Calorimeter Subsystem

Status and Issues

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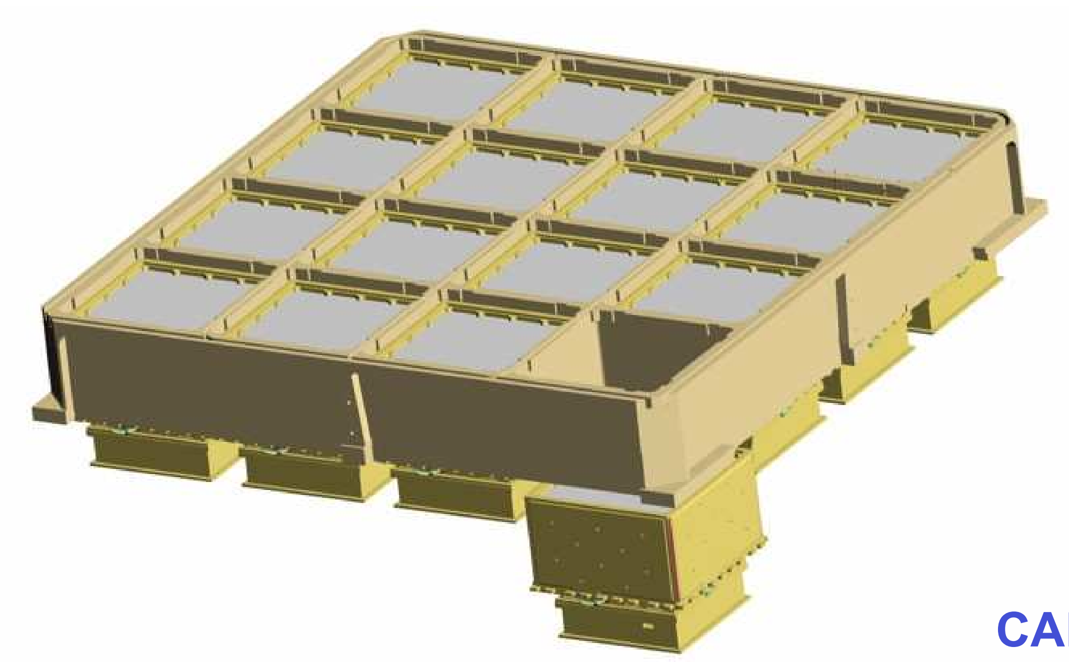
Outline

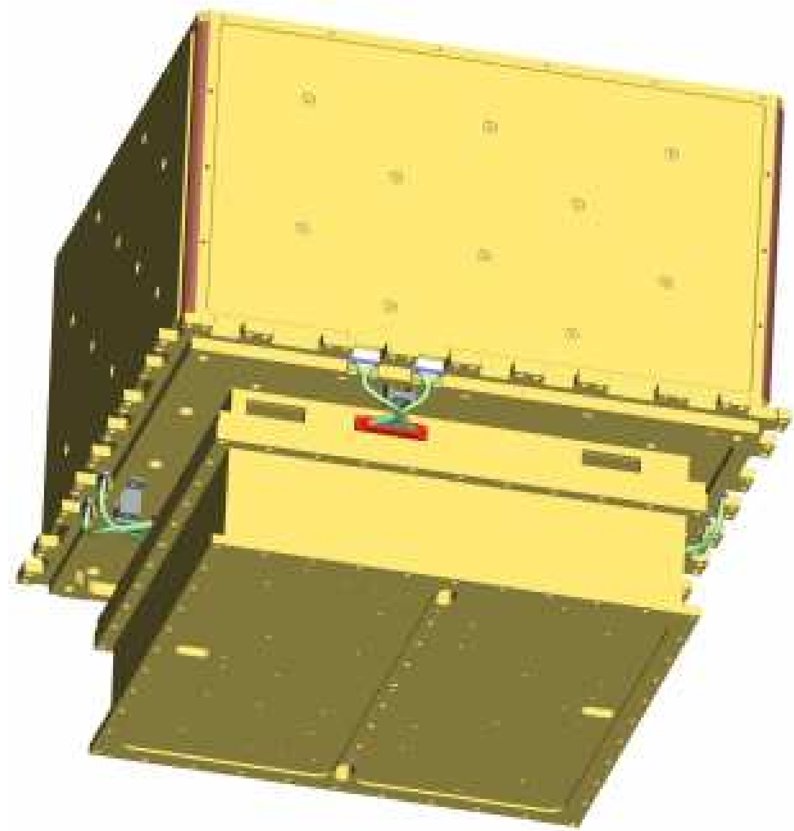
- Introduction
- Subsystem Status
- Engineering Model Construction and Test
- Flight Manufacturing Status
- The Future
- Issues and Concerns
- Summary
- GSI & CERN beam tests

Introduction - Modular Design

4 x 4 Array of Calorimeter Modules

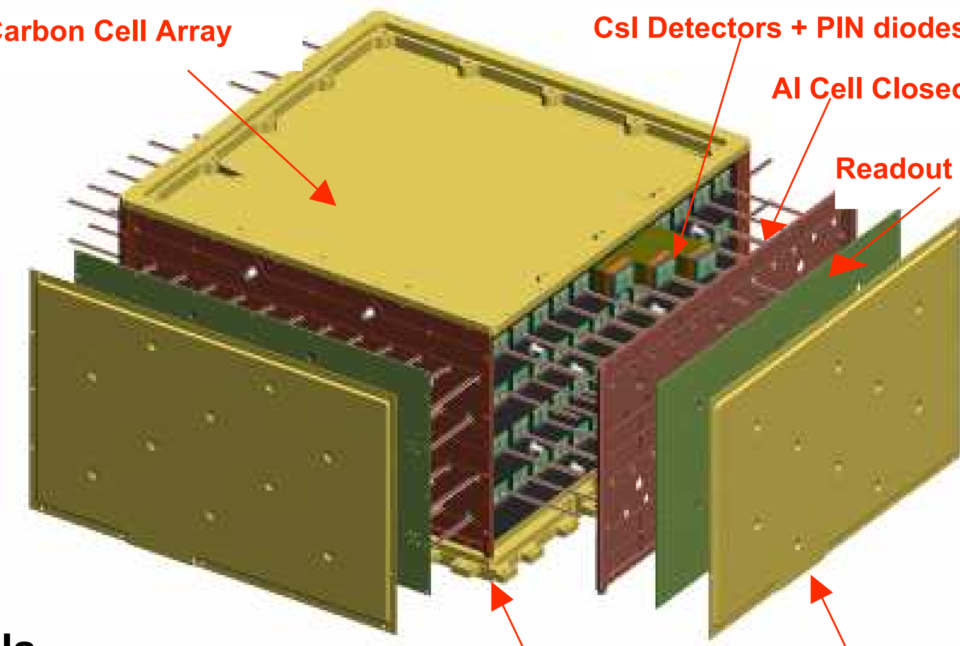


LAT GRID with16 CAL Modules



CAL Module with TEM and Power Supply mounted to base plate

Calorimeter Module Overview



Modular Design

4 x 4 array of calorimeter modules

Each Module

- 8 layers of 12 CsI(Tl) Crystals
  - Crystal dimensions: 27 x 20 x 326 mm
  - Hodoscopic stacking - alternating orthogonal layers
- Dual PIN photodiode on each end of crystals.
- Mechanical packaging – Carbon Composite cell structure

- Electronics boards attached to each side.
- Electronic readout to connectors at base of calorimeter.
- Outer wall is EMI shield and provides structural stiffness as well.

CAL Level III Key Requirements

Reference: LAT-SS-00018

Parameter	Requirement	Verification	Expected Performance
Energy Range	20 MeV – 300 GeV 20 MeV – 1 TeV (goal) 5 MeV – 100 GeV, single crystal	Simulation, Beam Tests	Required performance ~2 MeV threshold (BOM)
Energy Resolution (1 sigma)	< 20% (20 MeV < E < 100 MeV) < 10% (100 MeV < E < 10 GeV) < 6% (10 GeV < E < 300 GeV, incidence angle > 60 deg)	Simulations and EM and LAT calib unit Beam Tests	Simulations demonstrate required performance
Dead Time	< 100 μs per event < 20 μs per event (goal)	Test	< 19 μs per event
Low Energy Trigger High Energy Trigger	< 2 μs trigger latency	Test	< 1 μs
Mass	< 1440 kg (90.0 kg/module)	Test	1376 kg
Power	< 65 Watts (conditioned) (4.05 W/module)	Test	< 54 Watts (conditioned)
Temperature Range	– 10 to +25 C, operational – 20 to +40 C, storage – 30 to +50 C, qualification	Subsystem TV Test 4 cycles, acceptance 12 cycles, qualification	Required performance

Status - Loss of CNES Support in France

- In April, CNES (the French Space Agency) announced their withdrawal from planned commitments to the French contributions to GLAST
- As a consequence, CEA and IN2P3 were forced to reduce their hardware contributions to CAL.
  - Purchase of PIN photodiodes and the manufacture of CDEs was transferred from CEA to NRL.
  - The machining of aluminum and titanium parts of the CAL structure were transferred from IN2P3 to NRL.
  - Manufacture of composite structure will continue with IN2P3.
- The cost and schedule impact of this change was presented to the LAT International Finance Committee and the US sponsors.
  - The revised program and responsibilities have been approved and we are in the process of re-baselining the LAT cost and schedule.

