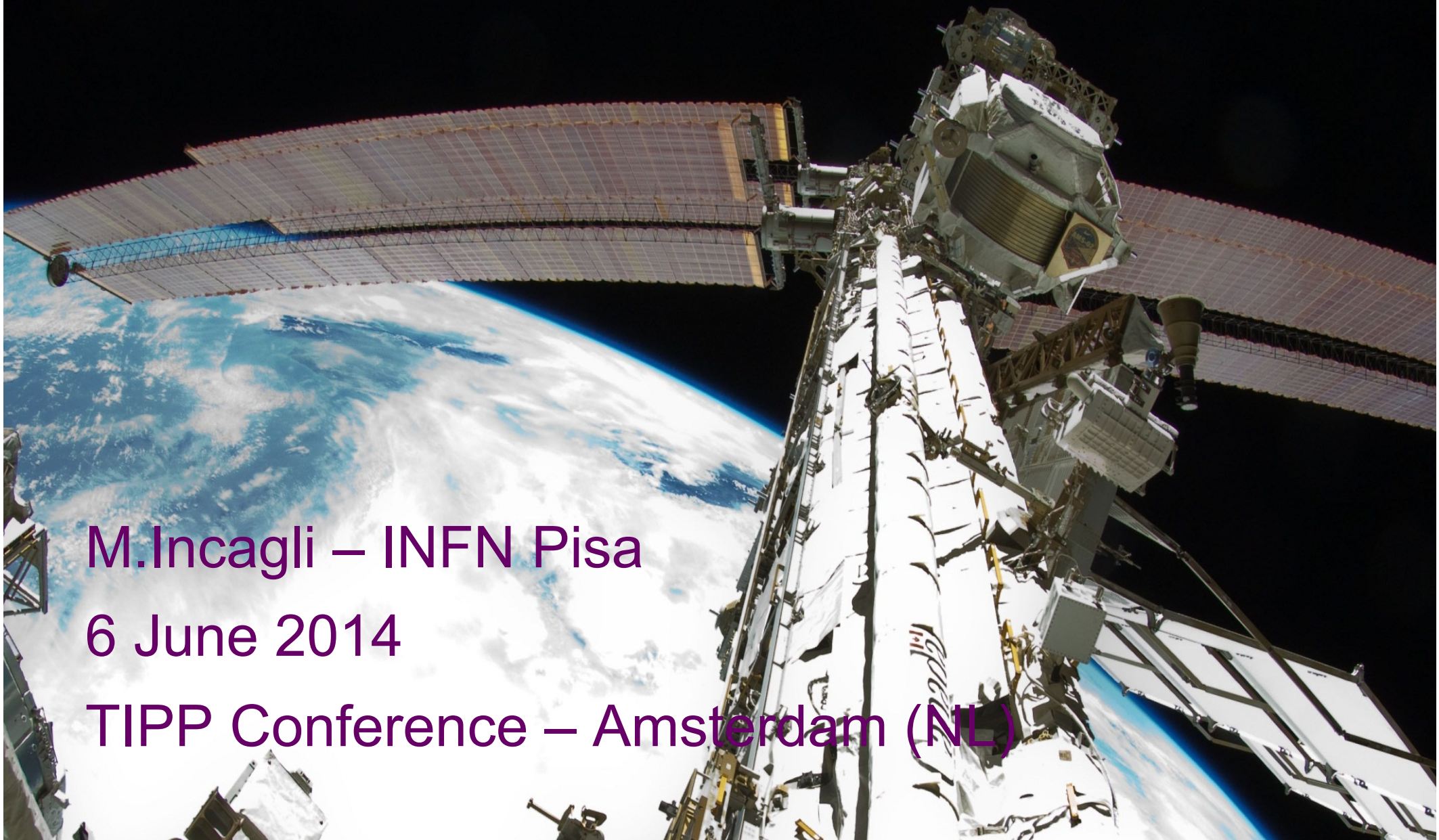
The AMS-02 Electromagnetic Calorimeter on the International Space Station



M.Incagli – INFN Pisa

6 June 2014

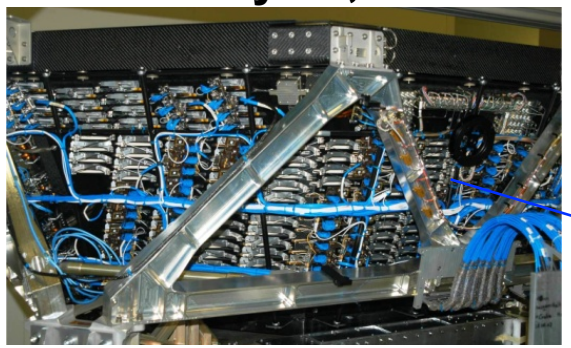
TIPP Conference – Amsterdam (NL)

AMS-02: A TeV precision, multipurpose spectrometer

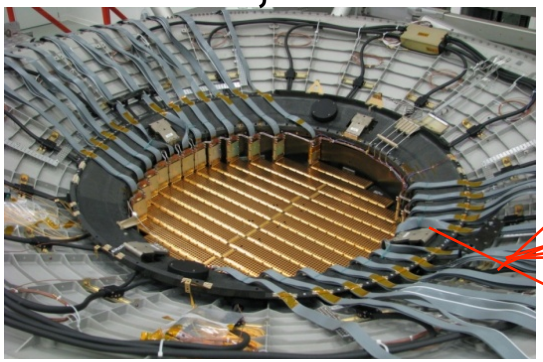
- Search and study of Anti-Matter (anti-helium)
- Indirect search for dark matter (positron/ electron fraction, anti-protons,etc...)
- Study of diffuse gamma rays
- Spectroscopy of cosmic rays (protons, electrons, ions, etc...)

