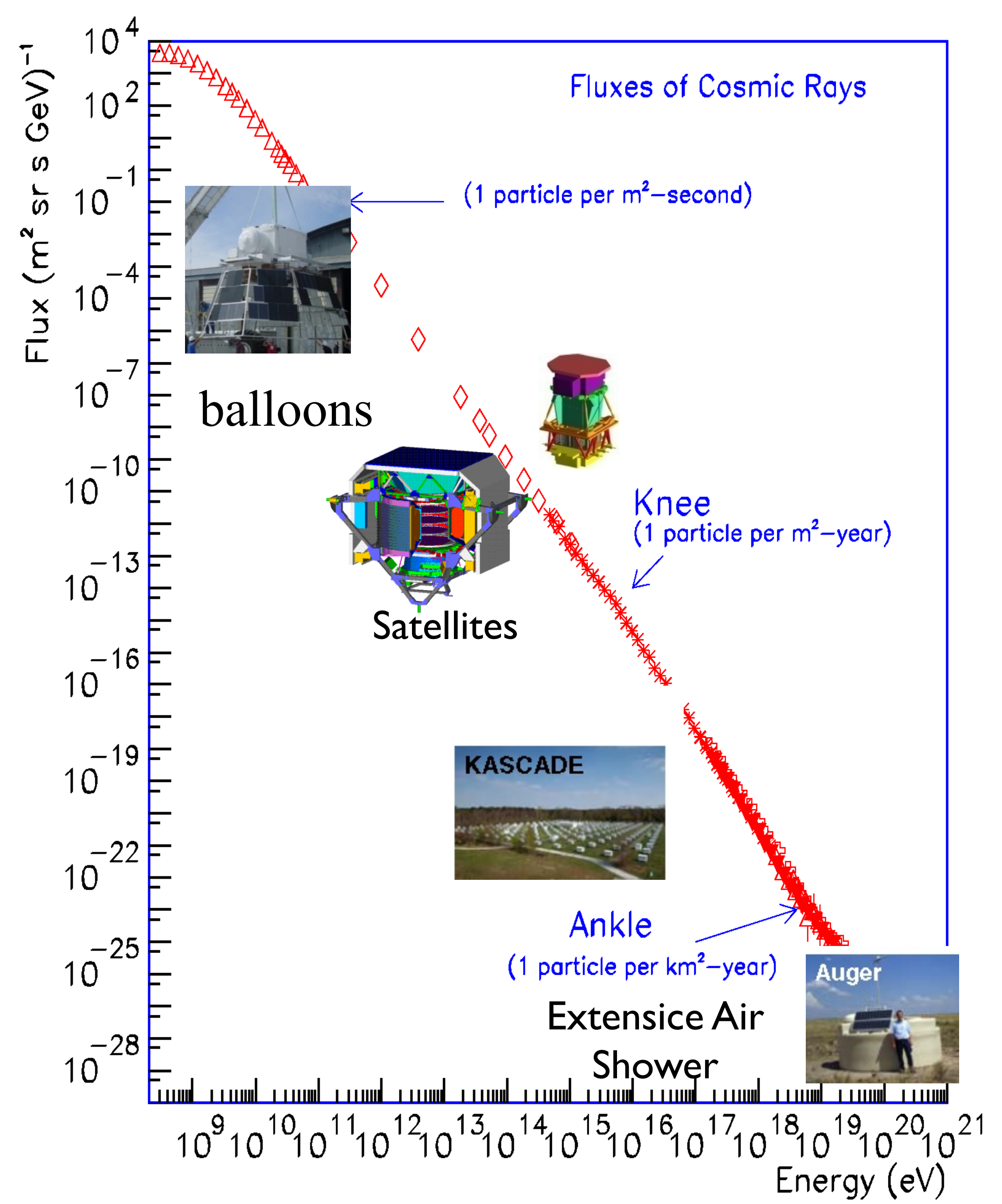
AMS : Alpha Magnetic Spectrometer

- ▷ Introduction
  - ▶ Principle
- ▷ AMS02
  - ▶ Construction and performance
- ▷ Physics
  - ▶ Cosmic rays
  - ▶ Dark Matter

S.Rosier Lees – LAPP
Physics of Multi Messengers , April 5 2011, Marseille

Cosmic Ray fluxes measurements



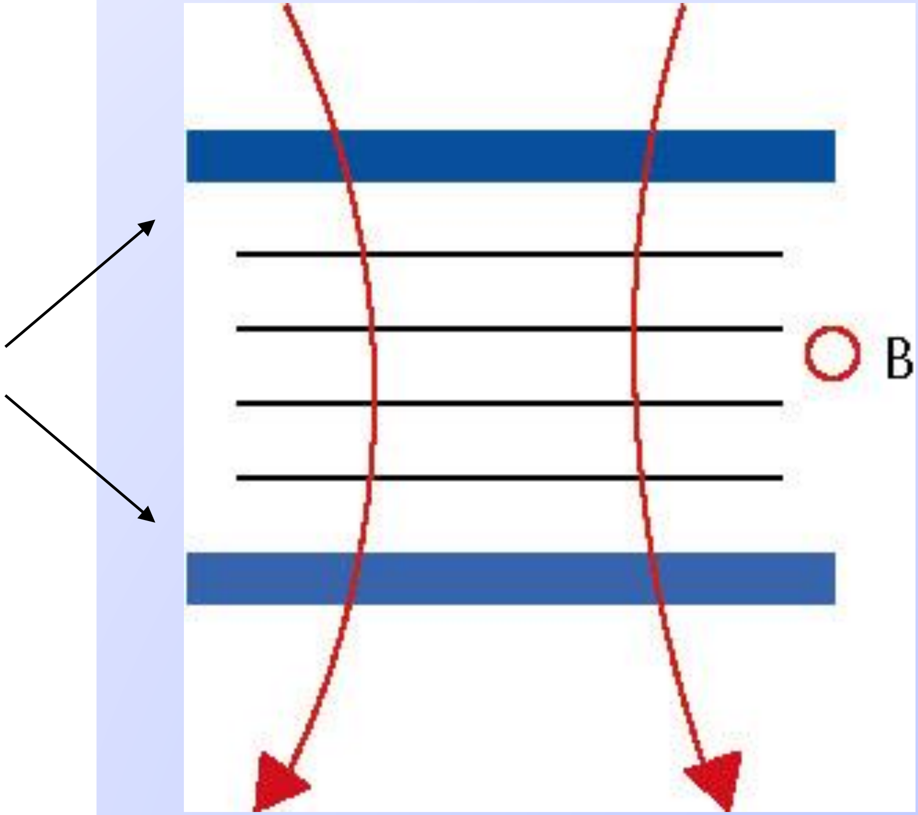
$$\frac{dN}{dE_0} \propto E_0^{-3}$$

Complementary devices and measurements for different energy ranges

- Nature of CR
- Origine of CR (sources)
- Propagation in different medium, galactic or extra galactic CR

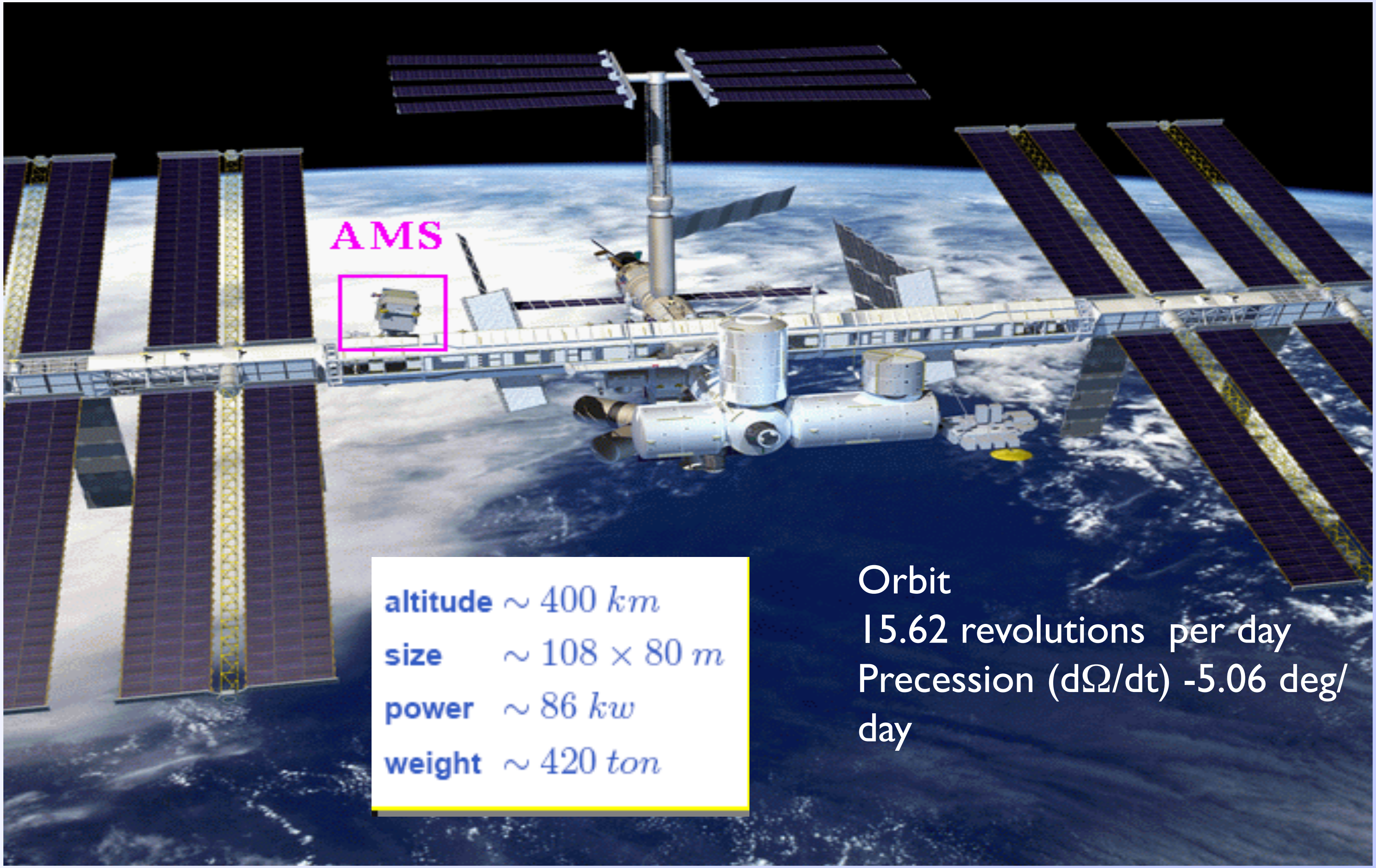
Detector principles

- Sign of the particle charge
  - A magnet and a tracker
  - $mv/Z \propto \rho B$
- Upstream and downstream particle separation
  - Timing measurement
- Identify the particle
  - Mass and Charge
  - Electromagnetic type
  - e/p separation
- Redondancy :
  - Few independent detectors Z, v



➔ **High energy physics detector in space**

Where : ISS (International Space Station)

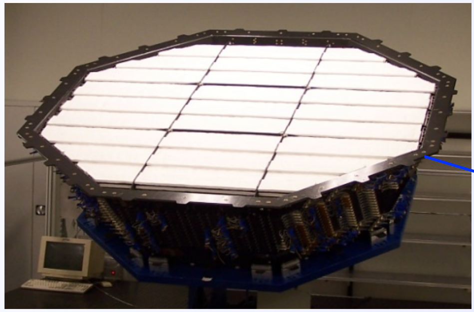


altitude	$\sim 400\ km$
size	$\sim 108 \times 80\ m$
power	$\sim 86\ kw$
weight	$\sim 420\ ton$

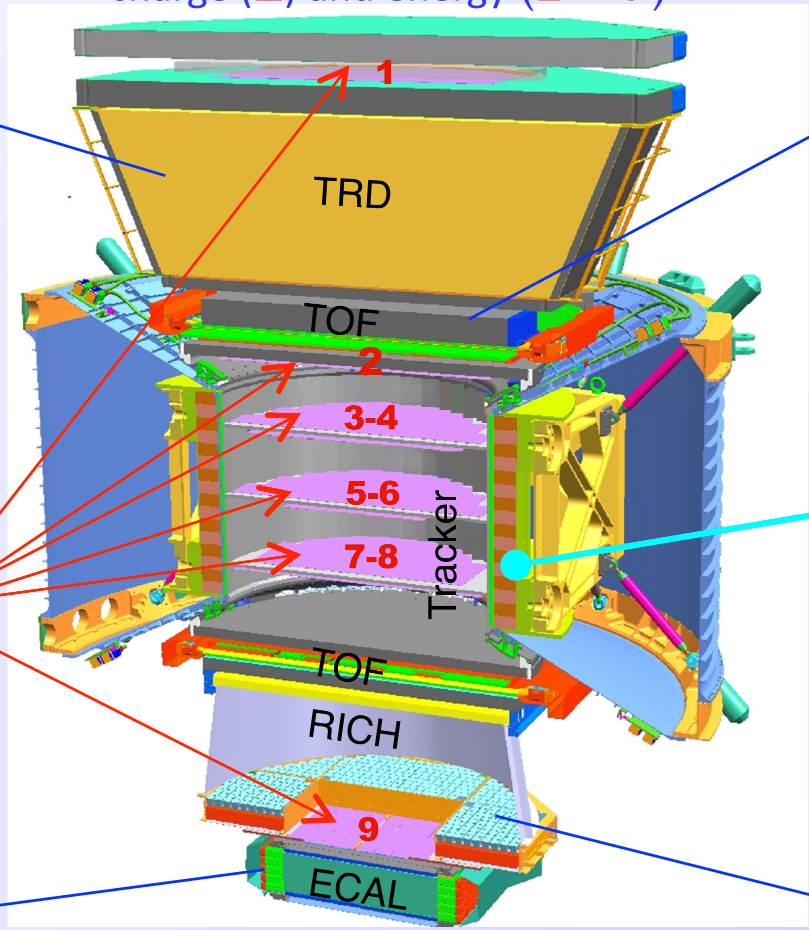
Orbit
15.62 revolutions per day
Precession ($d\Omega/dt$) -5.06 deg/day

AMS: A TeV precision, multipurpose spectrometer

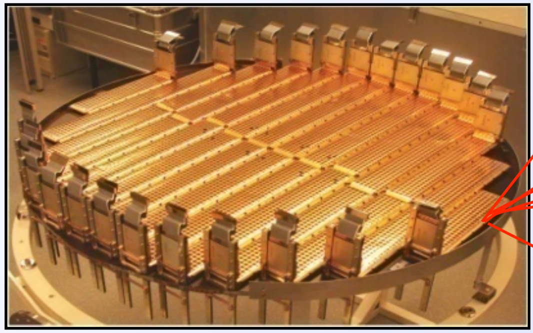
Identify e+, e- TRD



Particles and nuclei are defined by their charge (Z) and energy (E ~ P)

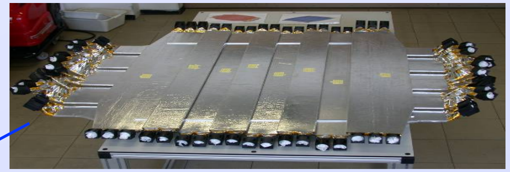


Silicon Tracker
Z, P

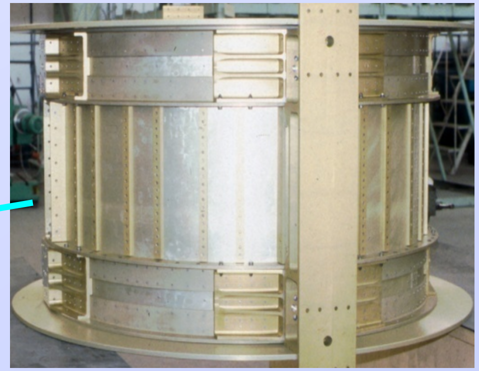


ECAL
E of e+, e-, γ

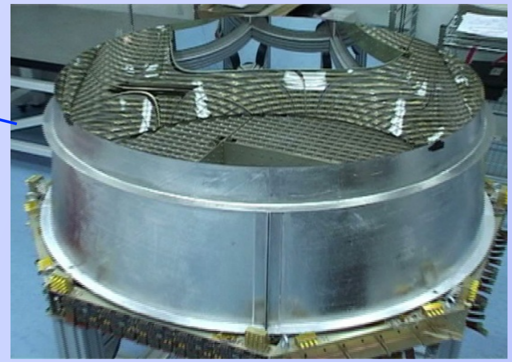
TOF
Z, E



Magnet
±Z

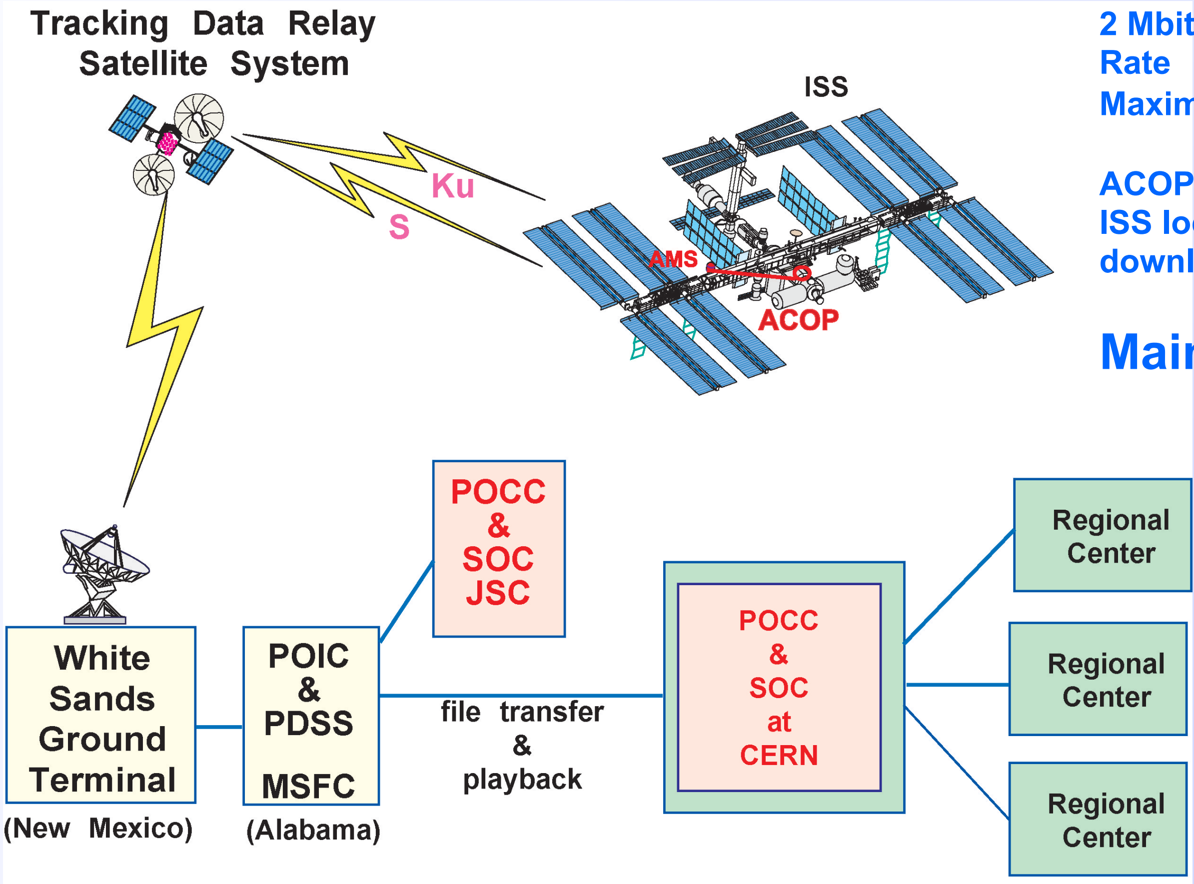


RICH
Z, E



Z, P are measured independently from Tracker, RICH, TOF and ECAL

Data Transfer



2 Mbits/sec average science data downlink Rate
Maximal Trigger rate 2 khz (MP rate 1khz)

ACOP (AMS Crew Operation Post) allows ISS local storage and backup of data when downlink is off.

Main processing center at CERN

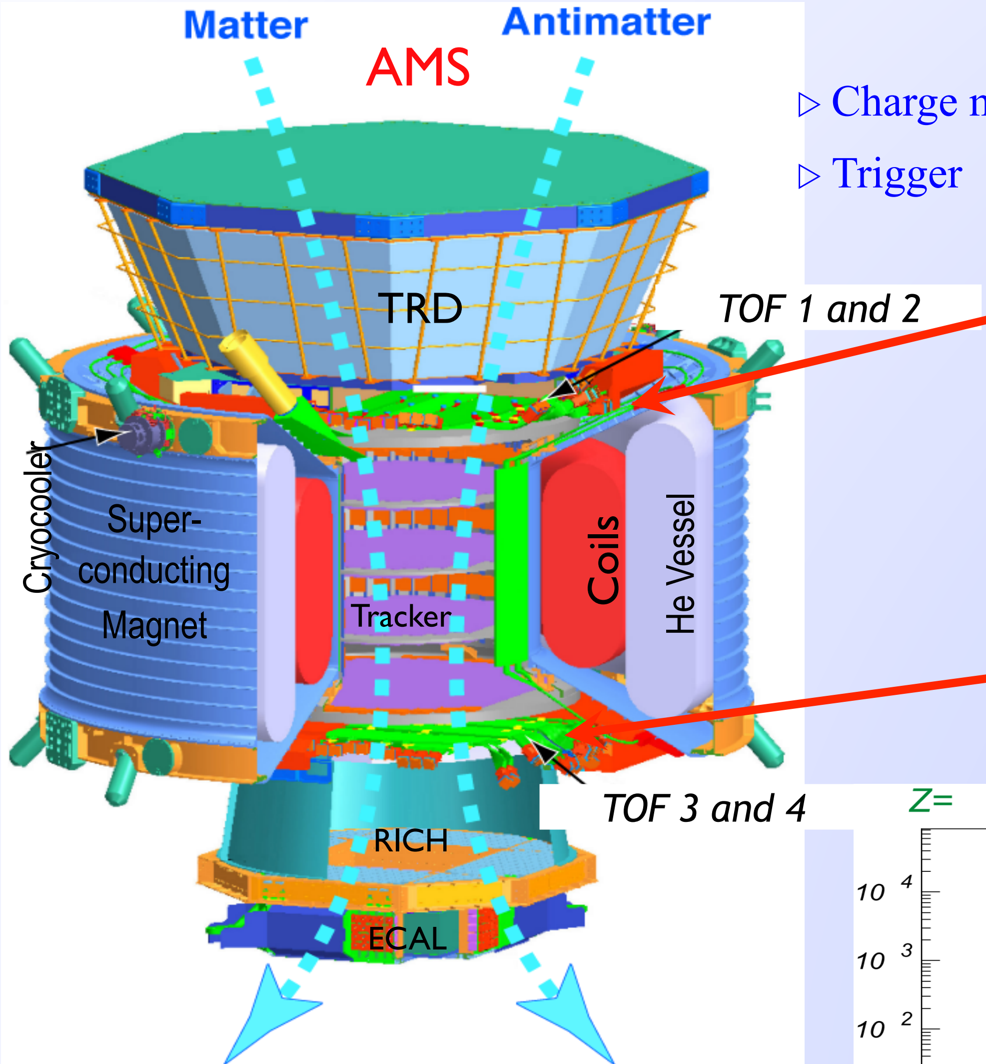
ACOP	AMS Crew Operation Post
POCC	Payload Operation Control Center
SOC	Science Operation Center
MSFC	Marshall Space Flight Center (Al)
JSC	Johnson Space Flight Center (Tx)