Revised CAL Team Roles for Flight

Organization	Flight Hardware Responsibility
Sweden	CsI Crystal procurement and acceptance test
France / IN2P3	Mechanical Structure design. Carbon composite cell structures fabrication and test. Elastomer bumpers and cords. MGSE and tooling Finite element and thermal analyses. Beam Test Planning and Support
France / CEA	Diode and CDE manufacturing test benches. CDE shipping containers.
Naval Research Lab	CAL Subsystem Management, System Engineering, & Mission Assurance. CDE manufacture and test. CAL Electronics Design & Fab, Digital ASIC design, CAL Module Assy & Test, LAT I&T Support
SLAC	CAL Analog ASIC Design, EM AFEE PCB layout

CAL Status

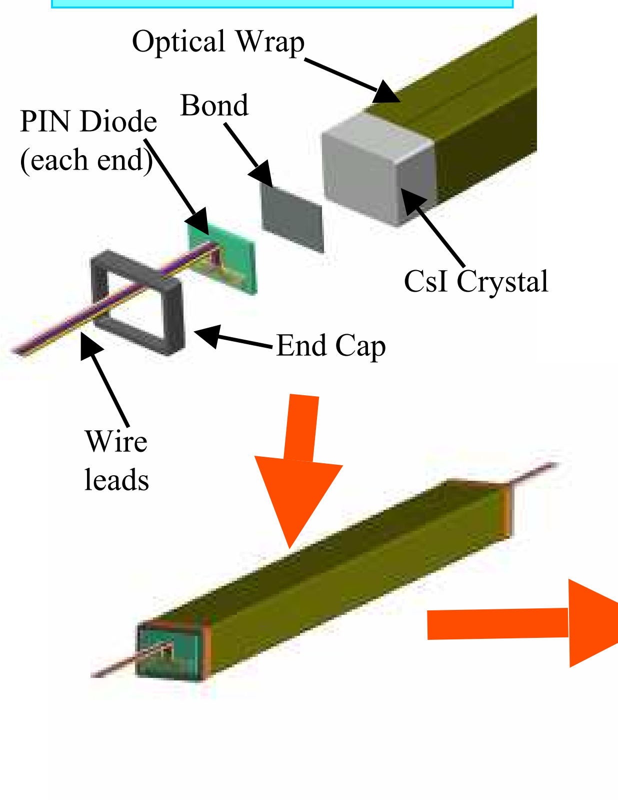
- CAL Subsystem successfully completed Peer Design Review (Mar ,03) and LAT Critical Design Review (May ,03).
- Engineering Model CAL assembly was completed in March.
- Environmental testing of EM CAL was completed in July.
  - Qualification level vibration tests
  - Qualification temperature Thermal Vac – 8 cycles.
  - EMI/EMC testing
- EM CAL was shipped to SLAC for Integration and Test activities in August.
- Design revisions for flight production are essentially complete
  - Modified carbon composite structure manufacturing technique
  - Modified PIN Diode optical window
  - New GCFE (analog ASIC) version
  - Modified CAL base plate to accommodate new CAL-GRID interface requirements.
- Delivery of flight components is well underway

Engineering Model CAL Manufacturing

Dual PIN Diodes (DPD) NRL/CEA

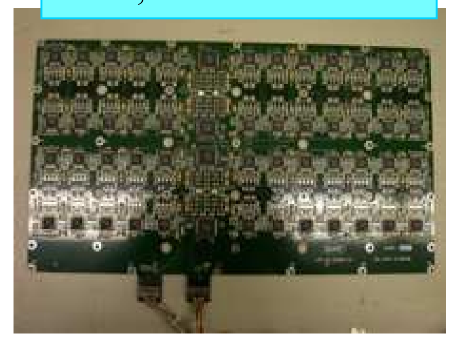
CsI Crystals Sweden (KTH)

Crystal Detector Element (CDE) Assembly NRL/CEA



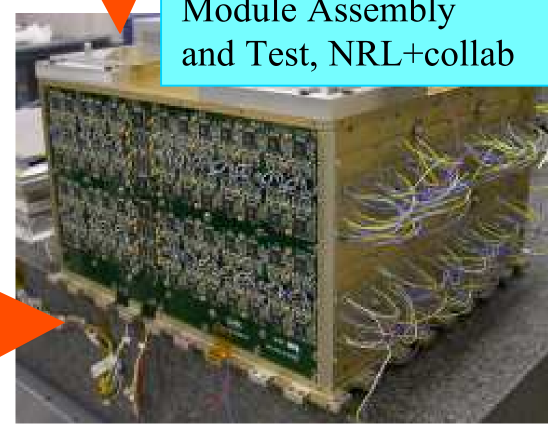
Mechanical Structure France (IN2P3/LLR)

Front-End Electronics NRL, SLAC



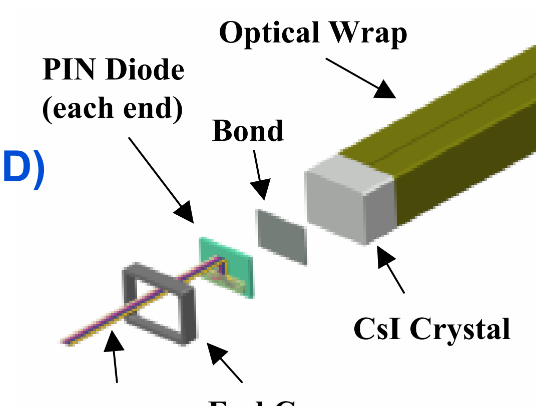
PreElectronics Module (PEM) Assembly NRL

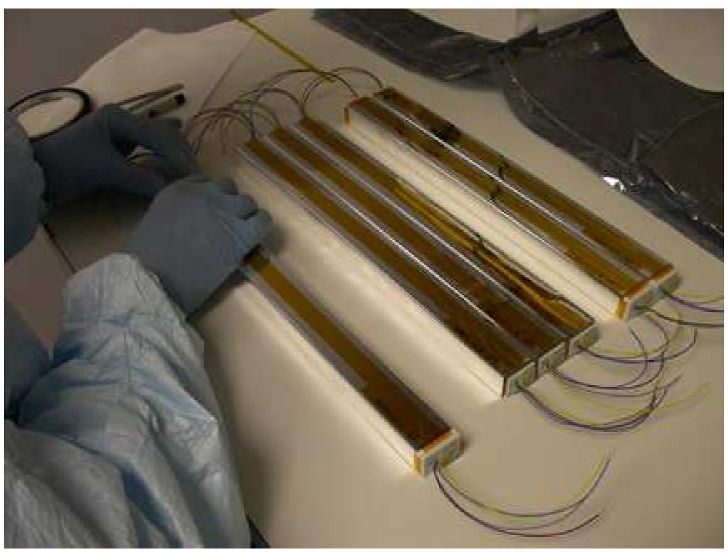
Module Assembly and Test, NRL+collab



CDE Components

- CDE has four components
  1. CsI(Tl) crystal
  2. Two PhotoDiode Assemblies (PDAs)
     - Hamamatsu S8576-01 Dual PhotoDiode (DPD)
     - Wire leads, soldered and staked
  3. Wrapper
     - 3M Visual Mirror VM2000 film
  4. Two end caps





EM CDEs during wrapping and attachment of end caps

Crystal Production - Sweden

Amcrys-H, Ukraine

Crystal Growing

a CsI Boule

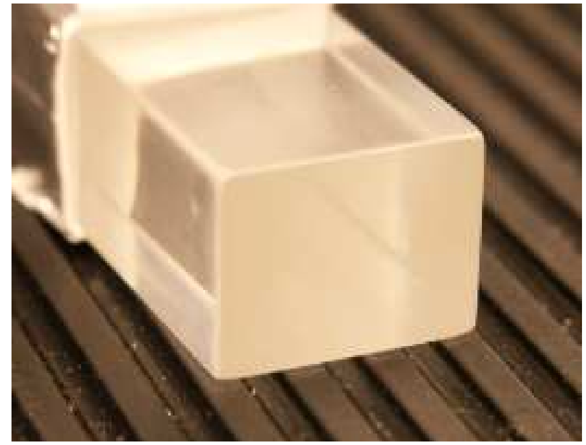
Crystal Cutting

Crystal Polishing

Kalmar Univ, Sweden

Crystal Mechanical and Optical Acceptance Testing

CsI(Tl) Crystal and PIN Photodiode



- **CsI(Tl) gives high light yield with PDs and good stopping power for EM showers**
  - 1536 crystals or ~1200 kg of CsI, each 326 mm x 26.7 mm x 19.9 mm
  - 100% inspection and test

- **PIN Photodiode spectral response well matched to CsI(Tl) scintillation**
  - Very small mass, volume, and power
  - Total 3072 required in LAT CAL
  - Two diodes to help cover dynamic range