AMS-02: a partcile detector in Space

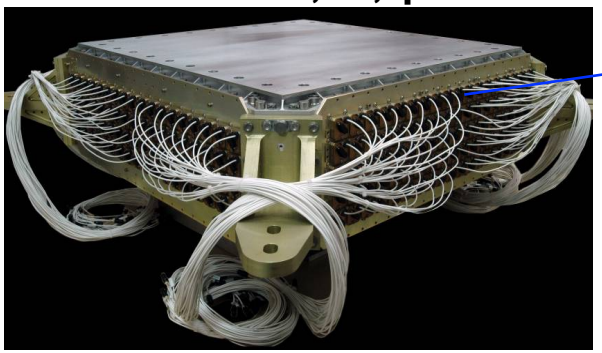
TRD
Identify e+, e-

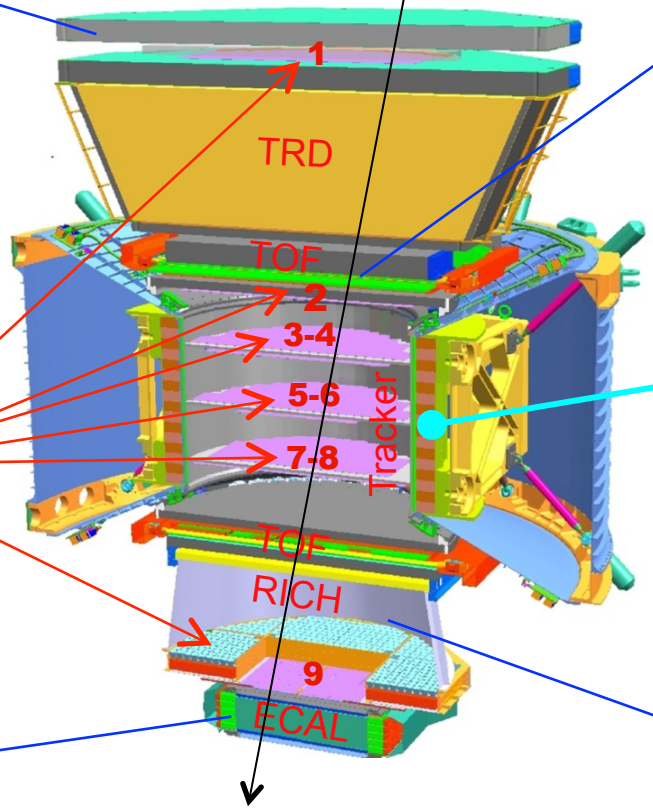


Silicon Tracker
Z, P



ECAL
E of e+, e-, γ

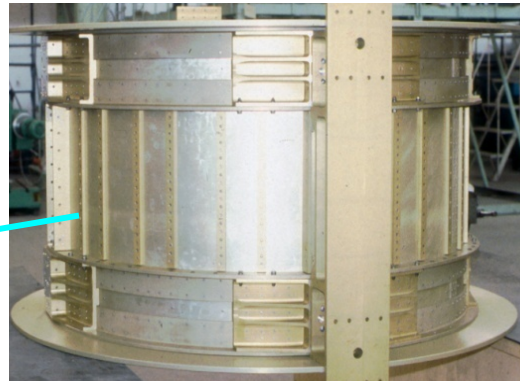




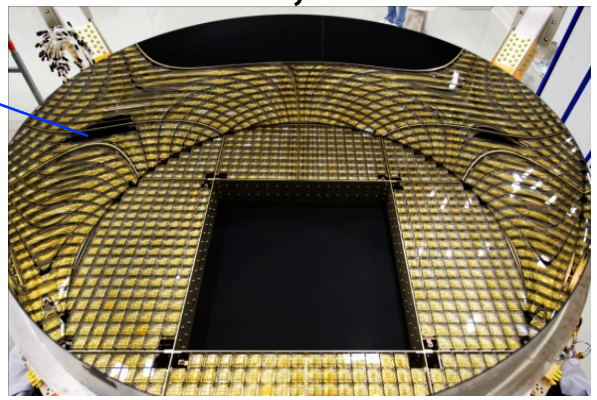
AMS02 characteristic: redundancy

TOF
Z, E

Magnet
±Z



RICH
Z, E

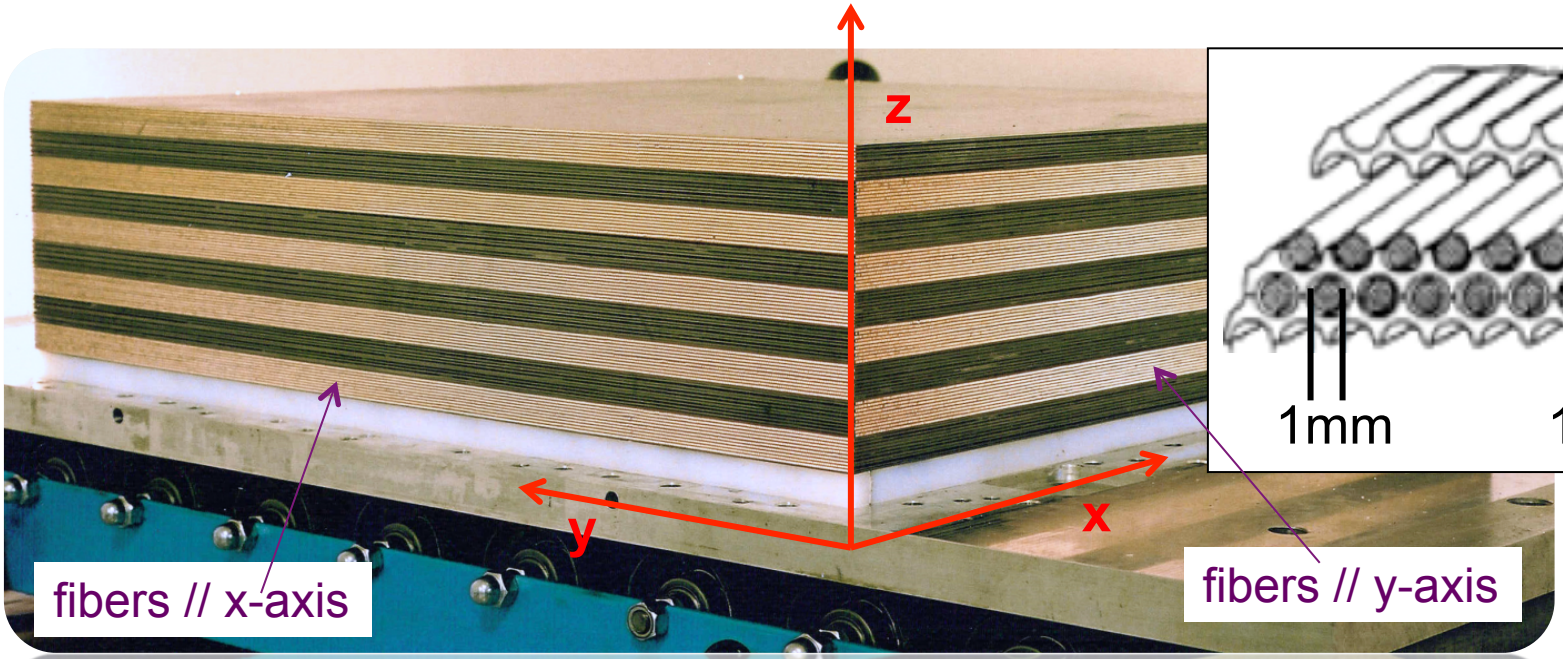


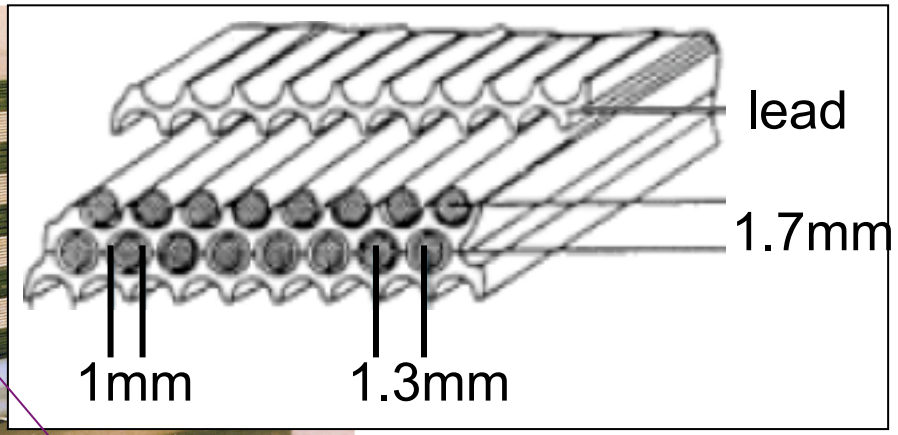
Constraints for a calorimeter in space

1. Good energy resolution but limited mass (~0.5 ton):
   - large sampling fraction → stocastic term of $\Delta E/E$
   - minimize leakage→ asymptotic constant term of $\Delta E/E$
2. Maximal separation between electron (positron) and proton showers:
   - high Z material → maximize the ratio X_0/λ_{int}
   - high granularity → sensitive to shower details
3. Trigger capabilities:
   - fast active material
4. Pointing capabilities (for photons and ECAL-trk matching):
   - high granularity

AMS-02 Electromagnetic Calorimeter

A precision, 3-D measurement of the direction and energy of gamma rays and electrons up to 1 TeV



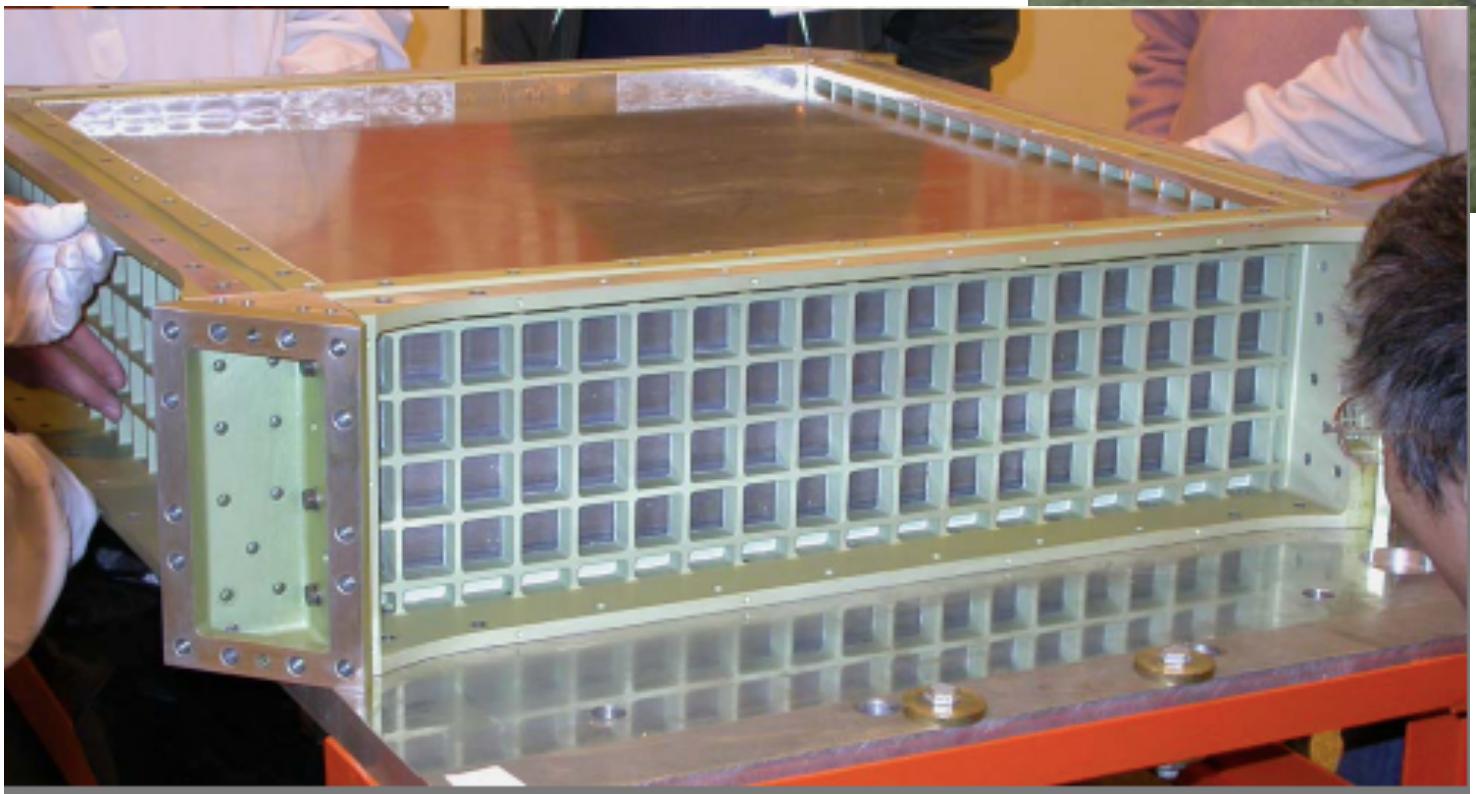


- Pb/scintillating fibers composite structure
  - 99 lead plates ~50000 scintillating fibers (ϕ = 1 mm)
  - Volume ratio (Pb/fibers/glue): 59/34/7
- Dimensions : 658 × 658 × 166 mm ; Weight: 489 kg
- Fibers along **x** and **y** view for a 3D shower reconstruction


Electromagnetic Calorimeter
ECAL

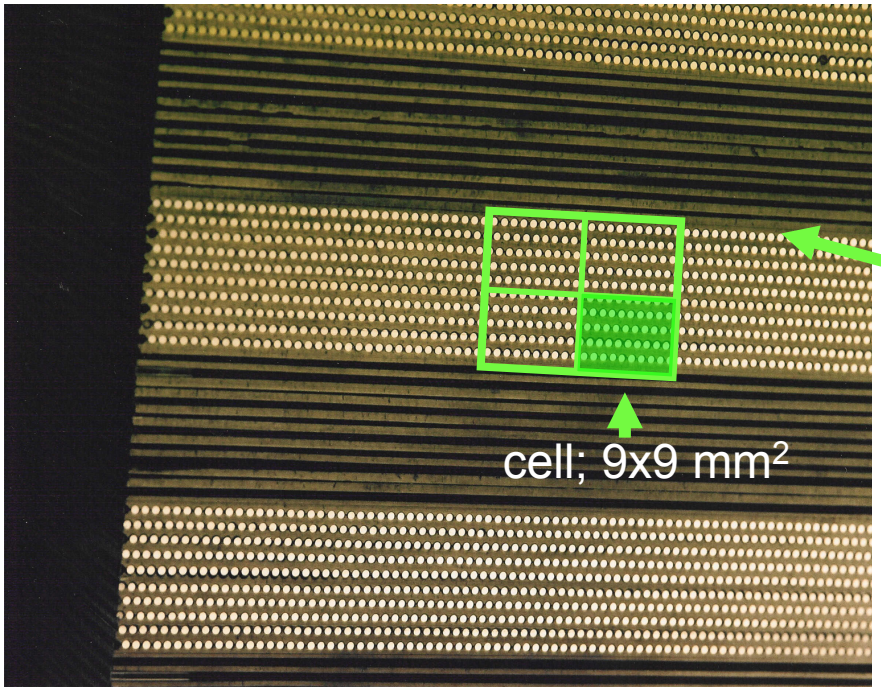
The mechanical frame

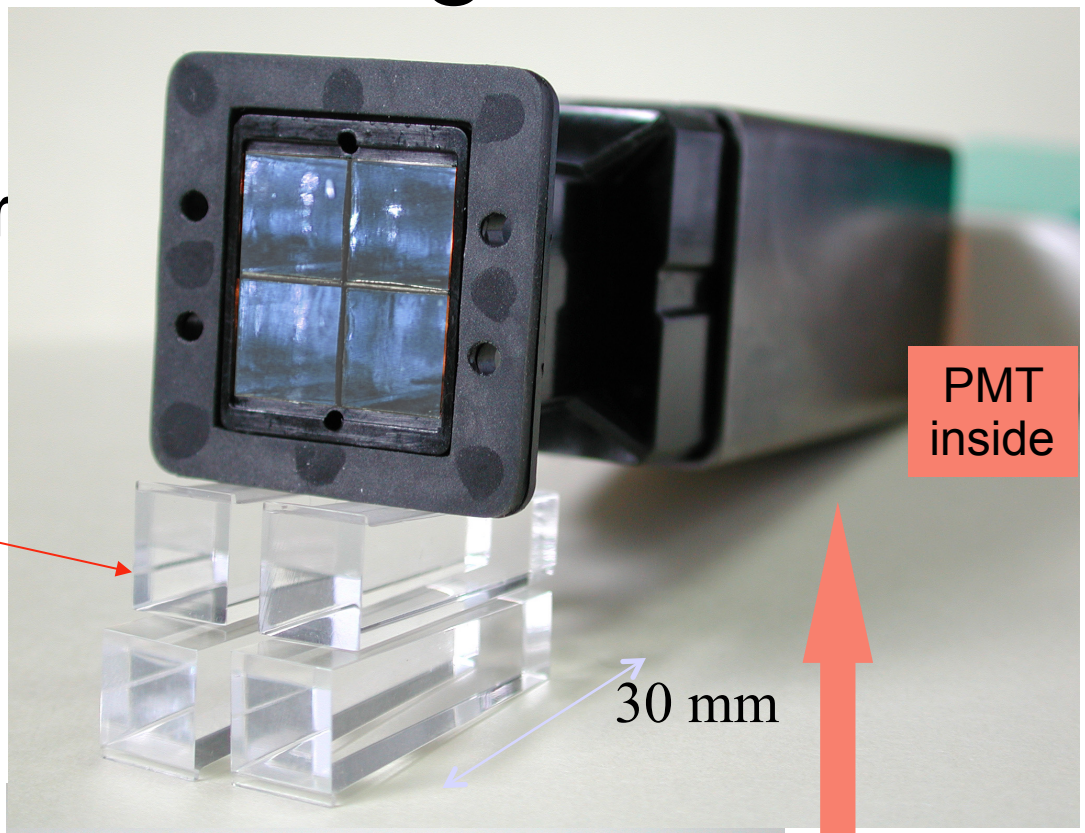
- The active part is inserted in a mechanical support structure holding the readout devices (Photo Multipliers - PMTs)

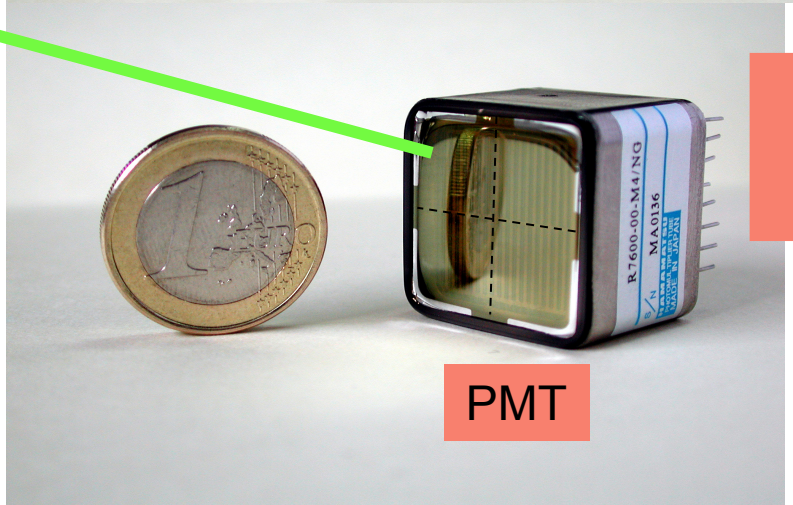


Reading out the signal

- A group of ~35 fibers is coupled to each of the four cells of a PMT through plastic light guides



