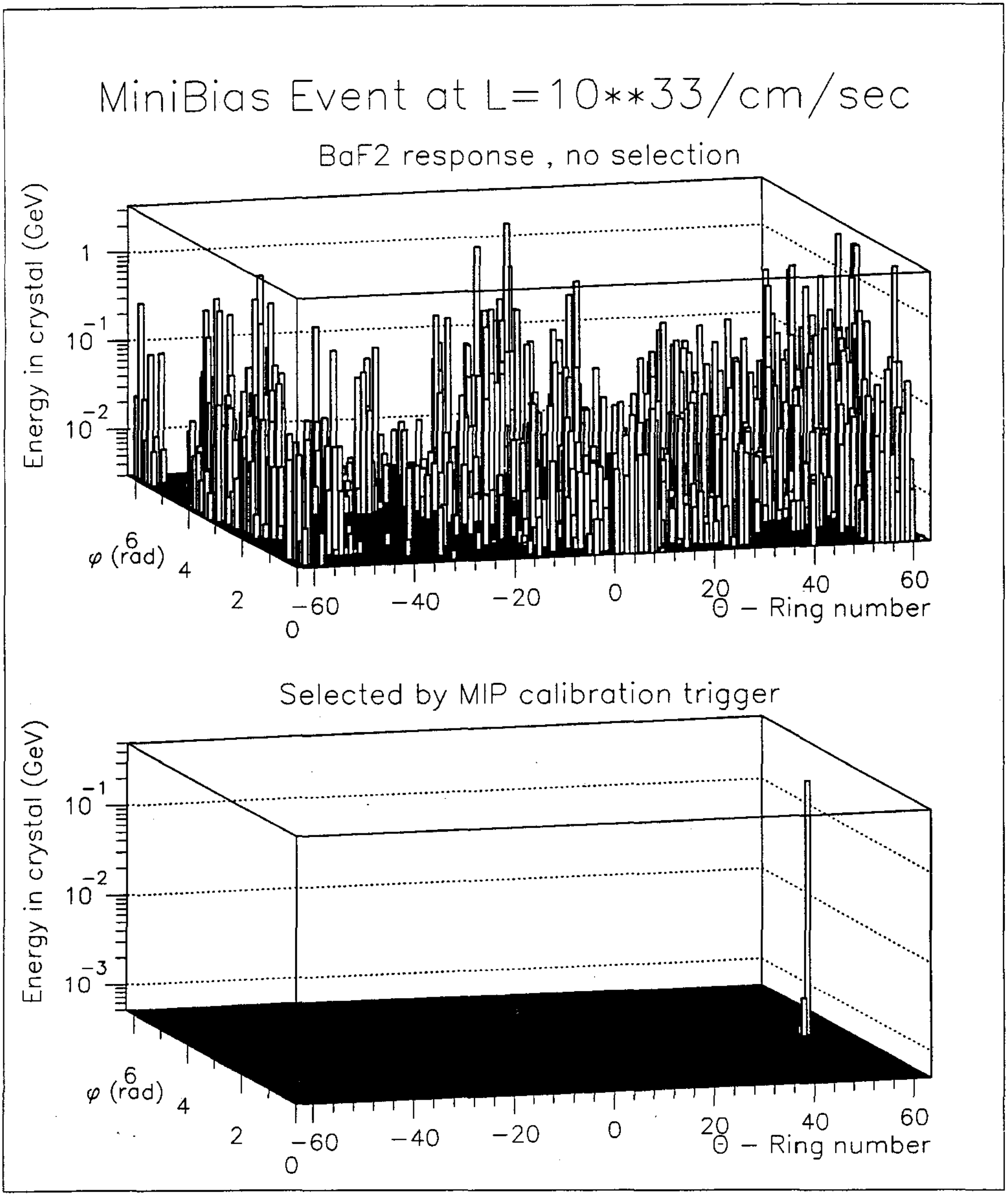

MiniBias Event at L=10**33/cm/sec
BaF2 response , no selection
Energy in crystal (GeV)
1
10^-1
10^-2
φ (rad)
6
4
2
0
-60
-40
-20
0
20
40
60
Θ – Ring number
Selected by MIP calibration trigger
Energy in crystal (GeV)
10^-1
10^-2
10^-3
φ (rad)
6
4
2
0
-60
-40
-20
0
20
40
60
Θ – Ring number

Fig. 3-1

4) Look at the MIP calibration trigger with 5x5 and 7x7 matrices.

REFERENCES

- [1] "Monte Carlo simulation of minimum bias events at the LHC energy", G.Ciapetti, A.Di Ciaccio, Large Hadron Collider Workshop, Proceedings Vol. II, CERN 90-10, ECFA 90-133, p.155
- [2] GEM Baseline 1, GEM TN-92-76 REV C, July 9, 1992

- [1.] Amplitude in single crystal in the range 0.25 - 0.50 GeV;
- [2.] Sum of 8 cristals surrounding one with MIP-hit in the matrix 3x3 less that threshold value (95 MeV threshold typically used);
- [3.] Max. amplitude in any of 8 crystals surrounding one with MIP-hit less than threshold value (70 MeV threshold typically used);
- [4.] Hit in hadronic module behind the corresponding crystal.

Example of MBE as it is seen by BaF_2 matrix is shown in Figure 3-1 on $\theta - \phi$ LEGO plot in logarithmic scale. Lower plot shows MIP in the end-cap E-M calorimeter selected with above criteria. Figure 3-2 shows LEGO plot with example of high P_t trigger event. Lower plot shows three MIPs which satisfy selection creteria. Figure 3-3 shows integrated MIP response of one crystal in the window 0.25-0.50 GeV obtained with high E_t trigger events with selection criteria listed above. The distribution in Figure 3-3 is well described by Gaussian with $\sigma \approx$ 12-14 %.

Selection creteria described above are very tough. These criteria will select hadrons wich traverse only one crystal, which have rather large E_t and which do not shower in the crystal.

To determine statistics required for 0.5 % calibration accuracy level clean muons from Z^0, W and b-quark decays were generated with Pythia 5.6 and GEANT 3.15 at higher statistics level (faster simulation than for complete events). Results of Gaussian fit in the interval 0.25-0.50 GeV are shown in Table 1. Taking into account that punchthrough spectrum looks like muons, but has softer tail, RMS value of 12 % shown in figure 3-3 looks reasonable.

To calibrate crystal with precision of 0.5 % approximately 1000 MIPs per crystal will be required. With total amount of crystals 16,000 one will need 16-20 millions of MIPS. With dedicated 100 HZ trigger required time for 0.5 % accuracy of calibration is $\sim$ 50 hours.

PLANS

1) Increase statistics of MBE and high P_t events ;

2) With high event statistics look at the η - disribution of selected MIPs and study peak position vs η and required calibration time vs η.

3) Optimize selection thresholds;

#3 IN-SITU CALIBRATION WITH MIP (A.Savin)

Major source of minimum ionizing signals in BaF2 is punchthrough pions. Since 50 cm of BaF_2 represents 1.7 λ_{inter} the probability of non-interaction for pion is $\sim$ 18 %. Energy loss per MIP is $\sim$ 350 MeV in 50 cm BaF_2.

Though such small signals doesn't provide absolute energy scale calibration (it can be done with $Z^0 \rightarrow e^+e^-$ for example) they will be extremly usefull for crystal to crystal calibration.

Disadvantage of MIP calibration is that in the existing readout scheme MIP signal will correspond to 10 ADC counts only. We assume that to employ the scheme of MIP calibration the electronics with wider dynamic range (or bi-linear response) should be used.

To look at MIP signals the MBE and moderately high E_t events are simulated with Pythia 5.6. All possible decay channels are left open. Low P_t cut of 1.9 GeV as suggested in [1] for MBE is used. Number of interactions per crossing is taken equal to 1.6 (distributed by Poisson). Z-coordinate of vertex is spreaded with Gaussian of 4.0 cm. No tracker information is used in event analysis.

Simple BaF_2 crystal calorimeter geometry [2] is simulated in GEANT 3.15. Magnetic field of 0.8 T is applied in the whole calorimeter volume. Particles (pions, photons, electrons, muons etc.) are transported through the tracker and e-m BaF_2 calorimeter; for MIP particles accurate geometry of the crystals, dE/dx, bremstrahlung and δ-electrons are simulated. No transport through hadron calorimeter is performed. Energy of each hit at the entrance of hadron calorimeter with corresponding lateral segmentation is recorded.

To select MIPs in the BaF_2 crystal one can try to use MBE events which will be routinely recorded for each physics trigger. Every SSC physics trigger event at luminosity 10^{33} will have on average 1.6 MBE pileuped event, so that selection of MIPs can be made during off-line analysis of physics data.

One can also think about dedicated "MIP calibration trigger" with the rate 100 to 1000 HZ. It should include requirement of moderately high E_t (matching the readout rate capabilities) and isolation selections in BaF_2 matrix (the latter to reduce the transfered data stream).

Following selection creteria can be used to isolate MIP-hits in BaF_2.

Uniformity Required
for BaF_2 crystals in GEM

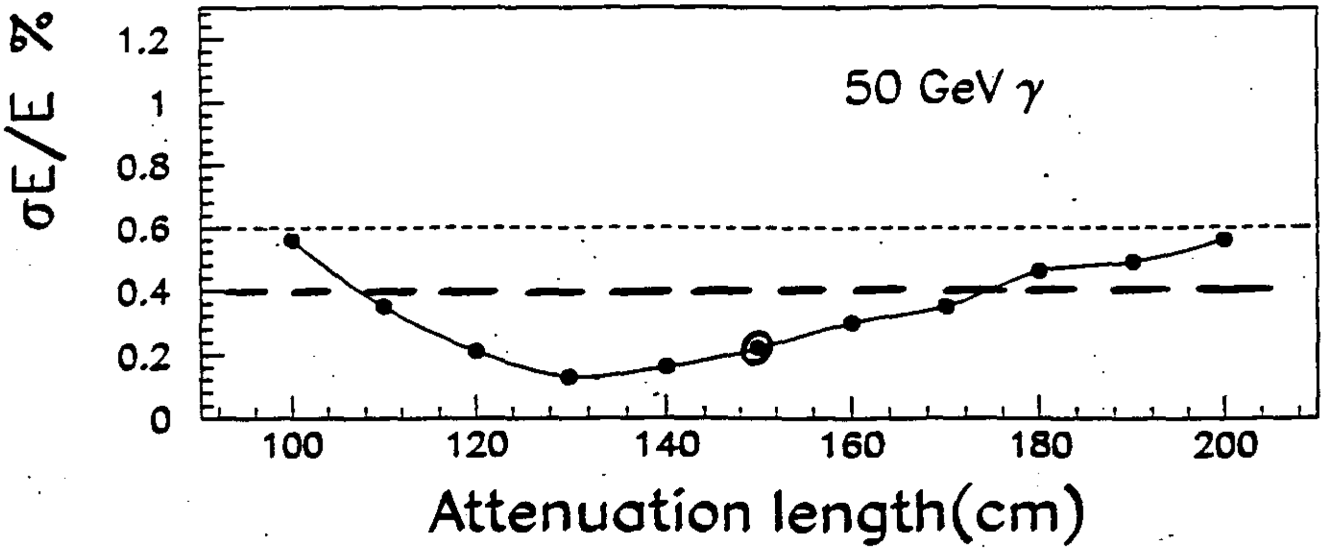
- Global non-uniformities common for all crystals or rather large group of crystals can be handled by production technology control and by precision coating

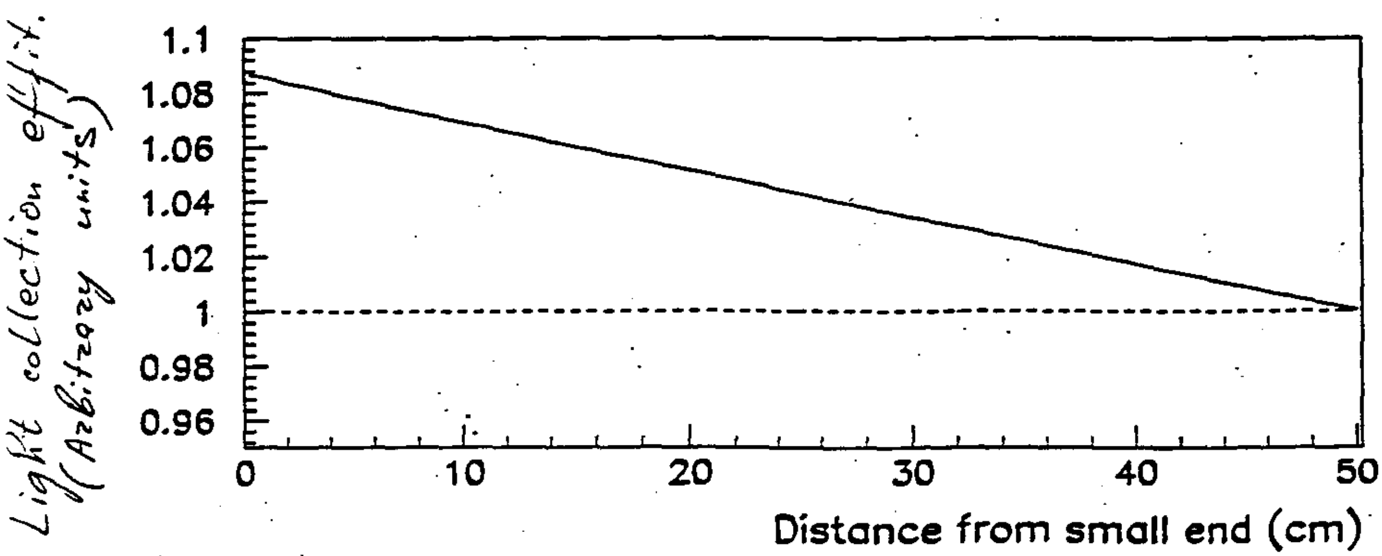
- Local non-uniformities involving individual crystals (like local impurities, glue joints etc.) should be detected by longitudinal scan of pre-irradiated crystals and rejected prior to installation.

- Local non-uniformity < 5%
- L_{att} after pre-irradiation $\geq$ 60 cm ("absorb." coating)
  L_{att} — " — $\geq$ 80 cm (MgF_2 + Al)

Annealing of all crystals

SCENARIO — all crystals were preradiated to λ=150cm and were uniform with λ=150cm



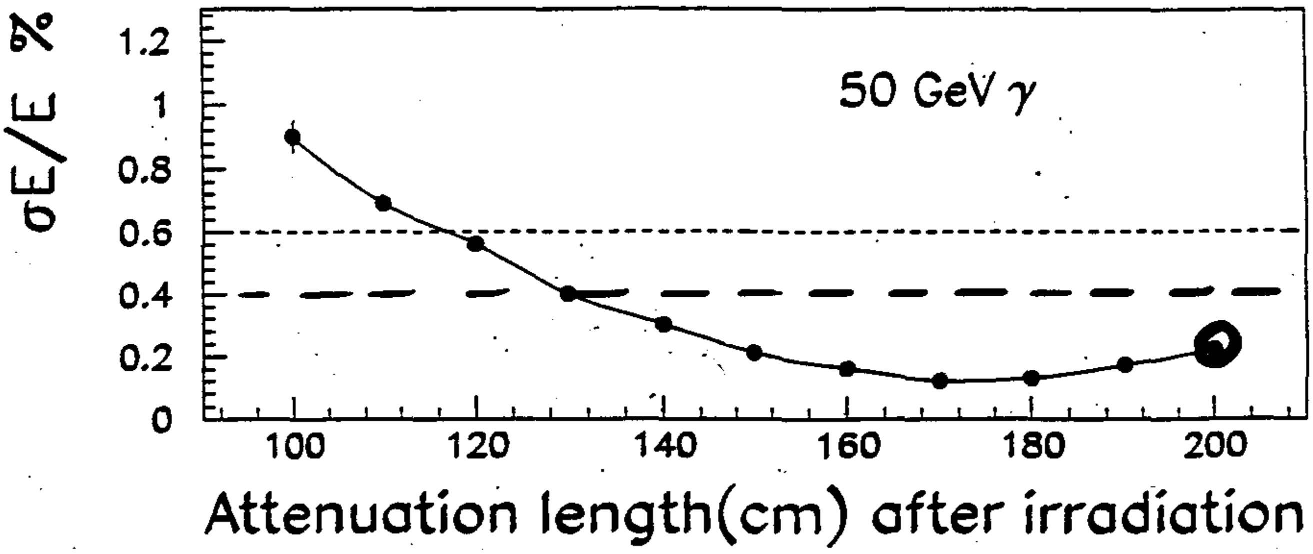


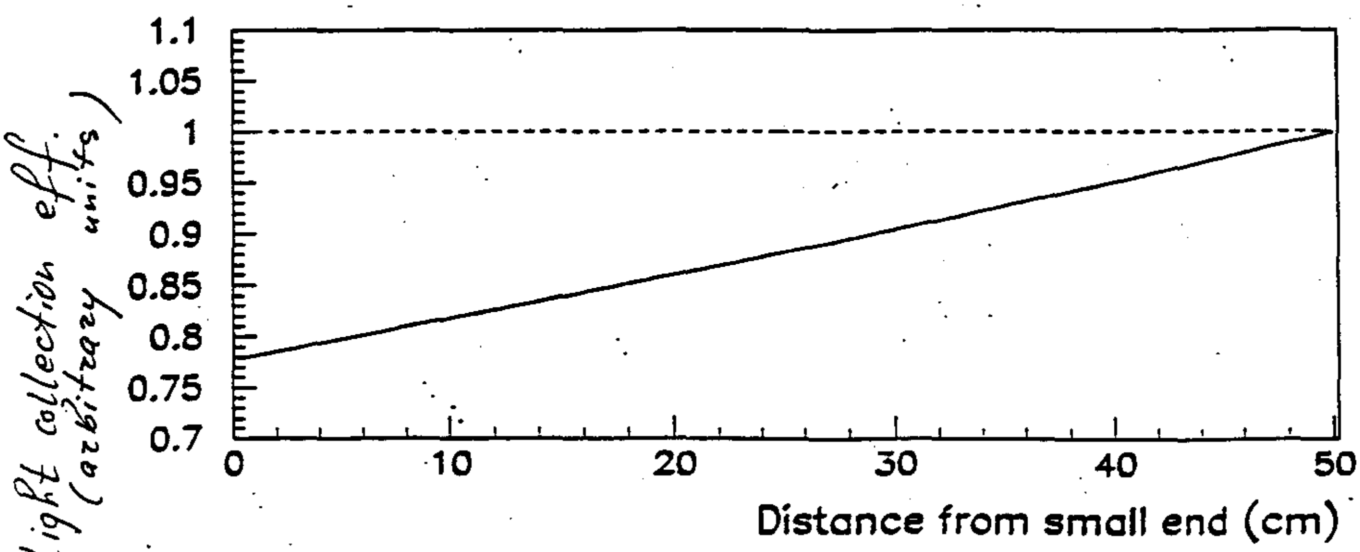
Nonuniformity for λ=200cm (after full recovering)

Fig 2-4

Radiation damage of all crystals

SCENARIO — all crystals were NOT preradiated and were uniform with λ=200cm





Nonuniformity for λ=100cm (at saturation)

Fig. 2-3

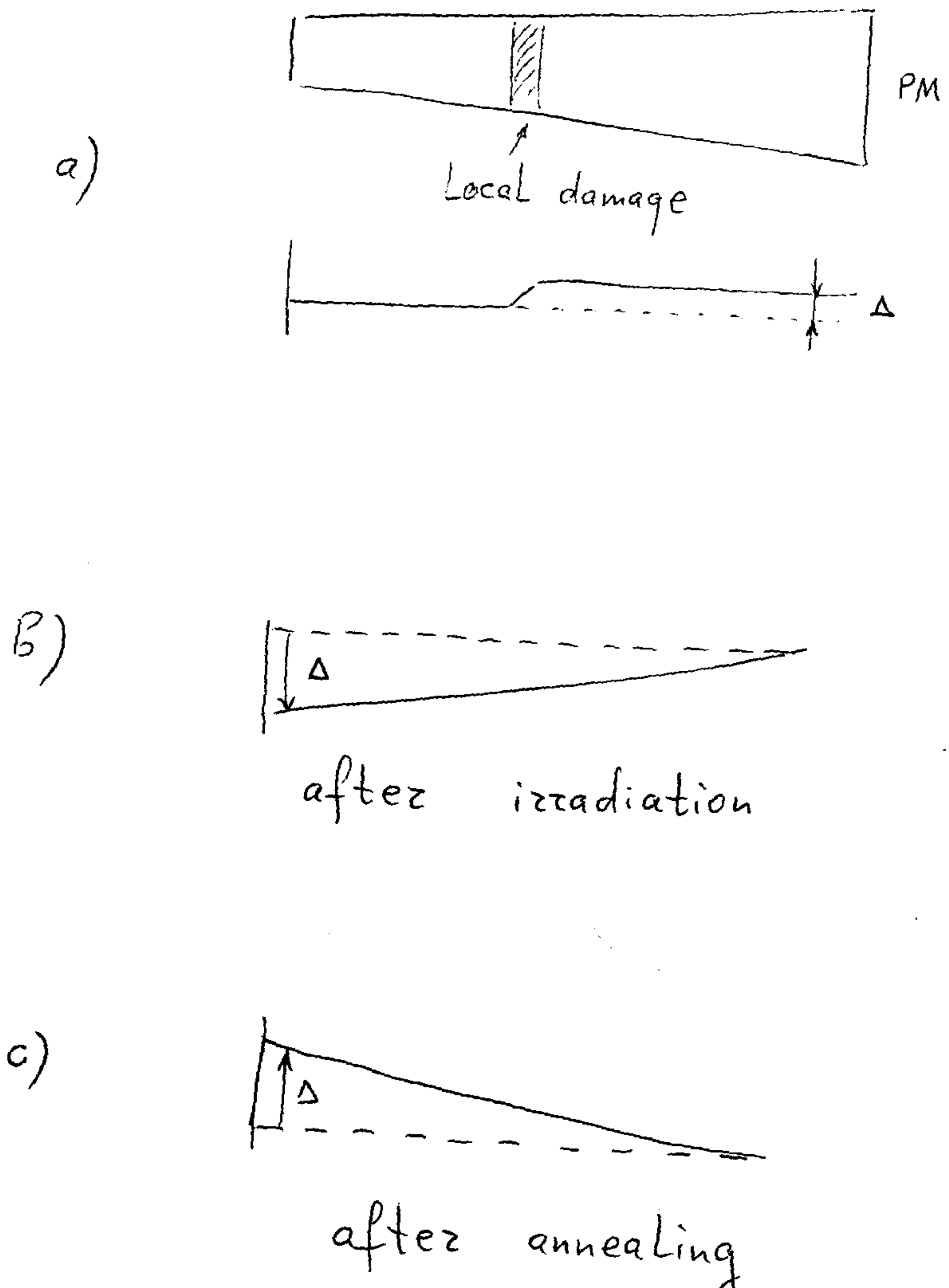
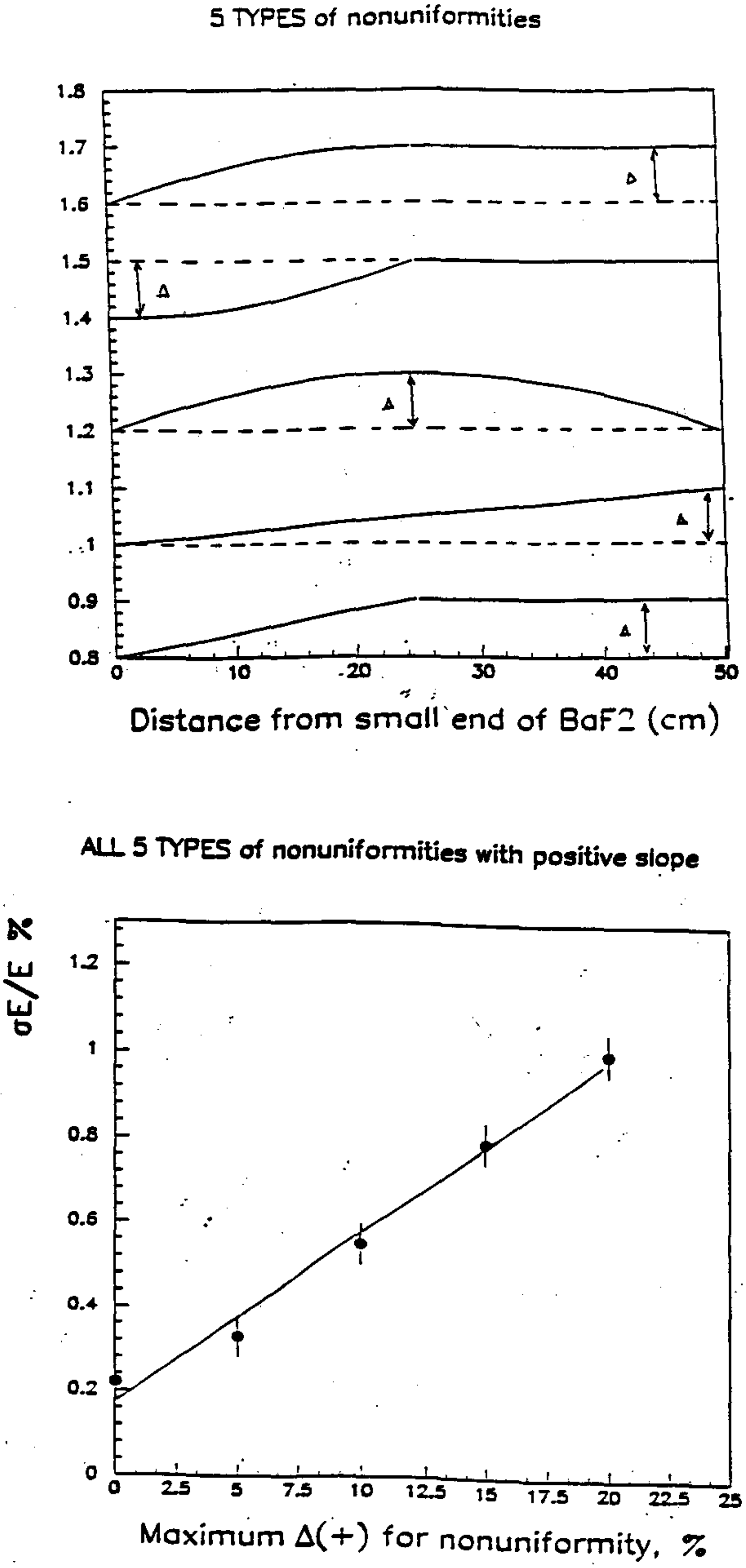


Fig. 2-2



GEANT3.16

5×5 BaF_2 crystals

Fig. 2-1

Required L_{att}

(continued)

- Crystal coating is being developed by LLNL. Several techniques are proposed which allow to control coating properties (still need more tests and demonstrations with real 50 cm long crystals and more supporting simulations with light transport Monte-Carlo)

- So far it was shown (only by MC simulations) that for coatings with constant but variable reflectance required uniformity (peak-to-peak < 3%) can be achieved

- For all polished crystals minimal L(att) = 53 cm. For larger L(att) absorbing coating with controlled density will be required

- For composite MgF2 / Al coating minimal L(att) = 78 cm

- In specifications (January 92)
  L(att) > 95 cm for irradiated crystals
  L(att) > 190 cm for fresh crystals

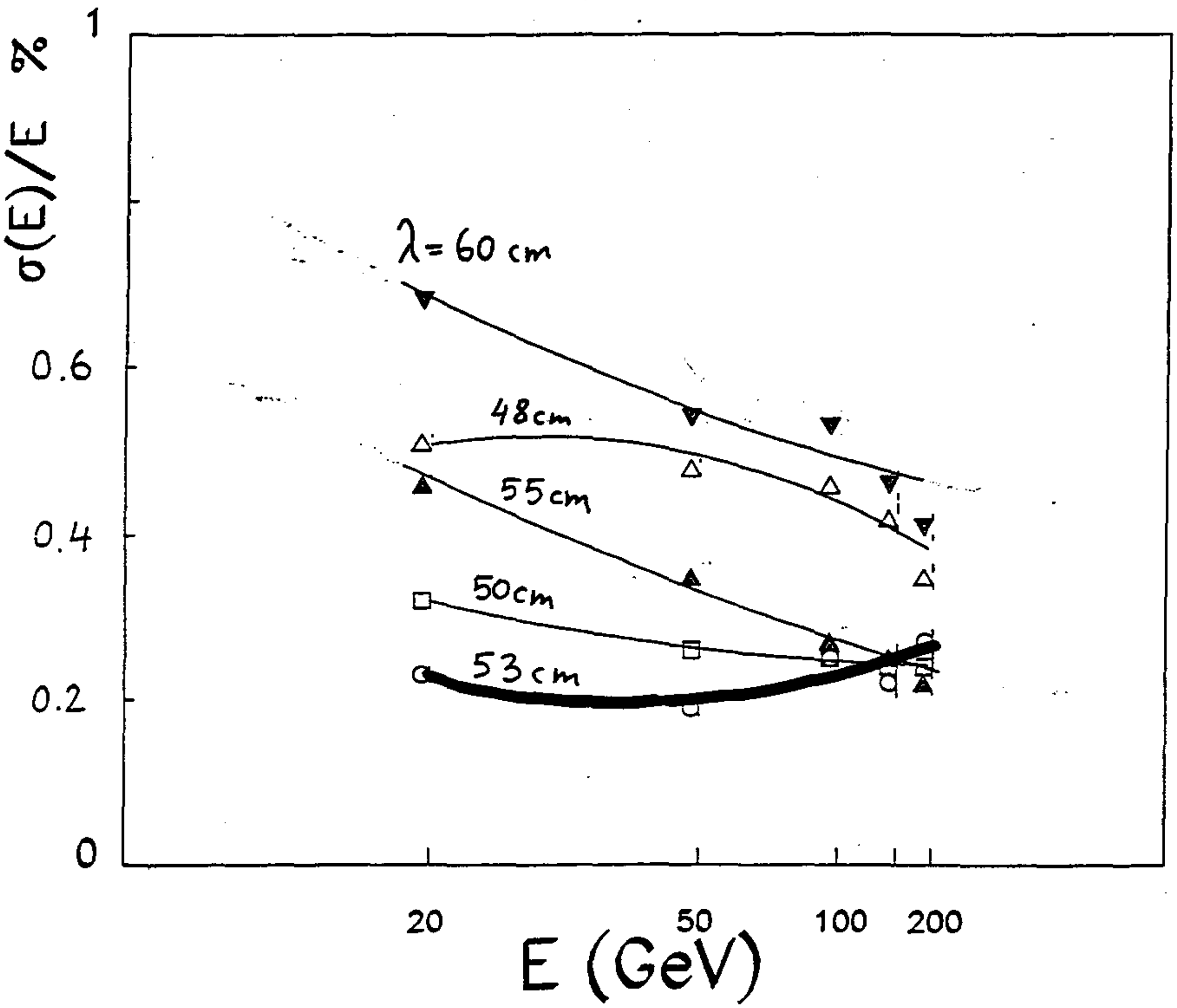
- Achieved so far :
  L(att) > ~~35~~ cm 40 cm

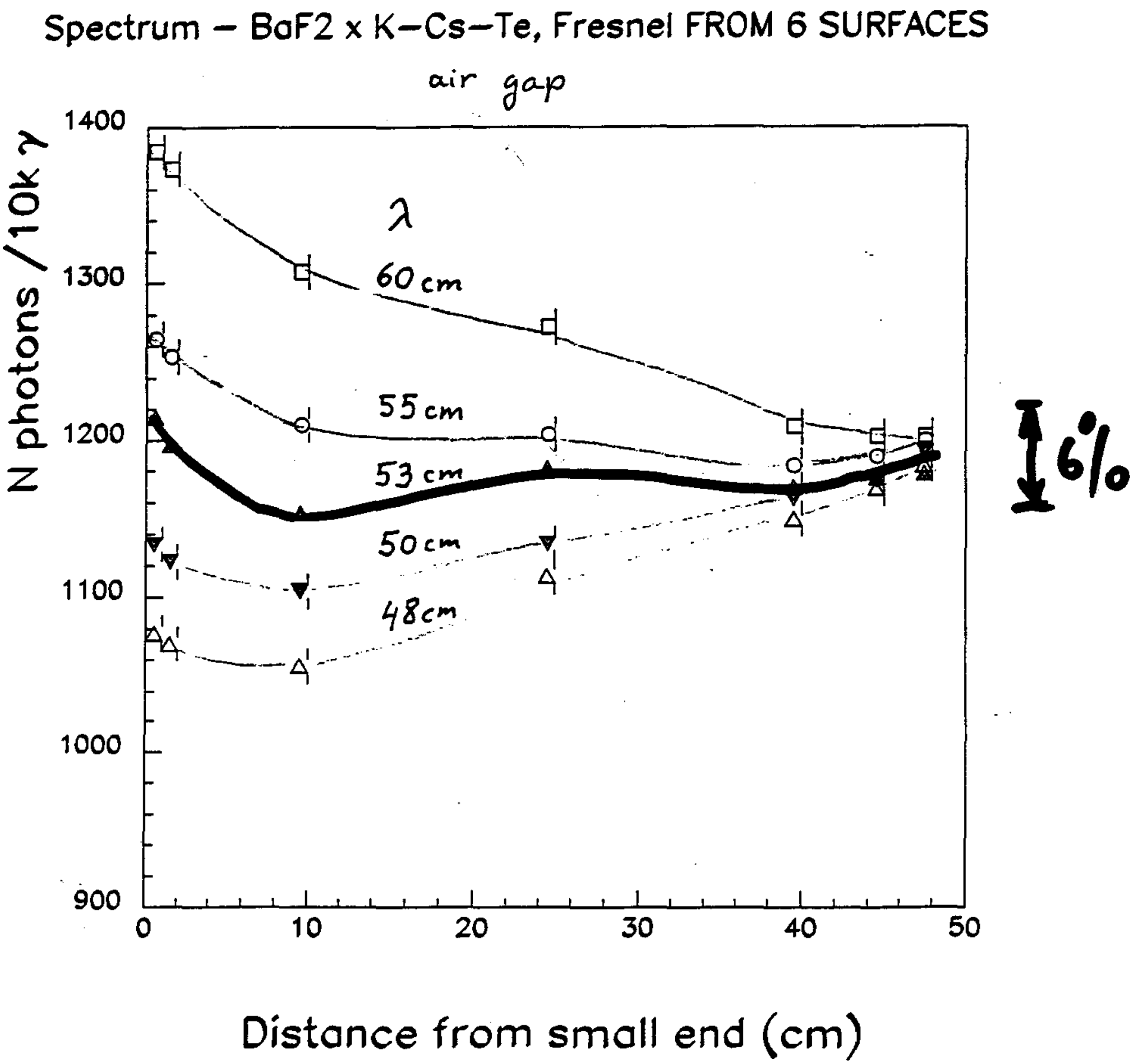
Required L_{att}

- Since the focusing effect and light absorption compete in the tapered crystals there is a minimal light attenuation length exist which can be compensated by focusing effect (plus crystal coating)
- For any light attenuation length larger than minimal the corresponding coating can be applied such that crystal response will be uniform
- If the light attenuation length would be the same for all crystals (minimal spread from crystal to crystal) and coating properties would be perfectly reproducible it would be the simplest way to obtain uniform crystal response
- If light attenuation length is different from crystal to crystal the coating that match this particular attenuation length should be applied in a controlled way to obtain required uniformity
- It needs to be demonstrated that crystals in mass production have uniform properties (attenuation length) and/or that coating is controlable to the accuracy that will allow to compensate variations of light attenuation length

GAMMA RESOLUTION — GEANT3

BaF2 (25 X0)





Spectrum – BaF2 x K–Cs–Te, Fresnel FROM 6 SURFACES
air gap
N photons /10k γ
1400
1300
1200
1100
1000
900
λ
60 cm
55 cm
53 cm
50 cm
48cm
6%
0
10
20
30
40
50
Distance from small end (cm)

might change their global transmittance but change might have different magnitude because of variation of individual properties of the crystals. In fig 2-2c the typical shape of such nonuniformity is shown. This type of damage might occur to all crystals in calorimeter.

One can study how effect mentioned above might affect the measured H^0 width. Simulations of $H^0 \rightarrow 2\gamma$ are being done with PYTHIA5.6, and γ-s induced showers with GEANT3.15. Nonuniformity in the BaF_2 crystals is picked up with random magnitude with the type choosen according to damage scenario. Calibration of all crystals by RFQ, MIP and electrons from Z^0 and W decays is assumed in this simulations. RFQ will produce calibration signal in the first few centimeters of crystal and corresponding scintillating light will travel through the crystal to photodetector, though MIP,Z^0 and W-calibrations will produce calibration signal distributed over the whole crystal. These different types of calibrations might be complementary.

With monoenergetic γ-s the effects of radiation damage (damage type (b)) and annealing of crystals (damage type (c)) are illustrated in Fig.2-3 and Fig.2-4 correspondingly. It was assumed that radiation damage (or annealing) occured to all crystals with the same magnitude of light attenuation length change. No RFQ calibration was assumed.

We plan to complete these studies by the end of August.

#2 LOCAL NON-UNIFORMITY (K.Shmakov)

In the previous simulations of the light collection for BaF_2 crystals it was shown that uniform responce $\delta \leq 5.$ % can be achieved for crystals with the absorbtion length $\geq$ 95 cm (BaF_2 specification) by appropriate coating. We assume that after production, coating and irradiation all crystals should meet these uniformity specifications. The type of nonuniformities (not only the absolute value) should also be checked. In our simulations (Fig.2-1) we have randomly picked up 5 different types of nonuniformities and their magnitudes for the matrix of 5x5 BaF_2 crystals. The resolution for 100 GeV monoenergetic γ demonstrates that 5 % maximum Δ uniformity will keep the total resolution below 0.4 %. Note that due to leakages even for perfectly uniform crystals the energy resolution (GEANT3 simulations) can be as good as 0.3 % for 100 GeV γ.

Following types of radiation damages are presently under study by us. Some first simple simulated examples how these types of radiation damage can affect the resolution are presented below.

- (a) **Local damage in individual crystal**

  Transition (attenuation length) of small zone inside one crystal can change. This effect might occur due to impurity layer inside the crystal - local light attenuation length will be modified though light output in this zone will be not affected. This type of damage occur to individual crystals which are randomly scattered in crystal matrix. In fig 2-2a typical shape of longitudinal nonuniformity for this case is shown.

- (b) **Common radiation damage**

  If common radiation damage occur which results in the change of transmittance for all crystals, magnitude of this change might vary from crystal to crystal. This type of damage might be similar for groups of crystals at similar θ. On fig 2-2b typical shape of such nonuniformity is shown.

- (c) **Annealing**

  Anealing might take place because of the long time between BaF_2 calorimeter installation and first data taking (3-4 years). All crystals which were pre-irradiated

Uniformity for λ_{att}=70 cm and different reflection from front facet (for side facets F=0.98) Polished crystal, no coating

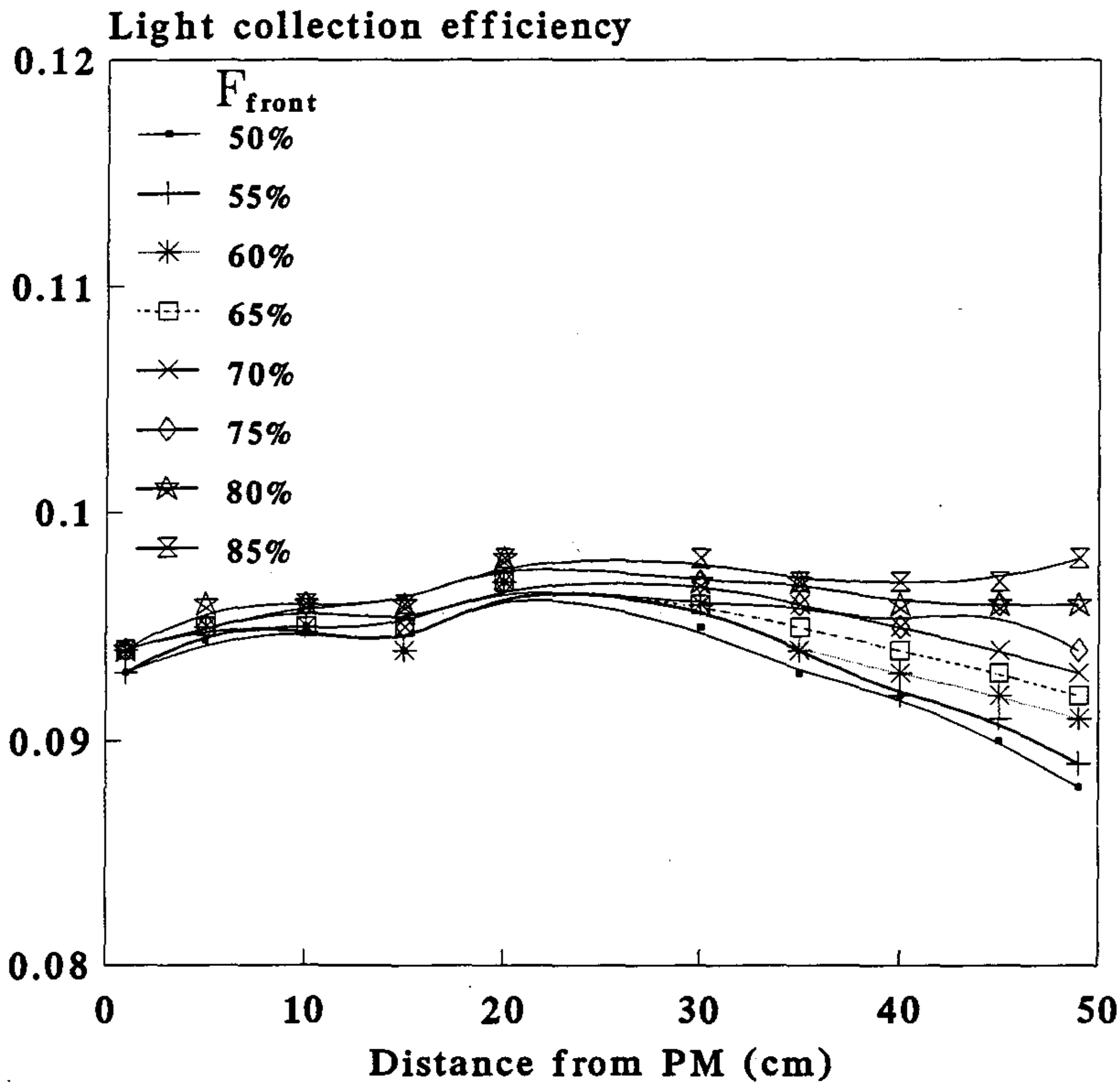


Fig 1-12

Uniformity for different λ_{att} and black spotted polished facets

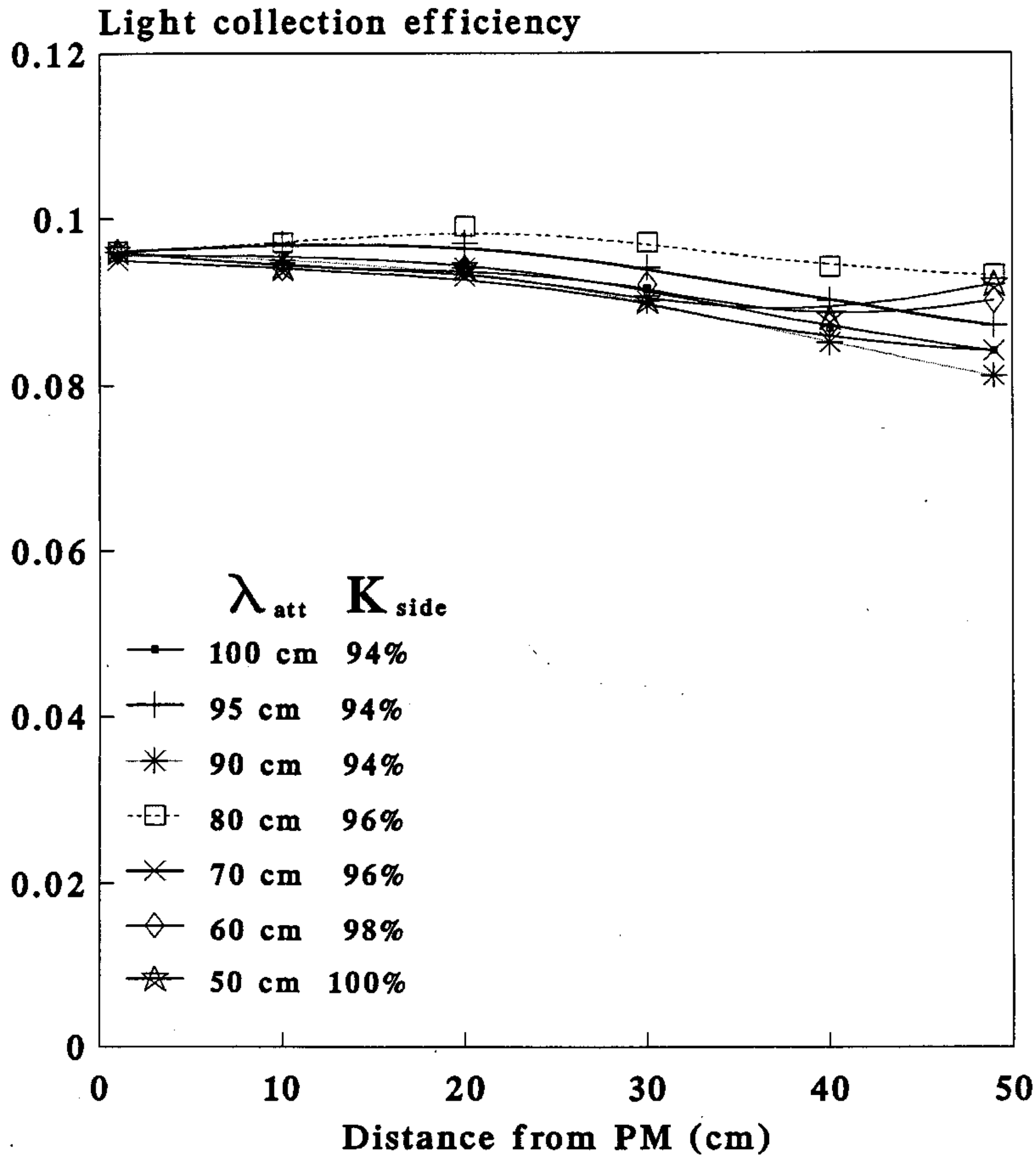


Fig 1-11

Uniformity for $\lambda_{att} = \infty$ and blackened polished facets

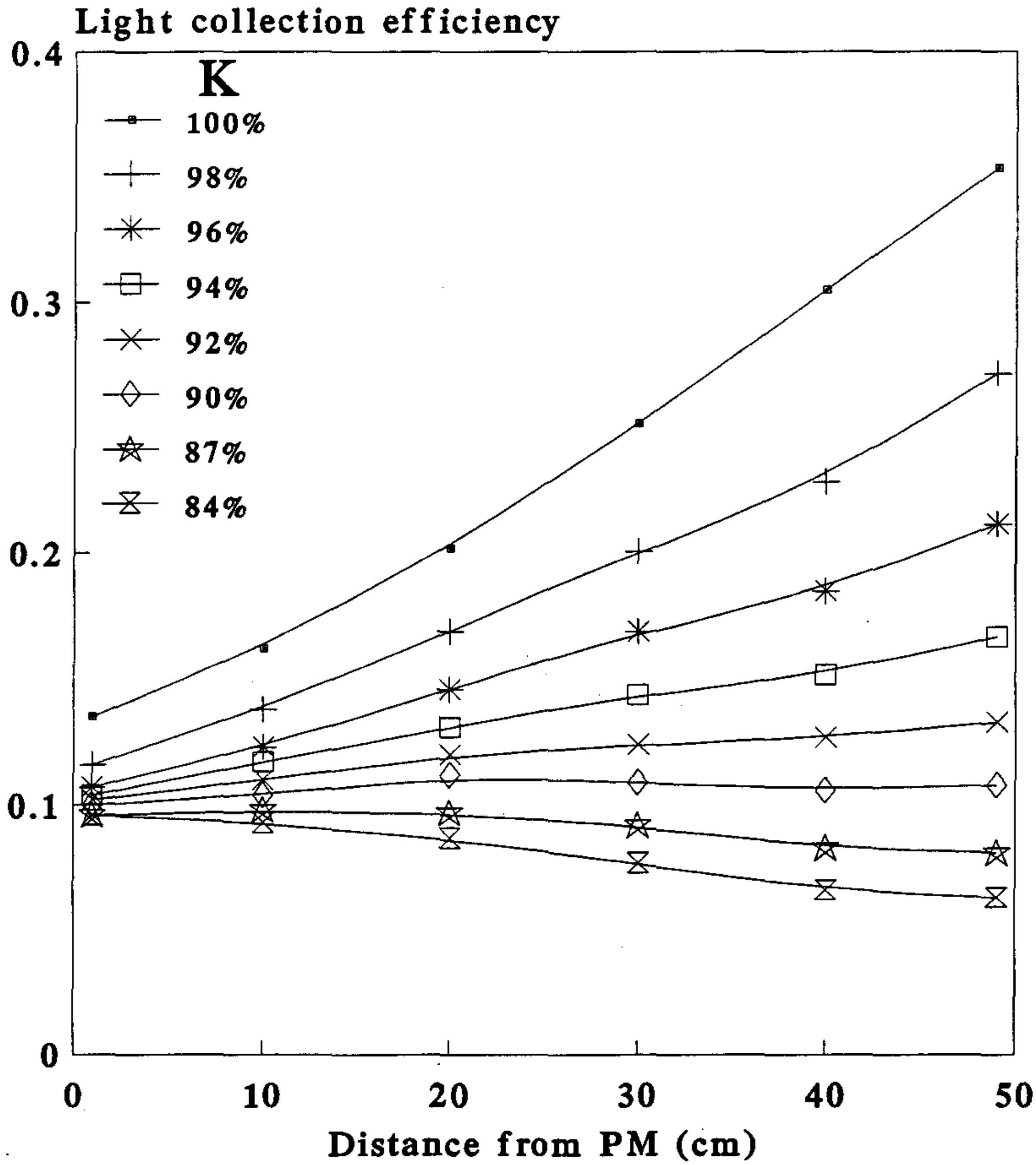


Fig 1-10

Uniformity for different λ_{att}
Polished facets, no coating

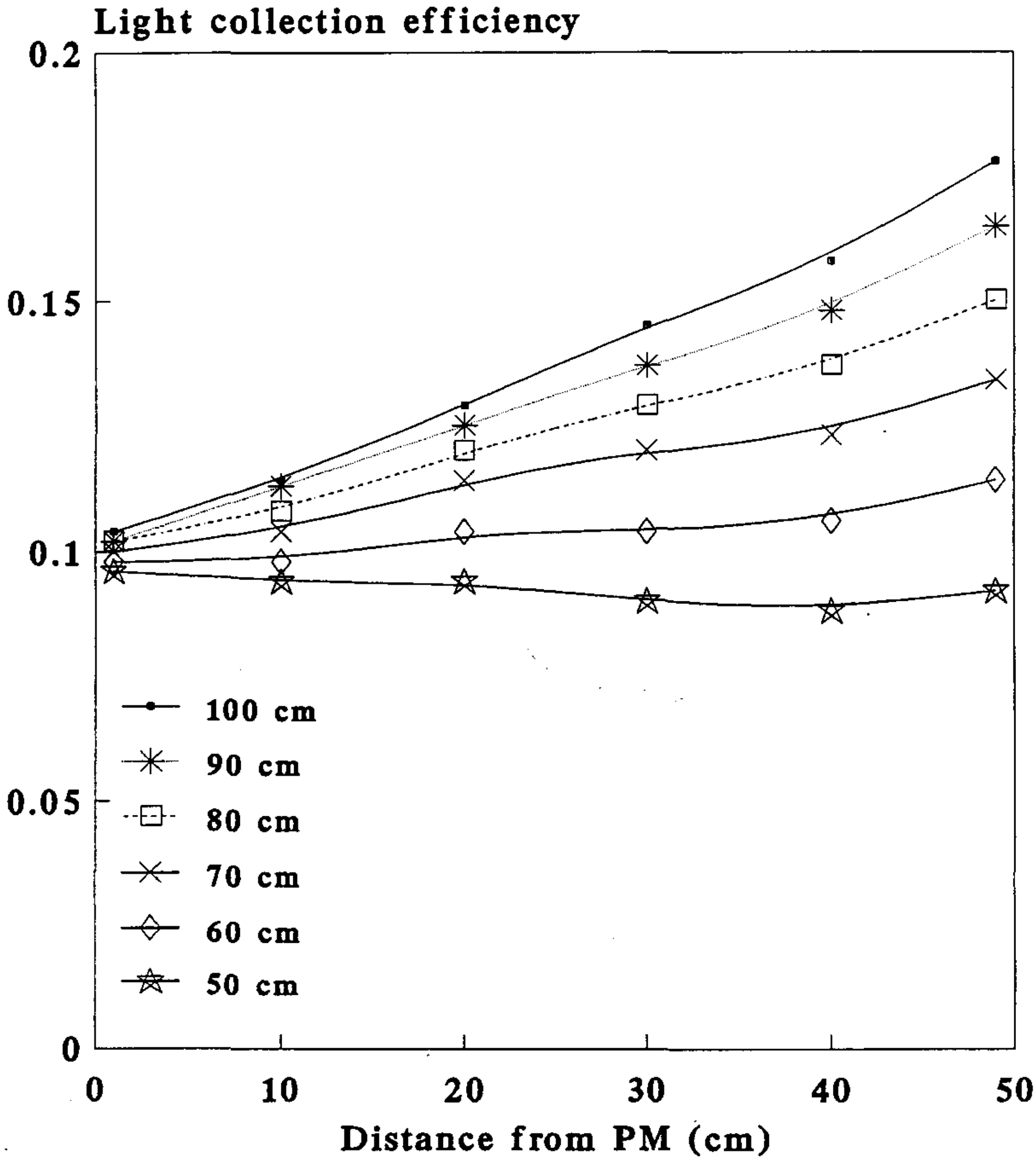


Fig 1-9

Uniformity for different λ_{att}
Polished facets, Al coating

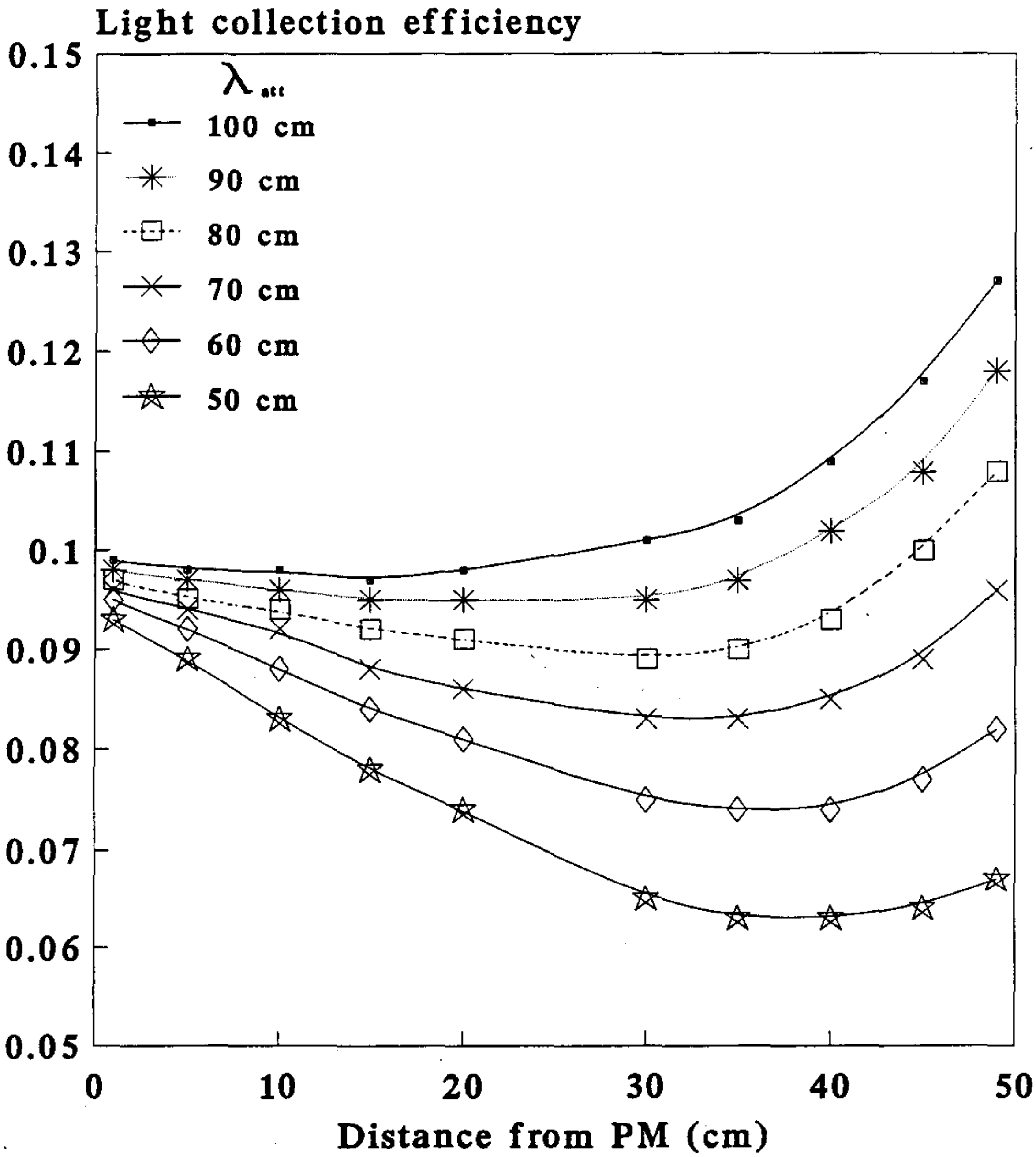


Fig 1-8

$\Delta\lambda_{att}$ = 10 cm (@ 78 cm optimum) ⇒ $\delta \sim \frac{12\%}{2} = 6\%$

Uniformity for different λ_{att} and transparent front facet (for side facets F=1.) MgF2(thin film) + Al coating

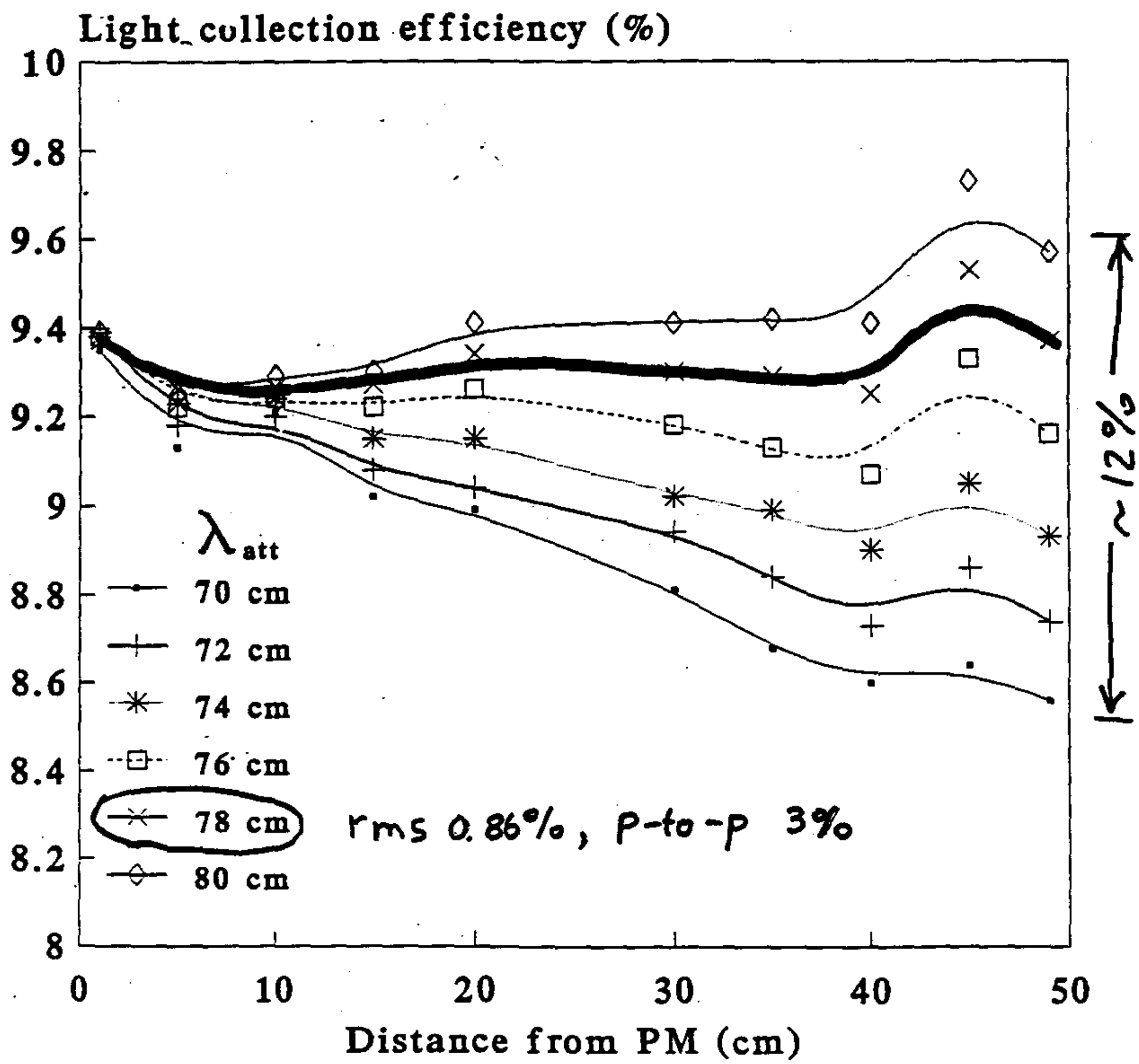


Fig 1-7 (b)

Uniformity for different λ_{att} and transparent front facet (for side facets F=1.) MgF2(thin film) + Al coating

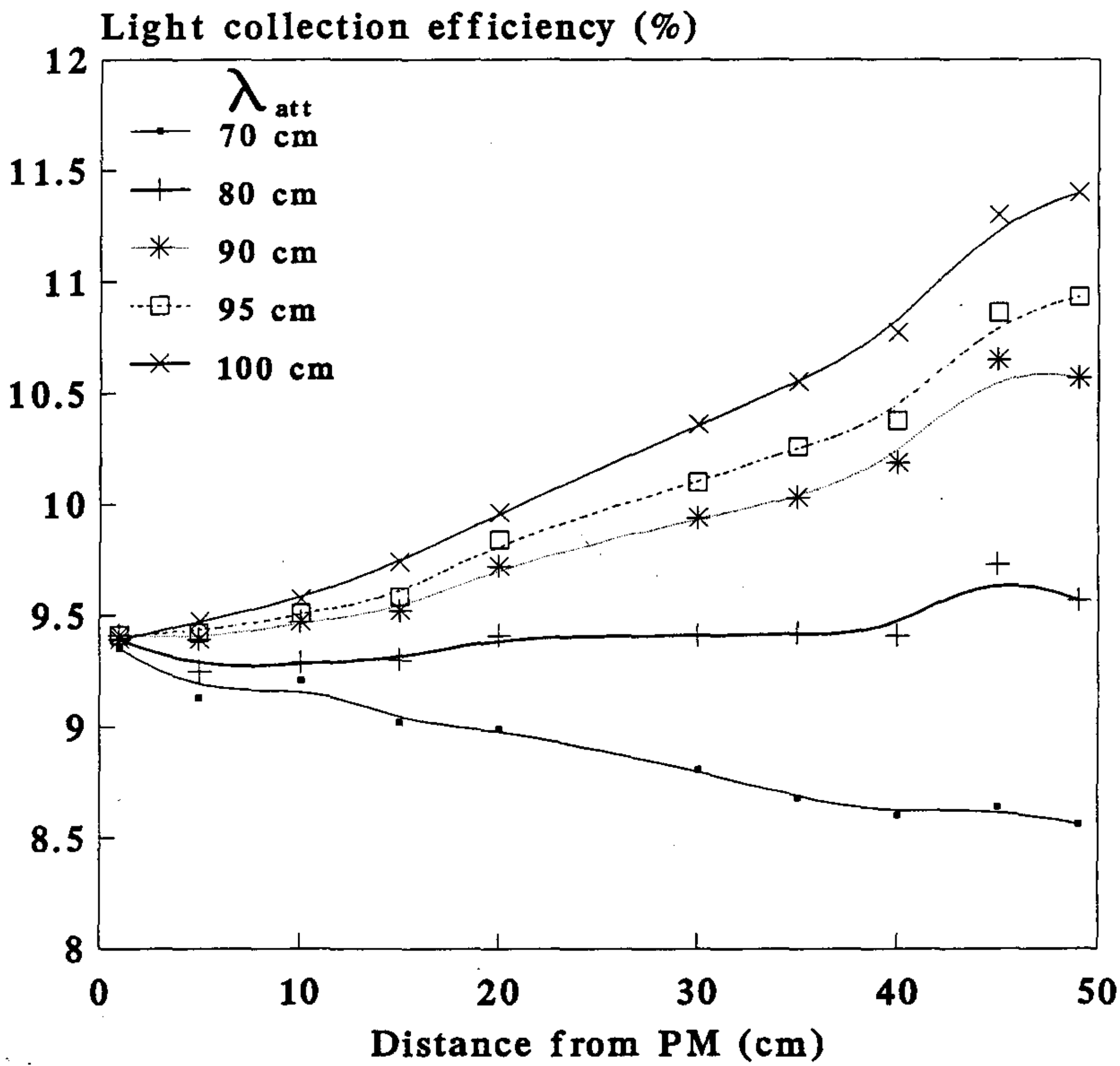


Fig 1-7 (a)

Uniformity for λ_{att}=70 cm and different reflection from front facet (for side facets F=0.99) MgF₂

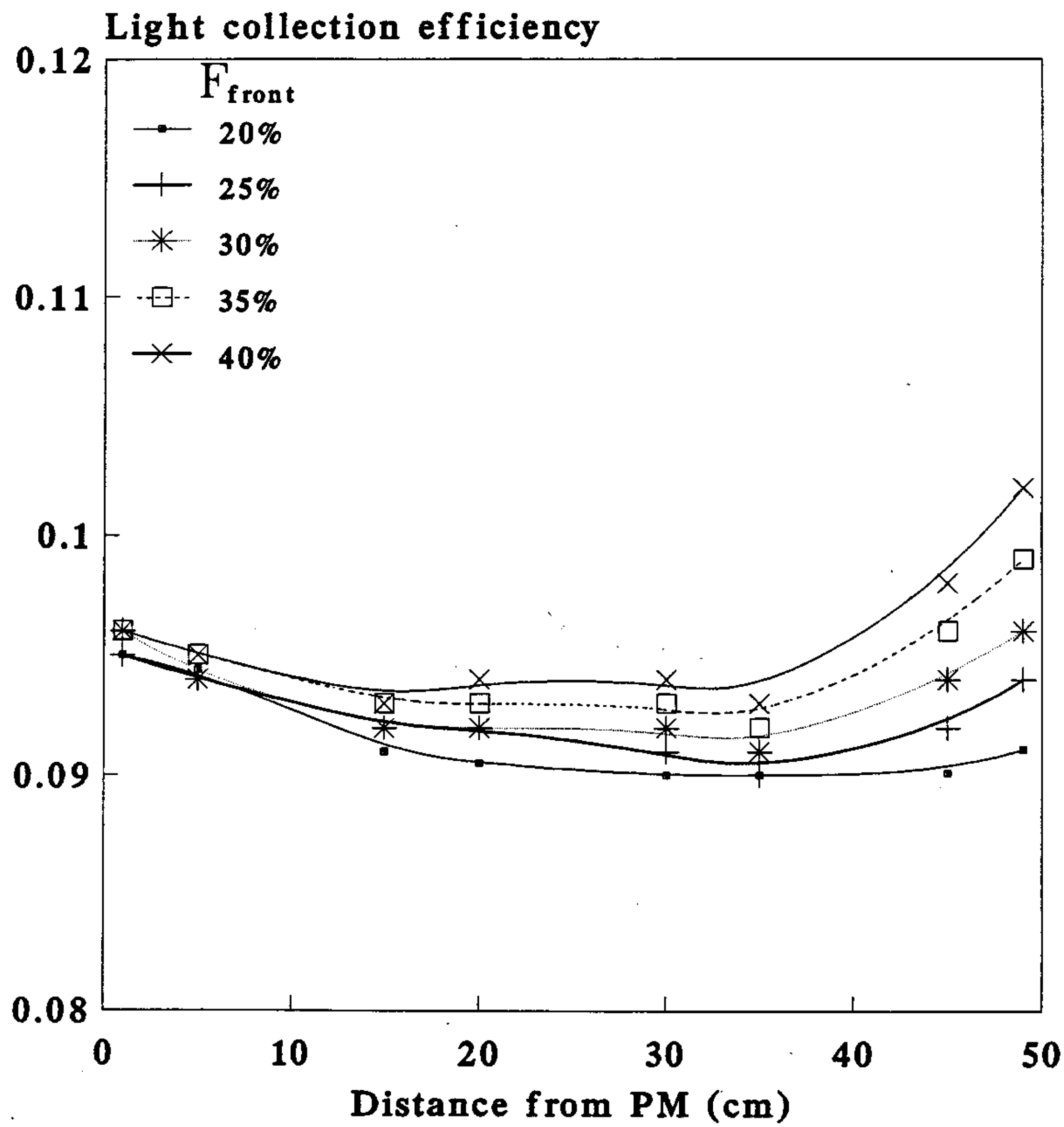


Fig 1-6 (c)

Uniformity for λ_{att}=70 cm and different reflection from front facet (for side facets F=0.98) MgF2

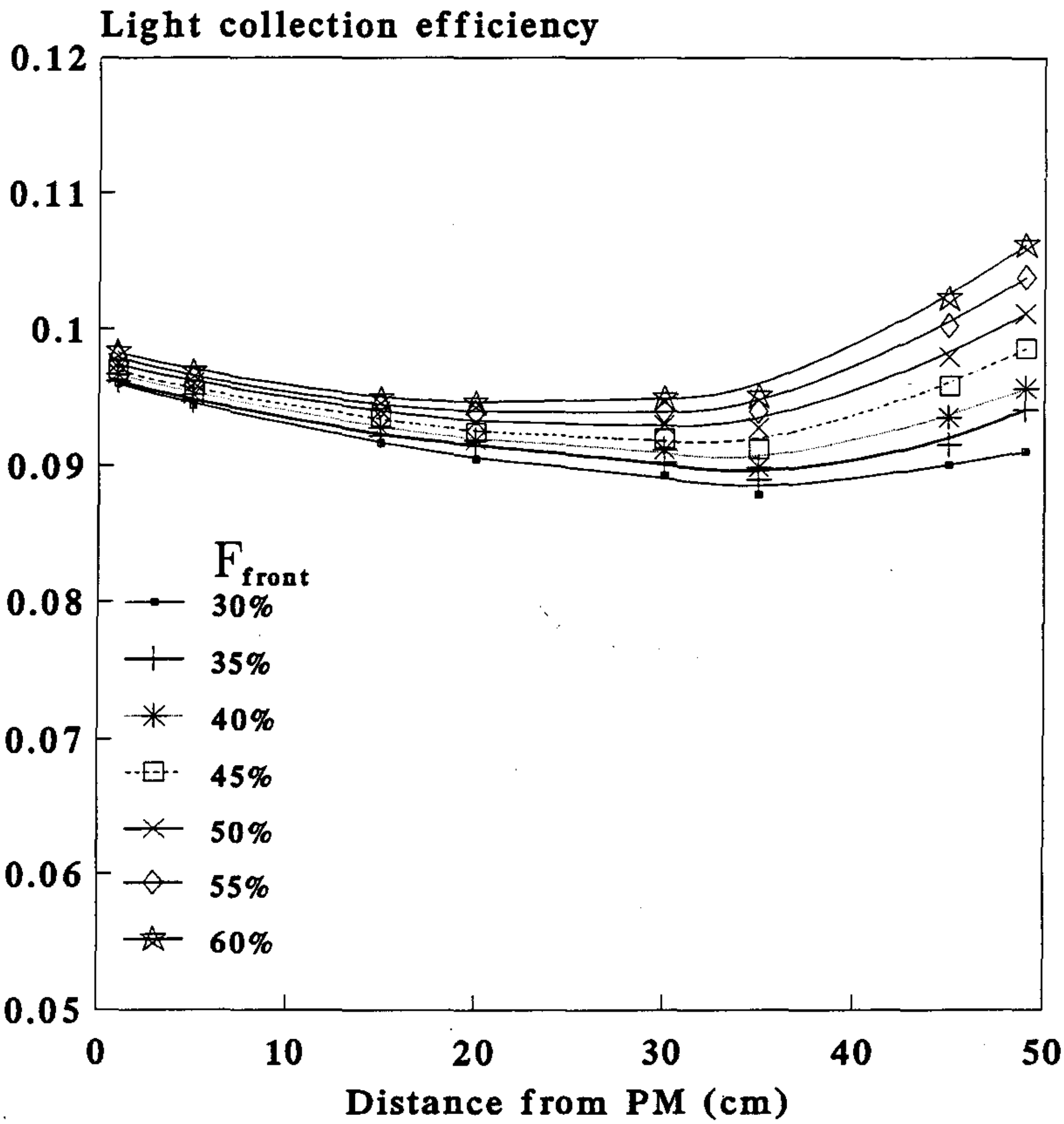


Fig 1-6 (b)

Uniformity for λ_{att}=70 cm and different reflection from front facet (for side facets F=0.95) MgF2