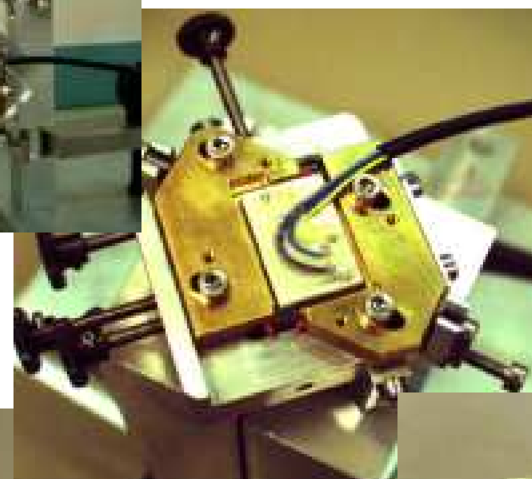
EM Photodiode Assembly

EM PDA-Crystal Bonding – CEA/France

End face polishing

Mold tooling & Glue injection

Support tooling



Mold removal after 24 hours

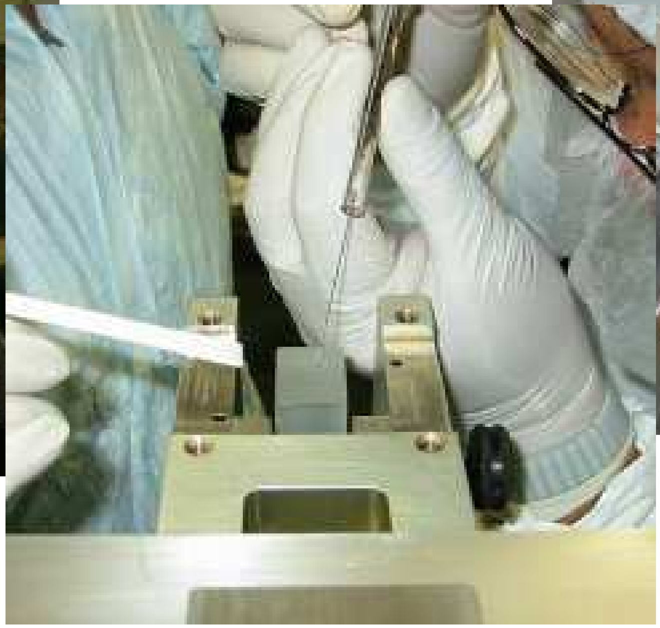
Primer deposition

Polymerization time = 7 days

EM PDA-Crystal Bonding – Swales

EM build:
110 CDEs at Swales
14 CDEs at Saclay

Hanging xtal in bonding fixture

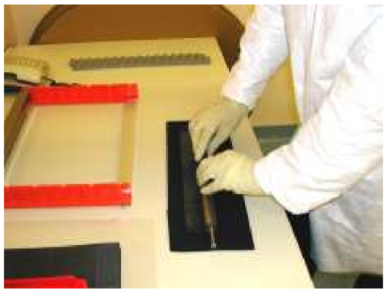


Priming xtal

Silicone injected, waiting to cure

Composite Structure – LLR Ecole Polytechnique

Wrapping of Mandrels



- Each Mandrel Wrapped with One Pre-Preg Ply

Preparation of Layer

- Stacking of Mandrels and Lateral Lay-Ups with Inserts
- Mechanical Pressure to Add Global Plies

Stacking of Layers

- Stacking of Layers, Base and Top Lay-Ups with Inserts

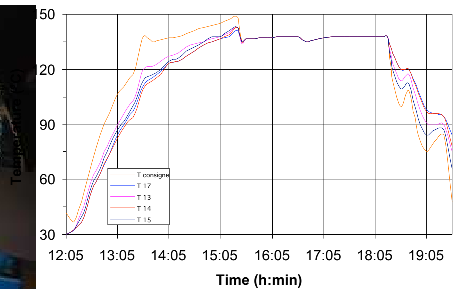
Closing of Mold

- 4 Side Plates and Cover
- Mechanical Stops to Control Outer Dimensions

Vacuum Bagging

- Release Film
- Breather Felt
- Vacuum Bag

Autoclave Curing



- Temperature 135°C
- Pressure 7 bars
- Cure Time 4h

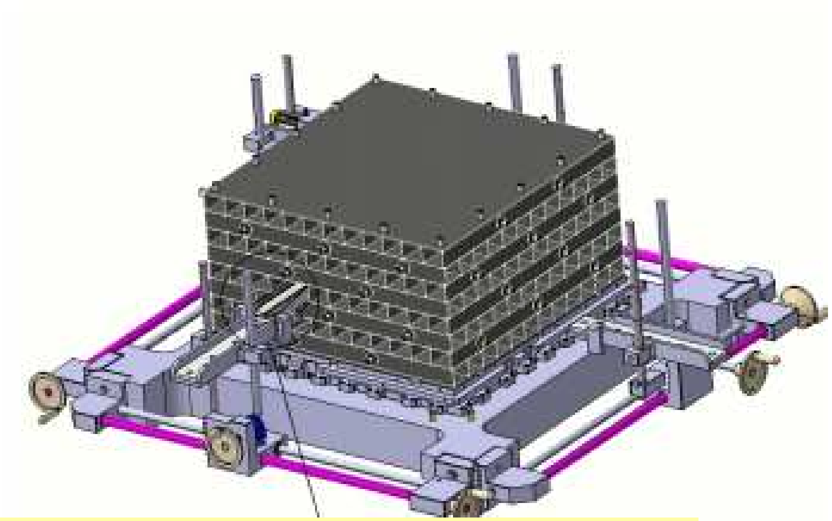
Structure Removal

- Removal of Layer Frame
- Removal of 96 Mandrels
- Cleaning

Metrology

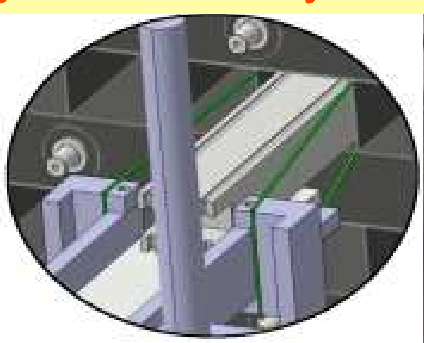
- Outer Dimensions
- Position of Inserts
- Dimension of Cells

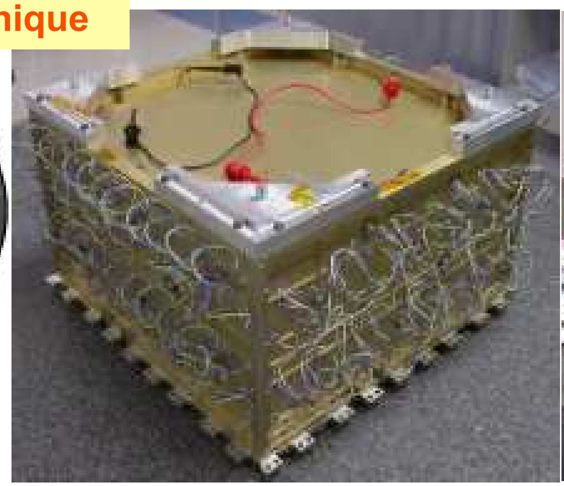
Pre Electronics Module (PEM) Assembly - NRL



CDE Insertion into Structure

Tooling – LLR Ecole Polytechnique



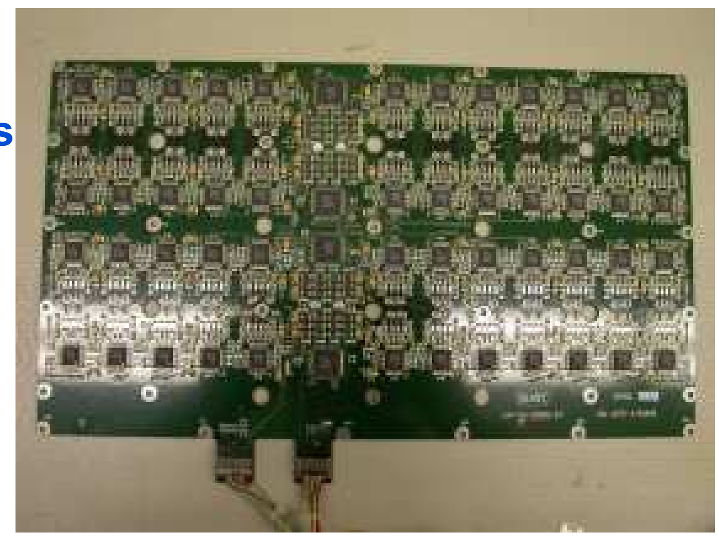


Completed PEM

PEM Acceptance Test

CAL Electronics – NRL/SLAC

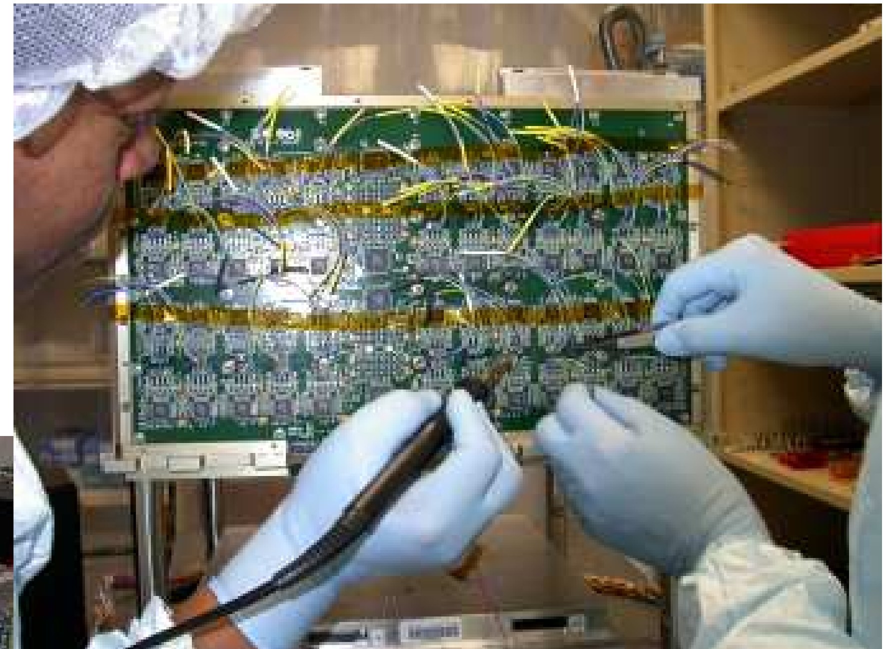
- Read out both ends of CsI crystals in hodoscopic array using PIN photodiodes
  - 4 printed circuit boards, one on each vertical face
  - Large dynamic range (few x 10^5)
  - Low noise (~2000 electrons noise)
  - Low power (~20 mW per crystal end)
  - Low dead time (20 μs)
  - Self triggering
- Implementation
  - Divide dynamic range into two input signals (dual PIN photodiode)
  - Use 1 custom analog and 1 custom digital ASIC to minimize power
  - Use COTS 12-bit successive approximation ADC on each crystal end to achieve low dead time.
  - Sparsify data (zero suppress)