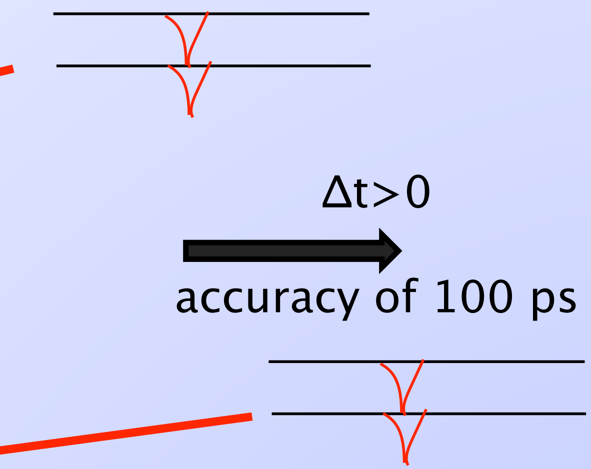
Time Of Flight

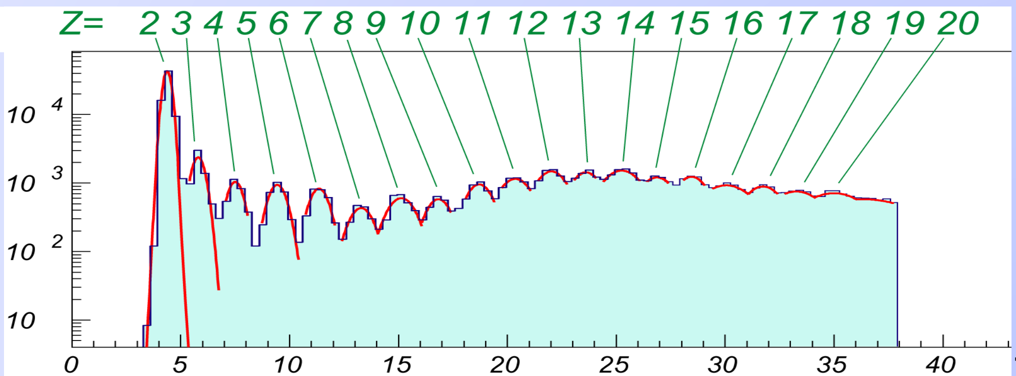
- ▷ Velocity measurement, v=distance/Δt

$$\Delta\beta/\beta \approx 3\%$$

- ▷ Charge measurement (Z^2)
- ▷ Trigger





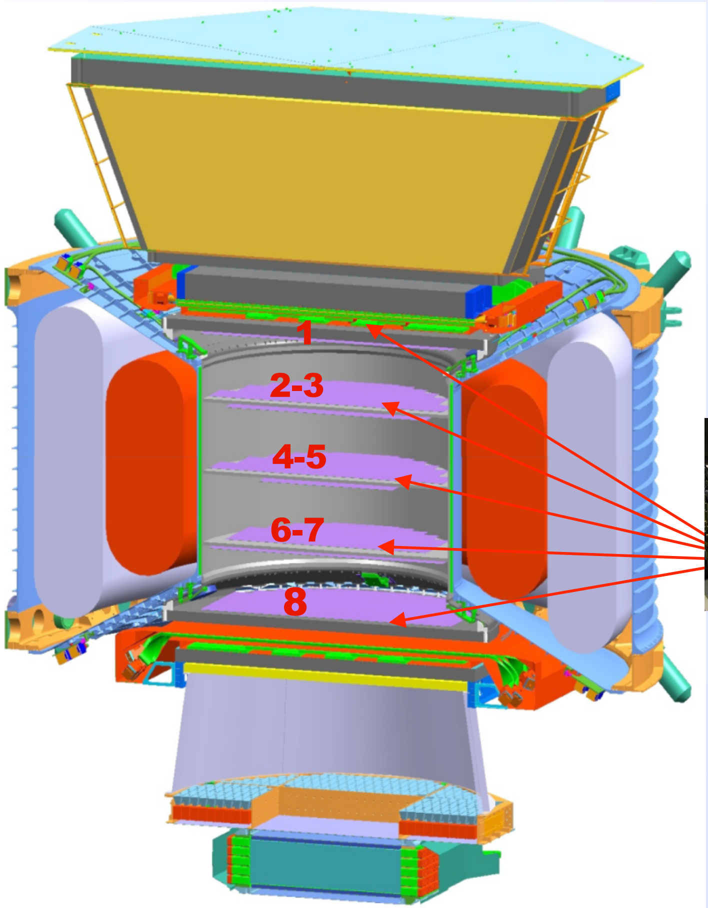


AMS-02

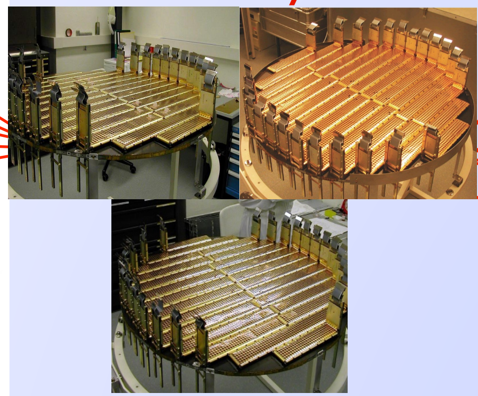
(3 yrs)
with SC Magnet

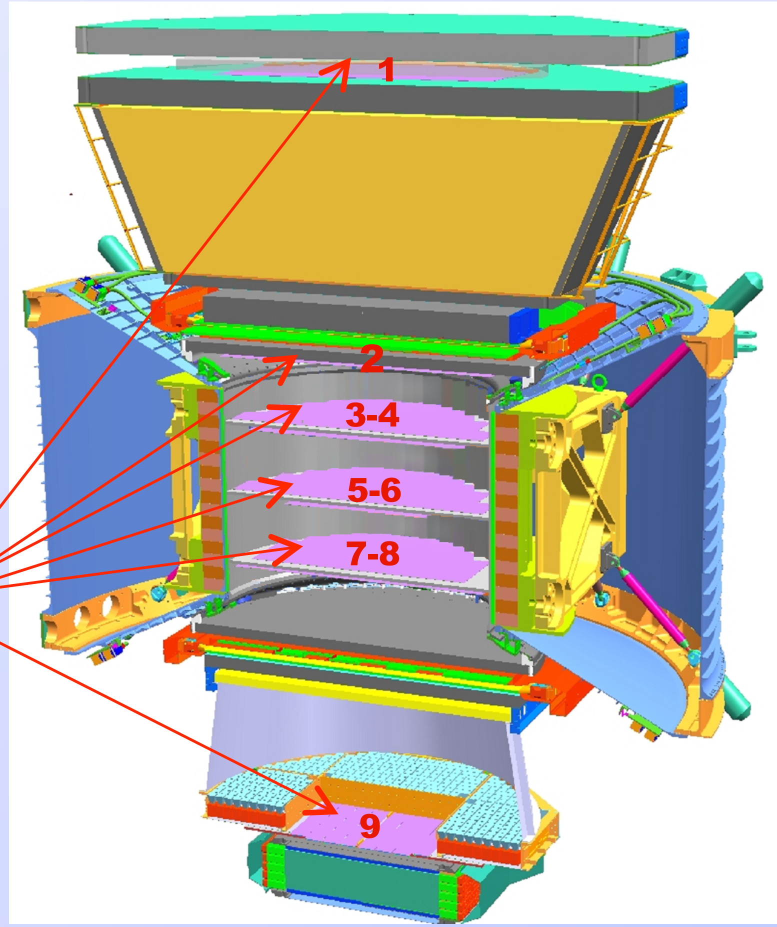
AMS-02

(10 Yrs to 18 yrs)
with Permanent Magnet
9 layers of Silicon

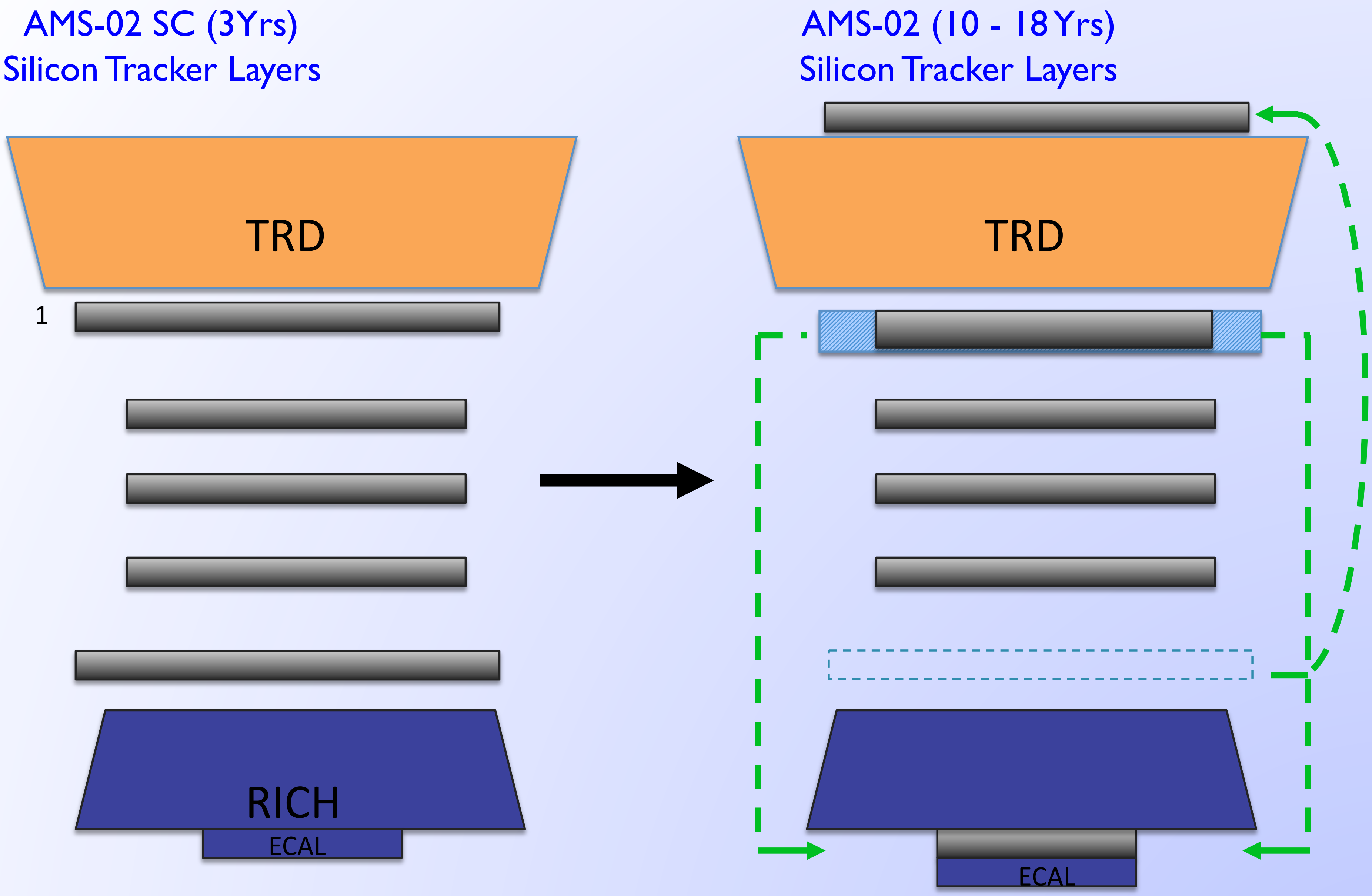


Silicon layers





Layers 1 and 9 are far away from the magnet.



Layer 9 comes from moving the ladders at the edge of the acceptance from layer 1. The layer 8 is moved on top ofthe TRD to become 1N.

No new silicon and no new electronics .

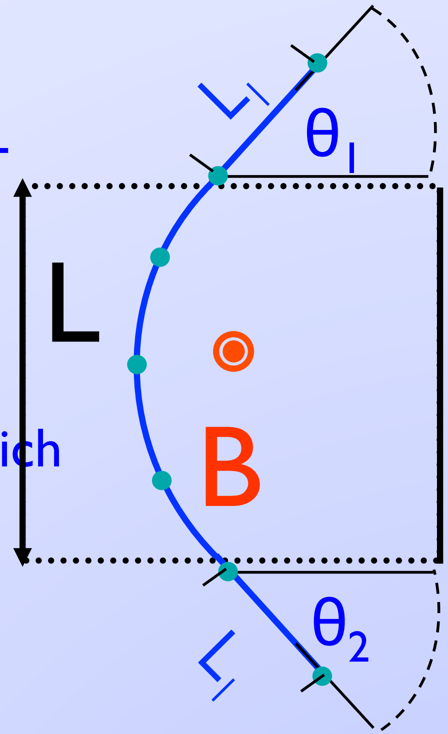
The momentum resolution ($\Delta p/p$) is the sum of two contributions:

1. Measurement inside the magnet with an effective length L

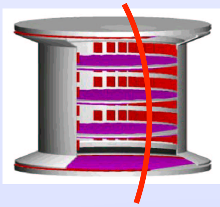
$$(z/p) \cdot (\Delta p/p) \; \alpha \; 1/BL^2$$

2. Measurement of the incident (θ_1) and exit (θ_2) angles which depend on the length L_1

$$(z/p) \cdot (\Delta p/p) \; \alpha \; 1/BLL_1$$



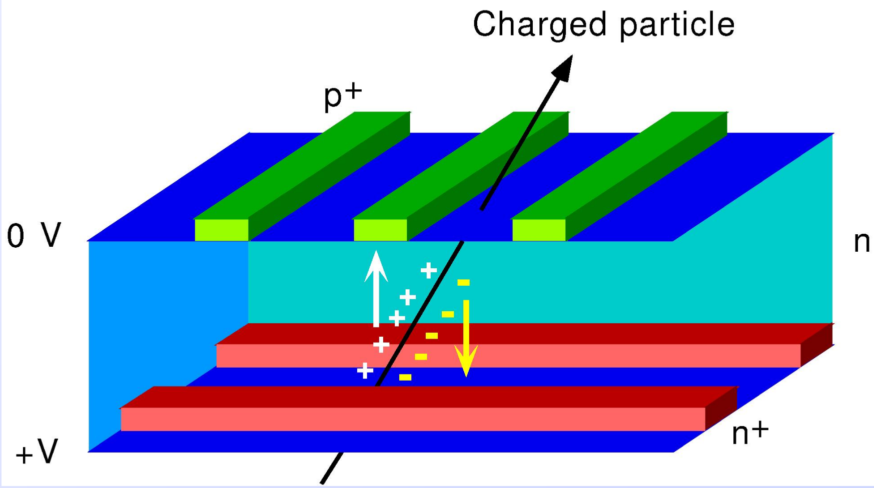
For both magnets, L ~ 80 cm,
but in the permanent magnet B is 5 times smaller
to maintain the same $\Delta p/p$ we increase L1 from ~15 cm (Superconducting Magnet) to ~125 cm (permanent magnet)



Silicon Tracker

▷ Principle

- The Tracker is built with close 2500 double sided silicon microstrip sensors, which allow to measure two coordinates with a single detector, reducing thus the material budget.

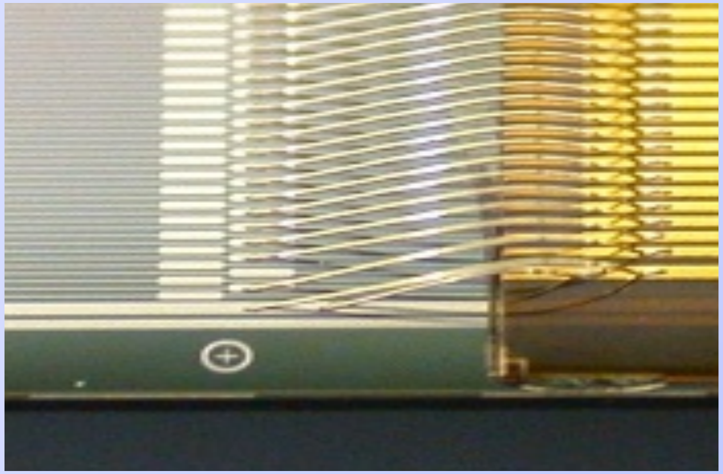


Measures:

▷ Rigidity P/Z up to few TV

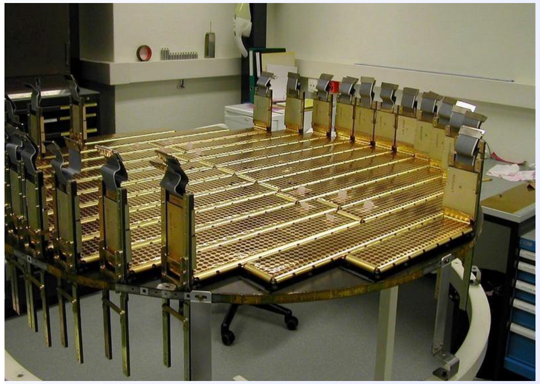
▷ Energy loss, dE/dx propor to Z^2

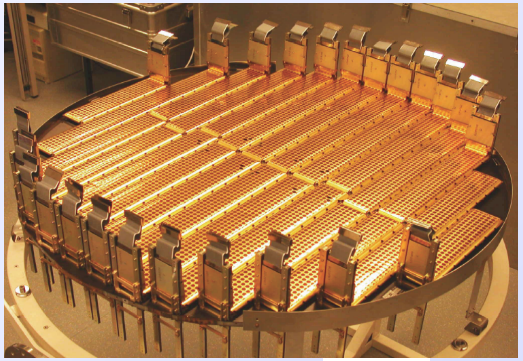
▷ Direction and energy of converted photons

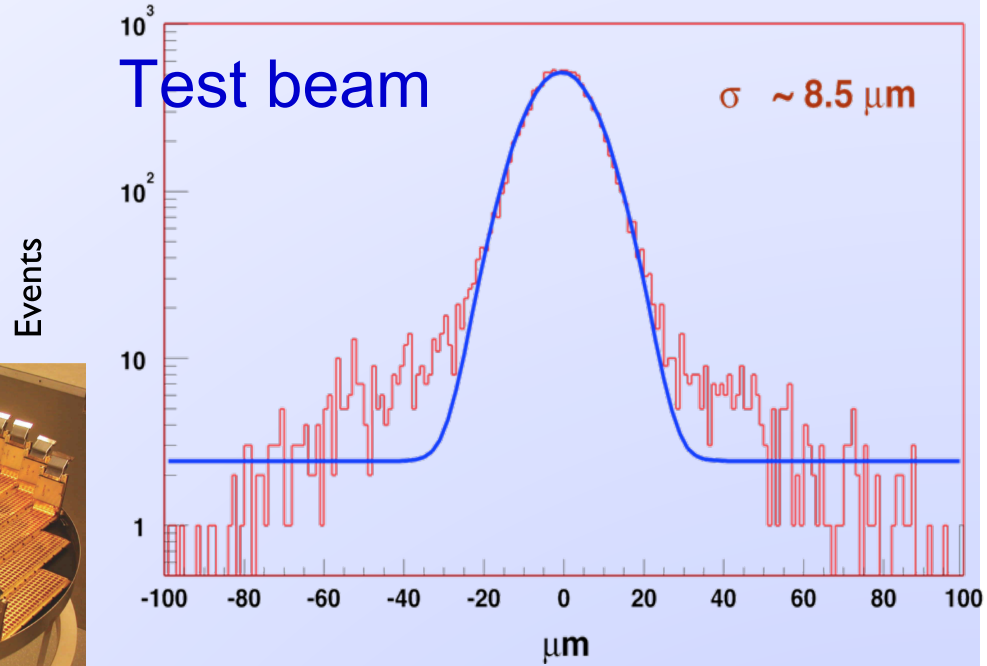


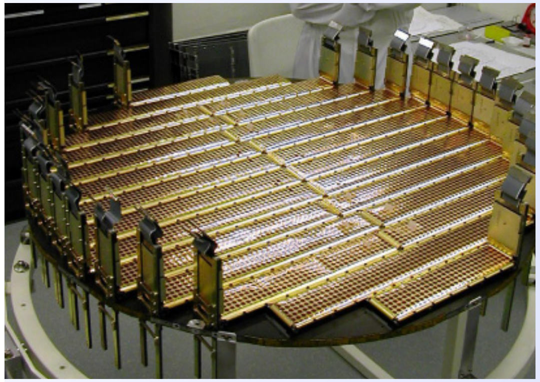
Silicon Tracker

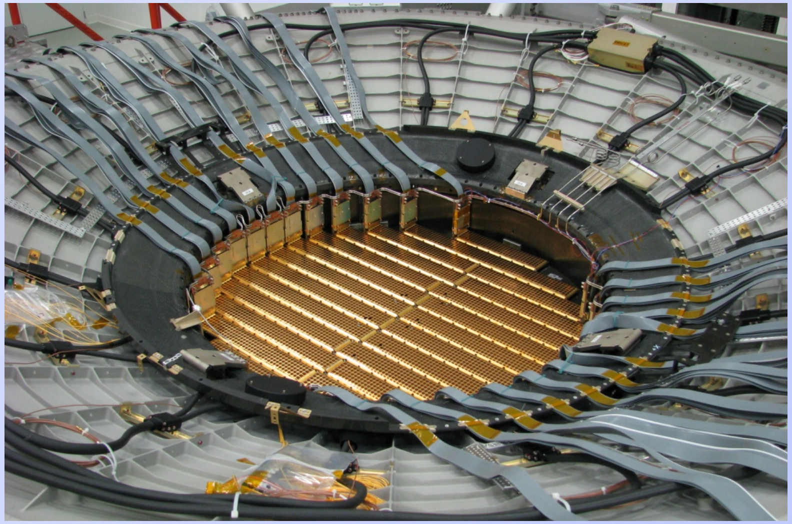
200,000 channels; alignment 3 μm







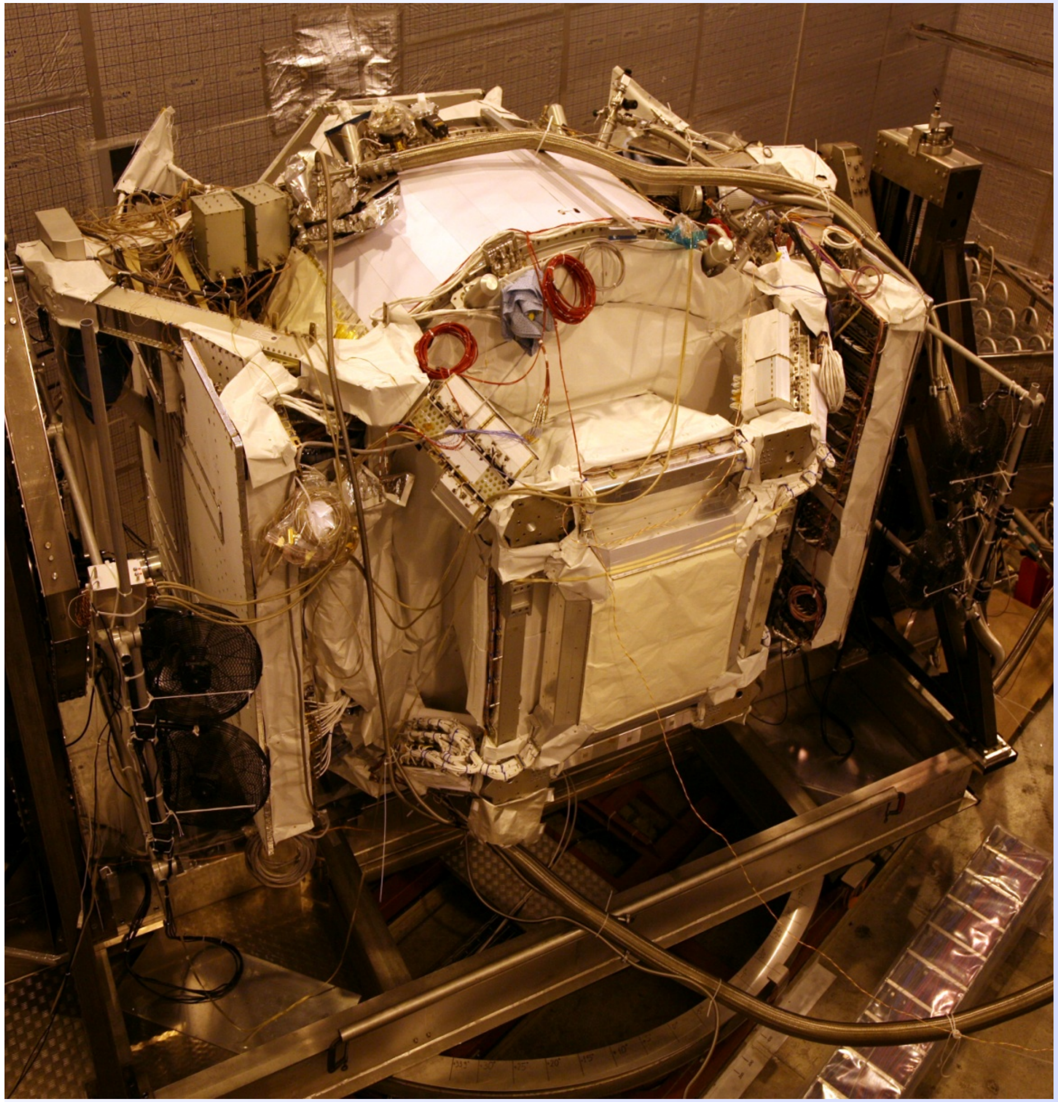


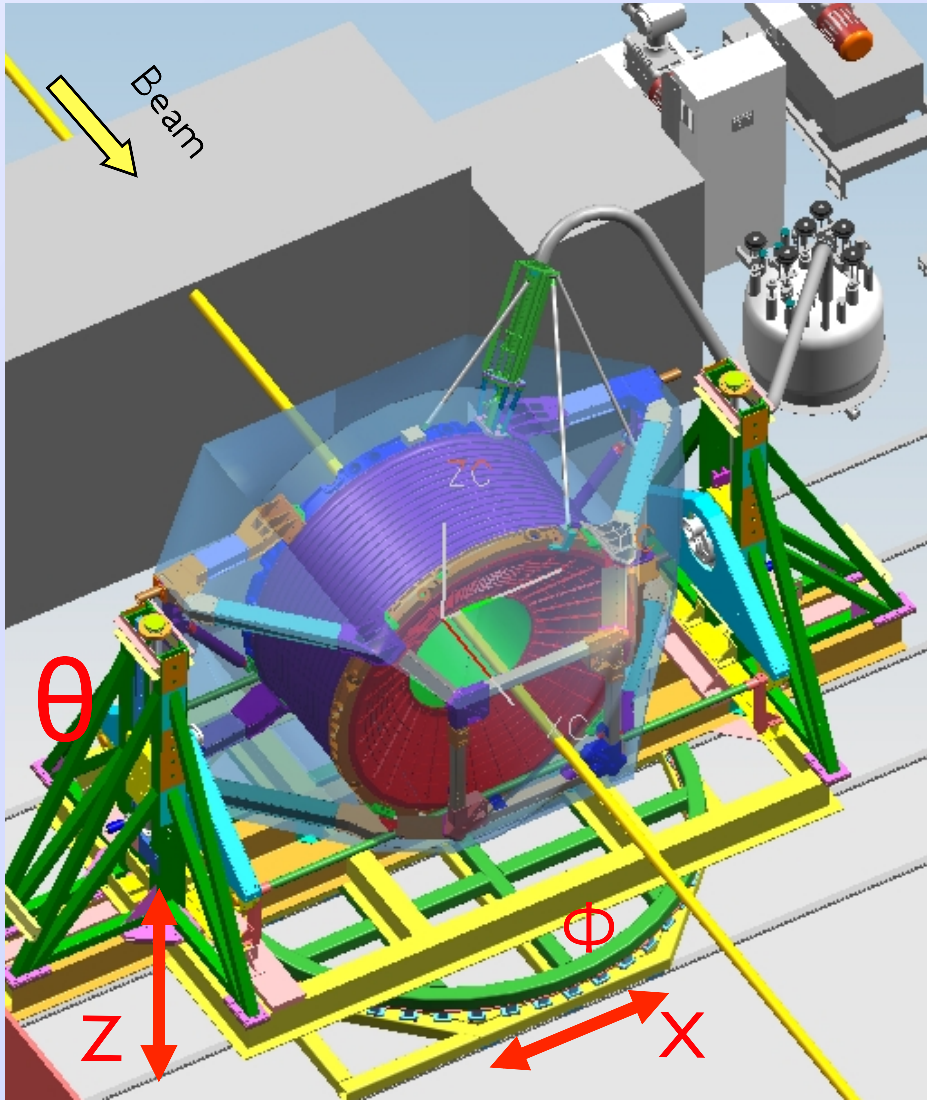


9 planes

AMS in Test Beam, Feb 4-8, 2010

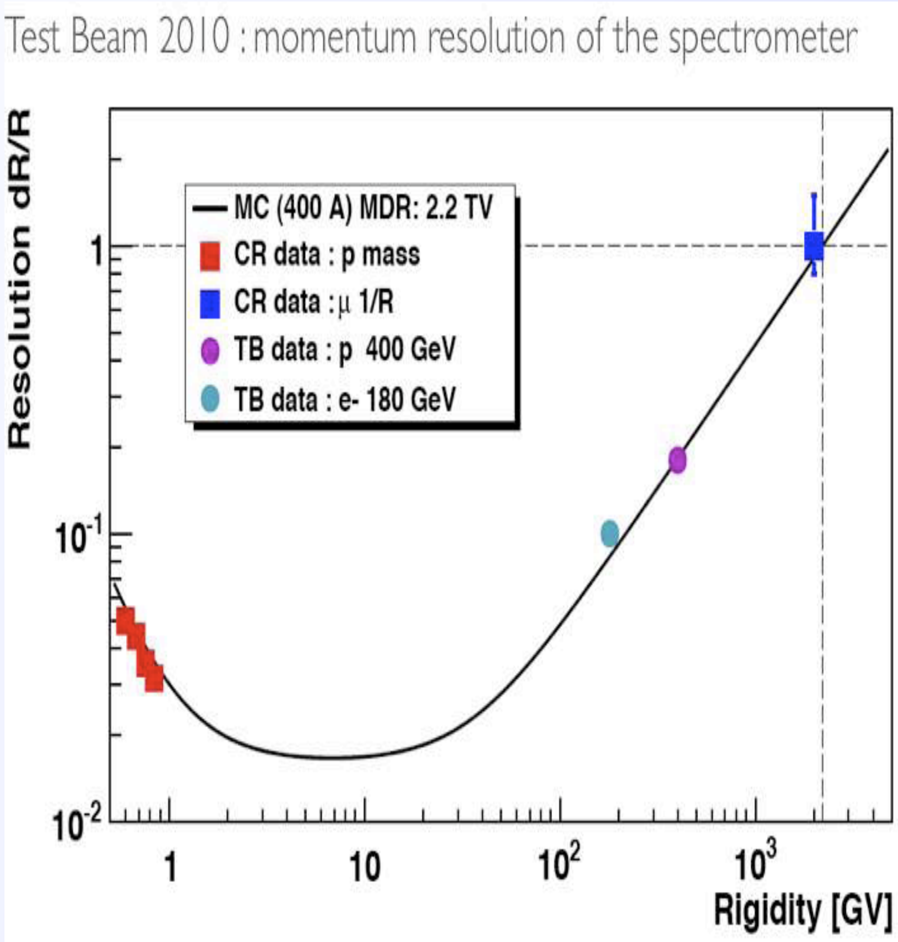
Tests were performed with the superconducting magnet charged to its design current of 400A and to 80A corresponding to the field of the AMS-01 permanent magnet.

