GEM TN-91-18

GEM Calorimetry Meeting
SSCL

October 1, 1991

Abstract:
Transparencies from the Calorimetry Meeting held at the SSC Lab on October 1, 1991.

GEM Calorimetry Meeting AGENDA

October 1, 1991

SSCL Auditorium

8am-9:30 am - technology subgroups meetings

9:30 am General calorimetry meeting begins

Introduction - J. Brau (20 minutes)

Engineering, costs, schedule, etc. - M. Rennich (30 minutes)

Hadron calorimetry for BaF2 - H. Newman (15 minutes)
- Liquid Scintillator? (30 minutes)
- Fiber? (30 minutes)
- Liquid Argon? (30 minutes)
- Discussion

Comparison of homogeneous with sampling cal - M. Chen (15 min)

12:30 pm Lunch

2:00 pm Begin afternoon session

Pre-radiator
- Monte Carlo studies of performance - J. Brau (30 minutes
- Pi zero identification - P. Mockett (20 min)
- Update on simulation studies - M. Clemen? + P. Cushmar

Forward Calorimetry
- Monte Carlo studies of performance - M. Shupe (30 minutes
- Tube Calorimeter Design - D.Makowiecki (20 mir)

Simulation Tools - N. DiGiacomo (20 minutes)

R&D Budget Request Discussion (60 minutes)

Plans for LoI Preparation

J. Brau

September 13, [illegible]

TO: Barry Barish and Bill Willis
FROM: Bob Adair and Jim Brau
SUBJECT: Calorimeter Group Consensus

The GEM Calorimeter Group met at the BNL Laboratory September 4th and 5th to review the GEM calorimeter options. During this meeting the group developed a clear consensus on its recommendation to the GEM Collaboration for next year's R&D plan. This consensus is summarized in the following statement:

> The GEM Calorimeter Group wishes to continue R&D on two calorimeter systems during the next year. These two systems include one with a very high resolution electromagnetic section, which the group finds highly desirable, if feasible, and one which offers a conservative approach, but also with a high resolution electromagnetic section.
>
> With this end in mind we wish to continue R&D on
>
> - BaF2 EM
> - Scintillator Hadron Calorimetry
>
> - Liquid Argon
> - Xe/Kr Sandwich for the barrel and LXe for the endcap
>
> The choice of scintillator technology (liquid or spaghetti) is being reviewed and will be chosen soon, no later than the LoI.
>
> We also wish to pursue R&D on forward calorimeters and have a coordinated research plan with [illegible] and liquid [illegible] scintillator options.
>
> Finally we are reviewing the physics arguments and performance potentials for a preshower. We will attempt to develop a consensus on a direction for this subsystem as soon as possible.

This consensus developed following a thorough review of each technology in which the proponents of each were asked to answer in writing and orally the questions and concerns expressed by others in the group. These reports are [illegible] in the GEM Technical Report, GEM TN-91-00009.

MINORITY REPORT

(submitted by Hans Paar with 13 signatures)

technology choices should be:

1. A sampling
BaF_2
Scin Fiber

EM calorimetry for all 3.

"resources required for proper R+D are negligible relative to the total cost of a subsystem"

The undersigned are convinced that the most promising technology [illegible] calorimetry R & D for GEM are Liquid Argon sampling (LAr), Barium Fluoride (BaF), and Scintillating Fiber (SF).

We believe this conclusion to be self-evident when one considers the status of the R & D of these three technologies, their promise as well as their disadvantages, and the resources, persistence and demonstrated dedication of their proponents. The combination of these three choices appears optimal for the fullfillment of the GEM physics goals since they have complementary advantages and risks in both electromagnetic and hadronic calorimetry. We consider it especially important to pursue electromagnetic calorimetry with all three technologies. Electromagnetic calorimetry is extraordinarily demanding relative to hadronic calorimetry. At this moment we have no technical reason to prefer one over the other. For example LAr and SF have demonstrated the same electromagnetic resolution in beamtests with parallel geometries; both must be reconfigured for projective geometry. Also precision calibration of BaF and SF appears equally difficult.

We advocate this prudent approach rather than trying to find one that fits in the framework of the charge to the calorimeter group. In our opinion the calorimeter group is right in not making a choice between BaF and sampling calorimetry for precision electromagnetic calorimetry. The only way the calorimeter group could reject one of them is if it could be demonstrated now that one is seriously flawed. Clearly this is not the case at this time: neither BaF nor the sampling calorimeter techniques have tested projective electromagnetic modules.

When forced to provide a decision on this issue at this time, one must weight the physics impact of each technology, such as the possible negative impact of BaF (e/h) upon jet energy measurements (supersymmetry, quark substructure, and unforeseen phenomena) and of sampling calorimetry upon the discovery of a light Higgs or unanticipated phenomena. Such judgements should be made by the collaboration as a whole and not by the calorimeter subgroup.

The consensus recommendation speaks of two calorimeter systems: one with a very high resolution electromagnetic section and one which offers a "conservative" approach. We take issue with the qualification "conservative" that has been attached to the LAr technique. This technique relies upon a projective accordion with a depth-dependent sampling fraction which has not been tested in a beam. In addition, two days after the calorimeter group attached the "conservative" qualification to the LAr technique, the suggestion was made by its proponents to investigate uranium instead of lead absorber plates for the hadron calorimeter section. We also note that only one very brief instrumentation paper exists about the fast LAr technique (a section in BNL Report 52244, 14 (1990) on HELIOS LAr with Uranium absorber plates (sic) that is not signed by the HELIOS collaboration). We are frustrated by the fact that so little technical information about the LAr technique is documented, a state of affairs unbecoming of a "conservative" technique.

The gravity of the decisions in any of the GEM detector subsystems is extraordinary: design, construction, and commissioning of subsystems such as the calorimeters will take of the order of ten years and their productive life must extend over a period of perhaps fifteen years after that. There are no second chances except during the period of R & D and only if that takes place prior to commencement of full scale construction. The resources required for proper R & D are negligible relative to the total cost of a subsystem. Early decisions taken without the benefit of prototype construction and beamtests of candidate techniques have in the past lead to much larger costs of subsystem construction and even to significant waste of money and resources.

Boston University:	Ed Booth, Robert Carey, Steve Dye, Jim Miller, B. Lee Roberts, Larry Sulak, Bill Worstell
U. of Calif. San Diego:	Hans Paar, Mike Sivertz
Michigan State:	Carl Bromberg
University of Iowa:	Nural Akchurin, Yasar Onel
Texas A&M:	Bob Webb

DISSENTING OPINION

If the GEM Collaboration would decide to go for either one of the two options mentioned in the "letter of consensus", it would have to face the problems arising from an extremely noncompensating e.m. section (estimated e/h ratio 1.6 in the case of the LAr accordion, 2.0 for BaF2).
A typical jet will deposit more than half of its energy in this section, with large and non-Gaussian event-to-event fluctuations. It is an illusion to think that the energy of jets can be measured with a precision better than 10% at any energy with such a device and the calorimetric missing E_T measurement would have a constant term that is even larger.
Therefore, I suggest to drop the hadron calorimeter all the way and replace it by a dense passive absorber. The hadronic energy measurement, to be performed exclusively with the e.m. calorimeter in this scenario, will not be much worse than in the case of a state-of-the art compensating hadron section backing up one of the two mentioned devices. On the other hand, a substantial amount of money can be saved in this way.

Richard Wigmans

DECISION CRITERIA

Sep 20-21 Caltech

tentative acceptance of Cal group recommended "2 prong approach"

1) L.A. - endorsed
   recomm. developing Accordion EM
   - optimize resol. w/ 1mm accord.
   + Liq. Kr. → 7% / $\sqrt{E}$

2) BaF_2 + scin. -
   endorse desirability of obtaining best possible resolution
   3 reservations
   1) risk of rad hard crystal in time frame unclear
   2) cost of LA + BaF_2 + scin R+D/engineering
   3) possible performance advantage over L.A. may be marginal

⇒ independent panel of experts to review rad hard crystals and propose [illegible]

⇒ some hope for sufficient R&D funds (SSCL + TNLBC)

Forward Calorimetry

Pre-radiators

"question looks confused"

- Please clarify!

Decision Group met again

Sep 27 @ SSCL

and re-affirmed this.

September 13, 1991

TO: Barry Barish and Bill Willis
FROM: Bob Adair and Jim Brau
SUBJECT: Calorimeter Group Consensus

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> * Liquid Argon
> * Xe/Kr Sandi for the barrel and LXe for the endcap
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> We also wish to pursue R&D on forward calorimetry and have a coordinated research plan with liquid argon and liquid scintillator options.
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> Finally we are reviewing the physics arguments and performance potentials for a preradiator. We will attempt to develop a consensus on a direction for this subsystem as soon as possible.

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Table 1: FY92 R&D Plan for Calorimeters

	Calorimeter	Engineering	Tests: beam and others	Cost, k$	
C	BaF_2	9×9 crystals; photodevice; electronics; carbon fiber	e and π resol'n, e/π sep., rad. damage; UV monitor	1172	
C	LXe/Kr/Ar Scint. & Ioniz.	precision beams; mirrors; drift diode and wire; FADC or Linear Gate,	e resol'n using in situ α calibrations; rad. hard, B-field, off-axis photon vertex; γ/π^o & e/π sep.; e/π ratio	895	515 from SSCL
?	Scin. Fiber	second generation towers	9 first generation tower (constant term, uniformity pile up, and B-field)	923	
?	Liquid Scint.	Complete prototype plane. Design and build full-size prototype module	One-plane beam tests, study uniformity, reproducibility, rad. damage, source calib.	1105	
OUT	Silicon	electronics; Si procurement; protoype	rad. damage	~~1675~~	
P	Silicon Preradiator	electronics; mechanical; cooling	rad. damage; e/π sep.; γ/π^o sep. EM cal energy correction	470	
C	LAr	EM: 1 mm Pb accordion prototype; HAD: studies of EST and parallel plates; studies of feedthroughs, purity, simulations; studies of combining scintillation light with sampling (Sandi)	beam tests, resolution; uniformity; radiation; reproducibility	~~1105~~ (~~$\times$1.48~~ if operating)	1677 +500 eng.
	~~Fast Chamber~~	~~mechanical; electronics; [illegible] 2 layer prototype~~	~~component rad. tests~~	~~750 ($\times$1.48 if operating)~~	
	Si-drift detectors	read-out electronics	rad. damage	290	
P F P	Forward	LA + LS	120	[redacted]	50 from SSCL +100 eng.
	Scin. Fib Pre-rad				

C = CONSENSUS F = FORWARD

? = CANDIDATE P = PRERADIATOR

****

Parameters of the Proposed Calorimeter Systems

for Simulation Study

****

According to consensus of the
calorimeter group meeting on September 4th and 6th at the SSCL, only
parameters of two options are presented:

1) BaF_2 combined with a scintillation hadron calorimeter
   (L.S. or Spaghetti); and

2) Liquid Argon with Xe/Kr option.

The configuration in the table represents what was costed.
The geometrical coverage is assumed as |eta| < 1.45 (26 degree)
for the barrel calorimeter, and 1.45 < |eta| < 2.5 or 3 for the endcaps.
The forward calorimeter is assumed to cover 3 < |eta| < 5. Since there
is no detailed design of forward calorimeter available, one may assume
a similar performance as the Liquid Argon hadron calorimeter.

The position resolution (delta X) of EMCs is defined for a 20 GeV
electron/gamma.

The energy resolution is defined as

(a/\sqrt{E} \oplus b)%

where \oplus represents add in quaduture.

The resolution of hadron calorimeter is defined for jet energy.
Thermal noise/cell (sigma_T/cell) is estimated according to proposed
readout schemes. For BaF_2, for example, the triode with gain of 4 was
assumed. If a multistage mesh structure PMT is used, the thermal noise
of BaF_2 may be futher reduced. The thermal noise in r=0.6 cone,
sima_T (r=0.6), is the sum of all channels in r=0.6 cone, assuming no
correlation. The pile-up noise (sigma_P) is estimated for
10^{33}/sec/cm^2 luminosity, assuming the readout schemes proposed.

1. Electromagnetic Calorimeter Parameters:

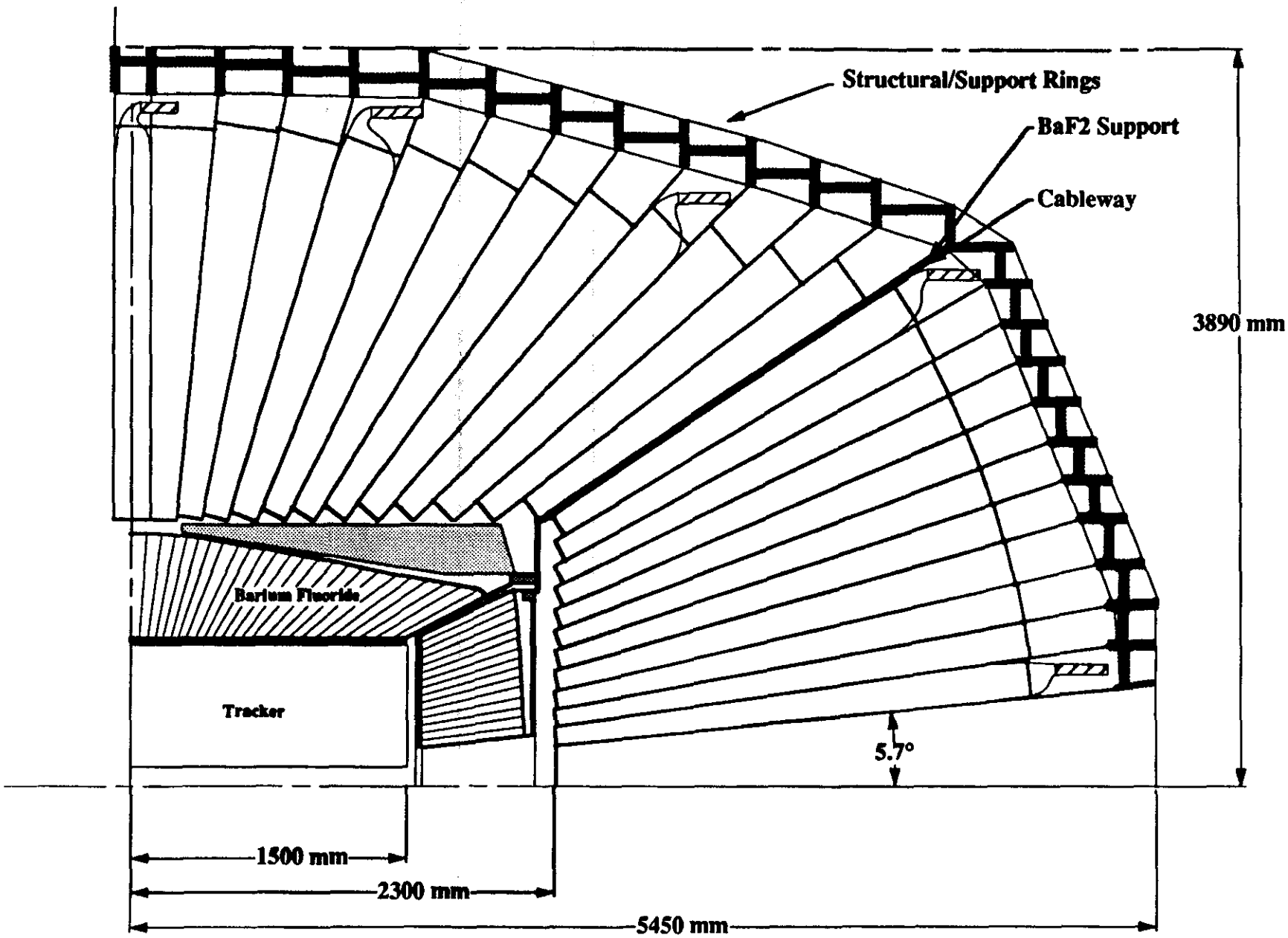
Option	BaF_2	L. Ar	Kr Barrel/Xe Endcap
eta_max	2.5	3.0	1.45 / 3.0
segmentation	0.04 x 0.04	0.04 x 0.04	0.04 x 0.04
Longitudinal Sample	1	3	2 / 3
peaking time (ns)	< 16	40	40 / < 16
delta X (mm)	1	1	1 / 1
a	2	7.5	7.5 / 2
b	0.5	0.5	0.5 / 0.5
sigma_T/cell (MeV)	10	15	15 / 10
sigma_T (r=0.6, GeV)	0.3	0.5	0.5 / 0.3
sigma_P (r=0.6, GeV)	0.85	1.2	1.2 / 0.85
pi_0/gamma rejection	No	No	Yes

2. Hadron Calorimeter Parameters:

Option	L. Ar	L.S.	Spaghetti
eta_max	3	3	3
segmentation	0.08 x 0.08	0.08 x 0.08	0.08 x 0.08
Longitudinal Sample	4	6	1
peaking time (ns)	100	< 16	< 16
a b	63 1.6	50 2	50 2
sigma_T (r=0.6, GeV) sigma_P (r=0.6, GeV)	3.0(***) 3.0	< 1 1	< 1 1

Note:
(***) One may use only 6 i.l. to obtain
veto energy measurement.

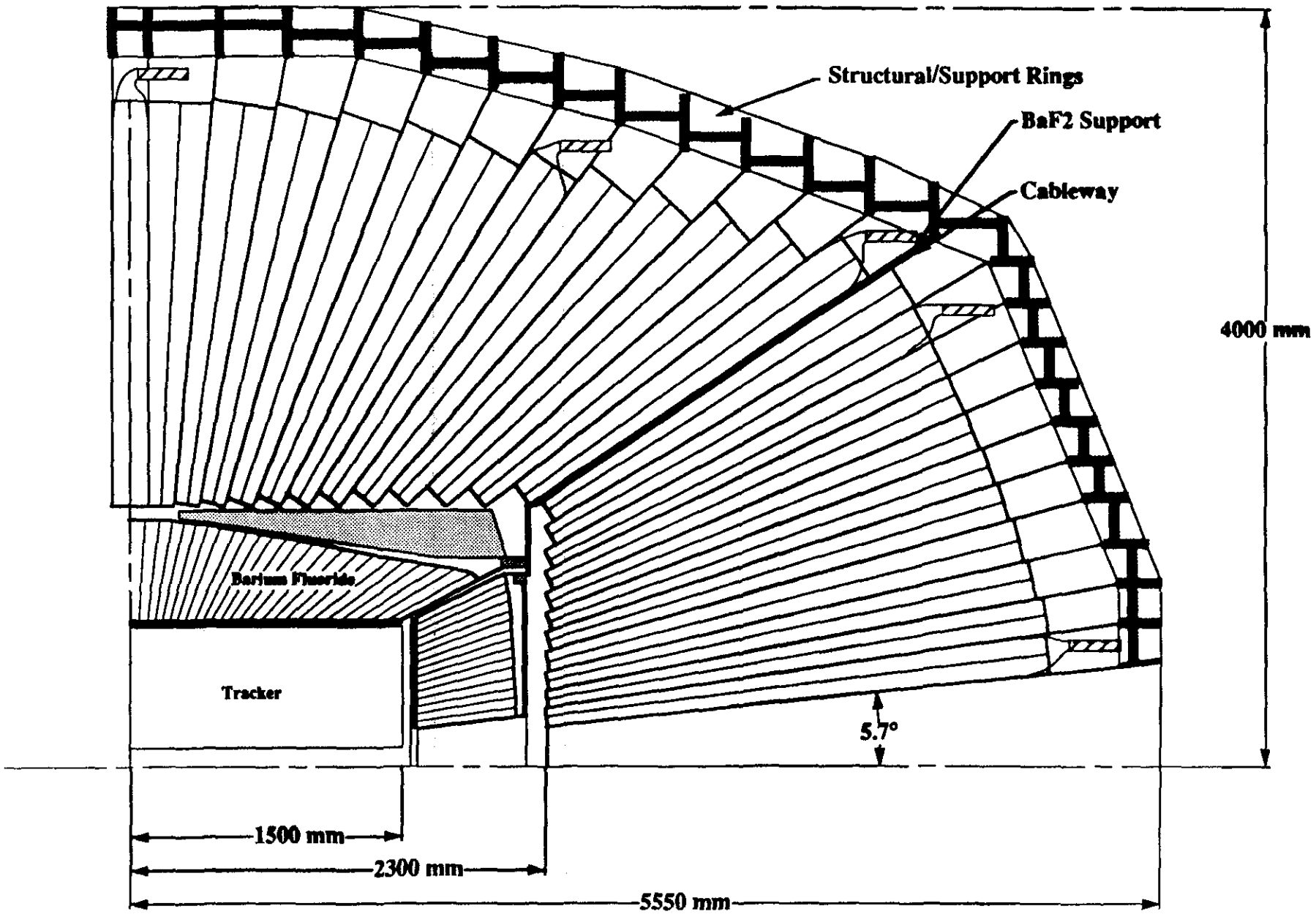
M. Rennich



Spaghetti Hadron Calorimeter
Lead Shot Filled/ 0.10 Segmentation
Barium Fluoride EM Calorimeter

G.03.SC.00038

Rennich



Spaghetti Hadron Calorimeter
Eutectic Fill/0.10 or 0.05 Segmentation
Barium Fluoride EM Calorimeter

LS.03.SC.00039

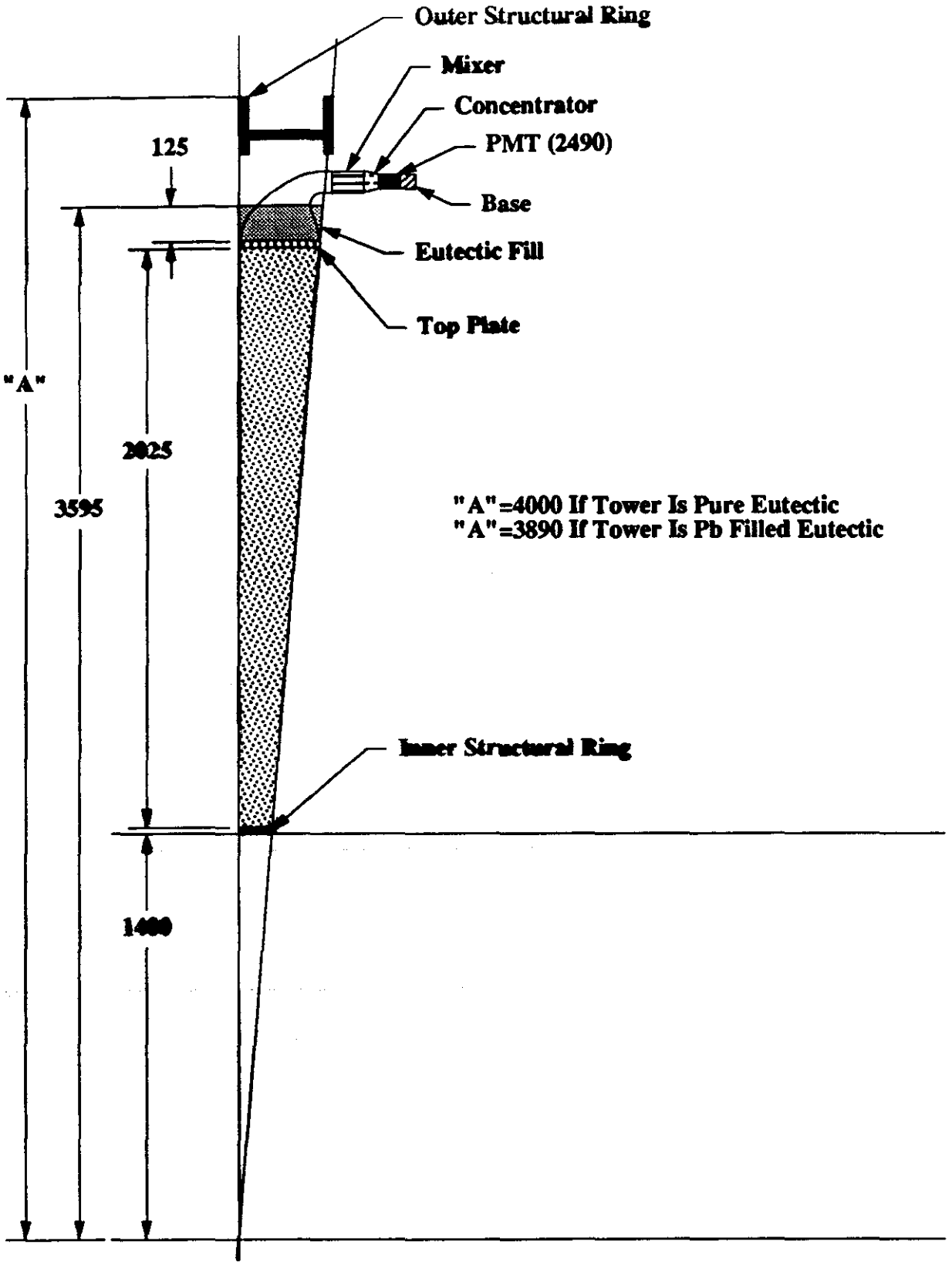
Rennich

GEM Parameters

Spaghetti Hadron Calorimeter: 0.08 Segmentation

Absorber Volume	274.72	M^3
Channels	5168	Each
Total Weight	2364.03	Metric Tons
Eutectic Lead	2000.4	Metric Tons
Structural Components	86.7	Metric Tons
Sheaths	244.96	Metric Tons
Fiber	31.97	Metric Tons
Percent Struct and Gaps in Absorber	6.50%	
Total Absorption Lenght	10.00	Lambda
Active Absorption Lenght	8.53	Lambda
Passive Absorption Lenght	1.47	Lambda
Mechanical Towers	5168	Each
Ring Assemblies	58	Each
Lenght of WLS Fiber	6,477,000	Meters
Number of WLS Fibers (3 mm)	3,700,000	Each
Number of Transm. Fibers (1 mm)	3,700,000	Each
Heat Generated by Electronics	<5000	Watts
Inner Radius	1400	mm
Outer Radius	4000	mm
Length	11100	mm

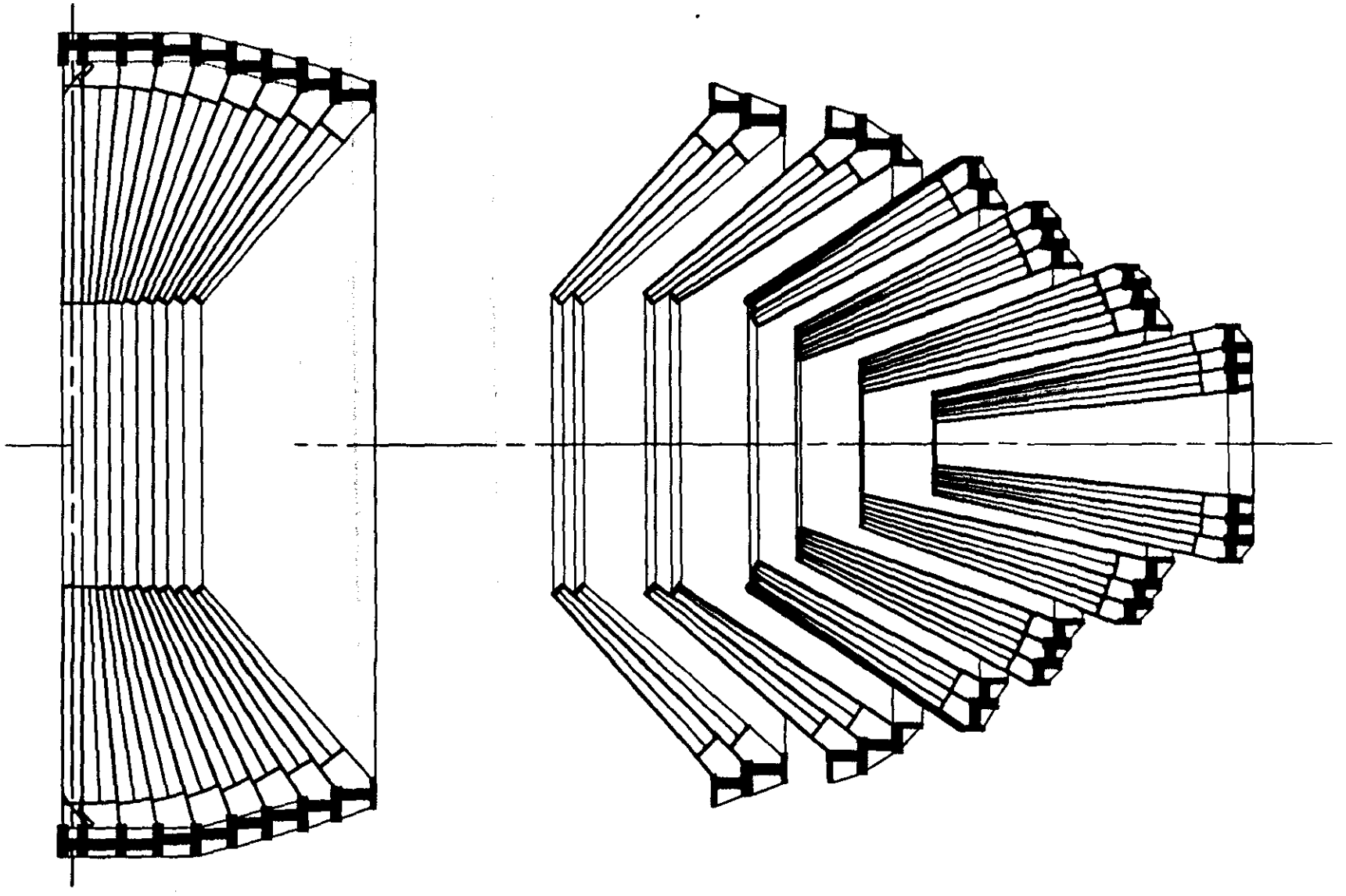
MARK RENNICH/ 9/19/91 : OAK RIDGE NATIONAL LABORATORY



Spaghetti Tower Height

Rennich

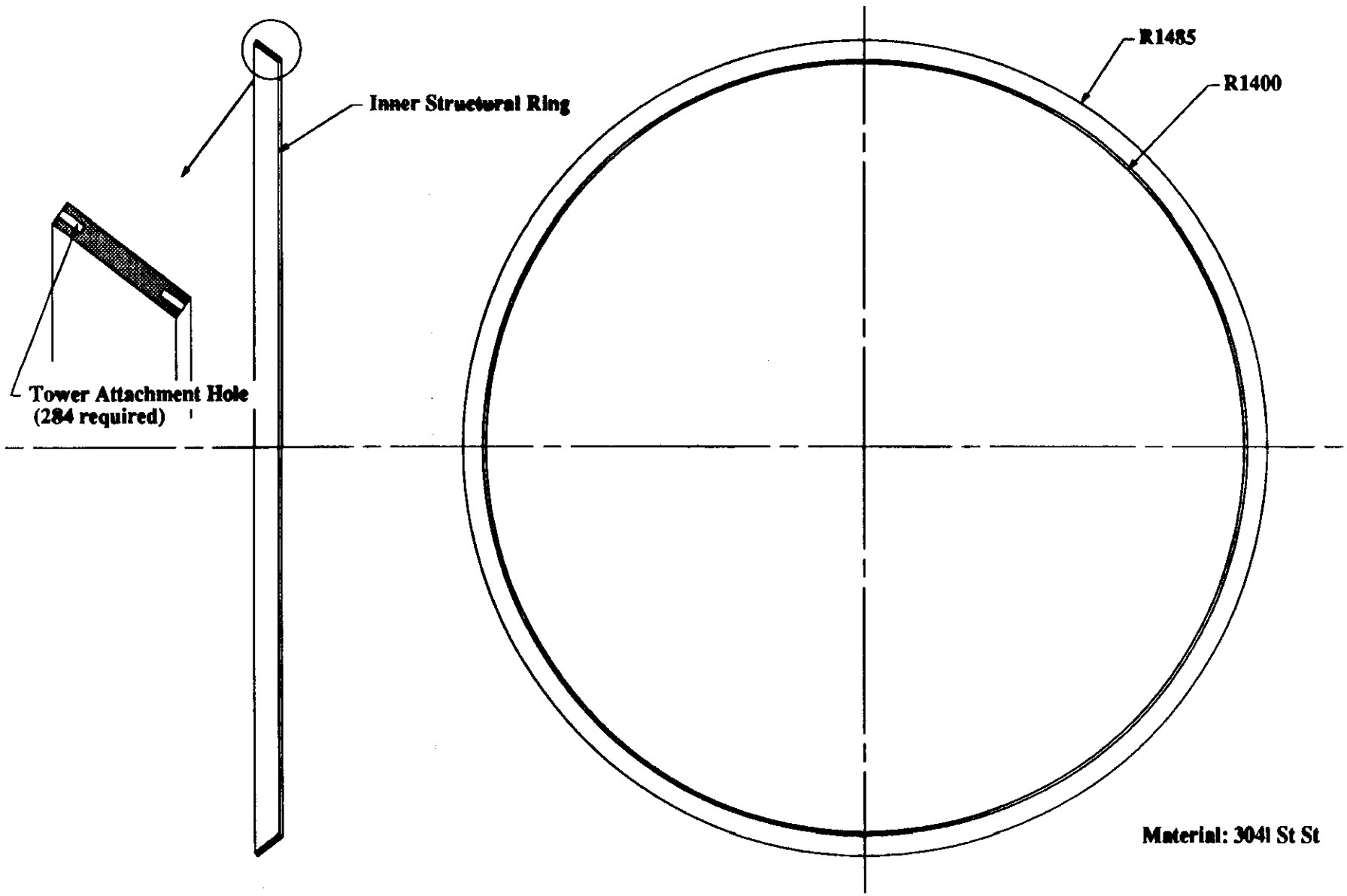
G.03.SC.00063



Spaghetti Hadron Calorimeter
Installation Modules
Maximum Weight 100 MT

G.03.SC.00057

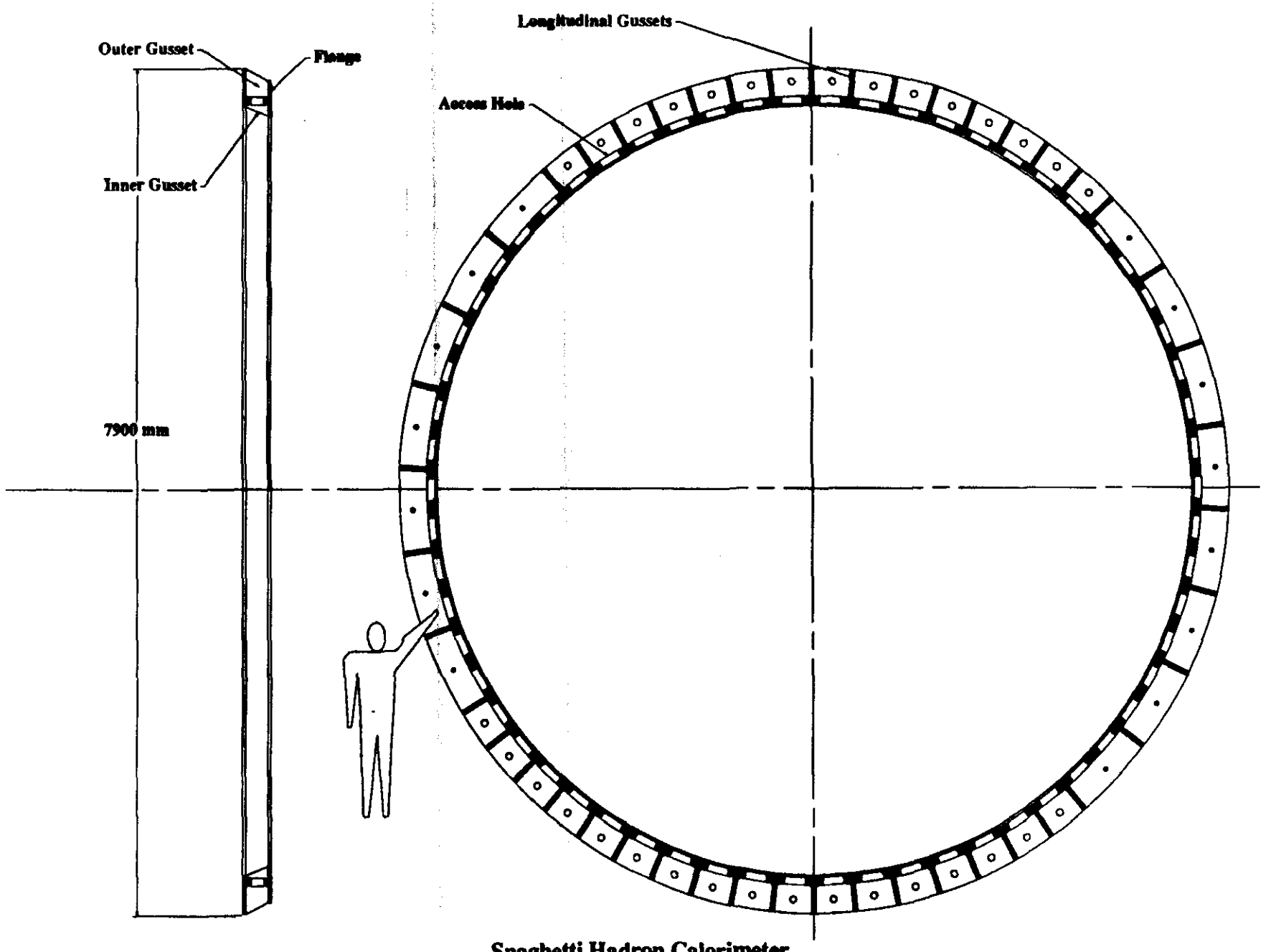
Rennich



Spaghetti Hadron Calorimeter
Typical Inner Structural Ring

G.03.SC.00050

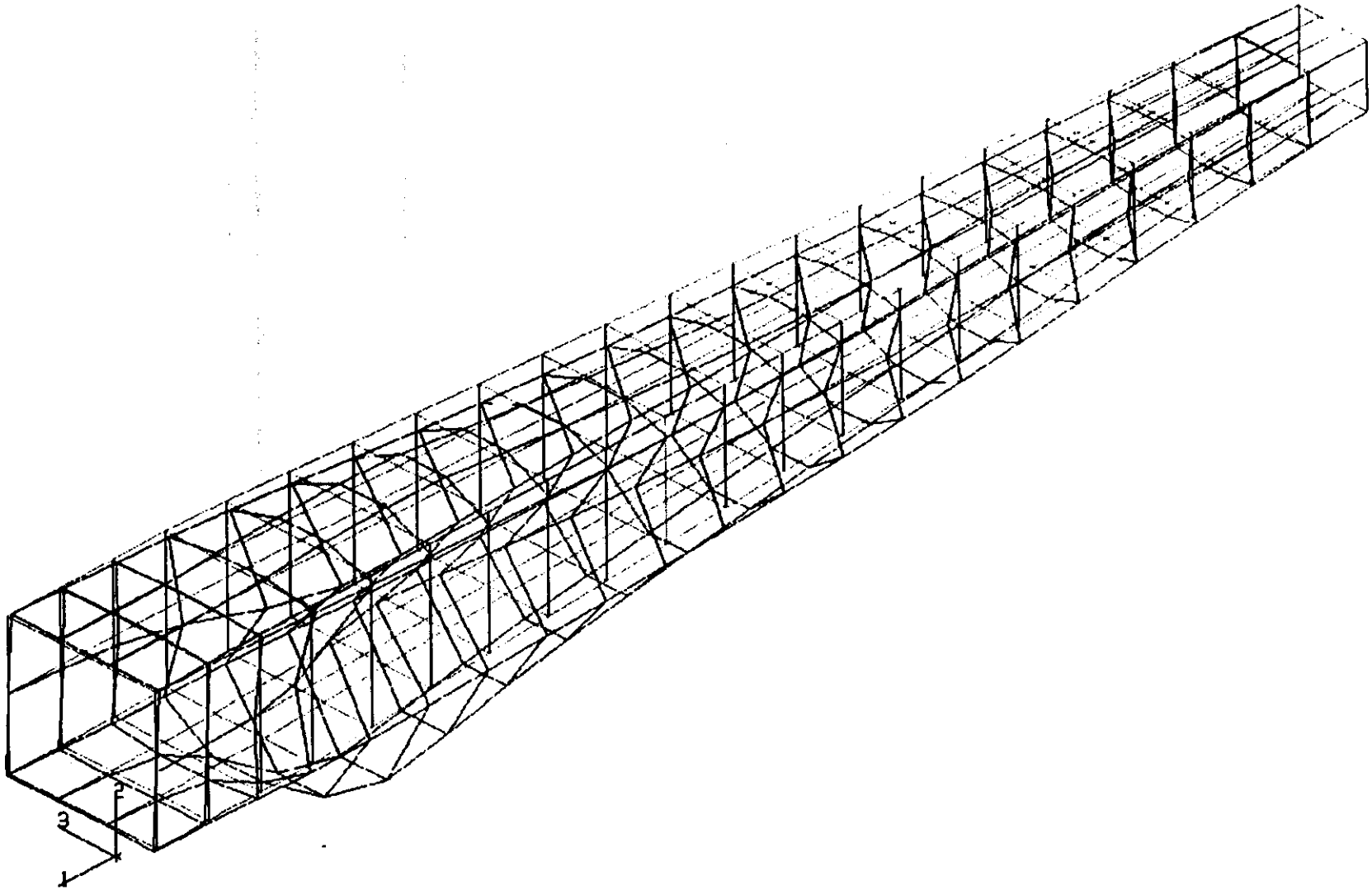
Rennich



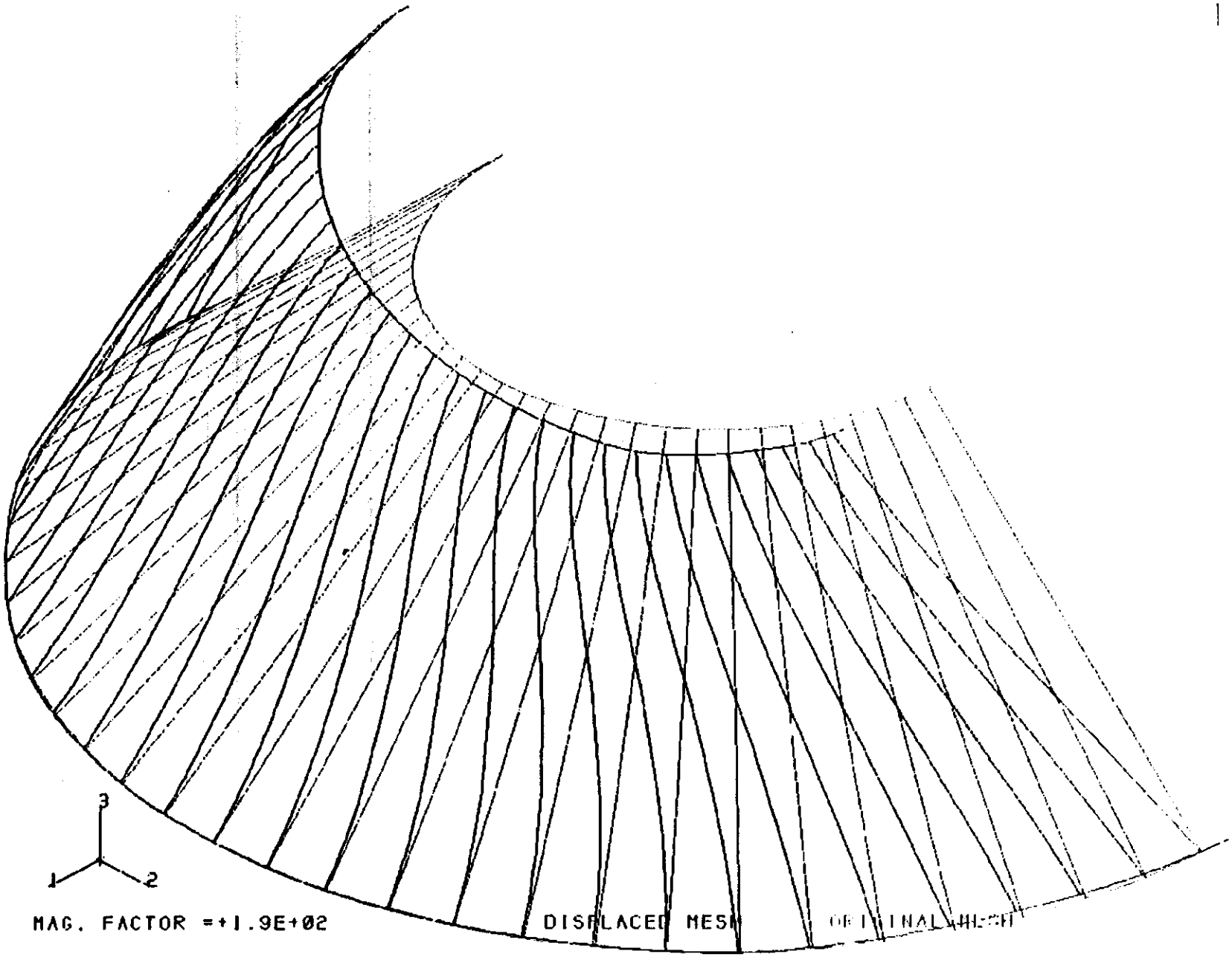
Spaghetti Hadron Calorimeter
Typical Tower Outer Structural Ring

G.03.SC.00051

Rennich

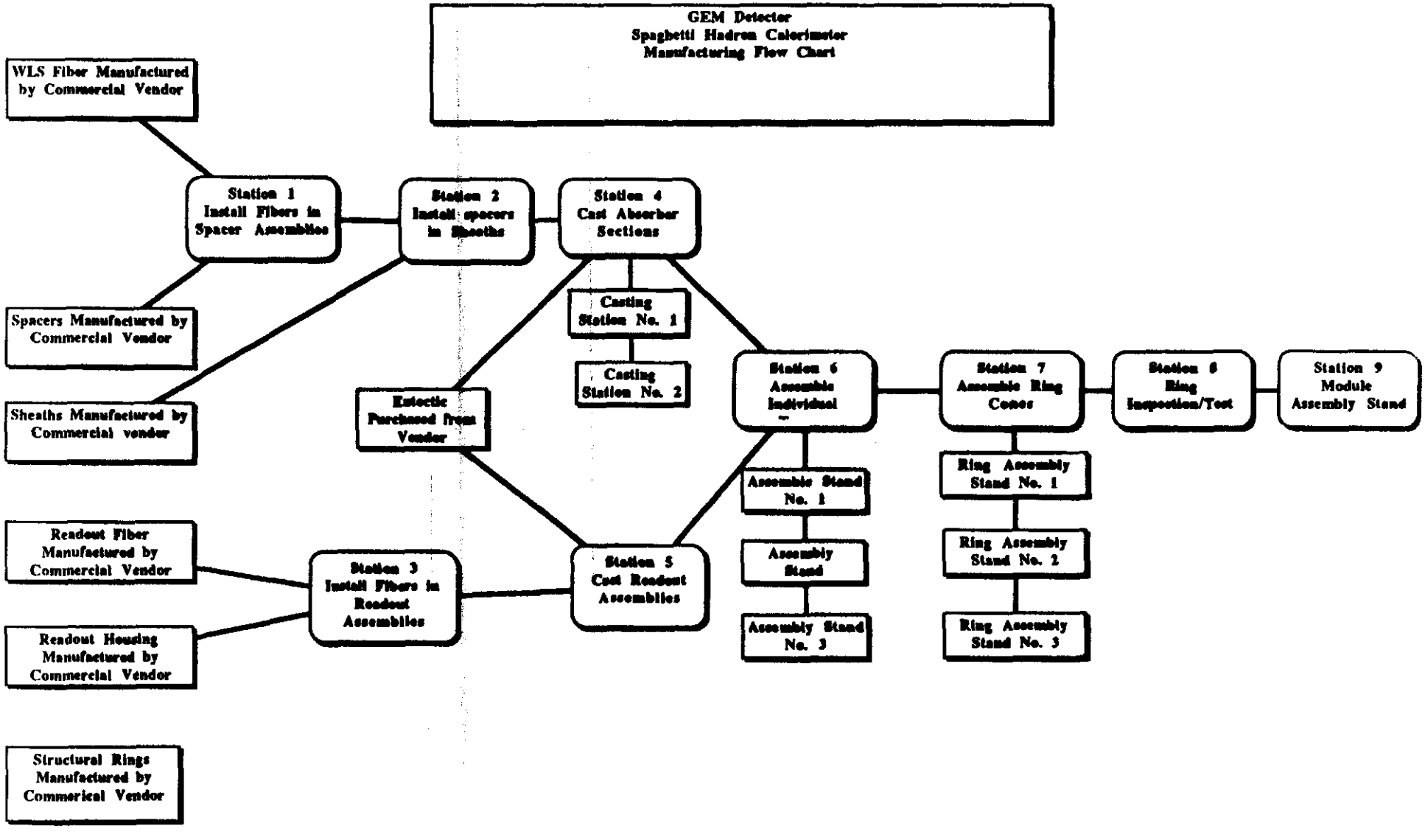


MAG. FACTOR =19.0E+01 DISPLACED MESH ORIGINAL MESH


3
1
2
MAG. FACTOR =+1.9E+02
DISPLACED MESH
ORIGINAL MESH

Summary of Structural Analysis of Spaghetti Hadron Calorimeter

	Support Scheme	Loading	Maximum Stress (psi)		Max. Defl. inch (mm)
Segment.	Individual Tower Analysis				
0.08	Simple Beam (2 mm Wall Thk)	Dead Weight	15500		0.0895 (2.3)
	Simple Beam (2/1.5 mm W. Thk.)	Dead Weight			
	Bottom of Ring Module	Dead Weight	1600		0
		Compression			
	Top Plate (2.5 cm thick)	Distributed	1693		.0041 (.105)
0.16	Simple Beam (5mm Wall Thk.)	Dead Weight	15500		0.0895 (2.3)
	45 Deg Ring Mod. Anal		Outer Ring	Inner Ring	
0.08	Moment of Inertia (Ixx/Iyy)		90/90	10.9/0.244	
	Area (in^2)		-	4.33	
	Eight Point-Fixed-Outer Ring	Dead Weight	8000	15000	0.122 (3.1)
	Saddle (180 Deg) Outer Support	Dead Weight	12000	24000	0.182 (4.6)
	Single Point-Bottom-Outer Ring	Dead Weight	90000	100000	0.85 (22)
	Eight Point -Fixed-Outer Ring	Dead Weight	8200	22600	0.165 (4.2)
		10 Mt int'l			
0.16	Moment of Inertia (Ixx/Iyy)		90/90	10.9/0.244	
	Area (in^2)		-	4.33	
	Eight Point-Fixed-Outer Ring	Dead Weight	9000	18000	0.102 (2.6)
	Central Ring Analysis				
	Beam Loading	1040 Mtons	2930		
	Fasteners	1040 Mtons			


GEM Detector
Spaghetti Hadron Calorimeter
Manufacturing Flow Chart
WLS Fiber Manufactured by Commercial Vendor
Station 1 Install Fibers in Spacer Assemblies
Station 2 Install spacers in Sheaths
Station 4 Cast Absorber Sections
Spacers Manufactured by Commercial Vendor
Sheaths Manufactured by Commercial vendor
Casting Station No. 1
Casting Station No. 2
Eutectic Purchased from Vendor
Station 6 Assemble Individual
Station 7 Assemble Ring Cones
Station 8 Ring Inspection/Test
Station 9 Module Assembly Stand
Assemble Stand No. 1
Assembly Stand
Assembly Stand No. 3
Ring Assembly Stand No. 1
Ring Assembly Stand No. 2
Ring Assembly Stand No. 3
Readout Fiber Manufactured by Commercial Vendor
Station 3 Install Fibers in Readout Assemblies
Station 5 Cast Readout Assemblies
Readout Housing Manufactured by Commercial Vendor
Structural Rings Manufactured by Commerical Vendor

Rennich

Spaghetti Hadron Calorimeter

Segmentation: 0.08

	STATION ONE
1.00	Assembly Spacer Arrays

Task Number	Task Descript.	Hours	Personnel	Unit Tot PHRS	Quantity	Tot. PHRS	Rate ($/PHR)	M&S (K$)
1.10	Retrieve Spacer plates	0.5	1	0.5	4936	2468	31	$76.51
1.20	Retrieve Top Plate	0.25	1	0.25	4936	1234	31	$38.25
1.30	Clean spacer plates	0.25	1	0.25	4936	1234	31	$38.25
1.40	Assemble Spacer plate stack	0.25	1	0.25	4936	1234	31	$38.25
1.50	Inspect Stack	0.25	1	0.25	4936	1234	31	$38.25
1.60	Install Rack in Fiber Install. Station	0.25	2	0.5	4936	2468	31	$76.51
1.70	Gather Fibers	0.5	1	0.5	4936	2468	31	$76.51
1.80	Cut and Inspect Fibers	1	1	1	4936	4936	31	$153.02
1.90	Install Fibers in Rack	3	2	6	4936	29616	31	$918.19
1.10	Expand spacer array	0.5	2	1	4936	4936	31	$153.02
1.11	Install spacer bars	0.5	2	1	4936	4936	31	$153.02
1.12	Inspect completed assembly	0.25	1	0.25	4936	1234	31	$38.25
1.13	Move assembly to Storage/STA 2	0.5	1	0.5	4936	2468	31	$76.51
	Totals for Station One	9		12.25		60466		$1,874.55

	STATION TWO
2.00	Assemble Sheaths

Task Number	Task Descript.	Hours	Personnel	Unit Tot PHRS	Quantity	Tot. PHRS	Rate ($/PHR)	M&S (K$)
2.01	Retrieve Sheath	0.5	2	1	4936	4936	31	$153.02
2.02	Inspect Sheath	0.25	2	0.5	4936	2468	31	$76.51
2.03	Clean Sheath	0.5	2	1	4936	4936	31	$153.02
2.04	Gather Spacer assembly	0.5	1	0.5	4936	2468	31	$76.51
2.05	Inspect Spacer Assembly	0.5	1	0.5	4936	2468	31	$76.51
2.06	Install Spacer Assembly in Sheath	0.5	2	1	4936	4936	31	$153.02
2.07	Inspect subassembly	0.5	1	0.5	4936	2468	31	$76.51
2.08	Mover subassembly to Storage/Sta 4	0.5	2	1	4936	4936	31	$153.02
	Totals for Station Two	3.75		6		29616		$918.19

STATION THREE

3.00 Assemble Readout Sections

Task Number	Task Descript.	Hours	Personnel	Unit Tot PHRS	Quantity	Tot. PHRS	Rate ($/PHR)	M&S (K$)
3.01	Gather Readout Frame	0.25	1	0.25	4936	1234	31	$38.25
3.02	Inspect Frame	0.25	1	0.25	4936	1234	31	$38.25
3.03	Clean Frame	0.1	1	0.1	4936	493.6	31	$15.30
3.04	Gather Readout Fibers	0.25	1	0.25	4936	1234	31	$38.25
3.05	Cut and Inspect Fibers	1	1	1	4936	4936	31	$153.02
3.06	Install Fibers in Frame	4	1	4	4936	19744	31	$612.06
3.07	Secure Fibers	1	1	1	4936	4936	31	$153.02
3.08	Finish Fiber termination end	3	1	3	4936	14808	31	$459.05
3.09	Inspect completed assembly	0.25	1	0.25	4936	1234	31	$38.25
3.10	Store Completed assembly	0.25	1	0.25	4936	1234	31	$38.25
	Totals for Station Three	10.35		10.35		$51097.6		$1,583.72

STATION FOUR

4.00 Cast Tower assemblies

Task Number	Task Descript.	Hours	Personnel	Unit Tot PHRS	Quantity	Tot. PHRS	Rate ($/PHR)	M&S (K$)
4.10	Retrieve Sheath from Storage	0.5	1	0.5	4936	2468	31	$76.51
4.20	Inspect sheath	0.25	1	0.25	4936	1234	31	$38.25
4.30	Assemble Mold and Frame	1	2	2	4936	9872	31	$306.03
4.40	Install Sheath in Mold	0.25	2	0.5	4936	2468	31	$76.51
4.50	Install Mold in Casting station	0.5	2	1	4936	4936	31	$153.02
4.60	Heat Melting Bath	2	0.1	0.2	4936	987.2	31	$30.60
4.70	Install Metal in Crucible	0.5	1	0.5	4936	2468	31	$76.51
4.80	Perform PreCasting Inspections	0.25	1	0.25	4936	1234	31	$38.25
4.90	Cast Tower Assemblies	1	1	1	4936	4936	31	$153.02
4.10	Remove Mold From Casting Station	0.5	2	1	4936	4936	31	$153.02
4.11	Supervise Mold Cool-Down Cycle	16	0.05	0.8	4936	3948.8	31	$122.41
4.12	Open Mold	1	2	2	4936	9872	31	$306.03
4.13	Clean Tower Assembly	0.5	1	0.5	4936	2468	31	$76.51
4.14	Inspect Tower Assembly	0.5	1	0.5	4936	2468	31	$76.51
4.15	Move Tower assembly to Station 5	0.5	2	1	4936	4936	31	$153.02
	Totals for Station Four	26.25		12		59232		$1,836.19

STATION FIVE

5.00 Cast Readout Assemblies

Task Number	Task Descript.	Hours	Personnel	Unit Tot PHRS	Quantity	Tot. PHRS	Rate ($/PHR)	M&S (K$)
5.01	Retrieve Readout Frame	0.5	1	0.5	[redacted]	[redacted]	31	[redacted]
5.02	Inspect Readout frame	0.5	1	0.5	[redacted]	[redacted]	31	[redacted]
5.03	Install frame in mold	0.5	2	1	[redacted]	[redacted]	31	[redacted]
5.04	Install Mold in Casting station	0.5	2	1	[redacted]	[redacted]	31	[redacted]
5.05	Fill mold with lead shot	0.25	1	0.25	[redacted]	[redacted]	31	[redacted]
5.07	Heat Molding Bath	1	0.1	0.1	[redacted]	[redacted]	31	[redacted]
5.08	Install Metal in Crucible	0.25	2	0.5	[redacted]	[redacted]	31	[redacted]
5.08	Perform PreCasting Inspections	0.25	2	0.5	[redacted]	[redacted]	31	[redacted]
5.09	Cast Readout assembly	1	2	2	[redacted]	[redacted]	31	[redacted]
5.10	Remove Assemly from Casting Station	0.5	2	1	[redacted]	[redacted]	31	[redacted]
5.11	Supervise Mold Cool-Down Cycle	0	[redacted]	0.4	[redacted]	1974.4	31	[redacted]
5.12	Open Mold	0.25	1	0.25	[redacted]	1234	31	[redacted]
5.13	Clean and Inspect Assembly	0.5	1	0.5	[redacted]	[redacted]	31	[redacted]
5.14	Inspect Assembly	0.5	1	0.5	[redacted]	[redacted]	31	[redacted]
5.15	Stage Casting in Machine Area	0.5	1	0.5	[redacted]	[redacted]	31	[redacted]
	Totals for Station Five	15		9.5		[redacted]		[redacted]

STATION SIX

6.00 Assemble Tower Components

Task Number	Task Descript.	Hours	Personnel	Unit Tot PHRS	Quantity	Tot. PHRS	Rate ($/PHR)	M&S (K$)
6.01	Adjust Tower Assembly Stand	1	2	2	[redacted]	116	31	[redacted]
6.02	Inspect Tower Assembly Stand	0.5	2	1	[redacted]	[redacted]	31	[redacted]
6.03	Locate and Transport Hadron Section	0.5	1	0.5	[redacted]	[redacted]	31	[redacted]
6.04	Locate and Transport Readout Section	0.5	1	0.5	[redacted]	[redacted]	31	[redacted]
6.05	Test Fit components	0.5	2	1	[redacted]	[redacted]	31	[redacted]
6.06	Attach Components	0.5	2	1	[redacted]	[redacted]	31	[redacted]
6.07	Inspect Tower Subassembly	0.25	2	0.5	[redacted]	[redacted]	31	[redacted]
6.08	Label and Store Subassembly	0.5	2	1	[redacted]	[redacted]	31	[redacted]
	Total for Station Six	4.25		7.5		22365		[redacted]

Production Tower Fabrication Totals	66.6		57.6		289679.6		[redacted]
Fitup Tower Fabrication Totals	0		75	232	17400		[redacted]
Production Tower Fabrication Totals					287079.6		[redacted]

STATION SEVEN

7.00 Assemble Cones @ Texas

Task Number	Task Descript.	Hours	Personload	Unit Tot PHRS	Quantity	Tot. PHRS	Rate ($/PHR)	M&S (K$)
7.01	Assemble Conical Fixture	5	2	10	58	580	26	$15.09
7.02	Inspect Conical Fixture	1	2	2	58	116	26	$3.02
7.03	Locate, Transport and Inspect Ring	3	2	6	58	348	26	$9.05
7.04	Install Outer Structural Ring	2	2	4	58	232	26	$6.03
7.05	Locate and Transport Tower Subass.	0.5	2	1	4030	4030	26	$104.84
7.06	Install Tower Subassemblies	0.5	2	1	4030	4030	26	$104.84
7.07	Inspect Partial Assembly	4	2	8	58	464	26	$12.06
7.08	Determine Dimensions of Fit-Up Towers	2	2	4	58	232	26	$6.03
7.09	Install Fit-up Towers	4	2	8	232	1856	26	$48.26
7.10	Install Inner Structural Ring	3	2	6	232	1392	26	$36.19
7.11	Complete Assembly of Ring	2	2	4	58	232	26	$6.03
7.12	Label and Store Ring	3	3	9	58	522	26	$13.57
	Total for Station Seven	30		63		15646		$412.69

STATION EIGHT

8.00 Test Subassemblies @ Texas

Task Number	Task Descript.	Hours	Personload	Unit Tot PHRS	Quantity	Tot. PHRS	Rate ($/PHR)	M&S (K$)
8.01	Move Ring to Test Station	3	3	9	58	522	26	$13.57
8.02	Install Phototubes	16	2	32	58	1856	26	$48.26
8.03	Install Test Harnesses	16	2	32	58	1856	26	$48.26
8.04	Start-up Test Apparatus	8	2	16	58	928	26	$24.13
8.05	Perform Operational Tests	24	2	48	58	2784	26	$72.38
8.06	Return Ring to Storage/Bin 8	3	3	9	58	522	26	$13.57
	Total for Station Eight	70		146		8468		$220.17

STATION NINE

9.00 Assembly Fit-up @ Texas

Task Number	Task Descript.	Hours	Personload	Unit Tot PHRS	Quantity	Tot. PHRS	Rate ($/PHR)	M&S (K$)
9.01	Move Subassemblies to Fit-up Stand	40	3	120	58	6960	26	$180.96
9.02	Install Wiring Harnesses/Shields	40	3	120	58	6960	26	$180.96
9.03	Operational Test	40	2	80	58	4640	26	$120.64
	Total for Station Nine	120		320		18560		$482.56

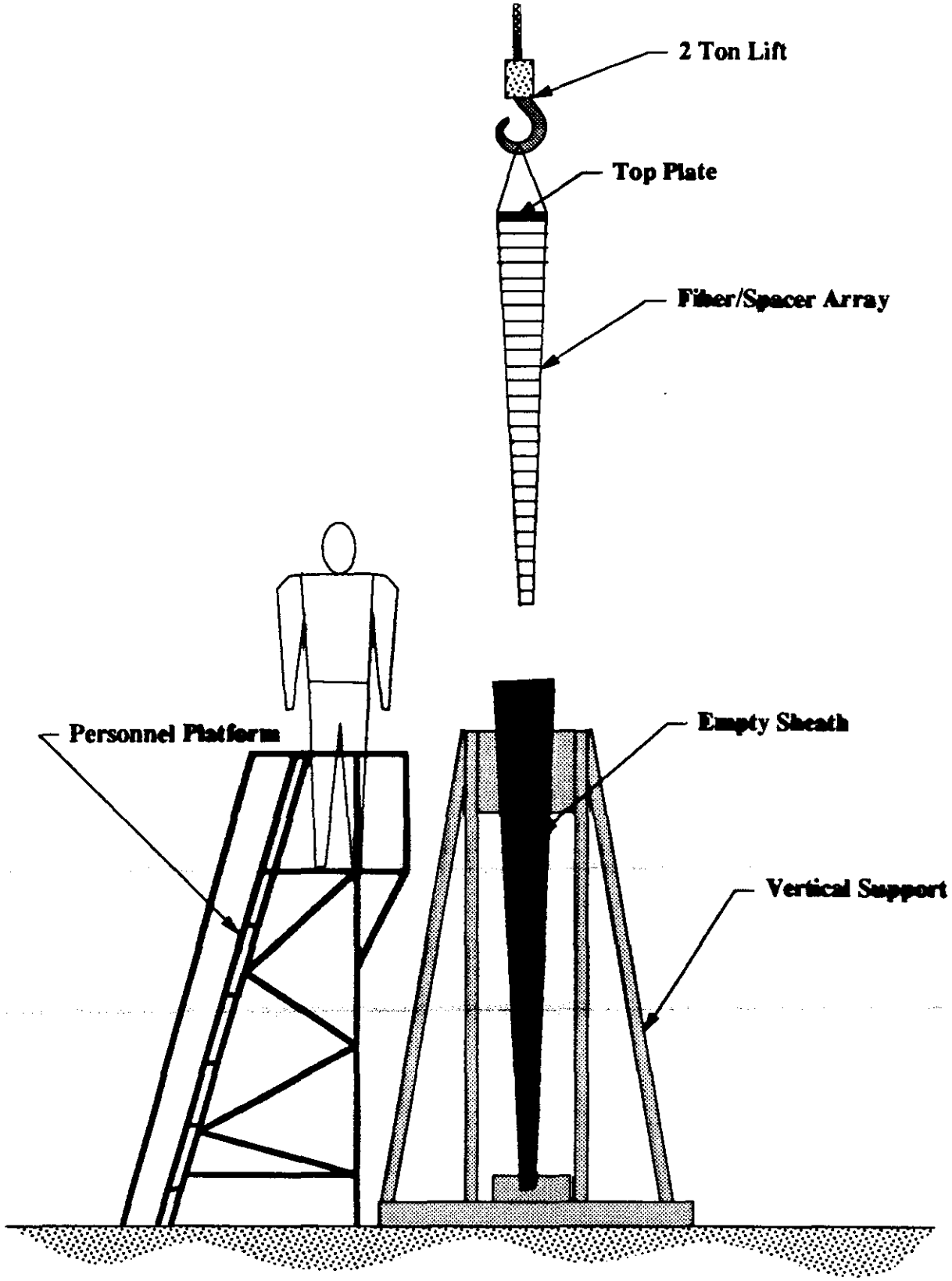
Accumulated Manpower Cost	309084	$10,014.19
Personnel Efficiency	1.25	$1,25
Estimated Manpower cost	412442	$12,517.74

Equipment Required For Spaghetti Calorimeter

Equipment	Quantity	Unit Cost	Total Cost
STATION ONE			
1.01 Fiber Cutting Machine	2	$7K	$14K
1.02 Spacer Alignment Fixture	2	$8K	$15K
1.03 Fiber Insertion Machine	2	$15K	$30K
1.04 Spacer Expansion Fixture	2	$10K	$20K
1.05 2T Monorail	1	$10K	$10K
STATION TWO			
2.01 Vertical spacer/sheath sec std	1	$15K	$15K
2.02 Personnel Platform	2	$2K	$4K
2.03 2 T Monorail	1	$10K	$10K
STATION THREE			
3.01 Fiber Installation Workstations	4	$10K	$40K
3.02 2 T Monorail	1	$20K	$20K
STATION FOUR			
4.01 Large Casting Systems	2	$250K	$500K
4.02 Molds	31	$7K	$217K
4.03 5 T Monorail	2	$20K	$40K
4.04 Setup Stands	5	$15K	$75K
4.05 Personnel Platforms	2	$10K	$20K
STATION FIVE			
5.01 Readout Casting Systems	1	$100K	$100K
5.02 Molds	31	$4K	$124K
5.03 2 T Monorail	2	$10K	$20K
STATION SIX			
6.01 Band Saw	1	$15K	$15K
6.02 Milling Machine	2	$250K	$500K
6.03 Tower Fixture	4	$10K	$40K
6.04 Readout Fixture	4	$10K	$40K
6.05 Tower Assembly Stand	2	$15K	$30K
6.06 Personnel Platform	2	$4K	$8K
6.07 5 T Monorail	2	$20K	$40K
STATION SEVEN			
7.01 Ring Assembly Stand	2	$125K	$250K
7.02 Ring Lifting Fixture	1	$100K	$100K
7.03 Ring Adapters	23	$10K	$230K
STATION EIGHT			
8.01 Vertical Assembly/Insp Stand	1	$250K	$250K
8.02 Ring Adapters	23	$10K	$230K
STATION NINE			
9.01 Subassembly Stand	2	$250K	$500K
9.02 Temporary Bracing	1	$50K	$50K
GENERAL EQUIPMENT			
10.01 Enviromental Control	1	$500K	$500K
10.02 Clothing	1	$50K	$50K
10.03 Cleaning Supplies	1	$50K	$50K
10.04 Tools	1	$100K	$100K
10.05 Temporary Use Items	1	$200K	$200K
10.06 Handling Carts (10 to 100 T)	5	$15K	$75K

Total **$4,532K**

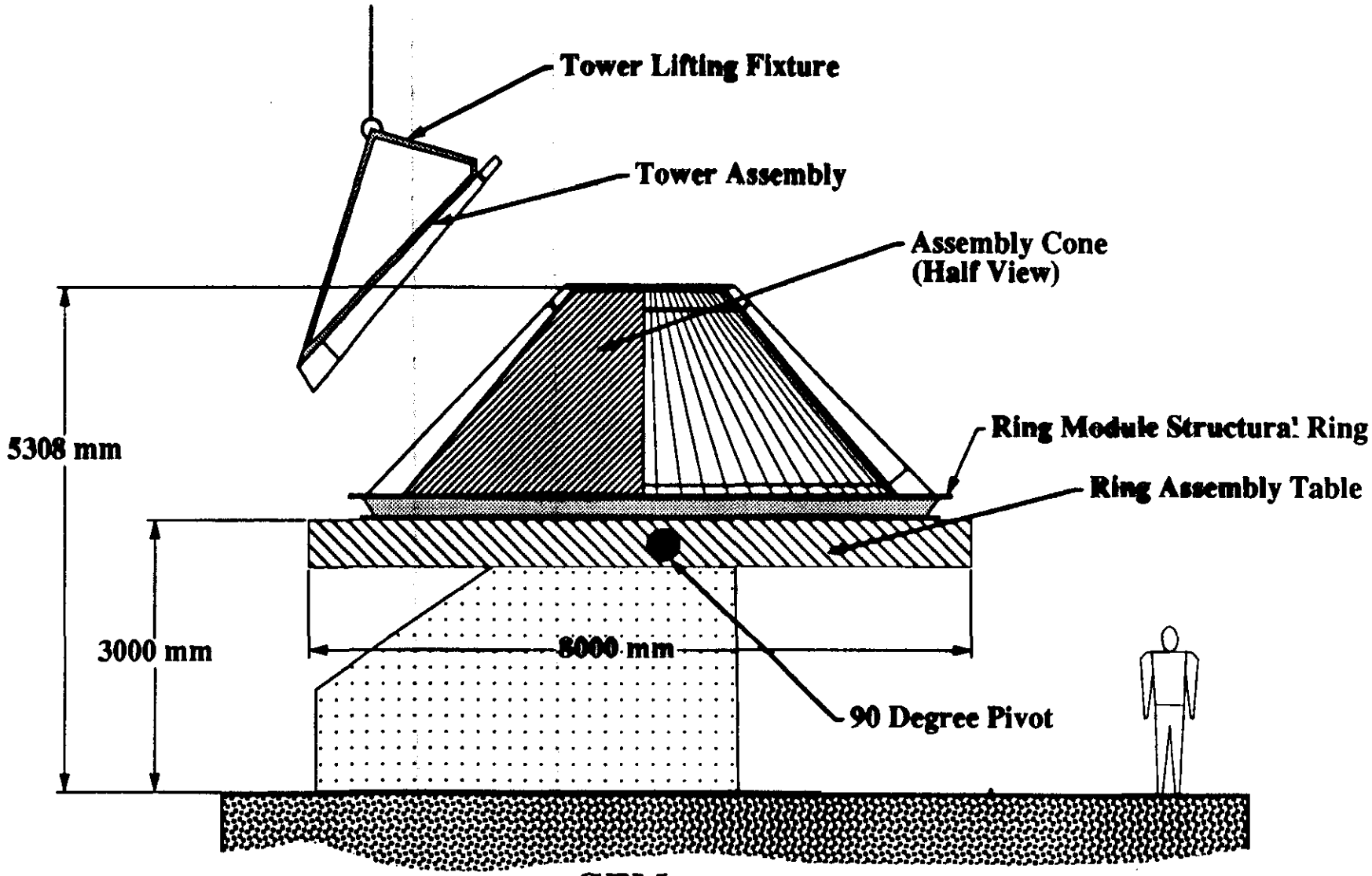
Mark Rennich/Oak Ridge National Laboratory/ 9-21-91



Spaghetti Hadron Calorimeter
Spacer Array Installation Stand

G.03.SC.00066

Rennich

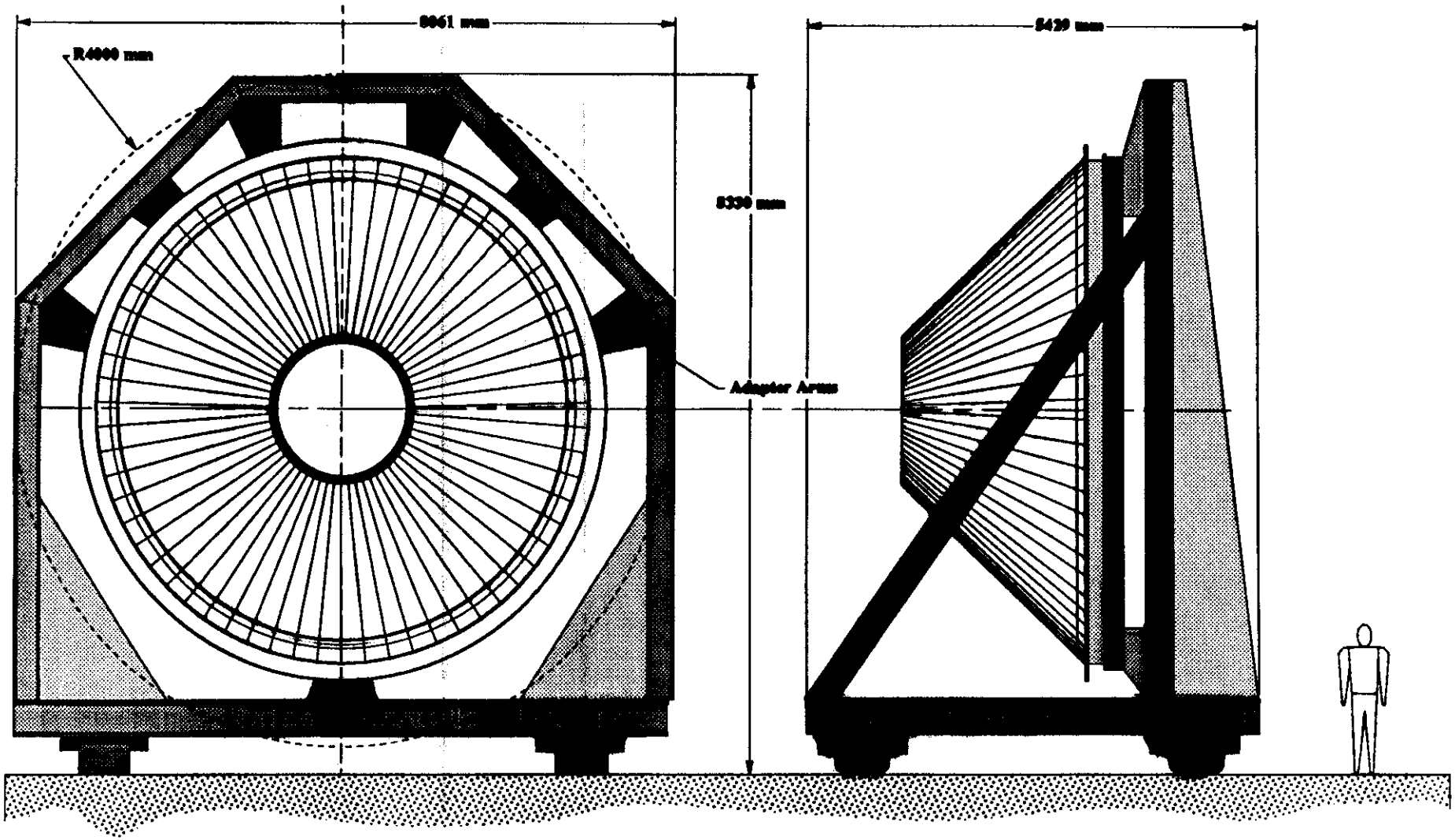


GEM
Spaghetti Calorimeter
Single Ring Module
Assembly Stand

G.03.SC.00034

CONCEPTUAL DRAWING

Rennich

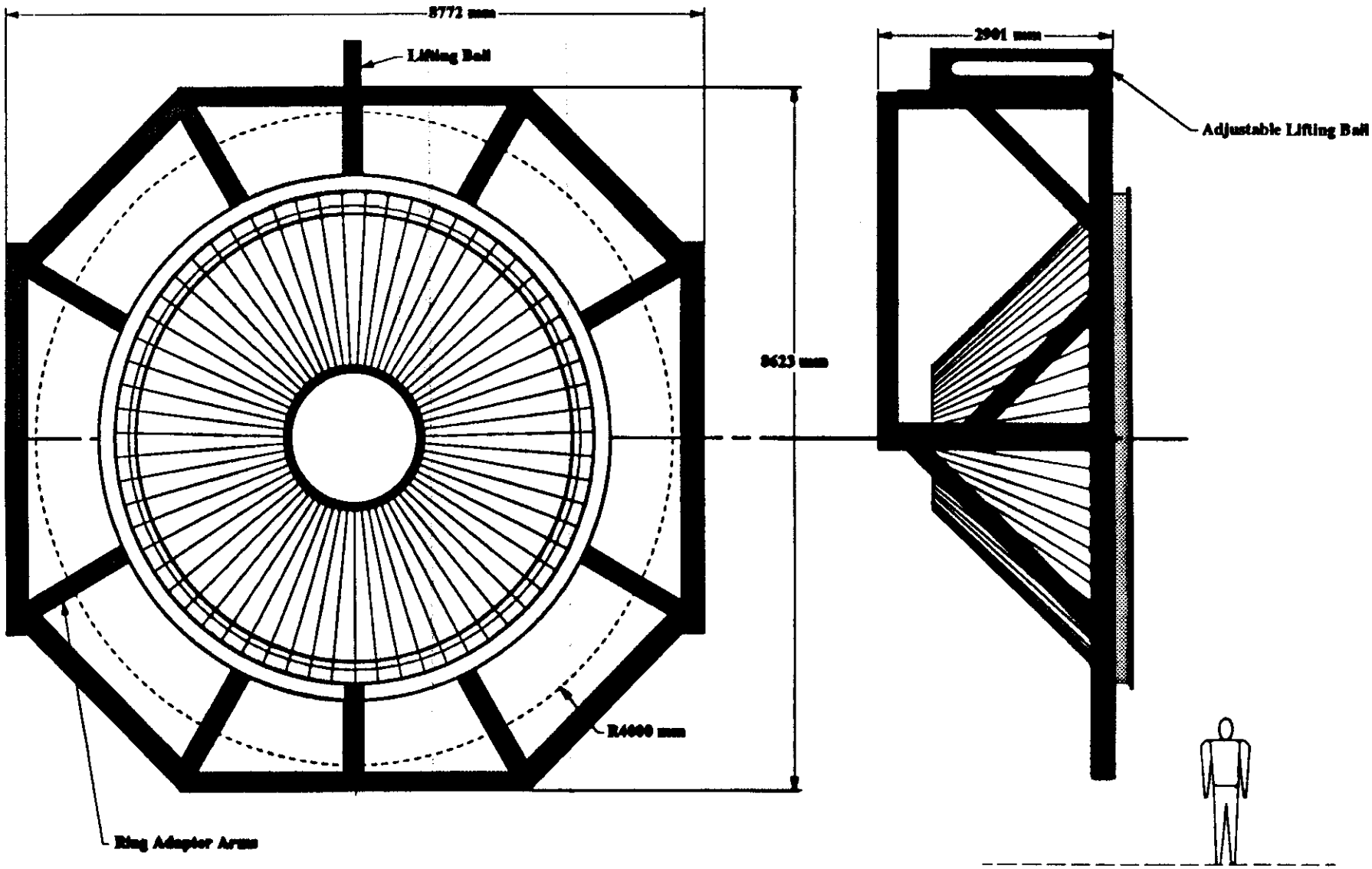


GEM Detector
Spaghetti Calorimeter
Single Ring Module
Test/Inspection Fixture

CONCEPTUAL DRAWING

G.03.SC.00060

Rennich



GEM Detector
Spaghetti Calorimeter
Single Ring Module
Lifting Fixture

LS.03.SC.00059

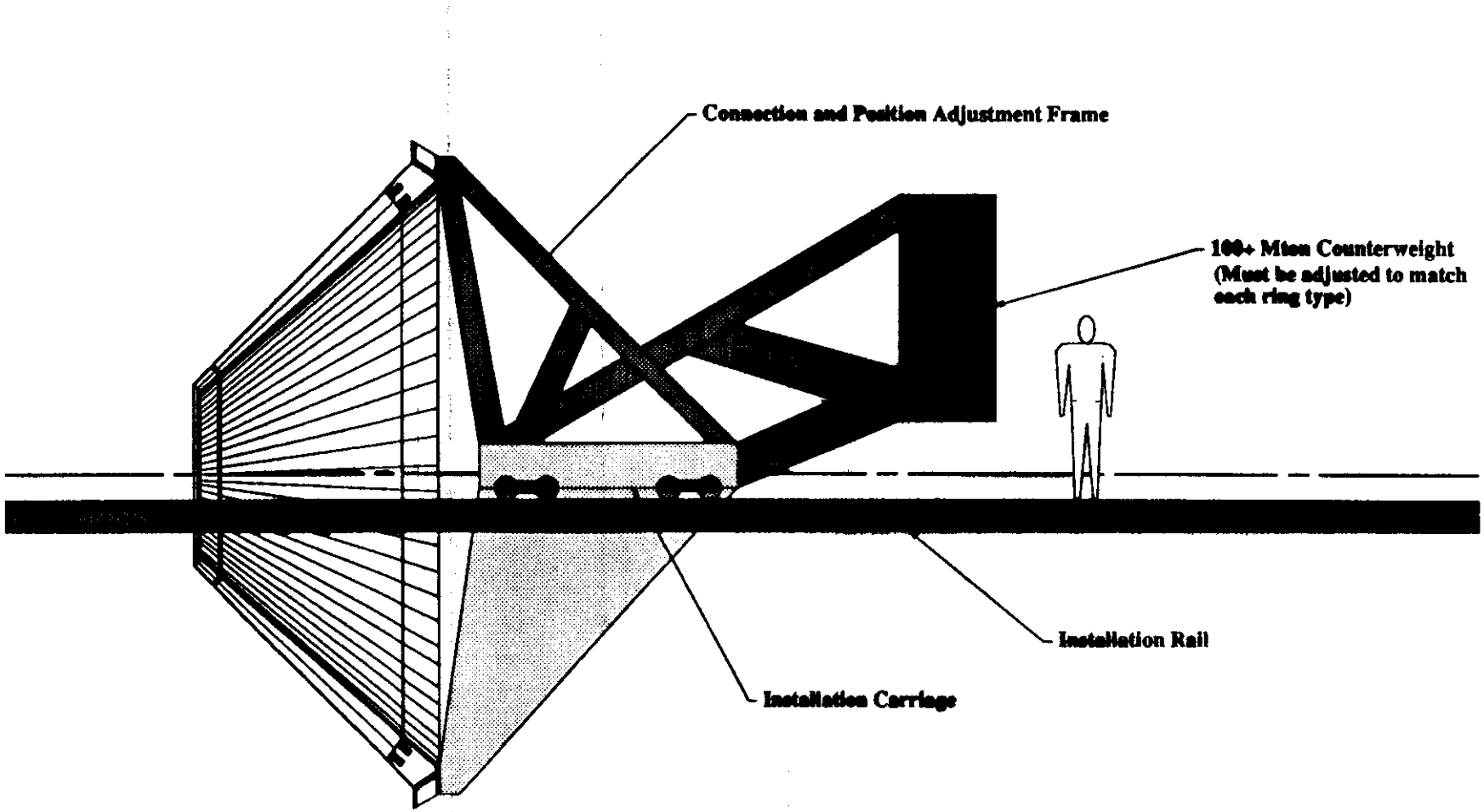
CONCEPTUAL DRAWING

Rennich

Installation Manpower-Spaghetti Hadron Calorimeter

Personnel	No.	Duration	Service Time	Total Hours	Hourly Rate	Cost
		Months	MH/Month			
Millwrights	4	4	170	2720	22.35	$60,792
Electrician	4	9	170	6120	29.86	$182,743
Crane Operator	1	9	170	1530	26.64	$40,759
Iron Worker	6	7	170	7140	22.35	$159,579
Pipe Fitter	4	6	170	4080	21.50	$87,720
Total	19			21590	122.70	$531,593

Preliminary-For Estimating Purposes Only



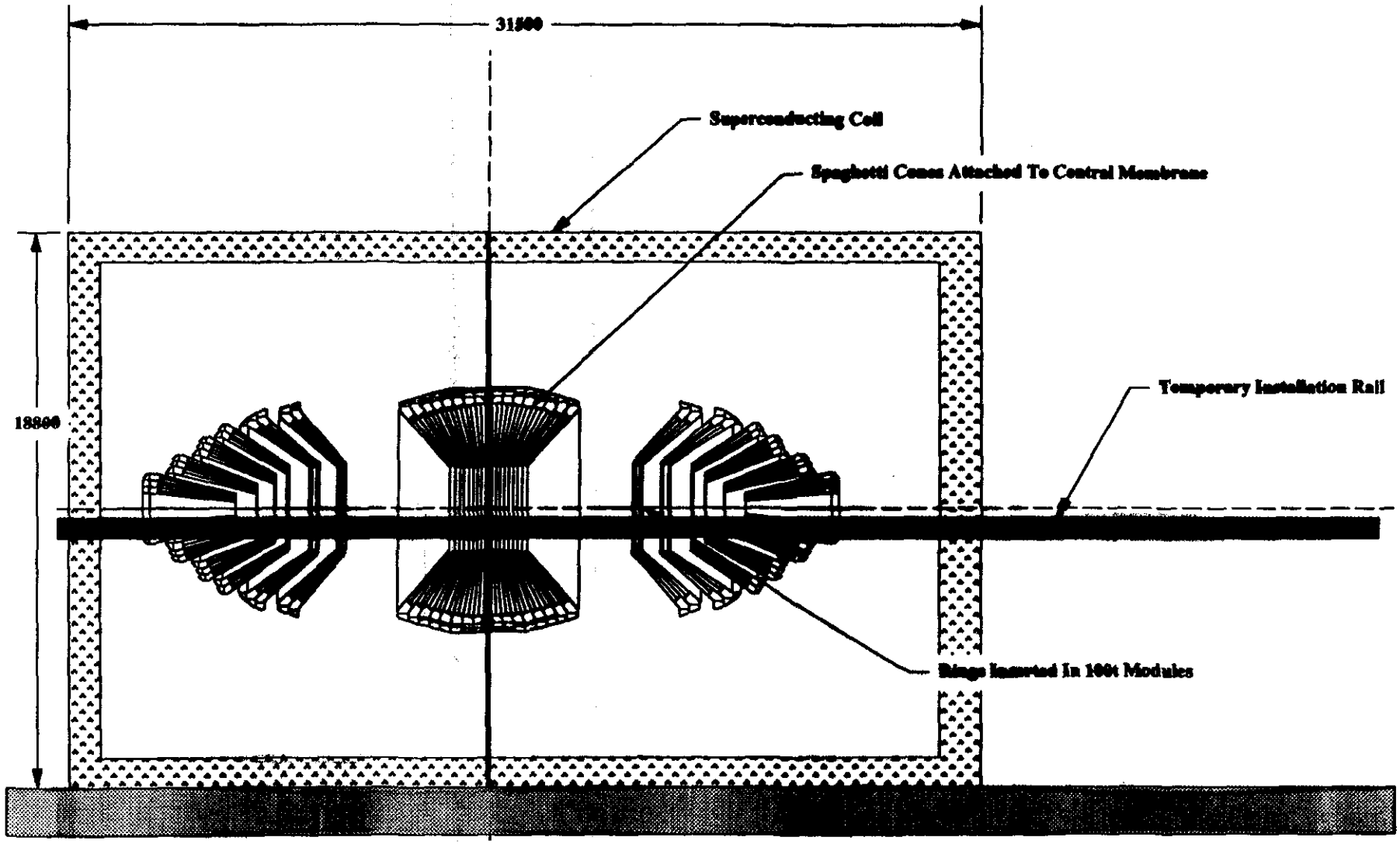
GEM Detector
Spaghetti Calorimeter
Ring Installation Transporter

G.03.SC.00047

CONCEPTUAL DRAWING

Rennich

Note: The Central Membrane Will Require Temporary Bracing During The Installation Process



GEM Detector
Spaghetti Hadron
Installation Sequence

G.03.SC.00067

Rennich

Spaghetti Calorimeter- 0.08 Segmentation

Fiber Frame/Light Guide Costing

	Element	Description	Quantity	Units	Unit Cost	Total
1.1	Base Plate	1.0 cm Drilled plate	11.28	lbs	$12.00	$135
1.2	PMT Frame	16 ga Sheetmetal	4.00	lbs	$8.00	$32
1.3	Fiber	1 mm Trans Fiber	466.19	meters	$0.22	$103
1.4	Light Mixer	Molded acrylic	1.00	ea	$25.00	$25
1.5	Shell	12 ga Sheetmetal	12.59	lbs	$4.00	$50
1.6	Fasteners	1/2 in	8.00	each	$1.00	$8

Total **$353**

All Metallic components are 304L stainless Steel
Fasteners are a non-magnetic metal
Assumes one readout fiber/WLS fiber

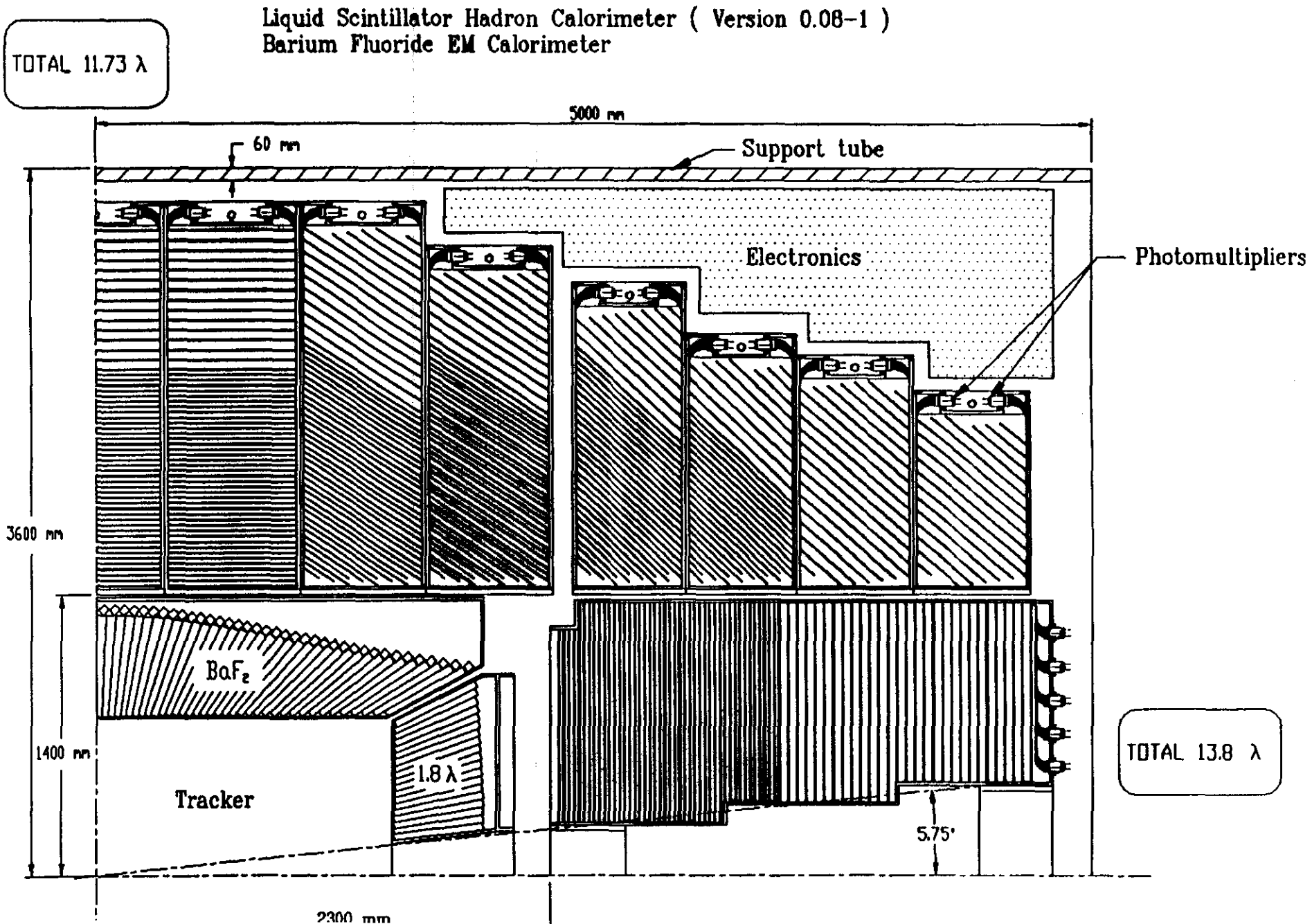
Spaghetti Hadron Calorimeter

Cost of Sheaths

0.1 Segmentation				
Material	Quantity	Units	Cost/Unit	
Sheetmetal	91.92	Lbs	5.5	$506
Bracing	28.52	Lbs	5.5	$157
Fasteners	16.00	Each	1	$16
Total				$678

0.08 Segmentation				
Material	Quantity	Units	Cost/Unit	
Sheetmetal	73.54	Lbs	5.5	$404
Bracing	25.42	Lbs	5.5	$140
Fasteners	16.00	Each	1	$16
Total				$560

0 16 Segmentation				
Material	Quantity	Units	Cost/Unit	
Sheetmetal	183.84	Lbs	5.5	$1,011
Bracing	53.00	Lbs	5.5	$292
Fasteners	16.00	Each	1.25	$20
Total				$1,323


Liquid Scintillator Hadron Calorimeter (Version 0.08-1)
Barium Fluoride EM Calorimeter
TOTAL 11.73 λ
5000 mm
60 mm
Support tube
Electronics
Photomultipliers
3600 mm
BaF2
1400 mm
Tracker
1.8 λ
5.75°
TOTAL 13.8 λ
2300 mm

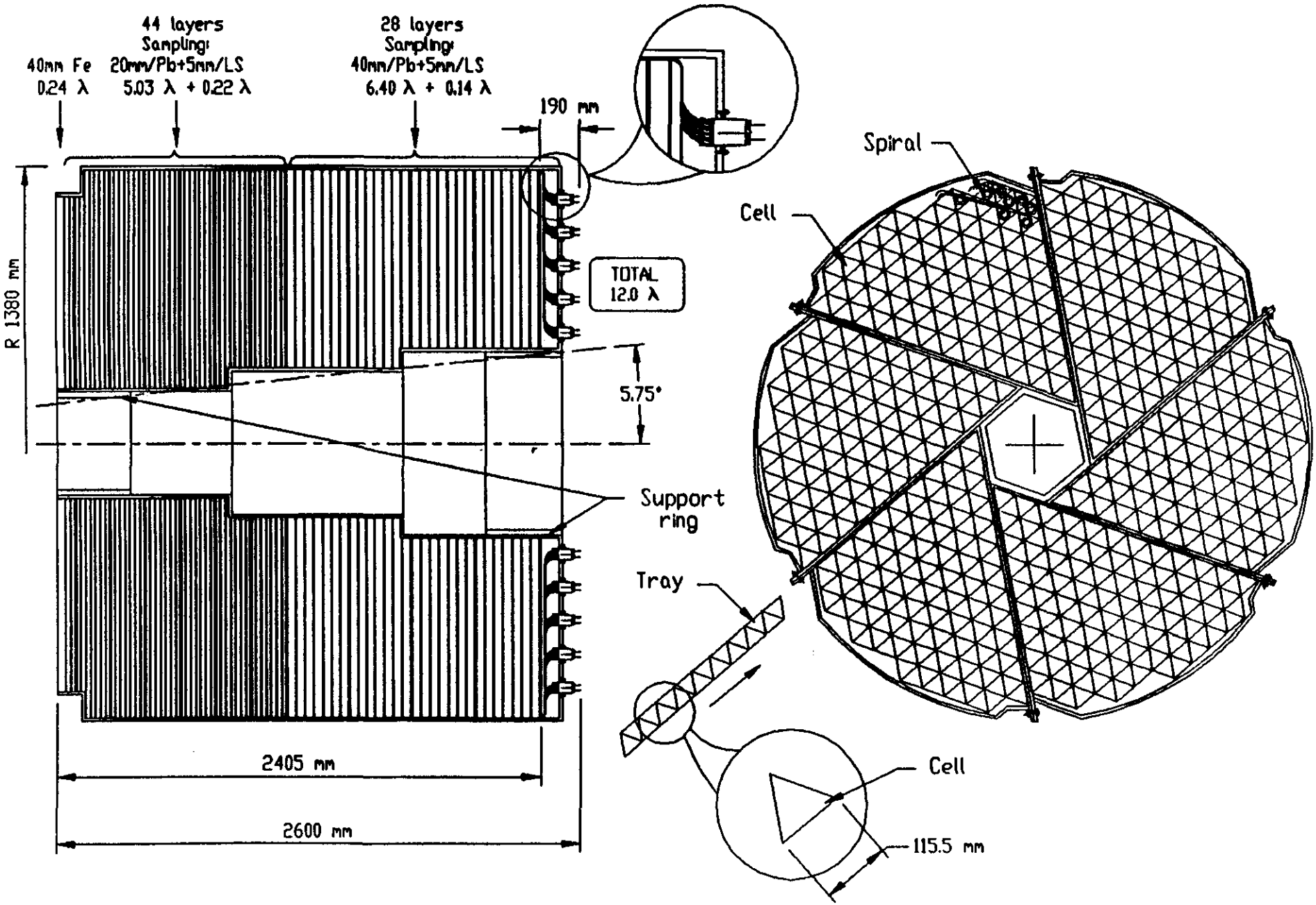
Preliminary

GEM Parameters

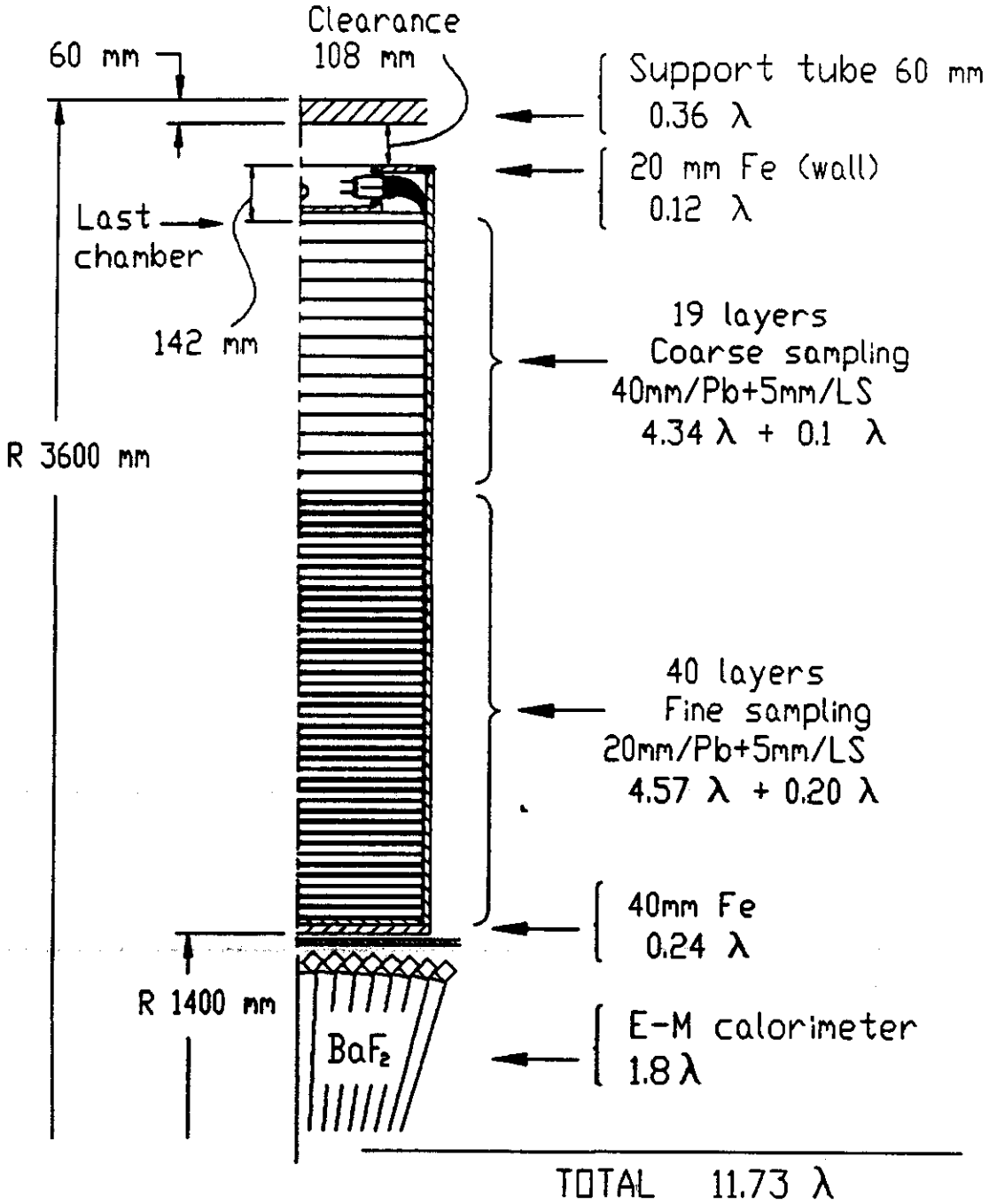
LIQUID SCINTILLATOR HADRON CALORIMETER

VOLUME	214.4 METERS CU.	M^3
NUMBER OF CHANNELS	26100	Each
TOTAL WEIGHT Metric	2028.7	Mtons
WEIGHT OF LEAD ABSORBER	1812.6	Mtons
WEIGHT OF STRUCTURAL COMPONENTS	173.4	Mtons
WEIGHT OF SENSE LAYER BOXES	42.7	Mtons
VOLUME OF LIQUID SCINTILLATOR	27000	Liters
PERCENT ABSORBER/SENSE BY VOLUME	89.70%	
PRECENT STRUCTURE BY VOLUME	10.30%	
NUMBER OF SUBASSEMBLIES	17	Each
NUMBER OF TOWERS	256	Each
NUMBER OF HADRON LAYER ASS.	5600	Each
NUMBER OF TAIL CATCHER LAYER ASS.	4800	Each
TOTAL NUMBER OF LAYERS	10400=(258 X 40.3)	Each
NUMBER OF FIBERS/SEGMENTS	607,000	Each
NUMBER OF TRAYS	129,000	Each
TOTAL LENGTH OF FIBERS	1,200,000	Meters
HEAT GENERATED BY ELECTRONICS	3500+	Watts
INNER RADIUS	1,400	mm
OUTER RADIUS (SUPPORT TUBE)	3,600	mm
LENGTH	10,000	mm

