Detection of electrons and positrons with the AMS-02 detector is space

Manuela Vecchi
National Central University, Taiwan

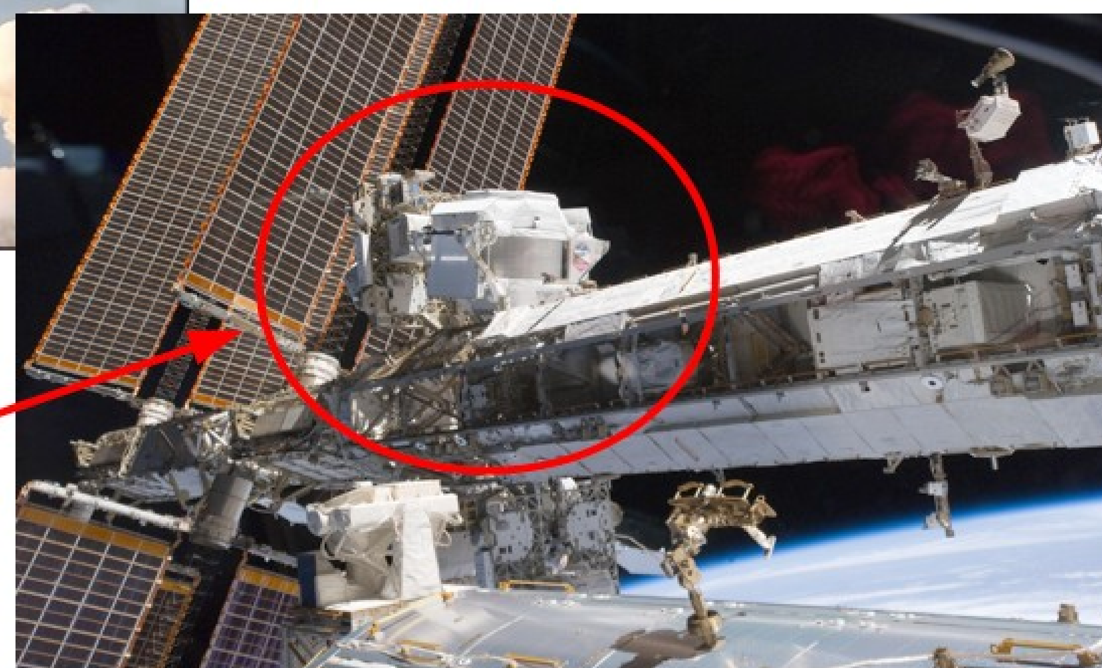
Centre de Physique des Particules de Marseille, March 4th 2013

AMS-02 on board of the ISS

High acceptance magnetic spectrometer (~ 500 $cm^2 sr$) on board of the International Space Station (ISS)

May 16th 2011: Launch of Endeavour shuttle (mission STS 134). AMS-02 is brought to space!

Data taking up to ~ 2020



AMS-02

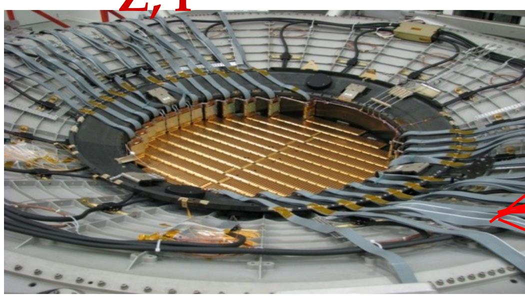
Scientific goals

- Spectra of Cosmic Rays in the GeV-TeV range.
- Direct search for antimatter in space.
- Indirect search for dark matter
- Cosmic rays propagation
- Gamma rays physics

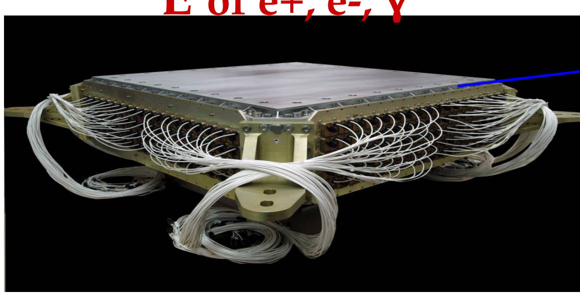
AMS-02: A TeV precision, multipurpose spectrometer

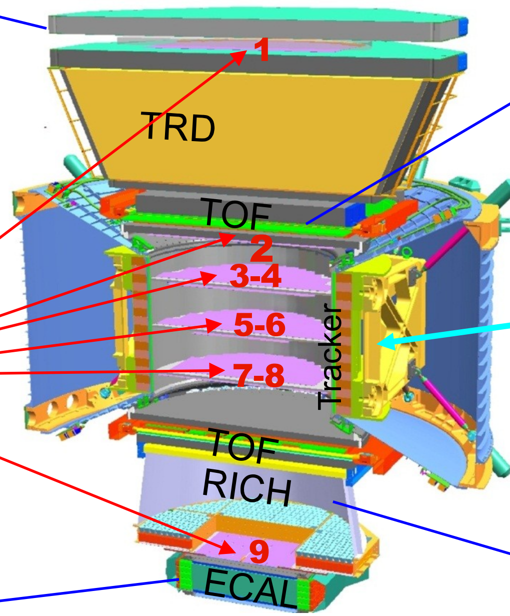
TRD
Identify e+, e-

Silicon Tracker
Z, P



ECAL
E of e+, e-, γ

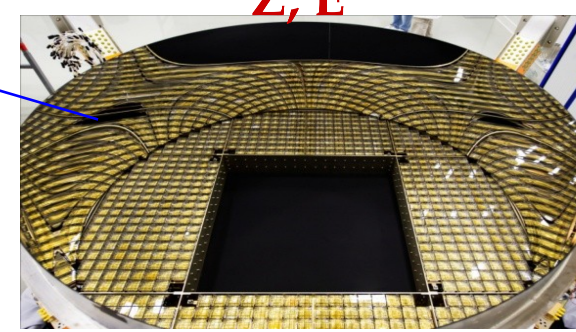




TOF
Z, E

Magnet (0.15T)
±Z

RICH
Z, E

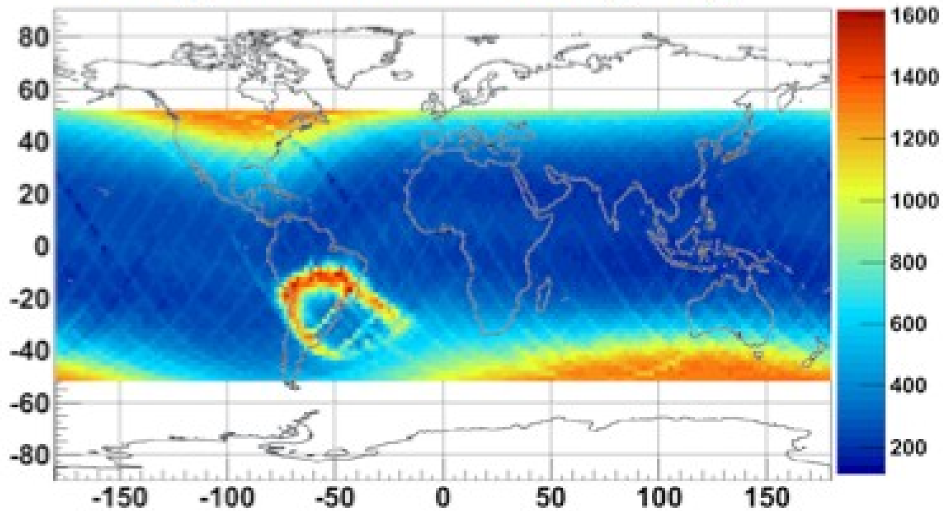


Z, P are measured independently by the Tracker, RICH, TOF and ECAL

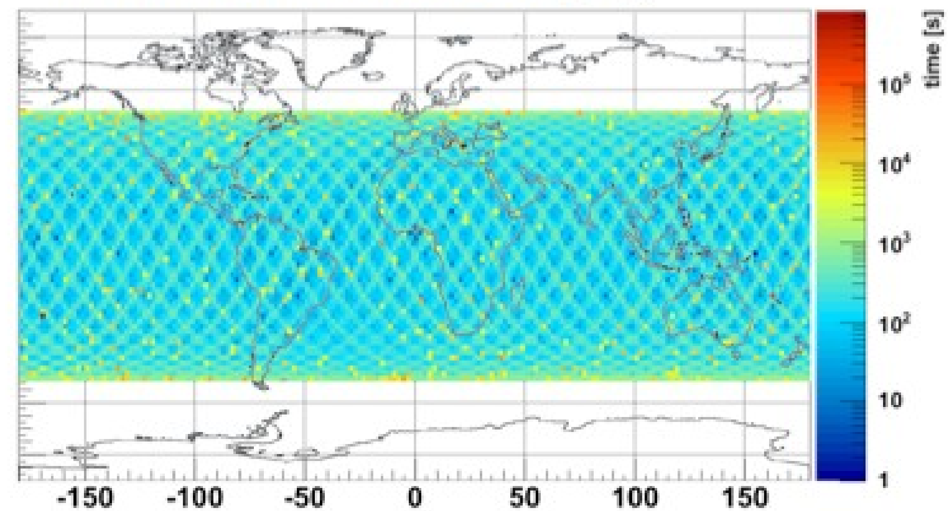
Dimensions: 5m x 4m x 3m
Weight: 8.5 tons
Power: 2500 W
Data downlink rate: >= 9Mbps