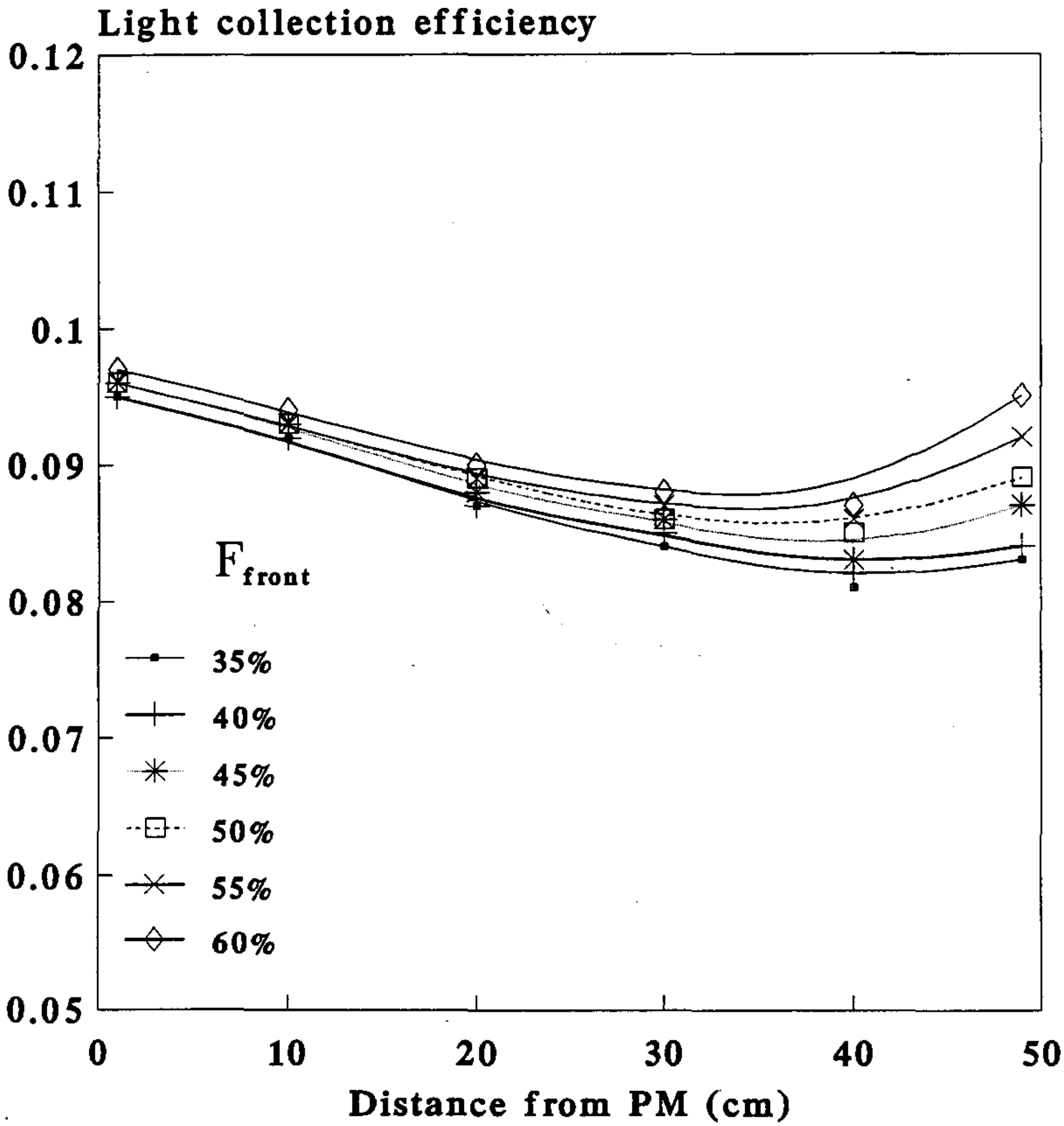


Fig 1-6 (a)

Uniformity for different λ_{att} and matched reflection factor F Coating - MgF2 (thin layer) + Al

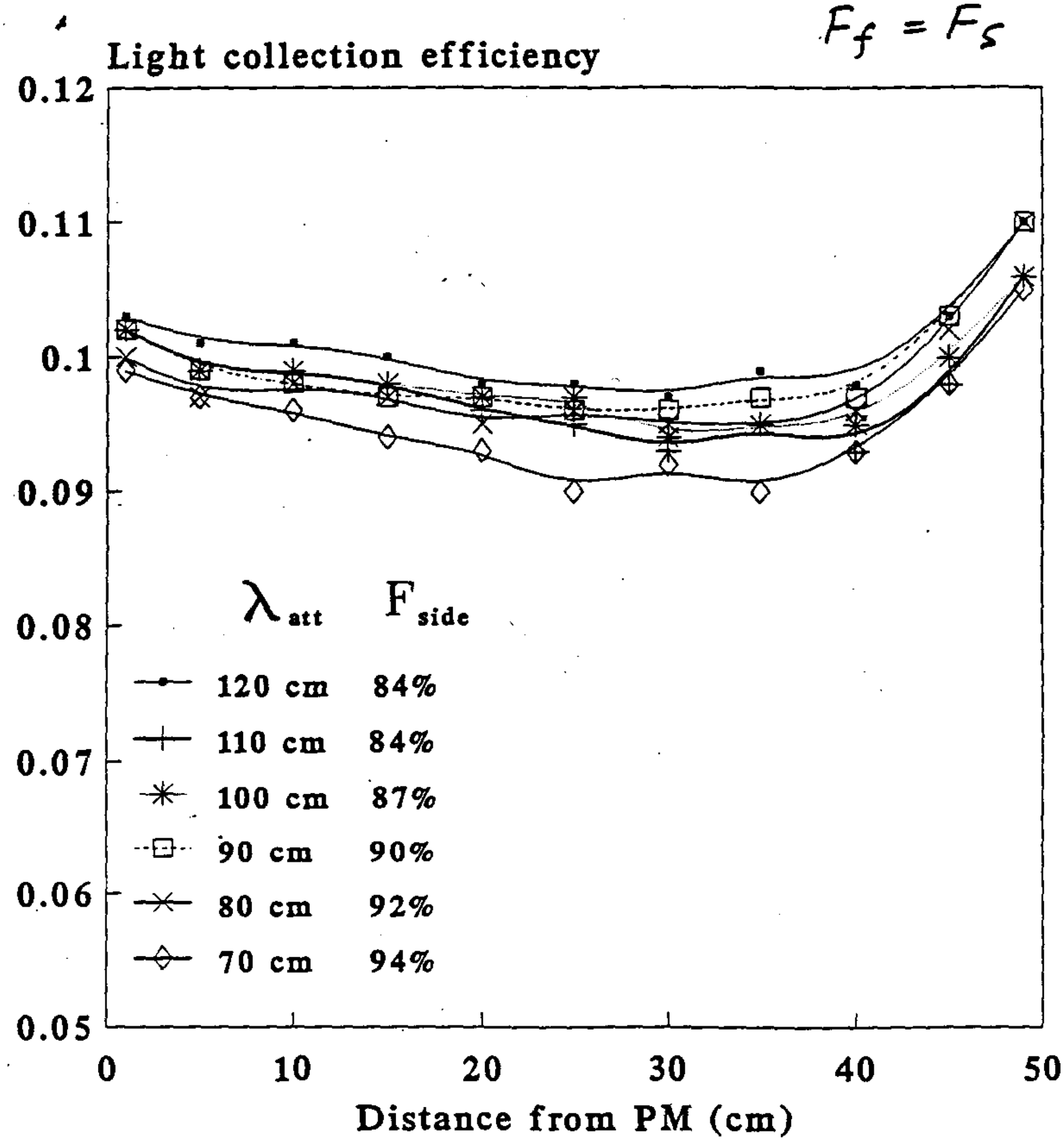


Fig. 1-E

Uniformity for $\lambda_{att} = \infty$ and different reflection factor F Coating - MgF2 (thin layer) + Al

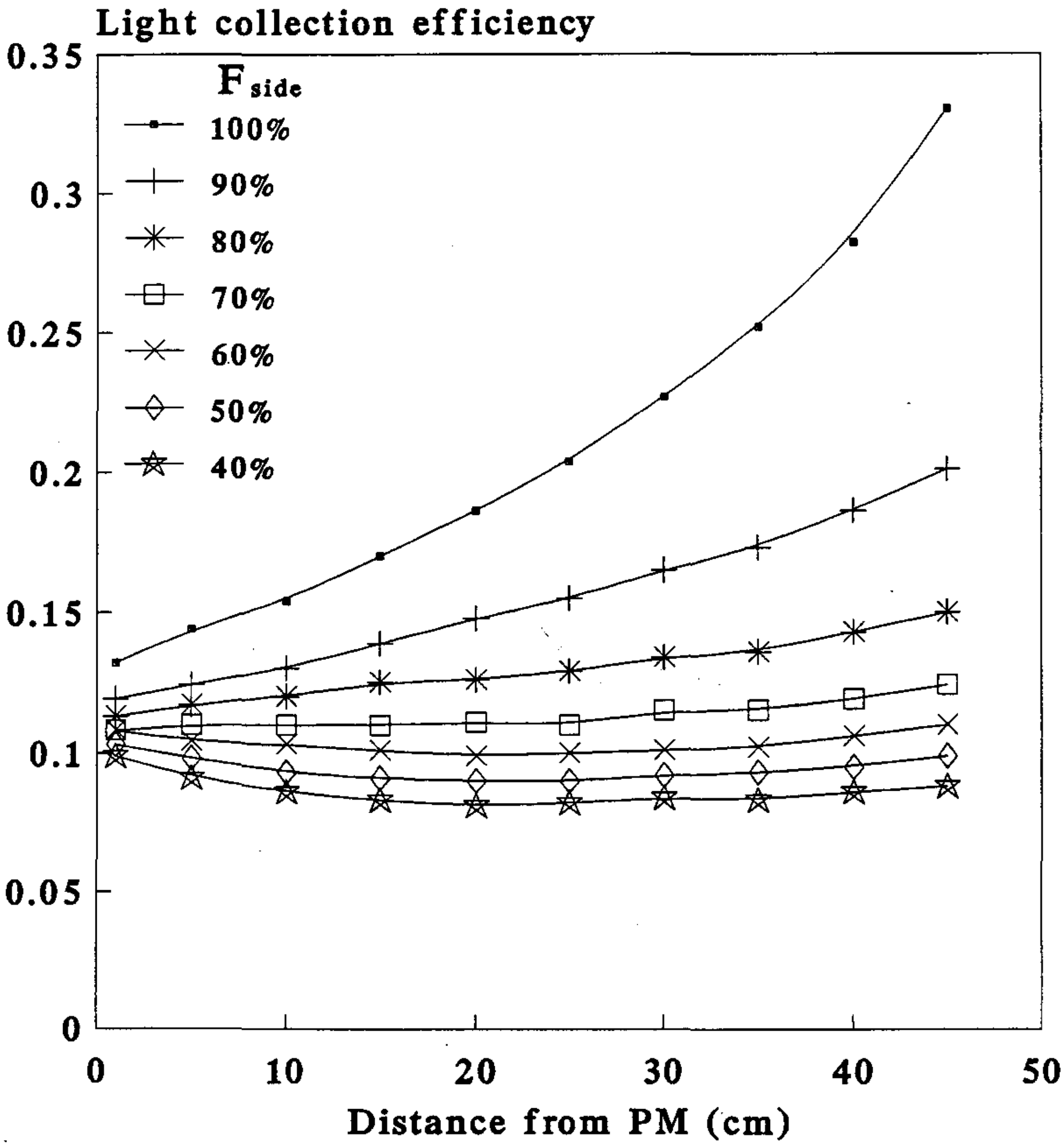


Fig1-4

Uniformity for different λ_{att}
MgF2(thin layer)+Al coating

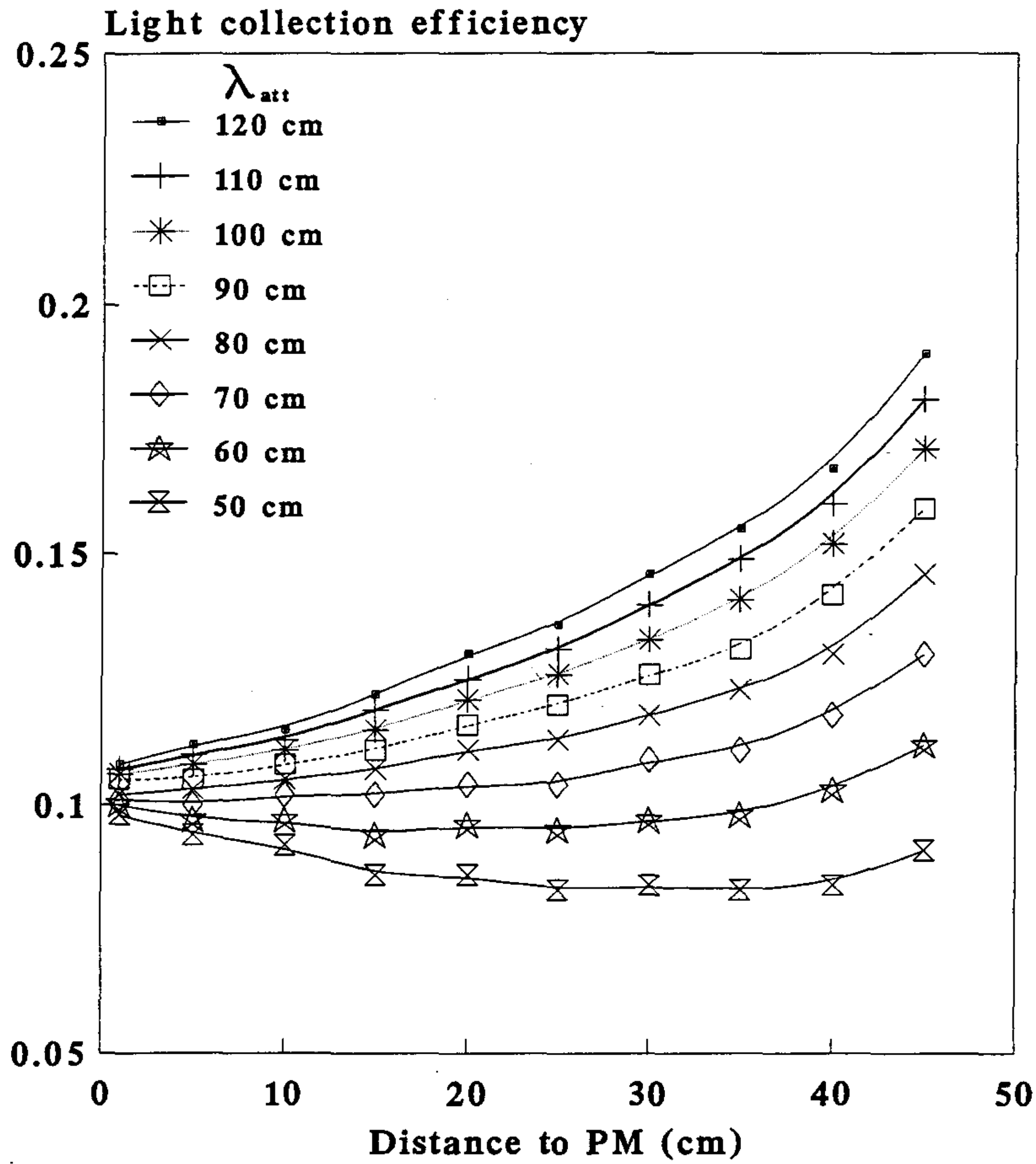
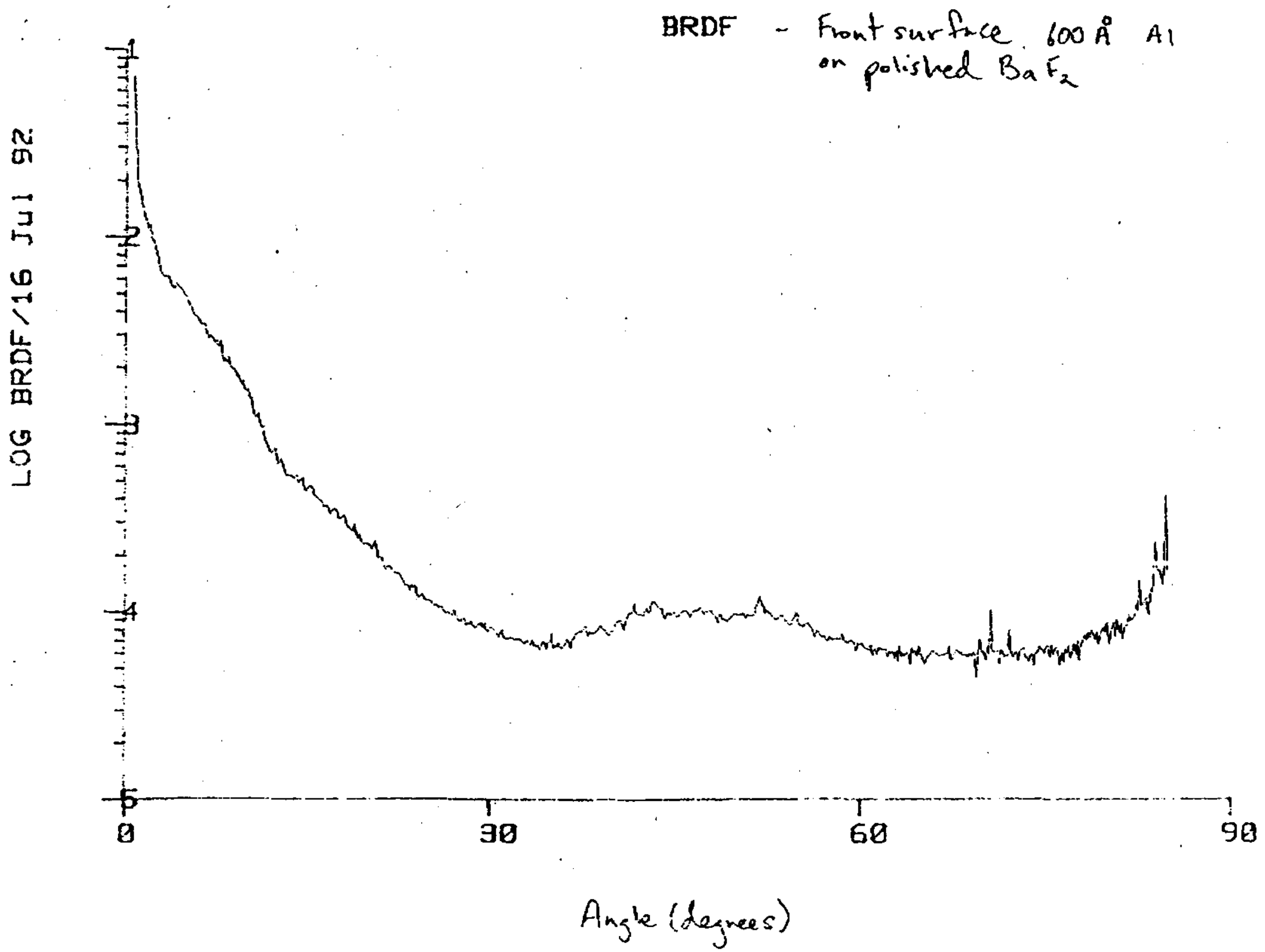


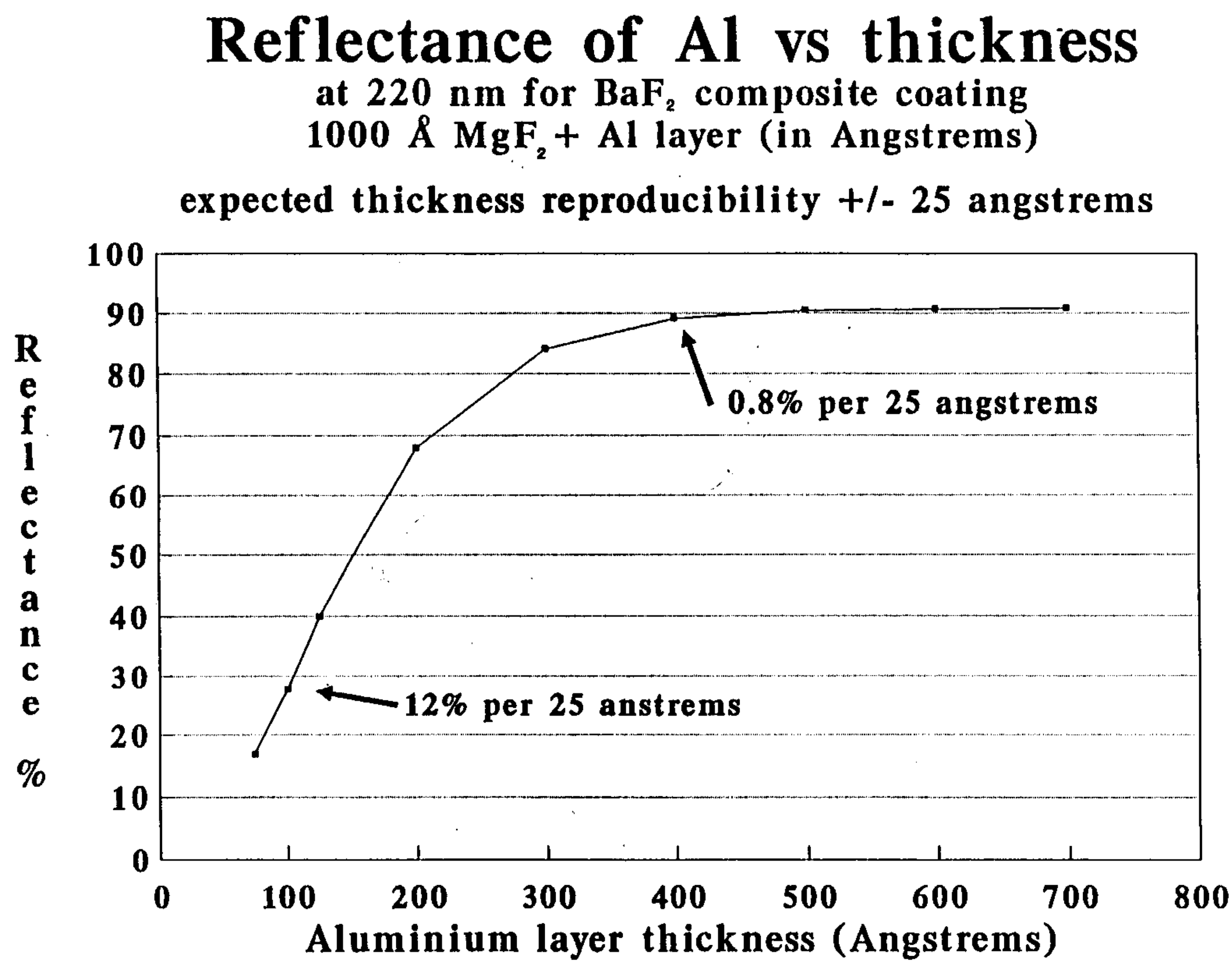
Fig.1-3



BRDF - Front surface 600 Å Al
on polished BaF2
LOG BRDF/16 Jul 92
1
2
3
4
5
0
30
60
90
Angle (degrees)

BaFL

Fig. 1-2


Reflectance of Al vs thickness
at 220 nm for BaF2 composite coating
1000 Å MgF2 + Al layer (in Angstrems)
expected thickness reproducibility +/- 25 angstrems
Reflectance %
Aluminium layer thickness (Angstrems)
0.8% per 25 angstrems
12% per 25 anstrems
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800

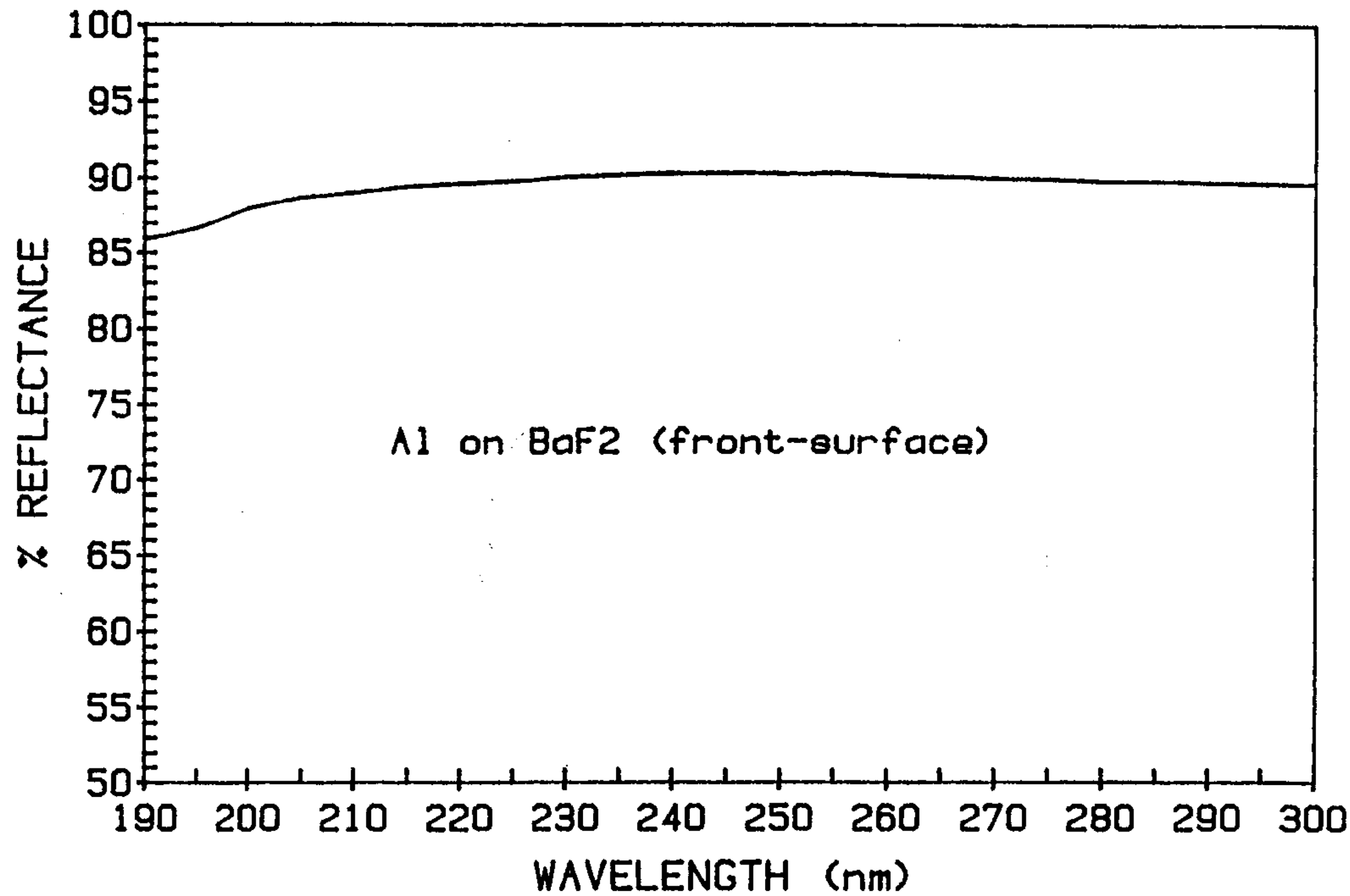
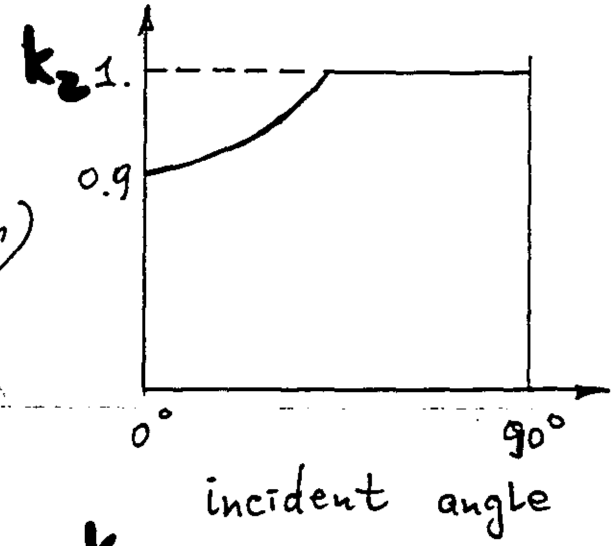
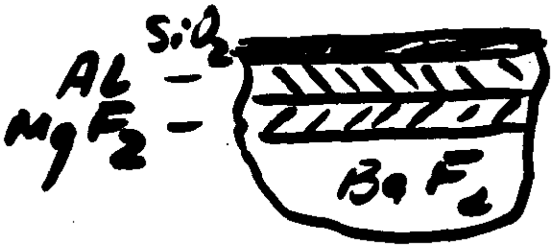

% REFLECTANCE
100
95
90
85
80
75
70
65
60
55
50
190
200
210
220
230
240
250
260
270
280
290
300
WAVELENGTH (nm)
Al on BaF2 (front-surface)

Fig. 1-1

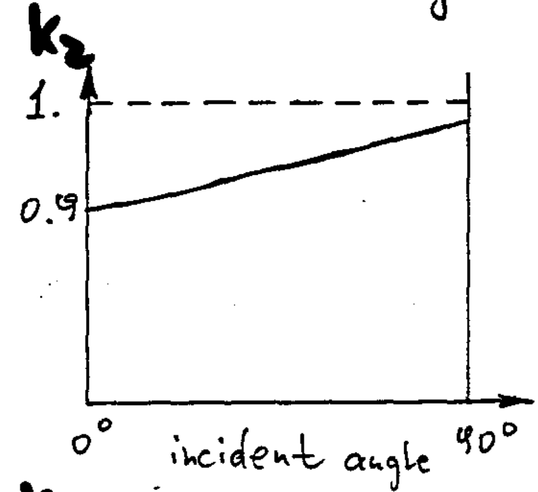
Possible methods of coating:

a) MgF_2 + AL + SiO_2 (protection)

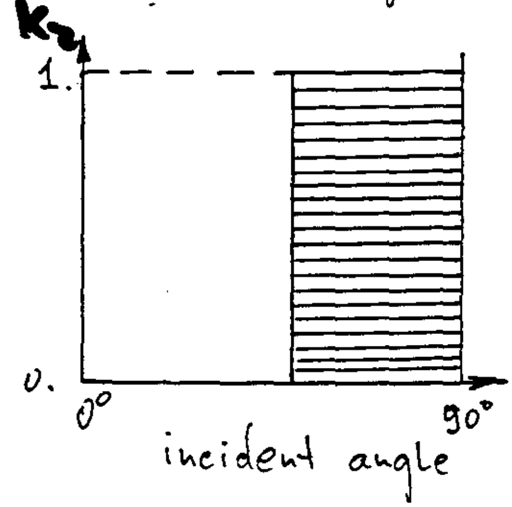


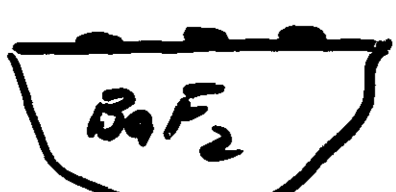


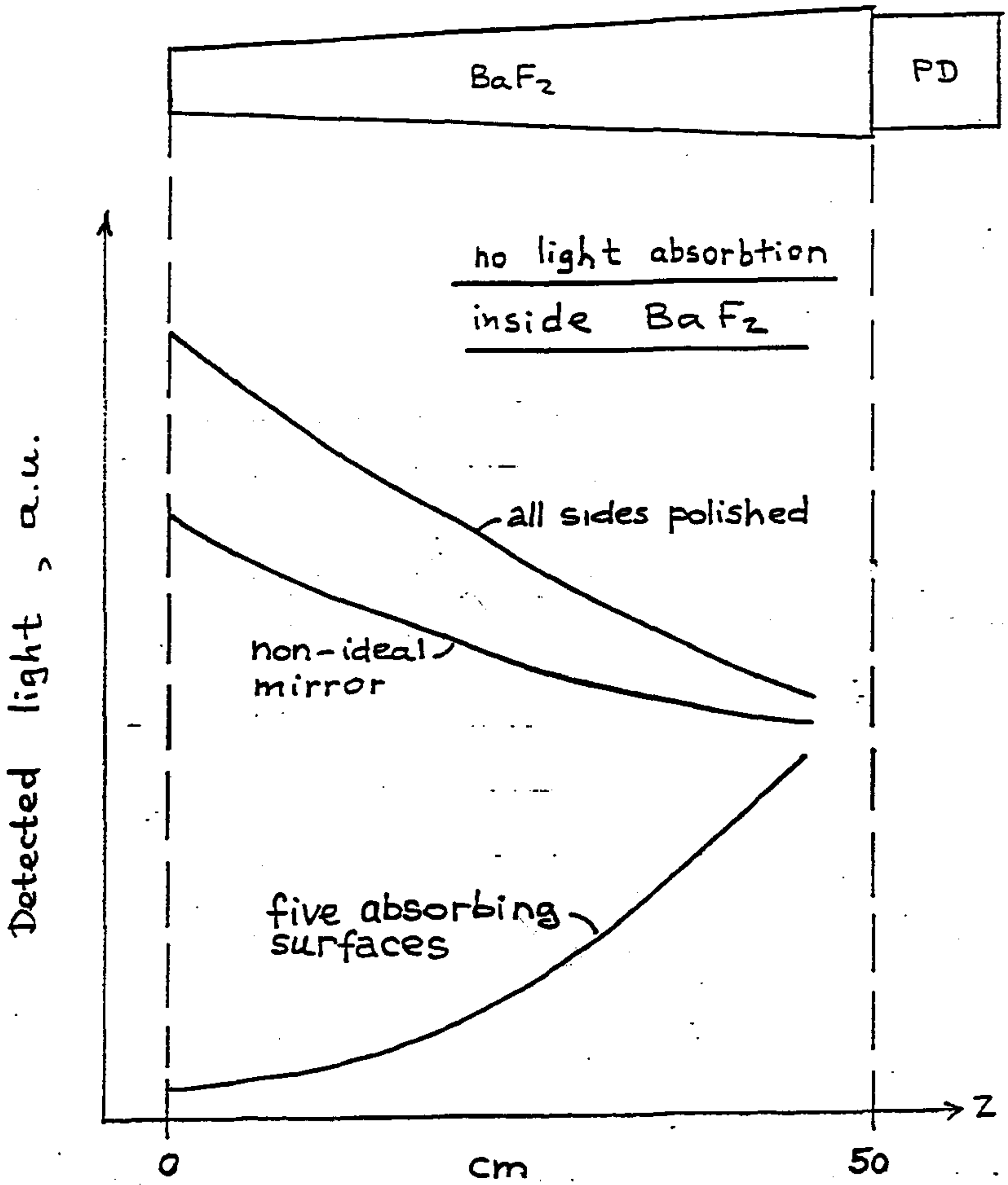
b) AL + SiO_2 (protection)



c) All polished crystals with absorption mask







Qualitive effects in BaF_2 coating

and Caltech.

REFERENCES

- [1] Liquid Scintillator Calorimetry
  A Research and Development Proposal Submitted to SSCL
  by LLNL,UMiss,ORNL,UT,TIFR,ITEP,IHEP; September 1991

- [2] Response to the Panel Questions from GEM
  Collaboration, SSCL, January 21, 1992

- [3] Ren-yuan Zhu, "On Quality Requirements to the Barium
  Fluoride Crystals, GEM TN-92-48, January 3,1992

absorbency factor are simulated. In Figure 1-12 for λ_{att} =70 cm absorbency factor for front facet is varied separetly. Peak to peak uniformity of ~ 4 % can be acieved in this case too.

With the coating technique of type (a) and (c) uniformity corresponding to $\delta < 2\%$ (non-uniformity parameter [3,2]) can be achieved. Actual choice of coating will depend on such factors as radiation damage and chemical stability of coating; total light yield; mechanical, chemical and optical protection of crystals; cost, etc. It is essential that results of these simulations should be verified by direct uniformity measurements with real coating for crystals with known properties (λ_{att} and absence of local non-uniformities). Such tests are presently being prepared at LLNL with X-source and at UCSD with cosmic muons. It will be extremly important to relate parameters in LTRANS simulations (reflection, absorbance coefficients, angular dependence etc.) with mechanically controlled parameters of the coating (thickness, density, etc.)

Further plans for light transport simulations include :

- verify optical light emission-reflection-refraction-absorption data base in LTRANS with direct measurements made at LLNL;

- simulate additional optical readout from front facet for segmented and non-segmented crystals;

- check uniformity for the crystals of different geometry (end-caps) and for the crystals on new shape (three surfaces at direct angles);

- simulate the effect of turning prizm on uniformity and light yield;

- simulate the effect of various photocathods (mechanical shape and spectral responce) on uniformity and light yield;

- simulate the UV light propagation in the BaF_2 crystal from UV flash lamp which is planned to be used for calibration and monitoring purposes;

- incorporate in LTRANS the data on radiation damage of BaF_2 in the GEM detector as function of θ, dose and radial position inside the crystal (source - V.Morgunov at SSCL);

- build into LTRANS radiation damage effect as variation of λ_{att} vs dose and time (according the measurements on radiation saturation and non-annealing effects for new radiation hard crystals; source - R. Zhu, Caltech);

- provide the simulation of uniformity measurements made at LLNL, UCSD, CERN these simulations that crystals have uniform bulk properties, i.e. contain no local non-uniformities such as impurity inclusions, bad quality glue interfaces, etc.

Type (a) coating :

Figure 1-3 shows simulated longitudinal non-uniformity scans for the BaF_2 crystal (four side and front facets are coated) and reflection factor $\mathcal{F}=1$ for different light attenuation length of BaF_2 material. Focusing effect is clearly seen for $\lambda_{att} > 70$ cm.

Figure 1-4 shows simulated non-uniformity scans for BaF_2 crystals with infinite light attenuation length when reflection factor $\mathcal{F}$ varies from 1.0 to 0.4.

Using data as those presented in Figs. 1-3 and 1-4 one can choose the matching combination of factor $\mathcal{F}$ to any particular λ_{att} to make the uniform responce of the crystals. This method is crossed checked by direct simulation of non-uniformity scan with matching pair of λ_{att} and $\mathcal{F}$ (Fig 1-5). The increase of responce near the far end of the crystal (from photodetector) is explained by the reflection of light from the front facet of the crystal. In further simulations reflection coefficient for front facet was varied independently. Fig. 1-6 shows for example that for $\lambda_{att}=70$ cm uniformity peak-to-peak of 5 % can be achieved. (See Figure 1-6 (c) with $\mathcal{F}_{front}$=25 %). In Figure 1-7 front facet of the crystal was left uncoated with Al and λ_{att} was varied. In this case uniform response $\pm$ 3 % peak-to-peak can be achieved for $\lambda_{att}=$ 78 cm. For $\lambda_{att}>$ 78 cm less reflective coating should be used. The key issue in this case is mechanical control of the reflectance of the coating. This question is under study at LLNL.

Type (b) coating :

Coating with aluminium deposited directly on BaF_2 surface looks less promissing. Figure 1-8 shows (four side and front facets coated) simulated longitudinal scan for this coating for various λ_{att} from 50 to 100 cm. This coating is less effective in correction of λ_{att} effect. Uniform response possibly can be achieved only for $\lambda_{att} >$ 100 cm.

Type (c) coating :

It was shown before [2] that for all polished crystals rather good response uniformity can be achieved for $\lambda_{att}=53$ cm. For larger λ_{att} coating type (c) should be effective. Figure 1-9 shows simulated longitudinal scan for all polished crystals vs varying λ_{att}. Figure 1-10 shows for $\lambda_{att} = \infty$ simulated longitudinal scan vs varying absorbency factor (the factor is percent of polished surface which remains non-absorbtive). Four side and front facets are coated. At Figure 1-11 matching combinations of λ_{att} and

#1 UNIFORMITY OF THE COATED CRYSTALS (E.Tarkovsky)

Monte Carlo simulations were performed with light transport code LTRANS [1]. Modifications in the LTRANS were made to include the properties of the new coating developed by LLNL. This work is done under tight contacts with LLNL.

Following possible methods of coating were considered:

(a) MgF_2 + Al + SiO_2 – protection.

Layer of MgF_2 with the thickness of fraction of wavelength provides total internal reflection within the angles defined by the refraction indices ratio at given wave length. At the larger angles the light is reflected from the thin layer of Al with the reflection coefficient being the function of incident angle (min $\sim$ 91% for normal incidence for non-polarized light). Fig.1-1 shows specular reflectance coefficient vs wavelength for the Al-coating as measured by LLNL. Fig.1-2 shows the angular dependence of the scattered light for specular reflectance from Al layer for normal incedence at 220 nm. After verification this dependence will be used for the further studies of coating with LTRANS. It is also assumed that Al-coating can be made with the reflectance which is factor $\mathcal{F}$ less than the reflectance at normal incidence ($\sim$ 91%). This can be made either by varying the thickness of Al layer or by spattering the Al over the crystal surface with variable density. Both methods are presently being studied by LLNL.

(b) Al + SiO_2 - protection.

properties of this coating are similar to that of the coating above with less effective reflection at small incident angle due to the absense of the total internal reflection mechanism.

(c) Polished crystals with uniform absorbing mask of variable density.

For all polished 50 cm long BaF_2 crystals with the light attenuation length (λ_{att}) more than 95 cm (as specified in the requirements after pre-irradiation) light focusing rather than light absorption effect dominates [2] and additional absorption mechanism (employed through the coating) will be required to trim the crystal responce to uniform. This method appears as most simple from technical point of view. This coating technique is presently beeing studied by LLNL too.

It is assumed that in all three methods the coating is uniformly diposited (constant density) over the surface of crystal. As will be shown below for some coating methods and for definite range of λ_{att} it is sufficient to have constant density coating in order to obtain the uniform longitudinal response of the crystals. It is also assumed for

Monte Carlo Studies for BaF_2 at ORNL

Progress Report

(Status July 31, 1992)

CONTENTS

BARIUM FLUORIDE PRECISION EM CALORIMETER For GEM

By the September Meeting, We Expect To Have *

- Improved Understanding and Control of Radiation Damage In Large Crystals } e.g. UV ANNEALING
- Small Rad Hard Crystals
- A Manufacturing Plan, With Finished Crystal Pairs, Mechanical Support, and Quality Control Done in China
- Demonstration of the Ability to Maintain The High Resolution In Situ
  - -- Uniformity, Stability and Calibration Studies, Cosmic Ray and UV Monitor Data
  - -- Constant Term of 0.5%

A Sufficient Demonstration of the Promise of the BaF2/Scintillating HCAL System for GEM

+ SELF ANNEALING STUDY
+ LONGITUDINAL SEGMENTATION STUDY (APD)

"Panel" Meeting In Late August

- PRODUCTION of LARGE CRYSTALS IN CHINA
- SMALL RAD HARD CRYSTALS from LLNL, OPTOVAC
- Data Relating Microstructural Materials Properties to Rad Hardness: CE&A
- COSMIC RAY TOWER + UV MONITOR DATA
- SIMULATIONS + TEST DATA On UV UNIFORMITY
- CALIBRATION SIMULATIONS

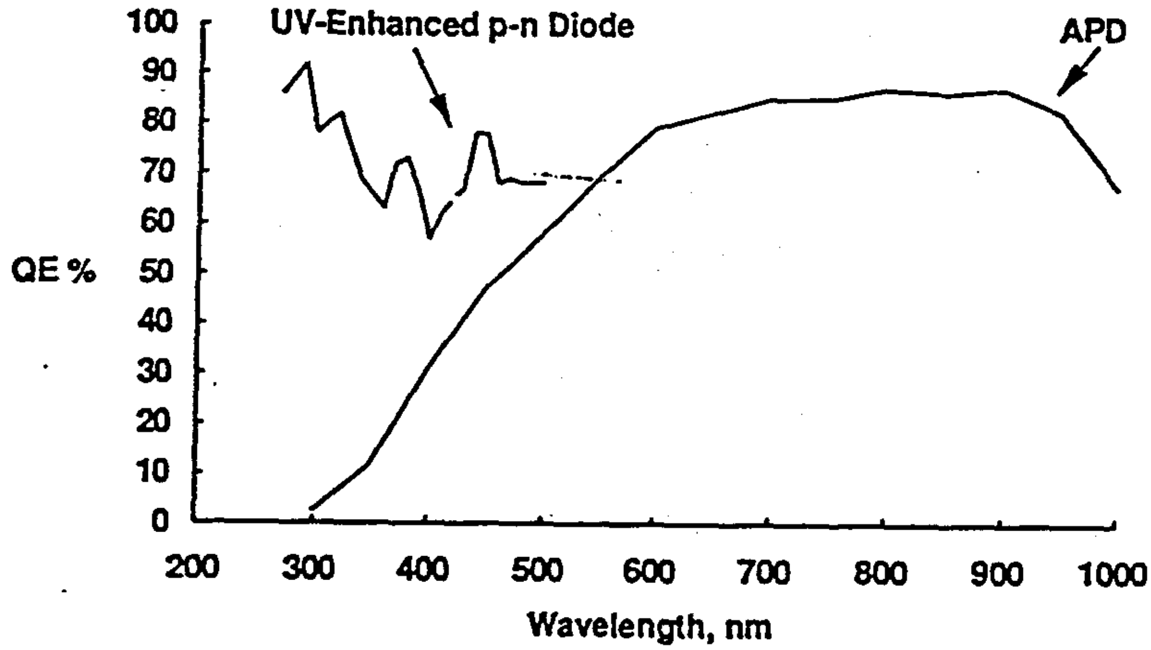
* In Situ ANNEALING TESTS

- Participation of Chinese Representatives
  Yin, Li, Wang

TITLE OF PROJECT: Avalanche Photodiodes for Barium Fluoride Calorimetry at the SSC

TECHNICAL ABSTRACT (Limit to space provided.):

The proposed project will extend the spectral response of currently available large-area avalanche photodiodes (APDs) into the blue and ultraviolet. Coupled with barium fluoride, a fast, high-atomic-number scintillator, a superlative high energy photon and electron detector, capable of operating in the high-rate environment of the Superconducting Super Collider, will then be provided. A photodetector to be used with barium fluoride must have short-wavelength response down to 190 nm. Although large-area p-i-n diodes with extended-UV response are available from a number of manufacturers, they are unsuitable for use with shaping times much faster than 2 microseconds because of poor noise performance. In contrast, APDs give improved rather than degraded performance with fast shaping times (down to around 0.01 microseconds) but at present their photoresponse falls off below about 400 nm. Advanced Photonix currently produces reliable and low-noise large-area APDs, with high production yield. We believe that a straightforward R&D program will extend the photoresponse of these large-area APDs into the blue and UV.



-Quantum efficiency *vs* wavelength for Advanced Photonix APDs, and for an Advanced Optoelectronics UV-enhanced p-n diode (measured at SDC)

BaF_2 EM CALORIMETER SILICON AVALANCHE PHOTODIODE (APD)* ADVANCED PHOTONIX, Inc. (API)

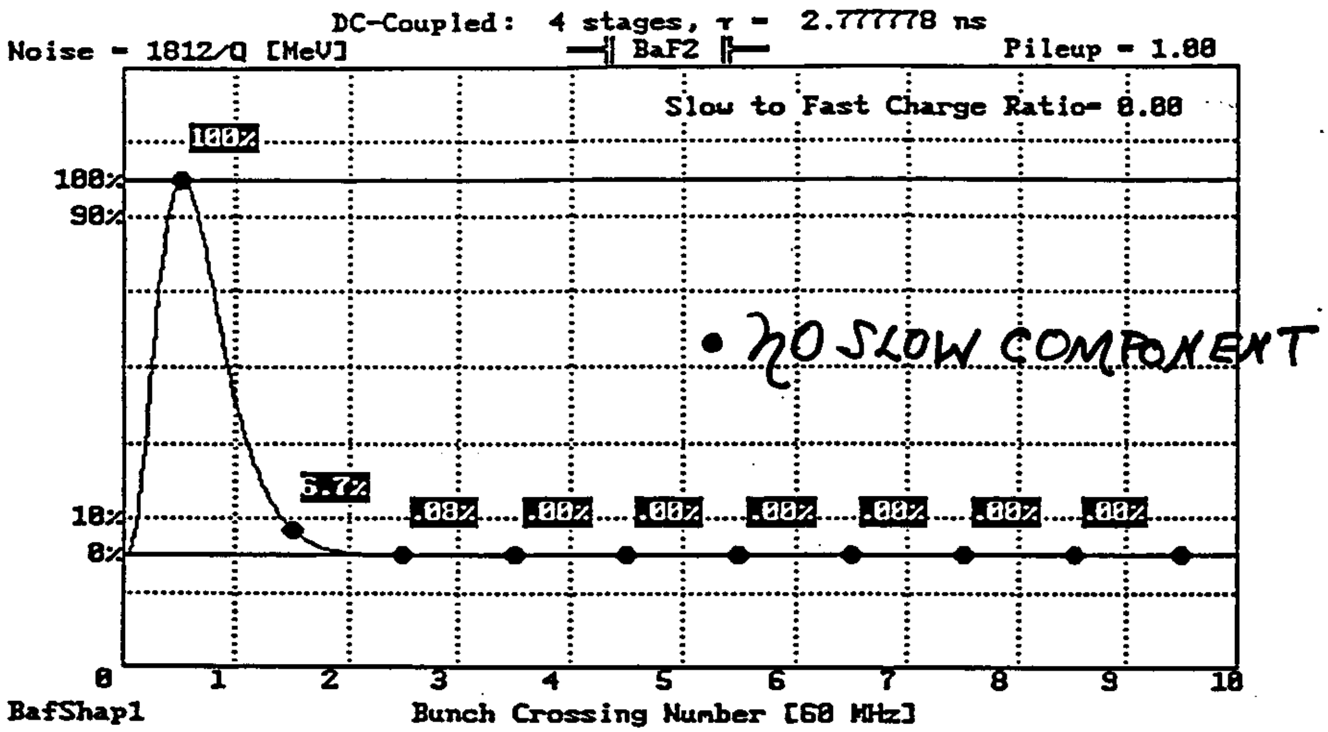
- BARE DIODE With Deposited Narrow Band UV Filter
- Q.E. To 80% (200 nm)
- RAD HARD (PD Tested to 0.4 MRad)
- LOW CAPACITANCE: 2-3 nsec RISE
- LOW NOISE: 0.25 nA/cm^2
- BUILT-IN GAIN (Use ≈ 200)
- VERY STABLE: TEMP. COMPENSATED (for -2%/°C)
- LARGE DYNAMIC RANGE
- MAGNETIC FIELD IMMUNE: COMPACT, NO TILT

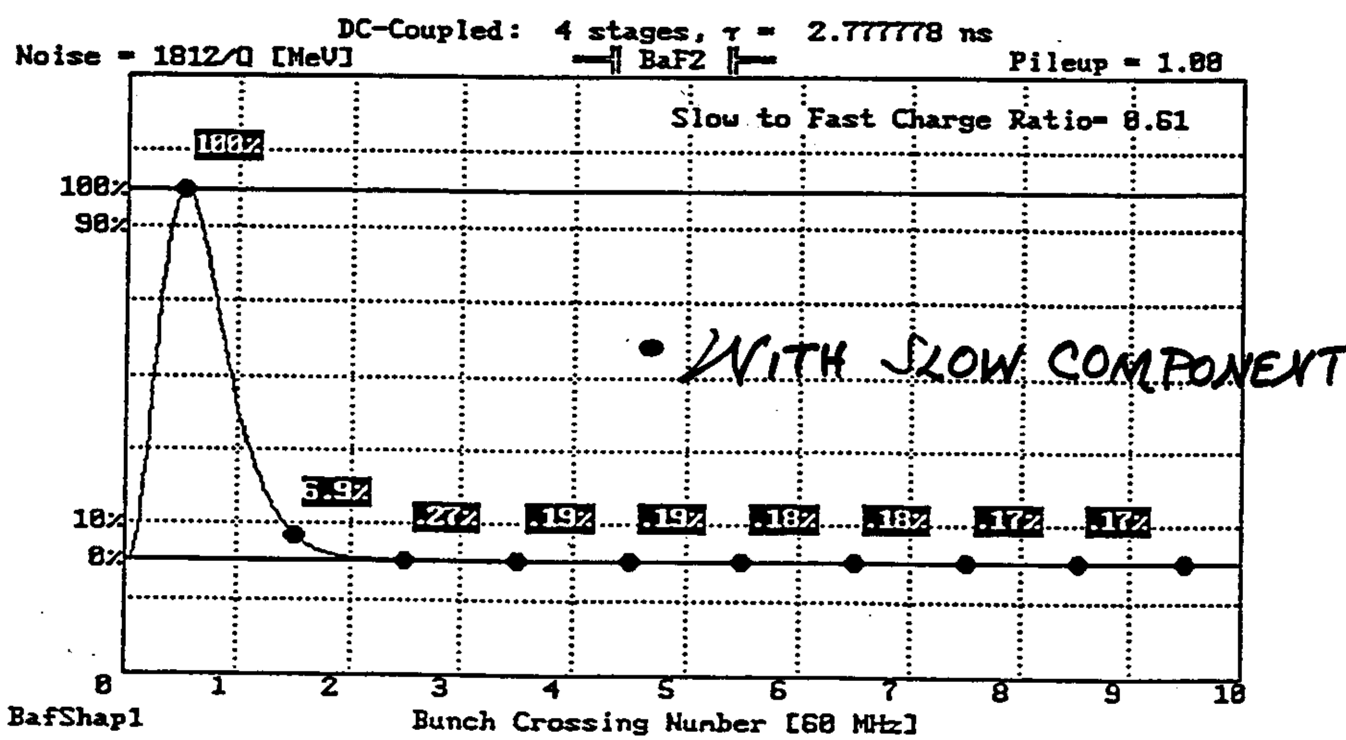
Development: Delivery of Several Large Area Diodes from API: $ 50 K

Other Vendors: Interest Expressed By Litton, Hughes, EG&G

→ BaF_2 With Two Long. Segments Under Study At ORNL, Caltech

• Peaking Time : 1 Bunch





• Princeton : FAST Shaping Design Study

The noise numbers are given in electrons, correctly normalized to the peak pulse height, so they should be divided by the number of electrons per MeV to convert the noise to MeV. (The noise numbers were obtained assuming a total capacitance at the input of 20 pF, and a forward transconductance of 50 mS.)

Peaking Time [bunches]	Number of Stages	Noise [e⁻]	f (No Slow Comp)	f (With Slow Comp)
½	2	1029	1.33	1.36
½	3	1421	1.15	1.16
→ ½	4	1812	1.08	1.08
→ 1	2	737	1.08	1.09
→ 1	3	1011	1.01	1.02
→ 1	4	1294	1.00	1.00
2	2	524	1.92	2.01
2	3	716	1.60	1.62
2	4	918	1.44	1.44

• PEAK in ≤1 Beam Crossing

• Pileup Factor f Near 1

• No Effect of Slow Component

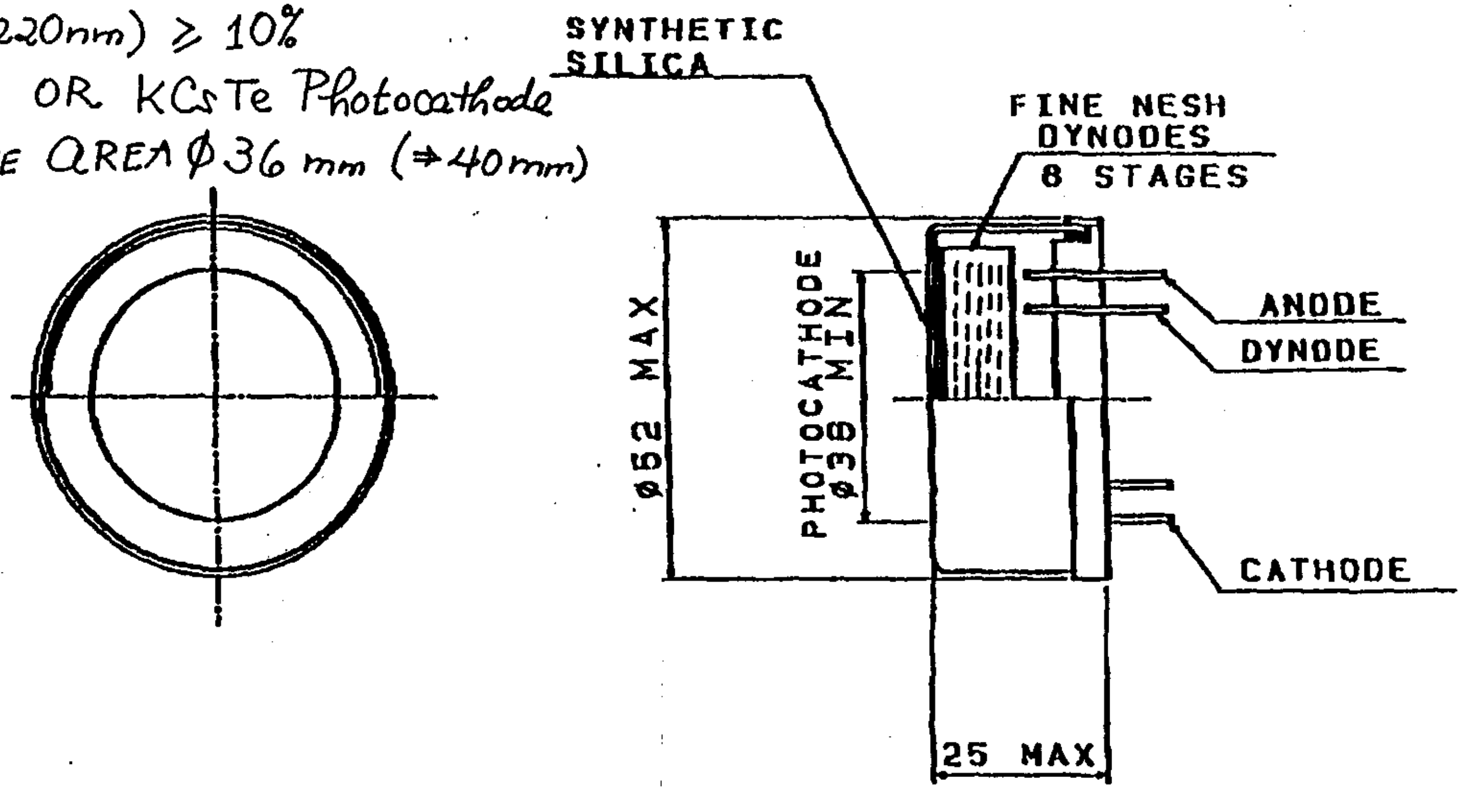
Note that even in the simplest scheme (the signal peaks in one bunch, with two stages: one pole-zero to eliminate the preamp tail and one integration) the pileup present is roughly the same as that for Liquid Argon with very fast shaping. Thus one sees that while BaF_2 calorimetry must address all of the issues relevant to high-performance EM calorimetry (noise, speed, precision, etc.) the intrinsic readout design is conceptually the simplest, due to the high speed of the fast component.

• NEW HAMAMATSU PROXIMITY FEW STAGE TUBE

ATT. BOB
RE: CAL TECH / PROX PMT.

- GAIN ≳ 30
- 25 mm THICK

→ QE (220nm) ≥ 10%
→ RbTe OR KCsTe Photocathode
→ Active Area φ36 mm (⇒ 40mm)



GENERAL TOLERANCE 一般公差			
DIMENSIONS 寸法	A	B	C
≤6	±0.10	±0.20	±0.30
6< ≤30	±0.15	±0.25	±0.50
30< ≤120	±0.25	±0.35	±0.80
120< ≤500	±0.40	±0.50	±1.40
500<	±0.80	±1.00	±2.00

ALT.	MARK	REASON	SIGN.	DATE

MATERIAL 材質:
QTY. 数量:
TREATMENT 処理:
SCALE 尺度: 1/1
FINISH 仕上:
PAINT 塗装:
DATE: 1992 · 6 · 18
APPD. 承認 | CHCK. 検図 | DESN. 設計 | DFT. 製図
HAMAMATSU PHOTONICS K.K.
TITLE 品名: P-PMT5
DRAWING NO. 図面番号: K9206L

Other Items

- READOUT: PRINCETON, ORNL
- APD & LONGITUDINAL SEGMENTATION
  - VERTEX FINDING

Q4

SIMULATIONS AND LAB TESTS:

Demonstrate High Resolution
Maintainable In Situ
Max. Constant Term 0.6%

EFFECTS TO BE INCLUDED

- (A) • Residual Non-Uniformity (As Installed)
- (B) • Non-Uniformity Due to Radiation: Non-Saturation Or Annealing In Situ
- (C) • Accuracy of Intercalibration (From Calibration Studies)

} SIMULATION GROUP (ORNL; CALTECH)

- (D) • POSSIBLE ANNEALING: TESTS
- (E) • Short Term Instabilities of Readout System.

} UCSD GROUP: CR TOWER + UV MONITOR

- (F) • Linearity, Linearity Calibration and Dynamic Range of Readout System.

UCSD; ORNL; PRINCETON

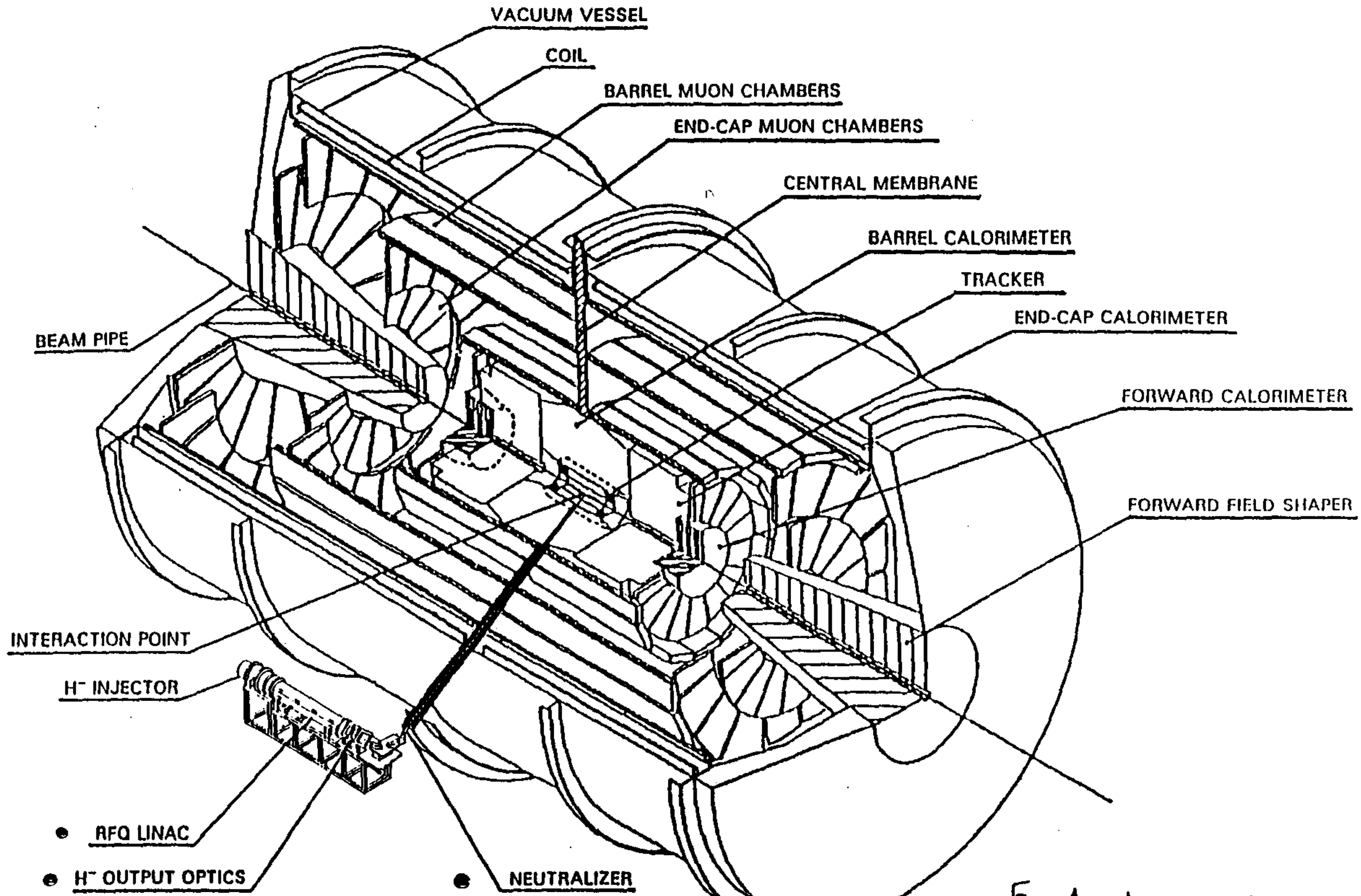


Fig 4.- Layout of GEM experiment with Model PL-4 RFQ Calibrator.

ACCSYS TECHNOLOGY, INC.

1177 Quarry Lane
Pleasanton, CA 94566
(415) 462-6949
FAX: (415) 462-6993

GEM Barium Fluoride Crystal Calorimeter Calibration System

The barium fluoride ($Ba F_2$) crystal calorimeter proposal for the GEM detector at the SSC Laboratory will be calibrated on-line using an RFQ linac to bombard a target with an intense pulsed proton beam to produce burst of photons. The present proposal for this RFQ calibration system can be satisfied by the AccSys Model PL-4 linac system operating with an H^- output beam that is stripped to H^0 in a gas neutralizer for transport into the center region of the detector through the magnetic field.

A drawing of the prototype Model PL-4 RFQ linac is shown in Fig. 1. This system, now being tested, is being developed for the U.S. Navy as a neutron generator. It is capable of a peak output current of more than 40 mA. The Navy unit uses an H^+ ion injector, but could be just as easily used with the H^- ion injector shown in Fig. 2. This rf driven H^- ion source is an upgraded version of the one in use at CERN for calibration of the BGO crystal calorimeter of the L3 experiment. A contract has been signed by AccSys with DESY to fabricate this H^- injector for use on the Linac III system at HERA.

As seen in Fig. 2, the ion source and acceleration gaps are mounted inside the grounded vacuum chamber for safety and to allow the hydrogen gas load from the ion source to be easily pumped away. The power from the ion source equipment cabinet to the injector is fed through an insulated tube, allowing the equipment cabinet to be located remotely for easy service and maintenance during operation of the accelerator within an experimental area.

The 35 keV H^- beam extracted from the ion source is transported and focused into the RFQ linac through a low energy beam transport (LEBT) system that uses two solenoid magnet lenses. The calculated beam optics design for the LEBT shows that the beam from the injector can be focussed properly into the RFQ using modest field magnets.

The H^- ion beam from the injector will be accelerated to a final energy of 3.85 MeV using a 3 m long RFQ operating at 425 MHz. This RFQ accelerator, used for the Model PL-4, was originally developed to generate neutrons for non-destructive testing, and was designed to be rugged and reliable. The detailed specification of this system are listed below:

Uniformity for different λ_{att} and transparent front facet (for side facets F=1.) MgF2(thin film) + Al coating

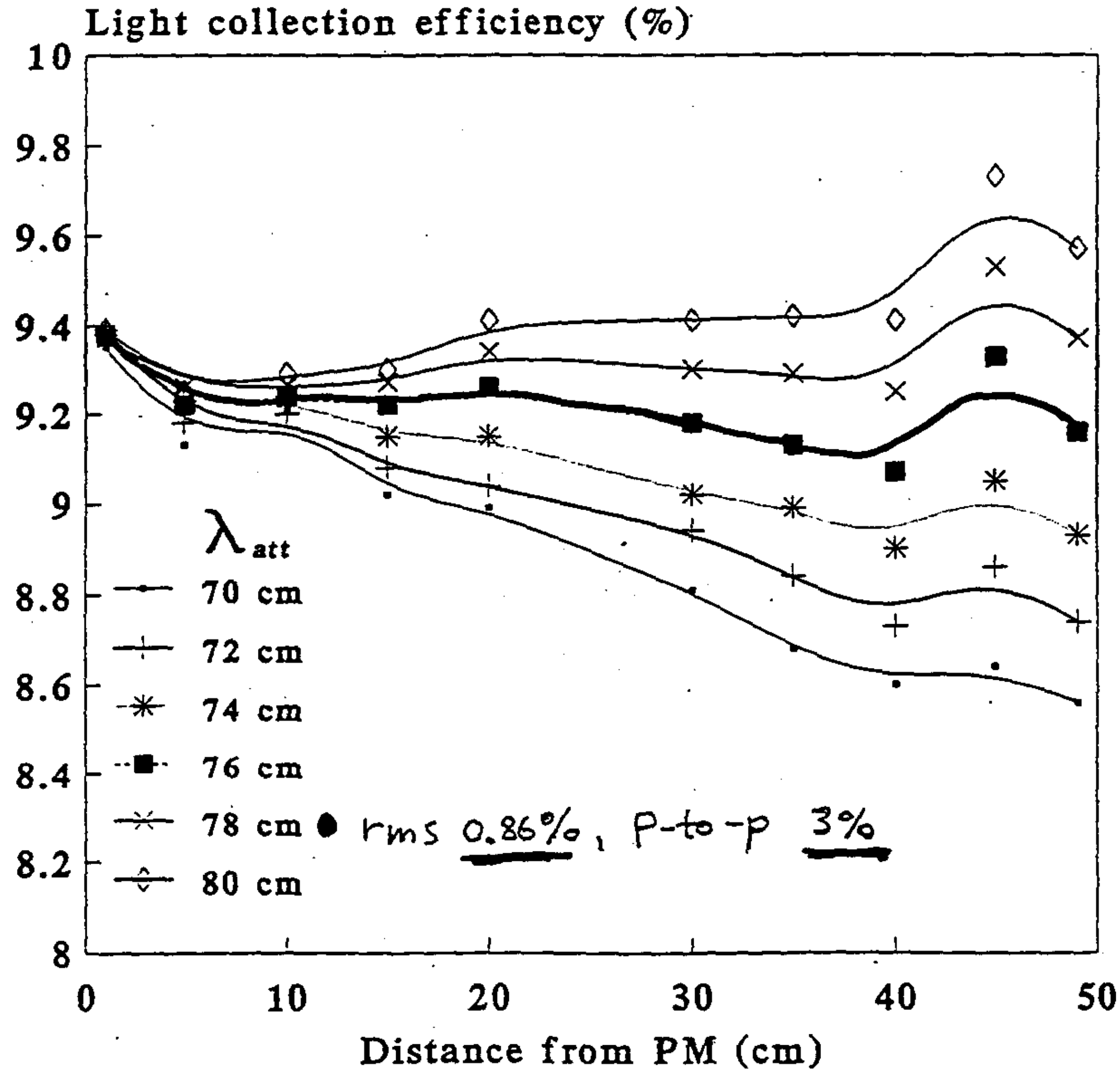
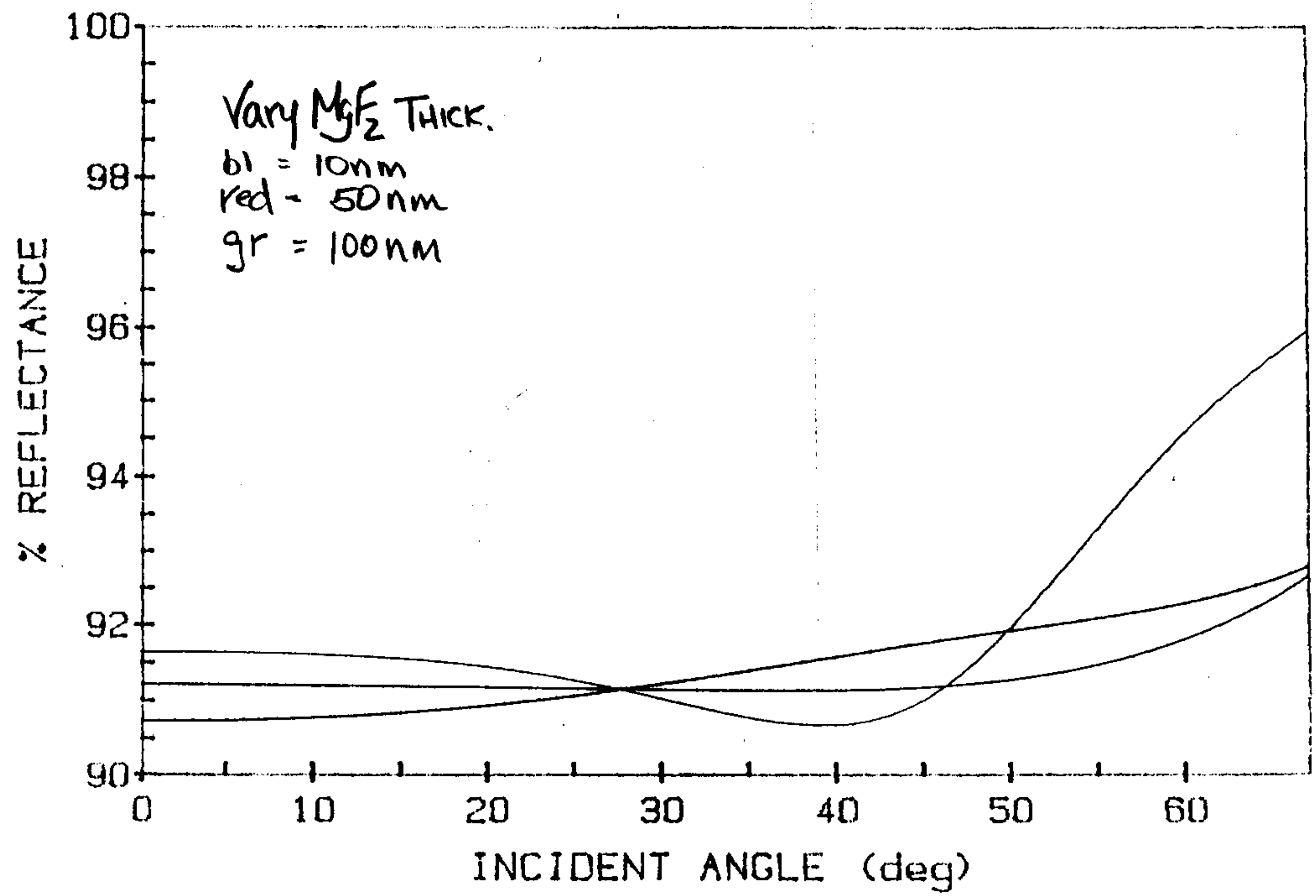
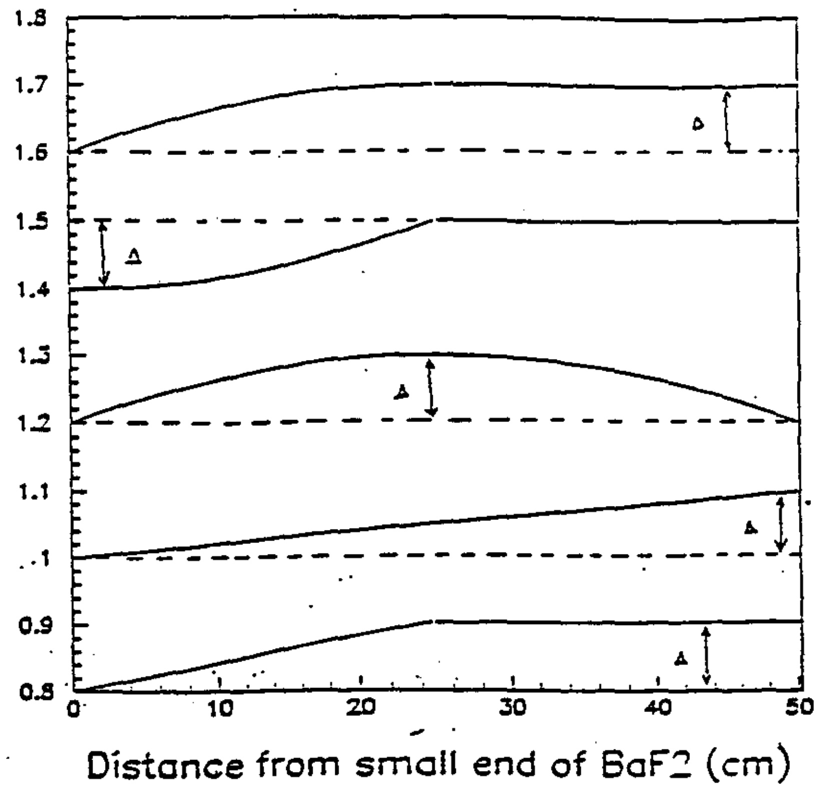


Fig 1-7 (b)


Vary MgF2 THICK.
bl = 10nm
red - 50nm
gr = 100nm
100
98
96
94
92
90
% REFLECTANCE
0
10
20
30
40
50
60
INCIDENT ANGLE (deg)

5 TYPES of nonuniformities



ALL 5 TYPES of nonuniformities with positive slope

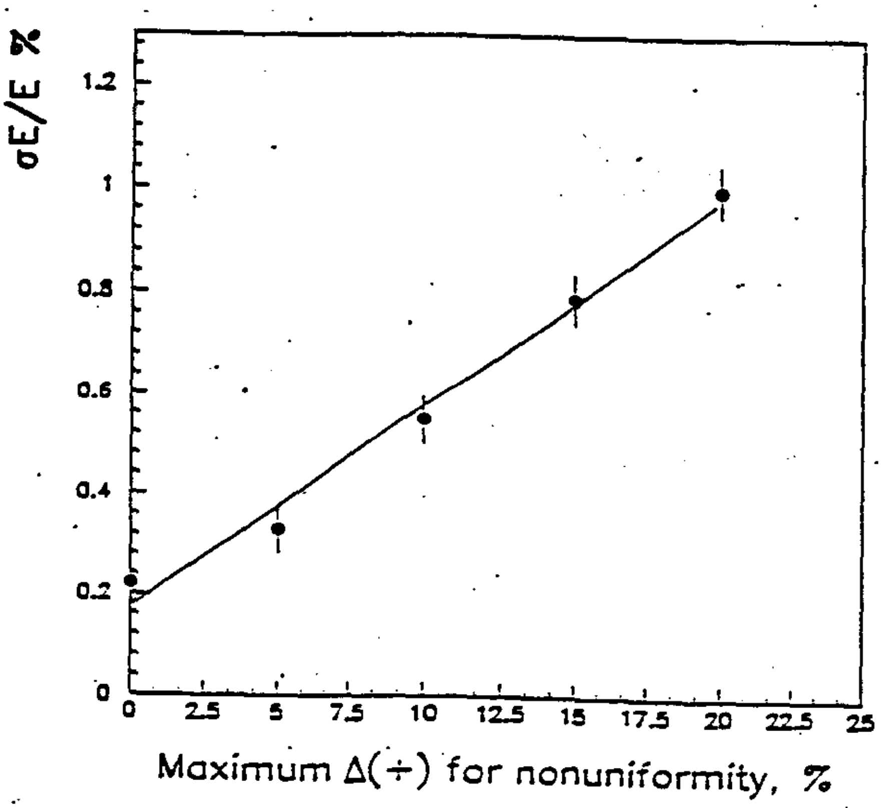


Fig. 2-1

Monte Carlo Studies for BaF_2 at ORNL

Progress Report

(Status July 31, 1992)

CONTENTS

- **Q3A: PREKADIATION:**
  - VIABLE Only if λ ≳ 70 cm REACHED
  - If so, then COHN Report ...
    - → NOTE: REJECTED TWICE BY PANEL
    - → EVIDENCE: LONG TERM IRRADIATION WITH HADRONS REQ'D.

