High-energy Gamma Rays detection with the AMS-02 electromagnetic calorimeter

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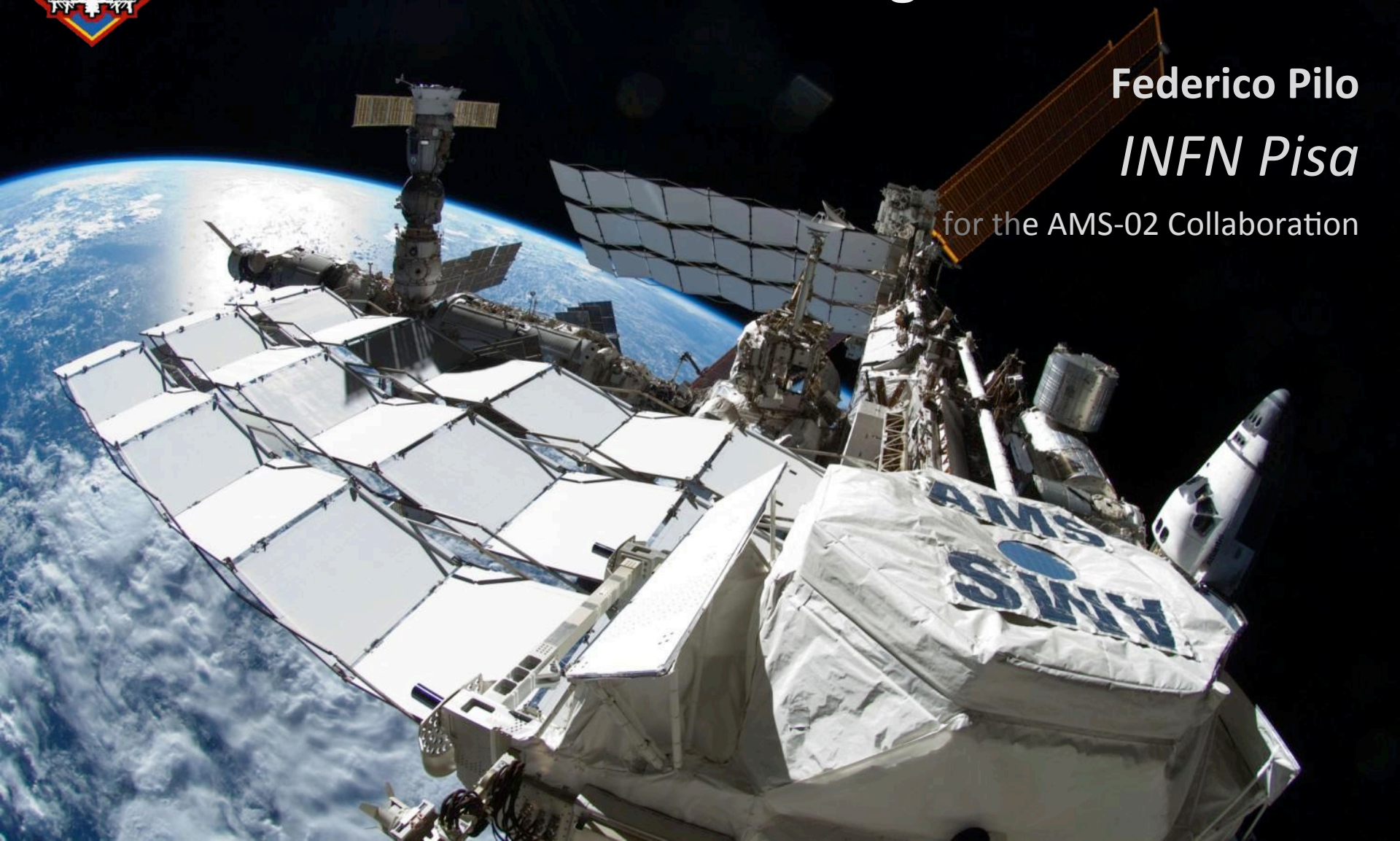
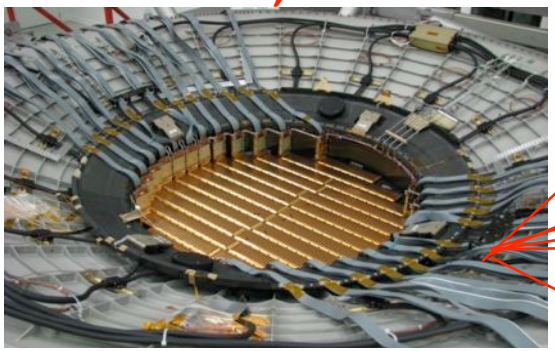
for the AMS-02 Collaboration



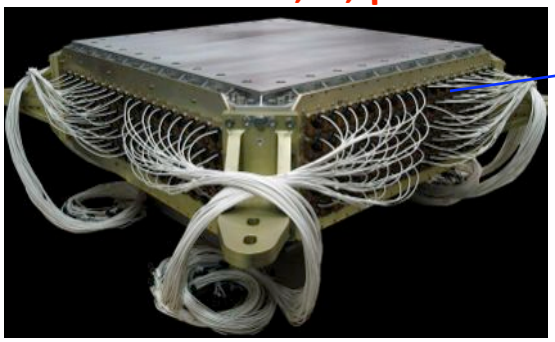
AMS: A TeV precision, multipurpose spectrometer

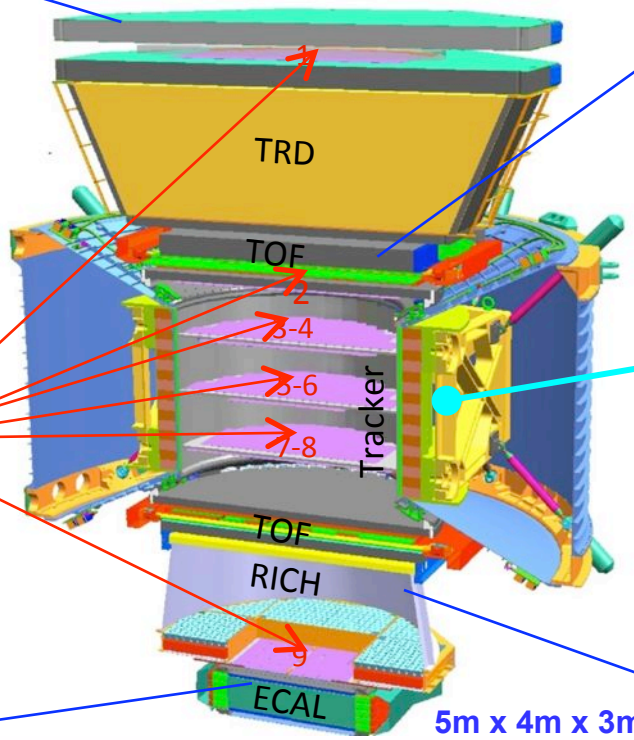
TRD
Identify e^+, e^-

Silicon Tracker
Z, P



ECAL
E of e^+, e^-, γ

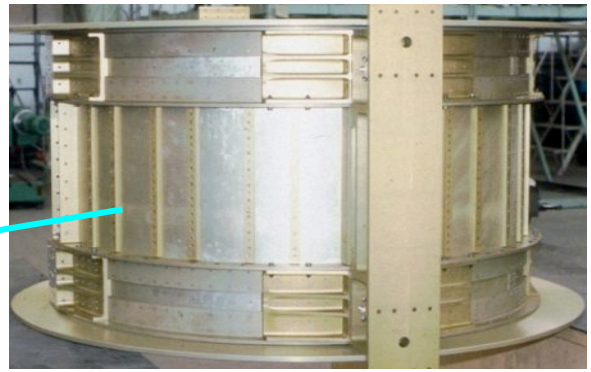




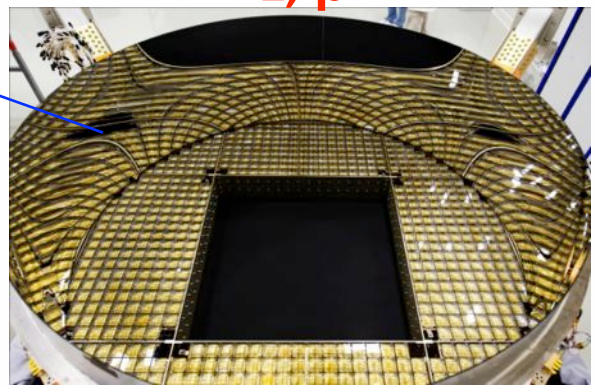
5m x 4m x 3m
7.5 tons

TOF
Z,β

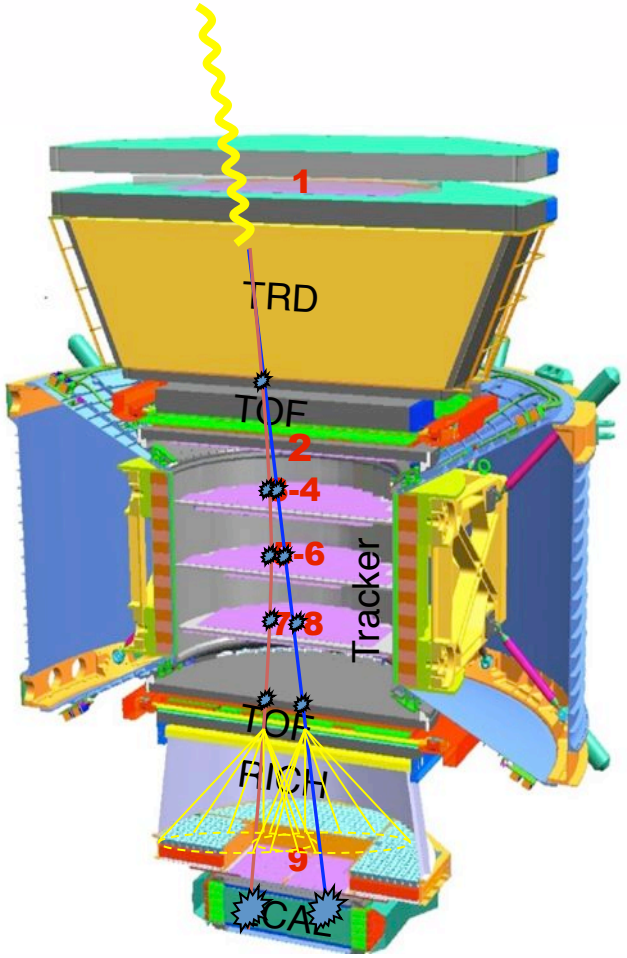
Magnet
±Z

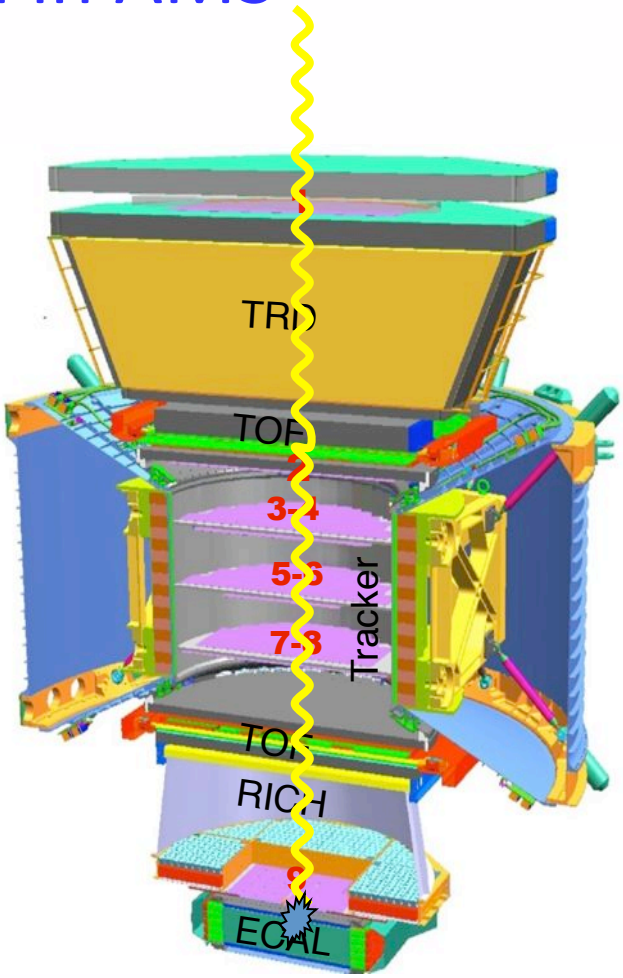


RICH
Z, β



Photon detection in AMS





Photon conversion

Direction (angle): from Tracker

Energy: from Tracker (and ECAL)

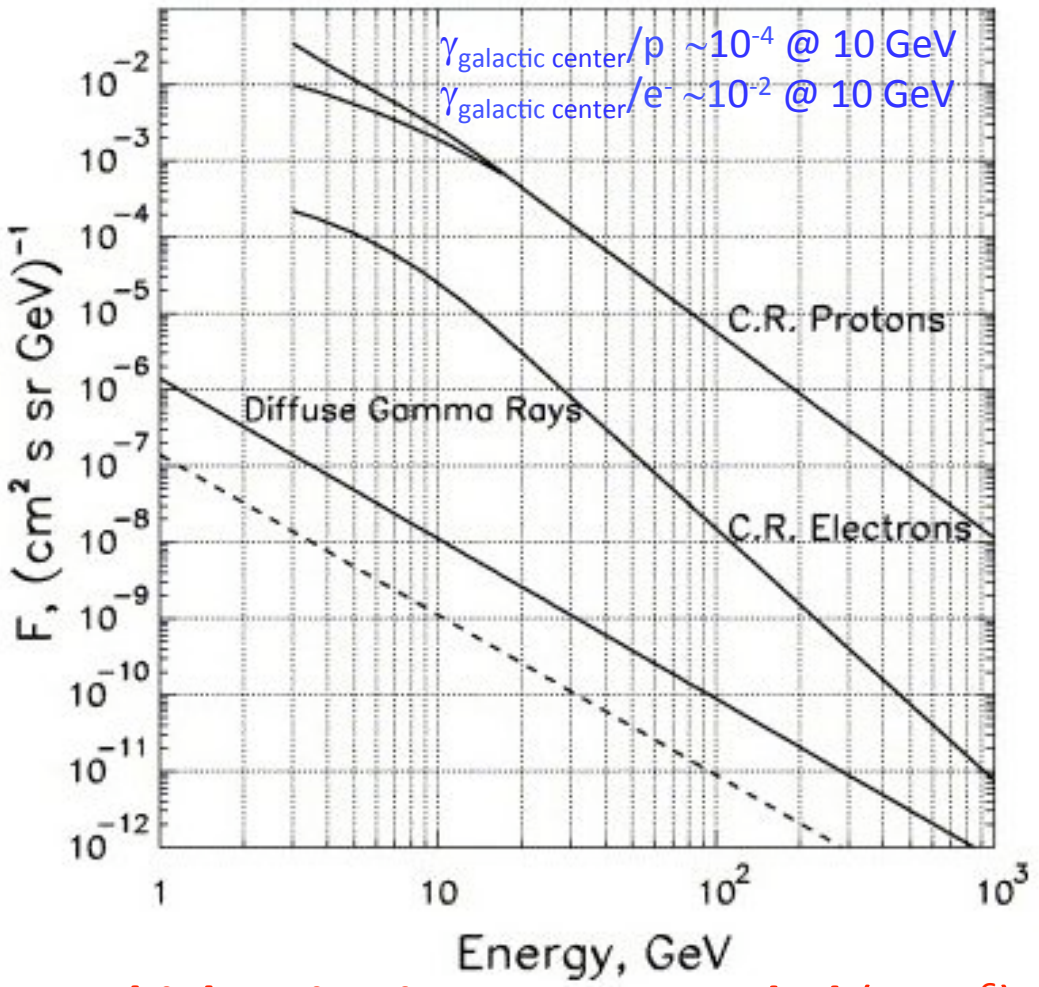
Single Photon (direct measurement)