End Cap assembly (12.0 λ)



Liquid Scintillator Hadron Calorimeter
Sampling structure scheme



λ_{Pb} = 175 mm

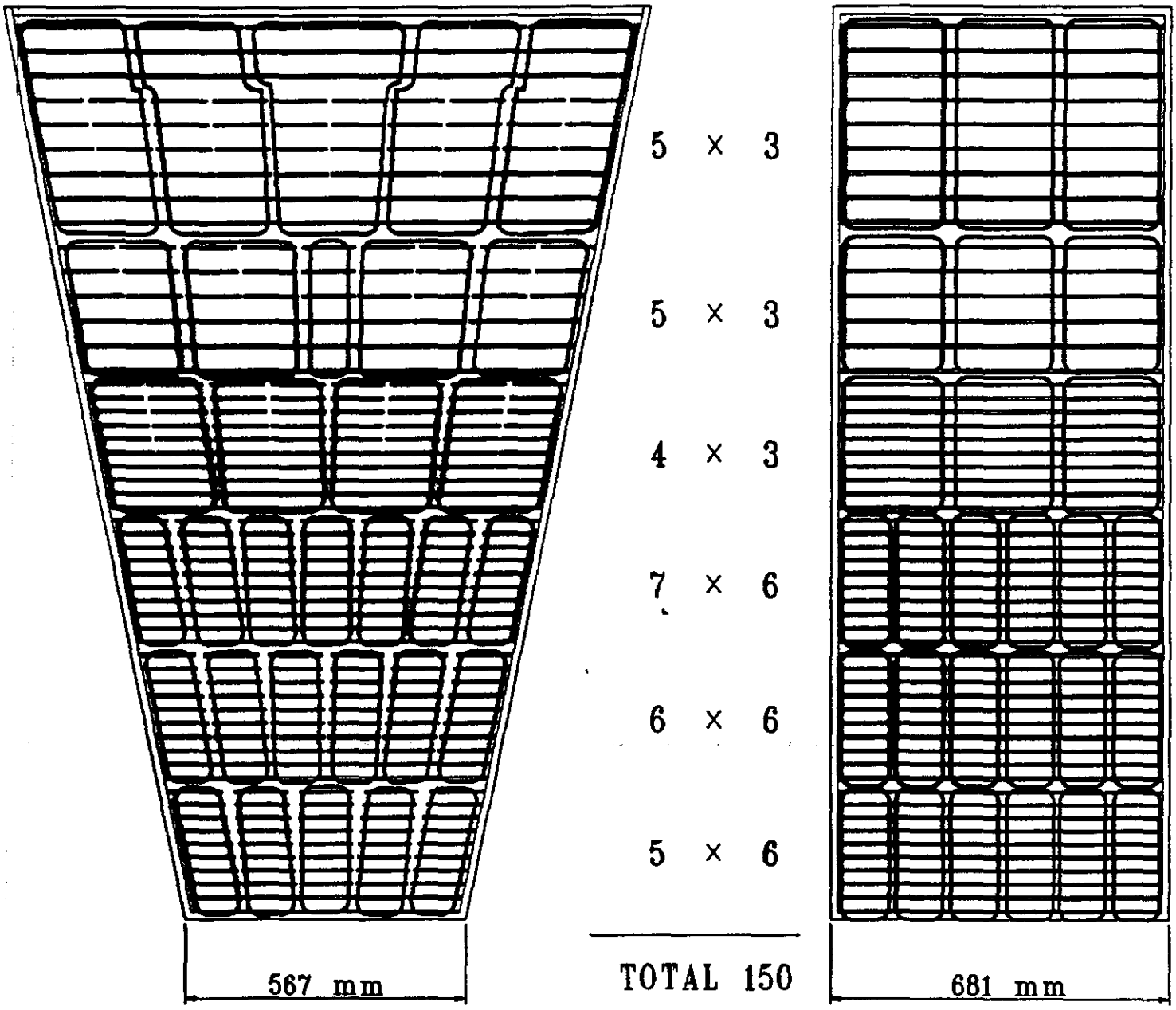
λ_{Fe} = 168 mm

λ_{Scl} = 1000 mm

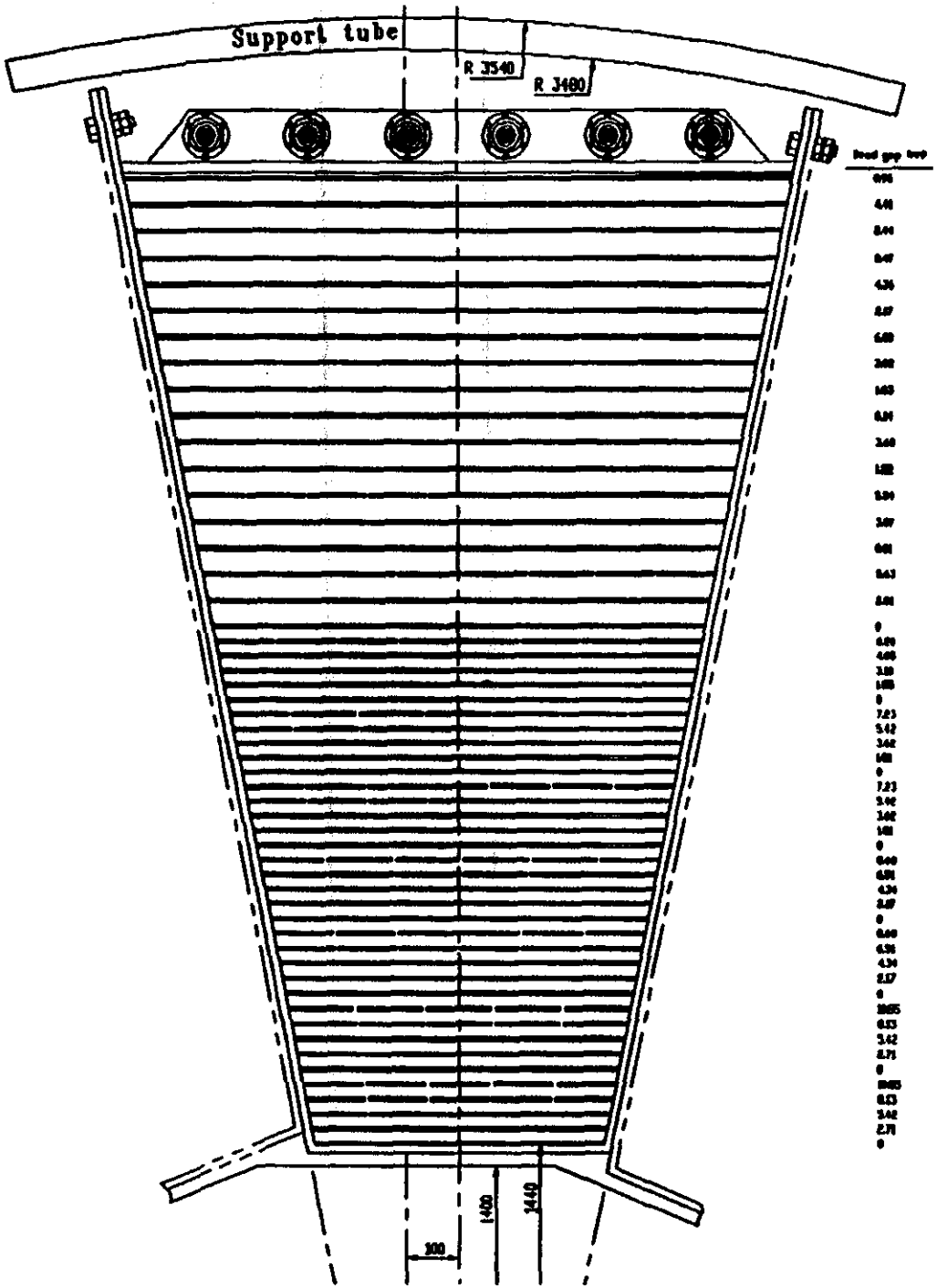
Version 0.08-1

Number of detector cells per module :
type 1 2442

Read out channels



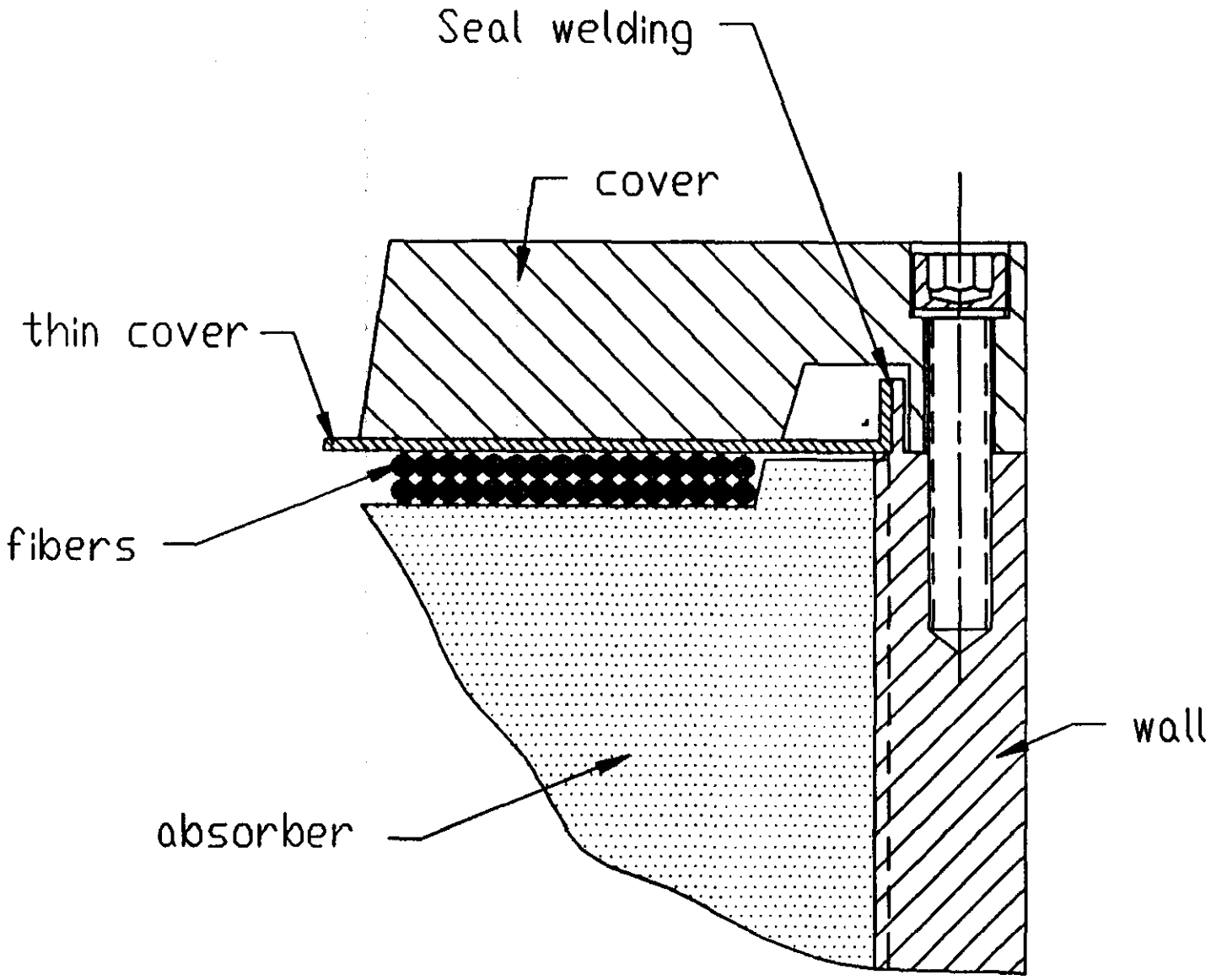
Version 008-2



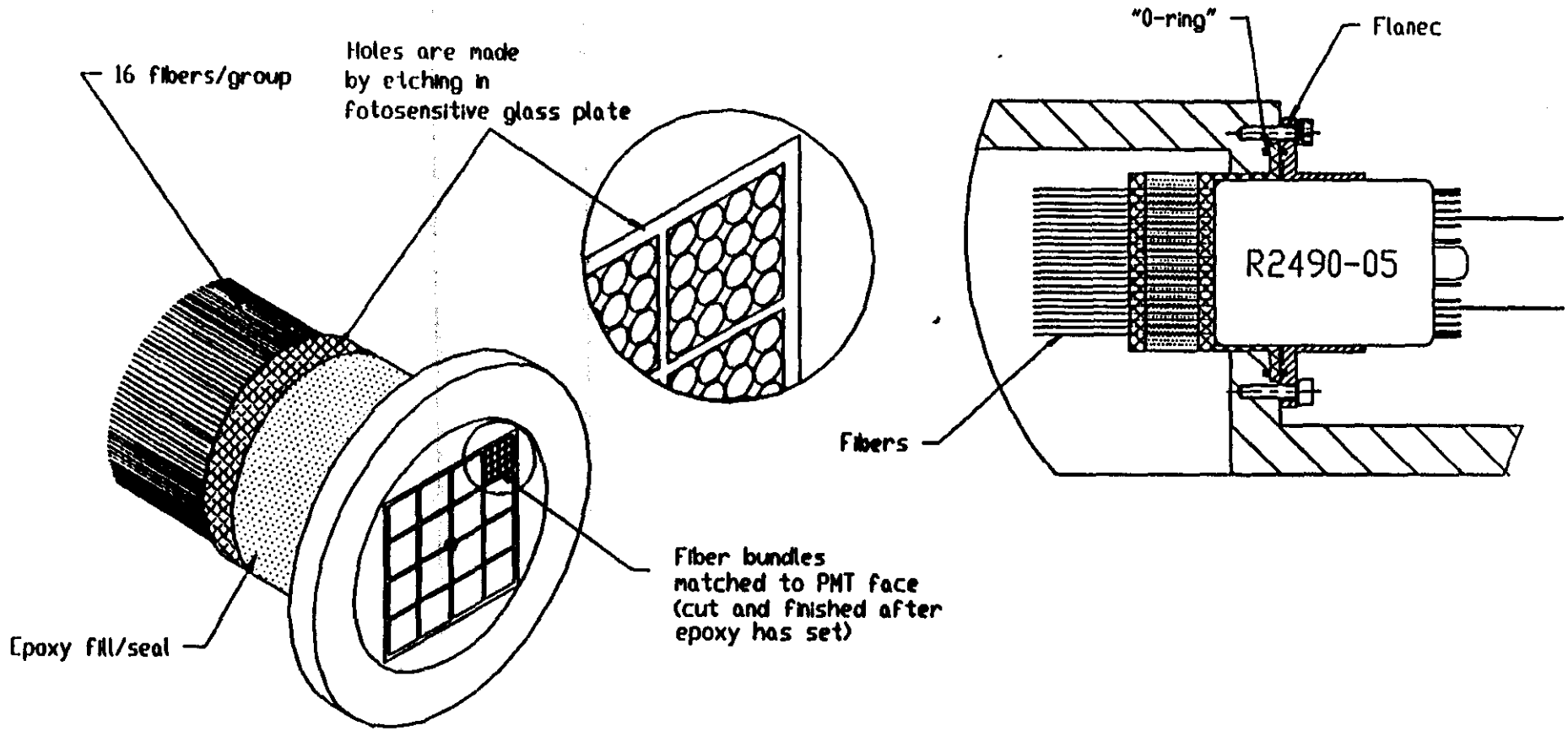
Types of cells	2
Types of WLS spirals	1
Front transversal segmentation	$\Delta\eta = \Delta\varphi = 0.08$
Number of detector cells per modules:	
type 1	1632
type 2	720
Fine/coarse sampling	35/18
Read out channels	150
PM per module	18
Thickness	1.784m or 9.43 λ

Dead walls	7.42 %
Dead gaps	2.62 %

Cell type 1 ——— 100.5 × 113.9 mm²
Cell type 2 ——— 119.3 × 113.9 mm²
Cell thickness 5 mm
Absorber thickness (fine sampling) 22.3 mm
Absorber thickness (coarse sampling) 47.5 mm

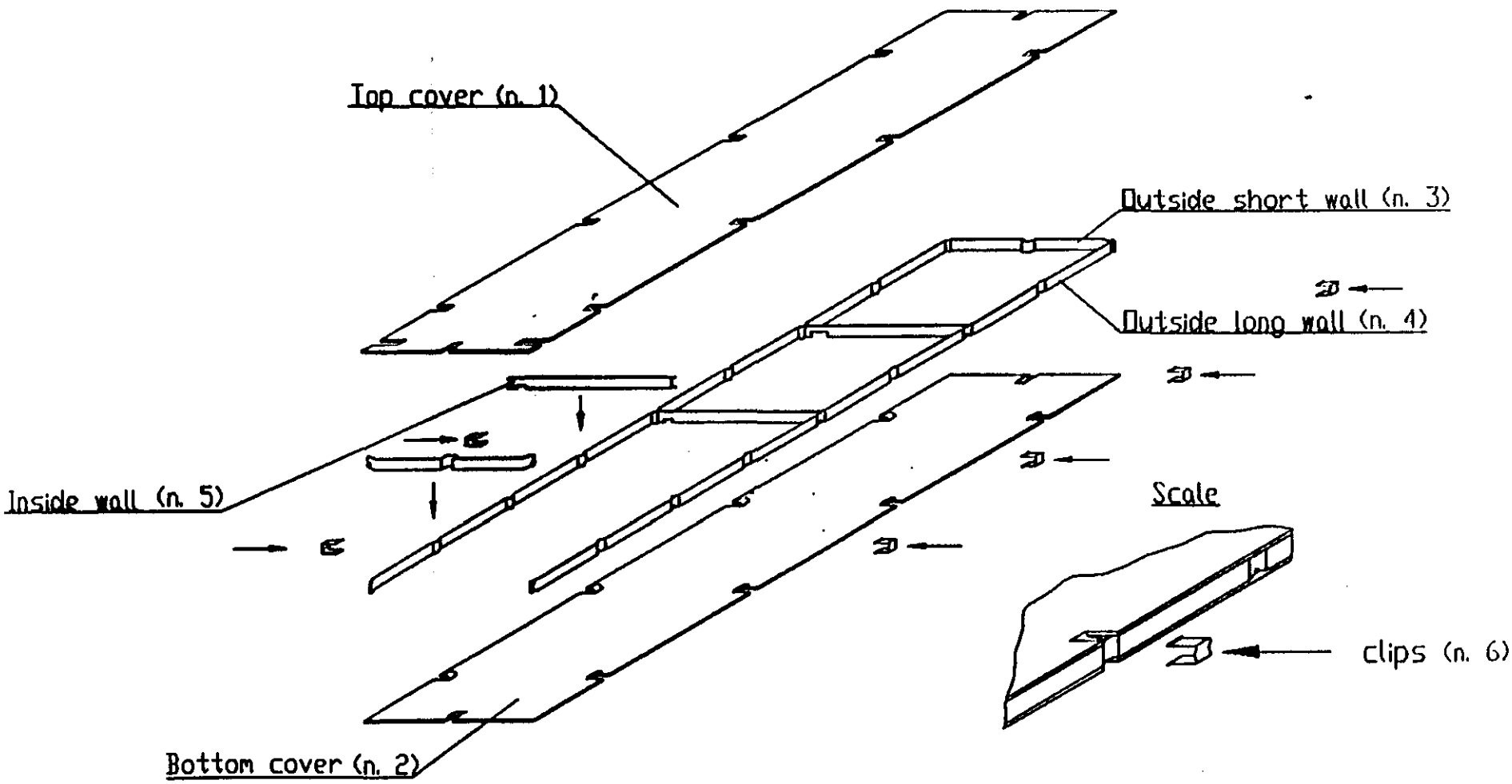


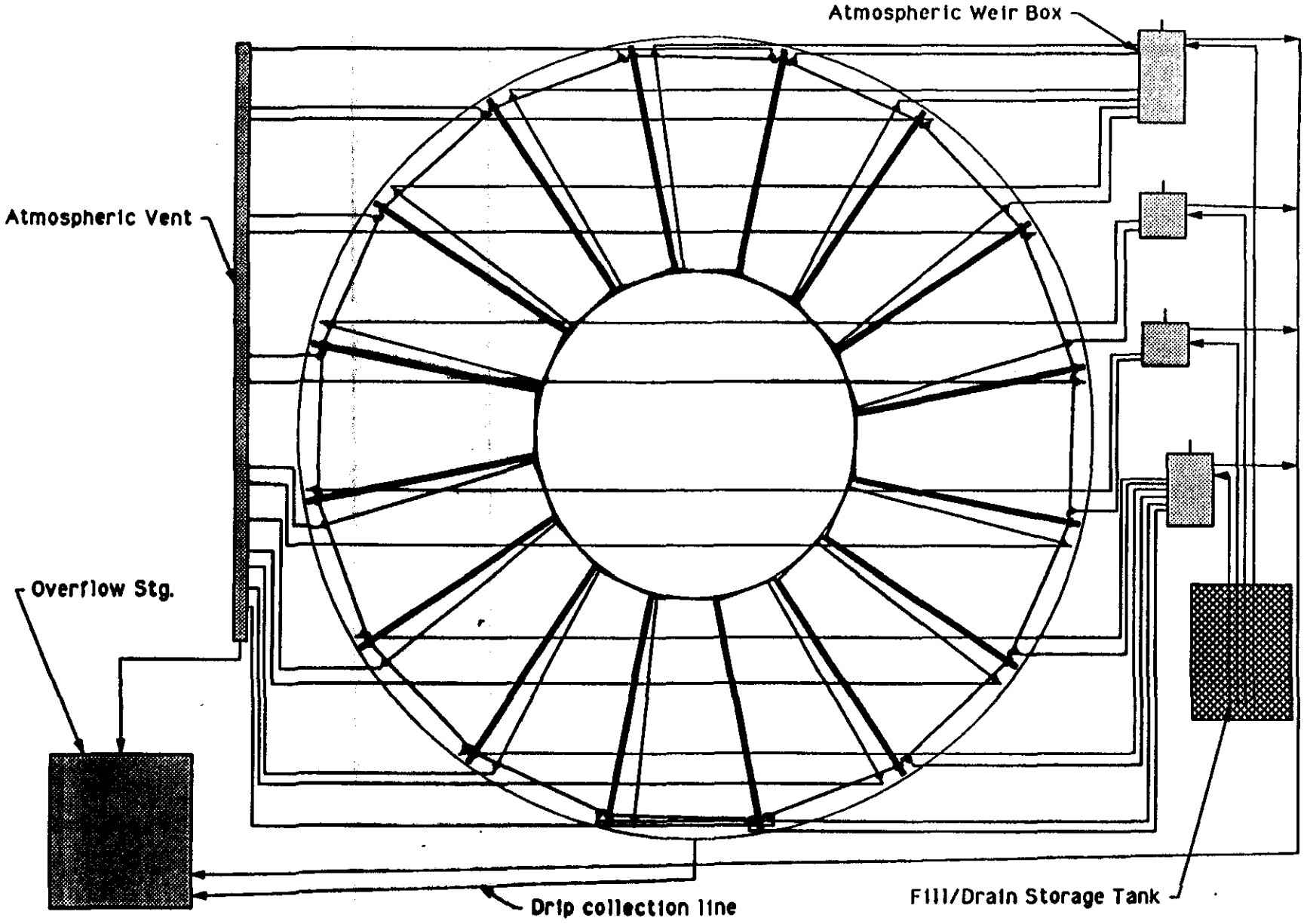
Sealing of the cover



Variation of Fiber Seal
for Liquid Scintillator HC module

LS detector tray assembly





Schematic Of Fill/Drain System For Central Module Of Liquid Scintillating L* Hadron Calorimeter

L.S.03.R.D.00019

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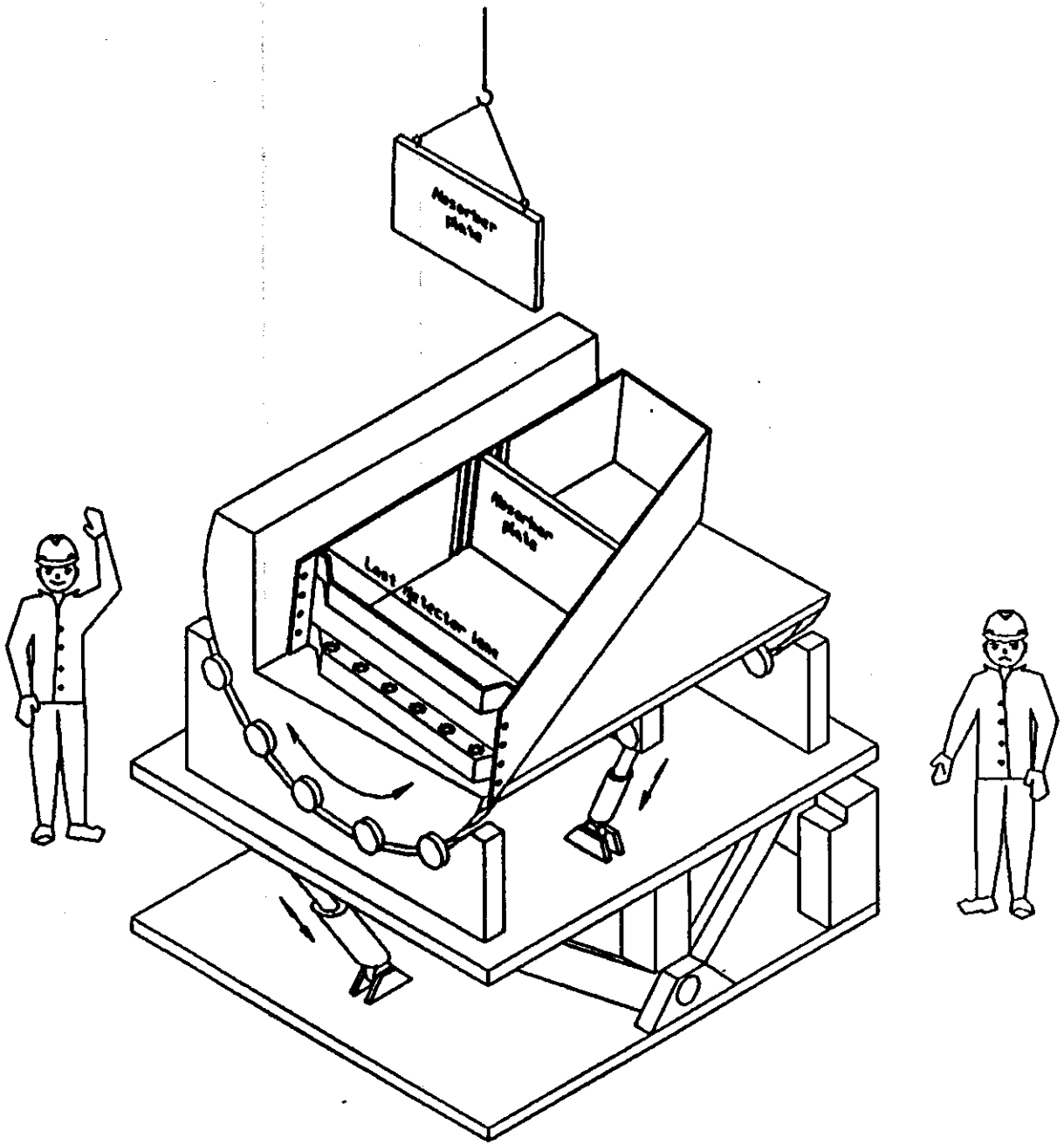
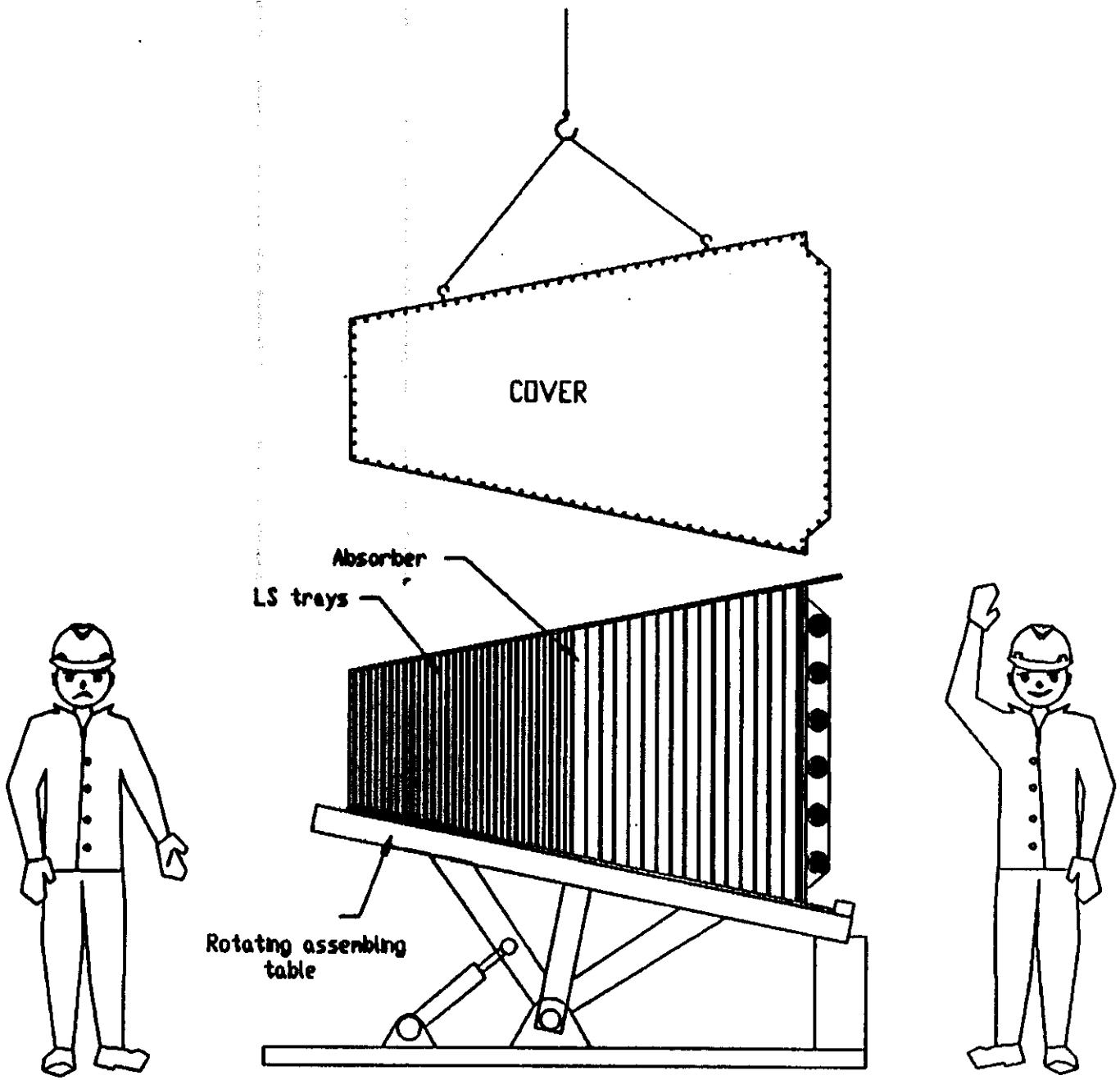
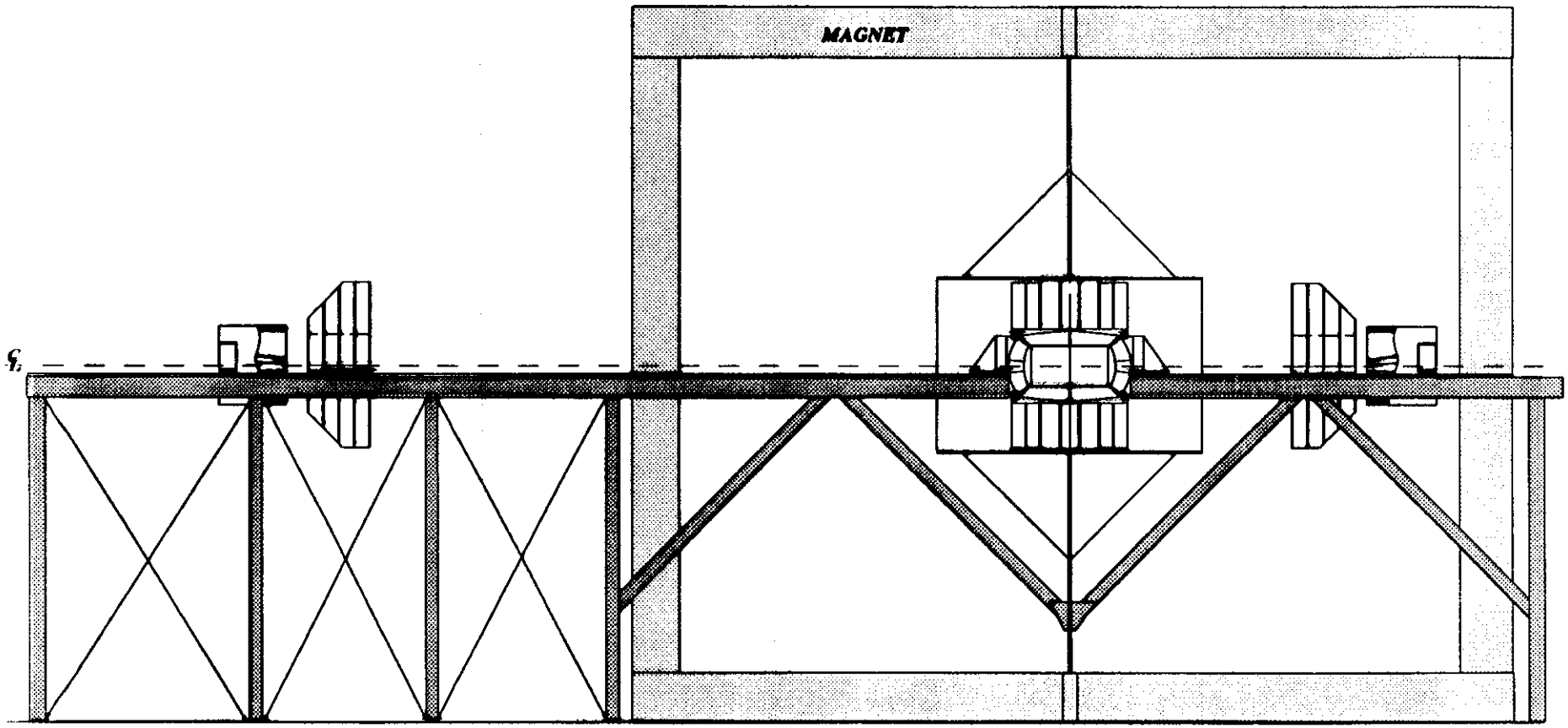

Reservoir Plate
Reservoir Plate
Lost Objective Item


COVER
Absorber
LS trays
Rotating assembling table



GEM Detector
Liquid Scintillator Hadron
Calorimeter Installation

G.03.INSTALL.00101

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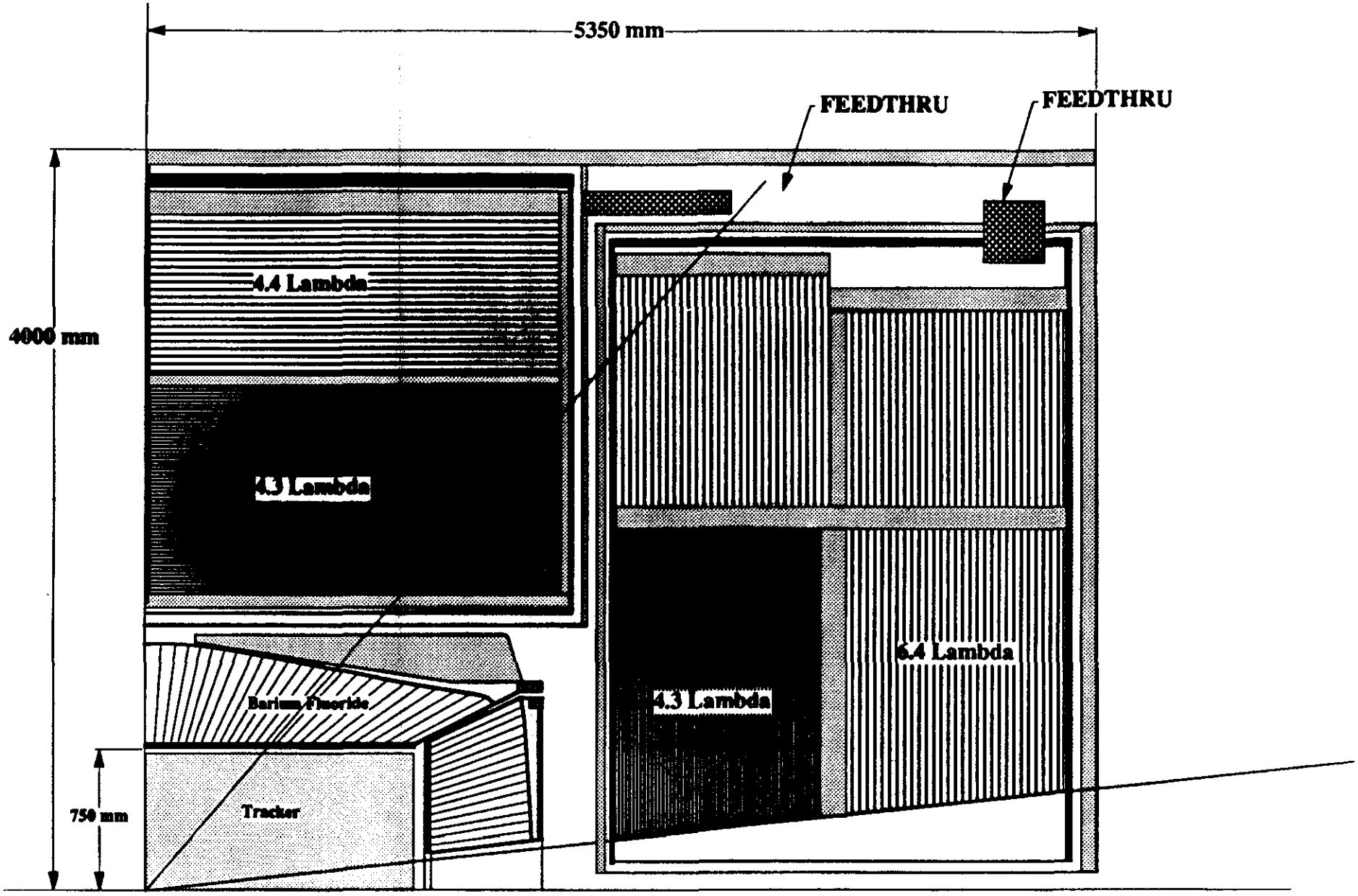


Total Thickness: 10.6 Lambda

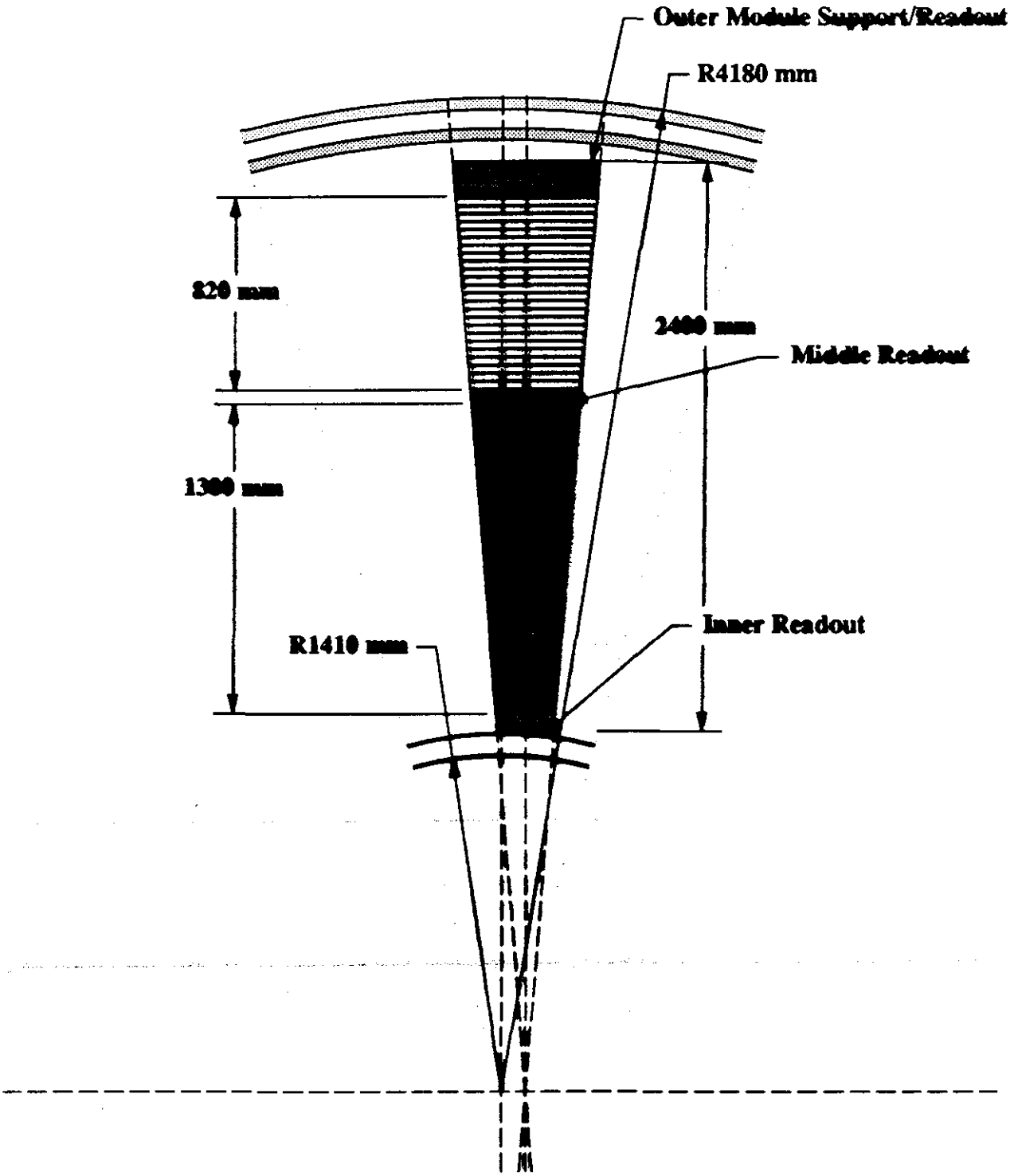
GEM
Liquid Argon Calorimeter
Barium Fluoride EM Section

Incomplete
Incomplete
Incomplete
Incomplete

G.03.LA.00030

Rennich

Total Absorption Length: 11.7 Lambda



GEM Detector
Liquid Argon
Hadron Tower

G.03.LA.00027

Rennich

Liquid Scintillator Hadron Calorimeter 0.08-Cost Analysis

	Catagory	Tot Uts	$K/UNIT	Units	Total Cost
1.00	Modules				
1.10	Lead	1812	$1.00000	Mtons	$1,812
1.20	Fiber	1.34E+06	$0.00035	Meters	$470
1.30	Shrouds	256	$6.61400	Each	$1,693
1.40	Trays	129700	$0.00200	each	$259
1.50	Liquid System	256	$2.50000	each	$640
1.60	Cal. Sources	607000	$0.00015	each	$91
1.70	Painting				$100
2.00	Sense Material	27000	$0.01800	Liters	$486
3.00	Readout				
3.10	Electronics	26100	$0.25000	Channels	$6,525
3.20	PMT's	3984	$1.00000	each	$3,984
4.00	Structure				
4.10	Inner Rings	12833	$0.00000	Each	$96
4.20	Support Gussets	24356	$0.00500	Each	$122
4.30	Tie Bars	48	$0.20000	Each	$10
4.40	Support Tube	235200	$0.00400	Each	$941
5.00	Assembly				
5.10	Ass & Test	1,157	$0.03400	Mill/tower	$13,000
5.20	Tooling				$2,840
5.30	Lead Processing	1923	$0.35000	Mtons	$673
6.00	Thermal Cont				$800
7.00	Testing				$2,500
8.00	Installation				
8.10	Install. Manp	14356	$0.02700	Mill	$388
8.20	Inst. Tooling				$2,500
9.00	Shipping				$500
	DIRECT COST				$40,609
	EDIA	25%			$10,152
	BASE COST				$50,762
	CONTINGENCY	25%			$12,690
	SUBTOTAL				$63,452
	R&D	11%			$6,980
	TOTAL				$70,432

PRELIMINARY

Scintillating Fiber Hadron Calorimeter 0.08 Segmentation With Lead Shot

	Catagory	Tot Uts	$K/UNIT	Units	Costs
1.00	Material				
1.10	Eutectic	727.12	$5.576	Mtons	$4,054
1.20	Lead Shot	1373.22	$0.992	Mtons	$1,362
1.30	Sheaths	5168	$0.548	Each	$2,832
1.40	Light Guides	5168	$0.353	Each	$1,824
1.50	Spacers	5168	$0.078	Each	$403
1.60	Top Plate	5168	$0.300	Each	$1,602
1.70	Calib. Loops	140	$2.000	Each	$280
2.00	Sense Material	6.05E+06	$0.001	Motons	$6,047
3.00	Readout				
3.10	PMT's	5168	$0.600	Each	$3,101
3.20	Electronics	5168	$0.250	Channels	$1,292
4.00	Structure				
4.10	Inner Rings	14931	$0.008	Lbs	$119
4.20	Outer Rings	185000	$0.012	Lbs	$2,220
5.00	Fab & Ass.				
5.10	Fab,Ass & Test				$12,613
5.20	Tooling				$4,557
6.00	Thermal Cont				$980
7.00	Testing				$2,500
8.00	Installation				
8.10	Install. Labor	18,796	$0.027	Man-Hour	$463
8.20	Install. Rails	600000	$0.0015	Lbs	$900
8.30	Install. Trucks	100000	$0.006	Lbs	$600
8.40	Module Pusher	2	$50.000	Each	$100
8.50	Temp Bracing	250000	$0.002	Lbs	$500
9.00	Shipping				$500
	Direct cost				$48,850
	EDIA	25%			$12,212
	Base Cost				$61,062
	Contingency	33%			$20,151
	Subtotal				$81,213
	R&D	11%			$8,933
	Total				$90,146

MARK RENNICH/OAK RIDGE NATIONAL LABORATORY/ 9-20-91

PRELIMINARY

Scintillating Fiber Hadron Calorimeter 0.08 Segmentation

	Catagory	Tot Uts	$K/UNIT	Units	Costs
1.00	Material				
1.10	Lead	2000.4	$5.576	Mton	$11,154
1.20	Sheaths	5168	$0.560	Each	$2,894
1.30	Light Guides	5168	$0.353	Each	$1,824
1.40	Spacers	5168	$0.084	Each	$434
1.50	Top Plate	5168	$0.321	Each	$1,659
1.60	Calib. Loops	140	$2.000	Each	$280
2.00	Sense Material	6.80E+06	$0.001	Meters	$6,801
3.00	Readout				
3.10	PMT's	5168	$0.600	Each	$3,101
3.20	Electronics	5168	$0.250	Channels	$1,292
4.00	Structure				
4.10	Inner Rings	14931	$0.008	Lbs	$119
4.20	Outer Rings	185000	$0.012	Lbs	$2,220
5.00	Fab & Ass.				
5.10	Fab,Ass & Test				$12,517
5.20	Tooling				$4,557
6.00	Thermal Cont				$900
7.00	Testing				$2,500
8.00	Installation				
8.10	Install. Labor	18,796	$0.027	Man-Hour	$463
8.20	Install. Rails	600000	$0.0015	Lbs	$900
8.30	Install. Trucks	100000	$0.006	Lbs	$600
8.40	Module Pusher	2	$50.000	Each	$100
8.50	Temp Bracing	250000	$0.0020	Lbs	$500
9.00	Shipping				$500
	Direct cost				$55,395
	EDIA	25%			$13,849
	Base Cost				$69,244
	Contingency	30%			$20,773
	Subtotal				$90,017
	R&D	11%			$9,902
	Total				$99,919

MARK RENNICH/OAK RIDGE NATIONAL LABORATORY/ 9-20-91

PRELIMINARY

Scintillating Fiber Hadron Calorimeter 0.1 Segmentation

	Catagory	Tot Uts	$K/UNIT	Units	Costs
1.00	Material				
1.10	Lead	2000.4	$5.576	Mton	$11,154
1.20	Sheaths	3308	$1.859	Each	$6,150
1.30	Light Guides	3308	$0.595	Each	$1,968
1.40	Spacers	3308	$0.132	Each	$437
1.50	Top Plate	3308	$0.641	Each	$2,120
1.60	Calib. Loops	120	$2.000	Each	$240
2.00	Sense Material	6.80E+06	$0.001	Meters	$6,801
3.00	Readout				
3.10	PMT's	3308	$0.600	Each	$1,985
3.20	Electronics	3308	$0.250	Channels	$827
4.00	Structure				
4.10	Inner Rings	14931	$0.008	Lbs	$119
4.20	Outer Rings	185000	$0.012	Lbs	$2,220
5.00	Fab & Ass.				
5.10	Fab,Ass & Test				$9,092
5.20	Tooling				$4,557
6.00	Thermal Cont				$900
7.00	Testing				$2,500
8.00	Installation				
8.10	Install. Labor	18,796	$0.027	Man-Hour	$463
8.20	Install. Rails	600000	0.0015	Lbs	$900
8.30	Install. Trucks	100000	$0.006	Lbs	$600
8.40	Module Pusher	2	$50.000	Each	$100
8.50	Temp Bracing	250000	$0.002	Lbs	$500
9.00	Shipping				$500
	Direct cost				$54,213
	EDIA	25%			$13,553
	Base Cost				$67,766
	Contingency	30%			$20,330
	Subtotal				$88,095
	R&D	11%			$9,690
	Total				$97,786

MARK RENNICH/OAK RIDGE NATIONAL LABORATORY/ 9-20-91

CALORIMETRY

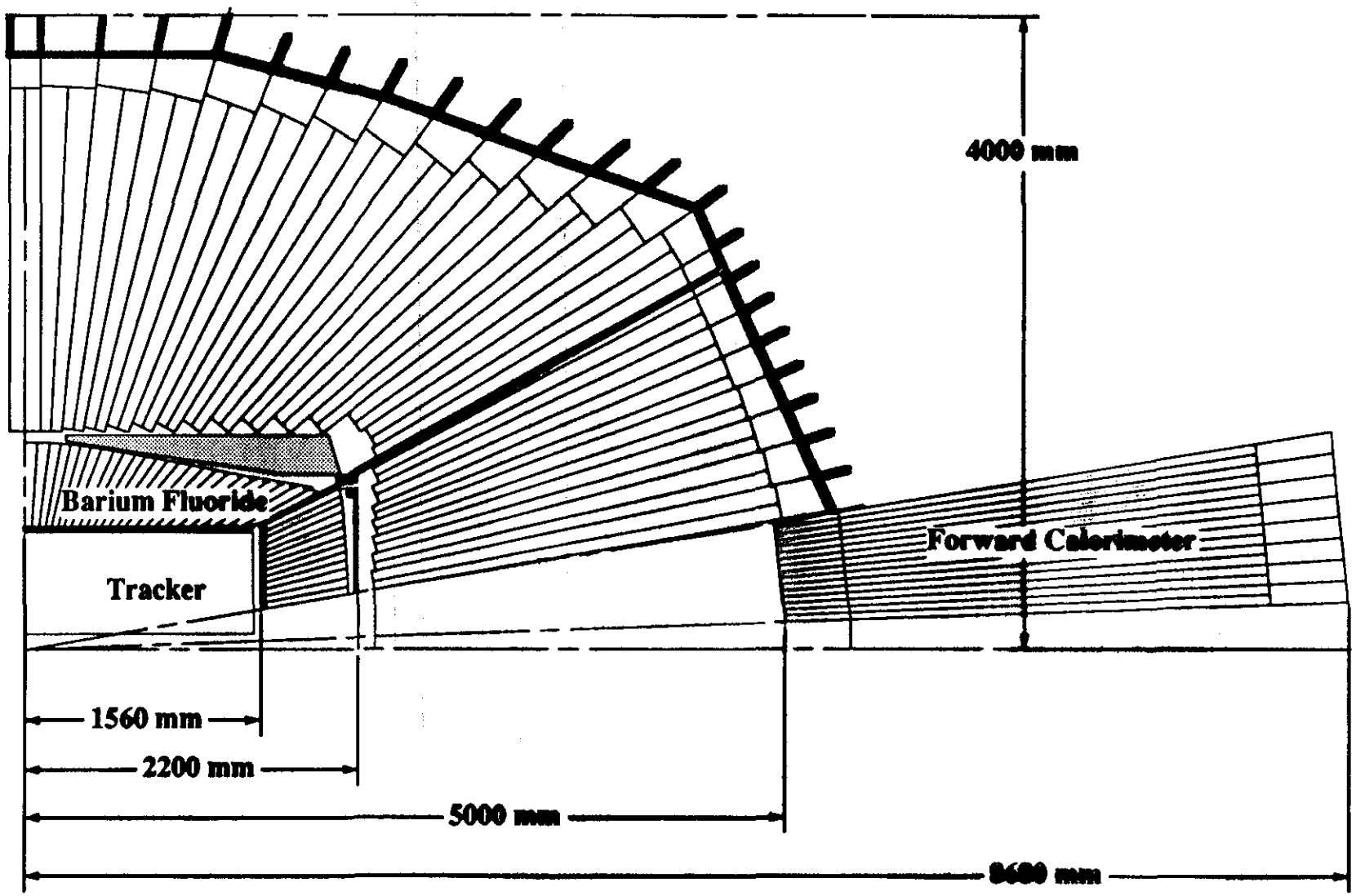
ORNL

Costing of Liquid Argon Hadron Only System

$ No Design Basis is Available
Sketch Used to Determine Size

$ Cost Based on $16 to19/Lb.

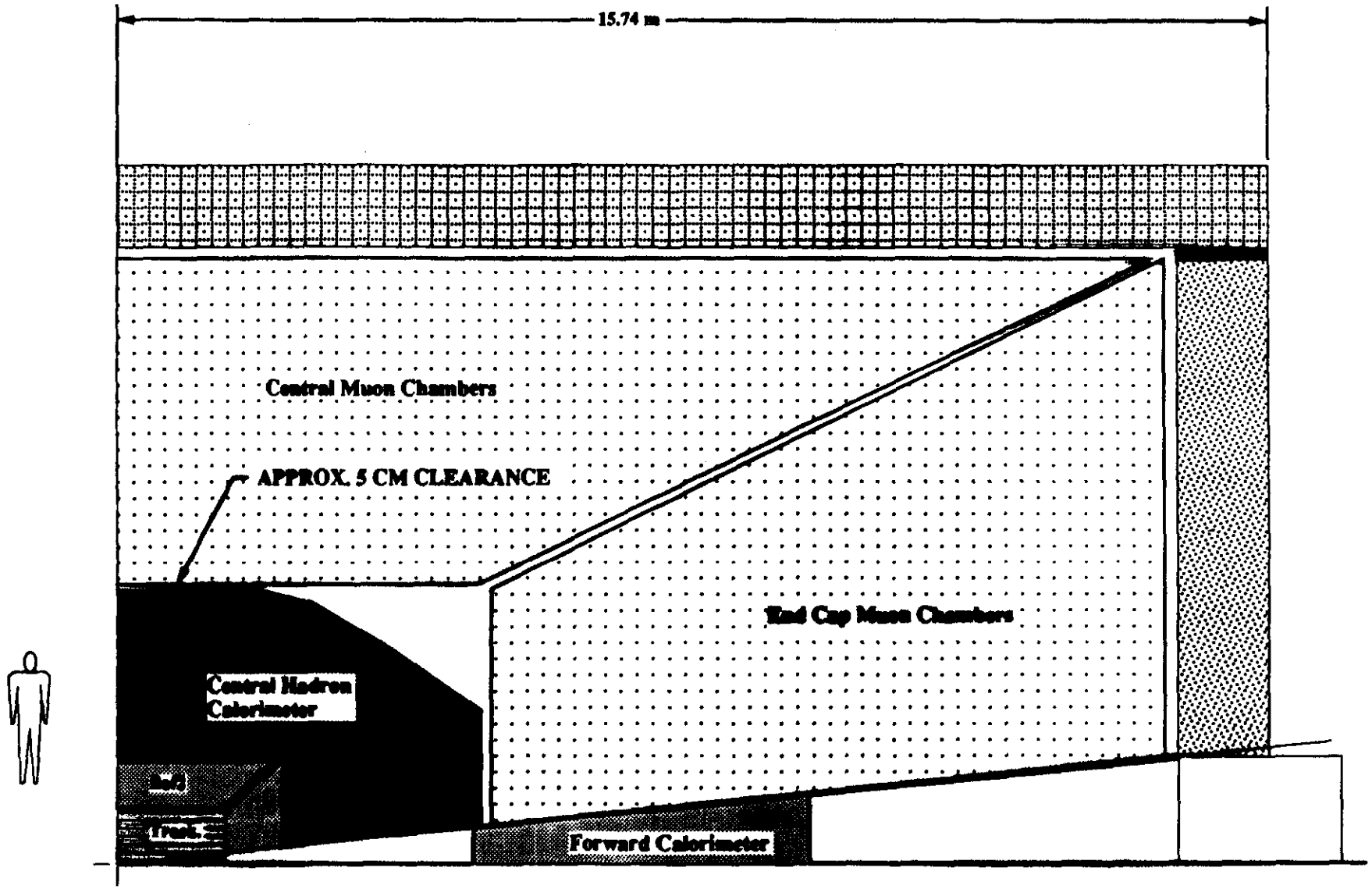
$ Total: $100,300K to $119,100K



GEM
Spaghetti Hadron Calorimeter
Barium Fluoride EM Calorimeter

G.03.FD.00010

Rennich



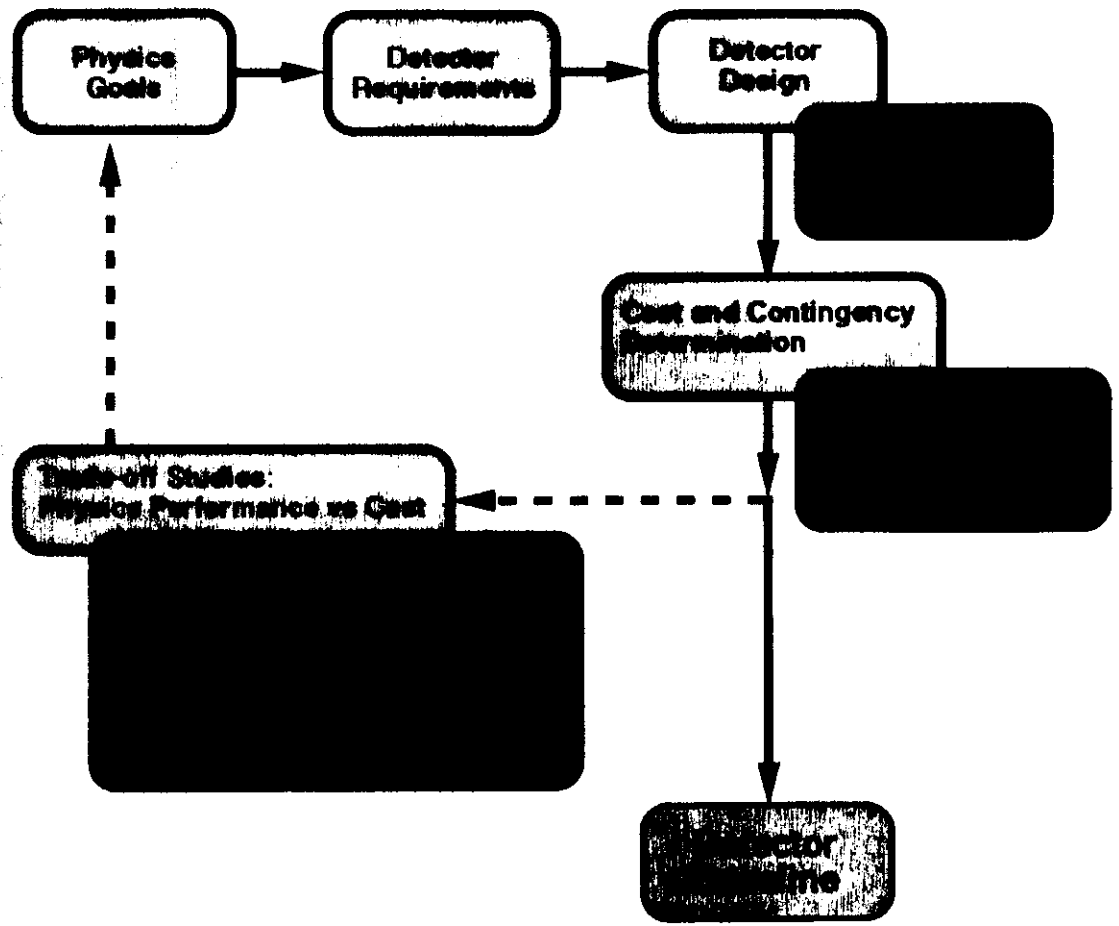
GEM Detector
Hadron Calorimeter
Maintenance Access

G.03.GN.00012

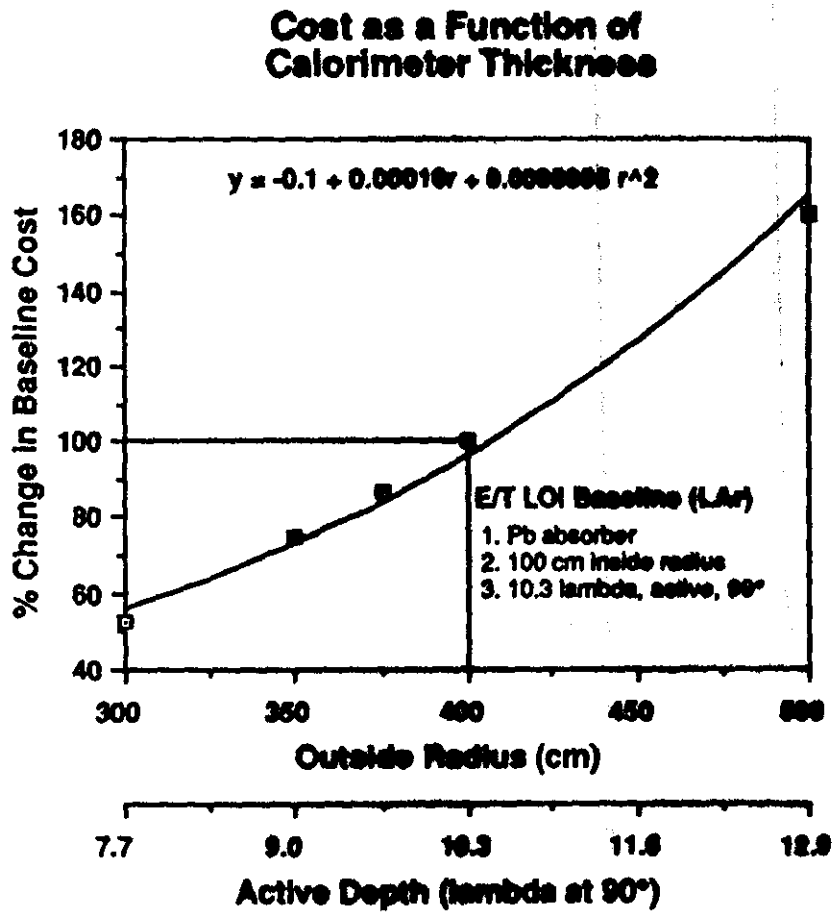
Rennich

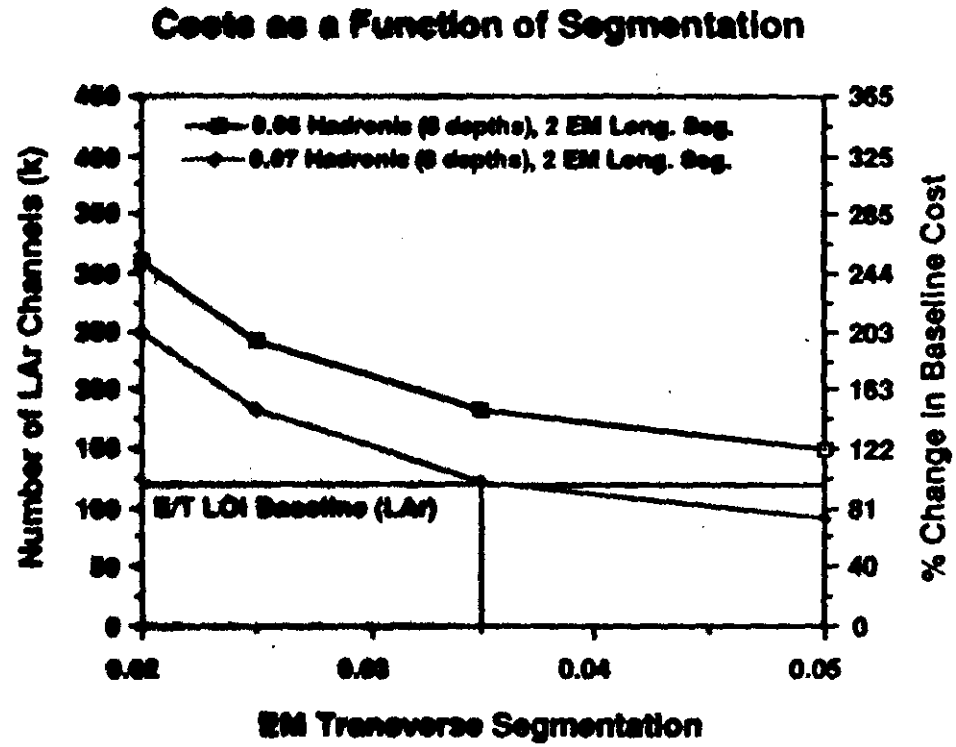
N. Digiacomo

Design to Cost Flow



Examples of LAr Calorimeter Cost/Performance Relationships





LAr Calorimeter Stack Layup

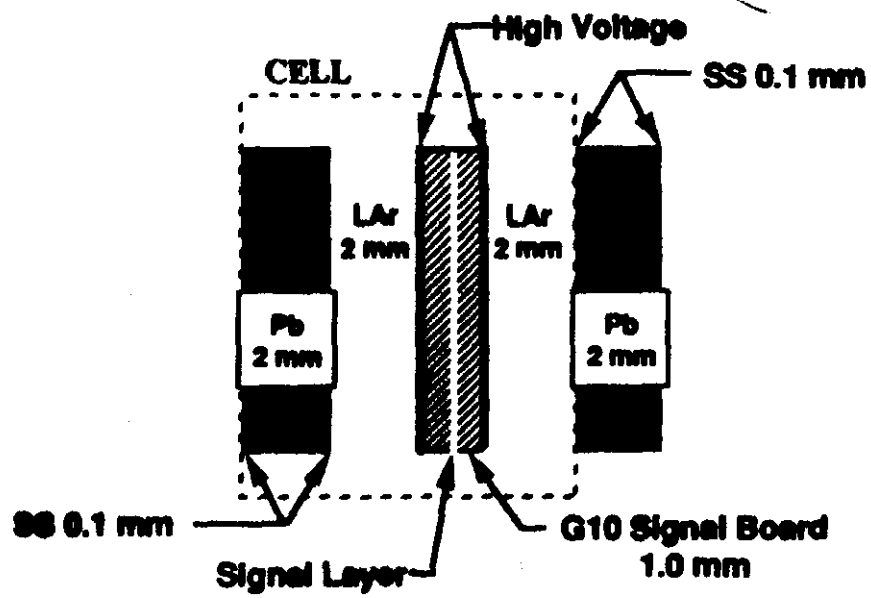
EM

ρ = 4.38 gm/cc

X_o = 1.79 cm

λ = 36.80 cm

Cell Length = 0.72 cm



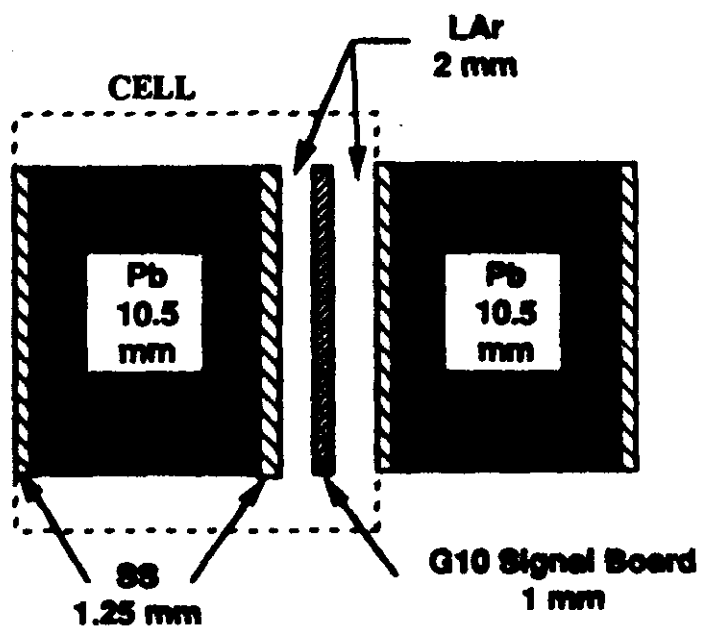
Hadronic

ρ = 8.13 gm/cc

X_o = 0.88 cm

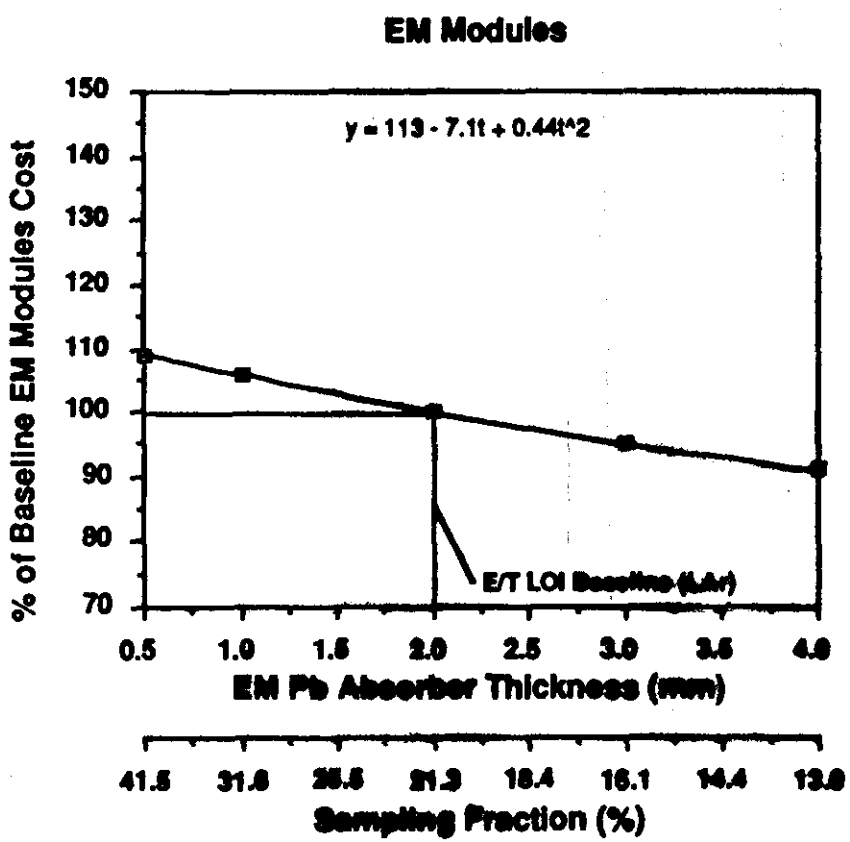
λ = 21.66 cm

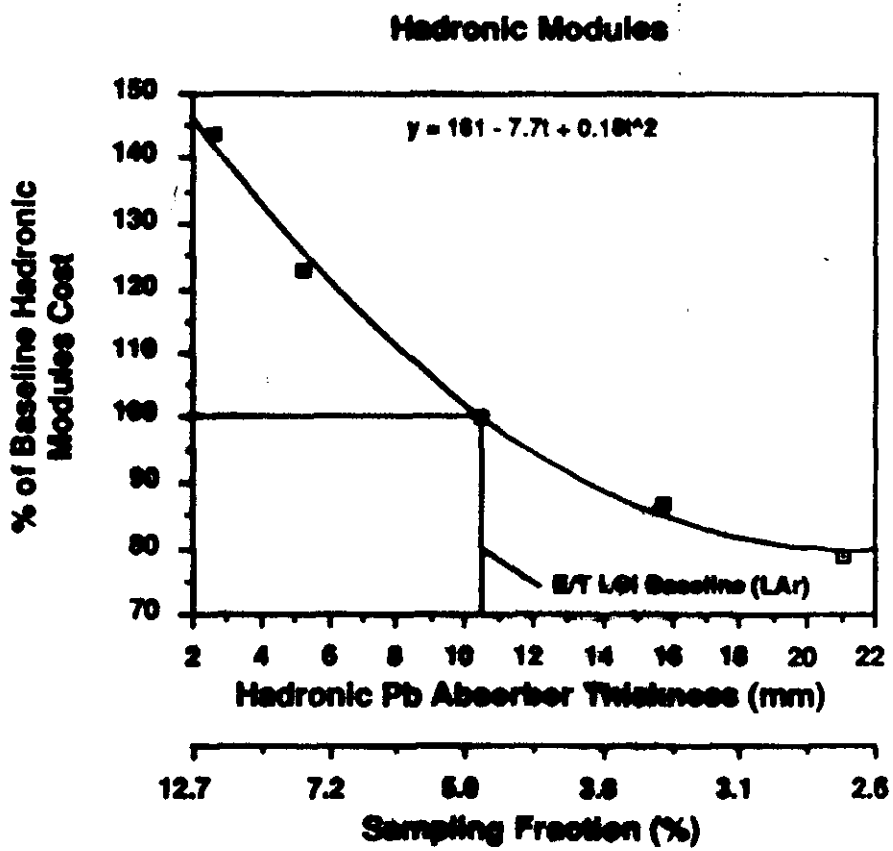
Cell Length = 1.8 cm



Examples of LAr Calorimeter Cost/Performance Relationships

LAr Module Costs as a Function of Sampling Fraction





H. Newman

GEM

A PRECISION LEPTON-PHOTON DETECTOR FOR THE SSC

- **CALORIMETRY GOALS: DRIVEN By PHYSICS**
  - **The Highest Resolution Calorimetry System for Leptons and Photons**
  - **Within Budget and Schedule**
  - **Radiation Hard**
  - **Complementary to SDC**

GEM

PHYSICS GOALS LEAD To TWO SYSTEM APPROACHES

- LOWER RISK SOLUTION EXISTS; NEEDS HIGHER EM RESOLUTION:

  ⇒ LIQUID ARGON With Fine Sampling Accordion EM

- HIGHER RISK SYSTEM, With POTENTIAL LARGE PERFORMANCE GAIN:

  ⇒ BaF_2 CRYSTAL EM, With SCINTILLATOR HCAL

  - NOTE: Radiation Hard Production Not Yet Achieved
    - Requires One Year of R&D
    - Expert Review Panel

GEM

TWO COMPLEMENTARY APPROACHES

RESULTING IN THE HIGHEST FEASIBLE RESOLUTION

- **LIQUID ARGON With ACCORDION EM; Liquid Krypton Option**
  - **Intrinsic Stability**
    ⇒ Ease of Calibration
  - **Tested in Large Systems (With Plates)**
    ⇒ Small Systematics
  - **Radiation Resistant**
  - **Uniform**
- **BaF_2 CRYSTAL EM, With SCINTILLATOR HCAL**
  - **Intrinsic Higher EM Resolution**
  - **Higher HCAL Speed:**
    ⇒ Lower Noise in Isolation Cone
  - **Effective Compensation:**
    ⇒ Small Constant Term for Jets
    With HCAL $e/\pi \approx 1$
  - **More λ for a Given Radius**

GEM CALORIMETRY

- **COMPLEMENTARY STRENGTHS:**

  INTRINSIC RESOL'N and SPEED $\Longleftrightarrow$ **LOWER RISK TECHNOLOGY**

- **COMPLEMENTARY TASKS for EM:**

  $\sigma_E/E = (a/\sqrt{E} \oplus b)\%$

  BaF_2 + SCINT. HCAL $\Longleftrightarrow$ **LIQUID ARGON**

  Reduce b $\leq$ 0.5% — **Reduce a $\leq$ 7%**

  ↑

  → DESIGN and SIMULATE as a SUBDETECTOR of GEM

BaF_2 + CALORIMETER SYSTEM:

Scintillating Fiber (SF) or Liquid Scintillator (LS); Liquid Argon Study

Choice of One Scintillator HCAL By Early November

HCAL SUBSYSTEM GOALS:

- Complement the BaF_2:
  $\Delta\eta \times \Delta\phi \approx 0.08 \times 0.08$

  $\Rightarrow$ Good Jet Resolution

  $\Rightarrow$ Missing E_T Resolution, (With Forward HCAL)

  $\Rightarrow$ Improved Lepton ID and Measurement

- Rapid Development: Ready for GEM System Choice By Design Report

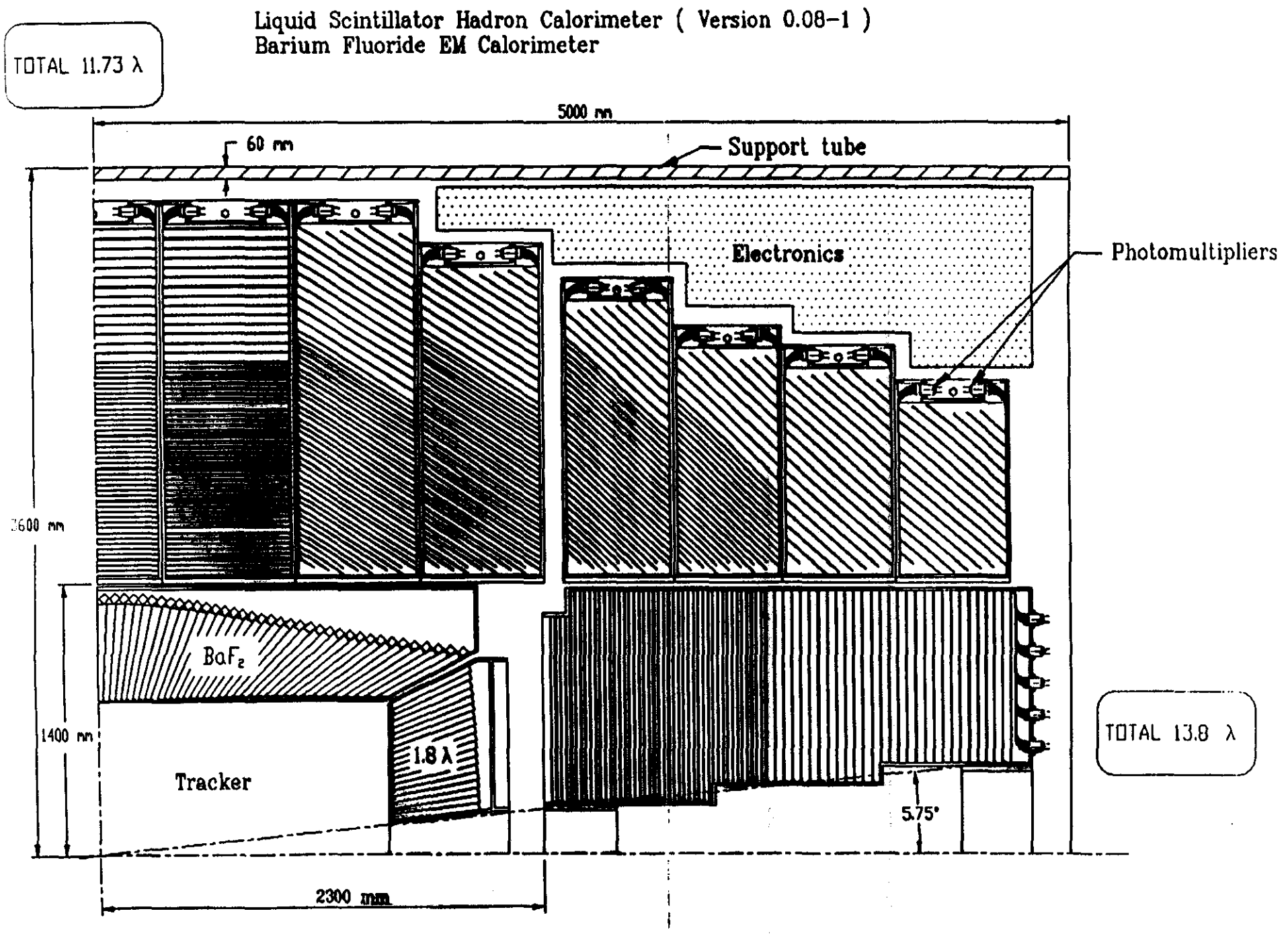
  $\Rightarrow$ Beam Test By Summer 1992

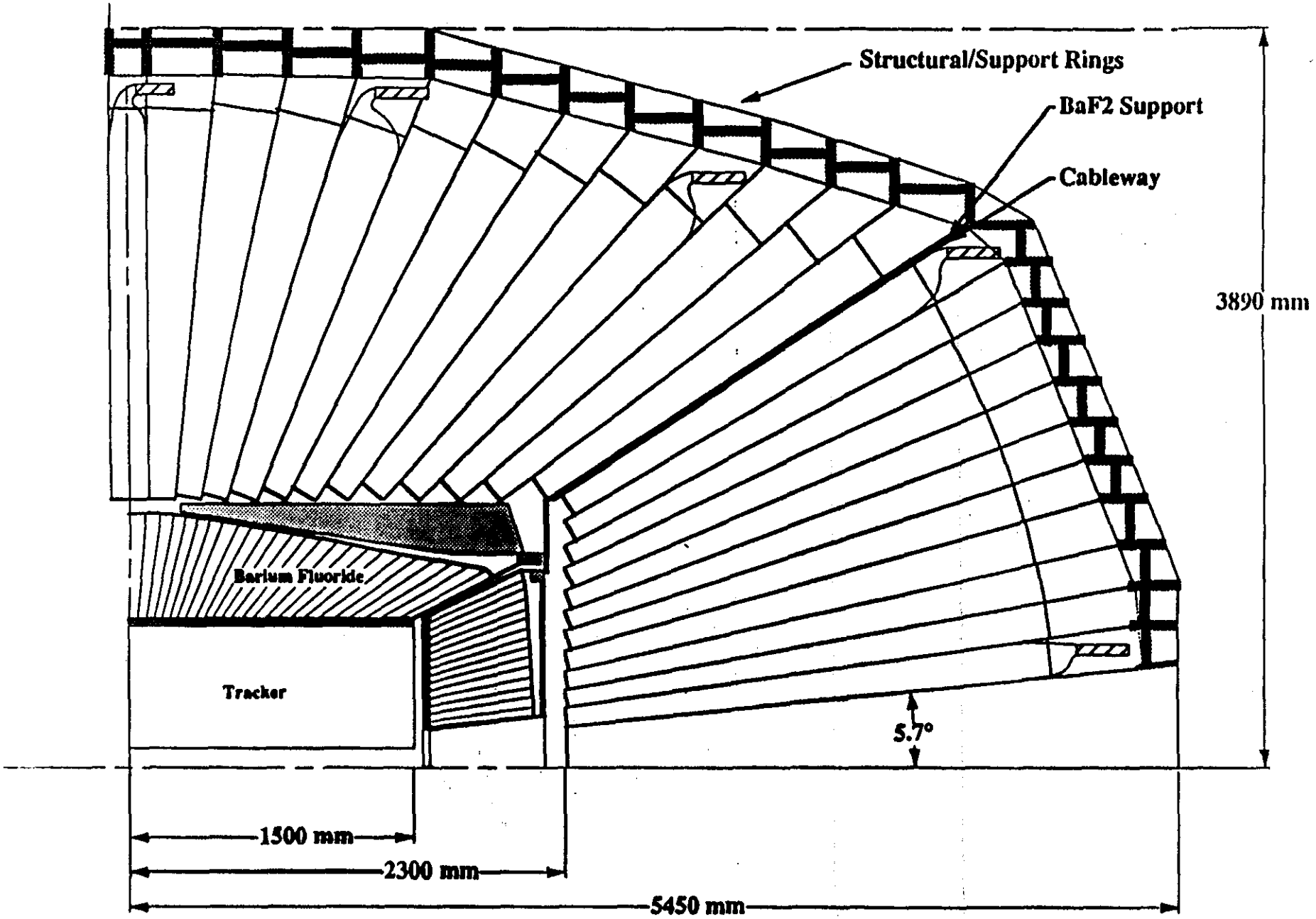
- Maximize GEM's Physics Capability

BaF_2 + HCAL CHOICE: GENERAL QUESTIONS:

Answers In October

- **Conceptual Design Layouts With Dimensions:**
  - ⇒ **LS: Module, Layer Structure, Fiber Readout**
  - ⇒ **SF: Module Structure, Fiber Readout**
  - ⇒ **LAr: Segmentation, Cryostat, Readout**
  - ⇒ **ALL: Mechanical Structures and Supports; Access/Assembly/Disassembly Scheme**
- **HCAL Depth (λ); Dead Spaces**

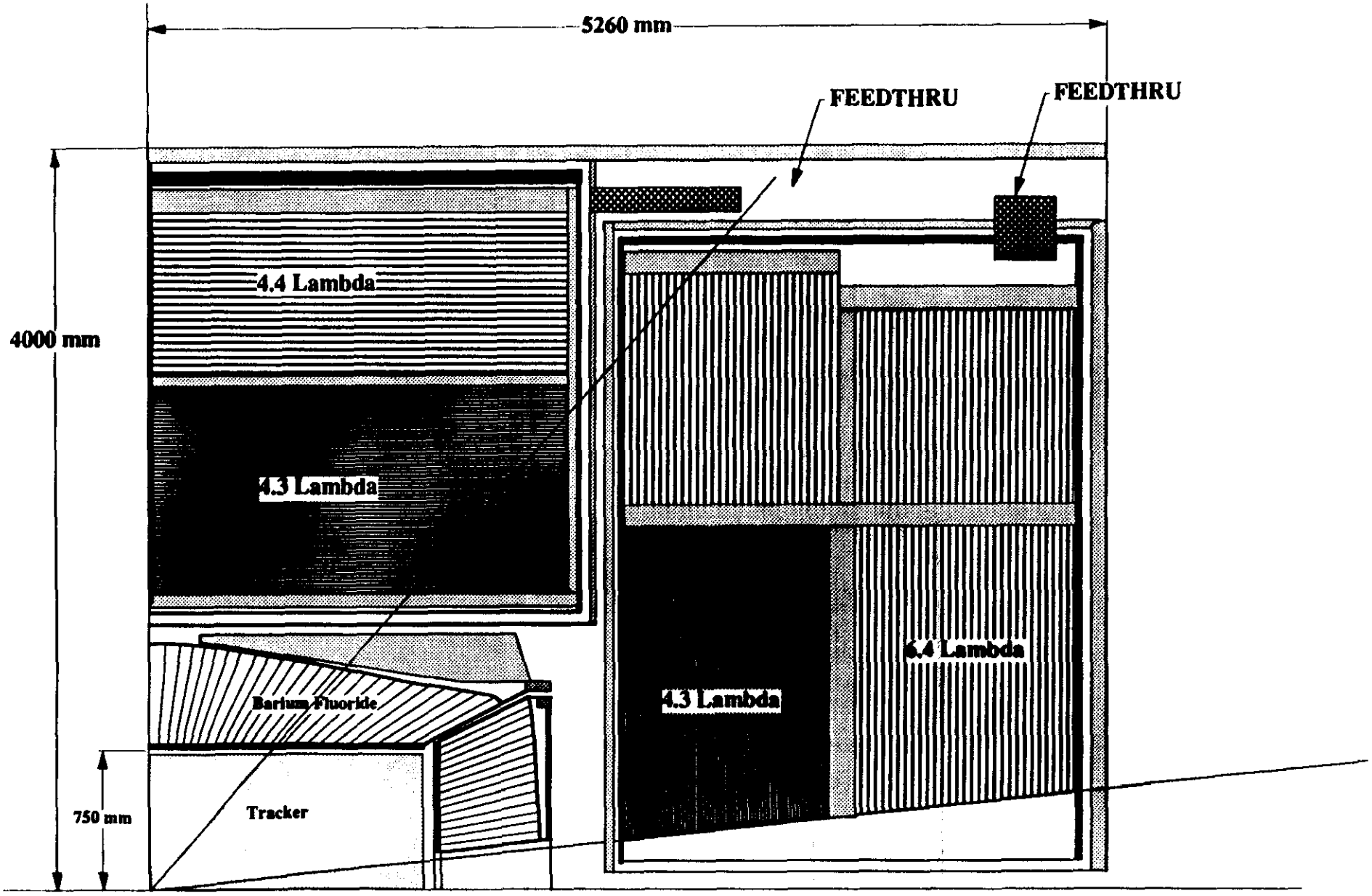

Liquid Scintillator Hadron Calorimeter (Version 0.08-1)
Barium Fluoride EM Calorimeter
TOTAL 11.73 λ
5000 mm
60 mm
Support tube
Electronics
Photomultipliers
3600 mm
BaF2
1400 mm
1.8 λ
Tracker
TOTAL 13.8 λ
5.75°
2300 mm



Spaghetti Hadron Calorimeter
Lead Shot Filled/ 0.10 Segmentation
Barium Fluoride EM Calorimeter

G.03.SC.00038

Rennich



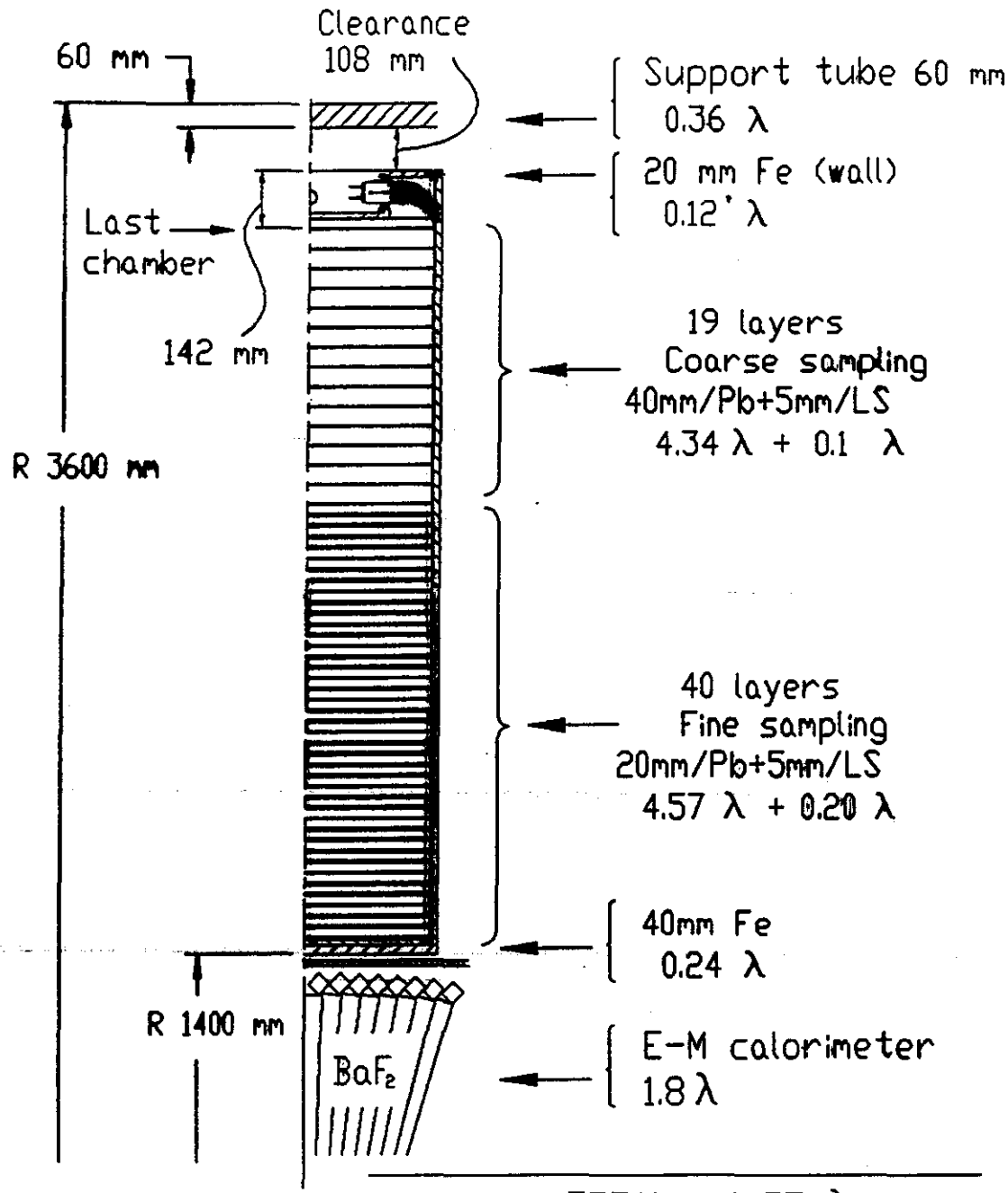
Total Thickness: 11 Lambda

G 03 I A 00019

GEM
Liquid Argon Calorimeter
Barium Fluoride EM Section

Incomplete
Incomplete
Incomplete

Liquid Scintillator Hadron Calorimeter
Sampling structure scheme



TOTAL 11.73 λ

λ_{Pb} = 175 mm

λ_{Fe} = 168 mm

λ_{Scl} = 1000 mm

BaF_2 + HCAL CHOICE: PHYSICS QUESTIONS

SIMULATION STUDY COMPLETED By NOVEMBER:

- **Energy Resolution, Behind BaF_2 for 20, 100, 500, 1000, ... GeV Jets**
  - **Performance For Typical, Mostly-EM, and Mostly-Hadronic Jets:**
    - ⇒ **Reconstructed Energy Distribution**
    - ⇒ **Missing E_T Distribution**
- **Can Longitudinal Segmentation in the HCAL Improve the Muon Resolution ?**
- **Can Longitudinal Segmentation in the HCAL Improve the BaF_2 Electron and γ Resol'n ?**
- NUMBER of $\lambda \Leftrightarrow$ Performance

BaF_2 + HCAL CHOICE: ASSOCIATED EFFECTS and ISSUES

- **Systematic Effects:**
  - ⇒ **Magnetic Field (0.8 Tesla)**
  - ⇒ **Non-Uniformities in Cells or Towers**
  - ⇒ **Fiber Attentuation Length, Non-Uniformity**
  - ⇒ **Mechanical Structure, Walls, and Typical 'Dead Regions'**
- **Effective Compensation: Hydrogenous, Compensating or Overcompensating HCAL.** *
- **Resolution as Function of e/h in EM Section, With Varying Reconstruction Algorithm.**
- **Transverse Segmentation Required by Physics**

* GEANT vs. HETC Study:

- Preliminary Results (ORNL)

Y. Kamyshkov

e / h in BaF_2

1. e/h in BGO :

   a) L3 20 x 20 cm^2 BGO/HC prototype beam test (1986)
   e/h < 2.0 (hadronic leakages)

   b) L3 Z^o-> 2 jets data
   e/h > 1.4 (from jet resolution optimization)

   c) L3 MC with leakage correcions for single hadrons
   e/h ~ 1.6 - 1.7

2. BaF_2 GEANT MC simulations (by K.Shmakov @ ORNL)

   a) GEANT gives e/h ~ 1.3 for BaF_2

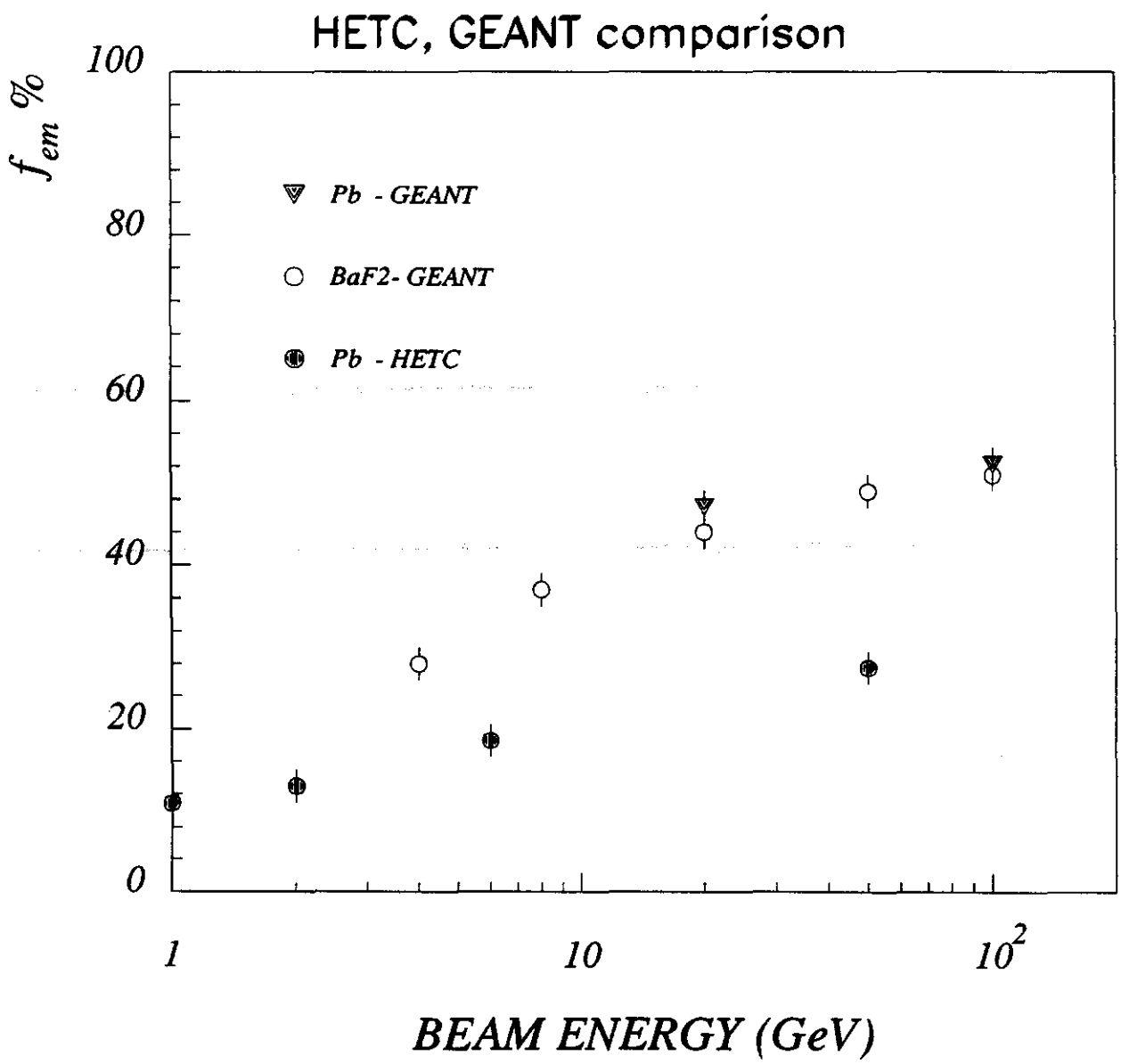
   b) e/h adjustment made (1.3 -> 1.7) by applying weights to e-m and hadronic components of hadronic shower in BaF_2; Energy dependence of e/h from GEANT is preserved.

   c) No transverse segmentation was simulated. No jet topological reconstruction was applied.

