Performance of the AMS02 Electromagnetic calorimeter

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On behalf of the AMS collaboration

CALOR2012 – June 6th 2012 - Santa Fe

Outline

- AMS02 in Space
  - An overview and physics goals
- The Electromagnetic Calorimeter
  - Description
  - Space Environment : Issues and performance
  - Calibration in space
  - Energy Measurement
  - Electron – Positron identification: e/P rejection
  - Conclusions

AMS02 – May 2011

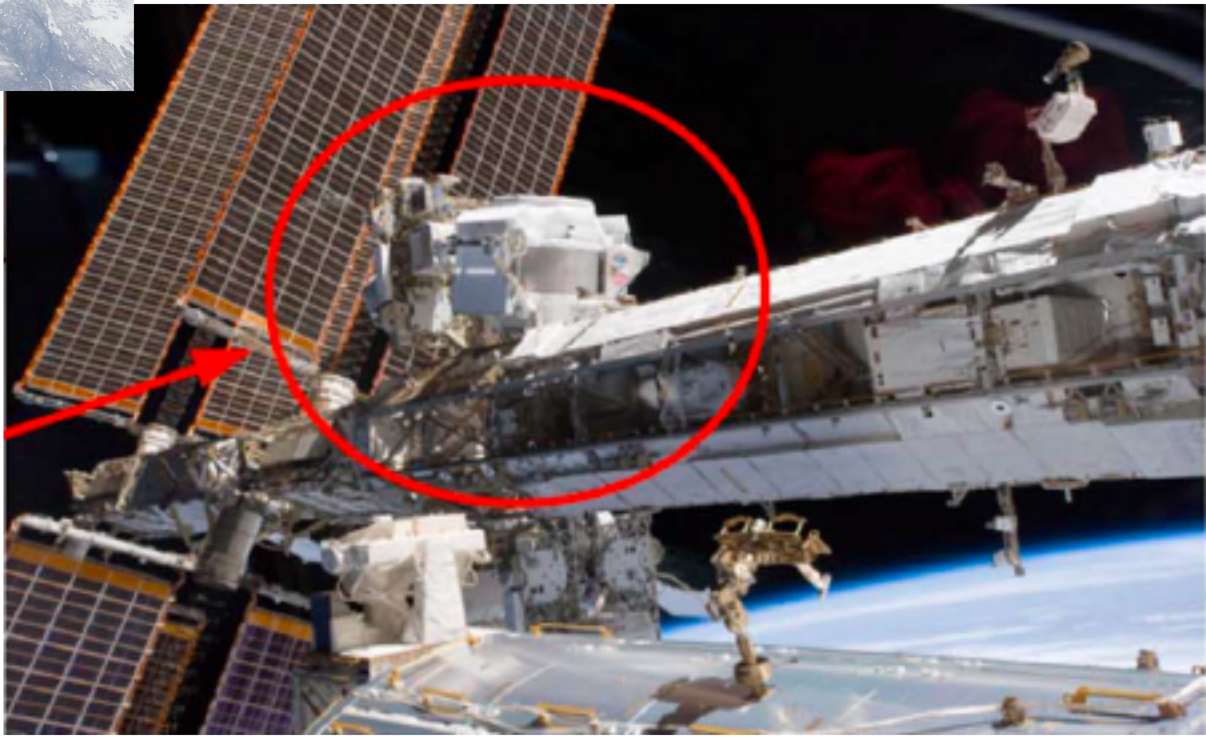
Cape Canaveral, May 16 2011.
STS 134 Mission, Launch of Endeavour Shuttle

Endeavour approaches the International Space Station (ISS ~300 km)

AMS02 on board of the ISS

AMS02 is grappled by the Shuttle Remote Manipulator System (SRMS)

May 19, 2011



May 19:

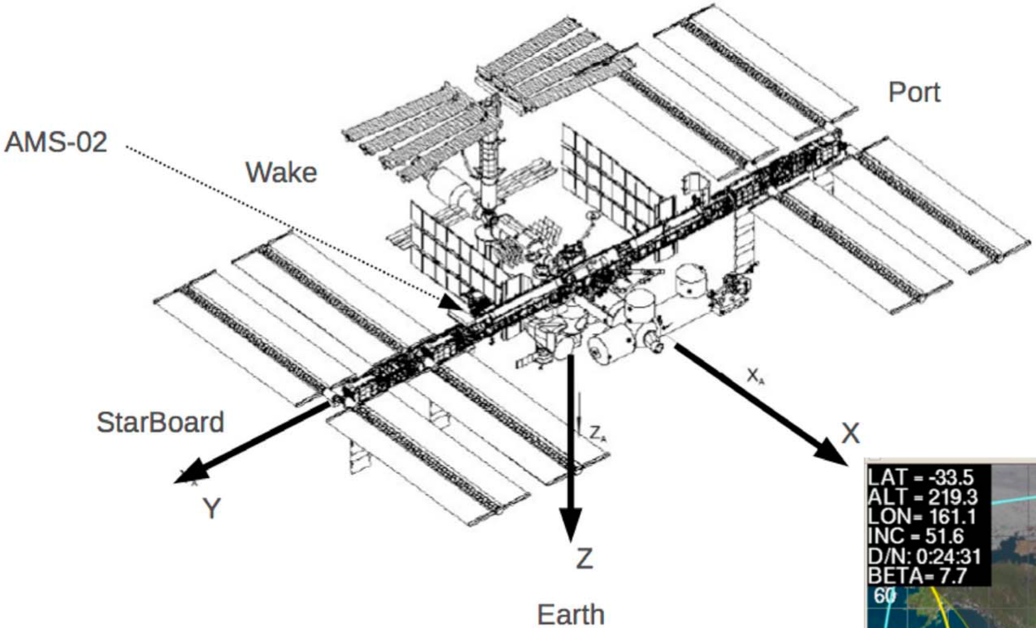
AMS installation completed on ISS at 5:15 CDT,

start taking data 9:35 CDT

Until 2020 ….

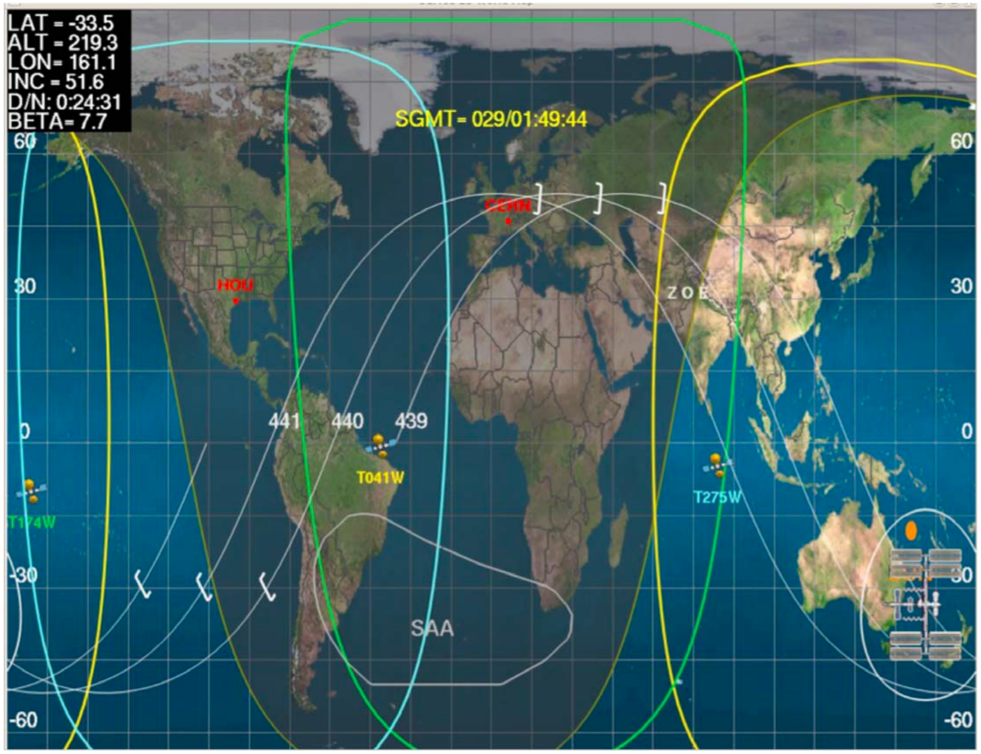
(CDT Central Daylight Time)

ISS orbit



ISS Size: 100 m

ISS velocity: 8km/s 4, one orbit every 90 mn

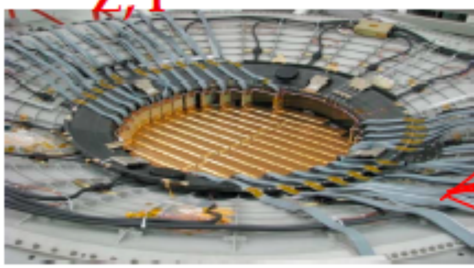


AMS02: A TeV precision, multi purpose Spectrometer

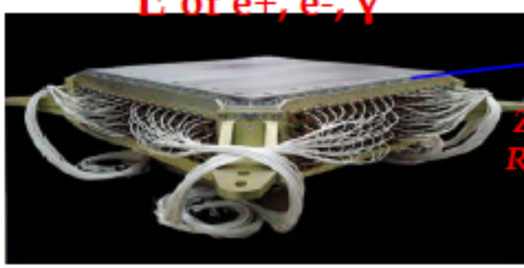
High Acceptance Spectrometer ~ 0.5m²sr

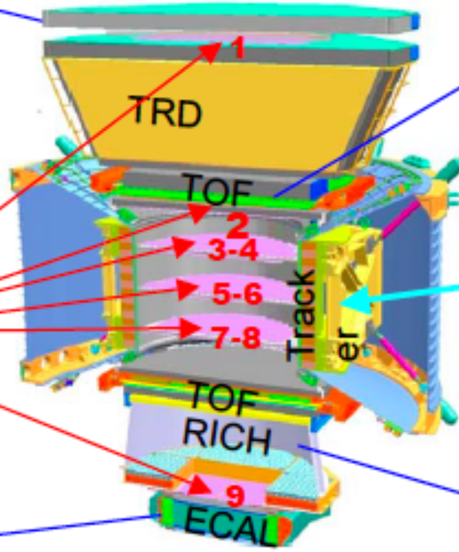
TRD
Identify e+, e-

Silicon Tracker
Z, P



ECAL
E of e+, e-, γ

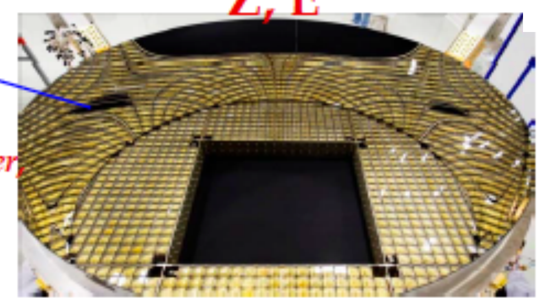




TOF
Z, E
β

Magnet (0.15T)
±Z

RICH
Z, E
β

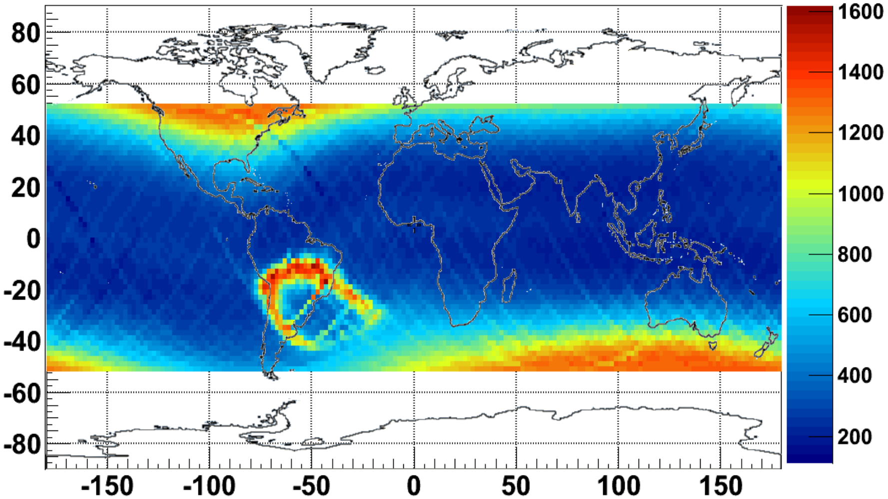


Z, P are measured independently by the Tracker, RICH, TOF and ECAL

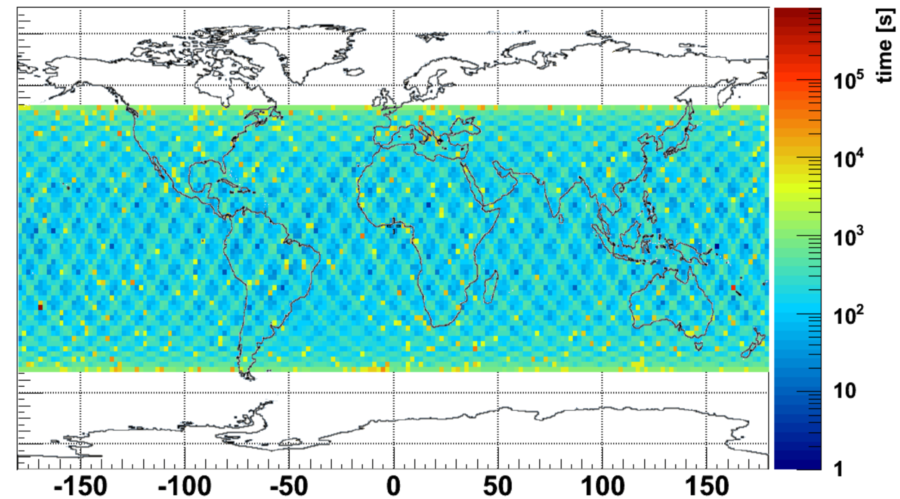
Dimensions: 5m x 4m x 3m
Weight: 8.5 tons
Power: 2500 W
Data downlink rate: >= 9Mbps

Orbital DAQ parameters

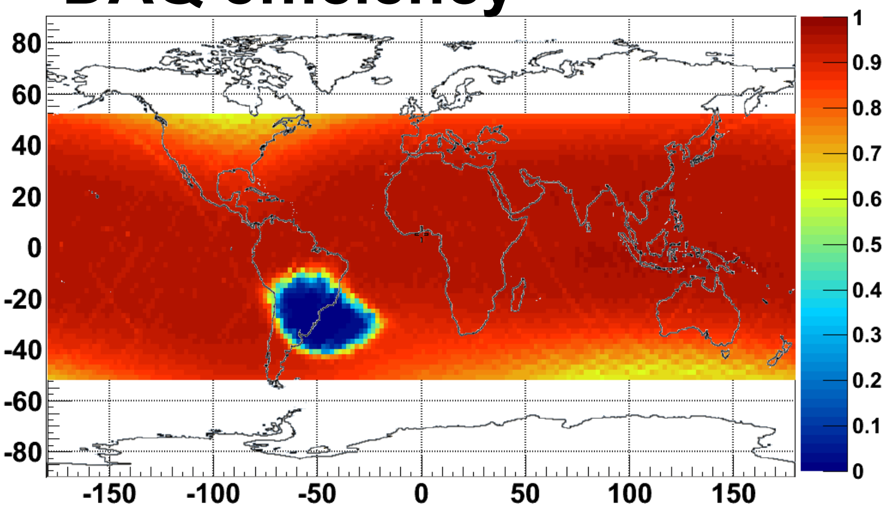
Acquisition rate [Hz]



Time at location [s]



DAQ efficiency



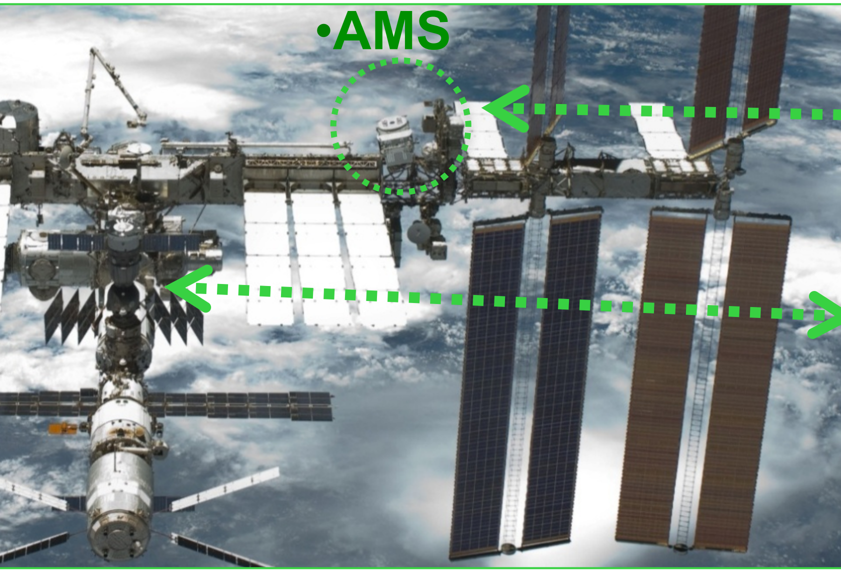
Particle rates vary from 200 to 2000 Hz per orbit

On average:

DAQ efficiency 85%

DAQ rate ~700Hz

AMS Data Flow



Astronaut at ISS AMS Laptop

Ku-Band
High Rate (down):
Events <10Mbit/s>

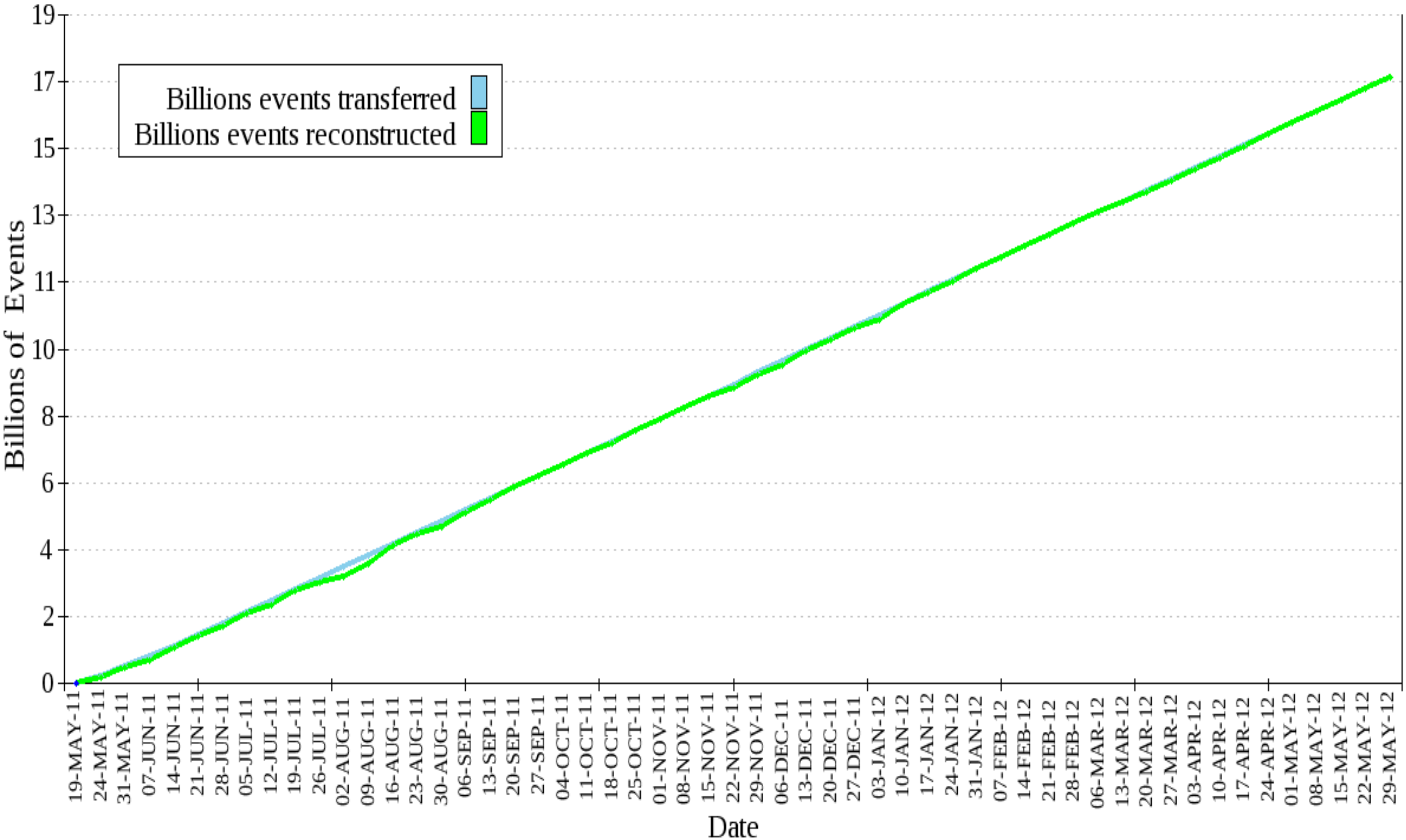
S-Band
Low Rate (up & down):
Commanding: 1 Kbit/s
Monitoring: 30 Kbit/s

AMS Payload Operations Control and Science Operations Centers (POCC, SOC) at CERN