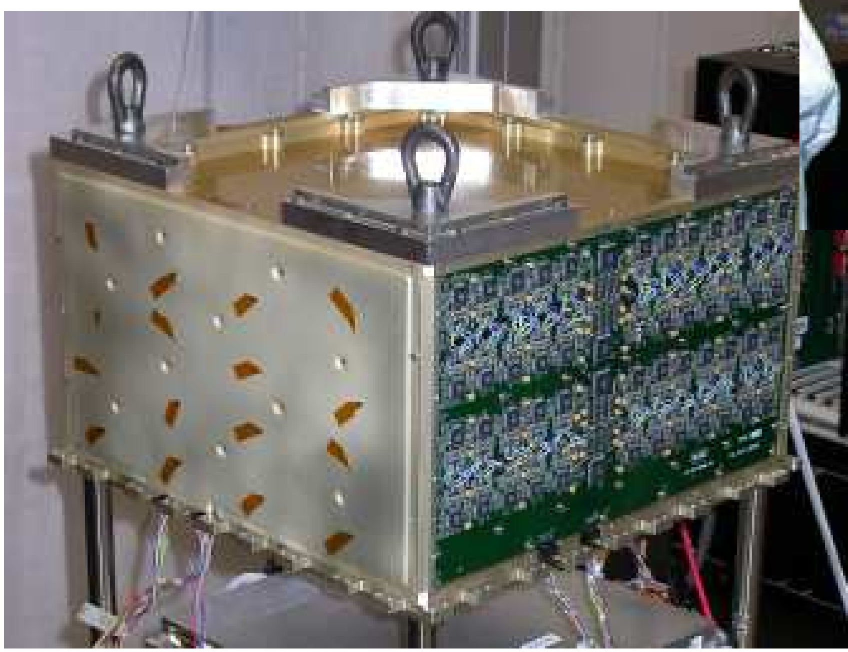


EM AFEE board

AFEE Board Installation

- Route, dress and solder 192 diode interconnect wires per AFEE board.
- Functional Test
- Stake wires
- Install Side Panels



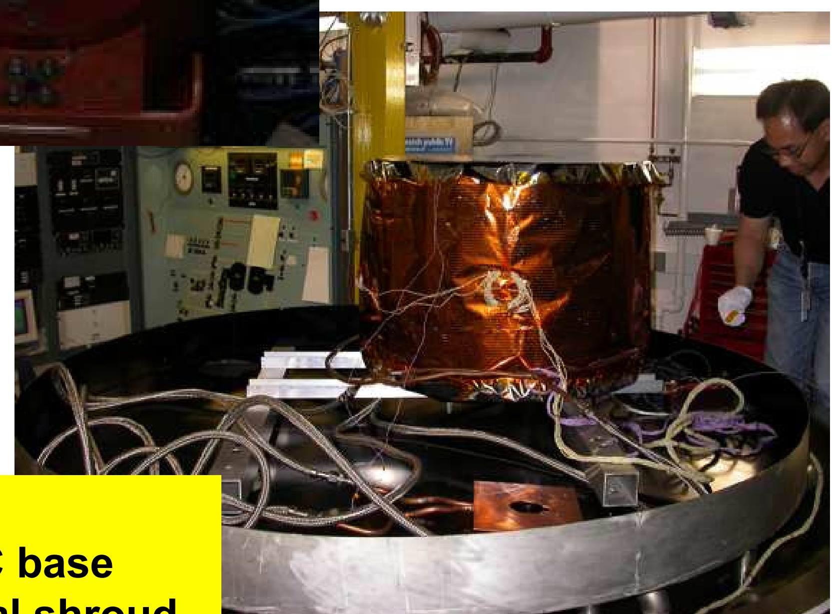


Installation of EM AFEE boards

EM CAL Testing

EM CAL on support stand w/ upper lifting fixtures attached

EM CAL in Vibration test
Mounted on vib table w/ accelerometers attached.



EM CAL in TVAC
Mounted on TVAC base covered w/ thermal shroud

EM Calorimeter at SLAC

On arrival at SLAC, EM CAL in and coming out of shipping container

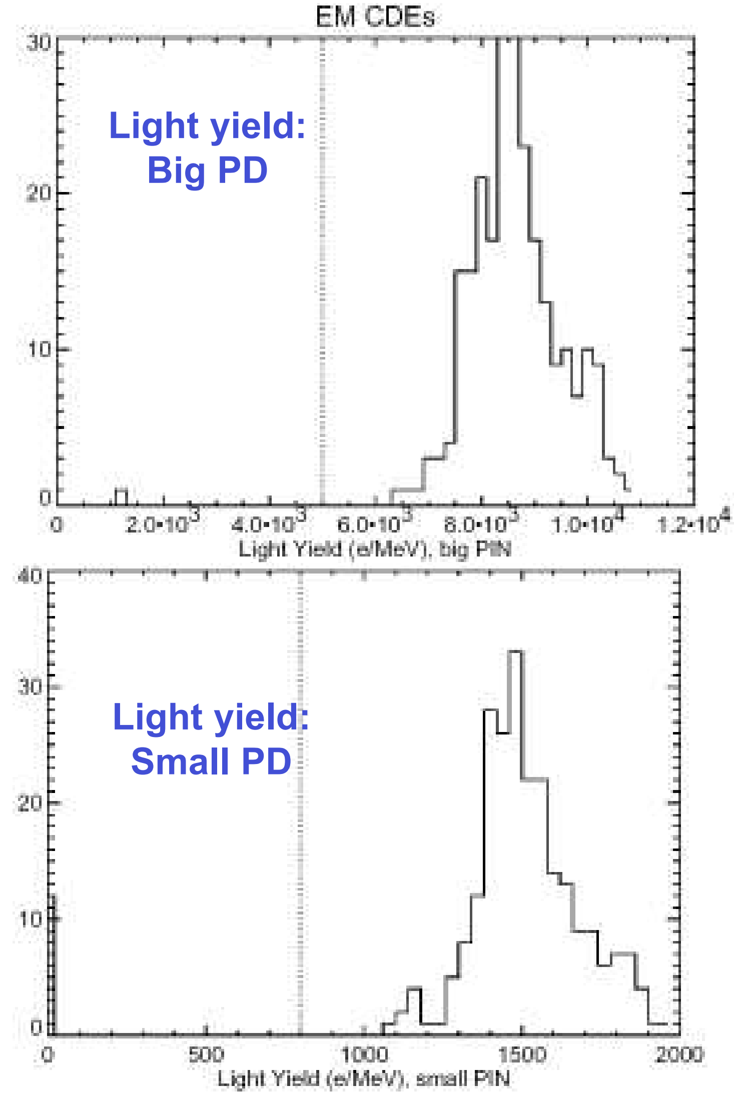
Trial insertion of EM CAL into one-bay grid

EM CDE Performance

- EM CDE build
  - 110 at Swales Aerospace
  - 14 at Saclay

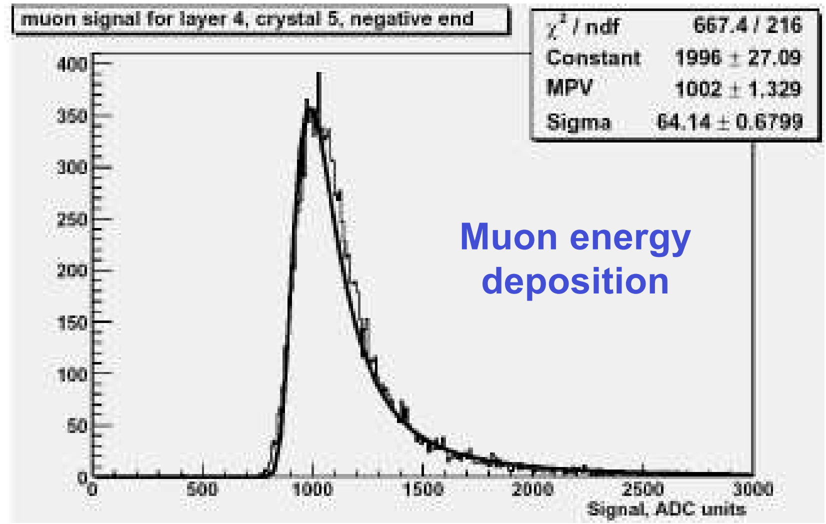
  Saclay and Swales CDEs have identical performance