- **Q3B: COATING:**
  - PROCESS (LLNL), IMPLEMENTATION (With ZHONGNAN), QUALITY CONTROL (IHEP) + TRIMMING SCHEME
  - SIMULATIONS (e.g. LOCAL NON-UNIF.).

Q3C: RESIDUAL NON-UNIFORMITY
- REQUIREMENTS: Δλ ALLOWED VERSUS λ ACHIEVED (SHMAKOV);
- CROSS REFERENCE to UV ANNEALING Scheme
- CROSS REFERENCE to MC STUDIES (Q4): Δ ≲ 5%

Q3D: CR TOWER: UCSD
- EVIDENCE of STABILITY over TIME
- WITH UV MONITORS (UCSD, CMU).

Q3E: CALIBRATIONS: A SEPARATE CHAPTER
- → METHODS + TIME for A GIVEN ACCURACY
- RFQ Layout: ORNL + ACCSYS
- SIMULATION of PHYSICS: →
  MIPS; INCLUSIVE e: E/p; Zφ; OTHER
- RELATIONSHIP to UV MONITOR RUNS
- [- RELATIONSHIP to UV ANNEAL RUNS]

ZHONGNAN OPTICAL INSTRUMENT FACTORY
FOR COLLABORATION ON THE PRECISION MACHINING AND POLISHING OF BARIUM FLUORIDE CRYSTALS

2) Zhongnan Optical Instrument Factory will provide one (1) crystal pair to LLNL to replace the damaged crystal pair received at LLNL on July 1, 1992. The specification for this crystal pair is the same as for the damaged crystal pair and is an effort to show Zhongnan's capability to provide crystals to final finished specification. This is a fully polished crystal pair, as opposed to the five crystal pairs in job 1), which are rough cut only, and will be polished at LLNL. The crystal pair for this task was delivered to Zhongnan on July 9, 1992 by Professor Z.Z. Dai from BGRI.

3) Zhongnan Optical Instrument Factory will prepare a single crystal, either a front or back crystal half, with a reflective optical coating, consisting of 1250 Å of aluminum with an outer protective layer of 2500 Å of silica (SiO_2). Care should be taken so that the end faces of the crystal are not coated. The four (4) long sides of the crystal only, should be coated. This finished crystal will be sent to LLNL for analysis. It should be noted that all six (6) faces of this crystal should be polished to the best possible finish prior to coating.

LETTER OF INTENT
BY
BARIUM FLUORIDE COLLABORATION
TO
ZHONGNAN OPTICAL INSTRUMENT FACTORY
FOR COLLABORATION ON THE PRECISION MACHINING AND POLISHING OF BARIUM FLUORIDE CRYSTALS

Representing the Barium Fluoride Collaboration:	Dr. Craig R. Wuest Lawrence Livermore National Laboratory for Professor Harvey Newman, Spokesman for Barium Fluoride Collaboration California Institute of Technology
Representing the Zhongnan Optical Instrument Factory:	Mr. Zhang Chunyuan, Zhongnan Optical Instrument Factory for Mr. Song Shubin, Chief Director Zhongnan Optical Instrument Factory

The conditions to be met are: 1) Successful demonstration of radiation resistant BaF_2, 2) Successful demonstration of machining and polishing of large BaF_2 crystal pairs, 3) Successful demonstration of reflective optical coating of BaF_2 , 4) Acceptance of the BaF_2 Electromagnetic calorimeter by the GEM Detector Executive Committee, 5) Continued approval for funding of the SSC by the United States government.

Zhongnan Optical Instrument Factory is called upon to perform tasks in support of items 2) and 3). LLNL, BGRI and SIC are working to satisfy the requirement of item 1). Items 4) and 5) are somewhat beyond our control.

Because of time constraints, we are reducing our short term goal to produce 5 crystal pairs. It

Date: July 22, 1992

Specification for An Instrument Inspecting BaF2 Crystals

Li Dacheng, Wang Dongsheng
Yu Guanzheng, Zhang Yunxiang

Dept. of Precision Instruments
Tsinghua-GEM Collaboration
Tsinghua University, Beijing China

This instrument has the performance which can inspect dimensions of BaF2 crystals (flatness, perpendicularity, contour, and all dimensions).

- A comparison between the new instrument and that used by Shanghai Institute of Ceramics (SIC):

Items	the new instrument	SIC's instrument
Measuring range	0-250mm and 0-500mm	0-250mm only
Measurement software	all measured objects	No
Resolution	0.3μm	0.5μm
Precision	+-3μm	+-5μm
The number of inductive gauging heads	84 heads	42 heads

Proposal for welding 7x7 cels supporting structure of GEM Detector Barrium Fluoride EM Calorimeter

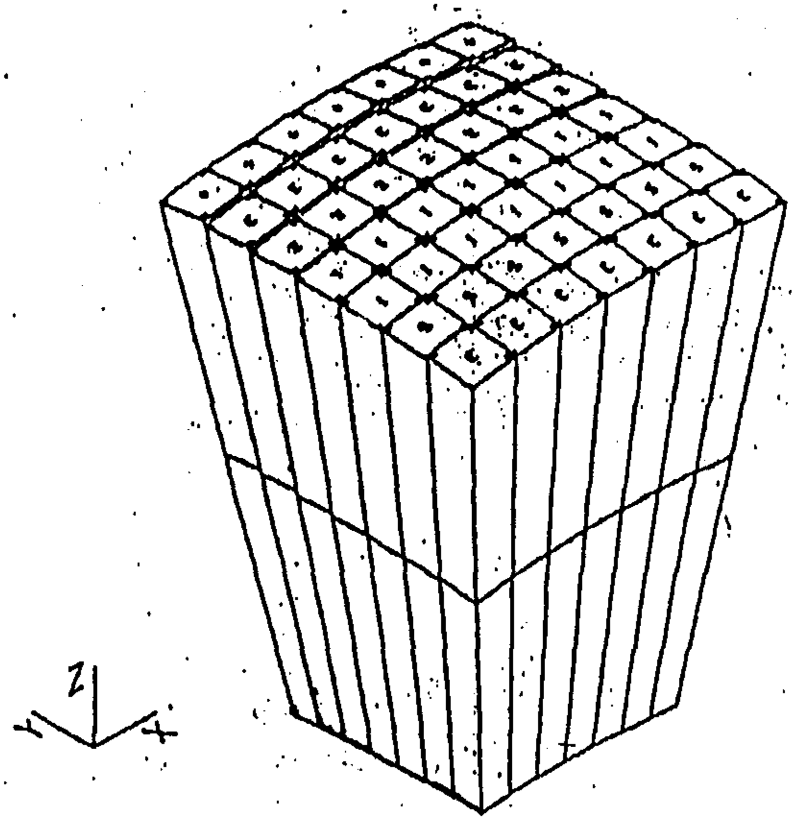
* TSINGHUA: 100μm Titanium alloy, LASER Welded Prototype Structure

Ke-ren Shi, Jia-lie Ren, Yun-ming Zhu
Wu-zhu Chen, Yan-xian Li, Bing-yi Yan

Dept. of Mechanical Engineering
Tsinghua GEM Collaboration
Tsinghua University, Beijing China
Fax: (861)2568116

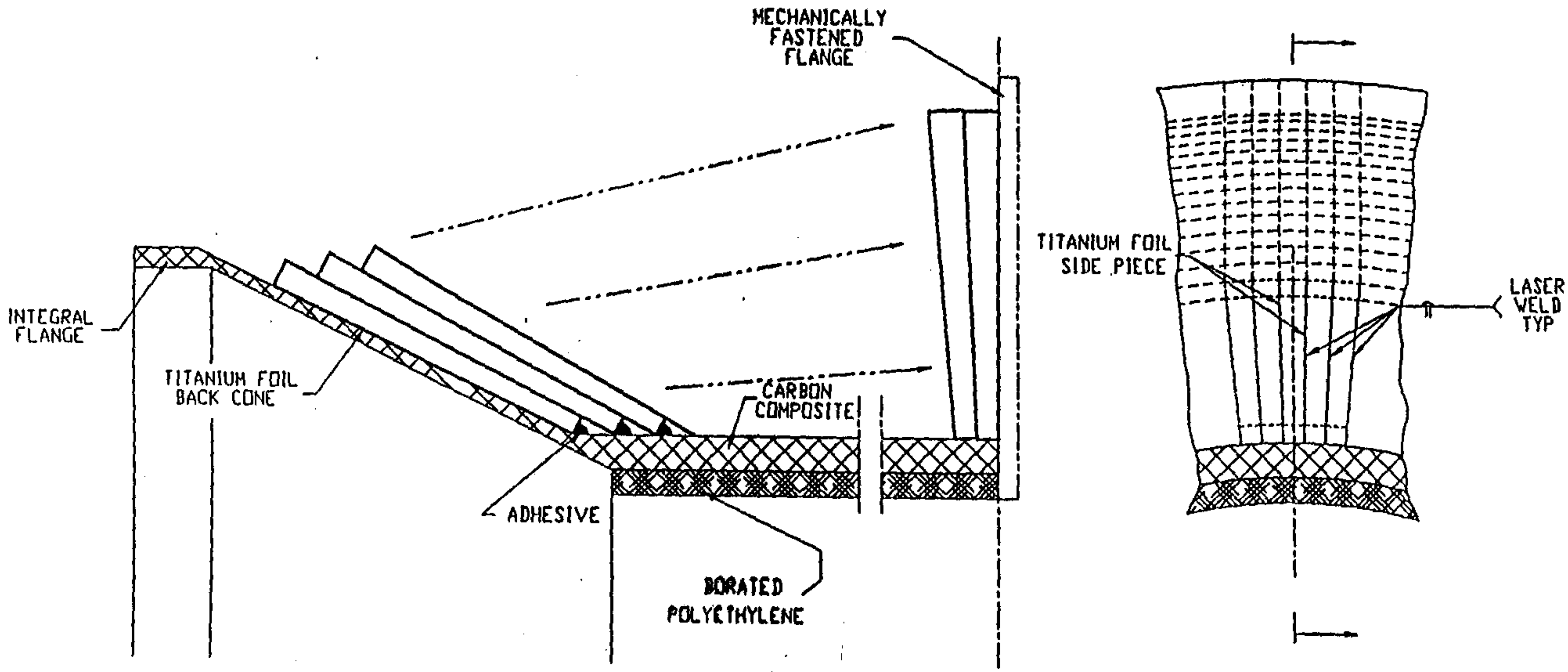
1. welding 7x7 cells of GEM Detector Supporting structure

1.1 Fig.1 shows the structure of 7x7 cells.



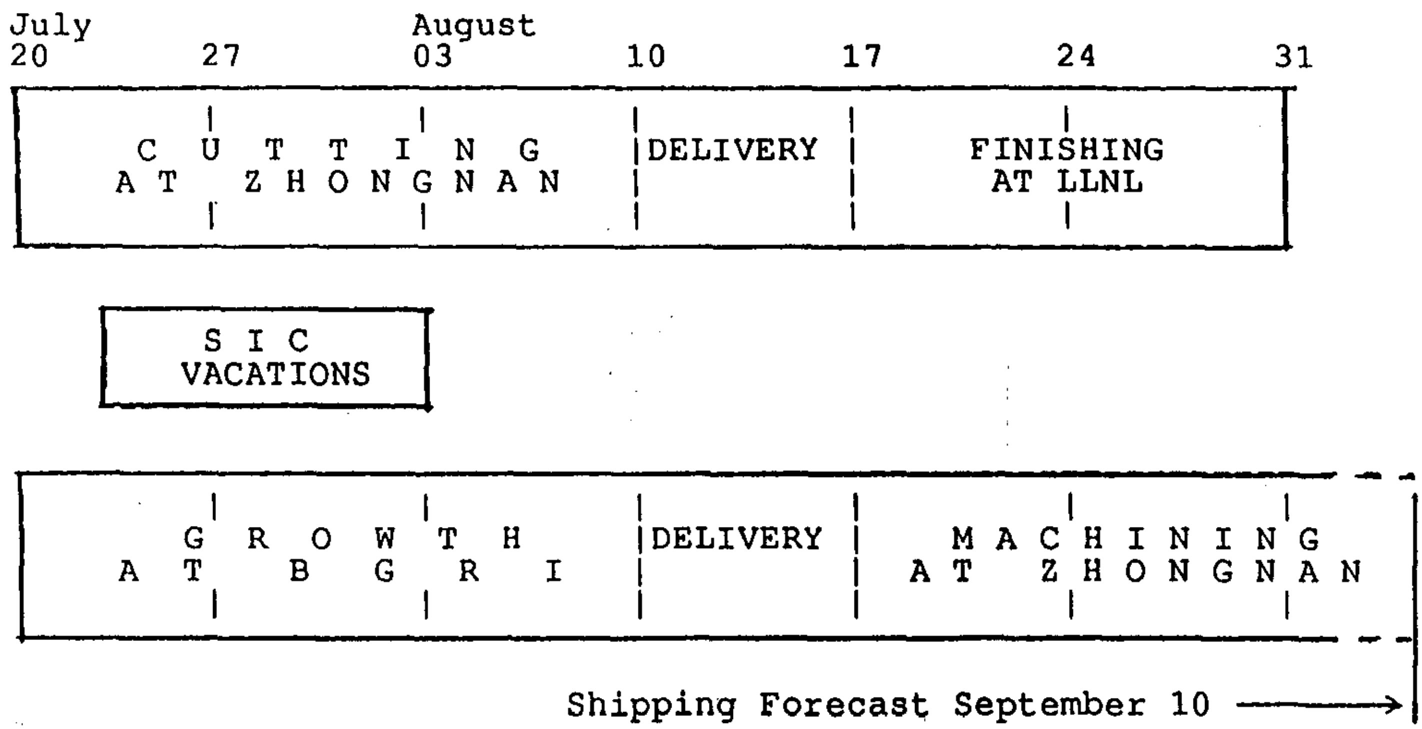
$30K

• 100μm TITANIUM alloy FOIL STRUCTURE
LASER (OR ELECTRON BEAM WELDED



CALORIMETER STRUCTURE ASSEMBLY - PART 3

CUTTING SCHEDULE AT ZHONGNAN (M. LEBEAU)



BaF_2 R&D STATUS (JULY 1992)
CRYSTAL MANUFACTURING PLAN

- CRYSTAL GROWTH: SIC, BGRI
- MECHANICAL PROCESSING AND INSPECTION: ZHONGNAN OPTICAL INSTRUMENT FACTORY
  - LoI for Full BaF_2 Production Signed July 14
  - Mass Production: 15 Pairs Per Day, For 3 Years.
  - Precision Cutting, Lapping, Polishing, and Optical Inspection Machines (1 μm, 1 μrad) Available
  - → Technology Transfer from LLNL: Final Lapping and Polishing Process
  - → Large Inductive Multipoint Inspection Machine (L3 Type), To Be Built at Tsinghua Univ.
- MECHANICAL STRUCTURE: TSINGHUA UNIVERSITY (ORNL)
  - CO_2 Laser Beam Welding of 100 μm Titanium Alloy Foils
  - Proposal for Complete 7×7 Precision Prototype Structure for $ 30K.
  - → Laser Welded Samples Meeting Specifications By Mid-August.
- → UV REFLECTIVE COATING: ZHONGNAN, BGRI (LLNL)
  - Production With BGRI 4 Meter Coating Tank
  - Technology Transfer from LLNL
- → QUALITY CONTROL and BENCH TESTS: IHEP BEIJING

Q1C EVIDENCE* of MANUFACTURABILITY & COST • UPDATE BOOKS

→ DETAILED GENERAL PLAN : ORNL; LLNL

→ POLISHING + SURFACE : B.FUCHS ✓

→ COATING PLAN : LLNL (METHOD); LLNL + ZHONGNAN (IMPLEMENTATION)

COST → $2.5/cc (NEGOTIATE COATING).

Q1D INCLUDE WORK REQUIRED TO PREPARE CRYSTALS AFTER DELIVERY

→ DEFINE QUALITY CONTROL STEPS: IHEP + ORNL, LLNL, CALTECH

→ TESTS • After POLISHING
• After COATING
• IRRADIATION : SPOT CHECKS

→ UNIFORMITY TESTS: COSMIC RAY TOWER

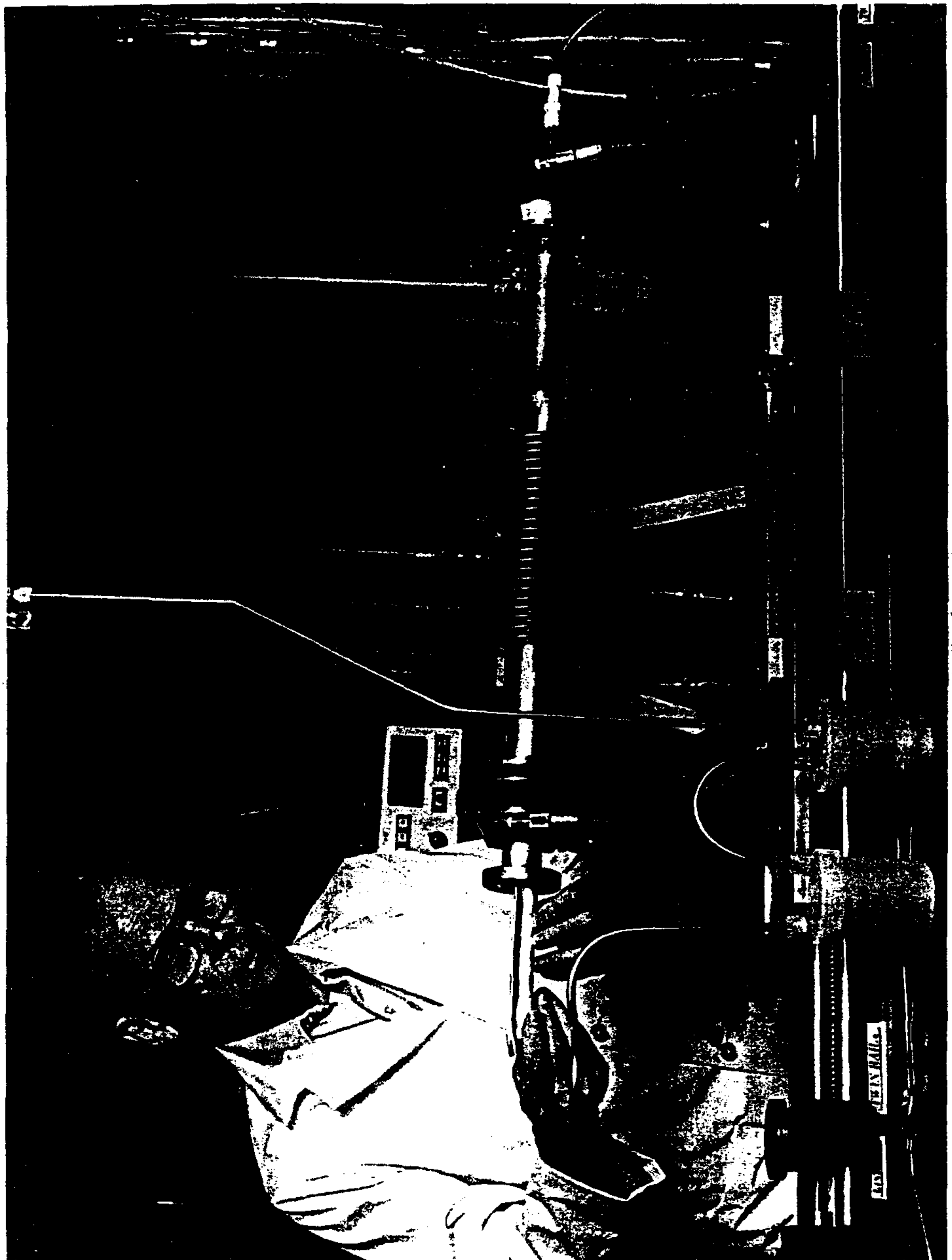
→ COATING ADJUSTMENT SCENARIO

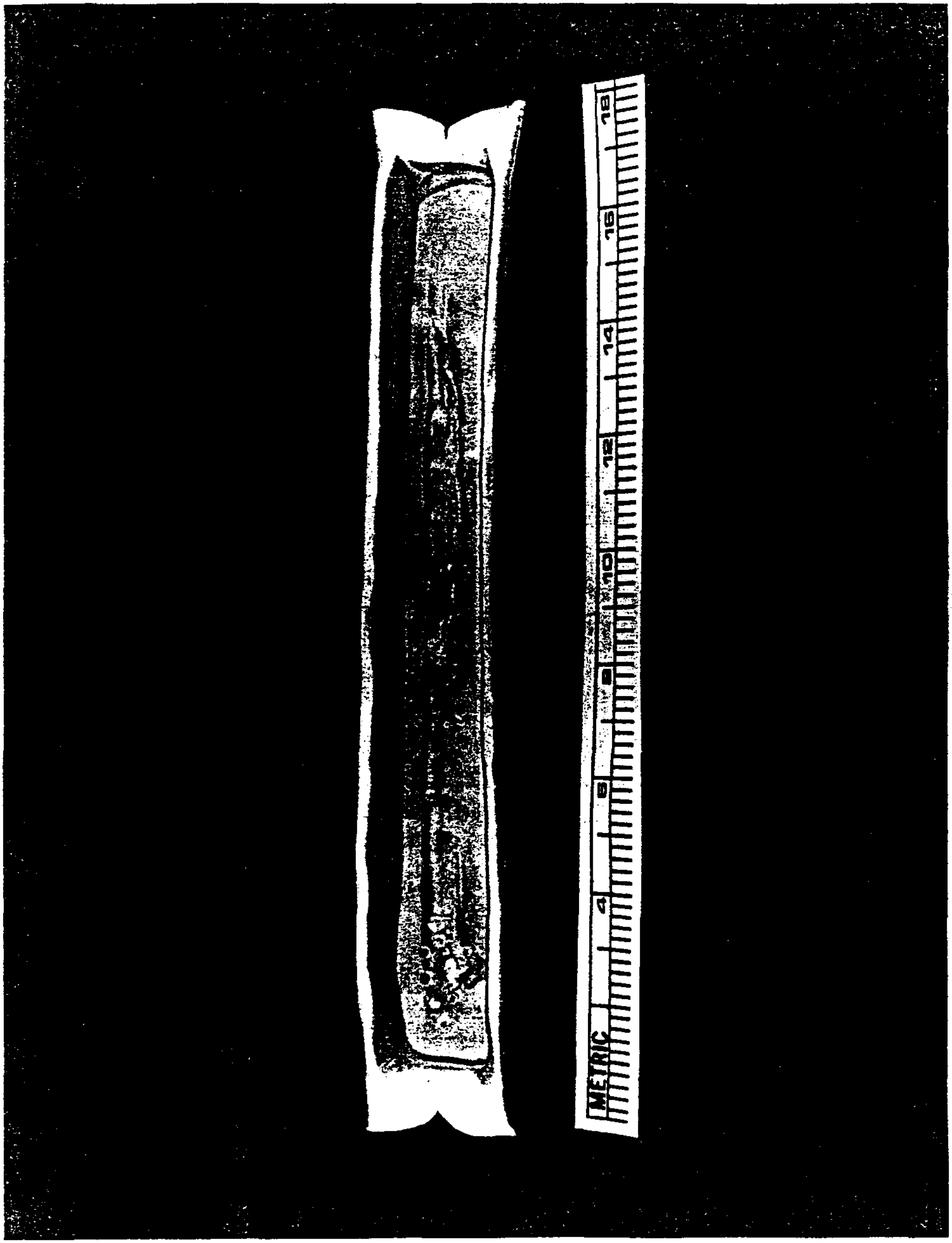
[→ UV ANNEALING VERIFICATION (After IRRADIATION SPOT CHECKS)

→ • GOAL: COMPLETED CRYSTAL PAIRS for $2.5/cc

* EVIDENCE: Refer to: L3

- CARBON FIBER PROTOTYPE STUDY ✓
- FEMA1 : CARBON FIBER ✓
- FEMA2 : Ti ALLOY FOIL
- CRYSTAL BARREL STRUCTURE (M.L.) + TESTS
- TSINGHUA PROPOSAL + SAMPLES
- ZHONGNAN CRYSTAL PAIR + COATED PIECE...
- MANUFACTURE + ASSEMBLY SEQUENCE




METRIC
4
6
8
10
12
14
16
18

- Q2: PRODUCE SMALL RAD HARD CRYSTALS
  → REVIEW SCHEDULE NOW
  - SELF-EVALUATION of EXPERIENCE at LLNL (AUG. 24)
  - STATUS; POTENTIAL FURTHER STEPS at LLNL
  - SELF-EVALUATION of ULTIMATE TIME for SUCCESS; TIME ESTIMATE? TESTS?

- REVIEW of Q1A, Q1B, Q2
  - By BaF_2 SUBPANEL 8/31 - 9/1
  - Begin ORGANIZATION of THIS Meeting NOW (H.N.).

- NOTE PANEL REPORT:
  "REFRACTORY METALS (W, Ta, Mo) WILL not WORK; THEY STICK" →
  - REVIEW IN LIGHT OF EXISTING LLNL EXPERIENCE
  - OVERALL REVIEW + COMMENT, AS SOON AS DRAFT IS AVAILABLE
  - ANALYSIS of DATA, By BaF_2 SUBPANEL

- UPDATED SUMMARY Reports By all GROUPS (LLNL, OPTOVAC, SIC, BGRI) By 8/24.

From: IN%"REN@ORNLSTC.BITNET" 8-AUG-1992 11:23:31.17
To: IN%"newman@CITHE1.CITHEP.CALTECH.EDU"
CC:
Subj: crystal bleaching light

ENGINEERING

Harvey,

We have begun to look into light annealing (bleaching) of crystals in-situ by calling several companies to see if it is as straight forward as it seems. Apparently it is. Of initial interest is Fiberoptic Engineering of Panama City FL (904-763-2209, Frank Pettis). They produce light/fiber sets for both remote lumination (e.g. the Constitution) and pulse light measurements. A "standard" product is a 150W Tungsten/Halogen lamp with a parabolic reflector and fiber attachment. The assembly focuses approximately 70% of the produced light to a bundle up to .5 inches in diameter. They prefer bundles of 125 micron fibers for flexibility and reliability (breaks are not fatal). The fibers can be bundled and grouped as required for distribution of light to multiple crystals. Both ends of the fibers are polished. They are willing to produce a single prototype unit based on our requirements. In fact he noted that they could rework the unit as needed to alter the distribution of fibers(?).

The Tung/Halogen lamp has as relatively short life of 200 hours at full power. There are innumerable alternatives which we can pick from once the requirements are better understood. A Cermex Xenon lamp seemed to be a favorite.

The quartz fiber is common and should not be a problem. Fiberoptic noted that they can work with all varieties of fiber.

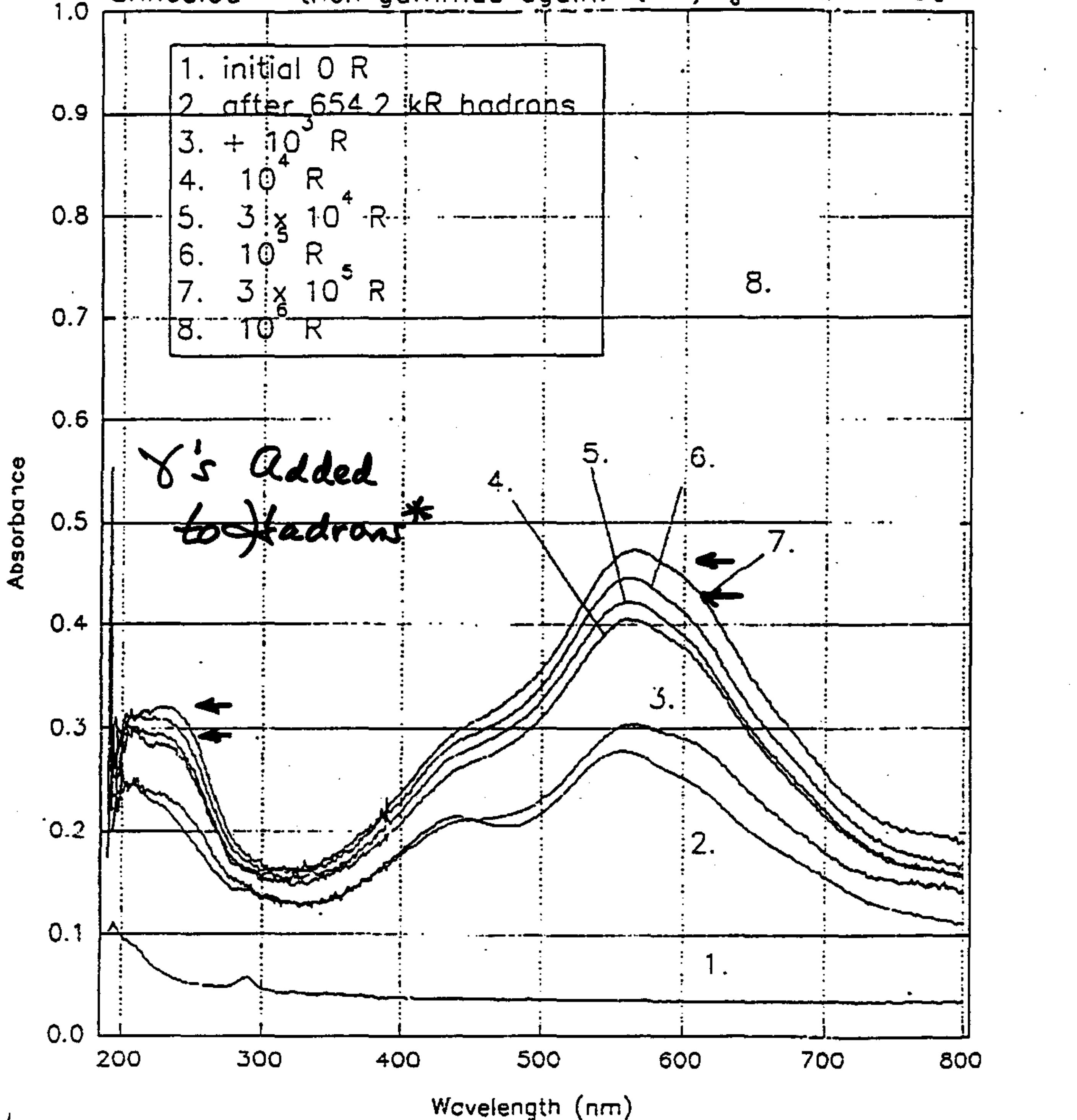
Coupling to the crystal is something we meet to discuss with you tomorrow. If a spot is not acceptable there are several diffusers which can be built into the crystal attachment fixture (e.g. mirrored cones)

Cheers, Mark

TODAY

• ANNEALED (500°C) ; HADRONS THEN

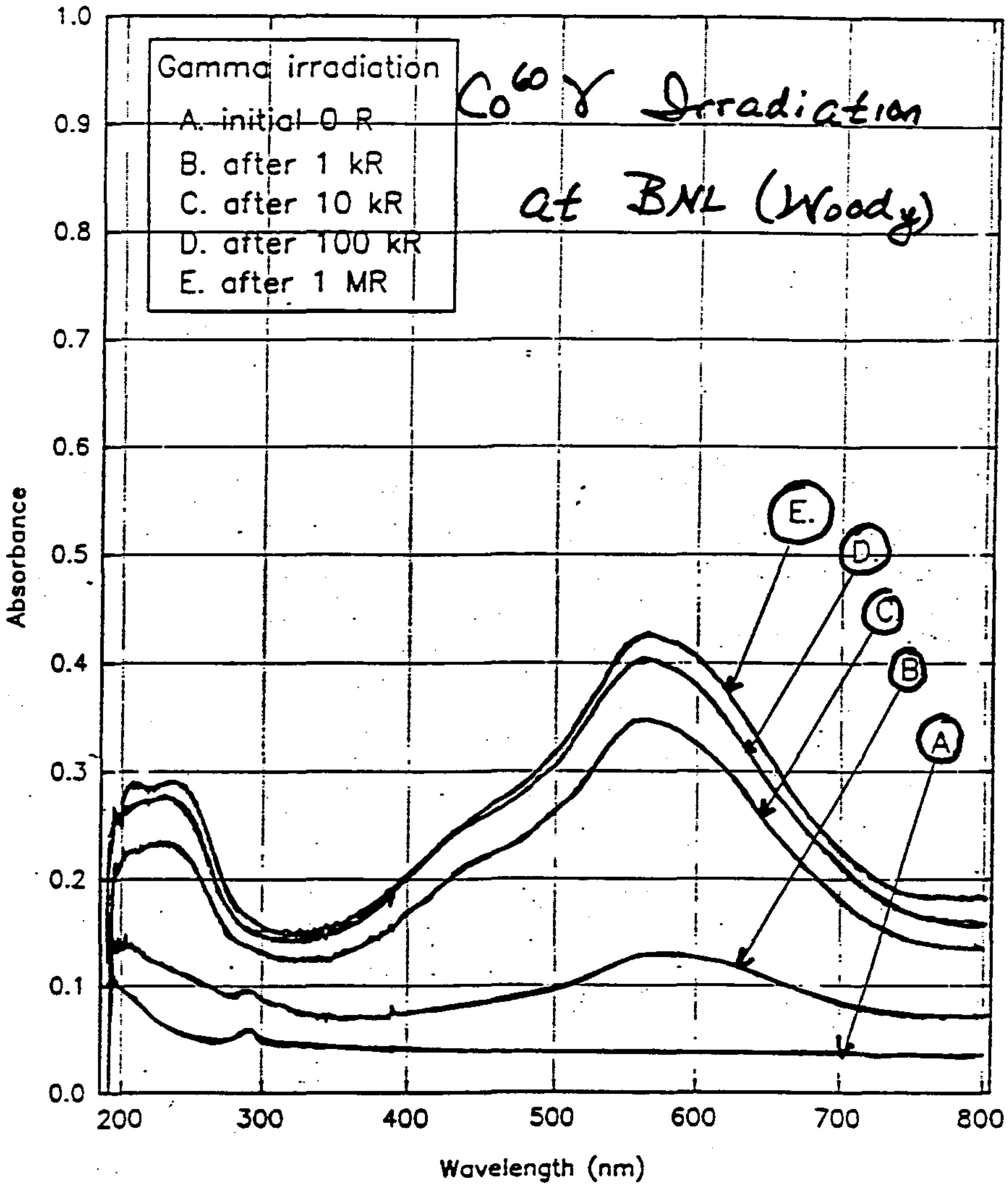
20cm BaF2 Trapezoid #sic703 PHOTONS 7/29/92
irradiated with gammas and annealed. hadrons - not
annealed - then gammas again. (i.e., gammas added to hadrons



* 2 MRAD HADRONS
+ 1 MRAD γ's

* Note 8/7 Curve vs. 7/29 vs. 7/27

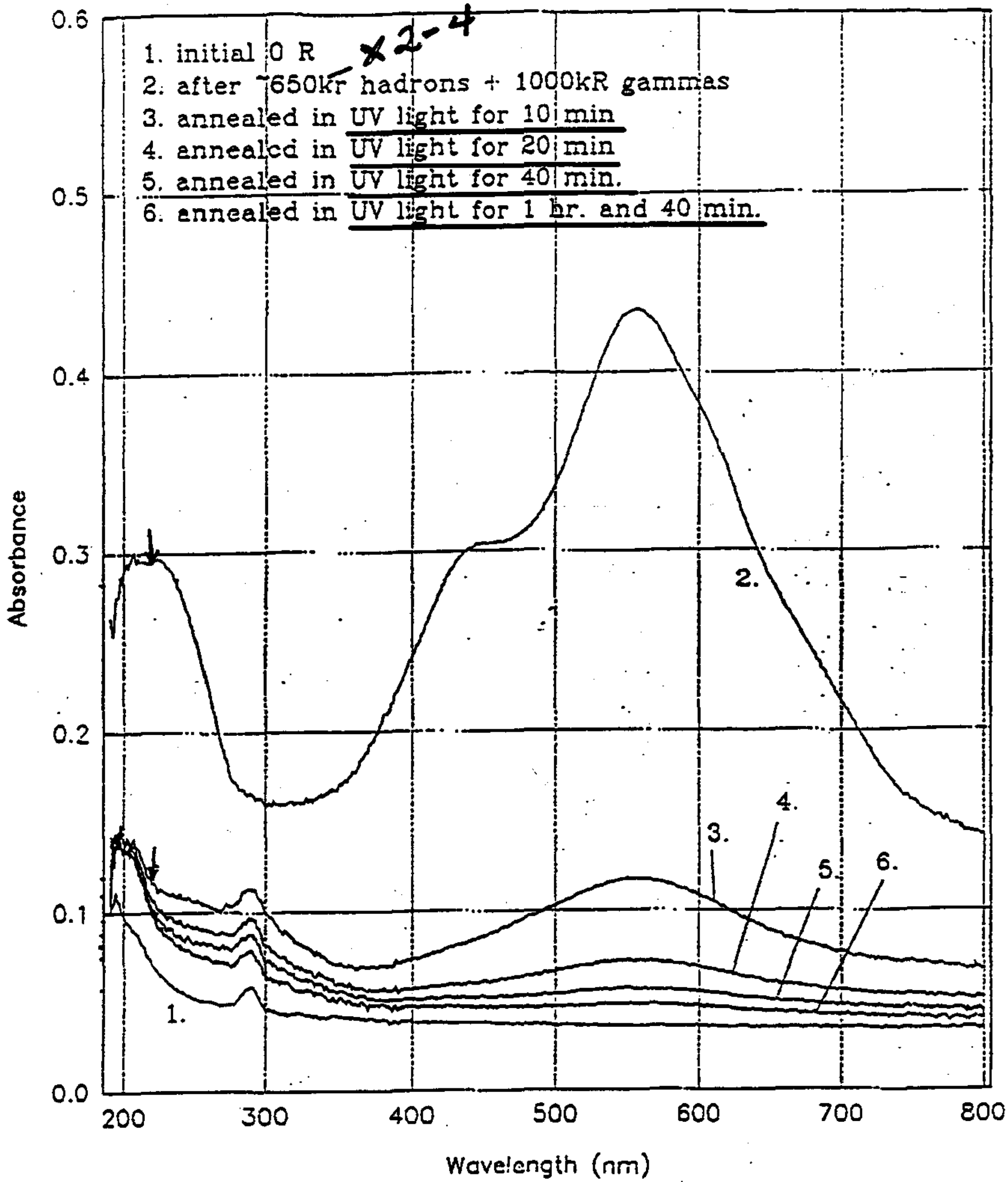
20cm BaF2 Trapezoid #sic703 7/28/92



- PREVIOUS: ANNEALED at 500 °C THEN Co^{60} γ's (Before Hadrons)

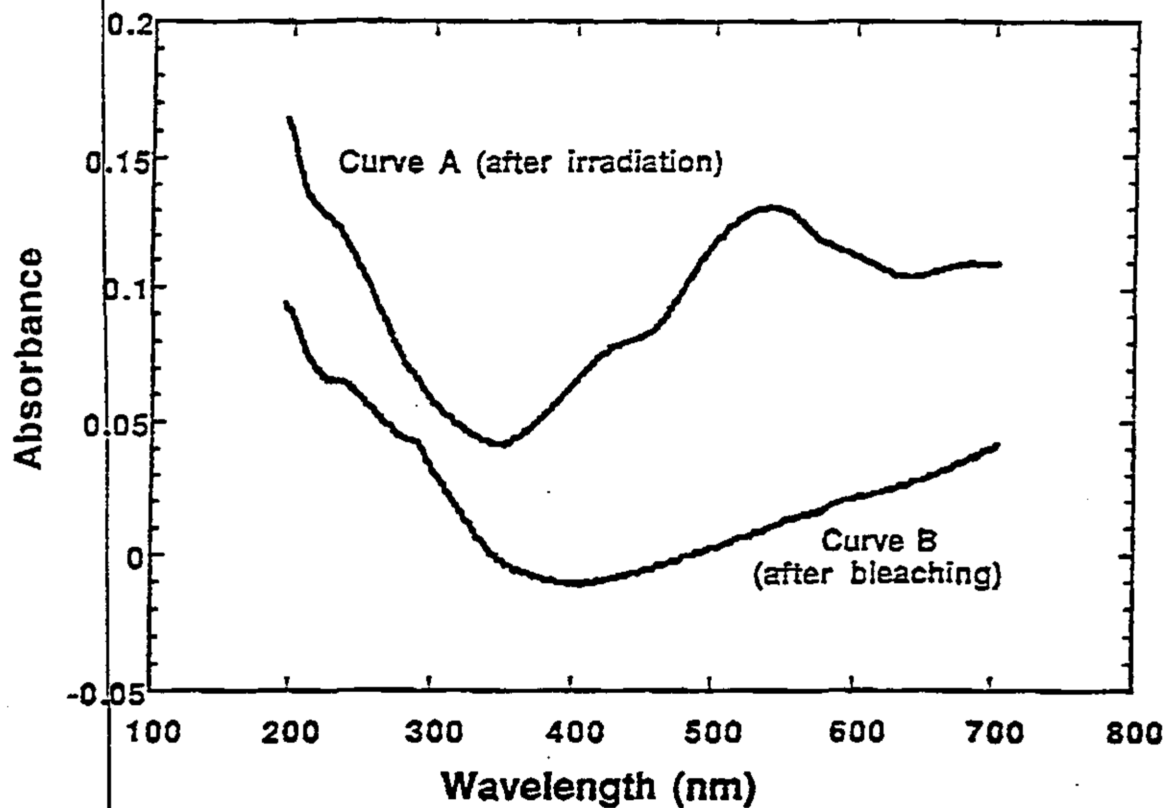
8/7/92

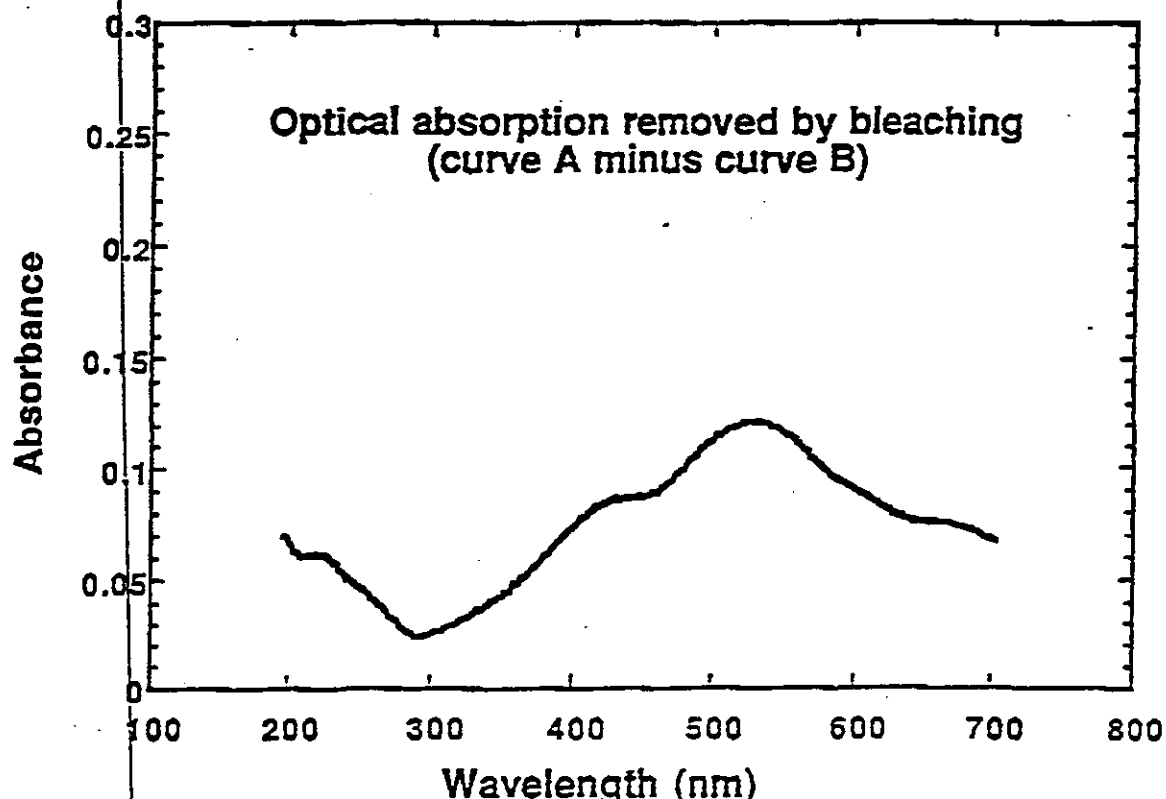
Radiation damage and recovery of SIC703 with exposure to UV light.



• BNL: ANNEALING WITH UV LIGHT

• WEST VIRGINIA UNIVERSITY





• BASELINE NOT SUBTRACTED
(1ST RESULTS)

• WEST VIRGINIA UNIVERSITY

PROGRESS REPORT

EFFECT OF OPTICAL BLEACHING ON RADIATION-INDUCED DEFECTS IN BaF_2

Submitted by:

Larry E. Halliburton, Michael P. Scripsick, and Gary J. Edwards
Physics Department, West Virginia University
Morgantown, WV 26506

August 8, 1992

Initial Results:

We have made a preliminary investigation of the effects of optical bleaching on radiation-induced defects in BaF_2. A relatively large piece of Chinese-grown material was irradiated at room temperature for 17.75 hours with ^{60}Co gamma rays. Total dose was approximately one Mrad. After irradiation, the optical absorption was taken from 197 to 800 nm and is shown as curve A in the upper portion of the accompanying figure. This curve represents the "raw" data and has not had the spectrometer's baseline subtracted. The optical path length in the crystal was about 2 cm. Significant absorption is present in the visible region and smaller absorption is present in the ultraviolet region. CURVE A

We exposed this sample to the output of a Hg arc lamp in our laboratory. Glass filters which allowed only light with wavelengths longer than 340 nm to pass were placed in the optical path before the sample. The lamp was operated at 200 Watts and the exposure time was 40 minutes. After this optical bleach with 340 nm and longer wavelengths, we again took the optical absorption spectrum of the sample from 197 to 800 nm. This is curve B in the upper portion of the accompanying figure. CURVE B

Next we took the difference between curves A and B. This difference spectrum is shown in the lower portion of the accompanying figure. Radiation-induced absorption in the ultraviolet region and in the visible region were destroyed by the 340 nm and longer bleaching light. An absorption spectrum taken after a subsequent bleach with the full output of the arc lamp (i.e., all wavelengths) was nearly identical to curve B above. These results suggest that optical bleaching with 340 nm and longer wavelength light can eliminate radiation-induced ultraviolet absorption bands in BaF_2. It is important to note that these are the results of one experiment and they must be verified in the future. DIFFERENCE CURVE

*

From: IN%"WUEST@si151a.llnl.gov" 7-AUG-1992 17:47:19.33

Well we are getting a first look at optical annealing and I have sent the data to ORNL and SSCL and also to the Fairmont Hotel in Dallas for Harvey. It appears that after 100 krad exposure to cobalt-60 a one inch cube reduced its transmission from 85% to 71% at 200 nm. After 90 minutes exposure to a small Pen-Ray mercury lamp in an aluminum foil lined beaker the crystal was remeasured and the transmission has improved to 77%. We will have another data point for an additional 90 minute exposure then we will leave the crystal over the weekend. On Monday we will put the fully annealed crystal (thermal annealing if necessary) back in the Co-60 with a halogen lamp nearby to determine that the bleaching can be achieved in situ. This will take us to about Wednesday morning. In the mean time we will assemble a second cube with a quartz fiber optic and a light source that we can use for the fiber. We will attempt to study color and intensity as well but I am not sure how far we will be by Friday.

Cheers,
Craig

p.s. if anyone wants to call me at home my number (510) 736-8992

- 100 kRads in 40 Hours;

Recovery:

- 90 MINUTES WITH SMALL UV Lamp

- T(220 nm): 89% → 74% → 80% [IDEAL: λ → ∞ ⇒ T = 91%]
  - Co60 (to 74%), SMALL UV Light (to 80%)
- (200 nm): 85% → 71% → 77% ⇒ 40% RECOVERY

It was the view of the panel, in my recollection, that all due haste should be placed on determining the power and frequency requirements for optical bleaching of current SIC crystals. This data, along with an engineering study on how to deliver light to the crystals during operation should be presented to GEM prior to September 4, 1992.

Additional items supporting In situ optical annealing include:

1) An estimate for the optical transmission rate of change in present SIC crystals is 0.002 percent/Rad (20cm crystal, 20% loss of transmission at 200nm for a 10KR irradiation). This yields the following:

Position	Radiation per year	Transmission change	Resets/hr for 0.5% Change
• 90 Deg	20kR/yr	0.017%/hr	0.034
• 30 Deg	50kR/yr	0.042%/hr	0.084
• 9 Deg	500kR/yr	0.417%/hr	0.84

- Thus, for even the most brutal SSC environments, bleaching on an hourly basis will exceed the design limit of less than 0.5% overall change in the optical transmission. Depending on the optical power level required, bleaching should not impact the live time operation of the BaF2 detector system.

2) Undamaged BaF2 crystal is transparent, allowing the bleaching photons to be preferentially absorbed where they are needed most, at the color centers.

3) The use of continuous optical exposure of crystals to long wavelength photons, below the solar blind cutoff, may completely eliminate measurable radiation induced transmission loss in existing SIC BaF2 crystals.

It was also the view of the panel, in my recollection, that crystal radiation hardness will improve during the production cycle. This is due to serval factors including aging of the crucibles, production controls, and increased operator experience. This effect was reported to be the case for several previous large scale crystal productions.

CHARLES EVANS & ASSOCIATES
SPECIALISTS IN MATERIALS CHARACTERIZATION

August 7, 1992

TO: Harvey Newman
Lauritsen Laboratory
California Institute of Technology
391 S. Holliston
Pasadena, CA 91125

FM: Michael D. Strathman

RE: Summary of Critical Issues in BaF2

In this report I will attempt to summarize some of the important findings of the Panel on Barium Fluoride and the relationship of these findings on the technical feasibility of BaF2 for use as a High Resolution Detector.

I. Preirradiation of crystals:
Not viable with existing quality crystals.

II. Optical annealing of BaF2 color centers:

a) Optical annealing is currently one of two STANDARD methods of annealing radiation induced color centers in BaF2. It is used to return irradiated crystals to their PREIRRADIATION level of transparency.

b) Optical annealing works with EXISTING crystals. Increased radiation hardness, while desirable, is not needed to return crystals to unirradiated transparency.

c) Optimum frequency and power required to bleach color centers in BaF2 should be determined. There is variability in the literature on this subject. Annealing conditions range from short low power exposures to several hours of ultraviolet light.

d) Thermal Luminescence data indicate that many of the traps in irradiated BaF2 are less than 0.6eV. This data suggests that long wavelength photons, desirable because they will not affect the overall noise of the solar blind photomultipliers, may be sufficient to bleach BaF2.

* e) If optical annealing can be implemented "in situ", it will allow existing SIC crystals to meet all GEM calorimeter requirements.

---

301 Chesapeake Drive • Redwood City • CA • 94063 • (415) 369-4567 • Telex 172747 • Fax (415) 369-7921

CONCLUSIONS

- BaF_2 is an intrinsically radiation-hard material, especially in the ultraviolet.

- Radiation-induced ultraviolet absorption bands are due to small concentrations of hydrogen/oxygen and transition-metal ions (Mn^{2+}).

Two ways to minimize radiation damage in BaF_2:

1. Continue to improve crystal growth procedures (progress is being made in this direction).

→ 2. Develop a post-growth procedure to remove unwanted impurities. One possibility is electrodiffusion, where an external electric field applied during irradiation drives impurities out of the crystal.

Sept.: IMPORTANT for further Outlook

BaF_2 R&D STATUS (JULY 1992)
SMALL PURE CRYSTAL PRODUCTION

- SMALL ULTRA-PURE CRYSTAL GROWTH at LLNL
  - Pretreatments With Specific Reactive Gases (Not Just HF)
  - Noble Metal Versus Coated Carbon Crucibles
  - Zone Refining to Increase Crystal Purity
  - First Pure Crystals: Target Date mid-August
- SMALL ULTRA-PURE CRYSTAL GROWTH at OPTOVAC
  - RGA $\Rightarrow$ Hydrolysis (Outgassing): Use Reactive Gas Scavenger
  - First Growth Runs Done To Fix Oven Cycle
  - Optipur Vs. Sublimed; Special Purity BaF_2 : CE&A GDMS Analysis
  - VUV Bandedge Study
  - → Growth Run With 3 Raw Materials (3 Ingots)
  - → Treated Carbon Crucibles Standard. Ta, Mo and W Pure Metal Crucible Trials in July - August
  - → First Pure Crystals: Goal Mid-August

BaF_2 R&D STATUS (July 1992):
CRYSTAL PRODUCTION (SIC, BGRI)

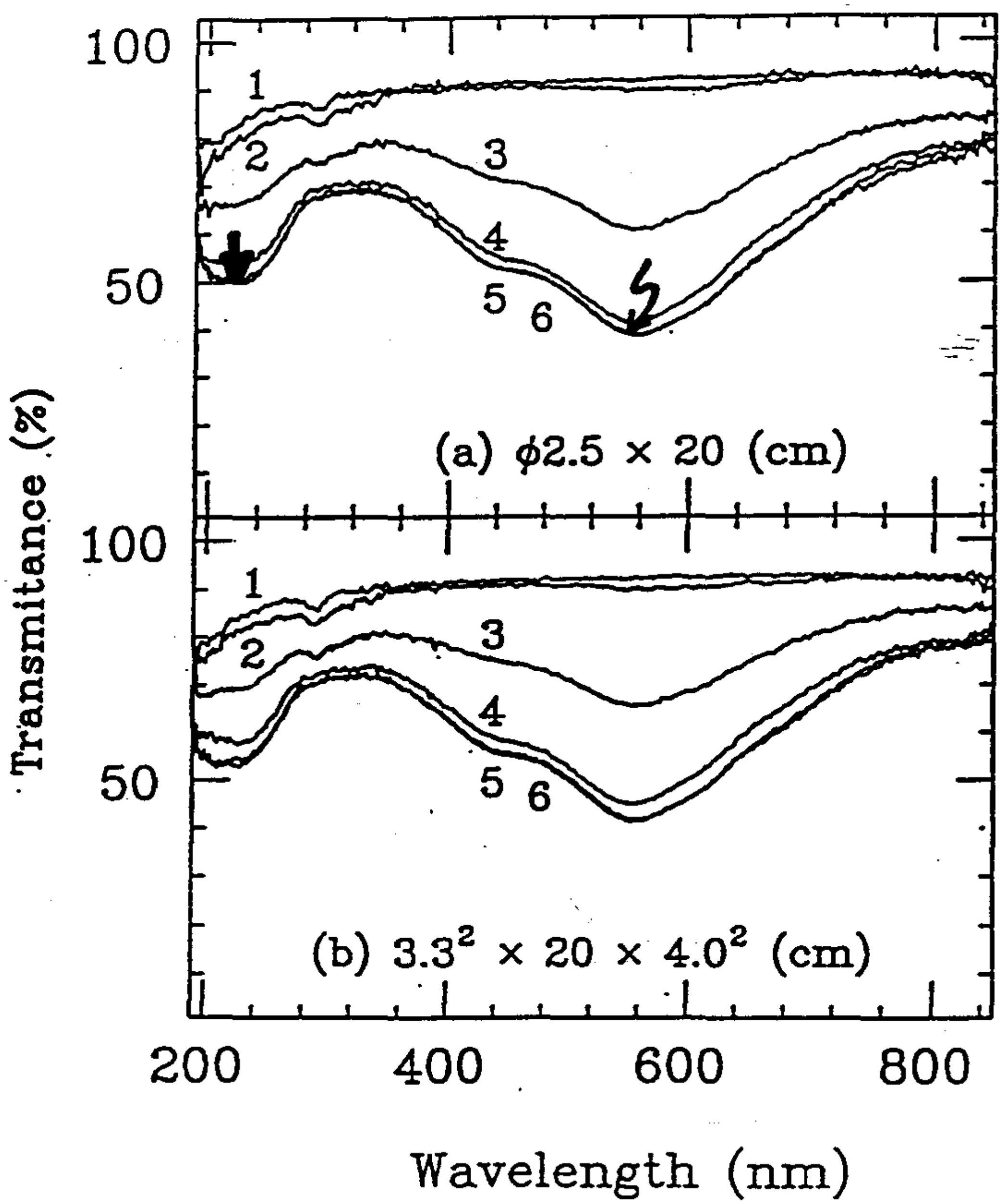
- NEWER CRYSTALS

- – T(220 nm) in 26 cm Crystal (SIC):
  48% After 1 MRad $\mathcal{L}_{att} \approx 40$ cm
  – 350 mm Crystal (BGRI): Heating System With High Gradient At Solid/Liquid Interface.

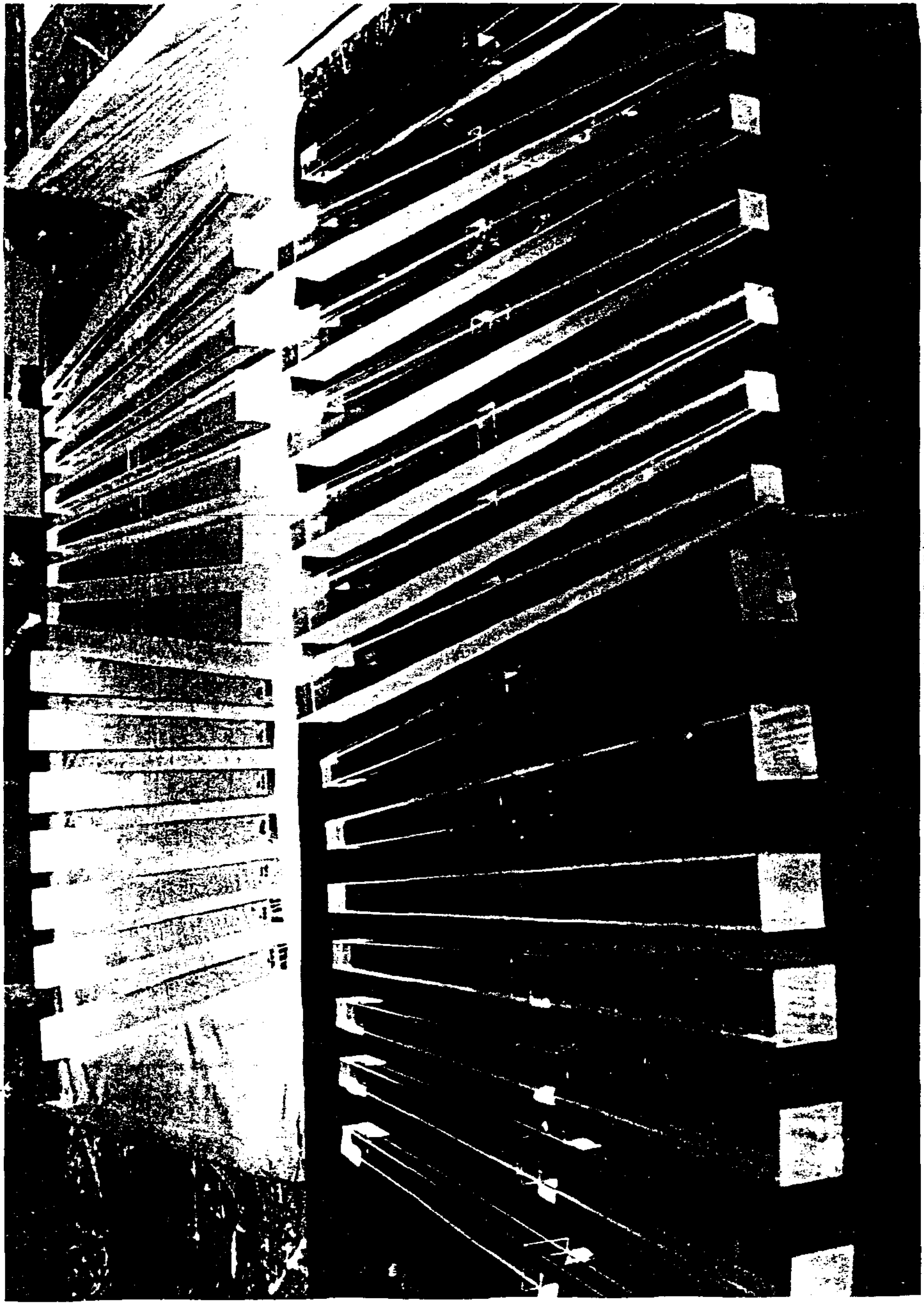
- – SIC: Several Improved Crystals From One of Four Factories (Hainan); '703' Scavenger
  - ⇒ Possible Correlation With Cr, Mg Traces
  - ⇒ Tests Needed at CE&A (GDMS, SIMS) and NRL (DRT) in August

- IMPROVED RAD HARD CRYSTALS in August:

- – Chemical Pre-Treatment (BGRI):
  Remove $Ba(OH)_2$
  – Dry Raw Materials With High Temperature Noble Gas Flow
  – High Vacuum Pre-Melting Furnace:
  Improved Residual OH^- Extraction
  – Growth In Higher Vacuum: Cold Trap
  – Improved Heating System: Higher Gradient At Solid/Liquid Interface
  – Optimize Growth and Anneal Cycle Parameters:
  – Continue To Study Impurity Effect, Damage Mechanism: Spectroscopy, EPR, e-Diffraction, EELS



Transmittance spectra of two 20 cm long BaF_2 crystals, recently produced at SIC, before (1) and after ^{60}Co γ-ray irradiation with dosage of 100 (2), 1k (3), 10k (4), 100k (5) and 1M (6) Rads.



- Q1A : DEMONSTRATE SUBSTANTIAL IMPROVEMENT in RAD HARDNESS
- Q1B : PRESENT DETAILED PLAN to OBTAIN final GEM QUALITY CRYSTALS

---

(1) → Q1A : CONTINUED WORK at SIC, BGRI : ($\lambda \geq 60$ cm ; 1 MRAD) [STATUS]

(2) → Q2 : NEW WORK at LLNL ($\lambda \geq 95$ cm ; 1 MRAD) [STATUS]

(3) → Q1B : If (1) and/or (2) SUCCEED ;
- REVISIT BNL DATA on SATURATION
- DUBNA (or GATCHINA) TEST :
  <u>DISCUSS NOW</u>

---

(4) → <u>ELSE</u> : <u>In SITU ANNEALING</u> (ONLY) WILL SATISFY GEM CRITERIA
- ENERGY ; ν(LIGHT) ; LAYOUT ; RUNNING MODE
- LAYOUT : ORNL
- TESTS : BNL , LLNL , WVU {LAMPS, LASERS}
- FIBER BUNDLES , DIFFUSER ; PHOTODEVICE : ORNL , UCSD

- BREAKDOWN of EACH QUESTION
- APPROACH ; ALTERNATIVES : RAD HARDNESS
- WHO WILL RESPOND to EACH PART:
  - STUDIES to BE DONE
  - STATUS REPORT SCHEDULE: DOCUMENT; SUMMARY
  - PRESENTATION
- MEETING SCHEDULE
  - BaF_2 SUBPANEL : AUG. 31 - Sept. 1
  - CALORIMETER GROUP : Sept. 2
  - COLLABORATION COUNCIL: Sept. 3
  - EXECUTIVE COMMITTEE: Sept. 4

  → DECISION

H. NEWMAN

• DISCUSSION of ANSWERS IN SEPTEMBER

APPENDIX A.

Requirements for Each GEM Electromagnetic Calorimeter Technology

The GEM Executive Committee reviewed the status of the EM calorimetry R&D Programs, and formulated the following list of requirements for each technology:

A. Requirements for BaF_2 Technology

1. (A) Demonstrate substantial improvement in the radiation resistance of large BaF2 crystals (20-25 cm long) towards the GEM specifications - reach absorption length of at least 60 cm at 220 nm after 1 MRad irradiation with photons, and if possible with high energy hadrons. Present (B) a detailed plan to obtain final GEM quality crystals, along with (C) evidence of manufacturability and cost, including (D) work required to prepare crystals after delivery.

2. As proposed by the Expert Panel, produce small radiation-hard crystals to demonstrate there are no fundamental limitations in making radiation hard BaF_2 crystals (e.g. absorption length $\geq$ 95 cm at 220 nm after 1 MRad)

3. Address in detail questions of (A) preradiation, (B) wrapping, (C) residual non-uniformity, in crystals we can practicably expect to manufacture. (D) Cosmic ray transverse measurements in produced crystals could provide useful data. Provide (E) a detailed practical plan for calibration of the BaF_2 system in-situ: describe the calibration strategy, RFQ layout, and the required calibration time for each proposed technique to achieve the necessary accuracy.

4. Show by MC and by lab tests that the following effects do not destroy the resolution of the BaF2 system (maximum tolerable constant term is 0.6%:

(A) – Residual non-uniformity (as installed);

(B) – Non-uniformity developed by possible further radiation damage of "saturated" crystals and/or by possible annealing; (Note - the expert panel and executive committee are not convinced of the proposal to preradiate the crystals) ←

(C) – Accuracy of intercalibration (see point 3);

(E) – Short term instabilities of readout system;

(F) – Linearity, linearity calibration and dynamic range of readout system.

(D) POSSIBLE ANNEALING

BaF_2 R&D STATUS (JULY 1992) ZHONGNAN OPTICAL INSTRUMENT FACTORY

Zhicheng, Hubei Province, China

- High Precision, Medium Precision Telescope Lenses, Mass Produced Optics (600 K Pieces Per Year)
- Precision Diamond Sawing, Grinding, Lapping and Polishing Machines Available
- Full Sized BaF_2 Crystals Already Processed: Cutting Speeds 2-3 mm Per Minute
- Optical Inspection Facility: Dimensions, Angles, Parallelism, Perpendicularity, Surface Roughness, Flatness, Internal Stresses, UV/VIS Transmission
- SHORT TERM PROGRAM:
  - Precision Cut, Diamond Polished Pair: Begun 7/20; Delivered To LLNL For Inspection By 8/10
  - Precision Polished Crystal Piece Coated At Zhongnan: 1250A° Al, 2500A° SiO_2
  - Provide Five Unpolished Crystal Pairs. To Be Finished, Inspected At LLNL; Tested At CE&A.

