Search for Antiparticles in Cosmic Rays in Space and the Earth's Atmosphere

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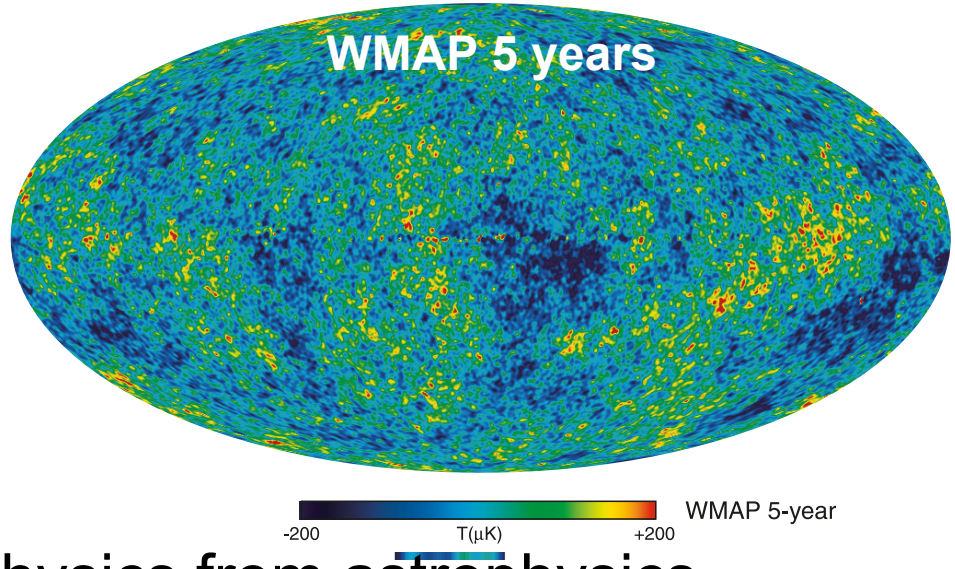
Overview

- cosmic ray physics in the GeV-TeV range
- the **AMS-02 detector** for the ISS in **Space**:
  - anticoincidence counter
    - qualification of hardware
    - integration
    - analysis
  - prospects for AMS-02
- the **PEBS detector** in **Earth‘s atmosphere**:
  - properties of Earth‘s atmosphere and magnetic field
  - simulation of cosmic ray measurements at the Southpole
  - prospects for PEBS

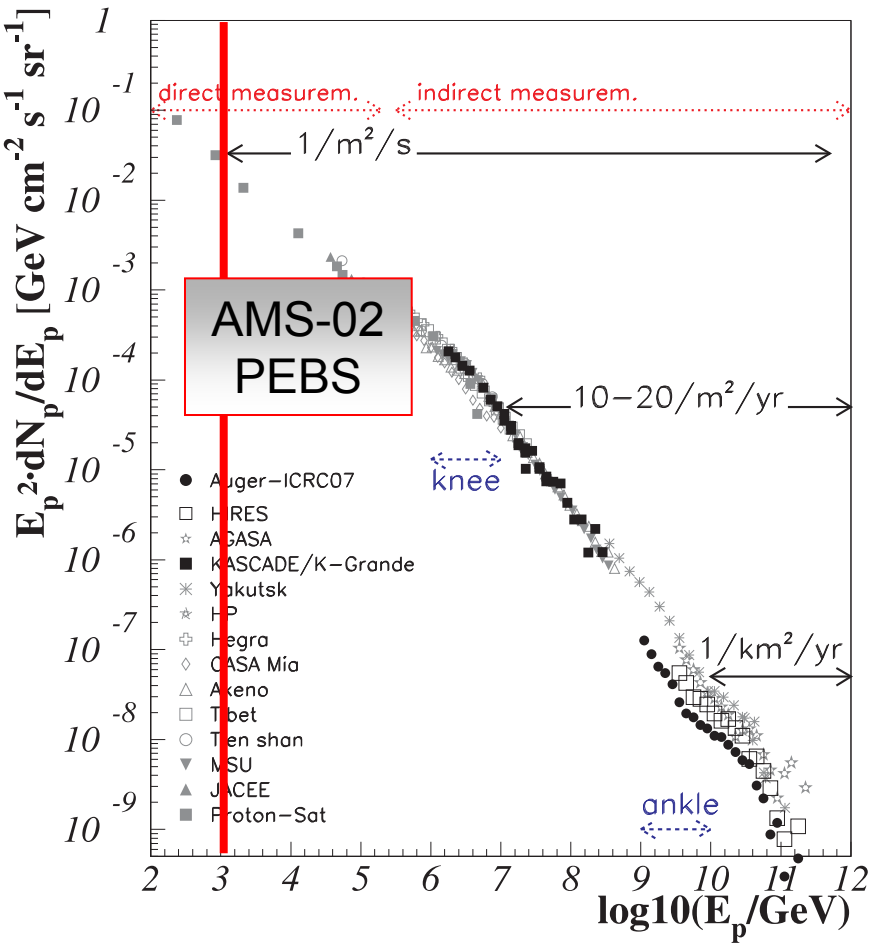
Particle & Astro Physics

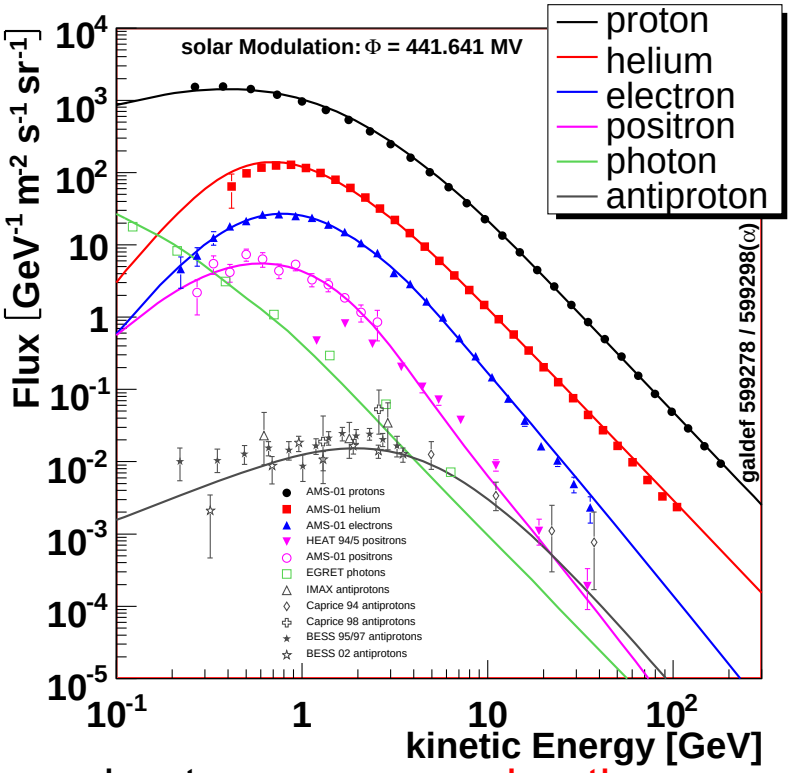


- particle physics & astrophysics are merging
- use particle physics methods in astrophysics and get input to particle physics from astrophysics

- **important observations cry for explanations:**
  - Dark matter exists! What is the nature? Supersymmetry, Kaluza-Klein,…
  - Where does the asymmetry between matter and antimatter in the universe come from?
  - …

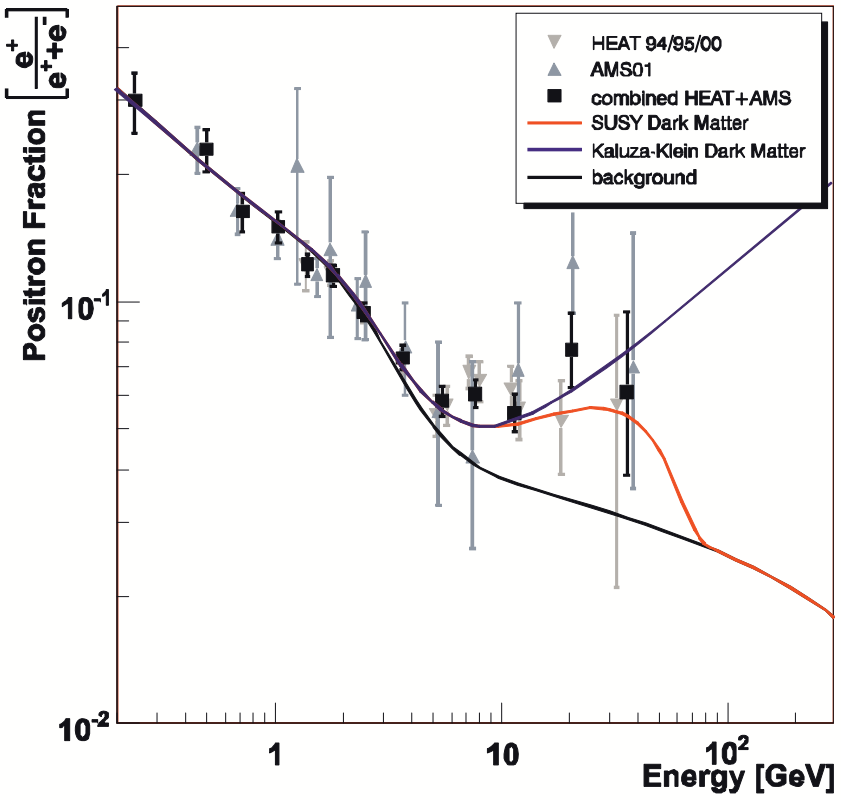
Cosmic Rays

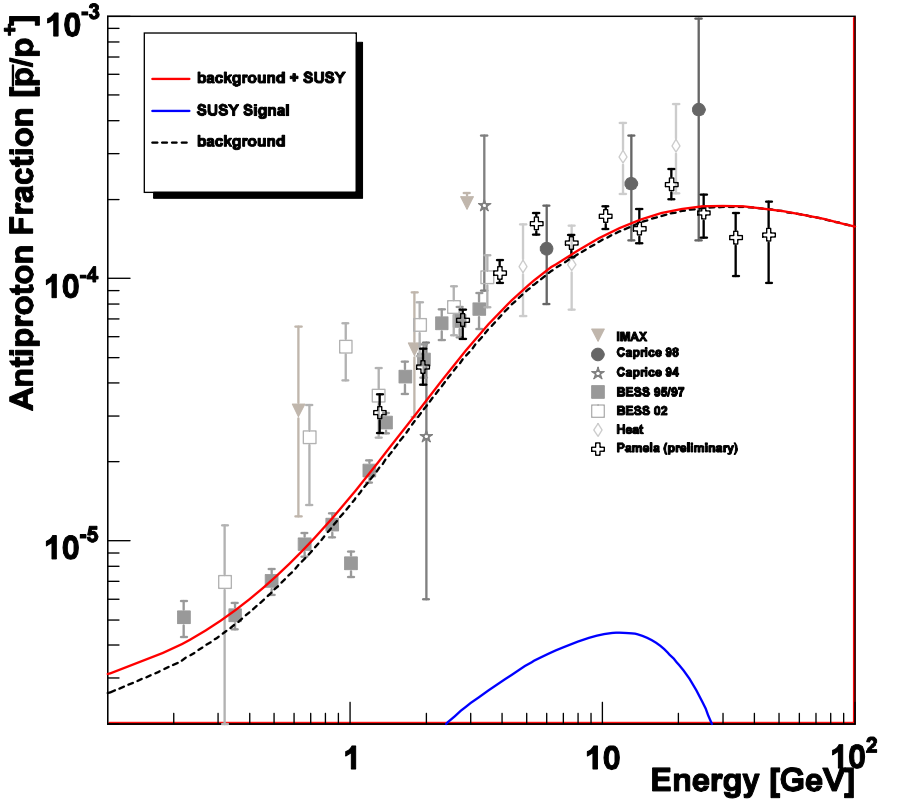




- learn about sources, acceleration, propagation, age, grammage of matter, halo size,…
- good agreement of models in the GeV-TeV range for particles, some unexplained features in antiparticle/photon spectra

Positrons & Antiprotons





- no primary sources for positrons and antiprotons are known
- sensitive to new physics: dark matter annihilations e.g. from new particles in supersymmetric or Kaluza-Klein Theories

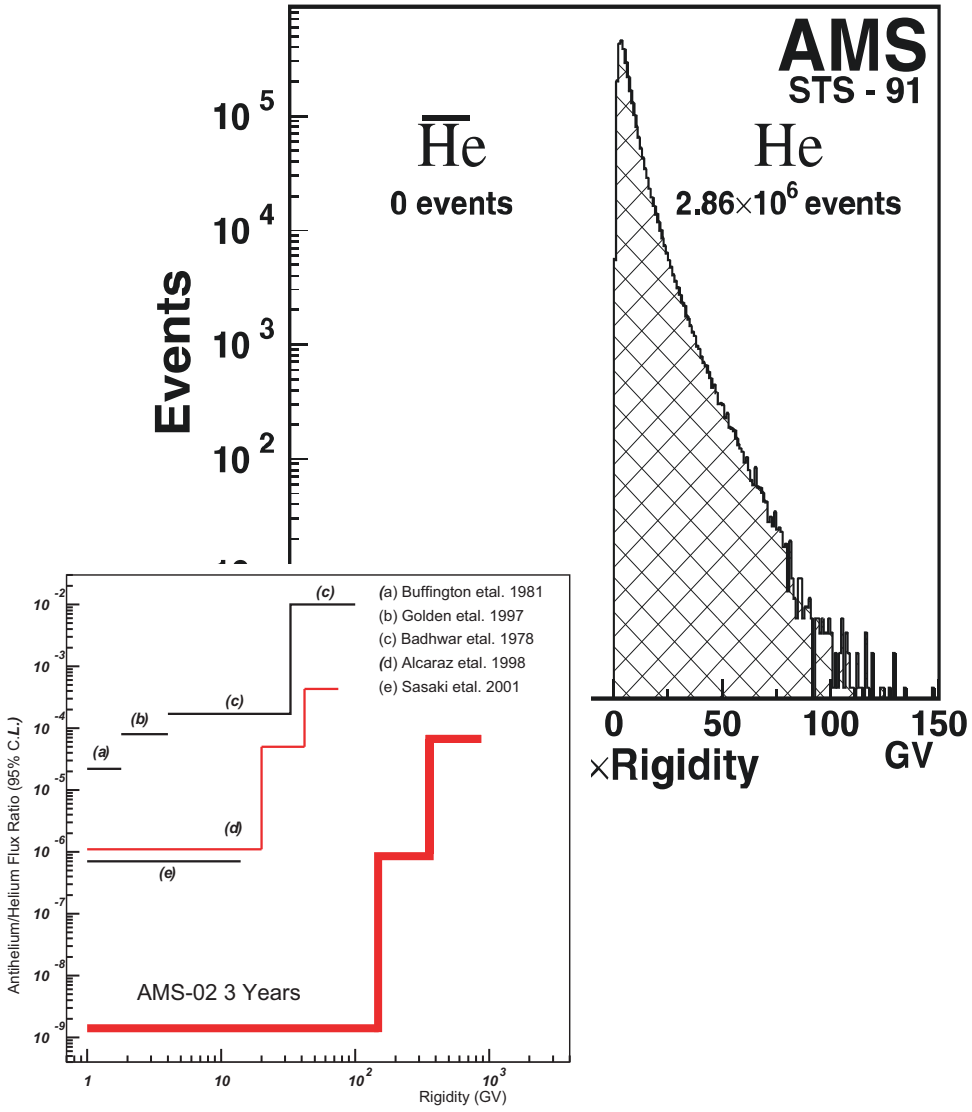
Antihelium

2 different appoaches for the explanation of the baryon asymmetry:

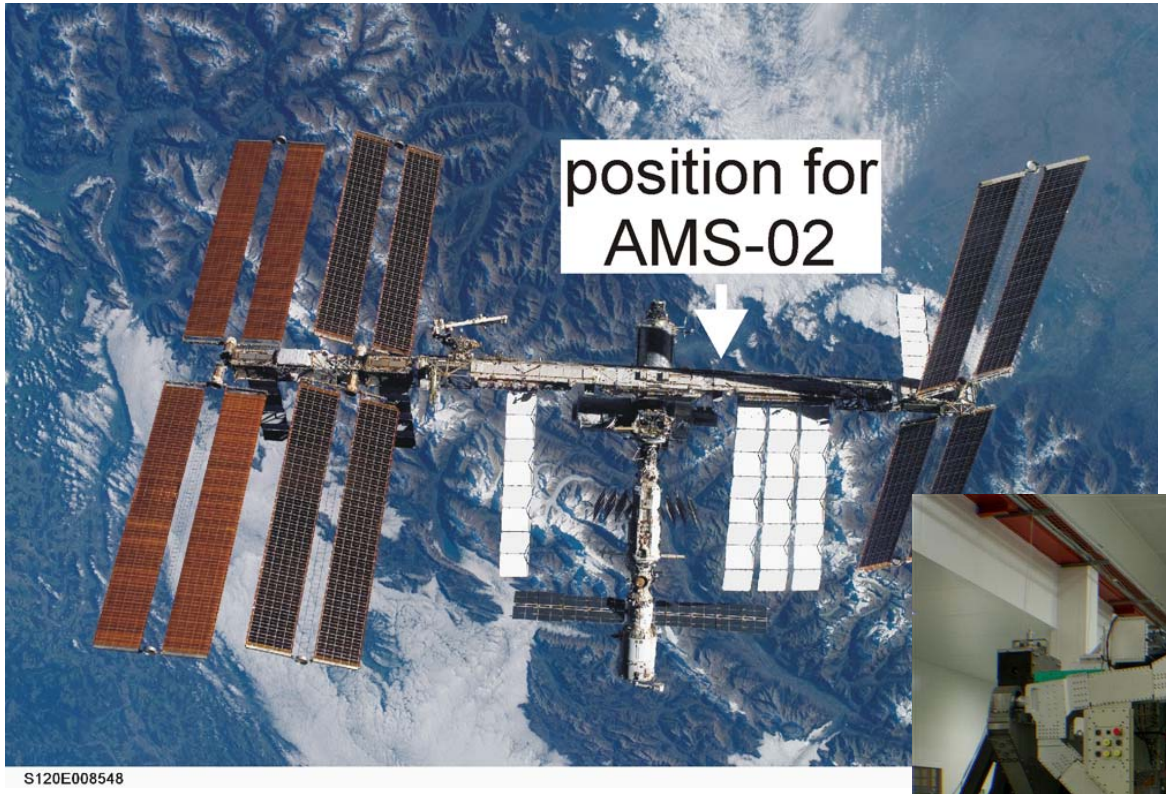
- dynamically: large CP violation is needed
- separation of matter and antimatter in the early universe

measurement:

- bound on antihelium gives constraint for the distance between galaxies and antigalaxies
  (NO(!) production of antihelium in the matter universe possible)

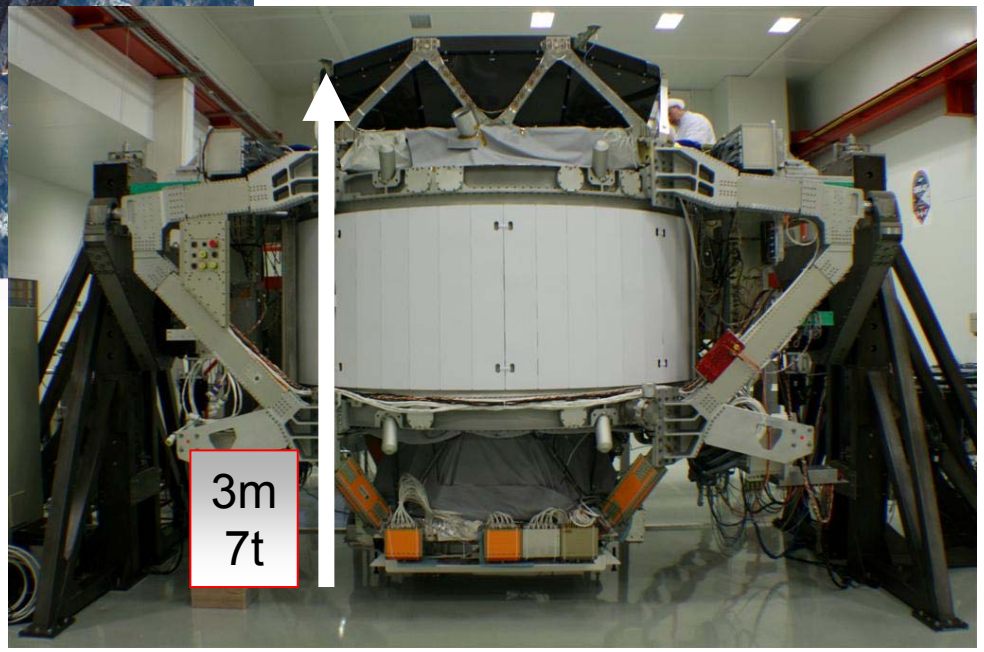


The AMS-02 Detector

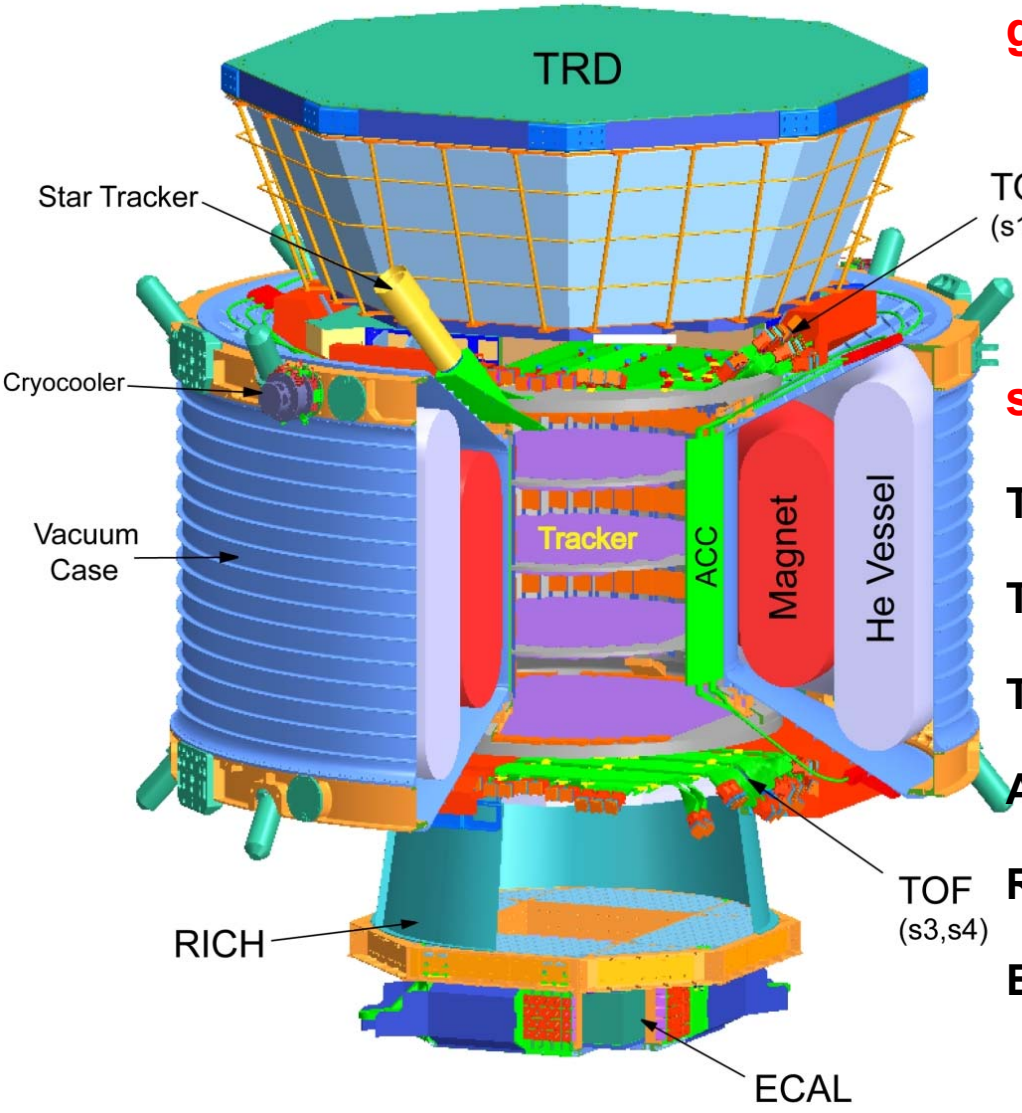


artist view of AMS-02
on the International Space Station
> 2010

AMS-02
in the clean room @ CERN



AMS-02 Overview



goals of AMS-02:

- precise spectroscopy of cosmic rays without interactions in the atmosphere on the ISS
- measurement/bounds on antimatter
- indirect dark matter search

subdetectors:

Transition Radiation Detector (TRD)
- classify particles by γ=E/m

Time of Flight (ToF)
- trigger, velocity, dE/dx

Tracker + supraconducting Magnet (1T)
- track reconstruction, momentum, dE/dx

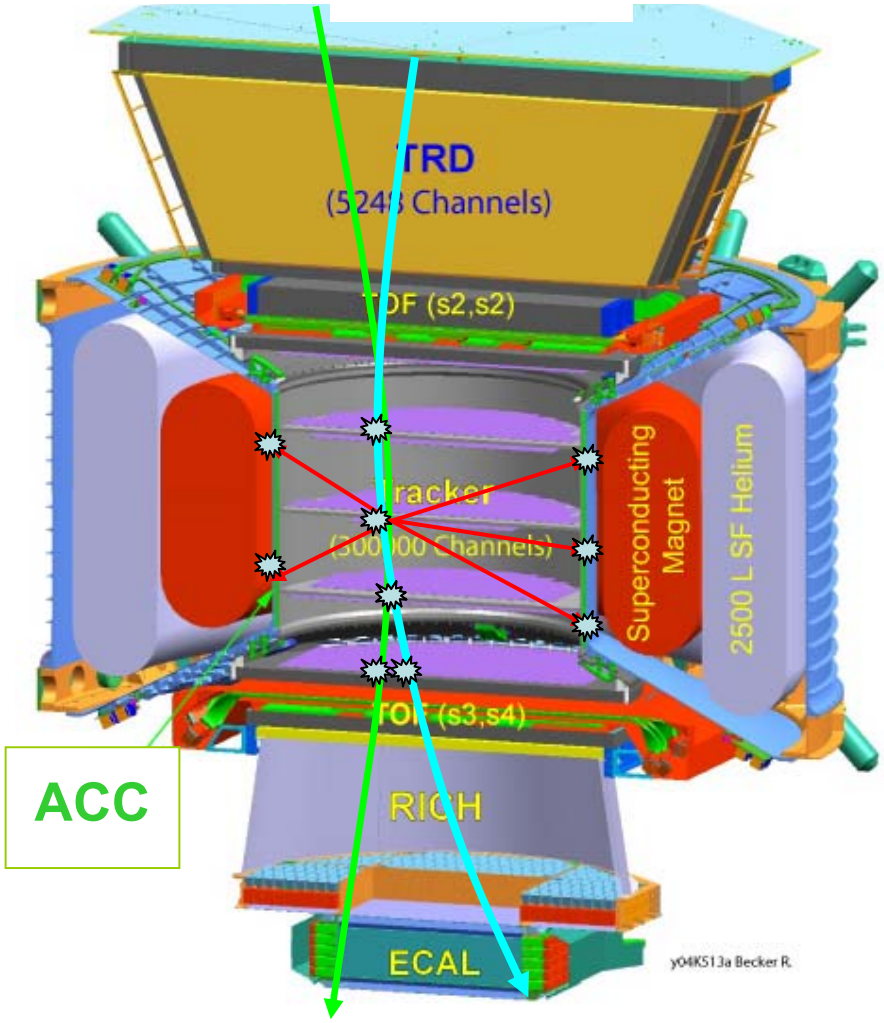
Anti-Coincidence Counter (ACC)
- event selection ⟶ next slide

