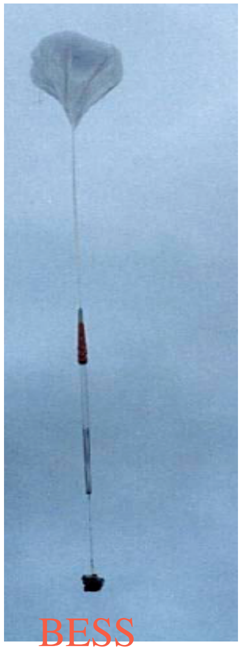
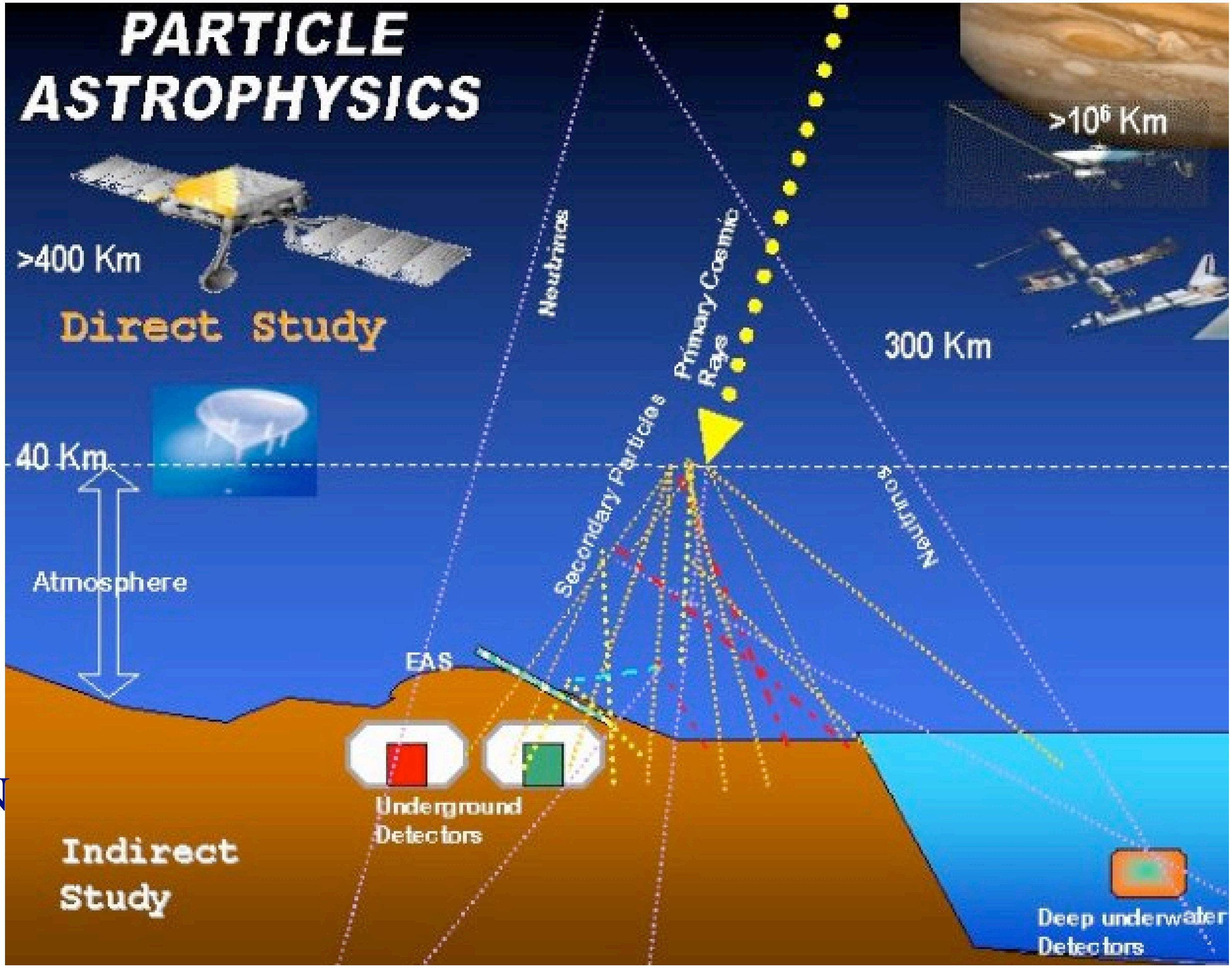
Direct detection of CRs



BESS



Thanks

to Francesco Cafagna

Bari INFN

A typical CR experiment for PID

Particle id: charge, mass, energy/momentum,

Spectrometer: gyroradius of a particle is proportional to the rigidity and inversely proportional to the magnetic field

Since B is known, Z and p can be measured

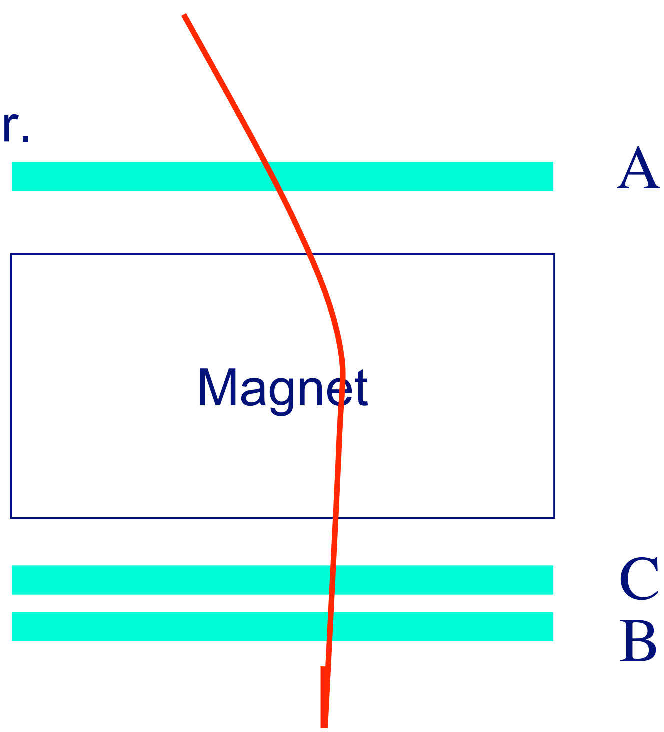
$$r_L = \left(\frac{pc}{Ze}\right)\frac{1}{Bc} \qquad R = \frac{pc}{Ze}$$

The momentum resolution is limited by the position measurement and by the multiple scattering in the magnet

A **ToF system** (e.g. A,C 2 scintillator counters or proportional counters or spark chambers) provide dE/dx, time, position and trigger.

Hence the time of flight of a particle over a known distance gives the velocity

Hence the particle is fully identified (Z and m)

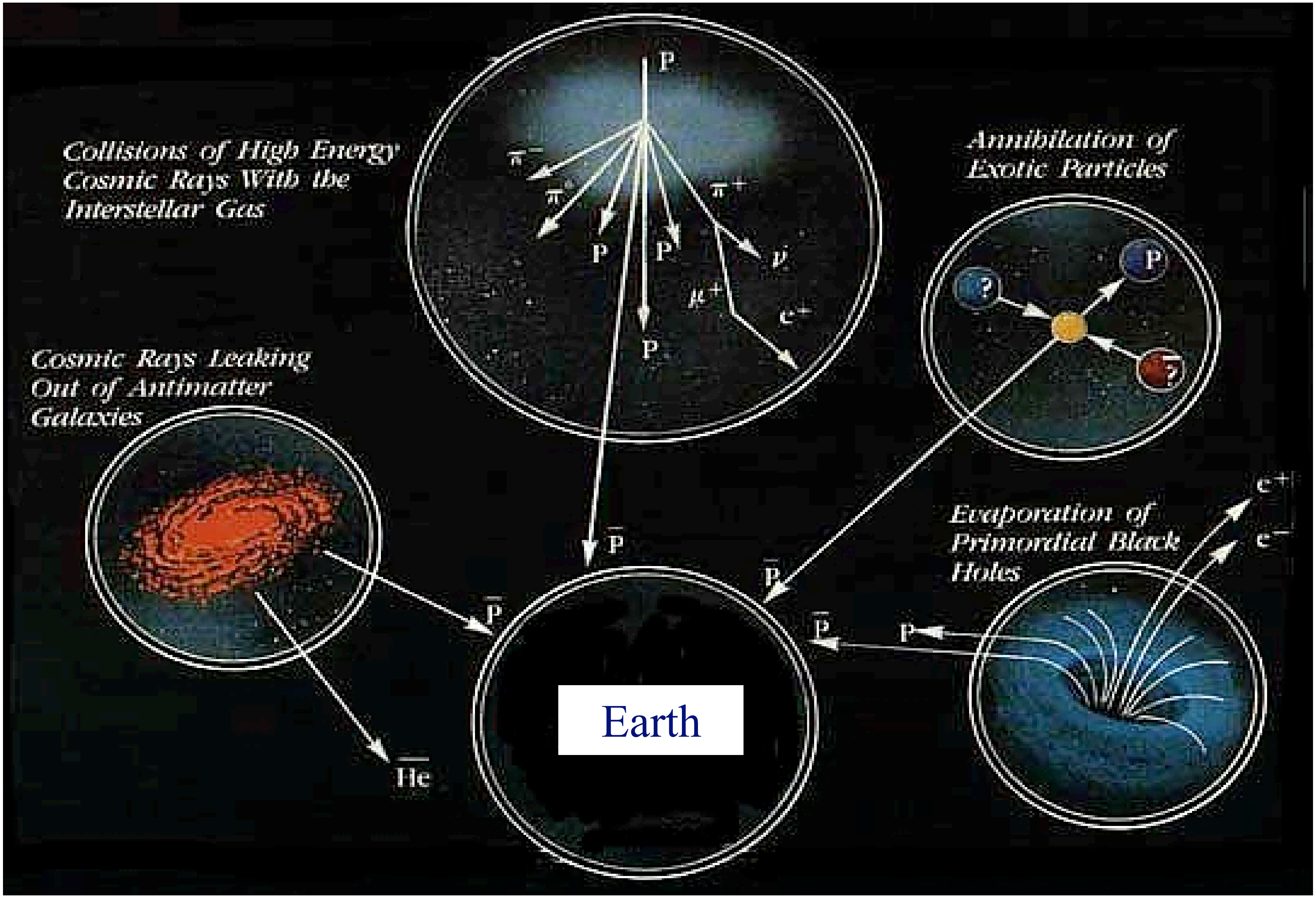


Occasionally a destructive detector (**calorimeter**) can be used to have an independent energy measurement

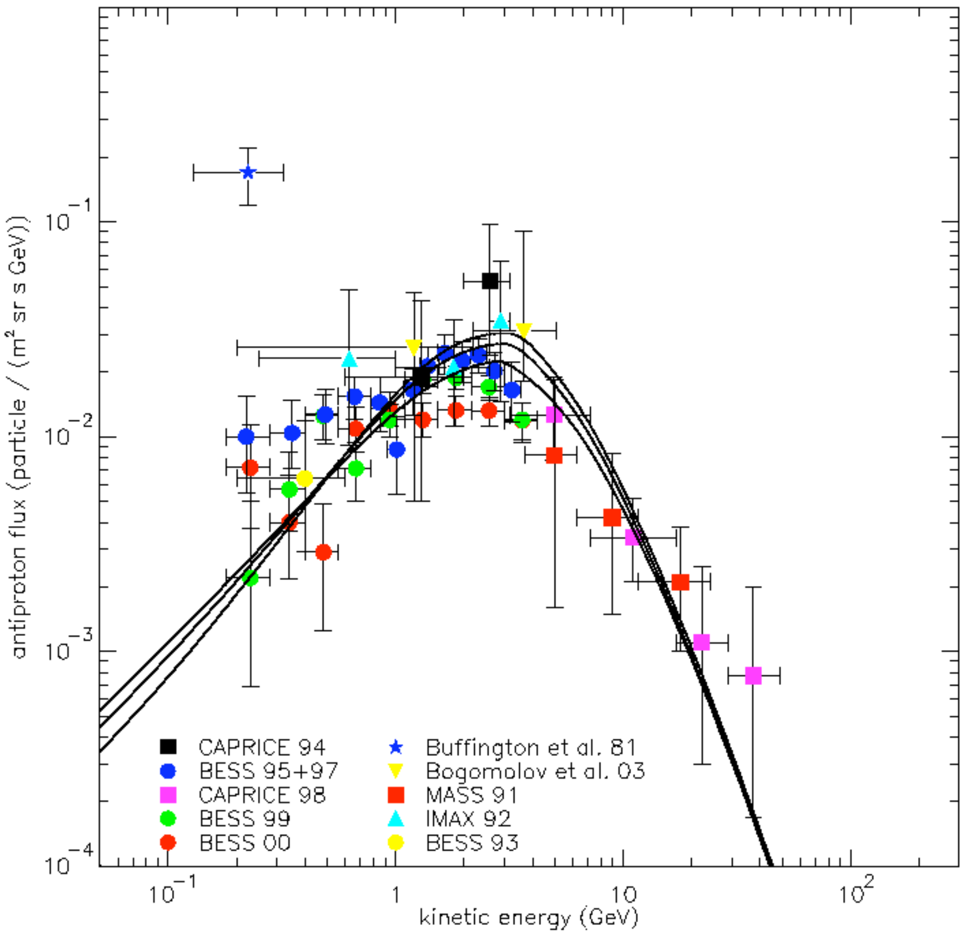
Searches for anti-matter and primary CR composition

- PAMELA
- AMS
- BESS
- Caprice
- Tiger, Atic, HEAT,Jacee, Runjob,…

Anti-matter in CRs



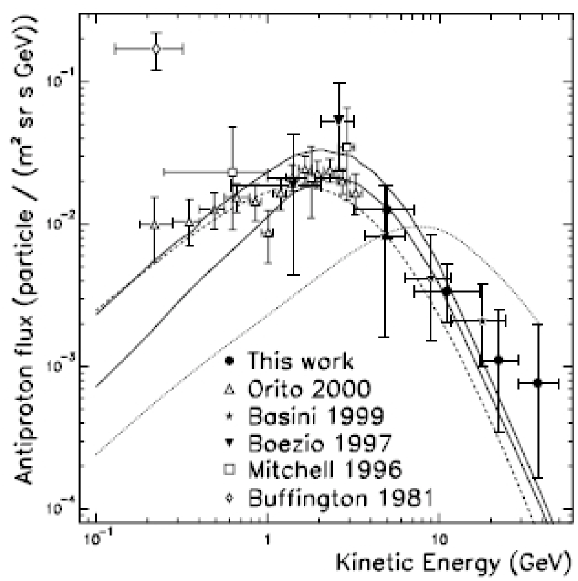
Absolute fluxes



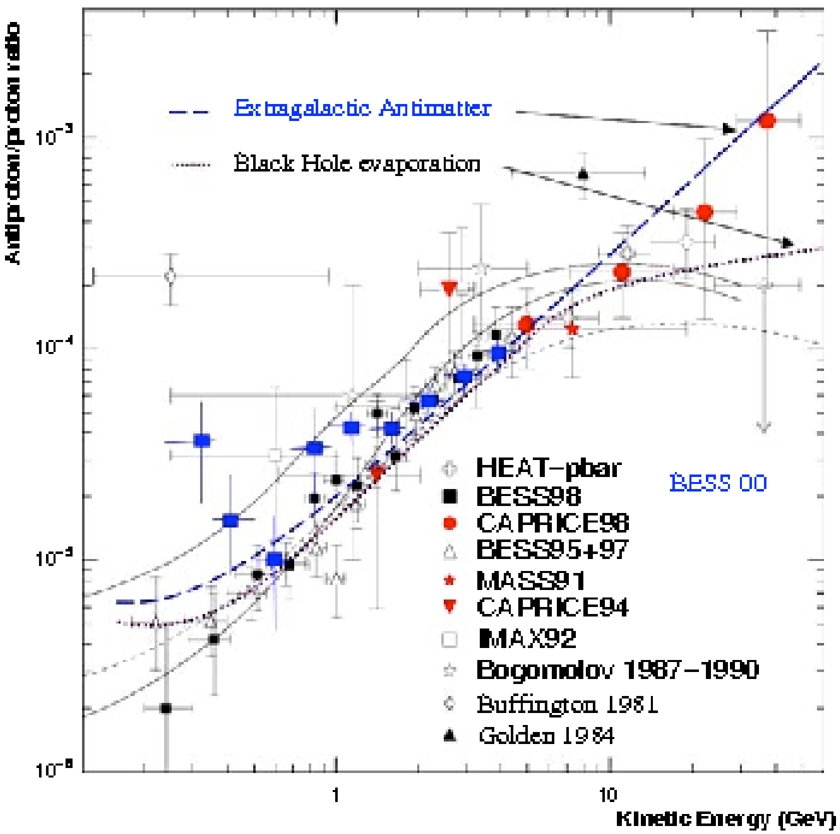
- No clear evidence
- But errors are large
- Ratios are better known
- Flattening at low energy

anti-matter from BH evaporation

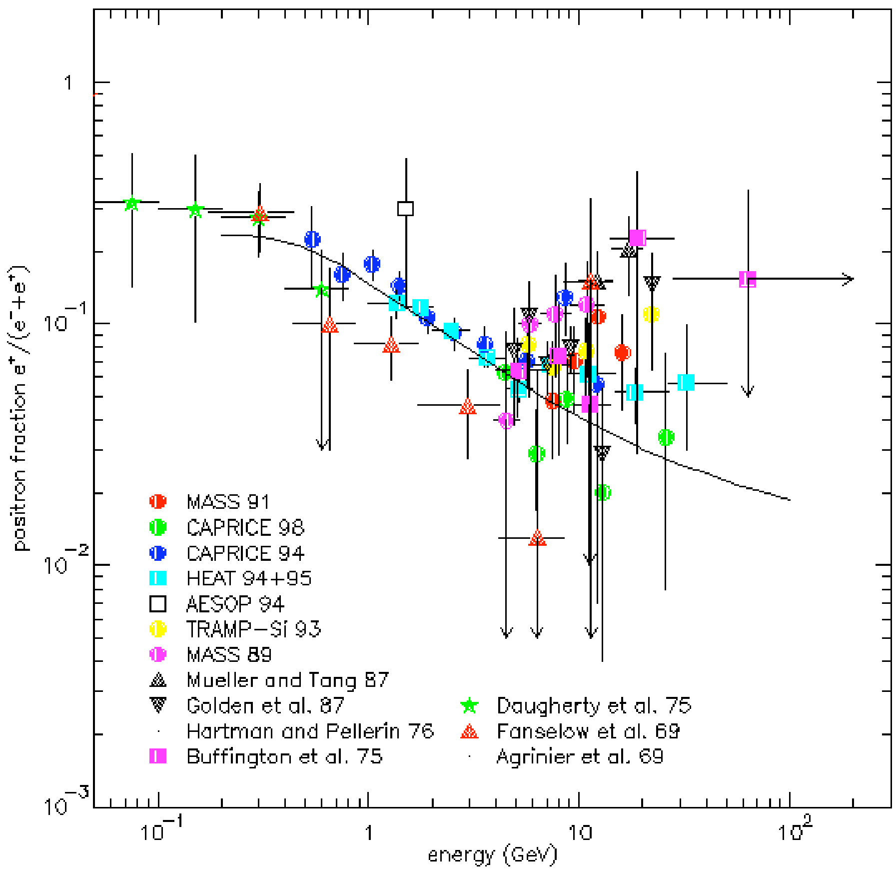
Decay of anti-matter at higher energies



Ratios



Antiproton/proton ratio
Extragalactic Antimatter
Black Hole evaporation
HEAT−pbar
BESS98
CAPRICE98
BESS95+97
MASS91
CAPRICE94
IMAX92
Bogomolov 1987−1990
Buffington 1981
Golden 1984
BESS 00
1
10
Kinetic Energy (GeV)



positron fraction $e^+/(e^-+e^+)$
1
10^{-1}
10^{-2}
10^{-3}
MASS 91
CAPRICE 98
CAPRICE 94
HEAT 94+95
AESOP 94
TRAMP−Si 93
MASS 89
Mueller and Tang 87
Golden et al. 87
Hartman and Pellerin 76
Buffington et al. 75
Daugherty et al. 75
Fanselow et al. 69
Agrinier et al. 69
10^{-1}
1
10
10^2
energy (GeV)

The Antimatter hunter toolkit

- Spectrometer:
  - We need to discriminate the particle charge
  - GOOD Maximum Detectable Rigidity (MDR): we need to push the measured rigidity range up to high energies
  - Magnet (permanent, superconducting at cryogenic T with currents) + Tracker (Gas detectors, solid state detectors)
- Particle discrimination:
  - We need to tag very few events out of a large background: positrons out of protons, antiprotons out of electrons
  - Typically we have to catch one antiparticle out of $10^{5 \div 6}$ particles

MDR of a Spectrometer

- What is the MDR ?
  - The rigidity for which the error $\Delta p/p$= 100%
- Why an MDR of 800 GV could mean a maximum momentum of 190 GeV/c ?
  - Spillover ! At high energy particle charge is confused due to the finite spectrometer precision
  - Fake antiprotons due to protons “spilling” into the antiprotons spectra