Orbital DAQ parameters

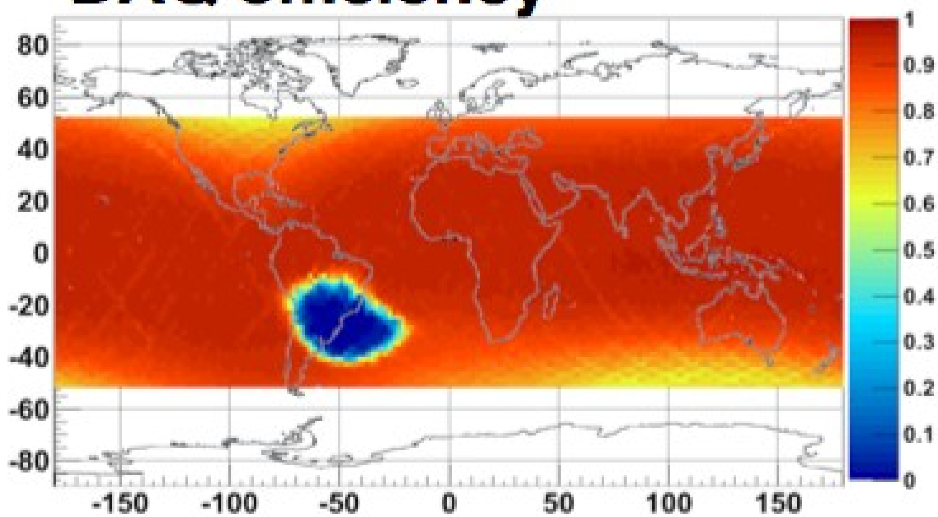
Acquisition rate [Hz]



Time at location [s]



DAQ efficiency

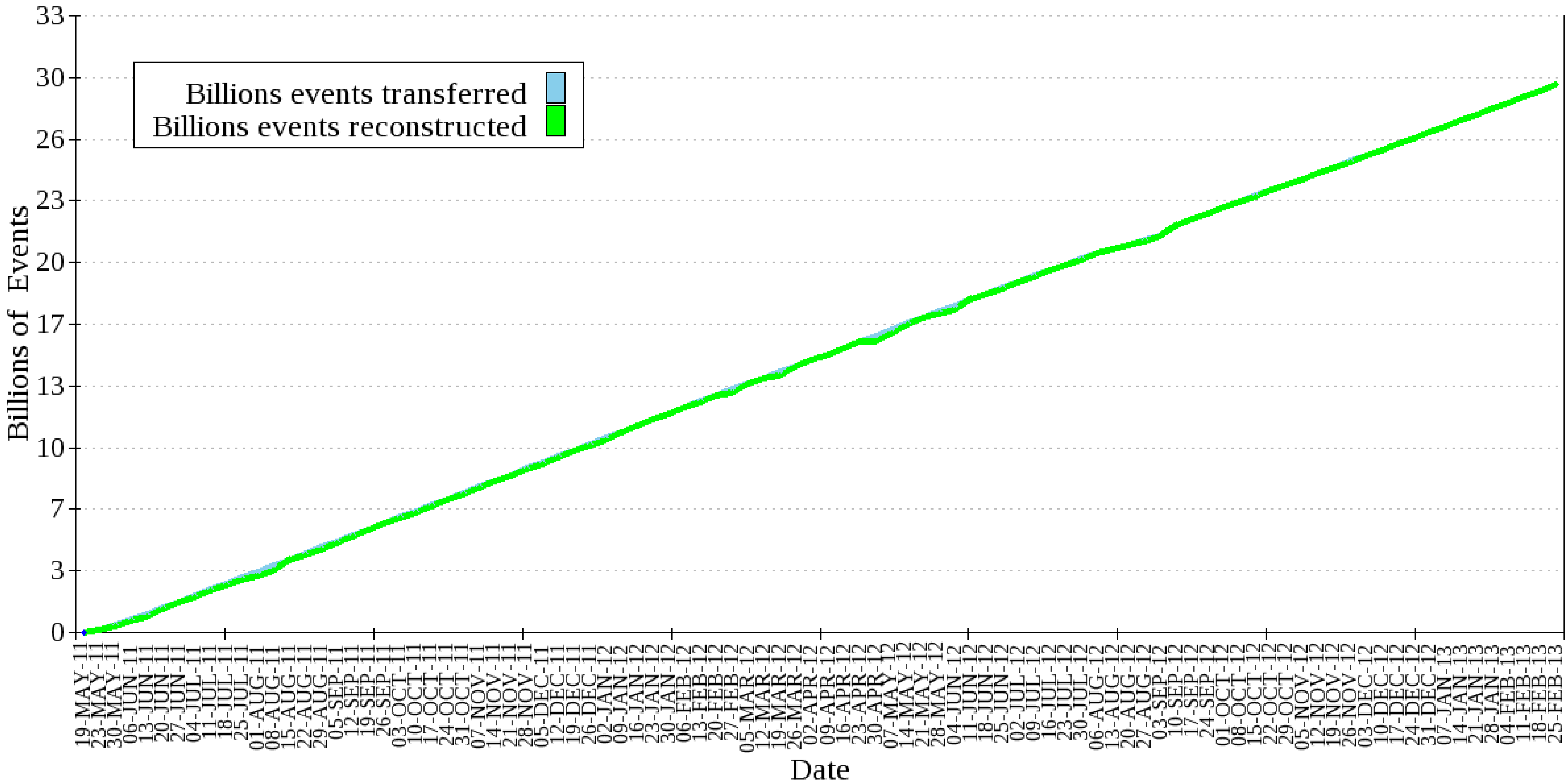


Particle rates: 200 to 2000 Hz per orbit

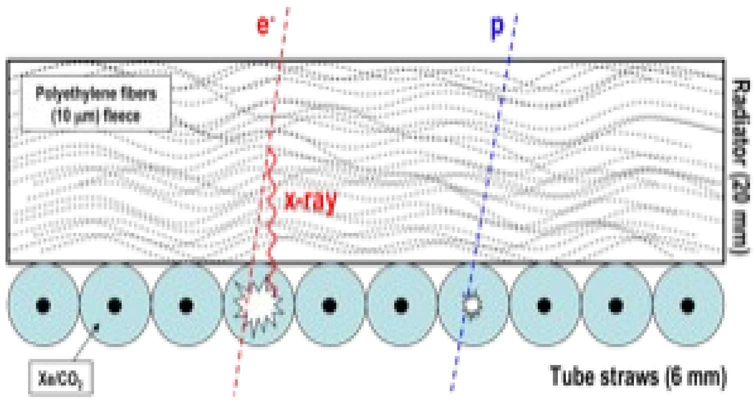
Orbit average:
DAQ efficiency ~ 80%
DAQ rate ~700Hz

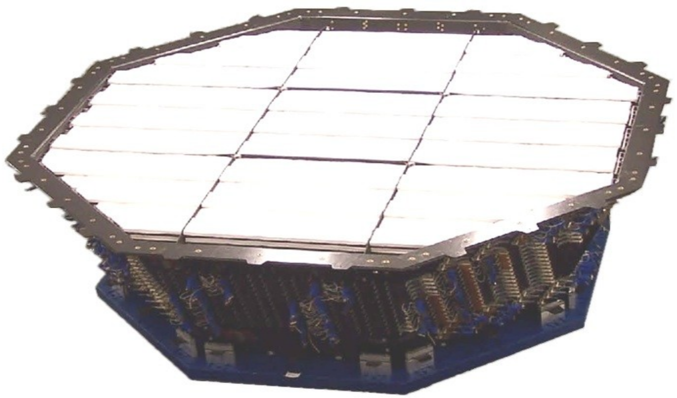
so far : 30 10^9 events
33 TB/yr

30 billion events (so far)!