Ring Image Cherenkov Detector (RICH)
- precise velocity mesaurement

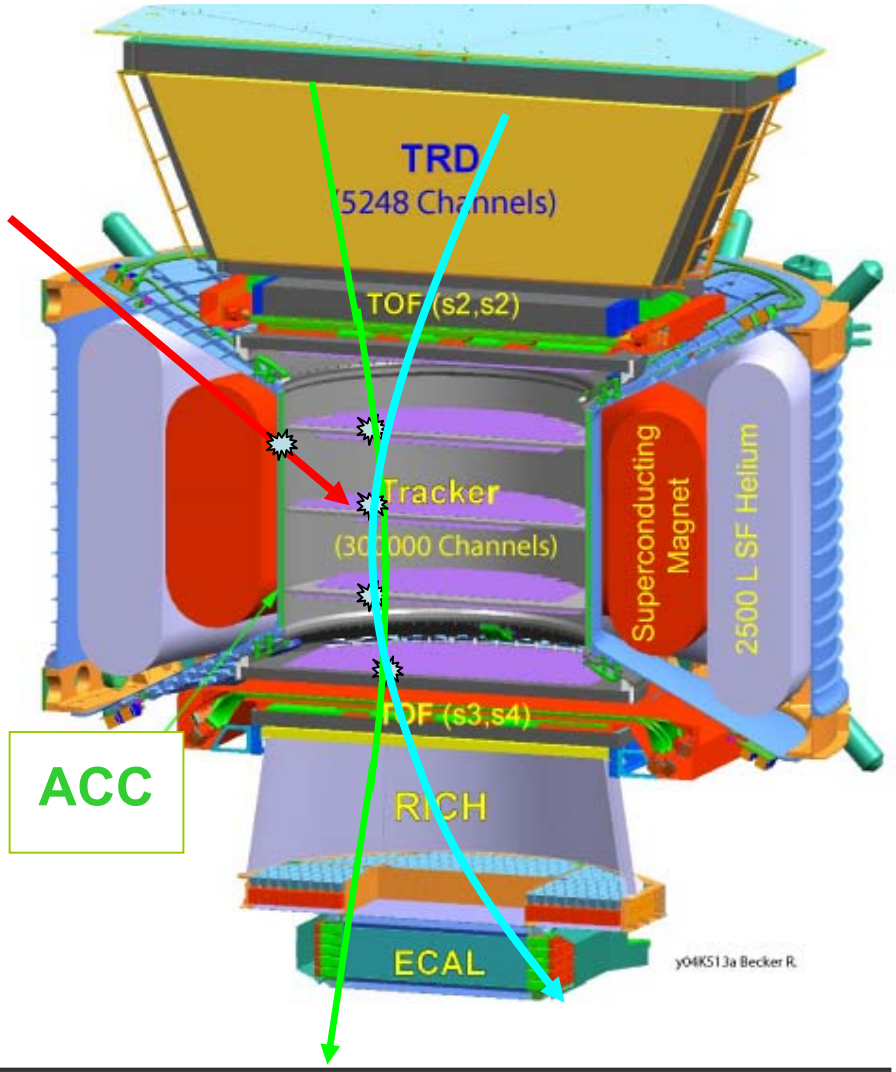
Electromagnetic Calorimeter (ECal)
- shower shape and energy determination

Important Events for the ACC

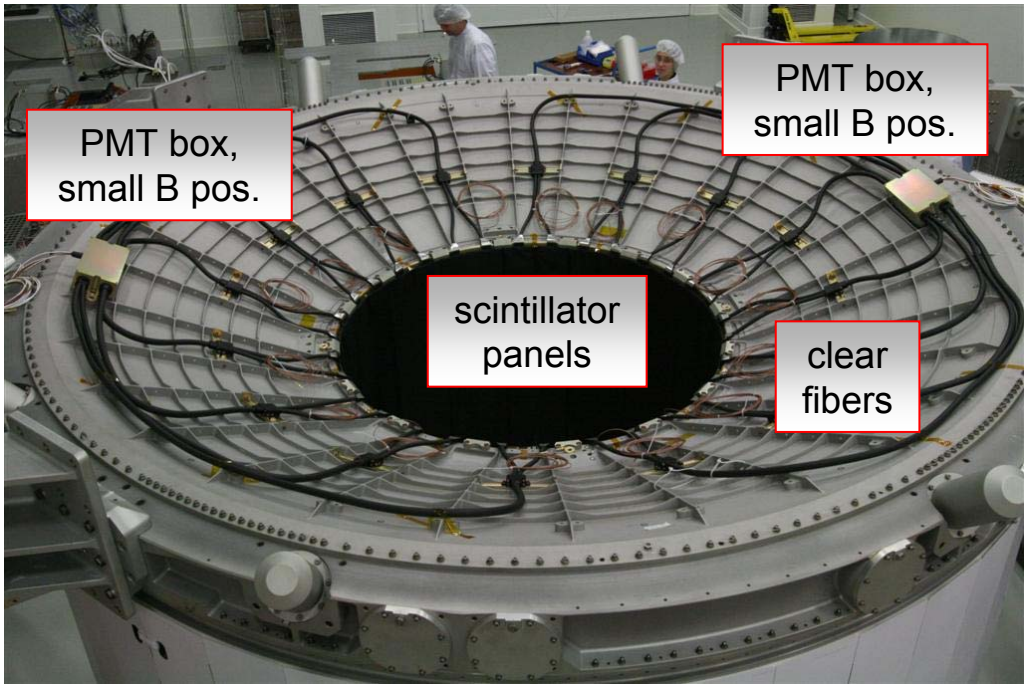
rejection of internal interactions



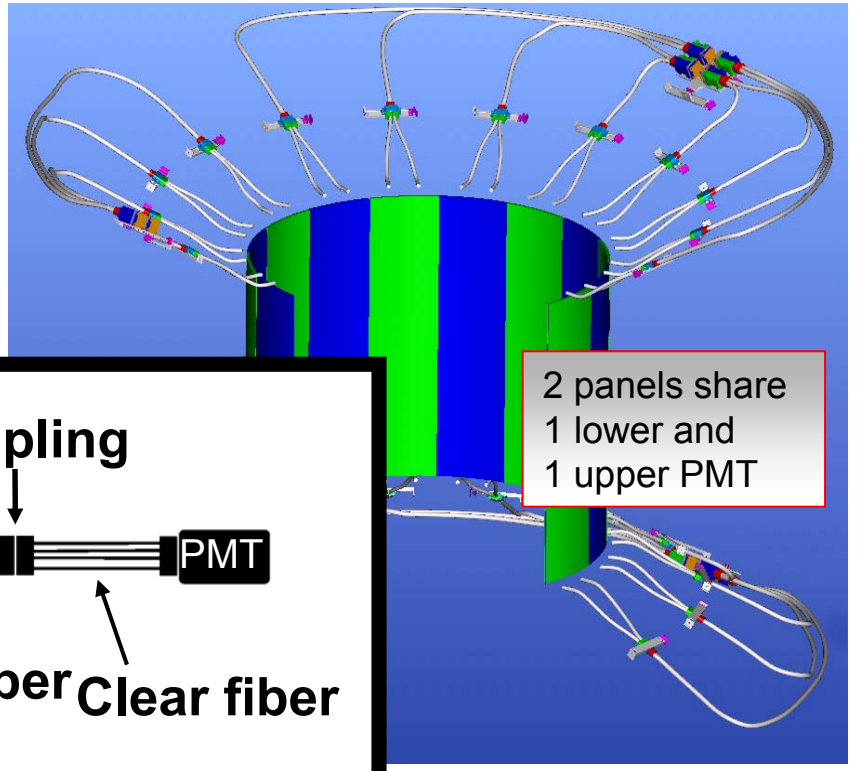
rejection of external particles

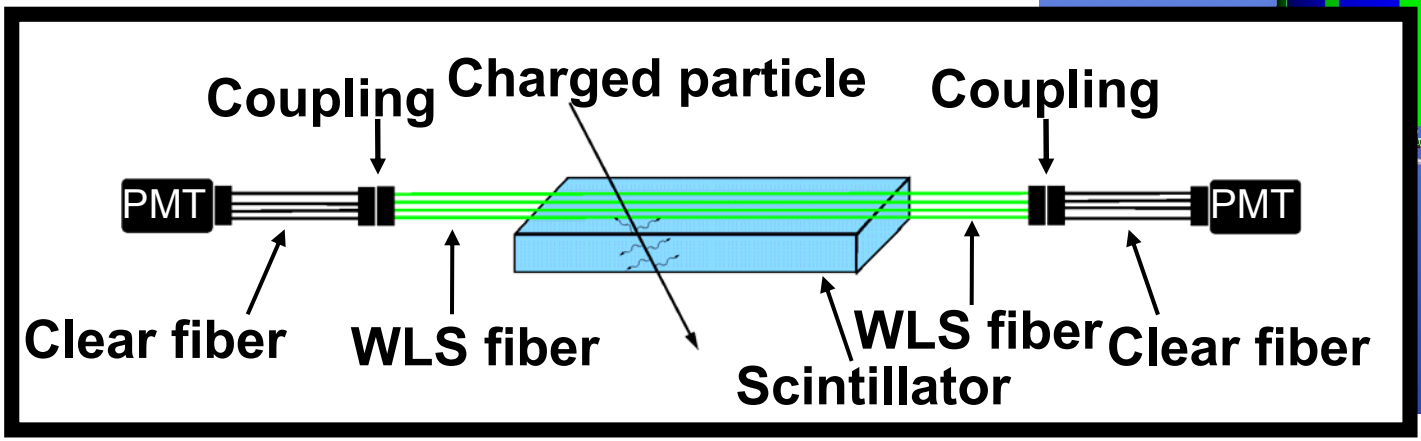


ACC System

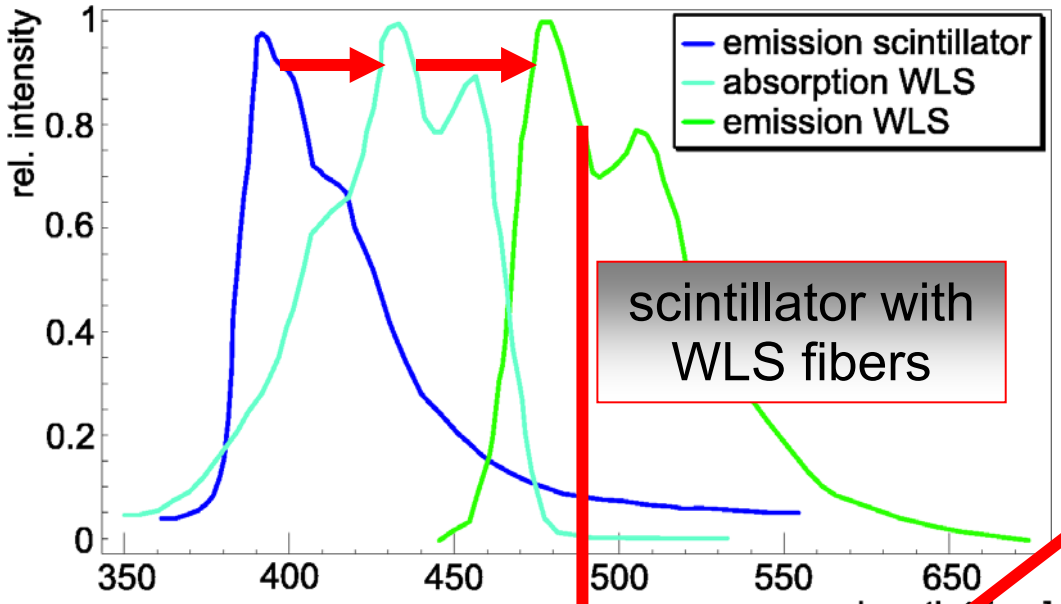


- small ACC inefficiency needed ($<10^{-4}$) for measurement of antimatter with very clean single tracks
- reduce trigger rate, fast detector (ns): e.g. south atlantic anomaly

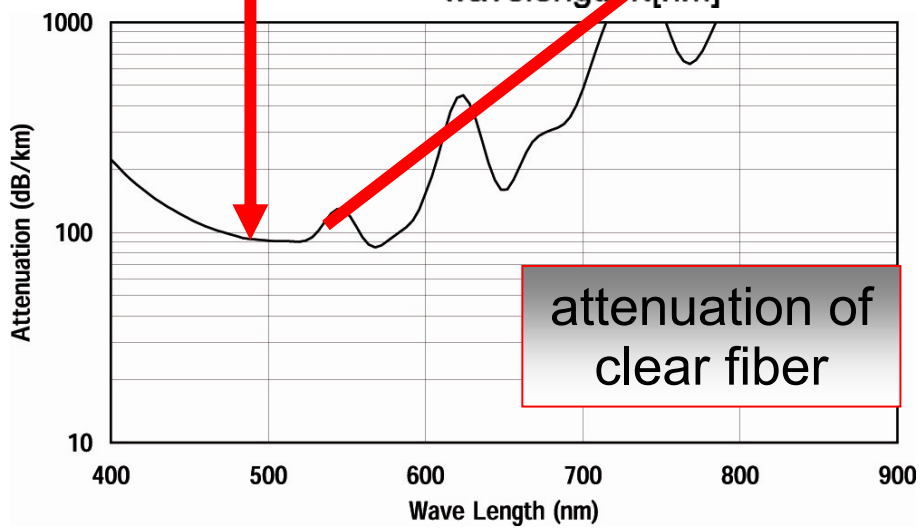




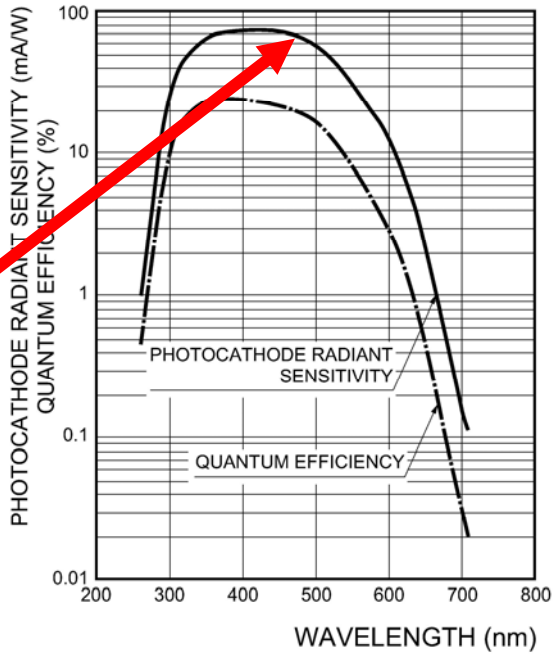
Light Signals



scintillator with WLS fibers

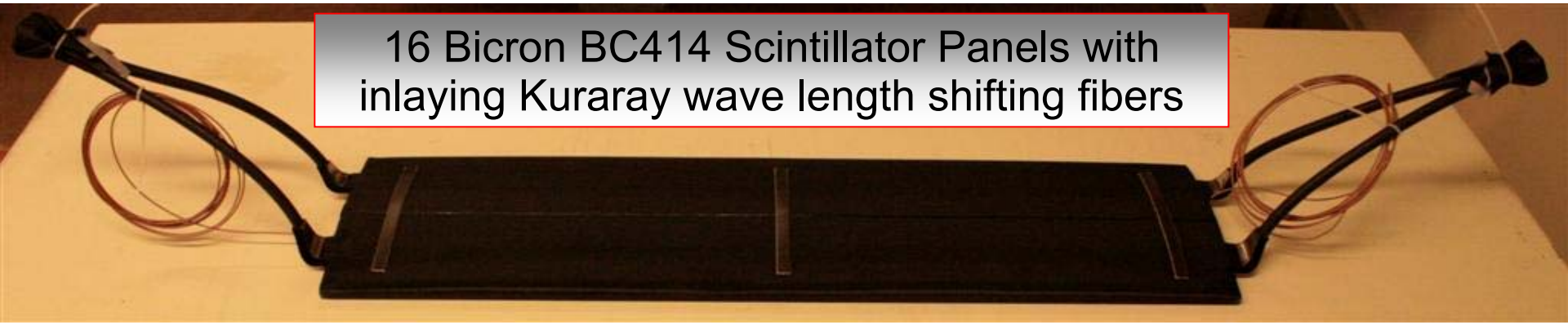


attenuation of clear fiber

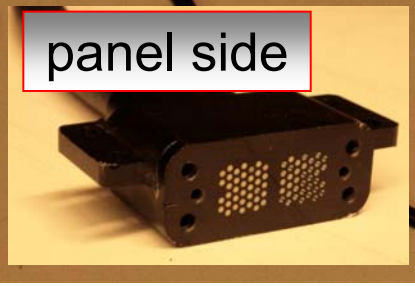


PMT quantum efficiency

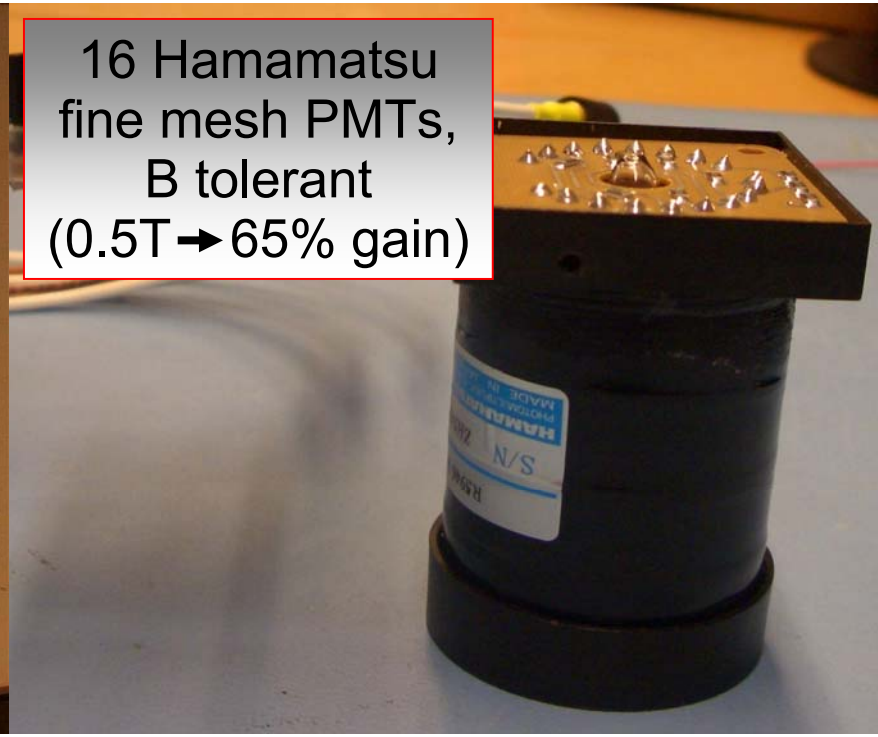
ACC Hardware Parts



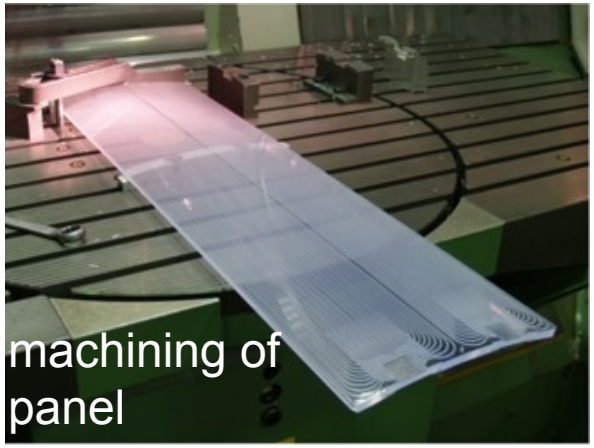
16 Y-shaped Toray
clear fiber cables

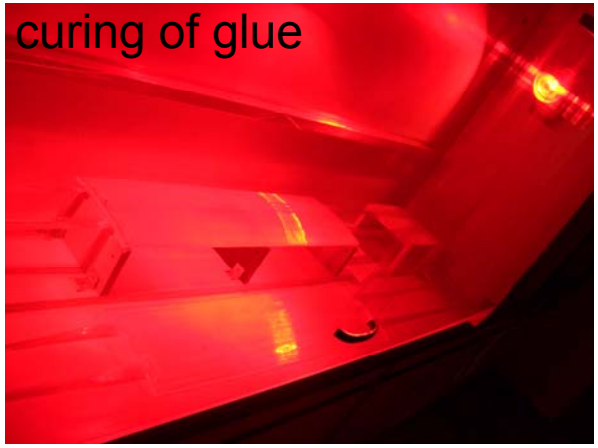


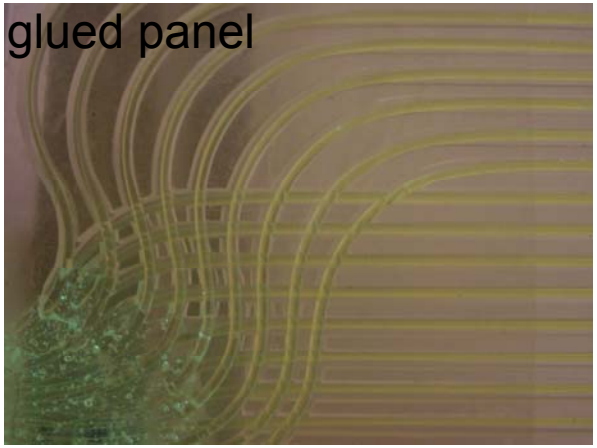
16 Hamamatsu
fine mesh PMTs,
B tolerant
(0.5T➡65% gain)

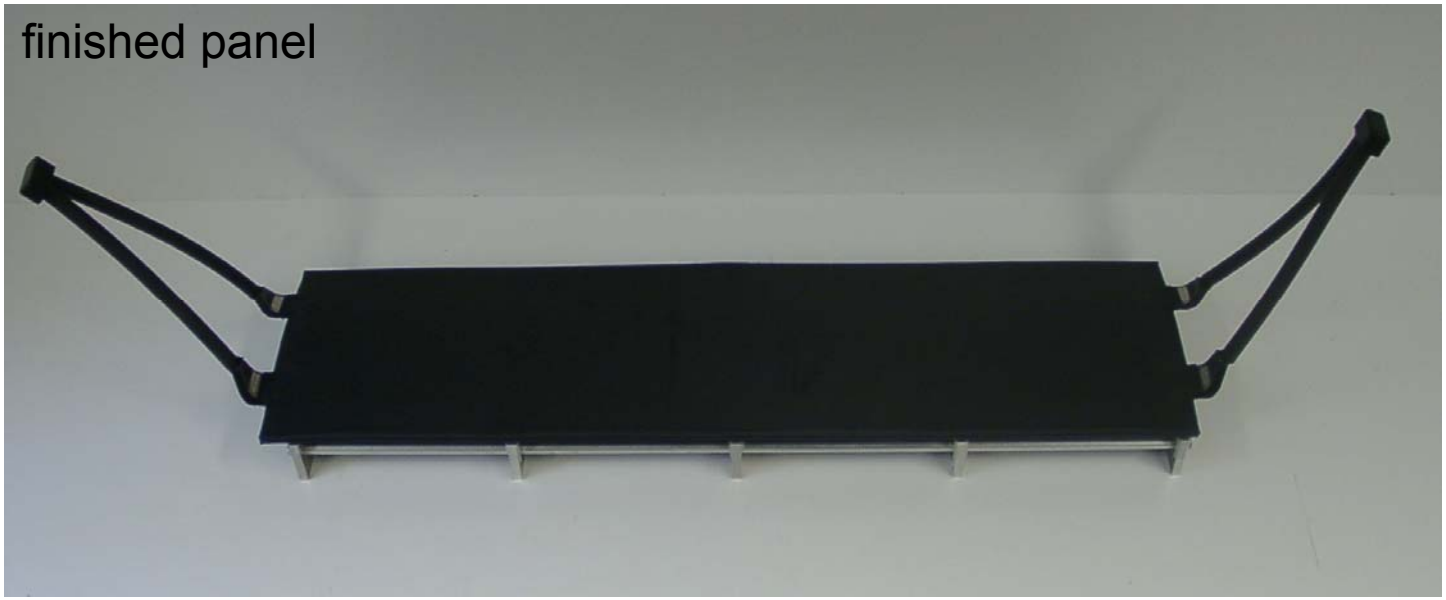


ACC Panel Production

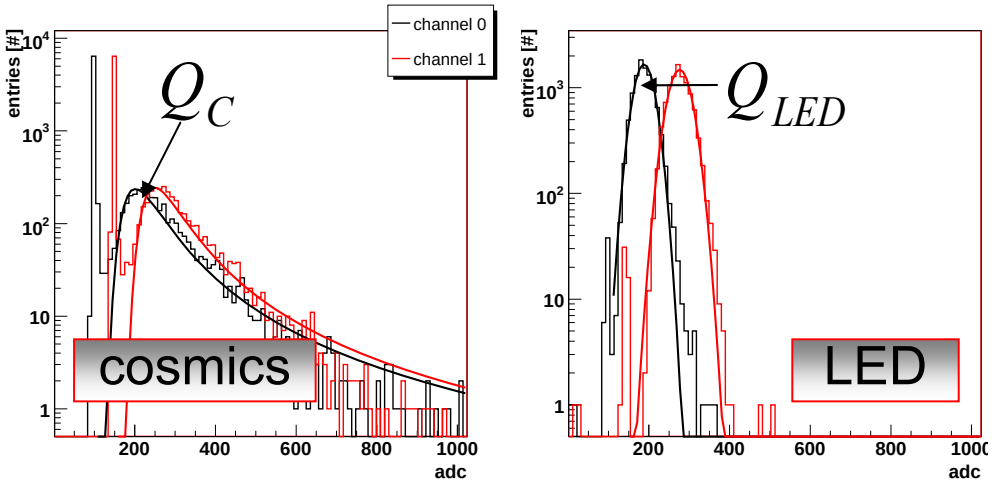


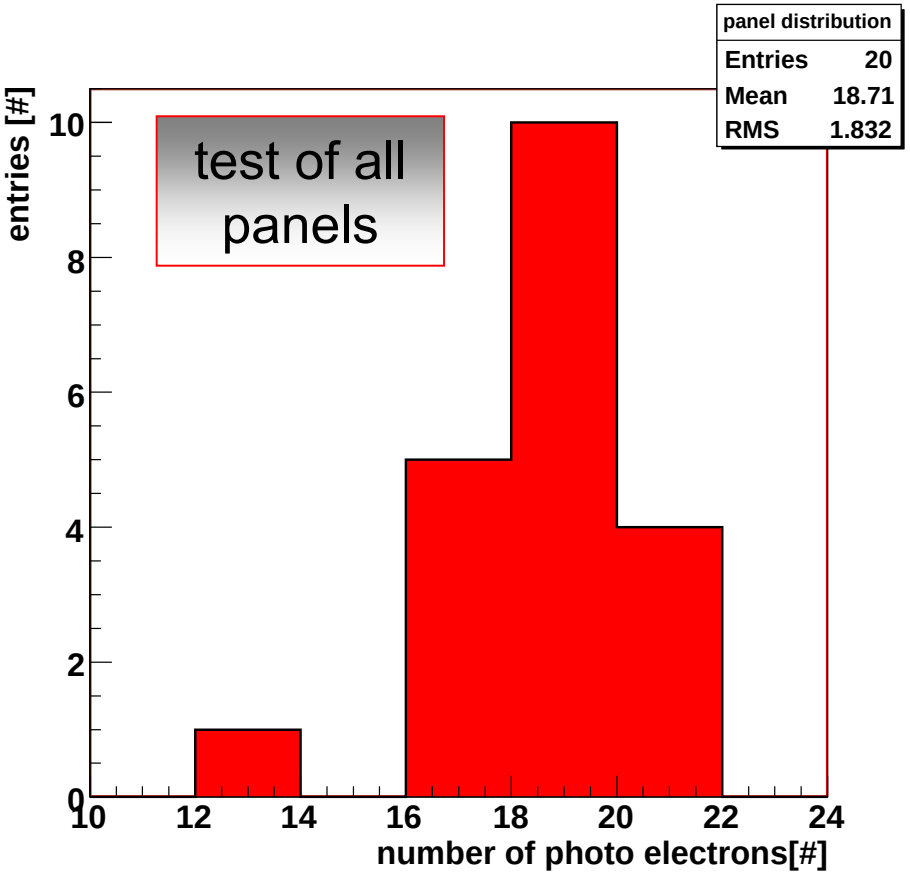






Panel Classification





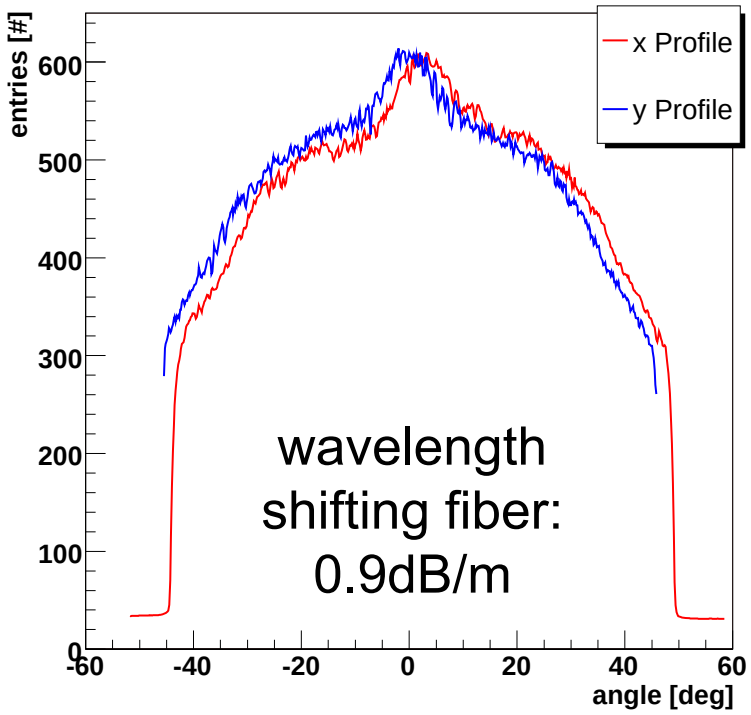
calculation of photo electron number:

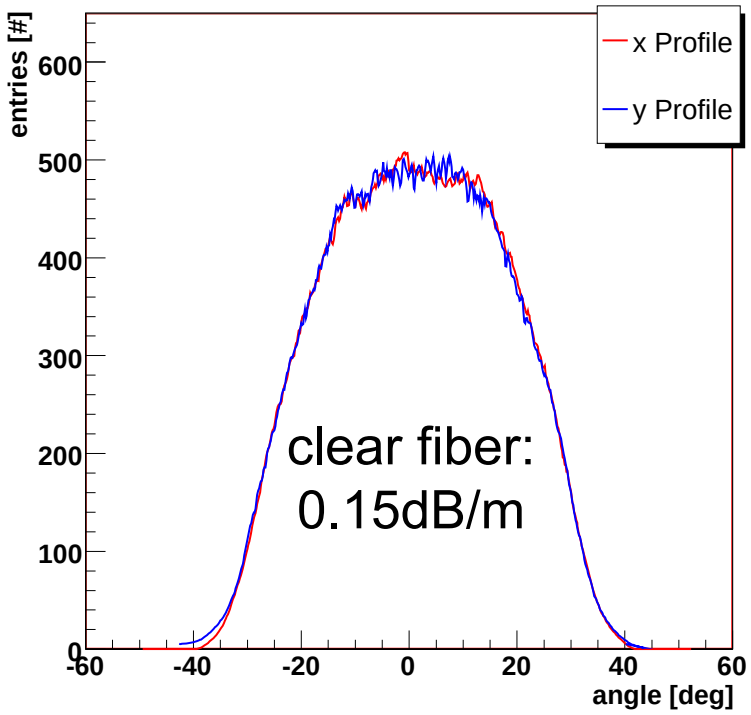
- measurement of MOP with cosmics
- calibration with LEDs implemented in panels

$$N_{pe} = \frac{Q_C Q_{LED}}{\sigma^2_{LED}}$$

	material	photo elec.
AMS-01	1.0cm	20
AMS-02	**0.8cm**	**19**

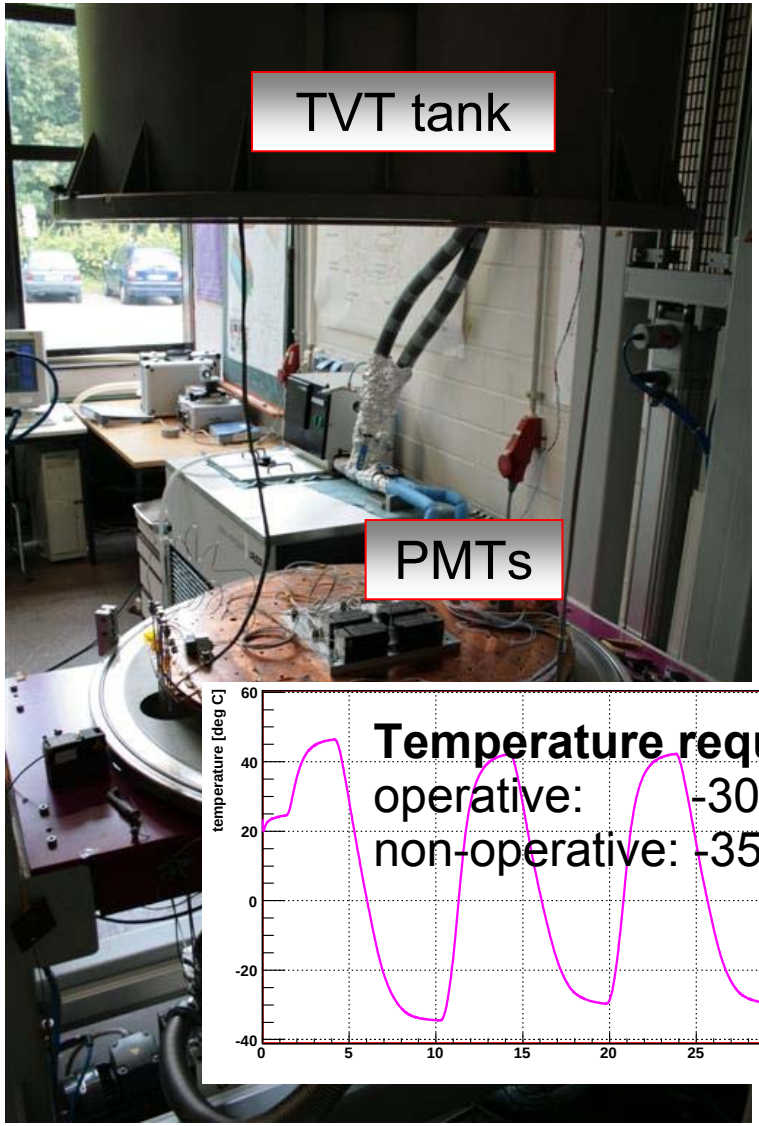
Coupling: WLS to Clear Fiber

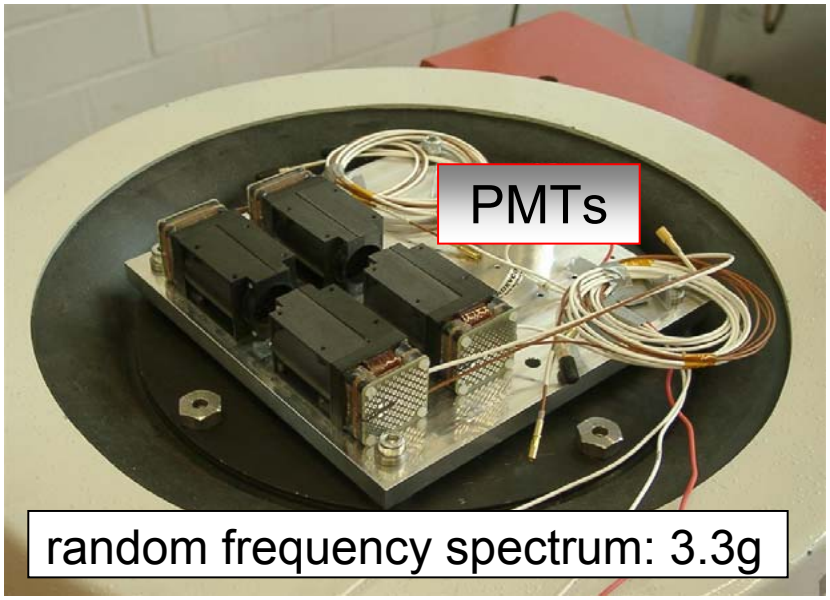




- acceptance angle matching of wavelength shifting fiber and clear fiber is important
- WLS: wide distribution due to reabsorption is also responsible for large attenuation

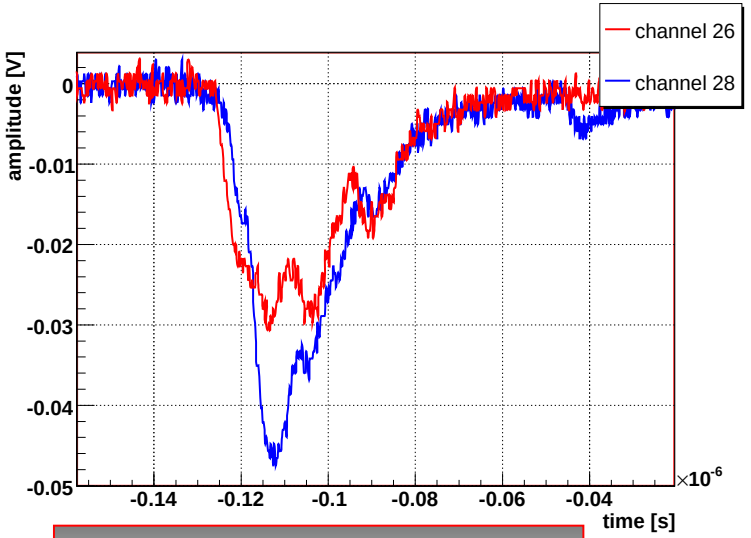
Space Qualification - PMTs





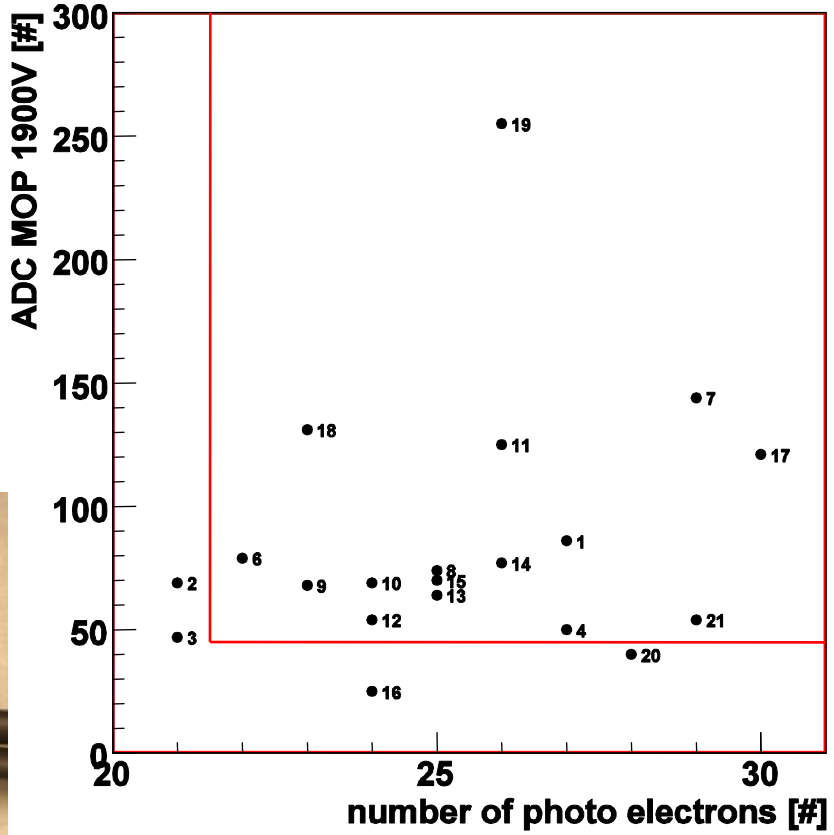
PMTs did not change within 5% after Space Qualification

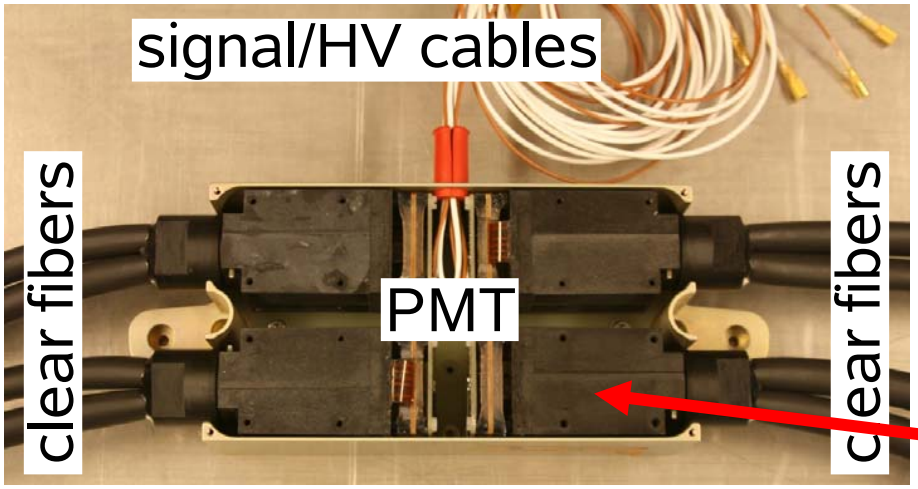
PMT Selection for Flight



typical signal shape

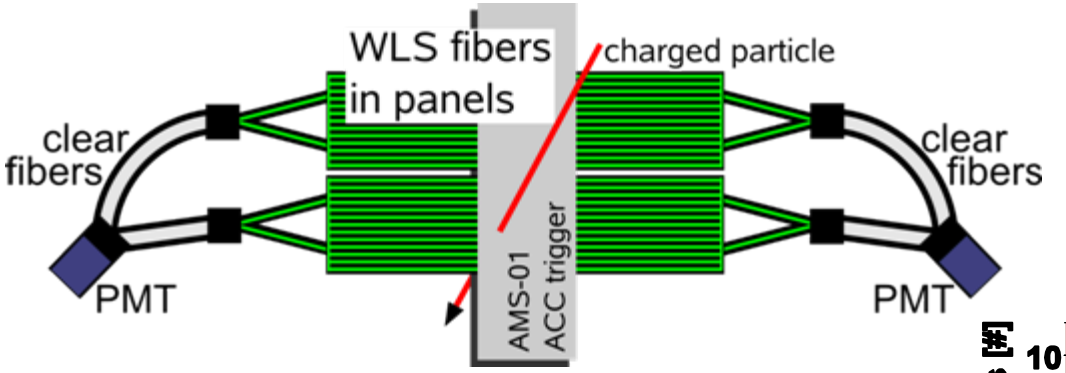
classification with gain and p.e. number



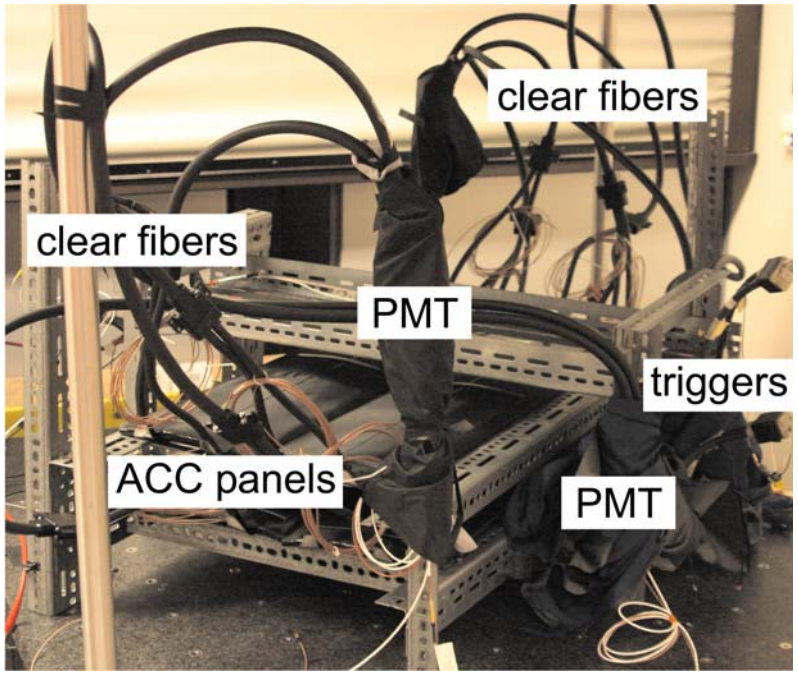


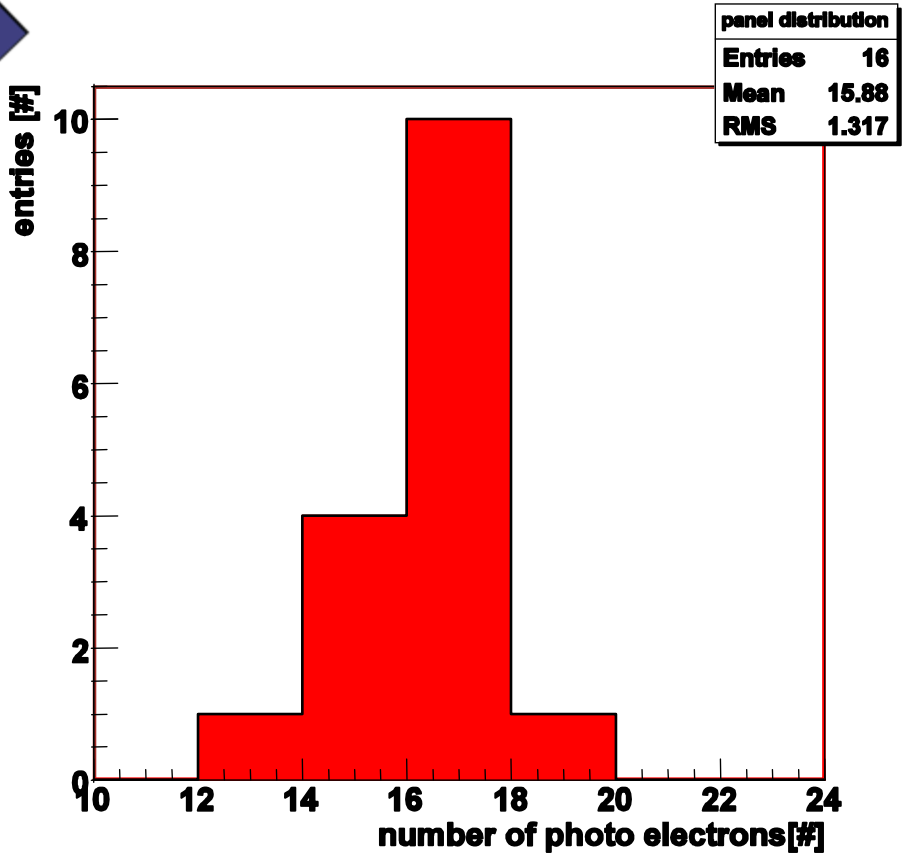
mounting in light and glass dust tight box

Complete System Test

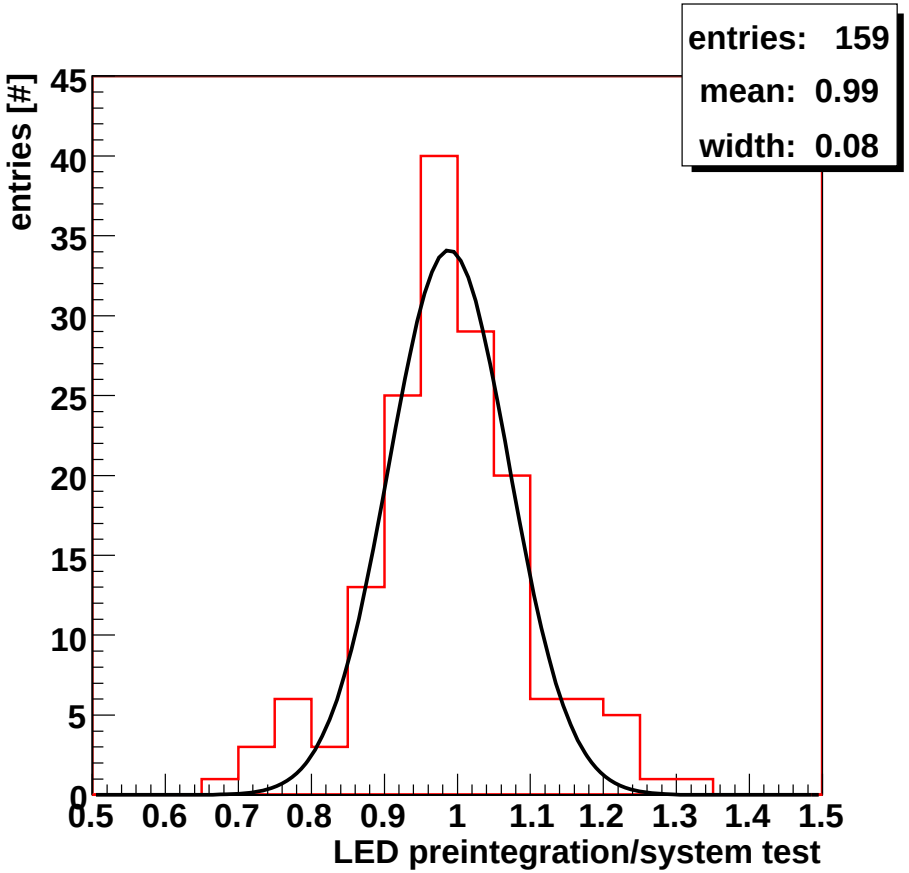


test of complete chain:
panel + clear fiber + PMT
show good results
(mean: 16 photo electrons)





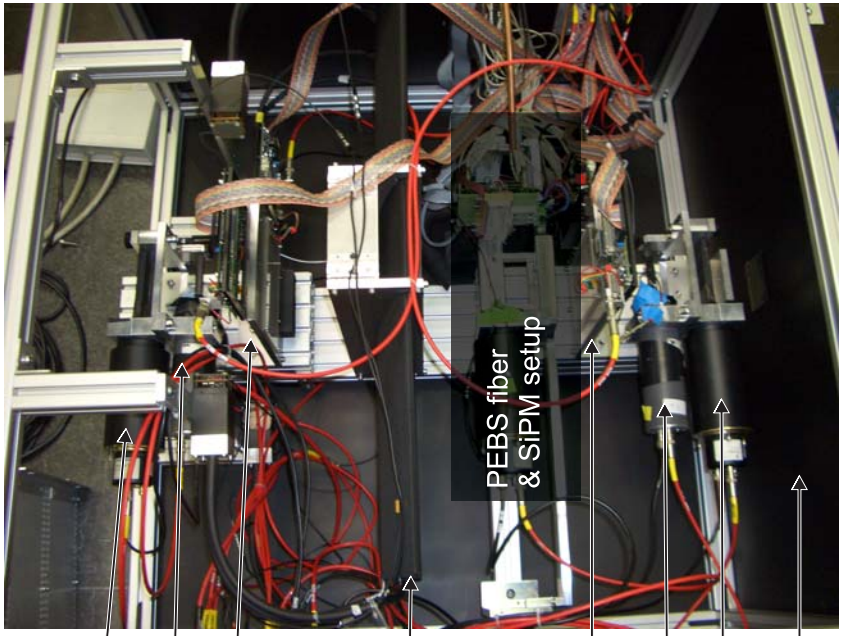
Preintegration

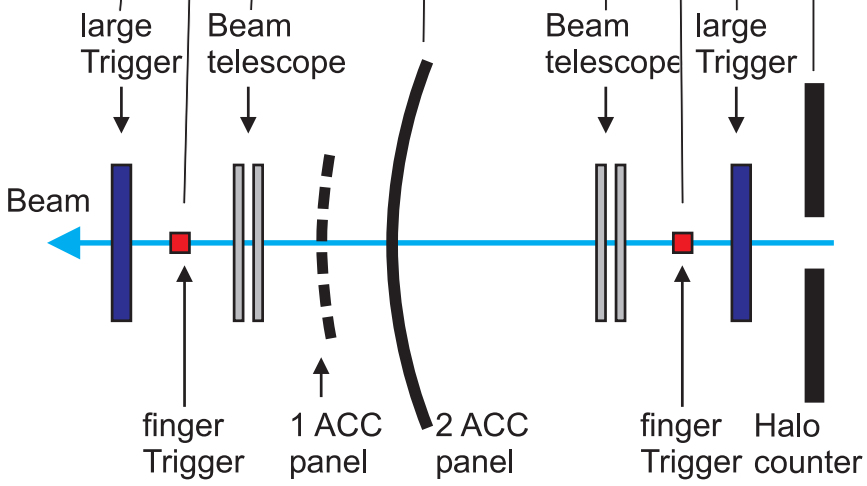


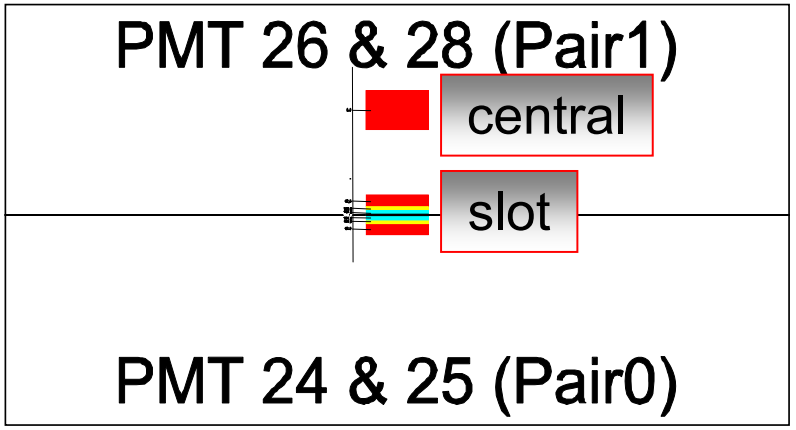
successful preintegration: 99 ± 8 %

LED test comparison (after/before)

Inefficiency Studies: Testbeam - Setup



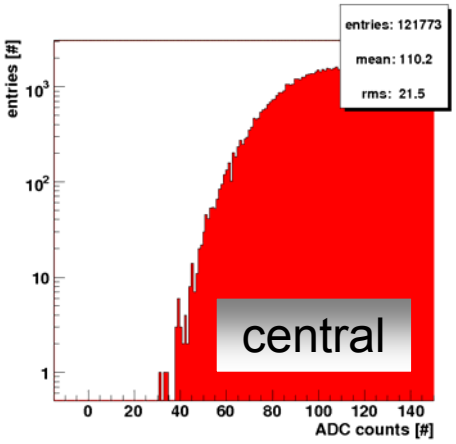


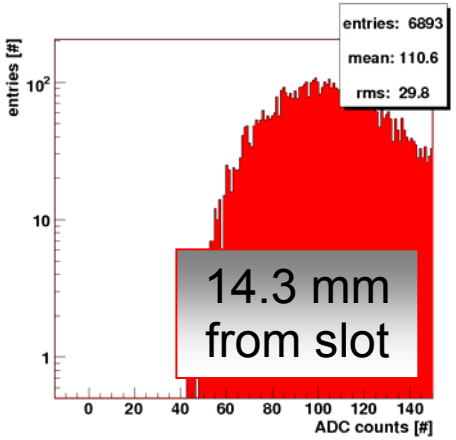


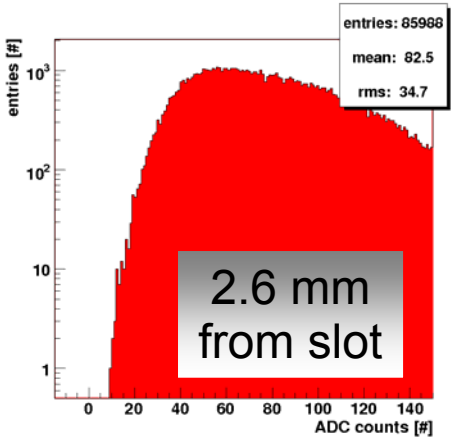
test of slot and central region

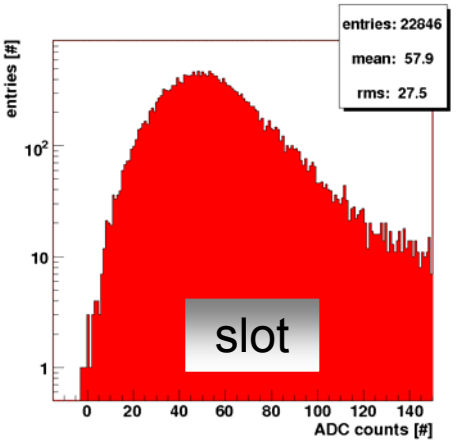
Testbeam – Inefficiency Measurement

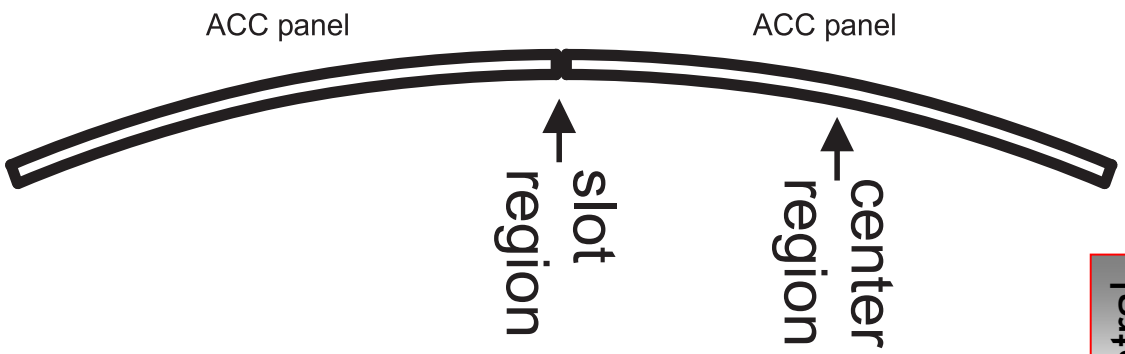
highest ADC counts from both PMTs on one panel for each event