AMS Computers at MSFC, AL

White Sands Ground Terminal, NM

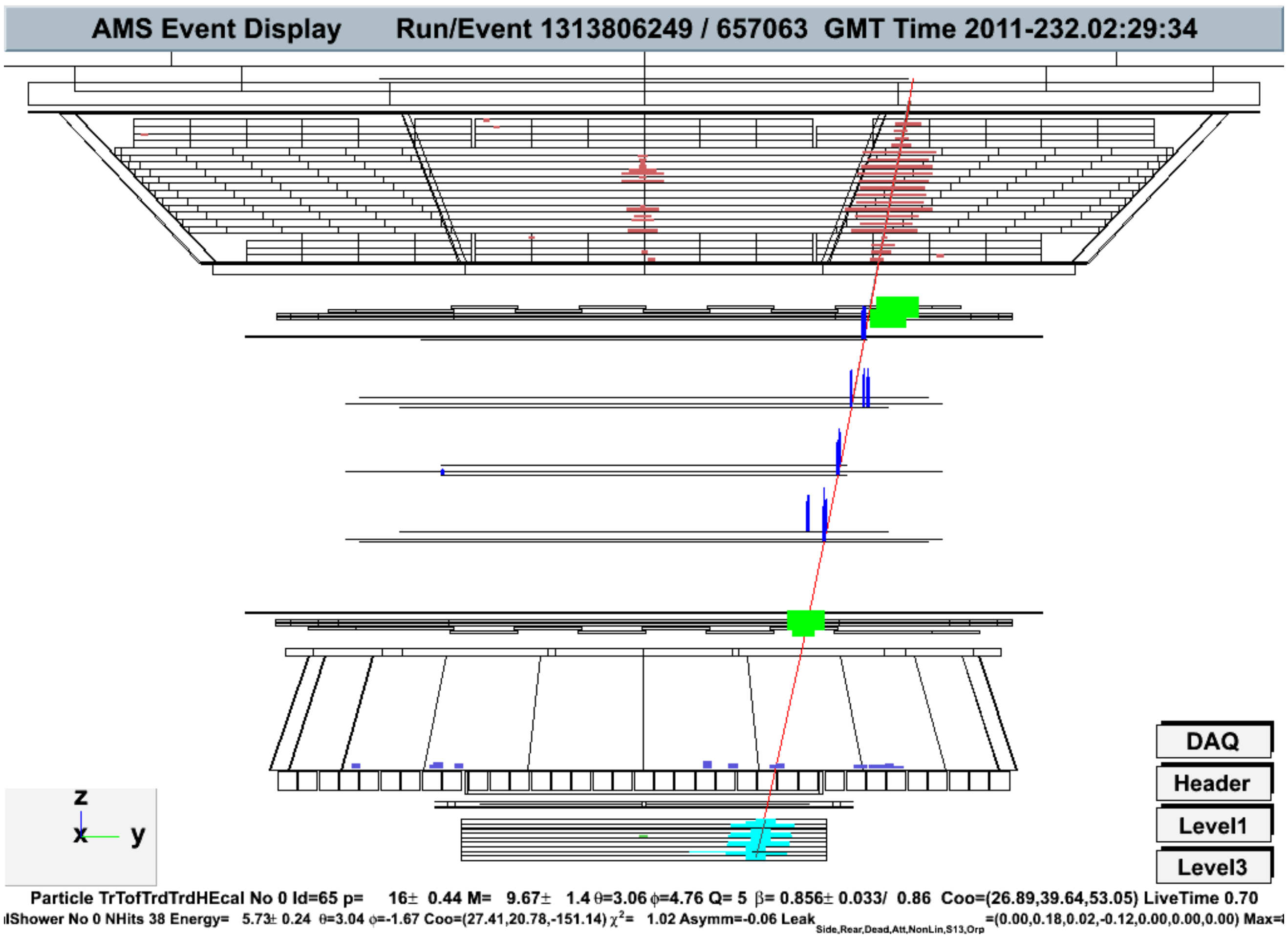
AMS has collected 17 billion of events



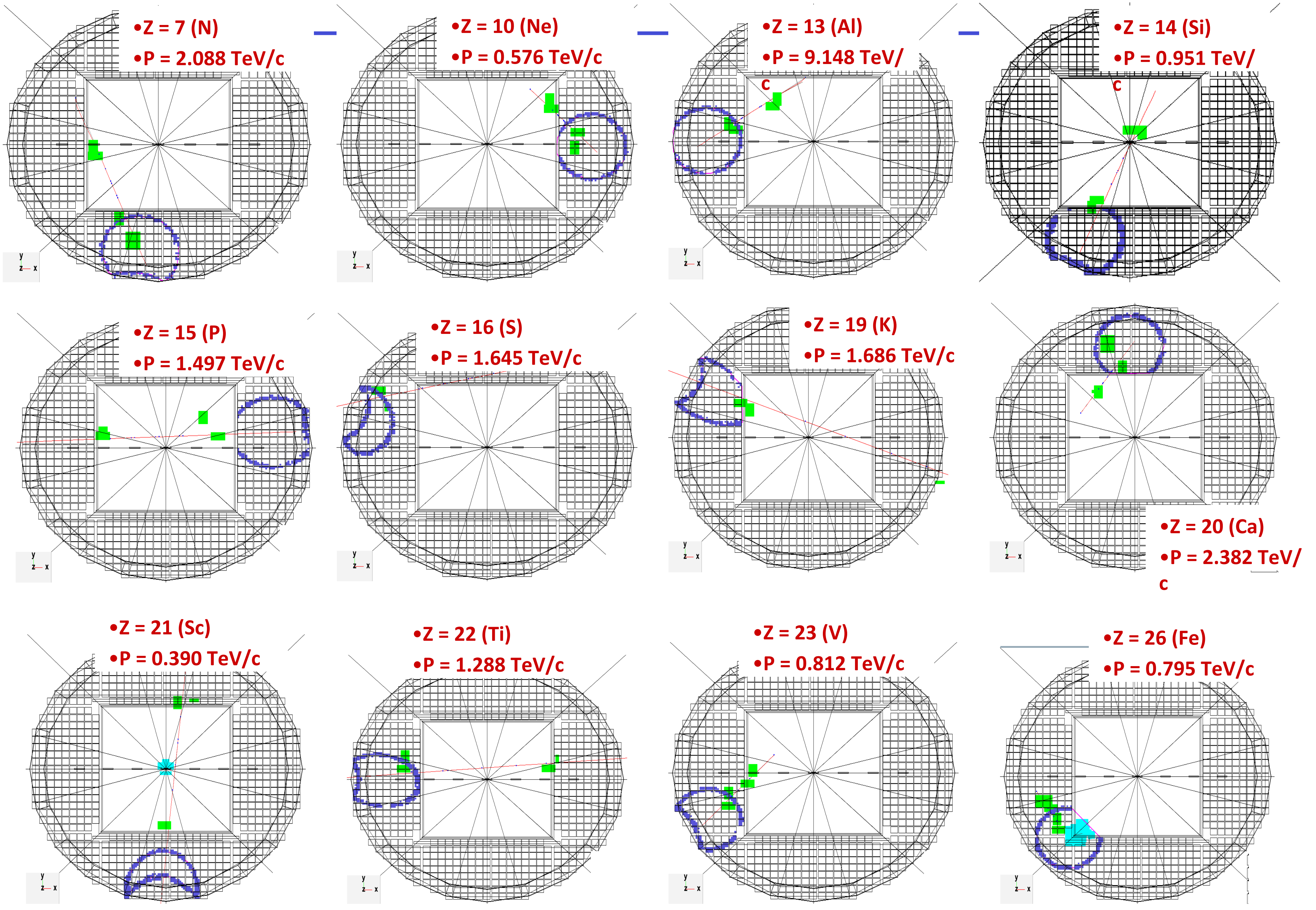
AMS Physics Potential

- Searches for primordial antimatter:
  - Anti-nuclei: He, …
- Dark Matter searches:
  - e^+ , $e^\pm$, p , γ…
  - simultaneous observation of several signal channels.
- Searches for new forms of matter:
  - strangelets, …
- Measuring CR spectra – refining propagation models;
- Study of local sources of high energy photons in the GeV-TeV:
- Study effects of solar modulation on CR spectra over 11 year solar cycle
- …

Boron candidate

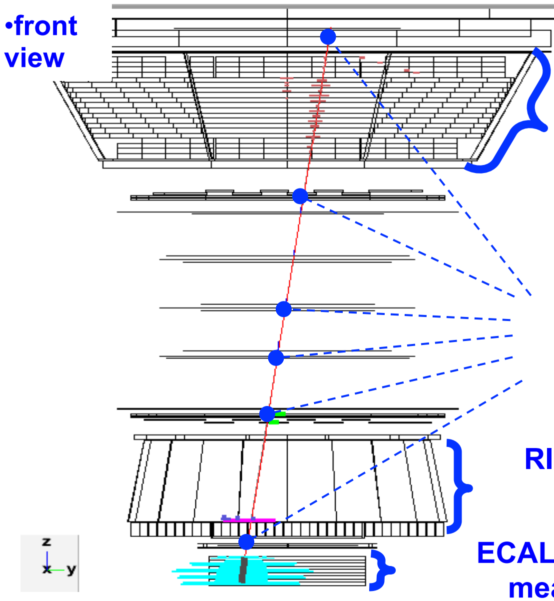


AMS data: Nuclei in the TeV range

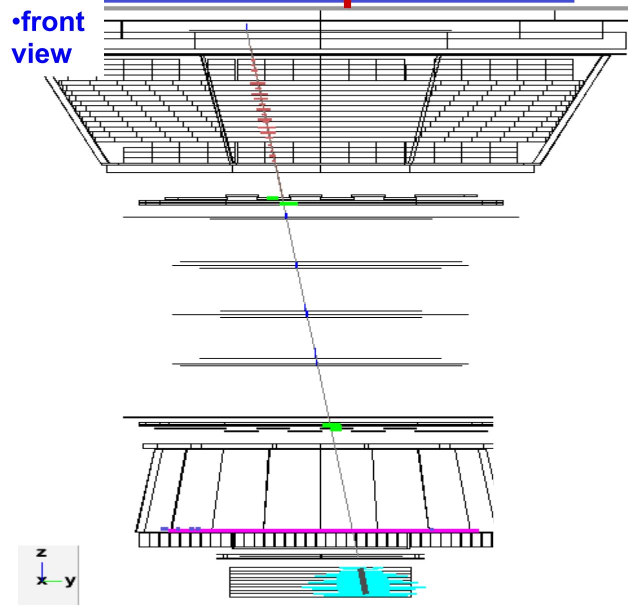


AMS data: High energy $e^{\pm}$

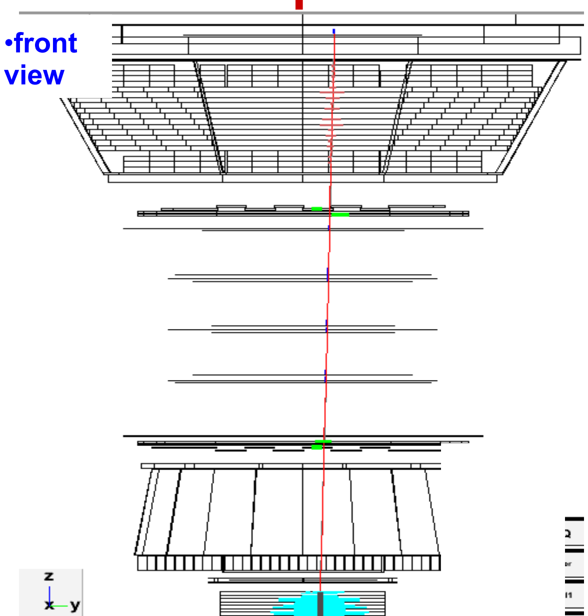
1.03 TeV electron



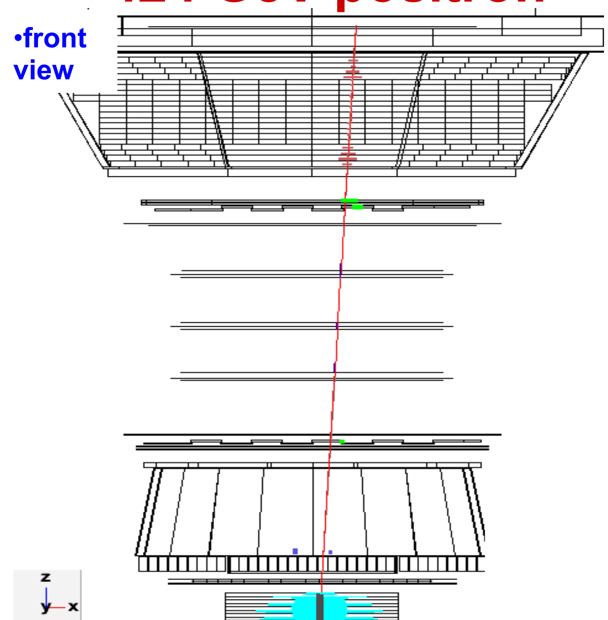
205 GeV positron



369 GeV positron

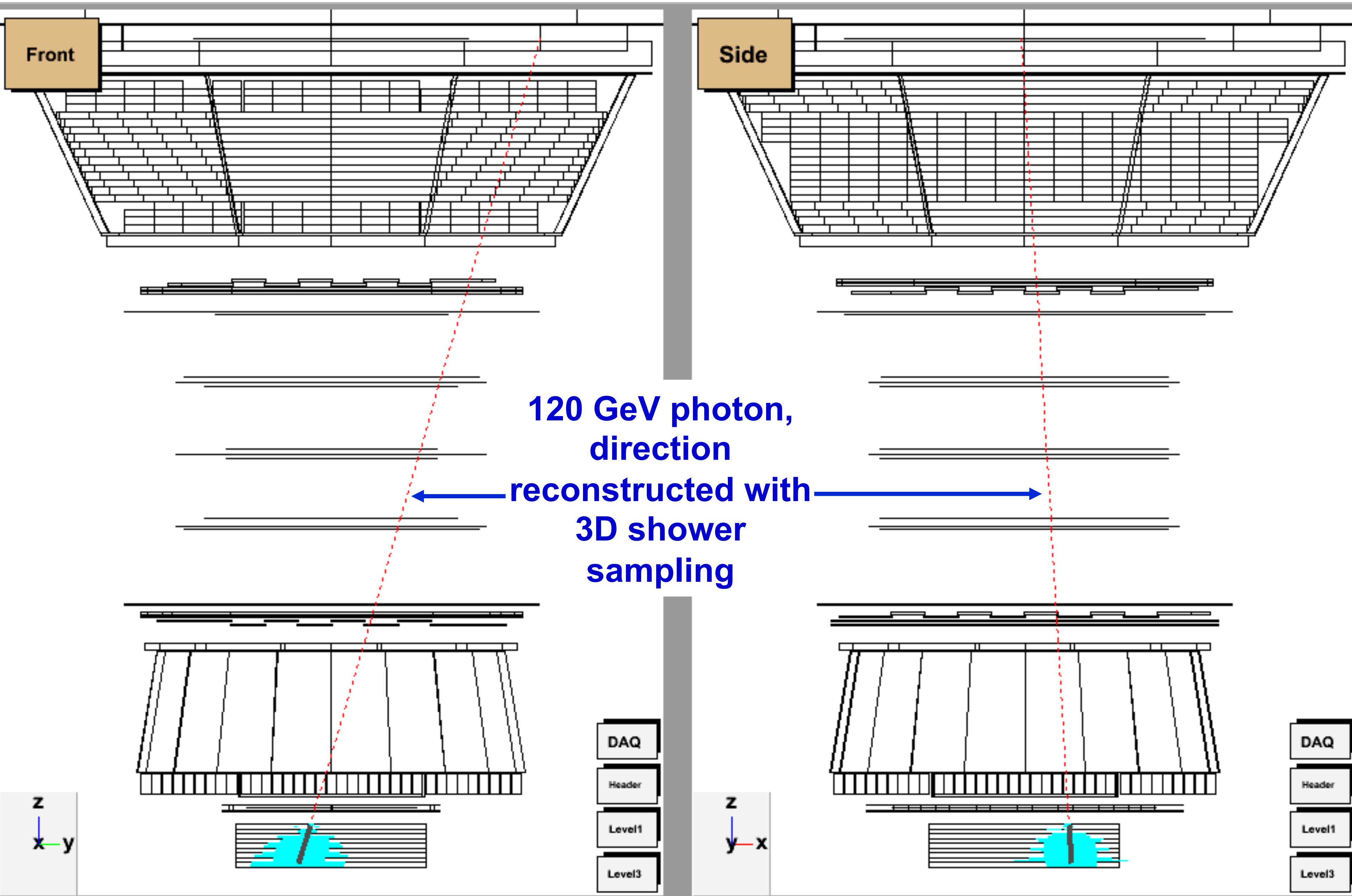


424 GeV positron



•120 GeV photon

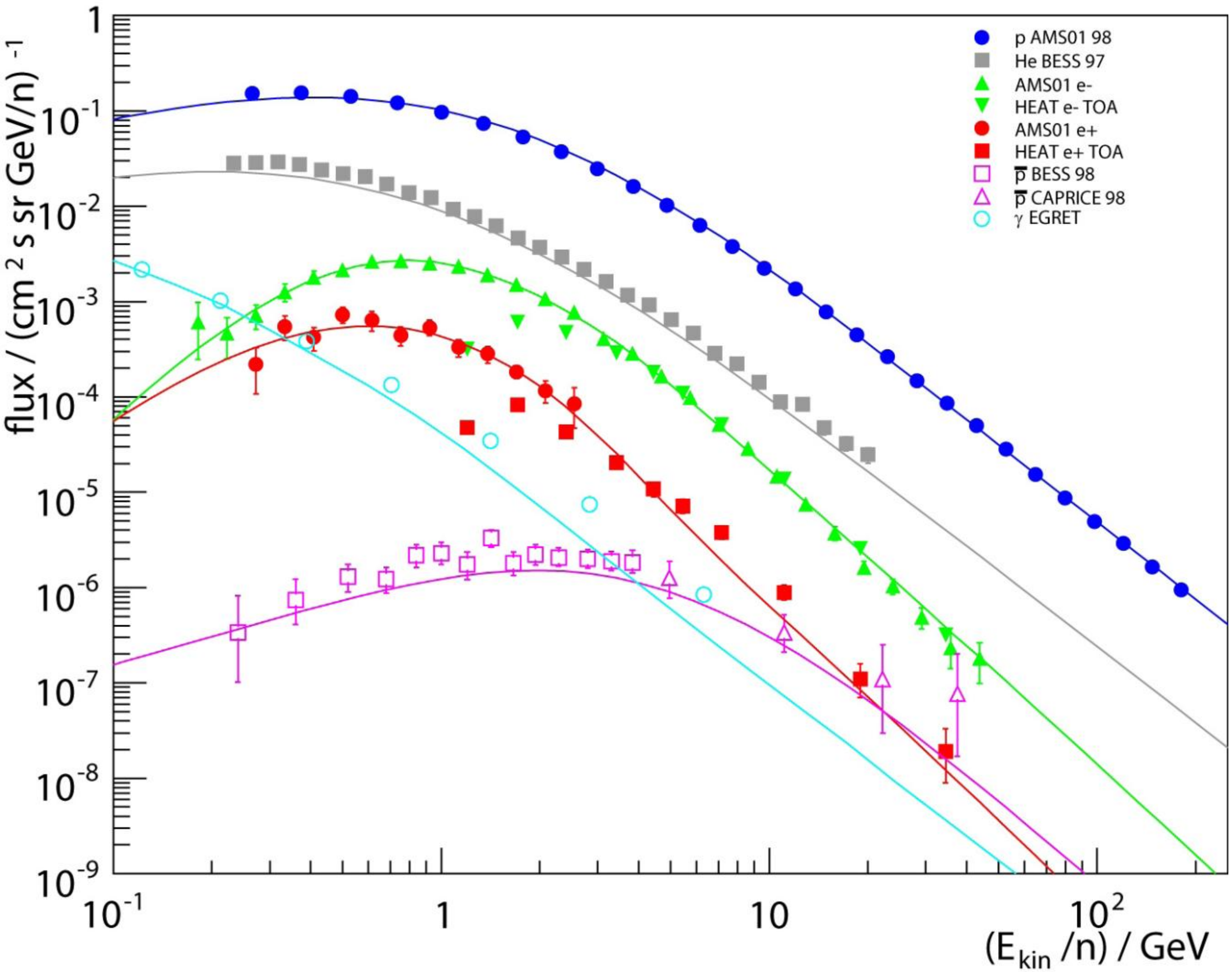
Unique Features: 17 X_0, 3D ECAL, measure γ to 1 TeV, time resolution of 1μsec



120 GeV photon, direction reconstructed with 3D shower sampling

Why do we need a calorimeter ?

Data before Pamela



@ 10 GeV

88%	**Protons**
10%	**Helium**
++1%	**Electrons**
++0.1%	**Positrons**
++0.01%	**Gamma rays**
0.001%	**Antiprotons**

Ecal: Physics Requirements for AMS02

The Ecal is required:

- To provide a separation factor e/p **10^{3}-10^{4}**

  – λ_I (Interaction length) / X_0 (radiation length) ~ 22

  -3D imaging electromagnetic shower reconstruction with a high granularity in the longitudinal and lateral views.

- to measure the energy for electrons, positrons and photons, with an efficiency ≥ 90%, up to ~ **1 TeV**

  -nX_0 ~ 17 is needed

- To trigger on non converted photons

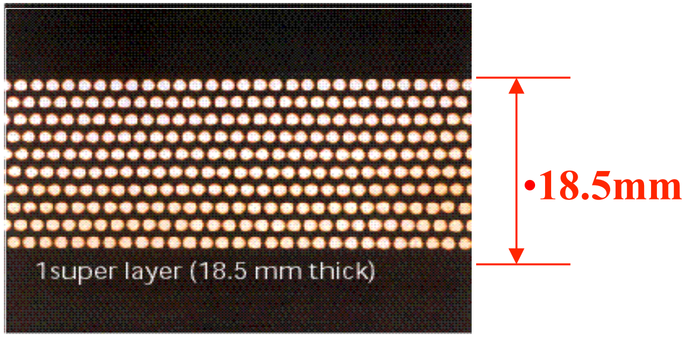
The calorimeter has been designed, realized and tested by the

INFN-Pisa (Italy), IHEP Beijing (China) and the LAPP-IN2P3 (France) groups

ECAL : Description

A 3-D sampling calorimeter made of lead foils and scintillating fibers

One Super Layer

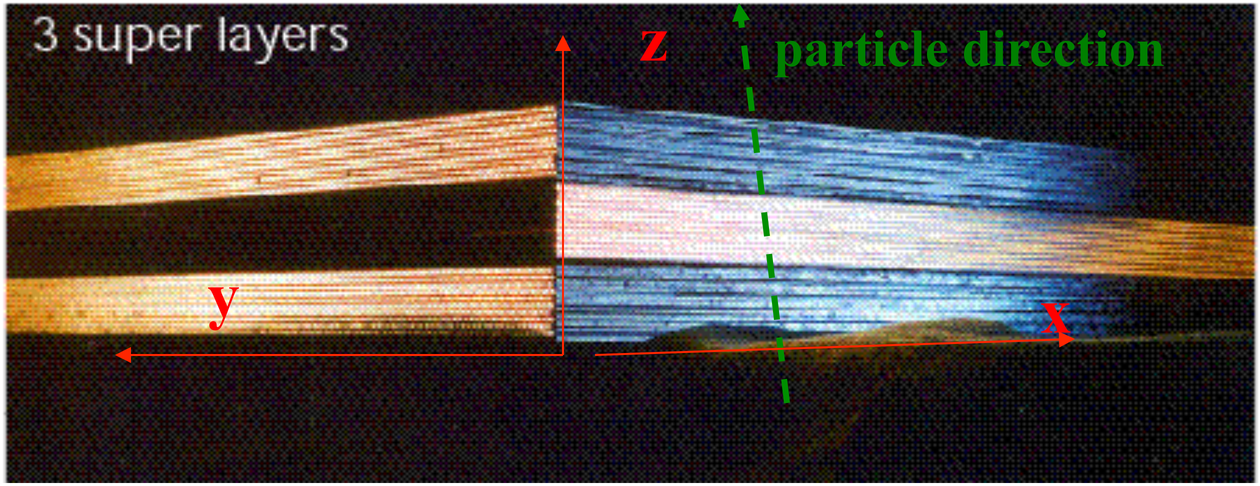


- Lead (58%), Scintillating fibers (33%), Optical glue (9%), Density ~ 6.8 g/cm3
- Dimensions 648x648x167 mm
- 9 super layers : 4 in The X view and 5 in the Y views
- Weight: 661 kg ("pancake" 512 kg)
- Acceptance : 0.06 m^2sr

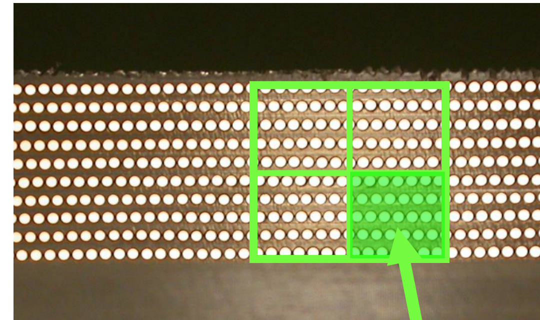
3D Imaging Calorimeter

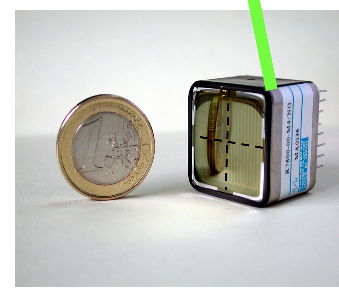
17 X_0

λ_I/X_0 ~22



Ecal front end and light collection





•Fibers read ,on one side, by 324 4-pixels pmt’s (324 PMTs Hamamatzu R7600-00-M4 (4 anodes).