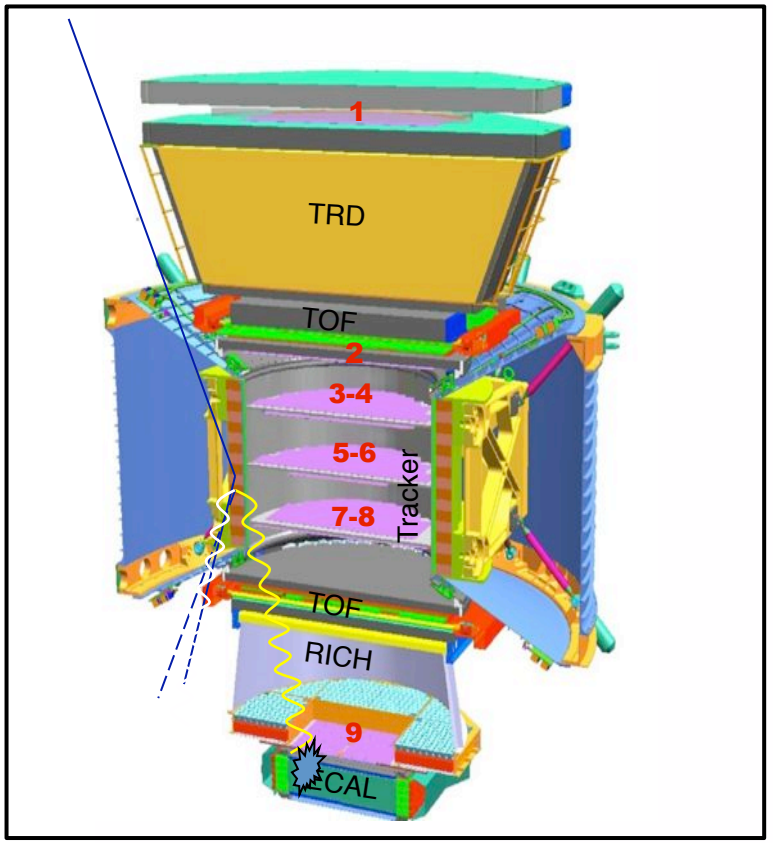
Direction (angle): from ECAL

Energy: from ECAL

Trigger: from ECAL

Backgrounds to Photon Identification





Background event: secondaries (π^0) from p interactions

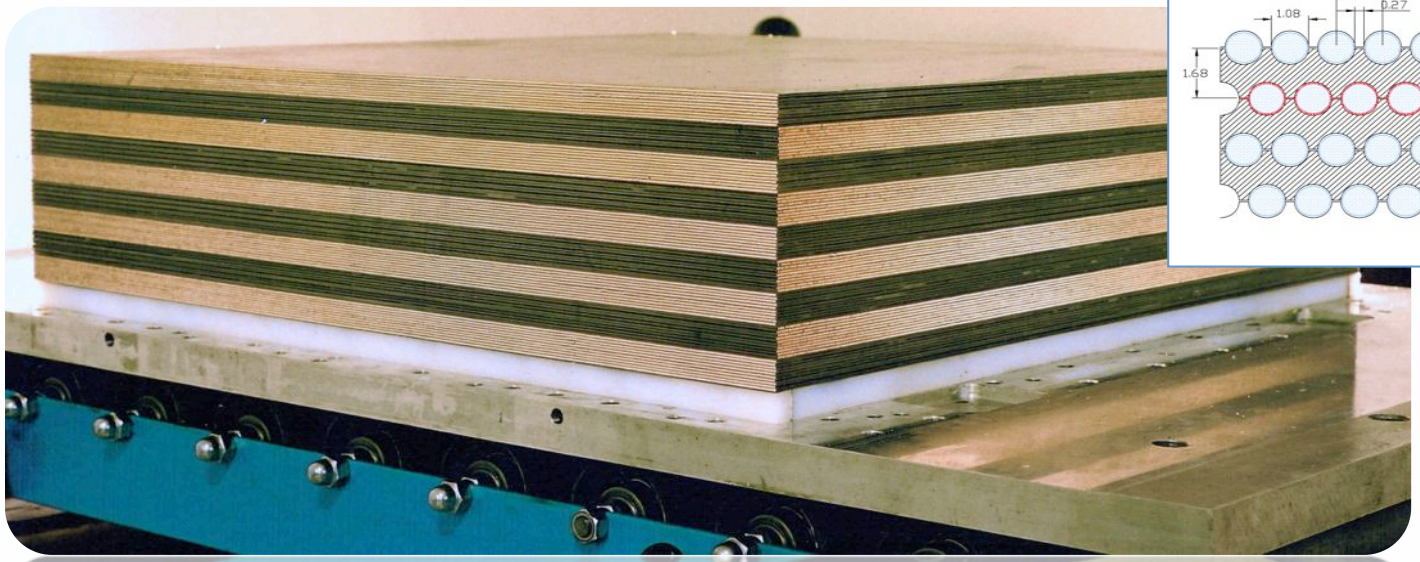
Very high Rejection power needed ($\sim 10^6$)

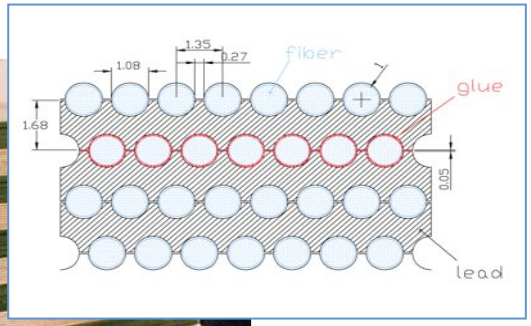
Using:

- electromagnetic/hadronic shower discrimination in ECAL
- γ direction inside AMS acceptance & NO activity in the other detectors

AMS-02 Electromagnetic Calorimeter

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

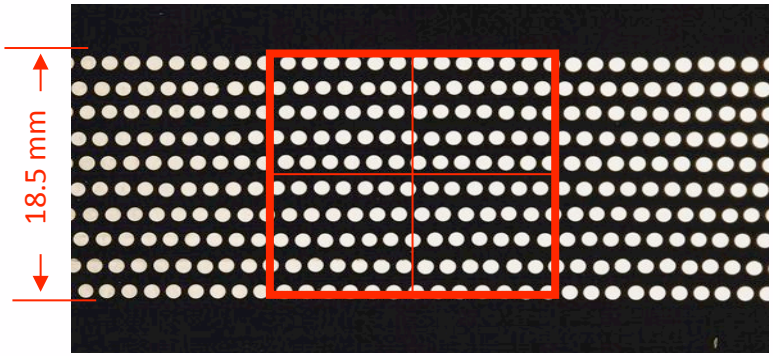




- Pb/scintillating fibers composite structure
  - 99 lead plates/>44000 scintillating fibers ($\phi = 1$ mm, PolyHiTech polifi 0244-100)
  - Volume ratio (Pb/fibers/glue): 59/34/7
- Dimensions : $658 \times 658 \times 166$ mm
- Weight: 489 kg

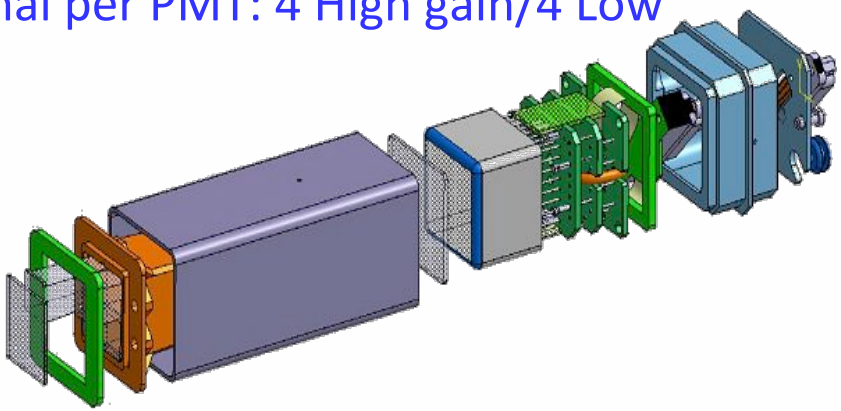
AMS-02 Electromagnetic Calorimeter

- Pile up of 9 Superlayers (5 in Y view, 4 in X)
- Radiation length (X_0): **9.8±0.2 mm**,
- Total thickness: **17.0±0.4 X_0**
- Interaction length: **~ 24 cm**



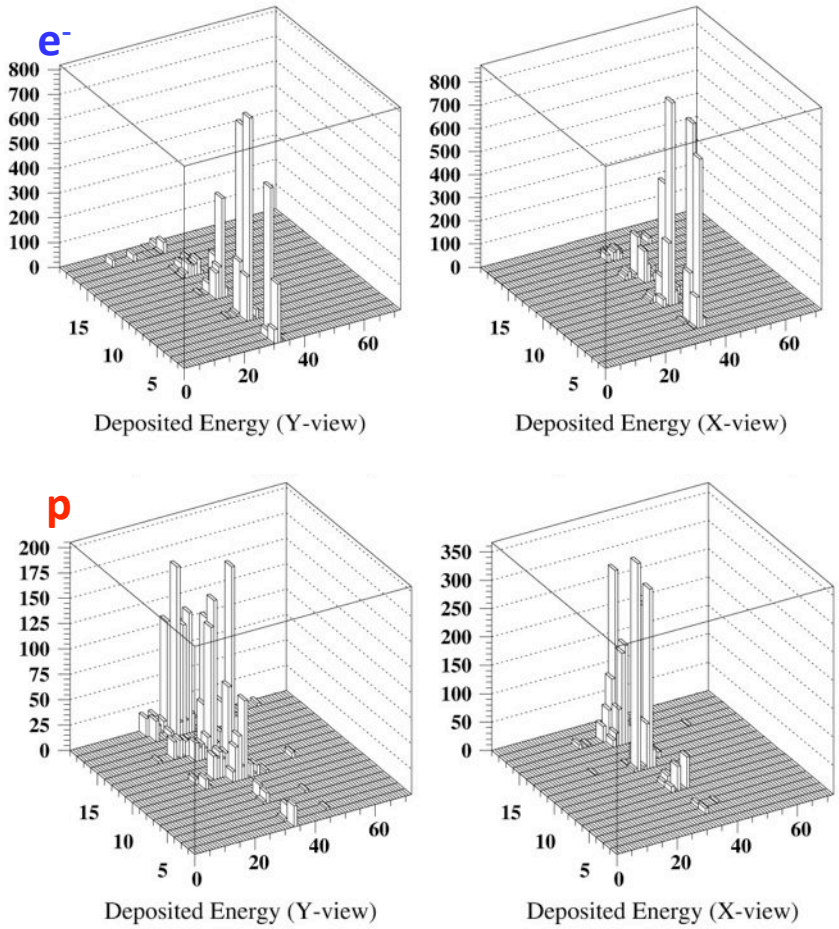
- Read-out granularity: 9×9 mm^2 (cell)
  - ~0.5 Moliere radius in X-Y, ~1 X_0 in Z
- **18 samplings in depth** (10 in Y view – B field bending plane, and 8 in X)
- 1296 cells (72 per layer), one-end SciFi read-out

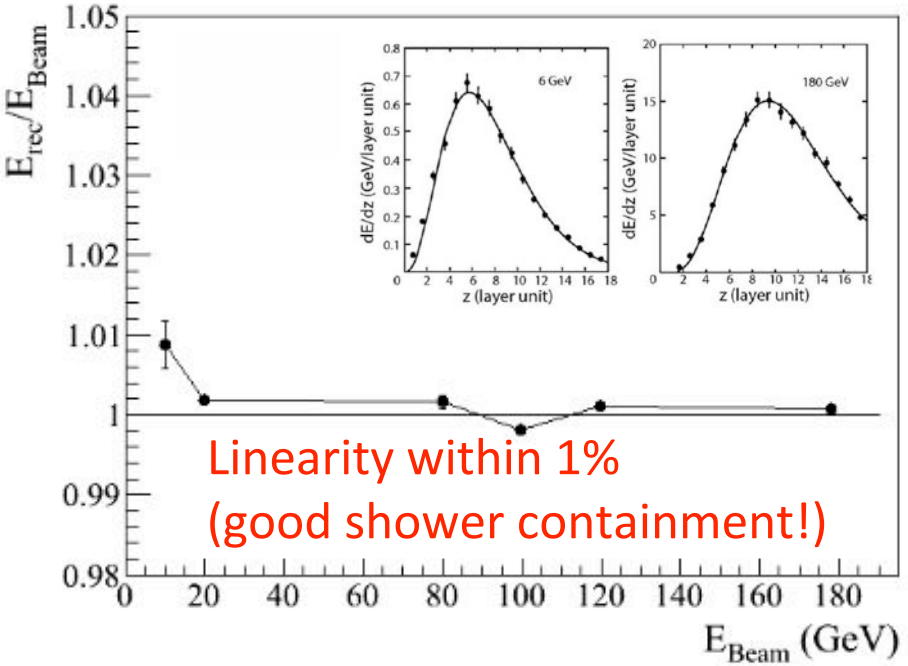
- To increase the dynamic range 9 Digital signal per PMT: 4 High gain/4 Low Gain + 1 Last Dynode
- The Analog signal from the Last Dynode is used in trigger