BaF_2 PRECISION EM CRYSTAL CALORIMETER NEW MAJOR R&D PARTNERS

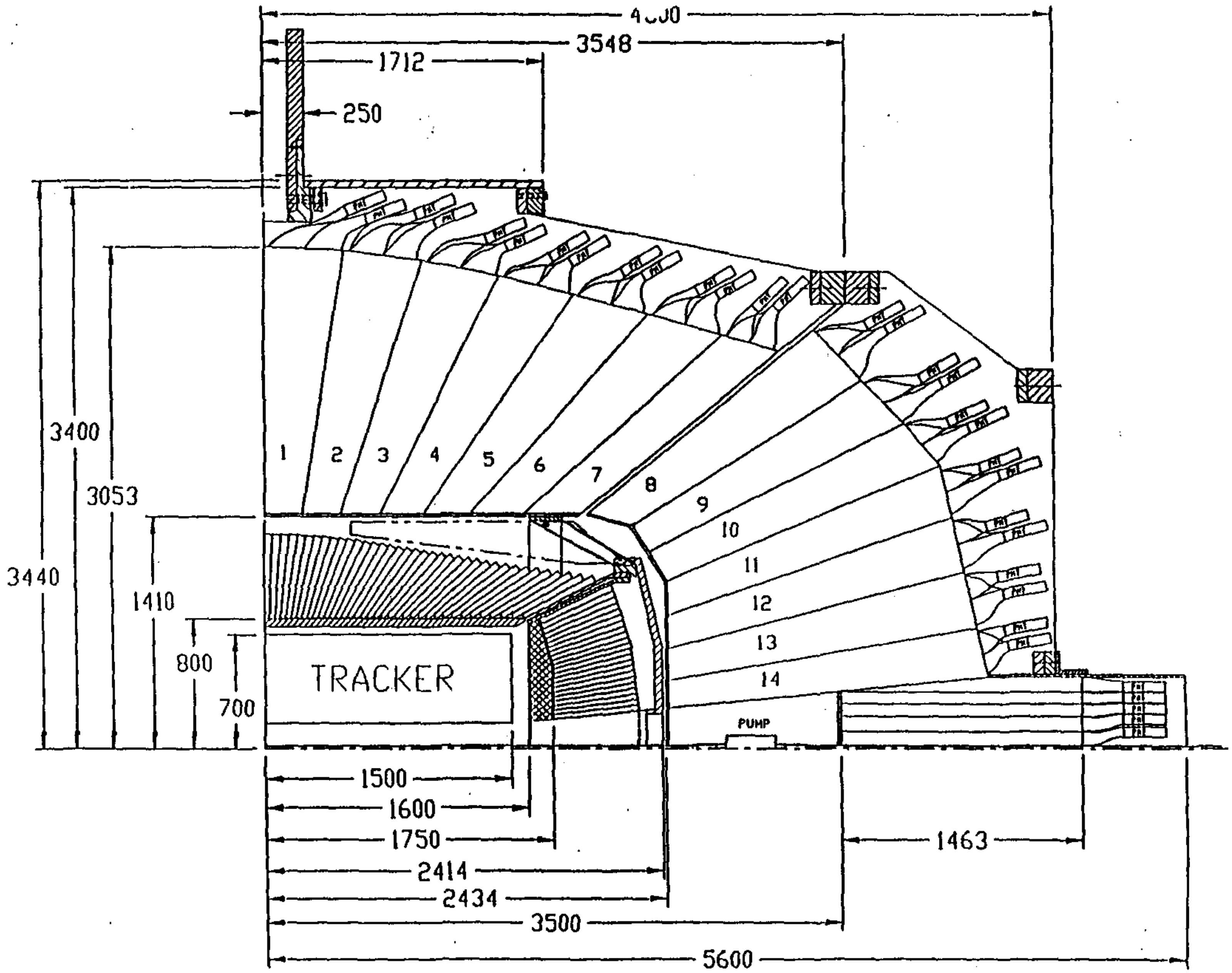
- LLNL
  - Crystal Mass Production Process Design and Engineering
  - Surface Preparation
  - UV Reflective Coating
  - Pure Rad Hard Crystal Growth
- ZHONGNAN OPTICAL INSTRUMENT FACTORY
  - Crystal Mechanical Processing
  - Production UV Coating With BGRI
- TSINGHUA UNIVERSITY
  - MechanicaL Support
  - Multipoint Inspection Machine
  - Readout Electronics

+ R&D :• St. Petersberg Nuclear Physics Institute (SbXPI)
  • Moscow Engineering Physics Institute (MEPhI)

A PRECISION BaF_2 CRYSTAL CALORIMETER FOR GEM AT THE SSC PROGRESS REPORT

California Institute of Technology
University of California, San Diego
Princeton University
Carnegie Mellon University
Brookhaven National Laboratory
Oak Ridge National Laboratory
Lawrence Livermore National Laboratory
Shanghai Institute of Ceramics
Beijing Glass Research Institute
Institute of HEP, Beijing
University of Science and Technology, Hefei
Tongji University, Shanghai
Tsinghua University, Shanghai
Zhongnan Optical Instrument Factory
Tata Institute of Fundamental Research, Bombay

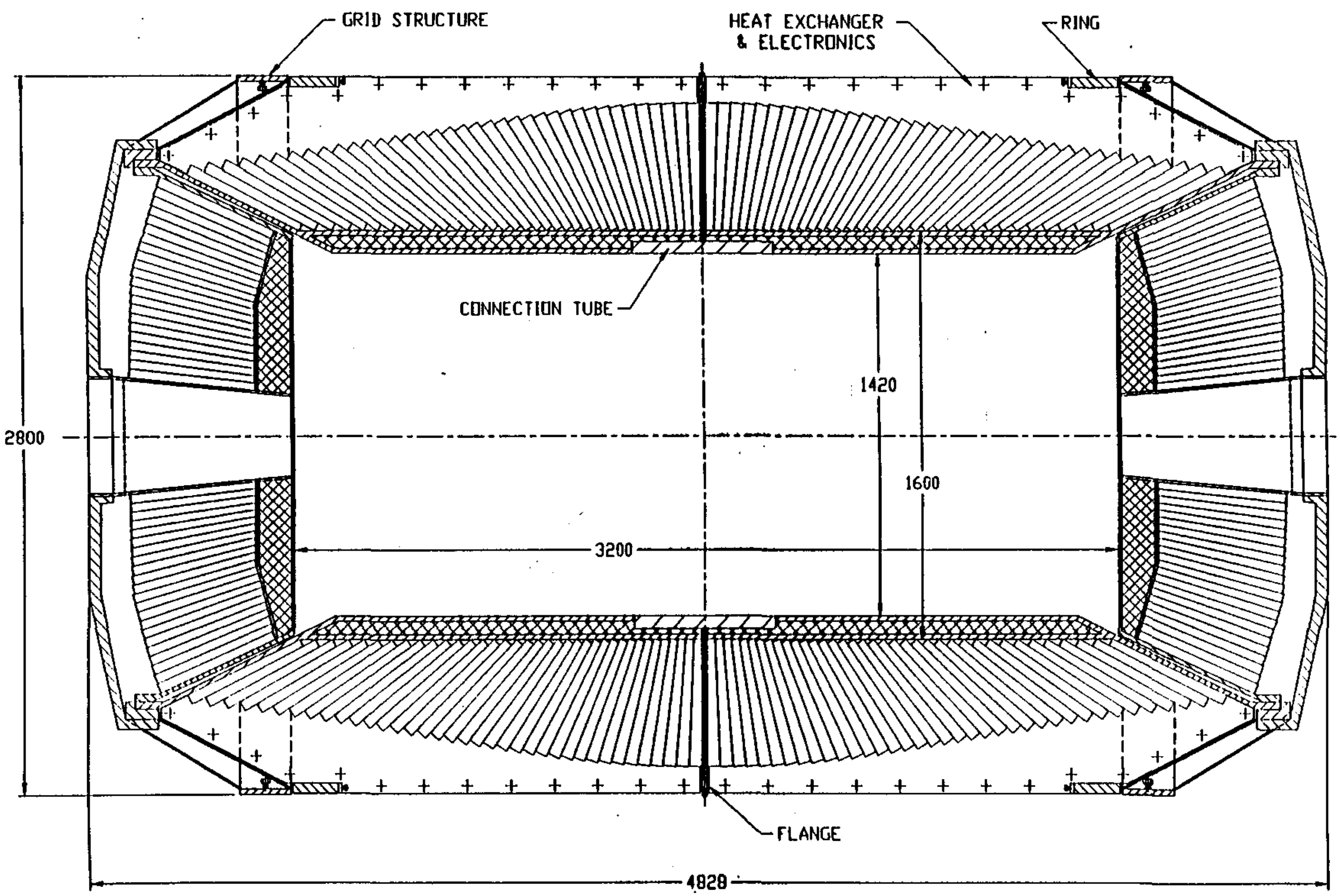
GEM Collaboration Council
August 5, 1992



GEM DETECTOR
Fiber Hadron Calorimeter
Fiber with BaF2 Design

A. SHIRIKIV

ORNL 7/17/92



A. SMIRNOV

GEM DETECTOR
EM BaF2 Design

7/22/92

H. NEWMAN

CALORIMETER GROUP

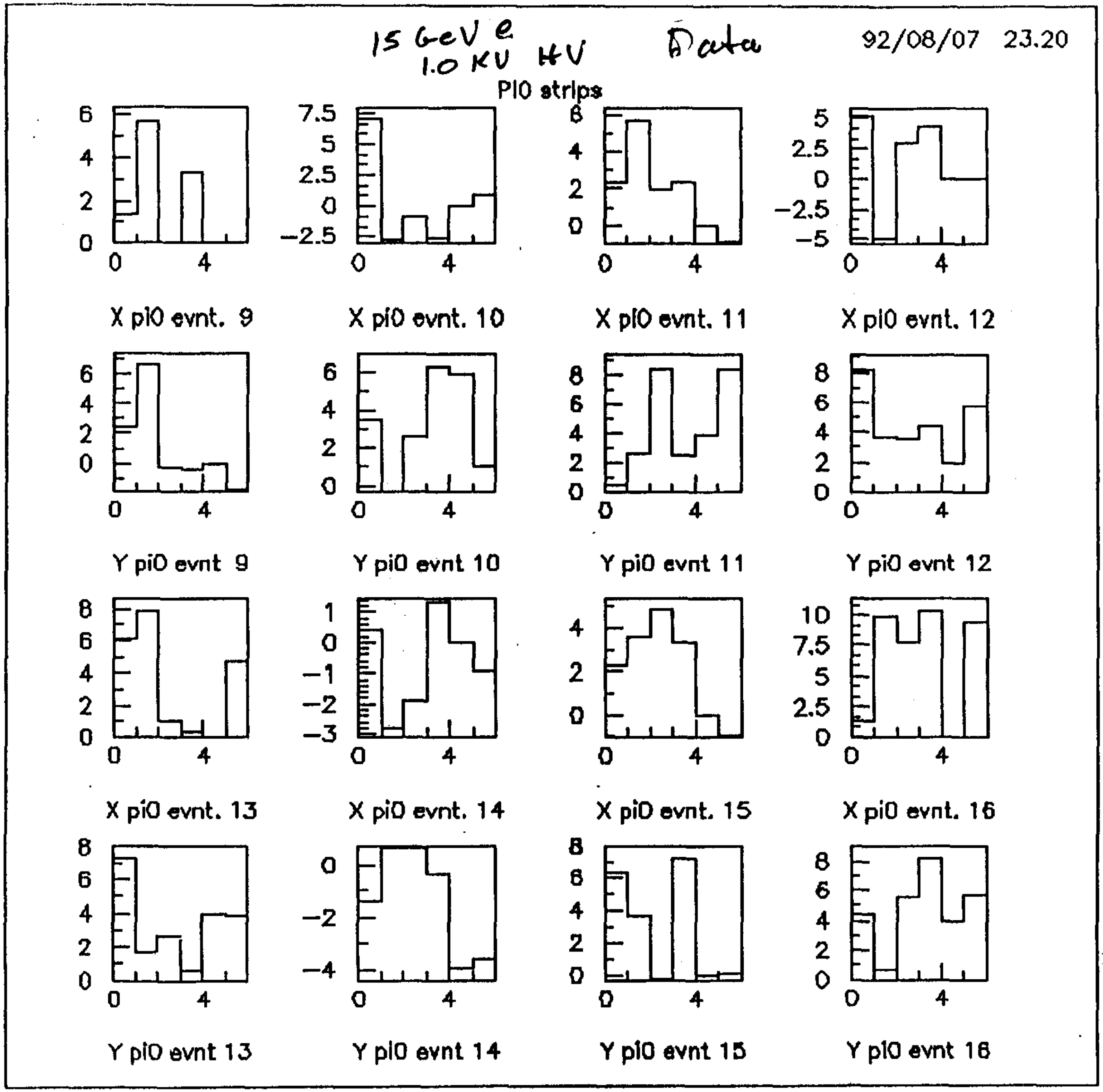
MEETING: AUGUST 9, 1992

BaF_2 SESSION

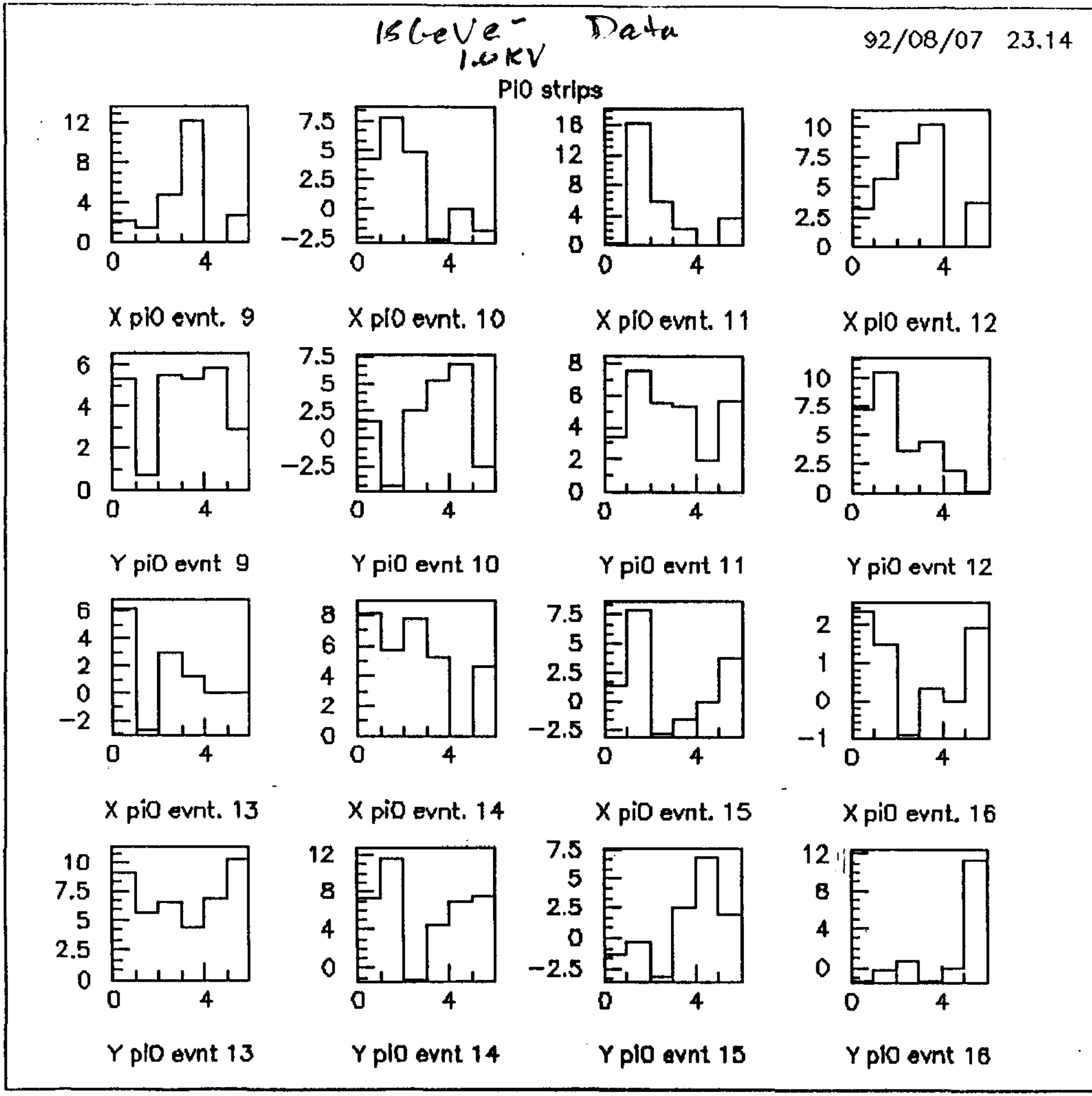
- 30': BaF_2 CALORIMETER: QUESTIONS & ANSWERS (H. NEWMAN)
  +DISCUSSION
- 15': LIGHT COLLECTION UNIFORMITY REQUIREMENTS (K. SHMAKOV)
- 10': Role of China in BaF_2 Calorimeter Production (Y.N. GUO)
- 20' BaF_2 DESIGN; MANUFACTURING PLAN (J. HECK; M. RENNICH)
- 15' CR STAND; UV MONITOR (H. KOBRAK)
- 10' Z∅ CALIBRATION (R. ZHU)
- 10' CALIBRATIONS (Y. EFREMENKO)
- 10' γ POINTING (X. SHI)
- 10' γ POINTING (Y. EFREMENKO)
-
-
-
- DISCUSSION

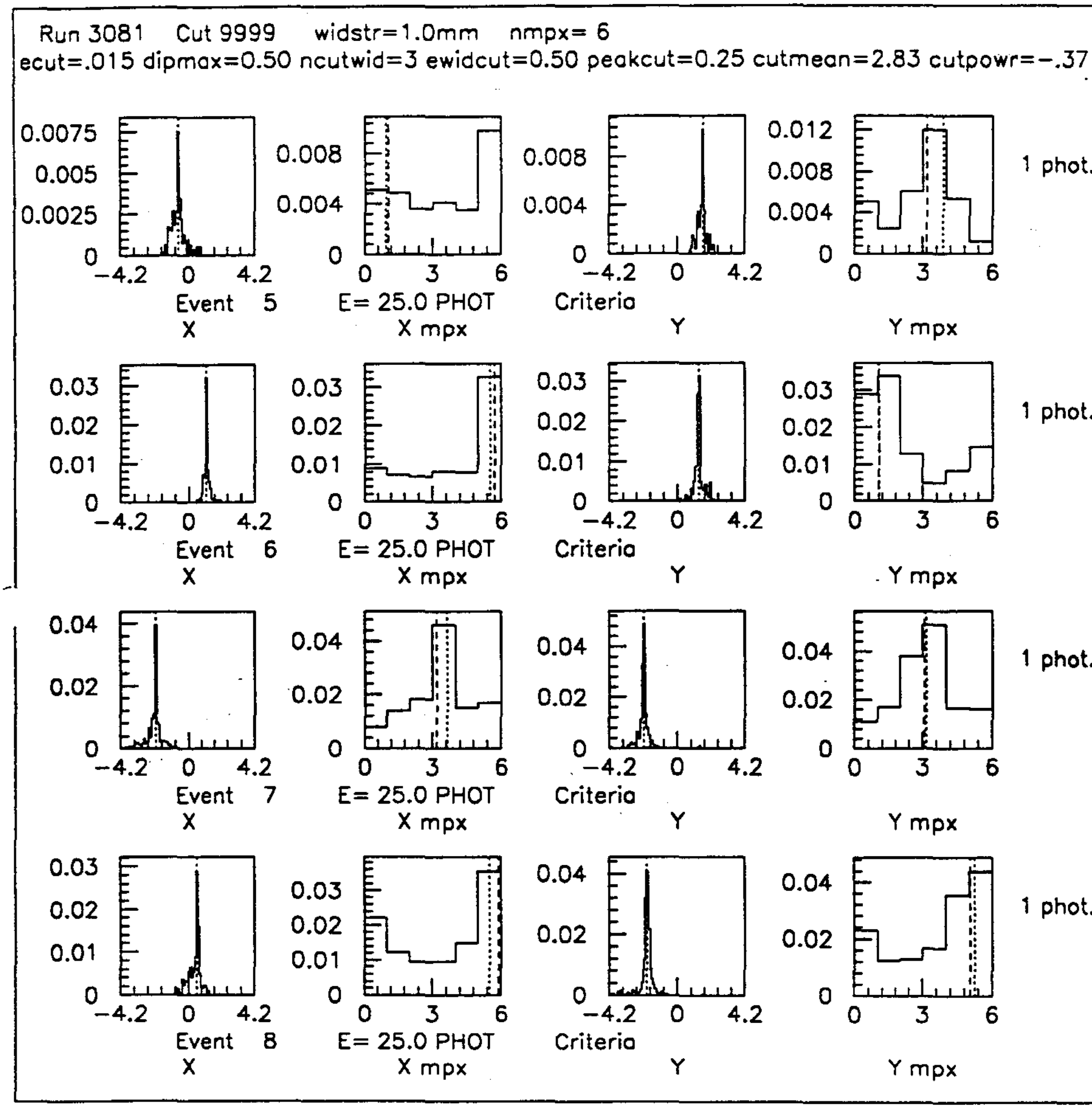
(LIMIT: 3 HOURS)
(SESSION TOTAL

→ MINUTES

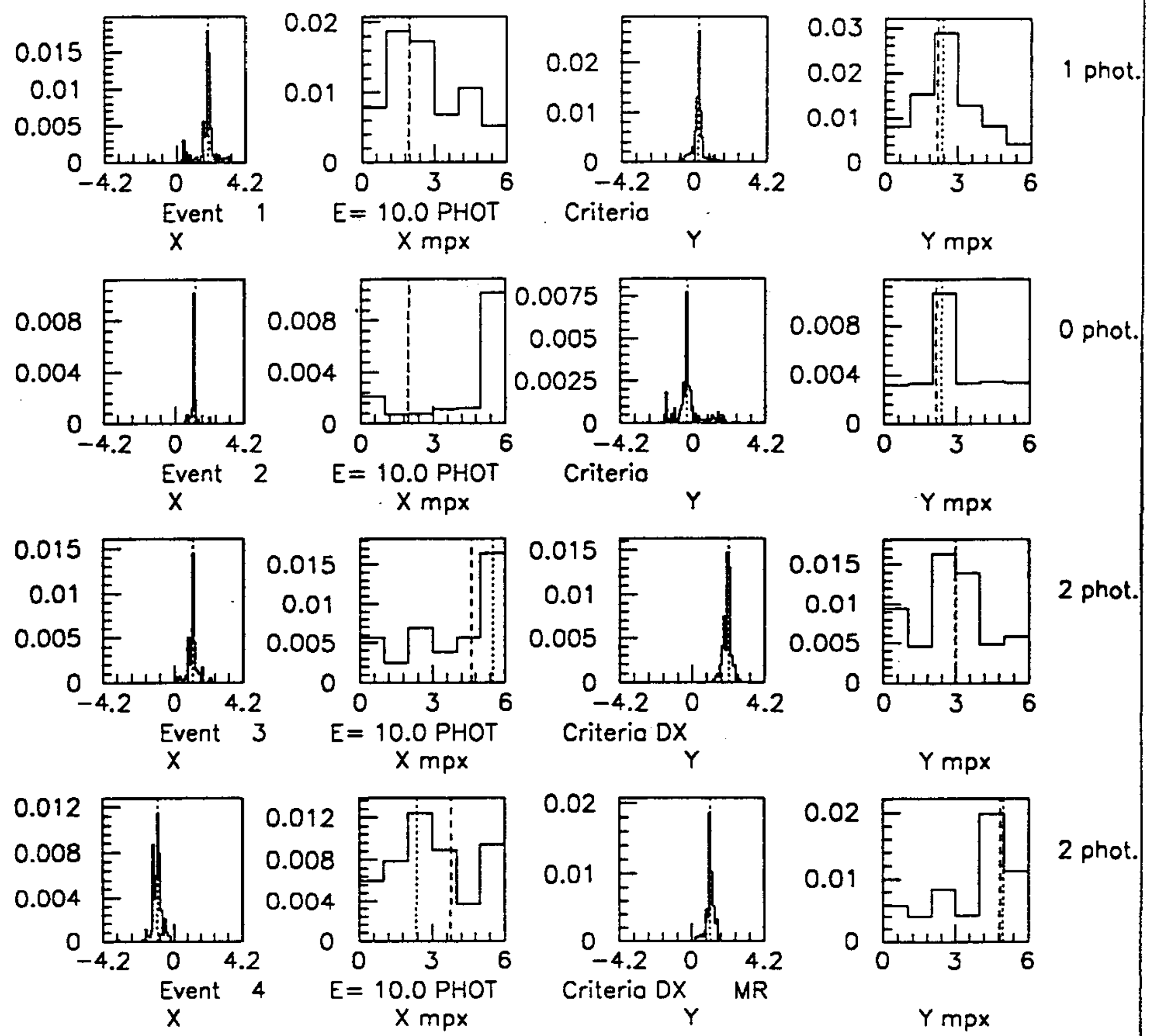


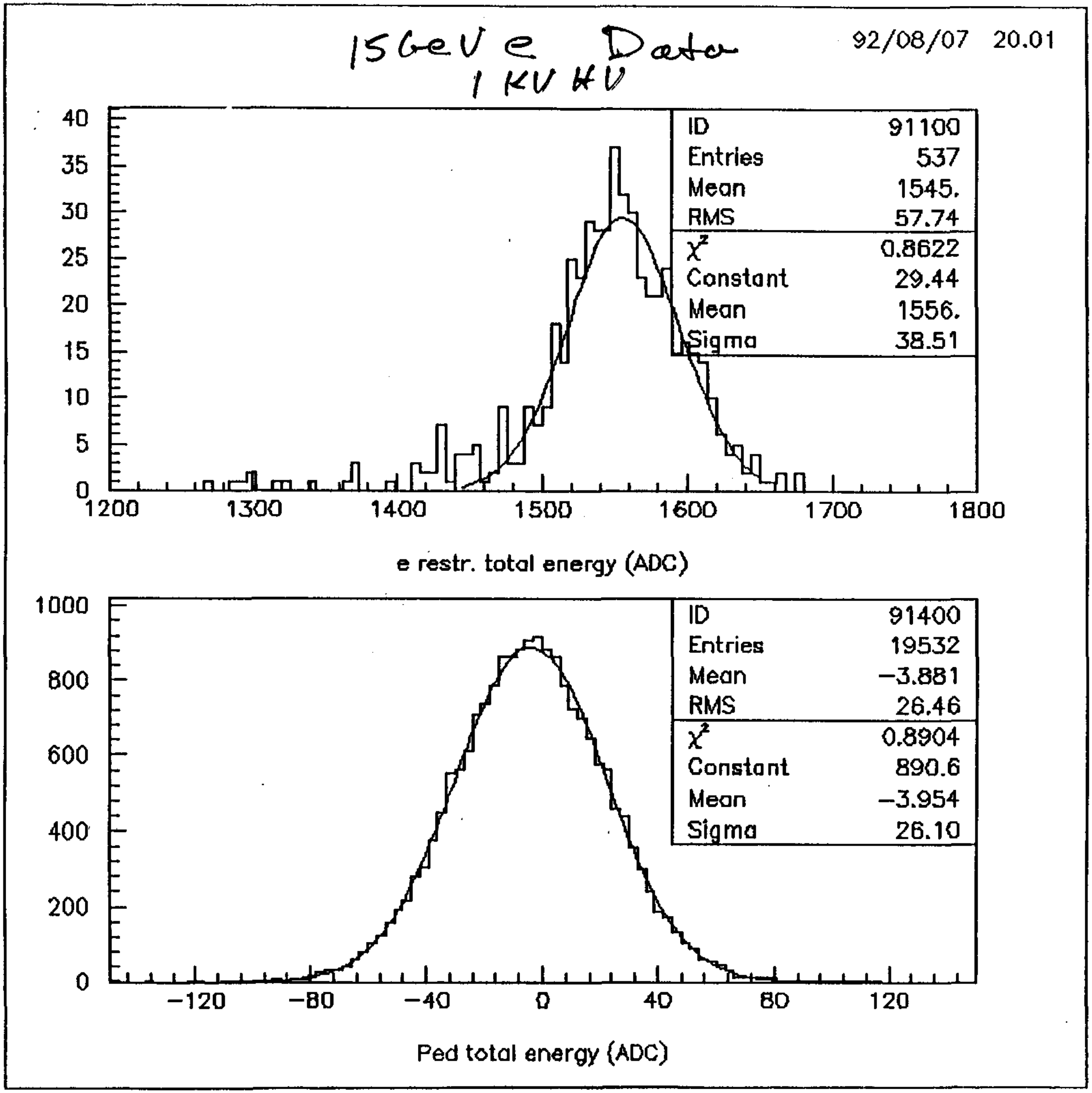
15 GeV e
1.0 KV HV
Data
92/08/07 23.20
PI0 strips
X pi0 evnt. 9
X pi0 evnt. 10
X pi0 evnt. 11
X pi0 evnt. 12
Y pi0 evnt 9
Y pi0 evnt 10
Y pi0 evnt 11
Y pi0 evnt 12
X pi0 evnt. 13
X pi0 evnt. 14
X pi0 evnt. 15
X pi0 evnt. 16
Y pi0 evnt 13
Y pi0 evnt 14
Y pi0 evnt 15
Y pi0 evnt 16

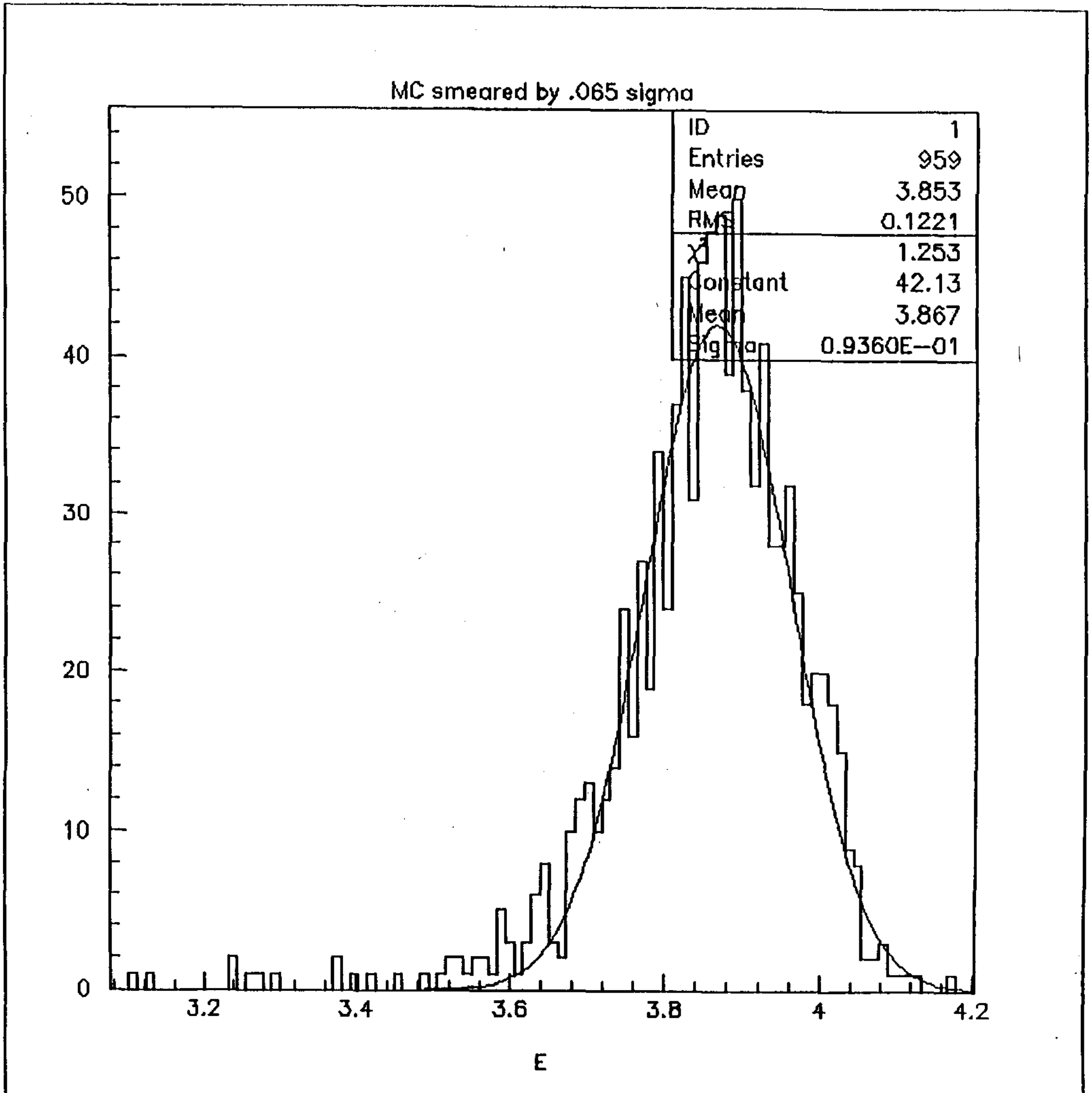

15GeV e- Data
1.0kV
92/08/07 23.14
PI0 strips
X pi0 evnt. 9
X pi0 evnt. 10
X pi0 evnt. 11
X pi0 evnt. 12
Y pi0 evnt 9
Y pi0 evnt 10
Y pi0 evnt 11
Y pi0 evnt 12
X pi0 evnt. 13
X pi0 evnt. 14
X pi0 evnt. 15
X pi0 evnt. 16
Y pi0 evnt 13
Y pi0 evnt 14
Y pi0 evnt 15
Y pi0 evnt 16


Run 3081 Cut 9999 widstr=1.0mm nmpx= 6
ecut=.015 dipmax=0.50 ncutwid=3 ewidcut=0.50 peakcut=0.25 cutmean=2.83 cutpowr=-.37
Event 5
E= 25.0 PHOT
Criteria
X
X mpx
Y
Y mpx
1 phot.
Event 6
E= 25.0 PHOT
Criteria
X
X mpx
Y
Y mpx
1 phot.
Event 7
E= 25.0 PHOT
Criteria
X
X mpx
Y
Y mpx
1 phot.
Event 8
E= 25.0 PHOT
Criteria
X
X mpx
Y
Y mpx
1 phot.

Run 3079 Cut 9999 widstr=1.0mm nmpx= 6
ecut=.015 dipmax=0.50 ncutwid=3 ewidcut=0.50 peakcut=0.25 cutmean=2.83 cutpowr=-.37




15GeV e Data
1 KV HV
92/08/07 20.01
ID 91100
Entries 537
Mean 1545.
RMS 57.74
χ² 0.8622
Constant 29.44
Mean 1556.
Sigma 38.51
0
5
10
15
20
25
30
35
40
1200
1300
1400
1500
1600
1700
1800
e restr. total energy (ADC)
ID 91400
Entries 19532
Mean −3.881
RMS 26.46
χ² 0.8904
Constant 890.6
Mean −3.954
Sigma 26.10
0
200
400
600
800
1000
−120
−80
−40
0
40
80
120
Ped total energy (ADC)

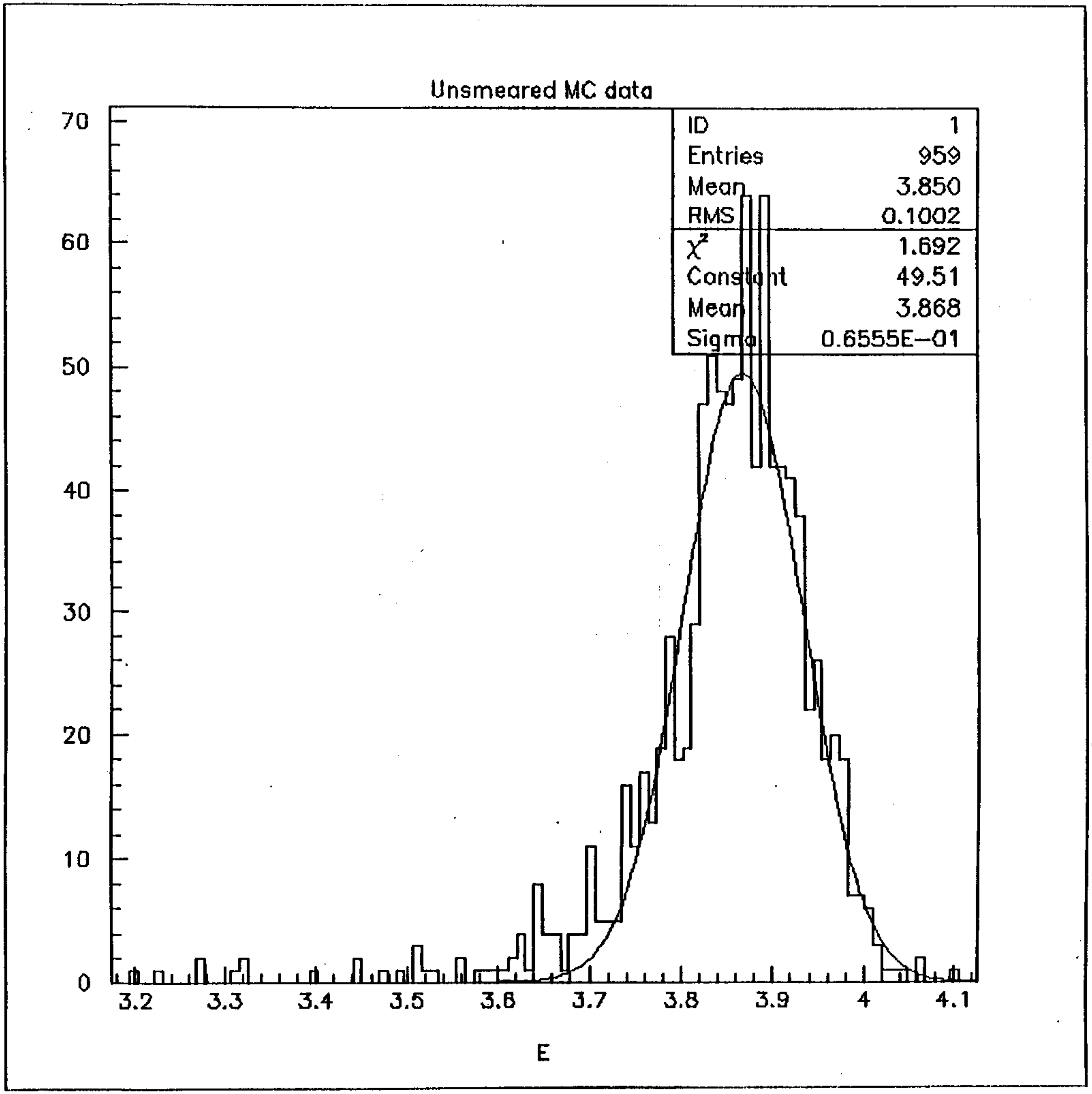


8/7/22

9

gaussian fit

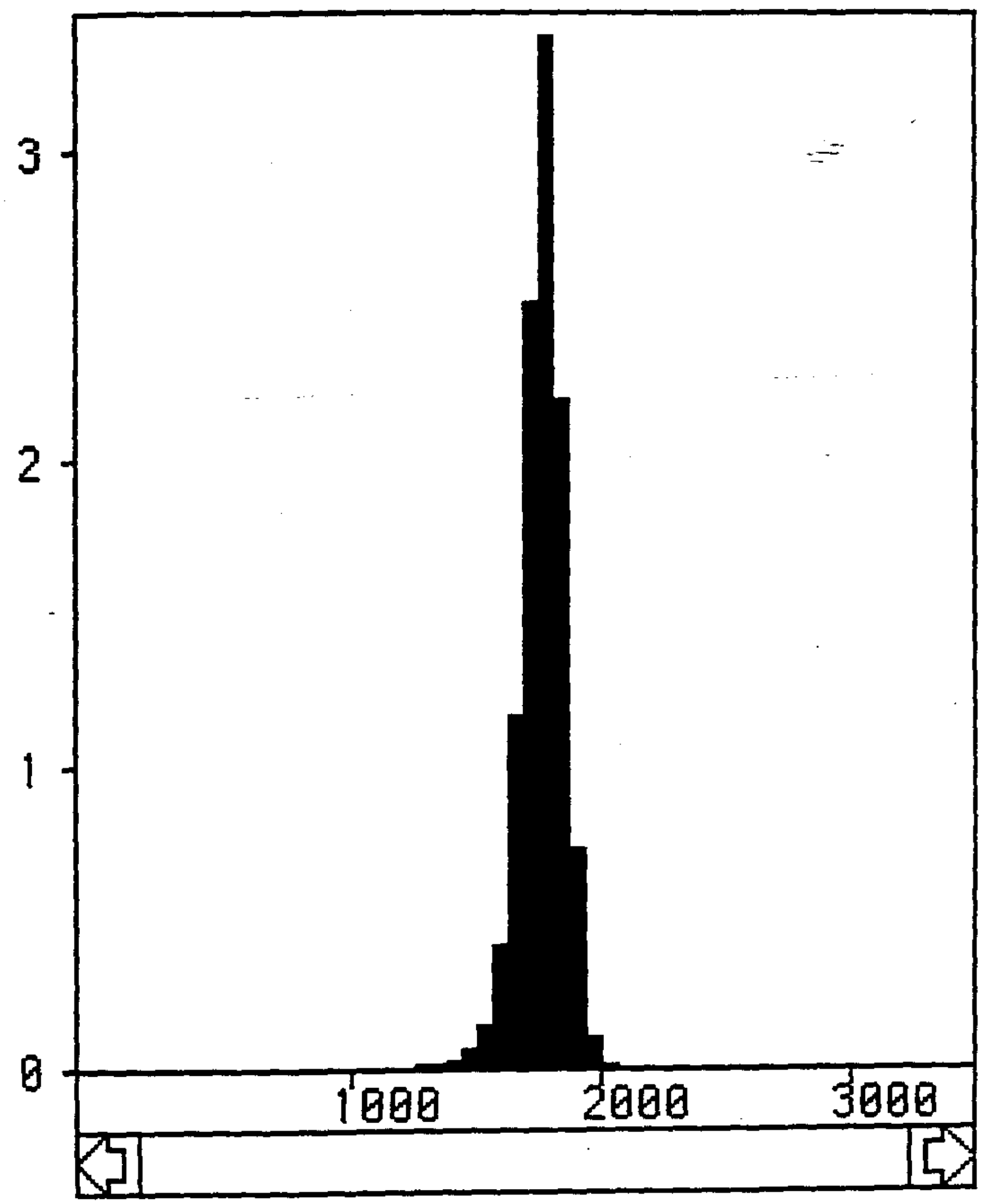
8/2/82


Unsmeared MC data
ID 1
Entries 959
Mean 3.850
RMS 0.1002
χ^2 1.692
Constant 49.51
Mean 3.868
Sigma 0.6555E-01
70
60
50
40
30
20
10
0
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
E

contents=10850   u/f=0   o/f=0

full scale y:3401   bin width:64

*10E3   CURSOR: x=   y=

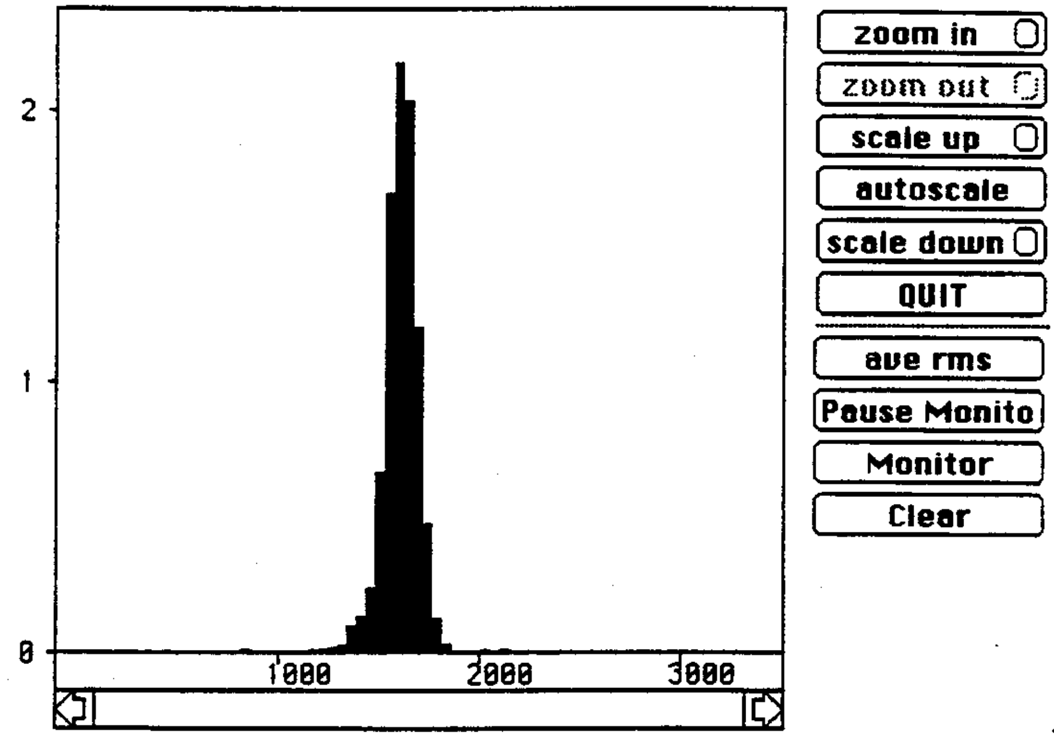


contents=902 u/f=0 o/f=0

run 376

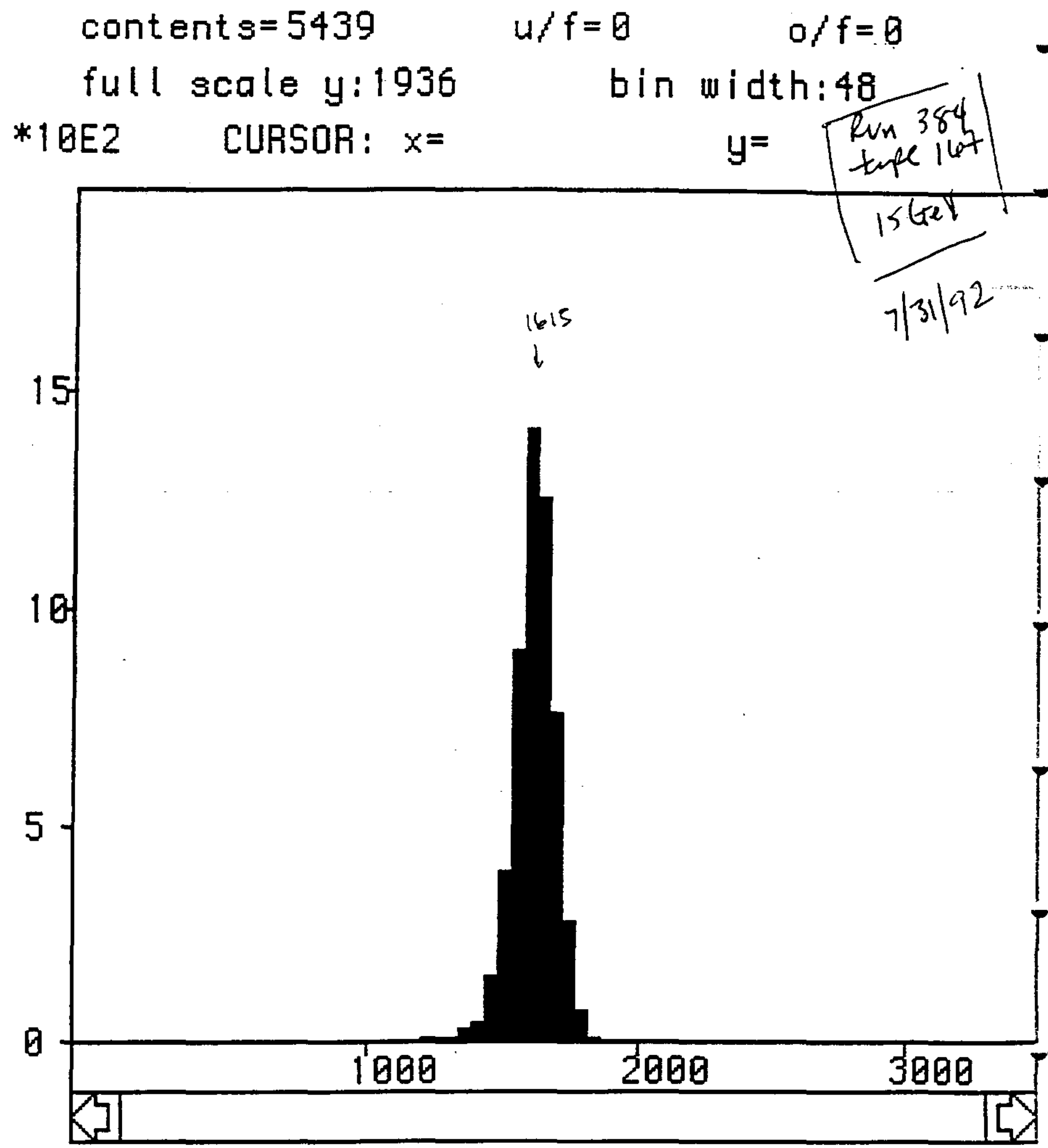
full scale y:235 bin width:48

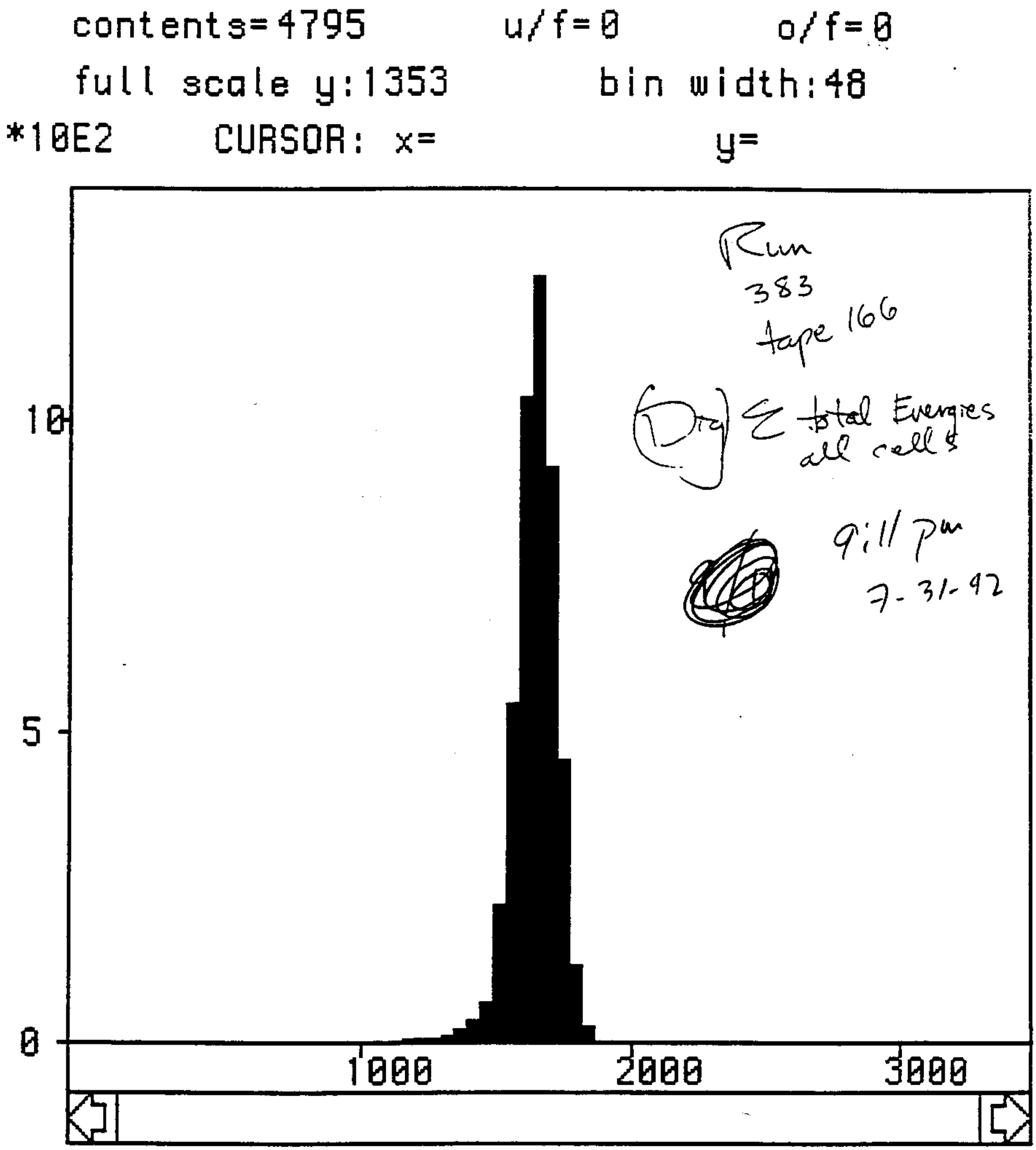
*10E2 CURSOR: x= y=



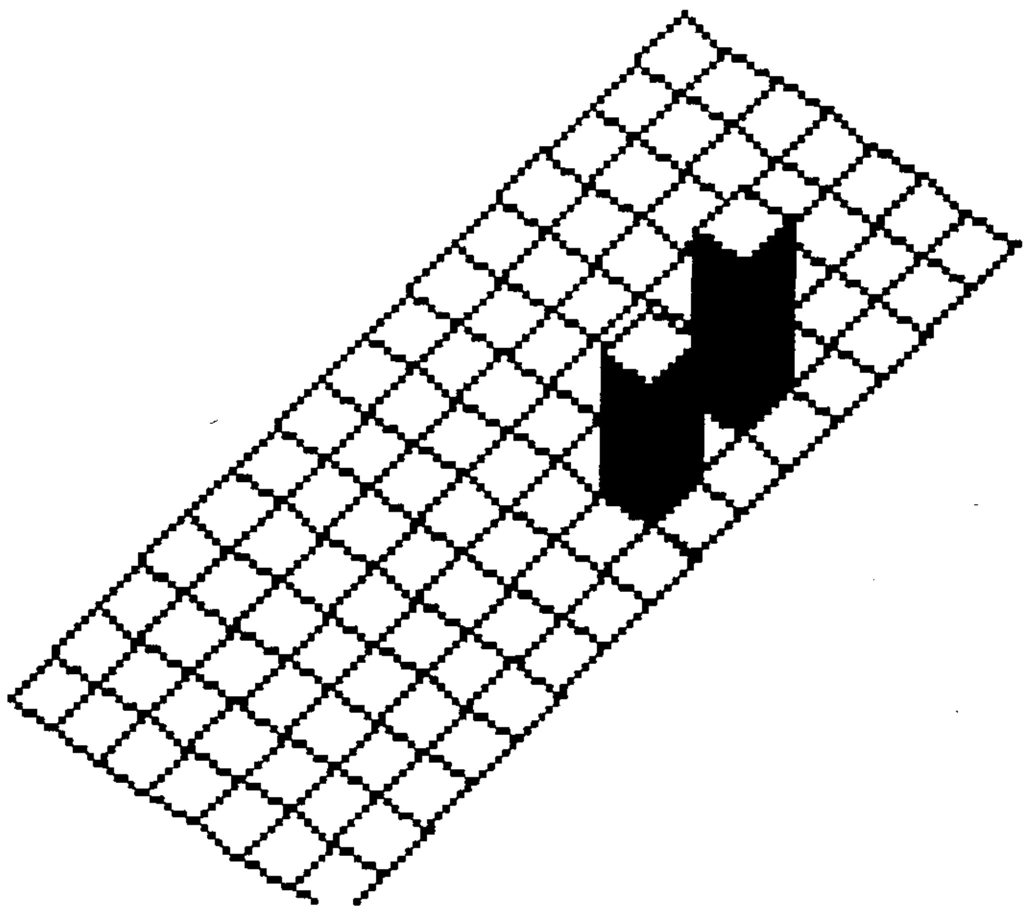
$\langle\rangle = 1612$

rms = 92.1


contents=5439
u/f=0
o/f=0
full scale y:1936
bin width:48
*10E2
CURSOR: x=
y=
Run 384
tape 167
15GeV
7/31/92
1615
15
10
5
0
1000
2000
3000


contents=4795
u/f=0
o/f=0
full scale y:1353
bin width:48
*10E2
CURSOR: x=
y=
10
5
0
1000
2000
3000
Run
383
tape 166
(Dig) Σ total Energies all cells
9:11 pm
7-31-92

310 EM1 MAX hit cell LEGO F
N=9759; highest bin=5356

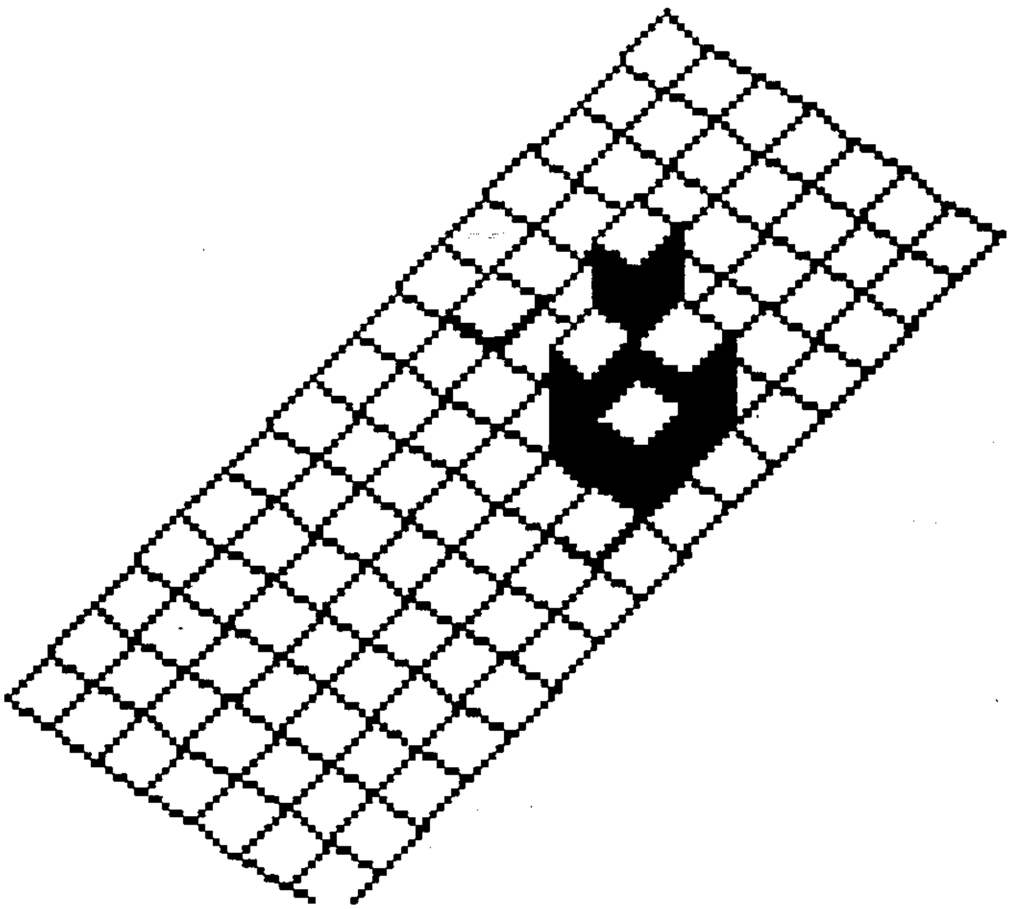


π^0

Run 382
tape 166
20:47
15Gev
7/31/92

311 EM2 MAX hit cell LEGO Pl
N=14554; highest bin=5420

Run 383
tape 166

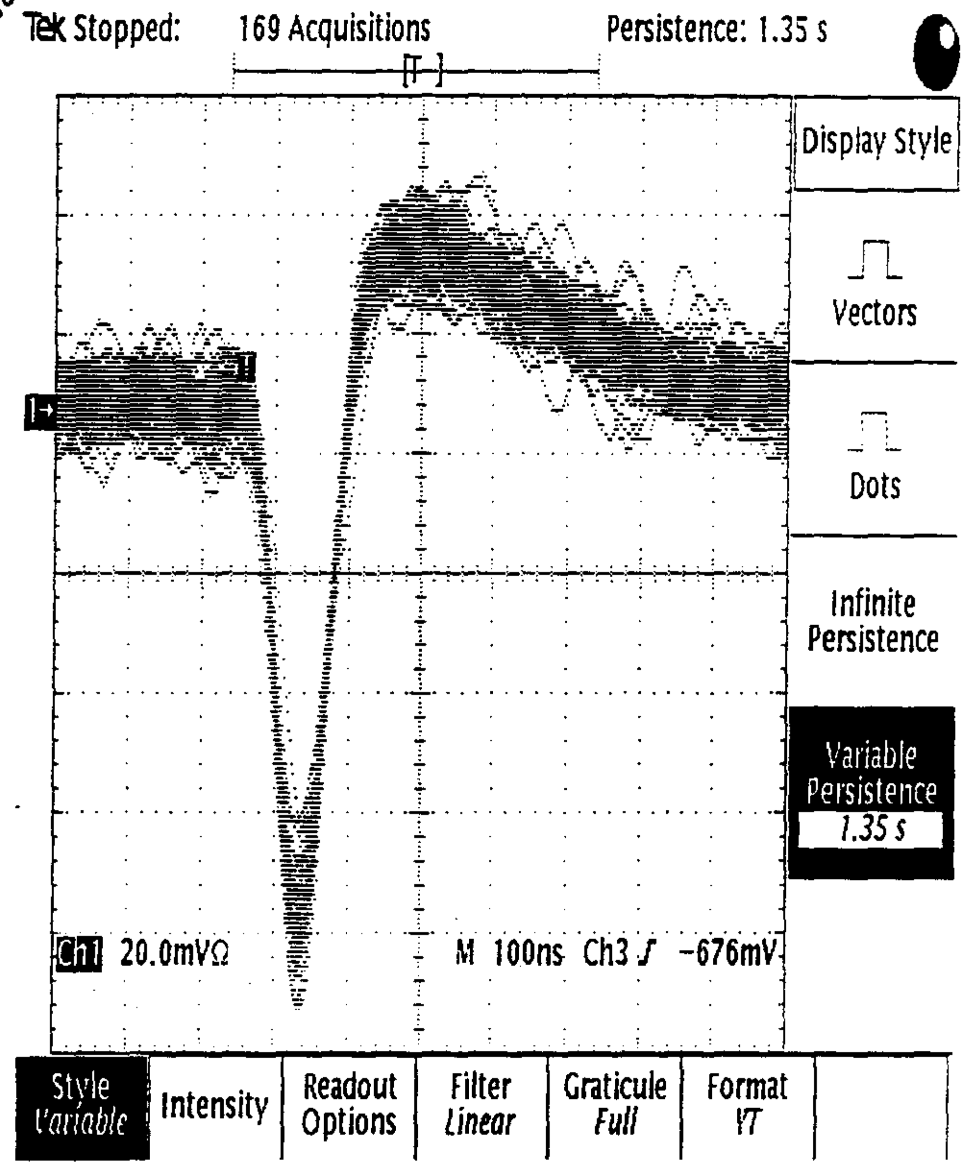


9:11 pm
7-31-92

12

2nd data   15 GeV   + 1KV power-supply   2:45 am 7/30/92

x°@ 750V



47

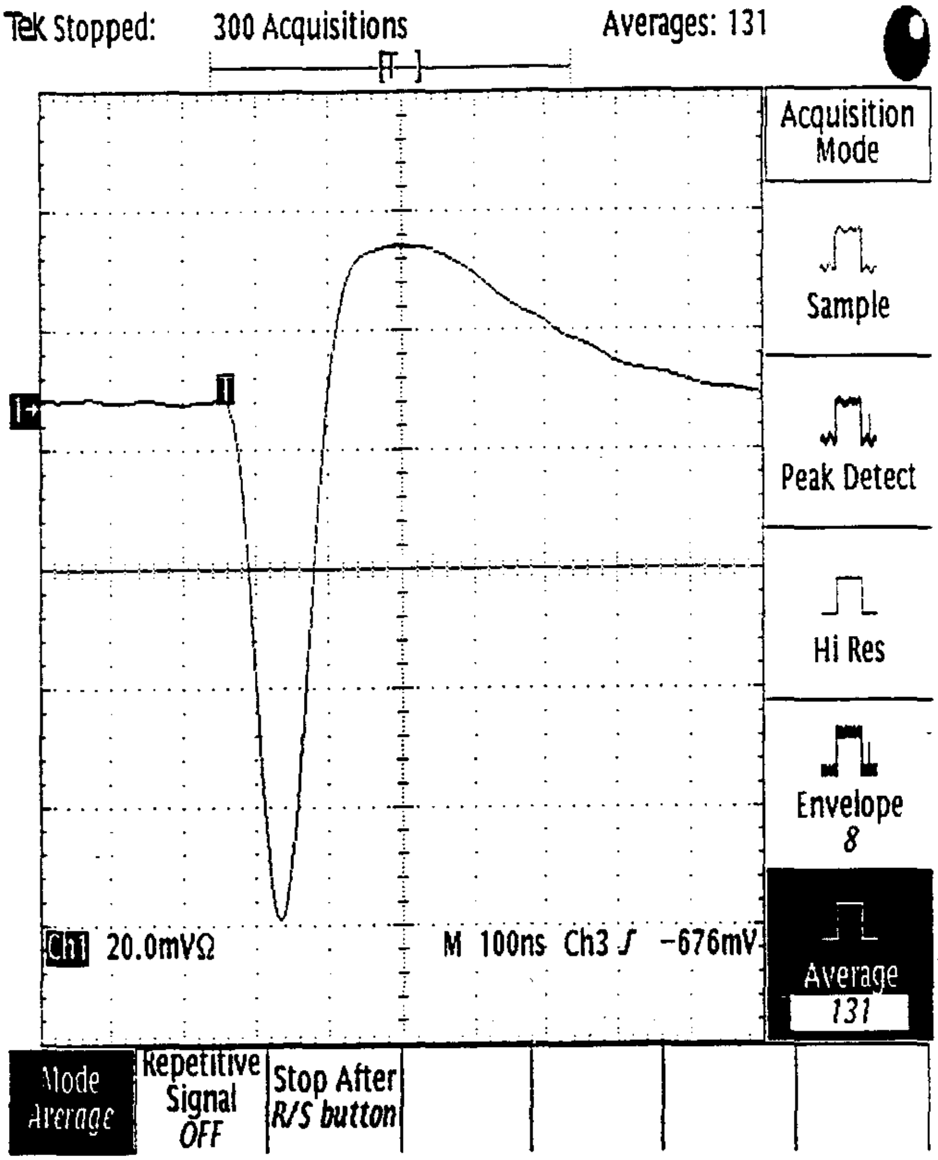
2nd data

t° @ 750

15 GeV +1KV power supply

Time averaged

2:45 am
7/30/92

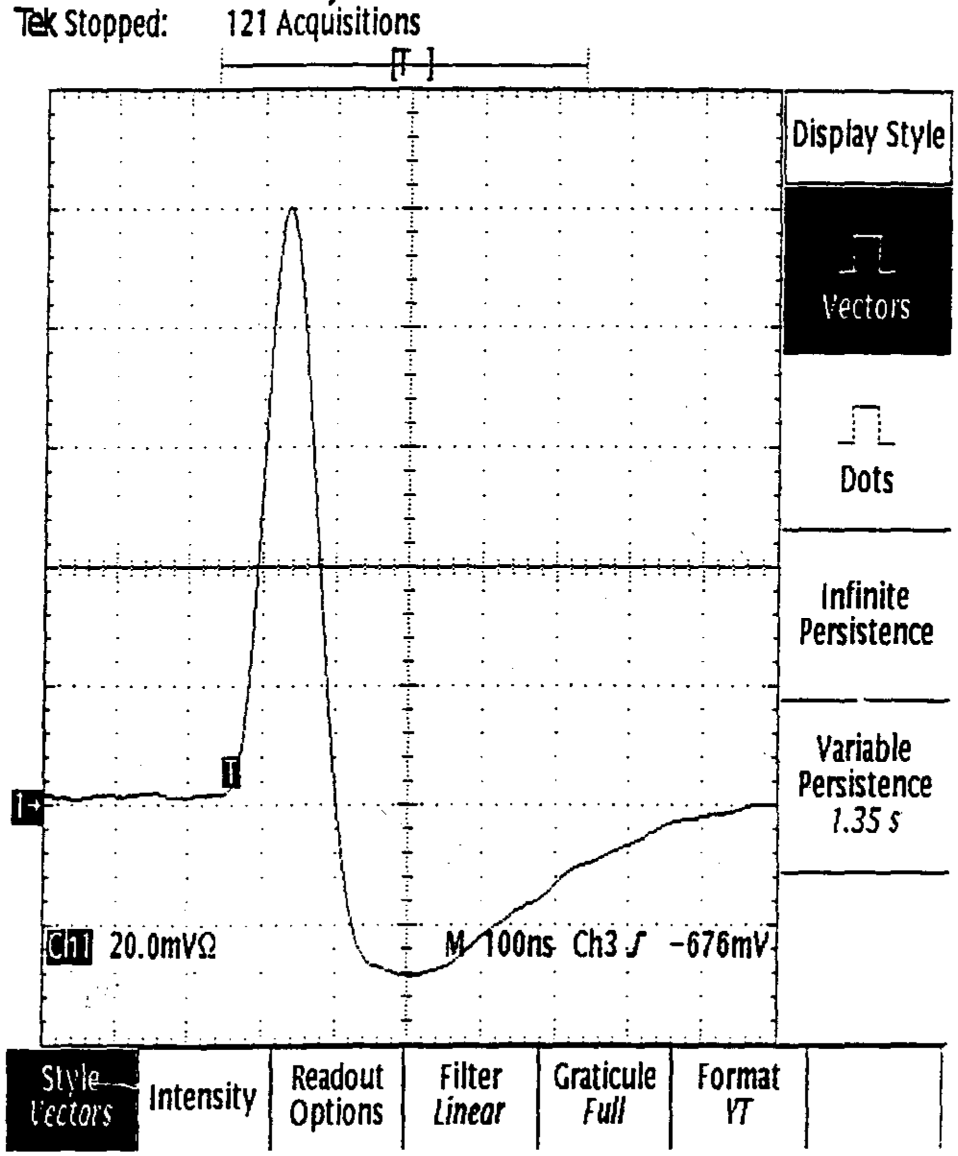


[redacted] [redacted]

Tam   1st data   15 GEV   7/30/92   2:25

-1KV power supply.

π° @ 750V



Time AVE.

END PLUG DESIGN
CHANNEL COUNT

We use projected areas to estimate the channel count in the end plug design. We assume the calorimeter starts at a radius of 84 cm in the barrel and at 159 cm in the end plugs. The projected tower size is 2.7 by 2.7 cm^2 at the front face. Our π^0 detector design requires the same channel count as the calorimeter which has one depth segment. We neglect the region beyond η equals 1.73 in the channel calculation for the barrel since it will be segmented and wired as a hadron region with few channels and connections. Under these conditions and assumptions the following channel counts are obtained:

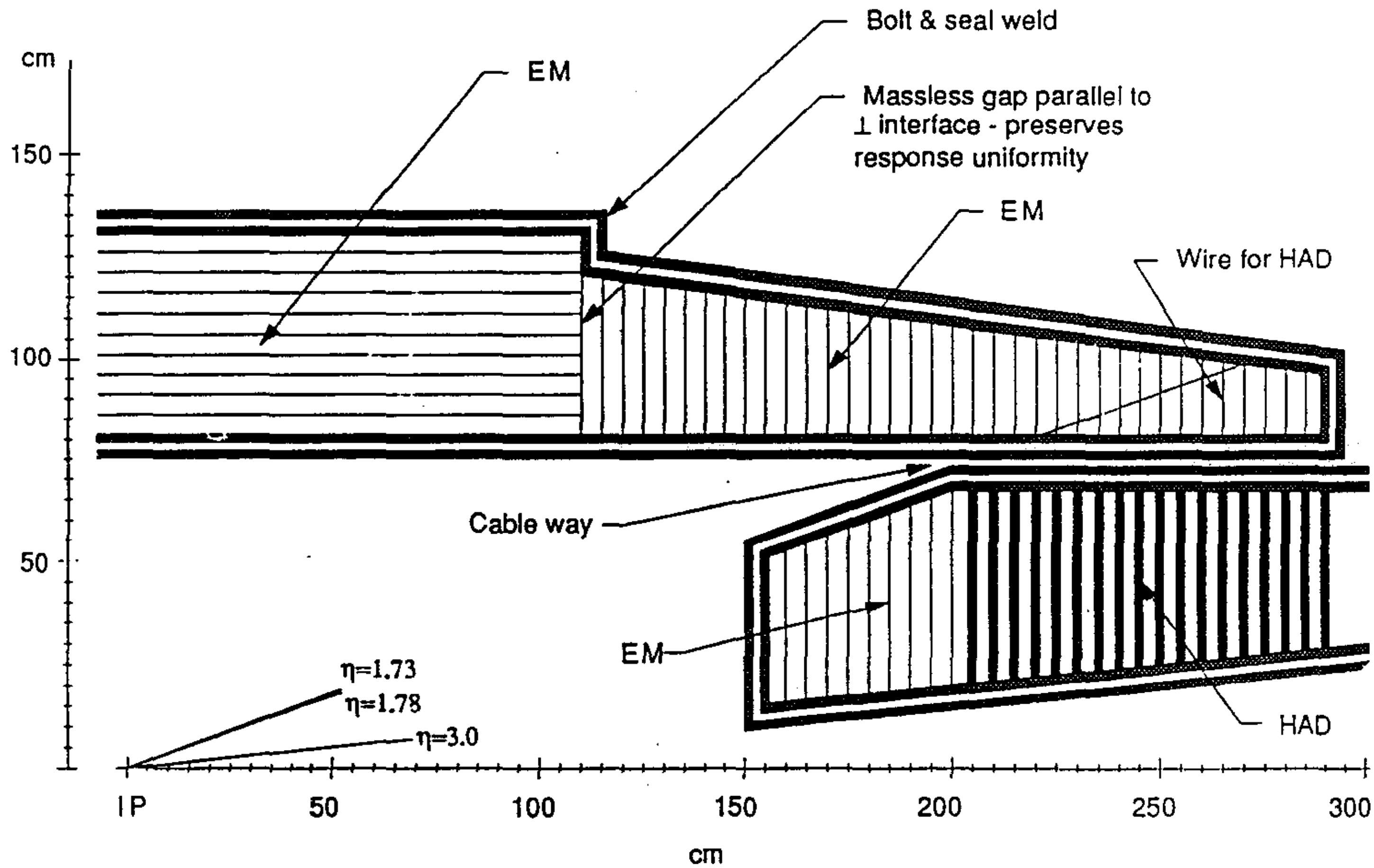
Barrel	21040 EM; 21040 π^0
End Plugs	2140 EM; 2140 π^0

Total Calorimeter 46360 channels, Plug Design

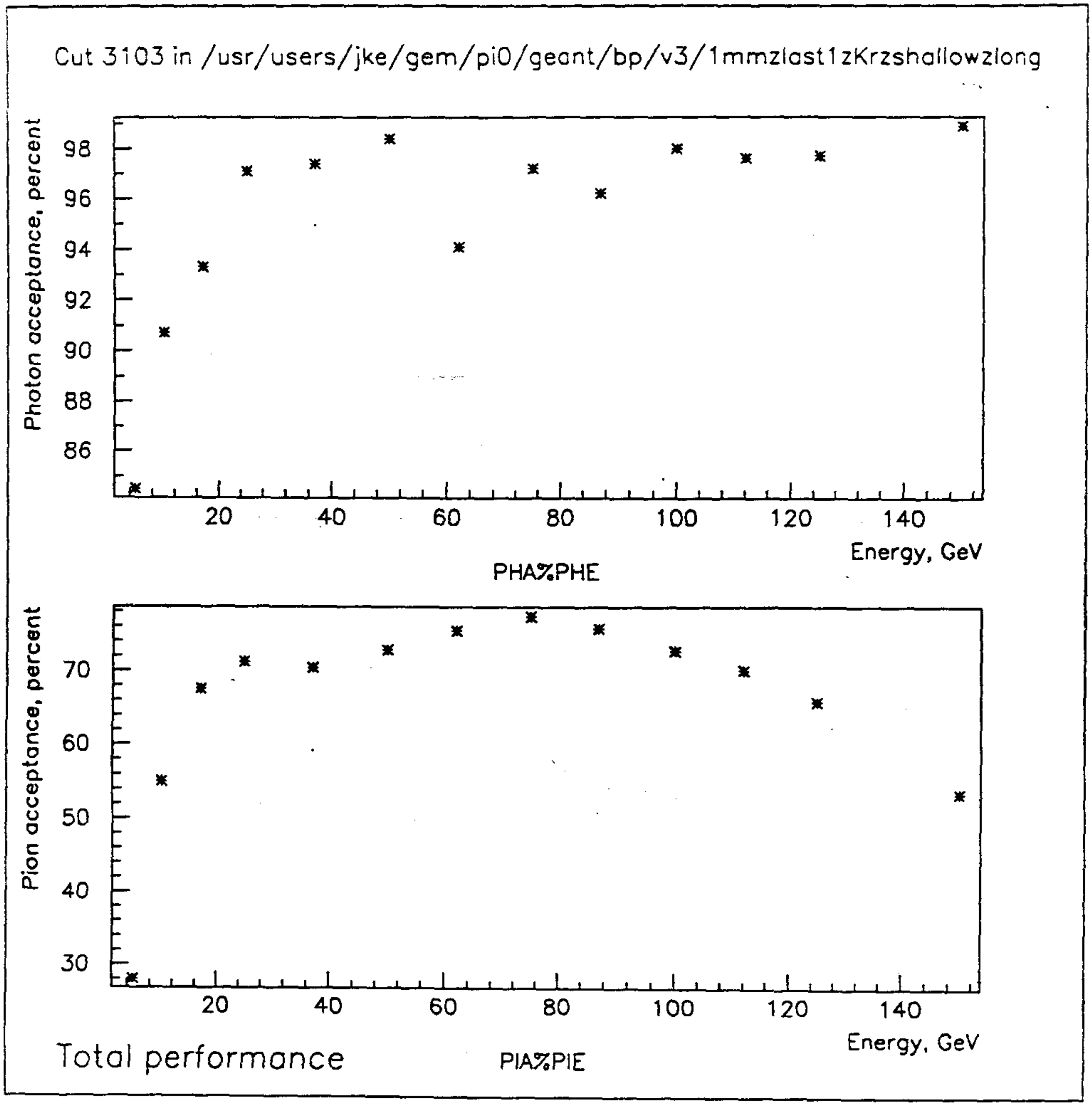
This is to be compared with the end cap design of 62272 channels for the LKr calorimeter(4.5% resolution) that was costed at $37.75 M. If we scale the cost by the channels required then we estimate an LKr end plug design would cost about $28 M.

An LAr design(6.5% resolution) has18% fewer plates and connections than an LKr design has but the same number of channels. In this case the costs should roughly scale for all components but the $9 M for electronics. We estimate the cost of an LAr parallel plate calorimeter to be $25 M.

