The RICH detector of the AMS experiment

Velocity and Charge reconstruction

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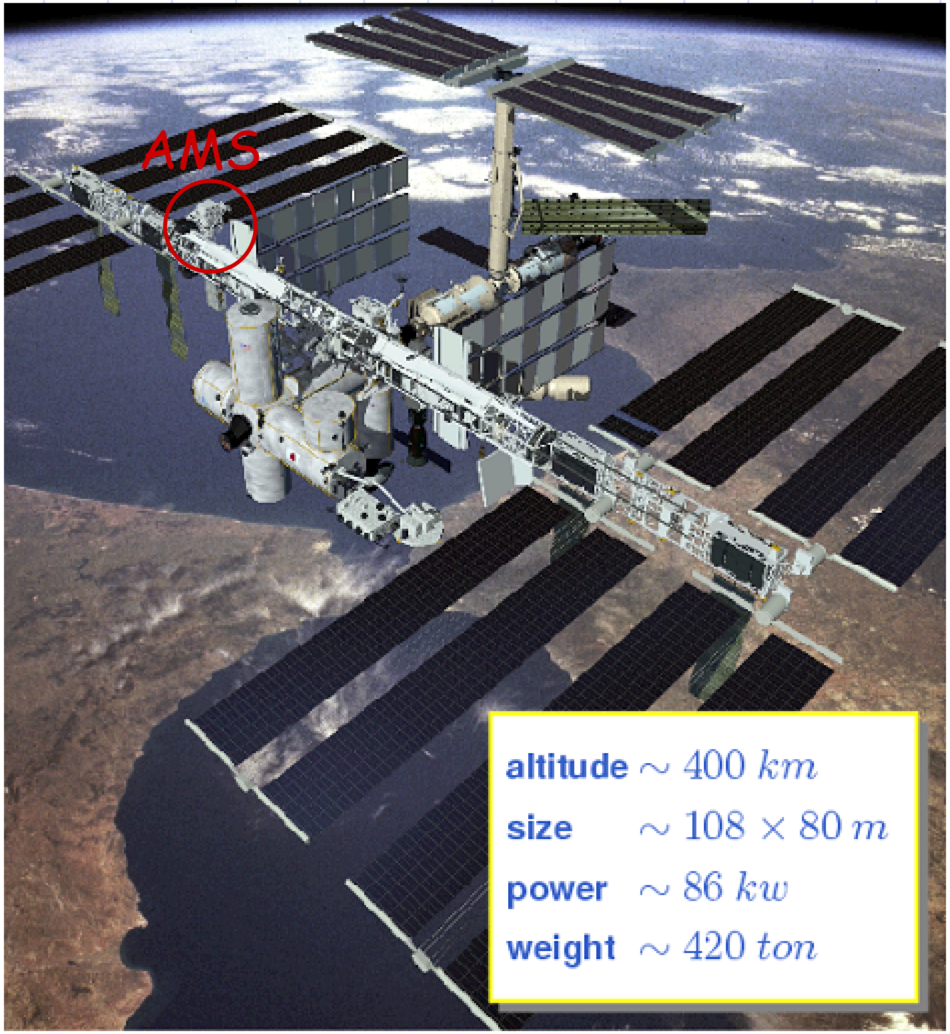
Outline

- The AMS experiment
- The RICH detector
- Velocity and Charge reconstruction methods
- RICH prototype tests
- 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 2007, for three years. Its physical 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
- Precision measurements on the relative abundance of different nuclei and isotopes of primary cosmic rays E<1 TeV



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

AMS Spectrometer Capabilities

- Particle bending

  Superconducting magnet
- Rigidity (p/Z)

