GEM TN-91-39

GEM Calorimeter Meeting
SSCL

November 6, 1991

Abstract:

Agenda and transparencies contributed to the GEM Calorimeter Meeting held on November 6, 1991.

see over)

NAME	INSTITUTION	E-MAIL ADDRESS
Paul Mockett	Univ. of Washington	MOCKETT @ UWAPHAST
MICHAEL SHUPE	UNIV. OF ARIZONA	UAZHEP:: SHUPE, SHUPE@ARIZRVAX
ANS COHN	ORNL	COHN @ UTKVX
AVID LISSAUER	BNL	LISSAUER @ BNLVMXA.
Harvey Newman	Caltech	NEWMAN @ CITHEX
Kathy Young	ORNL	KGY @ ORNLSTC
Laus Paar	UCSD	27833:: HPAAR
Jim Branson	UCSD	SDPH:: BRANSON
Martin Bauer	ORNL	MBB @ ORNL STC
Jin-yuan Zhu	CALTECH	ZHU @ CITHEX
John P. Rutherfoord	Univ. of Arizona	UAZHEP:: RUTHERFO
Howard Gordon	BNL	BNLCL6:: GORDONH GORDONH@BNLCL
Frank Plasil	ORNL	FZP @ ORNLSTC ; ORPHØ1:: FRANK
Sham Sumorok	MIT	MITLNS :: SUMOROK
Bob Webb	Texas A&M	26001 :: WEBB
TOM SHANNON	ORNL	SHANNONT @ ORNL STC
Jim REIDY	U. Miss	REIDY @ LMSPHY
MARK RENNICH	ORNL	REN @ ORNLSTC
Bob Adair	Yale	ADAIR @ YALEHEP
Larry Sulak	Boston	SULAK @ BUPHYC; BUPHYC:: SULA
Bill Worstell	Boston U.	BUPHYC:: WORSTELL
Charles Elder	Draper Lab.	
FRANCOIS AYER	DRAPER	fnayer@Draper.com
Bill Bugg	Tennessee	BUGG @ SLACVM
Cliff Eberle	ORNL	EBERLE @ SSCVX1. SSC. GOV
Steven M. Chae	ORNL	
Barry Barish	Caltech	BARISH @ CITHEX
Yuri Kamyshkov	ORNL/ITEP	Kamyshkov @ ORPHØ1

Agenda for the GEM Calorimeter Meeting, Wed. Nov 6, 1991

Room to be asigned, SSCL

8:00 - 9:30	LoI Preparation	J. Brau
9:30 - 9:45	Introduction: Scintillator Decision Plan Goal -To choose a scintillator hadron calorimeter (SHCAL) technology for GEM. Four principal issues in the choice: - Relative cost - Likelihood of a module ready for testing in 1992 - Longitudinal sampling - Relative complication of assembly, and maintenance in situ.	H. Newman
9:45 - 10:15	R&D Plans of the Combined Scintillator HCAL Group, for SF and LS Choices (Plan for how the SHCAL team will carry out a common R&D program in 1992, and will work together, given the choice of Fiber OR Liquid Scintillator.)	F. Plasil
10:15 - 10:45	Presentation: Principal Reasons to Choose a Liquid Scintillator (LS) HCAL	Y. Kamyshkov
10:45 - 11:15	Presentation: Principal Reasons to Choose an Scintillating Fiber (SF) HCAL	L. Sulak
11:15 - 11:40	Discussion of the Relative Cost of the SF and LS HCAL	R. Adair (M. Rennich)
11:40 - 11:50	Comments on Longitudinal Segmentation	J. Branson
11:50 - 12:00	Comments on Missing E_T and E_T Resolution (Speakers -- J. Branson (confirmed) and possibly: R. Webb, J. Rutherfoord).	J. Rutherfoord
12:00 - 1:00	LUNCH	
1:15 - 2:15	General Discussion of Tradeoffs	
2:15 - 3:00	Consensus	
3:00 - 3:15	Break	
3:15 - 6:00	LoI Polishing	

(If a decision is not reached by the calorimeter group by 3:00, a group of nine will assemble separately while the LoI polishing proceeds, to make a selection to be submitted to the Decision Group. This group of nine is planned to consist of: B. Barish, W. Willis, J. Brau, R. Adair, L. Sulak, H. Paar, F. Plasil, Y. Kamyshkov, and H. Newman. They will reach a decision by 6:15.)

GEM SCINTILLATOR HCAL DECISION

PRINCIPAL ISSUES

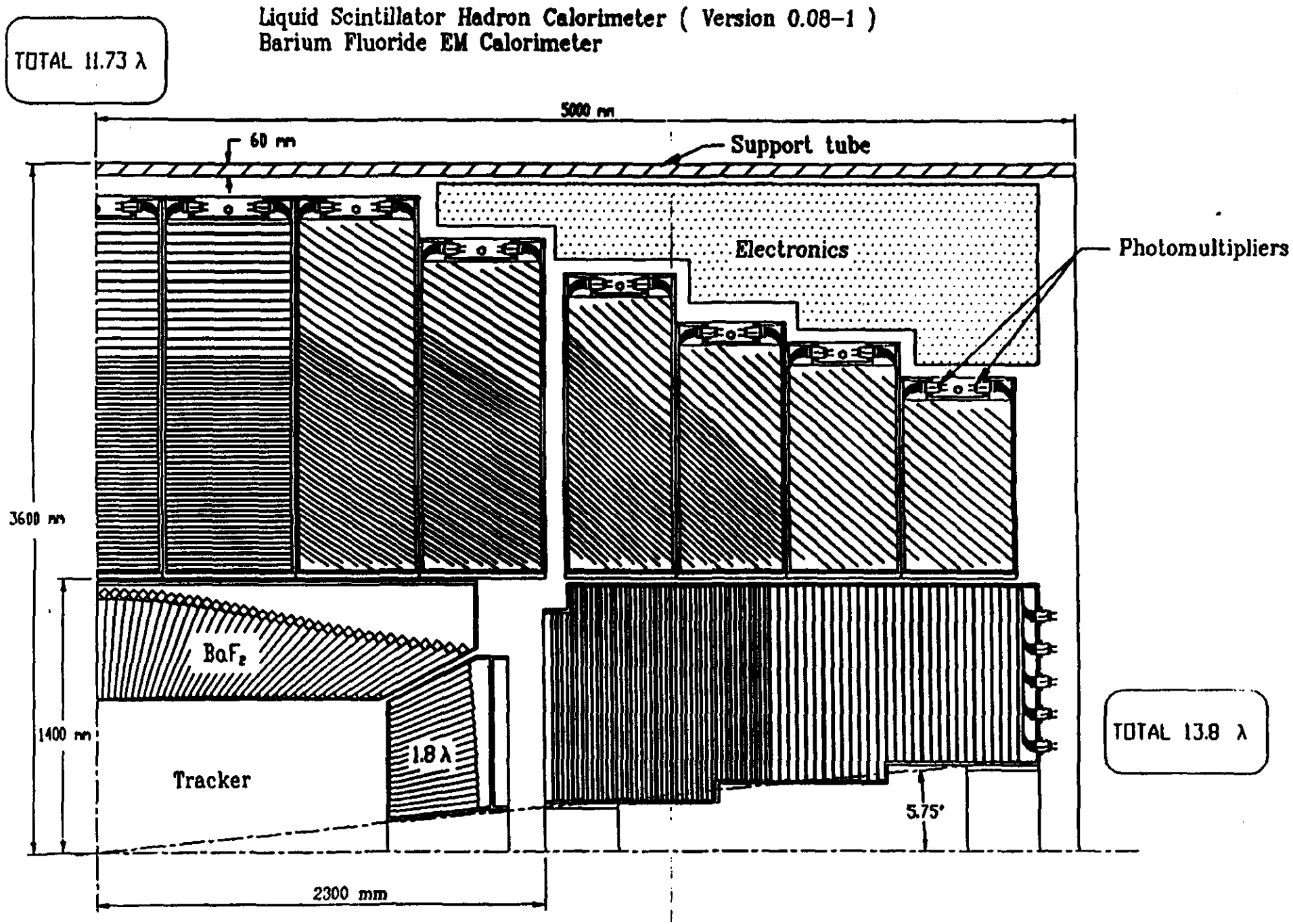
- Relative Cost
- Likelihood of a Module Ready for testing in 1992
- Longitudinal Sampling
- Relative Complication of Assembly, and Maintenance In Situ

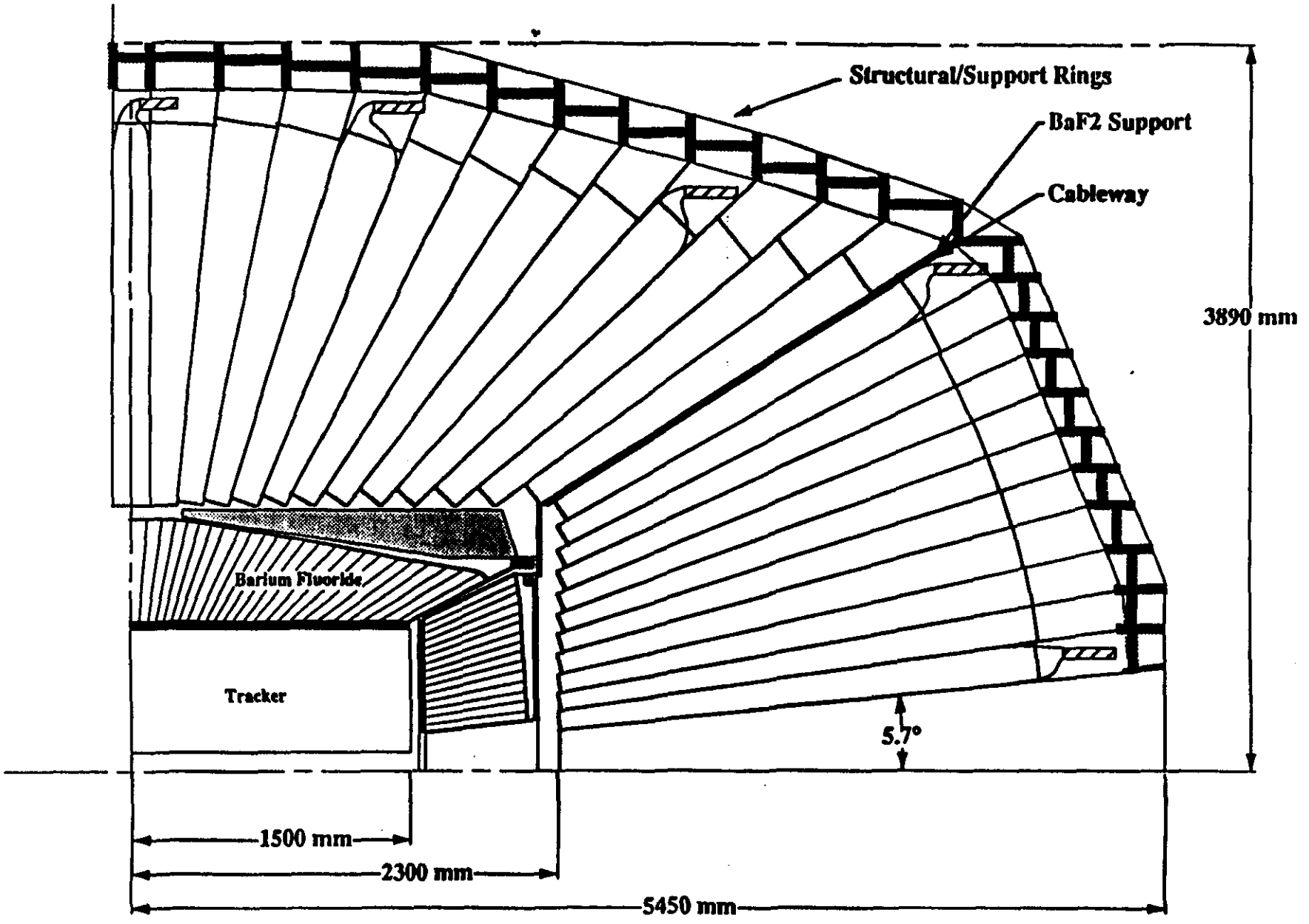
GEM SCINTILLATOR HCAL DECISION

Group of Nine Meeting
(Only if Necessary)

B. Barish, W. Willis, J. Brau, R. Adair, L. Sulak,
H. Paar, F. Plasil, Y. Kamyshkov, H. Newman

3:15	Meeting Opens
6:15 or Before	Scintillator HCAL Decision


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
5.75°
TOTAL 13.8 λ
2300 mm



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

G.03.SC.00038

Rennich

BaF_2 + HCAL CHOICE: PHYSICS QUESTIONS

SIMULATION STUDY

- **Energy Resolution, Behind BaF_2**
  for 20, 100, 500, ..., 5000 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 ?**

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: Optimization of Near-Compensating HCAL.**
  - ⇒ GEANT + CALOR Studies
- **Resolution as Function of e/h in EM Section, With Varying Reconstruction Algorithm.**
- **Minimal Sampling Required in the Tail-Catcher.**
- **Transverse Segmentation Required by Physics; Transverse-Longitudinal Tradeoff.**

BaF_2 + HCAL CHOICE: GENERAL QUESTIONS:

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

Common purpose:

- Highest possible EM resolution
  (BaF_2 ..... and failing that....)

- Inherently fast readout

SSCintCal and LS proponents
share these goals

(The Samios reaction)

Pledge to work together
Regardless of what decision is
made today.

If liquid scintillator is selected:

- Boston University will work on R+
- presumably many others

If scintillating fiber is selected:

- ORNL and U. of Tennessee will
work on R+D
- presumably many others

The ITEP Connection

- Yuri Kamyshkov and his team are commited to the liquid scintillator R & D project.

- ITEP assurances at the highest level (M. Danilov)

- Should GEM not go with liquid scintillator technology, LS R+D will be brought to logical stopping point

- Kamyshkov et al are not expected to be involved in GEM.

  THIS IN NO WAY REFLECTS ON OTHER GEM-ITEP UNDERSTANDING

The liquid scintillator R+D response to changing conditions:

- Joint BaF_2 + large hadronic module tests need to be performed in CERN next summer
- This will require an intense "fast-track" effort
- Build a large LS module
  - Bath-like
  - 1 x 1m ; 8.5 λ
  - 2cm Pb with 0.5cm LS
  - 70 layers
  - each layer 10 x 10 cells
  - about 600 readout channels
  - 6-10 longitudinal segments
  - use 16-anode PMT's (Hamamatsu R2490-05)

Other work if LS is selected:

- Design of actual GEM LS hadron calorimeter modules
- Build mechanical prototypes
- Verify leak-proof design
- Work on: fiber routing
  PM interface
  Scint. Liquid exchange
  Assembly procedures
  Mass production techniques

- Immediate: test of L.S plane at ITEP

- ORNL, ITEP, BU - joint responsibility
- Task allocation to be determined

  Possible emphasis:
  BU on CERN test module
  ORNL/ITEP on items listed above

Should Scintillating Fibers Prevail

- ORNL and UT are ready to join R&D effort
- Assignment of tasks to be determined.

ORNL strengths:

Engineering

Electronics

Interdisciplinary resources

What needs to be done?

1. Beam tests

- Complete tests with 4T 1st generation prototypes (Full-scale, projective, use catcher.

  - e + π's up to 150 GeV at Fermilab
  - stochastic & constant terms
  - study tower boundaries
  - compensation
  - position resolution + lateral profiles
  - pileup studies, resl^{n} degradation at high rates.

- Initiate tests with 15 T prototypes

  - at BNL (forget about constant term)
  - at CERN - coordinate w. SPACAL
  - at CERN with BaF_2 modules in front. - VERIFY EFFECTIVE COMPENSATION

2 - Design and Manufacture studies

- Develop fiber spacer-plate manufacturing techniques for 3 mm fibers
- Investigate various tower sheath designs
- Study interfaces between towers (optical + mechanical)
- Design structural supports
- Design cable routing
- Finite element analysis of proposed structures
- Study possible deformation and creep
- Construct 25 nested prototype hadronic towers
- Study alternative manufacturing techniques
- Understand costs of alternatives

Conclusion:

There is a lot to be accomplished in a short time regardless of which technique prevails!

Let's work together.

Personal note: ORNL is a team player, and committed to GEM.

Even if BaF_2/scintillator is not selected by GEM, ORNL intends to play a role in GEM calorimetry

Principal Reasons to Choose a LS HCal

Yu. Kamyshkov/ORNL Nov.9 SSCL

- √ Status of LS HC system / mechanics
- √ Radial extention / absorbtion length
- √ Longitudinal segmentation
- √ Prototype for beam tests in 1992

- Sampling plate plastic scintillator - most mature technique in calorimetry. Numerous beam prototypes were tested; real large systems were built. World best hadron calorimeters : ZEUS, NA-34 Related calorimeter physics is well understood. U/Sci 1:1 and Pb/Sci 4:1 - compensated abs/det ratios.

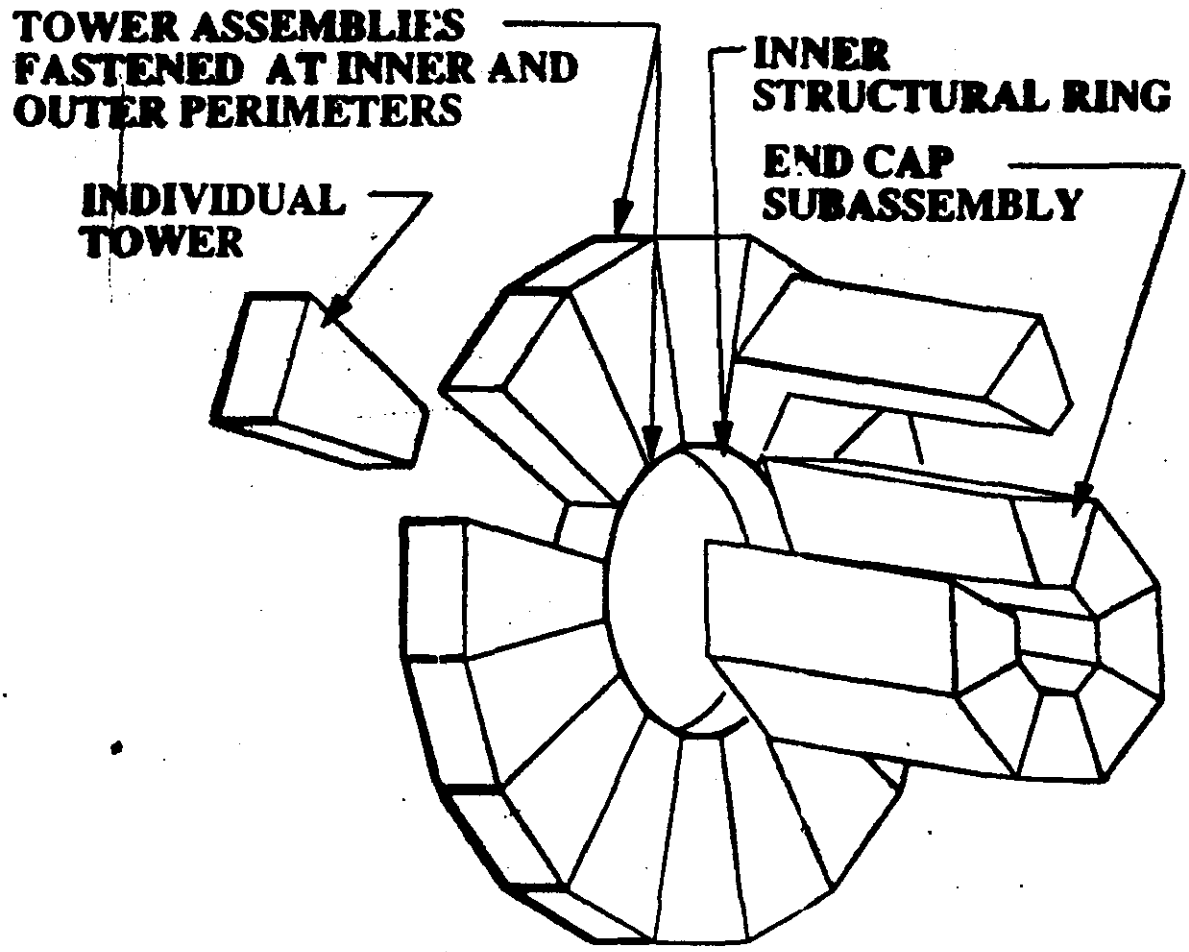
- WLS readout of plastic scintillators exists > 10 years (NA-24, e-m in ARGUS etc.)

- Proposed LS HCAL mechanical structure WAS prototyped for mechanical simplisity, assembly, servicability, transportability, calibration etc. (L3 hadron calorimeter at LEP).

What is particulary NEW in LS technique ?

- The way how the light is read out by WLS fibers
  - prototyped
- Chemical compatibility ? - > 70 years, under rad.
- Leaks ? - mechanicaly resolvable
- Beam tests ? - due in 1991/1992

HADRON CALORIMETER RING ASSEMBLY ARRANGEMENT



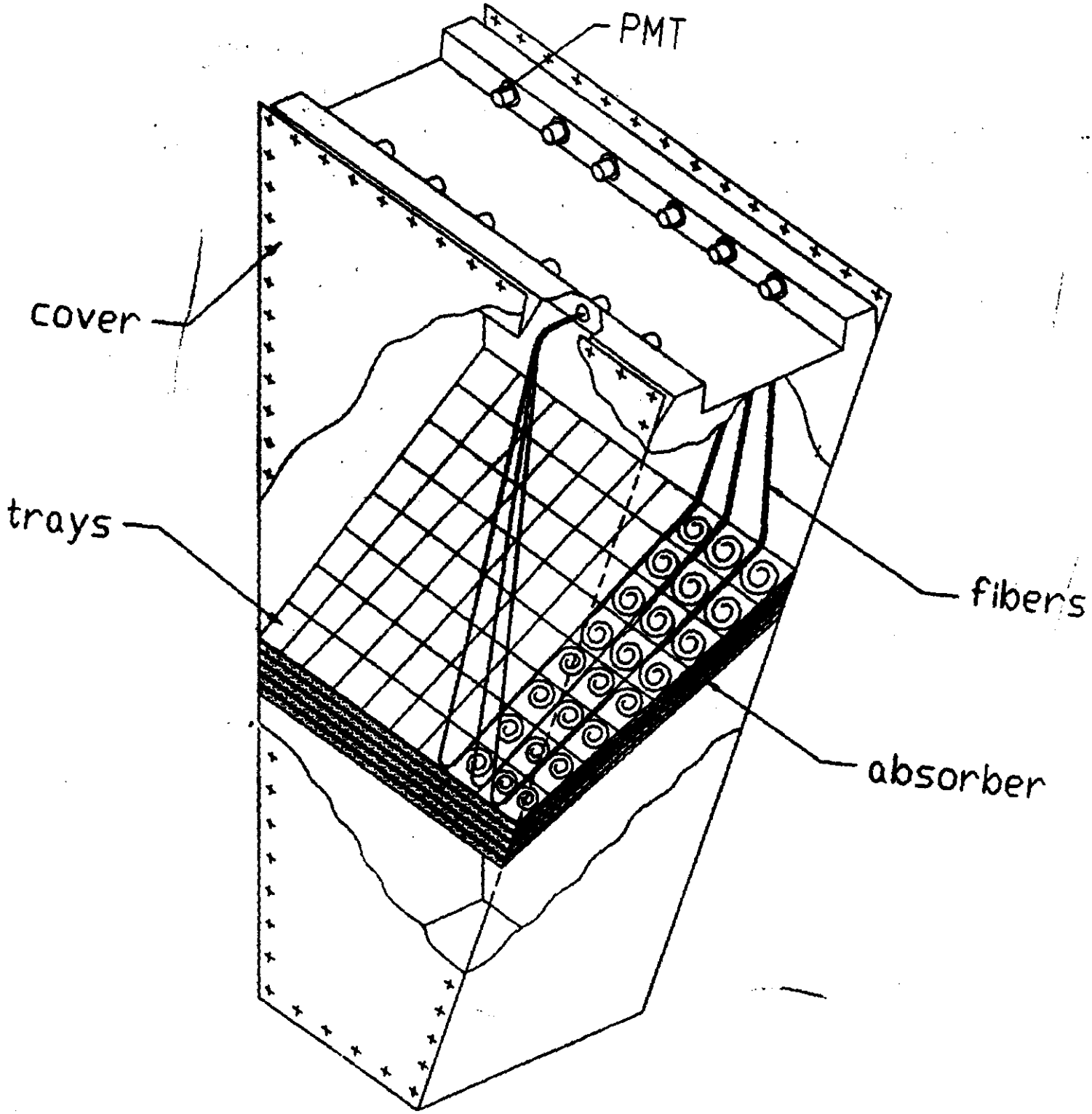
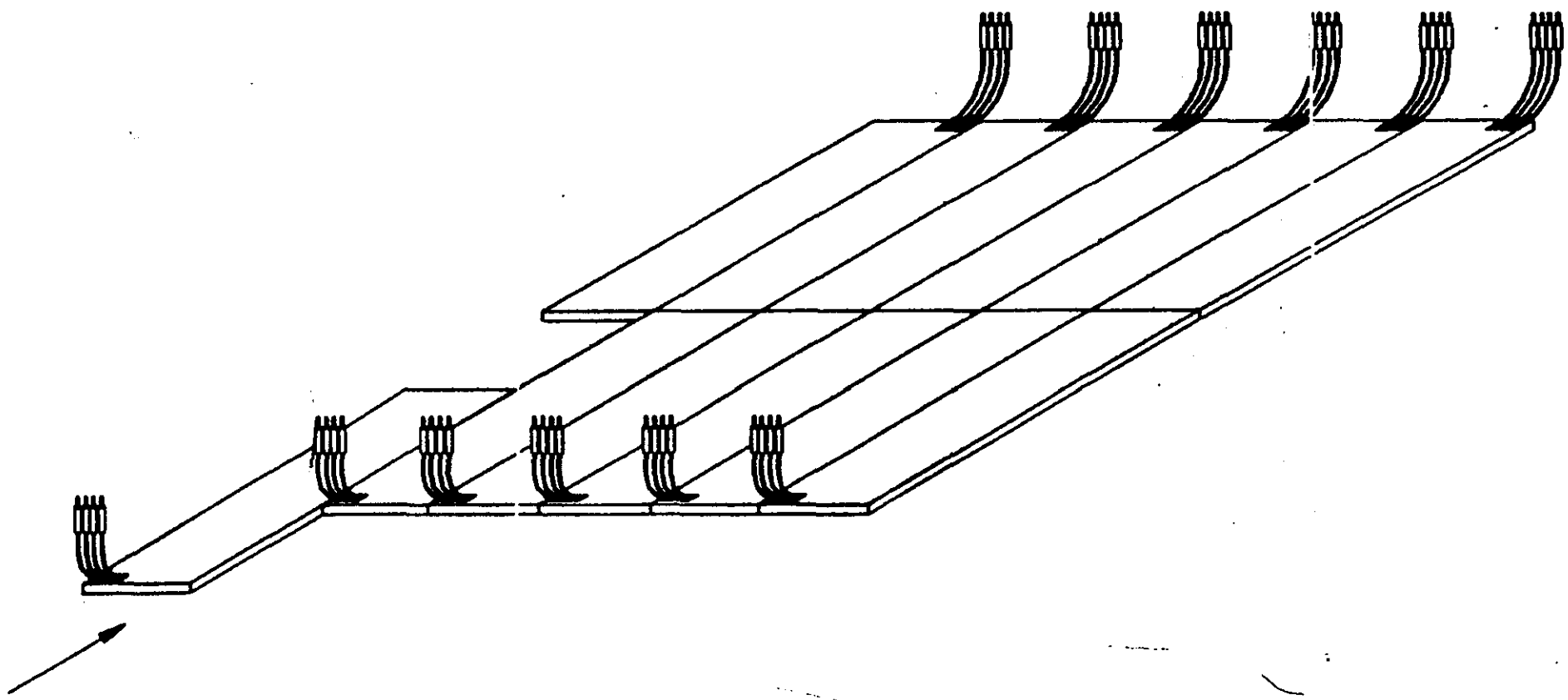
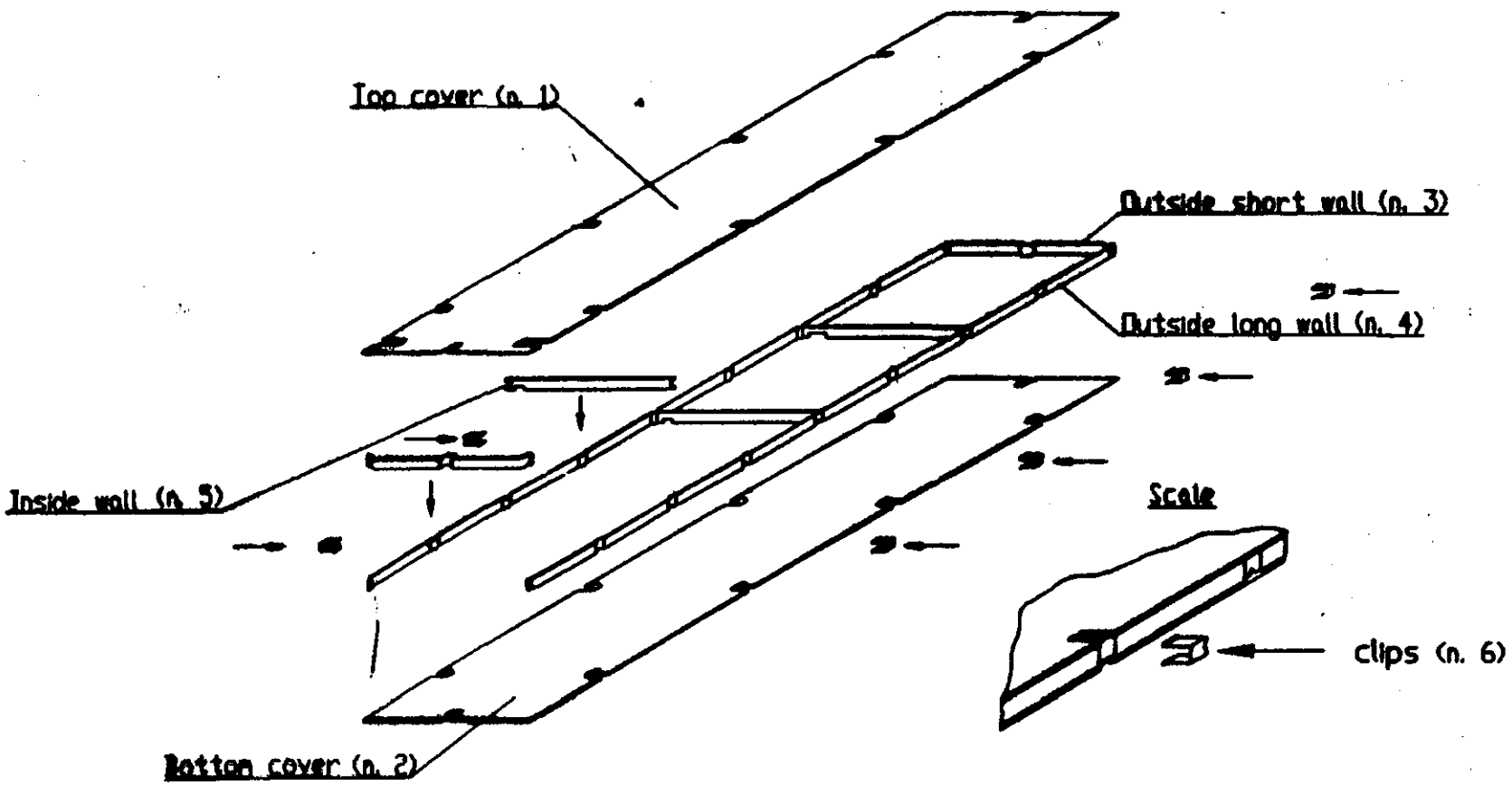