Spectrometer

$$R = \frac{pc}{Ze}$$

$$r_L = \left(\frac{pc}{Ze}\right)\frac{1}{Bc}$$

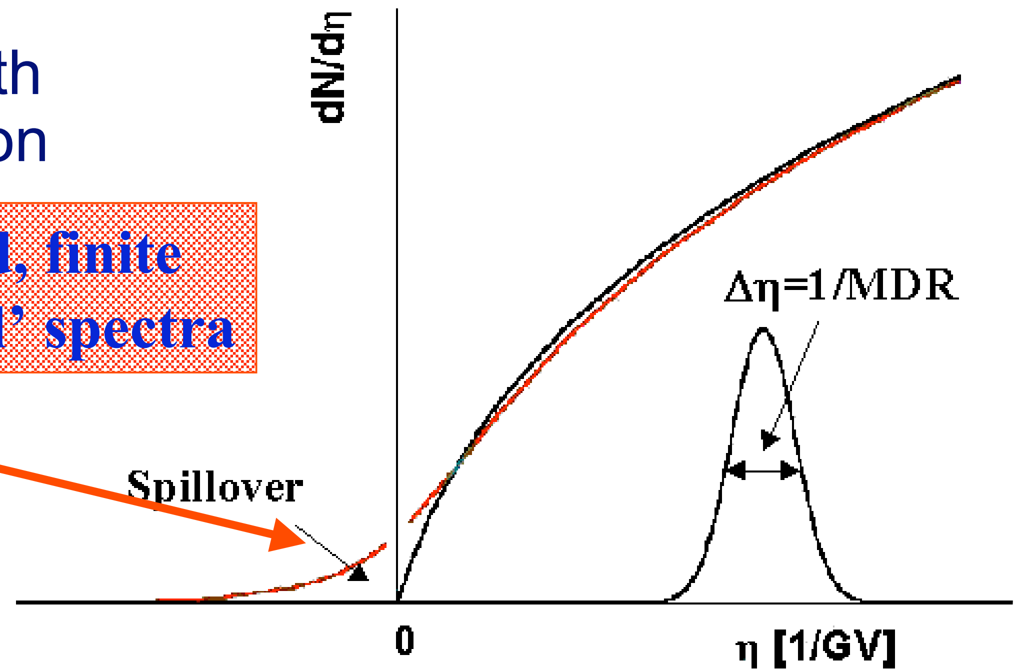
- We measure deflection: $\eta = 1/R \propto 1/p$

If p is high, small deflection, diffucult charge determination⇒spillover

- For this quantity error is gaussian
- Spillover is calculated convolving spectra with spectrometer resolution

If gaussian error added, finite resolution changes 'ideal' spectra

Exercise 9

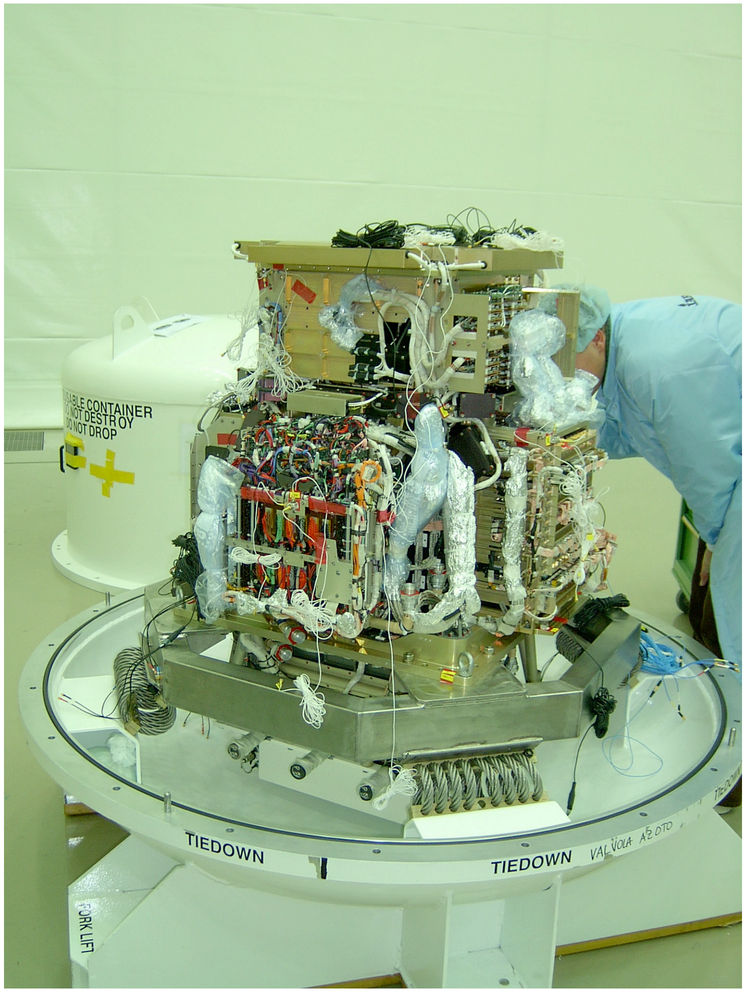


Particle discrimination

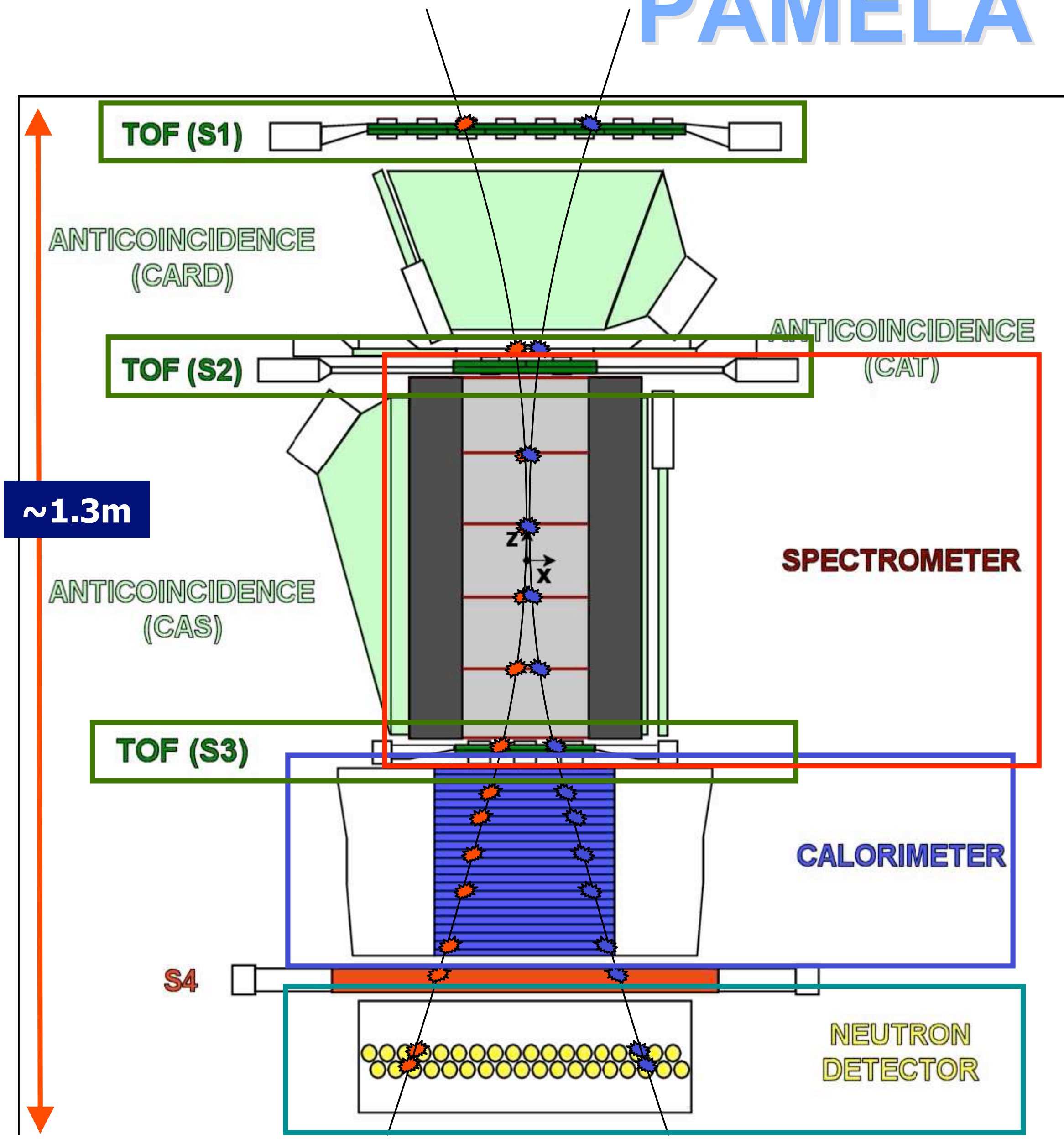
- Depends on the energy range we are interested in:
  - Low energy: TOF, Cherenkov, Pre Showers
  - High energy: RICH, TRD, electromagnetic calorimeters

PAMELA

- The observational objectives of the PAMELA instrument are to:
  - measure the spectra of antiprotons, positrons and nuclei in a wide range of energies,
  - to search for primordial antimatter,
  - to study the cosmic ray fluxes over half a solar cycle.
- PAMELA will be able to measure magnetic rigidities (momentum/charge) up to its Maximum Detectable Rigidity (MDR) of 700 GV/c).

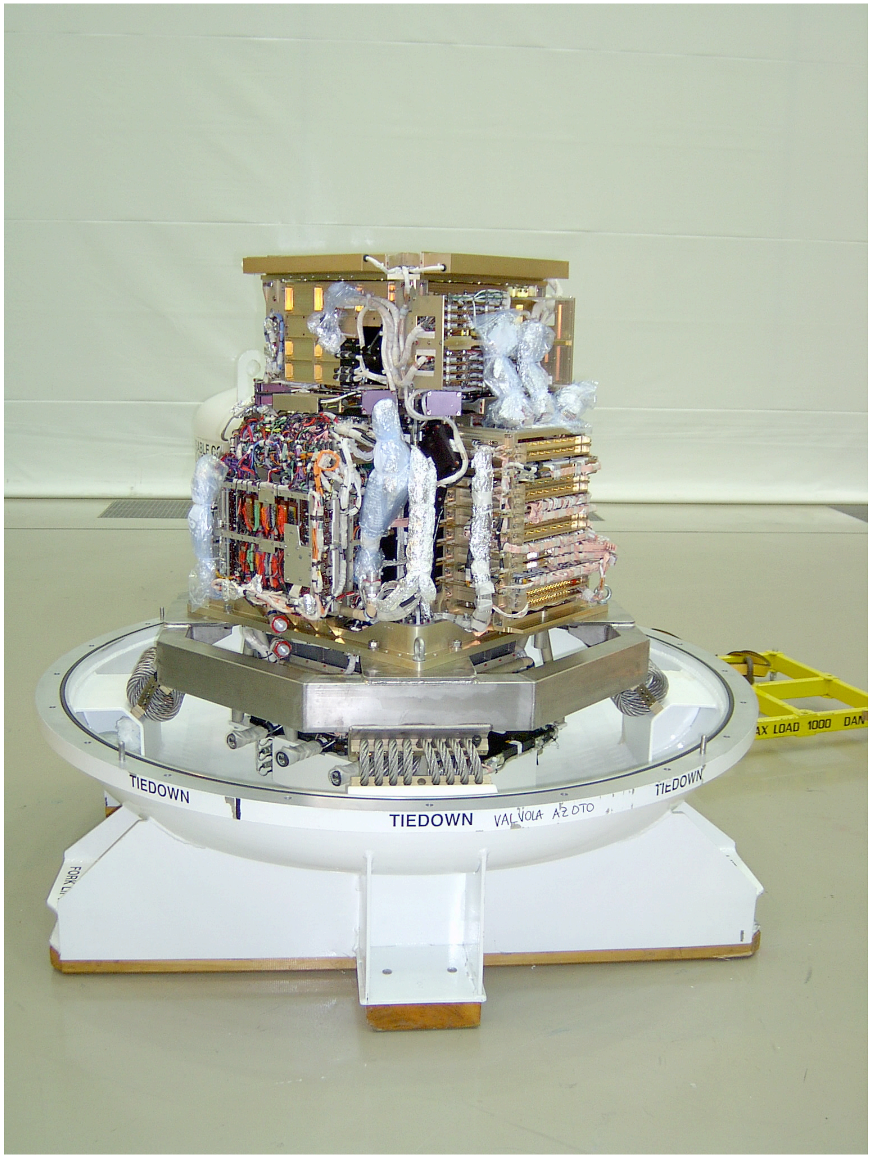


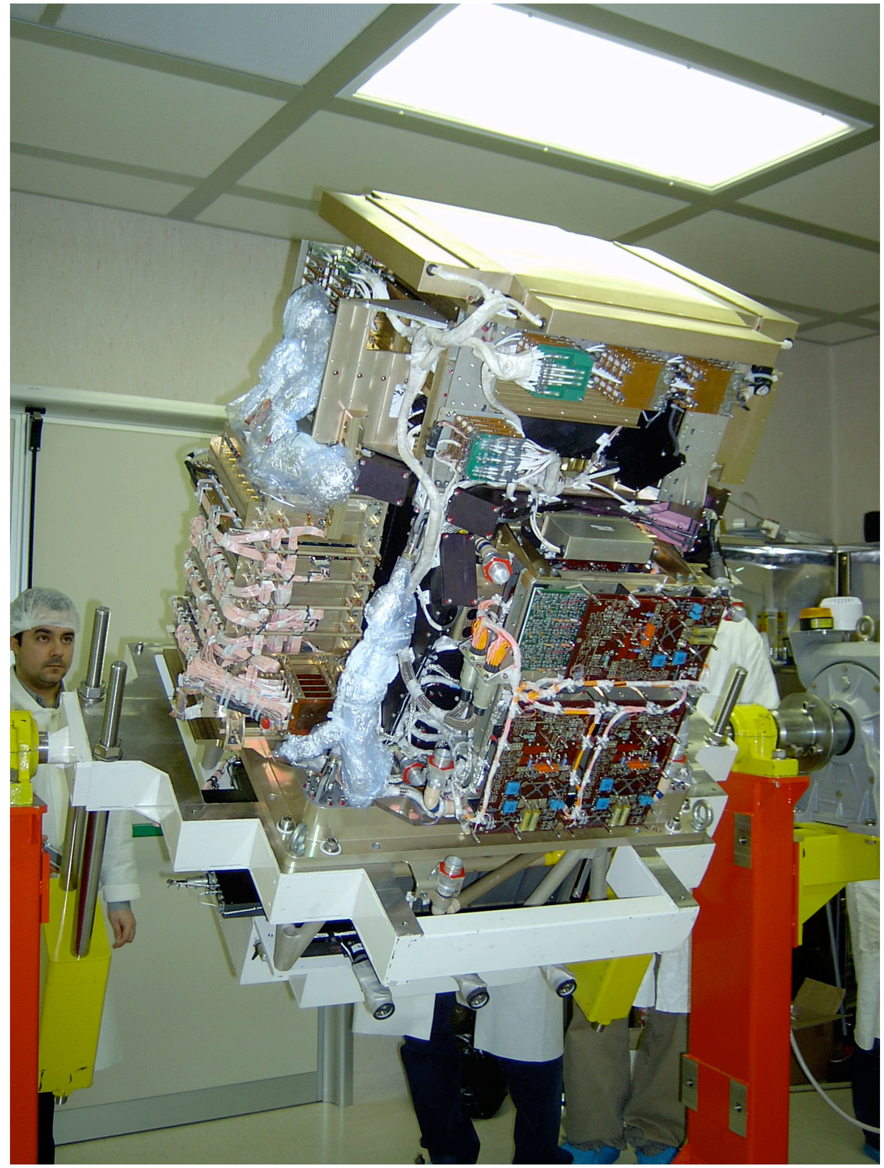
PAMELA

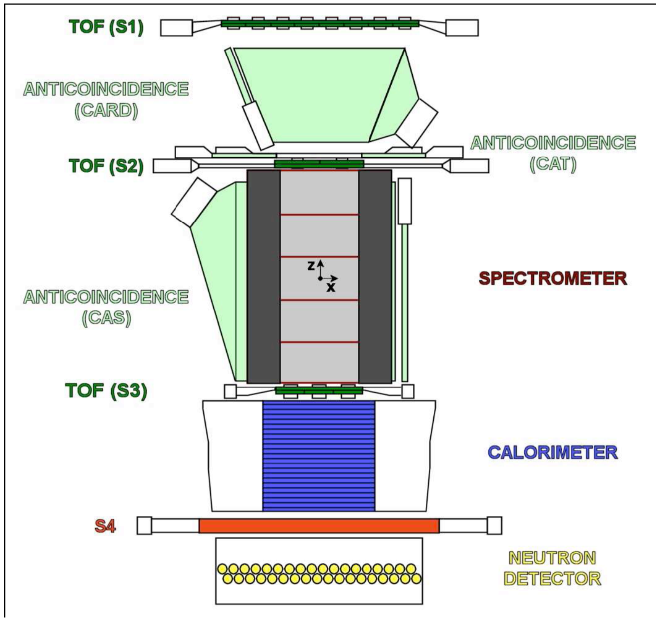


- Particle ID using:
  - TOF
  - Em. Calorimeter
  - Neutron detector
    ^{3}He n capture to help em/h shower id
- Rigidity determination using spectrometer
  permanent magnet and silicon tracker

PAMELA: the integration



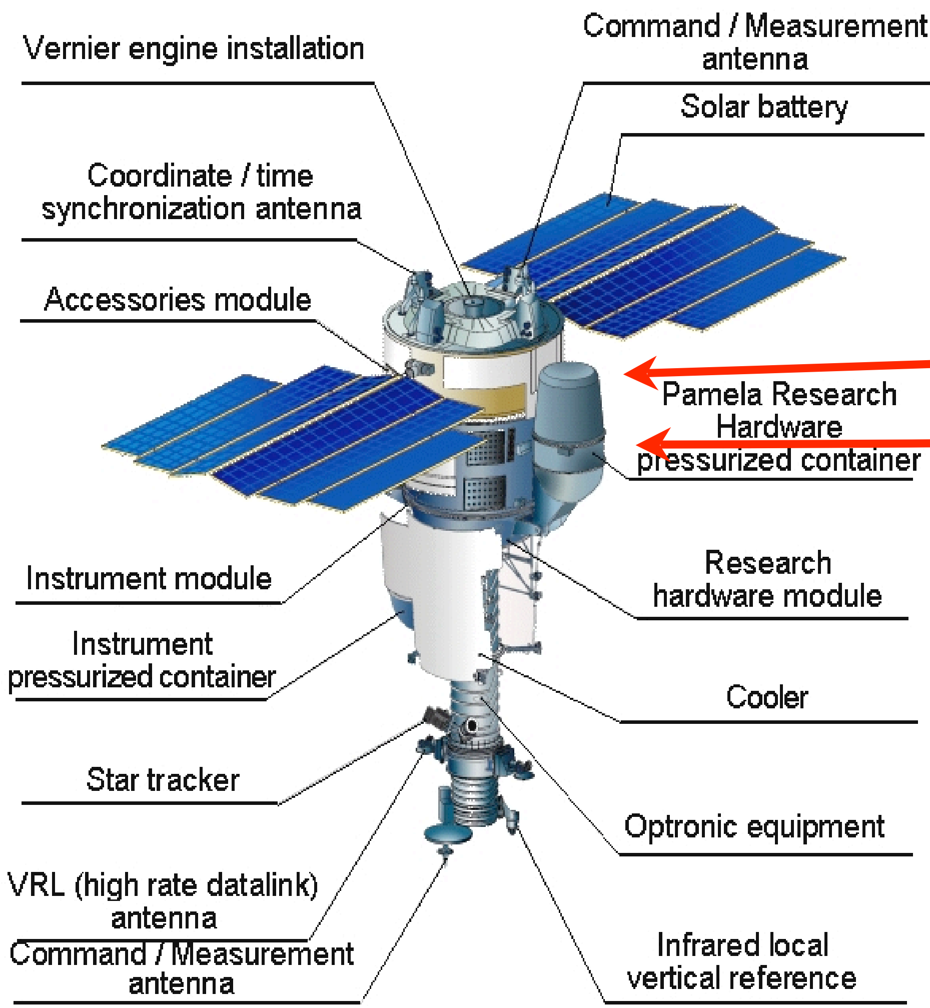




PAMELA

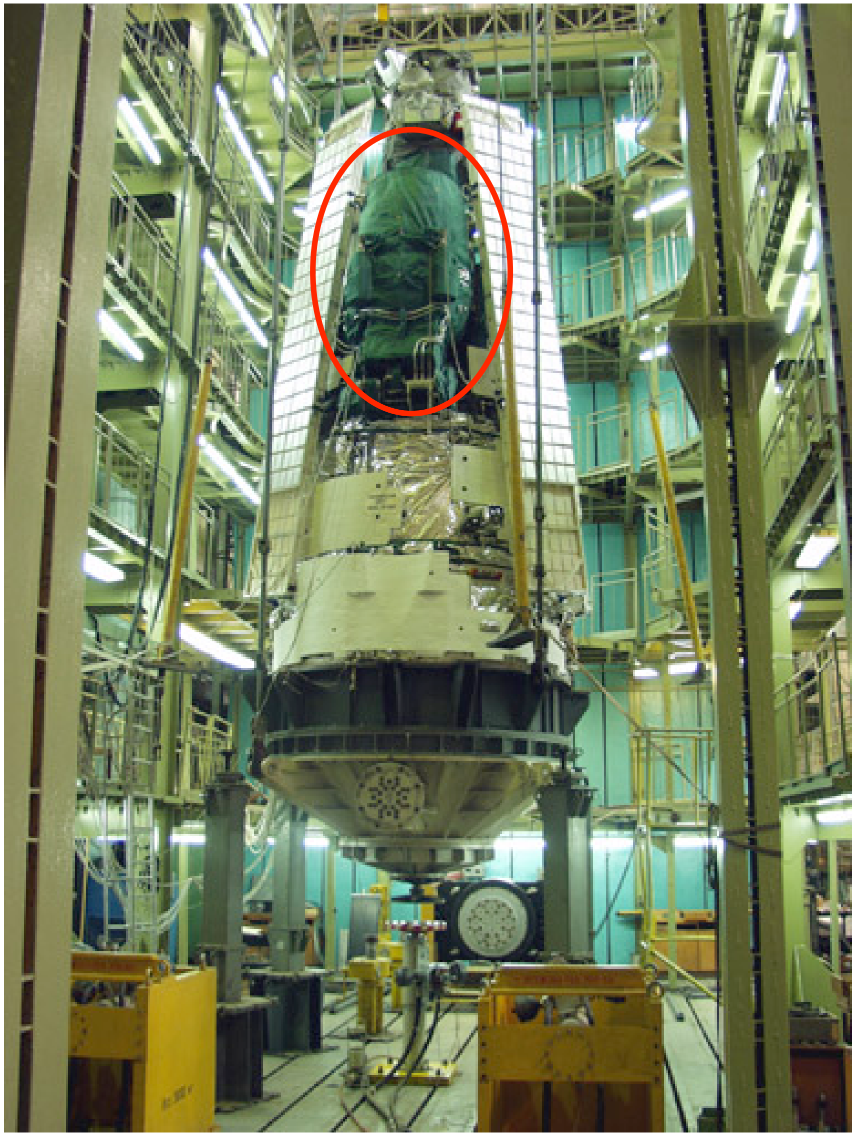
Particle	Number (3 yrs)	Energy Range
Protons	3.10^{8}	80 MeV - 700 GeV
Antiprotons	**$>3.10^{4}$**	**80 MeV - 190 GeV**
Electrons	6.10^{6}	50 MeV - 2 TeV
Positrons	**$>3.10^{5}$**	**50 MeV - 270 GeV**
He	4.10^{7}	80 MeV/n - 300 GeV/n
Be	4.10^{4}	80 MeV/n - 300 GeV/n
C	4.10^{5}	80 MeV/n - 300 GeV/n
Antihelium Limit (90% C.L.)	**7.10^{-8}**	**80 MeV/n - 30 GeV/n**

