GEM TN-92-175

Collaboration Council Meeting - SSCL

September 3, 1992

Abstract:

Agenda, attendees, and presentations of the GEM Collaboration Council Meeting held at the SSCL on September 3, 1992. Agenda items are: Status and News; Project Manager Report; Facilities Status; Magnet Update; Calorimetry Report; BaF_2; Liquid Argon; Overviews and Issues for Decision; and Muon Status/Plans toward Technology Choice.

GEM Collaboration Council Meeting
Agenda

Thursday, 9-3-92

9:00	GEM Status and News (Barish)
9:20	Project Manager Report (Sanders)
9:40	GEM Facilities Status (Wisniewski)
10:00	GEM Magnet Update (Deis)
10:30	Coffee Break
11:00	Calorimetry Report
	BaF_2 (Newman)
11:45	Liquid Krypton (Gordon)
12:30	Lunch
1:30	Overview and Issues for Decision (Kamyshkov)
2:00	Calorimetry Discussion (Barish)
2:30	Muon Status/Plans toward Technology Choice (Taylor)
3:00	Adjourn

The Executive Committee will meet following this meeting, both Thursday evening and Friday morning. A decision by the spokesmen will follow these meeting.

Participants List

9/9/92

LAST NAME	FIRST NAME	AFFILIATION
Baker	Howard	Draper Laboratory
Baltay	Charles	Yale University
Barish	Barry C.	California Inst. of Technology
Branson	James G	University of California - San Diego
Brau	James E.	University of Oregon
Bromberg	Carl	Michigan State University
Chargin	Anthony K.	Lawrence Livermore National Laboratory
Fackler	Orrin D.	Lawrence Livermore National Laboratory
Gordon	Howard	Brookhaven National Laboratory
Guo	Ya-Nan	Inst. of High Energy Physics, IHEP - Beijing
Kamyshkov	Yuri	Inst. for Theor. and Exper. Physics, (ITEP)
Kobrak	Hans E. G.	University of California - San Diego
Korytov	Andrey	Massachusetts Institute of Technology
Kroeger	Robert S.	University of Tennessee
Lane	Kenneth D.	Boston University
Lau	Kwong	University of Houston
Lissauer	David	Brookhaven National Laboratory
Liu	Gary	California Institute of Technology
Mockett	Paul M.	University of Washington
Mrenna	Stephen	California Inst. of Technology
Murtagh	Michael J.	Brookhaven National Laboratory
Newman	Harvey B.	California Inst. of Technology
Nutter	Scott	University of Michigan
Onel	Yasar	University of Iowa

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Osborne	Louis S.	Massachusetts Institute of Technology
Parsons	John	Columbia University
Plasil	Frank	Oak Ridge National Laboratory
Pless	Irwin A.	Massachusetts Institute of Technology
Prebys	Eric	Princeton University
Prokofiev	O. E.	Brookhaven National Laboratory
Read	Ken	Oak Ridge National Laboratory
Reidy	James J.	University of Mississippi
Rennich	Mark	Oak Ridge National Laboratory
Rutherfoord	John P.	University of Arizona
Shaevitz	Michael	Columbia University
Shaver	Leif	University of Arizona
Shi	Xiaorong	California Inst. of Technology
Stroynowski	Ryszard	Southern Methodist University
Sulak	Lawrence R.	Boston University
Sullivan	James D.	Massachusetts Institute of Technology
Taylor	Frank E.	Massachusetts Institute of Technology
Webb	Robert C.	Texas A&M University
Willis	William	Columbia University
Winn	David R.	Fairfield University
Womble	Ed	Draper Laboratory
Worstell	William A.	Boston University
Wuest	Craig R.	Lawrence Livermore National Laboratory
Yamamoto	H.	California Inst. of Technology

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Yanagisawa	Chiaki	State Univ. of New York at Stony Brook
Young	Kathy	Oak Ridge National Laboratory
Zhu	Ren-yuan	California Inst. of Technology

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DiGiacomo	Nicholas Joseph	Martin Marietta Astronautics Group

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Bonushkin	Yuri	SSC Laboratory
Eberle	Cliff	SSC Laboratory
Glebov	Vladimir	SSC Laboratory
Golutvin	Andrei	SSC Laboratory
Golutvin	Igor	SSC Laboratory
Gonzales	Arturo	SSC Laboratory
Guo	Ya-Nan	SSC Laboratory
Mitselmakher	Gena	SSC Laboratory
Morgan	Kate	SSC Laboratory
Morgounov	Vasilli	SSC Laboratory
Murat	Paul	SSC Laboratory
Ostapchuk	Andrey	SSC Laboratory
Paige	Frank	SSC Laboratory
Sanders	Gary	SSC Laboratory
Sheer	Irwin	SSC Laboratory
Stocker	Frank	SSC Laboratory
Tchistilin	Victor	SSC Laboratory
Vaniachine	Alexandre	SSC Laboratory
Villasenor	Luis	SSC Laboratory
Yost	George P.	SSC Laboratory
Yu	Xiao-qi	SSC Laboratory

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Presentation by:

Barry Barish

Status/News

- SSC Status
- GEM Facilities (Title I)
- Magnet Reviews (Management, Siskind)
- PAC (Calorimetry - Dec 2-4)
- TDR (Jan 31) 750 pages
  Outline
- PROJ MANAGER SEARCH
- CHAIRMAN - COLLABORATION COUNCIL
- CALORIMETRY DECISION
  NEW INFORMATION
  Liq Ar/Kr Eng. Review
  Beam Test Result
  BaF_2 Bleaching
  $H \to 2\gamma$ Task Force

DATES

Oct 8	SSCL	Collab Council
Nov 4-6	BNL	General Collab Mtg
Dec 3	SSCL	? (conflict with PAC Dec 2-4)

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Presentation by:

Gary Sanders

G. Sanders

FY93 GEM Funding Requests

1. Subsystem leaders collected preliminary funding requests.

2. R&D/Engineering Task Force (Webb, chair; Sanders, Harris) held first review meeting. Several total FY93 funding levels were considered.

3. Conclusions from this meeting:

   a. Requests for muon and calor. engineering were incomplete.

   b. Requsts were poorly justified in many cases. Coordination poor. Much duplication. No deliverables. No schedule...

   c. Requests did not display a strong sense of a program leading to a system, except for magnet and central tracker requests.

   d. Many individual questions were generated for specific requests.

   e. GEM needs about $36 million to stay on schedule. A $30 million budget may be adequate with all decisions made promptly and non-critical tasks delayed. SSCL guidance hints at $25 million.

4. Next step is individual contacts with subsystem leaders for refined proposals.

FY93 GEM Funding Requests (continued)

Next Steps:

1. **Mike Harris has requested complete engineering requests by September 4. Requests to include detailed breakdown of work by WBS, personnel, deliverables, expenditures, costs. Tight Statements of Work will be negotiated based upon these requests. Requests should be submitted through the subsystem leaders!**

2. **Sanders and Webb request revised and complete R&D and engineering requests from each subsystem to GEM Dept. by Sept. 18. These to include complete detail by institution and WBS element of work to be performed, deliverables, milestones, personnel, level of effort.**

3. **All work is to be funded from funds identified in the current GEM cost estimate. When the funds for a subsystem are expended, the subsystem should be complete. If it is not...! Funds expended outside of the cost estimate raise the cost of GEM.**

4. **Monthly reporting and quarterly reporting will be enhanced to serve the function of real performance and progress measurement. GEM will now be part of the SSCL Performance Measurement Baseline. This will be mandatory.**

5. **We are considering distributing 2/3 of the annual allocation at the beginning of FY93 and holding the remainder until a mid-year review is completed. If carried out properly, this should not disrupt funding for institutions who meet the agreed upon plans. This mechanism will be flexible to deal with the university grants and critical commitments. Please provide comments to me.**

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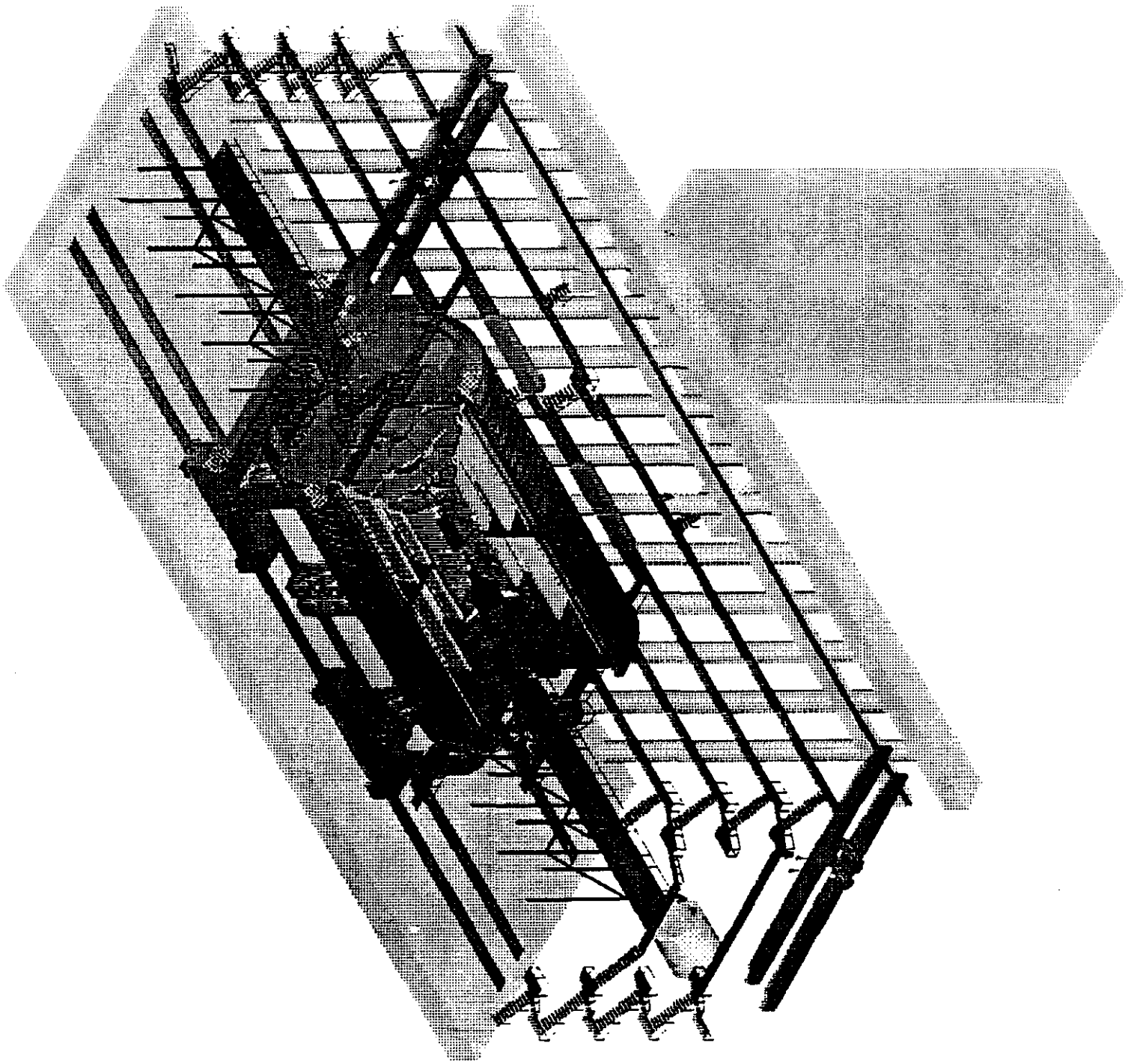
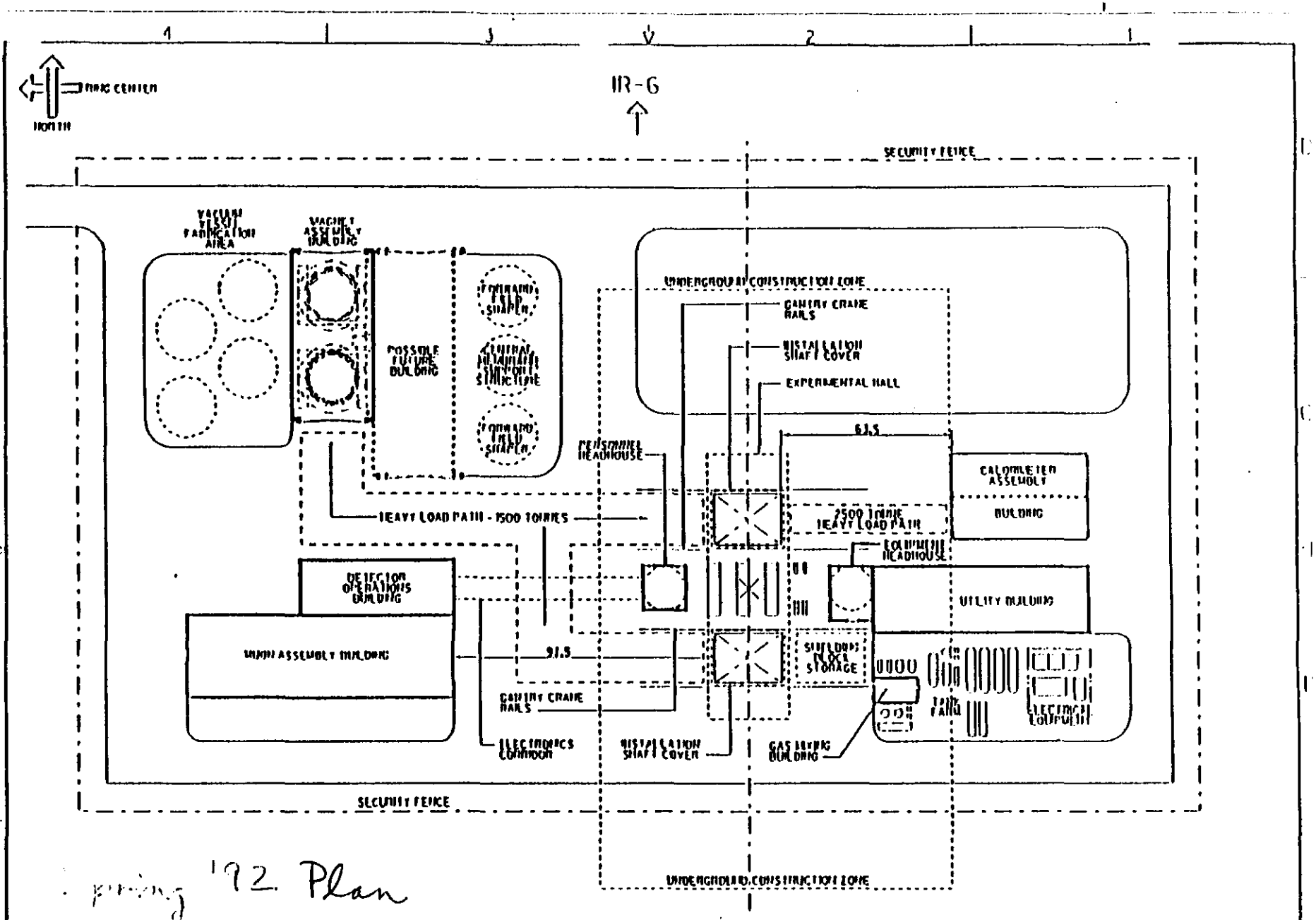
Presentation by:

Bill Wisniewski





'92 Plan

SITE PLAN

DIMENSIONS ARE SHOWN IN METERS UNLESS NOTED OTHERWISE.

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PHYSICS RESEARCH DIVISION

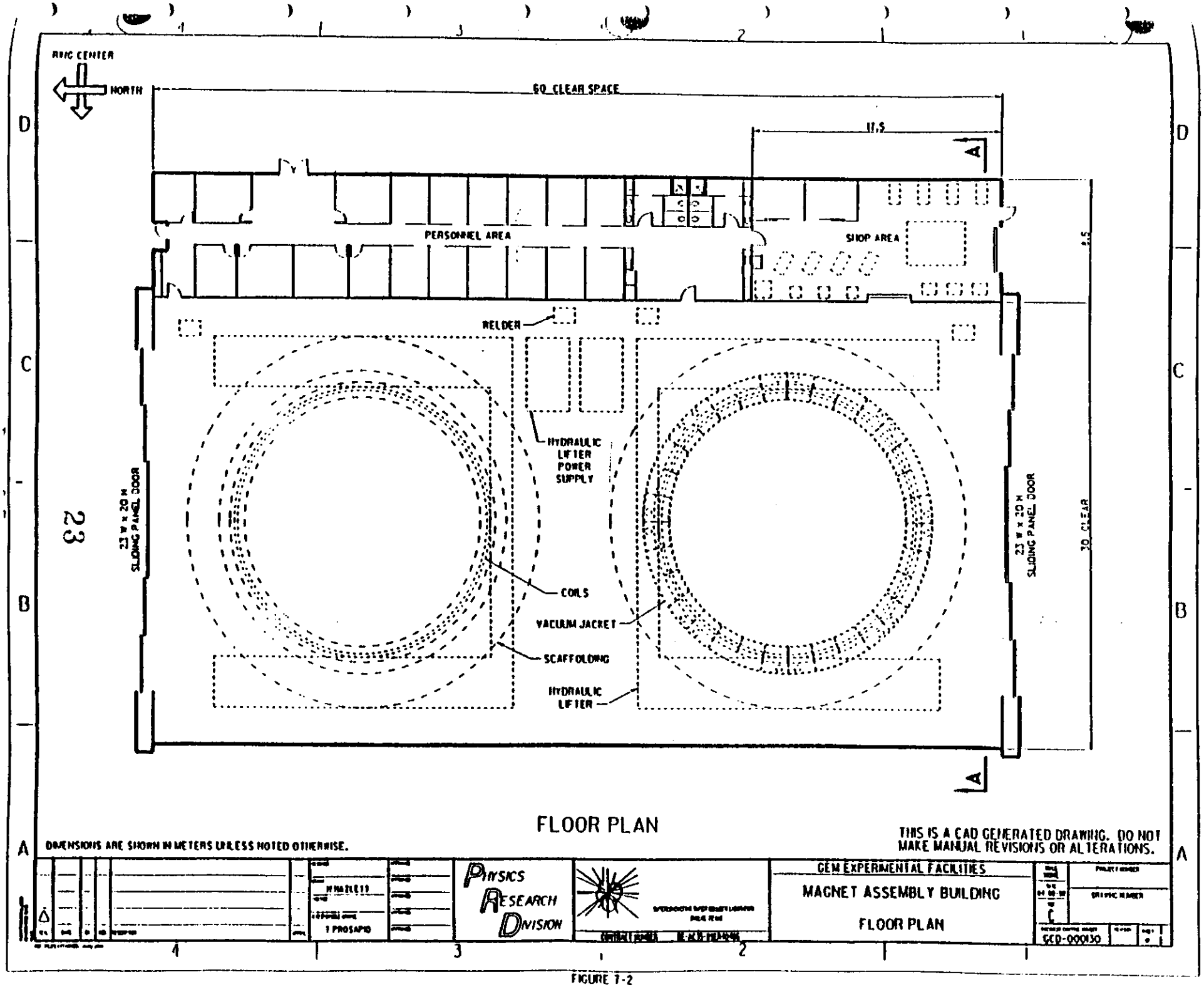
SSC

GEM EXPERIMENTAL FACILITIES

IR-5

SITE PLAN

22


RHIC CENTER
NORTH
60 CLEAR SPACE
11.5
A
PERSONNEL AREA
SHOP AREA
WELDER
HYDRAULIC LIFTER POWER SUPPLY
23 W x 20 H SLIDING PANEL DOOR
COILS
VACUUM JACKET
SCAFFOLDING
HYDRAULIC LIFTER
30 CLEAR
FLOOR PLAN
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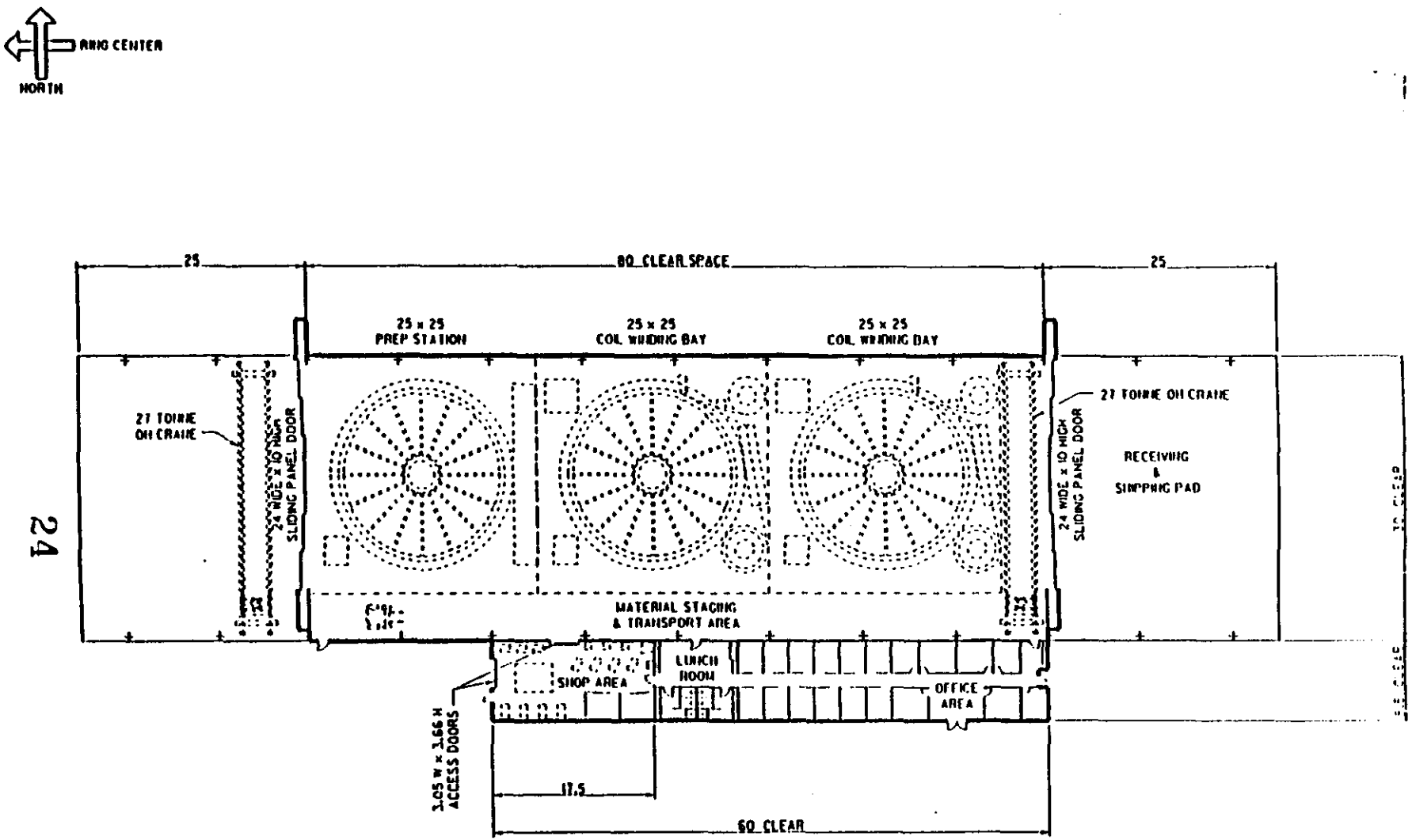
Physics Research Division
GEM EXPERIMENTAL FACILITIES
MAGNET ASSEMBLY BUILDING
FLOOR PLAN
GED-000130

FIGURE 7-2



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PHYSICS RESEARCH DIVISION

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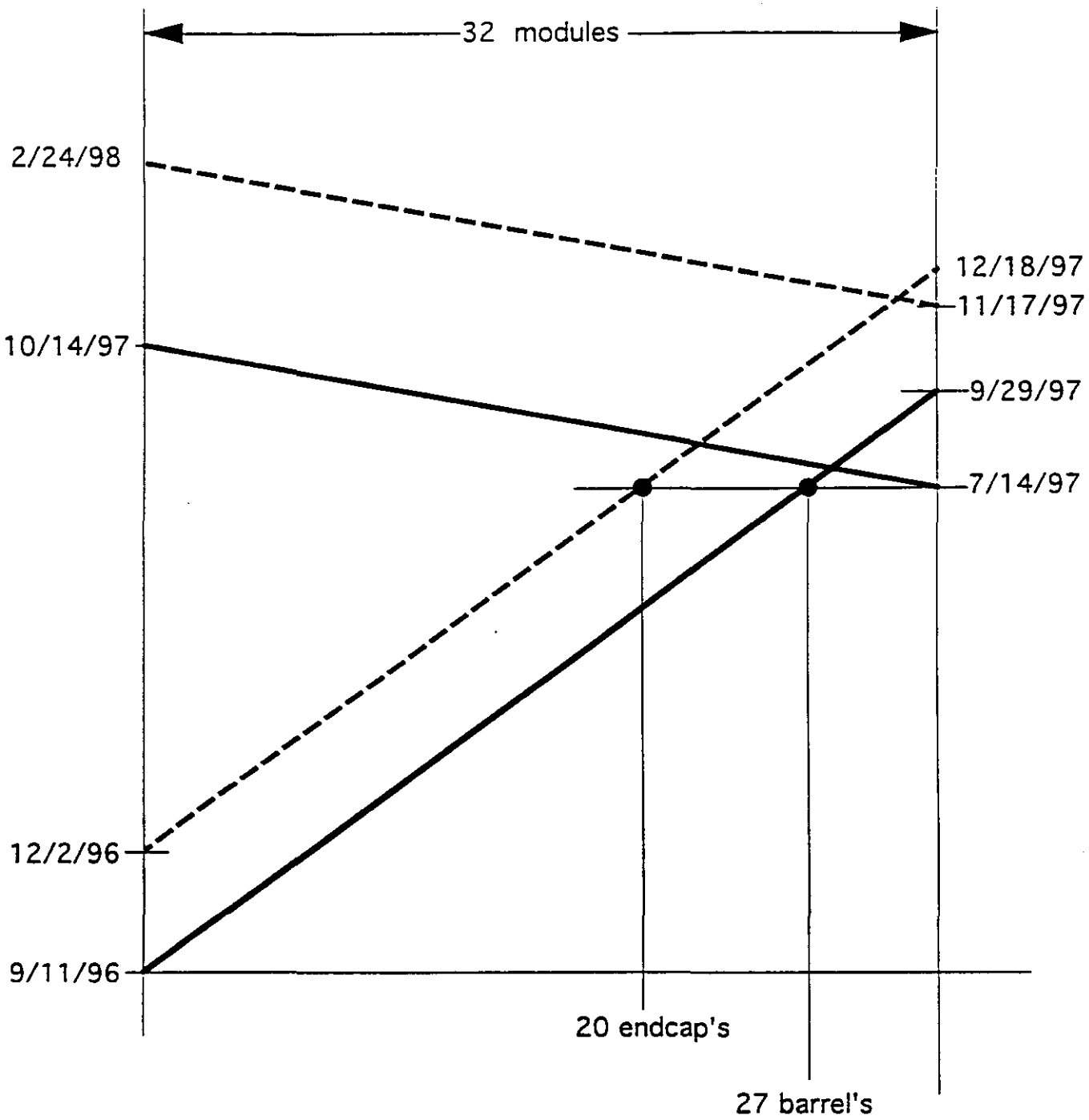
COIL WINDING BUILDING

FLOOR PLAN

GCD-000201



PRD/JPA
7/23/92

Detection systems need more space:

Driven by:

① better understanding of construction & assembly process

② schedule constraints

Solution:

Re-use space.

Get more space.

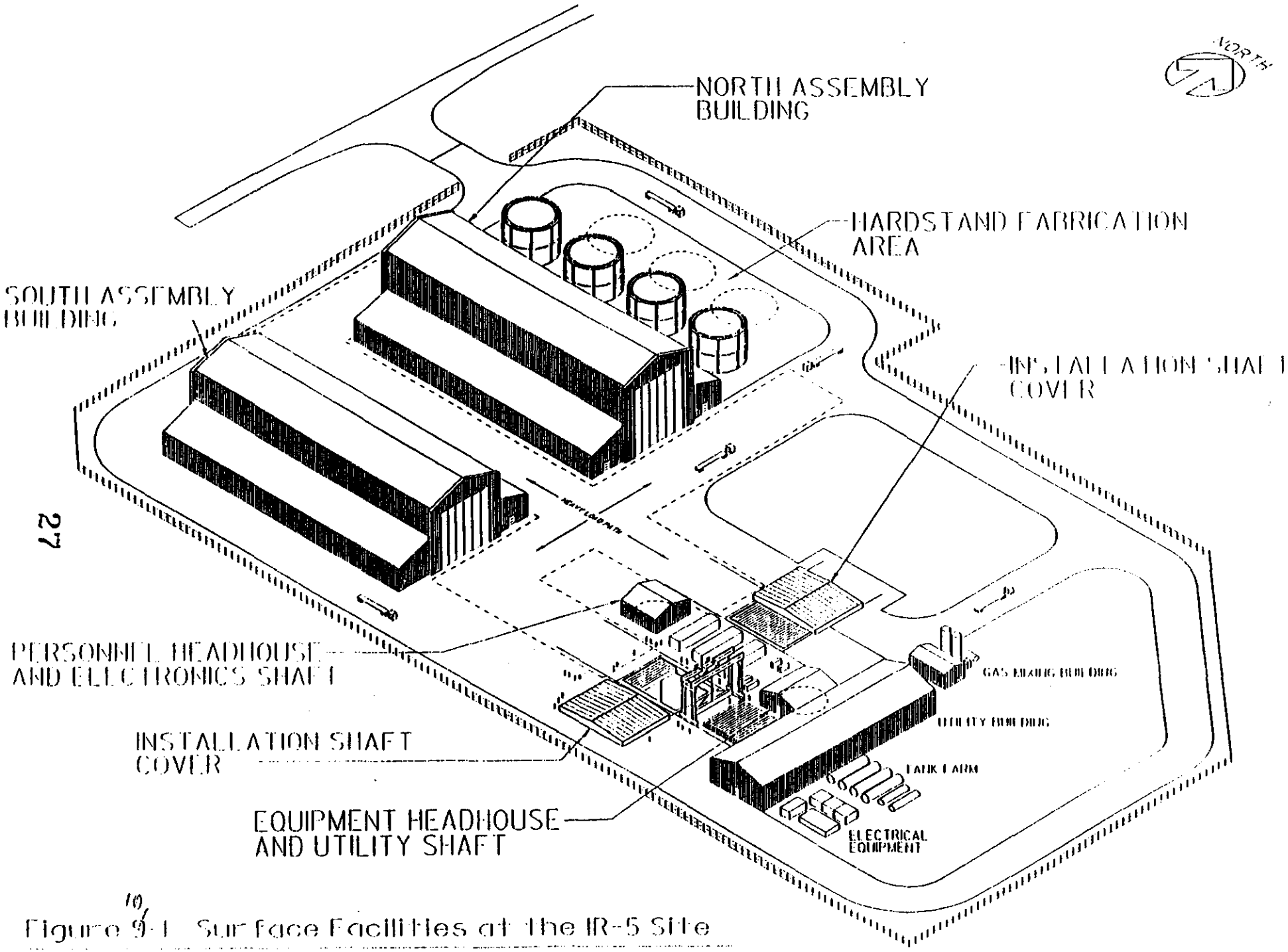


Figure 9-1 Surface Facilities at the IR-5 Site

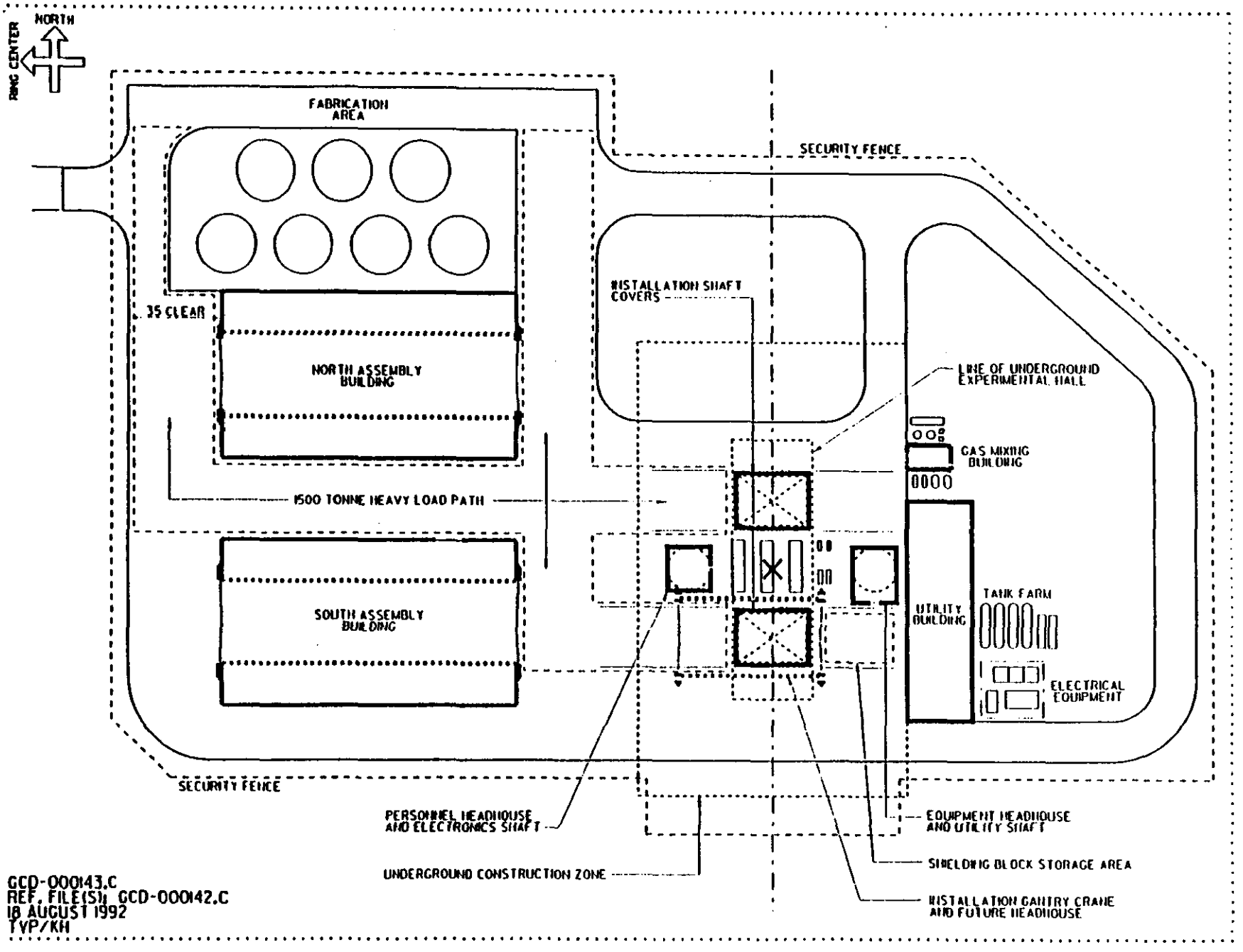


Figure 5-1 IR-5 Site Plan

Space budget:

Coil Winding Building	30 x 80 (x 12)	2400 m²	(+500 m² for long)
Magnet Assembly Building	30 x 60 (x 20)	1800 m²	(+530 m²)
Muon Assembly Building	30 x 100 (x 12)	3000 m²	(+136 m²)
Calorimeter Assembly Building	50 x 18 (x 14)	1500 m²	
	50 x 12 (x 14)		
Detector Operations Building	40 x 28 (x 2 levels)		2240 m²
		8700	3376 m²
South Assembly Building	30 x 110 (x 14/19) center	4950	
	15 x 110 (x 8) N. wing		
	15 x 110 (x 2 levels) sps		3300
North Assembly Building	30 x 110 (x 26)	6600	
	2 x (15 x 110 (x 10))		
		11550	~3300

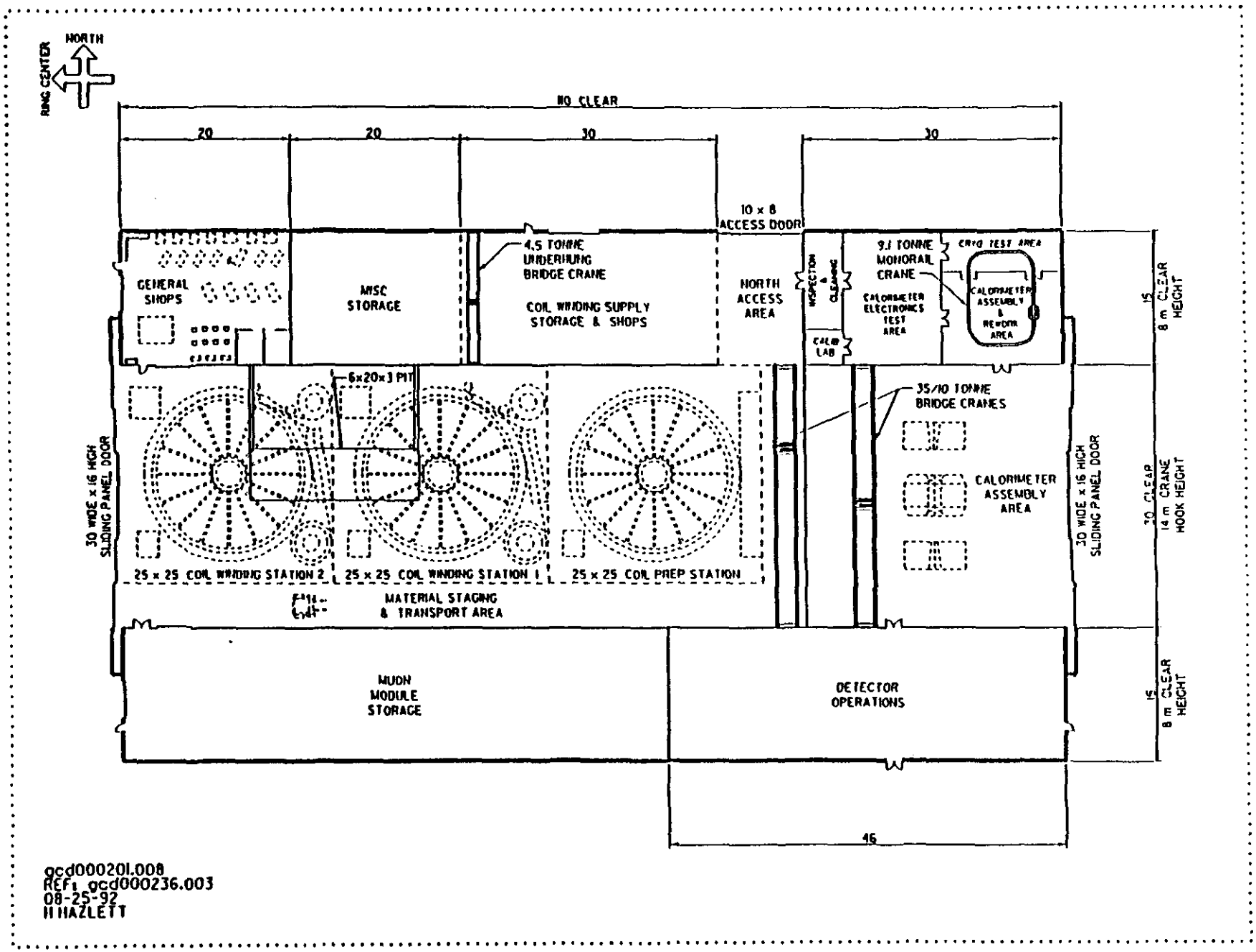


Figure 6-2 South Assembly Building Floor Plan.

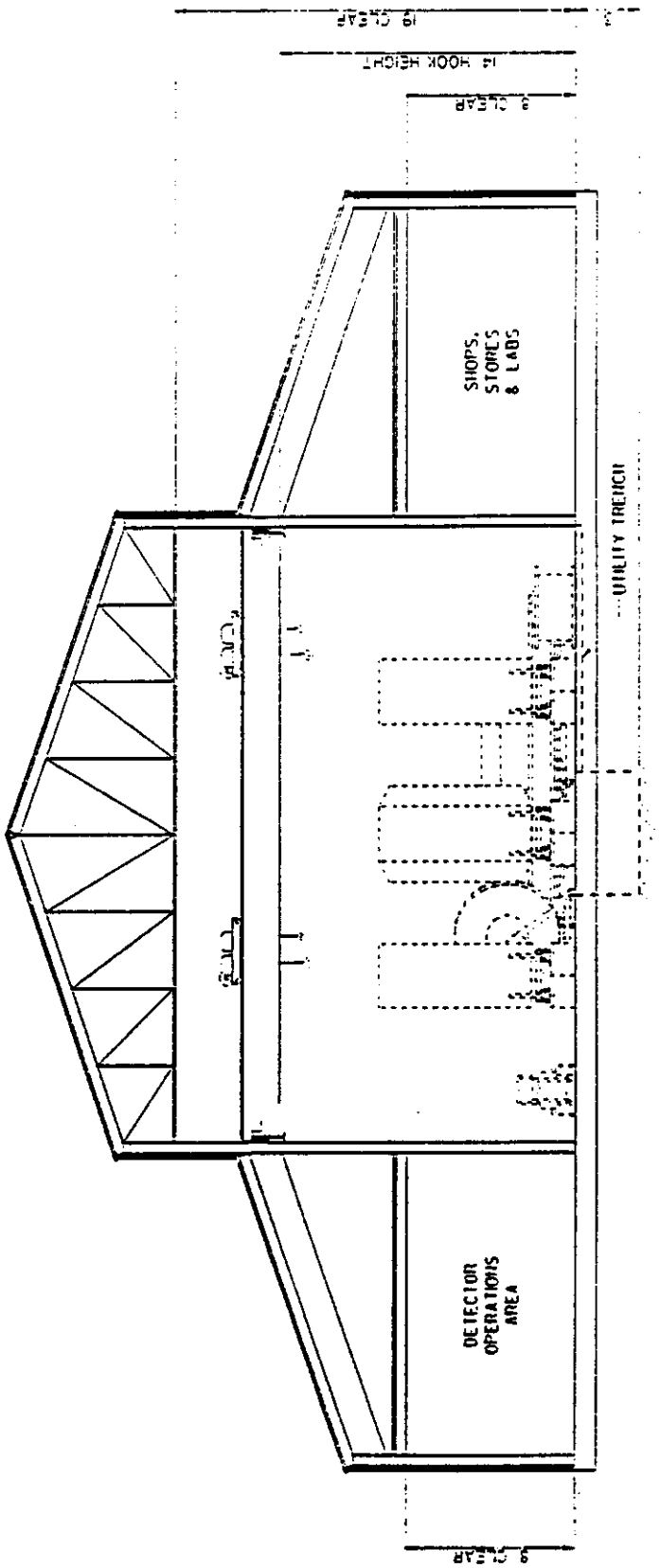


Figure 6-3 South Assembly Building Section.

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HHAZLETT

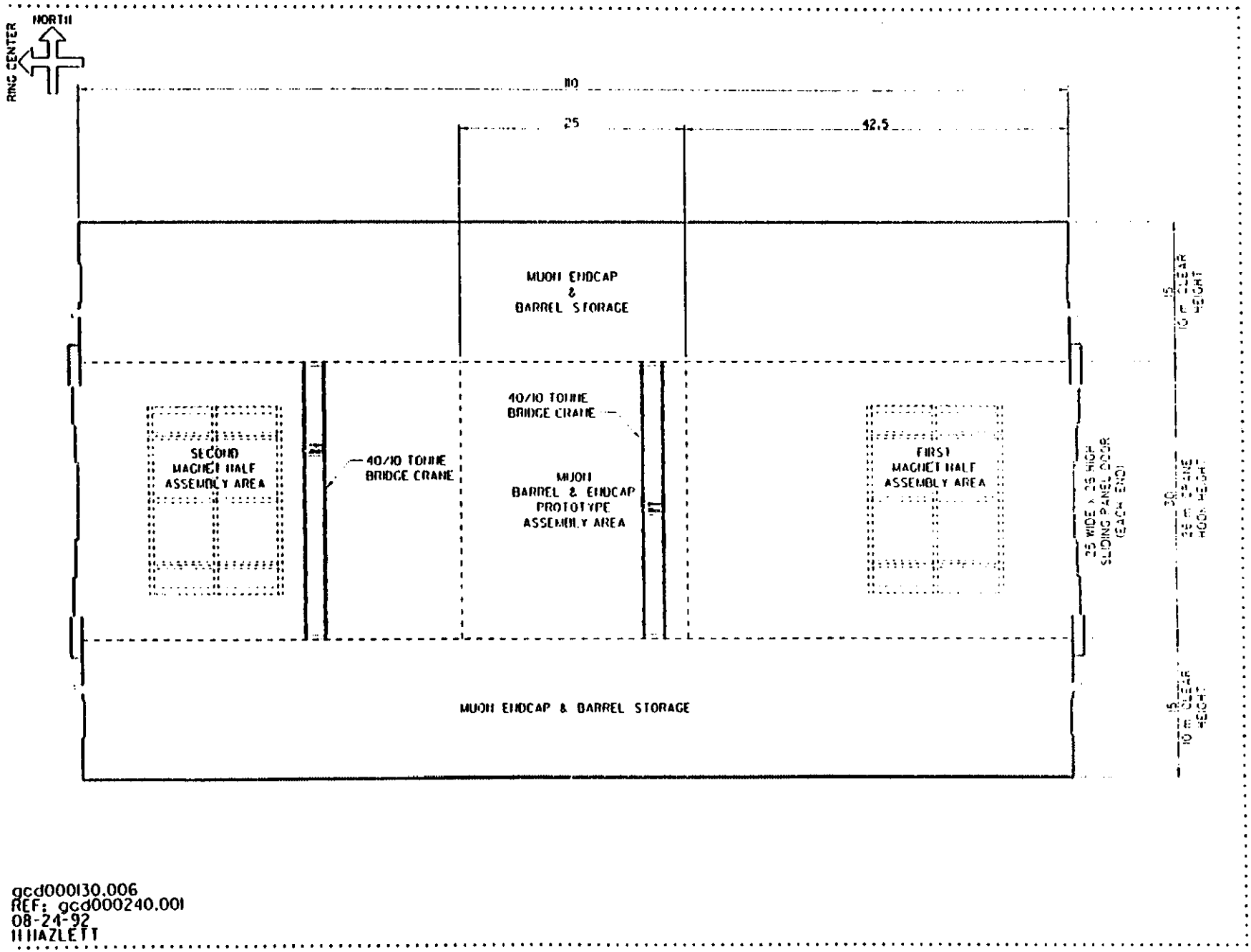
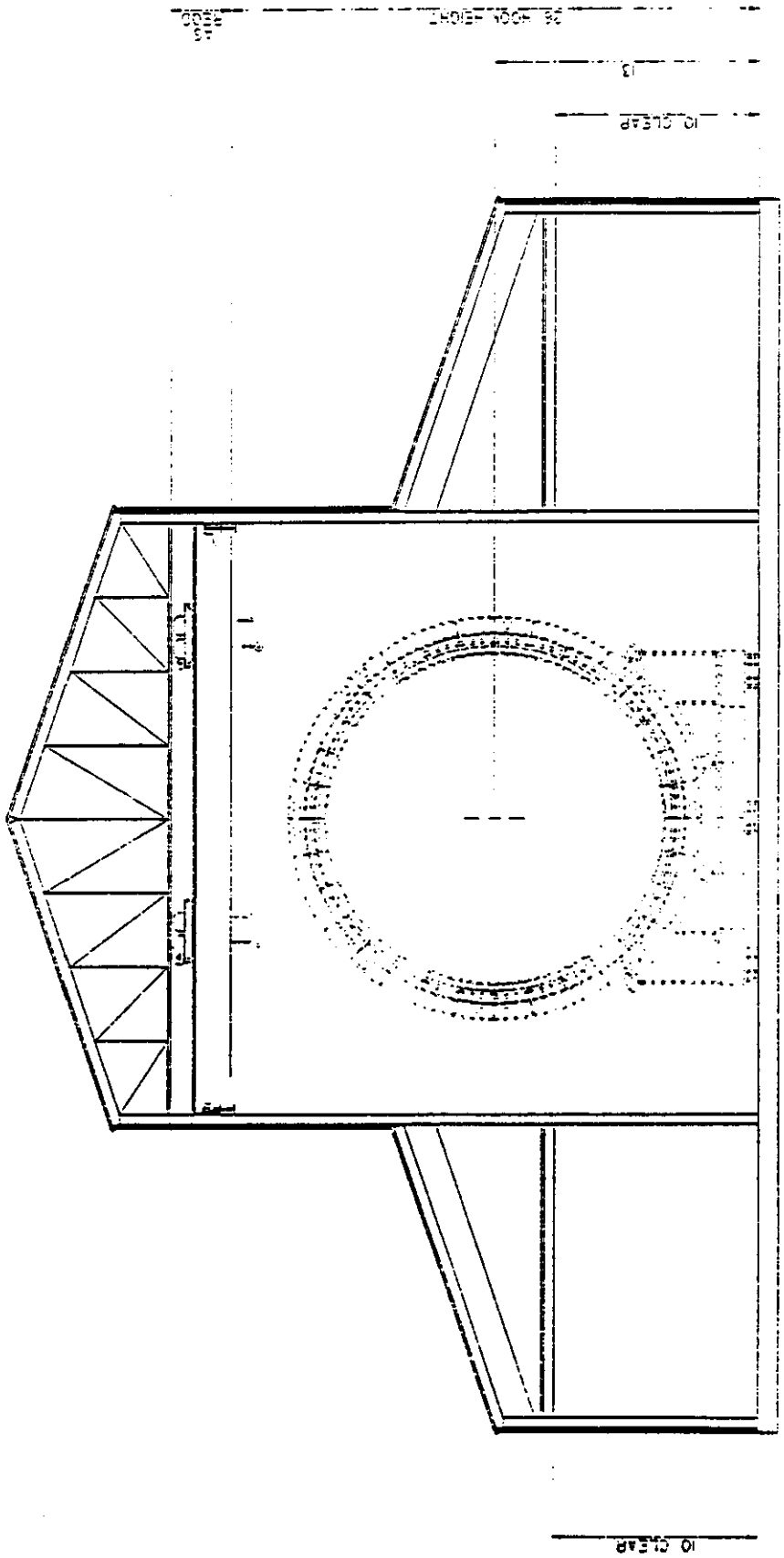


Figure 7-2 North Assembly Building Floor Plan



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HIIAZLETT

Figure 7-3 North Assembly Building Section

MAGNET DATES

Task:	Start:	Finish:	Duration:
Wind 1st batch of coils (including experimental coil)	5/2/94	4/18/95	11 months
Wind 2nd batch of coils	4/19/95	10/9/95	6 months
Assemble 1st magnet half	10/21/94	3/20/96	15 months
Assemble 2nd magnet half	5/4/95	6/6/96	12 months
Install magnet	4/22/96	11/12/96	6.5 months
Test and map magnet	11/13/96	3/24/97	4 months

9/23/92

MUON DATES

Task:	Start:	Finish:	Duration:
Magnet assembly building available for barrel prototype design and production	8/19/94	12/13/95	16 months
Magnet assembly building available for endcap prototype design and production	8/19/94	4/19/96	19 months
Convert magnet assembly building for muon production	6/7/96	8/8/96	2 months
Muon barrel production	8/9/96	9/29/97	13 months
Muon endcap production	10/28/96	12/18/97	13 months
Convert coil winding bay for muon storage	10/10/95	11/8/95	1 month
Convert coil winding bay for muon storage	5/27/97	7/28/97	2 months
Install Barrel Muon (No wiring, no alignment)	7/14/97	10/14/97	3 months
Install Endcap Muon (No wiring, no alignment) Begin barrel wiring	11/17/97	2/24/98	3 months
Connect services and test muon chambers	3/12/98	5/28/98	2.5 months
Align barrel and endcap muon chambers	4/16/97	9/21/99	5 months

9/23/92

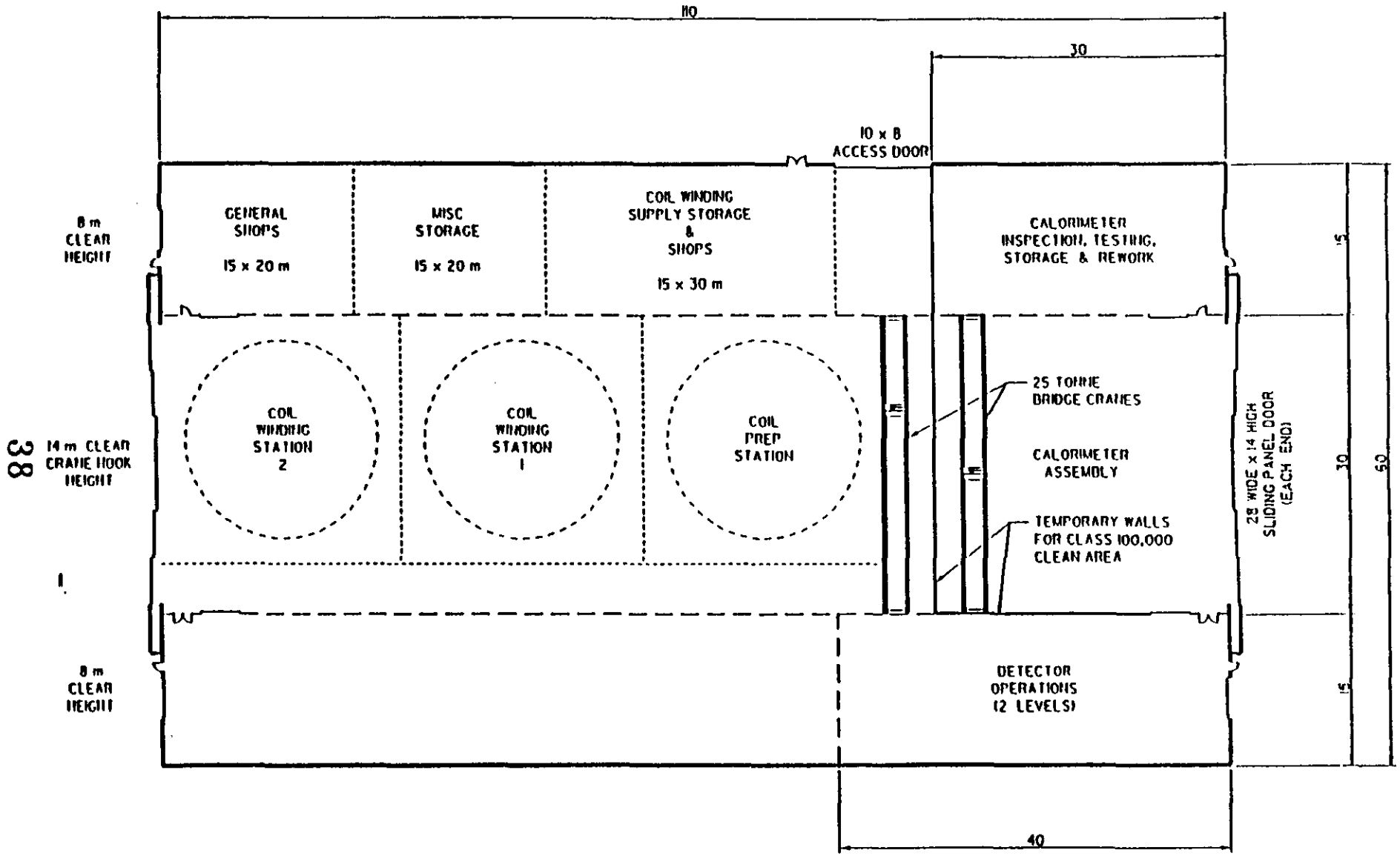
CALORIMETER DATES

Task:	Start:	Finish:	Duration:
Convert coil winding bay for calorimeter inspection	9/25/95	1/3/96	3 months
Convert coil winding bay for calorimeter assembly	10/10/95	1/18/96	3 months
Assemble barrel electromagnetic calorimeter	2/5/96	2/20/97	12 months
Assemble barrel hadron calorimeter	2/5/96	2/20/97	12 months
Insert EM barrel into hadron barrel	2/21/97	5/23/97	3 months
Assemble endcap calorimeter systems	2/5/96	2/20/97	12 months
Install calorimeter system	6/11/97	9/12/97	3 months
Finalize connections and cold test	9/15/97	11/14/97	2 months

9/23/92

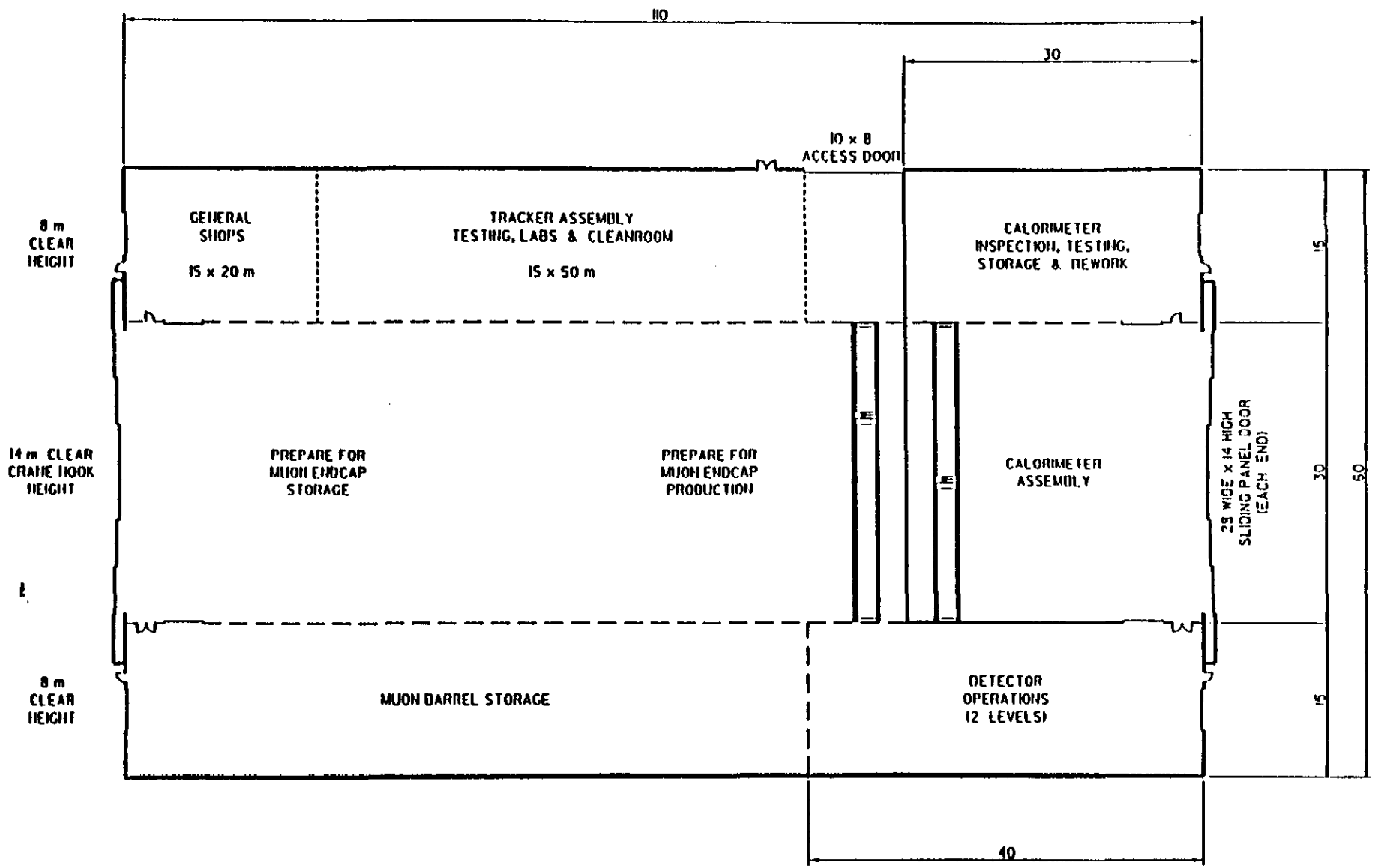
TRACKER DATES

Task:	Start:	Finish:	Duration:
Convert coil winding bay for tracker assembly	10/10/95	4/19/96	6 months
Assemble tracker	6/7/96	6/12/98	23 months
Install tracker	7/31/98	12/22/98	4.5 months
Test and checkout	12/23/98	3/1/99	2 months



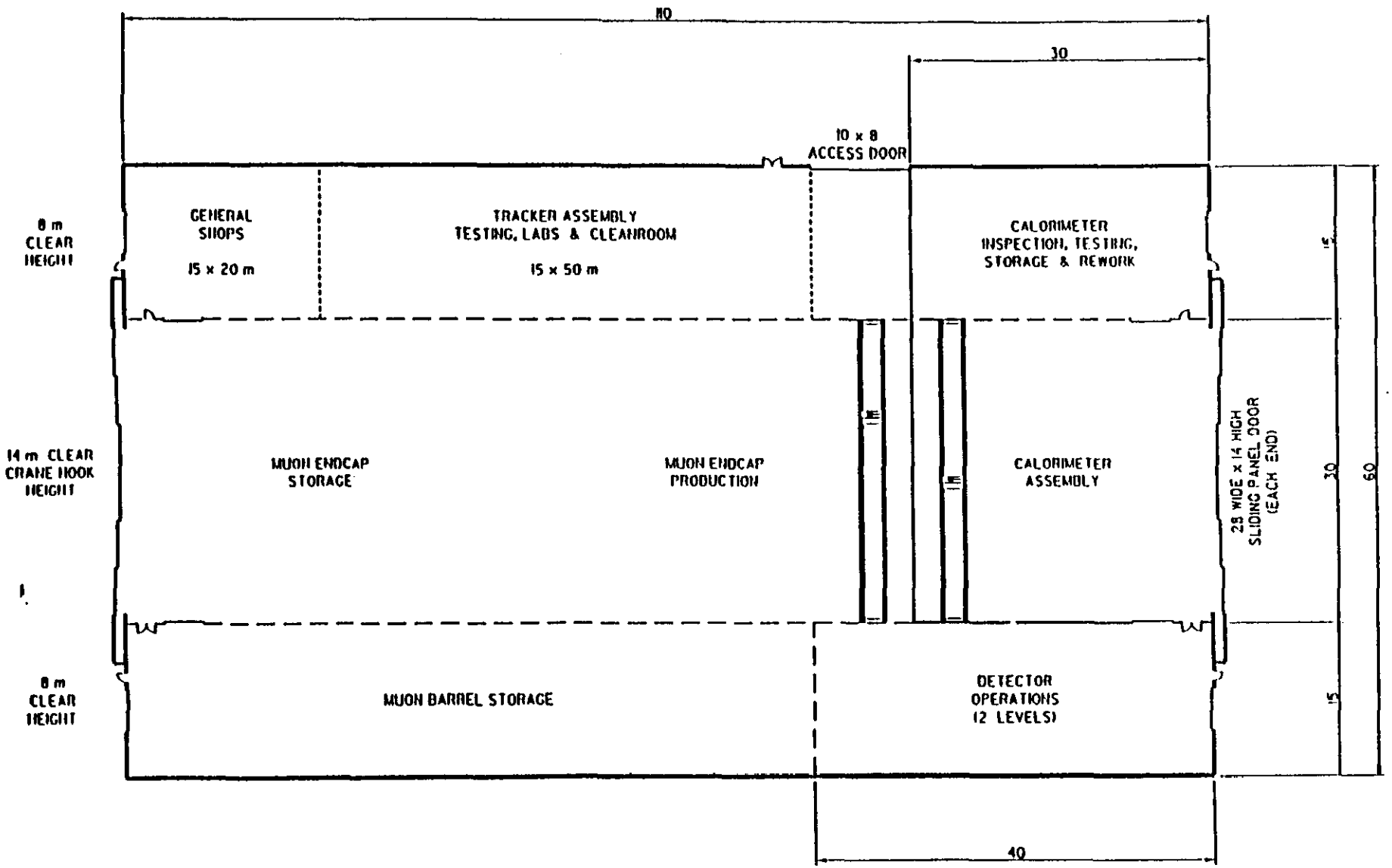
SOUTH ASSEMBLY BUILDING

FEB '94 - OCT '95



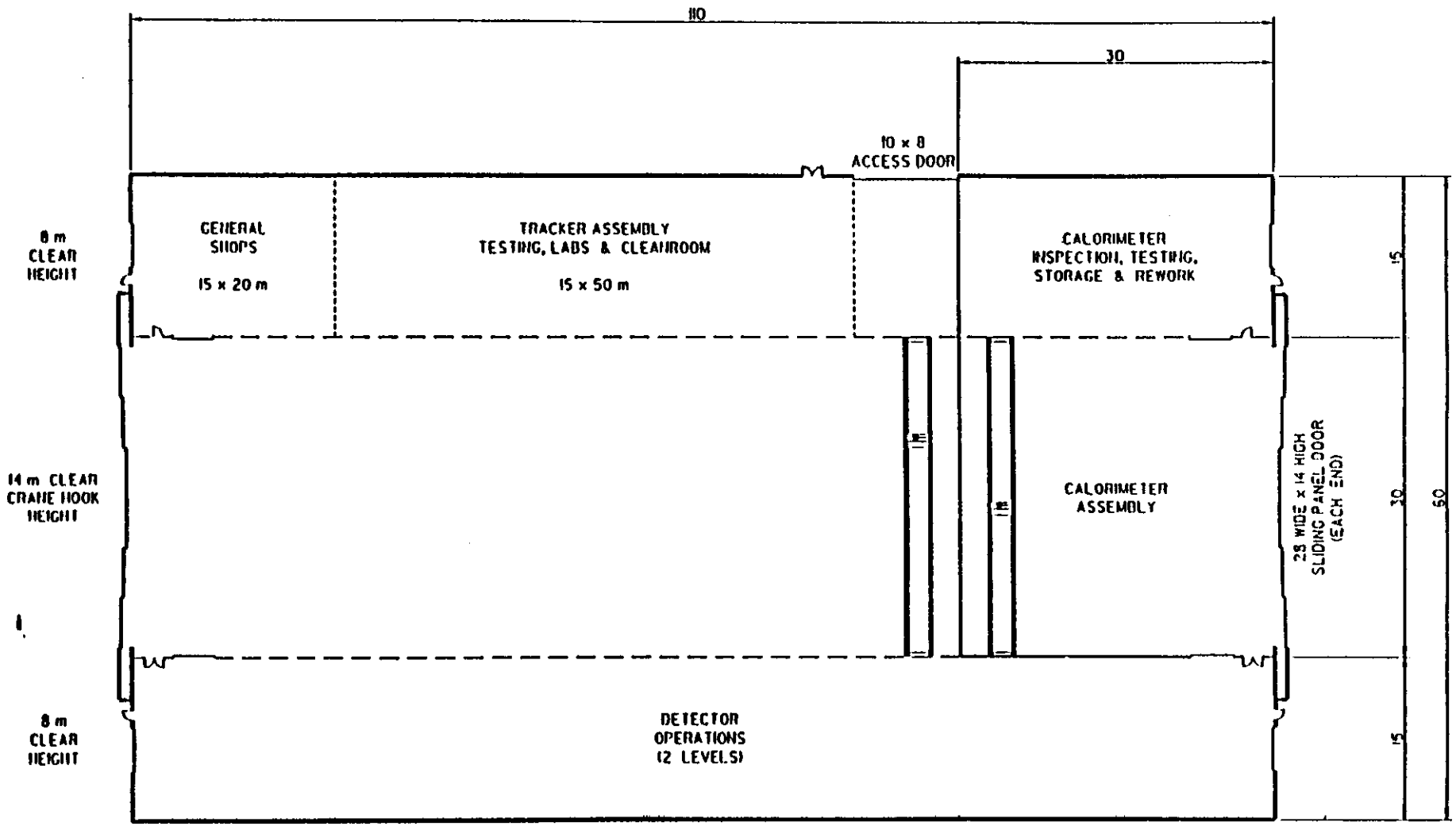
SOUTH ASSEMBLY BUILDING

SEPT '96 - DEC '96



SOUTH ASSEMBLY BUILDING

DEC '96 - DEC '97



SOUTH ASSEMBLY BUILDING

DEC '97 - DEC '99

SOUTH ASSY BLDG

Module by module scenario

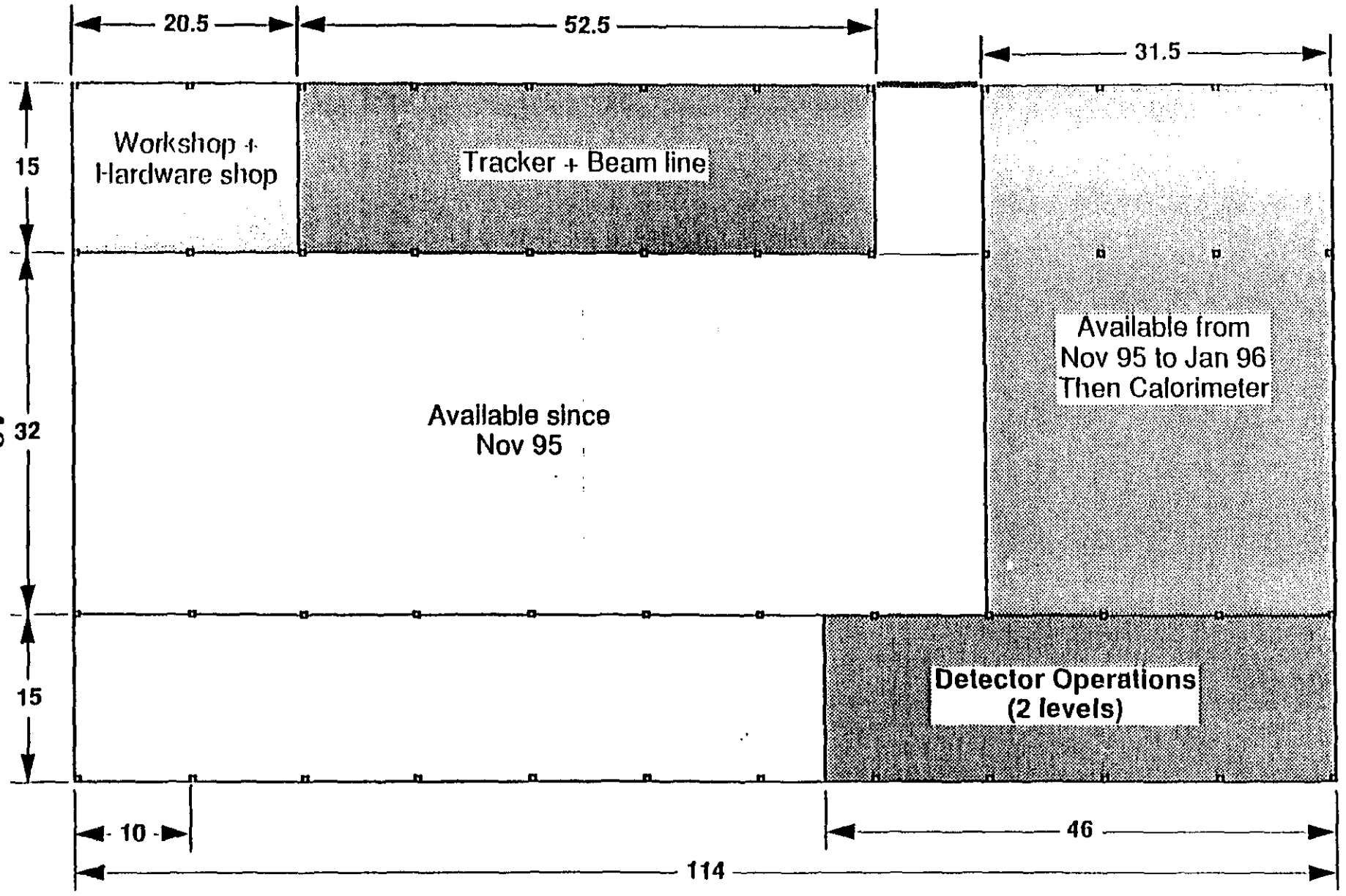


Fig 1

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SOUTH ASSY BLDG

Module by module scenario

54 peoples

Total storage capacity 21Barrel's
No chambers gas + electr. tests
1 crane of 30 t + 1 crane of 15 t
No Cloakr.+ Restr.+ Cafeteria

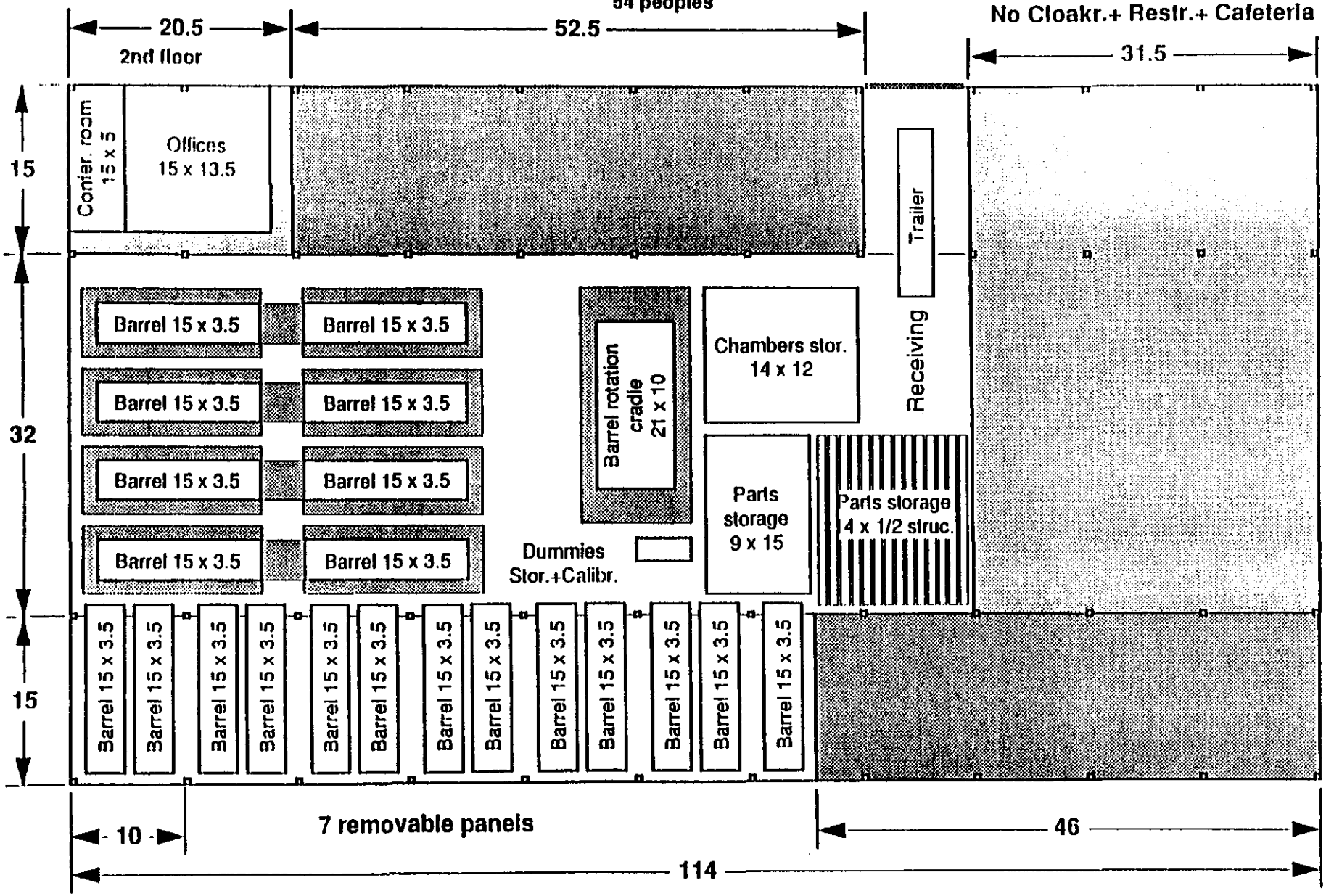

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Fig 2

SOUTH ASSY BLDG

Module by module scenario

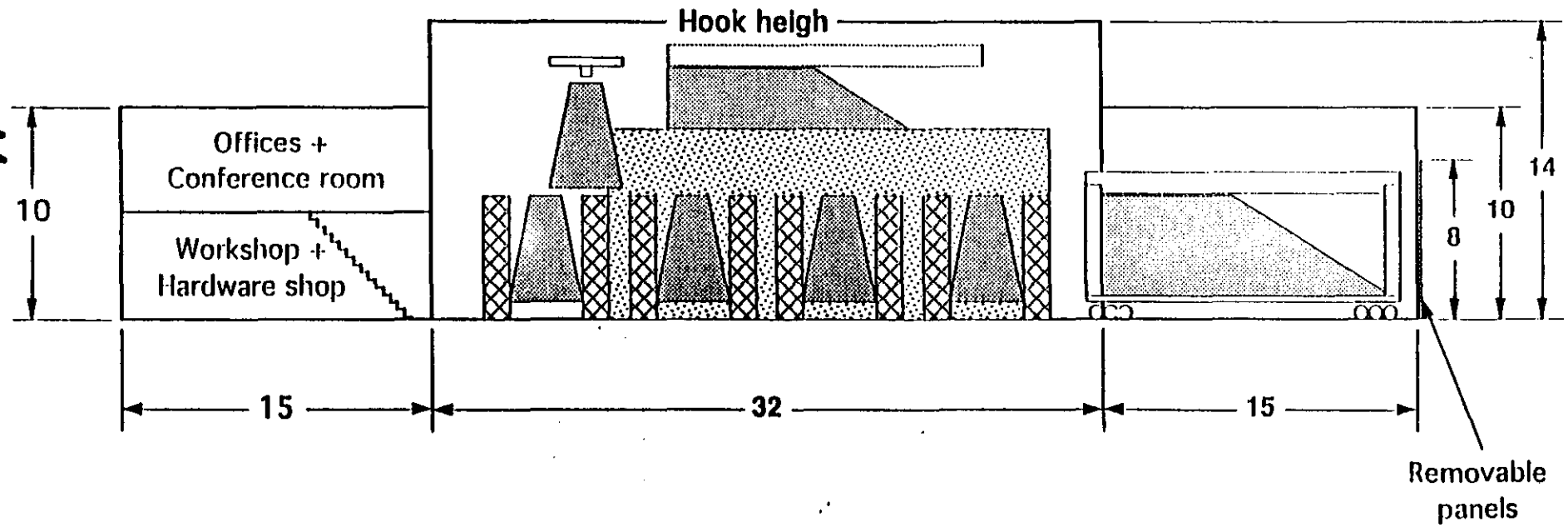

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Fig 3

NORTH ASSY BLDG

Module by module scenario

Prototypes sequence

1 crane of 25 t

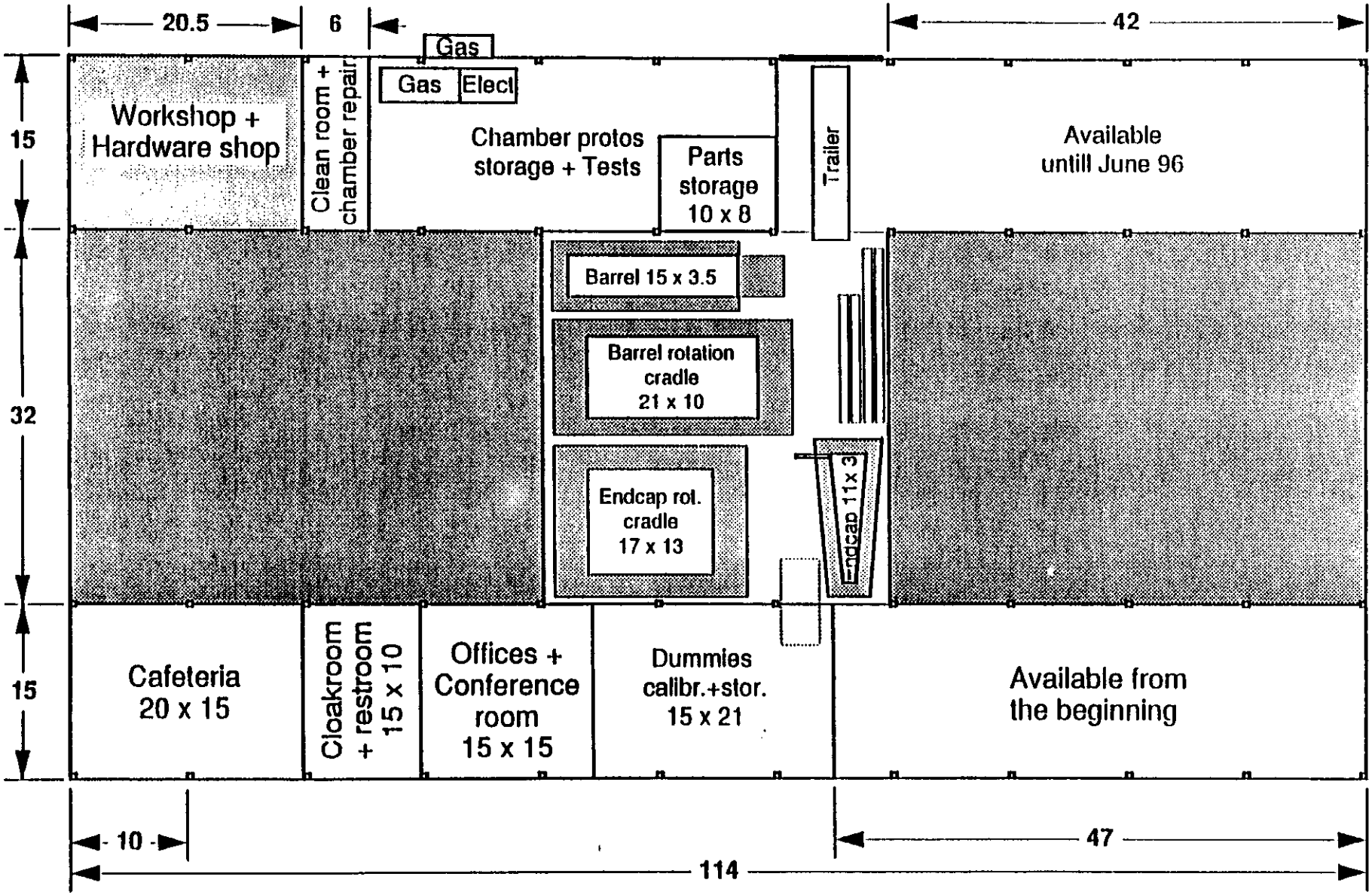

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FIG 5

NORTH ASSY BLDG

Module by module scenario

60 peoples

Total storage capacity 30 endcap's
All chambers gas + electr. tests
1 crane of 30 t + 1 crane of 15 t