Fig. 3

LS. Detector Layer (Plane)
consists of individual trays



LS detector tray assembly



HADRON CALORIMETER

OUTER RADIUS

Hadron Calorimeter outer radius has a fundamental implication for the overall Detector cost via costs of Muon and Magnet systems.

LS - min radial extention for given absorbtion thickness of HC or more absorbtion lengths for given radial extention.

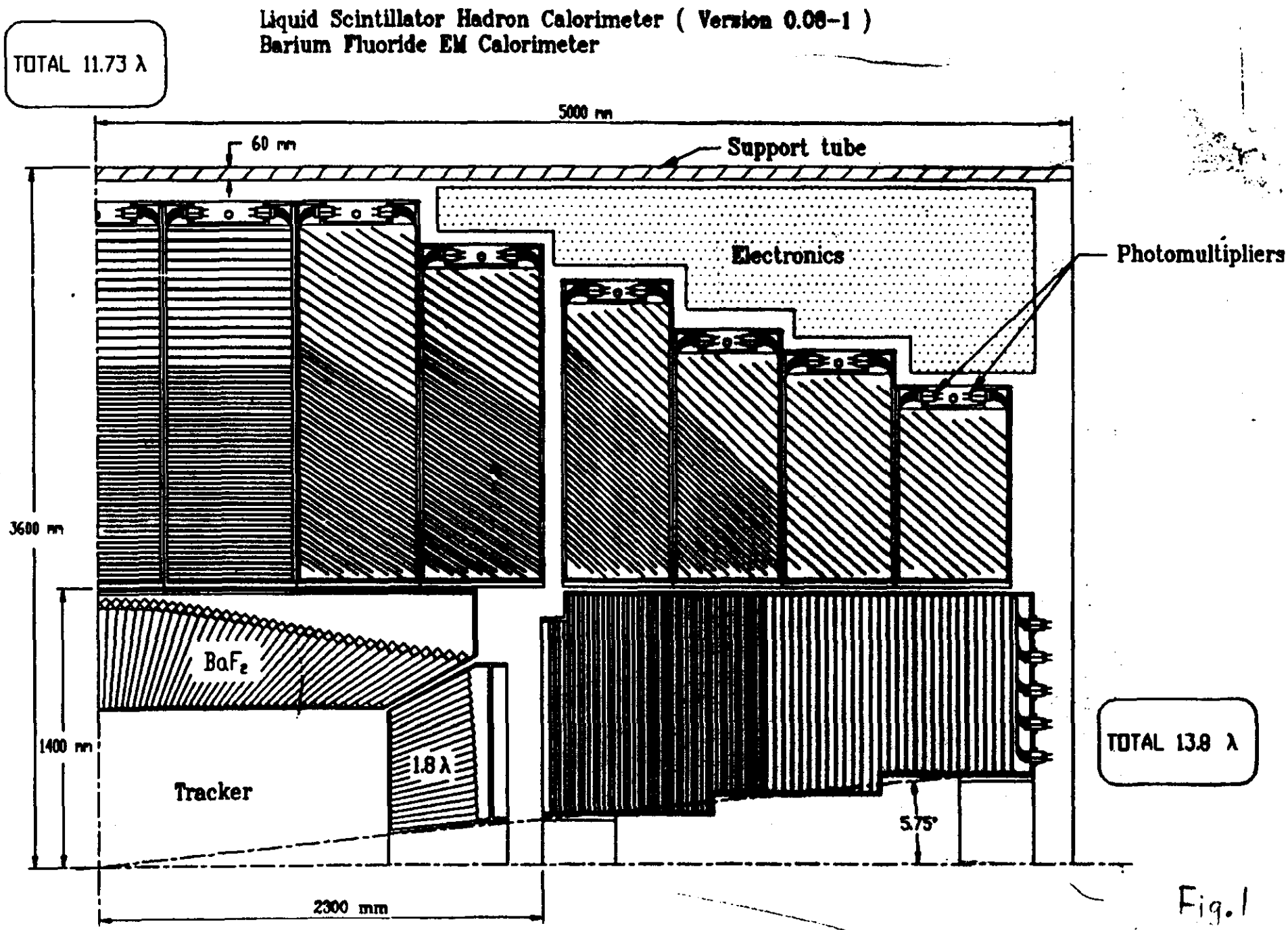
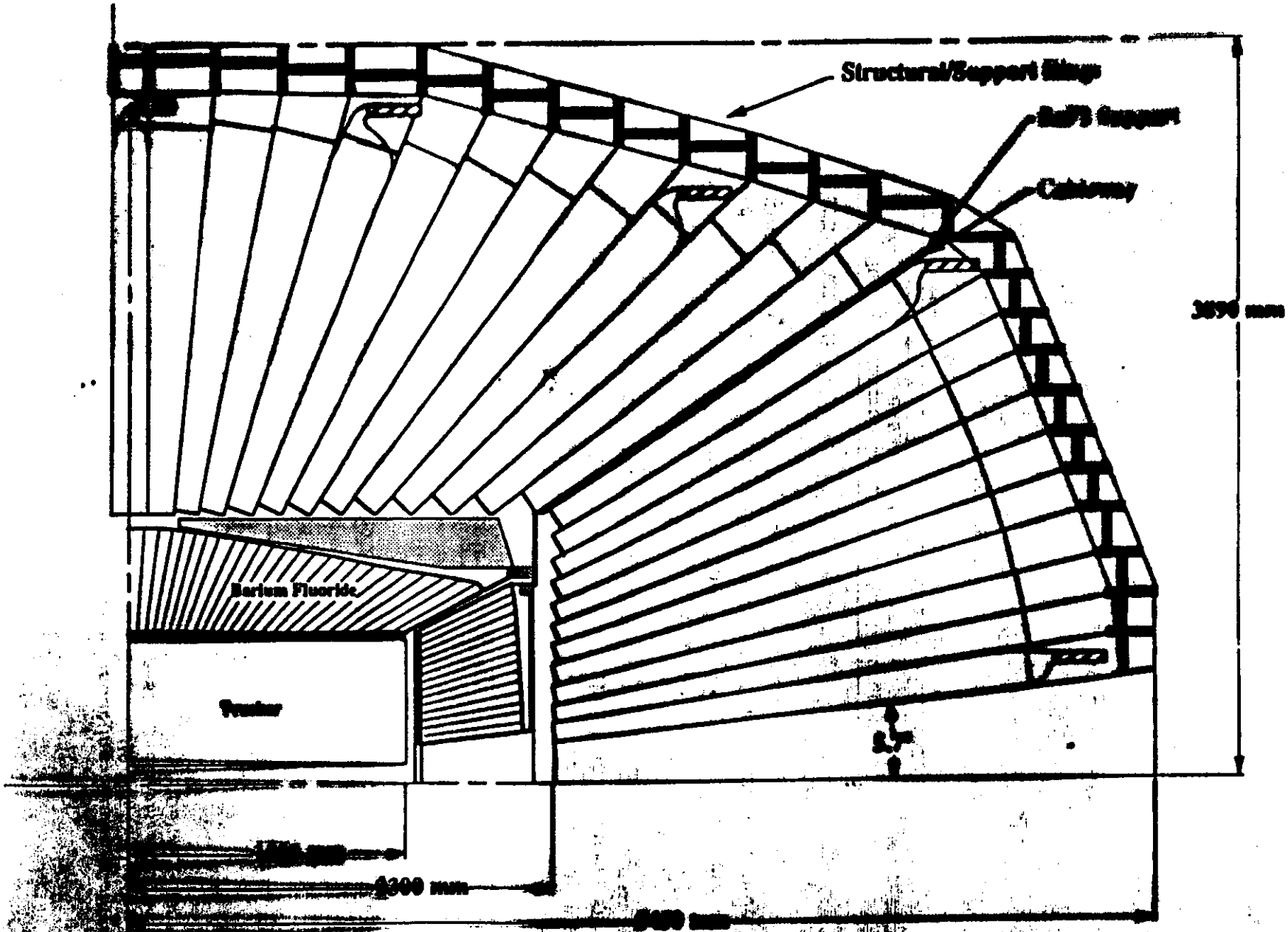

Liquid Scintillator Hadron Calorimeter (Version 0.08-1)
Barium Fluoride EM Calorimeter
TOTAL 11.73 λ
5000 mm
60 mm
Support tube
Electronics
Photomultipliers
3600 mm
BaF₂
1400 mm
1.8 λ
Tracker
5.75°
TOTAL 13.8 λ
2300 mm

Fig. 1

TABLE 1

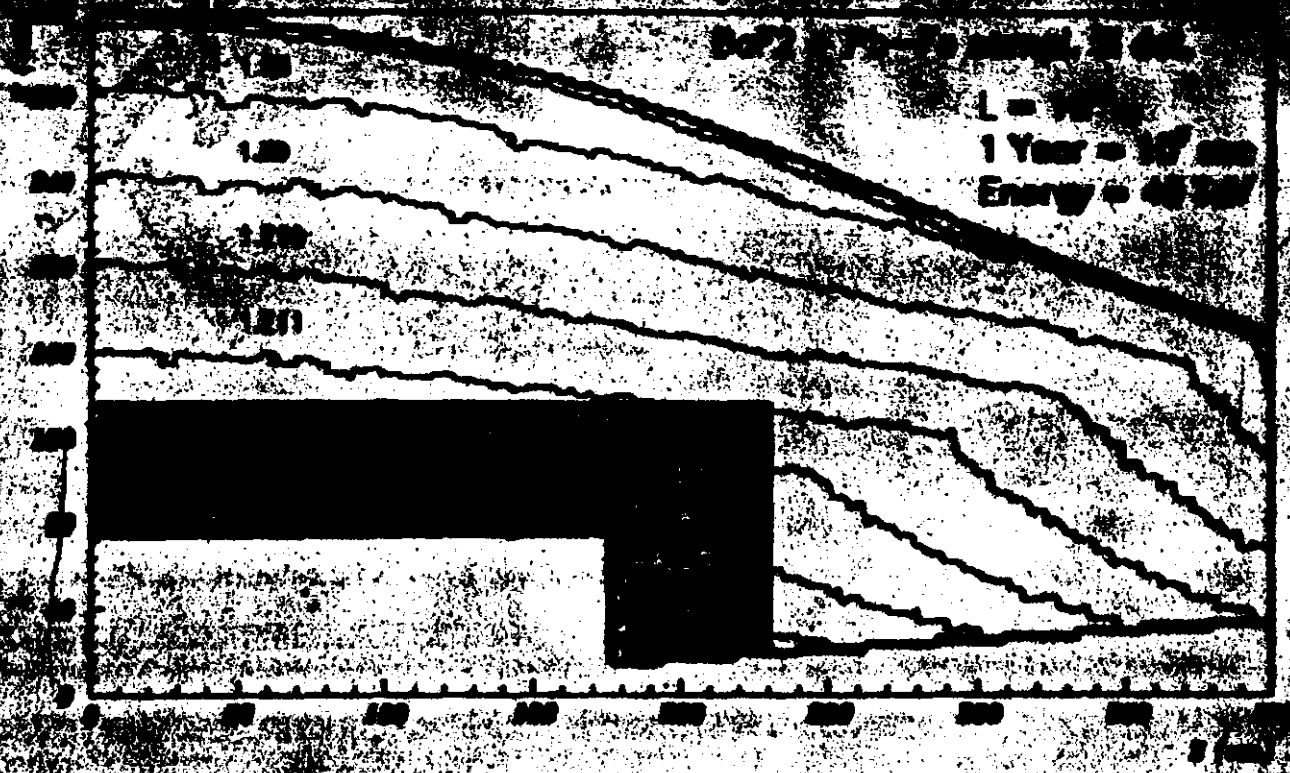
Major Advantages of Liquid Scintillator calorimetery in SSC environment.

- High operation speed;
- No radiation damage problem for liquid scintillator since it can be easily exchanged;
- High radiation resistance of WLS and clear transport fibers;
- Detector flexibility permits fine segmentation both transversaly and longitudinaly;
- Good energy resolution (e/h=1) as in well-understood high-performance plastic scintillator calorimeters;
- Simple mechanical modular design which ensures good uniformity and hermiticity and allows beam calibration of each module prior to installation in the experiment;
- Easy performance monitoring (with radioactive source per each readout channel);
- Good signal/noise ratio (1 mip $\sim$ 30 photoelectrons per readout channel in PMT);
- Low cost technology sutable for mass production.

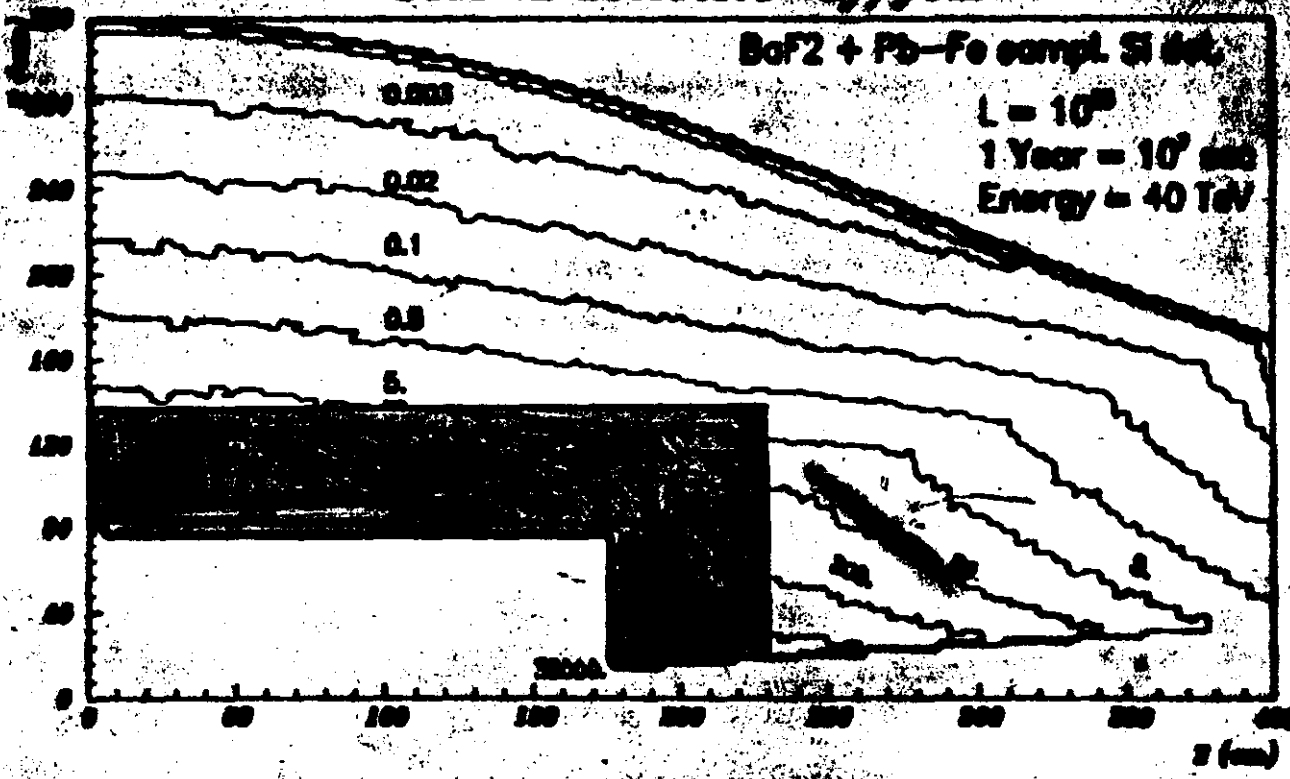

Structural/Support Rings
Cableway
Barium Fluoride
Tracker
3890 mm
5.7°
Hadron Calorimeter
Segmentation
Calorimeter

Longitudinal segmentation

- Muon / hadron separation (by shower profile)
- Muon bremstrahlung identification in HC
- Muon tracking in HC for coordinates and angle measurement
- Muon tracking in HC for trigger
- Provides more detailed topological event info
- Controls longitudinal hadronic leakages
- Helps to identify the e-m leakages from BaF_2 e-m calorimeter
- Reduces the effect of radiation damage on HC performance