Resurs DK satellite



- Satellite Mass: ~10 tons
- Pamela Container Total Mass: ~750 kg
- PAMELA Mass: 470 kg
- PAMELA Power: 380 W
- Orbit :
  - Elliptic (300 ÷ 600 km)
  - Inclination: 70.4°

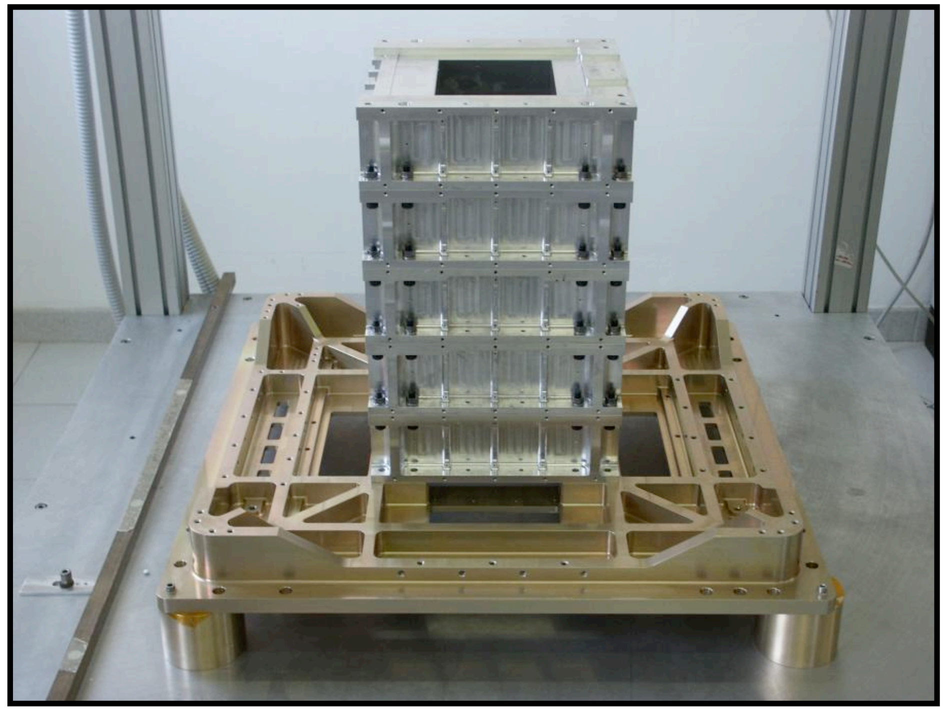
PAMELA in the satellite



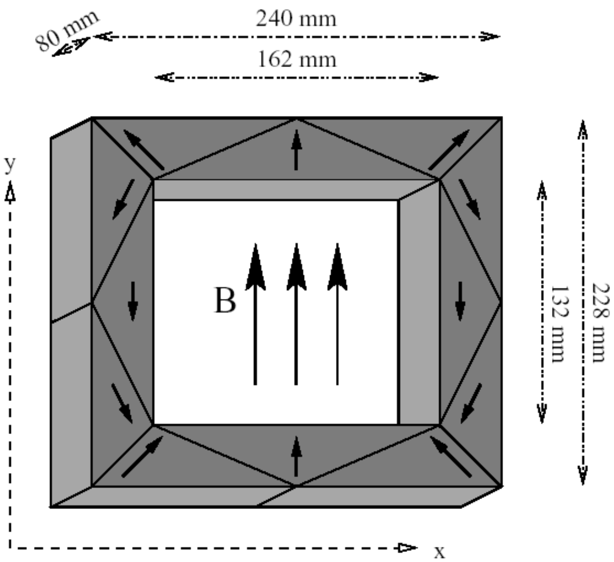
Magnetic Spectrometer

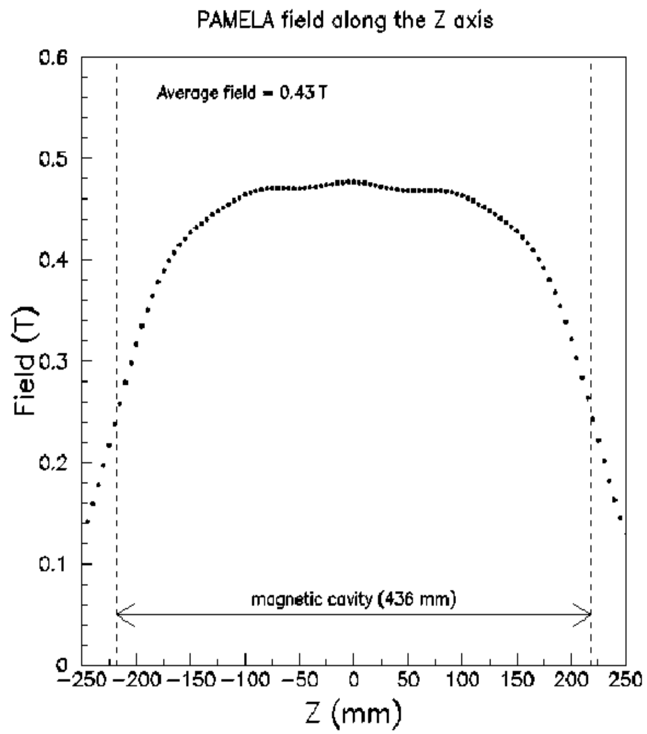
- **Permanent magnet**
  - 5 blocks of Nd-B-Fe
  - 0.48 T
    cavity
  - Magnetic tower =
    13.2 x 16.2 cm^2
    44.5 cm

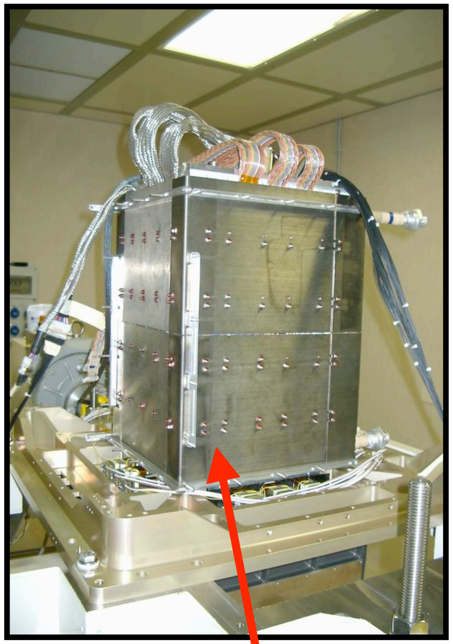
    20.5 cm^2 sr

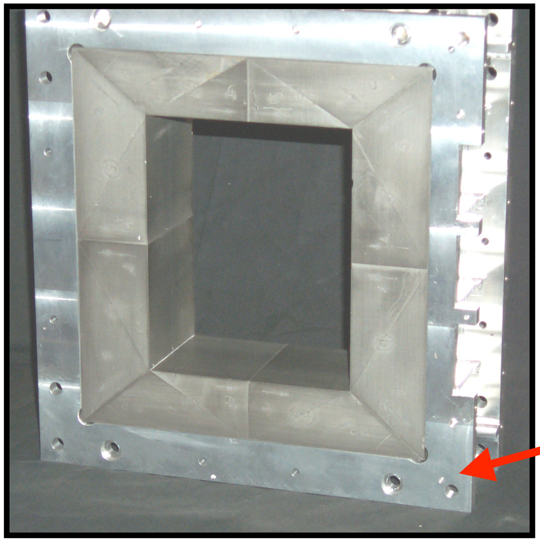


Magnet Construction







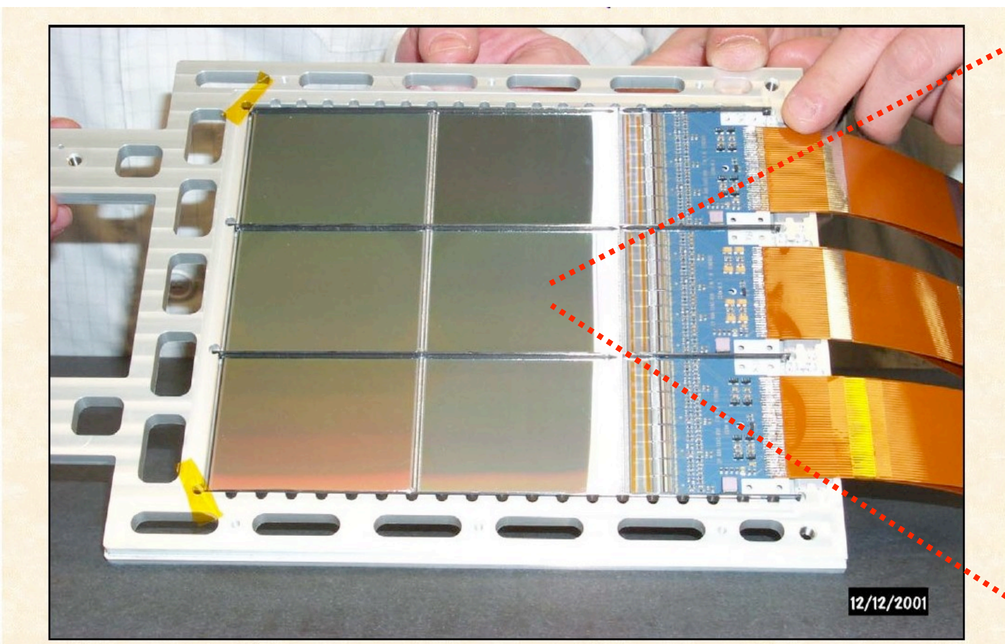


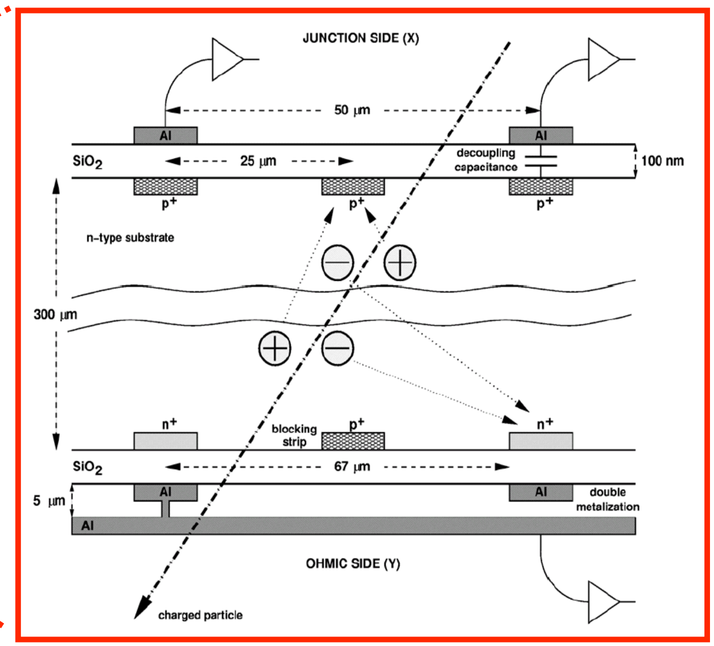
Support canister

Ferromagnetic shields

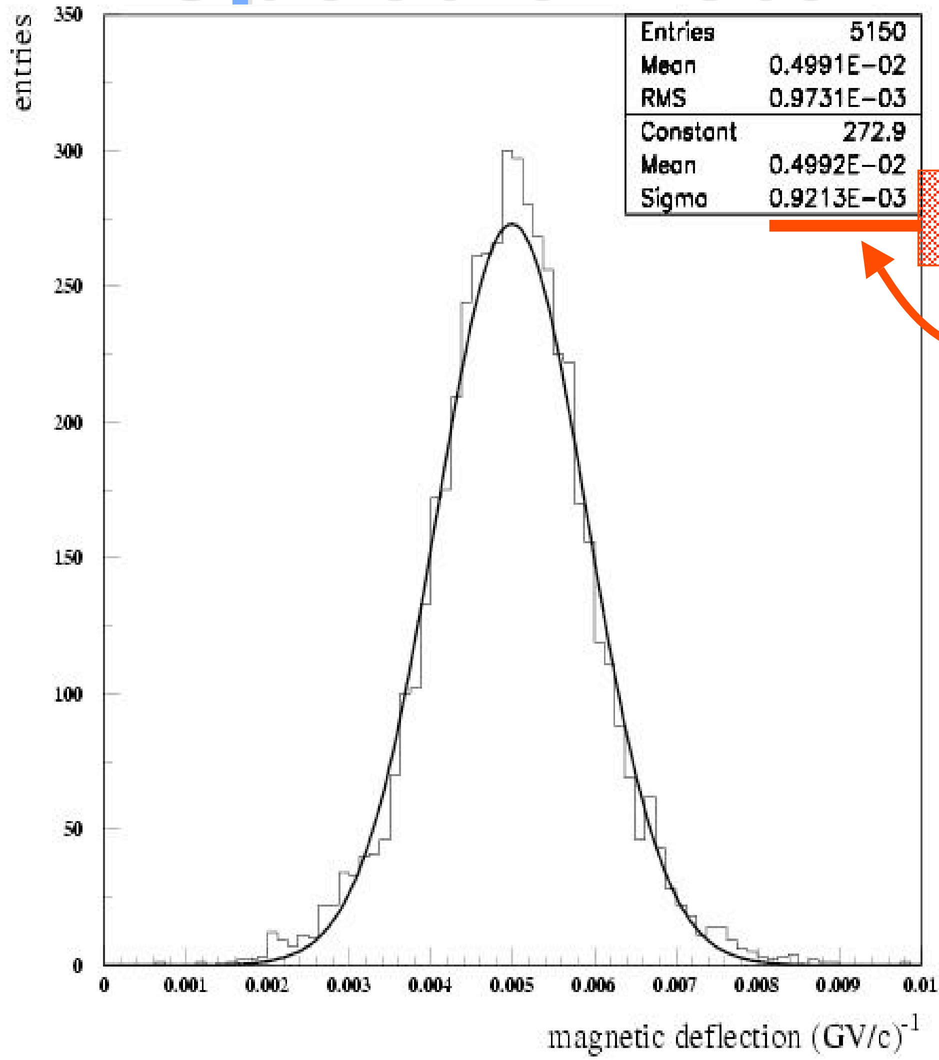
Silicon Planes

- **<u>Double-sided silicon microstrips</u>** (300 μm thick):
  - 25 μm implantation pitch (junction side) / 67 μm (ohmic side)
  - Strips mutually orthogonal on opposite sides
  - Readout pitch 50 μm





Spectrometer Resolution

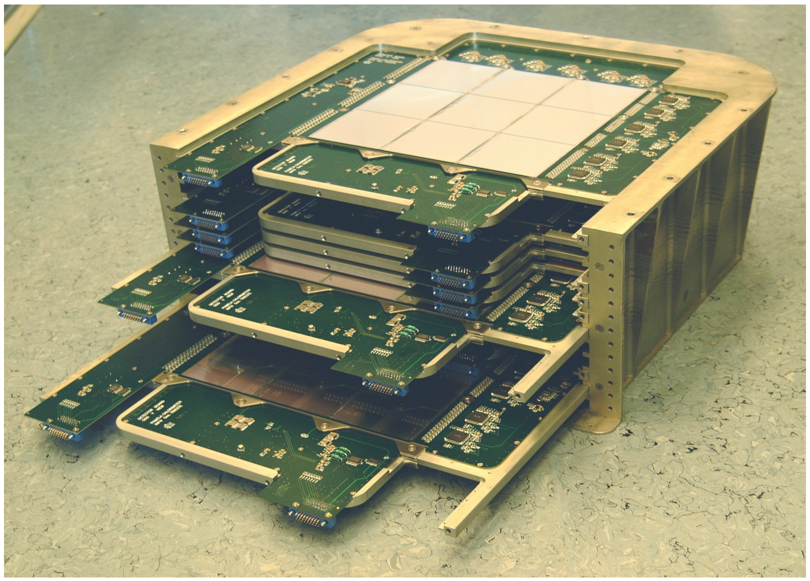


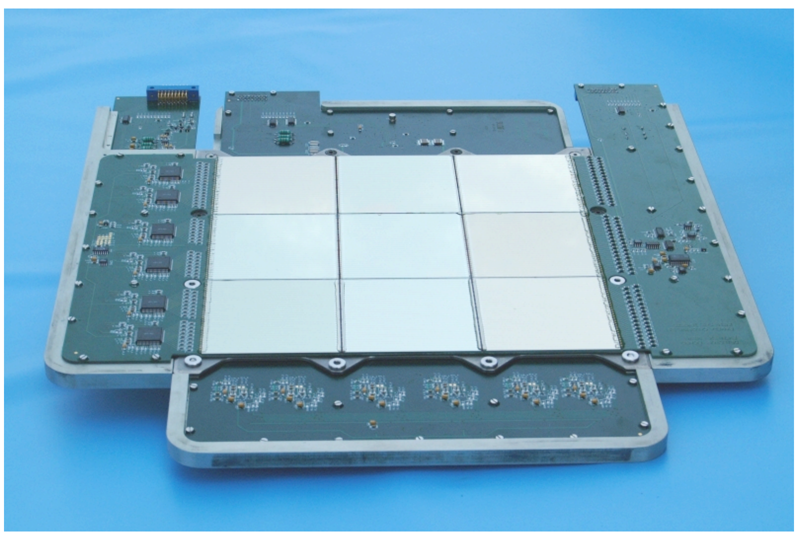
MDR ≅ 1080 GV ($\Delta p/p$ = 100%)

- SPS Testbeam data: p 200 GeV/c
  - x (bending = orthogonal to B) σ_x = 2.7μm
  - y (non-bending = parallel to y) σ_y = 12μm

PAMELA: Magnet

Si-W Imaging Calorimeter

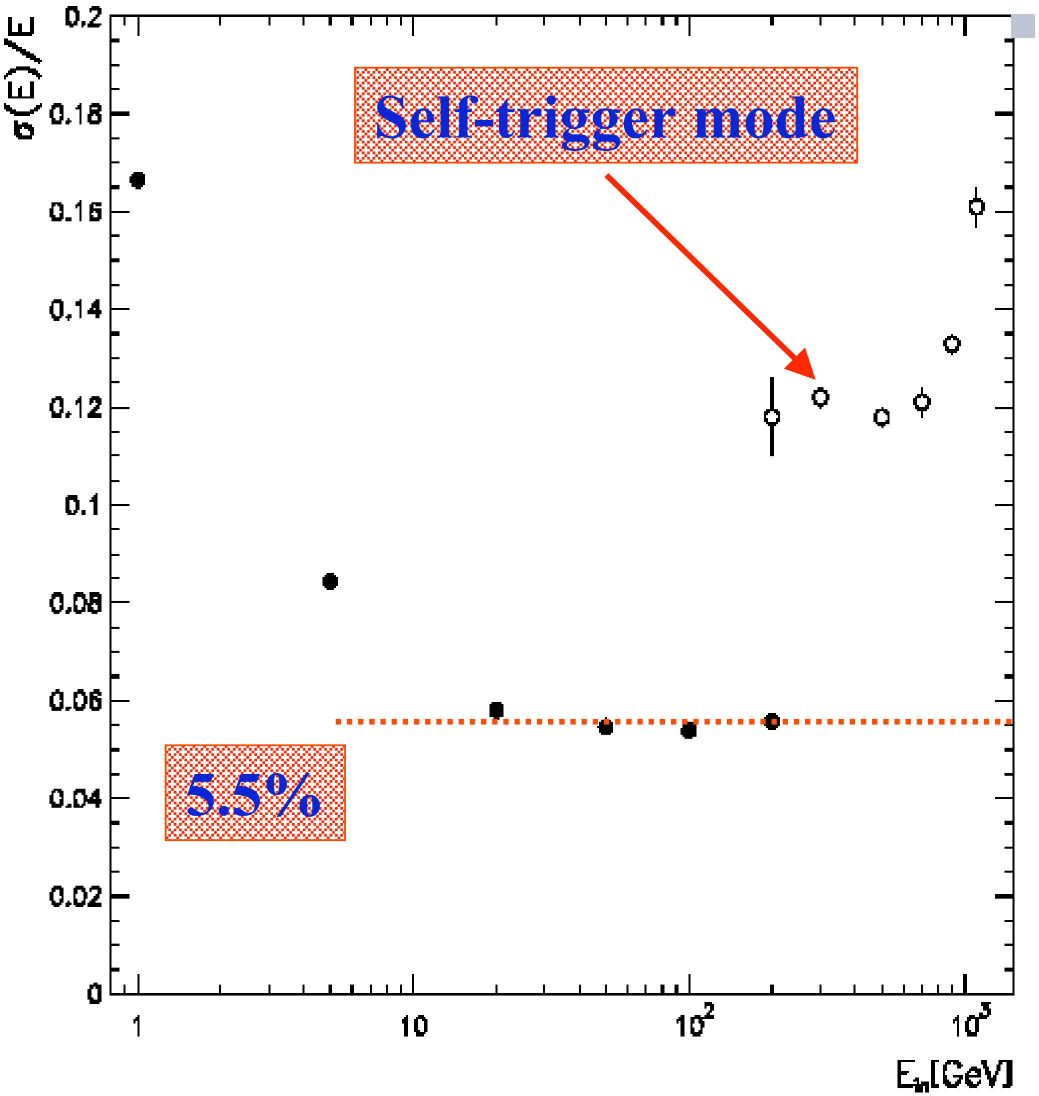




- 22 planes :
- Altenating layers of Si (380 μm) / W (2.6 mm)
- 96 strips (2.4 mm wide) per Si layer
- X & Y views
- 16 X_0 (0.6 λ_N) deep
- Total number of channels: 4224
- Wide dynamic range ≅