Birks coefficients for different detectors

Detector	BGO	Ba F_2	LAr	Plastic scintil.	Liquid scintil.
k_B $g/cm^2/MeV$	0.0013	? same as BGO	0.004 - 0.008	0.012	? same as plastic sc.

Electromagnetic fraction in a hadronic shower



e/h adjustment in GEANT

Responses for $e(\gamma)$ and charged hadrons are stored after GEANT separately as e_i- and h_i- hits

- Non corrected GEANT response for hadrons E_h

$$R_h^k = \sum_i e_i^k + \sum_j h_j^k \quad \text{or} \quad \langle R_h \rangle = \langle \Sigma e_i \rangle + \langle \Sigma h_i \rangle$$

i,j-th hit in k-th event

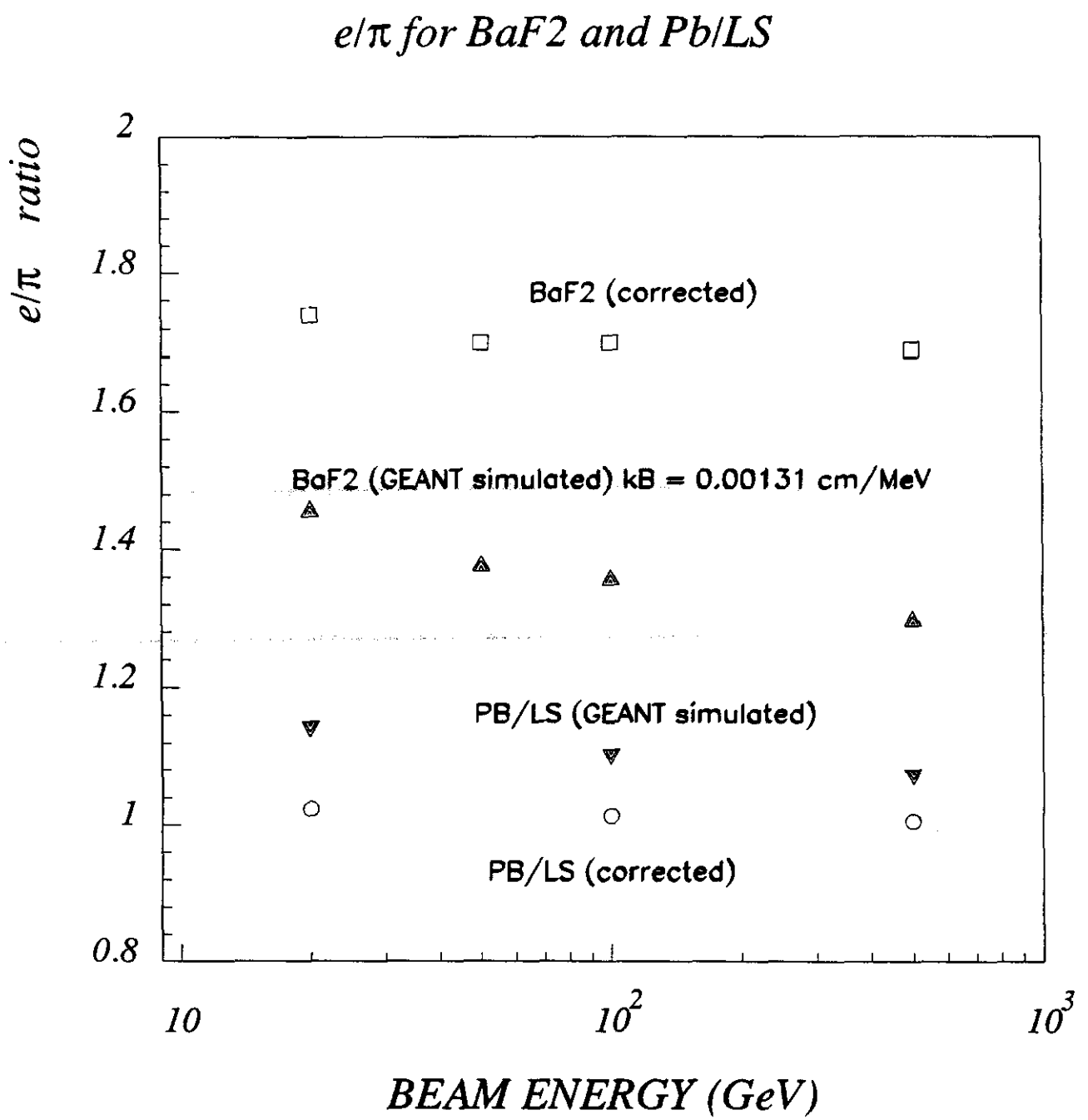
$$\left.\begin{aligned} &\frac{\langle \Sigma e_i \rangle}{E_h} \sim 0.55 \\ &\frac{\langle \Sigma h_i \rangle}{E_h} \sim 0.21 \ (BaF_2) \\ &\frac{\langle \Sigma h_i \rangle}{E_h} \sim 0.35 \ (Pb/LS) \end{aligned}\right\} \text{from noncorrected GEANT}$$

- Response for single electron : $R_e^m = \sum_i e_i^m$
- Response for single hadron : $\boxed{R_h^k = \varepsilon \sum_i e_i^k + \eta \sum_j h_j^k}$

$\varepsilon = 0.58$ to reduce the fraction of e-m component of hadronic shower in GEANT (see fig.)

$\eta \sim 1.3$ for BaF_2 to have $e/h = \langle R_e \rangle / \langle R_h \rangle \sim 1.7$

$\eta \sim 1.9$ for Pb/LS to have $e/h = \langle R_e \rangle / \langle R_h \rangle \sim 1.0$


e/π for BaF2 and Pb/LS
e/π ratio
2
1.8
1.6
1.4
1.2
1
0.8
BaF2 (corrected)
BaF2 (GEANT simulated) kB = 0.00131 cm/MeV
PB/LS (GEANT simulated)
PB/LS (corrected)
10
10^2
10^3
BEAM ENERGY (GeV)

Resolution optimization for the combined system $BaF_2 + Pb/LS$

b_i – response of BaF_2 in i-th event
h_i – response of Pb/LS HC in i-th event
Reconstructed energy:
$E_i^{rec} = \alpha b_i + \beta h_i$ – event by event if α, β are defined

$\langle E_i^{rec} \rangle = \alpha \langle b_i \rangle + \beta \langle h_i \rangle$ – averaging by events

For every monojet energy two constraints were applied to define α and β at this energy (E^{jet}) thus allowing for α and β energy dependence

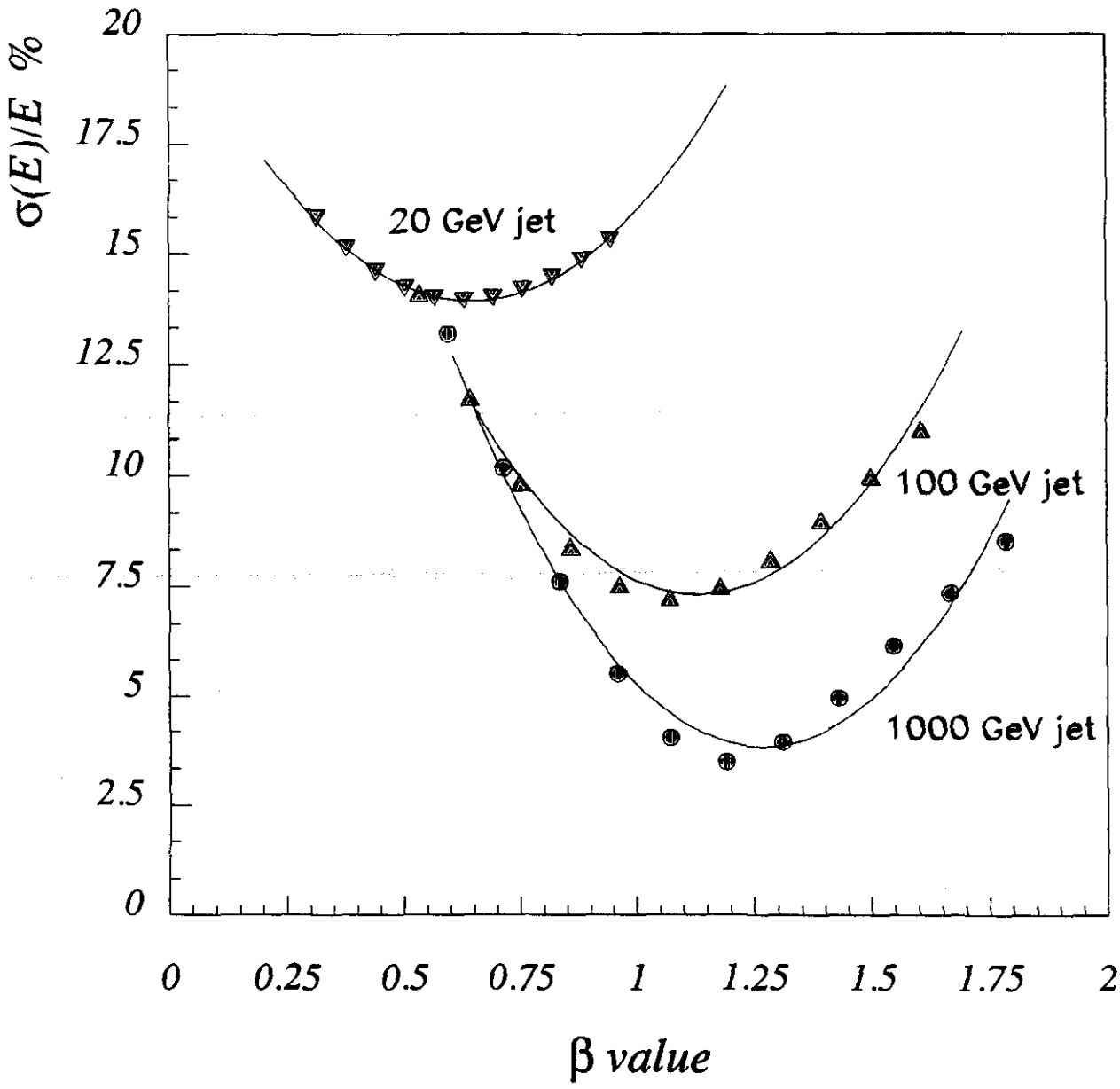
(1) $\langle E_i^{rec} \rangle = E^{jet} = \alpha \langle b_i \rangle + \beta \langle h_i \rangle$ or $\alpha = \dfrac{E^{jet} - \beta \langle h_i \rangle}{\langle b_i \rangle}$

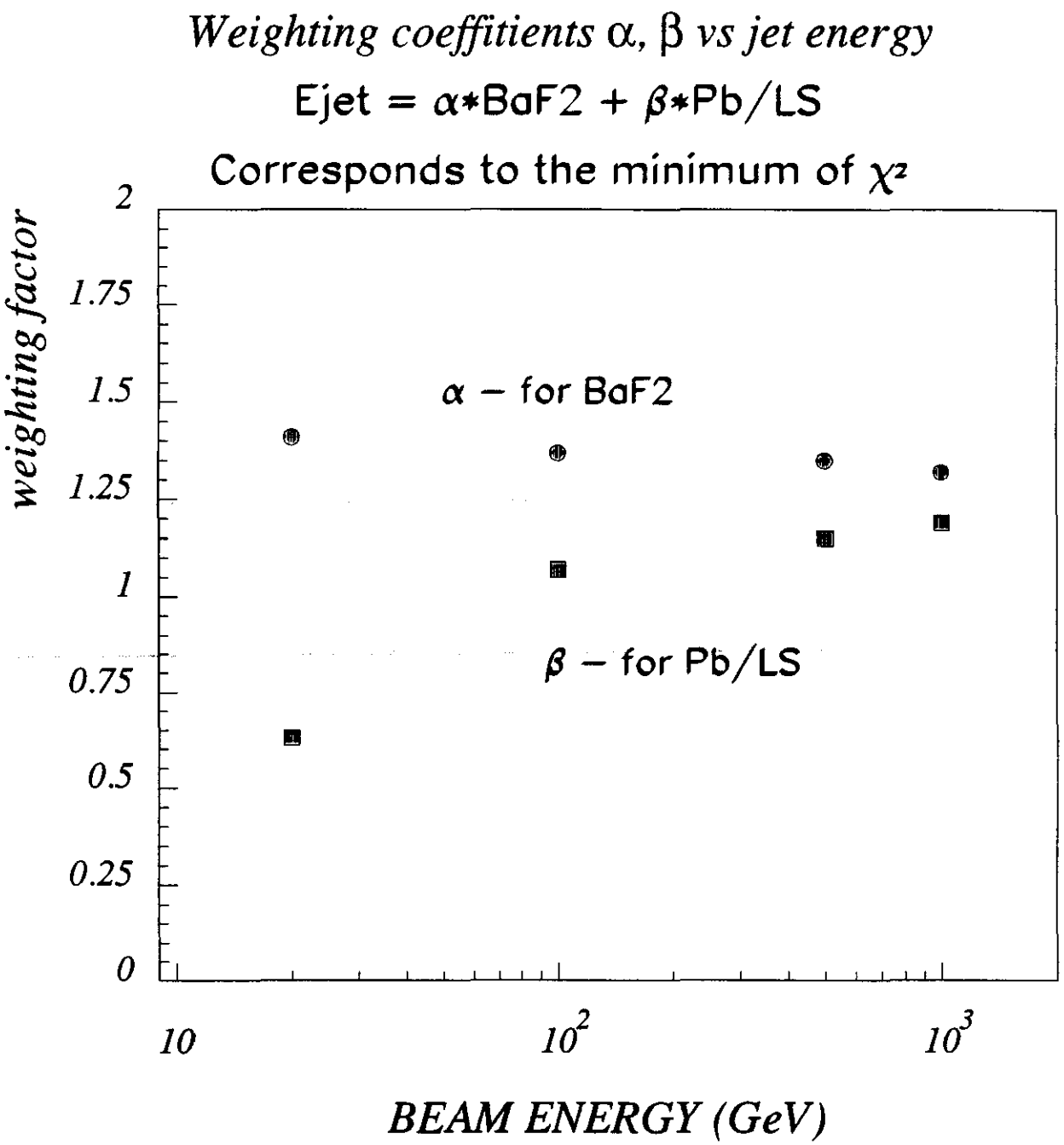
– this preserves linearity of average response

(2) $\min \chi^2 = \min \left\{ \sum_i (E_i^{rec} - E^{jet})^2 \right\}$

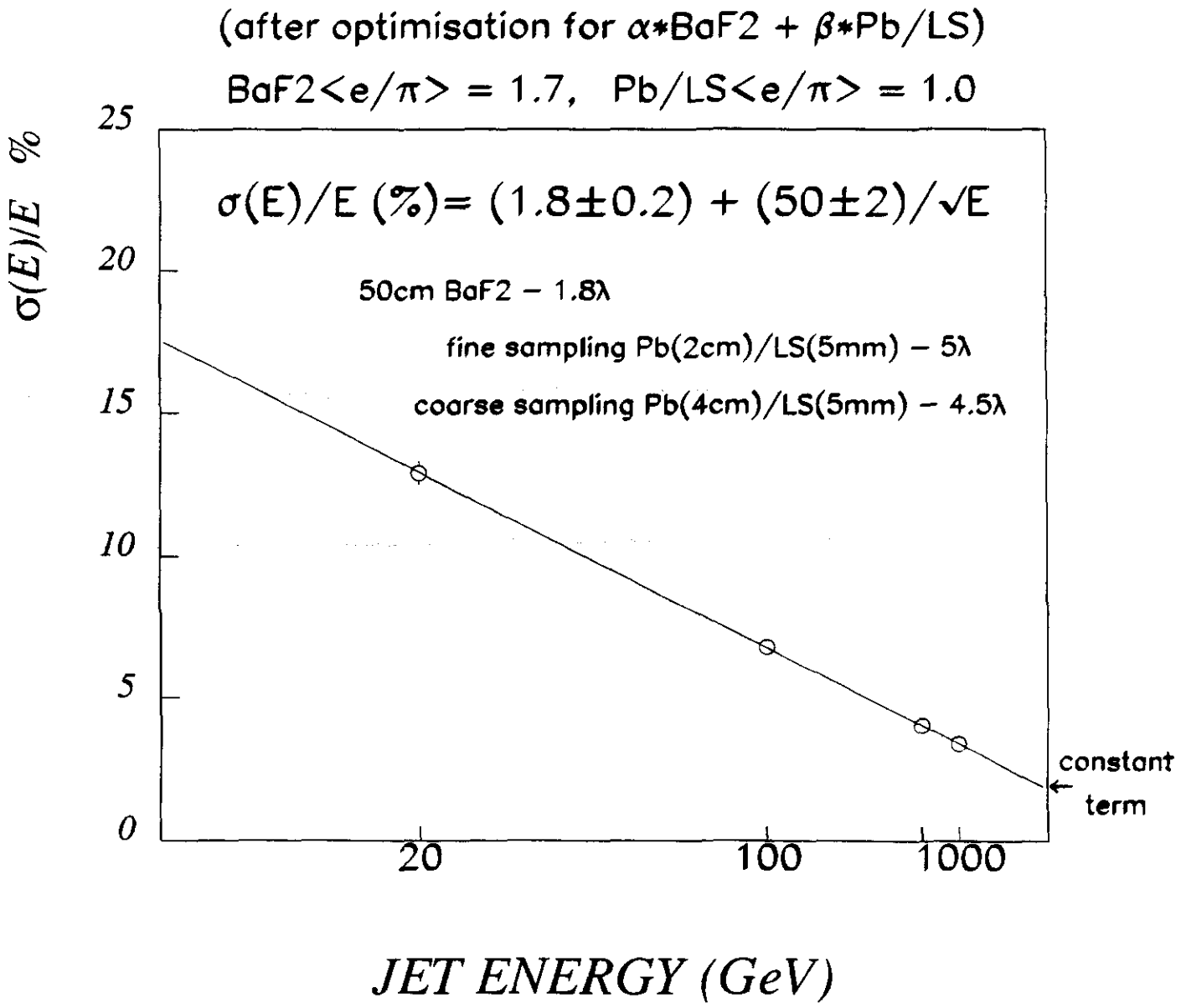
minimization of χ^2 vs single parameter β will define β (can be resolved analitically $\partial \chi^2 / \partial \beta = 0$ etc...)

Variation β(Pb/LS) near the optimum value

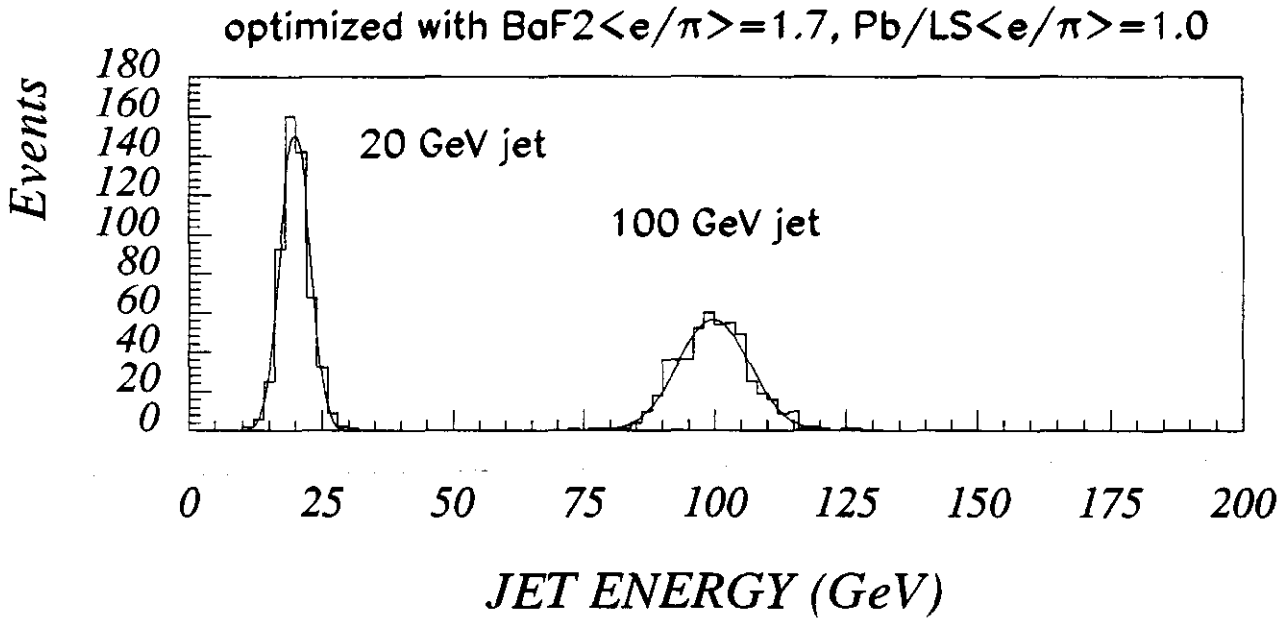


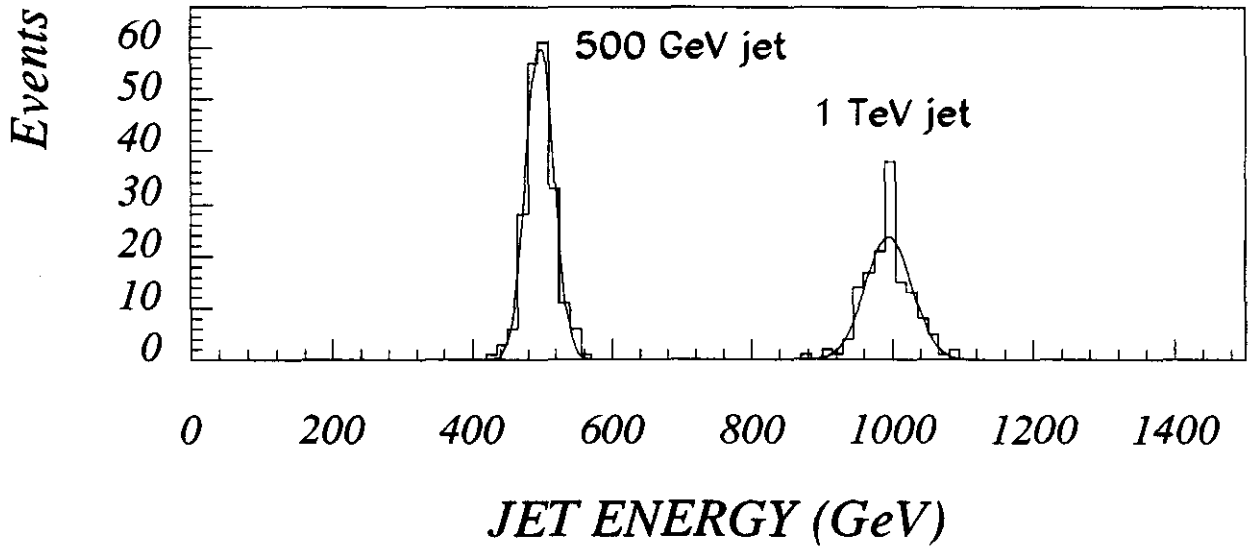

Weighting coeffitients α, β vs jet energy
Ejet = α*BaF2 + β*Pb/LS
Corresponds to the minimum of χ²
weighting factor
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
α – for BaF2
β – for Pb/LS
10
10²
10³
BEAM ENERGY (GeV)

JET RESOLUTION - GEANT3



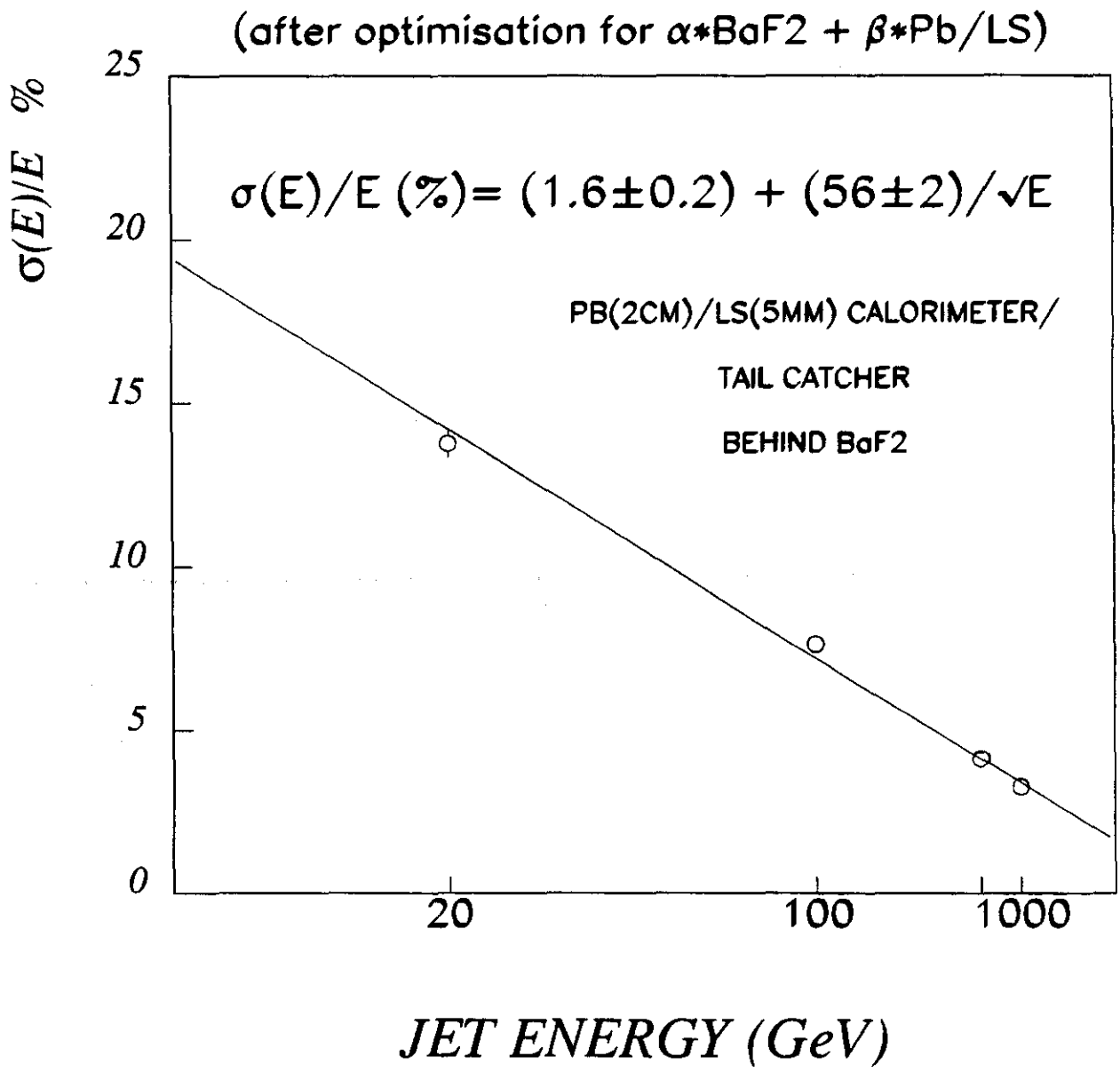
MONOJET RESOLUTION



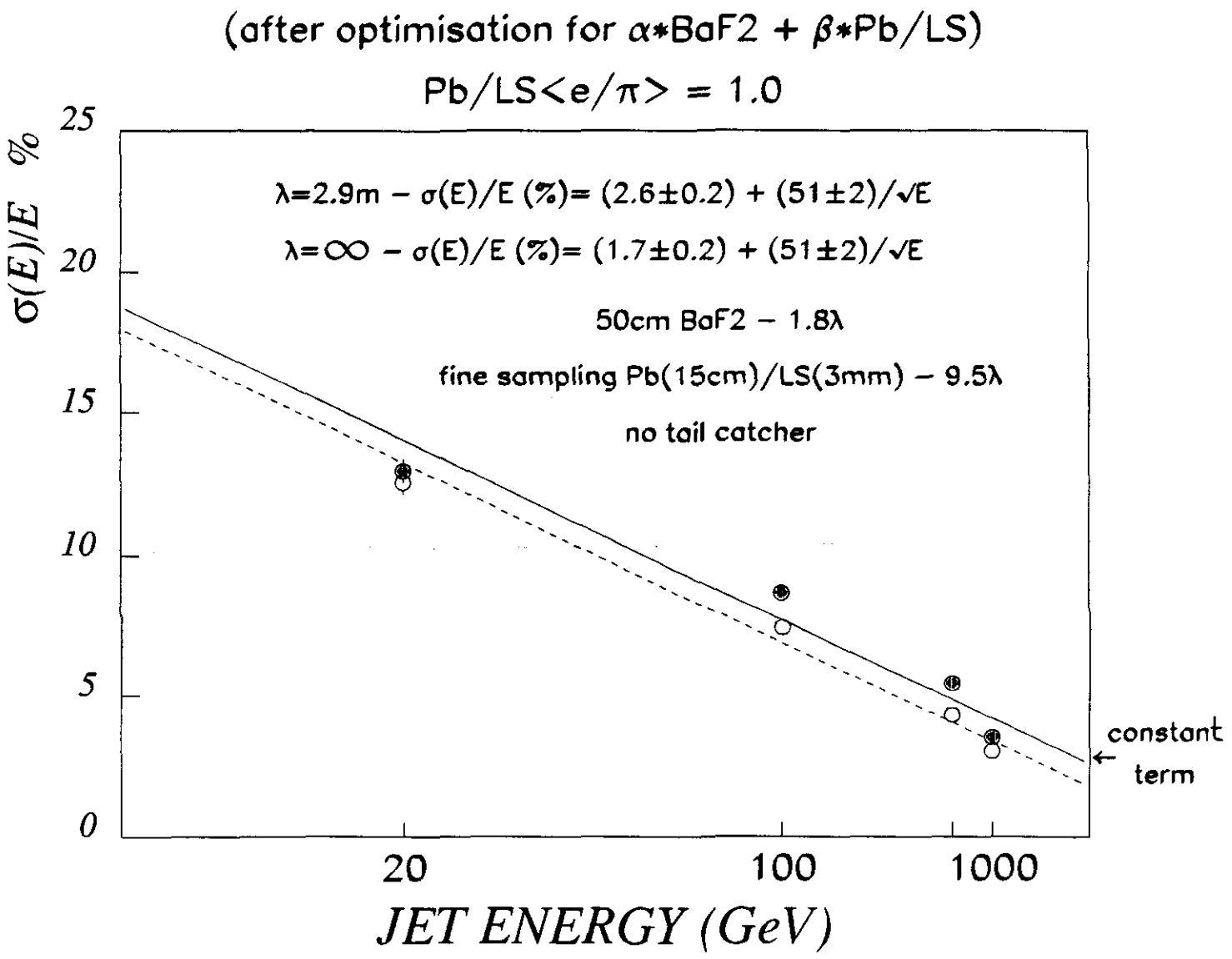


$e/h\,(BaF_2) \cong 1.3$; $e/h\,(HC) \simeq 1.0$

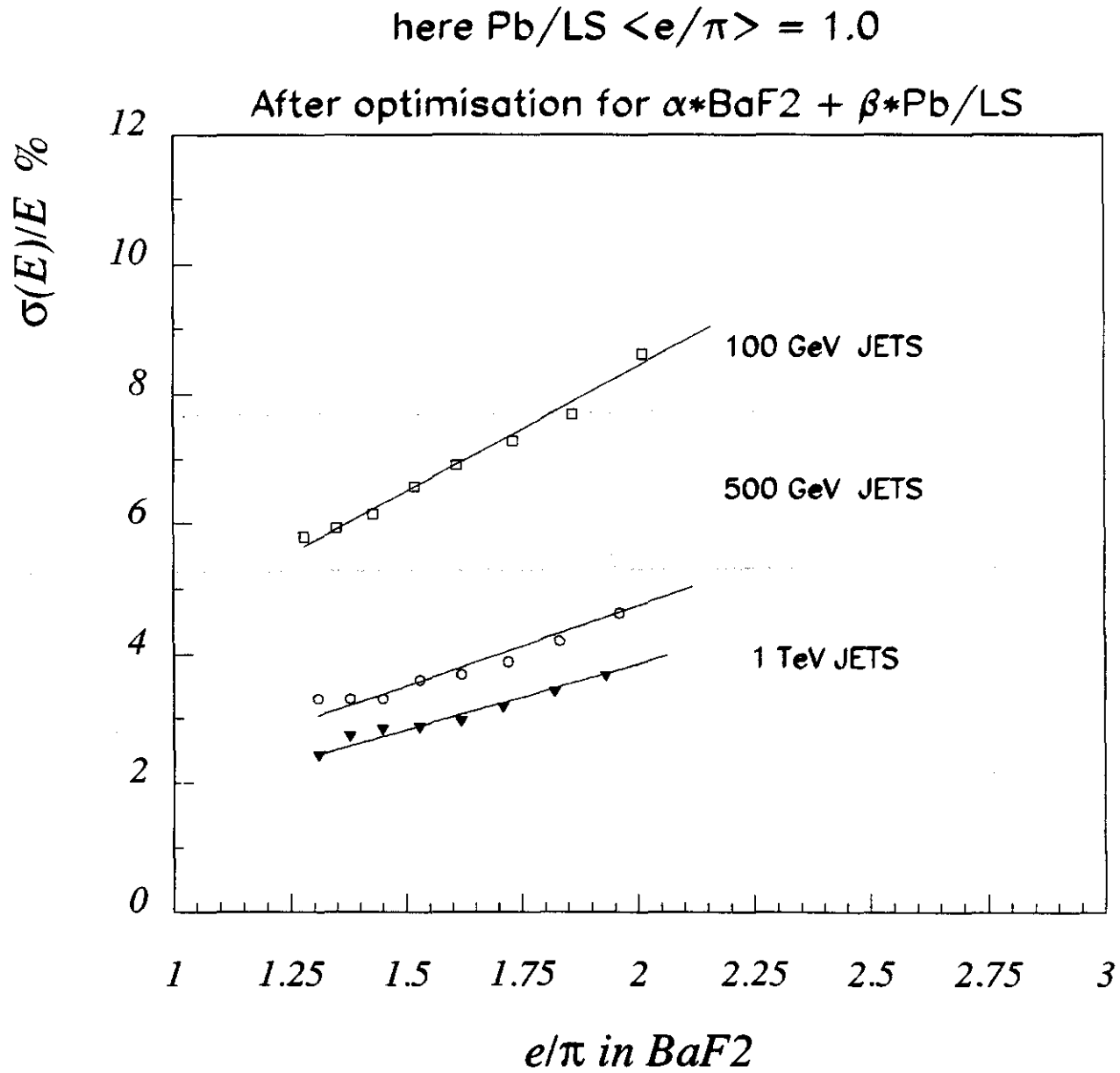
JET RESOLUTION - GEANT3



JET RESOLUTION - SPAGHETTI PLATE CALORIMETER



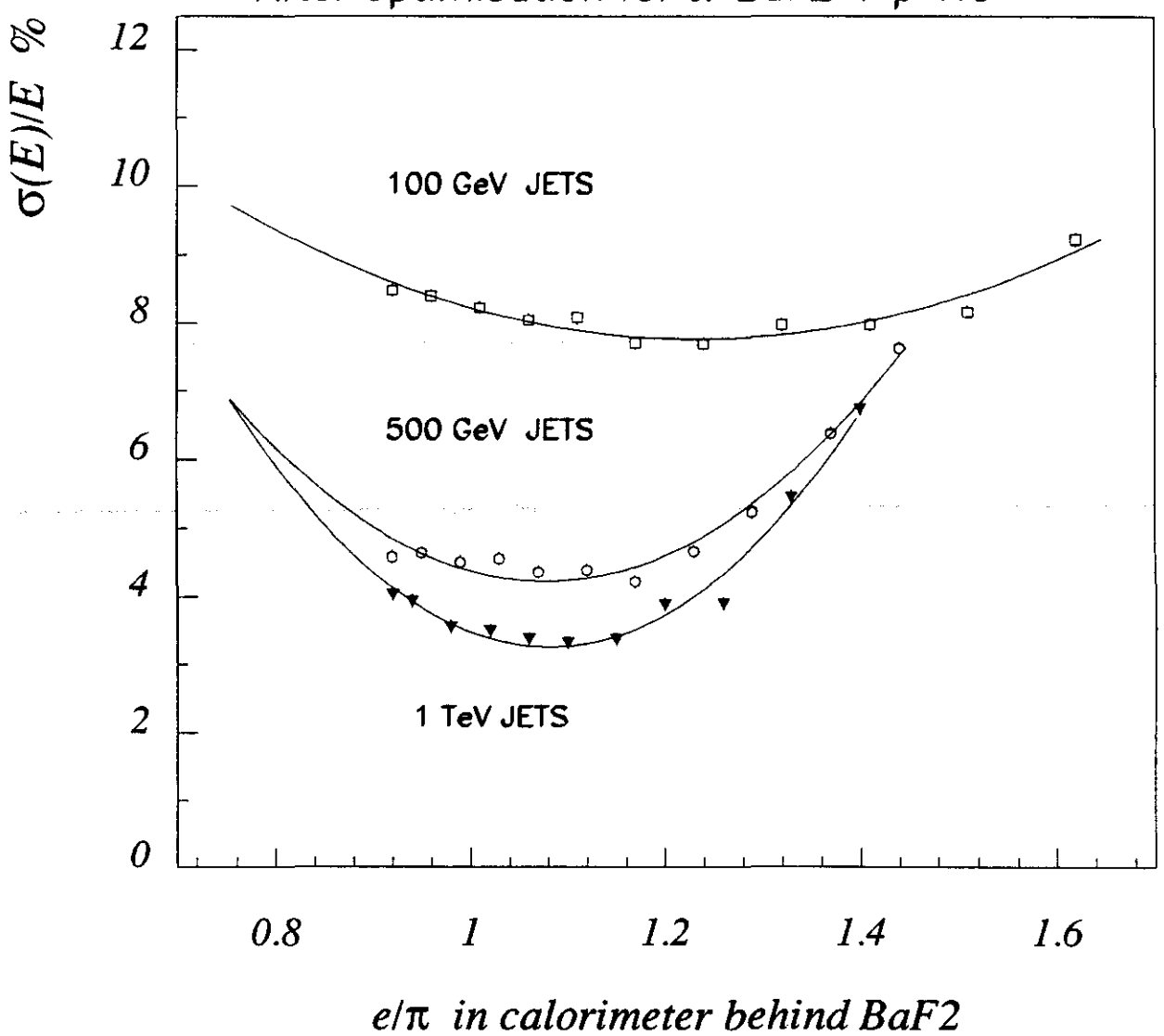
GEANT3 - JET RESOLUTION for (BaF2+Pb/LS) calorimeter

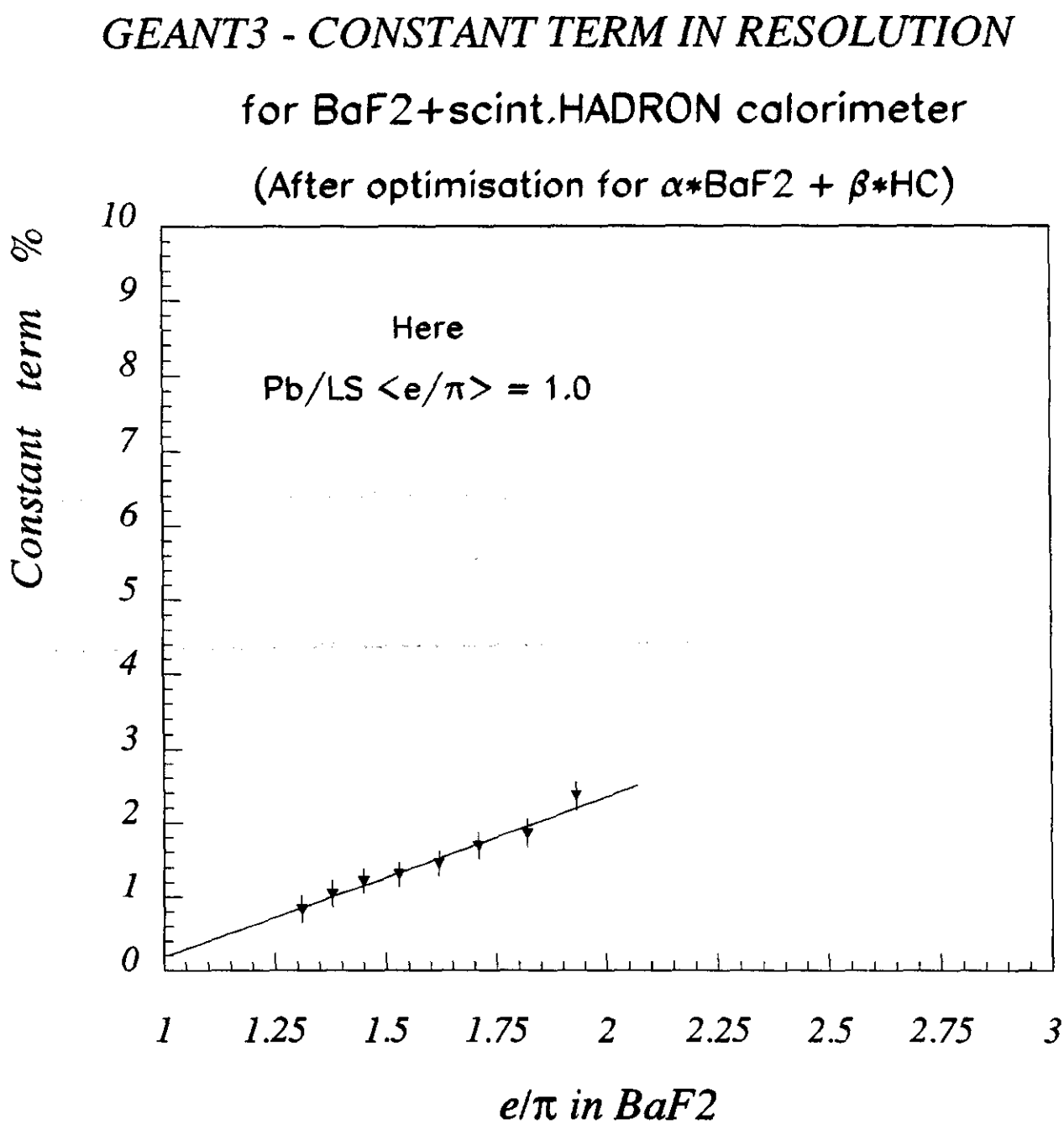


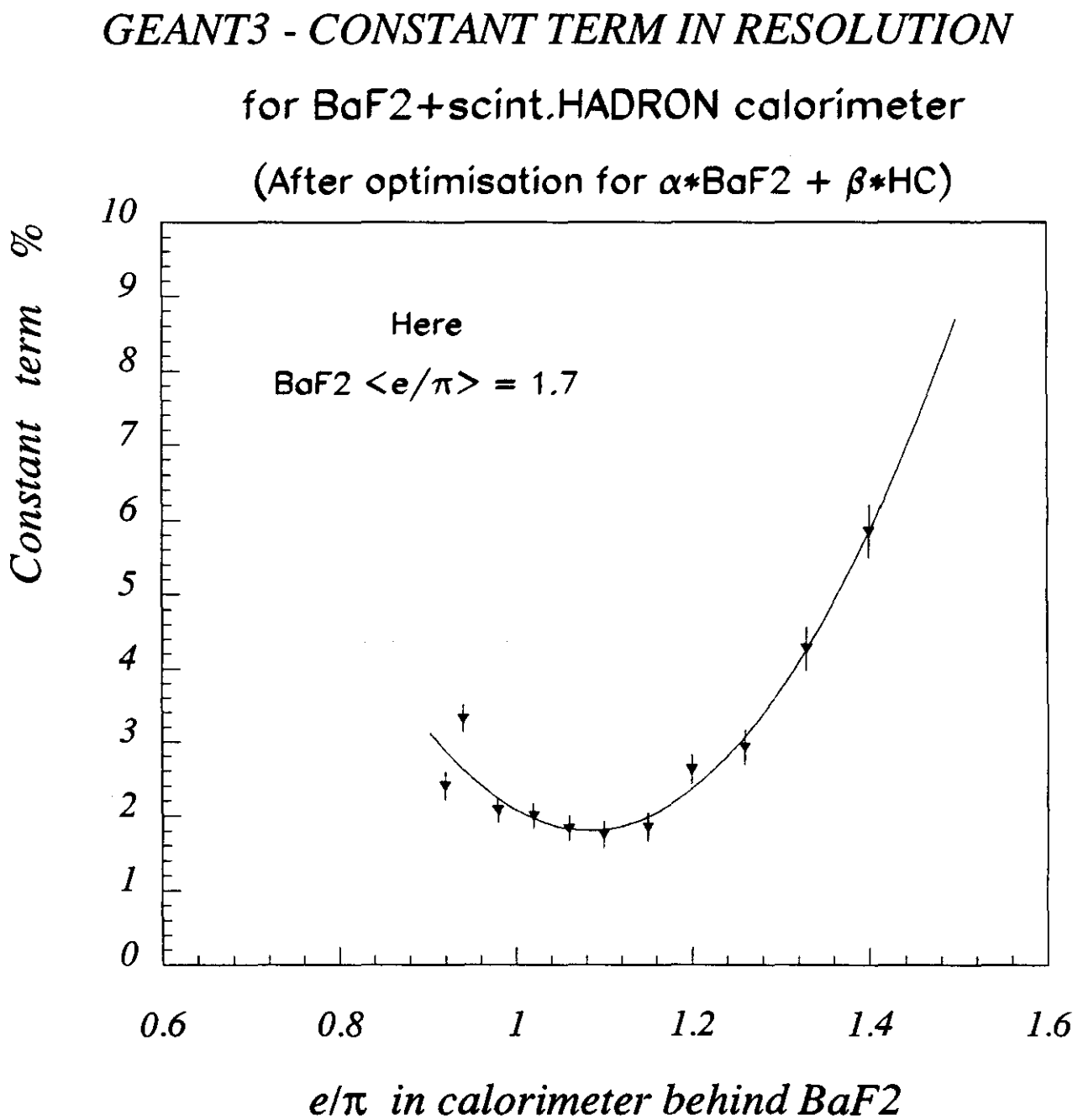
GEANT3 - JET RESOLUTION for BaF2+scint.HADRON calorimeter

here BaF2 <e/π> = 1.7

After optimisation for α*BaF2 + β*HC

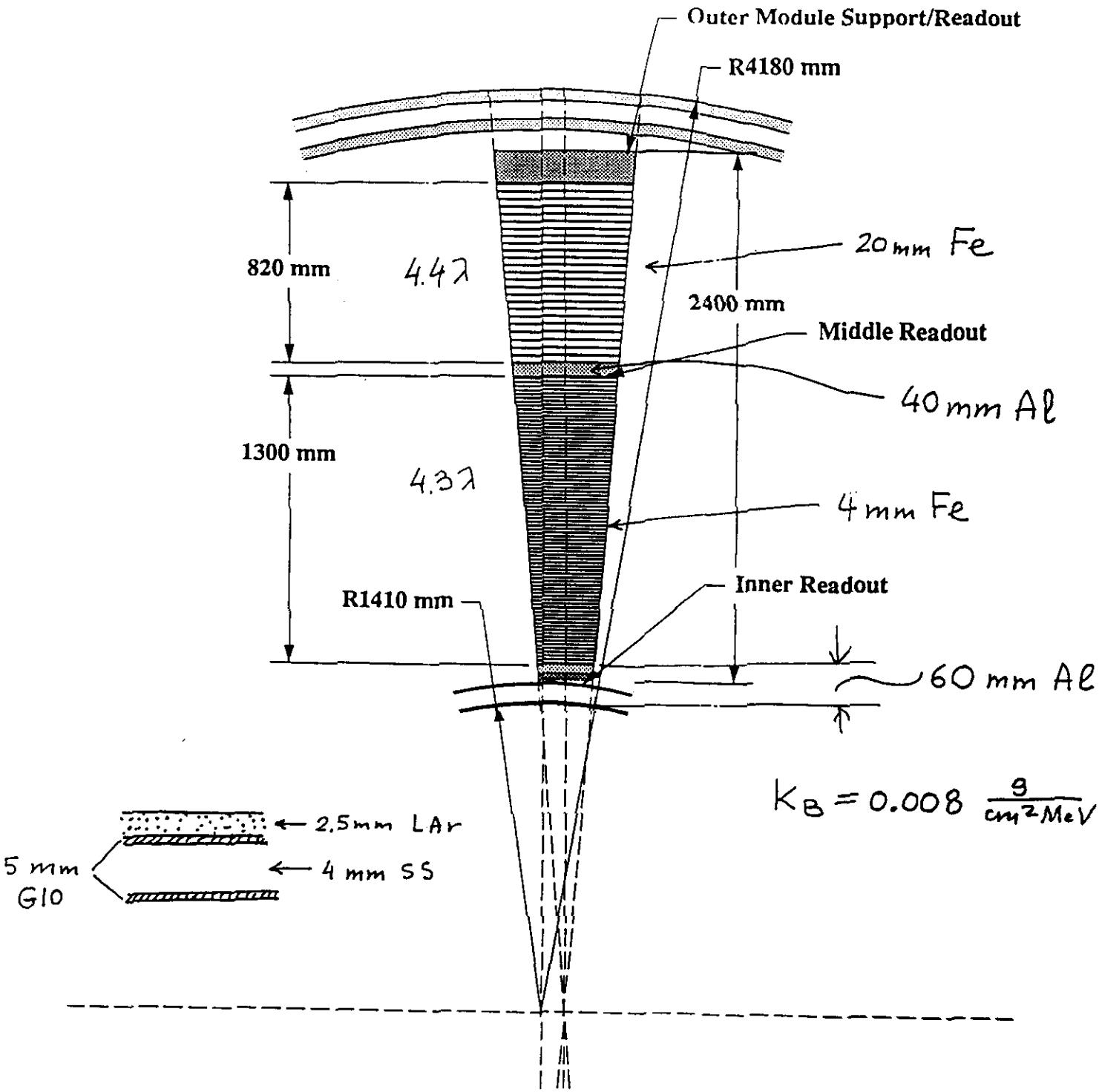



GEANT3 - CONSTANT TERM IN RESOLUTION
for BaF2+scint.HADRON calorimeter
(After optimisation for α*BaF2 + β*HC)
Here
Pb/LS <e/π> = 1.0
Constant term %
10
9
8
7
6
5
4
3
2
1
0
1
1.25
1.5
1.75
2
2.25
2.5
2.75
3
e/π in BaF2


GEANT3 - CONSTANT TERM IN RESOLUTION
for BaF2+scint.HADRON calorimeter
(After optimisation for α*BaF2 + β*HC)
Here
BaF2 <e/π> = 1.7
Constant term %
10
9
8
7
6
5
4
3
2
1
0
0.6
0.8
1
1.2
1.4
1.6
e/π in calorimeter behind BaF2

Total Absorption Length: 11.7 Lambda

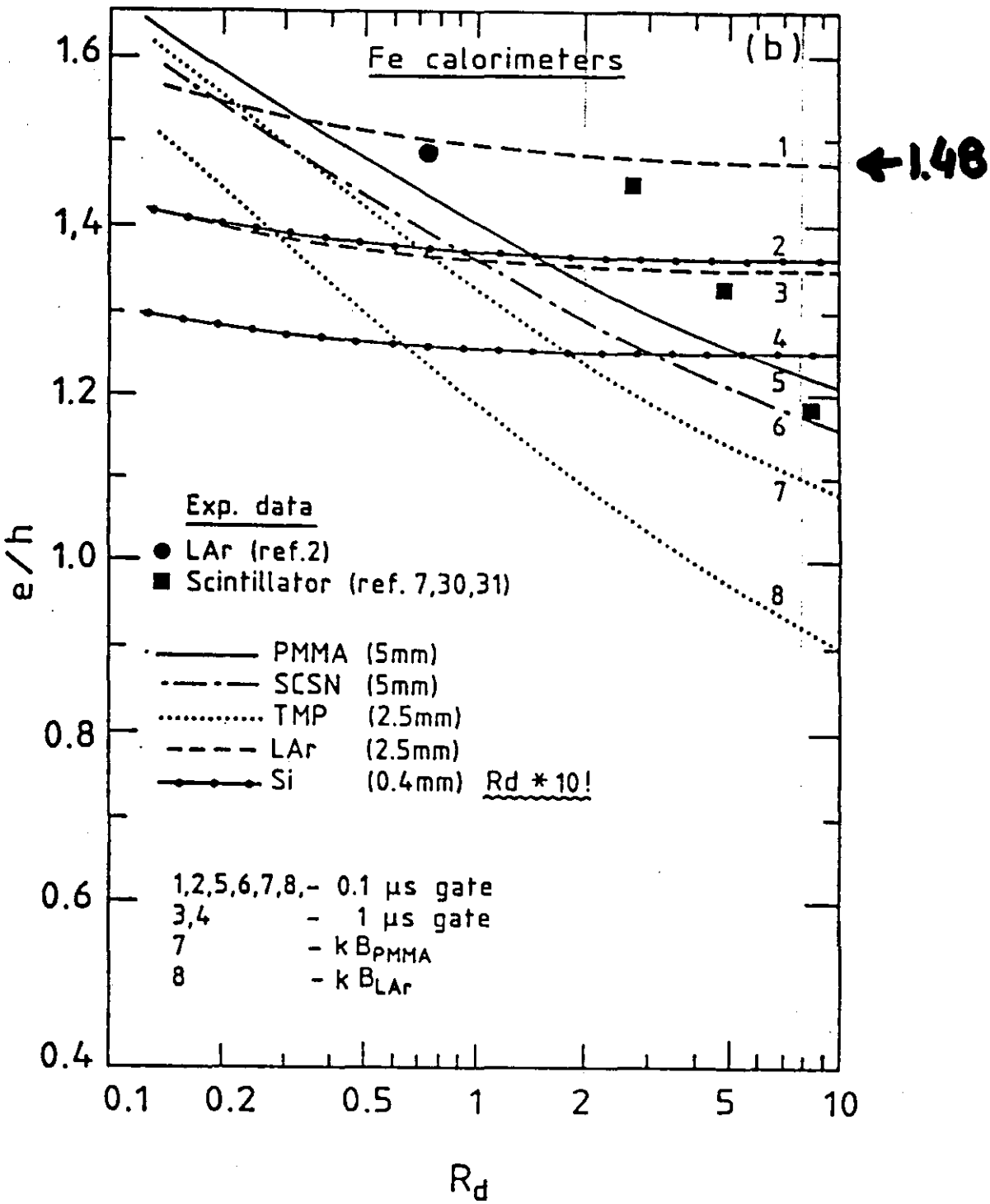
LAr assumptions



GEM Detector
Liquid Argon
Hadron Tower

G.03.LA.00027

Rennich

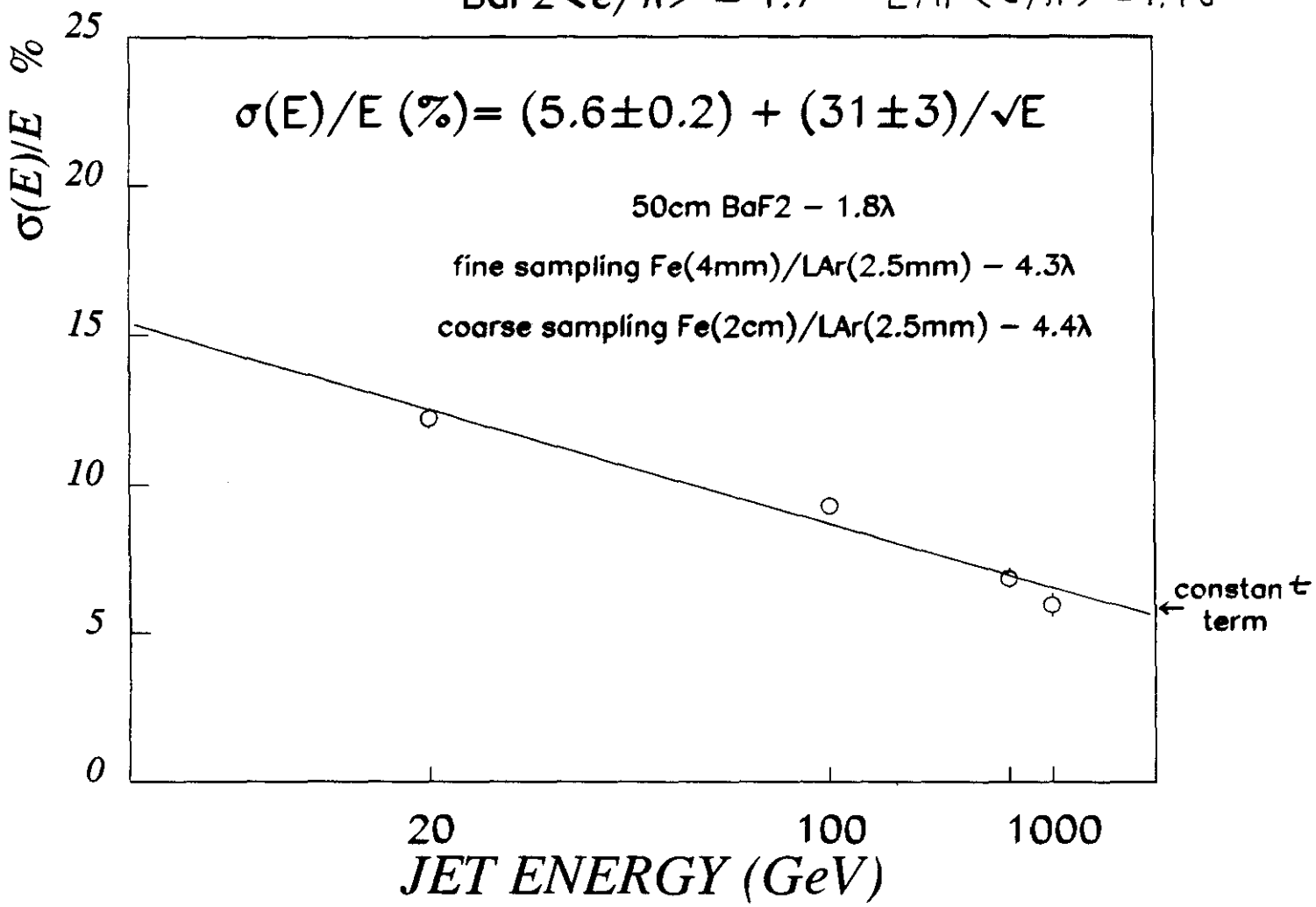

Fe calorimeters
(b)
1.6
1,4
1.2
1.0
0.8
0.6
0.4
e/h
0.1
0.2
0.5
1
2
5
10
R_d
1
2
3
4
5
6
7
8
Exp. data
LAr (ref.2)
Scintillator (ref. 7,30,31)
PMMA (5mm)
SCSN (5mm)
TMP (2.5mm)
LAr (2.5mm)
Si (0.4mm) Rd * 10!
1,2,5,6,7,8,- 0.1 μs gate
3,4 - 1 μs gate
7 - k B_{PMMA}
8 - k B_{LAr}
←1.48

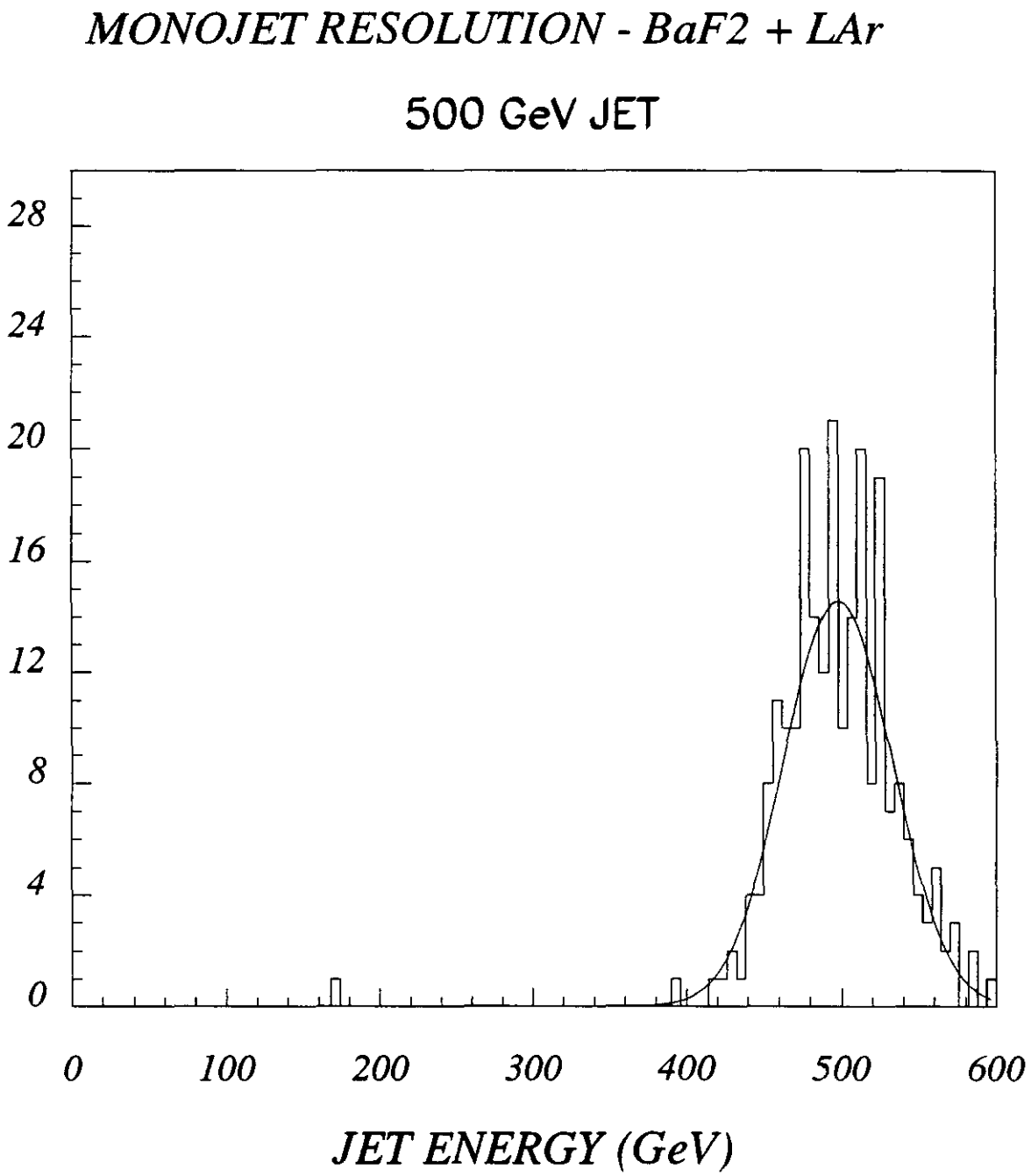
Geant yields LAr $\langle e/\pi \rangle = 1.36$ @ 50 GeV
Adjustment made $1.36 \rightarrow 1.48$

JET RESOLUTION for LAR

(after optimisation for α*BaF2 + β*Pb/LS)

BaF2$\langle e/\pi \rangle = 1.7$ LAr$\langle e/\pi \rangle = 1.48$




MONOJET RESOLUTION - BaF2 + LAr
500 GeV JET
28
24
20
16
12
8
4
0
0
100
200
300
400
500
600
JET ENERGY (GeV)

Thickness of Calorimeter

1. Punchthrough of π and K simulates μ

   $L_{tot} > 10.5\,\lambda$ @ 90°

2. Leakage fluctuations should not contribute to constant term of hadronic resolution

   $L_{tot} > 9.5\,\lambda$ @ 90°

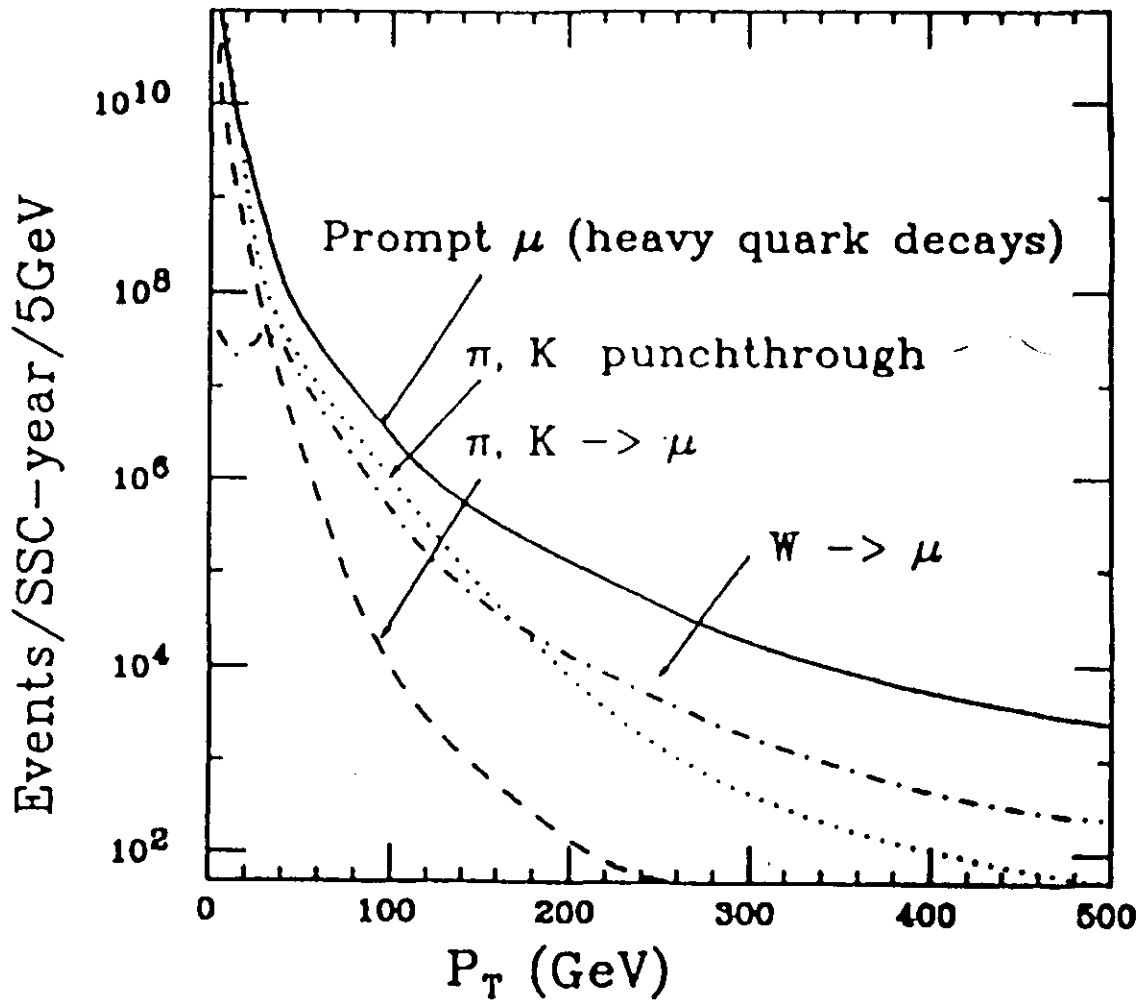
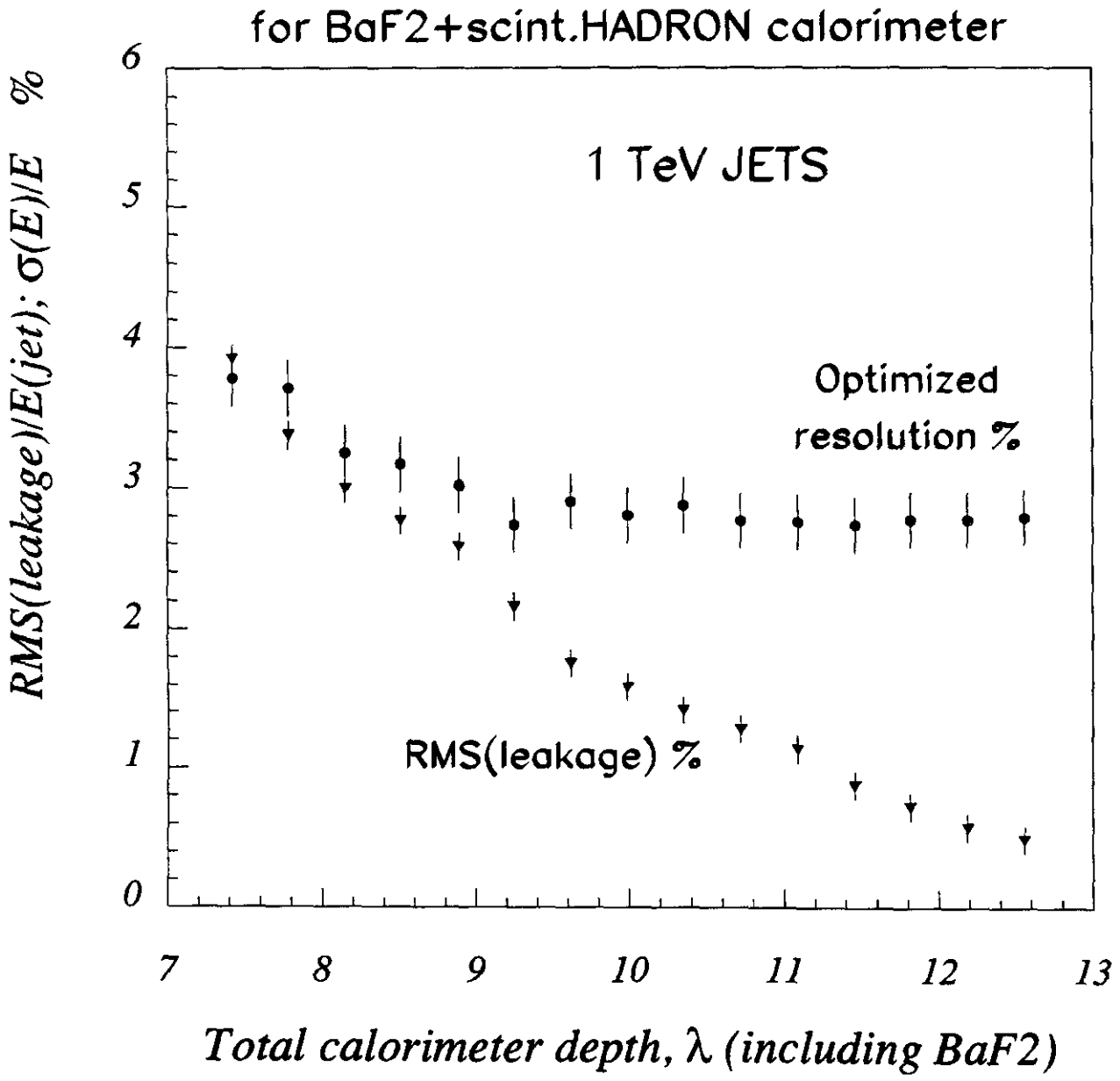


Fig. XII.5. Single muon rates and their origins.

11.7 λ @ 90°
13.9 λ @ 57°

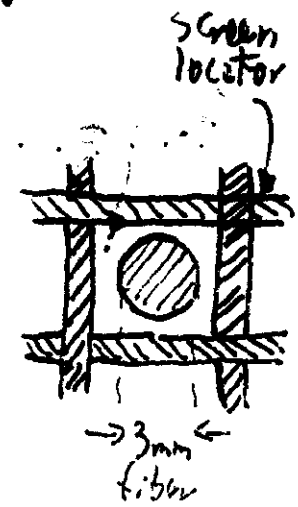
LEAKAGE FLUCTUATIONS IN CALORIMETER



L. Sulak

1) Safety in manufacturing procedures accessed & in place
OSHA
State } ≅ solder precaution

2) Many quarter-scale modules cast
lead shot flows - packing uniform - no distortion of fibers
no voids - many cross cuts & polishing
Draper & Lowell
stress tests ok
lead shot / eutectic compatible
... stress test ok
growth space into longitudinal dimension



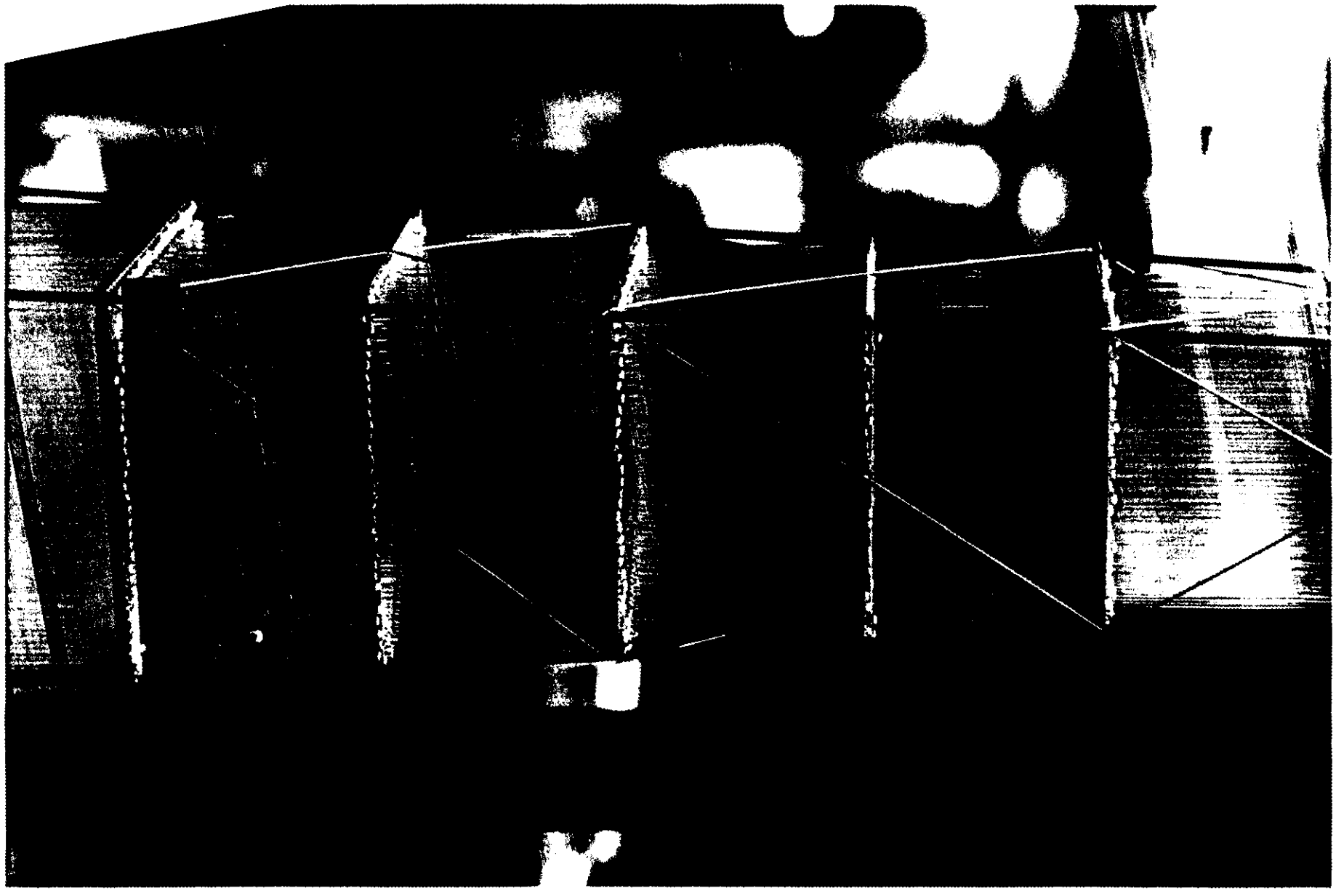
3) ½ Scale Cast with Clear fibers
no voids
flow thru septa ok
cross sections show uniform crystalization

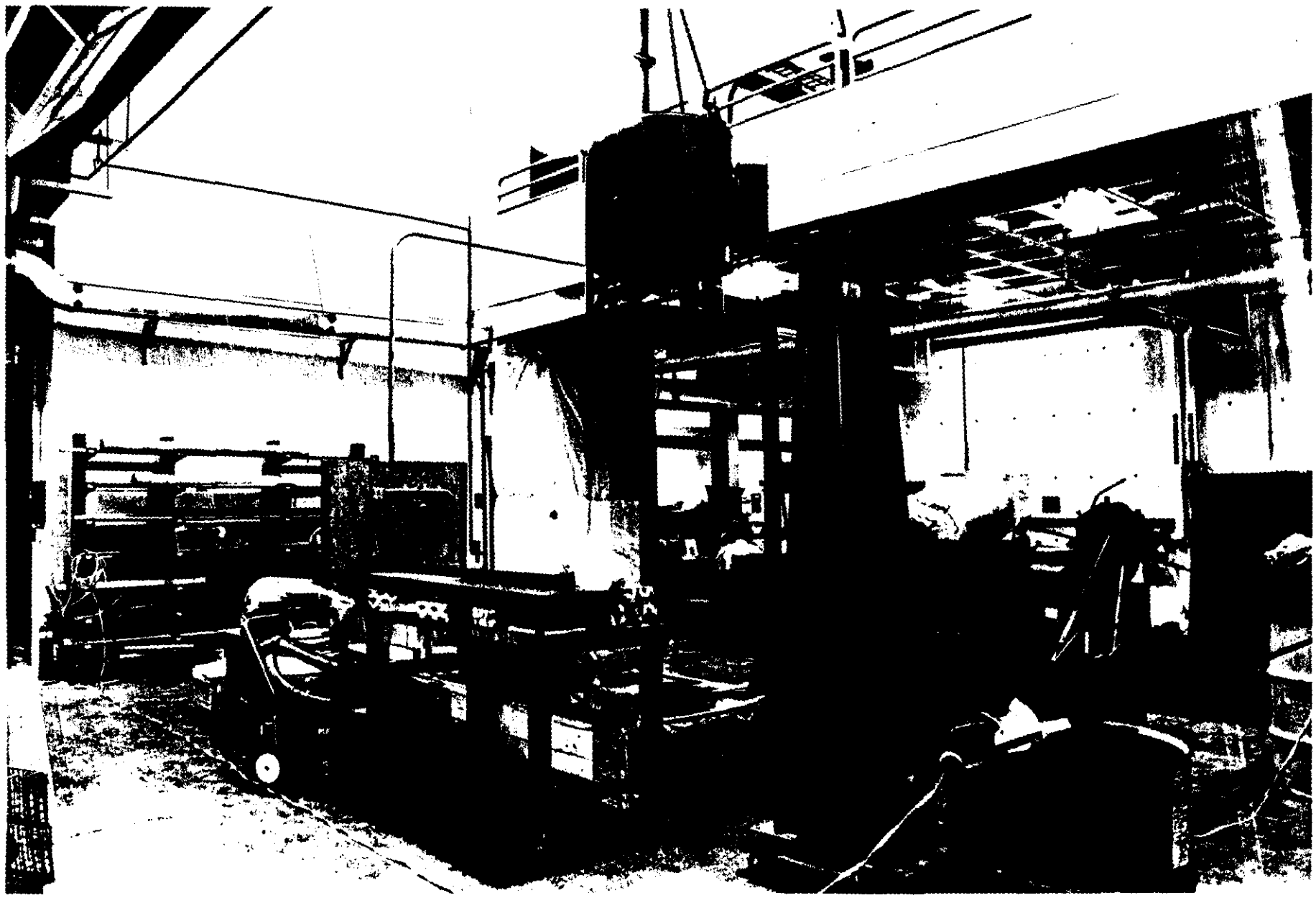
4) Steel screen for 3mm fiber produced by volume industry
excellent tolerances
rigidity
bonds well to eutectic ... lead shot flows thru easily with fibers installed

USD 5) All fibers scanned, tested within tolerance

6) Full Scale preform of 1mm fibers with "nail head" assembled

7) Full Scale casting with "screen" septa - Friday Oct 4
test of final manufacturing technique with Scintillator





8) Clear fiber readout of module in preparation

Fairfield 9) 9 – R 329 Hamamatsu in hand, tested with current tap on dynode for ^{60}Co calibration

Fairfield 10) N_2 laser + 16 channel optical fiber split operational matched to 1% Oak Ridge meeting

Prepa 11) Independent Costing ... stand by concepted values

FINAL TEST BEAM

MSU 1) Operational with 35 GeV, 20% electrons
soon 100 GeV continuous
200 GeV for short periods

MSU 2) 2 Integrated EM/Hadronic Dichromatic Towers operational
$(0.05)^2$
resolution and e/π to be measured

Illinois Hertzing 3) JETSET EM Calorimeter in place (6%/$\sqrt{E}$ at low energy)
1mm 50% 25 X_0 long (vs. 14 X_0 for CERN expt)

LIQUID FIBER
FORWARD CALORIMETRY

Minn 1) Halar "tubing" obtained
rad hard to 200 Mrad
$n = 1.4$
being cast into EM module as teflon was

independent cost estimate by Draper

September 30, 1991

Mark Rennich
ORNL

Ref: Your letter "GEM Spaghetti Calorimeter Design" dated Sept. 30 1991

Mark,

Since our meeting at ORNL on Sept. 17, Draper, due to funding limitations, has not pursued an alternate design nor developed a new cost estimate.

We have no reason to believe that the design that you have outlined will not work and believe strongly that it will.

However, as we stated on the 17th at ORNL and in our telecons since, there are significant differences in our cost estimates and these have not been resolved.

Dan Sullivan

cc: L. Sulak

PS: October 1, 1991

In a telecon with Larry Monday evening, he requested that I elaborate on the last statement above.
Over the past year and a half, Draper with BU and many others has developed a conceptual design, fabrication methodology, and appropriate costs for the spaghetti calorimeter. Your present design is similar to ours in many ways. As you know, we differ in certain key areas of the tower and calorimeter construction where we believe our approach results in an equally robust design at lower cost.

Larry: Please be sure Mark receives a copy of this before the meeting.

DISCUSSIONS

with Schmakov @ ONRL
& Newman's characterizations requested

Lob Carey 1). Plate-geometry "analog" of fiber system provided to ORNL

Parr 2) Analysis with SPACAL routines/experience

Carey 3) ONRL output to Boston
PAW-based readout & analysis codes developed
11/1/91 goal to answer questions

SPACAL

Poor

1.) SPACAL now running as hadron calorimeter - OMEGA exp't

2) ½ mm - 50% fiber EM designed
calculated to give 4%/√E

JETSET - EM

Hartzog

1) 2 years operation with 300 modules - stable since 9/90

2.) π^0 invariant mass width ⟺ 6%/√E
independent of γ impact point on calorimeter

- Brambery

3.) Constant term now being evaluated at FNAL
$14 X_0 \rightarrow 25 X_0$

baseline EM fiber calorimeter for GEM

Stochastic portion of EM resolution

response corresponding to 970 pe / GeV. This figure *includes* light losses in the lightguide system and losses due to attenuation in the fibers. An estimate of the transmission fraction from the block to the photomultiplier tube is 0.37 as explained in Reference [3].

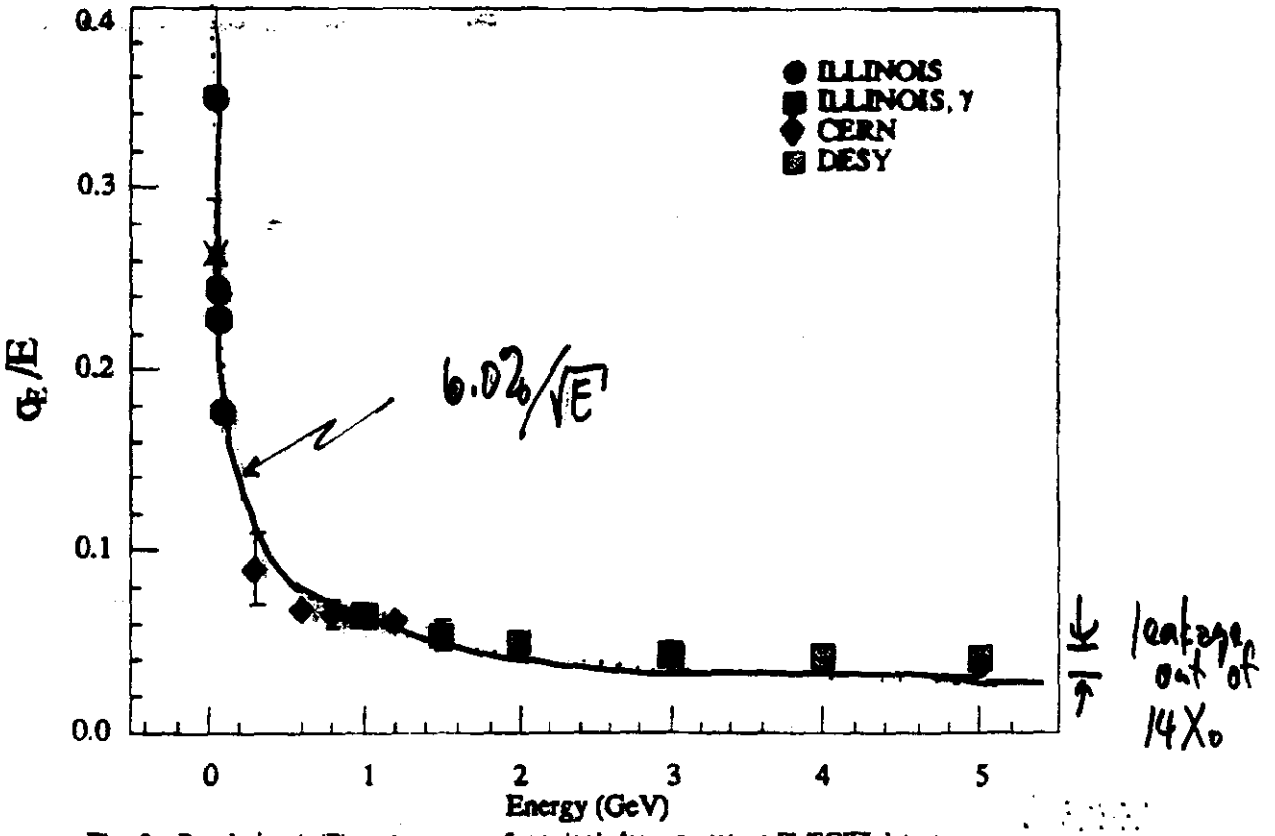


Fig. 2. Resolution (σ/E) versus energy for a single large prototype Pb/SCIFI detector. The solid line falls as $1/\sqrt{E}$ consistent with that expected from a detector dominated by sampling fluctuations. The data point at 0.045 GeV was obtained using monoenergetic photons, while the rest of the data used incident electrons.

The behavior of the energy resolution (σ/E) versus energy is shown in Fig. 2 for the prototype detector over a wide range of energies. The dotted line through the energy resolution data follows a $1/\sqrt{E}$ power law as expected for a detector whose resolution is principally determined by sampling fluctuations. Hereafter, the resolution of the detectors is quoted as

$$\frac{\sigma(E)}{E} = \frac{X}{\sqrt{E}}$$

with E in GeV. The value of X corresponding to the line drawn in the figure is 6.0%. The deviation of the data from the line at the highest energies is largely due to energy leakage.