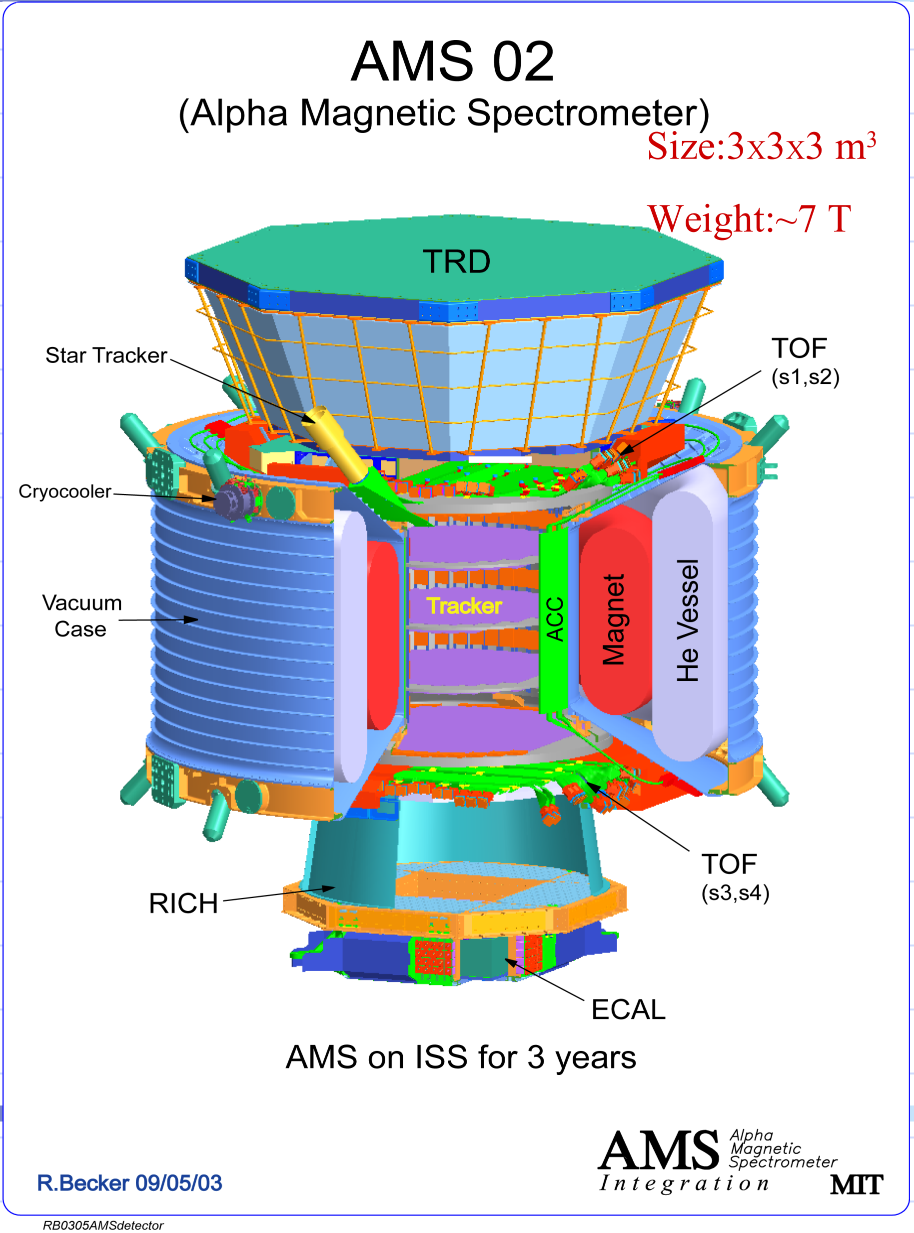
  Silicon Tracker
- Particle direction

  Time-of-Flight, Tracker, RICH
- Velocity (β)

  RICH, Time-of-Flight, TRD
- Charge (Q)

  RICH, Tracker, TOF
- Trigger

  TOF, ECAL, AntiCounter



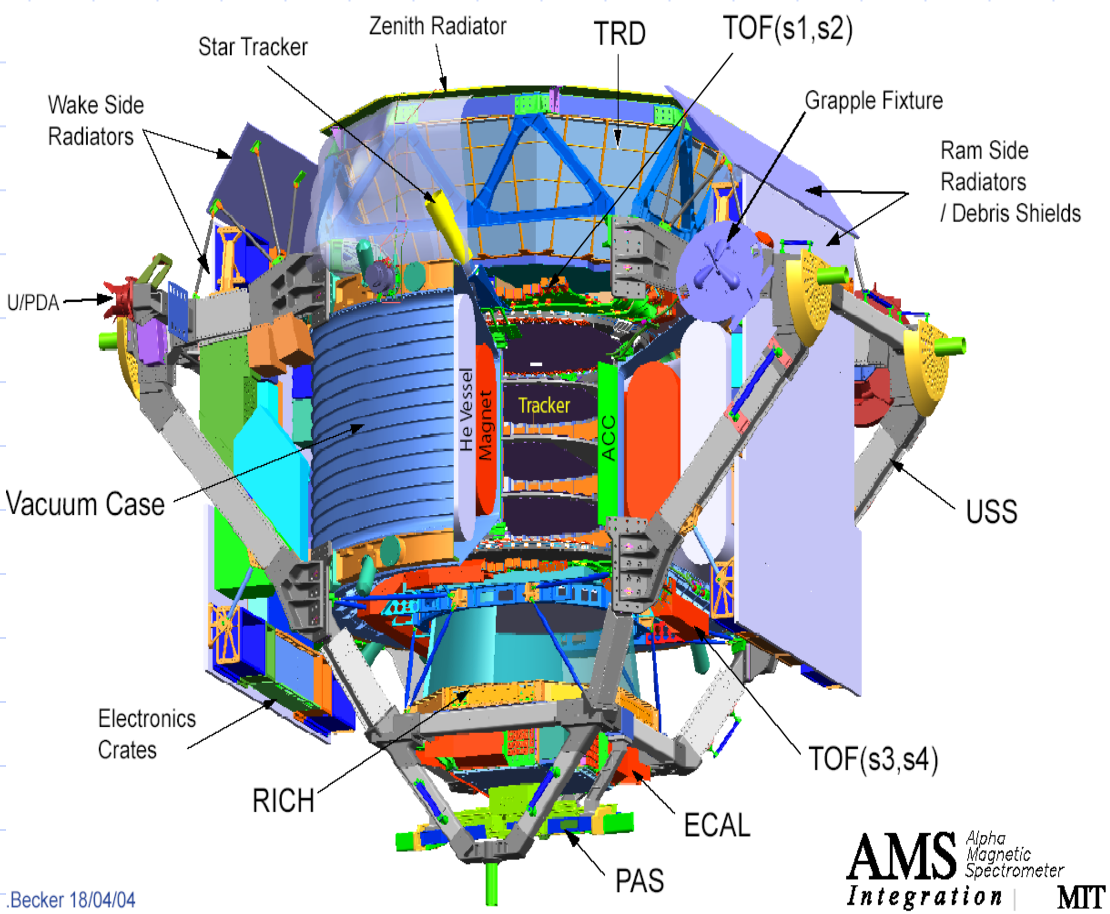
AMS Construction and Constraints:

Characteristics:

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

Constrains:

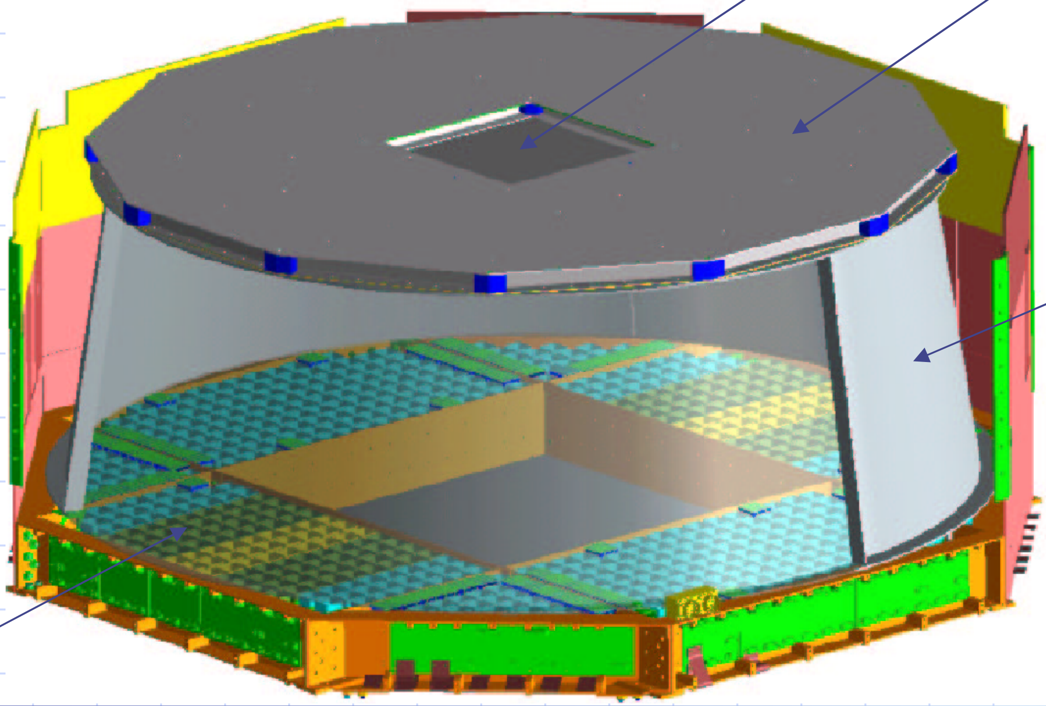
- ✓ Vibration
- ✓ Thermal environment
  day/night ~[-30,+50] ºC
- ✓ Limited power: 2 kW
- ✓ Must operate for 3+years
- ✓ No human intervention



RICH detector

The Ring Imaging Cerenkov of AMS is a proximity focusing detector with a dual radiator, a high reflectivity mirror and photomultiplier tubes