1 ÷ 1000 MIPs (released charge due to a MIP particle)

Calorimeter Energy Resolution



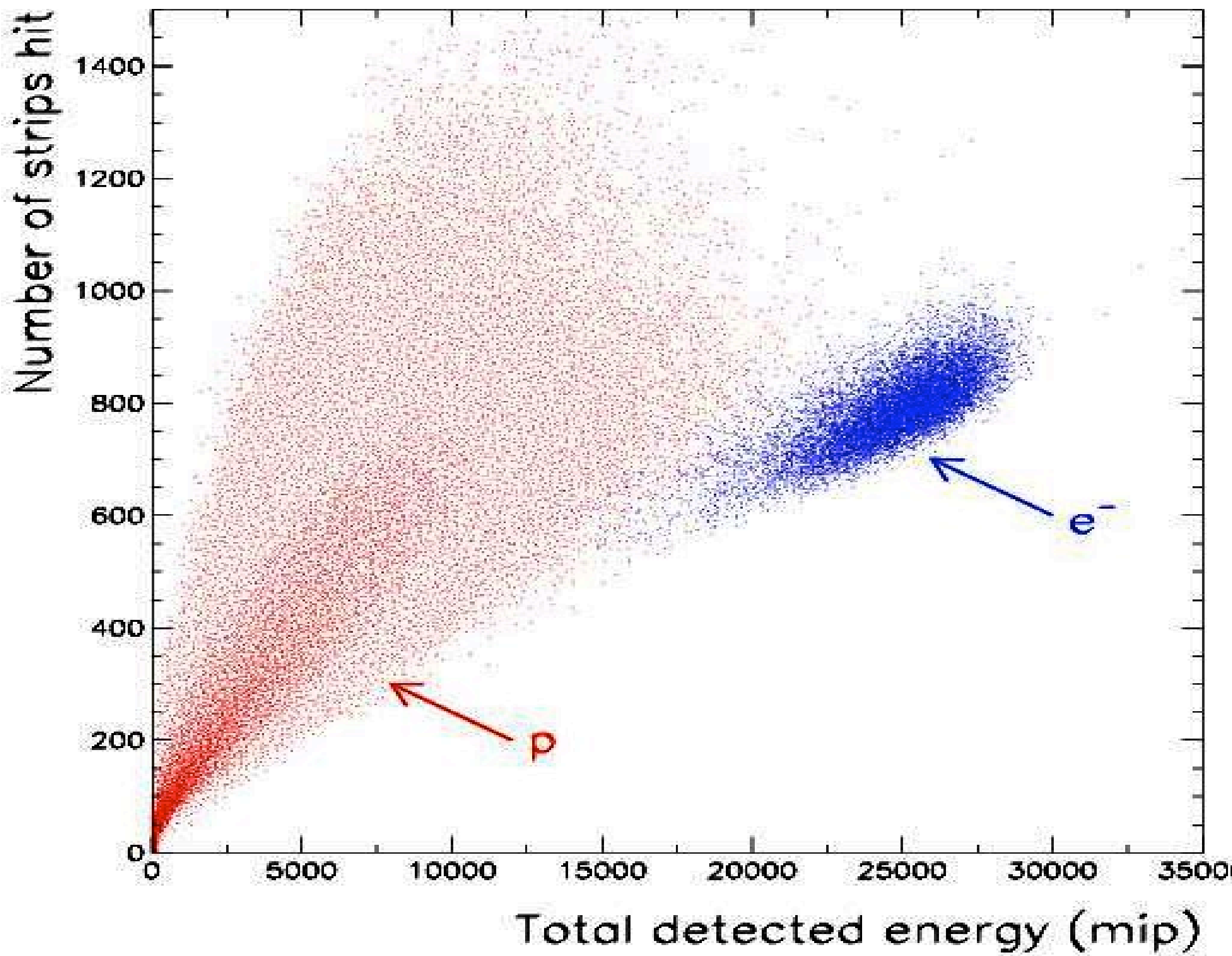
Self trigger mode:

- ~300 GeV → 2TeV 'electrons'
- Enter one of 1st 4 planes & cross ≥ 10 X_0
- acceptance: 600 cm^2sr

♣Eff(E_e > 300 GeV) > 99% (sim.)

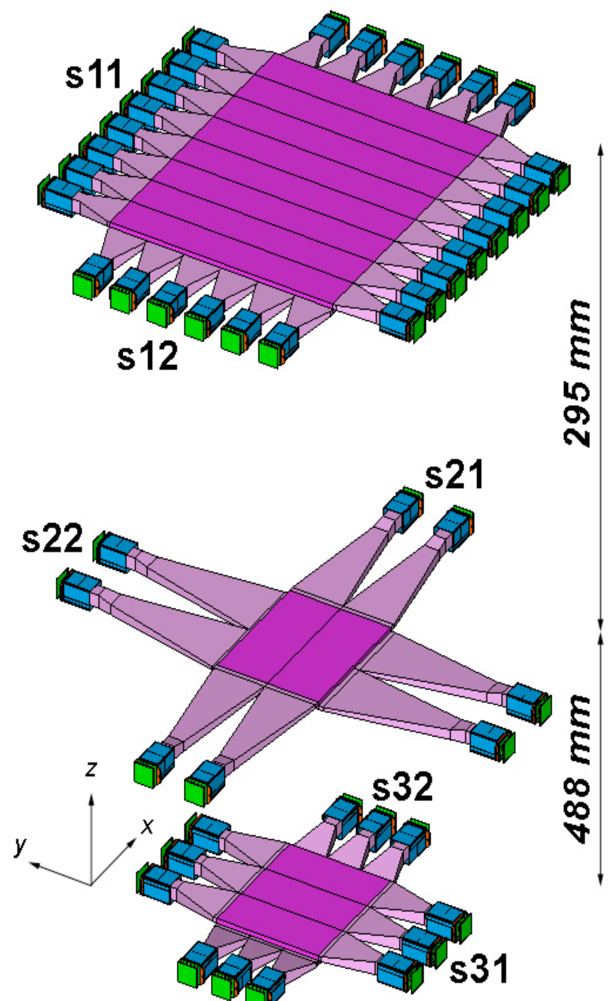
e-p Separation with the Calorimeter

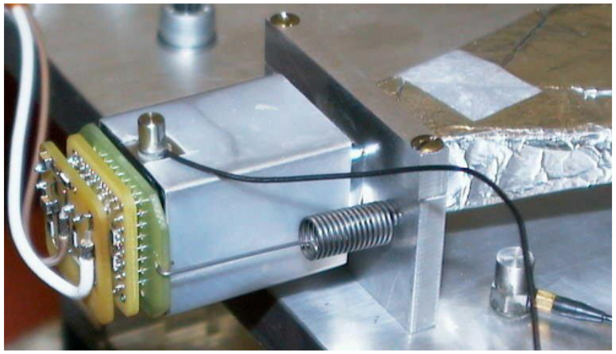
- SPS Test Beam Data:
  - p e⁻ @200 GeV/c
- Proton rejection factor ≅ 3 10^4
- Electron selection efficiency ≅ 95%

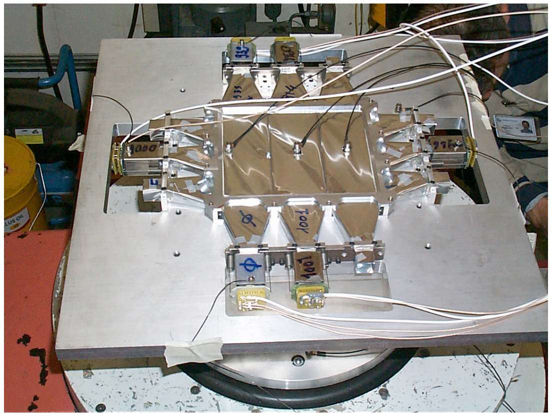


The TOF System

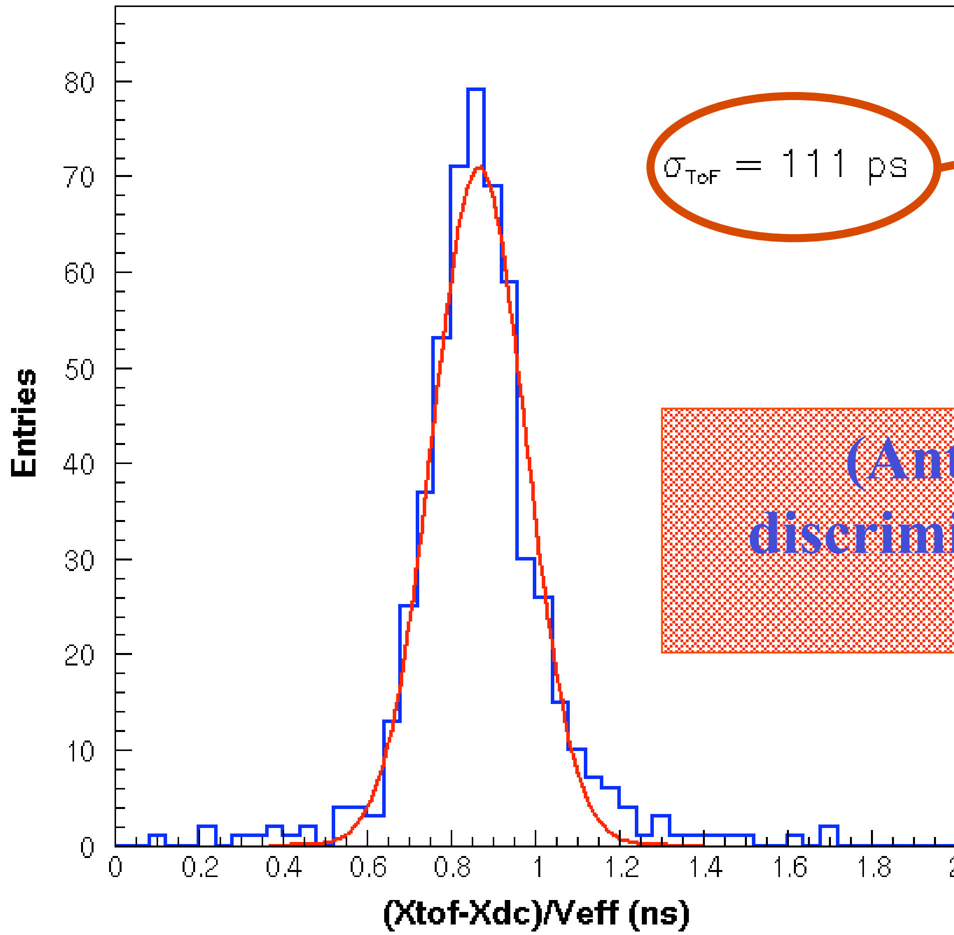
- **TOF:** Particle ID / albedo (from below) rejection
  - 3 planes of Scintillators S1, S2, S3
  - Each plane: 2 crossed layers, segmented into X- and Y- strips
  - Hamamatsu PMT R5900 (selected for Q.E. and to match scintillator strips)
- **TRIGGER:** (S1 x S2 x S3)
- **dE/dx** measurements (charge)





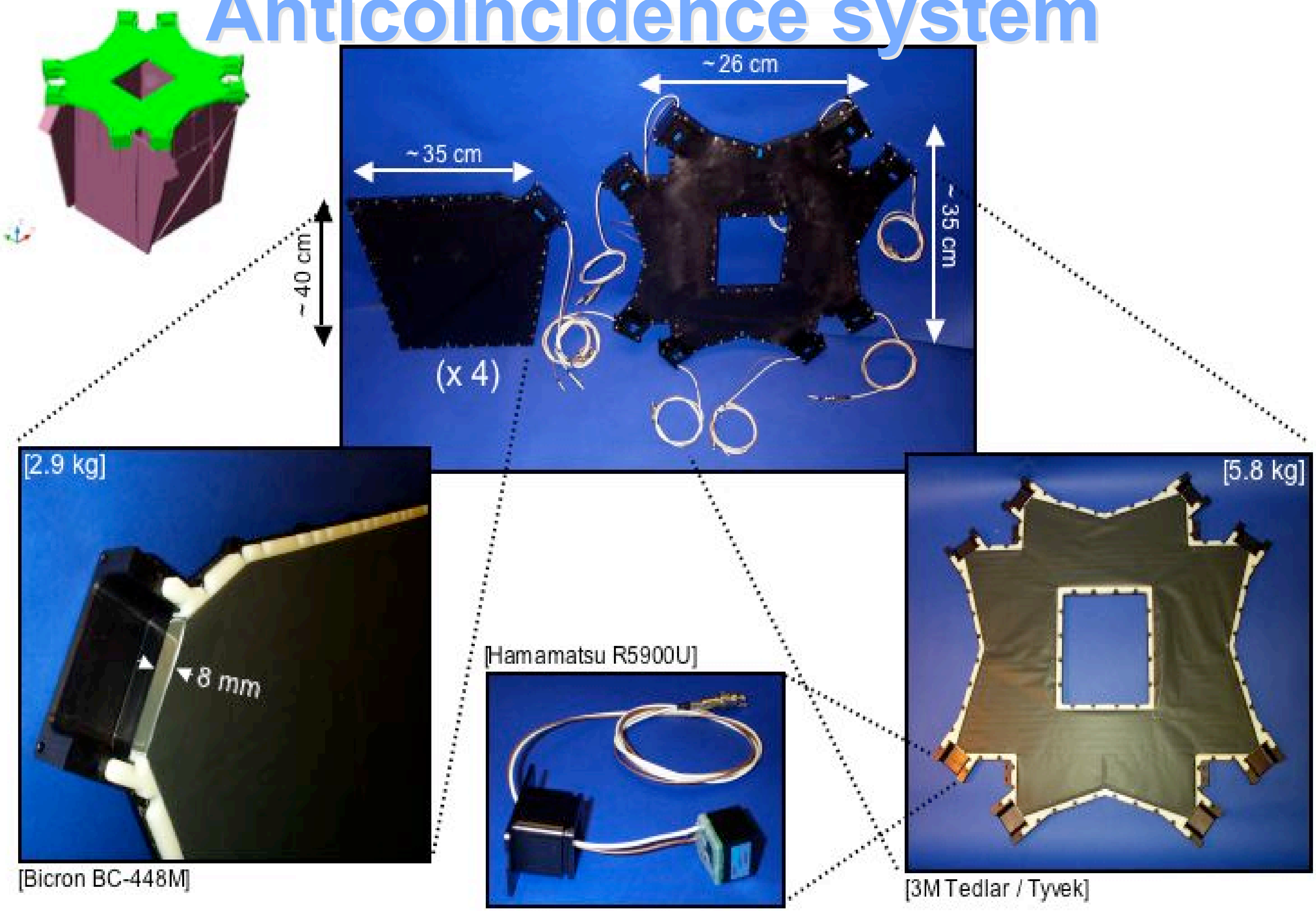


ToF Performance

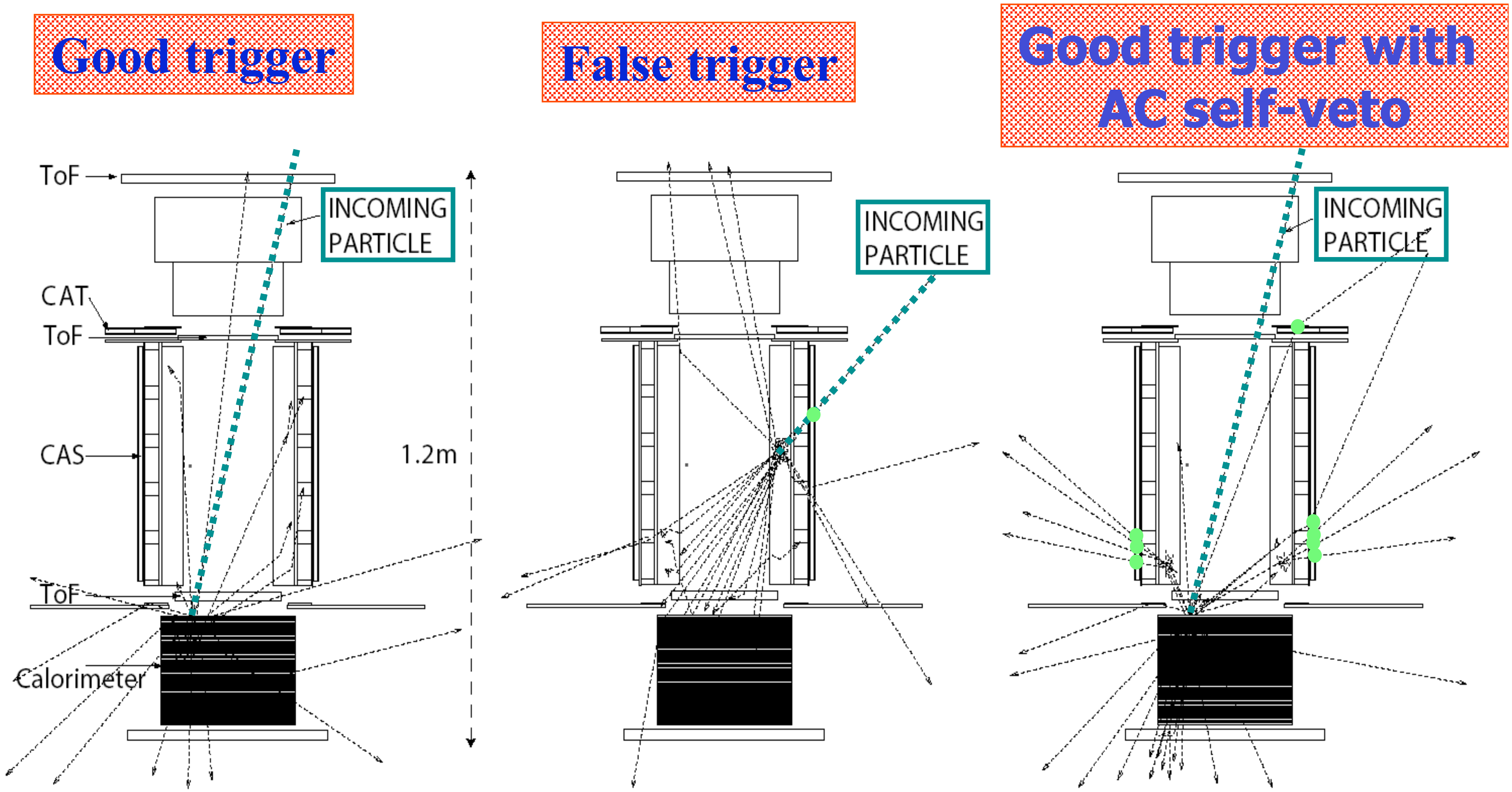


(Anti)proton/electron discrimination possible up to ~ 1.5 GeV/*c*

Anticoincidence system



Anticounter Purpose

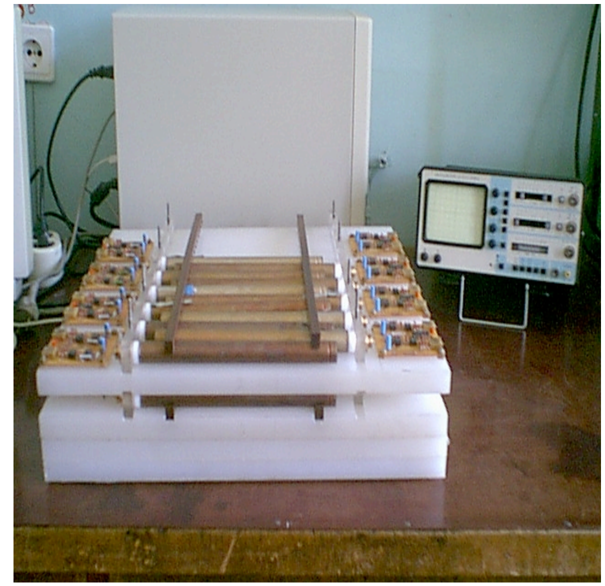


- AC are used offline or in L2 trigger to reduce false triggers

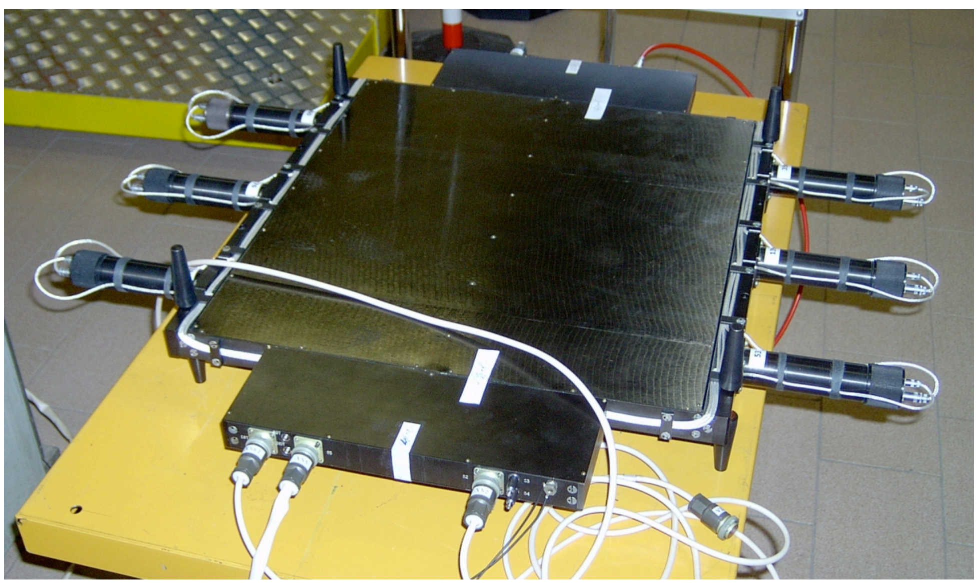
Shower Scintillator & Neutron Counter

- VHE $e^{\pm}$,E ~ 10^{11} eV ÷ 10^{13} eV using a Neutron Detector (ND) (more *n* in hadronic than EM showers):