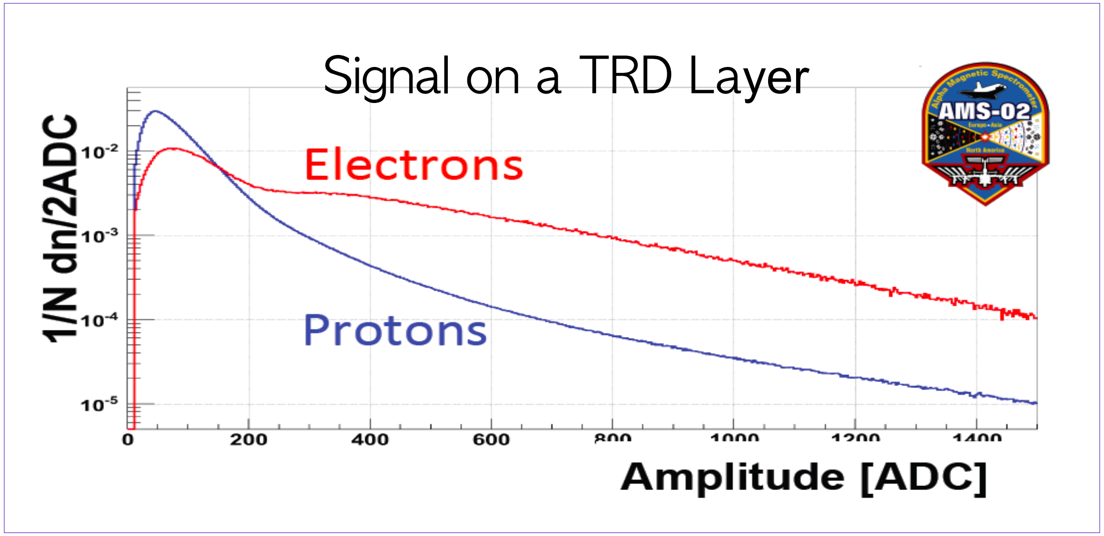


Transition Radiation Detector

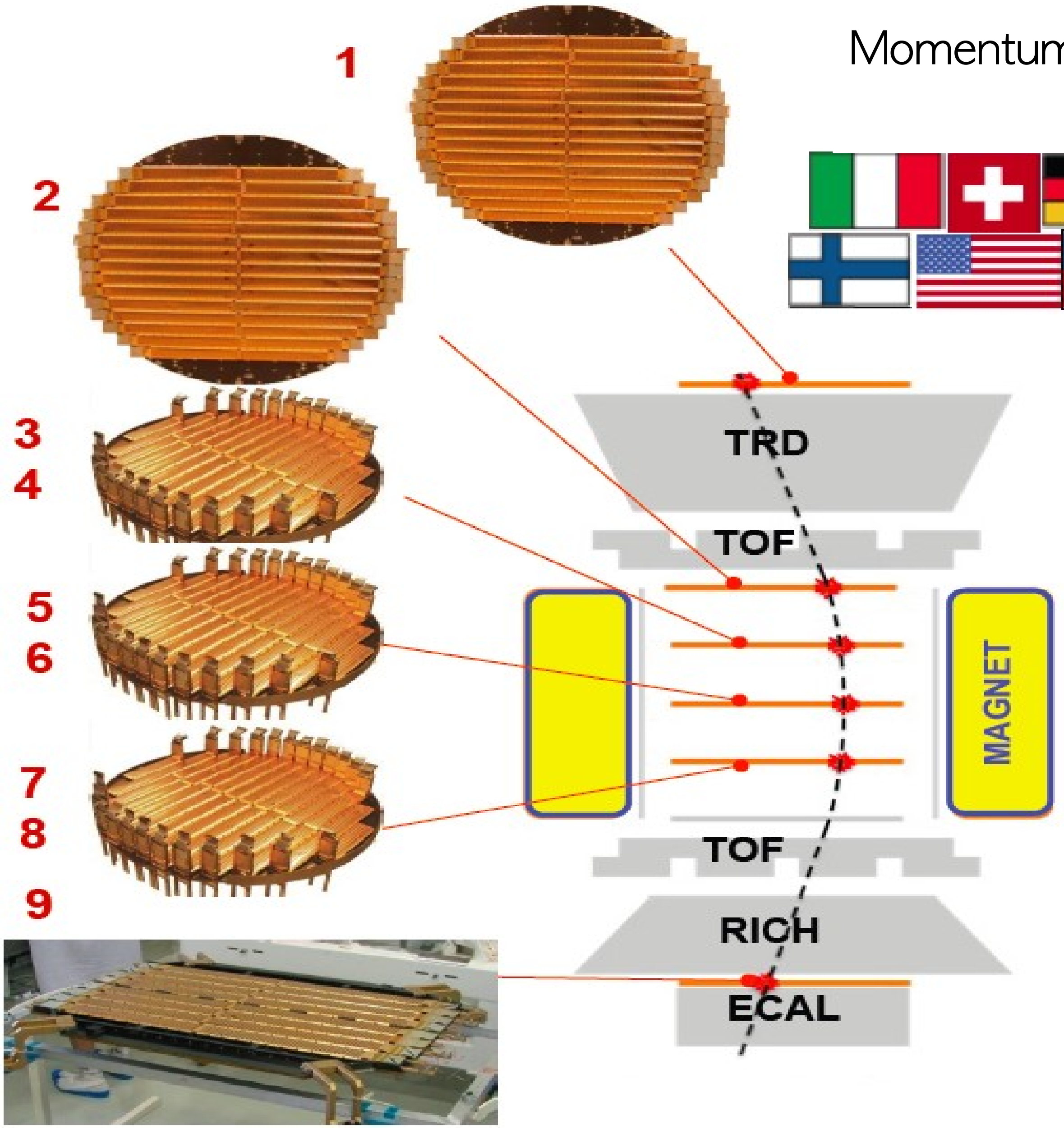




- Identifies e+ and e- by transition radiation and nuclei by dE/dX
- 20 layers of fleece radiator with XeCO2 straw tubes.
- Lepton-hadron discriminating power up to 400 GeV.



Tracker

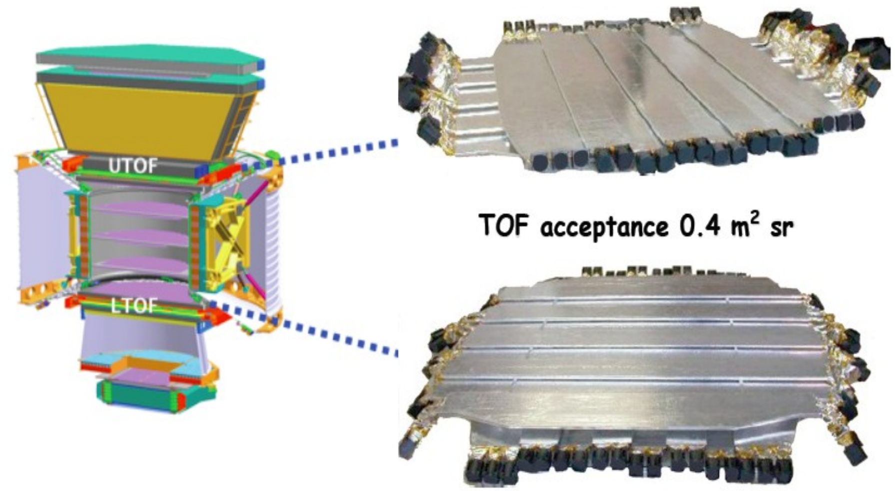


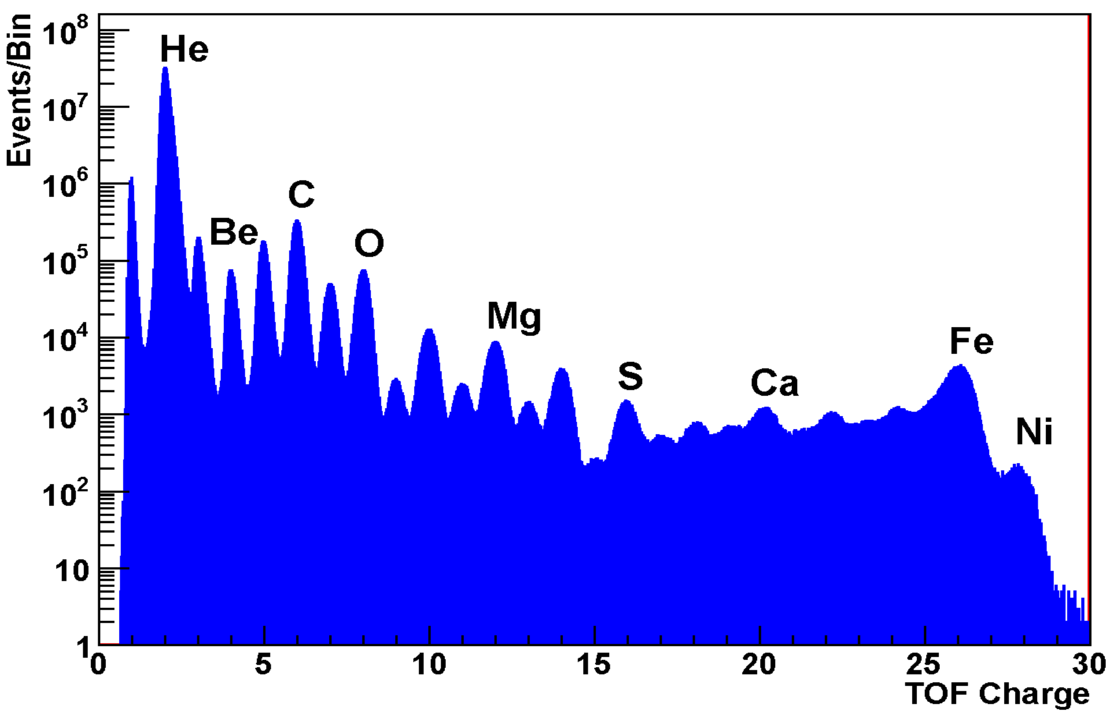
Momentum and charge measurement

- Acceptance ~ 500 cm^2sr
- 9 layers of double sided silicon
- detectors arranged in 192 ladders
- 10 μ m (30 μ m) spatial resolution along bending (non bending) plane
- Momentum resolution ~10% at 10 GeV, 25% @ 500 GeV
- Maximum Detectable Rigidity ~ 2 TeV
- Charge identification up to Iron
- B = 0.15T (permanent magnet)