- ✓ 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

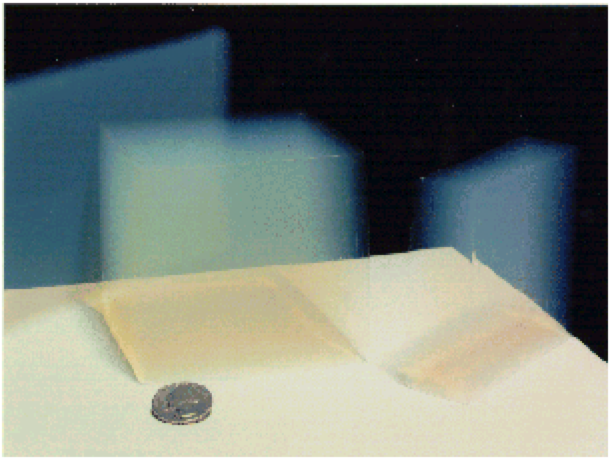


RICH Radiator

- **Cerenkov radiation**

  A charged particle travelling in a medium with a velocity higher than the light speed in the same medium produces Cerenkov radiation.

  $$\cos\theta_c = \frac{1}{\beta n}.$$



- **Radiator**

  Silica Aerogel n=1.05

  Sodium Fluoride (NaF) n=1.334

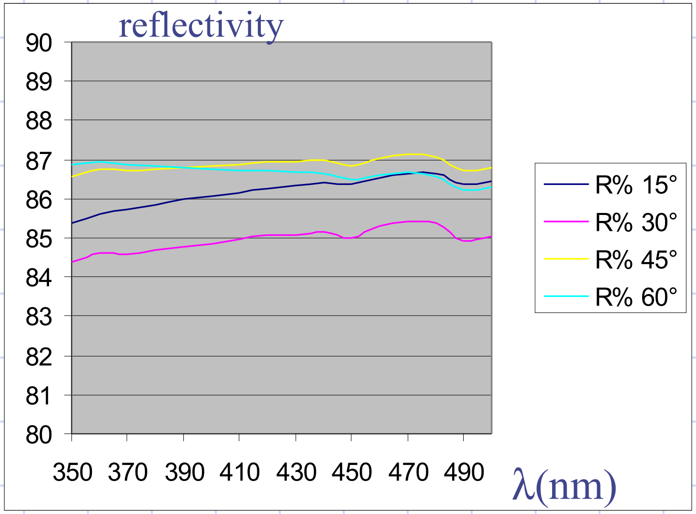
- **Rayleigh scattering:** directionality of Cerenkov photons lost (transparency decreases for UVs)

$$T \propto e^{-\frac{C\ x}{\lambda^4}}$$

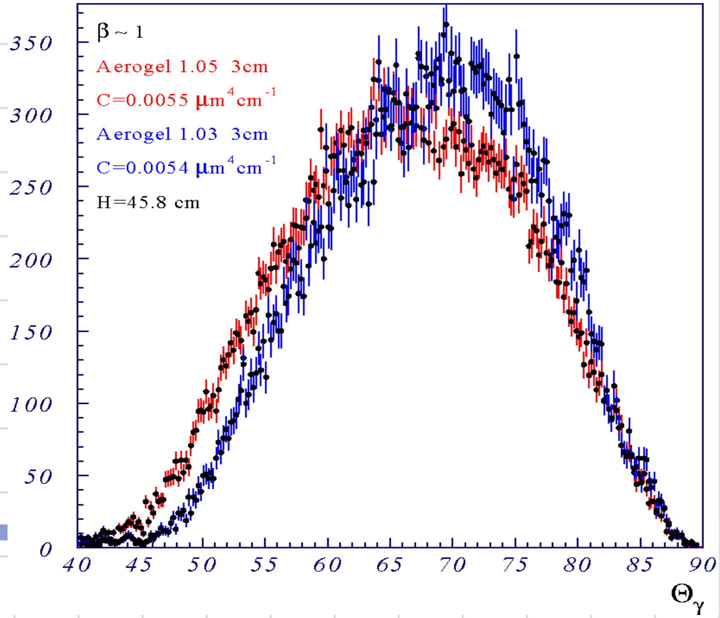
$$\mathrm{C} \equiv \text{clarity coefficient } \mathrm{C} = 0.0055\,\mu\mathrm{m}^4\mathrm{cm}^{-1}\,(n = 1.05)$$

RICH Reflector

- ~33% of the photons emerging from the radiator are pointed outside the detection matrix. A reflector was designed to direct them to the matrix.
- carbon fiber structure with Al and SiO_2 coating
- Reflectivity >85% at 420 nm