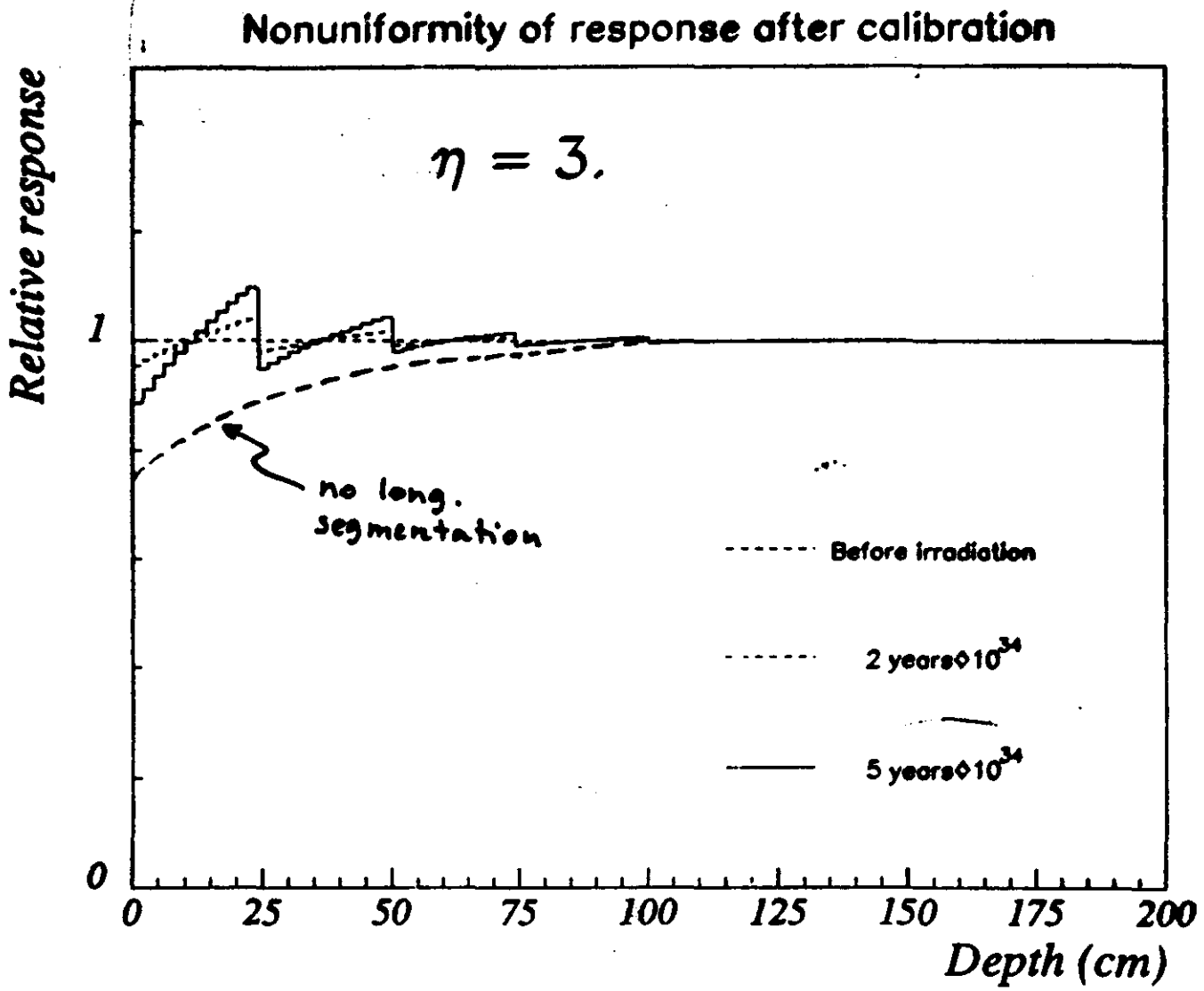


Doze in detectors Gy/year



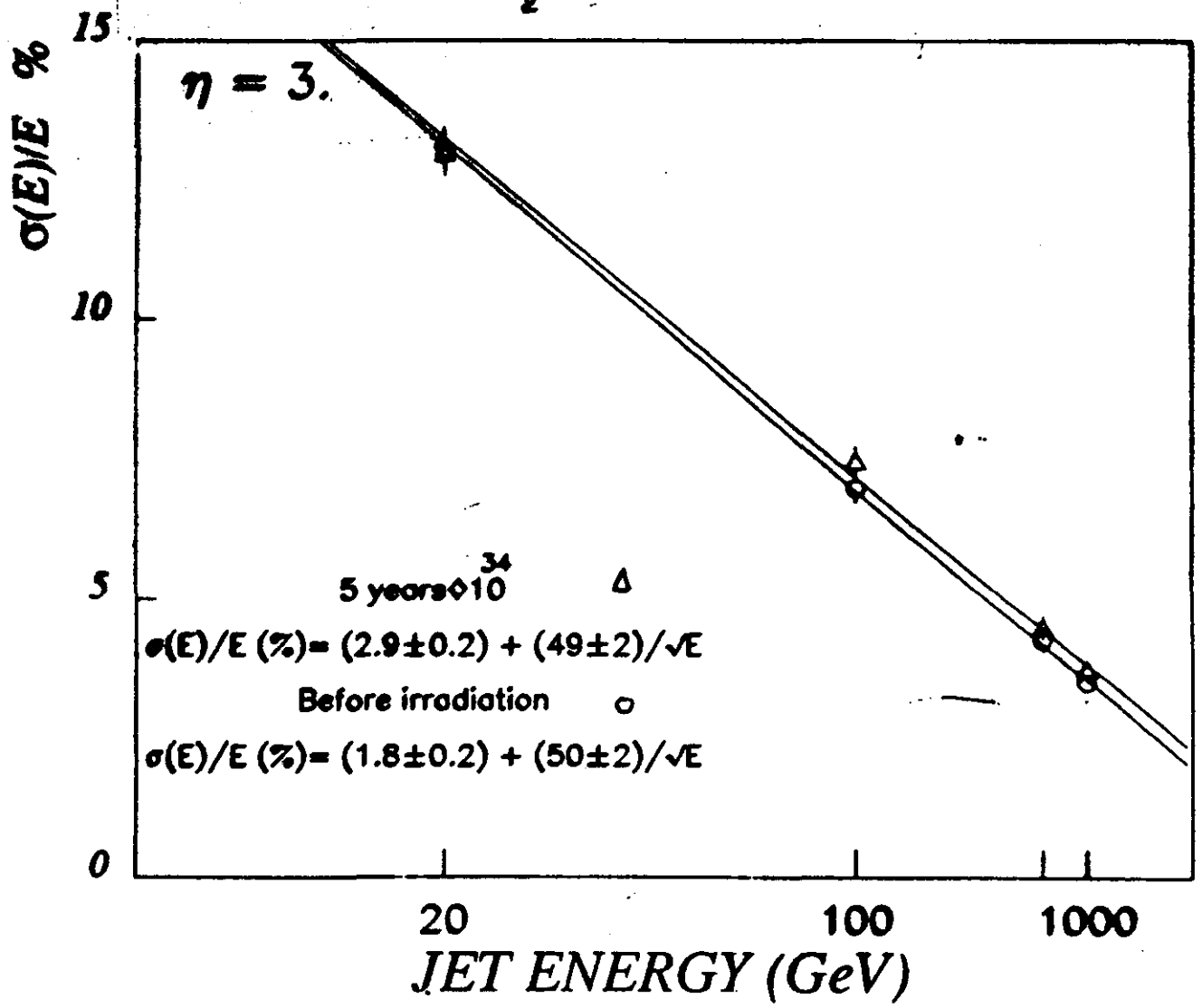
13.04.90 V.Morgunov

Liquid scintillator calorimeter



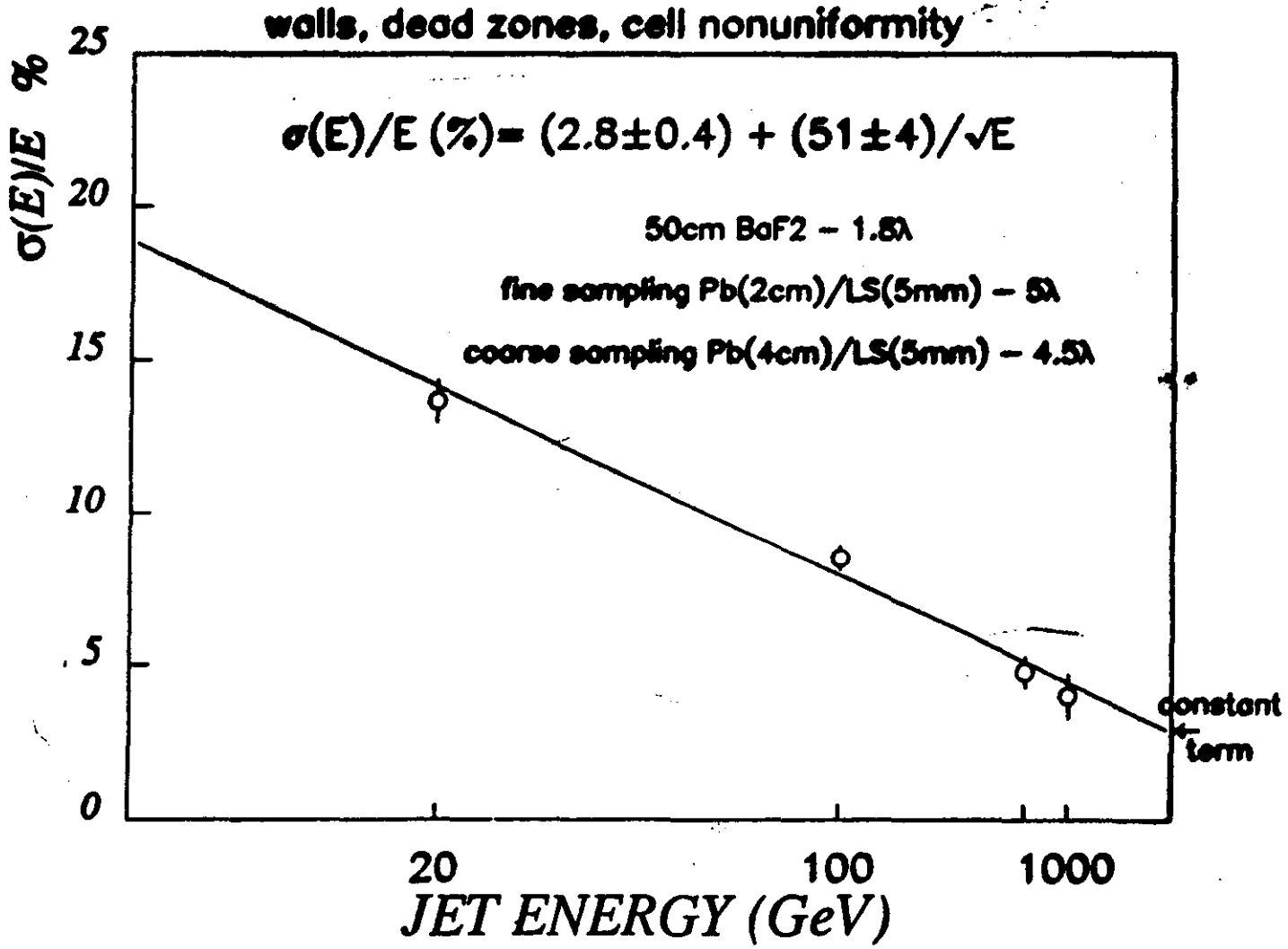
JET RESOLUTION - GEANT3

BaF_2 + LS HC (Version 2)



JET RESOLUTION - GEANT3

16 φ modules, 15 θ modules, real module geometry with walls, dead zones, cell nonuniformity



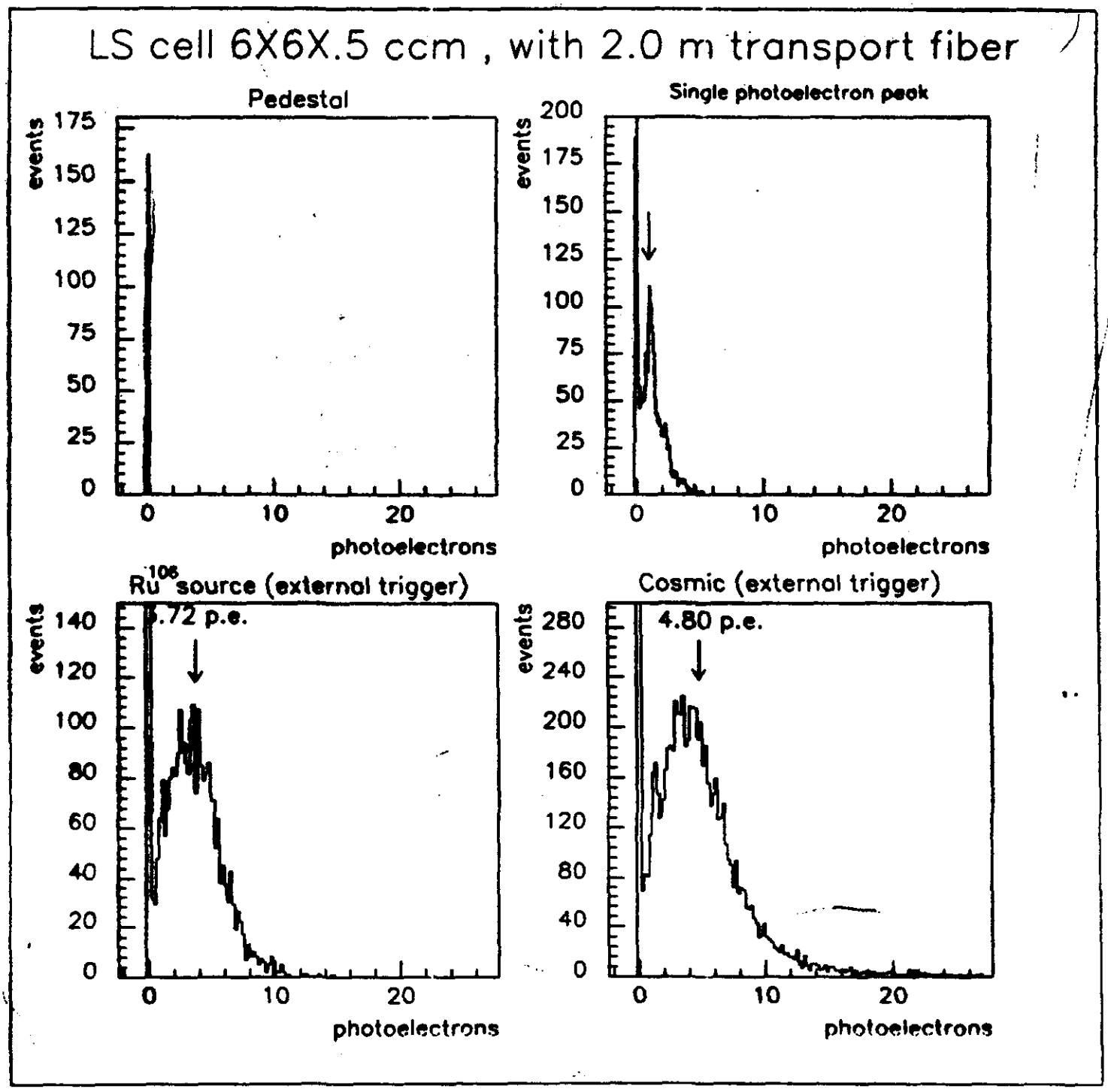

LS cell 6X6X.5 ccm , with 2.0 m transport fiber
Pedestal
events
photoelectrons
Single photoelectron peak
events
photoelectrons
Ru106 source (external trigger)
.72 p.e.
events
photoelectrons
Cosmic (external trigger)
4.80 p.e.
events
photoelectrons

TABLE 8

Light yield calculation for Liquid Scintillator cell.

(Parameters of the cell are ginvm in the text)

Average energy loss in 5 mm LS layer	0.9 MeV
Energy spent to create photon in anthracene	61 eV
Light output of BC517PKO relative to anthracene	35%
Monte Carlo factors	
Fraction of light intercepted and reemitted by WLS (BCF-9928) fiber in the cell (efficiency of WLS reemission 86%)	38%
Fraction of reemitted light captured and transported along the WLS fiber (BCF-9928)	3.9%
Transport efficiency of 2 m clear fiber	70%
Average Q.E. of Photocathode H1161H	9.6%
Total photoelectrons	5.1 p.e.

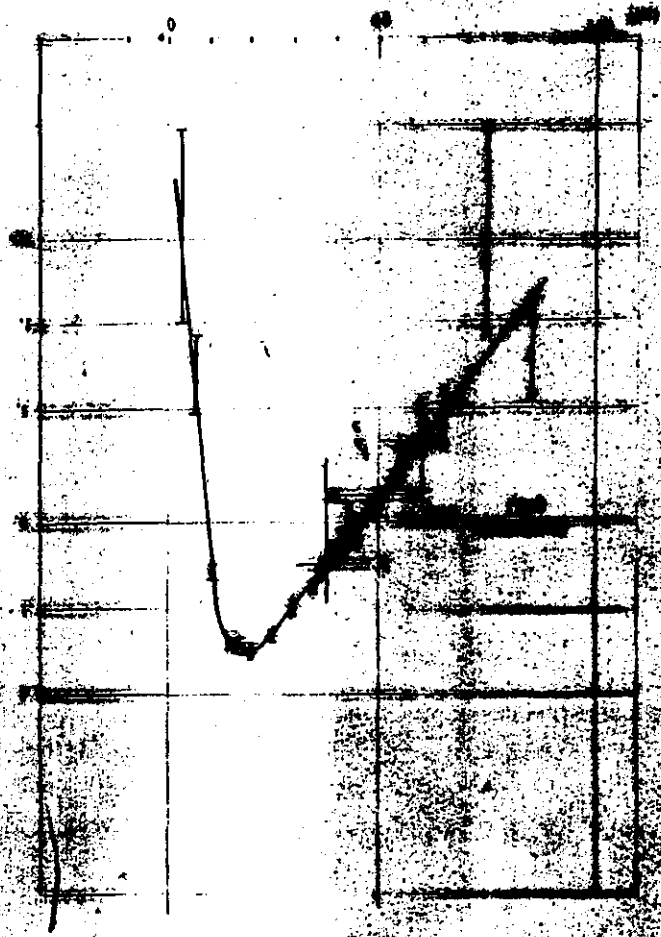
"μ" → ~ 240 p.e. / m.i.p. (total thick.)

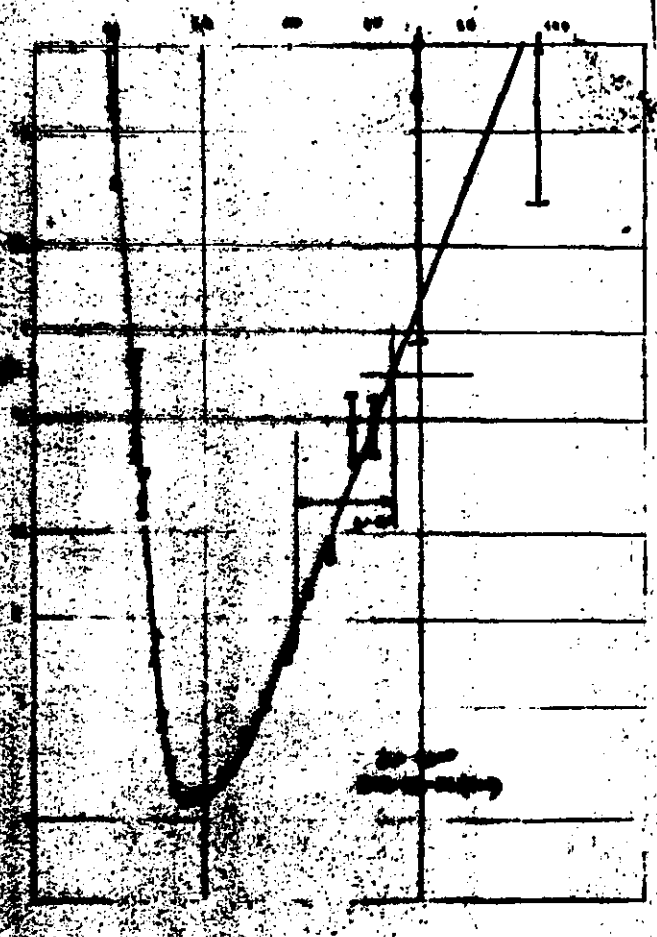
"h" → ~ 115 p.e. / GeV

Timing of LS + WLSF

Light bouncing in LS cell $6 \times 6 \times 0.5\ cm^3$	0.7 ns
Light collection by WLS within readout group	< 3 ns
Scintillator decay time (BC 517 P)	2.2 ns
PMT rise time (R2490-05)	2.1 ns
WLSF decay time (BCF-91)	~ 11 ns

needs improvement


KSJ



Beam tests by summer 1992 ?

- Type of LS, WLS fibers, clear fibers, fiber joints, PMT type, light yield, response uniformity of LS cell, simple mechanical construction of LS cells, trays and planes, fiber thermal shaping etc. - were addressed in previous R&D work (figs)

- Beam tests with single prototype plane (36 cells) are due at ITEP by December 1991 (figs). People from ORNL, ITEP, UT, LLNL, UMich are involved. Everybody welcome to join!

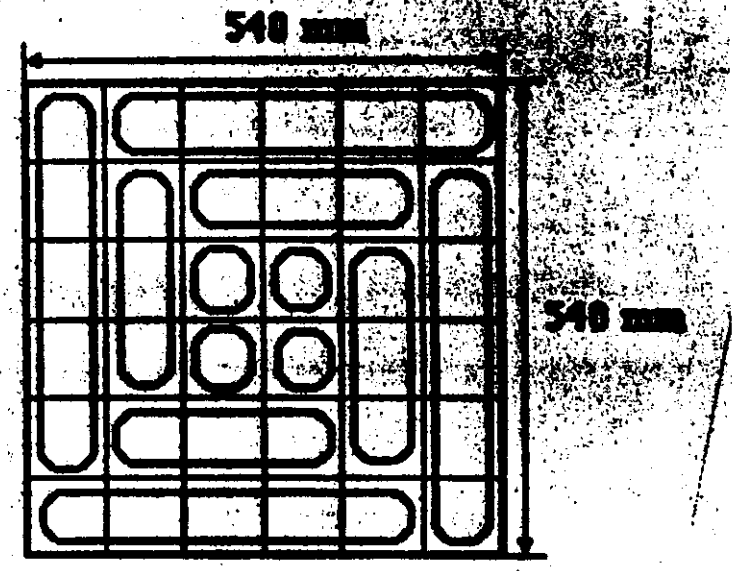
- Original idea (R&D proposal to SSCL) of one HC (GEM type with all mechanical issues demonstrated module construction by Nov. 92 was reconsidered to meet GEM requirements of beam tests at CERN with BaF2 in front by summer 92.

- Simplified prototype can be built by ORNL + ... by summer 1992. This will feature 70 Pb absorbers 20 mm thick + 5 mm LS gaps in bath-like design; 5-10 longitudinal segments, 8.5 abs. lengths, transverse size 100 cm x 100 cm, 7000 cells/fibers, 500-600 readout channels. Single plane test - prototype for that.

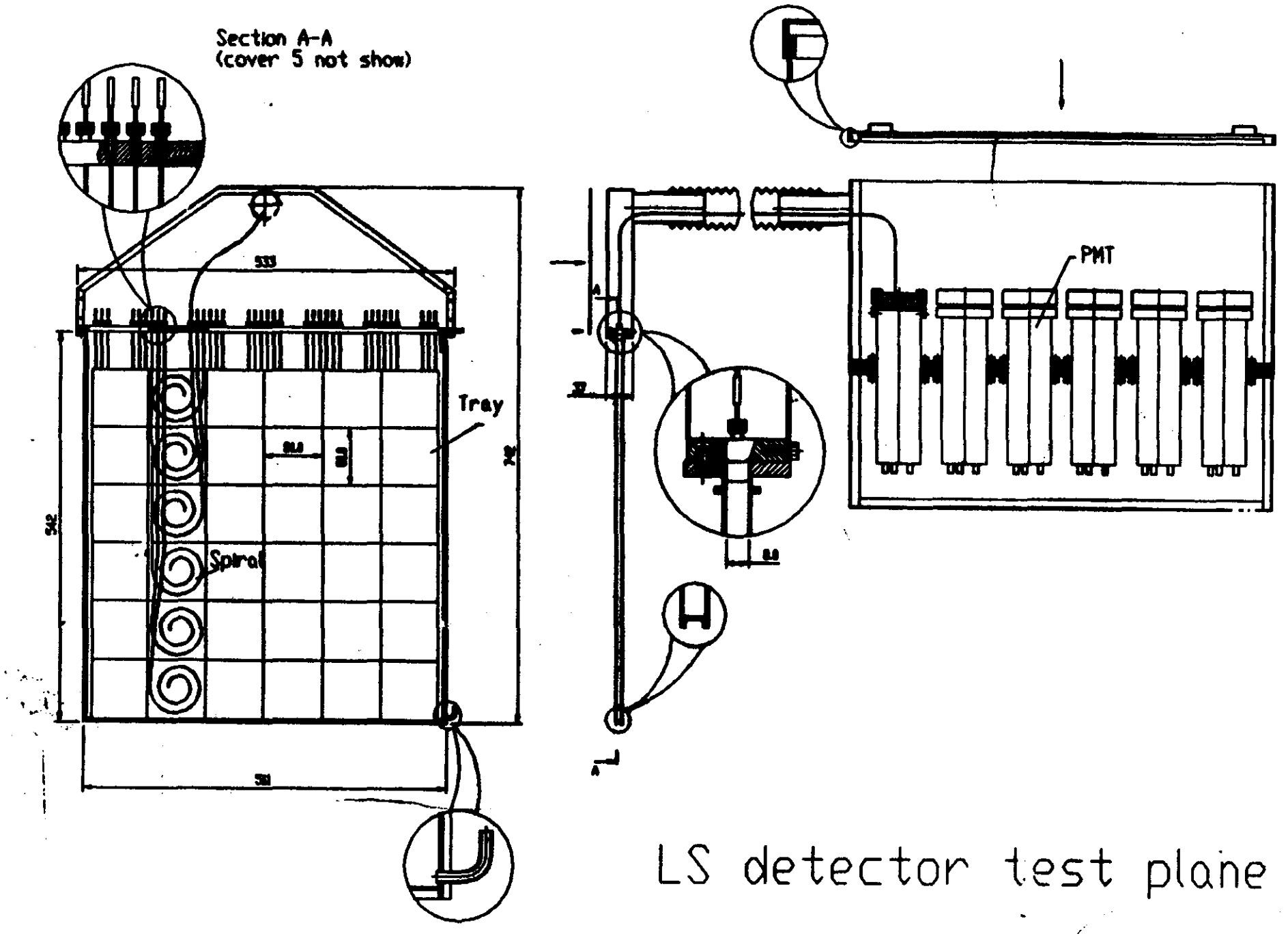
Beam tests with single detector plane

1. Build detector plane in a sealed shell, 3 m long transport fibers, system for scintillator filling.

36 LS cells 90x90 mm^2
36 fibers
36 α - sources
1 Hamamatsu PMT
12 readout channels



2. Get one 16 channels Hamamatsu PMT or 12-16 channels of appropriate photodetectors
3. Build 12-16 channels of amplifiers/cable drivers
4. Use LeCroy 2249A , data acquisition system, absorbers, mechanical supports and test beam at ITEP.
5. Target date for beam tests - ~~February 92.~~ December '91
6. Program : system performance test and e-m, hadronic shower scans in Lead absorber.


Section A-A
(cover 5 not show)
Tray
Spiral
PMT
LS detector test plane

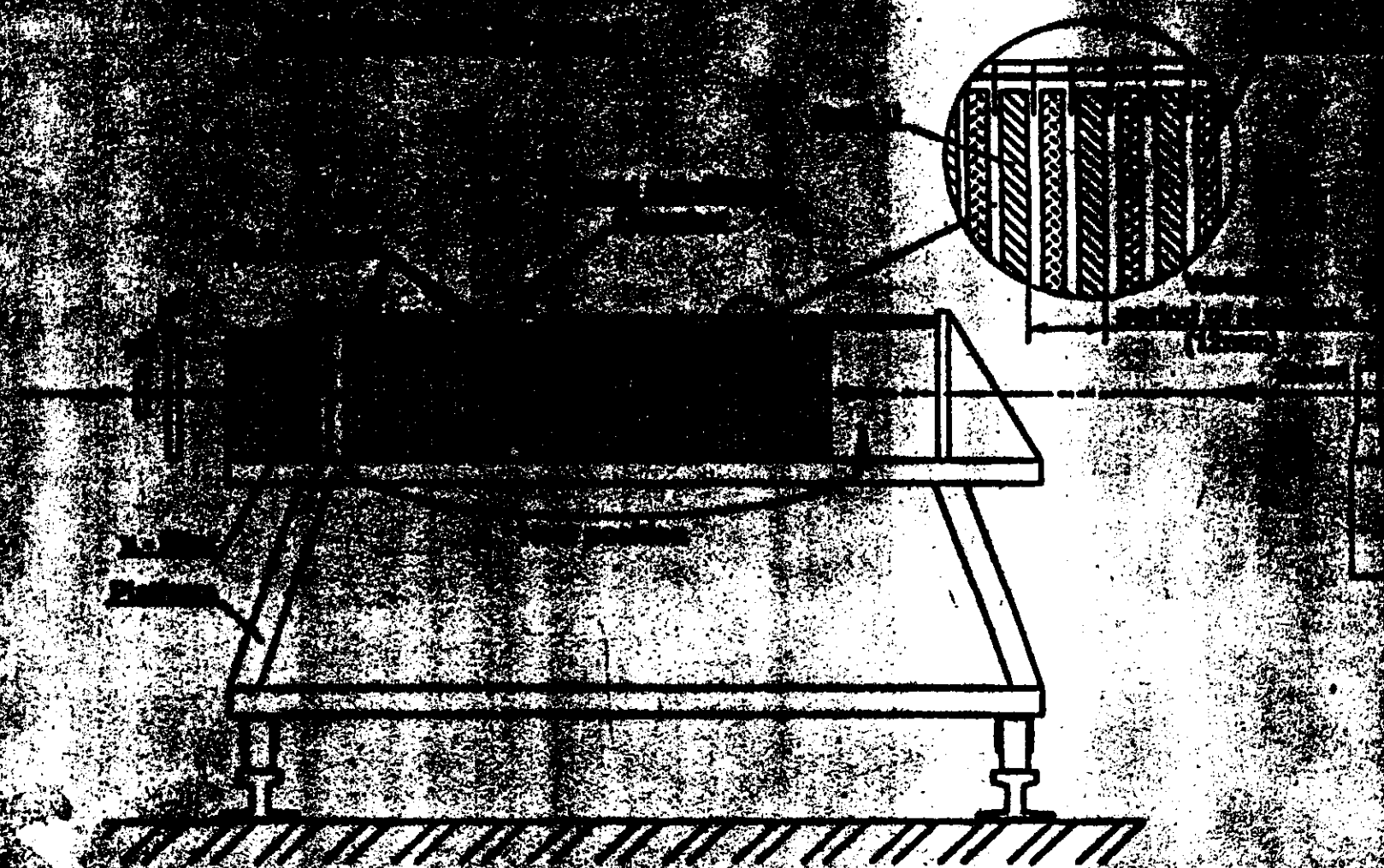


Fig.14 The beam test setup for the scanning through the absorber stack with a prototype plane of liquid scintillator chamber.