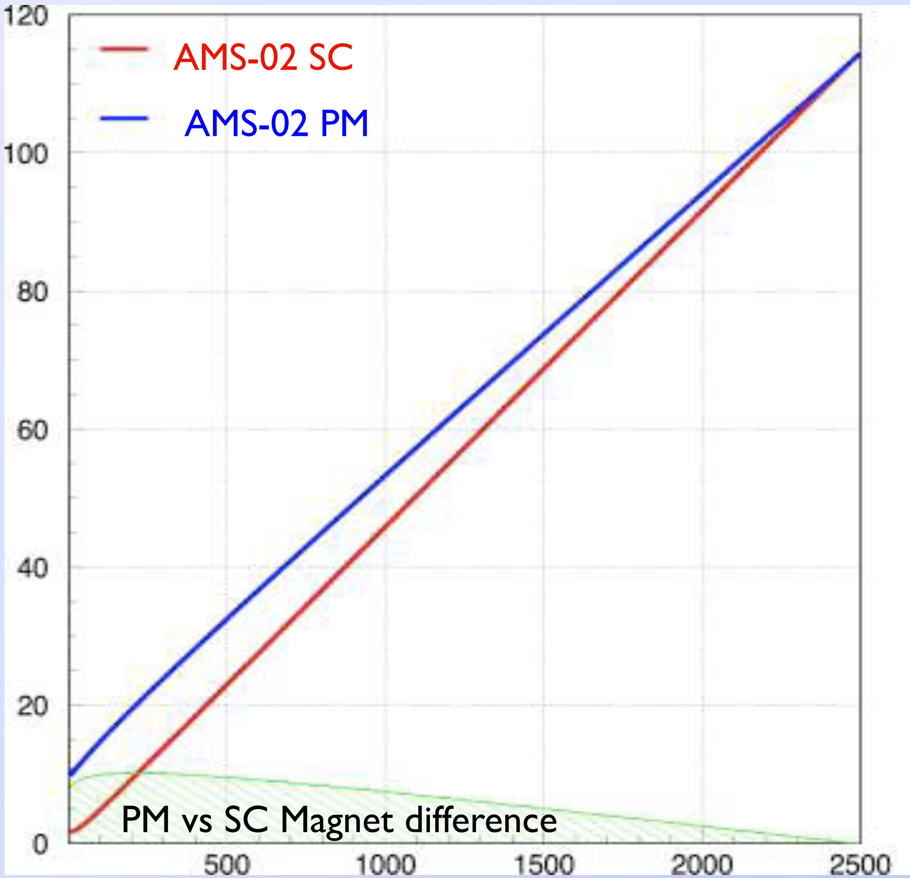




With 9 tracker planes, the resolution of AMS with the permanent magnet is equal (to 10%) to that the superconducting magnet.

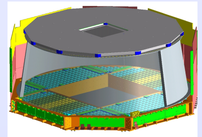
AMS-02 SC



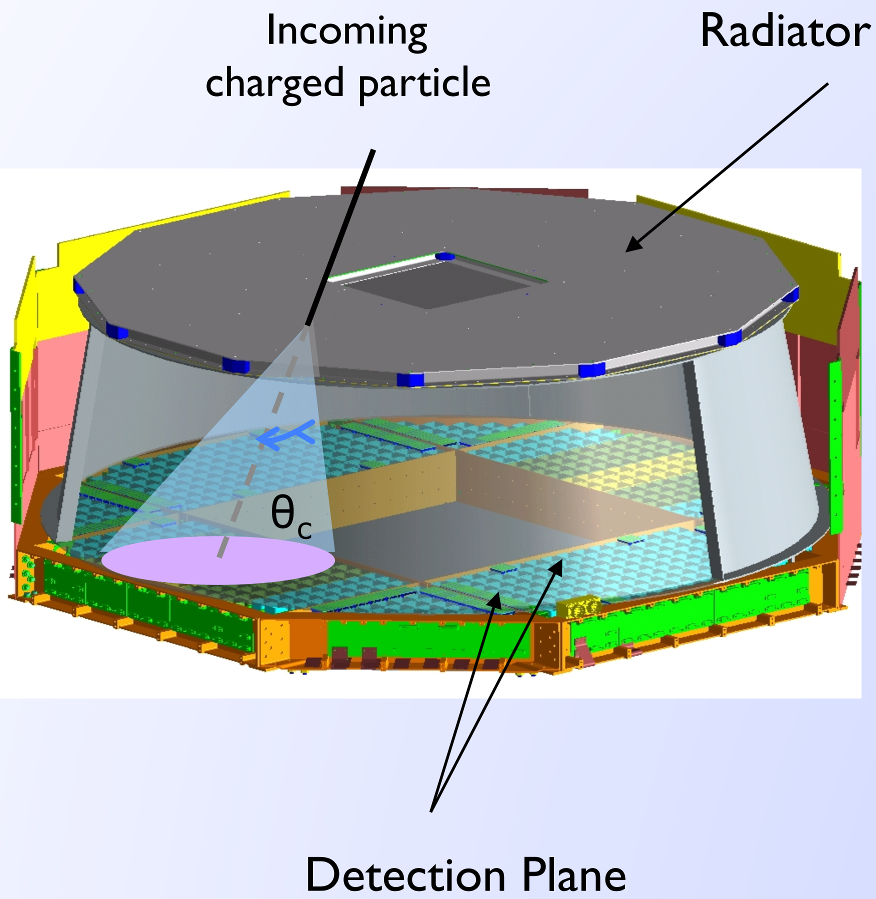


Proton Rigidity (GV)

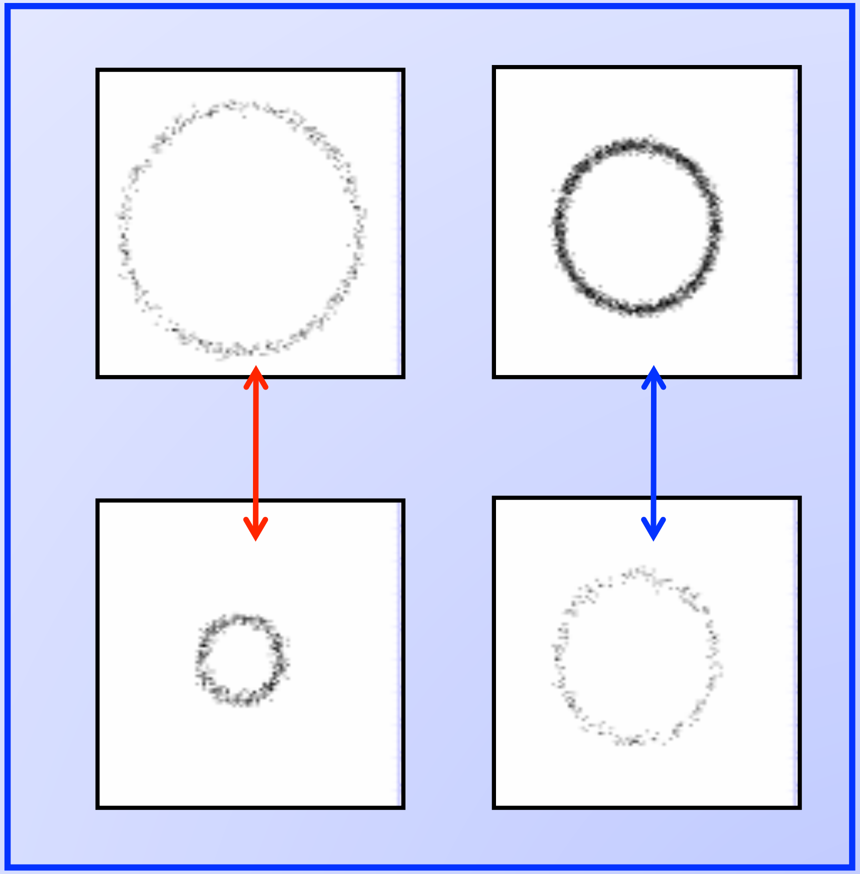
Ring Imaging Cherenkov



- ▷ Velocity and Charge measurements



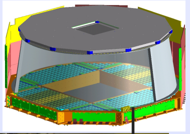
Photon Rings

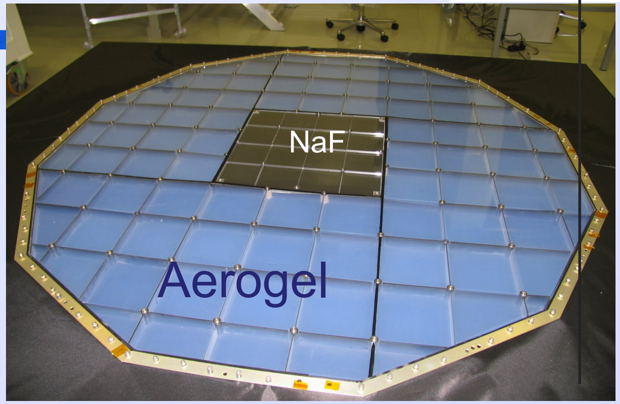


β Velocity measurement
(radius)
$\beta * n * \cos(\theta_c) = 1$

Z Electric Charge
Signal proportional to Z^2

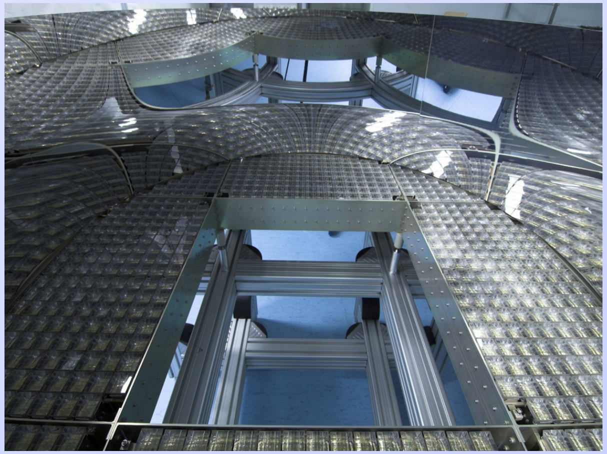
Ring Imaging Cerenkov



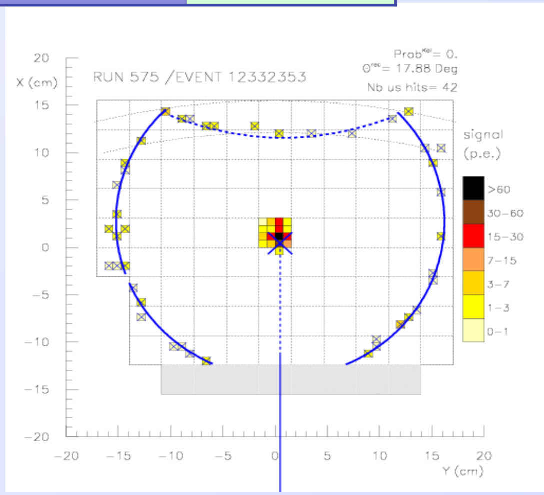


► **Dual solid radiator configuration**

	Aerogel	NaF
Refraction Index	1.05	1.33
Opening angle (deg)	17.8	41.5
Velocity threshold	0.952	0.752



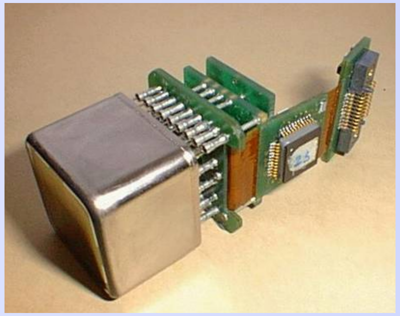
► **Conical Reflector**

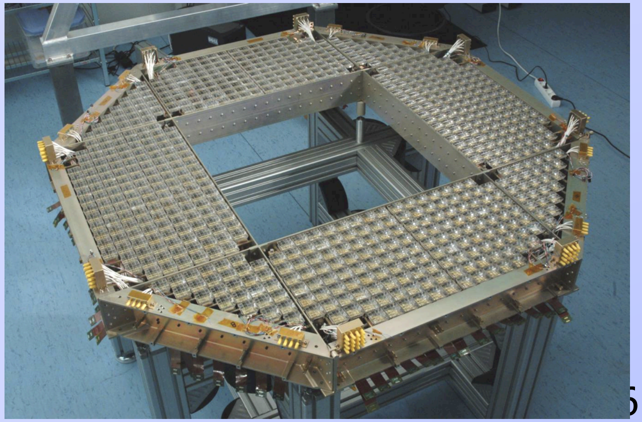


► **Photomultiplier matrix**

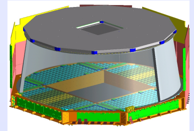
► **10880 pixels**

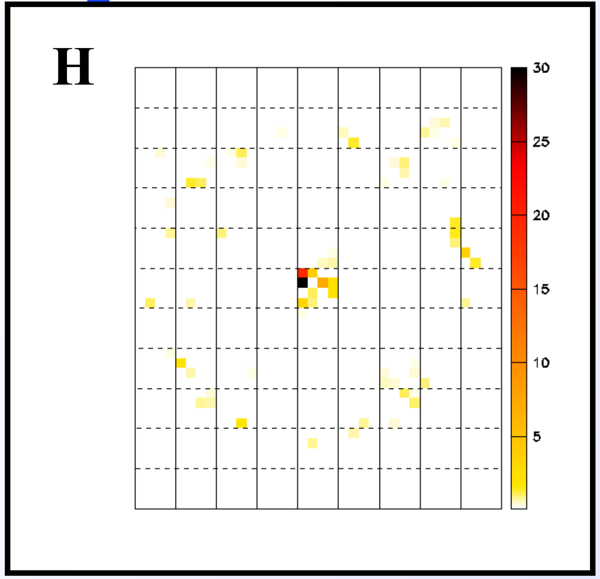
► **FE and light collection**



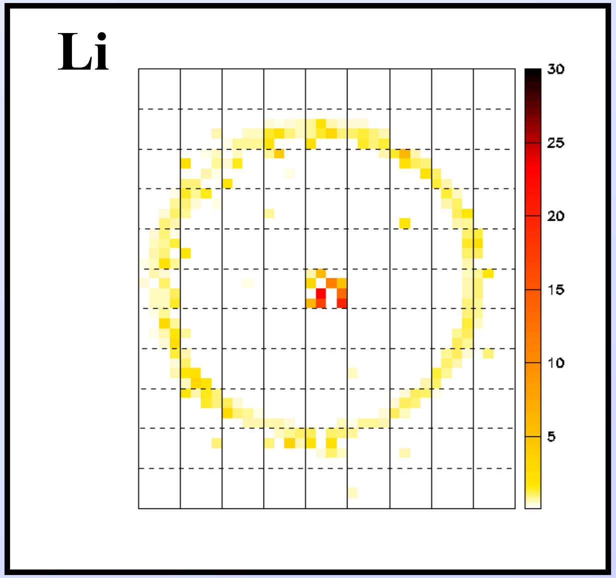


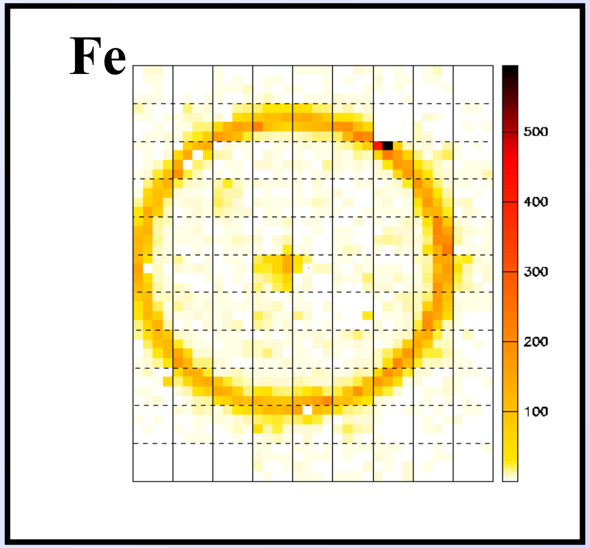
RICH – Charge Measurement

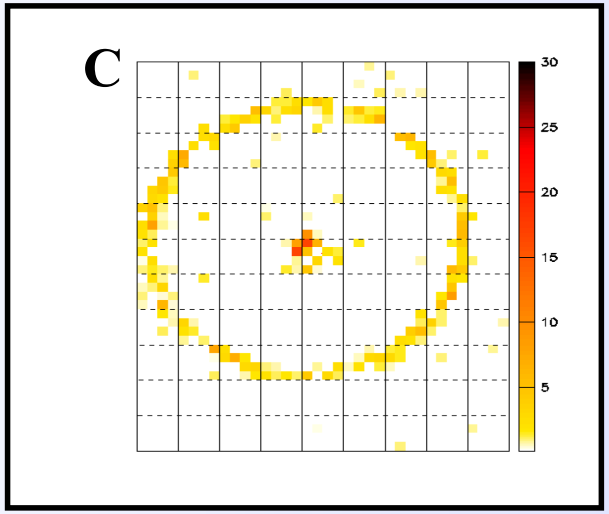




$E_k/n = 158$ GeV/n

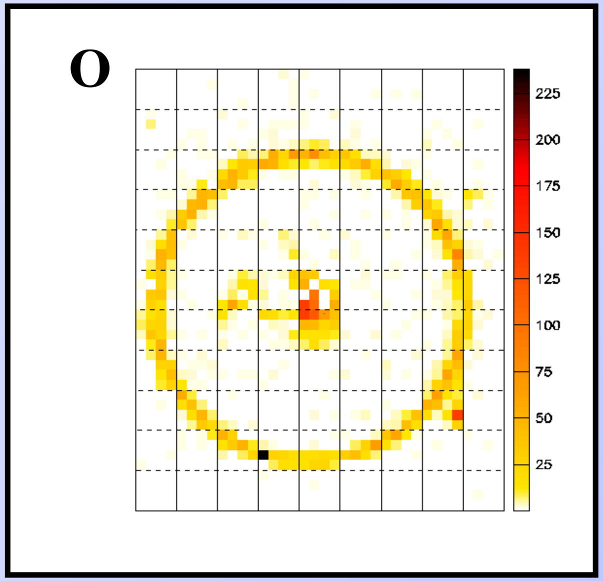




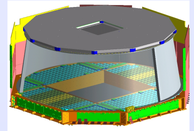


Collision products:

p, D, He^4, Li^6,…



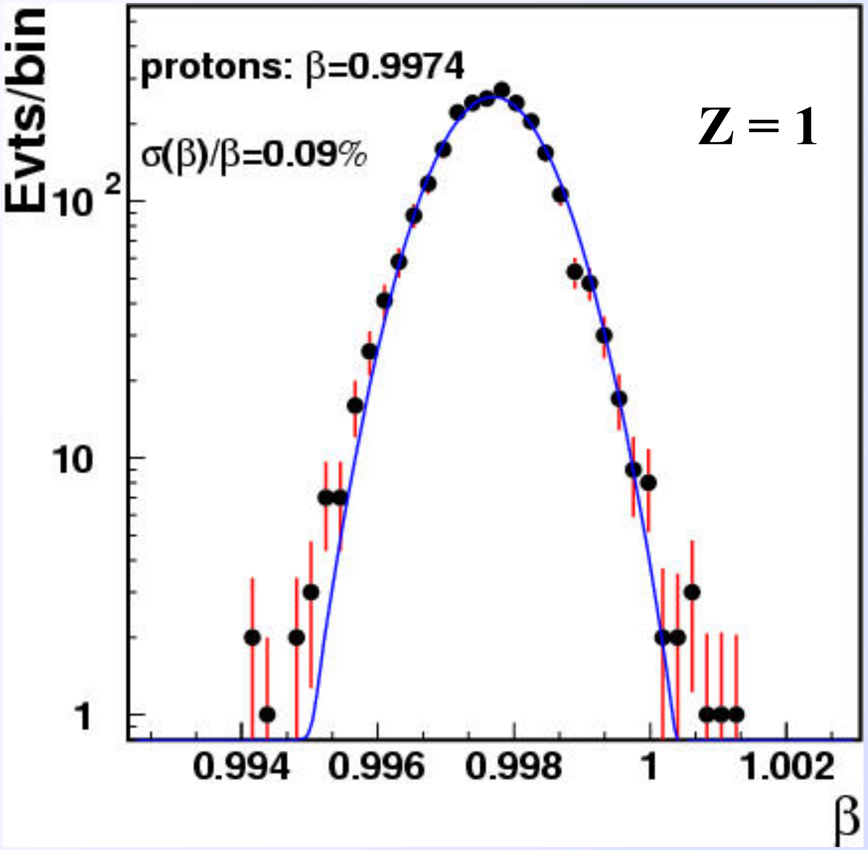
RICH – Velocity measurement

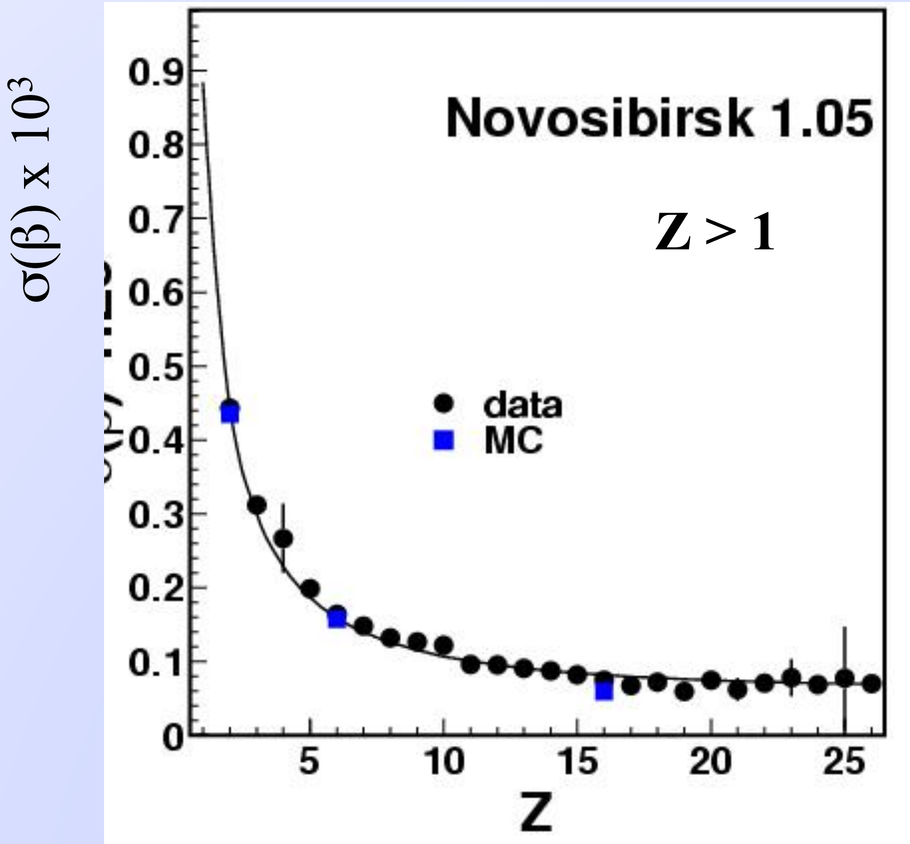


▷ Aerogel radiator (Beam test)

NaF

E_k/n=158 GeV/n

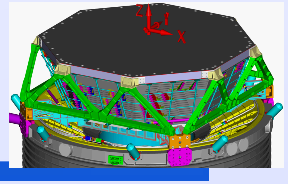




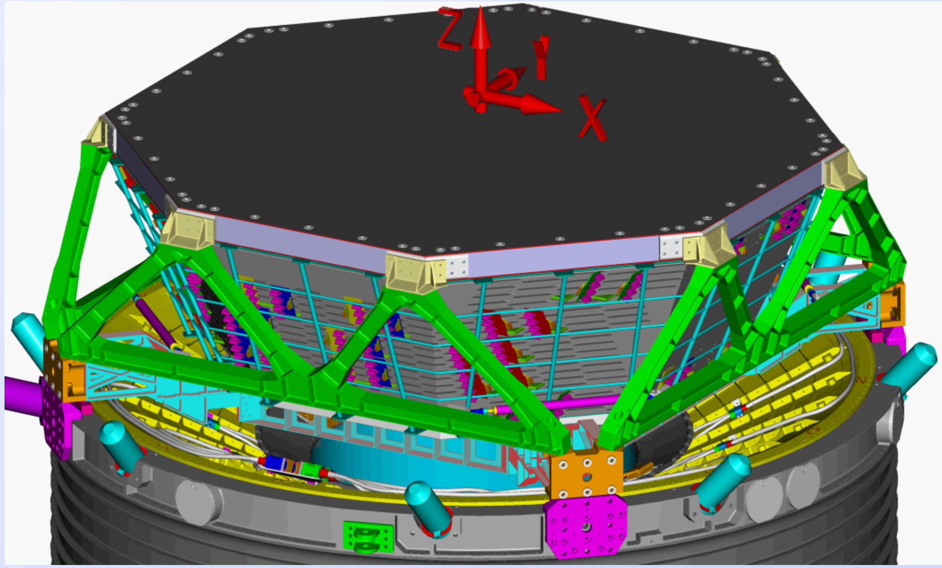
Resolution per hit is the same for direct and reflected hits

$$\left(\frac{\sigma_\beta}{\beta}\right)_Z \approx \frac{1}{Z}\left(\frac{\sigma_\beta}{\beta}\right)_{Z=1}$$

TRD



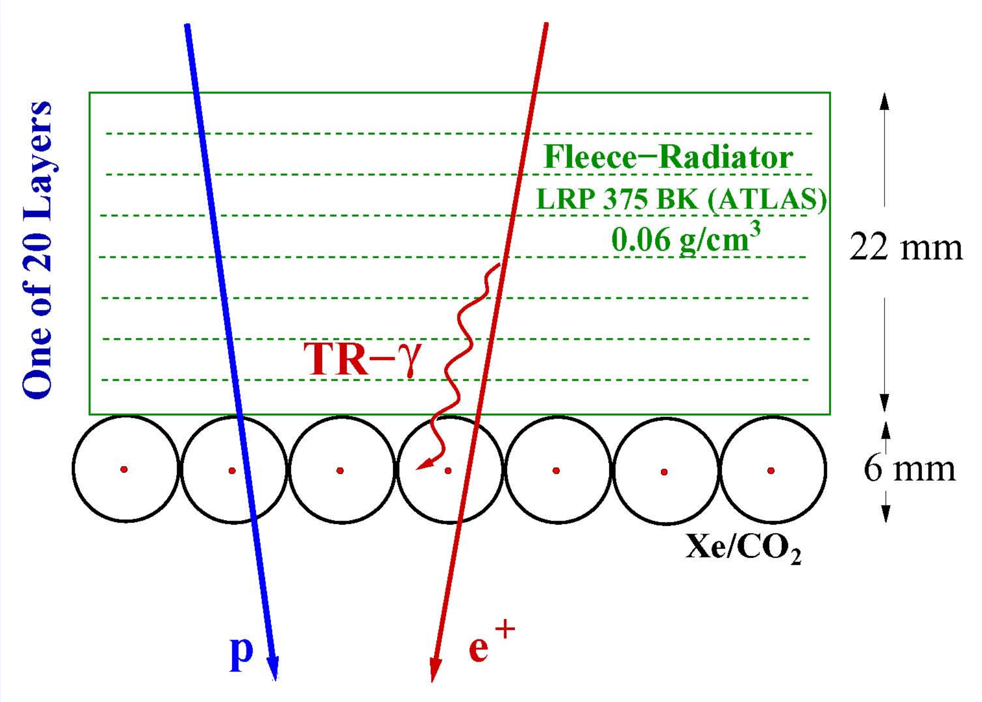
Proton rejection >10^2 1-300 GeV
acceptance: 0.45m^2sr