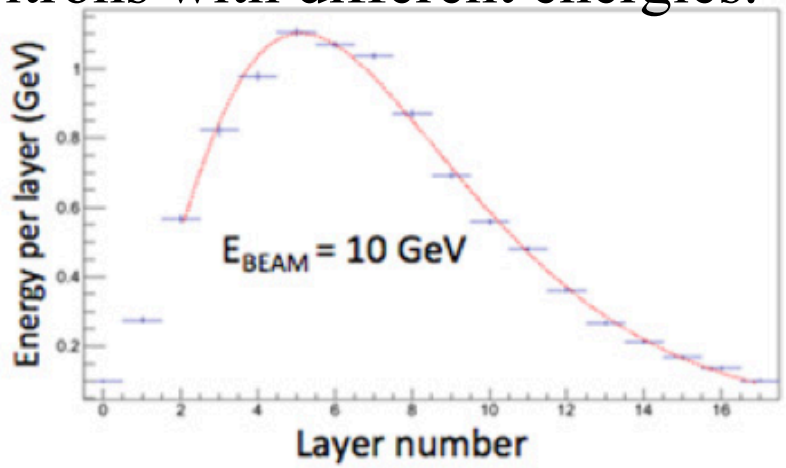


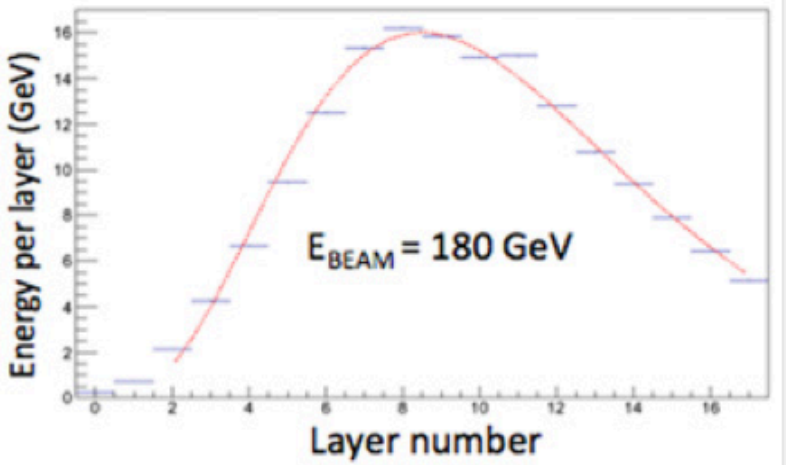


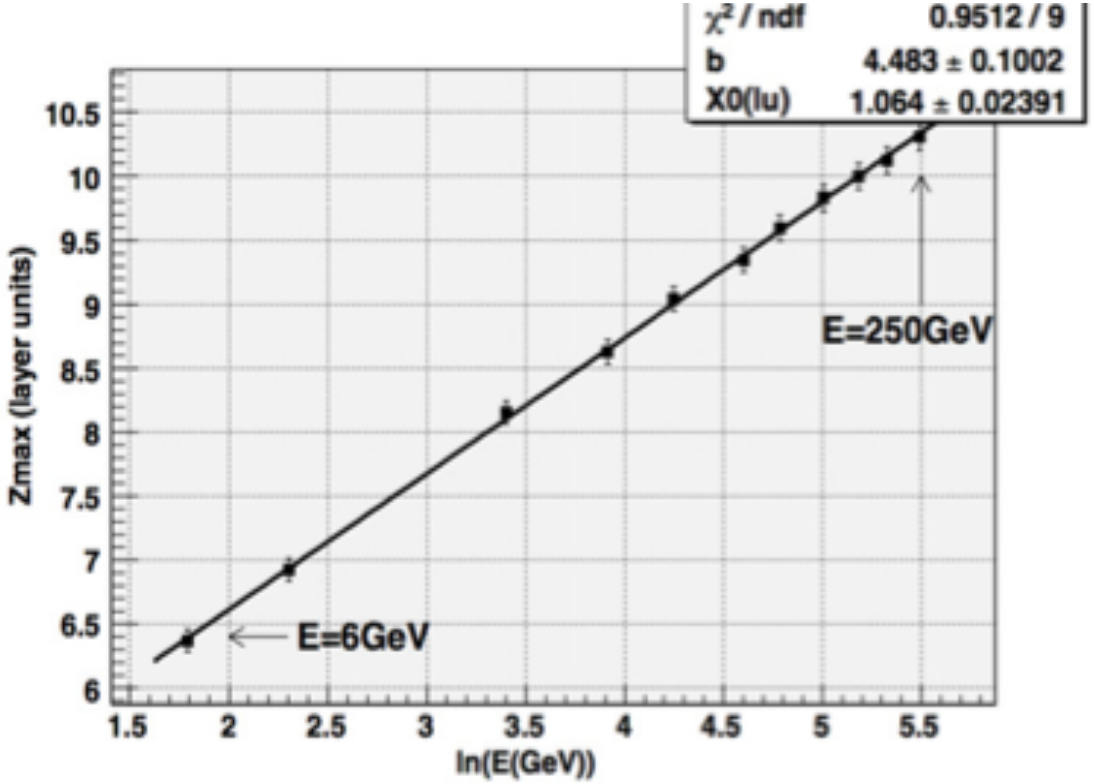

AMS02 TEST BEAM
ECAL

Calibrations: Radiation Length

Measurement of shower longitudinal development for electrons/ positrons with different energies.







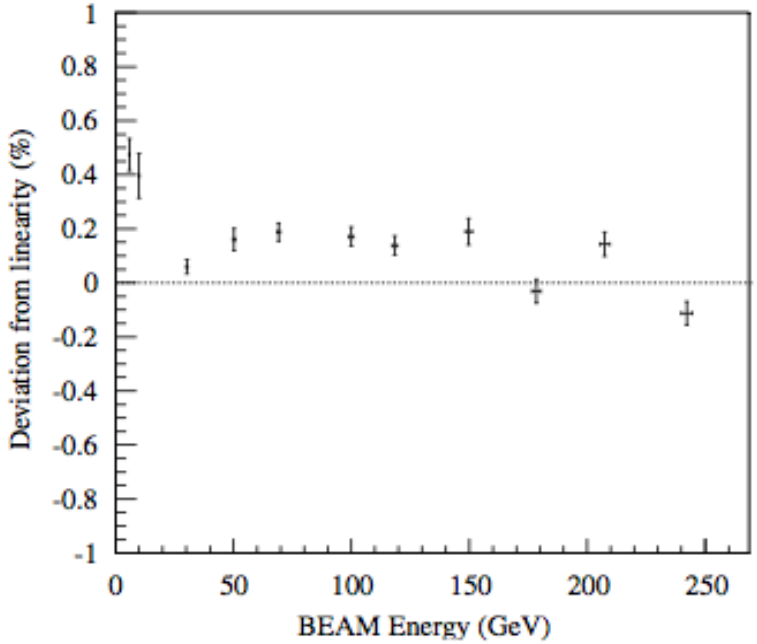
Longitudinal shape parametrized by Rossi function.

X_0 = 0.98 ± 0.02 cm

Total thickness ~ 17 X_0

Energy containment of ~ 80% for 1 TeV electrons.

Linearity and Energy Resolution

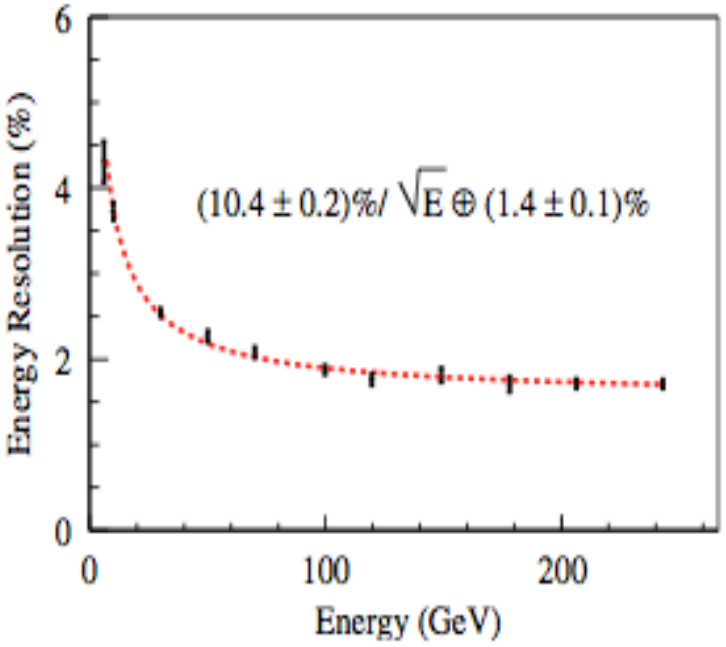


Good Linearity within 1% in the range 6-250 GeV

Good Resolution:

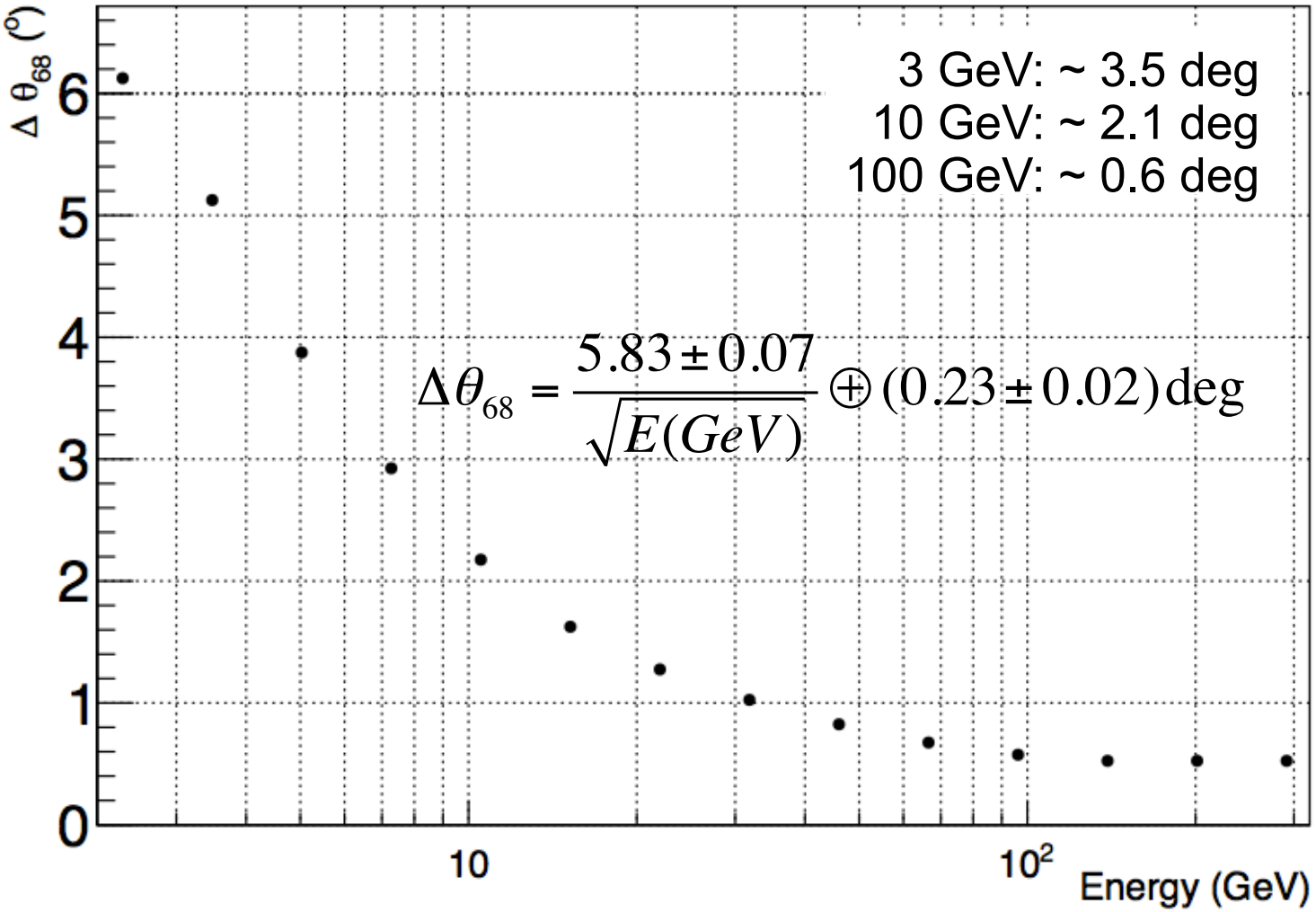
$$\frac{\sigma(E)}{E} = \frac{(10.4 \pm 0.2)\%}{\sqrt{E}} + (1.4 \pm 0.1)\%$$