END PLUG DESIGN
GEM LAr/LKr



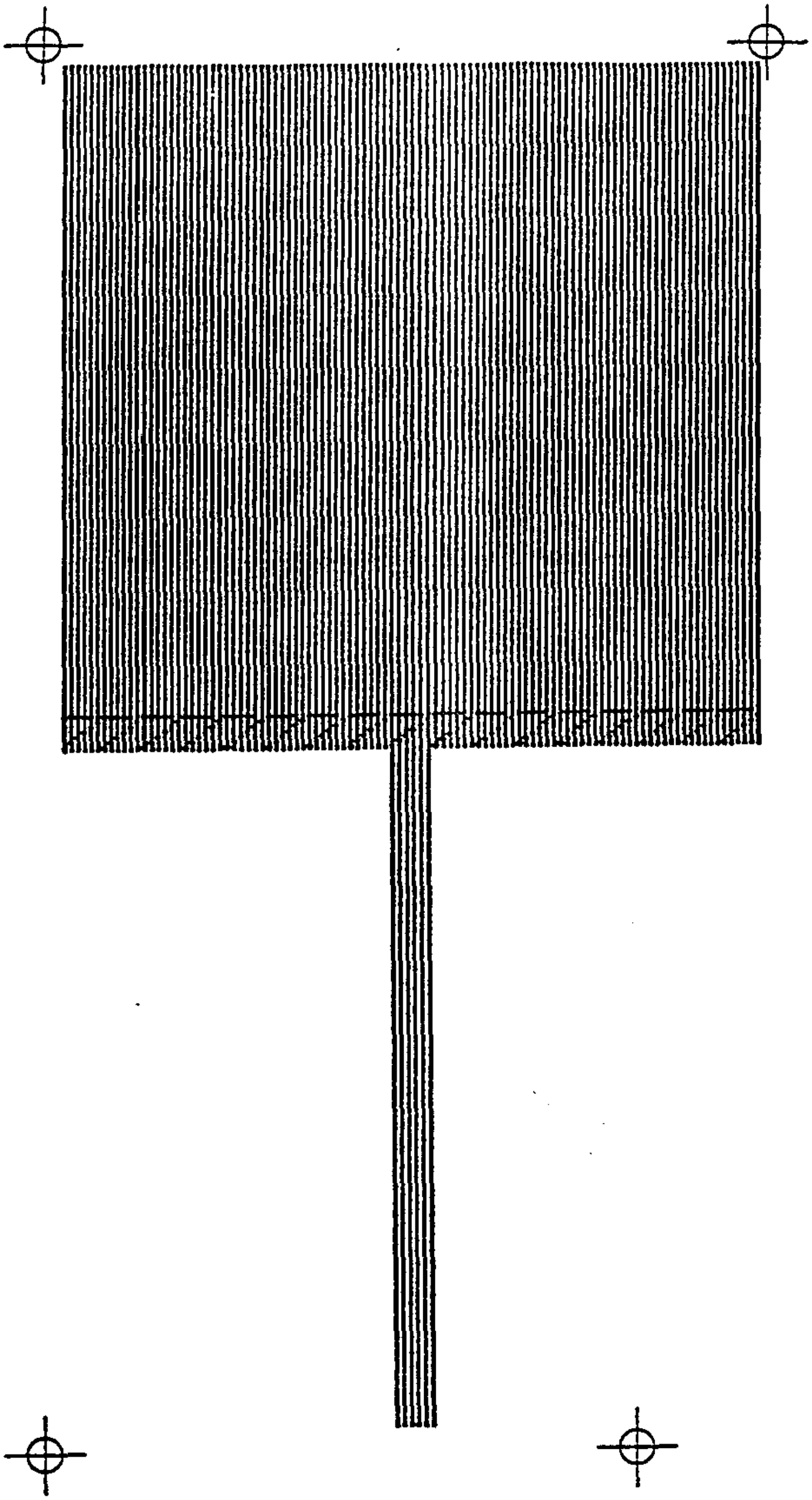
5/22/92
P. M. Mockett


Cut 3103 in /usr/users/jke/gem/pi0/geant/bp/v3/1mmzlast1zKrzshallowzlong
Photon acceptance, percent
98
96
94
92
90
88
86
20
40
60
80
100
120
140
Energy, GeV
PHA%PHE
Pion acceptance, percent
70
60
50
40
30
20
40
60
80
100
120
140
Energy, GeV
Total performance
PIA%PIE

```
==========================================================================
Runs in: /usr/users/jke/gem/pi0/geant/bp/v3/1mm_last1_Kr_shallow_long
Cut    : 3103
==========================================================================
```

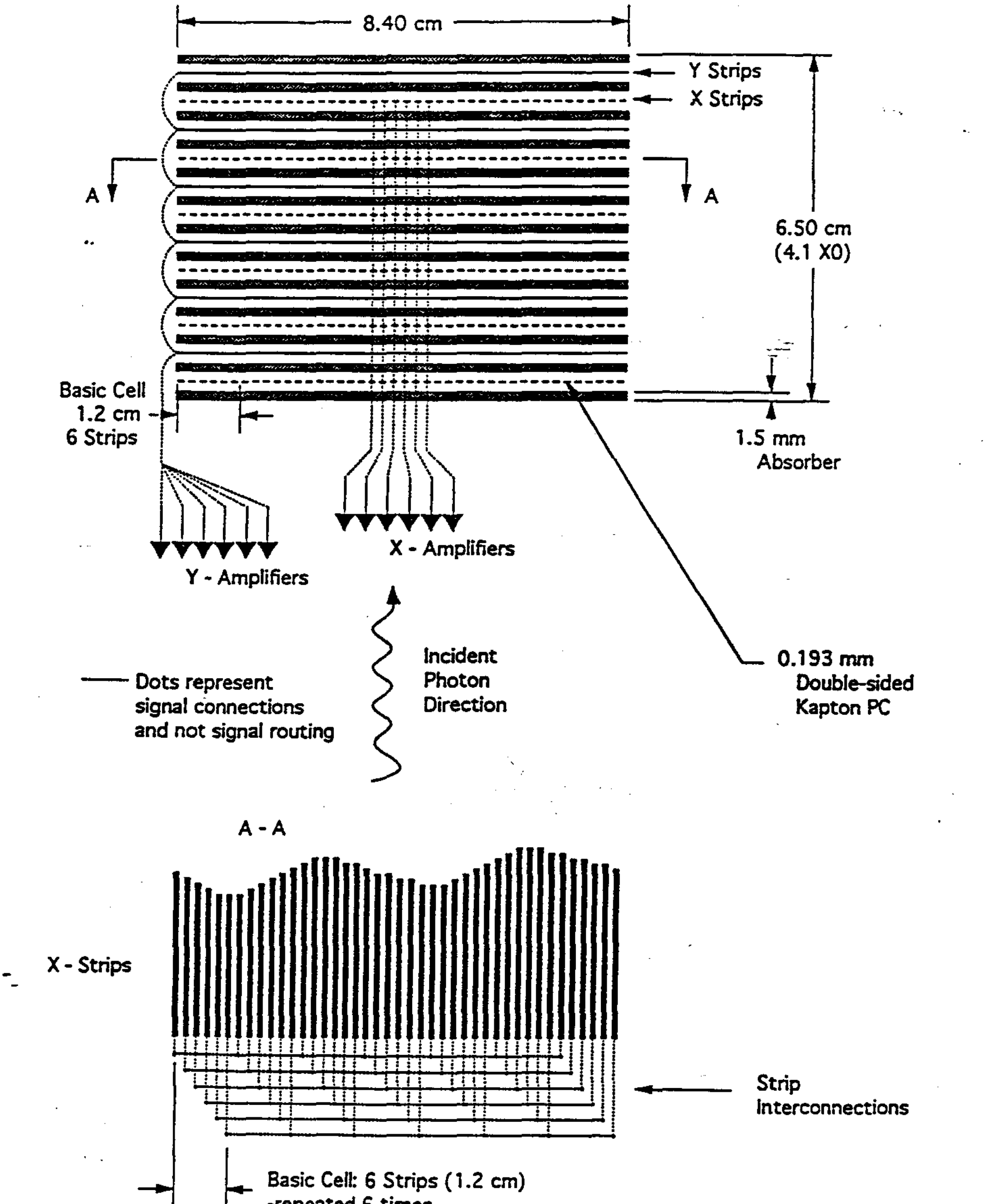
E,GeV		accep	%0	%1	%2	%mean	only	%dip	only	%wid	only	run
5.0	1	84.5	41.9	42.7	15.5	0.1	0.1	0.0	0.0	15.4	15.3	3806
5.0	7	28.0	39.2	32.8	28.0	6.6	3.9	0.0	0.0	24.1	21.4	3808
10.0	1	90.7	30.1	60.5	9.3	0.1	0.0	0.0	0.0	9.3	9.2	3811
10.0	7	55.0	18.1	26.9	55.0	42.1	26.8	0.0	0.0	28.2	12.9	3813
17.0	1	93.3	25.5	67.7	6.7	0.3	0.2	0.0	0.0	6.5	6.4	3816
17.0	7	67.5	11.6	20.9	67.5	60.9	42.9	0.0	0.0	24.6	6.5	3818
25.0	1	97.1	23.3	73.8	2.9	0.3	0.3	0.0	0.0	2.7	2.6	3821
25.0	7	71.2	8.5	20.3	71.2	66.9	48.9	0.0	0.0	22.3	4.3	3824
37.0	1	97.4	20.4	77.0	2.6	1.1	1.1	0.0	0.0	1.5	1.5	3826
37.0	7	70.4	8.3	21.3	70.4	67.2	54.6	0.0	0.0	15.8	3.2	3829
50.0	1	98.4	22.1	76.3	1.6	0.8	0.8	0.0	0.0	0.8	0.8	3831
50.0	7	72.8	5.0	22.2	72.8	70.0	54.4	0.0	0.0	18.4	2.8	3834
62.0	1	94.1	19.6	74.5	5.9	1.2	0.1	5.3	4.3	0.5	0.5	3837
62.0	7	75.4	6.3	18.3	75.4	66.5	31.2	34.9	6.3	15.6	1.1	3840
75.0	1	97.2	19.5	77.7	2.8	1.5	0.7	2.0	1.1	0.1	0.1	3842
75.0	7	77.3	6.4	16.3	77.3	68.1	33.6	37.4	7.1	12.0	0.8	3845
87.0	1	96.2	17.5	78.7	3.8	2.4	0.8	2.5	1.0	0.5	0.4	3847
87.0	7	75.7	4.8	19.5	75.7	61.3	28.3	40.3	10.1	13.5	2.1	3848
100.0	1	98.0	17.8	80.2	2.0	1.1	0.6	1.1	0.7	0.3	0.3	3849
100.0	7	72.7	4.1	23.2	72.7	57.2	27.2	39.6	12.0	10.9	2.4	3850
112.0	1	97.6	17.0	80.6	2.4	1.5	0.4	1.9	0.7	0.1	0.1	3851
112.0	7	70.1	3.5	26.5	70.1	52.0	23.7	37.6	12.5	13.1	5.0	3852
125.0	1	97.7	18.8	78.9	2.3	1.4	0.5	1.7	0.9	0.1	0.1	3853
125.0	7	65.8	4.7	29.5	65.8	48.2	22.7	32.3	9.2	16.1	7.8	3854
150.0	1	98.9	15.9	83.0	1.1	0.7	0.3	0.9	0.5	0.0	0.0	3855
150.0	7	53.4	4.0	42.6	53.4	37.6	17.3	23.2	6.5	16.9	9.2	3856

```
==================================================================
Cut     : 3103
==================================================================

Multiplexing:
-------------
Multiplexing factor                            [NMPX]= 6

Peak definition:
----------------
Energy required for peak (GeV)                 [ECUT]= .015
Min. frac. of biggest peak for second       [PEAKCUT]= 0.25

Dip cut:
--------
const for max frac. of biggest peak        [DICONST]= 1.11
const for max frac. of biggest peak         [DIPMAX]= -.013
Energy power for max frac. of biggest peak[DIPPOWR]= 1.
Energy to set fraction to HEDIP              [EDIP]=50.
Dip fraction above EDIP                      [HEDIP]= 0.5
Energy above which dip cut is on             [EDLOW]= 51.

dip fraction    = DIPCONST + DIPMAX * E^DIPPOWR : EDLOW<=E<EDIP
                        = HEDIP                           : E>= EDIP
                        = cut turned off                  : E<EDLOW

Width cut:
----------
Multiplier for width cut below WCTHRESH     [CUTWID]= 6.96
Power of energy for width cut              [WIDPOWR]= -.25
Energy thresh where widthcut->NWCLOWER    [WCTHRESH]= 50.
Higher energy width cut                   [NWCLOWER]= 2
Min. frac. of biggest peak for width       [EWIDCUT]= 0.6

width bin height cut     = INT(CUTWID * E^WIDPOWR)        : E < WCTHESH
                                = NWCLOWER                       : E>= EDIP

Mean position cut:
------------------
Mean offset for pi0 (in mm)                [CUTMEAN]= 6.75             bins, not cm!
Power of energy for mean offset scaling    [CUTPOWR]= -0.5
Tot. energy above which CUTMEAN->HEMEAN     [CUTOFF]= 63.
Mean difference cut above CUTOFF            [HEMEAN]= 0.65

mean offset cut = CUTMEAN*E^CUTPOWR      : E<CUTOFF
                        = HEMEAN                : E>= HEMEAN
```

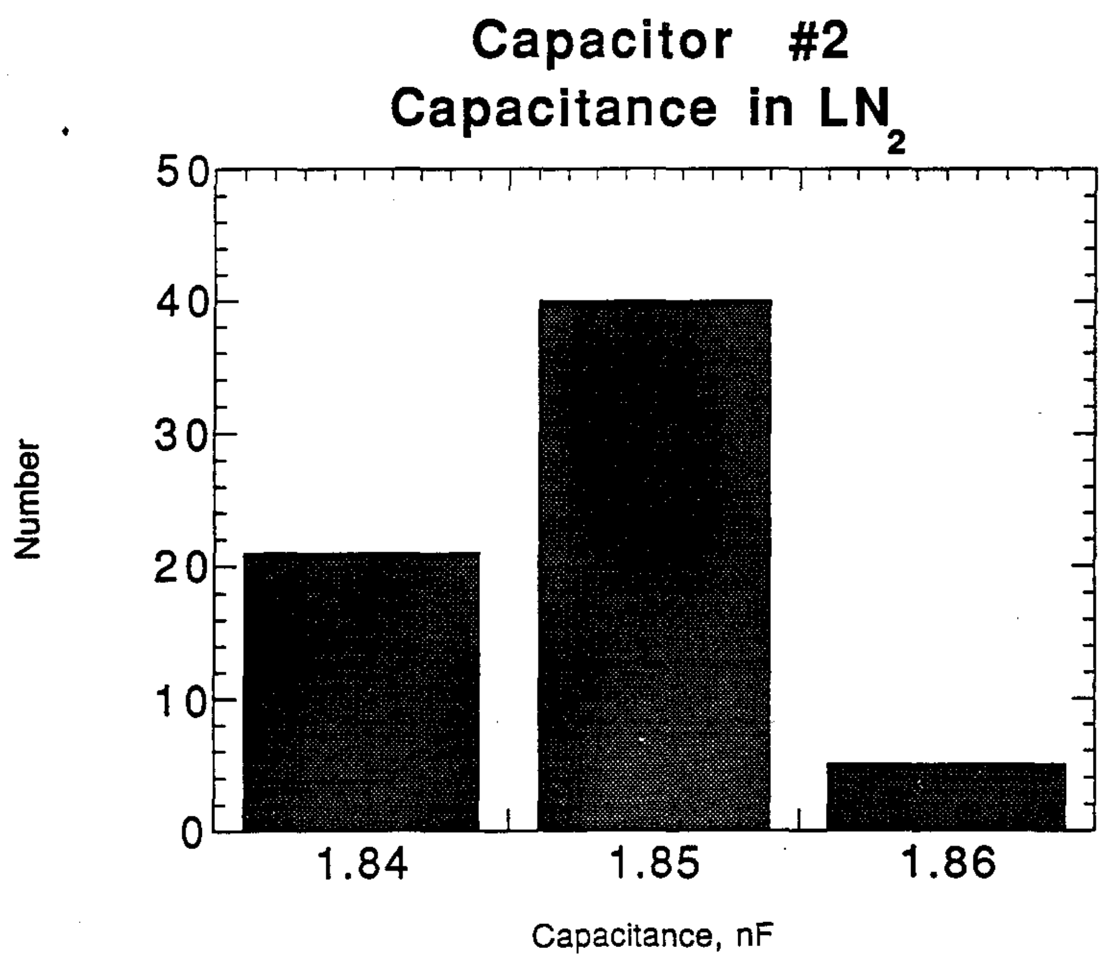


stripline side

(Parallel plate geometry)

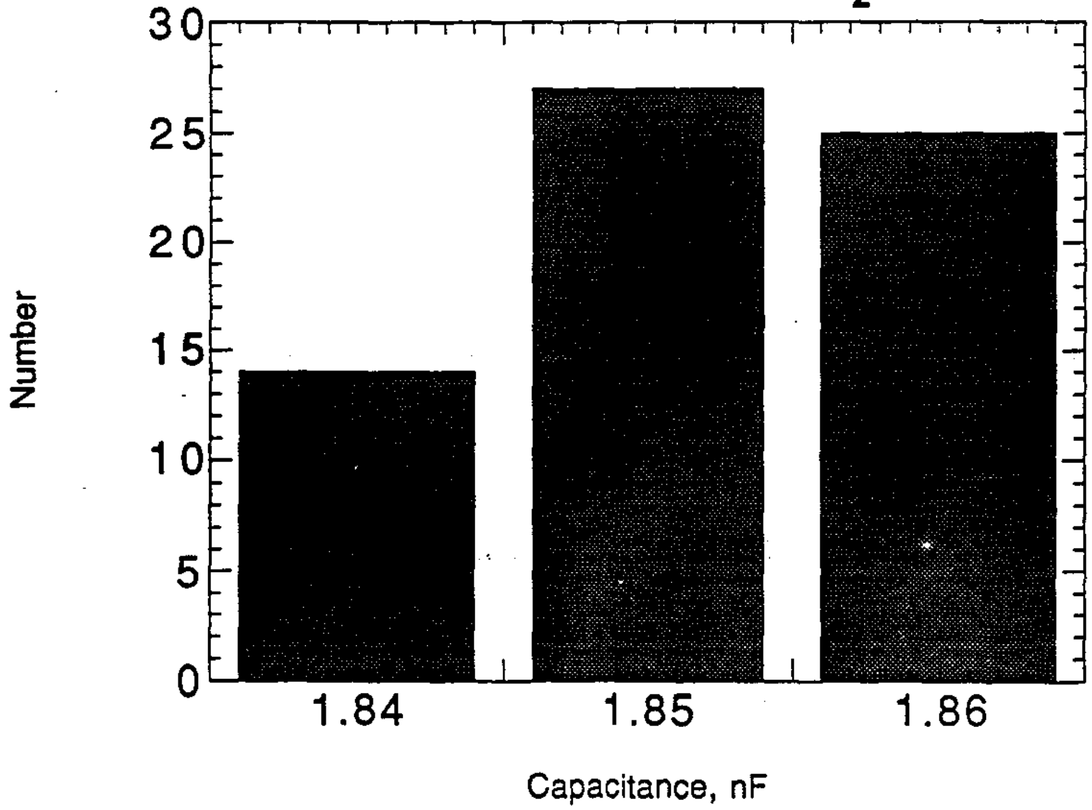


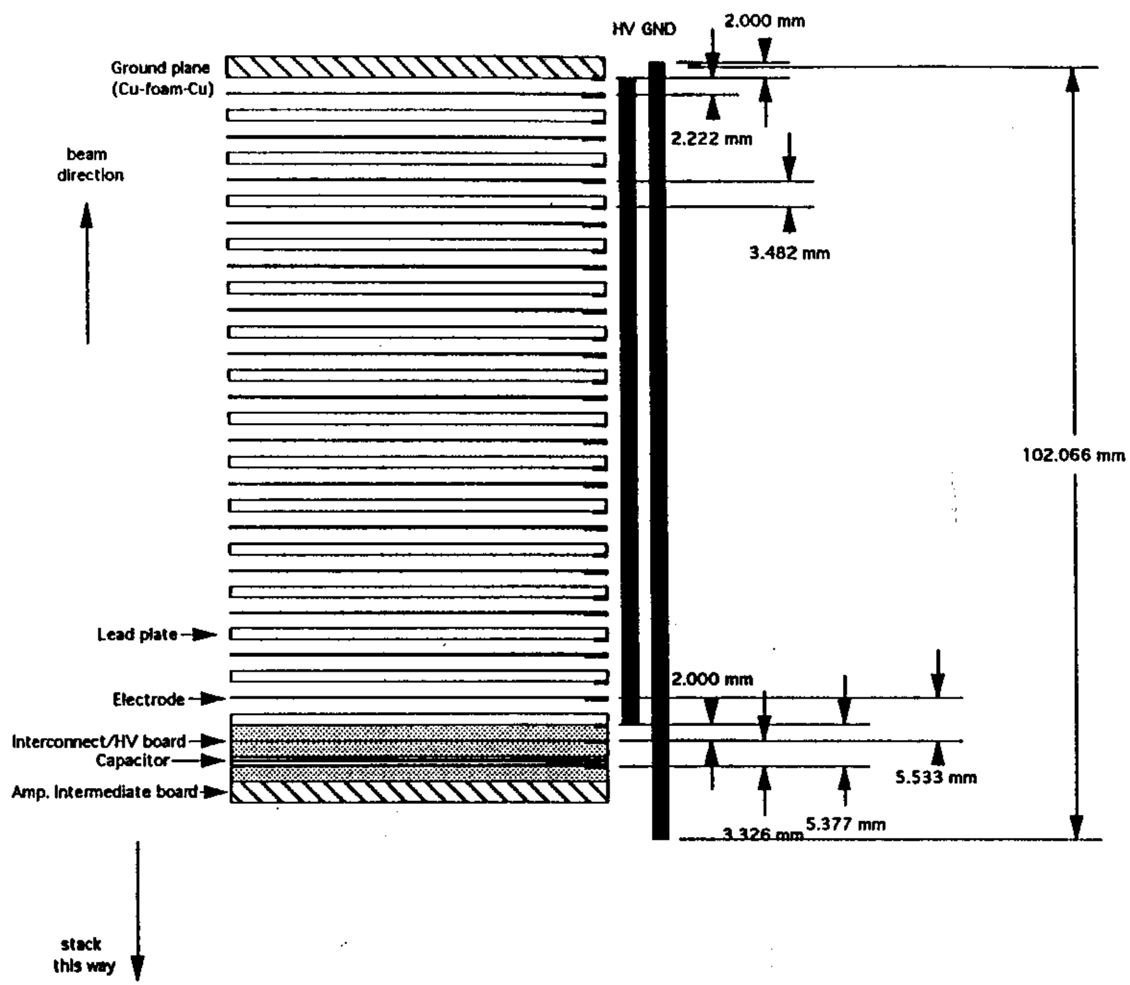
1/21/92



Capacitor #2
Capacitance in LN_2
Number
0
10
20
30
40
50
1.84
1.85
1.86
Capacitance, nF

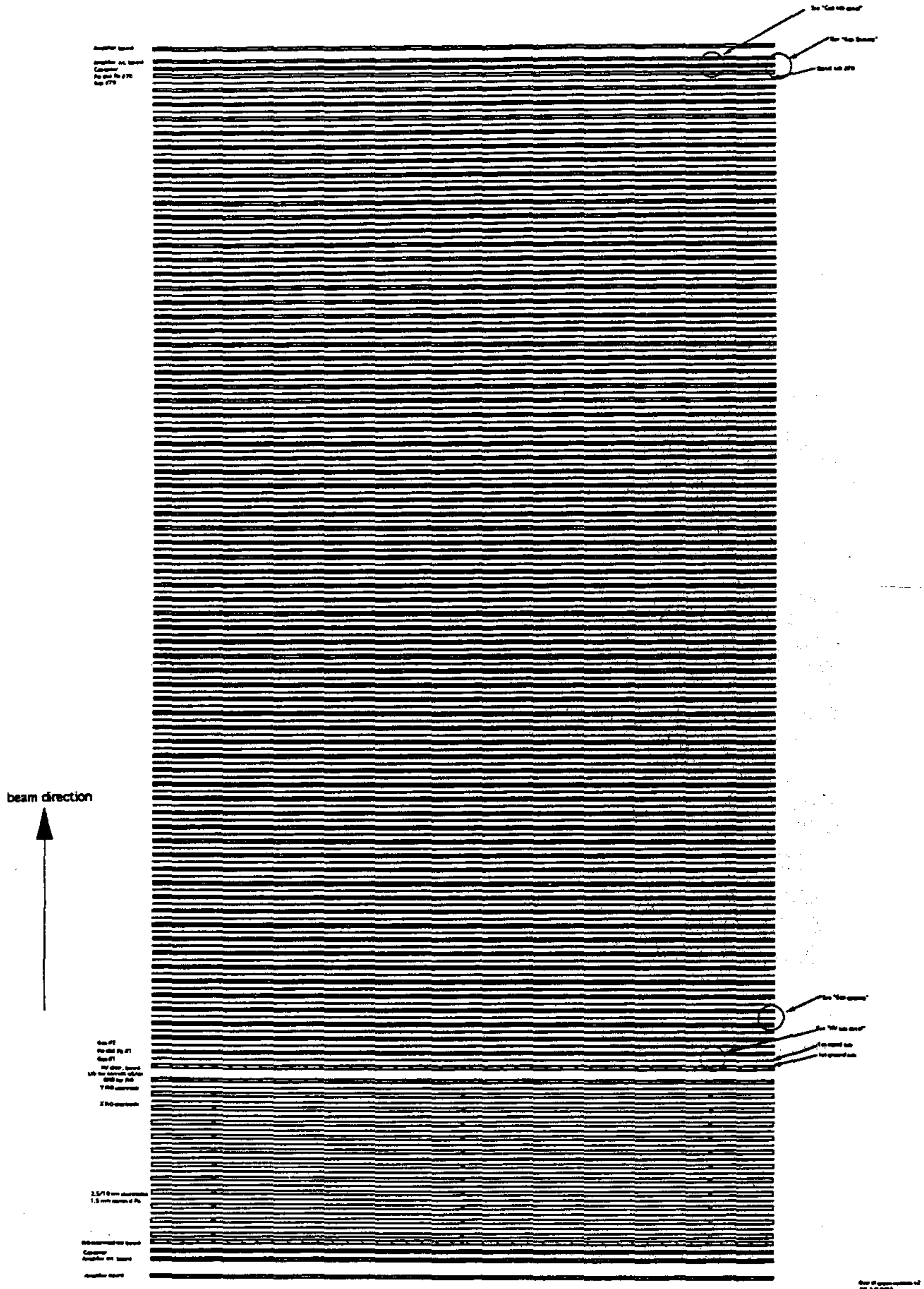
Capacitor #1
Capacitance in LN_2

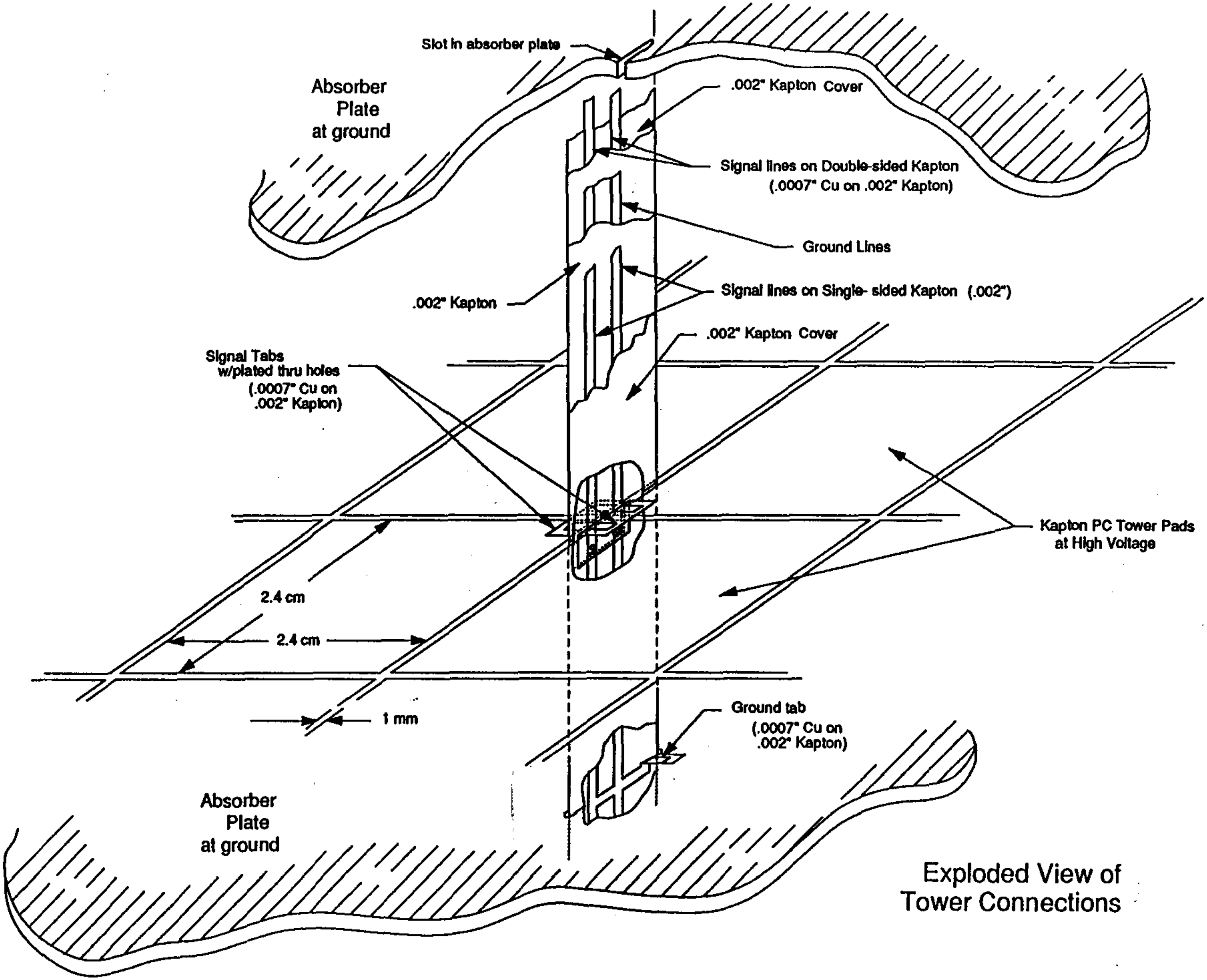




all dims reflect actual
measurements recorded in
*GEM EM Construction, p. 35

PiO gap details
v4
JKE 6/9/92


beam direction



Exploded View of Tower Connections

Preliminary Results ~5×5

σ 38.5 ADC

⇒ Pedestal unfolded

$\sigma' = 28.3$ ADC

σ'/E 1.8%

⇒ 7.0 ± 0.2% $\sigma/\sqrt{E}$ LAr

MC ⇒ 4.3%/$\sqrt{E}$, LKr

Conclusions:

Achieved Goals of Fast Parallel Plate Design (4.3%/$\sqrt{E}$ LKr)

Showed qualitative response in strips similar to MC ⇒ Good π^0 rejection.

⇒ Can build a fast competitively priced parallel plate calorimeter for GEM with

a) The best resolution

b) A π^0 detector at no increase in channel count or other costs

c) Construction - labor costs appreciably lower than M.R.'s first estimate

Preliminary Analysis

* Charge Collection

Raw 15 GeV e @ 10KV

1618 ADC Counts

* Corrections

Capacitance Coupling		x 1.45
High Voltage 1830:1400		x 1.31
Sampling Fraction	$\frac{20}{25.8} \times \frac{2.15}{2.05}$	x .813

Results: 2500 ADC Counts

* Noise

2.5 ADC Front (π^0)
4.7 ADC Back (EM CAL)
5x5 Approx 26 ADC

* Signal 15 GeV e^-

M Carlo - 6.5% / $\sqrt{E}$

Data

Corrections to be studied

- Higher Voltage
- Stability
- FERA Calibrations
- Front/Back Weighting
- M Carlo available towers
- Beam Momentum Spread

GEM

P. Mockett
SSCL 8/9/92

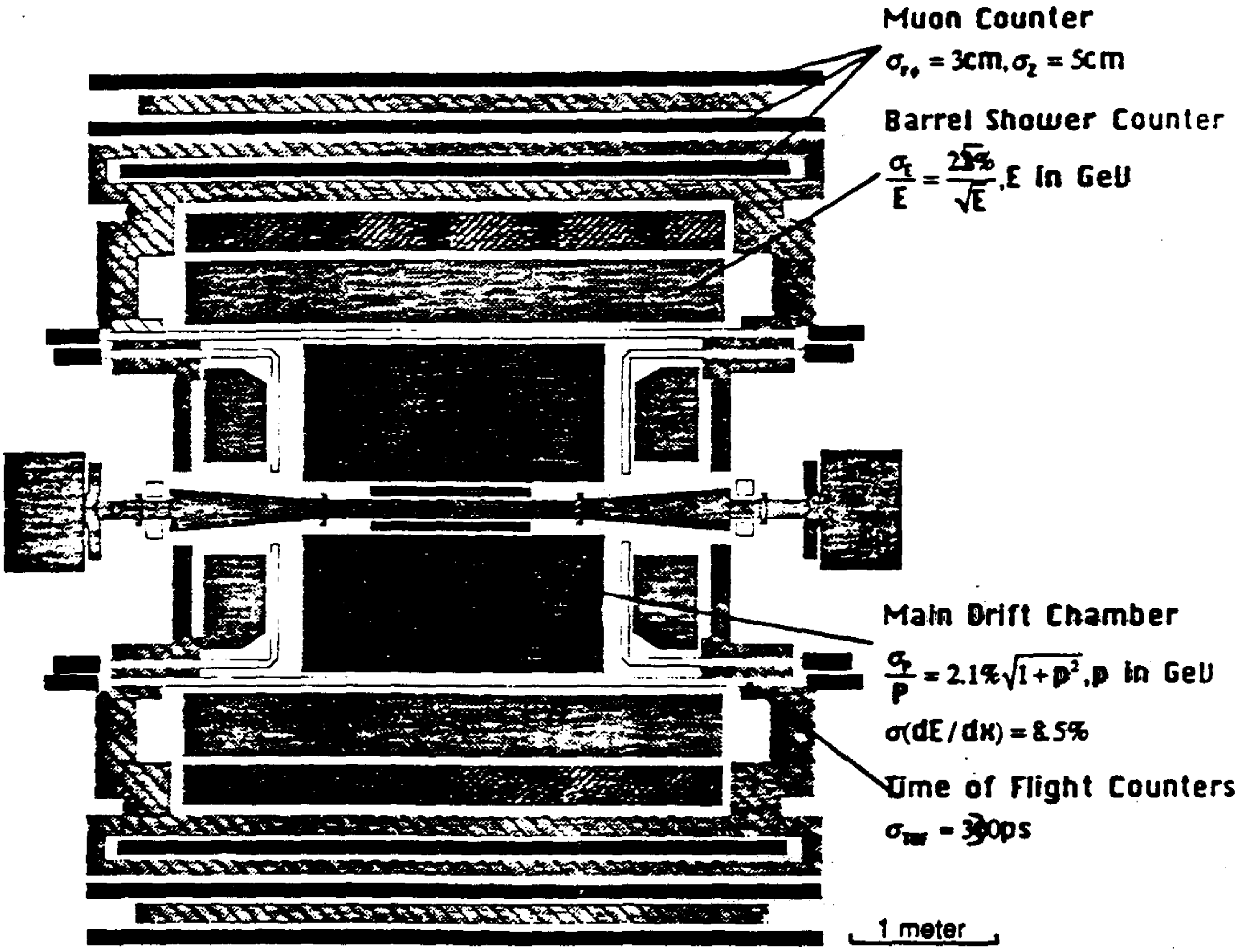
Parallel Plate Calorimeter Tests

* Parallel Plate LAr/LKr Calorimeter
  - Concept
  - Components
  - Construction

* π^0 Detector
  - Concept
  - Components
  - Construction

* Beam Tests @ BNL
  - Assembly
  - Testing
  - Moving into Beam
  - First Data
  - Data Taking

Paul Mockett
FM-15
Univ of Washington
Seattle, WA
98195



BES Detector

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

Endcap Shower Counter specifications

Distance from interaction regions	
Front layer	139.0 cm
Back layer	177.8 cm
Radius of sensitive regions	
Outer	105.4 cm
Inner	35.0 cm approx.
Radius of assemblies	
Outer	110.5 cm
Inner	32.5 cm
Polar angle of sensitive region	
Front outer	37.2 degrees
Front inner	14.1 degrees
Back outer	31.9 degrees
Back inner	11.1 degrees
Solid angle subtended	
Front	$2 \times 8.5\% \times 4\pi$
Back	$2 \times 6.5\% \times 4\pi$
Tube thickness, interior	1.17 cm
Tube width, interior	2.71 cm
Tube wall thickness	0.064 cm
Lead thickness per layer	0.279 cm
Adhesive thickness per layer	0.025 cm
Number of layers	24
Number of cells per layer	94
Sense wire type	Stablohm 800 s.s.
Sense wire diameter	37 μm
Gas type	80% argon, 20% methane
Gas flow	1 volume per day

Table 3

Barrel Shower Counter Specifications

Spool length	385.0 cm
Spool outer diameter	252 cm
Spool thickness	2.3 ±0.4 cm
Flange outer diameter	261.8 cm
Cell width, inner layer	2.4 cm
Cell width, outer layer	3.2 cm
Gas thickness per cell	1.27 cm
Length of active volume (including anterior ribs)	348.00 cm
Number of layers	24
Thickness of aluminum sheets	0.064 cm
Thickness of lead sheets	0.28 cm
Thickness of Al. Pb, Al glue sandwich	0.46 cm
Length of Pb sheets	348.00 cm
Number of Pb sheets per circumference	10
Width of ribs	2.67 cm
Height of I-beams	1.24 cm
Width of top flange of I-beams	1.02 cm
Thickness of I-beam material	0.076 cm
Sense wire type	Stablohm 800 s.s.
Sense wire diameter	46 μm
Gas	80% argon; 20% methane
Gas flow	10000 liters (one volume) pe

5. Electronics by Tsinghua Univ., IHEP and USTC

The three institutions are interested in joining the Electronics developing of Liquid Cal. of GEM. They have strong background of electronics, Tsinghua Univ. has also the facilities to develop boards.

Tsinghua Univ.:

Prof. Wang Jinjing
Senior Eng. Shao Beibei

IHEP:

Prof. Guo Yanan

USTC:

Prof. Yu Xiaqi

will contribute to the electronics development.

SUMMARY

We will contribute to GEM and support GEM strongly

with experienced physicists
skilllful engineers and technicians
cheaper labors for time-consuming work

I believe strongly we could accomplish the hard task which GEM gives us. I would contribute myself as much as possible in the next years.

3. Raw Materials in China

Lead	available
Stainless Steel	available
Copper	available
G10	need to be tested
Kapton	need to be tested
Prepreg	need to be tested
Silkscreen skill	available

4. Crocodile machine is creterion

The special Crocodile bending machine should be made in SAMF.
They should learn here what is the special demand and how to design it first.

More detail about the mechanical engineering waiting for the Senior Engineer of SAMF Mr. Zhang Shiyuan(Aug.22) come to discuss.

* Prototype developing and Detector Design in U.S.
* Manufacture in China

2. SAMF --- Mechanical manufature
Shanghai Aircroft Manufacture Factory

a. Skillful manpower

SAMF has long term collabration with IHEP during the constructure of Shower Counter of BEjing Spectrometer(BES-- Successful Tau mass masurement) from 1984 to 1988. The Shower counter is working in the Self Quench Stream mode. All the mechanical parts(Lead plates, Alum. frame) were manufactured in SAMF and assembling up in IHEP by SAMF.

The engineers and technicians in SAMF have very good training and skill, more important, they could UNDERSTAND and ACCEPT the strange ideas from the high energy physicists, so they could collaborate with us quite well.

b. Machinery facilities

SAMF is a very big factory with long history making airplanes, They also have the collaboration with U.S. airplane company to produce Aircraft for U.S..

Big press machine
Big Oven
Computer control machines
are available

Show the Shower Counter of BES here to convince that they could make the GEM Calorimeter also.

(An intention only)

The Manufacture of Liquid Calorimeter of GEM in CHINA

Presented by Chunhua Jiang , IHEP, Beijing, China

1. IHEP --- Quality Controll

IHEP would like to Contribute physicists to the Quality Control:

a. We will organize a group to take the responsibility to control the process of the manufacturing the absorber and electrodes plates. (no experience before)
First we need to learn here the detector working principle and properties so we could fully understand how to control and which parts we should pay specially attention and so on.
Than we could explain to the engineers and technicians of SAMF how manufacture the parts of the Cal., why the tolerances are very important.

b. Set up TEST CELL in IHEP

The Test Cell should include:
small LAr chamber, alpha sourse, beta sourse
readout electronics system (preamp...)
cryostat system
Use this mini system we could undersatnd the detector and test what kind materials we could use during the manufacture process, what poisons LAr, so we could guarantee the Cal. works properly after assembling to modules.
Physicists and instrumentation contributed by IHEP.
Some special electronics from BNL.

Krypton. —
— Preliminary !!

3X3 m.c: $7.11\% / \sqrt{E}$

$$\frac{\Delta E}{E} = \frac{7.56\%}{\sqrt{E}} \oplus \frac{53}{E} + 0$$

$$\frac{\Delta P}{P} = 0.5 - 0.7\%$$

$$\frac{\Delta E}{E} = \frac{7 - 7.3\%}{\sqrt{E}} \oplus \frac{53}{E} + 0$$

5X5: m.c: $6.3\% / \sqrt{E}$

$$\frac{\Delta E}{E} = \frac{6.9}{\sqrt{E}} \oplus \frac{85}{E} \oplus 0$$

$$\frac{\Delta P}{P} = 0.5 - 0.7\%$$

$$\frac{\Delta E}{E} = \frac{6.3 - 6.9}{\sqrt{E}} \oplus \frac{85}{E} \oplus 0$$

Preliminary Results!!

$$\frac{\Delta E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

I: Standard L.A. Module.

M.C: $7.3\%/\sqrt{E}$

$$\frac{\Delta E}{E} = \frac{8\%}{\sqrt{E}} \oplus \frac{.140}{E} \oplus 0$$

$$\frac{\Delta P}{P} = 0.5 - 0.7\ \%$$

$$\frac{\Delta E}{E} = \frac{7.5 - 7.8\ \%}{\sqrt{E}} \oplus \frac{140}{E} + 0$$

II 1 mm L.A.

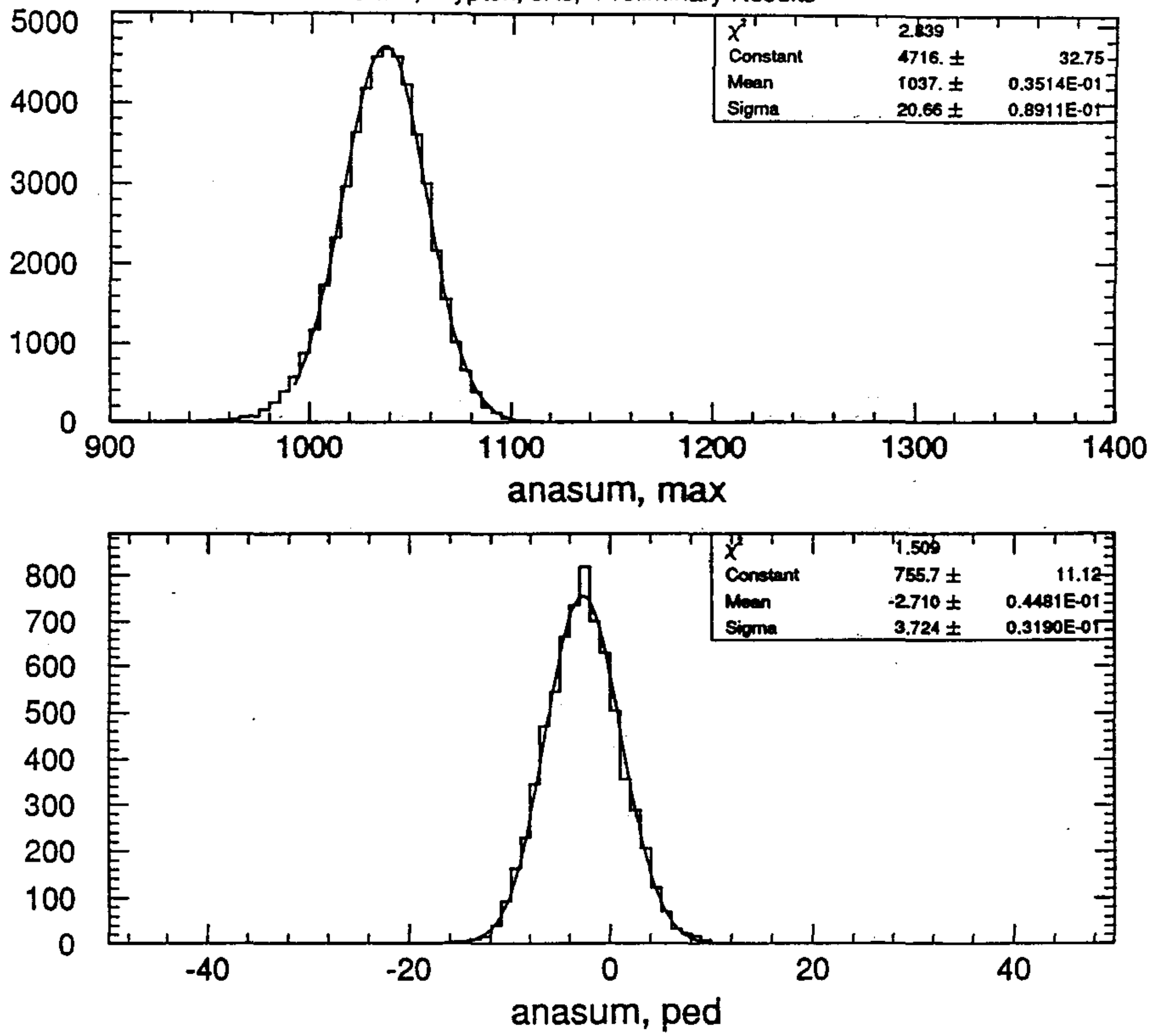
m.c $6.25\%/\sqrt{E}$

$$\Delta E/E = 6.4\%/\sqrt{E} \oplus 240/E \oplus 0$$

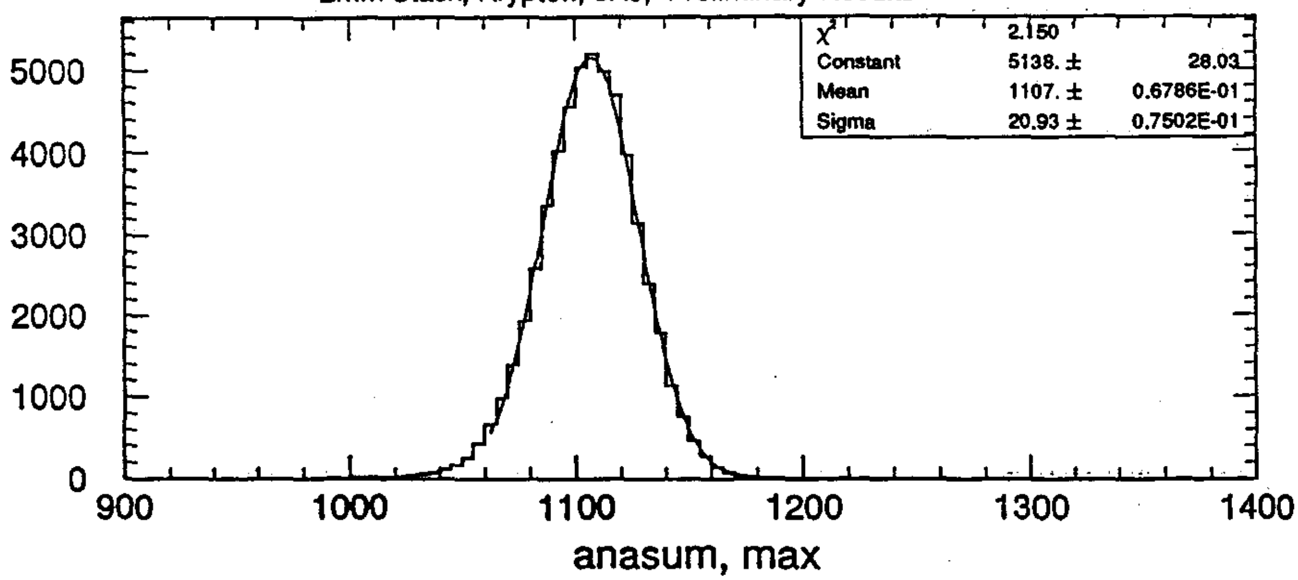
$$\frac{\Delta P}{P} = 0.5 - 0.7\%$$

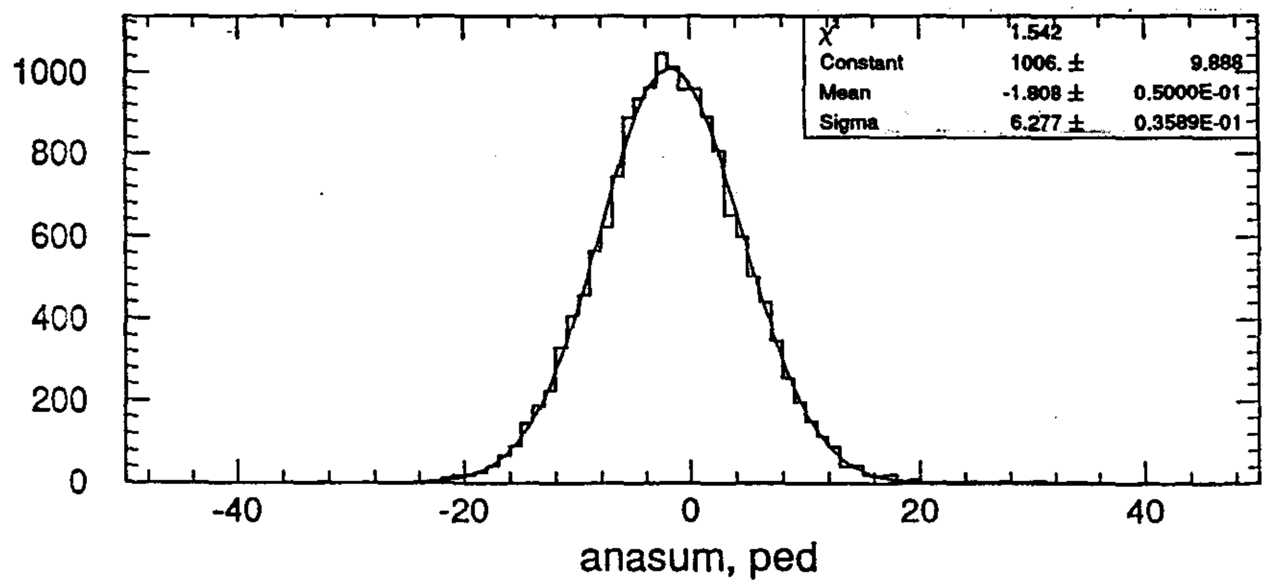
$$\Delta E/E = 6\%/\sqrt{E} \oplus 240/E \oplus 0.$$

2mm Stack, Krypton, 3X3, Preliminary Results

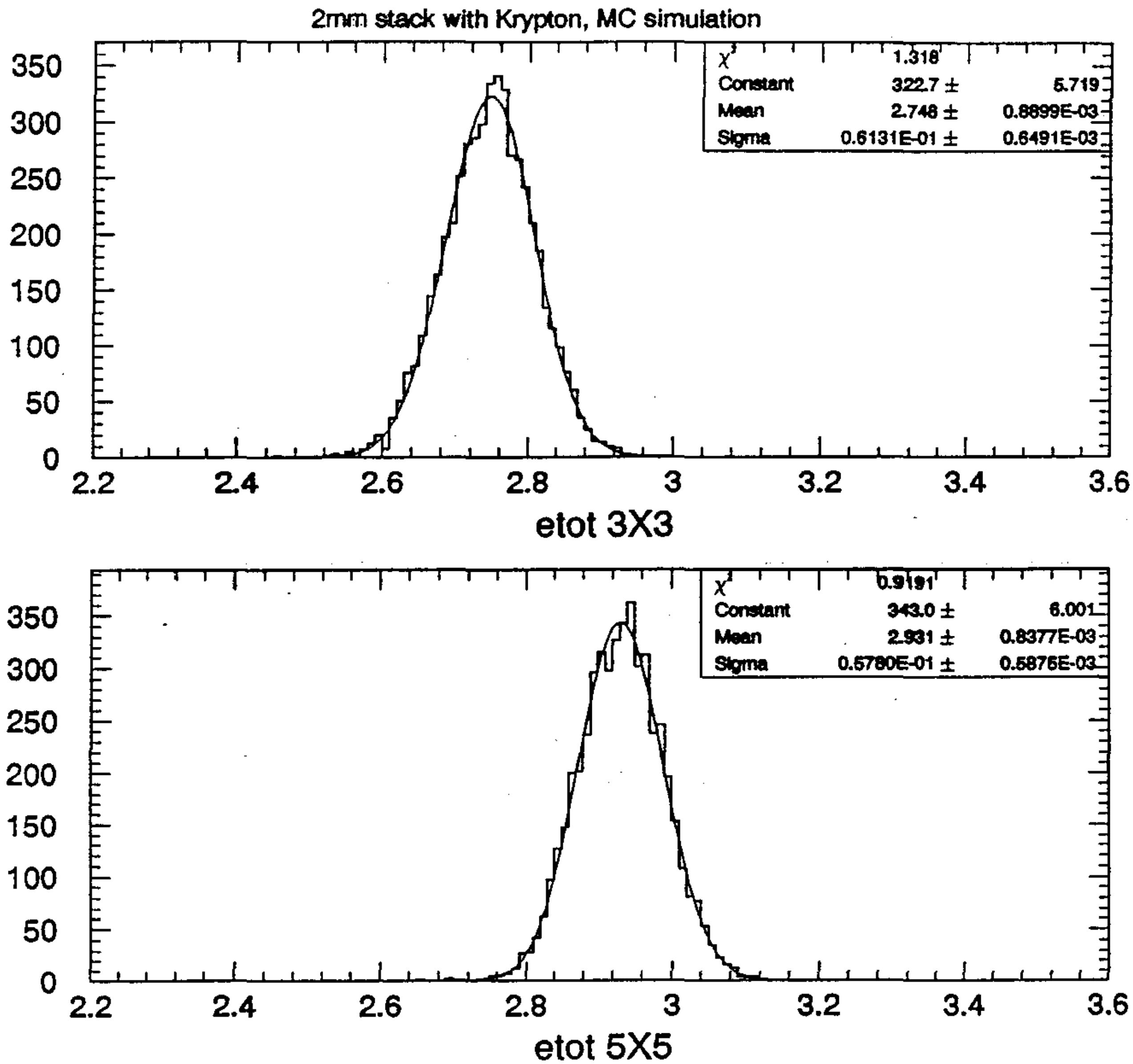


2mm Stack, Krypton, 5X5, Preliminary Results

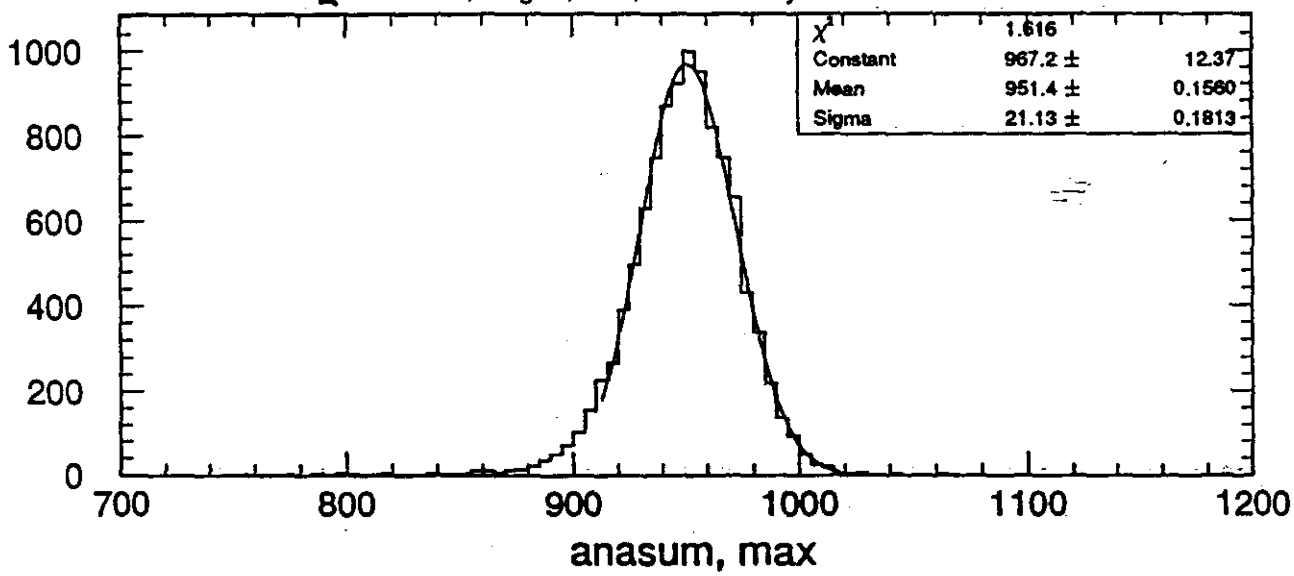


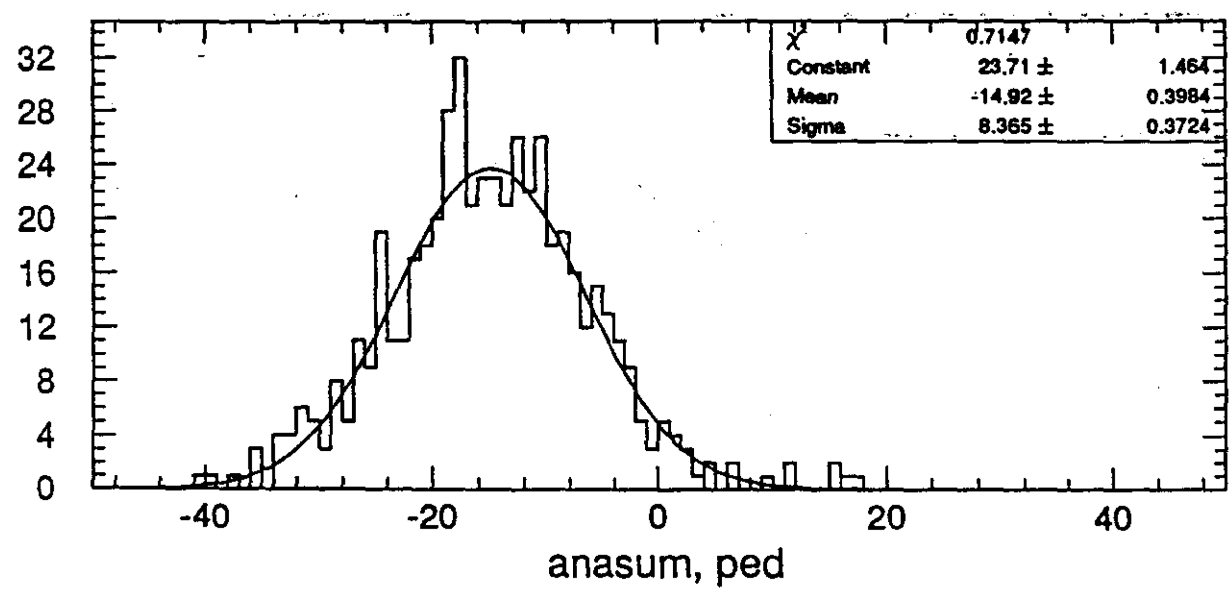


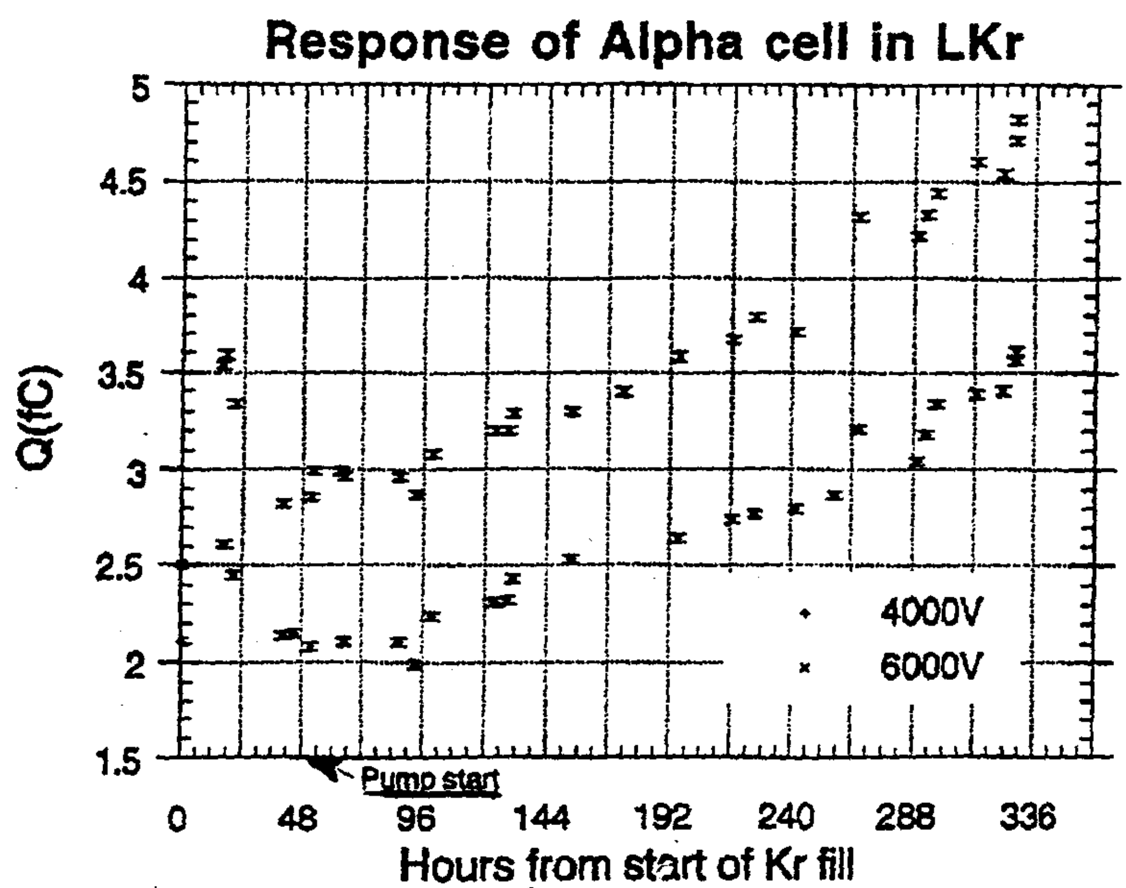
M.C: 3X3, 5X5 Krypton.

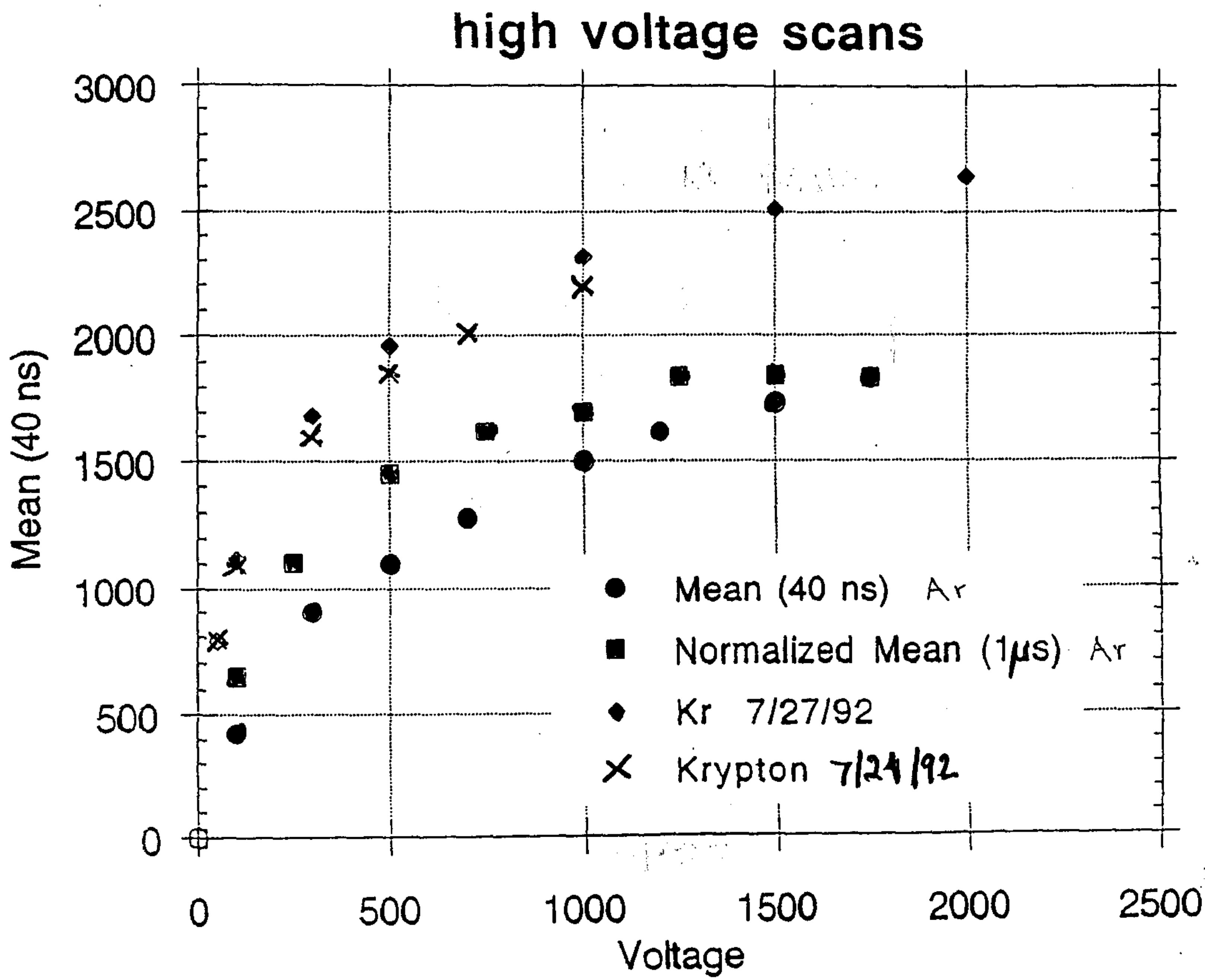


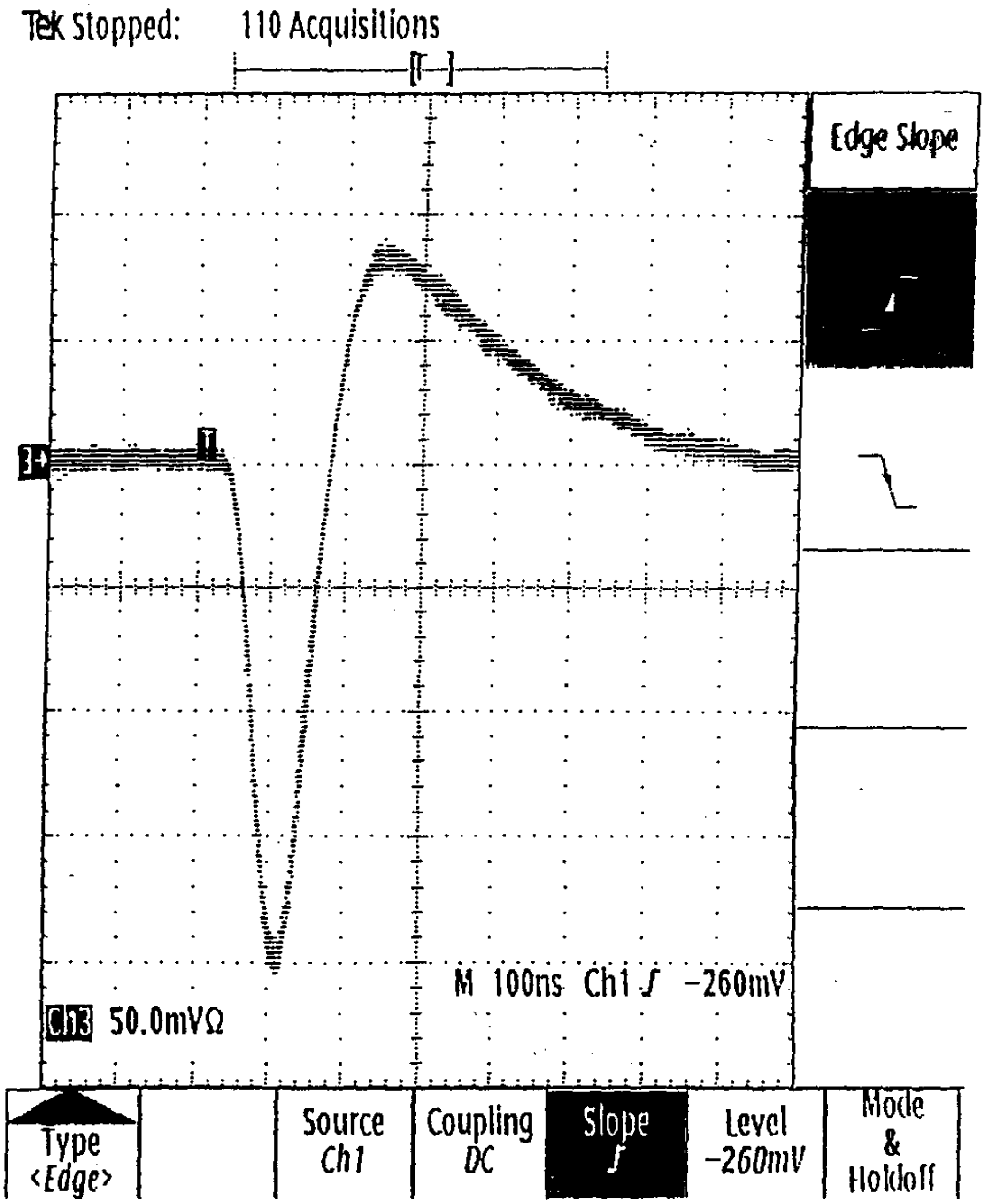
2mm Stack, Argon, 5X5, Preliminary Results






Response of Alpha cell in LKr
Q(fC)
5
4.5
4
3.5
3
2.5
2
1.5
4000V
6000V
Pump start
0
48
96
144
192
240
288
336
Hours from start of Kr fill


high voltage scans
Mean (40 ns)
Voltage
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
Mean (40 ns) Ar
Normalized Mean (1μs) Ar
Kr 7/27/92
Krypton 7/24/92



LKr, 2mm stack, 1.5kV

20GeV

Sum of ~150 channels

Multiple trace - variable persistence

Beam size: 2.5 x 5 cm^2

15 GeV e⁻

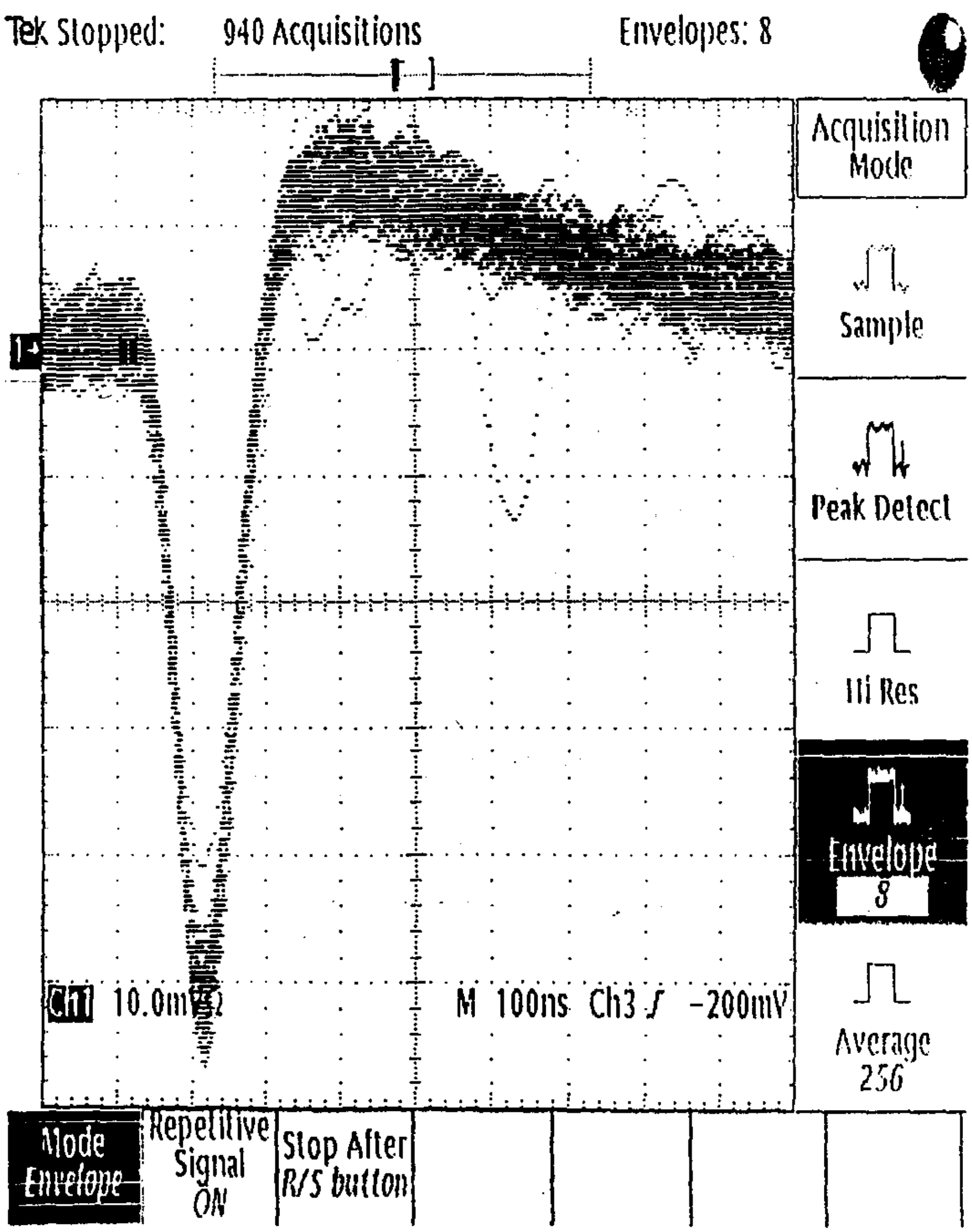
50 Volts !!!