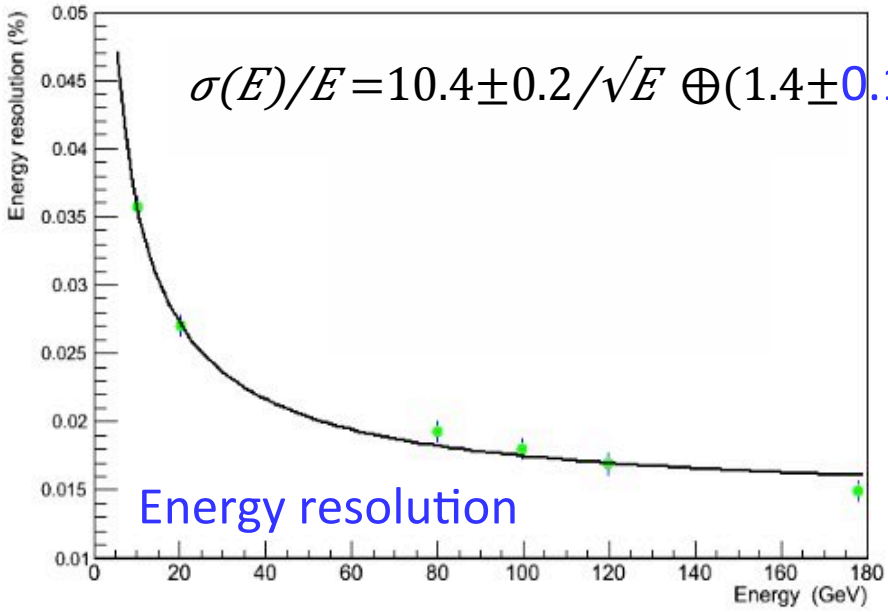


AMS in SPS Test Beam, August 2010 - ECAL Performances

3D Shower Imaging







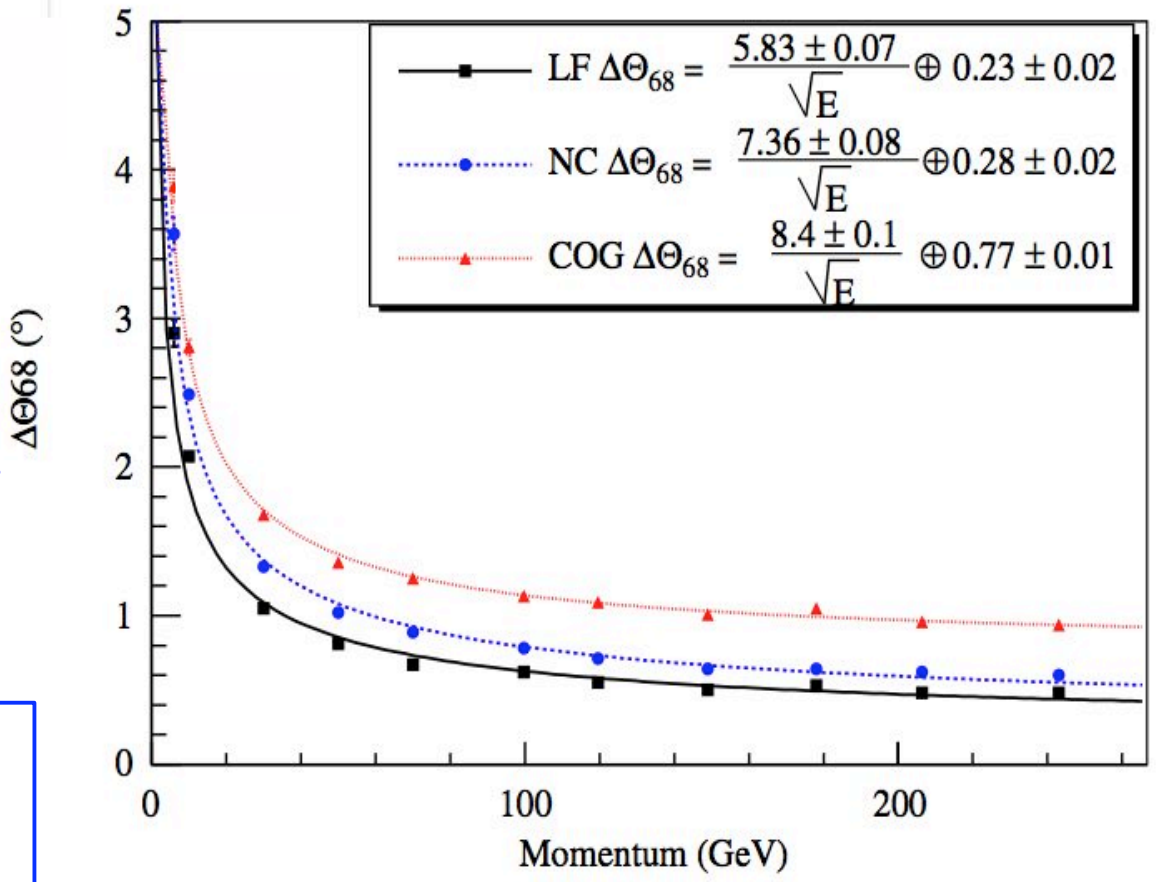
ECAL 3D Angular Resolution

The angular resolution is defined by the three-dimensional angular opening with respect to the incoming beam that contains 68% of the events
It is measured using Flight data (comparing the direction of electrons reconstructed by the ECAL with the one measured by the Tracker), Test Beam data (electron beam), MC photon samples

Three different algorithm:

1) *Center gravity Moment.* the energy weighted centers of the cells belonging to the shower
2) *Neighbor Cells .* the ratio of the energy deposited in the cells adjacent to the most energetic one as a function of the impinging position
3) *Lateral Fit.* Parameterization of lateral development

3 GeV: ~ 3.5 deg
10 GeV: ~ 2.1 deg
100 GeV: ~ 0.8 deg



ECAL Stand-Alone Trigger

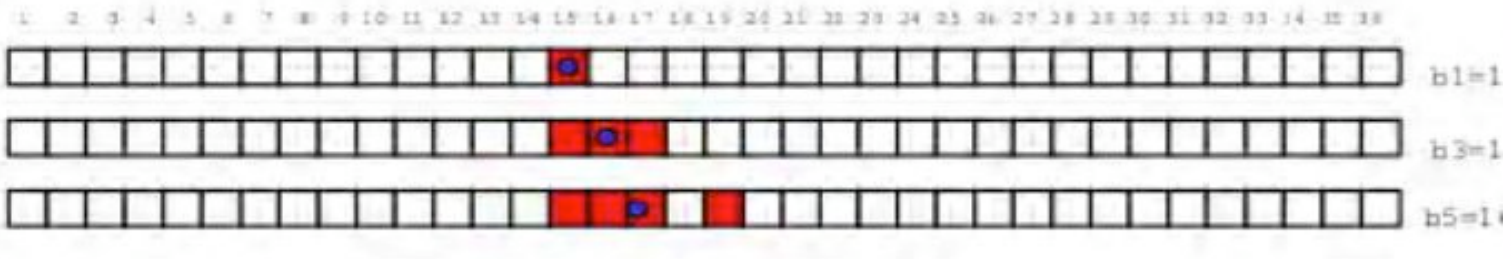
Design Specifications:

- **Efficiency: 100% for photons with E > 10 GeV; as high as possible down to the lowest possible energies**
- **Rate: LV1<100 Hz (<10% of AMS LV1 trigger rate)**
- High Robustness, low power consumption (15 W) and weight (<5 Kg)
- Timing: Fast Trigger signal within 180 ns; LV1 signal 650 ns after the Fast Trigger

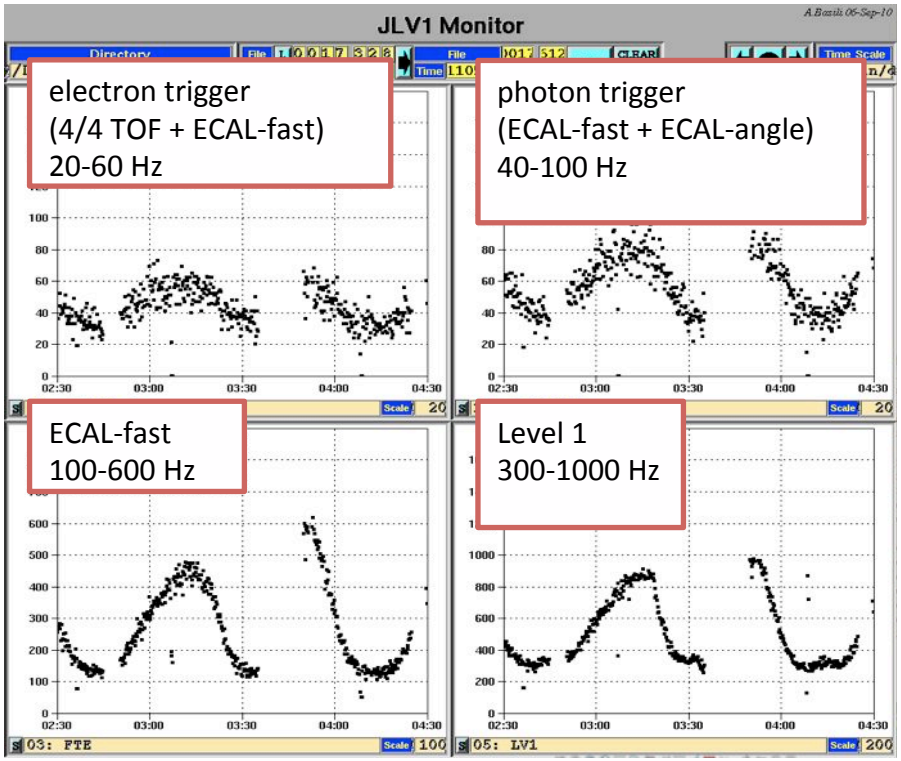
KEY features: Trigger Granularity of 1 PMT (i.e. Last Dynode signal) ⇒ good EM shower image reconstruction (1 PMT ≅ 1 Moliere Radius)

Two steps:

- Fast Trigger: fast decision provided by the count of PMT's above a selected threshold in central ECAL Superlayers (at least 2 out of 3 SL in each view must have at least 1 PMT above threshold)
- Level1Trigger: selection based on the incoming particle direction, using the distances between centers of gravity in SL belonging to the same view

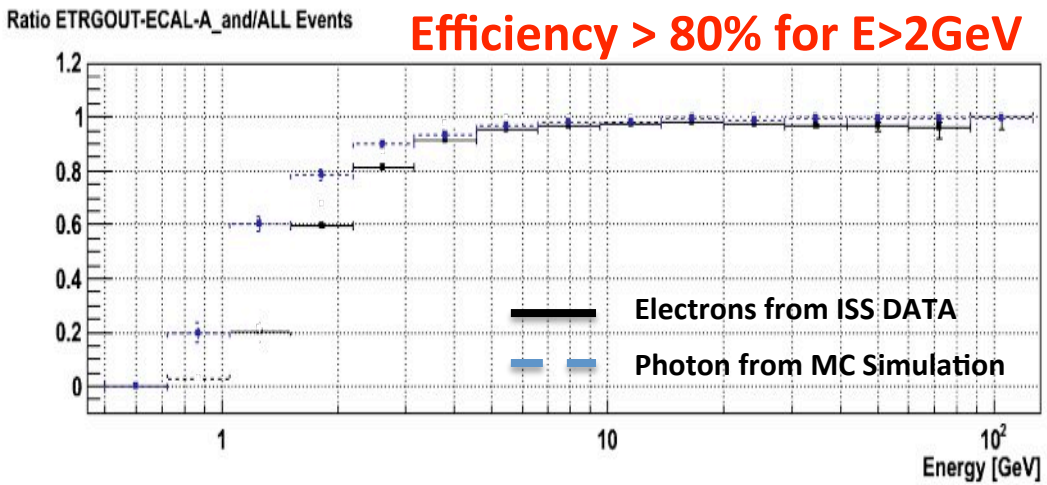


ECAL Trigger: In-orbit performances



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

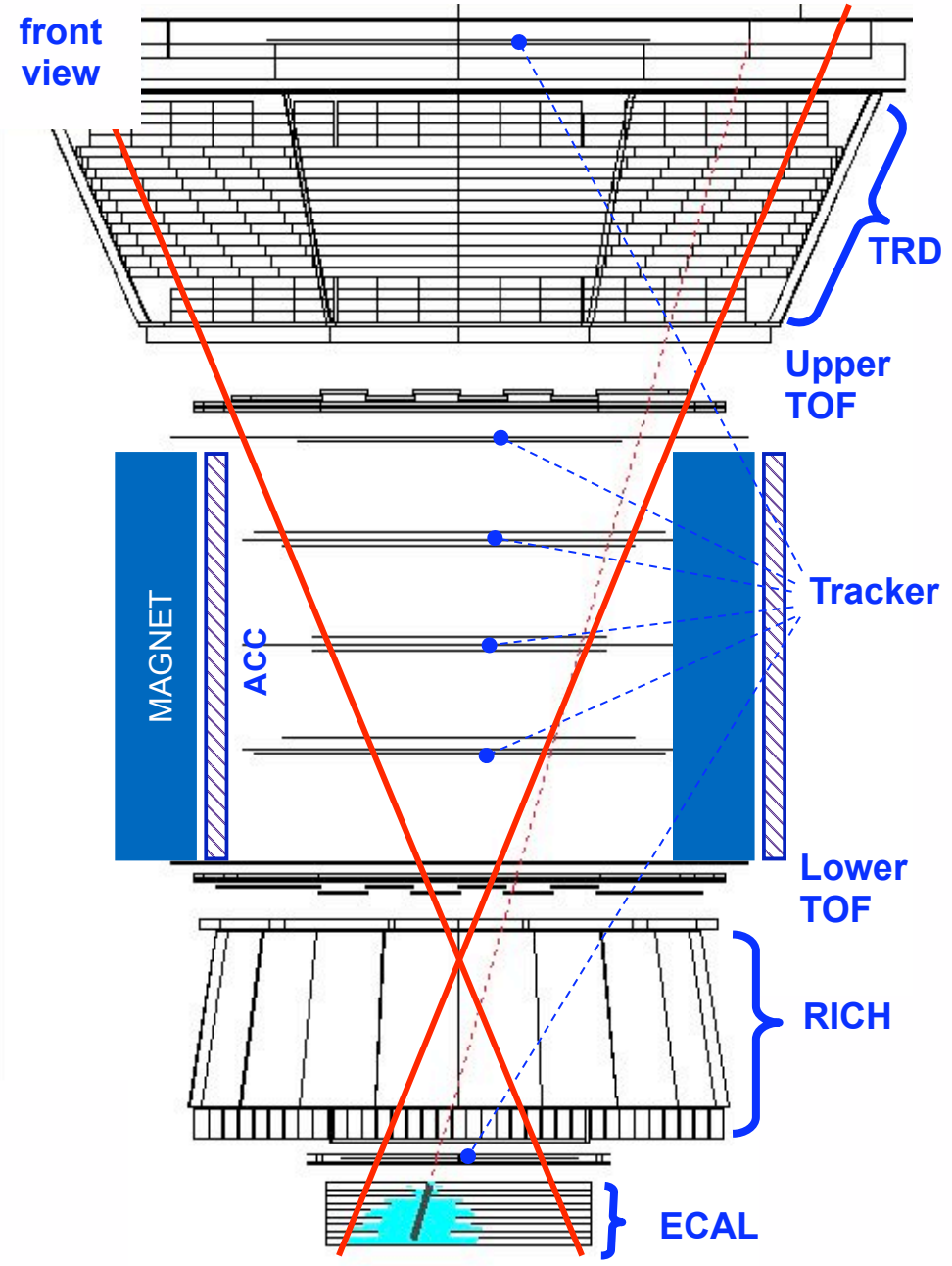
TRIGGER EFFICIENCY – It is calculated on a MC photon sample. The reliability of the MC simulation is verified comparing the efficiency curve on a MC electron sample with the one obtained from a Flight Data electron sample (TOF triggered, passing inside the ECAL acceptance)



Photon identification – Minimal Requirements

TRD
number of tracks <=2
Tracker
No reconstructed tracks
TOF
No reconstructed tracks (using all 4 layers)
ECAL
1 and only 1 shower