10 Gev:	~ 4.7%
100 Gev:	~ 2.5%
1000 GeV:	~ 1.7%

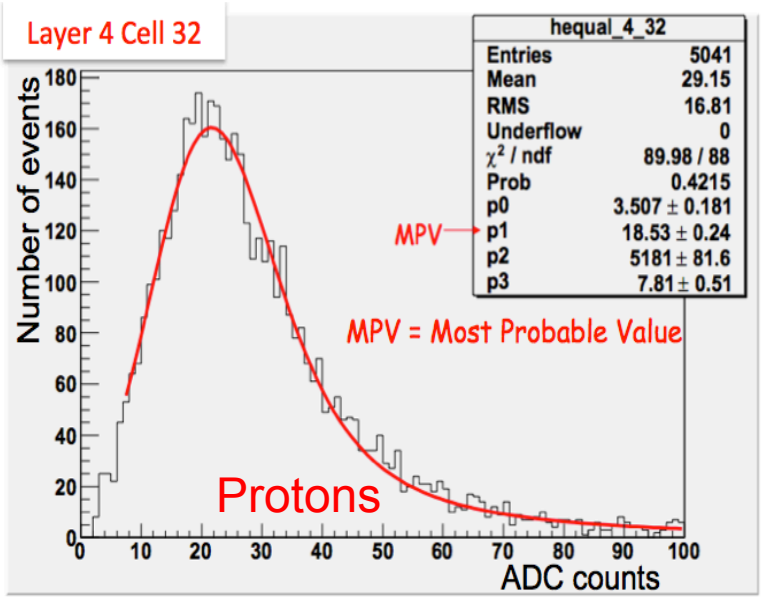


Angular Resolution

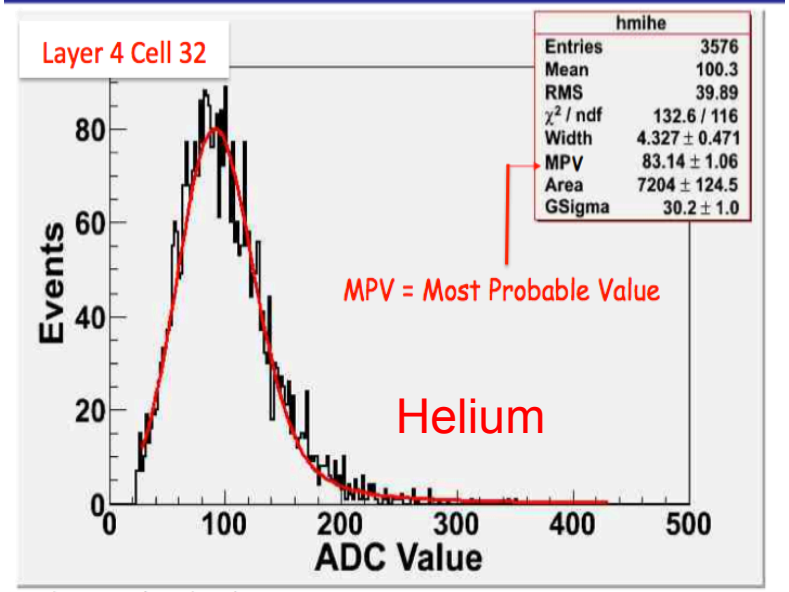
- The angular resolution is defined by the three-dimensional angular opening with respect to the incoming beam that contains 68% of the events.
- It has been measured on electron data by comparing the track extrapolated by the tracker with the shower axis defined by ECAL

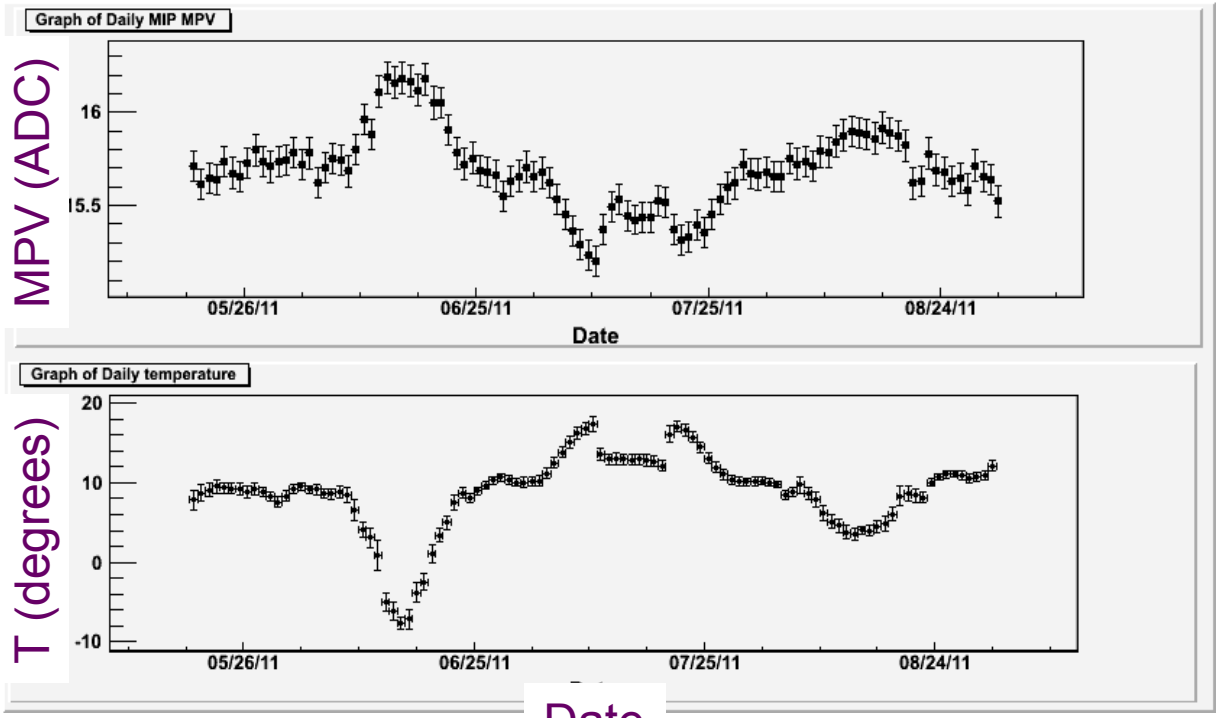


Calibrations: equalization and temperature



Cell equalization performed using proton and Helium Minimum Ionizing Particles (MIPs)





A dependence between MIP Most Probable Value (*MPV = gain*) and temperature was observed in flight data.

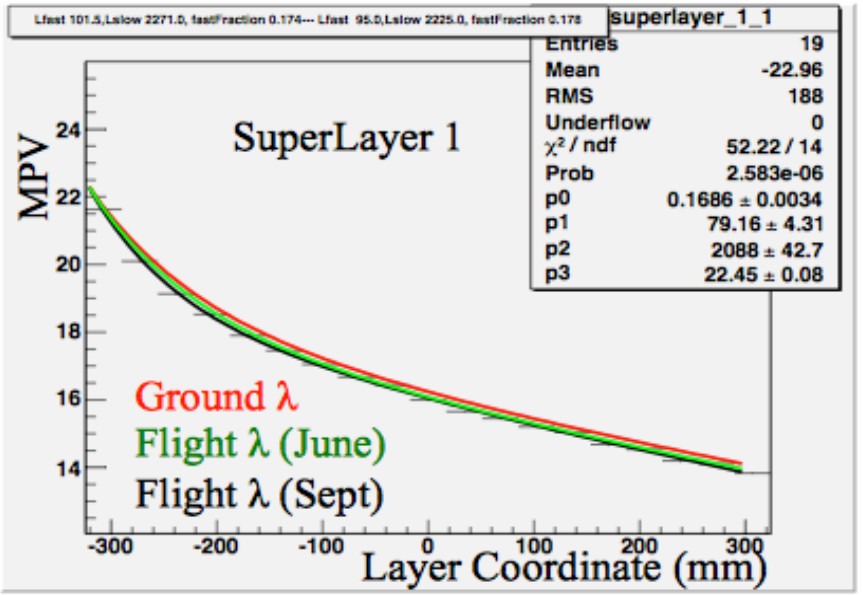
The PMT gain is anti-correlated with temperature and it changes by ~1% each 4degrees

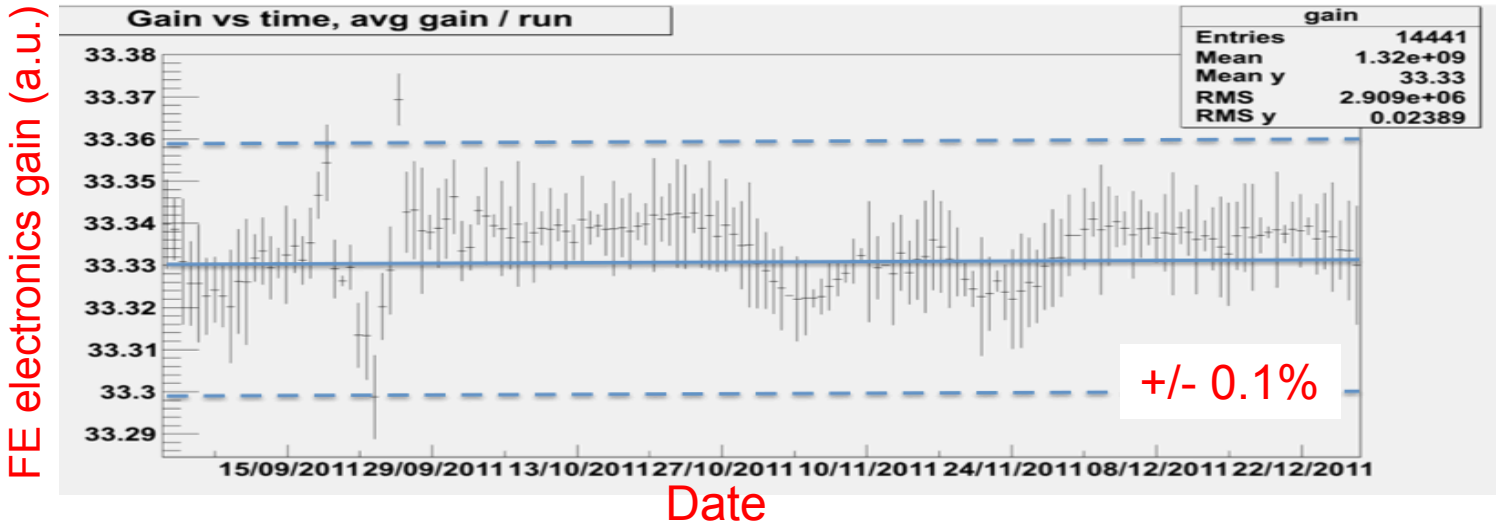
A Temperature correction is applied offline

In flight calibration checks

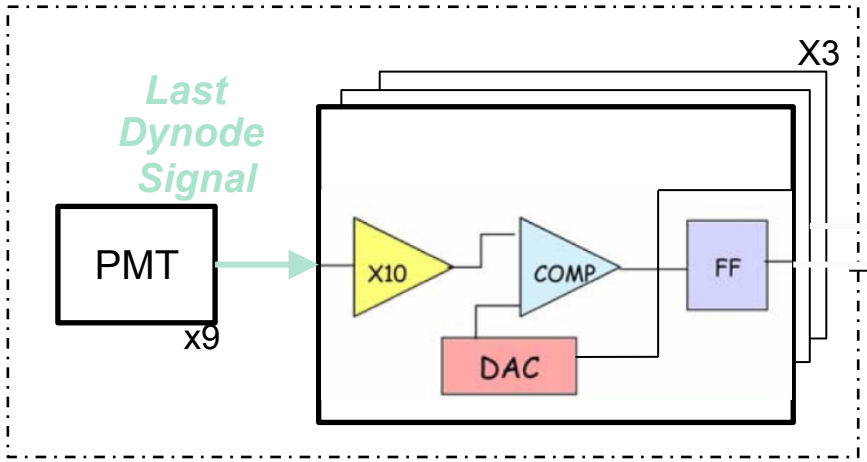
Check parameter stability:

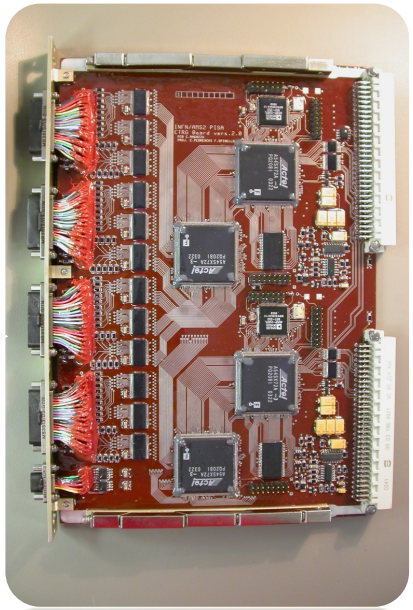
1) ADC pedestals: ~0.1%
   (recalculated each 45 minutes)
2) Light attenuation length
3) Linearity of electronics vs time





ECAL Trigger: hardware implementation





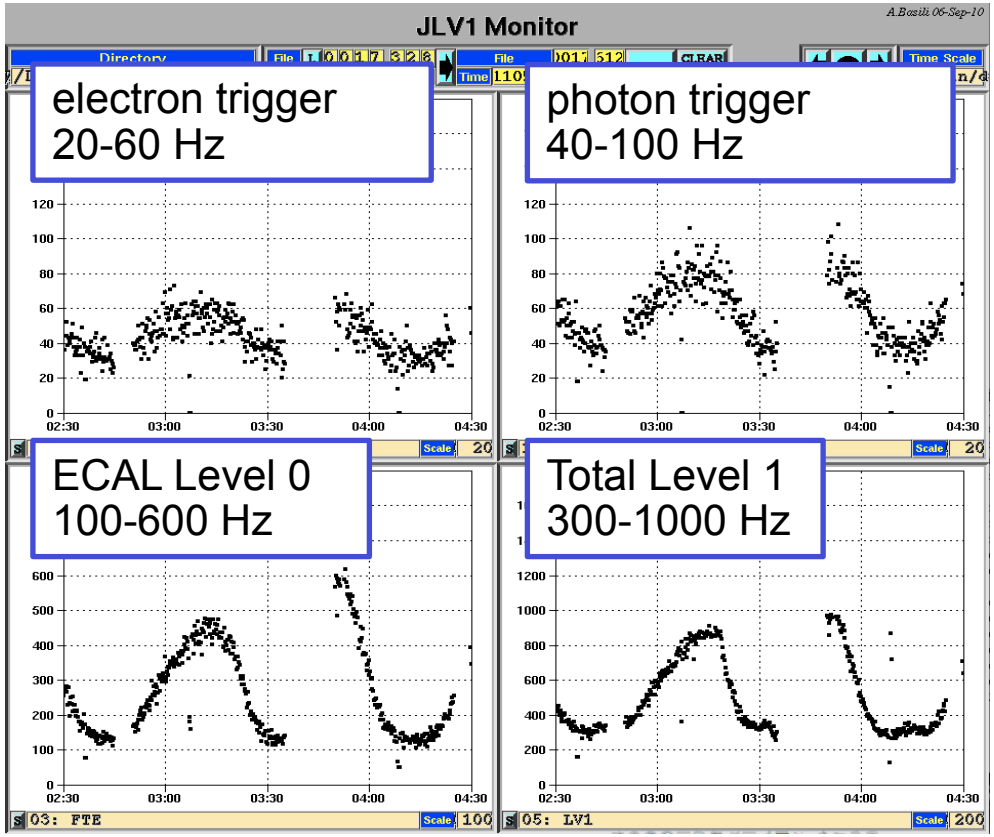
ANALOG SECTION:

- Each PMT signal is digitized at the Front End level
- Digital signals only used for trigger decision
- 108 Hits recorded in the x-view and 108 in the y-view

DIGITAL SECTION: ETRG BOARD

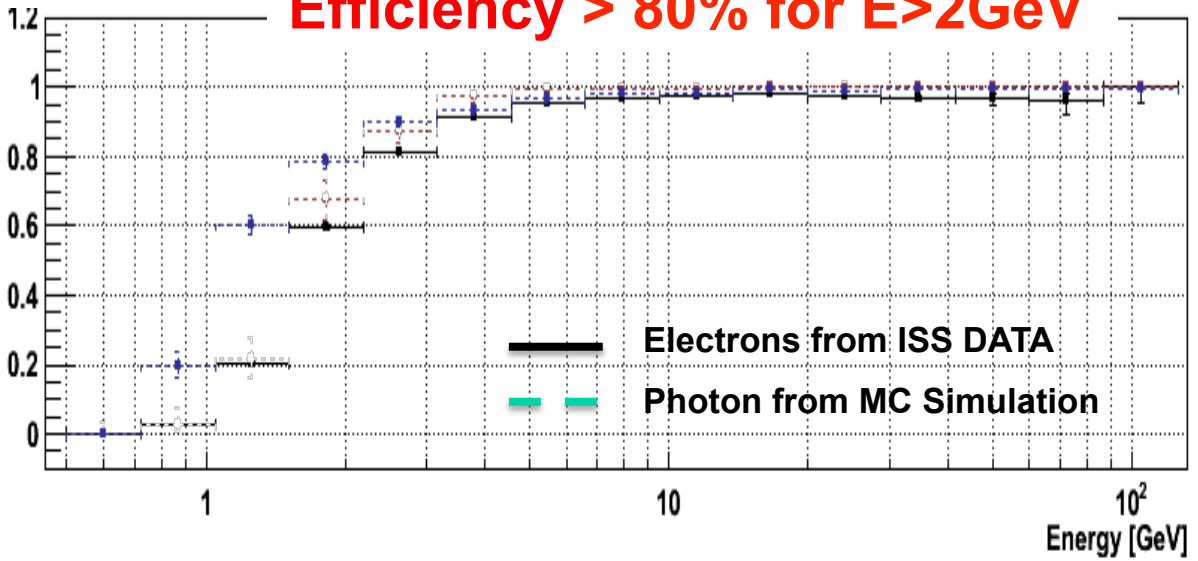
- Collects “dynode over threshold” signals related to one projection(X or Y)
- Performs trigger algorithm and sends the final decision to the main AMS Trigger board

ECAL Trigger: In-orbit performances



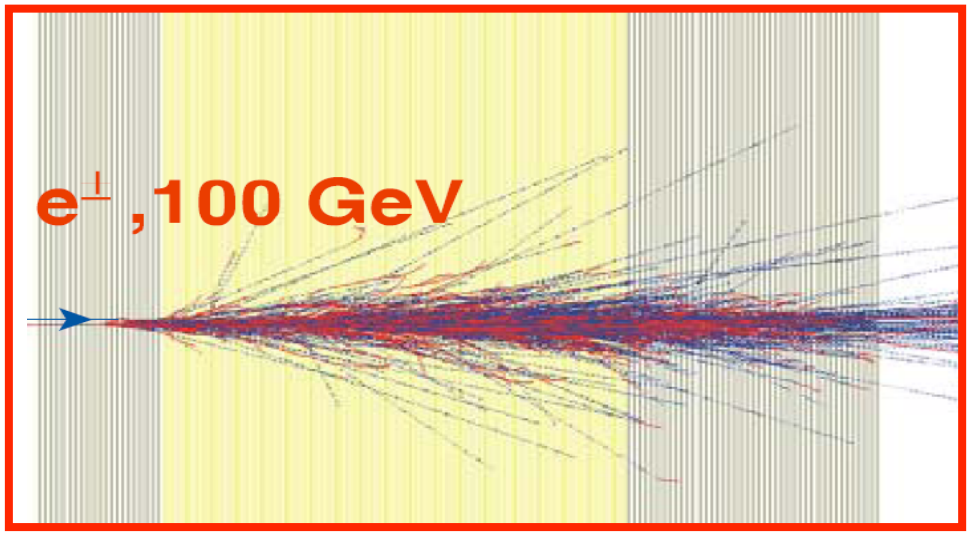
TRIGGER RATE – the photon trigger is ~10% of total Level 1 trigger, perfectly compatible with the design specification!