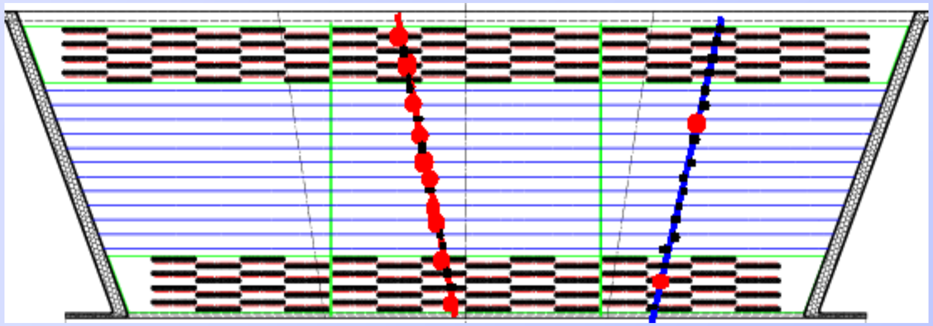
Choosen configuration for 60 cm height:
20 Layers each existing of:

- **22 mm fibre fleece**
- **Ø 6 mm straw tubes**

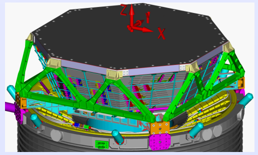
filled with Xe/CO_2 80%/20%



12 layers in the bending plane
2 x 4 layers in the non-bending plane



TRD - The AMS detector @ CERN

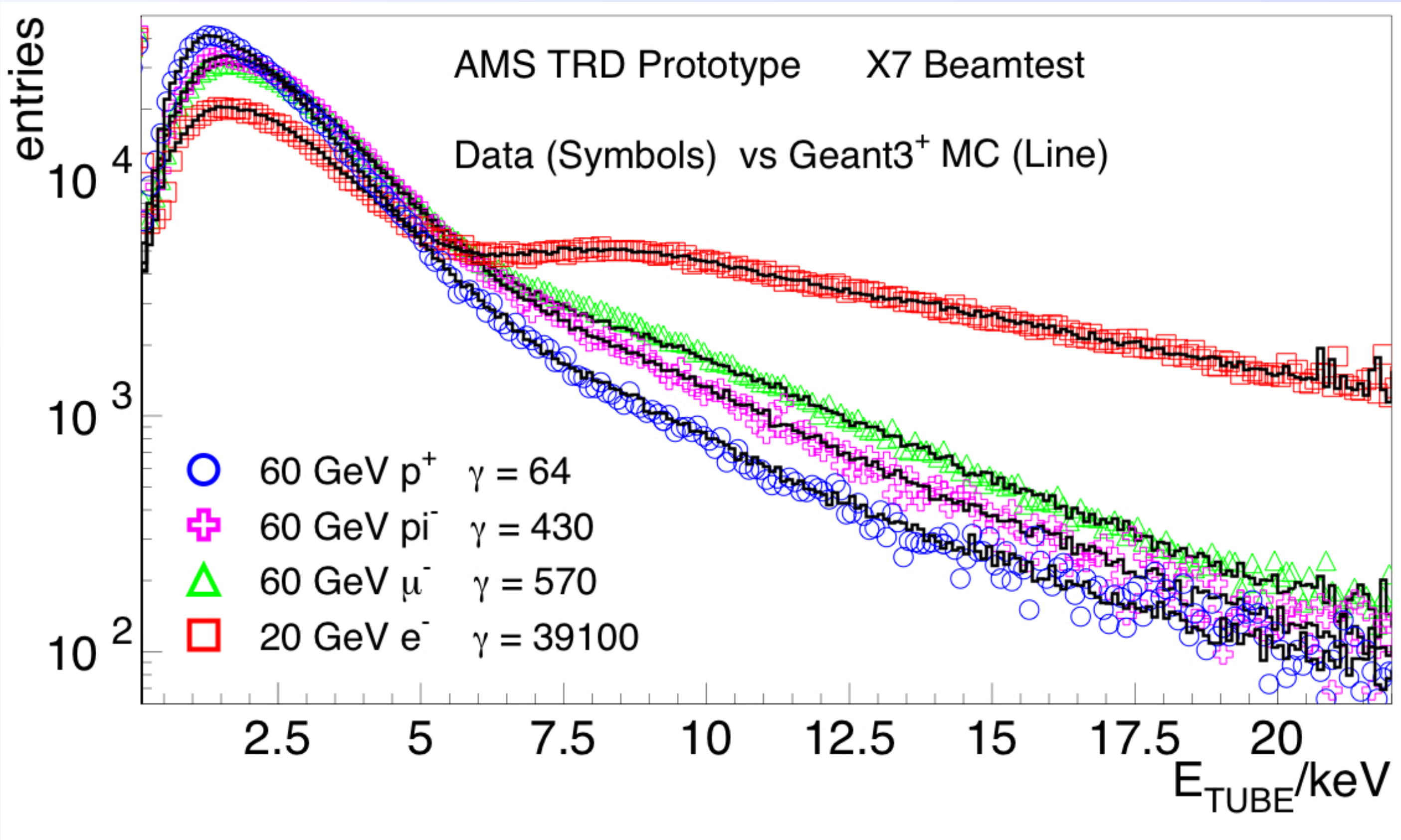


November 23, 2007

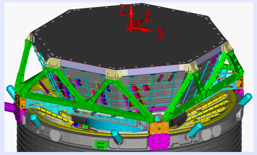
TDR – test beam results

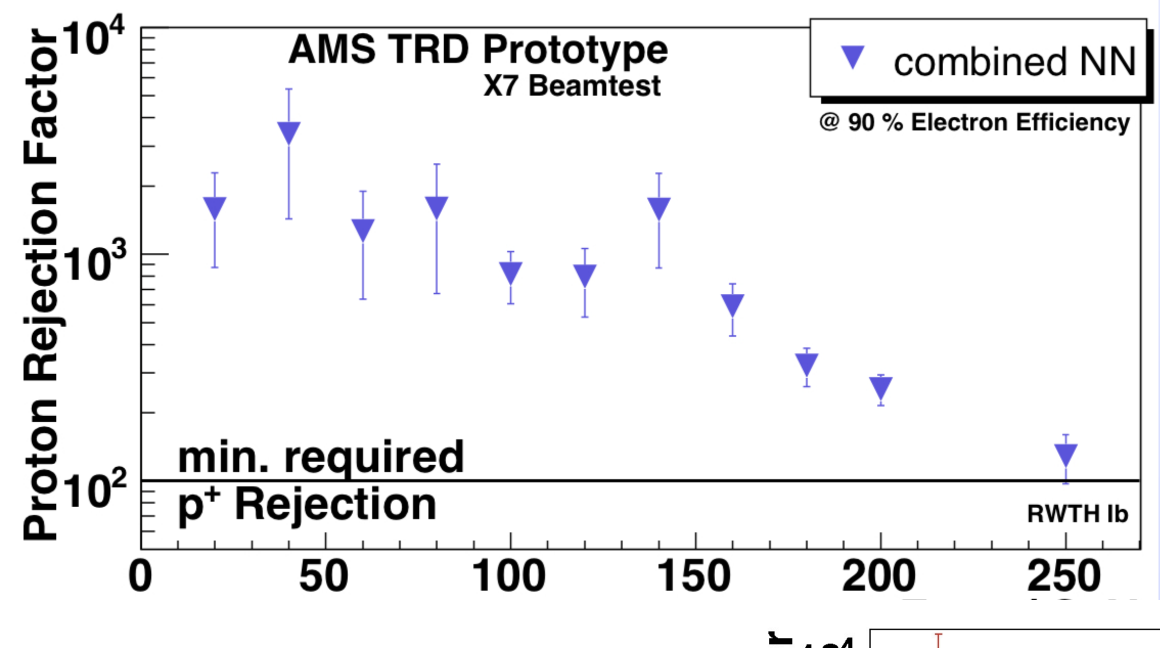
20 layer TRD detector in the test beam at CERN in 2000

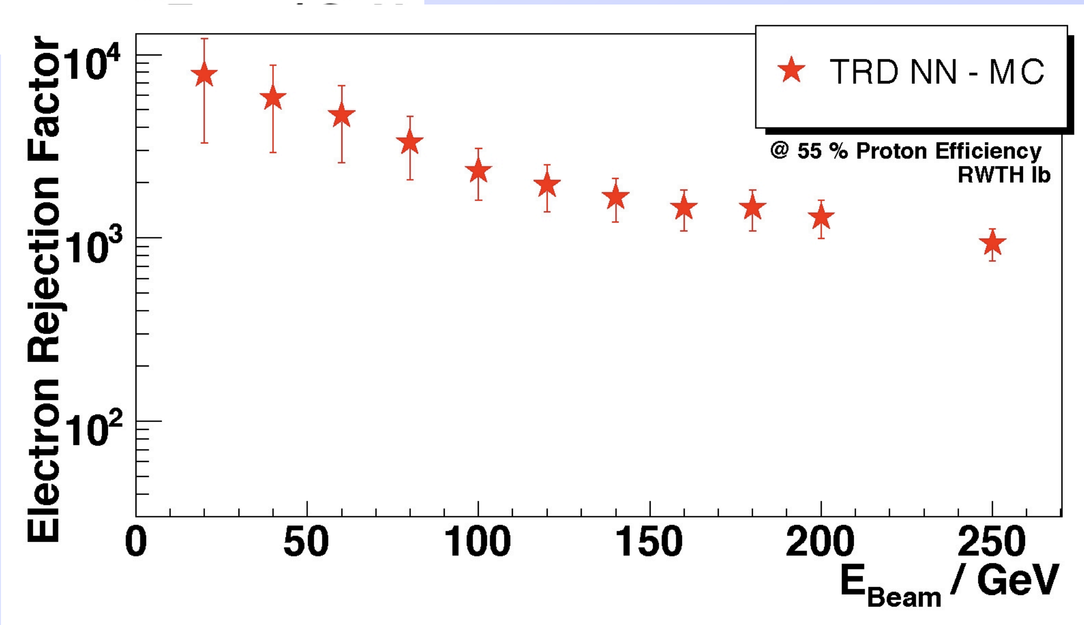
3 million events of p,e,μ,π @ 5-250 GeV



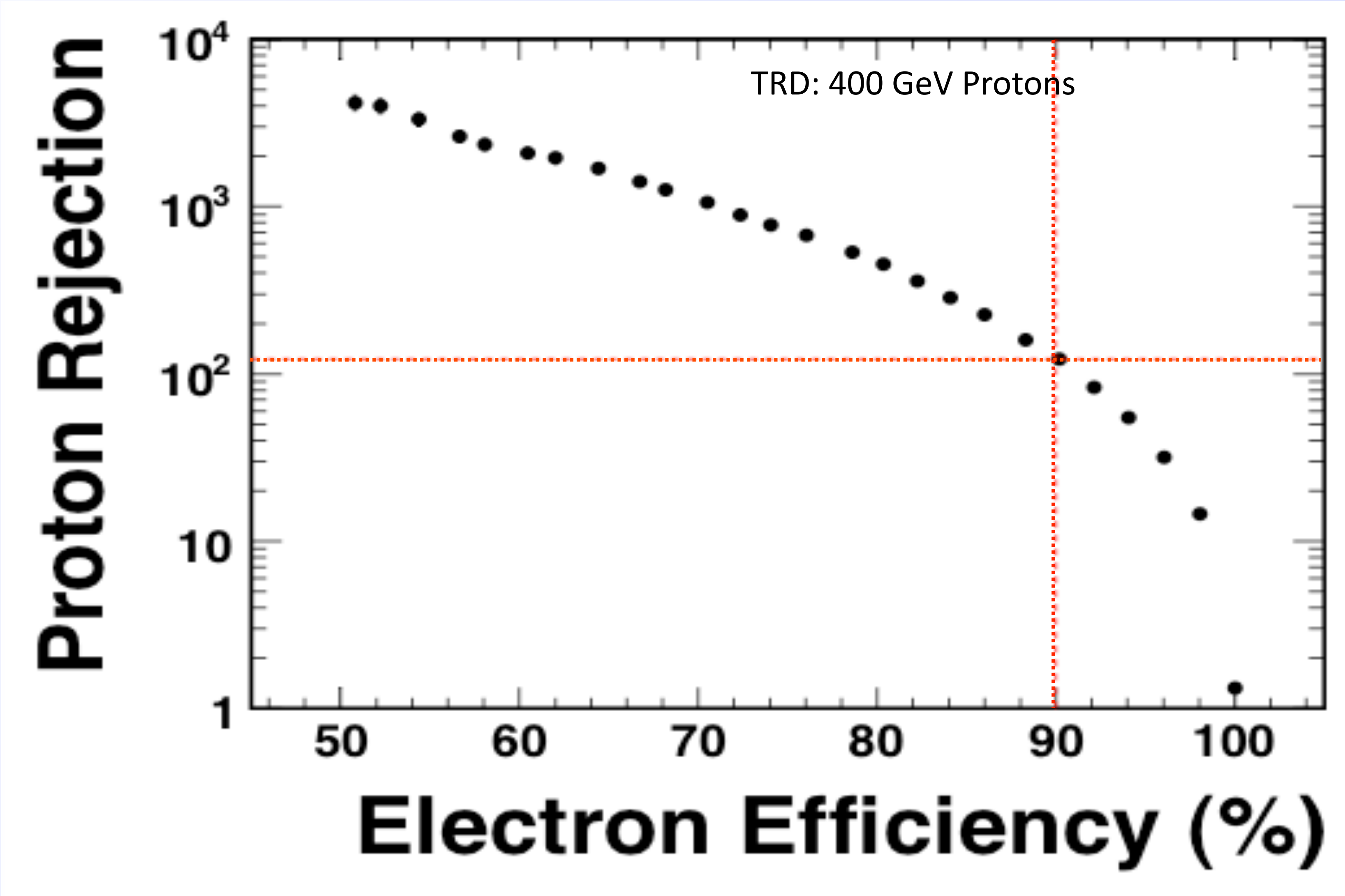
TDR – Test Beam Results



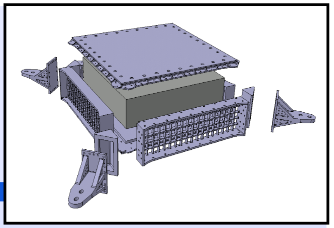




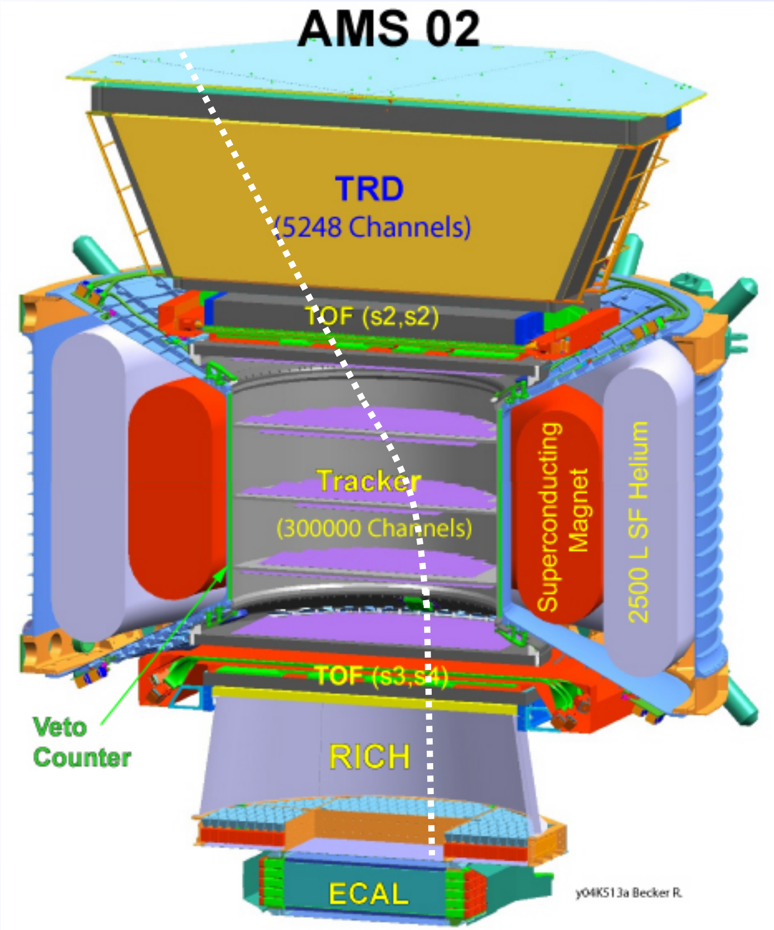
TDR – test beam results (2010)



Electromagnetic Calorimeter



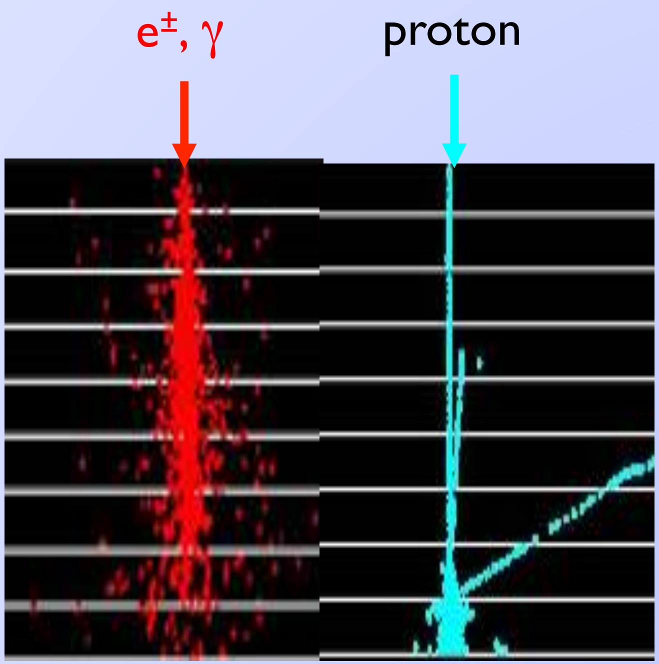
3D imaging calorimeter



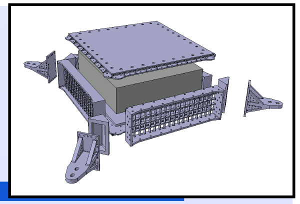
ECAL: last subdetector crossed by particles from outer space

:

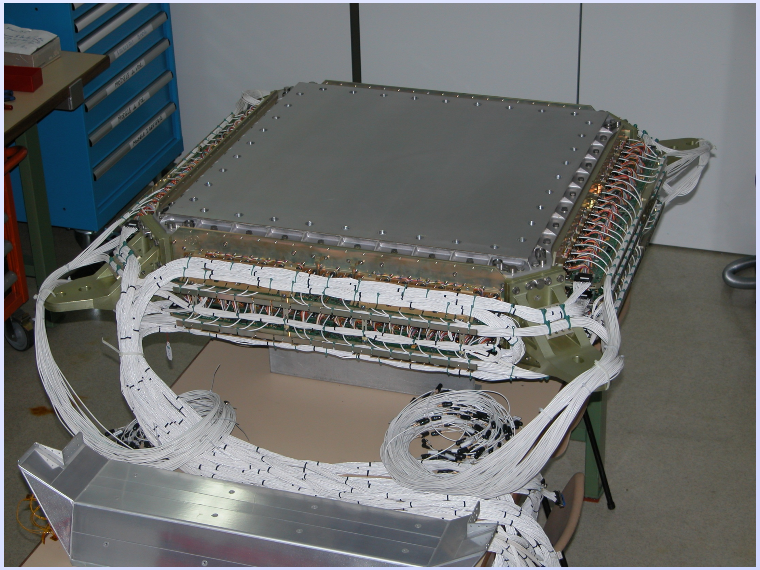
- ▷ Particle ID (e.m showers vs. hadron cascades)
- ▷ Energy measurement (e+,e-,γ) (up to 1TeV)
- ▷ Trigger system: on non interacting photons



Electromagnetic Calorimeter



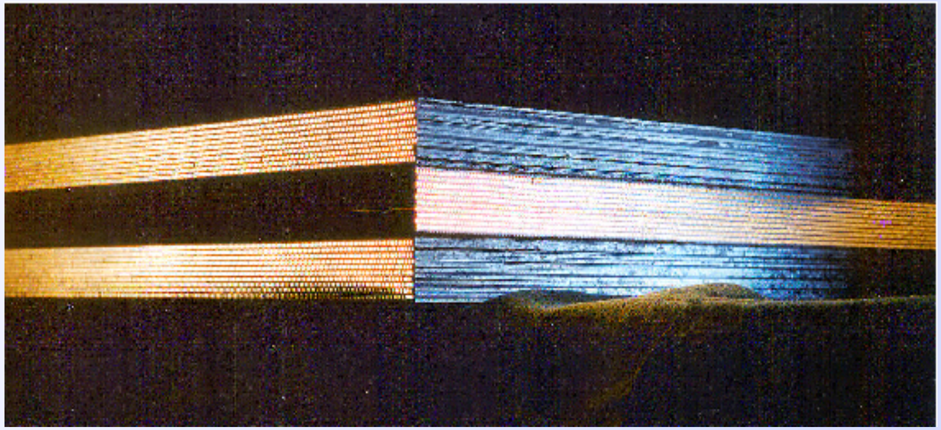
3D shower reconstruction



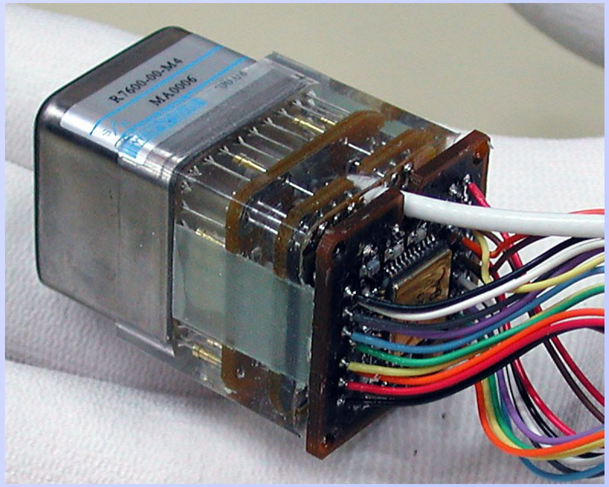
- Sampling calorimeter
- Pb/scintillating fibers structure

volume ratio Pb:fibers:glue : 60:34:6
dimensions : 658 × 658 × 166.5 mm^3
weight : 498 kg

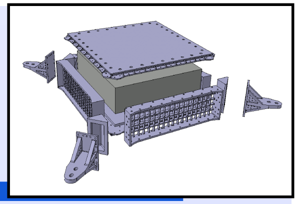
- Pile up of 9 “Superlayers”

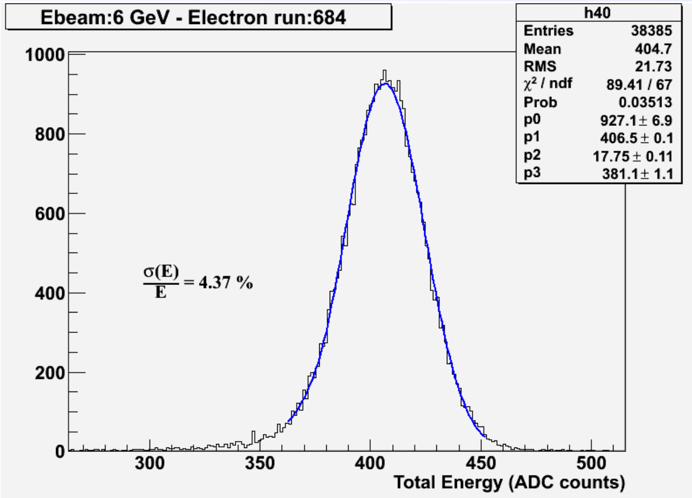


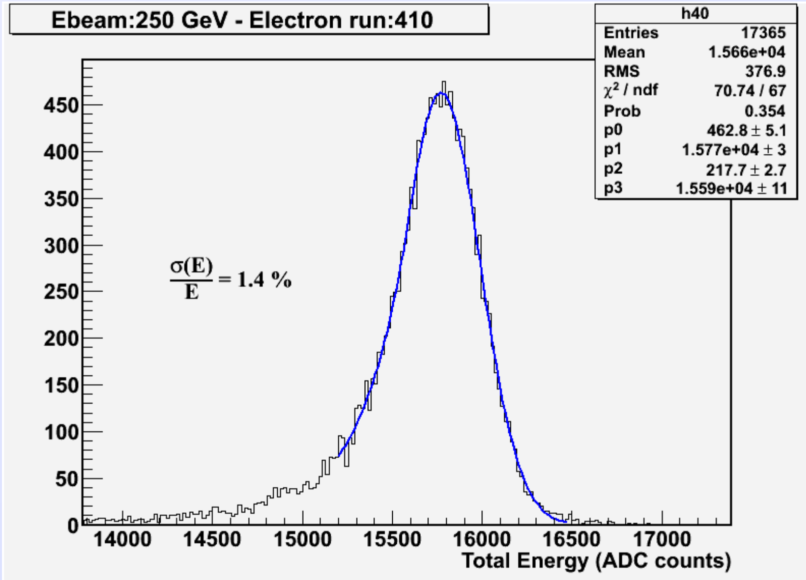
10 000 fibers, ϕ = 1 mm, distributed uniformly Inside 1,200 lb of lead



