Cosmic Ray Velocity and Electric Charge Measurements in the AMS experiment

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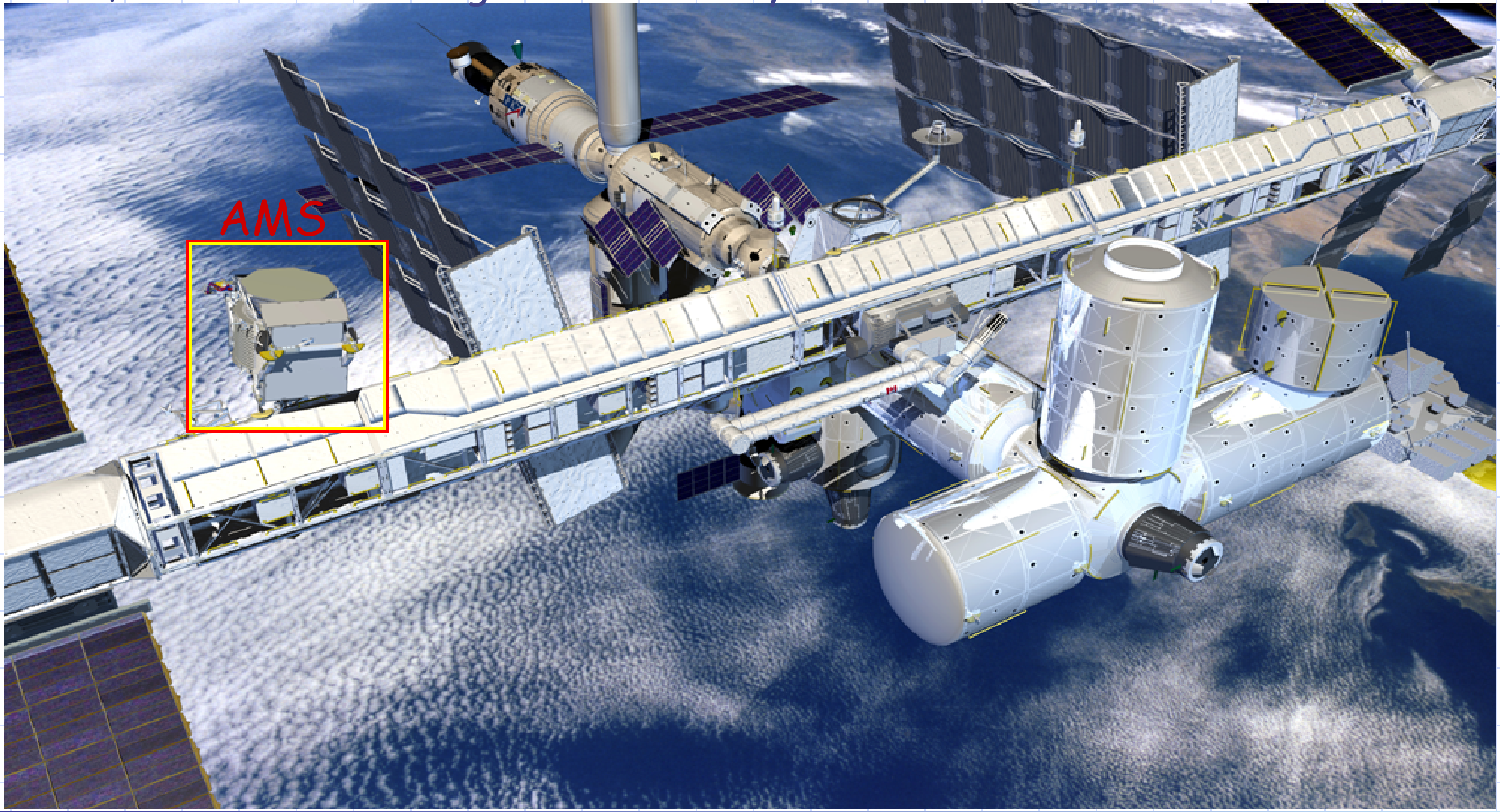
Outline

- The AMS experiment
  - Physics goals
  - Spectrometer
- The TOF detector
- The Silicon Tracker
- The RICH detector
- Velocity and Charge measurements
- Conclusions

AMS on the International Space Station

The Alpha Magnetic Spectrometer is a precision magnetic spectrometer scheduled to be installed in the International Space Station (ISS) by 2008, with a data taking of at least 3 years.



AMS on the International Space Station

AMS is a large international collaboration (~ 500 members). Its physics goals are:

- **Search for cosmic antimatter**, through the detection of antinuclei with $|Z| \geq 2$; for helium nuclei the upper limit of detection will be $\overline{He}/He < 10^{-9}$;

- **Search for dark matter** via annihilation signatures. Neutralino annihilations may contribute with anomalies on different spectra:
  - ✓ positron
  - ✓ antiproton
  - ✓ antideuteron
  - ✓ photons

- **Precision measurements** on the relative abundance of different nuclei and isotopes of primary cosmic rays E<1 TeV

Total statistics expected above 10^{10} events

AMS Spectrometer Capabilities

- Particle bending

  Superconducting magnet

- Rigidity (p/Z)

  Silicon Tracker

- Particle direction

  Time-of-Flight, Tracker, RICH

- **Velocity** (β)

  RICH, Time-of-Flight, Transition Radiation Detector

- **Charge** (Q)

  RICH, Tracker, Time-of-Flight

- Trigger

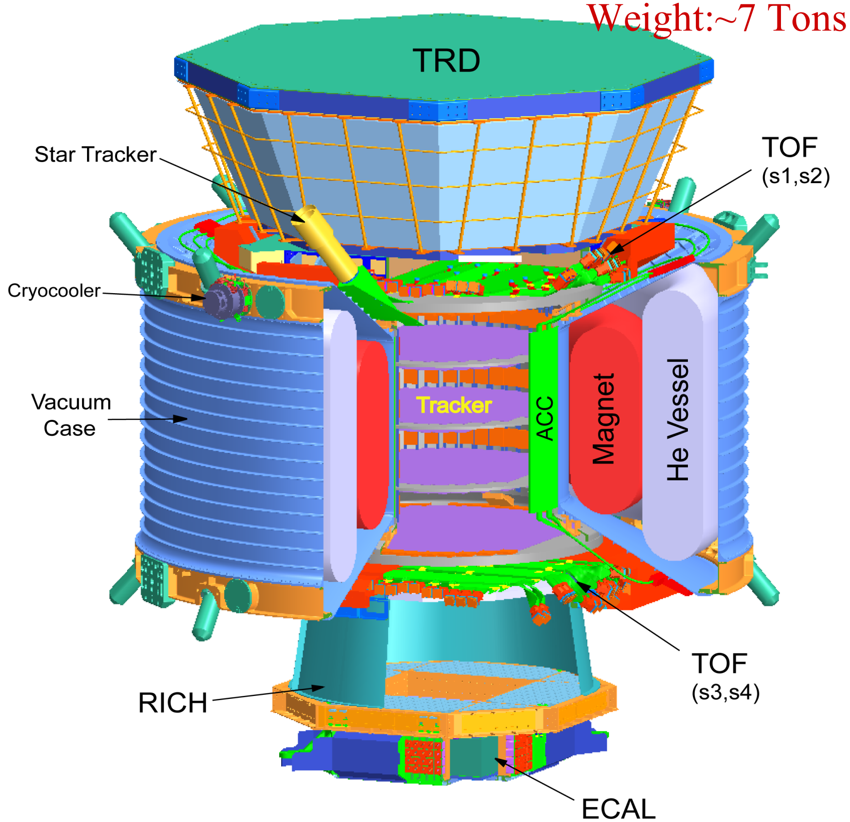
  Time-of-flight, ECAL, AntiCounter

AMS 02

(Alpha Magnetic Spectrometer)