ITEP test beam

- 10 GeV PS
- internal Be target , 3.5° beam
- available channel : ± 0.3 – 6 GeV/c, $\frac{\Delta p}{p} \sim 2\%$
- π, e , μ, p , d
- typical intencity 5–50 K pions per spill (length up to 1 sec, period 2.5 sec)
- beam size ~ 2×3 cm²
- Equipment (collimators, converters, beam sc. counters, 2 gas Cherenkovs , 2–3 λ muon filter, supports)
- beam MWPC (2 mm pitch) – in preparation
- available absorbers :

U (5 × 485 × 618)	– 100 plates
Pb (6 × 500 × 500)	– 100 plates
Fe (25 × 500 × 500)	– 40 plates

- NIM, CAMAC crates, PDP 11–40 for readout, 1600 bpi tape drive, 470 Mb hard disk, simple graphic, on–line DAQ sistem

Do we have enough "critical mass" for these beam tests ?

BU, BNL, UCSD, MU with

ORNL, UTK (workshop), LLNL, UMiss (workshop), ITEP

enough to build and test LS HC prototype at CERN by summer 1992. Start NOW.

Principal Reasons to Choose a Scintillating Fiber Hadron Calorimeter for the GEM Detector

L. Sulak for the SF Group

GEM Calorimeter
Working Group Meeting

SSC Laboratory

November 6, 1991

3) **Strength/Experience of Scintillating Fiber team**

SPACAL (for EAGLE @ LHC?)
- 15% US Contribution
- $2.5M effort
- 30 collaborators

SSCintCAL (for GEM @ SSC)
- $0.5M received in FY90
- $0.7M received in FY91
- $0.9M requested for FY92
- 40 collaborators/ 9 institutions

LS Collaboration (for GEM @ SSC?)
- $1.1M requested for FY92
- 72 collaborators (35 US) / 8 institutions (5 US)
- ITEP commitment to SSC/GEM?

4) **Additional option for EM calorimetry (no cost)**

SF provides 6%/sqrt(E) backup to BaF2 and LAr

LS high-resolution undeveloped

5) **Cost differences between liquid and fibers are within the errors between Draper and ORNL cost estimates**

Small cost differential coupled to projectivity for SF
3 Draper and 1 Martin Marietta reports
Explicit bids coming from industry

Second (review) of LS costing yet to be done

Reasons to Choose Scintillating Fibers over Liquid Scintillator for Hadron Calorimeter

1) Should choose technology for which prototypes have been built and tested

SPACAL -- 6 different prototypes built and tested
8 publications in NIM, 2 CERN reviews
13 Tons operational in Omega

SSCintCAL -- 3 different prototypes, 2 tested
2 SSC R & D reviews, 1 TNRLC review

JETSET -- 300 modules operation over 1.5 years

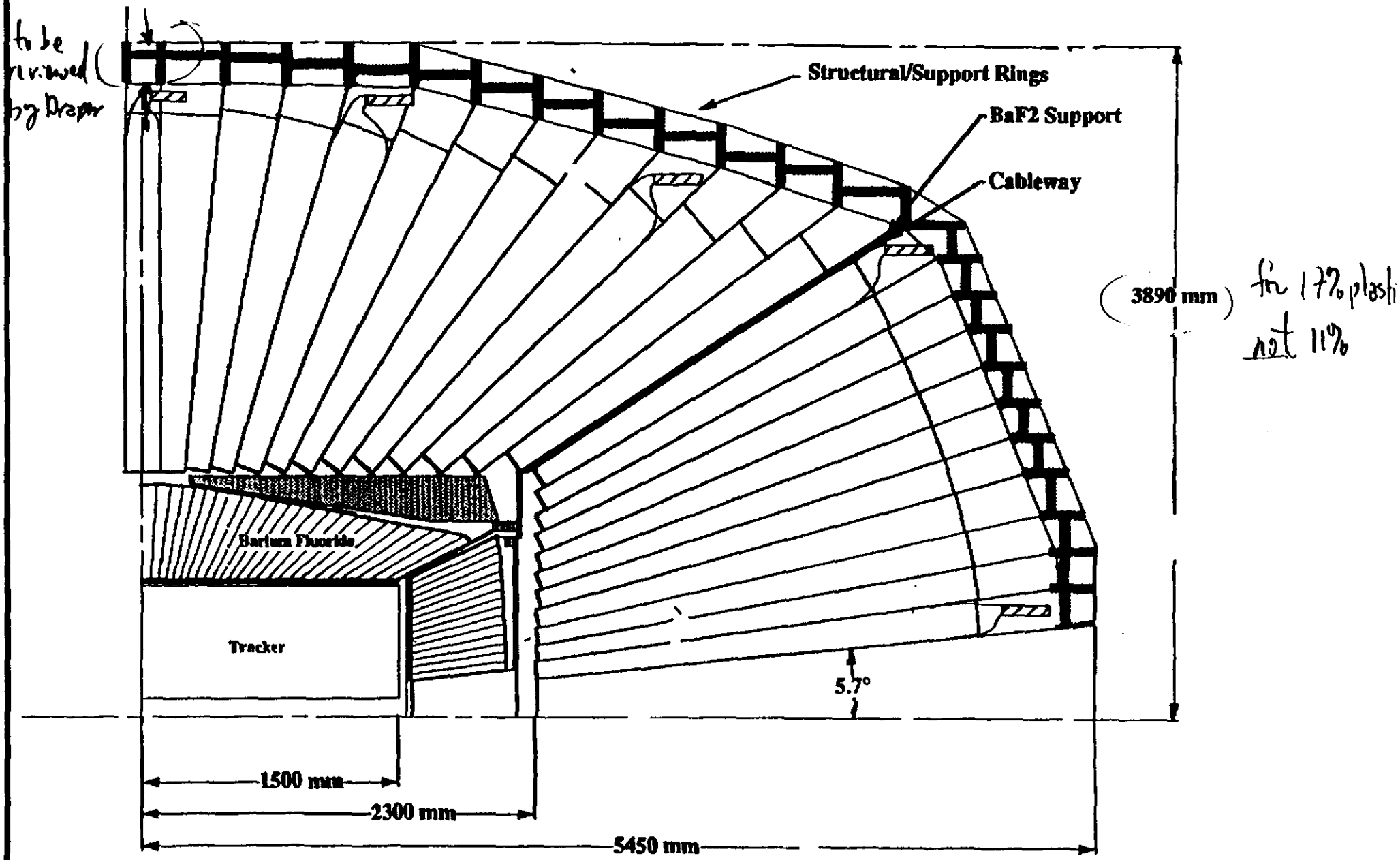
Liquid Scintillator -- No large prototypes.

2) 15-Ton Hadron shower-containing prototype complete by June 1992

Using existing infrastructure to build new modules
4 years into design and test beam program

Liquid scintillator R & D program much less developed
Insufficient time to design and test by November 1992

[illegible] design [illegible] projective



Spaghetti Hadron Calorimeter
Lead Shot Filled/ [illegible] Segmentation
Barium Fluoride E.M. Calorimeter

G.03.SC.00038

Rennich

Fiber Calorimetry

Detailed Prototype Work, Beam Test

* In GEM
  - KEK
  - * SPACAL — [illegible] — 15k [illegible]
  - * G-2
  - * SSCINTCAL
  - FERMILAB
  - * ILLINOIS — JETSET — [illegible]
  - TORINO
  - * UCSD
  - * TEXAS A&M
  - CERN
  - * MICHIGAN STATE
  - * BOSTON

[illegible]

OPERATIONAL EXPERIMENTS

... hundreds of towers

JETSET
PS 185
SPACAL

FIBER CALORIMETRY PUBLICATIONS

(6) "New results in scintillating fiber calorimetry," Contributed to the Proceedings of the Tucson SSC Workshop, February, 1990. Results of prototype studies for a spaghetti calorimeter, *Nucl. Inst. Meth.* A294, 193, 1990;

Status of scintillating fiber calorimetry, "Contributed to the Proceedings of the Division of Particles and Fields Conference, Houston, TX, January, 1990;

"The High Resolution Spaghetti Hadron Calorimeter," P. Jenni, P. Sonderegger, H.P. Paar, and R. Wigmans, NIKHEF report NIKHEF-H/87-7 (1987);

"Scintillating Fibre Calorimetry at the LHC," D. Acosta et al., CERN report CERN/DRDC/90-23 DRDC/P 1 (1990);]

"A Novel Way of Electron Identification in Calorimeters," R. Desalvo et al., *Nucl. Inst. Meth.* A279, 467 (1989);

"Results of Prototype Studies for a Spaghetti Calorimeter," D. Acosta et al., *Nucl. Inst. Meth.* A294, 193 (1990);

"Electron-Pion Discrimination with a Scintillating Fiber Calorimeter," D. Acosta et al., *Nucl. Inst. Meth.* A302, 36 (1991);

"Localizing Particles Showering in a Spaghetti Calorimeter," D. Acosta et al., CERN preprint CERN-PPE/91-11 (1991); Submitted to *Nucl. Inst. Meth.*

"Electron, Pion, and Multiparticle Detection with a Spaghetti Calorimeter," D. Acosta et al., CERN preprint CERN-PPE/91-85 (1991). Submitted to *Nucl. Inst. Meth*;

"Effects of Radiation Damage on Scintillating Fiber Calorimetry," D. Acosta et al., CERN preprint CERN-PPE/91-45 (1991). Submitted to *Nucl. Inst. Meth*;

"On Muon Production and Other Leakage Aspects of Pion Absorption in a Spaghetti Calorimeter," D. Acosta et al., Submitted to *Nucl. Inst. Meth*;

"Status of Scintillating Fiber Calorimetry," H.P. Paar. Proceedings of the ECFA Study Week on Instrumentation Technology for High-Luminosity Hadron Colliders, p. 207, Barcelona, Spain, 14-21 September 1989, edited by E. Fernandez and G. Jarlskog;

"Beam Tests of Large Lead and Scintillating FiberPrototype Calorimeters," H.P. Paar. Proceedings of the Symposium on Detector Research and Development for the Superconducting Super Collider, Ft. Worth, Texas, October 15-18, 1990;

"Review of Electron Pion Separation Methods Using Scintillating Fiber Calorimetry," M. Sivertz, Proceedings of the International Conference on Calorimetry in High Energy Physics, FNAL, October, 1990;

"A Dichromatic Scintillating Fiber Calorimeter," C. Bromberg et al, Proceedings of the Symposium on Detector R&D for the SSC, Fort Worth, October 1990;

"Cast Lead-Eutectic Solid and Liquid Scintillating Fiber Shower Calorimeters," T. Coan et al, Proceedings of the Symposium on Detector R&D for the SSC, Fort Worth, October 1990;

"The Manufacturing Engineering of a Hermetic Cast Fiber Calorimeter," T. Coan et al, Proceedings of the Symposium on Detector R&D for the SSC, Fort Worth, October 1990;

"Properties of Photodetectors for Scintillating Calorimeters at the SSC," D. Winn et al, Proceedings of the Symposium on Detector R&D for the SSC, Fort Worth, October 1990;

"Search for the Intermediate Mass Higgs," EMPACT/TEXAS Note 340 (1990);

"Beam Tests of a 13 Ton Lead and Scintillating Fiber Calorimeter," Proceedings of the Symposium on Detector R&D for the SSC, Fort Worth, October 1990;

"Scintillating Calorimetry for the SSC: A Progress Report and Request for Funds from the SSCintCal Collaboration," submitted, September 1990;

(7) *Nucl. Inst. and Meth.*, D.W. Hertzog et al., A294,446 (1990);

(8) See L* LOI.

Demonstrated Performance

- SPACAL results illustrate the level of performance achievable in terms of:
    1) Speed + Low Noise
    2) Energy Resolution + Compensation
    3) Uniformity + Hermeticity
    4) Shower Localization + Granularity
    5) Electron/Pion Separation

- Scintillating Fibers allow for flexible design, allowing for optimal cost/performance selection:
    1) Fiber diameter choice
    2) Fiber packing choice
    3) PM physics segmentation choice

-Radiation hardness demonstrated

(<1% change in constant term at 7 MRad)

test beam signals are fast...

time over 1/5 max gives e/π of el. 3.

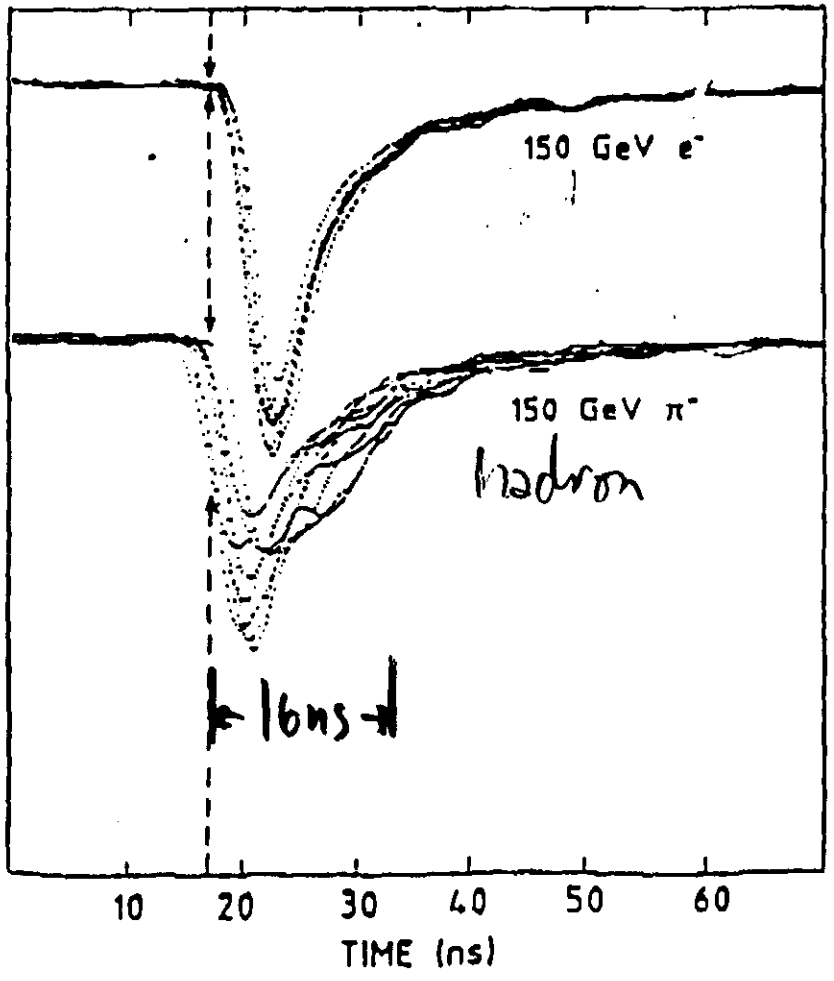


Figure 2a

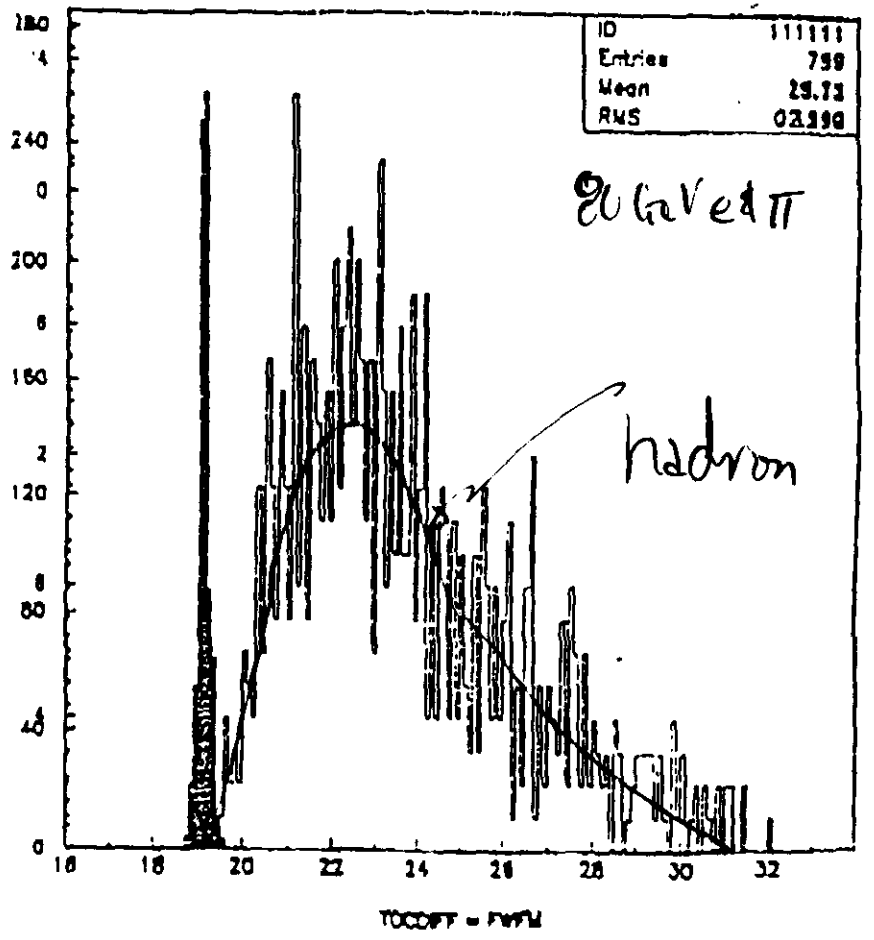
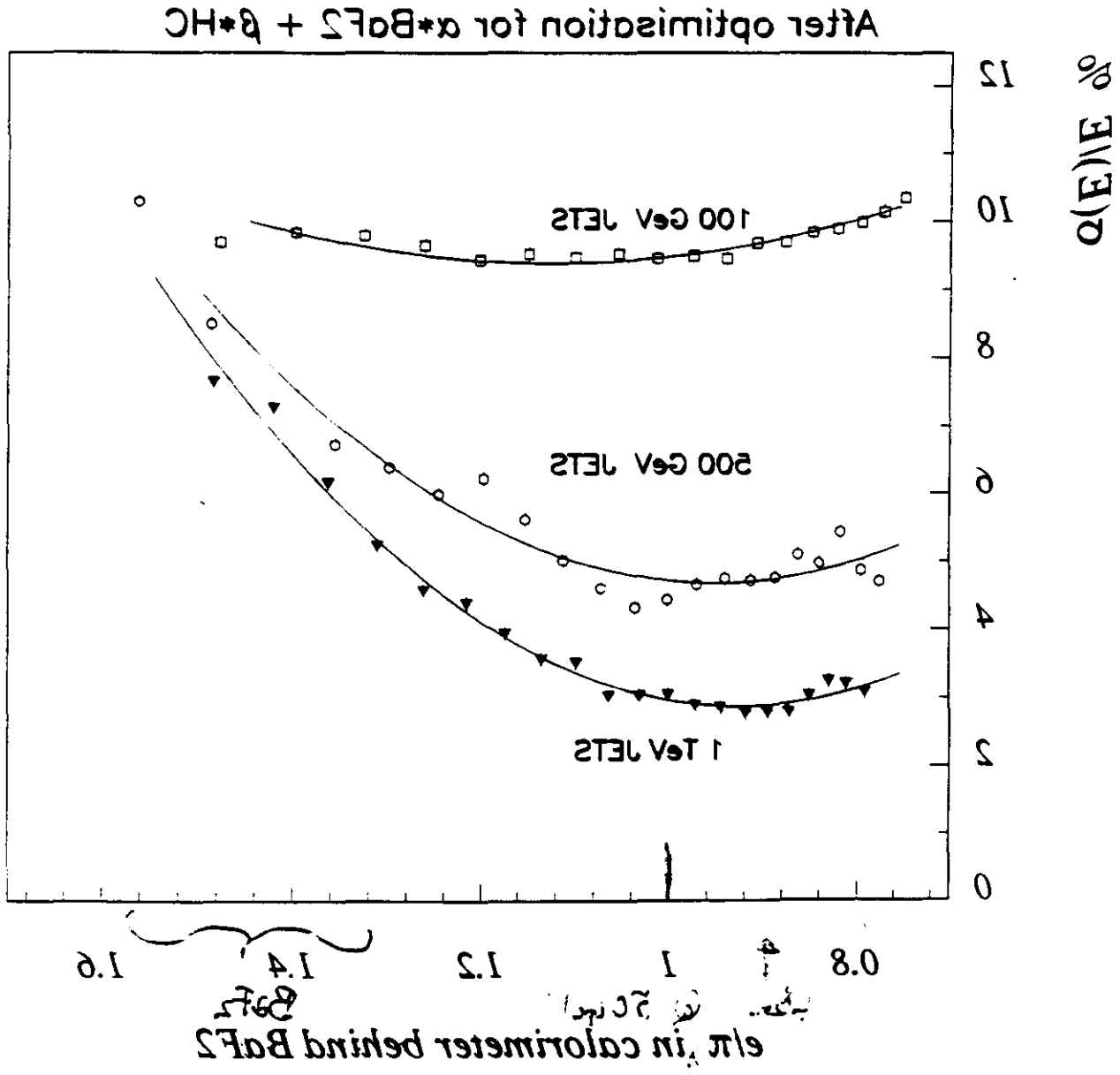
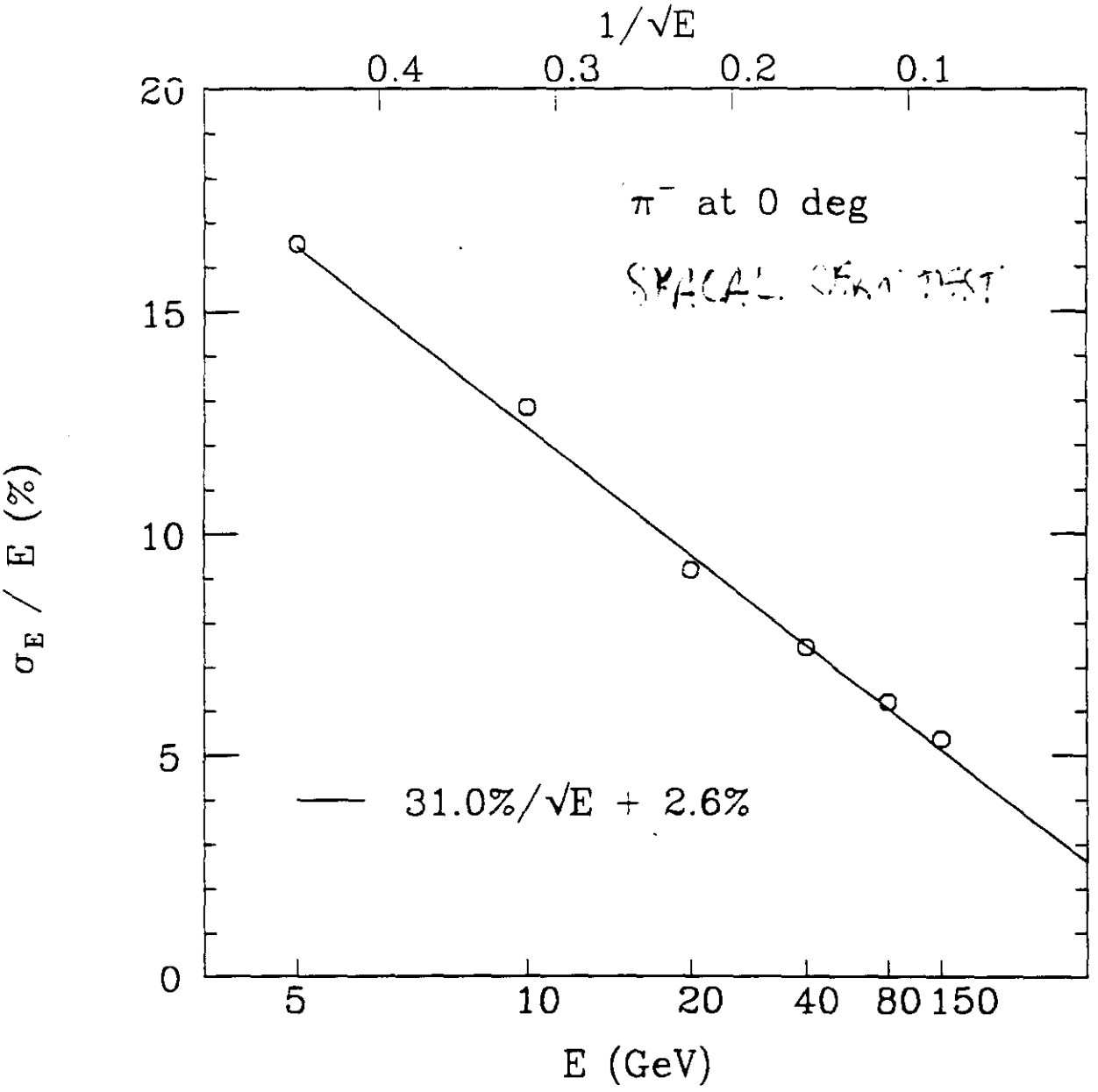


Figure 2b

GEANT3 - JET RESOLUTION for BaF2+scint.HADRON calorimeter



Hadronic Energy Resolution ?