Ecal – Energy Linearity







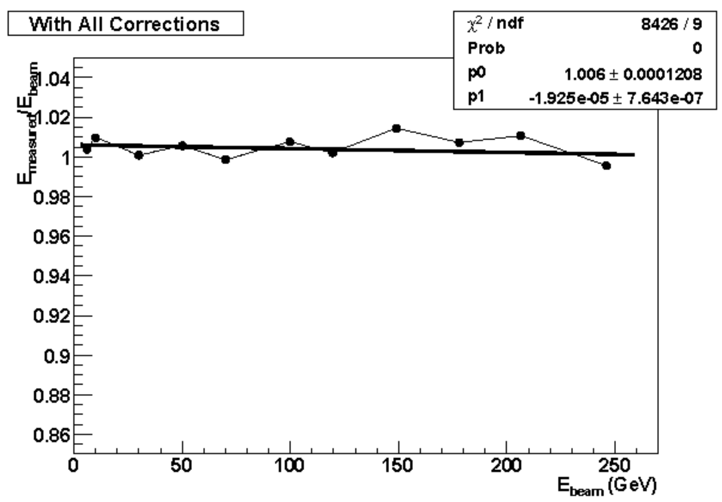
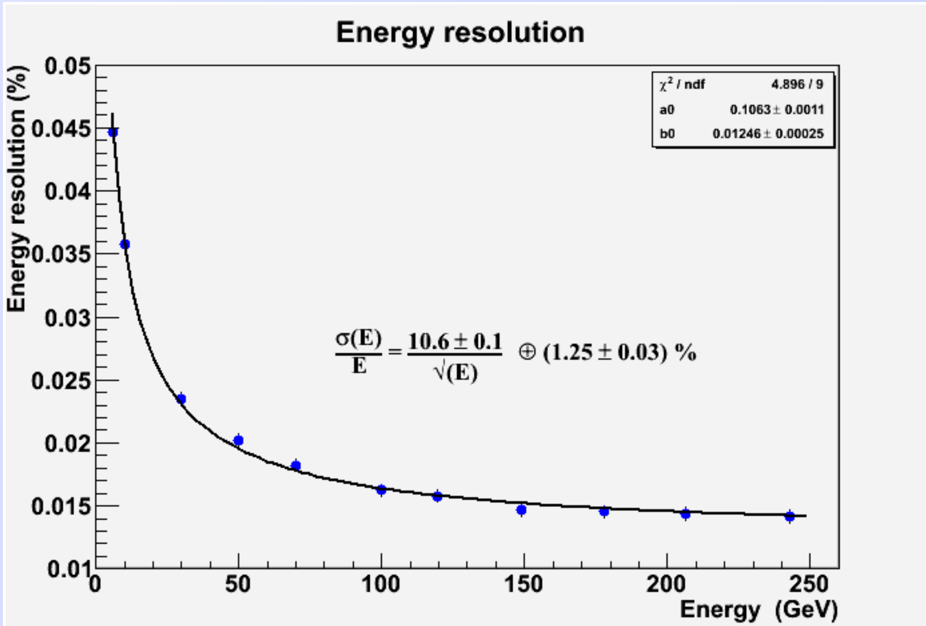
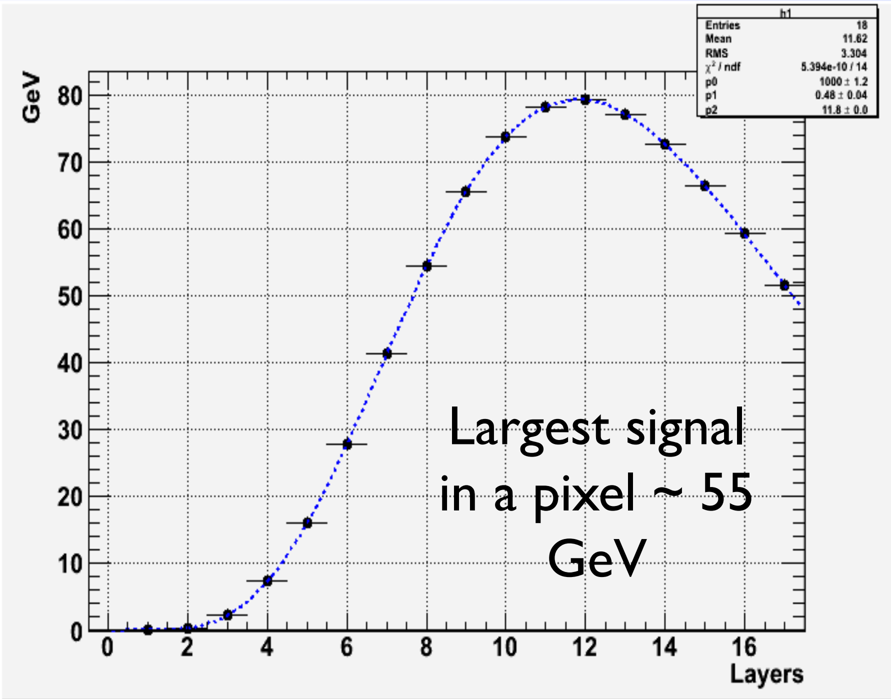


Figure 42: Improved impact correction



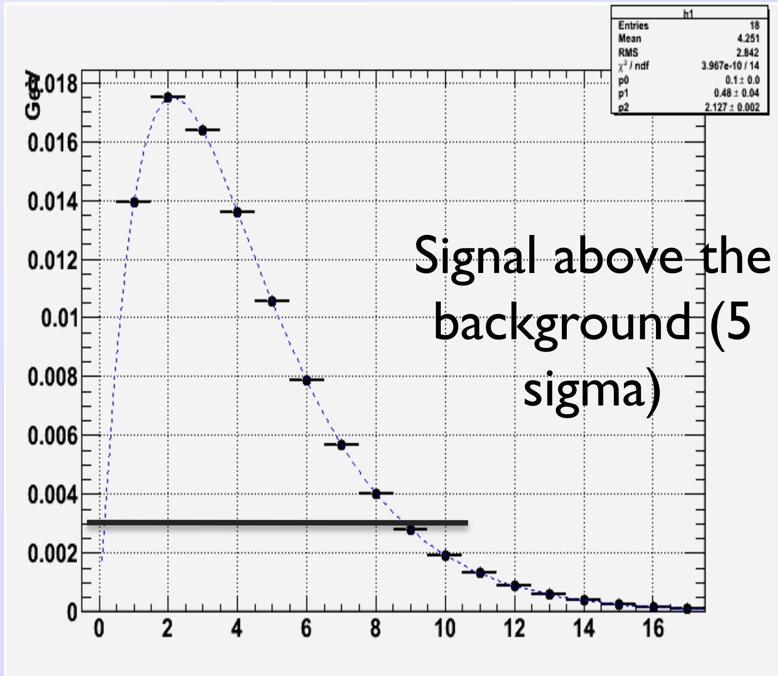
Total Radiation Length >~17 X_0

Maximum visible energy
given by the limit of non linearity
of the FE readout
(ie non linearity greater >3%)



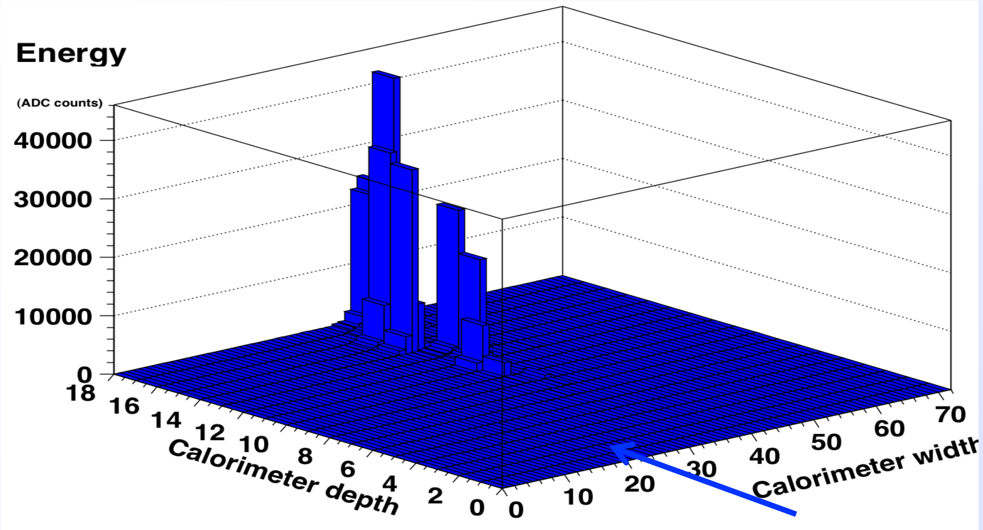
Longitudinal profile at 1 TeV

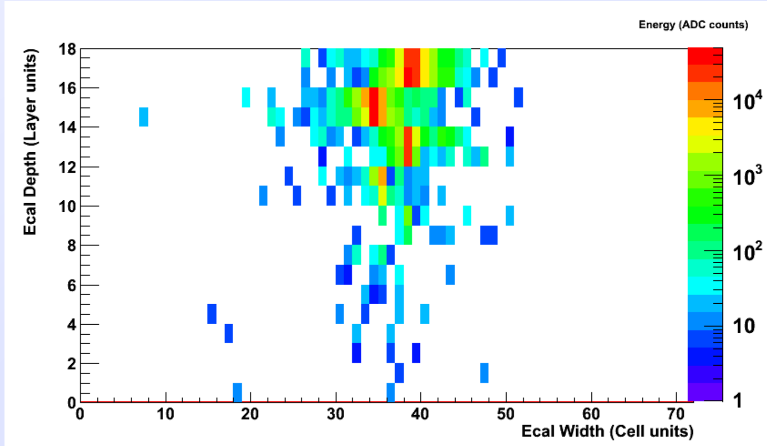
Minimum energy visible
constrained by the pedestal
width
0.4 ADC counts = 0.4 MeV, for
a MiP at 15 ADC counts



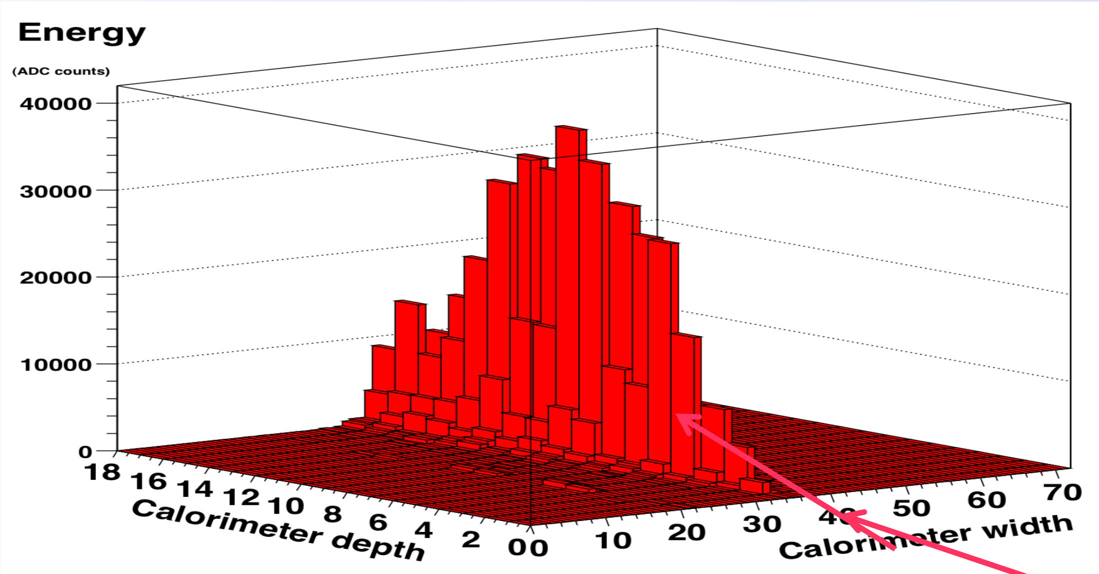
Longitudinal profile at 100 MeV

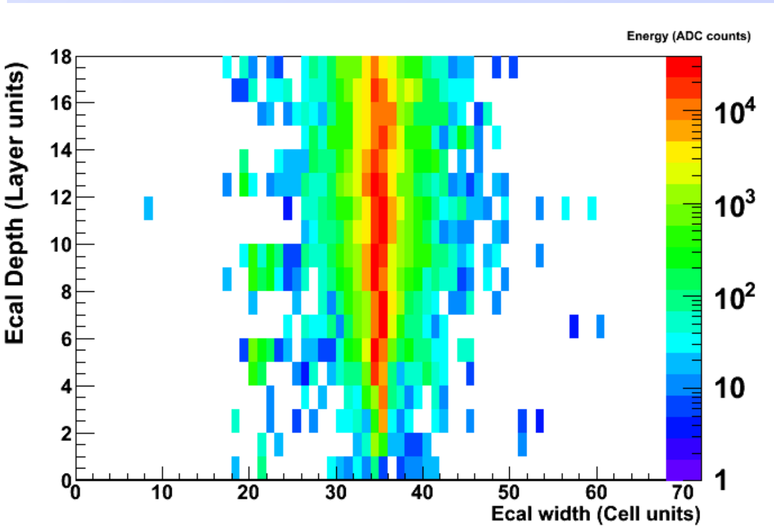
Fit parameters from Testbeam data 2007





Proton Beam (2010)
400 GeV

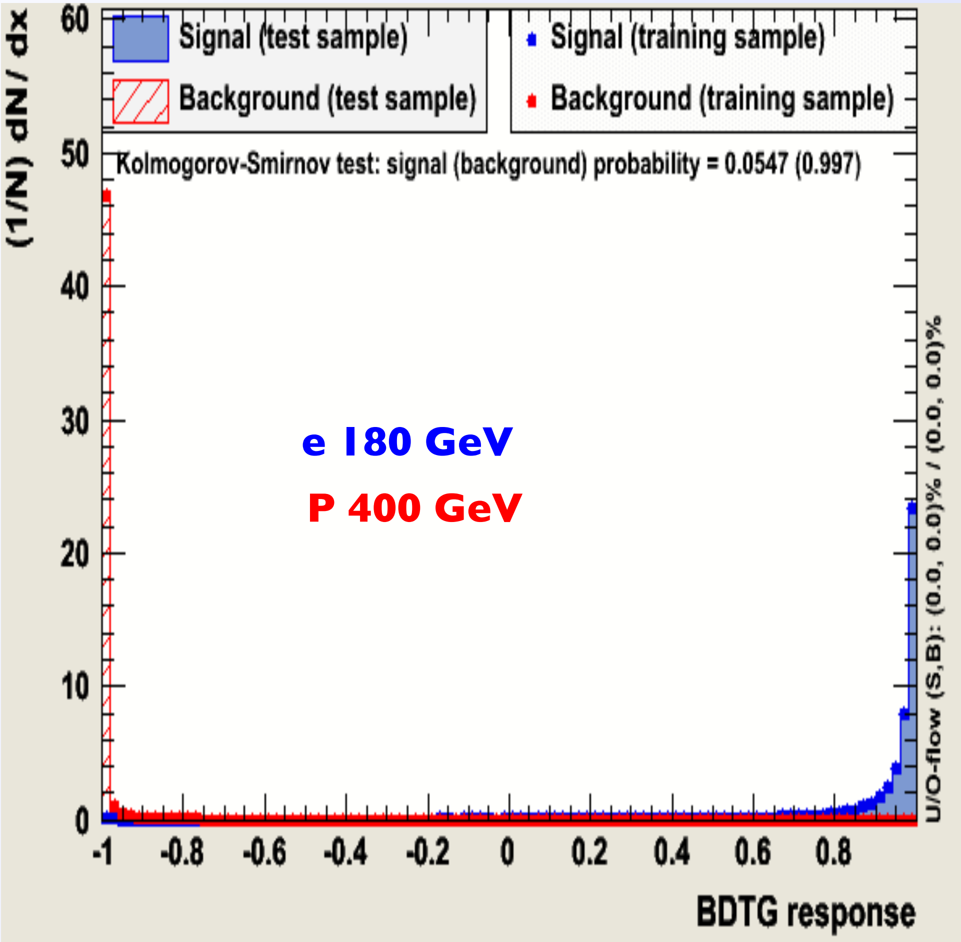


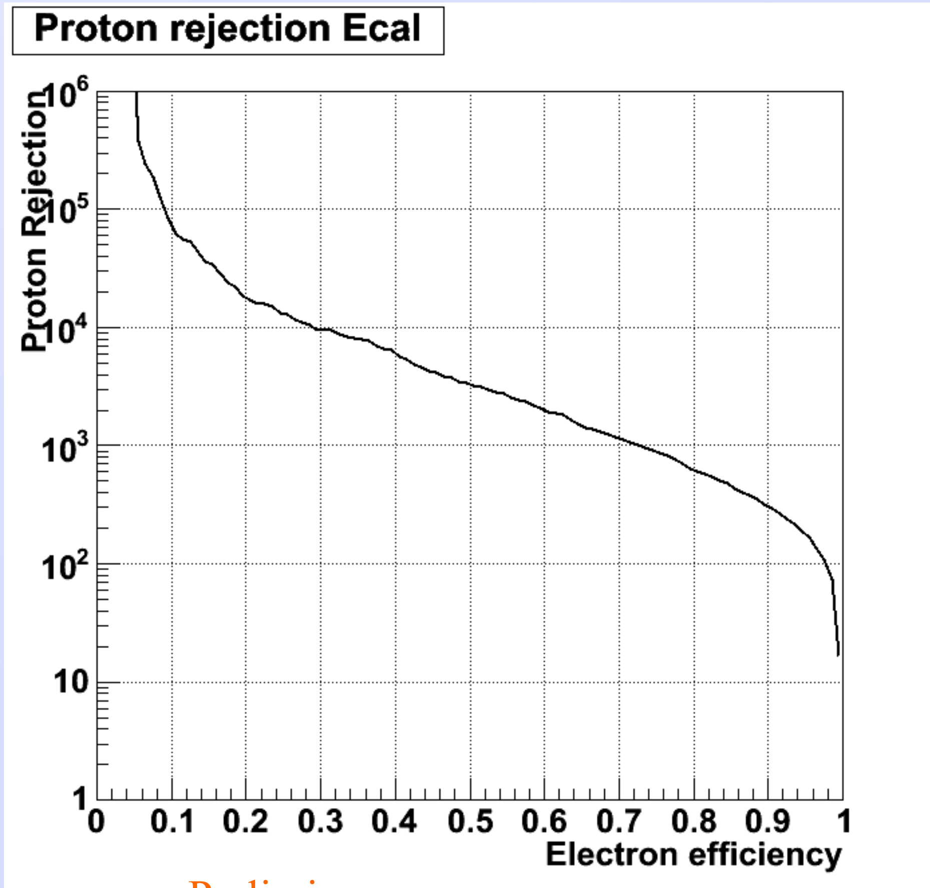


Electron Beam
250 GeV

Ecal variables for e/P rejection –TB 2010

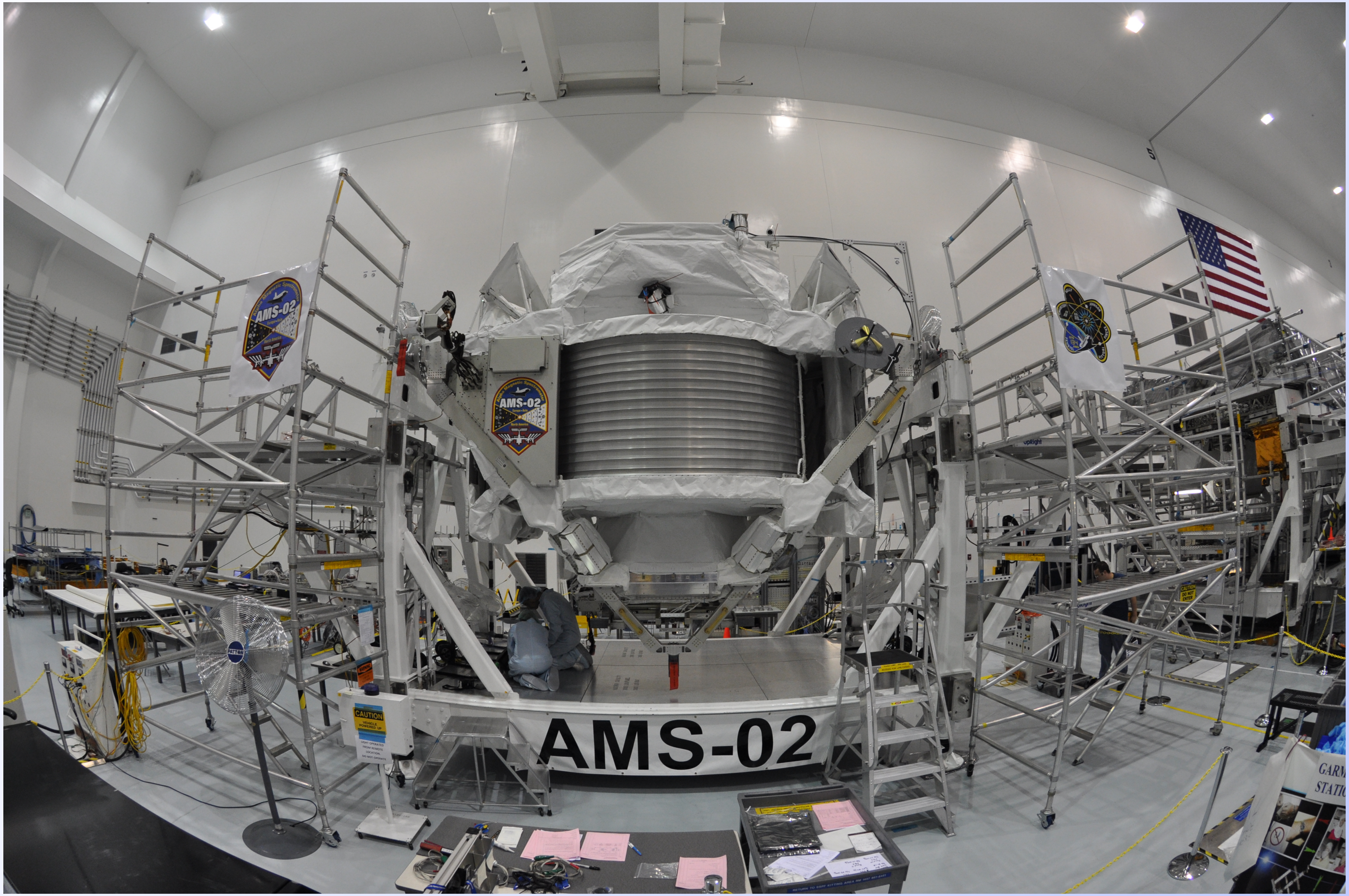
Boosted decision tree technique applied on the dataset with TMVA on ECAL variables



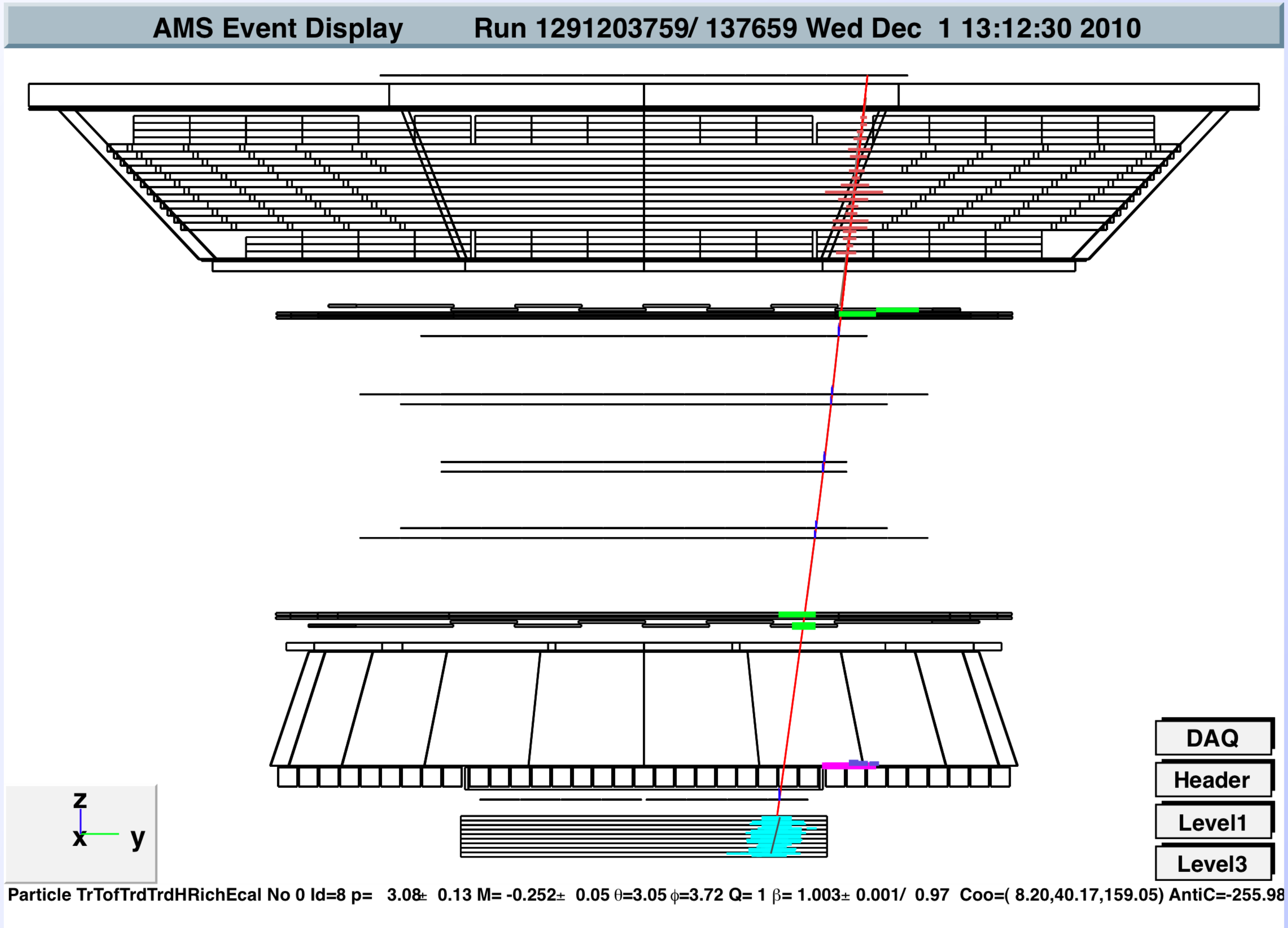


Preliminary

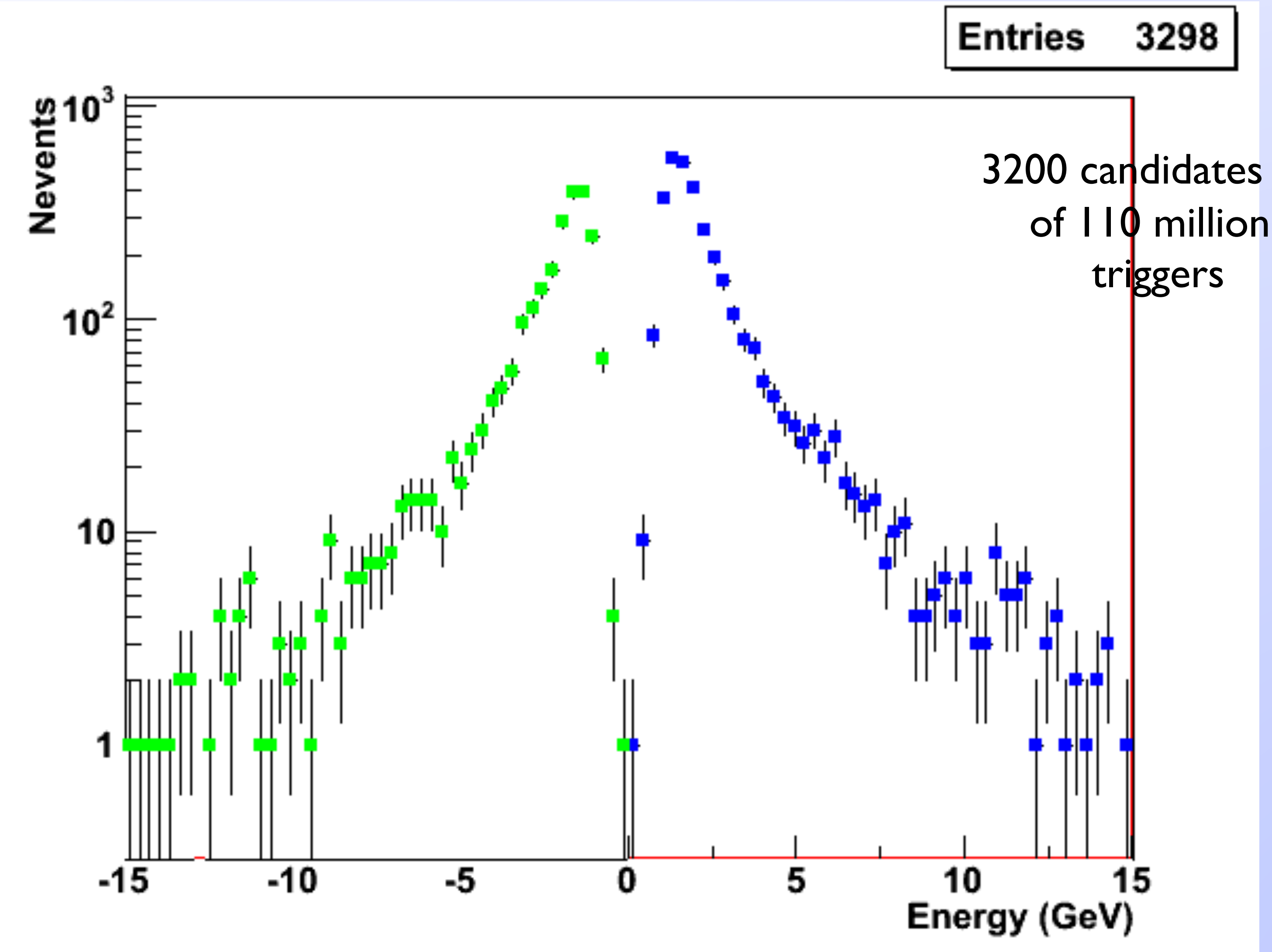
AMS in Kennedy Space Center (SSPF)