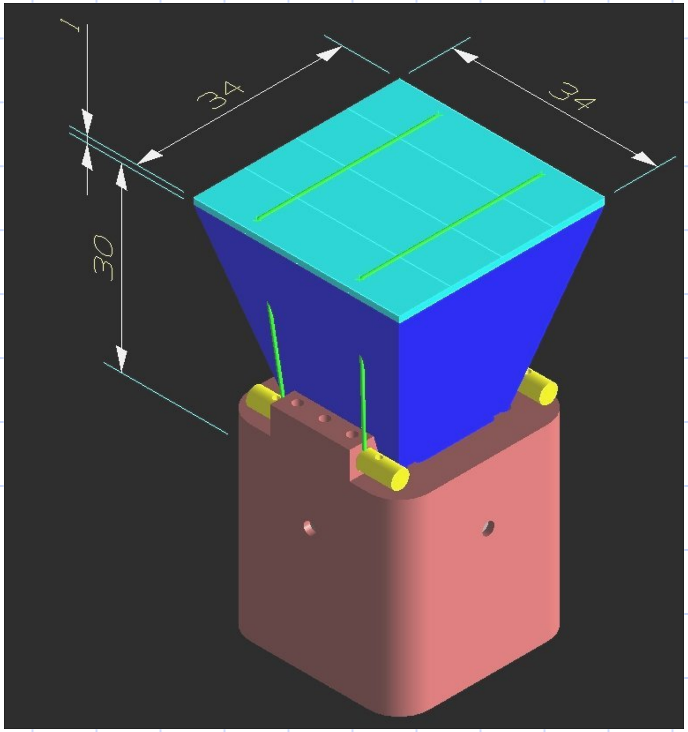
Photons' incident angle at the mirror in the flight setup, events within AMS acceptance

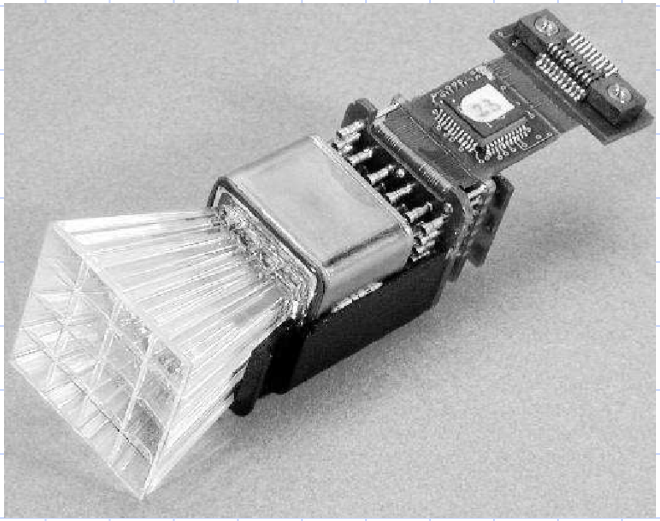


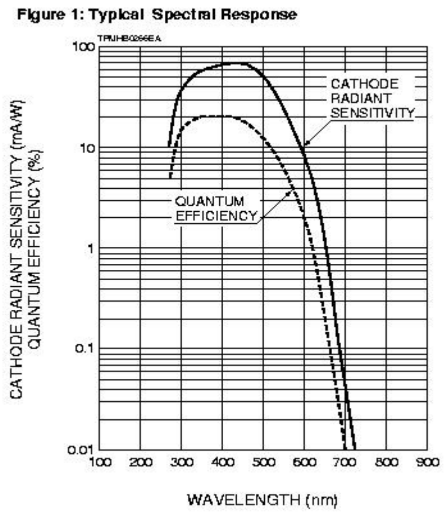
Detection Matrix

- Photomultipliers
  - matrix with 680 PMT's
  - 4 X 4 multianode R7600-00-M16 (**4.5 mm pitch)**
  - spectral response 300-650 nm (**maximum at λ = 420 nm)**
  - two readout amplifications (gain x1, x5)

  Z = 1 - 30   Npe ~ 1 - 10^4 pe







- **Light Guides**

  Plexiglass (n=1.49) solid guides

  Effective pixel size 8.5 mm

RICH constraints

To reach such a good resolution (accuracy) several aspects have to be controled:

- aerogel tiles:
  - tiles thickness uniformity
  - tiles optical characterization (clarity, refractive index)
  - aerogel aging
  - thermal, vaccum and vibration
- mirror reflectivity measured
- PMTs
  - thermal environment [-30,+50] ºC
  - maximum residual magnetic field ~300 G