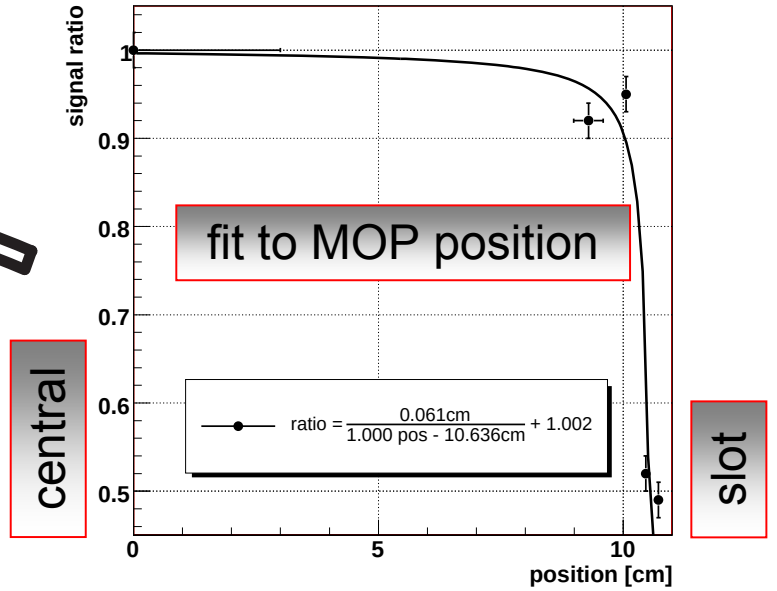




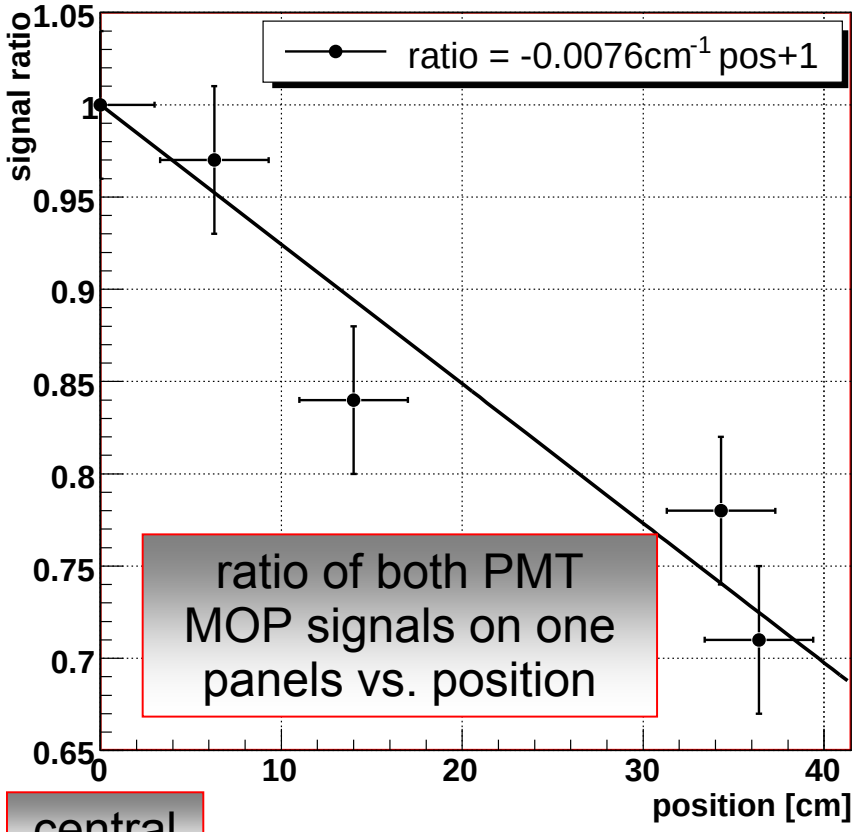






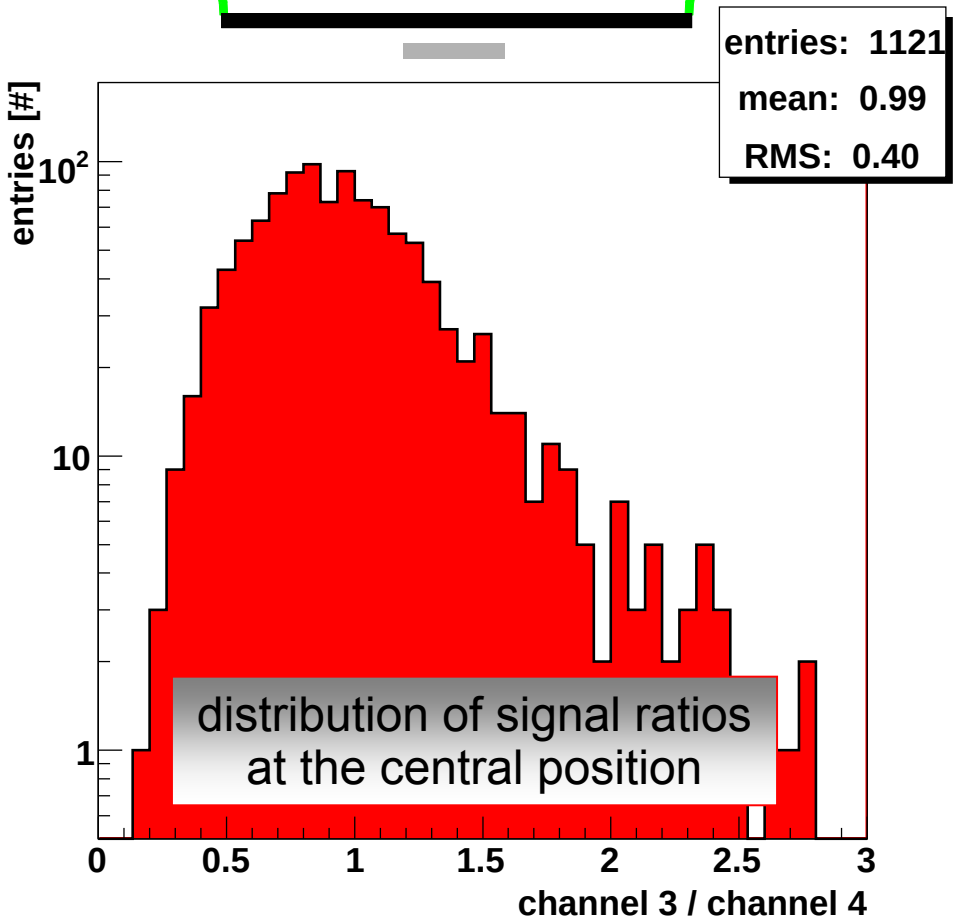


Signal Ratios



ratio of both PMT MOP signals on one panels vs. position

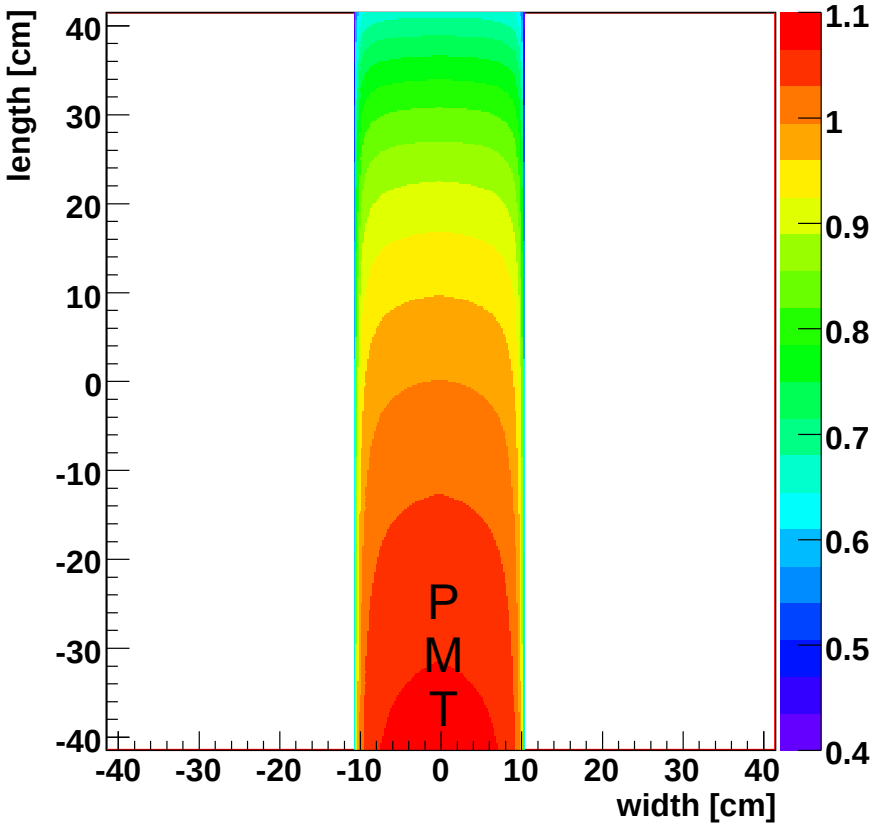
central



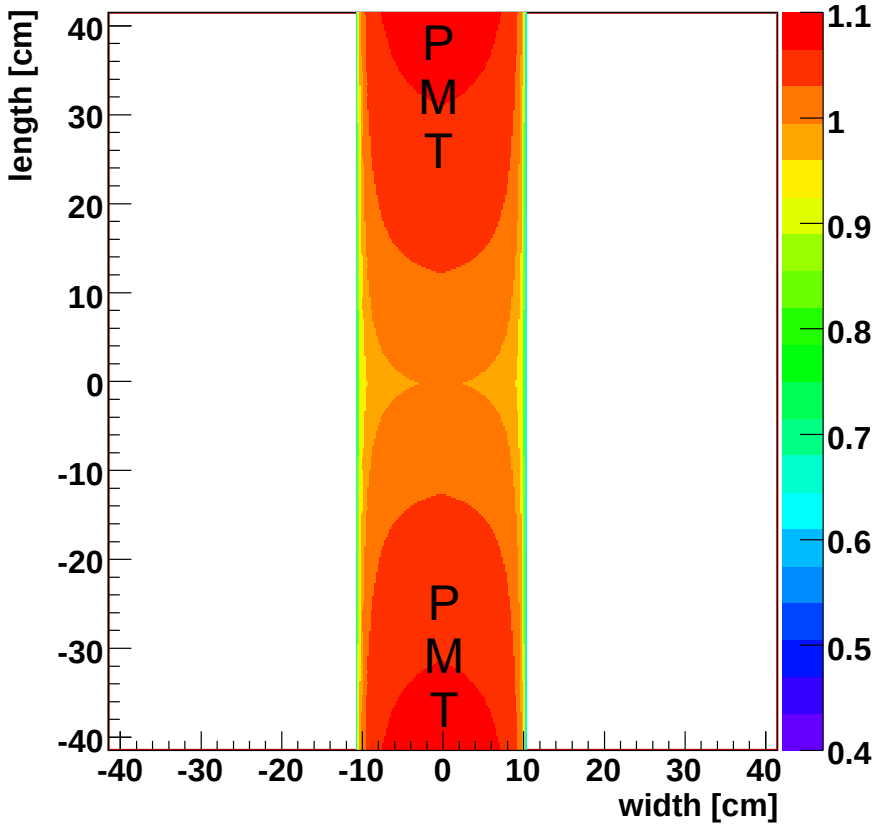
distribution of signal ratios at the central position

estimation of hit position

Signal Model



model for relative signal behaviour of one PMT

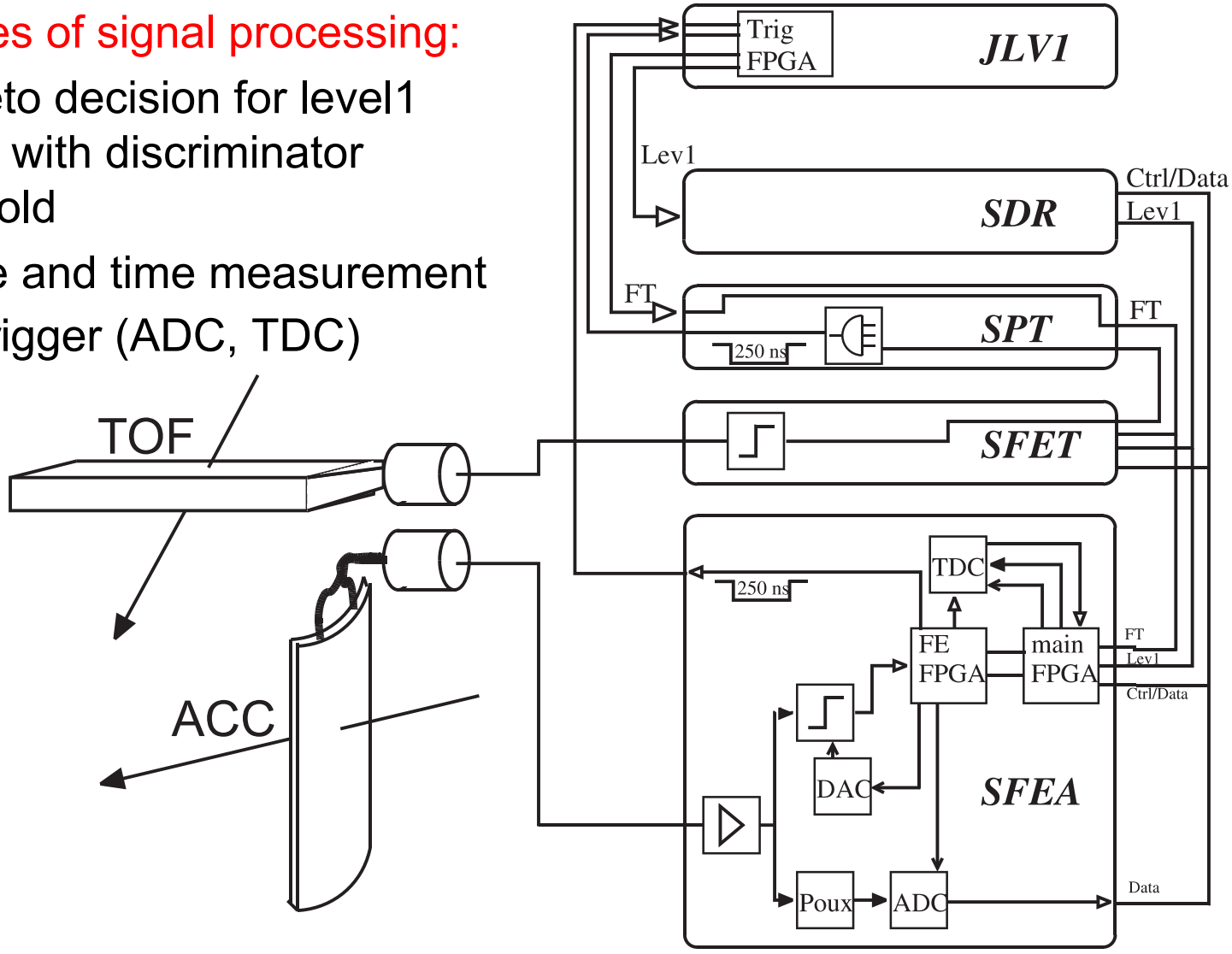


model for relative signal behaviour for the highest value of both PMTs

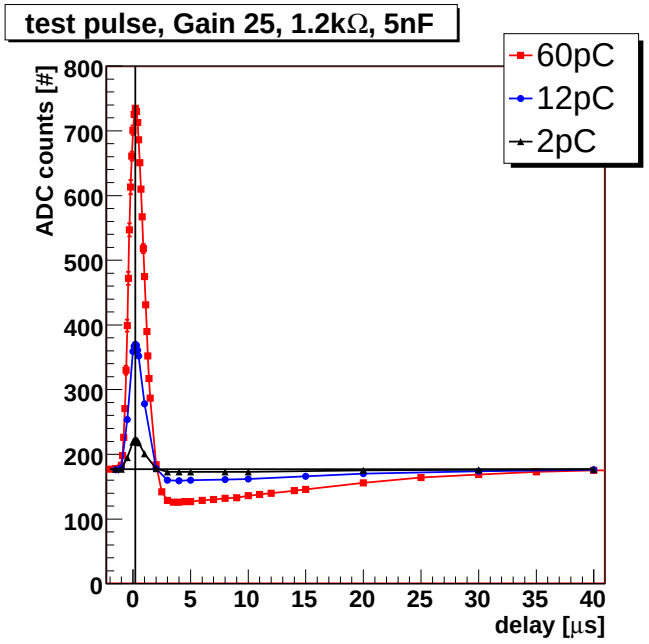
Flight Electronics

2 branches of signal processing:

- fast veto decision for level1 trigger with discriminator threshold
- charge and time measurement after trigger (ADC, TDC)

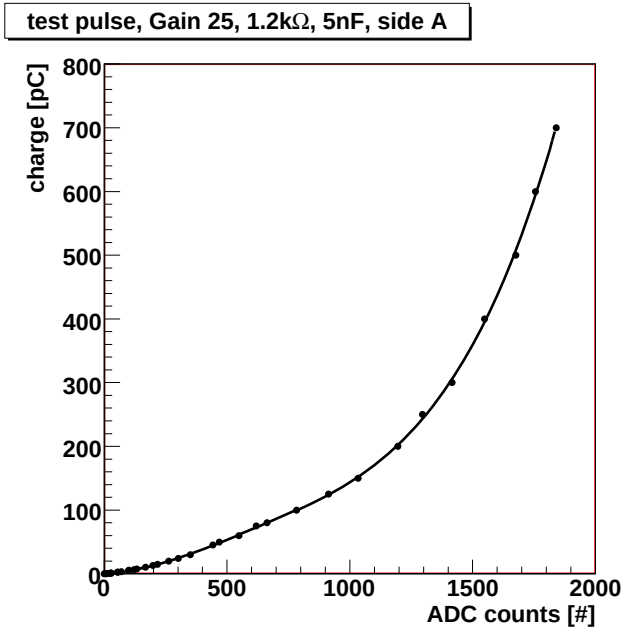


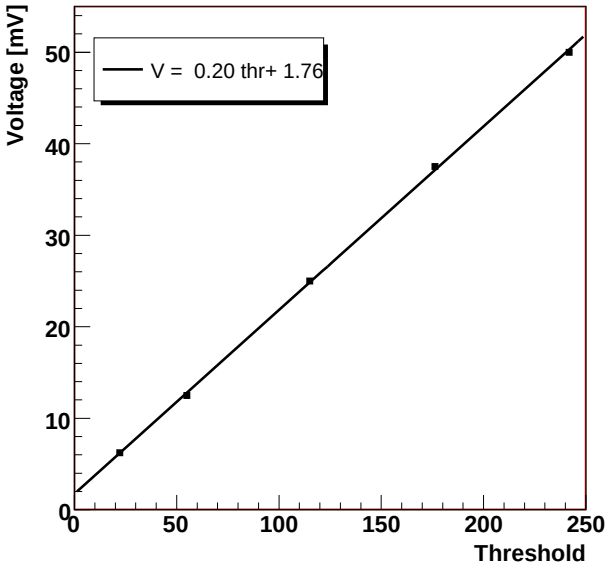
Flight Electronics: Calibration



time delay scan to get to the maximum signal of the ADC

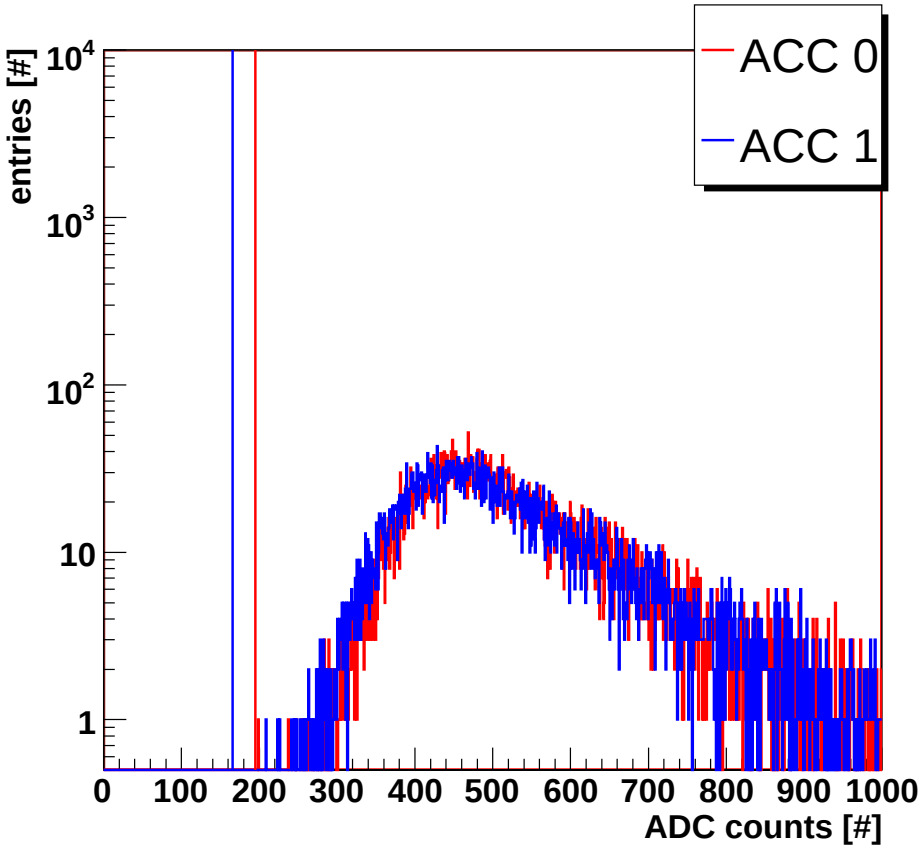
gauging of ADC charge measurement with test pulses: high resolution for small charges

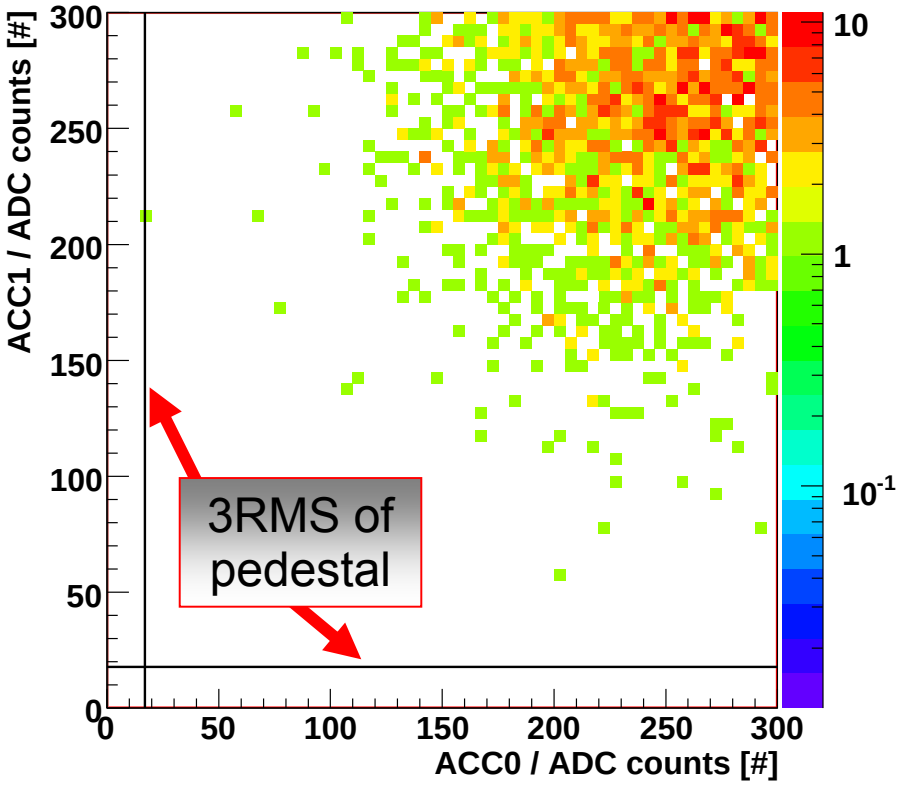




calibration of thresholds for the discrimination in the TDC

Flight Electronics

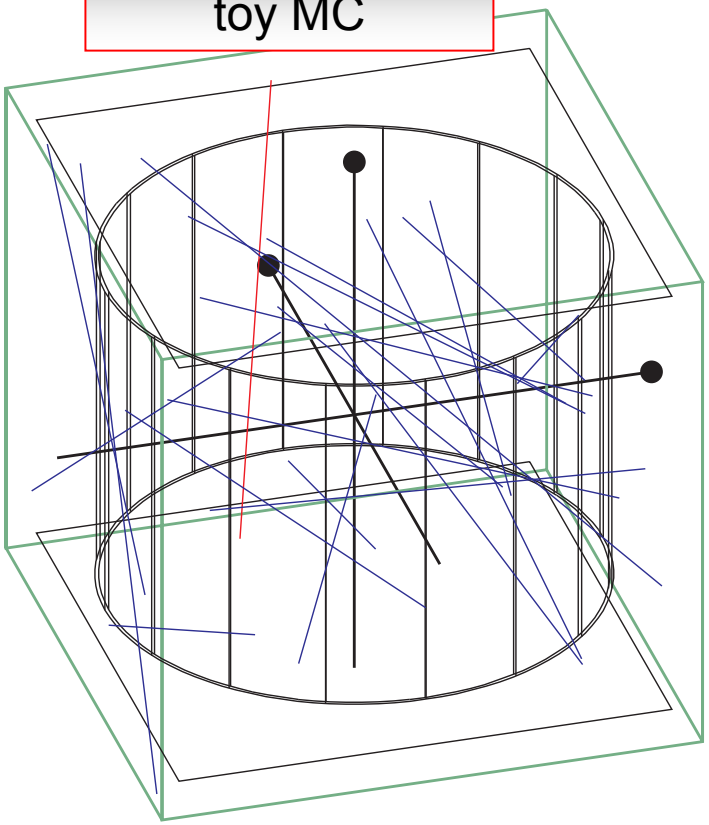


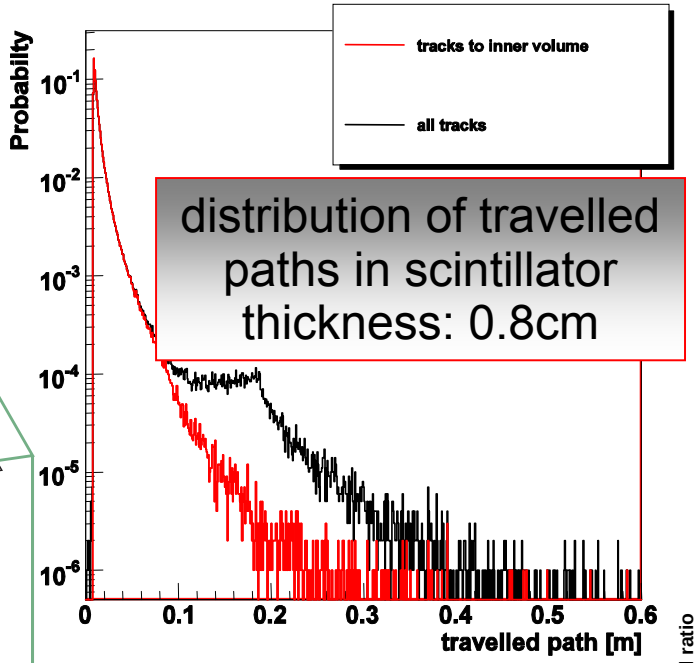


- 2 PMTs (ACC0/1) connected to one panel
- **no event missed out of 10000** by using the highest of both values

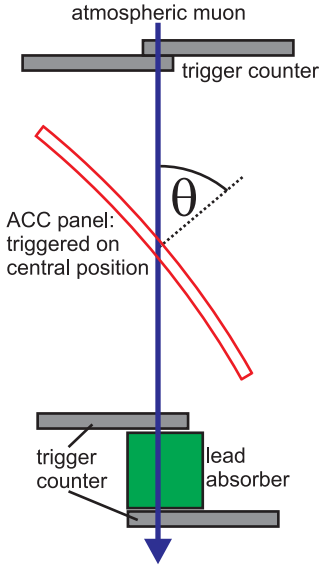
Isotropic Particle Distribution

isotropic particle toy MC

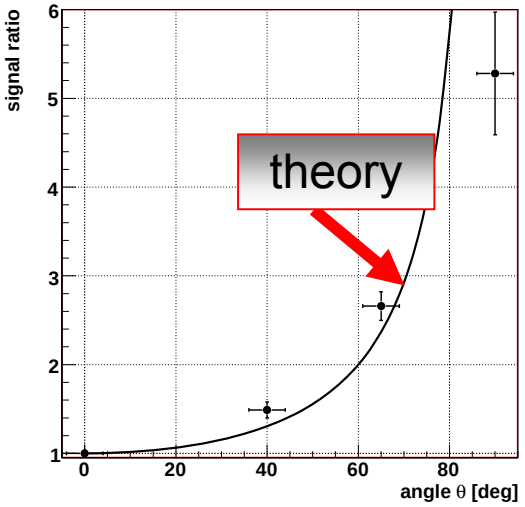




distribution of travelled paths in scintillator thickness: 0.8cm

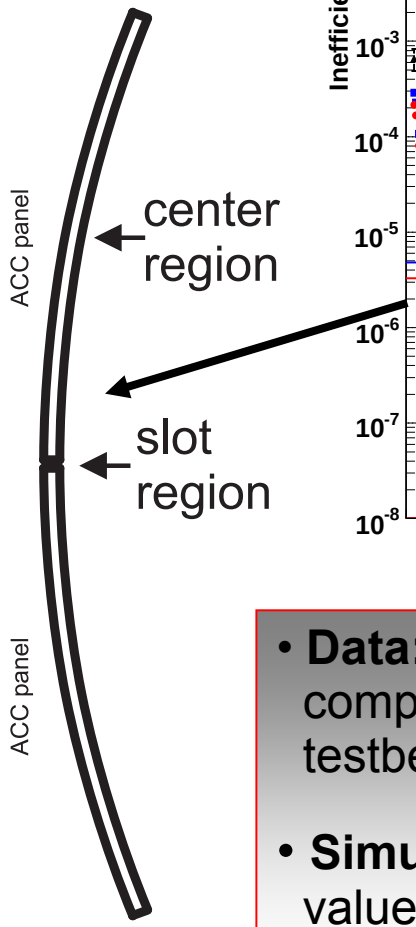


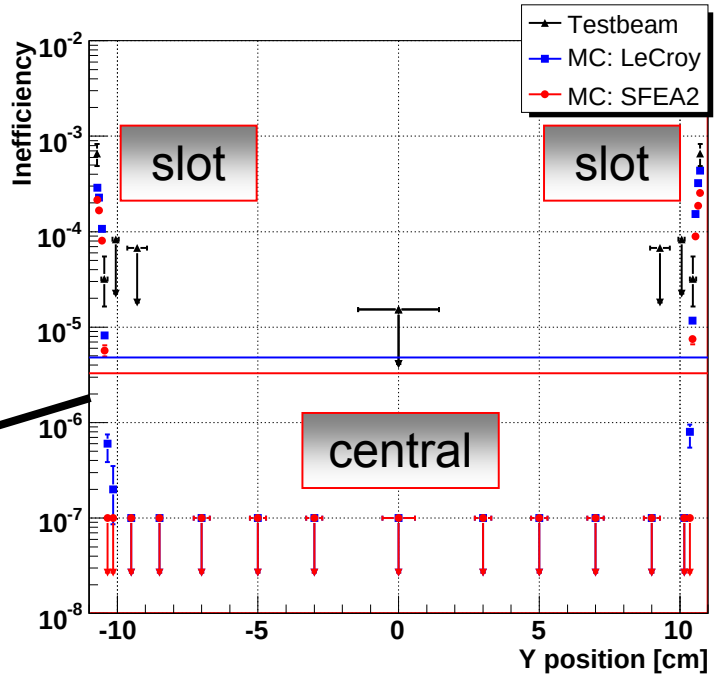
lab measurement of rel. signal vs. angle: **good agreement with theory**