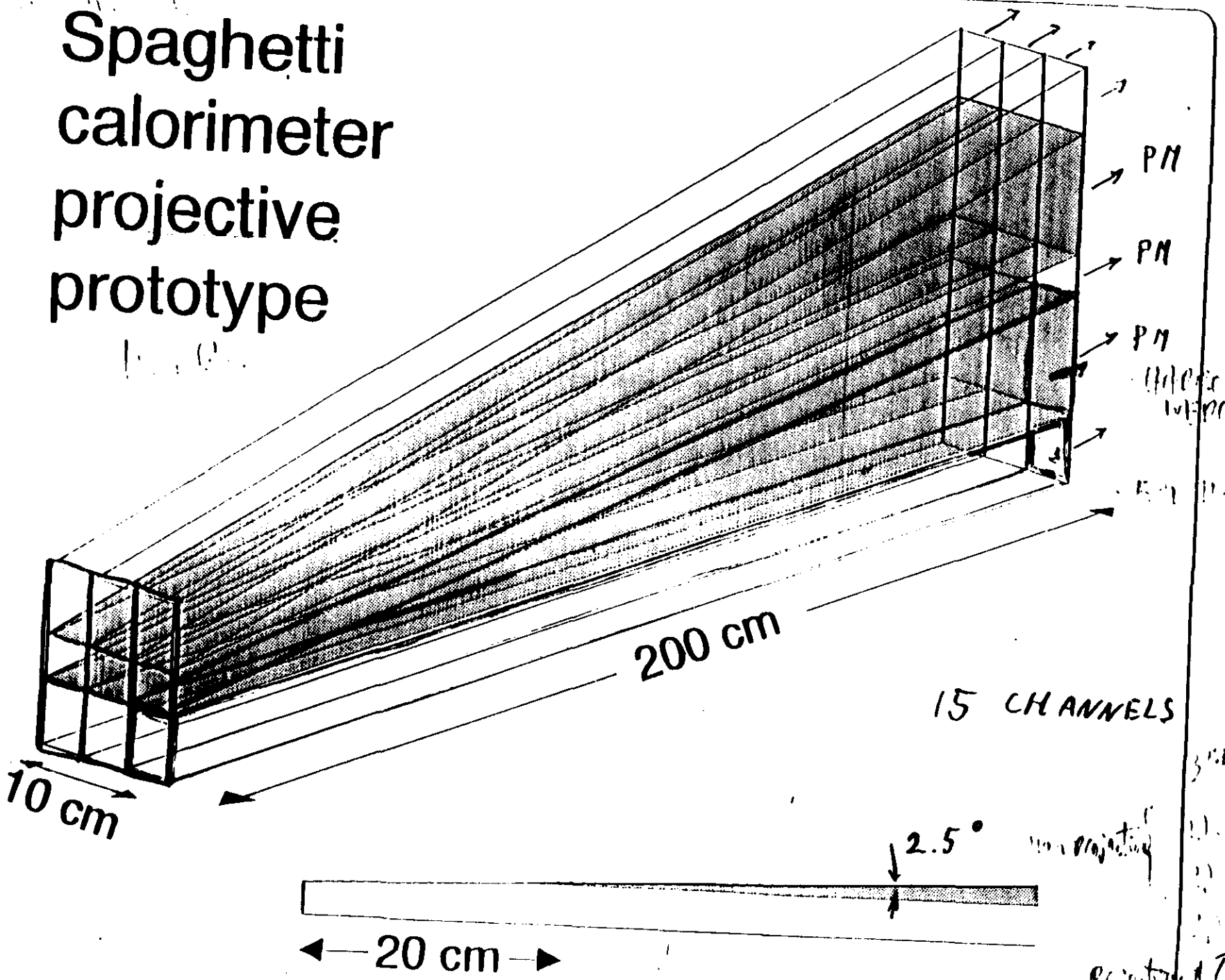
← measured

From a 1/E plastic fraction - 30% 1/E

From a 1/E plastic

← to be tested at FNAL this winter

Spaghetti calorimeter projective prototype



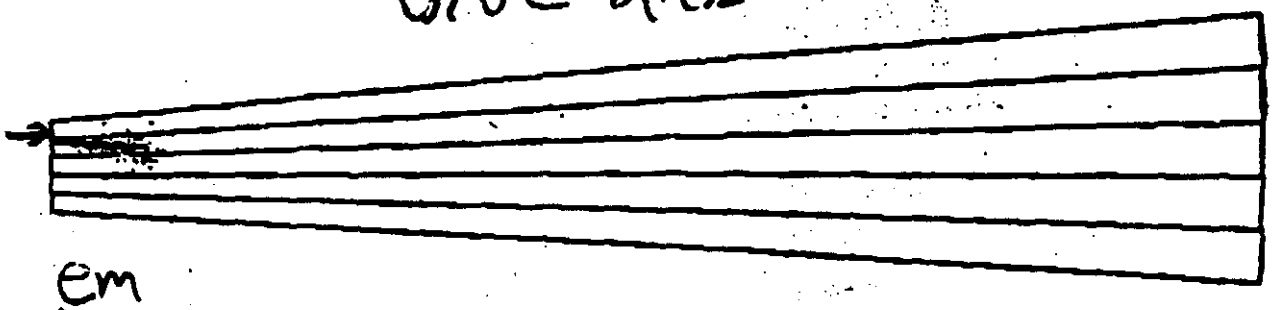
R.D.G

[illegible] and Thus [illegible] segmentation [illegible] highly [illegible]

... TRANSVERSE SEGMENTATION MORE USEFUL @ HIGH $\tilde{x}$

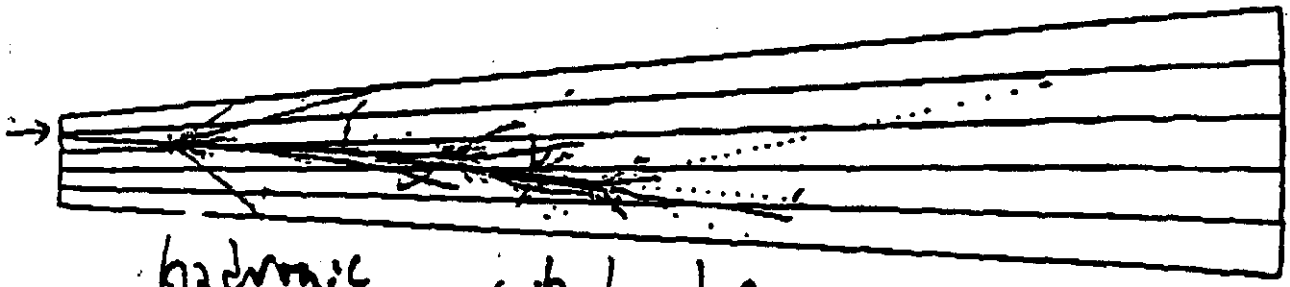
... necessary for good dijet mass reconstr
e, jet isolation cuts
e/jet discrimination

0.02 slices



em shower

Shower Profile of 50 GeV Electron



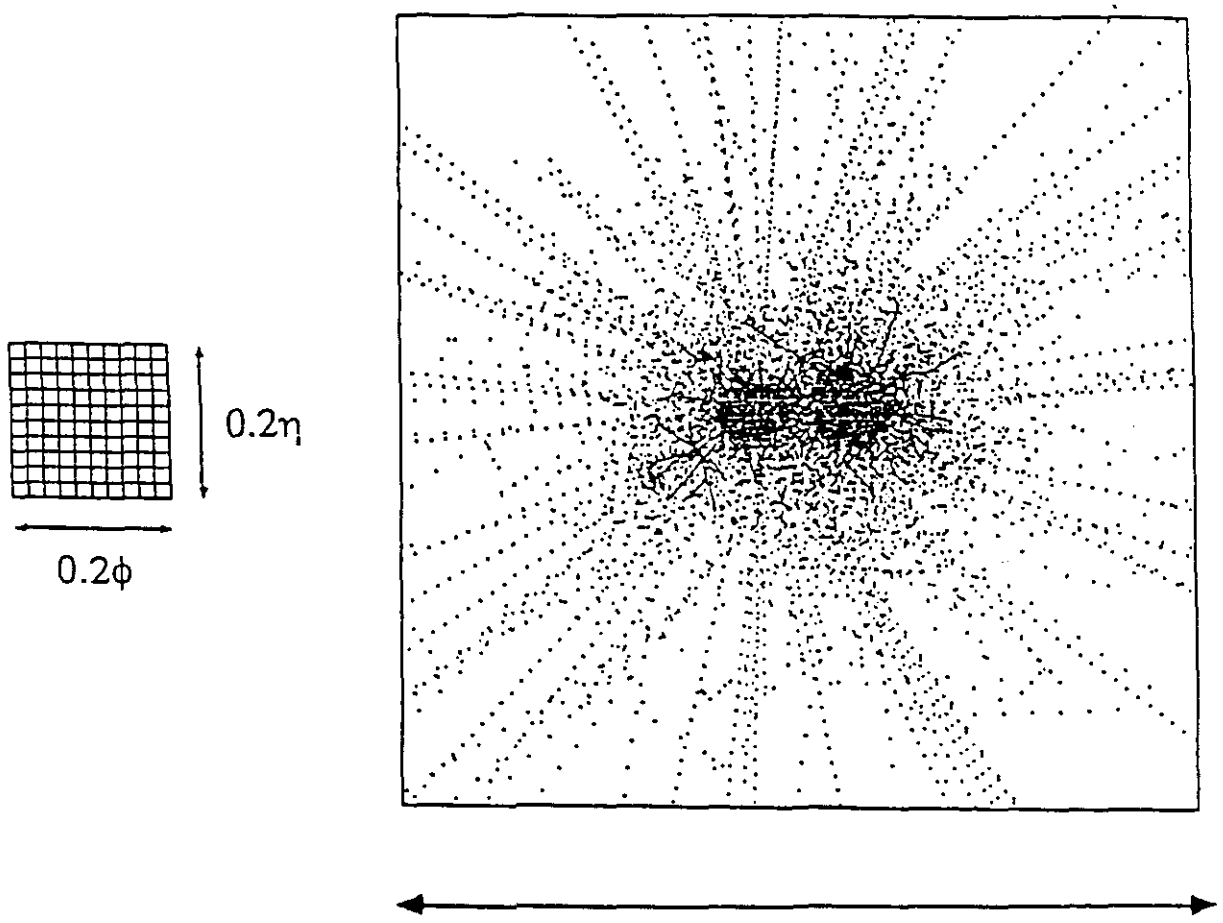
hadronic shower ... with local em

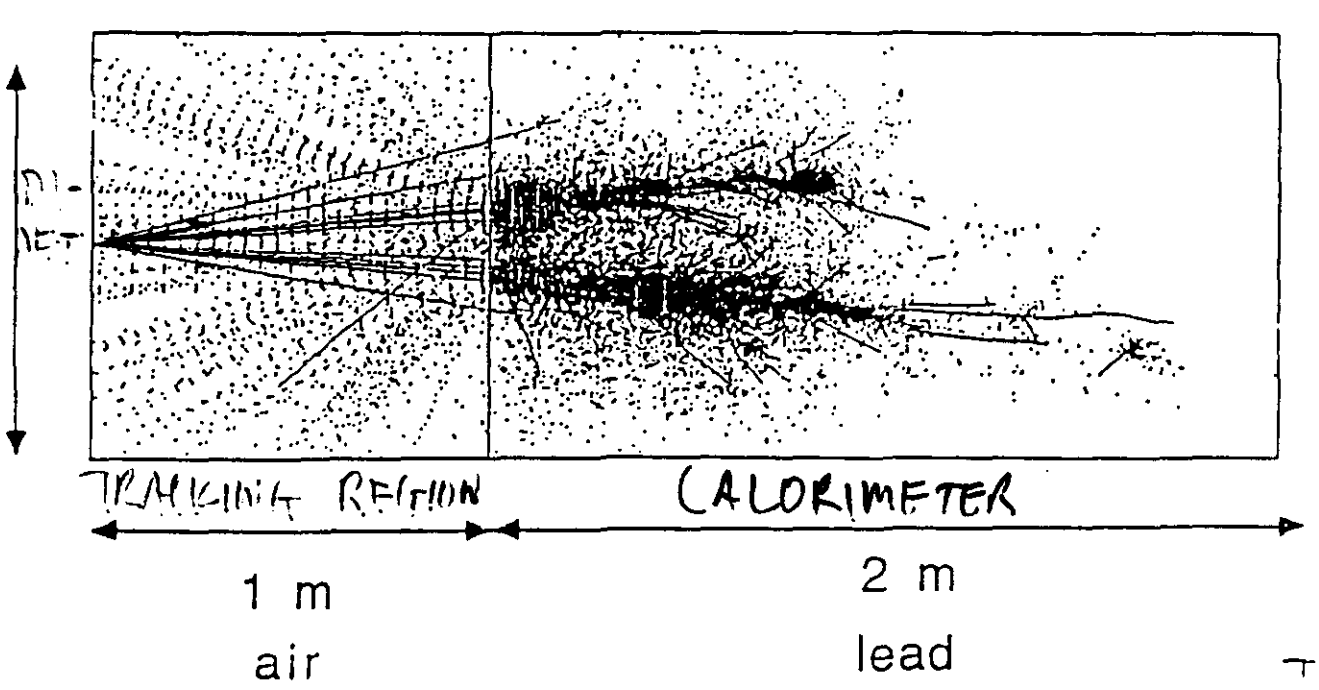
Shower Profile of 50 GeV Pion

Takasaki KFK

a Z-Boson, One TeV,

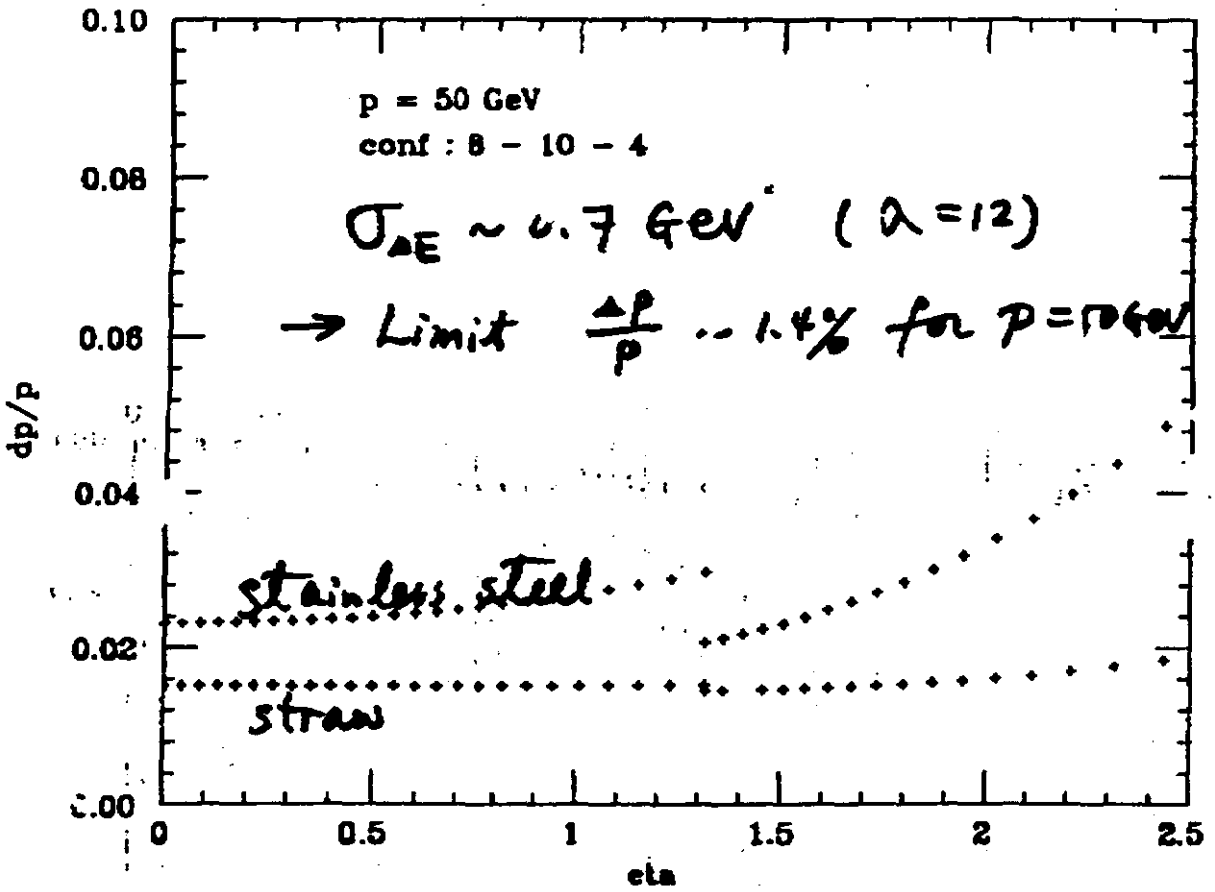
Decaying to a pair of Quarks





$$P_{\mu} = \Delta E + P_{chamber}$$

Bing Zhou



Cast Calorimeter Prototypes

For December 1991 FNAL Beamtest:

4 x 1-ton "supertowers", each containing
4 physics towers (0.05 η x 0.05 ϕ)

2mm diameter fibers
(RH-1 = fast and rad-hard)

11% Packing fraction (1/8)

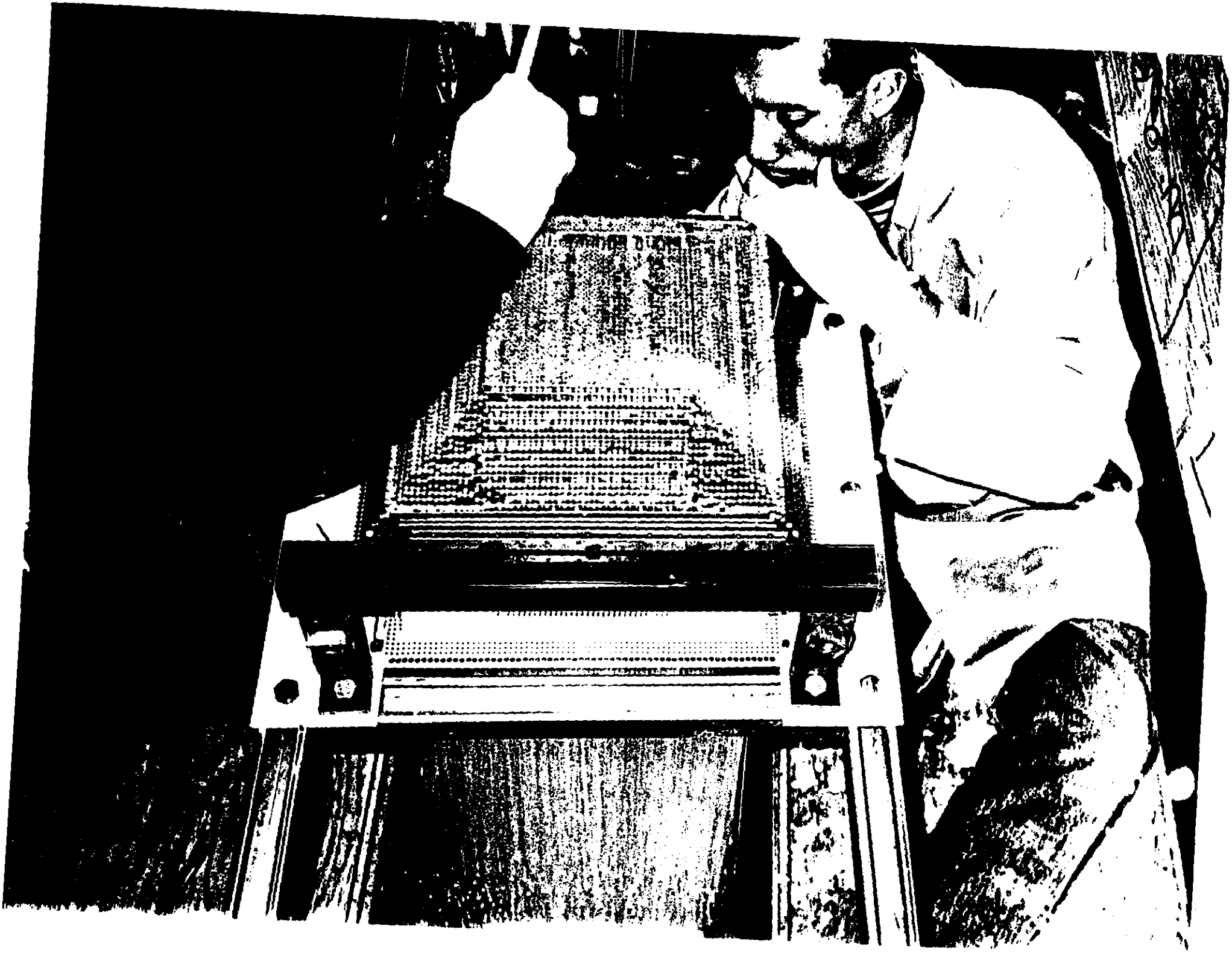
Recent developments:

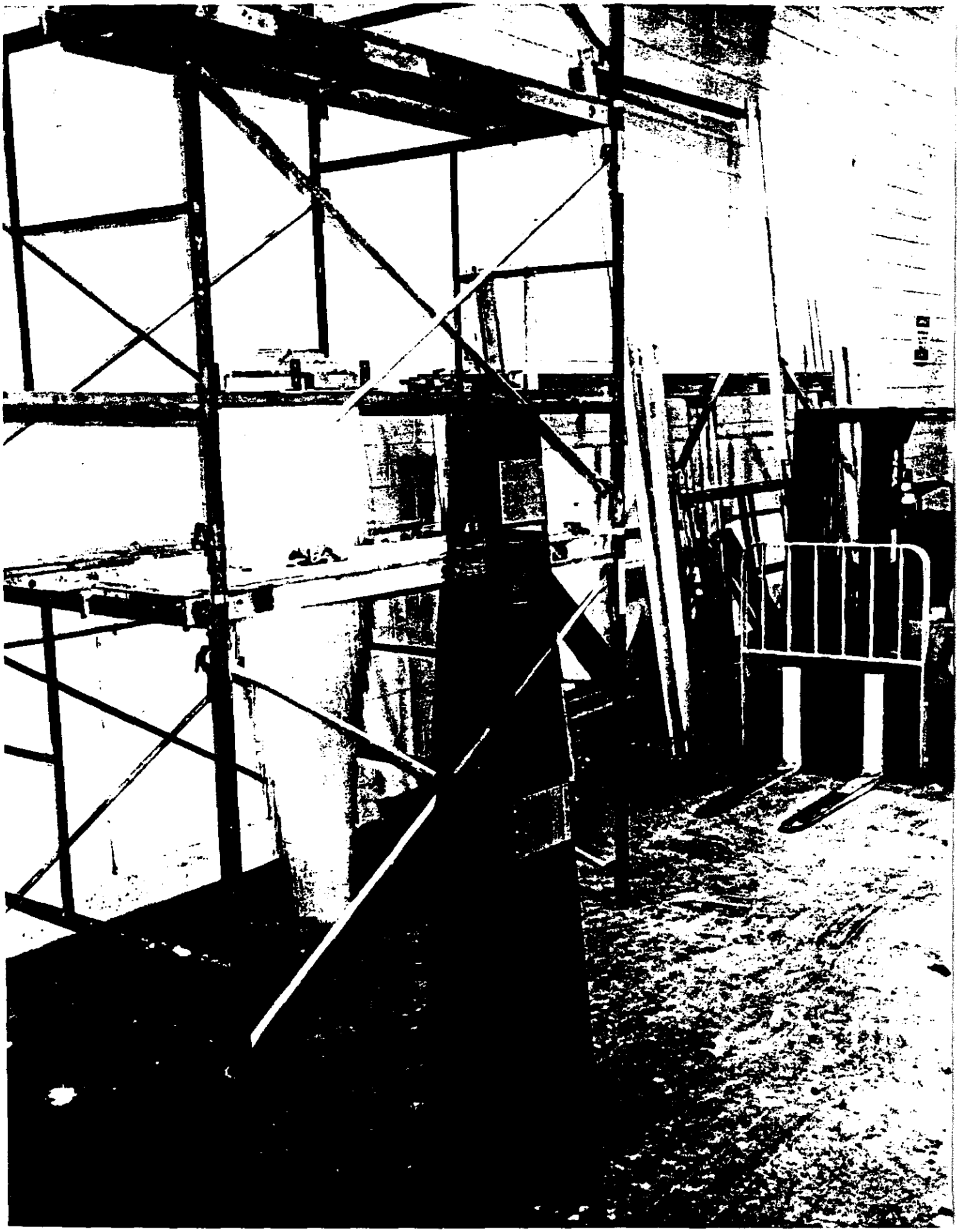
1) Cast 2 full-size modules,
first with 20% fibers, wire mesh spacers
second with 11% fibers, perforated plates

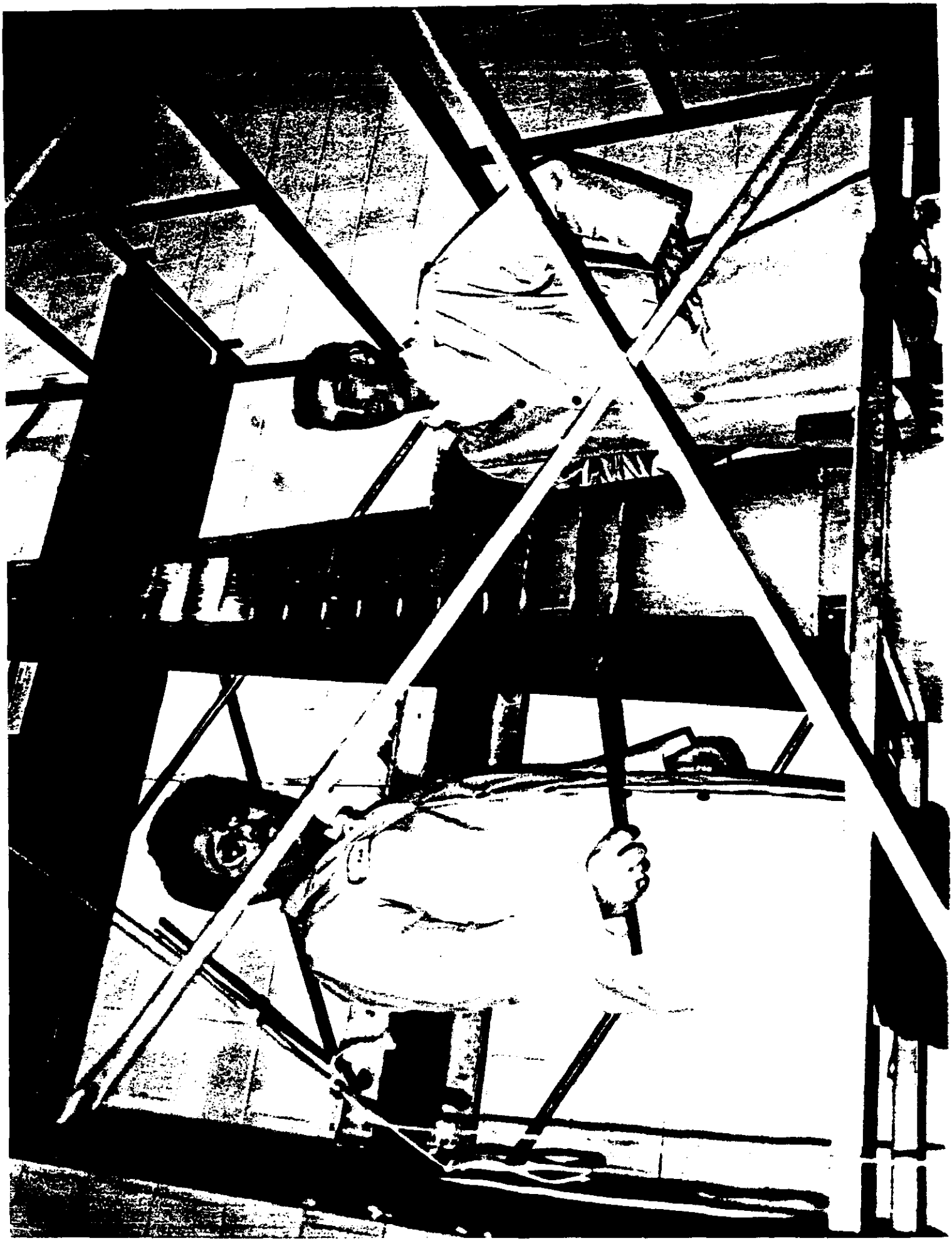
- Hand-threading of 4000 2mm fibers
  = 2 man-days
- Casting = 1 hour

2) Cast cylindrical sample tower
containing lead shot ("dust" granules)

- eutectic alloy successfully percolates
- eutectic melting point stays constant
- eutectic binds well to lead shot
- density ⇒ 60% Pb, 40% eutectic







Research Accomplishments and Renewal Proposal to TNRLC

The Engineering and Testing of a Fiber Calorimeter Prototype

The SSCintCal Collaboration

C. Lane
Drexel University, Philadelphia, PA 19104

D. Brown, R. Carey, S.T. Dye, E. Hazen, D. Higby,
J.P. Miller, B.L. Roberts, L. Sulak, C. Wang, W. Worstell
Boston University, Boston, MA 02215

D. Boucuzzi, D. Scrofani, K. Segall, D. Wall, D.R. Winn
Fairfield University, Fairfield, CT 06430

R. McNeil
Louisiana State University, Baton Rouge, LA 70803

C. Bromberg, J. Huston, R. Miller, C. Yosef
Michigan University, East Lansing, MI 48824

A. David, N. Diaczenko, S. Zaman, A. Sanzgiri, R. Webb
Texas A&M University, College Station, TX 77843

R. Wigmans
Texas Tech University, Lubbock, TX 79409

N. Akchurin, D. Jones, D. Kadrmas, J. Langland, E. McCliment
F. Olchowski, Y. Onel
University of Iowa–Iowa City, IA 52242

D. Acosta, J. Branson, B. Ong, H. Paar, M. Sivertz, D.Thomas
University of California–San Diego, La Jolla, CA 92093

with Government and National Laboratory Affiliates

F. Ayer, C. Elder, D. Sullivan
C.S. Draper Laboratory, Cambridge, MA 02138

M. Mishina, A. Para
Fermi National Accelerator Laboratory, Batavia, IL 60510

November 1, 1991

... with significant duty factors ...