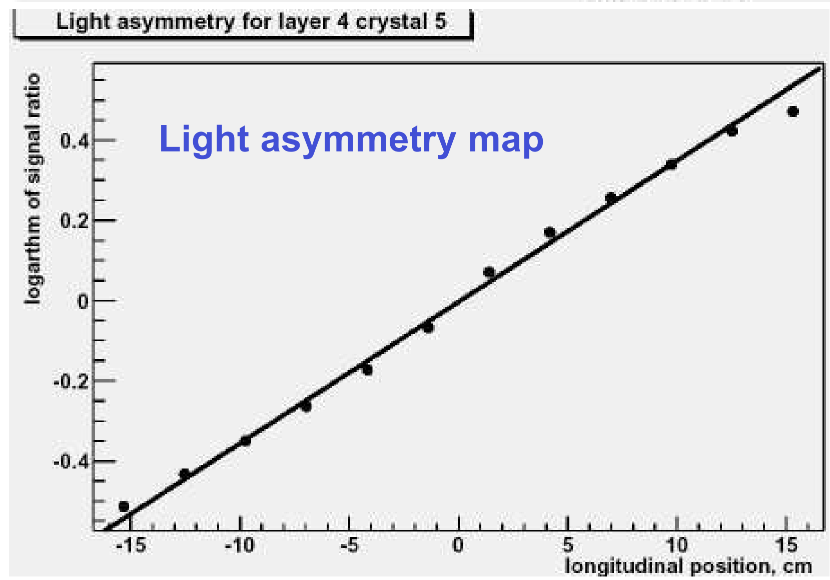
- Performance of EM CDEs
  - Light yield
    - Big PD within spec
      - Typical: 8000 e/MeV
      - EM Spec: >5000 e/MeV
    - Small PD within spec
      - Typical: 1500 e/MeV
      - EM Spec: >800 e/MeV



EM Pre-Electronics Module Performance

- **Performance of EM PEM**
  - Assembled PEM with GSE Checkout electronics
  - >5 million muons collected
  - Data being analyzed with Ground Science Analysis Software system
    - Muon trajectories imaged
    - CDE light tapers mapped

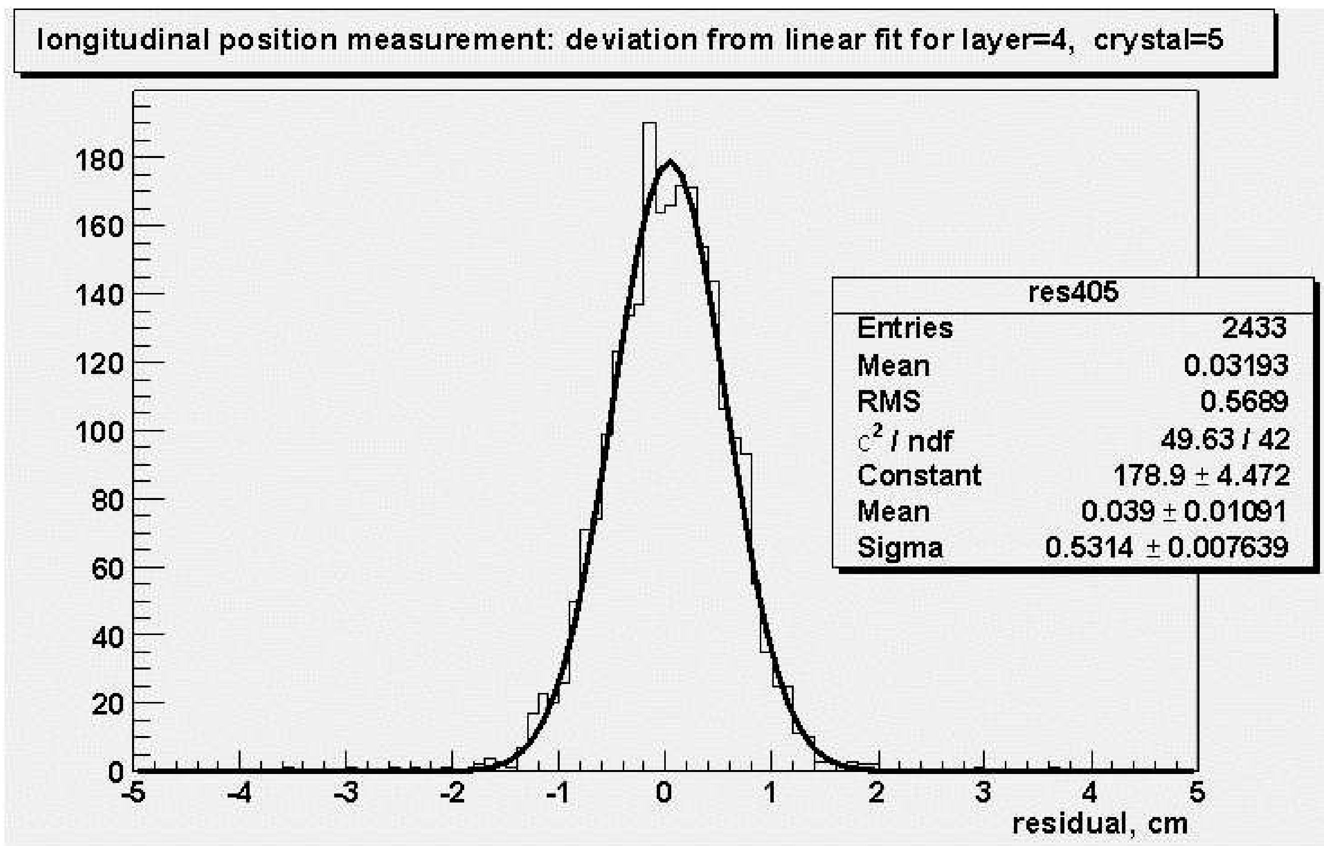




EM Module Imaging of Muon Tracks

- CAL muon position resolution using light tapering along the CsI log.
  - Light taper maps derived from CAL-only crystal hodoscope
  - No external hodoscopes!

5 mm resolution (rms)



Flight Manufacturing Status

- CsI Crystals
  - To date Kalmar has received 450 flight CsI xtals from Amcrys H. Of these, ~300 have been fully tested and shipped to NRL.
- PDA Manufacturing
  - NRL has received ~600 flight Dual PIN photodiodes.
  - PDA manufacturing process tooling and specification have been completed. Manufacturing vendor has been selected.
  - PDAs for pre-qual CDE units are being manufactured at NRL.
- CDEs
  - More than 30 CDEs have been bonded at Swales for training and tooling tests.
  - 12 copies of flight CDE bonding tooling have been manufactured.
  - Remaining Flight CDE manufacturing tooling (38 copies) has been released for manufacture.

Flight Manufacturing Status (2)

- Mechanical Structure
  - Revised, reviewed and released flight machined part drawings – all except base plate which requires review and approval by IPO.
  - Manufactured Structural Model 1 (SM1) carbon composite structure using flight-like tooling and autoclave at LLR. 2nd structure will be made in October.
- AFEE Electronics
  - Screening, qualification and test boards for AFEE ASICs, ADCs, DACs have been completed.
  - Flight ASICs have just been received from Mosis. Are now in packaging.
  - Revisions to EM AFEE schematic have been completed, new layout is in progress. Prototype board expected this month.

The Future

Nov 14, '03	Heavy ion beam test with EM CAL at GSI in Germany
Oct 15, '03	Start manufacture of flight CDE
Dec 25, '03	First PEM Assembled.
Feb 20, '04	First CAL Module Complete
May 28, '04	First CAL Module delivered to LAT I&T
Nov 02, '04	16^{th} CAL Module delivered to LAT I&T
Nov 16, '04	2 spare modules delivered to SLAC for beam test calibration

Issues and Concerns

- Calorimeter is critically dependent on plastic encapsulated microcircuits (~ 3300 ASICs, ~3000 ADCs and 250 DACs)
  - Screening and qualification of these will not be complete until Jan ,04.
- LAT-wide EMI/EMC design review may require modification / additions to CAL structure
  - A risk to the delivery schedule

Summary

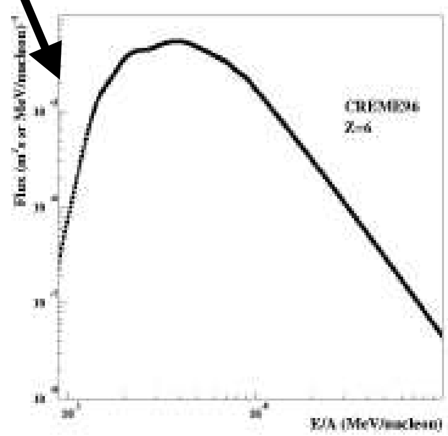
- Engineering Model CAL manufacture and test program has verified the CAL design and manufacturing processes.
  - A small number of component / process improvements have been made for flight.
  - EM CAL testing continues at SLAC as part of an integrated tower.
  - The EM will be tested at much higher energies at GSI with heavy ion beams.
- CAL module is expected to meet all its level III requirements.
- CAL has begun flight module manufacturing

“Damn the torpedoes, full speed ahead”