25

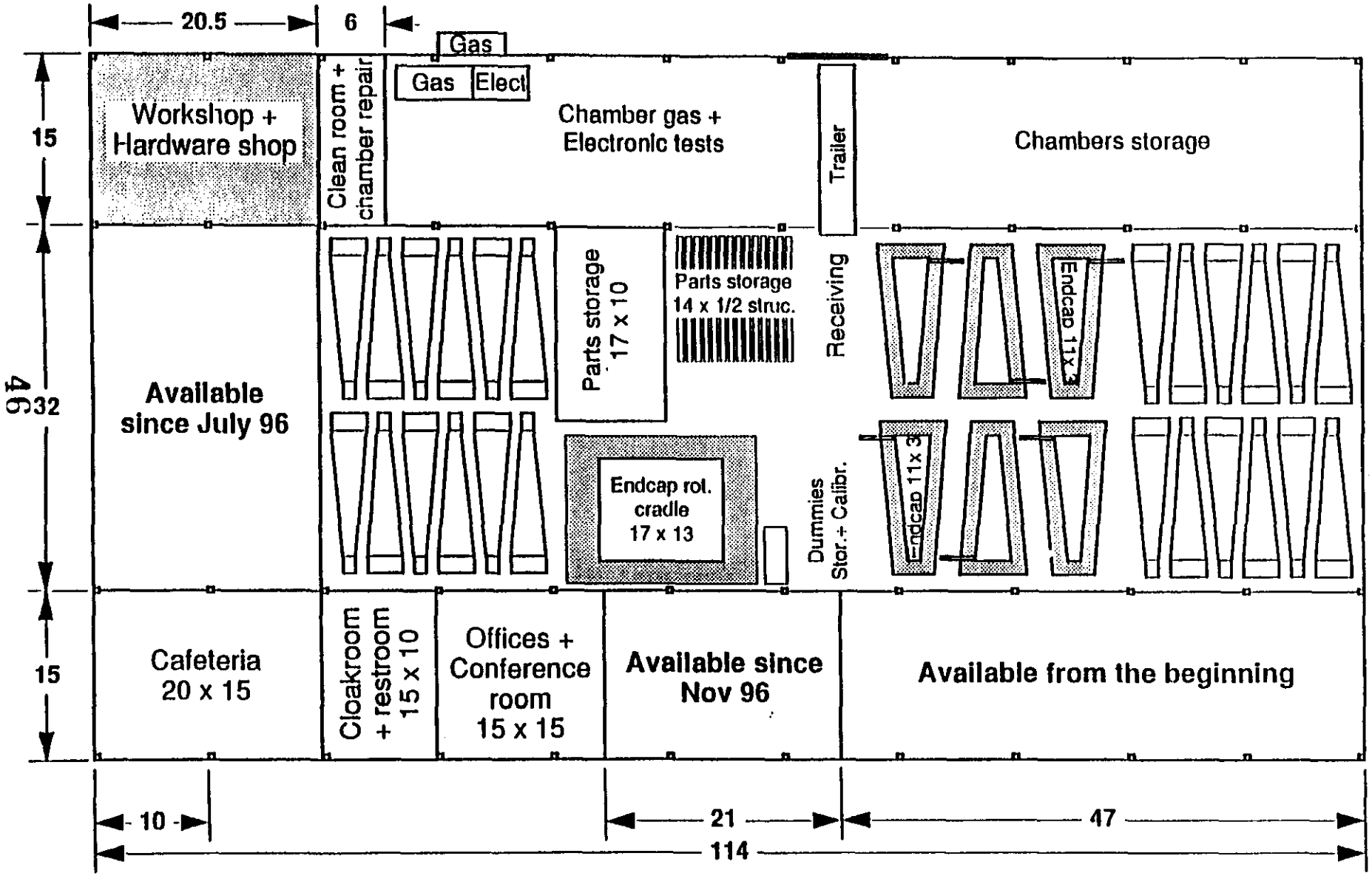

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Fig 6

46

NORTH ASSY BLDG

Module by module scenario

Version Barrel's 1st - Endcap's later

60 peoples

Total storage capacity 32 barrel's
All chambers gas + electr. tests
1 crane of 25 t + 1 crane of 15 t

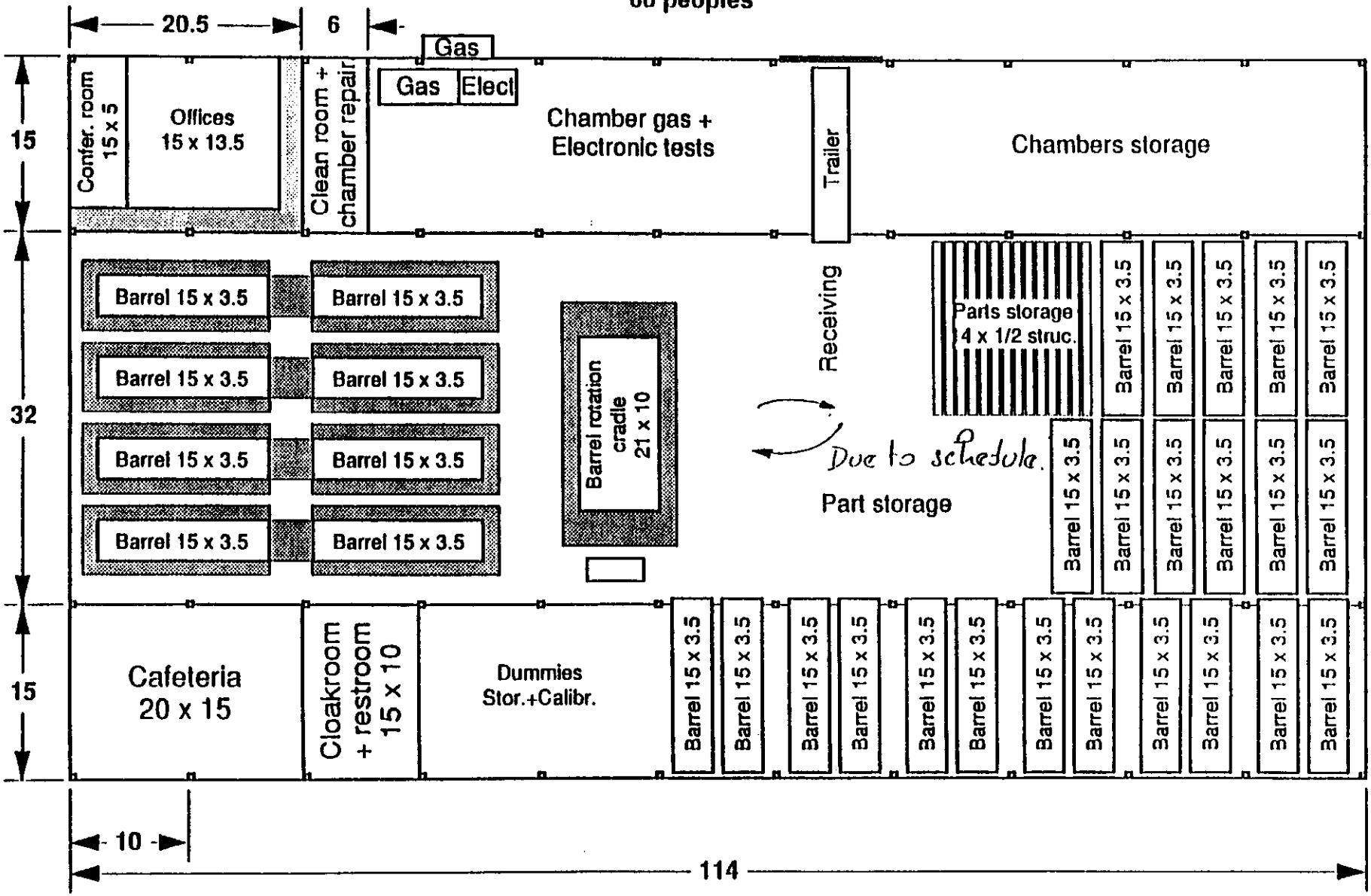

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Fig 10.

NORTH ASSY BLDG

Big wheels scenario

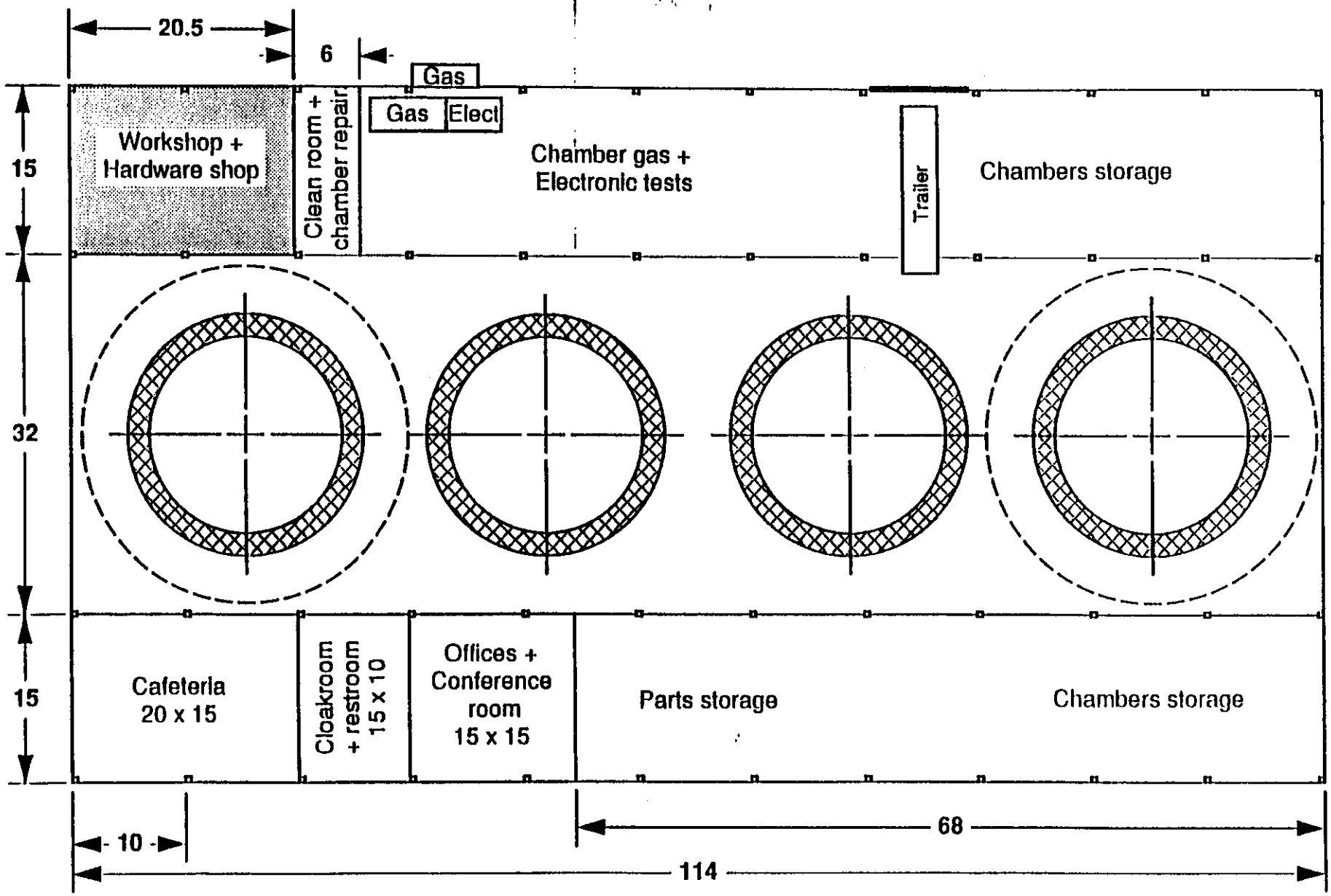

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Fig 12

NORTH ASSY BLDG

Big wheels scenario

Rotation inside

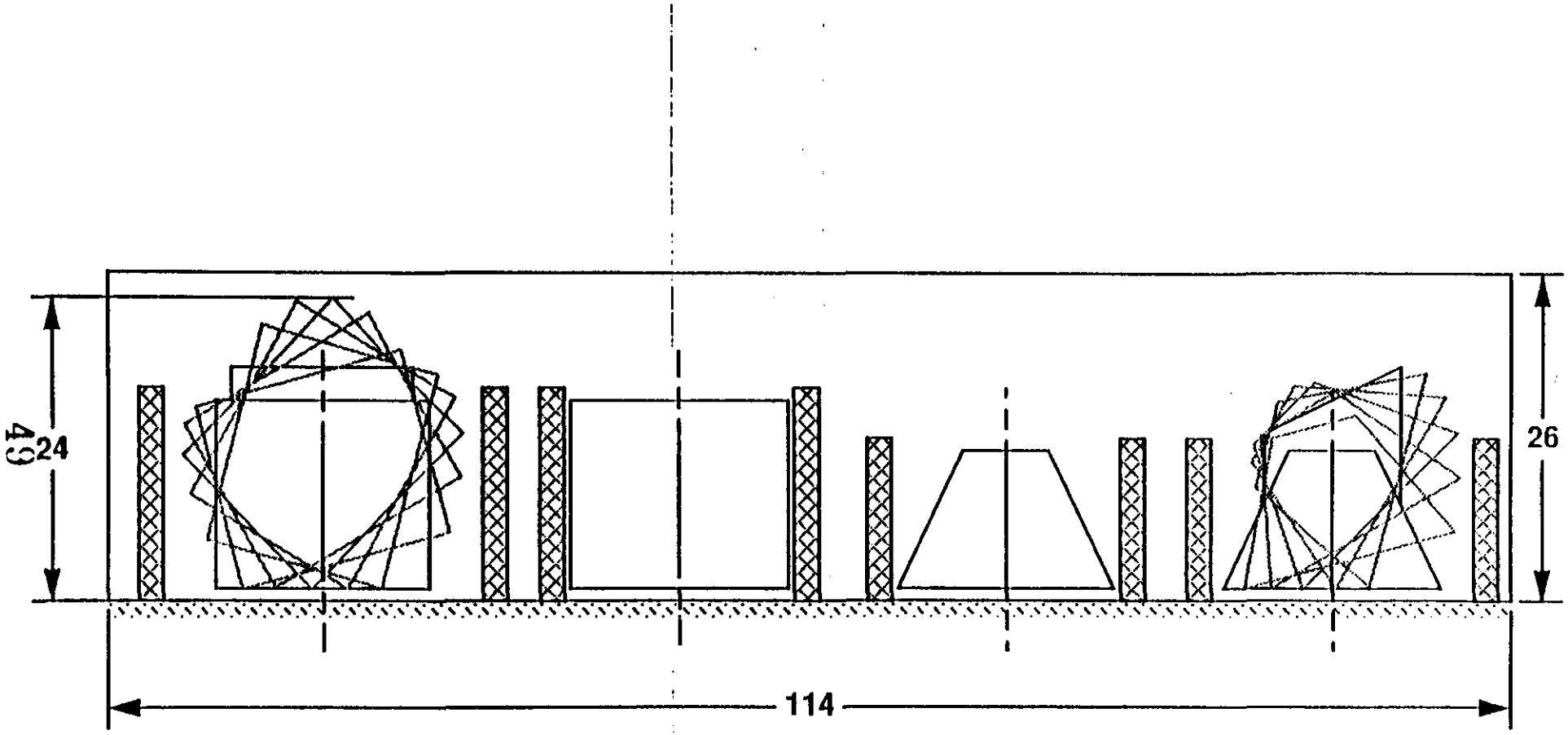

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Fig 13

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Presentation by:

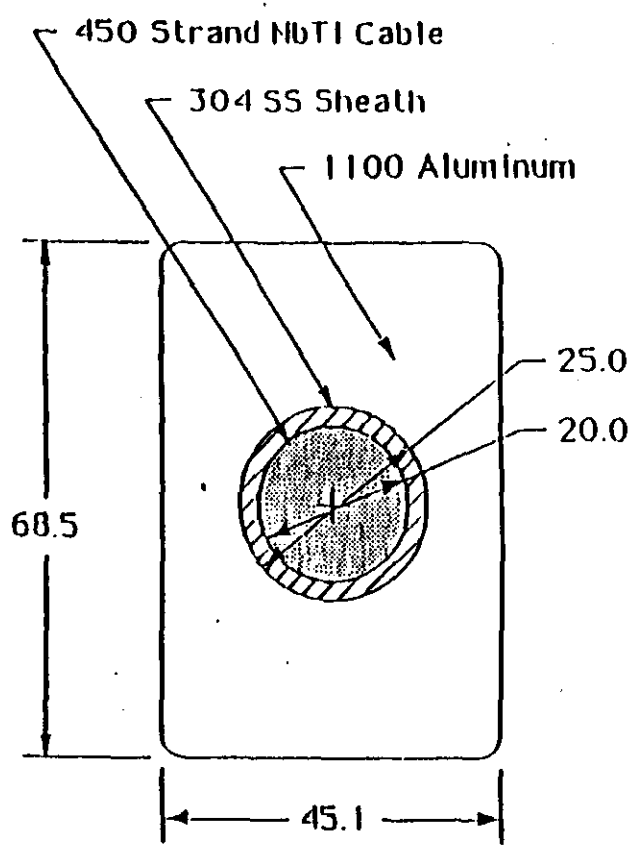
Gary Deis

G. Deis

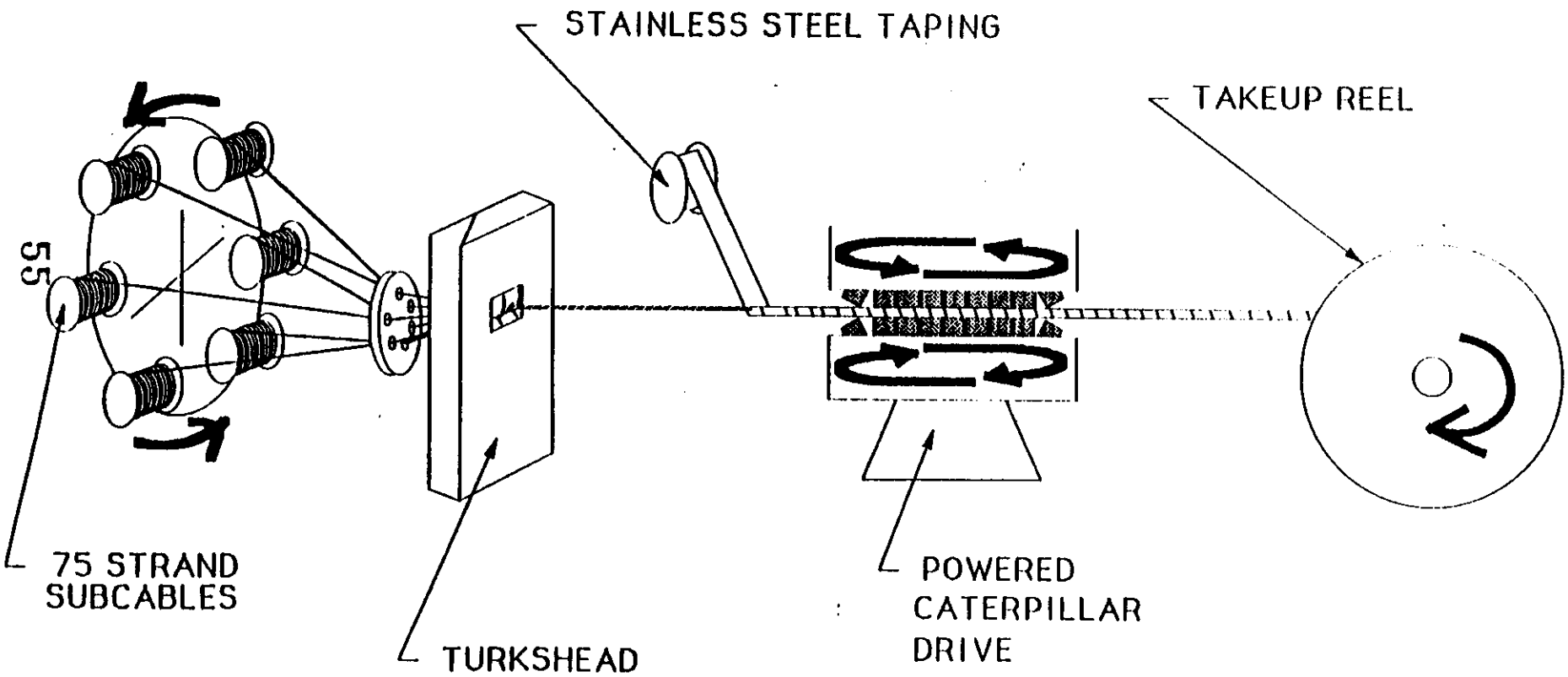
Magnet Subsystem August Progress (1)

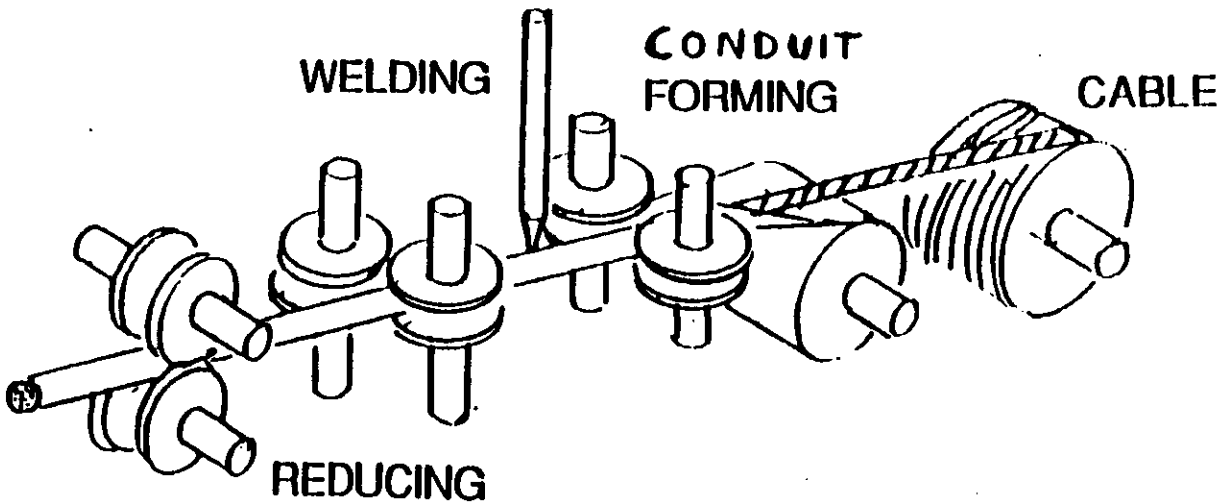
R&D tasks:

- In negotiation for purchase of superconducting strand for 1 short and 1 long length of test conductor
  - bids received from 3 vendors
- Work is in progress to place contracts for cabling, conduiting, sheathing of test cables
- Parts for a SC joint test are in fabrication
- First tests on conductor bending behavior have been completed
  - full-scale conductor (0.5m long) was bent to shipping-spool radius, then will be straightened


450 Strand NbTi Cable
304 SS Sheath
1100 Aluminum
25.0
20.0
68.5
45.1

FINAL STAGE CABLING PROCESS FOR GEM CABLE




WELDING
CONDUIT
FORMING
CABLE
REDUCING

Magnet Subsystem August Progress (2)

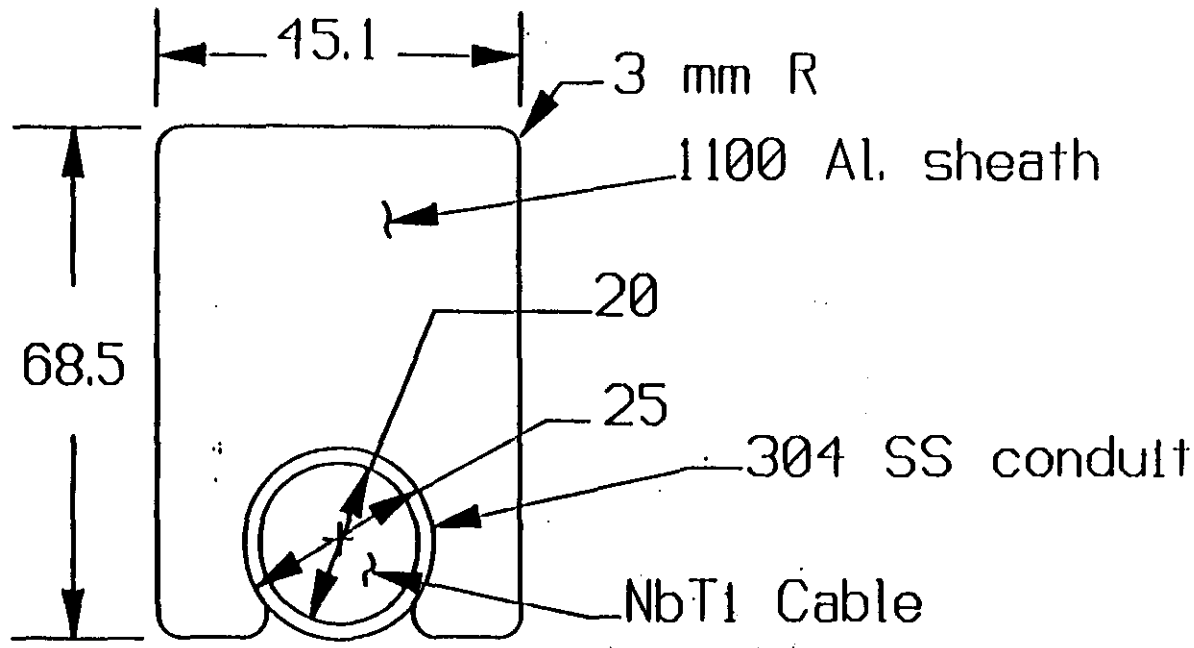
Major Procurements:

- "Prime" contract (final design, fabrication, assembly, installation, system engineering, etc)
  - Acquisition plan approved by DOE (late July)
  - Comments received on draft RFP from vendors and others. Changes being incorporated now.
  - Second (and last) "Vendor Information Meeting" was held 18 Aug
  - Detailed planning of scope, schedule, cost begun and nearly completed
  - Objective is to release RFP by end of September, and award contract in February 1993
- Conductor procurement (24 ea 1-km lengths of completed conductor, to be supplied to prime contractor)
  - Acquisition plan and technical specification drafted

Magnet Subsystem August Progress (3)

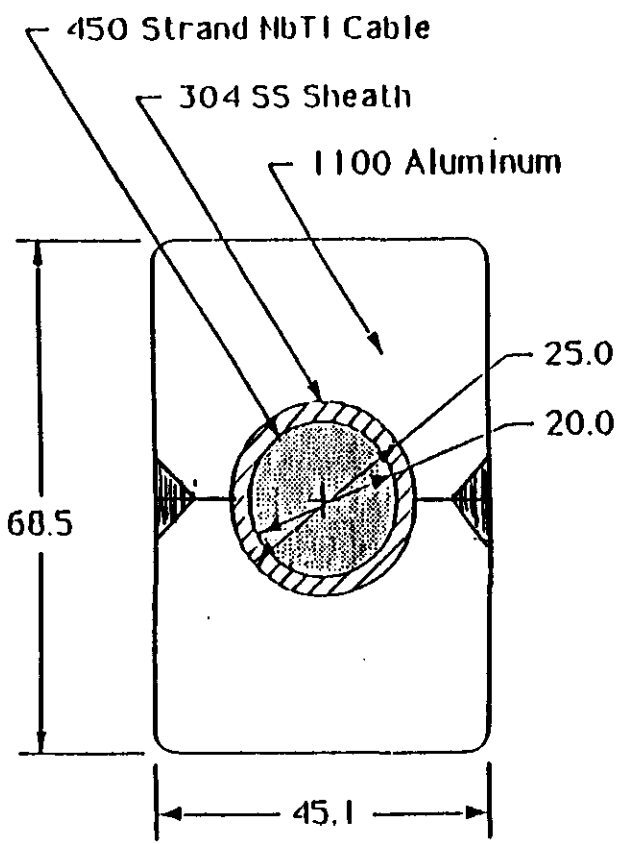
Engineering Design:

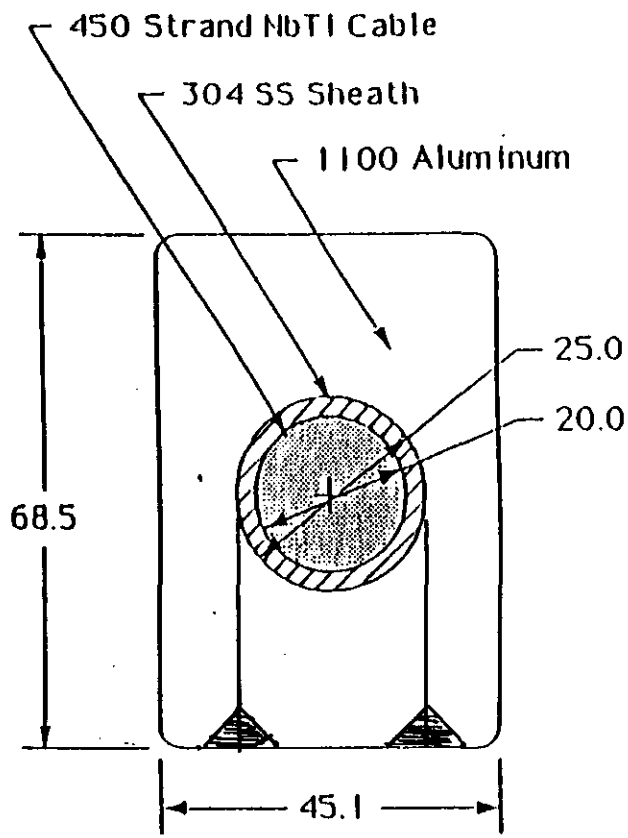
- Conductor - detailed analysis in progress to determine the best way to apply the Al sheath to the conductor
- Winding - tooling design initiated
- Vessel - many details revised, technical specification drafted, dynamic analysis nearly complete
- Assembly - detailed study of one approach completed
- Forward field shaper - 2 alternate support designs analyzed



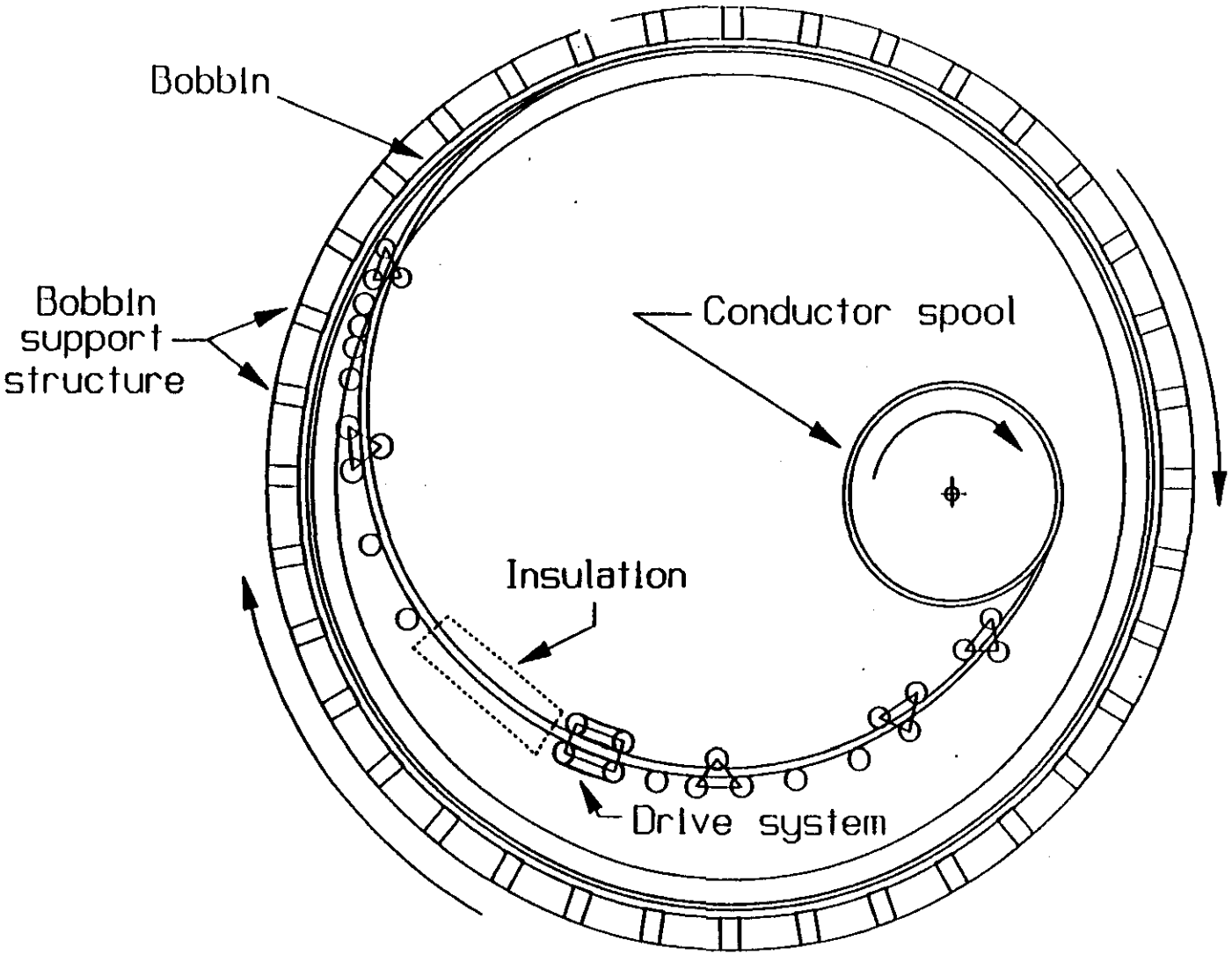
G.E.M Magnet Conductor (option 1)

(dimensions in mm)


450 Strand NbTi Cable
304 SS Sheath
1100 Aluminum
25.0
20.0
68.5
45.1

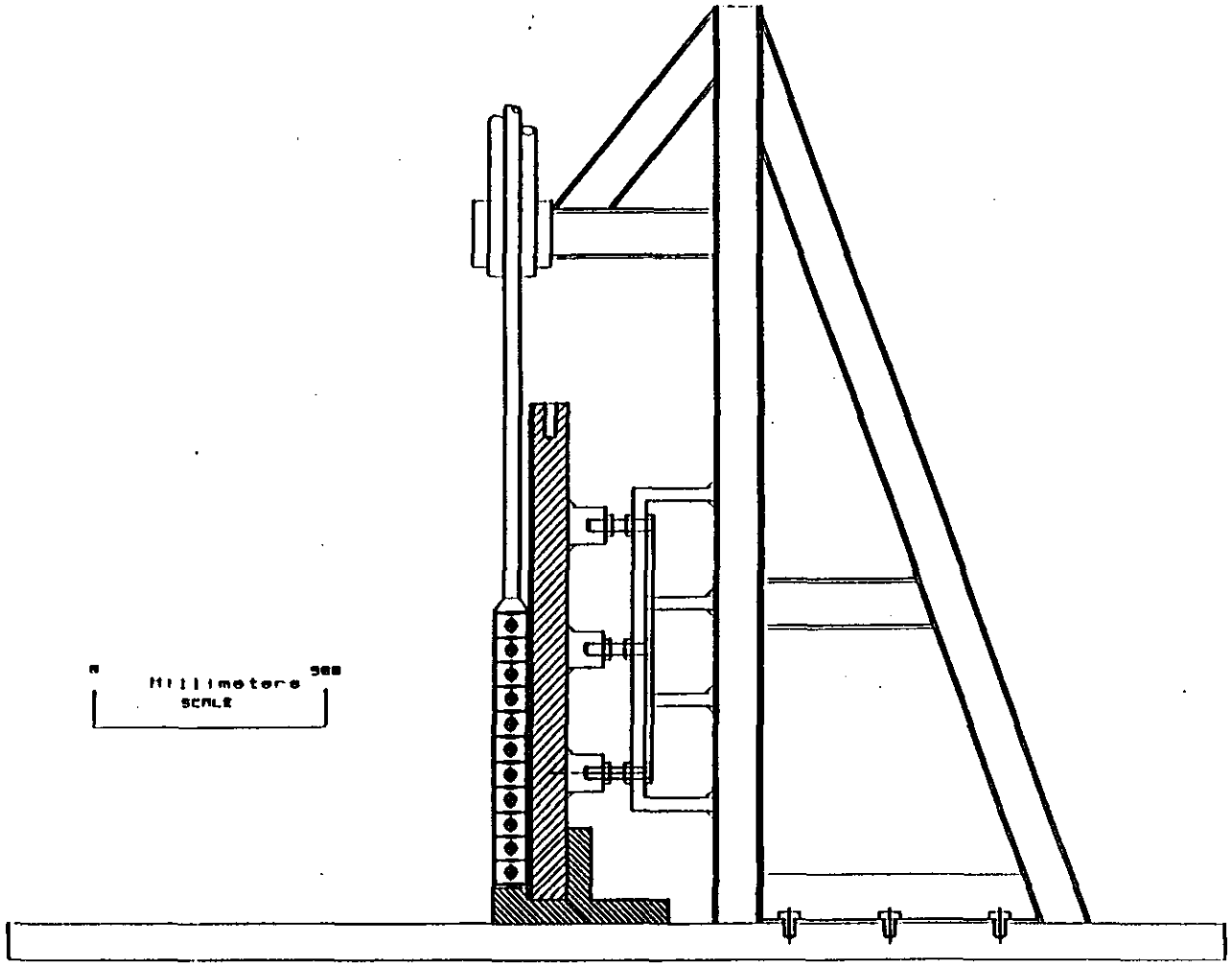

450 Strand NbTi Cable
304 SS Sheath
1100 Aluminum
25.0
20.0
68.5
45.1

Winding concept (plan view)

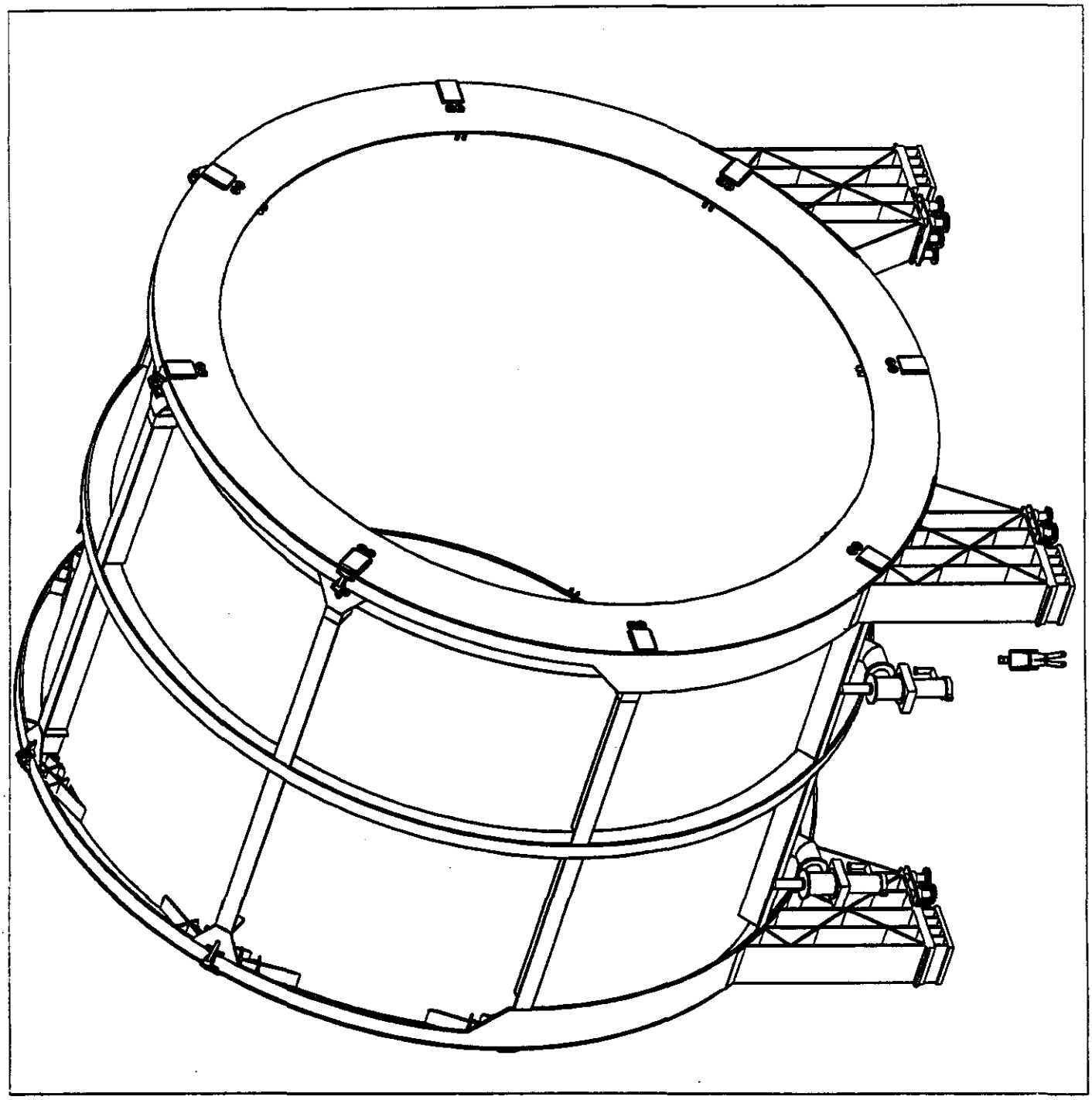


GEM-gd-101-20
6/29/92

Winding tooling (elevation view, axis at left)



GEM-gd-101-21
6/29/92



gem

γeμ

Presentation by:

Harvey Newman

Newman

BaF_2 CRYSTAL CALORIMETER THE PRECISION EM DETECTOR FOR GEM

By

California Institute of Technology
University of California, San Diego
Princeton University
Carnegie Mellon University
Brookhaven National Laboratory
Oak Ridge National Laboratory
Lawrence Livermore National Laboratory
Shanghai Institute of Ceramics
Beijing Glass Research Institute
Beijing Institute of High Energy Physics
Beijing University
Shanghai Institute of Nuclear Physics
Tongji University
Tsinghua University
Univ. of Science and Technology, Hefei
Zhongnan Optical Instrument Facility
Tata Institute of Fundamental Research

GEM COLLABORATION MEETINGS

September, 1992

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

BARIUM FLUORIDE CRYSTAL EM and SCINTILLATING FIBER HCAL

THE PRECISION CALORIMETER SYSTEM FOR GEM

- *HIGHER PHYSICS DISCOVERY POTENTIAL*
  - → Higher Electron and Photon Energy Resolution
- *HIGHER SPEED*
  - → Lower Noise for Isolation Cut
- *HERMITICITY, UNIFORMITY*
- *COMPACTNESS*
  - → Higher Muon Resolution
- *INTERNATIONAL R&D and MANUFACTURING TEAM READY TO START PRODUCTION IN 1993*
  - → 17 Institutions; 200 Collaborators

BaF_2 ELECTROMAGNETIC CALORIMETER FEATURES

- **Speed:**
  Gating Time $\leq$ 16 nsec
- **Energy Resolution:**
  $\Delta E/E = (2.0/\sqrt{E} \oplus 0.5)\%$
- **Position Resolution:**
  Δx and $\Delta y \approx 1$ mm
- **Segmentation:**
  $\Delta\eta \approx \Delta\phi \approx 0.04$
- **$e/\pi, \gamma/jet$, and e/jet**
  Separation: In 10^{-4} Range
- **Radiation Resistance:**
  MegaRads Per Year

BAF2 GEM CRYSTAL PRECISION EM CALORIMETER

ISSUES and CHALLENGES

- *PHYSICS CAPABILITIES*
  - → ENERGY RESOLUTION
  - → BACKGROUND SUPPRESSION
- *CRYSTALS FROM CHINA AT $ 2.5 Per CC*
  - → MANUFACTURING PLAN
  - → RADIATION HARDNESS
- *LIGHT ANNEALING*
  - → FREQUENCY, QUANTITY
  - → DESIGN, OPERATION CONCEPT
- *PRECISION CALIBRATIONS*
  - → ANALYSIS of RESOL'N In SITU
- *LIGHT COLLECTION UNIFORMITY*
  - → UV REFLECTIVE COATING
  - → CONTROL By ANNEALING, MONITORING
- *L3 PERFORMANCE*
  - → RESOL'N ACHIEVED; ANALYSIS
  - → RFQ SYSTEM

Report of the BaF_2 Expert Group
after its meeting of August 31 - September 1, 1992

1. Summary • RADIATION HARD BaF_2 CRYSTALS: LIGHT ANNEALING

At the last meeting of the BaF_2 Panel on August 3 and 4, 1992 it was recognized[2] that optical annealing of radiation damaged BaF_2 crystals "could make a calorimeter satisfying GEM's specification using present production crystals." The panel recommended that "this issue should be studied without delay." In the last three weeks new data on optical annealing including characterization of the spectral behavior, required intensity, and rate of bleaching has been obtained.[3]

Based on the data presented by researchers from 5 independent institutions, including Brookhaven National Laboratory (BNL), California Institute of Technology (CIT), Lawrence Livermore National Laboratory (LLNL), Tsing Hua/McGill University, and West Virginia University (WVU), the expert group concludes that optical annealing of radiation damage in BaF_2 with low intensity, visible light can essentially eliminate the radiation induced absorption of the fast component of the scintillation light.

In addition, there is a strong indication that in-situ illumination of the crystals while subjected to a radiation environment can counteract the effect of radiation-induced absorption. This optical annealing is effective for removing damage induced by both hadrons and gammas. Further, the level of annealing in the crystals is dependent on the wavelength of the bleaching light, with shorter wavelengths leading to greater and more rapid recovery.

We conclude that the issues of self-recovery, non-uniformity and non-saturation as stated in the Panel report of August 3-4 have been overcome. This means that the current quality of the production crystals available from China is sufficient to meet all GEM specifications as presented to the BaF_2 Panel.

BARIUM FLUORIDE PRECISION EM CALORIMETER

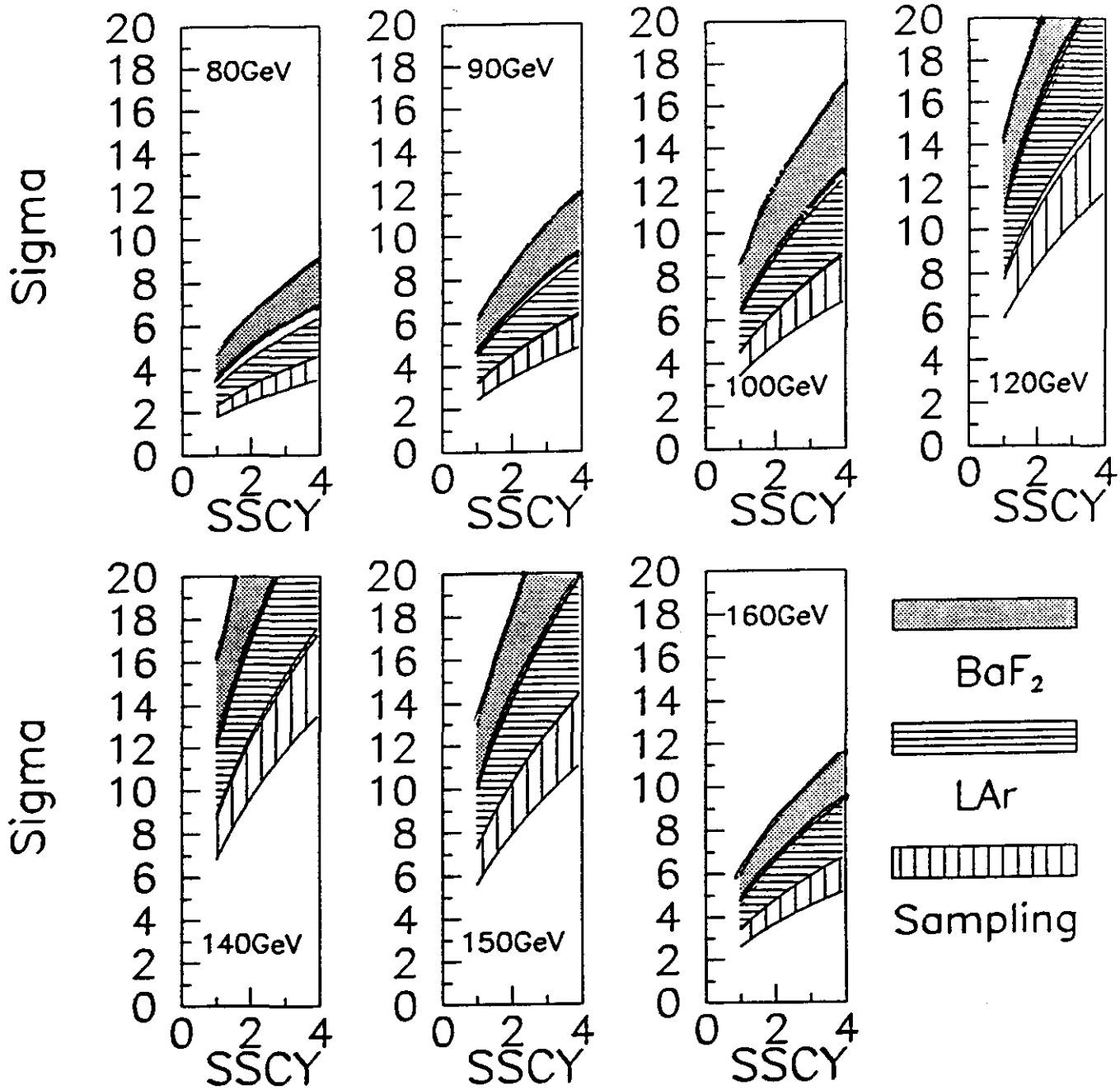
COST ISSUES

- *INTERNATIONAL COST*
  - → Quoted as Somewhat Higher
- *COUNTERBALANCING FACTORS*
  - → MANUFACTURING TEAM KNOWN
  - → MANUFACTURING TECHNOLOGY KNOWN
  - → FEWER HIDDEN COSTS

COST VERSUS PERFORMANCE:

ENHANCED MUON as Well as ELECTRON and PHOTON PHYSICS CAPABILITY

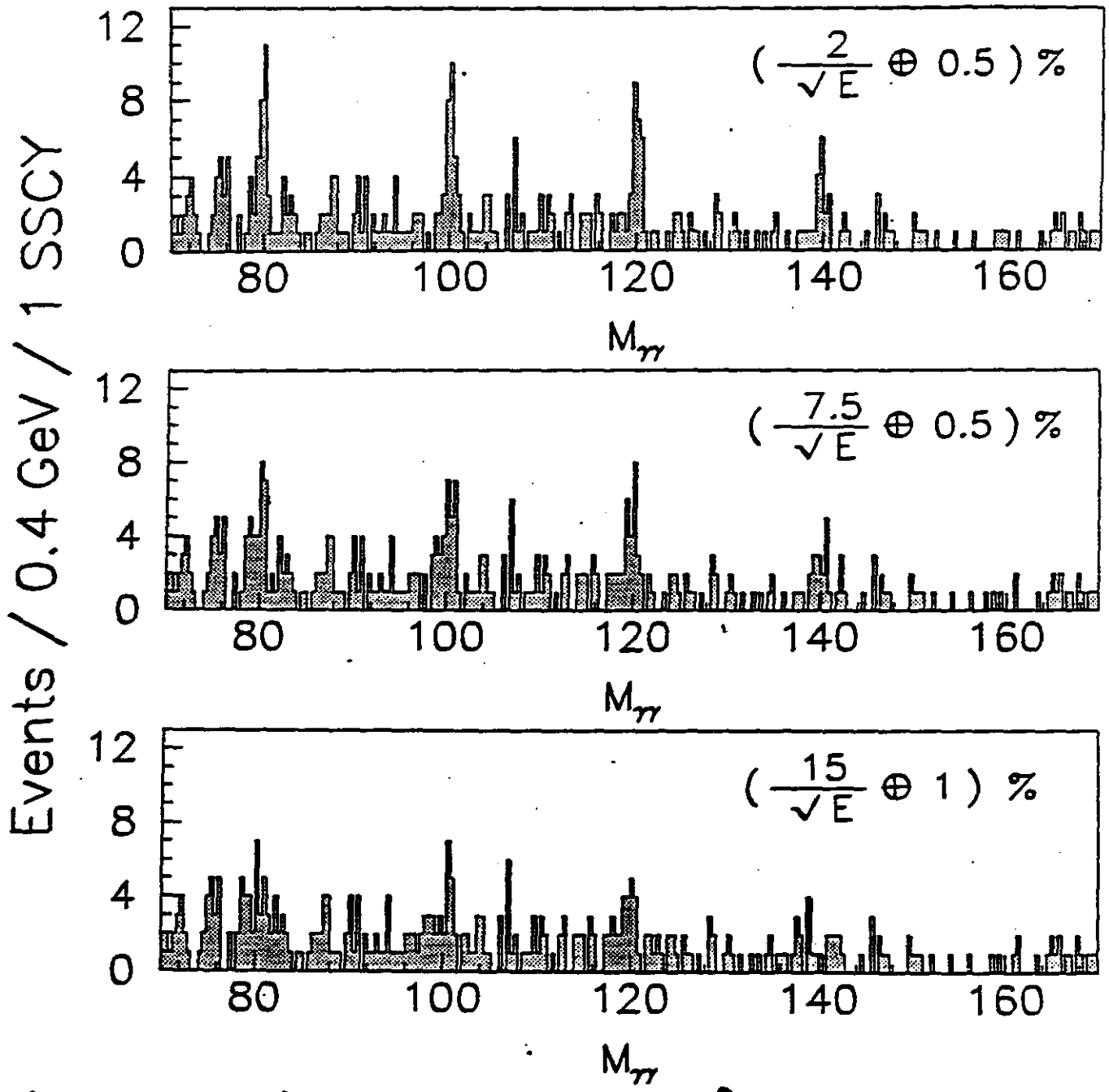
Significance of $H \rightarrow \gamma\gamma$



ALSO: • ESTABLISHING A SIGNAL FOR A NEW, RARE PROCESS (FEW EVENTS): SIGNAL SIGNIFICANCE INCREASED FOR HIGHER RESOLUTION SYSTEM

• H. Yamamoto (9/2): "5σ" is really 10σ on Plot.

$H(t\bar{t}/W) \rightarrow \gamma\gamma + e/\mu + X$



- HIGHER SIGNIFICANCE for VERY RARE PHOTON + LEPTON PROCESSES
- ≥ 1 LEPTON → POINTING NOT NEEDED.

BaF2 FEATURES:

VERY WELL MATCHED TO GEM GOALS

PHYSICS GROUP RATINGS:

- RESOLUTION 10
- ISOLATION 9
  - (Pileup & Thermal Noise)
- SURVIVABILITY 8
- HCAL CHOICE 5
  - (Missing E_t, Hermiticity, Jet Resol'n)
- γ/π^0 SEPARATION 2
- POINTING 1-5

BARIUM FLUORIDE CRYSTALS RADIATION DAMAGE RESULTS

- CRYSTAL PRODUCTION IN CHINA
  - T(220 nm) in 26 cm Crystal: 49% After 1 MRad
  - Further Improvements: Purity and Vacuum
- MATERIALS STUDIES (Panel Summary)

  → "BaF_2 Is Intrinsically Very Radiation Hard"

  → "Further Reduction of Trace Impurities, Due To Purer Source Materials and Improved Vacuum, Should Yield More Radiation Hard Crystals"
- DAMAGE FROM ALL PARTICLES ANNEALABLE
  - Thermal (Complete) or Light
- MEV NEUTRON IRRADIATION: Little of No Effect
  - To $\sim 10^{14}$ MeV Neutrons/cm^2 In Small Crystals
- SMALL PURE CRYSTAL GROWTH at LLNL, OPTOVAC — PROCEEDING

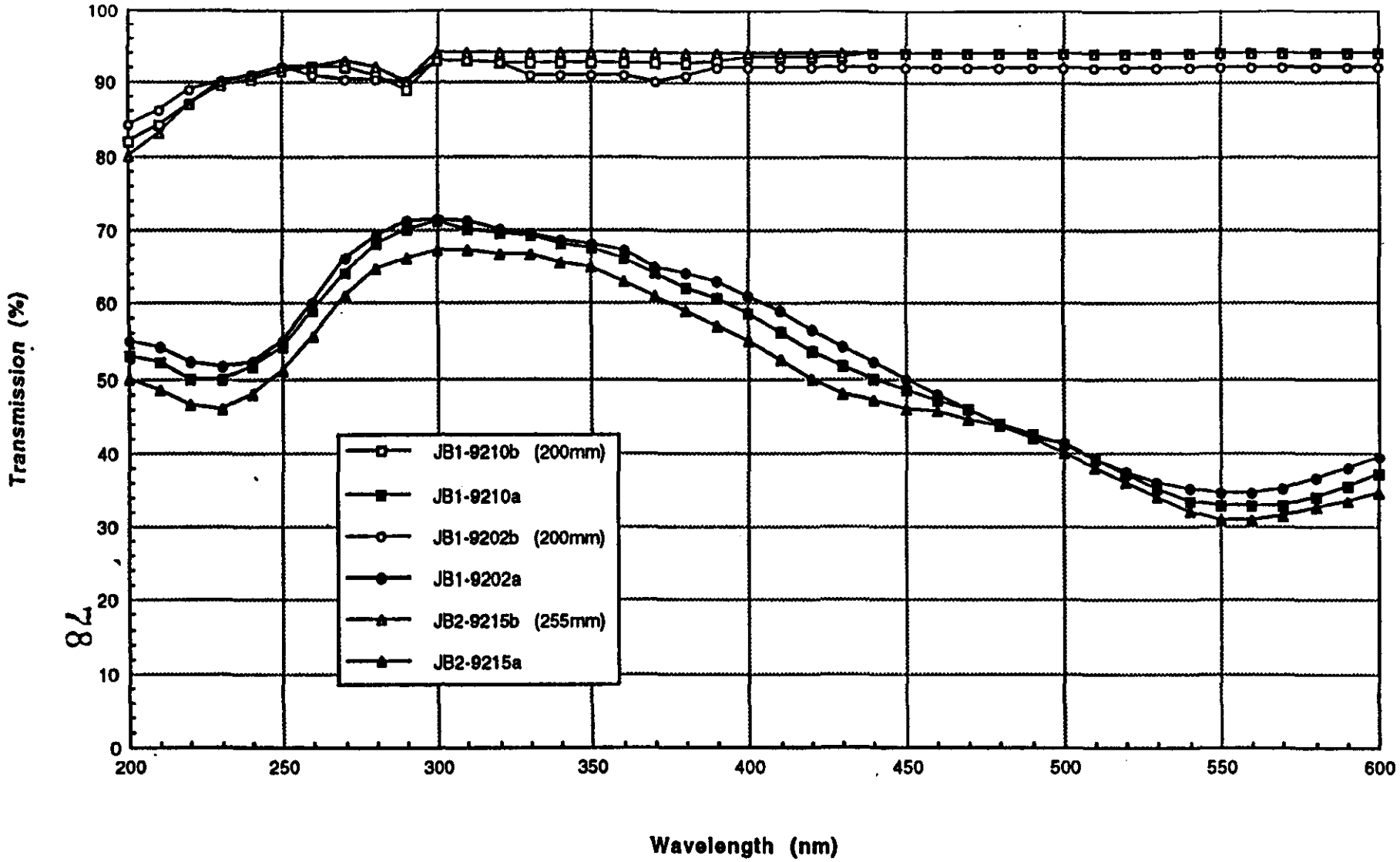


Fig.11 Transmission spectra of several new grown crystals before and after 1 MRad 60Co irradiation

- RAW MATERIALS free of $Ba(OH)_2$ are the KEY → - MULTIPLE SUPPLIERS
  - CONSISTENT QUALITY.

Potential in Further Quality Improvement

1. We now understand the **purification process** of raw materials;

2. We now have a well established **processing technique** to produce the best BaF_2 crystals in the world;

3. We have several additional measures to be implemented:

   - Using vitreounized crucible;
   - Installation of a mass spectrometer probe in the growing furnace to analyze the composition of residual gas;
   - Improved oven design is underway — the first prototype will be produced at the end of 1992;*
   - An oven with a cold trap (an order of magnitude higher vacuum) has not yet be used in production.

4. We now understand the **Mechanism** of the radiation damage of BaF_2 crystals;

* MASS PRODUCTION PROTOTYPE ALREADY BUILT; UNDER TEST. – 15 – 20 CRYSTAL CAPACITY

A telephone recording from BGRI 1/9/92

Two ovens of very good quality crystals have just come out.One oven using raw material from Beijing chemical industrial factory ,two crystals,each of length of 395 mm.Another oven ,material from Haian,5 crystals,each of length of 305 mm.

Two crystals each from one oven,being irradiated to a dose of 1 MRads within 10 hours.The transmittances have been measured two hours after irradiation. Only 15% reductions have been measured for crystals of length 110 mm(for the same measurements they did before, the reduction were ~30%). For the reason of poor polishing, the T% before irra. were 60% only. So three crystals have been brought to Shanghai for better polishing and measurement. After irra.,the transpaency looks much lightetrthan the provious crystals. For the 395 mm crystal,the transparency of about 300 mm leng. is very good after irra.. For the 305 mm crystal,250 mm .of the crystal is bright and transparent.

recording by R.SHANG.

Crystal Production Scenario

- SSC ready for Physics: October 1998;
- Installation of Central Tracker: July 1998;
- Installation of End Caps: April 1998;
- Installation of Barrel: January 1998;
- Crystal Production:
  - 1994: 10% of total amount of crystals;
  - 1995: 30% of total amount of crystals;
  - 1996: 40% of total amount of crystals;
  - 1997: 20% of total amount of crystals.
- All crystals will be finished by July 1997.

Z.W. YIN: 30 OVENS CONSTRUCTED IN 1993
20 OVENS CONSTRUCTED IN 1994

中国科学院上海硅酸盐研究所
SHANGHAI INSTITUTE OF CERAMICS
CHINESE ACADEMY OF SCIENCES
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FACSIMILE MESSAGE

FAX No.: +001-818-791-3951
ATTN: Prof. Barry Barish, High Energy Physics, Caltech
Prof. William Willis, Nevis Laboratory, Columbia University
FROM: Prof. Dong-Sheng Yan
DATE: August 21, 1992

Dear Professors Barish and Willis:

I was informed by Prof. Ren-Yuan Zhu that you will be having a panel meeting on BaF_2 at the end of August. You are possibly aware that in the last few months since we signed our MOU we have got to know more and more about the factors influencing radiation damage through good research. My colleagues at the Shanghai Institute of Ceramics have taken measures to improve their equipments and crystal growth technique. Better crystals have turned out successively as they have expected. And further improvements can be envisaged to be achieved in the not too distant future. The Shanghai Institute as well as the Chinese Academy lend them full support for their untiring efforts as we usually do. The past record of SIC of serving the high energy physics community also provides you and us with confidence that they will meet with their goal within the time frame that is available. I expect this statement may help you to make a more proper assessment thus leading to a more profitable decision in the long run for your noble endeavour.

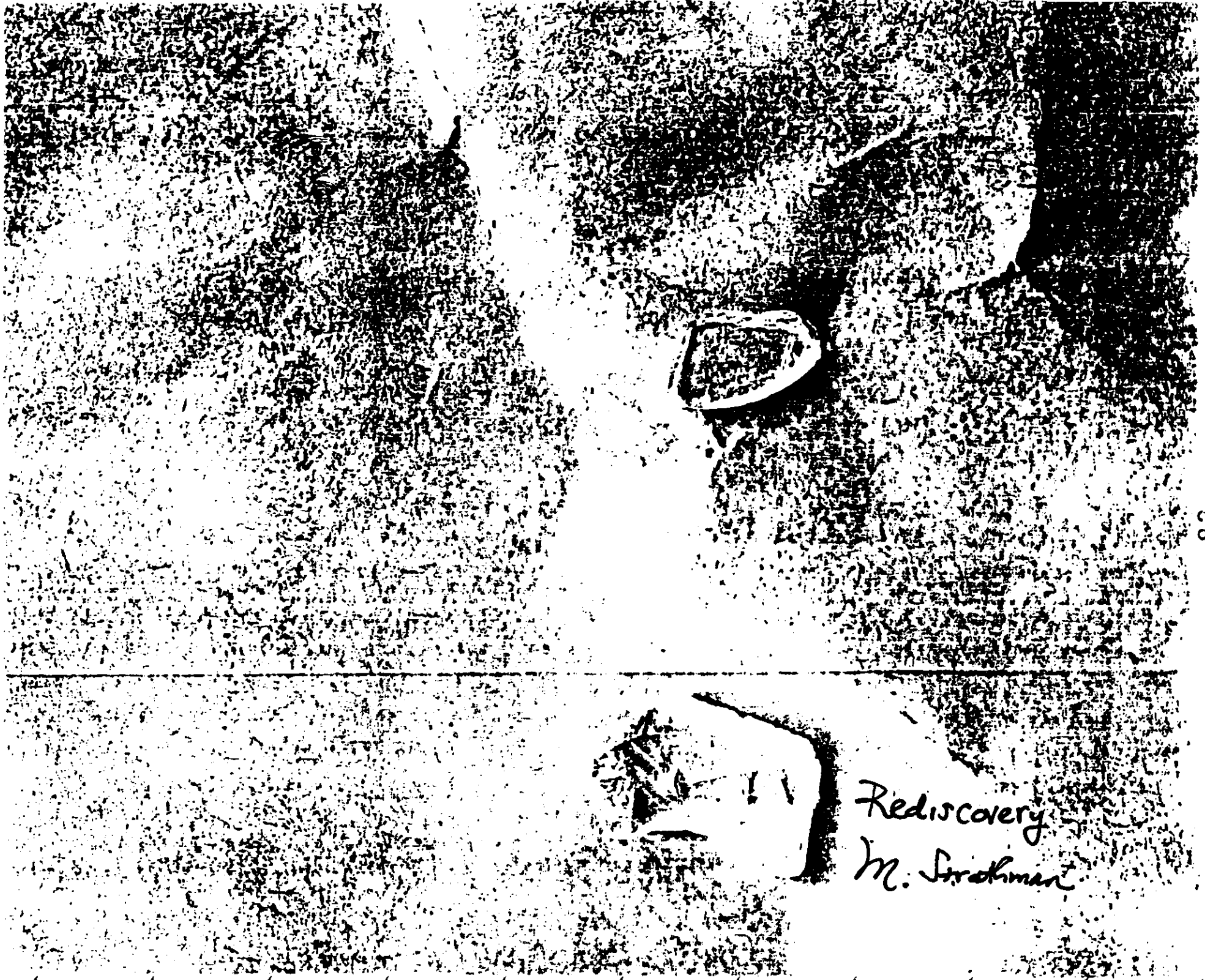
With best regards,

Yours sincerely,

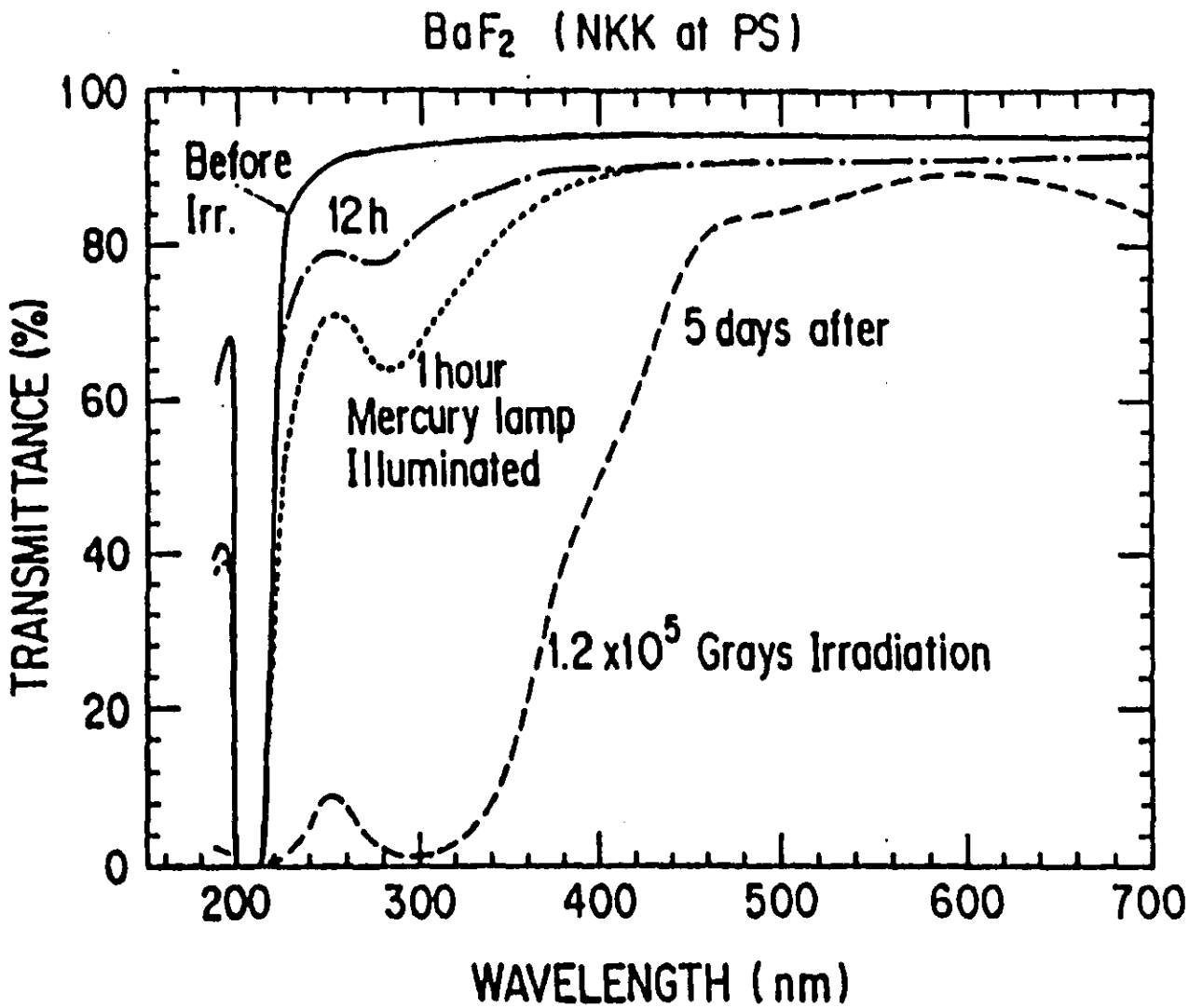
D.S. Yan

Prof. D.S. Yan
Member of the Presidium,
Chinese Academy of Sciences
Director Emeritus,
Shanghai Institute of Ceramics, CAS

c.c. Dr. R.Y. Zhu
Prof. Z.W. Yin


Rediscovery
M. Strathman

Bleaching WITH UV



1986: Annealing Effect Not Usable UNTIL SIC/BGRI Quality Crystals

Ca. 1991

Recoveries of the transmittance in BaF_2 (NKK) with illumination of the mercury lamp after irradiation by 1.2×10^5 Gy. The lines are solid (before irradiation), dash–dotted (after illumination of 12 h), dotted (after illumination of 1 h) and dashed (before illumination.)

• LIGHT ANNEALING of BaF2 at BNL

UV and Visible Light Bleaching of Radiation Damage in S.I.C. BaF2 sample #SIC703

Sean P. Stoll

Brookhaven National Laboratory

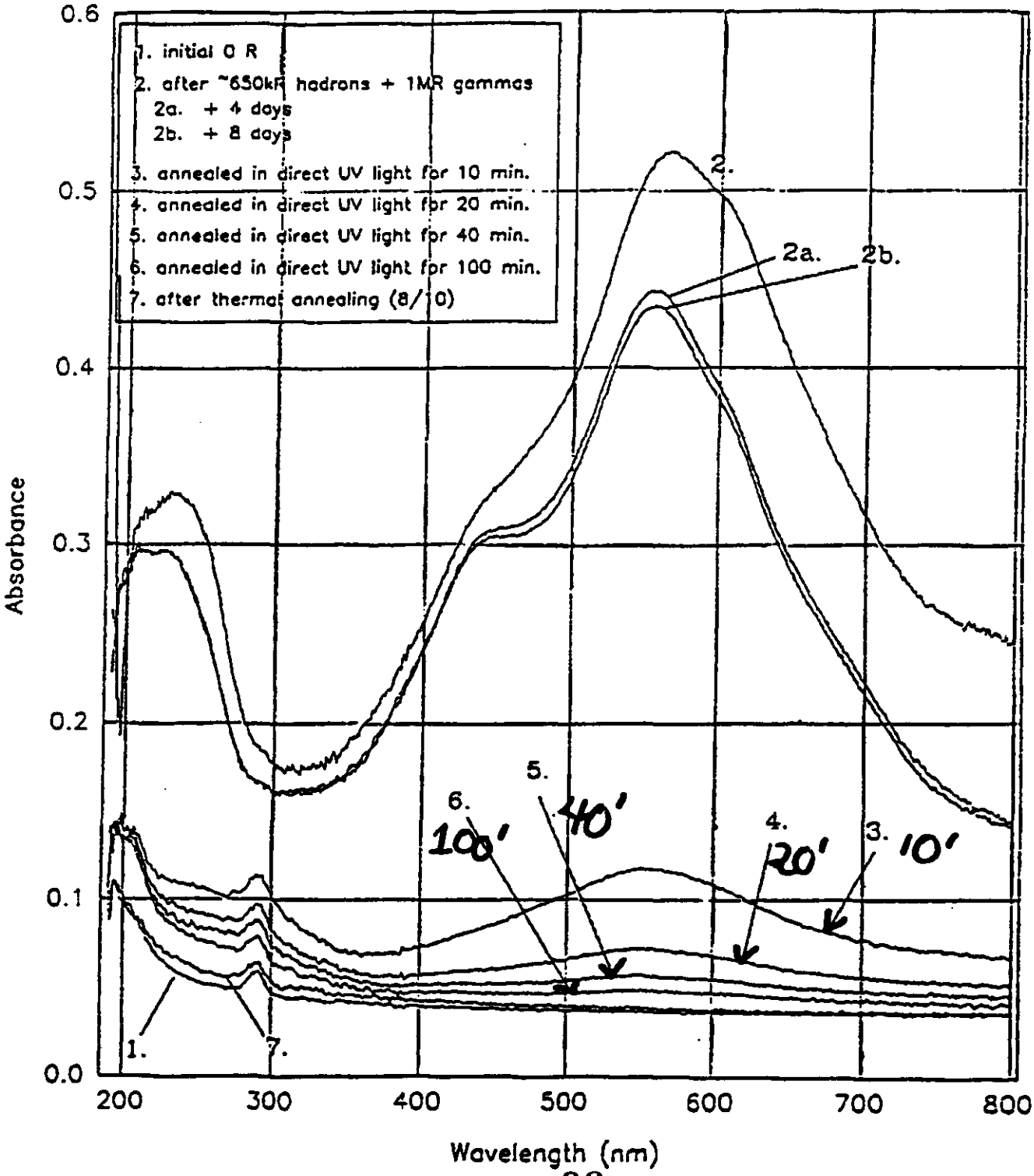
8/24/92

DIRECT ANNEALIN & THROUGH FIBERS

UV (Hg) LAMP FOLLOWING
2MRADS HADRONS + 1MRAD γ's

Fig. 6. 8/10/92

Radiation damage and recovery of SIC703 with exposure to direct UV light, and thermal annealing.