Hartzog et al. Proc. Int. Conf. Calor. in HEP 20/10 – 11/96 FNAL

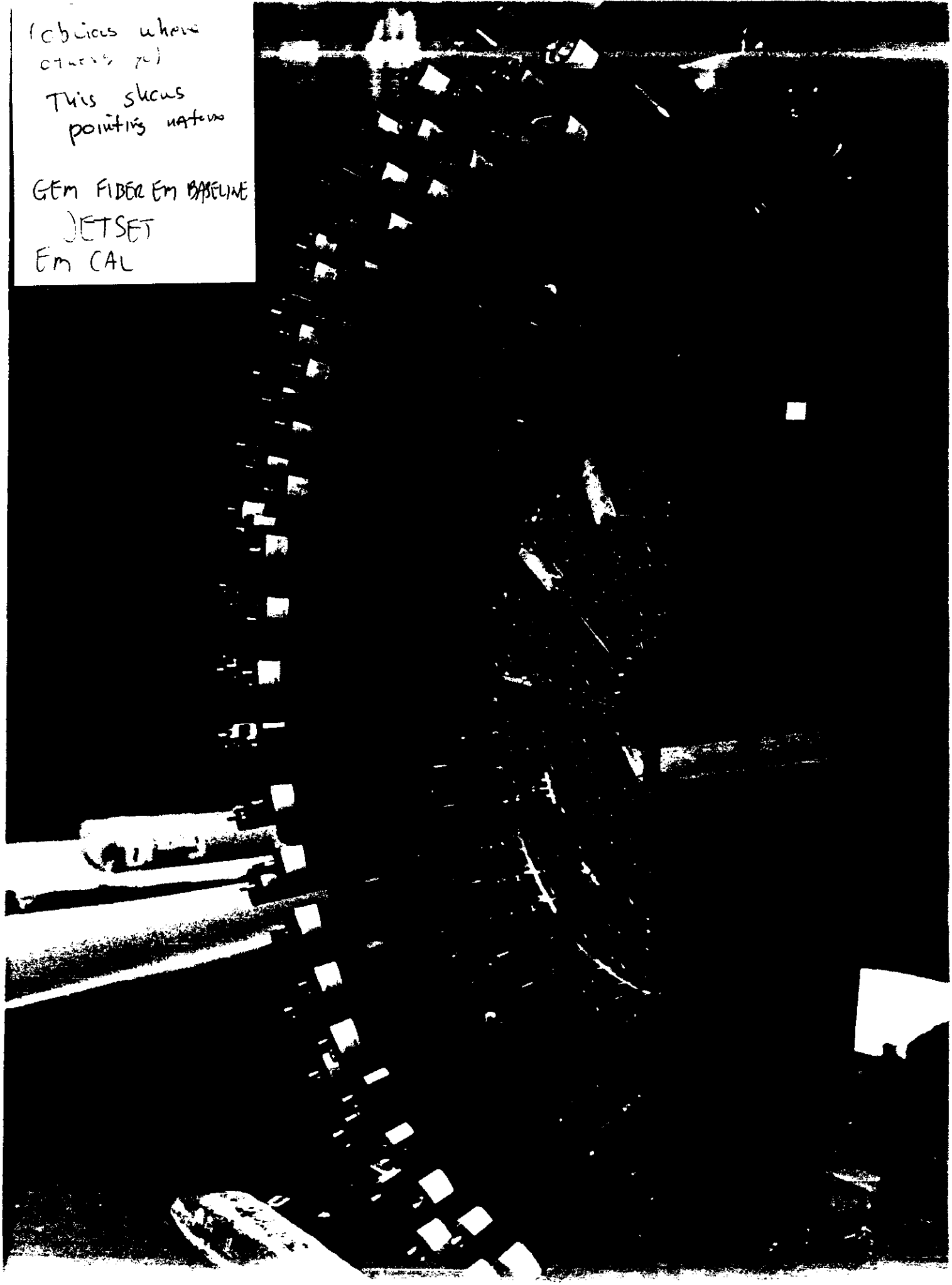
(obvious where others go)

This shows pointing nature

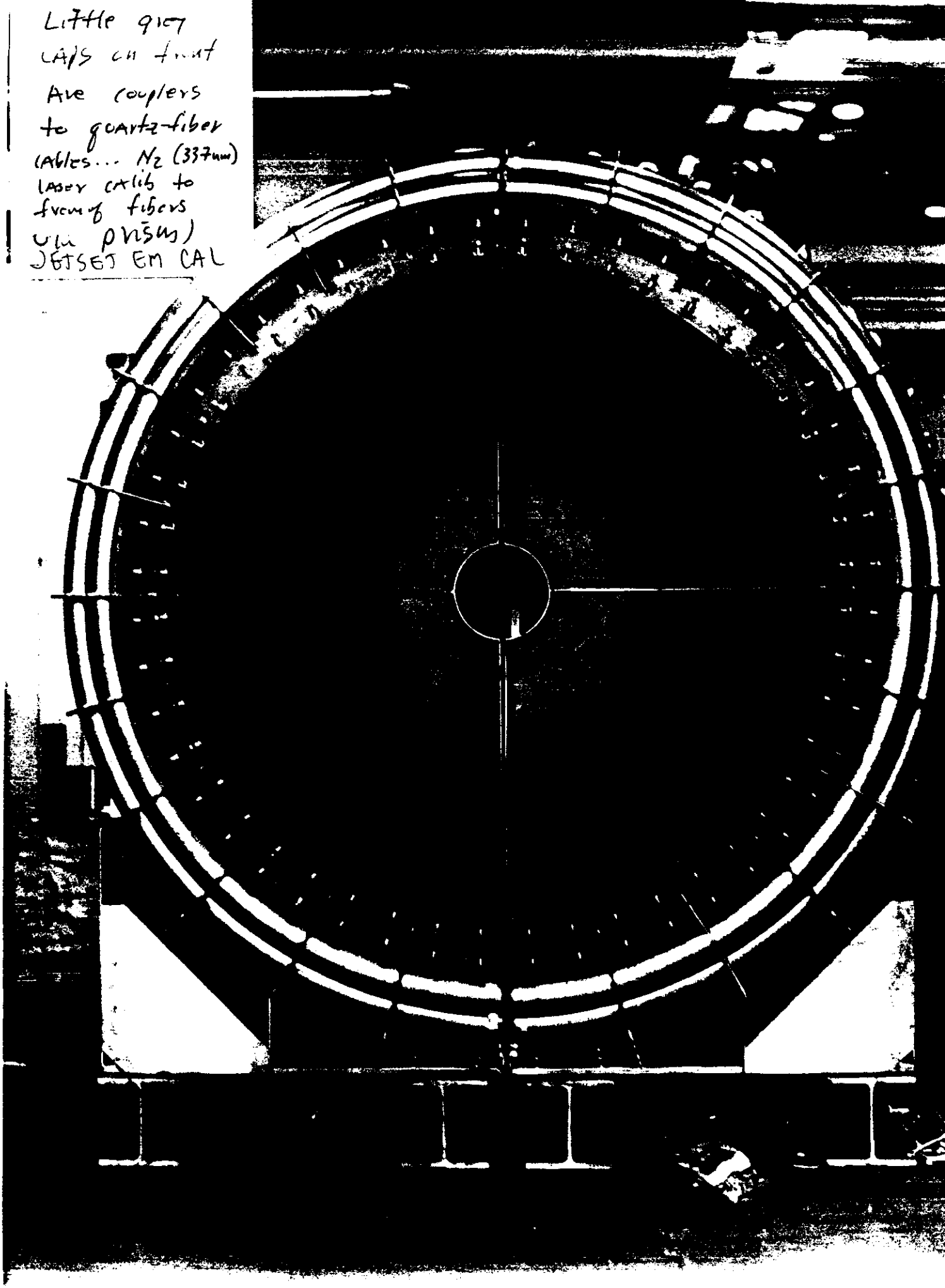
GEM FIBER EM BASELINE

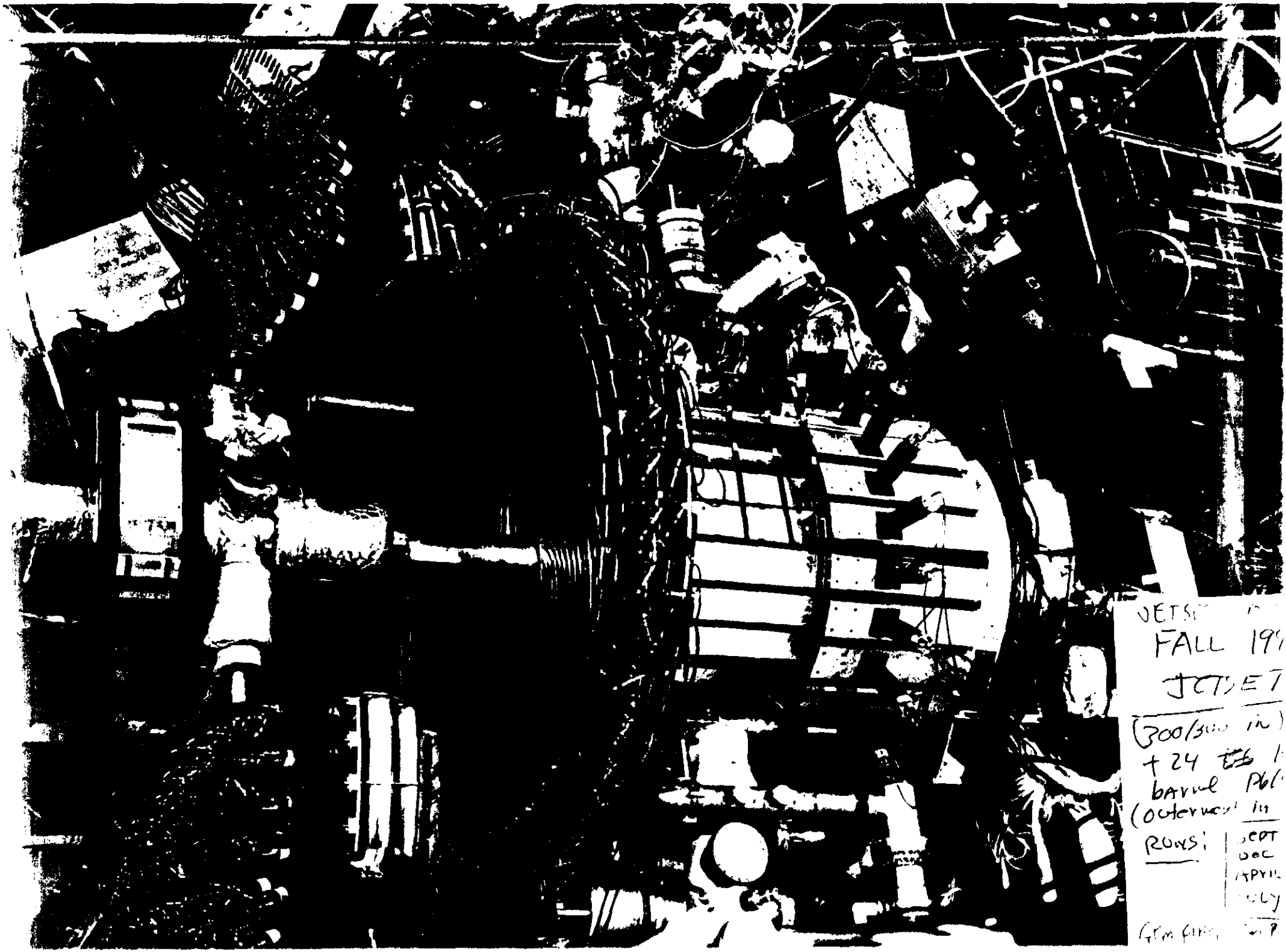
JETSET

EM CAL



Little 9107
CAPS on front
Are couplers
to quartz-fiber
cables... N_2 (337nm)
laser calib to
front of fibers
via prisms)
JETSET EM CAL




FALL 19
JCTJET
(300/300 in)
+24
barrel
(outerwall in
RUNS:
SEPT
DEC
APRIL
JULY

H. Gordon

Liquid "Argon" Approach to the Highest Resolution Calorimeter System for GEM

Accordion for EM (RD3)

Energy Resolution $\frac{\Delta E}{E} = \frac{10.1 \pm 0.4\%}{\sqrt{E}} \oplus (0.2 \pm 0.2)\%$

Linearity $<< 1\%$

Position Resolution $\Delta x = 4.4\,mm/\sqrt{E}$

Angular Resolution $\Delta\theta = 6.1$ mrad @ 120 GeV

Uniformity

NA31 $< 0.5\%$ (vs. time <u>and</u> position)

RD3 $< 0.4\%$

Fast shaping $\Rightarrow$ less sensitive to gap variations

Calibration - goal 0.1%

Hadronic

Parallel Plate Geometry (aka DØ, SLD, H1 ..)
with "electrostatic" transformer

Absorber choice Fe / Pb / DU

BNL results $\frac{\Delta E}{E} \cong 60\%/\sqrt{E}$

R+D Plans

EM – improve $\frac{\Delta E}{E}$ to $\frac{7\%}{\sqrt{E}}$

a) 1-mm accordion + Argon

b) Krypton + 2mm accordion

Hadron – Construct + beam test prototype

Engineering

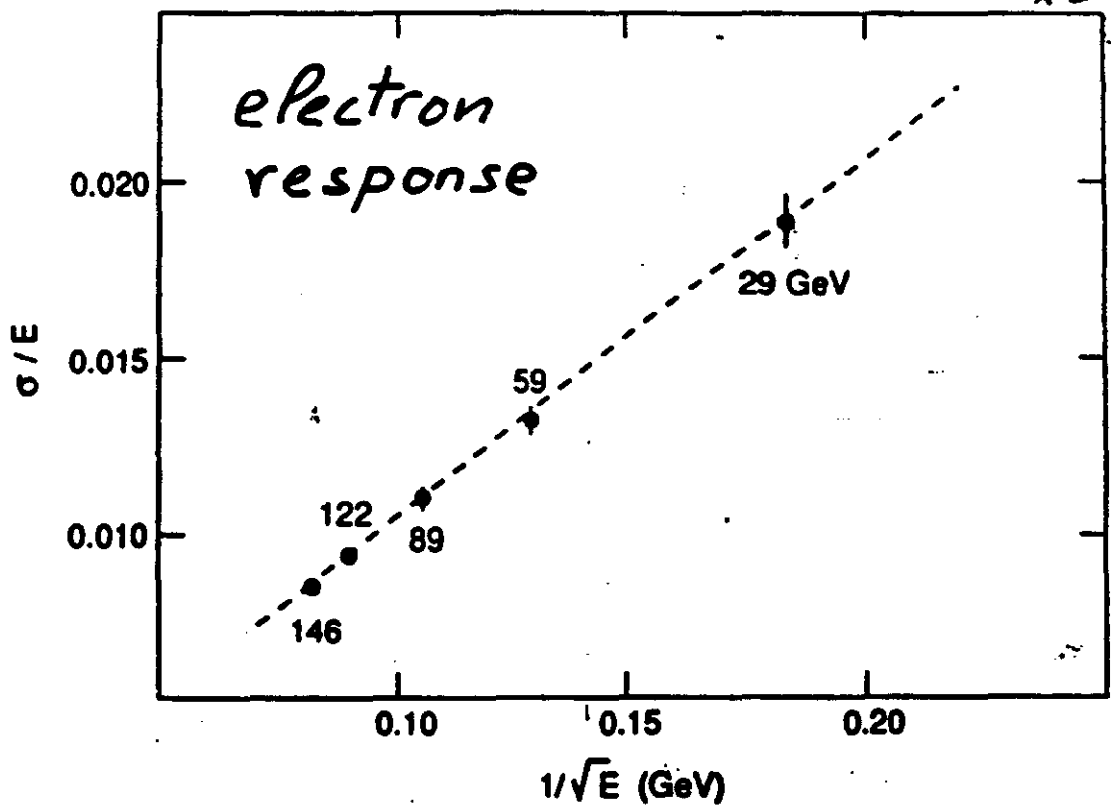
Integrated design

33-7-9

Energy Resolution

Fit: $\frac{\sigma}{E} = \frac{K}{\sqrt{E}} + c$

5x5 cluster



▲ 100 ns readout

'90 data

(5x5) = 13.6 x 12.5 cm²

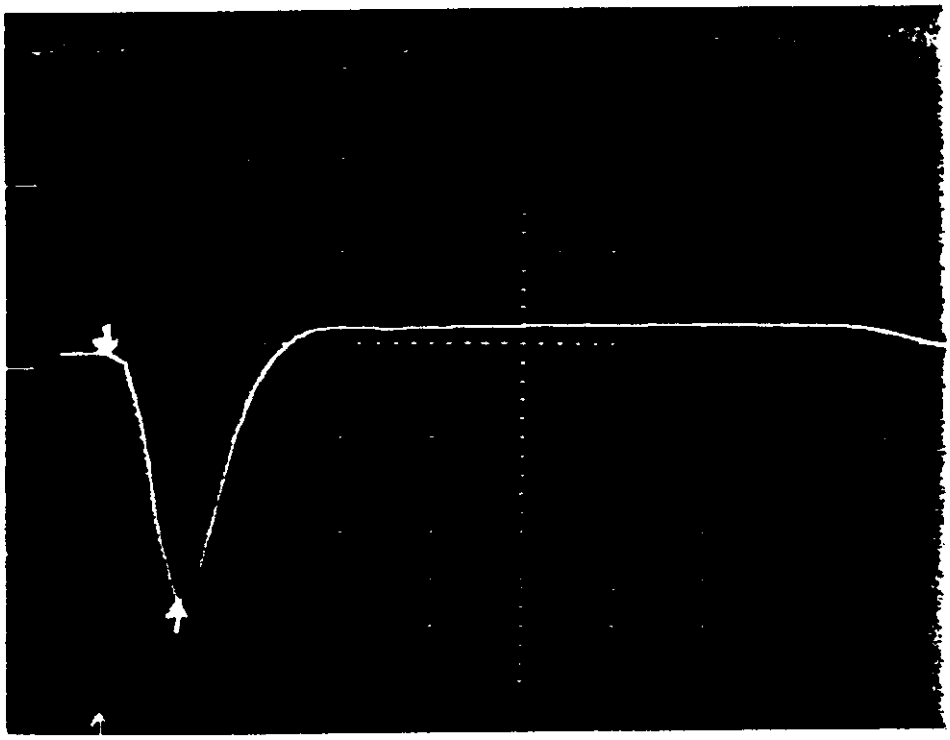
$$\frac{\sigma}{E} = \frac{10.0 \pm 0.6}{\sqrt{E}} + (0.0 \pm 0.1)\ \%$$

$$\frac{\sigma}{E} = \frac{10.1 \pm 0.4}{\sqrt{E}} \oplus (0.2 \pm 0.2)\ \%$$

(3 x 3) = 8.1 x 7.5 cm²

compatible results

Accordion Waveforms 1991 Data



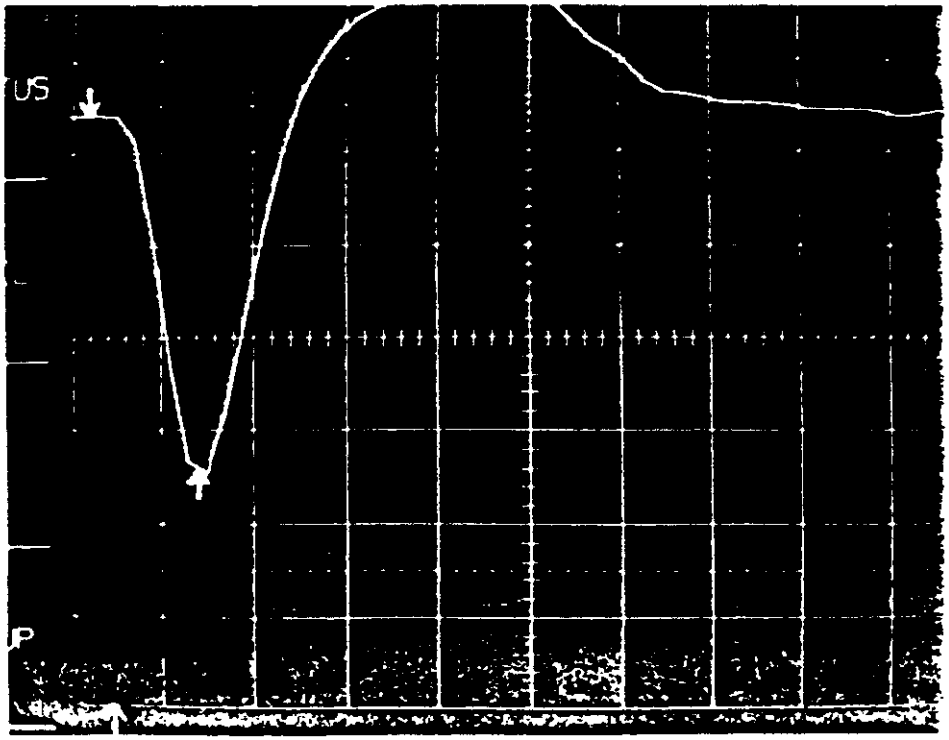
60GeV e

2mm gap

$t_p = 20$ns

single trace

→ ← 50nsec

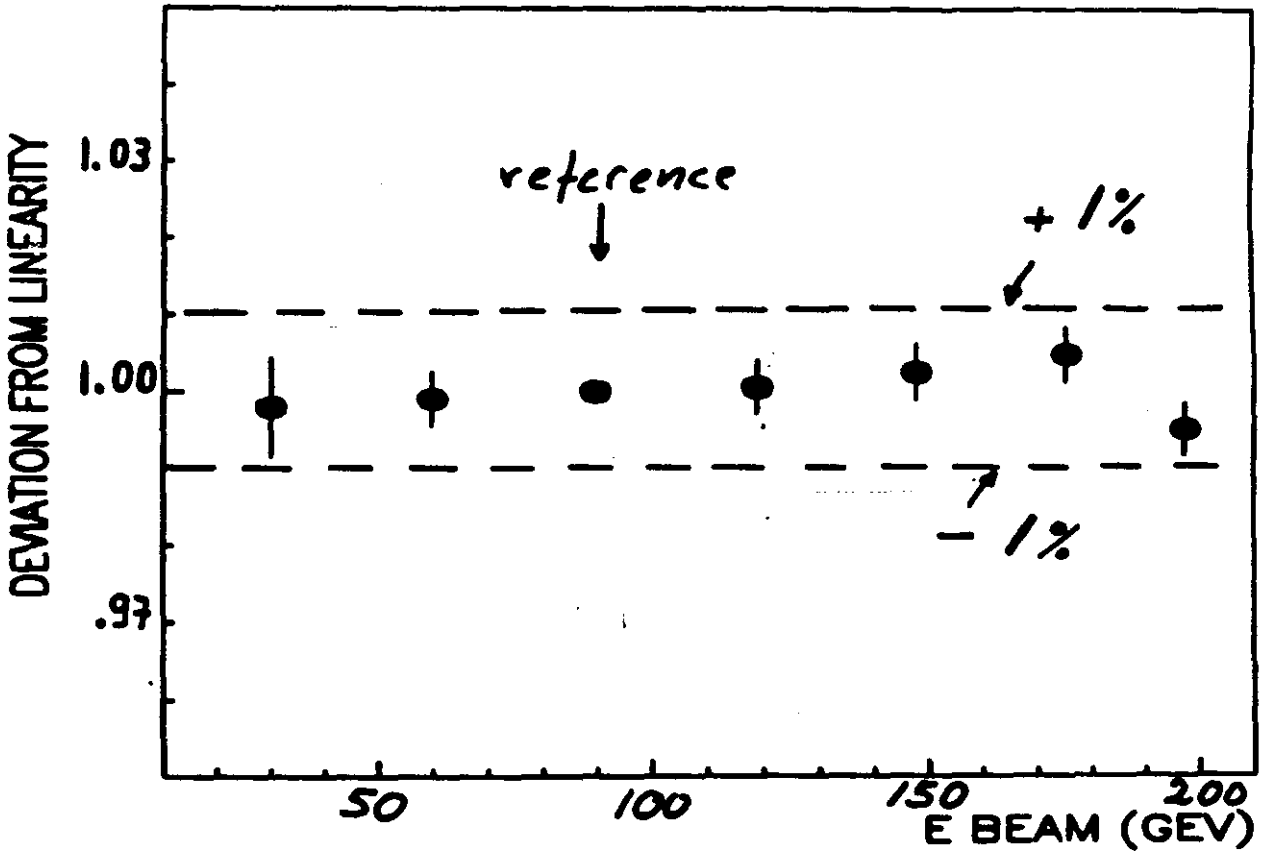


Preshower

1mm gap

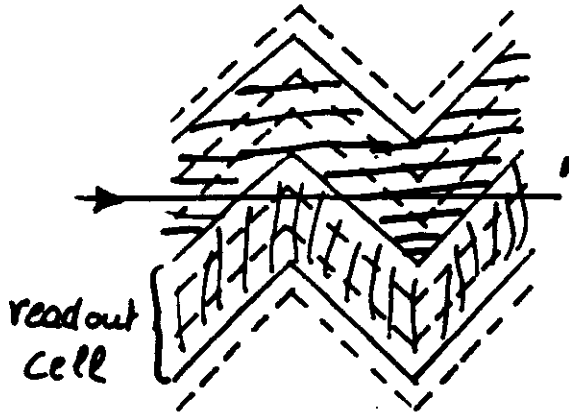
Linearity of the response (electrons)

- Electron data taken at several beam energies
  30, 60, 90, 120, 150, 175, 197 GeV



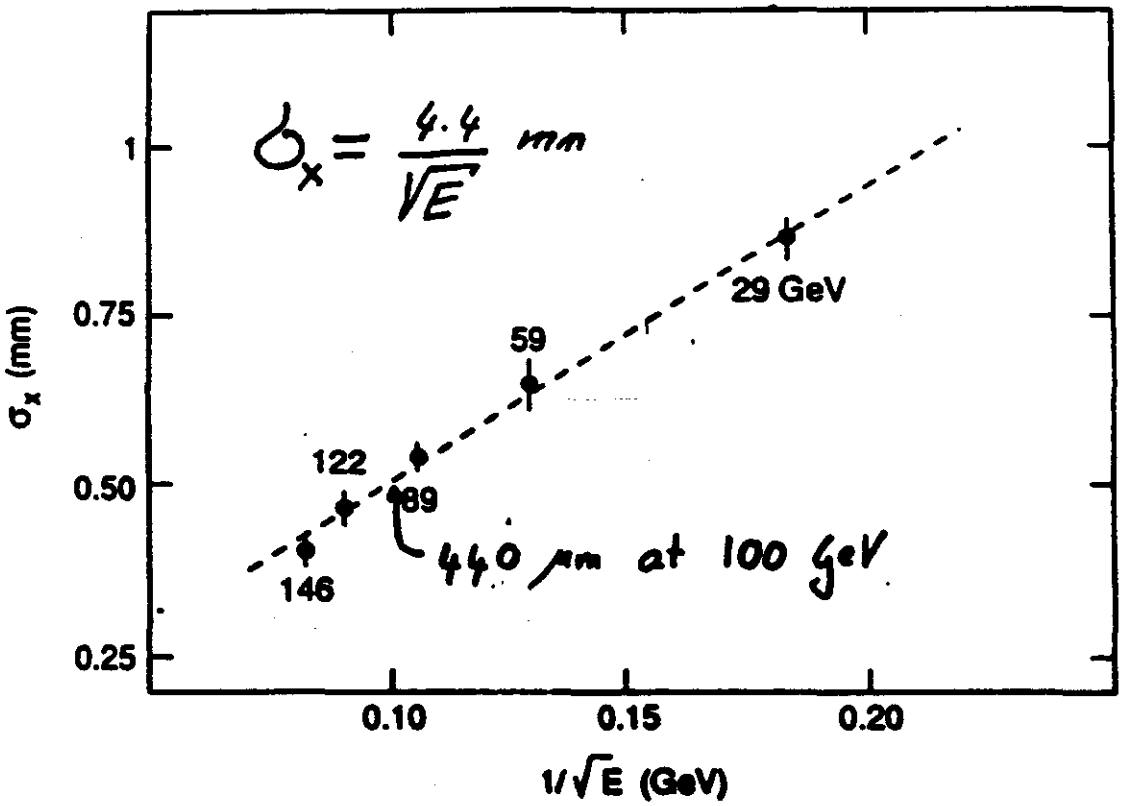
- for fast shaping (20ns)
- no longitudinal leakage corrections
- 3 x 3 clustering

Spatial resolution: along x (ACCORDION FOLDS)



always 2 readout cells are involved

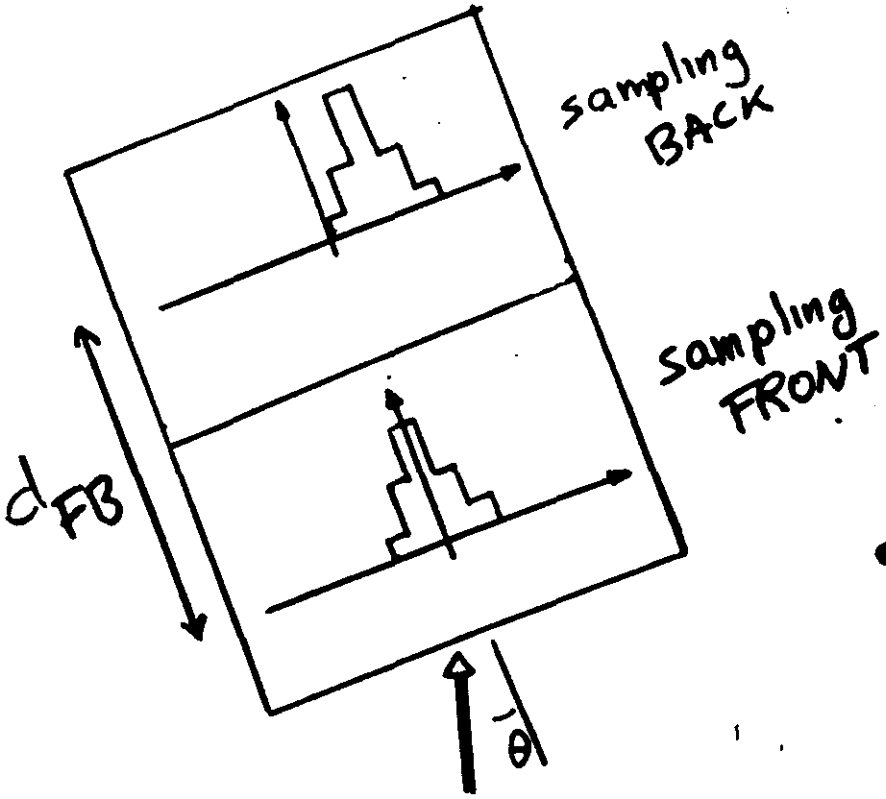
better energy sharing
⇕
better spatial resolution (σ_x)



readout 100 ns

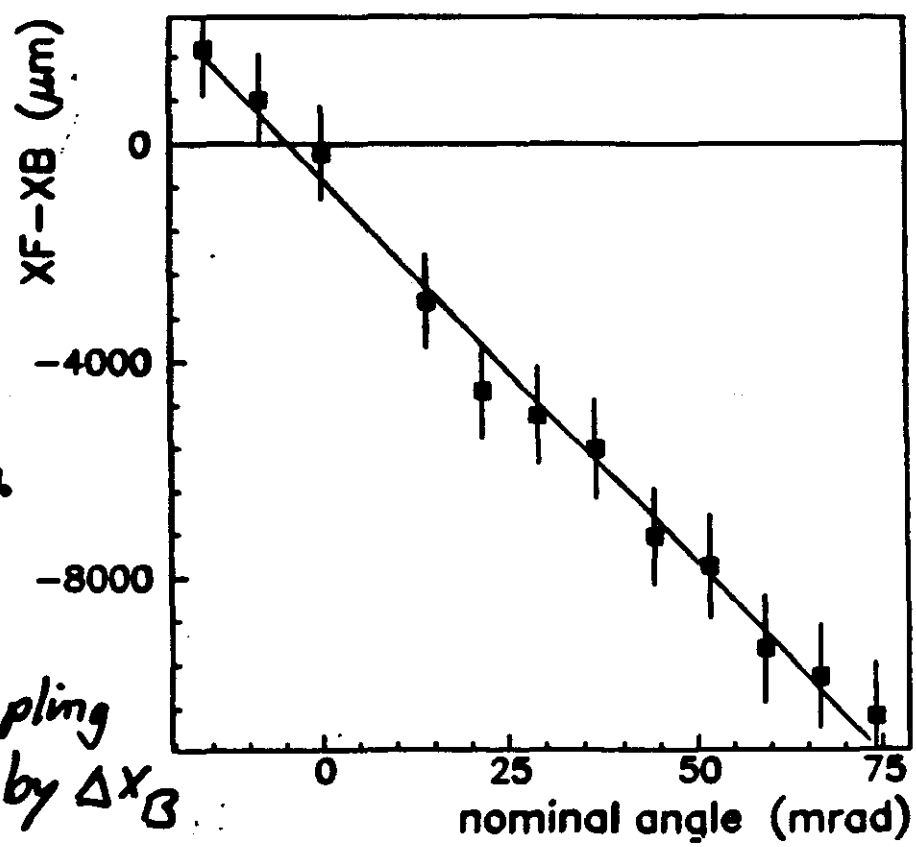
- same results with the fast shaping (20 ns)
- no bias $X_{calor} = X_{Impact} \pm$ resolution
- in Y it behaves like a conventional pad detector $Y_{calor} = f(Y_{impact}) \pm$ resolution
- at 100 ns σ_x (muon) = 1.80 ± 0.05 mm

Angular resolution



$$\theta = \frac{X_B - X_F}{d_{FB}}$$

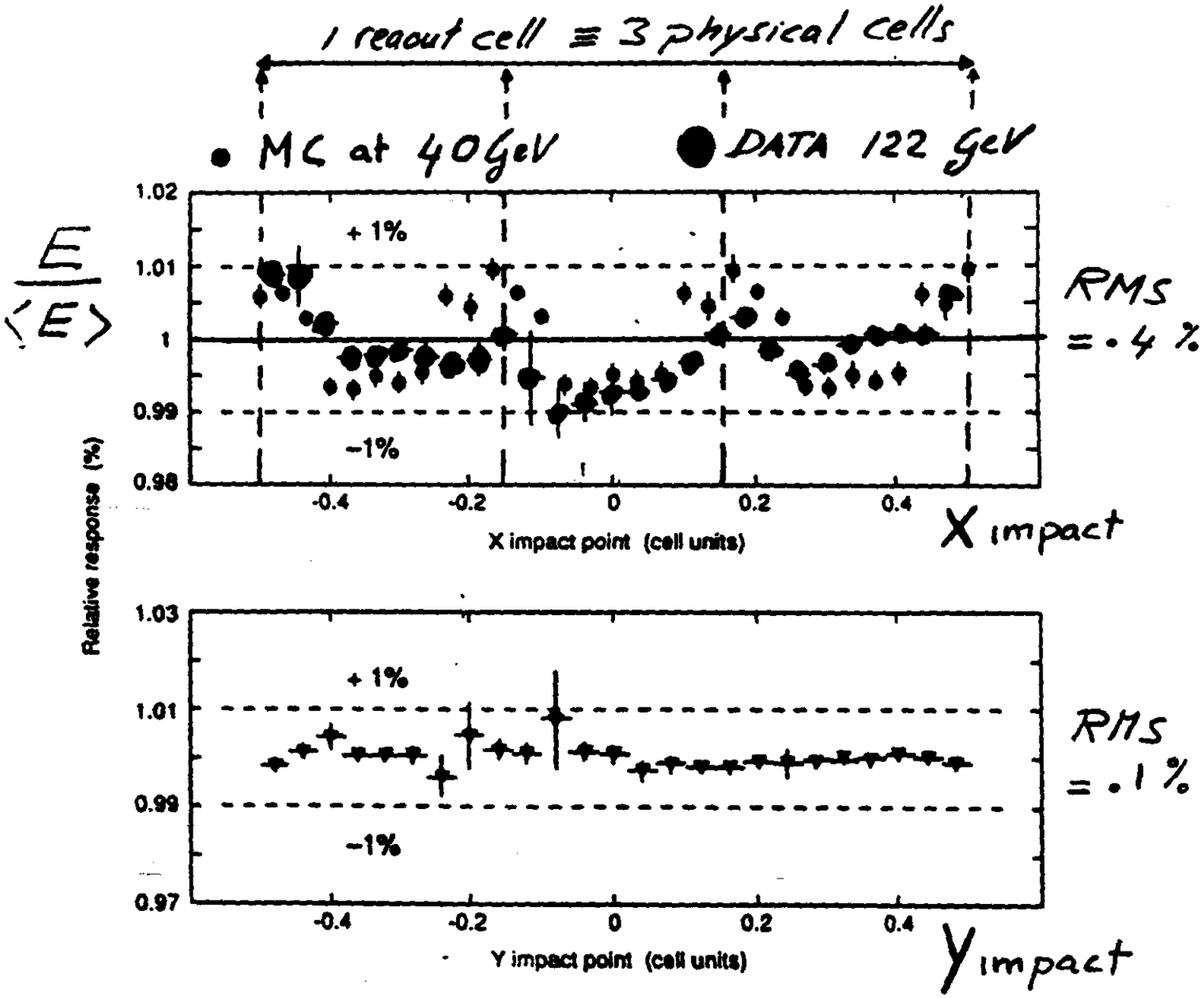
- calibrated by rotating the calorimeter on a platform



- $\Delta\theta = 6.1$ mrad at 120 GeV
- same result with the fast readout
- not optimized longitudinal sampling $\rightarrow \Delta\theta$ dominated by ΔX_B

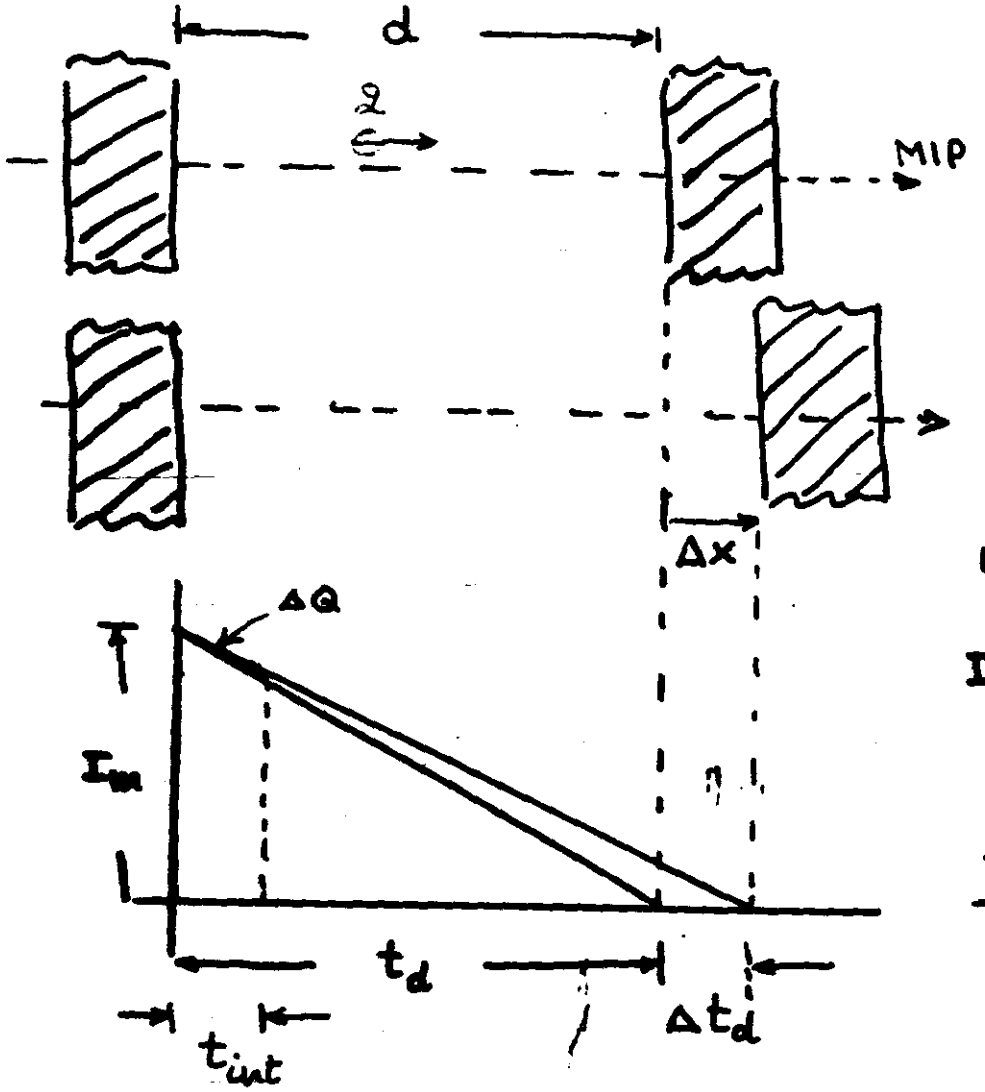
Signal uniformity

cell level



LMR — Gap variations and Calibration

Pulse width



single carrier:

$$i = \frac{\ell}{t_d} = \ell \frac{v_e}{d}$$

MIP responce:

$$I_m = e \frac{dn_e}{dx} \frac{d}{t_d}$$

$$= e \frac{dn_e}{dx} v_e$$

I_m is independent of d!

Long integration: $t_{int} > t_d$ $\quad Q_s = \frac{1}{2} I_m t_d$

Short integration: $t_{int} \ll t_d$ $\quad Q_s = I_m t_{int}\left(1 - \frac{1}{2}\frac{t_{int}}{t_d}\right)$

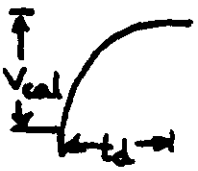
$$\frac{\Delta Q_s / I_m t_{int}}{\Delta t_d / t_d} = \frac{1}{2}\frac{t_{int}}{t_d} \approx \frac{1}{20} \quad \text{for} \quad \begin{array}{l} d = 2\,mm\,(400\,nm) \\ t_{int} = 40\,\mu sec \end{array}$$

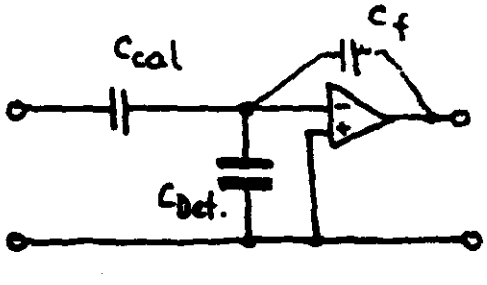
$\therefore$ 20% gap variation results in 1% signal variation.

Calibration should be by I_m and not by $Q = \frac{1}{2} I_m t_d$!

Liv Calibration

1) $Q = CV_{cal}$

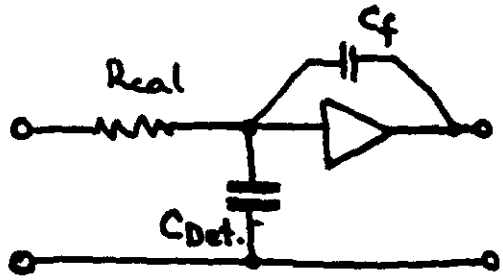




Conventional charge calibration

$$\frac{\delta C_{cal}}{C_{cal}} \approx 1\text{-}2\%$$

2) $I_{in} = \frac{V_{cal}}{R_{cal}}$

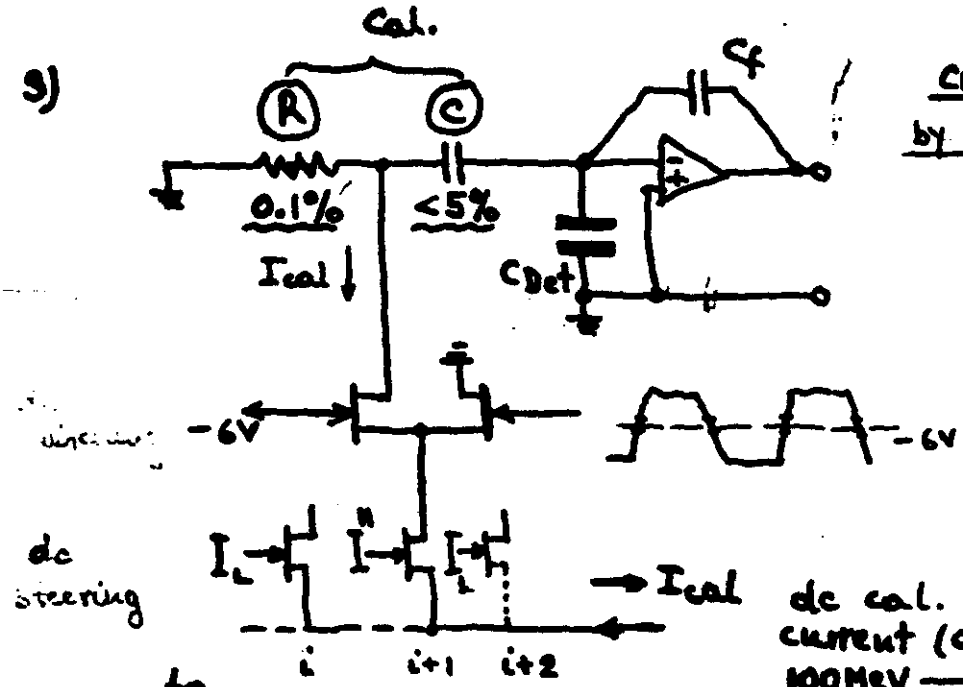


Current calibration

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

- distribution of precisely controlled pulses needed

3)

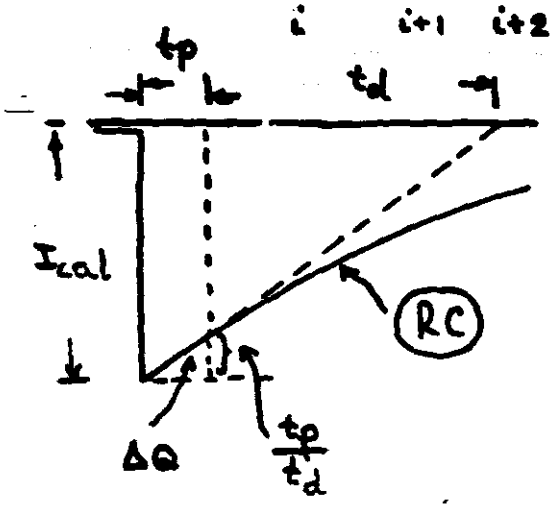


Current calibration by local pulse generation

- dc current distributed
- 5% in c's results in 0.125% calibration

dc cal. current (0–2.5 μA)
100 MeV ⟶ 2 TeV

leakage pA after 850 MR
100 pA ⇒ 0.1 MeV



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

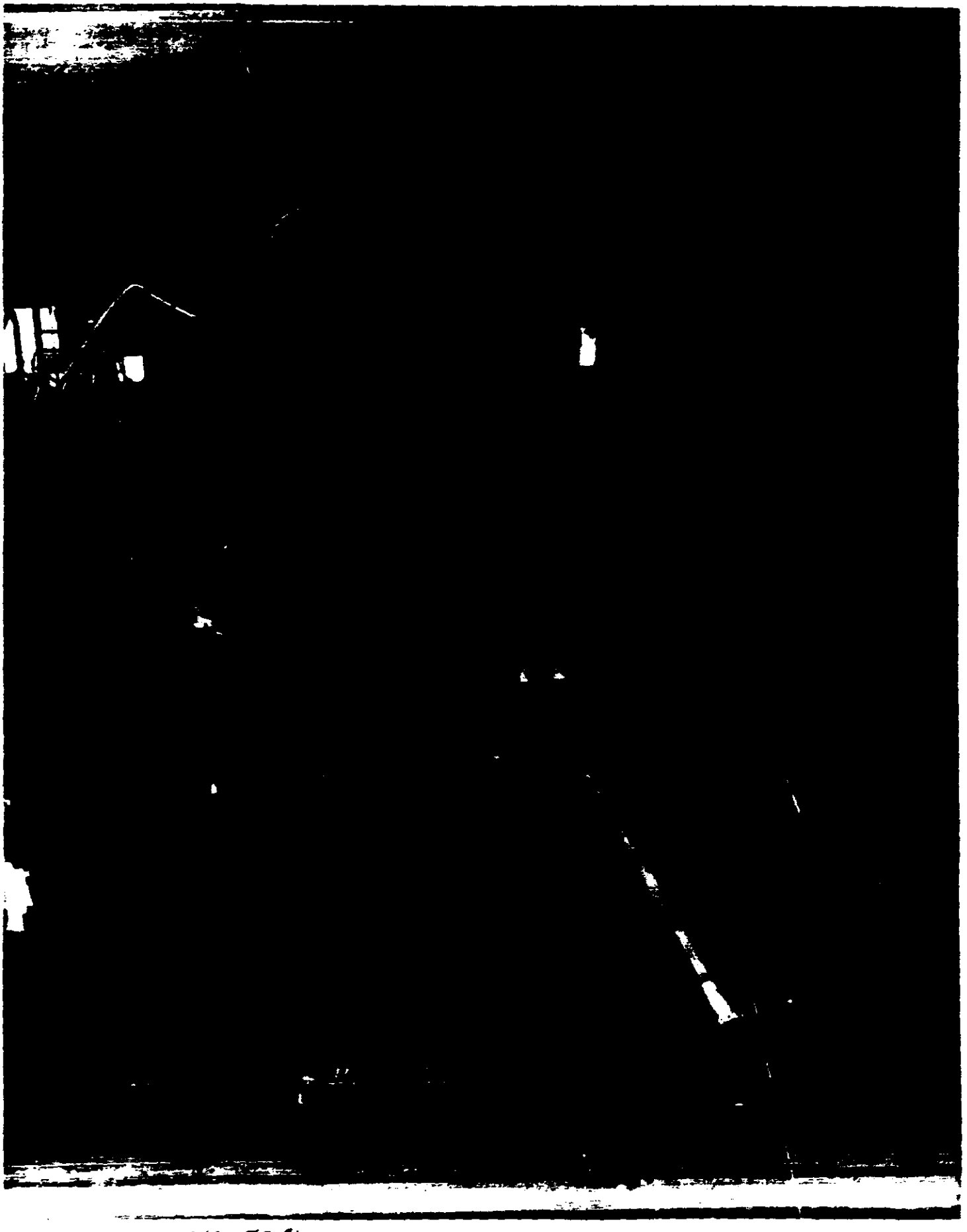
$$\frac{\Delta Q}{Q_{cal}} = \frac{1}{2}\frac{t_p}{t_d} \approx \frac{1}{40}$$

$t_p = 20$ nsec
$t_d = 400$ nsec

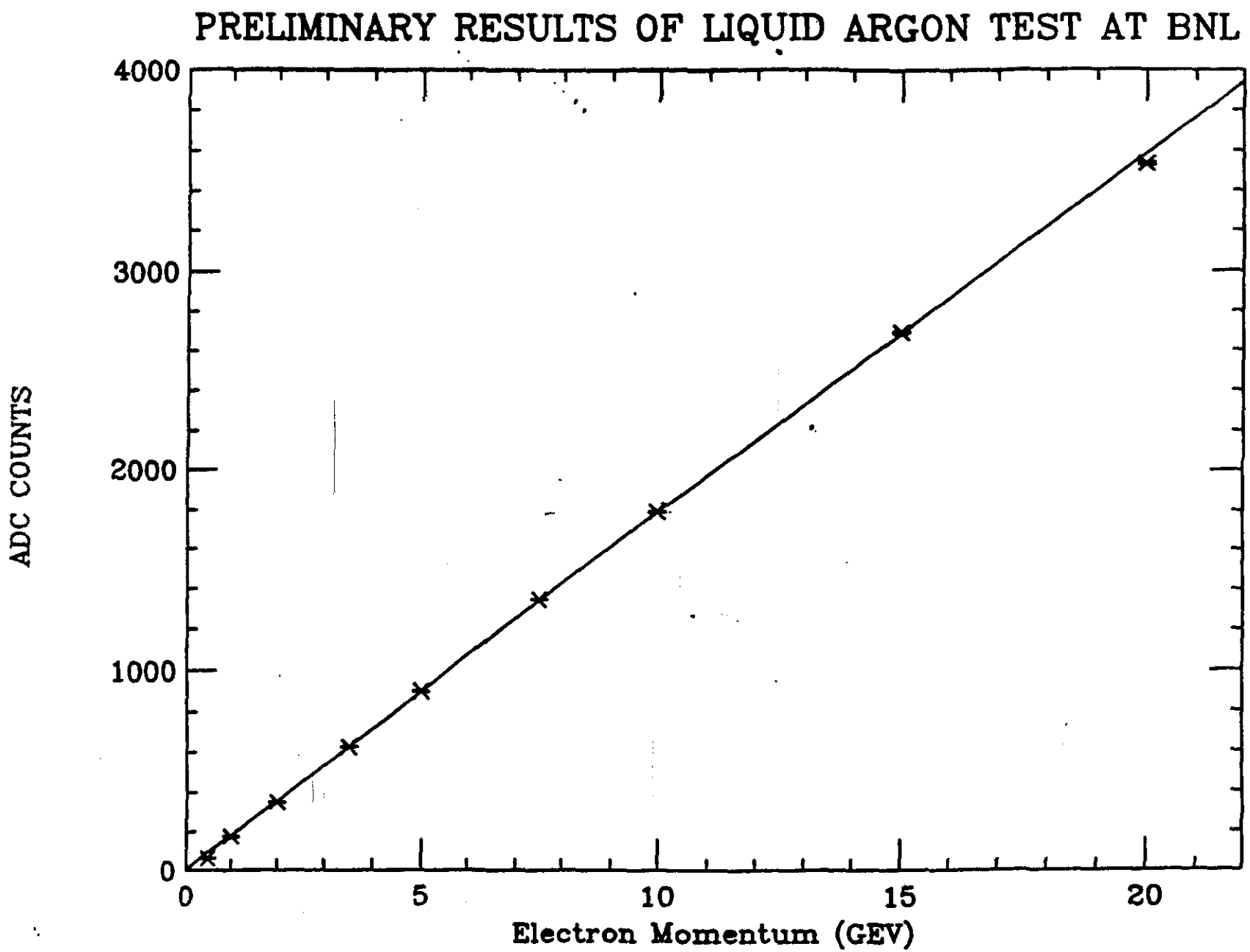
$$\frac{\delta Q_{cal}}{Q_{cal}} \approx \frac{1}{40}\left(\frac{\delta R}{R}, \frac{\delta C}{C}, \frac{\delta(RC)}{RC}\right)$$

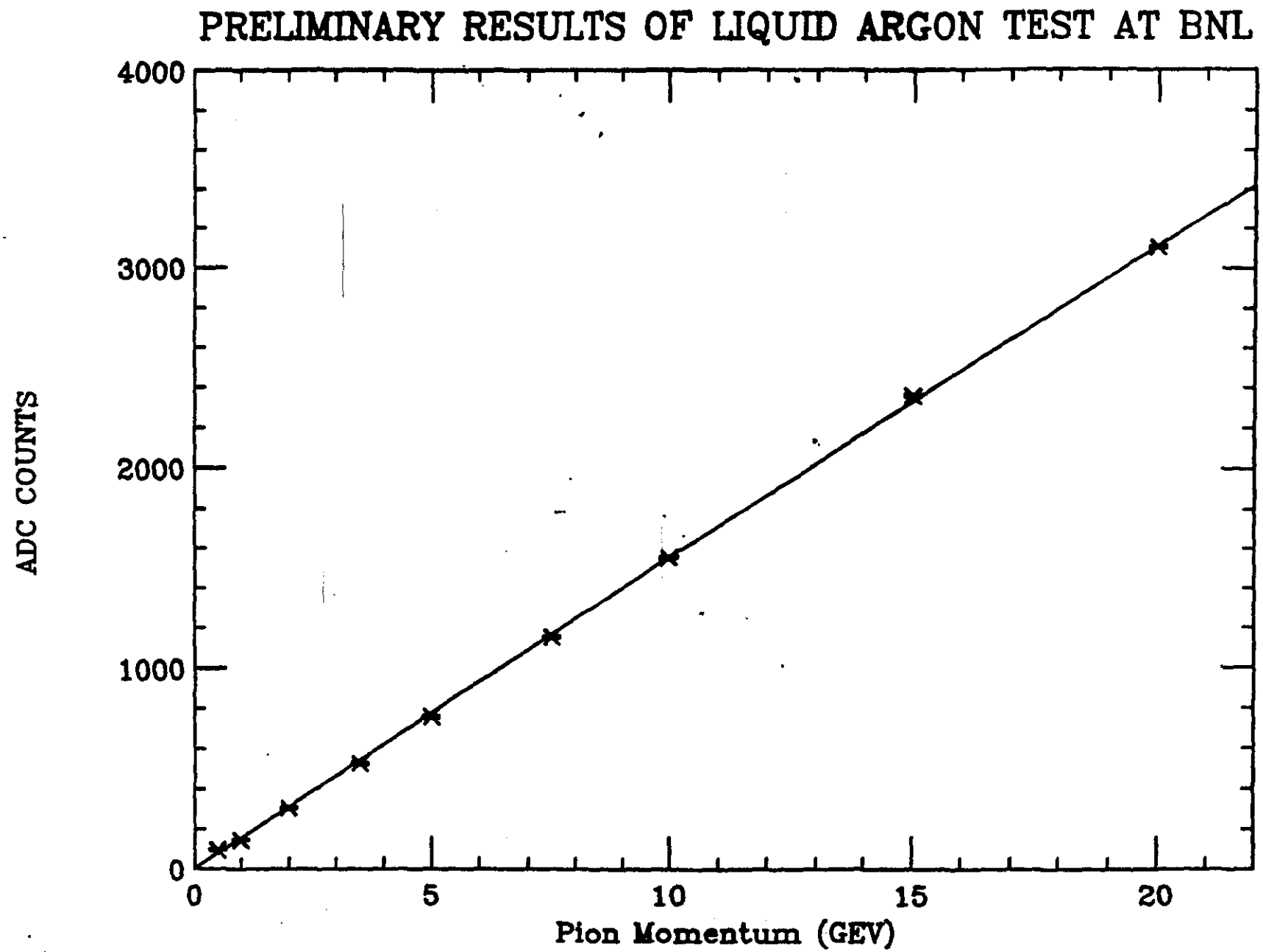
Switch parameters (V_t, noise, etc.) do not influence calibration.

$I_{gl} < 10^{-3} I_{cal}$ (min) after radiation.

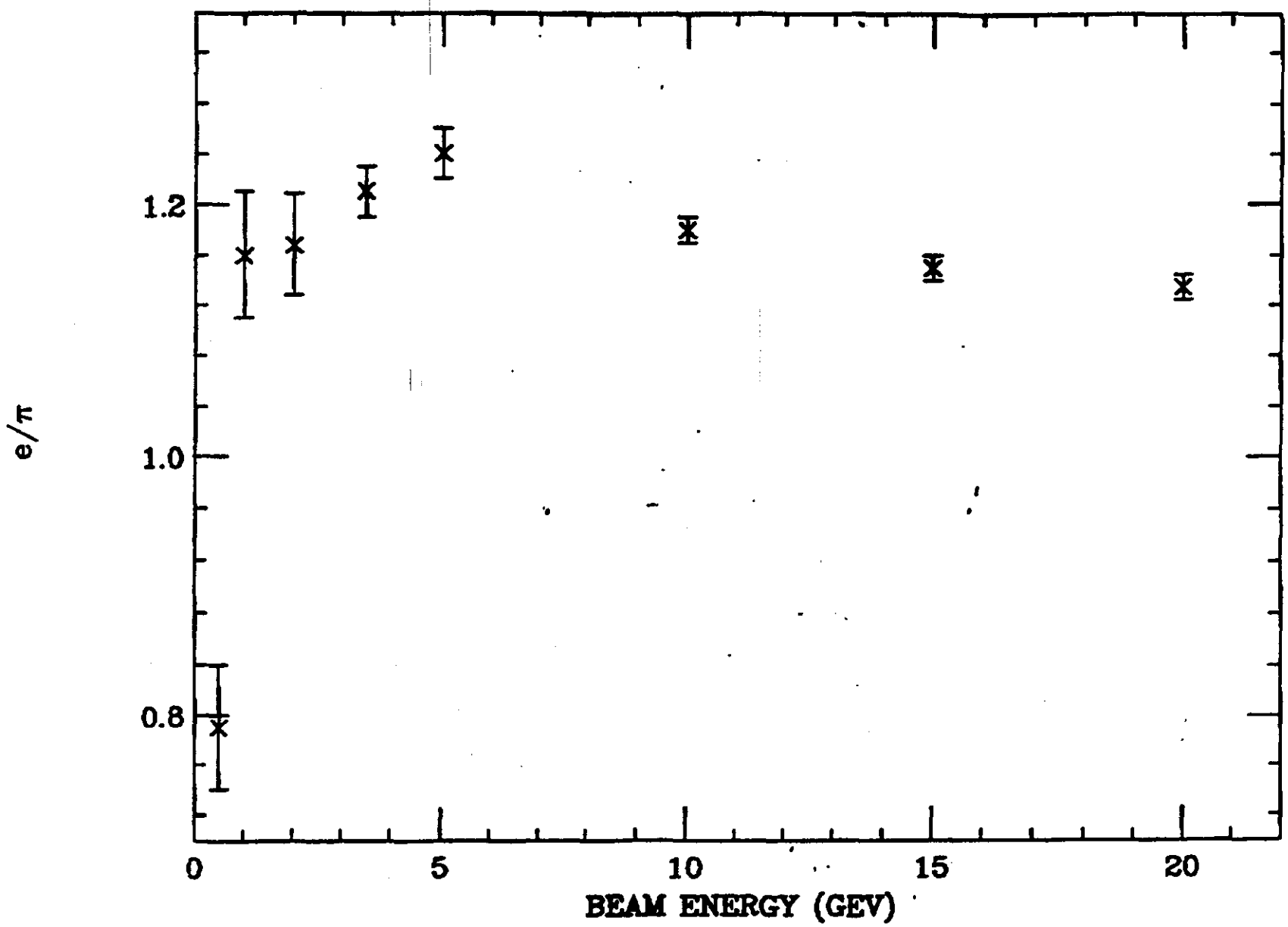


CN7-55-91


PRELIMINARY RESULTS OF LIQUID ARGON TEST AT BNL
ADC COUNTS
4000
3000
2000
1000
0
0
5
10
15
20
Electron Momentum (GEV)


PRELIMINARY RESULTS OF LIQUID ARGON TEST AT BNL
ADC COUNTS
4000
3000
2000
1000
0
0
5
10
15
20
Pion Momentum (GEV)

Preliminary Results of Liquid Argon Test at BNL



Liquid Argon Specs

EM

$\gtrsim 25 X_0$

$\Delta\eta \times \Delta\phi = 0.04$

3 longitudinal readouts

$\Delta E/E \lesssim \frac{7\%}{\sqrt{E}} \oplus 0.5\%$

$|\eta| < 3$

Hadron

$\sim 11 \lambda$ active

$\Delta\eta \times \Delta\phi = 0.08$

4 longitudinal divisions

$\frac{\Delta E}{E} \sim \frac{60\%}{\sqrt{E}} \oplus 2\%$

$|\eta| < 5.5$

$\sim 80{,}000$ channels

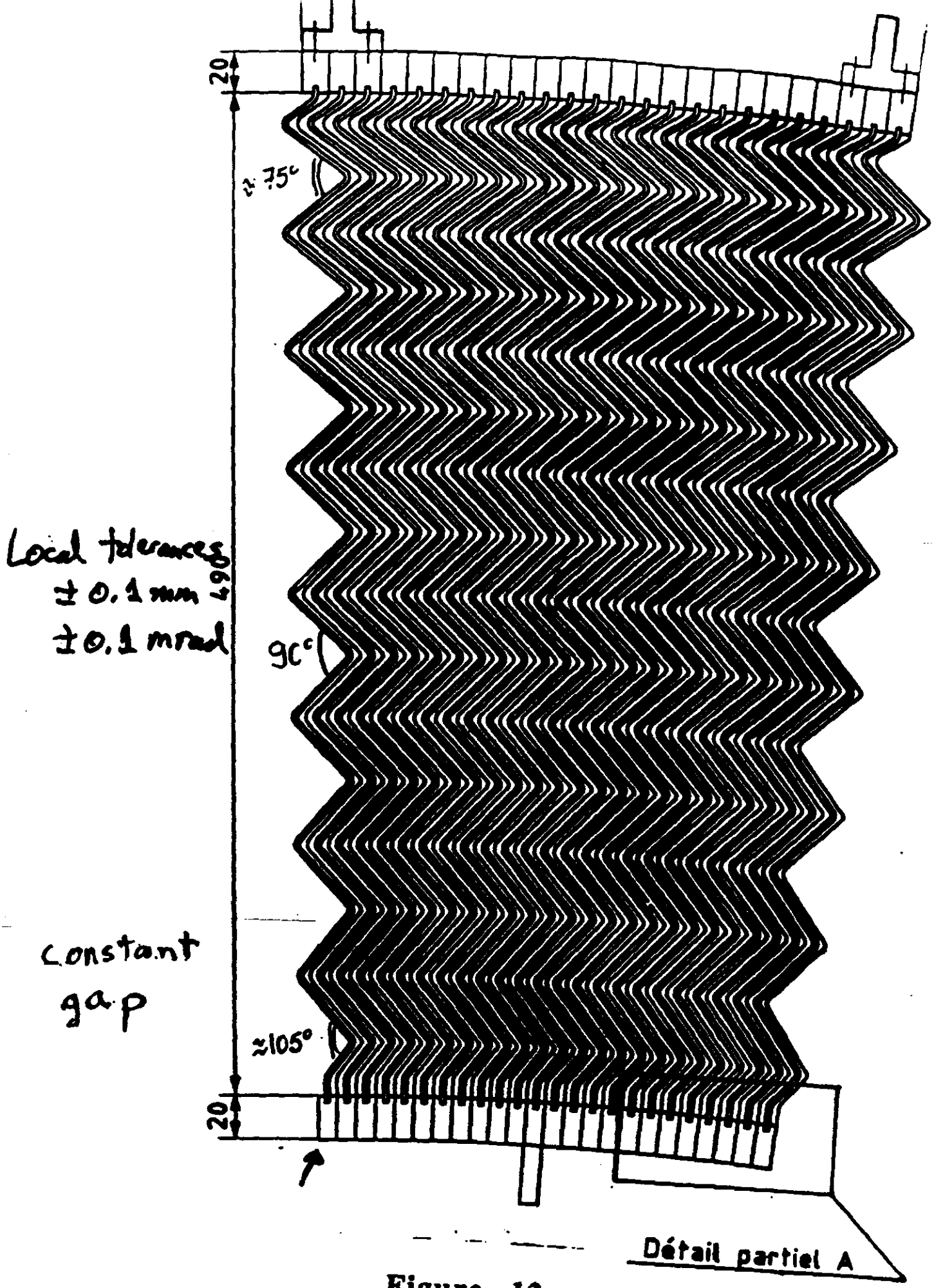
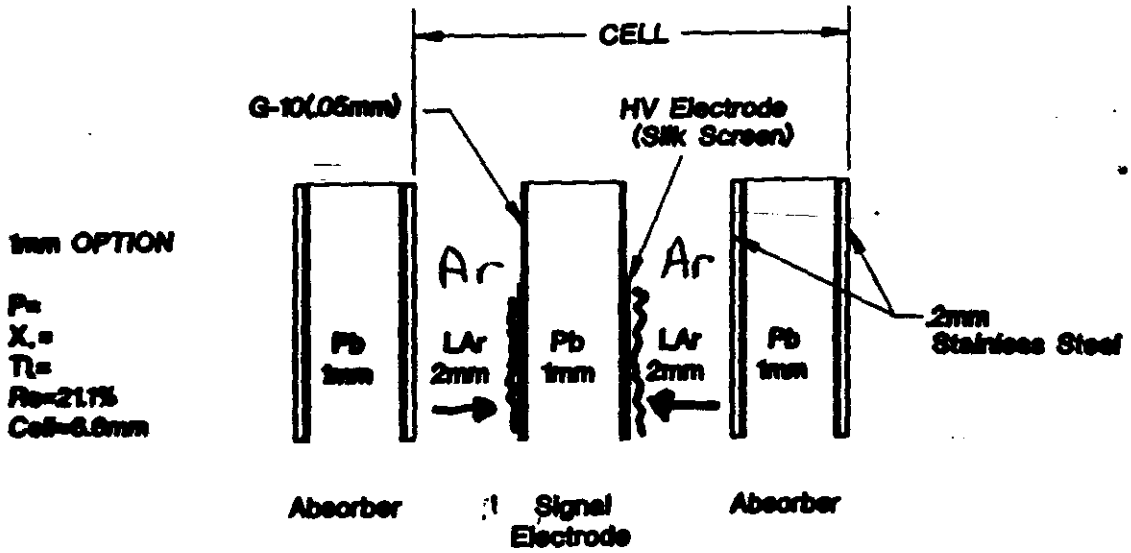
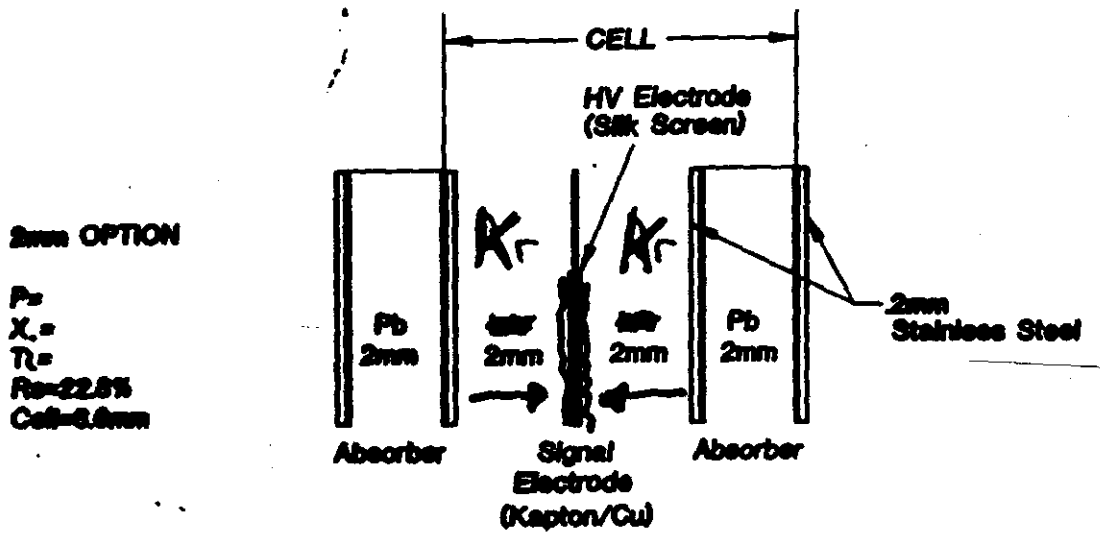
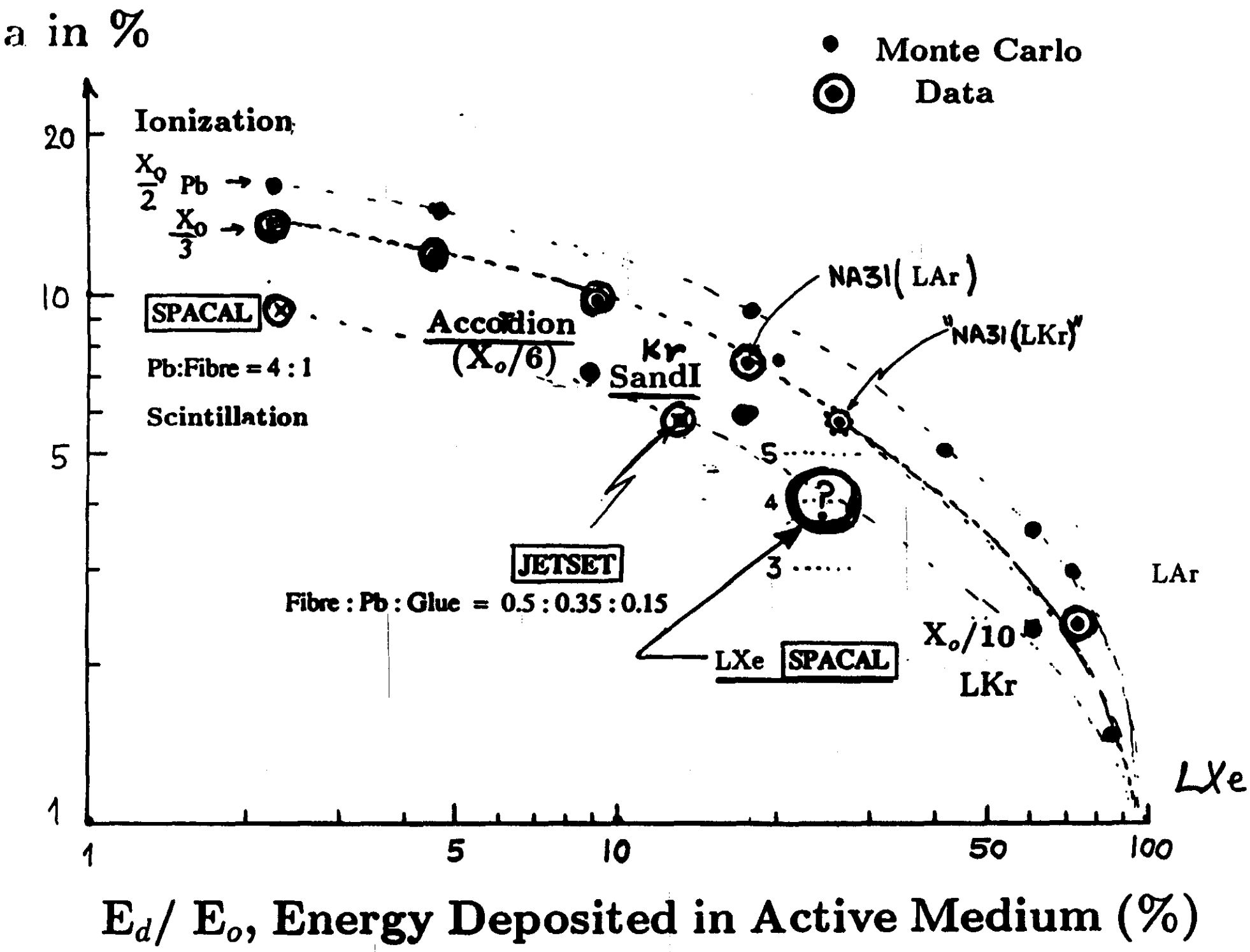

20
≈75°
Local tolerances
±0.1 mm
±0.1 mrad
490
90°
constant
gap
≈105°
20
Détail partiel A

Figure 12

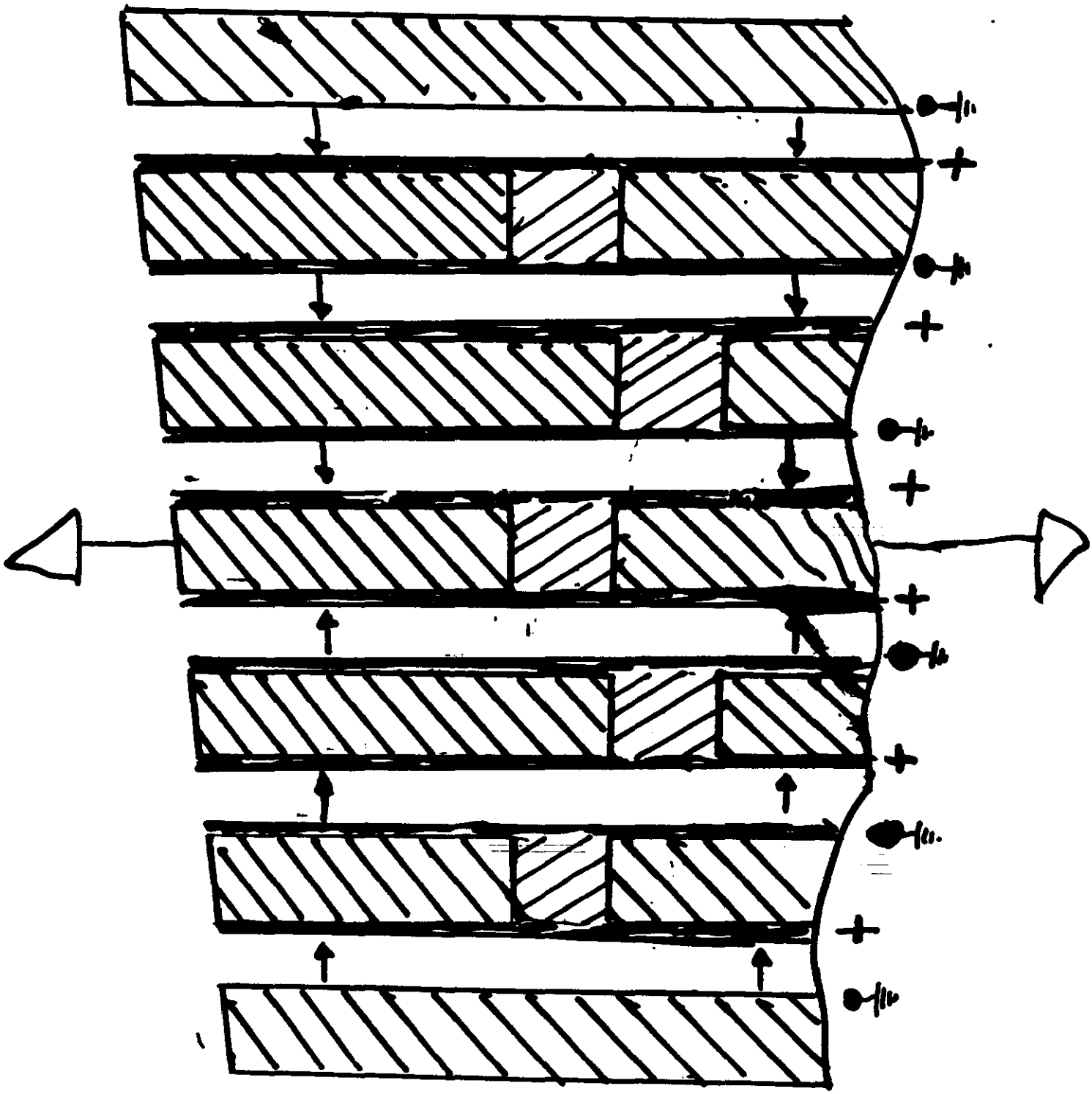
EM Configuration



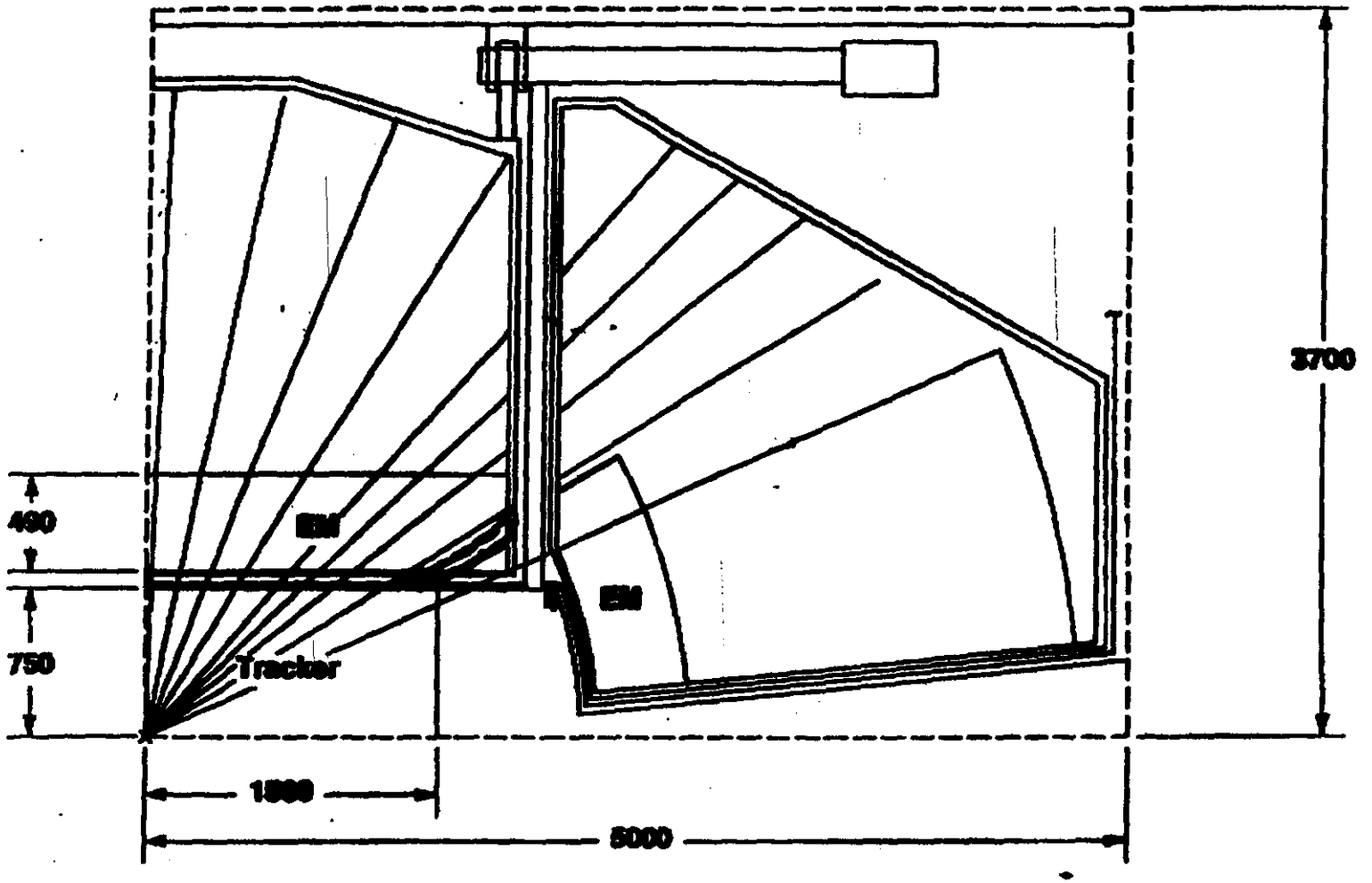



a in %
Monte Carlo
Data
Ionization
$\frac{X_0}{2}$ Pb
$\frac{X_0}{3}$
SPACAL
Pb:Fibre = 4 : 1
Scintillation
Accordion
($X_o/6$)
Kr
SandI
NA31(LAr)
"NA31(LKr)"
JETSET
Fibre : Pb : Glue = 0.5 : 0.35 : 0.15
LXe SPACAL
$X_o/10$
LKr
LAr
LXe
20
10
5
1
1
5
10
50
100
E_d/ E_o, Energy Deposited in Active Medium (%)

HADRONIC "Electrostatic" transformer



GEM Medium Barrel Configuration



MARTIN MARIETTA

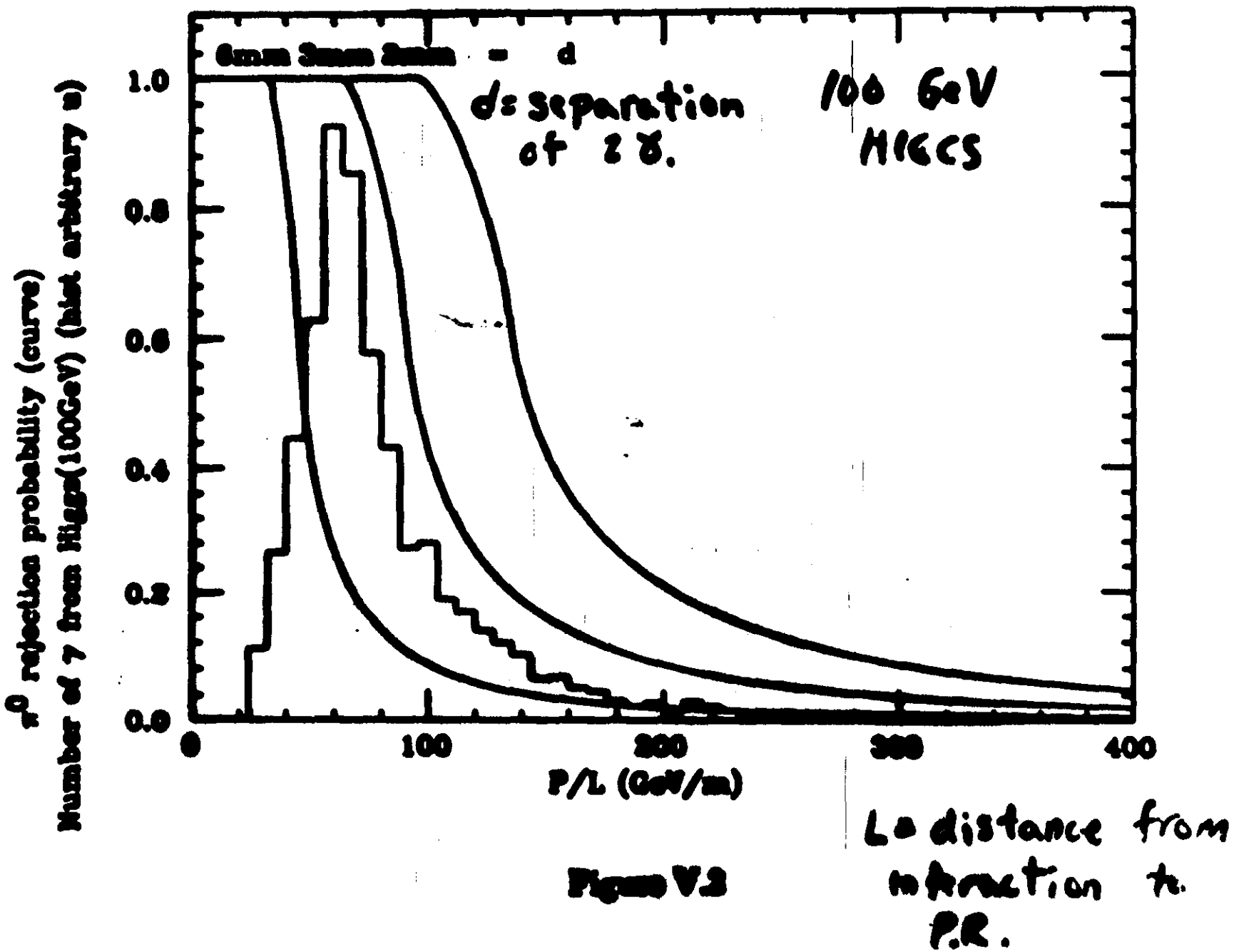
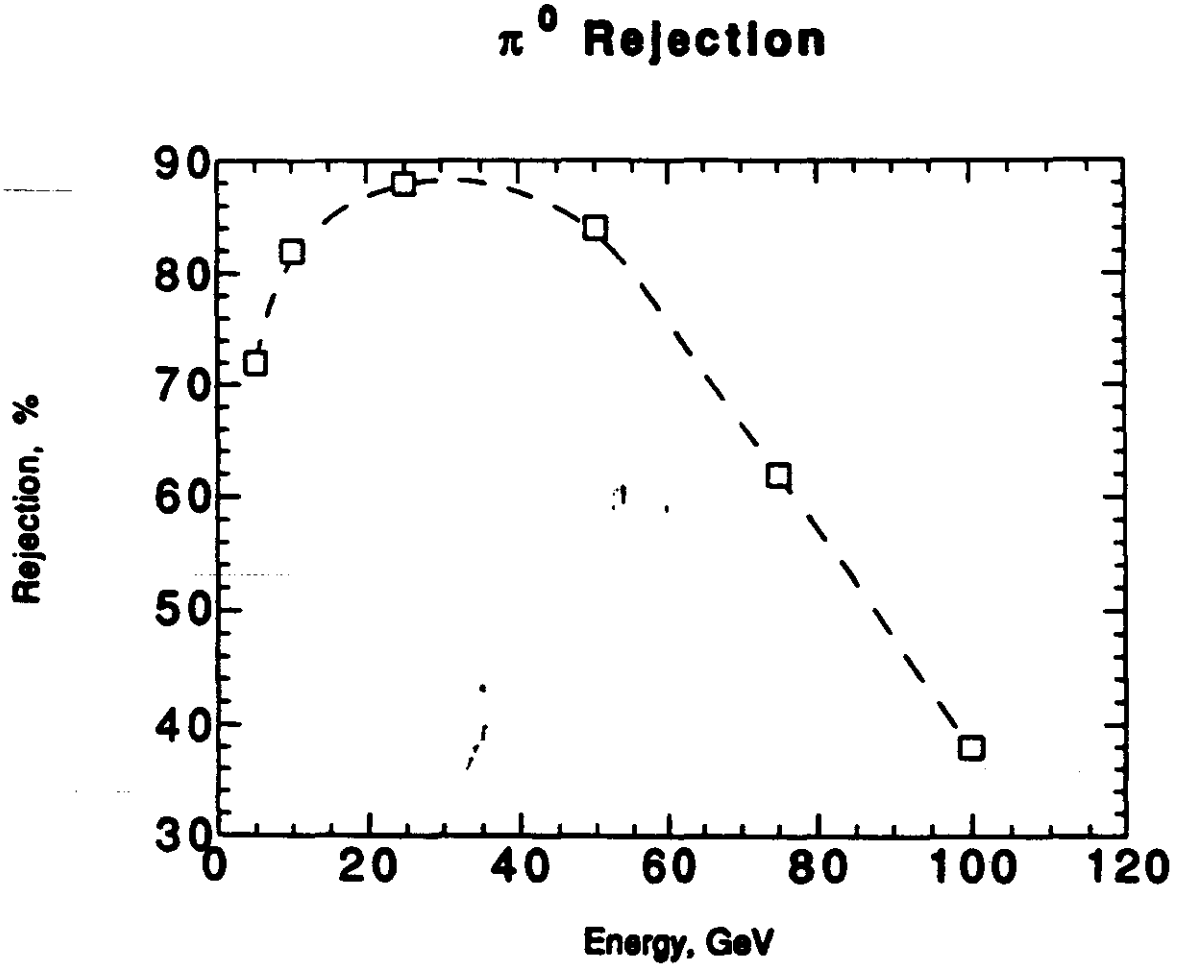

6mm 3mm 3mm - d
d = separation of 2 γ.
100 GeV HIGGS
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
P/L (GeV/m)
π0 rejection probability (curve)
Number of γ from Higgs(100GeV) (hist arbitrary ∝)
L = distance from interaction to P.R.

Figure V.2

2mm strips X + y in LAr



85 cm @ 90°

$\epsilon = 100\%$ for γ's

Options for Preradiator

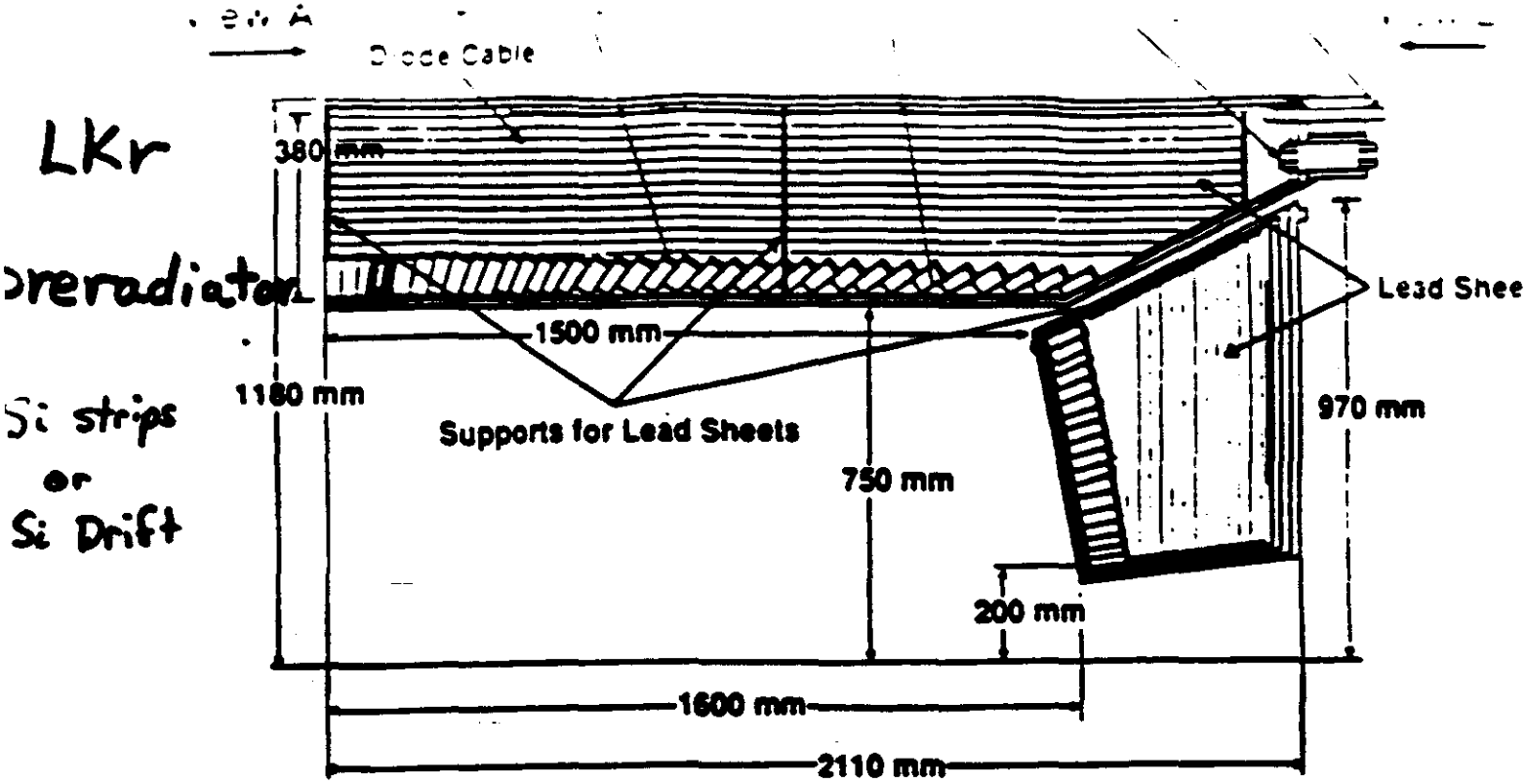
Calorimeter alone can provide rejection

(γ/π^0)	4	$\epsilon_\gamma = 90\%$
(γ/π^0)	10	$\epsilon_\gamma = 80\%$

1) 2mm strips in argon $(3\text{-}4\,X_0)$
   (with ganging preserve total number of channels)

2) silicon strips inside or outside cryostat

3) silicon drift



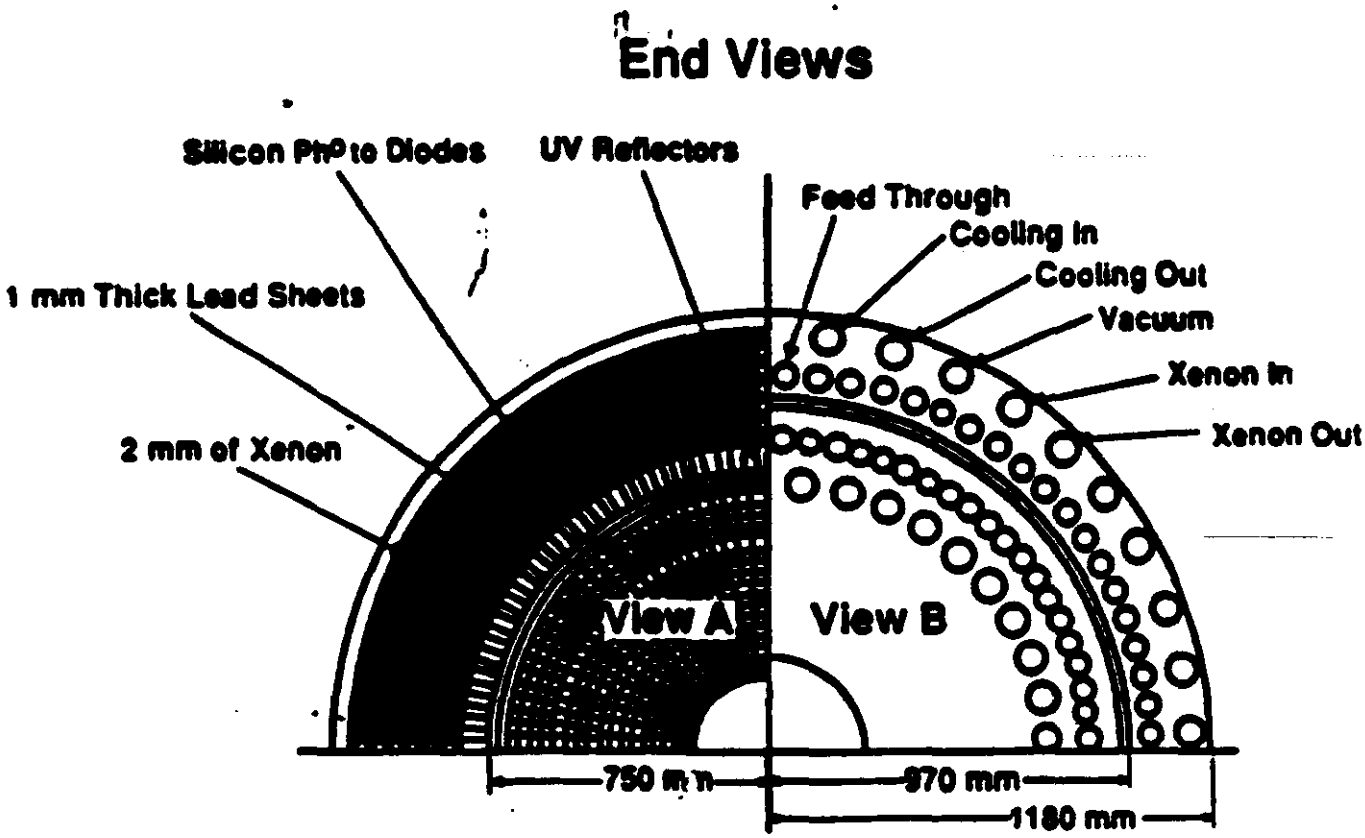


Figure 21: Side and end views of one quadrant of SandI electromagnetic detector using LKr + 5% LXe. SandI has a homogeneous section in the front, with a UV diode collecting scintillation light from the first 10 cm of the homogeneous noble liquid; followed by a drift diode to detect the positions of showers; and a sampling ionization calorimeter in the back (e.g. Accordion).