  $n + {}^{3}He \rightarrow p + {}^{3}H + 765$ keV
- 2 x 18 ^{3}He proportional counters (polyethylene / Cd envelope)

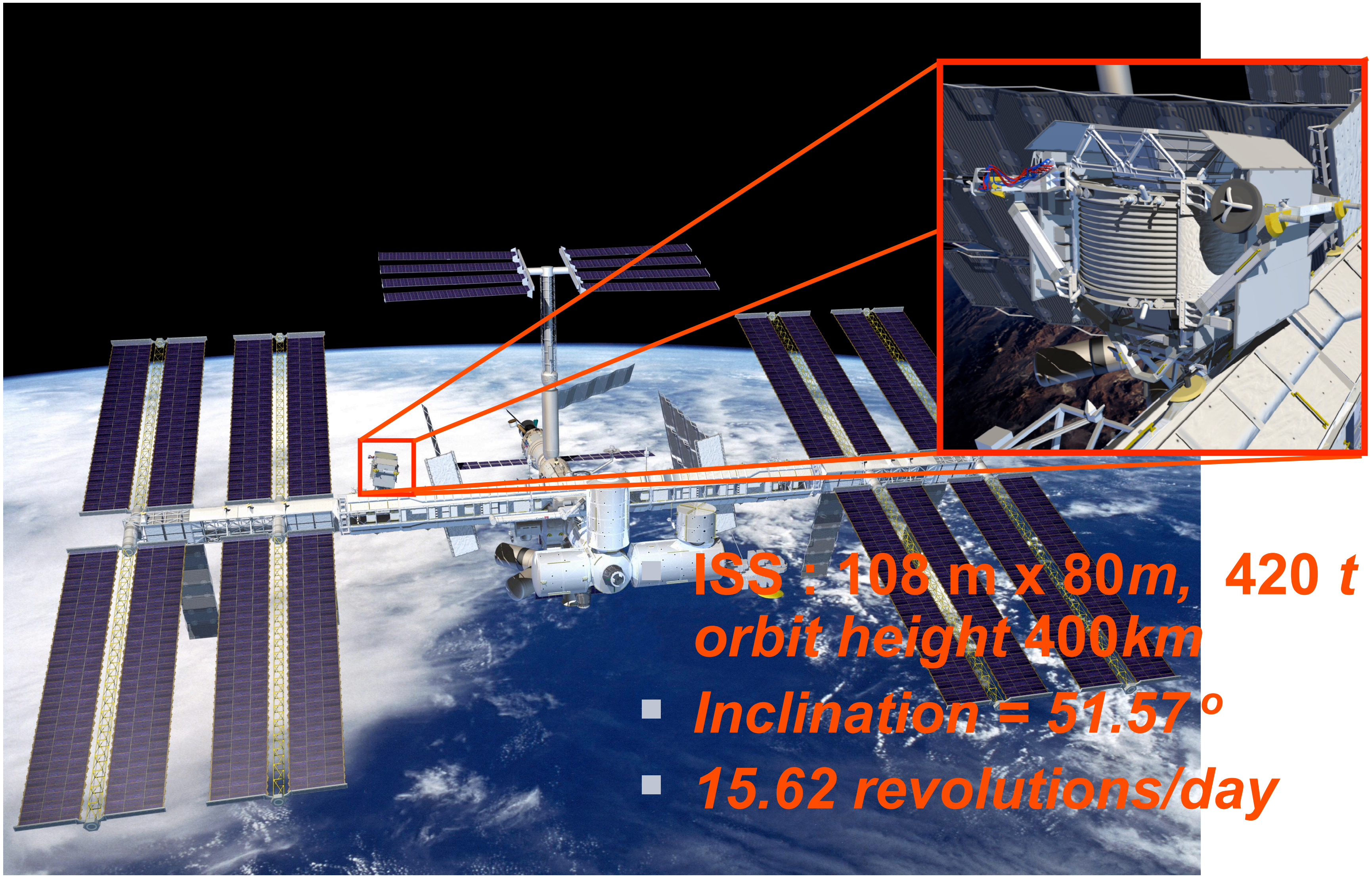


Trigger



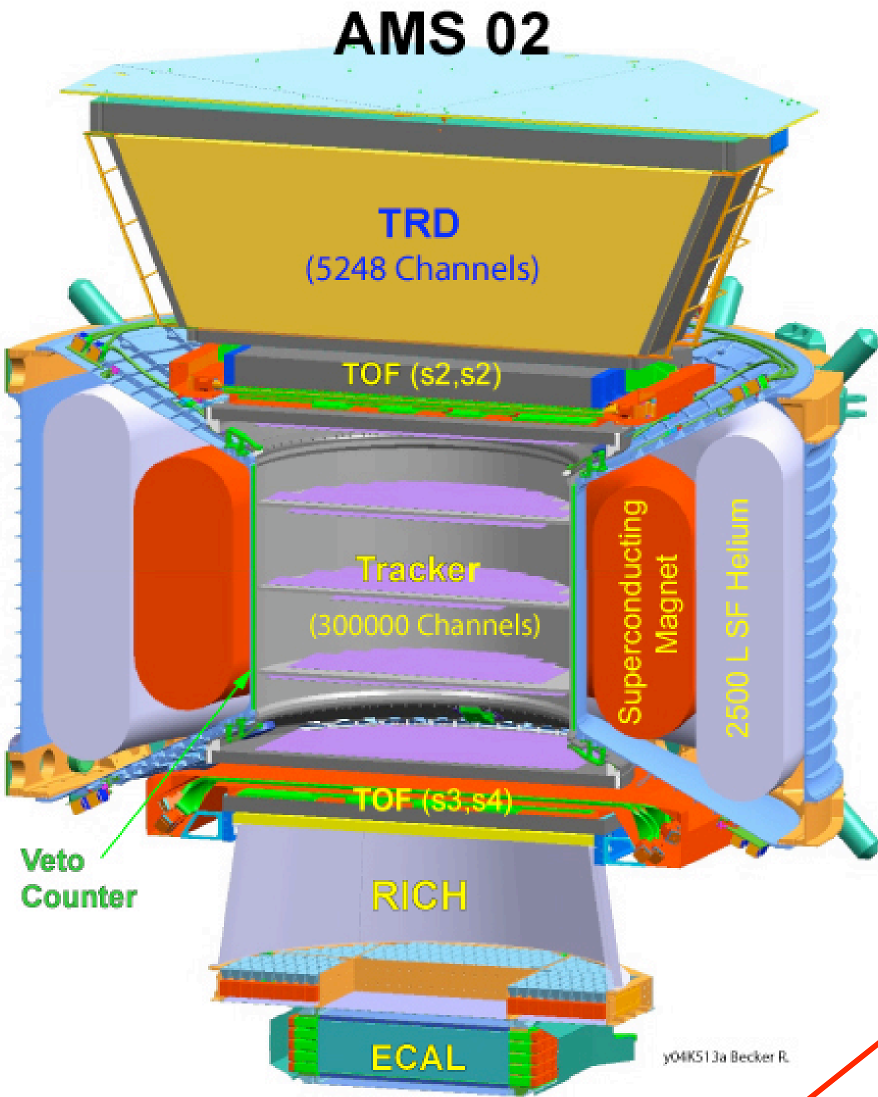
- ND triggered by a plastic scintillator: 482 mm x 482 mm x 10 mm
- 6 PMT read-out
- Dynamic range: 1÷ 1000 MIP

AMS: General



ISS : 108 m x 80*m*, 420 *t*
orbit height 400km

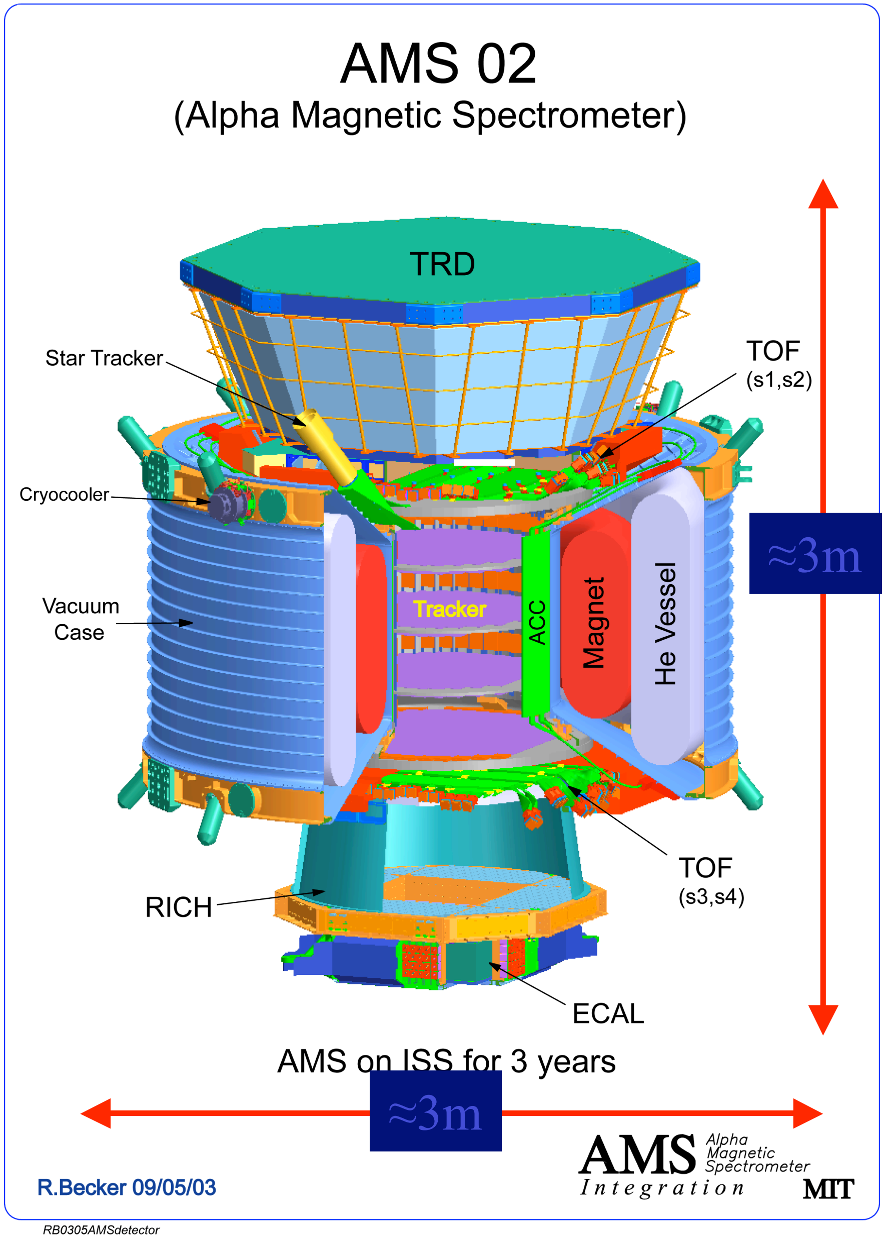
- ***Inclination = 51.57 °***
- ***15.62 revolutions/day***



AMS: General

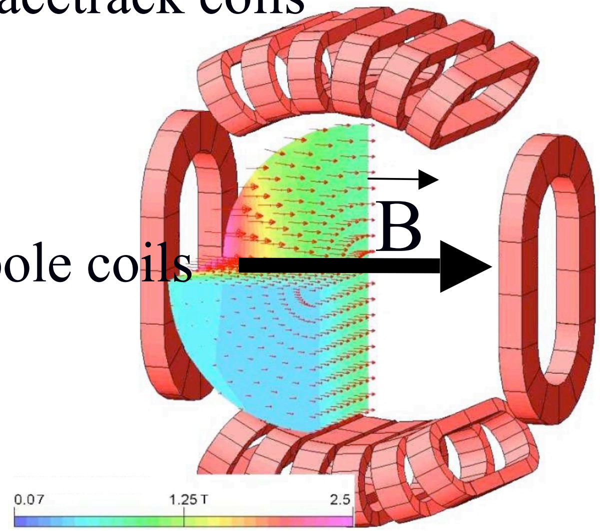
- TRD (e/p)
- Scintillator system (TOF) (β, dE/dx, trigger)
- Superconducting magnet (BL^2= 0.85 Tm^2)
- Silicon Tracker (rigidity, charge)
- RICH (β, charge)
- Em. Calorimeter(energy, e/p)

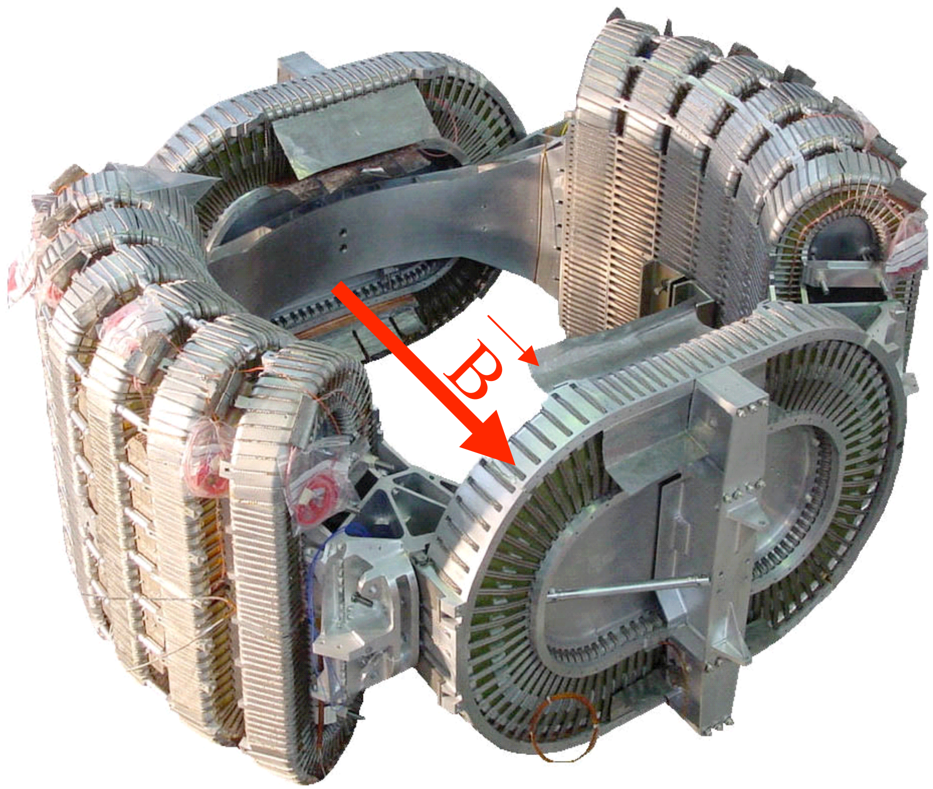
AMS: General

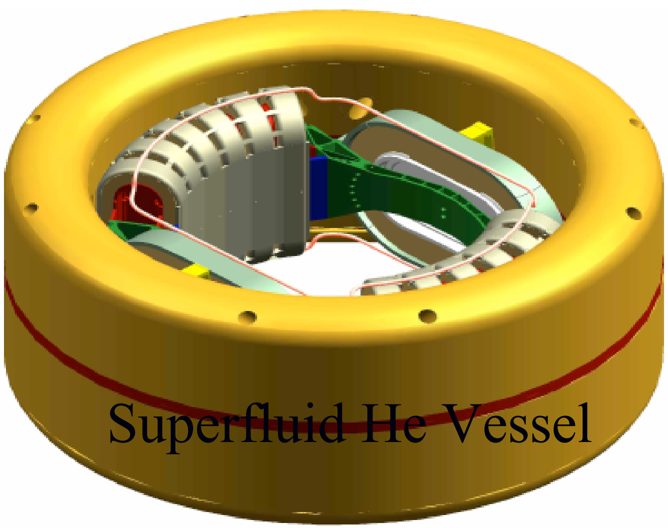


- Large geometrical acceptance: 0.45 m^2 sr
- Long exposure: 3 years
- Redundant measurements
- High vacuum
- High radiation levels
- Strong gradients of temperature -60°C ÷ +40°C
- Weight < 7 Tons
- Power consumption < 3kW

Superconducting Magnet







Diameter = 1.2 *m*, Height = 0.8 *m*, Weight = 2.3 *t*

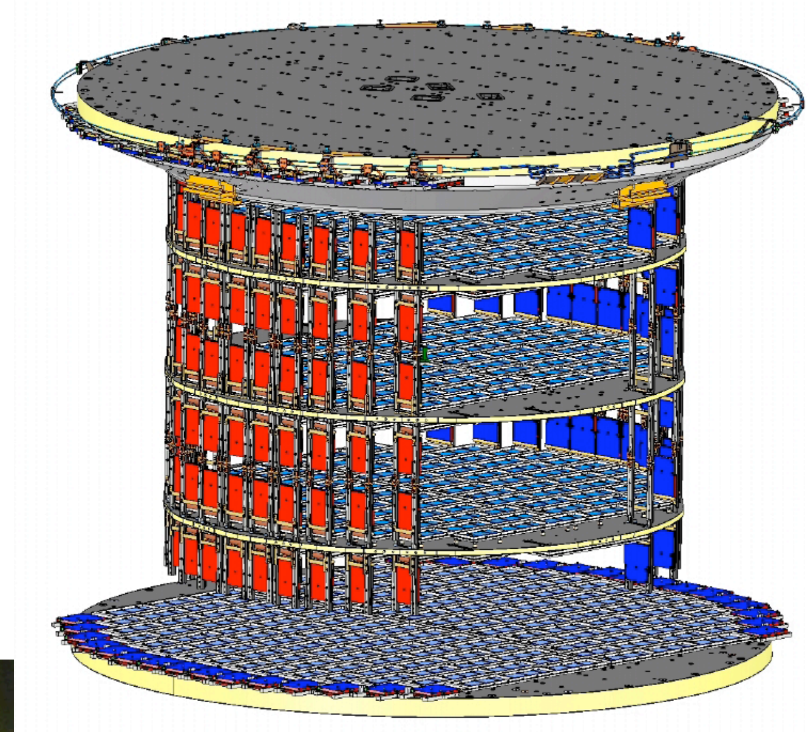
B_{dipol} = 0.860 [T], E_{stored} = 1.15 MJ, I = 459.5[A]

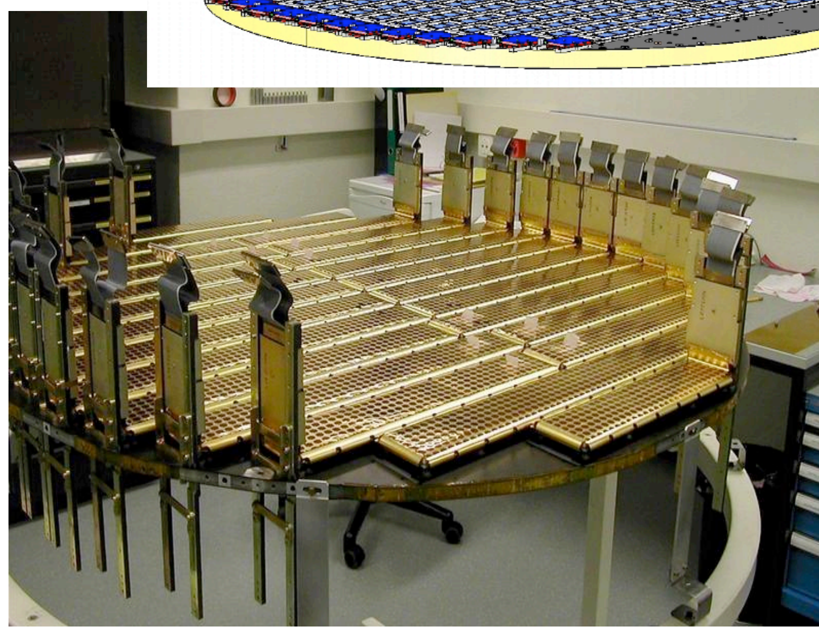
Cold Heat Exchanger : Superfluid Helium (-271.35°, 2500 *l*)