Quantitative Determination of Light Frequency; Intensity:

R. Zhu
& D. Ma
Caltech

Experiment Setup

The light from a monochromator (BAUSCH & LOMB, Grating 1200 Grove/mm, 10 nm width) was shot through the large end of the tapered 25 cm long BaF_2 crystals with a rectangular spot of 0.8" (height) × 1" (width).

No reflector was placed at any surface of the crystal.

The transmittance of the crystals was measured frequently until a saturated value was reached. The same procedure was repeated for red (700 nm), green (500 nm), blue (400 nm) and UV (300 nm).

Bleach SIC302 with Different Wavelengths

Time (hours)	T(%)	λ (cm)	$1/\lambda$ (1/m)	λ_{1M}/λ
Before Irradiation				
	87.2	779	0.13	
1 MRad Irradiation by ^{60}Co γ-ray				
	43.5	34.5	2.9	1.00
Under 700 nm Red Light				
0.	43.5	34.5	2.9	1.00
2.	47.6	39.3	2.5	0.88
4.5	54.6	50.1	2.0	0.69
14.5	63.6	72.2	1.4	0.45
24.	67.1	85.3	1.2	0.40
30.	70.	99.6	1.0	0.35
35.	69.5	97.1	1.0	0.35
Under 500 nm Green Light				
35.5	71.	105.6	0.95	0.33
37.	71.2	106.9	0.94	0.32
39.5	71.3	107.5	0.93	0.32
43.	71.3	107.5	0.93	0.32
Under 400 nm Blue Light				
43.5	72.4	115.0	0.87	0.30
44.5	76.2	150.3	0.67	0.23
54.5	78.9	190.	0.53	0.18
64.	78.5	183.	0.55	0.19
65.	78.3	180.	0.56	0.19
Under 300 nm UV Light				
66.	79.1	194.	0.52	0.18
67.	78.7	186	0.54	0.19
75.	79.5	202	0.50	0.17
89.5	80.4	221	0.45	0.16
95.	81.1	240	0.42	0.15

700 nm

500 nm

400 nm

Bleach BaF_2 Crystals with 400 nm Light

SIC302 - 0.85 mWatt/cm²
- After 1MRAD

Time (hr)	T(%)	λ (cm)	$1/\lambda$ (1/m)	λ_{1M}/λ
0.	43.3	34	2.9	1.00
0.5	58.7	59	1.7	0.50
1.0	64.6	76	1.3	0.46
1.5	67.9	89	1.1	0.39
2.5	71.8	111	0.90	0.31
4.5	74.6	133	0.75	0.26
12.0	78.5	182	0.55	0.19
13.0	78.0	175	0.57	0.20

Bleach BaF_2 Crystals with 400 nm Light

SIC402

Time (hr)	T(%)	λ (cm)	$1/\lambda$ (1/m)	λ_{1M}/λ
0.	48.6	41	2.5	1.00
1.0	61.6	66	1.5	0.61
1.5	66.8	85	1.2	0.48
3.5	72.4	115	0.87	0.35
6.5	76.9	159	0.63	0.26
8.5	77.7	170	0.59	0.24
9.5	77.8	173	0.58	0.23
18.5	78.4	181	0.55	0.22

- CRYSTALS REACH A STABLE ATTENUATION Length ≐ 180 cm
  - CONSISTENT

Color Center Equilibrium

$$D_{eq} = \frac{bRD_{all}}{aI + bR}$$

$$I_{eq} = 0.67R\,\frac{2.5 - 1/\lambda_w}{1/\lambda_w - 0.55}$$

- D_{eq}: bleachable color center density in equilibrium;
- I_{eq}: light intensity to establish D_{eq};

Intensity Needed to Maintain $\lambda = 150$ cm

$\lvert\eta\rvert$	0	1	2.5
Dose Rate (kRad/hour)	0.02	0.04	0.4
I (mW/cm^2)	0.21	0.42	4.2

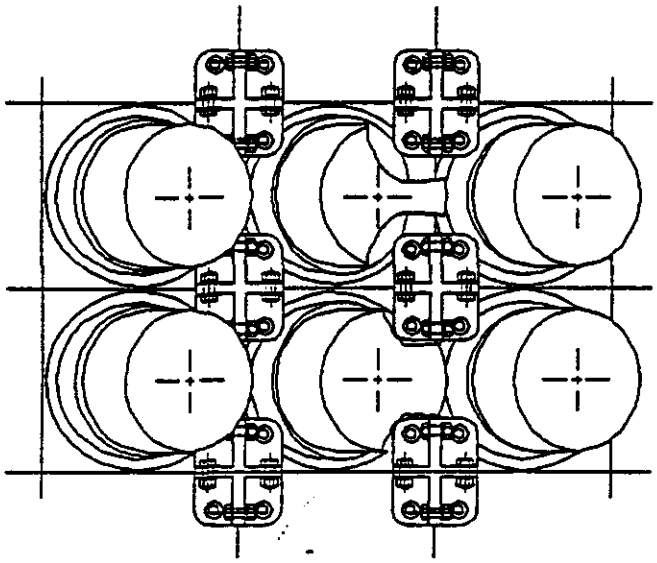
- The total power required for barrel is around 52 W, while the two endcaps need 100 W.

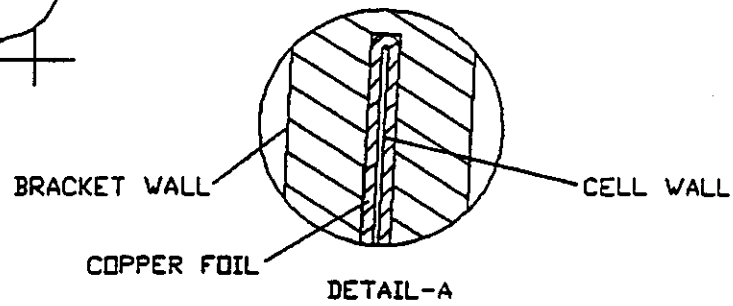
- $\lesssim 10$ Standard LAMPS
- Reflector, Kinetic Effects Not Taken Into Account → Less Light Req'd.

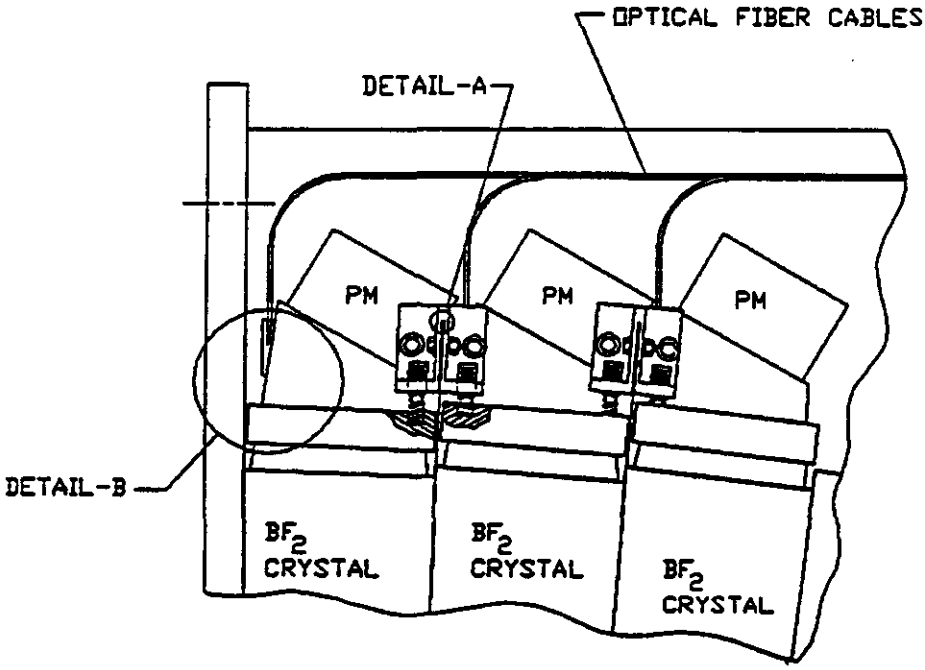
Conclusion

a BaF_2 calorimeter can be built with current production crystals from China. With an effective 150 W light source, the entire BaF_2 calorimeter can be set to work at $\lambda_{eq} = 150$ cm.

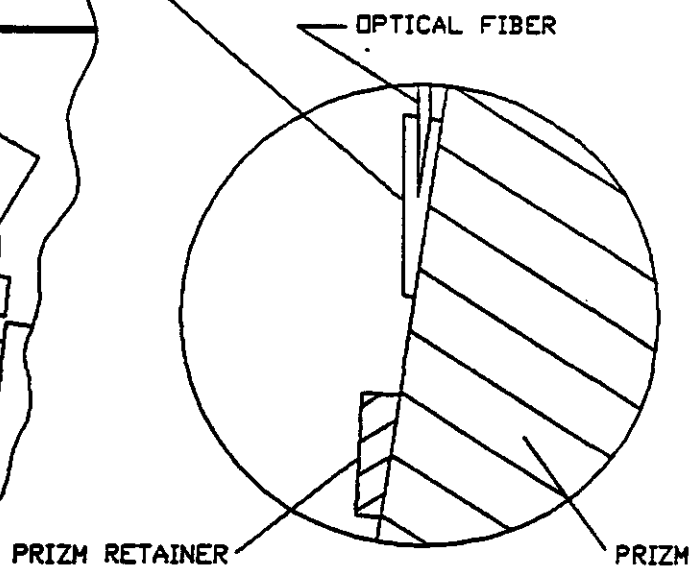
The key issue of radiation damage problem of BaF_2 project thus is solved.







VIEW WITHOUT CELL WALL



DETAIL-B

FIRST TYPE OF CRYSTAL FIXATION

ORNL

BaF_2 EM CALORIMETER

ENERGY RESOLUTION

$$\left(\frac{\Delta E}{E}\right)^2 = \left(\frac{a_0}{E}\right)^2 + \left(\frac{a_1}{\sqrt{E}}\right)^2 + b^2$$

First Two Terms Small for $E \geq 5$ GeV:

- a_0, from Electronic Noise: $\approx$ 2%.
- a_1, "Photostatistics": Below 1%

Systematic Term b Dominant;
Has Contributions:

$$b^2 = b_S{}^2 + b_G{}^2 + b_{NU}{}^2 + b_{NL}{}^2 + b_C{}^2$$

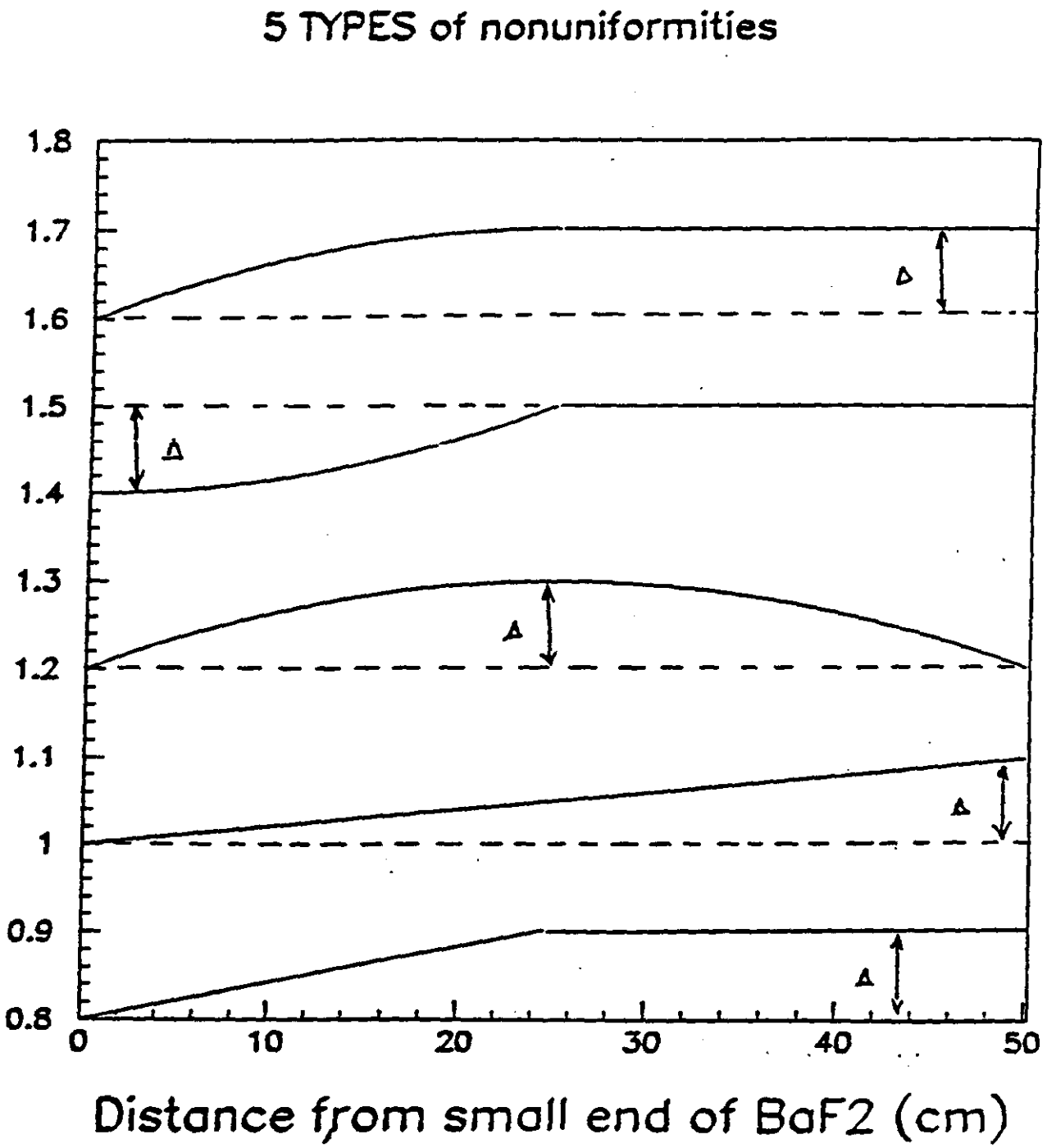
WHERE

- b_S Fluctuations of EM Shower (GEANT)
- b_G Shower Leakage (Front, Back, Side), and Inactive Material (GEANT)
- b_{NU} Nonuniformity of Light Response $\approx$ 0.25%
- b_{NL} Nonlinearities and Short Term Instabilities of Photodevice, Readout $\approx$ 0.2%
- b_C Residual Intercalibration Error $\approx$ 0.25%; AFTER b_{NU}, b_{NL} Taken Into Account

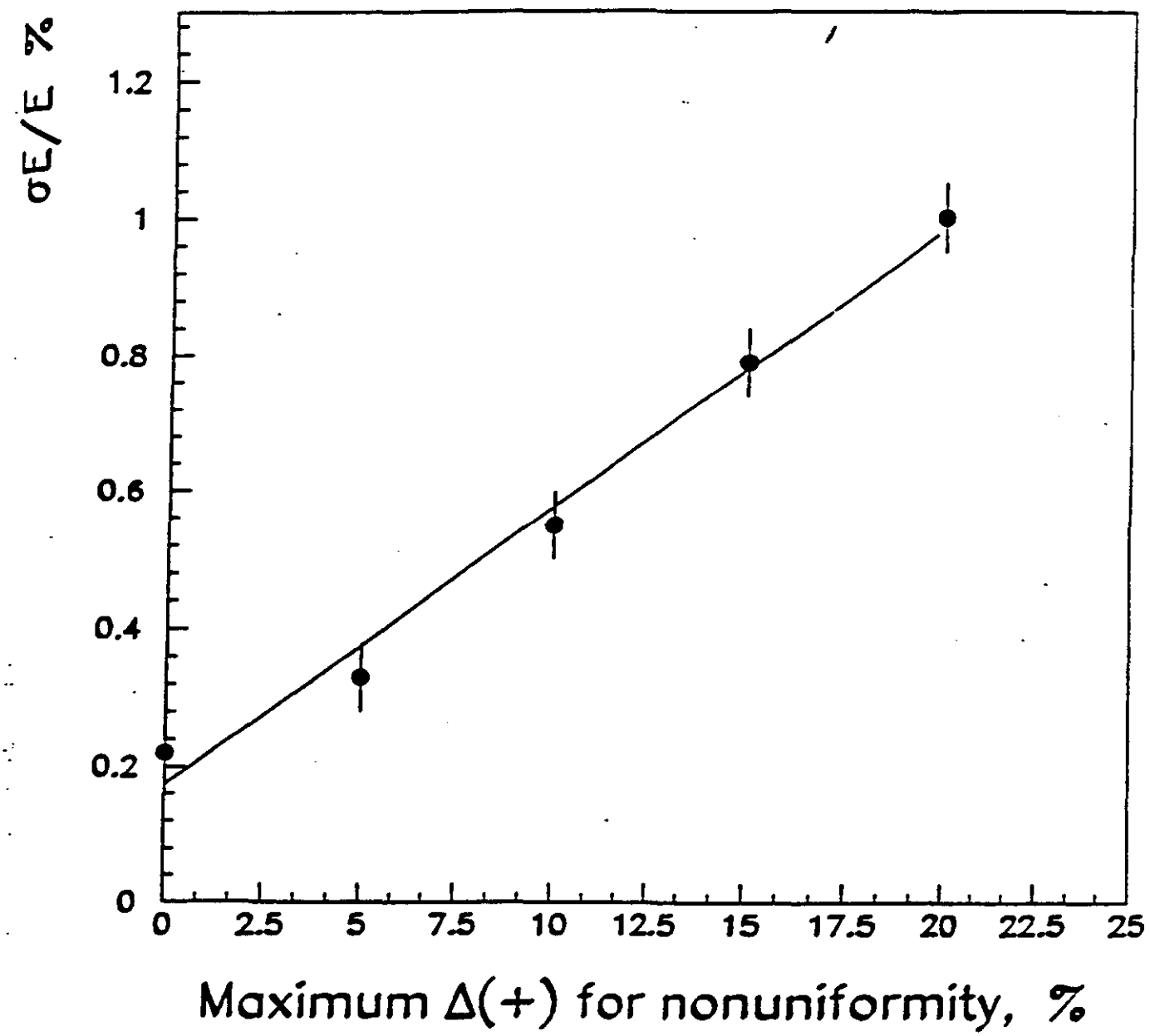
→ (As Achieved in CLEO II; Planned In KTeV).

E (GeV)	5	10	100	500
Electrical Noise	0.4	0.2	0.02	0.004
Photoelectrons	0.2	0.14	0.045	0.02
GEANT b_S and b_G	0.60	0.43	0.30	0.36
Nonuniformity b_{NU}	0.25	0.25	0.25	0.25
Nonlinearity b_{NL}	0.2	0.2	0.2	0.2
Intercalibration b_C	0.25	0.25	0.25	0.25
Total	0.85	0.64	0.51	0.54

Table 3: Summary of Contributions to the Energy Resolution of the BaF_2 Calorimeter (In Percent)

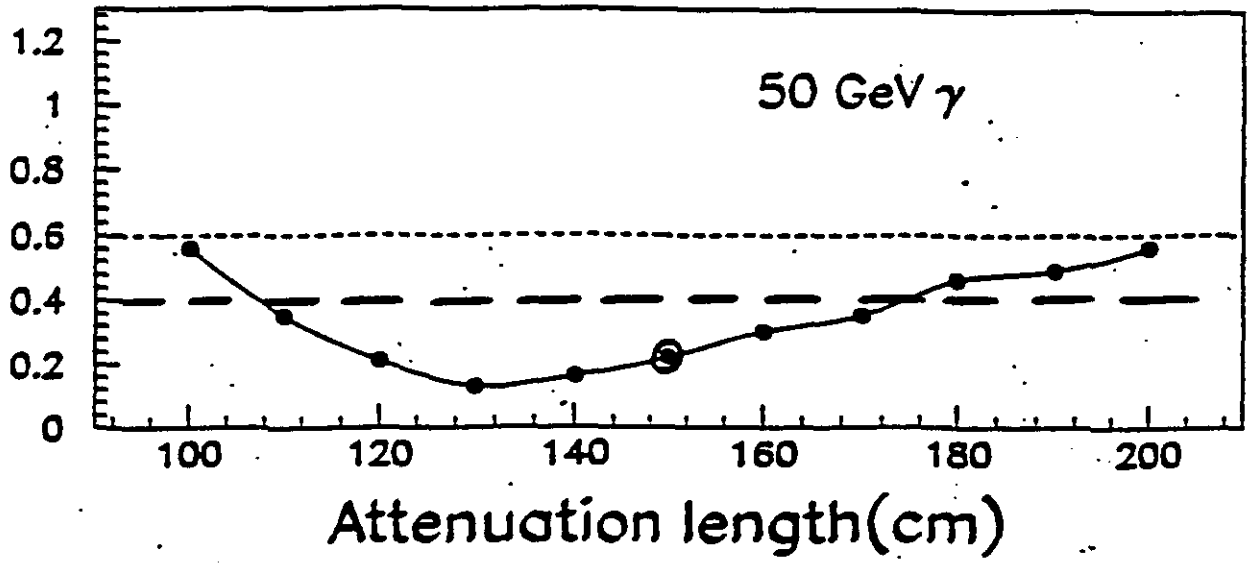

5 TYPES of nonuniformities
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0
10
20
30
40
50
Δ
Distance from small end of BaF2 (cm)

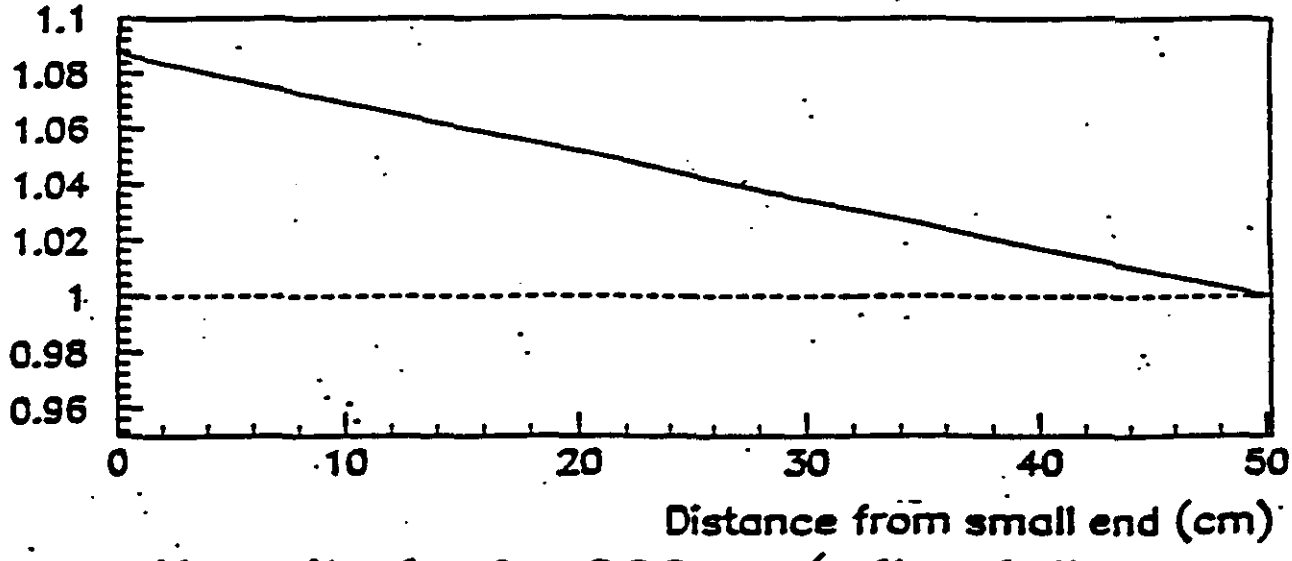
ALL 5 TYPES of nonuniformities with positive slope



SCENARIO – all crystals were preradiated to λ=150cm

and were uniform with λ=150cm



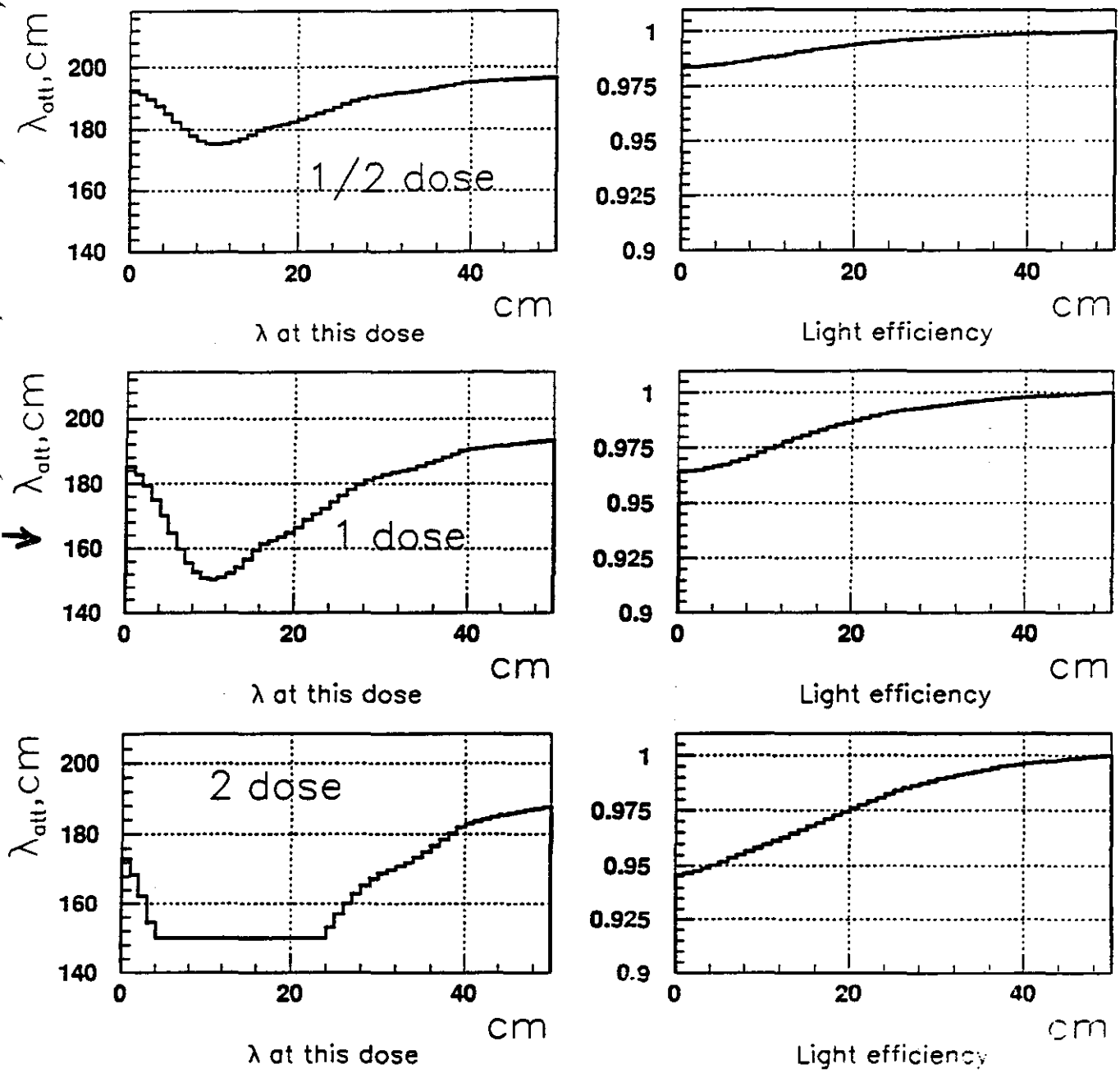


Nonuniformity for λ=200cm (after full recovering)

LIGHT Response & UNIFORMITY DURING a TRANSITION

K. SHMAKOV

Transition from Latt=200cm to 150cm



- Net Result : Resolution gets Better During Transition

NONLINEARITY & SHORT TERM INSTABILITY CONTRIBUTION b_{NL}

(PHOTODEVICE ; READOUT)

→ STABILITY

GRID MESH DYNODE TUBES ↗ I fluct.

- R4480 at J_{NAL}: 0.15% ($G \sim 10^3$)
- R4406 TRIODE or PENTODE : ~0.1% EXPECTED ($G \sim 6$ to 30)

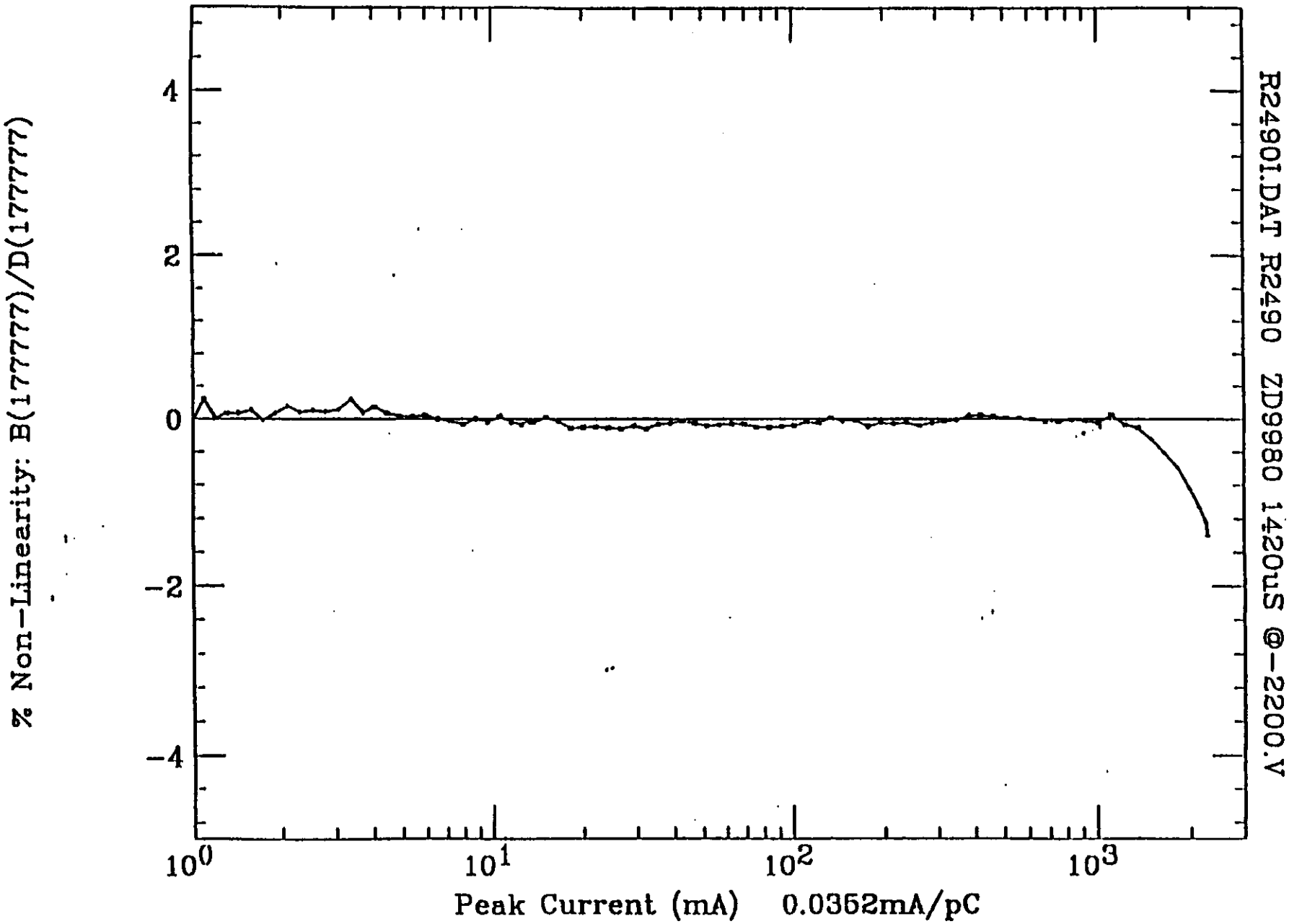
→ NONLINEARITY

- R4406 Rated at -2% at 100 mA
  → At 2 TeV (32 mA) : ≈0.5% {CALIB. TO 0.1%}
- NEW HAMAMATSU TUBES:
  ⇒ - MEASURED LINEAR TO 0.1% TO 1000 mA !
  → Compare KTeV R4598 : +2% at 200 mA, ≤0.5% at 40 mA

READOUT : 0.2% at TOP of Range

b_{NL} TOTAL : 0.24% at 2 TeV (32 mA PEAK)
≲ 0.2% to 500 GeV

Hamamatsu R2490 PMT



BaF_2 CALIBRATIONS

- CALIBRATION FROM $Z^0 \rightarrow e^+e^-$
  0.4% Biweekly; 0.3% Monthly.
  ($\Upsilon \rightarrow e^+e^-$ Under Study)
- UV FLASH LAMP or LASER MONITOR
  - L3 Xenon Lamp Example: 0.14% Stability Over 45 Days.
  - CLEO II claims 0.25% Xe lamp monitor.
- MIPs MONITOR
  (Inclusive Isolated Sail Through)
  - 3000 MIPs/Crystal $\Rightarrow$ 0.3% Accurate ($\sim$ 1 sec of running)
  - 1 KHz Dedicated Trigger (Branch Off Level 2):
    - 0.3% Each $\approx$ 20 Hours (Barrel)
    - 0.3% Each $\approx$ 6 Hours (Endcap)
  - Systematics
    - Shift of Peak at High Luminosity: Measure $\mathcal{L}$ to $\pm 2 \times 10^{33}$ (easy)
    - Higher Threshold Calibration for $\mathcal{L} \approx 10^{34}$
- RFQ MONITOR (30 Hz, 10μsec, 10 mA H^0)
  - Below 0.1% (Statistical) Within 2 Minutes.
  - 1.5 GeV Equivalent in Farthest Crystal; 25 GeV Per Crystal Typical
  - 0.3% Stability Demonstrated

Overall Intercalibration Error $b_C = 0.25\%$

Z^0 Calibration

Algorithm

H. Yamamoto.

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

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

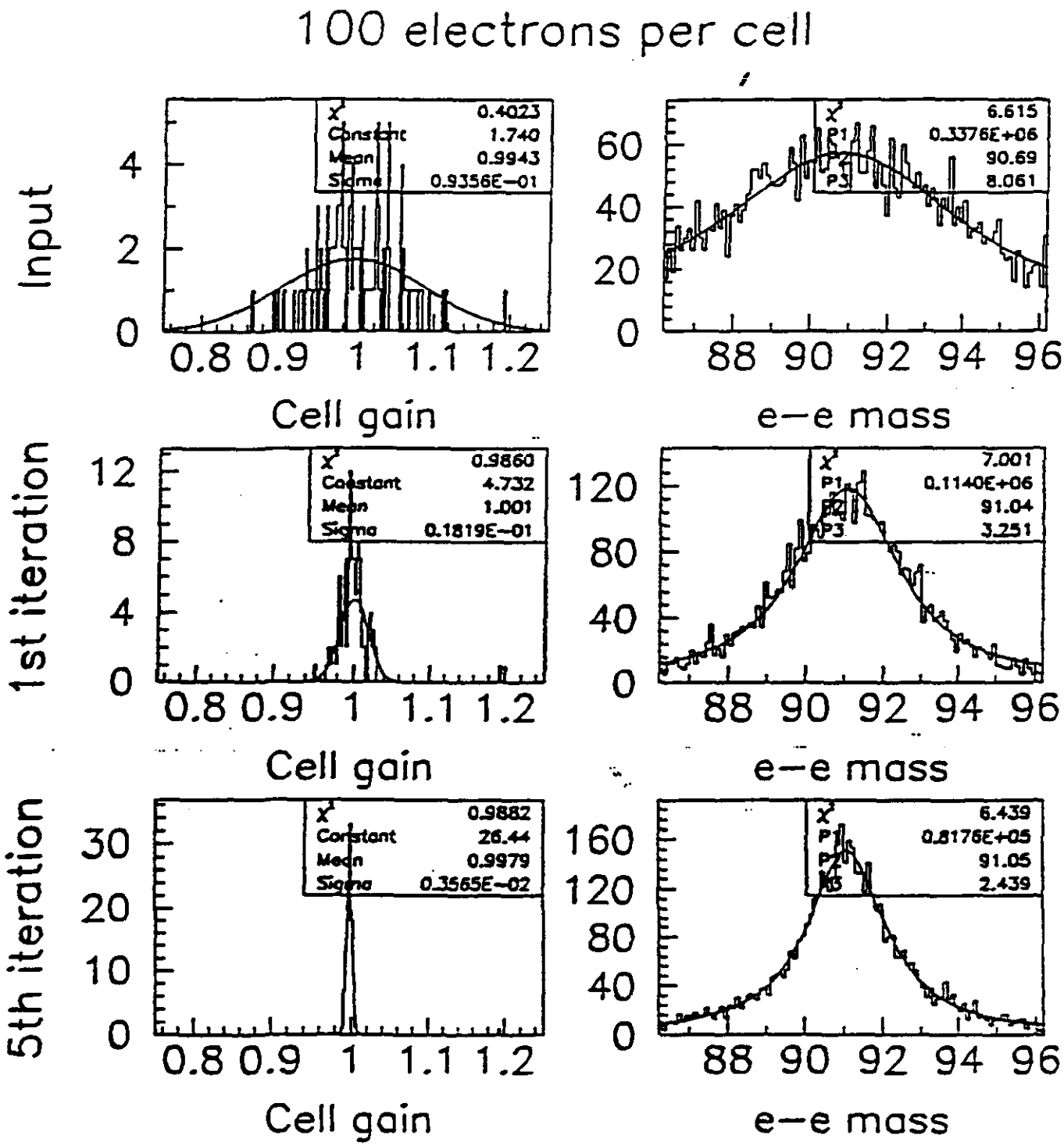
3. Repeat the second process for all crystals.

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

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

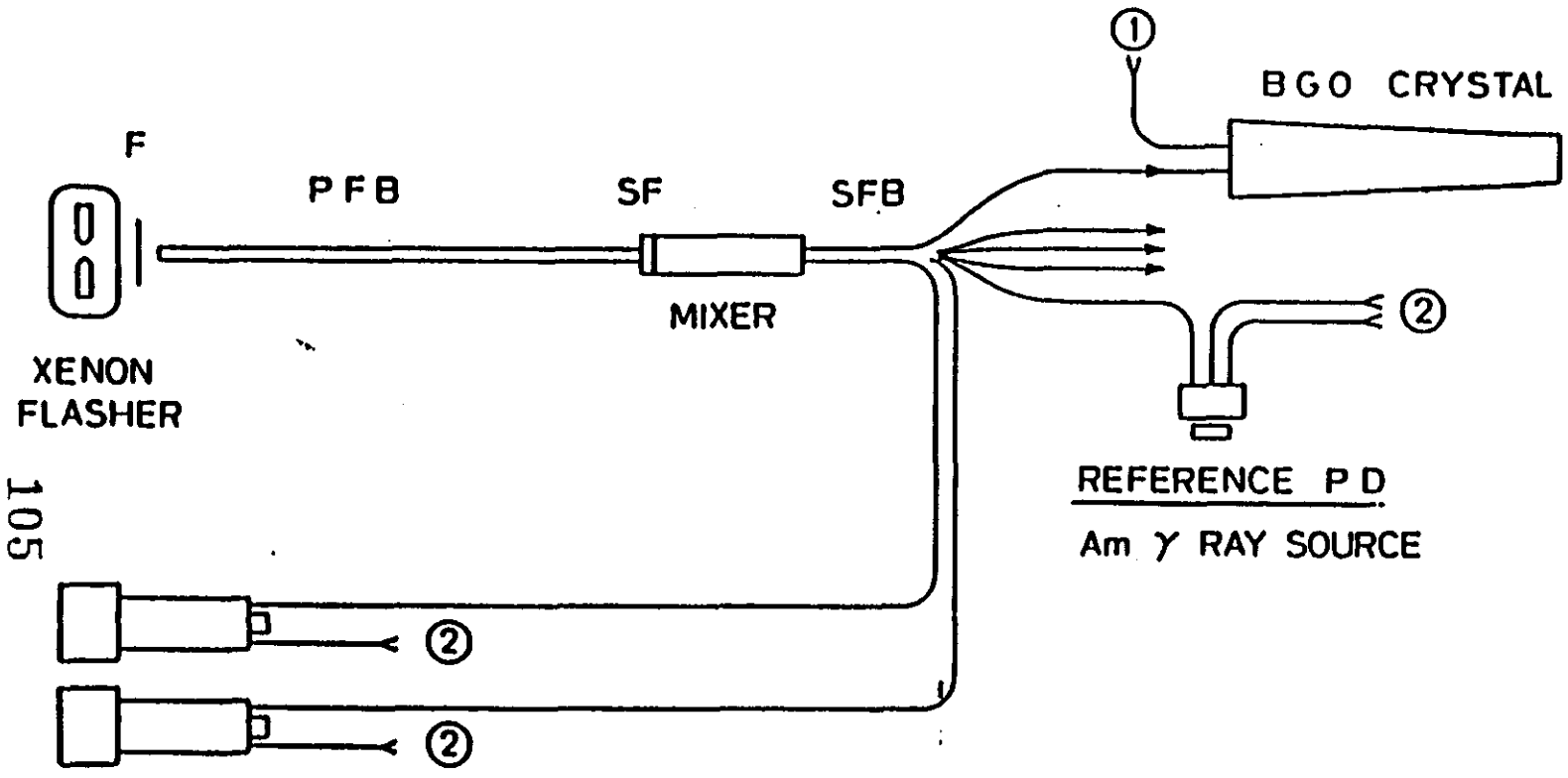
Accuracy

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


100 electrons per cell
Input
1st iteration
5th iteration
Cell gain
e−e mass
χ² 0.4023
Constant 1.740
Mean 0.9943
Sigma 0.9356E−01
χ² 6.615
P1 0.3376E+06
P2 90.69
P3 8.061
χ² 0.9860
Constant 4.732
Mean 1.001
Sigma 0.1819E−01
χ² 7.001
P1 0.1140E+06
P2 91.04
P3 3.251
χ² 0.9882
Constant 26.44
Mean 0.9979
Sigma 0.3565E−02
χ² 6.439
P1 0.8176E+05
P2 91.05
P3 2.439

L3 XENON LAMP MONITOR

BGO MONITORING SYSTEM (L3)



PFB : PRIMARY FIBER BUNDLE

SFB : SECONDARY FIBER BUNDLE

SF : SPECTRAL FILTERS

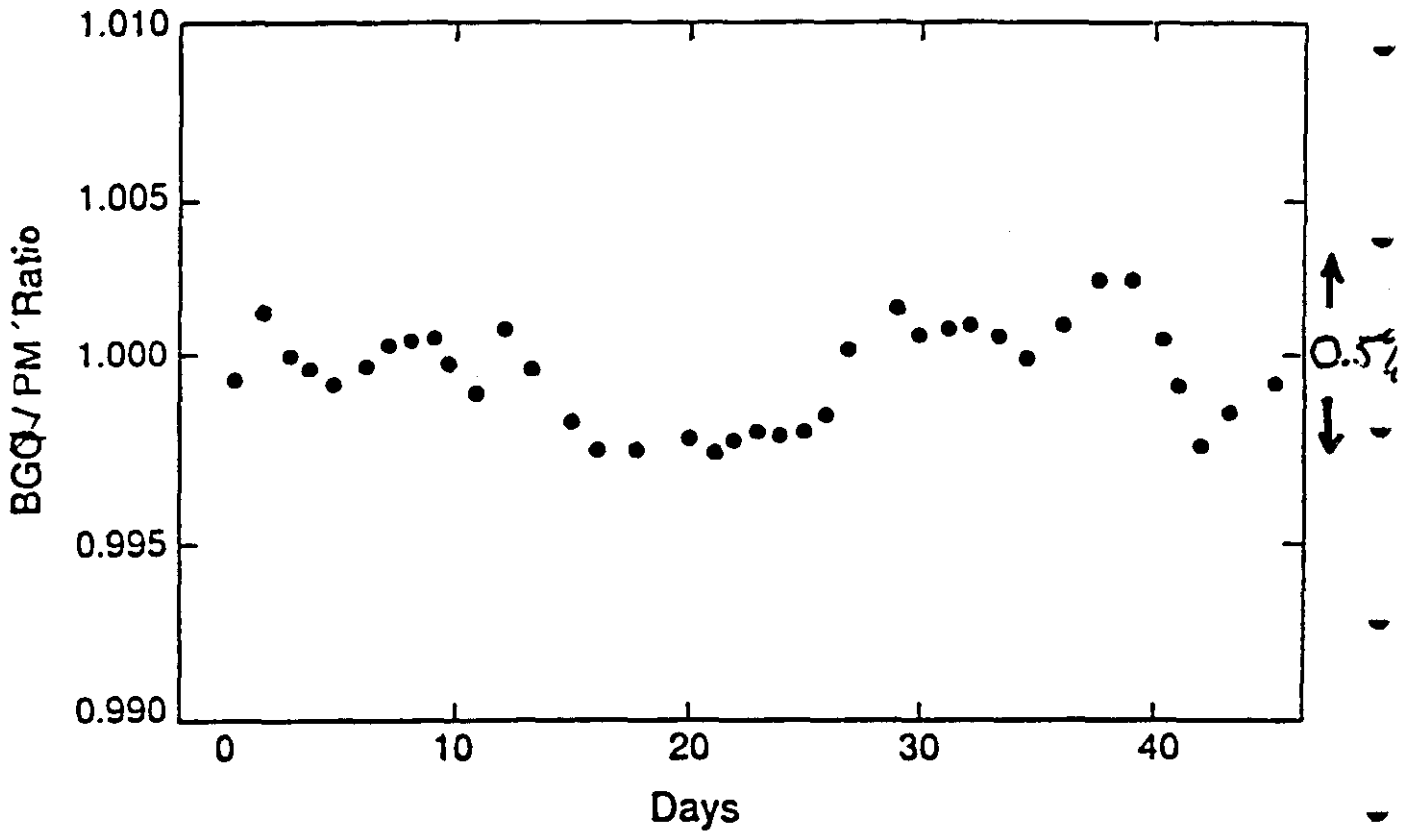
F : ATTENUATION FILTERS (OPTIONAL)

① : FROM SECOND LAMP

② : FROM OTHER MIXERS

Figure C 8

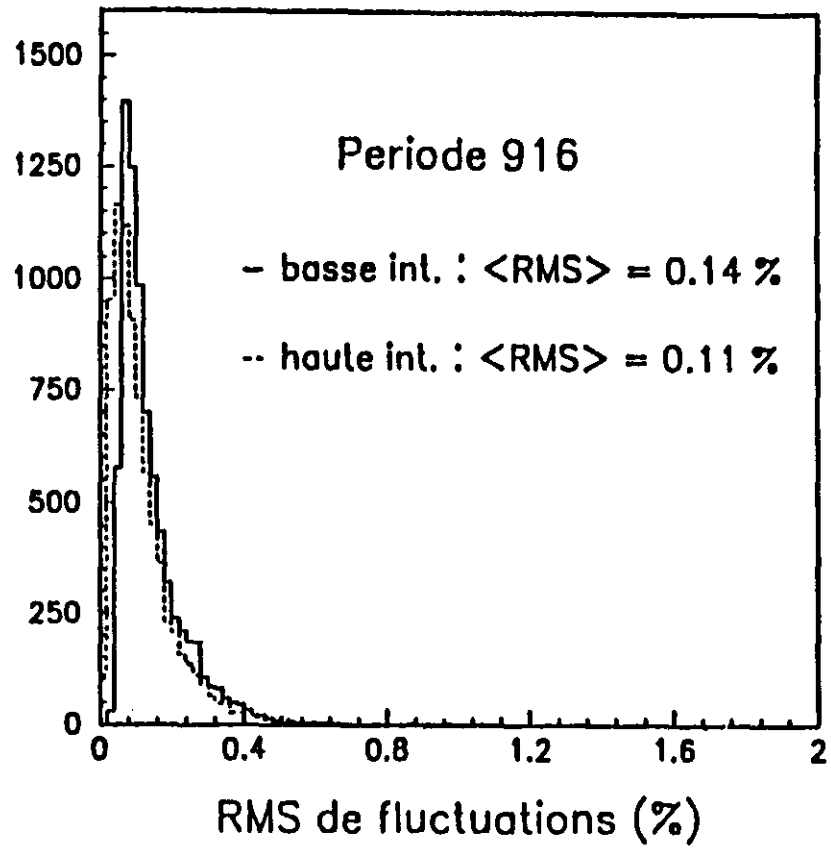
• L3 XENON LAMP SYSTEM



The amplitude for a typical BGO crystal, relative to the corresponding reference PMT, during a calibration period.

• Fluctuation for a Typical Crystal : $\frac{\text{BGO Response}}{\text{Reference PM Response}}$ During a LEP Period

L3 XENON LAMP MONITOR



• STABLE to 0.11 - 0.15 %
→ over a 45 Day LEP PERIOD

Distribution des fluctuations RMS des $\mathcal{I}_i$ pour les cristaux du barrel pendant la 6ème période de calibration à LEP en 1991.

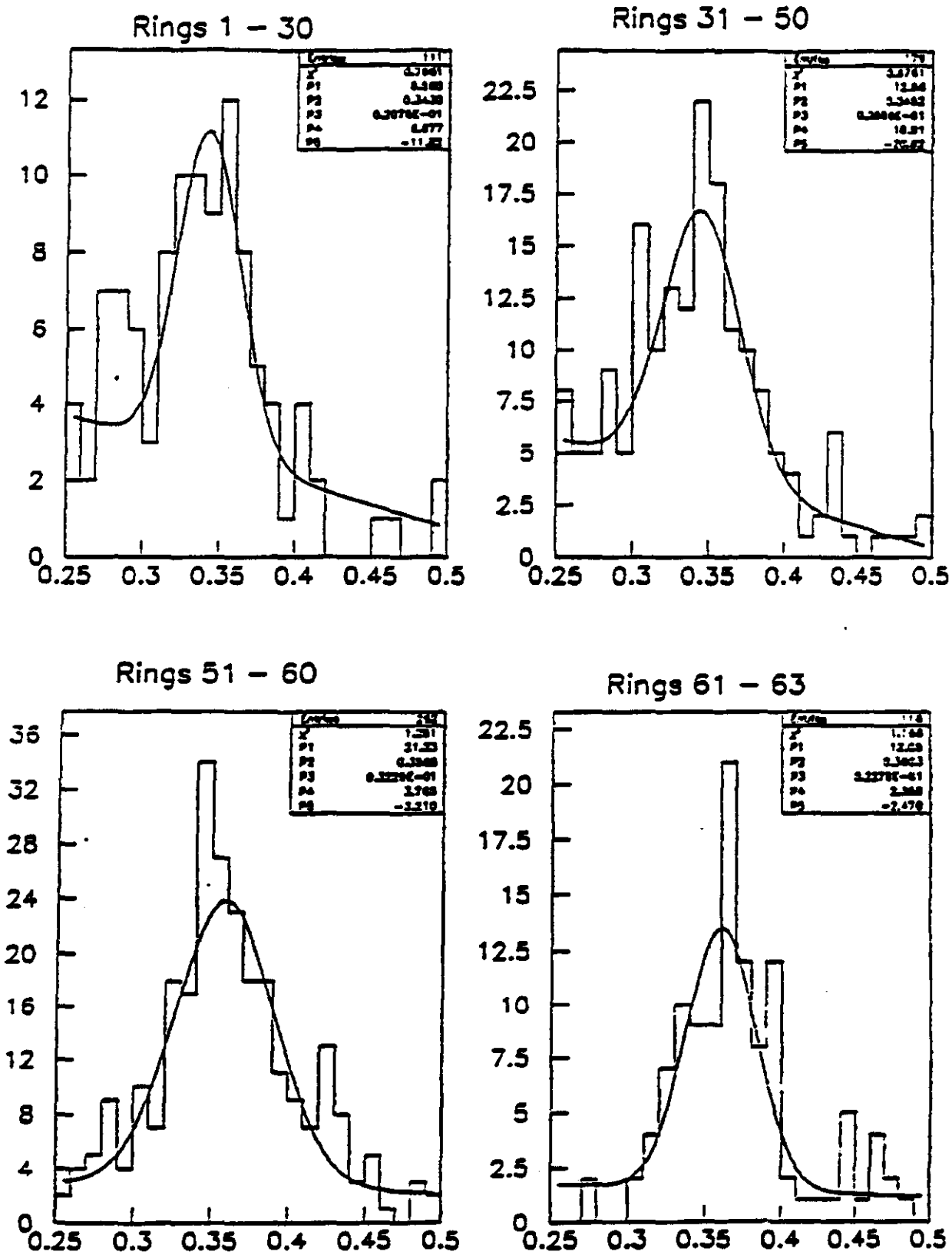
Energy Resolution in the CLEO II CsI

The CLEO II collaboration achieves similar monitoring precision as does L3, but, has more copious physics processes available to provide a better absolute calibration. They use Xe flash lamps to monitor the time dependence of their photodiodes. For absolute calibration over a wide energy range, CLEO uses three physics processes:

- 1) π^0 decays below 2 GeV,
- 2) photon energies in $ee\gamma$ events above 500 MeV, and
- 3) back to back $\gamma\gamma$ events at the beam energy.

Their calibration procedure has maintained an absolute run-to-run gain of $\pm 0.25\%$ as checked by bhabha energies and π^0 masses over time. They claim a calibration accurate to 1.% at 25 MeV, 0.5% at 100 MeV, and 0.2% at 5 GeV.

3000 MIPS / crystal needed for 0.3% calibration. (1 second)



isolation (3x3) = 95 mev

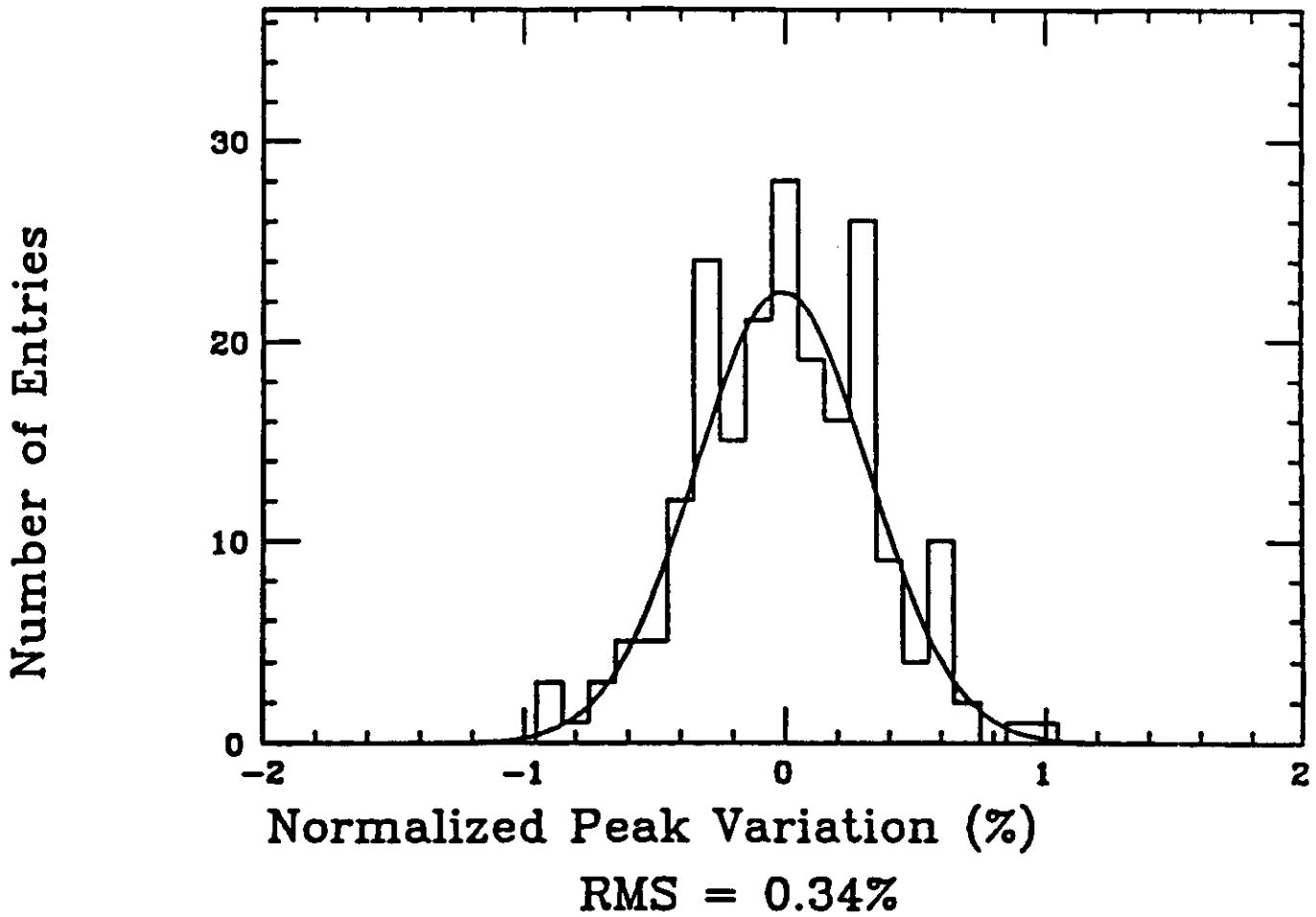
~20 hours for 1 kHz trigger

GEM Radiofrequency Quadrupole (RFQ) CALIBRATION SYSTEM

- PRINCIPLE: Radiative Capture in Fluoride Target
  - Bursts Of 6 MeV Photons
    $\Rightarrow$ Equivalent High Energy Photon
- 3.85 MeV $H^- \rightarrow H^0$ Beam:
  Beam Parameters (Adjustable):
  - 10 mA On Target, 10 μsec, 30 Hz
  - 300 TeV Per Pulse Over 4π
  - 25 GeV Typical Per Crystal;
    1.5 GeV In 'Farthest' Crystal
- TEST RESULTS (AccSys Prototype):
  - Calibrate All Crystals
    to 0.3% in a Few Minutes

Statistical Calibration
Error Below 0.1%
Within Two Minute Run

• accsys TEST:



Variations of BGO normalized peak positions

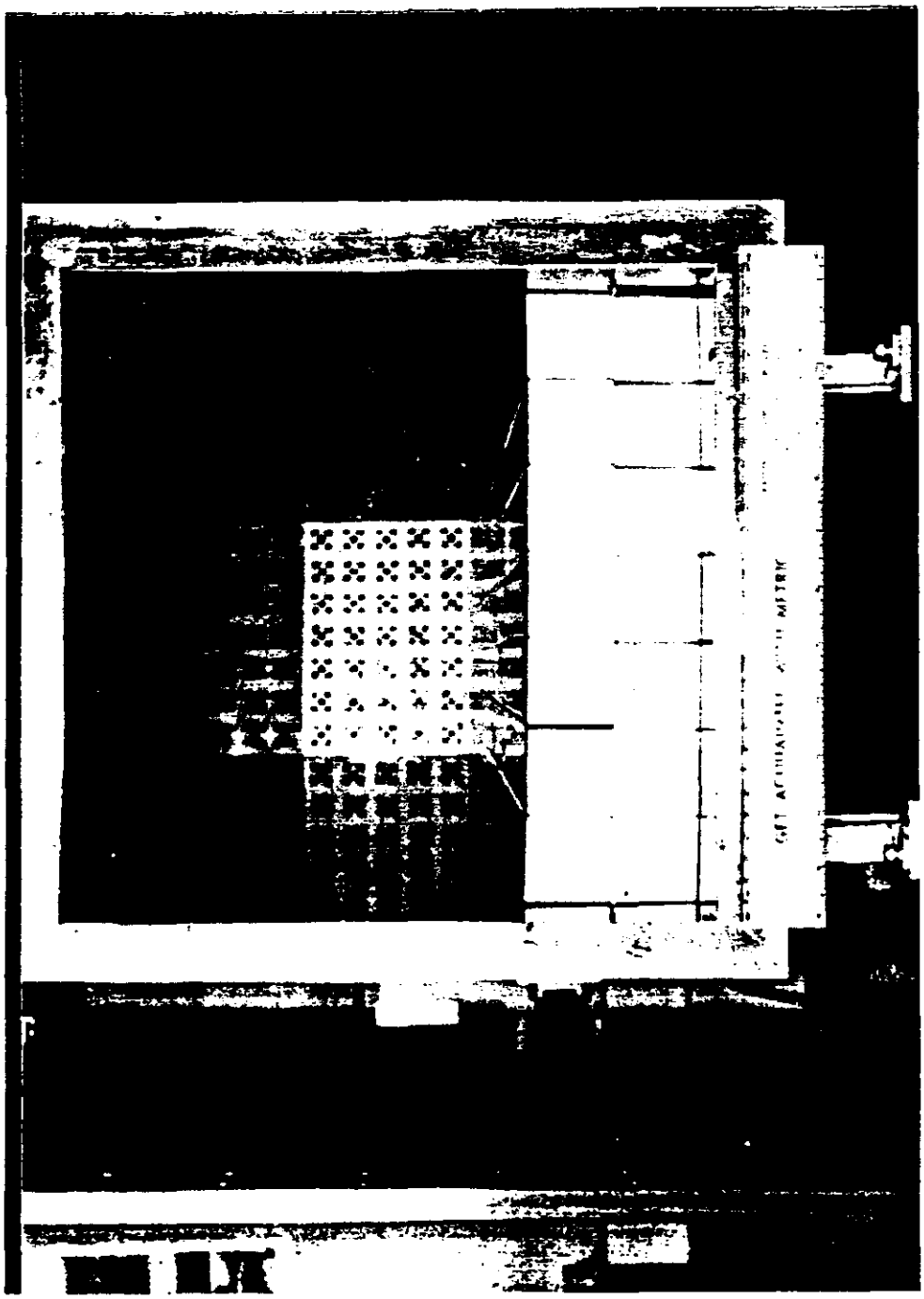
→ SIMULTANEOUS RESULT: BaF2 Counters : 0.29%

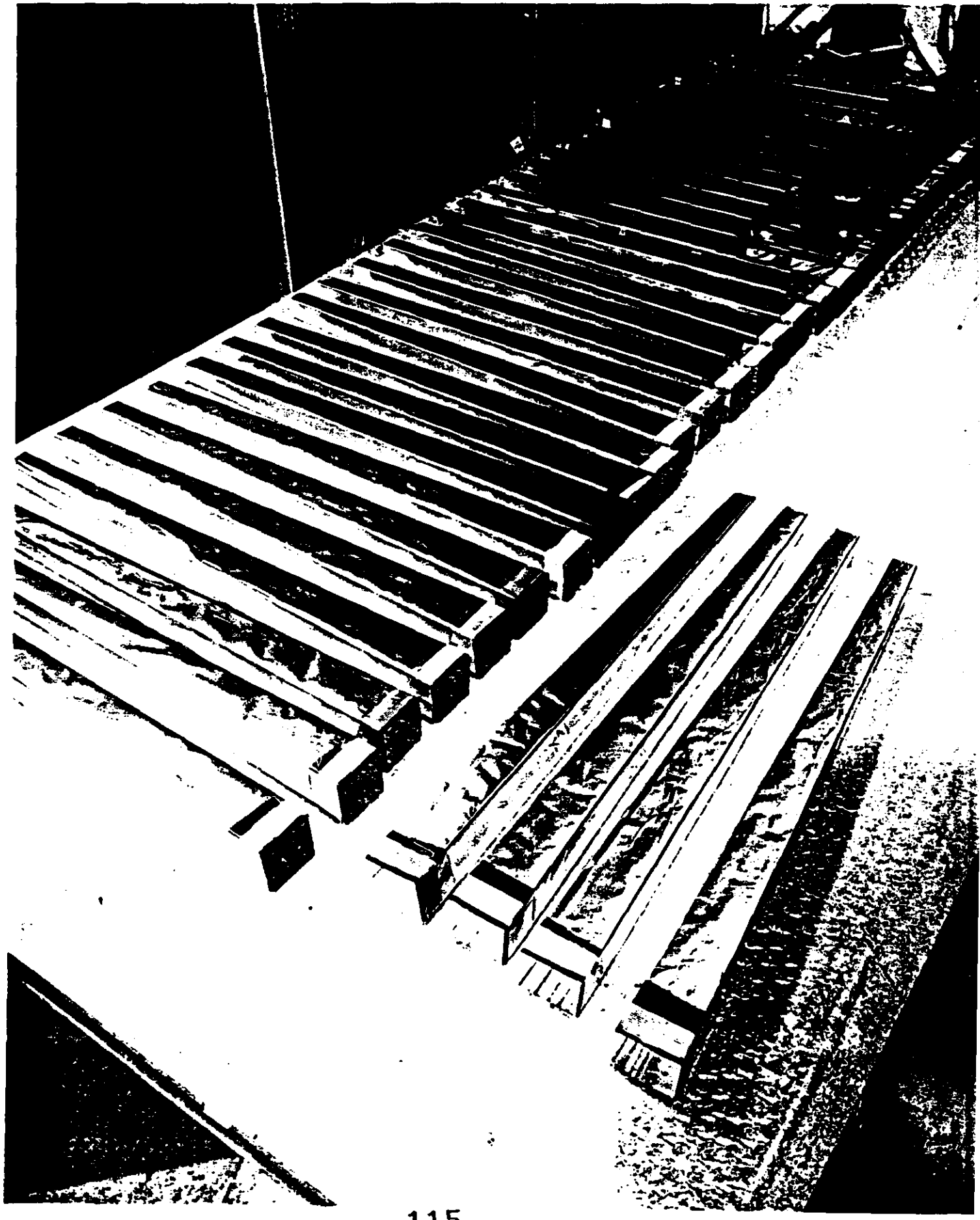
MY CONCLUSION

J. Branson

- The process $Z^0 \rightarrow e^+e^-$ will provide an ideal calibration for $H^0 \rightarrow \gamma\gamma$.
- Both L3 and CLEO II have monitored 4π crystal arrays to 0.25% over periods of a month with Xe lamps. These experiments were not requiring 0.5% resolution.
- GEM will have better uniformity, more monitors, and more physics to calibrate on than did L3 or CLEO.
- Energy sharing reduces effect of calibration by $\sim \sqrt{2}$.
- GEM should achieve 0.25% or better in BaF_2.

- The need for calibration is not specific to crystals. We will need a calibration and a monitor in liquid Krypton. We must be sensitive to signal variations (due to impurities) within single readout channels.
- No examples of 4π liquid Krypton detectors exist to verify, by example, that this type of calibration is possible.





BaF_2 EM CALORIMETER
12/91 BEAM TEST
(FERMILAB T-849)

- BEAM
  - Spot Size: 40 mm × 40 mm
  - Angular Spread: 1.7 mrad
  - Momentum: 68 GeV/c
  - Momentum Spread : 3 GeV/c (FWHM)
  - Electron Tag: TRD

- BEAM SPECTROMETER
  - Momentum Resol'n $0.5 \pm 0.2\%$
- "CLEAN BEAM" CUTS
  - Spectrometer Impact Matches Calorimeter
  - Only One Particle in Calorimeter

BaF_2 EM CALORIMETER
1991 FNAL BEAM TEST

CALORIMETER RESOLUTION: BaF_2-SPECTROMETER DIFFERENCE

- Resolution 20×20 mm^2: 1.0%
- Instrumental Contributions
  - Spectrometer Resol'n: $0.5 \pm 0.2\%$
  - Pedestal Diff. Linearity: 0.4%
- BaF_2 Matrix Resolution (at 68 GeV):

→ – 0.77 (+0.12 – 0.18)%

→ – Consistent With Expected Resol'n: 0.6%

→ • Crystal Non-Uniformity: $\approx$ 0.6%; Not Less Than 0.5%

- Possible Calorimeter Resolution: 0 To 0.7%

• L3 BGO Calorimeter Resolution

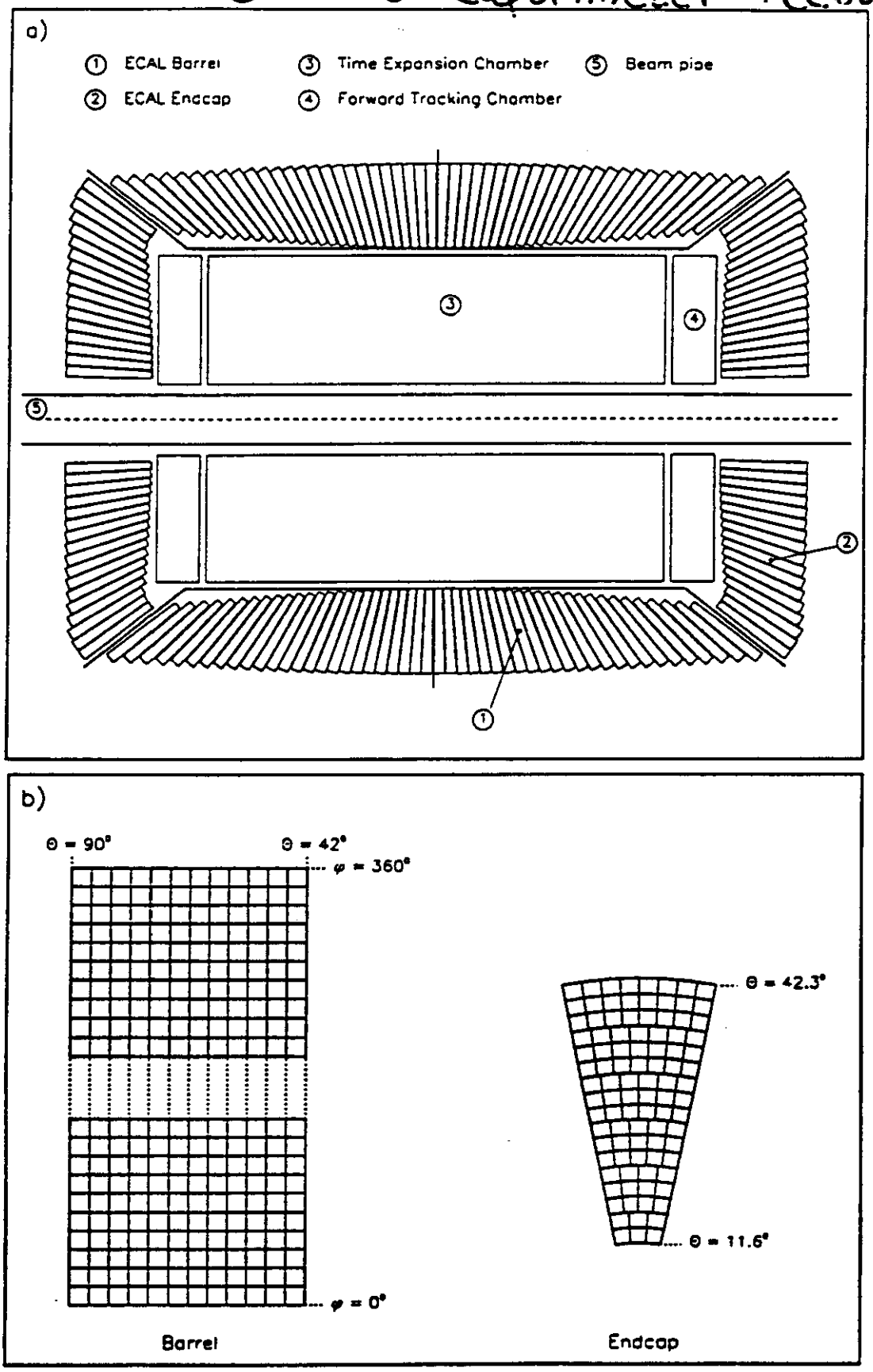


Figure 2.7: *The crystal arrangement in the electromagnetic calorimeter. a) A longitudinal cut through the detector. b) A transverse cut through the barrel and an endcap sector.*

• RUNNING at LEP : WITH TEST BEAM RESOLUTION

L3 PRECISION EM BGO CALORIMETER

- "RUNNING" WITH DESIGN RESOLUTION : $\leq \frac{2\%}{\sqrt{E}} \oplus 0.5\%$

  at LEP

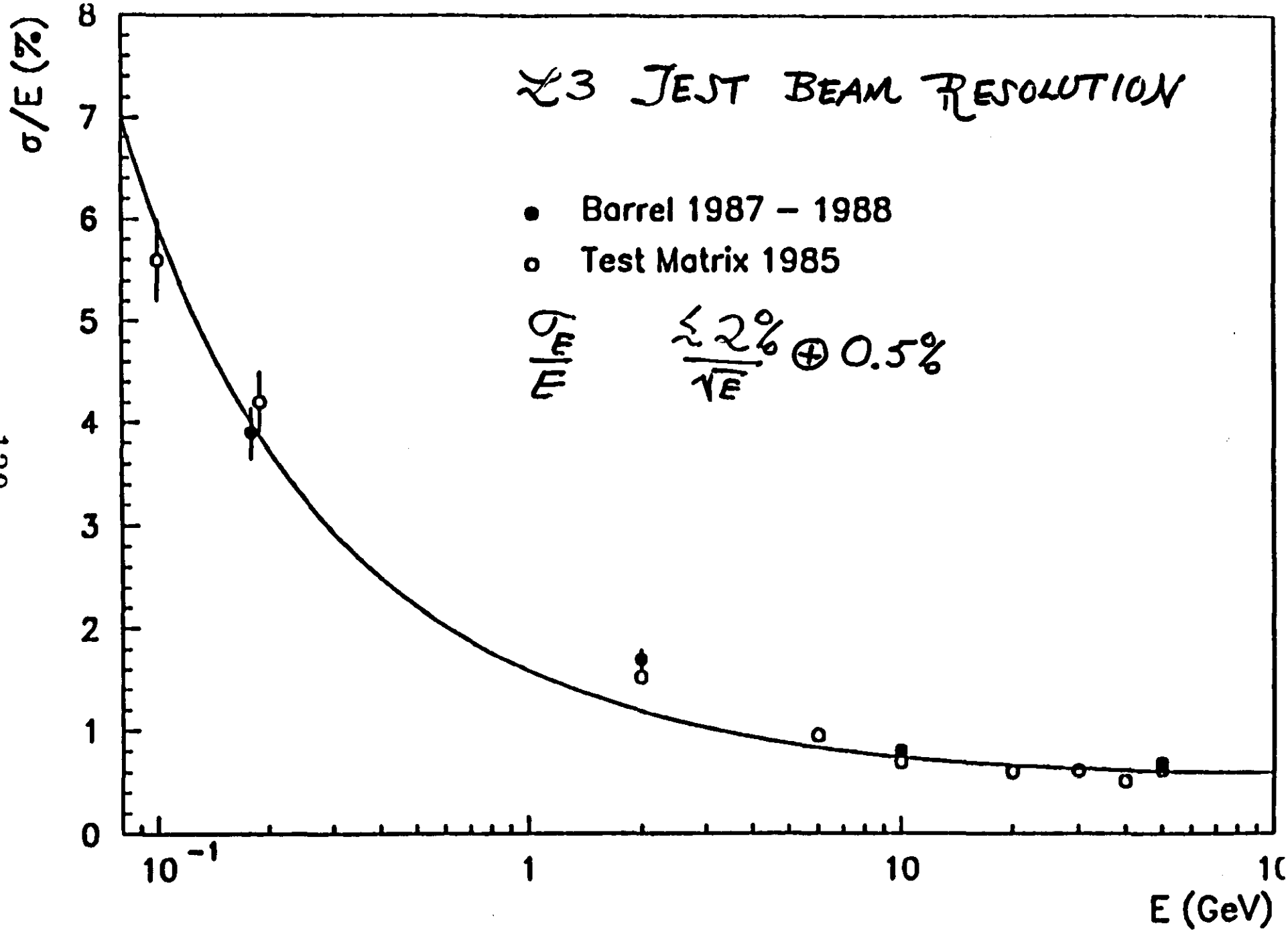
- MEASUREMENT of e^+, e^- from $e^+e^-(\gamma)$ at Z^0 : $\left(\frac{\sigma_E}{E}\right)$

→ ① – RADIATIVE Effects 0.7±0.05%

→ ② – XENON LAMP MONITOR (CALIBRATION TRANSPORT) 0.8±0.1%

→ ③ – BEAM TEST RESOL'N 0.6%

- $\sigma_{MEASURED} = 1.25\% \doteq \sigma_{calc}$
- $\sigma_{calc} = 0.7 \oplus 0.8 \oplus 0.6 = 1.25\%$ ± 0.12%



Test beam energy resolution of the BGO detector.

• L3 TEST BEAM RESOLUTION

Test beam energy resolution of the BGO detector.

The data points can be approximated by the function:

$$\frac{\sigma(E)}{E} \approx \sqrt{\left(\frac{\sigma_{in}}{\sqrt{E}} + \sigma_{mat}\right)^2 + \sigma_{leak}^2 + \sigma_{noise}^2 + \sigma_{beam}^2 + \sigma_{cal}^2} \quad ,$$

containing the following components:

- σ_{in}, the intrinsic resolution due to shower fluctuations; estimated to be $\approx 0.5\%$.
- σ_{mat}, the contribution of material and light collection inhomogeneities in the BGO crystals; estimated to be $\approx 0.3\%$
- σ_{leak}, the contribution due to the fact that the showers are not completely contained in the crystals; its effect on the resolution was ($\sigma_{leak} = 0.2\sqrt{E_{leak}/E}$). $\approx 0.18\%$ at 45.5 GeV
- σ_{noise}, the contribution from electronic noise; in chapter 4 we arrived at an electronic noise contribution of approximately 4 MeV. small
- σ_{beam}, the contribution to the observed resolution coming from the spread of the momenta of the incoming beam particles; the observed spreads can be parametrized by $\sigma_{beam} = 1.25\%/\sqrt{E}$
- σ_{cal}, the precision of the calibration constants; in the previous section a value of 0.4% was derived. • (including BGO TEMP. : $-1.55\%/°C$)

At low energies, the detector resolution is dominated by shower fluctuations and electronic noise, while at high energies the performance is limited by the leakage fluctuations and the calibration precision.