J. Brau

GEM Preradiator

J. Brau, R. Frey, K. Furuno, D. Strom, X. Yang

ROLE OF PRERADIATOR

** π^0/γ DISCRIMINATION

* ELECTRON TRIGGER (eg. B:)

ELECTRON PURIFICATION
(π/γ OVERLAP, CHG. EXCH. REJ)

MEASURE γ POINTING (W/ EM CAL)

BEAM CROSSING BUCKET TAG

PROTOTYPE UNDER CONSTRUCTION
AT OREGON IN COLLABORATION
WITH SILICON EM CAL CELL
(SEE SIMSWTEP AND)

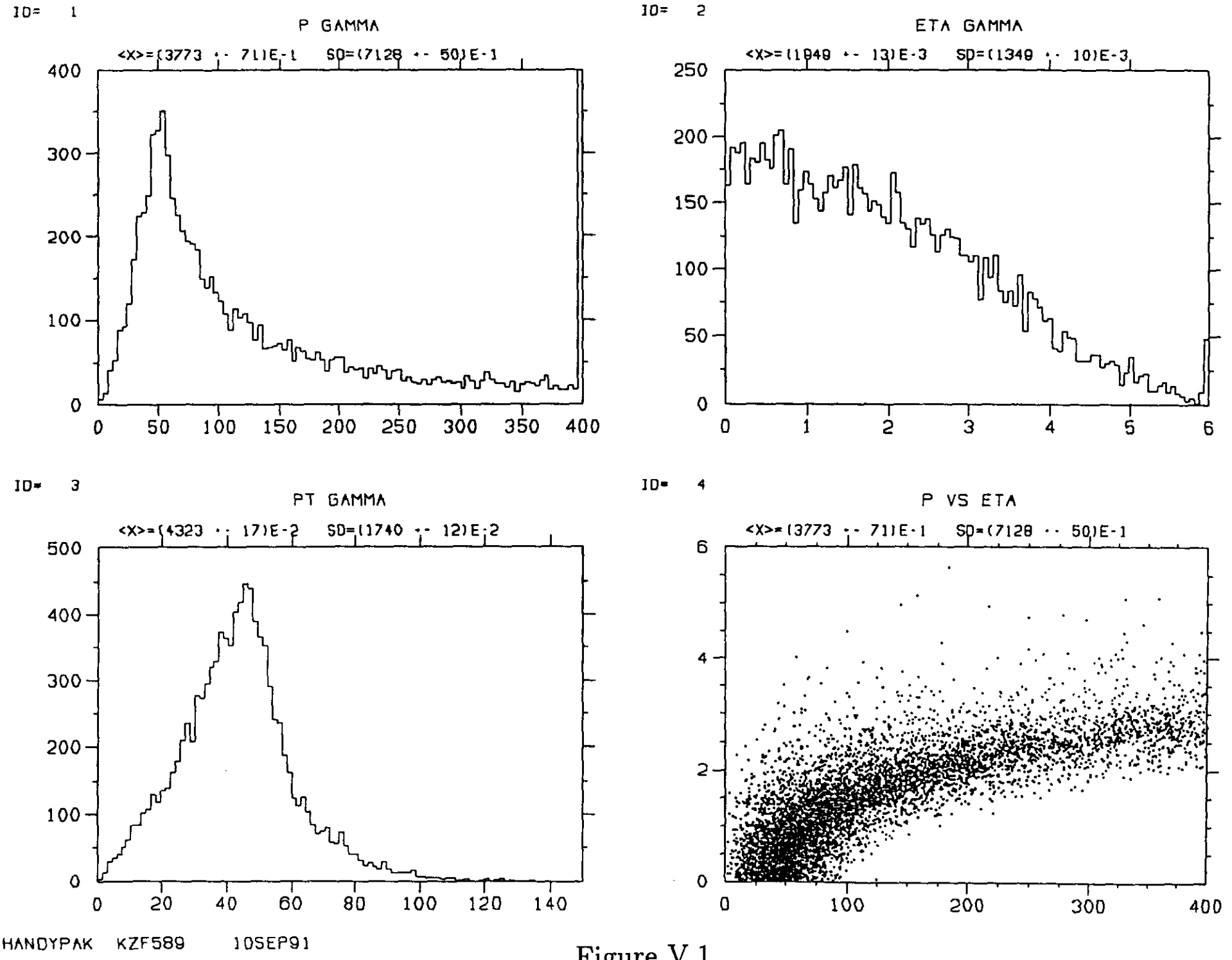

ID= 1
P GAMMA
<X>=(3773 +- 71)E-1 SD=(7128 +- 50)E-1
ID= 2
ETA GAMMA
<X>=(1949 +- 13)E-3 SD=(1349 +- 10)E-3
ID= 3
PT GAMMA
<X>=(4323 +- 17)E-2 SD=(1740 +- 12)E-2
ID= 4
P VS ETA
<X>=(3773 +- 71)E-1 SD=(7128 +- 50)E-1
HANDYPAK KZF589 10SEP91

Figure V.1

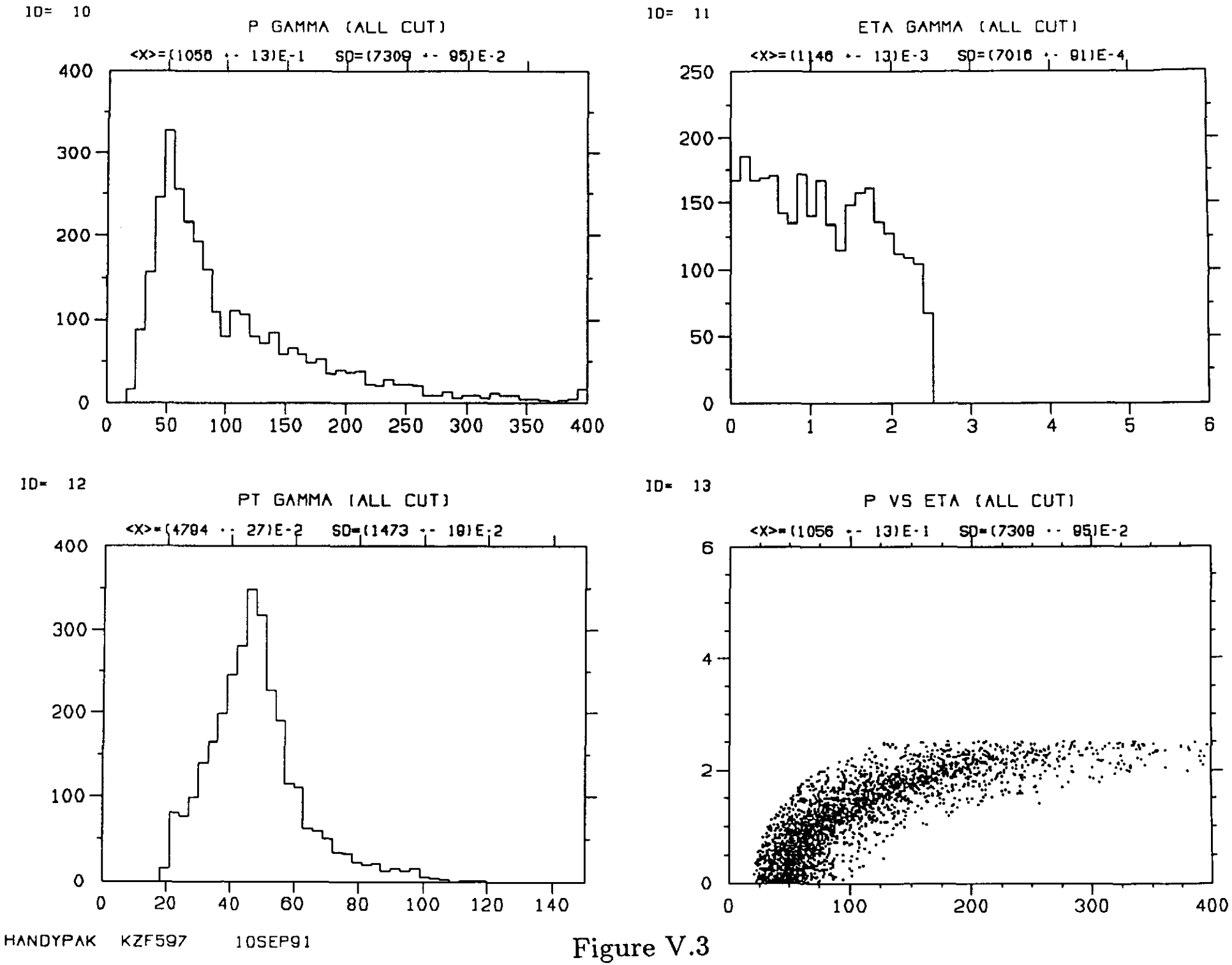
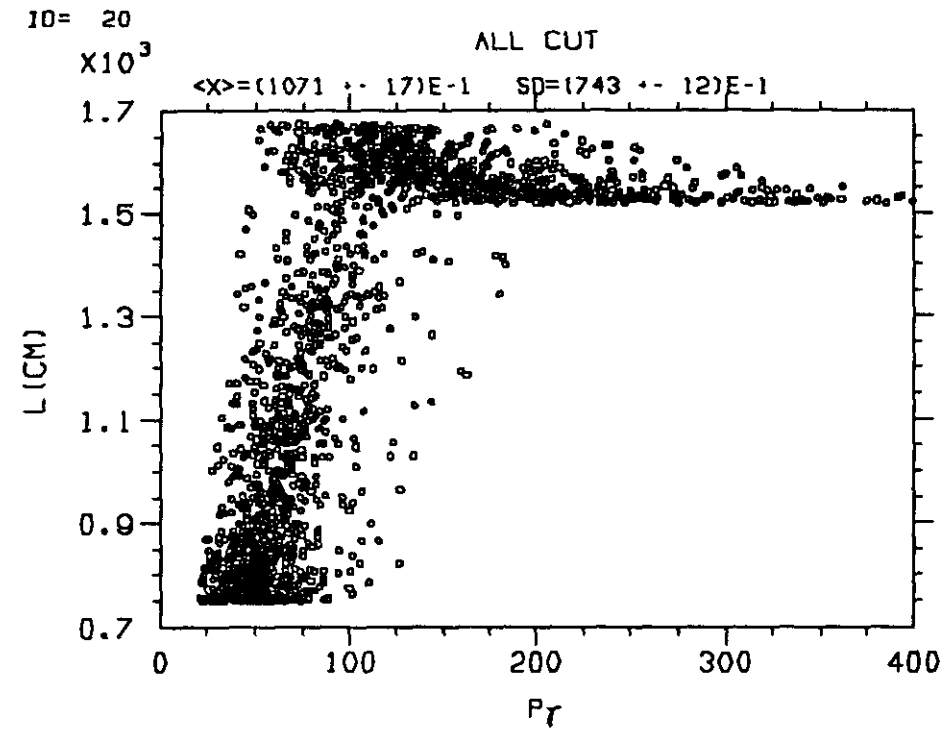
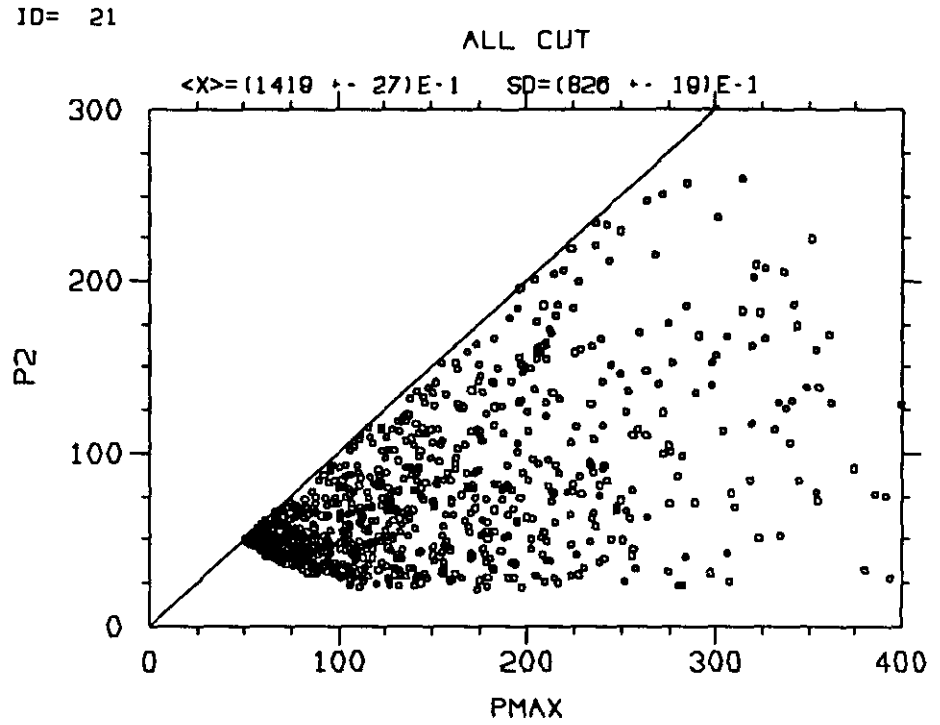
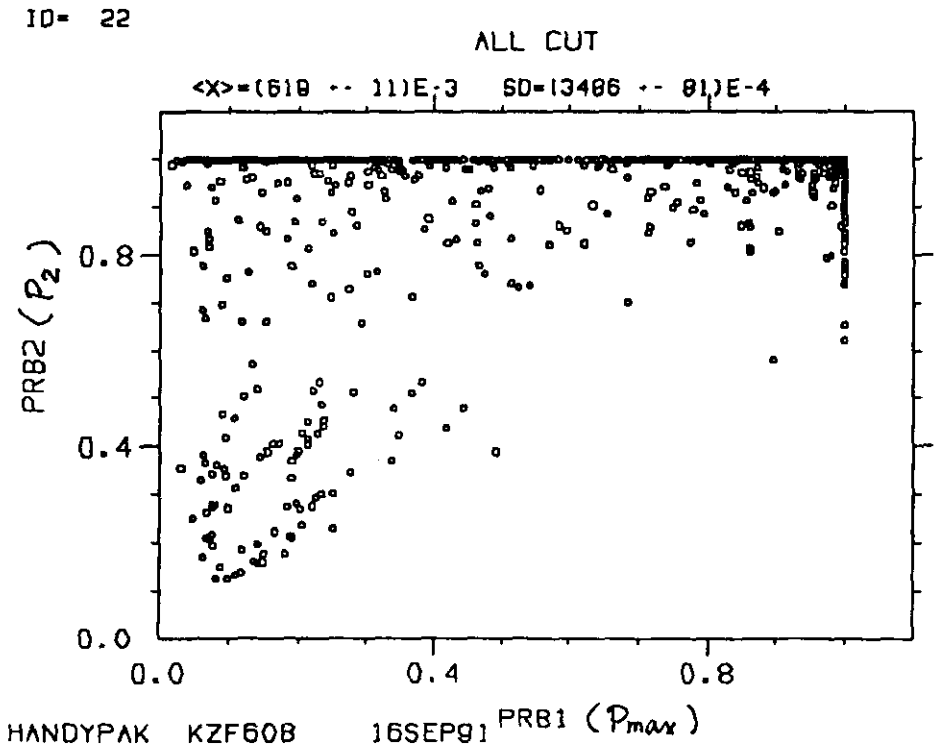

ID= 10
P GAMMA (ALL CUT)
<X>=(1056 +- 13)E-1 SD=(7309 +- 95)E-2
ID= 11
ETA GAMMA (ALL CUT)
<X>=(1146 +- 13)E-3 SD=(7016 +- 91)E-4
ID= 12
PT GAMMA (ALL CUT)
<X>=(4794 +- 27)E-2 SD=(1473 +- 18)E-2
ID= 13
P VS ETA (ALL CUT)
<X>=(1056 +- 13)E-1 SD=(7309 +- 95)E-2
HANDYPAK KZF597 10SEP91

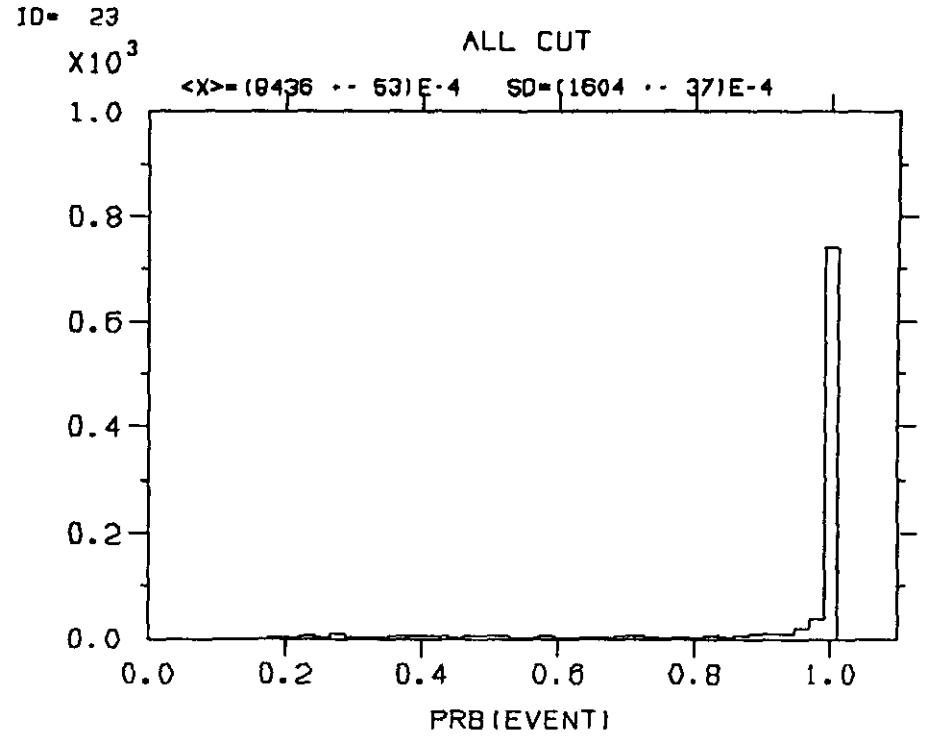
Figure V.3

3mm cut

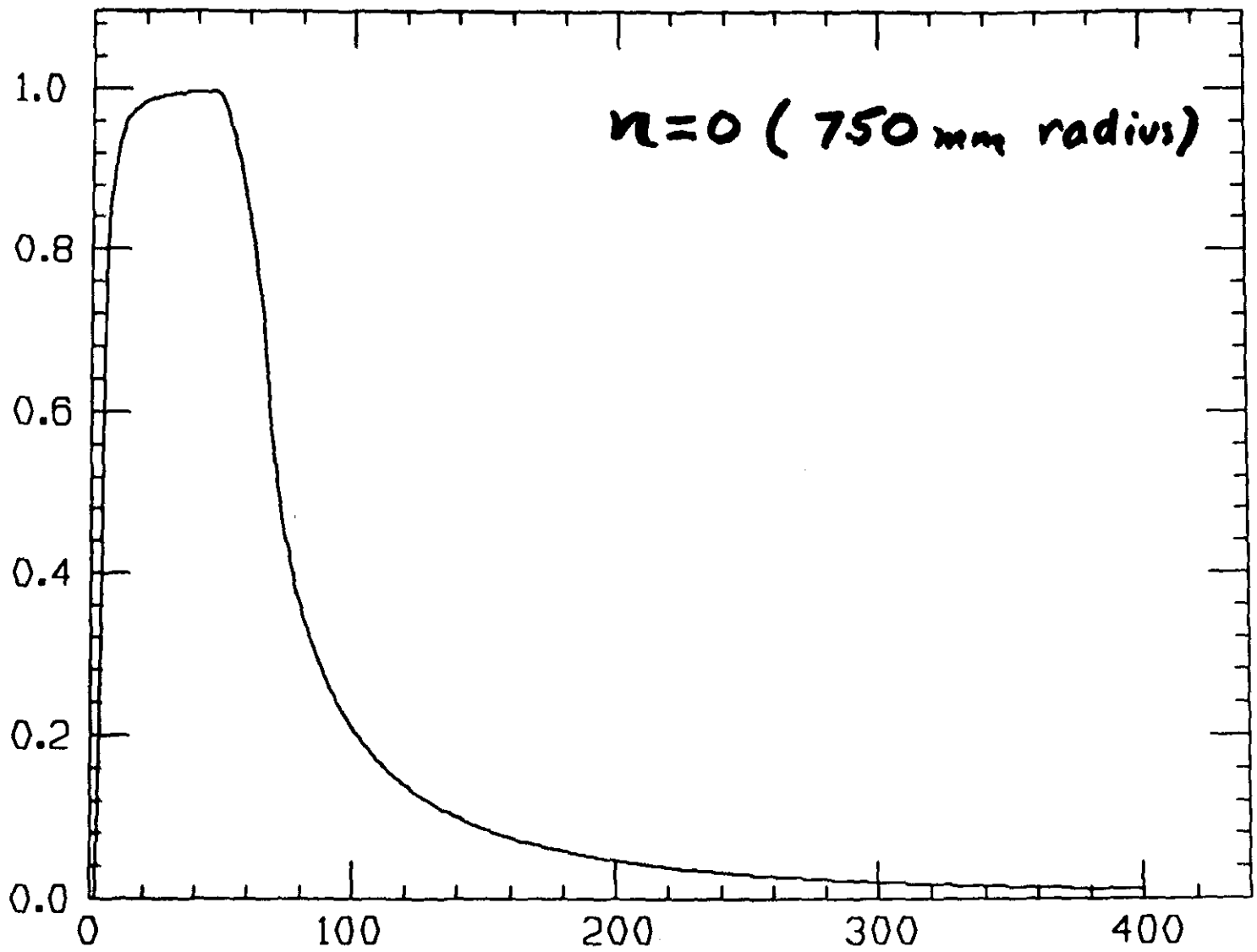








HANDYPAK KZF60B 16SEP91


n=0 (750 mm radius)
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400

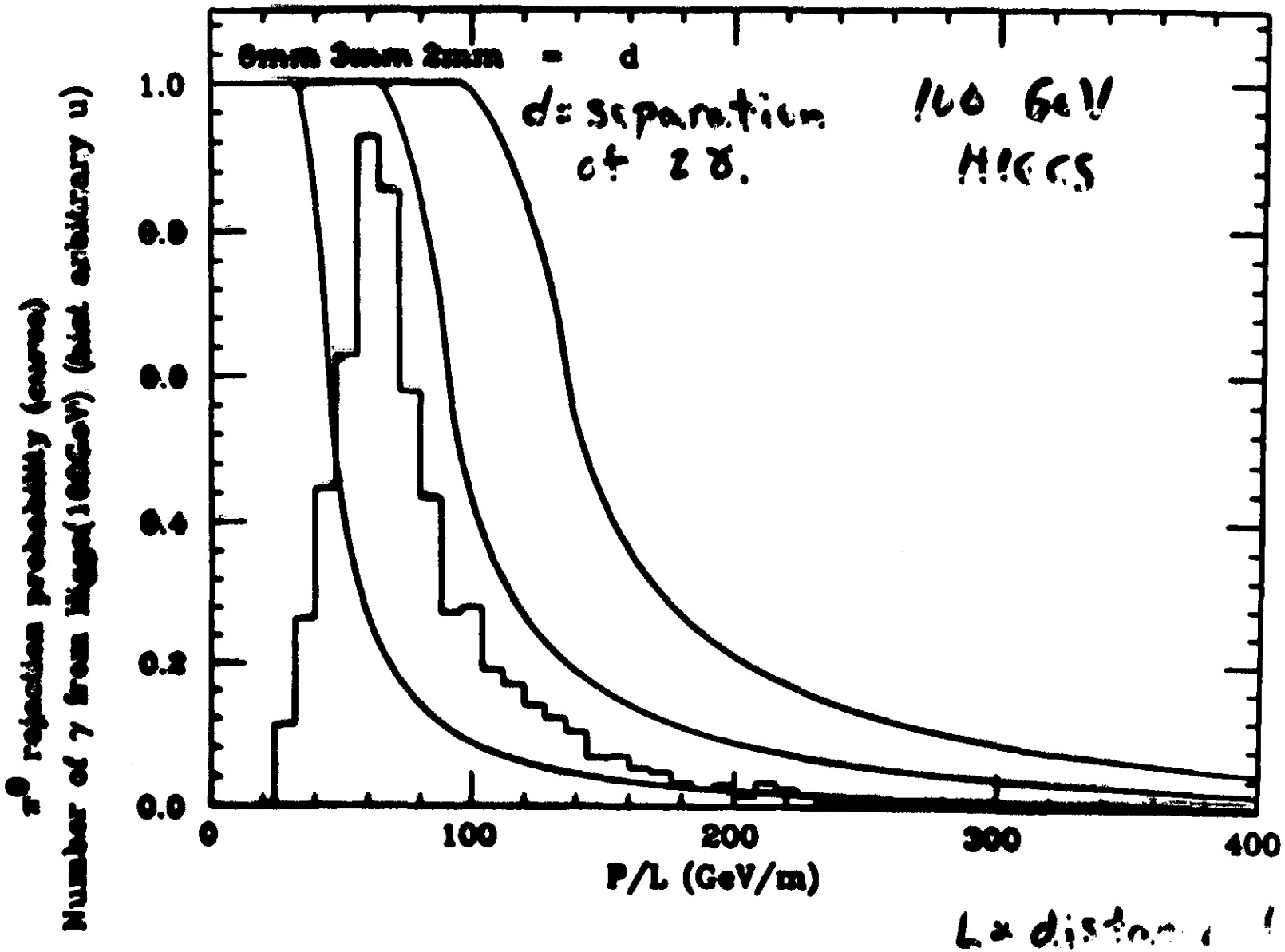
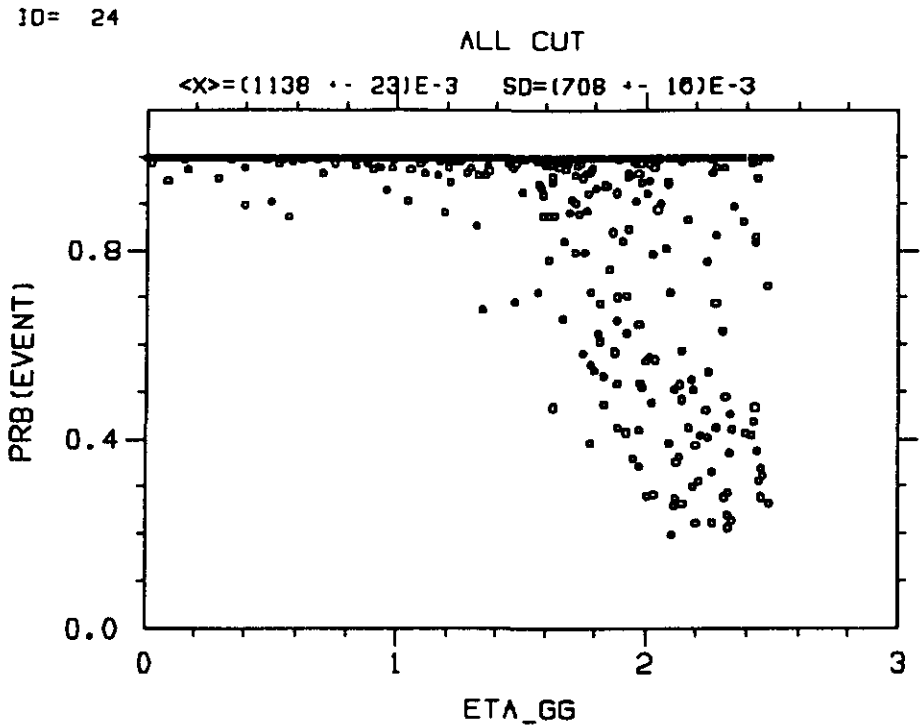
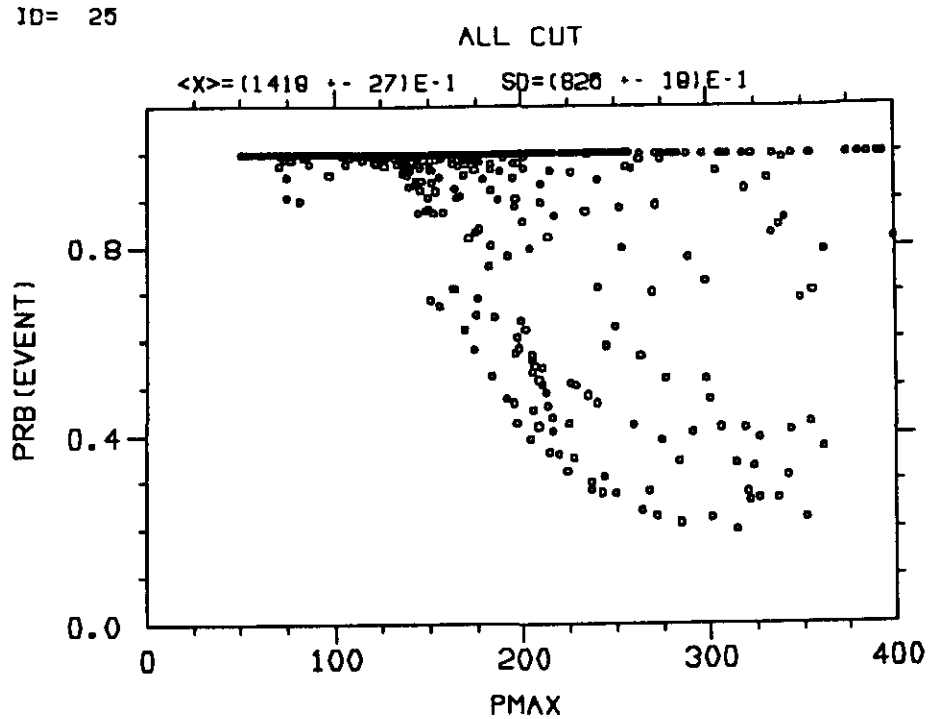


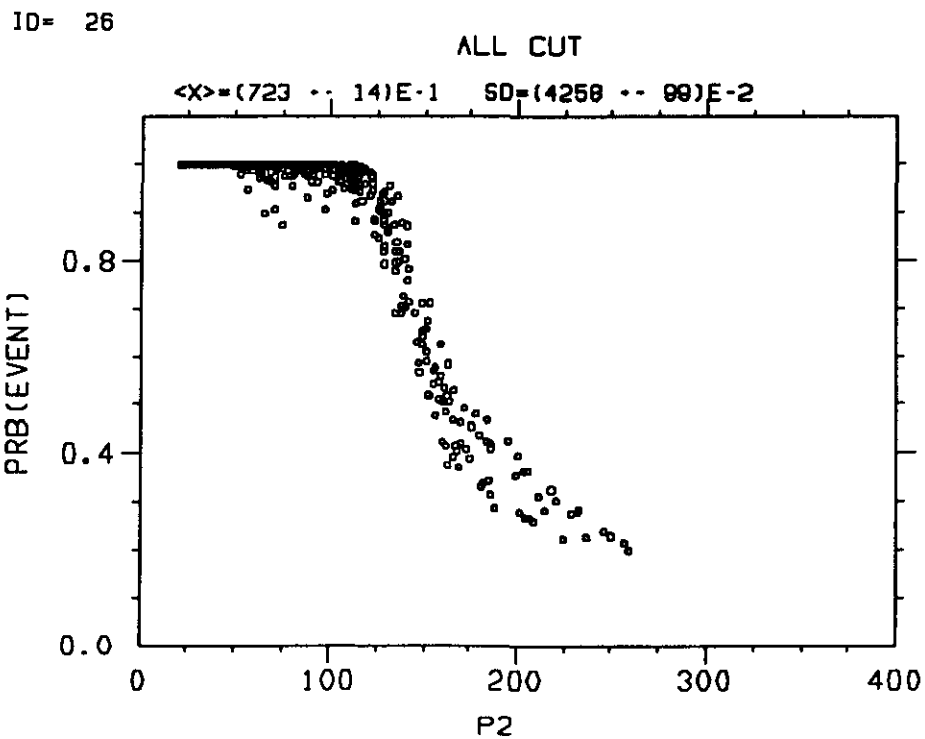
Figure V.2

L: distance in detector
P.R.

3 mm cut







$$Prob(ev) = Prob(\gamma_1) + Prob(\gamma_2) - Prob(\gamma_1)\cdot Prob(\gamma_2)$$

all cut :

$|\eta_\gamma| < 2.5$

$|\eta_{\gamma\gamma}| < 3$

$|\cos\theta^*_\gamma| < 0.8$

$E_{T_\gamma} < 20$ GeV.

932 ev.

37 %

232 ev/SSC year

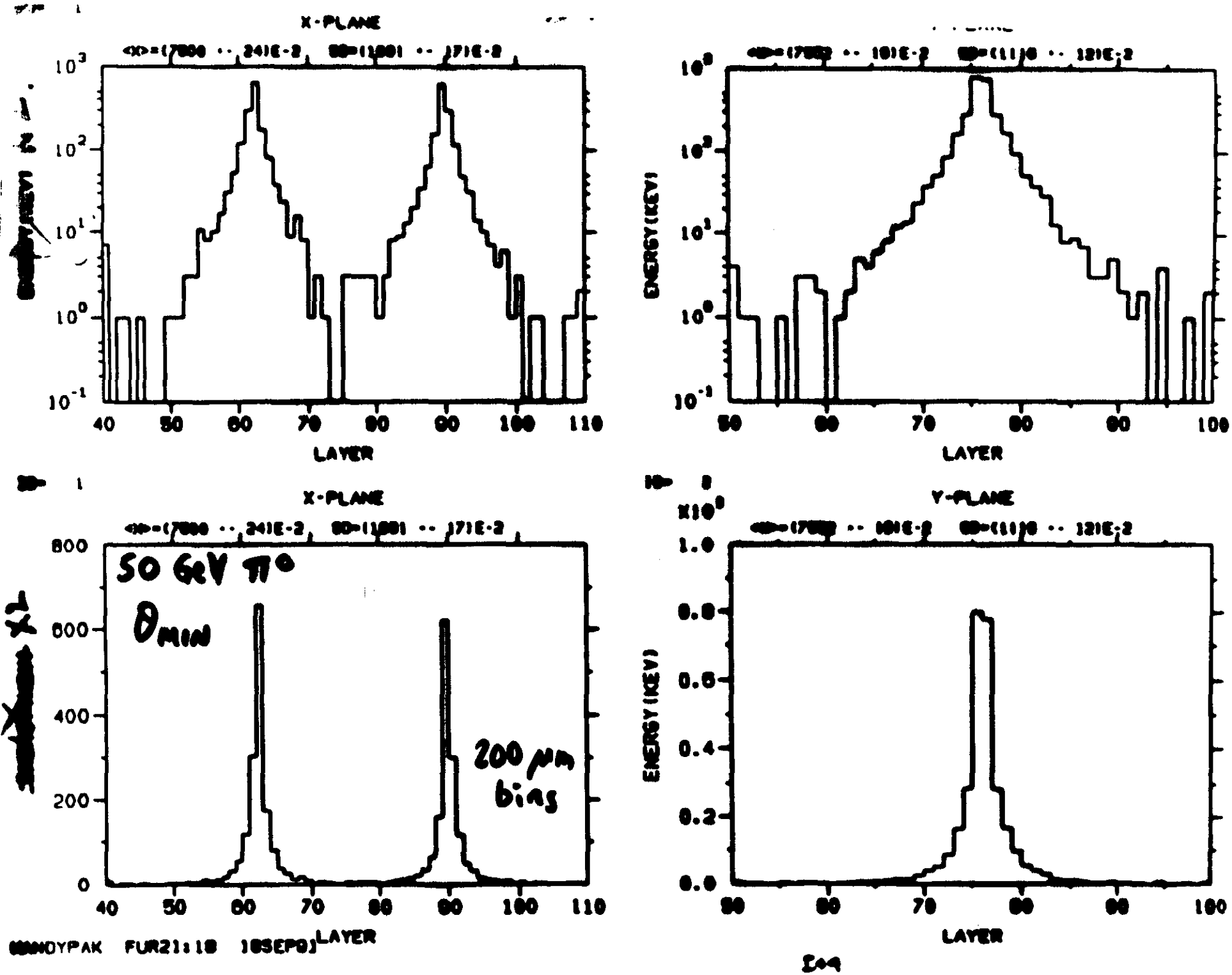
production
H(100)
$P_t > 1$ GeV

no cut :

$|\cos\theta_\gamma| \leq 1$

2496 ev

621 ev/SSC year


X-PLANE
LAYER
ENERGY (KEV)
X-PLANE
LAYER
ENERGY (KEV)
50 GeV π⁰
θMIN
200 μm
bias
Y-PLANE
LAYER
ENERGY (KEV)
LAYER

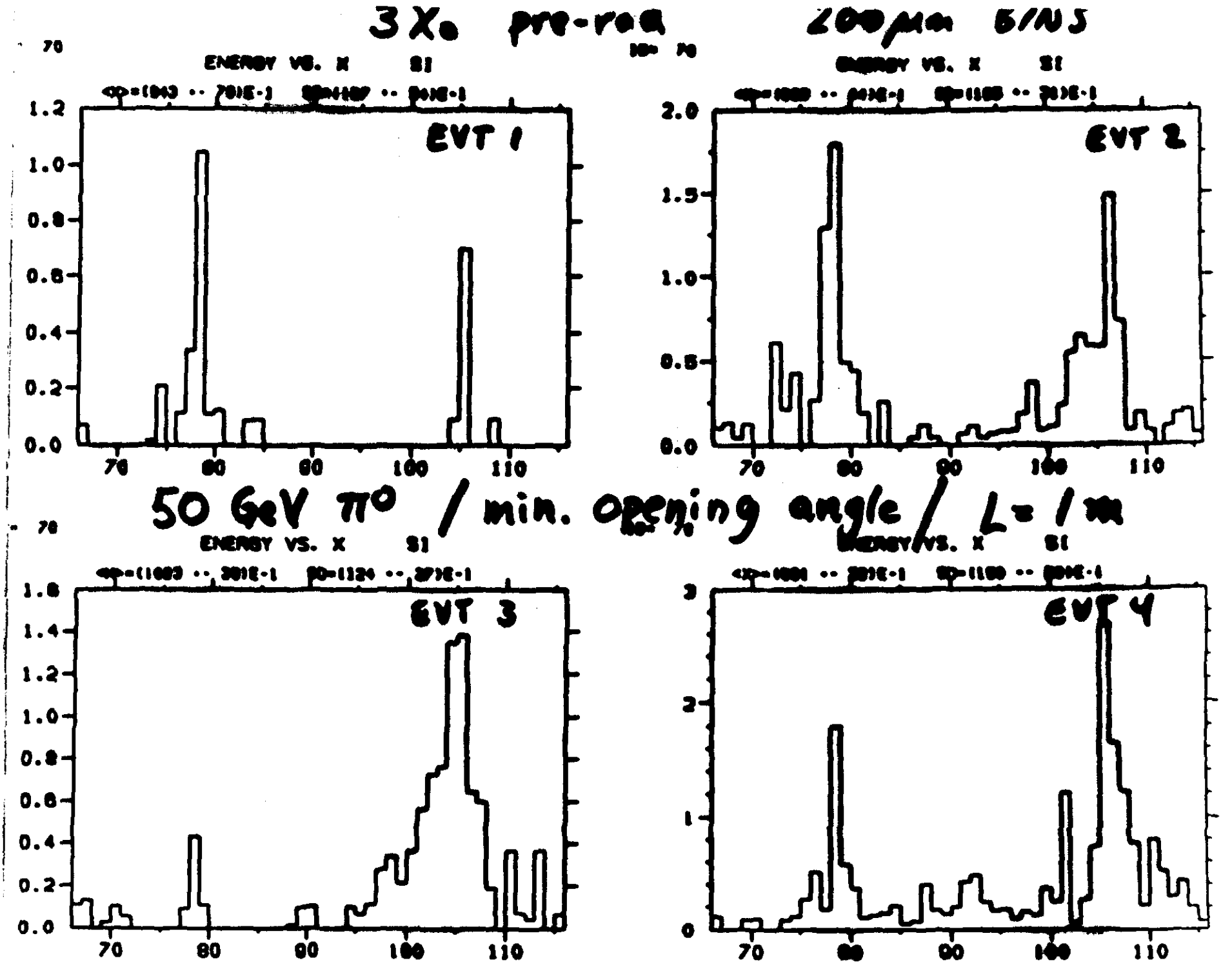
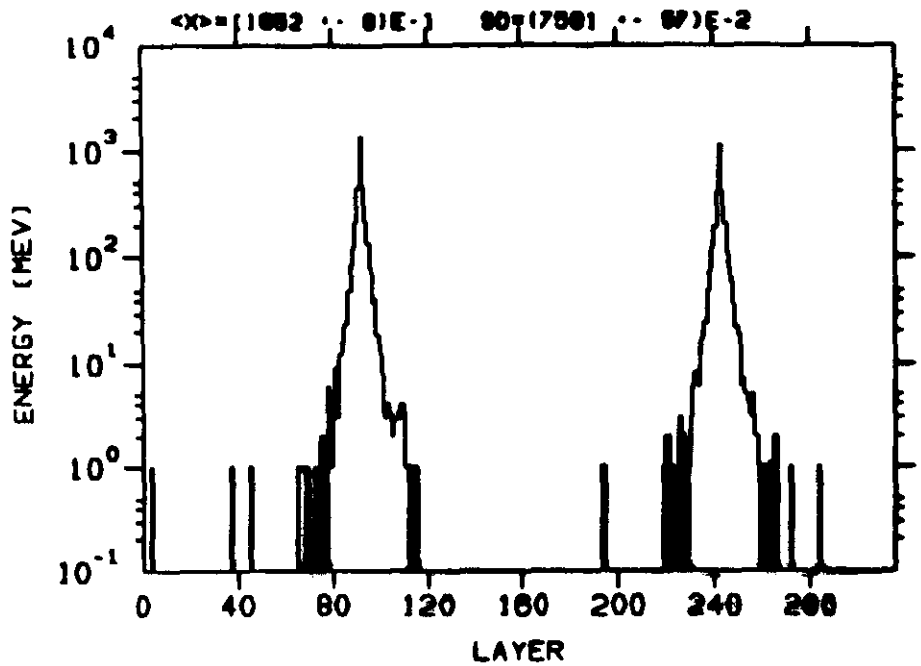

3 X₀ pre-rad
200μm S/N5
ENERGY VS. X
EVT 1
EVT 2
50 GeV π⁰ / min. opening angle / L = 1 m
EVT 3
EVT 4
YPAK X1A15:42 05EP91

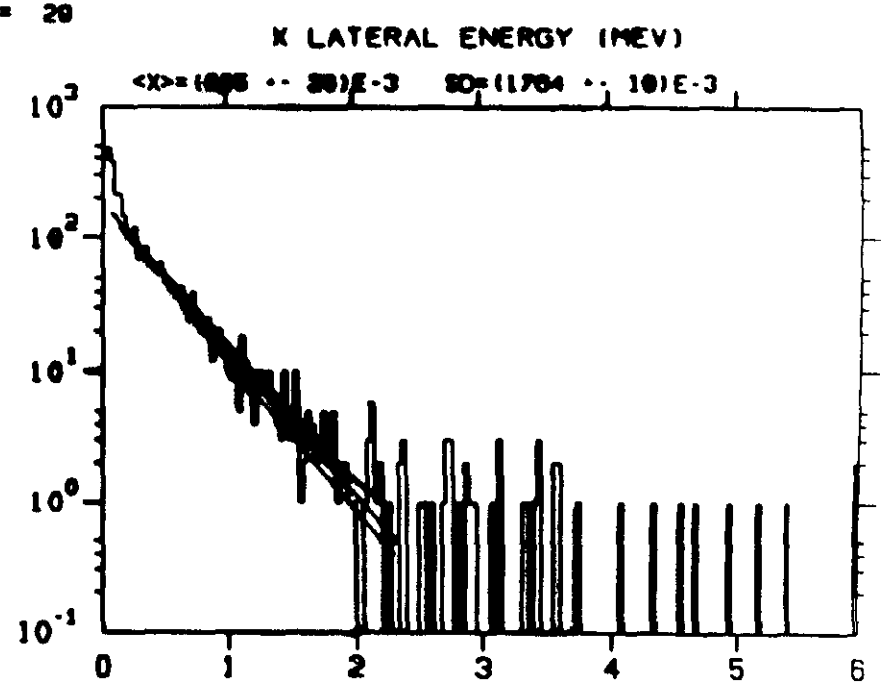
Figure V.5

γ 100 GeV

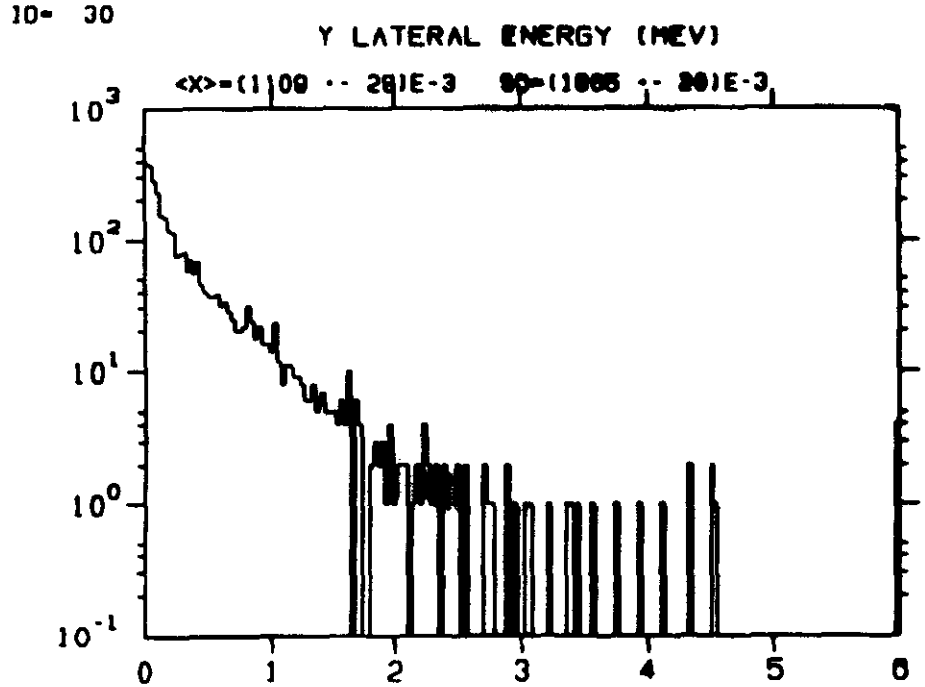
ID= 1



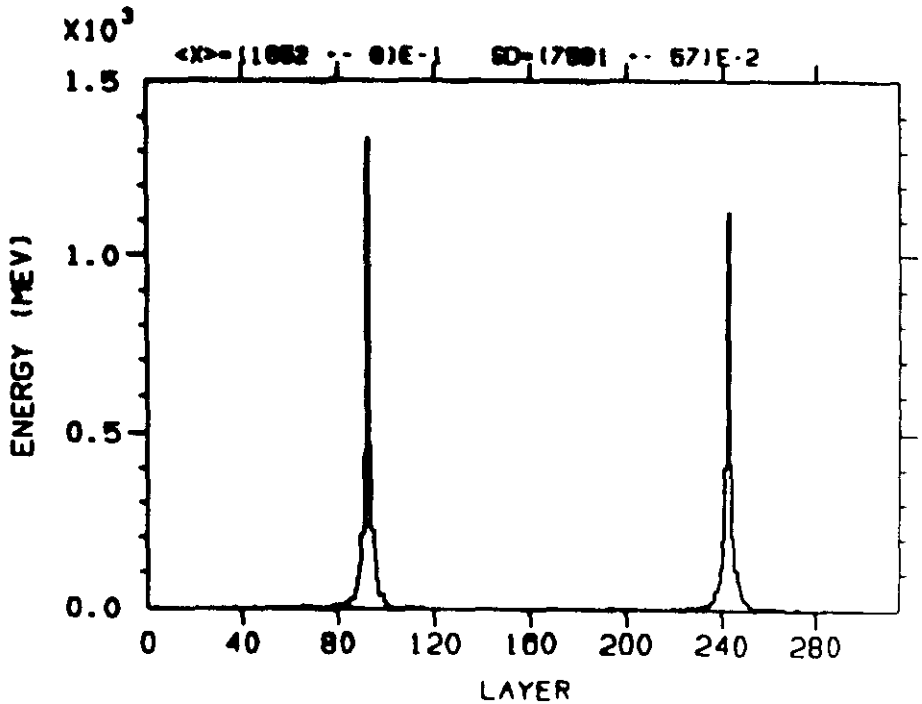
ID= 20



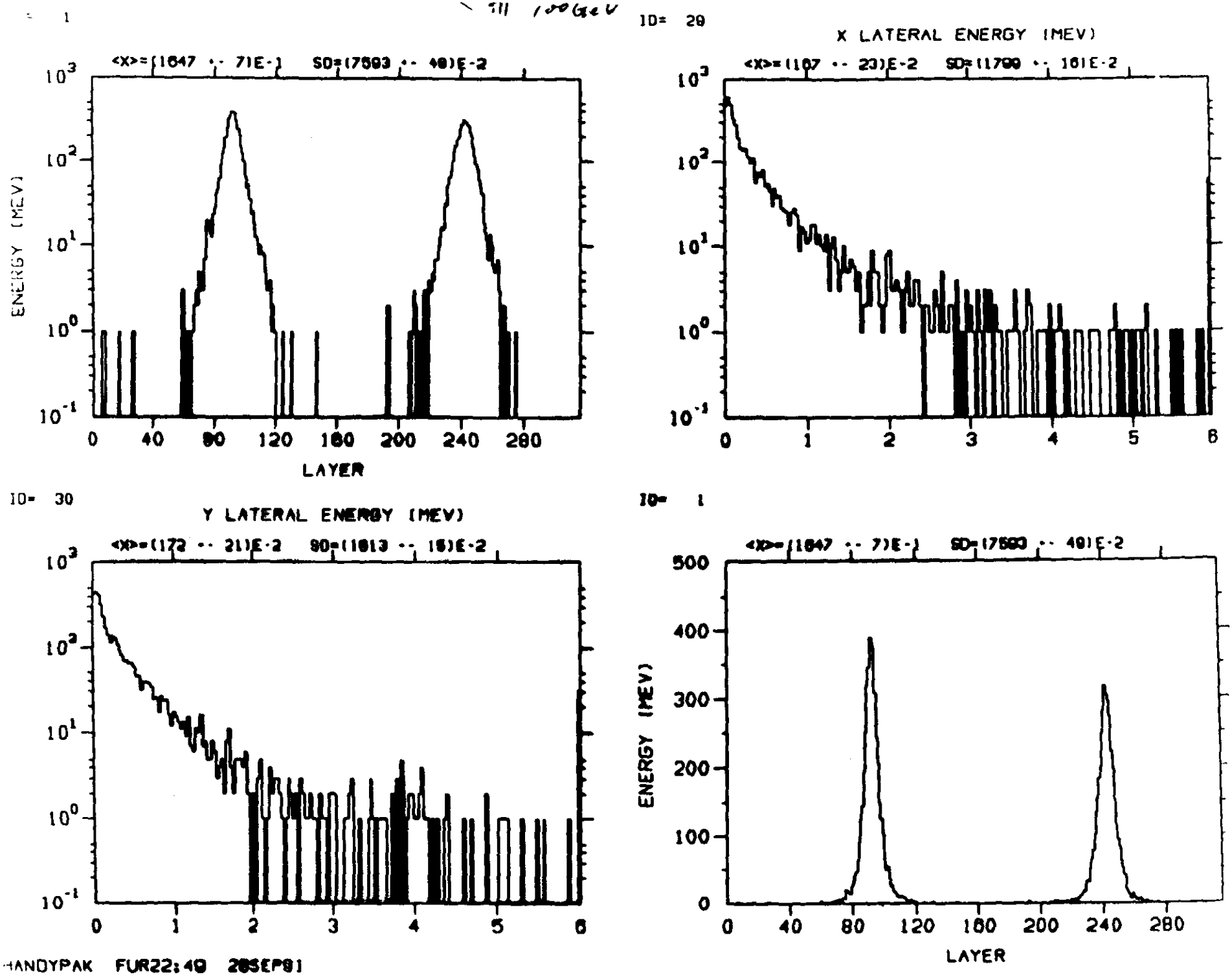
ID= 30

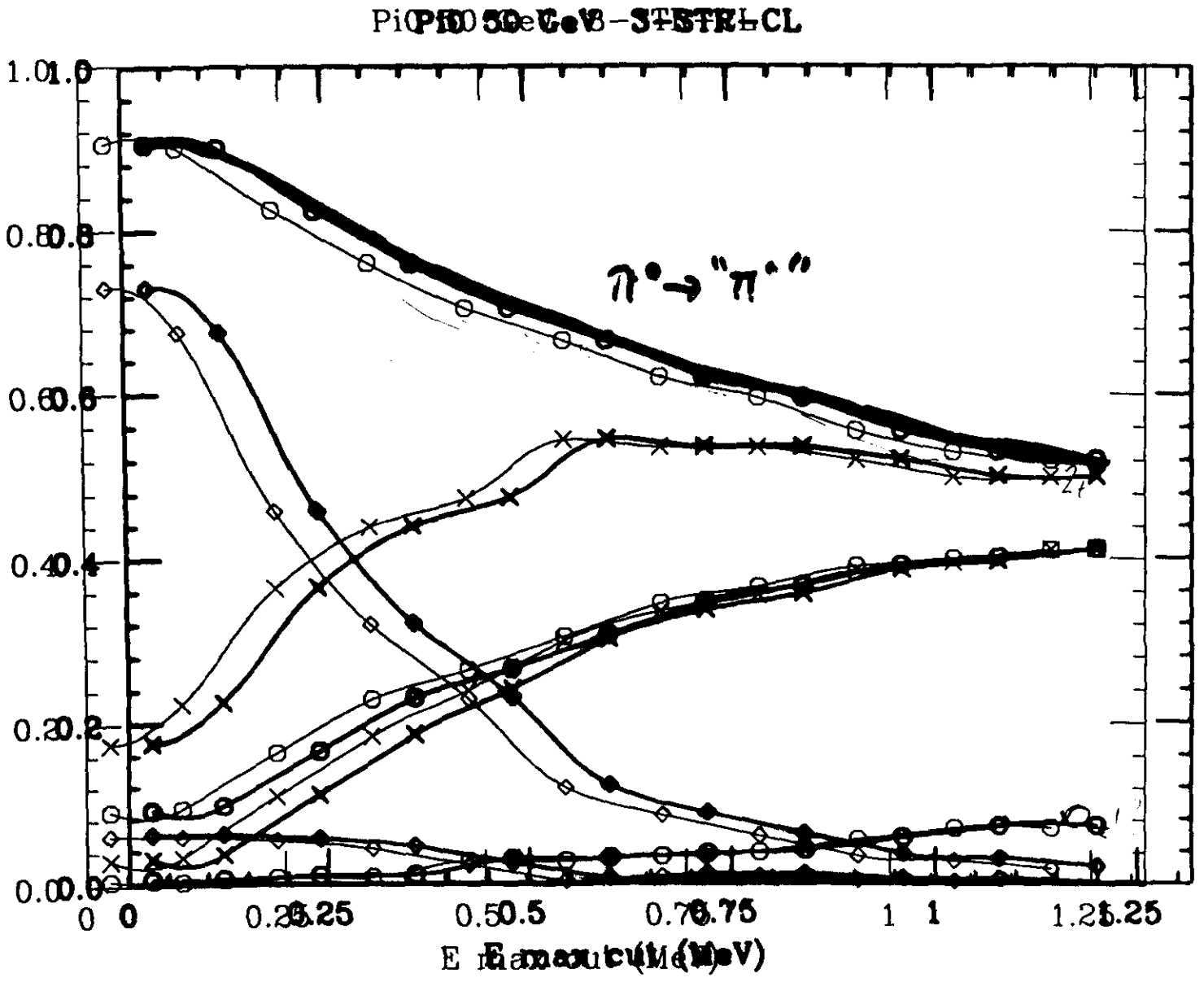


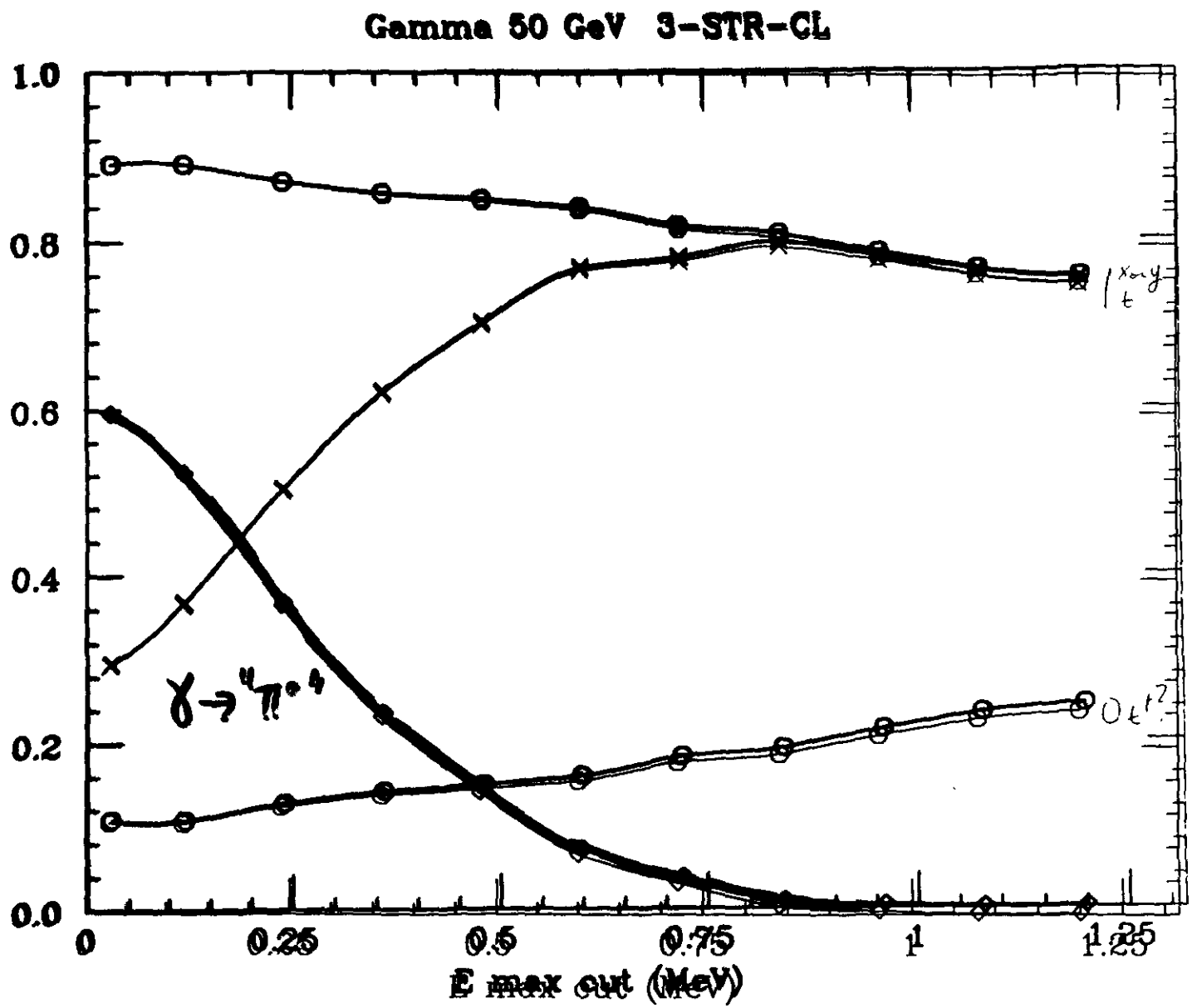
ID= 1

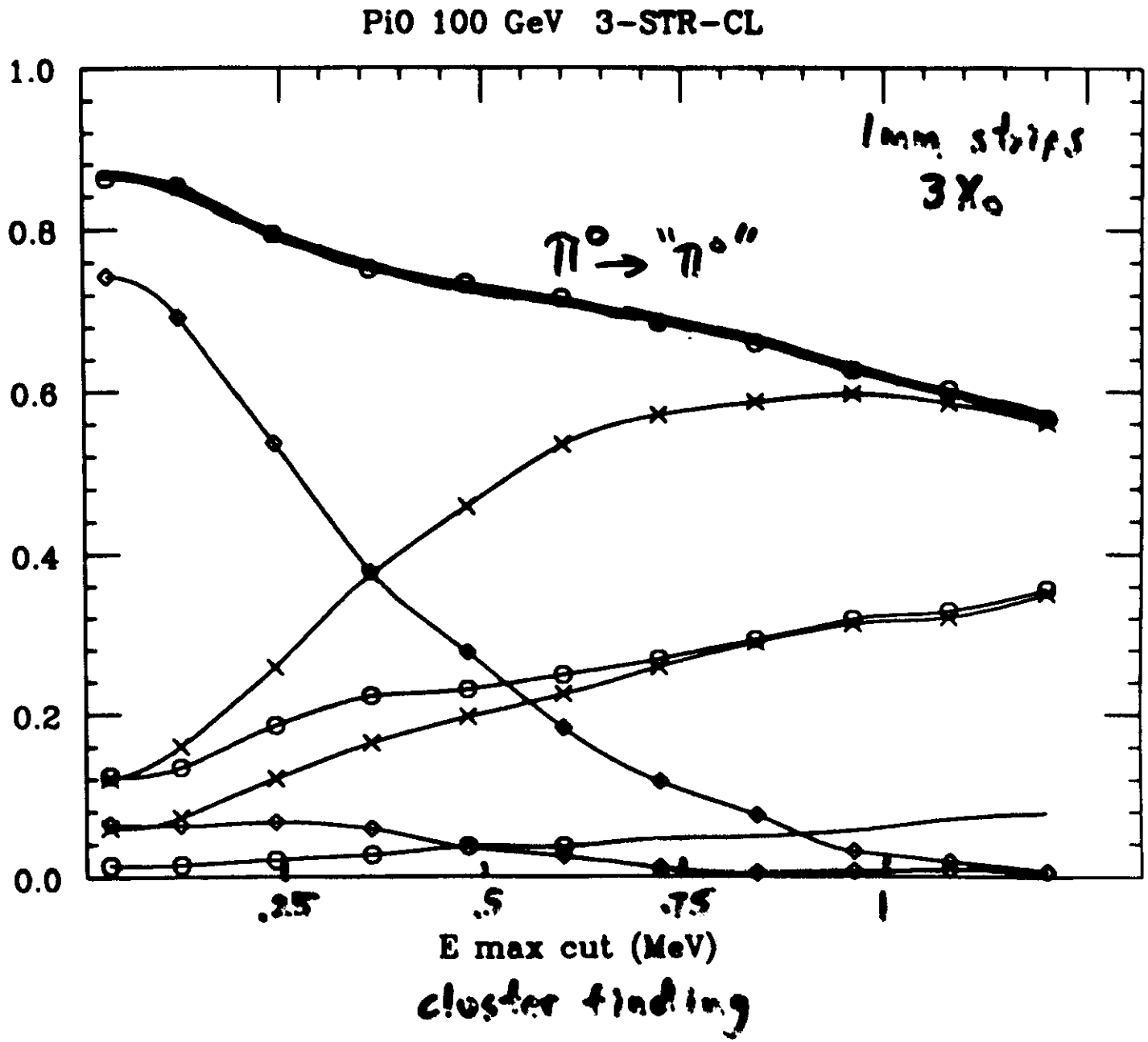


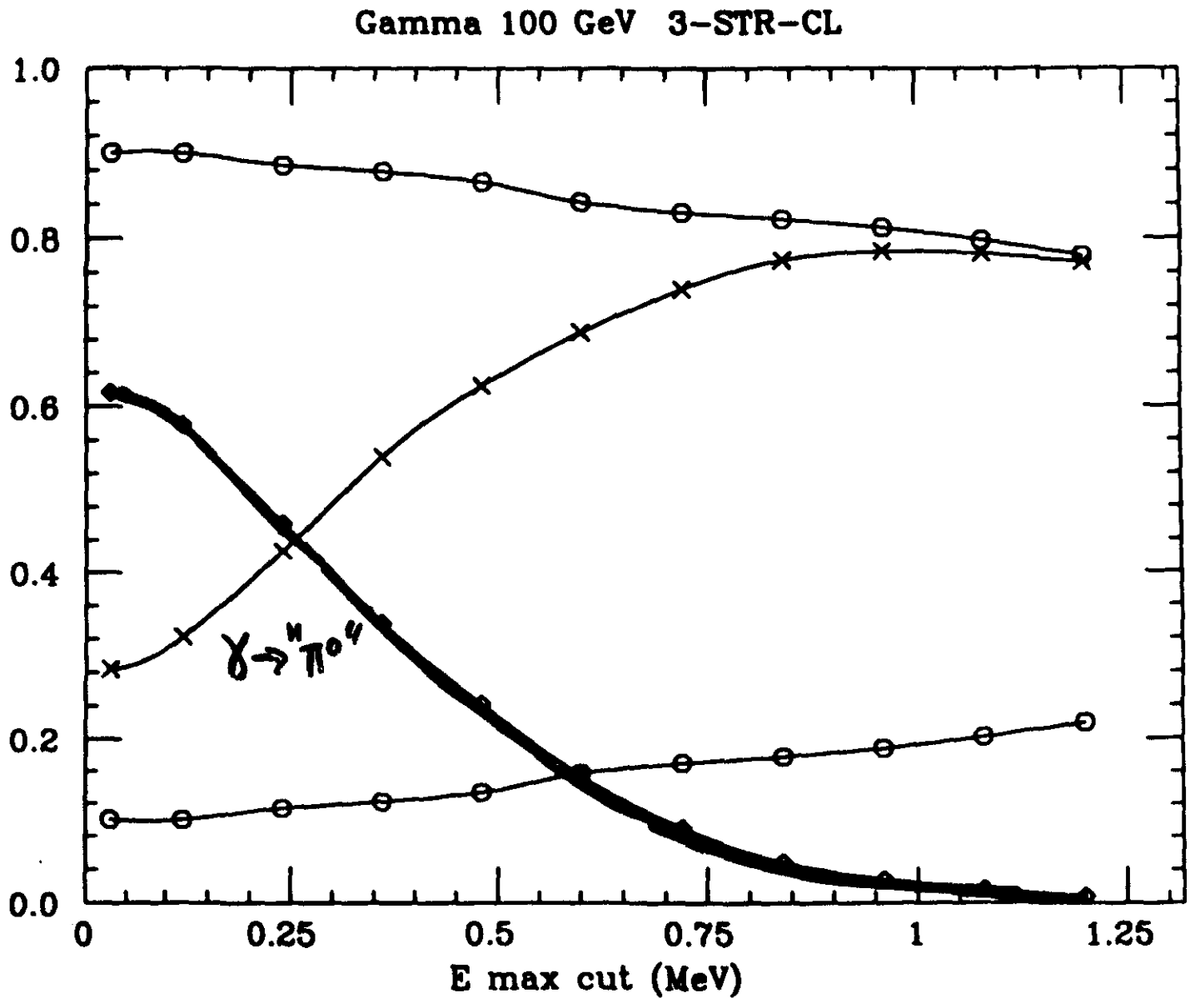
HANDYPAK FUR22:35 28SEP91


1
ID= 29
X LATERAL ENERGY (MEV)
<X>=(1647 +- 71)E-1 SD=(7593 +- 49)E-2
<X>=(107 +- 23)E-2 SD=(1799 +- 161)E-2
ENERGY (MEV)
LAYER
ID= 30
Y LATERAL ENERGY (MEV)
<X>=(172 +- 21)E-2 SD=(1813 +- 15)E-2
ID= 1
<X>=(1647 +- 7)E-1 SD=(7593 +- 49)E-2
ENERGY (MEV)
LAYER
HANDYPAK FUR22:49 28SEP81


Pi 50 GeV - STRL
1.0
0.8
0.6
0.4
0.2
0.0
0
0.25
0.5
0.75
1
1.25
E (MeV)
π° → "π°"


Gamma 50 GeV 3-STR-CL
1.0
0.8
0.6
0.4
0.2
0.0
0
0.25
0.5
0.75
1
1.25
E max cut (MeV)
γ→"π°"


PiO 100 GeV 3-STR-CL
1.0
0.8
0.6
0.4
0.2
0.0
.25
.5
.75
1
E max cut (MeV)
1mm strips
3X₀
π° → "π°"
cluster finding


Gamma 100 GeV 3-STR-CL
1.0
0.8
0.6
0.4
0.2
0.0
0
0.25
0.5
0.75
1
1.25
E max cut (MeV)
γ→"π°"

SIGNIFICANCE ENHANCEMENT FACTOR (S_F)

APPROXIMATELY:

shower shape

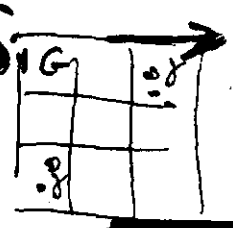
$$S_{IG} \sim \frac{N_{HIGGS\to\gamma\gamma}}{\sqrt{B_{\gamma j} + B_{jj} + B_{\gamma\gamma}}}$$

ASSUME $B_{\gamma j} \approx B_{jj} \equiv B$

$\approx B_{\gamma\gamma}$

THEN

S_{IG}



$$\frac{\epsilon_\gamma^2 \, N_{HIGGS\to\gamma\gamma}}{\sqrt{\epsilon_\gamma \bar{\epsilon}_j B_{\gamma j} + \bar{\epsilon}_j \bar{\epsilon}_j B_{jj} + \epsilon_\gamma^2 B_{\gamma\gamma}}} \equiv S_F(S_{IG})$$

$$\boxed{S_F = \frac{\epsilon_\gamma^2}{\sqrt{(\epsilon_\gamma \bar{\epsilon}_j + \bar{\epsilon}_j^2 + \epsilon_\gamma^2)/2}}}$$

$$\epsilon_j = 1 - \bar{\epsilon}_j$$

1) FIRST ASSUME ALL FAKE-JETS ARE SINGLE π^0

(CONSERVATIVE ASSUMPTION

ϵ_j \ ϵ_γ =	1.0	0.9	0.8
.7	1.47	1.30	1.13
.8	1.55	1.38	1.21

---

2) <u>BUT</u> ~½ OF JETS ARE MULTI-π^0

(ASSUME THESE ARE REJECTED)

ϵ_j \ ϵ_γ =	1.0	0.9	0.8
.7	1.60	1.42	
.8	1.64	1.47	

HOWEVER

BEWARE THAT JET BACKGROUND ARE VERY UNCERTAIN

SUPPOSE $B_{j\gamma} = B_{jj} = 10 B_{\gamma\gamma}$

$$S_F = \frac{\epsilon_\gamma^2}{\sqrt{(10\epsilon_\gamma \bar{\epsilon}_j + \bar{\epsilon}_j^2 + \epsilon_j^2)/21}}$$

IF $\epsilon_j = .7$ $\epsilon_\gamma = .9$ + jet multi-π reject.

$S_F = 2.4$

CONCLUSION

Pre-radiator with 1mm strips in X AND Y can improve significance of Higgs signal by a factor of 1.4 → 2.4

Preshower Detector as a Trigger

- Stand-alone E/M trigger will catch e's & γ's to some threshold (~30 GeV)
- Lower threshold is possible by adding a track requirement for e's.

  (gain is limited to the background for conversions
  .1 X_0 ⇒ 10% of photons convert)

- Very Preliminary studies show that $\pi\,\pi^0$ overlap can be reduced far below the conversion background

  e.g. at 50 GeV fewer than 1/100 $\pi\,\pi^0$ overlap within 3 mm

P. Mockett

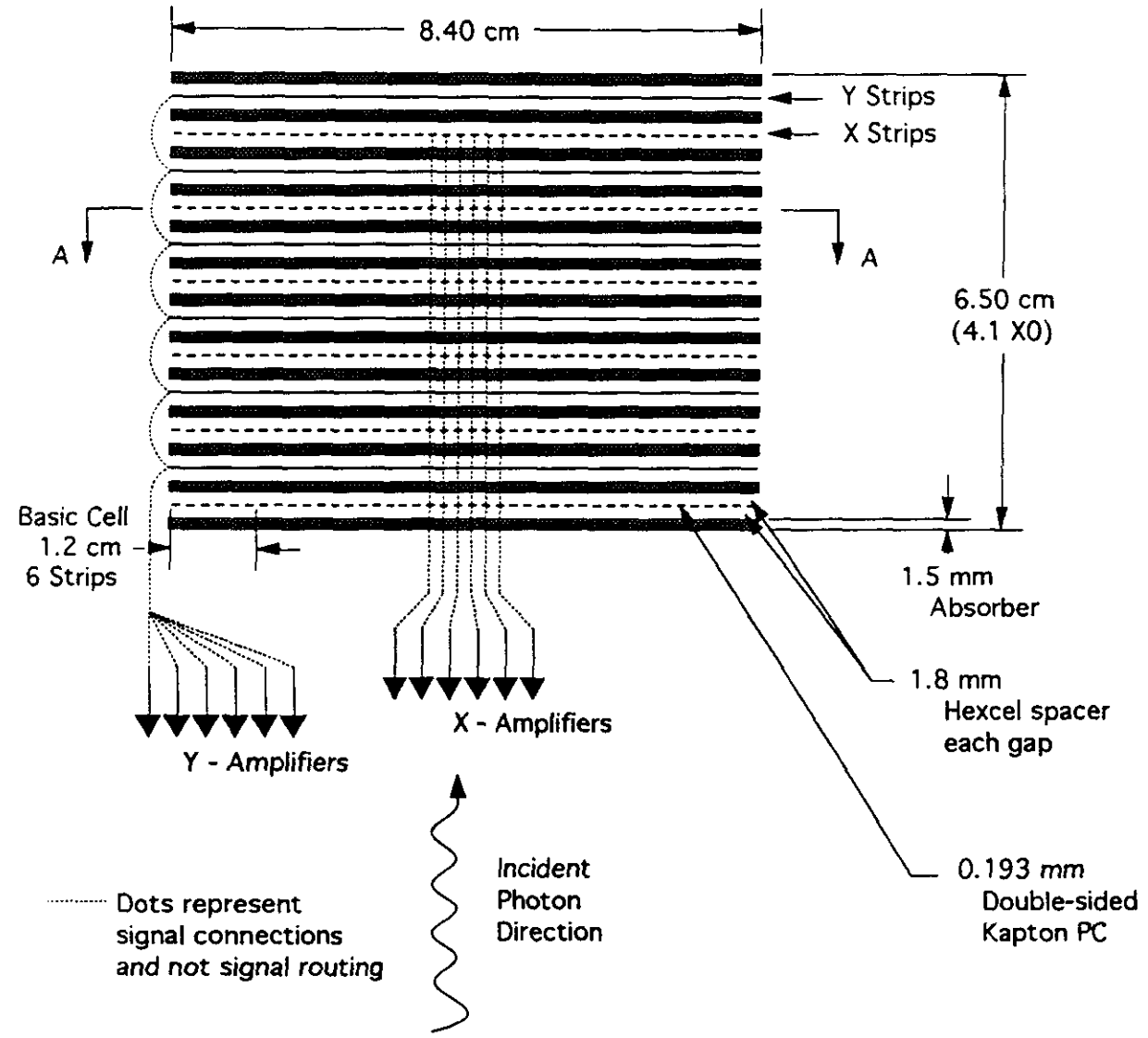
P. Mockett
U. of Washington
September 13, 1991

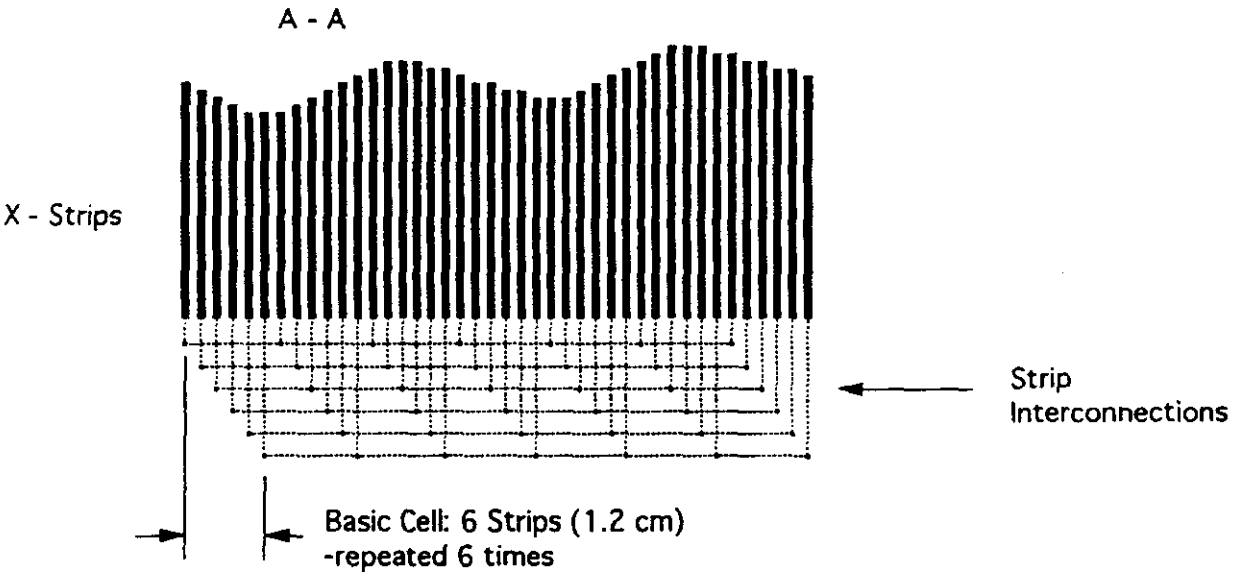
A Pizero Identifier for GEM

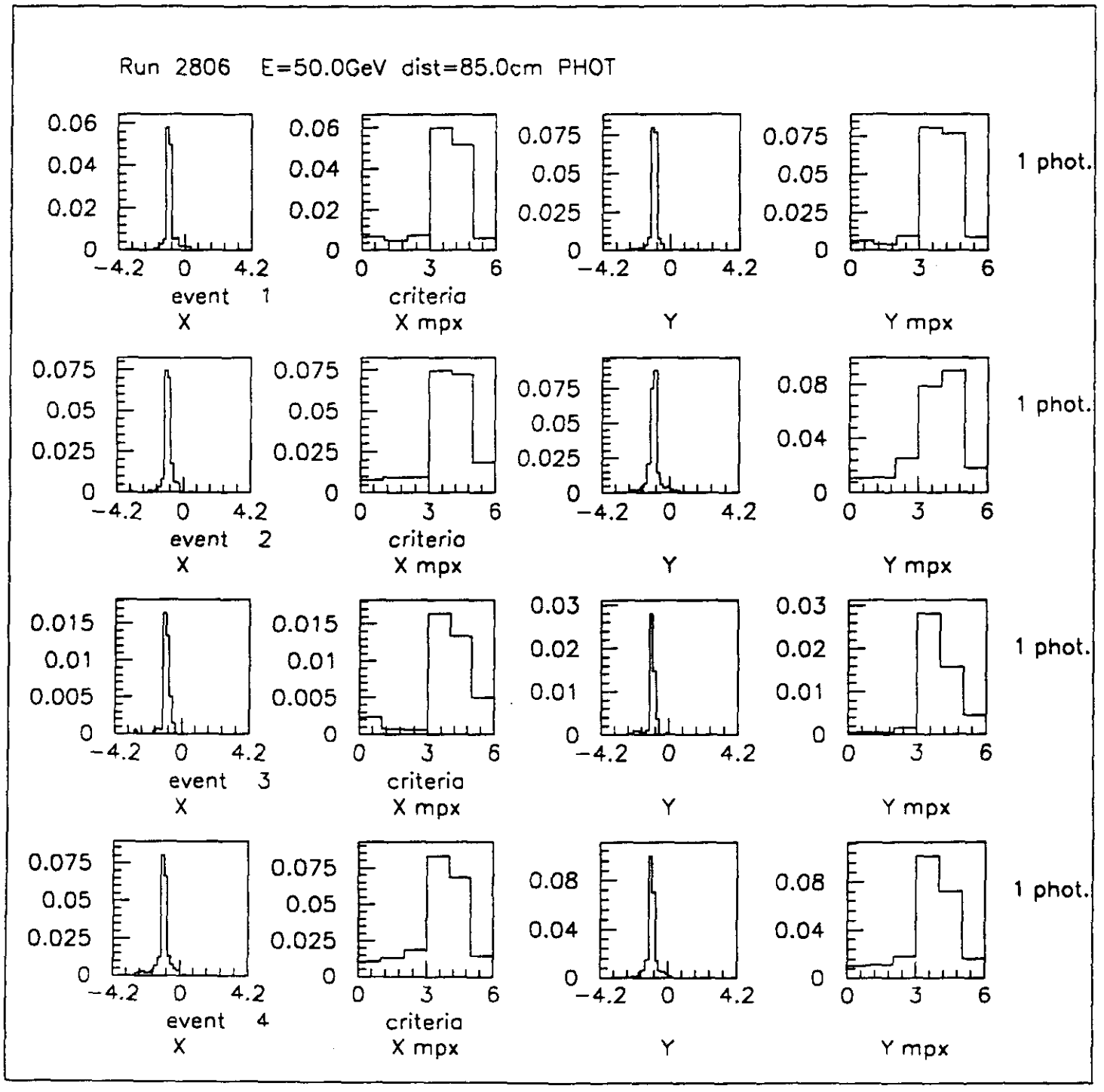
The pizero detector serves as a front end of the EM stack. There is of course flexibility in the details but we are considering a system about 8 cm by 8 cm(covering 16 towers). It would be about 4 X0 thick with the same plate thickness as the remainder of the stack. Alternate gaps would be viewed by x and y strips. The strips would have 2 mm pitch and every sixth strip connected together. The x strips would be read by 6 channels and the y strips would be read by 6 channels. Hence the signals from different sub regions would be folded on top of each other. Jon Eisenberg has been Monte Carlo testing an algorithm he devised to separate one gamma from two gammas. The first tests look encouraging. He is getting 100% acceptance of one gamma and a good rejection of pizeros. We are still in the process of optimizing the cuts. The pictures accompanying this note are for 50 GeV single gammas and 50 GeV pizeros at 85 cm. The pizeros are at minimum opening.

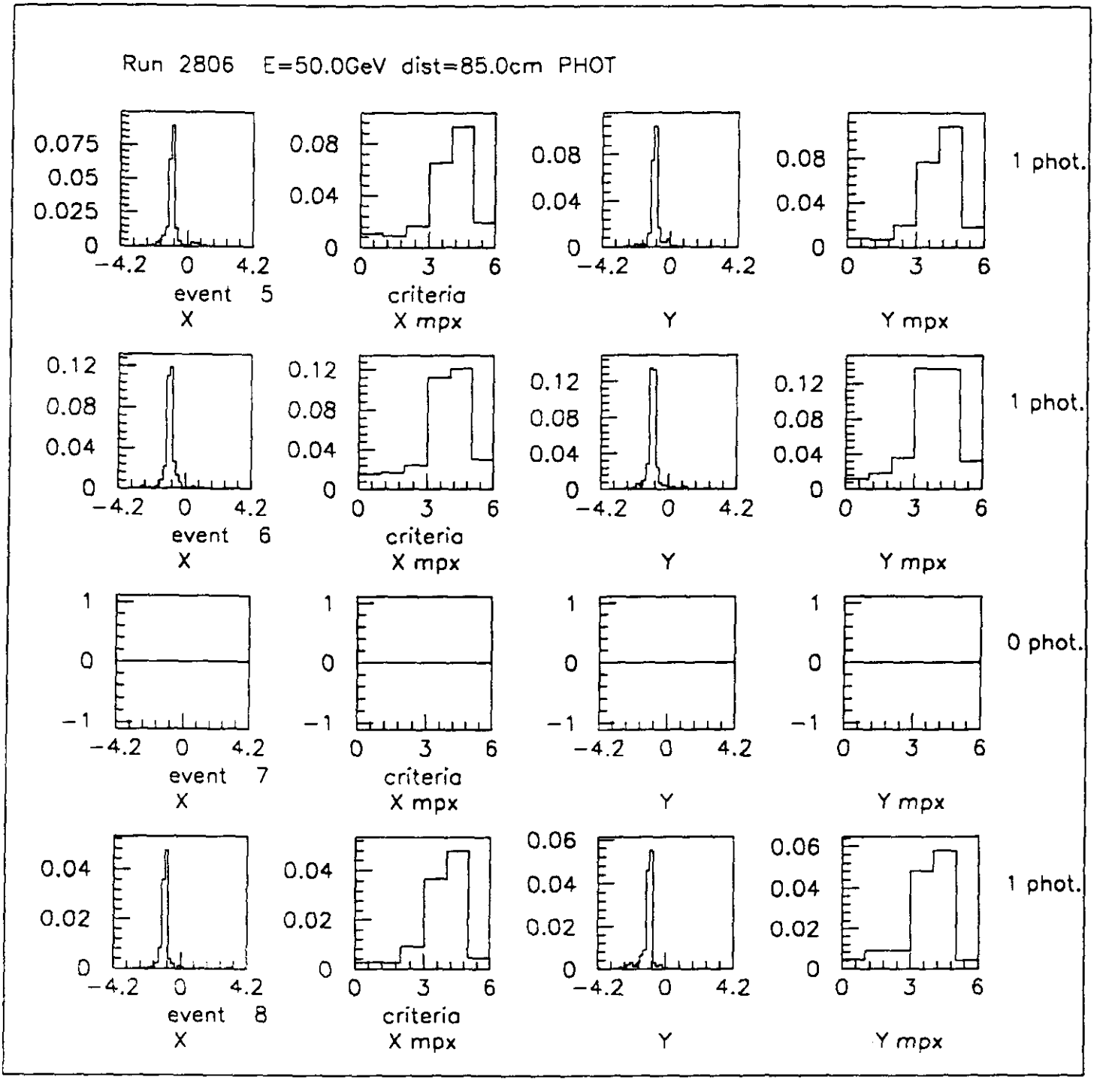
π^0 IDENTIFIER SCHEMATIC

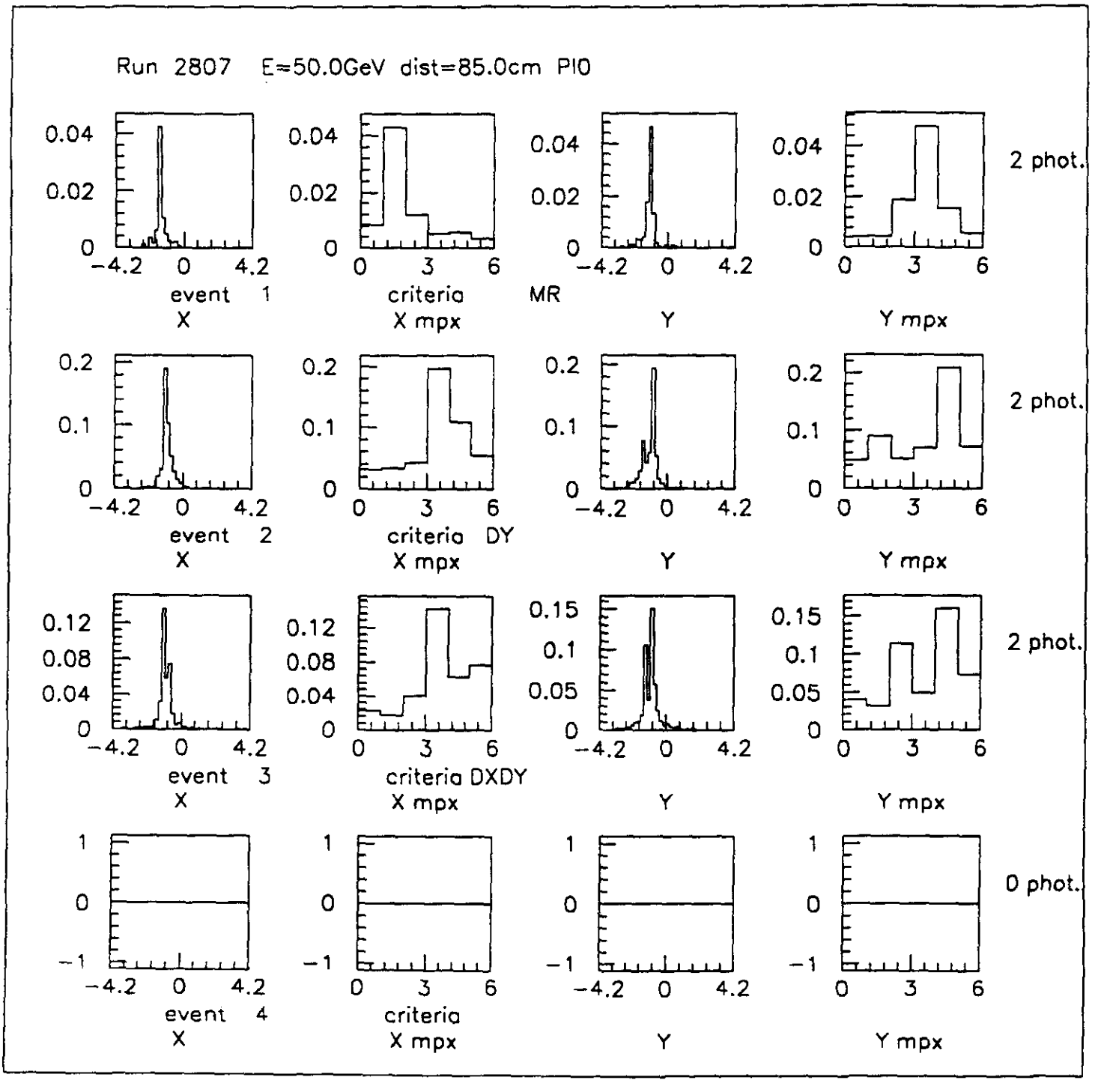
(Parallel plate geometry)

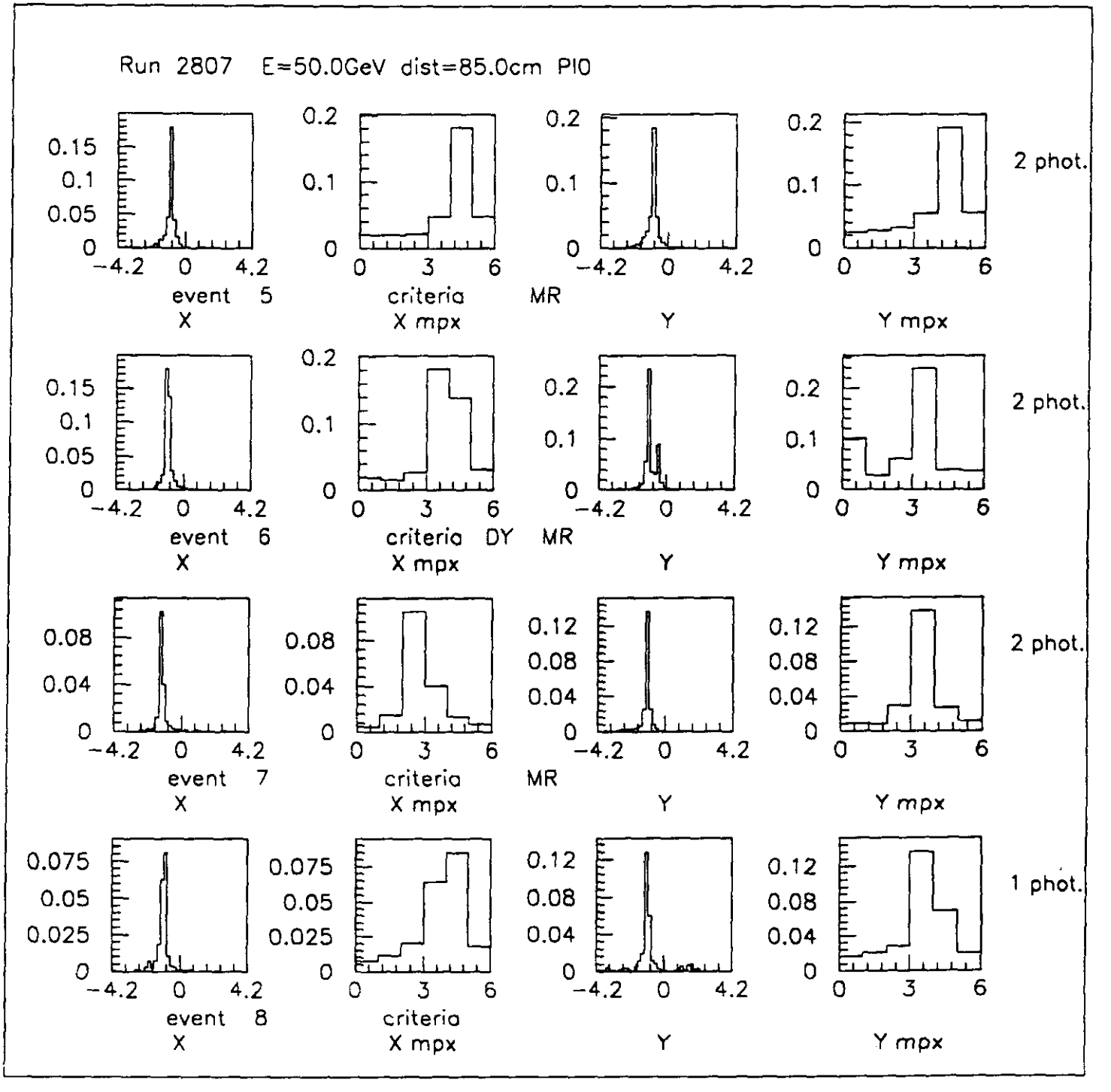


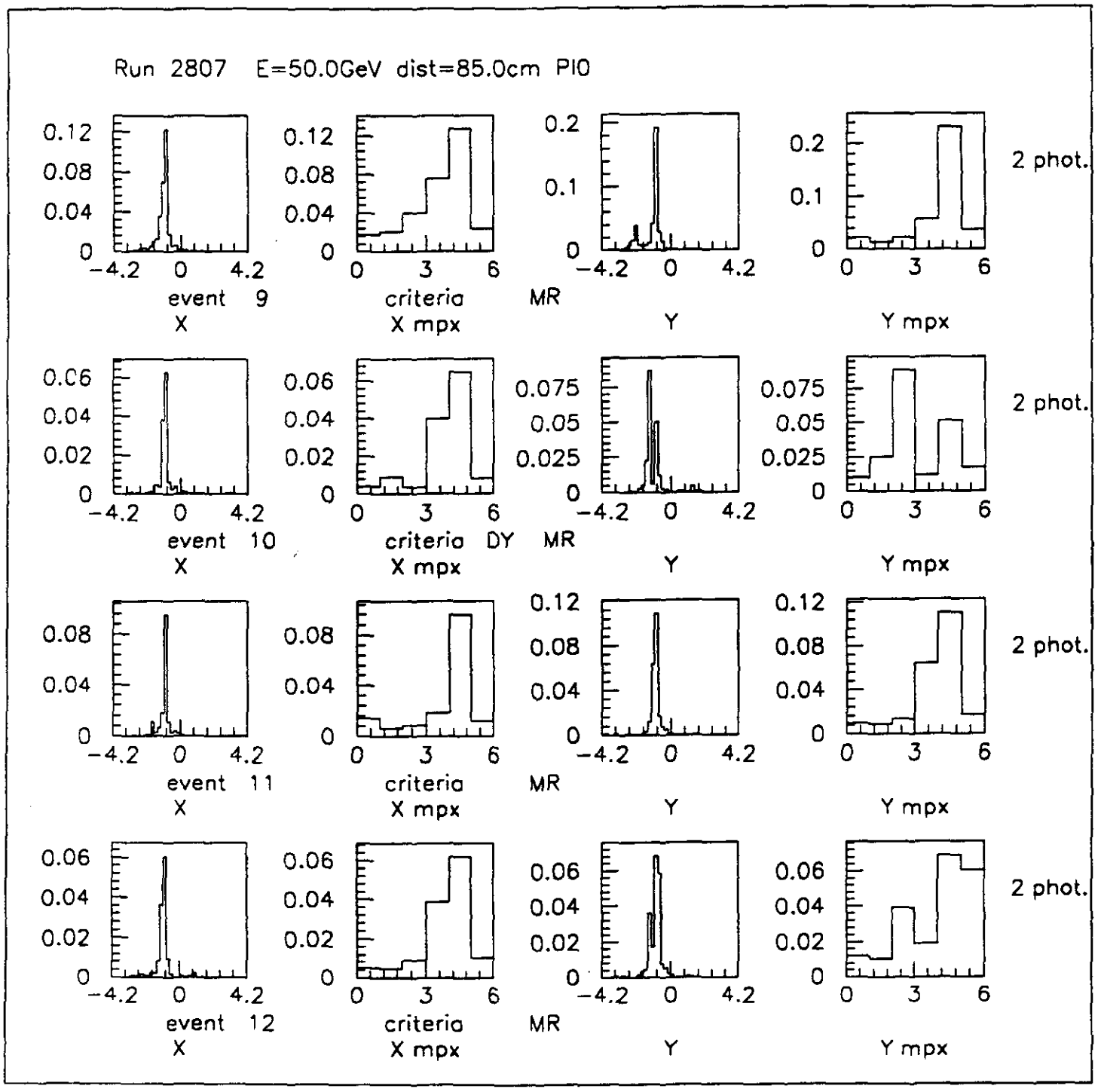


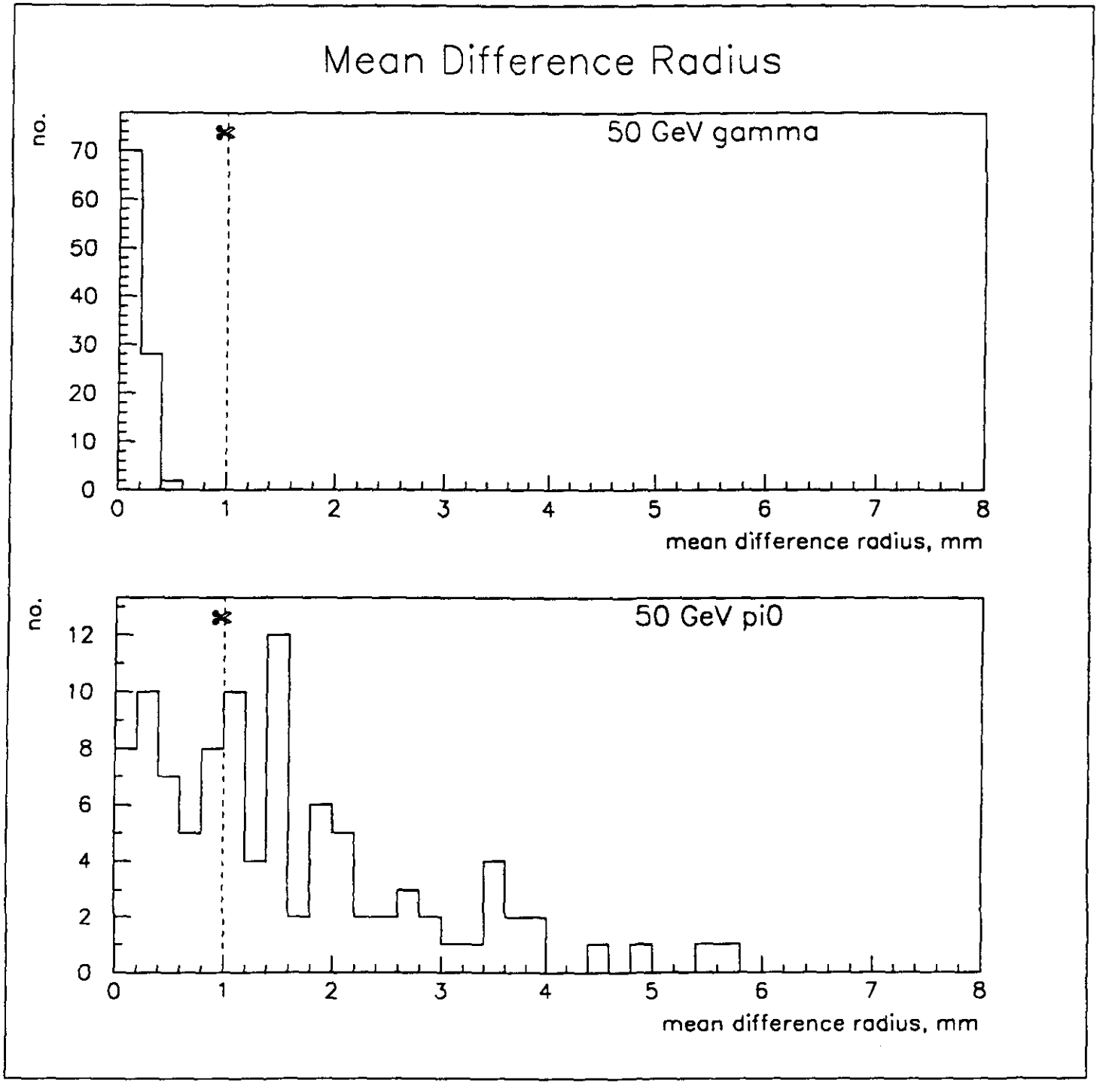

Run 2806 E=50.0GeV dist=85.0cm PHOT
event 1
X
criteria
X mpx
Y
Y mpx
1 phot.
event 2
X
criteria
X mpx
Y
Y mpx
1 phot.
event 3
X
criteria
X mpx
Y
Y mpx
1 phot.
event 4
X
criteria
X mpx
Y
Y mpx
1 phot.


Run 2806 E=50.0GeV dist=85.0cm PHOT
event 5
X
criteria
X mpx
Y
Y mpx
1 phot.
event 6
X
criteria
X mpx
Y
Y mpx
1 phot.
event 7
X
criteria
X mpx
Y
Y mpx
0 phot.
event 8
X
criteria
X mpx
Y
Y mpx
1 phot.

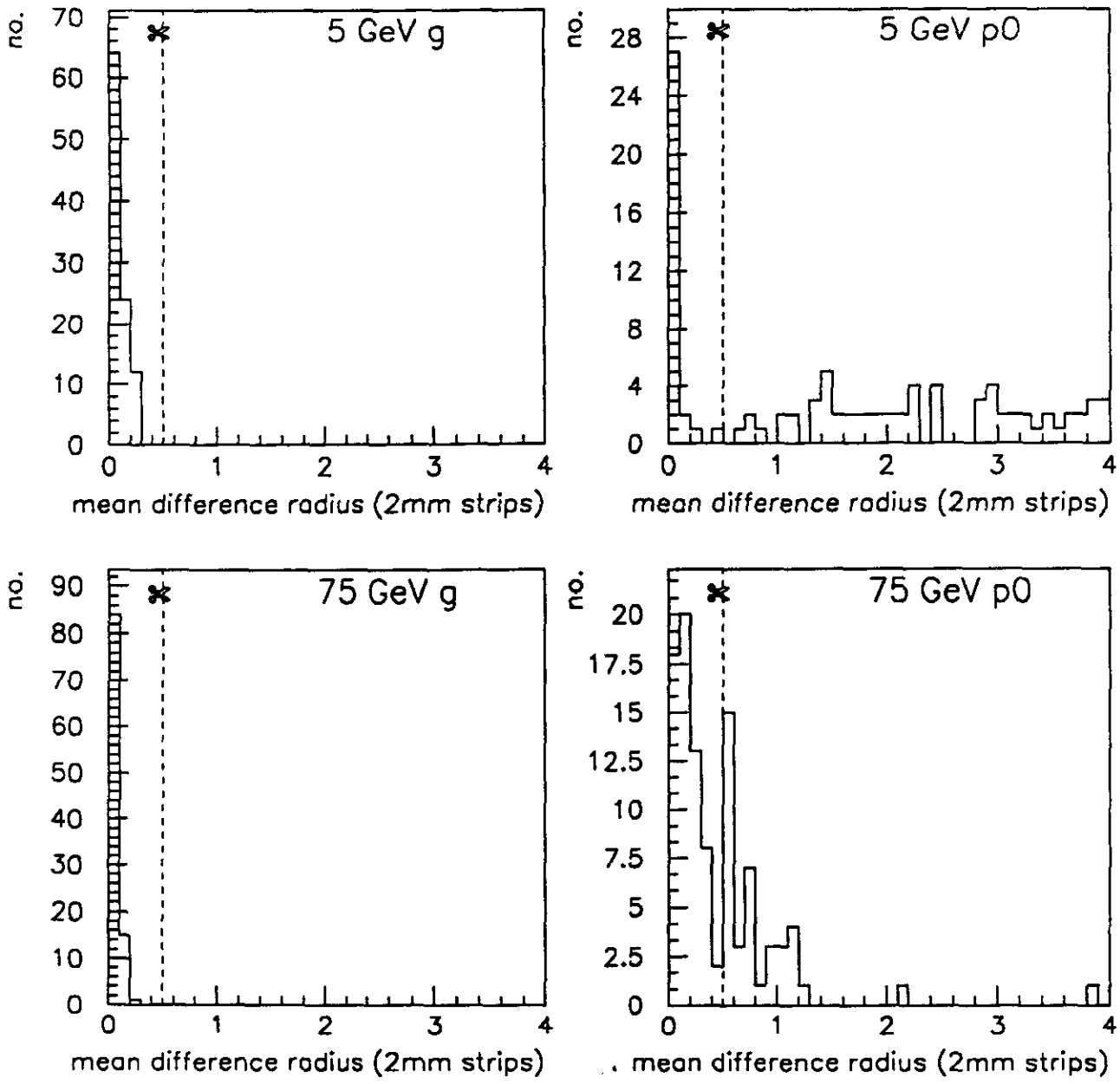

Run 2807 E=50.0GeV dist=85.0cm PI0
event 1
X
criteria MR
X mpx
Y
Y mpx
2 phot.
event 2
X
criteria DY
X mpx
Y
Y mpx
2 phot.
event 3
X
criteria DXDY
X mpx
Y
Y mpx
2 phot.
event 4
X
criteria
X mpx
Y
Y mpx
0 phot.


Run 2807 E=50.0GeV dist=85.0cm PI0
event 5
criteria MR
X
X mpx
Y
Y mpx
2 phot.
event 6
criteria DY MR
X
X mpx
Y
Y mpx
2 phot.
event 7
criteria MR
X
X mpx
Y
Y mpx
2 phot.
event 8
criteria
X
X mpx
Y
Y mpx
1 phot.


Run 2807 E=50.0GeV dist=85.0cm PI0
event 9
X
criteria
X mpx
MR
Y
Y mpx
2 phot.
event 10
X
criteria DY
X mpx
MR
Y
Y mpx
2 phot.
event 11
X
criteria
X mpx
MR
Y
Y mpx
2 phot.
event 12
X
criteria
X mpx
MR
Y
Y mpx
2 phot.


Mean Difference Radius
no.
50 GeV gamma
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
mean difference radius, mm
no.
50 GeV pi0
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
mean difference radius, mm

Mean Difference Radius Cut

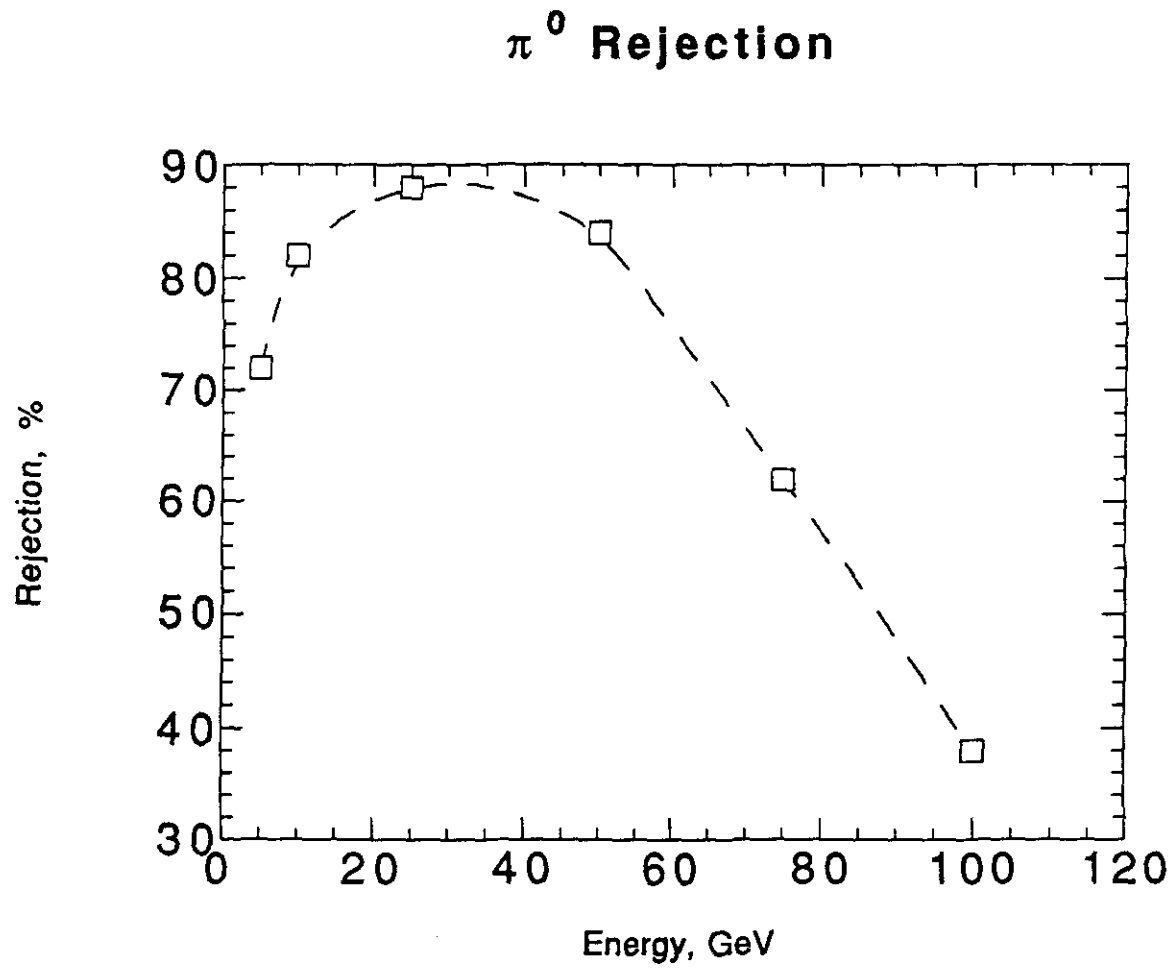


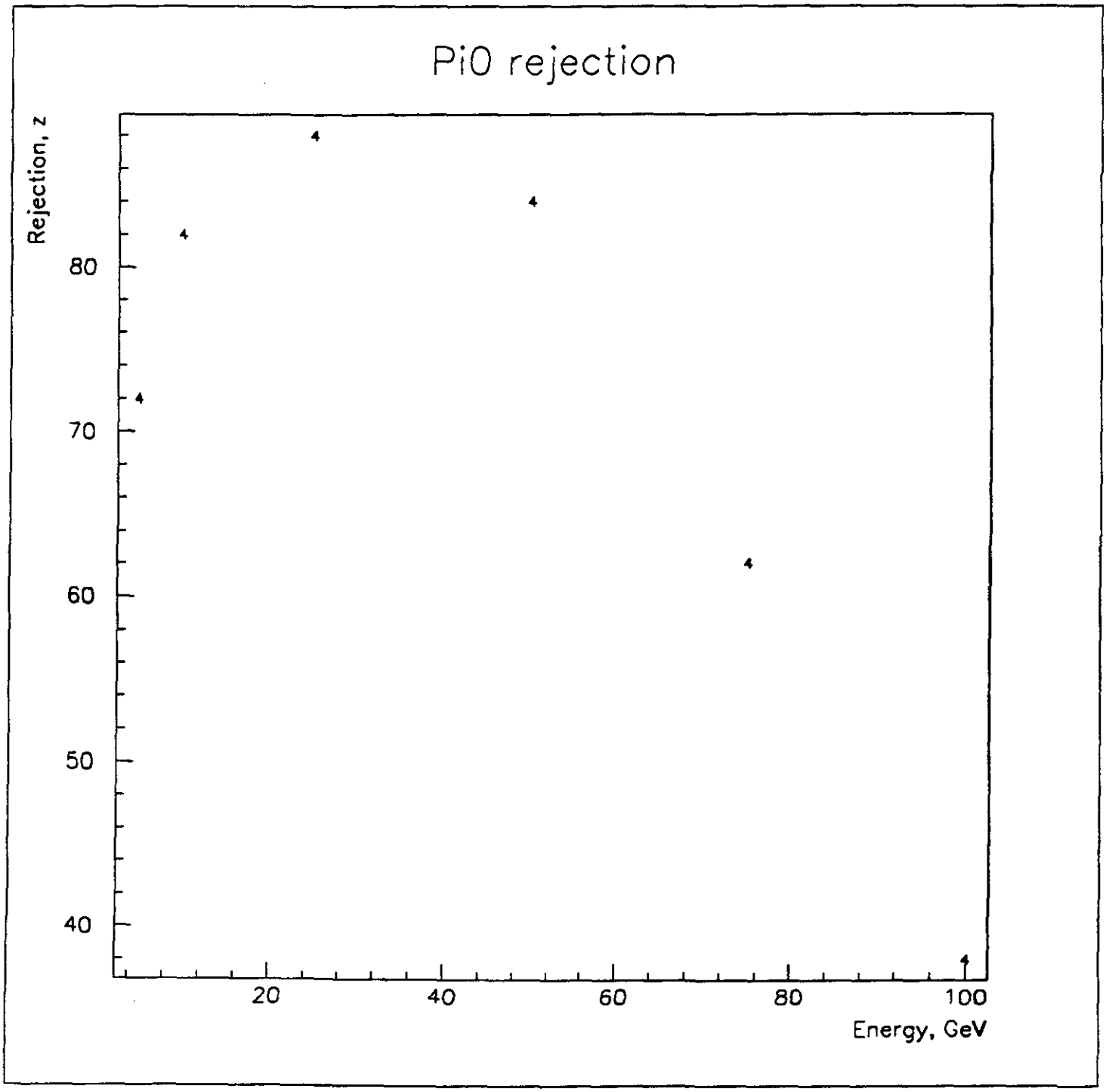
π^0 Indentifier Cuts

Cut	Value	Description
ECUT	0.03 GeV	amount which a peak must be greater than
DIPMAX	50 %	percentage of larger peak that dip between two peaks must be less than
EWIDCUT	50 %	percentage of the larger peak that all bins in the peak must be greater than
PEAKCUT	25 %	percentage of the higher peak that the lower peak must be greater than
CUTMEAN	1 mm	minimum amount that the strip mean must be away (radius) from the shower mean position
NCUTWID	2 strips	number of strips that a peak must be wider than to be considered 2 photons

π^0 Identifier
Acceptances and Cut Performances

incident particle		accept.	number of photons			number selected by cuts					
E (GeV)		(%)	0 (%)	1 (%)	2 (%)	mean (%)	mean only	dip (%)	dip only	width (%)	width only
5	γ	97	41	56	3	0	0	0	0	3	3
5	π^0	72	25	3	72	69	43	21	1	14	2
10	γ	98	30	68	2	1	1	0	0	1	1
10	π^0	82	15	3	82	81	56	18	0	14	0
25	γ	100	22	78	0	0	0	0	0	0	0
25	π^0	88	7	5	88	85	47	41	2	21	0
50	γ	100	18	82	0	0	0	0	0	0	0
50	π^0	84	5	11	84	62	34	56	20	8	2
75	γ	100	17	83	0	0	0	0	0	0	0
75	π^0	62	7	31	62	39	22	35	16	11	7
100	γ	100	20	80	0	0	0	0	0	0	0
100	π^0	38	3	59	38	29	21	16	9	2	0


π⁰ Rejection
Rejection, %
90
80
70
60
50
40
30
0
20
40
60
80
100
120
Energy, GeV


PiO rejection
Rejection, z
80
70
60
50
40
20
40
60
80
100
Energy, GeV

Future Cuts

- **Dependence of ECUT (peak threshold) on total shower energy**
  will reduce number of zero photon events at lower energies
- **Dependence of NCUTWID on sum of peak energies**
  when conversion is deep (lower sum of peak energies) tighten width that is considered one photon

M. Chen

How Can Sampling Calorimeters Approach Homogeneous Calorimeters in Energy Resolution?