=>**High granularity: ~ 0.9 x 0.9 cm^2**

Readout cells: ~ 1 X0(Z) 0.5 R_M (X,Y)

18 Longitudinal samplings

• From the MIP (10 MeV) ≥ 10*Ped_{RMS} to the TeV

=> **a dynamic range of 60000** implying 2 dynamic ranges for each pixel (ADC 12 bits) and the dynode for redundancy

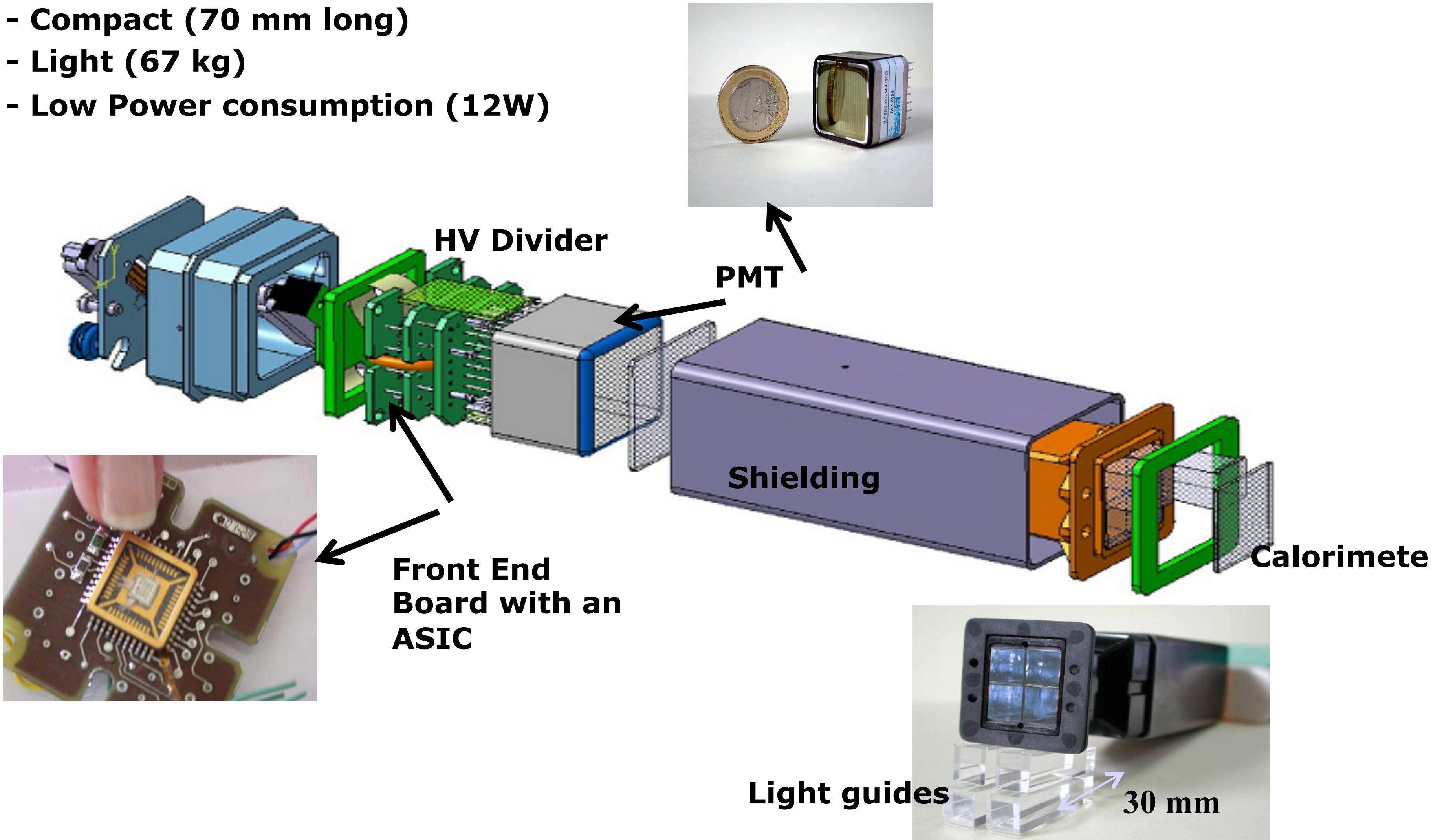
- **High Gain(HG): 0.4 MeV- 1.6 GeV**
- **Low Gain(LG): 150 MeV -55 GeV**

1296 HG, 1296 LG, 324 dynodes

• Stand alone gamma trigger: use of the dynode, amplified by a factor 10, for 6 central super layers. 216 channels

Front End and light collection system

- Robust (fulfill space constraints)
- Compact (70 mm long)
- Light (67 kg)
- Low Power consumption (12W)



Ecal:Extensively tested before the launch

Two calorimeters have been built: Engineering Model (IM) and the Flight Model(FM)

- IM : 2001-2005

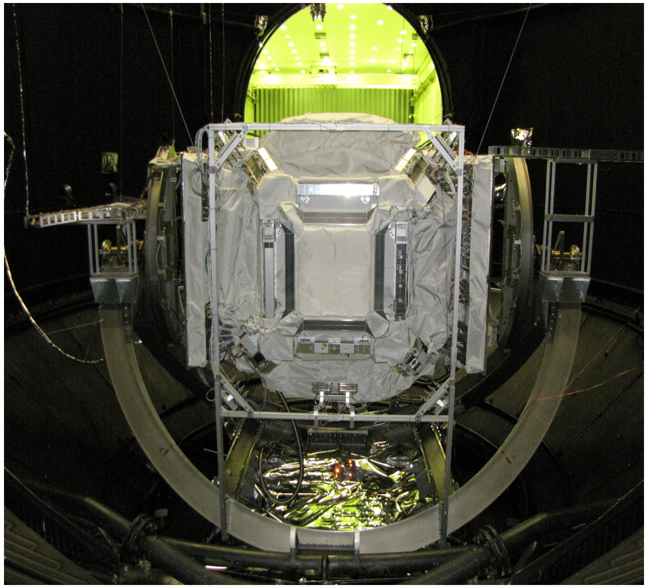
  (qualification tests and TB2002 =>Calor 2002)

- FM :

  2006->2008 Ecal Standalone (Test beam 2007 => Calor 2008)

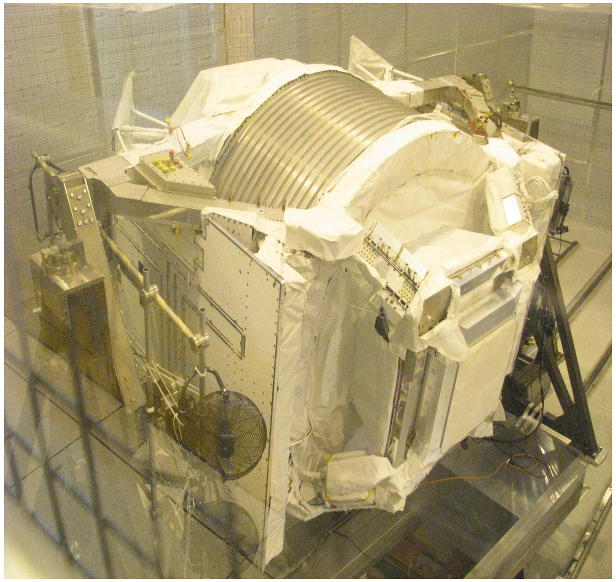
  2008-2009 :AMS Assembly

Thermal Vacuum Tests,330 hours



ESA, April, 2010, ESTEC, Noordwijk

Test Beam(e+,e--,Protons@400 GeV, pions)



CERN, 8-20 August 2010,

KSC , cosmic rays

NASA, Cape Canaveral,

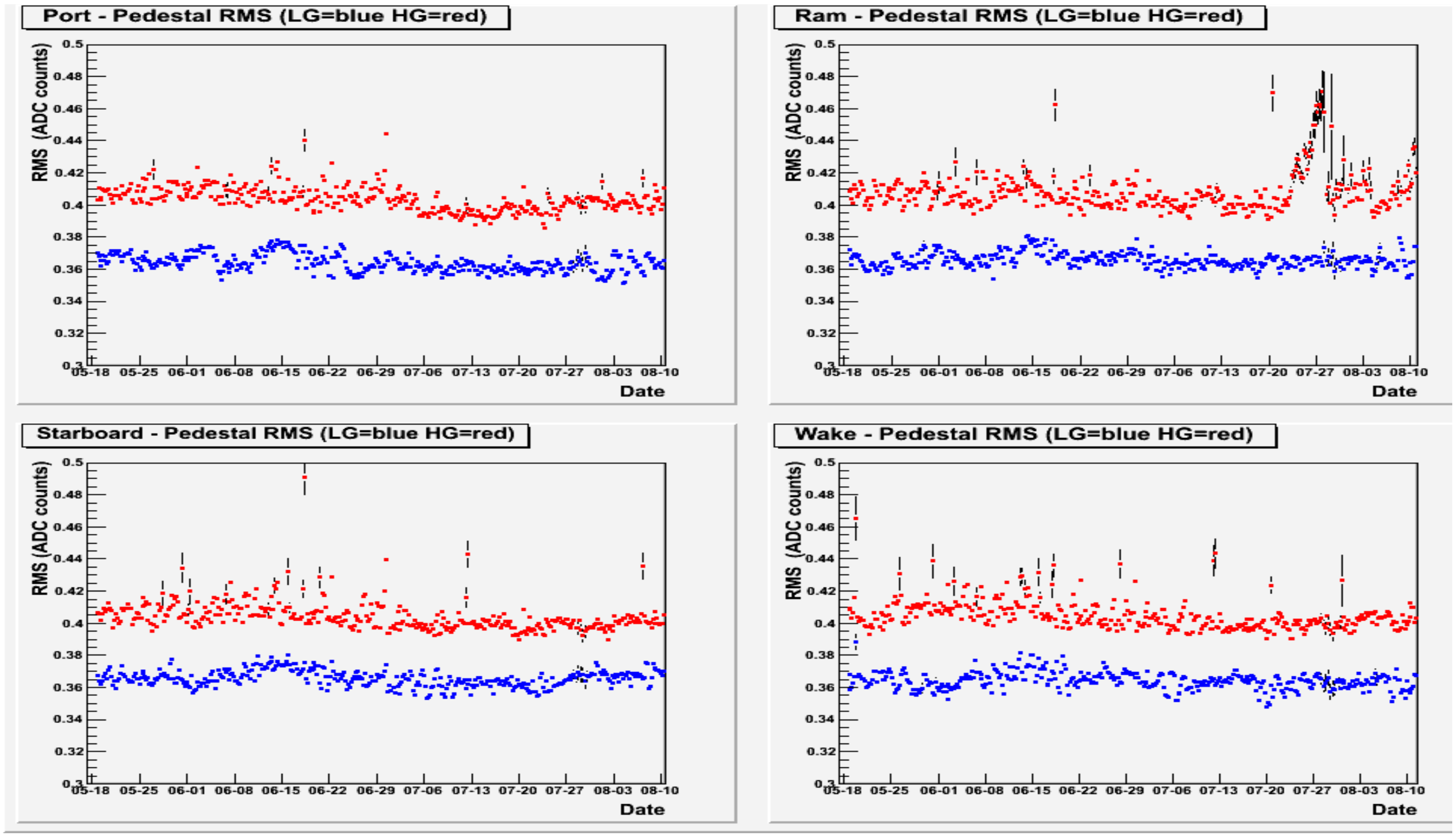
30 August 2010 – March 2011

Space Environment: issues and Performance

- Electromagnetic Compatibility (EMC)
  - RMS of the pedestal for the 4 faces as a function of time (3 first months)

Low Gain , <RMS>= 0.37 ADC counts HIGH gain , <RMS>= 0.41 ADC counts

Similar to what was expected and measured on Ground (Cern, ESTEC or KSC)



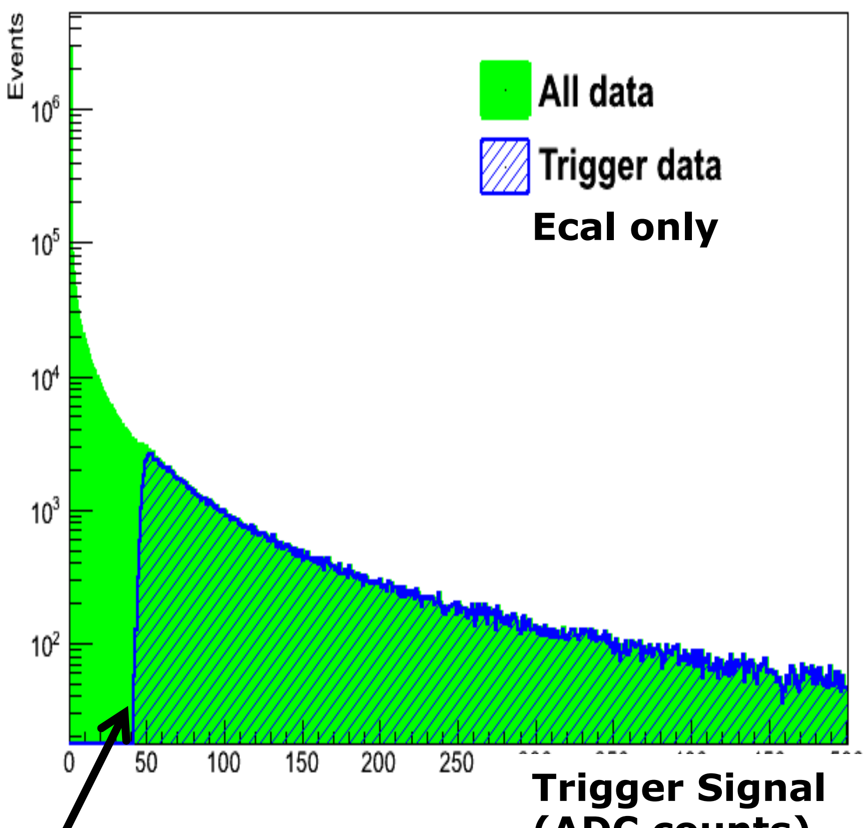
1 PMT dead before launch, one lost after the Launch, 4 pixels noisy but usable

Space Environment: issues and Performance

- Electromagnetic Compatibility (EMC) and Analog Trigger

Threshold at the level of 2 mV => very sensitive to any noisy environment

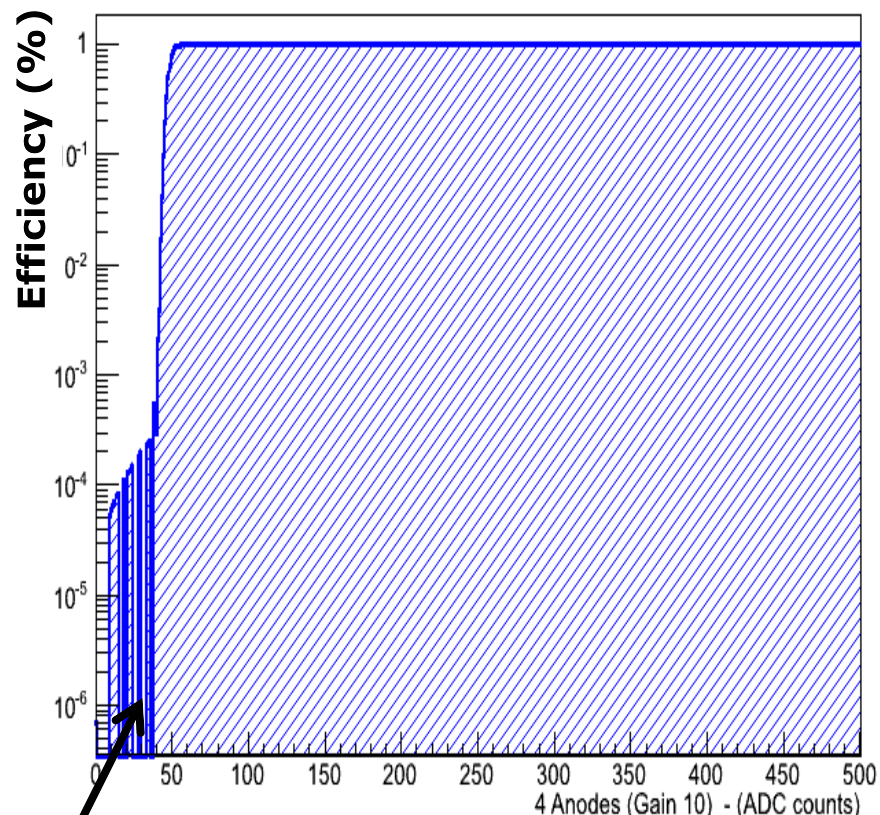
SL 6 PMT 16 – 5 days of statistics



Trigger Signal (ADC counts)

Threshold

Efficiency for one channel as expected



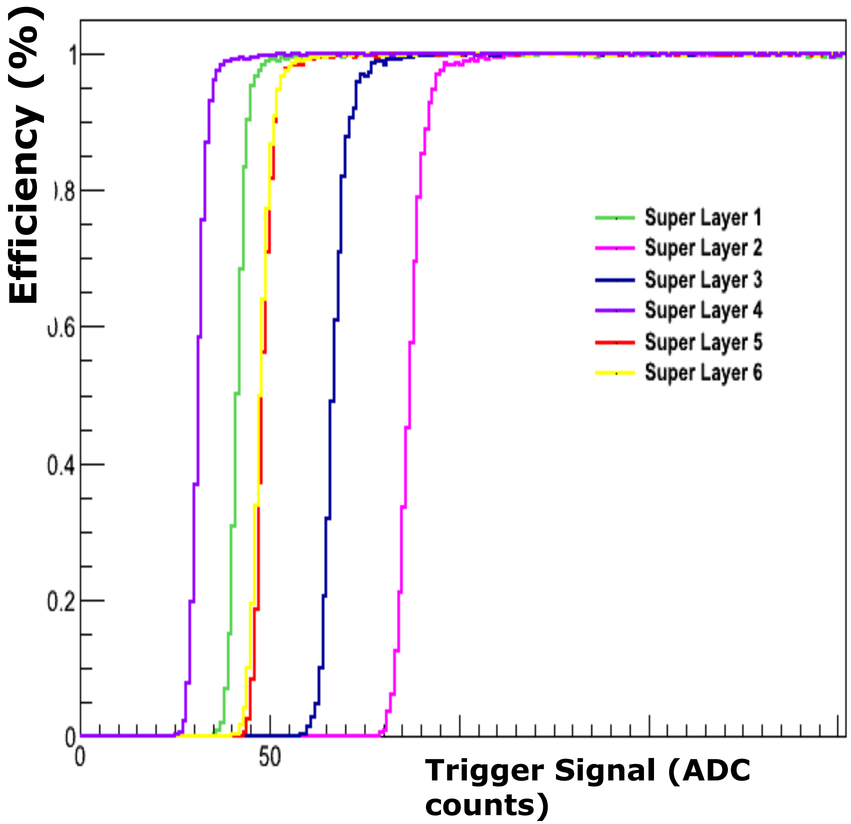
Below he threshold : Fake trigger rate or noise: A factor 10 better than what measured on ground

Space Environment: issues and Performance

- Electromagnetic Compatibility (EMC) and Analog Trigger

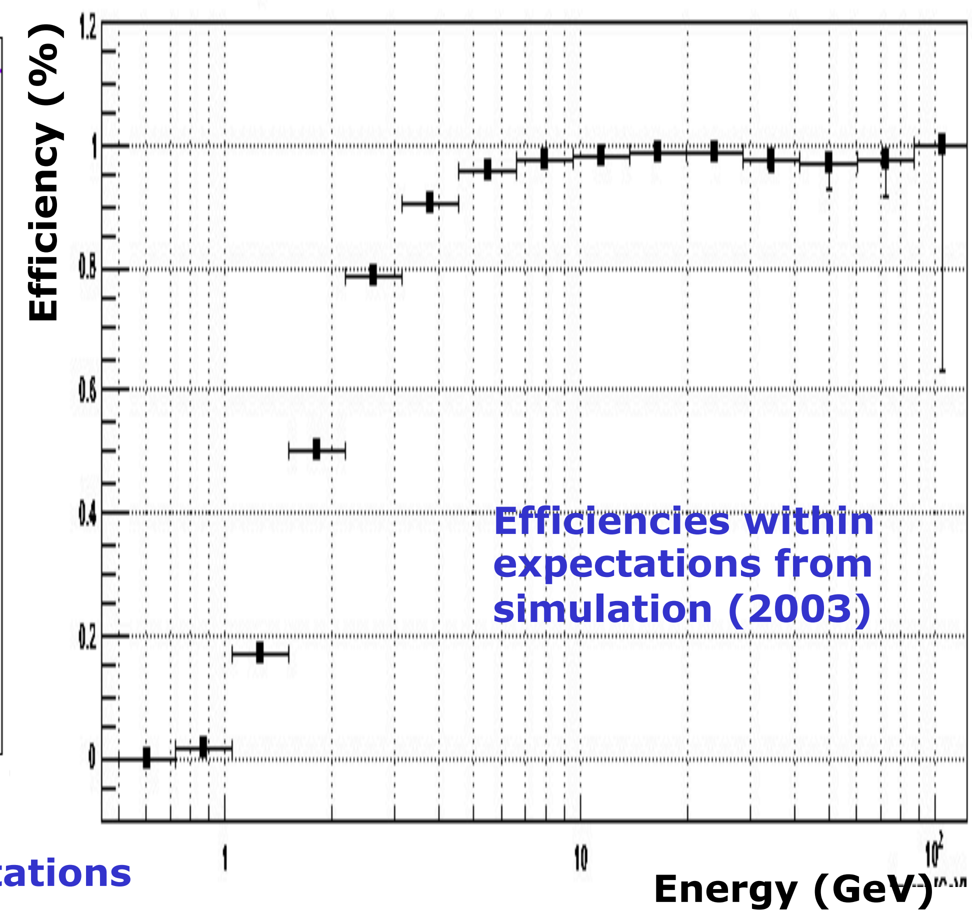
  Threshold at the level of 2 mV (60 MeV) => very sensitive to any noisy environment