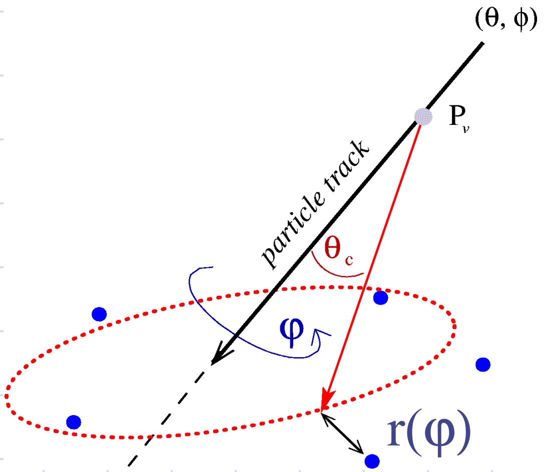
θ_c reconstruction: a likelihood approach

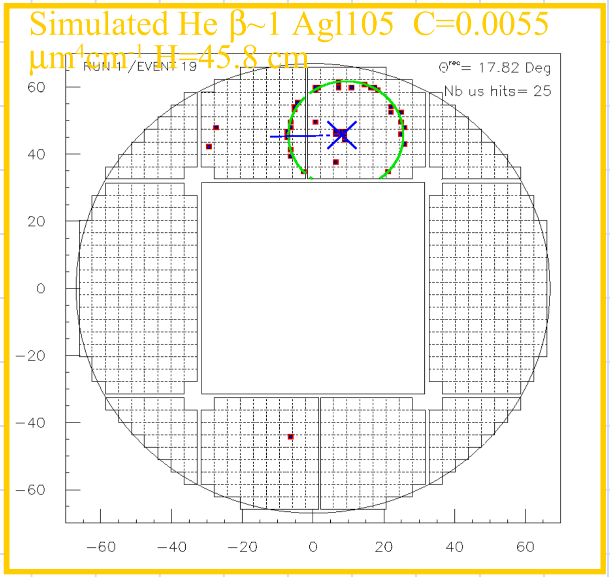
The maximization of a likelihood function provides the best θ_c angle

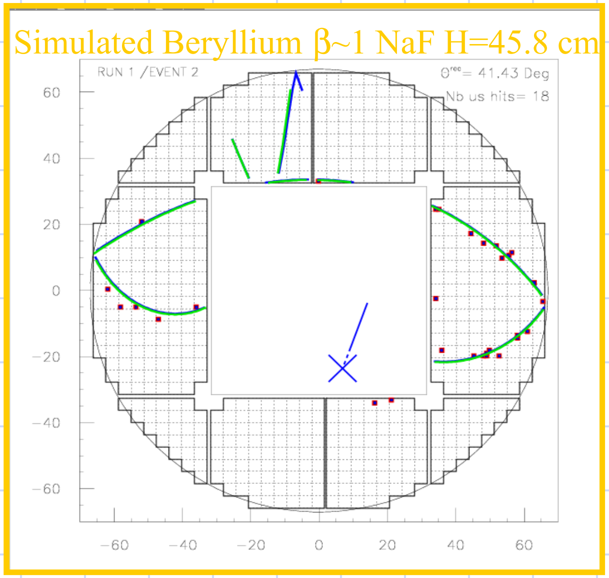
$$L(\theta_c) = \prod_{i=1}^{N_{hits}} P_i^{npe_i}\{r_i(\varphi_i(\theta_c))\}$$

$r_i \equiv$ closest distance to the Cerenkov pattern

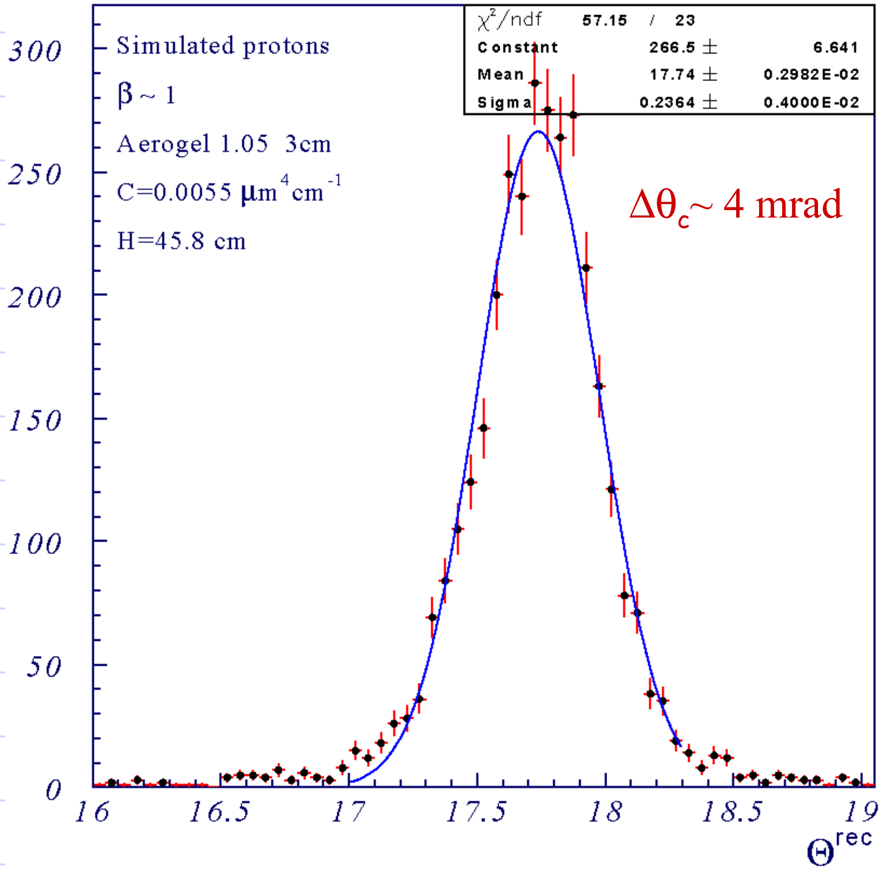
$P_i \equiv$ probability of a hit belong to the pattern