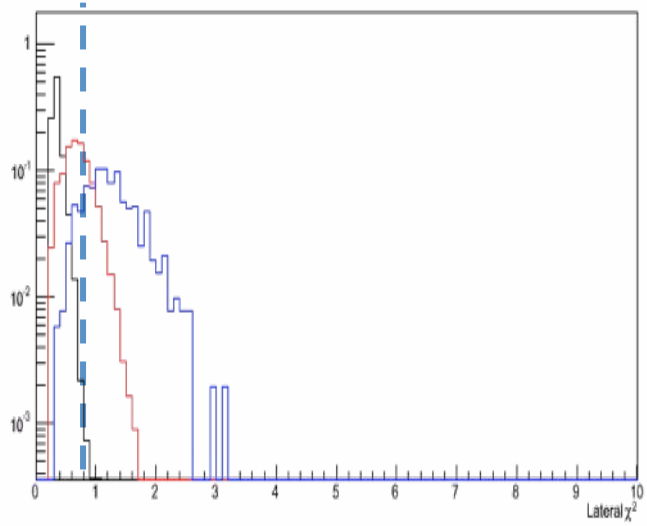
FIDUCIAL VOLUME
Reconstructed γ direction: - crosses last ECAL layer at least 1 PMT far from the edge - doesn't cross tracker support structure: r<50 cm @ z=50cm - reconstructed Θ <20°



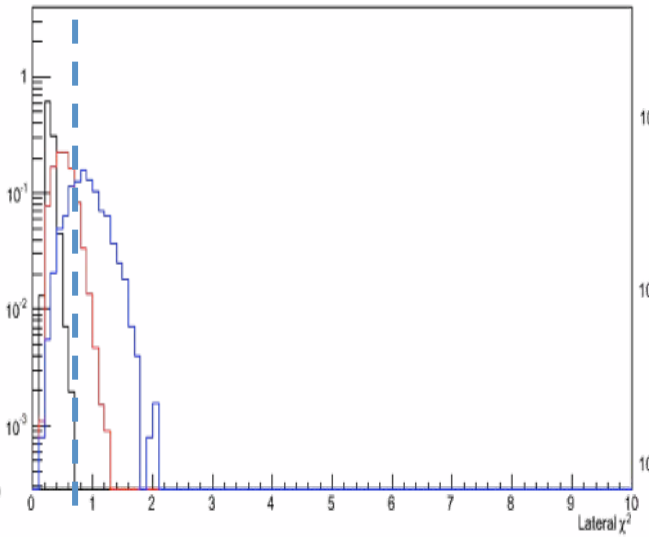
Electromagnetic Shower selection in ECAL

Many parameters regarding the longitudinal and the lateral shape of the shower are measured in order that reflect the differences between hadronic cascades and electromagnetic showers

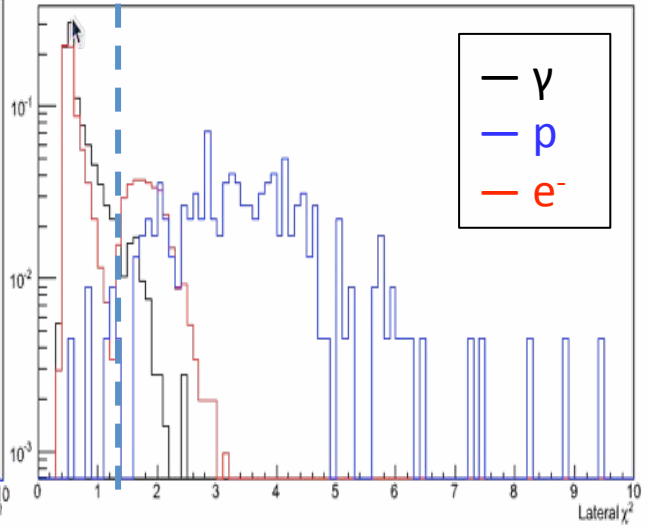
Exploiting the characteristics of the lateral shape: Lateral χ^2



E=4 GeV



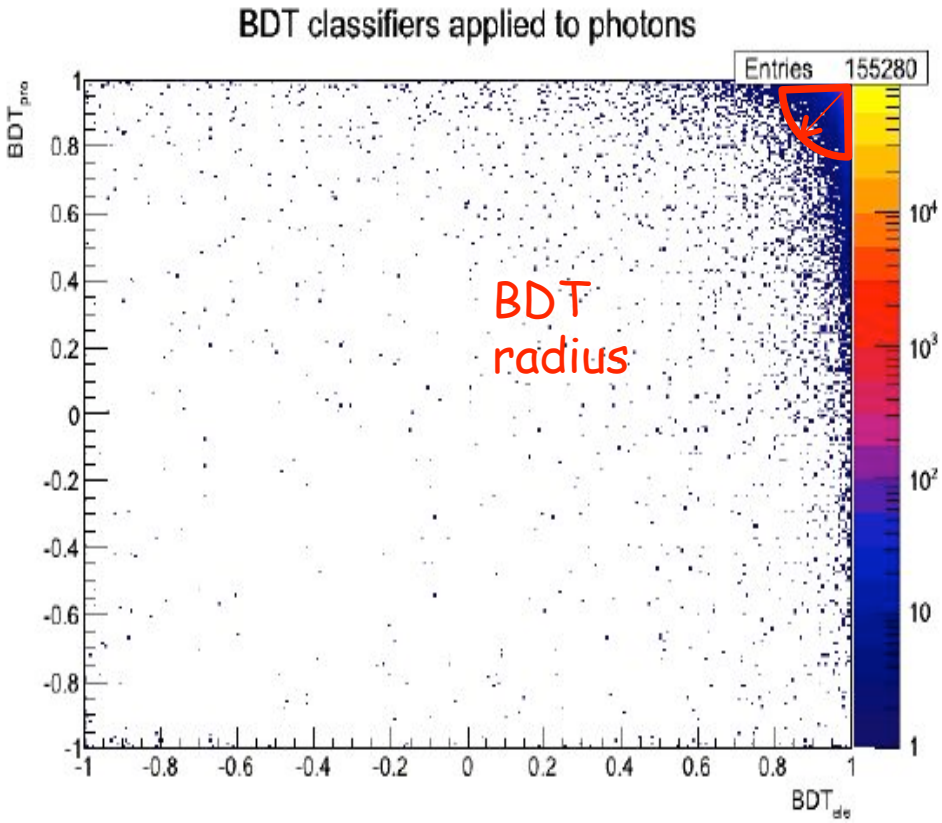
E=10 GeV



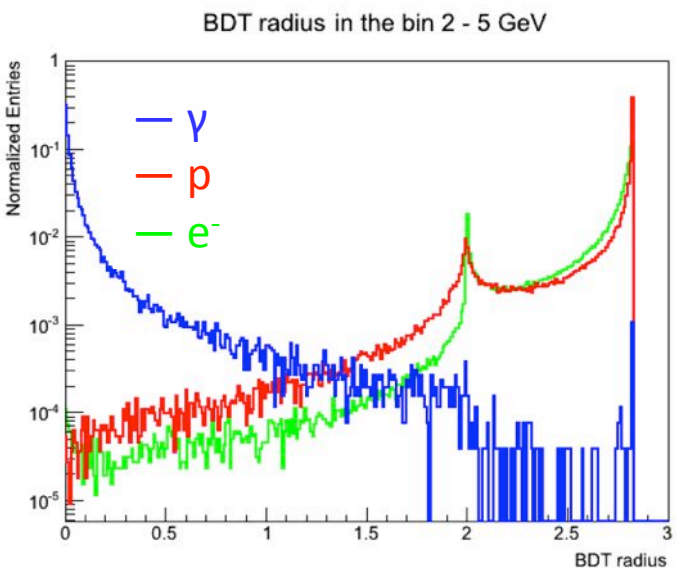
E=100 GeV

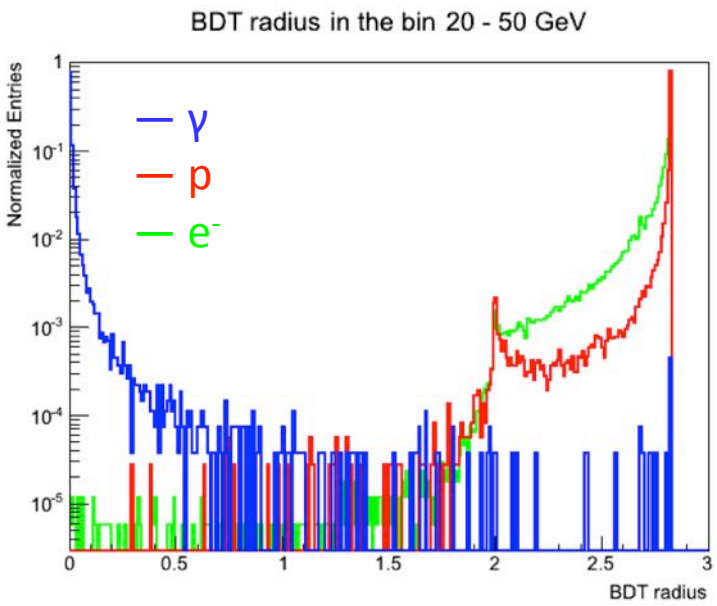
Candidate photon selection – BDT's

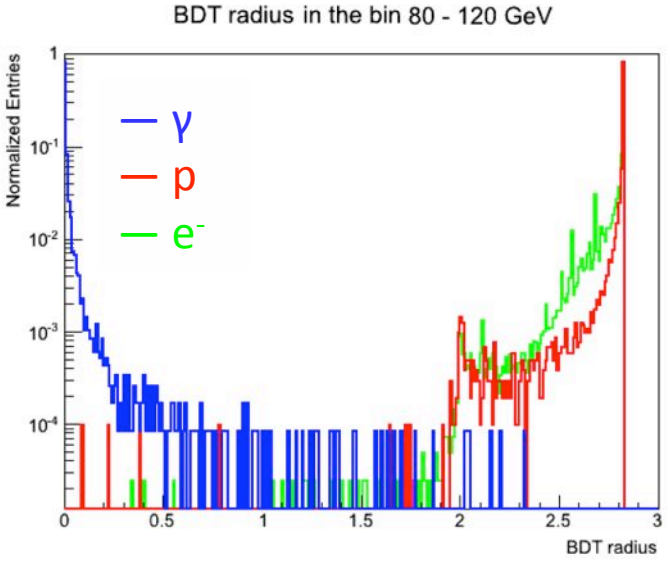
- 2 BDT classifiers are used to select photon events:
  - photons vs protons
  - photons vs electrons
- BDT's are a combination of:
  - variables describing the 3D electromagnetic shower shape in ECAL
  - variables measuring the activity in other AMS sub-detectors (like Energy deposit in the 4 TOF layers, time difference between the TOF hits closest to shower axis in the 4 TOF layers, TRD tracks and minimum TRD track distance from shower axis)

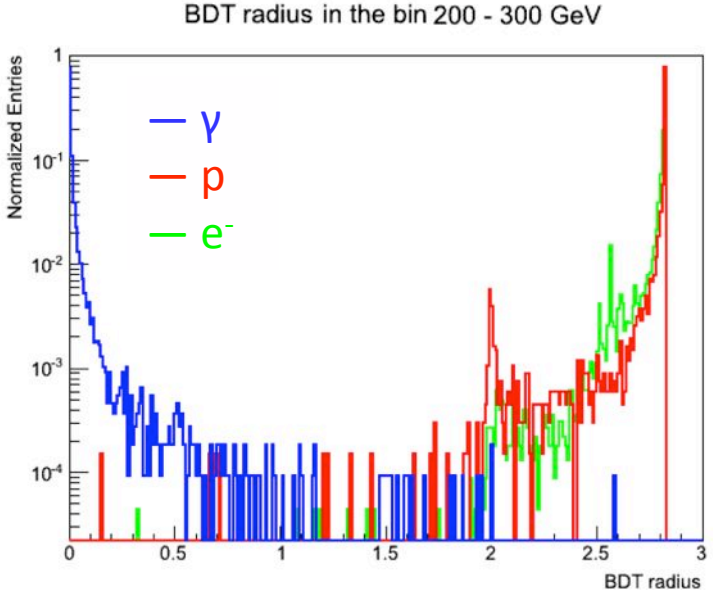


BDTs combined ("BDT radius")