6 Superlayers are included in the trigger, with 5 different thresholds (60 meV to 180 meV)

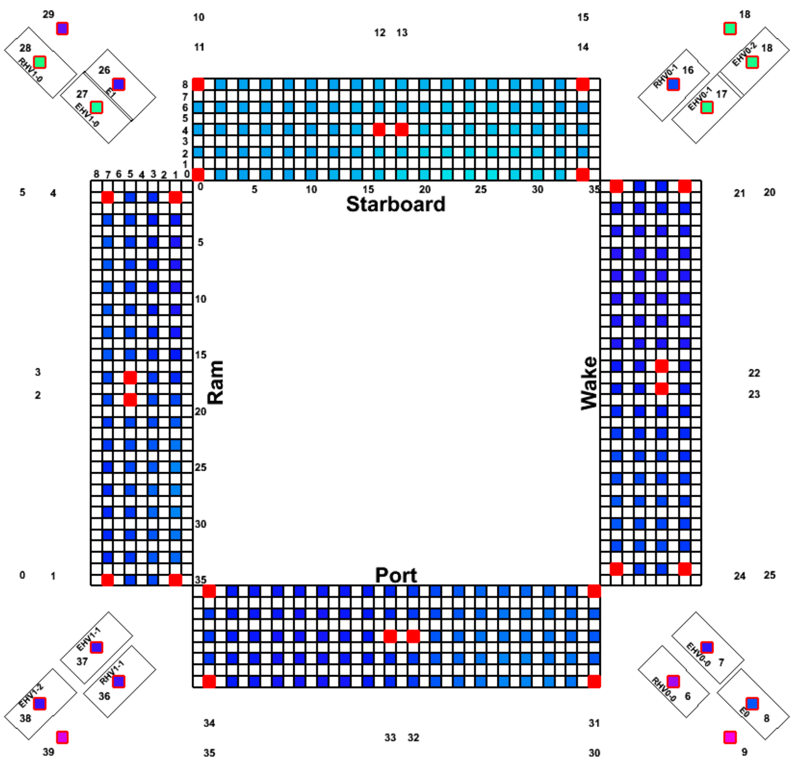


Thresholds and rising time within expectations

Photon trigger efficiency measured on ISS electrons



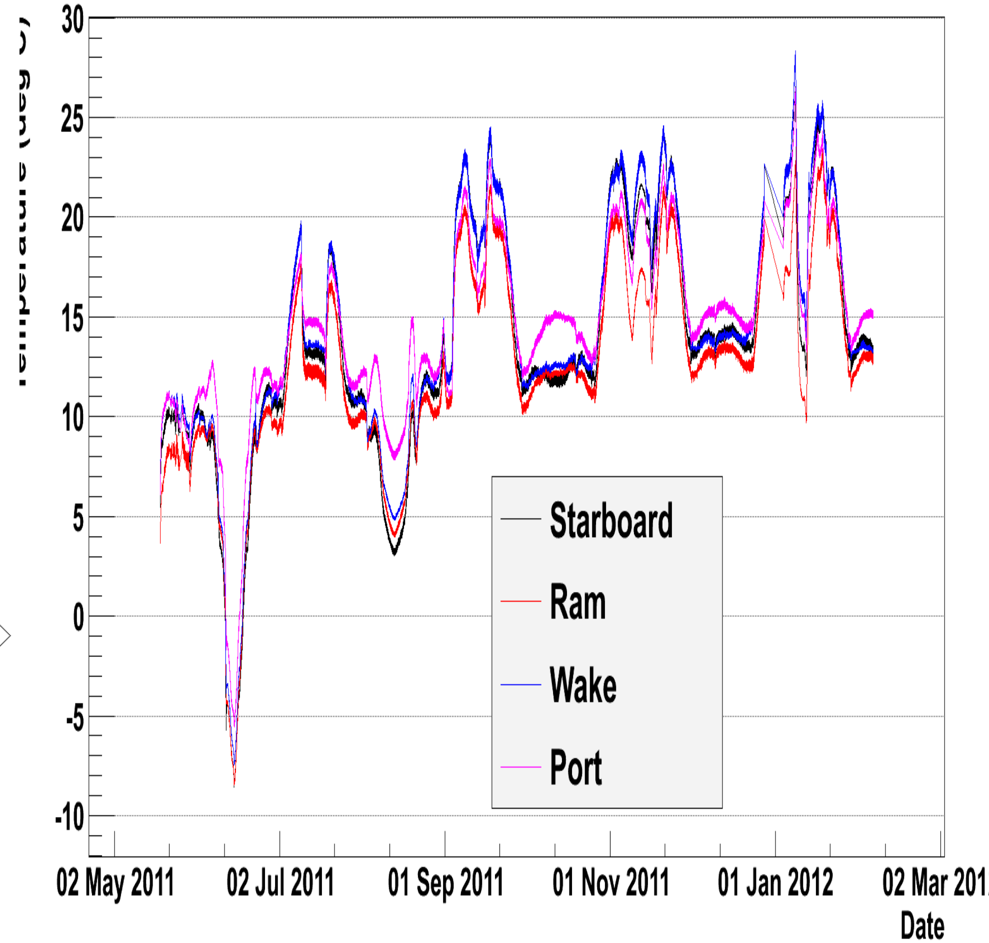
Space Environments: temperature issues



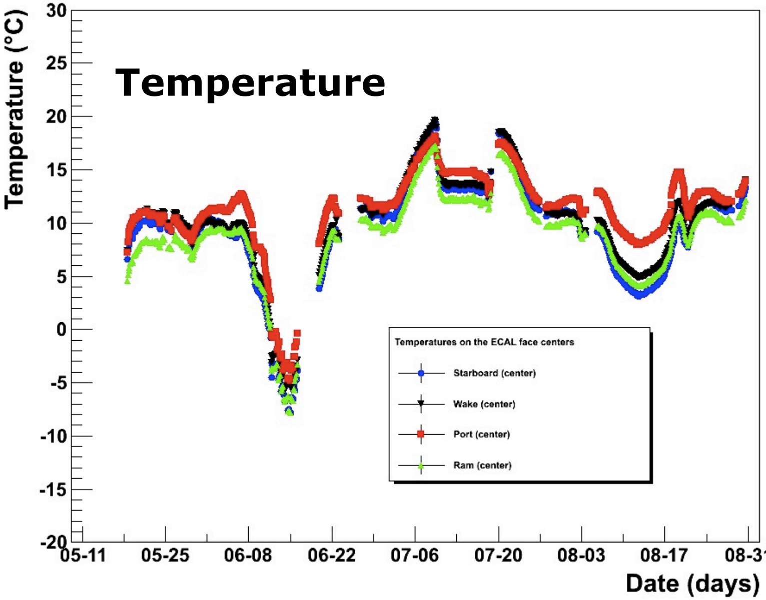
- 40 Thermal sensors
- Read every 2s

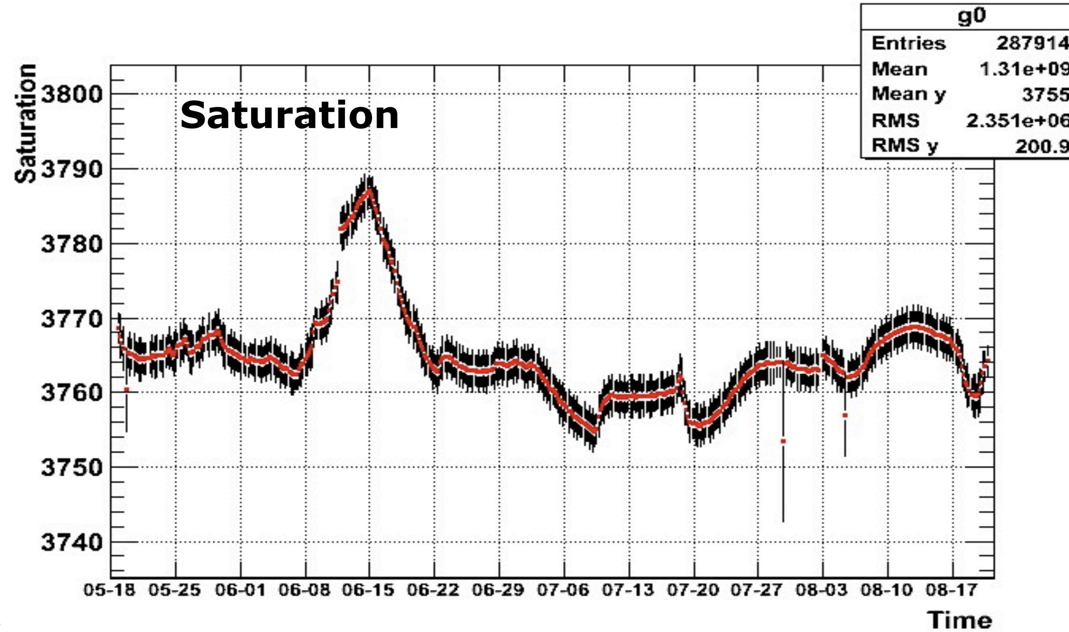
Temperature variation on each face of the calorimeter

Amplitude :-10^{0}C-28^{0}C



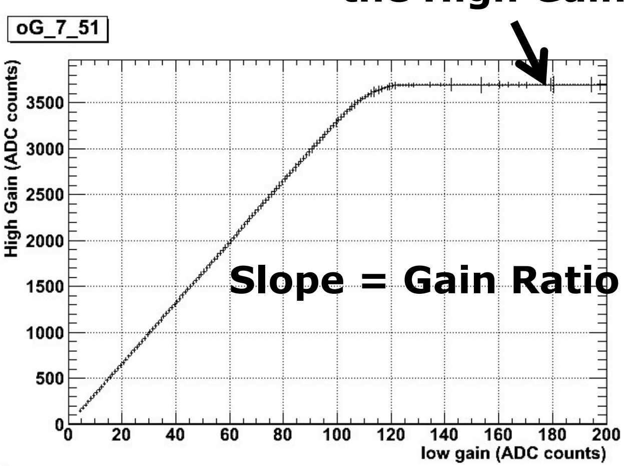
Space Environments: temperature issues



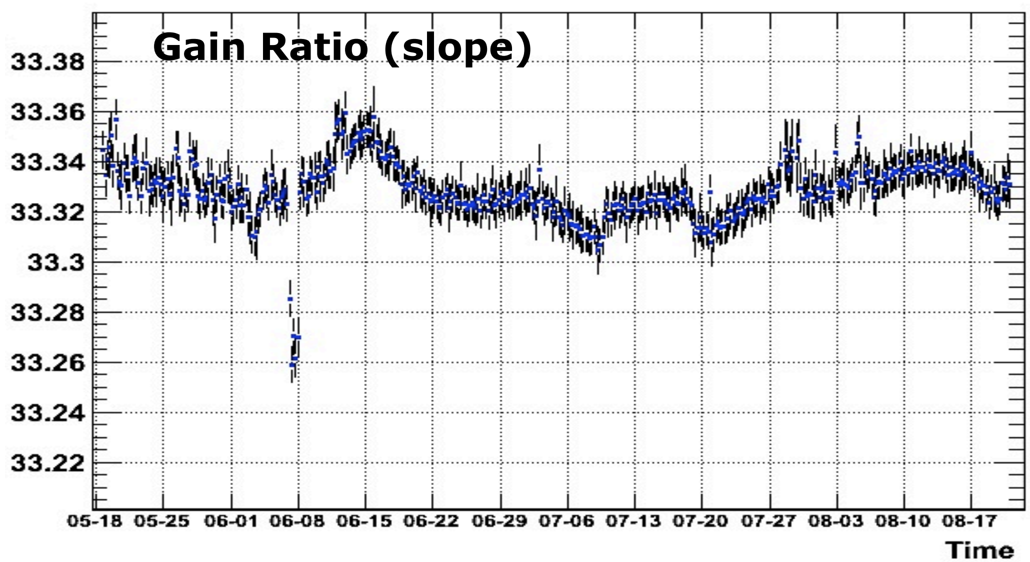


Saturation on the High Gain

High Gain

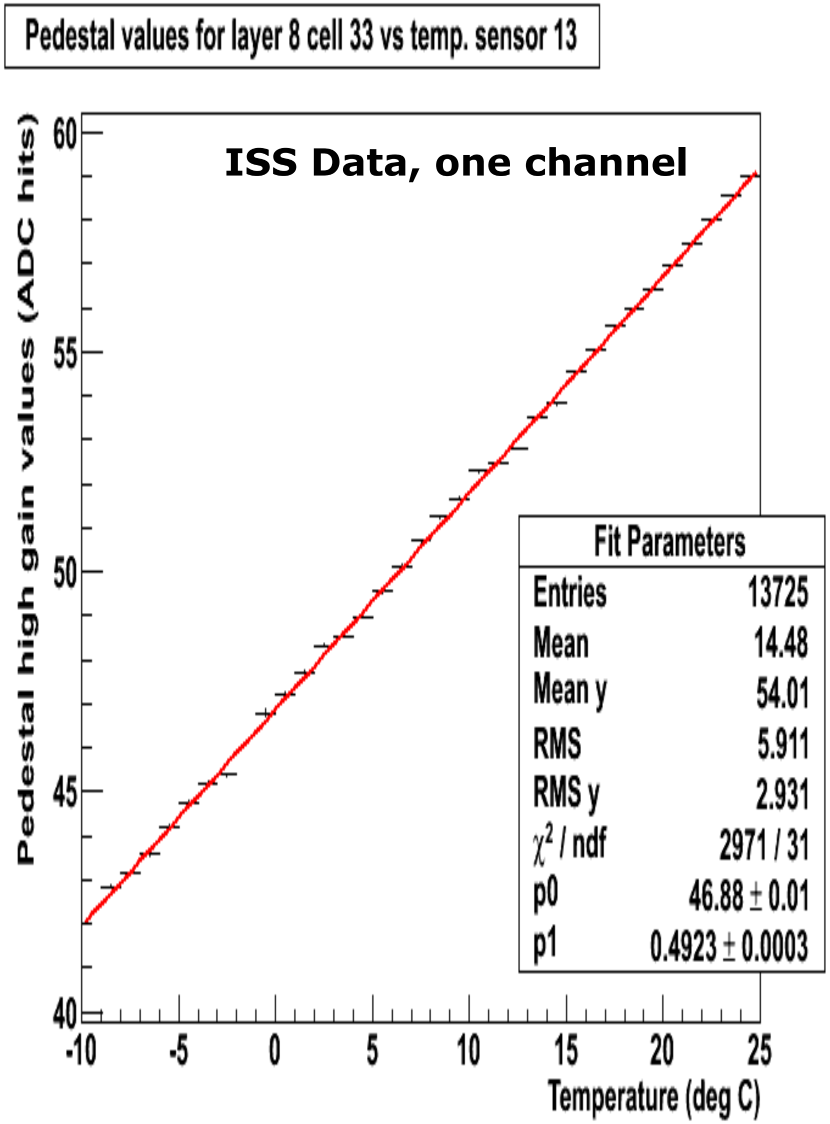


Low Gain



Space Environments: temperature issues

Front end performance: pedestal, gain ratio and saturation



ΔPed/Ped $= +510^{-3}$ per ^{0}C

ΔGain/Gain $= -3\times10^{-5}$ per ^{0}C

ΔSat/Sat $= -6\times10^{-4}$ per ^{0}C

Precisely Monitored.

In very good agreement with previous measurements on ground

Calibration in space

With an accuracy at the level of 1%, we will rely on the test beam data (especially for the absolute calibration) and will follow the evolution versus time with the MIP.

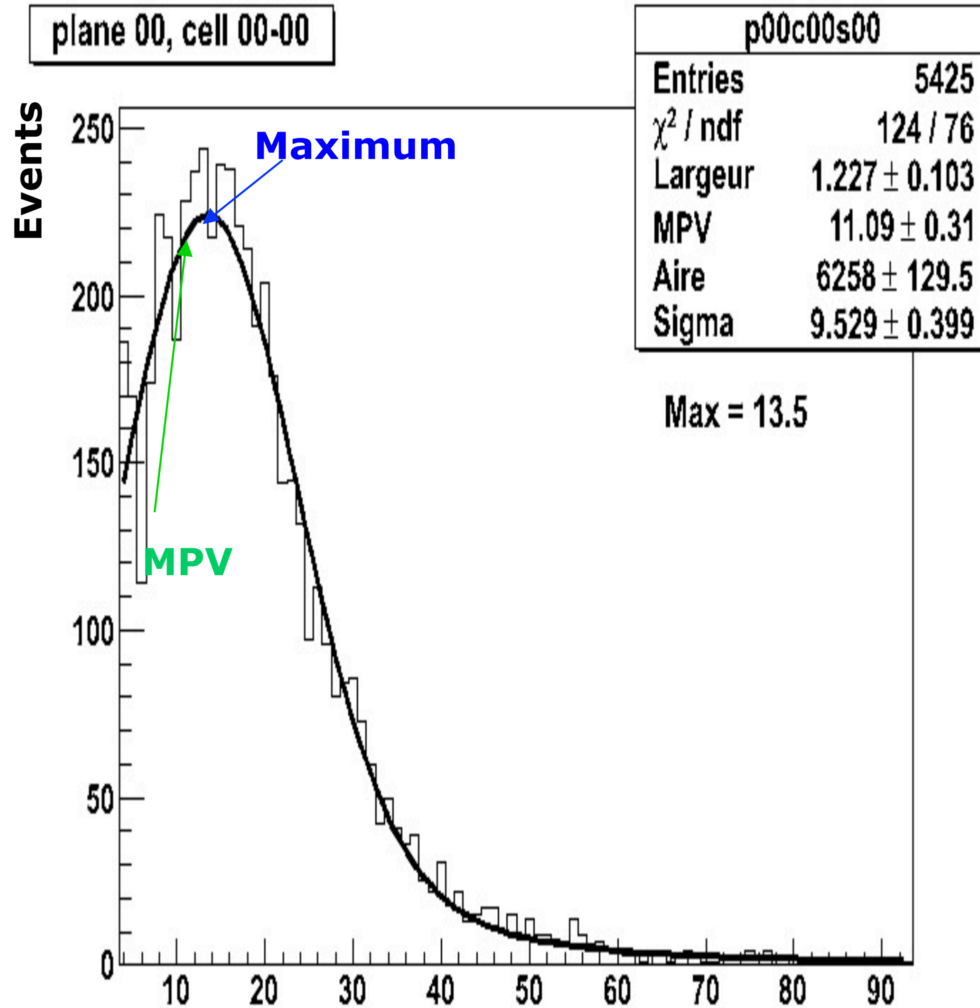
- High Gain, MIP will be used for Proton, He and Nuclei

With higher Z (Z>3)

- Low GAIN: Monitoring gain ratio
- Future :
  - Converted photons

Calibration in Space : Minimum ionizing Particle

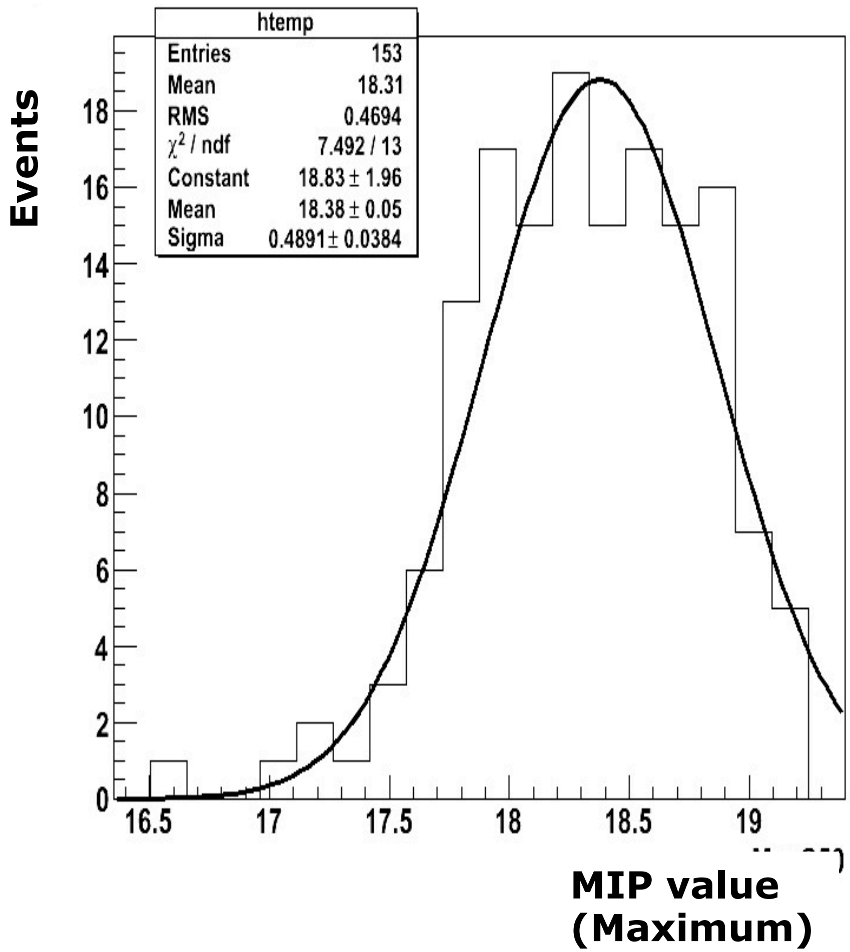
- Performed on the 1296 pixels
- Using both Hydrogen and Helium nuclei
- a fit of a landau convoluted to a Gaussian is performed to measure the Most Probable Value or the Maximum
- The detector response is then equalized accordingly (one HV supply for 4 pixels)