Long Duration Operation without refill

AMS: Tracker

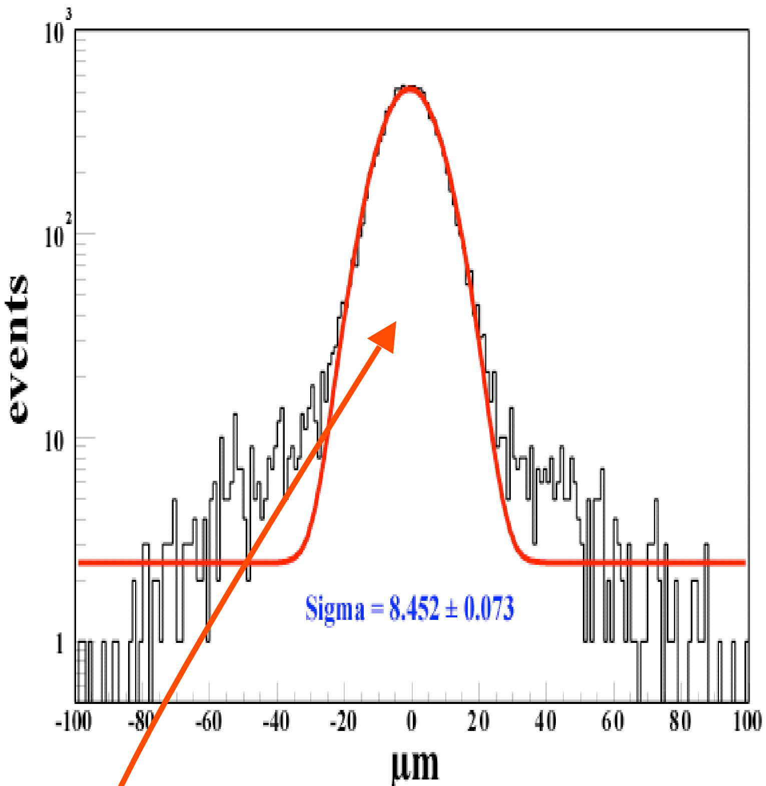
- 2264 Double sided Silicon wafers
- 640 readout strips on implantation or p-side (bending coordinate)
- 384 readout strips on junction or n-side (non-bending coordinate)
- Combined into 192 Ladders of 7-15 sensors
- 1024 readout channels for each ladder, total of ~ 200k channels
- Ladders arranged on 8 layers piled up in 5 planes
- ~ 6.4m^2 total

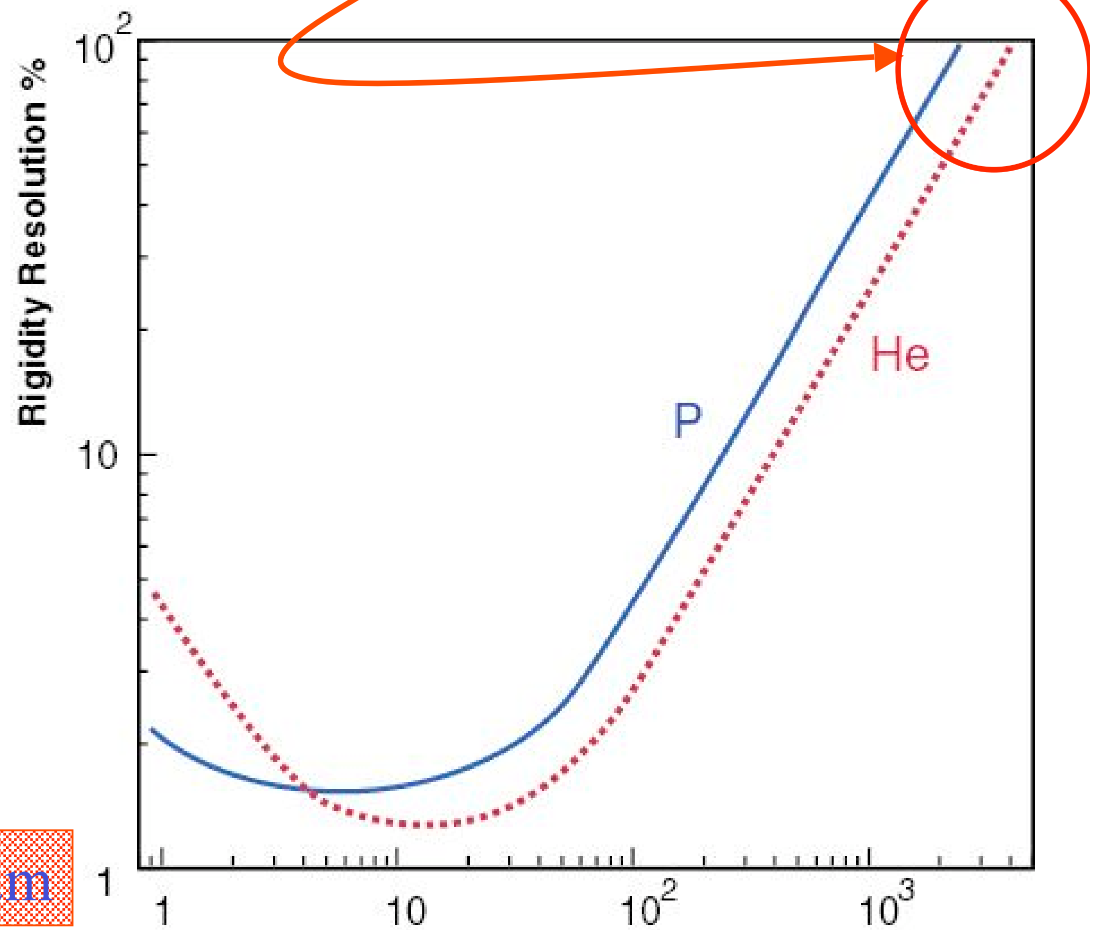




AMS: Tracker

MDR ≅ 3000GV ($\Delta p/p = 100\%$)

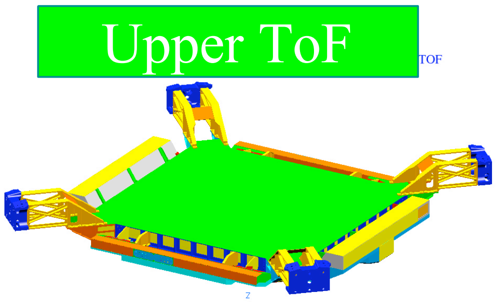


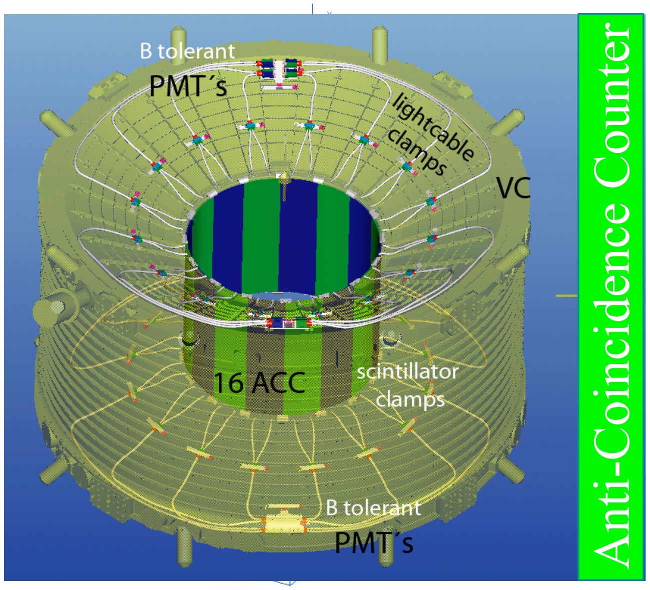


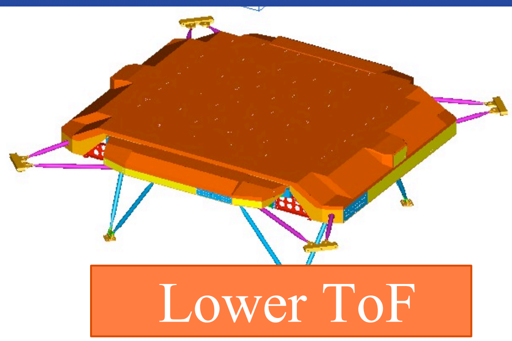
Spatial resolution ~ 10µm

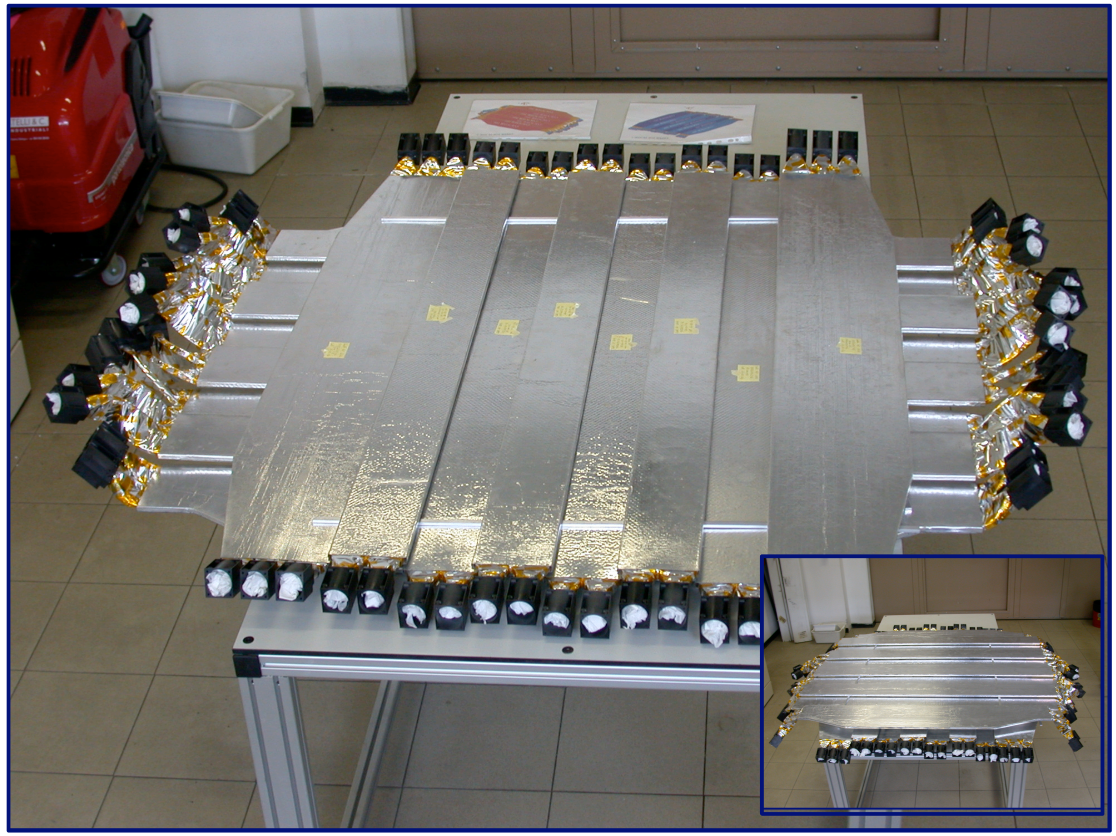
120 GeV/c muon beam

ToF & ACC









Fast Trigger$_{prim}$ $\sigma_t \leq 130$ [ps]

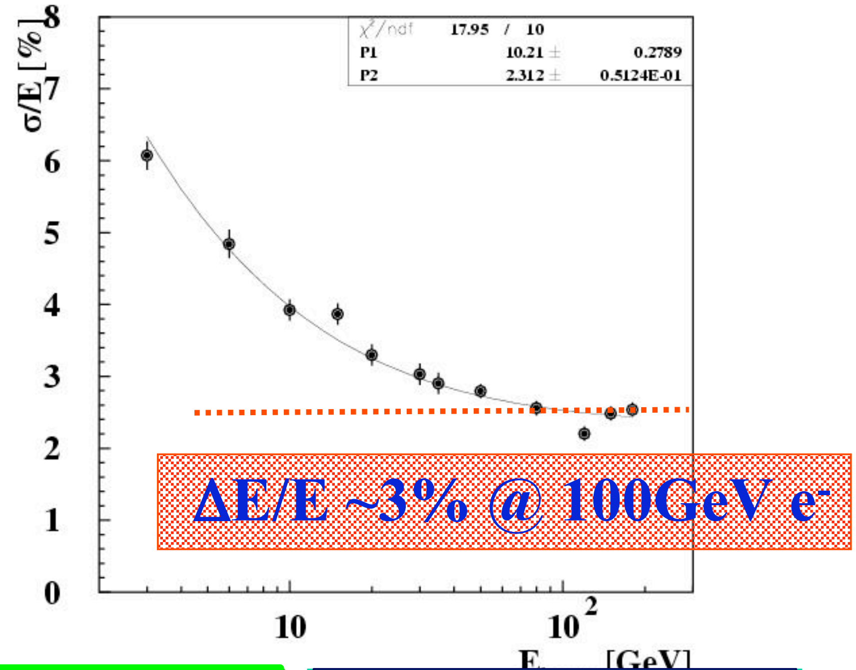
Layers = 4 (2 + 2) Area = 8 m^2

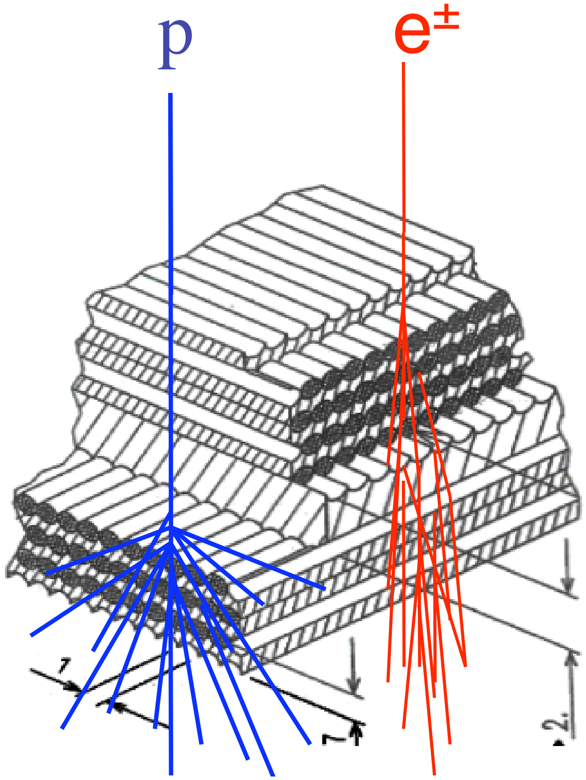
ToF : 34 Paddles

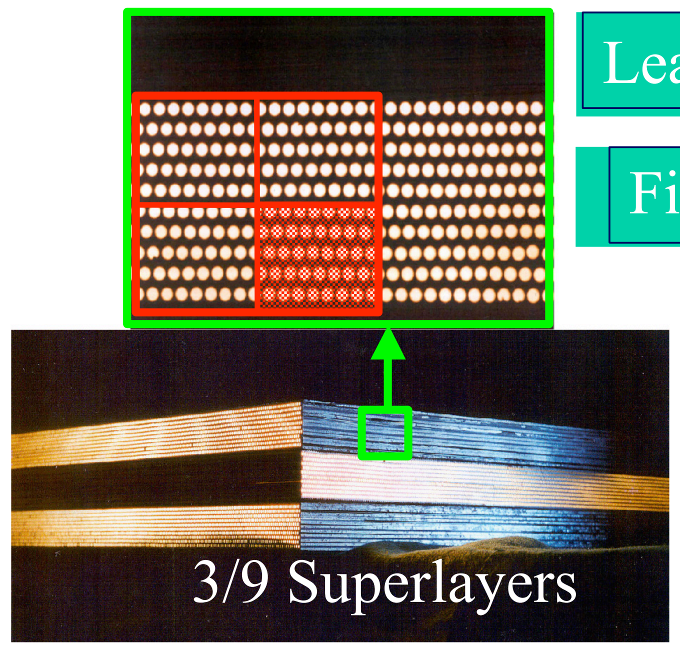
ACC : 16 Cylindrical Shell Paddles

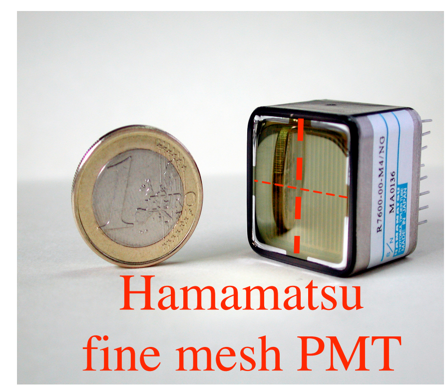
AMS: Em. Calo.

- 9 Superlayers (Pb + Fiber Sandwich)
- 16.4 X_o and ~ 0.5 $\lambda_{nucl.}$
- Standalone Gamma Trigger
- 65x65 cm^2, m= 640 kg, 324 PMTs



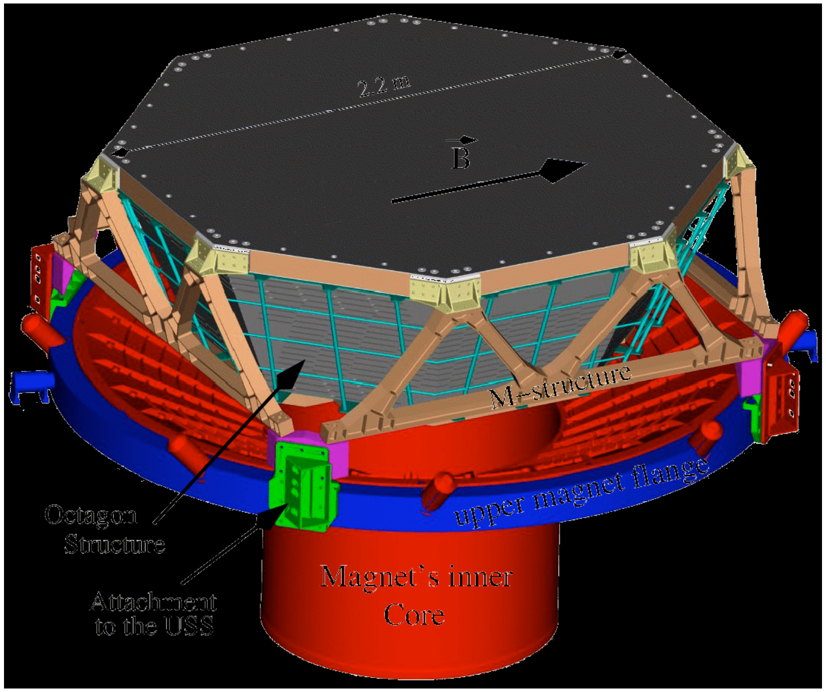


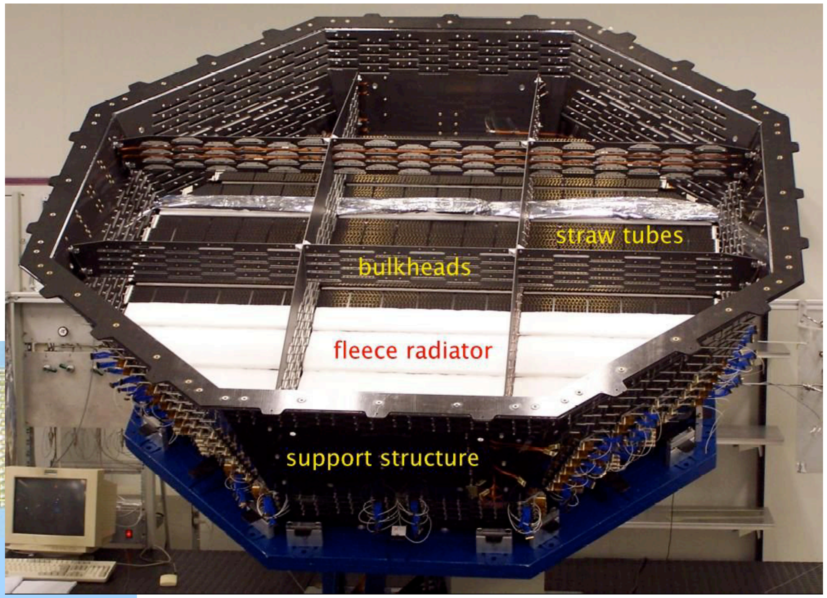


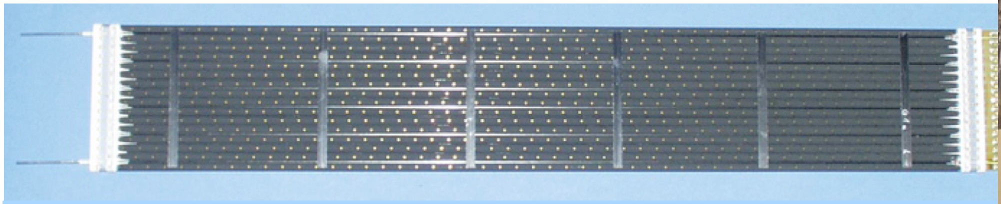


AMS: TRD

- 2.2x 2.2x0.8 m^3 , 350 kg, 20 layers of straw tubes. Radiator: 2 cm polyethylene/ polypropylene 10 mm fibre fleece. Gas mixture is $Xe:CO_2$ 80:20% (1 bar)
- Conical octagon structure made of aluminum honeycomb with carbon-fibre skins and bulkheads
- Mechanical precision: 100 mm to assure gas gain homogeneity below 2%
- 4 lower and upper oriented parallel to the magnetic field, middle 12 perpendicular to it, for 3D tracking