Time Of Flight

TOF goals :
- Trigger;
- Determination of the particle velocity (β);
- Albedo rejection;
- Charge identification from dE/dX.

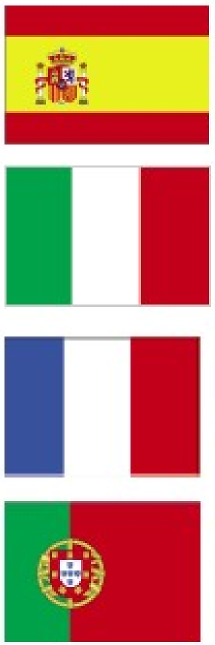


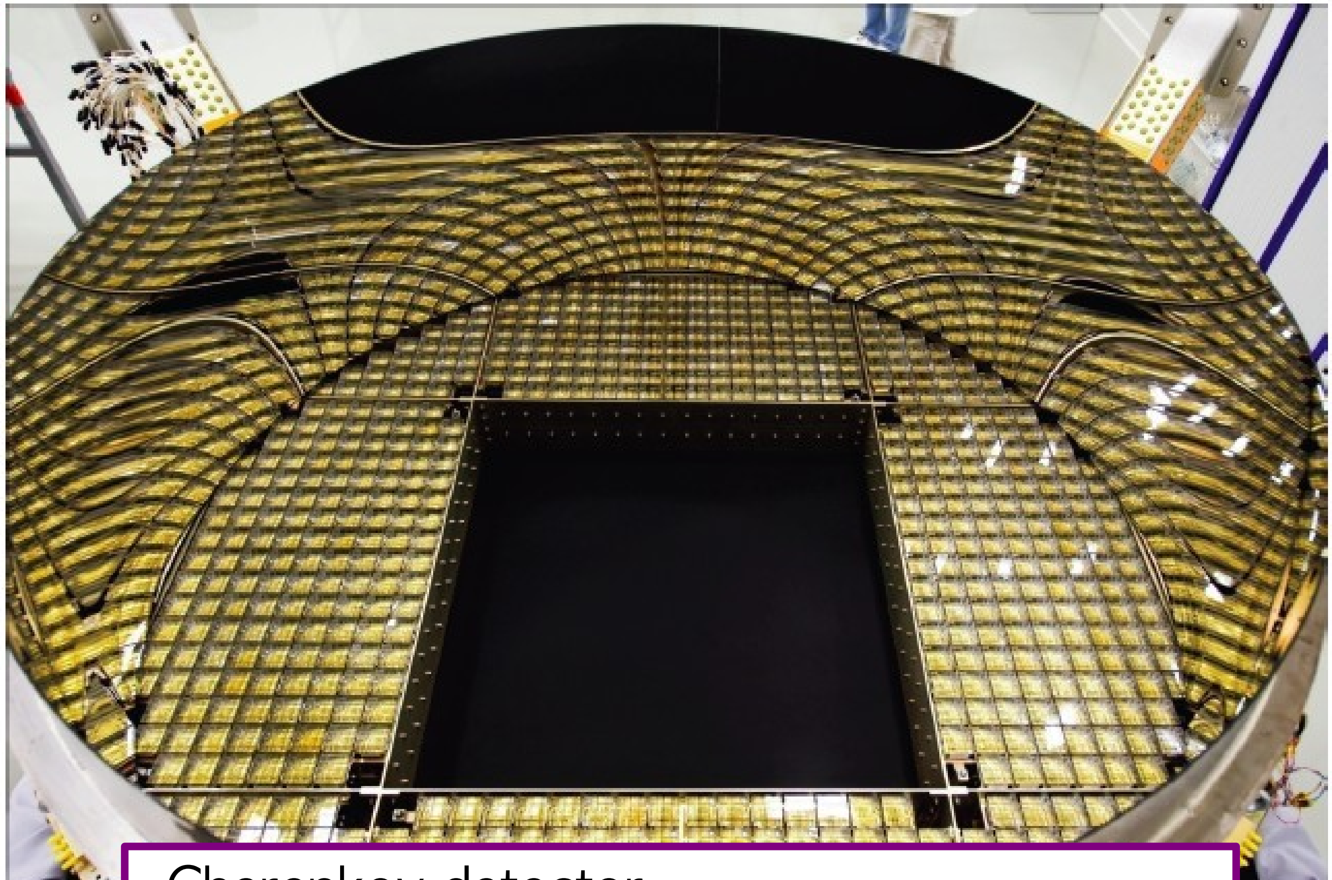


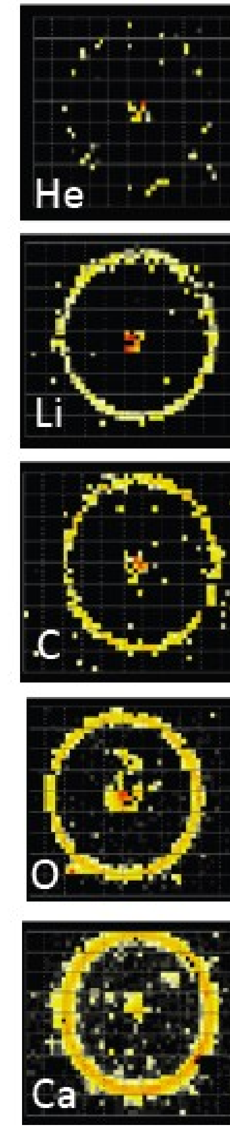
Performance :

- Z=1 : $\Delta t \sim 120$ ps, $\Delta\beta/\beta \sim 4\%$

Ring Imaging Cherenkov Detector

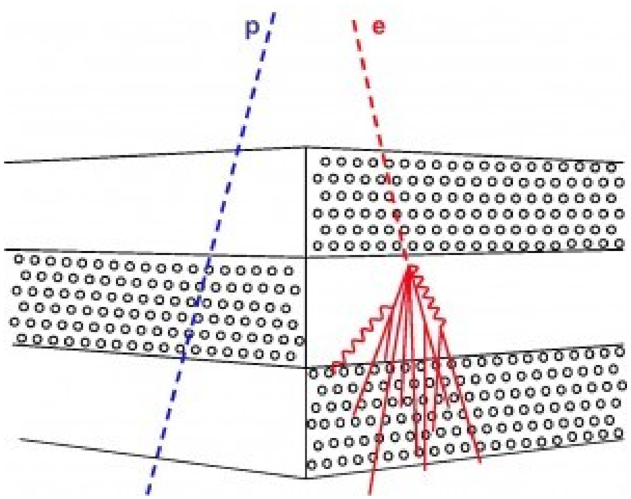






- Cherenkov detector
- 680 PMTs, 10880 photosensors
- Identify charge and velocity of nuclei
- Beta resolution ~ 0.1% Z=1, 0.01% Z>5

Why do we need ECAL ?