Stability of the MIP signal - ISS data

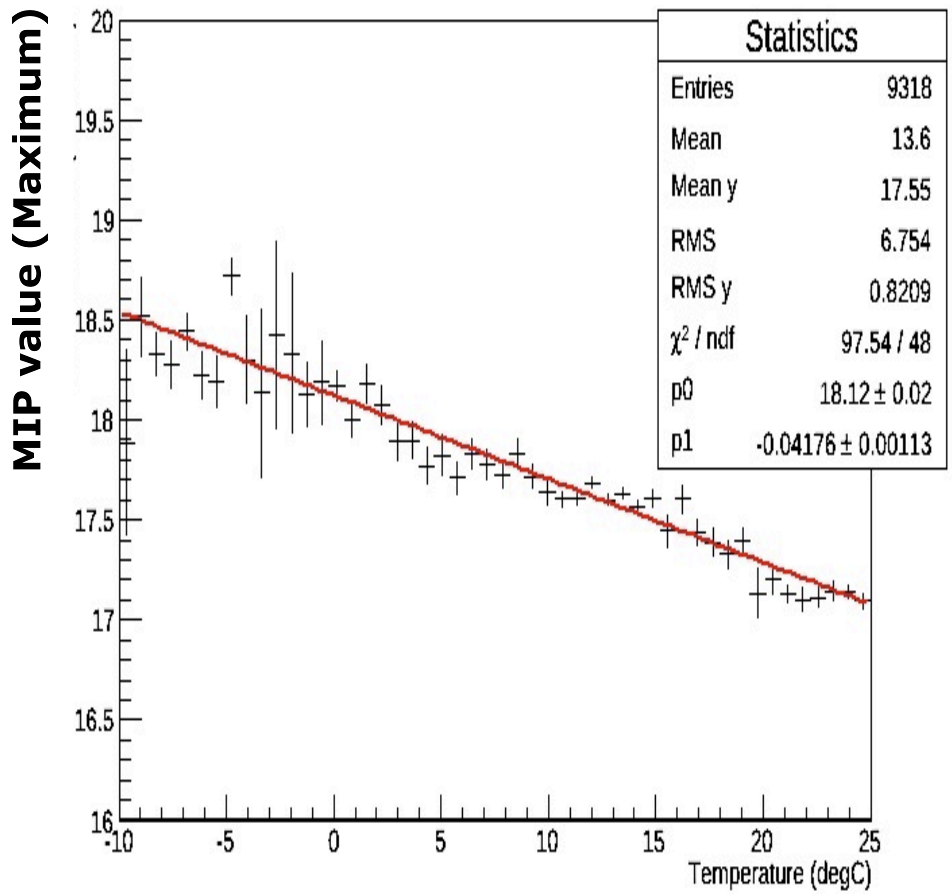
150 days, for one cell,

Relative spread of 3%

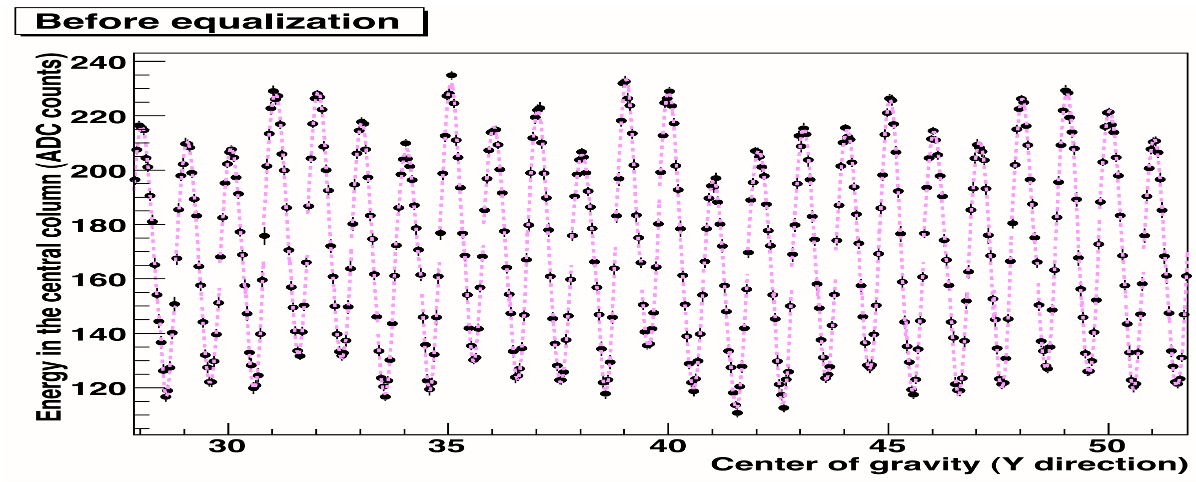


Anti-correlated with temperature

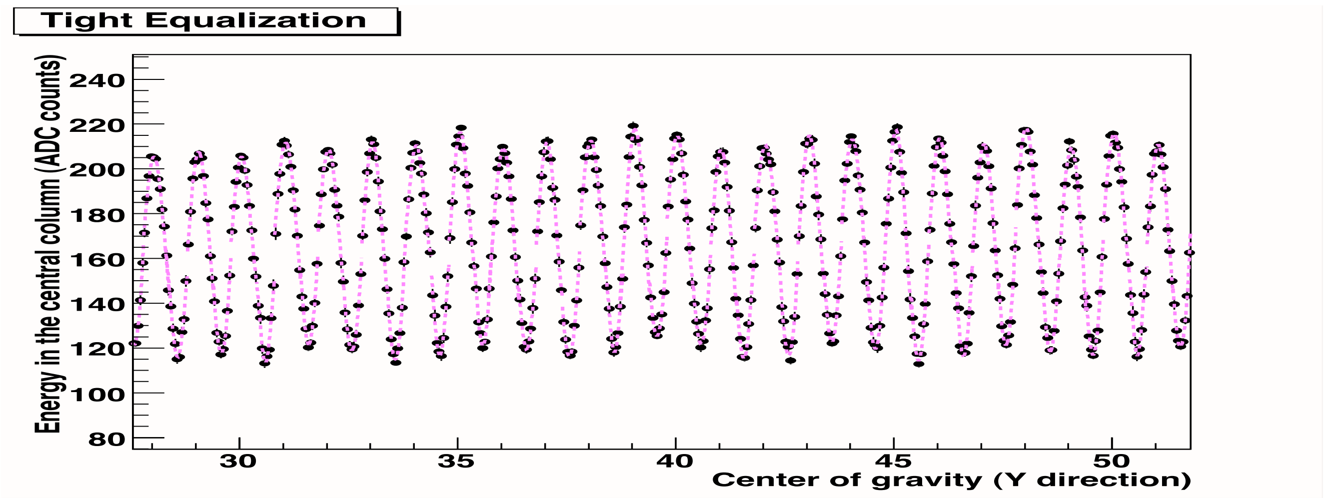
ΔMIP/MIP = -2.5×10^{-3} per ^{0}C



Equalization with MIP on Test Beam electrons

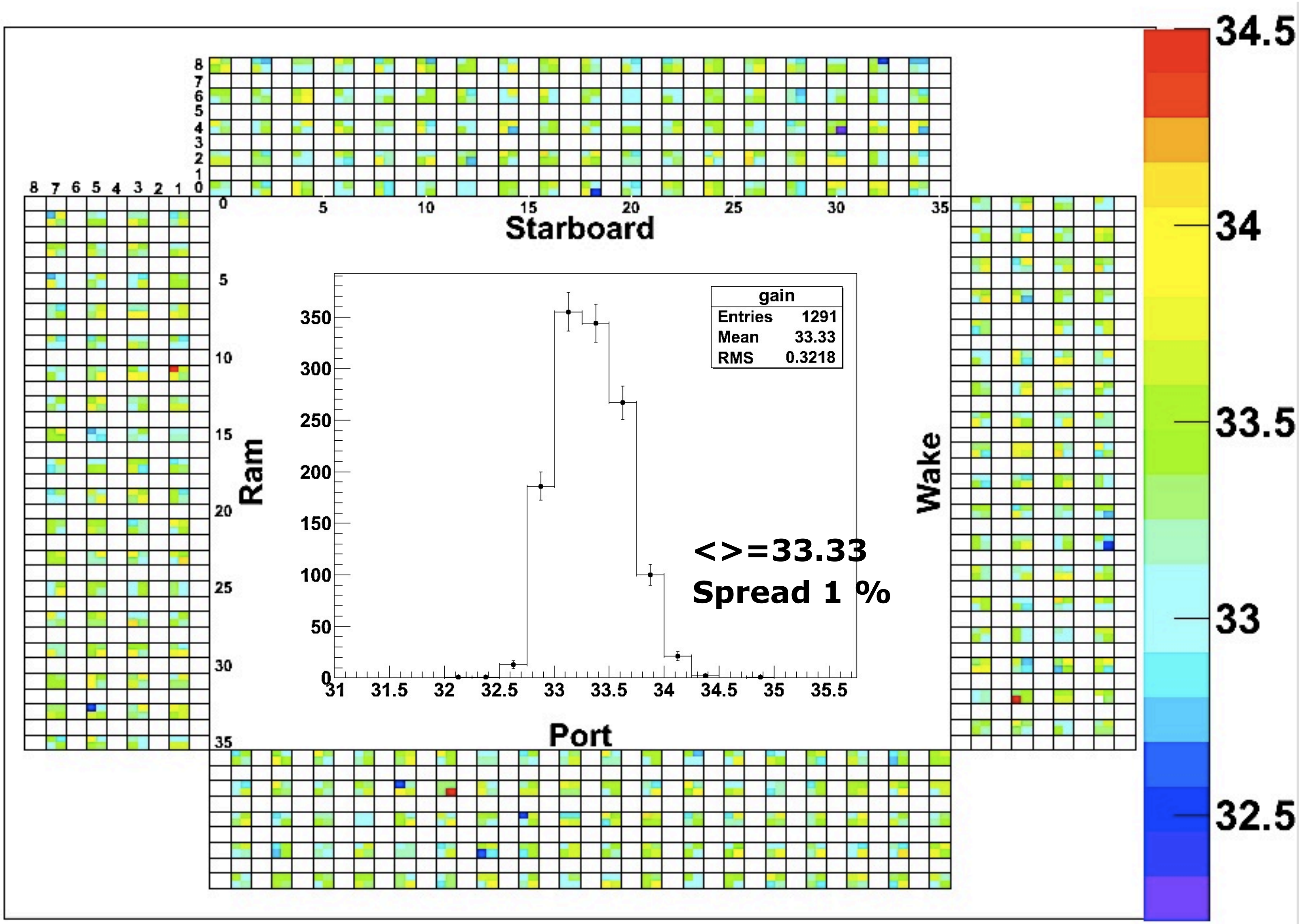


Before equalization



After equalization

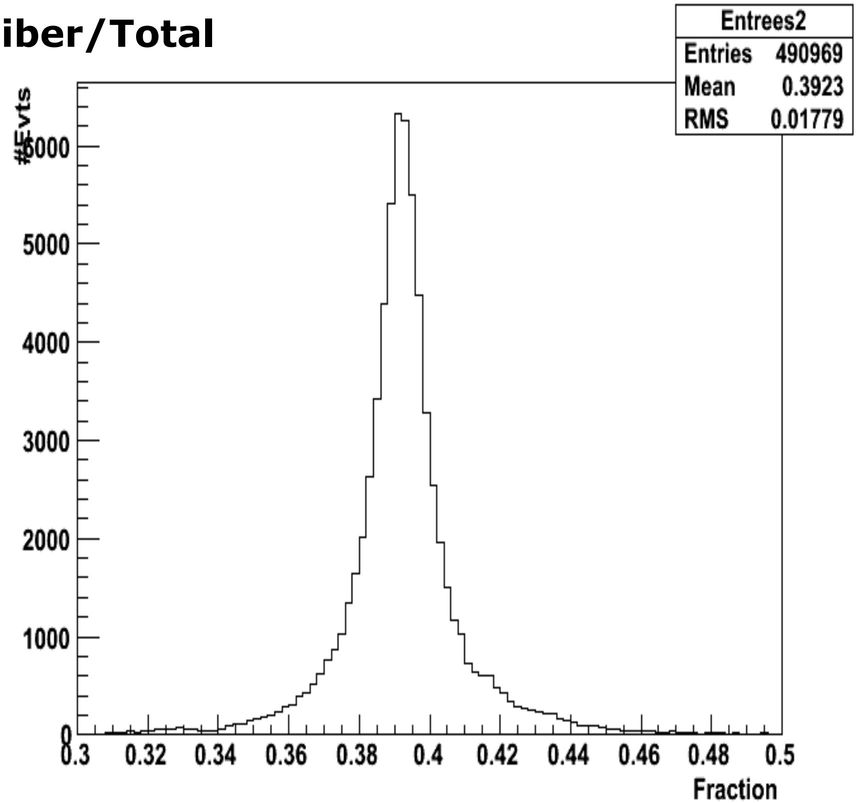
MAP of the gain ratio – ISS data



dE/dX measurements - ISS data

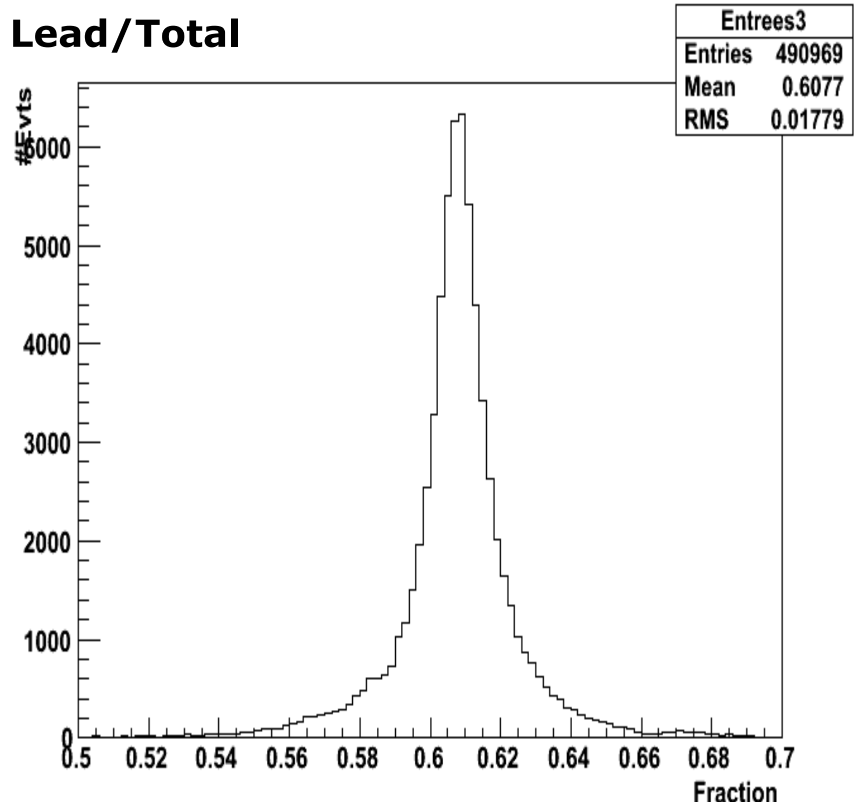
dX measurement: Use of the track information from the tracker (direction, impact) to measure the path length in the calorimeter (lead, fibers and total)

Fiber/Total



Fraction

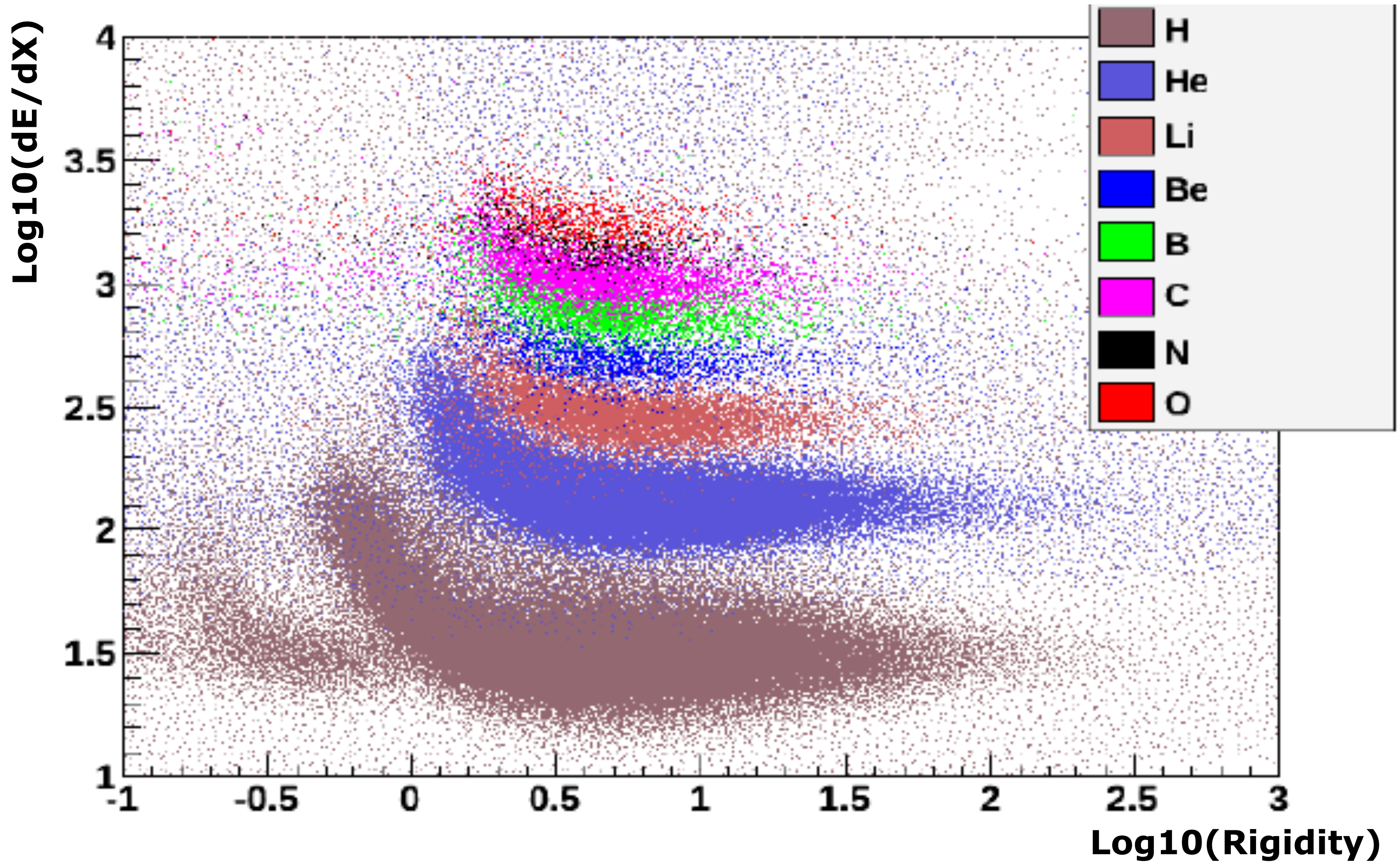
Lead/Total



Fraction

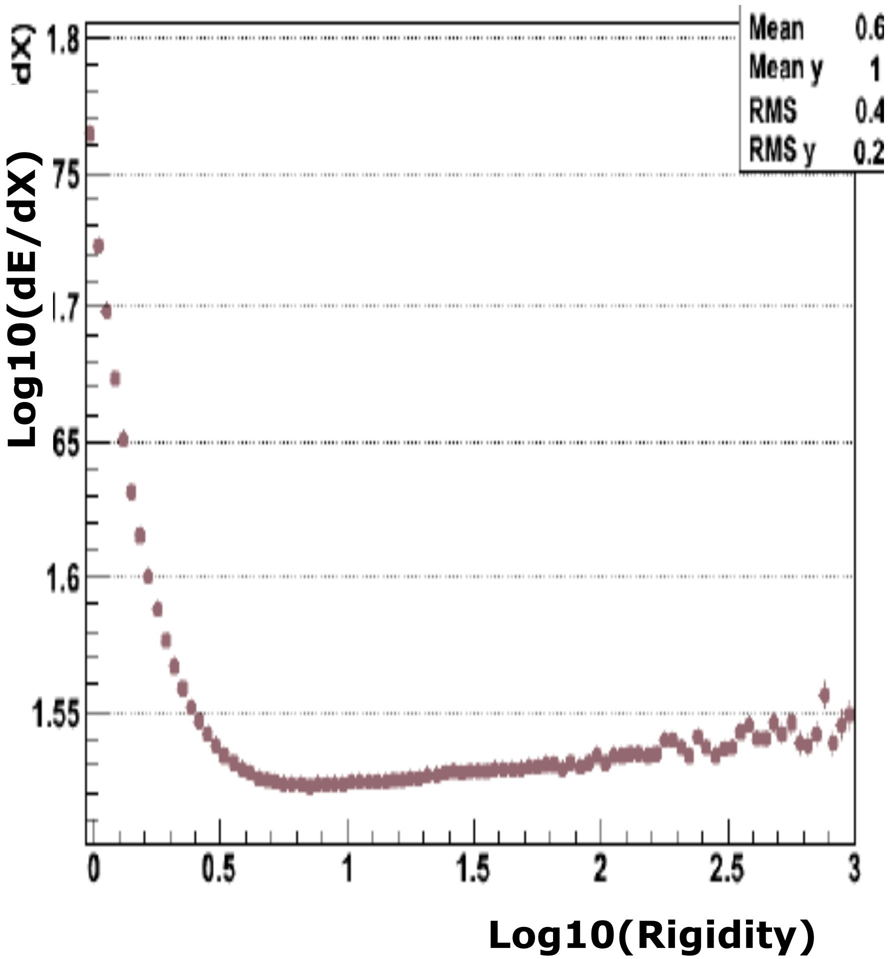
dE/dX measurements with ISS data

- Selecting Nuclei using the Charge measurements in the tracker and the ToF, and the Rigidity of the tracker
- Include in the dE/dX measurement only layers at the MIP

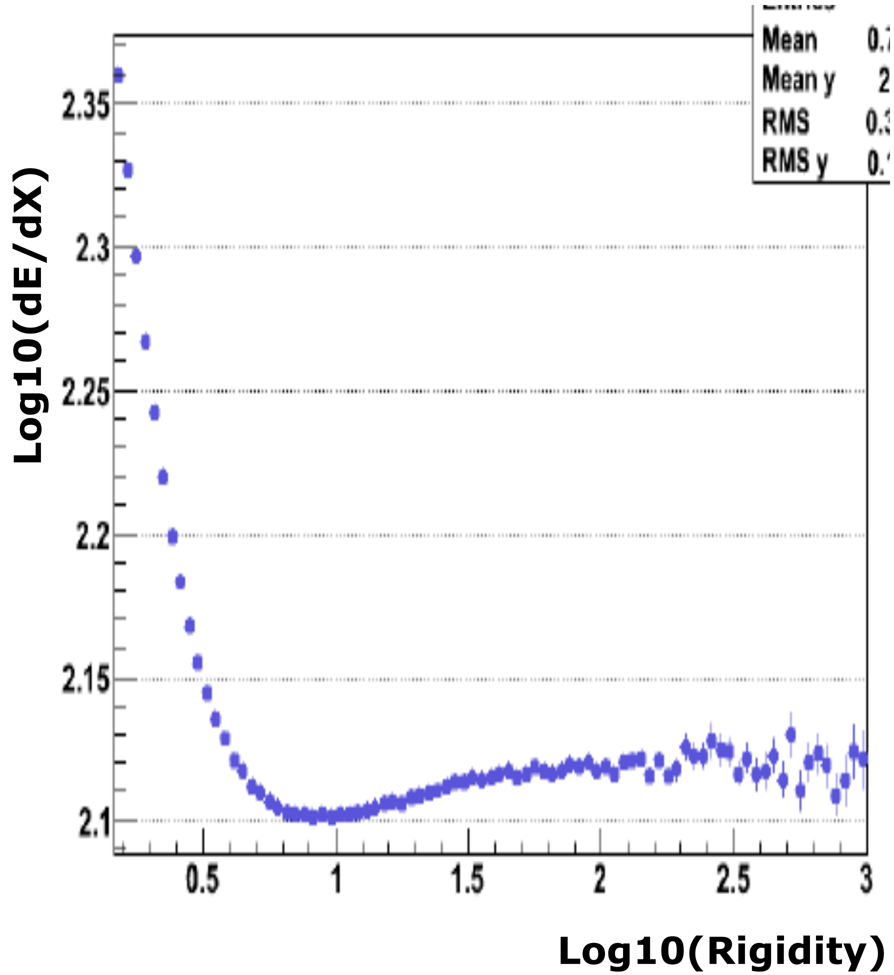


dE/dX measurements with ISS data

Hydrogen Nuclei

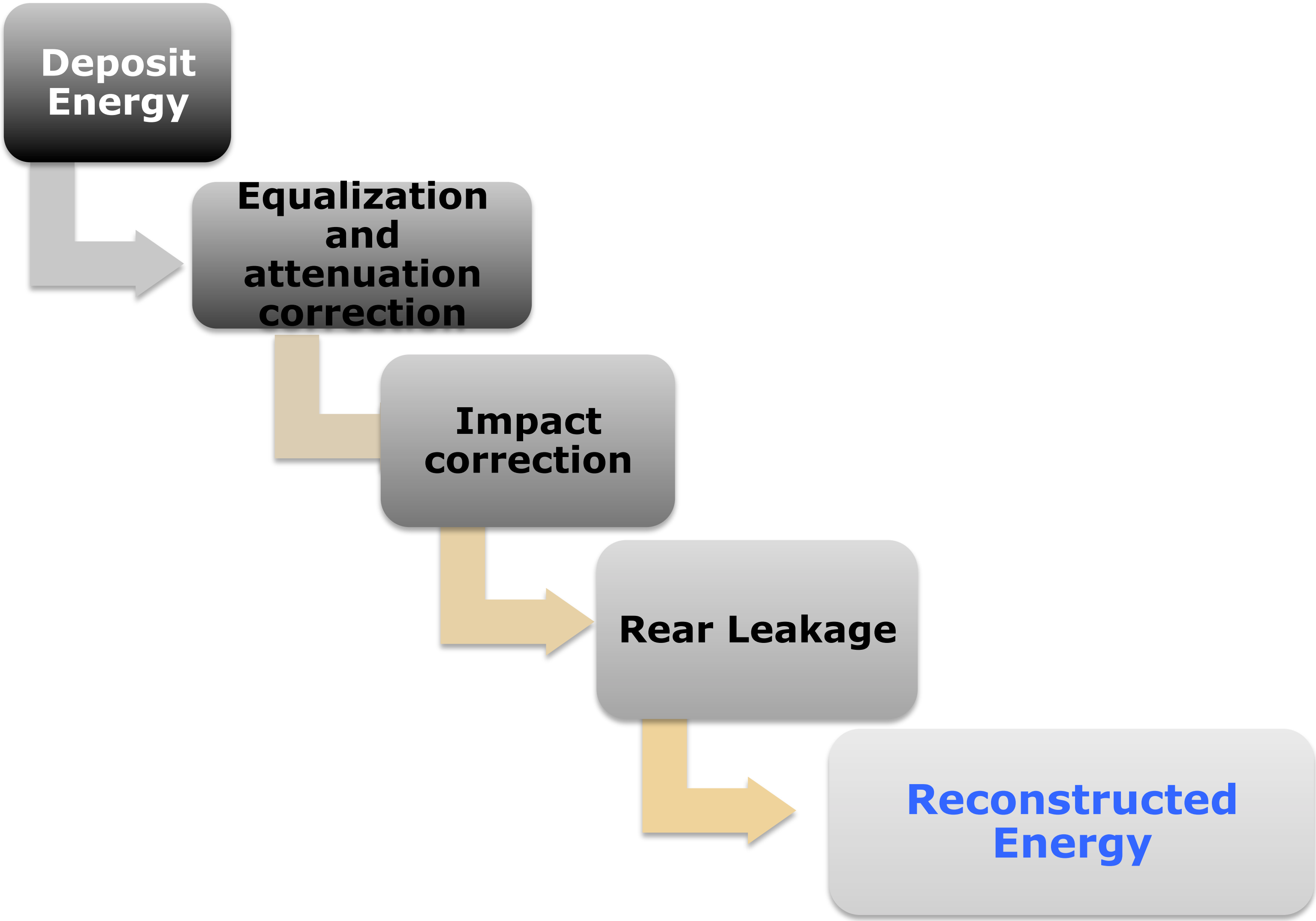


Helium Nuclei



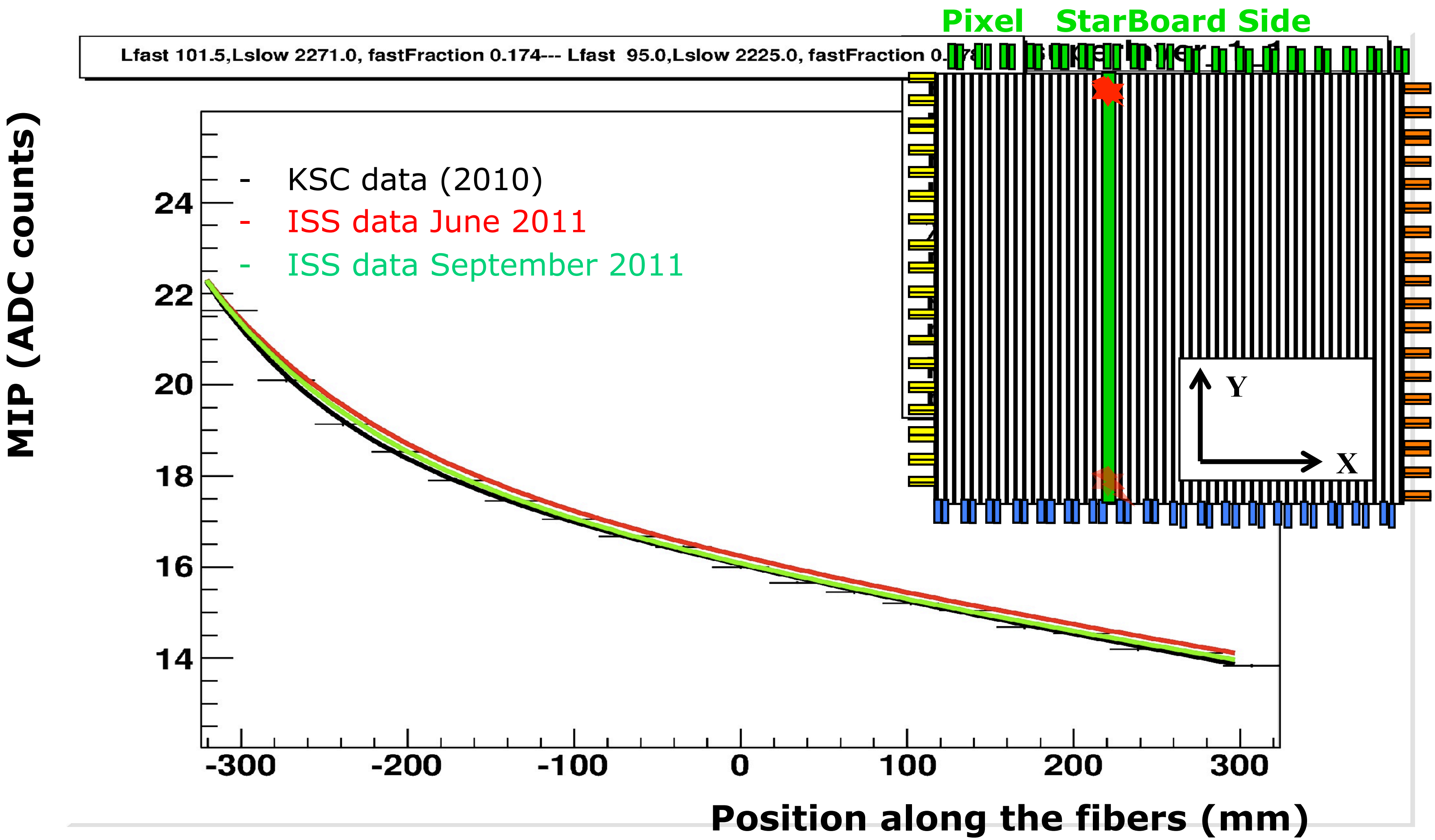
As expected the minimum scales in Y axis as Z^2