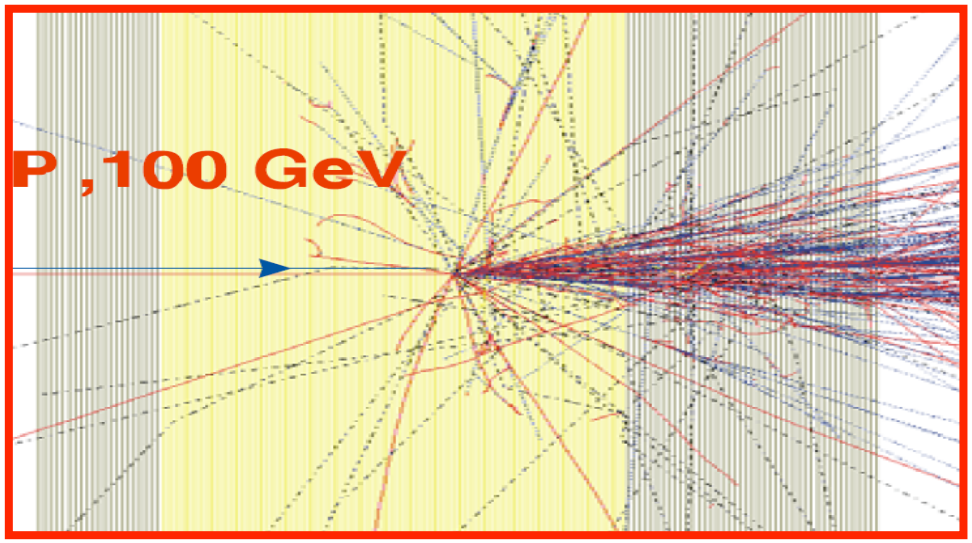
Efficiency > 80% for E>2GeV



Proton rejection

Protons/positrons ratio: 10^3-10^4

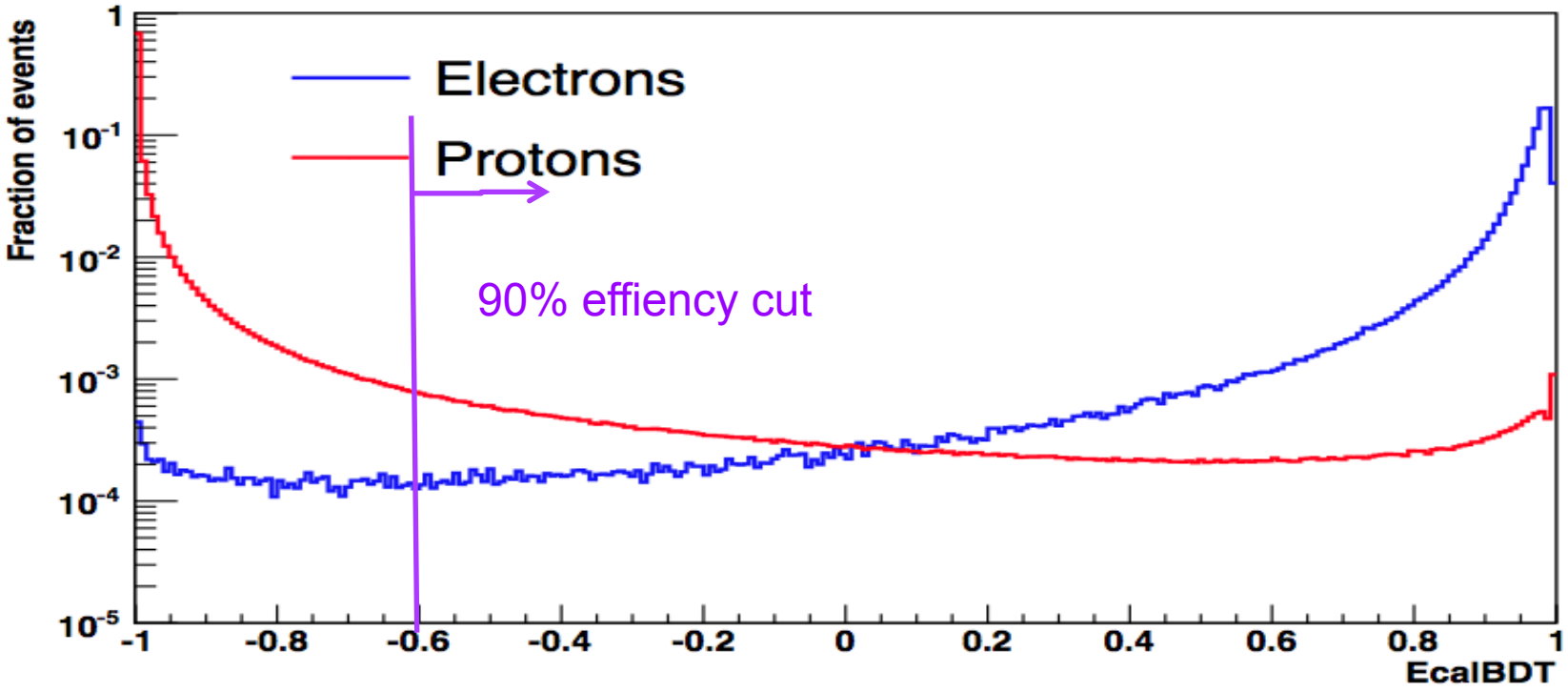




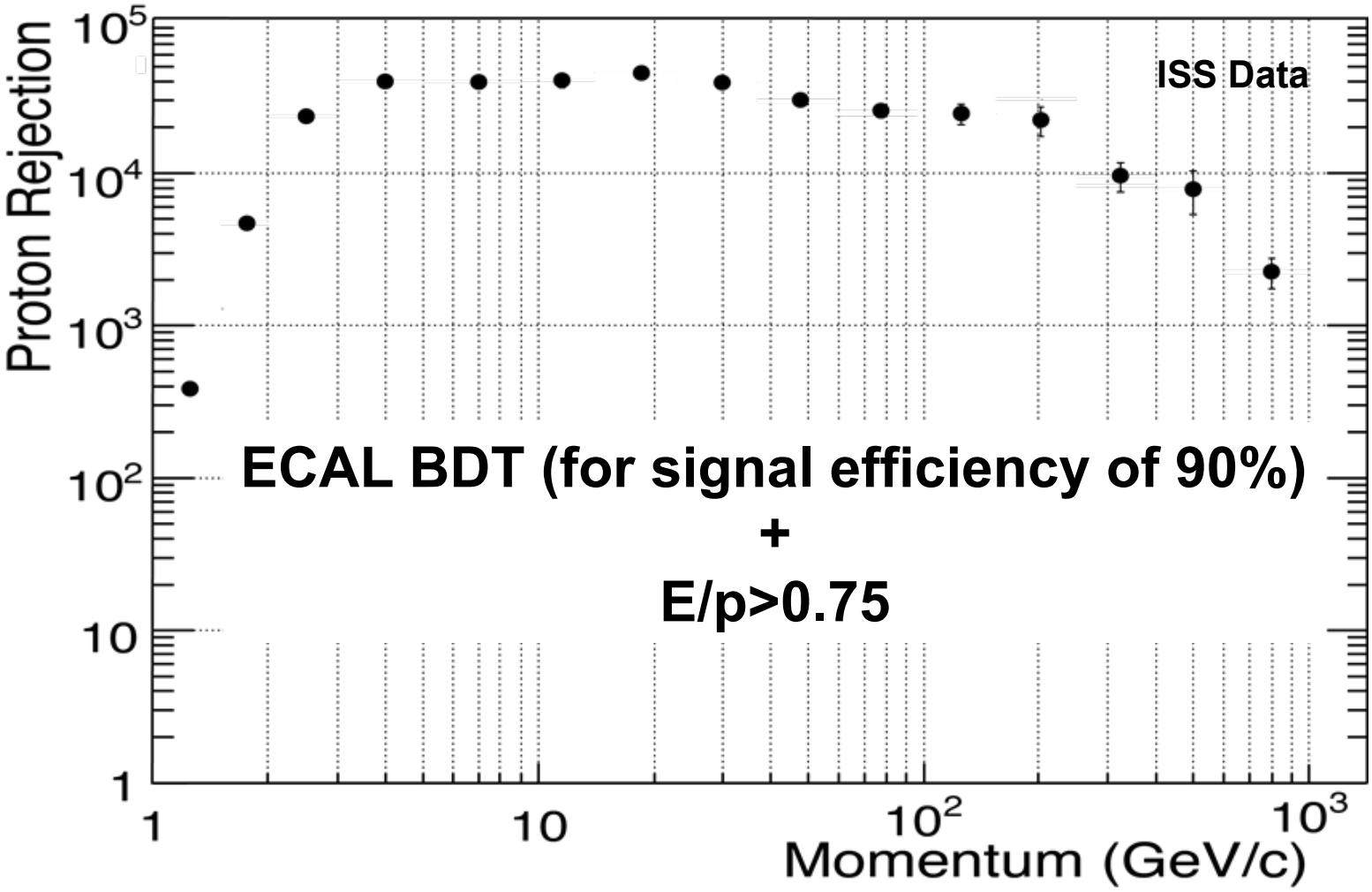
1. High granularity:
   - Different shape and development of hadronic shower with respect to electromagnetic one.
2. High resolution:
   - Mismatch between the ECAL energy and the tracker momentum for hadronic showers.

Proton rejection (1)

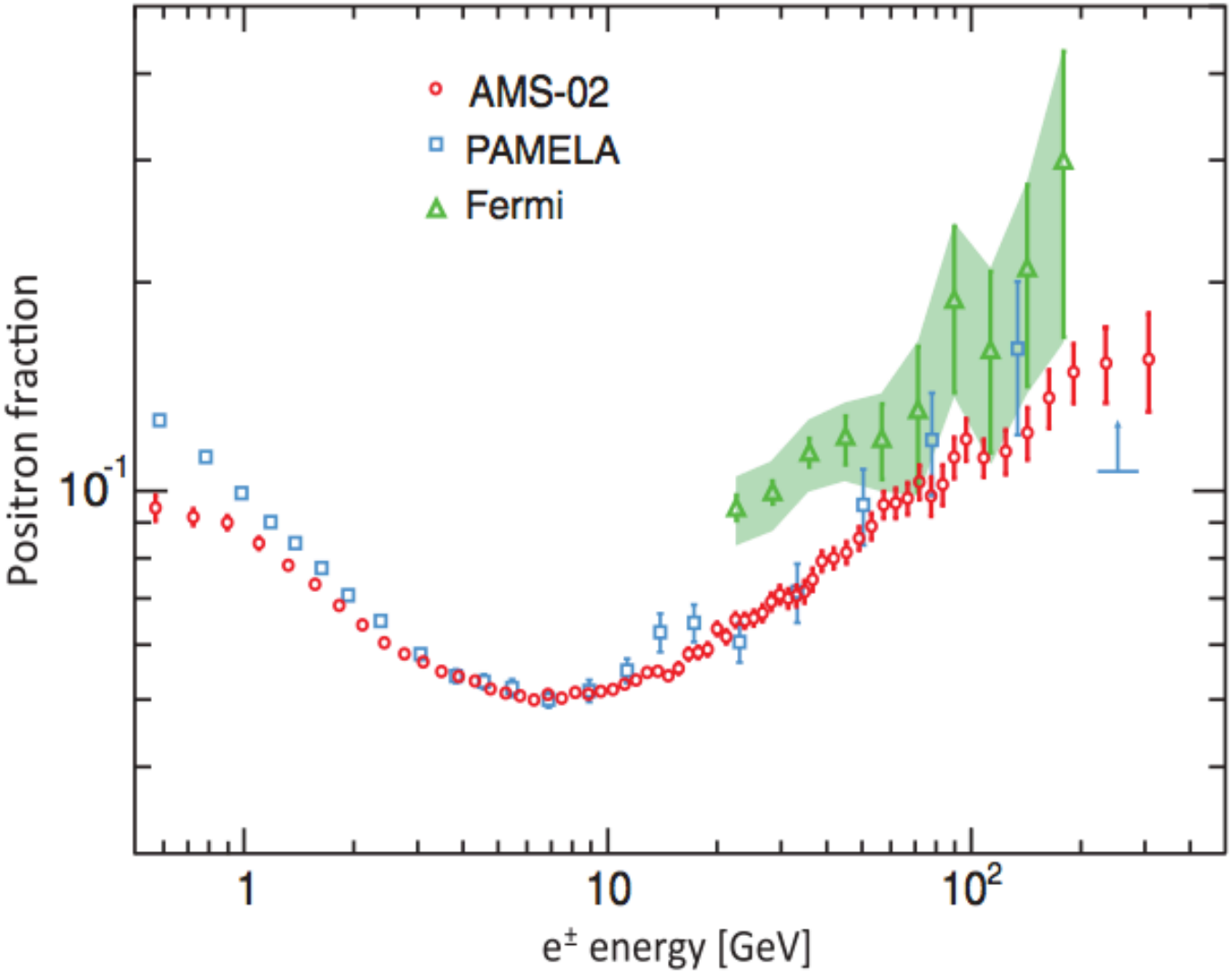
- Classification procedure done using Multi Variate Analysis (MVA) techniques
- Boosted Decision Tree (BDT) using ecal variables:
  - energy in each layer, longitudinal shape, lateral shape, etc....
- electrons and protons used for the training have been selected using the sign of the Tracker and the TRD information



Proton rejection (2)



Positron Fraction



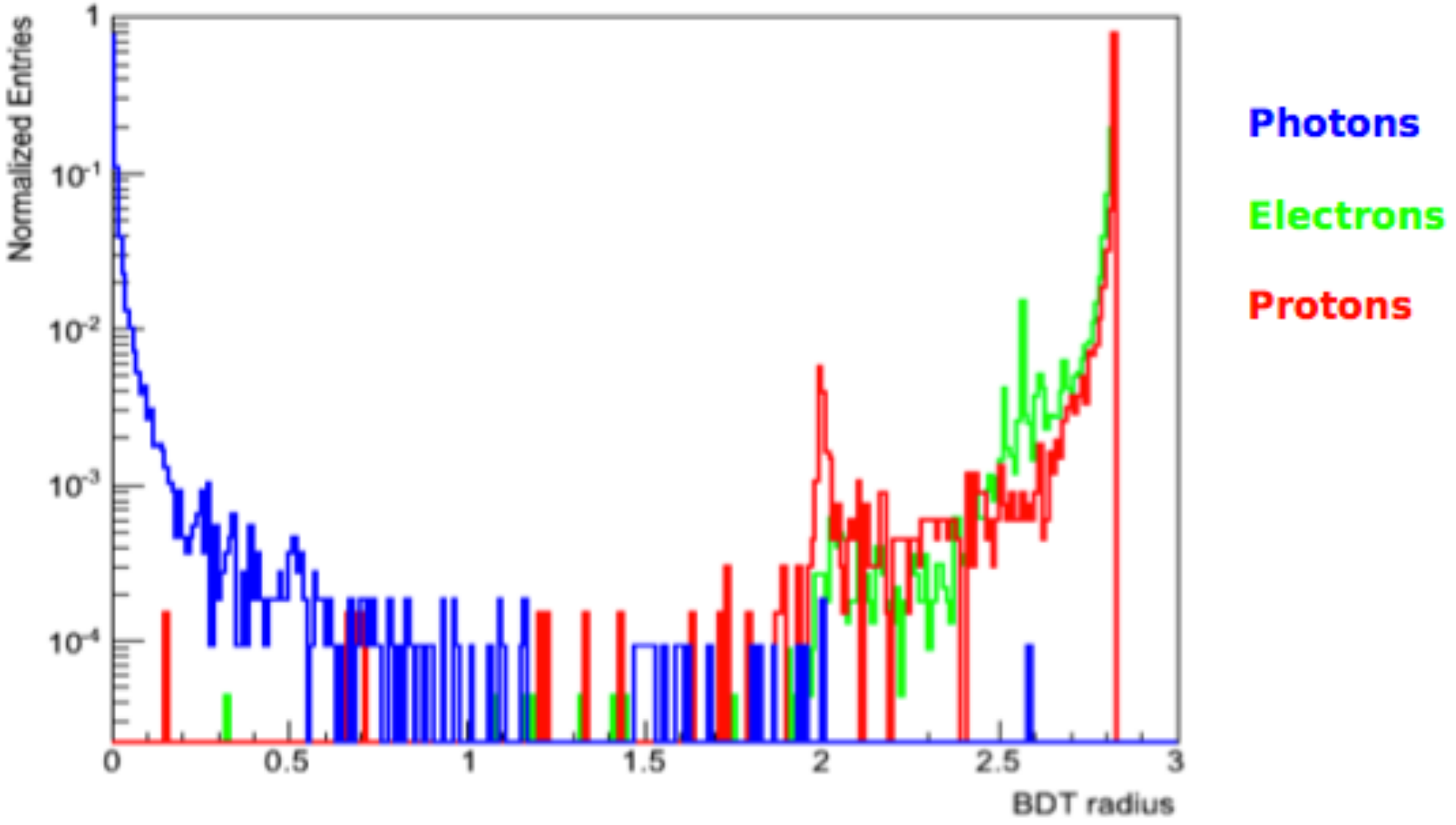
Bin width defined by Ecal Energy resolution, at energies E<100GeV and by statistics at larger energies