In-orbit calibration

Geomagnetic cutoff

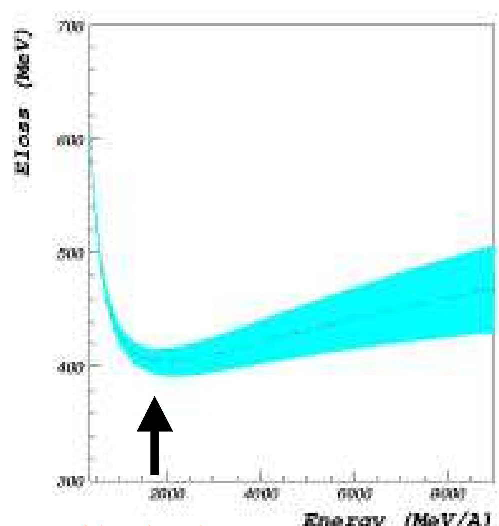
CR energy spectrum



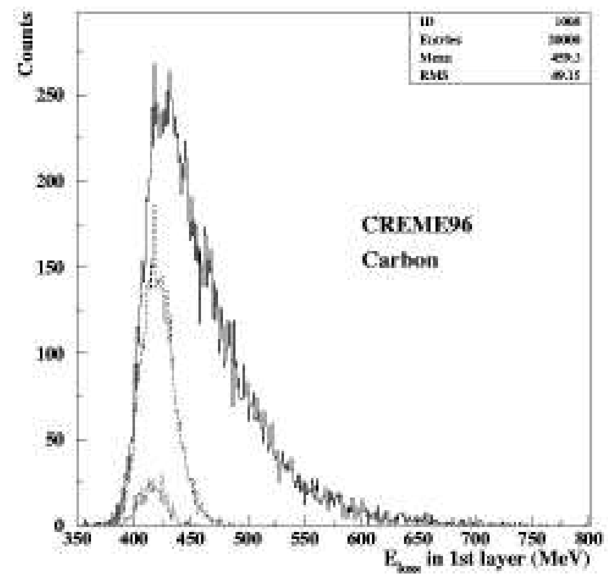
Use of the ionisation energy loss of cosmic-ray heavy ions

C, N, O, Mg, Si, Fe

E_{loss} (E)



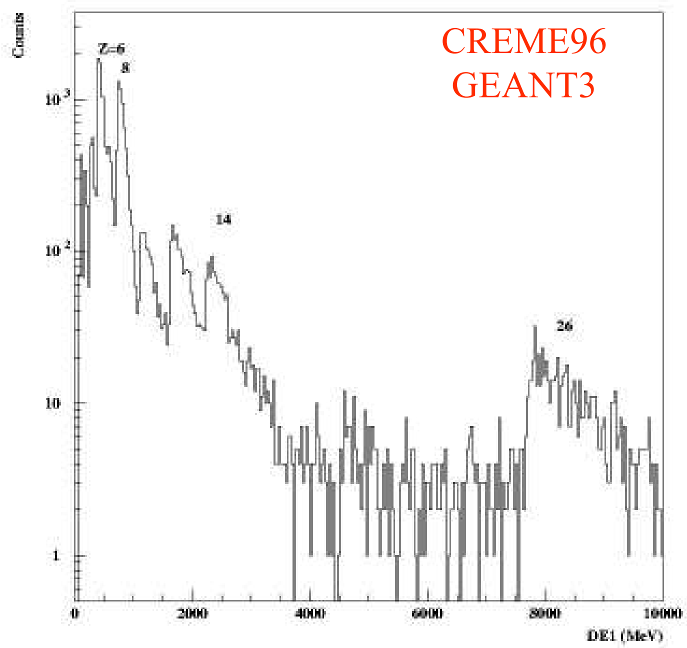
minimum of ionisation



"minimum-ionisation" peak

In-orbit calibration (2)

Simulated energy-loss distribution



We need to:

- know the CsI light function L(E,Z), non-linear because of quenching effects;

- test algorithms for rejecting reaction events (variation of Eloss between adjacent layers).

Quenching effects in CsI

High ionisation density → non-radiative decay channel

("activation-depletion„ hypothesis, exciton destruction at activator sites, recombination...)

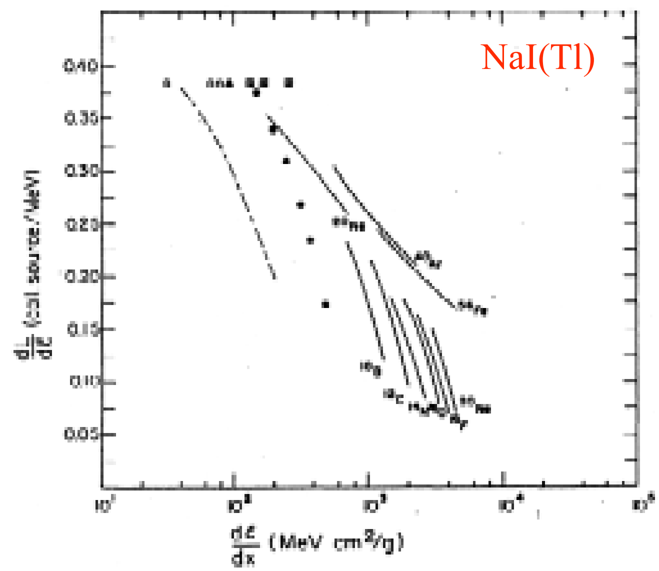
Low energy: Birk's formula

$L(E) \propto E/(1+k_B\, dE/dx)$ k_B: quenching factor

High energy:

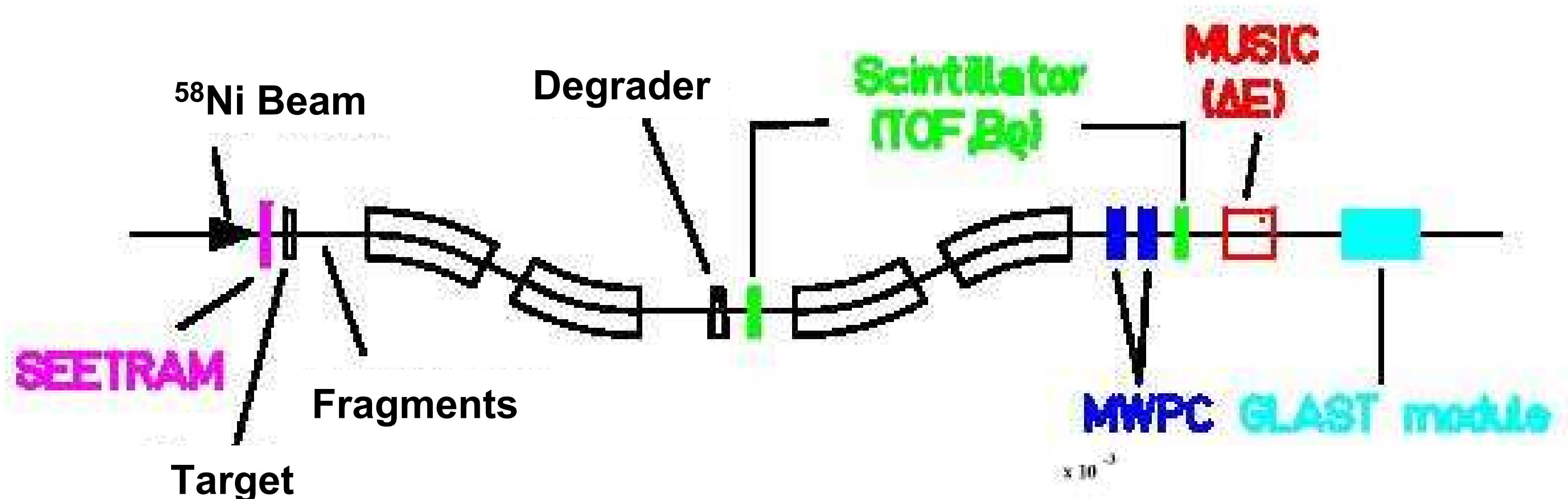
at a given dE/dx, E is higher for greater Z → more d electrons → less quenching

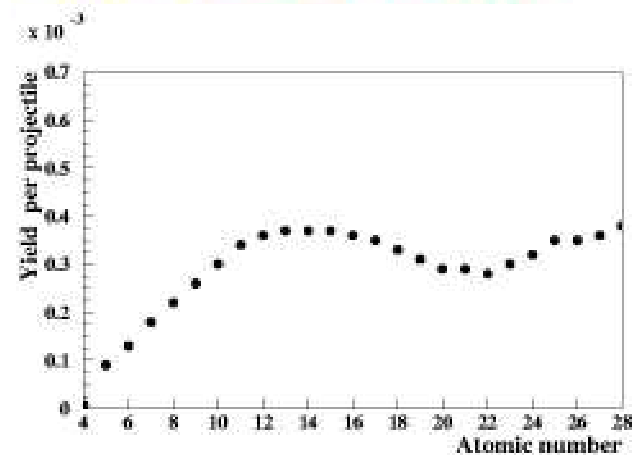
Very scarce data at high energy!



Salamon and Ahlen

Experimental setup at GSI





One single beam: ^{58}Ni from 100 to 1700 MeV/nucleon
All fragments are produced simultaneously.
The spectrometer offers great flexibility!

Why do a beam test at CERN?

The LAT will cover the 20 MeV-300 GeV range, but the calibration at SLAC will be limited to 30 GeV. Wouldn't be data at higher energies be useful? Although rare, photons with E>10 GeV will (arguably) be the most interesting, the 10 GeV-100 GeV domain has barely been explored.

Only little ressource is needed to get these data.