Energy Measurement



Light attenuation Correction – KSC and ISS data

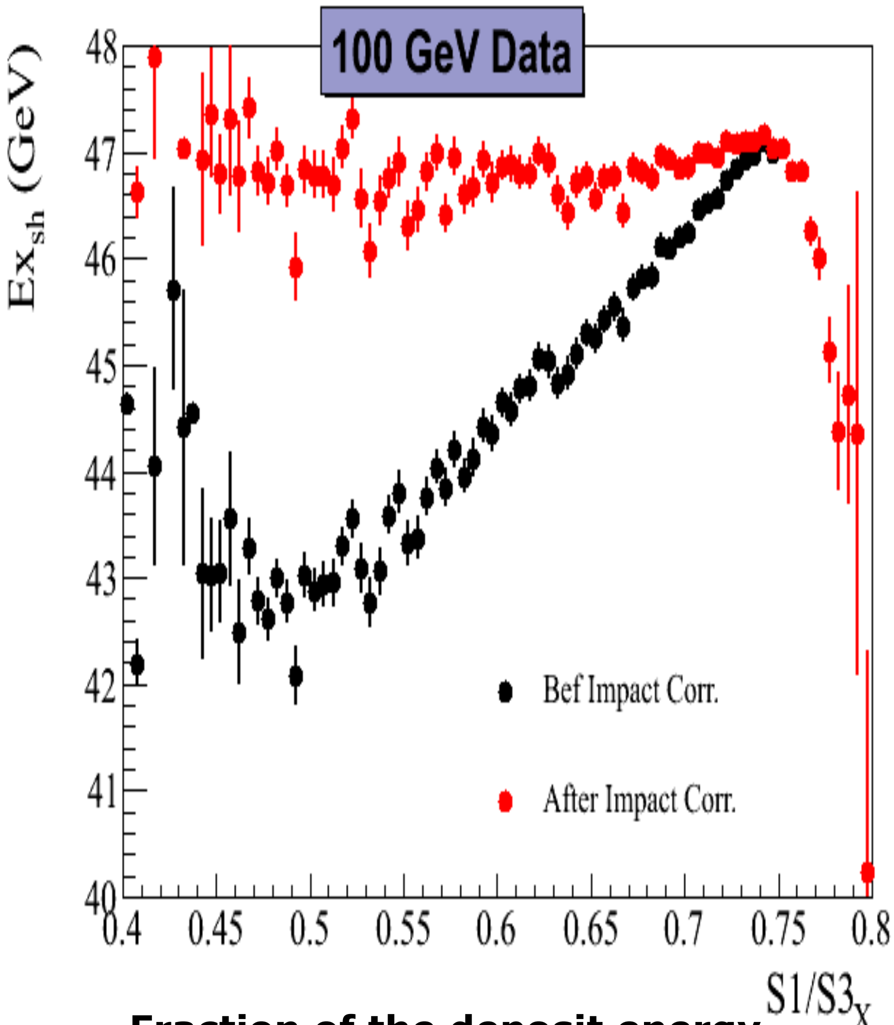
Stable within 1% between Ground and Space data



3 parameters (f, λ_{fast} and λ_{slow}) have been measured for the 18 layers

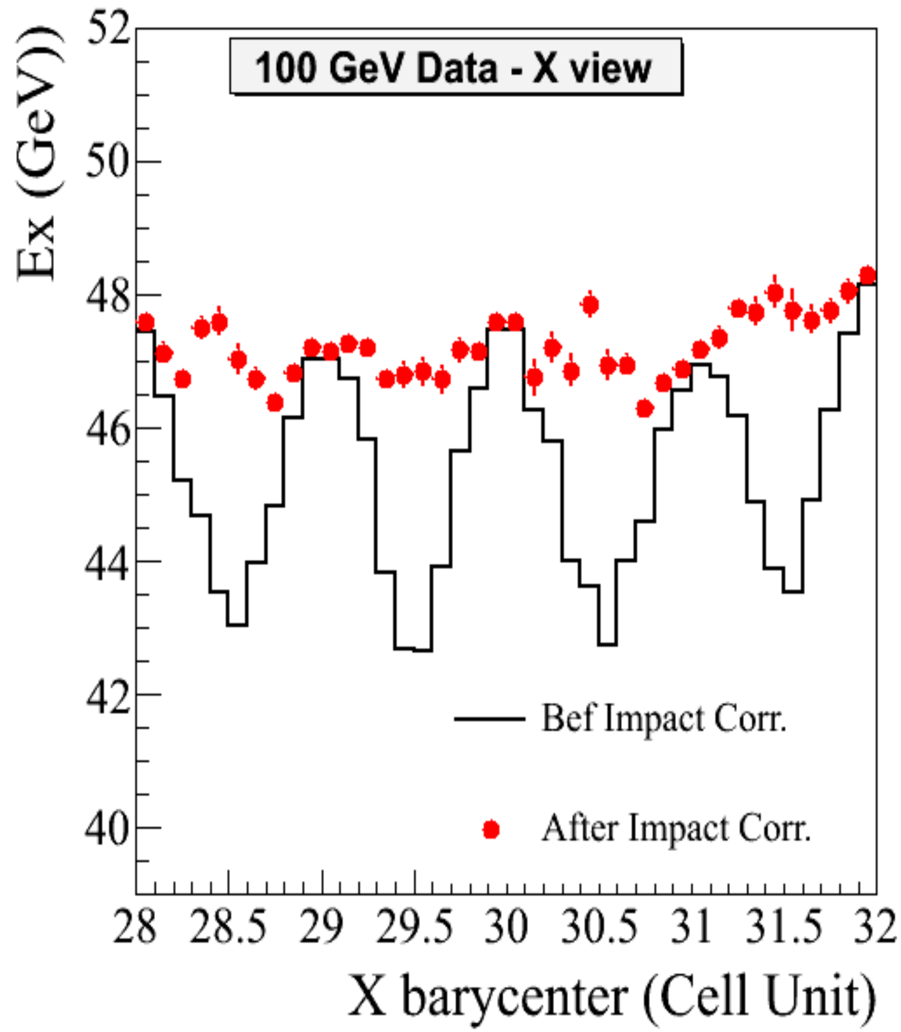
Impact Correction

Test beam Data (Aug 2010)



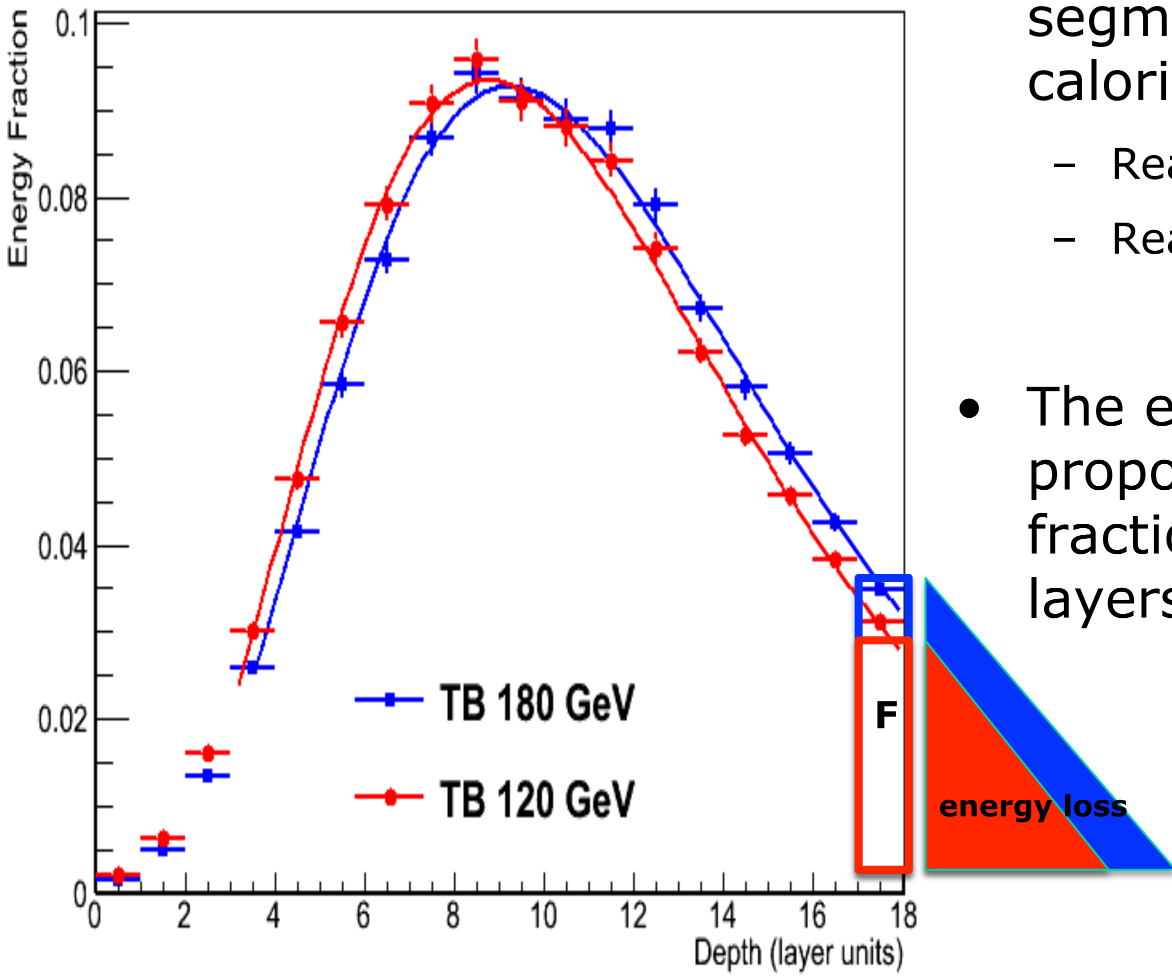
Fraction of the deposit energy in the core of the shower in X view

~10 % effect at most



Rear Leakage Correction - Principle

Test beam Data (Aug 2010)

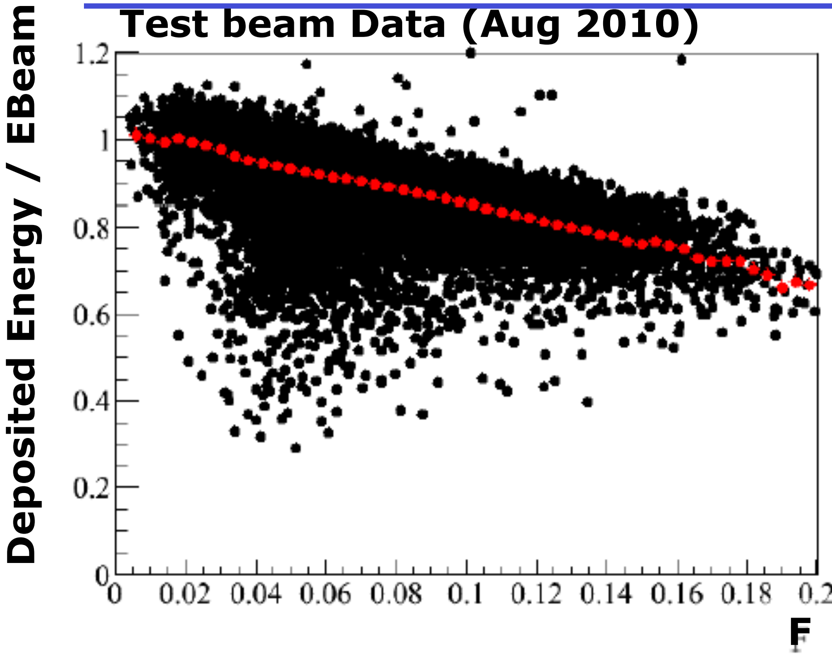


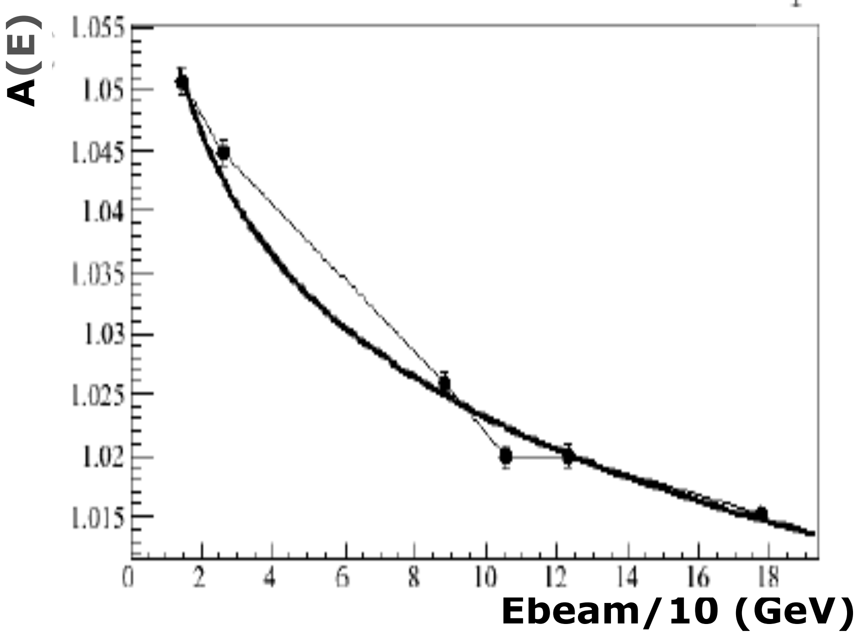
- Using the longitudinal segmentation of the calorimeter, with 17 X0
  - Rear leakage~7 % @ 100 GeV
  - Rear leakage ~ 16 % @ 1000 GeV

- The energy loss (triangle) is proportional to the energy fraction deposited in the 2 last layers : F

$$F = (E_{16} + E_{17}) / \sum_{l=0}^{l=17} E_l$$

Rear Leakage Correction





$$E_{electron} = E_{deposit} / (A(E) + B * F)$$

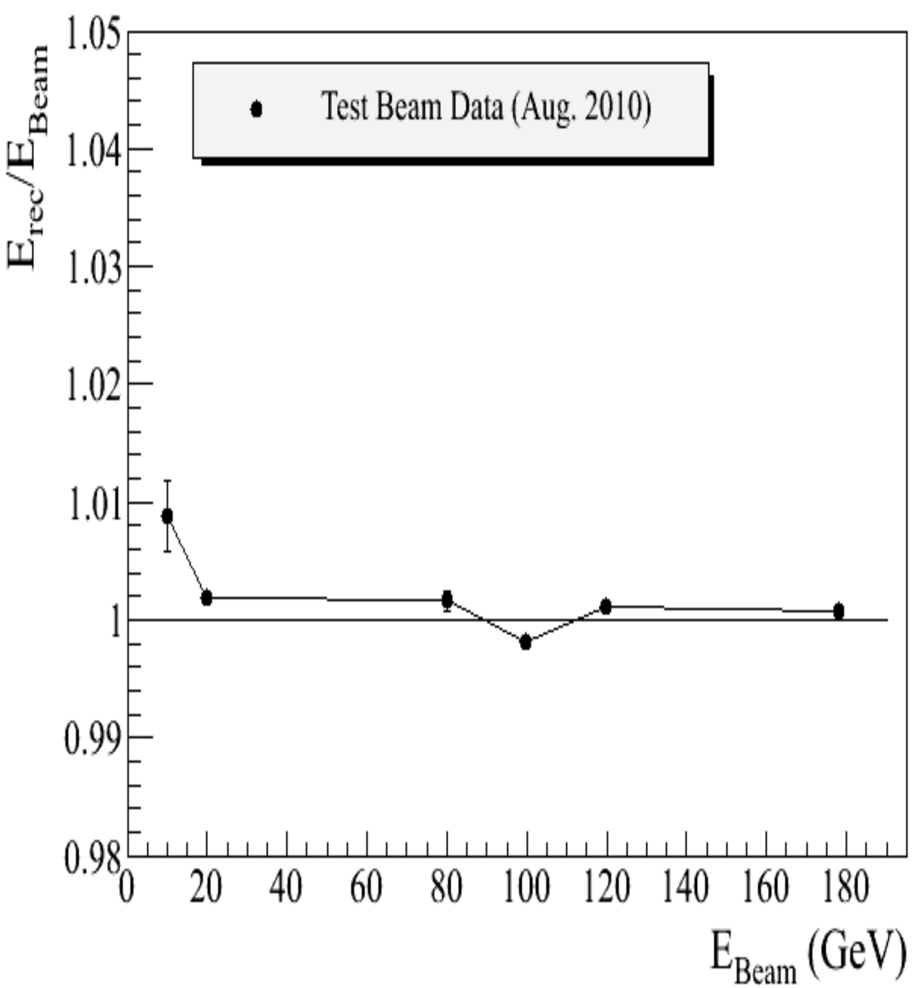
$$B = < slope >$$

Iterative method

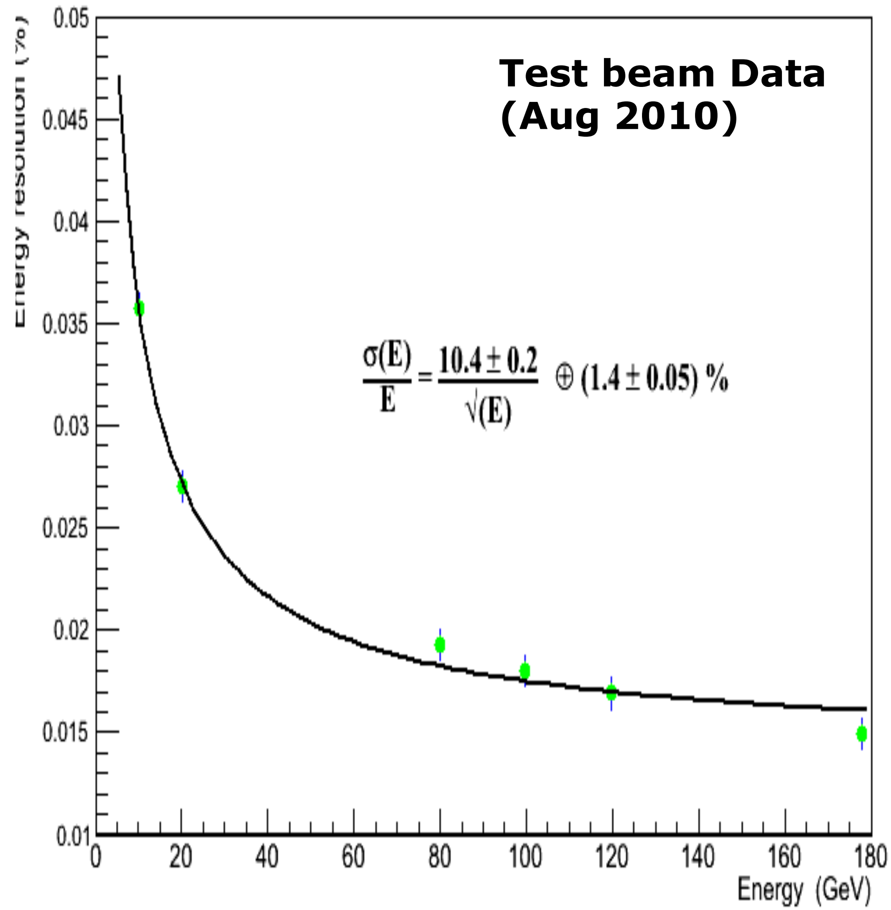
1. Determine the slope term, **B,** averaged on all the Test Beam energies
2. Find the Energy dependence of **A(E)**
3. Systematics can be controlled using another rear leakage correction by fitting the complete Longitudinal Profile or performing a 3D fit of the shower

Energy Linearity and Energy resolution

Linearity better than 1%



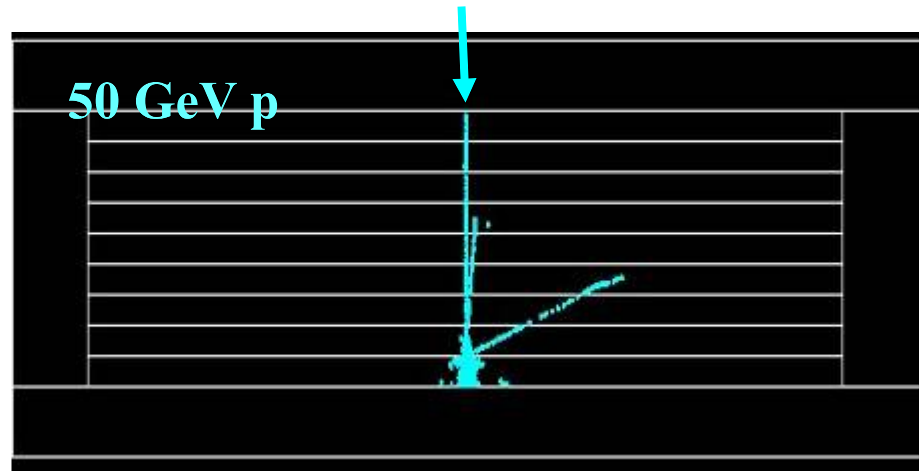
Energy resolution better than 2 % for Energy>80 GeV

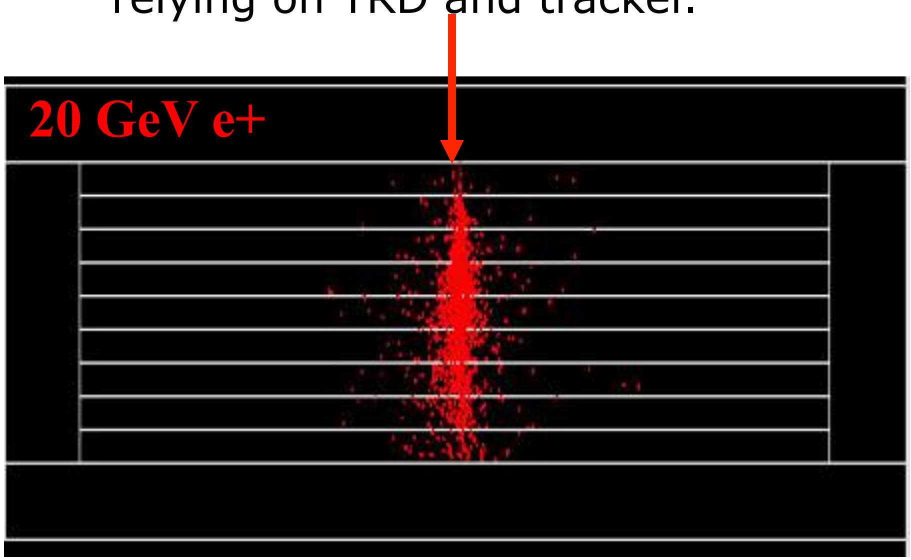


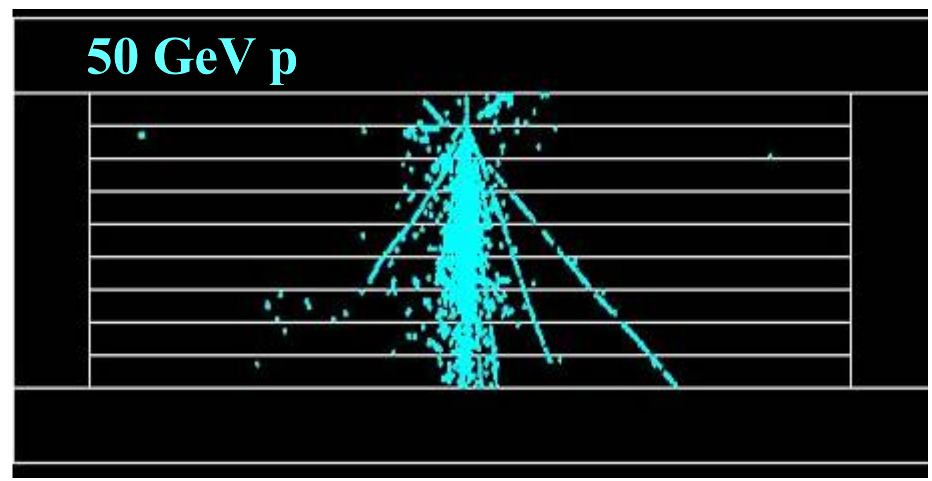
e/P rejection

- Identify proton interacting in the first layers
- Exploit the EM shower shape properties in the 3 dimensions (reduced variables and at the layer or cell levels)
- Compare the Deposit Energy with the momentum measured in the tracker
- Use Test beam data and ISS data relying on TRD and tracker.