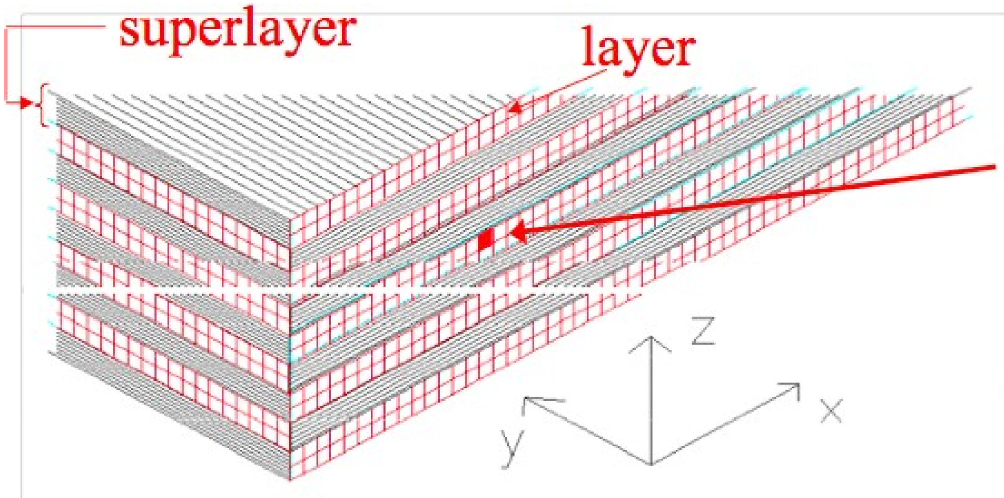
- To **Measure the energy** of e^{+}, e^{-} and γ .

- To **separate** e^{+} **from** p *in the GeV to TeV region.*

- To directly **measure high energy photons** with accurate energy and direction determination.

Electromagnetic Calorimeter

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

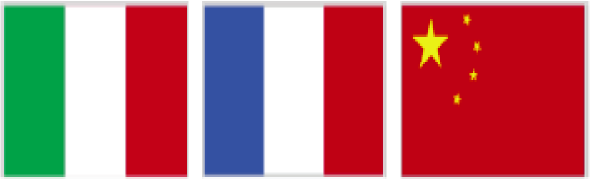


High granularity: ~ 0.9 x 0.9 cm

Readout cells: ~ 1 X_0(Z) 0.5 $R_{molière}$(X,Y)

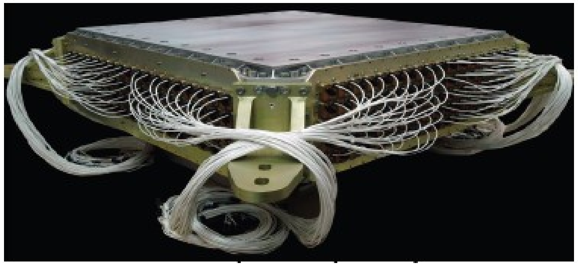
18 Longitudinal samplings

18 x 72 = 1296 cells ➔ 3D sampling

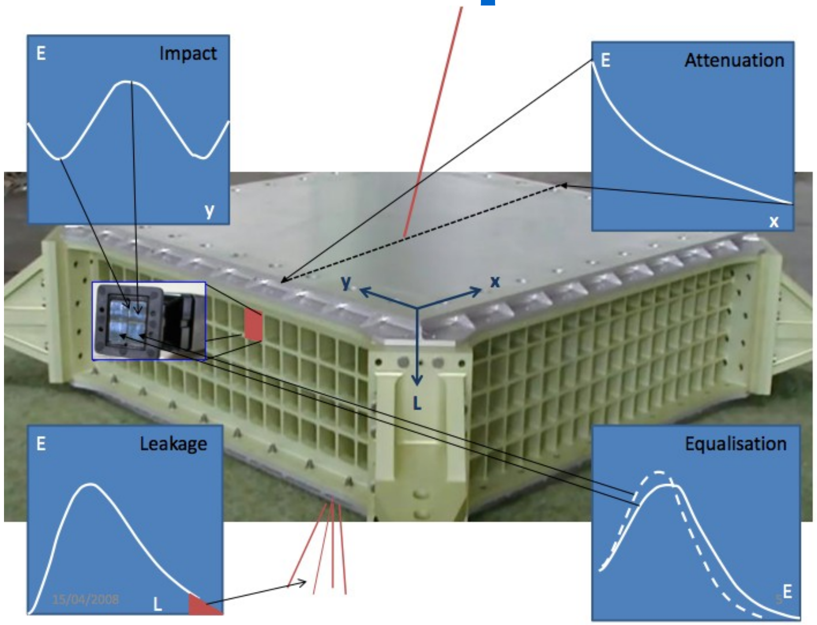


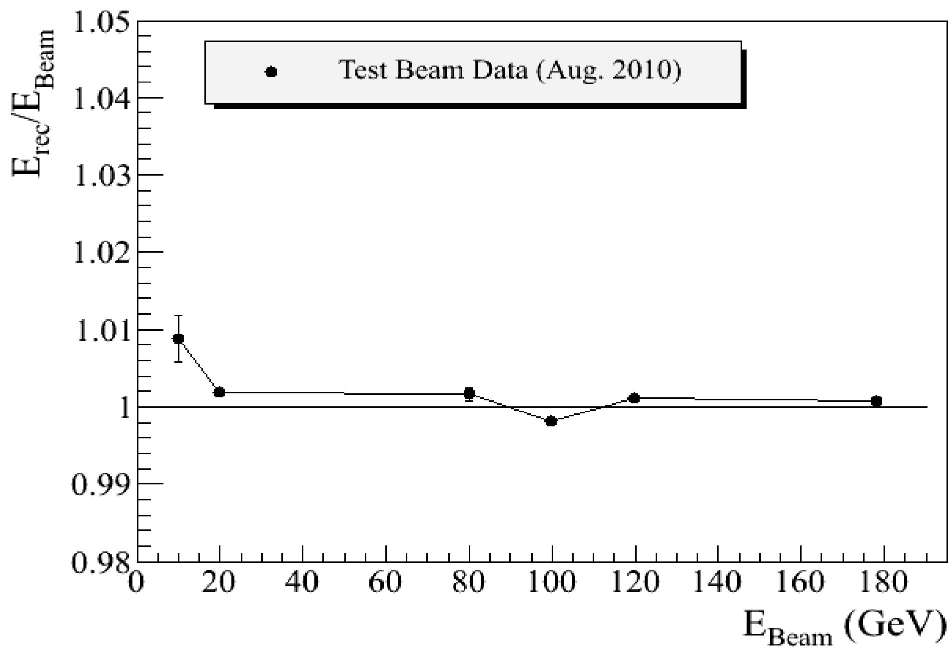
- Lead (58%), Scintillating fibers (33%), Optical glue (9%), Density ~ 6.8 g/cm^3
- Dimensions 648x648x167 mm

(17 X_0, λ_I / X_0~ 22)