At ≥ 45.5 GeV : $\frac{\sigma_{in}}{\sqrt{E}}$; Cross term small

$\rightarrow \left(\sigma_{mat}^2 + \sigma_{leak}^2 + \sigma_{cal}^2\right)^{1/2} \approx 0.53\%$

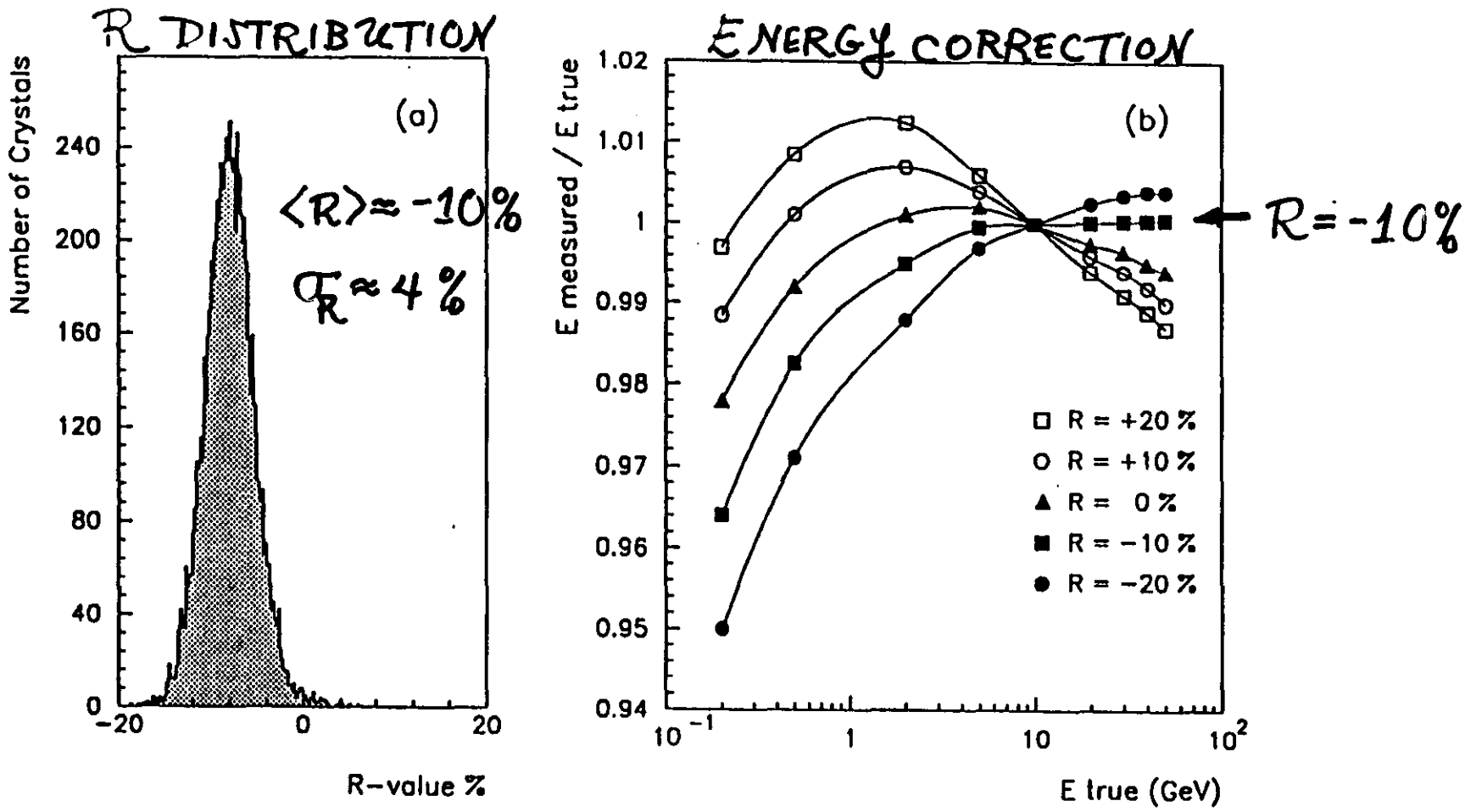
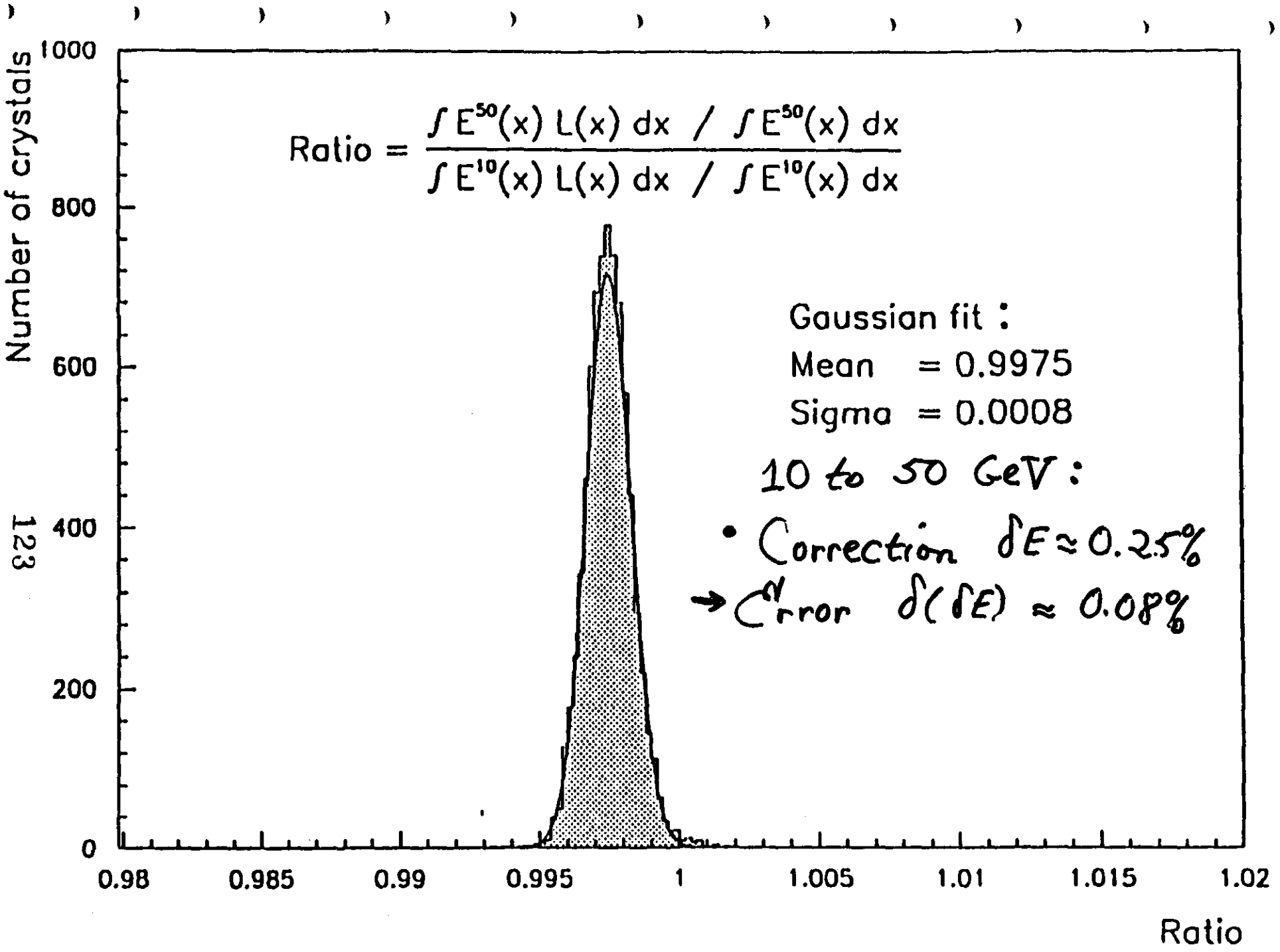


Figure 5.2: *(a) The distribution of the light uniformity factors R. (b) The energy correction as function of the incoming energy for various R-values.*

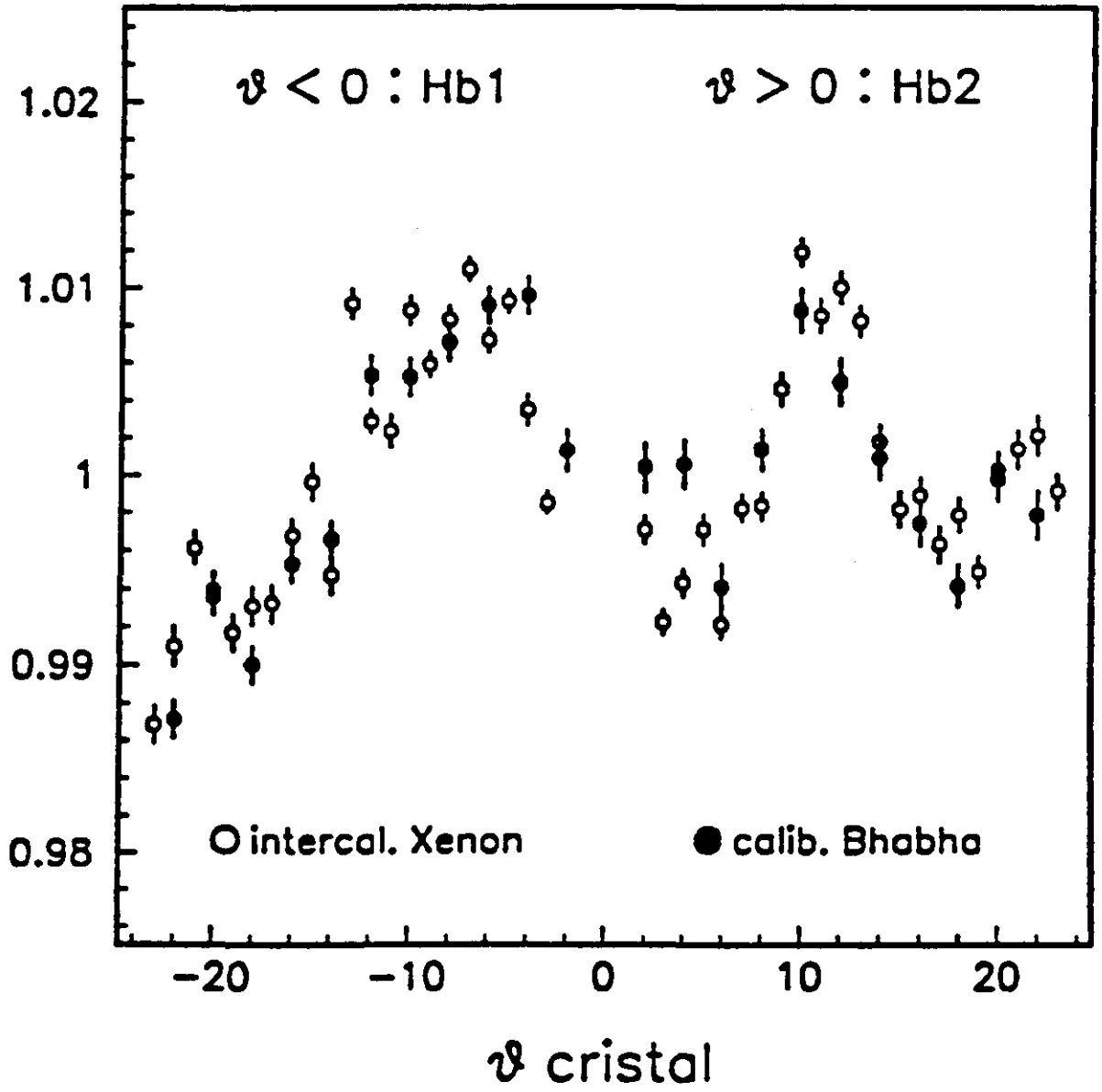
- CORRECT USING KNOWN R,
- → OR CONVOLUTE L(x), SHOWER PROFILE



The light collection effect for showers of 10 and 50 GeV.

• TEST BEAM vs. LEP Calibration:

- Average Response Shift of Crystal Rings
- XENON Lamp Versus Bhabhas



Comparison of the structure in θ of the gain changes measured at LEP using Bhabha events, with respect to the gains measured at the CERN X3 test beam.

• Calibration (average) of GROUPS of Crystals recovered With Bhabhas

• Recovery of Individual Crystal's Calibration Would be Possible

- CALIBRATION TRANSFORT: SPS TO LEP

Overall ⟨Correction⟩: SPS → LEP
X3

- Bhabhas : 0.955
- Xenon : 0.954

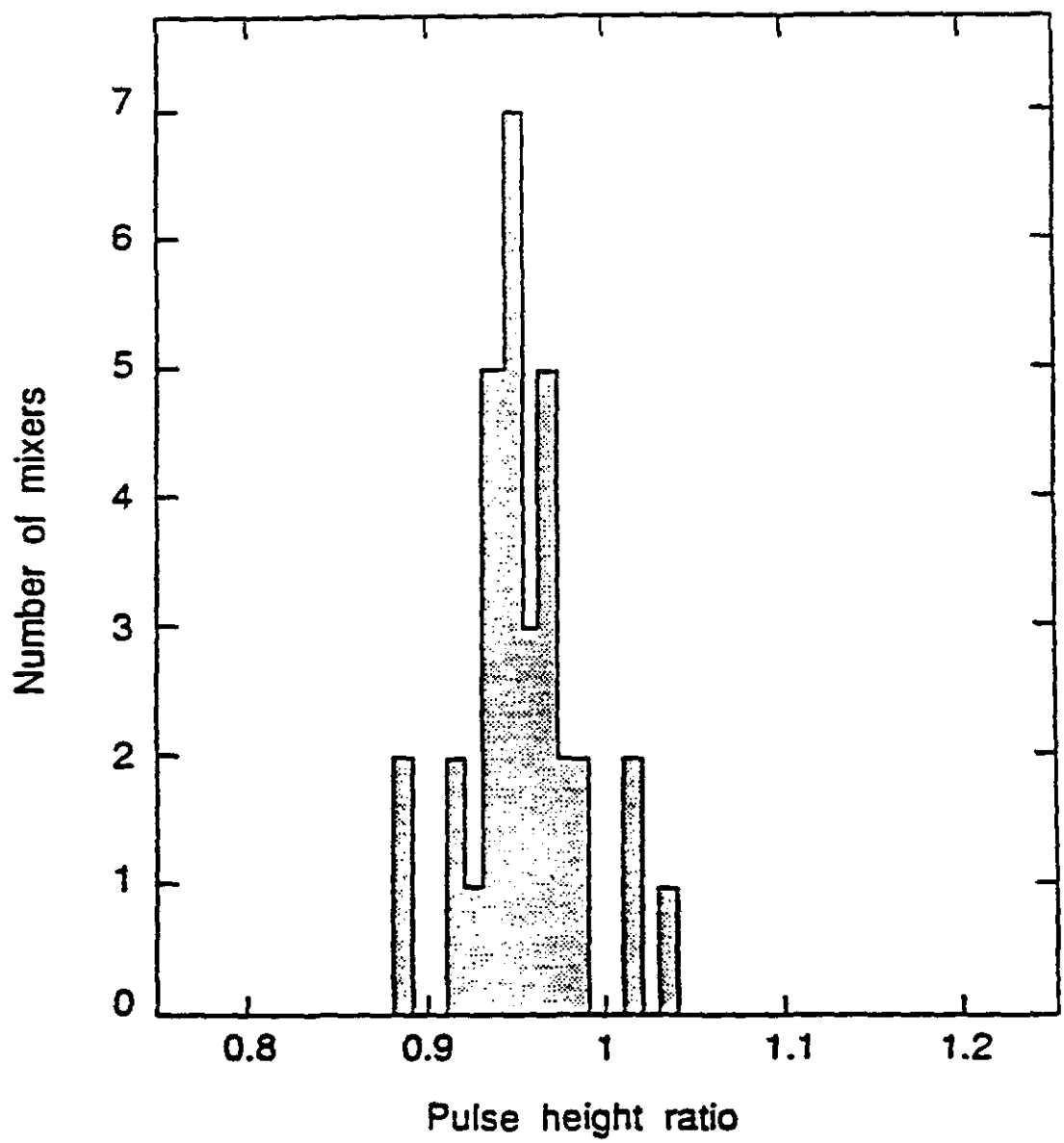
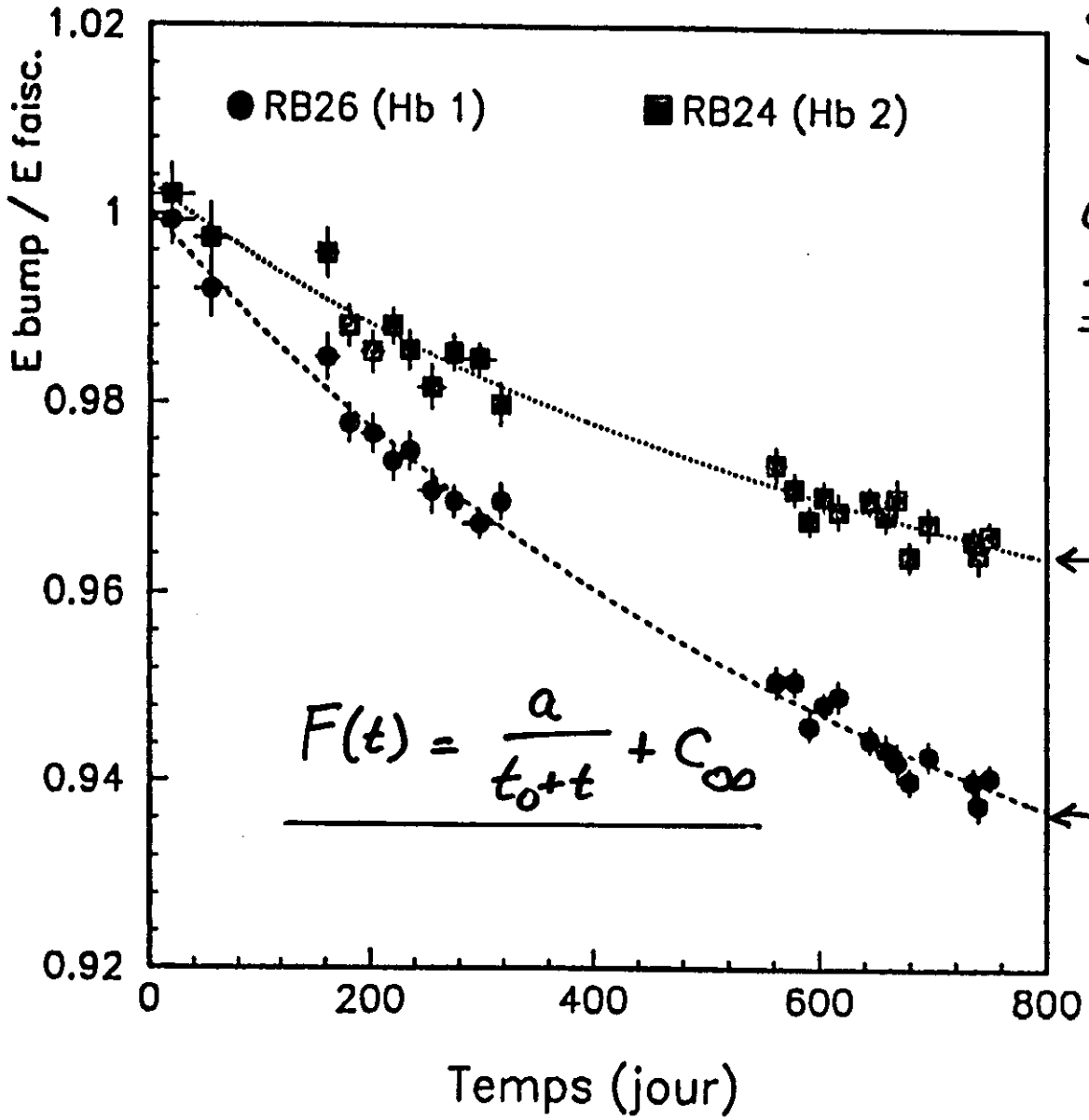


Figure 12: Ratio of the average xenon pulse heights at LEP and at the SPS. All crys belonging to the same mixer are summed together. The xenon light pulses are normal



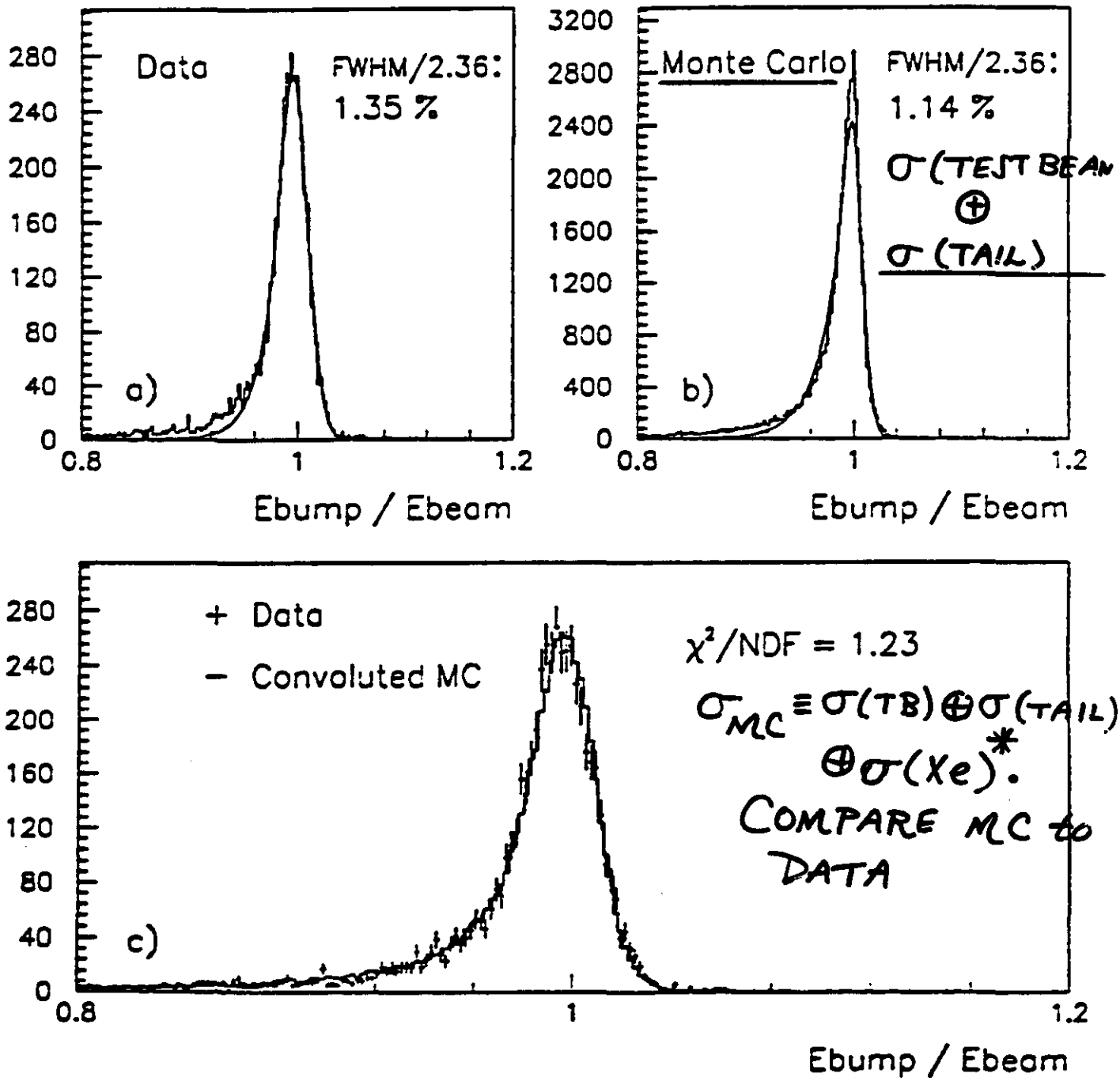
Time Evolution of Bhabha e^+ & e^- Energies, in Two Half Barrels.

$C_\infty = 0.916 \pm 0.003$
$t_0 = 977 \pm 69$ Day

$C_\infty = 0.847 \pm 0.003$
$t_0 = 1137 \pm 39$ DAY.

Evolution des signaux d'événements Bhabha pour les deux Hbs de BGO en fonction du temps à LEP. L'échelle de temps horizontale débute le 1er octobre 1989.

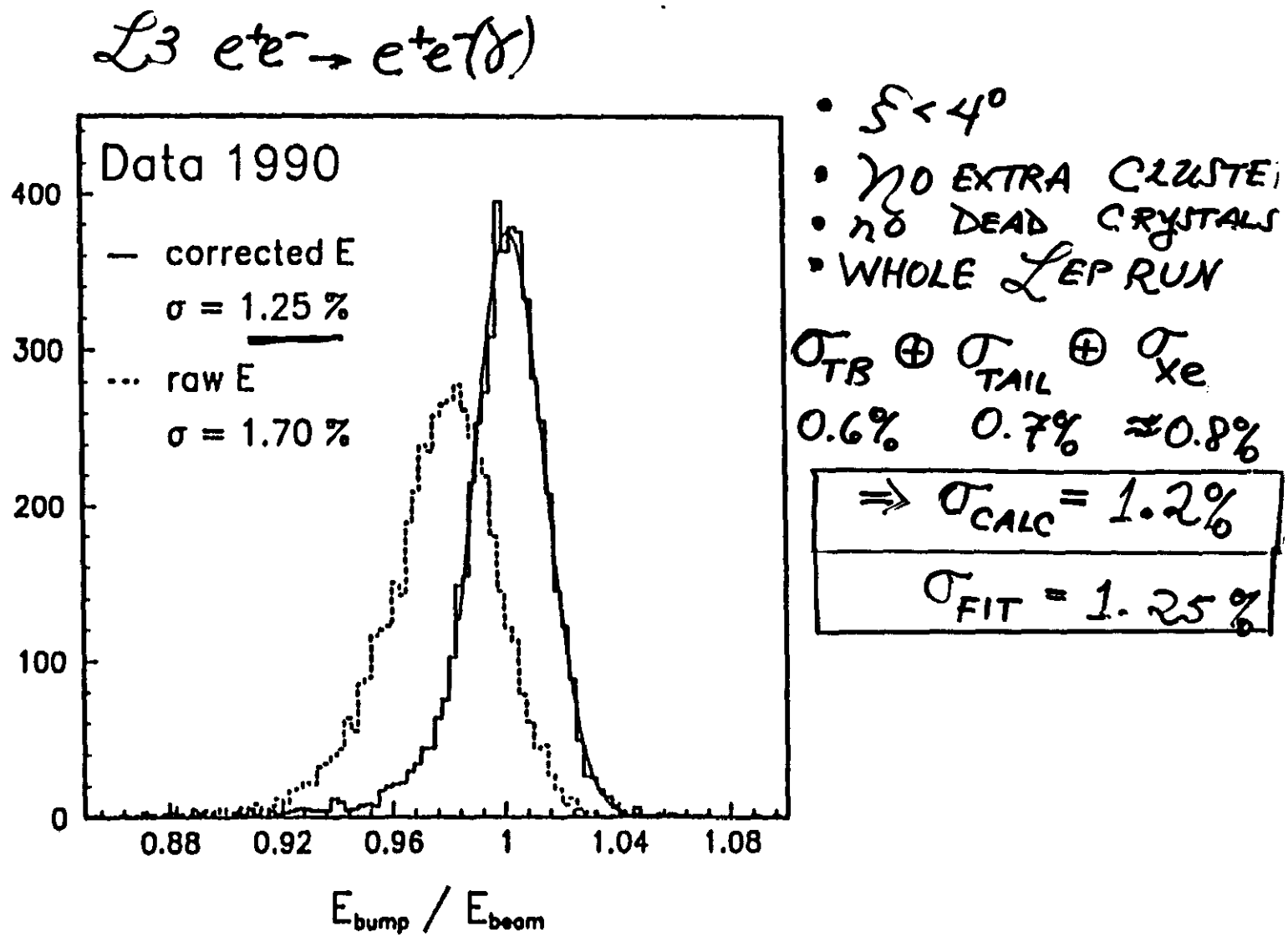
L3 Energy Resolution
($e^+e^- \to e^+e^-(\gamma)$: all Events)**



Comparison of the reconstructed energy of an electron or positron in Bhabha events. a) Real data b) Monte Carlo c) Comparison of the data bump with the convoluted Monte Carlo.

*σ(Xe) ≈ 0.7% to 0.8% (agrees)

[illegible] of Clusters With



Distribution en énergie (divisée par l'énergie du faisceau) des bumps sélectionnés pour la calibration avant et après application des corrections pour l'année 1990.

L3 BHABHA ANALYSIS and ENERGY RESOLUTION SUMMARY

1) $\sigma_{MEASURED}$ — $1.25 \pm 0.05\%$

2) $\sigma_{RADIATIVE\ TAIL}$ — $0.7 \pm 0.05\%$

3) $\sigma_{XENON\ LAMP\ CALIBRATION}$ — $0.8 \pm 0.1\%$

$\rightarrow \sigma_{BGO}(\text{at LEP}) = 1 \ominus 2 \ominus 3 = 0.6^{+0.16}_{-0.26}\%$

SUBTRACT IN QUADRATURE

$$\boxed{\begin{array}{l} \text{RESULT: } \sigma_{BGO}(\text{TEST BEAM}) = 0.6\% \leftarrow \\ \sigma_{BGO}(\text{at LEP}) \in 0.4 - 0.8\% \leftarrow \end{array}}$$

NOTE: WITH PHYSICS Calibrations:

- $\boxed{\text{If}}$ COULD Correct WITHIN XENON REGIONS TO $\approx 0.3\%$ $\Rightarrow$ THEN
- ENERGY RESOLUTION WOULD BE 1.0% for Bhabhas at LEP;
- OR $\frac{\delta M}{M} = 0.4\%$ for a narrow RESONANCE

BaF_2 PRECISION EM CALORIMETER

4 YEARS R&D* ⇒ MANUFACTURE

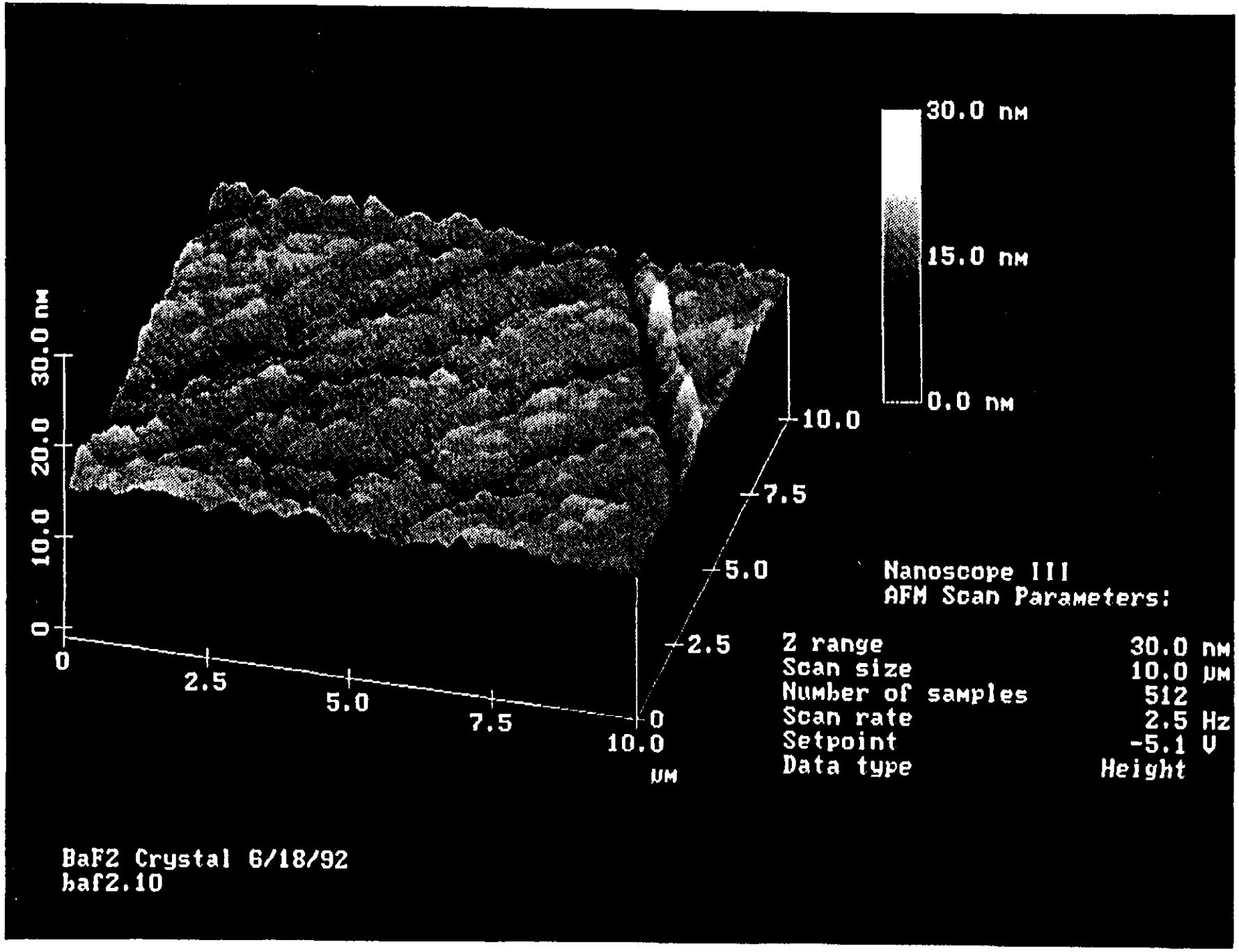
1988 → 1993

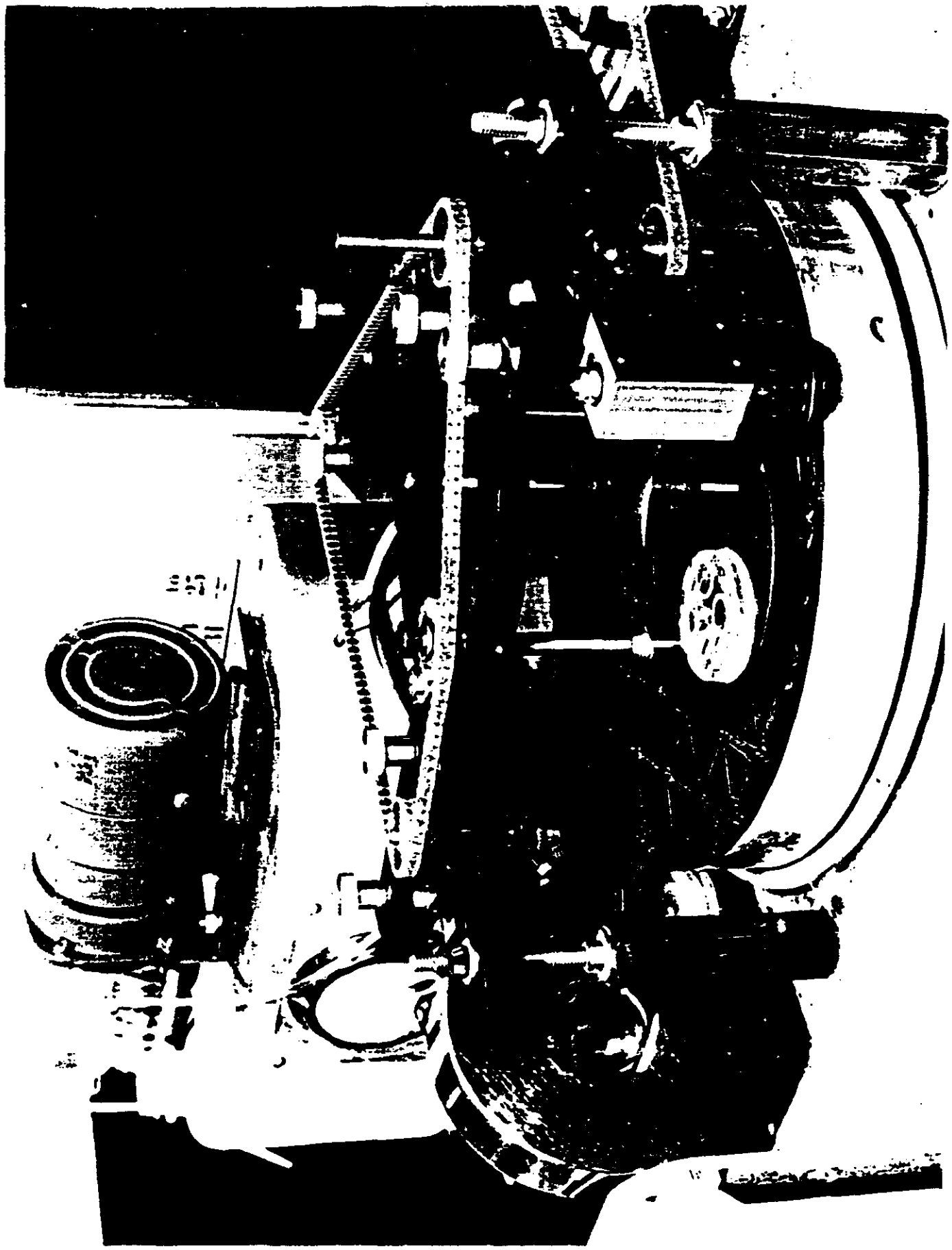
- Large Radiation Hard Mass Produced Crystals At $ 2.5 Per cc (SIC, BGRI)
- Production of Crystal Pairs Accurate To $\leq 100\ \mu m$ Accuracy (Zhongnan, Tsinghua, LLNL, ORNL)
- Radiation Damage Tests and Improvements (SIC, BGRI, Tongji, SINR, Caltech, BNL, LLNL, CE&A, WVA, Optovac)
- In Situ Annealing for Rad Hardness (BNL, Caltech, LLNL, UCSD, WVA, Tsinghua)
- Precision Crystal Surface Polish and Coat: Pulse Height Uniform to $\leq 5\%$ (LLNL, Zhongnan, BGRI, ORNL)
- Thin Laser Welded Titanium Alloy Support – Carbon Fiber Experience, FEMA (ORNL, Tsinghua)
- Precision Calibration and Gain Monitoring (Caltech, UCSD, IHEP, CMU, ORNL)
- Fast Linear Front End Readout (Princeton, ORNL, Tsinghua; Caltech, UCSD))
- Quality Control, Inspection, Test, Assembly (IHEP, USTC, Tsinghua, UCSD, CALTECH)

* + SUCCESSFUL BEAM TEST

BaF_2 PRECISION EM CRYSTAL CALORIMETER NEW MAJOR R&D PARTNERS

- LLNL
  - Crystal Mass Production Process Design and Engineering
  - Surface Preparation
  - UV Reflective Coating
  - Pure Rad Hard Crystal Growth
- ZHONGNAN OPTICAL INSTRUMENT FACTORY
  - Crystal Mechanical Processing
  - Production UV Coating With BGRI


30.0 nm
15.0 nm
0.0 nm
30.0 nm
20.0
10.0
0
0
2.5
5.0
7.5
10.0
µm
10.0
7.5
5.0
2.5
0
Nanoscope III
AFM Scan Parameters:
Z range 30.0 nm
Scan size 10.0 µm
Number of samples 512
Scan rate 2.5 Hz
Setpoint -5.1 V
Data type Height
BaF2 Crystal 6/18/92
baf2.10



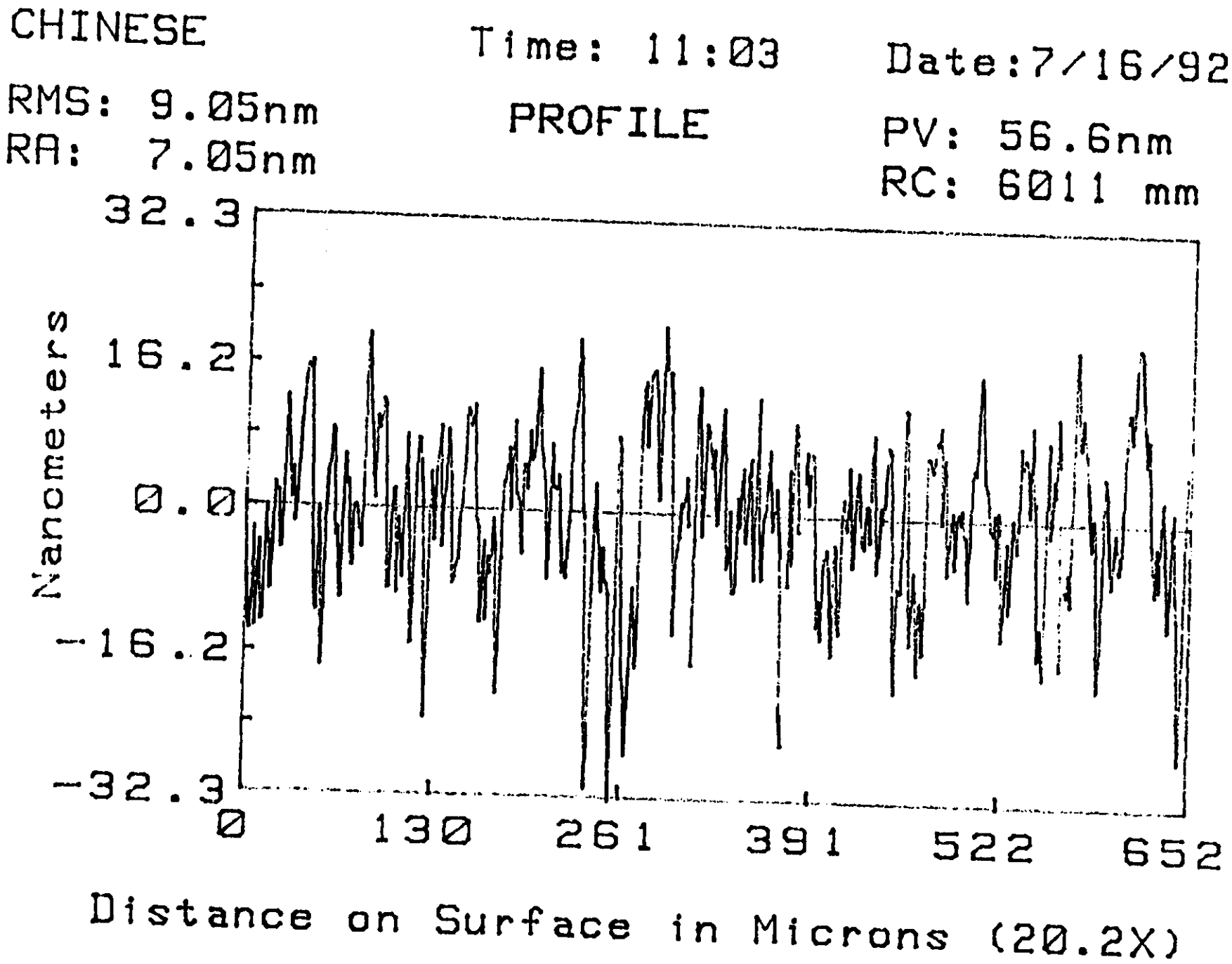
Barium Fluoride R&D at LLNL

- Second trip to China by LLNL and ORNL engineers - B. Fuchs, J. Heck
  - Transfer of LLNL polishing technology to Zhongnan Optical Instrument Factory and SIC – successful demonstration of 9 Å RMS polish using Zhongnan facility.
  - Further refinement of crystal mechanical specification and production plan.
  - Crystals received at LLNL for demonstration of 5 crystal polishing fixture.
  - Pyrolytically coated carbon crucible delivered to SIC for melt studies.

- Continued work on UV reflective coatings:
  - Full 50 cm crystal pair coated with Al, response measured with x-rays and gamma rays.
  - Barium fluoride prism fabricated to measure total internal reflectance of magnesium fluoride/aluminum reflective layer – comparison with calculations.
  - Full 50 cm crystal pair being coated with MgF_2/Al coating.

- Continued work on small crystal growing:
  - Reactive Atmosphere Processing (RAP), zone refining and Czolchrowski furnace runs in progress.

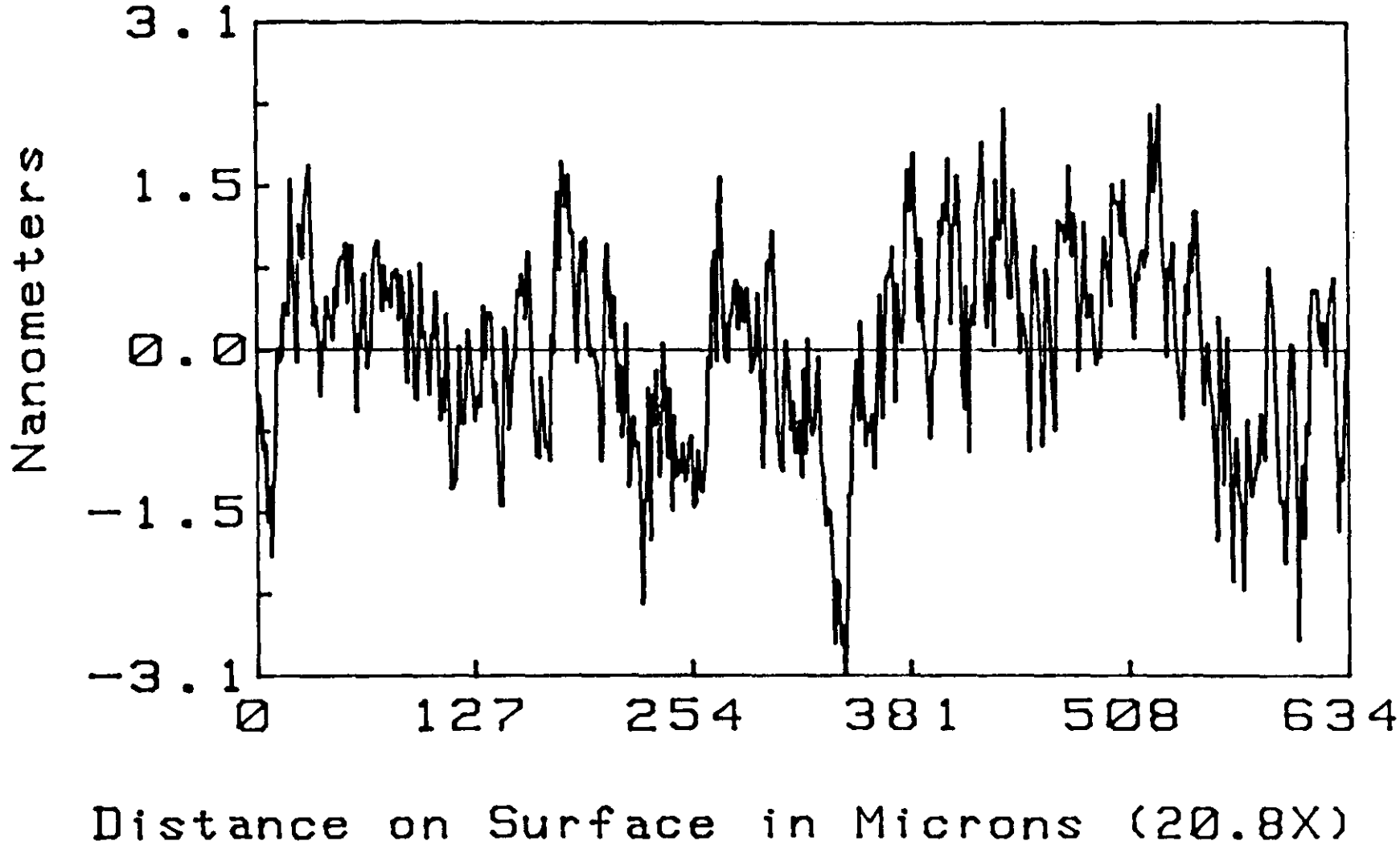
- Optical annealing of irradiated crystals:
  - Results for in-situ UV annealing show factor of 5 decrease in transmission loss compared to crystal irradiated in darkness (-1.4% vs. -7.1%) – 0.004W/cm2 Hg lamp, 2.9 krad/hr Co-60, 84 Krad total dose.

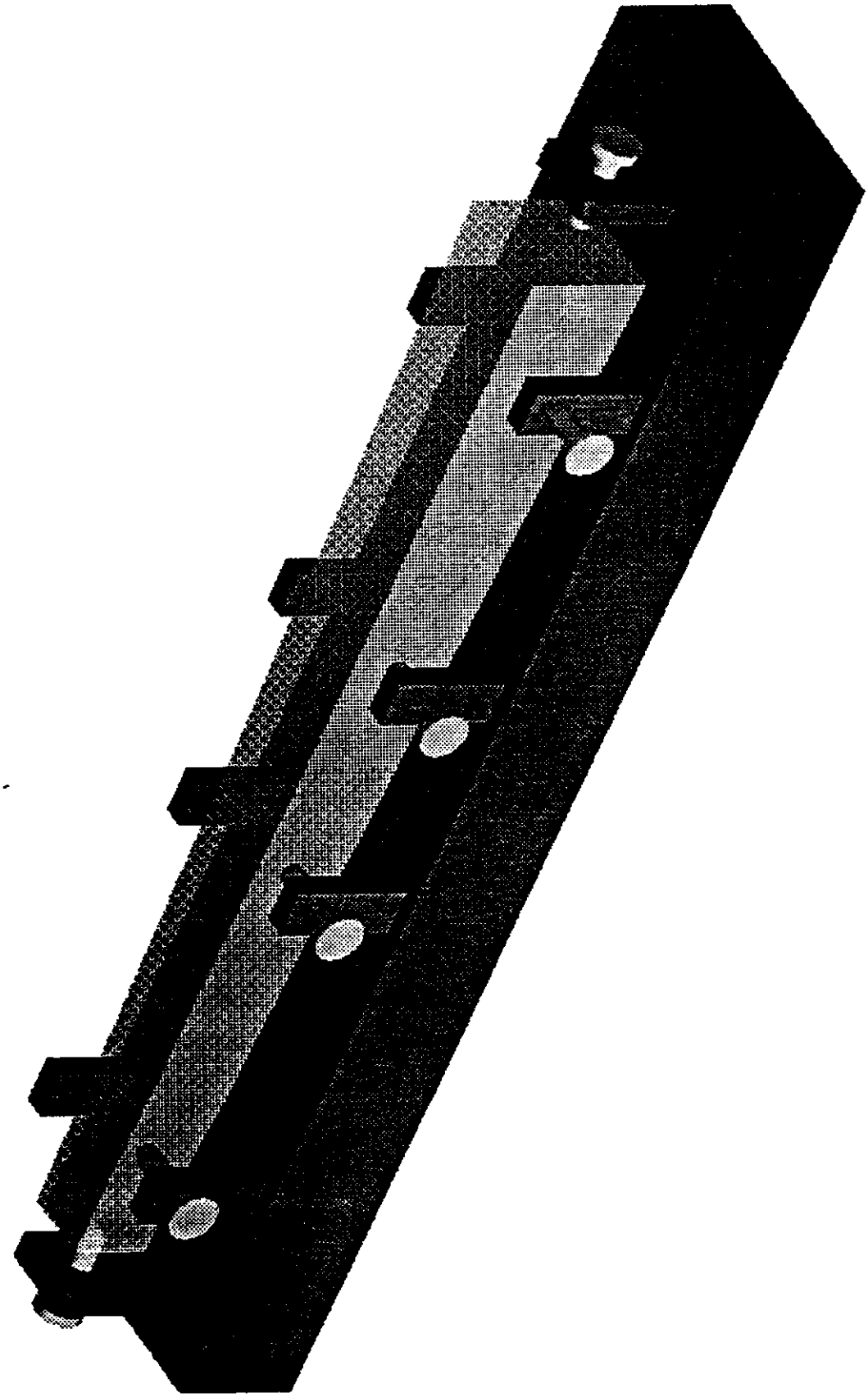

CHINESE
Time: 11:03
Date:7/16/92
RMS: 9.05nm
RA: 7.05nm
PROFILE
PV: 56.6nm
RC: 6011 mm
32.3
16.2
0.0
-16.2
-32.3
Nanometers
0
130
261
391
522
652
Distance on Surface in Microns (20.2X)

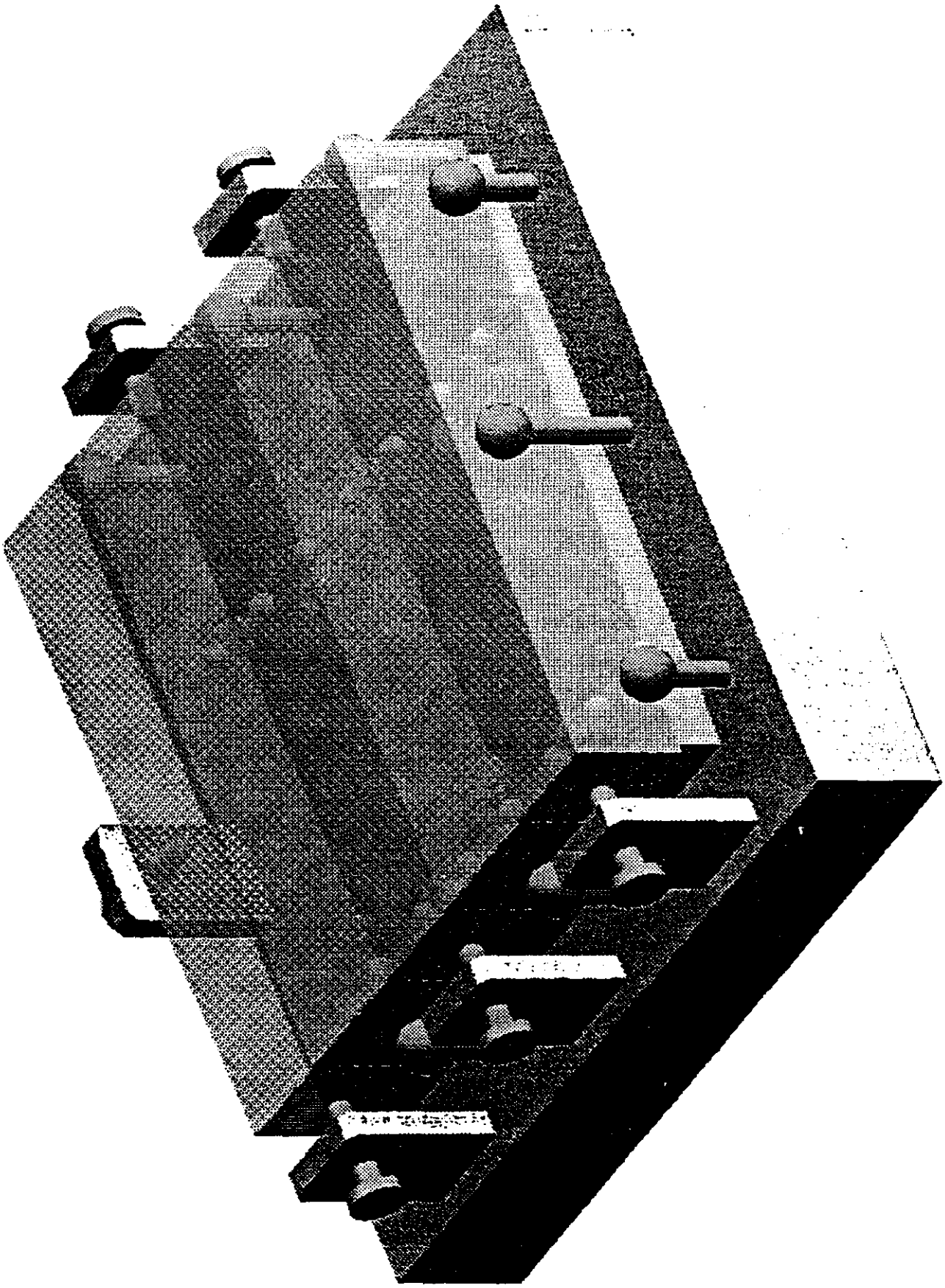
BaF2-X2 Time: 9:55 Date:8/28/92

RMS: 0.934nm PROFILE PV: 5.39nm

RA: 0.754nm RC: 13.6 km



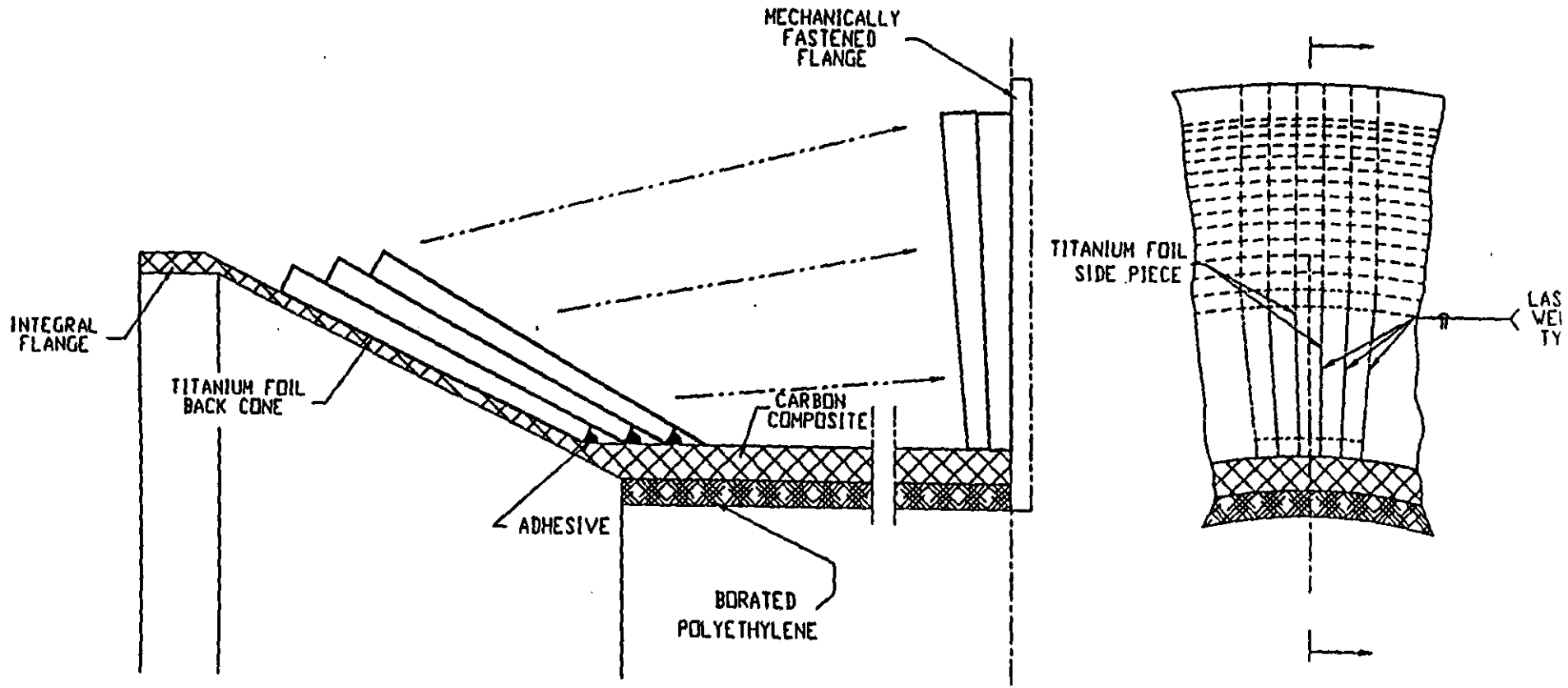




BaF_2 PRECISION EM CRYSTAL CALORIMETER NEW MAJOR R&D PARTNERS (Cont'd)

- TSINGHUA UNIVERSITY
  Seven Departments
  - Mechanical Support, Protoype
  - Multipoint Inspection Machine
  - Readout Electronics
  - Laser Calibration, Annealing
  - Readout Electronics
- IHEP BEIJING
  USTC HEFEI
  - Quality Control; Cosmic Ray Tower
  - Electronics
  - Assembly
  - RFQ Calibrator

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



CALORIMETER STRUCTURE ASSEMBLY - PART 3

• TESTS in STRASBOURG:
50μm Foils Routinely Welded By Vendor

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

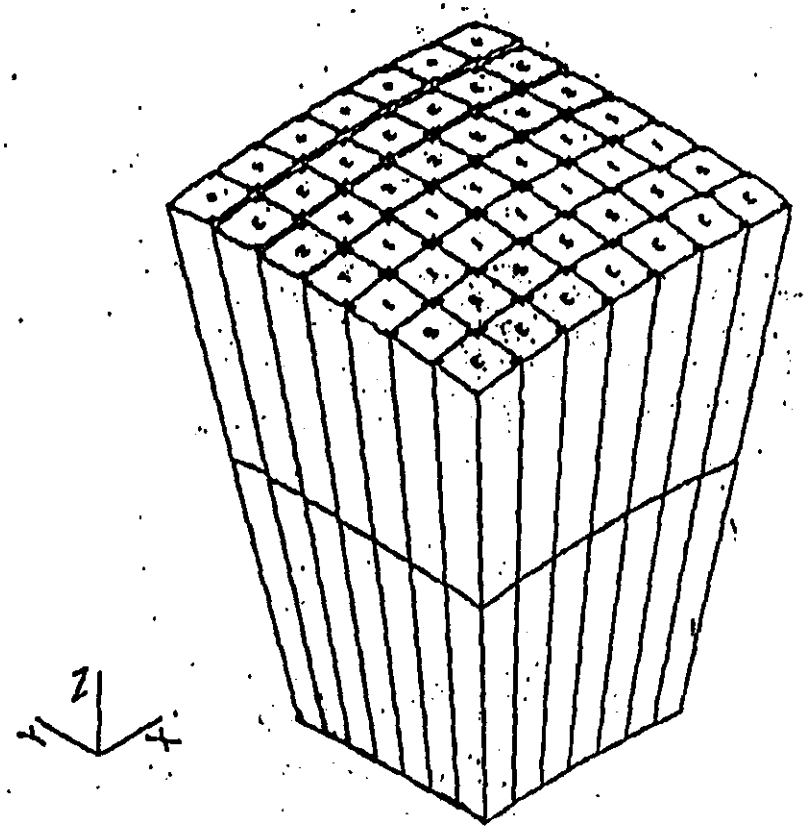
TSINGHUA:
100μm Titanium
Alloy, LASER Welded
Prototype Structure

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

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

1. welding 7x7 cells of GEM Detector Supporting structure

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



$30K

Date: July 22, 1992

Specification for
• An Instrument Inspecting BaF2 Crystals

Li Dacheng, Wang Dongsheng
Yu Guanzheng, Zhang Yunxiang

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

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

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

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

Constructing Cosmic Ray Test Stand at IHEP & USTC for GEM BaF_2 Calorimeter

Institute of High Energy Physics
and
University of Science & Technology of China

August 30, 1992

1 Goal

In constructing GEM's precision barium fluoride (BaF_2) crystal calorimeter, crystal quality control and acceptance test for each crystal must be performed before assembling. Items to be tested include crystal's light yield and light response uniformity. Those crystals with uniformity better than 3% will be accepted and recorded in database. The crystals of GEM BaF_2 calorimeter will be produced by Shanghai Institute of Ceramics (SIC) at Shanghai, China, and Beijing Glass Research Institute (BGRI) at Beijing, China. We propose to establish cosmic ray test stands at Institute of High Energy Physics (IHEP) and University of Science and Technology of China (USTC) to carry out this task.

2 Method

We propose to test each BaF_2 crystal by using cosmic muon with minimum ionization in crystal. Each crystal is divided to 25 sections along axial length. These sections

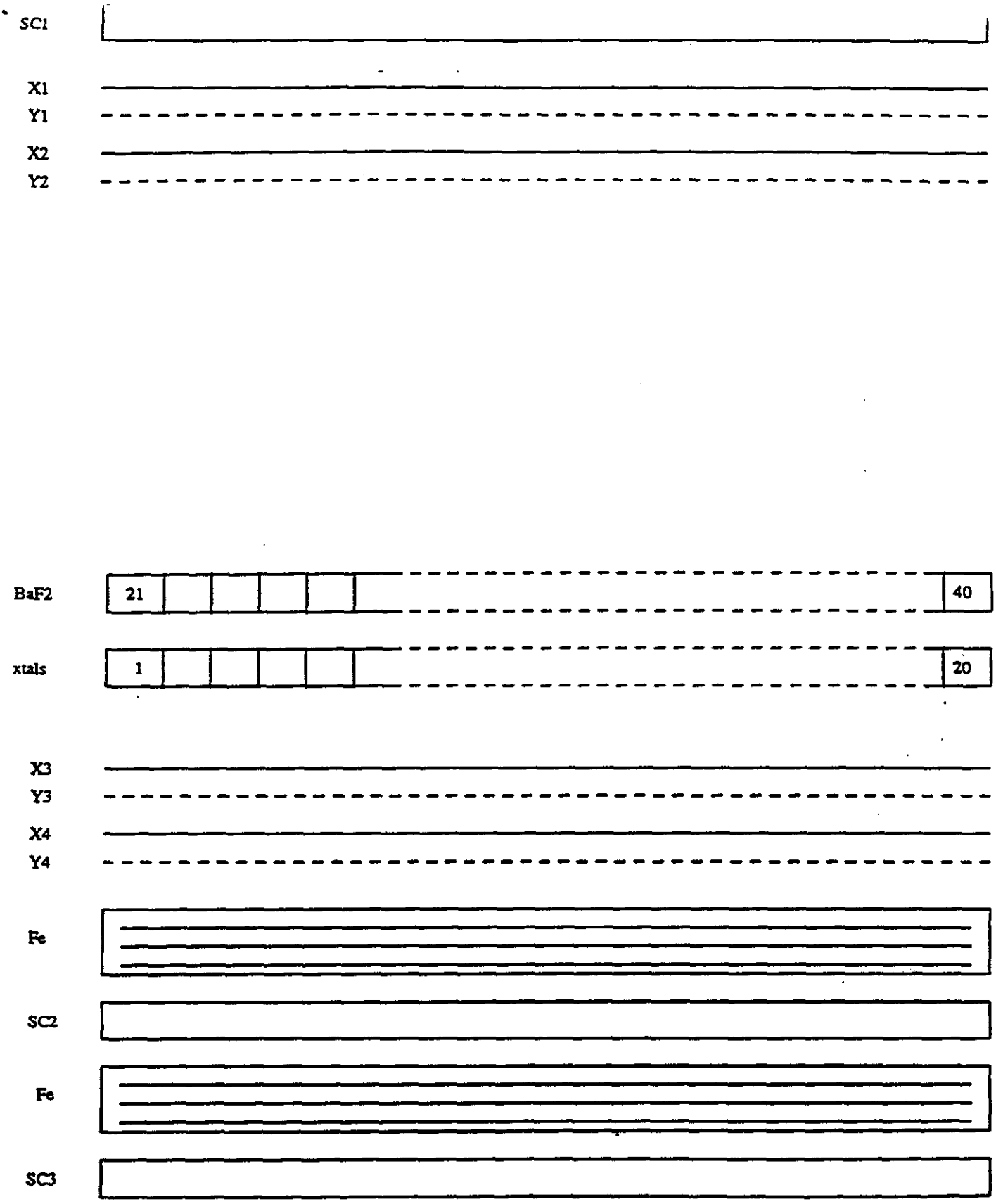


Fig.1 BaF2 Cosmic Ray Test Apparatus

BARIUM FLUORIDE CRYSTAL EM and SCINTILLATING FIBER HCAL

THE PRECISION CALORIMETER SYSTEM FOR GEM

- HIGHEST PHYSICS DISCOVERY POTENTIAL
  - → IN THE INTERMEDIATE MASS RANGE
- RADIATION STABLE
  - → USING CRYSTALS oF EXISTING QUALITY
- FASTEST
- MULTIPLE PRECISION CALIBRATIONS
- WORKING COLLIDER DETECTOR SYSTEMS
  - → CRYSTAL BALL, CLEO II, CUSB, L3
- WELL MATCHED TO SCINTILLATING FIBER HCAL
  - → "TUNABLE" COMPENSATION, GEOMETRY, SPEED

MEETS GEM'S REQUIREMENTS

READY TO START PRODUCTION BY A STRONG INTERNATIONAL TEAM STARTING IN 1993

gem

γeμ

Presentation by:

Howard Gordon

H. Gordon
September 3, 1992

Liquid Argon/Krypton Calorimetry

Decision

Questions From The Executive Committee

B. Requirements for LAr-Kr technology :

1. Demonstrate by beam tests stochastic term in resolution for non-projective geometry $<7\%/\sqrt{E}$. Determine angular dependence of this resolution.

BNL Beam Test: "2 mm" Krypton - $(6.72\pm0.035)\backslash\sqrt{E}\oplus(0.0\pm0.2)$

Angular resolution via Monte Carlo

2. Produce detailed mechanical design/analysis of EM barrel and end caps with optimization of gap between barrel and end cap, wall thicknesses, etc.

Engineering Panel Review, Aug. 14, 1992

3. Demonstrate by MC simulations for realistic projective geometry and full angular range (between 90 and 5.7 degrees) the resolution $<7\%/\sqrt{E}+0.4\%$ and physics consequences of the gap between the gap between the barrel and endcap, wall thicknesses, etc.

The 1992 GEM LAr/Kr Accordion Calorimeter Group

D. Lissauer.

O. Benary, [9], S. Cannon, [5], W. Cleland[7],
I. Ferguson[2], C. Finley[5], A. Gordeev[6],
H. Gordon[3], E. Kistenev[3], P. Kroon[3],
M. Leltchouk[5], D. Lissauer[3], H. Ma[3],
D. Makowiecki[3], A. Maslennikov[4], S. McCorkle[3],
D. Onoprienko[6], A. Onuchin[4], Y. Oren[9],
V. Panin[4], J. Parsons[5], V. Radeka[3], L. Rogers[3],
D. Rahm[3], S. Rescia[3], J. Rutherfoord[2],
M. Seman[5], M. Smith[3], J. Sondericker III[3],
R. Steiner[1], D. Stephani[3], E. Stern[7], I. Stumer[3],
H. Takai[3], H. Themann[8], Y. Tikhonov[4]

[1] Adelphi University, Garden City, NY
[2] University of Arizona, Tucson, AZ
[3] Brookhaven National Laboratory, Upton, NY 11973
[4] Budker Institute for Nuclear Physics, Novosibirsk, Russia
[5] Columbia University, New York, NY
[6] Oak Ridge National Laboratory, Oak Ridge, TN
[7] University of Pittsburgh, Pittsburgh, PA
[8] SUNY at Stony Brook, Stony Brook, NY
[9] Tel-Aviv University, Tel-Aviv, Israel

The Liquid Argon Test.

Objectives:

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

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

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

2) Position Resolution & e/π separation.

Chevron Design

3) Trigger.

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

4) Calibration.

New calibration system. 0.1-0.2 %

5) Electronic readout.

AMU – ZEUS electronics.
Track and hold.

6) Simulations.

Non projective geometry
Quasi projective
Projective geometry

7) Bending machine

Bending machine for Projective Geometry.

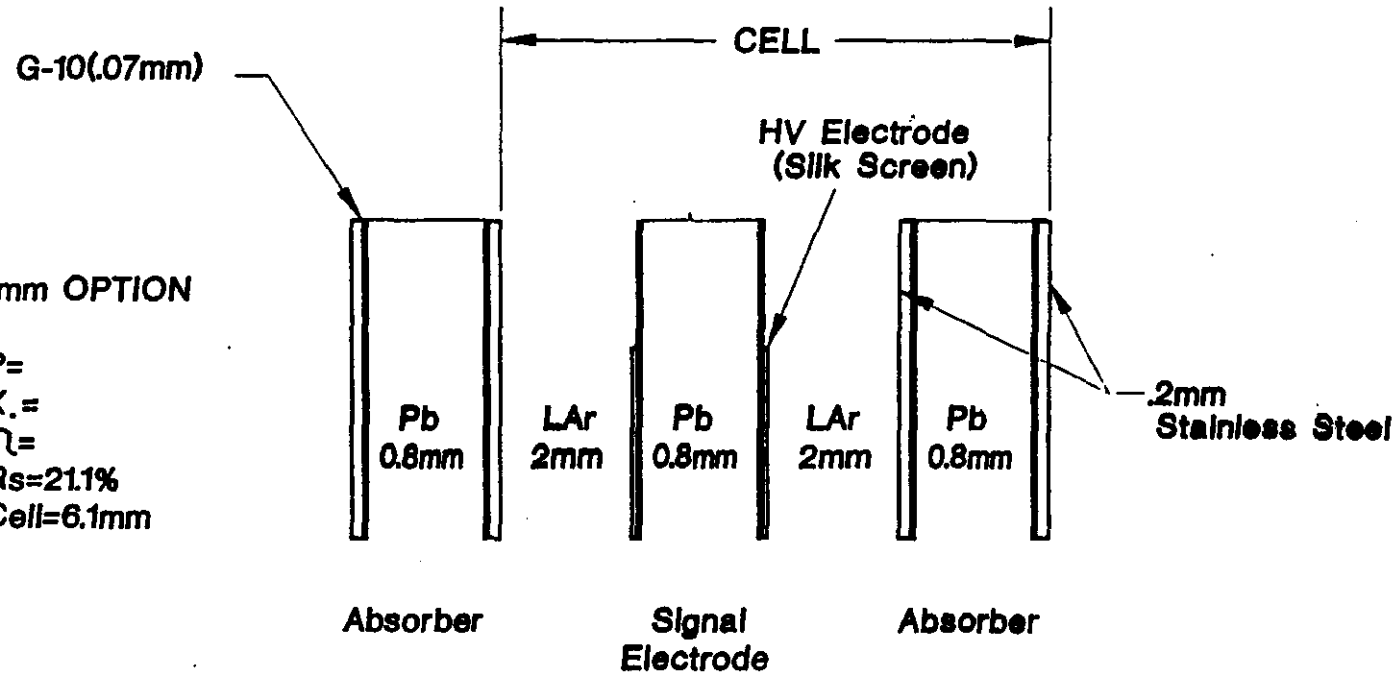
EM CONFIGURATION

A3 TESTS

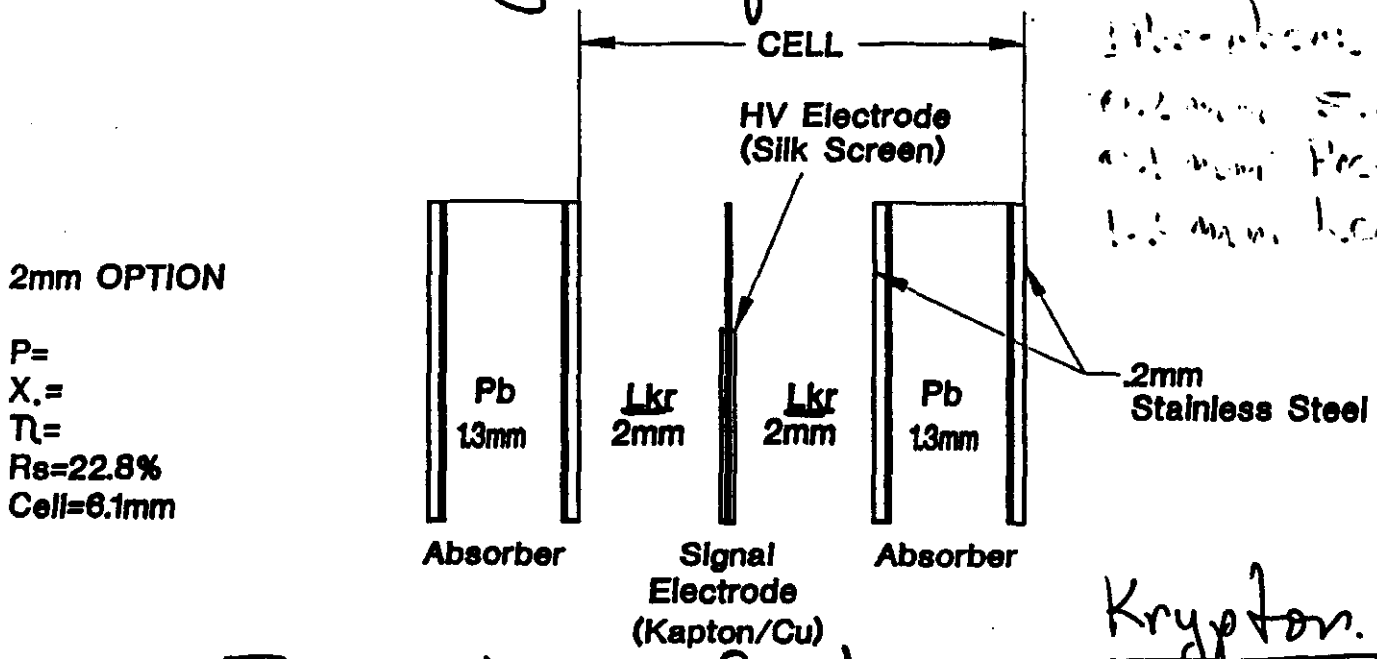
	1 mm OPTION	2 mm OPTION
ABSORBER		
Lead	0.8 mm	1.3 mm
Prepreg	2 X 0.1 mm	2 X 0.1 mm
Stainless	2 X 0.2 mm	2 X 0.2 mm
SIGNAL ELECTRODES		
Lead	0.8 mm	.....
Prepreg	2 X 0.06 mm	.....
Polysulfone	2 X 0.05 mm	.....
Kapton	.....	0.36 mm
Copper	2 X 0.04 mm	2 X 0.04 mm
Res Ink	2 X 15 um	2 X 15 um
ARGON GAP	2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

MARCH 24, 1992

EM Configuration



Sampling frequency.