LK

HV: 50V

15 GeV e⁻

7/27/92



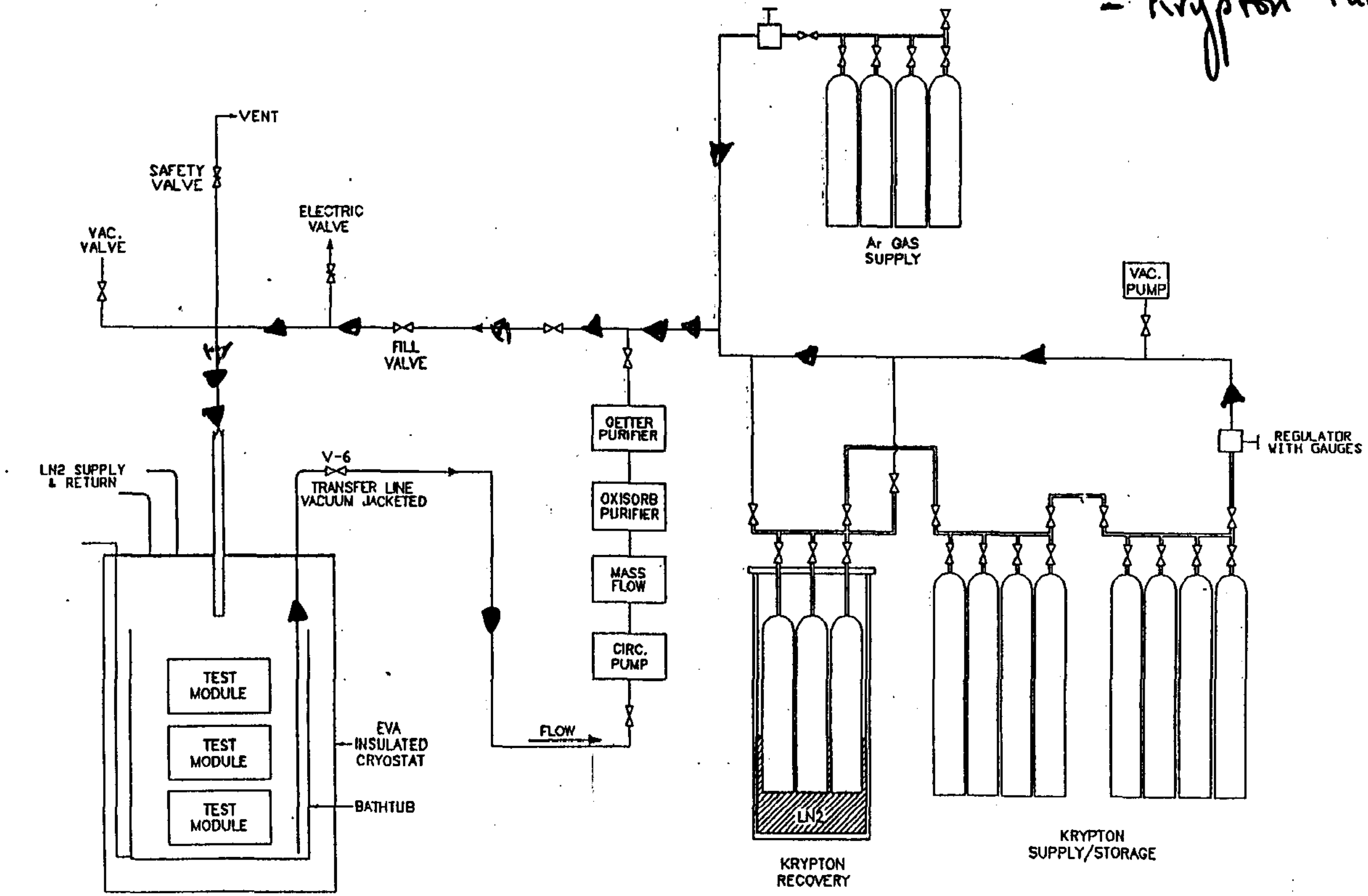
L Kr "2 mm" 50 nsec

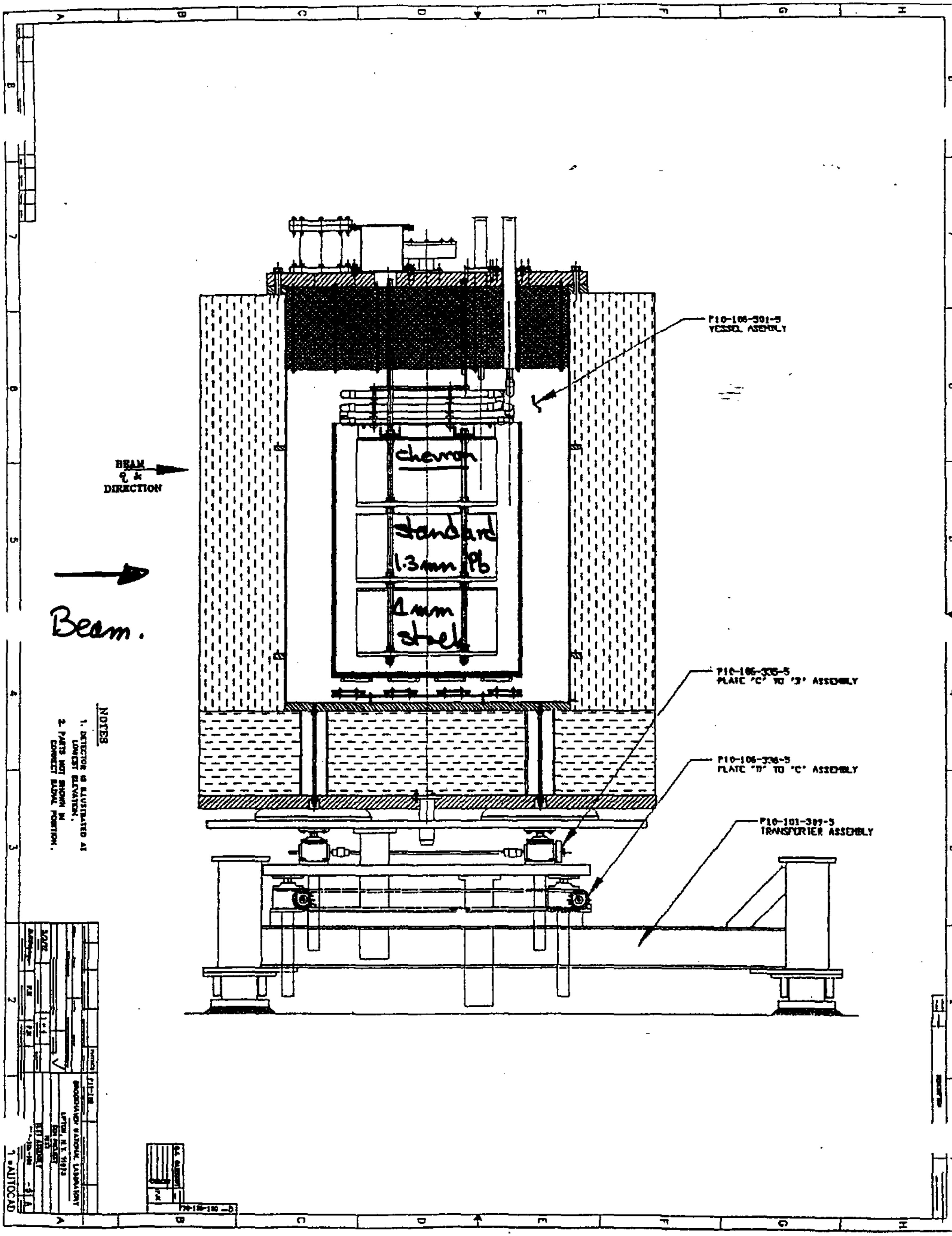
15 GeV

- Argon fill.

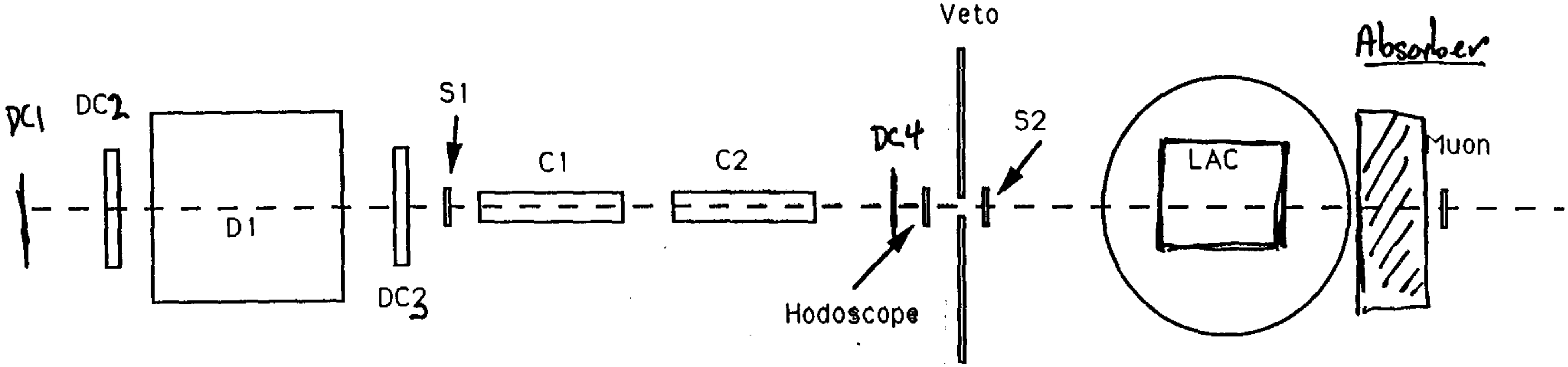
- Krypton fill

- Krypton Purification




P10-106-301-5
VESSEL ASSEMBLY
BEAM
℄ &
DIRECTION
chevron
standard
1.3mm Pb
1mm
steel
Beam.
P10-106-335-5
PLATE "C" TO "B" ASSEMBLY
P10-106-336-5
PLATE "D" TO "C" ASSEMBLY
P10-101-309-5
TRANSPORTER ASSEMBLY
NOTES
1. DETECTOR IS ILLUSTRATED AT LOWEST ELEVATION.
2. PARTS NOT SHOWN IN CORRECT RADIAL POSITION.
BROOKHAVEN NATIONAL LABORATORY
UPTON, N.Y. 11973
1=AUTOCAD

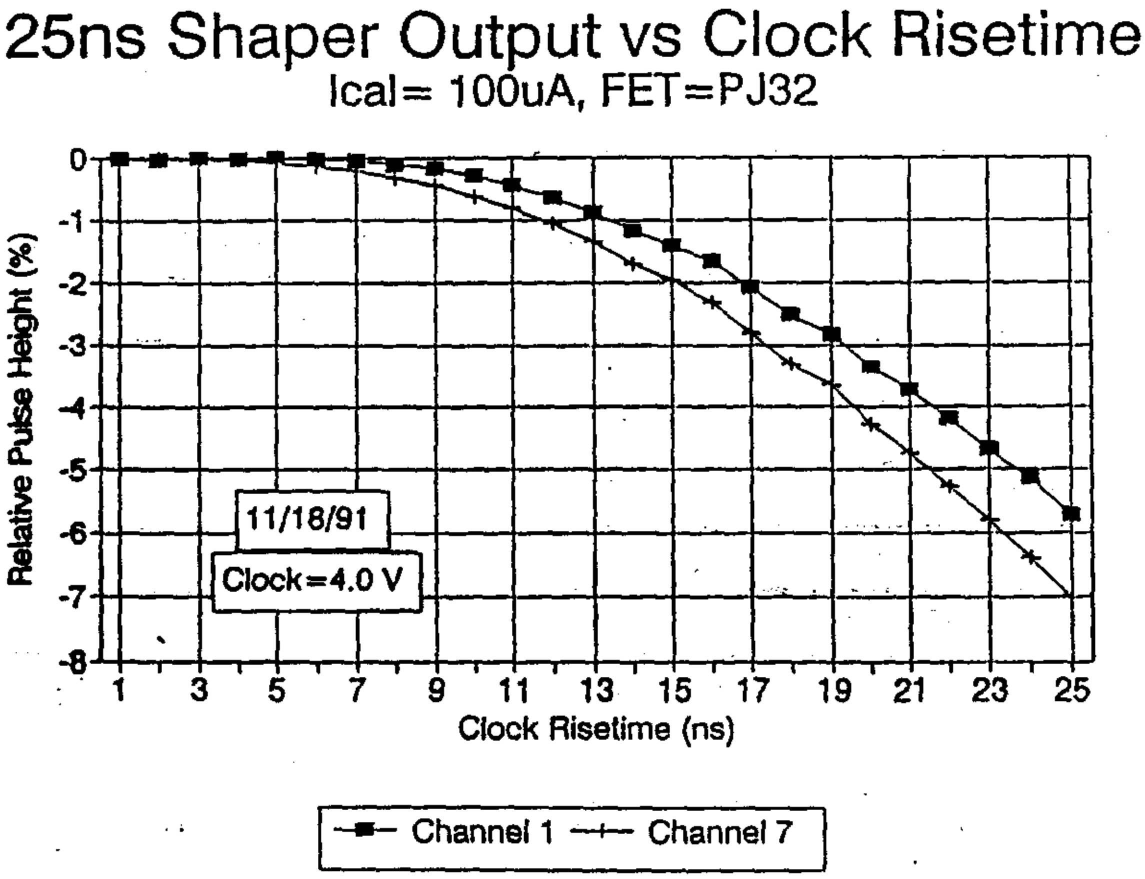
A3 - Beam Line: AGS.



Beam: 0.5 Gev → 20 Gev

$\bar{p} / \pi / e^-$

$\sim 10^6$ pps.



<u>Calibration:</u>

Clock signal has to be known to better than 3-5 n-sec. to get 0.1%.

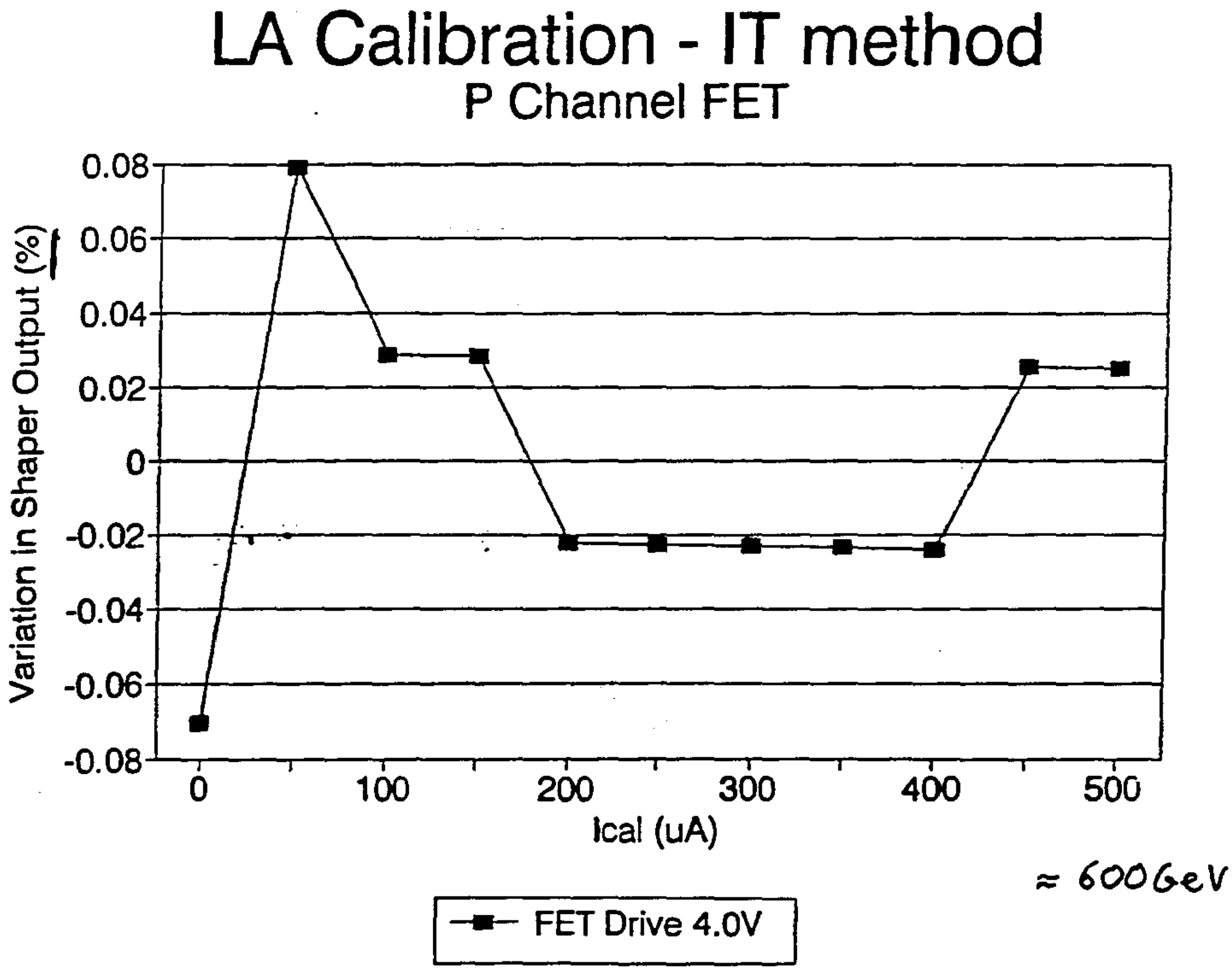
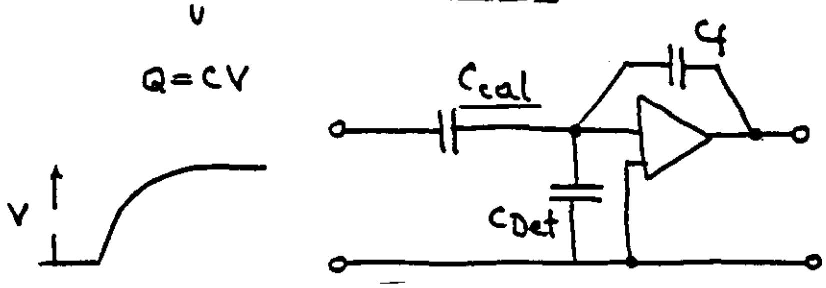

LA Calibration - IT method
P Channel FET
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
Variation in Shaper Output (%)
0
100
200
300
400
500
Ical (uA)
≈ 600GeV
FET Drive 4.0V

Fig. 5

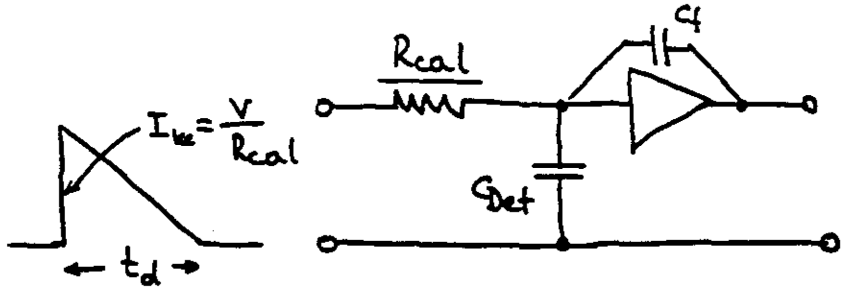
Charge Calibration

1) $Q = CV$



$$\frac{\delta C_{cal}}{C_{cal}} \approx 2\%$$

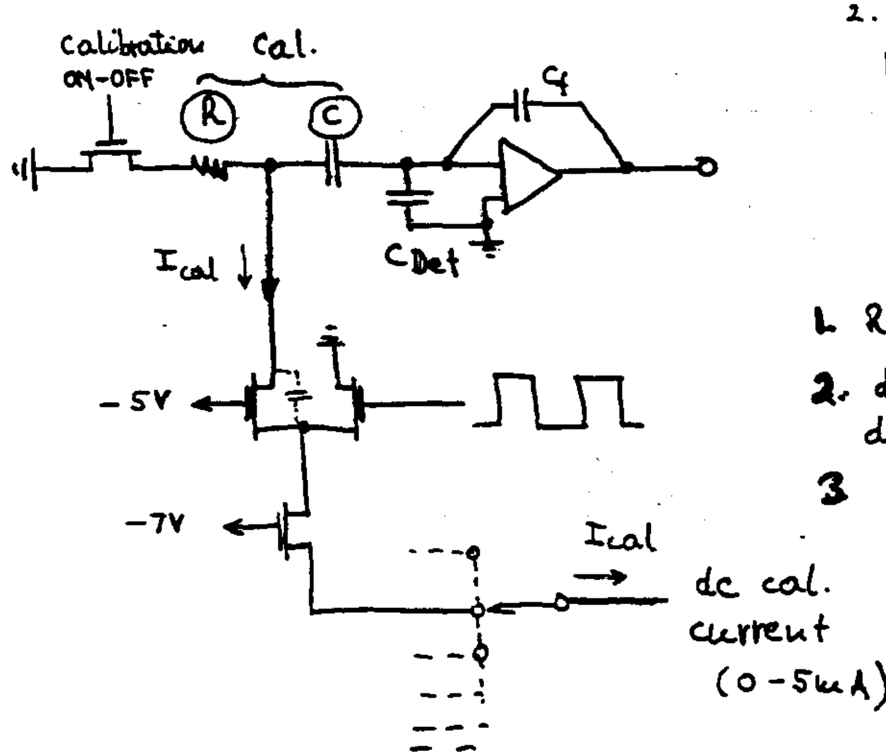
2)



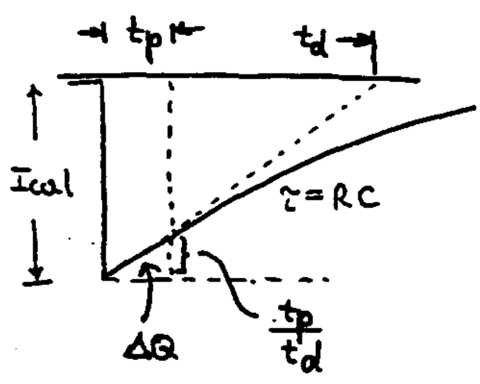
$$\frac{\delta R_{cal}}{R_{cal}} \approx 0.1\%$$

Problems:
1. Low R needed
2. Distribution of precisely controlled pulses.

3)



1. R can be low
2. dc current distributed
3. 10% R's and c's result in 0.5% calibration.

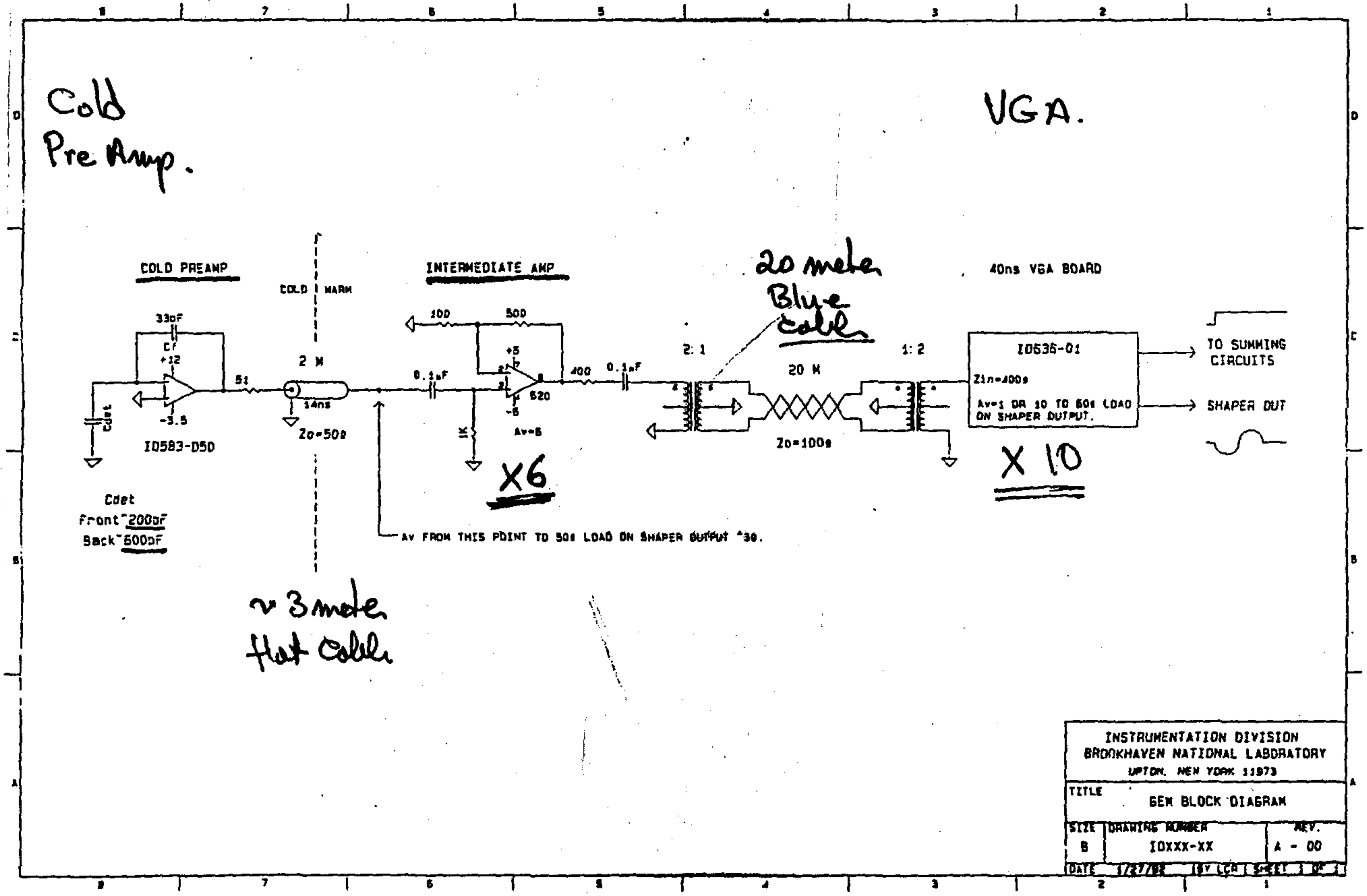


$$Q_{cal} = I_{cal} \cdot t_p \left(1 - \frac{1}{2}\frac{t_p}{t_d}\right)$$

$$\frac{\Delta Q}{Q_{cal}} = \frac{1}{2}\frac{t_p}{t_d} \approx \frac{1}{20} \quad \text{for} \quad t_p = 40\,\text{nsec}, \; t_d = 400\,\text{nsec}$$

$$\boxed{\frac{\delta I_{cal}}{I_{cal}} = \frac{1}{20}\left(\frac{\delta R}{R}, \frac{\delta C}{C}\right)}$$

switch parameters (V_T and noise) do not influence calibration.

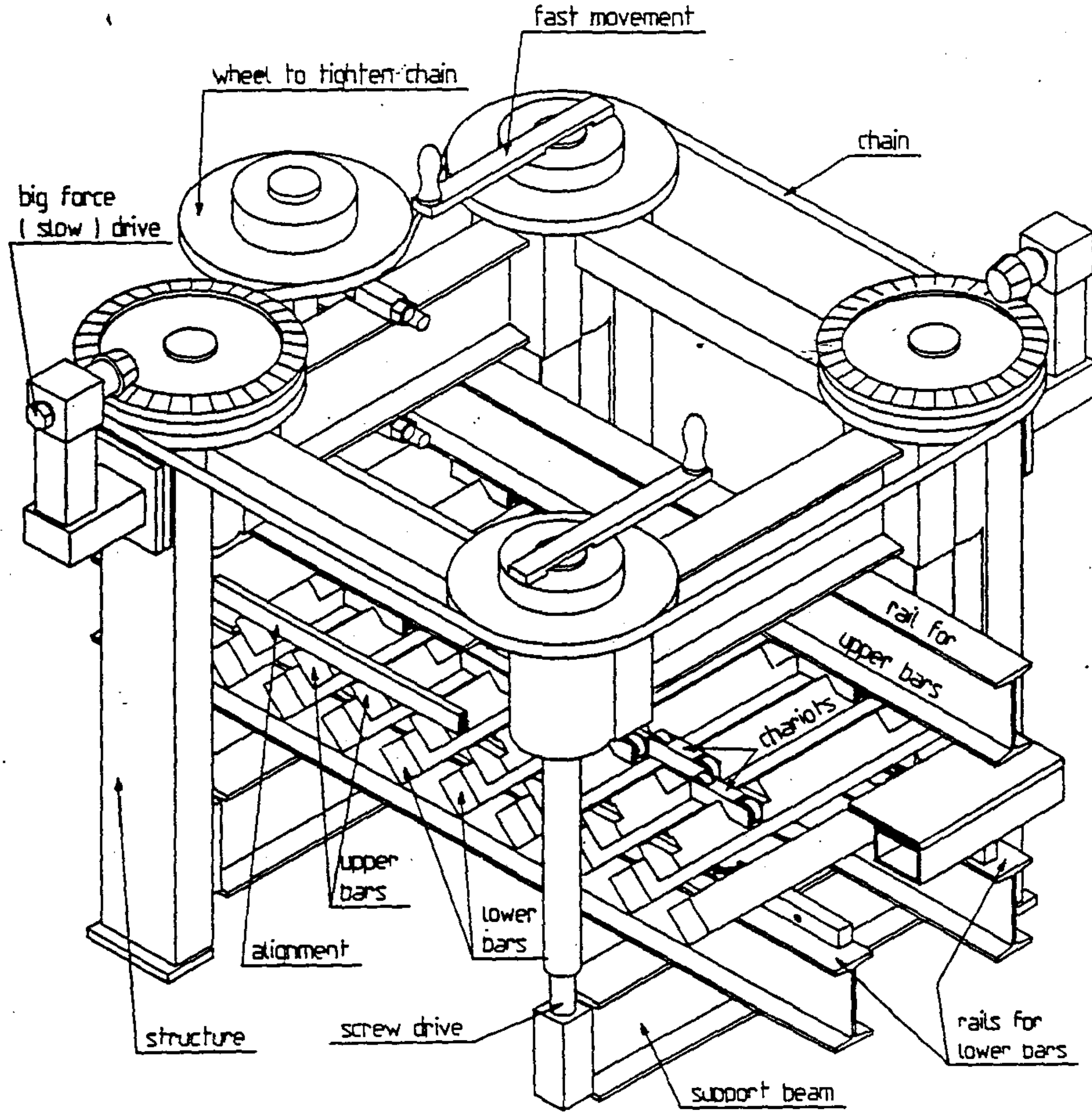

Cold
Pre Amp.
VGA.
COLD PREAMP
COLD | WARM
INTERMEDIATE AMP
20 meter
Blue cable
40ns VGA BOARD
33pF
Cf
+12
-3.5
Cdet
51
2 M
14ns
Zo=50Ω
ID583-D50
100
500
+5
-5
520
Av=5
1K
0.1μF
400
0.1μF
2:1
20 M
Zo=100Ω
1:2
ID636-01
Zin=400Ω
Av=1 OR 10 TO 50Ω LOAD ON SHAPER OUTPUT.
TO SUMMING CIRCUITS
SHAPER OUT
X6
X 10
Cdet
Front ~200pF
Back ~500pF
AV FROM THIS POINT TO 50Ω LOAD ON SHAPER OUTPUT ~30.
~ 3 meter
flat cable
INSTRUMENTATION DIVISION
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973
TITLE
GEM BLOCK DIAGRAM
SIZE
B
DRAWING NUMBER
IDXXX-XX
REV.
A - 00
DATE
BY LCH

EM CONFIGURATION

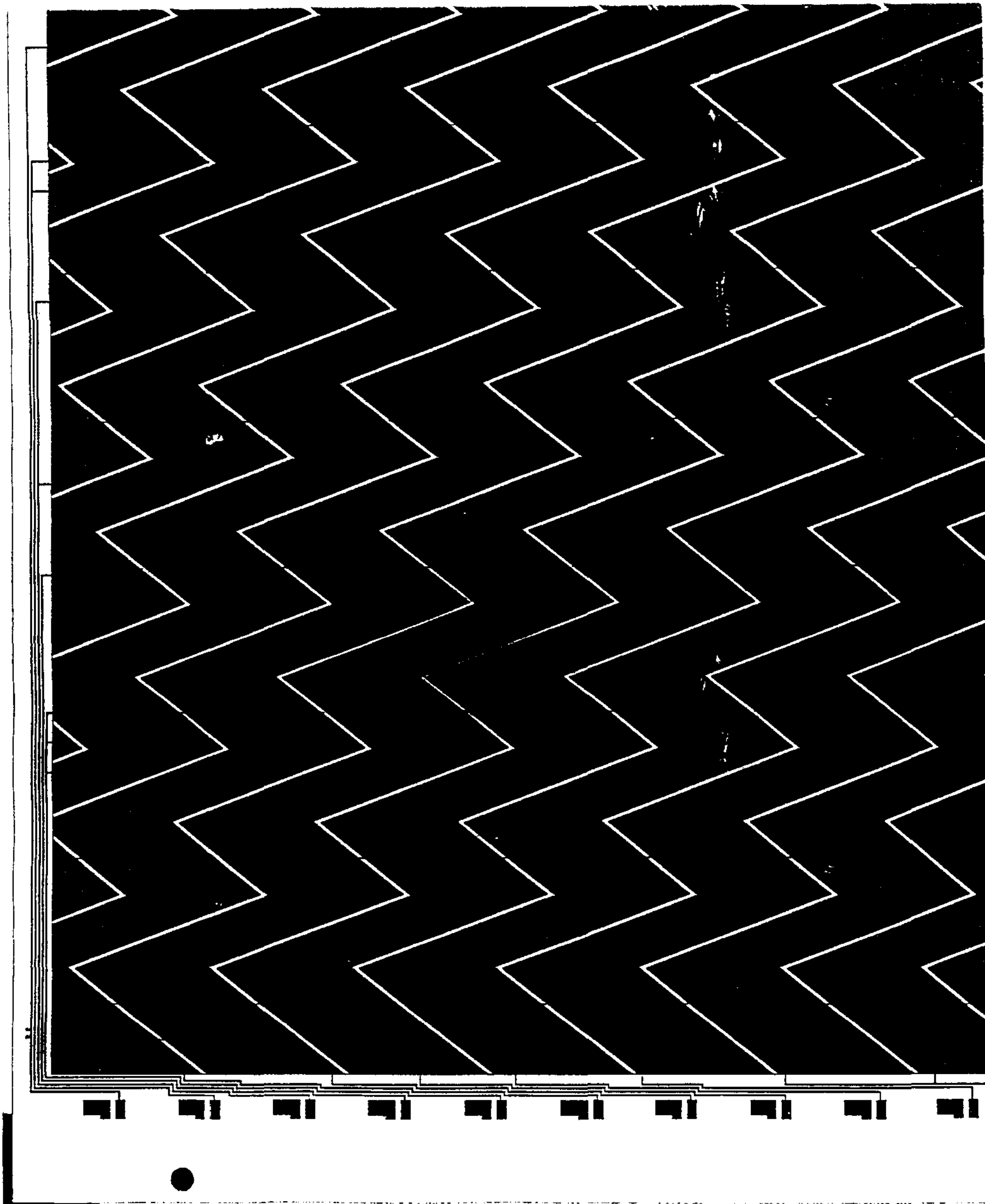
A3 TESTS

	1 mm OPTION	2 mm OPTION
ABSORBER		
Lead	0.8 mm	1.3 mm
Prepreg	2 X 0.1 mm	2 X 0.1 mm
Stainless	2 X 0.2 mm	2 X 0.2 mm
SIGNAL		
ELECTRODES		
Lead	0.8 mm	....
Prepreg	2 X 0.06 mm	....
Polysulfone	2 X 0.05 mm	....
Kapton	....	0.36 mm
Copper	2 X 0.04 mm	2 X 0.04 mm
Res Ink	2 X 15 um	2 X 15 um
ARGON GAP	2 X 1.93 mm	2 X 2.00 mm
CELL	6.4 mm	6.4 mm

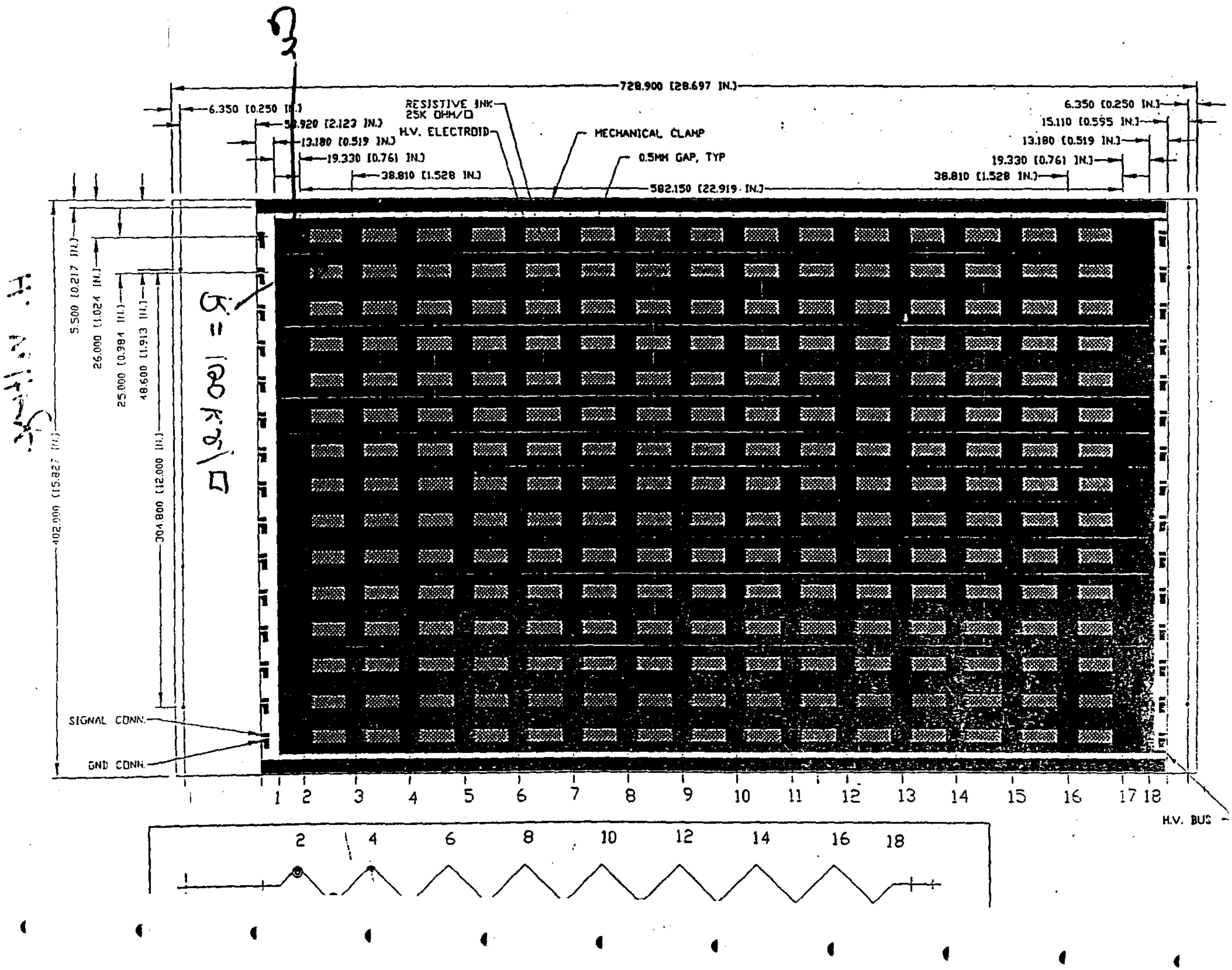
MARCH 24, 1992

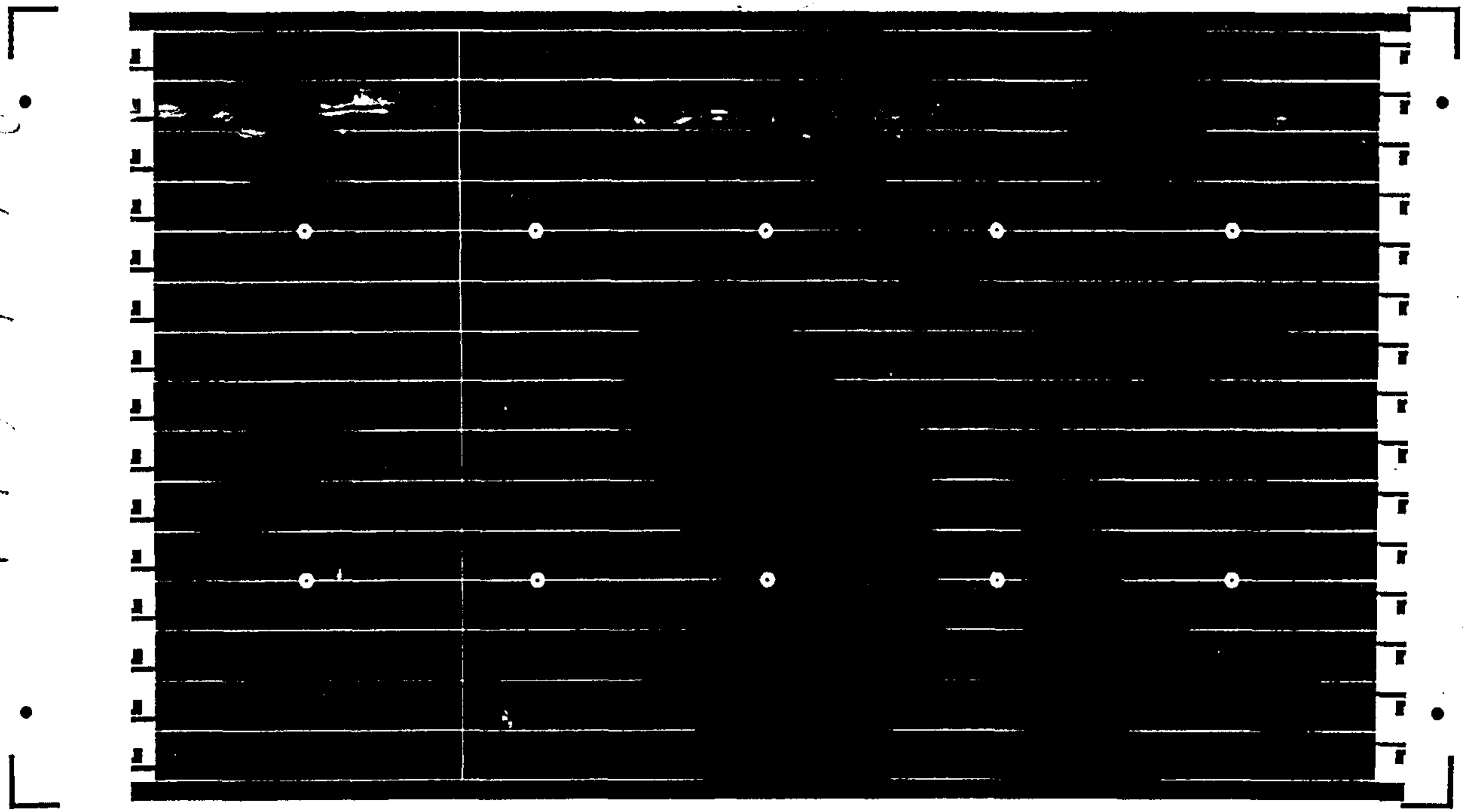


SANDWICH BENDING DEVICE



Chevron Readout elect.


728.900 [28.697 IN.]
6.350 [0.250 IN.]
53.920 [2.123 IN.]
13.180 [0.519 IN.]
19.330 [0.761 IN.]
38.810 [1.528 IN.]
582.150 [22.919 IN.]
15.110 [0.595 IN.]
RESISTIVE INK 25K OHM/□
H.V. ELECTRODE
MECHANICAL CLAMP
0.5MM GAP, TYP
5.500 [0.217 IN.]
26.000 [1.024 IN.]
25.000 [0.984 IN.]
48.600 [1.913 IN.]
304.800 [12.000 IN.]
402.000 [15.827 IN.]
SIGNAL CONN.
GND CONN.
H.V. BUS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
2 4 6 8 10 12 14 16 18



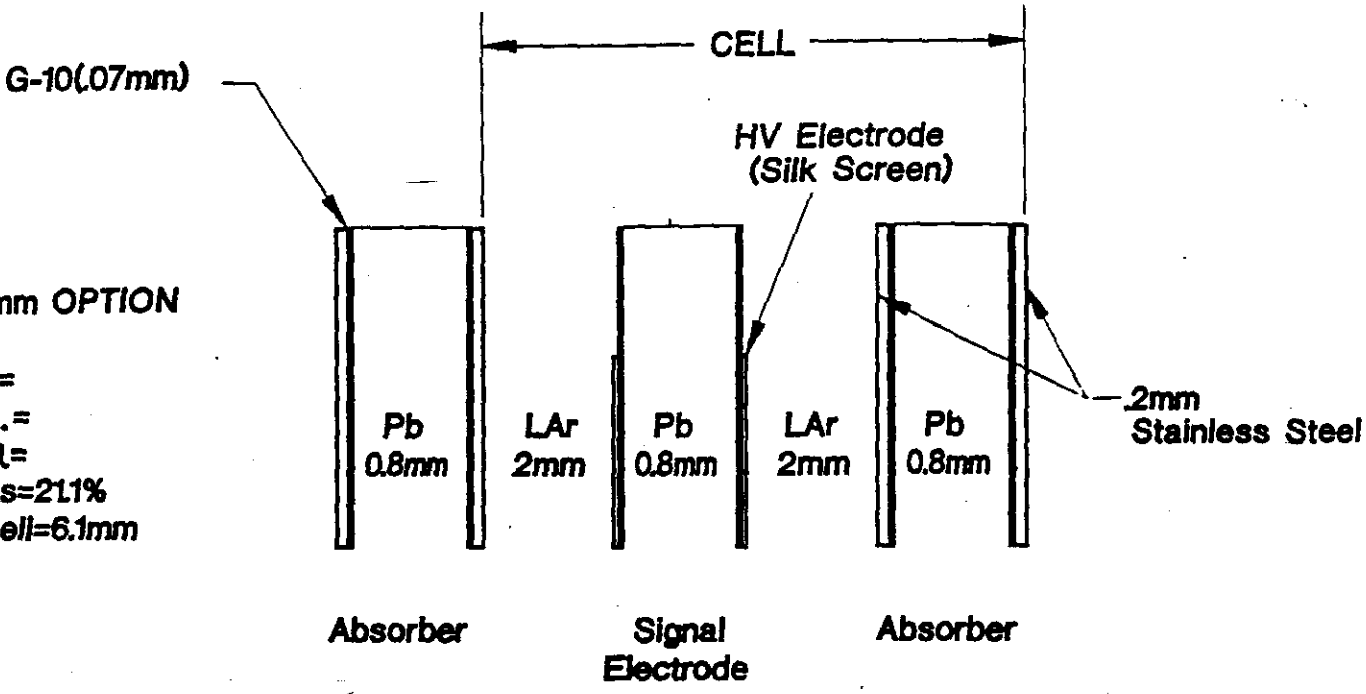
BROOKHAVEN NATIONAL LAB, P/'' I0634 LEVEL 2.

2/20/92
RON RYAN
ACAD FILE, I0634_L2.DWG

EM Configuration

1mm OPTION

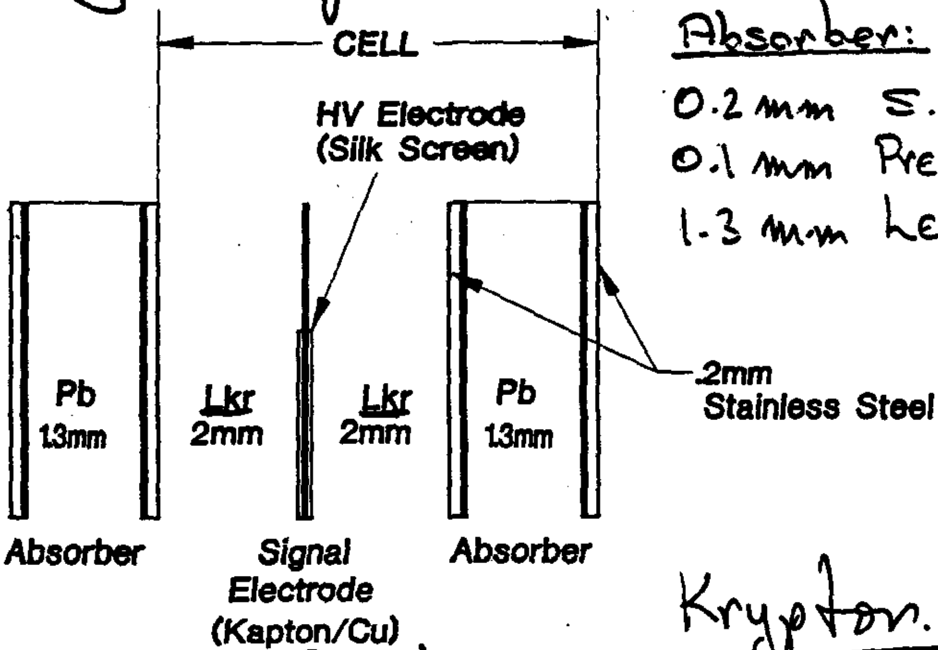
P=
X.=
η=
Rs=21.1%
Cell=6.1mm



Sampling frequency.

2mm OPTION

P=
X.=
η=
Rs=22.8%
Cell=6.1mm



Absorber:
0.2 mm S.S
0.1 mm Prepreg
1.3 mm Lead.

Krypton.

Sampling fraction.

The Liquid Argon Test.

Objectives:

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

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

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

2) Position Resolution & e/π separation.

Chevron Design

3) Trigger.

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

4) Calibration.

New calibration system. 0.1-0.2 %

5) Electronic readout.

AMU – ZEUS electronics.
Track and hold.

6) Simulations.

Non projective geometry
Quasi projective
Projective geometry

7) Bending machine

Bending machine for Projective Geometry.

The 1992 GEM LAr/Kr Accordion Calorimeter Group

D. Lissauer.

O. Benary,[9] , S. Cannon,[5] , W. Cleland[7] ,
I. Ferguson[2] , C. Finley[5] , A. Gordeev[6] ,
H. Gordon[3] , E. Kistenev[3] , P. Kroon[3] ,
M. Leltchouk[5] , D. Lissauer[3] , H. Ma[3] ,
D. Makowiecki[3] , A. Maslennikov[4] , S. McCorkle[3] ,
D. Onoprienko[6] , A. Onuchin[4] , Y. Oren[9] ,
V. Panin[4] , J. Parsons[5] , V. Radeka[3] , L. Rogers[3] ,
D. Rahm[3] , S. Rescia[3] , J. Rutherfoord[2] ,
M. Seman[5] , M. Smith[3] , J. Sondericker III[3] ,
R. Steiner[1] , D. Stephani[3] , E. Stern[7] , I. Stumer[3] ,
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[6] Oak Ridge National Laboratory, Oak Ridge, TN
[7] University of Pittsburgh, Pittsburgh, PA
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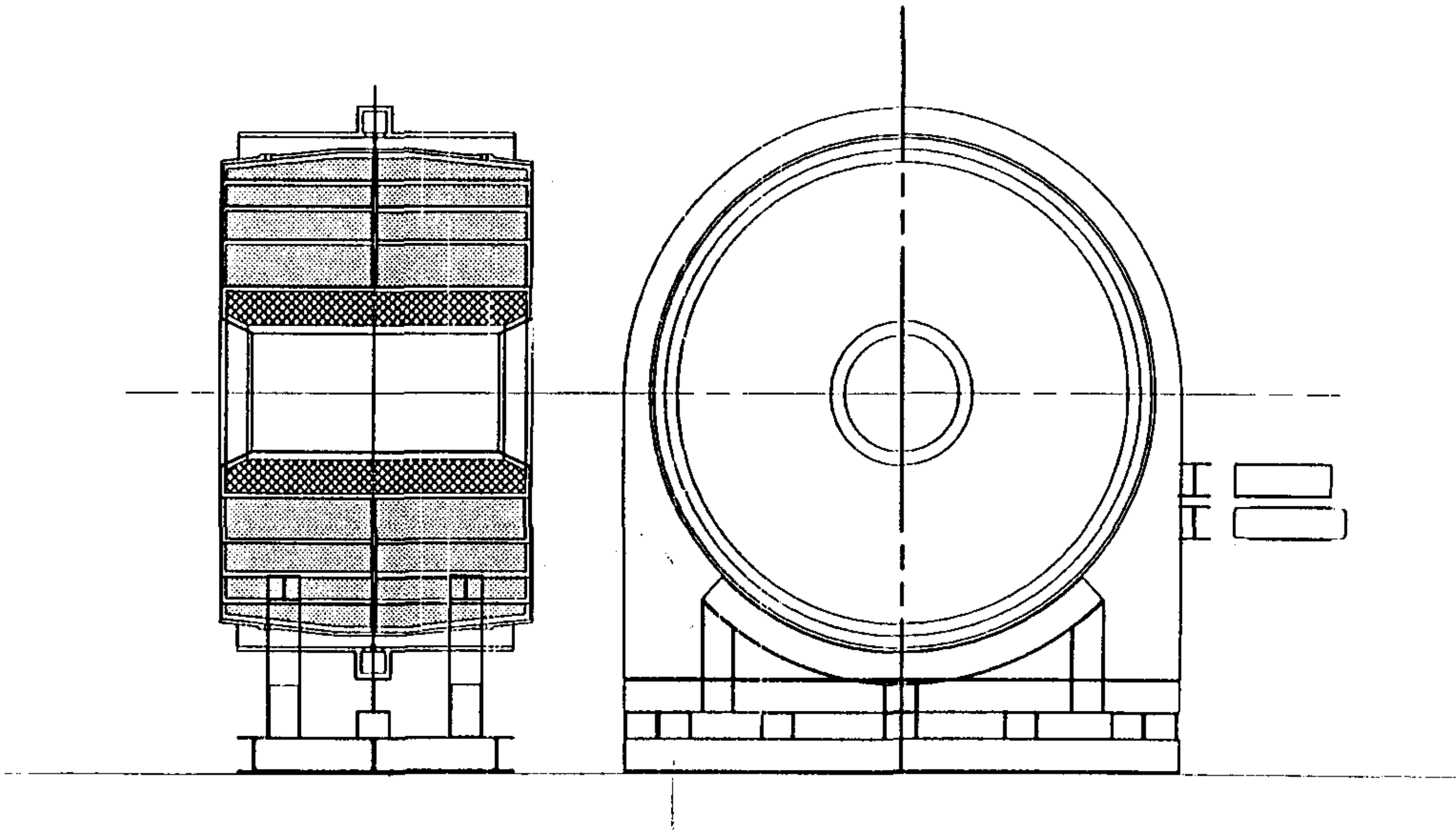
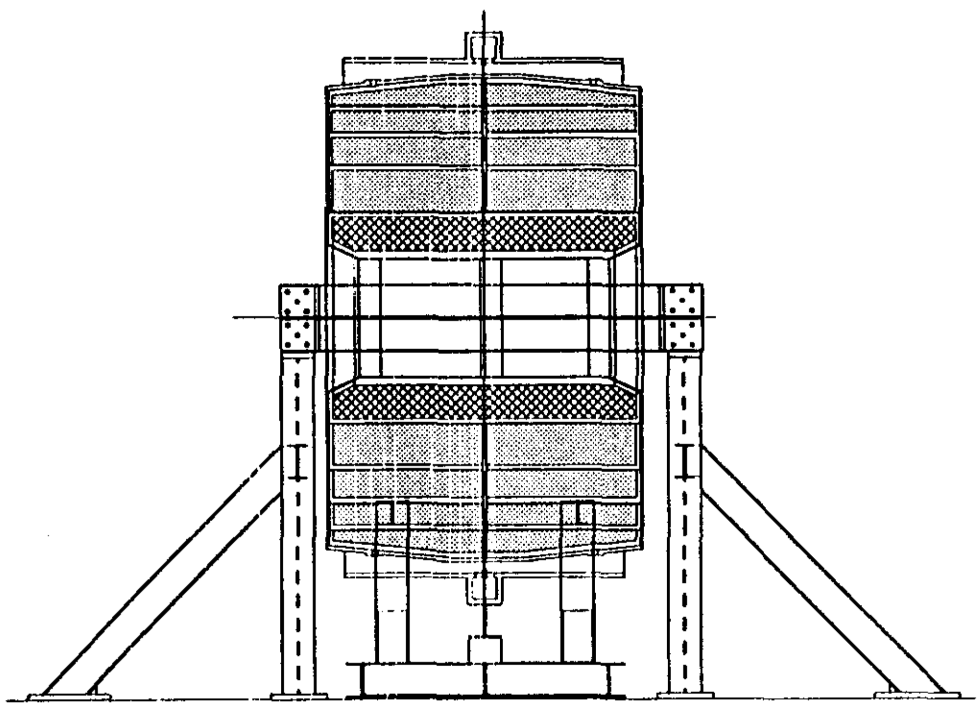
[9] Tel-Aviv University, Tel-Aviv, Israel



Rev NEW
W/ BROGAN/[illegible]
26 JUNE 1992

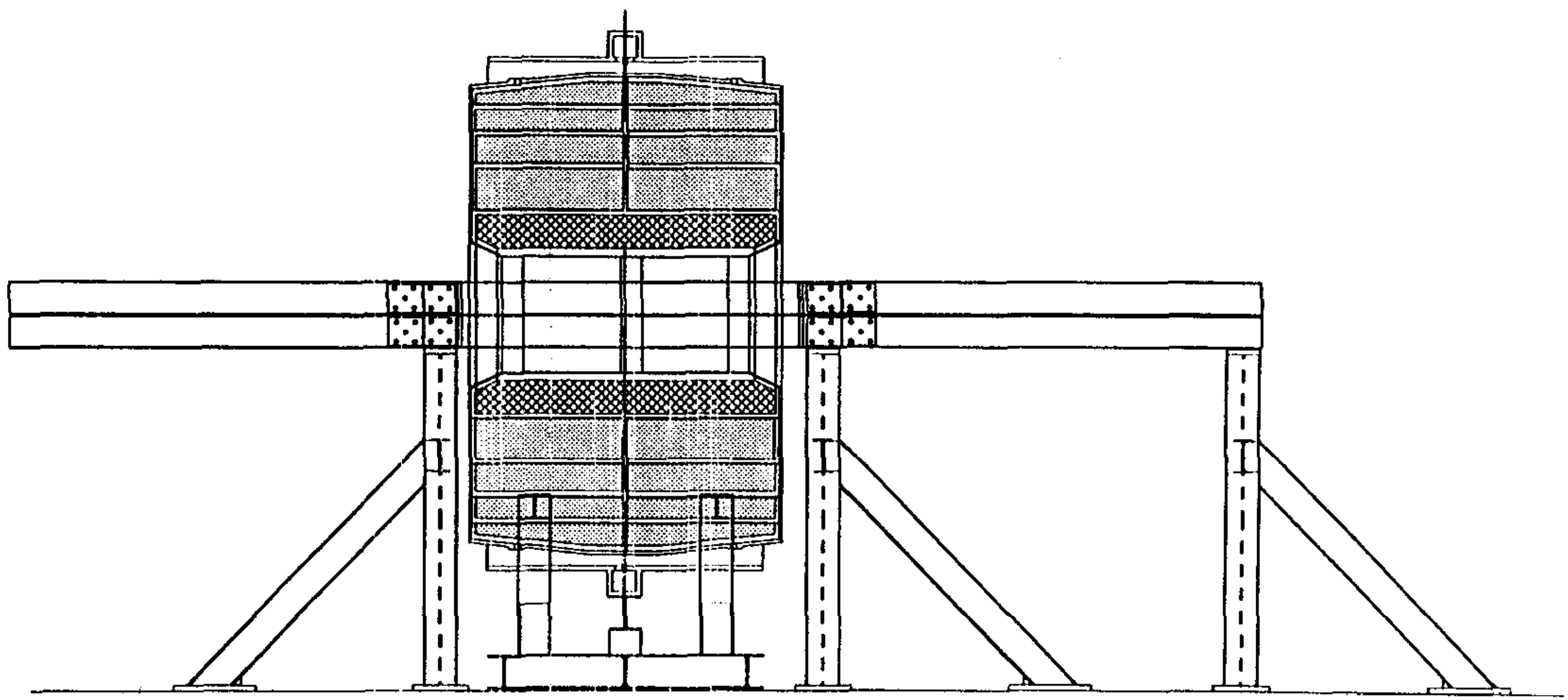
EM Inserted With outboard Stantion and Extention Beams Removed,
Ready for Close-out



Rev NEW
BROGAN/
26 JUNE 1992

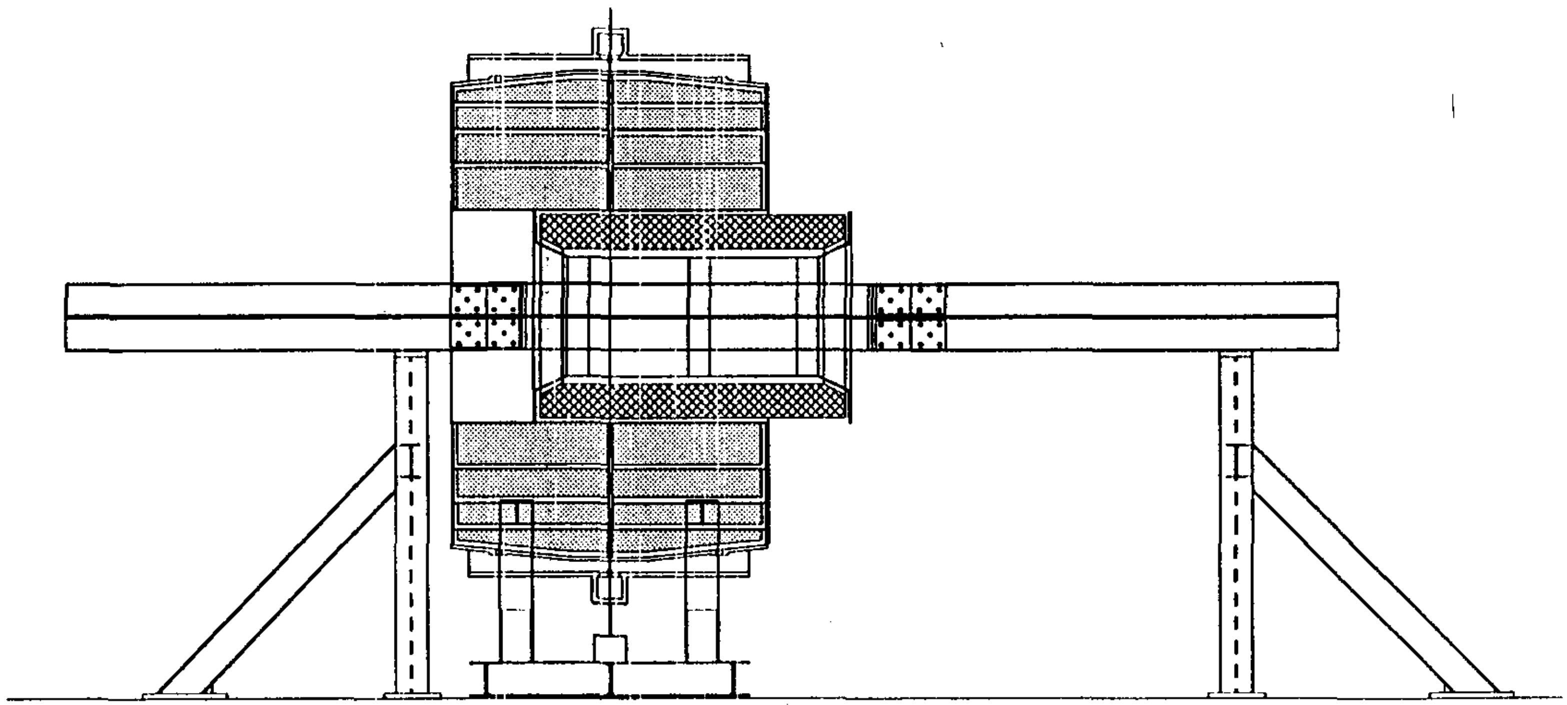
8

EM at Partial Insertion With Center Stantion Replaced



Rev NEW
BROGAN/[illegible]
26 JUNE 1992

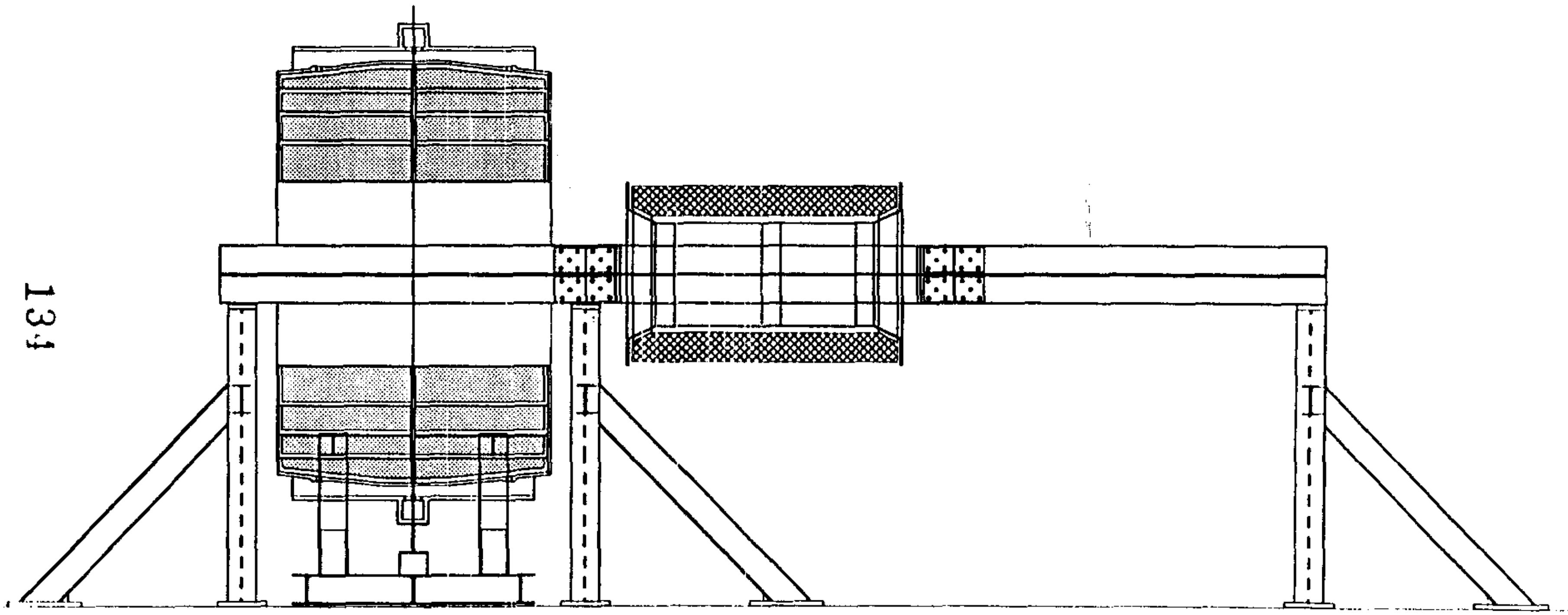
EM at Partial Insertion With Outboard Stantion Moved Inboard and Center Stantion Removed



Rev. NEW
BROGAN/[illegible]
26 JUNE 199?