Positron/electron event

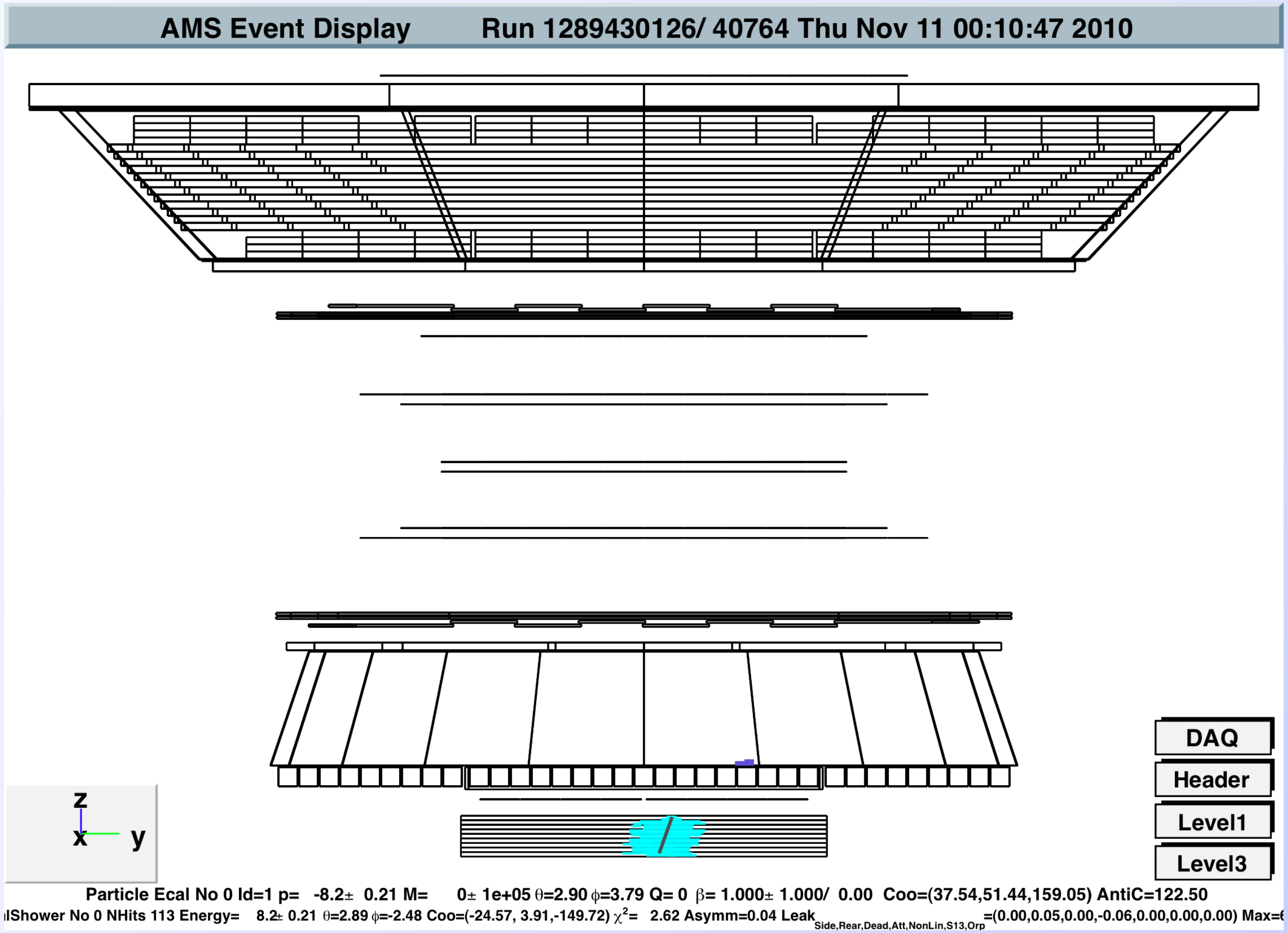


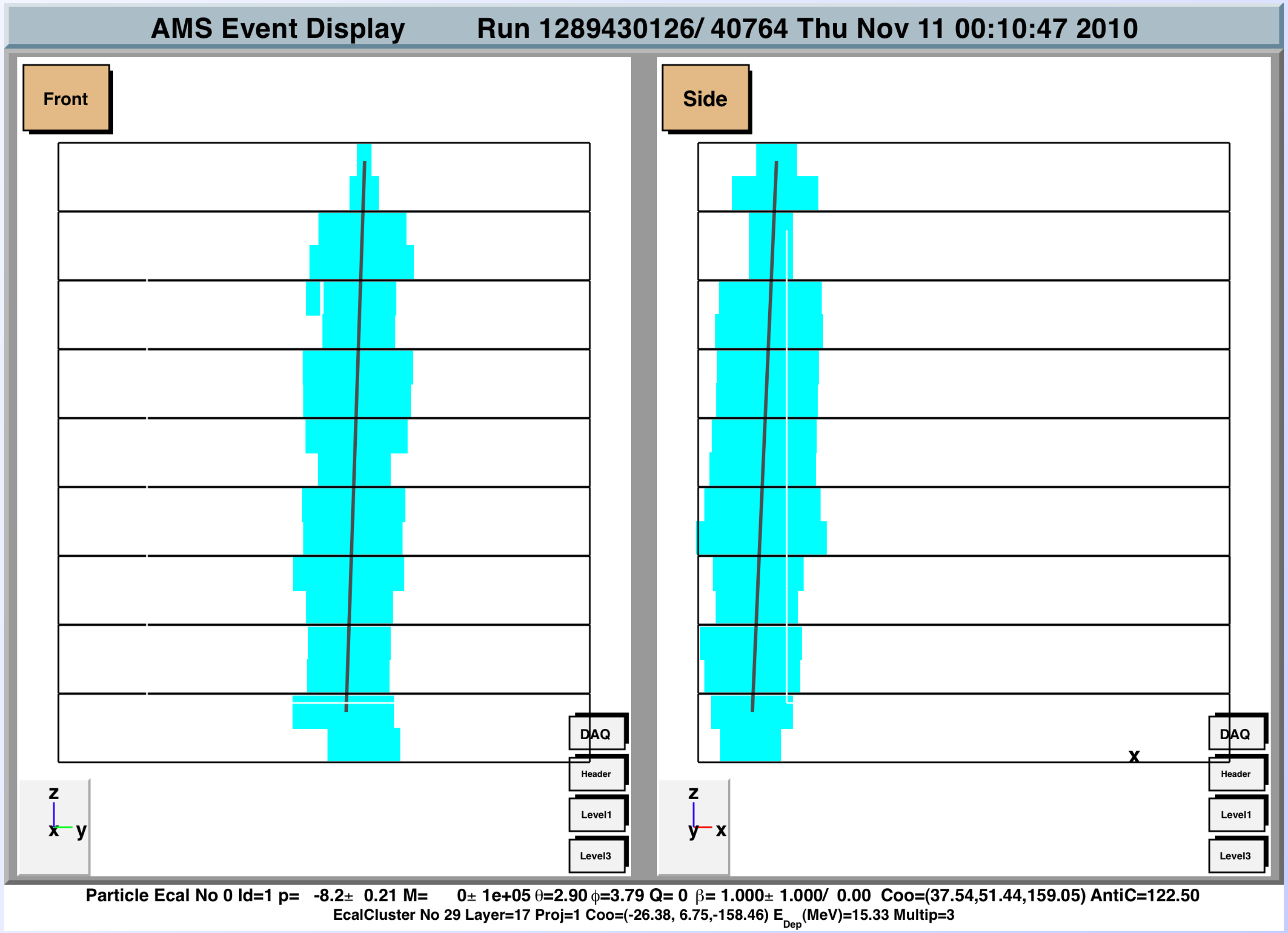
Electron & Positron like at KSC



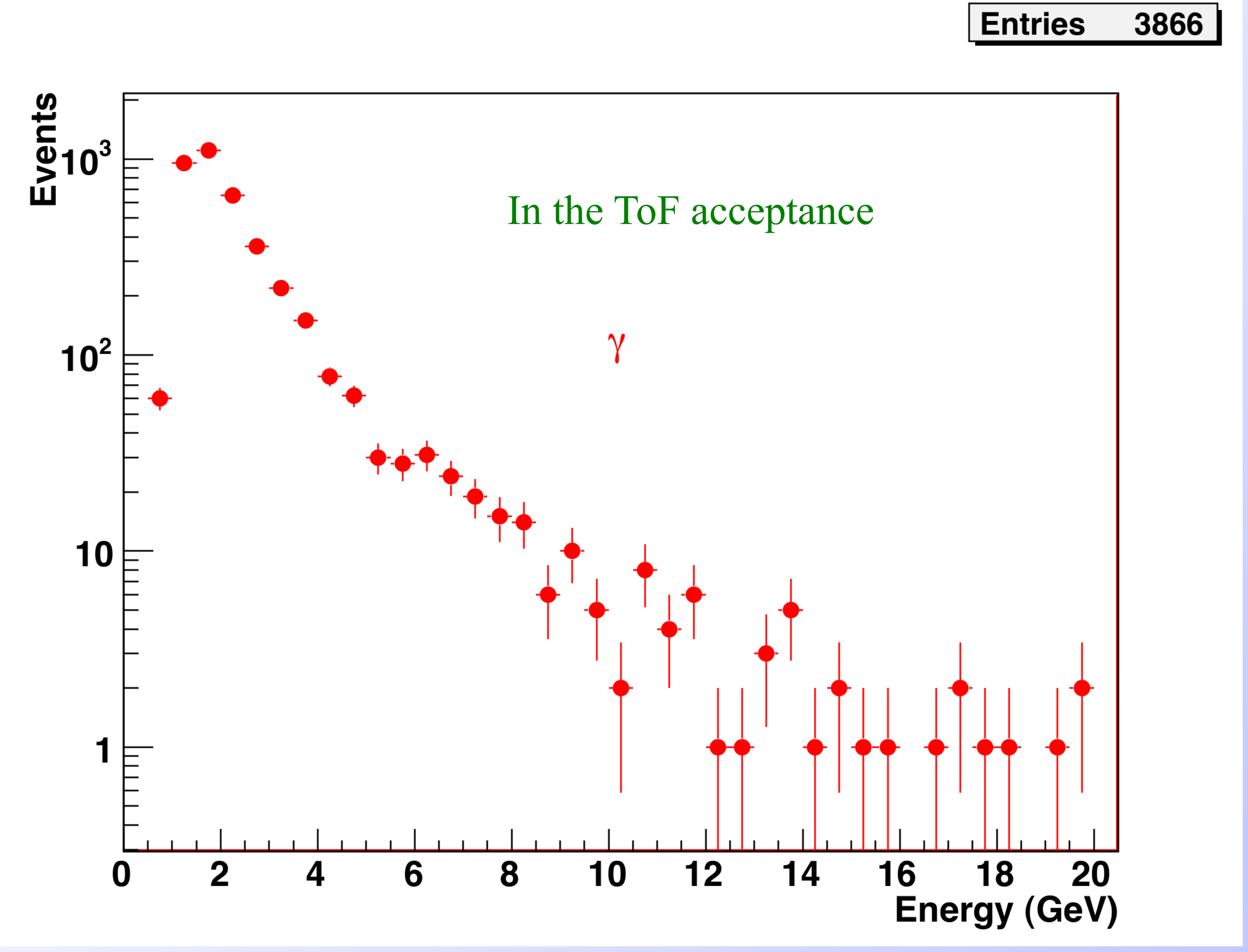
3200 candidates out of 110 millions triggers

Photon Candidate (1)

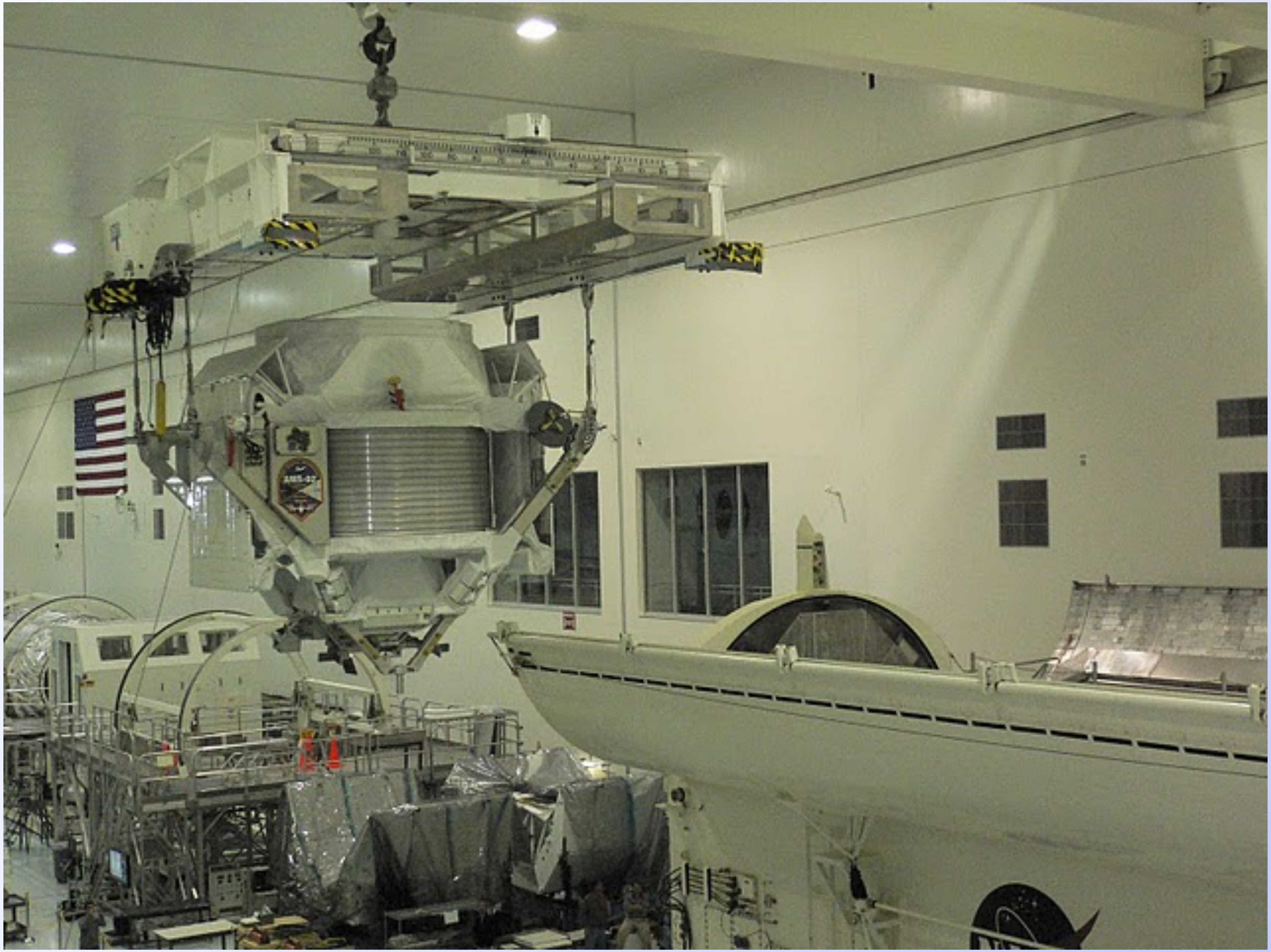



AMS Event Display
Run 1289430126/ 40764 Thu Nov 11 00:10:47 2010
Front
Side
DAQ
Header
Level1
Level3
z
x
y
Particle Ecal No 0 Id=1 p= -8.2± 0.21 M= 0± 1e+05 θ=2.90 φ=3.79 Q= 0 β= 1.000± 1.000/ 0.00 Coo=(37.54,51.44,159.05) AntiC=122.50
EcalCluster No 29 Layer=17 Proj=1 Coo=(-26.38, 6.75,-158.46) E_Dep(MeV)=15.33 Multip=3

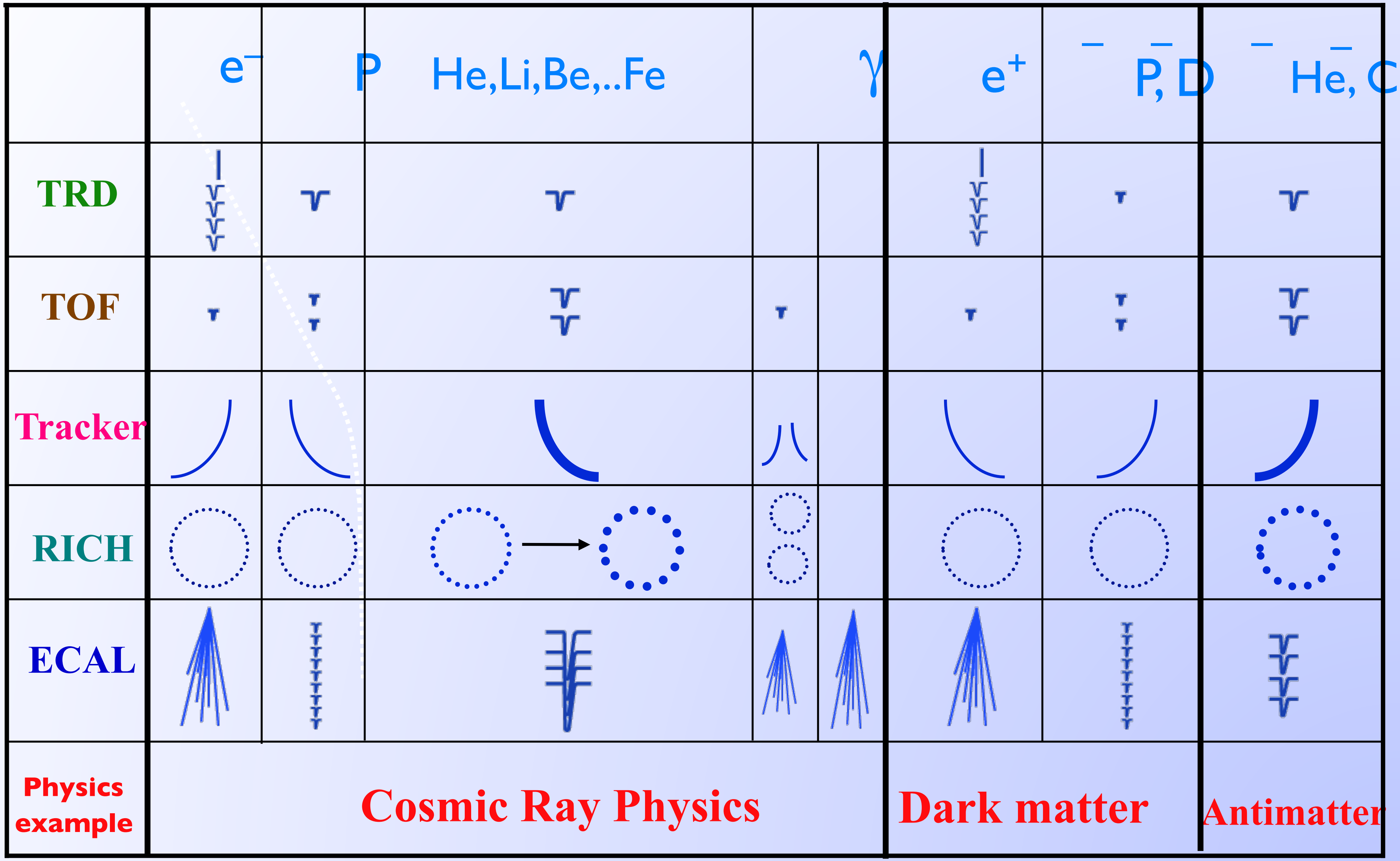
Photon spectrum KSC



AMS 02 to the canister



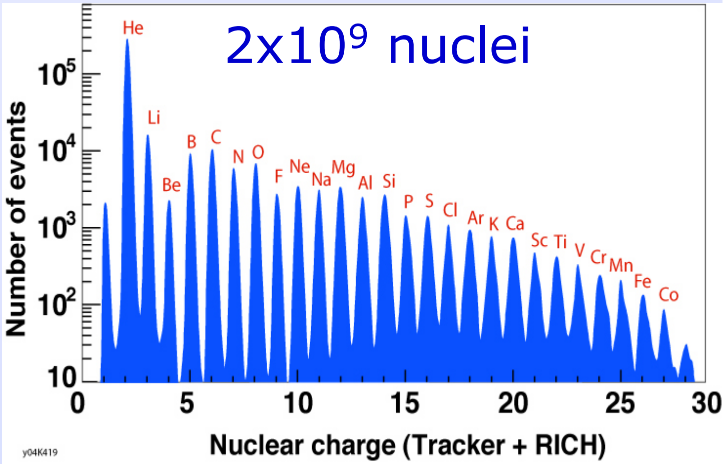
$\Delta t = 100$ ps, $\Delta x = 10$ µm, $\Delta v/v = 0.001$, $\Delta E/E =$ 1-2 %

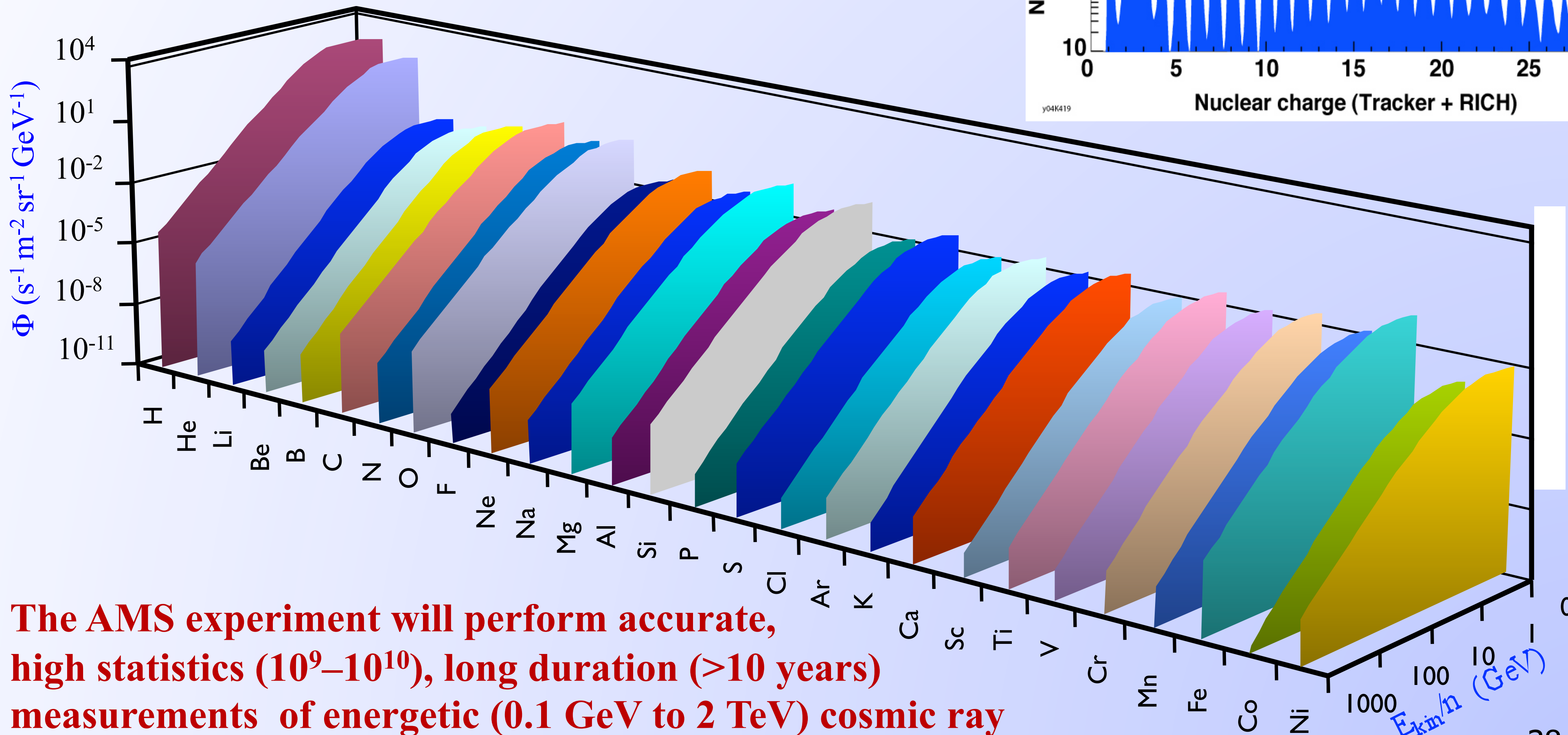


Precision study on the property of cosmic rays

- Composition at different energies

(1 GeV, 100 GeV, 1 TeV)