θ_c reconstruction with the 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	$Z=1$, $\beta \sim 1$
Agl103	$\Delta\theta_c \sim 3$ mrad
Agl105	$\Delta\theta_c \sim 4$ mrad
NaF	$\Delta\theta_c \sim 8$ mrad

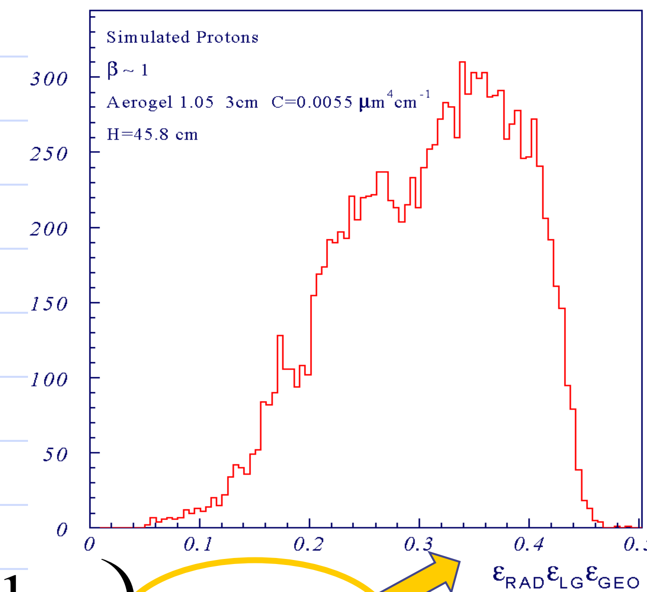
Charge reconstruction

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
- geometrical 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})