6

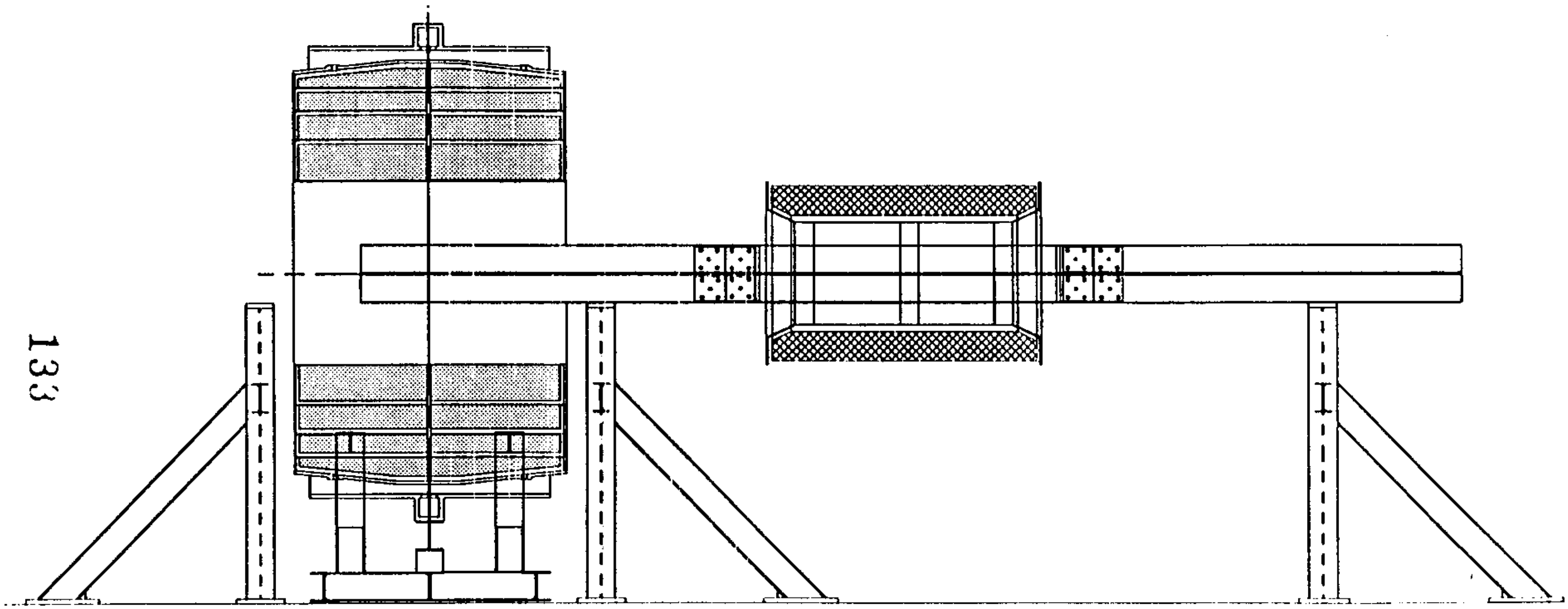
EM at Partial Insertion With Support Beam Through the Hadronic Section



Rev NEW
BROGAN/[illegible]
26 JUNE 1992

5

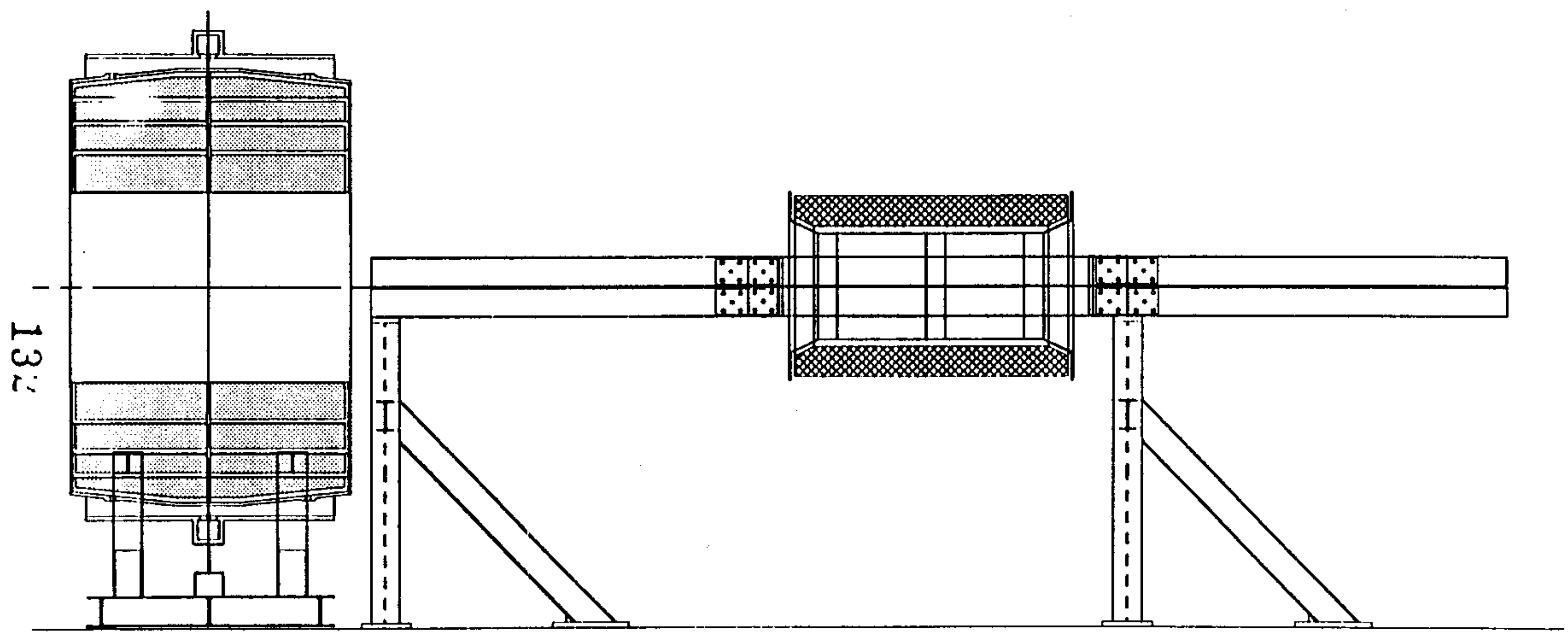
EM Insertion Process Started With Stantion Moved to Receive the Support Beam



Rev. NEW
BROGAN/MMAG
26 JUNE 1992

23

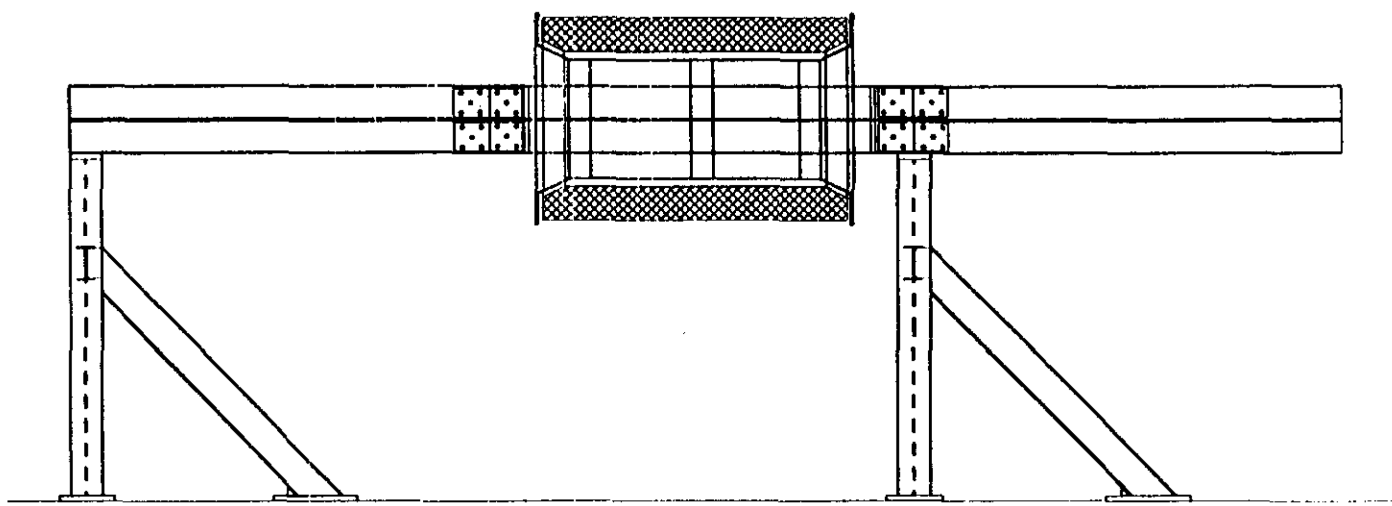
EM Ready for Insertion Into the Barrel Hadronic Section



Rev NEW
BROGAN [illegible]
26 JUNE 1992

3

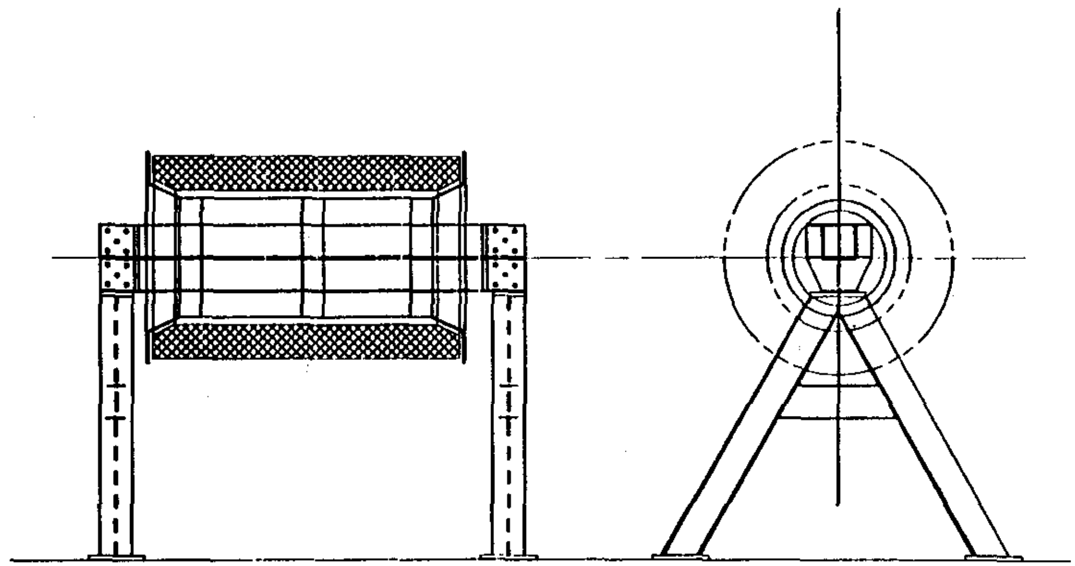
EM Support Beam With Extentions on the Insertion Stantions



Rev. NEW
BROGAN, LIHAG
26 JUNE 1992

2

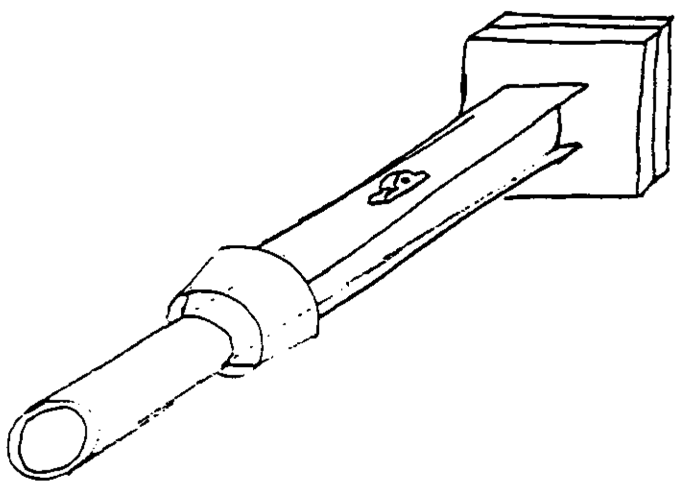
EM Subassembly Complete



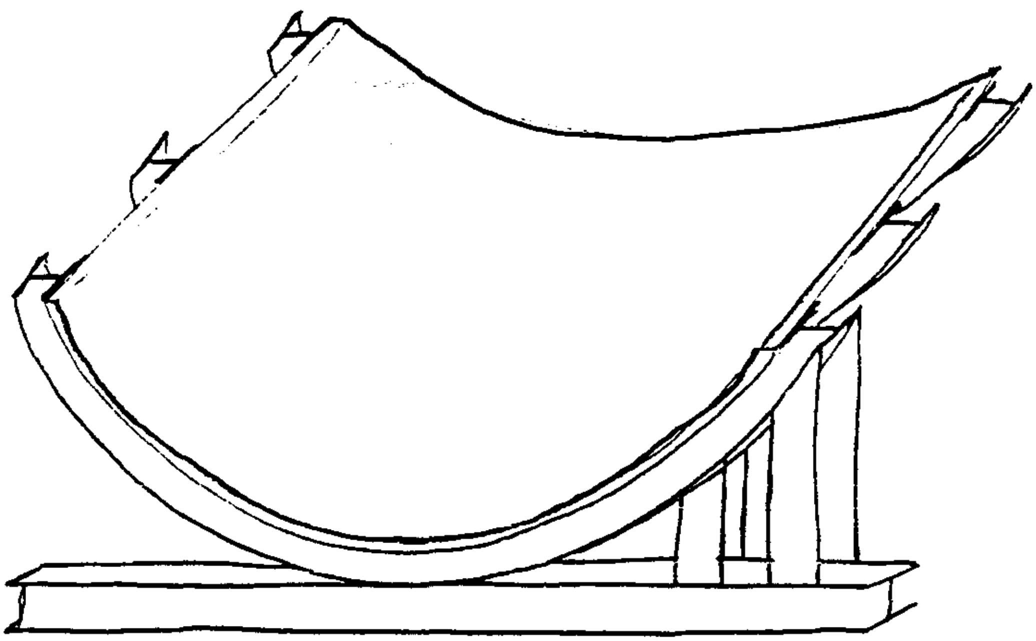
Rev NEW
BROGAN [illegible]
26 JUNE 1992

GEM Baseline, End Cap

Funnel Insertion Tool



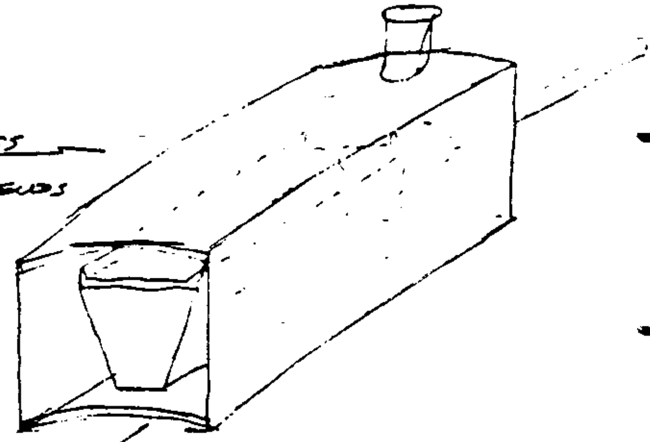
GEM Baseline, End Cap
Vacuum Vessel Cradle

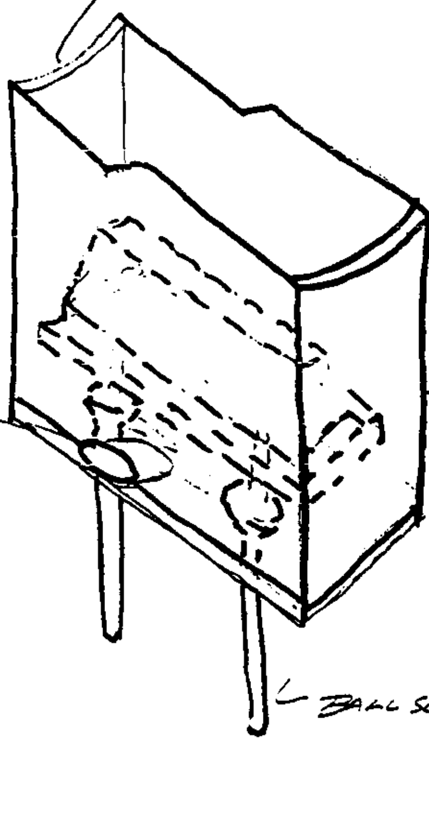


Brokau
30 July 92

9 GEM Baseline, End Cap

Module Insertion Tools (5x)

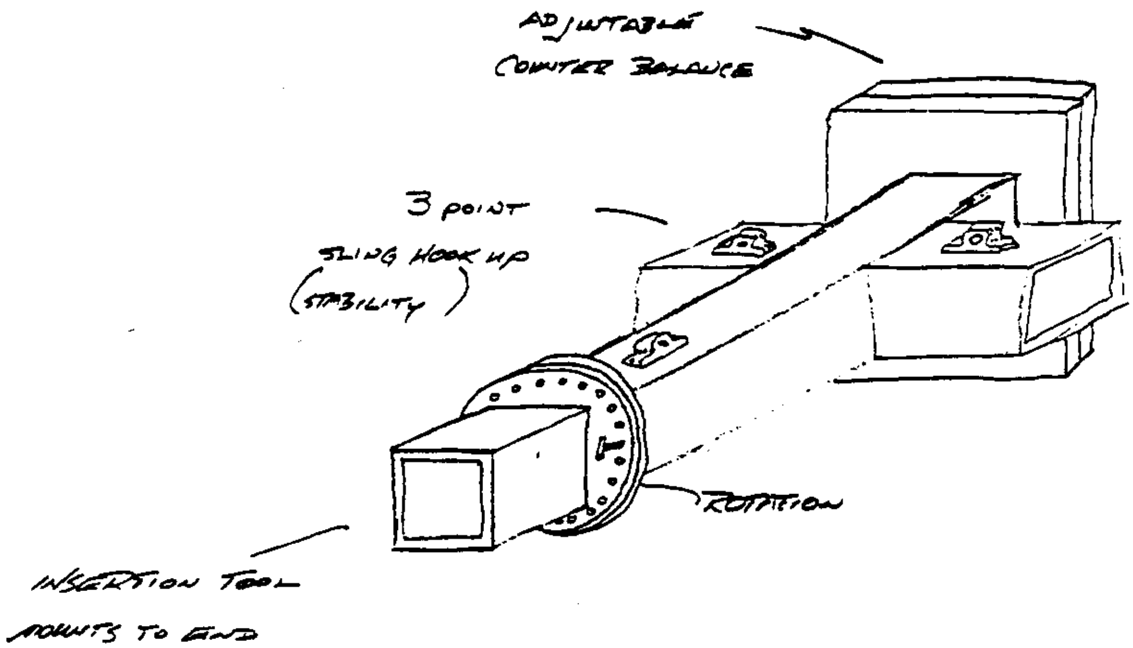




Brogan

GEM Baseline, EndCap

End Insertion Spreader (2x min)



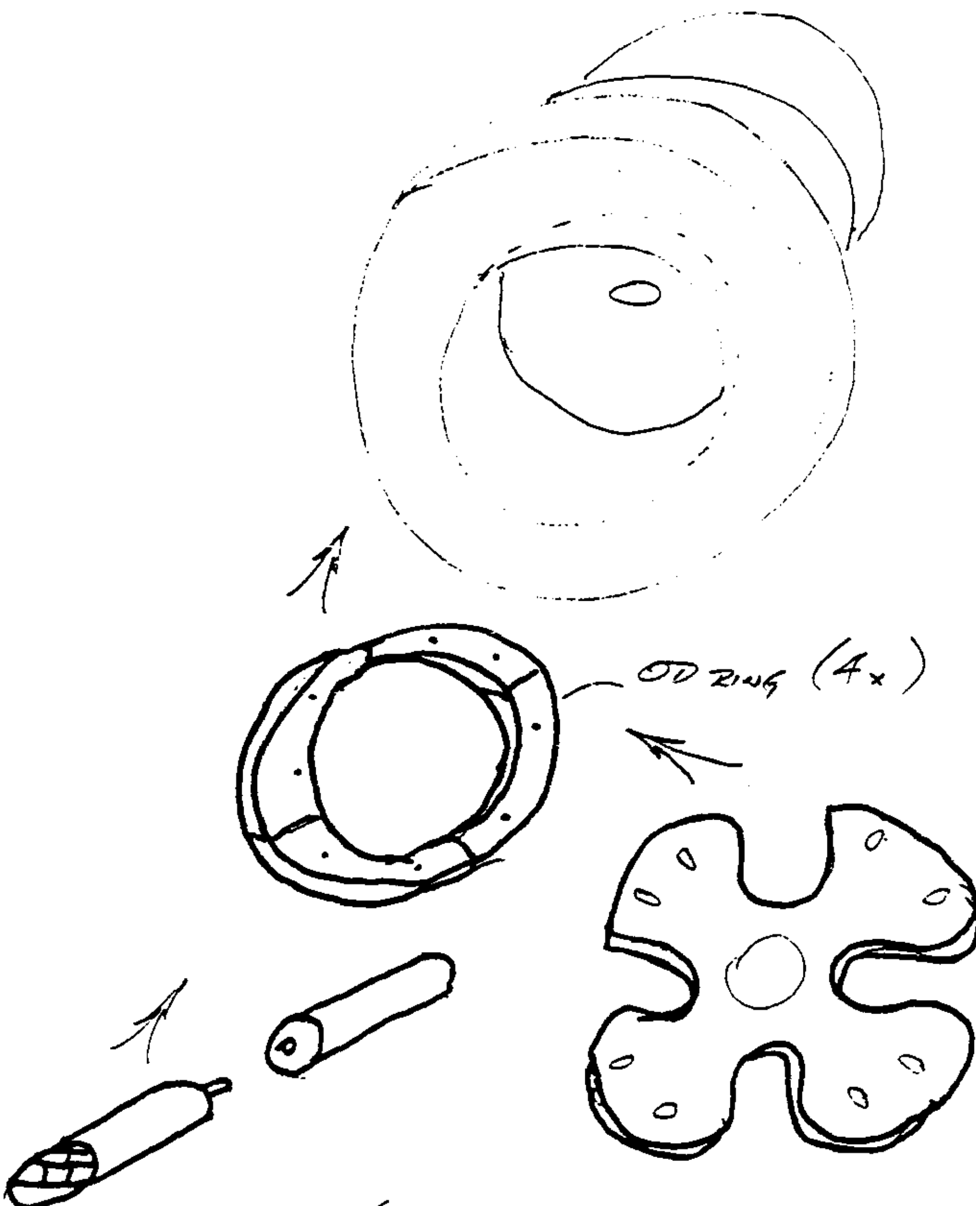
BOGAN

GEM Baseline, EndCap

Outside Spool Mandrel (2x)

2 each ring/spyder assy in each end of spool, connected by split support shaft

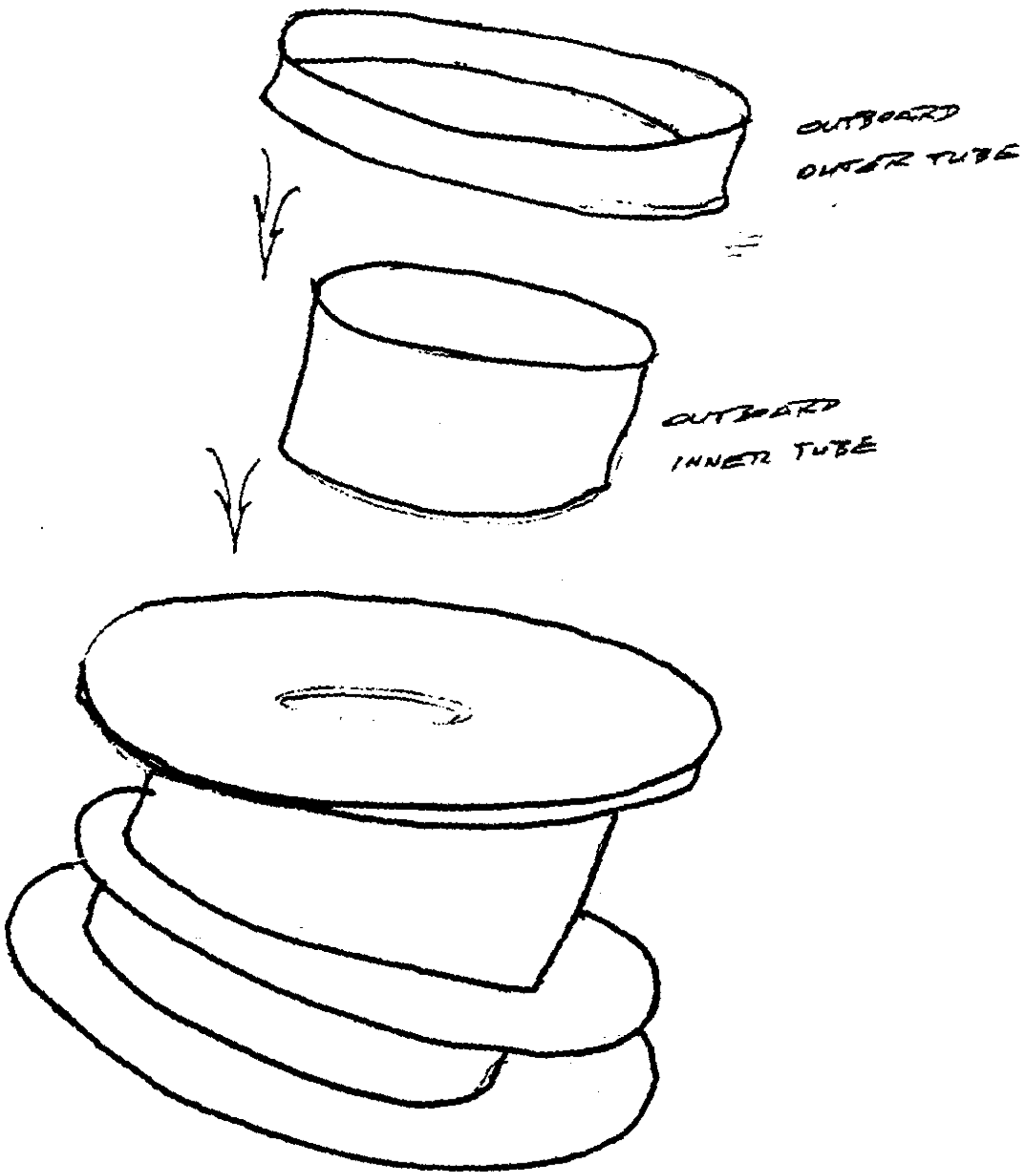
Install mandrel with spool horizontal and the shipping tools in place - used for handling



Split support (1x) shaft with connect thru center washer

BROGAN

…EA1 Baseline, End Cap
Cryo Outside Spool
Weld Assy / Shipping Tools

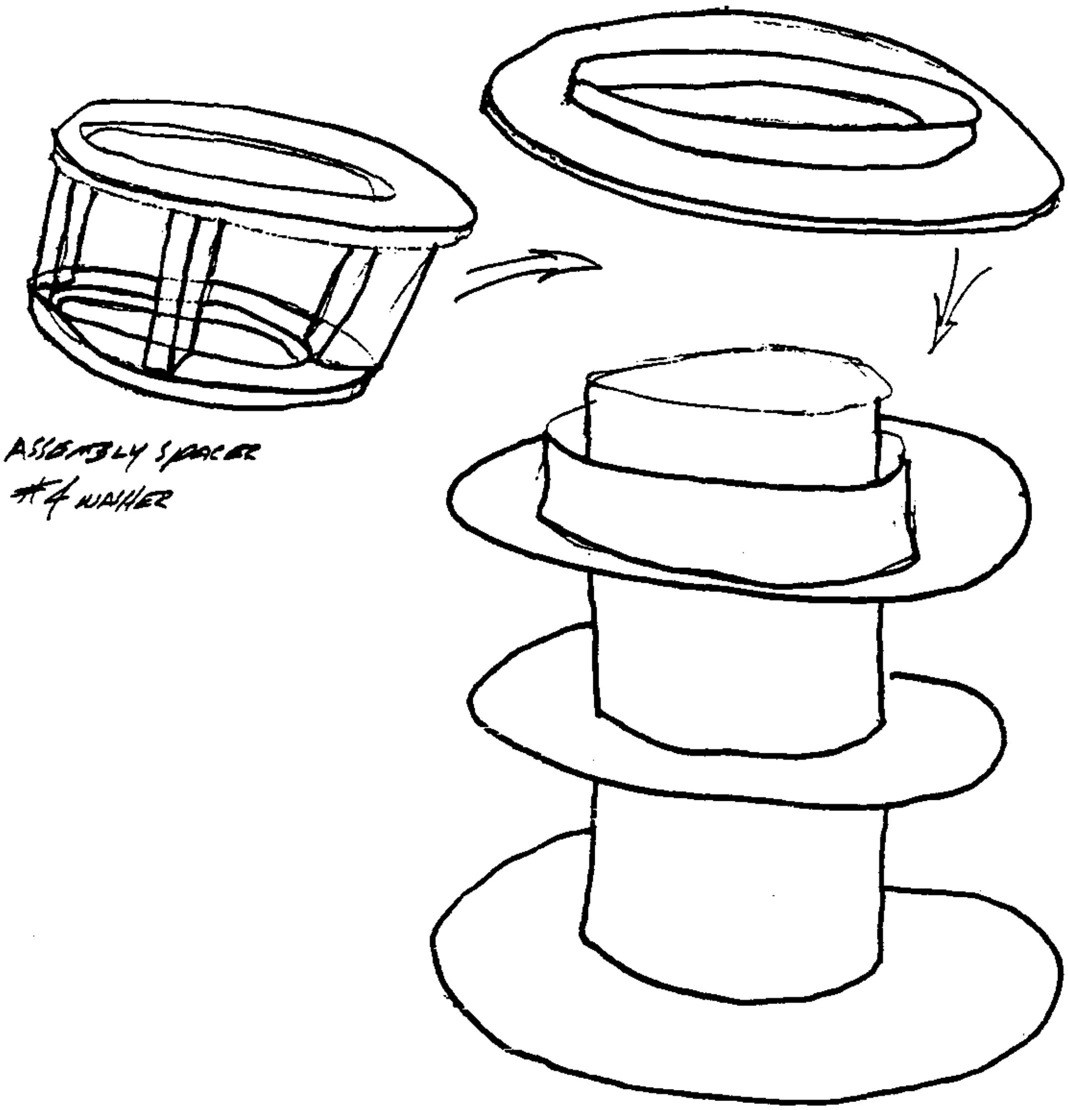


DRAGAN

GEM Baseline, End Cap

Cryo Outside Spool
Weld Assy / Shipping Tools

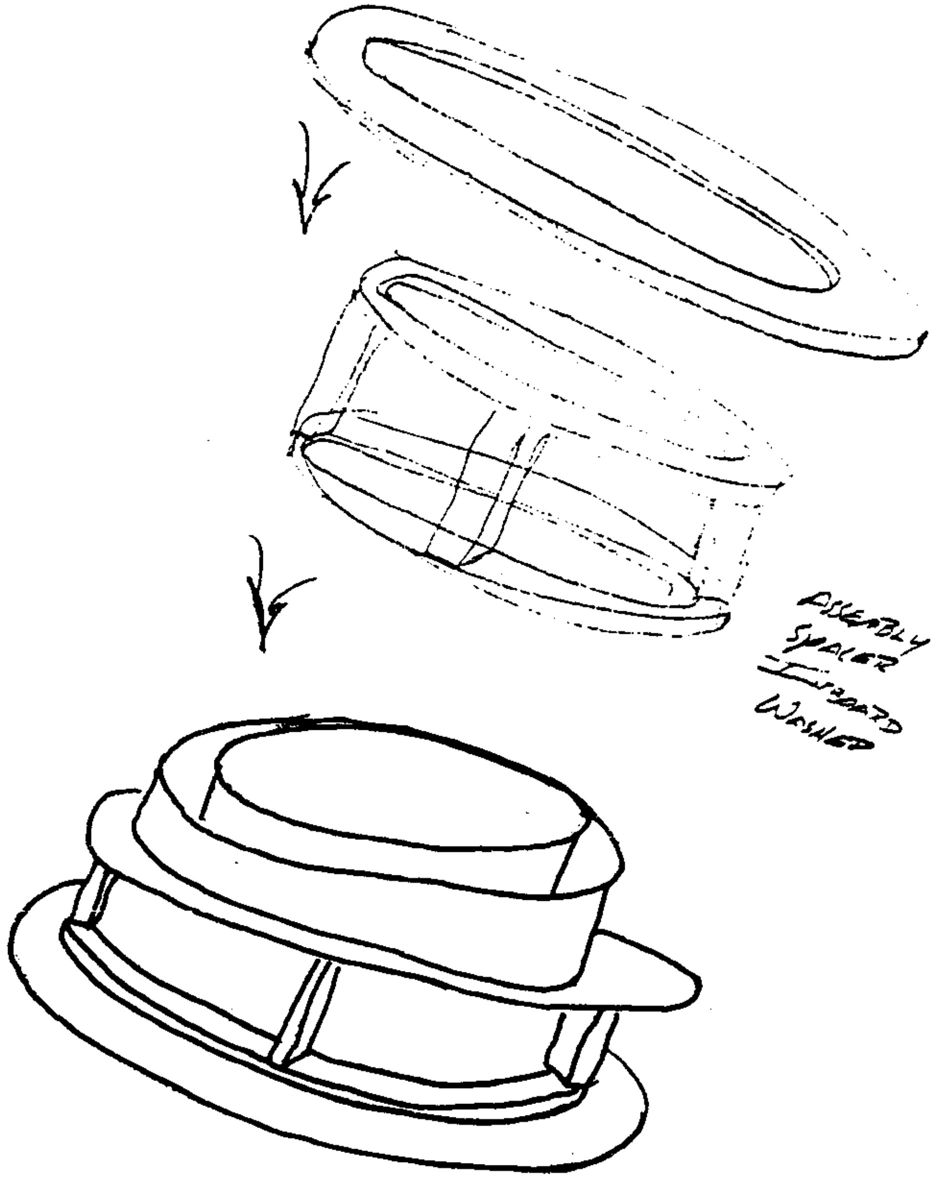
14



BROWN

FEM Baseline, End Cap

Cryo Outside Spool
Weld Assy / Shipping Tools

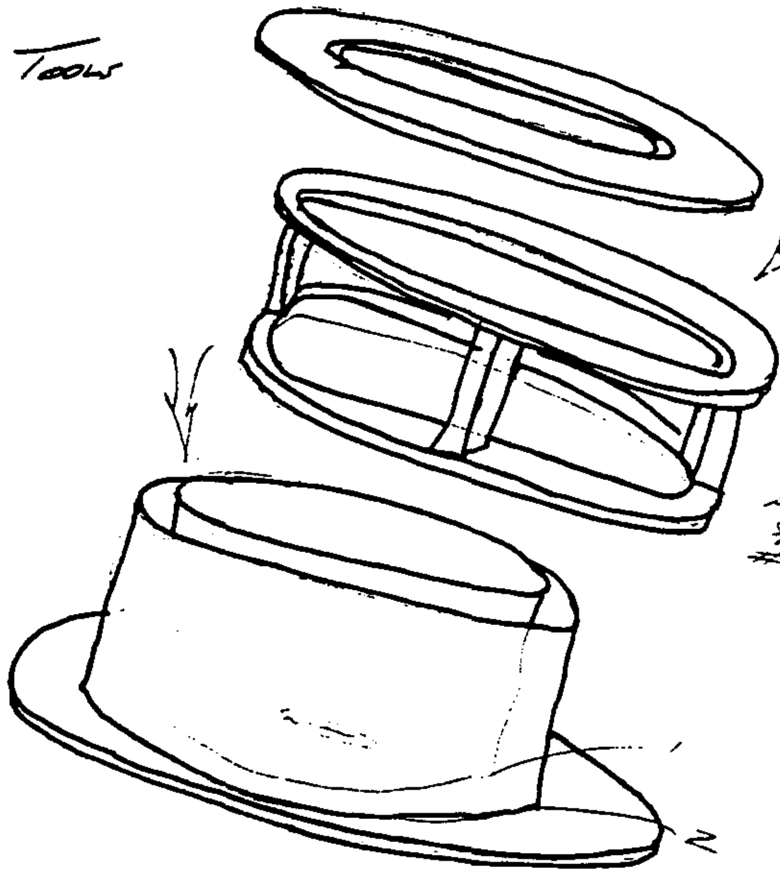


Brogan

GEM Baseline, EndCap

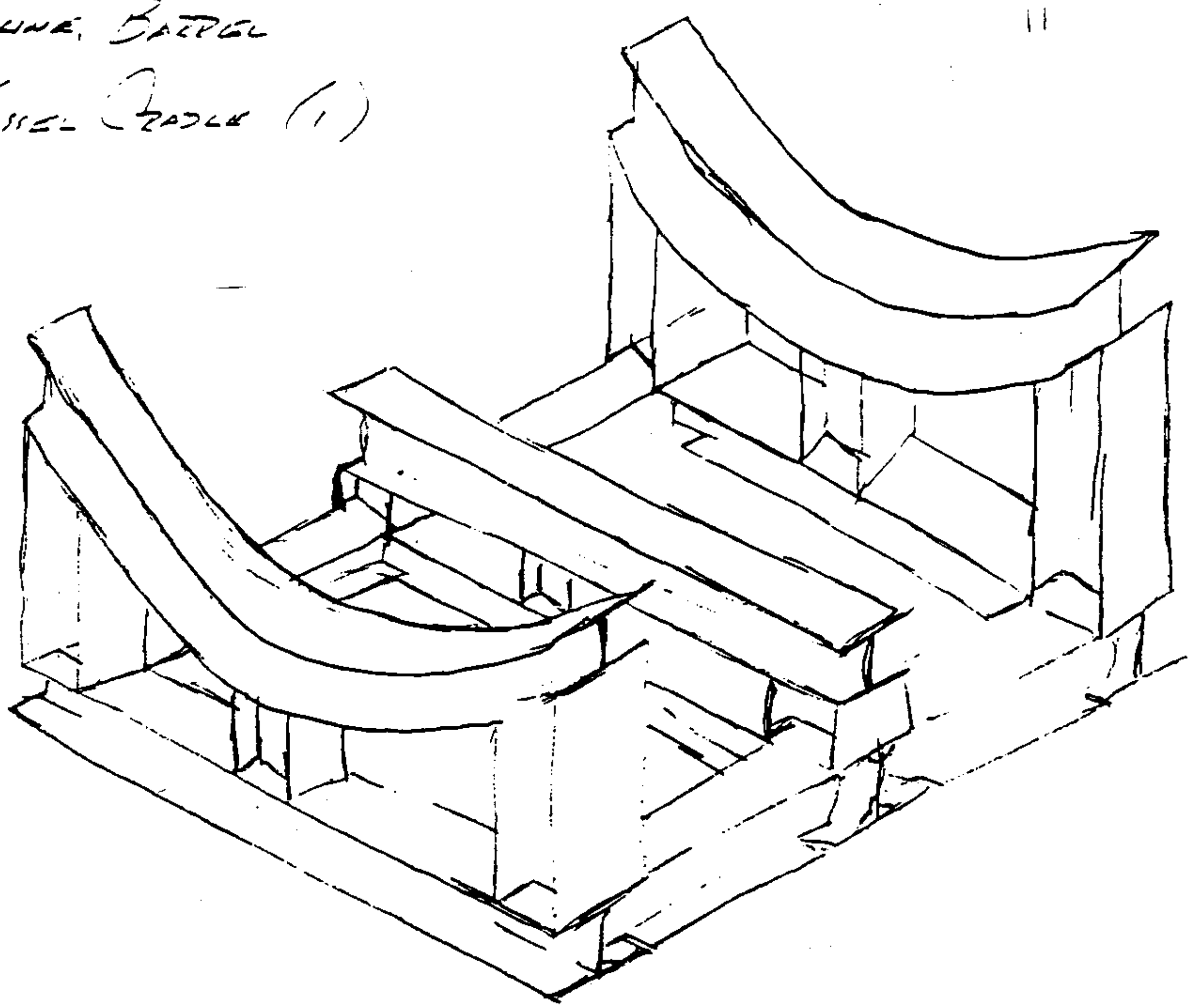
12

Cryo Outside Spool
Weld Assy / Shipping Tools



GEM Baseline, Barrel

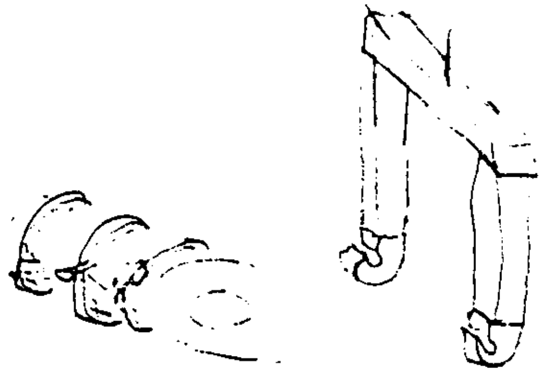
Vacuum Vessel Cradle (1)



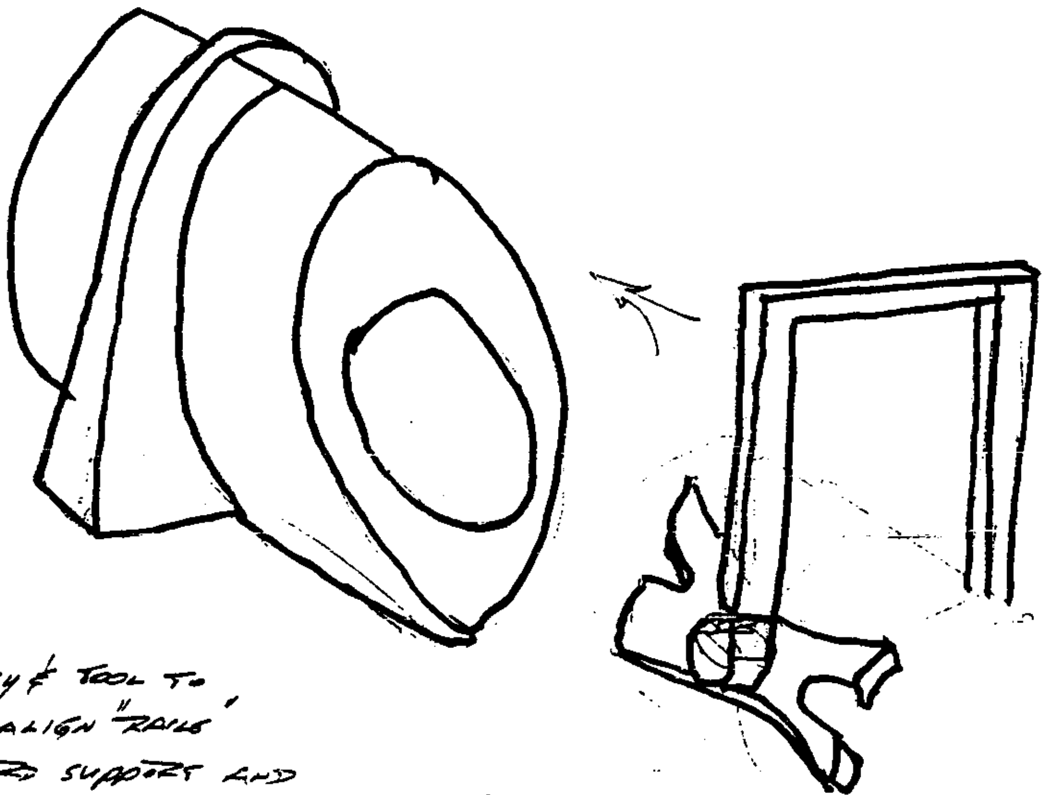
B. Rogan
10 Jul 92

GEM Baseline, Drill

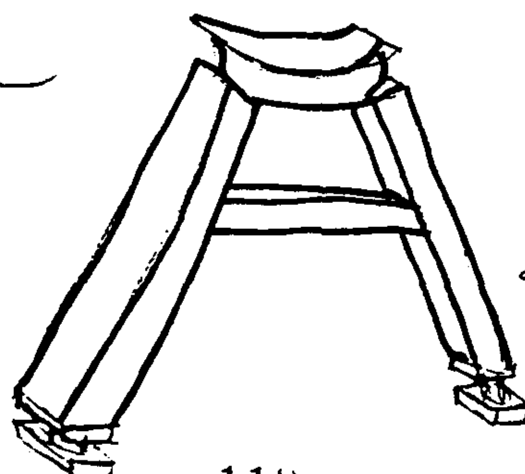
EM Assembly Insertion Fixtures



EM Spreader



MATE EM ASSY & TOOL TO HADRONIC ASSY, ALIGN "RAILS" POSITION OUTBOARD SUPPORT AND RELEASE HOIST, "ROLL TRANSFER" EM ASSY FROM TOOL INTO CALORIMETER



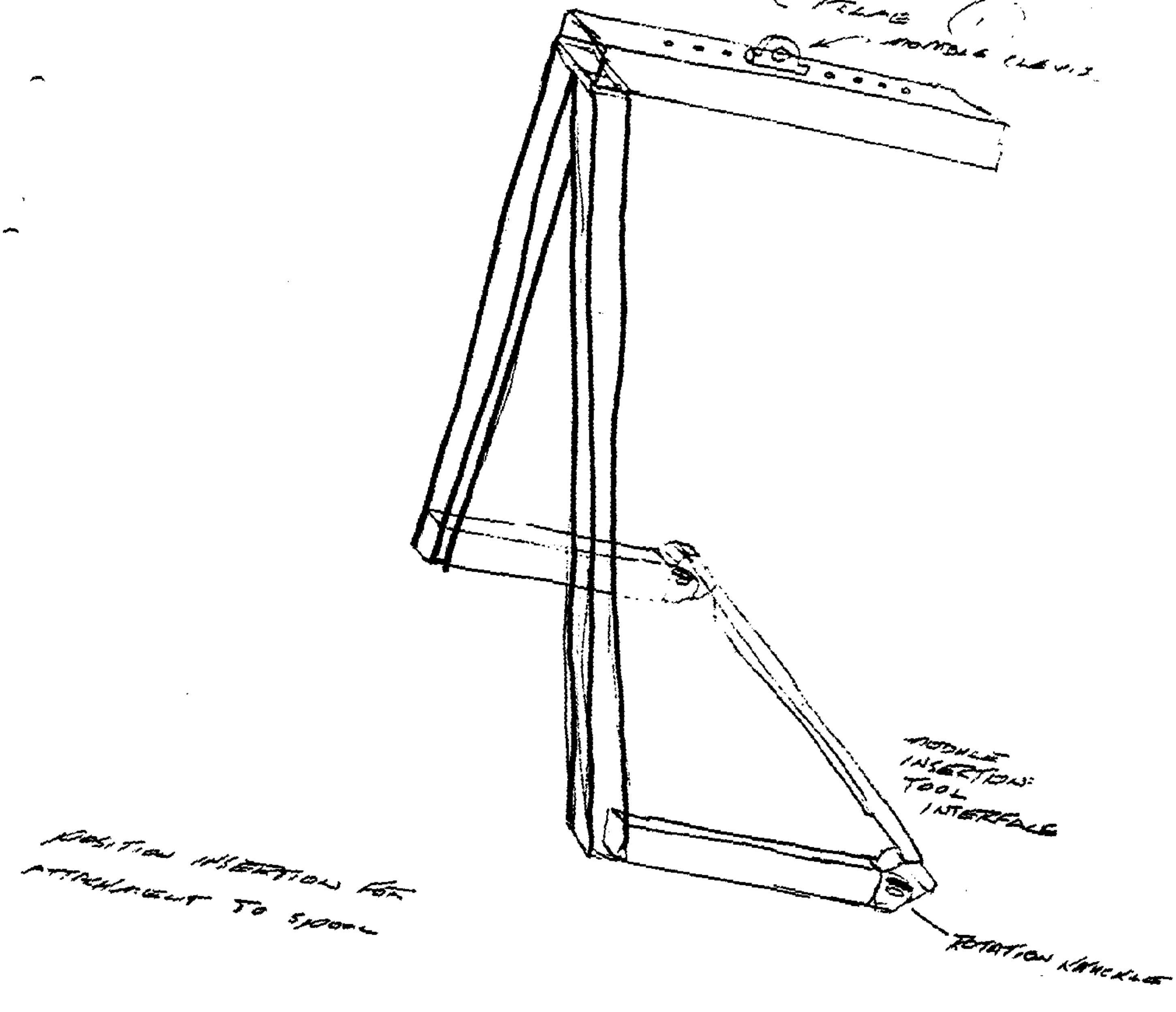
OUTBOARD SUPPORT STAND

Brogan
26 J. . 9?

9EM Baseline

Vertonic Module Insertion Hoist C Frame (1)

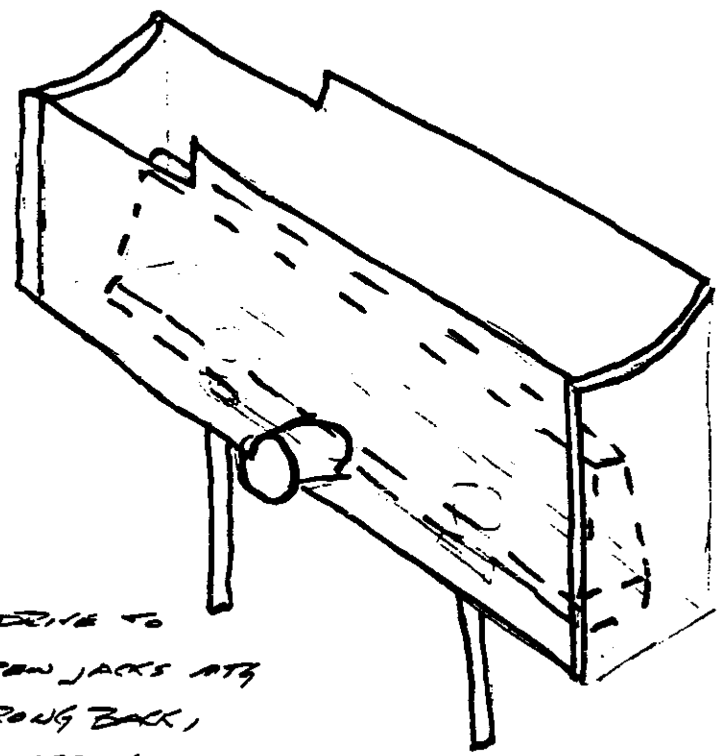
9



Brogan

GEM Baseline

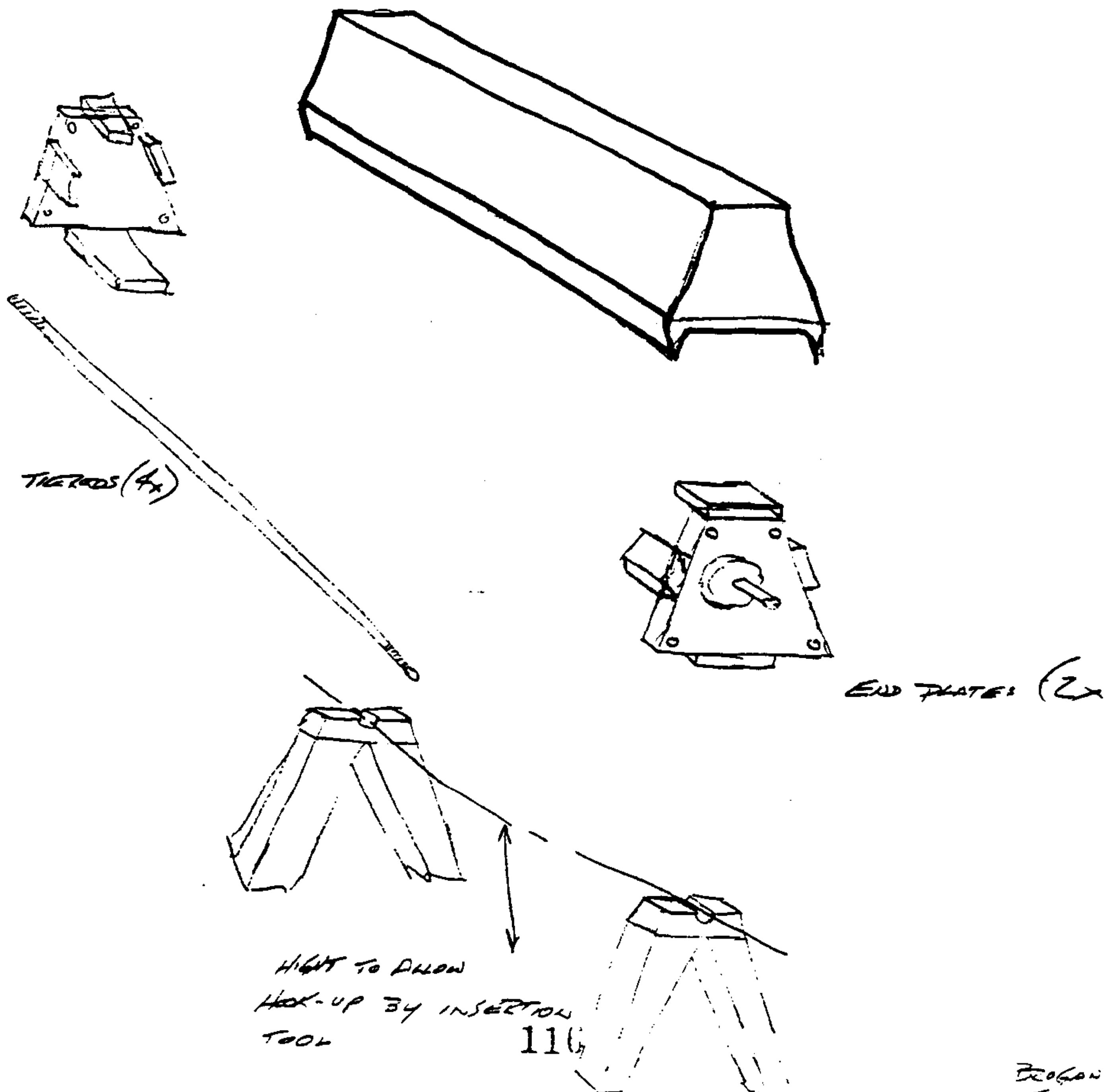
Vertical Module Insertion Tool (2)



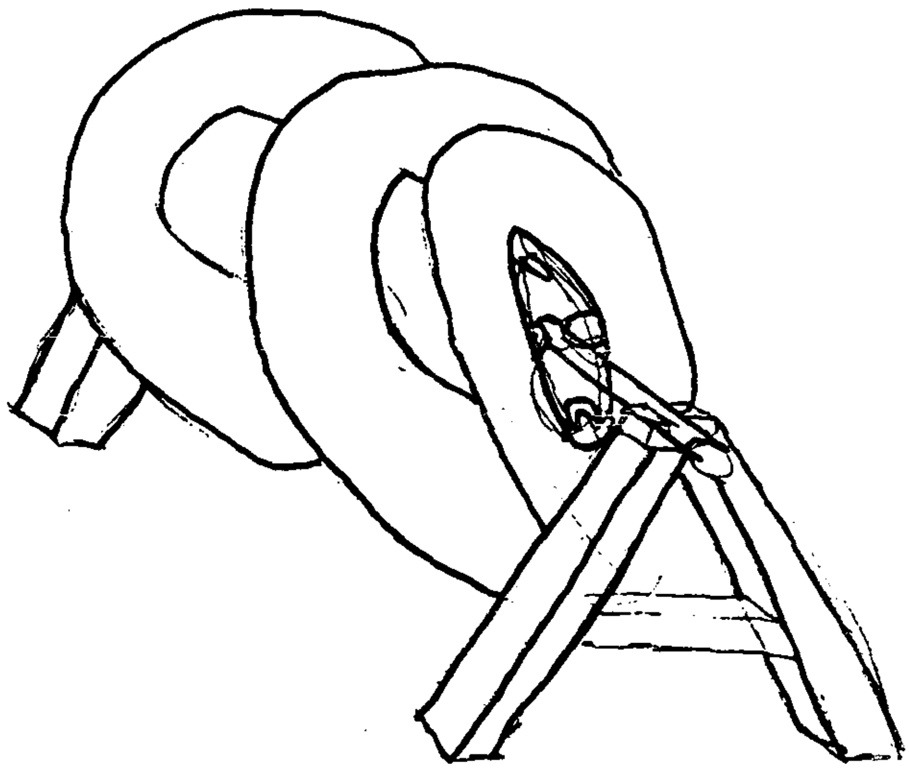
DC SERVO DRIVE TO
TWO BALL SCREW JACKS ATT
ON TOOL STRONG BACK,
END PLATES ATTACH TO
SPOOL WASHERS, KEYWAYS IN
TOOL MATCH KEYWAY IN SPOOL
SERVO POSITIONS MODULE

FLA Fixture

Lattice Module Rotation Tool



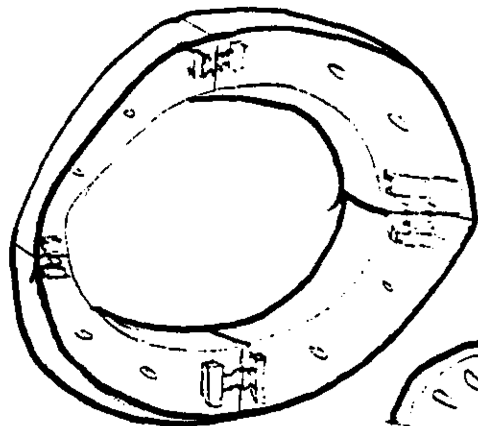
BROGAN
30 JULY 02



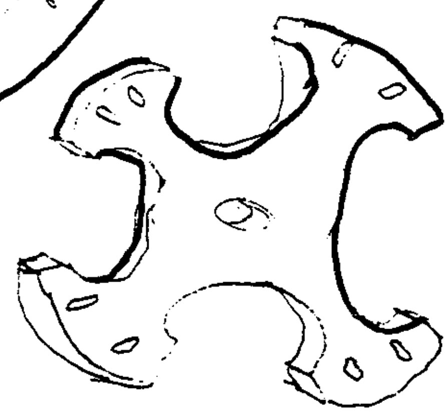
FEM Baseline

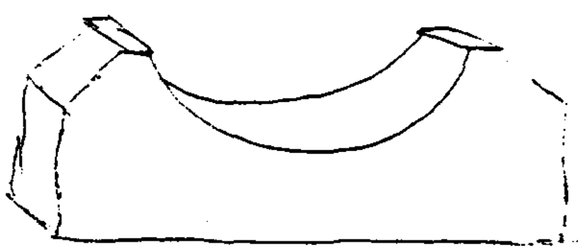
Upstream Spool Tube Mandrel

MANDREL (3x)



SPYDER (3x)



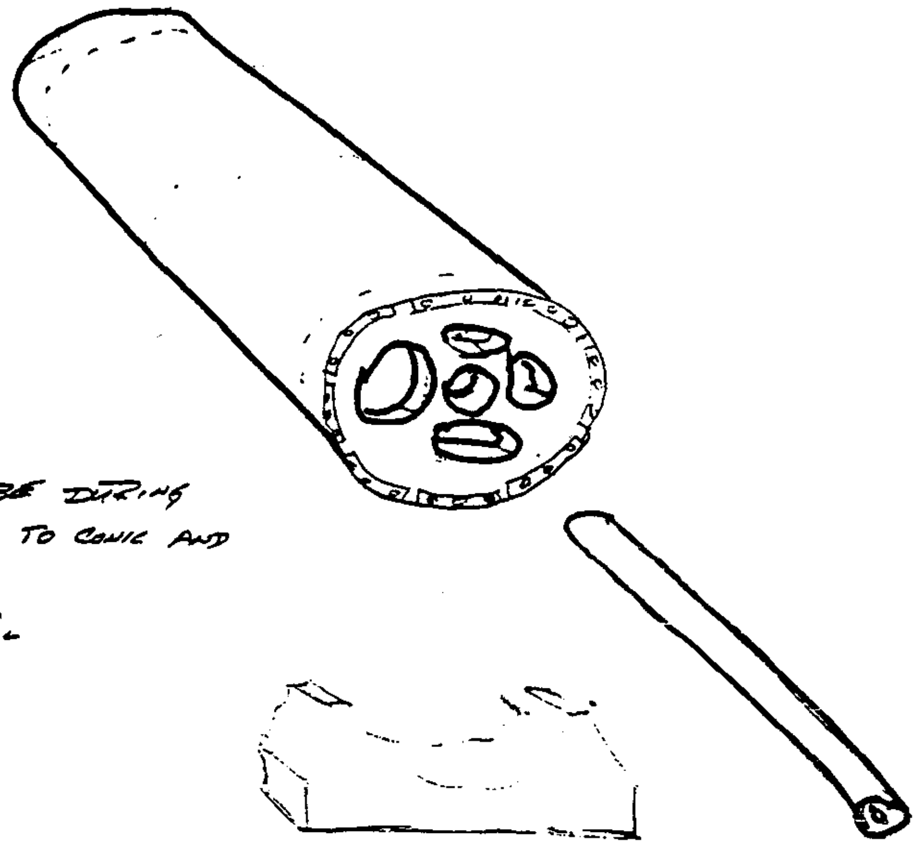


TUBE FAB CRADLE

29 July 92

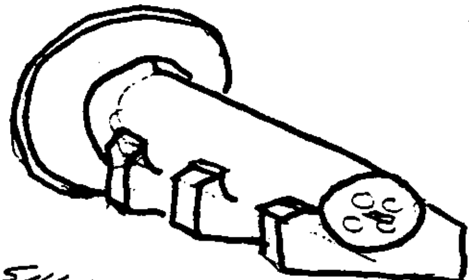
FEM - Baseline

EM Coil Tube Mandrel (1)



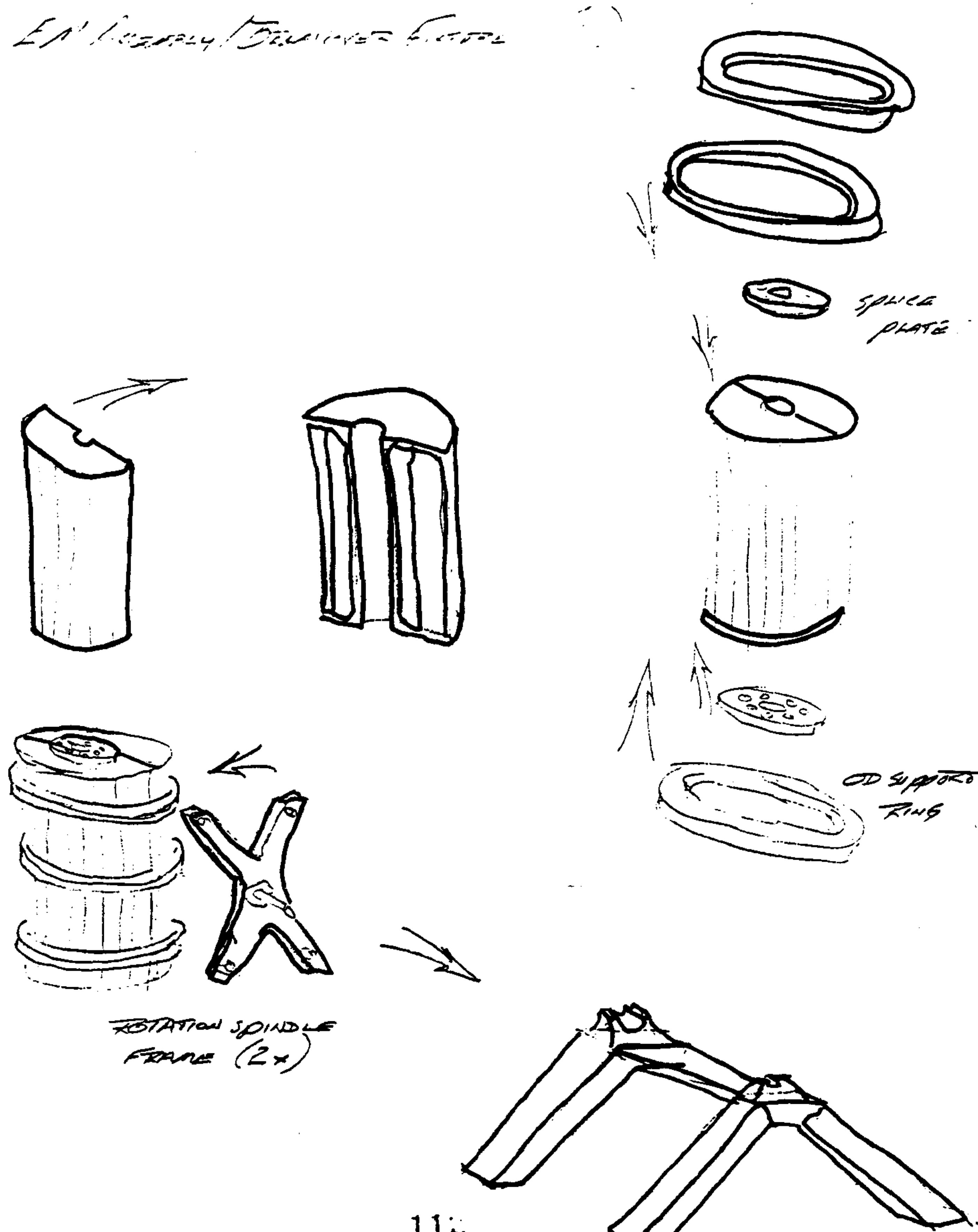
Use to support tube during fab, mate & weld to conic and transport
handling beam incl.

Shipping cradle (3x)



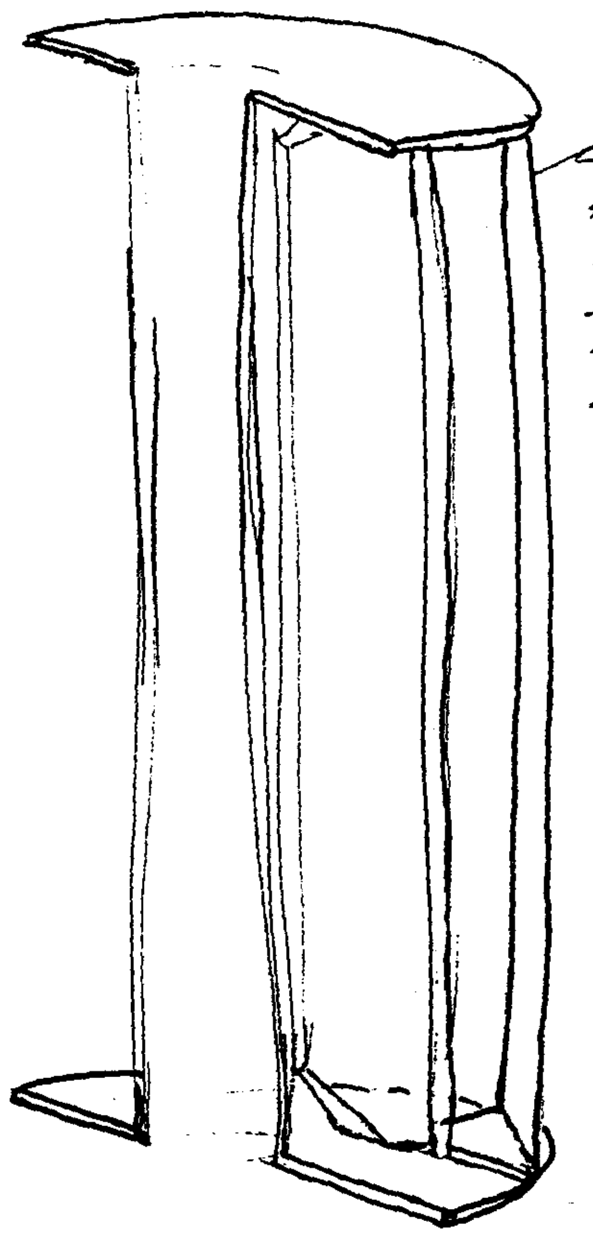
Ship configuration

P. T. Egan
29 Jul 92


SPLICE PLATE
OD SUPPORT RING
ROTATION SPINDLE FRAME (2x)
STAND

[illegible]

EA CLAMSHELL ASSY TOOL

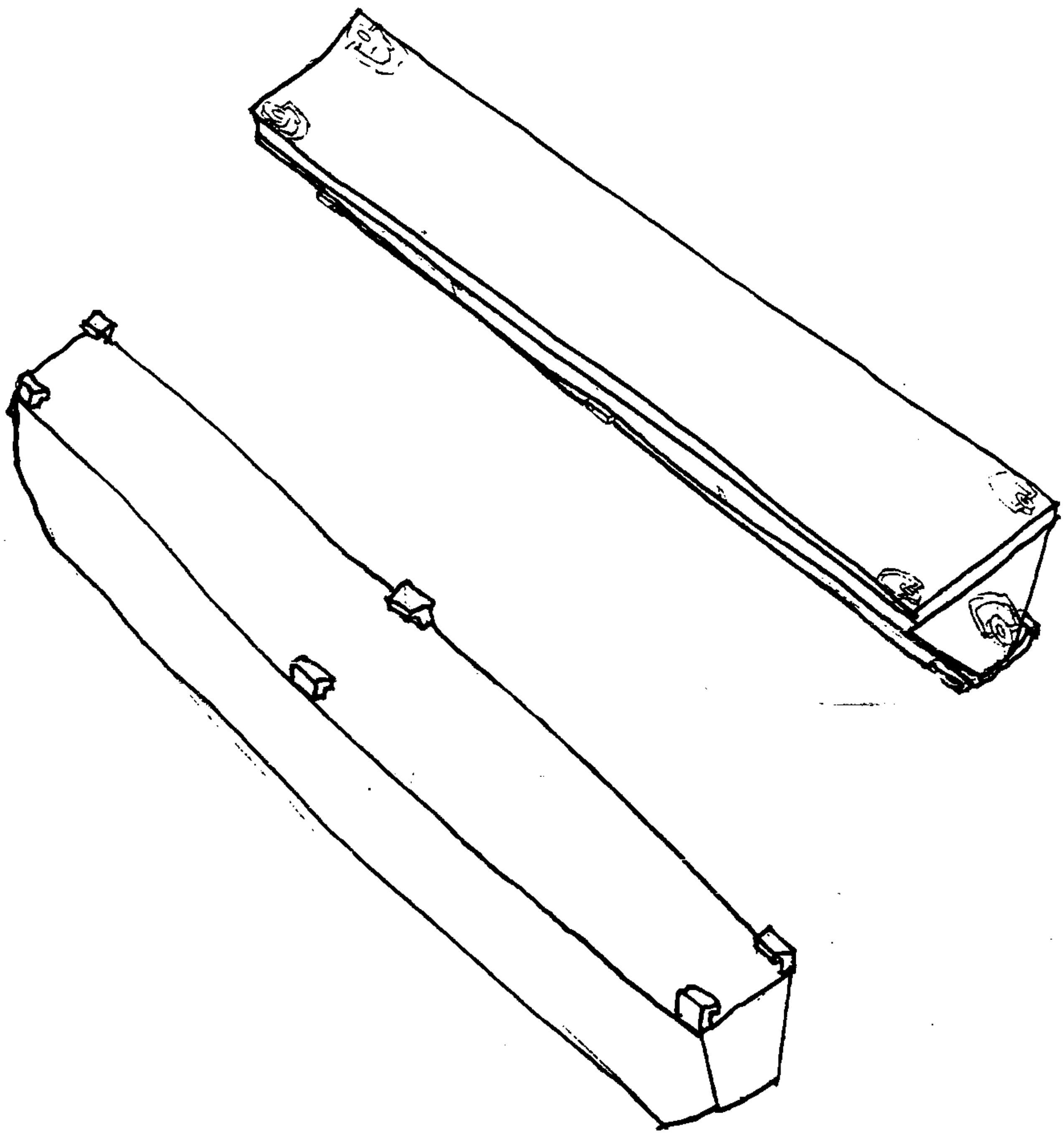


STRONGBACK LOCATE & PINS TO TOOL FOR ALLIGNMENT, MODULE SHIMED AND FITTED A/F AND TIED TO EACH OTHER

BROGAN

GEM - BASELINE - EM

EM MODULE STRONGBACK (40)



BROGAN

Calorimeter Engineering Question

8. *Integrated Calorimeter Assembly Fixturing*

Request: Provide a listing of fabrication, assembly and installation fixturing, including sketches, required for the construction of the liquid argon integrated calorimeter. Designate fixturing which will be required for the EM only as well.

Specific Concern:

- *The fixturing is not explicitly referenced in the cost estimate.*

Answer:

- *All of the special and standard tools are considered in the cost input although at a relatively high level. Definition of the required fixturing is an integral part of the thought process while developing the assembly flows for the calorimeter. At each step in the assembly the equipment, fixtures, and tools are conceptualized. Operations are envisioned to be performed with standard tools and equipment whenever possible and special tool concepts are invented only when no existing tools are known to be available. During the manufacturing flow development phase the tool concepts are carried only to the level of function and basic construction (see attached sketches).*

OPEN PLAN (R)

Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:36:06
Page: 14

GEM Liquid Argon Calorimeter

Martin Marietta

Timescale: 01 JAN 93 | 01 JAN 94 | 01 JAN 95 | 01 JAN 96 | 01 JAN 97 | 01 JAN 98

ACTIVITY	
	Timenow
02.1.6	*Test Beam Program*
02.1.6	*Test Beam Program*
02.1.6	Δ S/Test Beam Program
02.1.6.1	Cryostat Engineering
02.1.6.2	Modules Engineering
02.1.6.3	Electronics Engineering
02.1.6.4	Fixtures Engineering
02.1.6.5	Test Labor Engineering
02.1.6.1	Δ Cryostat Proc/Fab
02.1.6.2	Δ Modules Proc/Fab
02.1.6.3	Electronics Proc/Fab
02.1.6.4	Fixtures Proc/Fab
02.1.6.5	Test Labor
02.1.6	Δ C/Test Beam Program
02.1.7	*Installation & Test*
02.1.7	*Installation & Test*
02.1.7	Installation & Test Engineering
02.1.7	Installation & Test Proc/Fab
02.1.8	*Electronics*
02.1.8	*Electronics*
02.1.8	Electronics Engineering
02.1.8	Electronics Proc/Fab
02.1.9	*Subsystem Management & Integration*
02.1.9	*Subsystem Management & Integration*
02.1.9	Δ S/Subsystem Management & Integration
02.1.9.1	Project Management and Admin
02.1.9.2	Resource Management
02.1.9.3	ES&H
02.1.9.4	Quality Assurance
02.1.9.5	System Integration
02.1.9.6	Travel
02.1.9	Subsystem Management & Integration Δ

108

Legend
- In progress
- Planned
- Critical

Signatures
Prep: ____________
Aprv ____________

OPEN PLAN (R)

Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:38:06
Page: 13

GEM Liquid Argon Calorimeter

Martin Marietta

Timeline: 01 JAN 93 | 01 JAN 94 | 01 JAN 95 | 01 JAN 96 | 01 JAN 97 | 01 JAN 98

← Timenow

ACTIVITY	
02.1.3	Test Equipment Proc/Fab
02 1 4	*Cryogenic System*
02 1 4	*Cryogenic System*
02.1.4	Δ S/Cryogenic System
02.1.4.01	Local Argon Storage LN System Engineerin
02.1.4.02	LN Source System At Surface Engineering
02.1.4.03	LN Conditioning Systems Engineering
02.1.4.04	Argon Dewar Fill and Dist System Eng
02.1.4.05	Argon Dewar to Argon Condit System Eng
02.1.4.06	Argon Conditioner System Engineering
02.1.4.07	Module Cooling System Engineering
02.1.4.08	Argon Boiler Engineering
02.1.4.09	LN Boiler Engineering
02.1.4.10	Argon Supply Storage Dewars Engineering
02.1.4.11	Vacuum System Engineering
02.1.4.12	Argon Pump and Purge System Engineering
02.1.4.13	Installation Engineering
02.1.4.01	Local Argon Storage LN System Proc/Fab
02.1.4.02	LN Source System At Surface Proc/Fab
02.1.4.03	LN Conditioning Systems Proc/Fab
02.1.4.04	Argon Dewar Fill and Dist Sys Proc/Fab
02.1.4.05	Argon Dewar to Argon Condit System Proc
02.1.4.06	Argon Conditioner System Proc/Fab
02.1.4.07	Module Cooling System Proc/Fab
02.1.4.08	Argon Boiler Proc/Fab
02 1.4.09	LN Boiler Proc/Fab
02.1.4.10	Argon Supply Storage Dewars Proc/Fab
02.1.4.11	Vacuum System Proc/Fab
02.1.4.12	Argon Pump and Purge System Proc/Fab
02.1.4.13	Cryo System Installation
02.1.4	C/Cryogenic System Δ
02.1.5	*Facilities*
02 1 5	*Facilities*
02.1.5	Facilities Engineering
02.1.5	Facilities

107

Legend
▬-In progress
▨-Planned
▩-Critical

Signatures
Prep: ______
Apvy: ______

OPEN PLAN (R)

Report: MUDNBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:38:08
Page: 12

GEM Liquid Argon Calorimeter

Martin Marietta

ACTIVITY		01 JAN 93 – 01 JAN 98
		Timenow
02 1 2 4S	*South Endcap Assembly*	
02.1.2.4	SET UP MANDREL	
02.1.2.4	IN LINE TEST	
02.1.2.4	S/SECOND ENDCAP ASSY	
02.1.2.4	BUILD Ar VESSEL SUBASSY	
02.1.2.4	WELD WASHER	
02.1.2.4	WELD FRWD HALF MID-CYLINDER	
02.1.2.4	WELD FLAT PORTION ON Ar HEADWL	
02.1.2.4	WELD INNER CYLINDER	
02.1.2.4	WELD REAR Ar HEADWALL	
02.1.2.4	CALORIMETER MONOLITH ASSY	
02.1.2.4	INNER HADRONIC MODULES (2)	
02.1.2.4	FRWD MONOLITHIC EM RINGS (2)	
02.1.2.4	POSITION CABLE SUPPORT TOOL	
02.1.2.4	INSTALL MONOTITH ON VSL SUBASY	
02.1.2.4	WELD MID-CYLINDER SEGMENTS	
02.1.2.4	MOUNT OUTER HADRONIC MODULES	
02.1.2.4	WELD Ar VESSEL OUTER SHELL	
02.1.2.4	WELD ELLIPTICAL HEAD	
02.1.2.4	SUPPORT ENDCAP	
02.1.2.4	REMOVE MANDREL	
02.1.2.4	MOUNT ON ROTATION INSERT TOOL	
02.1.2.4	POSITION INNER VAC ASSY	
02.1.2.4	POSITION REAR HEADWALL ASSY	
02.1.2.4	WELD OUTER VAC/ELLIP HD HALFAS	
02.1.2.4	WELD TO REAR HEADWALL	
02.1.2.4	WELD STANCHION VAC JACKETS	
02.1.2.4	FINAL TEST	
02.1.2.4	AVAIL FOR TRANSPORT TO HALL	
02.1.2.4	TRANSPORT TO HALL	
02.1.2.4	INSTALLATION	
02.1.2.5	*Transportation*	
02 1 2 5	*Transportation*	
02.1 2.5	Transportation Engineering	
02.1 2.5	Transportation	
02 1 3	*Test Equipment*	
02 1 3	*Test Equipment*	
02.1.3	Test Equipment Engineering	

Legend
- In progress
- Planned
- Critical

Signatures
Prep: ____
Aprv: ____

OPEN PLAN (R)

Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL93
Time: 10:38:06
Page: 11

GEM Liquid Argon Calorimeter

Martin Marietta

Timeline: 01 JAN 93 | 01 JAN 94 | 01 JAN 95 | 01 JAN 96 | 01 JAN 97 | 01 JAN 98

Timenow

ACTIVITY	
02.1.2.3.5	EM Accordion Tool Proc/Fab
02.1.2.3.6	Plumbing Layout Tool Proc/Fab
02.1.2.3	C/Tooling/Fixtures Δ
02.1.2.4	*End Calorimeter Assembly/Test/Checkout*
02 1 2 4	*End Calorimeter Assembly/Test/Checkout*
02.1.2.4	S/End Calorimeter Assembly/Test/Checkout Δ
02.1.2.4	C/End Calorimeter Assembly/Test/Checkout Δ
02 1 2 4N	*North Endcap Assembly*
02.1.2.4	IN LINE TEST
02.1.2.4	Δ S/FIRST ENDCAP ASSY
02.1.2.4	SET UP MANDREL
02.1.2.4	BUILD Ar VESSEL SUBASSY
02.1.2.4	WELD WASHER
02.1.2.4	WELD FRWD HALF MID-CYLINDER
02.1.2.4	WELD FLAT PROTION Ar HEADWALL
02.1.2.4	WELD INNER CYLINDER
02.1.2.4	WELD REAR Ar HEADWALL
02.1.2.4	CALORIMETER MONOLITH ASSY
02.1.2.4	INNER HADRONIC MODULES (2)
02.1.2.4	FRWD MONOLITHIC EM RINGS (2)
02.1.2.4	POSITION CABLE SUPPORT TOOL
02.1.2.4	INSTAL MONOLITH VESSEL SUBASSY
02.1.2.4	WELD MID-CYLINDER SEGMENTS
02.1.2.4	MOUNT OUTER HADRONIC MODULES
02.1.2.4	WELD Ar VESSEL OUTER SHELL
02.1.2.4	WELD ELLIPTICAL HEAD
02.1.2.4	SUPPORT ENDCAP
02.1.2.4	REMOVE MANDREL
02.1.2.4	MOUNT ON ROTATION INSERT TOOL
02.1.2.4	POSITION INNER VAC ASSY
02.1.2.4	POSITION REAR HEADWALL ASSY
02.1.2.4	WELD OUTER VAC SHELL/ELLIP HD
02.1.2.4	WELD TO REAR HEADWALL
02.1.2.4	WELD STANCHION VAC JACKETS
02.1.2.4	FINAL TEST
02.1.2.4	TRANSPORT TO HALL
02.1.2.4	AVAIL FOR TRANSPORT TO HALL Δ
02.1.2.4	INSTALLATION

105

Legend
- In progress
- Planned
- Critical

Signatures
Prep: ______
Apprv: ______

OPEN PLAN (R)

Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:38:08
Page: 10

GEM Liquid Argon Calorimeter

Martin Marietta

ACTIVITY	01 JAN 93	01 JAN 94	01 JAN 95	01 JAN 96	01 JAN 97	01 JAN 98
	Timenow					

ACTIVITY	
02.1.2.2.2.5	Seal Weld Strip Engineering
02.1.2.2.2.6	Vacuum Vessel Assembly Engineering
02.1.2.2.2.1	Outer Shell Proc
02.1.2.2.2.2	Inner Shell Proc
02.1.2.2.2.3	Head (2) Proc/Fab
02.1.2.2.2.4	Supports Proc/Fab
02.1.2.2.2.5	Seal Weld Strip Proc
02.1.2.2.2.6	Δ Vacuum Vessel Assembly
02.1.2.2.2	Δ C/Vacuum Vessel
02.1.2.2.3	*LAr Vessel Cold Mass Support Posts (4)*
02.1.2.2.3	LAr Vesl Cold Mass Supt Posts (4) Engine
02.1.2.2.3	LAr Vesl Cold Mass Supt Posts (4) Proc/F
02.1.2.2.4	*Endcap Rail Support*
02.1.2.2.4	Endcap Rail Support Engineering
02.1.2.2.4	Endcap Rail Support Proc/Fab
02.1.2.2.5	*Feedthrus*
02.1.2.2.5	Δ S/Feedthrus
02.1.2.2.5.1	Cold Feedthru Assembly Engineering
02.1.2.2.5.2	Conduction Heat Intercept (CHI) Engineer
02.1.2.2.5.3	Assembly Engineering
02.1.2.2.5.1	Cold Feedthru Assembly Proc/Fab
02.1.2.2.5.2	Conduction Heat Intercept (CHI) Proc/Fab
02.1.2.2.5.3	Feedthru Assembly
02.1.2.2.5	Δ C/Feedthrus
02.1.2.3	*Tooling/Fixtures*
02.1.2.3	*Tooling/Fixtures*
02.1.2.3	Δ S/Tooling/Fixtures
02.1.2.3.1	Stacking Fixture Engineering
02.1.2.3.2	Cryostat Assembly Fixture Engineering
02.1.2.3.3	Lifting Fixture Engineering
02.1.2.3.4	Shipping Crates Engineering
02.1.2.3.5	EM Accordion Tool Engineering
02.1.2.3.6	Plumbing Layout Tool Engineering
02.1.2.3.1	Stacking Fixture Proc/Fab
02.1.2.3.2	Cryostat Assembly Fixture Proc/Fab
02.1.2.3.3	Lifting Fixture Proc/Fab
02.1.2.3.4	Shipping Crates Proc/Fab