Size: $3x3x3 \ m^3$

Weight: ~7 Tons



AMS on ISS for 3 years

R.Becker 09/05/03

AMS Alpha Magnetic Spectrometer Integration MIT

RB0305AMSdetector

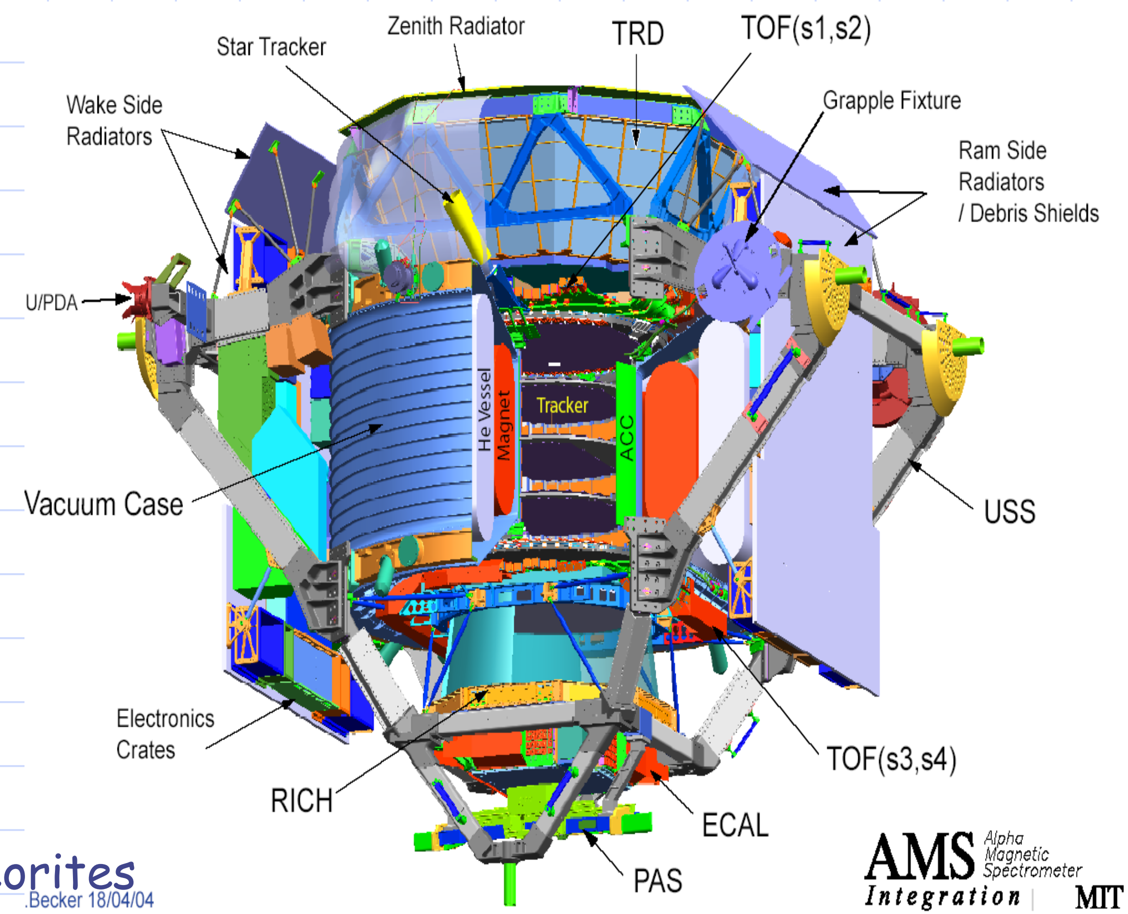
AMS Construction and Constraints:

Characteristics:

- Size:3X3X3 m^3
- Weight: ~7 Tons

Constraints:

- ✓ Vibration
- ✓ Thermal environment
  day/night ~[-30,+50] ºC
- ✓ Limited power: 3 kW
- ✓ Vacuum: < 10^{-10} Torr
- ✓ Radiation: Ionizing Flux
- ✓ Orbital Debris and Micrometeorites
- ✓ Must operate for 3+years
- ✓ No human intervention



Detector Requirements:

Antimatter

Detection of antinuclei would be a clear signal of the existence of antimatter

- charge identification
- rigidity measurement
- albedo rejection
- strong system redundancy

Dark Matter

Signals: $\bar{p}$, e^{+}, γ, $\bar{d}$

- charge measurement
- velocity measurement
- rigidity measurement
- γ detection

Astrophysics

Detection of a large range of nuclei (Z)

Ability to identify different isotopes

- charge measurement
- velocity measurement
- rigidity measurement

Charge and velocity are redundantly measured with AMS

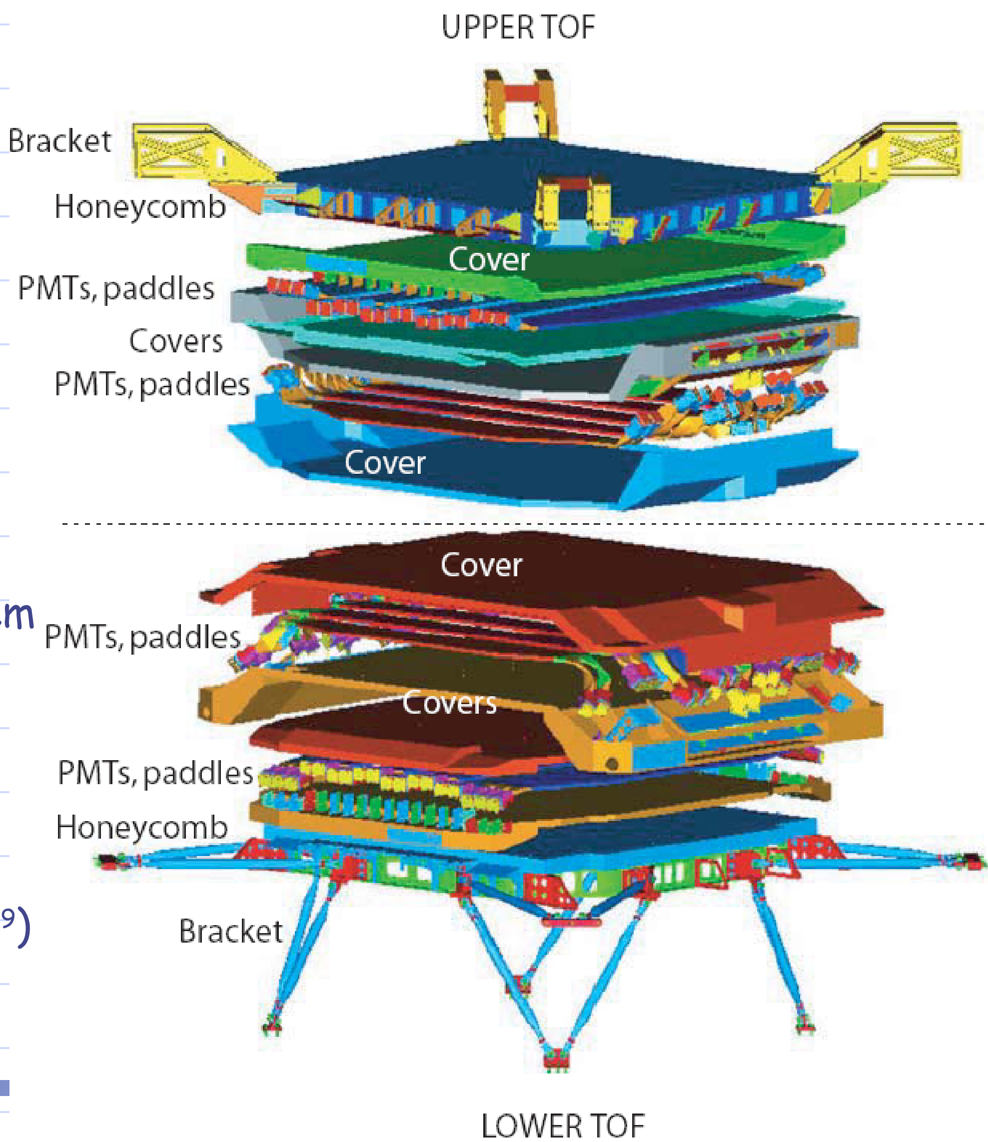
Time-of-Flight (TOF)