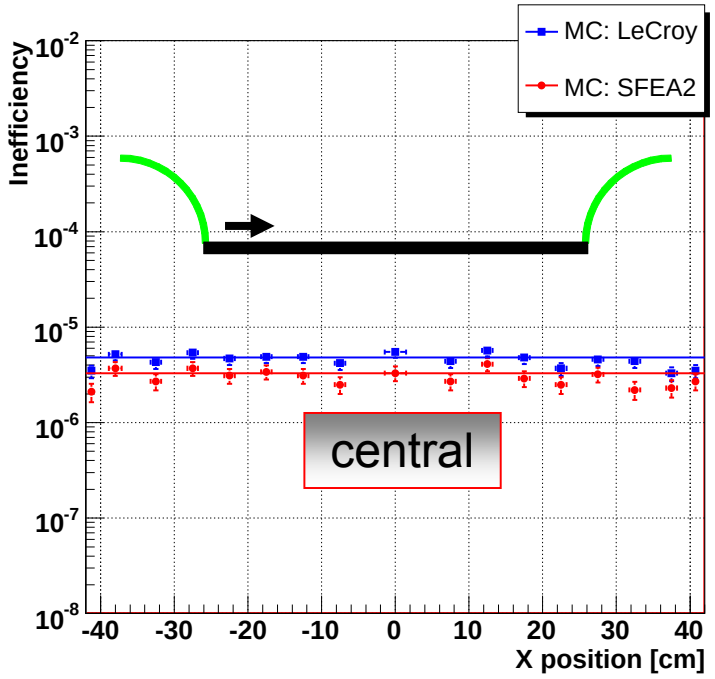


- **beamtest**: straight infall to panel
- **space**: isotropic particle distribution leads to **longer** path lengths in scinitillator

Inefficiency Model

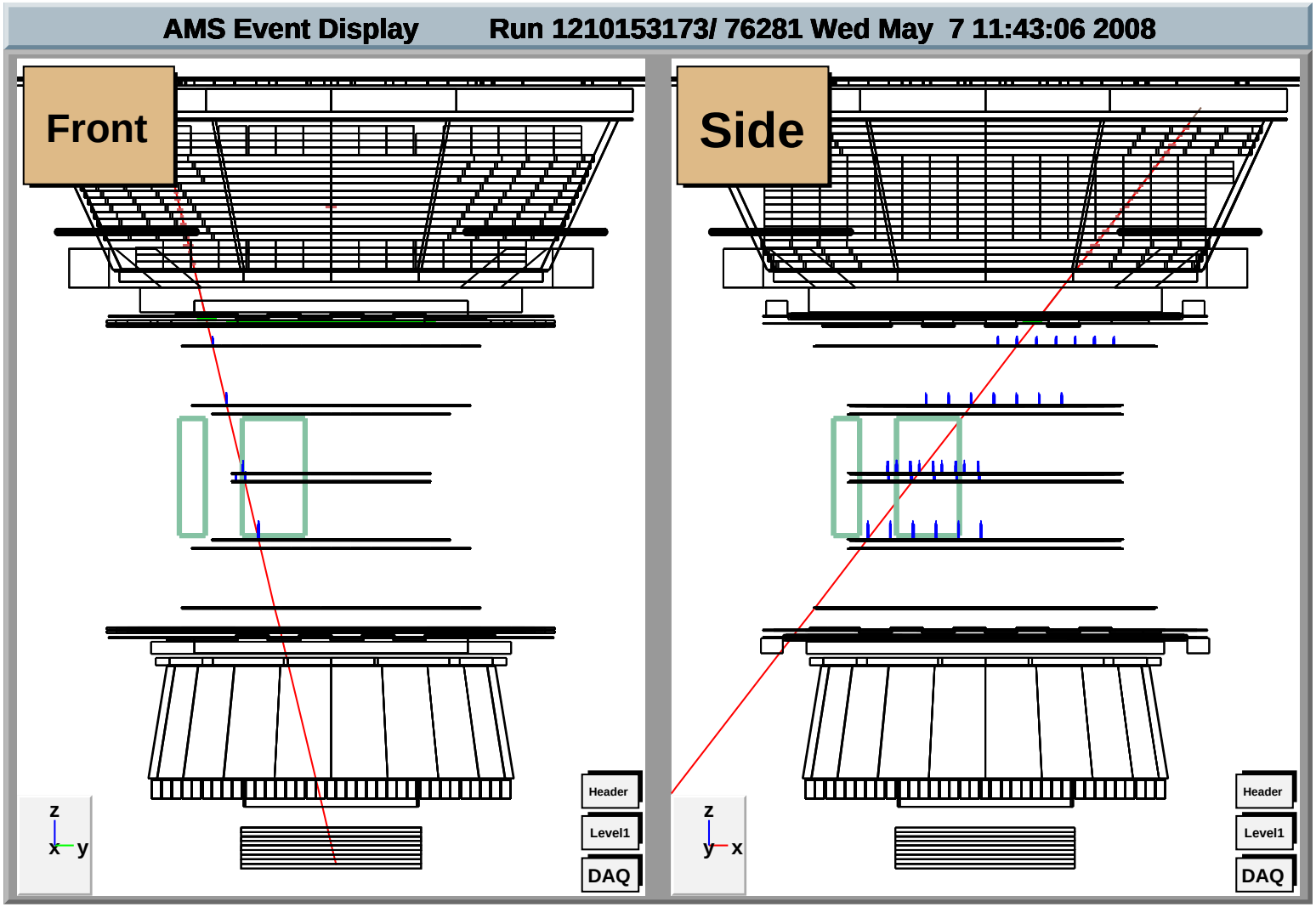




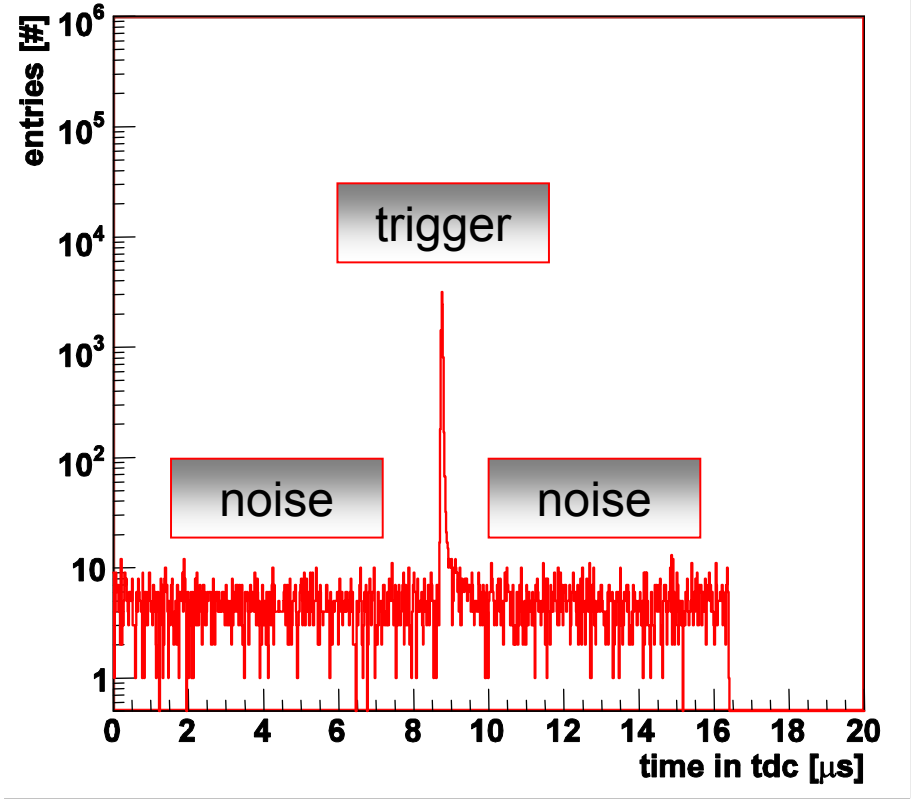


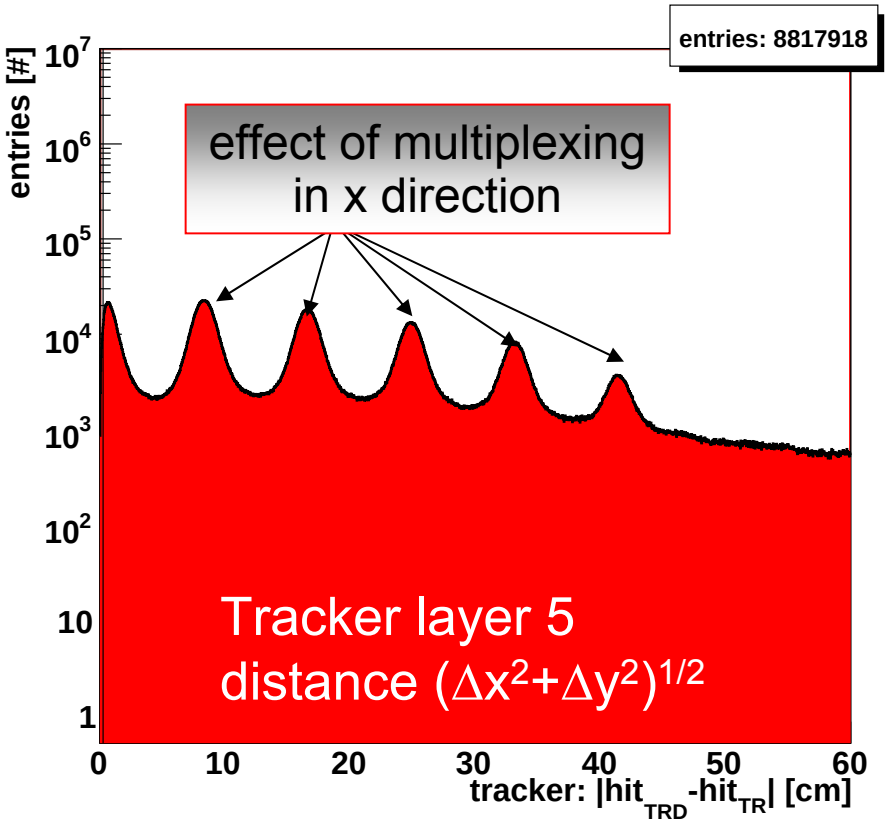
- **Data:** Mean inefficiency for **one complete ACC panel** with complete system test results and isotropic particle distribution and testbeam electronics: **$5 \cdot 10^{-5}$**
- **Simulation:** use of testbeam spectra with extrapolation to small values, system test, flight electronics, position measurements, isotropic particle distribution, smearing of signal values: **$5 \cdot 10^{-6}$**

AMS-02 Cosmics: Eventdisplay



Event Selection

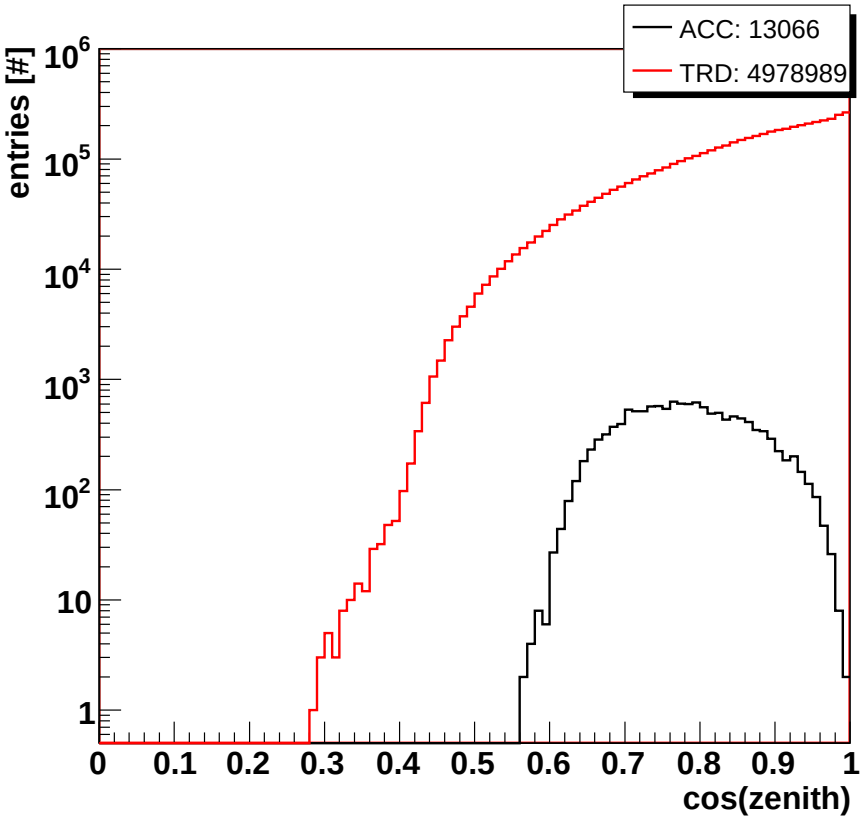




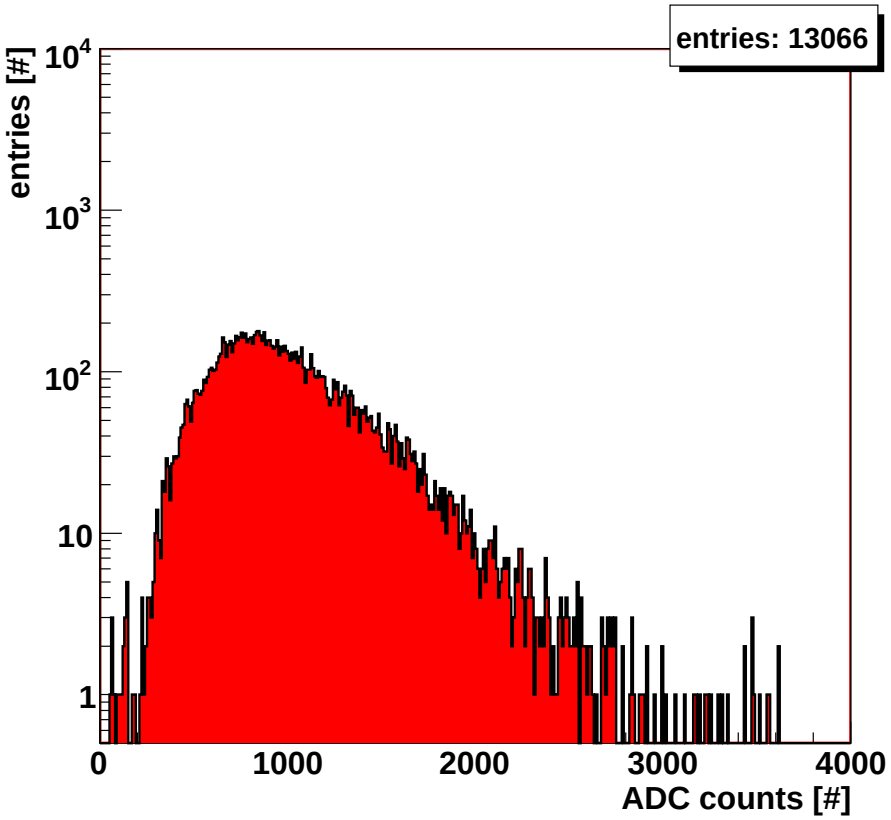
time of hit in TDC for 1 hit per event
require for selection at least one hit within 80ns of trigger

matching of TRD track with tracker:
- **at least two tracker hits within 0.25cm**
- **one hit within 0.25cm in last layer before extrapolated hit position in ACC**

AMS-02 Cosmics

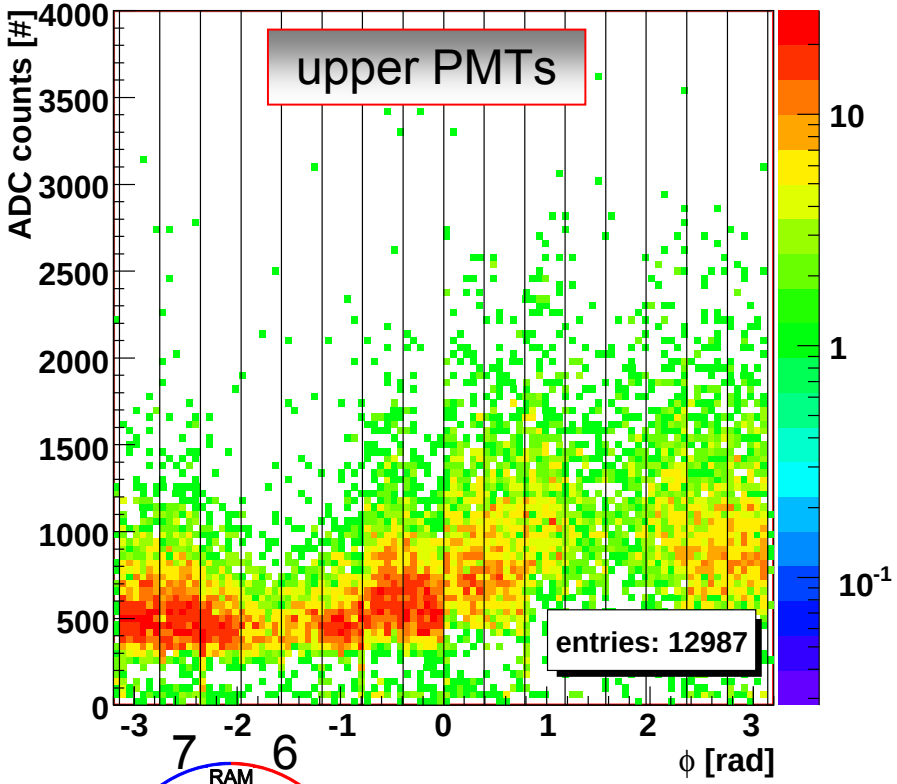


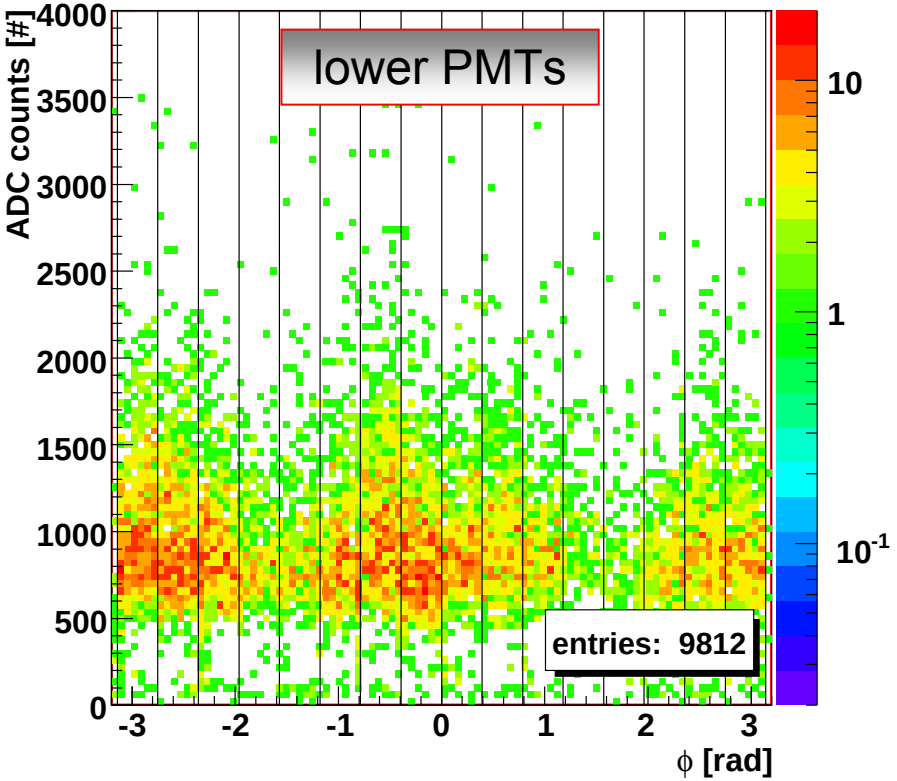
zenith angles for all good TRD
and for ACC events surviving all cuts

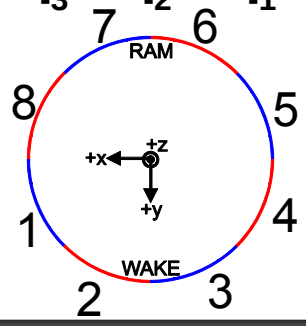


highest ADC value for each
event surviving tracker cuts:
no events below 30 (3RMS)
Inefficiency < $7.7 \cdot 10^{-5}$

AMS-02 Cosmics: Signals

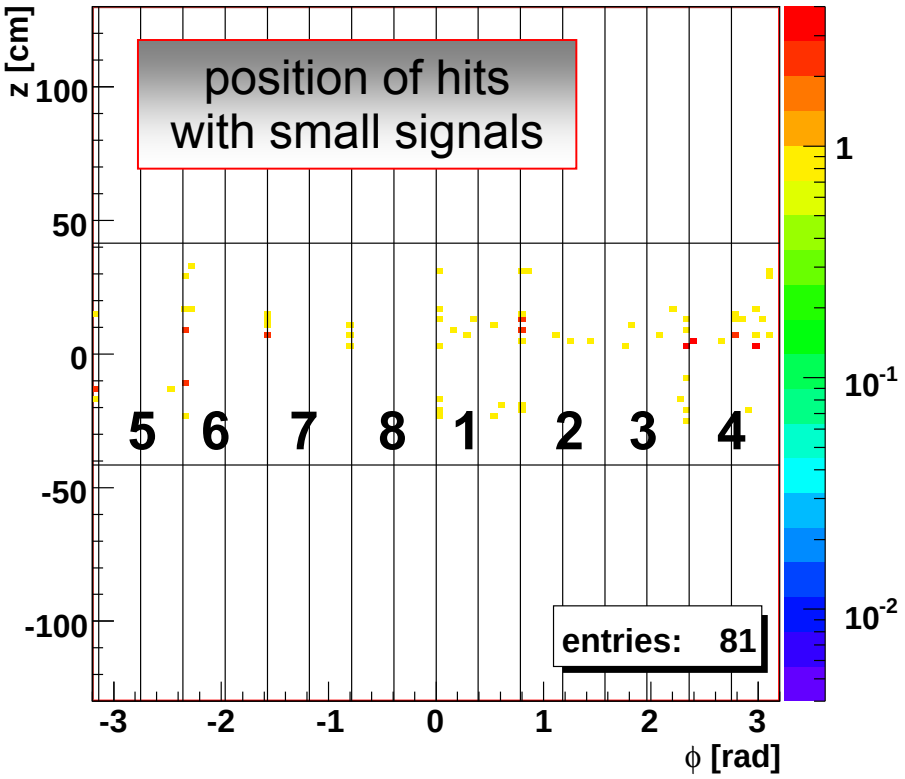


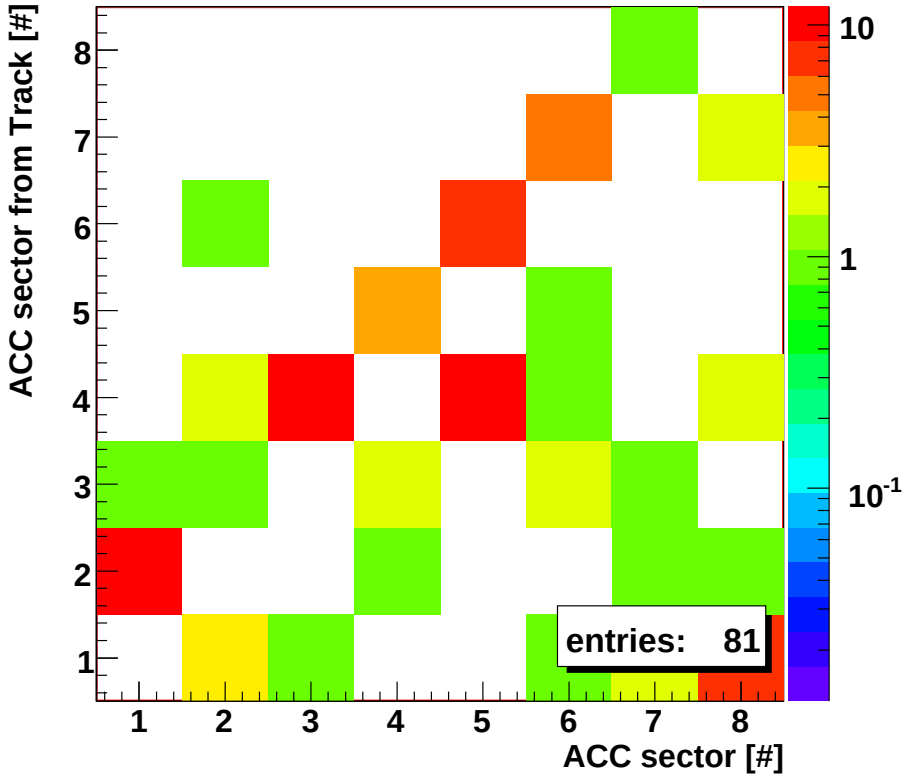




not very well configured:
- mix of EM, QM and FM
- different settings and conditions

Position Matching: ACC/Track



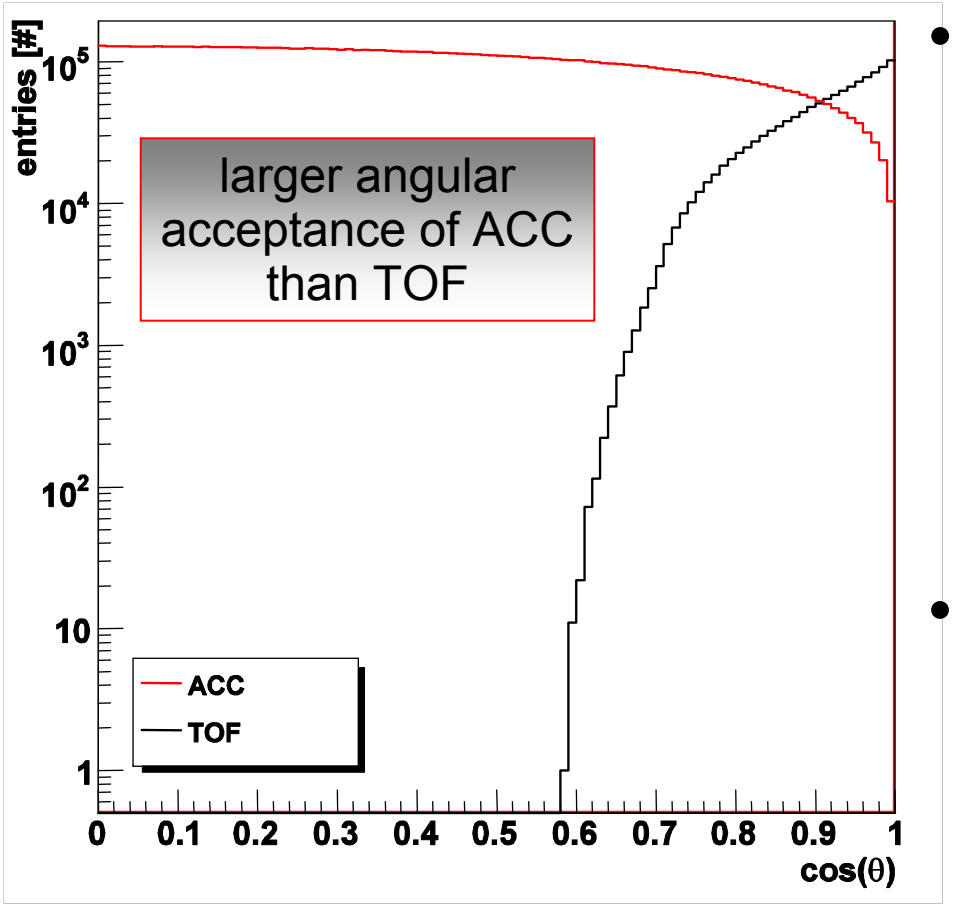


position of hits below 30 very close to adjacent panel:

- adjacent panels show normal signals
- TRD/tracker matching not precise enough
- scattering in detector