A summary of what discussed here:
LAr, SPACAL, BaF_2, LXe/Kr, ...
A Proposal for Unification

High Resolution Sampling Electromagnetic Calorimeter Using LXe Filled Capillaries

- JETSET Hertzog et al., NIM A294 (1990) 446.

  Pb / Plastic Scintillating Fibre Calorimeter

  - Volume Ratio
    Fibre : Pb : Glue = 0.5 : 0.35 : 0.15

    1 mm diameter fibres placed on corners of equilateral triangles of side 1.35 mm.

    X_0 = 1.61 cm

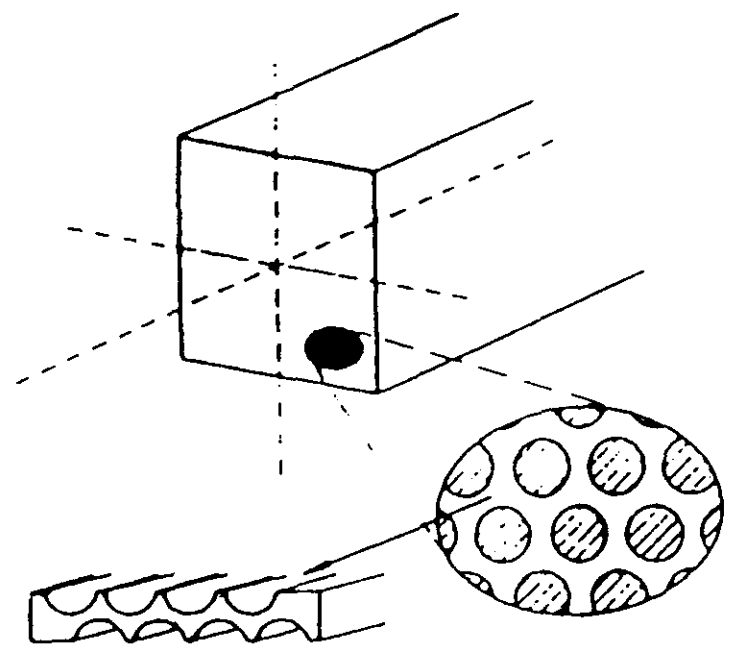
  - Test Results
    10 x 10 x 22 cm^3 ($14X_0$) Calorimeter

    Resolution : $\sigma / E = 6.3\ \% / \sqrt{E}$

    No. of p.e. / GeV = 970

    $\sigma / \sqrt{E} = 5.4\% / \sqrt{E}$ if photo-statistics removed

    % energy deposited in scintillator ~ 13 %.



'ACAL CERN PPE/91-85

olume ratio Pb:Fibre = 4 : 1
nm diamter plastic fibres
3% of incident energy in scint.
$_{)}$=7.2 mm, R_M = 20 mm

E = 12.9%/√E + 1.2% at 3°

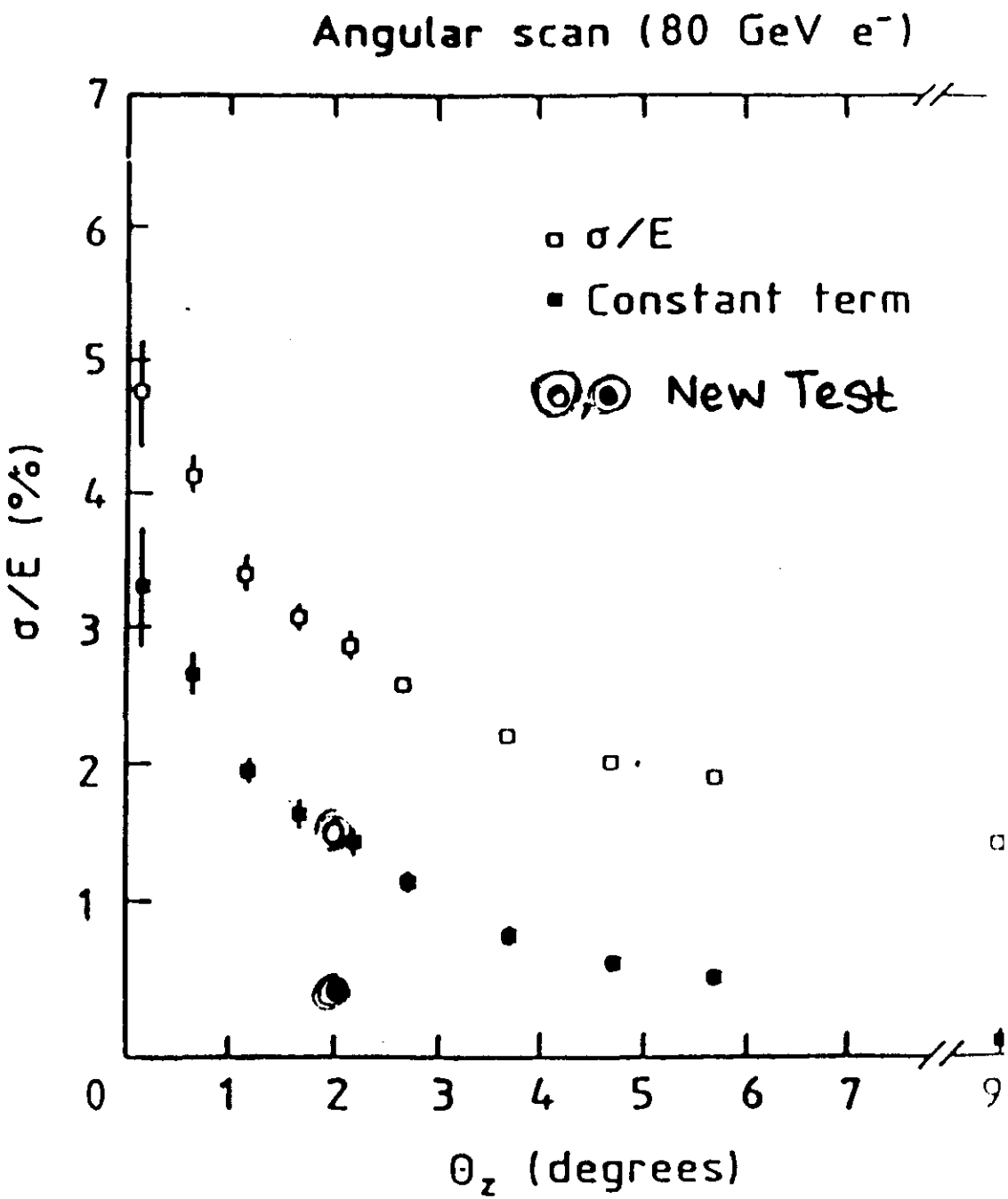
eliminary Results from New Tests

L. Poggioli (P.Comm)

5 mm diameter fibres
t keeping the same volume ratio

E = 9.5 %√E + 0.4% at 2°

otoelectron statistics : 500 / GeV
% --> 8.4 %



Comparison between Three Kr- and Xe Calorimeters

	Kr-Calorimeter	Xe-Calorimeter	
	[USSR-Italy]	[USSR]	[Japan]
Gap	20 mm	12.0 mm	3.5 mm
Thickness of Electrodes	0.5 mm G-10 + 2.35 μm Cu	50 μm Al	125 μm Kapton + 2 x 18 μm Cu
Length of Calorimeter	76 cm(16.4 X_0)	50 cm(17.7 X_0)	70 cm(25.4 X_0)
Diameter of Calorimeter	42 cm(9.5 X_0)	25 cm(9.0 X_0)	30 cm(10.8 X_0)
Number of Readouts	19	1	20
Thickness of Entrance Window	2 mm Fe(0.13 X_0)	?	1 mm Fe(0.06 X_0)
Energy Resolution	1.7 % for 1.2 GeV positrons	3.4 %/$\sqrt{E(GeV)}$	0.80 % for 1 GeV 0.38 % for 5 GeV 0.30 % for 10 GeV

1. Intrinsic sampling fluctuations,

2. Noise,

3. Fluctuation of nonvisible energy ($< E_c$).

1. Intrinsic sampling fluctuations:

$$\delta E/E = (3.2\%)\ \sqrt{(E_{cr}/E)\,t/E}$$

t = thickness of a layer in rad.

Mean fraction of detectable tracks:

$F(z) = e^{-z}[1 + z \ln(z/L_{cr})]$,

with $z = 2.29\ E_c/E_{cr}$.

Better resolution for Xe, Kr than Ar.

Smaller E_{cr}:

10 MeV (Xe), 15 MeV (Kr) and 30 MeV (LAr).

2. Higher dE/dx:

dE/dx(LXe)=3.8 MeV/cm,

dE/dx(LKr)=3 MeV/cm,

dE/dx(LAr)=2.1 MeV/cm.

3. Fluctuation of nonvisible energy ($< E_c$):

	LXe	LKr	LAr
Critical E, Ecr	10	15	30 MeV
dE/dx (MeV)	2.1	3	3.8
Light yield	1	0.6	0.4

Resolution due to

1. Intrinsic sampling fluctuations,

2. Noise,

3. Fluctuation of nonvisible energy ($< E_c$).

1. Intrinsic sampling fluctuations:

$$\delta E/E = (3.2\%)\sqrt{(E_c/F)(t/E)}$$

t = thickness of a layer in X_0;
Mean fraction of detectable tracks:
$F(z) = e^{-z}[1 + z \ln(z/1.326)]$,
with $z = 2.29\, E_c/E_\beta$.
Better resolution for Xe, Kr, than Ar.
Smaller E_{cr}:
10 MeV (Xe), 15 MeV (Kr) and 30 MeV (LAr),

2. Higher dE/dx:
dE/dx(LXe)=3.8 MeV/cm),
dE/dx(LKr)=3 MeV/cm),
dE/dx(LAr)=2.1 MeV/cm.

3. Fluctuation of nonvisible energy ($< E_c$):

	LXe	LKr	LAr	
Critical E, Ecr	10	15	30	MeV
dE/dx (MeV)	2.1	3	3.8	

1. **Intrinsic sampling fluctuations:**

$$\delta E/E = (3.2\%)\ \sqrt{(E_{cr}/F)(t/E)}$$

t= thickness of a layer in Xo;
Mean fraction of detectable tracks:
$F(z) = e^z\ [1+ z \ln (z / 1.526)]$,
with $z = 2.29\ E_c/E_{cr}$.
Better resolution for Xe, Kr, than Ar.
Smaller E_{cr}:
10 MeV (Xe), 15 MeV (Kr) and 30 MeV (LAr),

2. **Higher dE/dx:**
dE/dx(LXe)=3.8 MeV/cm),
dE/dx(LKr)=3 MeV/cm),
dE/dx(LAr)=2.1 MeV/cm.

3. **Fluctuation of nonvisible energy ($< E_c$):**

Resolution due to

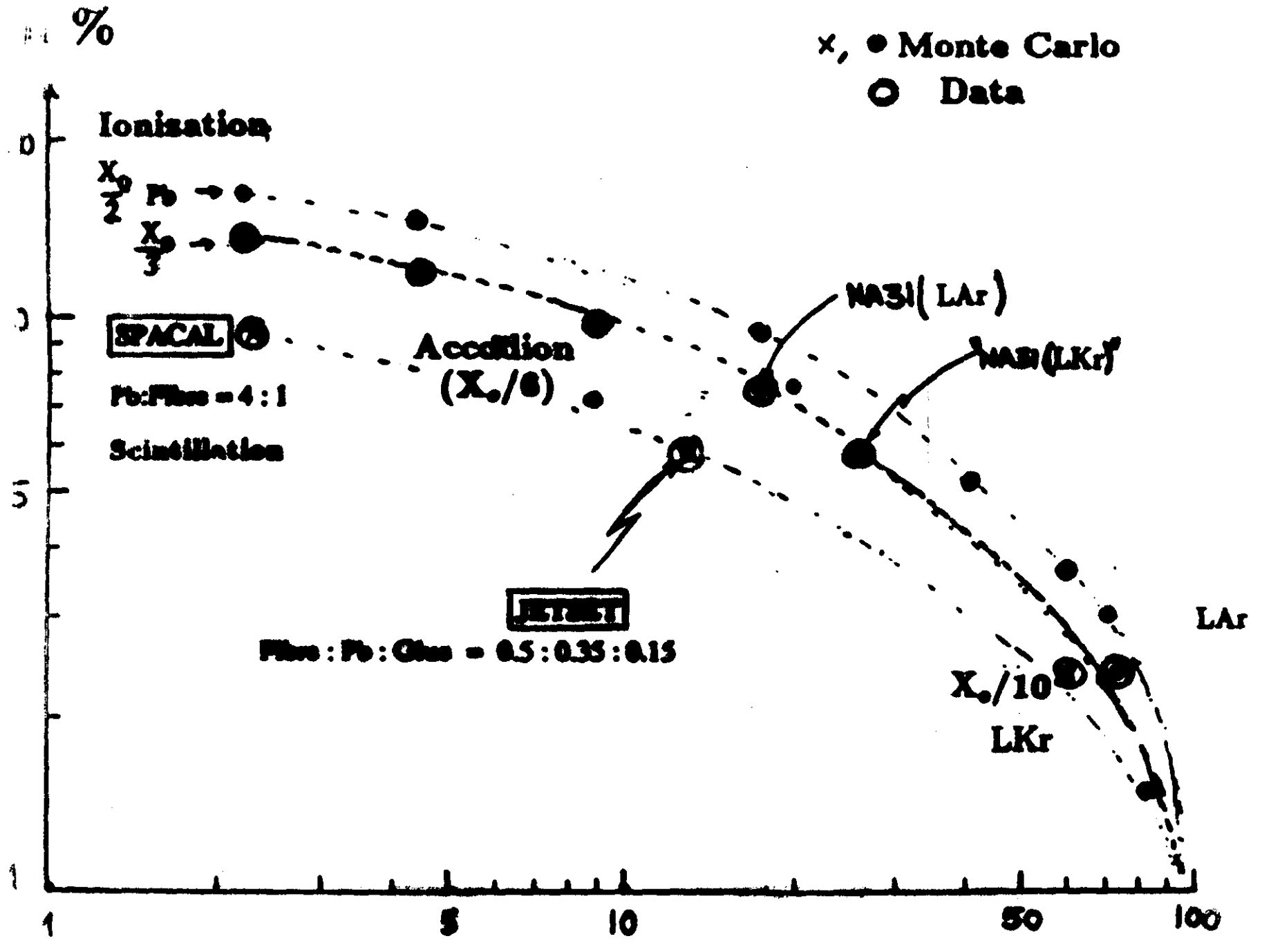
1. Intrinsic sampling fluctuations,

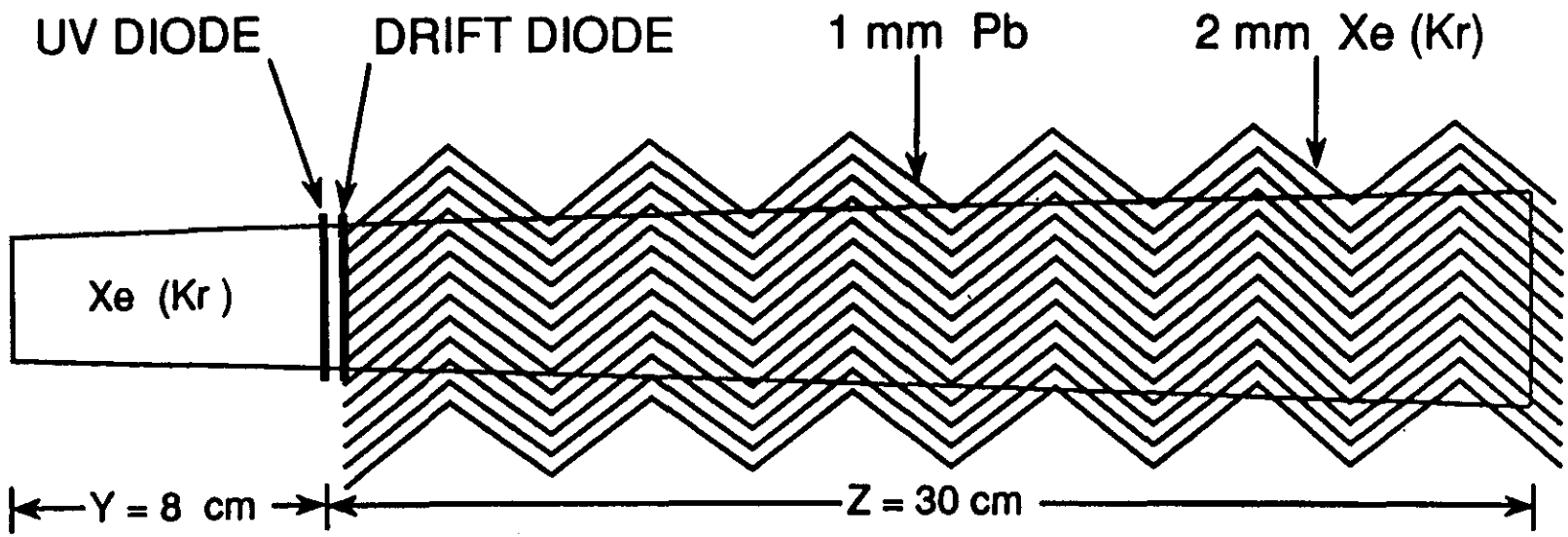
2. Noise,

3. Fluctuation of nonvisible energy ($< E_c$).

	LXe	LKr	LAr	
Critical E, Ecr	10	15	30	MeV
dE/dx (MeV)	2.1	3	3.8	
Light yield	1	0.6	0.4	
W (eV)	15.6	20.5	23.6	

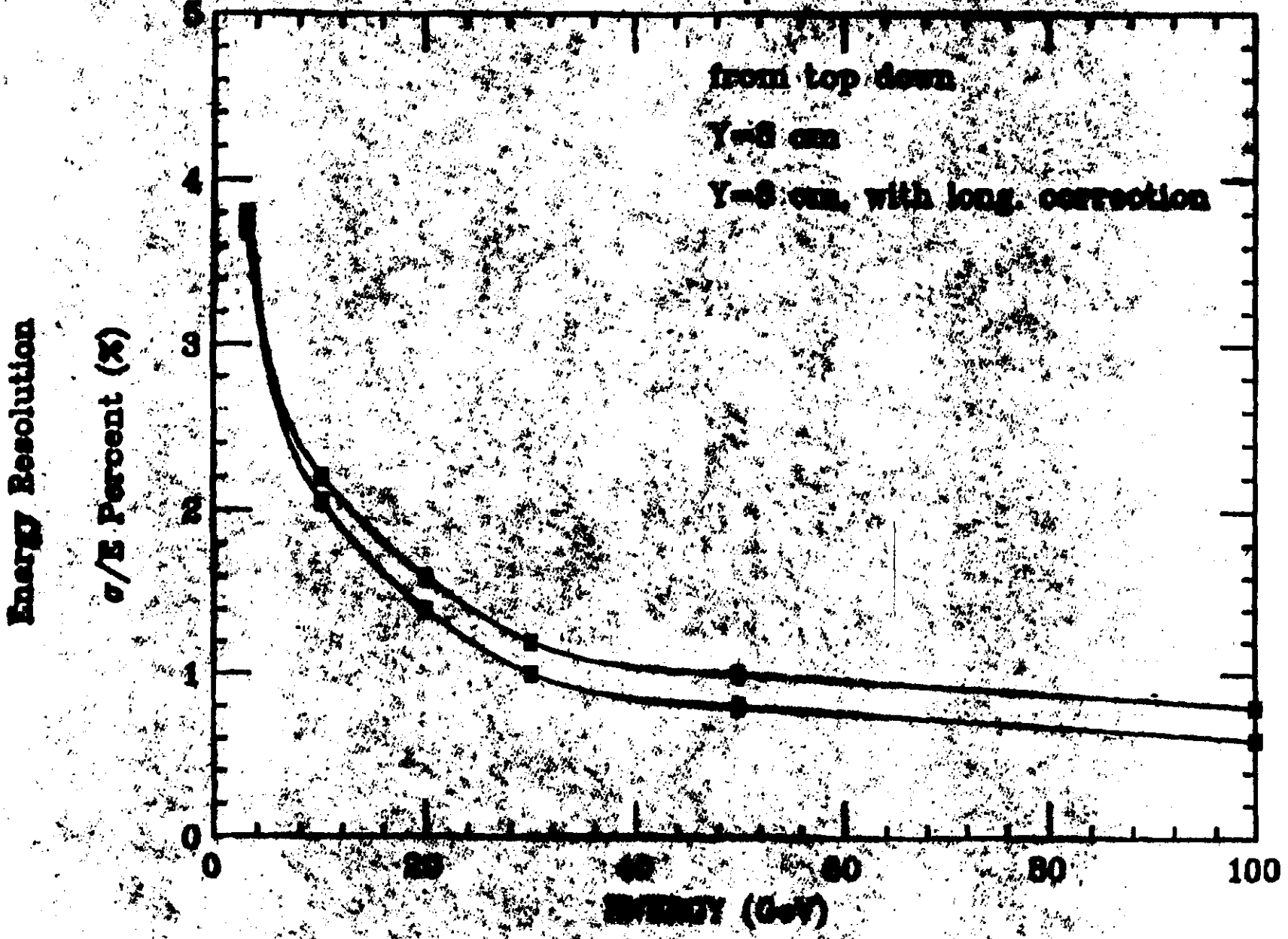
$E^q \backslash E^o$, Energy Deposited in Active Medium (%)

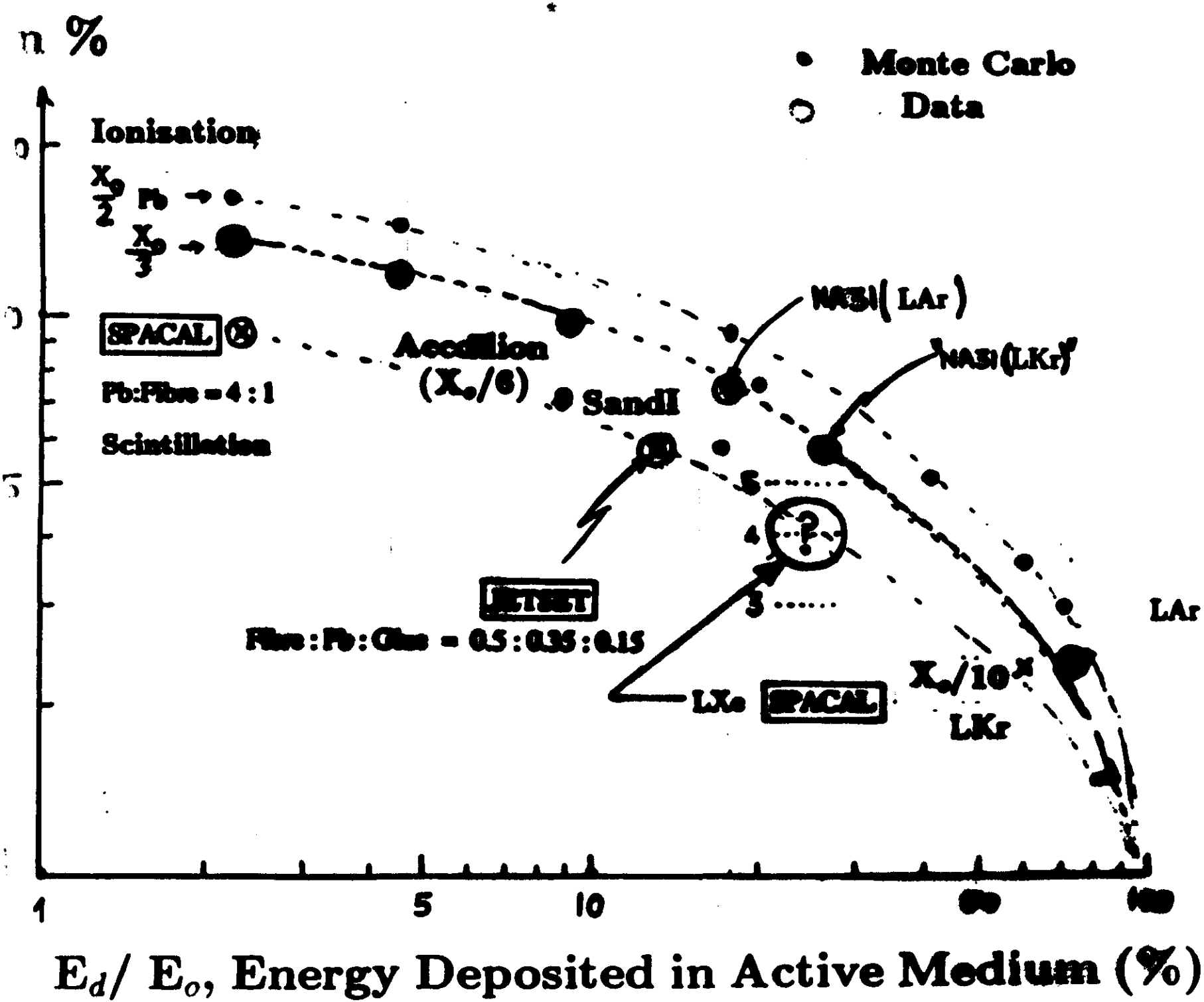

%
×, ● Monte Carlo
○ Data
Ionization
$\frac{X_0}{2}$ Pb
$\frac{X_0}{3}$
SPACAL
Pb:Fibre = 4 : 1
Scintillation
Accordion
(X_0/8)
NA31(LAr)
NA31(LKr)
Fibre : Pb : Glue = 0.5 : 0.35 : 0.15
LAr
X_0/10
LKr
1
5
10
50
100
E_d/ E_0, Energy Deposited in Active Medium (%)



DRIFT DIODE to detect / veto 2 showers from π^0

Homogeneous and Sampling Lxe Detector




n %
Monte Carlo
Data
Ionization
Pb
SPACAL
Pb:Fibre = 4 : 1
Scintillation
Accollion
(X₀/6)
Sandll
NASI(LAr)
NASI(LKr)
LETBET
Fibre : Pb : Glue = 0.5 : 0.35 : 0.15
LXe
SPACAL
X₀/10
LKr
LAr
1
5
10
E_d/ E_o, Energy Deposited in Active Medium (%)

LXe Macaroni

Consider a Calorimeter with volume ratio **Pb : LXe = 1 : 1**

- Use capillaries of 900μm diameter and 50 μm wall thickness.
  Effective X_0 = 0.93 cm (27 Xo = 25 cm !), R_M ~ 1.9 cm
  ~ 1 λ

- Volume of LXe ~ 3 m^3 (large volume cost : 2.5 M$ / m^3 / 2)

- % energy deposited in LXe ~ 25 %

- Expected energy resolution ~ 4% / √E + b

Light Yield

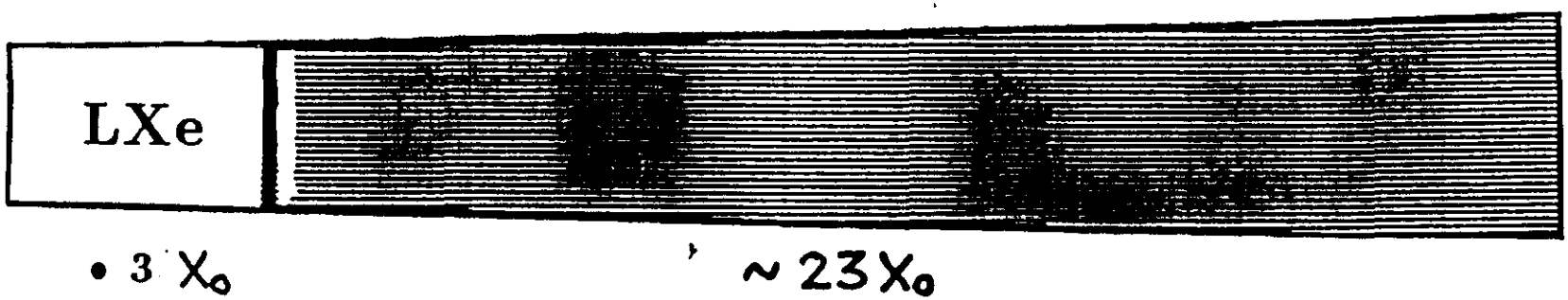
At 175 nm : n(MgF_2) ~ 1.45, n(LXe) = 1.8

Capture light ~10%

p.e./GeV = 0.25 (fract) 3.10^7 (γ's/GeV) 0.1 . 0.5 (q.e.) ~ 10^6 p.e.

use Si photodiodes ==> Can work in Magnetic Field

- Idea can be tested by single tube:Oct. 1991 and then
  full size module:mid-92
  at the level of a protoype that can contain a high energy e.m. shower



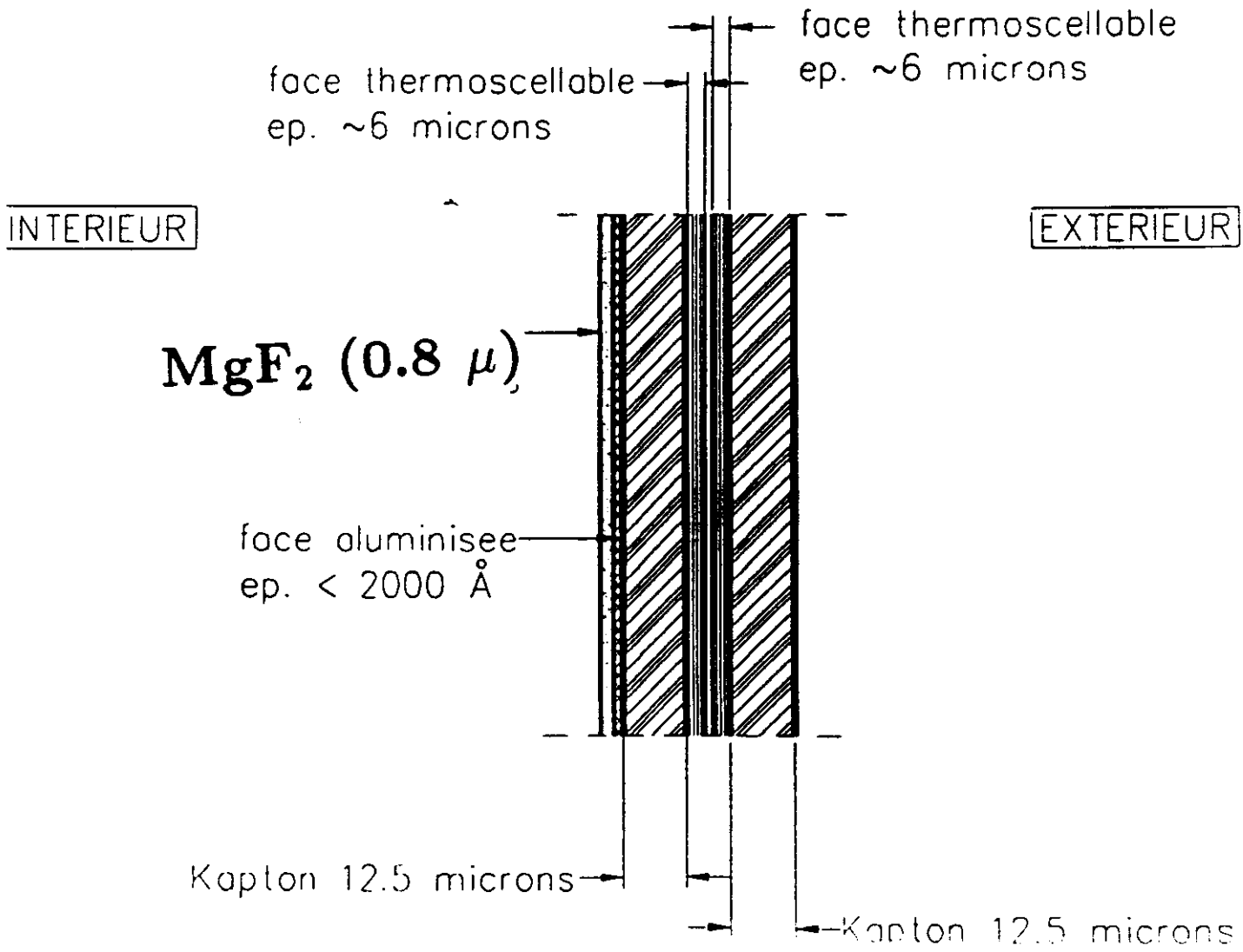
- Advantages compared with Spacal
  Much better fibre to fibre uniformity
  Core material in direct contact with photo-device
  LXe, MgF_2: radiation hard
  Si photodiodes at low temps are possible more radiation hard
  triode: calibration with α's

FABRICATION DE PAILLES KAPTON

Pailles: diametre interieur=4 H7 longueur= 550 mm
par 2 couches soudees de Kapton
face aluminisee MgF_2 a l'interieur de la paille.
epaisseur totale paille: kapton 12.5
kapton 12.5
thermoscel. 12

(circonference paille ø 4 = 12.57)
(surface totale kapton = 13827 mm²)

COUPE PAILLE ø 4



Resolution of EM sampling calorimeters:

$$\sigma_E/E = (a/\sqrt{E} + b) \oplus$$

$$\oplus\ c/E$$

Option	BaF2	LAr	Xe Barrel/Xe Endcap
a	2	7	6 / 1

$$\delta E/E = (a/\sqrt{E} + b)\ \%$$

Option	b	
	SandJ	Lke Measurement	Lke
1. calibration	0.2	
	0.4	<0.2
2. shower fluctuation	0.6	0.4	<0.25
3. instability	Lattice/Photodiode	
	is stable/calibratable	
4. radiation damages	Xe/Al/MgF2 all hard	Xe/Al/MgF2 all hard
5. Uniformity	Oct. 91	Oct. 91
	Contact with liq. is stabl	

2. Shower fluctuation for a 5x5 cell LXe detector can be reduced to 0.25

5x5 LXe cell is big enough to contain high energy electron/photon as shown below:

	10 GeV	100GeV	
o trans. leak.	0.65%	0.39%	
x5(no long. corr.)	0.65%	0.39%	-->transv. leak small
x5(long. corr.)	0.5%	0.25%	<--depth measurement import

Conclusions:

LKr-Accordion and LXe-SPACAL illustrate the versability of a Liquid Detector, Using Many Liquids for the Same Structure and Many Structure with the Same Cryostat.

$$\delta E/E = (4/\sqrt{E} + 0.5)\ \%$$

is a perfect match between the two terms and for Higgs Physics.

M. Shupe

UNIV. OF ARIZONA
CCT, 1991

DESIGN CRITERIA FOR FORWARD CALORIMETER.

- PHYSICS:
  1. $\not{E}_T$ COVERAGE TO $\sim |\eta| = 5.0$, WITH RESOLUTION UP TO $\sqrt{\ }$ IMPOSED LIMIT.
  2. JET RESOLUTION $\Rightarrow$ p_T RESOLUTION
- RADIATION HARDNESS:
  TO IONIZING RADIATION NEAR e SHOWER MAX. AND NEUTRON FLUX.
- INTEGRATE INTO FORWARD REGION DETECTOR.
- HIGH RATE CAPABILITY:
  (FOR LIQUID ARGON)
  1. USE SHORT SHAPING TIMES, AND SMALL GAPS.
  2. CALCULATE AND MEASURE + ION PILEUP.
- COST
  (FOR PROPOSED DESIGN)
  1. COST OF TUNGSTEN
  2. CHANNEL COUNT

etc..

Physics Requiring a Forward Calorimeter

Missing E_T

Higgs

$$H \rightarrow ZZ \rightarrow \ell^+\ell^-\nu\bar{\nu}$$
$$H \rightarrow ZZ \rightarrow \ell^+\ell^-\tau\bar{\tau}$$

New heavy quarks

SUSY

Technicolor

$$\rho^{\pm}_{TC} \rightarrow W^{\pm}Z^{o} \rightarrow \ell^{\pm}\nu\ell^+\ell^-$$

Leptoquarks $gg \rightarrow P_3P_3 \rightarrow b\tau\bar{b}\bar{\tau}$

New Gauge Bosons

$$W'^{\pm} \rightarrow \ell^{\pm}\nu$$

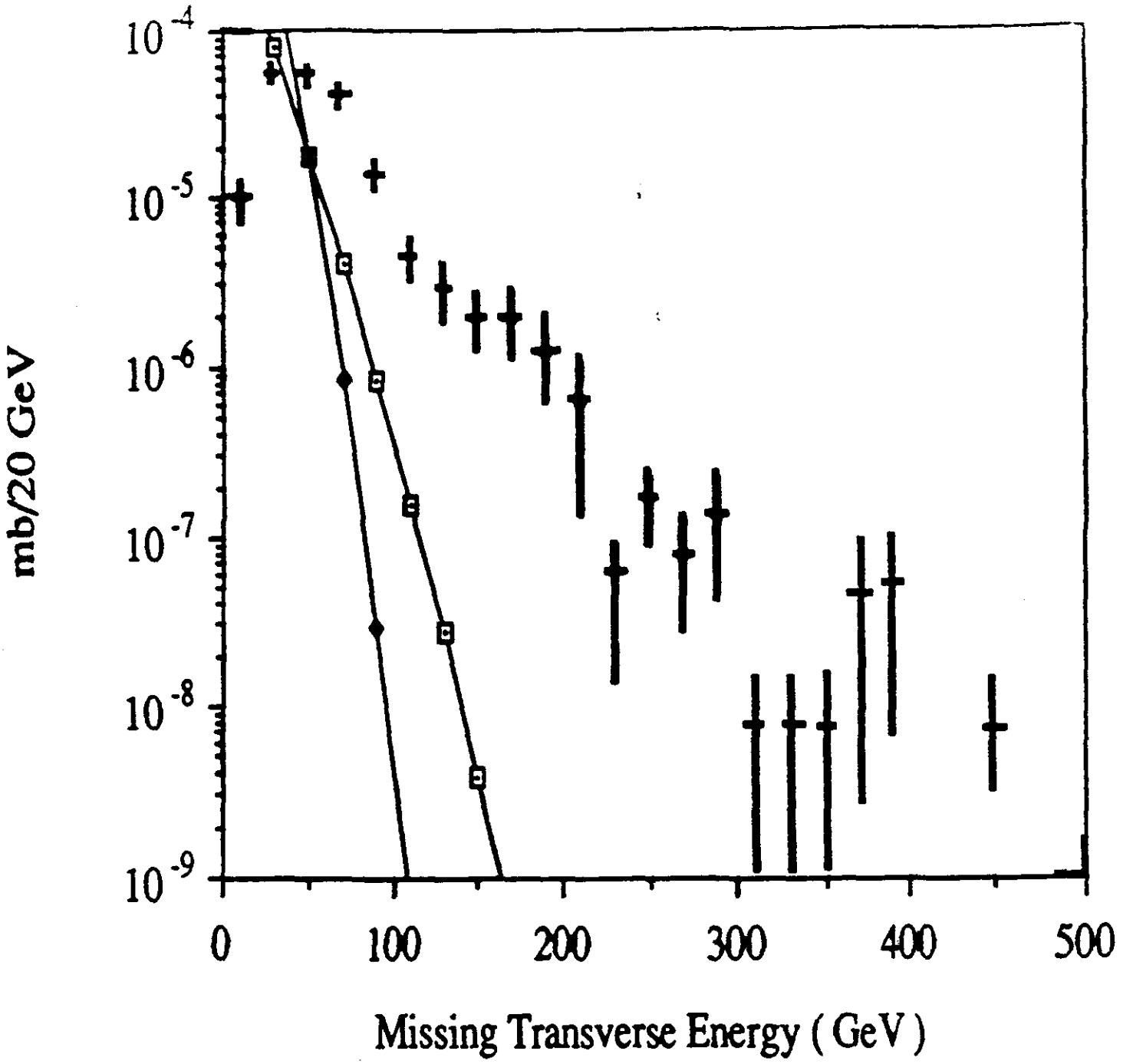
Other sources of boson pairs

$$W^{\pm}Z^{o} \rightarrow \ell^{\pm}\nu\ell^+\ell^-$$
$$W^{\pm}W^{\pm} \rightarrow \ell^{\pm}\nu\ell^{\pm}\nu$$
$$W^+W^- \rightarrow \ell^+\nu\ell^-\nu \text{ if separable from } t\bar{t}$$

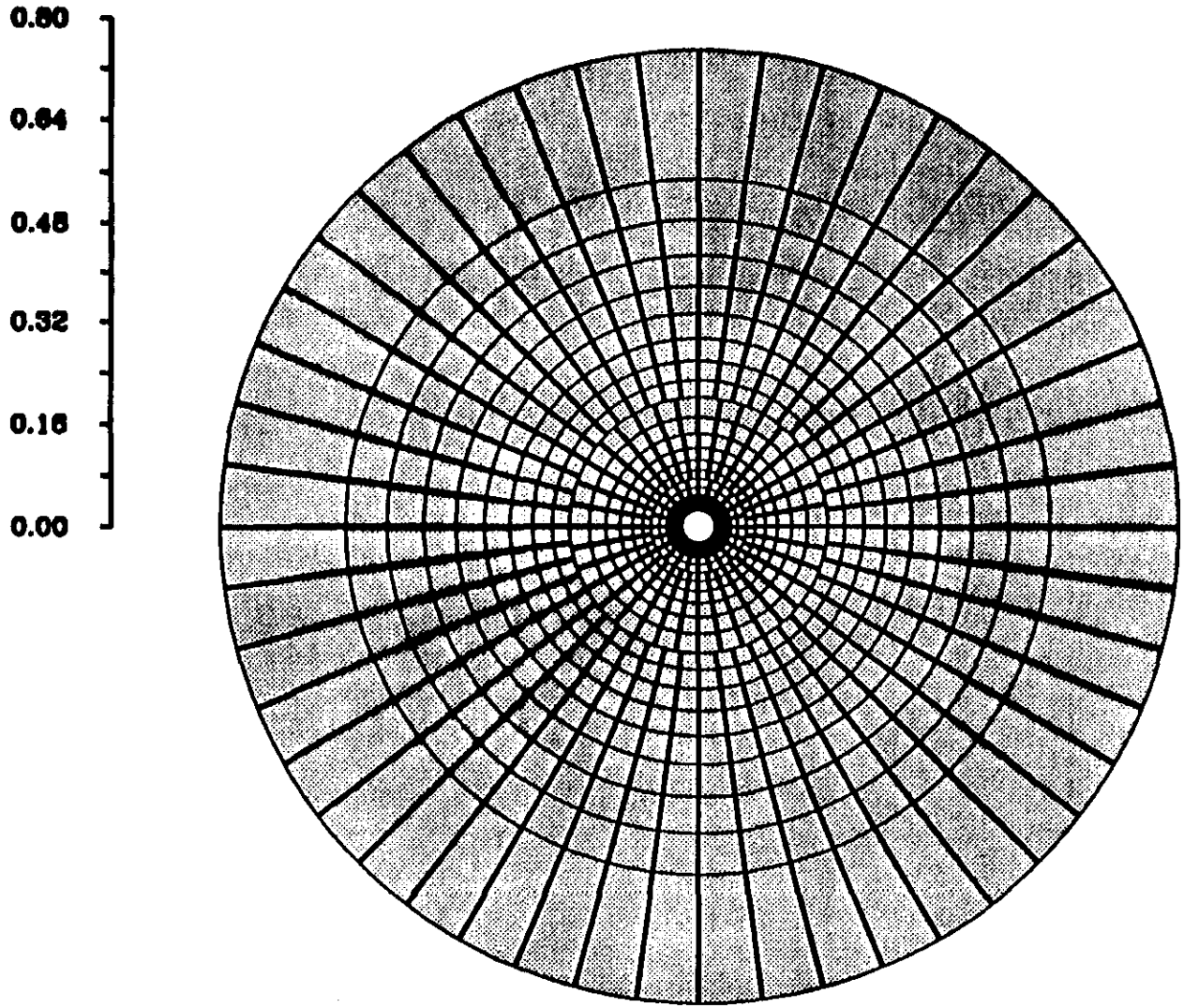
Forward Jets

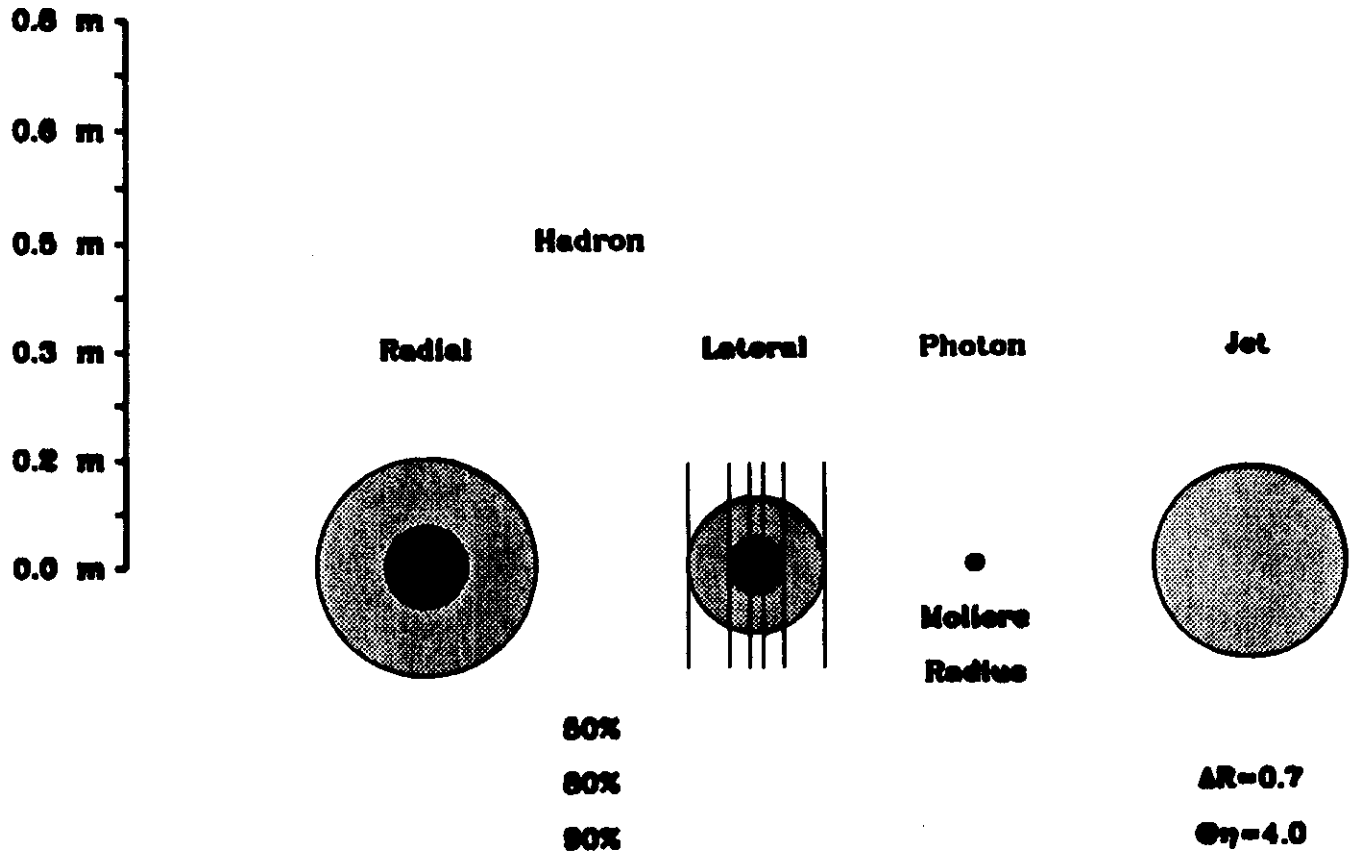
VV scattering with forward jet tagging

Low x physics via forward di-jets



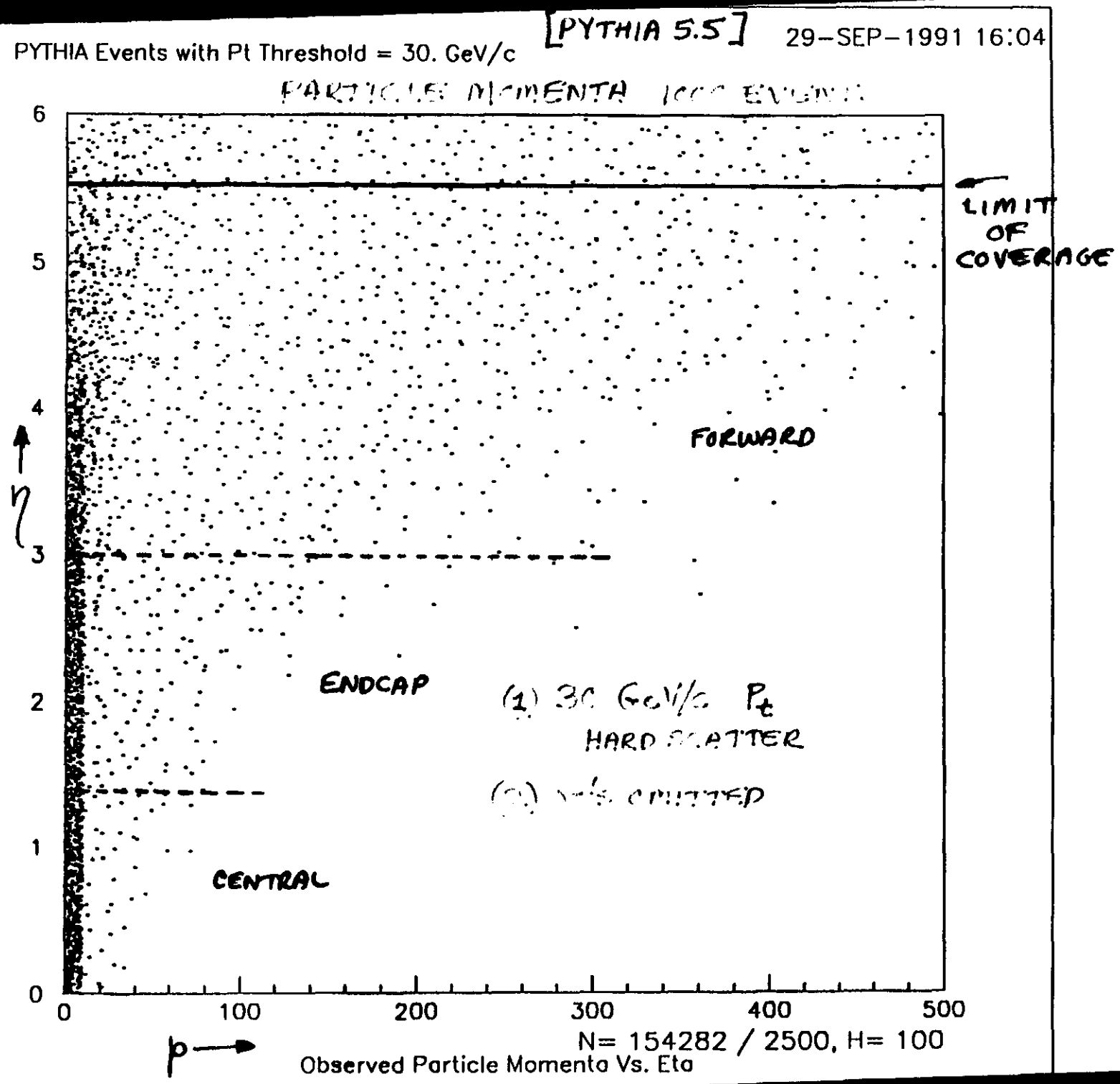
igure 2 . The missing transverse energy cross scetion due to neutrino :c .uction (data points), whole jet fluctuations into the cryostat edge (solid iamonds) and "electromagnetic" jet fluctuations (open squares) is show. he neutrino cross section has ignored processes with energies less than 50 eV while the other two mechanisims have included these energies.


0.80
0.64
0.48
0.32
0.16
0.00


0.8 m
0.6 m
0.5 m
0.3 m
0.2 m
0.0 m
Hadron
Radial
Lateral
Photon
Jet
Moliere
Radius
50%
80%
90%
ΔR=0.7
Δη=4.0

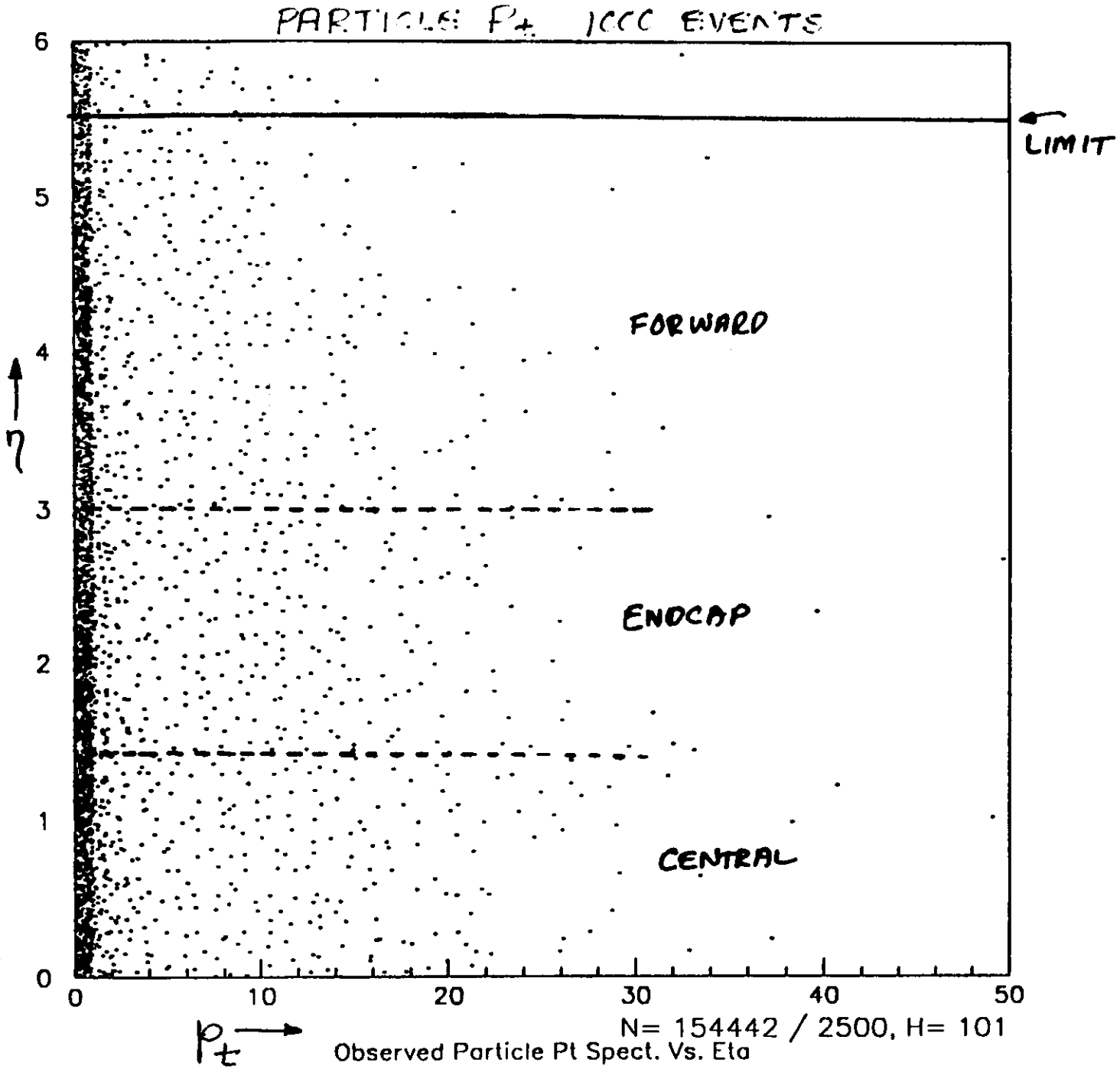
PROPERTIES OF CALORIMETER MATERIALS (METALS ORDERED X_0/λ)

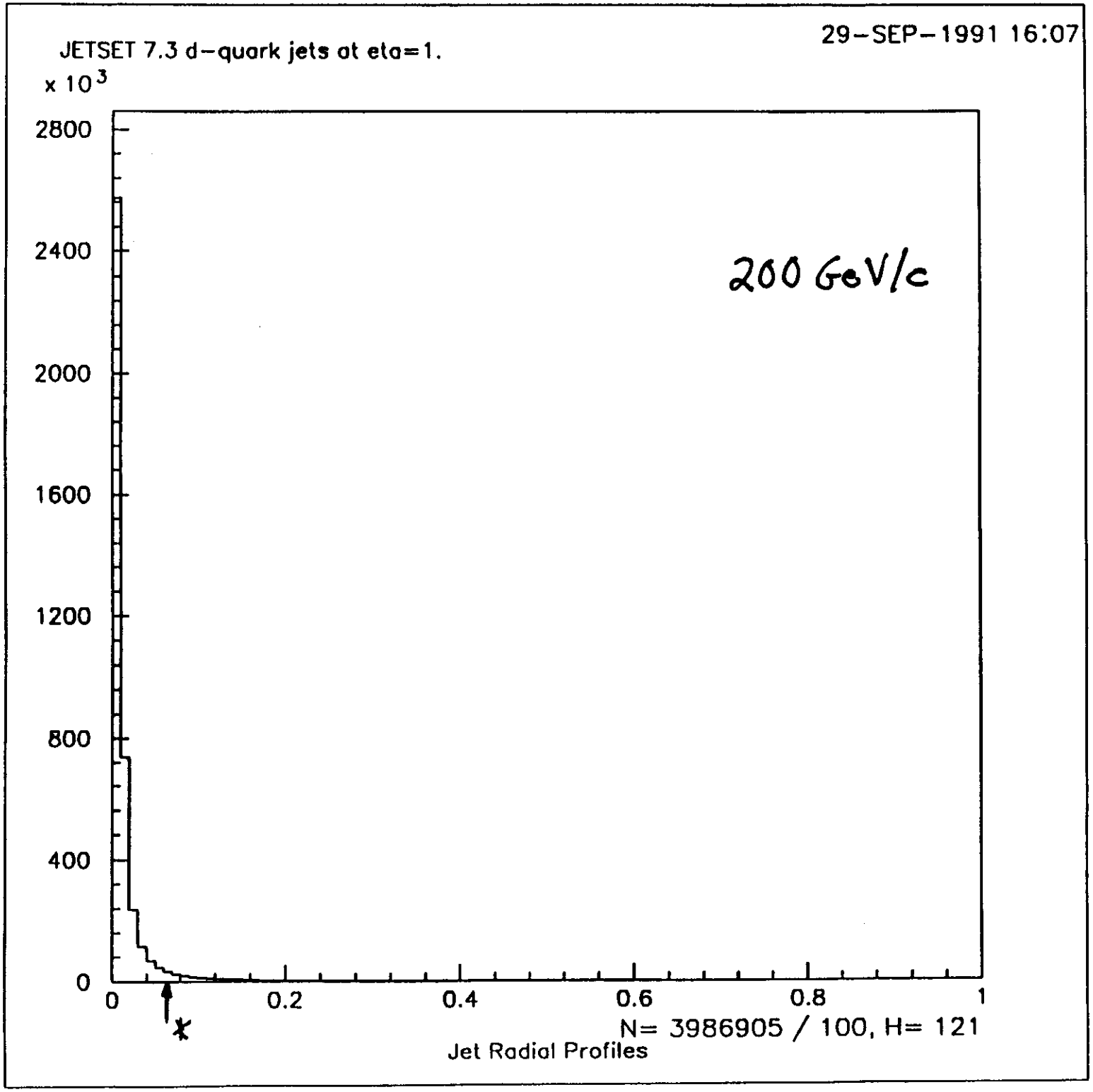
	λ (cm)	X_0 (cm)	$\# X_0/1\lambda$	ϵ_{CRIT} (MeV)	$\rho_{MOLIERE}$ (cm)
Fe	16.75	[illegible]	9.52	20.5	1.90
Cu	15.06	[illegible]	10.50	19.7	1.61
W	9.59	[illegible]	[illegible]	7.94	.94
Pb	17.01	[illegible]	[illegible]	7.4	1.63
U	10.5	[illegible]	[illegible]	6.54	[illegible]
BaF_2	[illegible]	[illegible]	14.[illegible]	[illegible]	[illegible]

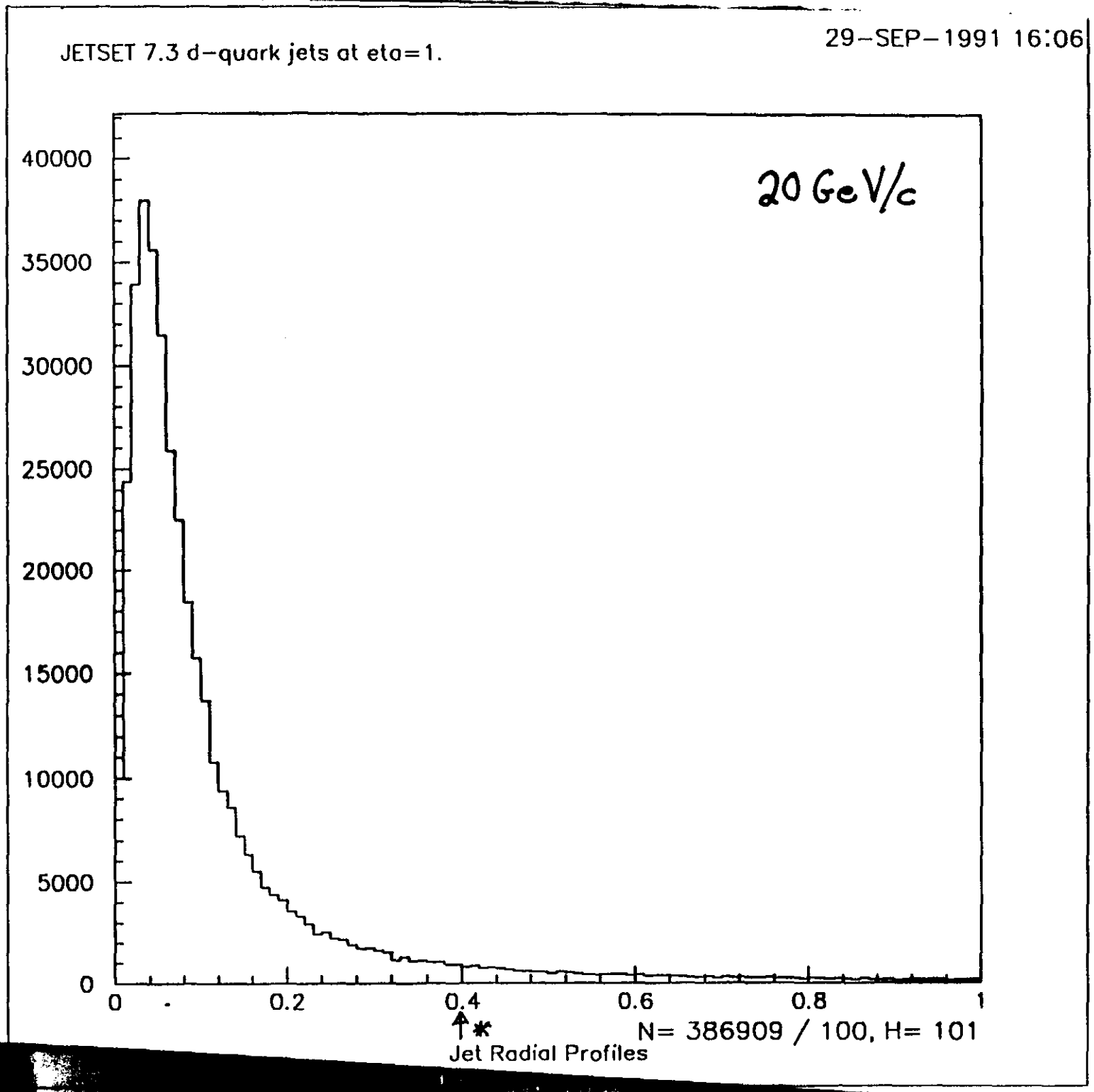

[PYTHIA 5.5]
29-SEP-1991 16:04
PYTHIA Events with Pt Threshold = 30. GeV/c
PARTICLE MOMENTA
LIMIT OF COVERAGE
FORWARD
ENDCAP
CENTRAL
(1) 30 GeV/c Pt HARD SCATTER
η
p
N= 154282 / 2500, H= 100
Observed Particle Momenta Vs. Eta

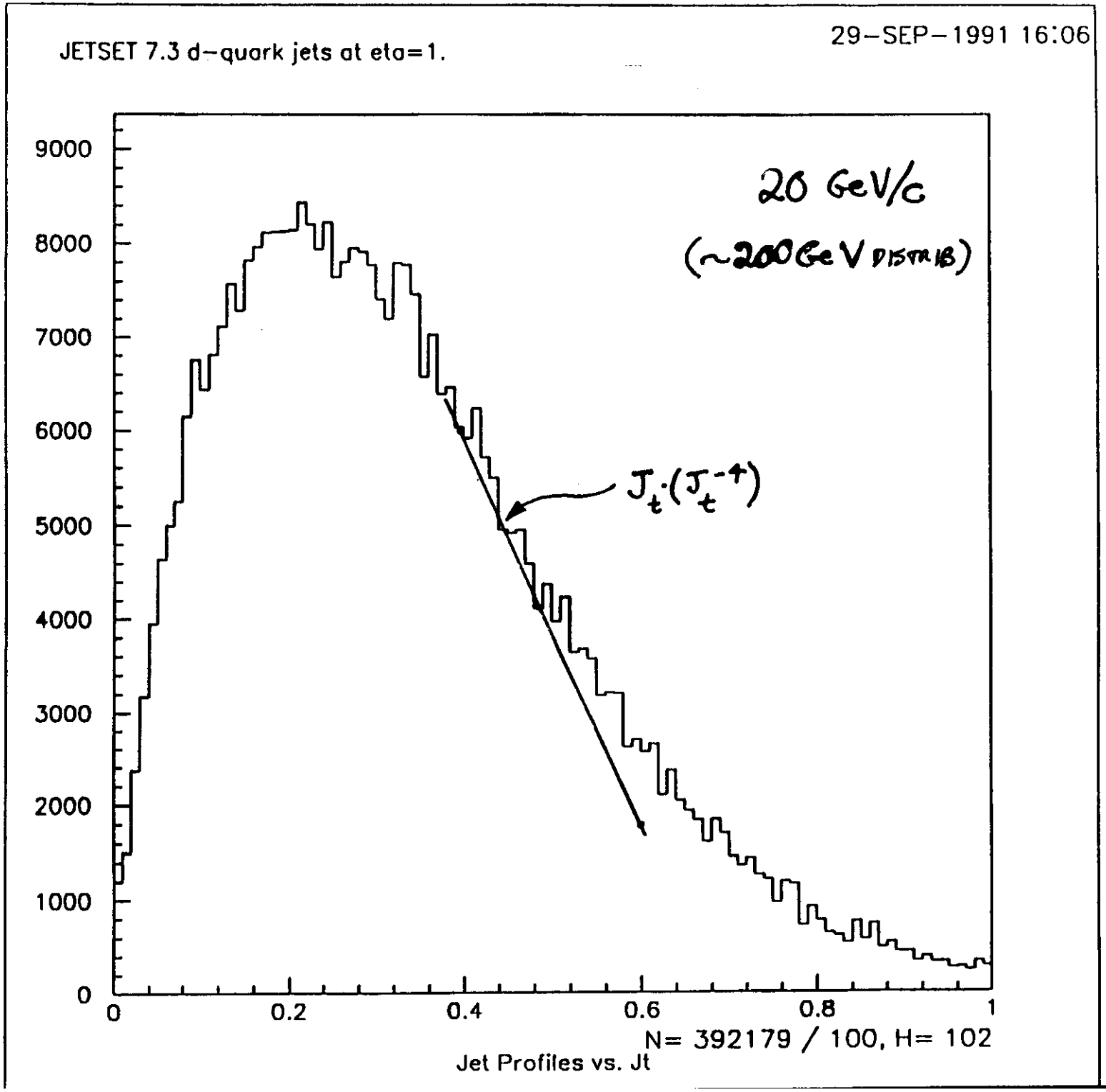
PYTHIA Events with Pt Threshold = 30. GeV/c

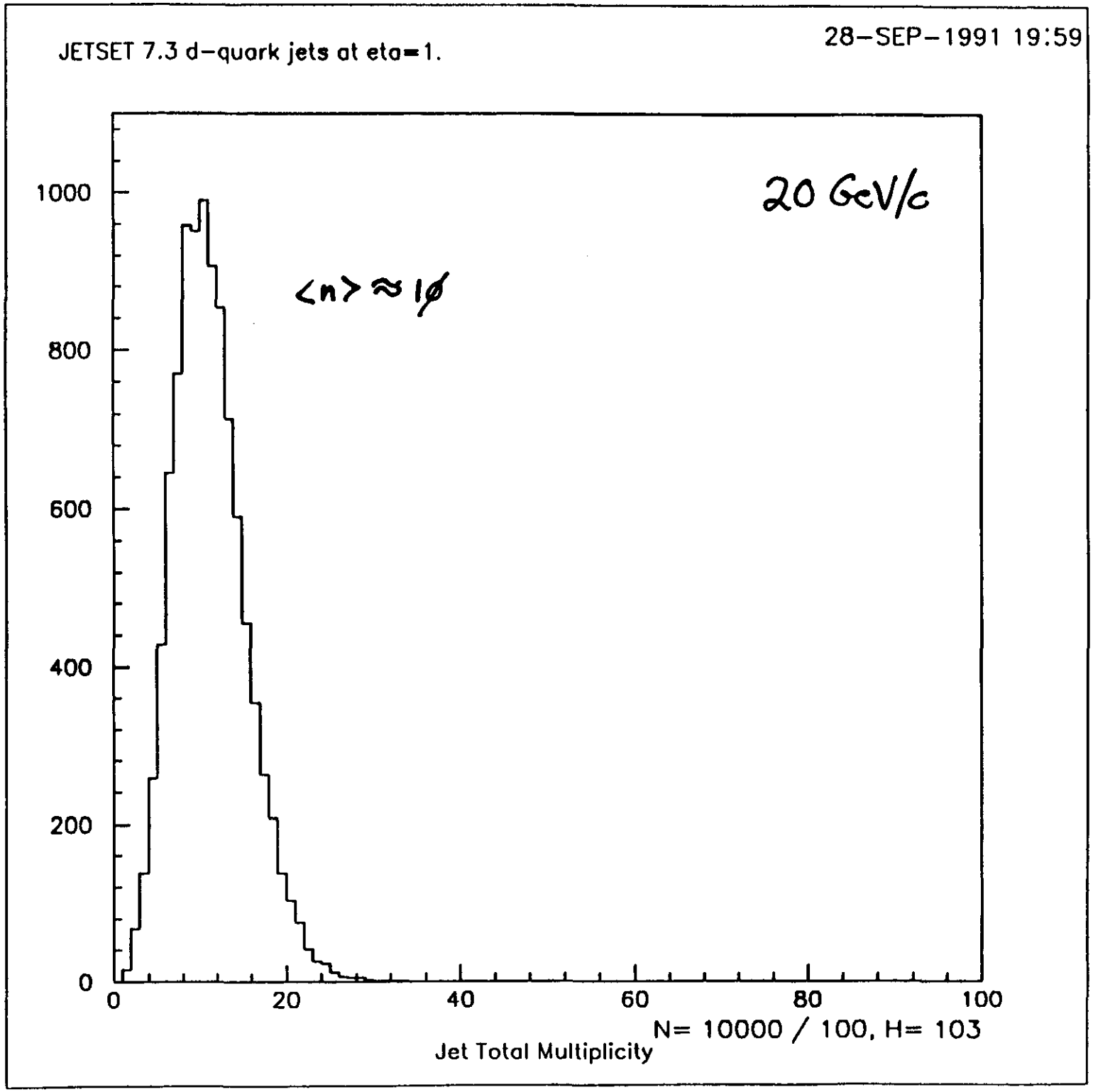
29-SEP-1991 16:04

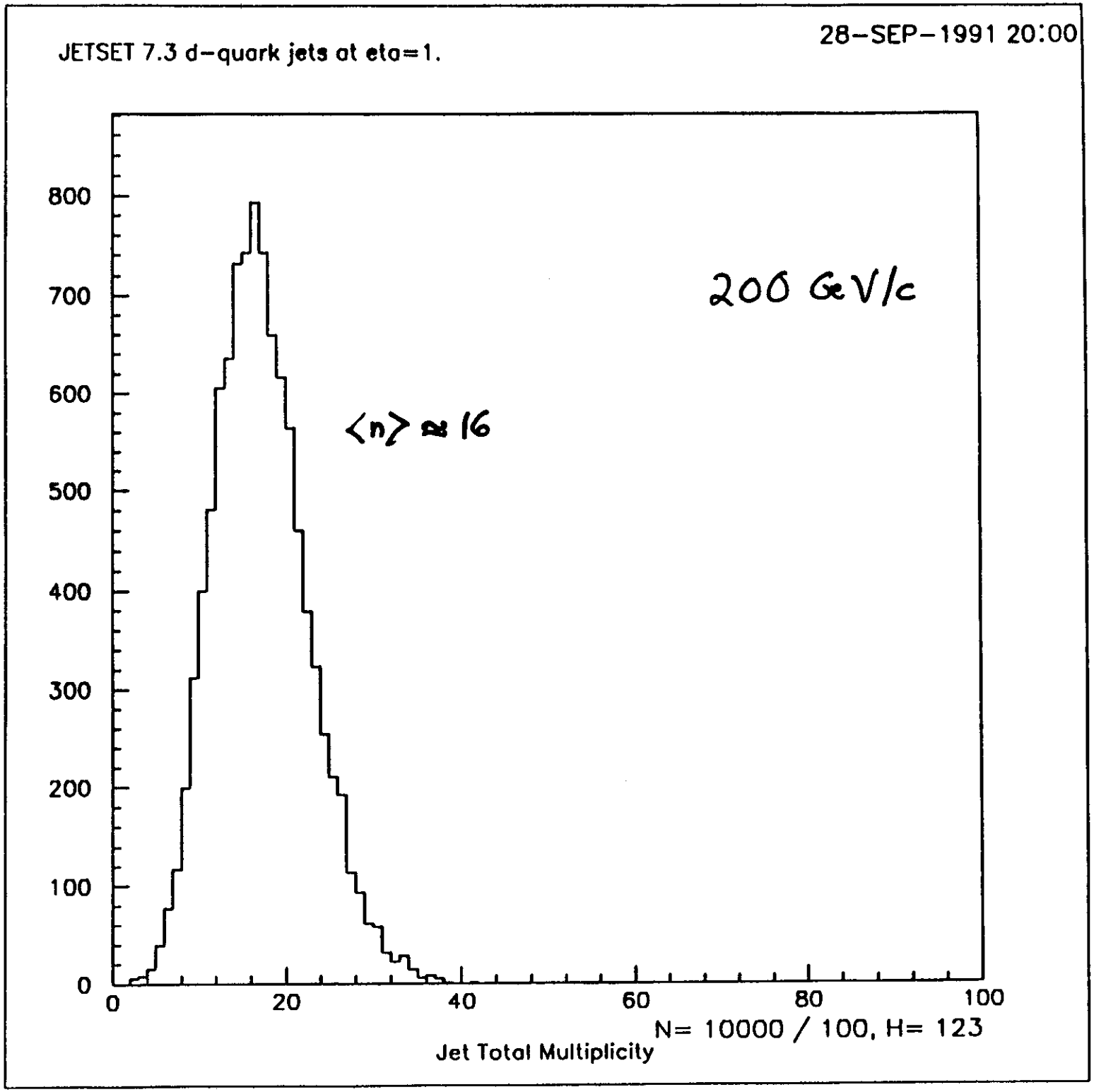


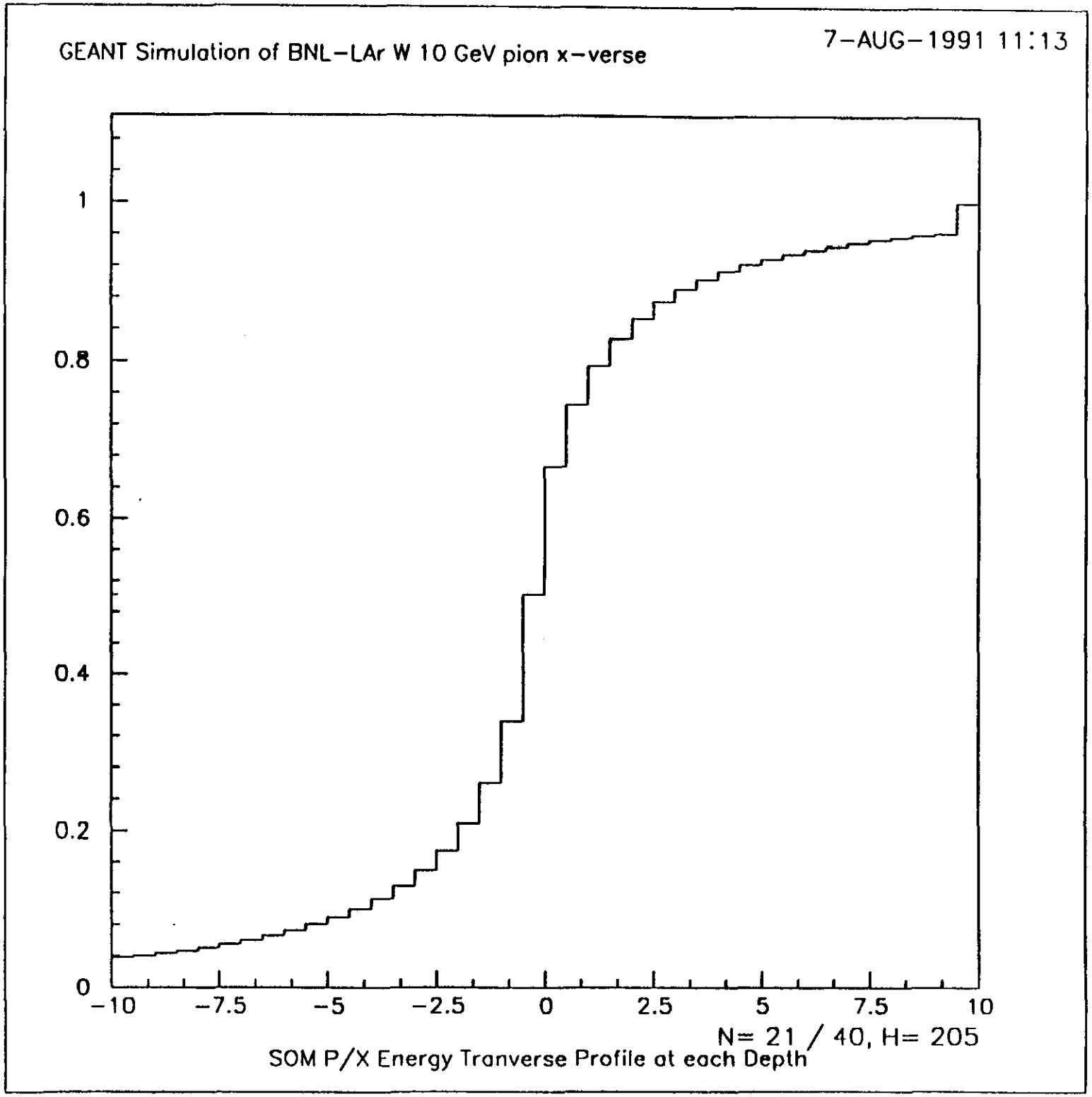

JETSET 7.3 d-quark jets at eta=1.
29-SEP-1991 16:07
x 10^3
2800
2400
2000
1600
1200
800
400
0
0
0.2
0.4
0.6
0.8
1
200 GeV/c
N= 3986905 / 100, H= 121
Jet Radial Profiles


JETSET 7.3 d-quark jets at eta=1.
29-SEP-1991 16:06
20 GeV/c
40000
35000
30000
25000
20000
15000
10000
5000
0
0
0.2
0.4
0.6
0.8
1
N= 386909 / 100, H= 101
Jet Radial Profiles


JETSET 7.3 d-quark jets at eta=1.
29-SEP-1991 16:06
20 GeV/c
(~200 GeV DISTRIB)
$J_t \cdot (J_t^{-1})$
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.2
0.4
0.6
0.8
1
N= 392179 / 100, H= 102
Jet Profiles vs. Jt


JETSET 7.3 d-quark jets at eta=1.
28-SEP-1991 19:59
20 GeV/c
<n> ≈ 1ø
1000
800
600
400
200
0
0
20
40
60
80
100
N= 10000 / 100, H= 103
Jet Total Multiplicity

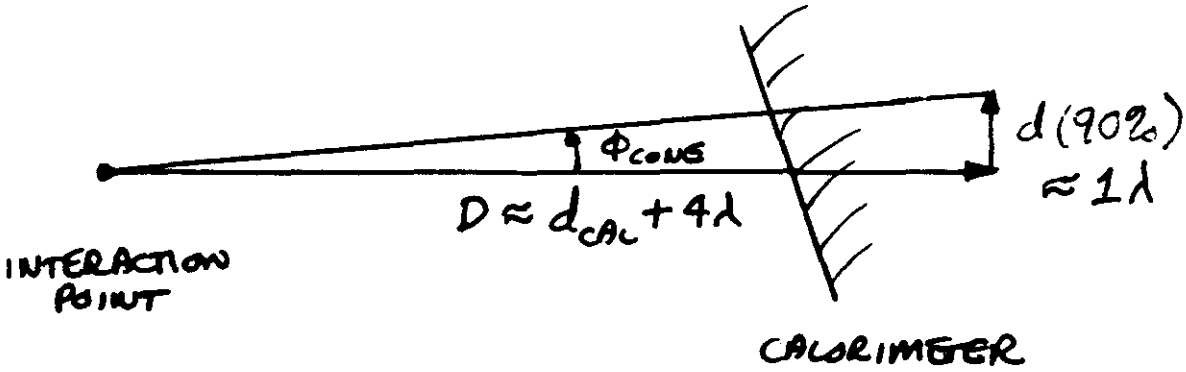

JETSET 7.3 d-quark jets at eta=1.
28-SEP-1991 20:00
200 GeV/c
<n> ≈ 16
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
N= 10000 / 100, H= 123
Jet Total Multiplicity


GEANT Simulation of BNL-LAr W 10 GeV pion x-verse
7-AUG-1991 11:13
1
0.8
0.6
0.4
0.2
0
-10
-7.5
-5
-2.5
0
2.5
5
7.5
10
N= 21 / 40, H= 205
SOM P/X Energy Tranverse Profile at each Depth

90% 9cm
≈ λ

HADRONIC SHOWER AND JET CONTAINMENT

HADRONS.

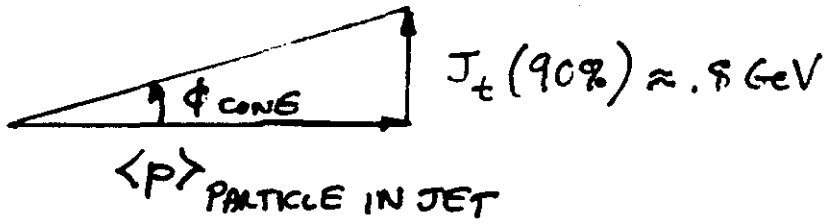


$d(90\%)$ IS THE LATERAL CONTAINMENT RADIUS TO CONTAIN 90% OF SHOWER ENERGY.

$$\Rightarrow \phi_{CONE} \approx \frac{d(90)}{D} \approx \frac{\lambda}{d_{CAL} + 4\lambda}$$

JETS.

(MUCH MORE QUALITATIVE AT MOMENT)



ORDER OF MAGNITUDE $\Rightarrow \langle p \rangle_{PIJ} \approx P_{JET}/\langle n \rangle$

$$\Rightarrow \phi_{CONE} \approx \frac{J_t(90)}{P_{JET}/\langle n \rangle}$$

EG. 20 GeV/c, $\langle n \rangle \approx 10 \Rightarrow \phi_{CONE} \approx \frac{.8}{20} = .4$

NOTE: 1/ [illegible] DEPENDENCE! [illegible]

	20 GeV	200 GeV
$\eta = 0$ $D = 100$ CM $\lambda = 20$ CM $(d\eta/d\theta = 1)$	[illegible] [illegible]	[illegible] [illegible]
$\eta = 4.0$ $D = 500$ CM $\lambda = 10$ CM $(d\eta/d\theta) = \frac{1}{.036}$	$\phi_{HAD} = .02$ $\Delta\eta = .55$ $\phi_{MET} = .4$ $\Delta\eta = 11.1$ (BEAM THICK)	$\phi_{HAD} = .0[illegible]$ $\Delta\eta = .5[illegible]$ $\phi_{MET} = .0[illegible]4$ $\Delta\eta = 1.78$ (GEOMETRY)

$(p_T = 20 = E \quad p = 550$ AT $\eta = 4.0)$

5. CONCLUSIONS:

1. MAY CONSIDER p DIAGNOSTIC CASES TO REDUCE SMEARING.

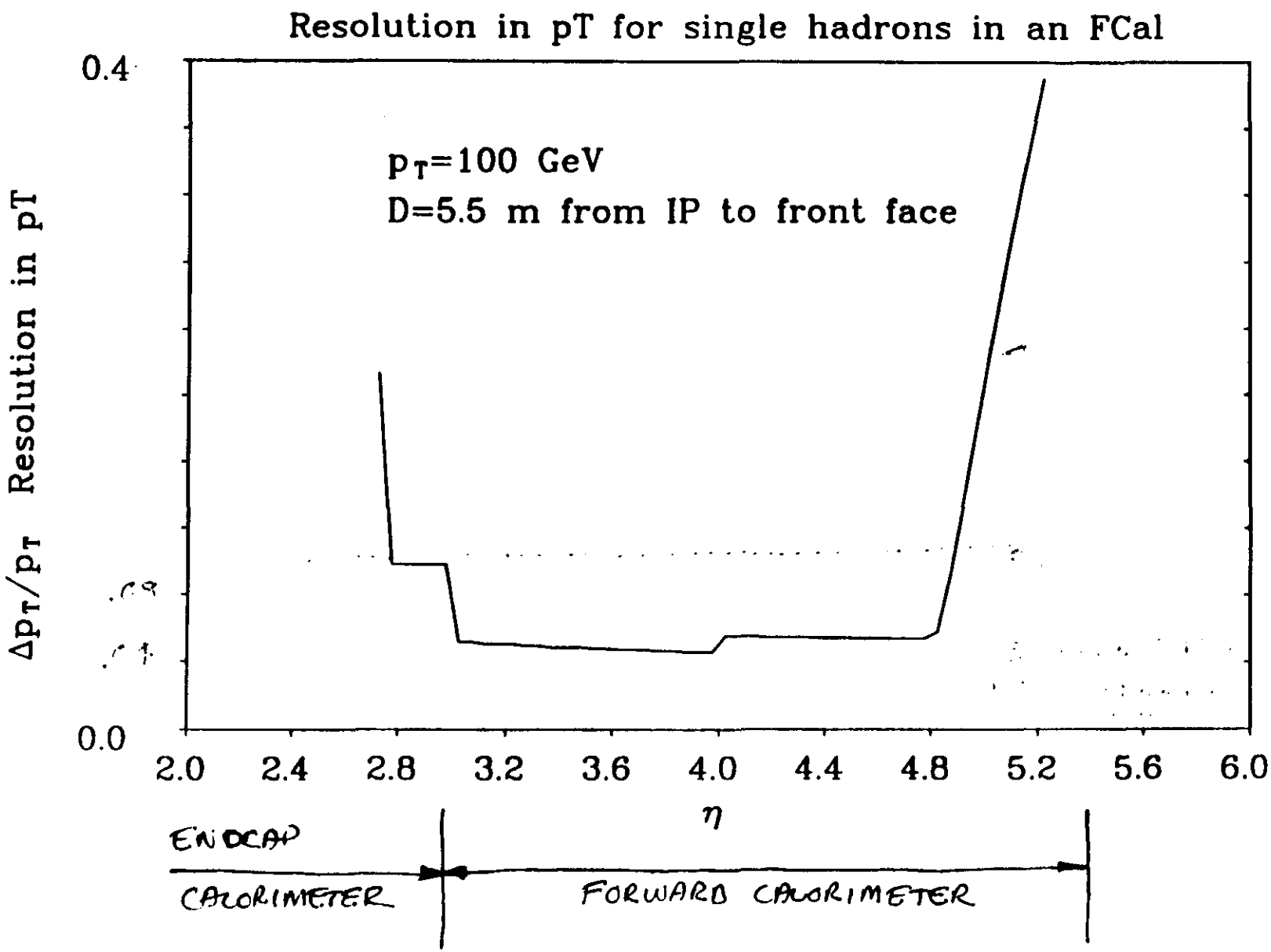
2. JET THRUST [illegible] ARE [illegible] FOR FIRST [illegible]

(illegible)

(illegible)

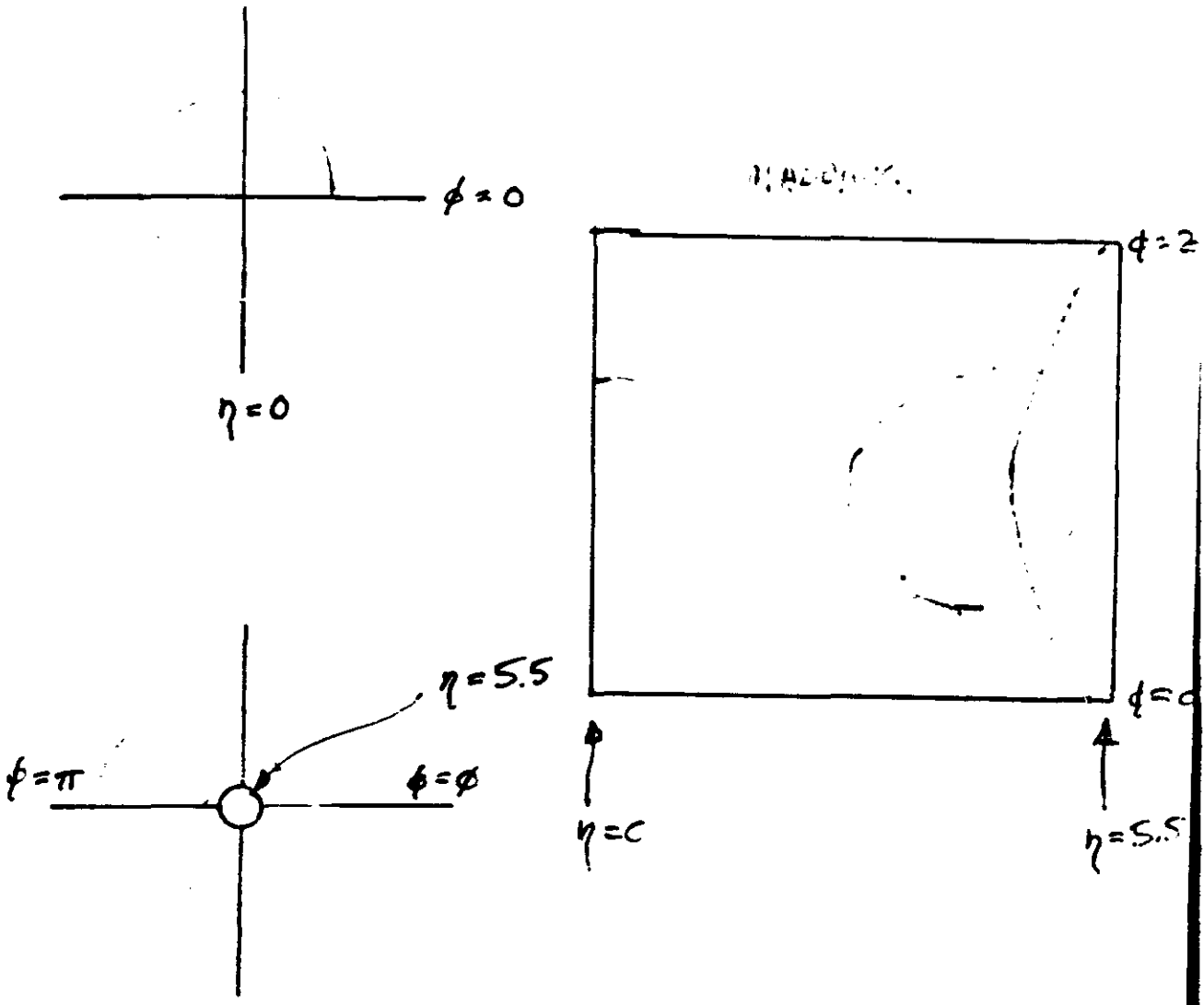
SIMPLE ANALYSIS TAKING: $\Delta E = \frac{\Delta E_{CELL}}{\sqrt{12}}$,

$$\frac{\delta p_T}{p_T} \approx \sqrt{\left(\frac{\delta p}{p}\right)^2 + \left(\frac{\sigma_E}{E}\right)^2}$$



JET MAPPING AT HIGH η

→ THE "MERCATOR PROBLEM"



SIMULATIONS WITH GEANT 3.14 (LCG54)

```
*  IPFIS =        1.  IDRAY =        1.  IANNI =        1. *
*  IBREM =        1.  IHADR =        3.  IMUNU =        0. *
*  IDCAY =        1.  ILOSS =        3.  IMULS =        2. *
*  IRAYL =        0.                                        *
*                                                           *
*     Special TPAR for TMED   1   W    TUNGSTEN             *
*     -------------------------                             *
*  CUTGAM= 10.00 KEV  CUTELE= 10.00 KEV  CUTNEU=100.00 KEV *
*  CUTHAD=100.00 KEV  CUTMUO=  1.00 MEV                     *
*  BCUTE = 10.00 KEV  BCUTM =100.00 KEV                     *
*  DCUTE = 10.00 KEV  DCUTM = 10.00 KEV  PPCUTM= 10.00 MEV *
*  IPAIR =        1.  ICOMP =        1.  IPHOT =        1. *
*  IPFIS =        1.  IDRAY =        1.  IANNI =        1. *
*  IBREM =        1.  IHADR =        3.  IMUNU =        0. *
*  IDCAY =        1.  ILOSS =        3.  IMULS =        2. *
*  IRAYL =        0.                                        *
*                                                           *
*                                                           *
*     Special TPAR for TMED   2   KAPT    KAPTON             *
*     -------------------------                             *
*  CUTGAM= 10.00 KEV  CUTELE= 10.00 KEV  CUTNEU=100.00 KEV *
*  CUTHAD=100.00 KEV  CUTMUO=  1.00 MEV                     *
*  BCUTE = 10.00 KEV  BCUTM =100.00 KEV                     *
*  DCUTE = 10.00 KEV  DCUTM = 10.00 KEV  PPCUTM= 10.00 MEV *
*  IPAIR =        1.  ICOMP =        1.  IPHOT =        1. *
*  IPFIS =        1.  IDRAY =        1.  IANNI =        1. *
*  IBREM =        1.  IHADR =        3.  IMUNU =        0. *
*  IDCAY =        1.  ILOSS =        3.  IMULS =        2. *
*  IRAYL =        0.                                        *
*
```

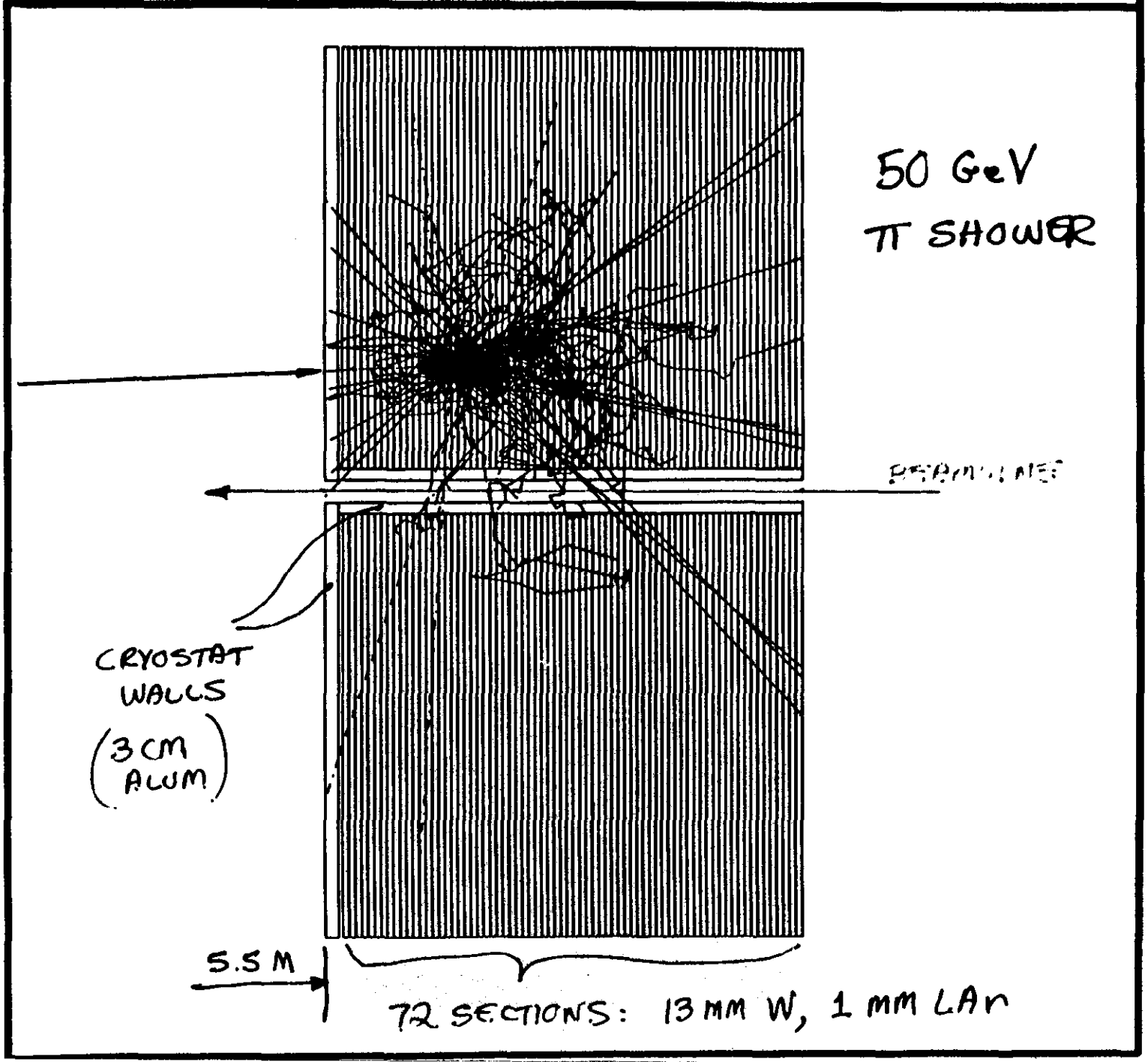
CUTOFFS ARE 1 MeV E.M. 1 MeV HADRONIC.