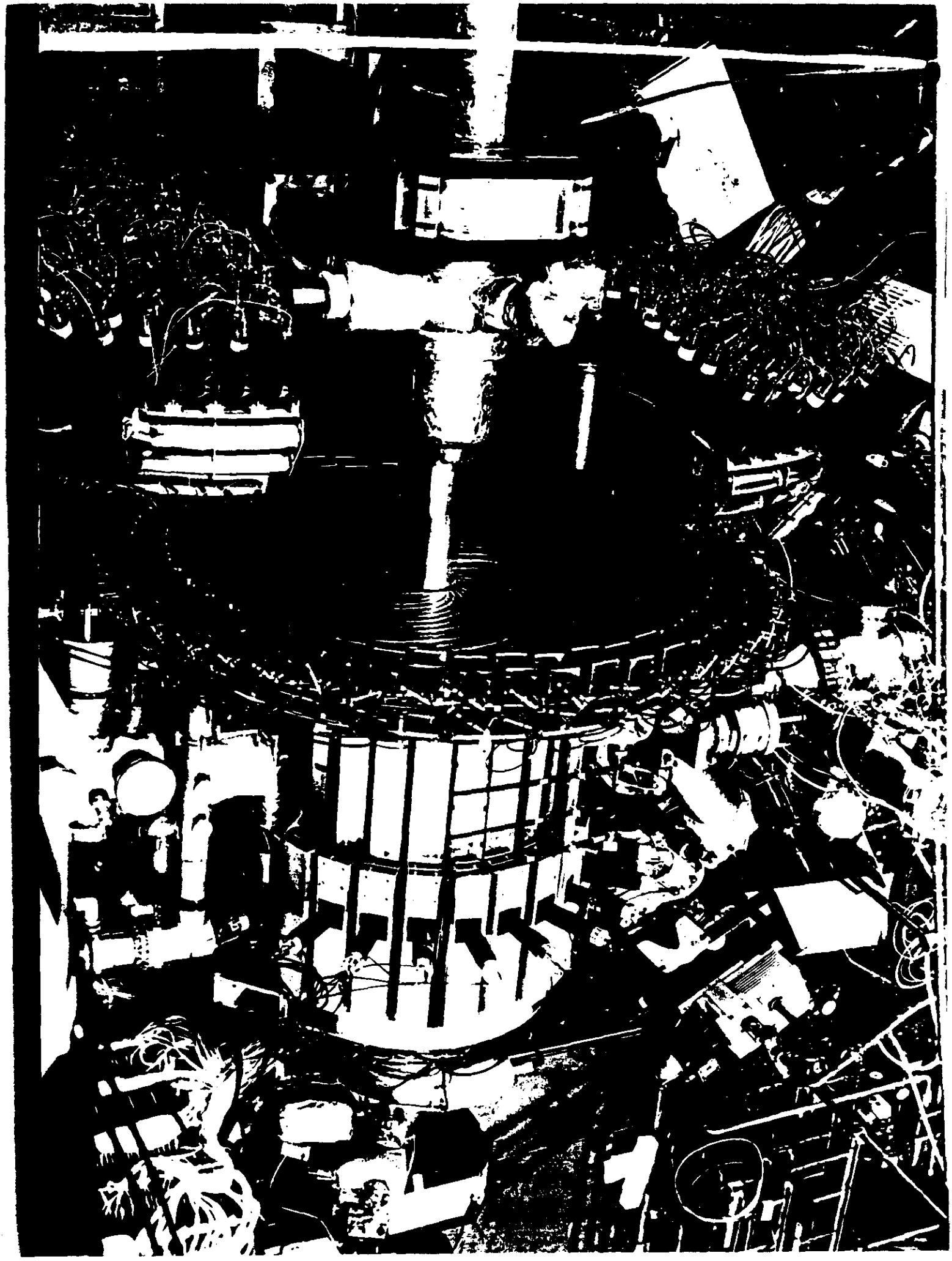
A. Personnel

c. 1/3 participation in GEP calorimeter session

The list of participating institutions, the names of the people in each (identifying the contact person and overall manager), and the percent of their (research) time which will be dedicated to the project are listed below (these percentages should be doubled when taking into account the TNRLC funded time dedicated to this project):

Contact persons for SSCintCAL: Hans P. Paar and Lawrence R. Sulak

Boston University	Lawrence R. Sulak	25%	contact person
	William A. Worstell	25%	
	James P. Miller	15%	
	B. Lee Roberts	15%	
	Robert C. Carey	25%	
	Spencer Klein	15%	
	Steven T. Dye	5%	
Fairfield University	David Winn	25%	contact person
	Dan Wall	15%	undergraduate
	Ken Segal	15%	undergraduate
	undergrad student 3	10%	
	V. Podrasky	10%	technician
Michigan State University	Carl Bromberg	5%	contact person
	Joe Huston	5%	
	R. Miller	5%	
	R. Richards	10%	engineer
	R. Hipple	20%	programmer
University of California, San Diego	Mike Sivertz	25%	contact person
	Hans Paar	25%	
	Don Thomas	10%	
	Darin Acosta	25%	graduate student
	Beale Ong	25%	graduate student
	graduate student 3	25%	
	Anthony Bajic	15%	undergrad student
	Roger Gedminas	15%	undergrad student
	Arthur Hull	15%	undergrad student
	James Pinon	15%	undergrad student
	Bob Schreiner	15%	undergrad student
	Tracy Taylor	15%	undergrad student
Texas A & M	Bob Webb	15%	contact person
	postdoc	25%	
	graduate student 1	25%	
	graduate student 2	25%	
Drexel University	Charles Lane	8.3%	contact person
Louisiana State University	Roger McNeill	5%	contact person



FY92 R&D/Engineering Program

Manufacturing Plan:

Goal = 15 Ton-prototype in beam by 6/92

2mm --> 3mm fiber + lead shot absorber (60%)

1 Ton --> 2.5 Ton Supertowers
(.10 η x .10 φ --> .16 η x .16 φ)
GEM = 1300 castings (not 5168 castings of BNL)

6 Supertowers = 15 Tons
contains >90% of hadronic shower

Industrial/National Lab collaborators
- prepare fiber preform
- cast supertowers

Beam Test Plans:

1) BNL in June 1992
   - Calibration
   - Resolution
   - compensation, e/π @ 20 GeV

2) CERN in August 1992 (with SPACAL)
   - High energy, constant term

GEM Hadron Calorimeter

Maintenance/Accessibility:

1) Monolithic, modular, fully projective geometry matched to BaF2

   No summing/balancing signals over many PMTs/towers to provide trigger
   ... no grey filters

2) Self-supporting cantilevered structure

   Suspended either from septum or assembly fixture

   Stress measurements of eutectic demonstrates no creep in GEM (no rigidity in current design)
   assumes [illegible]

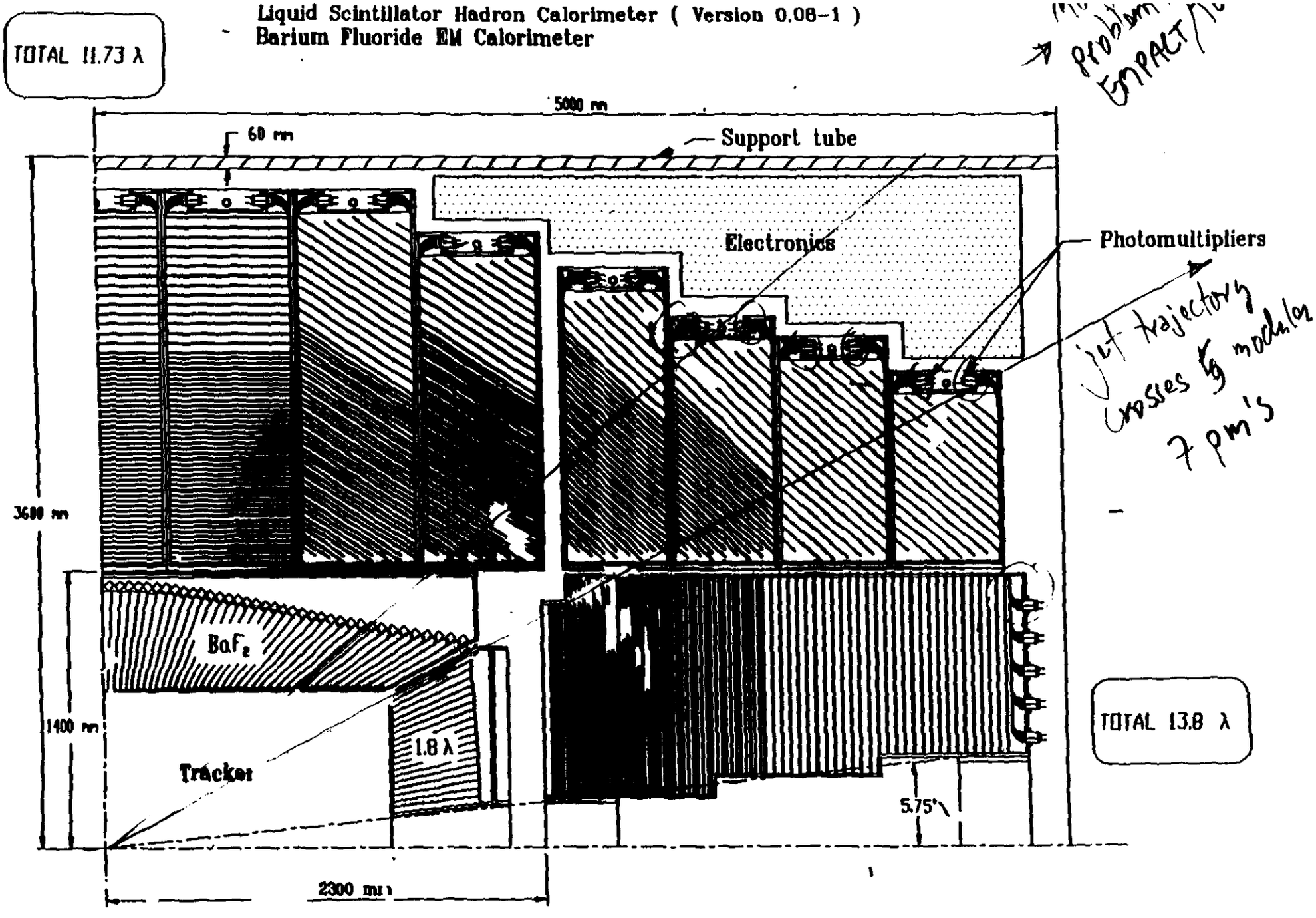
3) Detailed structural design underway

   - access issues
   - revised structural support
   - assembly fixturing design

[illegible] work for 2 different detectors

TEX+
[illegible]

Liquid Scintillator Hadron Calorimeter (Version 0.08-1)
Barium Fluoride EM Calorimeter



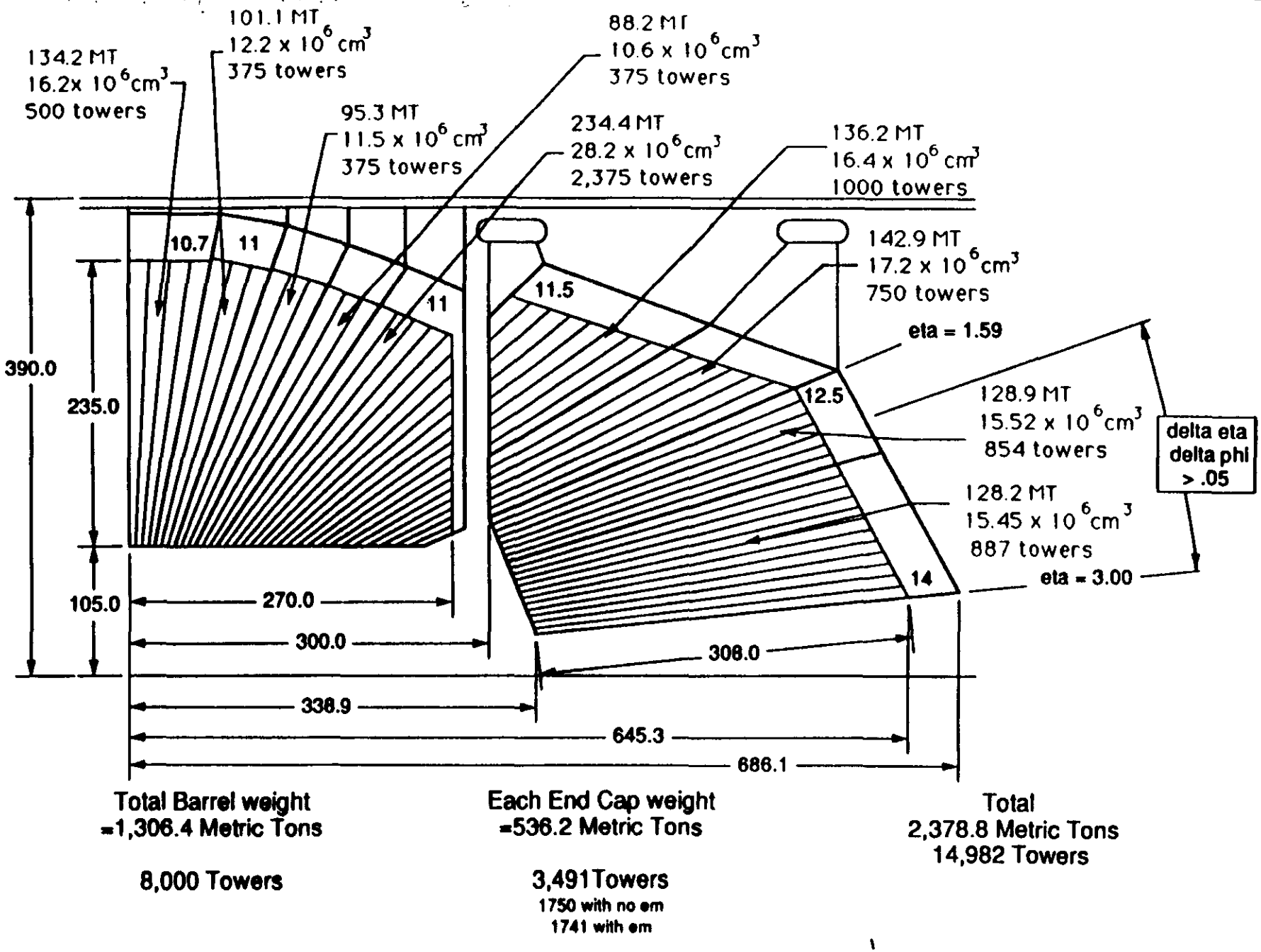


Figure 3. SPACAL LOI Baseline Configuration

Scintillator Calorimeter Support

Structural Design and Evaluation

F. Ayer
C. Elder

The Charles Stark Draper Laboratory, Inc.
Cambridge, MA

31 May 1990

EMPACT/TEXAS TECHNICAL NOTE 359

TOWER MANUFACTURING AND COSTING FOR SCINTILLATING FIBER CALORIMETERS

FINAL REPORT

November 26, 1990

by

F. Ayer
C. Elder
J. Gorman
R. Gustavson

The Charles Stark Draper Laboratory, Inc.
555 Technology Square
Cambridge, Massachusetts 02139

The Charles Stark Draper Laboratory
555 Technology Square
Cambridge, MA 02139

EMPACT/TEXAS TECHNICAL NOTE 339

STATUS OF EMPACT/TEXAS SPACAL CALORIMETER ENGINEERING DESIGN

Prepared by:

J. Brogan, N. DiGiacomo, G. Flores,
K. Killian, L. Mason, J. Petry, J. Pohlen,
J. Timbrook, and T. Wright

December 3, 1990

SCIENCE SYSTEMS
MARTIN MARIETTA ASTRONAUTICS GROUP

EEC-91-1261

GEM DETECTOR

COST ESTIMATE FOR

THE SPAGHETTI HADRON CALORIMETER

F. Ayer
C. Elder
D. Sullivan
E. Womble

Draper Laboratory

4 September 1991

Cost Issues:

Materials/Fabrication--Vendor's Bids:

1) Fiber preform with 11% packing of 3mm diameter fibers (including preform threading)
   - Bicron = $5.1M
   - Optectron = $5.0M

2) Lead "dust" shot
   - Taracorp = $0.48 / lb.
   - Division Lead = $0.55 / lb.

3) Commercial casting:

   Bids by 11/15/91 on 6 supertowers for FY92 and 1300 supertowers for GEM

   - Cerro Metal Alloys
   - Bath Iron Works

   - Oak Ridge National Laboratory

4) Steel sheaths:
   - Ainslie Corp (e-beam=$200/sheath or TIG welding = $100/sheath)

MACHINERY

Vol. 51 No. 7 MARCH

Dies Made From Cerrobend or Limited Production

By KENNETH C. CATHCART, Experimental Department
Lockheed Aircraft Corporation, Burbank, Calif.

EXPERIMENTAL shops of aircraft factories and far-flung plane repair depots have at least one thing in common—a vital need for tools and dies that can be made with minimum time and expense. The fabrication of many sheet-metal parts for prototype plane models requires tooling similar or identical to that used in actual mass production. But since design changes are so often necessary during the construction and after completion of the first experimental plane, it is impractical, because of the time and cost involved, to build the first plane with standard tooling. Repair bases have the same problem

Downscoped Dragon Lab Cost ... $57M

GEM CALORIMETER

SCINTILLATING FIBER HADRON CALORIMETER

COST ANALYSIS C

	Category	Tot Uts	$K Unit	Units	Costs $K
1.00	Towers				
1.10A	Ostalloy 50%	948	5.58	Mton	$5,290
1.10B	Lead Shot 50%	1139	.99	Mton	$1,128
1.20	Fiber	5.7E+06	.00127	Meters	$7,239
1.30	PMT's	3308	0.30	Each	$992
1.40	Sheaths + Cover Plate	3308	.40	Each	$1,323
1.50	Light Guides	3308	0.20	Each	$662
1.60	Spacer Plates	3308	0.20	Each	$662
2.00	Electronics	3308	0.25	Channels	$827
3.00	Structure	160,000	0.005	LBS	$800
4.00	Thermal Cont				$200
5.00	Fab & Ass.				
5.10	Fab. Ass. & Test	15.8	0.045	M-H/tower	$9,380
5.20	Tooling				$3,000
6.00	Testing				
6.10	Test Beam				$1,000
6.20	Test Equip				
7.00	Transport				$500
8.00	Installation				
8.10	Install. Labor	17,000	$45/MH	Man-Hour	$765
8.20	Install. Equip				$1000
DIRECT COST					$35,068
EDIA		29%			$8,767
BASE COST					$43,835
CONTINGENCY*		25%, 10%			$8,000
SUBTOTAL					$51,835
R&D		11% should be 3%?			$5,702
TOTAL					$57,537

*Contingency: 10% on lead, fiber, and steel
25% on other items

... see presentation of Dan Sullivan Francois Ayer after lunch.

How do the two detector designs differ in c

Cost Estimate Differences
CDSL/ORNL

1) Fiber Materials,	$ 8.3M	ORNL
Threading,	- 5.1M	CDSL
Preform Preparation	-------	
10.3% fiber vs. 16.7%	$ 3.2M	
28.72% Contingency *11% R&D	x 1.43	= $4.6 M
2) Top Support Plate		
5168 @ $310 each (Machined)	$ 1.6M	ORNL
5168 @ $70 each (Die Cast)	-0.4M	CDSL

	$ 1.2M x 1.43	= $1.7 M
3) Module Fabrication (Manufacturing Segmentation)		
.08 x .08 Supertowers		
$1.6K/Supertower	$ 8.1M	ORNL
.16 x .16 Supertowers		
$4.4K/Supertower	- 5.7M	CDSL

	$ 2.4M x 1.43	= $3.4 M
4) Sheathing		
Sheet Metal Jackets		
5168 @ $400 each	$ 2.1M	ORNL
Larger Sheaths		
1300 @ $1000 each	- 1.3M	CDSL

	$ 0.8M x 1.43	= $1.1M
5) Support Structure		
Inner + Outer Rings	$ 2.2M	ORNL
($12/lb x 85T)		
Inner + Outer Rings	- 1.1M	CDSL
($8/lb x 60T)	-------	
	$ 1.1M x 1.43	= $1.6M

[illegible] M difference,

TOTAL ABOVE = **$12.4M**

⇒ maximum real cost of projectivity/simplicity [illegible]

... see Francois Myers discussion

Scintillator Hadron Calorimeter Performance Comparison

1) Projective Geometry/Triggering:

SF Cal naturally projective
trigger = 1 PMT/tower

LS Cal requires summing signals over different towers and depths to generate fast trigger, requires complex mapping

2) Uniformity/Constant Term:

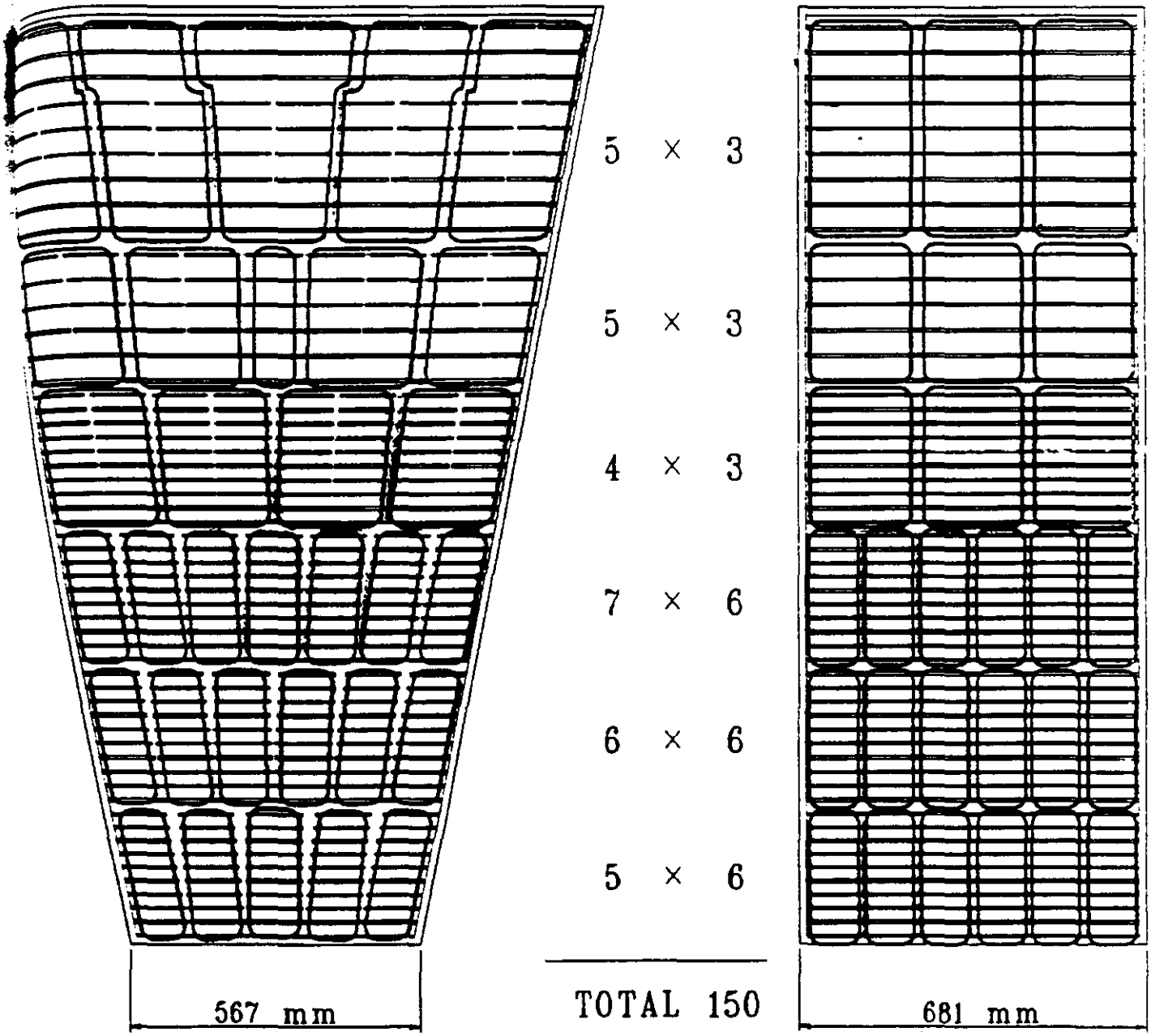
SF Cal has simple unit cell 1cm x 1cm
- same transversely and in depth
- many 3mm fibers per shower
- simple internal structure