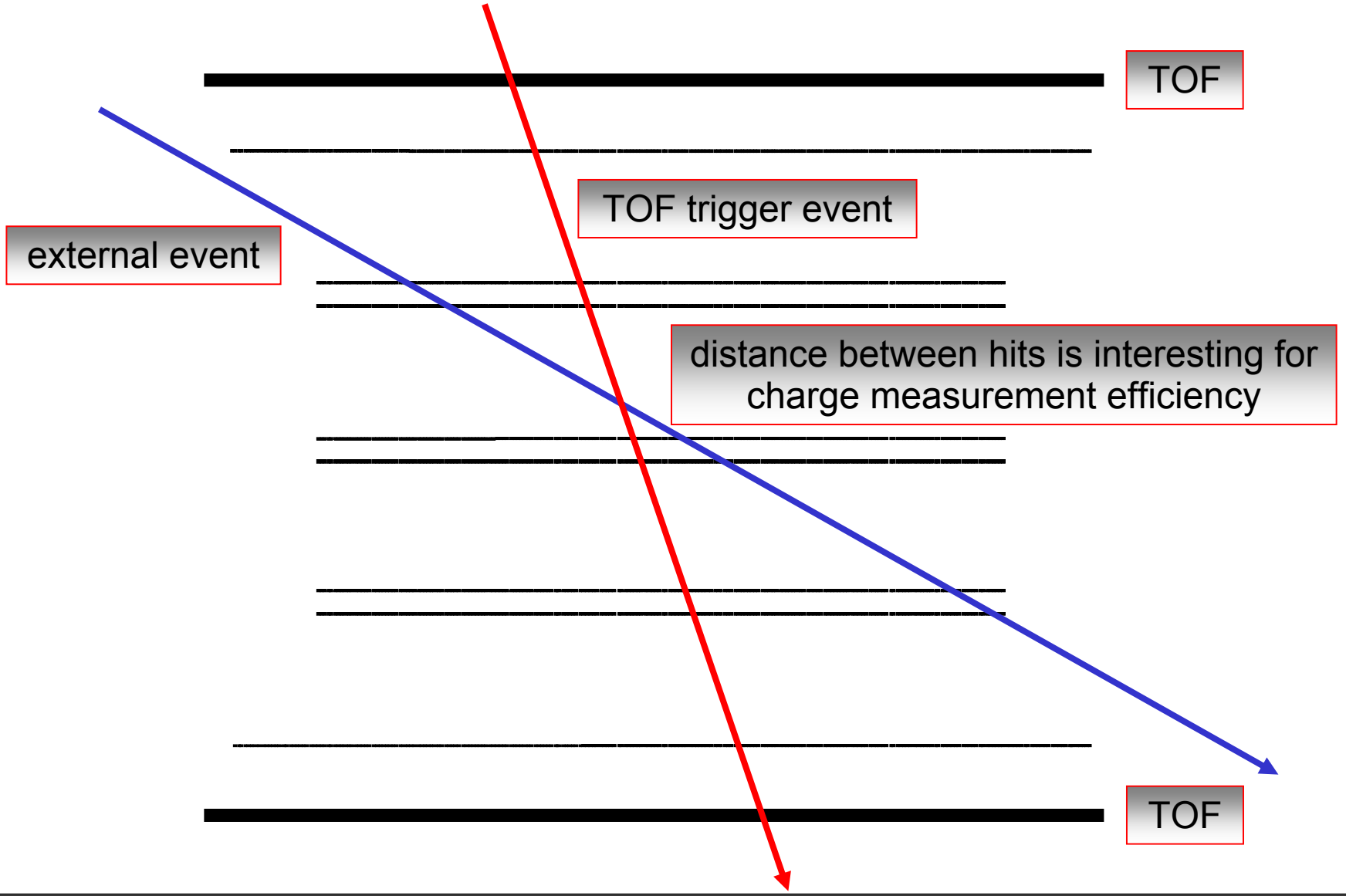
no events missed
out of 13000 ACC events
considering the complete ACC

Antihelium with AMS-02

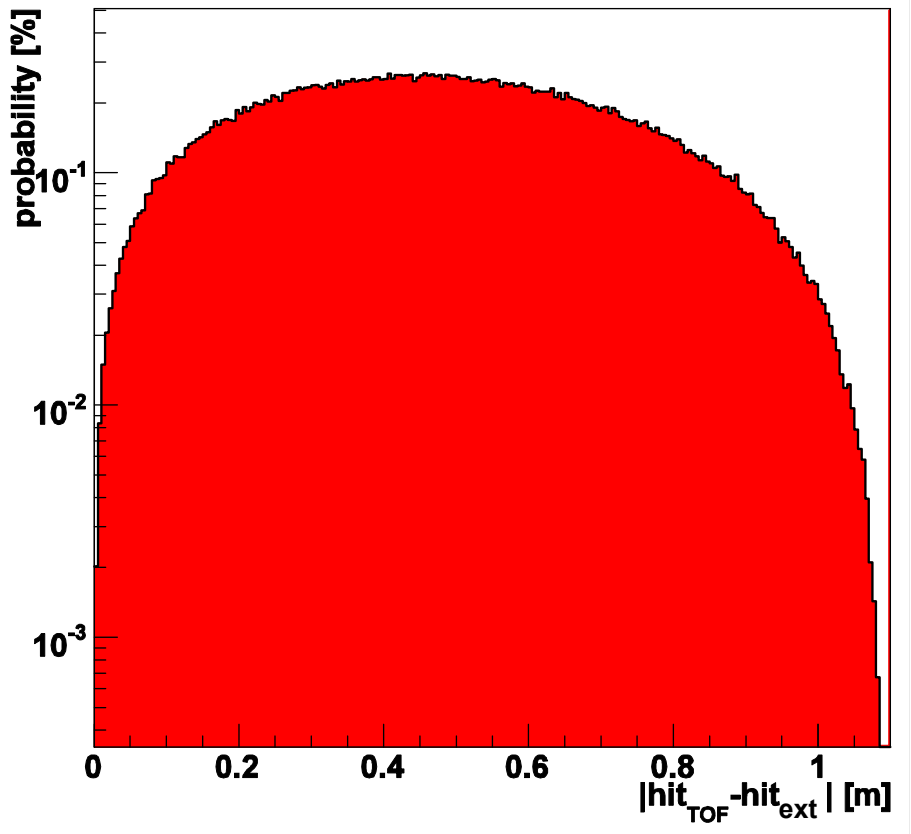


- check for the ability to measure particles between triggers with the ACC which could **spoil the charge determination**
- **toy MC with TOF, Tracker and ACC** with isotropic particle distribution and without magnetic field

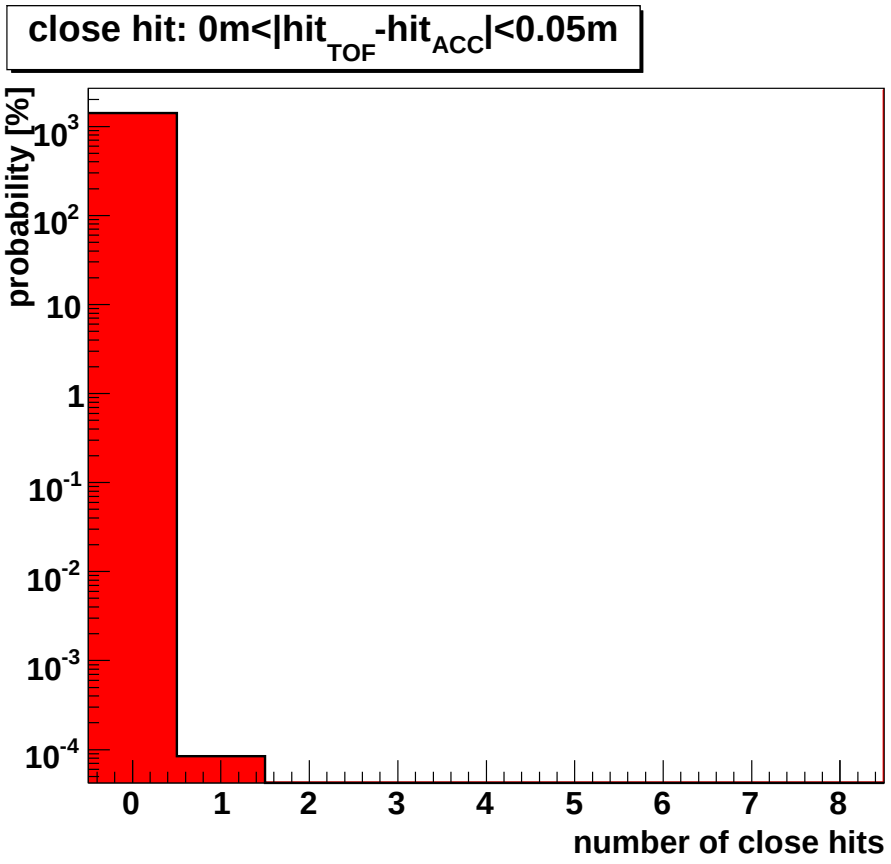
Antihelium with AMS-02



Antihelium with AMS-02



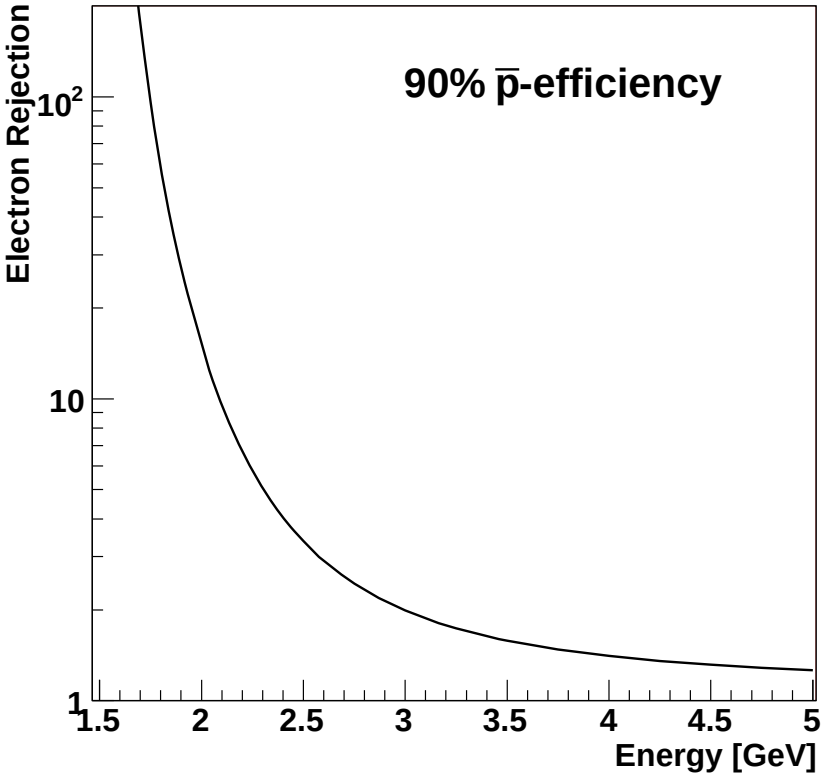
distance in tracker layers between TOF trigger events and external events

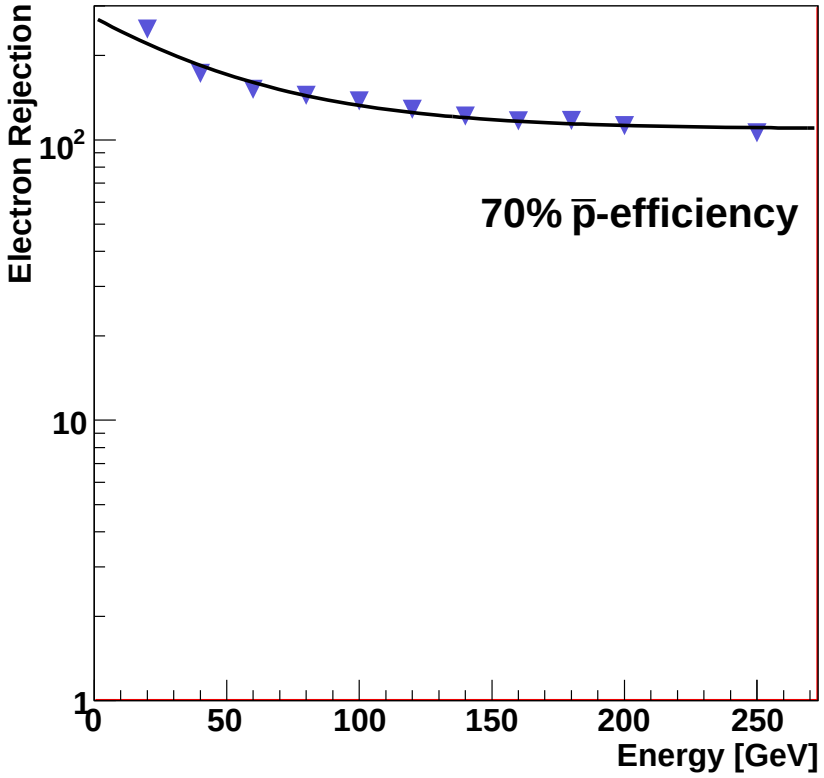


probabilty for close hits (<5cm) not longer than 80ns from trigger @ 2kHz

external hits can be nearly completly excluded to spoil charge measurement

Antiprotons with TRD, TOF and Tracker

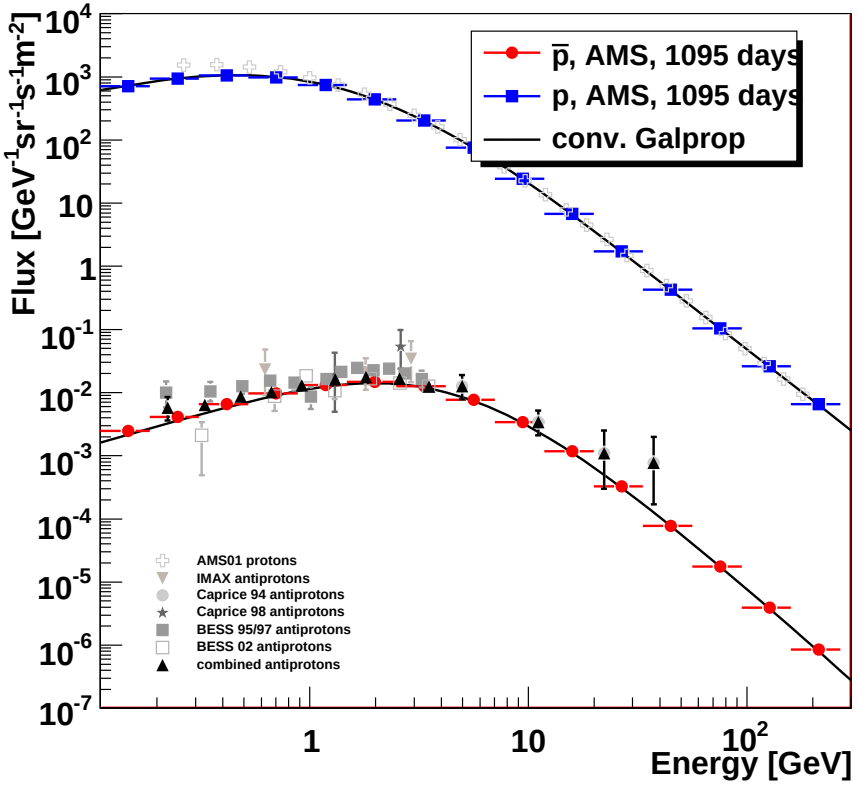


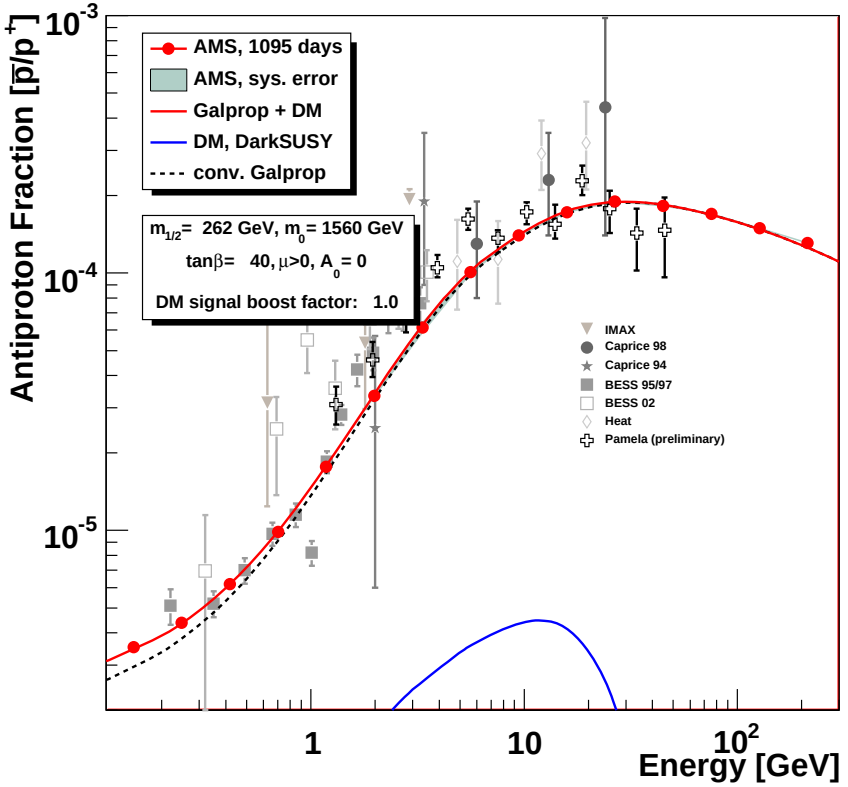


electron rejection from time resolution of TOF (100ps) due to different masses

electron rejection from TRD from Lorentz factor γ=E/m due to different masses

Antiprotons with TRD, TOF and Tracker



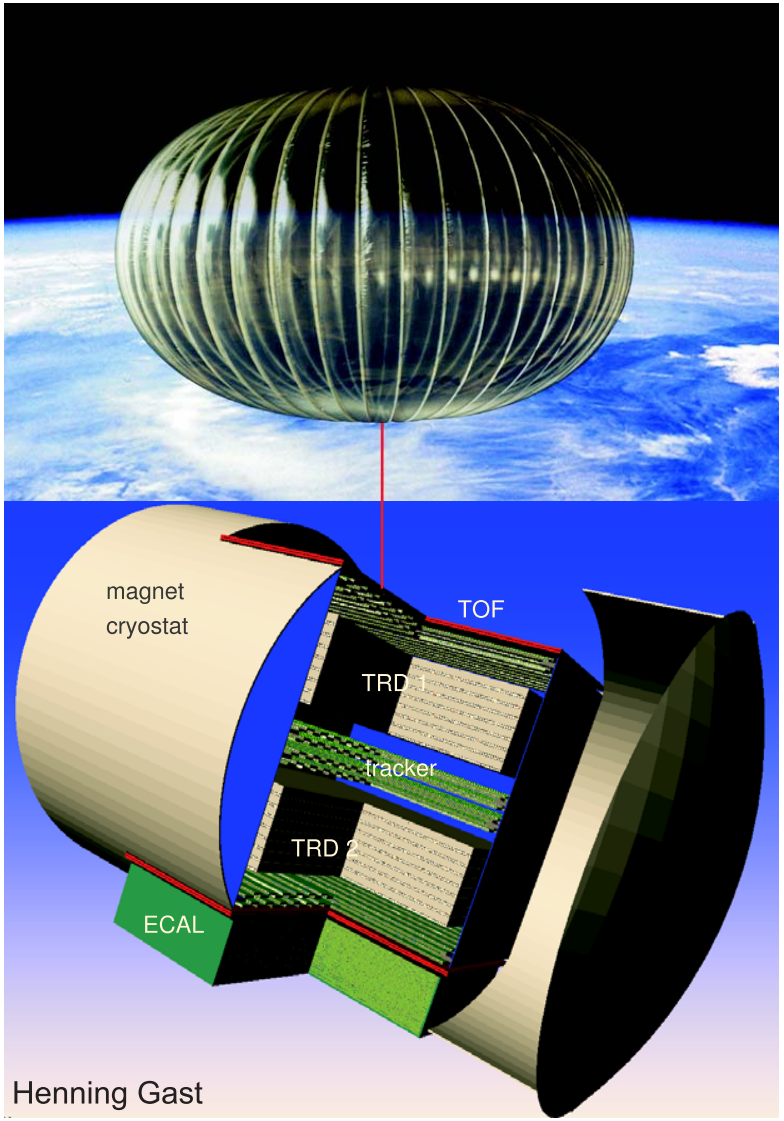


measurement over 3 years with:

- acceptance = 0.4m^{2}sr
- 63% efficiency
- 10% systematic errors to the knowledge of detector properties
- tracker resolution is not important in this energy range (σ_p=0.04%/GeV·p⊕1.5%)

good measurement of antiprotons without electromagnetic calorimeter possible

PEBS – Cosmic Rays in the Atmosphere



Positron

Electron

Balloon

Spectrometer

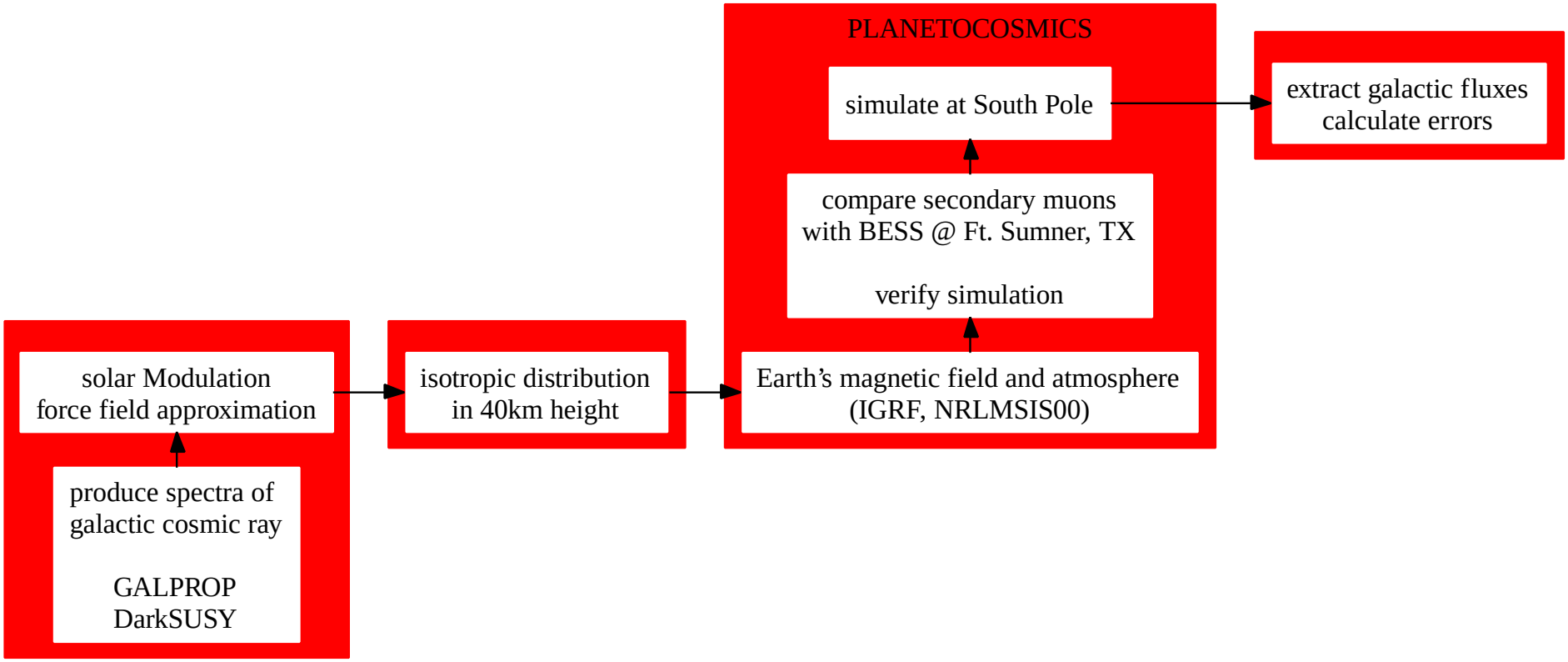
detector proposal:

- cosmic ray measurements @ North- or Southpole
- balloon in 40km altitude in the atmosphere and magnetic field

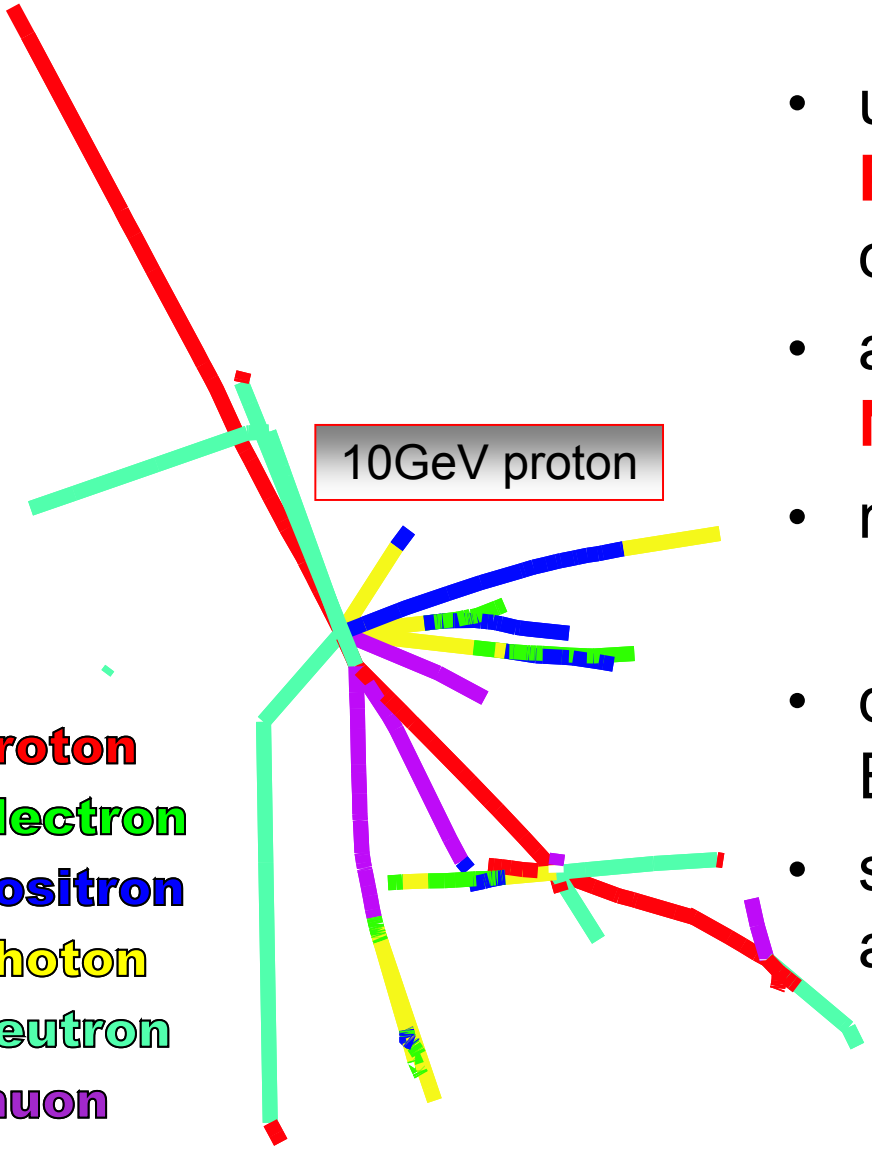
detector properties:

- flight time: 100days (total)
- acceptance: $0.4 m^2 sr$
- magnetic field: 1T
- weight: < 2t