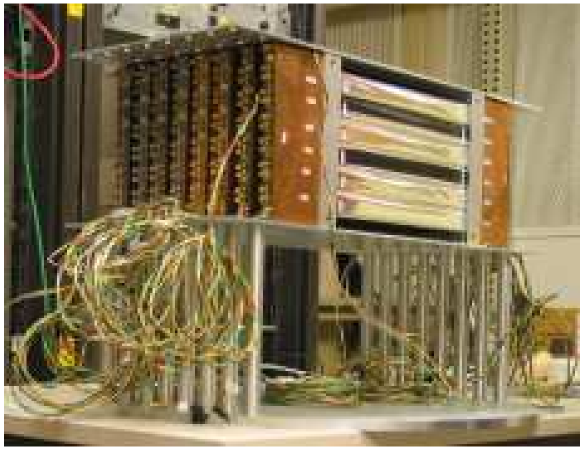
Our calorimeter is fairly thin: on-axis photons deposit only ~40% of their energy within the CAL: energy reconstruction for those is based on profile fitting. Surprisingly few data on shower profiles in the literature.

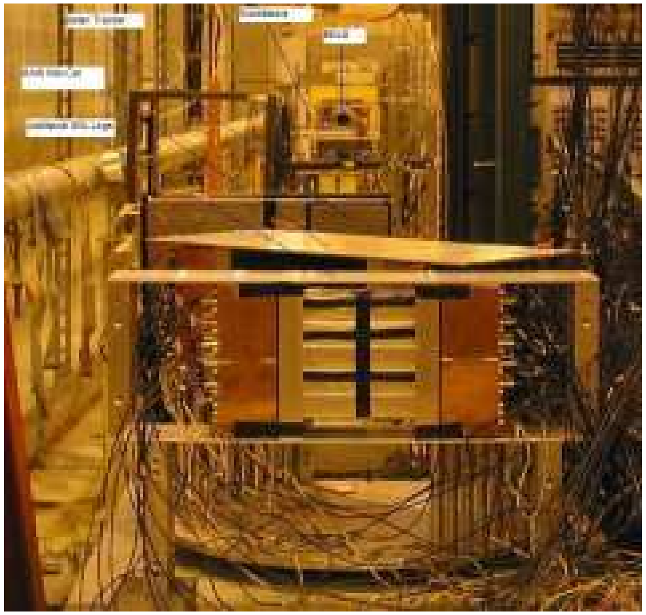
CERN is a good place:
GLAST is an “accepted experiment,, at CERN.
Different beams (secondary+tertiary) are available with a great flexibility: electrons, pions,muons with energies up to 150 (300) GeV, down to 10 GeV
CERN shut down in 2005. Beam available for GLAST in 2004 (?)

Experimental Method

Duration : 1 week of beam time on the H6 beam line (Aug 7-13)
Detectors: 48 CDEs (AMCRYS): 8 Bordeaux, 15 CEA, 25 Kalmar+CEA
arranged in 8 layers of 6
15 CDEs (BTEM) from NRL arranged in 3 layers of 5
positioned on a moving table + rotating table (48)
Electronics: 222 channels
preamp + 2 sets of shaping amplifiers
low-gain “x1„„ high-gain “x20„
commercial VME ADCs (CAEN 785)
Localization: 2 X-Y Silicon chambers (Trieste)
Trigger: 2x2x0.2 cm^3 plastic scintillator located 6 m in front of the detector
Beams: electrons at 10-20-50-80-120-150 GeV, 20 GeV muons, 20 GeV pions
Count rate: 100 Hz
“Converter„: 15x15 cm^2 Pb sheets of various thicknesses (0-16 X_0, 1.3 X_0)
People: Bordeaux: 7, Kalmar: 3, CEA: 2, Trieste:2

Setup





Energy Calibration

All we have for absolute calibration are muons E-deposits.
Can we use the muon data alone (E_{dep}~12 MeV) to establish the calibration up to tens of GeV?

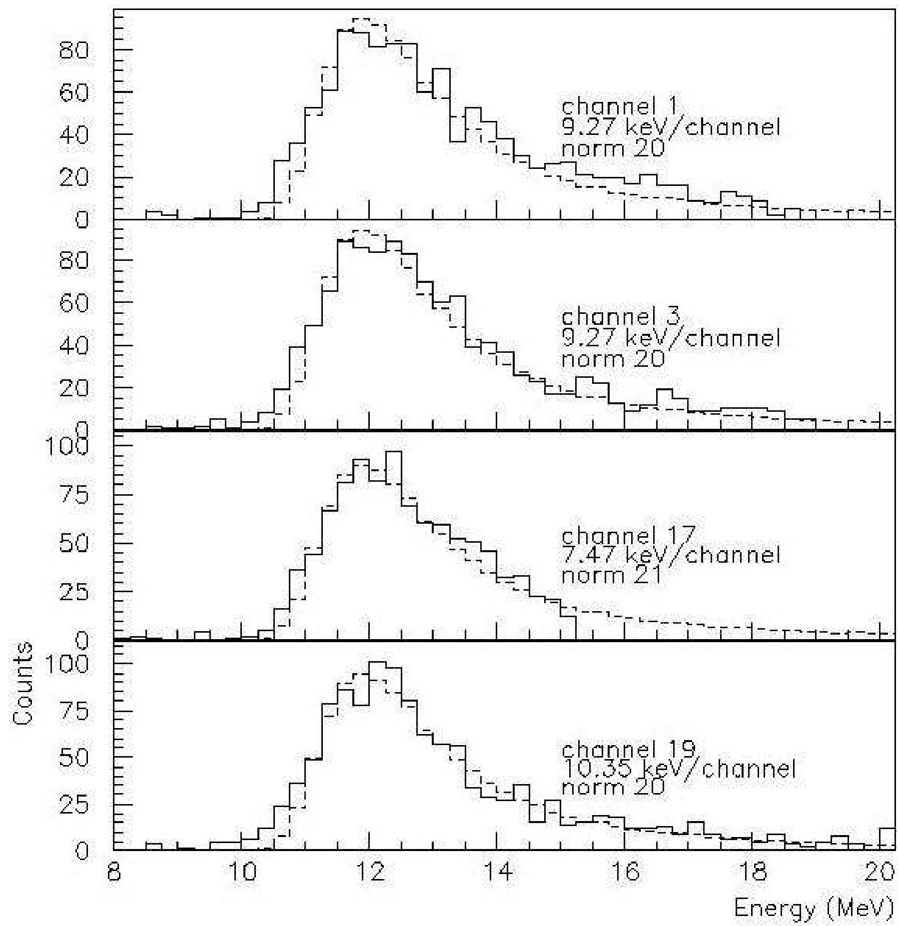
Procedure:
Muons in Big Diodes (BD) corrected for attenuation*
Conversion Slope for BDs with high-gain amplifiers
Pulser: relative gains between low- and high-gain amplifiers
Conversion slopes for Big Diodes with low-gain amplifiers
Small-diode vs Big-diode correlation using beam data:
Conversion slopes for Small Diodes