Construction

- 4 planes of plastic scintillators
- a total of 34 paddles with 12 cm
- 2/3 PMTs for light readout at both ends
- light guides twisted/bent to minimize magnetic field effects

It provides

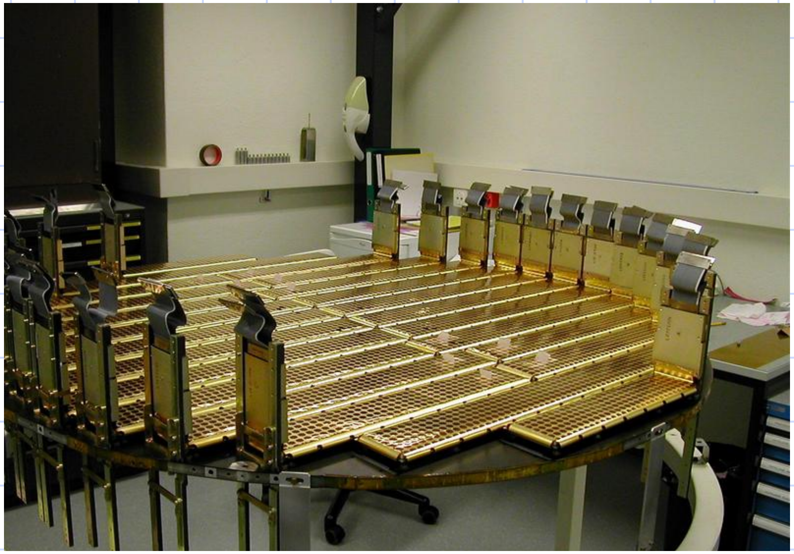
- fast trigger to the data acquisition system
- time resolution of 120 ps for protons
- velocity measurement
- absolute charge measurement up to Z~20
- upward/downward particle separation (10^{-9})



Microstrip Silicon Tracker

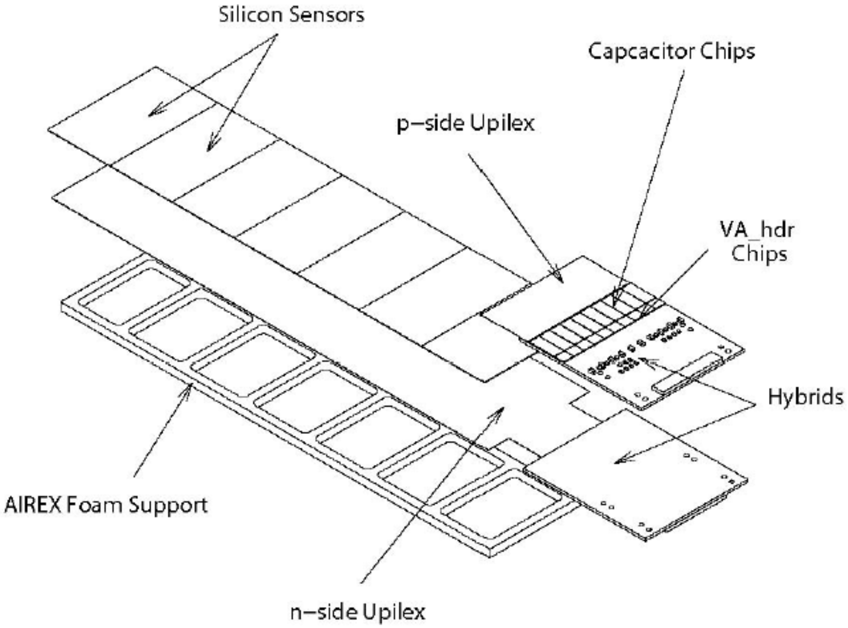
Construction

- a total of 5 planes (3 inside the magnet and 2 outside)
- 8 layers of double-sided silicon microstrip sensors (tot~7m^2)
- a total of ~2500 sensors arranged on 192 ladders
- accuracy of sensor relative position better than 5 μm

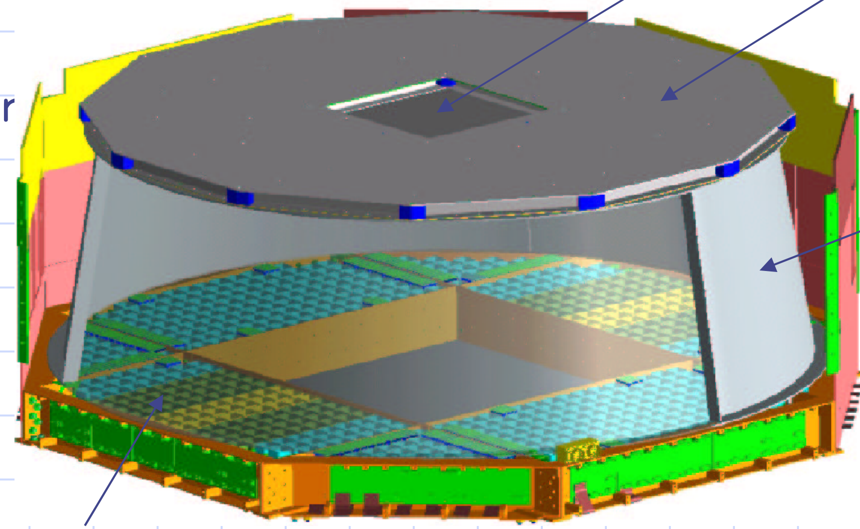


It provides

- 8 independent position measurements of the particle. Spatial resolution:
  10 μm on the bending plane
  30 μm on the non-bending plane
- particle rigidity (R=pc/Z) up to 1-2 TV
- electric charge (Z) from energy deposition (dE/dx) up to Z~26



Ring Imaging Cerenkov Detector (RICH)



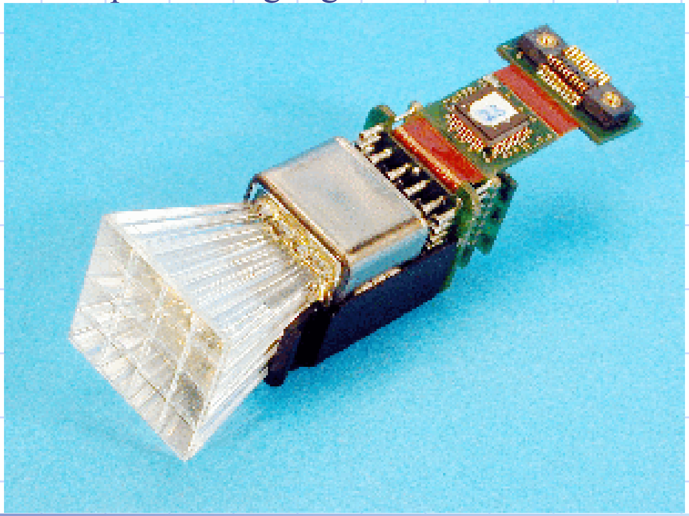
Construction

- proximity focusing Ring Imaging Detector
- double solid radiator configuration:

Silica Aerogel n=1.05 (3cm)

Sodium Fluoride (NaF) n=1.334 (0.5cm)

- conical reflector
- photomultiplier matrix of 680 PMTs
- spatial pixel granularity: 8.5x8.5mm^2



It provides

- velocity measurement $\frac{\Delta\beta}{\beta} \sim 0.1\%$ (Z=1)
- charge measurement Z~26 ΔZ~0.2
- redundancy on albedo rejection
- e/p separation

Velocity measurement

TOF

Crossing time between scintillator planes is measured $\beta = \frac{\Delta L}{\Delta t}$

RICH

Cerenkov angle (θ_c) measured $\cos\theta_c = \frac{1}{\beta n}.$

Two reconstruction methods were developed:

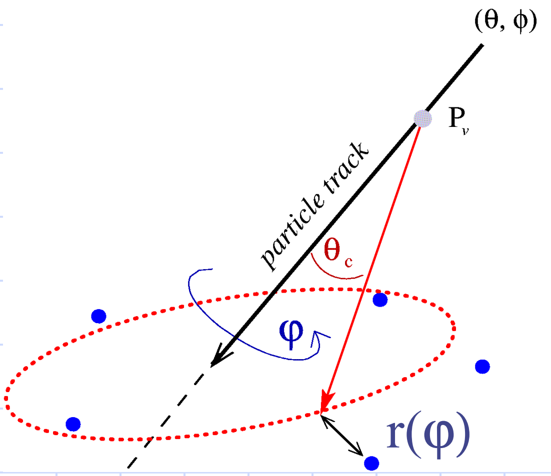
✓ a geometrical method based on a hit by hit reconstruction

✓ a method using all the hits with the maximization of a likelihood function providing the best θ_c angle

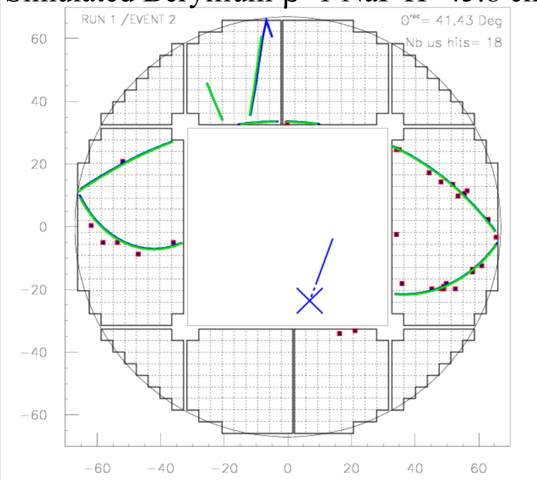
$$L(\theta_c) = \prod_{i=1}^{N_{hits}} P_i^{npe_i}\{r_i(\varphi_i(\theta_c))\}$$

$r_i \equiv$ closest distance to the Cerenkov pattern

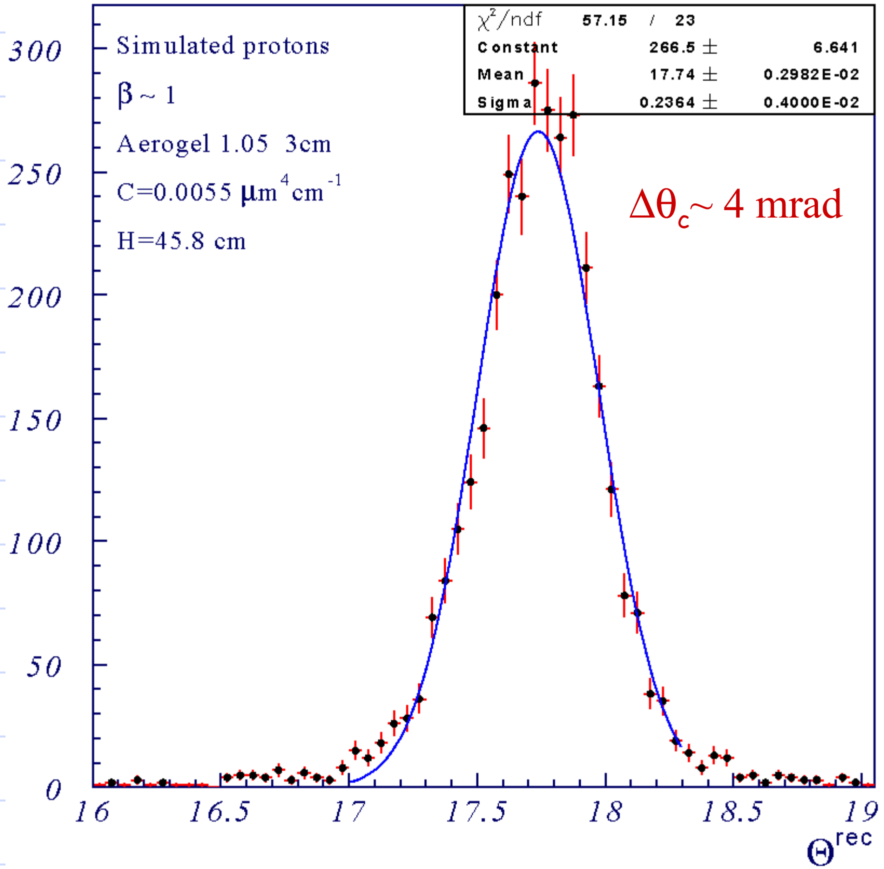
$P_i \equiv$ probability of a hit belong to the pattern



Simulated Beryllium β~1 NaF H=45.8 cm



θ_c reconstruction with the RICH flight setup, MC simulation



Flight setup, events within all the RICH acceptance

The uncertainty in θ_c deals with:

- pixel size (granularity) ~ 8.5 mm
- radiator thickness (3cm)
- chromaticity

radiator	$Z=1, \beta\sim1$
Agl105	$\Delta\theta_c \sim 4$ mrad
NaF	$\Delta\theta_c \sim 8$ mrad

Charge measurement

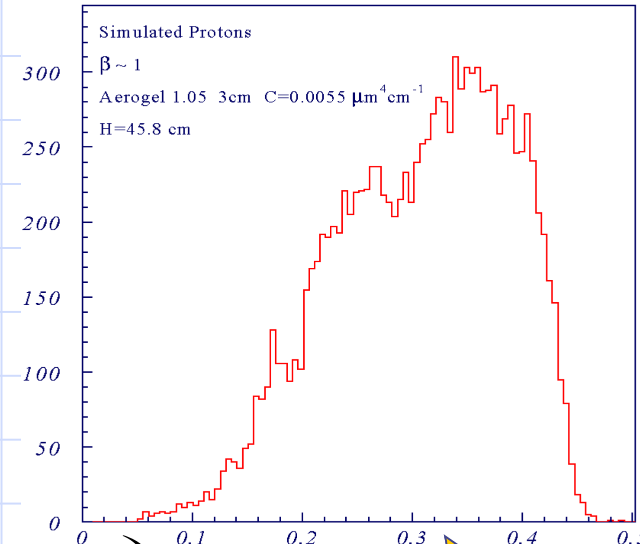
TOF, Tracker: Sampling of particle energy deposition $\Delta E \propto Z^2$