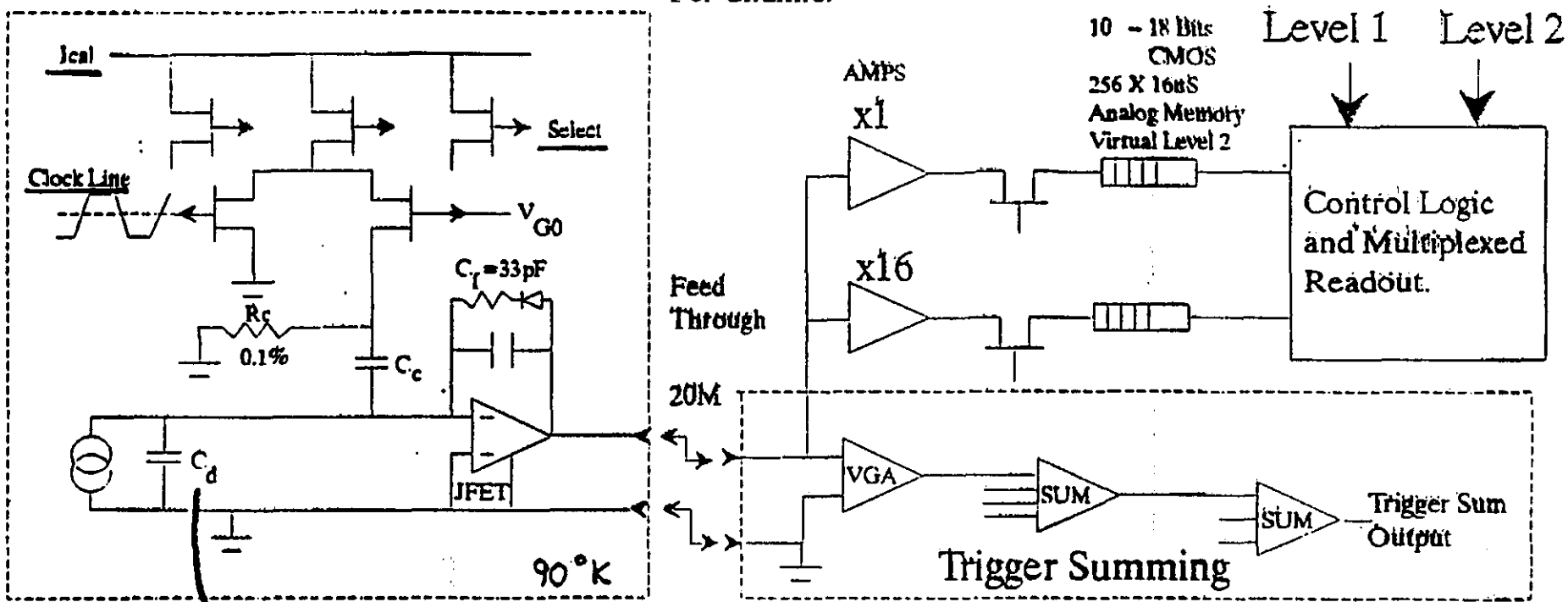


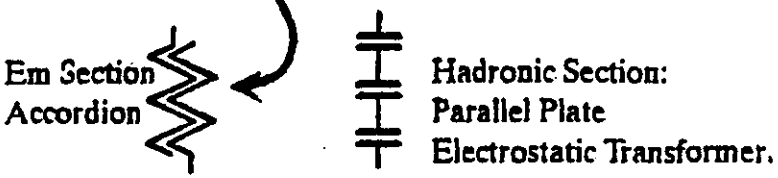
Krypton.

Sampling fraction.

Calibration System and Preamplifier

Notes:
Dynamic Range 25MeV -- 2.5 TeV
(Em) 25 uV -- 2.5 V
Per Channel





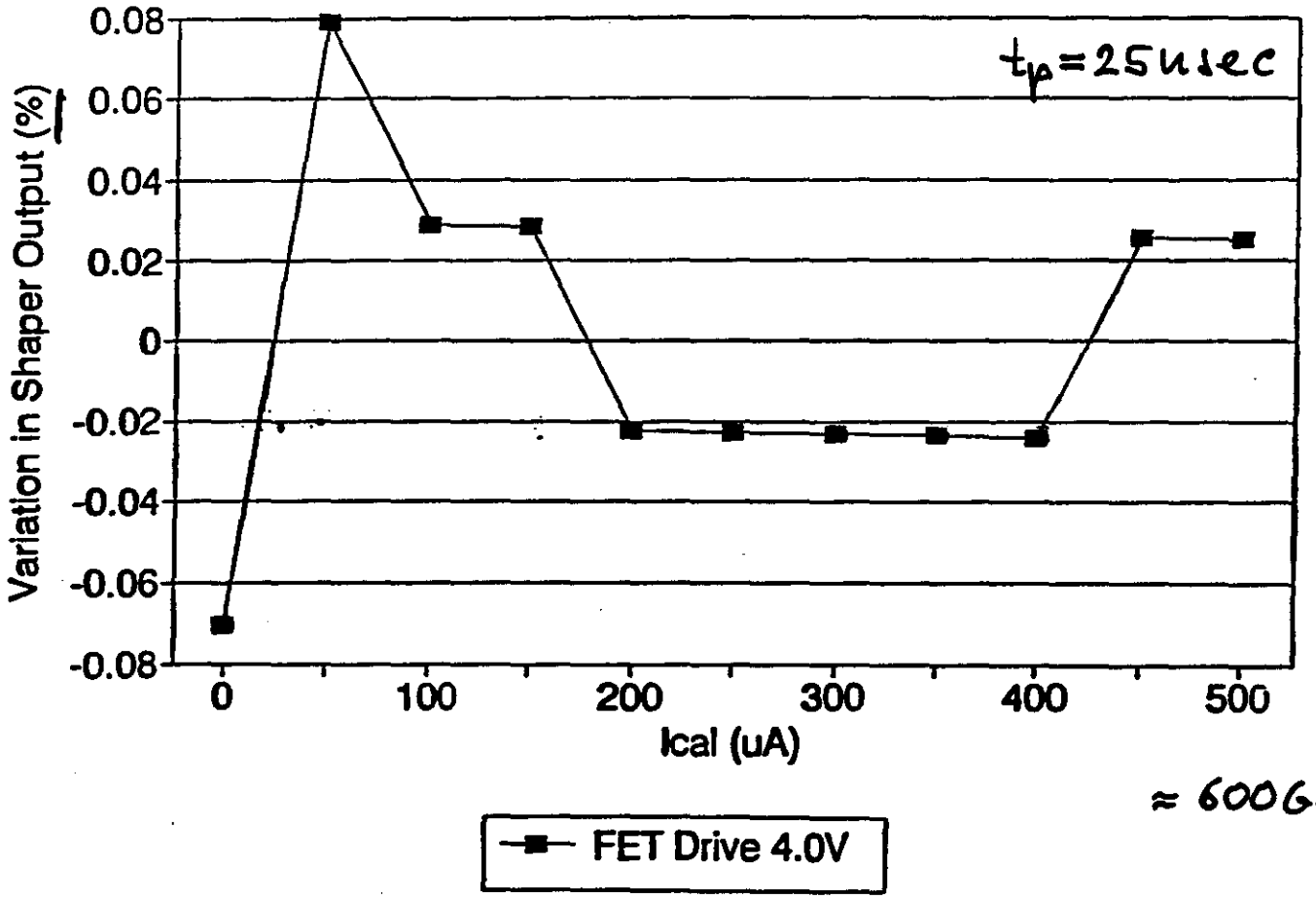
$\approx 10^{14}$ n/cm²

$\approx$ 10 - 30 M rad

0.1 - 0.2% calibration

LA Calibration - IT method

P Channel FET

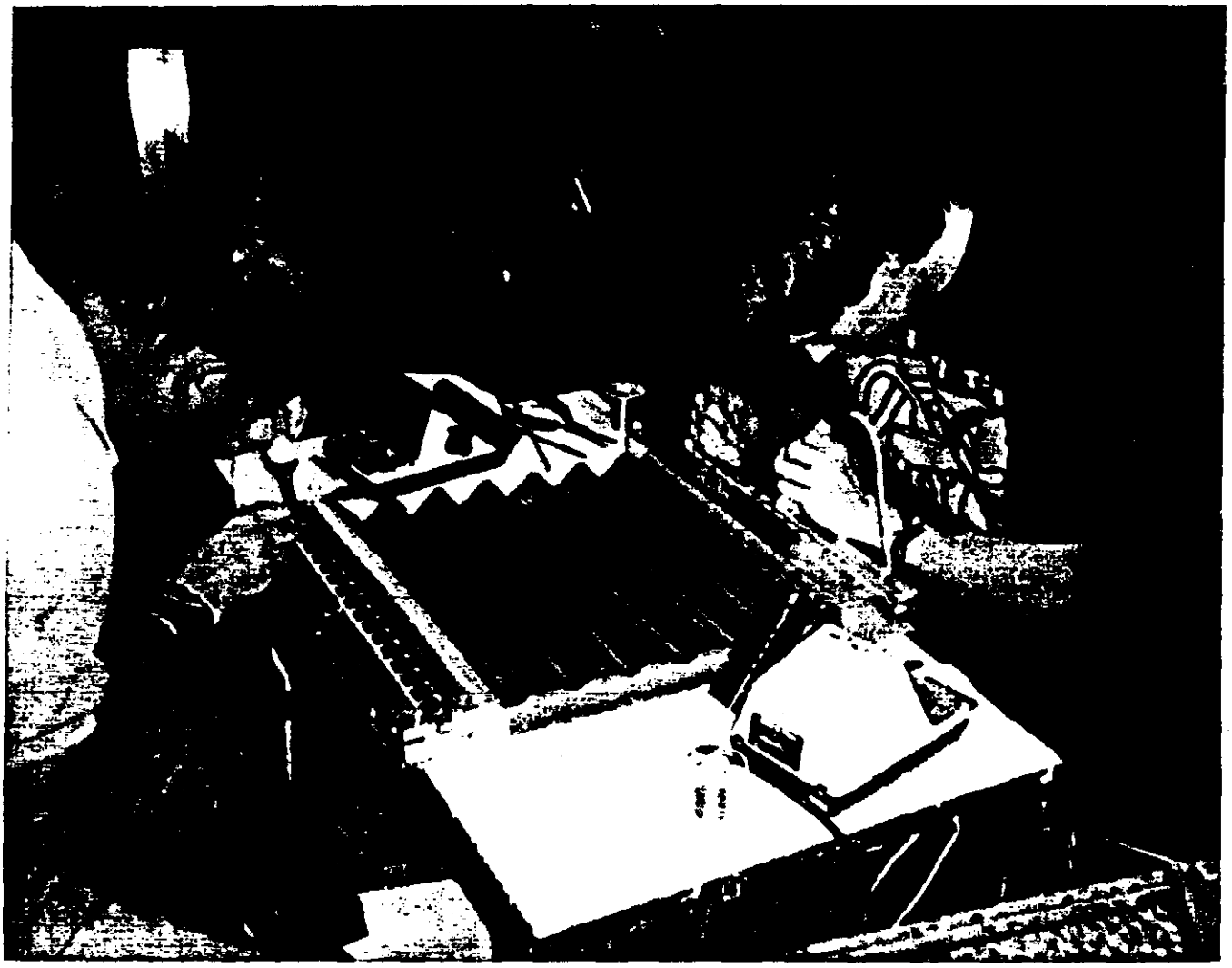


≈ 600GeV

Fig. 5

Emphasize how little if any corrections and data manipulation are needed.

You can do it !!!



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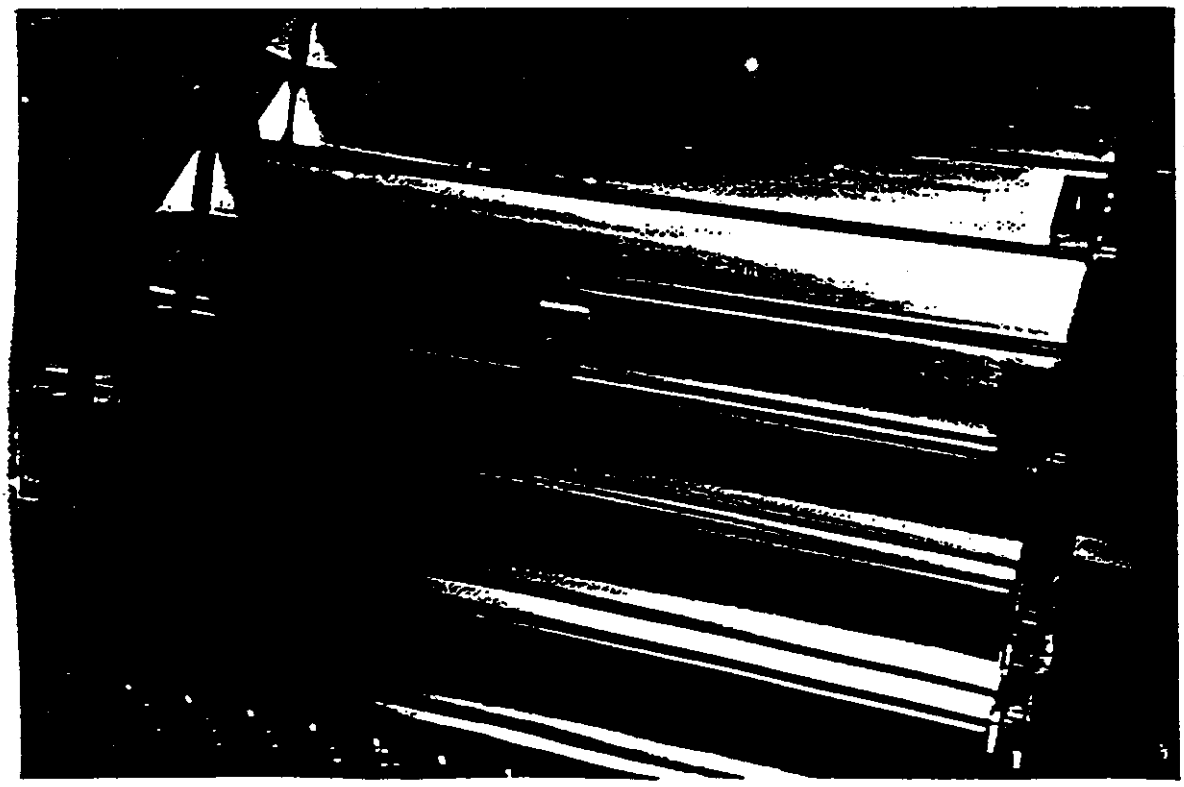
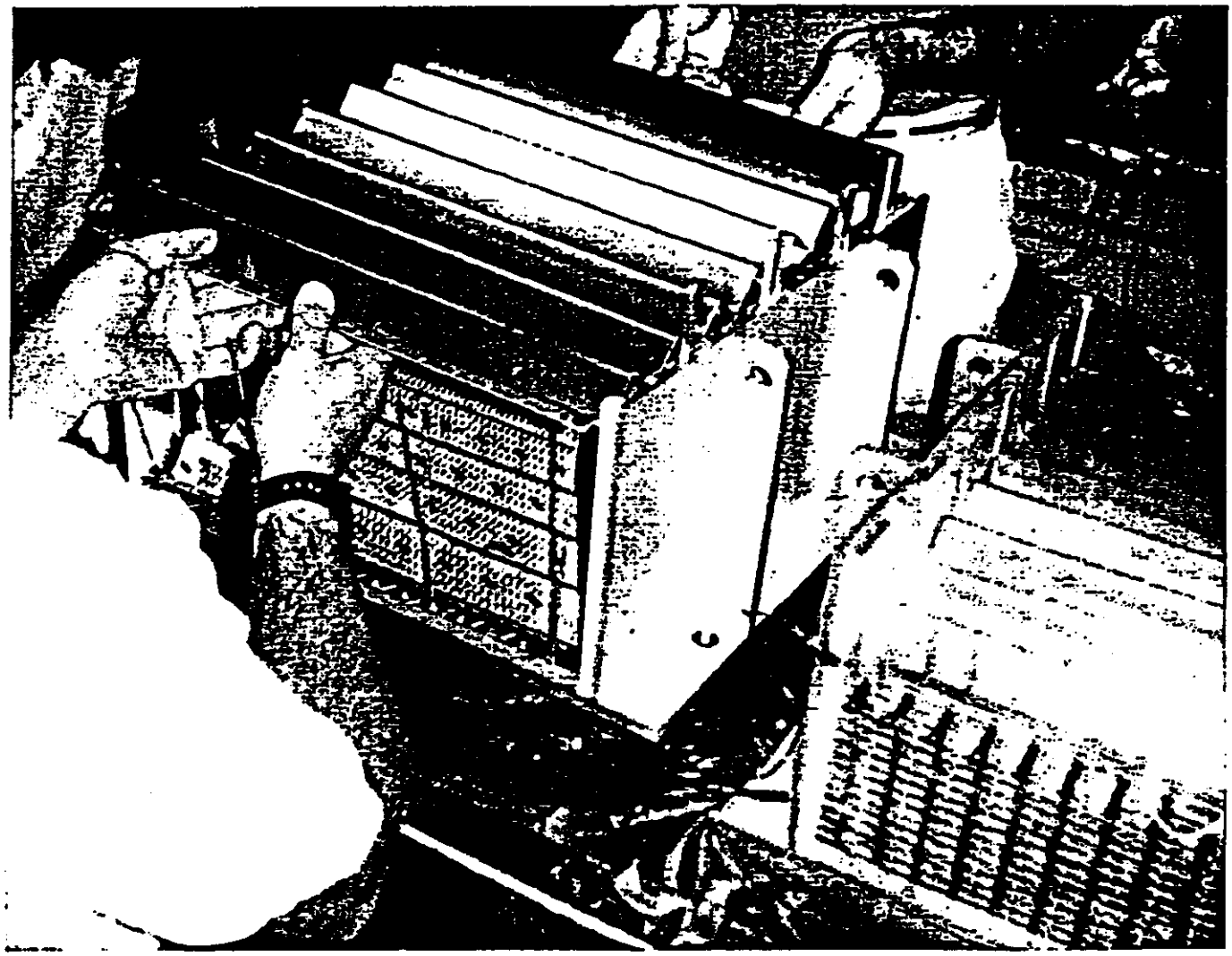
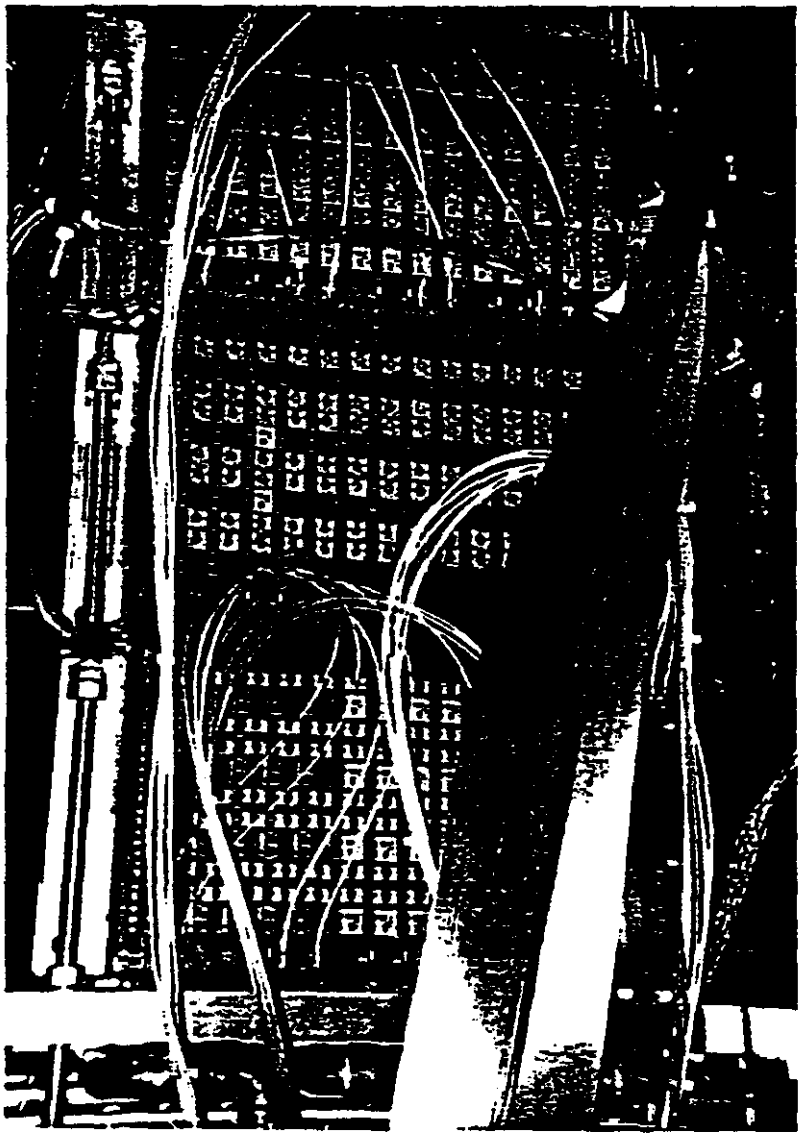
[5] Columbia University, New York, NY
[6] Oak Ridge National Laboratory, Oak Ridge, TN
[7] University of Pittsburgh, Pittsburgh, PA
[8] SUNY at Stony Brook, Stony Brook, NY
[9] Tel-Aviv University, Tel-Aviv, Israel

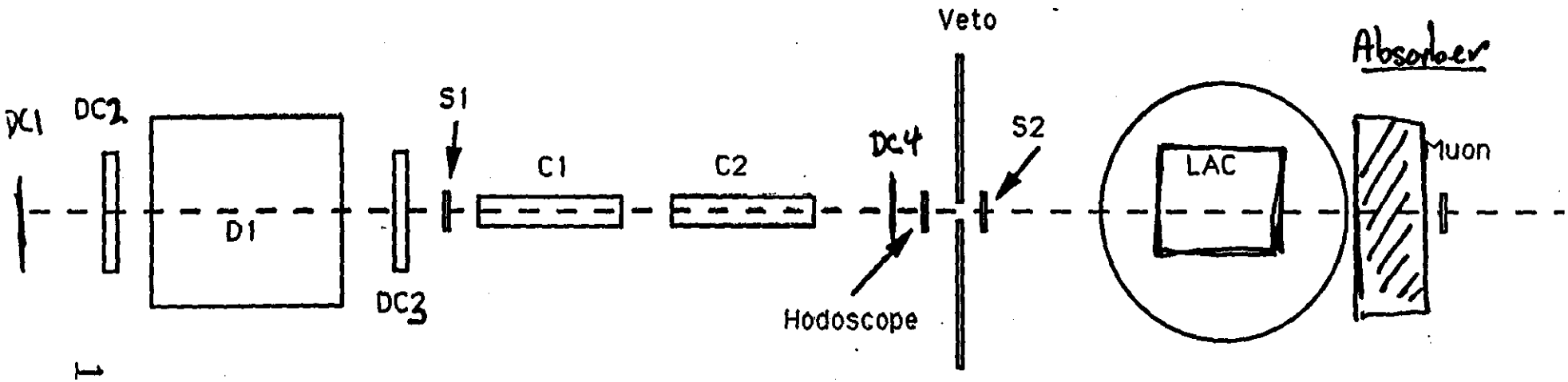
DUMBUS







A3 – Beam Line: AGS.



Beam: 0.5 Gev → 20 Gev

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

$\sim 10^6$ pps.

Krypton: 2mm.

3x3

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

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

5x5

$$\frac{\Delta E}{E} = \frac{6.90}{\sqrt{E}} \oplus \frac{85}{E} \oplus 0\%$$

$$\frac{\Delta E}{E} = \frac{6.7\%}{\sqrt{E}} \oplus \frac{85}{E} \oplus 0\%$$

Preliminary Results:
1992 BNL Test.

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

Standard L.A. (1.3 mm Pb Absorbe.)

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

$$\frac{\Delta E}{E} = \frac{8\%}{\sqrt{E}} \oplus \frac{0.140}{E} \oplus 0$$

Note: Const. term Assum to be ϕ. Noise meas. on MT Events.

$\Delta P/P$: ½ − 0.7%
1 mm L.A

$$\frac{\Delta E}{E} = \frac{7.6}{\sqrt{E}} \oplus \frac{0.140}{E} \oplus 0$$

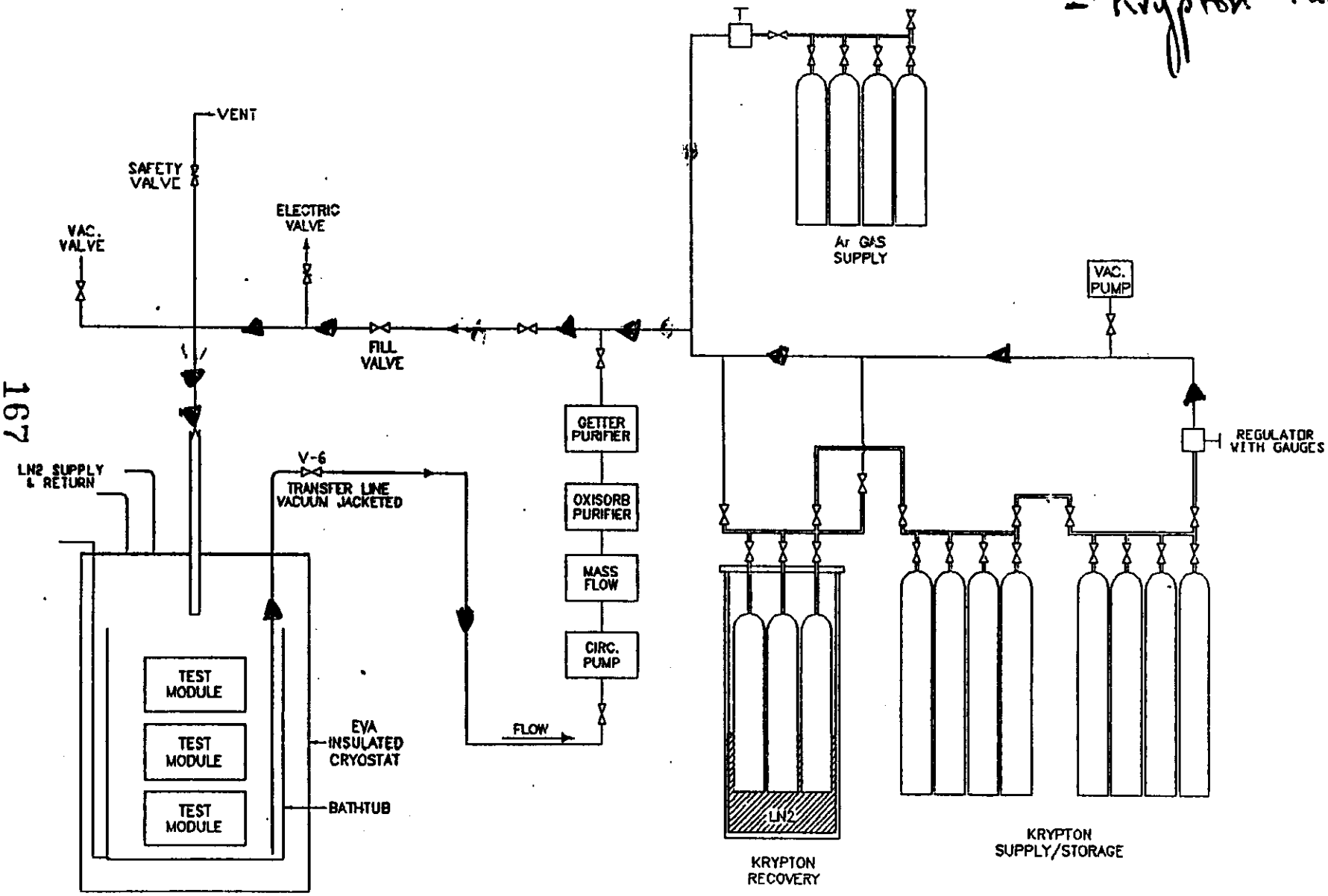
M.C. $6.25\% / \sqrt{E}$

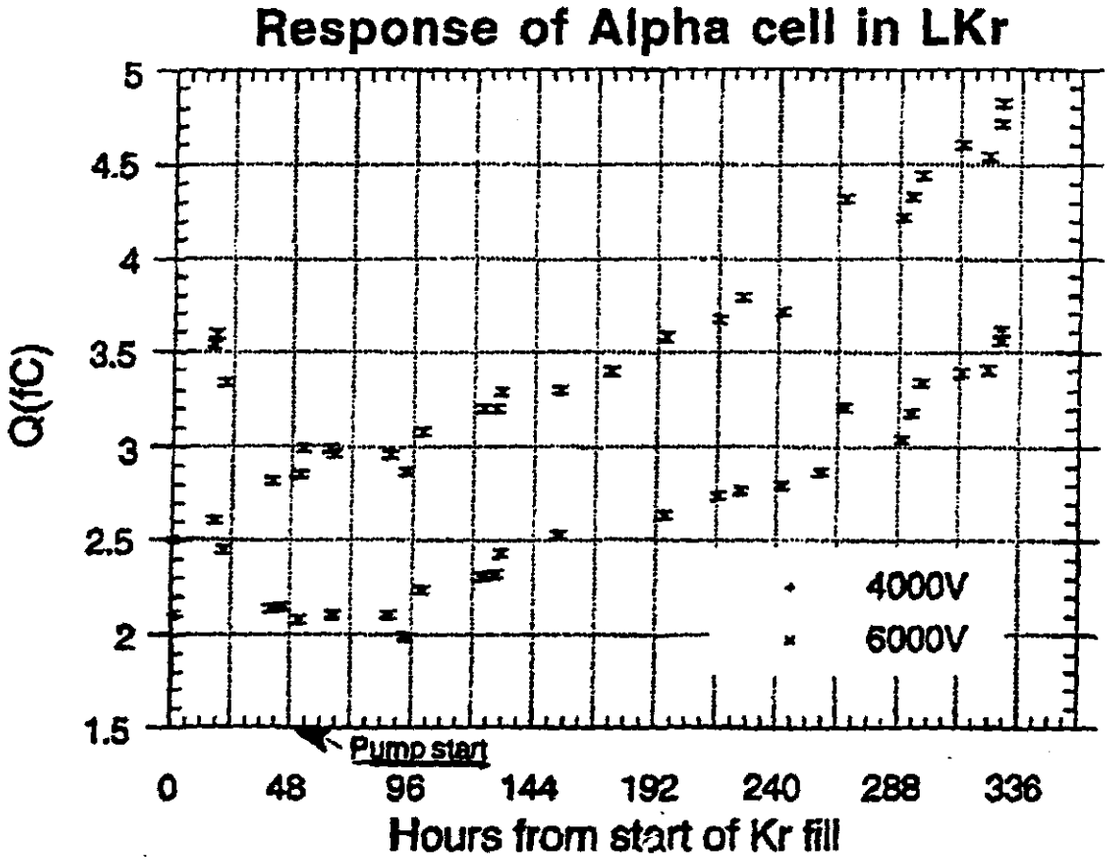
$$\frac{\Delta E}{E} = \frac{6.4}{\sqrt{E}} \oplus \frac{0.240}{E} \oplus 0$$

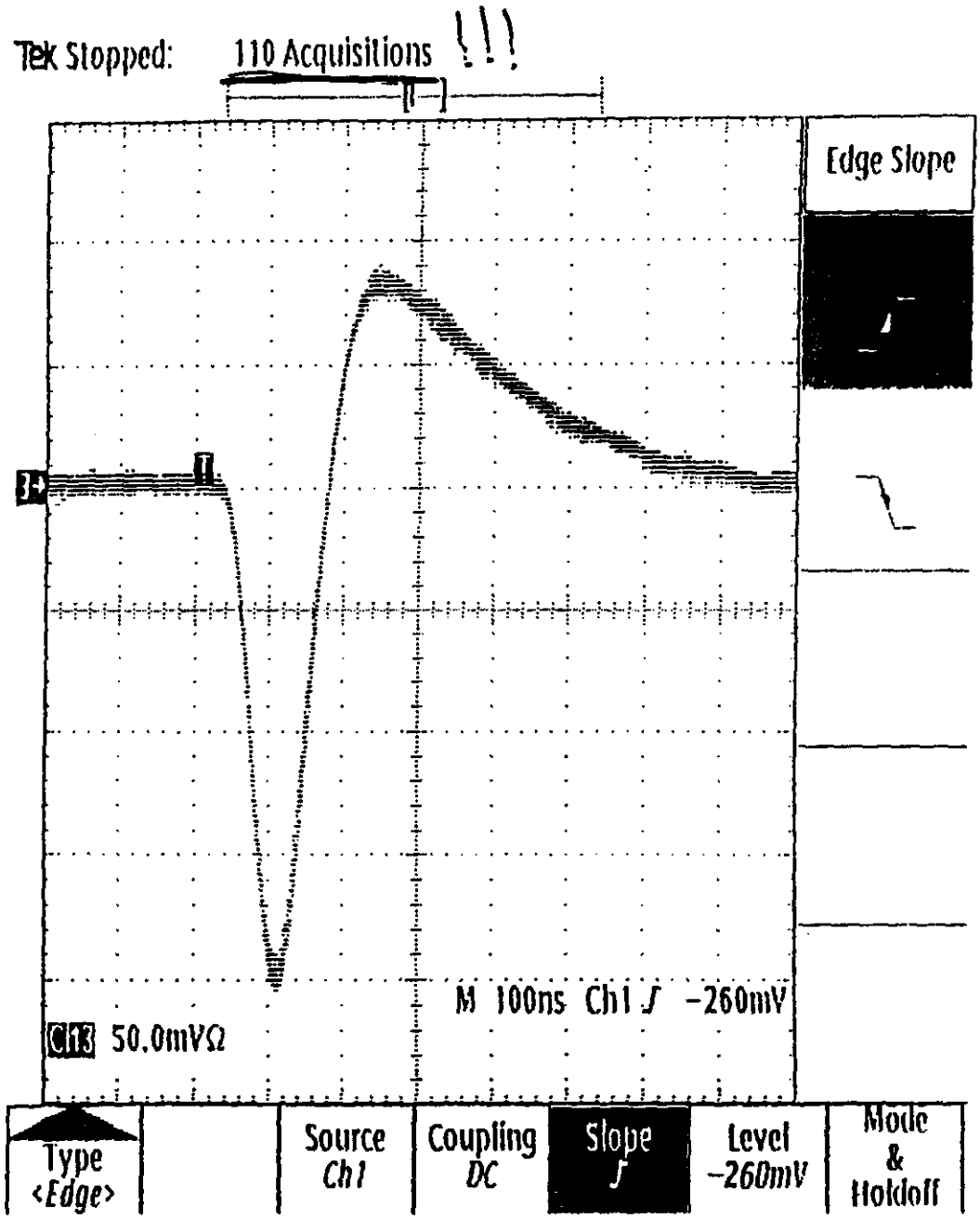
$\frac{\Delta P}{P}$: ½ − 0.7%

$$\frac{\Delta E}{E} = \frac{6}{\sqrt{E}} \oplus \frac{0.240}{E} \oplus 0$$

- Krypton fill
- Krypton Purification




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



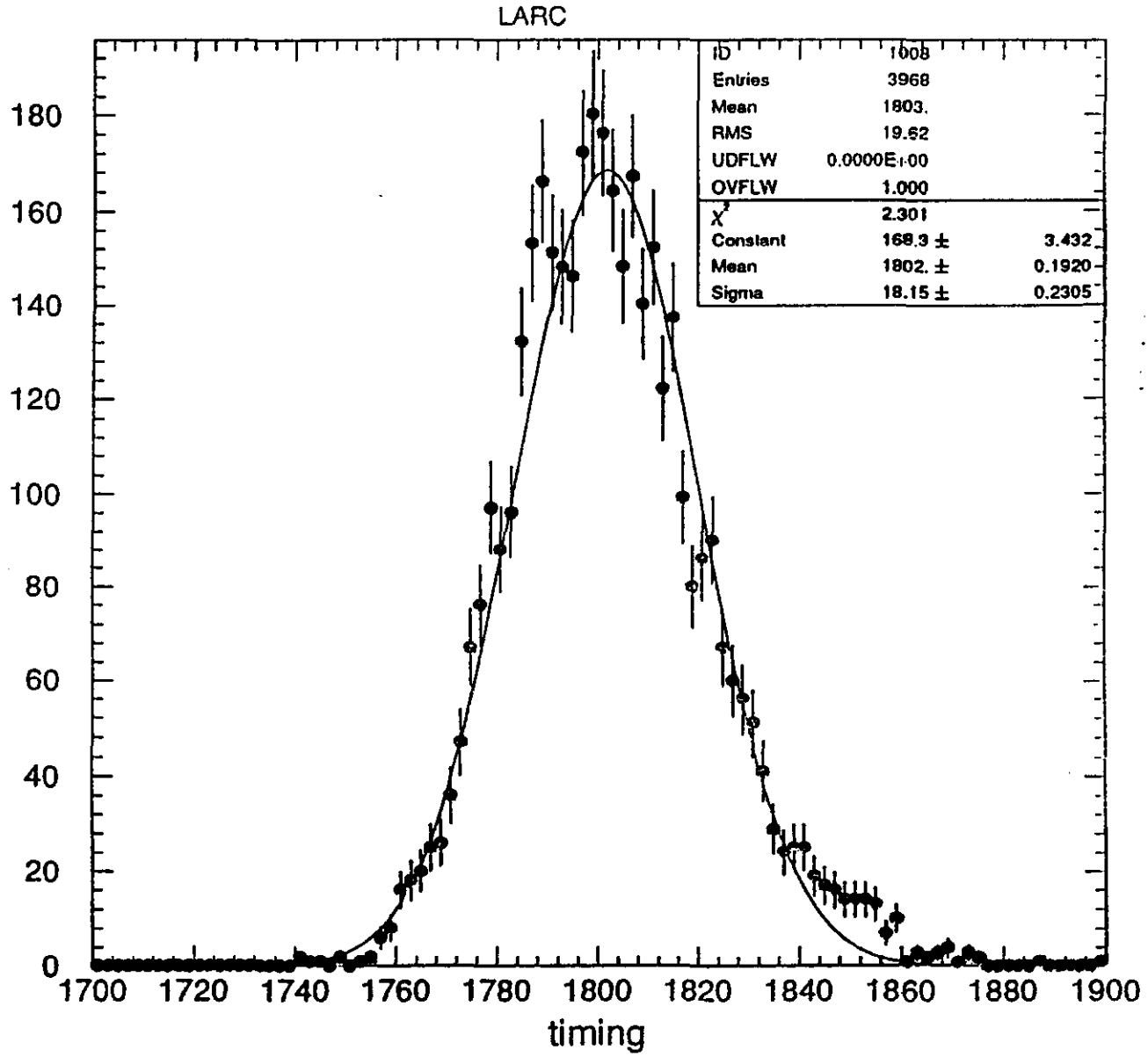
L Kr , 2 mm stack , 1.5 kV

206eV

Sum of ~150 channels

Multiple trace - variable persistence

Beam size : 2.5 x 5 cm^2

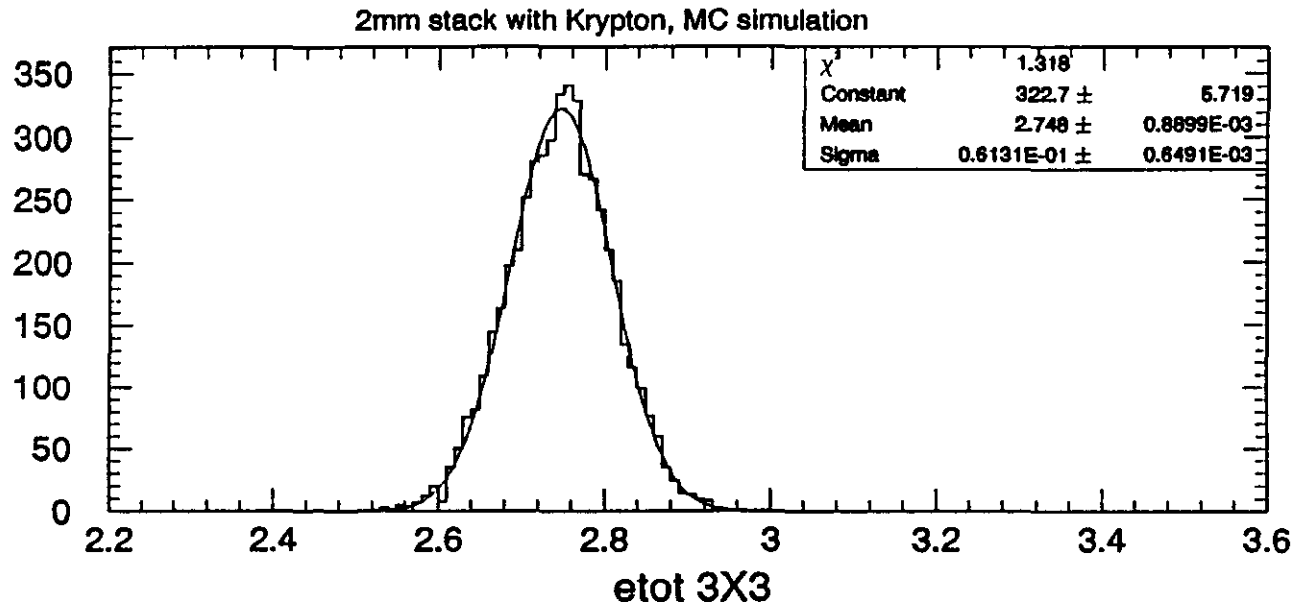


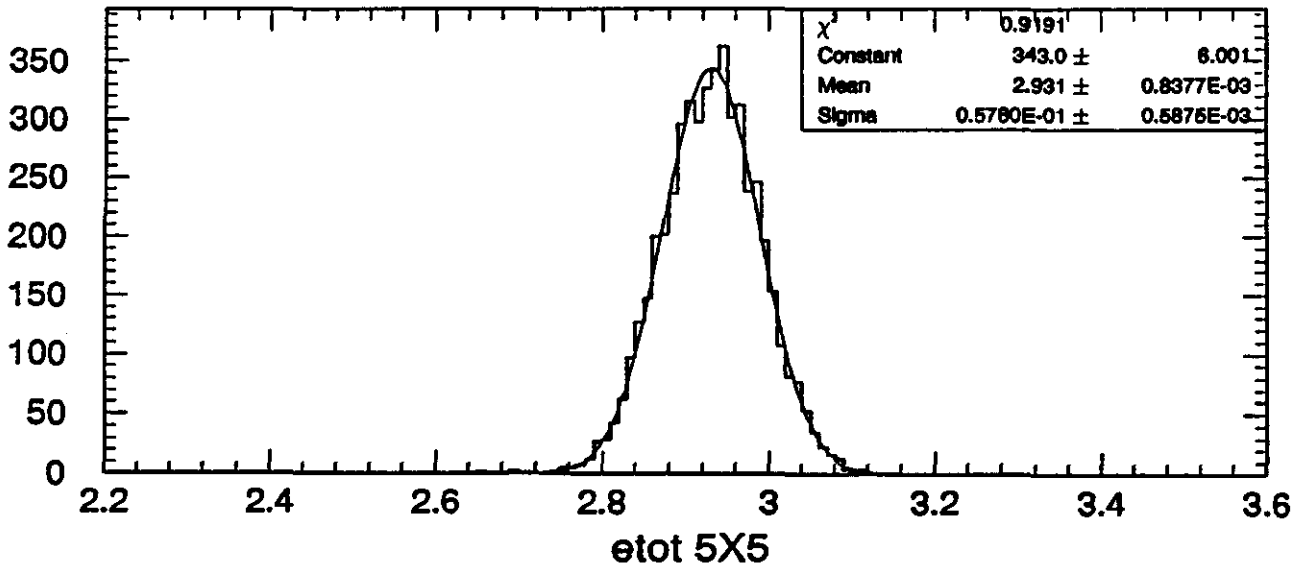
15 GeV.

50 ps/bin

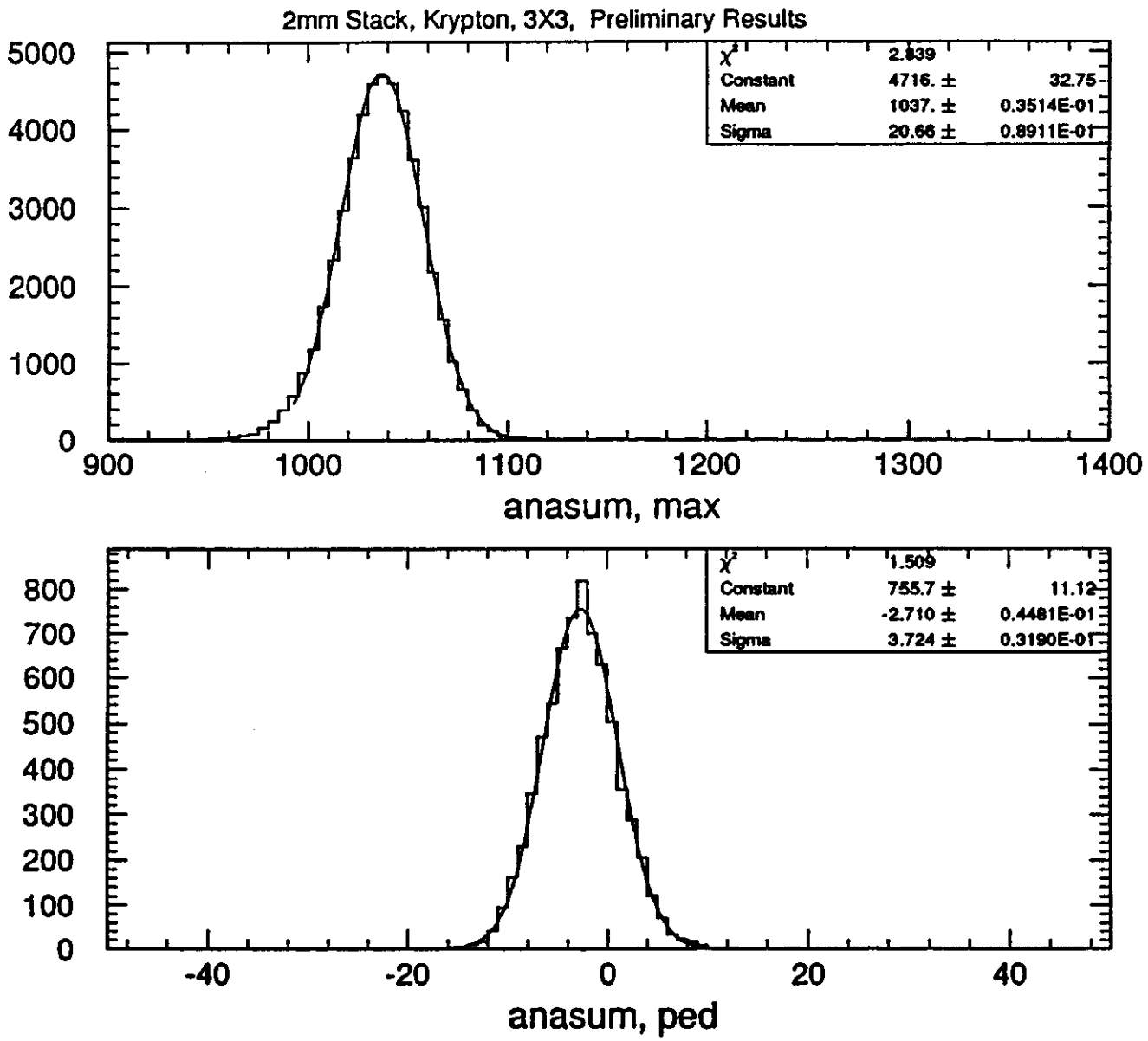
$\Delta t < 1$ ns

M.C: 3X3, 5X5 Krypton

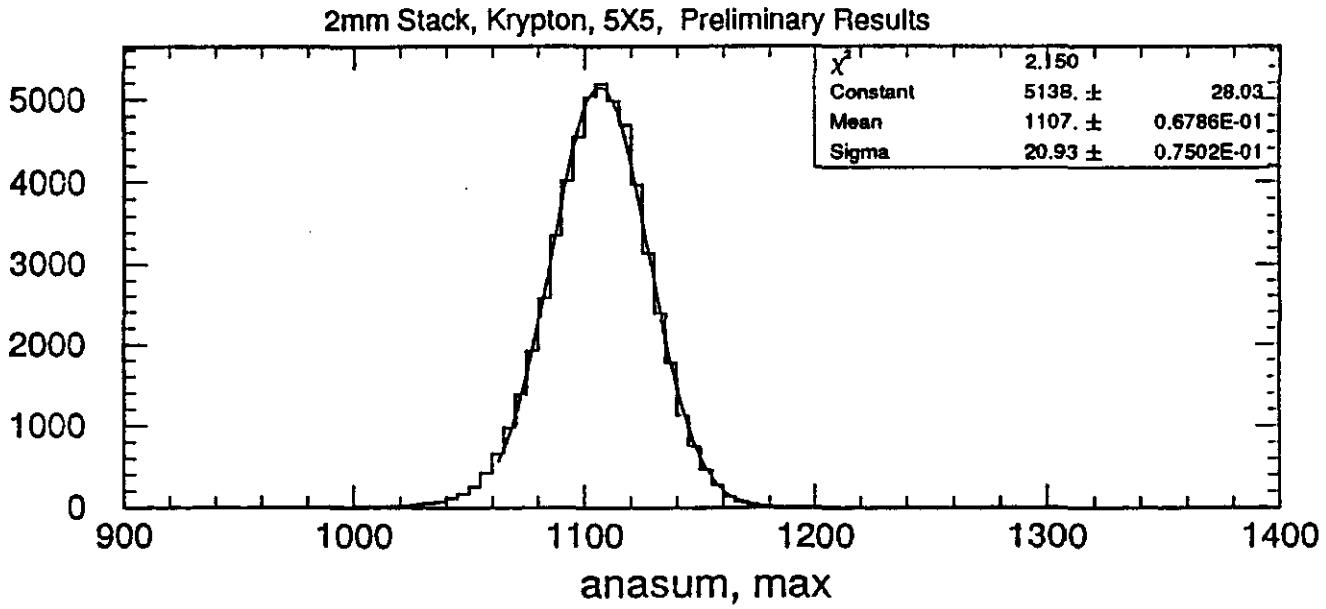


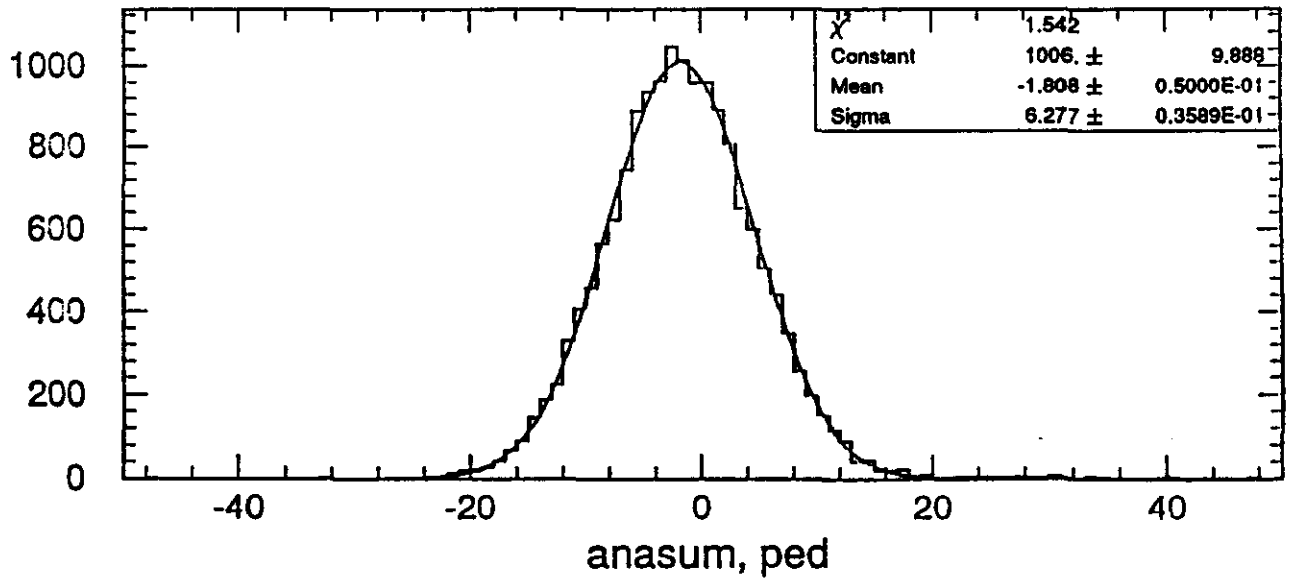


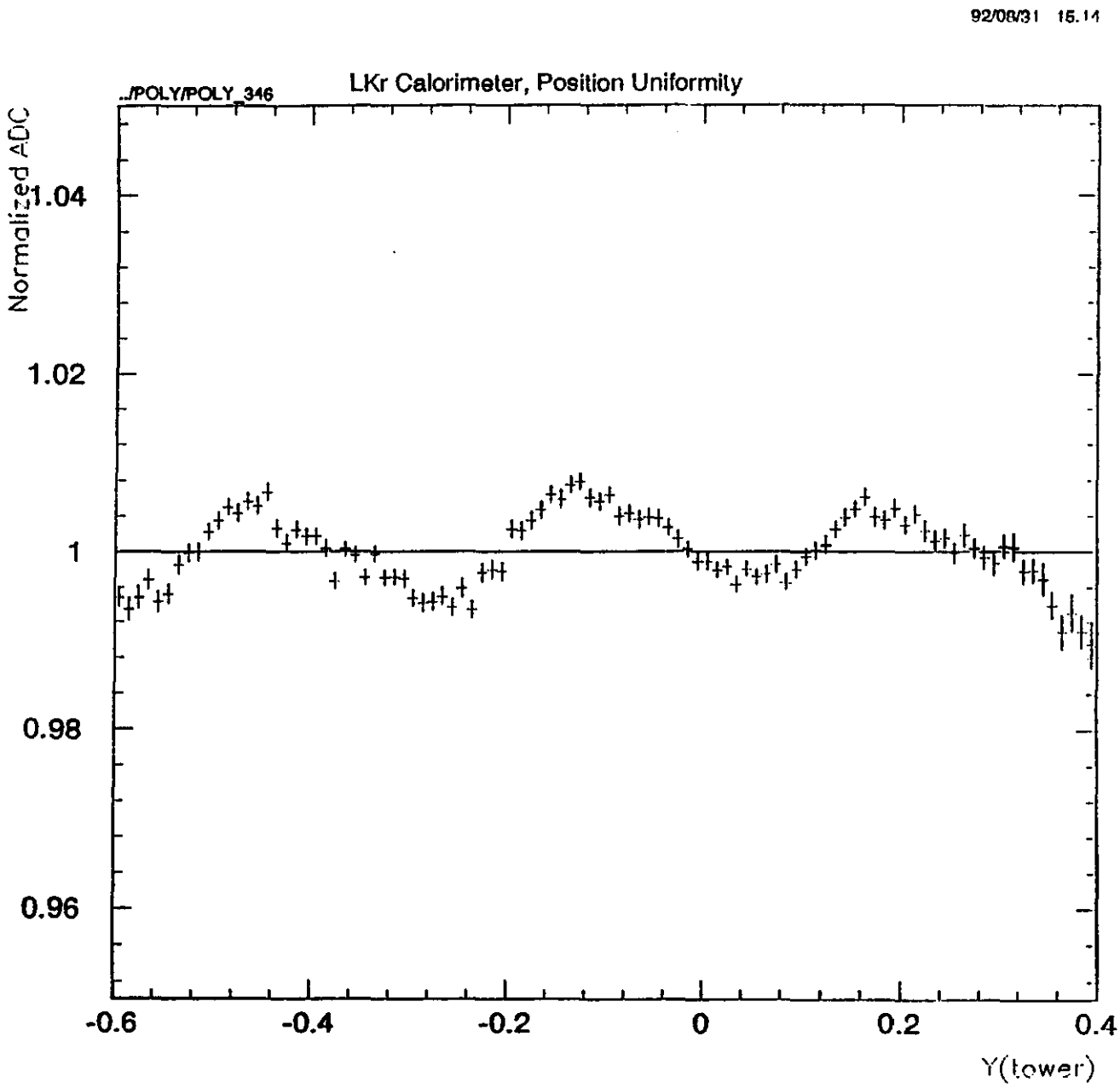
15 GeV, e, 2.2.2

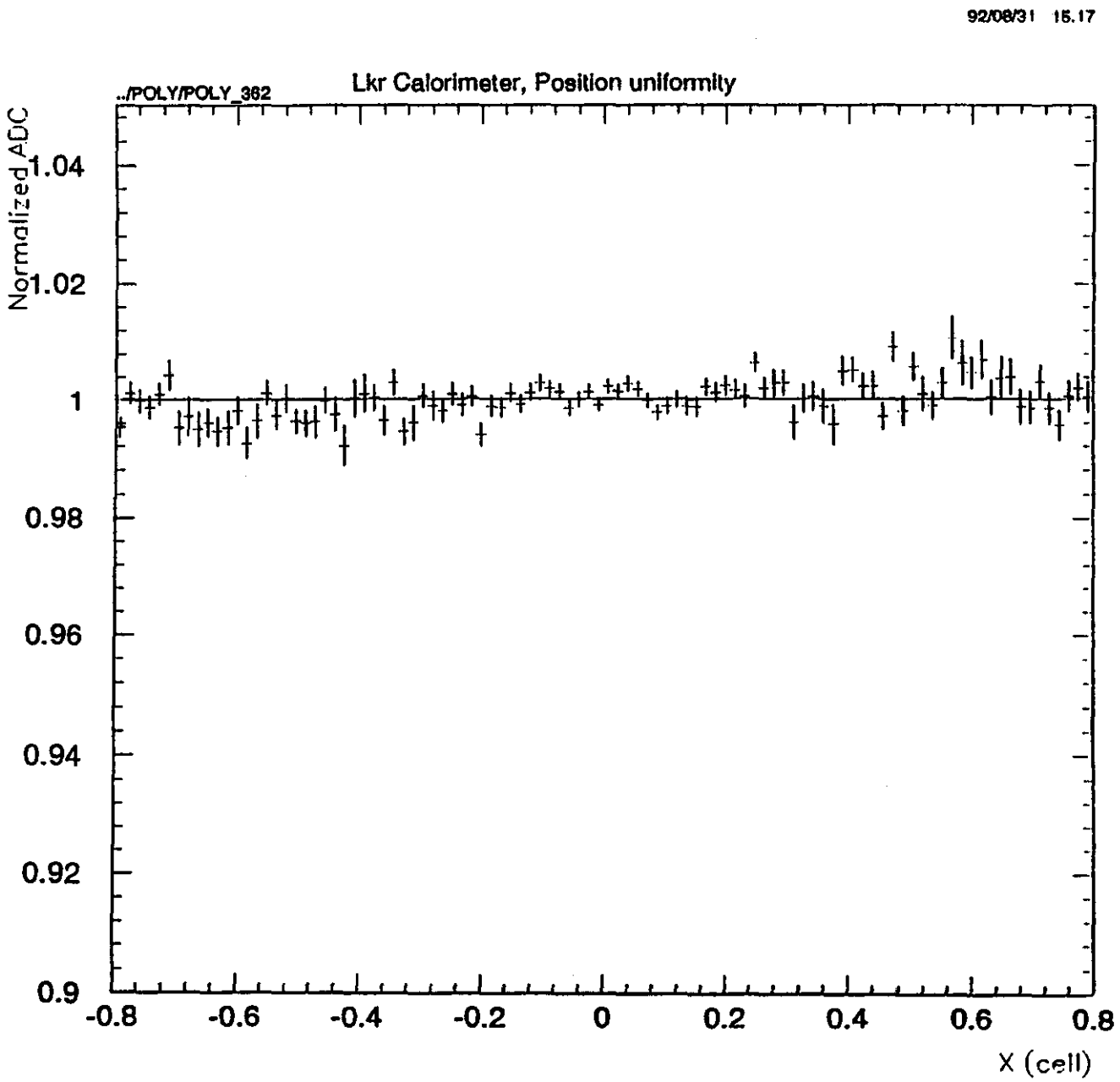

2mm Stack, Krypton, 3X3, Preliminary Results
χ^2 2.839
Constant 4716. ± 32.75
Mean 1037. ± 0.3514E-01
Sigma 20.66 ± 0.8911E-01
5000
4000
3000
2000
1000
0
900
1000
1100
1200
1300
1400
anasum, max
χ^2 1.509
Constant 755.7 ± 11.12
Mean -2.710 ± 0.4481E-01
Sigma 3.724 ± 0.3190E-01
800
700
600
500
400
300
200
100
0
-40
-20
0
20
40
anasum, ped

15 GeV, e⁻: [illegible]

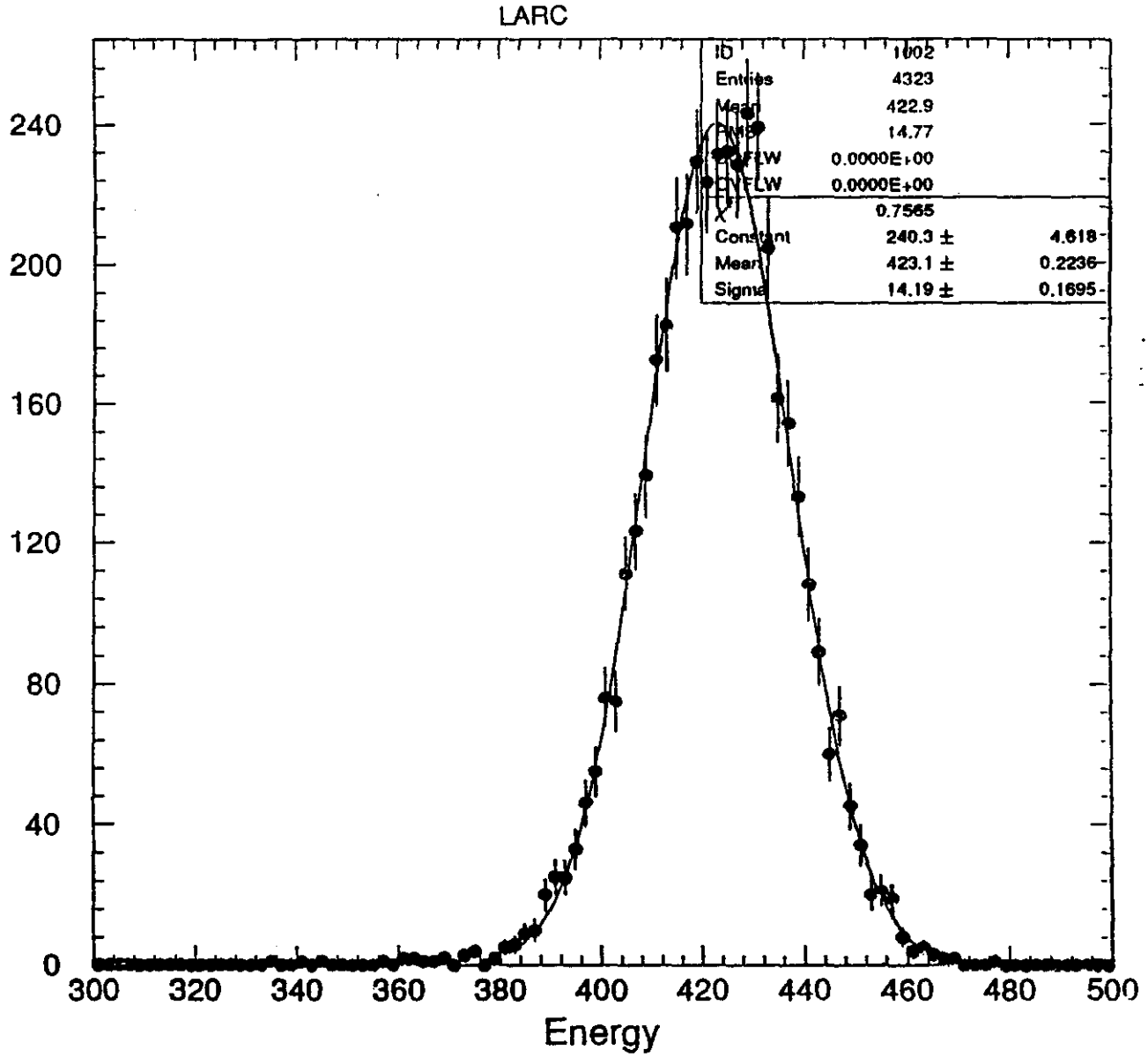

2mm Stack, Krypton, 5X5, Preliminary Results
χ^2 2.150
Constant 5138. ± 28.03
Mean 1107. ± 0.6786E-01
Sigma 20.93 ± 0.7502E-01
5000
4000
3000
2000
1000
0
900
1000
1100
1200
1300
1400
anasum, max


χ^2 1.542
Constant 1006. ± 9.888
Mean -1.808 ± 0.5000E-01
Sigma 6.277 ± 0.3589E-01
1000
800
600
400
200
0
-40
-20
0
20
40
anasum, ped


92/08/31 15.14
../POLY/POLY_346
LKr Calorimeter, Position Uniformity
Normalized ADC
1.04
1.02
1
0.98
0.96
-0.6
-0.4
-0.2
0
0.2
0.4
Y(tower)


92/08/31 15.17
../POLY/POLY_362
Lkr Calorimeter, Position uniformity
Normalized ADC
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
X (cell)

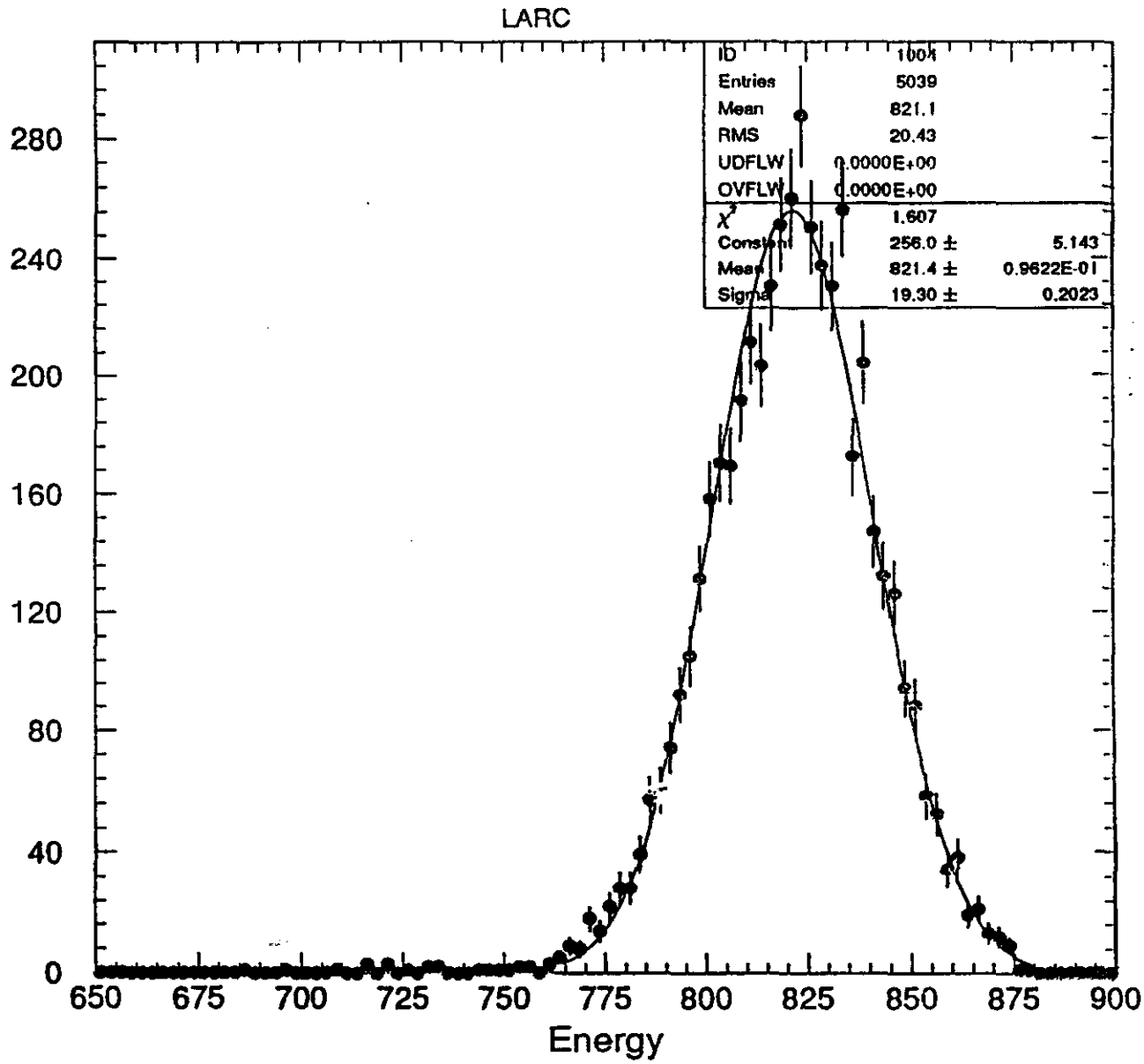
X



5 Gev.

$(3.04 \pm 0.021)\%$ $\quad \frac{\Delta P}{P} = \frac{1}{2}\%$ $\quad (3.00 \pm 0.021)\%$

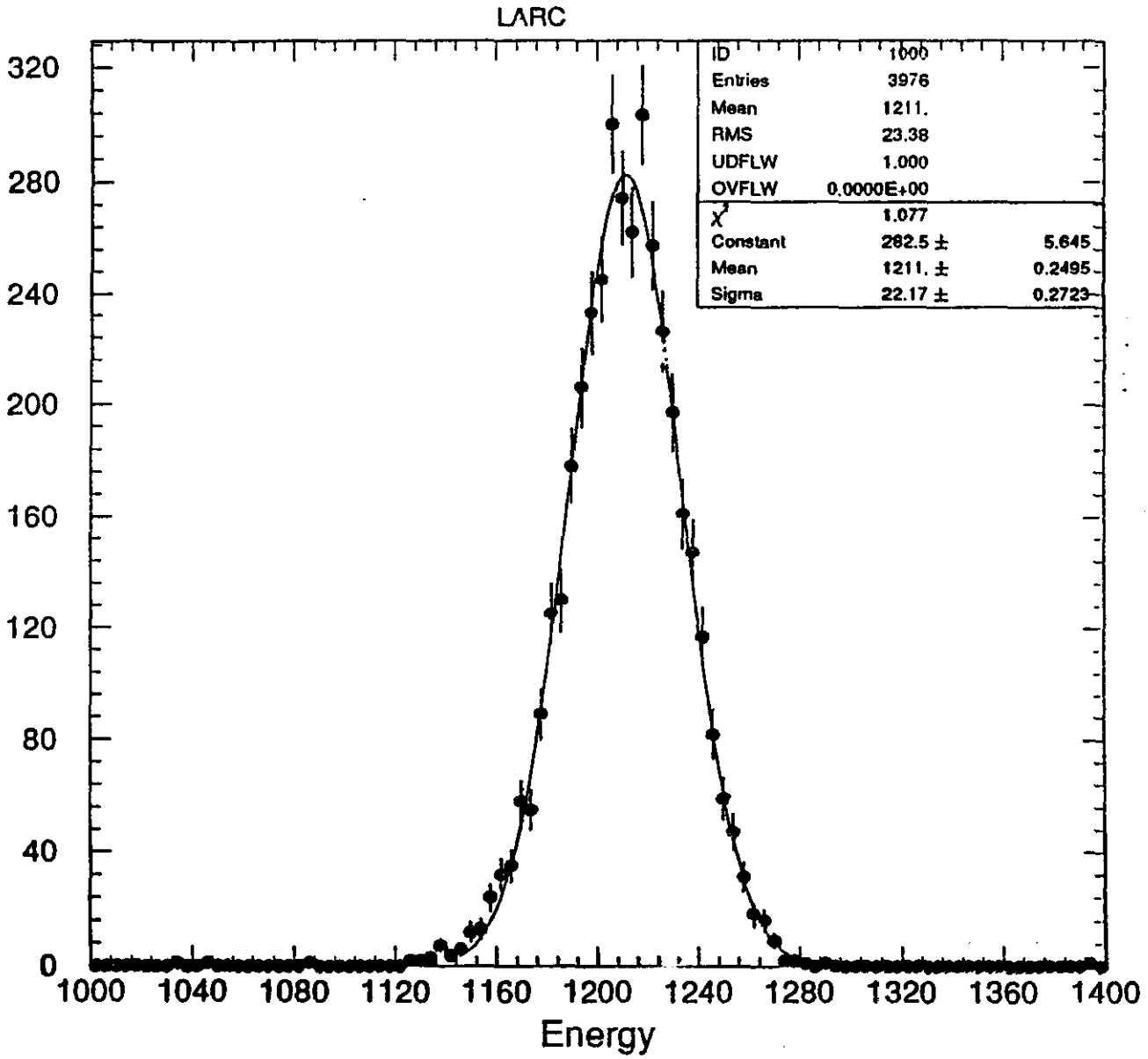
$6.8\%/\sqrt{E} + \frac{0.08}{E}$ $\quad$ $6.7\%/\sqrt{E} + \frac{0.08}{E}$



10 Gev.

$(2.23 \pm 0.023)\%$ $\frac{\Delta P}{P} = 1.1\%$ $(2.12 \pm 0.013)\%$

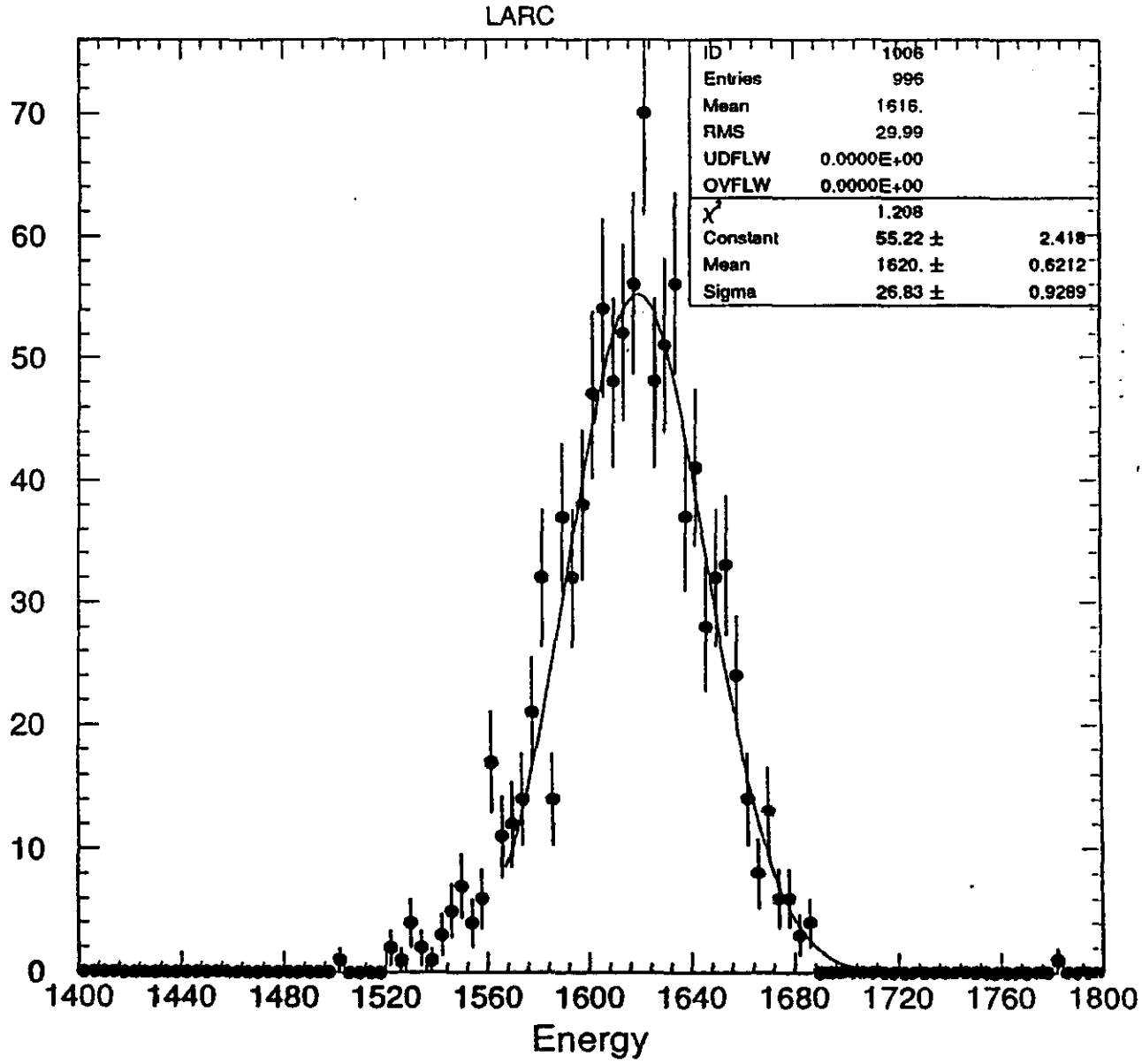
$7.05/\sqrt{E} + \frac{0.08}{E}$ 177 $6.86/\sqrt{E} + \frac{0.08}{E}$



15 GeV.

$(1.74 \pm 0.021)\%$ $\frac{\Delta P}{P} = 1.1\%$ $(1.61 \pm 0.21)\%$

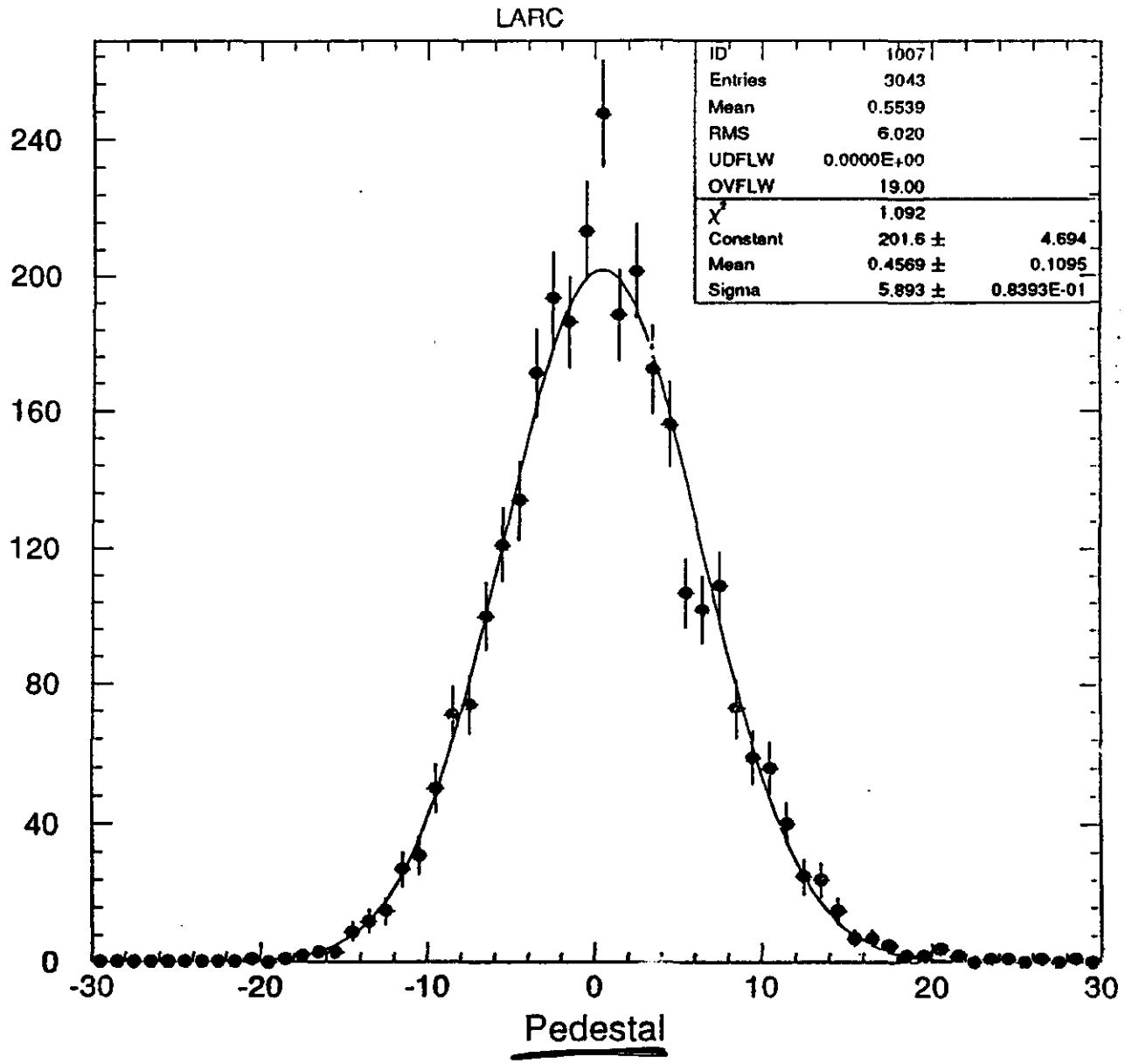
$6.8\%/\sqrt{E} + \frac{.08}{E}$ $\frac{6.54}{\sqrt{E}} + \frac{0.08}{E}$