Simulation in Geant4

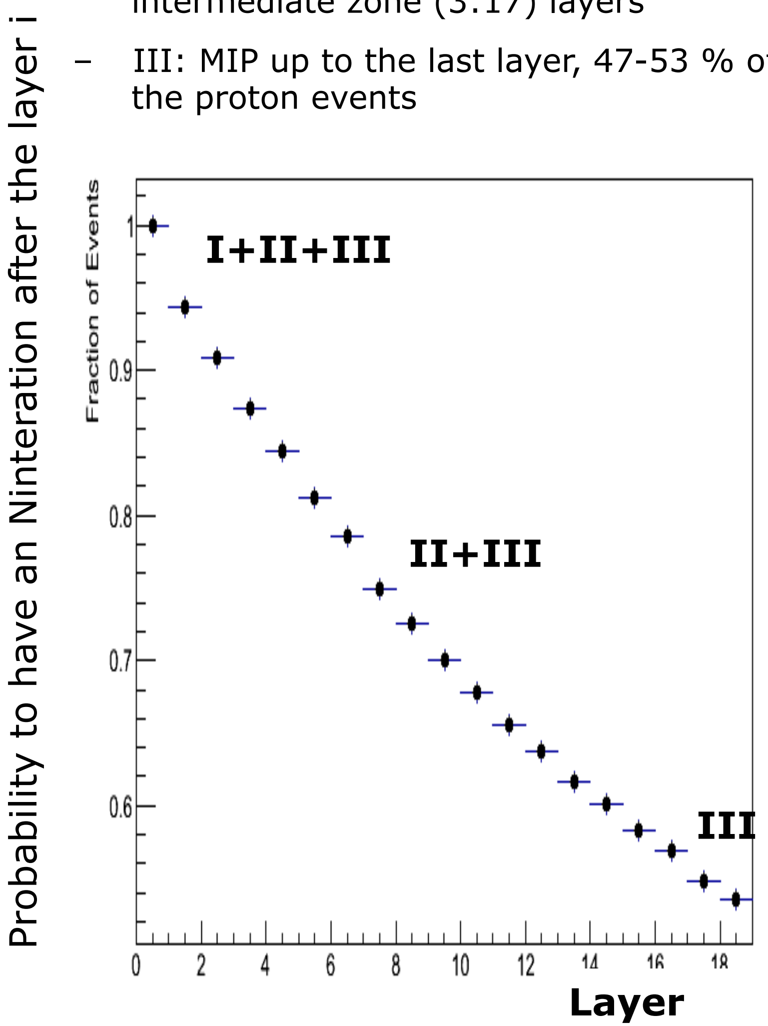


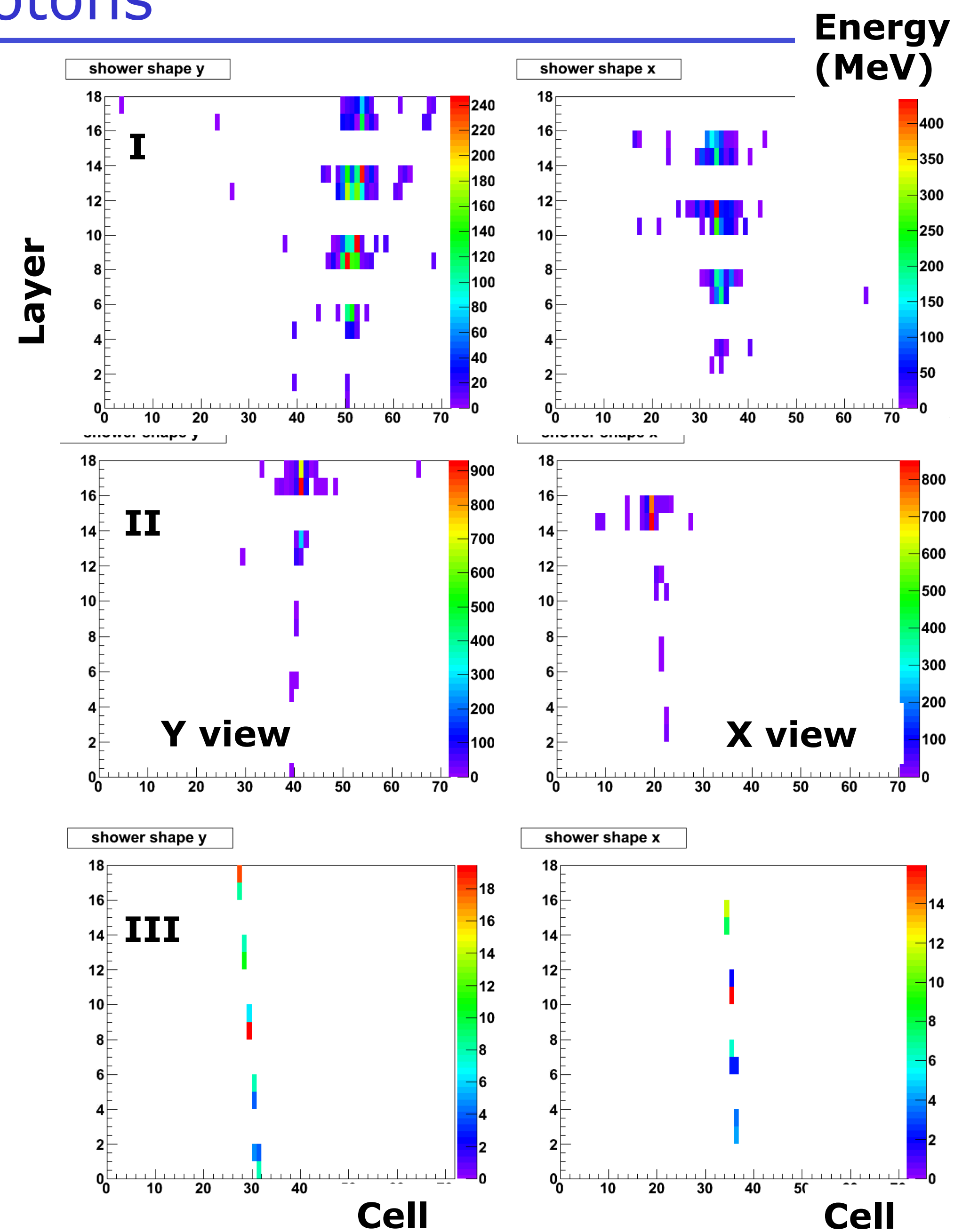




e/P rejection - ISS protons

- 3 regimes
  - I: Nuclear Interaction occurs before the 3 first layers (~ 10-15 %)
  - II: Nuclear interaction in the intermediate zone (3:17) layers
  - III: MIP up to the last layer, 47-53 % of the proton events

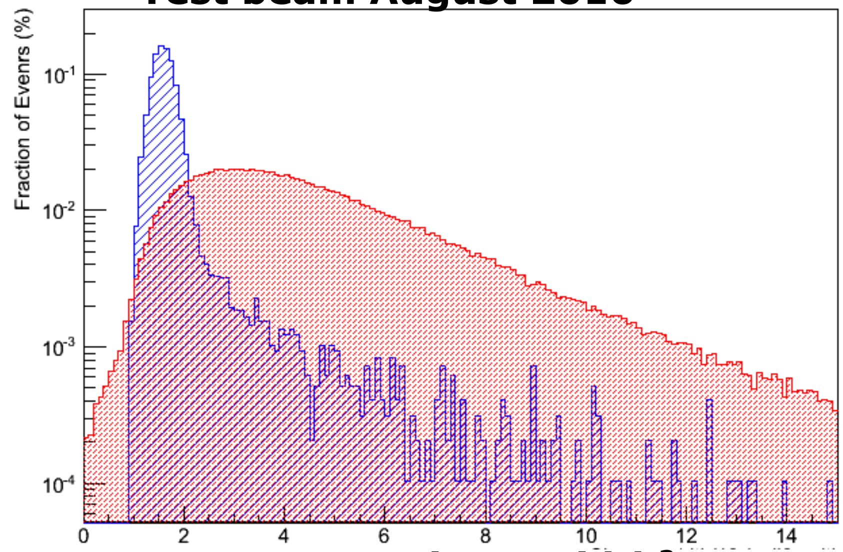




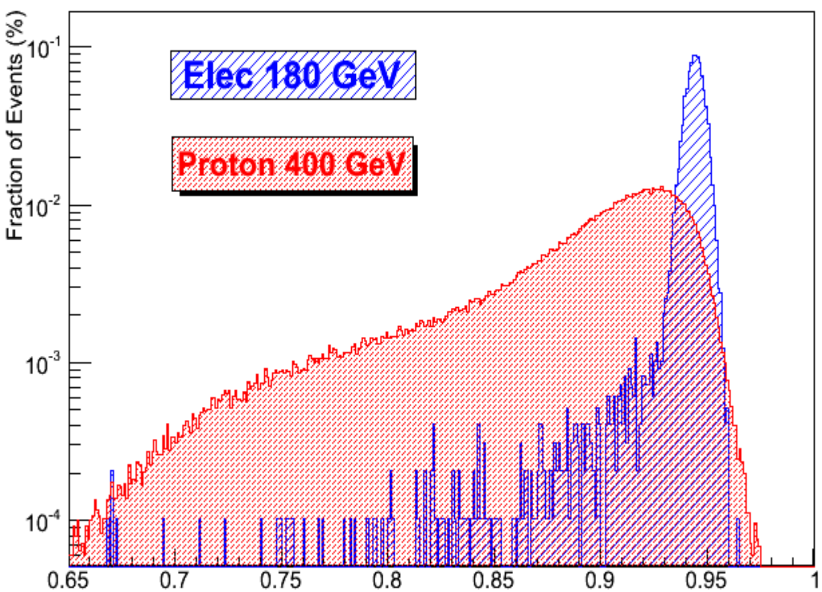
e/P rejection – Global Variables

- Shower shape behaviour in the 3 dimensions
  - Z : Longitudinal profile fit: position of the maximum, rear leakage estimate, chi^2 of the fit …
  - Lateral profile : width , fraction of energy deposit in 1.5 Moliere radius, in X and Y views
  - 3D variable: Footprint, multiplicity etc
- Rejection factor ranging from 50-100 for an efficiency of 80-90% => need of multivariate Analysis

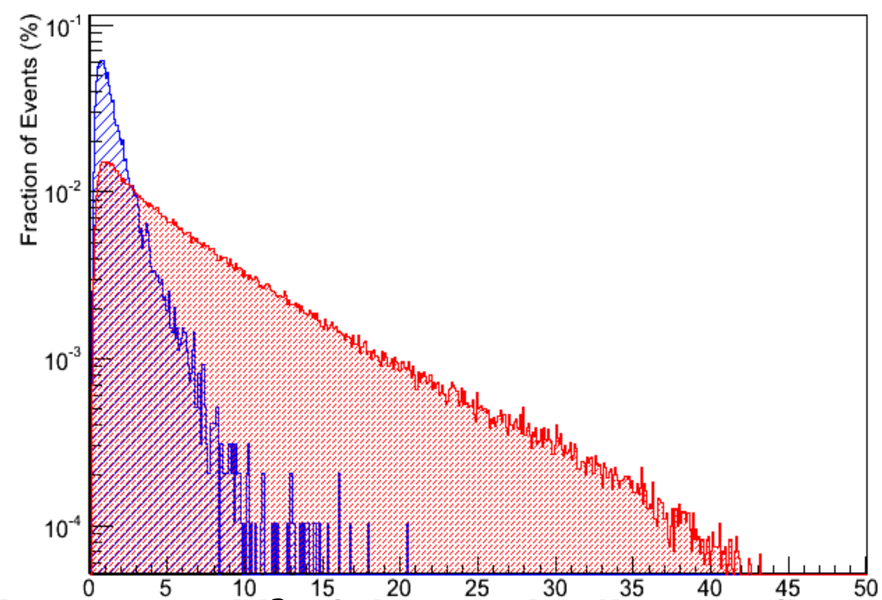
Test beam August 2010



X view -Width^2

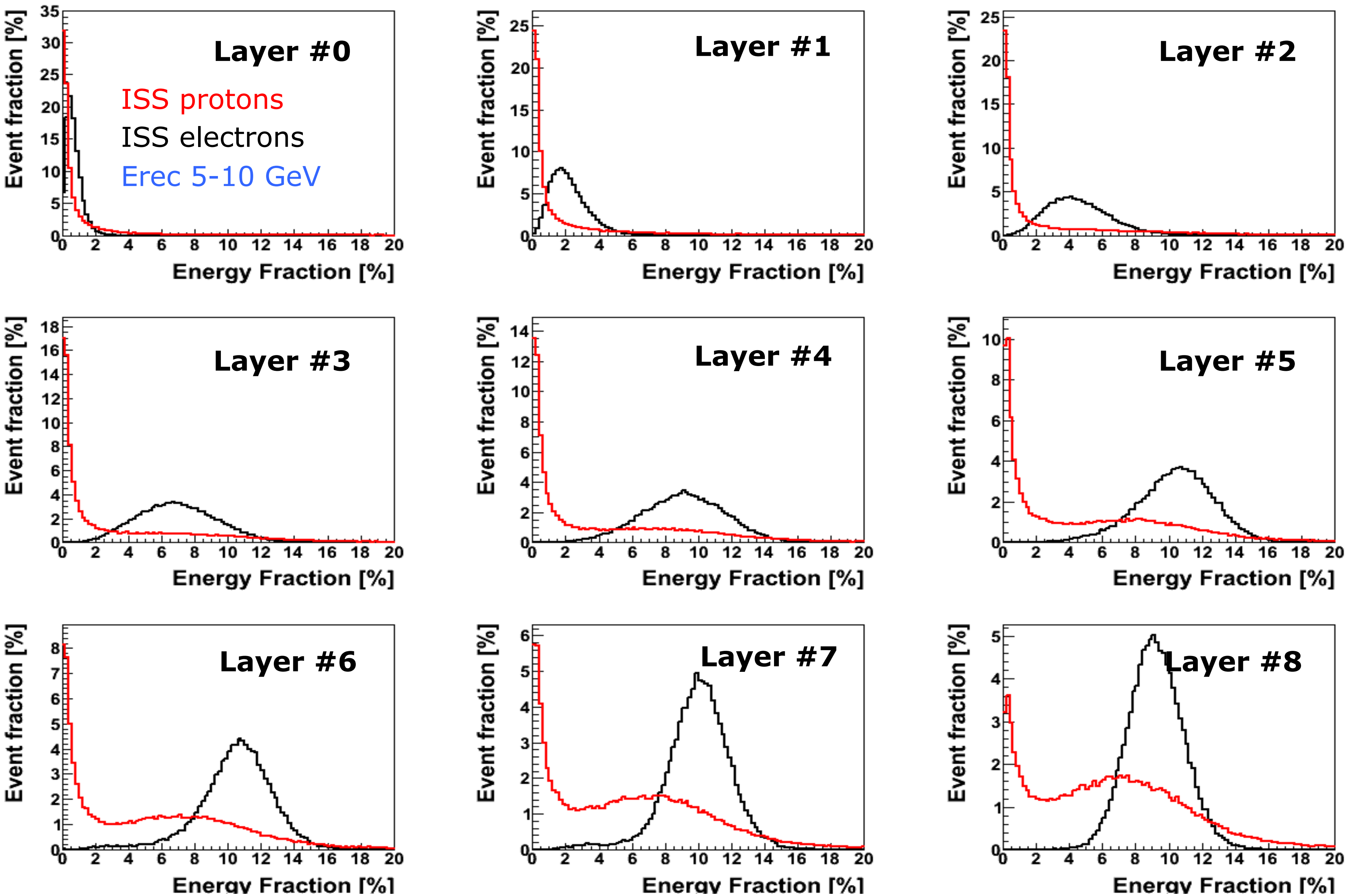


Y View – fraction of Energy in 1.5 Moliere Radius

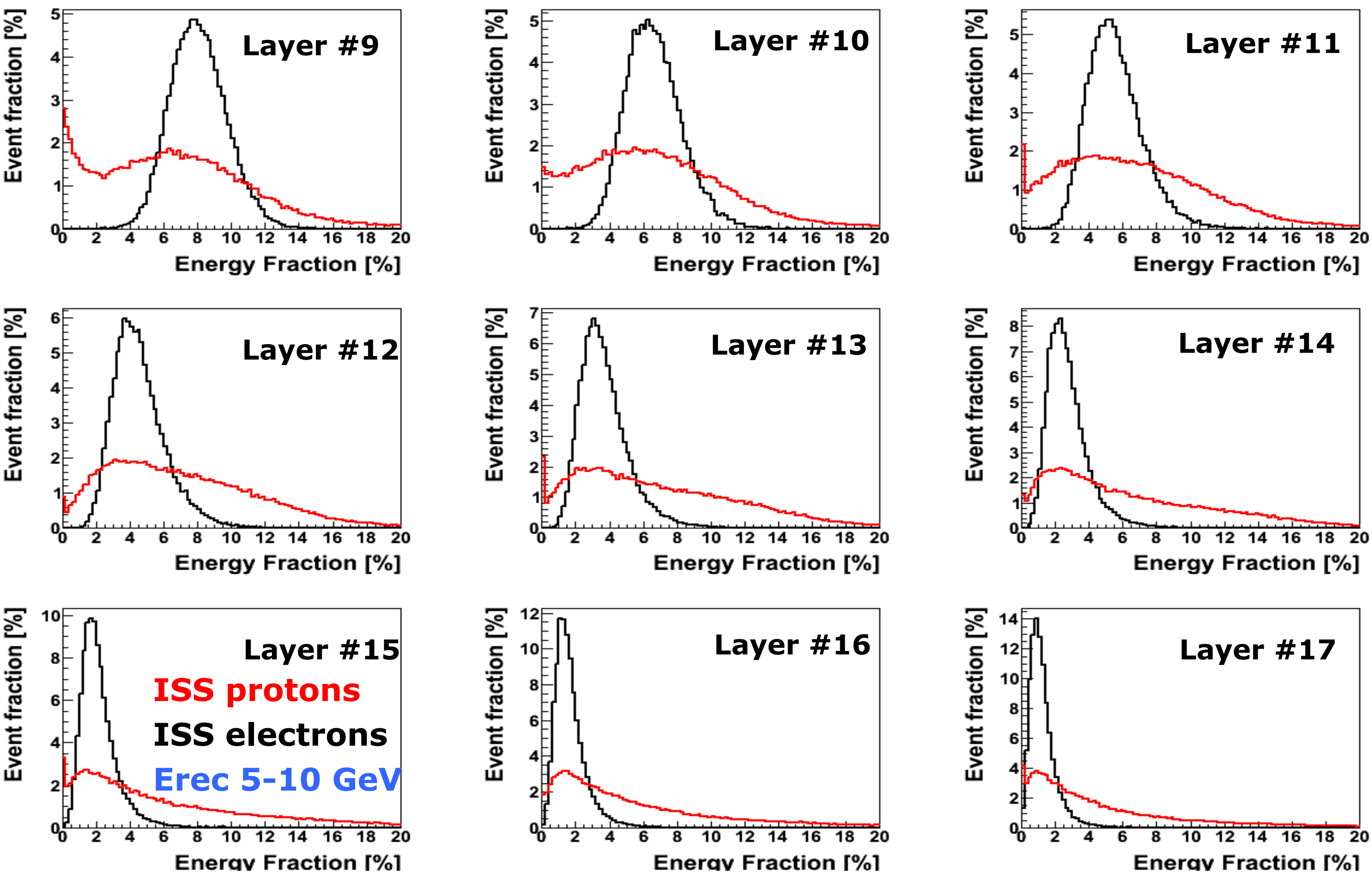


Chi^2 of the longitudinal profile

e/P rejection - Deposit energy fraction per layer



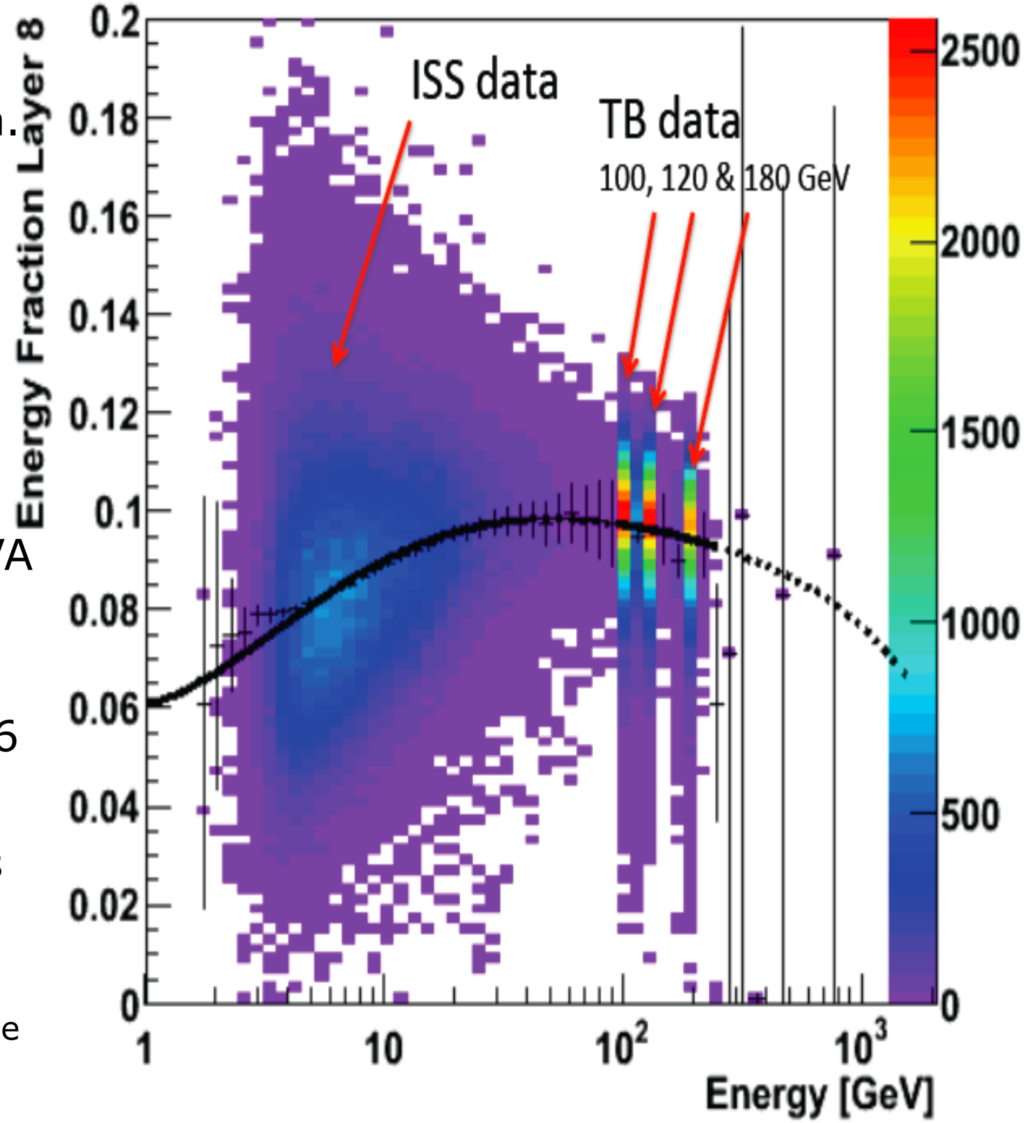
e-/P rejection - Deposit energy fraction per layer



e-/P rejection – Multivariate Analysis

- Test beam and ISS data preselected with the TRD and the tracker are used. The training is performed on a subsample of data.
- Different techniques are used
  - Boost decision tree
  - Neural network
  - Likelihood …
- Example of Analysis based on Boost Decision Tree using the TMVA package
  - Inputs: Global and detailed variables at the layer level (56 in total)
  - Correlation between variables and the Energy dependence included.