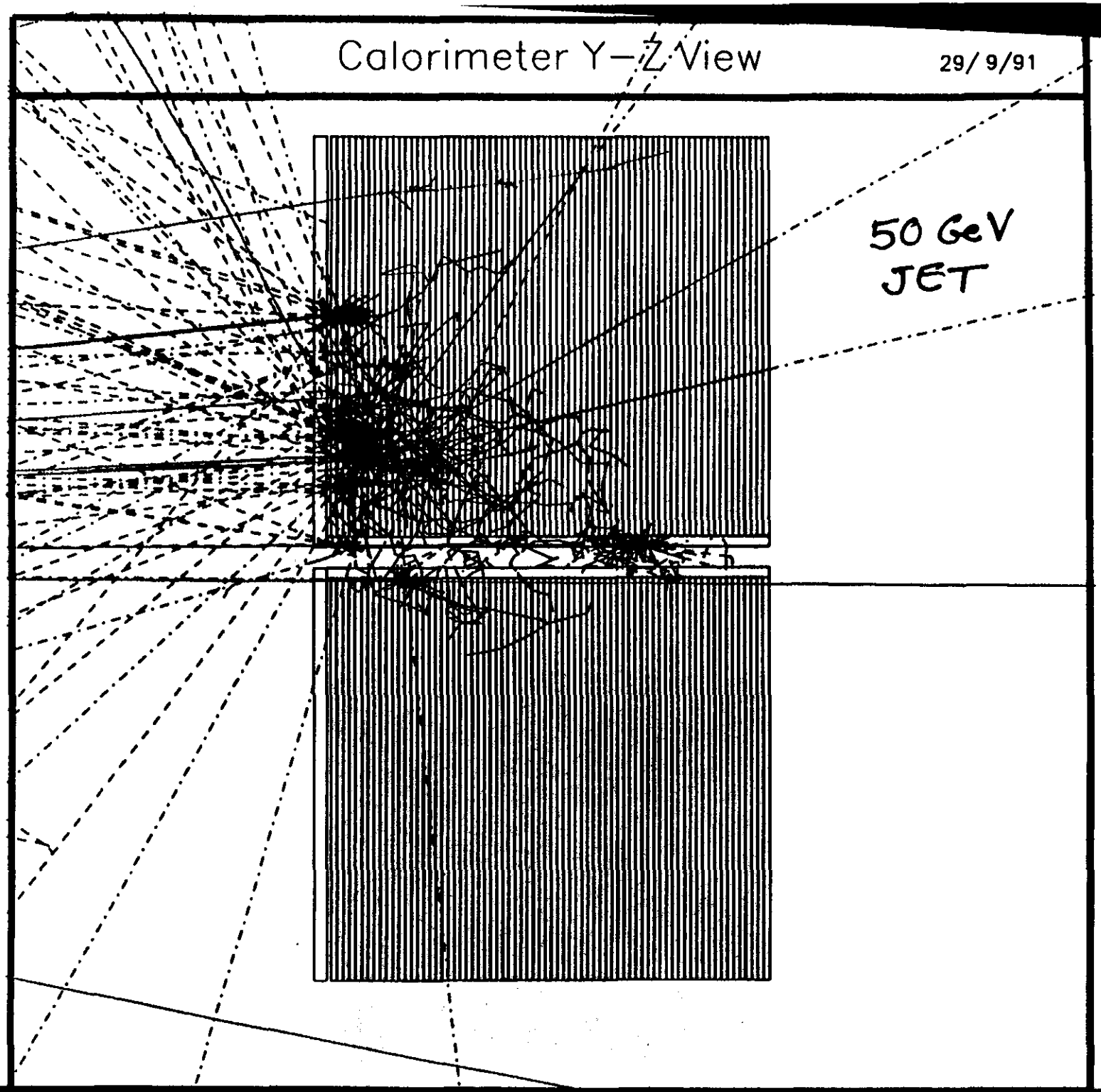
```
***** GPHYSI error for material nr   18
      Tracking medium NR   2 and  13 have different parameters

*                                                           *
*     Special TPAR for TMED   3   LAR    LIQUID ARGON        *
*     -------------------------                             *
*  CUTGAM= 10.00 KEV  CUTELE= 10.00 KEV  CUTNEU=100.00 KEV *
*  CUTHAD=100.00 KEV  CUTMUO=  1.00 MEV                     *
*  BCUTE = 10.00 KEV  BCUTM =100.00 KEV                     *
*  DCUTE = 10.00 KEV  DCUTM = 10.00 KEV  PPCUTM= 10.00 MEV *
*  IPAIR =        1.  ICOMP =        1.  IPHOT =        1. *
*  IPFIS =        1.  IDRAY =        1.  IANNI =        1. *
*  IBREM =        1.  IHADR =        3.  IMUNU =        0. *
*  IDCAY =        1.  ILOSS =        3.  IMULS =        2. *
*  IRAYL =        0.                                        *
*                                                           *

***** GPHYSI error for material nr   17
      Tracking medium NR   3 and  14 have different parameters

*                                                           *
*     Special TPAR for TMED   4   CU                        *
*     -------------------------                             *
*  CUTGAM= 10.00 KEV  CUTELE= 10.00 KEV  CUTNEU=100.00 KEV *
*  CUTHAD=100.00 KEV  CUTMUO=  1.00 MEV                     *
*  BCUTE = 10.00 KEV  BCUTM =100.00 KEV                     *
*  DCUTE = 10.00 KEV  DCUTM = 10.00 KEV  PPCUTM= 10.00 MEV *
*  IPAIR =        1.  ICOMP =        1.  IPHOT =        1. *
```

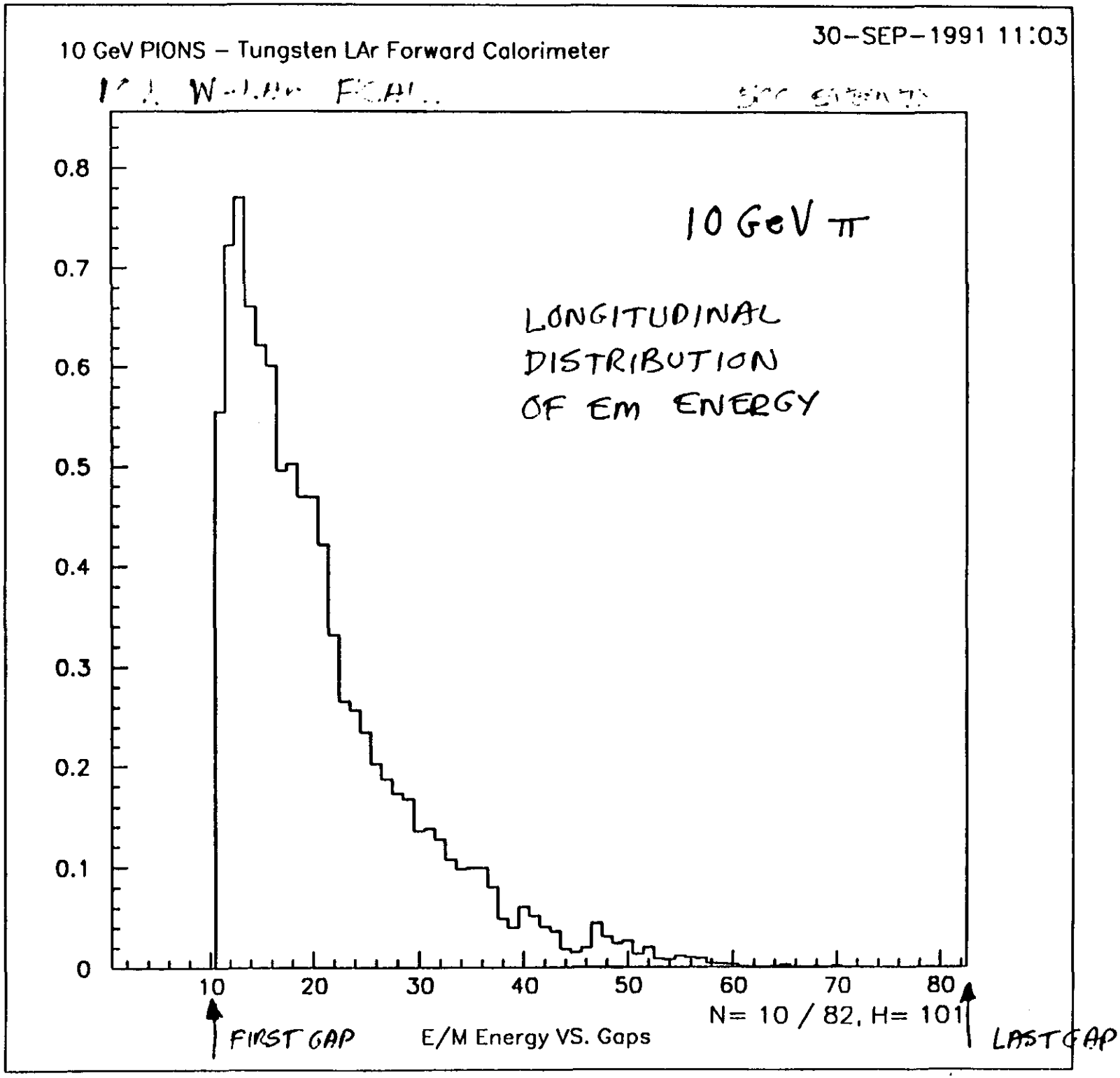
π 50 GeV

Calorimeter Y–Z View

24/9/91

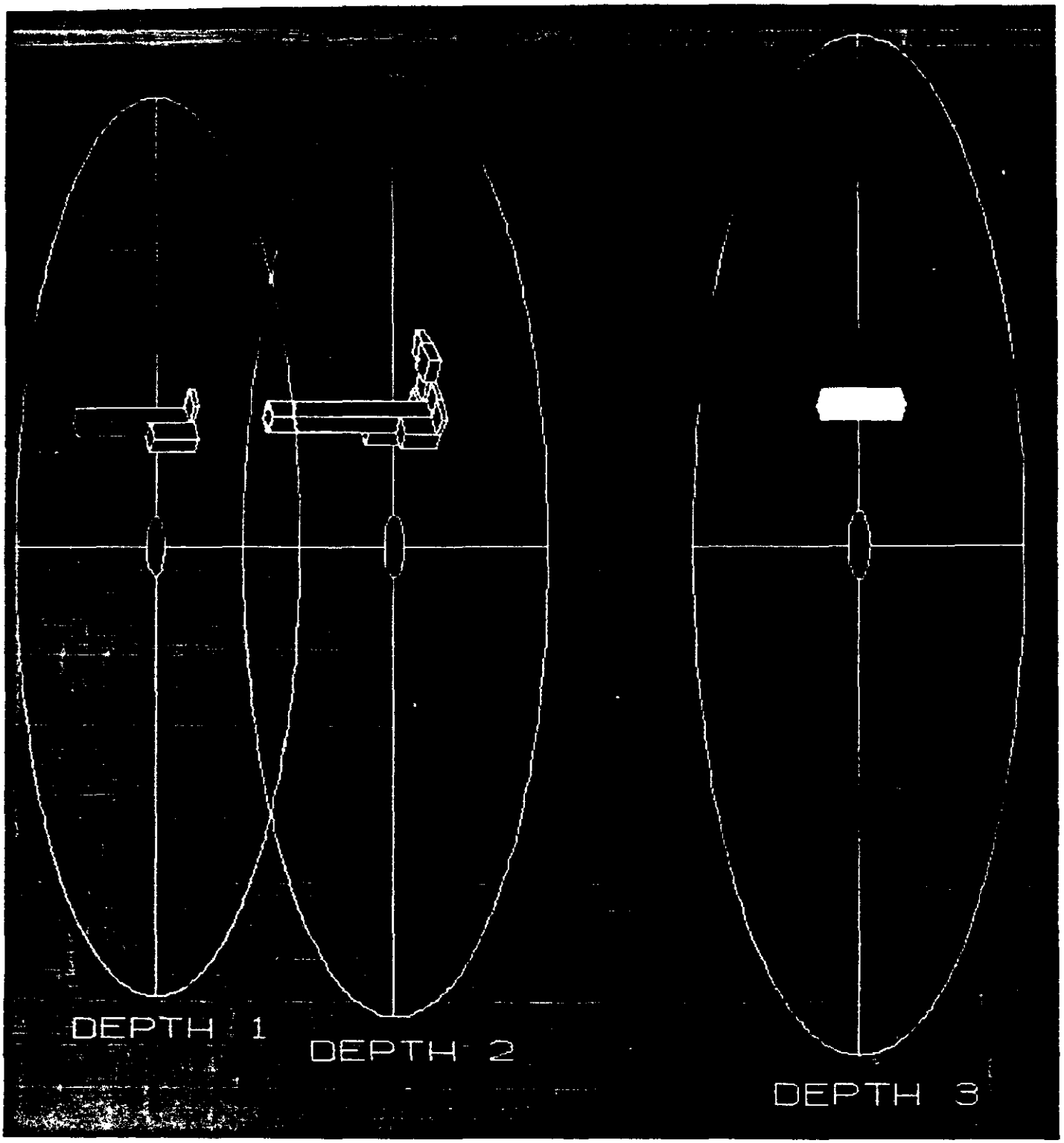



Calorimeter Y–Z View
29/ 9/91
50 GeV
JET


10 GeV PIONS – Tungsten LAr Forward Calorimeter
30-SEP-1991 11:03
10 GeV π
LONGITUDINAL
DISTRIBUTION
OF EM ENERGY
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60
70
80
N= 10 / 82, H= 101
FIRST GAP
E/M Energy VS. Gaps
LAST GAP

ENERGY IN DEPTHS

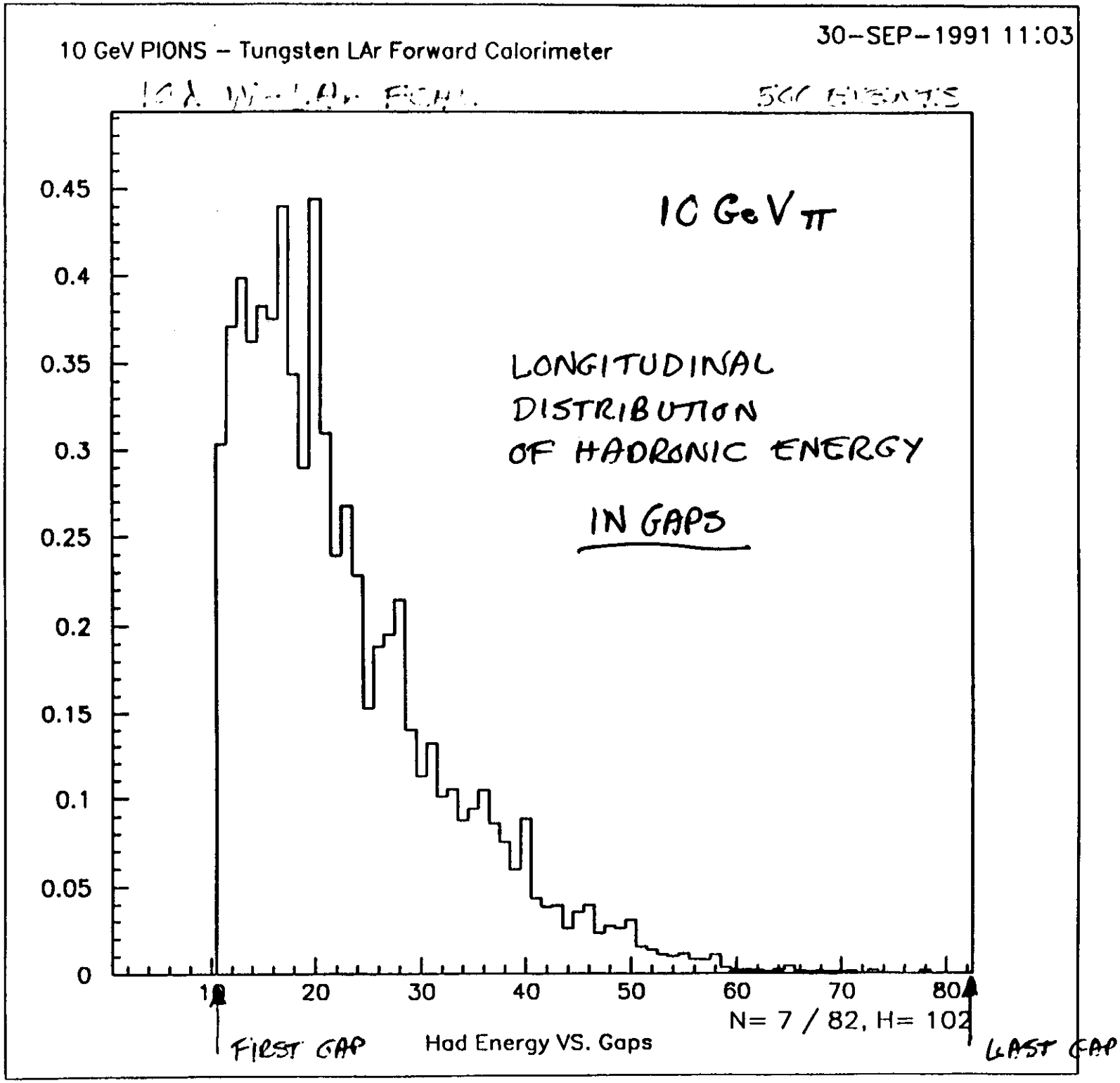
3 GANGED DEPTHS IN FCAL



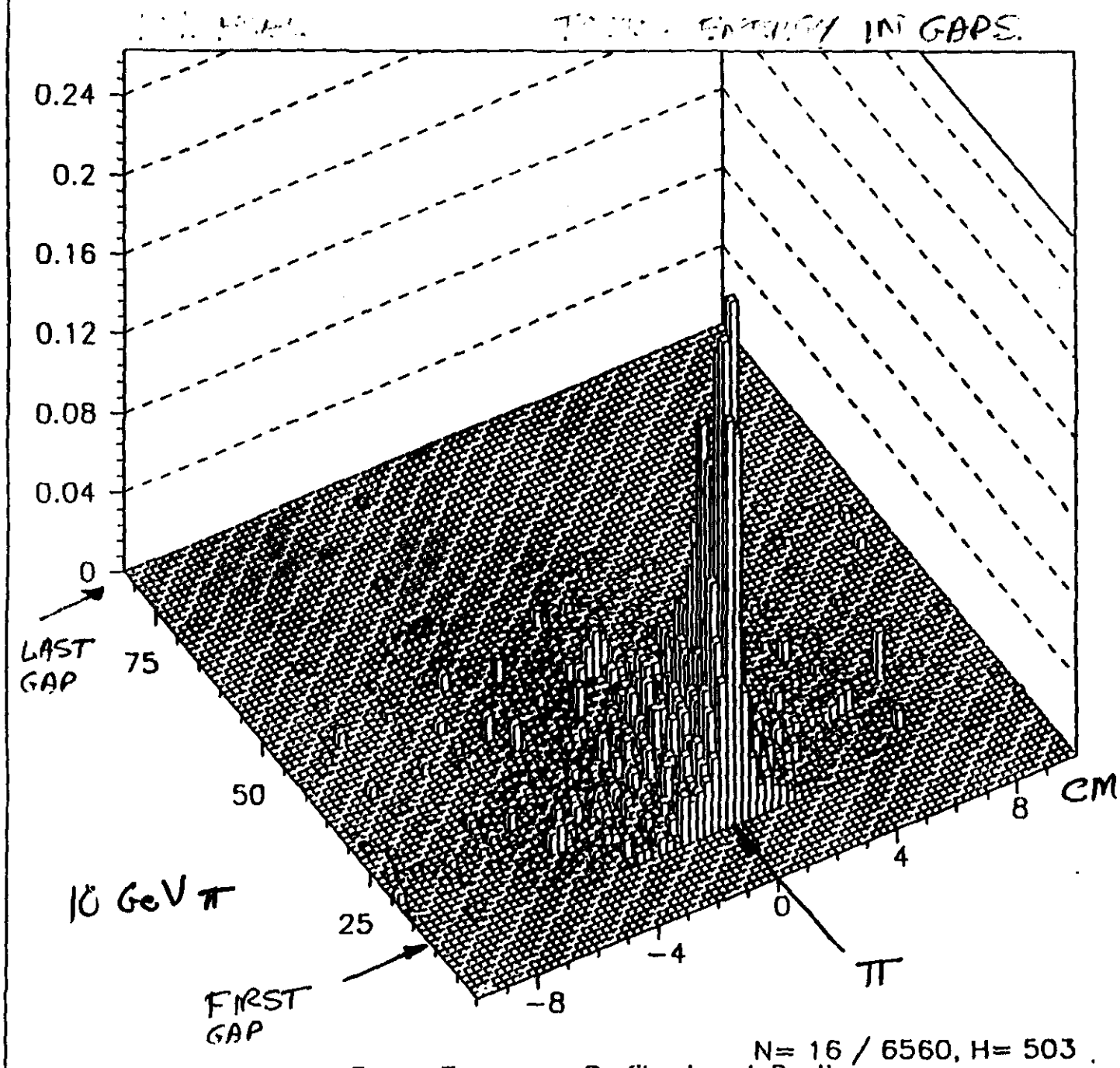
$20X_\phi$ DEEP

5λ DEEP
$(-20X_\phi)$

5λ DEEP

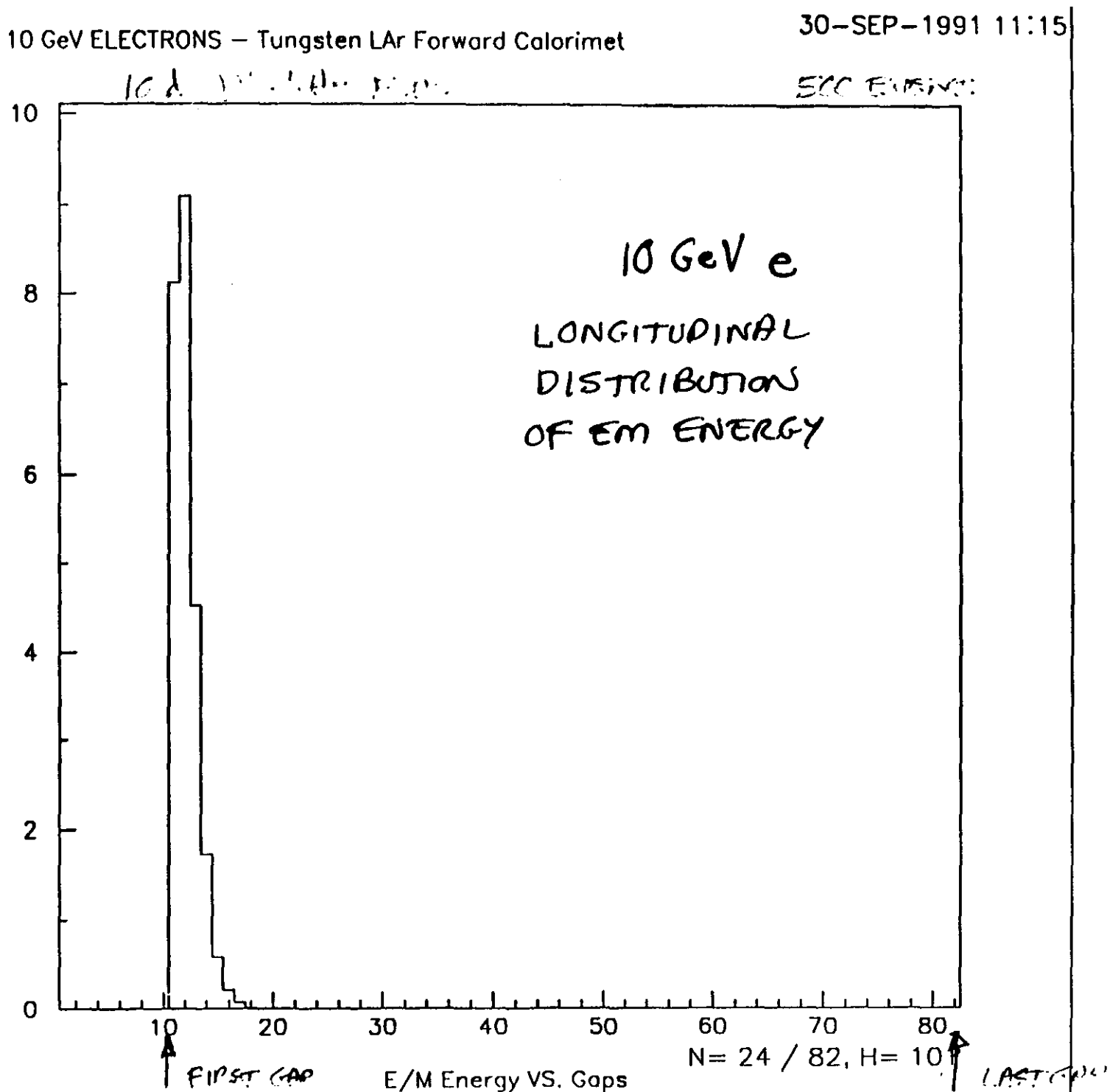

10 GeV PIONS – Tungsten LAr Forward Calorimeter
30-SEP-1991 11:03
10 GeV π
LONGITUDINAL
DISTRIBUTION
OF HADRONIC ENERGY
IN GAPS
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1
20
30
40
50
60
70
80
N= 7 / 82, H= 102
FIRST GAP
Had Energy VS. Gaps
LAST GAP

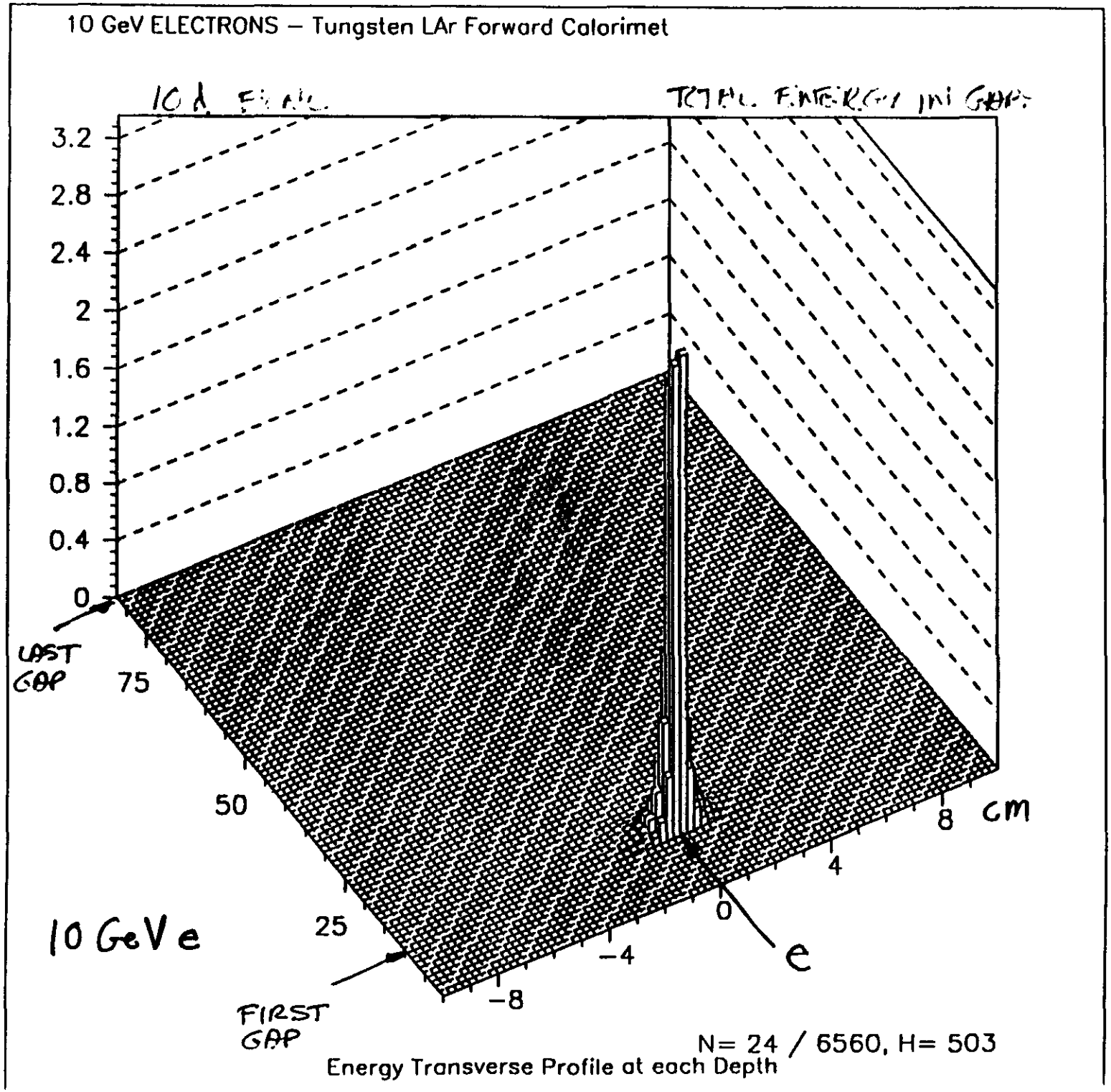
10 GeV PIONS – Tungsten LAr Forward Calorimeter

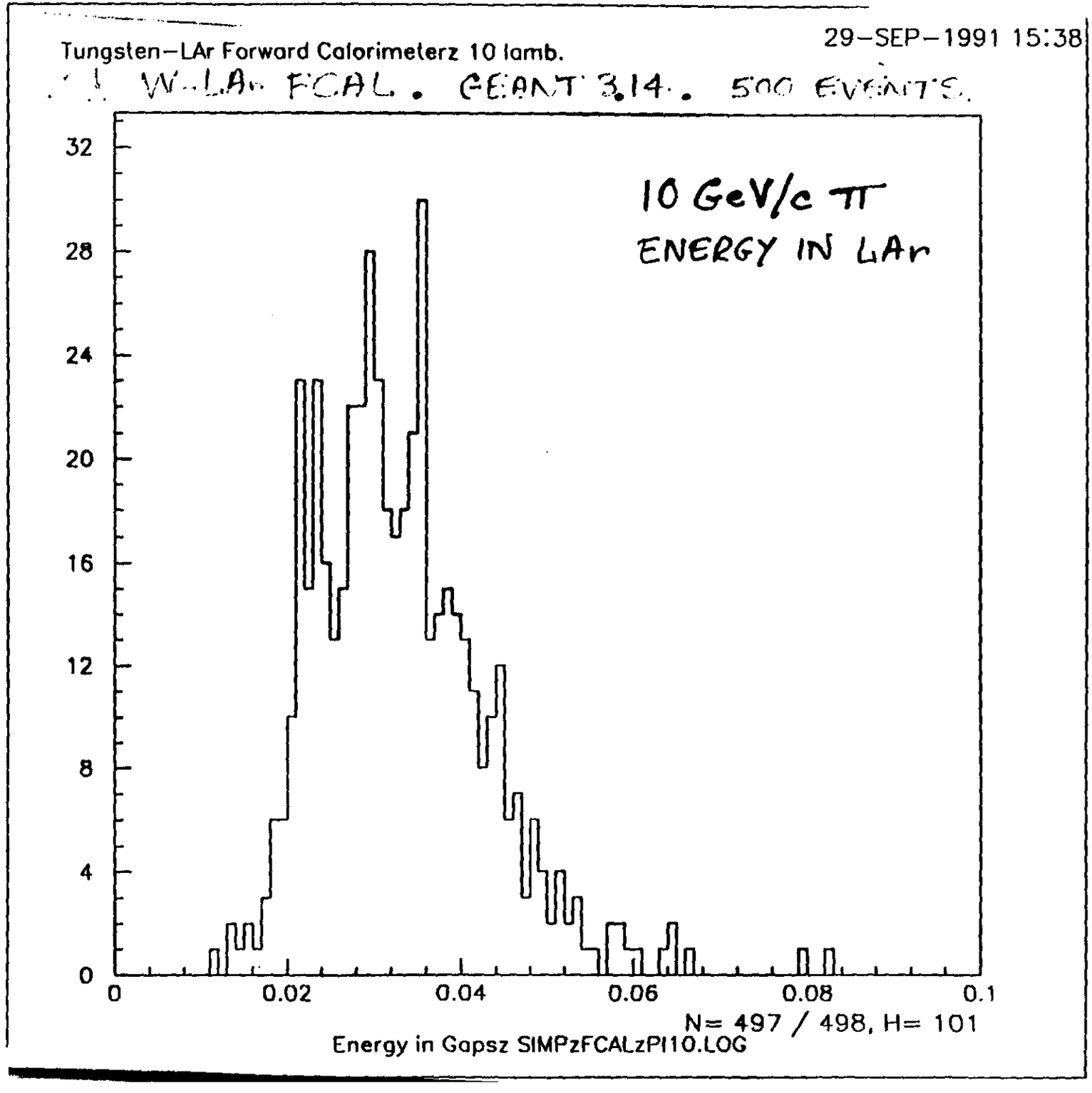


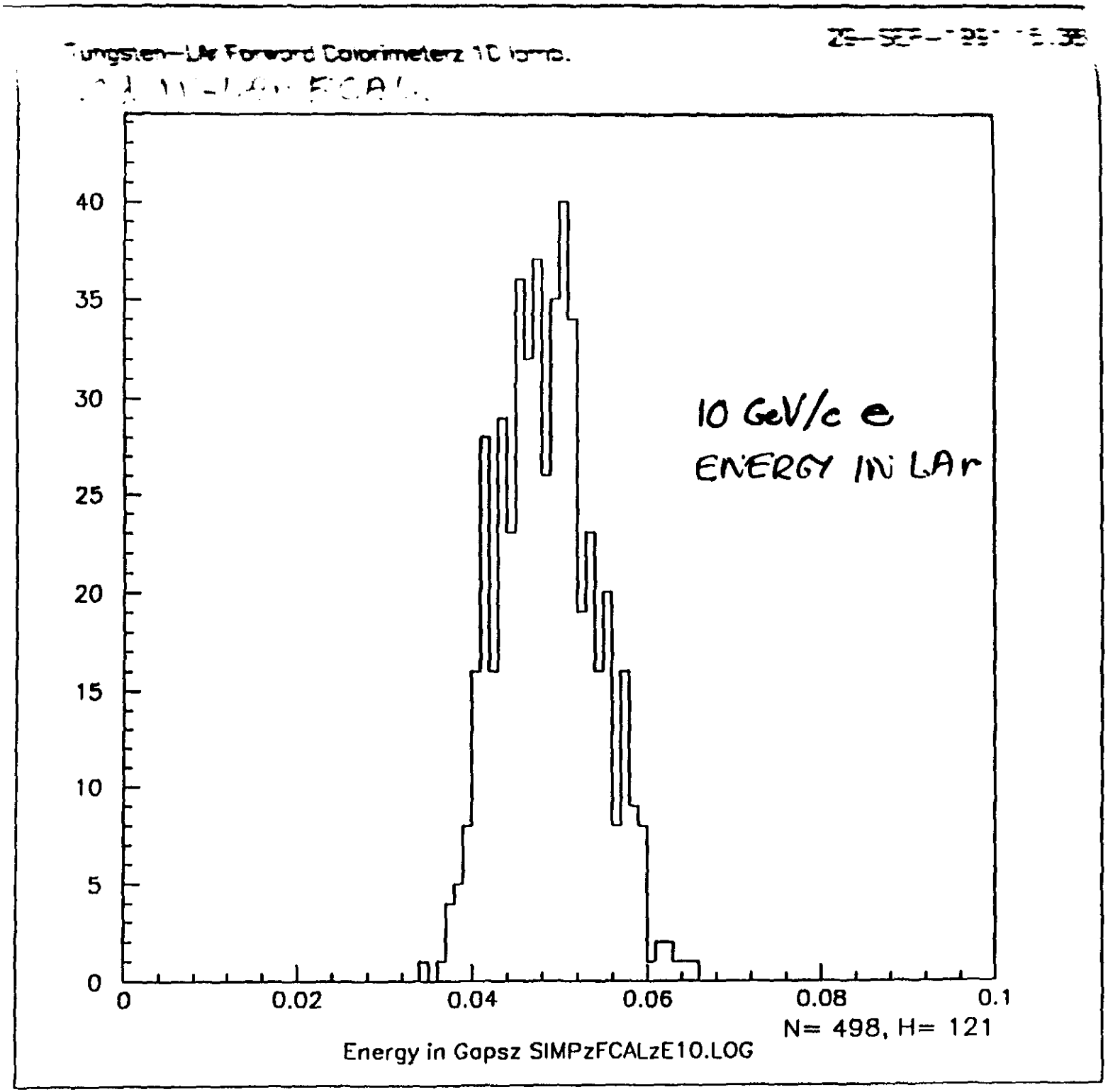
N= 16 / 6560, H= 503

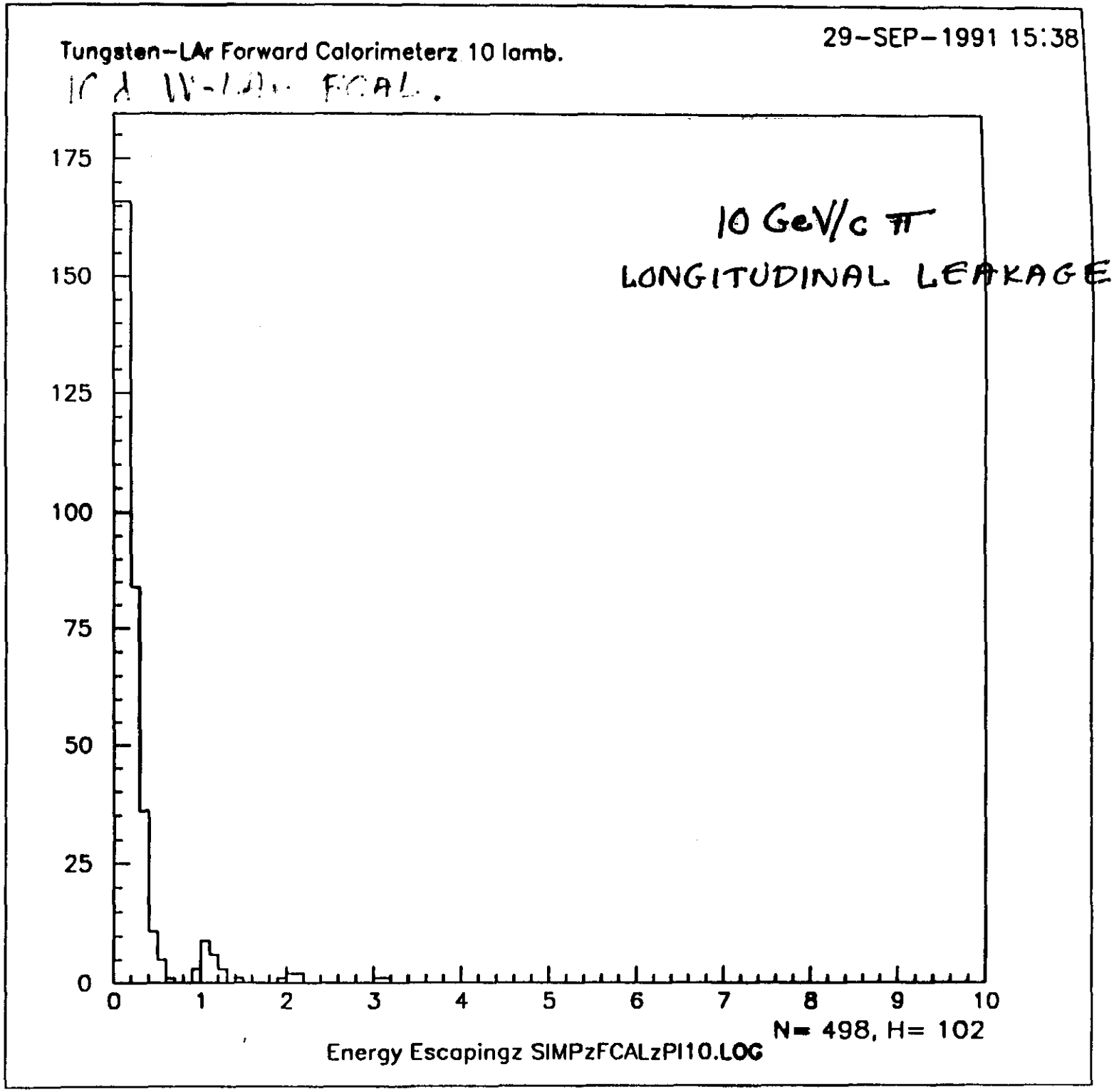
Energy Transverse Profile at each Depth


10 GeV ELECTRONS – Tungsten LAr Forward Calorimet
30-SEP-1991 11:15
10 GeV e
LONGITUDINAL
DISTRIBUTION
OF EM ENERGY
10
8
6
4
2
0
10
20
30
40
50
60
70
80
N= 24 / 82, H= 10
FIRST GAP
E/M Energy VS. Gaps


10 GeV ELECTRONS – Tungsten LAr Forward Calorimet
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0
LAST GAP
75
50
25
FIRST GAP
10 GeV e
−8
−4
0
4
8
cm
e
N= 24 / 6560, H= 503
Energy Transverse Profile at each Depth


Tungsten–LAr Forward Calorimeterz 10 lamb.
29–SEP–1991 15:38
W-LAr FCAL. GEANT 3.14. 500 EVENTS.
10 GeV/c π
ENERGY IN LAr
32
28
24
20
16
12
8
4
0
0
0.02
0.04
0.06
0.08
0.1
N= 497 / 498, H= 101
Energy in Gapsz SIMPzFCALzPI10.LOG

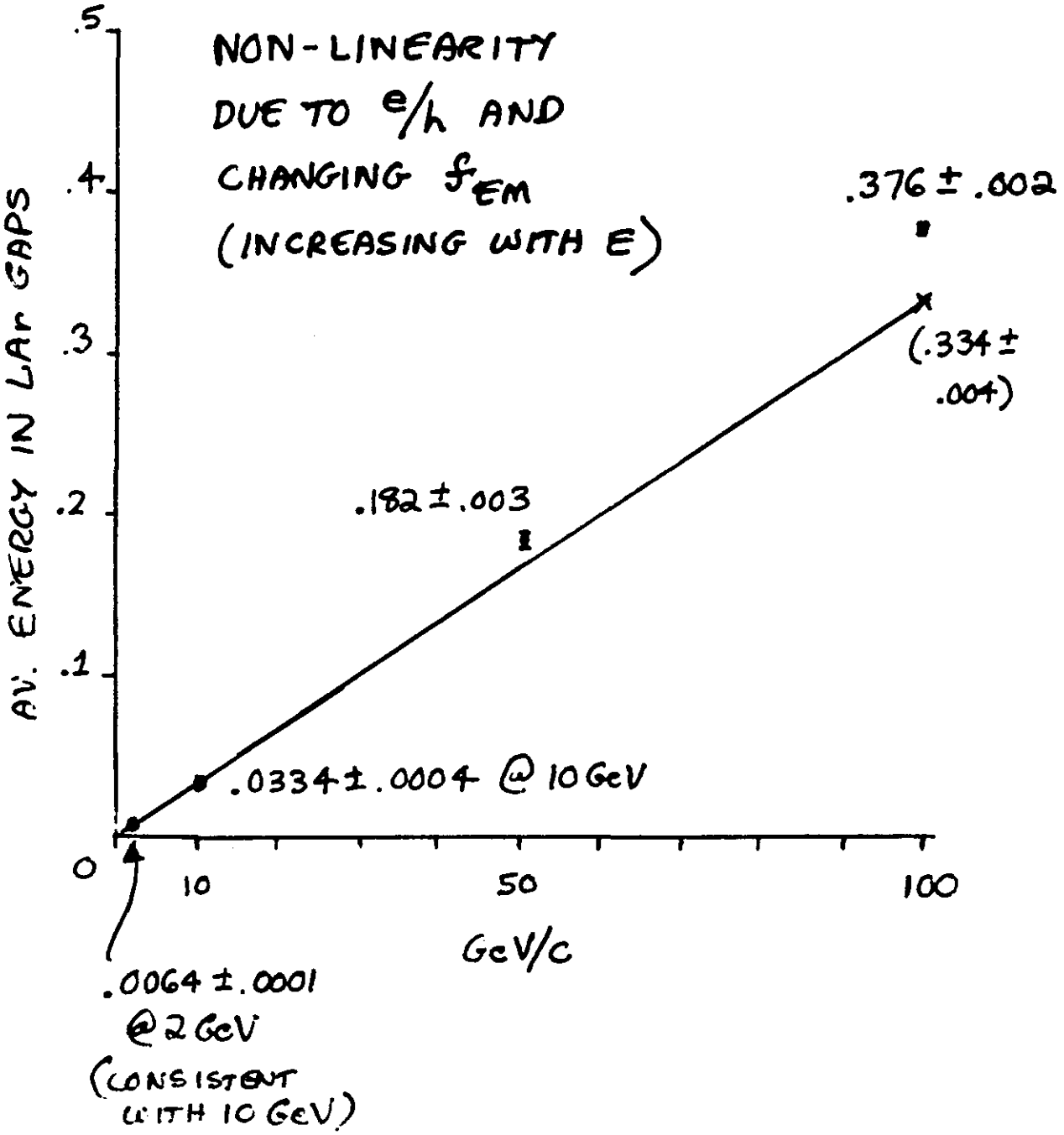

Tungsten–LAr Forward Calorimeterz 10 ions.
10 GeV/c e
ENERGY IN LAr
40
35
30
25
20
15
10
5
0
0
0.02
0.04
0.06
0.08
0.1
N= 498, H= 121
Energy in Gapsz SIMPzFCALzE10.LOG


Tungsten-LAr Forward Calorimeterz 10 lamb.
29-SEP-1991 15:38
10 GeV/c π
LONGITUDINAL LEAKAGE
175
150
125
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
N= 498, H= 102
Energy Escapingz SIMPzFCALzPI10.LOG

SIGNAL AND RESOLUTIONS IN W-LAR FCAL

(MOSTLY 10λ) (500 EVTS)

	SIGNAL (e/π)	RMS WIDTH	1/√E TERM	E ESC.	[illegible]
[illegible]	.0064 ± .0001 (1.47)	.0039	.857 ± .073	.039 ± (.072)	.052
[illegible]	.0094 ± .0001	.0027	.401 ± .013	NEGL.	
[illegible]	.0334 ± .0004 (1.46)	.0113	1.07 ± .03	.233 (.346)	.109
[illegible]	.0487 ± .0002	.0054	.354 ± .011	NEGL.	
[illegible]	.182 ± .003 (1.35)	.026	1.01 ± .11	1.56 (2.37)	.336
(SMALL STARS) [illegible]	.246 ± .001	.016	.450 ± .041	NEGL	
[illegible]	.378 ± .002	.043	1.12 ± .04	4.51 (7.43)	.743
[illegible]	.493 ± .001	.021	.424 ± .019	NEGL	
[illegible]	.379 ± .002	.043	1.14 ± .06	1.60 (1.94)	.194

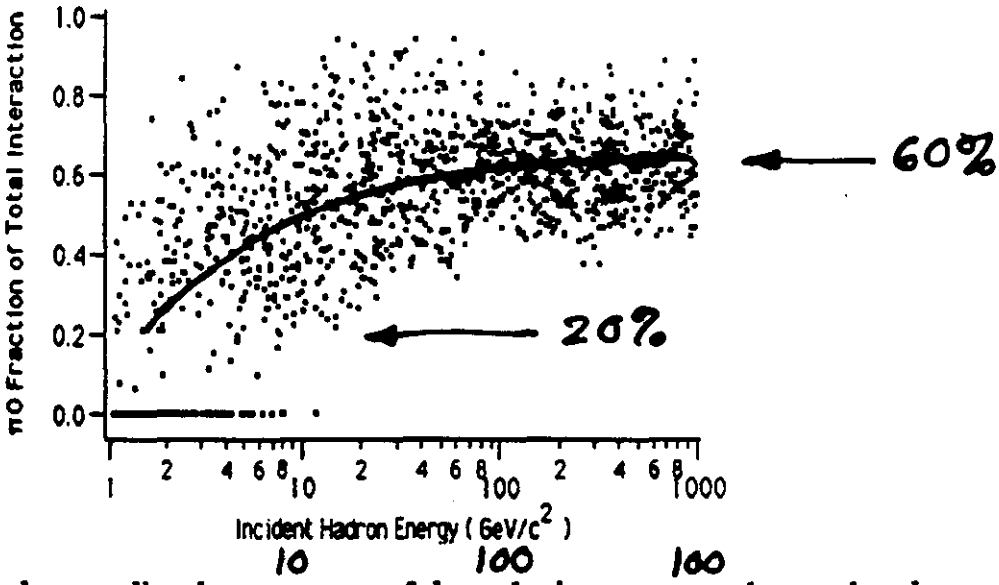

NON-LINEARITY
DUE TO e/h AND
CHANGING f_{EM}
(INCREASING WITH E)
.376 ± .002
(.334 ± .004)
.182 ± .003
.0334 ± .0004 @ 10 GeV
.0064 ± .0001
@ 2 GeV
(CONSISTENT WITH 10 GeV)
AV. ENERGY IN LAr GAPS
GeV/c
0
.1
.2
.3
.4
.5
10
50
100

Calorimeter e/h Effects on Reconstructing High Pt W/Z → Hadrons

G. E. Forden
University of Arizona

The fractional energy deposited by secondary π^0s (as given by GFLASH) :

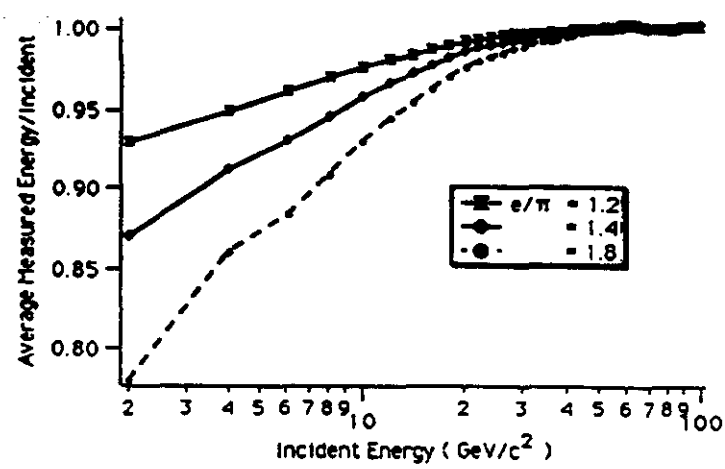
EM FRACTION IN HADRONIC SHOWERS

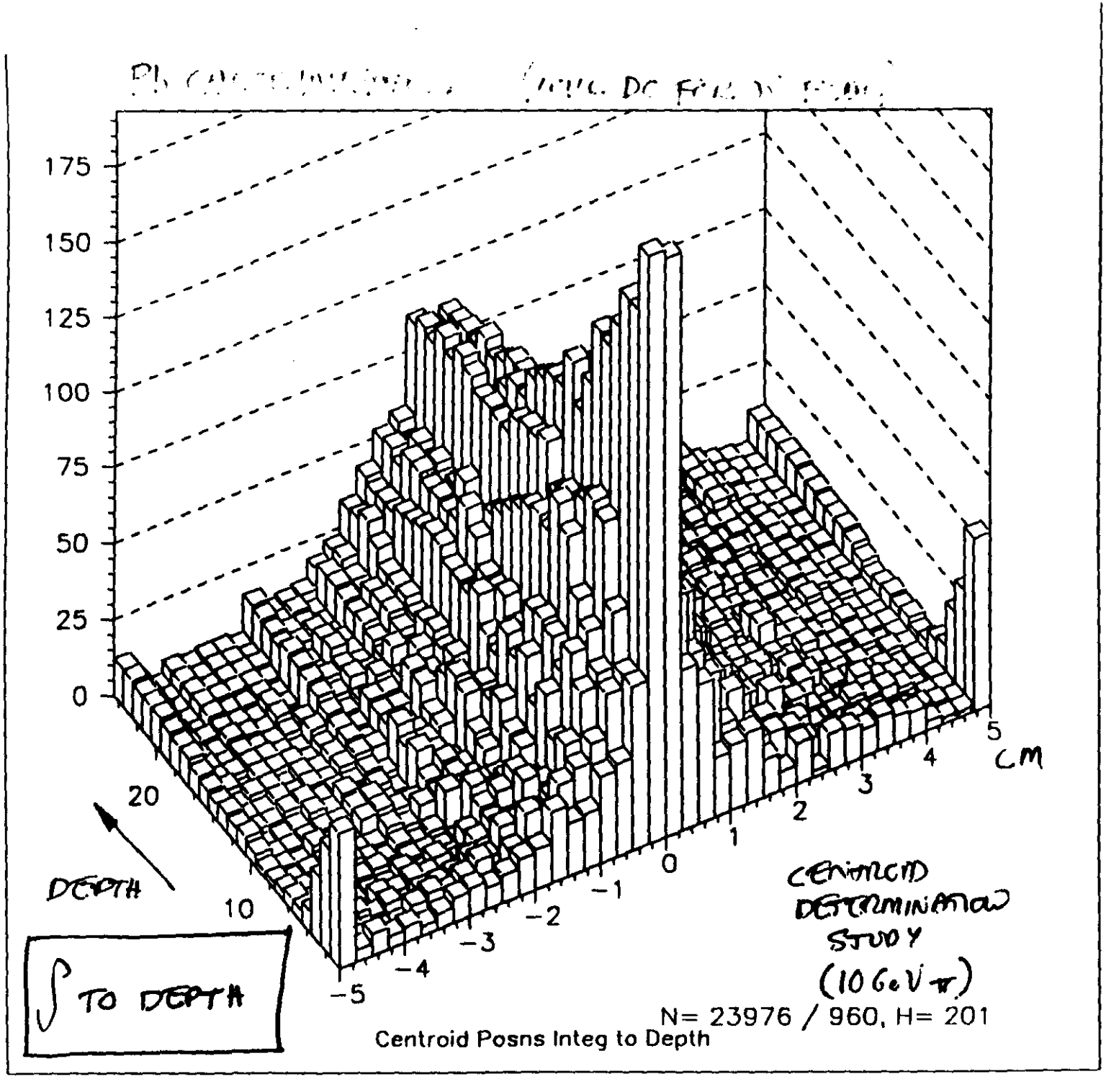


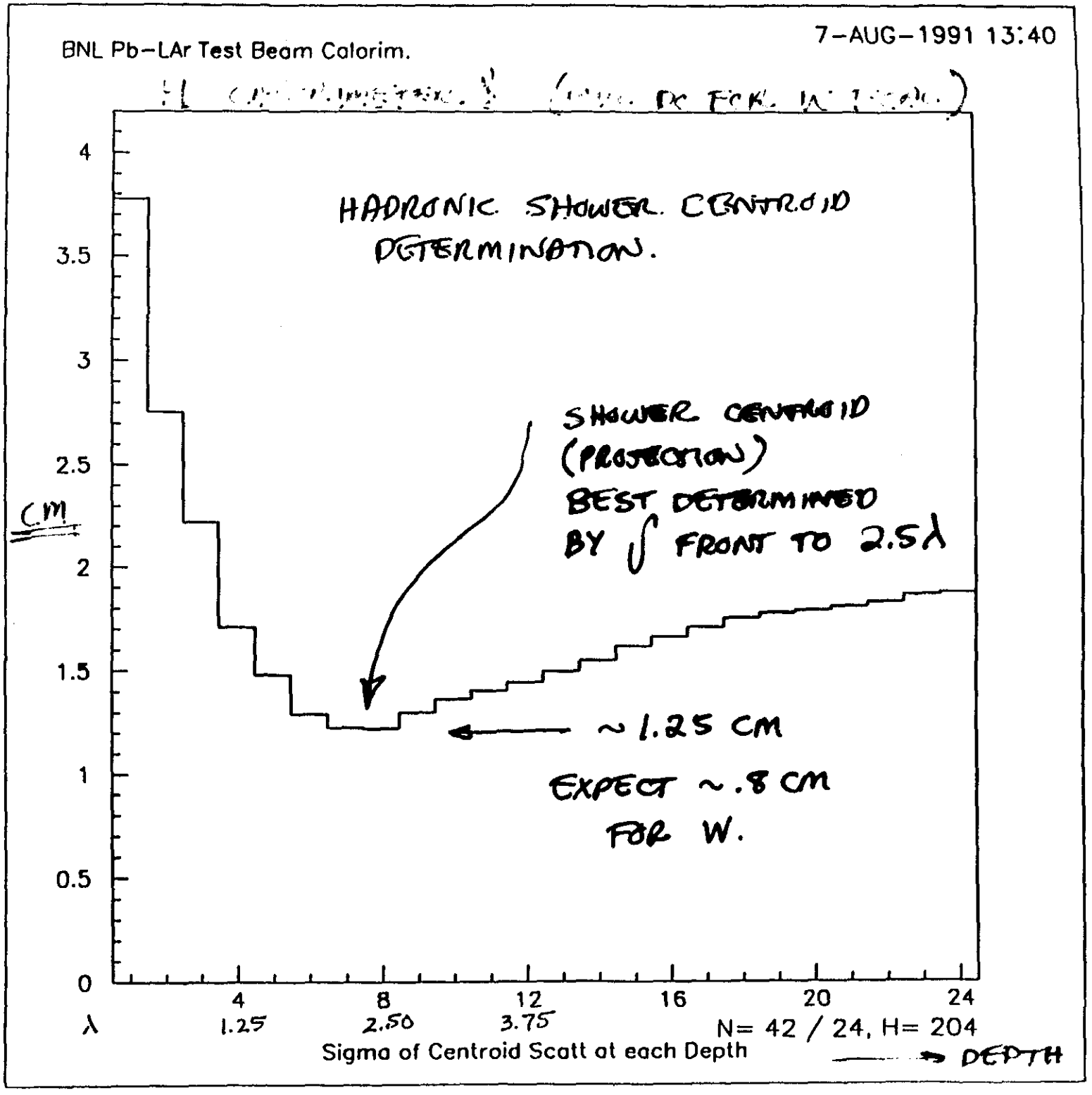
This fraction is used to predict the response of the calorimeter on a shower by shower basis using the relation:

$$E_{obs} = K\left\{f_\pi + \left(1 - f_\pi\right)\left(\frac{e}{h}\right)^{-1}\right\} E_{inc}$$

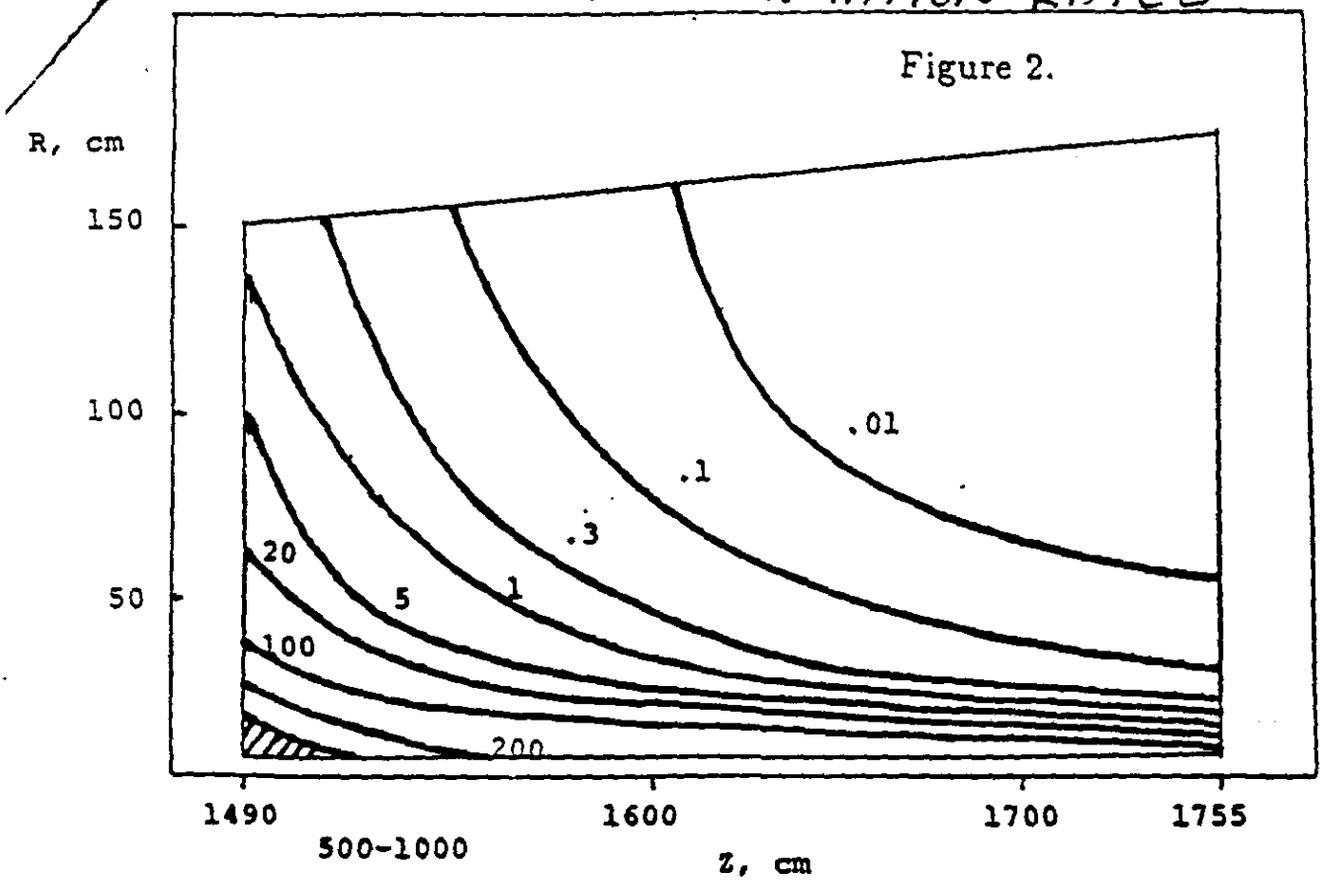
The average response to hadrons given by this model:




175
150
125
100
75
50
25
0
20
10
DEPTH
-5
-4
-3
-2
-1
0
1
2
3
4
5
CM
∫ TO DEPTH
CENTROID
DETERMINATION
STUDY
(10 GeV π)
N= 23976 / 960, H= 201
Centroid Posns Integ to Depth


BNL Pb–LAr Test Beam Calorim.
7–AUG–1991 13:40
HADRONIC SHOWER CENTROID DETERMINATION.
SHOWER CENTROID (PROJECTION) BEST DETERMINED BY ∫ FRONT TO 2.5λ
~1.25 CM
EXPECT ~.8 CM FOR W.
CM
4
3.5
3
2.5
2
1.5
1
0.5
0
λ
4
1.25
8
2.50
12
3.75
16
20
24
N= 42 / 24, H= 204
Sigma of Centroid Scatt at each Depth
DEPTH

IONIZING RADIATION RATES



Forward Calorimeter Dose Rates (Mrad/Year)

MATERIALS

RADIATION RESISTIVITY OF DETECTOR MATERIALS

The following table is meant to be a rough indication of the doses that detector materials can withstand. The first column indicates the service life dose, and the second, the dose to failure. The actual doses will depend on the dose rate, the type of radiation, temperature, mechanical stress, and other parameters.

MATERIAL	SERVICE DOSE (Mrad)	FAILURE DOSE (Mrad)
→ ✓ Connectors	1000	10000
✗ Cables	5	100
→ ✓ Epoxy	500	5000
✗ Foam	50	100
→ ✓ Kapton	1000	10000
✗ Mylar	10	200
✗ Nylon	2	50
✗ Delrin	1	10
✗ Si rubber	5	50
✗ Teflon	0	0.5
✗ Tefzel	1	5
→ ✓ G-10	1000	5000
→ ✓ Ceramics	-	10000
✓ Standard Electronics	.01-1.	

TO COMPLETE SOON

1. $\not{E}_T$ AND JET RESOLUTIONS FROM FULL-GEANT GANGED-CELL SIMULATIONS. (PYTHIA + ISAJET)

2. ADD JETFINDER

3. ADD ELECTRONIC NOISE

4. ADD PILEUP EVENTS.

(SIMULATE TO 500 GeV → 5 TeV RANGE)

LAr-TUNGSTEN FCAL OPTION FOR GEM

SUMMARY

- MANY BASIC DESIGN PARAMETERS TO BE DETERMINED BY INTEGRATION INTO GEM (FCAL SOMEWHAT FLEXIBLE)

- SMALL DETECTOR ⇒ SMALL RAW MATERIAL COSTS AND CHANNEL COUNTS

- EXPECT RAD. HARDNESS OF LAr. CARE TAKEN WITH ANY OTHER MATERIALS NEAR BEAMPIPE.

- (+) ION MOBILITY MEASUREMENT CRITICAL FOR HIGHEST η

- R+D EFFORT COMBINABLE WITH OTHER FCAL AND LAr WORK.

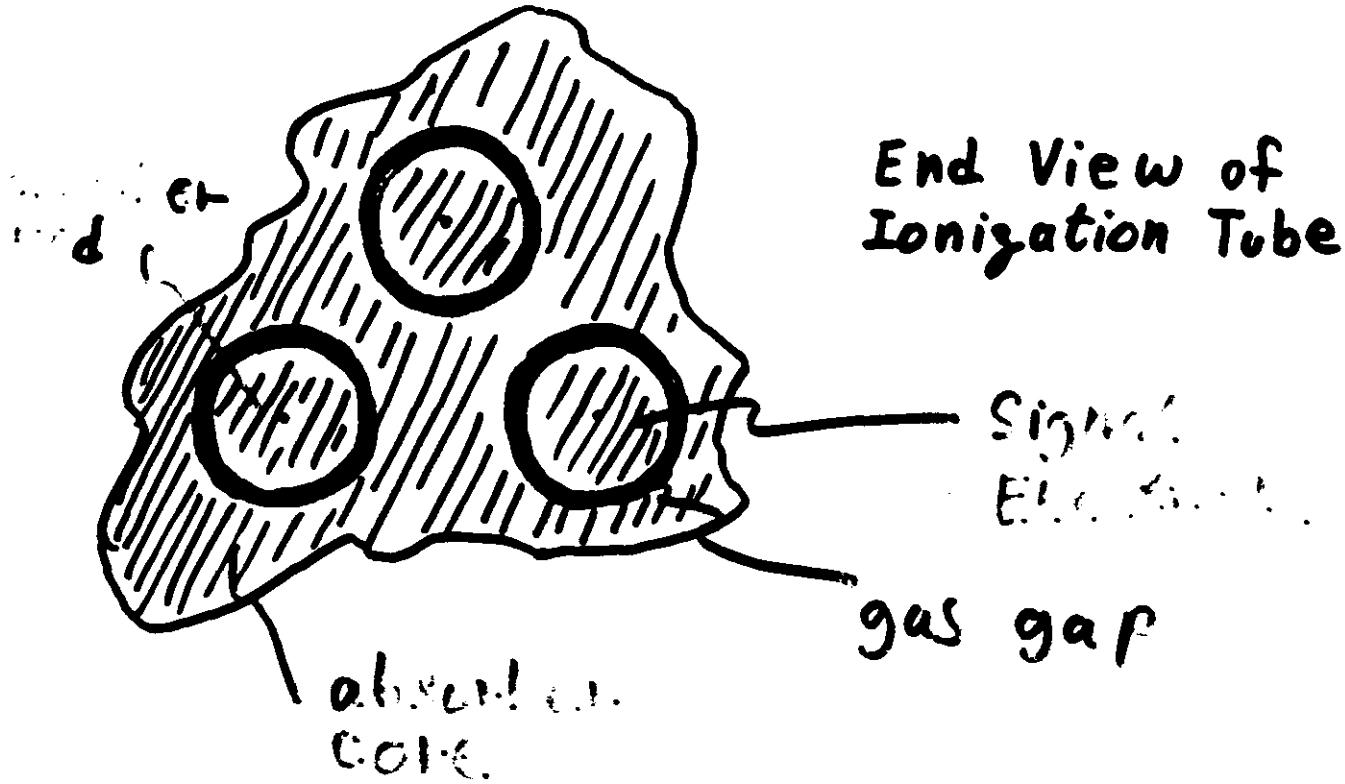
D. Makowiecki

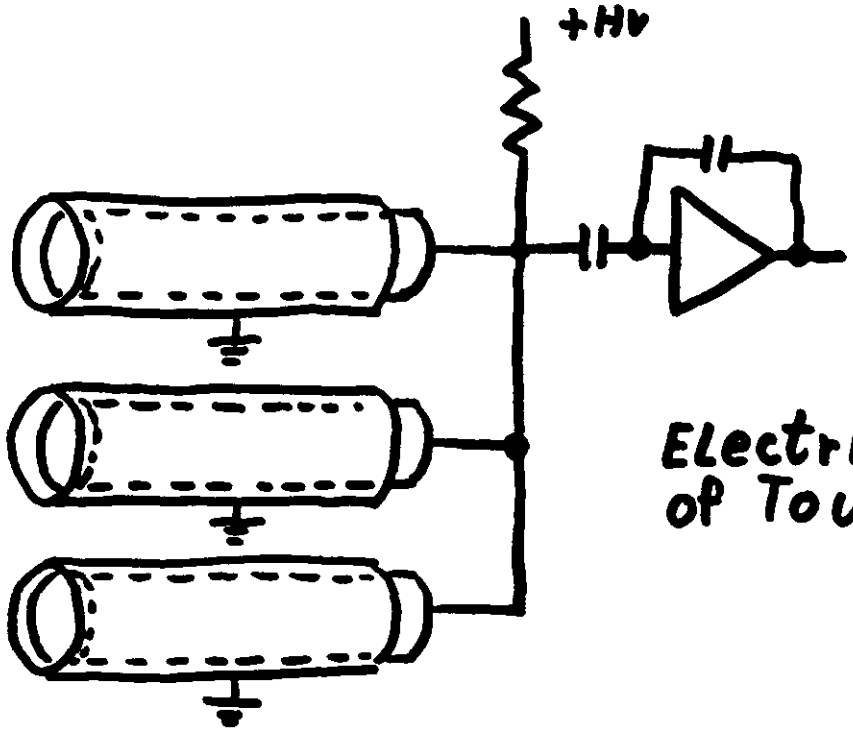
E. Kistenev
S. Rescia
D. Makowiecki

HIGH PRESSURE GASEOUS IONIZATION TUBES

ADVANTAGES:

- ABILITY TO HANDLE HIGH RATES
- DRIFT TIME FASTER THAN IN LIQUIDS
- SPACE CHARGE EFFECT REDUCED
- UNIFORMITY
- EASE OF CALIBRATION
- RADIATION HARD





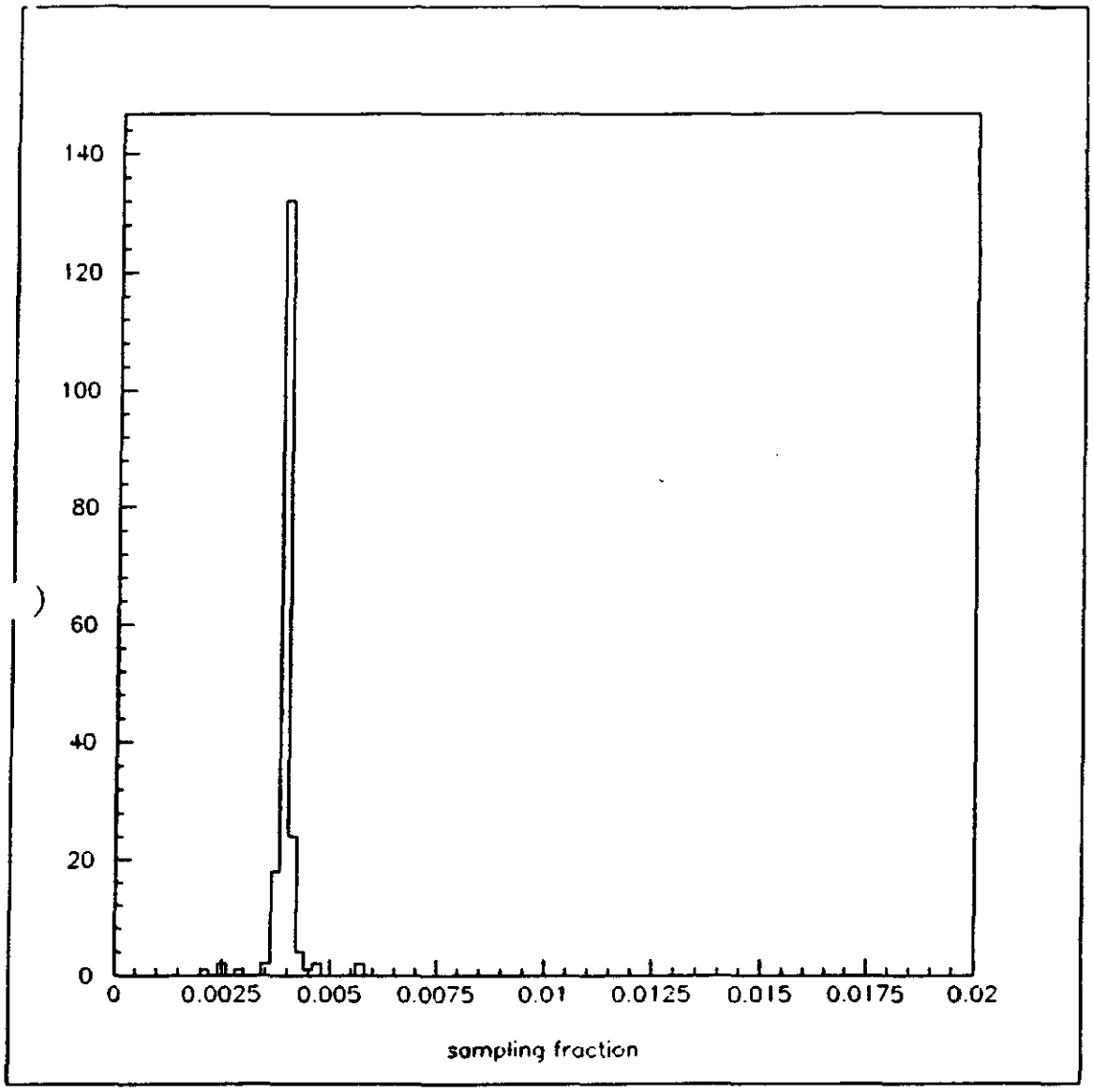
Electrical Schematic
of Towers

absorber core: Pb, W

absorber rod: Pb, W, DU

The sampling fraction for a tube calorimeter computed along the random path perpendicular to the tube axis is equal to _

• ext t. diam [mm]	10	10	20	20	10	10
• gap [mm]	1	2	1	2	1	2
• p [atm]	50					
• absorber	Pb	Pb	Pb	Pb	W	W
• sensitive Volume [%]	24	44	13	24	24	44
• sampl. frac. [%]	.39	.92	.18	.39	.25	.60


140
120
100
80
60
40
20
0
0
0.0025
0.005
0.0075
0.01
0.0125
0.015
0.0175
0.02
sampling fraction

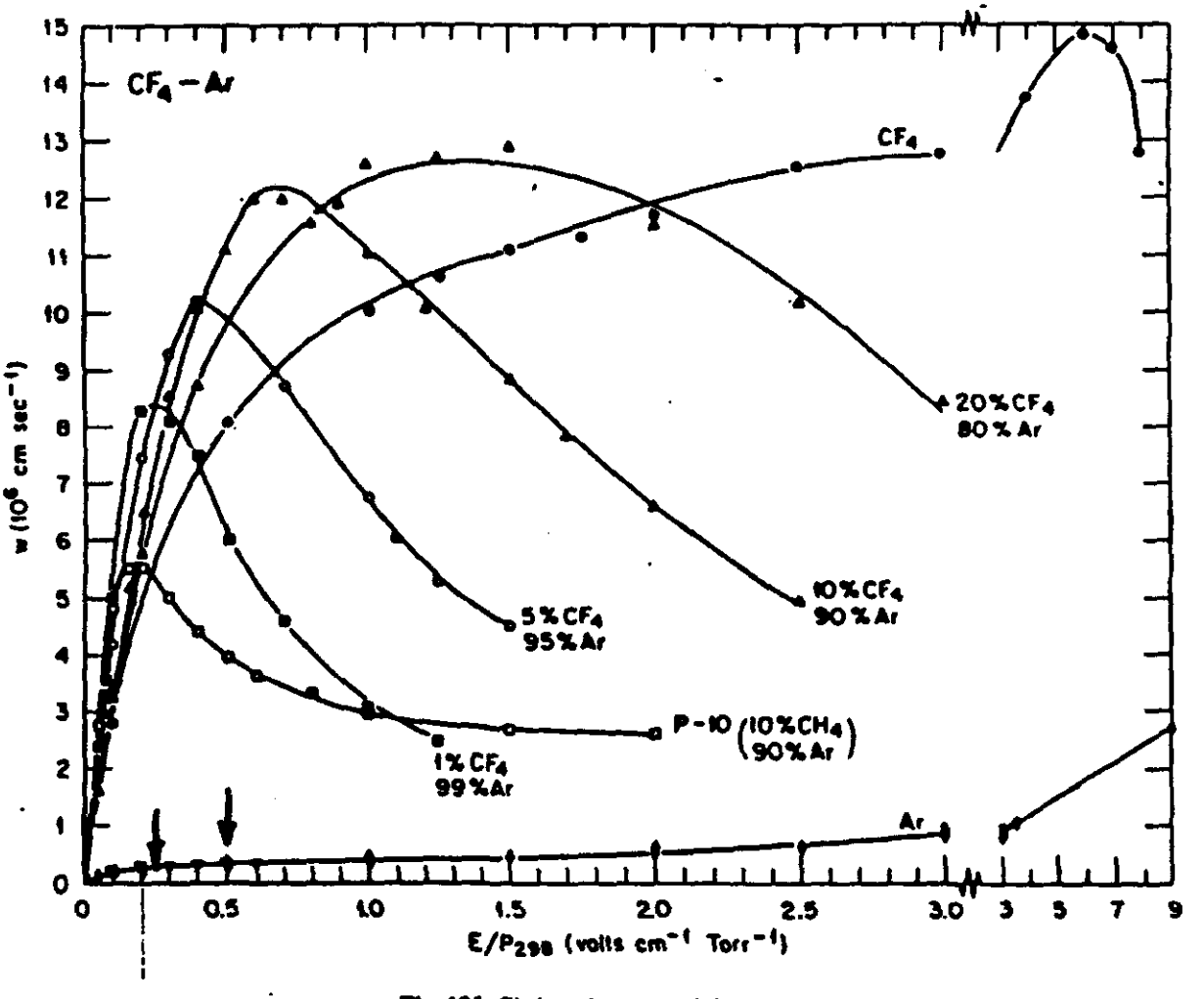
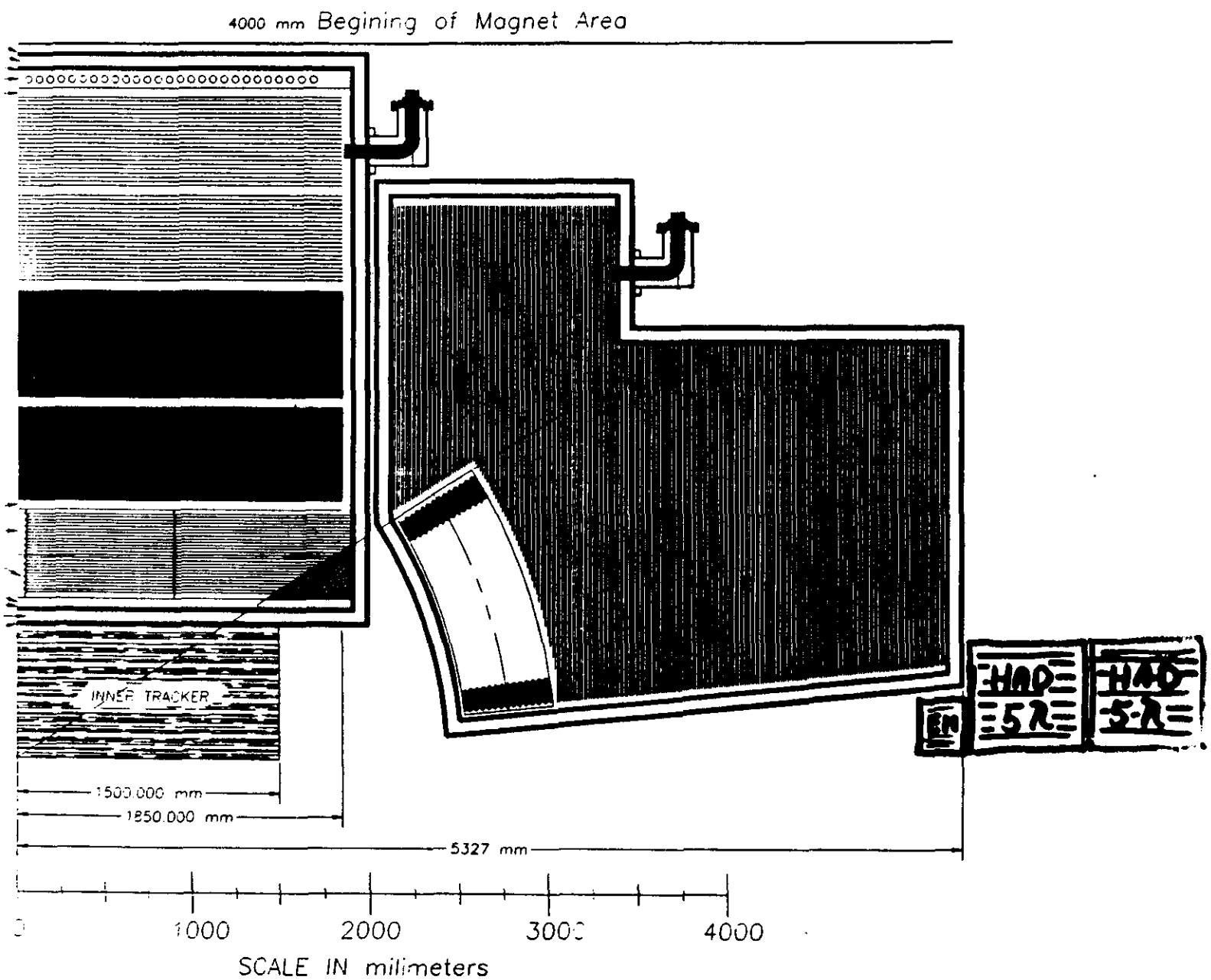


Fig. 125 Christophorou et al. (1979)

→ 19KV/cm @ 50 atm.

→ 9.5KV/cm @ 50 atm.


4000 mm Begining of Magnet Area
INNER TRACKER
1500.000 mm
1850.000 mm
5327 mm
EM
HAD 5λ
HAD 5λ
0
1000
2000
3000
4000
SCALE IN milimeters

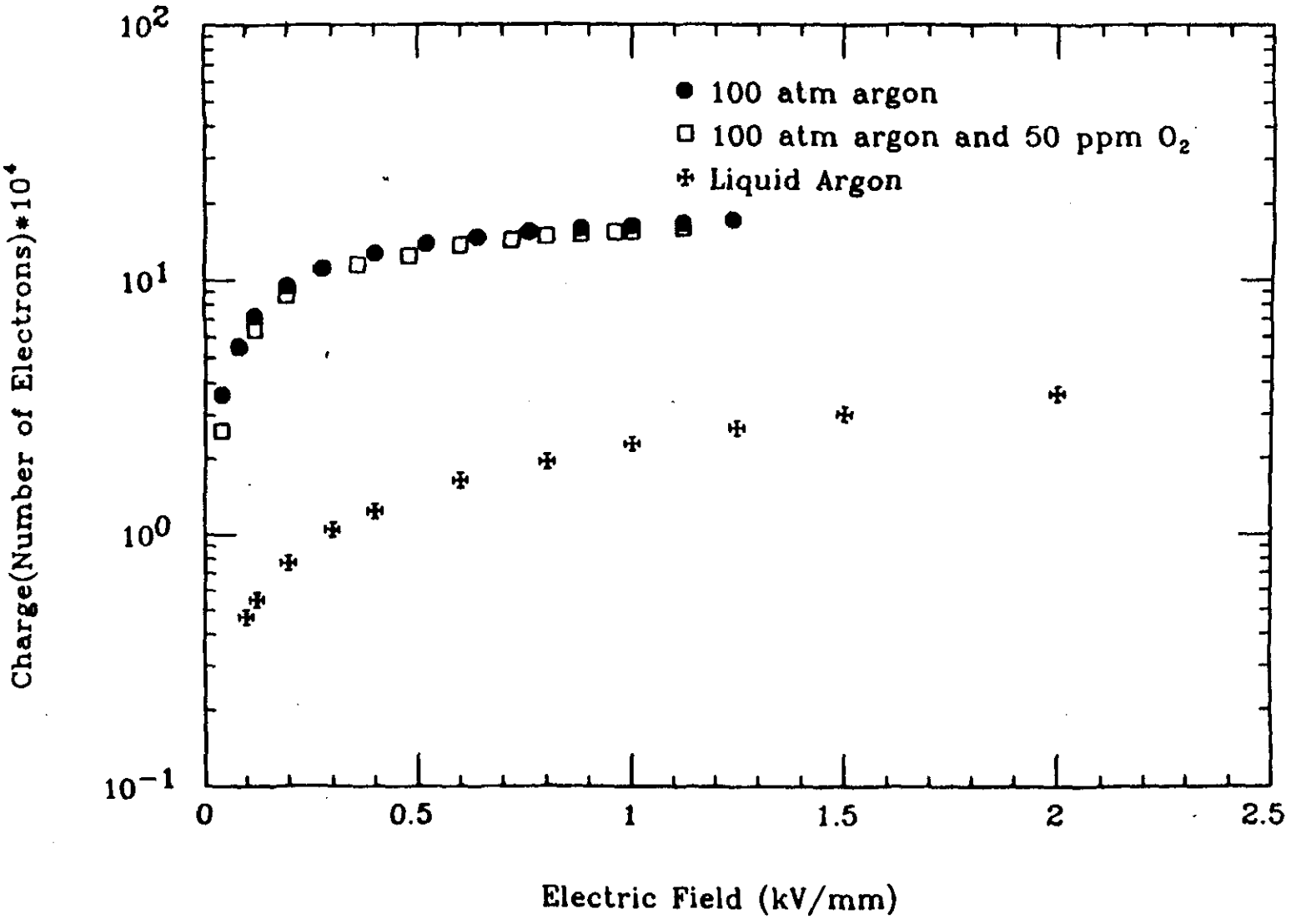

100 atm argon
100 atm argon and 50 ppm O_2
Liquid Argon
Charge(Number of Electrons)*10^4
10^2
10^1
10^0
10^{-1}
0
0.5
1
1.5
2
2.5
Electric Field (kV/mm)

Figure 2

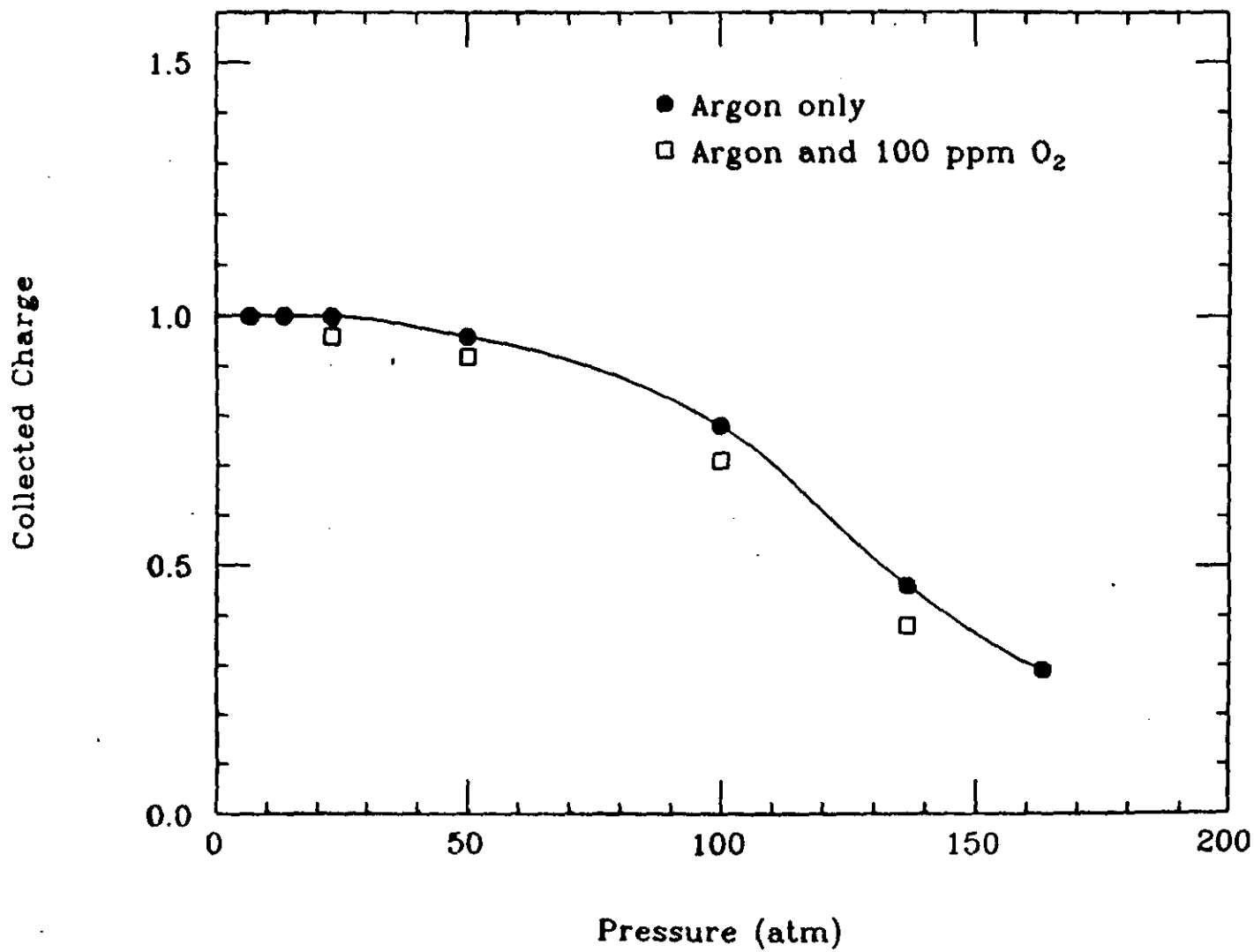
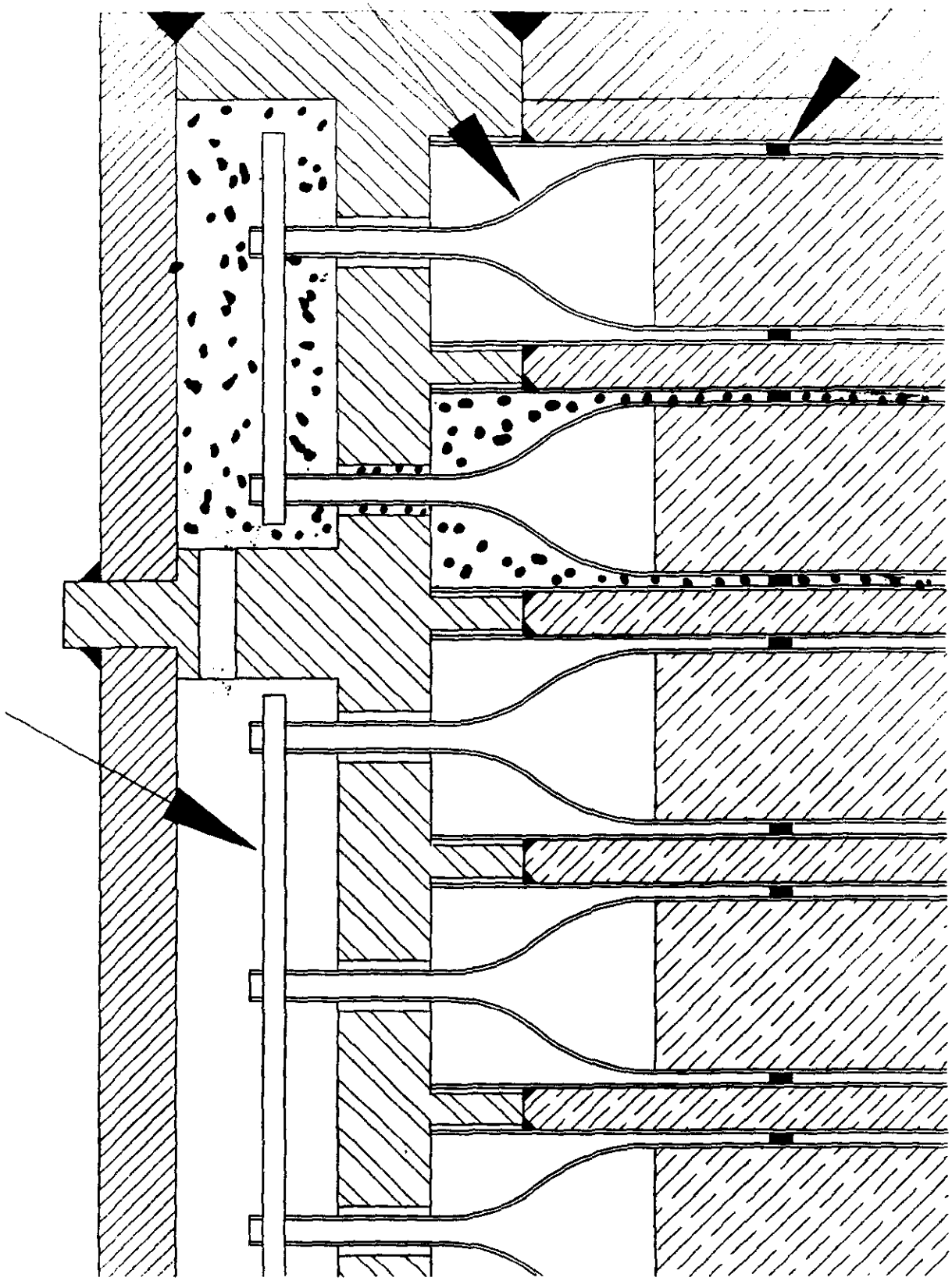
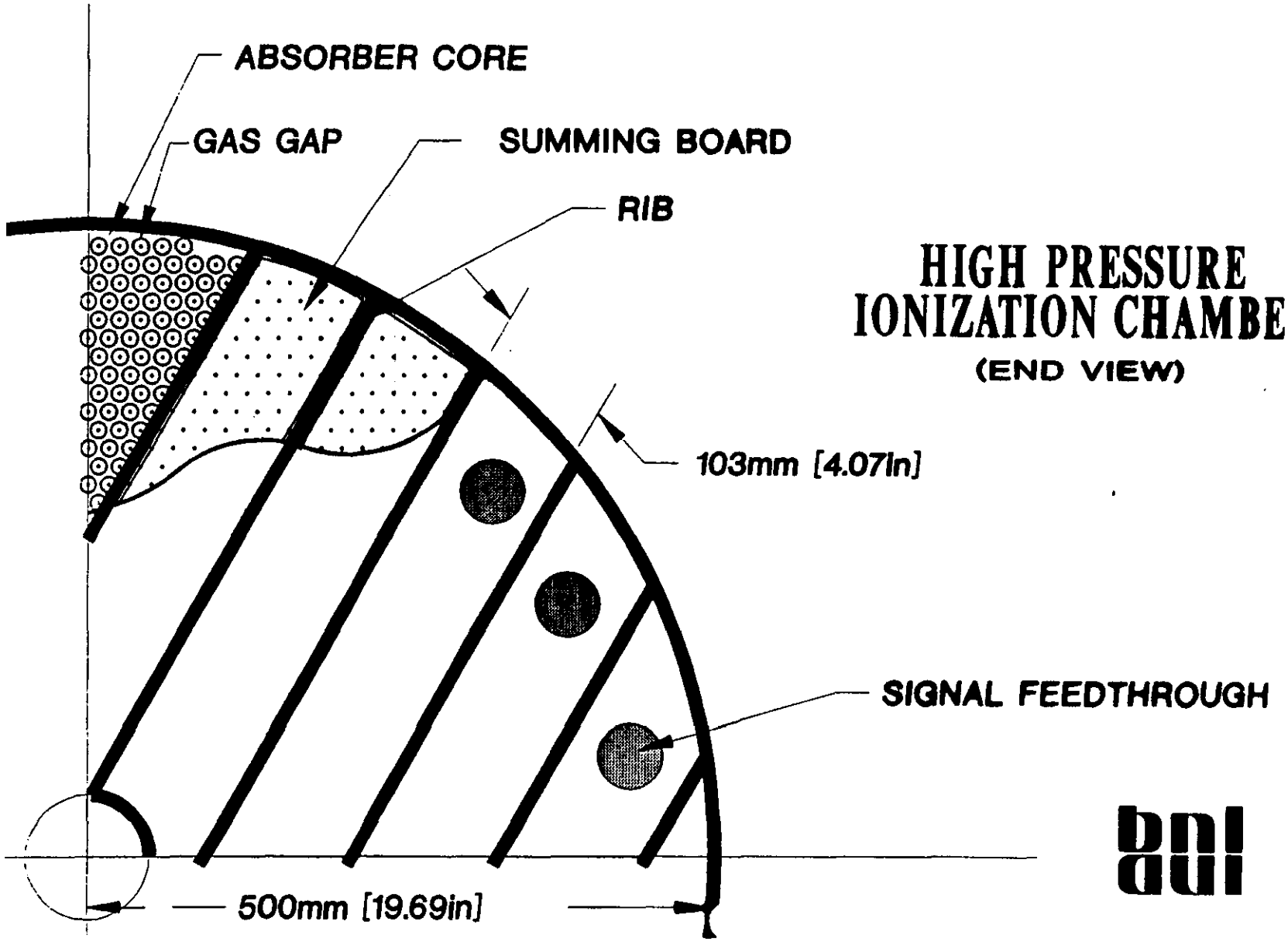