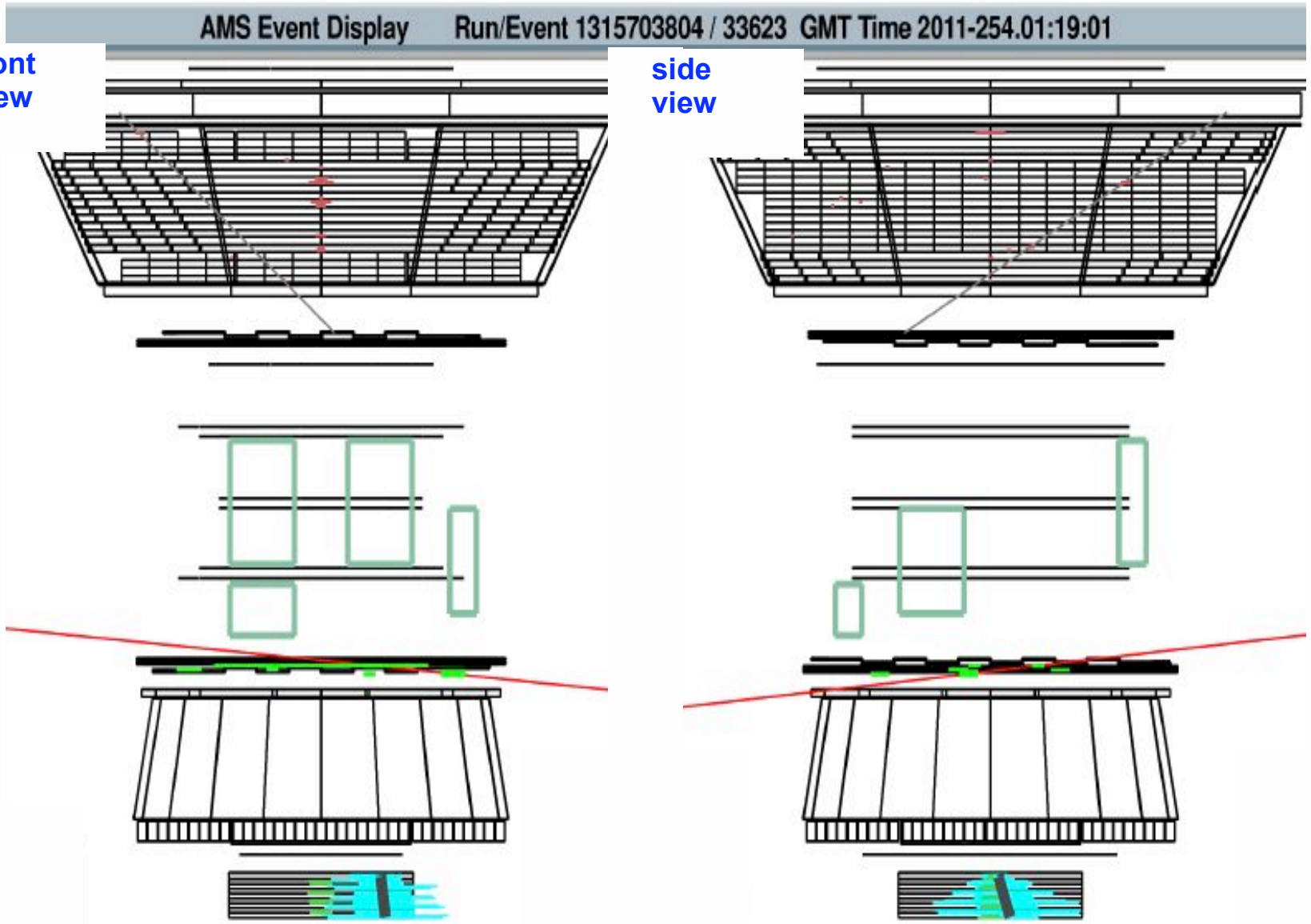




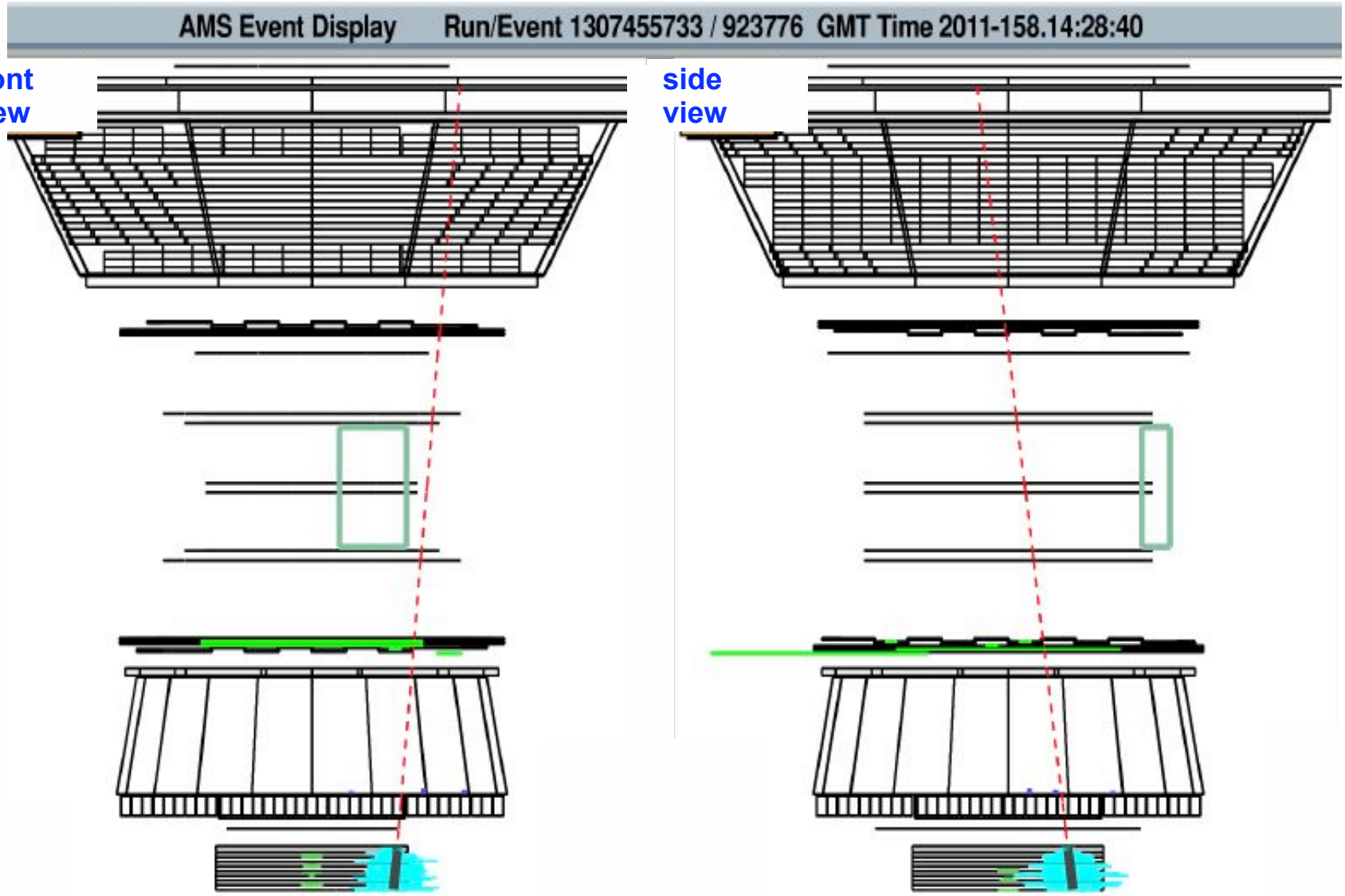




Photon E=253 GeV



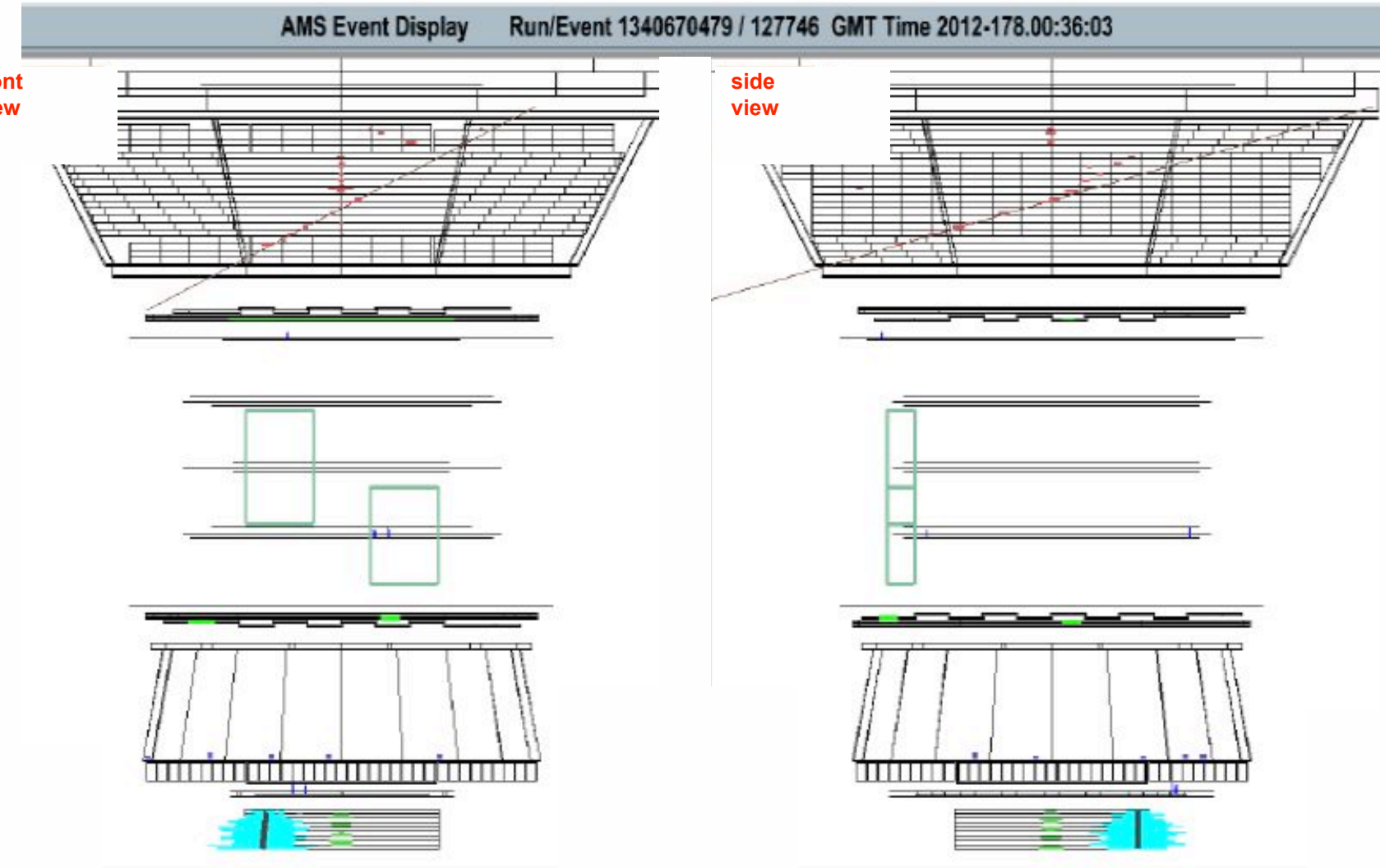
Photon E=676 GeV



REJECTED EVENT

by cuts on the shape of the shower longitudinal profile in ECAL

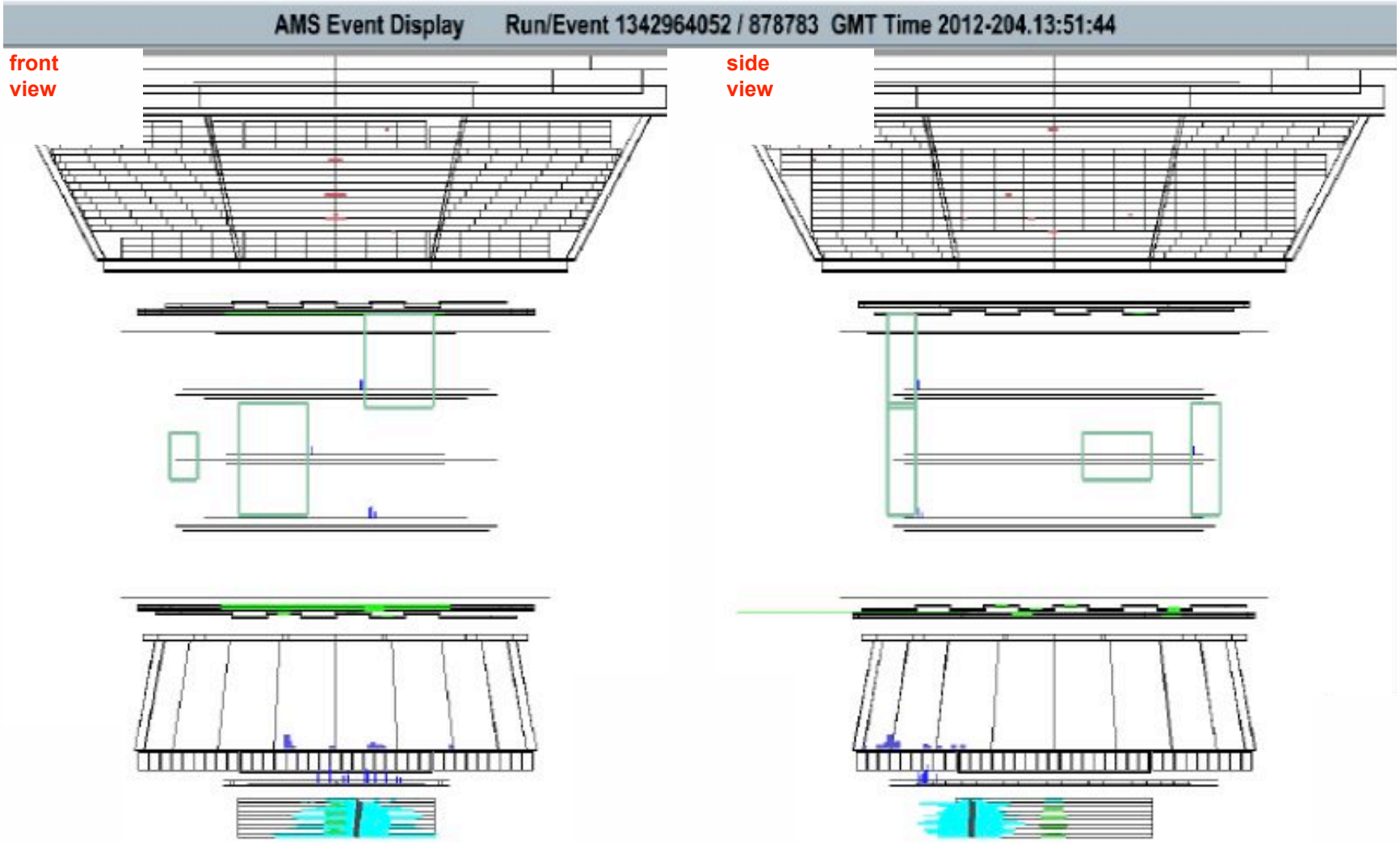
E=468 GeV



REJECTED EVENT

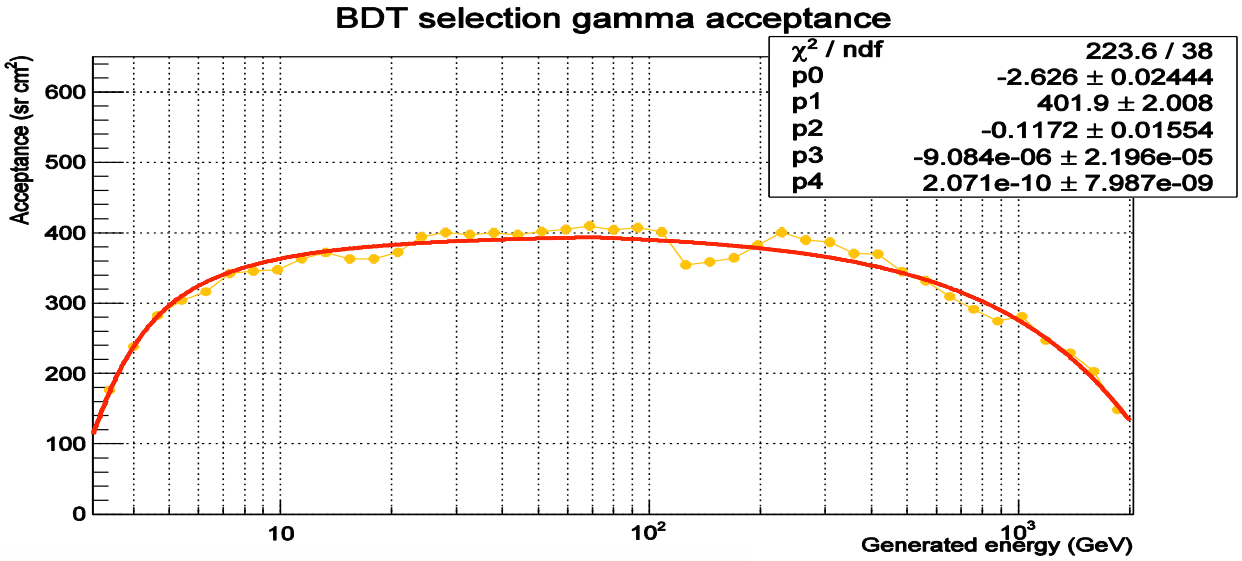
by cuts on the shape of the shower longitudinal profile in ECAL