Analysis Scheme



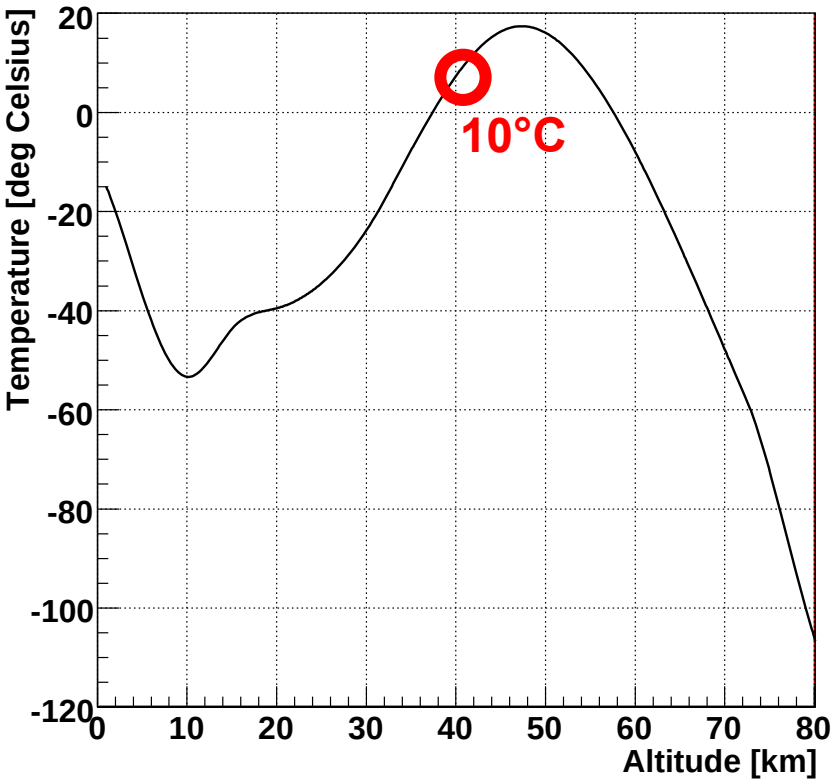
Air Shower



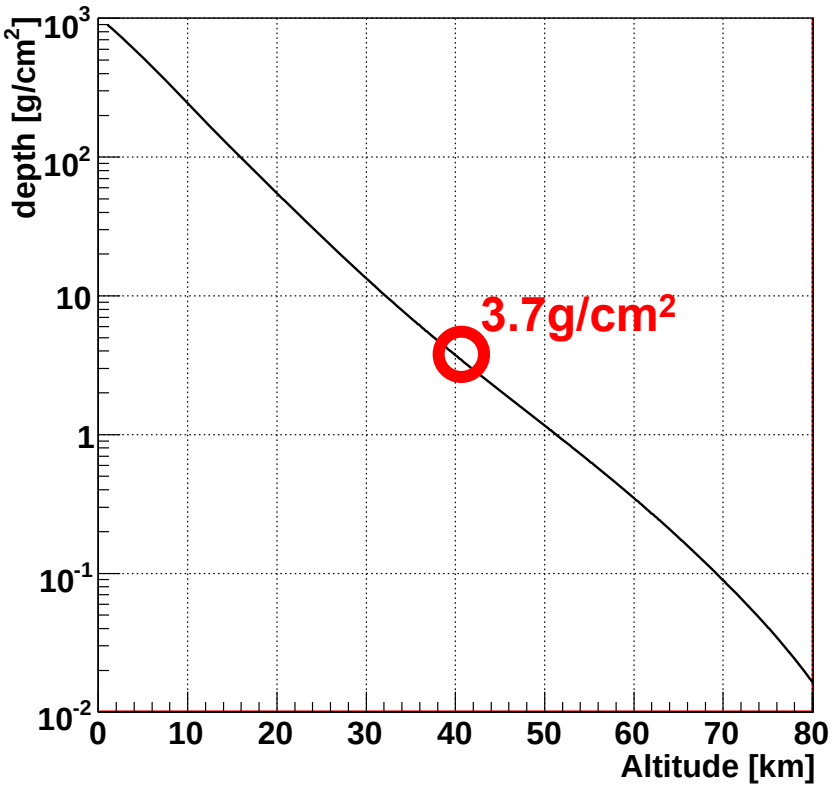
- use of program package: **PLANETOCOSMICS** based on GEANT4
- atmospheric model: **NRLMSISE00**
- magnetic field: **IGRF 2005**

- detection planes around the Earth
- start particles in 500km altitude

Properties of the Atmosphere

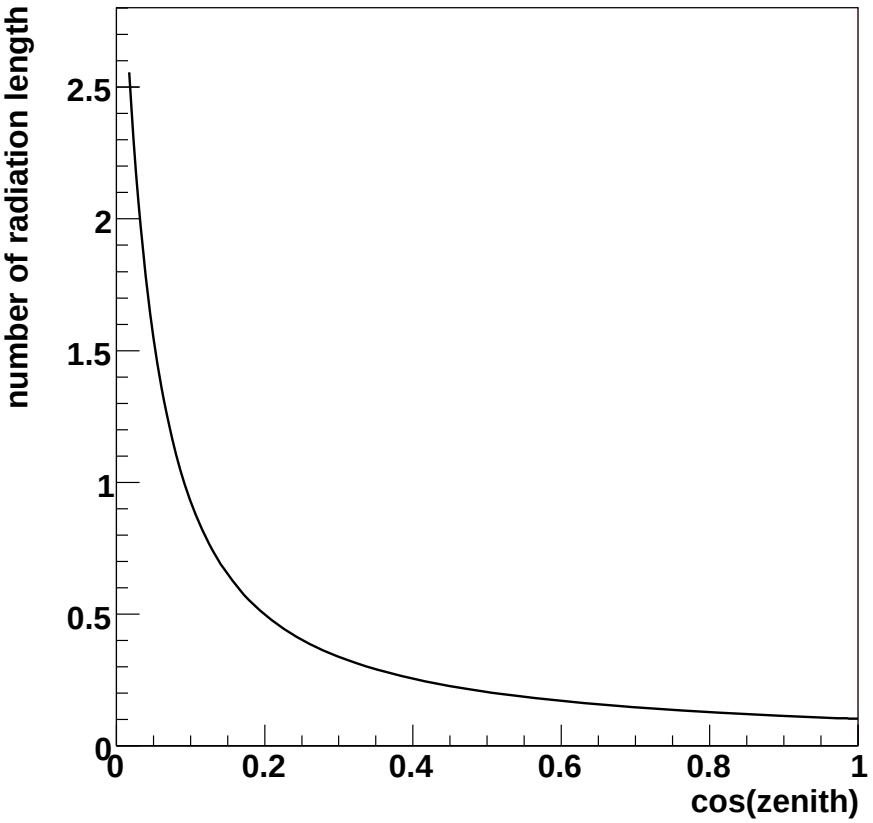


kinetic gas temperature of the atmosphere at latitude -75°, December (Southpole)

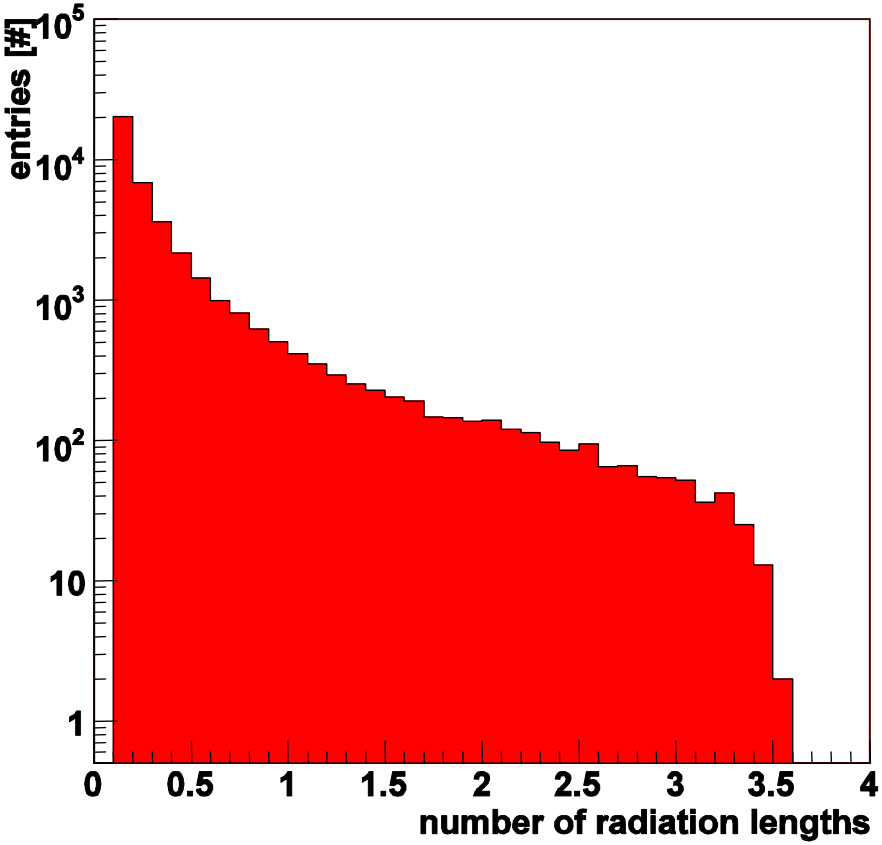


depth (integrated density) of atmosphere for zenith angle = 0°, latitude -75°, December (Southpole)

Radiation Lengths

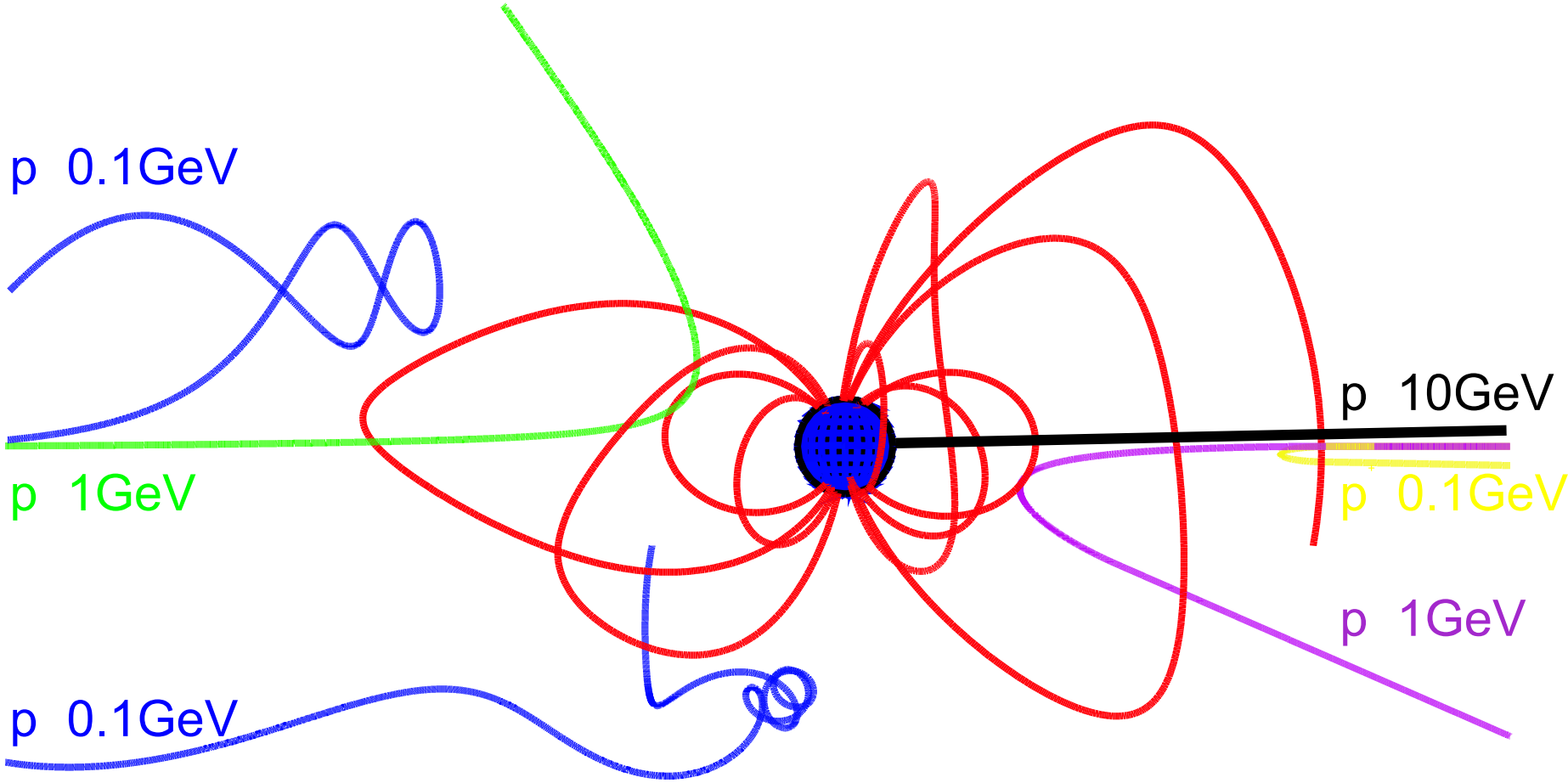


number of crossed radiation lengths depends on zenith angle

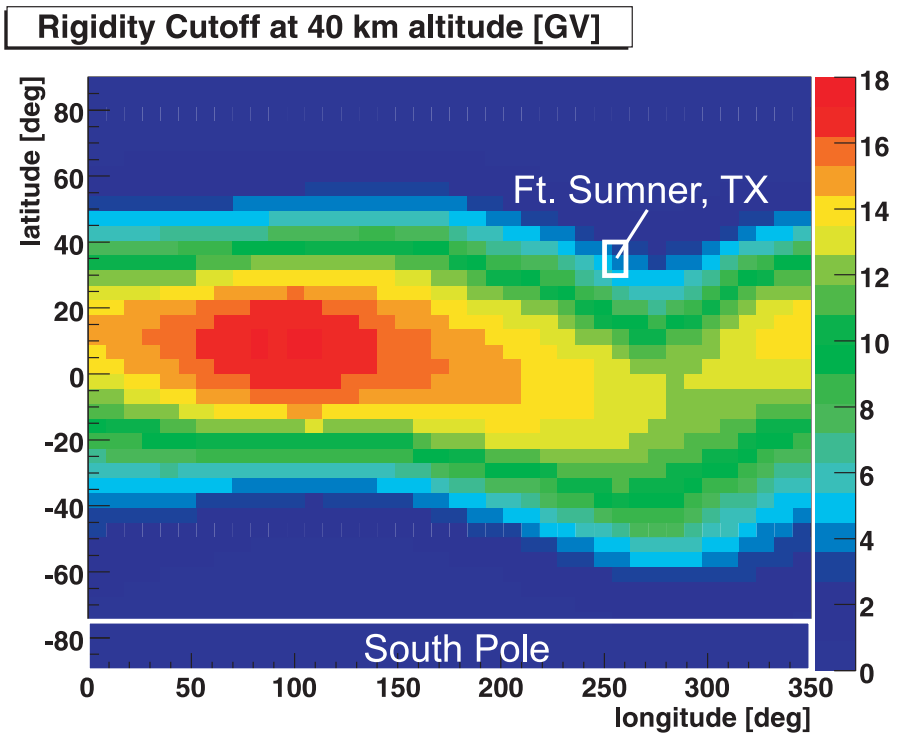


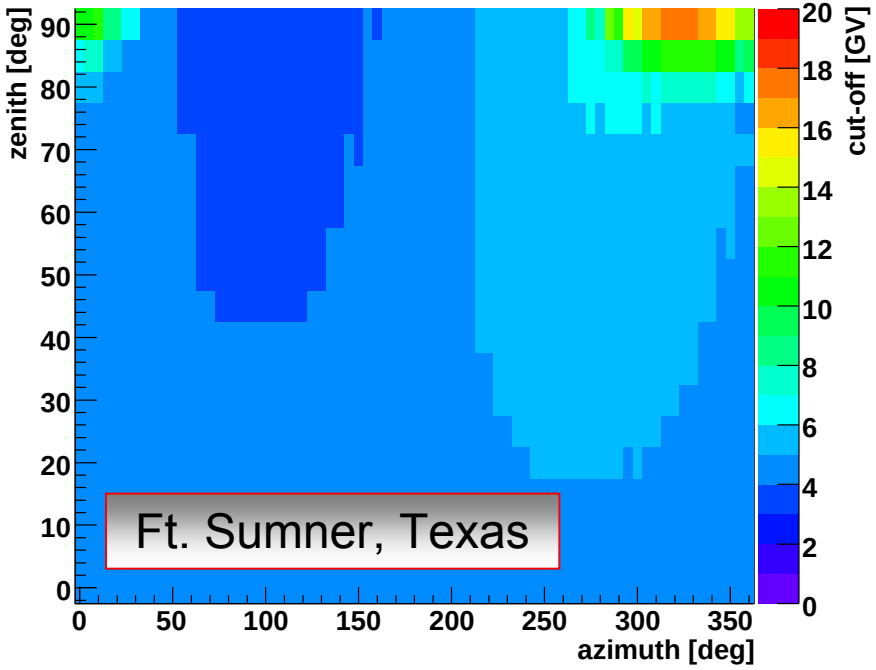
distribution of crossed radiation lengths before 40km during summer at Southpole using an isotropic particle distribution

Magnetic Field



Geomagnetic Cut-off

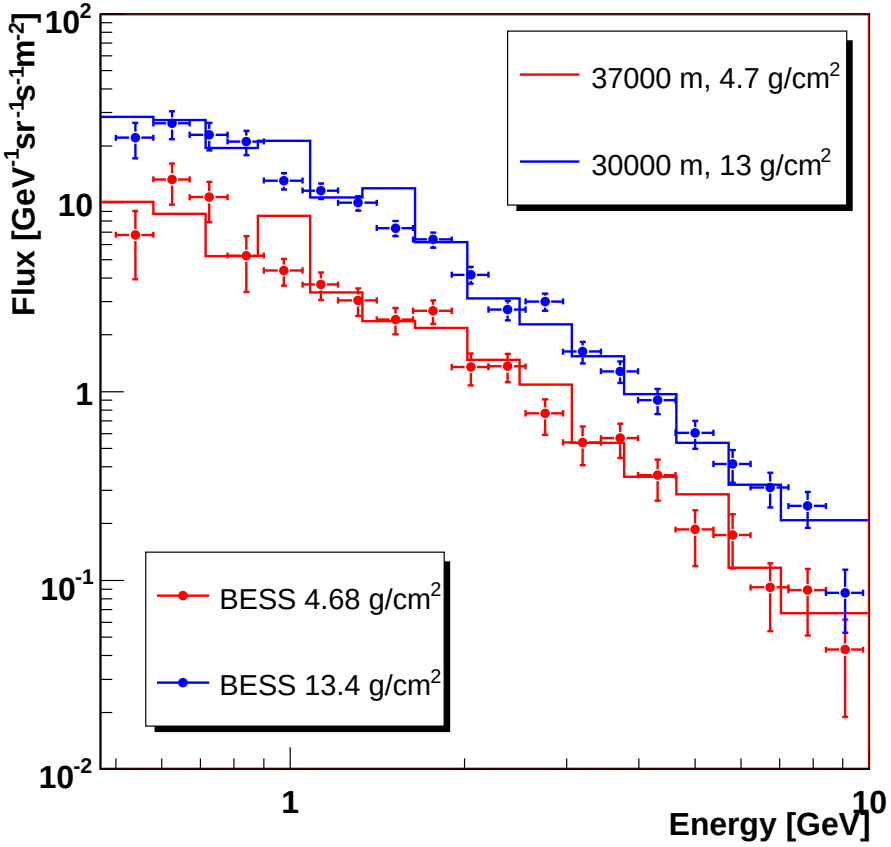


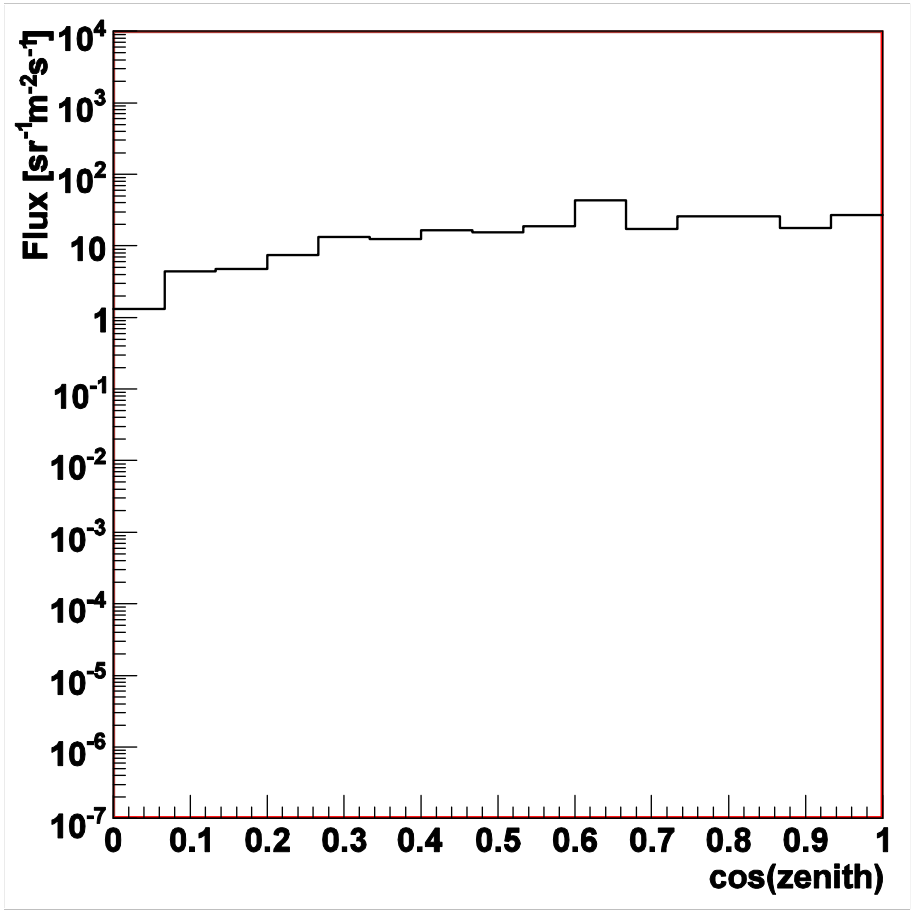


geomagnetic cut-off for particles with zenith angle = 0°

geomagnetic cut-off depends on zenith and azimuth at each location

BESS Muon Data in Texas



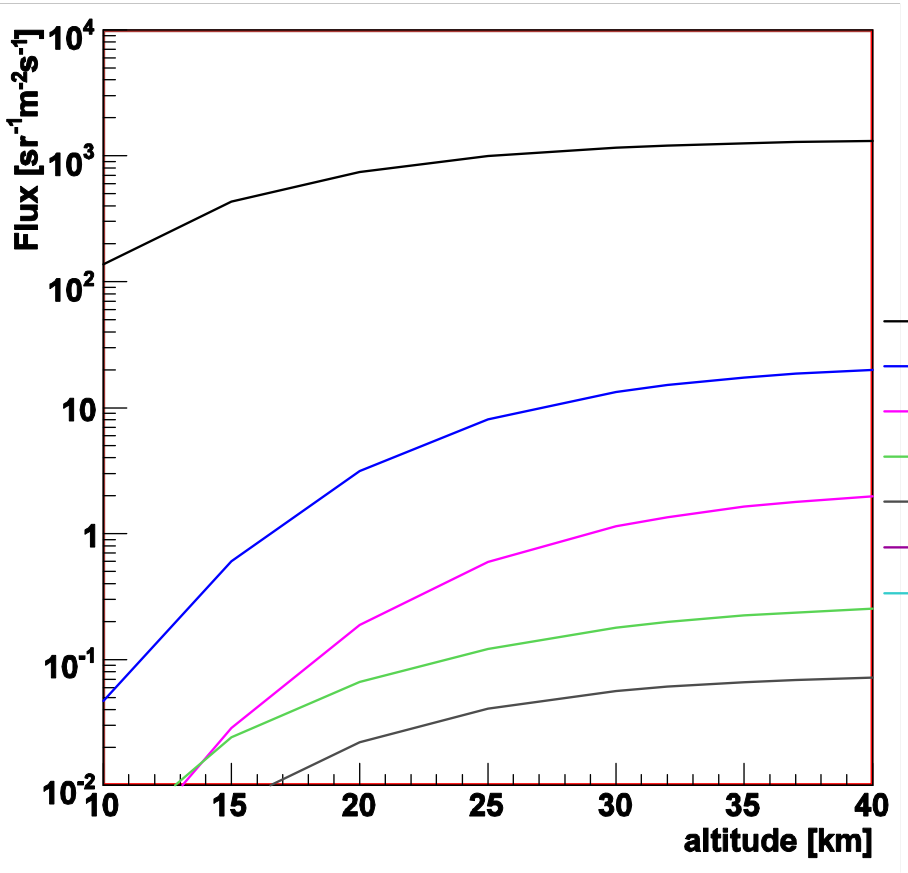


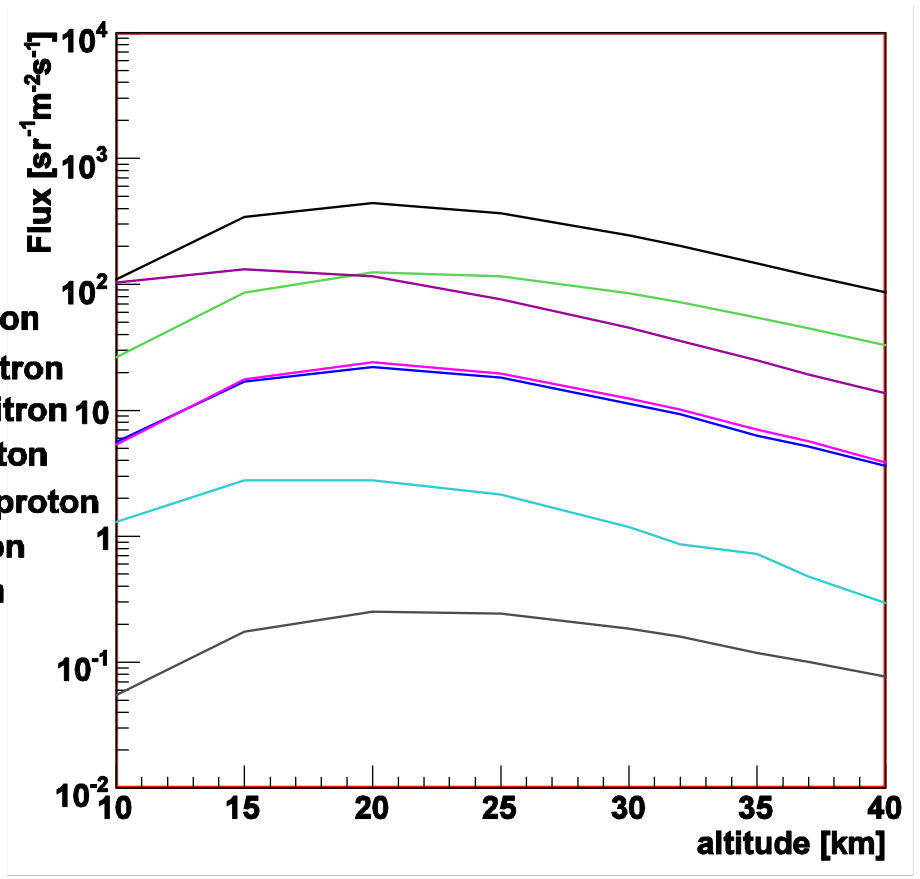
good agreement of simulated secondary muons with BESS data at Ft. Sumner

simulated angular distribution for muons in 37km altitude

Simulation works, now Southpole

Fluxes in different Altitudes

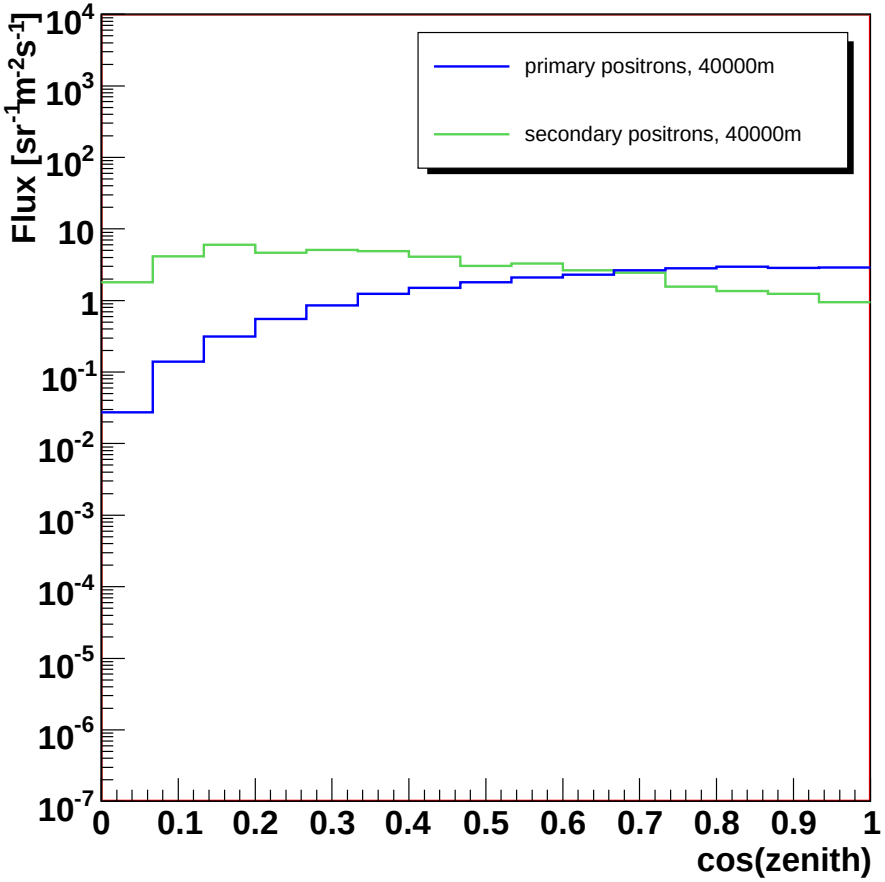




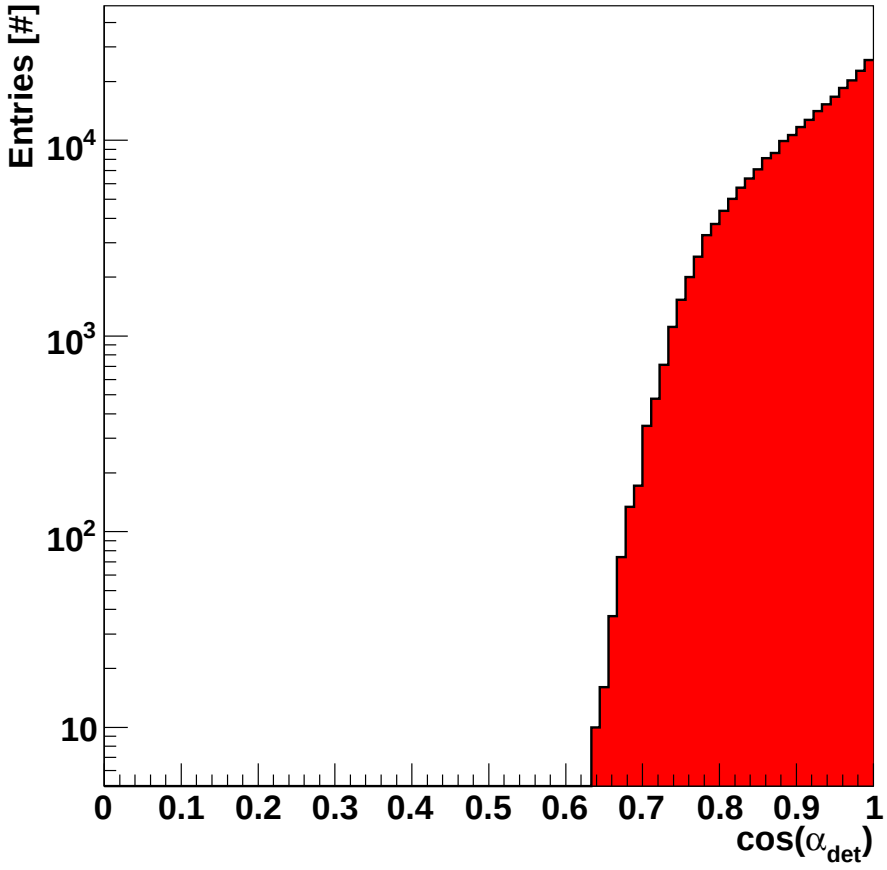
integrated flux (1-130GeV): primary particles