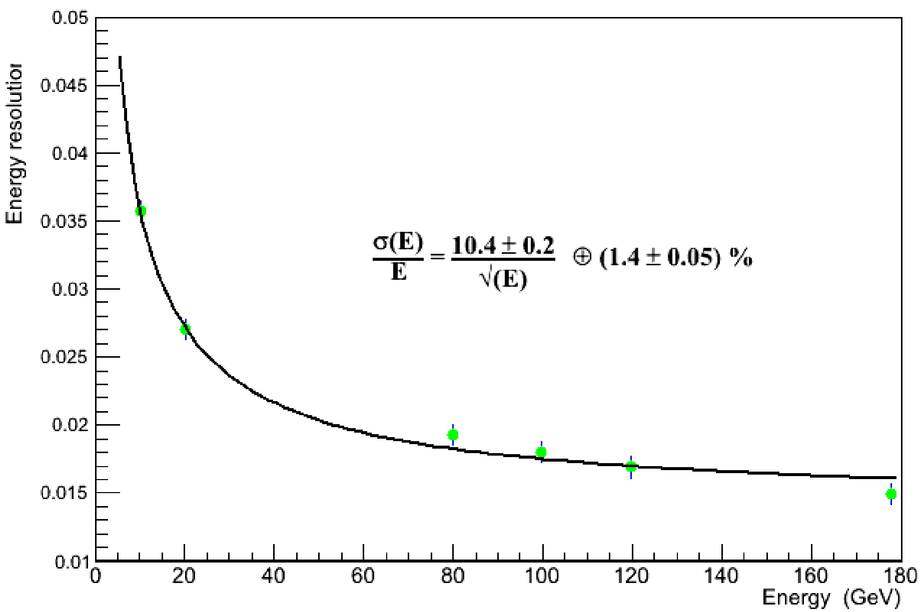
ECAL performance: Energy Resolution





2010 Test Beam :

- Linearity better than 1%
- Resolution better than 2% @ 100 GeV



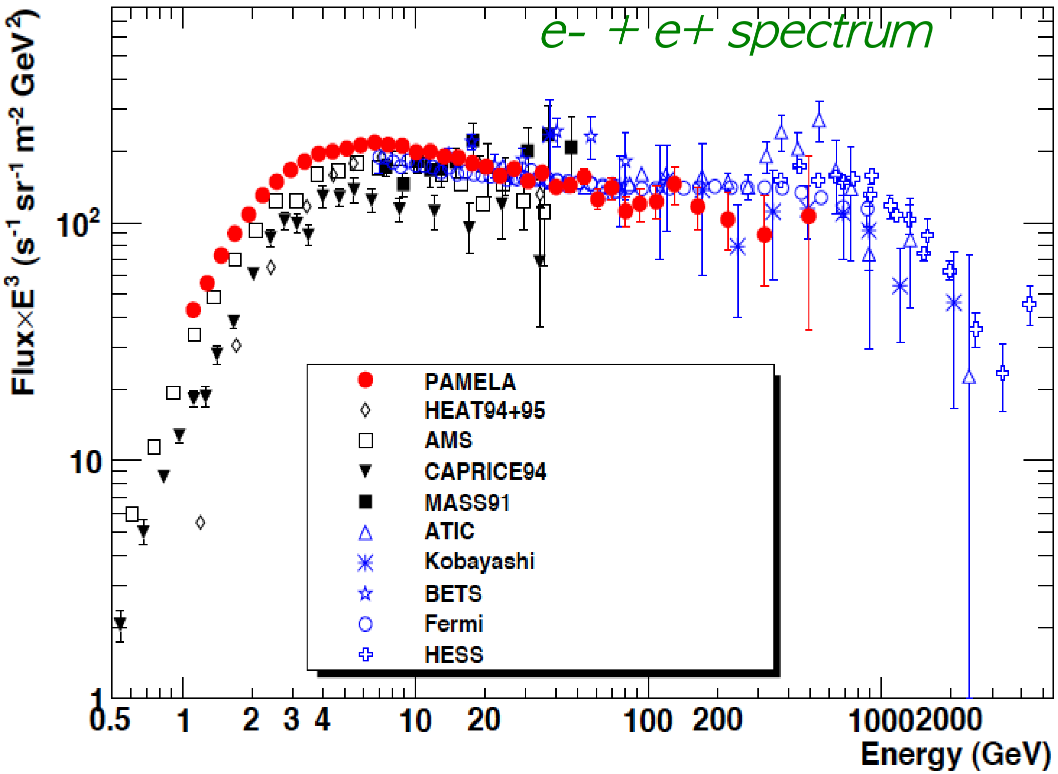
Electrons and positrons in Cosmic Rays : state of the art

Electron spectrum is determinated by:
- Slope of injection (power law)
- Energy Losses (Synchrotron, IC)
- Diffusion in Galactic magnetic field.

Electron horizon is limited by severe energy losses to within few kpc.

Conventional scenario :
- Cosmic Rays are produced in SuperNova Remnants
- e^+, e^- are secondaries from CR collisions with Inter-stellar medium.

Electrons and positrons in Cosmic Rays : state of the art



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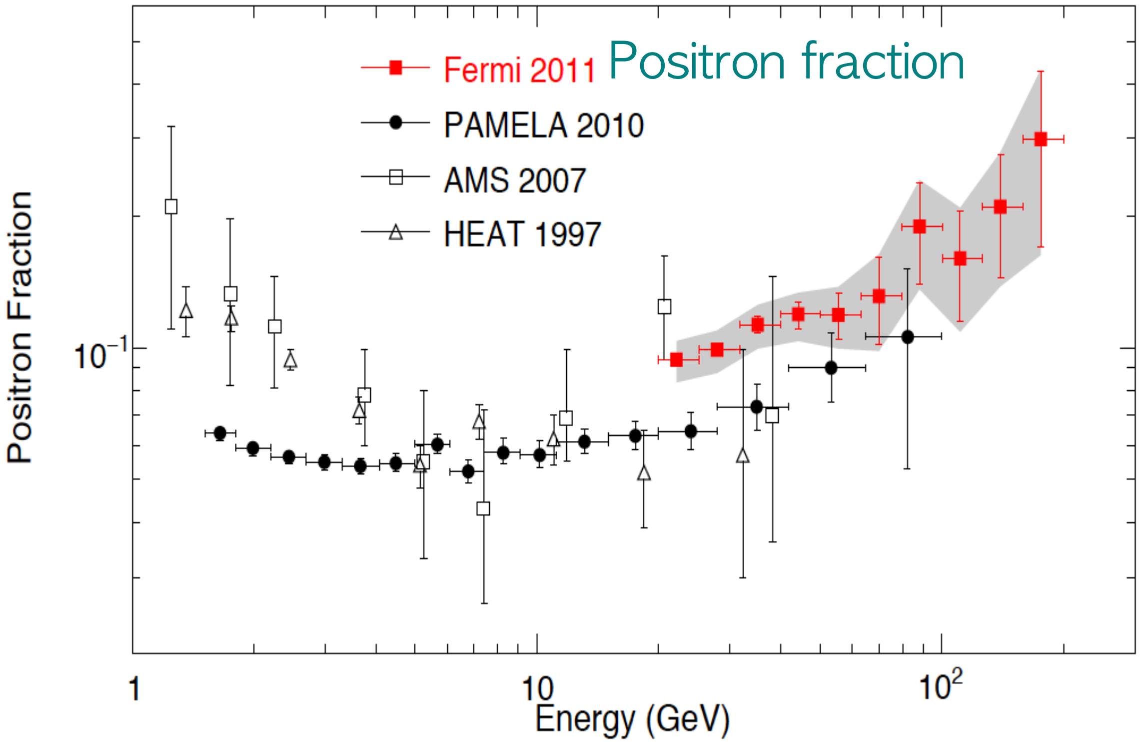
Measured all electron spectrum :
- Low E dominated by solar modulation.
- A bump @ 600 GeV is observed by ATIC.
- A sharp cutoff is observed by HESS @ 1 TeV.
- Positron fraction measured by satellite PAMELA, is in contrast with pure secondary origin.

Electrons and positrons in Cosmic Rays : state of the art (II)



Nearby additional sources of e^+, e^-

- *Astrophysic source: pulsars*
- *Exotic source: Dark matter*

7.7 billion electrons and positrons between 0.5-350 GeV identified by AMS-02 between Mai 2011 and December 2012.

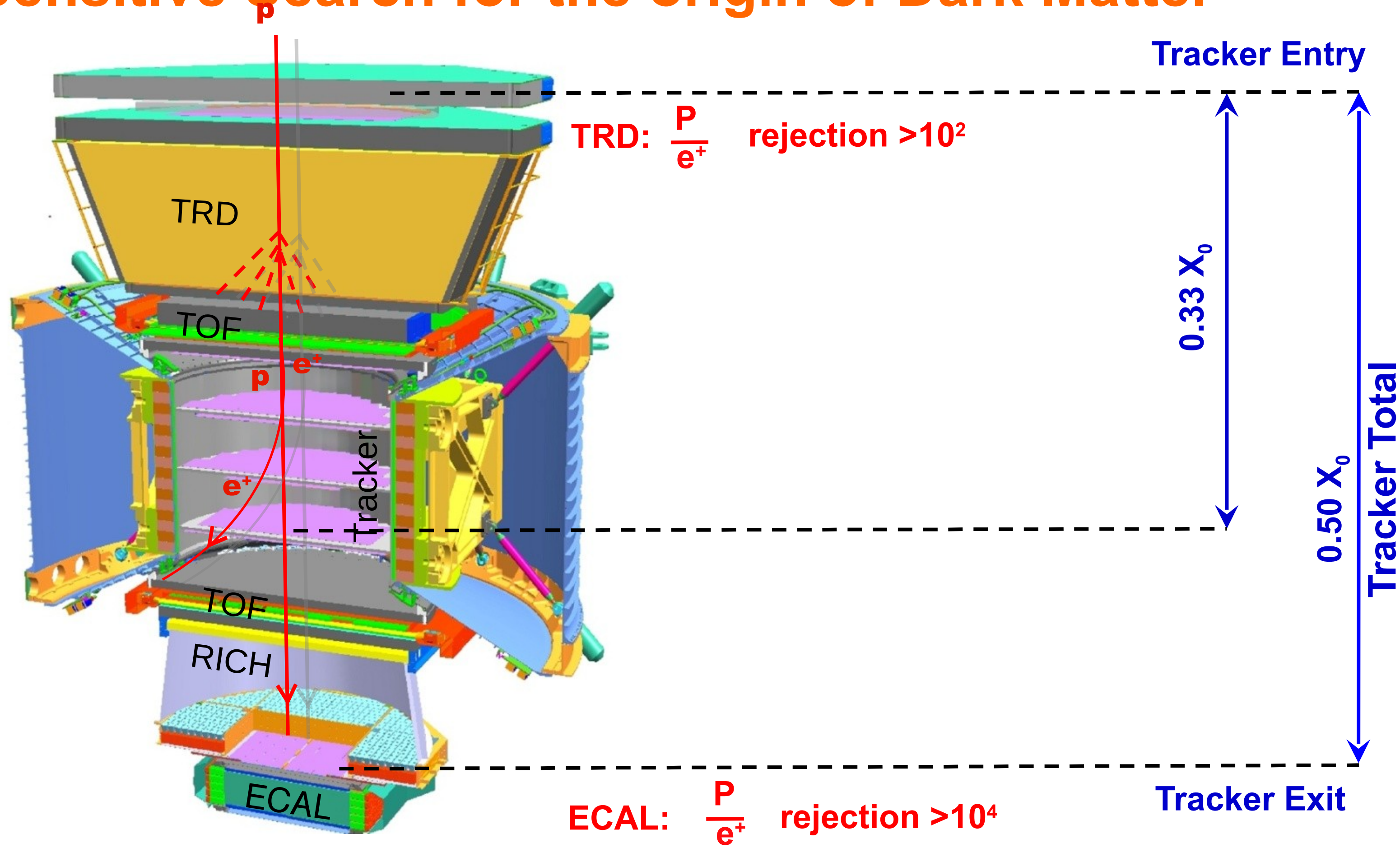
Electrons and positrons in Cosmic Rays detected by AMS

Keys of success :

- redundancy of sub-detectors
- ECAL energy resolution.
- Large data sample.