E=864 GeV

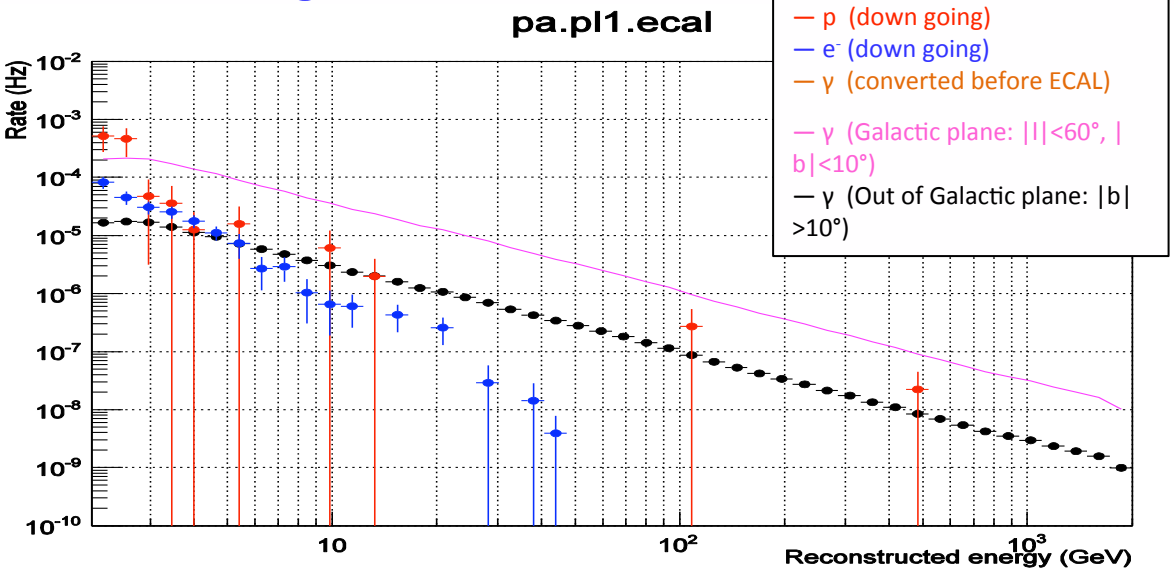


Acceptance and Background Rates

Differential acceptance as a function of the photon energy



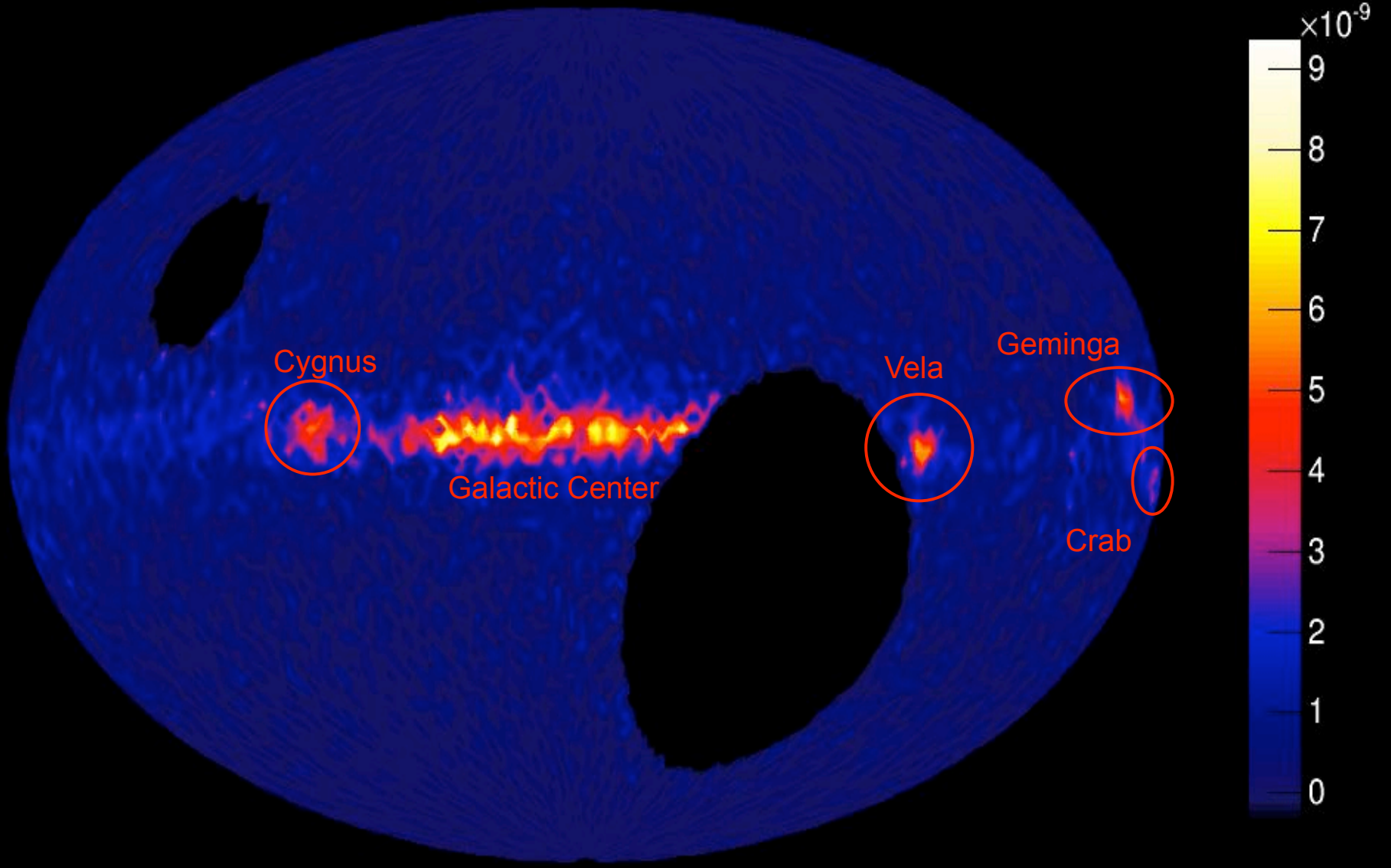
Residual background rates



Even considering the feeble flux out of the galactic plane the expected **contamination above 30 GeV is lower than 10%**: it's possible to look at the high energy gamma sky and search for high energy sources

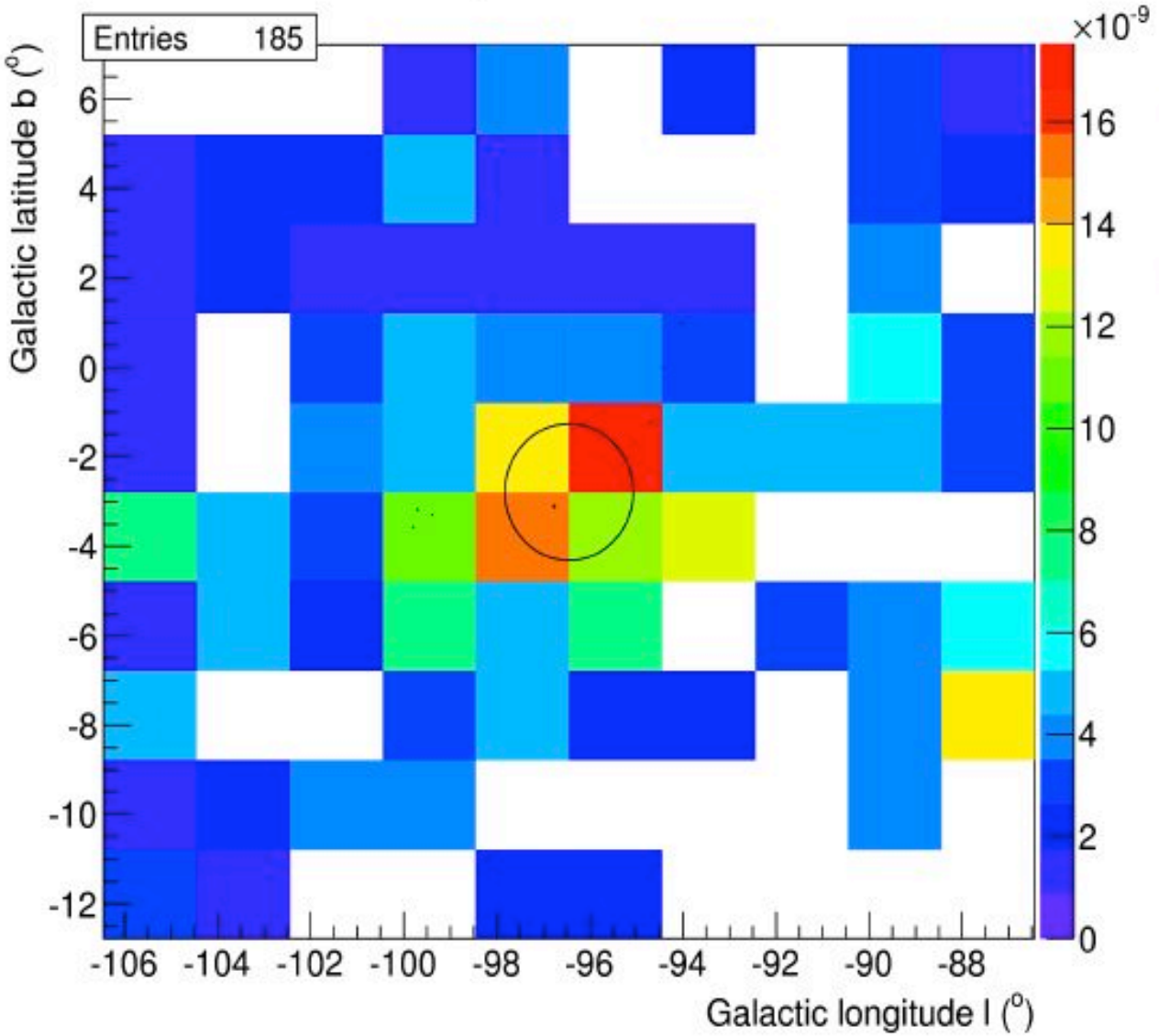
! Geomagnetic cut-off not considered: overestimated background below ~10 GeV

Gamma all-sky map for E>5 GeV



The Map is obtained for a period of 2 year of data taking, correcting for the exposure of the instrument (i.e. the effective area convoluted with the detection live-time)

Pointing accuracy: Vela (3<E<10 GeV)



DIFFERENCE FROMFERMI LAT2YEARS CATALOG

Δl=-0.4±0.5

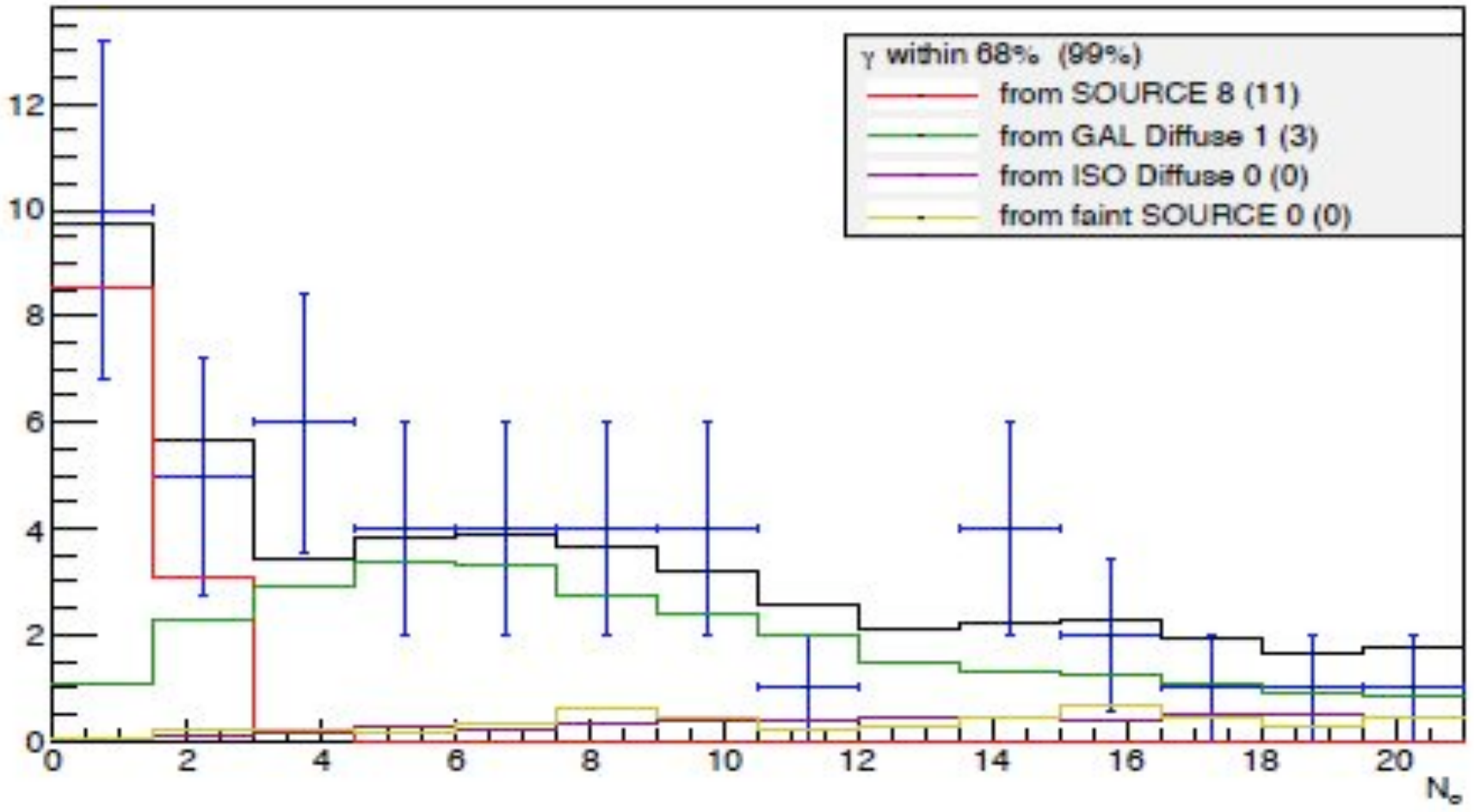
Δb=-0.3±0.3

σ(l)=3.0±0.7

σ(b)=1.9±0.3

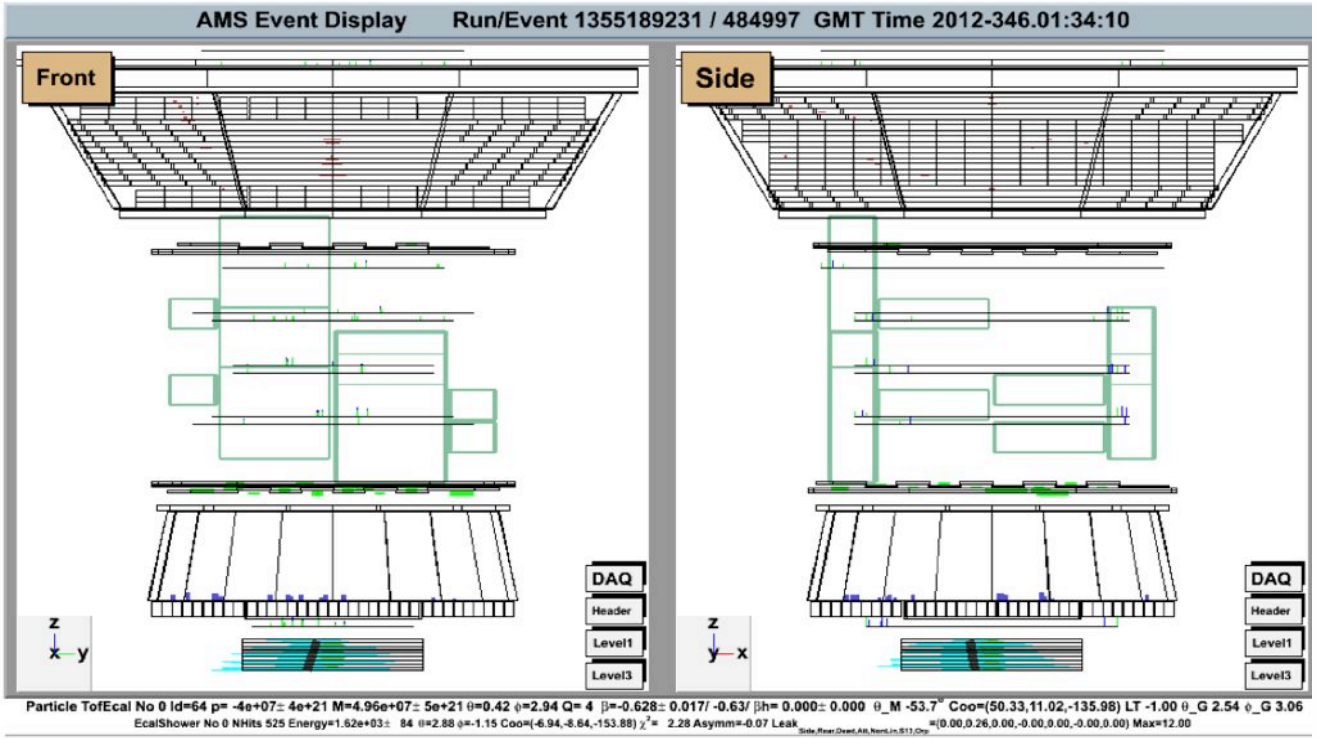
ΔΘ ~ 3.5° as expected (included error of position and orientation of AMS)