*attenuation coefficients: Left/Right dependence on position

Energy calibration with a 20 GeV muon beam

——— data

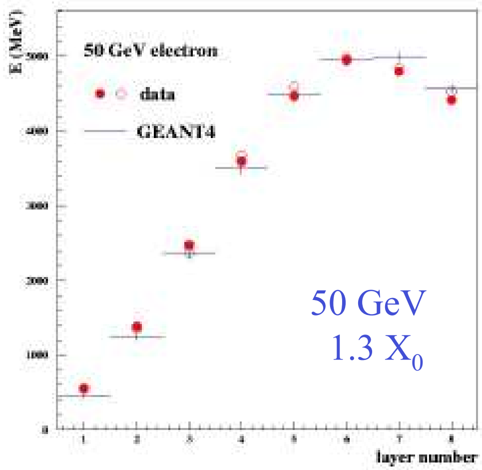
- - - - MC GEANT3

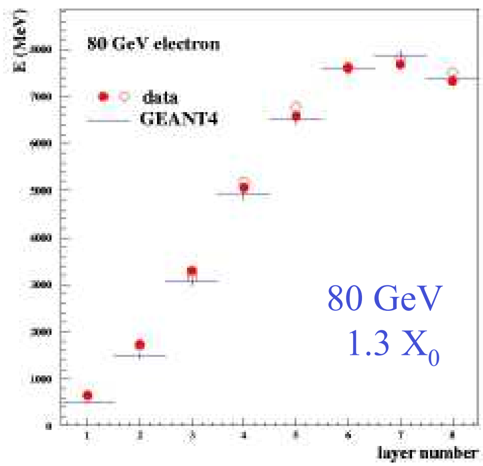


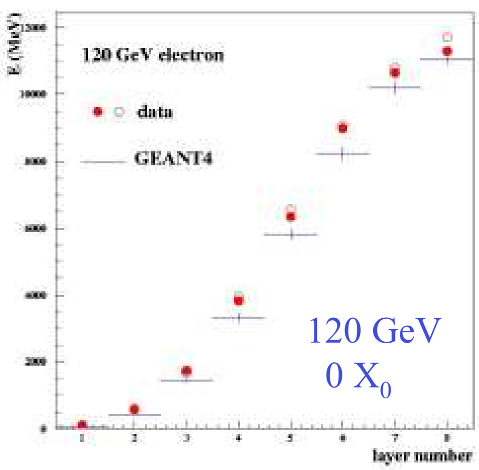
2002 experiment

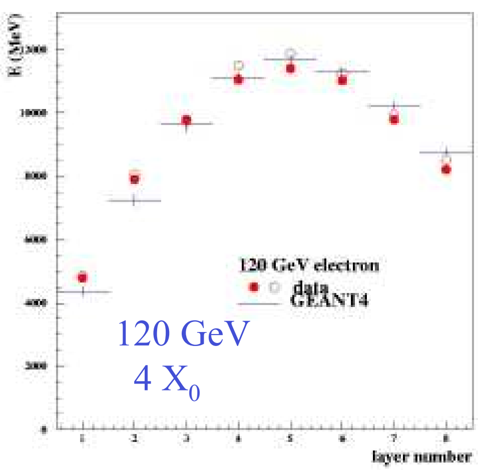
high-gain amplifiers

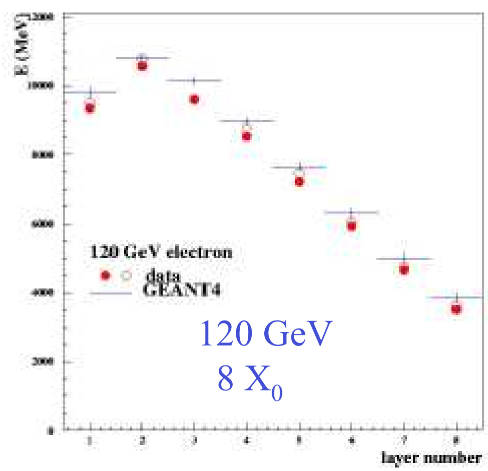
Longitudinal shower profiles



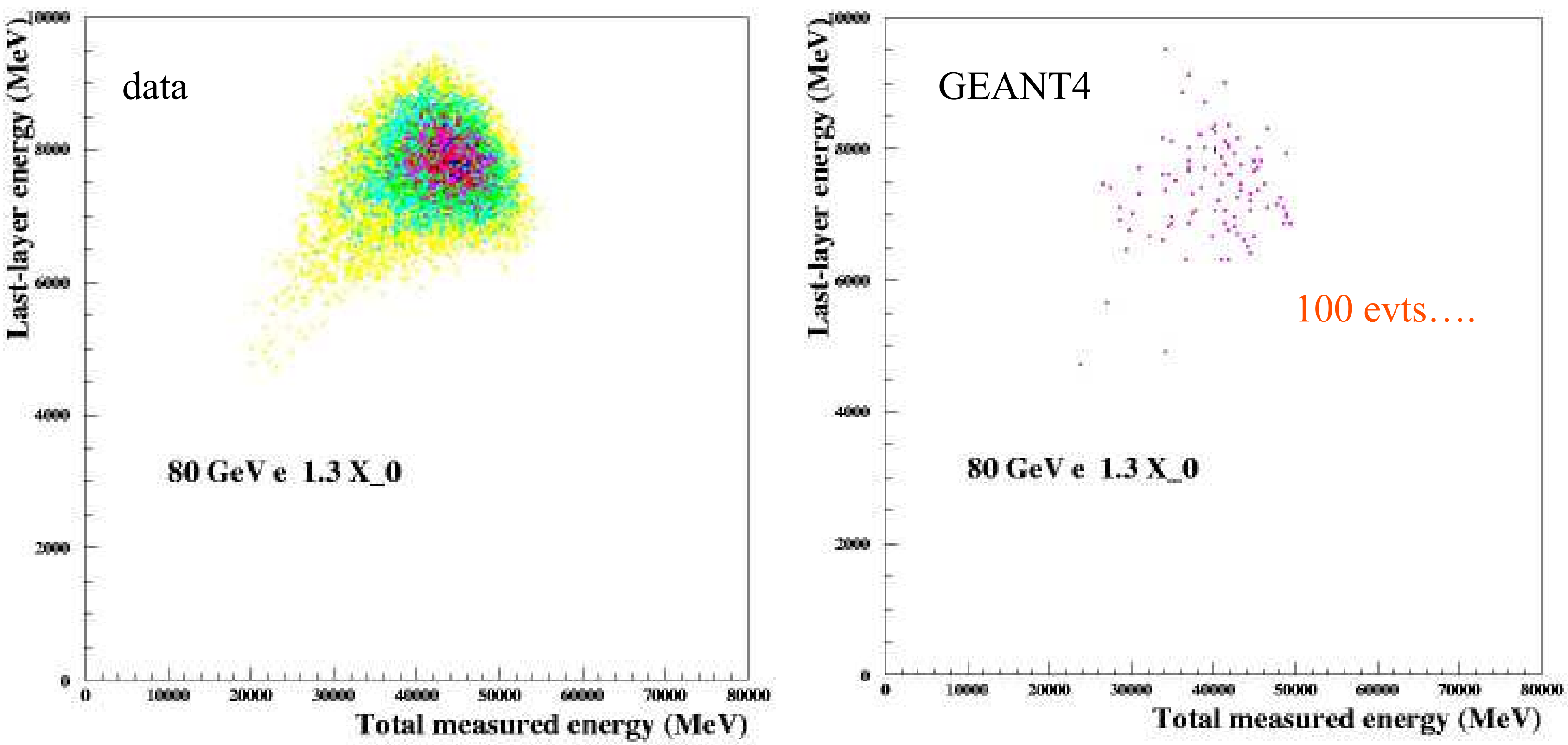




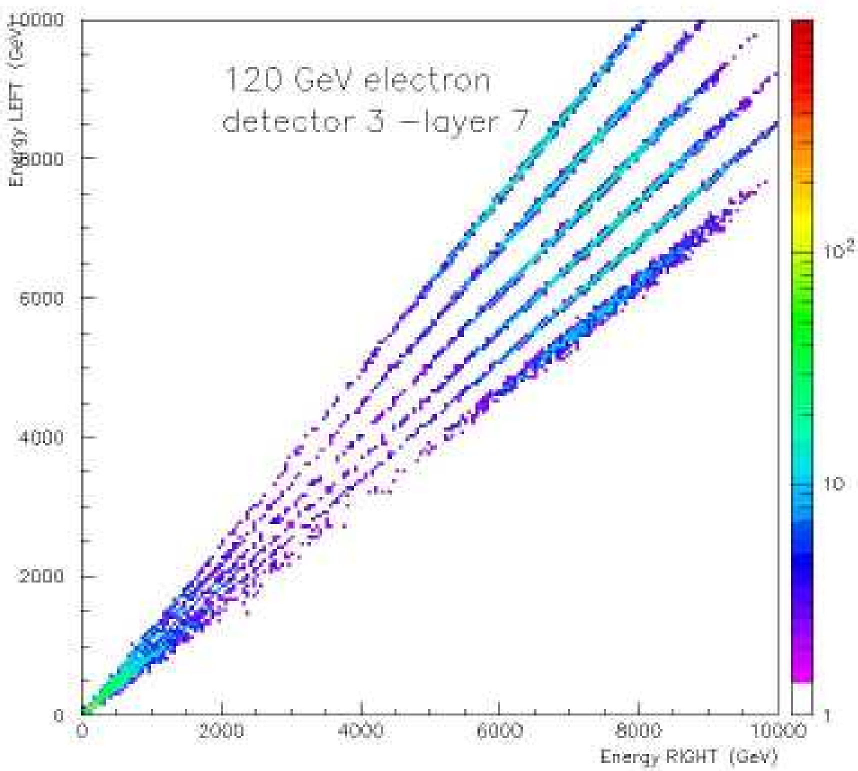


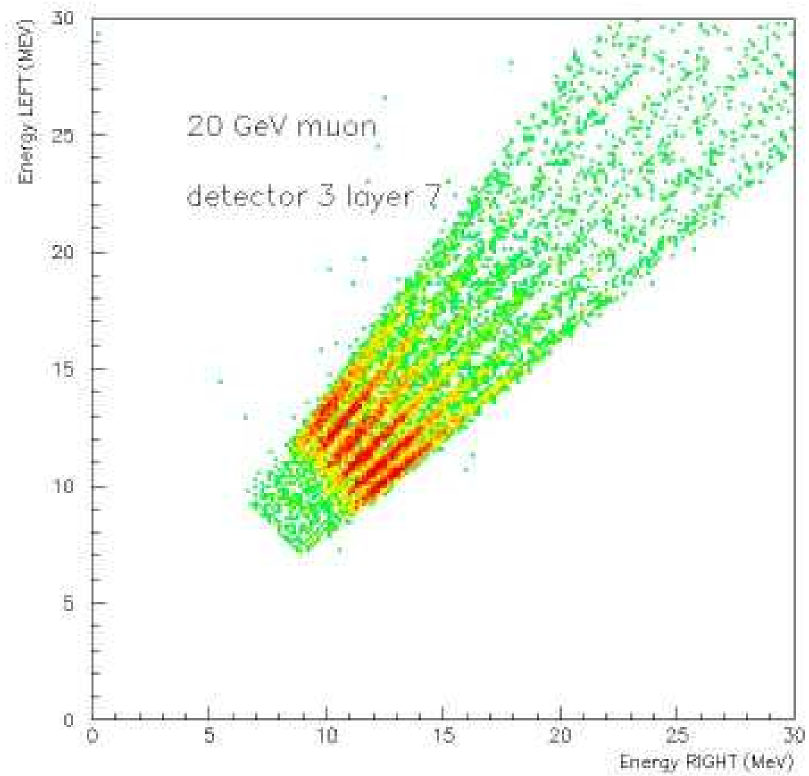


Last layer correlation



Light collection asymmetry





Position measurement