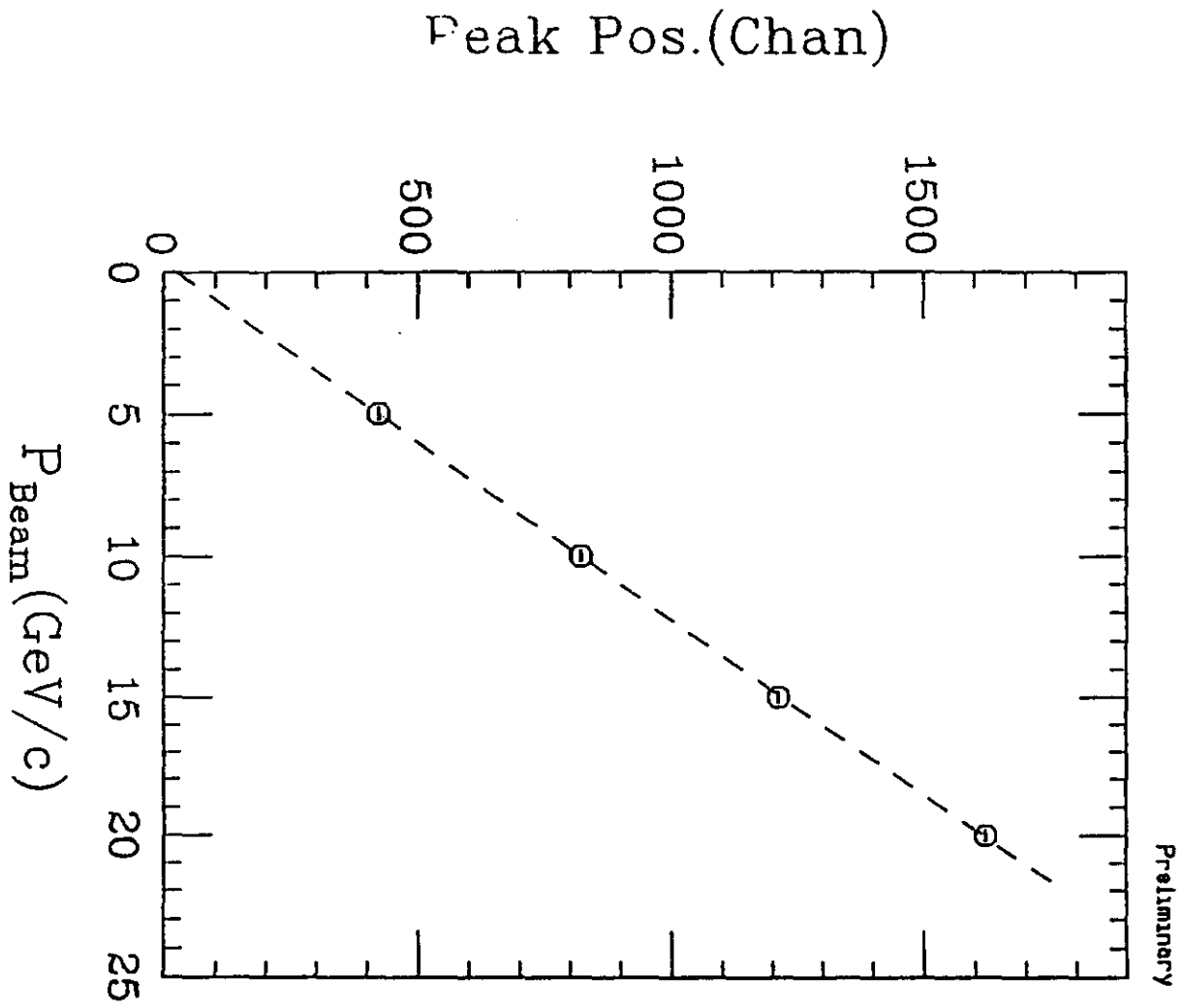


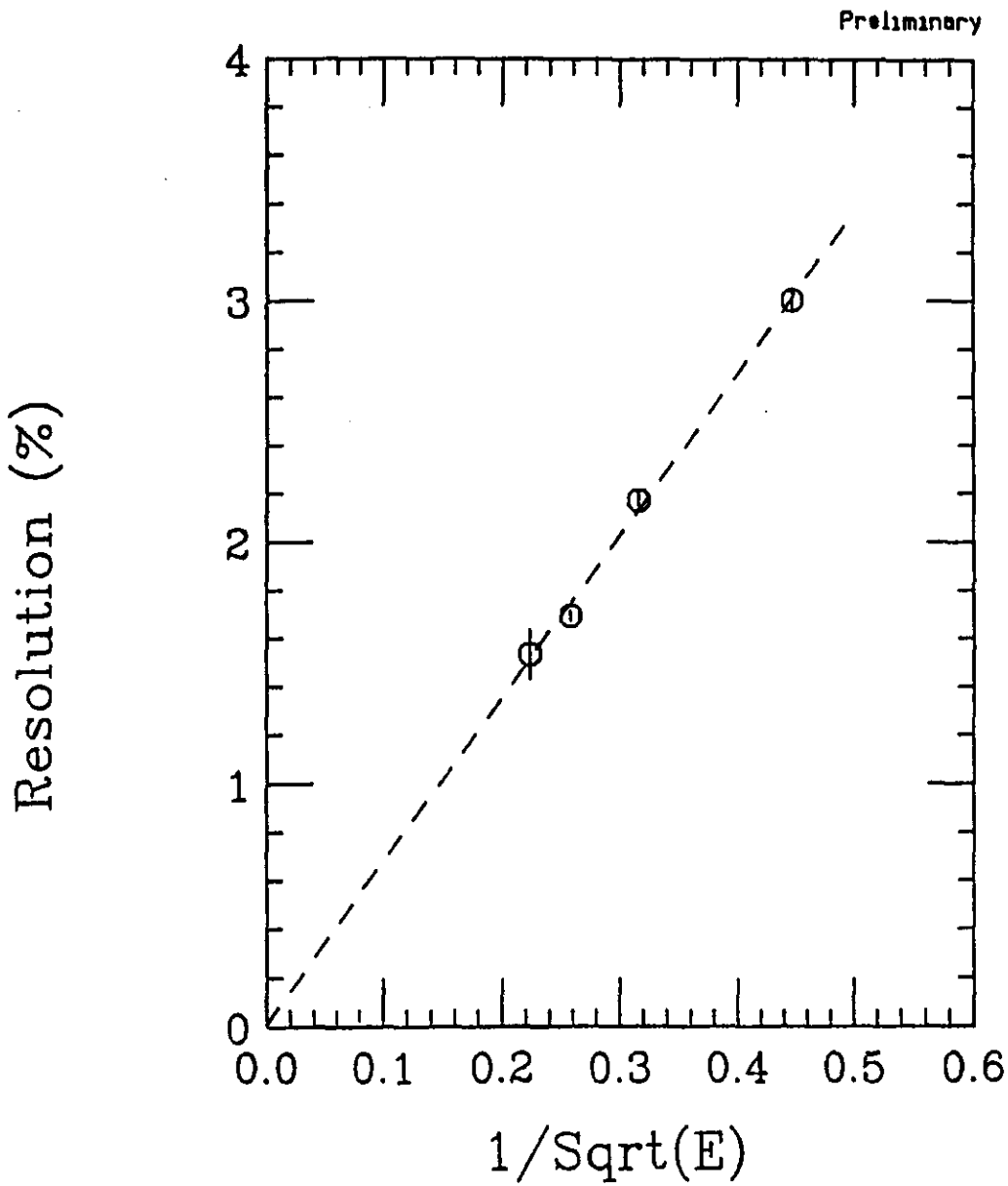
20 Gev

(1.61 ± 0.1) % $\frac{\Delta p}{p} = 1\frac{1}{2}\%$ (1.53 ± 0.1) %

$7.2\%/\sqrt{E} + \frac{0.08}{E}$ $\frac{6.84}{\sqrt{E}} + \frac{0.08}{E}$


LARC
ID 1007
Entries 3043
Mean 0.5539
RMS 6.020
UDFLW 0.0000E+00
OVFLW 19.00
χ^2 1.092
Constant 201.6 ± 4.694
Mean 0.4569 ± 0.1095
Sigma 5.893 ± 0.8393E-01
240
200
160
120
80
40
0
-30
-20
-10
0
10
20
30
Pedestal


Preliminary
1500
1000
500
0
Peak Pos.(Chan)
0
5
10
15
20
25
P_{Beam}(GeV/c)



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

$$c = (0.0 \pm 0.2)\%$$

$$\frac{b}{E} = 0.08\ \mathrm{GeV}/E$$

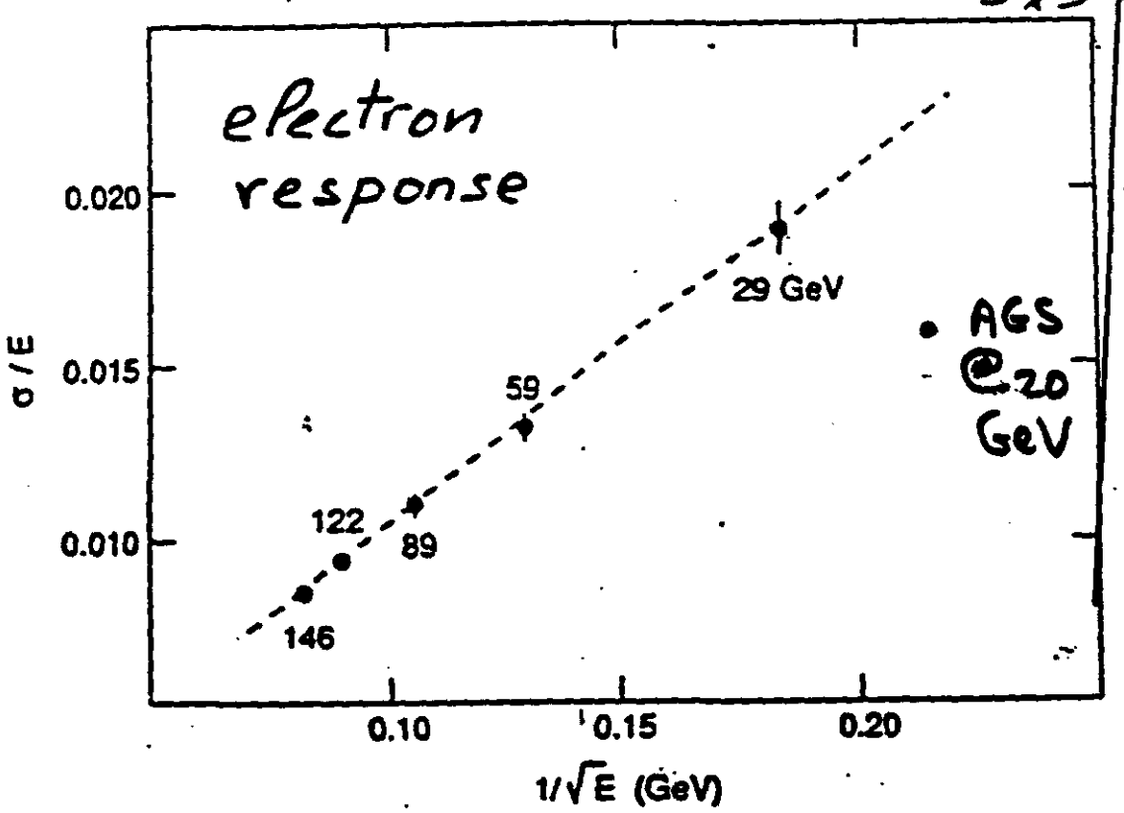
$$\frac{a}{\sqrt{E}} = \frac{(6.72 \pm 0.35)\%}{\sqrt{E}}$$

Energy Resolution

RD3

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

5x5 cluster



▲ 100 ns readout, '90 data

• AGS @ 20 GeV

(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

Energy Resolution $\sigma/\sqrt{E}$		
Stack	Measurement*	Monte Carlo
1 mm Ar	6.1 - 5.8	6.25
2 mm Ar	7.5 - 7.8	7.3
2 mm Kr	6.3 - 6.9	6.3

After
subtracting beam spread of 0.5-0.7%

Sept. 2/92

FIRST LOOK AT LAr/LKr Testbeam Data Taken with NEWS Sampling Electronics

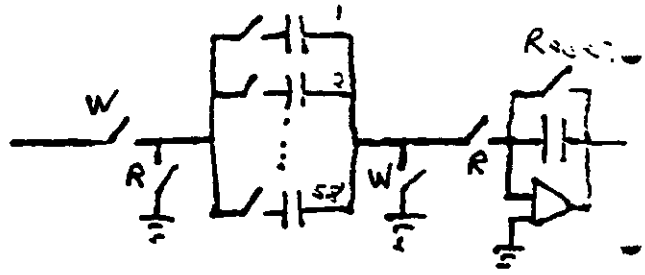
→ 192 channels of custom electronics which sample I/P signal every 18 ns and digitize samples for triggered evts with 12-bit ADCs.

→ took ~100k 5, 10, 15 GeV electron triggers (+ ≤20k 20 GeV) with 2 mm stack LKr HV = 1.5 kV

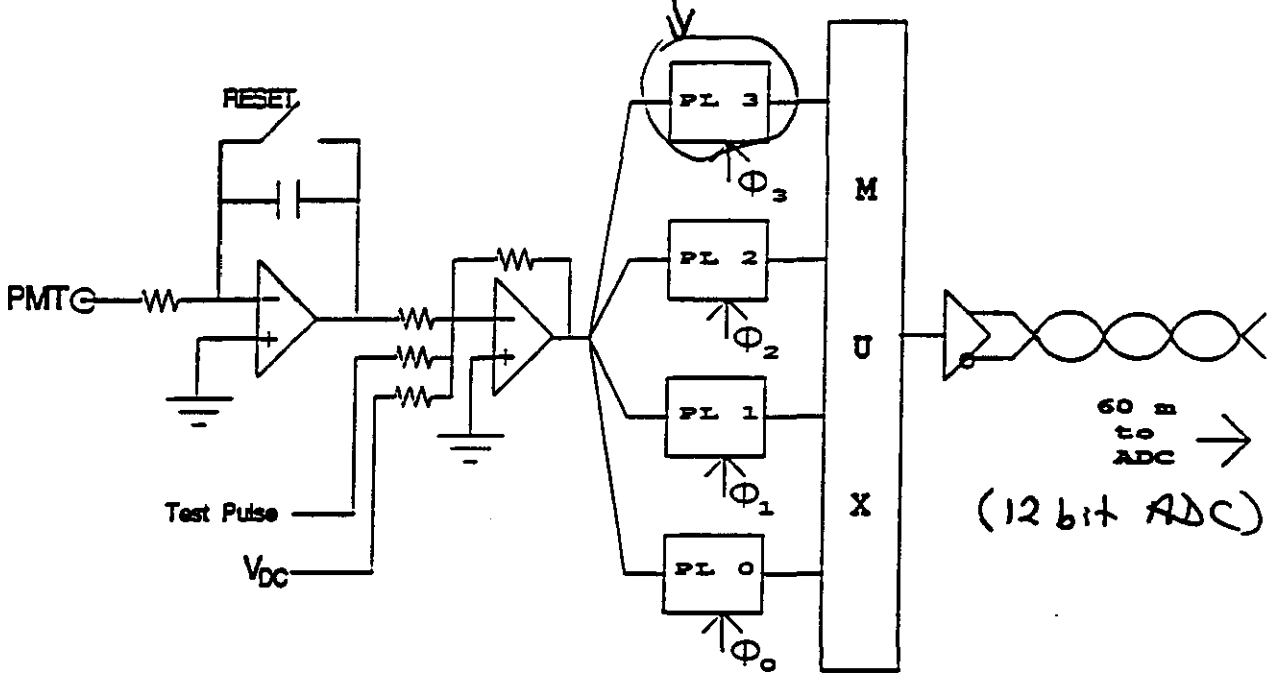
(+ some LAr data)

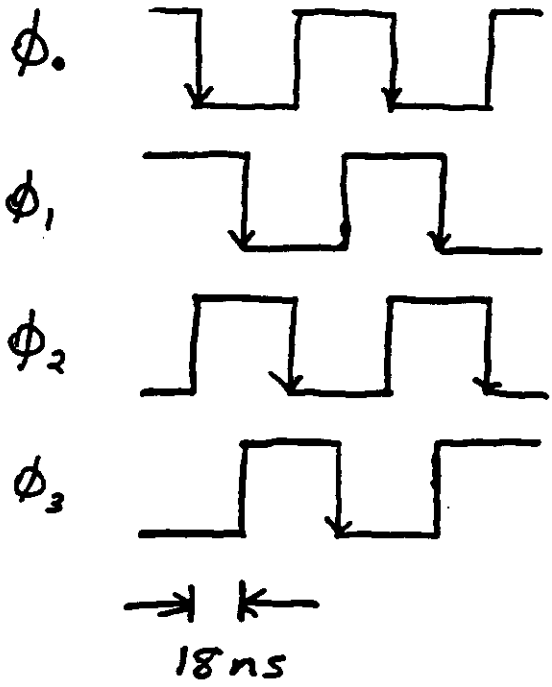
→ so far, look only at data for 5×5 analog sums (1 forward, 1 backward)

ELECTRONICS



ZEUS switched-capacitor pipeline chip





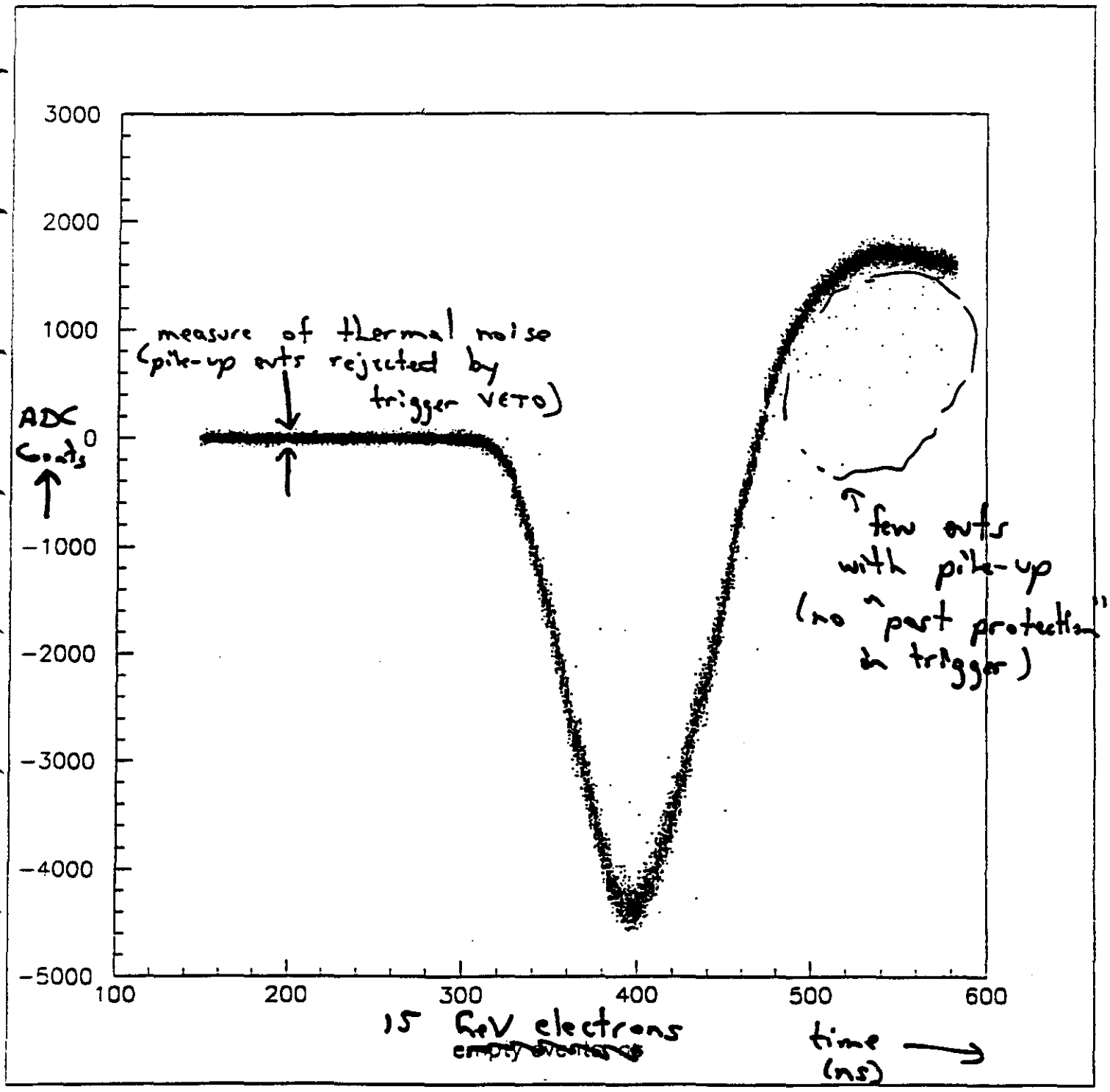
- clock the 4 PL chips out of phase
  ↳ effective time between samples = 18 ns

- 58 samples / PL
  ⇒ 232 samples
  (> 4 μs !)

- trigger timed with TDC to 0.5 ns wrt [illegible]

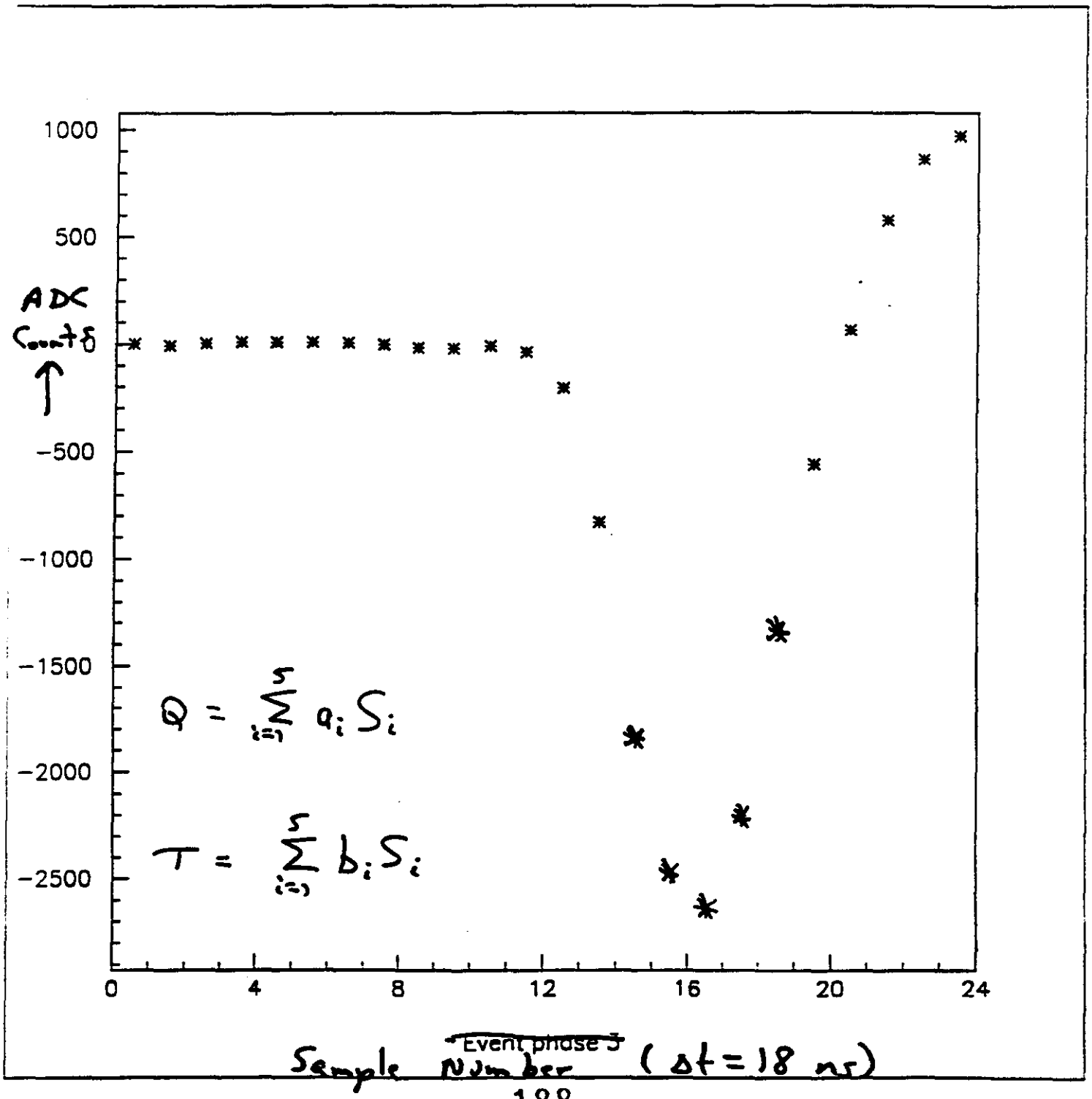
- particle arrival time is <u>asynchronous</u> wrt sampling clock,
  but measured with TDC (bin size = 50 ps)

- add samples for forward + Rear sums and use TDC to overlay events to see <u>pulse shape</u>



Samples for Forward Sum for 15 GeV e^- Trigger

(after subt. of mean baseline)

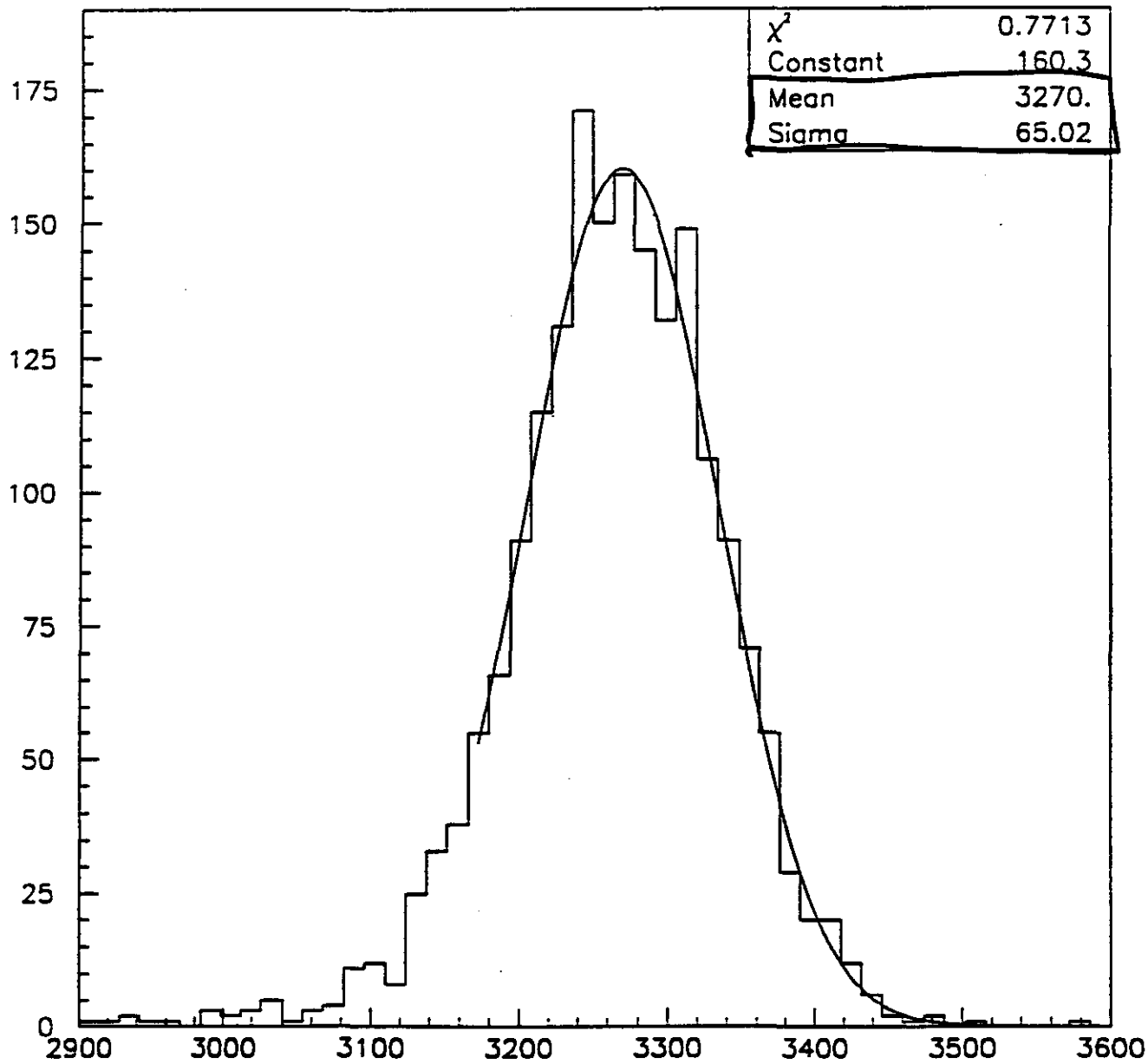


After noise subt^n.,

$$\sigma = \sqrt{65.02^2 - 13.55^2} = 63.59$$

ie. $\frac{\sigma}{E} = \frac{63.59}{3270} = 1.94\%$ @ 15 GeV

$$\boxed{\frac{\sigma}{E} = \frac{7.5\%}{\sqrt{E}} \oplus \frac{62\ \text{MeV}}{E}}$$



15 GeV Electron Events

Improvements not yet incorporated:

- optimize weights as f(TDC)
- optimize Forward/Rear weighting
- correct for event-to-event momentum
- require center cell of 5x5 has max. energy to avoid transverse leakage
  (non-Gaussian tail on low E side)

Time resolution not yet analyzed.

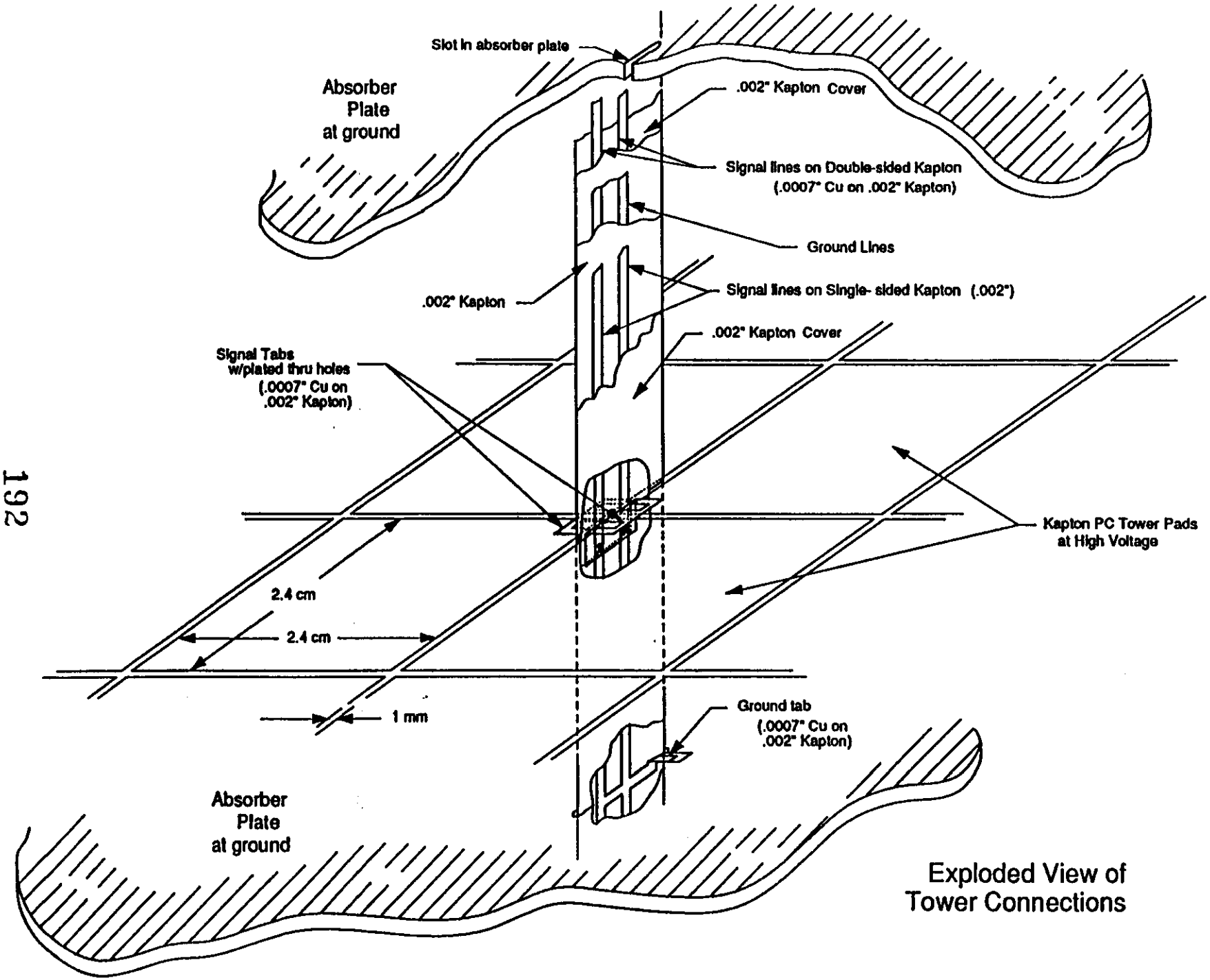
↳ however, using multiple samples provides sensitive measurement of time.

eg. ZEUS Calorimeter readout results

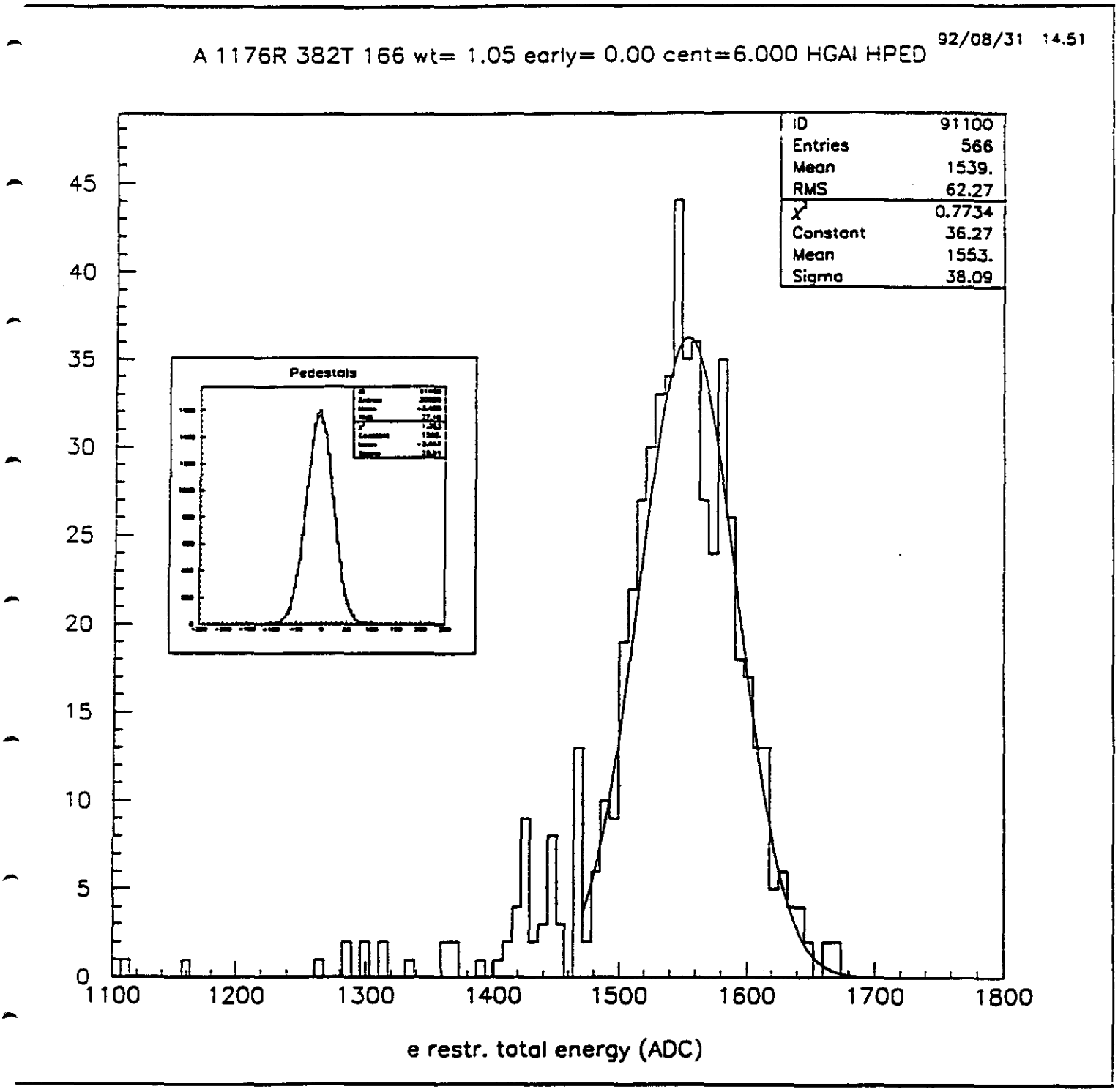
SSCL 9/2/92

LAr / LKr
PARALLEL PLATE CALORIMETER TEST

University of Washington



Exploded View of Tower Connections



$(6.88 \pm .2)\ \frac{\%}{\sqrt{E}}$

$MC = (6.52 \pm .1)\ \%/\sqrt{E}$

M. Seman

ɜers DIRECTIVES OPTIMIZED for this run :

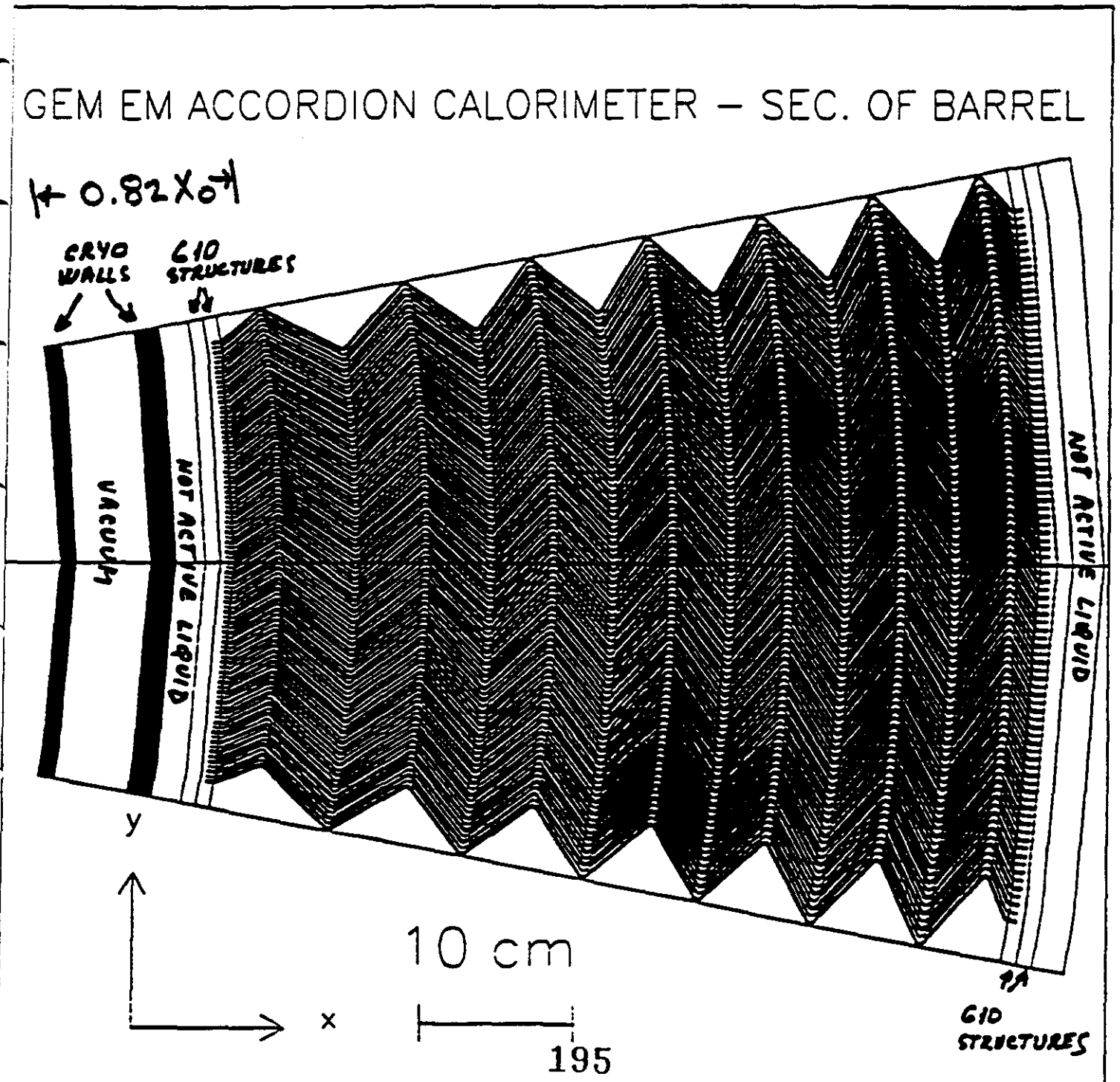
```
 75.00 cm  - Rin  of WARM CRYO wall (Al)
 76.00 cm  - Rout of WARM CRYO wall
 80.90 cm  - Rin  of COLD CRYO wall (Al)
 82.50 cm  - Rout of COLD CRYO wall
           - FRONT STRUCTURE :
               2.00 cm  - LKr GAP
               1.00 cm  - G10 for Electronics+Cables+Spacers
               1.00 cm  - G10 FRAME with SS sheet holders
 86.43 cm  - INNER RADIUS of ACCORDION STRUCTURE
           - ACCORDION STRUCTURE :
             0.095785 cm  - LEAD thickness
             0.135785 cm  - ABSORBER thickness
             0.190254 cm  - LKr thickness
             0.556293 cm  - CELL thickness
                  840     - Total number of CELLS
                    4     - Number of CELLS in TOWER
                  210     - Number of TOWERS
             0.029920 rad - TOWER dimension in PHI
             0.003740 rad - DELTA
                4.900     - Ratio BETA/DELTA   β/δ = 4.9 ≈ 5
             0.018326 rad - BETA
             30.70820 deg - ALFA of first stack
             57.47947 deg - ALFA of last stack
                   14     - Number of STACKS
138.53 cm  - OUTER RADIUS of ACCORDION STRUCTURE
           - BACKWARD STRUCTURE :
               1.00 cm  - G10 FRAME with SS sheet holders
               1.00 cm  - G10 for Electronics+Cables+Spacers
               2.00 cm  - LKr GAP
142.53 cm  - Rout of EM CAL
```

MEAN CORNER RADIUS - 2.5 mm

SS - 2 x 0.15 mm

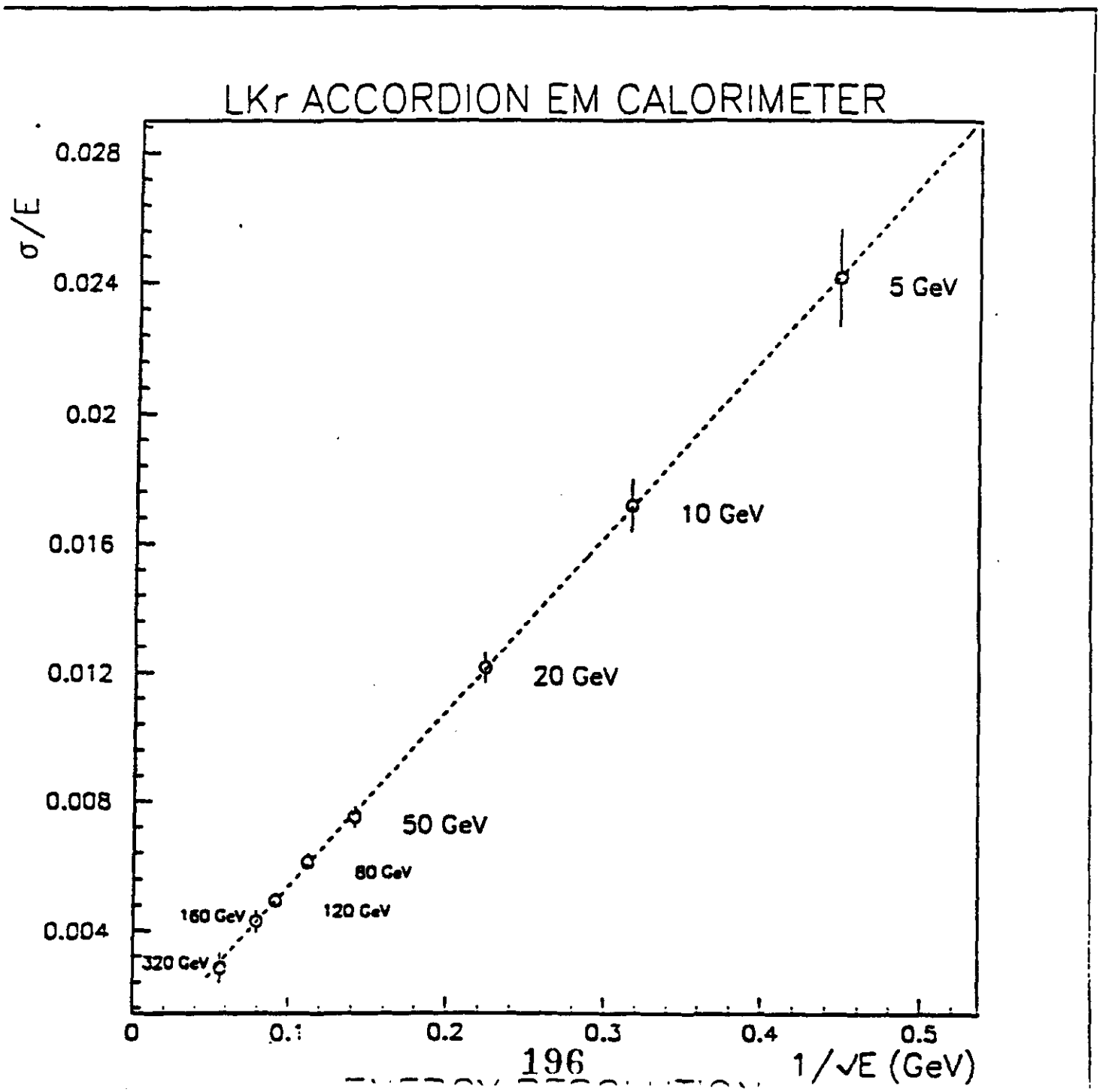
GLUE - 2 x 0.05 mm

M. Seman


GEM EM ACCORDION CALORIMETER – SEC. OF BARREL
0.82 X0
CRYO WALLS
G10 STRUCTURES
VACUUM
NOT ACTIVE LIQUID
NOT ACTIVE LIQUID
G10 STRUCTURES
y
x
10 cm

M. Seman

RESOLUTION AT ENERGIES ≥ 120 GeV
IS CORRECTED FOR LEAKAGE. ! ?



M. Šeman

THETA DEPENDENCE OF ENERGY RESOLUTION

LKr

THETA [DEG]	ENERGY [GeV]	$\sigma/\sqrt{E}$ [%] ± 0.2 %	Pb thickness 0.44 mm
90	50	5.3	
45	50	6.4	
30	50	8.8 ± 0.25 %	5.8
90	10	5.4	
60	10	5.45	
30	10	8.2	

LAr : 2. STRUCTURE [25 X_0 in 52.1 cm]

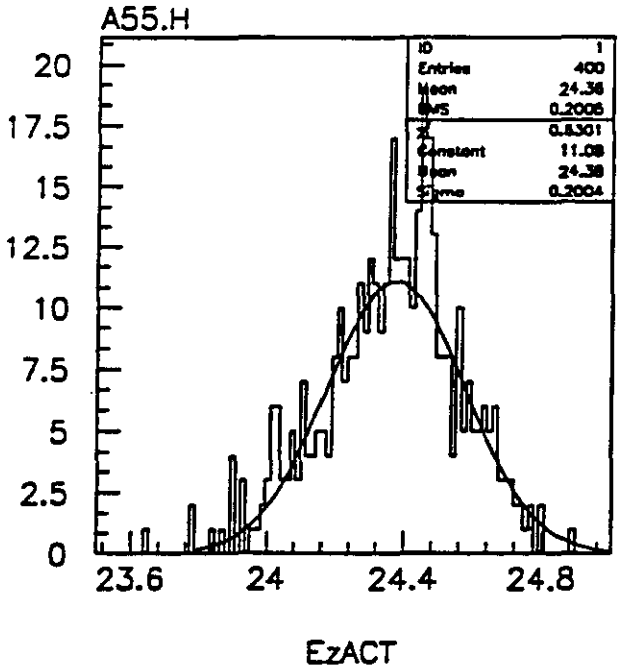
THETA [DEG]	ENERGY [GeV]	RESOLUTION $\sigma/\sqrt{E}$ [%] ± 0.2 %
90	50	7.03
90	10	6.91
45	10	7.82

M. Leltchouk

γ 50 GeV

$\theta = 30^\circ$ 17/06/92 20.04

$29 X_0$



$$\frac{\sigma_E}{E} = \frac{5.8\%}{\sqrt{E}}$$

48% of E in LKr

M. Leltchouk

7×7 towers

$$\frac{\sigma_E}{E} = \frac{\sigma_1}{\sqrt{E}}$$

	50 GeV	100 GeV
σ_1 hist, %	5.82 ± 0.21	5.97 ± 0.24
σ_1 fit, %	5.78 ± 0.21	5.87 ± 0.24

no place for large constant term.

:t of the Noble Liquid Calorimeter Review Panel

ers of the Panel:
Ron Barber, Jim Brau, Mike Harris, Bruno Mansoulie, Nicolai Martovetsky, Michael Marx, Mark Rennich, Bill Wisniewski(chair).

ndees:
Steven Bellario, Nick DiGiacomo, Brian Easom, Howard Gordon, Chunhua Jiang, Mark Lajczok, David Lissauer, Lyle Mason, Greg Velasquez.

:ge to the Panel:
The panel is asked to review the status of the noble liquid calorimeter. Special attention should be paid to the accordion electromagnetic portion of the calorimeter.The panel should focus on the engineering viability of the design.

.clusion of the Panel:

The panel identified NO SHOW-STOPPERS in the conceptual design presented by the design team.

The design of the integrated noble liquid calorimeter is at an early stage of development. We believe that completion of this compact design, though feasible, will be very challenging.

The design of the electromagnetic-only calorimeter also appears to be feasible. However, the lack of a scheme that permits all of the barrel signals to be passed through the dewar wall threatens the viability of this option.

We suggest that, if either of the noble liquid calorimeter options is chosen, a detailed technical engineering review be held within a few months.

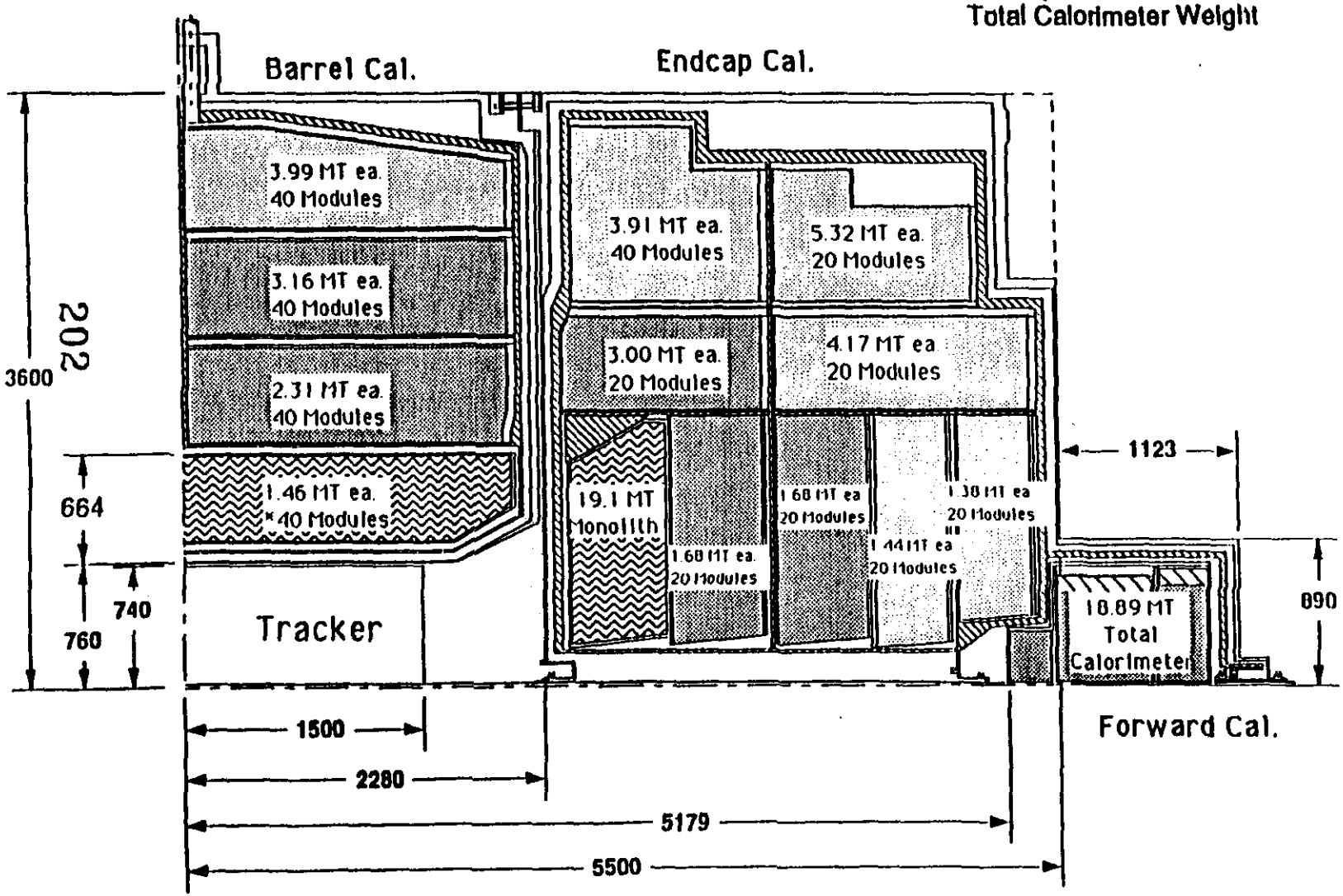
:mments and Concerns:
Although the panel found nothing in the design that would lead to the failure of the calorimeter, we nevertheless have concerns about features of the design. Some of these features

Loss of η between 1.40 -- 1.54 in baseline design

Dead Material ~ 1 X_0 Massless gap built into design.

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

Central Barrel Calorimeter Weight	891 MT
Endcap Calorimeter Weight Each	626 MT
Total Calorimeter Weight	2,143 MT



Dimensions in millimeters
Module count is the number of modules in phi direction.

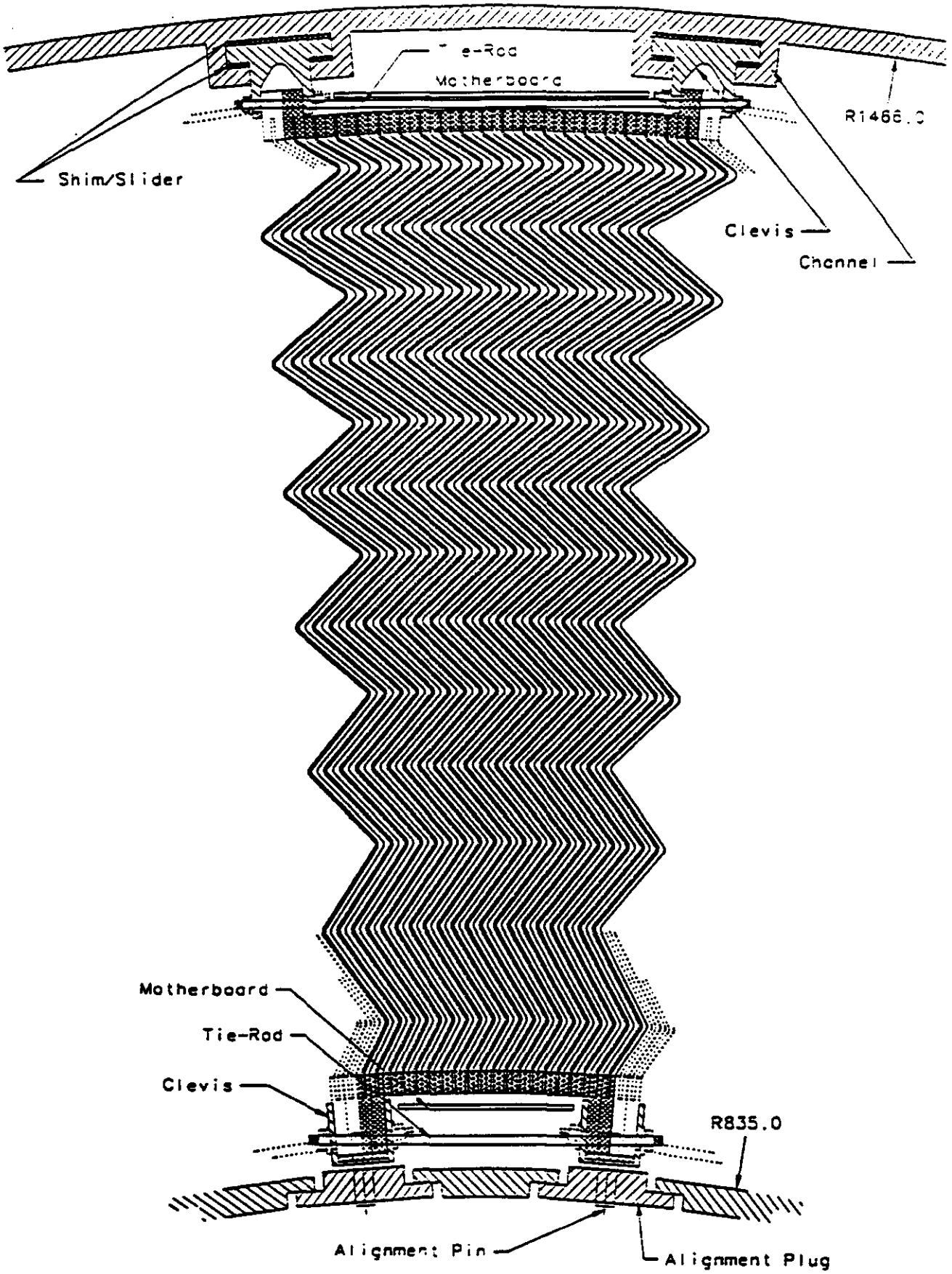
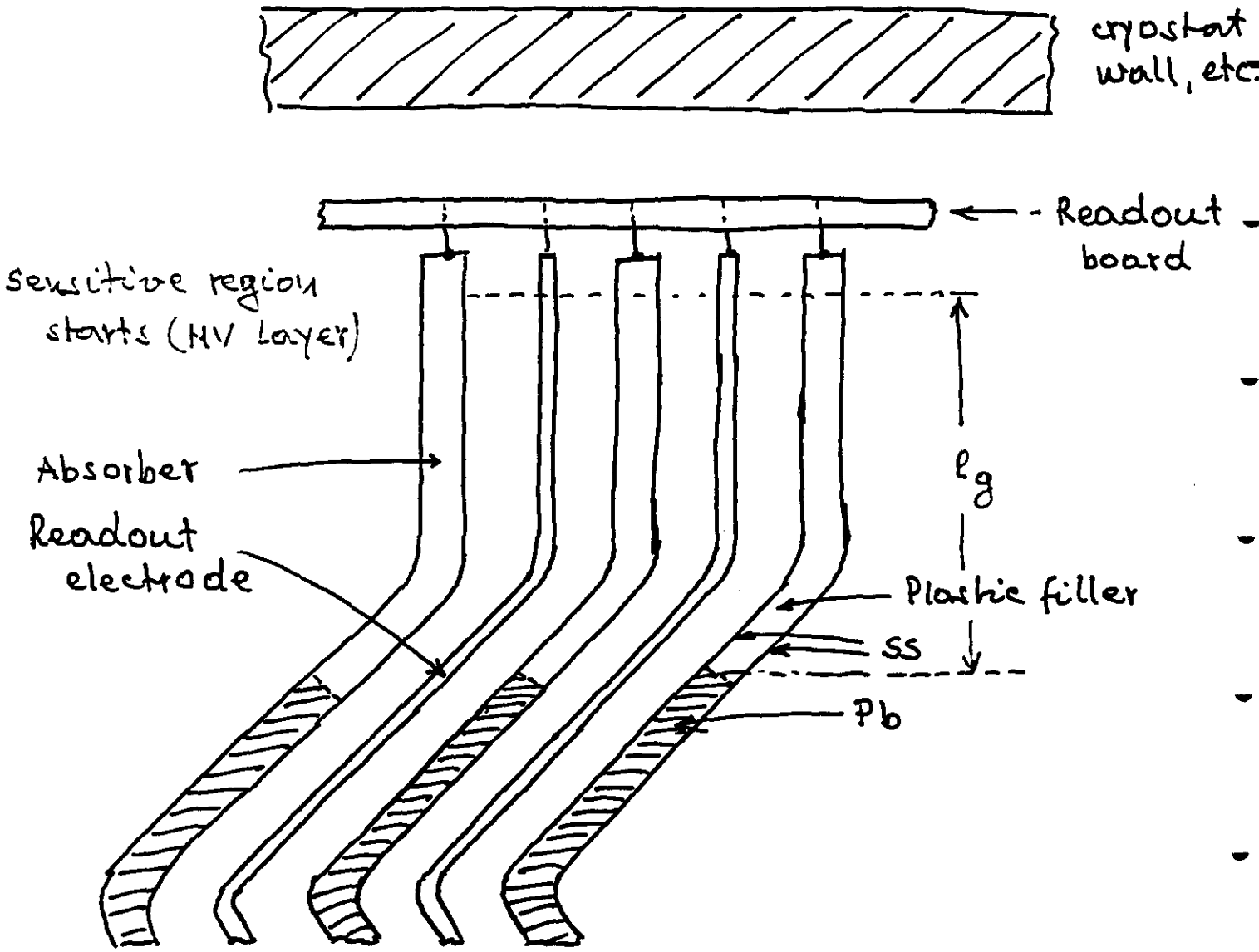
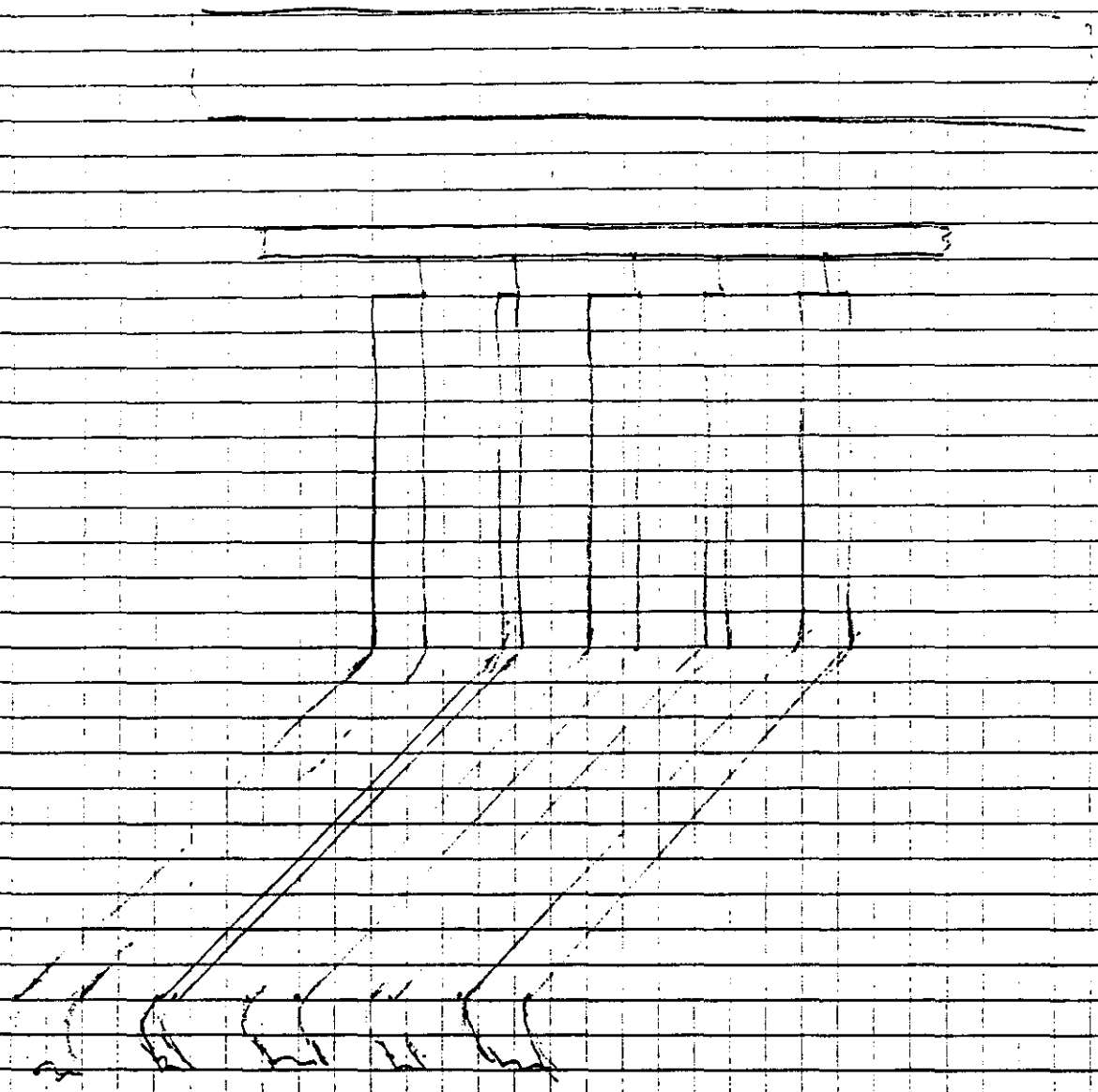


Figure 1-3a. Typical Module Lay-up in Section

017



"Massless gap" length $\ell_g \approx 12$ mm/rad. length of material in front



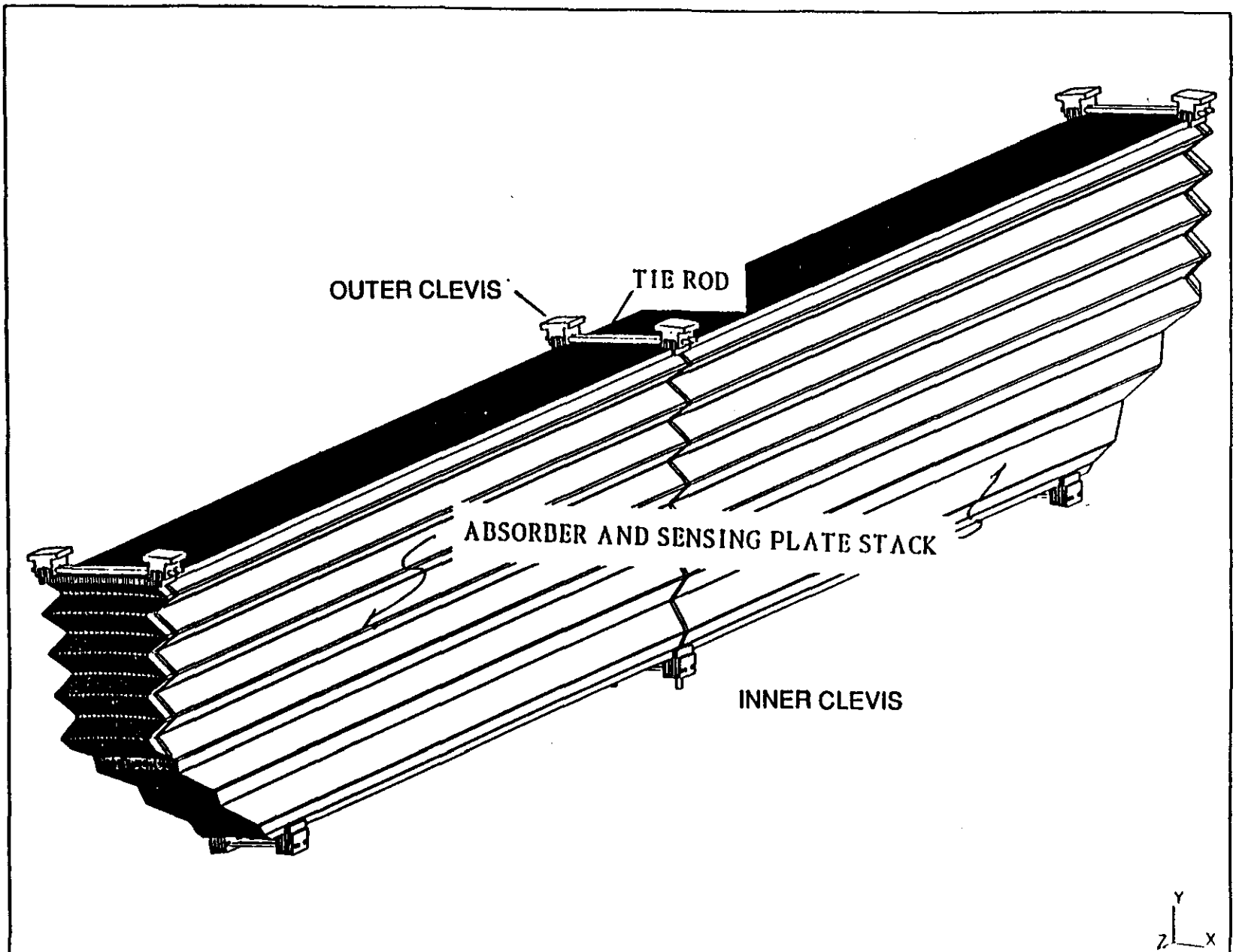


Figure 1-1 Barrel EM Module Assembly

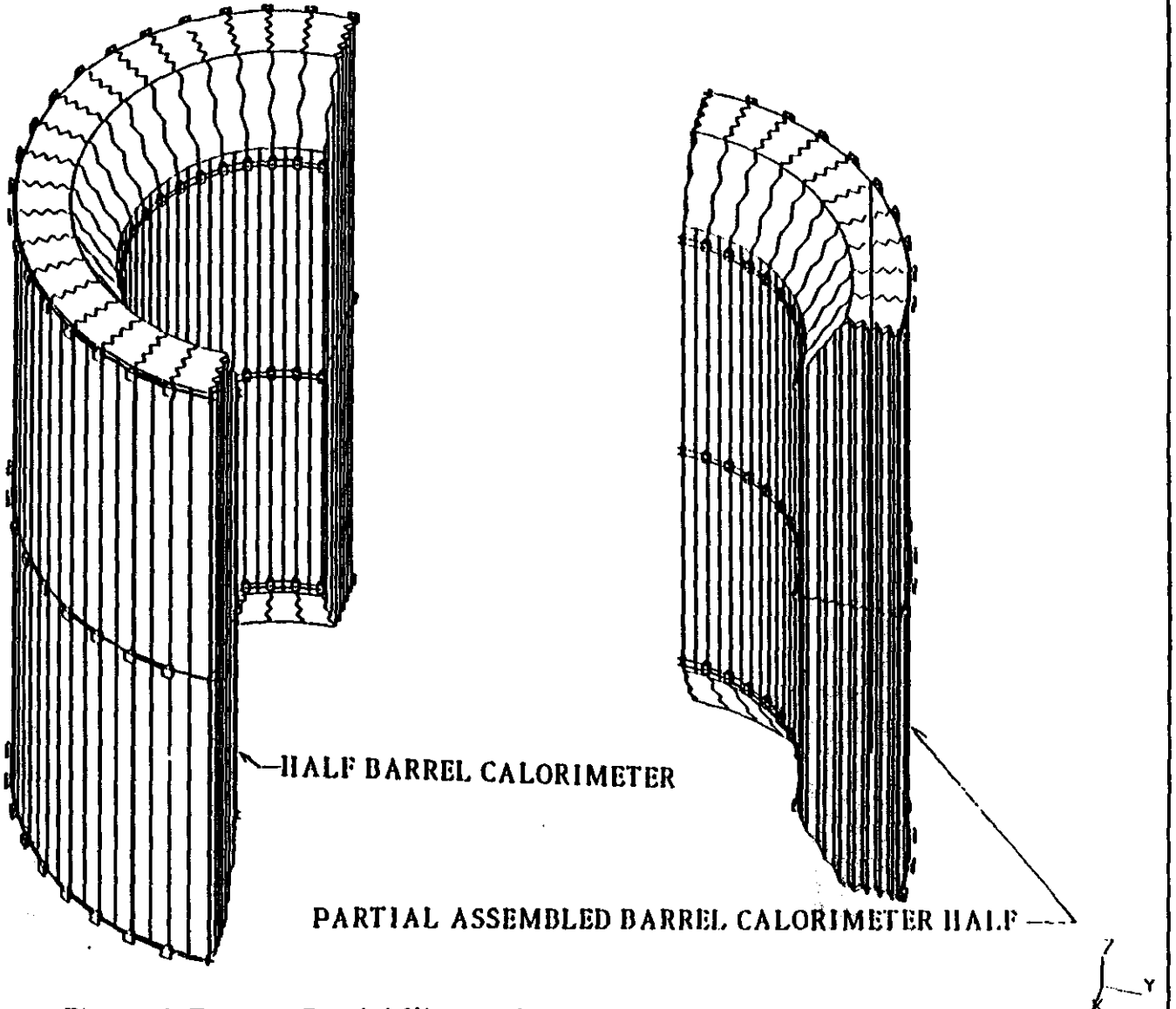
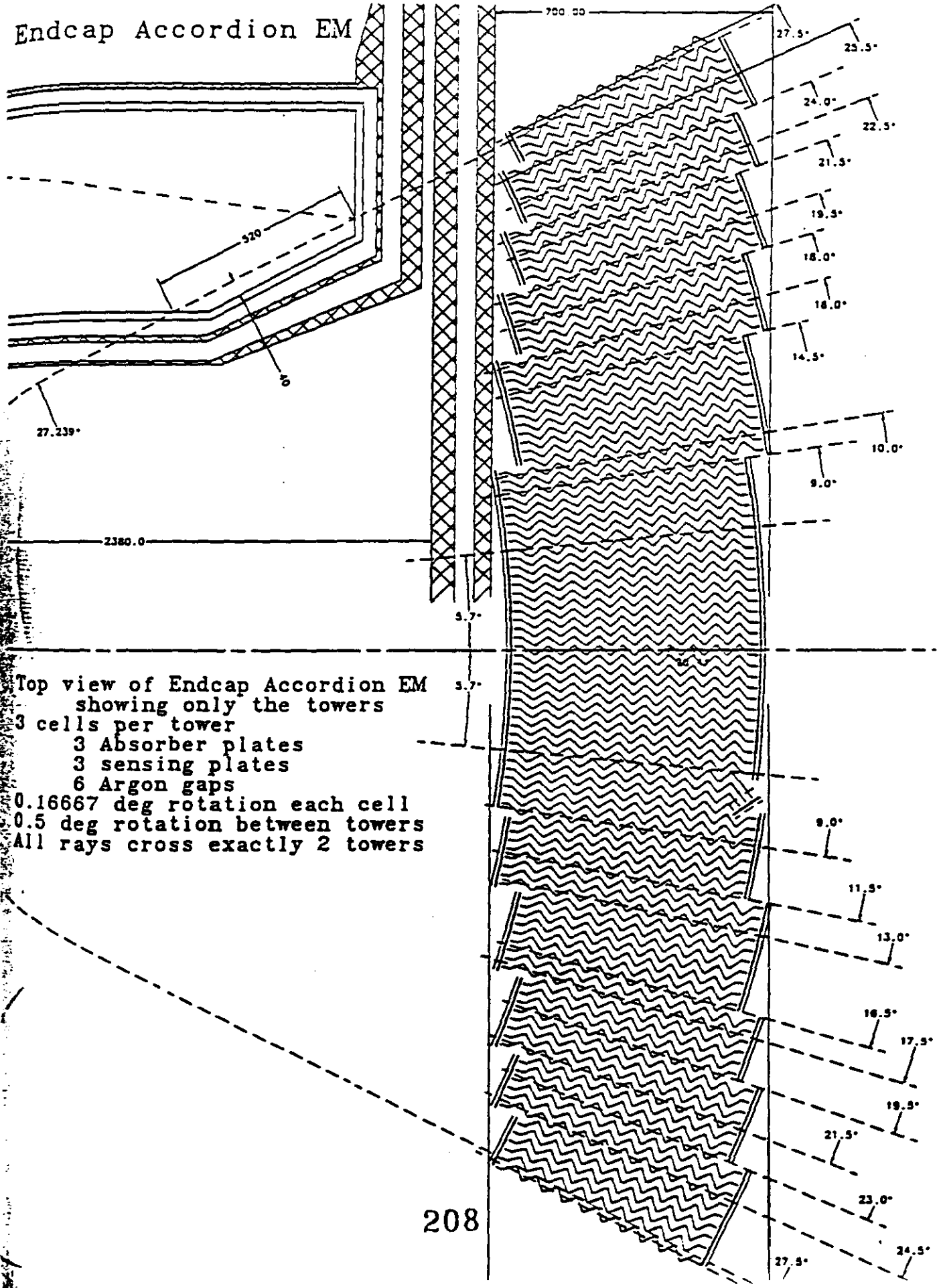


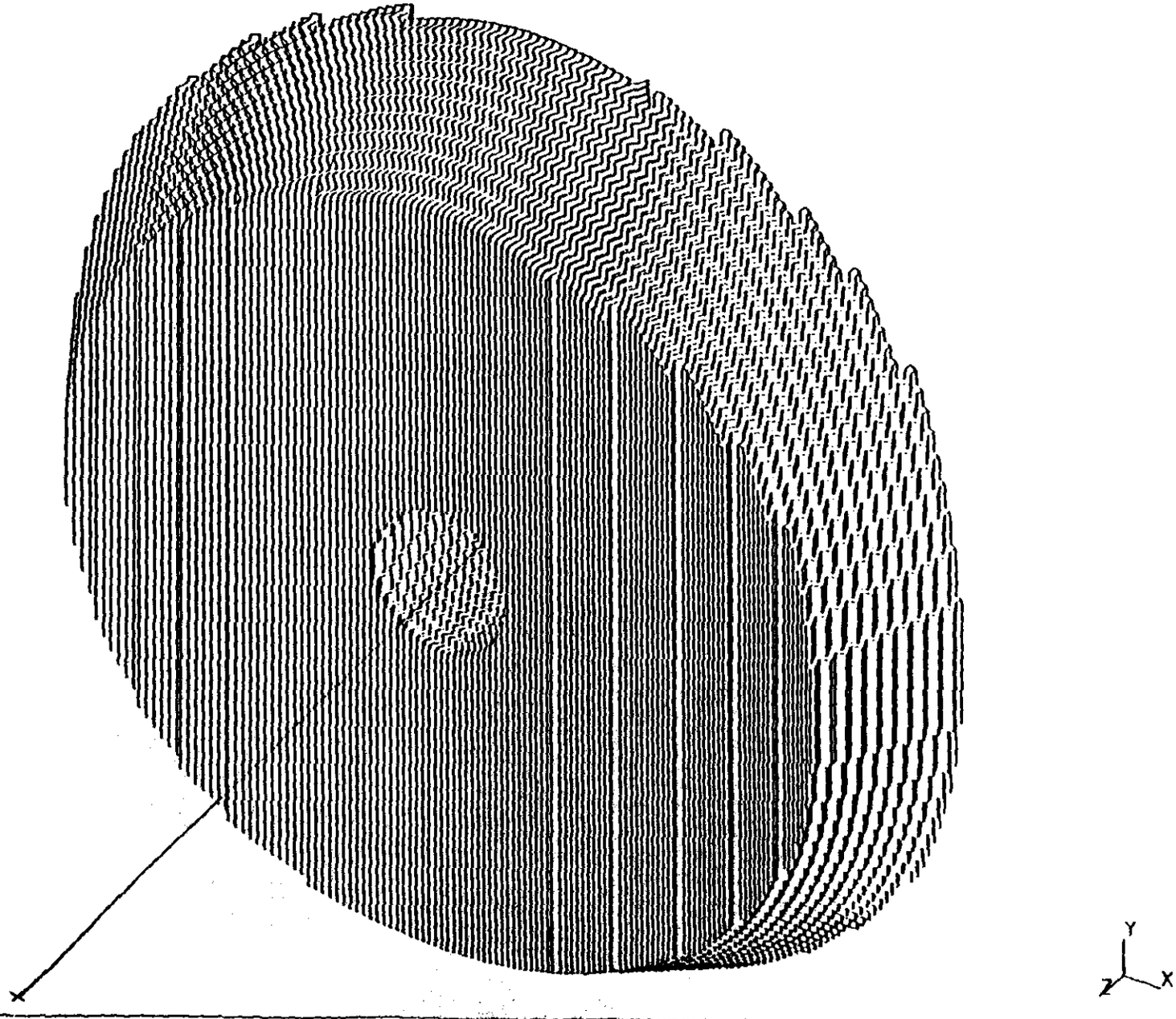
Figure 1-7 Partial View of Modules assembled in Halves

Endcap Accordion EM



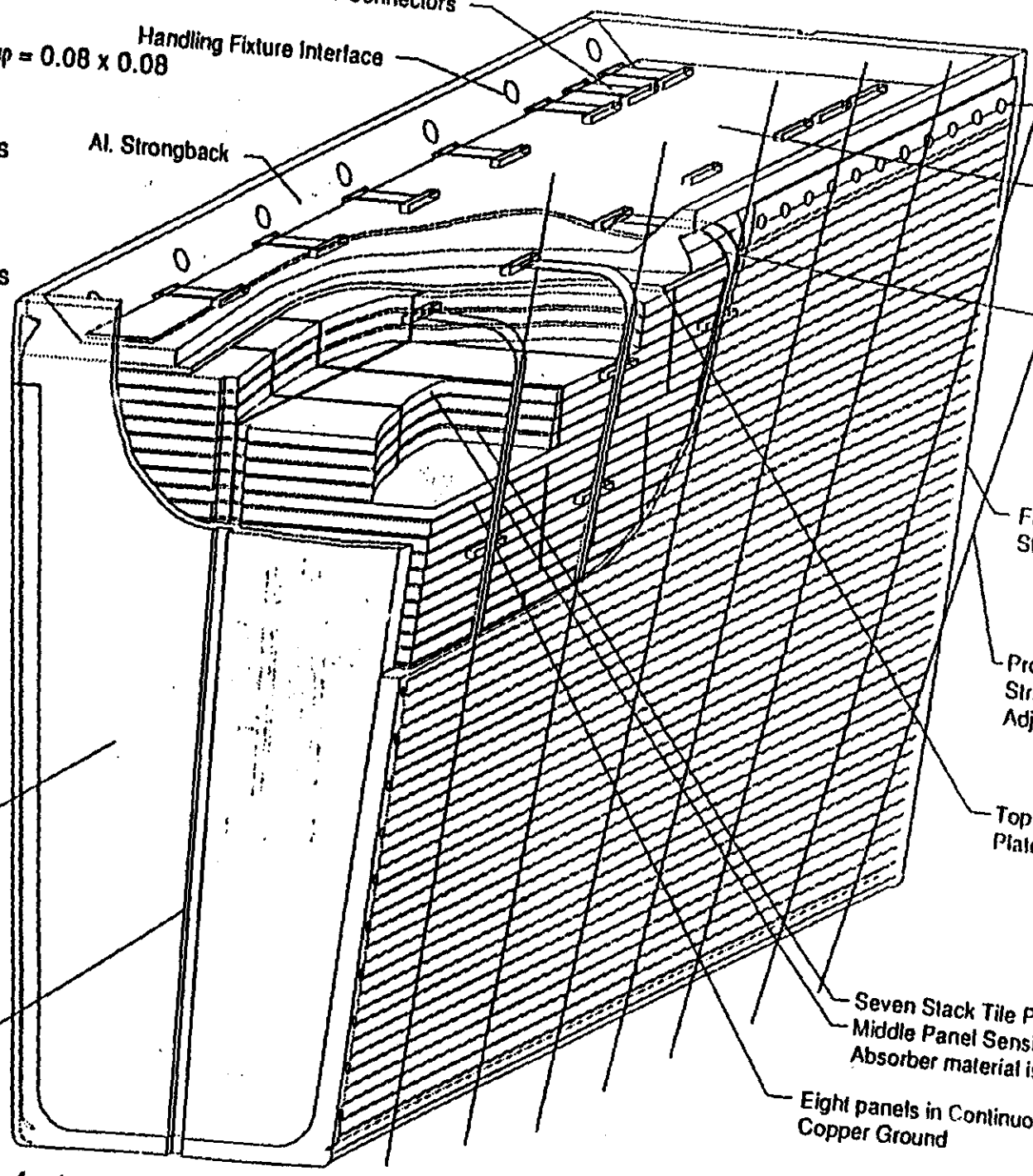
Top view of Endcap Accordion EM
showing only the towers
3 cells per tower
3 Absorber plates
3 sensing plates
6 Argon gaps
0.16667 deg rotation each cell
0.5 deg rotation between towers
All rays cross exactly 2 towers

Endcap Accordion EM



Hadron Module # 2

Six Cells Depth
Segmentation $\Delta\eta \times \Delta\varphi = 0.08 \times 0.08$
80 Modules Required
Wt. = 2.38 MT each
Each Module Contains the Following:
1 - Top Ground Plate
1 - Bottom Gnd Plate
5 - Included Gnd Plates
36 - Tile Plates Containing 948 Tile
6 - Sensing Plates Containing 258 Tile
1 - Strongback
1 - Structural Shell
2 - End Plates
28 - Towers with Strip Lines and Electronics
X - Mother Boards



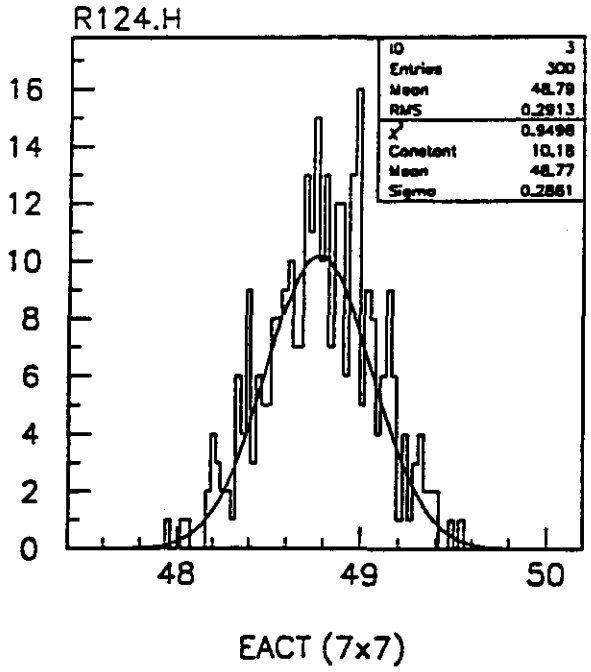
210 005

LLMason GEMLAC HadMod

γ 100 GeV

$\theta = 30°$ 92/08/29 16.21

$29\ X_0$



$$\frac{\sigma_E}{E} = \frac{5.9\%}{\sqrt{E}}$$

Can Liquid Argon/Krypton Find H->$\gamma\gamma$?