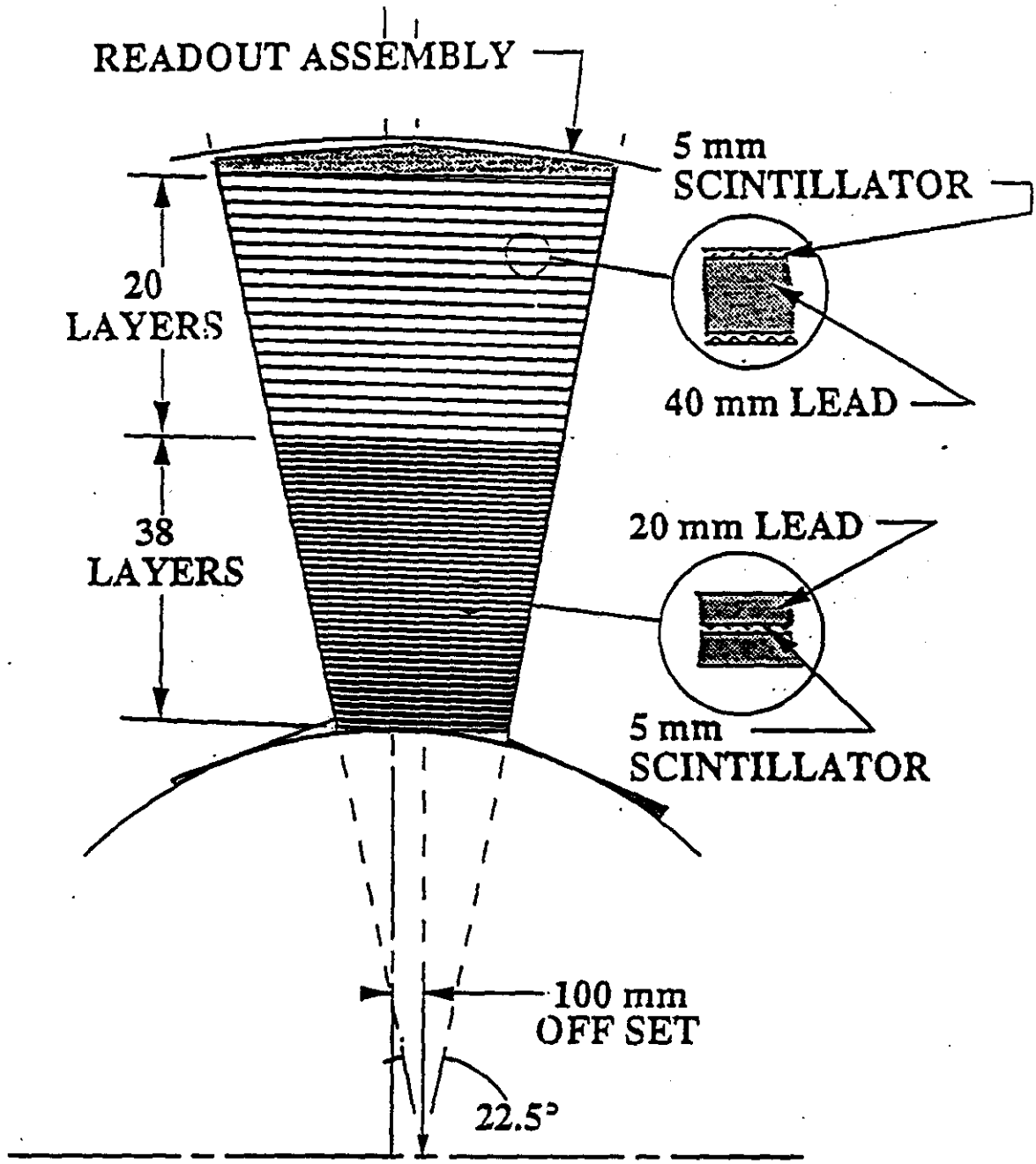
LS Cal has 10cm x 10cm x 5mm plates,
- 2 different sampling fractions (2cm/4cm lead plates) in depth
- few fibers per shower
- complex internal structure

Version 0.08-1

Number of detector cells per module :
type 1 2442

Read out channels





HADRON CALORIMETER
TOWER ASSEMBLY

Fig. 3

3) **Hermeticity:**

SF Cal has 8mm double-wall thickness between supertowers (non-projective)

LS Cal has 30mm double-wall thickness between supertowers (non-projective)

4) **Speed:**

SF Cal requires only wavelength shift from UV to blue (with RH1-type blue rad-hard fiber decay time = 3ns)

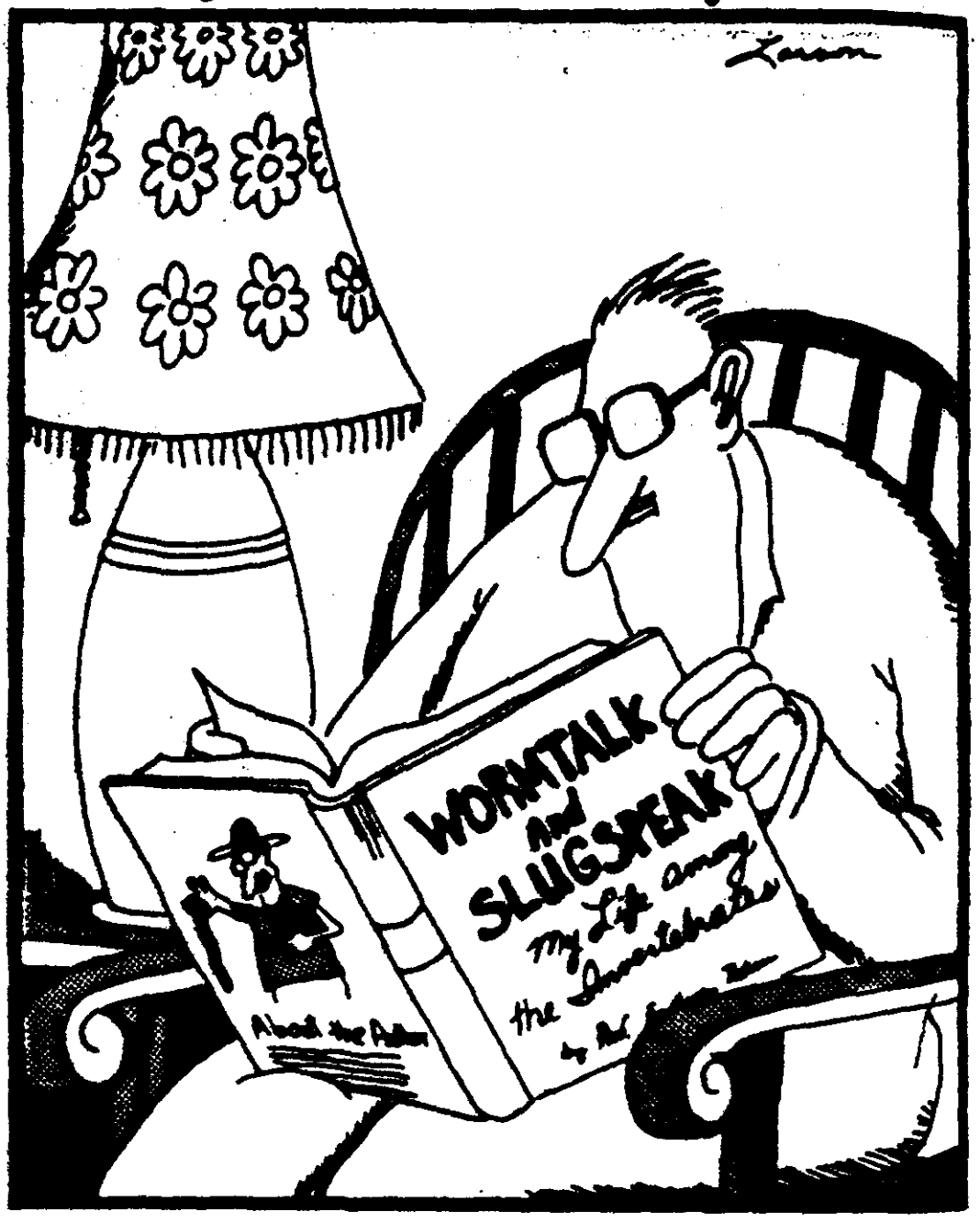
LS Cal requires double wavelength shift from UV to blue to green WLS fiber --> secondary fluor decay time =11 ns

5) **Segmentation:**

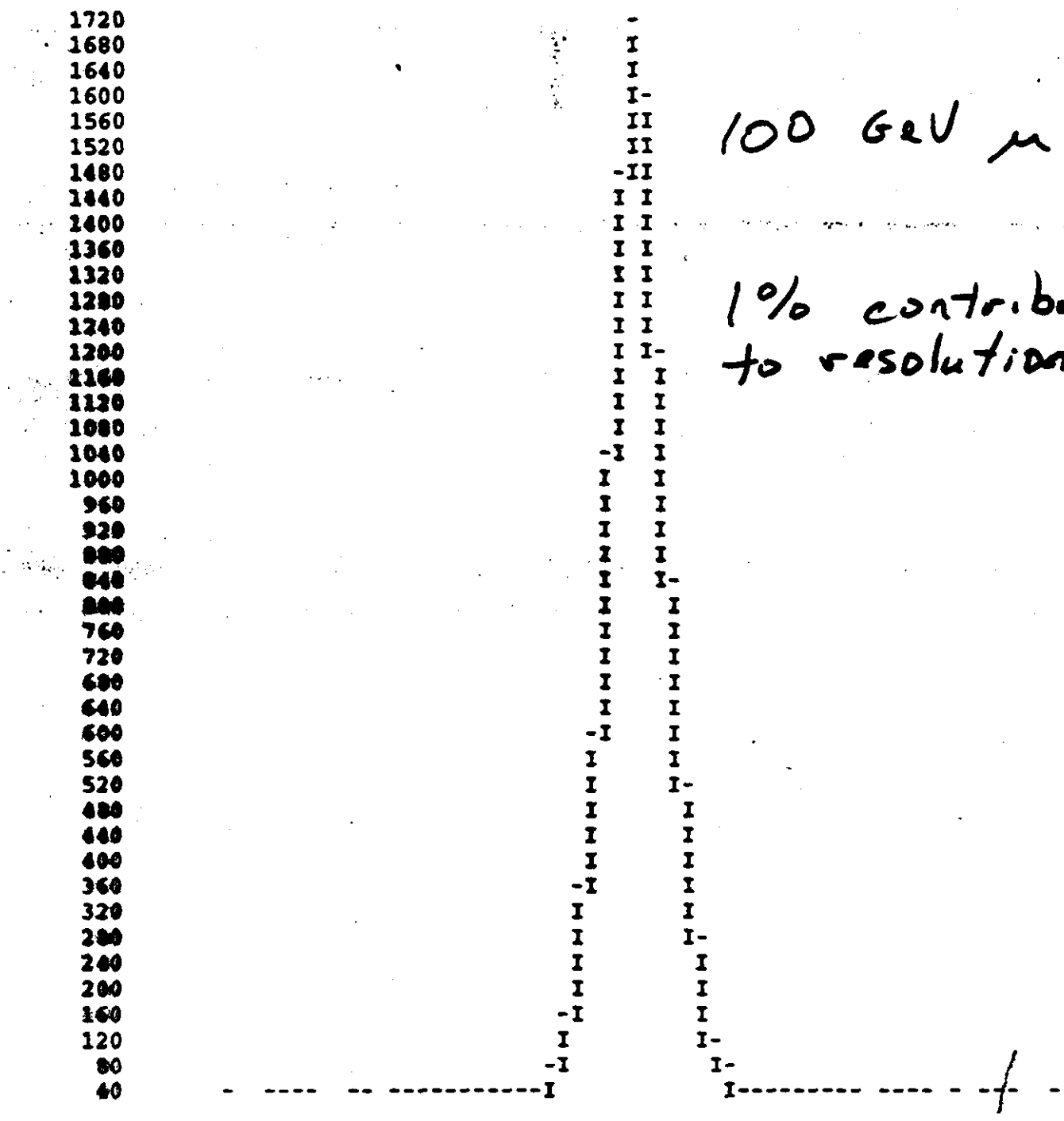
SF Cal can be upgraded for additional lateral segmentation + 2 depths

LS Cal can be upgraded for additional longitudinal segmentation

Longitudinal Segmentation



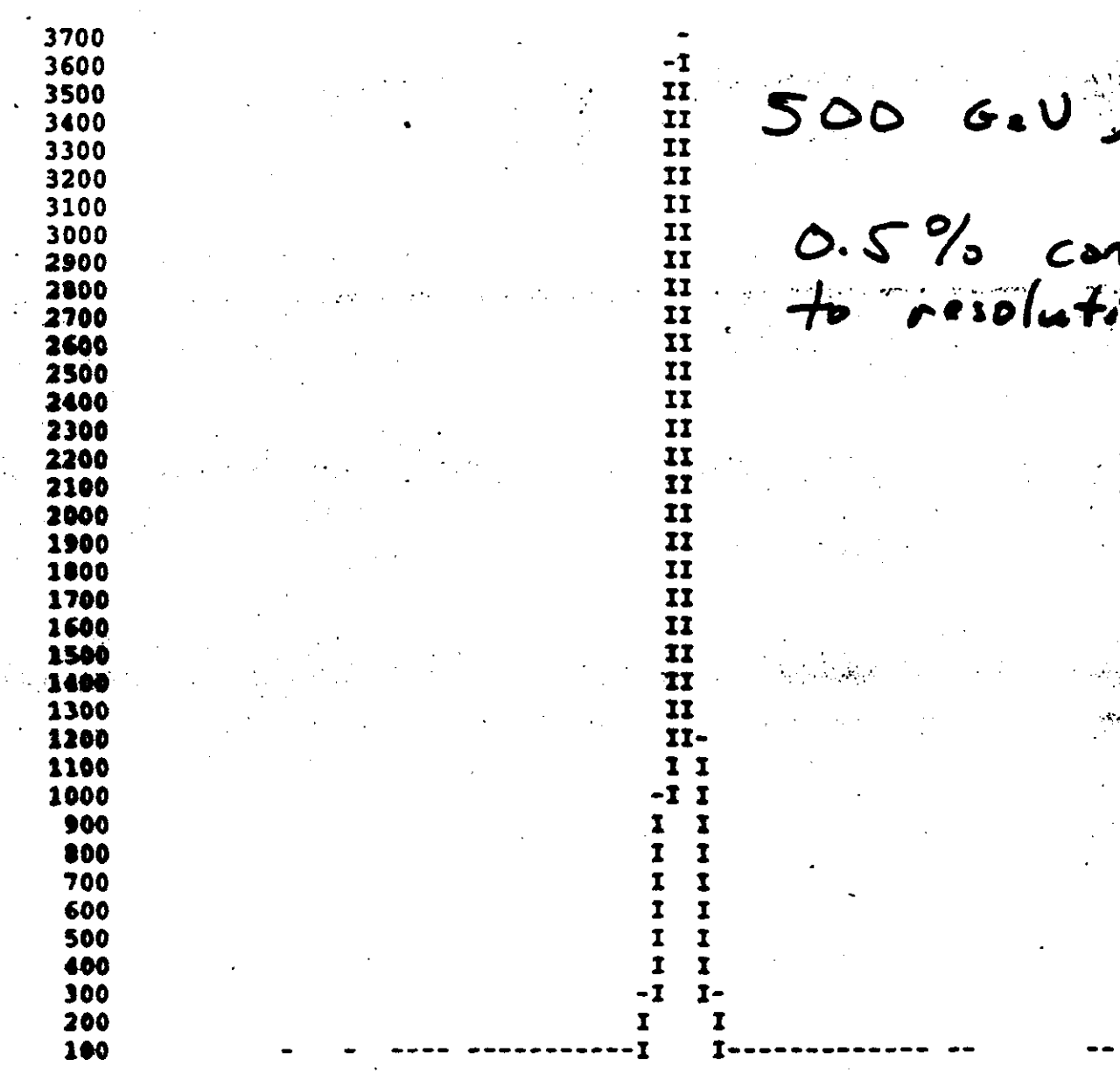
Energy Resolution after correcting for measured Hcal energy assuming [redacted]



100 GeV μ

1% contribution to resolution.

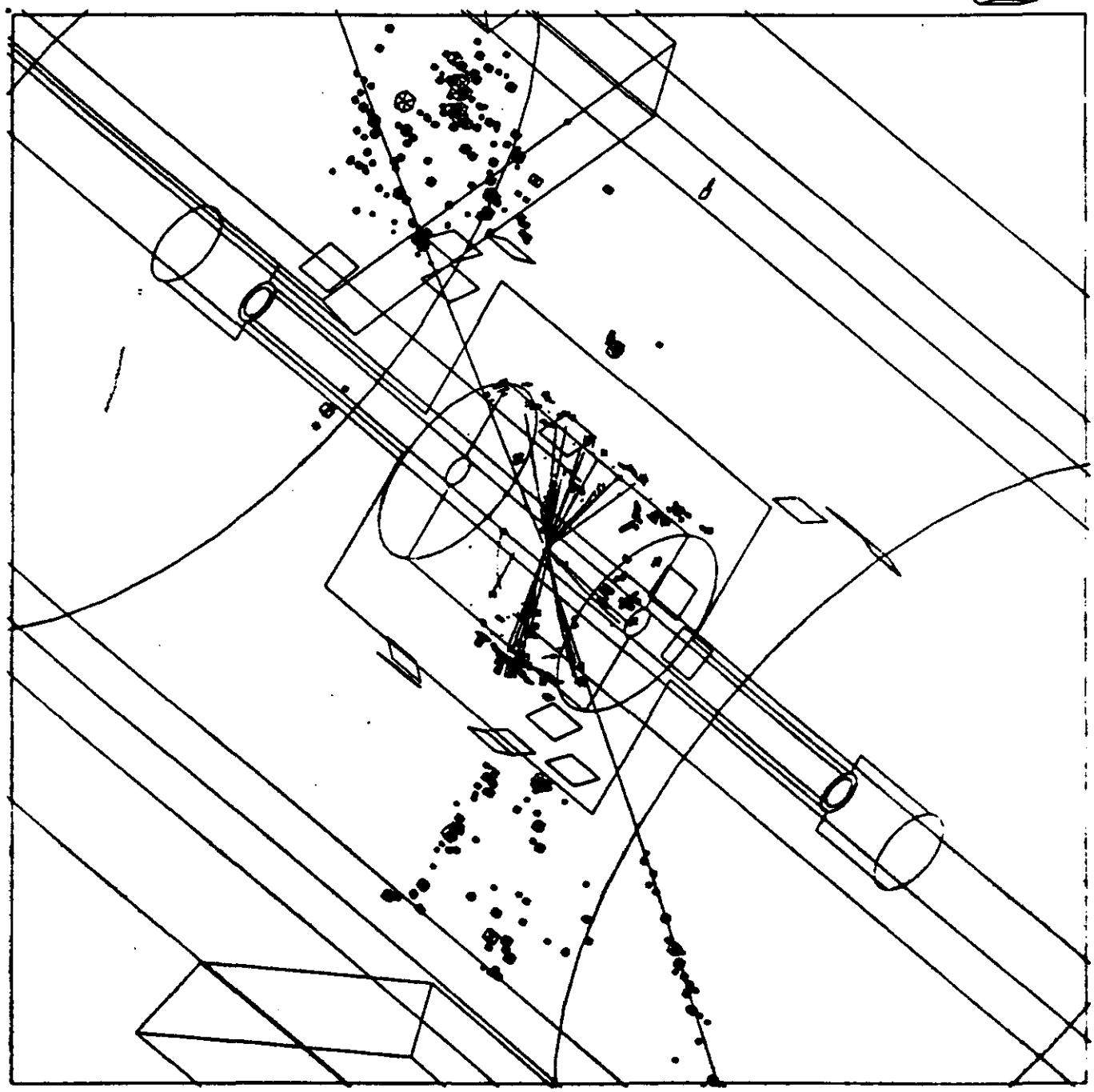
Energy Resolution after correcting for measured Hcal energy assuming 30%/sqrt(E) + 3%



500 GeV μ

0.5% contribution to resolution

Run # 187502 Event # 11456 Total Energy: 69.51 GeV

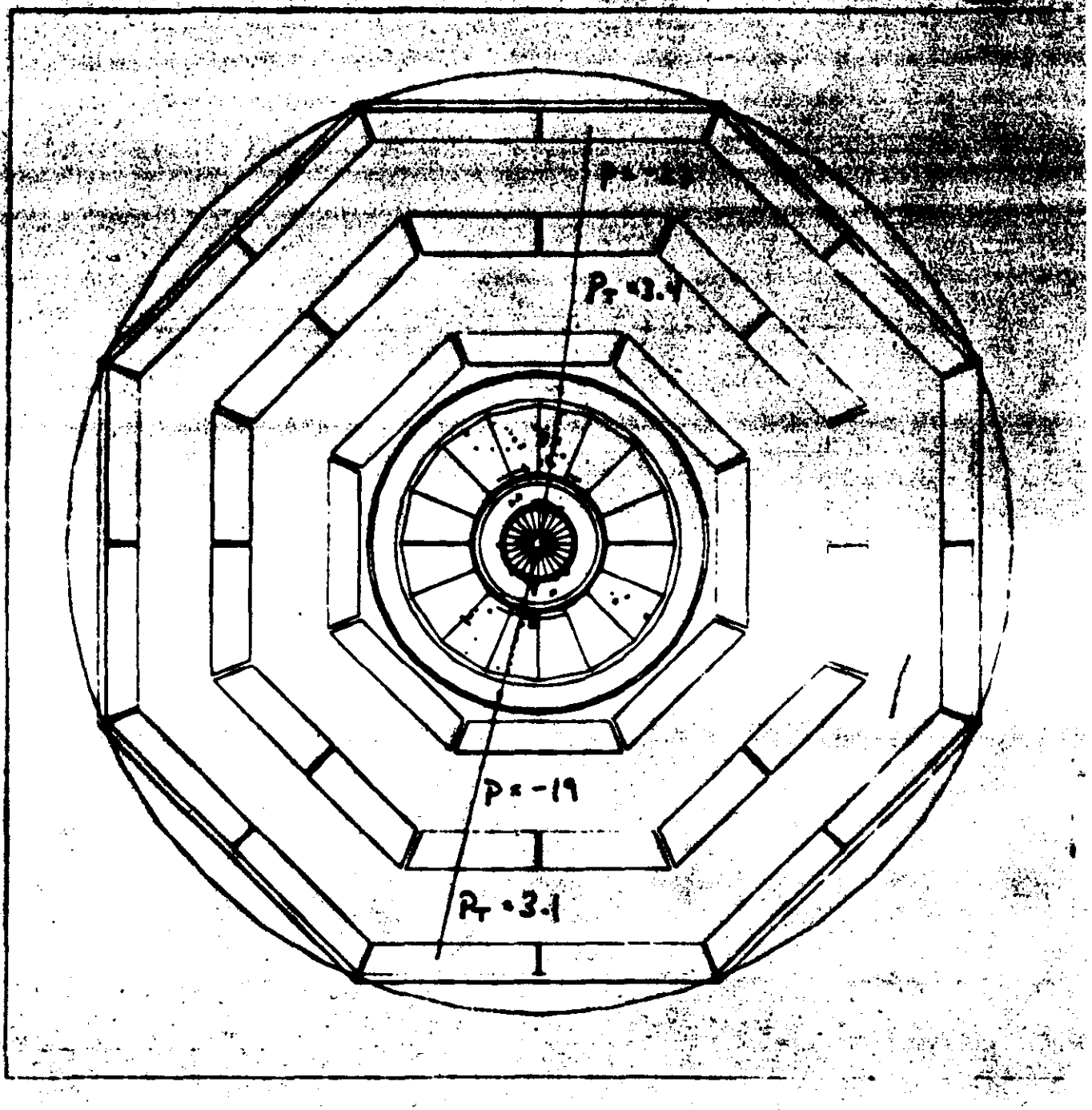


Transverse Imbalance : 0.03 GeV **Longitudinal Imbalance: -0.01 GeV**

Thrust: .7876 **Major: .3494** **Minor: .2463**

	spaghetti works?	important?
γ, e		
$e\pi$ separation SPACAL, separate EM	OK	
γ leakage need thick enough EM. (BaF_2 prism & readout)	OK	
isolation cut	OK	
μ		
energy loss correction (see study)	OK	
pattern recognition (used in L3)	?	*
muon veto (used in L3) pp?	NO	
punch through rejection (b) not used in L3 (11.7 λ)	NO	
missing E_T		
leakage detection dominated by ν above 10λ	OK	

Run # 93001 Event # 4967 Total Energy:



jets

energy correction — OK

jet pattern recognition — ?