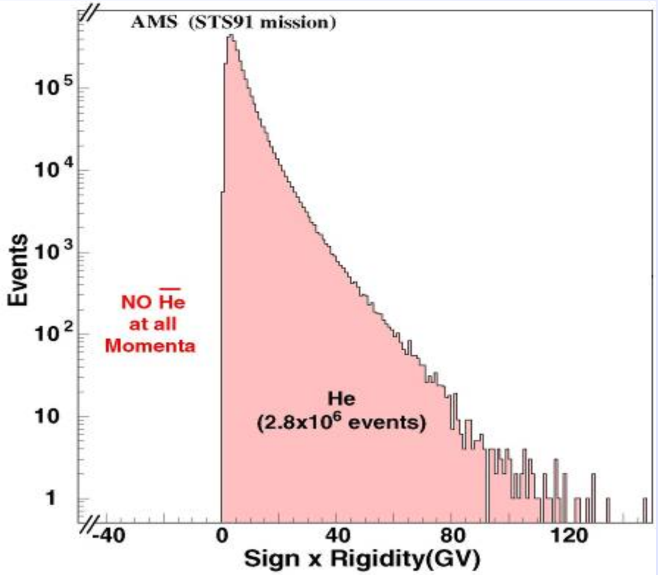


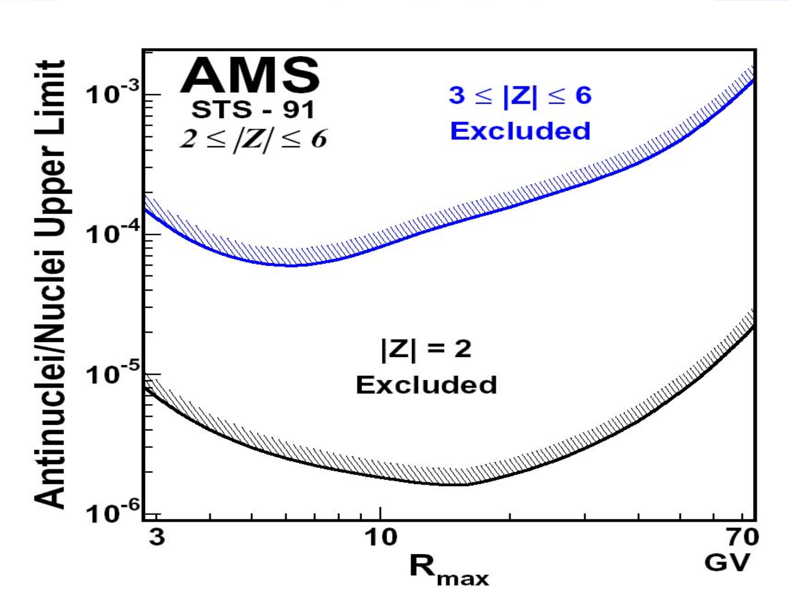


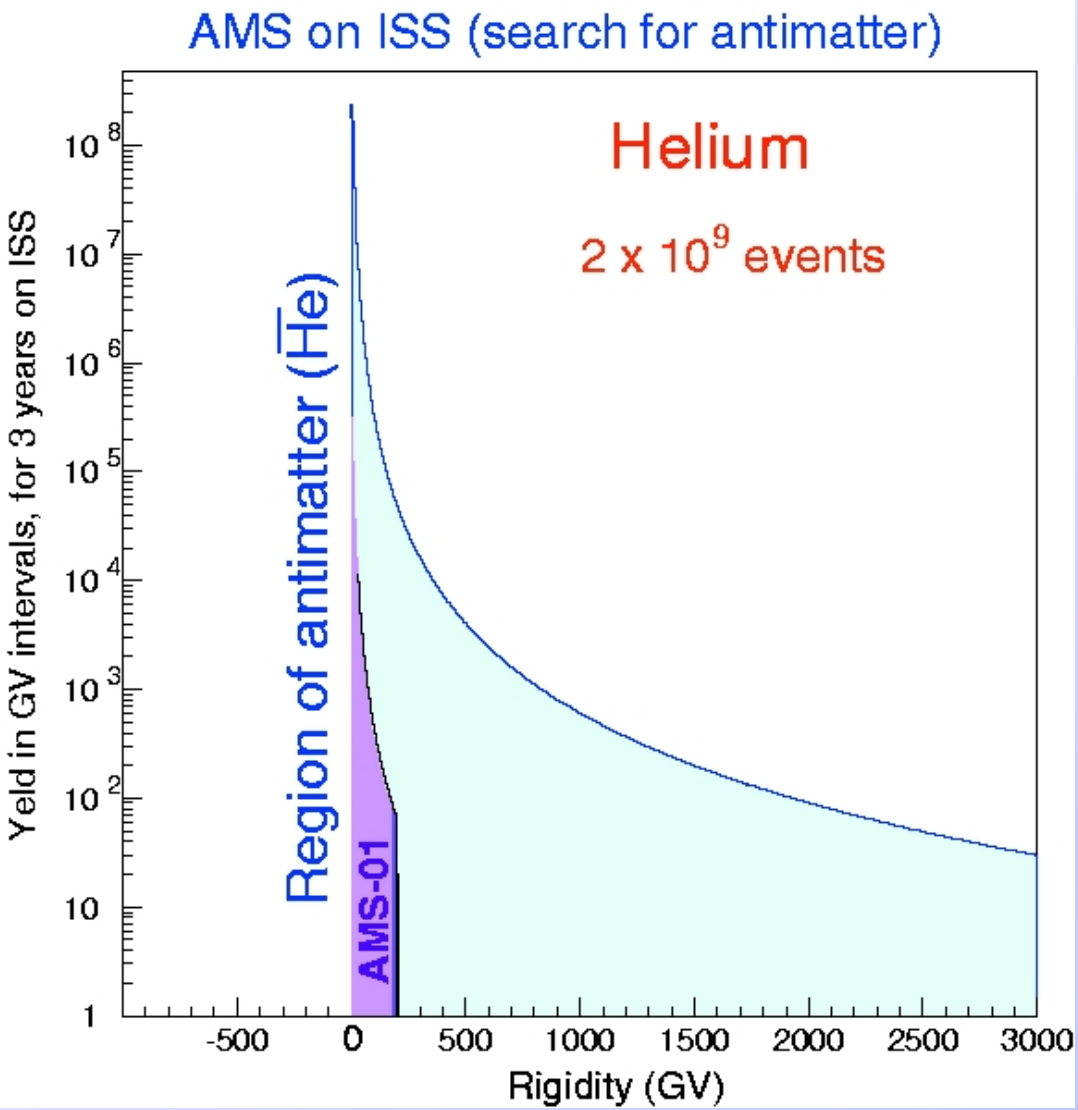
The AMS experiment will perform accurate, high statistics (10^9–10^{10}), long duration (>10 years) measurements of energetic (0.1 GeV to 2 TeV) cosmic ray spectra in space.

Antimatter (Anti He)

AMS-01

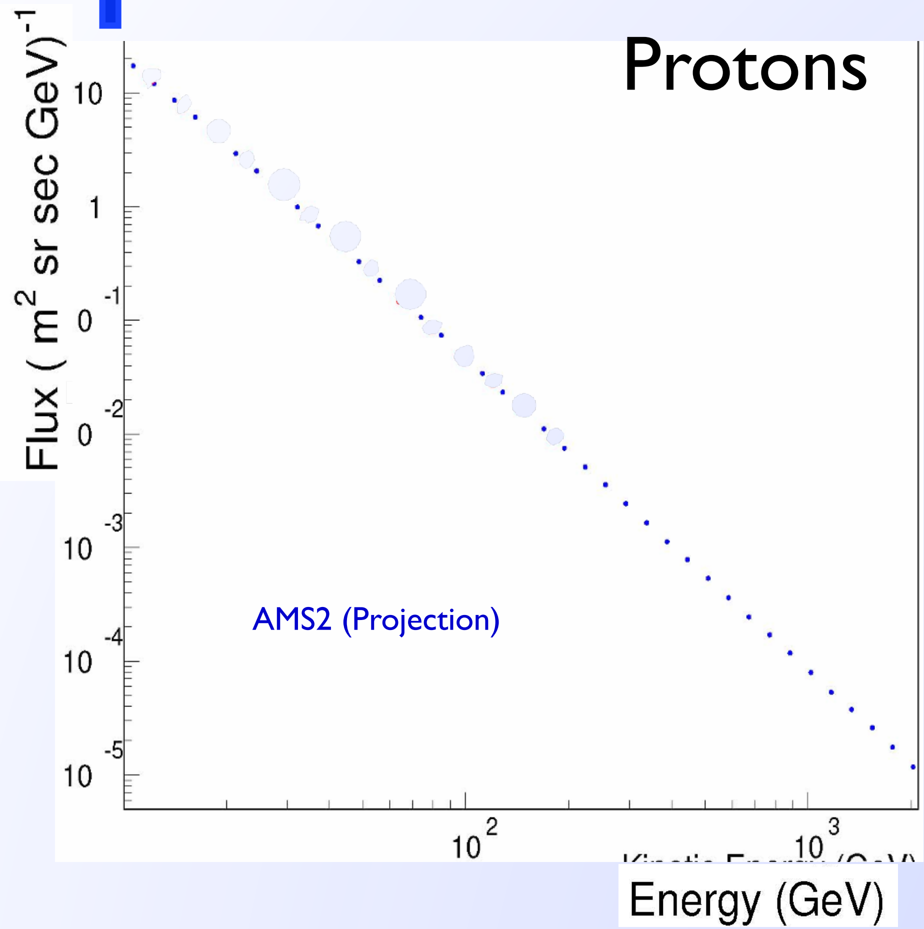




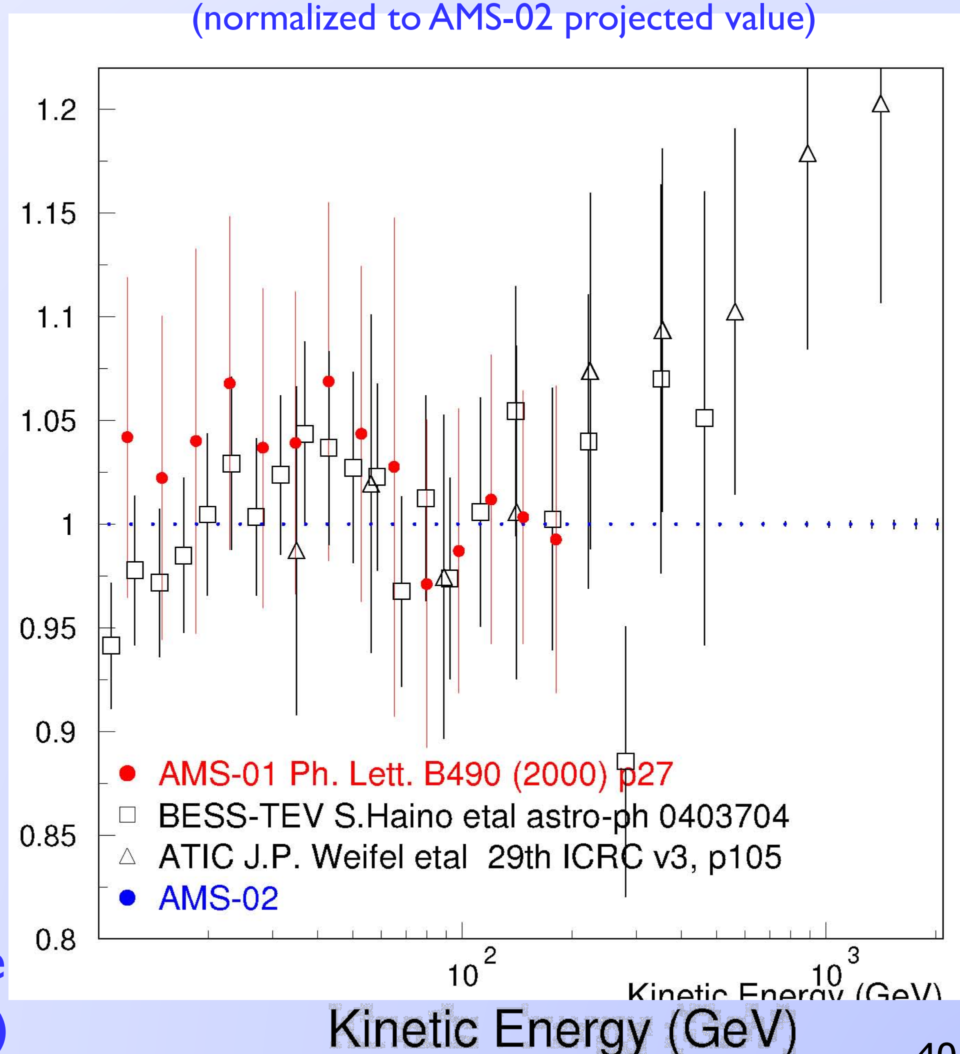


Protons

γ



Relative Proton Fluxes
(normalized to AMS-02 projected value)

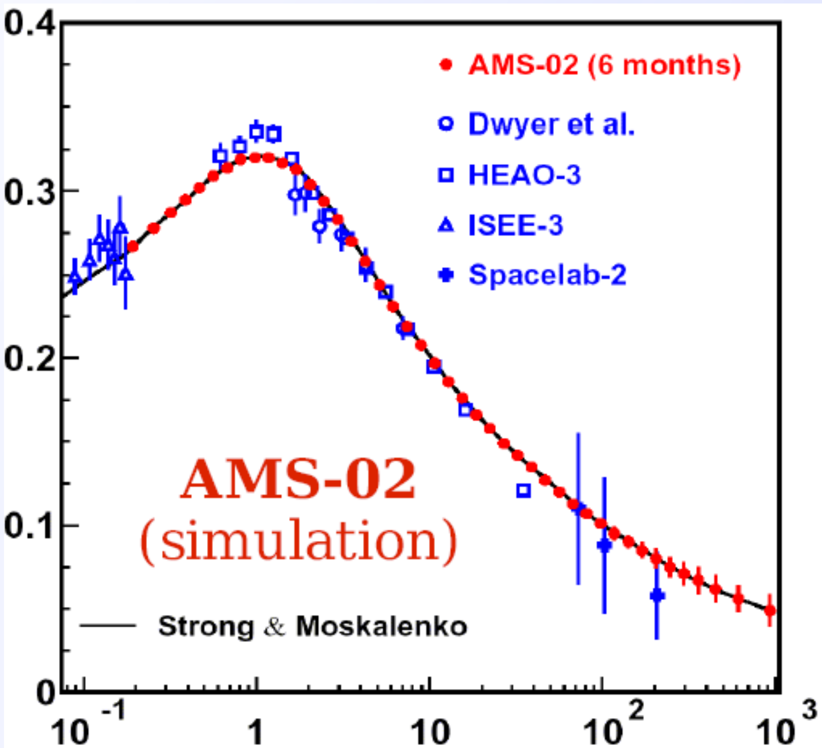


Caveat: Pamela not yet included in the comparison (cf last Publication, Pr, HE)

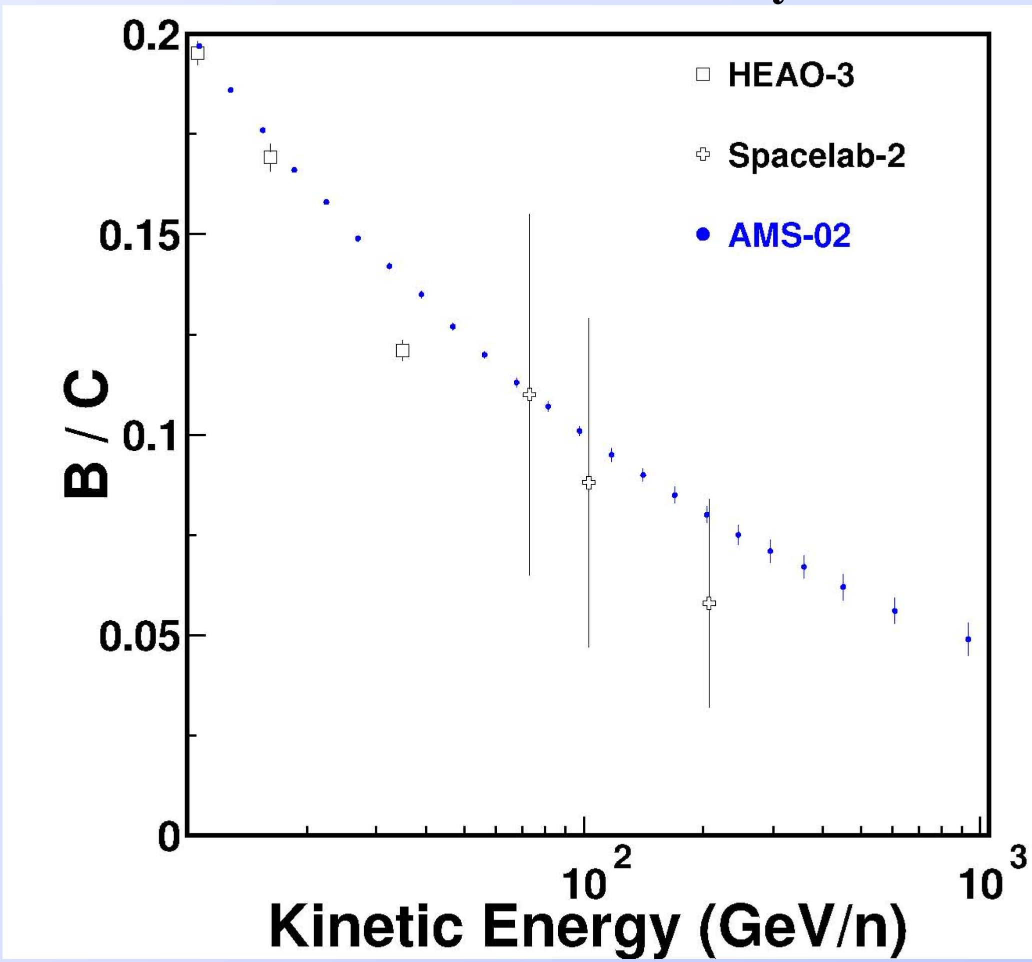
Diffusion – B/C

δ index

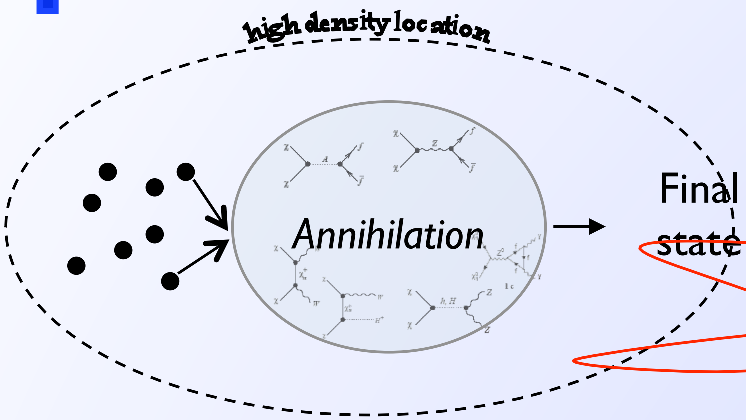
- Propagation parameters (diffusion coefficient)

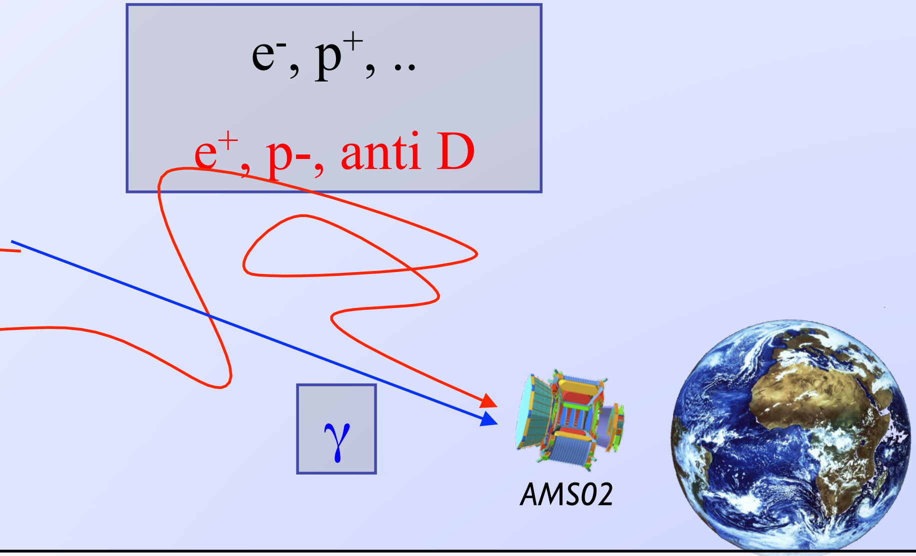


10^4 B > 100 GeV/n in 3 years



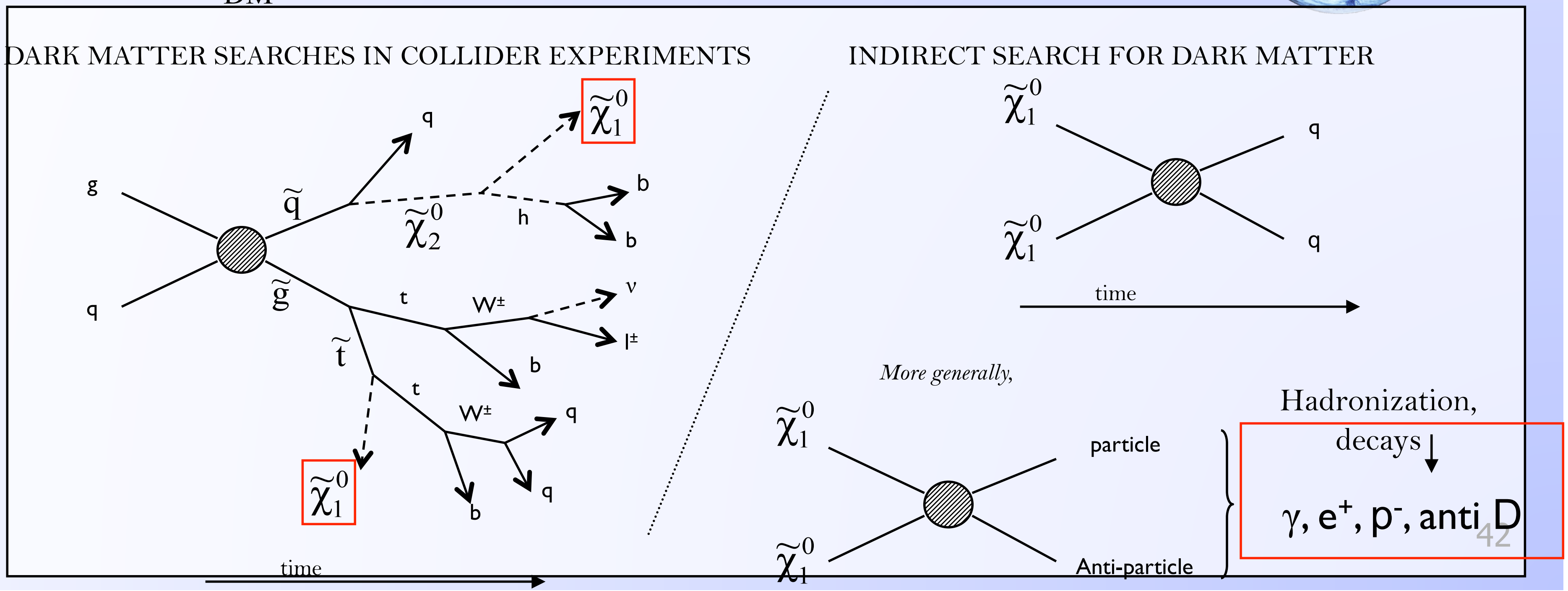
Indirect search for dark matter



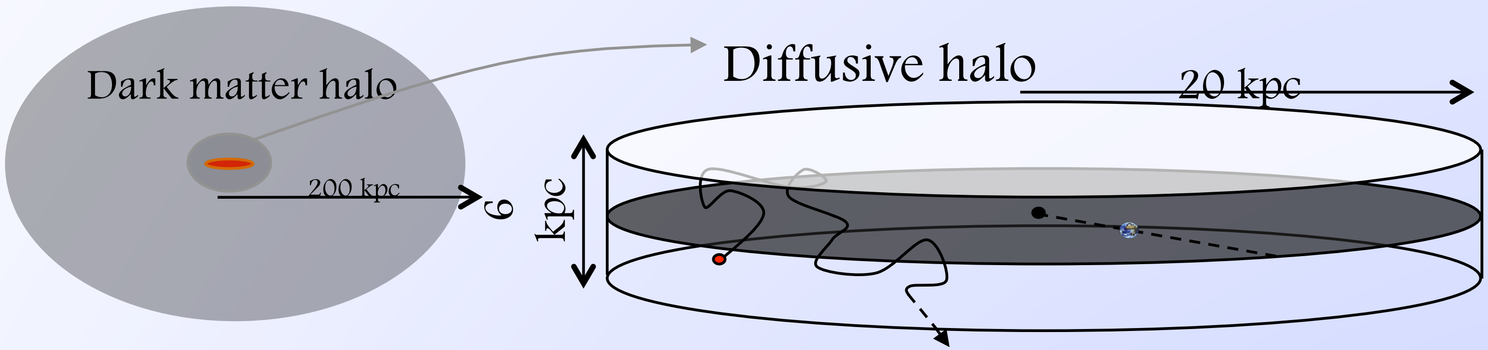


$$\langle \sigma_{ann} v \rangle = 3 \cdot 10^{-26}\ \mathrm{cm^3/sec}$$

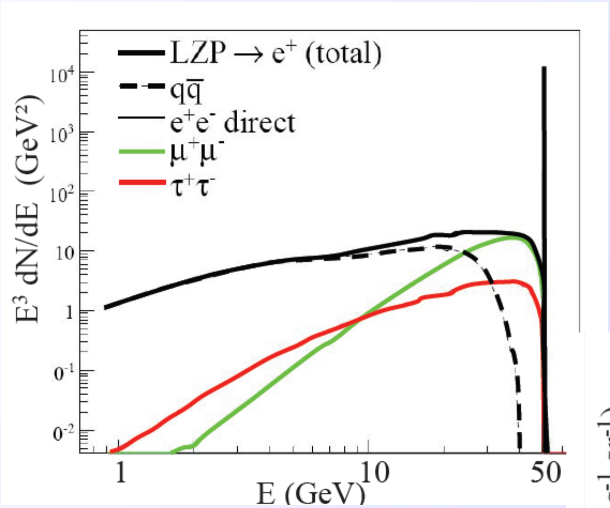
$$\Omega_{DM} \simeq 0.23$$



positron signal : production and propagation

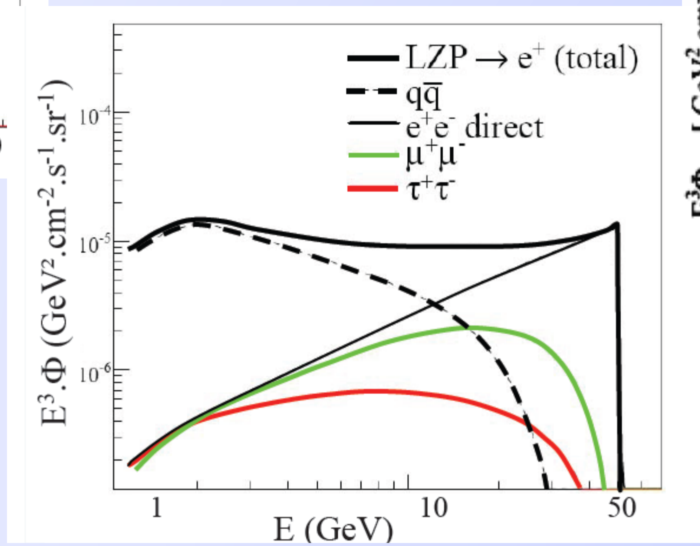


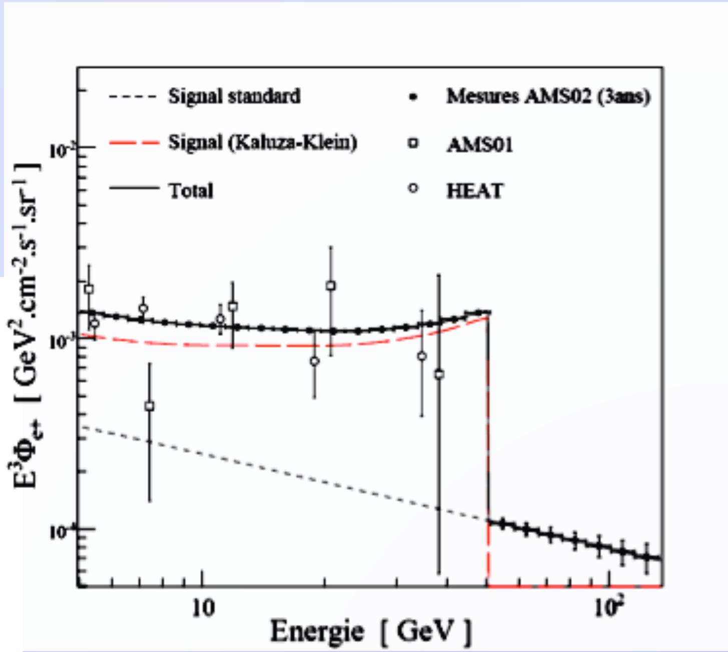
AMS – 3 years



source

After propagation



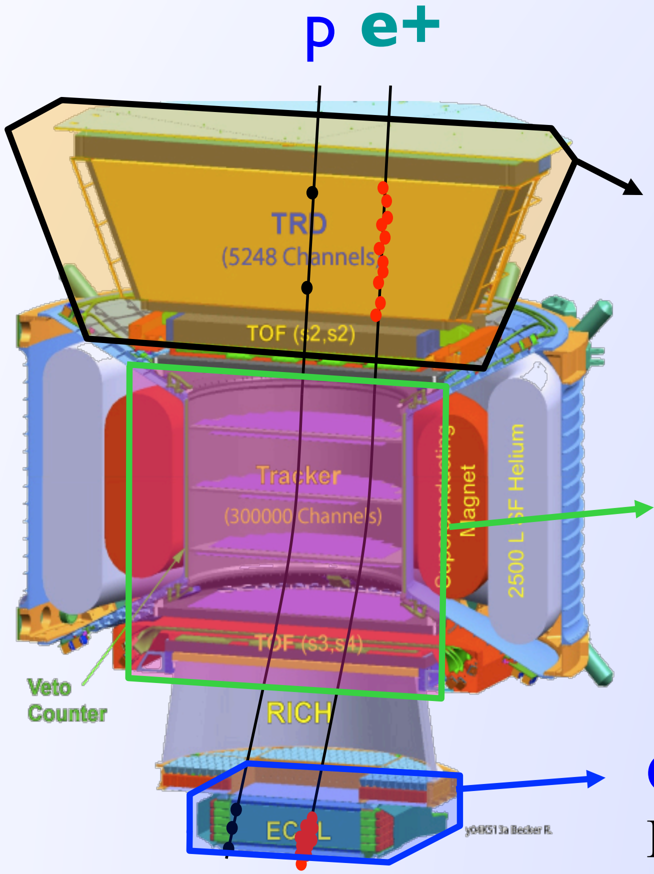


Positron

e^+

▷ **Background**

- protons : $\Phi_p \sim 10^{3\text{-}4} * \Phi_{e+}$
- electrons : $\Phi_{e-} \sim 10 * \Phi_{e+}$