Main issue is rejection of jet-jet, jet-γ background.

New analyses by Tomasz S., Andrei G., Misha D., Sasha V., and Misha L. show new analysis techniques which help both technologies to reduce the background to ~1/3 of the irreducible background.

H. Gordon
Sept. 2, 1992

Advantages of the Baseline **Integrated** LAr/Kr Design

1) Experience from D0, H1, SLD, E706, NA34

ALL EM+HADRON calorimeters

D0 & H1 producing physics!

2) Services at outside where there is more room and less physics impact.
Signal and HV feedthroughs
Liquid Lines
Vacuum and Vent Lines

3) One INTEGRATED R&D program for the calorimeter, electronics, trigger, readout.
Plenty of work for all

4) 50-60%/sqrt(E), 4 Longitudinal Divisions, low enough thermal and pileup noise

5) Strength of Collaboration - hopefully entire GEM Calorimeter Group

Recent additions: Rochester and Stony Brook

RD2/EAGLE - our unsigned partner testing projective accordion this fall

3 56 AM Moiche Pripstein – surveyors

noon →

~~9:24 9:26 Bob Penzias → Xi Xia → Student~~

301 – 903 – 3705

8 03 – Sam Lindenbaum – wolf Kern – active region of C7

7850

3942

4821 3918

Xi Xia → Chen – LBL head & shoulders above others

better than people's impression

comes across more positively due to personality – outgoing & positive friendly –

not good verbally – written quality poor –

he worked on thesis @ CLEO, Gil said – Better than most grad students at Cornell!

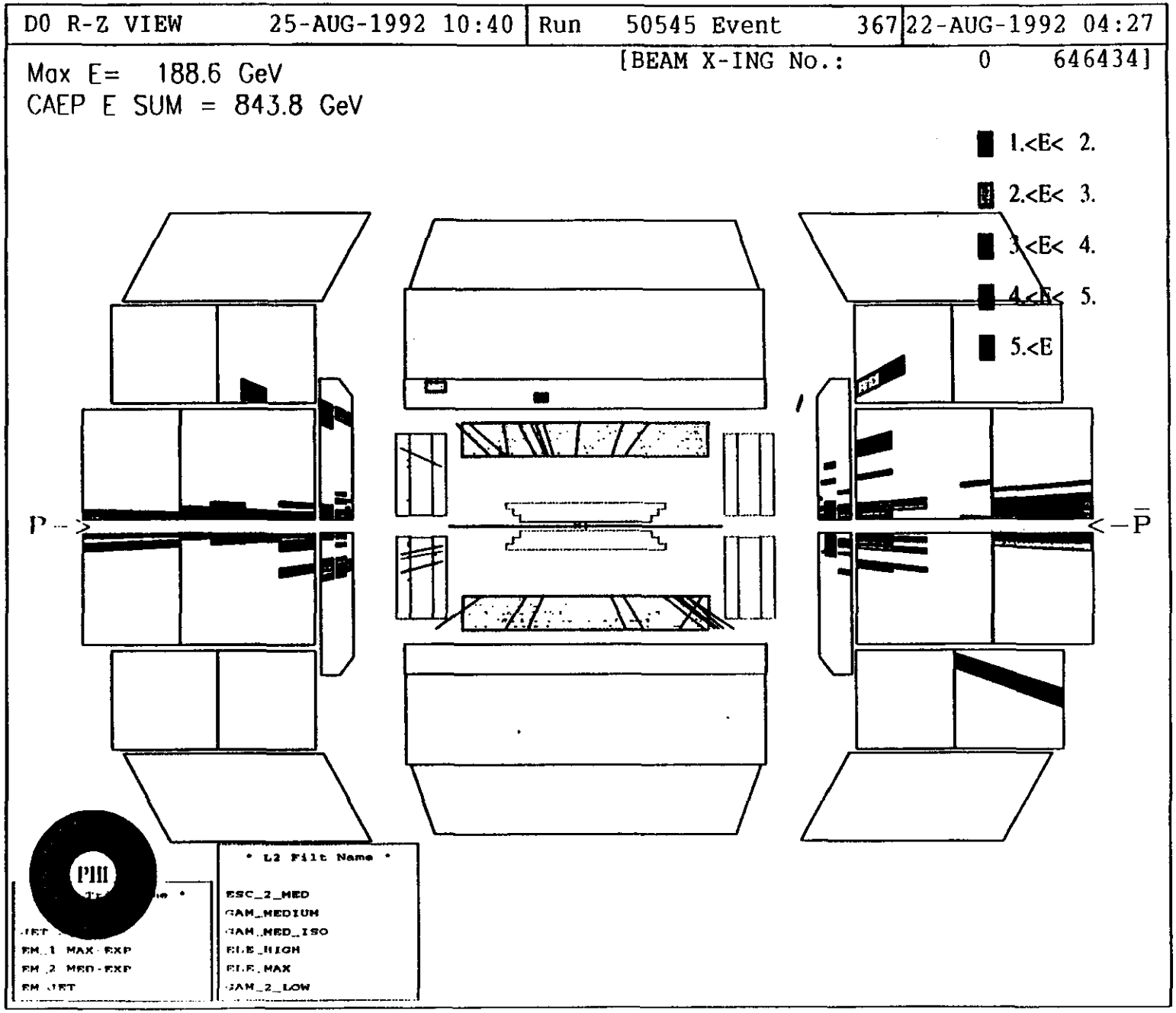
Difficult analysis of [illegible] – hard working guy.

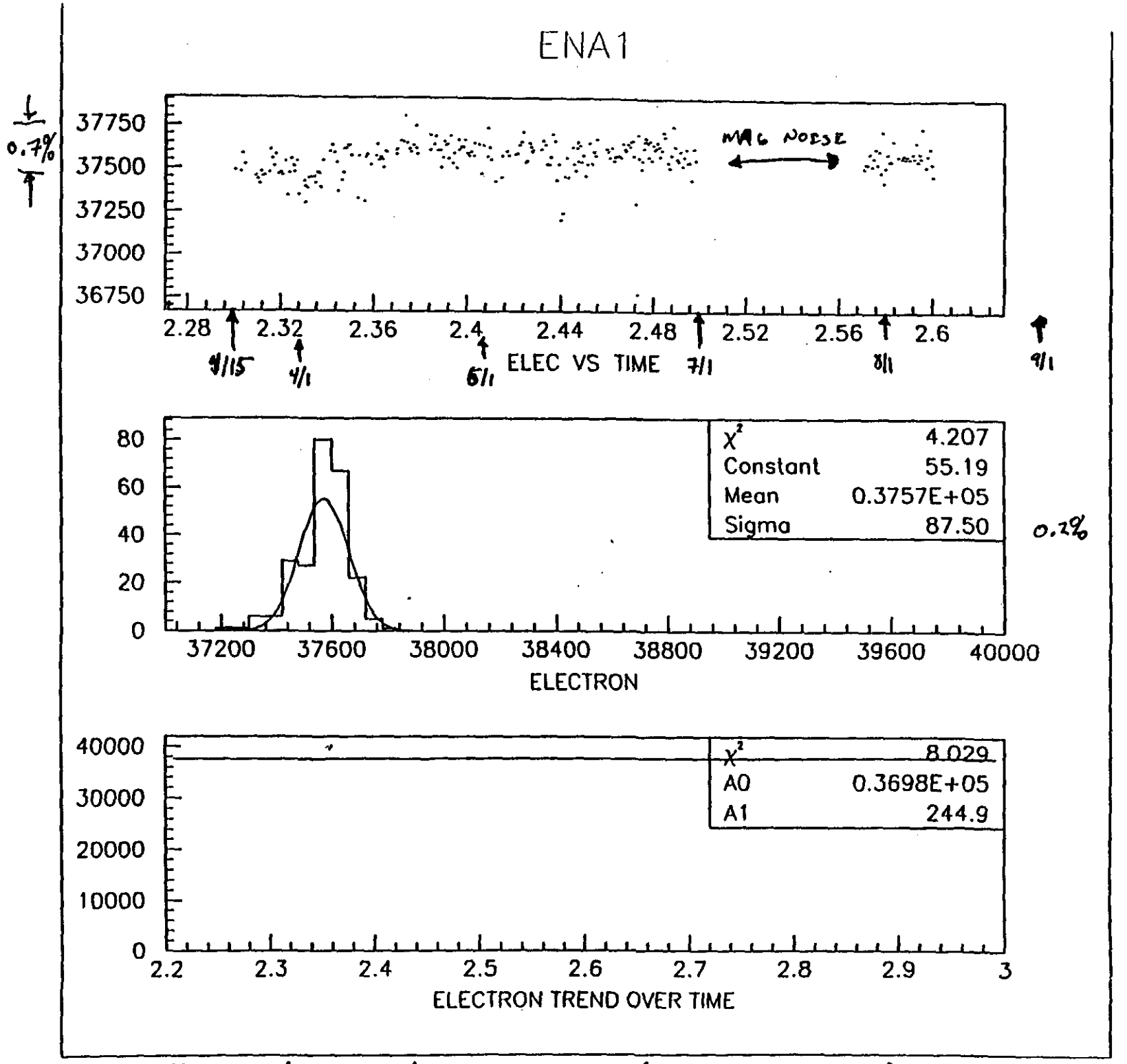
Maybe – doesn't relate, limited –

46 years old now! Not well known – concentrated on software, age of senior physicist – delayed education due to cultural revolution – Ph.D. thesis done quickly – ~ 1 year

fast analysis –

DØ Z-candidate





.083 2/1
.166 3/1
.25 4/1
.33 5/1
.42 6/1
.5 7/1
.583 8/1

At Dallas HL quoted <0.2% stability over the last year.

H. Gordon
Sept. 2, 1992

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ALL EM+HADRON calorimeters

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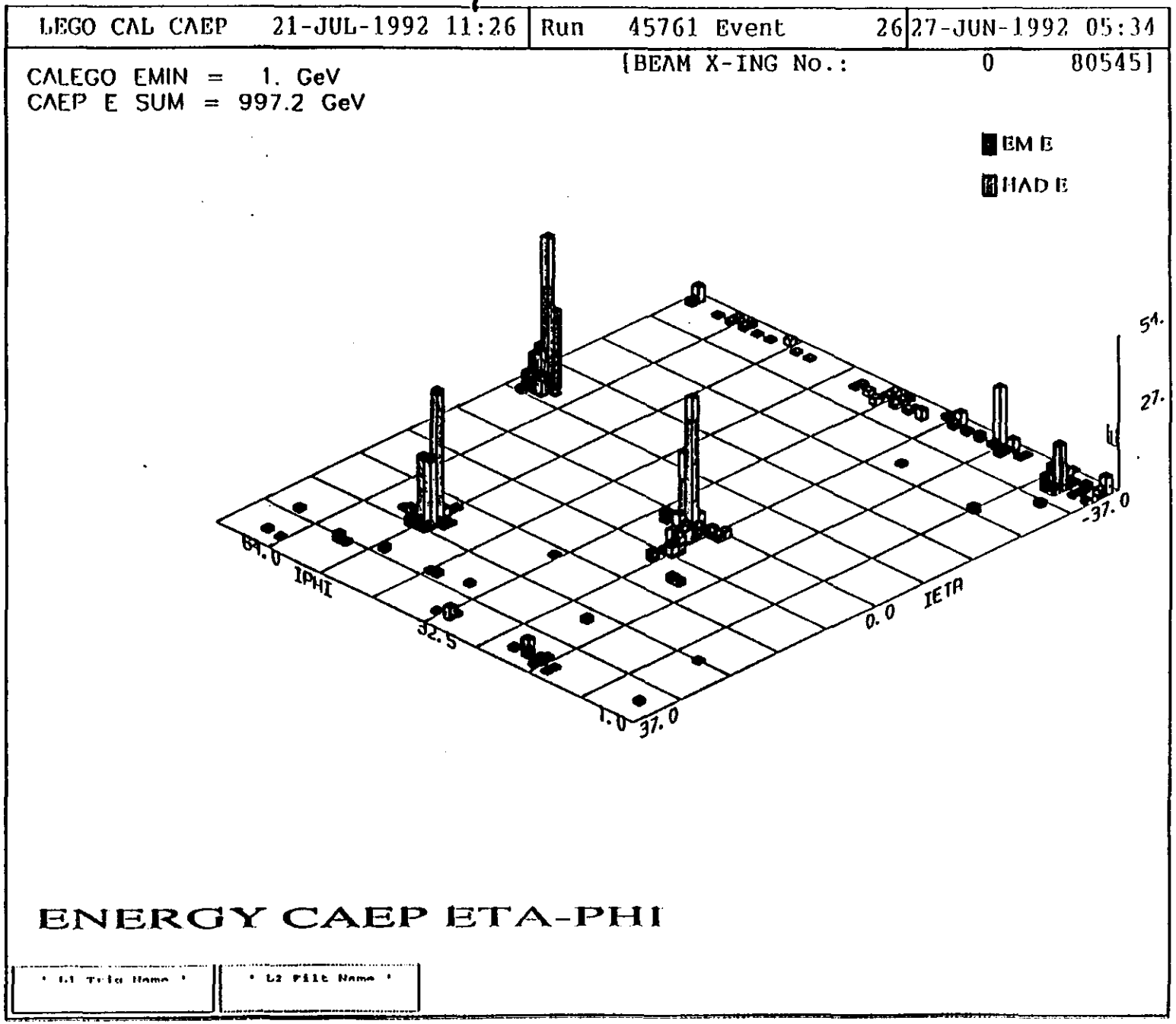
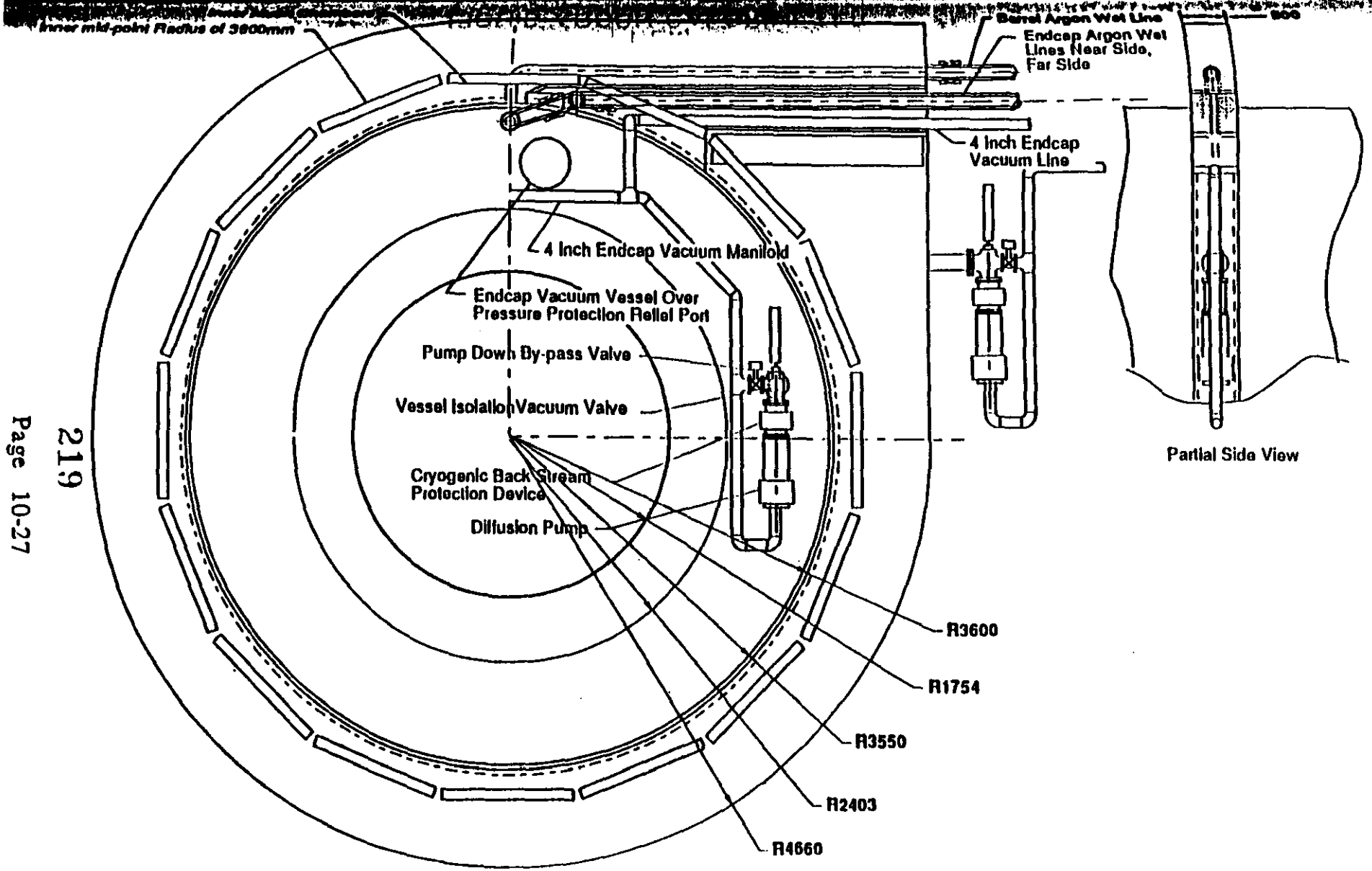
5) Strength of Collaboration - hopefully entire GEM Calorimeter Group

Recent additions: Rochester and Stony Brook

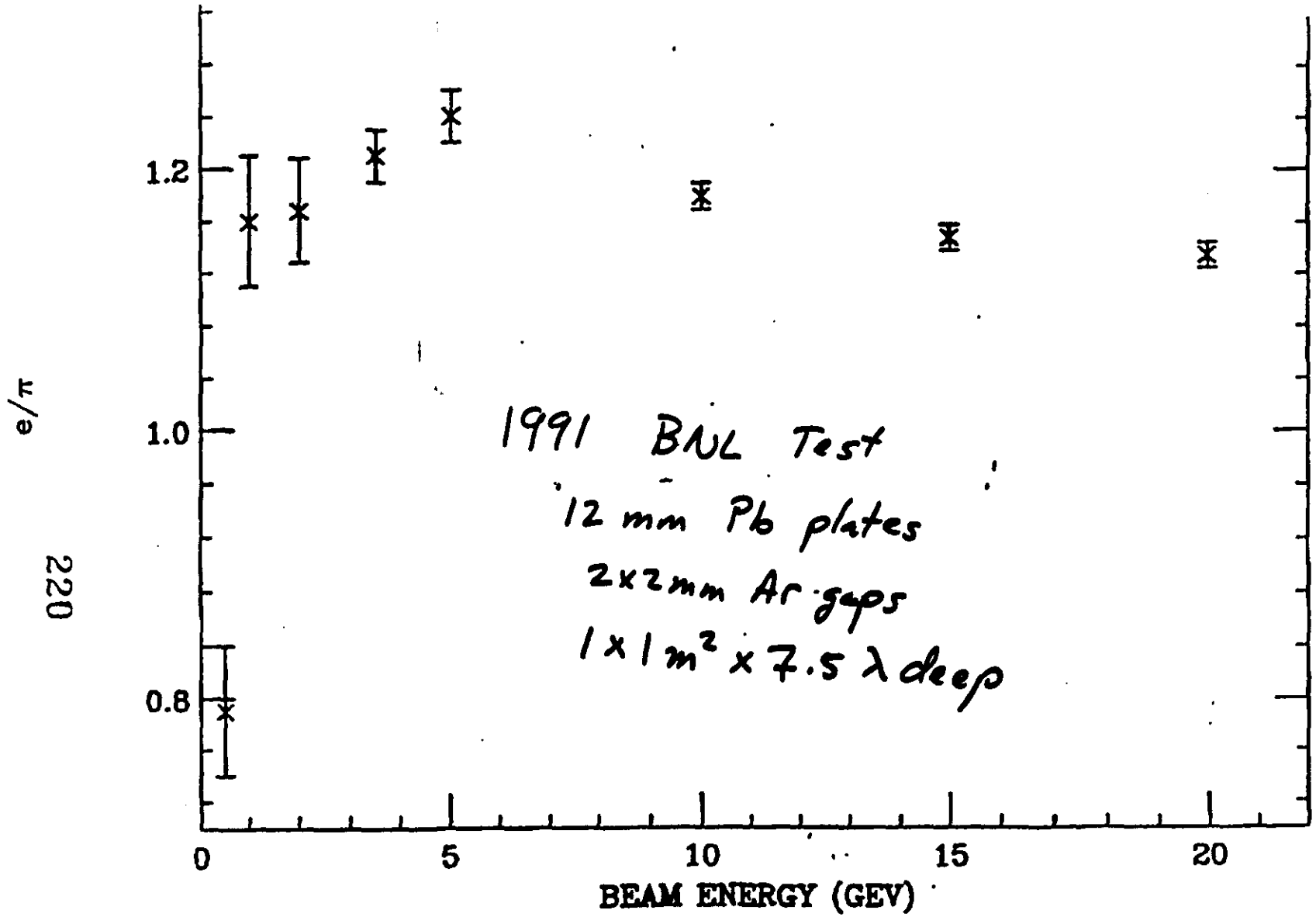
DØ 3 JET event



and Argon Wet Line to Head Vessel

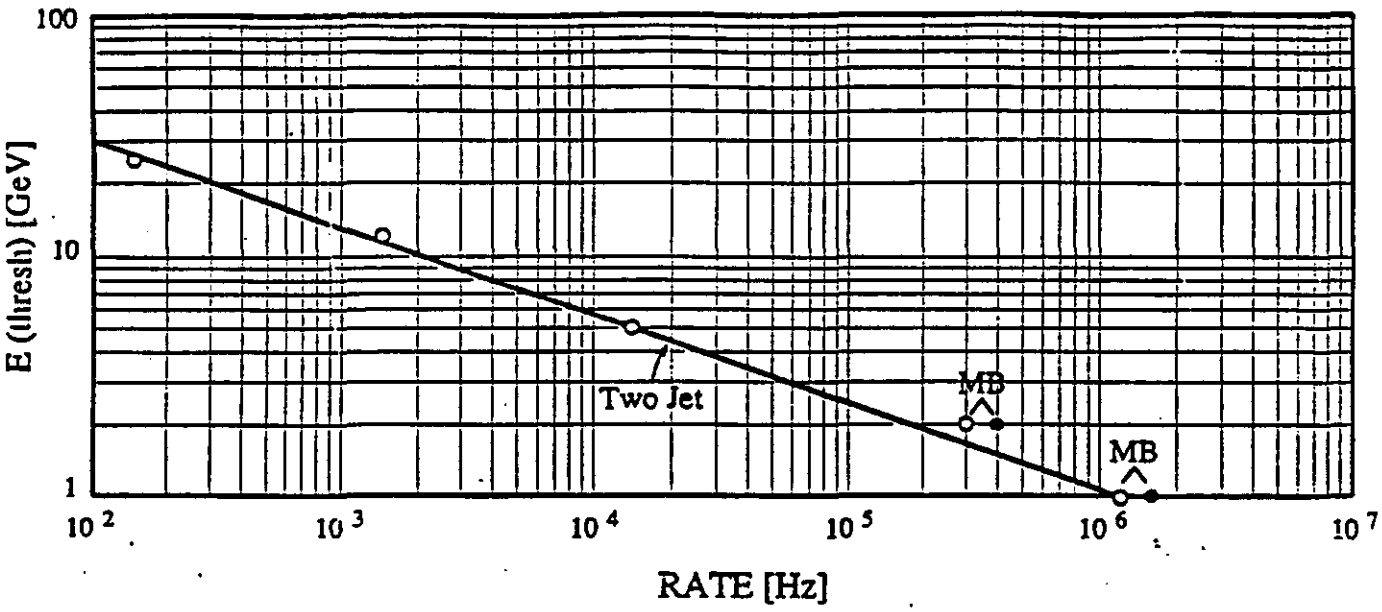


Endcap Calorimeter End View Showing Vacuum System and Argon Wet Line to Head Vessel


1991 BNL Test
12 mm Pb plates
2x2mm Ar gaps
1x1m² x 7.5 λ deep
e/π
1.2
1.0
0.8
0
5
10
15
20
BEAM ENERGY (GEV)

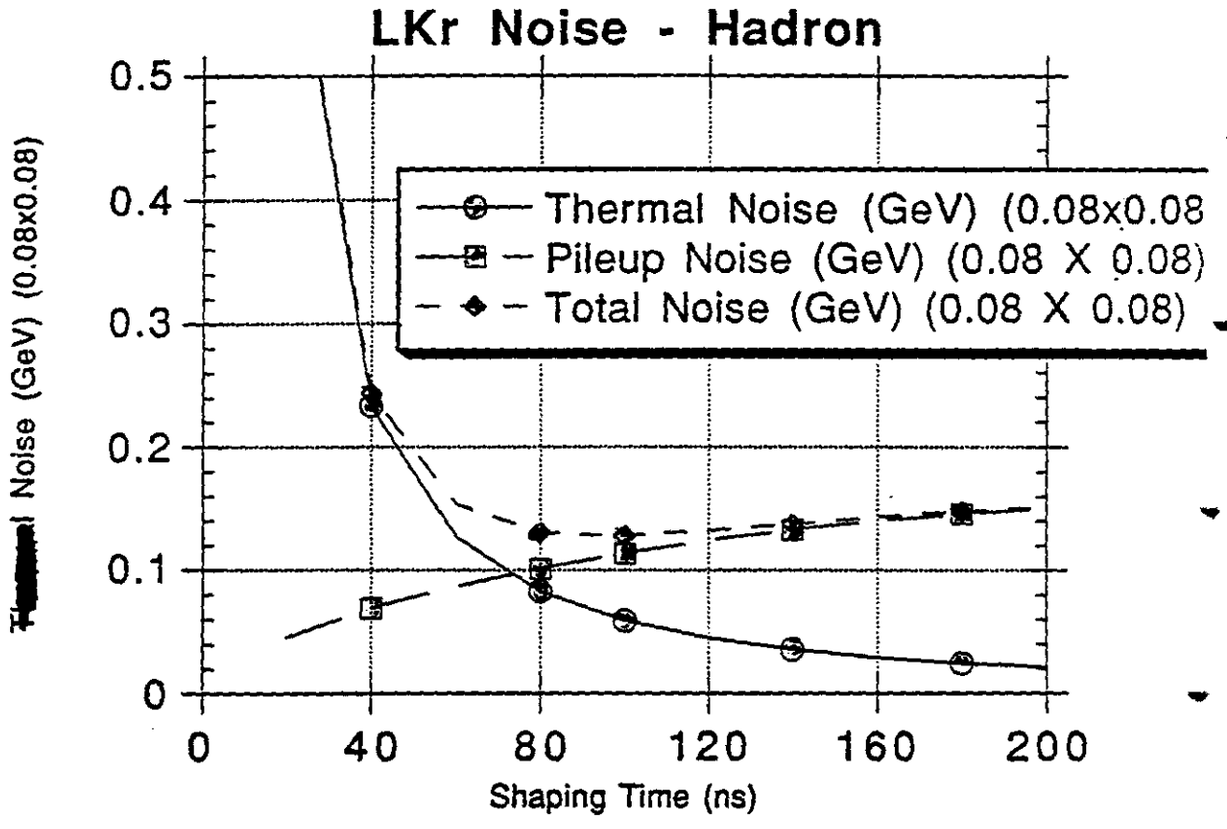
BACKGROUND AND PHYSICS RATES

Rate of 0.32x0.32 EM+Hadronic Trigger Sum
vs. Threshold Energy (at $L=10^{33} cm^{2} sec^{-1}$)



- Bunch crossing 16ns
- Interactions/b.c. 1.6 @ $L=10^{33}$ cm^{-2} s^{-1}
- Highly selective trigger necessary (rejection factor of 1000–10000). Level 1 decision latency≈ 2–3 μsec.
- Very low physics rate:
  Higgs-->4 leptons (M=500MeV) 10^{-5} s^{-1}
- Signal path of all calorimeter channels has a storage element to accomodate for Level 1 decision time.
- Level 1 trigger will tag all signals pertaining to the corresponding bunch crossing for further storage (Virtual Level 2) or for transfer/digitization.

Even at LHC, consensus is that LAr is an excellent choice for calorimetry.


LKr Noise - Hadron
Thermal Noise (GeV) (0.08x0.08)
Pileup Noise (GeV) (0.08 X 0.08)
Total Noise (GeV) (0.08 X 0.08)
0.5
0.4
0.3
0.2
0.1
0
0
40
80
120
160
200
Shaping Time (ns)

Institutions involved in the BNL Test:

Adelphi University
University of Arizona
Brookhaven National Laboratory
Budker Institute for Nuclear Physics, Novosibirsk, Russia
Columbia University
Oak Ridge National Laboratory
University of Pittsburgh
University of Washington
Tel-Aviv University

Came to work on test — fabrication, assembly, test, shifts

Other groups that will join (we hope all the GEM Calorimeter Group +)

IHEP(Beijing)
Tsinghua University
University of Science and Technology(Hefei)
Beijing University

(Shanghai Aircraft Manufacture Factory)

New Delhi University
ITEP(Moscow)
Rochester
SUNY - Stony Brook

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Rochester
SUNY - Stony Brook

UNIVERSITY OF ROCHESTER

Proposed GEM Electro-Magnetic Calorimeter Group

Personnel

T. Ferbel (DOE), F. Lobkowicz (NSF), P. Slattery (DOE)

E706

J. Dunlea (DOE), G. Fanourakis [50%] (NSF),
J. Ftacnik (NSF), G. Ginther (DOE), M. Zielinski (DOE)

DZero

G. Blazey (DOE), G. Fanourakis [50%] (NSF), S. Gruenendahl (DOE)

LAr Calorimetry Experience

LAC – I

1978 –> 1981

x - y Geometry [.90 m x 1.40 m]
2 mm Pb Plates ; 2 mm LAr Gaps
1.27 cm readout ; 12 rl [front] / 12 rl [back]
unfocussed geometry
NIM 216, 381 (1983)

E272 – Coulomb Dissociation [156 - 260 GeV/c]
E629 – Direct Photon Production [200 GeV/c]

LAC – II

1987 –> 1992 –> ??

r - ϕ Geometry [r = .22 m –> r = 1.60 m]
2 mm Pb Plates ; 2.5 mm LAr Gaps
0.55 cm readout [r-strips] ; 10 rl [front] / 20 rl [back]
focussed geometry
NIM A235, 332 (1985)

E706 – Direct Photon Production [500 - 800 GeV/c]

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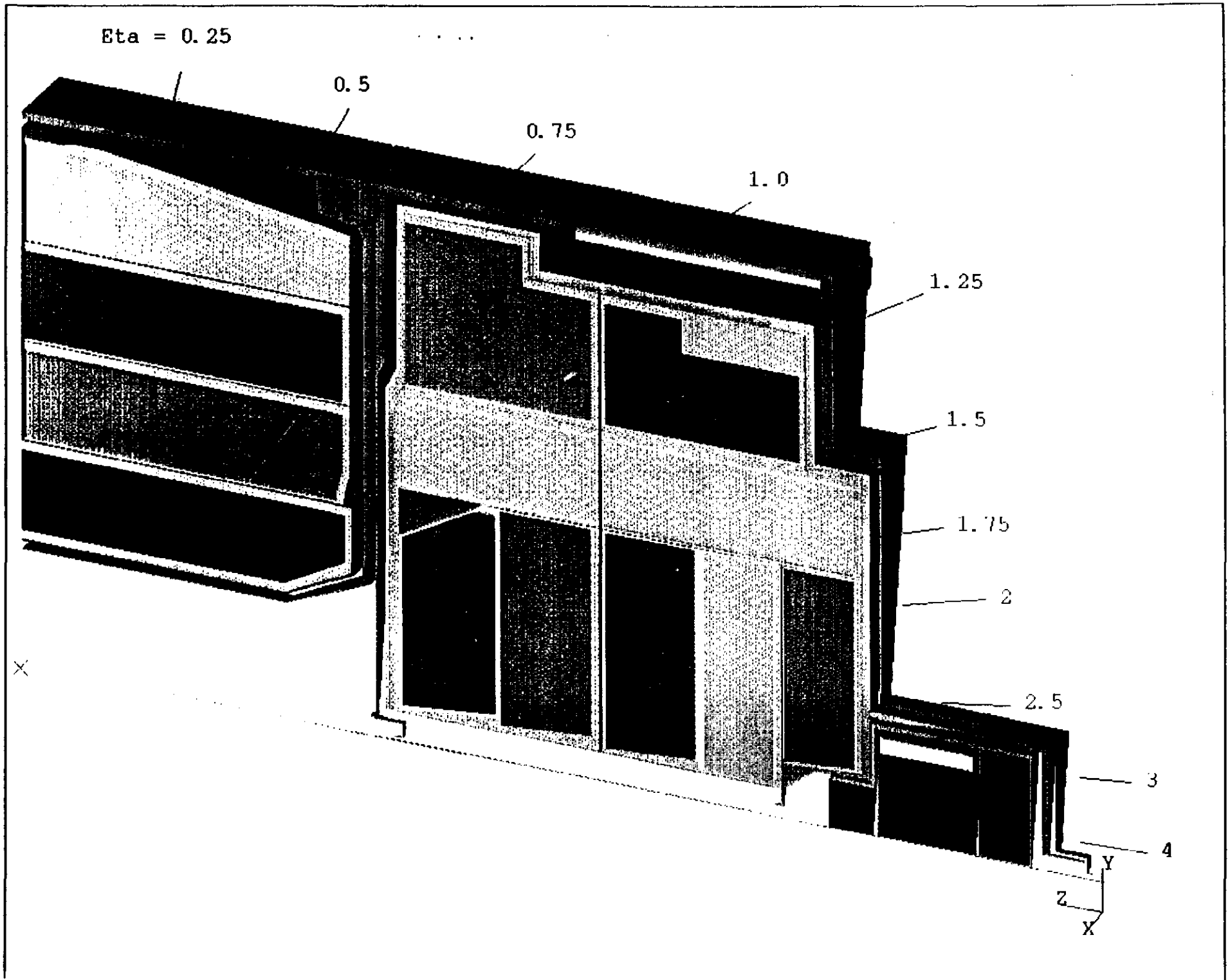
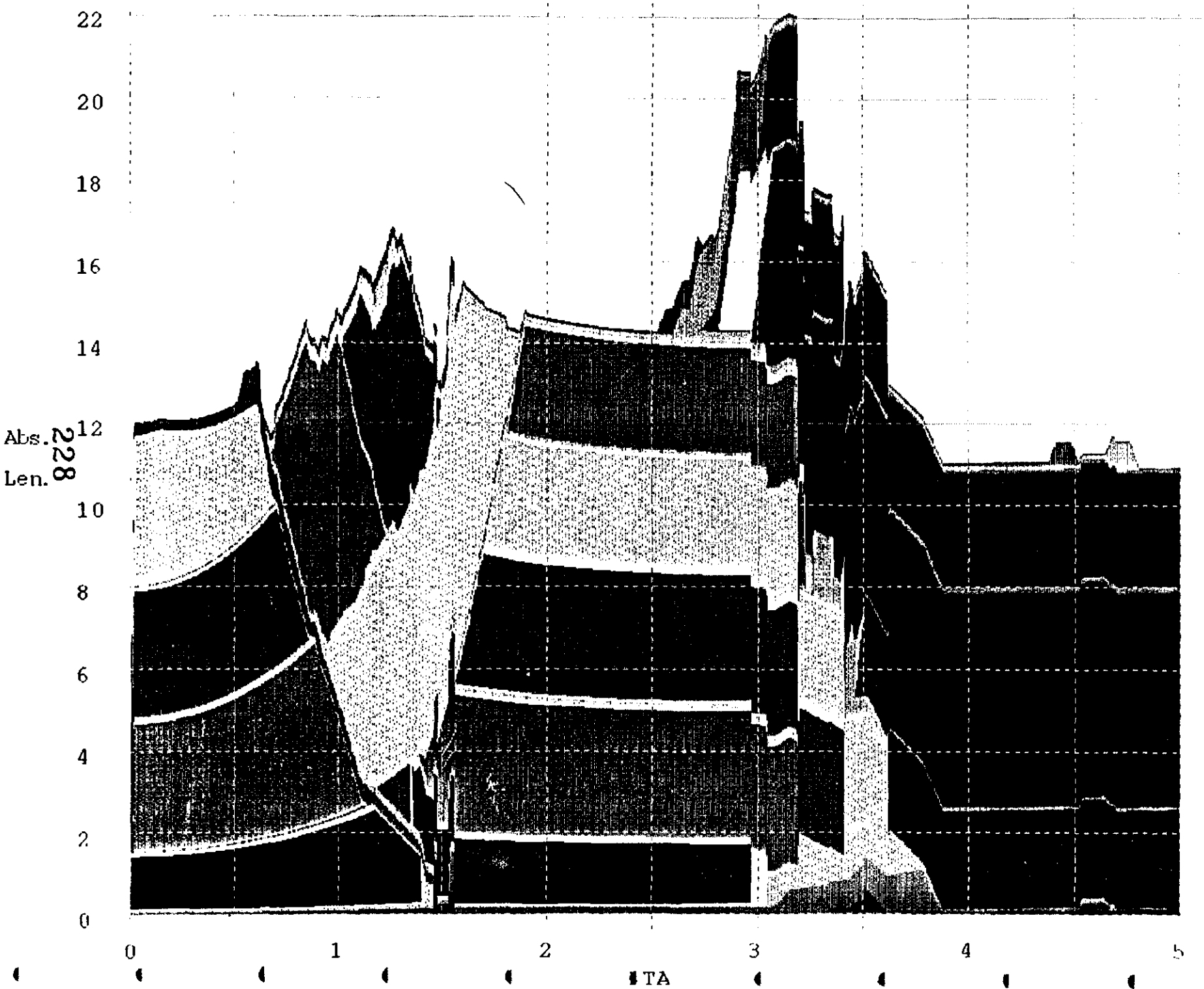

Eta = 0.25
0.5
0.75
1.0
1.25
1.5
1.75
2
2.5
3
4
Y
Z
X


22
20
18
16
14
12
10
8
6
4
2
0
Abs.
Len.
0
1
2
3
4
5
TA

Reasons to Pick LAr/Kr

1. Better energy resolution of the entire calorimeter.

   Calibration @ 40 ns demonstrated
   Uniformity - x,y variation of accordion
   Stability - very slow time constants
   Argon: D0, H1, NA34, E706...

2. Better Position Resolution - pointing.
   Smaller cell size, longitudinal division
   RD3 4.4mm/$\sqrt{E}$

3. Excellent Timing Resolution - Robust to 10^{34}

   System Measured for EM ~ 1 ns

4. Not Sole Source for Production
   Therefore savings can be realized by optimizing production sources: overseas, universities, etc. For example, Shanghai Aircraft Manufacturing Factory

5. Strong Core Team - Would like the ENTIRE Calorimeter Group to Join

Be firm!

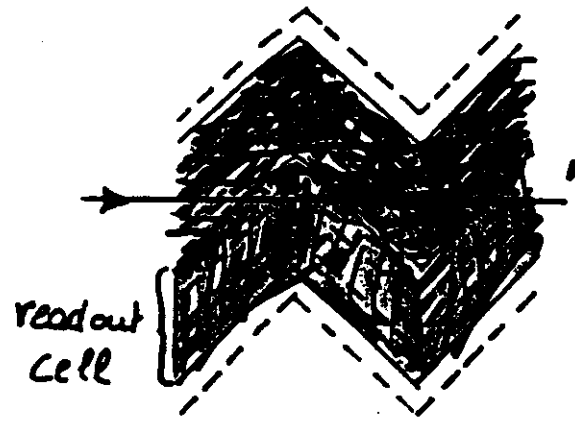
Our intercalibration 0.1%

Physics calibration for establishing the overall renormalization only.

No xenon tubes, etc.

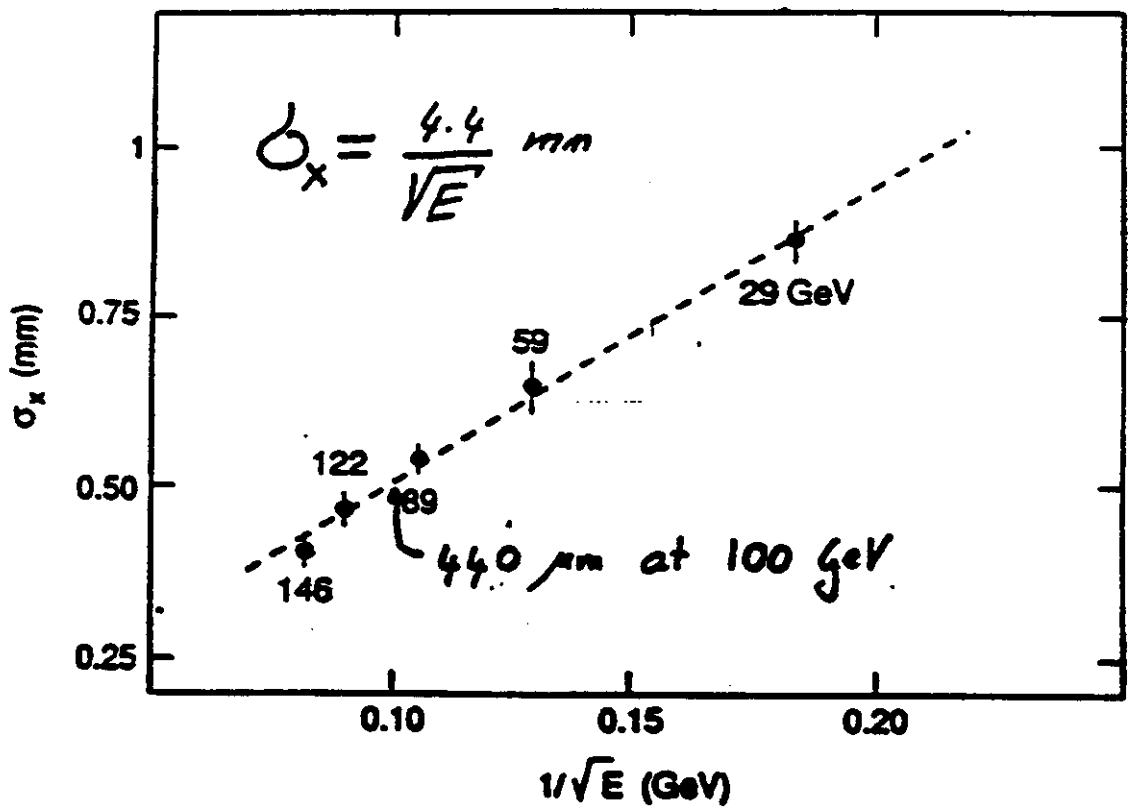
RD3

Spatial resolution: along x (ACCORDION FOLDS)



always 2 readout cells are involved

better energy sharing
⇕
better spatial resolution (σ_x)



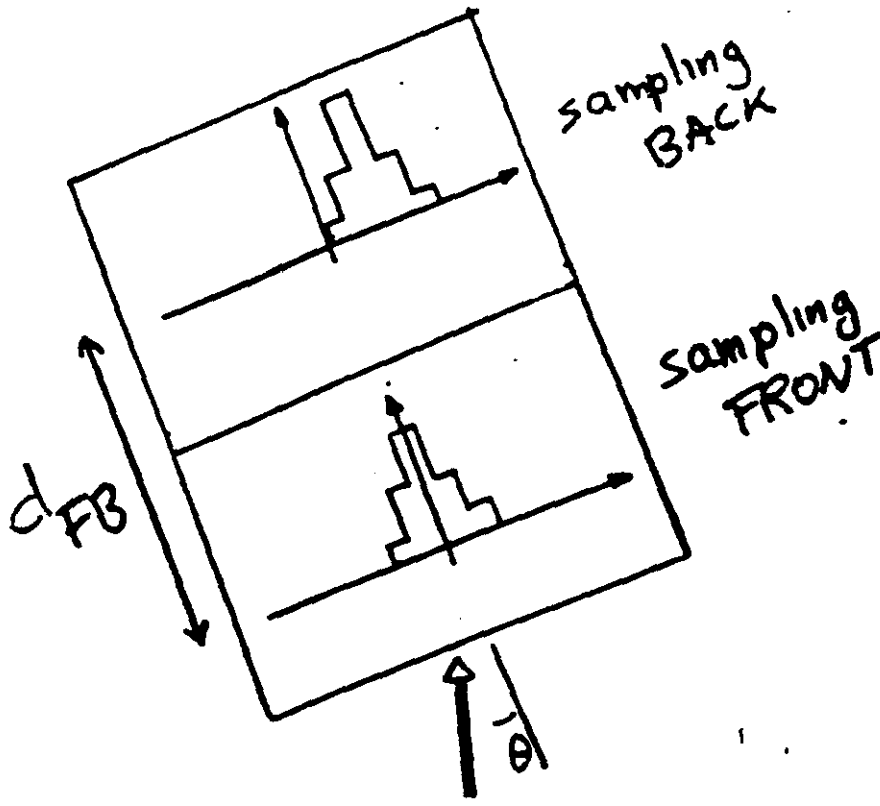
readout 100 ns

- 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 (muon) = 1.80 ± 0.05 mm

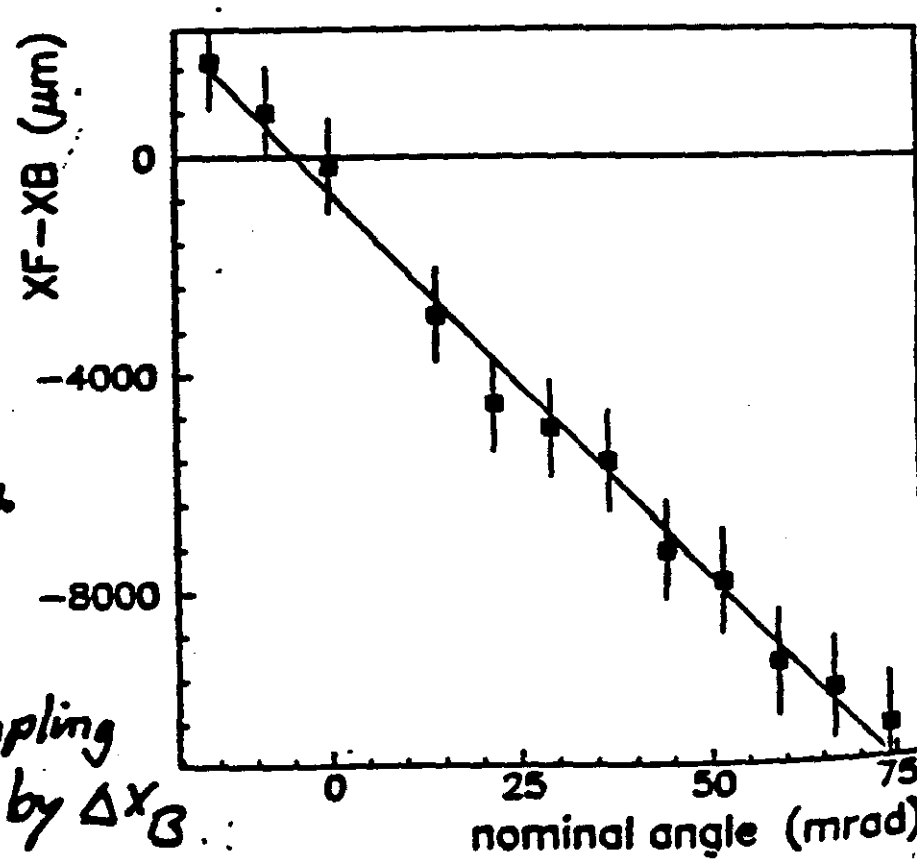
Angular resolution

RD3



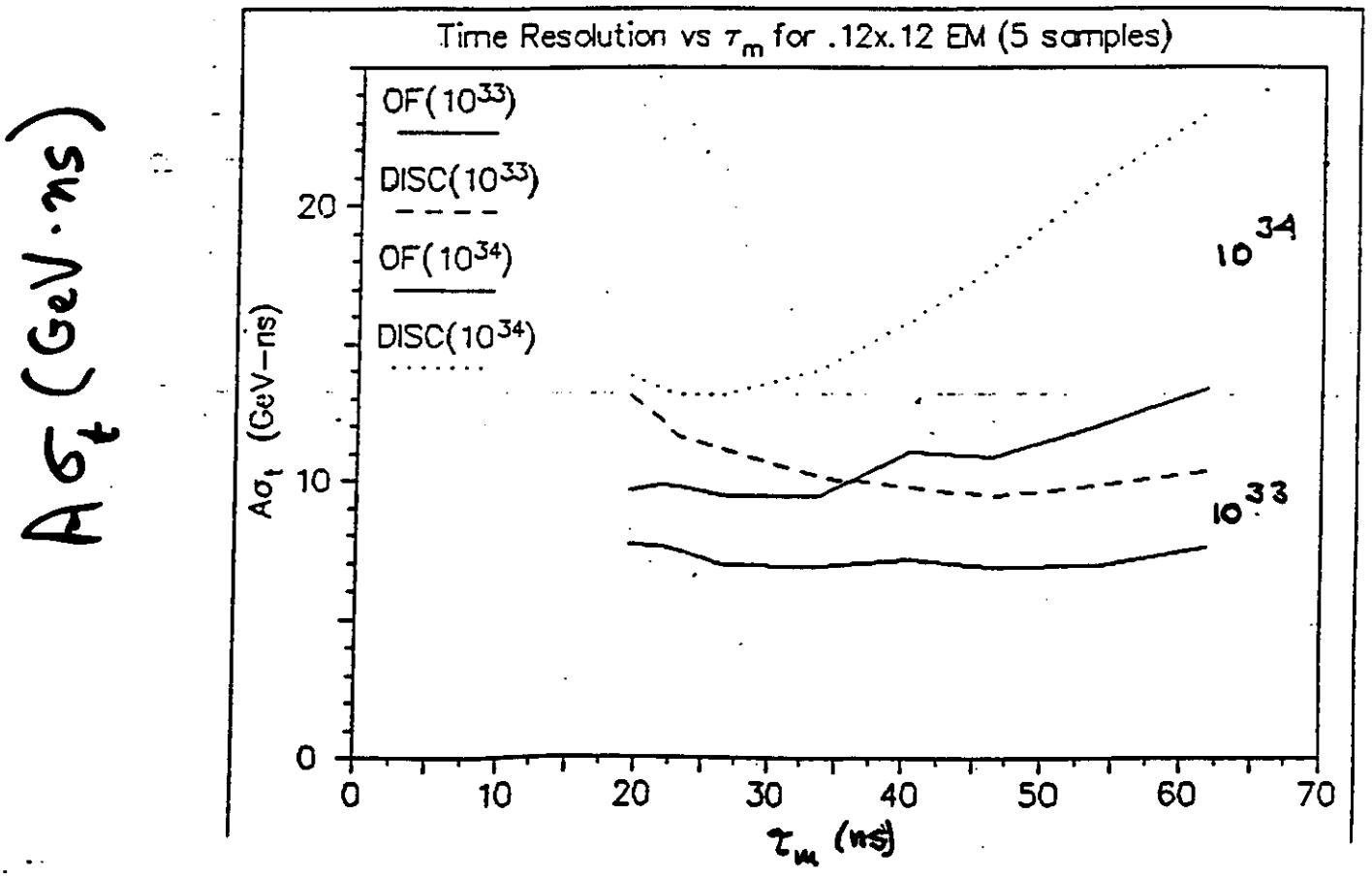
$$\theta = \frac{X_B - X_F}{d_{FB}}$$

- 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

W. Cleland


Time Resolution vs τ_m for .12x.12 EM (5 samples)
OF(10^{33})
DISC(10^{33})
OF(10^{34})
DISC(10^{34})
10^{34}
10^{33}
$A\sigma_t$ (GeV-ns)
τ_m (ns)
0
10
20
30
40
50
60
70

gem

γeμ

Presentation by:

Yuri Kamyshkov

Kamyshkov

M E M O R A N D U M

To : GEM Executive Committee

From : B.Barish, Yu.Kamyshkov

Subject : Points of Comparison for Two e-m Calorimeter Techniques in GEM

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1. ENERGY RESOLUTION

Following comparison of contributions to e-m resolution is made for two e-m options : BaF2 and LAr/LKr. These numbers represent best possible knowledge of different contributions and not necesseraly garantee that it is possible to acheive this resolution in the real GEM detector.

(matrix of 5x5 cells, E in GeV)

	BaF2	Liq Kr	Liq Ar
Energy dependent terms			
Thermal noise	3.0%/E	8.5%/E	14%/E
Sampling fluct.	-	5.2%/sqrt(E)	7.5%/sqrt(E)
Sampling fluct. @30 degree	-	5.9%/sqrt(E) (for 1/2 Pb)	7.8%/sqrt(E) (for 1/2 Pb)
(Photo)electron stat.	1%/sqrt(E)	< 0.1%/sqrt(E)	< 0.1%/sqrt(E)

Dead material (energy dependent terms)

	BaF2	LKr
Dead material in front of e-m @)	0.25Xo-tracker @ 90 degree	1.0Xo-tracker @ 90 degree (not optimized)

Effect of dead material for LKr/Ar option is particulary important at the end of the barrel (theta = 30 degree) where resolution can significantly degrade. Massless gap implemetation will be necessary to bring resolution back to the level of approx. 7%/sqrt(E) for LKr e-m calorimeter.

Constant terms

	BaF2	LKr/Ar
Leakages (@ ~100 GeV) (non-corrected by HC) + radiation effects	0.30%	0.30%
Initial residual longit. non-uniformity	0.15%	-
Transverse non-unif. residual after corr.	0.15%	0.12% (optimized RD3 term)
Photodetector linearity and stability	0.2%	-
Electronics (non-lin,digitiz.,etc.)	0.2%	0.2%
Calibration systematics	0.25%	0.1%
Total constant term	0.53%	0.4%

2. BACKGROUND SUPPRESSION

Detailed analysis of backgrounds for two GEM e-m calorimeter options is given in the report of H.Yamamoto and R.Zhu GEM TN-92-126. Relevant issues have been reviewed recently by the H->2 gamma task force. Irreducible gamma-gamma background is about 30 pb (almost independent on the technique), gamma-jet background in the R.Zhu analysis is 20 pb and 70 pb and jet-jet background 20 and 30 pb for BaF2 and LAr respectively. The difference between technologies is mainly due to lower speed and larger thermal noise in LAr/LKr. More ellaborated analysis (particulary for the LAr technique) of physics cuts made by T.Skwarnicki and A.Golutvin have shown that at luminosity 10**33 gamma-jet and jet-jet backgrounds for both techniques in the baseline configuration can be essentially reduced (still better for BaF2) without reduction of the significance level.

At higher luminosity (10**34) the capabilities of both techniques to cope with the background have not yet been studied sufficiently. However, existing simulations (J.Brau, B.Cleland, F.Paige, J.Rutherford) indicate that as the luminosity increases beyond the 10**33 level, there might be no large gain in the significance rate (sigmas/SSC year) for the H0->2 gamma process.

Both e-m calorimetry techniques as described in the baseline do not employ high granularity position detectors (shower max or preradiator types) and, therefore, the capability of the baseline GEM e-m calorimeter to suppress the coalescing gammas from pi_0 decays is a factor off 2-3 worse than that of SDC (@25GeV).

If the real physics (jet-jet and jet-gamma) and environmental background in GEM will be worse than what we are simulating, (PAC for example was concerned that the real background might be higher by a factor of 5) or if the physics at 40 TeV will turn out to be very different from present expectations, the GEM detector might need a high-granularity position detector inside the e-m calorimeter to suppress pi_0 and to improve pointing. This provides motivation for calorimeter scheme which is flexible and robust under these conditions. In this case the LKr/Ar system has this flexibility since it is more naturally suited to employ either a shower max or a preradiator type of device. Here the scheme proposed by Paul Mockett, with parallel plates and LKr may have advantages over the accordion configuration by employing simply better pointing and pi_0 rejection without large increase in the cost. This scheme is not sufficiently developed in the engineering sense.

For BaF2 a shower max detector can be implemented in principle, e.g. a layer of a two dimentional Si behind the first 5Xo of crystal. (This idea is being used in the CMS design). This solution is difficult because of the following fundamental issues (presently not resolved):
a) how to calibrate pairs of crystals in each tower?
b) how to support crystals in this structure?
c) how to achieve uniform front crystal readout?

The relative importance of several detector features relevant to e-m calorimetry have been discussed by GEM Physics Group on the Meeting September 2. Folowing significance factors have been assigned (10 is the highest) :

Energy resolution	10
Isolation (pileup & noise)	9
Suppression of isolated pi_0	2
Pointing in calorimeter	? <5
Gamma/e acceptance	
Performance at 10**34 (detectors must survive)	8
Hadron Calorimeter (missing Et, jets)	5

3. POINTING

In LKr/Ar (baseline configuration) detailed simulations of realistic pointing with two longitudinal segments (8Xo and 17Xo) have been shown to have the following consequences for H0->2 gamma detection

	Relative significance
Low luminosity	
Ideal LKr (5.5%/sqrt(E) - perfect position)	1.00
Known vertex, parametrized resolution, dead regions	0.80
Unknown vertex	0.47
10 ** 33 luminosity	
Random vertex (if ambiguous)	0.56
Realistic pointing (LKr)	0.68
10 ** 34 luminosity	
Random vertex (if ambiguous)	0.37
Realistic pointing (LKr)	0.51

For BaF2 system pointing is not implemented in the baseline design. Implementation proposed by proponents : two BaF2 pieces with front and back readout will have better (or same) angular pointing capability as LKr/Ar system where pointing is build into baseline configuration. Two crystal scheme has non resolved questions of calibration and light uniformity collection for the front crystal. BaF2 scheme with one crystal and two readout devices (front and back) seems to be more technically viable but has somewhat worse pointing resolution. Either of BaF2 pointing schemes imply that compact solid state photodiodes or APDs should be used for readout. In the baseline design readout is based on vacuum photo triodes, which should be placed properly in the magnetic field. Additional R&D work is required to develop alternative readout.

Implementation of a shower max or a preradiator detectors inside the e-m calorimeter for both techniques should provide additionally to pi_0 rejection the better pointing than in baseline configurations. This is a serious consideration which need to be studied for the final TDR calorimeter design.

4. RADIATION DAMAGE AND RESPONSE STABILITY

LAr/Kr is proven by other low luminosity experiments to be radiation hard and stable below 0.1% . Stability of the response is the major advantage of this technique.

In a high-radiation environment the choice of construction materials and good purification are important (particulary for LKr) so as not to poison the ionization medium and to provide response stability. Excluders in the liquid volume are not desirable since, under irradiation, they can be the source of impurities and because they might prevent heating/cooling convection. No tests have been made so far to address these issues. If poisoning occurs, the advantage of a liquid technique is that the liquid can be exchanged or purified.

For Barium Fluoride radiation damage has been the major concern. The radiation damage issues for BaF2 have been reviewed by an Expert Panel in December 91, January 92 and August 92. This Panel considered the prospects and methods of obtaining rad.hard crystals. Final report of the Panel is appended. Major conclusions of this report are the following :

- Best produced crystals are still not yet able to survive the SSC experimental environment without suffering degradation.

- Preradiation is not a viable solution to the radiation damage problem because of self-recovery, non saturation, and nonuniformities of the crystals.

- The only solution for the problem of radiation damage is to use annealing of the crystals by exposure to light in situ. Such method could make a calorimeter satisfying GEM's specifications using PRESENT production crystals.

Following the recomendations of the Panel the light annealing of BaF2 crystals in situ have been agressively studied and new production crystals from China were obtained. For these reasons several Panel members were reconvined on August 31 - September 1 to asses technically this new information. Report of this Expert Group (appended) concludes that OPTICAL ANNEALING OD RADIATION DAMAGE IN THE BaF2 WITH LOW INTENSITY, VISIBLE LIGHT CAN ESSENTIALLY ELIMINATE THE RADIATION INDUCED ABSORBTION OF THE FAST COMPONENT OF THE SCINTILLATION LIGHT.

In addition, there is a strong indication that in-situ illumination of the crystals while subjected to a radiation environment can counteract the effect of radiation-induced absorption. This optical annealing is effective for removing demage induced by both hadrons and gammas. Further, the level of annealing in the crystals is dependent on the wavelength of the bleaching light, with shorter wavelengths leading to greater and more rapid recovery.

It is concluded also that the issues of self-recovery, non-uniformity and non-saturation as stated in the Panel report of August 3-4 have been overcome. This means that the current quality of the production crystals available from China is sufficient to meet all GEM specifications as presented to the BaF2 Panel.

5. PILEUP NOISE

Analysis of pileup noise is given in the report of H.Yamamoto and R.Zhu GEM TN-92-126. Simulations for pileup noise have been done also by D.Marlow, P.Denes and T.Skwarnicki. Recent works (T.Skwarnicki and A.Golutvin) show that effects of pileup noise can be reduced by more carefull analysis.

From the stand point of pileup effects BaF2 technique is generally better since it is intrinsically faster.

It is possible to improve pileup noise electronically (past-future subtraction) on the expense of higher electronics throughoutput.

6. CALIBRATION STRATEGY AND ACCURACY

BaF2 group has proposed a complex scheme of calibration designed to result in overall intercalibration accuracy of 0.25%. It includes :

- Calibration with physics events Z0->e+e- (0.4% Biweekly, 0.3% Monthly at nominal liminosity) will provide absolute as well as crystal to crystal calibration.

Other calibration systems intended to monitor the sensitivity and maintain the relative calibration at the level of 0.3% are :

- Inclusive isolated sail through hadrons (MIPs)
  (0.3% accuracy with dedicated 1KHz trigger within 6-20 hours)
- RFQ monitor
  (accuracy 0.1% within 2 min; 0.3% stability demonstrated)
- UV flash lamp or laser monitor
  (L3 Xe lamp example 0.14% satbility over 45 days)

LKr/Ar group rely essentially on the electronical calibration only (0.1%) assuming that e-m detector prior to installation will be calibrated with the high energy beam and from that time on the calibration constants will not change with time. Although this assumption is based on the long term experience of operation of LAr systems it has not been veryfied experimentally for GEM design.

7. ENGINEERING MANUFACTURING CONSIDERATIONS

Noble Liquid EM

Excess material in front of the active EM region will require the addition of a "massless gap" layer or other special design innovations. It appears that achieving .9Xo (exclusive of tracker and poly/boron) is the best that can be achieved with the current baseline design. The basic problem is the large number of different layers required rather than a single problem layer.

The barrel accordion assembly is subject to difficult manufacturing and assembly tolerancing. In order to produce a uniform array the gaps and misalignments resulting from the tolerances will require both extremely precise machining and a high level of assembly craftsmanship. The details of these problems in the proposed design were a major concern of an recent Engineering review (see attached Report).

The parallel plate arrangement may offer some advantages in assembly and manufacturing if a reliable and fast solder joint technique can be found or developed.

As described below the inclusion of the noble liquid EM in an integrated assembly will result in either a larger diameter system or a less dense calorimeter (~11 lambda at eta=0.0)

Barium Fluoride EM

Although laser welding of titanium foils has been demonstrated it relies on a combination of the proper equipment and precise fixturing set-ups. As with the barrel accordion, the control of tolerance stack-up will be critical and will require a very high level of craftsmanship.

The production schedule for the barium fluoride crystals is extremely tight. Even with installation of the EM calorimeter after the installation of the muon system the crystals will be the critical path item.

A substantial amount of new capital equipment must be purchased and commissioned by the PRC before full-scale crystal production can begin. Of particular concern are the estimated 50 vacuum furnaces which will be required to produce an average of 20 boules at a time rather than the current operating units which produce 4.

3. COST COMPARISON

A. US Cost Basis Comparisons:
(Official GEM estimates by ORNL,MMAG,Princeton)

	LAr Integrated	Scintillating	LKr Hybrid
Hadron+EM	$101,000K		
Hadron		$57,000K	$63,000K
EM		$78,000K	$42,500K
Kr in the Barrel	$19,500K	$0K	$2,000K
Subtotal	$120,500K	$135,000K	$107,500K
SAIC *)	+0/-4%	+19%/-4%	+9%/-7%
Forward	$10,000K	$10,000K	$10,000K
PreRad	$0K	$0K	$0K
Electronics	$22,000K	$6,000K	$19,000K
LKr Total	$152,500K	$151,000K	$136,500K
(LAr Total	$133,000K)		

*) uncertanties to this numbers as set by independent SAIC cost review

B. International Cost Basis Comparison *) :

(The funding required from US sources is shown)

	LAr Integrated	Scintillating	LKr Hybrid
Hadron+EM	$76,000K		
Hadron		$41,000K	$45,000K
EM		$65,000K	$32,000K
Kr in the Barrel	$6500K		$1000K
Subtotal	$82,500K	$106,000K	$78,000K
Forward	$0K	$0K	$0K
Electronics	$11,000K	$3,000K	$9,500K
LKr Total	$93,500K	$109,000K	$87,500K
(LAr Total	$87,000K)		

*) This is a extremely tentative comparison in which the following assumptions have been made:

a. Liquid Krypton reduced by two thirds through contributions
b. Electronics cost reduced by half through contributions
c. Fiber hadron reduced by 28% through contributions
d. Noble liquid costs reduced by 25% through contrib.
e. Forward calorimeter provided at no cost.
f. BaF2 calorimeter cost reduced by 9% through contributions

Conclusions:

It is more difficult to reduce the cost of Barium Fluoride significantly due to the large fixed cost of the crystal array.

9. Schedule

Schedules have been prepared for each of the three calorimeter system options based on the current GEM baseline schedule. Potential problems are:

Noble liquid integrated option:

Installation in the GEM allotted 4 months does not appear to be realistic (8 months is required according to design report)

Manufacturing plan is unknown

Scintillating option:

Installation schedule can be met.

Production of the crystals within the allotted fabrication period will be difficult. The PRC is assuming 3 years of full production with a one year start-up period. This results in the last crystals arriving very late in the final assembly process. Beam testing and assembly of the last end cap will have to be accelerated to have it ready for installation in April 1998.

Hybrid option:

Both production and installation schedules can be met.

The liquid krypton barrel will be installed inside the fiber hadron before final testing is complete. If a significant vessel or feedthrough integrity problem arises at this time the repair process could significantly interfere with the overall GEM schedule if the hadron barrel has to be moved to provide access.

10. CALORIMETER INTEGRATION

Noble Liquid Integrated:

The compactness of teh current design appears to be difficult to achieve. (see Engineering report). It is likely that either the diameter will be increased or the calorimeter density reduced.

Scintillating:

The RFQ calibration system will protrude through the outer tracker. It will also remove the equivalent of a fiber hadron readout tower.

Hybrid:

The cryogenic utilities require special passages through the fiber hadron calorimeter. These passages significantly reduce the performance of an estimated 16 towers or 2% of the total.

General Interface Comments:

Tracker design should has no more than .2 Xo in order not to degrade the performance of the EM calorimeter.

The forward calorimeter design specifications are not well enough defined to provide a basis for configuration judgments.

II. INSTITUTIONAL RESPONSIBILITIES AND INTERNATIONAL COLLABORATIONS.

BaF2 EM

A strong international collaboration led by Caltech group has been formed in support of this technology, primarily with several institutions in China (nine institutes and over hundred collaborators). These institutions appear to be dedicated to the success of the venture, and some have strong vested interests. Commitments regarding the cost of the crystals are in place. Several Russian groups expressed their interest in the crystal calorimeter project, some with potential crystal production.

The US base of the BaF2 collaboration is strong with several active groups (e.g. San Diego, LLNL, Princeton, CMU) making major contributions. Engineering issues are addressed by ORNL in collaboration with several Chinese institutions and with the advice of CERN staff members.

Though the general plan seems viable, closer coordination will be required with China including the US progect management playing the responsible role in China.