High energy γ from known sources

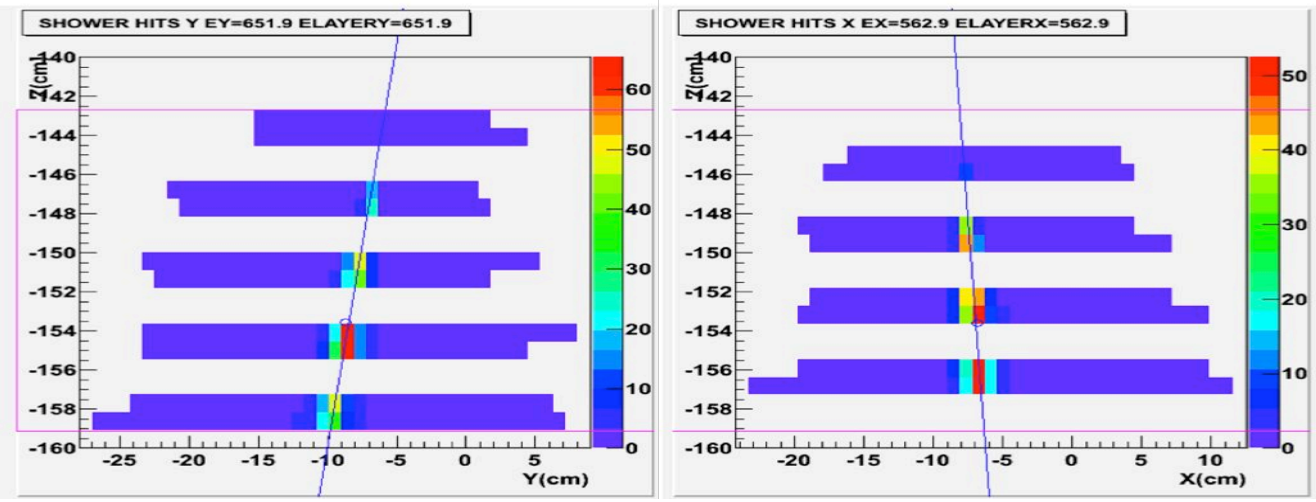


Distance in number of σ (error in the incoming direction reconstruction) from nearest sources for candidate photons of E_γ>100 GeV compared to the same distribution for various type of γ rays

A 1.7 TeV photon ?

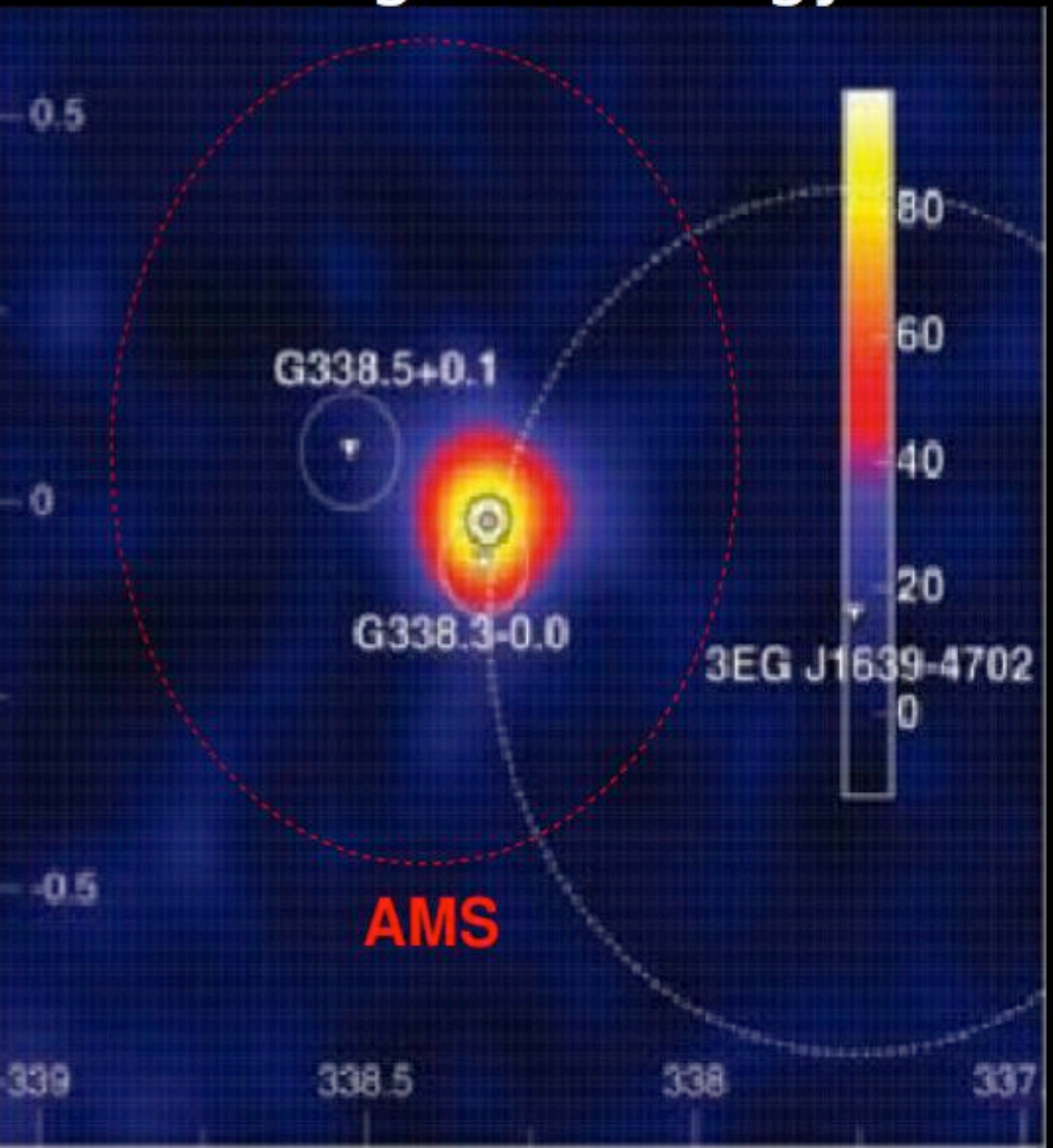


No hits correlated with the ECAL shower axis



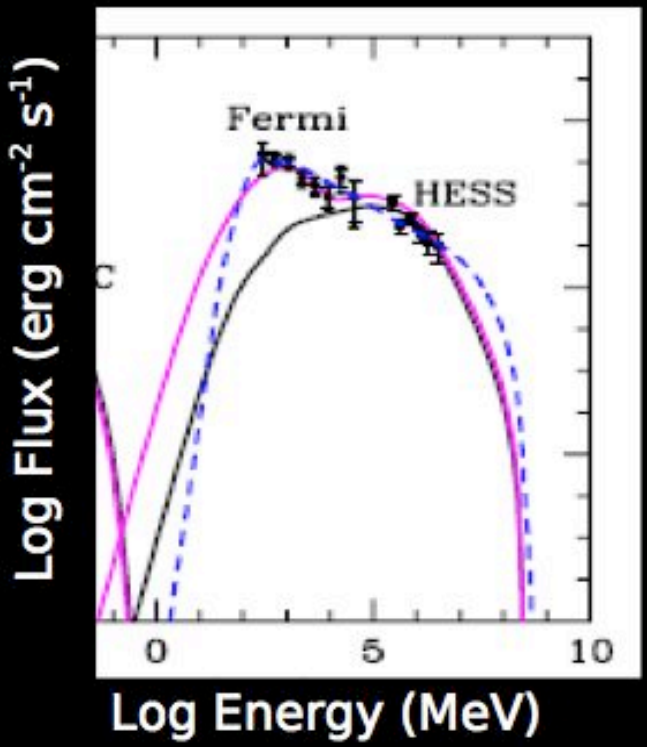
Good electromagnetic shower in ECAL

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°



Summary

AMS-02 is able to detect high energy photons thanks to its 3D imaging calorimeter

Despite its small acceptance, AMS is capable of providing significant measurements of HE γ-ray fluxes reaching the TeV region, up to now covered by ground based Cherenkov telescopes

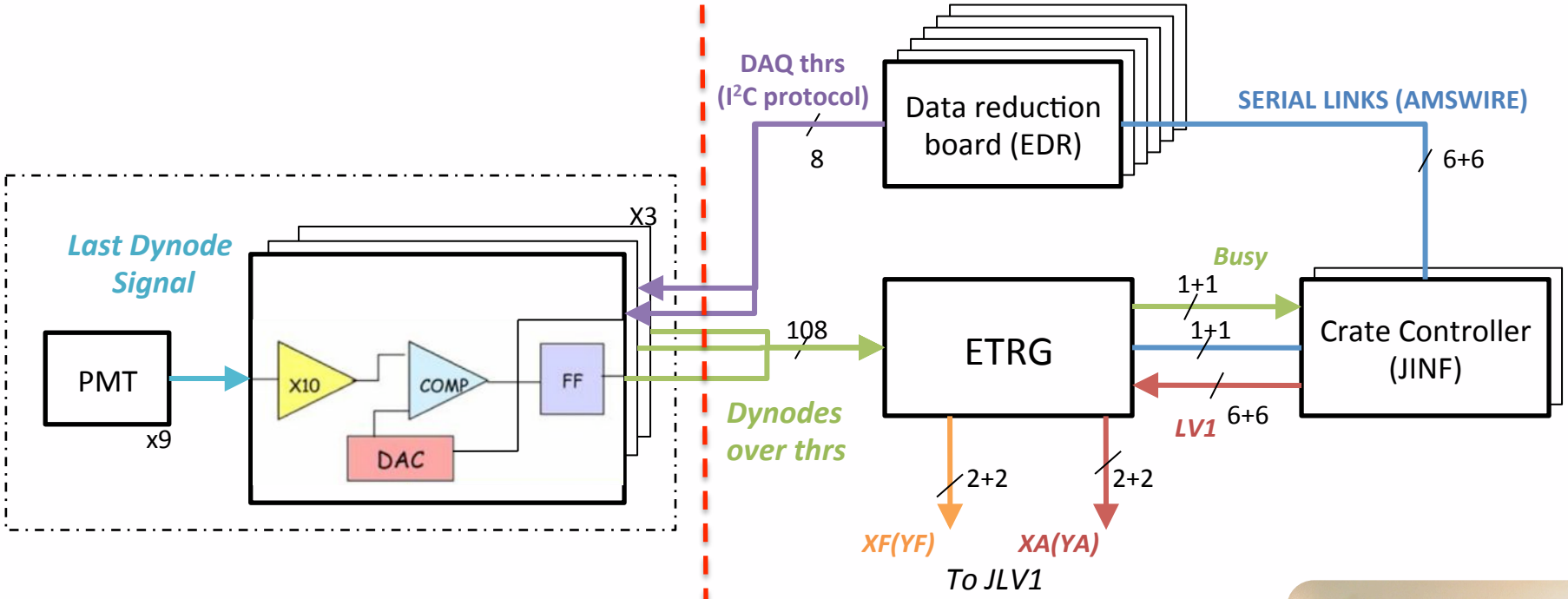
Lot of work in progress to improve data reconstruction (most of efforts concentrated on the e/p rejection power and the reconstruction of the particle incoming direction)

Data collected in the first years of mission are very promising:

- **the calorimeter works as expected with >80% trigger efficiency for 2 GeV photon**
- **Measurement of γ diffuse spectrum ongoing**
- **High energy γ rays emitted by known sources are clearly detected; with larger statistics AMS is potentially capable of identify new very high energy γ sources**

Spare slides

ECAL Trigger: hardware implementation

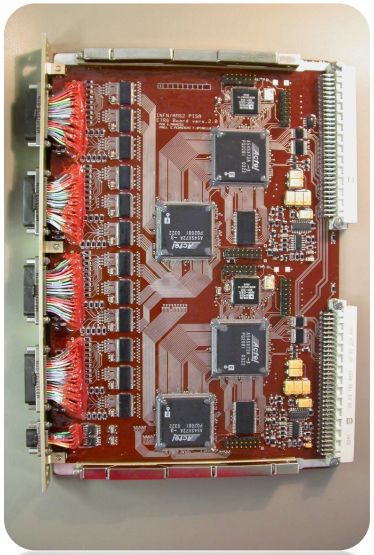


ANALOG SECTION

- PMT last dynode signal is fed to a comparator (Maxim MAX976)
- Comparator threshold is set using a 12 bit DAC: 1 DAC count ≈ 0.488mV
- 1 threshold setting per Superlayer (36 PMTs)
- 108 Hits recorded in the ETRG event

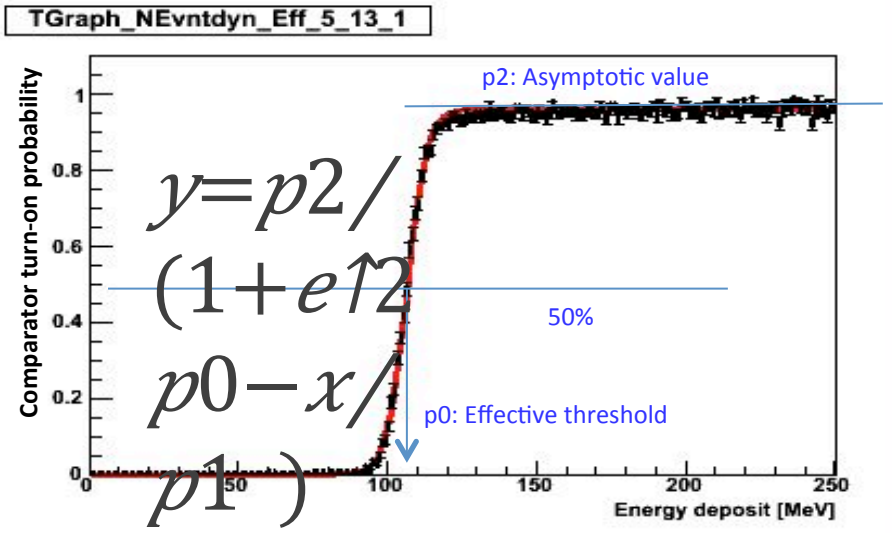
DIGITAL SECTION: ETRG BOARD

- Collects "dynode over threshold" signals related to one projection(X or Y)
- Performs trigger algorithm computations (according to the defined trigger strategy) and send the final decision to the main AMS Trigger board (JLV1)