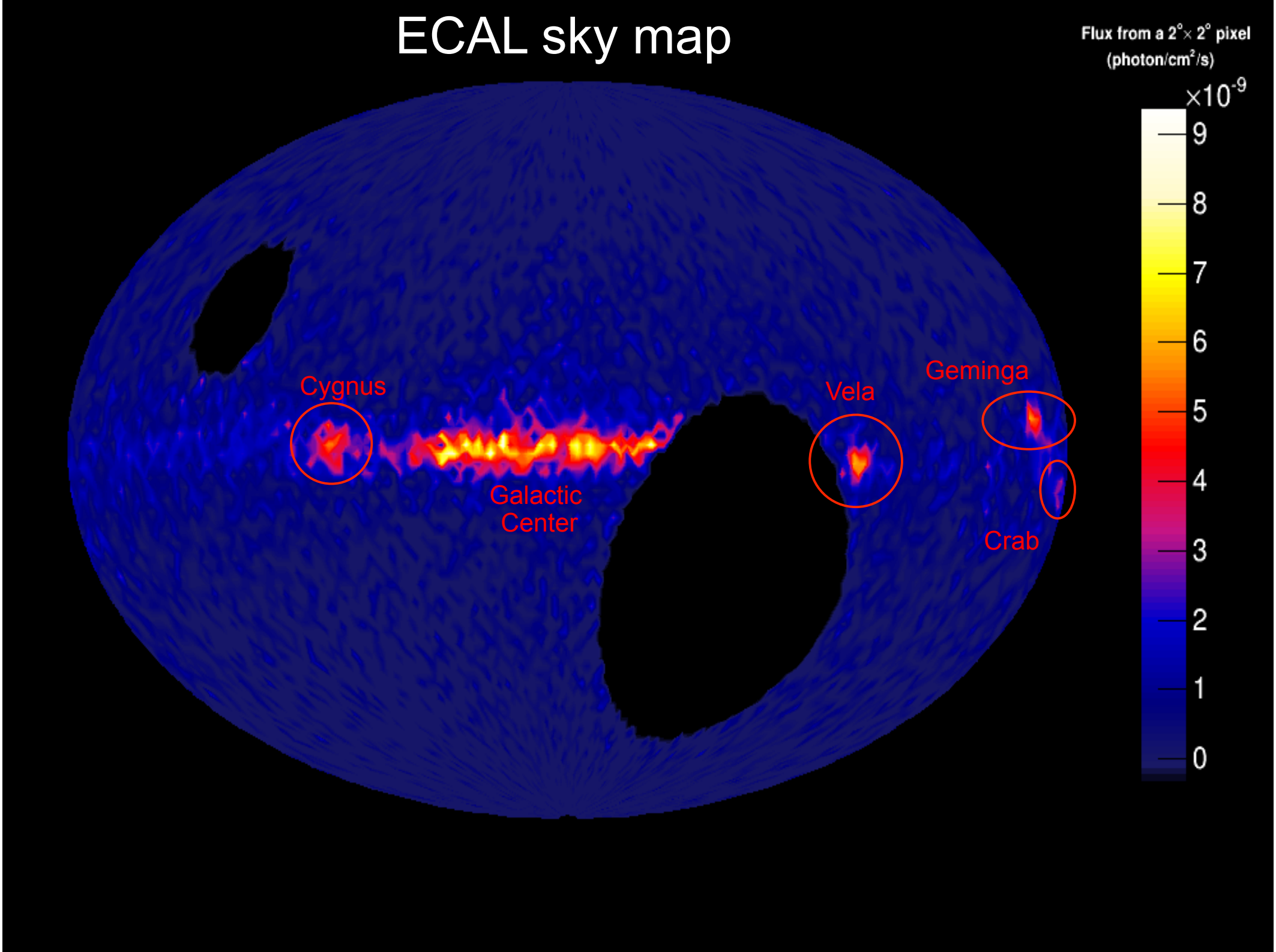
Photon physics in AMS using ECAL

- Above Ecal only 0.6 X_0 → ~63% of the photons reach ECAL without interactions
- ECAL triggers on these photons with efficiency ~100% at E>5GeV
- ECAL pointing capabilities ~0.5° at E=100 GeV
  - not a pointing device, but some angular information to correlate with known sources
- High energy measured with ~2% resolution (compare with ~10%)
  - useful for "line search" in photon spectrum
- Major limitation in physics capabilities: *small angular acceptance* (factor 20 less than Fermi)

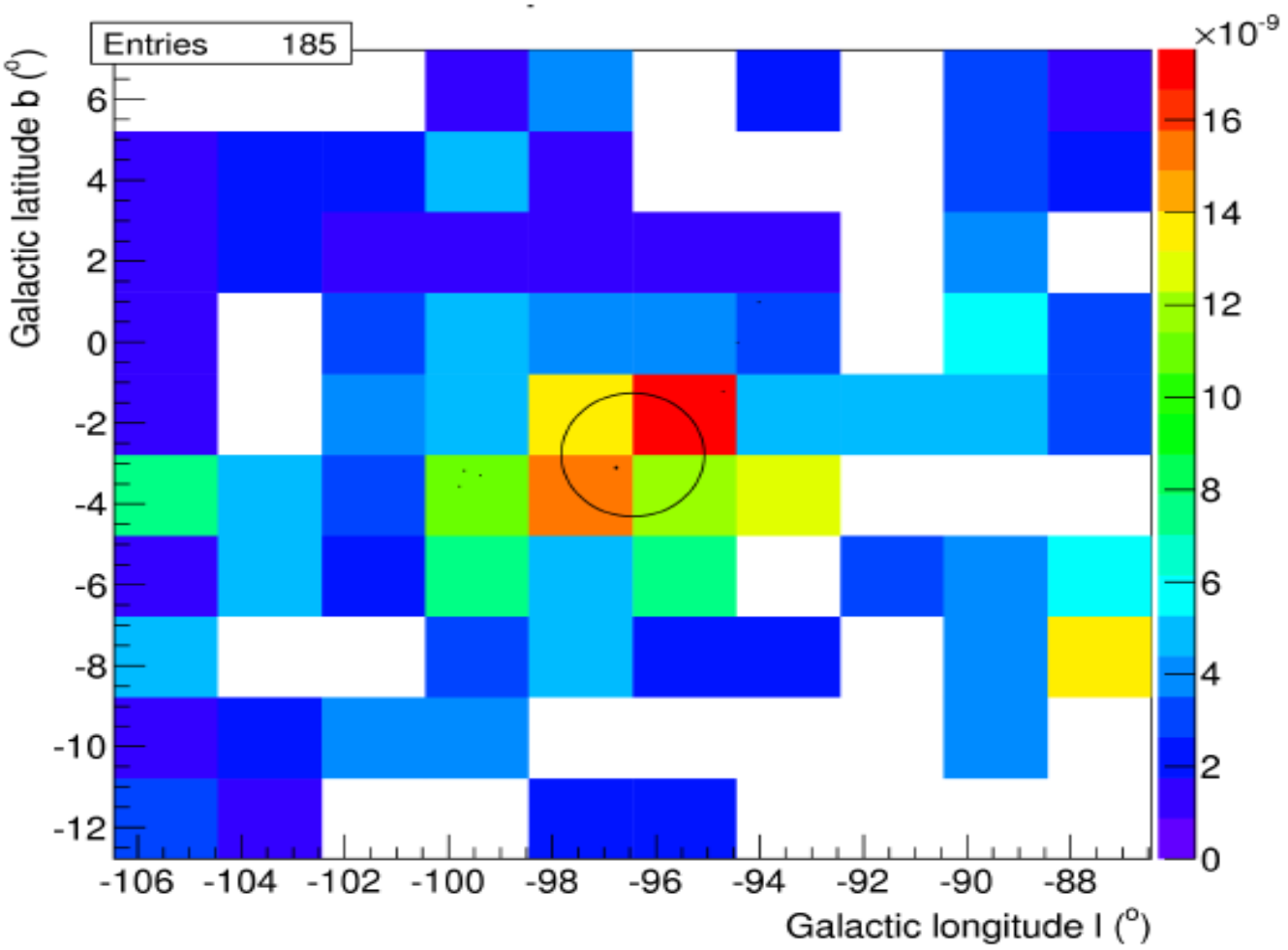
Photon identification

- Photons identified with a BDT technique similar to electrons
- Photon BDT uses information from all the detector: shower shape and presence of hits above ECAL




ECAL sky map
Flux from a 2°× 2° pixel
(photon/cm²/s)
×10⁻⁹
9
8
7
6
5
4
3
2
1
0
Cygnus
Galactic
Center
Vela
Geminga
Crab