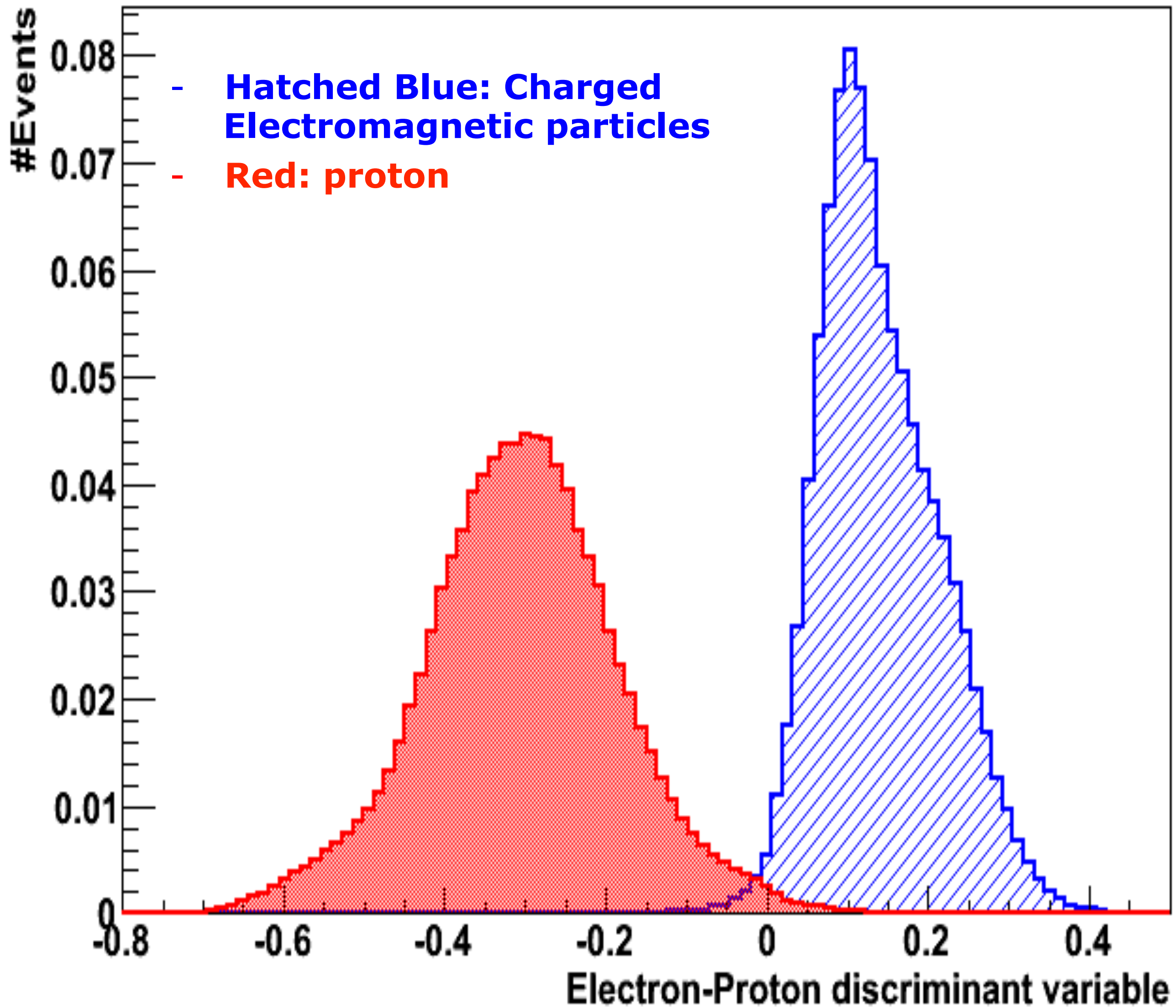
*(using a normalization function fitted on the MC on a larger energy range)



e-/P rejection with ECAL

- Ecal Standalone Estimator + E/P matching: Rejection greater than 4000 for an efficiency of 90 %
- Combined to other detector (TRD) an overall rejection factor of 10^6 is achieved .
- Based on data only.

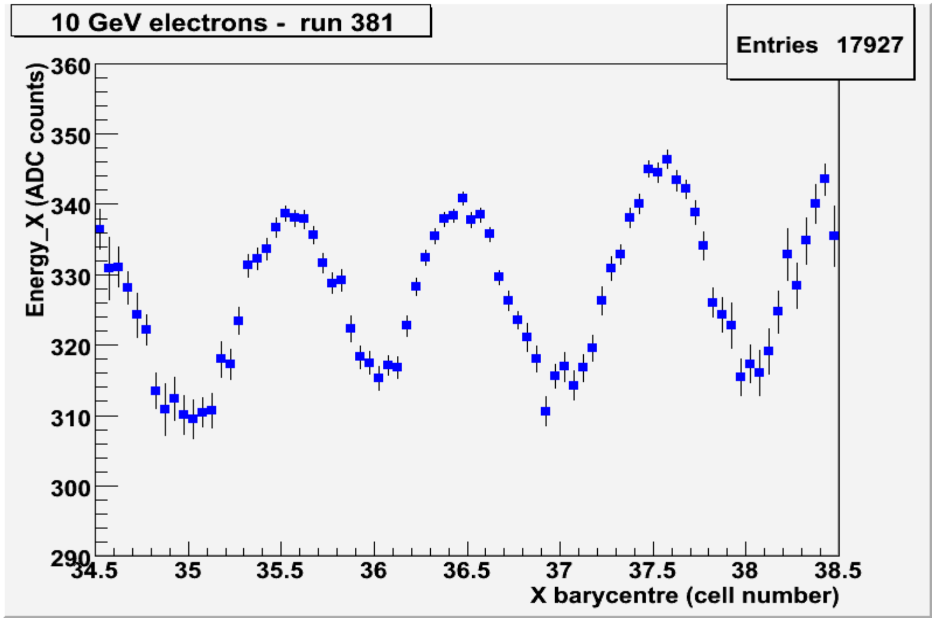
ISS Data – ECAL Boost Decision Tree

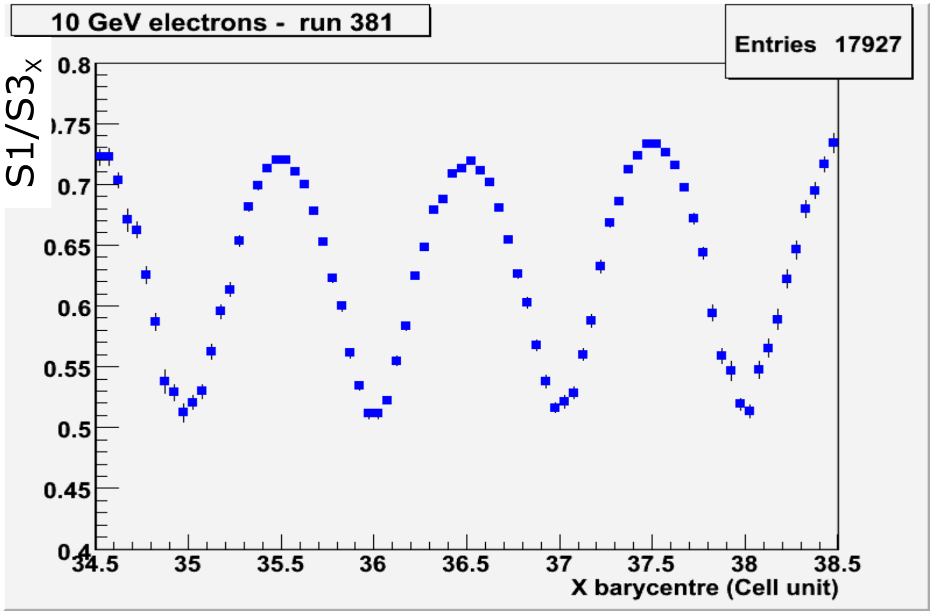


Summary

- AMS02 is operating on the ISS since the 19th May 2011 and has collected 17 billions of events: All AMS subsystems are fully operational with the performance expected from ground measurements.
- Variation of ambient conditions (temperature in first place) is accounted for, with proper calibrations and alignments
- The calorimeter behaves as expected and is precisely monitored.
- The ECAL performance in term of Energy resolution and e/P rejection are within expectation. The GeV to TeV will be covered by AMS02, for electrons, positrons and gamma ray.
- Analyses are going on. Science will come soon.

Impact Correction – Principle





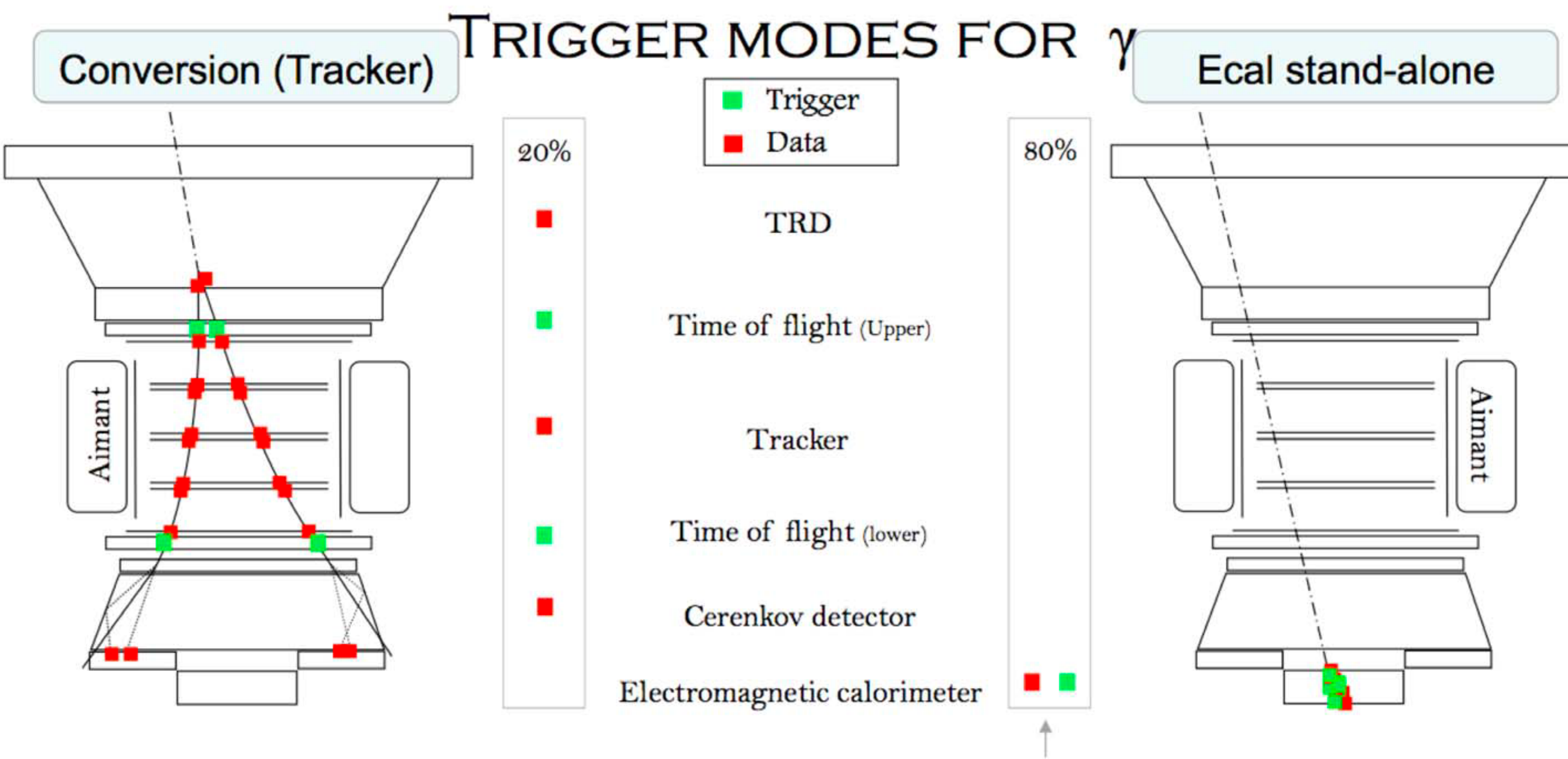
A standalone method, developed on TB2007 data (CG, CALOR2008)

- Due to the dead zones, the deposit energy is not constant as a function of the impact point in the cell
  => need of a correction

- For geometrical reason, the faction of the energy deposit in the core of the shower (S1~0.5 Moliere radius) over the deposit energy in 1.5 Moliere radius (S3) depends on the impact point.
- This fraction **S1/S3,** is measured in each view separately ($S1/S3_X$, $S1S3_Y$)

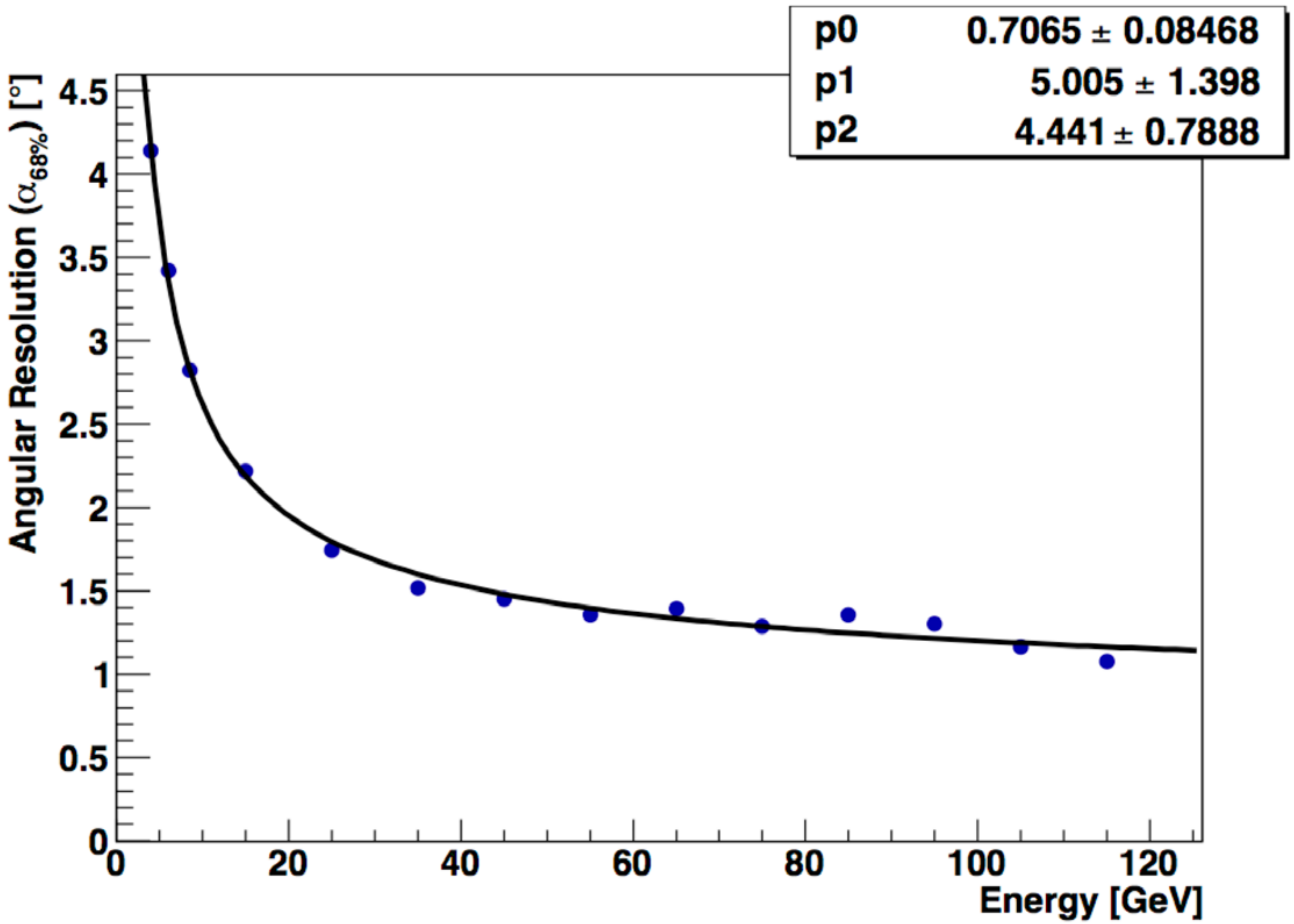
=> Looking at the dependence of the energy with S1/S3

Gamma detection mode

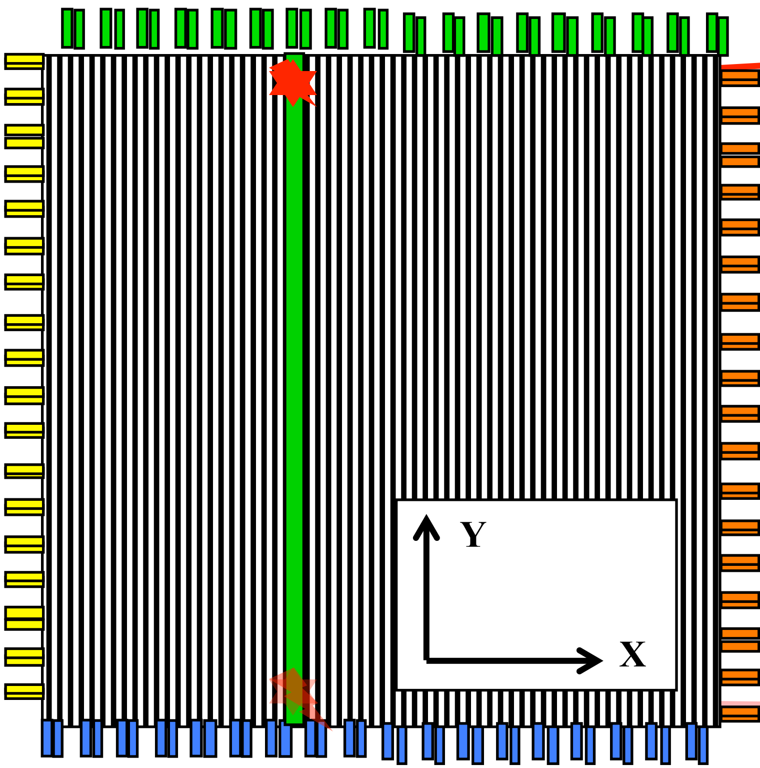


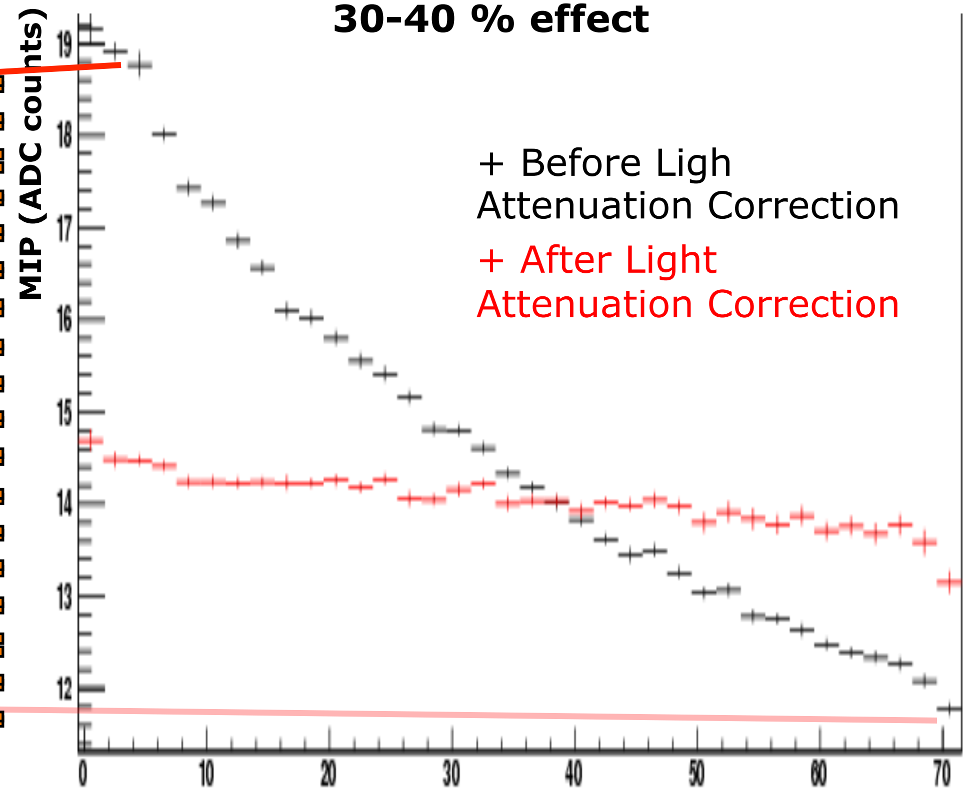
Ecal Angular resolution

On electron from flight data= compare track position with the center of gravity



Light Attenuation Correction





$$F_{att} = f \times exp(-\frac{X}{\lambda_{fast}}) + (1-f) \times exp(-\frac{X}{\lambda_{slow}})$$

3 parameters (f, λ_{fast} and λ_{slow}) have been measured for the 18 layers