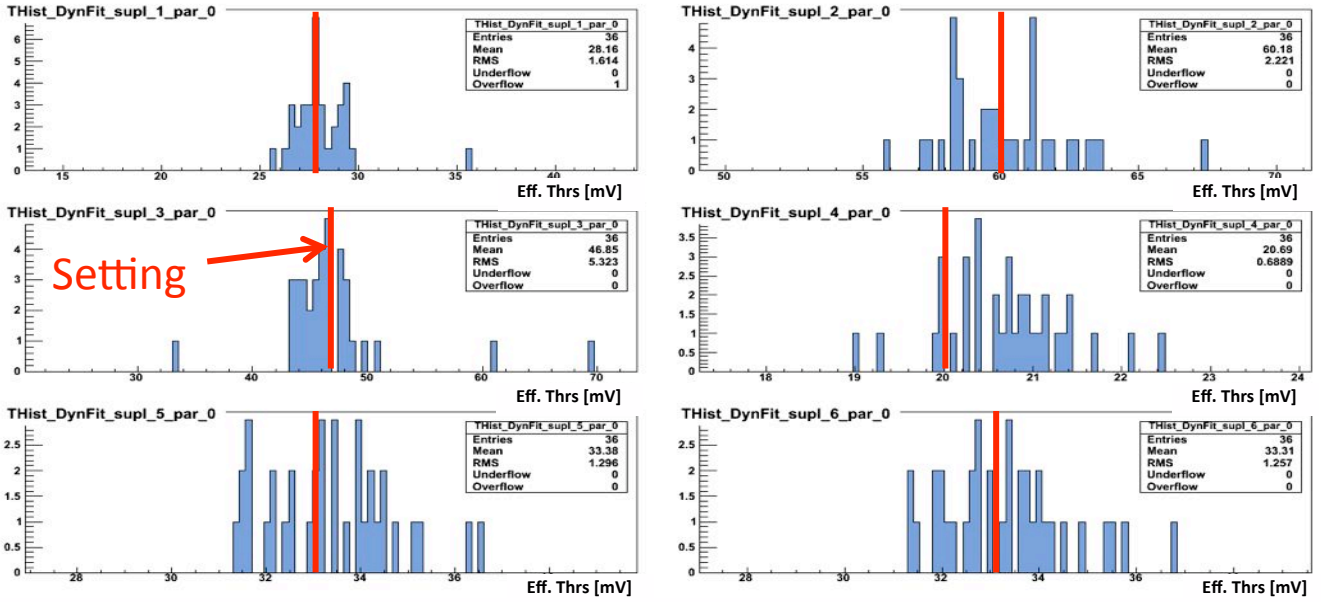
ECAL Trigger: In flight performances

From on-line monitoring it's possible to fit the transfer functions of the comparators

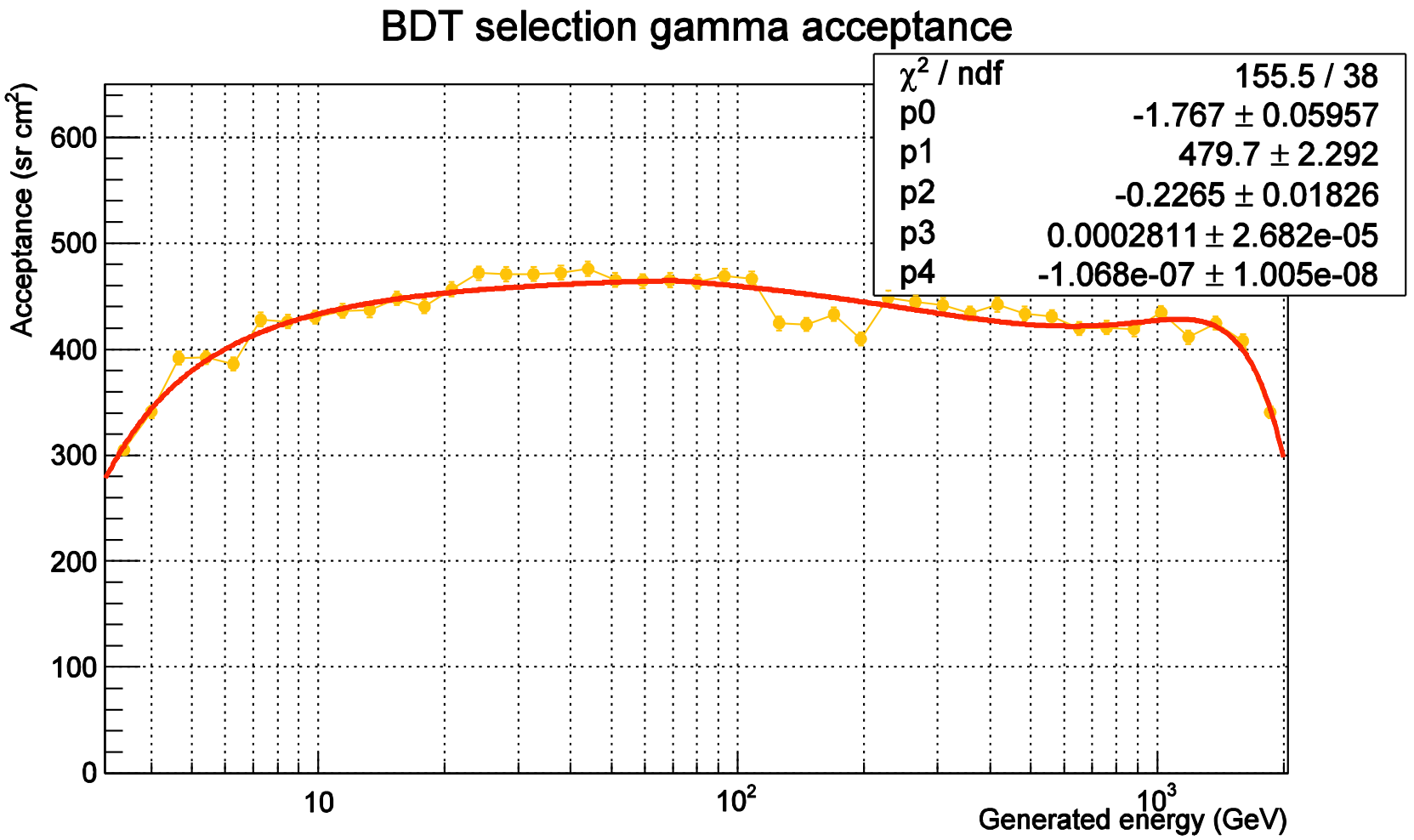


Superlayer ID	Threshold Setting	Effective Threshold (mean)
1	26,84	28,16
2	60,02	60
3	46,85	46,85
4	20	20,69
5	33,18	33,38
6	33,18	33,31

Measurements from Dynode signal height (mV)

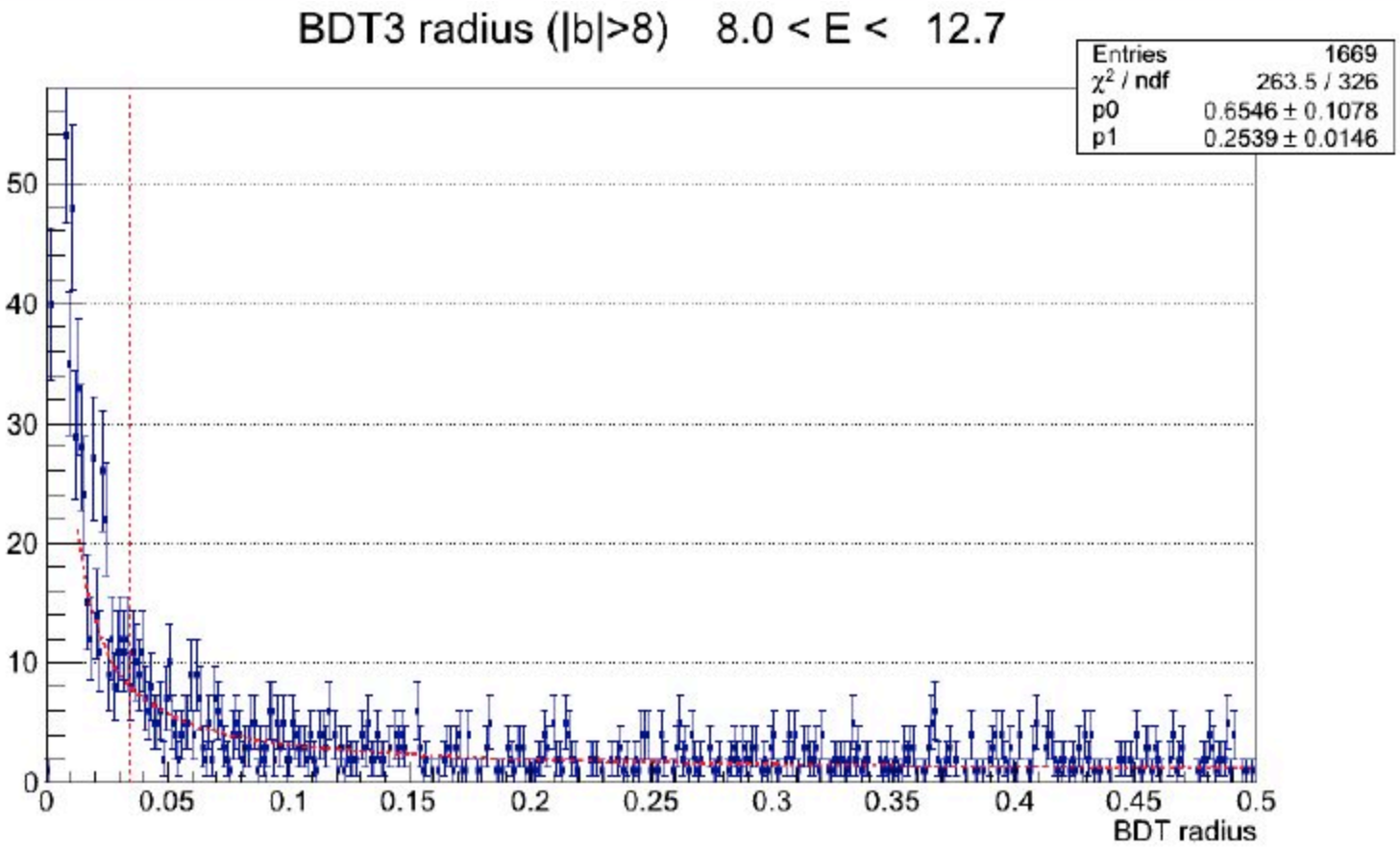


Acceptance for gamma after BDT cut (without TRD)



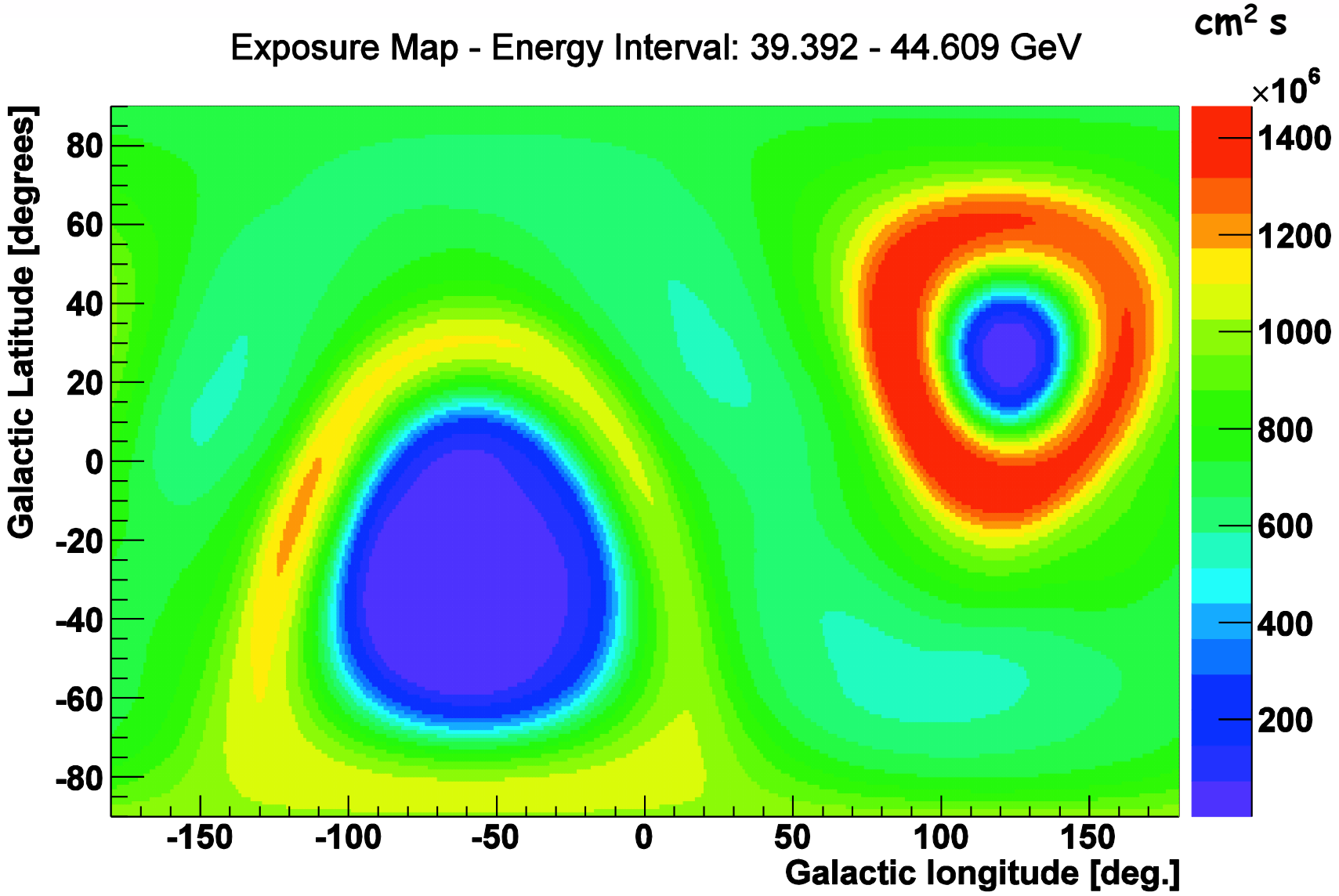
Fermi acceptance is quoted as 20000 sr cm3 below 100 GeV,
Decreases with energy due to worse identification capability

Background subraction from Data



Plateau is subtracted under the signal peak.
Converted photon contribution to plateau is negligible

Exposure map for a given energy bin: Contain Acceptance and Time



Gamma from Sources above 27 GeV