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})



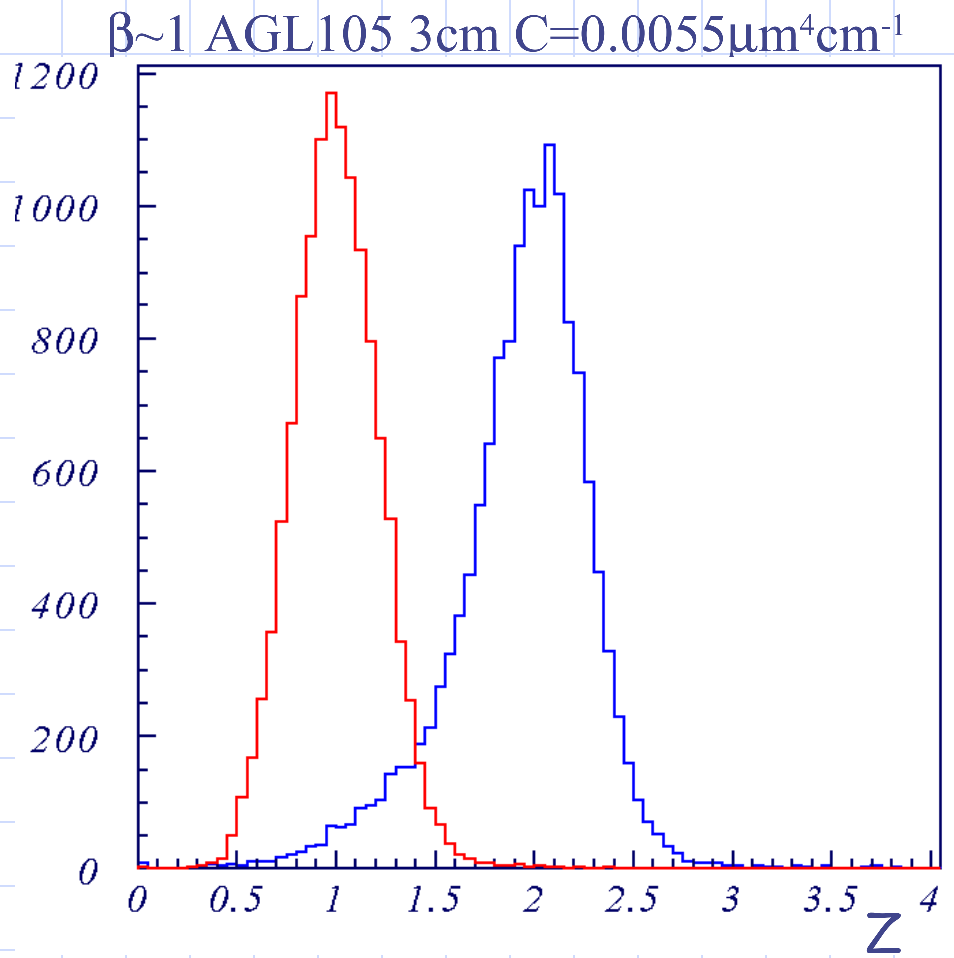
$\varepsilon_{RAD}\varepsilon_{LG}\varepsilon_{GEO}$

$$N_{pe} \propto Z^2 \Delta L \left(1 - \frac{1}{\beta^2 n^2}\right) \varepsilon_{rad}\varepsilon_{geo}\varepsilon_{lg}\varepsilon_{pmt}$$

$$\varepsilon_{tot}(\theta_c, \theta, \phi, P_I)$$

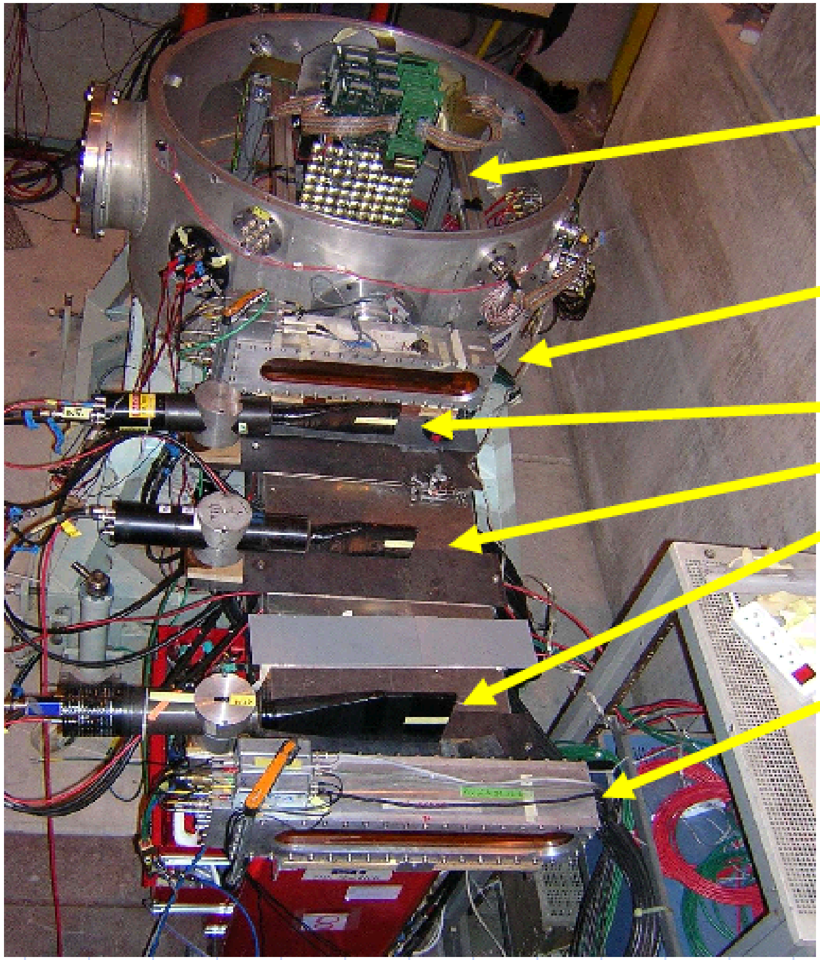
Charge reconstruction with RICH: MC simulation