- Charge-one particles (within ECAL acceptance) identified by TOF+Tracker+ECAL.
- Lepton/hadron discrimination with TRD+ECAL+TRK
- Main sources of background :
  - Lepton/hadron mis-identification (*p identified as e+*)
  - Charge confusion (*e- identified as e+*) :
    - Interactions along the track (radiating e- resulting in high E/P)
    - Spillover due to finite tracker momentum resolution (small E/P)

Sensitive Search for the origin of Dark Matter

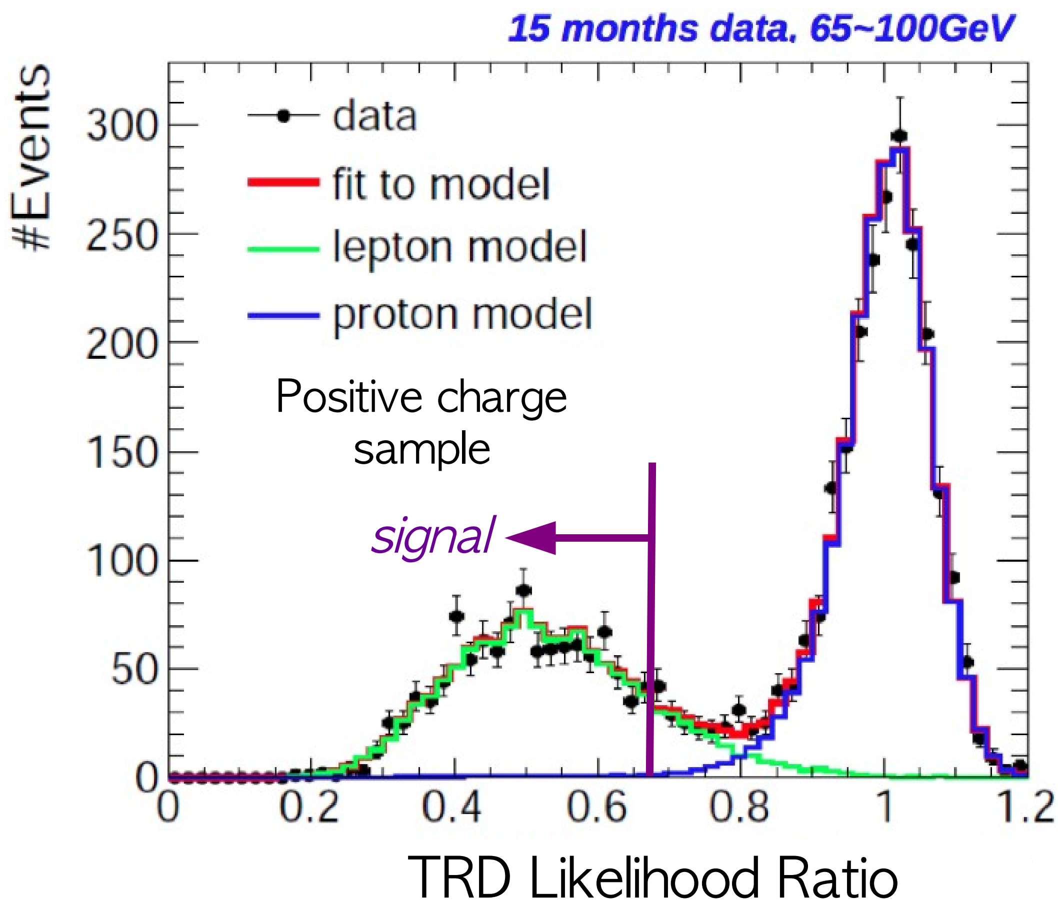


a) Minimal material in the TRD and TOF
So that the detector does not become a source of e^+.

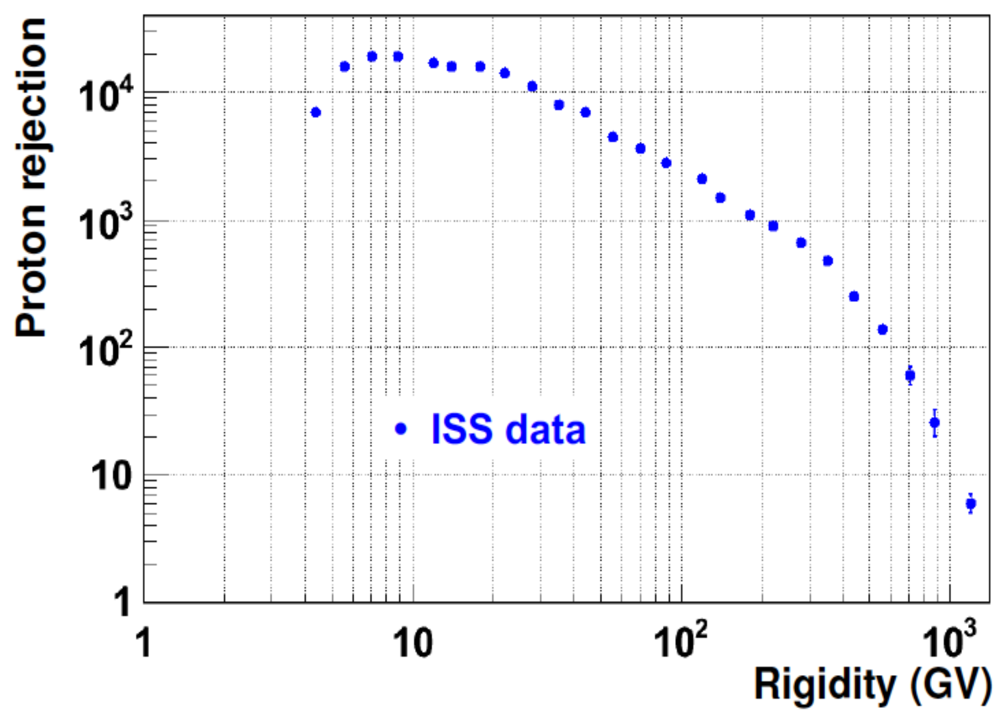
b) A magnet separates TRD and ECAL so that e^+ produced in TRD will be swept away and not enter ECAL
In this way the rejection power of TRD and ECAL are independent

c) Matching momentum of 9 tracker planes with ECAL energy measurements

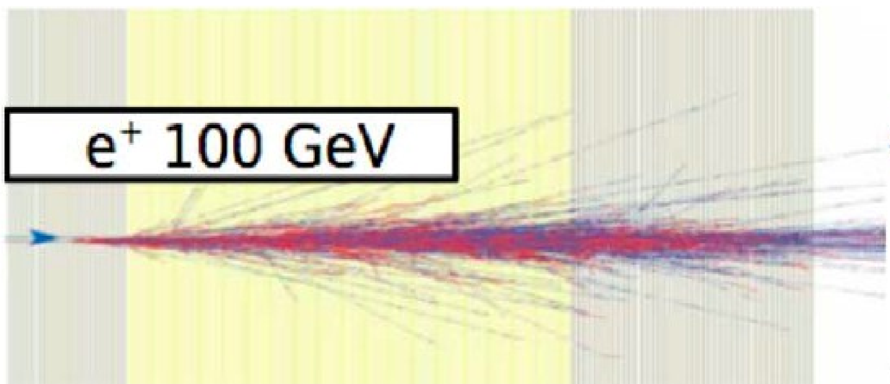
Lepton-hadron separation with TRD



The energy deposition in the TRD layers is combined to build Likelihood function for electron and protons.