LKr/LAr EM

The US effort involves mainly the BNL group, with engineering support from Martin Marietta, Denver. Two other US groups are presently involved in noble liquid technologies: Seattle and Tucson. However, they are not integrated into the mainstream effort. Seattle offers an alternative configuration to that being studied at BNL, and Tucson has concentrated it's efforts on the forward system. It is not clear if Martin Marietta Denver will be in a position to continue to provide engineering services beyond the completion of the Technical Design Report. ORNL could, in principle, help in this area.

Regarding international collaboration, initial contacts are in place with one Chinese group (IHEP) and with a potential Chinese vendor (Shanghai Aircraft Industry). In addition, the possibility exists that Novosibirsk will provide the LKr. The terms for these international prospects have not been worked out. Strong ties exist between the BNL group and CERN-based groups (RD3) performing similar R&D work for LHC.

Institutional and international considerations for the LKr/LAr hadron calorimeter may relate to the choice the EM calorimeter.

For the hybrid case, the scintillating fiber collaboration is broadly-based with a large number of US institutions actively participating. Engineering work has been performed by Draper and by ORNL. As in the case of the accordion EM calorimeter, strong ties exist between the US groups and CERN-based groups performing similar R&D work (RD1). An aggressive strategy has been pursued by the proponents regarding international contributions. For example, negotiations are underway to obtain large quantities of copper from Albania at a very favorable price. If this option is choosen, realistic production plan, responsibility scheme and assembly schedule must be developed.

The integrated Noble Liquid Option poses additional problems. Since the noble liquid work has been carried out essentially single-handedly by the BNL group (with engineering support of Martin Marietta, Denver), the effort must be significantly broadened within the US including viable management structure. In addition, aggressive effort will be required to involve non-US groups in this technology, where there is little previous experience.

Report of the BaF_2 Expert Group
after its meeting of August 31 - September 1, 1992

Abstract

The BaF_2 expert group met on August 31, and September 1, 1992 at the SSC Laboratory to review *new* data regarding radiation damage issues on BaF_2 crystals obtained since the August 3-4, 1992 BaF_2 Panel meeting. This BaF_2 expert group - comprised of a sub-set of the original Panel members[1] - was convened at the request of the spokesman for the BaF_2 collaboration, Professor Harvey Newman, with the authorization of the GEM Detector Management. Data was presented on the first day by various researchers, including the proponents of BaF_2 Electromagnetic Calorimeter. This data included new results on optical annealing of radiation damaged crystals as well as the implementation of annealing methods and systems in-situ. In addition new information was presented by representatives from the Shanghai Institute of Ceramics/ Chinese Academy of Sciences on barium fluoride crystal production issues.

1. Summary

At the last meeting of the BaF_2 Panel on August 3 and 4, 1992 it was recognized[2] that optical annealing of radiation damaged BaF_2 crystals "could make a calorimeter satisfying GEM's specification using present production crystals." The panel recommended that "this issue should be studied without delay." In the last three weeks new data on optical annealing including characterization of the spectral behavior, required intensity, and rate of bleaching has been obtained.[3]

Based on the data presented by researchers from 5 independent institutions, including Brookhaven National Laboratory (BNL), California Institute of Technology (CIT), Lawrence Livermore National Laboratory (LLNL), Tsing Hua/McGill University, and West Virginia University (WVU), the expert group concludes that **optical annealing of radiation damage in BaF_2 with low intensity, visible light can essentially eliminate the radiation induced absorption of the fast component of the scintillation light.**

In addition, there is a strong indication that in-situ illumination of the crystals while subjected to a radiation environment can counteract the effect of radiation-induced absorption. This optical annealing is effective for removing damage induced by both hadrons and gammas. Further, the level of annealing in the crystals is dependent on the wavelength of the bleaching light, with shorter wavelengths leading to greater and more rapid recovery.

We conclude that the issues of self-recovery, non-uniformity and non-saturation as stated in the Panel report of August 3-4 have been overcome. This means that the current quality of the production crystals available from China is sufficient to meet all GEM specifications as presented to the BaF_2 Panel.

2. New Experimental Facts

A. Visible light (i.e., $\lambda > 400$ nm, for which the presently proposed photodetectors have minimal sensitivity) removes all the visible absorption and nearly all of the UV absorption due to radiation-induced damage in BaF_2 crystals (see accompanying Table and Figures in Appendix I). This is because induced defects have multiple absorption bands throughout the spectrum. Bleaching one component band can destroy all bands associated with that absorption center.

B. Experimental results indicate that the amount of light needed to overcome the radiation-induced absorption at 400 rad/hour, typical of the dose rate expected at $\eta = 2.5$ in the GEM detector, is of the order of milliwatts/cm^2. This intensity is easily accommodated by standard silica fiber-optic technology.

C. The total amount of light required to achieve the necessary optical annealing in the calorimeter is estimated to be of the order of kilowatts and appears to be within the scope of standard laser or high intensity lamp technology.

D. Results from WVU and CIT indicate that visible light annealing exhibits a time behavior characterized by a rapid bleaching of absorption centers followed by a longer term recovery.

E. For a given wavelength of annealing light, the rate of photobleaching appears to reach a constant level after a time, related to the absolute intensity of the annealing light. Application of additional light of shorter wavelength then causes a further photobleaching to an improved level of absorbance at 220 nm.

F. Calculations indicate that by monitoring the absorbance of the crystals in the calorimeter, optical annealing can be utilized to tailor the crystals in different parts of the calorimeter in order to optimize performance.

3. Crystal Growth

As mentioned in the Section 1, currently available crystals from China can meet or exceed the GEM specification for optical clarity utilizing optical annealing. Because of this fact, the current quality of raw material available in China is sufficient. At present, material of the requisite quality is being manufactured in batch sizes of several hundred kilograms. Therefore, a development program to scale up to full production is not required. There is a high confidence level that the same quality material can be manufactured by different sources.

A prototype production furnace capable of growing 15-20 crystals in a single run has been constructed and is being commissioned at the Beijing Glass Research Institute. In addition, improvements in the vacuum system have been implemented in an existing furnace at Shanghai Institute of Ceramics, however no crystals from this furnace have been made available for study at this time.

Improvements in optical quality of the Chinese BaF_2 crystals after irradiation, reported in the December, 1991 BaF_2 Panel Meeting, were initially attributed to the addition of a scavenger, designated "703." Since that time, improvement in the quality of raw material (reduction of OH content) has led to a cessation of the use of 703 and a return to the well-proven technique of scavenging with PbF_2.

Extensive chemical and structural analysis was performed on one of the FNAL (T-series) crystals and one of the new, more radiation-hard SIC (S-series) crystals. The two major differences found between these crystals were the presence of 2 orders of magnitude (11,000 ppmw) greater concentration of strontium in the T-series crystals and improved structure in the new S-series crystal. More work is needed to unambiguously establish the link between chemical and structural characteristics and radiation hardness.

Since the last Panel meeting, two growth runs were completed at Optovac. The first using ordinary grade powder and the second using custom-manufactured material of higher chemical purity. Samples from the first run were sent to WVU and annealing measurements have been made. Also, a sample from this run, sent to CIT, was tested by irradiation to 1 Mrad and optically annealed. The results obtained by WVU and CIT are consistent with each other, showing similar radiation sensitivity.

Samples from the second run were only made available to CIT on August 28 and there has not been sufficient time to perform measurements on these crystals. Samples from this run were also sent to BNL at the same time.

LLNL is currently growing crystals using high grade source material in both zone-refining and Czolchrowski melt furnaces. Crystals will be available for analysis in early September.

4. Mechanical Processing in China

A number of site visits have been made by physicists and engineers to facilities in China that have the capability to mechanically process the BaF_2 ingots into their final shape and surface finish. Based on the assessment of these facilities by experts on mechanical and optical processing, there is sufficient expertise and capability in China to process the full 16,000 crystals needed for the calorimeter, provided there is the expeditious implementation of the required number of cutting, grinding and polishing machines..

In addition, the technology needed to achieve high quality surfaces and UV reflective coatings is being transferred to the Chinese. Recent visits have resulted in the production of crystals in China with surface finishes rivaling the best achieved in the US.

5. Conclusions

The data presented to this group is very encouraging and we recommend that work continue on the effects of optical annealing of radiation-induced damage in BaF_2. Among the subjects to be studied are:

A. Further quantify the effects of light intensity and wavelength dependence on annealing.

B. Irradiate crystals to different total dose levels in the range of 1 krad to 50 krad followed by optical annealing in order to study the effect of the amount of induced damage on the bleaching rate.

C. Perform in-situ illumination of full-sized crystals during irradiation using prototype fiber-optic light delivery systems.

D. Investigate potential light sources for optical annealing and delivery systems.

References:

1. Members of the BaF_2 Expert Group were: Dr. Paul Schotanus - Chairman, Dr. Robert Sparrow, Dr. Michael Strathman, Dr. Larry Halliburton, Dr. Craig Wuest, and Mr. Baruch (Ben) Fuchs.

   Additional Attendees and/or Presenters: Prof. H. Newman, Prof. R. Zhu, Prof. Z. W. Yin, Prof. Y. Kamyshkov, Prof. R. C. Shang, Prof. J. Branson, Prof. H. Kobrak, Prof. Y. N. Guo, Prof. X. Q. Yu.

2. "Report of the the BaF_2 Panel after its third meeting on August 3-4, 1992," Prof. Stan Majewski, Chairman, August, 1992.

3. "BaF_2 Meeting - SSCL," GEM TN-92-166, August 31, 1992.

4. "Monte Carlo Studies for BaF2 at ORNL," Progress Report presented at August 3-4 Panel Meeting by Prof. Y. Kamyshkov, Oak Ridge National Laboratory, July 31, 1992.

5. H. Newman, Spokesman, "GEM Detector BaF_2 Precision EM Calorimeter Selection Report," August 25, 1992.

6. Da-an Ma and Ren-yuan Zhu, "Light Attenuation Length of Barium Fluoride Crystals," CALT-68-1811, GEM TN-92-148, August 30, 1992.

7. L. E. Halliburton, G. J. Edwards, M. P. Scripsick, "Effect of Optical Bleaching on Radiation-induced Defects in BaF_2," West Virginia University Technical Report, August 31, 1992.

8. C. R. Wuest and G. J. Mauger, "Effects of Light Exposure on Irradiated Barium Fluoride Crystals," Lawrence Livermore National Laboratory, August 27, 1992.

9. S. P. Stoll, "UV and Visible Light Bleaching of Radiation in SIC BaF_2 Sample #SIC703," Brookhaven National Laboratory, August 24, 1992.

10. Da-an Ma and Ren-yuan Zhu, "On Optical Bleach of Barium Fluoride Crystals." CALT-68-1812, GEM TN-92-149, August 30, 1992.

11. Y. N. Guo, "Constructing Cosmic Ray Test Stand at IHEP & USTC for GEM BaF2 Calorimeter." August 30, 1992.

12. C. R. Wuest, B. Fuchs, and W. Kway, "Barium Fluoride R&D at LLNL." GEM TN-92-168, July, 1992.

APPENDIX I

Measurement of Light Attenuation Length at 220 nm before irradiation, after irradiation to approximately 1 Mrad (Co-60), after bleaching with 488 nm (Ar^+ laser), and after additional bleaching with > 340 nm light (Hg lamp).[7]

		Light Attenuation Length (LAL) at 220 nm			
Sample	Length	As-received	After 1 Mrad	After 488 nm	After >340 nm
Optovac	12.5 cm	315 cm	21 cm	75 cm	108 cm
SIC S106	2.5 cm	>400 cm	23 cm	96 cm	338 cm
SIC (FNAL)	12.5 cm	>400 cm	33 cm	229 cm	315 cm
SIC (FNAL) (repeat)	12.5 cm	>400 cm	33 cm	199 cm	315 cm

Specification set by the GEM Executive Committee in March, 1992:

LAL (@ 220 nm) - unirradiated crystals - 190 cm

LAL (@ 220 nm) - irradiated crystals - 95 cm

Figures:

These figures are meant to show the general effects of optical annealing as well as current work on simulations and engineering of an annealing system and are by no means a complete representation of the data that was presented to the expert group.

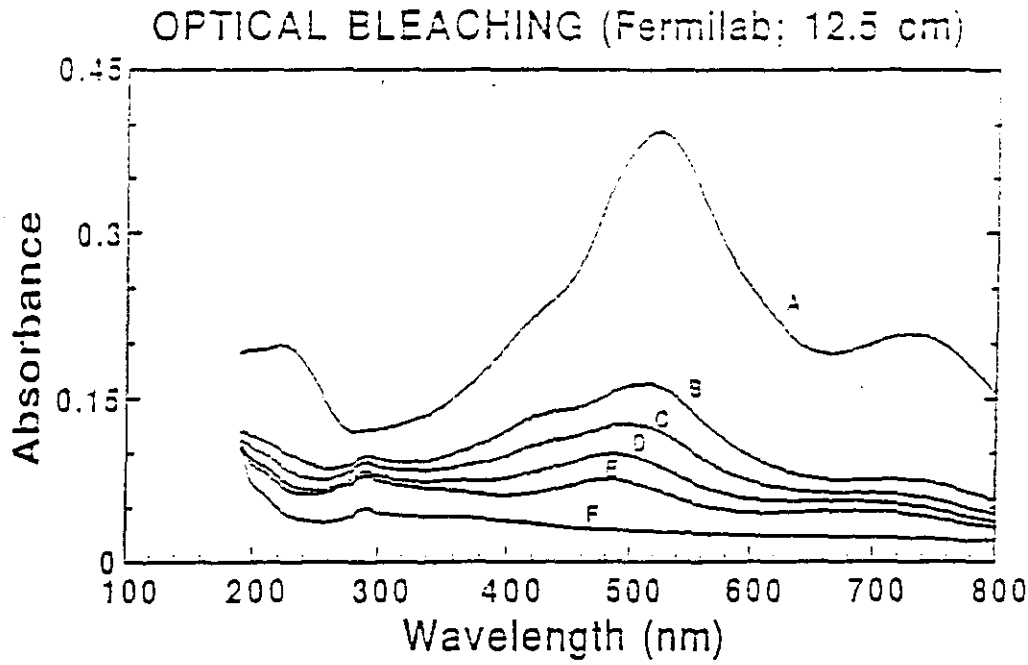
1. Measurement of optical bleaching of 12.5 cm SIC (FNAL) crystal from Reference 7. The top figure shows the as-received absorbance (curve F) followed by the absorbance after 1 Mrad irradiation (curve A) and a series of optical bleachings using 488 nm laser light over a period of 30 minutes. The bottom figure shows the data beginning with curve E on an expanded vertical scale. Continued bleaching with 488 nm light is shown in curve G, followed by additional bleaching with >340 nm light (curve H) and full UVexposure (curve I). Curve I is seen to fall very nearly on the original as-received curve F. The spectral absorbance data shown here is valid for wavelengths greater than 200 nm. The data for wavelengths less than 200 nm is not accurate due to limitations in the spectrophotometer system.

2. Measurement of optical bleaching of 20 cm long trapezoidal BaF_2 crystal (40 mm x 40 mm at the larger end and 34 mm x 34 mm at the smaller end) from Reference 9. This crystal is designated SIC703 and was manufactured at the Shanghai Institute of

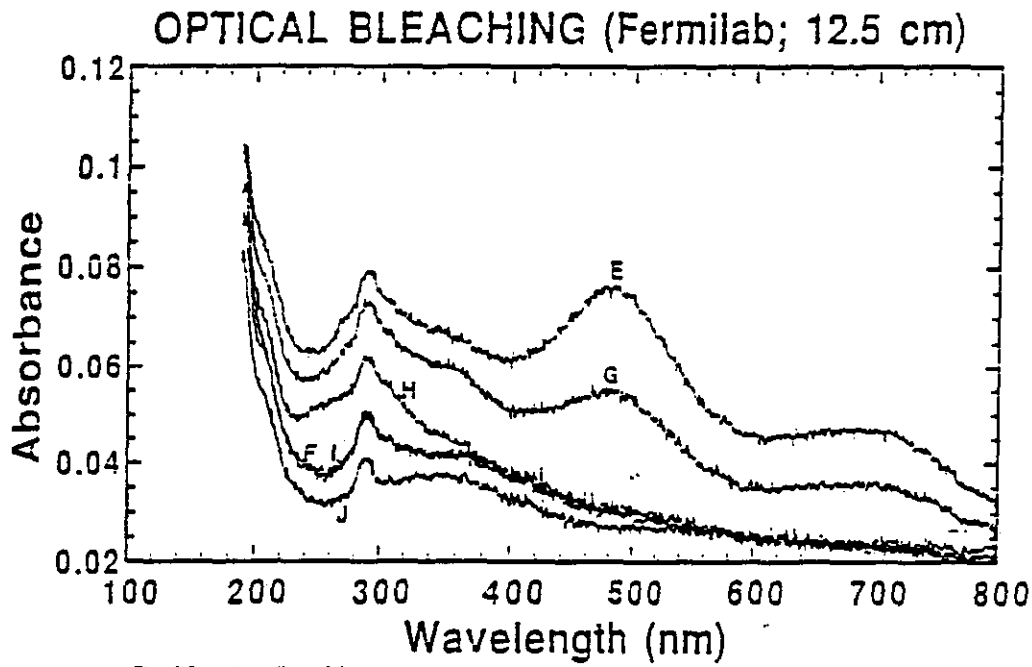
Ceramics. The figure shows the behavior of the crystal exposed to various amounts of UV light after irradiation to approximately 2 Mrad of hadrons plus 1 Mrad of gammas (the hadron dose is estimated from TLDs used for gamma dosimetry and is approximately 4 times the indicated TLD dose). Optical bleaching was performed using an unfiltered mercury light source with emission in the visible and the UV. Dramatic recovery is noted after only 10 minutes of light exposure. Additional light exposure leads to further recovery as indicated in the figure. Additional data on UV and visible annealing can be found in References 3, 8 and 10.

3. Computer simulation of the light transport in a 50 cm long crystal illuminated by a single fiber in a particular injection scenario. This calculation was performed by E. Tarkovsky at ORNL. The 3-dimensional plots show the profile of the light at the corresponding position along the length of the crystal. Perfectly reflecting walls are assumed in this calculation. Near the top of the crystal the light is seen to be nearly isotropic in cross section. Diffuse scattering due to imperfect reflection at the walls and multiple reflections will further enhance this effect.

4. Proposed ORNL design for fixing fiber-optic cables to PMT prisms attached to the BaF_2 crystals (provided by M. Rennich).



A: 24 hrs ^{60}Co irradiation
B: 10 min @ 488 nm
C: 20 min @ 488 nm
D: 40 min @ 488 nm
E: 80 min @ 488 nm
F: As-received



E: 80 min @ 488 nm
F: As-received
G: 160 min @ 488 nm
H: 10 min >340 nm
I: 10 min full UV
J: 3 hrs 500°C N_2 anneal

Figure 1

Radiation damage and recovery of S 0700 with exposure to direct UV light and thermal annealing.

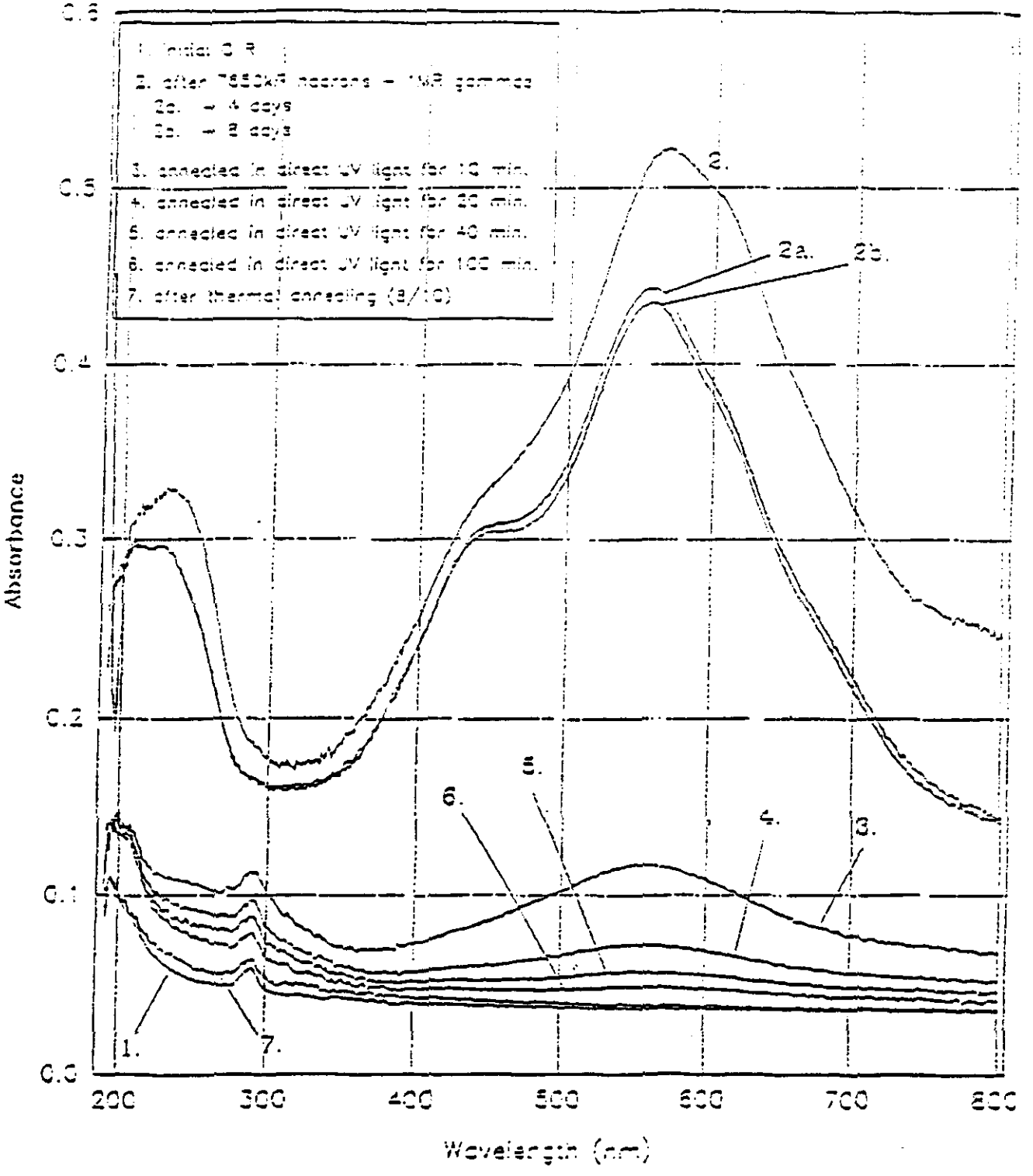
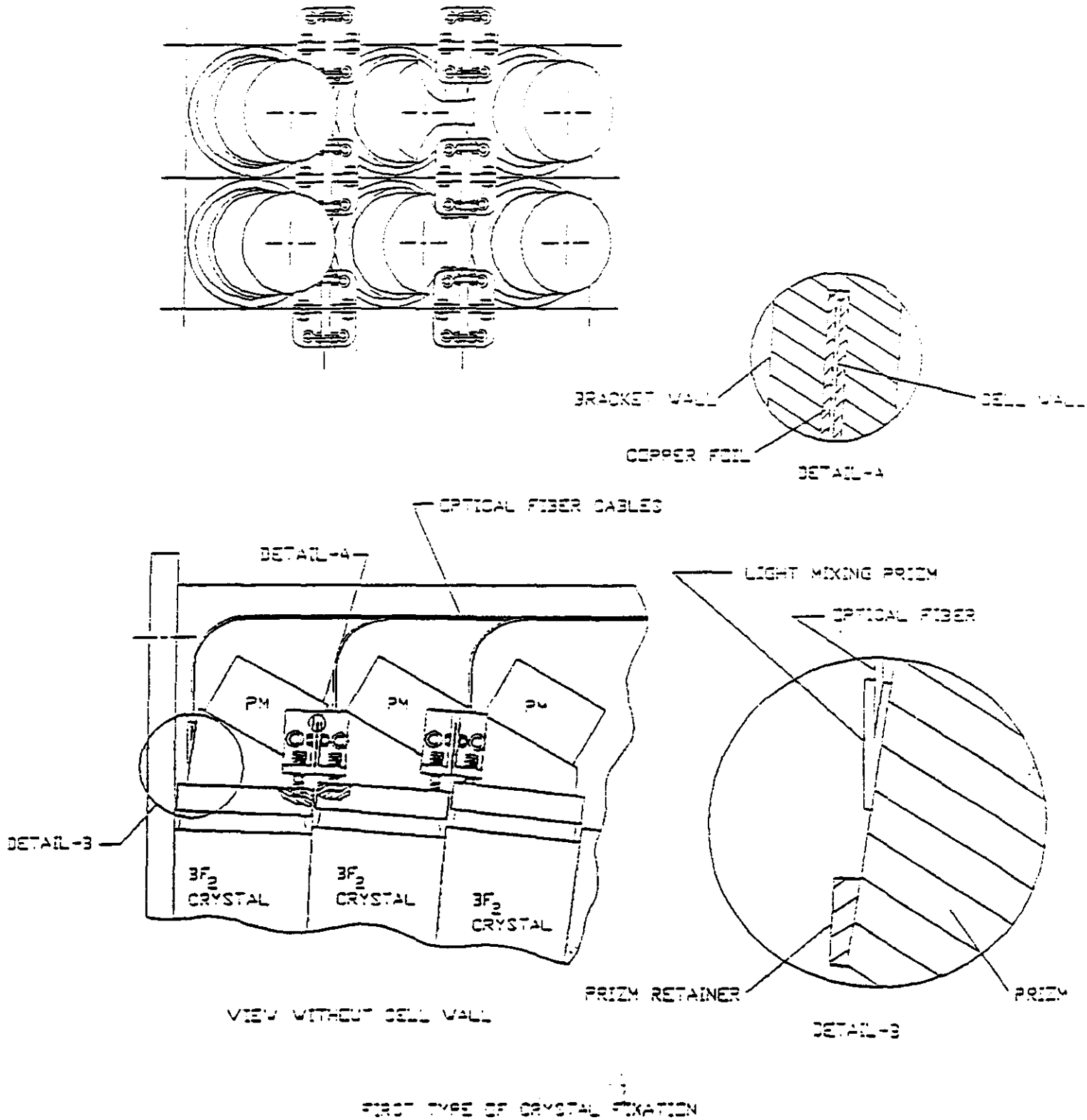


Figure 2

Figure 3



FIRST TYPE OF CRYSTAL FIXATION

Figure 4

REPORT OF THE BaF_2 PANEL

After its third meeting on August 3-4, 1992

1. Summary

The BaF_2 Panel met on August 3 and 4 at the SSC Laboratory. The Agenda for the meeting is included (Attachment 1). The meeting started with a session with the participation of the GEM representatives, including the proponents. During this session the results of the radiation damage tests, material studies as well as production efforts in the US and China were reviewed. The panel discussed and summarized in its closed session the current status of the R&D effort to develop radiation hard barium fluoride for the high precision electromagnetic calorimeter of the GEM detector.

A lot of good work has been done in developing and understanding high quality BaF_2 crystals. The crystals produced in China are the best produced anywhere to date. Good as they are, they are still not yet able to survive the SSC experimental environment without suffering degradation.

The fundamental issue with BaF_2 is still the one of purity and radiation hardness. The proposal of the BaF_2 advocates is to rely upon preirradiation and saturation of radiation damage to produce stable crystals. There was an unanimous agreement of the panel that with the knowledge presently available, preirradiation is not a viable solution to the radiation damage problem because of self-recovery, non saturation, and nonuniformities of the crystals.

The only solution we see at present for the problem of radiation damage is to use annealing of the crystals by exposure to light *in situ*. Such a method could make a calorimeter satisfying GEM's specifications using <u>present</u> production crystals. It is not known what intensity or wavelength light would be most useful for this purpose, and this issue should be studied without delay.

2. Radiation Damage - Experimental Facts

Following a long discussion of the presented results the panel came with the following list of the main established experimental facts (based on small number of tested samples):

- there is no evidence for intrinsic scintillation loss up to the highest tested doses,
- there is no significant transmission damage caused by MeV neutrons up to fluences of $\sim 10^{14}$ n/cm^2 in small crystals (this is explained by a much lower interaction cross section for MeV neutrons than that for ionizing radiation),
- there is saturation observed in transmission and light output for irradiation with low energy (Co-60) gamma rays,
- saturation in transmission is not established for GeV hadrons,
- induced absorption due to hadrons in a GeV range is similar to that due to low energy gammas; however, after hadron irradiation the induced absorption

due to an additional dose of low energy gamma rays in a test performed at high dose rate increase beyond the saturation limit observed for gammas only.

- induced absorption due to hadrons is fully annealable by thermal treatment @500 °C.

- induced optical absorption due to low energy gammas can be annealed, at least partially, using UV and visible light.

- there is evidence for slow, long term self-recovery of optical absorption at room temperature.

- there is non-uniformity of induced absorption after irradiation along crystal length in presently available long samples.

- there is induced radioactivity of the order of 10 mRem/hr in large crystals after hadron dose of the order of 1 MRad.

3. Results of the Recent Material Studies and Correlation Between Contamination and Radiation Damage

- pure BaF_2 is intrinsically a very radiation hard material, and there is a very strong connection observed between radiation induced absorption and the level of impurities in the crystal matrix, however no exact correlation between radiation damage and the identified contaminant species and their level was yet established; further reduction of trace impurities due to better source material and improved vacuum should yield more radiation hard crystals,

- crystals with rare earth and high Sr contamination showed higher induced post-irradiation absorption,

- crystals doped with OH^- at high temperature show high induced absorption,

- crystals produced in China in 1991 (crystals from the FNAL test) have large (10-100 micron) precipitates randomly distributed in the bulk material, while the new (such as S52) samples produced with a new oxygen scavenger "703" show small, 0.1 - 5 micron, interconnected inclusions exhibiting a "swirl pattern".

4. Surface Quality and Radiation Damage

The practical diamond pitch polish technique developed at LLNL produces a superior crystalline surface as compared to the existing technology at the Shanghai Institute of Ceramics (SIC). No direct correlation between surface quality and radiation resistance was established up to now, but it is expected that good quality surface will improve reflectance and will prevent surface defects from propagating into crystal. In addition it will be useful for several mechanical aspects associated with the crystal production such as coating and gluing.

5. Long Crystal Production in China

The crystals produced in China are the best crystals available, but they still do not, as yet, meet minimum requirements for radiation hardness. Having been encouraged by the rate of progress up to December 1991, the panel did not see as significant a progress made since then. It is not clear what role the rate of flow of money to the Chinese played in this. An improvement was made in purity of raw material, and it was established that different sources have significantly different qualities. A concern of the panel is whether the best source can supply the required amount (50 tons per annum) of high purity material. Also, the panel would like to know the status of the prototype production furnace and if its design has been proven in order to meet the proposed procurement schedule. The panel was impressed with the development of resources in China for the entire production from procurement of raw material to coating by involvement of additional institutions.

6. Production of High Quality Small Samples

As of this time(August 4) there are still no high purity small samples produced in the special parallel R&D effort suggested by the panel after its second meeting. However, the first batch of several such samples are expected during the month of August from LLNL and Optovac. The studies at Optovac have shown that refractory metals (W, Te, Mn) do not look promising as alternatives to graphite crucibles presently used in China because of chemical reaction or sticking. Coated graphite crucibles are expected to reduce the cationic leaking from the graphite into the melt.

7. Recommendation on Continued R&D

There is a good possibility that if more time were available for a continued vigorous R&D program, the GEM crystal specifications could be met. The highest priority should be given to the study of a technique of optical annealing of crystals *in situ*. The issue of saturation in radiation induced absorption due to hadrons and photons should be studied further, and the effect of different dose rate should be defined. Work on production of good quality long, radiation hard crystals should continue, including:

- characterization of precipitates in crystals to establish correlation between their structure and the radiation damage level in the furnaces,

- availability of improved raw material with respect to impurities,

- implementation of improved vacuum system,

- on the basis of the results obtained at LLNL and Optovac, the panel encourages SIC to procure full size pyrolitically coated crucibles from LLNL,

- proof of design of production equipment and processes for full scale production should be delivered,

- the impact of the hadron induced radioactivity on operation of the detector should be studied with more irradiations and simulations,

- effect of reflective coating on radiation resistance of crystals should be studied including possible chemical reactions between irradiation products such as F and aluminum from the coating.

Additionally, the panel recommends a higher level of coordination between the US and Chinese parts of the collaboration.

Providing that new important experimental results from the continuing R&D effort will become available before the technology choice is made for the GEM electromagnetic calorimeter, the experimental situation should be again reevaluated at that time. This was the last scheduled meeting of the full panel, but many panel members have expressed their willingness to help with this later review.

8. Additional Information

The panel was helped during its discussions by three researchers who have recently joined the BaF_2 R&D program: Dr. Craig Wuest and Dr. Ben Fuchs from Livermore and Dr. Larry Halliburton from University of West Virginia. The regular panel members are listed in Attachment 2. C. Dozier and M. Rothschild did not take part in the third meeting.

Attachment I

Agenda for the Third BaF_2 Panel Meeting
Dallas, 03-04 August 1992

SSCLab, Building 4, Strategy Room
Monday, August 3, 1992

(The asterisk (*) used when GEM BaF_2 and/or GEM representatives will be present).

9:00 *Opening Remarks*, Fred Gilman, Harvey Lynch (SSCL)

9:15 *Reminder of the Charge, Discussion of the Agenda*, Harvey Lynch (SSCL)

9:30* *Reports on the Latest R&D Activities and Status by the GEM BaF_2 Group*:
(1) *Activities in the US*
(2) *Work in China*, by Harvey Newman, Ren-Yuan Zhu

10:30* *Short Summary of the Stability Requirements*, Yuri Kamyshkov (GEM)

10:40* Coffee Break

11:00* *Material Characterization of BaF_2 at CEA*, Michael Strathman

11:55* *Spectroscopic Characterization of Point Defects in BaF_2*, Larry Halliburton (University West Virginia)

12:15* Working Lunch (Strategy Room)

13:00* *Gamma, Neutron and Hadron Radiation Damage Studies of BaF_2*, Craig Woody

13:30* *Surface Preparation and Analysis, Reflective Coating, High Purity Crystal Growing*, Craig Wuest, Ben Fuchs (Livermore)

14:15* *Site Visit of Several Facilities in China*, Craig Wuest (Livermore)

15:00* *Short Contributions*, by different speakers

15:30* Coffee Break

16:00 *Comments on Important Issues*, Paul Schotanus

16:30 *Round Table Technical Discussion* (and the proposed discussion leader):
- Summary of BaF_2 Radiation Damage Situation (Craig Woody)
- Feasibility of Pre-Irradiation Treatment, Saturation, Recovery (Self-annealing) and Theoretical Understanding of the Effects (Paul Schotanus)
- Summary of Material Analysis Results (Michael Strathman))
- Production of High Purity Crystals with Good Surface Quality (Robert Sparrow)
- Evaluation of the Production Efforts in China (Robert Sparrow)

18:00 Meeting Adjourned

19:30 Dinner at Javier's

SSCLab, Building 4, Strategy Room

Tuesday, August 4, 1992

8:15*	*Meeting with the GEM Collaboration Representatives*
9:00	*Continuation of the Panel Technical Discussion*
10:15	Coffee Break
10:45	*Panel Recommendation, Preparation of the Report:* *Assessment of Radiation Hardness of Crystals* *Assessment of Production Capability* *Still Unsolved Issues Relevant to the Technology Choice* *"Final" Recommendation*
12:00	Working Lunch
13:00	*Continuation of Preparation of the Panel Report*
15:00	*Discussion of the Draft by the Panel* *Preparation of the Revised Version*
17:15	End of Meeting

Attachment II

BaF_2 Panel Members

Abraham, Marvin
Chen, Yok
Craig, Richard
Dozier, Charles
Drukier, Andrew
Fuchs, Ben
Halliburton, Larry
King, Steve
LeCoq, Paul
Lynch, Harvey
Majewski, Stanley
Rothschild, Mordechai
Schotanus, Paul
Sparrow, Bob
Strathman, Michael
Woody, Craig
Wuest, Craig

Report of the Noble Liquid Calorimeter Review Panel

Members of the Panel:
Ron Barber, Jim Brau, Mike Harris, Bruno Mansoulie, Nicolai Martovetsky, Michael Marx, Mark Rennich, Bill Wisniewski(chair).

Attendees:
Steven Bellario, Nick DiGiacomo, Brian Eason, Howard Gordon, Chunhua Jiang, Mark Lajczok, David Lissauer, Lyle Mason, Greg Velasquez.

Charge to the Panel:
The panel is asked to review the status of the noble liquid calorimeter. Special attention should be paid to the accordion electromagnetic portion of the calorimeter.The panel should focus on the engineering viability of the design.

Brief Summary of the Review:
The calorimeter design was reviewed on Friday, 14 August. The presentations, given by Mason, Eason and Lajczok, paralleled the 'Responses to Questions Regarding Engineering Issues of the GEM Noble Liquid Calorimetry Options'. This report, which had been submitted to the panel in advance of the review, was written in response to the eight questions given to the design team in July.

During the first half of the review the panel concentrated on the EM calorimeter. The final seven questions were addressed more cursorily during the afternoon session: Presentations were limited to those issues which panel members felt required clarification or discussion beyond that contained in the written responses.

Conclusion of the Panel:

The panel identified NO SHOW-STOPPERS in the conceptual design presented by the design team.

The design of the integrated noble liquid calorimeter is at an early stage of development. We believe that completion of this compact design, though feasible, will be very challenging.

The design of the electromagnetic-only calorimeter also appears to be feasible. However, the lack of a scheme that permits all of the barrel signals to be passed through the dewar wall threatens the viability of this option.

We suggest that, if either of the noble liquid calorimeter options is chosen, a detailed technical engineering review be held within a few months.

Comments and Concerns:
Although the panel found nothing in the design that would lead to the failure of the calorimeter, we nevertheless have concerns about features of the design. Some of these features

may increase the risk associated with these calorimeter options. We note that the design is currently weak on detailed specifications and requirements, especially in the electromagnetic part of the calorimeter. We recommend the preparation of a document which details specifications and relates them to performance requirements. Many of our comments are advisory in nature. We hope that the engineering team will consider them in the evolving design of the calorimeter.

Electromagnetic Calorimeter:

Structure: There was a great deal of concern about the viability of the accordion structure. Much of this was relieved by Bruno Mansoulie's comments about a prototype that has been built by the RD3 Collaboration at CERN. This prototype has been cooled and tested. However, this prototype is significantly shorter than the GEM barrel EM design (.4m vs 4.3m; a 2m module is in production), and, though it has a radiator with similar design, has differences in internal structure and dimensional details from GEM. This leads us to suggest the need for an R&D program.

Thermal contraction modelling of the accordion plate is at the very early stage of considering single plate initial and final states. This model suggests that the lead in the steel-prepreg-lead sandwich may creep. This modelling should be expanded to consider the ensemble of plates that constitute a module and the assembly of modules that constitute the calorimeter. The detailed structure of the plates, including the planned grading of lead thickness along the length of the module and the filler strips, needs to be studied. In order to understand the level of risk associated with the radiator design, full size accordion plates should be subjected to many thermal cycles to verify that delamination, buckling, etc., do not occur.

During the calorimeter cooldown process, temperature differentials develop between the radiator structure and the liquid vessel. It is important to understand the spatial interaction of these calorimeter components during this process using models. The design should include appropriate tolerances. The details of the cooldown procedure can mitigate potential problems.

Assembly: The assembly scheme presented is too complicated. The 120 sliders which must be aligned 40 at a time during insertion of the electromagnetic calorimeter into the outer liquid vessel, or into the integrated calorimeter, is an example of excessive complication. The scheme also involves welding stepped alignment plugs, into which the modules' inner radius alignment pins extend to prevent asymmetric slippage during contraction, through the inner liquid vessel. The sort of weld intended here is often prone to failure, which would lead to leaks into the vacuum volume. There is an abiding impression that the radiator/vacuum vessel assembly is overconstrained.

The amount of material in front of the first active element in the accordion is not optimal. The gap which contains the inner tie-rods and the inner motherboards for the electronics also contains, in the case of krypton, about a radiation length of liquid before the first sensitive element. The design should attempt to minimize this additional material.

In the case of the integrated liquid calorimeter,

real estate for location of signal feed-throughs is available. In the case of the electromagnetic-only calorimeter, there is currently no viable plan for signal feed-throughs. The limited surface area available for feed-throughs on this smaller cylinder presents an extremely serious challenge which should be addressed addressed quickly.

Integrated Calorimeter:

The design of the integrated calorimeter is extraordinarily compact. This is a considerable achievement. However, this may increase the design's susceptibility to problems.

Tolerances specified in the hadronic module stack-up are tight. It may be difficult to maintain the module thickness to 1% (between 5.4 and 7.7mm) during construction.

The gaps between the vacuum vessel and liquid vessel are very small. The 50mm separation that is allotted will be crowded with cooling tubes welded to the outside of the liquid vessel as well as with multi-layer insulation blankets. (A liquid nitrogen cooling tube layout has not been done). We are concerned about the vacuum vessel in the region of barrel-endcap interface. Studies should be performed to determine if the vacuum vessel will need to be heated in order to avoid brittle fracture. In addition, thermal effects on the tracker gas system should be evaluated. The design should address the interface problem of the calorimeter's thermal effects on the neighboring systems: what is required to return the system boundary to ambient temperatures?

The barrel feed-through region, which is located in the outer corner of the barrel near the endcap-barrel interface, is crowded because of the tight spatial constraints. The vacuum gap pinches down on the side of the feed-through closer to the central detector support (see Fig. 2-11,18 in 'Responses...'). It will be very difficult to install these these cables. Unless care is taken, the cables could easily provide a thermal conduction path between the cold mass and room temperature. Sufficient space is available in the endcap so that this problem is not expected there.

The compactness of the design limits the ability to do many of the welds with ease. The tight tolerances force delicate cables to pass close to weld points. Plans for limiting cable damage have been identified. We feel that the efficacy of these techniques should be demonstrated. Verification of weld integrity should also be addressed: What technique is needed? Is there space to do it?

Mitigation of the effects of catastrophic vacuum loss should be investigated as well as the effects of large liquid leaks into the vacuum volume. The thickness of both the inmost vacuum and liquid vessel walls ought to be re-examined.

An interface design of the calorimeter to the central detector support joint should be generated. Proposed gussets from the central detector support to the calorimeter outer vacuum vessel will affect the vessel strength and will complicate the design.

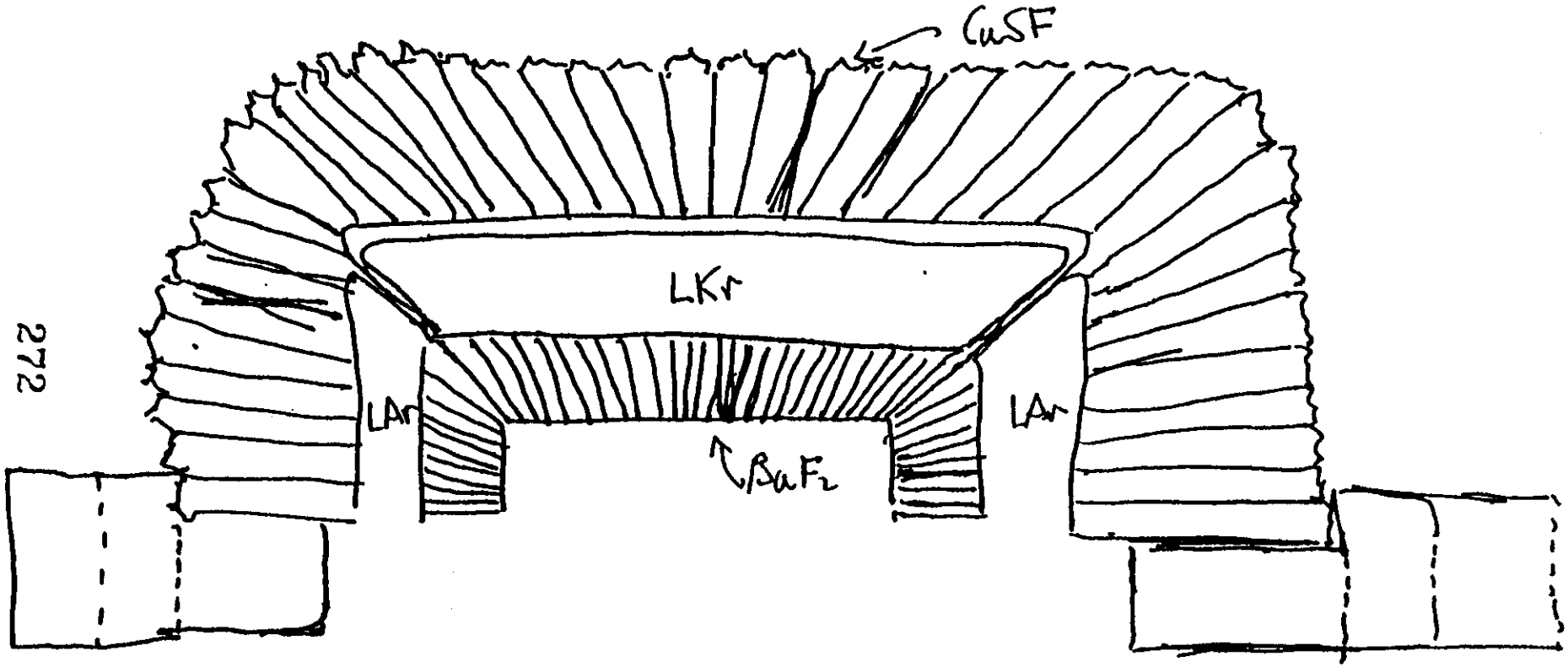
The presence of active electronic components inside the liquid volume introduces a heat source. The combined stay-cooling tube scheme appears promising. More effort is needed

here. Concerning the components themselves, Howard Gordon assured us that devices known to have good radiation hardness characteristics will be used. Nevertheless, we feel that the lack of redundancy in the present design should be remedied.

Schedule:

The schedule for installation of the calorimeter has not been optimized. A revised schedule that matches the proposed GEM global installation schedule should be prepared before the beginning of September.

The panel hopes that the design team will attempt to avoid radial growth of the calorimeter as the conceptual design presented proceeds through the full engineering process.



Designed by K.Lane

Reasons to Pick LAr/Kr

1. Better energy resolution of the entire calorimeter.

   Calibration @ 40 ns demonstrated
   Uniformity - x,y variation of accordion
   Stability - very slow time constants
   Argon: D0, H1, NA34, E706...

2. Better Position Resolution - pointing.
   Smaller cell size, longitudinal division
   RD3 4.4mm/$\sqrt{E}$

3. Excellent Timing Resolution - Robust to 10^{34}

   System Measured for EM ~ 1 ns

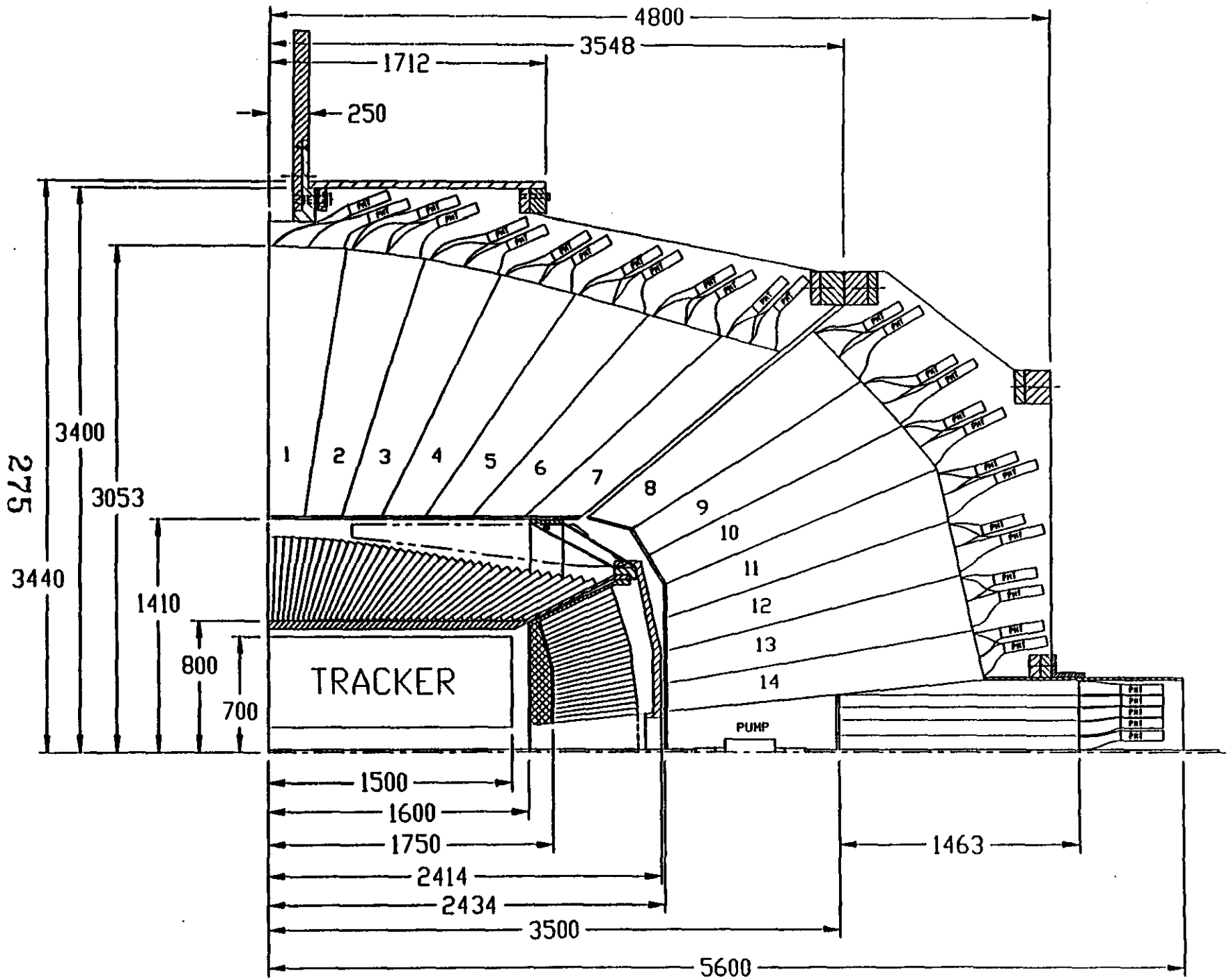
4. Not Sole Source for Production
   Therefore savings can be realized by optimizing production sources: overseas, universities, etc. For example, Shanghai Aircraft Manufacturing Factory

5. Strong Core Team - Would like the ENTIRE Calorimeter Group to Join

BARIUM FLUORIDE CRYSTAL EM and SCINTILLATING FIBER HCAL

THE PRECISION CALORIMETER SYSTEM FOR GEM

- *HIGHER PHYSICS DISCOVERY POTENTIAL*
  - → Higher Electron and Photon Energy Resolution
- *HIGHER SPEED*
  - → Lower Noise for Isolation Cut
- *HERMITICITY, UNIFORMITY*
- *COMPACTNESS*
  - → Higher Muon Resolution
- *INTERNATIONAL R&D and MANUFACTURING TEAM READY TO START PRODUCTION IN 1993*
  - → 17 Institutions; 200 Collaborators

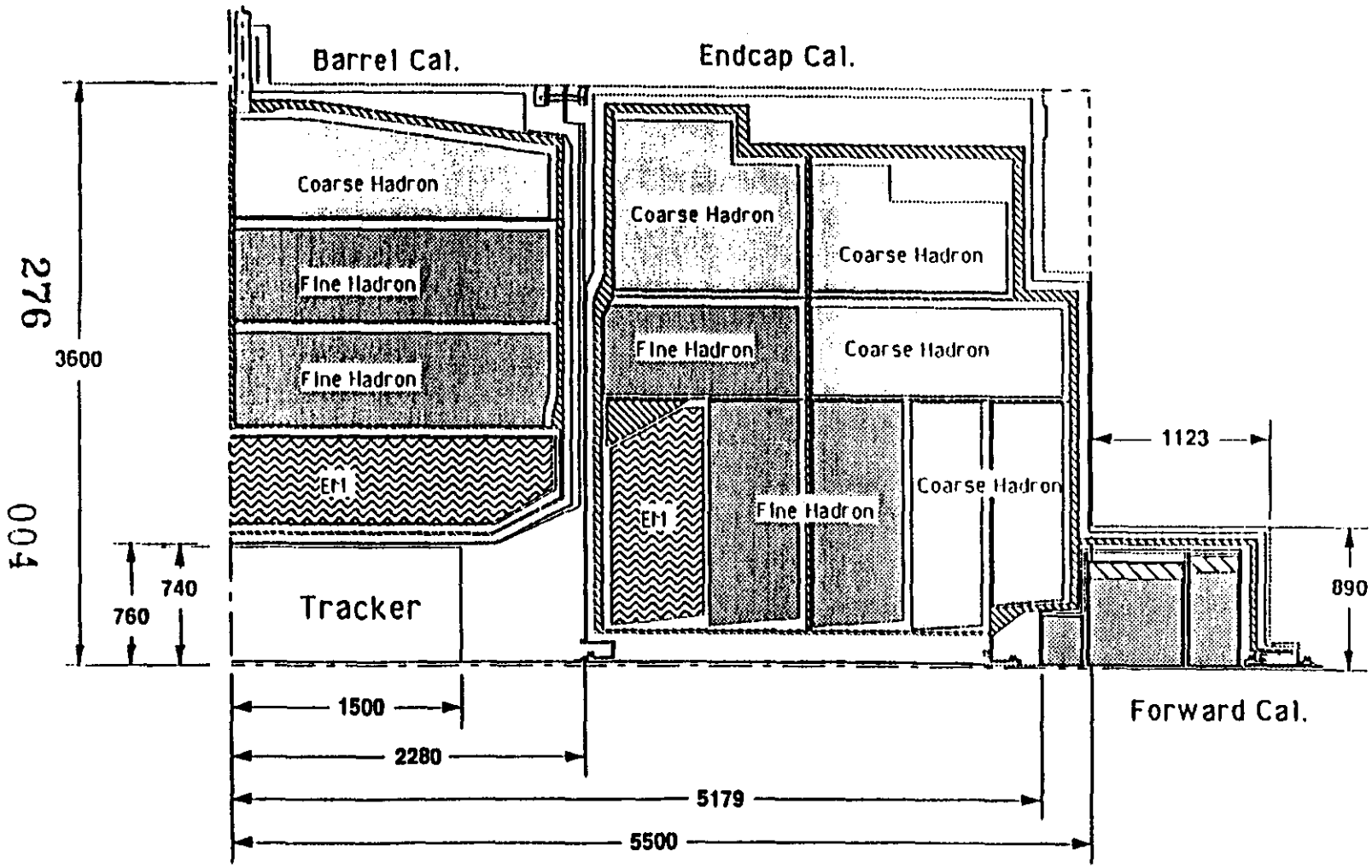


GEM DETECTOR
Fiber Hadron Calorimeter
Fiber with BaF2 Design

A. SHIRIKOV

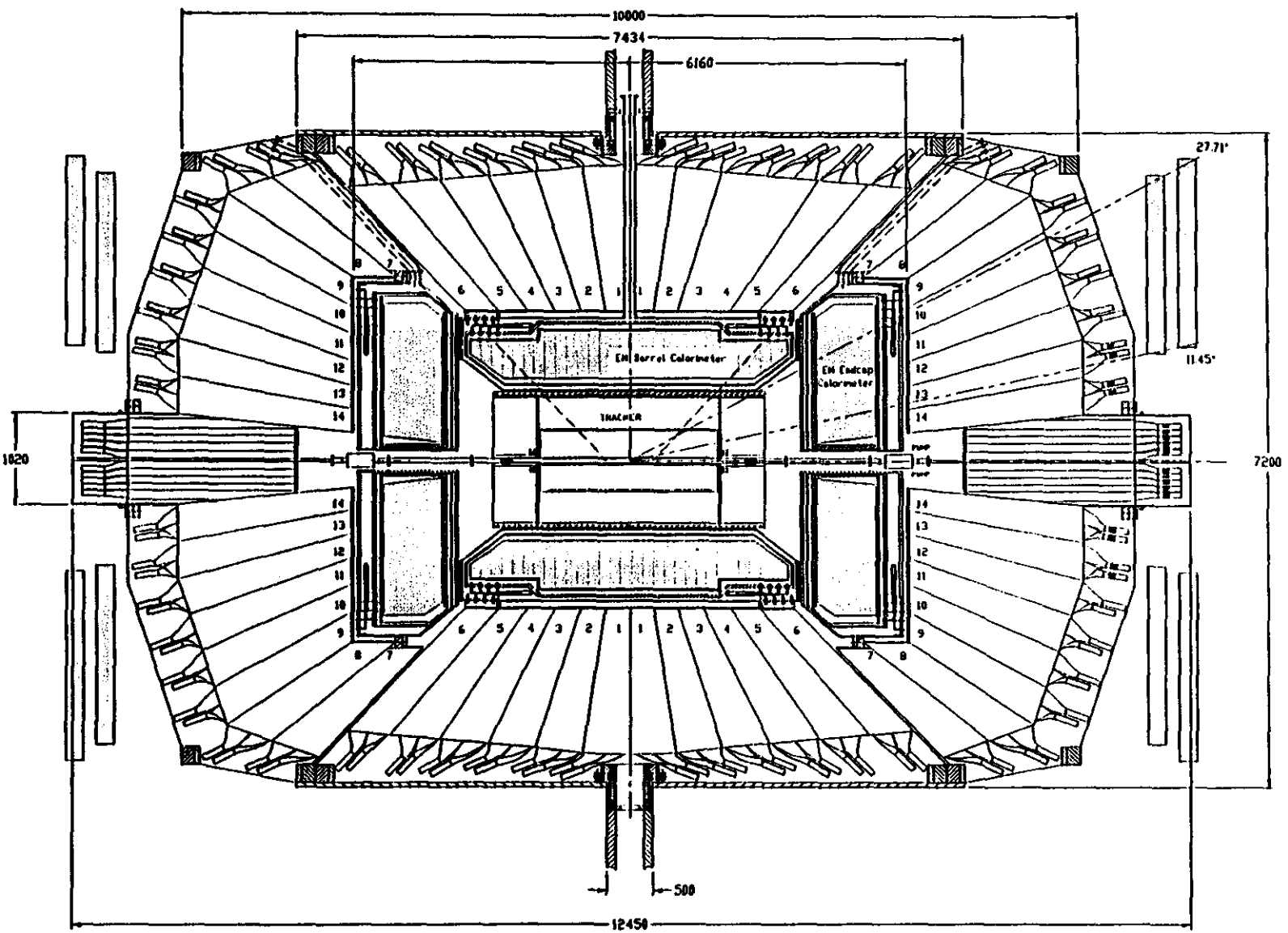
ORNL 7/17/92

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



Dimensions in millimeters

LLMASON 920520 BASEL


10000
7434
6160
27.71°
11.45°
EM Barrel Calorimeter
EM Endcap Calorimeter
TRACKER
1820
7200
500
12450

277

GEM Executive Committee requirements to BaF2 and LAr-Kr technologies

The Executive Committee at the meeting Feb. 20th has reviewed the status of e-m calorimetry R&D Programs and has formulated the list of requirements for each technology which should be met before the management of the Collaboration will proceed with the choice of one of the options. Our plan is to make the choice before the end of August 92, and preferably earlier.
Response to the requirements must be reported to Collaboration management by the specified date or earlier, in order to allow proper consideration.
It was noted by the Executive Committee that the BaF2 technology has a lower probability of success in its R&D Program, because of possible radiation damage and other effects which can destroy the small constant term in energy resolution.

A. Requirements for BaF2 technology :

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

   by August 1, 1992

2. As proposed by the expert panel, produce small radiation-hard crystals to demonstrate there are no fundamental limitations in making rad hard BaF2 crystals. (eg. absorbtion length >= 95 cm at 220 nm after 1 MRad)

   by August 1, 1992

3. Address in detail questions of preradiation, wrapping, residual non-uniformity, etc in crystals we can practicably expect to manufacture. Cosmic ray transverse measurements in produced crystals could provide useful data. Provide detailed practical plan for calibration of BaF2 system in-situ :describe calibration strategy, RFQ layout, required calibration time for each proposed technique to achieve necessary accuracy.

   by July 1, 1992

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

   - residual non-uniformity (as installed);
   - non-uniformity developed by possible further radiation damage of "saturated" crystals and/or by possible annealing;
     (note - the expert panel and executive committee are not convinced of the proposal to preradiate the crystals)
   - accuracy of intercalibration (see point 3);
   - short term instabilities of readout system;
   - linearity, linearity calibration and dynamic range of readout system.

   by July 1,1992

B. Requirements for LAr-Kr technology :

1. Demonstrate by beam tests stochastic term in resolution for non-projective geometry <= 7%/sqrt(E). Determine angular dependence of this resolution.
by August 1,1992

2. Produce detailed mechanical design/analysis of e-m barrel and end caps with optimization of gap between barrel and end cap, wall thicknesses, etc.
by July 1,1992

3. Demonstrate by MC simulations for realistic projective geometry and full angular range (between 90 and 5.7 degrees) the resolution
<= 7%/sqrt(E) + 0.4%
and physics consequences of the gap between barrel and end cap, wall thicknesses, etc.
by July 1, 1992

Additional requirements for LAr-Kr technology :

(proposed by individual members of exec. committee and members of calorimeter group)

by the time of e-m decision

1. Show Higgs -> 2 gamma spectra (mass range 80-150 GeV) for realistic e-m LAr-Kr detector and background simulations.

2. Provide detailed practical plan for calibration of LAr-Kr detector in situ. Provide an evidence that electronic calibration is equivalent to the detector calibration with the required accuracy.

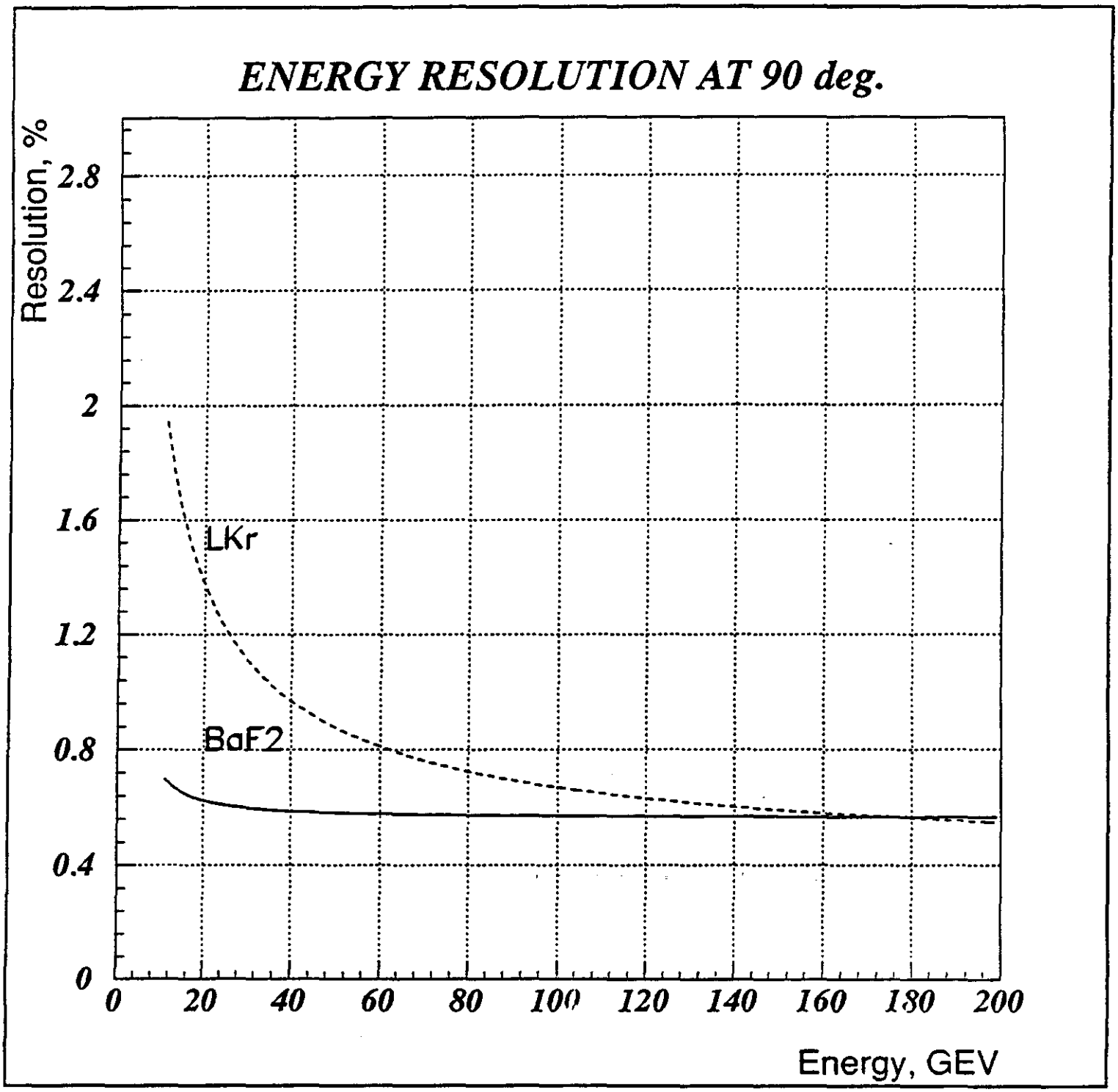
3. Provide experimental proof of radiation stability of LAr-Kr e-m system (for actually used materials).

4. Provide the results of the benchmark tests of LAr-Kr electronics which demonstarate required linearity, dynamic range, white and coherent noise in the real accordion system, cross talks and means of linearity calibration.

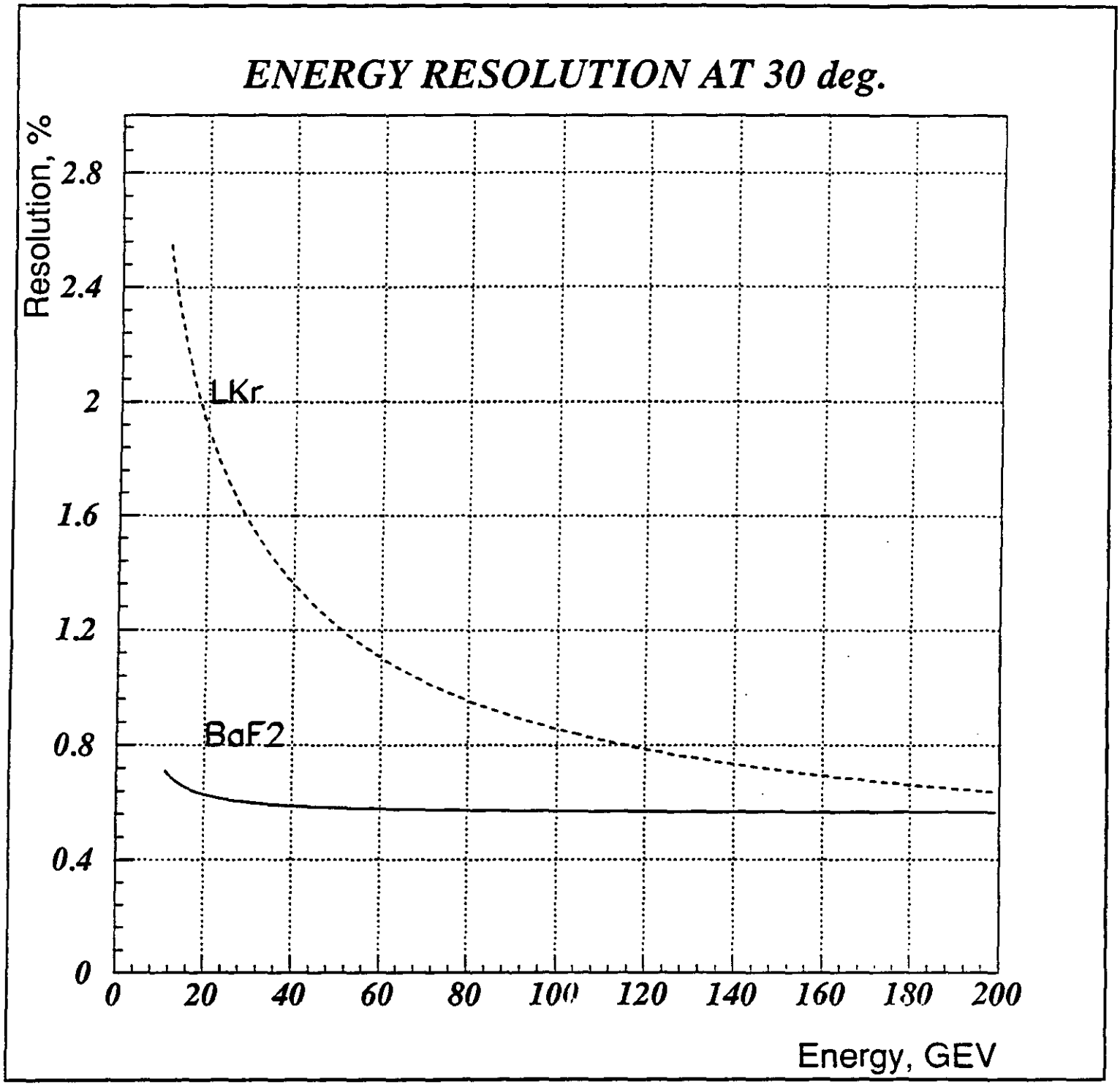
DECISION:

In August, a decision will be made between the two technologies based on our best judgement of the expected performance of each technology, balanced against the cost and risk involved in each. A primary choice will be made for our e-m calorimeter for the TDR. Depending on the status of open questions at the time of making the decision, a strategy will be developed for continuing the development of the second technology at a considerably lower level, while these outstanding issues are resolved for the primary option and to allow the proponents to smoothly finish their R&D program.

The final decision will be made by the spokesmen, after considering the evidence presented for each technology and receiving the advice of the Executive Committee.



Y. Efremenko Aug 30.92

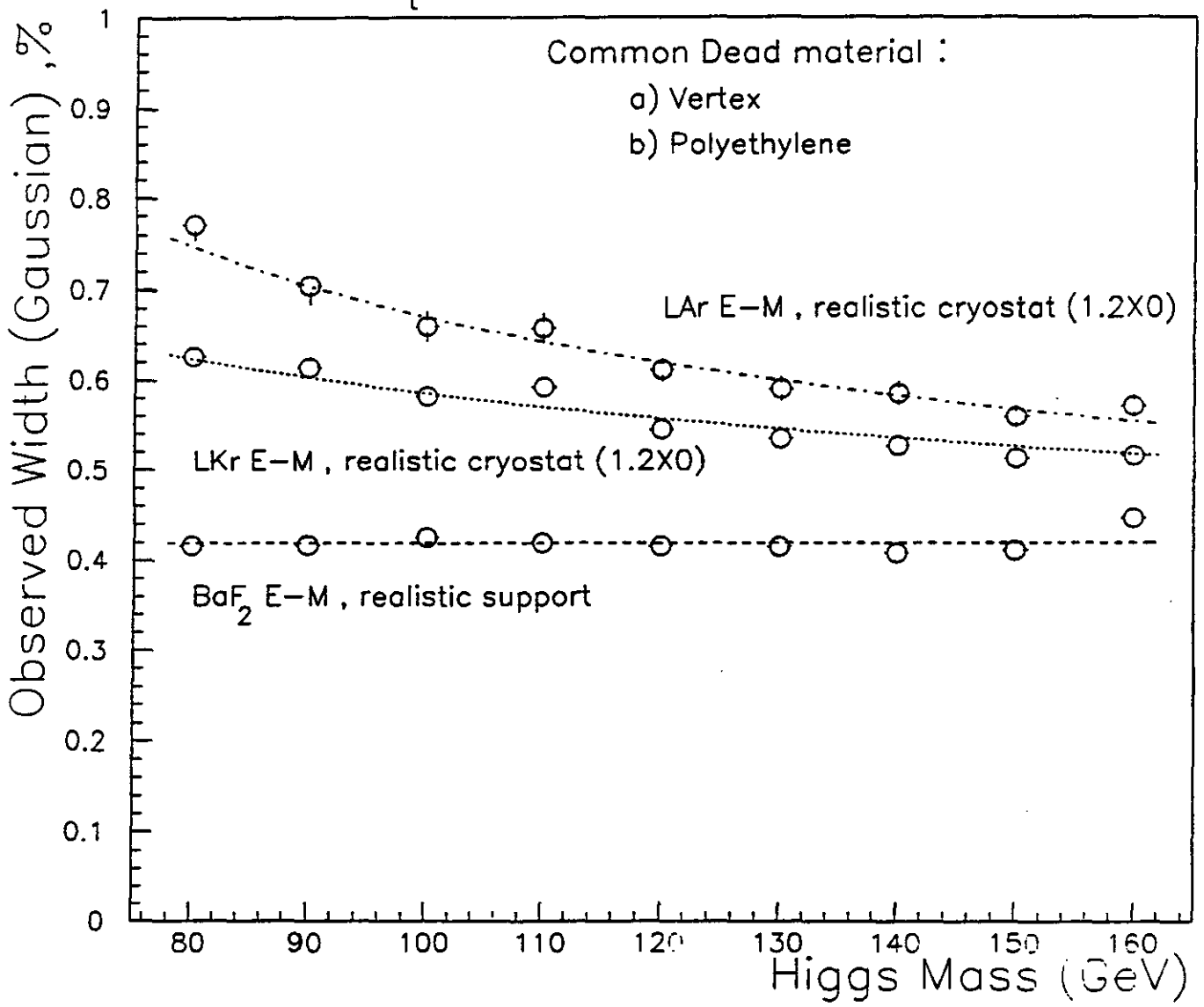


Yu Efremenko, Aug 30, 92

92/08/30 12.40

HIGGS MASS RECONSTRUCTION

PYTHIA5.6 m_t = 150 GeV ,perfect position resolution



A.Savin

Calorimeter System Cost Comparison
"US Cost Basis"

	LAr Integrated	Scintillating	LKr Hybrid
Hadron	$101,000K	$57,000K	$63,000K
Barrel LKr	$19,500K	$0K	$2,000K
EM		$78,000K	$42,500K
Forward	$10,000K	$10,000K	$10,000K
PreRad	$0K	$0K	$0K
Electronics	$22,000K	$6,000K	$19,000K
LKr Total	**$152,500K**	**$151,000K**	**$136,500K**
LAr Total	**$133,000K**		**$134,500K**

Calorimeter System Cost Comparison
"International Cost Basis"

	LAr Integ.	Contrib.	Scintill.	Contrib.	LKr Hybrid	Contrib.
Hadron	$76,000K	25%	$41,000K	28%	$45,000K	28%
EM (Other)			$33,000K	28%	$31,000K	28%
LKr/Crystals	$6,500K	33%	$31,000K	0%	$1,000K	33%
Subtotal	$82,500K		$105,000K		$77,000K	
Forward	$0K	100%	$0K	100%	$0K	100%
PreRad	$0K	na	$0K	na	$0K	na
Electronics	$11,000K	50%	$3,000K	50%	$9,500K	50%
LKr Total	**$93,500K**		**$108,000K**		**$86,500K**	
LAr Total	$87,000K					

UNRESOLVED DETECTOR R & D ISSUES

(group reached consensus for these issues)

1. MATERIALS COMPATABILITY WITH LKR (NOT NEEDED IF LAR IS FALLBACK)
2. DEMONSTRATION OF ELECTRONICS THAT PRESERVE SPEED ADVANTAGE OF BAF2
3. BEAM DEMONSTRATION OF REQUIRED CONSTANT TERM AND ITS ANGULAR DEPENDENCE IN ENERGY RESOLUTION OF LKR
4. DEMONSTRATION OF POINTING IN BAF2 (IF NEED FOR POINTING IS DEMONSTRATED)
5. OPTIMISATION OF THICKNESS OF DEAD MATERIAL IN FRONT OF EM CALORIMETER

OTHER POINTS WERE DISCUSSED

- Higgs-2gamma at higher luminosity
- Importance of pointing and preradiator
- Ti-structure for BaF2

gem

γeμ

Presentation by:

Frank Taylor

F. E. Taylor
9/2/92

STATUS OF GEM MUON SYSTEM

Issues:

- Big wheel or separate sector?
  - sectors slightly favored
  - finish analysis
    - bending of sector
    - cost of installation tooling
  - final recommendation by 10/1/92
- 3λ passive in calorimeter?
- Which technologies?
  - chambers for tracking
  - alignment scheme
  - chambers for trigger
  - reports due 9/28/92
  - presentations 10/6/92

- R&D plan for FY93
  - organize by tasks not institutions
    - chamber R&D
    - chamber prototype fabrication
    - engineering support for chambers
    - TTR and test beam
  - first draft due 9/11/92
  - final draft due 10/1/92

Chambers to be delivered to TTR:

Technology	Chamber size	TTR delivery date
PDT-JINR	1 m x 4 m x 8 layers	7/28/92 (delivered)
PDT-MSU	1.3 m x 3.8 m x 4 layers	9/11/92
LSDT	1 m x 4 m x 4 layers	9/20/92
RPC	~1 m x 2 m x 2 layers	9/20/92
CSC-BU	0.5 m x 0.6 m x 3 x 2 layers	9/16/92
CSC-BNL	0.6 m x 0.6 m x 2x4 layers	9/15/92
CSC-BNL	1 m x 1.8 m x 4 layers	---------
CSC-UH	0.5 m x 1 m x 3 layers	9/15/92
CSC-JINR	1.1 m x 1.5 m x 2 layers	9/28/92 +

• Barrel Issues:

1. Which is the more attractive drift technology - PDT or LSDT ?

2. Will the RPCs perform in terms of jitter, background sensitivity ?

3. In case RPCs are not accepted, is there an alternative trigger ?

4. Will the CSCs perform in barrel in terms of alignment, costs ?

• Endcap Issues:

1. Will the CSCs perform in terms of resolutions, background, costs ?

Technology Decision Process:

- Appoint 3 to 4 outside reviewers
- Inputs
  - Proponent Reports due 9/28/92
  - Engineering Report due 9/28/92 will provide a uniform appraisal of alignment, mechanical design, costs
  - Comments of outside reviewers
- Open presentations 10/6/92
  - Each advocate 1hr talk 0.5 hr Q&A
- Muon Steering Committee meets with outside reviewers 10/6/92
- Steering Committee makes a rating morning10/7/92
- Rating presented to Muon Group afternoon 10/7/92.
- Collaboration Council Meeting 10/8/92
- Rating presented to GEM EC 10/8/92

Boundary Conditions:

- Rating made on 10/6/92 defines Baseline 2.

- Final decision follows TTR tests and completed FY92 R&D program.

- No new Chamber R&D funds until above are completed.