Simulated protons and heliums within AMS statistics



Test Beam 2003: experimental setup

✓ October 2003 test beam at CERN with fragments of Indium beam 158 GeV/nuc



Prototype &
RO electronics

- MWPC

- dE/dx
  - Scintillators
  - Cerenkov

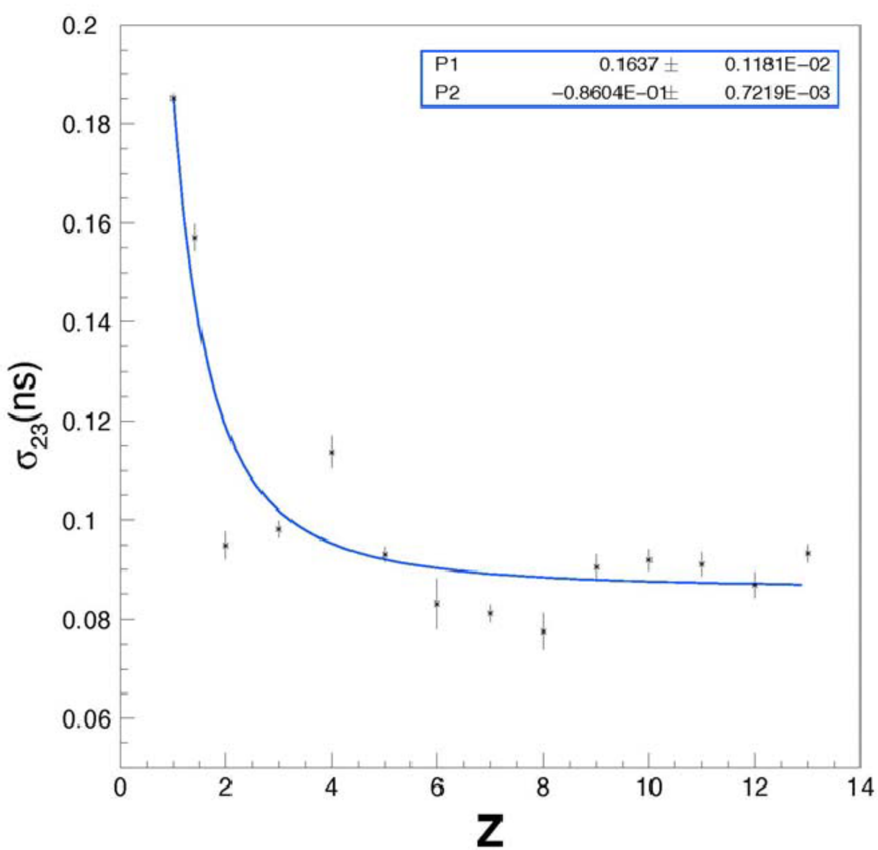
- MWPC

⊕ Tracker Prototype
⊕ TOF Prototype

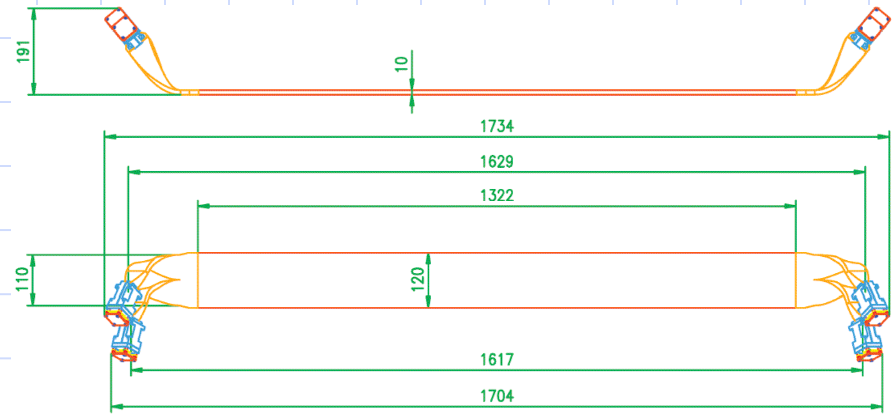
TOF Velocity measurement (β)

$$\beta = \frac{\Delta L}{\Delta t}$$

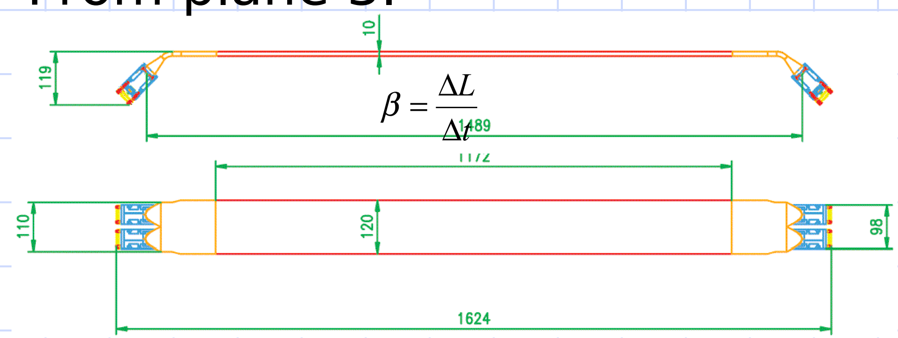
C2->C3 Time of flight resolution



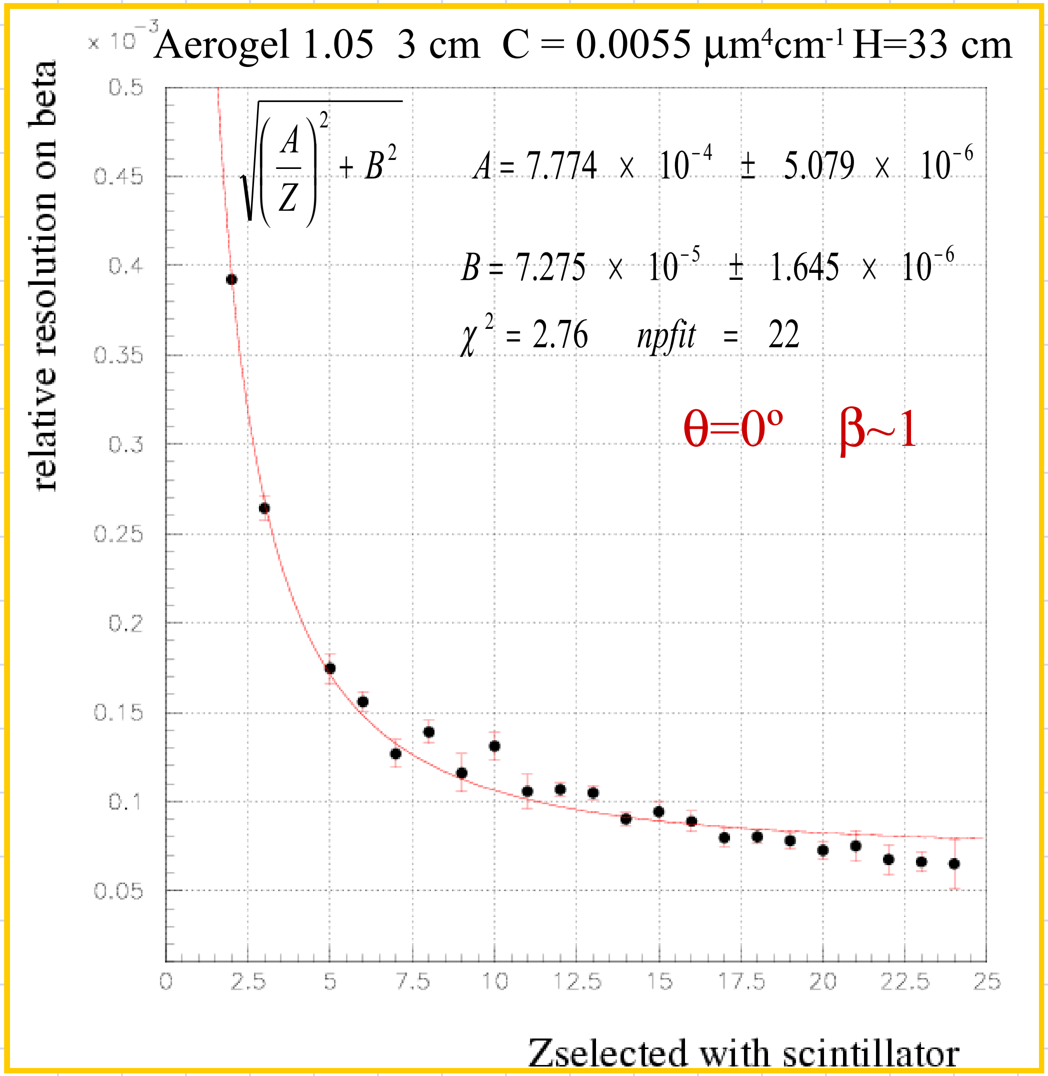
Counter C2: bent and twisted light guides. From plane 2.