104

Legend
- In progress
- Planned
- Critical

Signatures
Prep: ____________
Apry: ____________

OPEN PLAN (R)

Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 31JUL92
Time: 10:38:06
Page: 9

GEM Liquid Argon Calorimeter

Martin Marietta

Timeline columns: 01 JAN 93 | 01 JAN 94 | 01 JAN 95 | 01 JAN 96 | 01 JAN 97 | 01 JAN 98

← Timenow

ACTIVITY	
02.1.2.1.2.8.4	Module Assembly/Test
02.1.2.1.2.8	Δ C/Module 14 (40)
02 1 2.2	*Cryostat Endcap Calorimeter*
02 1 2 2	*Cryostat Endcap Calorimeter*
02.1.2.2	Δ S/Cryostat Endcap Calorimeter
02.1.2.2	C/Cryostat Endcap Calorimeter Δ
02 1.2 2.1	*Argon Vessel*
02.1.2.2.1.04	Inner Shell Proc
02.1.2.2.1	Δ S/Argon Vessel
02.1.2.2.1.01	Outer Shell Engineering
02.1.2.2.1.02	Center Shell (2) Engineering
02.1.2.2.1.03	Center Washer Engineering
02.1.2.2.1.04	Inner Shell Engineering
02.1.2.2.1.05	Inner Shell Assembly Engineering
02.1.2.2.1.06	Feedthru Interface Plate Engineering
02.1.2.2.1.07	Cooling Coils Engineering
02.1.2.2.1.08	Two-Phased N2 Preamp Cooling Circ Eng
02.1.2.2.1.09	Fill Ports (2) Engineering
02.1.2.2.1.10	Drain Port Engineering
02.1.2.2.1.11	Seal Weld Strips Engineering
02.1.2.2.1.12	Argon Vessel Assembly Engineering
02.1.2.2.1.01	Outer Shell Proc/Fab
02.1.2.2.1.02	Center Shell (2) Proc/Fab
02.1.2.2.1.03	Center Washer Proc/Fab
02.1.2.2.1.05	Inner Shell Assembly Proc/Fab
02.1.2.2.1.06	Feedthru Interface Plate Proc/Fab
02.1.2.2.1.07	Cooling Coils Proc/Fab
02.1.2.2.1.08	Two-Phased N2 Preamp Cooling Circ
02.1.2.2.1.09	Fill Ports (2) Proc/Fab
02.1.2.2.1.10	Drain Port Proc/Fab
02.1.2.2.1.11	Seal Weld Strips Proc/Fab
02.1.2.2.1.12	Δ Argon Vessel Assembly
02.1.2.2.1	Δ C/Argon Vessel
02 1 2 2 2	*Vacuum Vessel*
02.1.2.2.2	Δ S/Vacuum Vessel
02.1.2.2.2.1	Outer Shell Engineering
02.1.2.2.2.2	Inner Shell Engineering
02.1.2.2.2.3	Head (2) Engineering
02.1.2.2.2.4	Supports Engineering

103

Legend
■ - In progress
▨ - Planned
▧ - Critical

Signatures
Prep: ______
Aprv: ______

OPEN PLAN (R)
Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:38:06
Page: 9

GEM Liquid Argon Calorimeter

Martin Marietta

ACTIVITY	01 JAN 93	01 JAN 94	01 JAN 95	01 JAN 96	01 JAN 97	01 JAN 98
	Timenow					
02.1.2.1.2.5.1	Absorber Engineering					
02.1.2.1.2.5.2	G10 Boards Engineering					
02.1.2.1.2.5.3	Other Module Structure Engineering					
02.1.2.1.2.5.4	Module Assembly/Test Engineering					
02.1.2.1.2.5.1	Absorber Proc/Fab					
02.1.2.1.2.5.2	G10 Boards Proc/Fab					
02.1.2.1.2.5.3	Other Module Structure Proc/Fab					
02.1.2.1.2.5.4	Module Assembly/Test					
02.1.2.1.2.5	C/Module 11 (40)					
02 1 2 1 2 6	*Module 12 (80)*					
02.1.2.1.2.6	S/Module 12 (80)					
02.1.2.1.2.6.1	Absorber Engineering					
02.1.2.1.2.6.2	G10 Boards Engineering					
02.1.2.1.2.6.3	Other Module Structure Engineering					
02.1.2.1.2.6.4	Module Assembly/Test Engineering					
02.1.2.1.2.6.1	Absorber Proc/Fab					
02.1.2.1.2.6.2	G10 Boards Proc/Fab					
02.1.2.1.2.6.3	Other Module Structure Proc/Fab					
02.1.2.1.2.6.4	Module Assembly/Test					
02.1.2.1.2.6	C/Module 12 (80)					
02 1 2 1 2 7	*Module 13 (40)*					
02.1.2.1.2.7	S/Module 13 (40)					
02.1.2.1.2.7.1	Absorber Engineering					
02.1.2.1.2.7.2	G10 Boards Engineering					
02.1.2.1.2.7.3	Other Module Structure Engineering					
02.1.2.1.2.7.4	Module Assembly/Test Engineering					
02.1.2.1.2.7.1	Absorber Proc/Fab					
02.1.2.1.2.7.2	G10 Boards Proc/Fab					
02.1.2.1.2.7.3	Other Module Structure Proc/Fab					
02.1.2.1.2.7.4	Module Assembly/Test					
02.1.2.1.2.7	C/Module 13 (40)					
02 1 2 1 2 8	*Module 14 (40)*					
02.1.2.1.2.8	S/Module 14 (40)					
02.1.2.1.2.8.1	Absorber Engineering					
02.1.2.1.2.8.2	G10 Boards Engineering					
02.1.2.1.2.8.3	Other Module Structure Engineering					
02.1.2.1.2.8.4	Module Assembly/Test Engineering					
02.1.2.1.2.8.1	Absorber Proc/Fab					
02.1.2.1.2.8.2	G10 Boards Proc/Fab					
02.1.2.1.2.8.3	Other Module Structure Proc/Fab					

Legend
- In progress
- Planned
- Critical

Signatures
Prep: ____________
Aprv: ____________

OPEN PLAN (R)

Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:38:08
Page: 7

GEM Liquid Argon Calorimeter

Martin Marietta

Timescale: 01 JAN 93 | 01 JAN 94 | 01 JAN 95 | 01 JAN 96 | 01 JAN 97 | 01 JAN 98

Timenow

ACTIVITY	
02.1.2.1.2.1.3	Other Module Structure Proc/Fab
02.1.2.1.2.1.4	Module Assembly/Test
02.1.2.1.2.1	C/Module 7 (20)
02 1 2 1 2 2	*Module 8 (20)*
02.1.2.1.2.2	S/Module 8 (20)
02.1.2.1.2.2.1	Absorber Engineering
02.1.2.1.2.2.2	G10 Boards Engineering
02.1.2.1.2.2.3	Other Module Structure Engineering
02.1.2.1.2.2.4	Module Assembly/Test Engineering
02.1.2.1.2.2.1	Absorber Proc/Fab
02.1.2.1.2.2.2	G10 Boards Proc/Fab
02.1.2.1.2.2.3	Other Module Structure Proc/Fab
02.1.2.1.2.2.4	Module Assembly/Test
02.1.2.1.2.2	C/Module 8 (20)
02 1 2 1 2 3	*Module 9 (20)*
02.1.2.1.2.3	S/Module 9 (20)
02.1.2.1.2.3.1	Absorber Engineering
02.1.2.1.2.3.2	G10 Boards Engineering
02.1.2.1.2.3.3	Other Module Structure Engineering
02.1.2.1.2.3.4	Module Assembly/Test Engineering
02.1.2.1.2.3.1	Absorber Proc/Fab
02.1.2.1.2.3.2	G10 Boards Proc/Fab
02.1.2.1.2.3.3	Other Module Structure Proc/Fab
02.1.2.1.2.3.4	Module Assembly/Test
02.1.2.1.2.3	C/Module 9 (20)
02 1 2 1 2 4	*Module 10 (40)*
02.1.2.1.2.4	S/Module 10 (40)
02.1.2.1.2.4.1	Absorber Engineering
02.1.2.1.2.4.2	G10 Boards Engineering
02.1.2.1.2.4.3	Other Module Structure Engineering
02.1.2.1.2.4.4	Module Assembly/Test Engineering
02.1.2.1.2.4.1	Absorber Proc/Fab
02.1.2.1.2.4.2	G10 Boards Proc/Fab
02.1.2.1.2.4.3	Other Module Structure
02.1.2.1.2.4.4	Module Assembly/Test
02.1.2.1.2.4	C/Module 10 (40)
02 1 2 1 2 5	*Module 11 (40)*
02.1.2.1.2.5	S/Module 11 (40)

101

Legend
- In progress
- Planned
- Critical

Signatures
Prep: ______
Aprv: ______

OPEN PLAN (R)

Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:38:06
Page: 8

GEM Liquid Argon Calorimeter

Martin Marietta

Timeline columns: 01 JAN 93 | 01 JAN 94 | 01 JAN 95 | 01 JAN 96 | 01 JAN 97 | 01 JAN 98

← Timenow

ACTIVITY	
02 1.2	*Endcap Calorimeter*
02 1 2	*Endcap Calorimeter (2)*
02.1.2	Δ S/Endcap Calorimeter (2)
02.1.2	C/Endcap Calorimeter (2) Δ
02 1.2 1	*Modules*
02 1 2 1	*Modules*
02.1.2.1	Δ S/Modules
02.1.2.1	Δ C/Modules
02 1 2 1 1	*Accordion EM Section*
02.1.2.1.1	Δ S/Accordion EM Section
02.1.2.1.1	Δ C/Accordion EM Section
02 1 2 1.1 1	*Module 6 (2)*
02.1.2.1.1.1	Δ S/Module 6 (2)
02.1.2.1.1.1.1	Absorber Engineering
02.1 2.1.1.1.2	G10 Boards Engineering
02.1.2.1.1.1.3	Other Module Structure Engineering
02.1.2.1.1.1.4	Module Assembly/Test Engineering
02.1.2.1.1.1.1	Absorber Proc/Fab
02.1.2.1.1.1.2	G10 Boards Proc/Fab
02.1.2.1.1.1.3	Other Module Structure Proc/Fab
02 1 2.1.1.1.4	Module Assembly/Test
02.1.2.1.1.1	Δ C/Module 6 (2)
02 1 2 1 2	*Hadronic Section*
02 1.2.1.2	Δ S/Hadronic Section
02.1.2.1.2	Δ Hadronic Section
02 1 2 1.2 1	*Module 7 (20)*
02.1.2.1.2.1	Δ S/Module 7 (20)
02.1.2.1.2.1.1	Absorber Engineering
02.1.2.1.2.1.2	G10 Boards Engineering
02.1.2.1.2.1.3	Other Module Structure Engineering
02.1.2.1.2.1.4	Module Assembly/Test Engineering
02.1.2.1.2.1.1	Absorber Proc/Fab
02.1.2.1.2.1.2	G10 Boards Proc/Fab

100

Legend
■ - In progress
▨ - Planned
▨ - Critical

Signatures
Prep: ____________
Apvy: ____________

OPEN PLAN (R)

Report: MUONBARS
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:38:08
Page: 8

GEM Liquid Argon Calorimeter

Martin Marietta

ACTIVITY	01 JAN 93 – 01 JAN 98
	Timenow
02.1.1.3.6	Automated Welding Engineering
02.1.1.3.7	Plumbing Layout Tool Engineering
02.1.1.3.1	Stacking Fixtures Proc/Fab
02.1.1.3.2	Cryostat Assembly Fixtures Proc/Fab
02.1.1.3.3	Lifting Fixtures Proc/Fab
02.1.1.3.4	Shipping Crates Proc/Fab
02.1.1.3.5	Module Installation Fixture Proc/Fab
02.1.1.3 7	Plumbing Layout Tool Proc/Fab
02.1.1.3	C/Tooling/Fixtures
02.1.1.4	Barrel Calorimeter Assembly/Test/Checkout
02 1 1 4	Barrel Calorimeter Assembly/Test/Checkout
02.1.1.4	IN LINE TEST
02.1.1.4	S/Barrel Calorimeter Assembly/Test/CO
02.1.1.4	S/CENTRAL BARREL ASSY
02.1.1.4	SET UP MANDREL&LOAD SPT TUBE
02.1.1.4	WASHERS/WALLS AVAILABLE
02.1.1.4	INSTALL CAL MODULES
02.1.1.4	INSTALL CABLE SUPPORT TOOL
02.1.1.4	ROUTE CABLES
02.1.1.4	INSTALL Ar OUTER SHELL
02.1.1.4	MOVE TO CRADLE
02.1.1.4	PRE-ALIGNMENT
02.1.1.4	INSTALL IN OUTER VAC SHELL
02.1.1.4	CYLINDRICAL SPT BEAMS PLACED
02.1.1.4	INSTALL PINNED RADIAL LINKS
02.1.1.4	ALIGNMENT
02.1.1.4	WELD INNER VAC SHELL
02.1.1.4	WELD ENDCAP VAC SHELLS
02 1.1.4	INSTALL FEEDTHROUGHS
02.1.1.4	FINAL TEST
02.1.1.4	AVAIL FOR TRANSPORT TO HALL
02.1.1.4	TRANSPORT TO HALL
02.1.1.4	INSTALLATION
02.1.1.4	SYSTEM CHECKOUT
02.1.1.4	C/Barrel Calorimeter Assembly/Test/CO
02 1 1.5	Transportation
02 1 1 5	Transportation
02.1.1.5	Transportation Engineering
02.1.1.5	Transportation

099

Legend
- In progress
- Planned
- Critical

Signatures
Prep: ____________
Apprv: ____________

OPEN PLAN (R)

Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:38:08
Page: 4

GEM Liquid Argon Calorimeter

Martin Marietta

Timescale: 01 JAN 93 | 01 JAN 94 | 01 JAN 95 | 01 JAN 96 | 01 JAN 97 | 01 JAN 98

Timenow

ACTIVITY	
02 1.1.2.2.1	Outer Shell Engineering
02.1.1.2.2.2	Inner Shell Engineering
02.1.1.2.2.3	Head (2) Engineering
02.1.1.2.2.4	Supports Engineering
02.1.1.2.2.5	Seal Weld Strips Engineering
02.1.1.2.2.6	Vacuum Vessel Assembly Engineering
02 1.1.2.2.1	Outer Shell Proc
02.1.1.2.2.2	Inner Shell Proc
02.1.1.2.2.3	Head (2) Proc/Fab
02.1.1.2.2.4	Supports Proc/Fab
02.1.1.2.2.5	Seal Weld Strips Proc/Fab
02.1.1.2.2.6	Δ Vacuum Vessel Assembly
02.1.1.2.2	Δ C/Vacuum Vessel
02 1.1.2.3	*LAr Vessel Cold Mass Support Posts (4)*
02.1.1.2.3	LAr Vesl Cold Mass Supt Posts (4) Eng
02.1.1.2.3	LAr Vessel Cold Mass Support Posts (4)
02 1 1 2.4	*Barrel Rail Support*
02.1.1.2.4	Barrel Rail Support Engineering
02.1.1.2.4	Barrel Rail Support Proc/Fab
02 1 1 2 5	*Feedthrus*
02.1.1.2.5	Δ S/Feedthrus
02.1.1.2.5.1	Cold Feedthru Assembly Engineering
02.1.1.2.5.2	Conduction Heat Intercept (CHI) Engineer
02.1.1.2.5.3	Assembly Engineering
02.1.1.2.5.1	Cold Feedthru Assembly Proc/Fab
02.1.1.2.5.2	Conduction Heat Intercept (CHI) Proc/Fab
02.1.1.2.5.3	Feedthru Assembly
02 1.1.2.5	Δ C/Feedthrus
02 1 1.3	*Tooling/Fixtures*
02 1 1 3	*Tooling/Fixtures*
02 1.1.3.6	Δ Automated Welding Proc/Fab
02.1.1.3	Δ S/Tooling/Fixtures
02.1.1.3.1	Stacking Fixtures Engineering
02.1.1.3.2	Cryostat Assembly Fixtures Engineering
02 1.1.3.3	Lifting Fixtures Engineering
02.1.1.3.4	Shipping Crates Engineering
02.1.1.3.5	Module Installation Fixture Engineering

Legend
- In progress
- Planned
- Critical

Signatures
Prep: ____________
Aprv: ____________

OPEN PLAN (R)

Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:38:08
Page: 3

GEM Liquid Argon Calorimeter

Martin Marietta

Timescale: 01 JAN 93 | 01 JAN 94 | 01 JAN 95 | 01 JAN 96 | 01 JAN 97 | 01 JAN 98

ACTIVITY	
	Timenow
02.1.1.1.2.4.4	Module Assembly/Test Engineering
02.1.1.1.2.4.1	Absorber Proc/Fab
02.1.1.1.2.4.2	G10 Boards Proc/Fab
02.1.1.1.2.4.3	Other Module Structure Proc/Fab
02.1.1.1.2.4.4	Module Assembly/Test
02.1.1.1.2.4	Δ C/Module 5 (80)
02 1.1.2	*Cryostat Barrel Calorimeter*
02 1 1 2	*Cryostat Barrel Calorimeter*
02.1.1.2	Δ S/Cryostat Barrel Calorimeter
02.1.1.2	C/Cryostat Barrel Calorimeter Δ
02 1 1.2 1	*Argon Vessel*
02.1.1.2.1	Δ S/Argon Vessel
02.1.1.2.1.01	Outer Shell Engineering
02.1.1.2.1.02	Center Shell (2) Engineering
02.1.1.2.1.03	Center Washer Engineering
02.1.1.2.1.04	Inner Shell Engineering
02.1.1.2.1.05	Inner Shell Assembly Engineering
02.1.1.2.1.06	Feedthru Interface Plate Engineering
02.1.1.2.1.07	Cooling Coils Engineering
02.1.1.2.1.08	Two-Phase N2 Preamp Cooling Circuits Eng
02.1.1.2.1.09	Fill Ports (2) Engineering
02.1.1.2.1.10	Drain Port Engineering
02.1.1.2.1.11	Seal Weld Strips Engineering
02.1.1.2.1.12	Argon Vessel Assembly Engineering
02.1.1.2.1.01	Outer Shell Proc
02.1.1.2.1.02	Center Shell (2) Proc/Fab
02.1.1.2.1.03	Center Washer Proc/Fab
02.1.1.2.1.04	Inner Shell Proc/Fab
02.1.1.2.1.05	Inner Shell Assembly Proc/Fab
02.1.1.2.1.06	Feedthru Interface Plate Proc/Fab
02.1.1.2.1.07	Cooling Coils Proc/Fab
02.1.1.2.1.08	Two-Phase N2 Preamp Cooling Circu
02.1.1.2.1.09	Fill Ports (2) Proc/Fab
02.1.1.2.1.10	Drain Port Proc/Fab
02.1.1.2.1.11	Seal Weld Strips Proc/Fab
02.1.1.2.1.12	Δ Argon Vessel Assembly
02.1 1.2.1	Δ C/Argon Vessel
02 1 1 2 2	*Vacuum Vessel*
02.1.1.2.2	Δ S/Vacuum Vessel

097

Legend
- In progress
- Planned
- Critical

Signatures

Prep: ____________

Aprv: ____________

OPEN PLAN (R)

Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:38:08
Page: 2

GEM Liquid Argon Calorimeter

Martin Marietta

ACTIVITY	01 JAN 93 – 01 JAN 98
	← Timenow
02 1 1 1 2.1	*Module 2 (80)*
02.1.1.1.2.1	Δ S/Module 2 (80)
02.1.1.1.2.1.1	Absorber Engineering
02.1.1.1.2.1.2	G10 Boards Engineering
02.1.1.1.2.1.3	Other Module Structure Engineering
02.1.1.1.2.1.4	Module Assembly/Test Engineering
02.1.1.1.2.1.1	Absorber Proc/Fab
02.1.1.1.2.1.2	G10 Boards Proc/Fab
02.1.1.1.2.1.3	Other Module Structure Proc/Fab
02.1.1.1.2.1.4	Module Assembly/Test
02.1.1.1.2.1	Δ C/Module 2 (80)
02 1 1 1 2.2	*Module 3 (80)*
02.1.1.1.2.2	Δ S/Module 3 (80)
02.1.1.1.2.2.1	Absorber Engineering
02.1.1.1.2.2.2	G10 Boards Engineering
02.1.1.1.2.2.3	Other Module Structure Engineering
02.1.1.1.2.2.4	Module Assembly/Test Engineering
02.1.1.1.2.2.1	Absorber Proc/Fab
02.1.1.1.2.2.2	G10 Boards Proc/Fab
02.1.1.1.2.2.3	Other Module Structure Proc/Fab
02.1.1.1.2.2.4	Module Assembly/Test
02.1.1.1.2.2	Δ C/Module 3 (80)
02 1 1 1 2 3	*Module 4 (80)*
02.1.1.1.2.3	Δ S/Module 4 (80)
02.1.1.1.2.3.1	Absorber Engineering
02.1.1.1.2.3.2	G10 Boards Engineering
02.1.1.1.2.3.3	Other Module Structure Engineering
02.1.1.1.2.3.4	Module Assembly/Test Engineering
02.1.1.1.2.3.1	Absorber Proc/Fab
02.1.1.1.2.3.2	G10 Boards Proc/Fab
02.1.1.1.2.3.3	Other Module Structure Proc/Fab
02.1.1.1.2.3.4	Module Assembly/Test
02.1.1.1.2.3	Δ C/Module 4 (80)
02 1 1 1 2.4	*Module 5 (80)*
02.1.1.1.2.4	Δ S/Module 5 (80)
02.1.1.1.2.4.1	Absorber Engineering
02.1.1.1.2.4.2	G10 Boards Engineering
02.1.1.1.2.4.3	Other Module Structure Engineering

960

Legend
- In progress
- Planned
- Critical

Signatures
Prep: ____________
Aprv: ____________

OPEN PLAN (R)

Report: MUONBAR1
Project: GEMLAC
Time Now: 01JAN93
Date: 21JUL92
Time: 10:36:08
Page: 1

GEM Liquid Argon Calorimeter

Martin Marietta

Timescale: 01 JAN 93 | 01 JAN 94 | 01 JAN 95 | 01 JAN 96 | 01 JAN 97 | 01 JAN 98

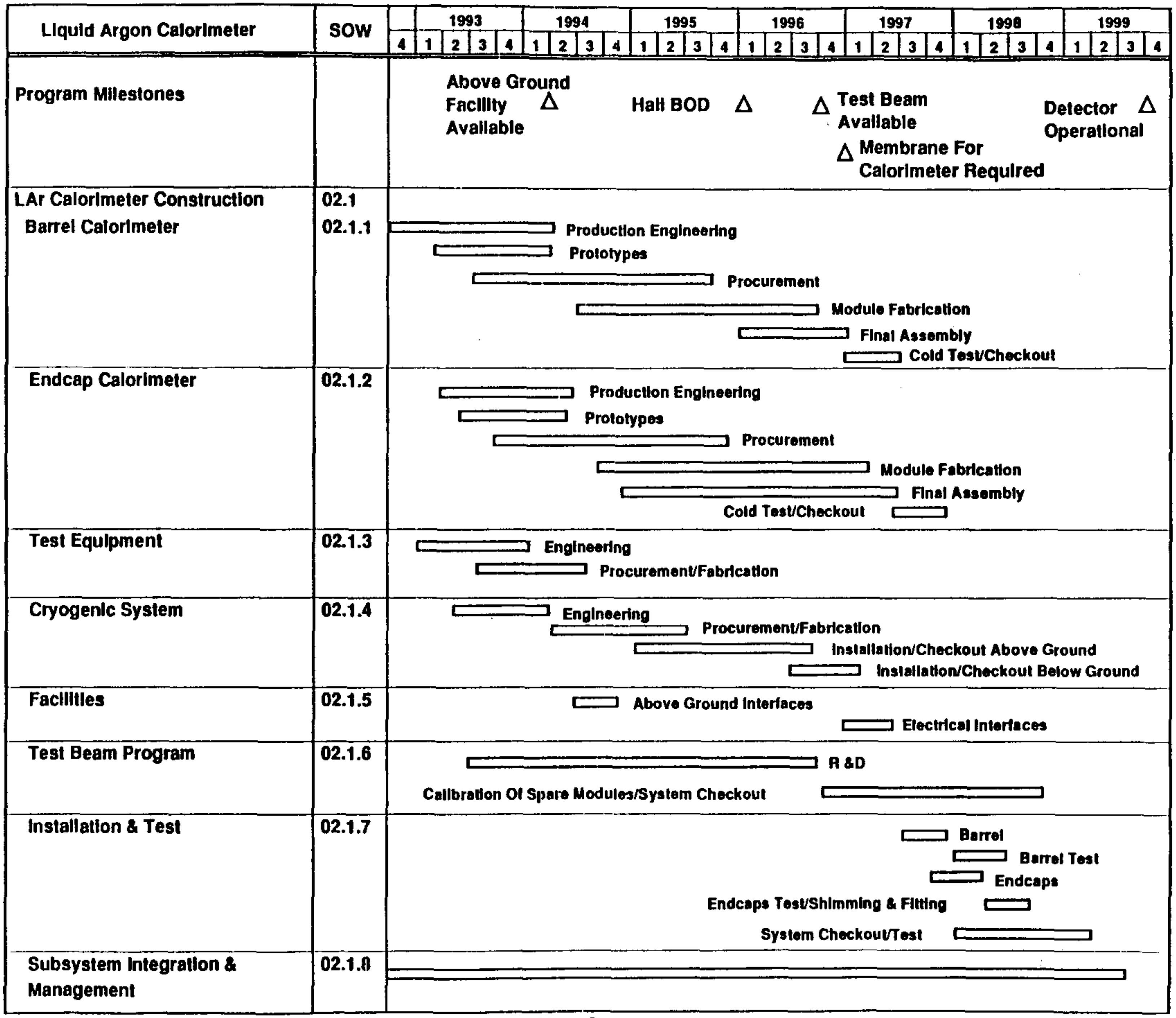
← Timenow

ACTIVITY	
02 1	*Program Milestones*
02 1	*LAr Calorimeter Construction*
02.1	Δ Start Final Design GEM LAC
02.1	Δ S/LAr Calorimeter Construction
02.1	C/LAr Calorimeter Construction Δ
02 1 1	*Barrel Calorimeter*
02 1 1	*Barrel Calorimeter*
02.1.1	Δ S/Barrel Calorimeter
02.1.1	C/Barrel Calorimeter Δ
02.1 1 1	*Modules*
02 1 1 1	*Modules*
02.1.1.1	Δ S/Modules
02.1.1.1	Δ C/Modules
02 1 1.1 1	*Accordion EM Section*
02.1.1.1.1	Δ S/Accordion EM Section
02.1.1.1.1	Δ C/Accordion EM Section
02 1 1.1 1.1	*Module 1 (40)*
02.1.1.1.1.1	Δ S/Module 1 (40)
02.1.1.1.1.1.1	Absorber Engineering
02.1.1.1.1.1.2	G10 Boards Engineering
02.1 1.1.1.1.3	Other Module Structure Engineering
02.1 1.1.1.1.4	Module Assembly/Test Engineering
02.1 1.1.1.1.1	Absorber Proc/Fab
02.1.1.1.1.1.2	G10 Boards Proc/Fab
02.1.1.1.1.1.3	Other Module Structure Proc/Fab
02.1.1.1.1.1.4	Module Assembly/Test
02.1.1.1.1.1	Δ C/Module 1 (40)
02 1.1 1 2	*Hadronic Section*
02.1.1.1.2	Δ S/Hadronic Section
02.1.1.1.2	Δ C/Hadronic Section

095

Legend
- In progress
- Planned
- Critical

Signatures
Prep: ____________
Aprv: ____________



Preliminary

GEM LAC EM ONLY

	Engr/ Design ($k)	M&S ($k)	Inspec/ Admin ($k)	Proc/ Fab ($k)	Assy ($k)	Instl ($k)	Cont. ($k)	WBS Total ($k)
LAr Calorimeter:	6,362	666	1,111	18,183	4,482	266	10,840	42,112
Research & Devel.	546	61	110	1,802	444	26	1,057	4,047
Concep./Prelim. Design	1,051	53	0	0	0	0	171	1,274
Construction	4,765	552	1,001	16,381	4,038	240	9,612	36,790
Modules	433	22	473	7,845	2,449	0	5,176	16,399
Barrel EM	217	11	322	3,784	1,667	0	2,743	8,742
Barrel Hadronic	0	0	0	0	0	0	0	0
Endcap EM	217	11	151	4,062	783	0	2,434	7,657
Endcap Hadronic	0	0	0	0	0	0	0	0
Cryostat	785	39	55	1,510	256	0	990	3,635
Barrel Krypton Vessel	148	7	9	78	32	0	71	345
Barrel Vacuum Vessel	102	5	1	25	3	0	30	166
Endcap Krypton Vessel	123	6	7	106	35	0	71	348
Endcap Vacuum Vessel	115	6	1	71	2	0	44	238
Supports	21	1	3	89	13	0	31	158
Feedthrus	275	14	35	1,141	171	0	743	2,380
Calorimeter Assy.	964	48	58	37	229	0	340	1,676
Tooling/Fixtures	1,017	61	22	1,966	145	0	936	4,350
Stacking Fixtures	163	11	0	470	0	0	180	878
Cryostat Assy Fixtures	282	19	0	261	0	0	171	827
Lifting Fixtures	124	8	0	118	0	0	75	367
Shipping Crates	41	3	0	490	0	0	141	688
Module Installation Fixture	97	5	0	105	0	0	58	264
Hadronic Fixture	0	0	0	0	0	0	0	0
Cooling Tube Layout Tool	78	4	0	105	0	0	45	231
EM Accordion Fixture	233	12	22	418	145	0	265	1,095
Test Equipment	33	2	6	387	16	0	106	550
Transportation	61	3	0	41	0	0	18	124
Cryogenic System	306	15	96	2,499	377	0	1,120	4,413
Equipment (above ground)	33	2	0	913	0	0	209	1,157
Test Beam Program	0	0	0	1,149	0	0	299	1,447
Installation/Test	144	7	18	34	0	214	108	524
Subsys. Mgt. & Integr.	988	353	274	0	565	26	309	2,515

Add $9.42 M for Krypton (21,560 liters @ $437/liter)

8/5/92 - 8:08 AM

Liquid Argon Calorimeter Summary WBS

	Engr/ Design ($k)	M&S ($k)	Inspec/ Admin ($k)	Proc/ Fab ($k)	Assy ($k)	Instl ($k)	Cont. ($k)	WBS Total ($k)
LAr Calorimeter:	12,694	1,305	4,404	41,048	18,413	895	21,872	100,632
Research & Devel.	1,154	124	436	4,068	1,825	89	2,151	9,846
Concep./Prelim. Design	1,051	53	0	0	0	0	171	1,274
Construction	10,490	1,128	3,968	36,981	16,588	806	19,551	89,511
Modules	2,963	148	2,264	19,573	11,726	0	11,312	47,986
Barrel EM	217	11	260	4,593	1,348	0	2,970	9,399
Barrel Hadronic	679	34	729	5,162	3,773	0	2,553	12,930
Endcap EM	217	11	106	3,350	550	0	1,977	6,210
Endcap Hadronic	1,850	93	1,169	6,468	6,055	0	3,812	19,448
Cryostat	1,339	67	76	2,835	484	0	1,756	6,557
Barrel Argon Vessel	298	15	9	249	57	0	163	791
Barrel Vacuum Vessel	64	3	6	95	42	0	47	257
Endcap Argon Vessel	334	17	10	236	58	0	165	818
Endcap Vacuum Vessel	115	6	9	104	55	0	70	358
Supports	34	2	3	252	17	0	76	384
Feedthrus	494	25	39	1,899	257	0	1,235	3,949
Calorimeter Assy.	2,282	114	391	2,133	1,543	0	1,659	8,122
Tooling/Fixtures	1,261	63	39	3,805	145	0	1,437	6,751
Stacking Fixtures	217	11	0	878	0	0	286	1,392
Cryostat Assy Fixtures	341	17	0	1,150	0	0	392	1,900
Lifting Fixtures	165	8	0	418	0	0	154	746
Shipping Crates	54	3	0	472	0	0	137	665
Module Installation Fixture	97	5	0	209	0	0	87	398
Hadronic Fixture	76	4	0	157	0	0	66	302
Cooling Tube Layout Tool	78	4	0	105	0	0	45	231
EM Accordion Fixture	233	12	39	418	145	0	271	1,117
Test Equipment	33	2	6	470	22	0	128	661
Transportation	90	5	0	429	0	0	93	617
Cryogenic System	306	15	96	2,498	377	0	724	4,017
Equipment (above ground)	95	5	0	1,341	0	0	317	1,758
Test Beam Program	0	0	0	3,829	0	0	996	4,825
Installation/Test	288	14	50	67	0	708	293	1,421
Subsys. Mgt. & Integr.	1,831	695	1,046	0	2,291	98	835	6,797

7. *Calorimeter Cost and Schedules*

Request: Provide the following information for the three calorimeter options (Integrated Liquid Argon, Scintillator and Hybrid):

- Engineering Cost and Duration,
- Fabrication Cost and Duration,
- Assembly Cost and Duration,
- Installation Cost and Duration,
- Overall Cost estimates,
- Total Schedules,
- Tabulations of Labor Loading at SSCL,
- Physics parameters.

Summary - Integrated Liquid Argon (Construction Only)

	Cost ($K)	Duration	
		From	To
Engineering	10,490	4th Q '92	3rd Q '96
Fabrication	36,981	3rd Q '93	4th Q '95
Assembly	16,588	2nd Q '94	2nd Q '97
Installation	806	3rd Q '97	2nd Q '99
Overall Cost*	89,511	4th Q'92	2nd Q '99

Summary - EM Only (Construction Only)

	Cost ($K)	Duration	
		From	To
Engineering	4,765	4th Q '92	3rd Q '96
Fabrication	16,381	1st Q '94	2nd Q '95
Assembly	4,038	3rd Q '94	2nd Q '97
Installation	240	3rd Q '97	2nd Q '99
Overall Cost*	36,790	4th Q'92	2nd Q '99

** Includes Engr/Design, M&S, Inspec/Admin, Proc/Fab, Assy, Instl, and Contingency*

Please see following pages for additional detail

Calorimeter Engineering Question

6. **Integrated Liquid Argon Installation/Testing**

Request: Provide an outline of the testing of the liquid argon calorimeter prior to and after installation in the experimental hall.

Specfic Concerns:

- *Surface testing of the three completed cryostat assemblies will require substantial time, material and manpower.*

- *Surface testing will have to be repeated in the experimental hall due to the transport and handling required between the assembly areas and the final positioning of the the detector.*

- *If final testing is only performed in the experimental hall the cost and schedule risk will be unacceptable.*

Answer:

- *First we plan to test representative modules in the test beam at the SSCL. Some of these modules, such as an endcap EM monolith, will be the actual module that will be used in the experiment. This testing will give us the experience to cope with the installation in the experimental hall.*

We outlined above the electrical tests invisaged at every step of the assembly and installation. In addition we plan to do a cold test of the completed calorimeter upstairs in the assembly hall. This would involve vacuum and liquid nitrogen services. We would probably not need to fill with argon, but might plan for this as well. The cost of providing these services to the assembly hall are also not very large.

Notes: All Dimensions In mm
See Figures 5-4 & 5-5 for Detail of Weld Zones

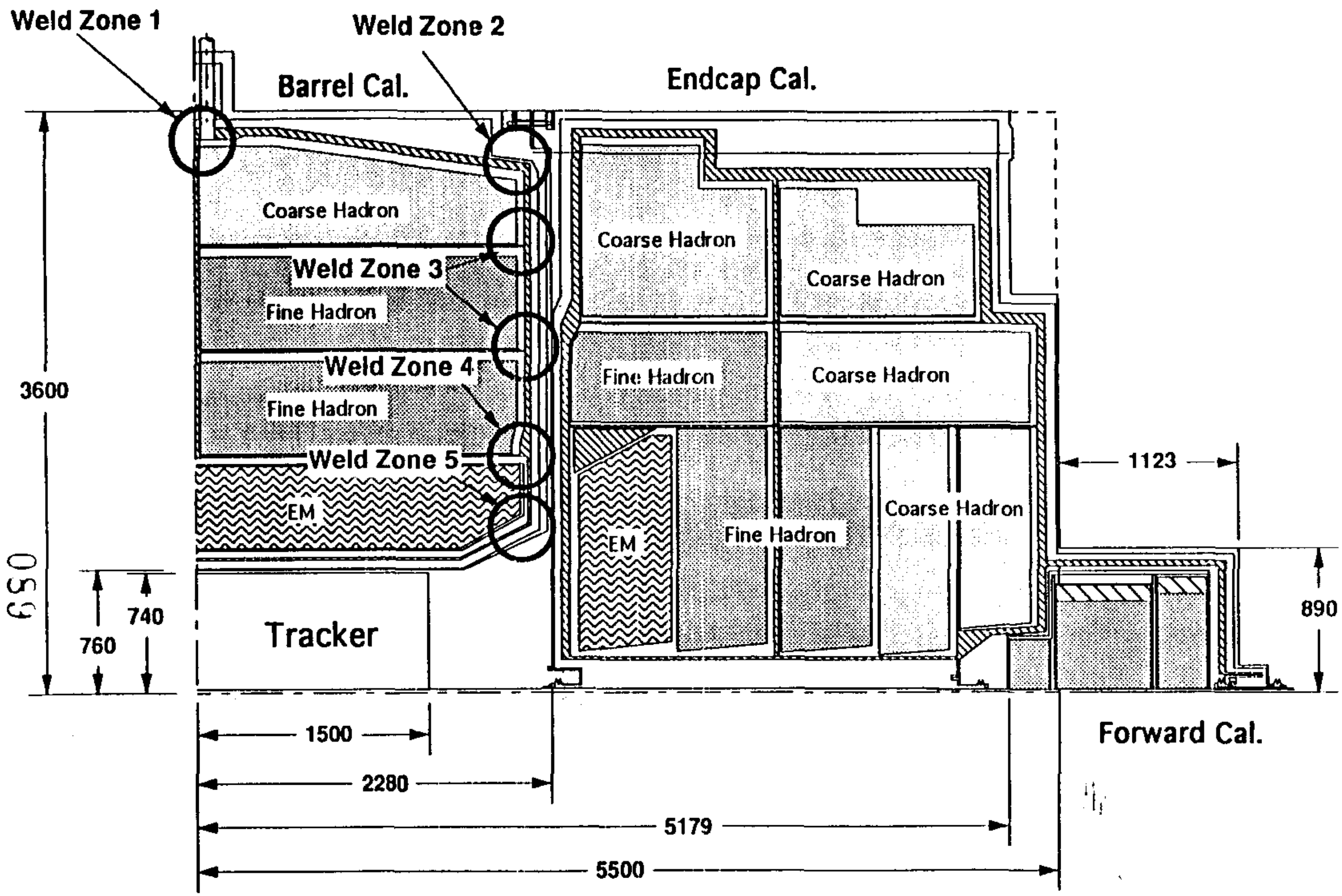


Figure 5-6. Reference Calorimeter Configuration

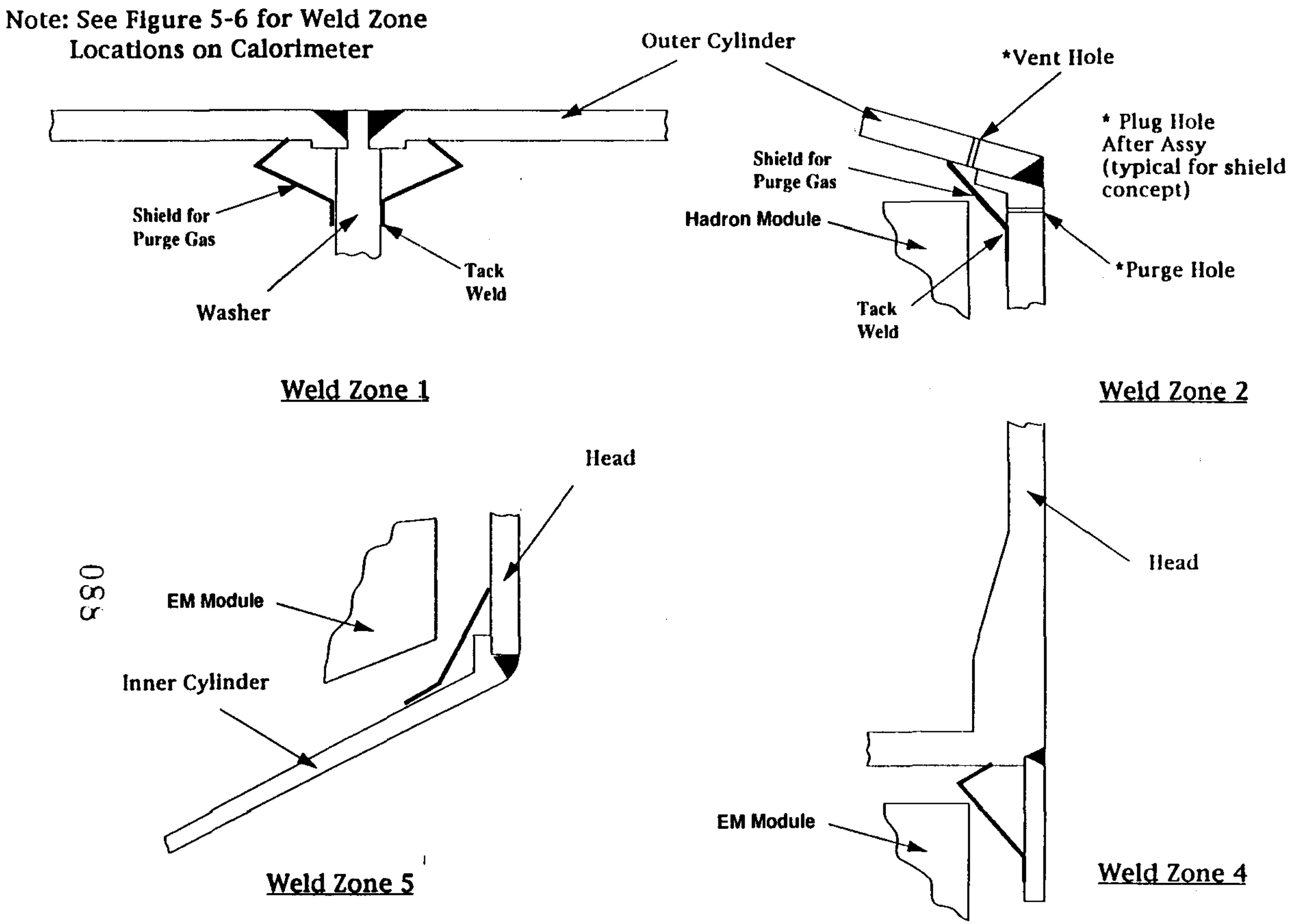


Figure 5-5 Weld Joints(Baseline) Shielded & Purged During Assembly of Barrel EM Calorimeter

Note: See Figure 5-6 for Weld Zone Locations on Calorimeter

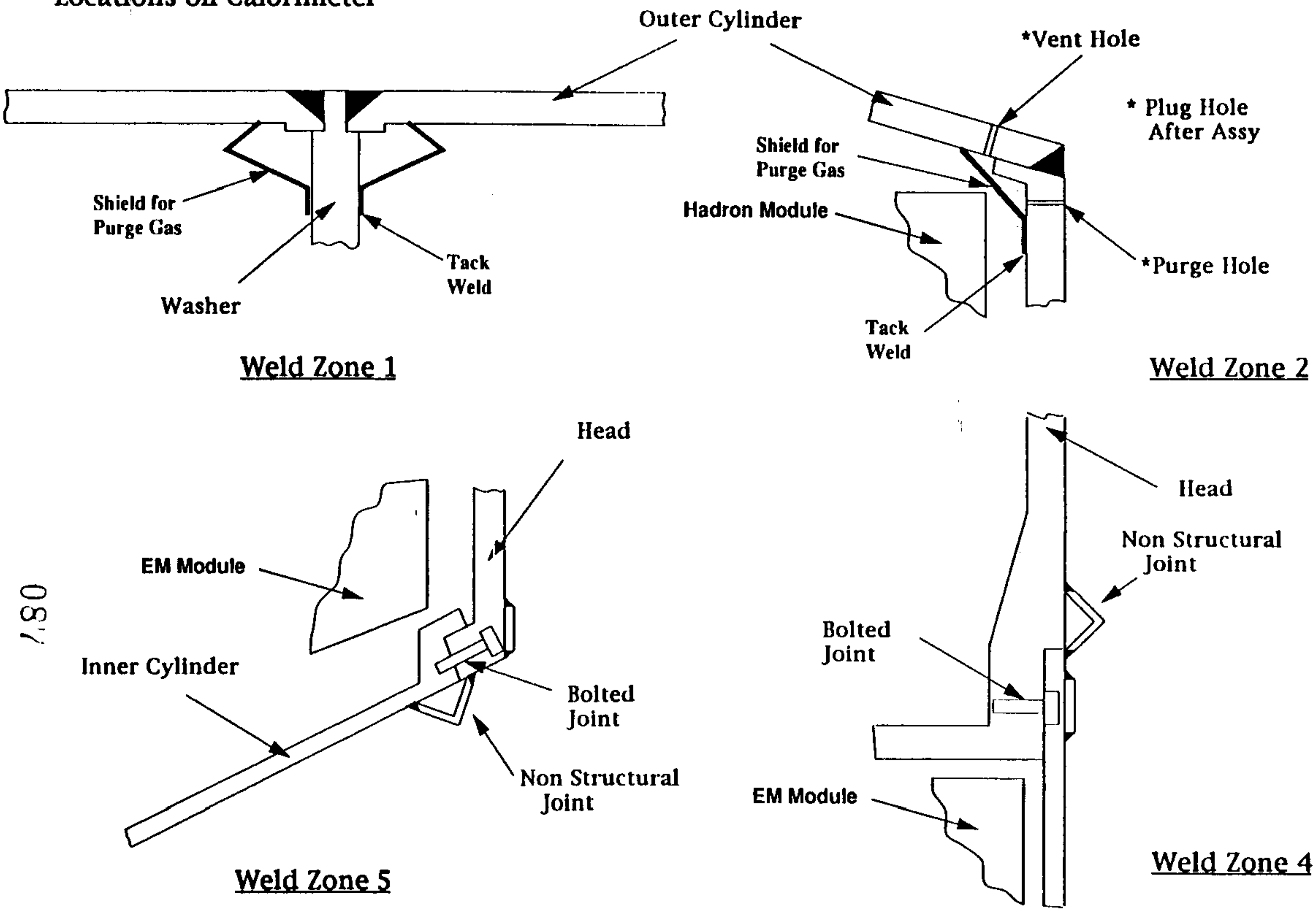


Figure 5-4 Weld Joints Shielded & Purged During Assembly of Barrel EM Calorimeter

KRBarnstable Module Supt Endview

Note: See Figure 5-6 for Weld Zone Locations on Calorimeter

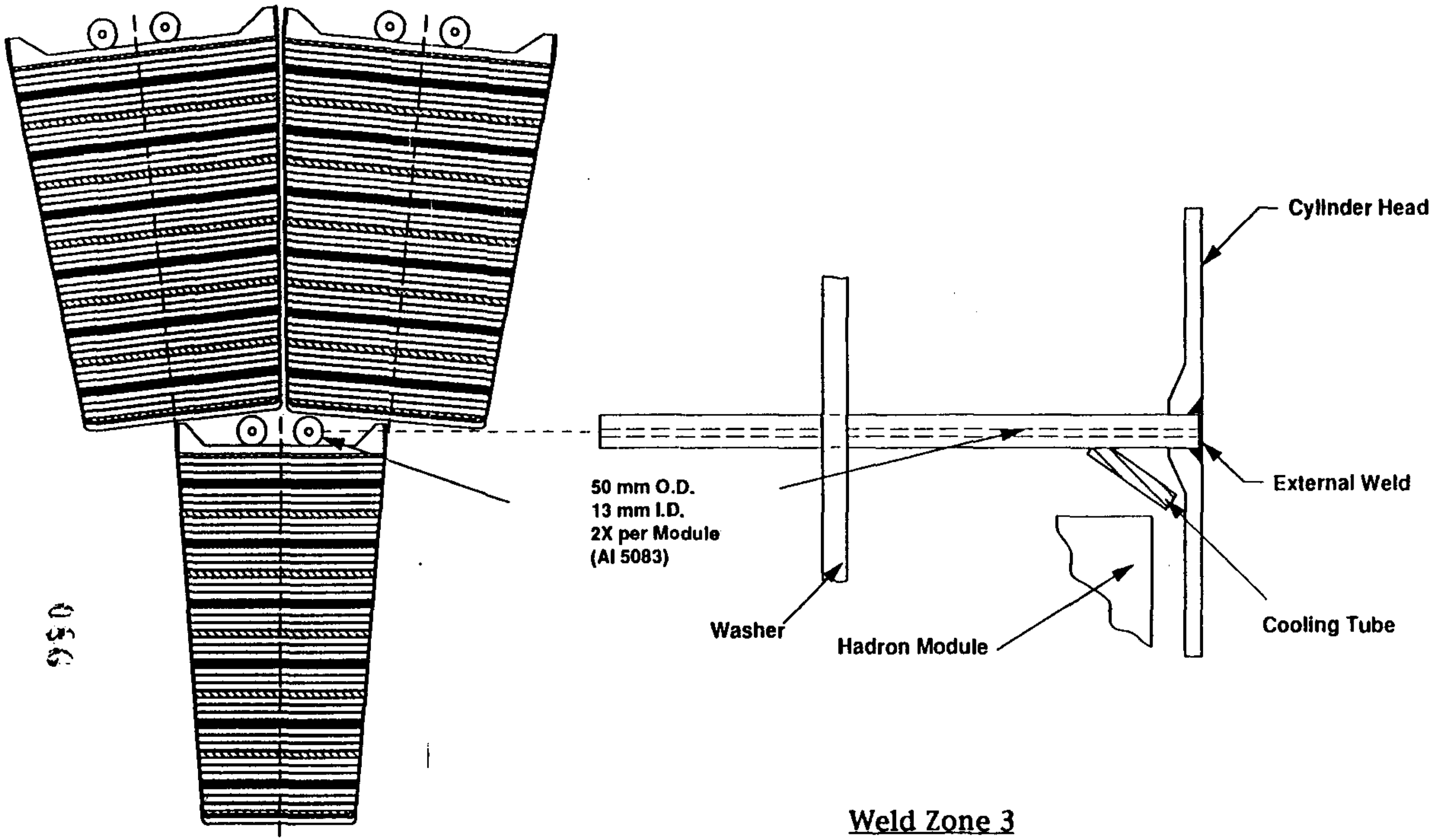


Figure 5-3 Cooling Tube Hadron Module Stay Concept

KRBarnstable Module Supt Endview

Note: See Figure 5-6 for Weld Zone Locations on Calorimeter

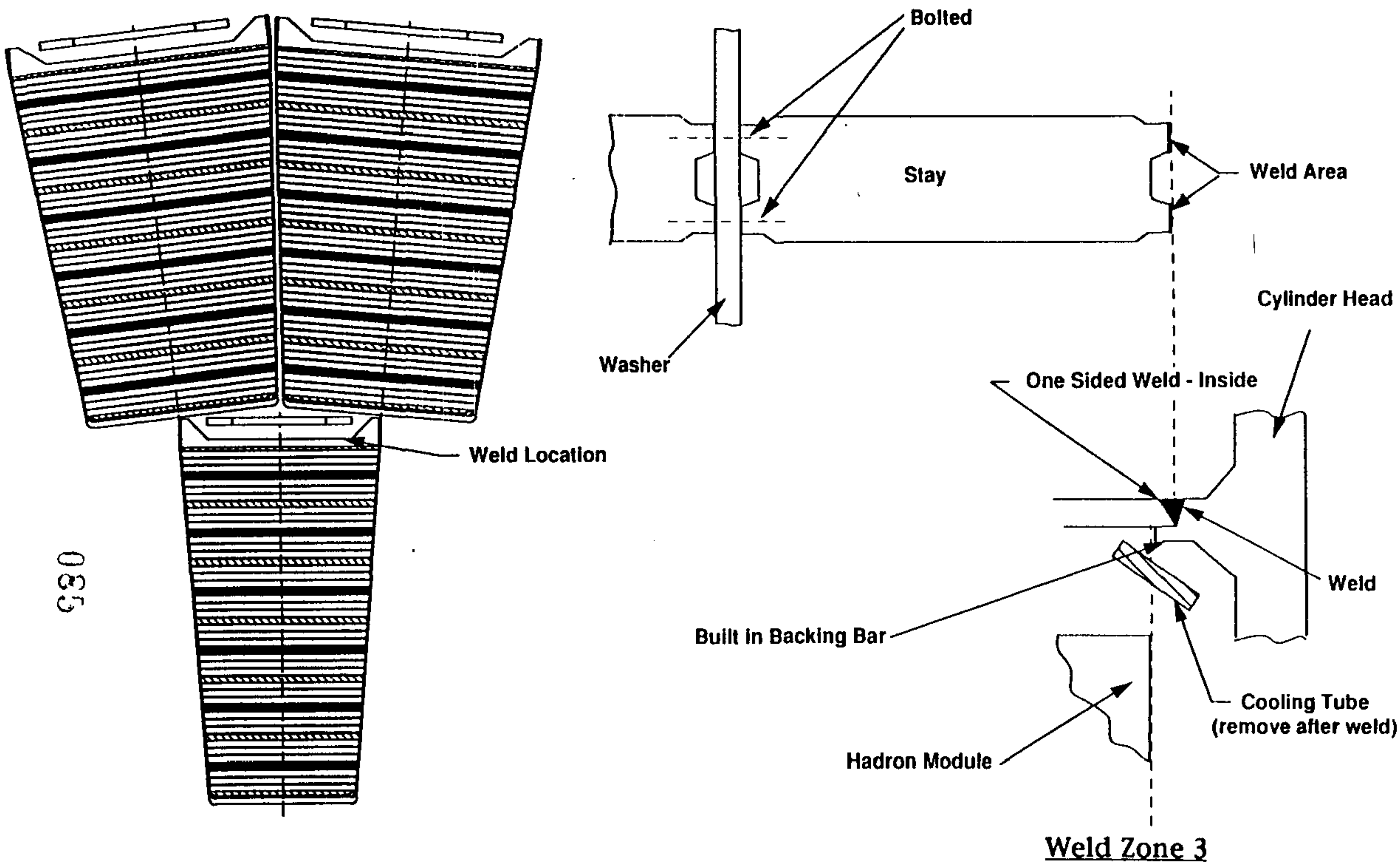


Figure 5-2 Solid Plate(Baseline) Hadron Module Stay Concept

050

KRBarnstable Module Supt Endview

- Sealing the liquid argon vessel after the installation of the EM assembly involves significant risk due to proximity of the welds to the cables. However, by using shields in the vicinity of the weld joints and by using bolted connections this risk can be minimized (reference Figures 5-4 & 5-5).

Figure 5-2. Solid Plate Hadron Module Stay Concept

Figure 5-3. Cooling Tube Hadron Module Stay Concept

Figure 5-4. Weld Joints Shielded & Purged During Assembly of Barrel EM Calorimeter

Figure 5-5. Weld Joints(Baseline) Shielded & Purged During Assembly of Barrel EM Calorimeter

Figure 5-6. Reference Calorimeter Configuration

Calorimeter Engineering Question (continued)

5. *Integrated Liquid Argon Calorimeter Assembly Procedure*

Request: Provide sketches explaining the test and installation sequence of the barrel EM calorimeter in the integrated liquid argon calorimeter.

Specific Concerns:

- *Sealing the liquid argon vessel after the installation of the EM assembly appears to involve significant risk due to proximity of the welds to the cables.*

Answers:

- *Approach shown in Figures 5-4 & 5-5 has been taken to mitigate the risk. However, test coupons should be studied to evaluate the extent of this concern.*

Data:

083

- There is considerable risk to the EM cabling due to the proximity of the welds to the cables. This is especially true if the stays are solid plates (reference Figure 5-2). Since we must mitigate the heat, careful cable management, limited heat input during welding and some more shielding (insulating) will be necessary. A solid plate stay concept can utilize cooling tubes during the welding operation to prevent heat damage to cabling. These cooling tubes can be removed after the module stay welding operation is completed. Additional valuable space will be used to incorporate a backing bar in the design as required by ASME code.

- Instead of using solid plates as stays better options exist. One such option would be to replace the solid plate stay with two tubes (reference Figure 5-3). The tubes would serve a dual role by acting as a stay and providing an active cooling tube for cooling the preamps during operational usage. The welding and overall assembly is easier and less heat input is required for the necessary partial penetration weld. This concept also eliminates the need for a backing bar since a full penetration weld is no longer required. The final weld is made on the outside and the overall heat input and cable shielding concerns are less.

Calorimeter Engineering Question

5. Integrated Liquid Argon Calorimeter Assembly Procedure

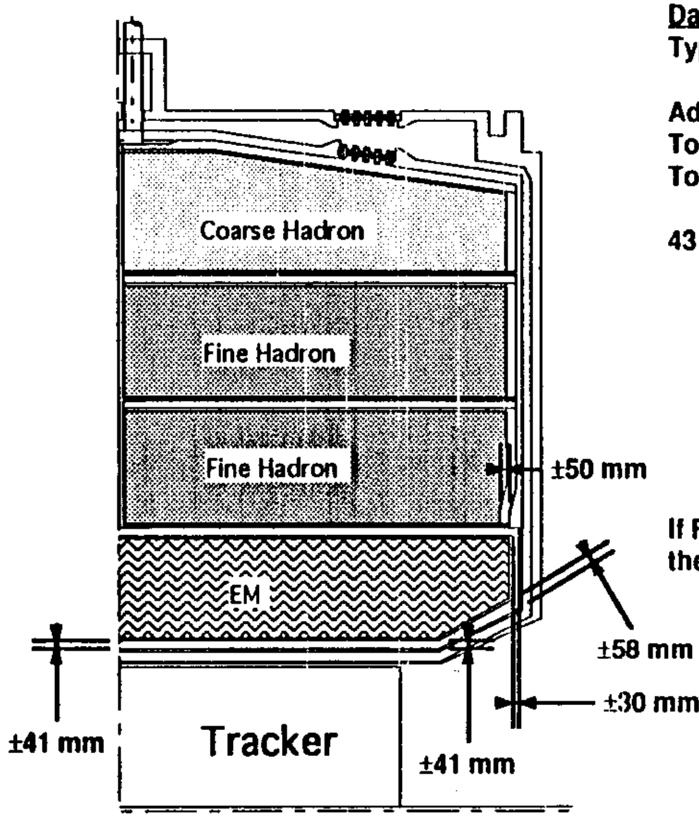
Request: Provide sketches explaining the test and installation sequence of the barrel EM calorimeter in the integrated liquid argon calorimeter.

Specific Concern:

- *The fully assembled barrel (62 Mt) and endcap (13.2 Mt) accordion calorimeters must be functionally tested prior to the installation in the integrated assembly.*

Answer:

- *The test of any noble liquid calorimeter involves, the measurement of the capacitance of each channel to check the connections, the measurement of the leakage current at high voltage to eliminate shorts, and the full test of the preamps and calibration circuits. These tests will be done at every major stage in the assembly and installation. If these tests are successful we will be confident that the calorimeter will function correctly. We do not require the beam testing of all modules of the calorimeter.*



<u>Data (Per 9º Segment):</u>
Typical For Front and Back Segmentation

Add 10% for extra wires (clock channels, calibration channels, etc.)
Towers in Eta = 43
Towers in Phi = 5

43 towers x 5 towers x 1.1 = 236 pairs of wires
x 2 wires / channel

= 472 wires / 50 wires/cable

= 10 cables
<u>x ±2 mm / cable</u>
20 mm Cable Space

If Front & Back Segmentation cabling is Stacked,
the Cable Space = 40 mm. If off-set the cabling height remains 20mm.

Figure 5-1 EM Channel Cable Management

Calorimeter Engineering Question

5. *Integrated Liquid Argon Calorimeter Assembly Procedure*

Request: Provide sketches explaining the test and installation sequence of the barrel EM calorimeter in the integrated liquid argon calorimeter.

Specific Concerns:

- *The proposed EM installation operation does not appear to provide for the routing of cables and services from the EM to the barrel feedthrus.*

Answer:

- *EM installation operation does provide for the routing of cables and services as shown in Figure 5-1.*

Data:

- 30 mm of radial space is allocated between the cryostat wall and both the inner radius and ends of the EM section. It is estimated that 20 mm of space is required for these areas. The space between the EM and hadronic modules will carry twice as many cables and so 50 mm of space has been allocated in these areas (see Figure 5-1).

Figure 5-1. EM Channel Cable Management *hadronic modules. In the hadron calorimeter, tiles of copper need to be arranged and then laminated. This is a labor intensive activity.*

Specific Concern:

- *Facilities at the SSCL will require special atmospheric conditioning and will thus add significant cost to the overall project.*

Answer:

- *The requirement is that the relative humidity be less than 40% and that a modest clean room environment be established. The goals for the clean room are that debris of the size of a fraction of a mm be excluded. This is not the kind of clean room that is difficult or expensive to establish. We are talking about the order of a very few hundred thousands of dollars. A model would be the clean room built at Fermilab for the D0 detector.*

Calorimeter Engineering Question

4. Integrated Liquid Argon Calorimeter Fabrication

Request: Outline the general procedure for the manufacture of the Integrated Liquid Argon Calorimeter by an international collaborator.

Specific Concern:

- *The large aluminum vessels will require relatively sophisicated and difficult procedures which may not be possible for most international collaborating institutions.*

Due to the size of the assembly and the method of fabrication the cost estimate specifies that approximately 40% (est., 183 PY) of all fabrication/test/installation labor will be performed at the SSCL.

It will be difficult to enforce quality control standards if module work is performed off-shore and final testing is completed when the cryostats are closed at the SSCL. Of particular concern are the potential problems with dirt, shipping, and mishandling between the module fabrication source and the SSCL.

Answer:

- *The cryostat costs are about 5% of the entire calorimeter budget. So even in the worst case, it could be made entirely in the US. However, we are open to contributions that potential GEM collaborators can make. The assembly of the cryostat involves many smaller pieces which could be fabricated off-shore and put together on site. The cryostat is aluminum and so cleaning, shipping and handling should be able to be easily accomplished. The quality control question applies to ANYTHING made ANYWHERE. There needs to be involvement by the physicists in the collaboration both in the U.S. and off-shore to insure that any piece made is inspected and tested at the site where it is fabricated.*

We are now talking seriously with our Chinese collaborators in GEM about the fabrication in China. There is genuine interest on the part of the Chinese. However, we are not at the stage in the discussion where we know whether just module components would be fabricated in China or assembled modules. Much of the labor is in the preparation of the parts both for the EM modules and especially for the

	Barrel and Endcap Thermal Expansion and Loads						
	Dimensions	mm	Loads	lbs	MT Total	MT ea.	
Endcap	L1	3689	Load1	1214082	552	275.93	
	L2	4853	Load2	185118	84	42.072	
	Cg	3843	Weight	1399200	636	318	check
Barrel	Four Equally Loaded Stanchions				900	225	
Moments=Load1*L1+Load2*L2-Weight*Cg							
Load1+Load2=Weight							
Load1*L1+(Weight-L1)*Load2=Weight*Cg							
Load1=(Weight*Cg-Weight*L2)/(L1-L2)							
Thermal Expansion for AL 5083 (296 to 86°K)							
Dimensions	Integrated	Delta L		Delta L from			
mm	thermal	total deflection		undeflected position			
Length	Expansion	mm	inches	inches			
L	Delta L/L						
3892	0.004	15.57	0.61	± 0.305			
3619	0.004	14.48	0.57	± 0.285			
4150	0.004	16.60	0.65	± 0.325			

Figure 3-4 Loads & Analysis Results for Barrel & Endcap Stanchion (continued)

TK Solver was used to size the stanchions using criteria outlined by the AISC. The Roark & Young beam column equations together with the structural equations given by the AISC are presented below for your information:

```
*    call crit(P,E,I,L;Pcr,k,err)
*    call get_tab(matl#,matl,E)
*    call case(W,E,I,L,a,k,P;RA,MA,thetaA,yA,RB,MB,thetaB,yB,case)
*    call load(E,I,L,a,RA,MA,thetaA,yA,x,k,P,W,0,0,0;V,M,theta,y)
*    z=t/2
C    z=given('z,z,'_)
*    if given('z) then st=M*z/I else st='_
*    if known('axis,1,0)=0 then I%c='_
*    if I%c<>'_ then sty=M/I%c else sty='_
*    call clear()
*    if plot='y then call genplot(E,I,a,RA,MA,thetaA,yA,L,I%c,k,P,W,0,0,0)
*    if table='y then call gentable(W,0,0,0)
*    bt=Pt/P*b
*    At=bt*t
*    I= 1/12*b*t^3
*    r=t/sqrt(12)
*    A=b*t
     "AISC ASD 9th edition p.5-42"
*    Fa=12*pi()^2*E/(23*(K*L/r)^2)
*    Pcr1=Fa*A
*    fa=P/A
     "AISC ASD 9th edition p.5-48"
*    Fb=.75*Fy
*    Fv=.40*Fy
*    fb=MB*c/I
*    c=t/2
     "AISC ASD 9th edition p.5-54"
*    Cm=.85
*    if fcratio>=1 then comb=fa/Fa+fb/Fb
*    if fcratio<1 then comb=fa/Fa+(Cm/(1-fa/Fa))*fb/Fb
*    fcratio=fa/Fa
*    comb1=(fa/(0.6*Fy))+abs(fb/Fb)
*    comb2=(fa/Fa)+(fb/Fb)
```

Figure 3-4. Loads & Analysis Results for Barrel & Endcap Stanchions (continued)

Endcap Calorimeter Supports (continued)
Front stanchion load is 275MT

Input	Name	Output	Unit	Comment
				AT RIGHT END:
	RB	-32790.1	lb	Vertical reaction
	MB	479693.72	in-lb	Reaction Bending moment
	thetaB	0	rad	Slope
	yB	0	in	Deflection
				MARGIN OF SAFETY BASED ON AISC
	Fb	105000	psi	allowable bending stress
	Fv	56000	psi	allowable axial stress
	fb	21596.289	psi	applied bending stress
	fa	2360.6009	psi	applied axial stress
	Cm	.85		AISC restraint constant
	fcratio	.58187669		ratio of fa/Fa
				if fa/Fa> 0.15
1	comb			margin of safety(<=1.0)
	comb1	.23378134		margin of safety(<=1.0)
				if fa/Fa<= 0.15
	comb2	.78755563		margin of safety(<=1.0)

Figure 3-4. Loads & Analysis Results for Barrel & Endcap Stanchions (continued)

Endcap Calorimeter Supports
Front support loads is 275MT

Input	Name	Output	Unit	Comment
24	L		in	Length of beam(input)
	b	492.86668	in	length of plate(input)
.52	t		in	thickness of plate(input)
	r	.15011107	in	radius of gyration
	A	256.29067	in^2	area of plate
2.9E7	E		psi	Young's Modulus(input)
	I	5.775	in^4	Area moment of inertia
	z	.26	in	Neutral axis to stress point
	c	.26		max distance to neutral axis(t/2)
				FOR FIXED/GUIDED BEAM AISC ASD p.5-135
1.2	K			effective length factor(input)
140000	Fy		psi	yield stress(input)
	bt	492.86668	in	Total stantion length
605000	Pt		in	Total stantion load
	At	256.29067	in^2	Total stantion area(input)
				LOAD ON STANCHION
0	a		in	Lateral Load distance from left end
	W	-32790.1	lb	Lateral Load
605000	P		lb	Axial Compressive Load(input)
				CRITICAL BUCKLING LOAD ON STANCHION
	Pcr	2869680.2	lb	CRITICAL Compressive Load(EULER)
	err	'_		Caution Message
				CRITICAL Compressive Load(AISC)
	Pcr1	1039739.2		Pcr1<Pcr
	Fa	4056.8749	lb	CRITICAL Compressive Load(AISC) Fa<Pcr
				AT SECTION:
0	x		in	Distance from left end
	V	0	lb	Transverse shear
	M	-479693.7	in-lb	Bending moment
	theta	0	rad	Slope
	y	.285	in	Deflection
				Stress:(Axial Load Comp NOT Included)
	st	'_	psi	Fiber stress at stress point z
	sty	'_	psi	Max Fiber stress at extremity y
				AT LEFT END:
	RA	0	lb	Vertical reaction
	MA	-479693.7	in-lb	Reaction Bending moment
	thetaA	0	rad	Slope
.285	yA		in	Deflection (input)

Figure 3-4. Loads & Analysis Results for Barrel & Endcap Stanchions

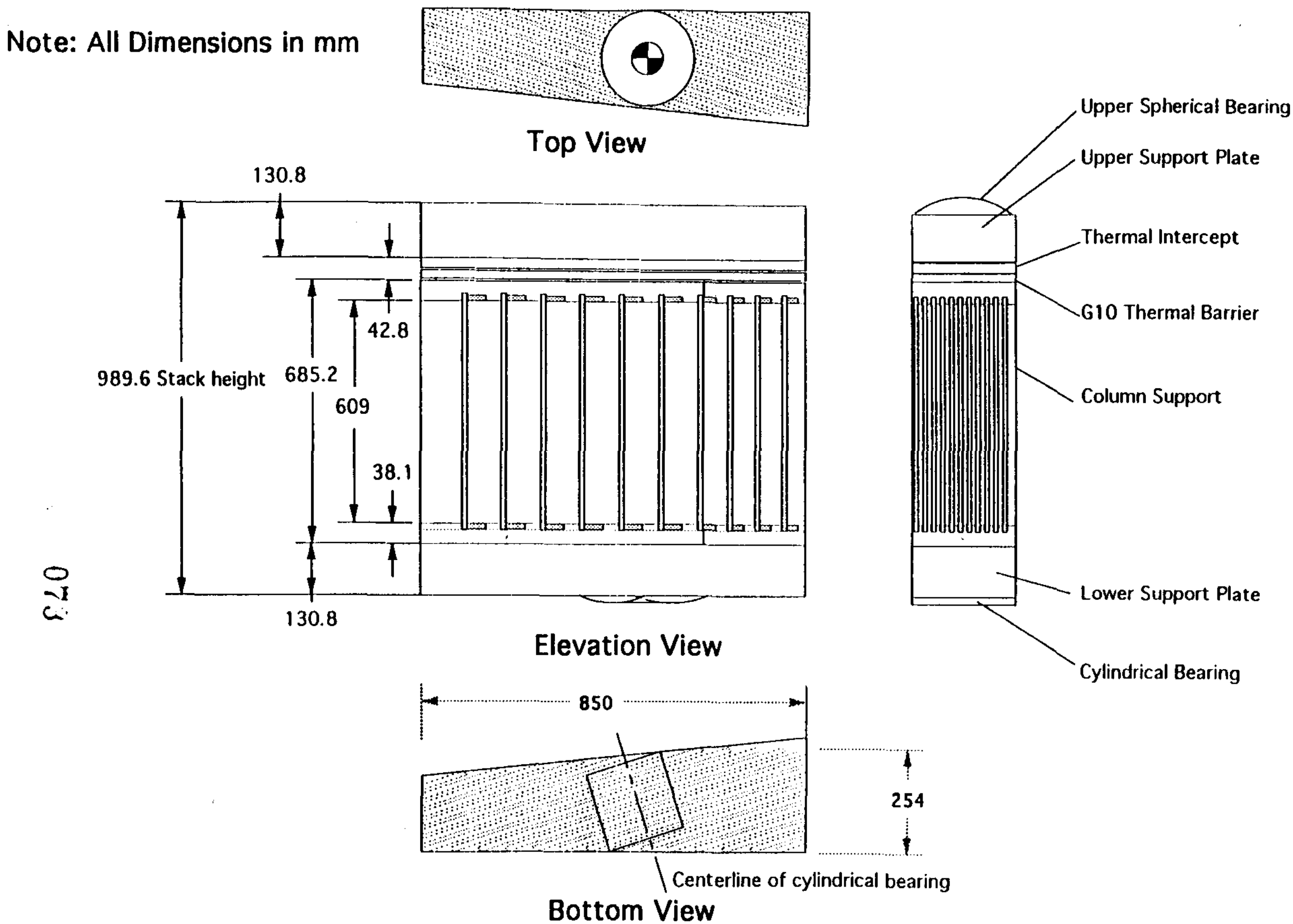


Figure 3-3b Barrel Stanchion Assembly

LLMason 920717 Column Support

$H^0 \rightarrow 2\gamma$ Physics Task Force

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3.2 Calorimetry

The committee is concerned about the GEM approach to calorimetry, as described in the various documents submitted for the July review (GEM Baseline 1 and responses to the December 1991 PAC Report):

1) The overriding concern is the ability of GEM electromagnetic calorimetry to identify photons. The GEM group aims at excellent electromagnetic energy resolution; however, the ability to reject jet backgrounds was given insufficient emphasis in the design. An impressive and very thorough study of GEM performance, focused on $H \to \gamma\gamma$, has been described in GEM-TN-92-126, for both electromagnetic calorimeter options. The results are summarized in Tables 13 and 14 of that document. Some comments follow:

   a) Jet backgrounds
   From Table 13, we can extract the excess jet background (from γ-jet and jet-jet), above the "irreducible" background, that remains after shower isolation and shape cuts; as compared to the "irreducible" backgrounds (from $\gamma\gamma$ + irreducible γ-jet and jet-jet). The expected rates correspond to 20pb for excess jet backgrounds versus 52pb for irreducible backgrounds with BaF_2, and 77pb for excess jet backgrounds versus 58pb for irreducible backgrounds with LAr. For a Higgs mass of 90 GeV, this corresponds to 4σ and 2σ significances for BaF_2 and LAr respectively, in one SSC year. The large uncertainties (of order of a factor of 5 or more) in the jet backgrounds indicate that even these levels of significance may not be achieved.

   b) Measurement of photon direction
   The BaF_2 calorimeter has no longitudinal segmentation and therefore does not provide a measurement of the photon direction. The selection of the highest multiplicity vertex as the primary Higgs vertex has not been demonstrated to be a solution to this problem.

From these considerations, we are concerned that the GEM baseline design may not be adequate for $H \to \gamma\gamma$, and for γ-identification in general.

Points for comparison

- E - resolution constant term (contributions) } H.G. HN
- E - resolution stochastic term
- Pointing K.S., Y.E, S.S
- Jet background suppression Task force
- Pile up noise T.S., P.D.
- Thermal noise (coherent noise) BaF ? LAr !
- Radiation damage H.G., BaF2
- Shower shape analysis < RY # TN 91-53 / H.M.
- Calibration a) physics Caltech + ORNL
  b) electronics
- Cost US / Practical cost M.R.
- Risk M.R.
- Mechanical design (FEA etc.) M.R.
- Schedule and manufact. plan M.R.
- Who will build?
- Quality control and responsibility
- Sign vs. Lum T.F, J.R.
- Digitization, electron D.M. & P.D - technology independent