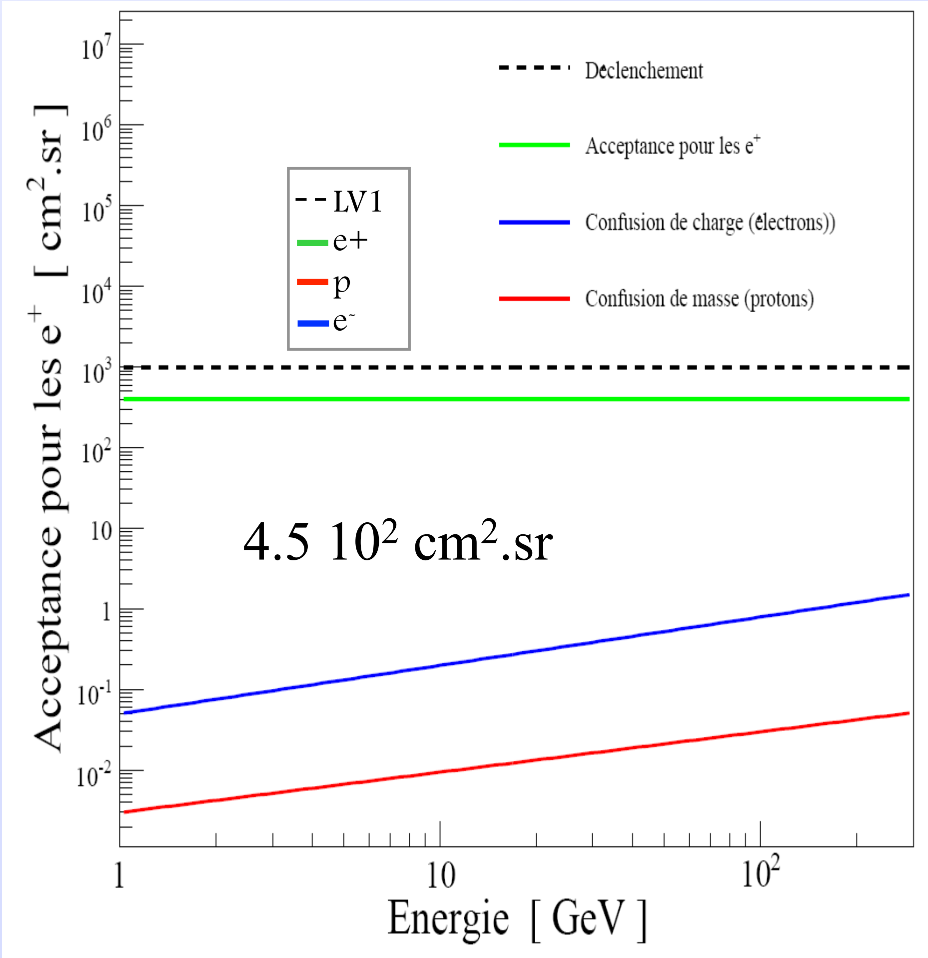


TRD : Deposited energy

Tracker / calorimeter: E/p ratio

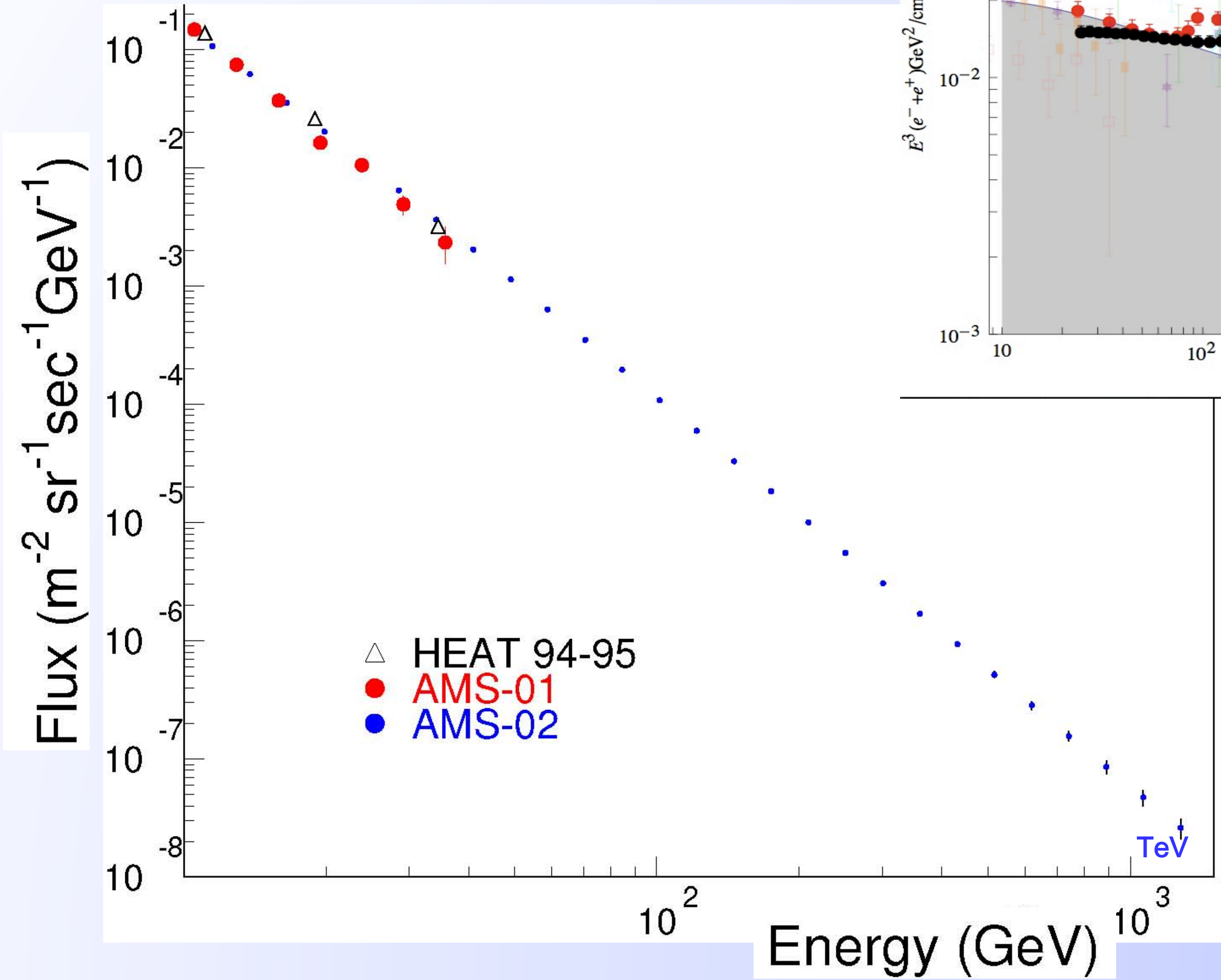
Calorimeter : Electromagnetic shower properties

$A_{e+} / A_p \sim 10^5$

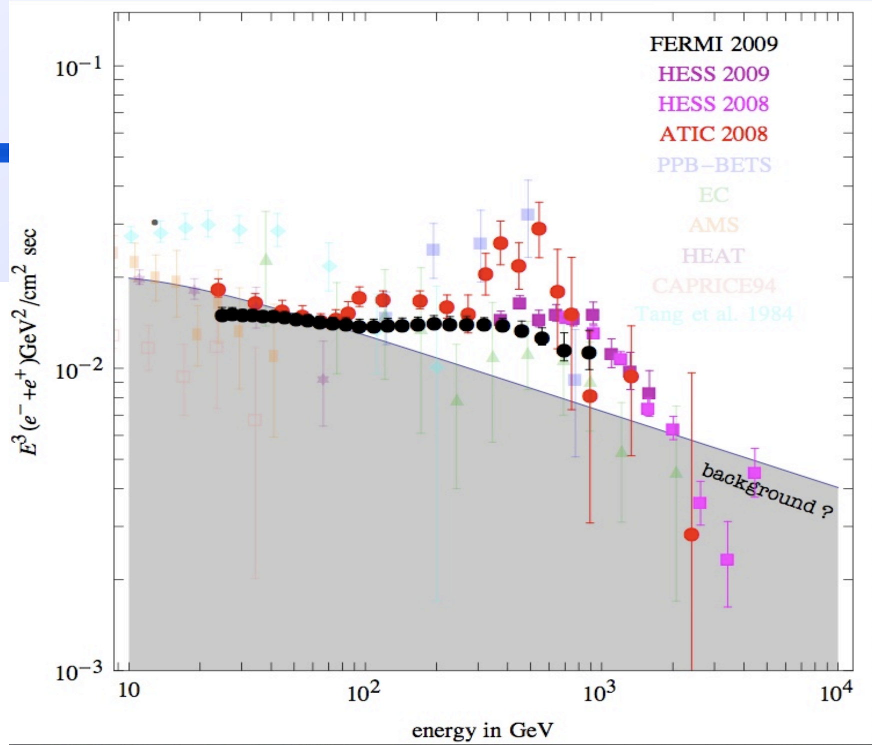


e^+ : 1 GeV ~ 300 GeV

Electrons

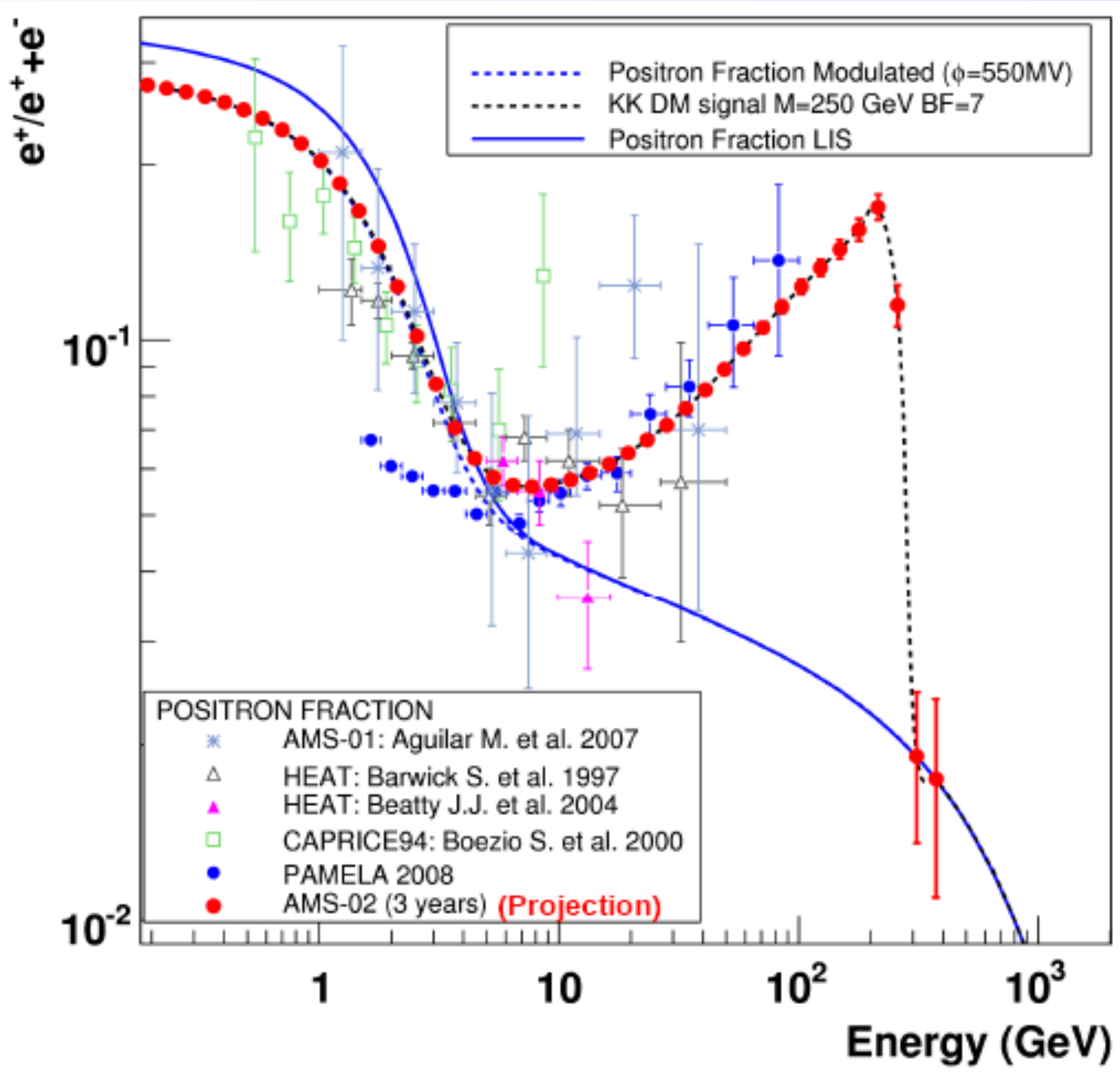


Flux (m^{-2} sr^{-1}sec^{-1}GeV^{-1})
Energy (GeV)
HEAT 94-95
AMS-01
AMS-02
TeV



FERMI 2009
HESS 2009
HESS 2008
ATIC 2008
PPB–BETS
EC
AMS
HEAT
CAPRICE94
Tang et al. 1984
background ?
$E^3(e^-+e^+)$GeV^2/cm^2 sec
energy in GeV

Positrons



e^+
e⁺/e⁺+e⁻
Positron Fraction Modulated (φ=550MV)
KK DM signal M=250 GeV BF=7
Positron Fraction LIS
10^{-1}
10^{-2}
POSITRON FRACTION
AMS-01: Aguilar M. et al. 2007
HEAT: Barwick S. et al. 1997
HEAT: Beatty J.J. et al. 2004
CAPRICE94: Boezio S. et al. 2000
PAMELA 2008
AMS-02 (3 years) (Projection)
1
10
10^2
10^3
Energy (GeV)

April 2011

- ▶ Detector complete and tested (ESA,CERN,KSC)
- ▶ Waiting for launch (19->29 April) and data (Launch+4)

Constraints from space

- ▷ Weight : 7 tons (exp. LHC ~ 1000 tonnes)
- ▷ Low consumption : 2 kW (conso fer électrique)
- ▷ Temperature: ± 50 ºC
- ▷ No human assistance redundancy
- ▷ Vacuum
- ▷ Launch
- ▷ Tests (radiation, thermal, EMI and vibration)

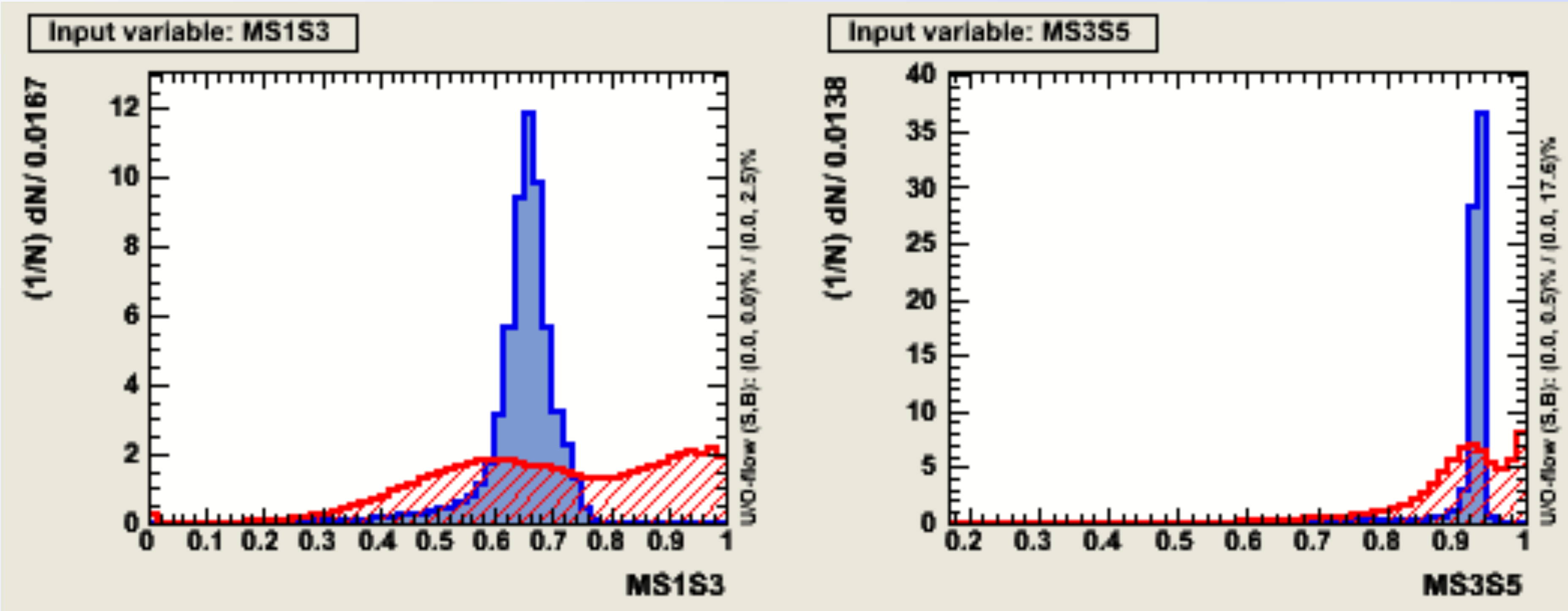
➔ AMS01, 1998 + Qualification Model and flight Model for each sub detectors

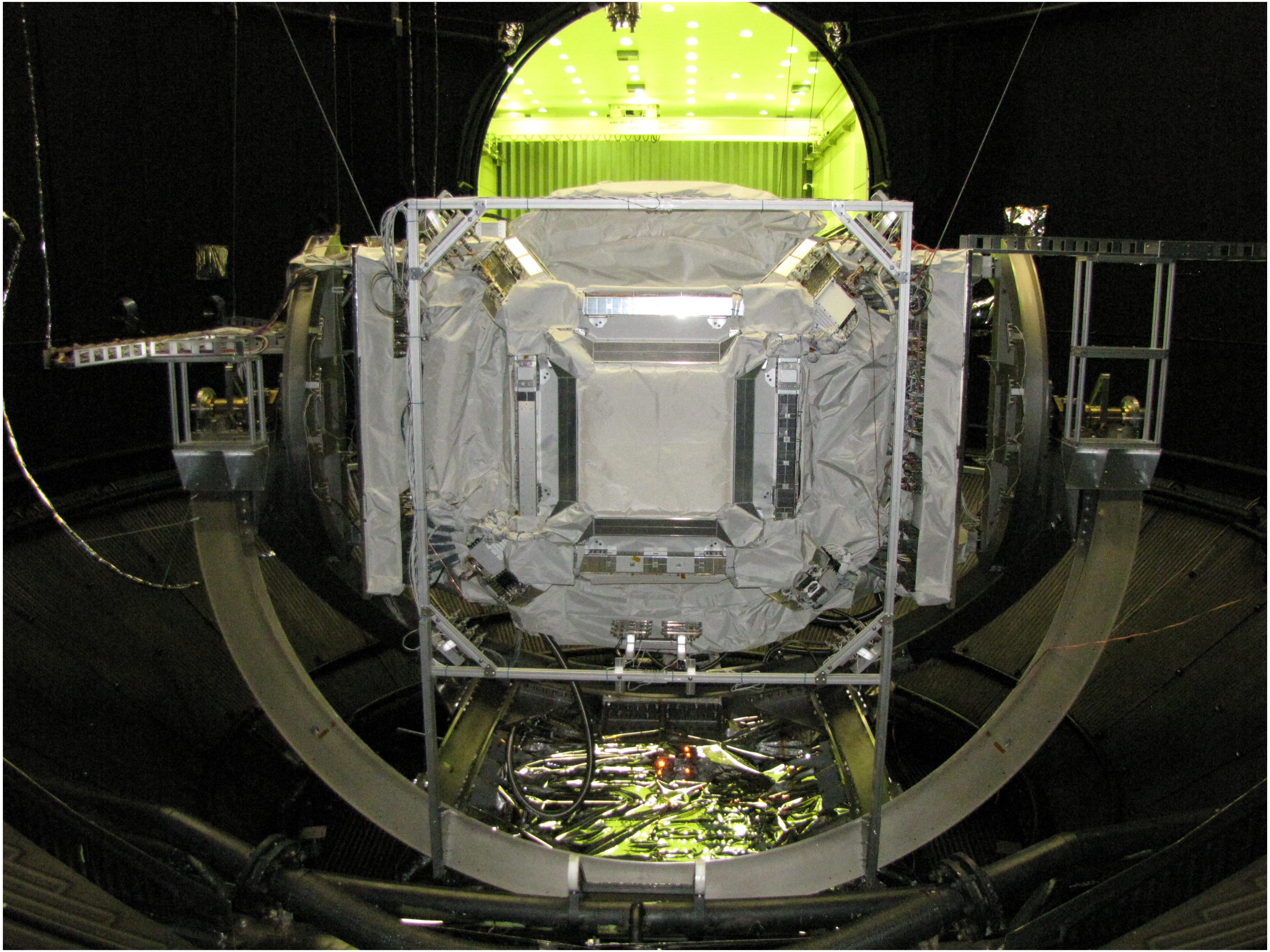
Ecal variables for e/P rejection –TB 2010

Variables based on the lateral and longitudinale properties of the EM showers

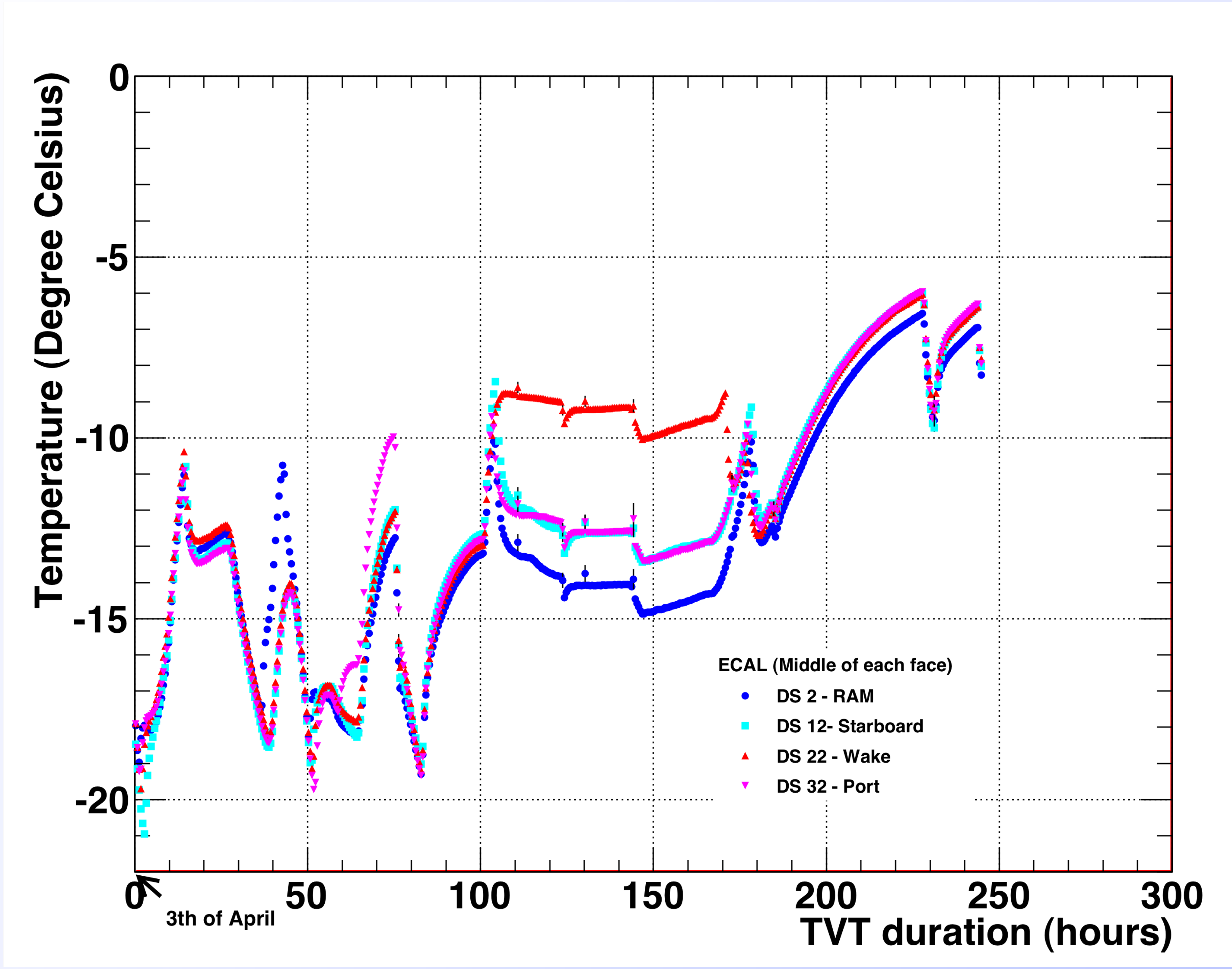
e 180 GeV

P 400 GeV





Associating the Dallas sensors



Linear dependence (HG)