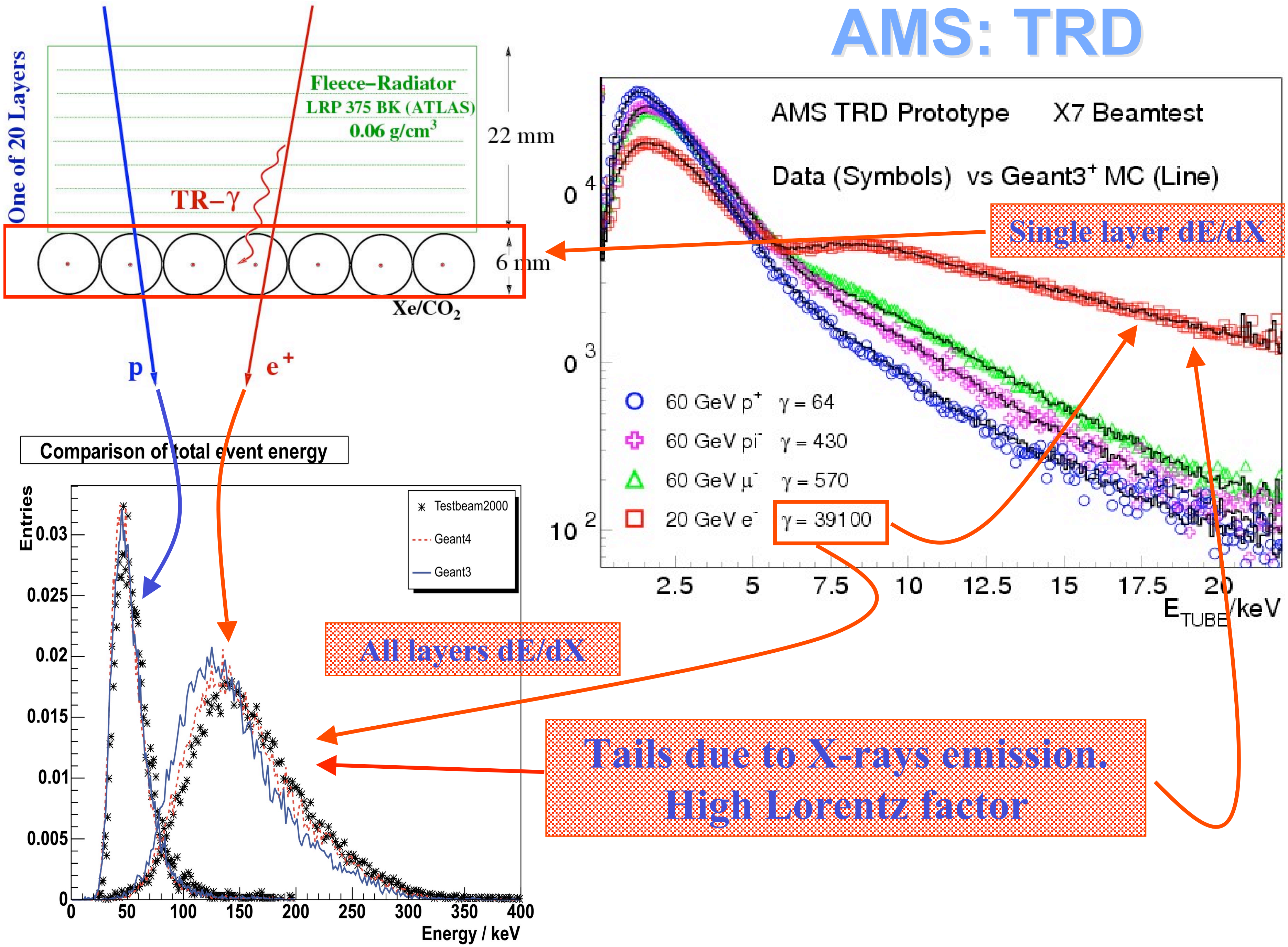






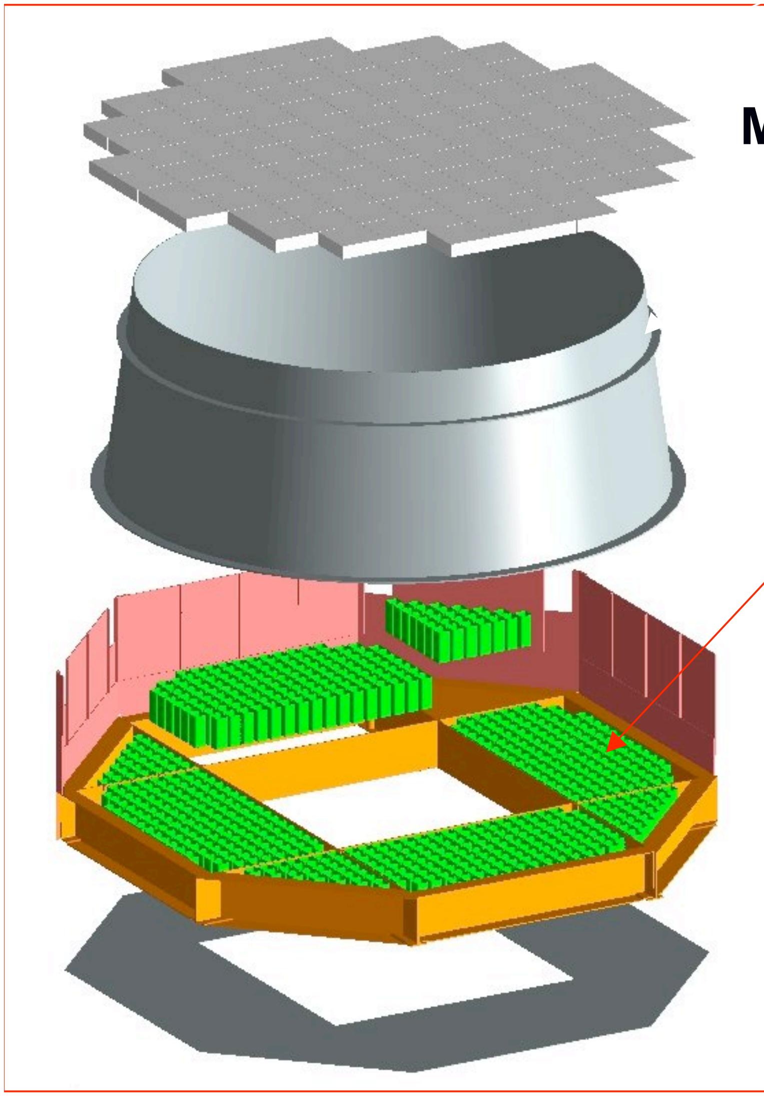
One of 328 Straw Modules

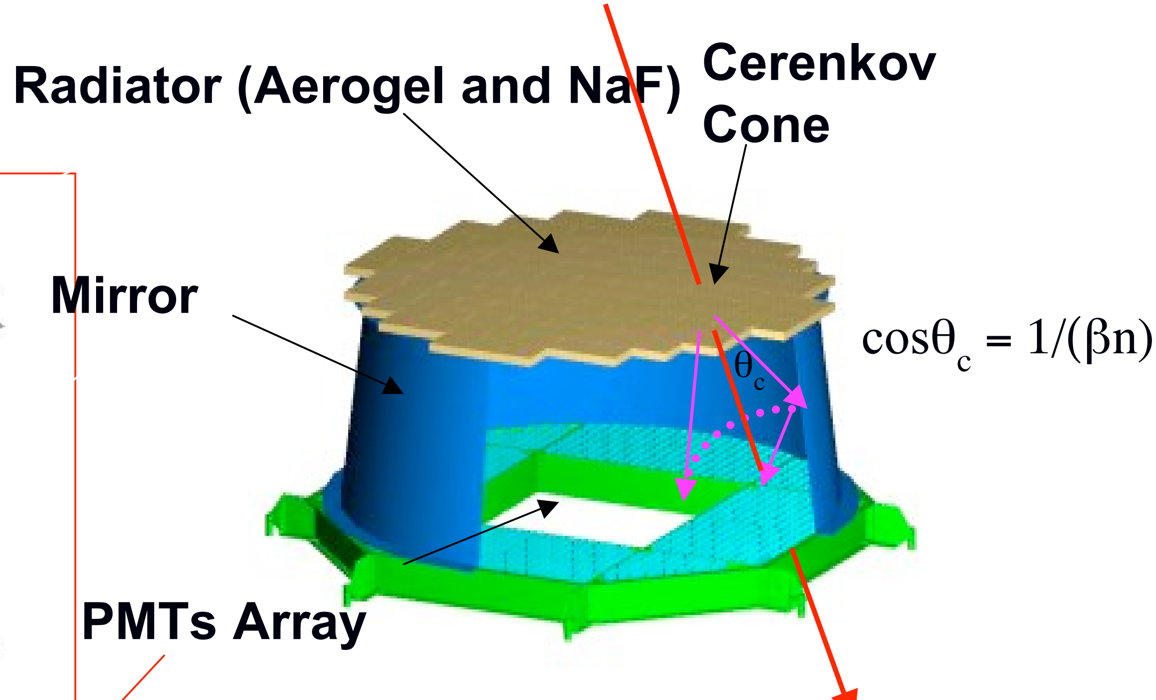
AMS: TRD



One of 20 Layers
Fleece–Radiator
LRP 375 BK (ATLAS)
0.06 g/cm3
22 mm
TR–γ
6 mm
Xe/CO2
p
e+
AMS TRD Prototype X7 Beamtest
Data (Symbols) vs Geant3+ MC (Line)
Single layer dE/dX
60 GeV p+ γ = 64
60 GeV pi- γ = 430
60 GeV μ- γ = 570
20 GeV e- γ = 39100
ETUBE/keV
Comparison of total event energy
Entries
Testbeam2000
Geant4
Geant3
Energy / keV
All layers dE/dX
Tails due to X-rays emission.
High Lorentz factor

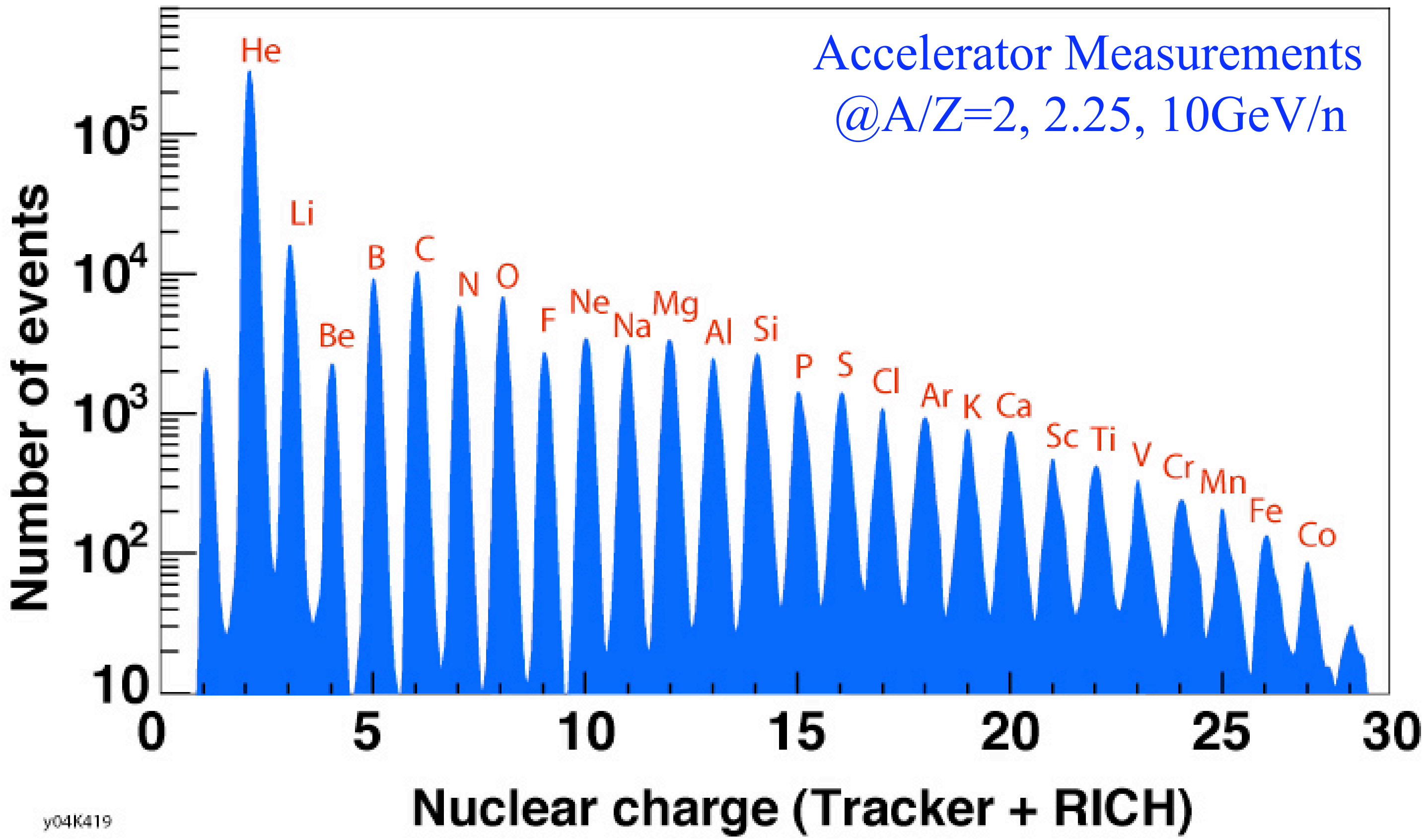
AMS: Rich





- Rad. NaF(n=1.336) in central region and Aerogel (n=1.035) elsewhere
- 680 PMT's Array, Spatial Pixel 8.5×8.5 mm^2
- Velocity Res.: $\Delta\beta/\beta$ = 0.07 % (Z=1)
- Charge Measurement: Z ≤ 26 (w/ Tracker + ToF)
- Charge $N_\gamma \sim Z^2 \Delta L \sin \Theta_C$
- Mass: $m(\beta,Z,R) = p/c \times \mathrm{sqrt}(n^2\cos^2\Theta_C - 1) = (pc/Ze) \times Ze/c^2 \times \mathrm{sqrt}(1-\beta^2)/\beta = RZe \times \mathrm{sqrt}(1-\beta^2)/\beta c^2$

AMS: Rich



Accelerator Measurements
@A/Z=2, 2.25, 10GeV/n
He
Li
Be
B
C
N
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Number of events
10
10²
10³
10⁴
10⁵
0
5
10
15
20
25
30
Nuclear charge (Tracker + RICH)
y04K419

Charge measurement

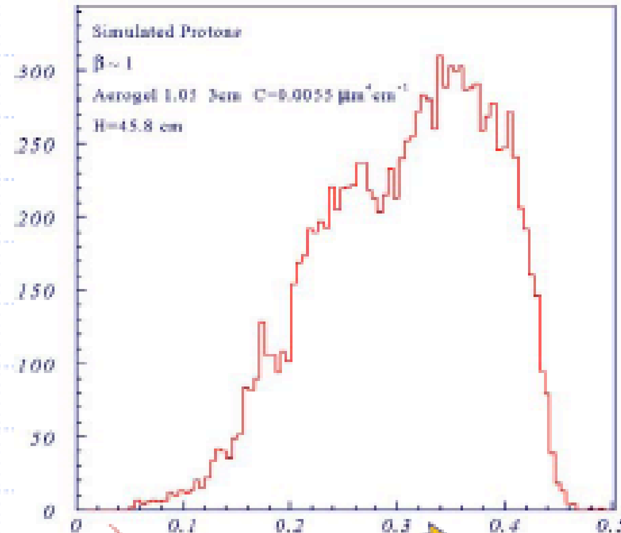
TOF, Tracker: Sampling of particle energy deposition $\Delta E \propto Z^2$

RICH: The number of Cerenkov radiated photons when a charged particle crosses a radiator path ΔL, depends on its charge Z

$$N \propto Z^2 \Delta L \left(1 - \frac{1}{\beta^2 n^2}\right)$$

Their detection on the PMT matrix close to the expected pattern depends on:

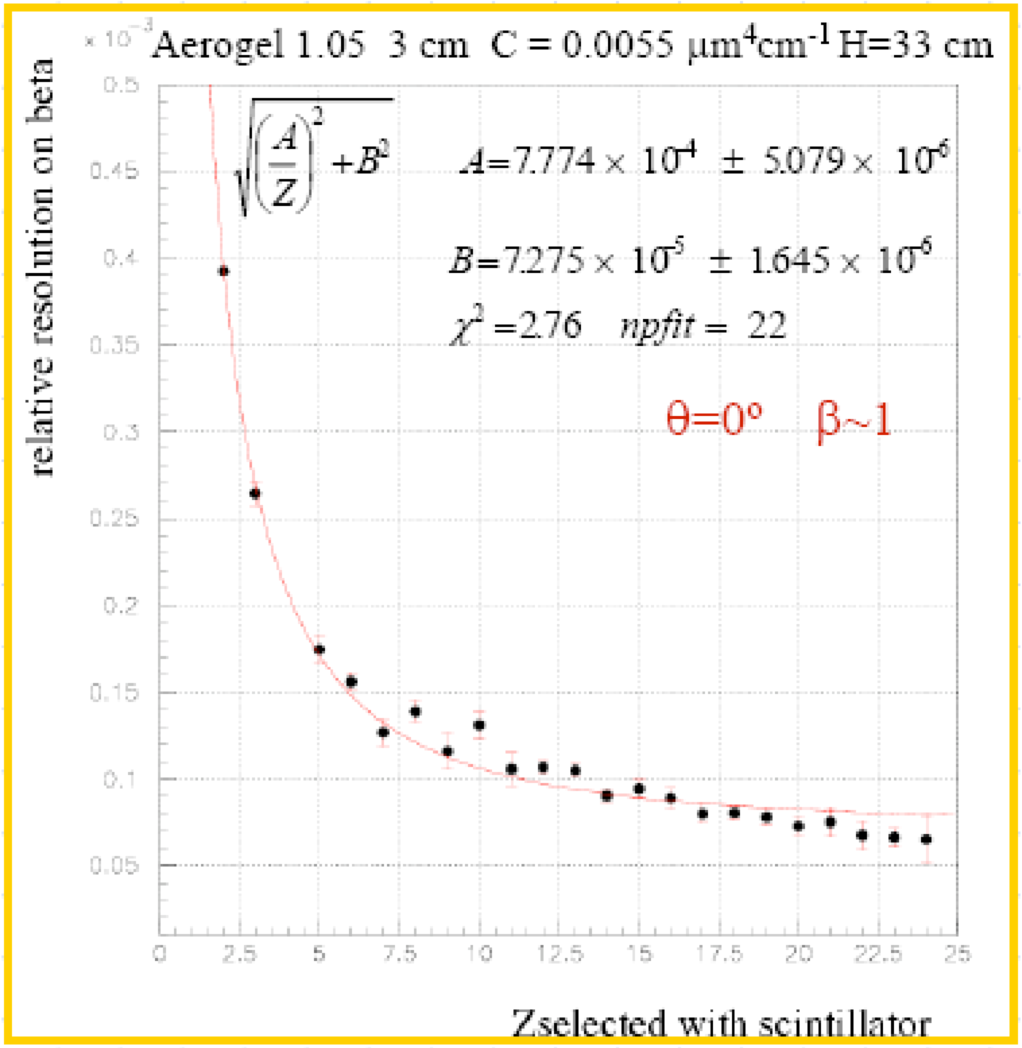
- radiator interactions (ε_{rad}) :
  - absorption and scattering
- photon ring acceptance (ε_{geo}) :
  - photons lost through the radiator lateral and inner walls
  - mirror reflectivity
  - photons falling into the non-active area
- light guide losses (ε_{lg})
- PMT quantum efficiency (ε_{pmt})

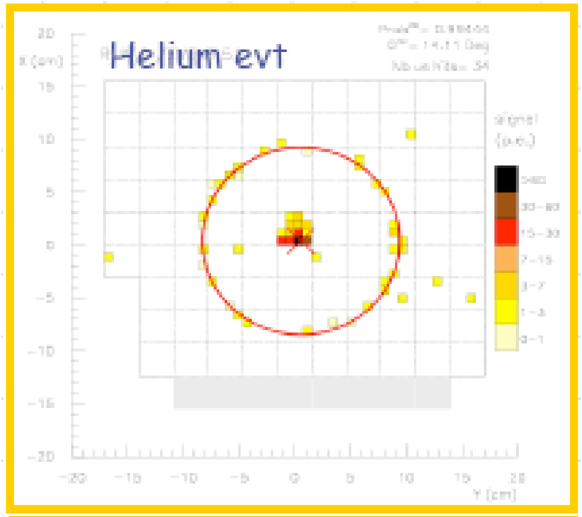


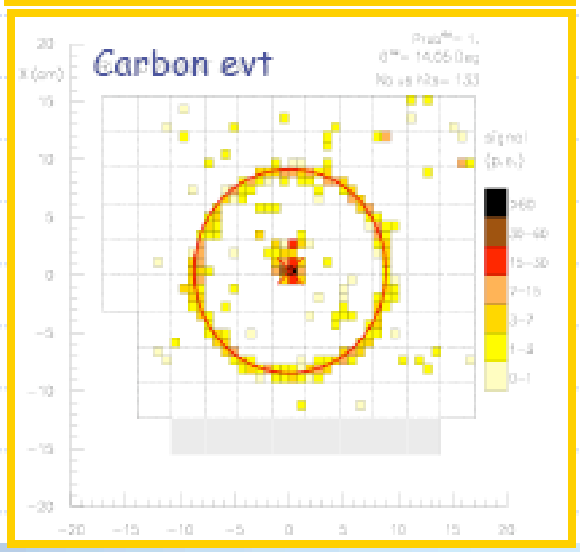
$$N_{pe} \propto Z^2 \Delta L \left(1 - \frac{1}{\beta^2 n^2}\right) \underbrace{\varepsilon_{rad}\, \varepsilon_{geo}\, \varepsilon_{lg}\, \varepsilon_{pmt}}_{\varepsilon_{tot}(\theta_c, \theta, \phi, P_I)}$$