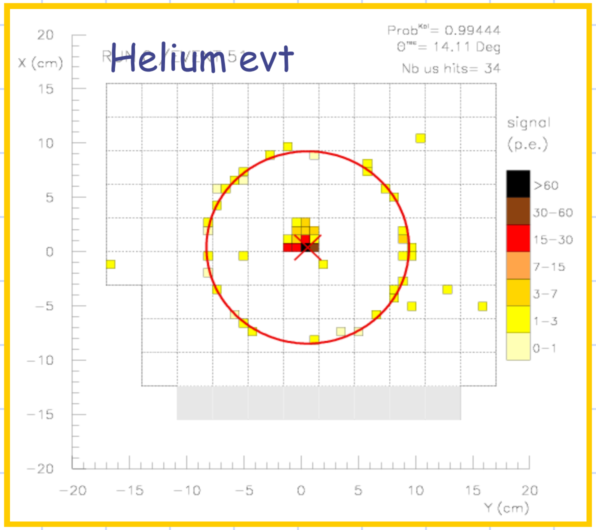


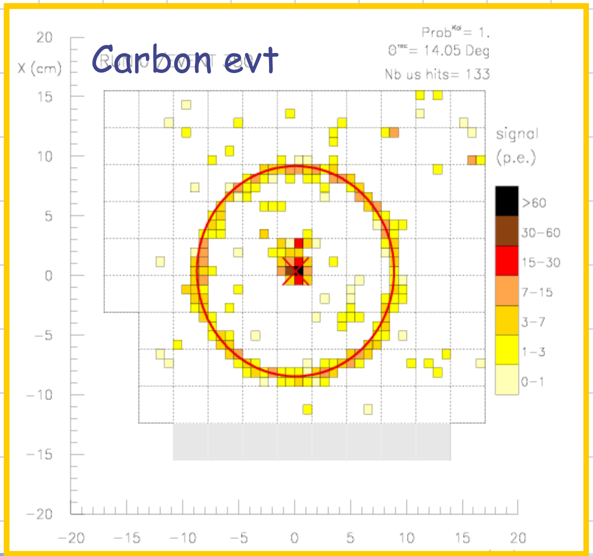
Counter C3: bent light guides. From plane 3.



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

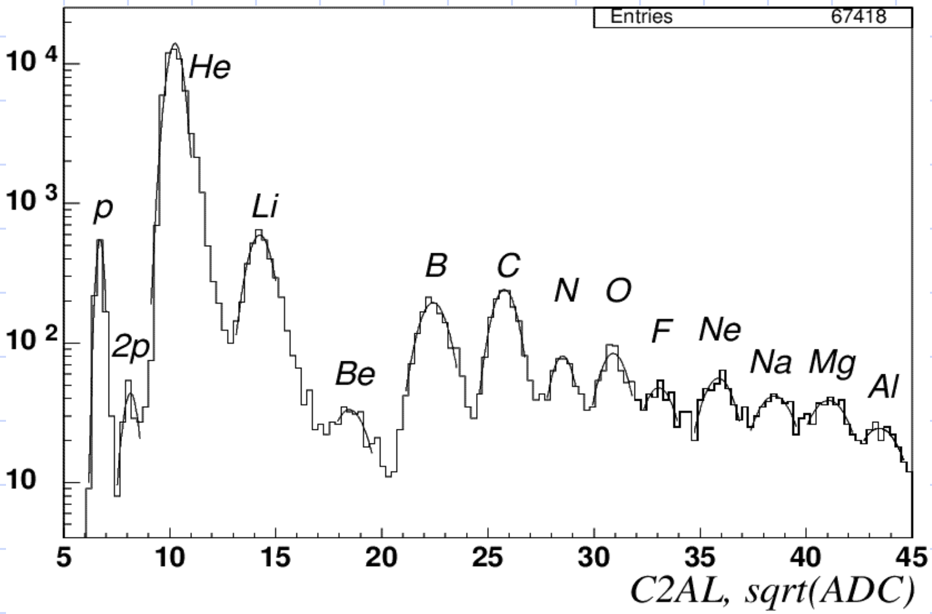




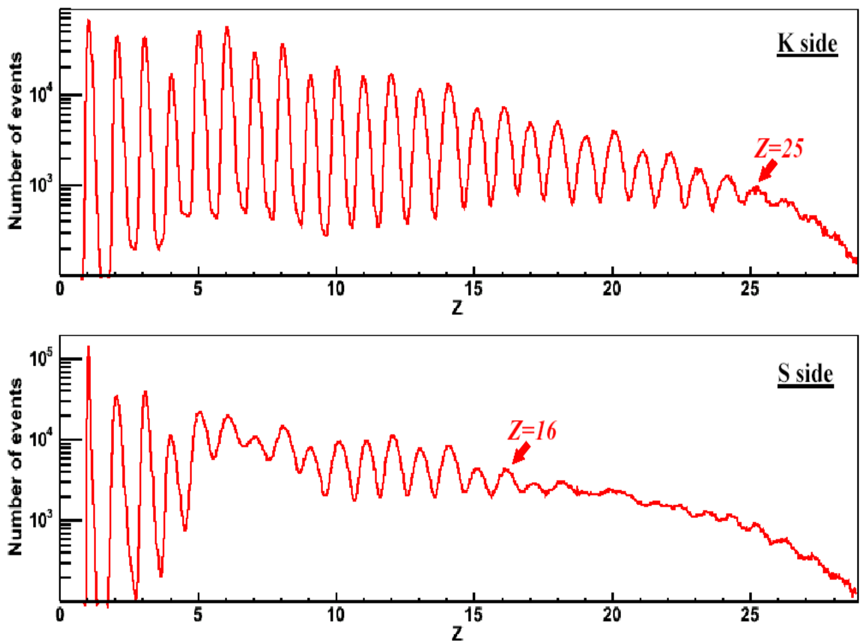


Charge measurement (Z)

TOF



Tracker



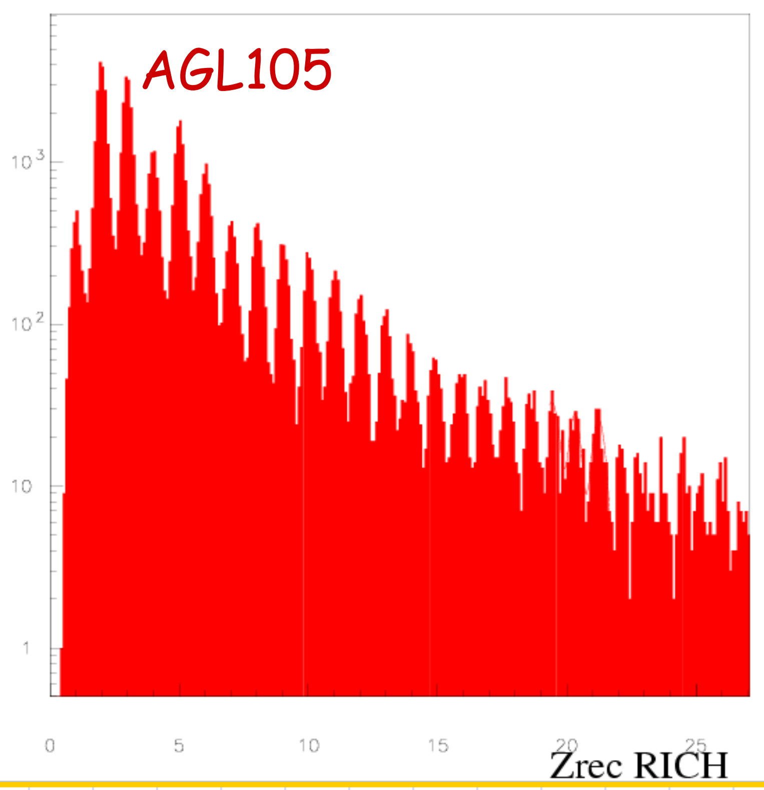
- ✓ 4 ΔE samples
- ✓ Charge separation on a scintillator bar up to Z~12