τ jets — OK

redundancy

tracker off

Ecal off (out) — *

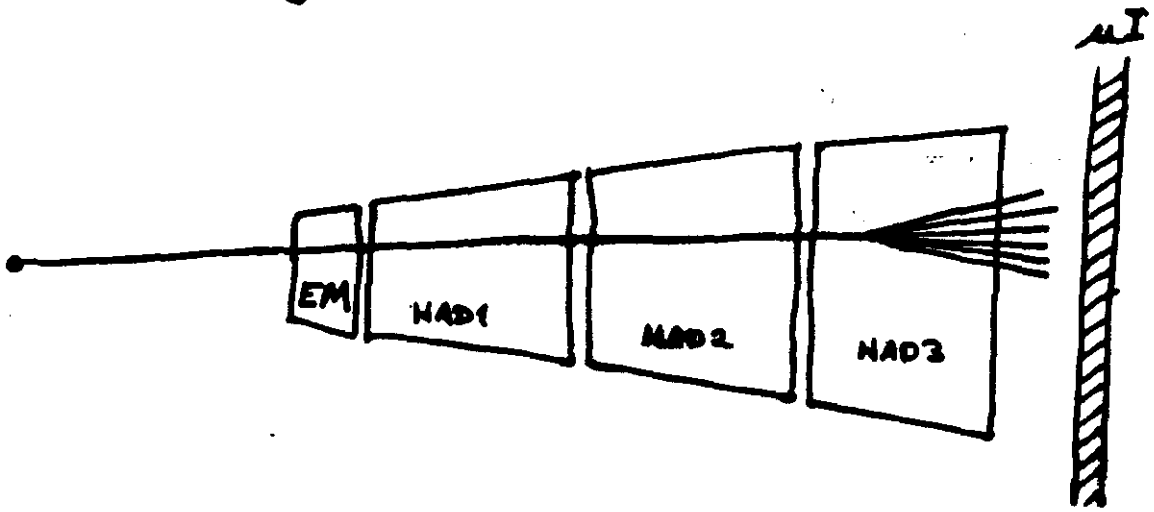
μ-chambers off — *

We don't have any compelling reason why we need longitudinal segmentation

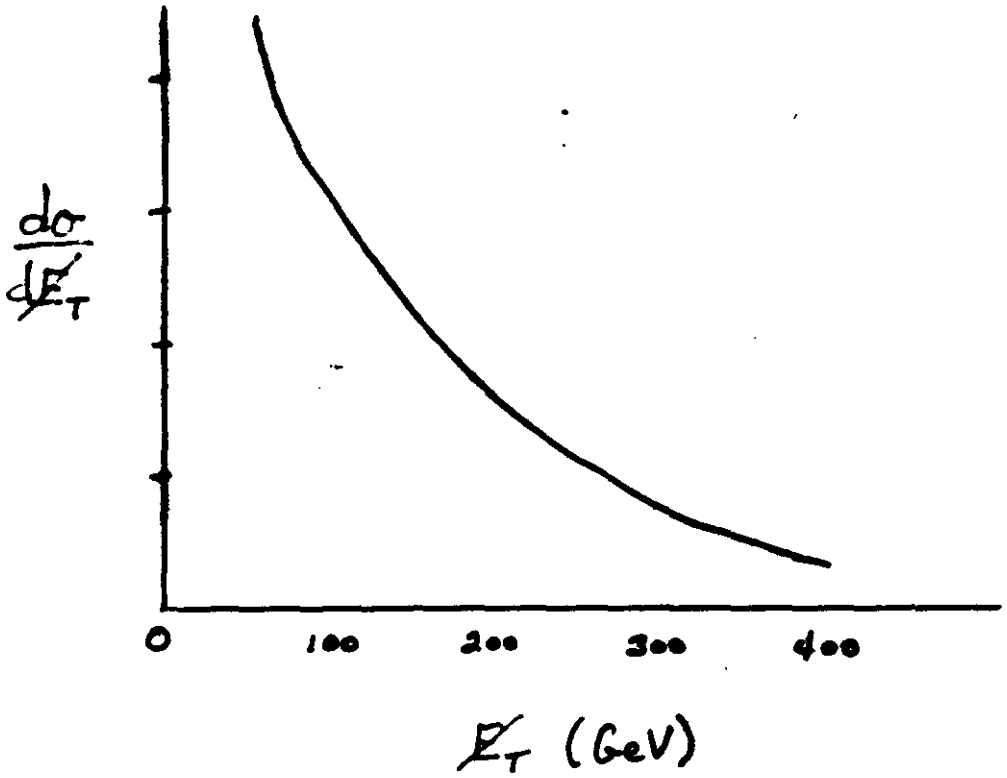
The (3D) pattern recognition in the μ-chambers seems to be the most important.

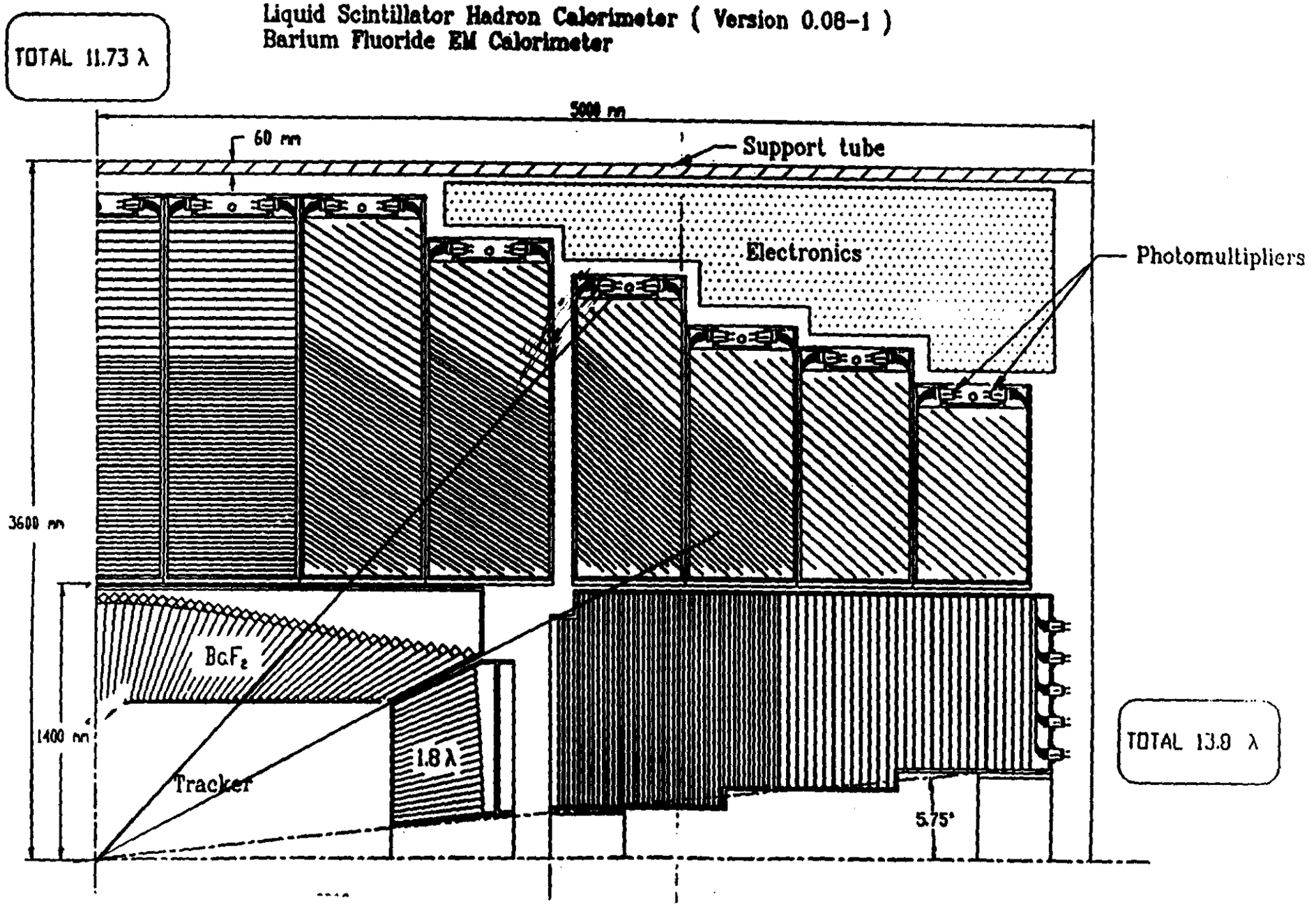
The sum of all the reasons make it an important but not vital consideration.

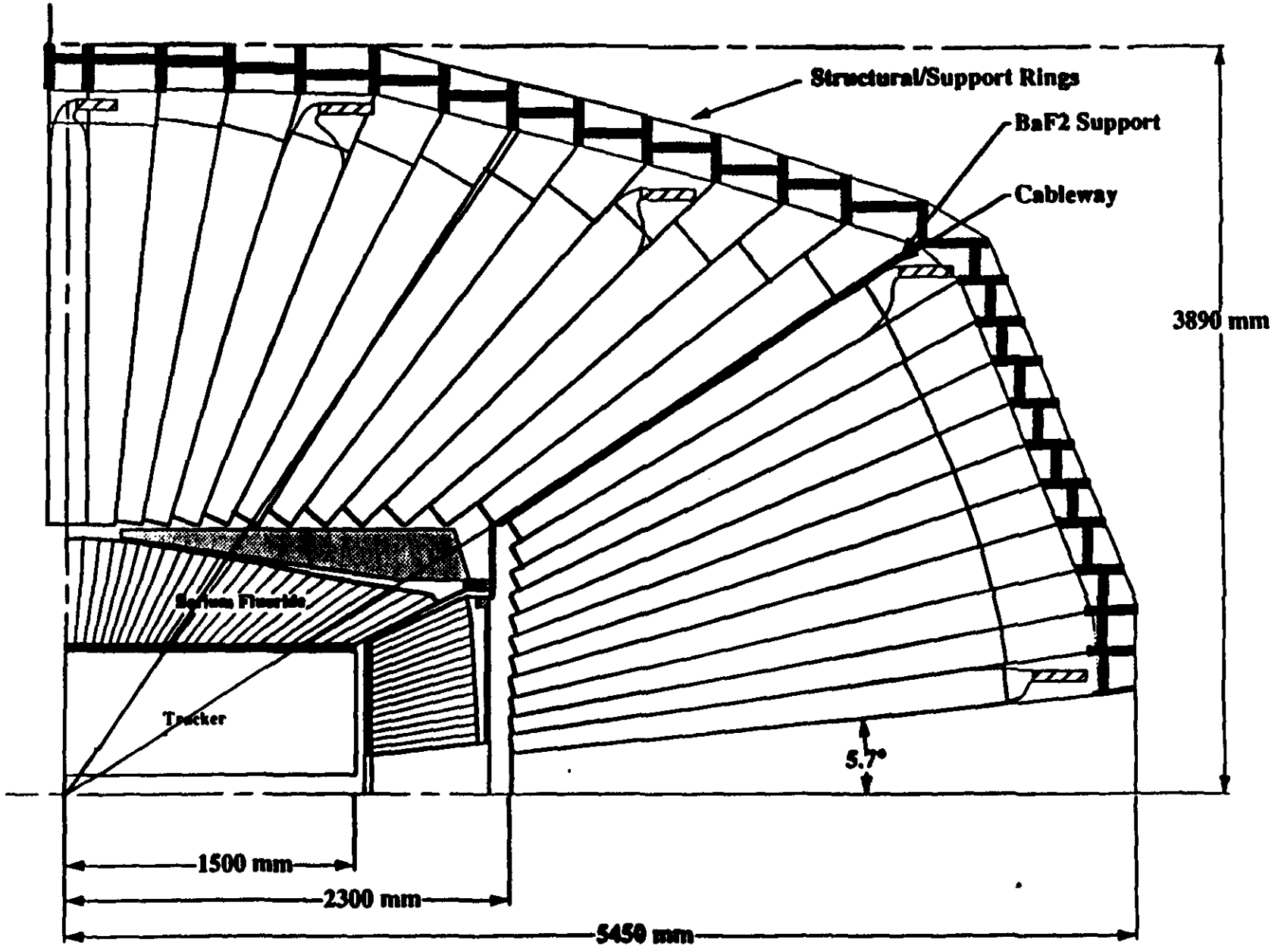
Missing E_T Resolution and Tails



1) Late developing showers contribute to tails
2) Cracks/Dead material contribute to resolution




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
5.75°
TOTAL 13.8 λ


Structural/Support Rings
BaF2 Support
Cableway
3890 mm
Tracker
5.7°
1500 mm
2300 mm
5450 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
INNER RADIUS	1,400	mm
OUTER RADIUS (SUPPORT TUBE)	3,700	mm
LENGTH	10,000	mm

MARK RENNICH/ 11/1/91 : OAK RIDGE NATIONAL LABORATORY

GEM Parameters

Spaghetti Hadron Calorimeter: 0.08 Segmentation

Lead Shot Filled (61.4%)

Absorber Volume	244.26	M^3
Channels	5168	Each
Total Weight	2400.87	Metric Tons
Lead Shot	1373.22	Metric Tons
Eutectic	727.12	Metric Tons
Structural Components	83.94	Metric Tons
Sheaths	188.12	Metric Tons
Fiber	28.47	Metric Tons
Percent Gaps in Absorber	3.00%	
Total Absorption Lenght	10.00	Lambda
Active Absorption Lenght	8.80	Lambda
Passive Absorption Lenght	1.20	Lambda
Mechanical Towers	5168	Each
Ring Assemblies	58	Each
Lenght of WLS Fiber	5,759,000	Meters
Number of WLS Fibers (3 mm)	2,879,500	Each
Number of Transm. Fibers (1 mm)	2,879,500	Each
Inner Radius	1400	mm
Outer Radius	3900	mm
Length	11100	mm

COMPARISON OF 0.08 HADRON CALORIMETER ESTIMATES

		Liq Scint	Spaghetti	Difference
	Catagory			
1.00	R&D	$5,494	$6,404	Larger Program
2.00	Conceptural Design	$405	$405	Same
3.00	Towers	$18,804	$29,114	Spaghetti Has Higher Fab/Mat'l Cost
	(Sense Material)	$508	$5,759	Fiber vs. Liquid
4.00	Ring Modules	$5,032	$5,204	Spaghetti Has More Complex Shape
5.00	Electronics	$11,354	$8,494	Liguid Has More Channels
6.00	Thermal Cont	$1,166	$1,166	Same
7.00	Beam Testing/Calib.	$2,077	$2,077	Same
8.00	System Assembly	$2,033	$1,916	Liquid Has More Assembly Ops.
9.00	Installation	$3,480	$4,246	Spaghetti Has More Complex Shape
10.00	Project Management	$4,689	$4,689	Same
	DIRECT COST	$55,042	$69,474	
	CONTINGENCY	26.12%	28.72%	
	TOTAL	$69,419	$89,427	

Cost Estimate Differences
CDSL/ORNL

1) Fiber Materials,	$ 8.3M	ORNL	
Threading,	- 5.1M	CDSL	
Preform Preparation	-------		
10.3% fiber vs. 16.7%	$ 3.2M		
28.72% Contingency x 1.11 R&D	x 1.43		= $4.6 M
2) Top Support Plate			
5168 @ $310 each (Machined)	$ 1.6M	ORNL	
5168 @ $70 each (Zinc Cast)	-0.4M	CDSL	

	$ 1.2M x 1.43		= $1.7 M
3) Module Fabrication (Manufacturing Segmentation)			
.08 x .08 Supertowers			
$1.6K/Supertower	$ 8.1M	ORNL	
.16 x .16 Supertowers			
$4.4K/Supertower	- 5.7M	CDSL	

	$ 2.4M x 1.43 = $3.4 M		
4) Sheathing			
Sheet Metal Jackets			
5168 @ $400 each	$ 2.1M	ORNL	
Larger Sheaths			
1300 @ $1000 each	- 1.3M	CDSL	

	$ 0.8M x 1.43 = $1.1M		
5) Support Structure			
Inner + Outer Rings ($12/lb x 85T)	$ 2.2M	ORNL	
Inner + Outer Rings ($8/lb x 60T)	- 1.1M	CDSL	

	$ 1.1M x 1.43 = $1.6M		
TOTAL ABOVE			= $12.4M

GEM SCINTILLATOR HCAL DECISION

PRINCIPAL ISSUES

- Relative Cost
- Likelihood of a Module Ready for testing in 1992
- Longitudinal Sampling
- Relative Complication of Assembly, and Maintenance In Situ

DURING THE PAST MONTH THE TWO GROUPS (LS + SF) HAVE DEVELOPED A COMMON R+D PLAN

A LARGE FRACTION OF THE COLLABORATORS WORKING ON THE TECHNOLOGY <u>NOT</u> CHOSEN WILL JOIN IN ON THE <u>CHOSEN EFFORT</u>

Principal Reasons to Choose a LS HCal

Yu. Kamyshkov/ORNL Nov.5 SSCL

- √ Status of LS HC system / mechanics
- √ Radial extention / absorbtion length
- √ Longitudinal segmentation
- √ Prototype for beam tests in 1992

Reasons to Choose Scintillating Fibers over Liquid Scintillator for Hadron Calorimeter

1) Should choose technology for which prototypes have been built and tested

SPACAL -- 6 different prototypes built and tested
8 publications in NIM, 2 CERN reviews
13 Tons operational in Omega

SSCintCAL -- 3 different prototypes, 2 tested
2 SSC R & D reviews, 1 TNRLC review

JETSET -- 300 modules operation over 1.5 years

Liquid Scintillator -- No large prototypes.

2) 15-Ton Hadron shower-containing prototype complete by June 1992

Using existing infrastructure to build new modules
4 years into design and test beam program

Liquid scintillator R & D program much less developed
Insufficient time to design and test by November 1992

3) **Strength/Experience of Scintillating Fiber team**

SPACAL (for EAGLE @ LHC?)
- 15% US Contribution
- $2.5M effort
- 30 collaborators

SSCintCAL (for GEM @ SSC)
- $0.5M received in FY90
- $0.7M received in FY91
- $0.9M requested for FY92
- 40 collaborators/ 9 institutions

LS Collaboration (for GEM @ SSC?)
- $1.1M requested for FY92
- 72 collaborators (35 US) / 8 institutions (5 US)
- ITEP commitment to SSC/GEM?

important contribution

4) **Additional option for EM calorimetry (no cost)**

in R&D

SF provides 6%/sqrt(E) backup to BaF2 and LAr

LS high-resolution undeveloped

5) **Cost differences between liquid and fibers are within the errors between Draper and ORNL cost estimates**

Small cost differential coupled to projectivity for SF
3 Draper and 1 Martin Marietta reports
Explicit bids coming from industry

Second review of LS costing yet to be done

	spaghetti works?
γ, e	
$e\pi$ separation SPACAL, separate EM	OK
γ leakage need thick enough EM. (BaF_2 prism & readout)	OK
isolation cut	OK
μ	
energy loss correction (see study)	OK
pattern recognition (used in L3)	? *
muon veto (used in L3) pp?	NO
punch through rejection (b) not used in L3 (11.7 λ)	NO
missing E_T	
leakage detection dominated by ν above 10λ	OK

jets

energy correction	OK
jet pattern recognition	?
τ jets	OK

redundancy

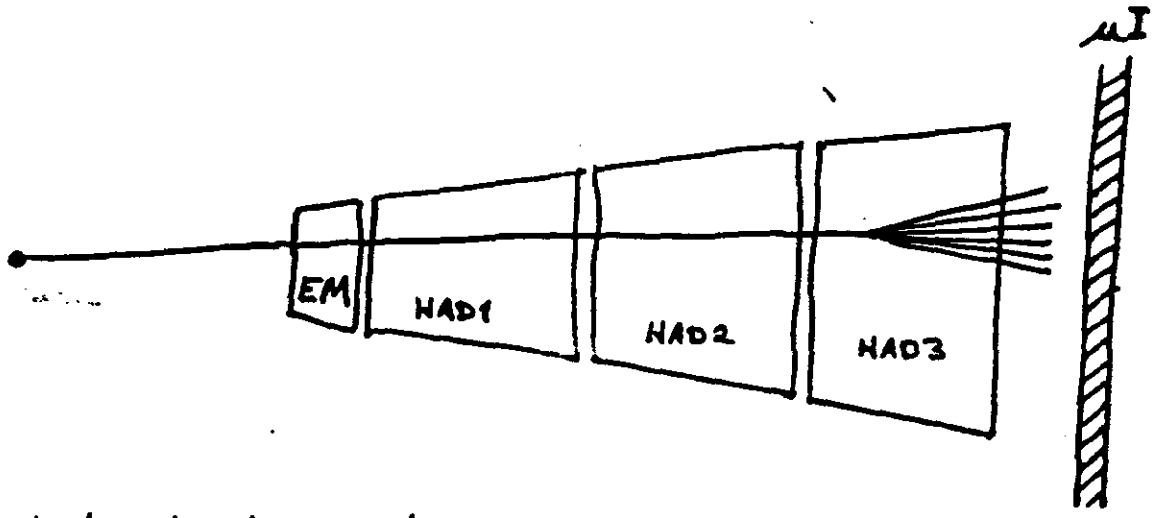
tracker off	
Ecal off (out)	*
μ-chambers off	*

We don't have any compellin reason why we need longitudinal segmentation

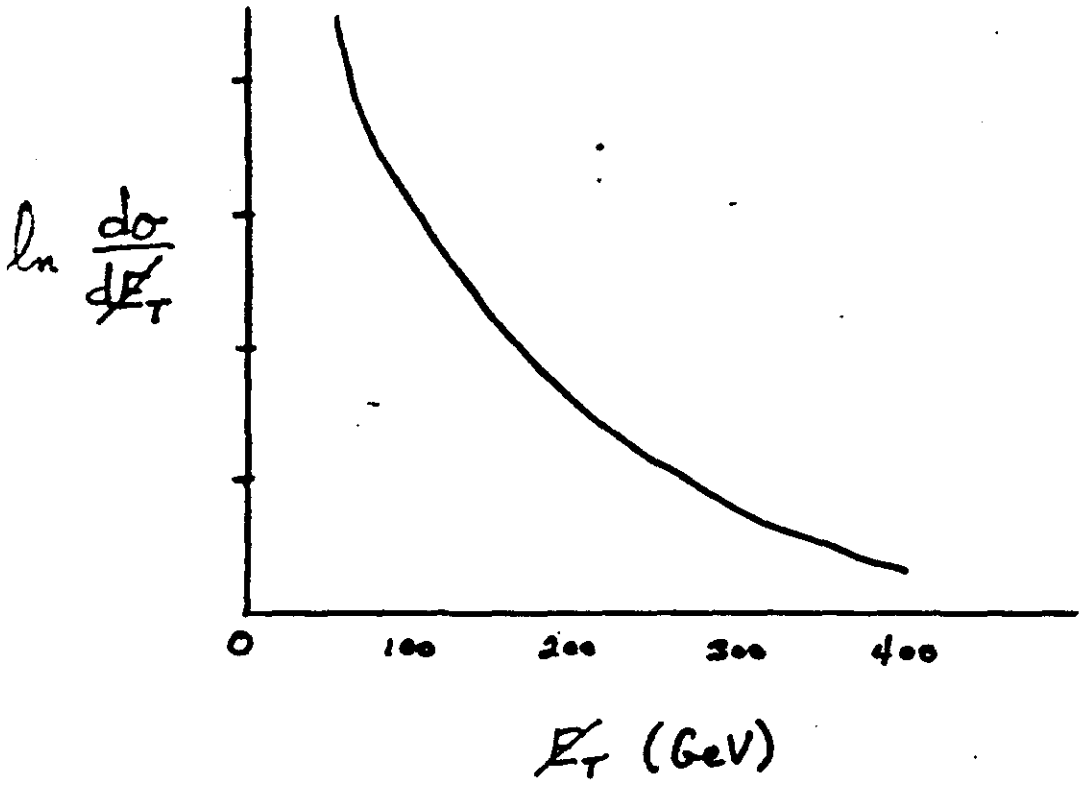
The (3D) pattern recognition in the μ-chambers seems to be the most important.

The sum of all the reasons make it an important but not vital consideration.

Missing E_T Resolution and Tails



1) Late developing showers contribute to tails
2) Cracks/Dead material contribute to resolution



COMPARISON OF 0.08 HADRON CALORIMETER ESTIMATES

	Catagory	Liq Scint	Spaghetti	Difference
1.00	R&D	$5,494	$6,404	Larger Program
2.00	Conceptural Design	$405	$405	Same
3.00	Towers	$18,804	$29,114	Spaghetti Has Higher Fab/Mat'l Cost
	(Sense Material)	$508	$5,759	Fiber vs. Liquid
4.00	Ring Modules	$5,032	$5,204	Spaghetti Has More Complex Shape
5.00	Electronics	$11,354	$8,494	Liquid Has More Channels
6.00	Thermal Cont	$1,166	$1,166	Same
7.00	Beam Testing/Calib.	$2,077	$2,077	Same
8.00	System Assembly	$2,033	$1,916	Liquid Has More Assembly Ops.
9.00	Installation	$3,480	$4,246	Spaghetti Has More Complex Shape
10.00	Project Management	$4,689	$4,689	Same
	DIRECT COST	$55,042	$69,474	
	CONTINGENCY	26.12%	28.72%	
	TOTAL	$69,419	$89,427	

Cost Estimate Differences
CDSL/ORNL

1) Fiber Materials,	$ 8.3M	ORNL	
Threading,	- 5.1M	CDSL	
Preform Preparation	-------		
10.3% fiber vs. 16.7%	$ 3.2M		
28.72% Contingency x 1.11 R&D	x 1.43		= $4.6 M
2) Top Support Plate			
5168 @ $310 each (Machined)	$ 1.6M	ORNL	
5168 @ $70 each (Zinc Cast)	-0.4M	CDSL	

	$ 1.2M x 1.43		= $1.7 M
3) Module Fabrication (Manufacturing Segmentation)			
.08 x .08 Supertowers			
$1.6K/Supertower	$ 8.1M	ORNL	
.16 x .16 Supertowers			
$4.4K/Supertower	- 5.7M	CDSL	

	$ 2.4M x 1.43 = $3.4 M		
4) Sheathing			
Sheet Metal Jackets			
5168 @ $400 each	$ 2.1M	ORNL	
Larger Sheaths			
1300 @ $1000 each	- 1.3M	CDSL	

	$ 0.8M x 1.43 = $1.1M		
5) Support Structure			
Inner + Outer Rings ($12/lb x 85T)	$ 2.2M	ORNL	
Inner + Outer Rings ($8/lb x 60T)	- 1.1M	CDSL	

	$ 1.1M x 1.43 = $1.6M		
TOTAL ABOVE			**= $12.4M**

OPINIONS VARIED

FROM: "either would work equally well"

TO: "both solutions look equally risky"

ISSUES

COST - favored LS

Work by Rennich, Ayres, Adair etal reduced SF differences to ≈ 5%

PROJECTIVE - favored SF

LONGITUDINAL SAMPLING - favored LS

Moderated by possibility of long. sampl. with SF

MATURITY OF TECHNOLOGY - favored SF

+ others

VERY CLOSE CALL

CAL GROUP COMMISSIONED

"GROUP OF NINE"

TO MAKE CHOICE

GEM SCINTILLATOR HCAL DECISION

Group of Nine Meeting
(Only if Necessary)

B. Barish, W. Willis, J. Brau, R. Adair, L. Sulak,
H. Paar, F. Plasil, Y. Kamyshkov, H. Newman

3:15	Meeting Opens
6:15 or Before	Scintillator HCAL Decision

CHOICE:

SCINTILLATING FIBER

(group is urged to develop an affordable scheme for <u>some</u> longitudinal sampling.)

WORK IS ~~[illegible]~~ CONTINUES TODAY ON GEM SCIFI CALORIMET BY A LARGER AND STRONGER TEAM.