integrated flux (1-130GeV): secondary particles

Detector Acceptance

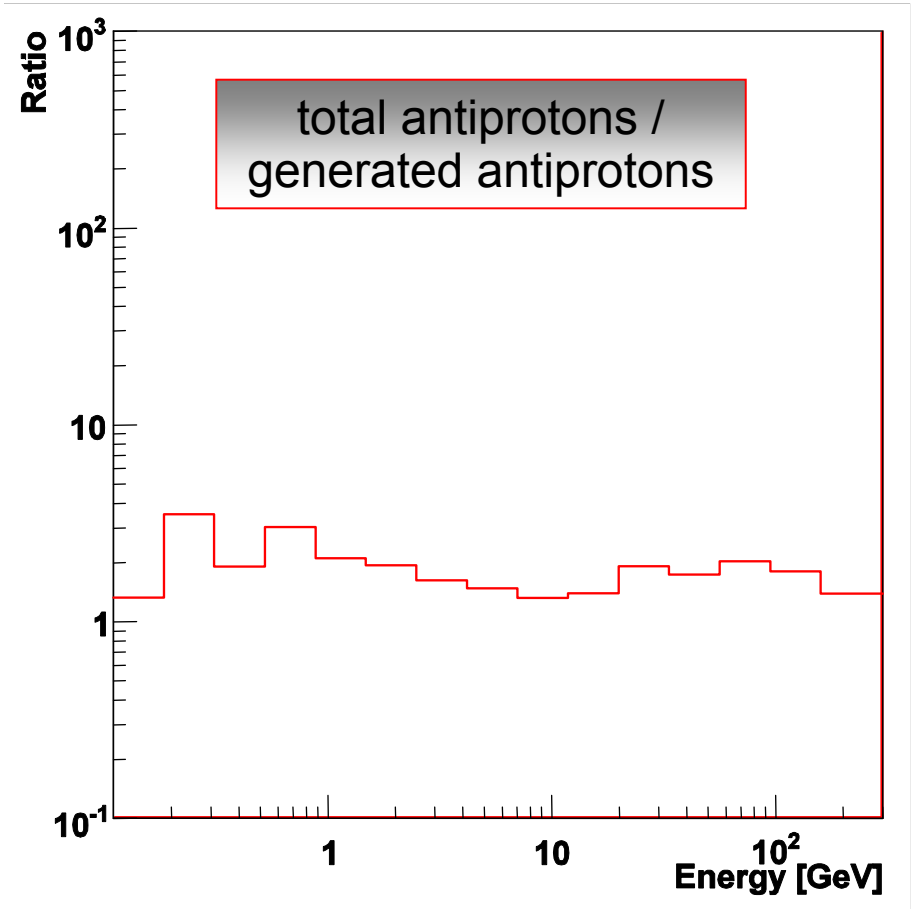


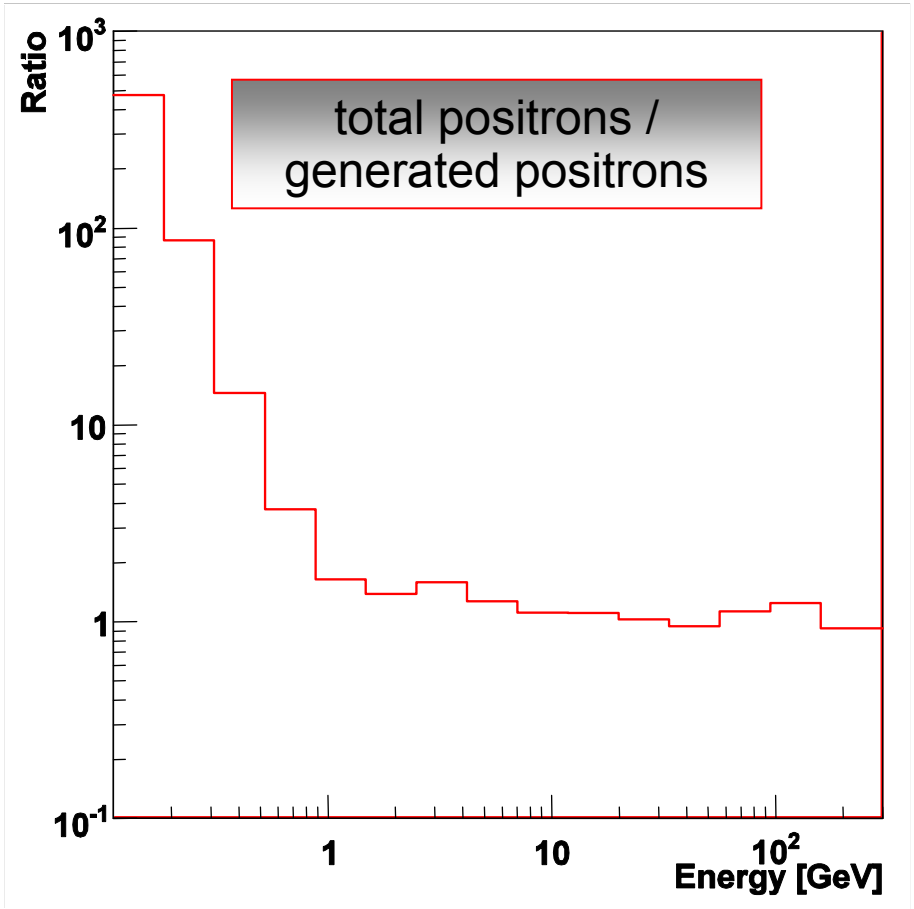
angular distribution of secondary and primary positrons



angular acceptance of PEBS works as filter on secondaries

Atmospheric Attenuation in 40 km

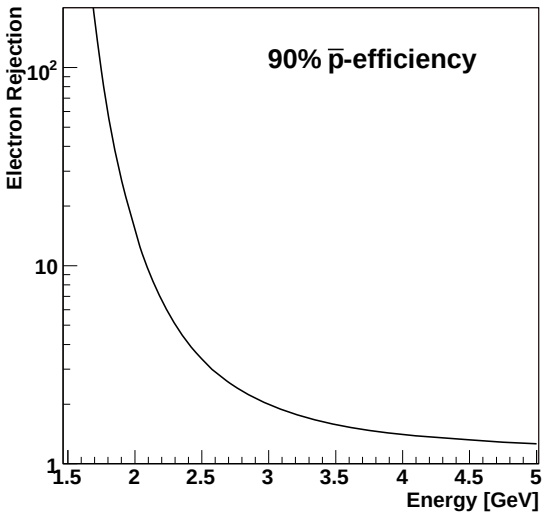


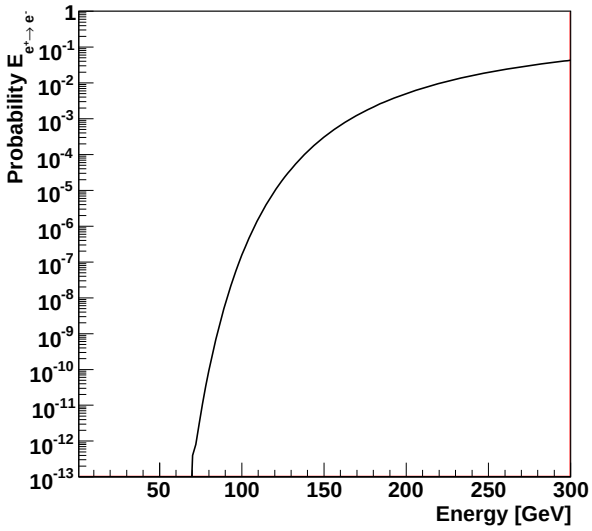


atmosphere is electromagnetically much more effective

Detector Properties

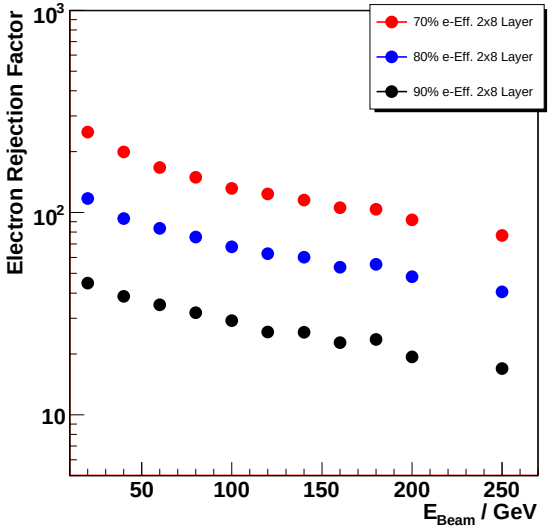
electron/ antiproton rejection from TOF

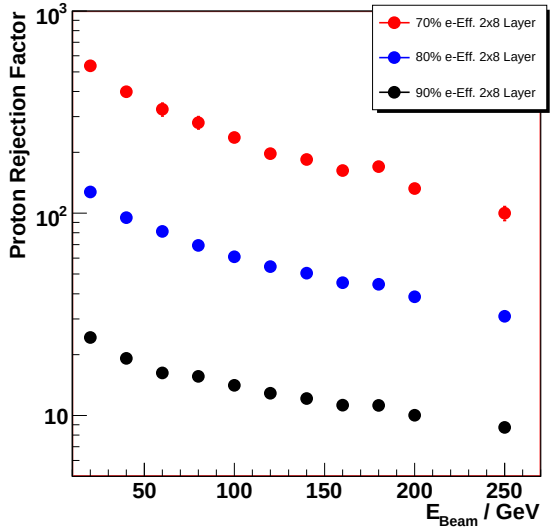




electron/ positron rejection from tracker

electron/ antiproton rejection from TRD

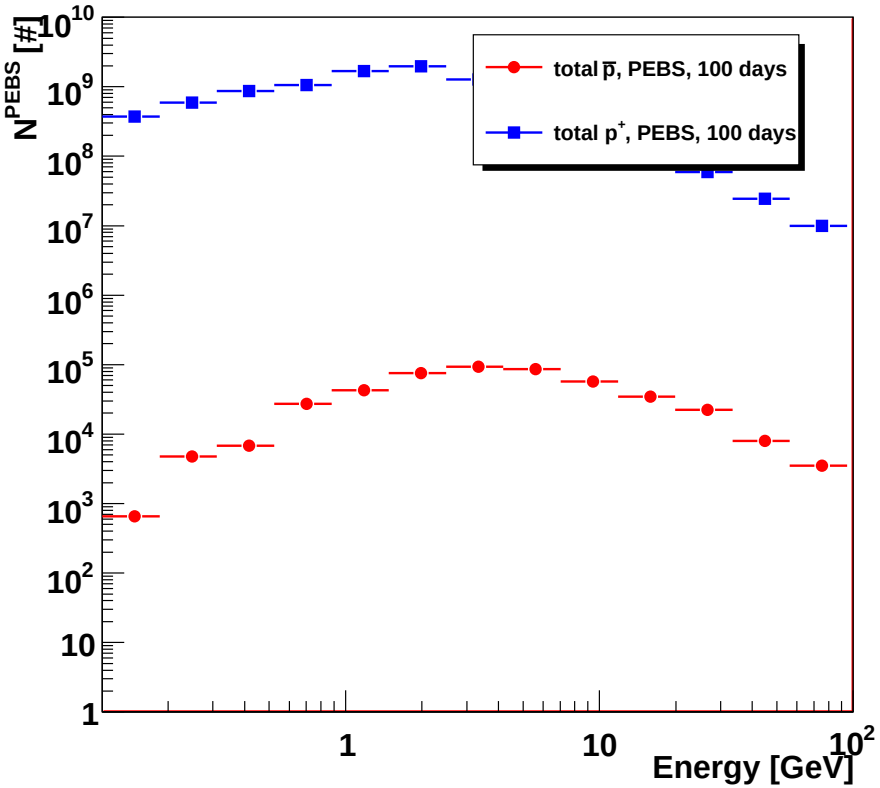




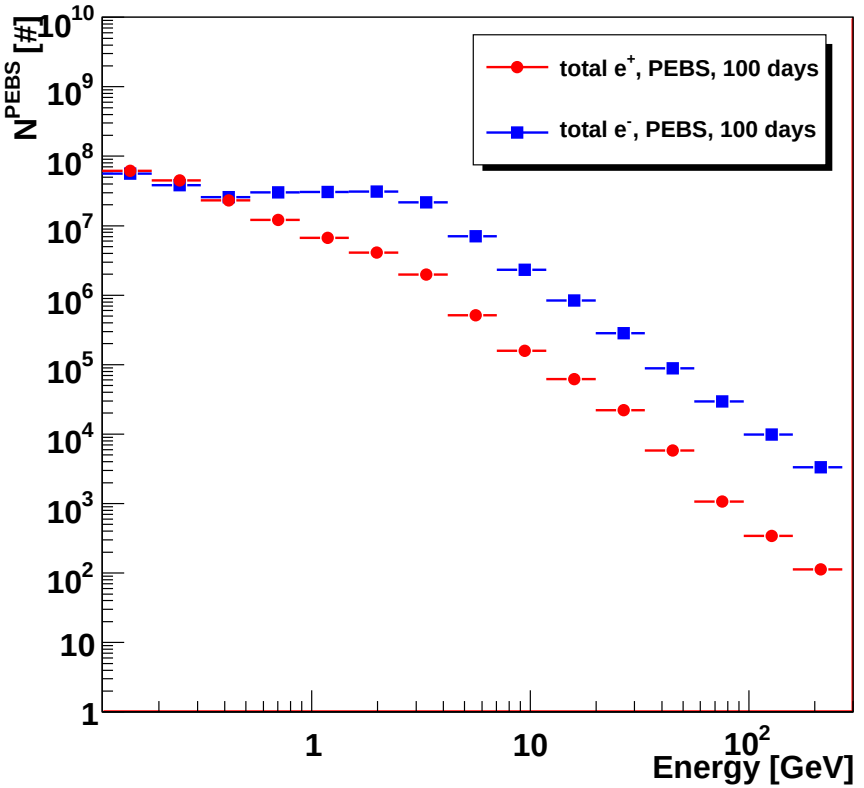
proton/ positron rejection from TRD

Ecal rejections
p^+/e^+ and e^-/p^-: 5000
(70% Efficiency)

Total Number of Particles

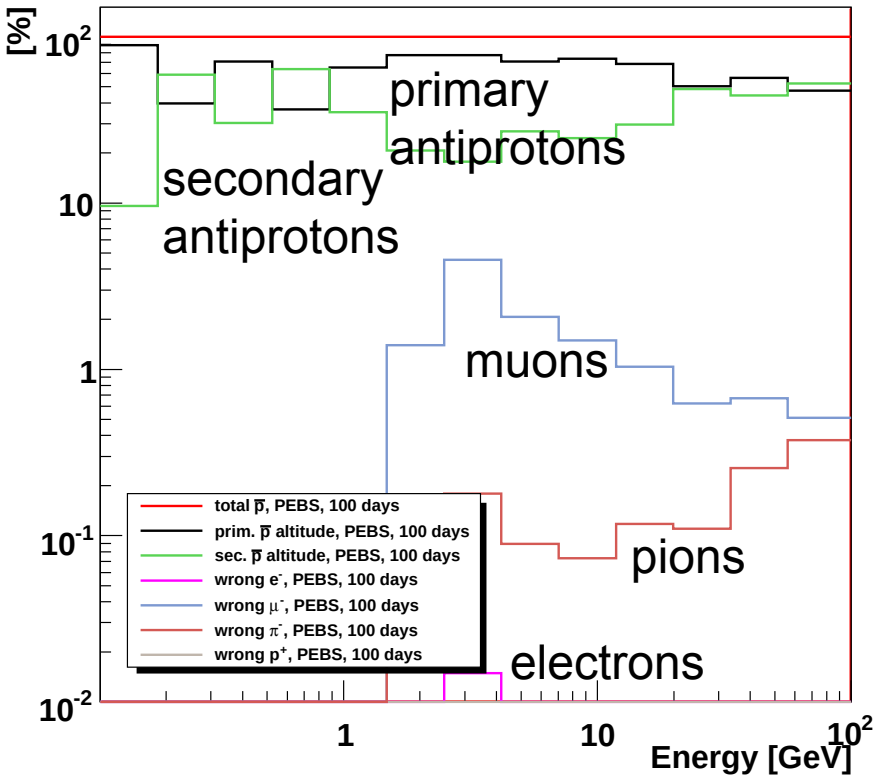


protons and antiprotons

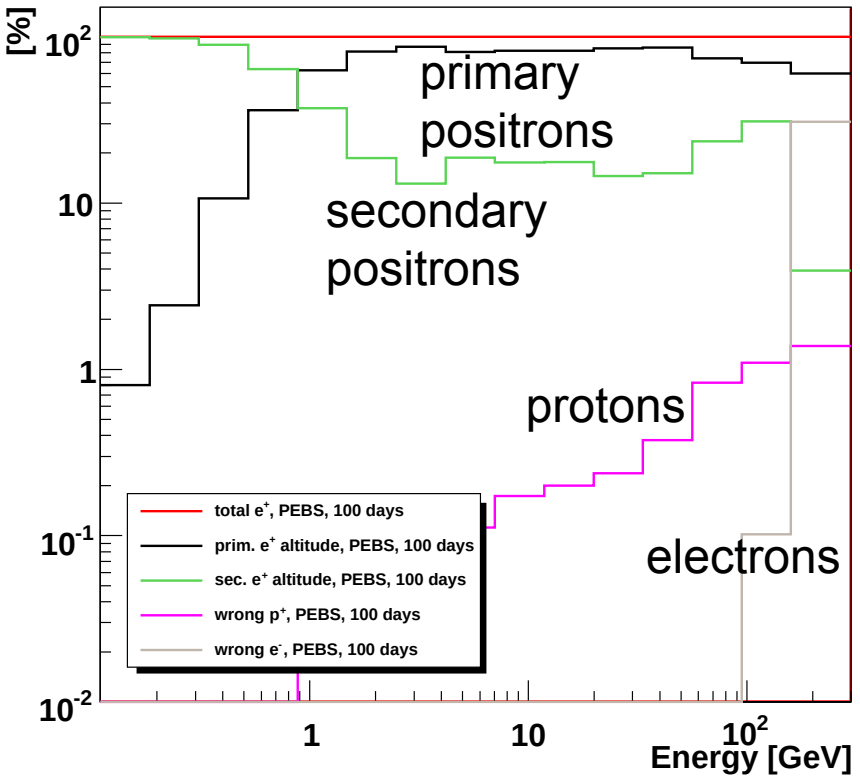


electrons and positrons

Composition



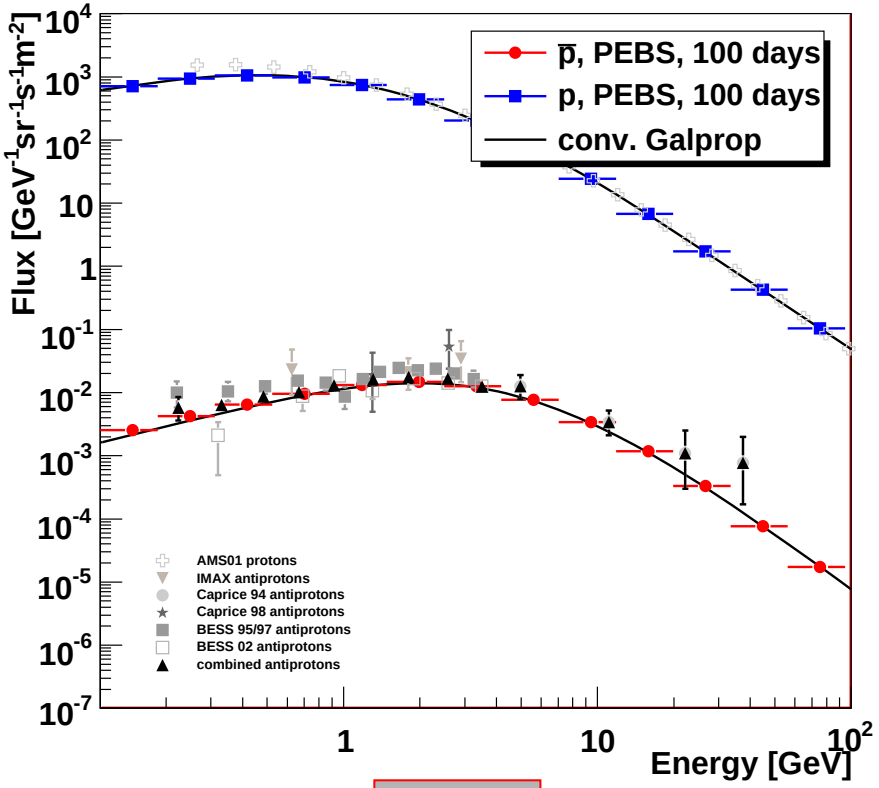
antiprotons



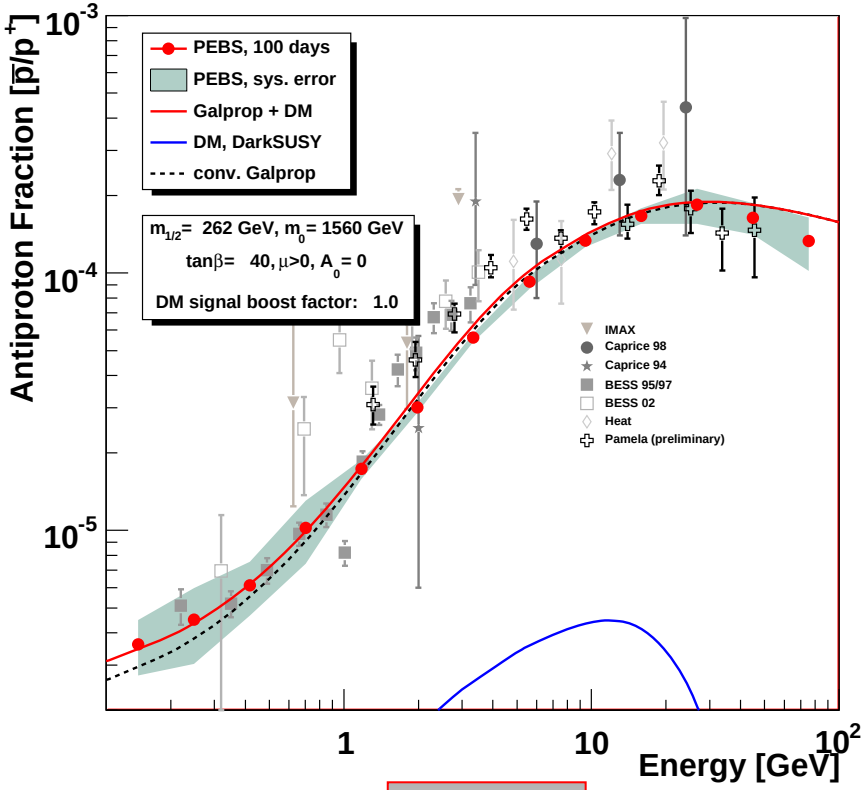
positrons

using the according rejections and efficiencies for each type

Antiprotons



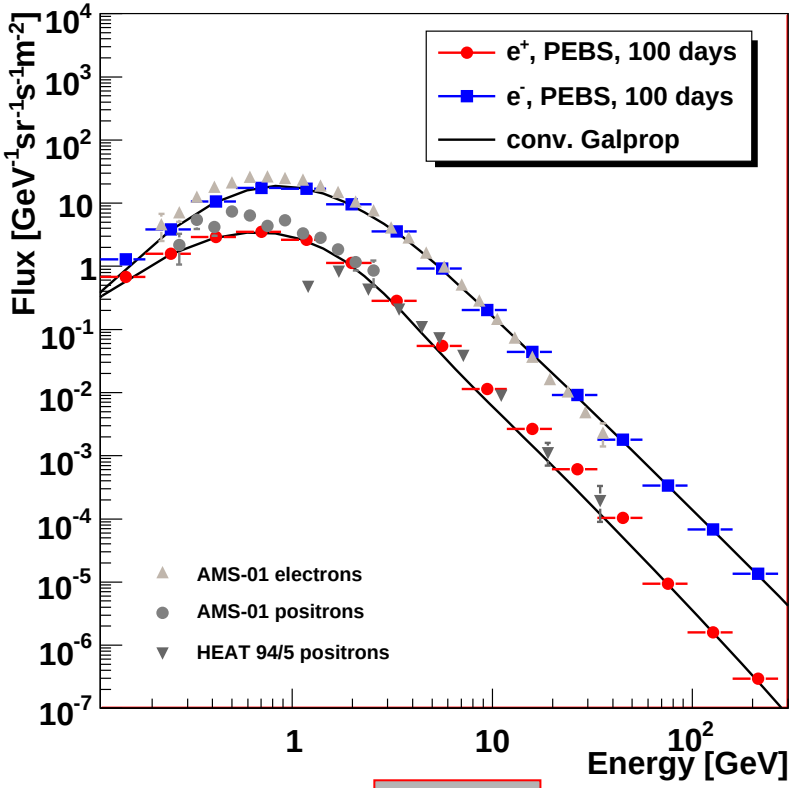
fluxes



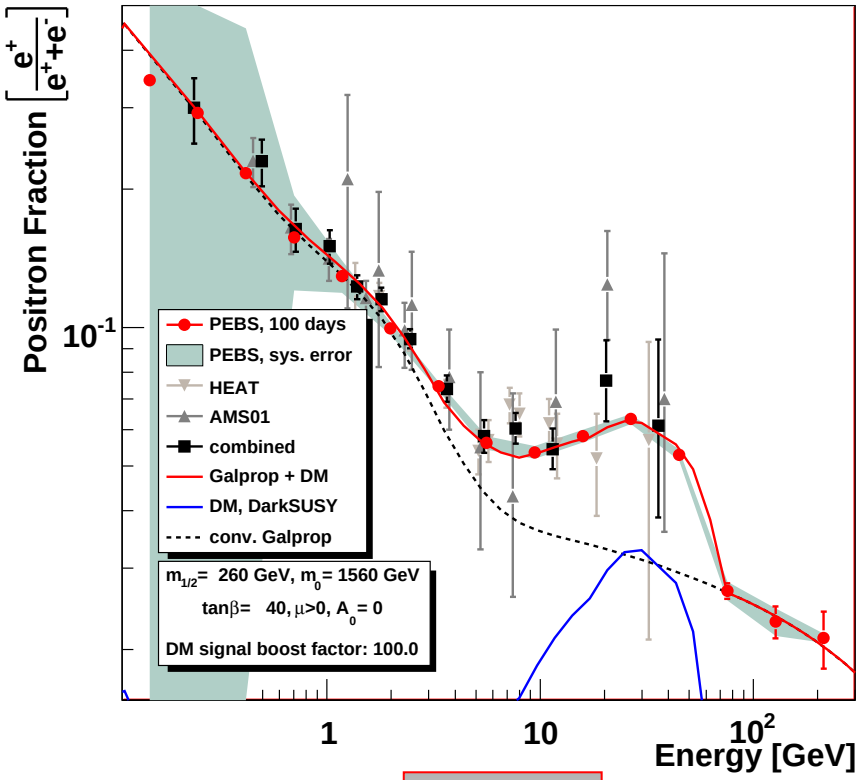
fraction

using the according rejections and efficiencies for each type
with systematic errors for detectors of 3% and 15% for the atmosphere

Positrons



fluxes



fraction

using the according rejections and efficiencies for each type
with systematic errors for detectors of 3% and 15% for the atmosphere

Conclusion

- **ACC system for AMS-02 works!**
  - scintillators, clear fibers, PMTs: good
  - flight electronics: good
  - preintegration done!
  - cosmic test of AMS-02
  - good inefficiency of about 10^{-5} for antimatter search
- **PEBS prospects are promising!**
  - atmospheric and magnetic simulations work fine
  - good capabilities to measure positrons and antiprotons and Southpole or Northpole