Pointing Accurancy: Vela [3,10] GeV



DIFFERENCE FROMFERMI LAT2YEARS CATALOG

$\Delta l = -0.4 \pm 0.5$

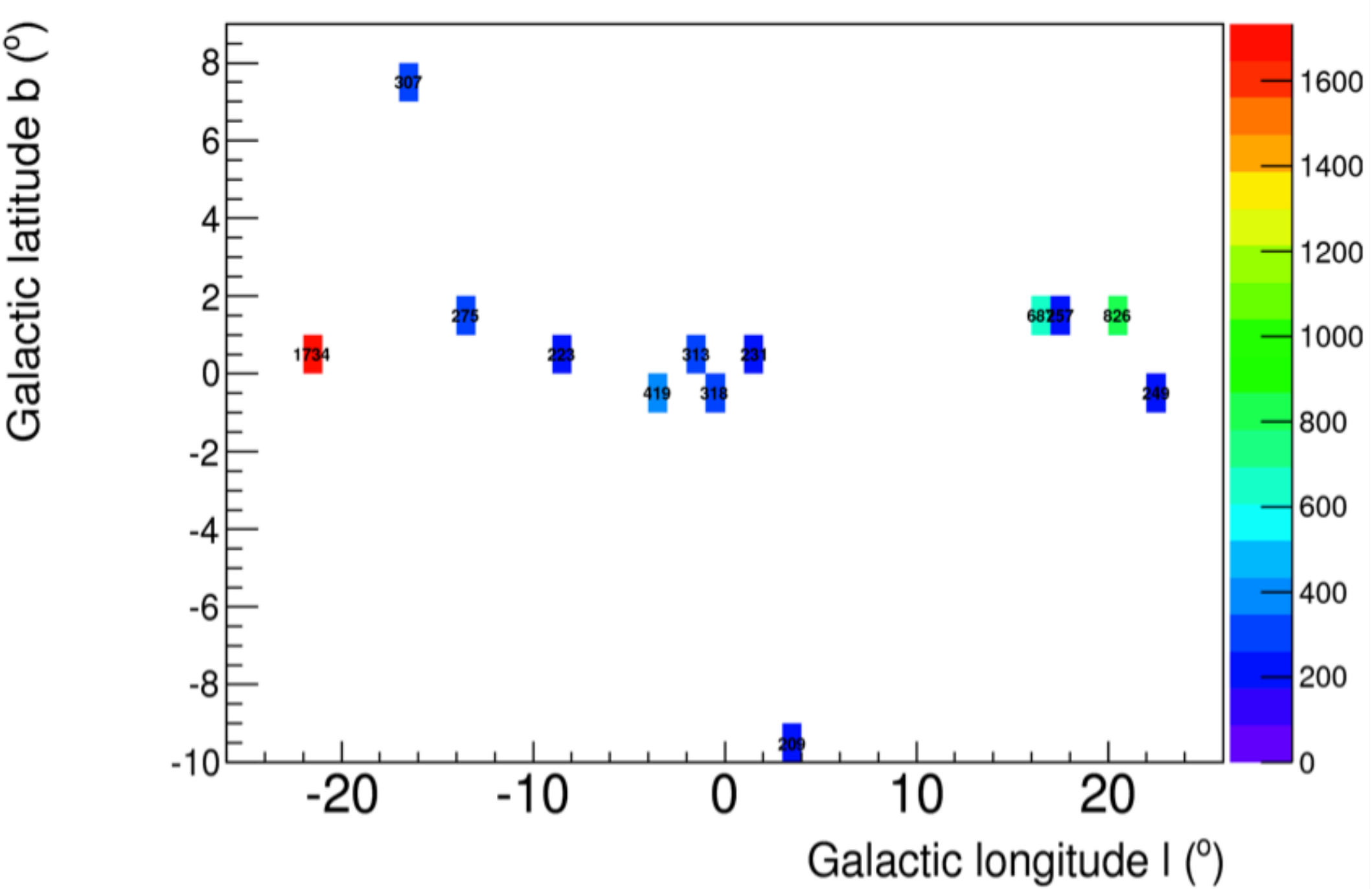
$\Delta b = -0.3 \pm 0.3$

$\sigma(l) = 3.0 \pm 0.7$

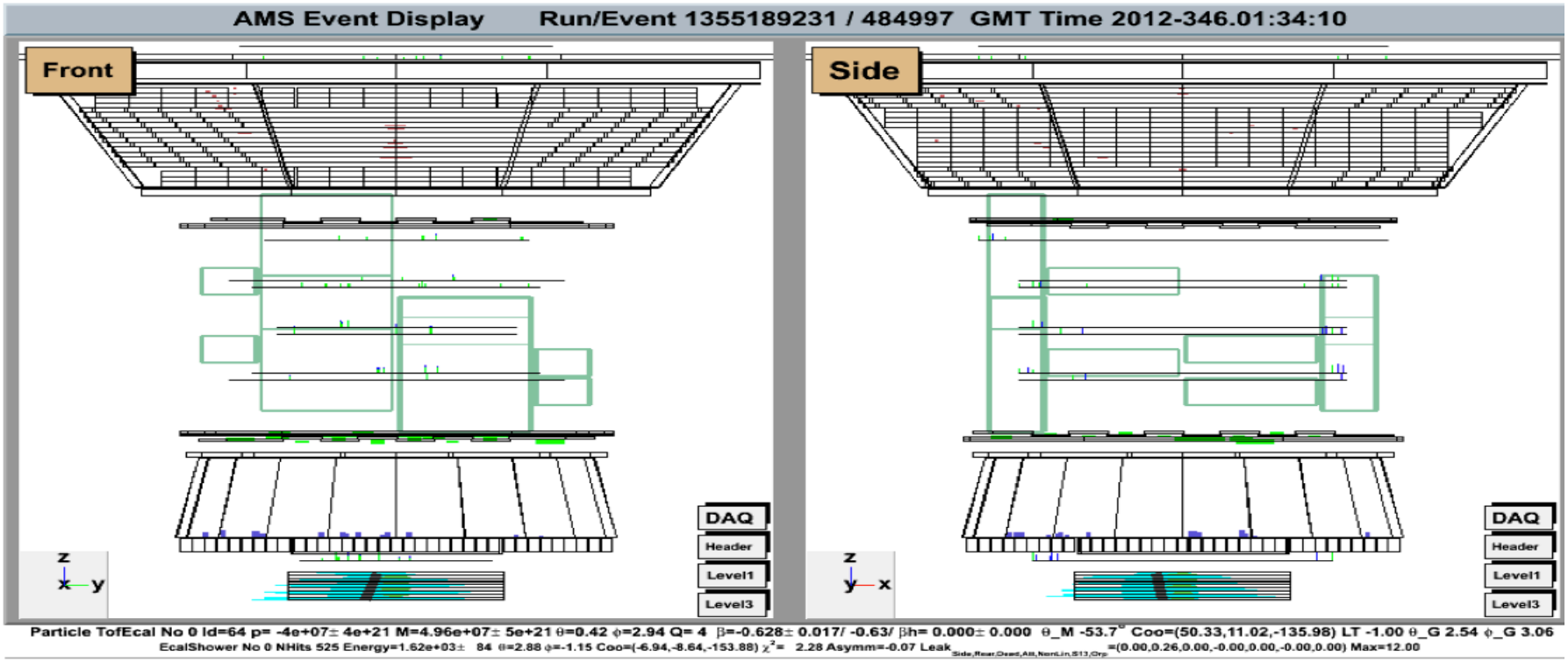
$\sigma(b) = 1.9 \pm 0.3$

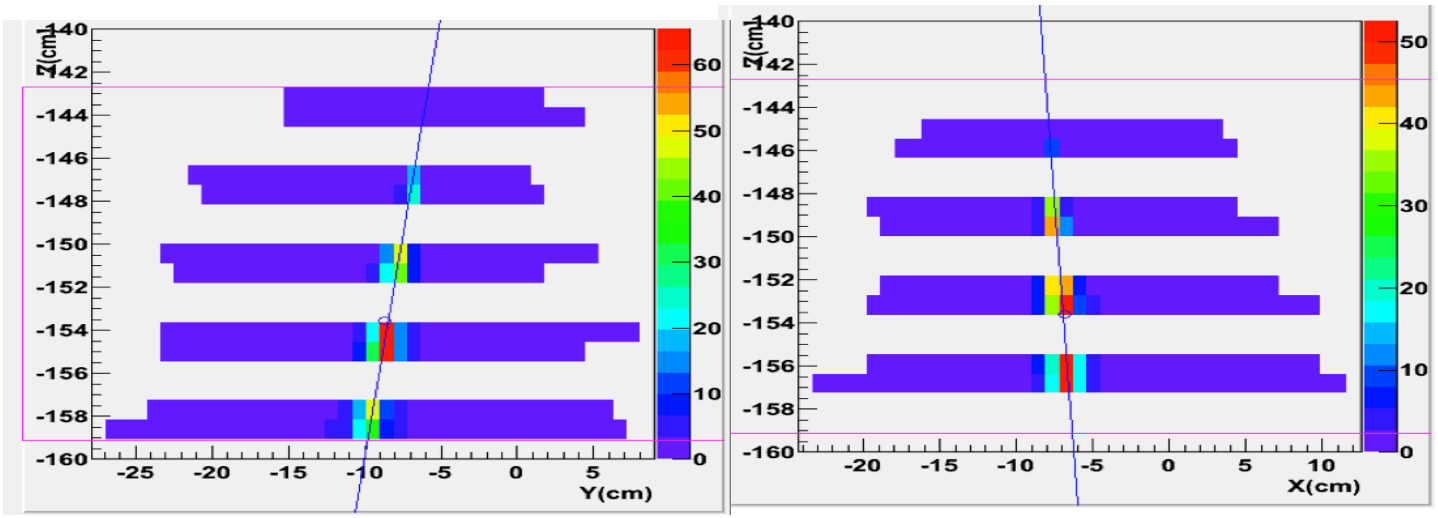
Standard deviation of galactic coordinates includes error of position and orientation of AMS

High energy photons from galactic center



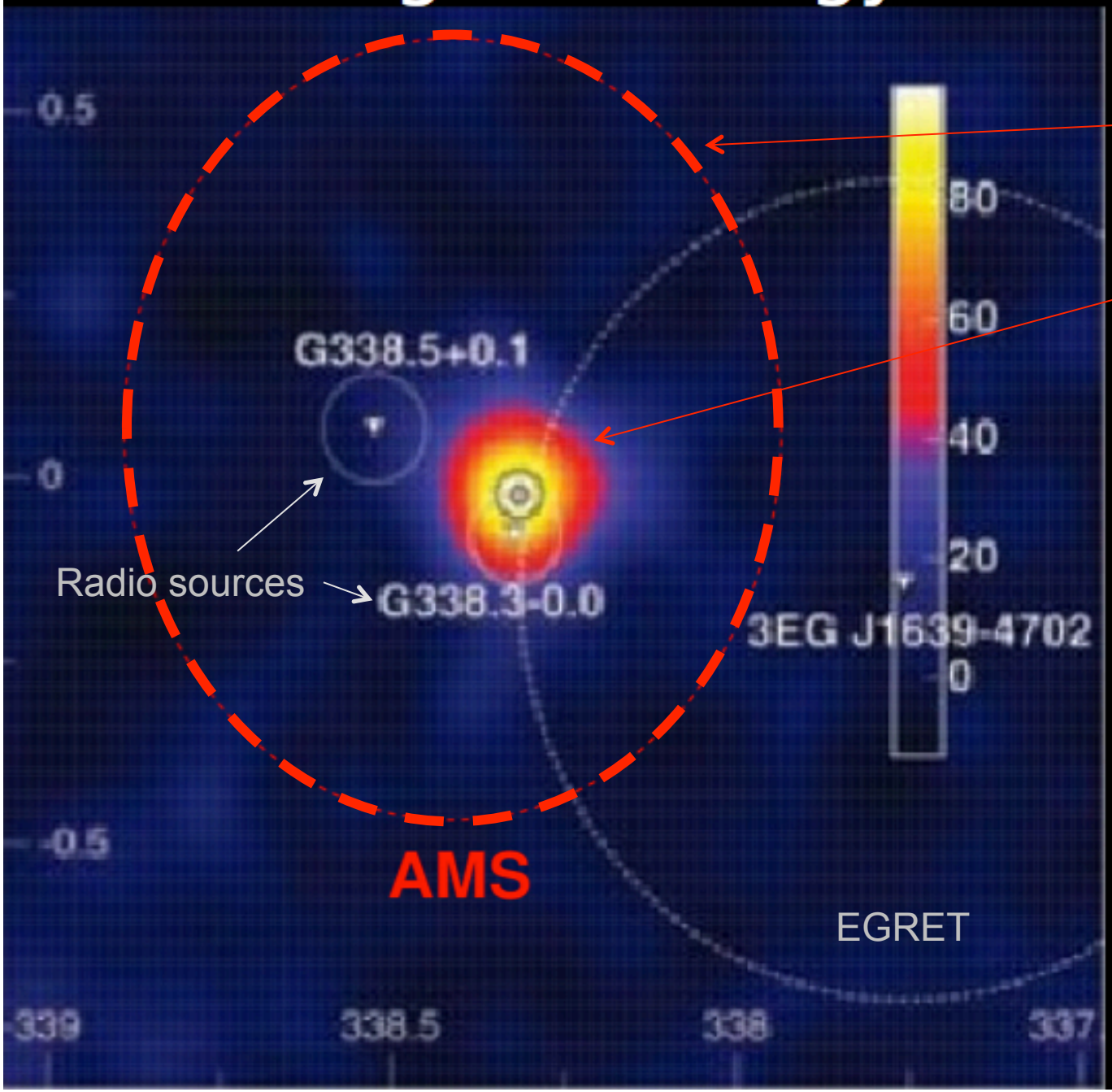
A 1.7 TeV photon





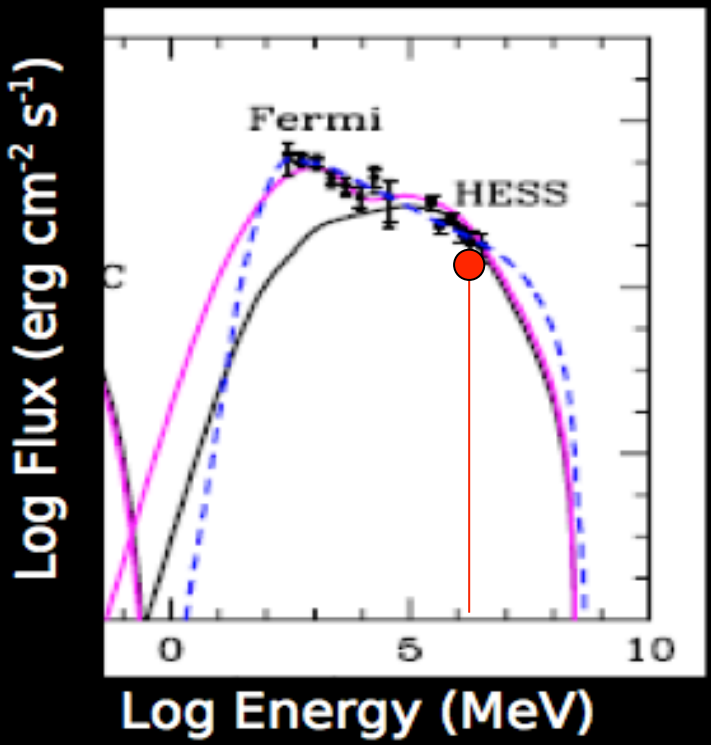
- Good Shower in Ecal
- Only few "backsplash" hits not correlated with the shower axis

The highest energy AMS ECAL photon



AMS: l=338.4° ± 0.5°
b= 0.05° ± 0.5°

HESS J1640-465:
l=338.316° ± 0.007°
b= -0.021° ± 0.007°



Conclusions

- After 3 years of data taking, Ecal is performing according to expectations
- Energy scale and angular resolution checked with flight data → no degradation effects observed
- ECAL energy resolution and ep identification are the key for AMS scientific results on electron/positron measurements
- Although not in the AMS mainstream, high energy photon physics is also possible thanks to ECAL energy resolution, pointing capabilities and standalone trigger