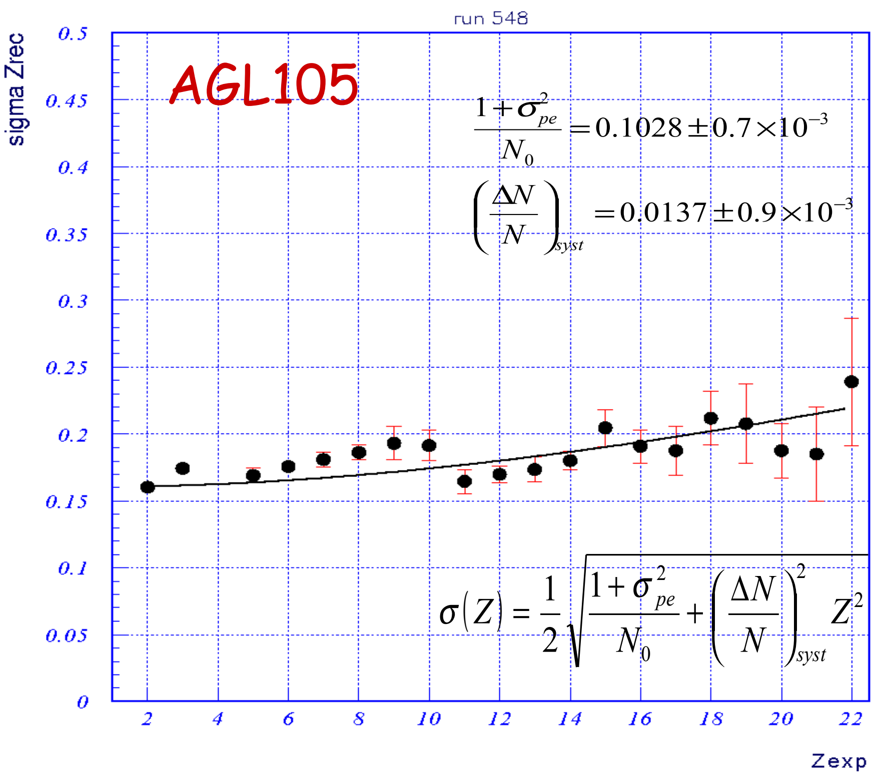
- ✓ 10-12 ΔE samples
- ✓ Charge separation for a 5-6-ladder setup up Z~25 (K side) Z~16 (S side)

Charge measurement with RICH

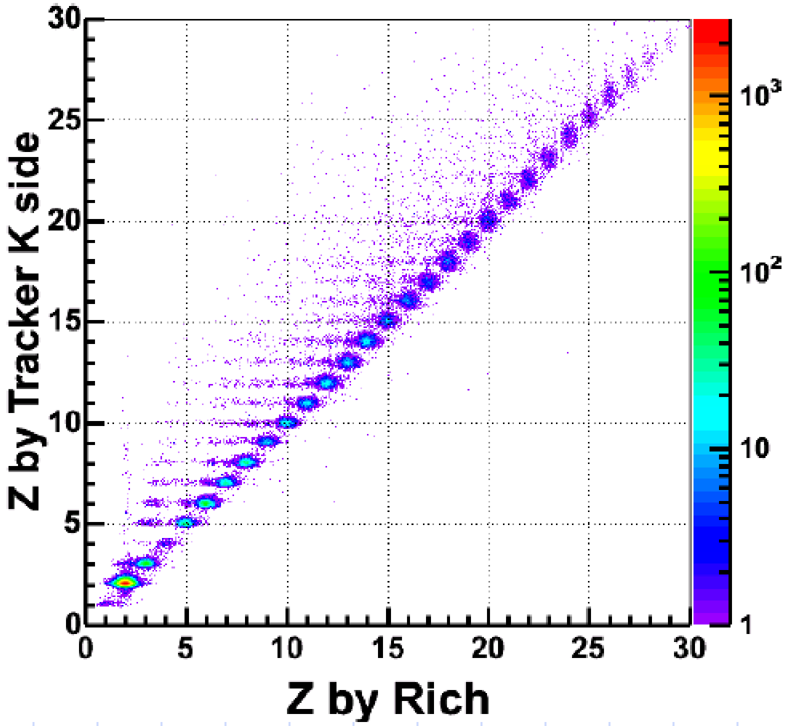
θ=0° β~1

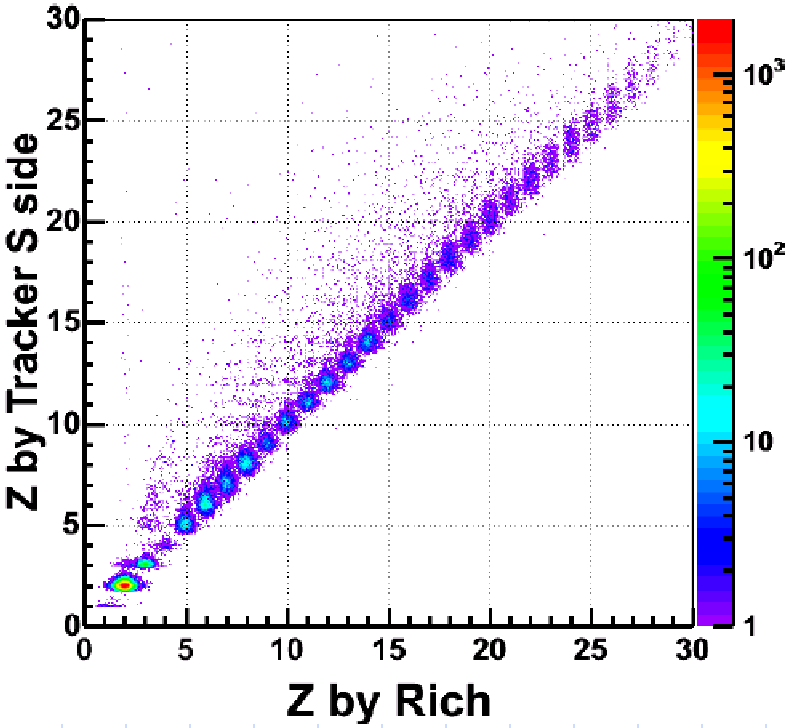
Charge separation up to Z~26





Charge measurement with Tracker.vs.RICH





A good correlation achieved between the charge measured by the Tracker and by the RICH

Conclusions

- The detector will be installed on the International Space Station in 2008 for three years at least
- The fundamental physical issues will be:
  - Antimatter sensitivity of the order 10^{-9}
  - Dark matter searches through different signatures (e^+, $\bar{p}$, γ)
- AMS-02 will allow unprecedented precision and statistics in the measurement of cosmic rays outside the earth's atmosphere
  - charge separation up to Z~26 (Iron)
  - very precise velocity measurement $\frac{\Delta\beta}{\beta} = 0.1\%$
  - isotopic separation up to ~(8-10) GeV/nuc