Luis Arruda, LIP Lisbon

RICH velocity measurement (β): a prototype (96 PMTs) was tested







The BESS experiment

Balloon-borne Experiment with Superconducting Spectrometer

Joint project of Japanese and USA Institutions to search for antimatter in the cosmic radiation

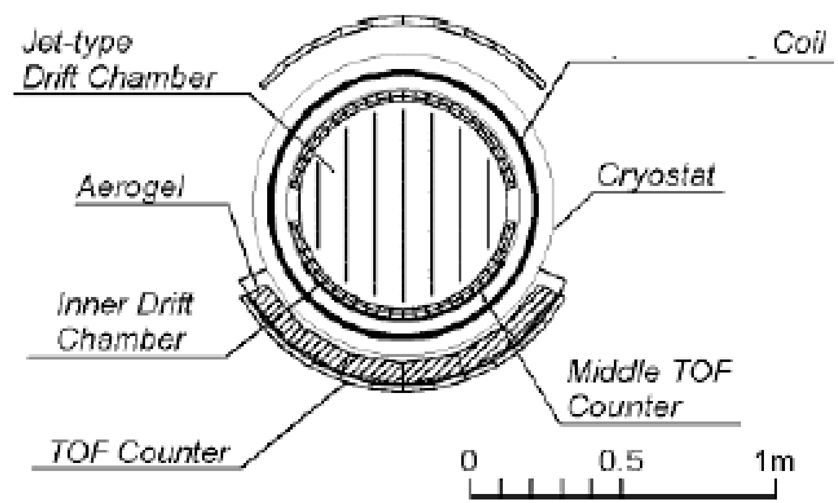
http://bess.kek.jp/

http://universe.gsfc.nasa.gov/astroparticles/programs/bess/

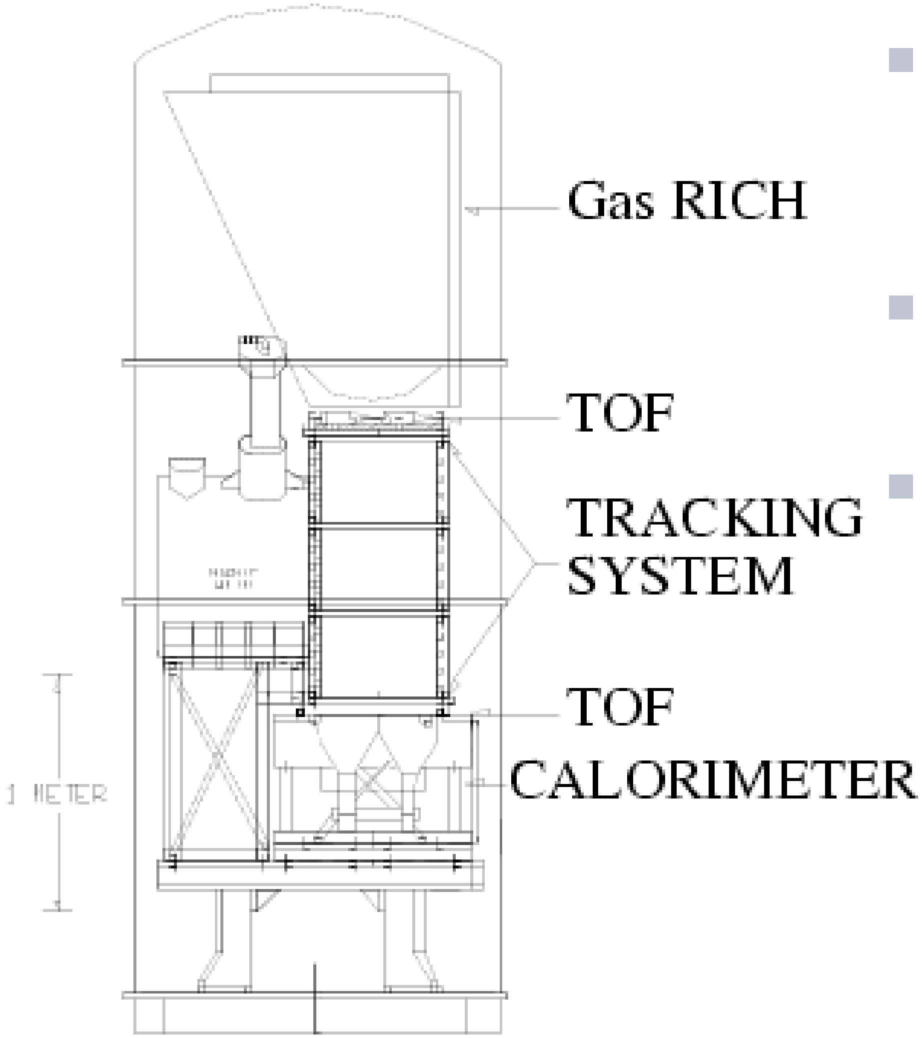
Last flight: 8 days from McMurdo (Antartica) in Dec 2004

BESS detector:

- Top and bottom Tof scintillators that also measure the particle energy loss
- Aerogel Cherenkov counter mounted under the top ToF
- 2 inner drift chambers (IDC) inside the magnetic field space
- Central tracking device in magnetic field region made of JET type drift chambers

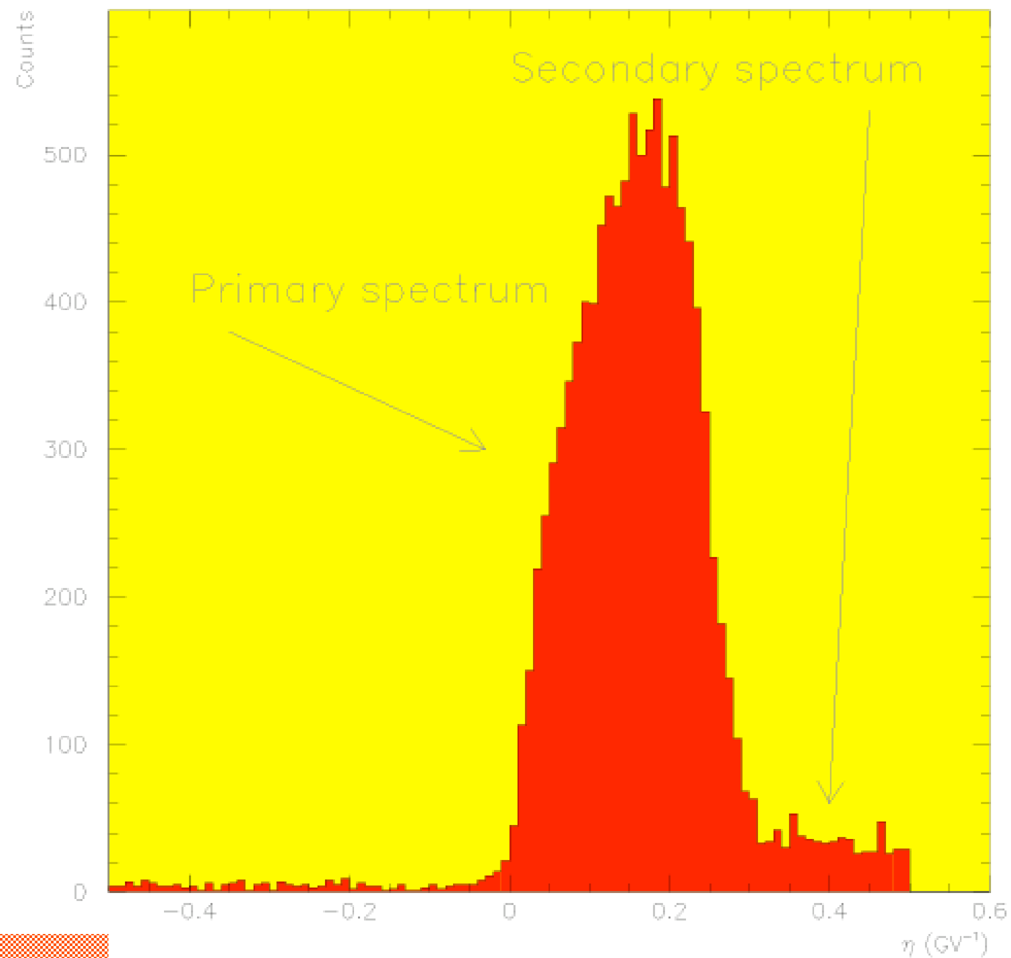


Finally ..... CAPRICE 98 !



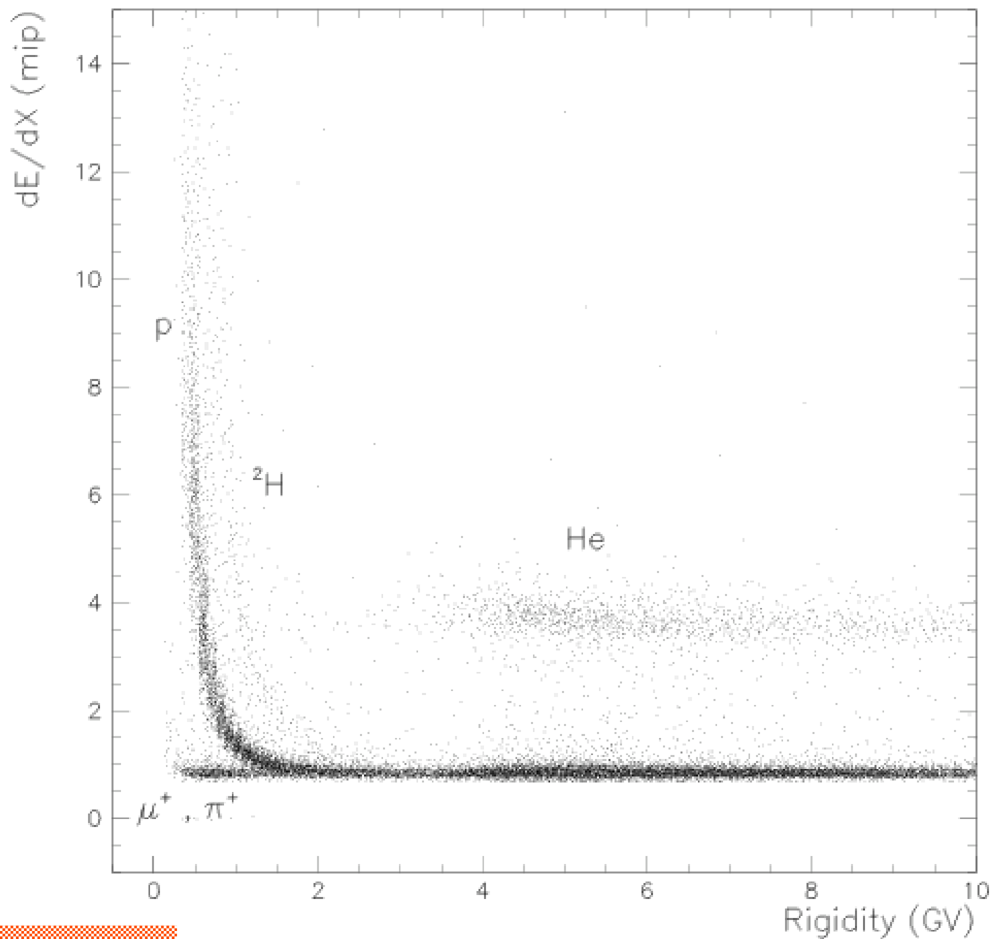
- For the first time a GAS RICH together with a Silicon calorimeter.
- Mass resolved $\bar{p}$ for E> 18 GeV
- Redundancy and cross-measurements

In flight Performances



Spectrometer

In flight Performances

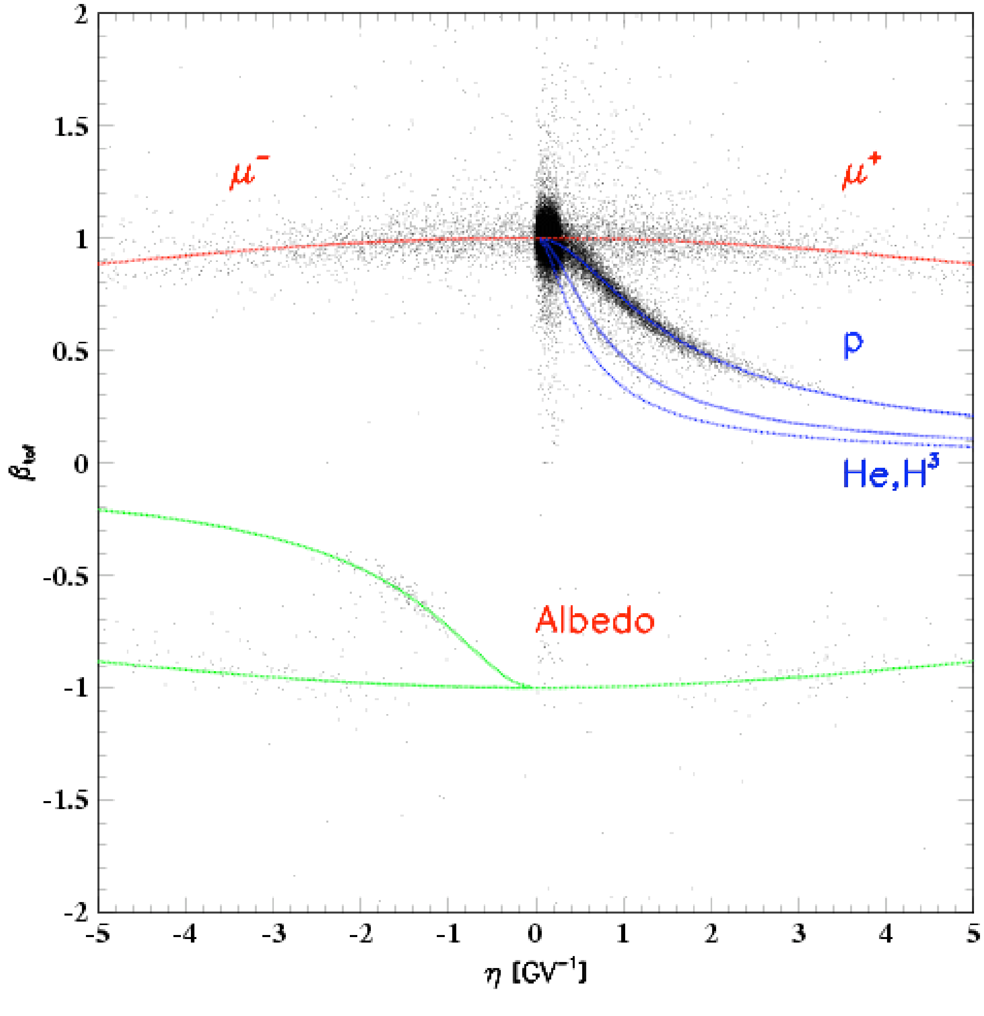


$dE/dx \propto Z^2$

vs p

Silicon calorimeter

In flight Performances

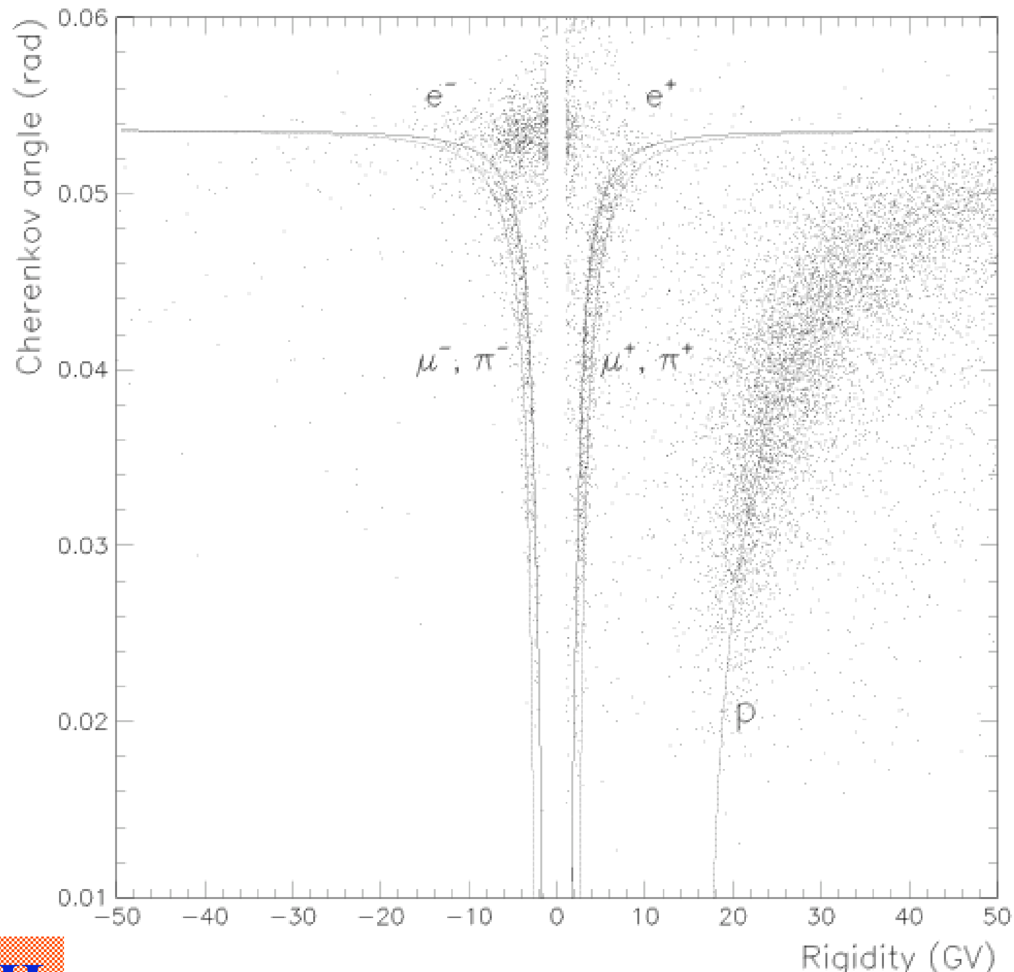


β vs 1/p -> mass

TOF

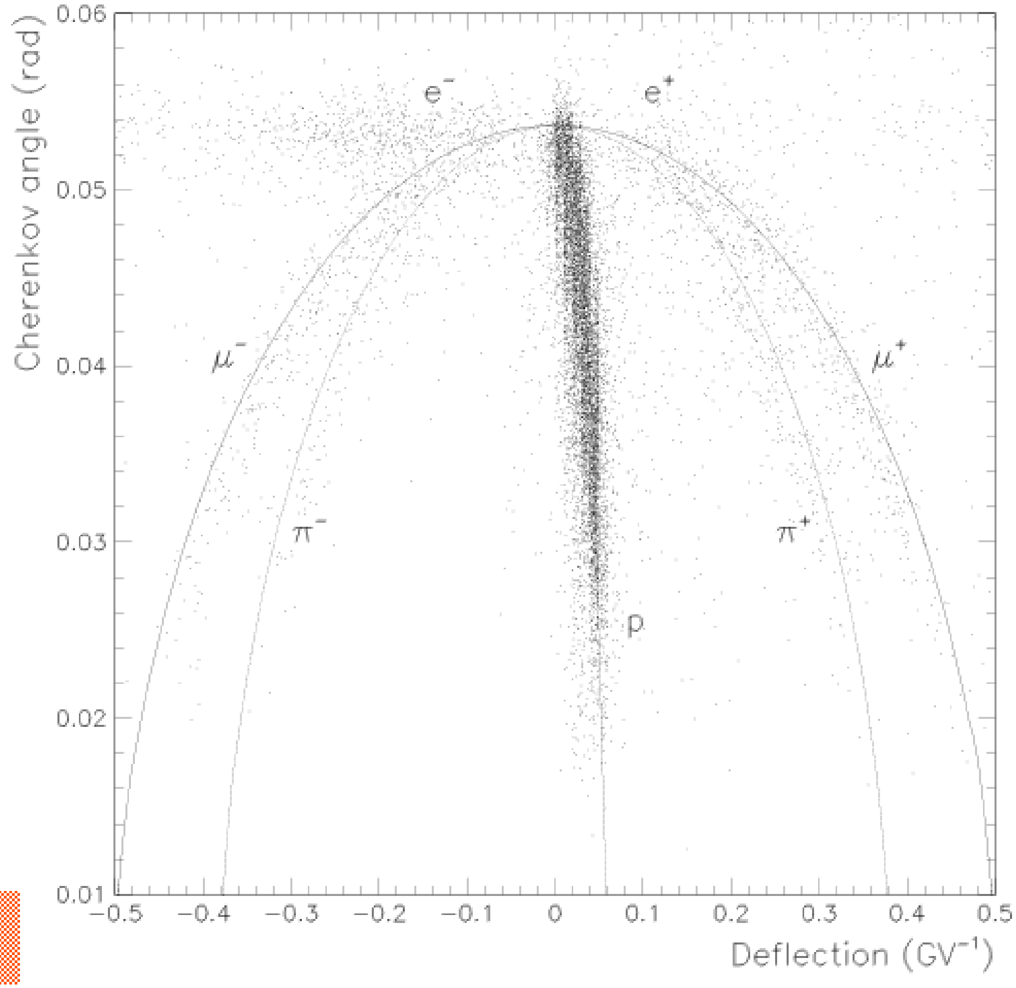
In flight Performances

β and p -> mass



GAS-RICH

In flight Performances



GAS-RICH

Exercise

Find a paper published by one of the described experiments or by another balloon experiment performing primary CR composition/anti-matter measurements and describe a measurement they perform and the detectors used for this purpose.