Argon only
Argon and 100 ppm O_2
Collected Charge
1.5
1.0
0.5
0.0
0
50
100
150
200
Pressure (atm)

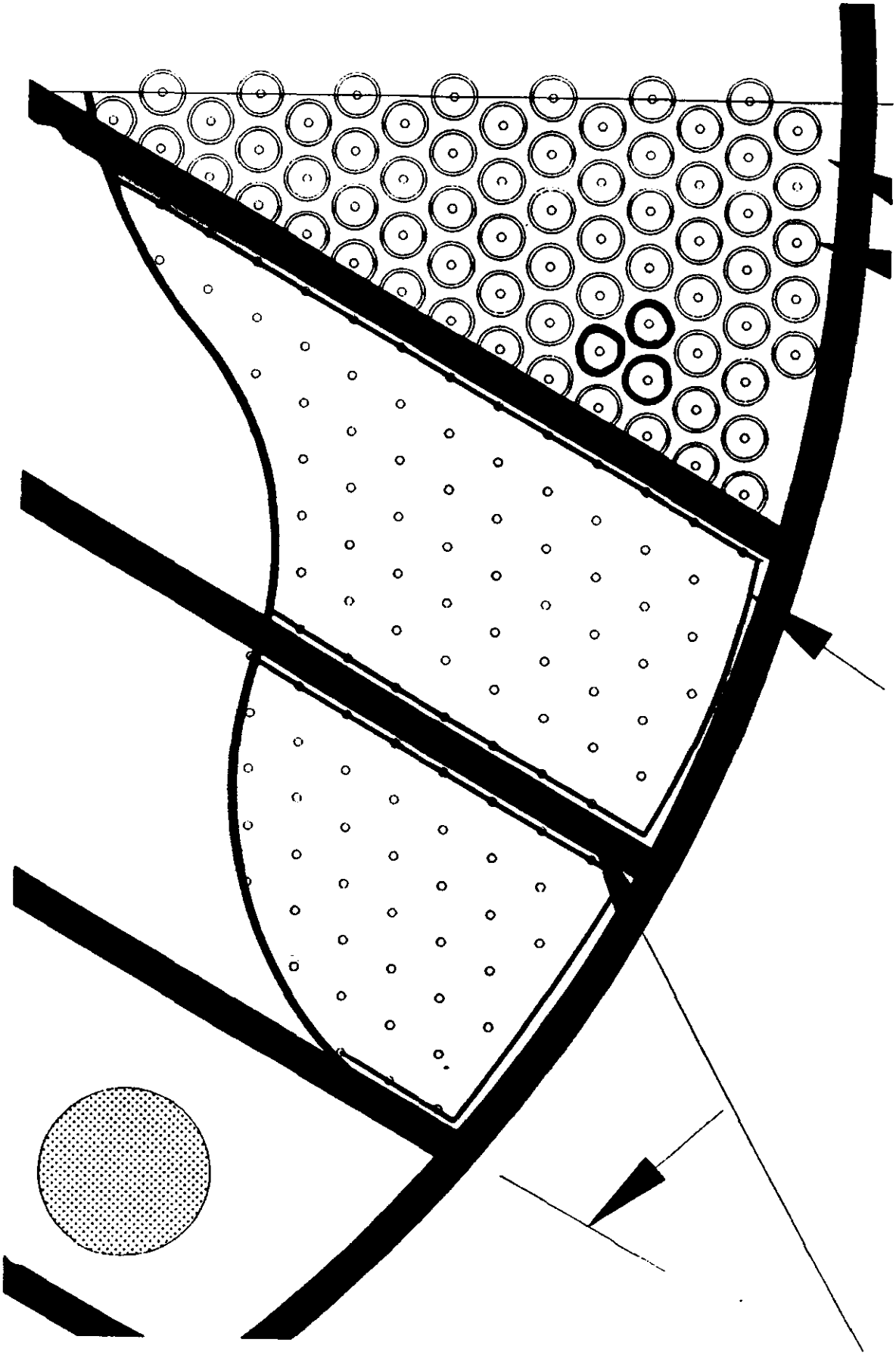
Figure 3

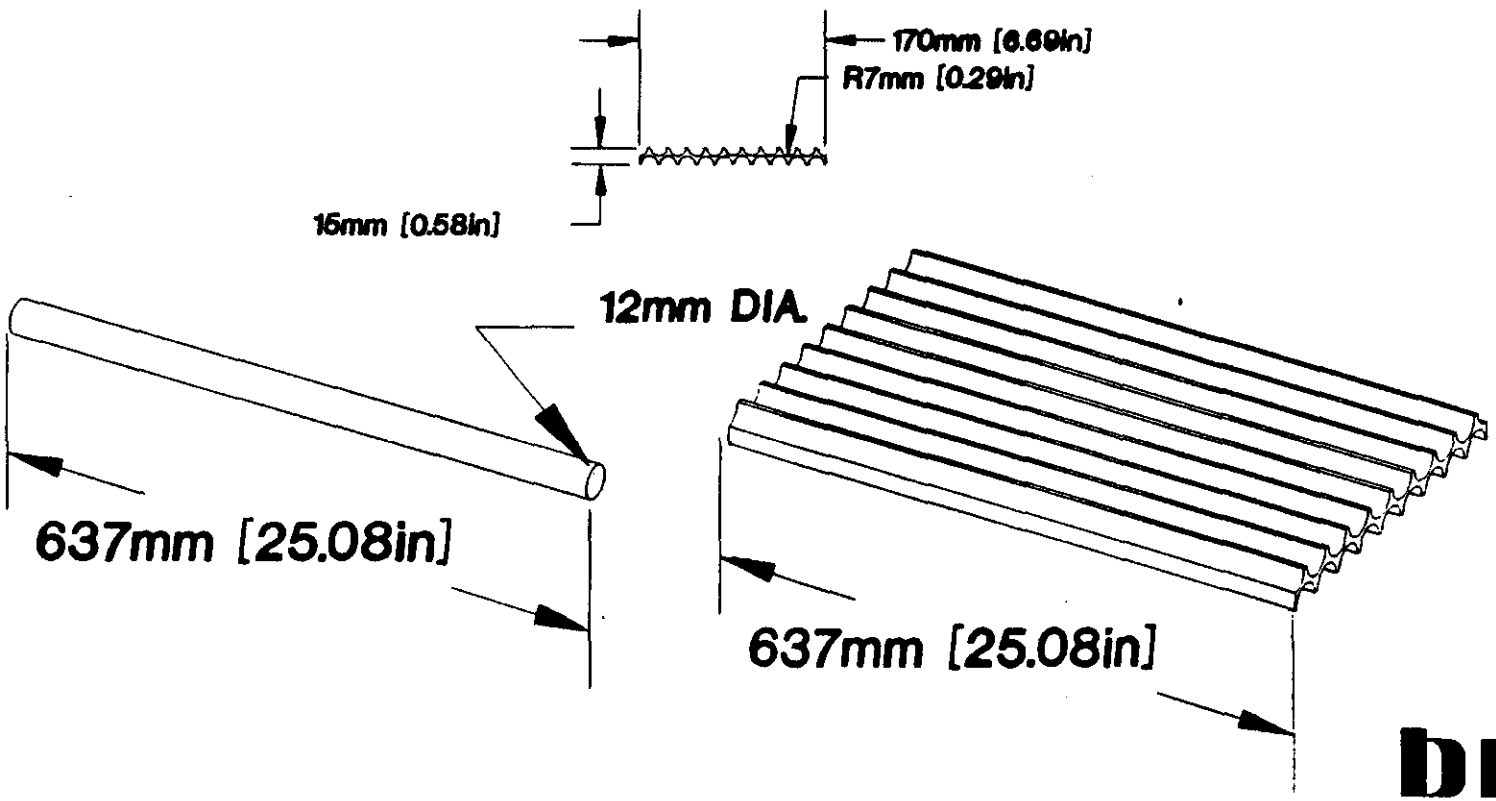




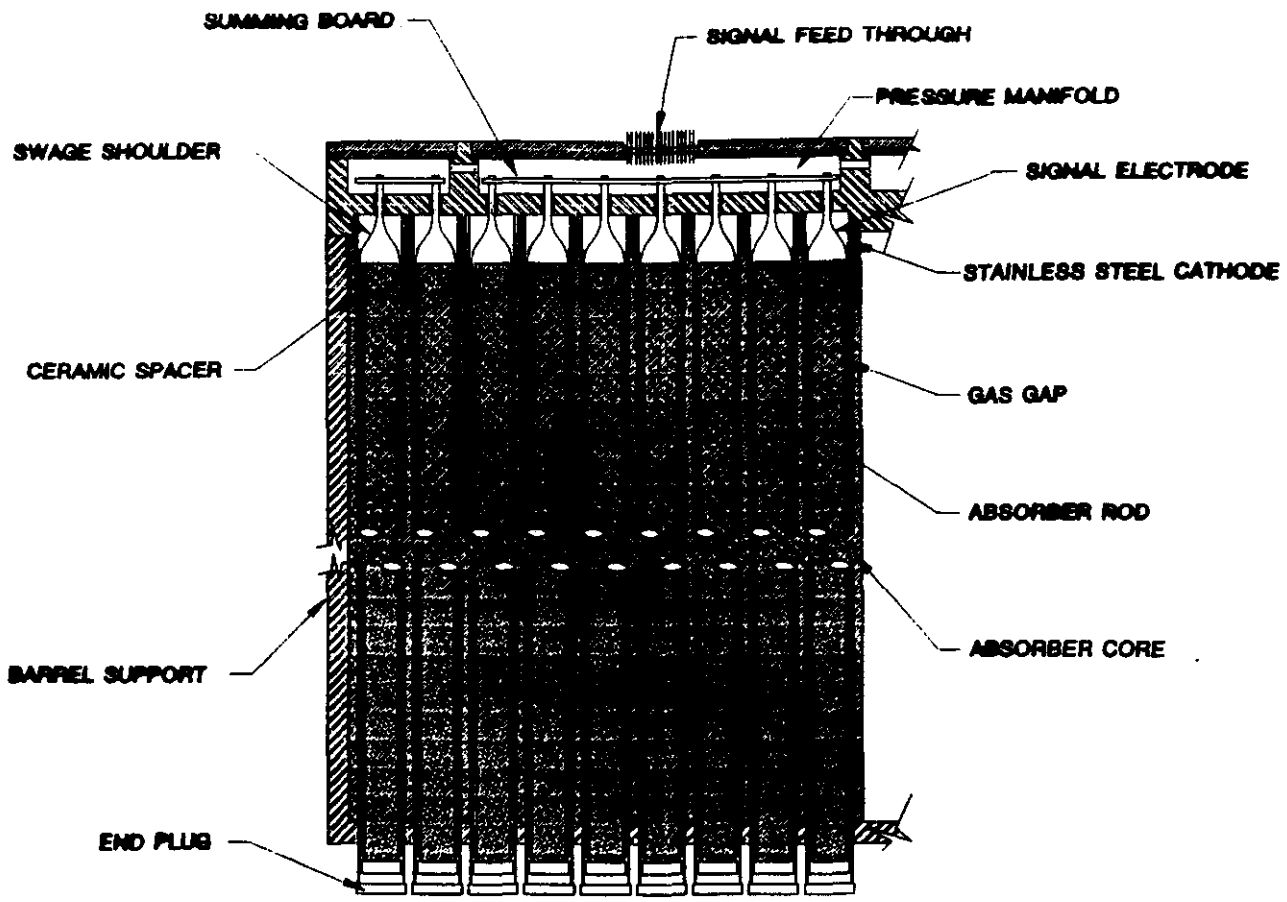
HIGH PRESSURE IONIZATION CHAMBER

(END VIEW)




170mm [6.69in]
R7mm [0.29in]
15mm [0.58in]
12mm DIA.
637mm [25.08in]
637mm [25.08in]

D. Materick



HIGH PRESSURE IONIZATION CHAMBER

(CROSS SECTION)

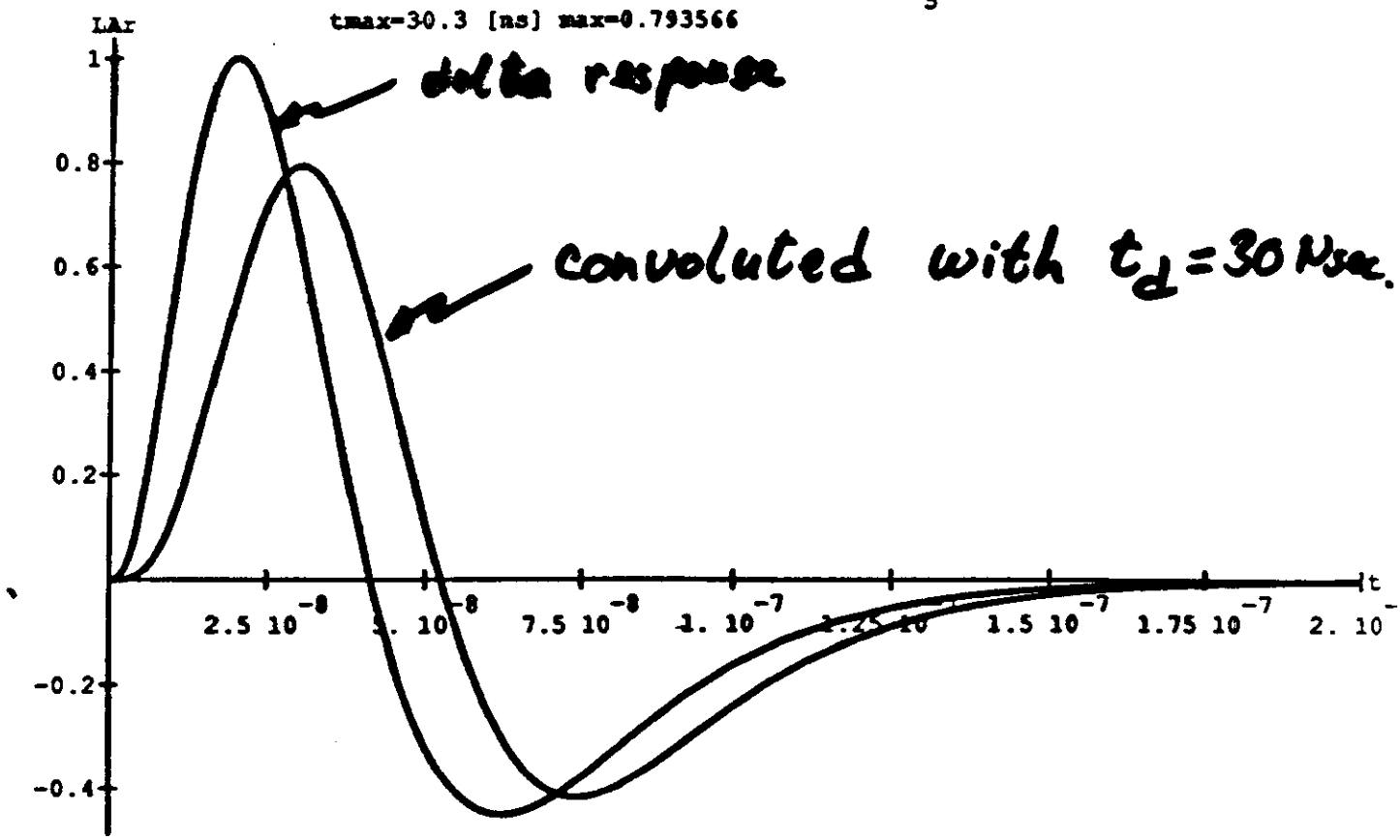
bnl

[redacted] response normalized to unity delta response

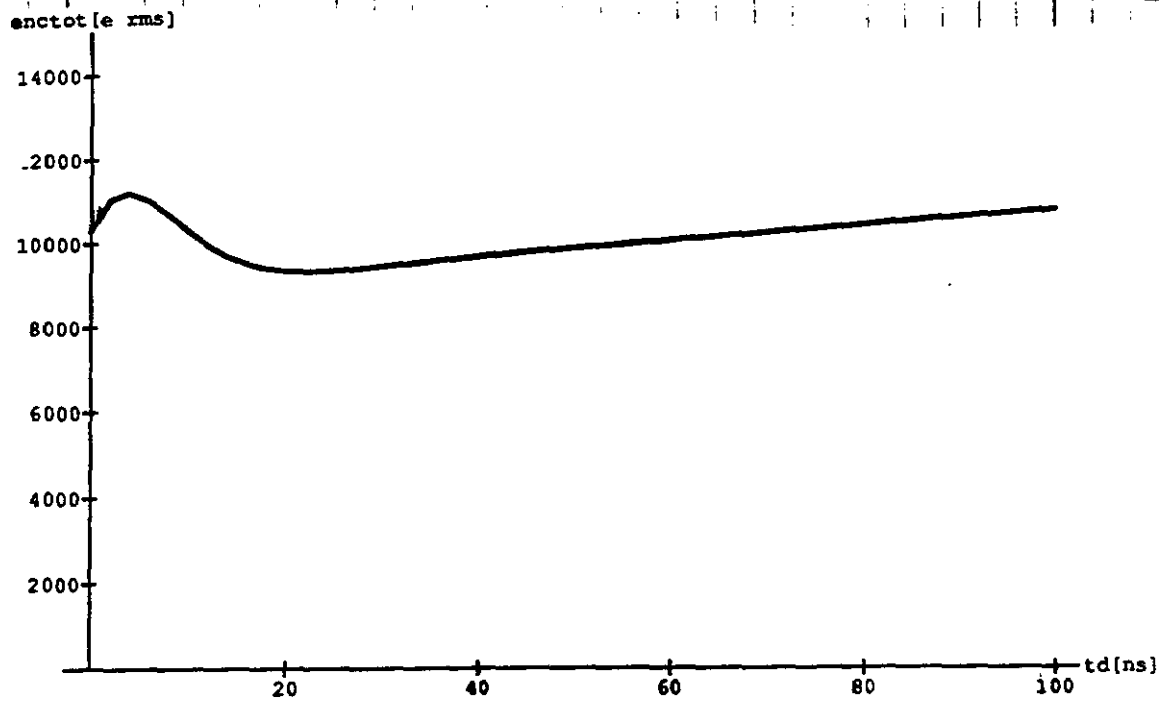
$$\{H[s]=, \frac{7.396\ 10^{-17}\ s^{2}}{(1.+8.6\ 10^{-9}\ s)^{4}\ (1.+2.\ 10^{-8}\ s)}\}$$

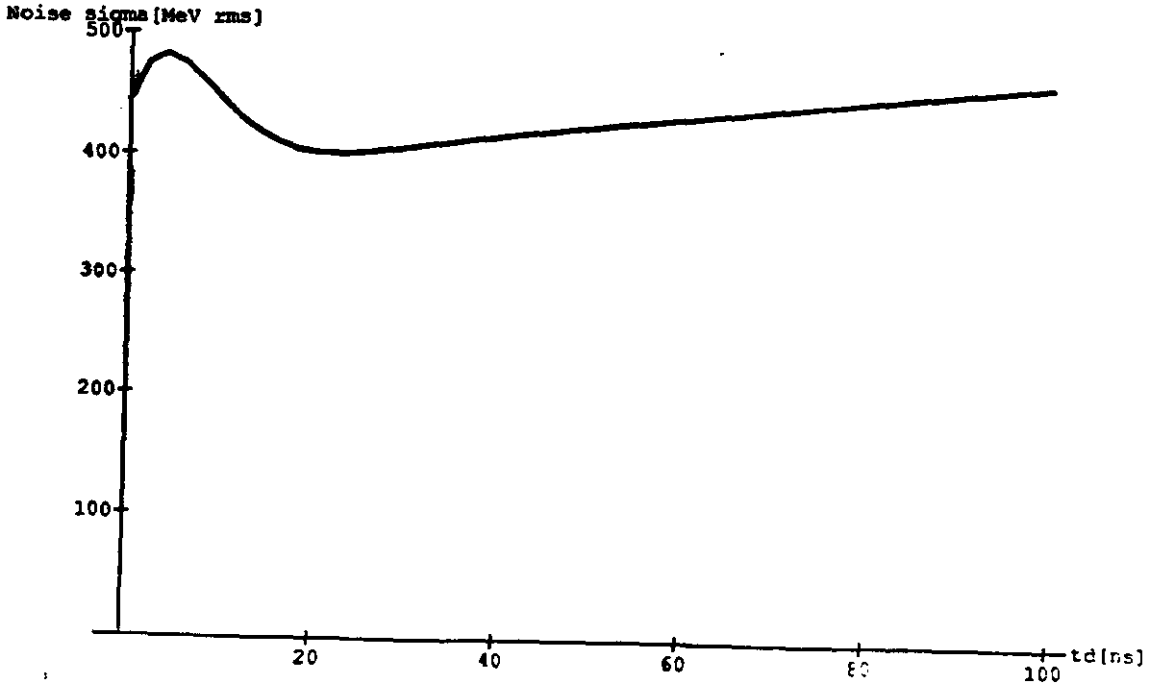
zo=50[ohm] Cd=400[pF] tauw=20[ns] taush=$\frac{43}{5}$[ns] td=30[ns]

tmax=30.3 [ns] max=0.793566



Yu. Kamyshkov


enctot[e rms]
14000
12000
10000
8000
6000
4000
2000
20
40
60
80
100
td[ns]


Noise sigma[MeV rms]
500
400
300
200
100
20
40
60
100
td[ns]

Liquid Scintillator

vs

Spaghetti

vs

Liquid Argon

behind BaF_2

Studies at ORNL, presented by Yu.Kamyshkov

SSCL, October 2, 1991

Tail catcher = coarse sampling part

- Fine sampling part : 20 mm Pb + 5 mm LS

  $\sim 5\,\lambda + 1.8\,\lambda\ (BaF_2)$

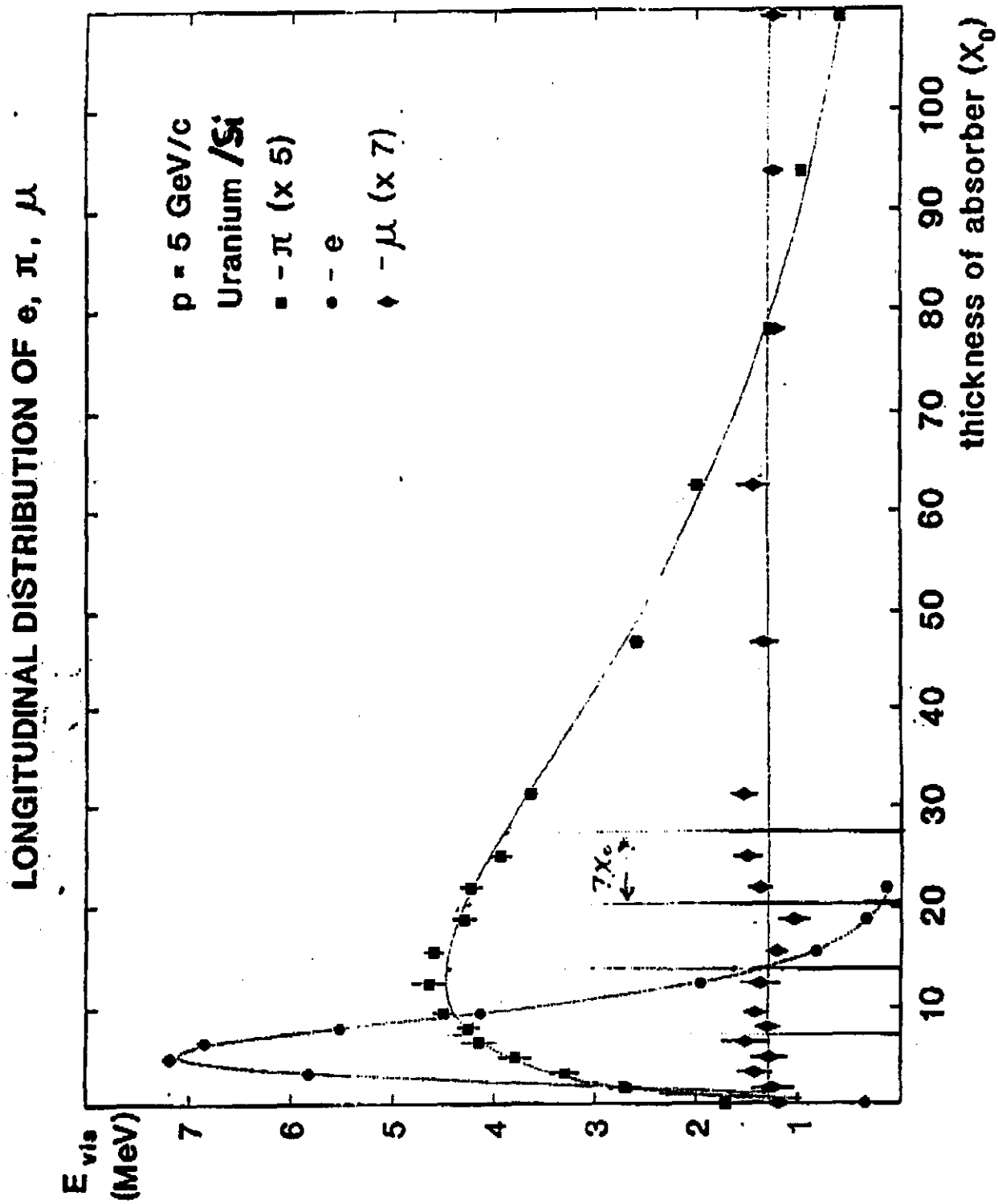
- Coarse sampling part : 40 mm Pb + 5 mm LS

  $\sim 4.5\,\lambda$

- This structure exists in Pb/LS design since November last year. Cost of this structure is estimated (by M.J.R.) in September 20 book. Performance was shown before.

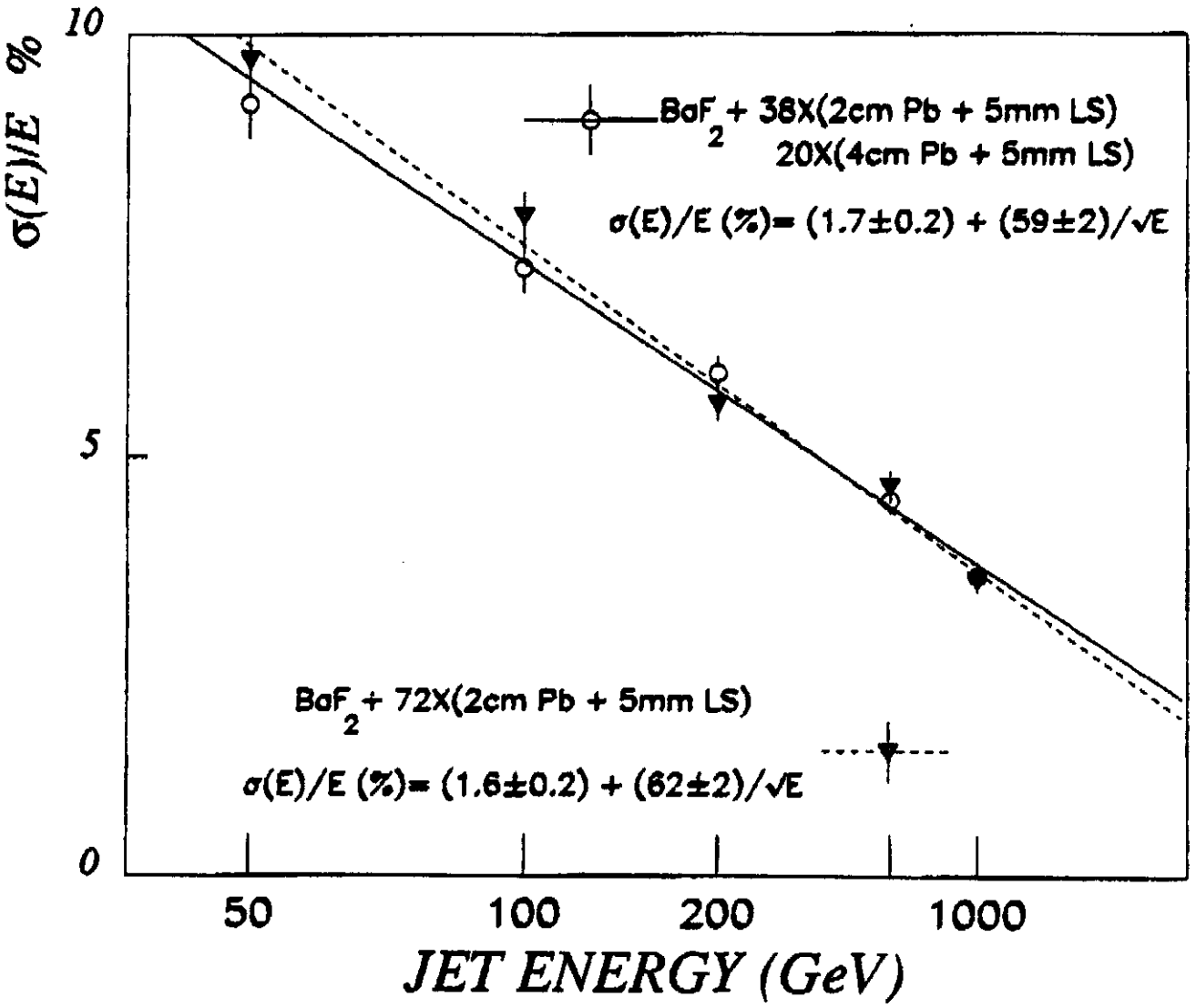
- Tail catcher saves ~ 10 cm of radial space, reduce number of cells and fibers (but not the number of readout channels)

- Combined with overall reduction of absorption thickness down to 10.7λ, all uniform 20 mm thickness is feasible without increase of radial space (outer radius reduces to 3500 mm).
  Number of cells/fibers -> 943 K , trays -> 203 K
  Number of readout channels -> 26 K

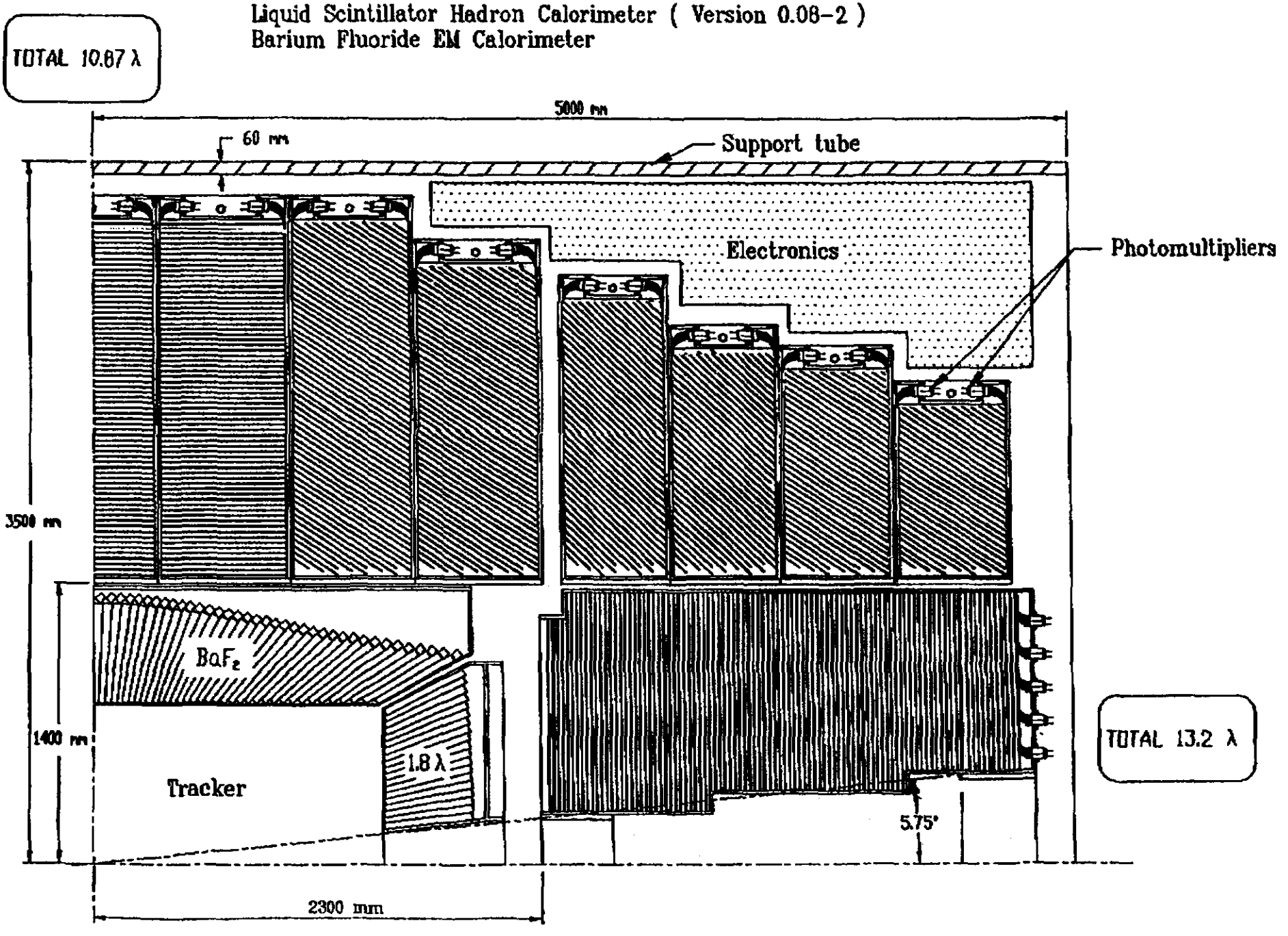

LONGITUDINAL DISTRIBUTION OF e, π, μ
p = 5 GeV/c
Uranium /Si
■ - π (x 5)
● - e
♦ - μ (x 7)
7X₀
E vis (MeV)
1
2
3
4
5
6
7
10
20
30
40
50
60
70
80
90
100
thickness of absorber (X₀)

V. Shoutko
Nov 1990

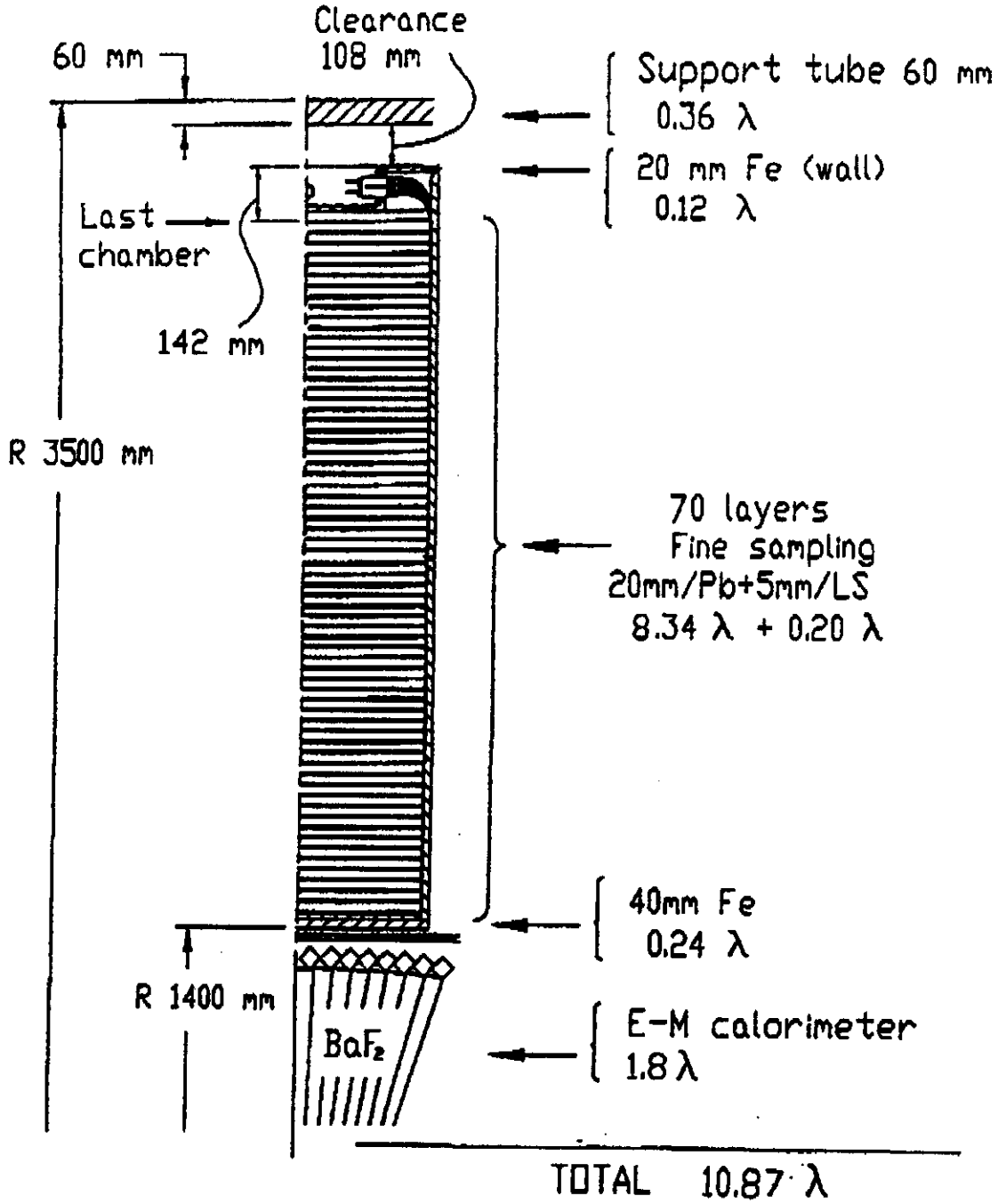
JET RESOLUTION - GEANT3



Liquid Scintillator Hadron Calorimeter (Version 0.08-2)
Barium Fluoride EM Calorimeter



Liquid Scintillator Hadron Calorimeter
Sampling structure scheme
(uniform sampling)



λ_{Pb} = 175 mm

λ_{Fe} = 168 mm

λ_{Scl} = 1000 mm

I.Ver. 08-01 with fine and coarse sampling

40 layers x (20 mm Pb + 5 mm LS) +
19 layers x (40 mm Pb + 5 mm LS)

Total thickness with BaF2 in front and support structure 11.73 lambda

Outer radius 3605 mm

	rings	cells	trays	channels
90deg	3	118k	30k	7.2k
30deg	4	172k	43k	8.6k
45deg	8	138k	35k	6.8k
endcaps	2	179k	22k	3.5k
total		607k	130k	26.1k

II.Ver. 08-02 - all fine sampling

70 layers x (20 mm Pb + 5 mm LS)

Total thickness with BaF2 in front and support structure 10.87 lambda

Outer radius 3500 mm

	rings	cells	trays	channels
90deg	3	168k	42k	7.2k
30deg	4	310k	78k	8.6k
45deg	8	225k	57k	6.8k
endcaps	2	240k	30k	3.5k
total		943k	207k	26.1k

Muon radiation losses in HC and longitudinal segmentation

1. Bremsstrahlung energy measurement.
   In Spaghetti - effect of light att. length

2. Recognition of muon radiation losses :
   for muons - em clasters uniformly distributed in radial directions ; for hadrons - characteristic longitudinal energy deposit profile.
   (MC simulation is due)

3. Longitudinal segmentation allows to build ISOLATED MUON trigger
   (MC simulation is due)

4. Longitudinal segmentation and brickwall structure of readout cells improve the accuracy of muon tracking in HC
   (MC simulation is due)

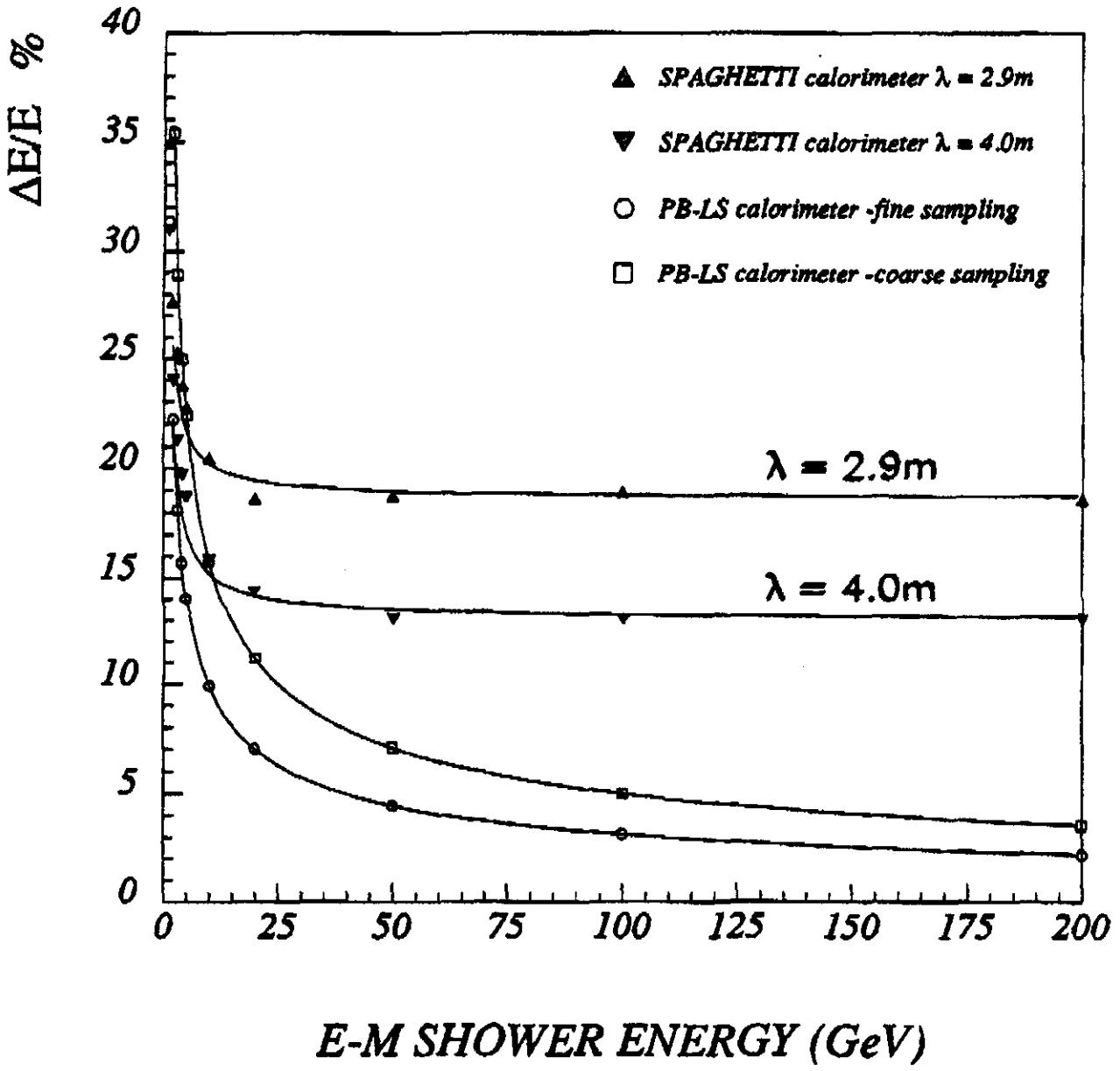
Initial em resolution

Spaghetti : $25\%/\sqrt{E}$

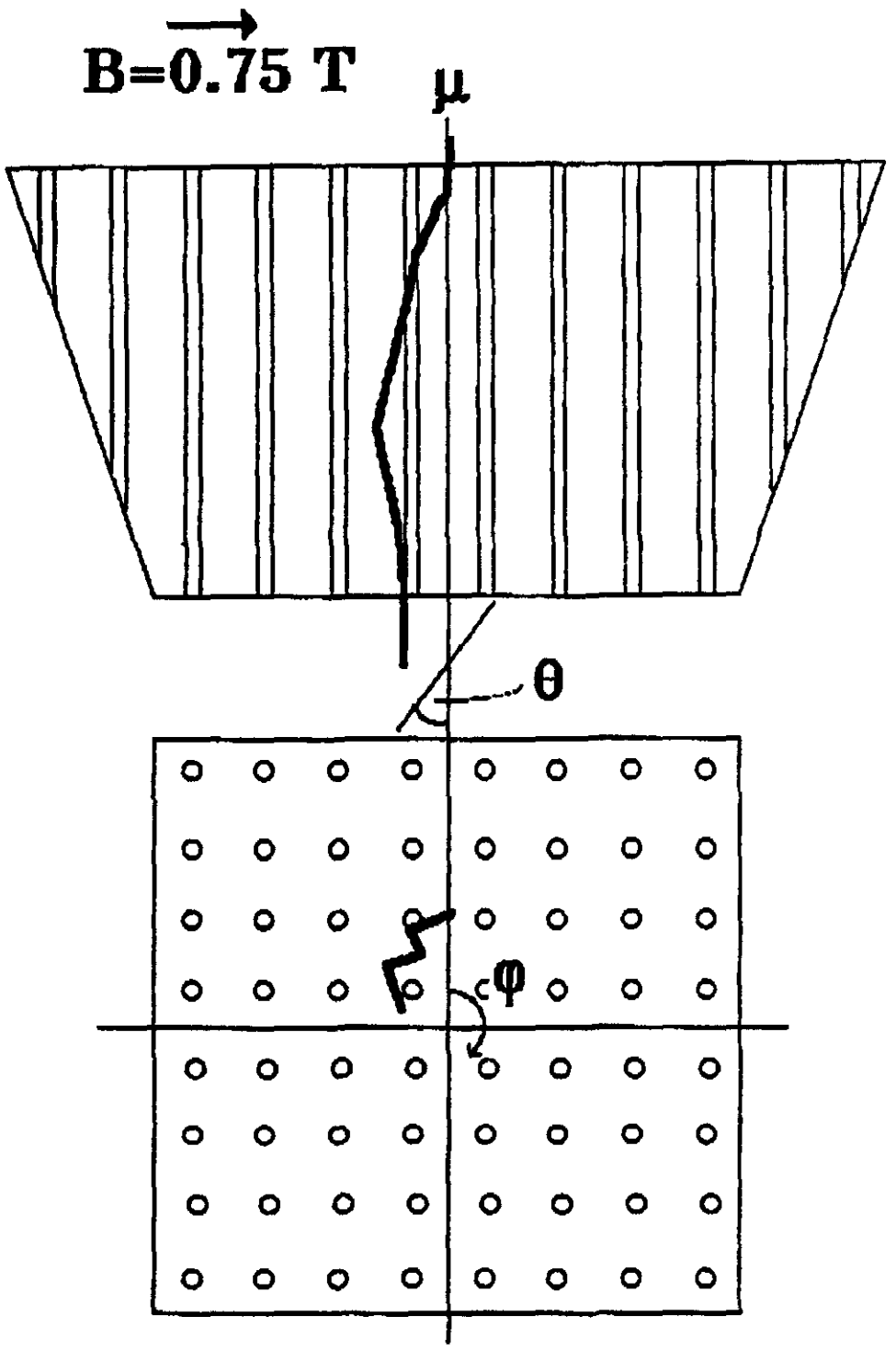
Pb/LS (fine part, 20mm) : $31.5\%/\sqrt{E}$

Pb/LS (coarse part, 40mm) : $50\%/\sqrt{E}$

RESOLUTION for e-m showers from MUON energy loss



Fiber "holes" in spaghetti



$\theta = 0^\circ$ $(\varphi = 0^\circ)$

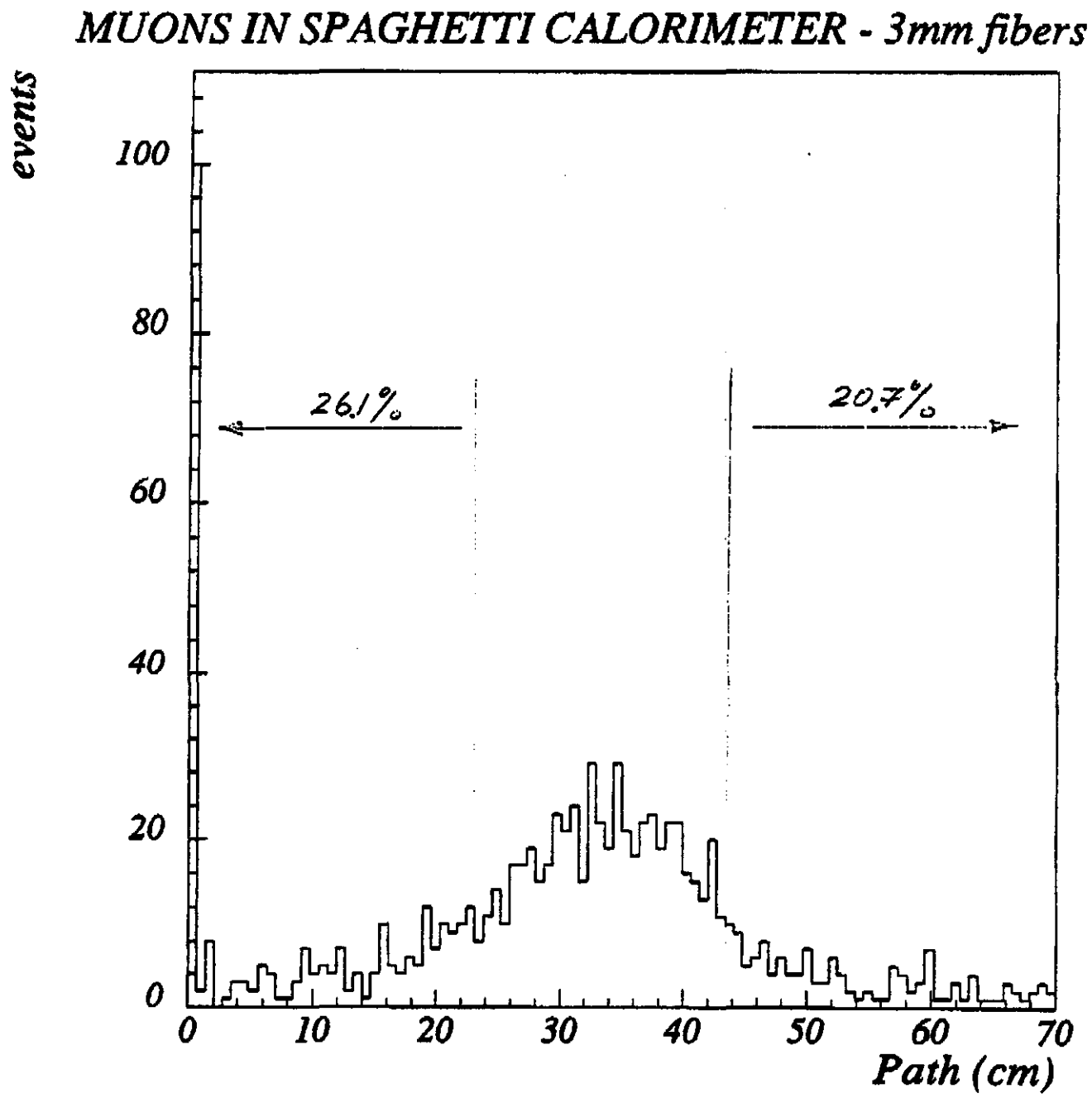
100 GeV/c μ^-

1000. events

B = 0.75T

Magnetic field, multiple scattering are included

muon rad. losses are not included

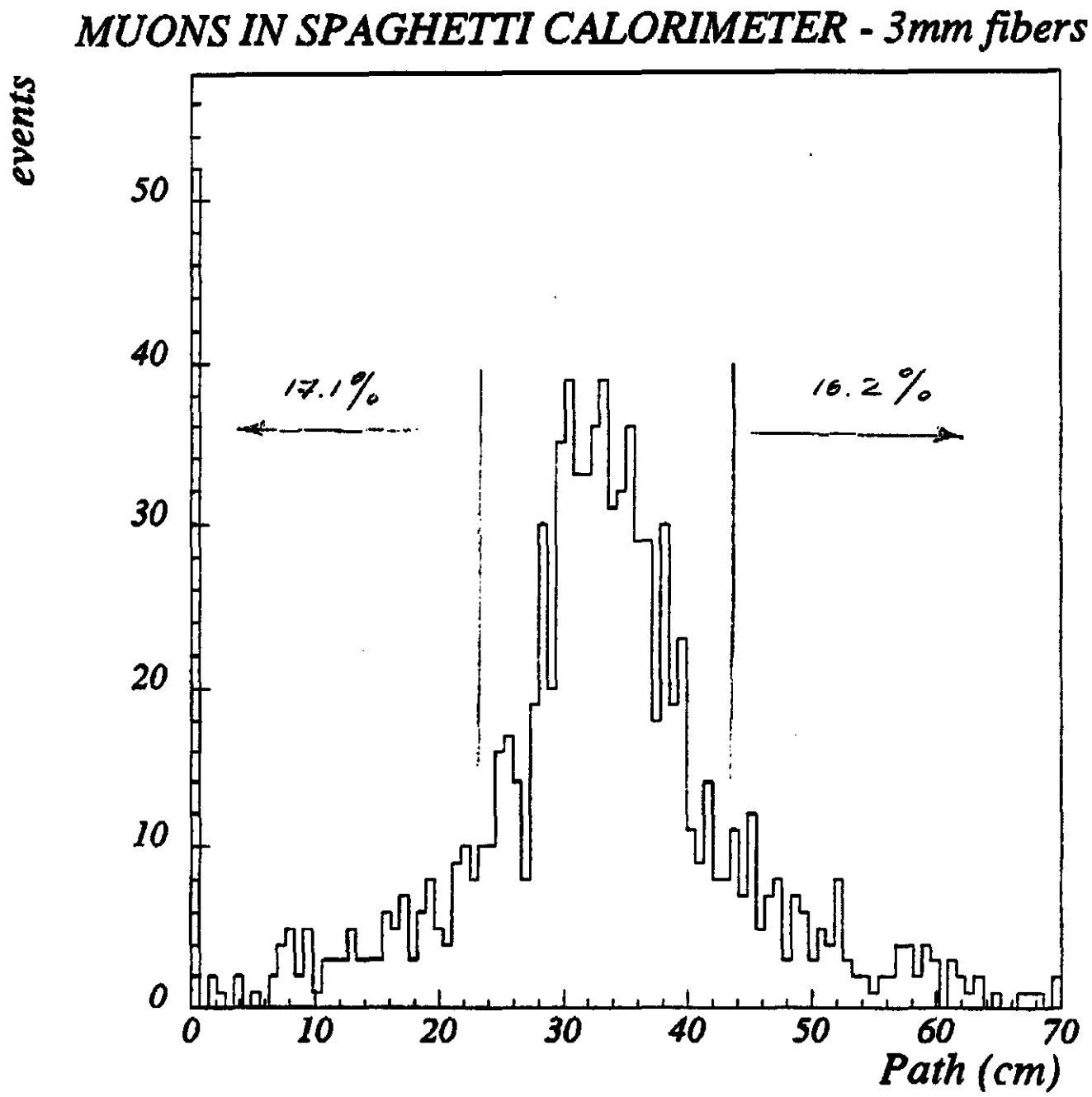


$\theta = 3^\circ \quad \varphi = 0^\circ$

100 GeV/c μ^-

1000 events

B = 0.75 T

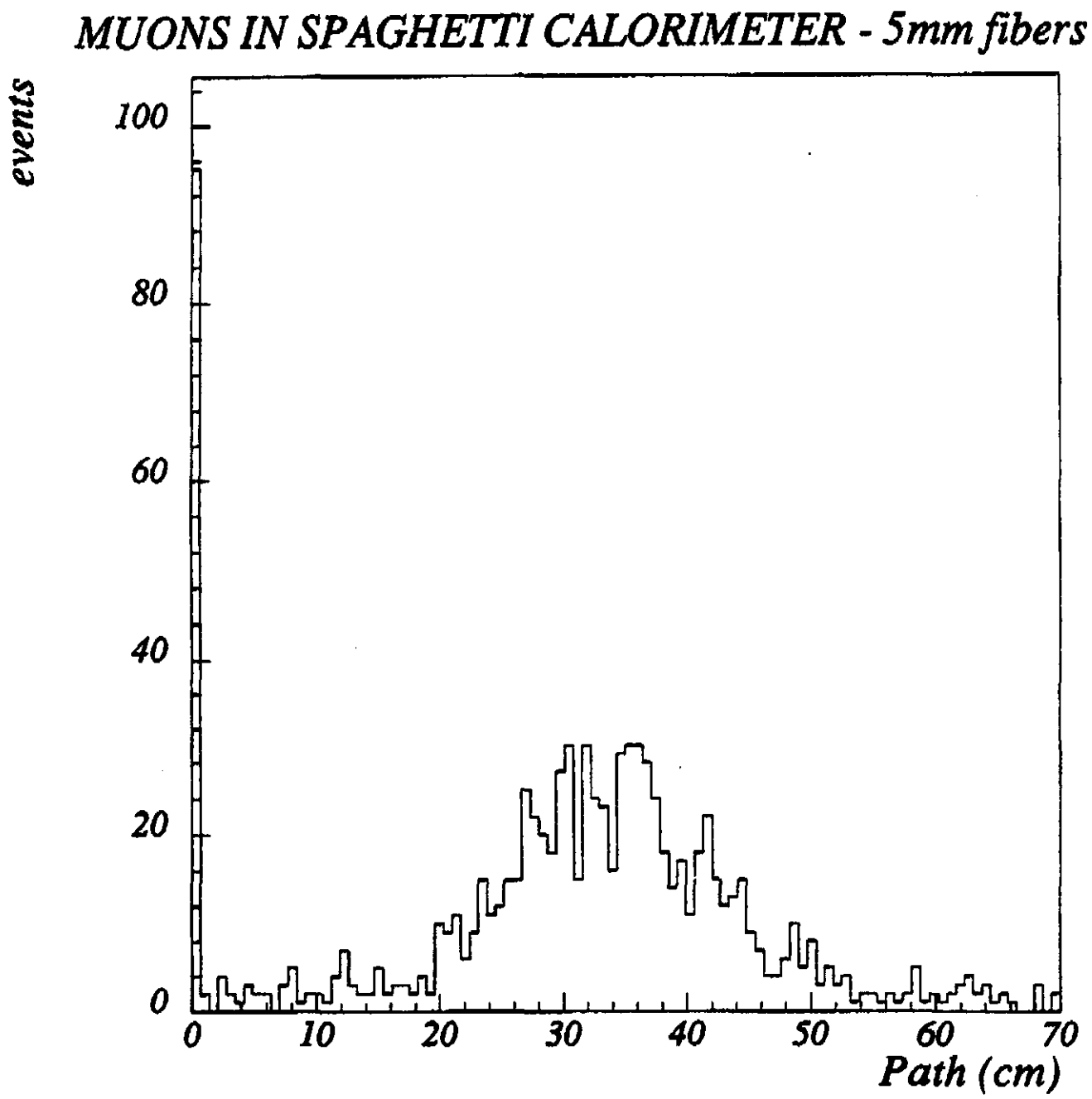


$\theta = 3^\circ$, $\varphi = 0^\circ$

100 GeV/c μ^-

1000 events

B = 0.75 T

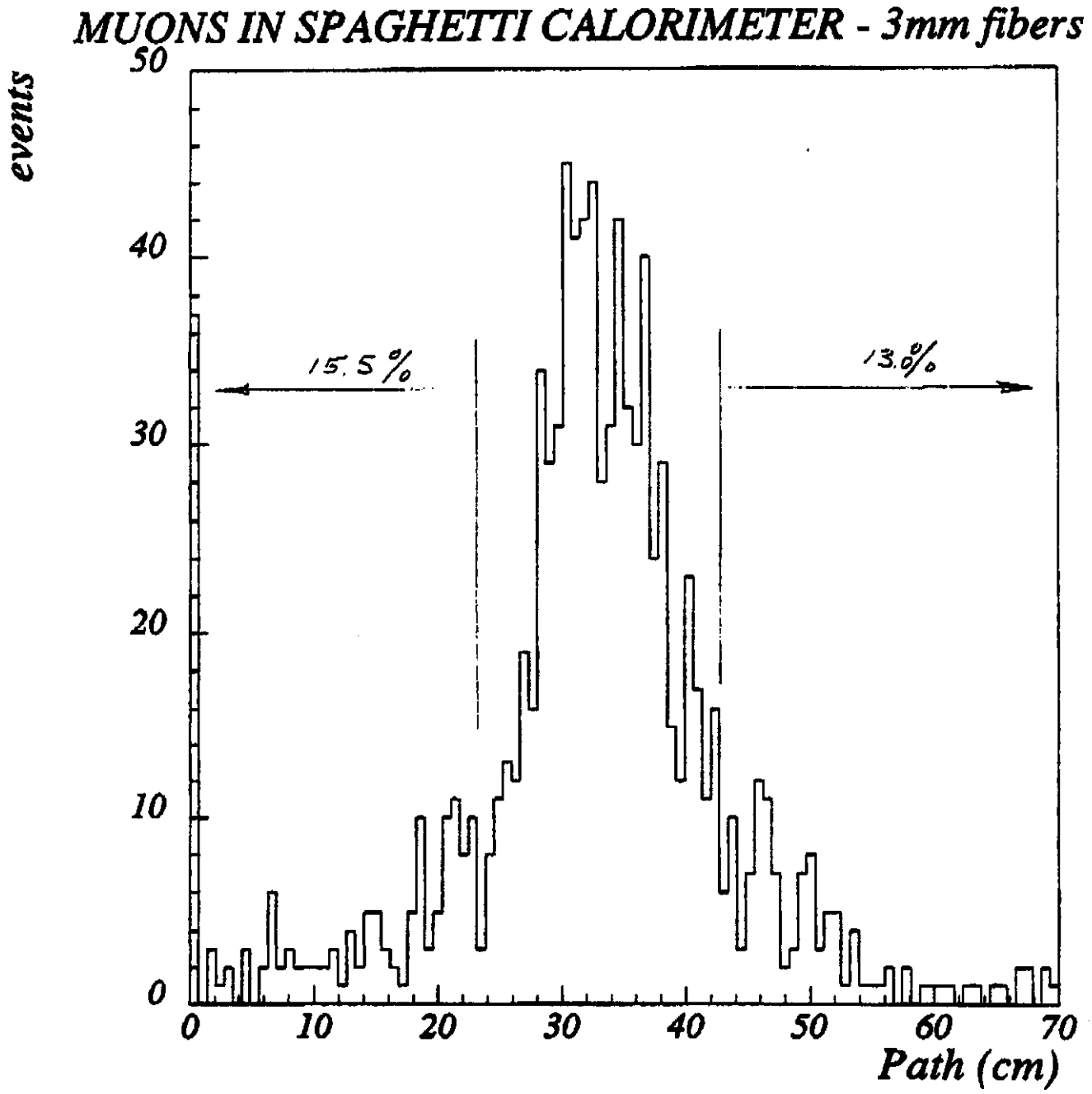


$\theta = 3^\circ$ $\varphi = 30^\circ$

100 GeV/c μ^-

1000 events

B = 0.75 T

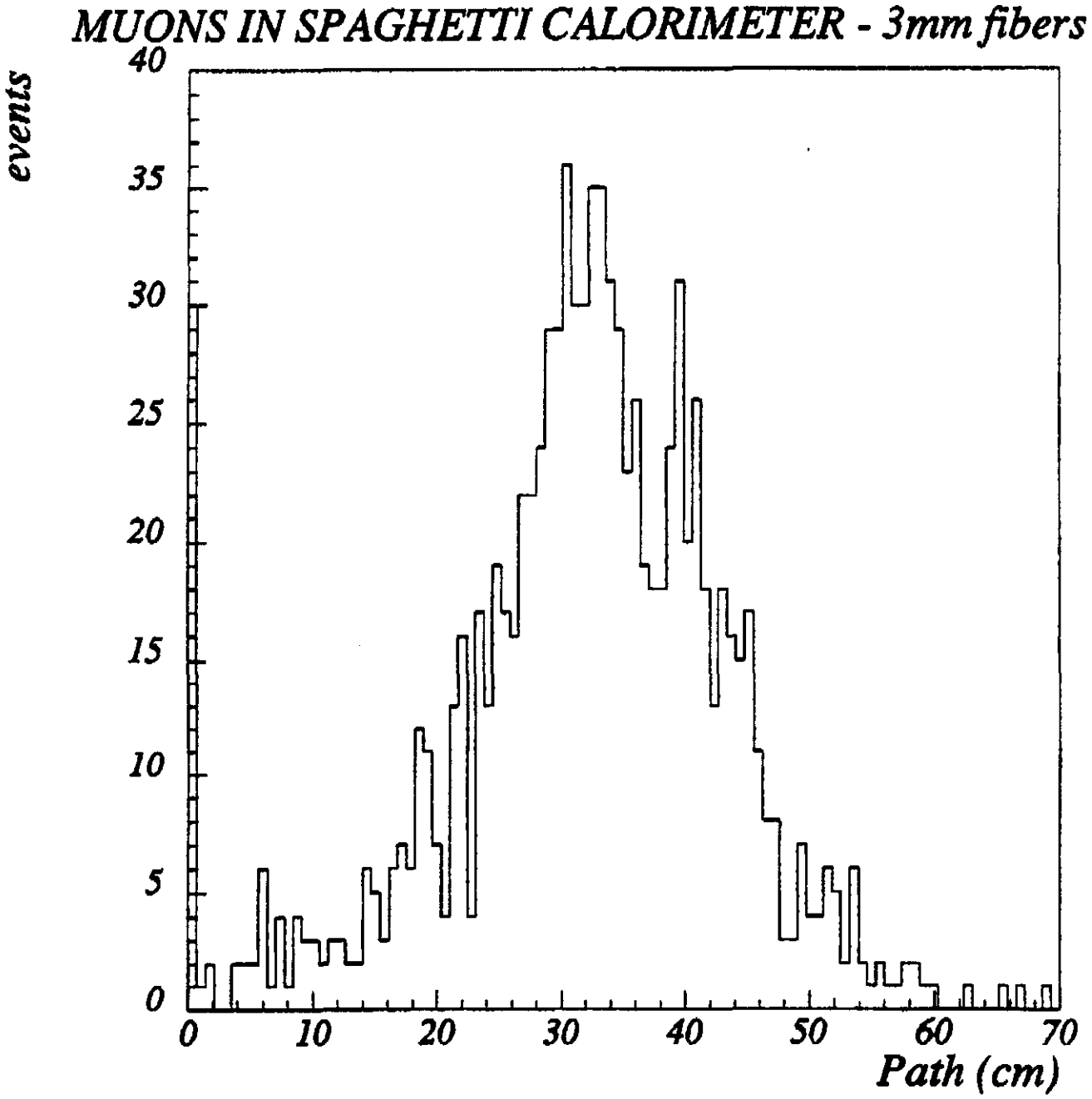


$\theta = 3^\circ$ $\varphi = 30^\circ$

500 GeV/c μ

1000 events

B = 0.75 T



COMPARISON OF LIGHT YIELD FOR MUONS AND HADRONS

I SPAGHETTI :

Start with muons. Muon assumed to be MIP.

1. Path in fiber (L(module)=2m, fraciton of fiber 1/5 vol.)

   <l>=200cm/6=33.3cm

2. Energy deposit by MIP in polystyrene

   Edep=<l>*dE/dx=33.3cm*2.01MeV/cm=67.MeV

3. Light output 60% Anthracene (61 eV/photon in Anthracene)

   Nphot=67.MeV*0.6/(61eV/photon)=659,000 photons

4. Captured in fiber via total internal reflection angle 21.4 degree --> aperture 3.4%.
   [Bill Worstel mentioned total int. reflection angle of 15 degree; this will result in aperture 1.7%]

   Nphot=659,000*0.034=22,400 photons

5. Light yield averaged by fiber attenuation (Latt=1.8m, no filter, no mirror)
   Y=Latt/Lmod*(1.-exp(-Lmod/Latt))=62%

   Nphot=22,400*0.62=13,890 photons

6. Filtering (lambda < 450 nm) increases fiber uniformity but reduces response be average factor 0.327 +- 0.057
   [Data from z-scan long John, R.Wigmans, Calorimetry in HEP, Lecture at CERN, January 1989]

   Nphot=13,890*0.327=4,542 photons

7. Splicing of 3 mm SF with 1 mm clear transport fiber (factor < 1/9)

   Nphot=4,542*1/9=505 photons

8. 20% loss due to light concentrating/mixing interface :

   Nphot=505*0.8=404 photons

9. For PMT R2490-05 : Q.E. 16% for lambda > 450 nm
   (Q.E. 22% for lambda 390 nm)

------> Response (MIP) = 404*0.2 = 65 p.e./MIP

10. Average muon energy loss in spaghetti 2m long module ~ 1.94 GeV.
    mu/e ratio for Pb sampling structure is ~ 1.6
    [see for example R.Wigmans, Advances in Hadron Calorimetry, CERN-PRE/91-39, 25 February 1991]

------> Response (1 GeV hadronic energy) = 65/1.94/1.6 = 21 p.e.

COMPARISON OF LIGHT YIELD FOR MUONS AND HADRONS

II.SPAGHETTI (Bill Worstel estimate).

1.Measured response - 400 photoelectros/GeV for 1mm fibers.

"AS NOTED IN THE BASELINE DESIGN REPORT, SPACAL MEASURED A FILTERED LIGHT YIELD OF 400 PE/GEV WITH 1MM FIBERS. THE QUANTUM EFFICIENCY FOR THE PMT USED WAS COMPARABLE TO THAT OF A R2490. THE 3-1 TRANSITION LOSES A GEOMETRIC FACTOR OF 9, AND WITH UP TO 20% LOSSES COMBINED FROM INTERFACES ONE IS DOWN TO 36 PE/GEV."

2.take into account 3mm-->1mm splice :

------> 400*0.8/9 = 36 p.e./GeV

"I BELIEVE FROM SPACAL A MIP IS ABOUT 4 GEV EQUIVALENT (I WILL CHECK THIS, BUT SEE FIGURE 9 IN THE BASELINE DESIGN REPORT). THIS IS CONSISTENT WITH 20 MeV/cm dE/dX. Thus I'd say about 150 PE/mip."

3. MIP in GeV :

Eutectic:	dE/dx=11.0MeV/cm (49%)
Lead :	dE/dx=12.8MeV/cm (61%)
Fiber :	dE/dx= 2.0MeV/cm (1:5)
	dE/dx=9.68MeV/cm

------> L=2m ---> MIP = 1.94 GeV ---> MIP = 70 p.e.

COMPARISON OF LIGHT YIELD FOR MUONS AND HADRONS

III. PB/LS SAMPLING CALORIMETER

1. Measured response (from test cell with 2m transport fiber)

   N1 = 4 p.e.

2. For 59 planes in calorimeter :

------> Response (mu) = 236 p.e./MIP

3. In Pb/LS calorimeter L(lead)=156cm, dE/dx=12.7MeV/cm MIP=1.98GeV

   L(scnt)=27.5cm, dE/dx=1.7MeV/cm MIP=46.7MeV

   MIP=2.03GeV

------> Response (h) = 236/2.03 = 116 p.e./GeV

Calibration & Monitoring

I. Spaghetti : Co-60 or Sc-137 moving source in 2.7% of towers.
Calibration signal = 0.6 p.e.
DC measurements are required (each source > 10 mCi)

II. Liquid Scintillator : U-235 source in every cell
calibration signal = 8 p.e. approx.
with 900 Hz rate calibration to 1% within minutes

III. Liquid Argon : Test pulse at every preamplifier input
(Radiation stability of test circuit components ?)

MAJOR NON - SENSITIVE (DEAD) REGIONS in HC

I. Spaghetti : Projective separation between barrel and endcaps

II. Liquid Scintillator : most compact cable way break
(needed only for cables)

III. Liquid Argon : Large gap (due to cryostat) between barrel and endcaps.

Beam Tests of Towers/Modules

I. Spaghetti : Will it be possible to measure individual towers or group of towers in the test beam before assembly ?

II. Liquid Scintillator : 256 individual transportable and testable modules

III. Liquid Argon : Will it be possible to measure the response of the HC with BaF2 in front prior to installation in the pit?

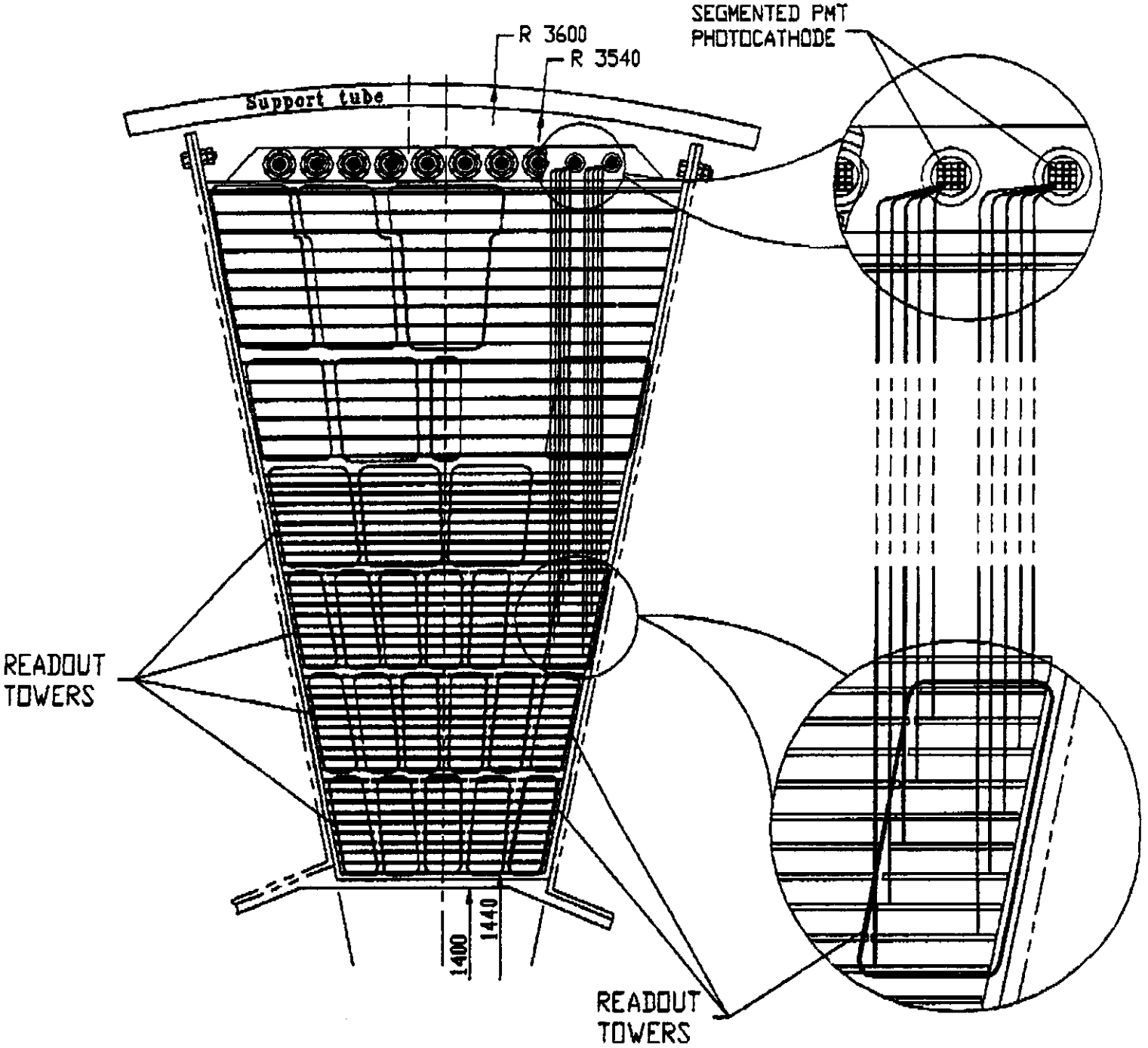
What will happen if one PMT or amplifier board will die ?

This consideration is particulary important because front end readout elements (PMTs and preamps) are practically non-accessible

I. Spaghetti : Consequences for missing Pt measurements has to be understood by MC simulations

II. Liquid Scintillator : With "robust readout option" (interleaved layers go to different photocathodes; double number of PMT) - almost no changes in response and resolution. Included in base line cost estimate (Sept. 20)

III. Liquid Argon : interleaved robust readout is feasible.



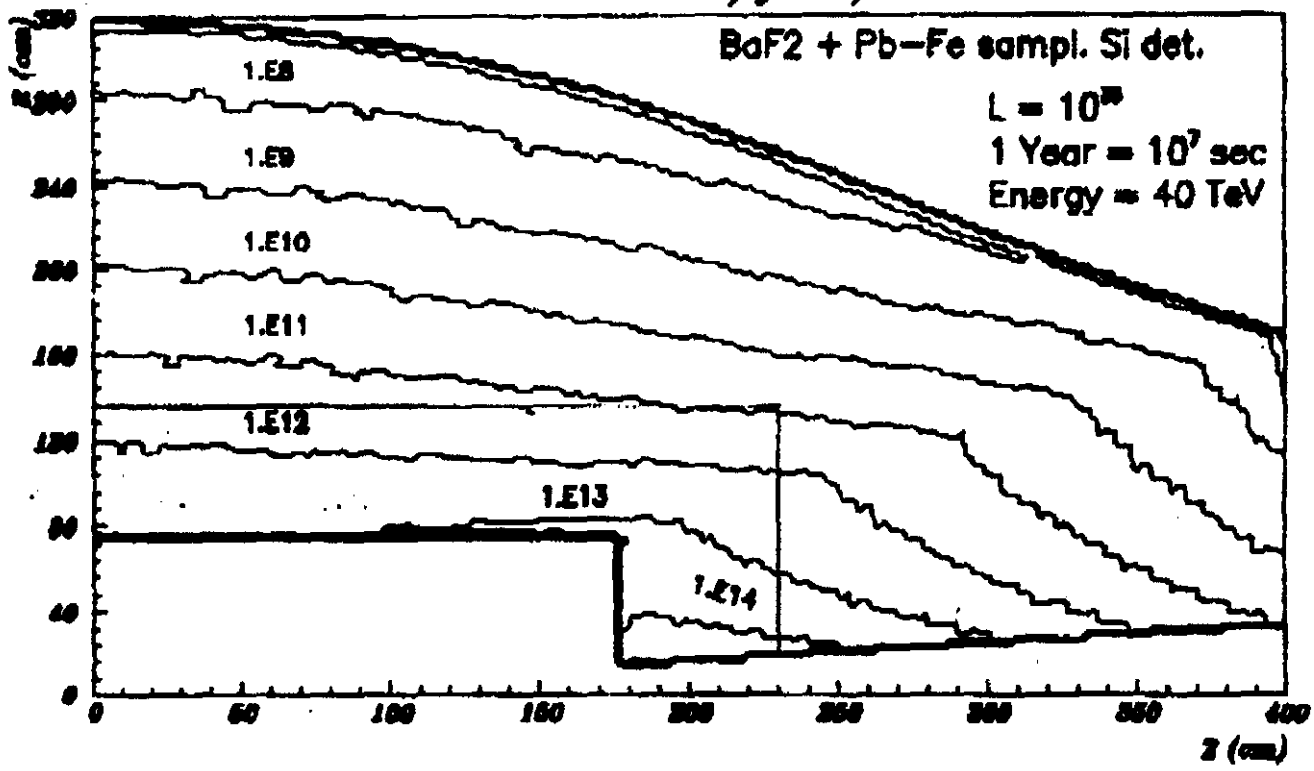
Version of robust LS fiber readout

each readout tower is viewed by two PMT
number of PMT is doubled

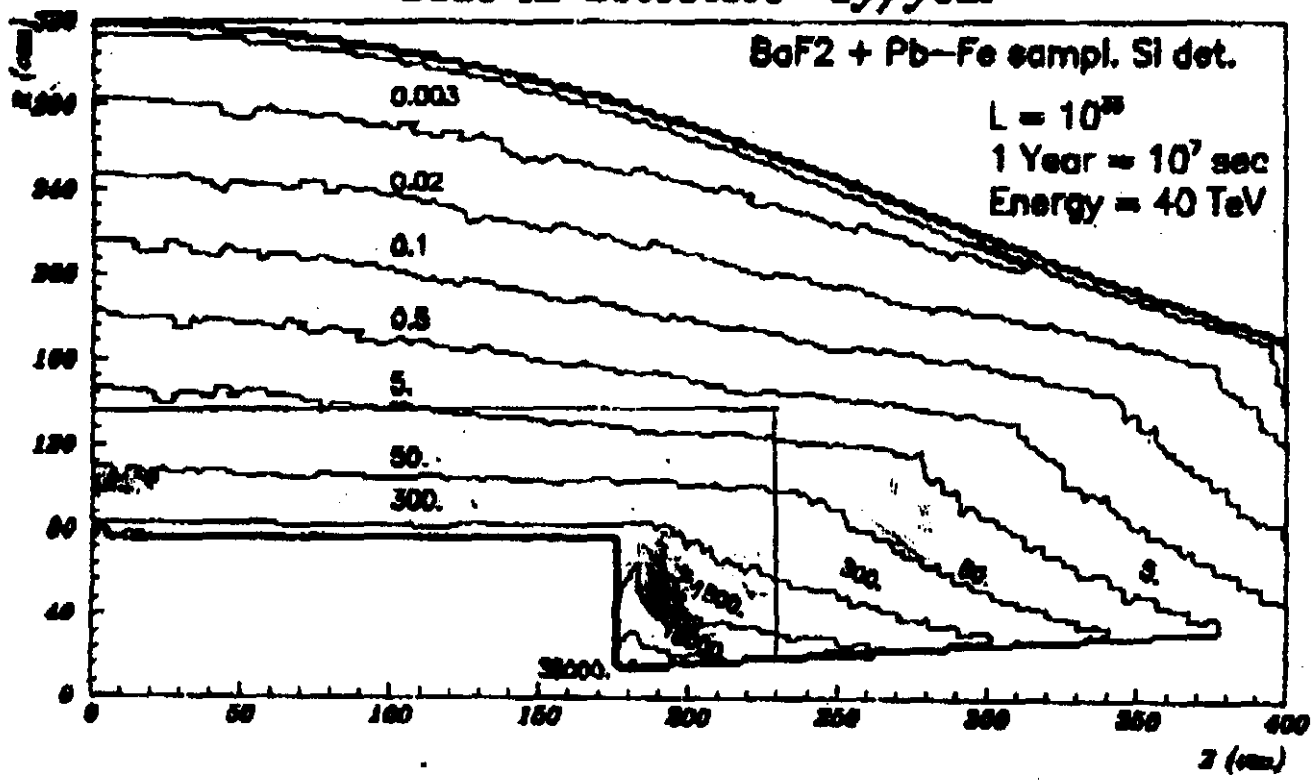
09/23/91

A. SMIRNOV

Neutron flux /year/cm2



Doze in detectors Gy/year



13.04.90 V.Morgunov

MODEL OF LIGHT COLLECTION IN IRRADIATED FIBER

(see A.Maio, CERN 90-10, ECFA 90-133, vol 3, Dec 1990)

Irradiation affects local light output as well as light absorption length in the fiber. This model fits experimental data for following scintillating fibers : SCSN38,SCSN81,S101A,3HF,3HF+PTP;

1.Local light output depends on dose exponentially :

(1) $I(z,D(x))=I0*\exp(-D(x)/g)$; $D(x)$ - dose of irradiation;

2.Absorbtion of light depends linearly on dose :

(2) $k(x)=k0+a*D(x)$;

$k(x)=1/Latt(D(x))$, $k0=1/Latt0$ (nonirradiated);

(3) $$\frac{dI(x,D)}{dx} = - I(x,D(x))*(k0+a*D(x));$$

3.Expression (1) and solution of (3) give dependence of light output on doze and on light emission distance x :

(4) $I(x,D)=I0*\exp(-D(x)/g)*\exp(-x/Latt0)*\exp(-a*D')$,

where D' is integrated dose from 0 to x;

$D' = \text{Integral } \{0,x\}\ D(z)dz$; $[D']=Mrad*cm$

PARAMETERS a AND g IN FORMULA (4) FOR DIFFERENT FIBERS

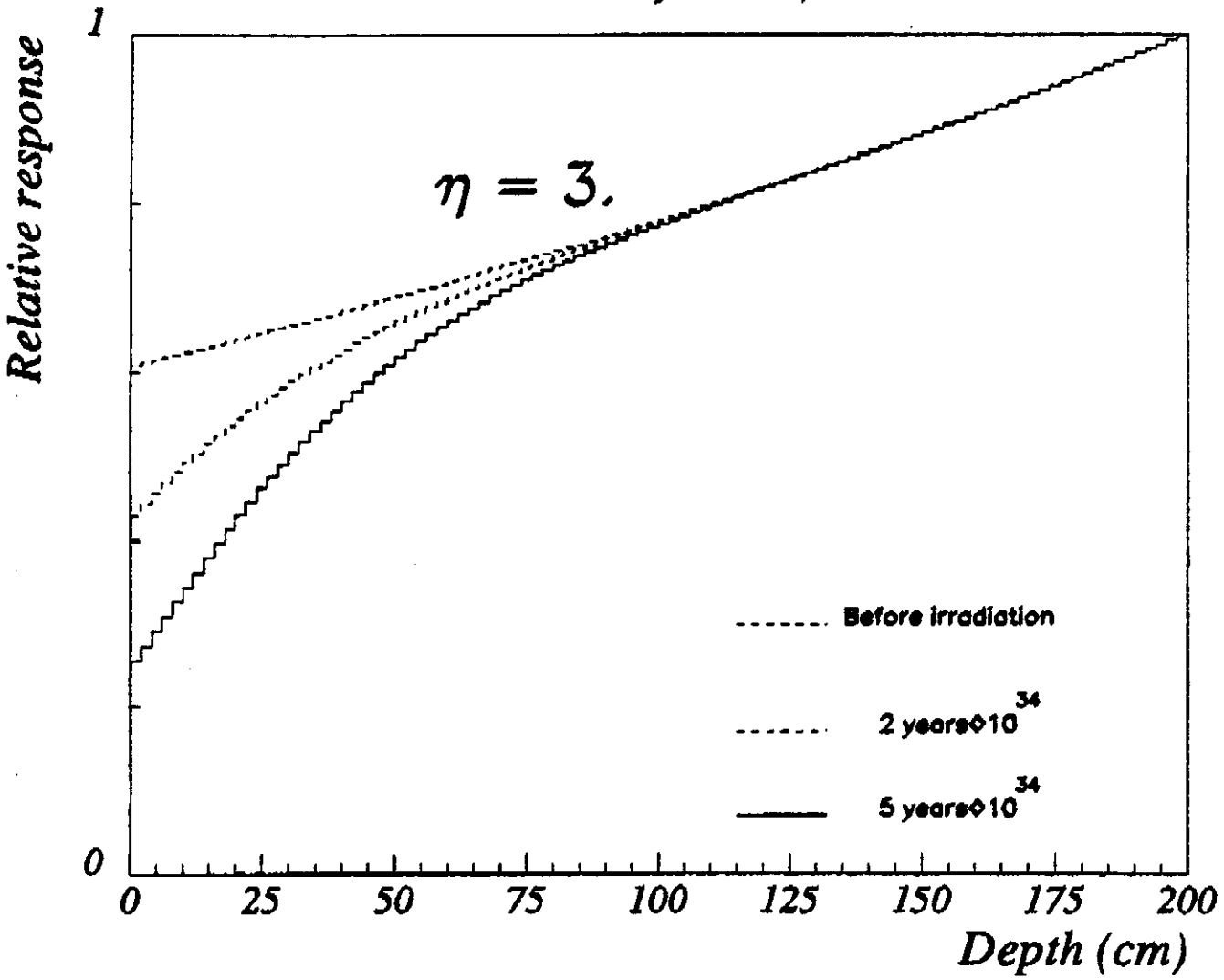
g - parameter describing light output reduction
[g]=Mrad (the larger - the better)

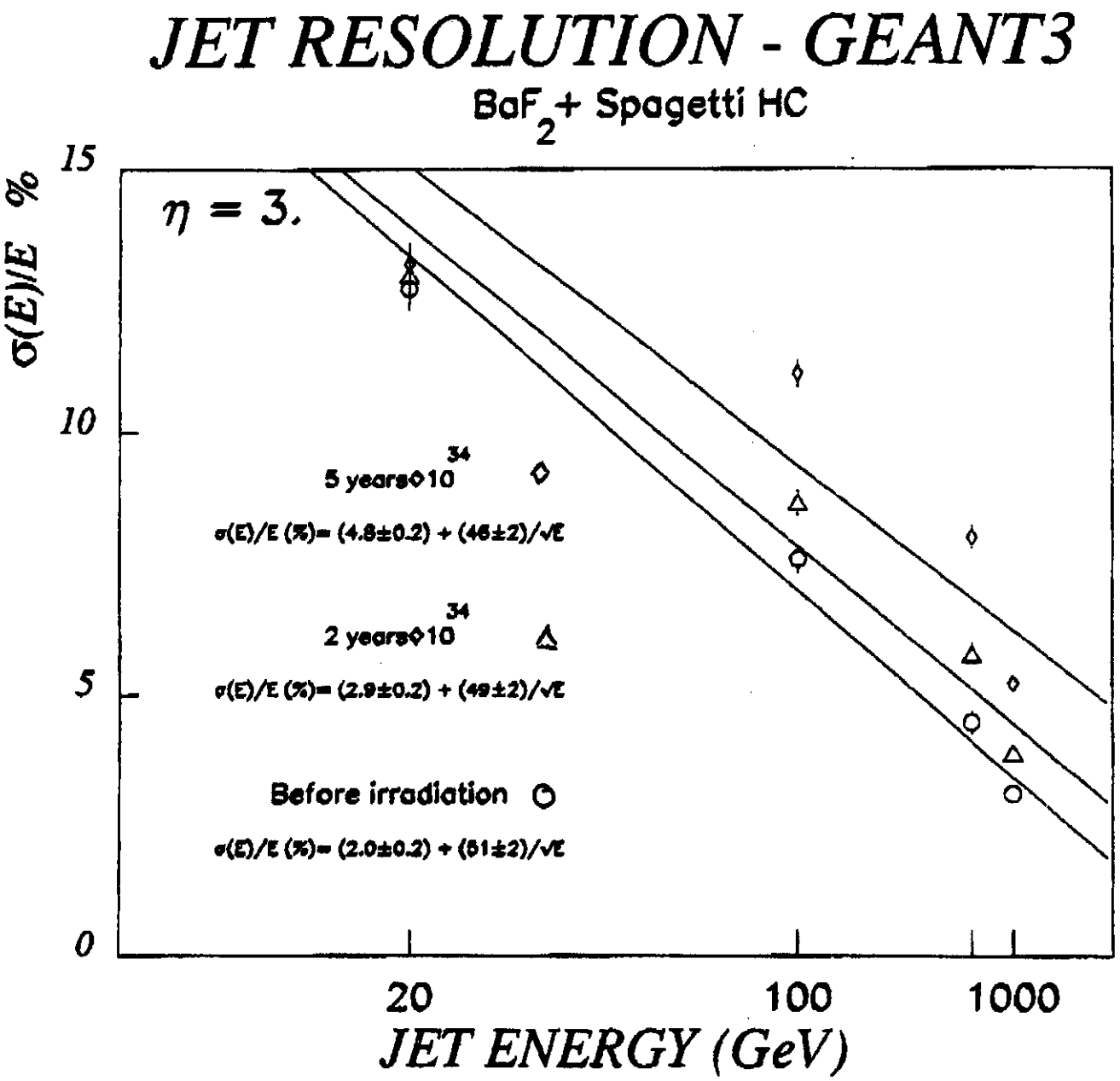
a - parameter describing light attenuation length reduction
[a]=1/(Mrad*cm) (the smaller - the better)

SCSN81		RH-1 assumed to be better than SCSN81		BCF-91 (Version 1)		BCF-91 (Version 2)		BCF-98 (clear fiber)	
a	g	a	g	a	g	a	g	a	g
0.0043	63.1	0.0040	66.0	.00008	20.0	.00008	125.	.00002	-

Spagetti calorimeter

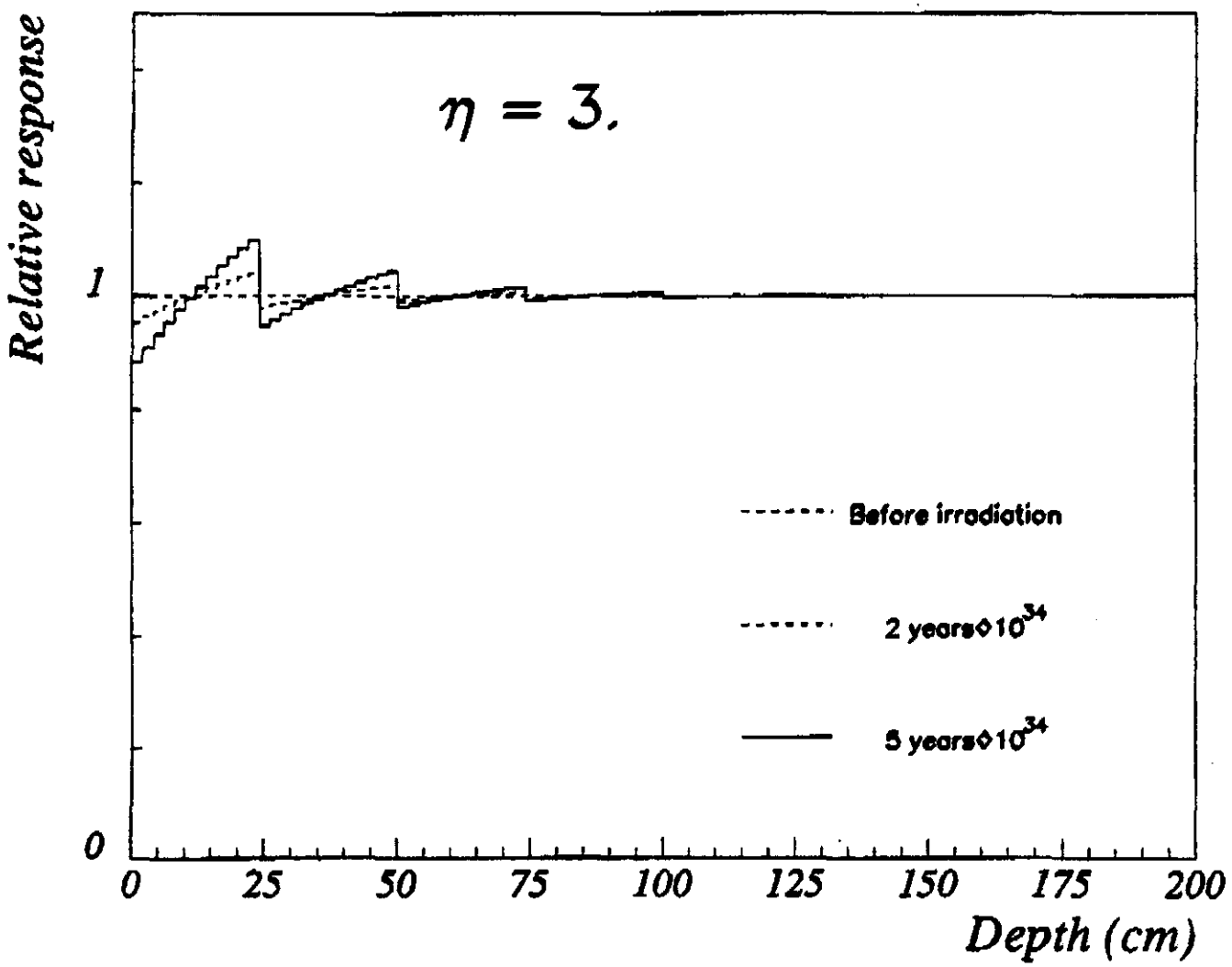
Nonuniformity of response

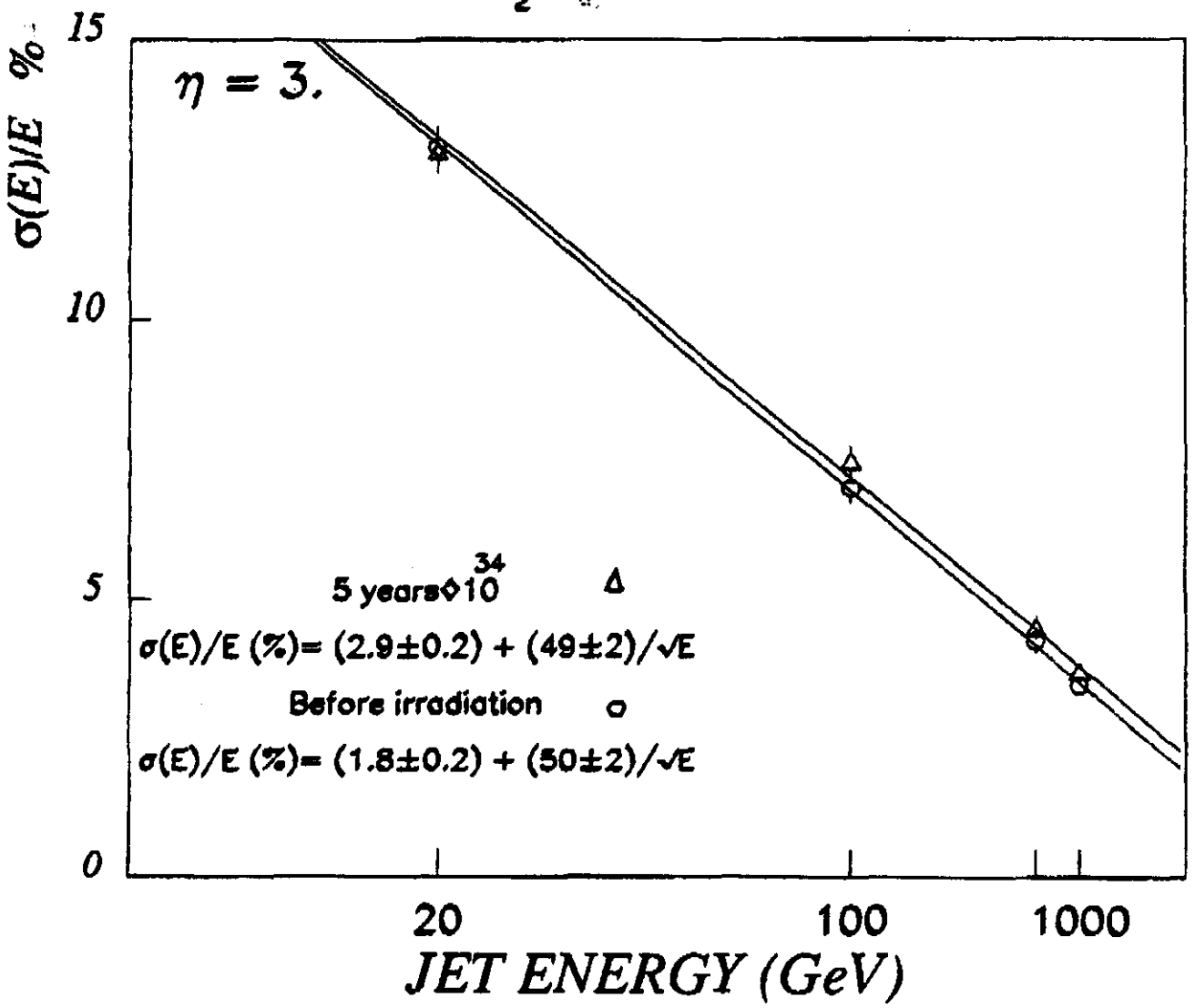



JET RESOLUTION - GEANT3
BaF2 + Spagetti HC
η = 3.
σ(E)/E %
15
10
5
0
5 years◇10^34
σ(E)/E (%)= (4.8±0.2) + (46±2)/√E
2 years△10^34
σ(E)/E (%)= (2.9±0.2) + (49±2)/√E
Before irradiation ○
σ(E)/E (%)= (2.0±0.2) + (51±2)/√E
20
100
1000
JET ENERGY (GeV)

Liquid scintillator calorimeter

Nonuniformity of response after calibration



JET RESOLUTION - GEANT3

BaF_2 + LS HC (Version 2)