Lepton hadron separation with ECAL

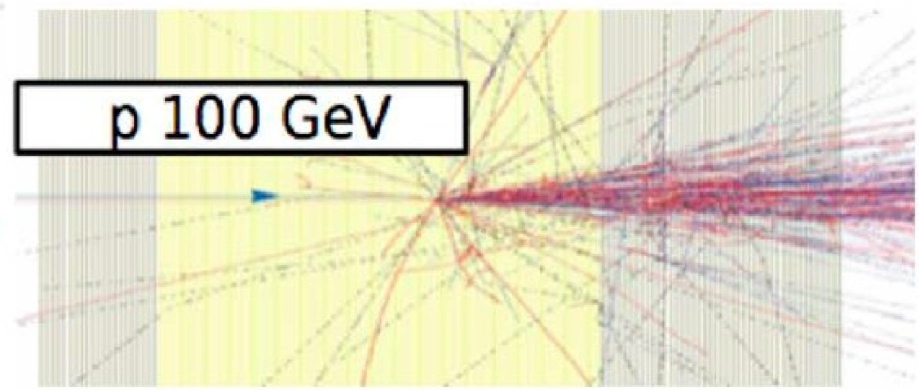


Positron 100 GeV

Longitudinally contained

Shower lateral size ~ $R_{molière}$(2cm)

$E_{ECAL} \sim P_{TRK}$

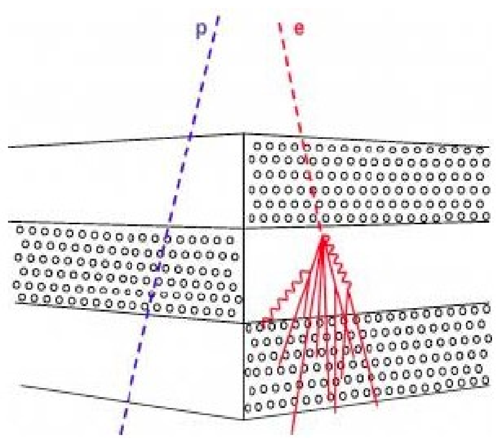


Proton 100 GeV

Longitudinal Leak

Shower lateral size >> $R_{molière}$

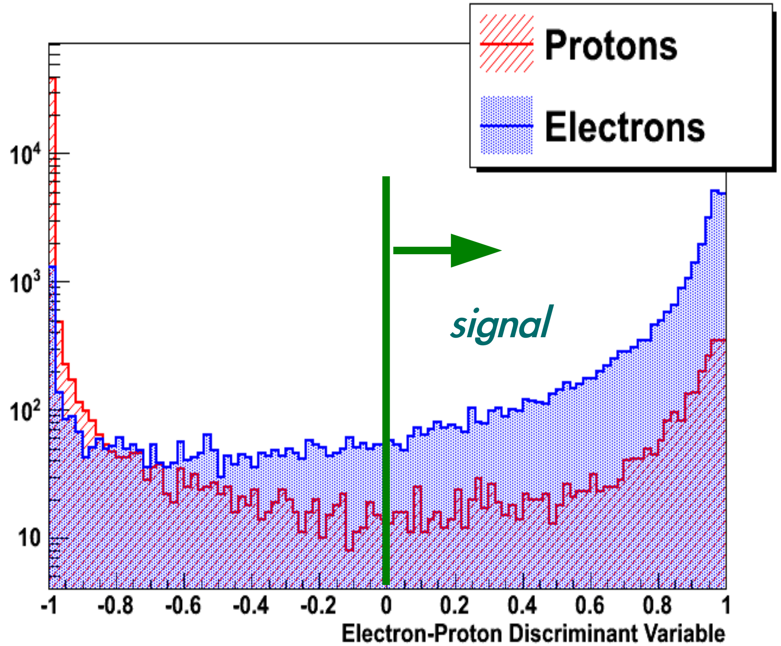
$E_{ECAL} \ll P_{TRK}$

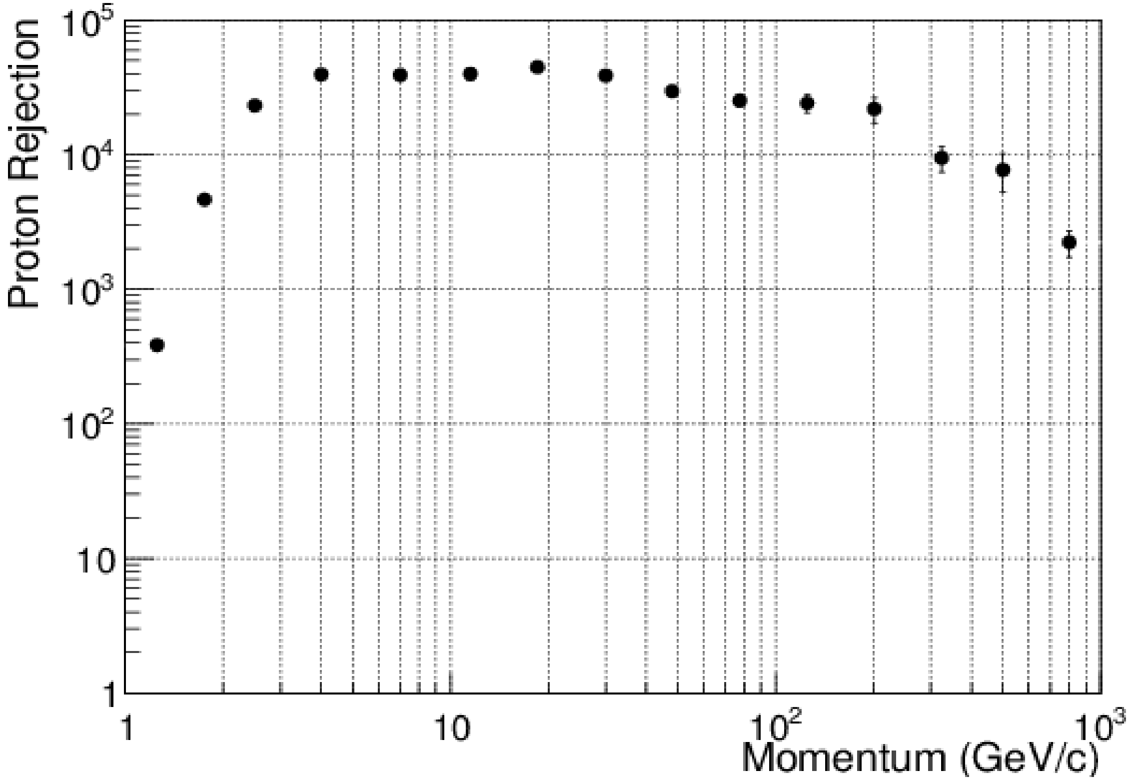


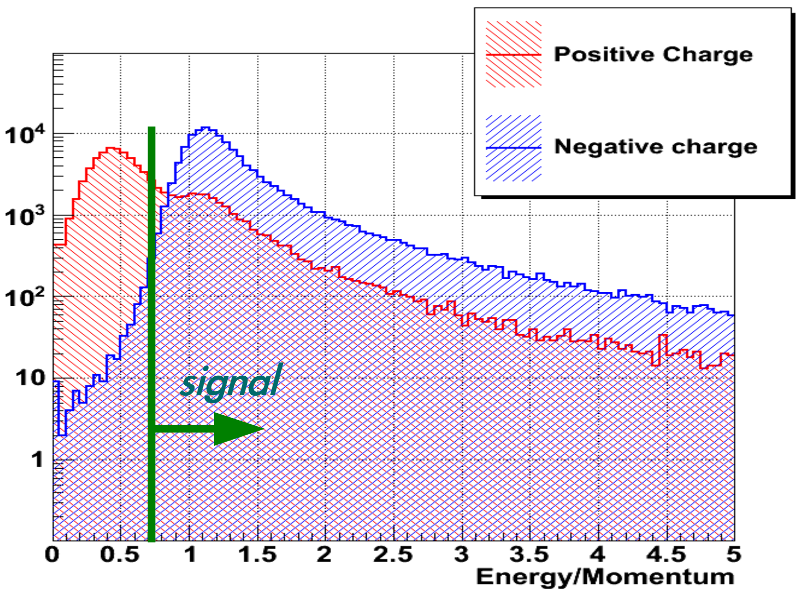
Proton rejection with ECAL:

- ✓ Energy fraction in each layer
- ✓ Shower lateral width in each layer
- ✓ Shower longitudinal profile
- ✓ Shower 3D profile

ECAL+ Tracker Proton Rejection







•Ecal Estimator + E/P matching: Background Rejection >10000 (90 % efficiency on signal)

•Combined with TRD an overall rejection factor> 10^6 is achieved .

Take home message

AMS works very well !

- AMS02 is in space, onboard the ISS, since May 16th 2011.
- The detector is running smoothly its performance is constantly monitored and within expectations.
- Given its large acceptance AMS-02 will collect an enormous amount of data over its lifetime (~10%reached so far), leading to cosmic ray measurements with unprecedented statistics.

Concerning electrons and positrons measurement :

- The redundancy of AMS-02 sub-detectors allows for lepton/hadron separation at the level of 10^6 in the GeV to TeV range.
- Excellent energy resolution, few % at E>100 GeV.
- The positron fraction paper is ready for submission.
- The spectrum of primary electrons and positrons will be studied over a very large statistics, up to TeV energies.

Thank you !