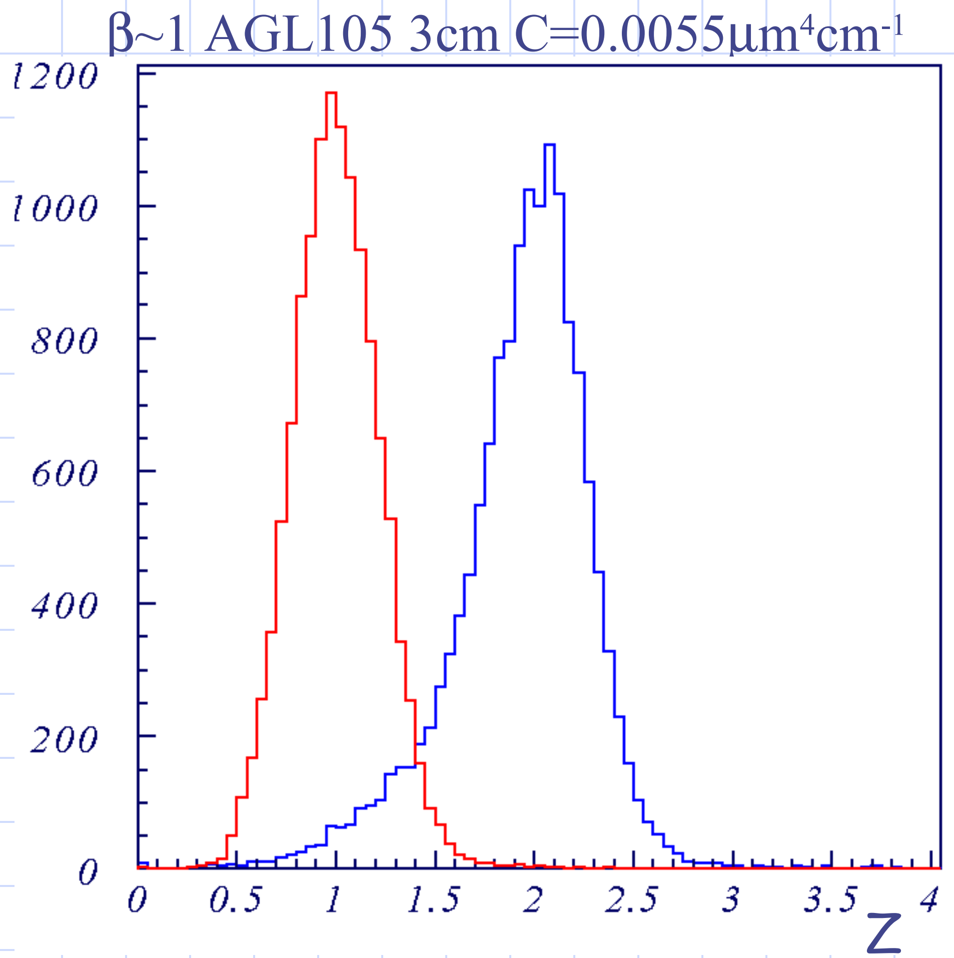


$$N_{pe} \propto Z^2 \Delta L \left(1 - \frac{1}{\beta^2 n^2}\right) \varepsilon_{rad}\,\varepsilon_{geo}\,\varepsilon_{lg}\,\varepsilon_{pmt}$$

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

Charge reconstruction: MC simulation

Simulated protons and heliums within AMS statistics



RICH PROTOTYPE

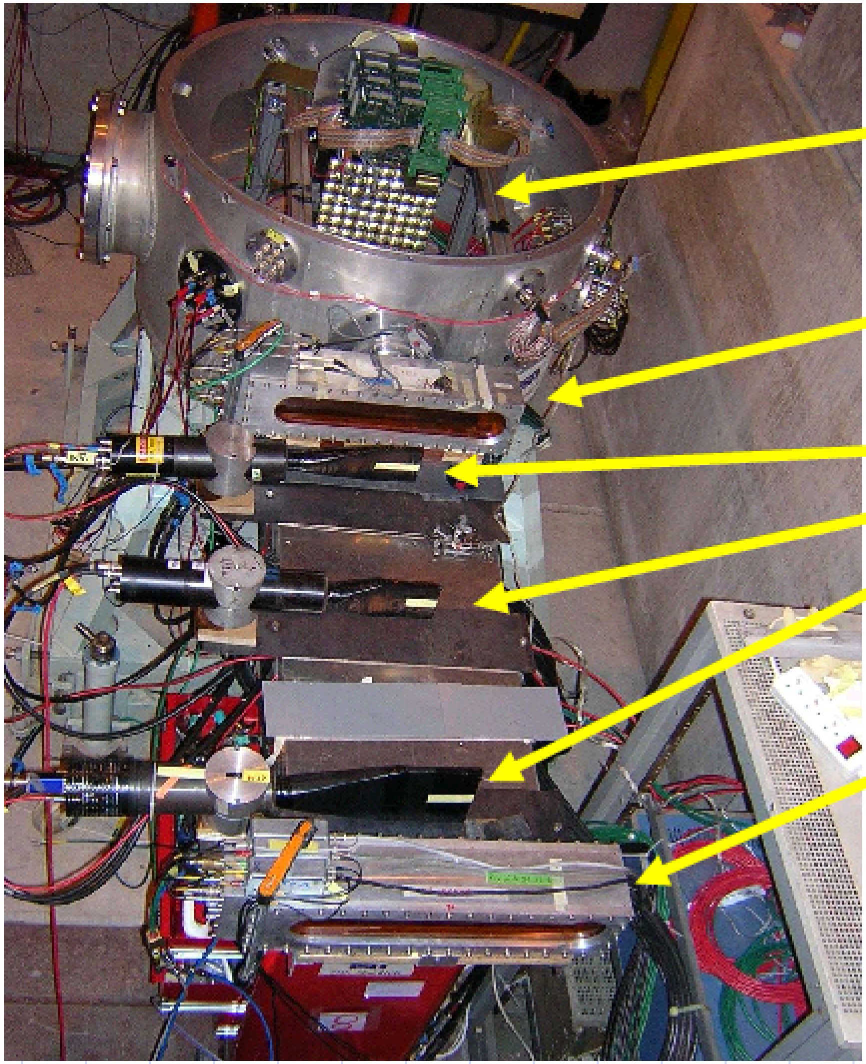
A small scale prototype with a detection matrix with 96 PMT's has been assembled:

- ✓ Test electronics
- ✓ Test radiators:
  - Uniformity of tiles
  - Light yield
  - Detection range in Z
  - Velocity resolution
- ✓ Mirror integration

Tests

- ✓ Cosmics ISN (Grenoble) 2001/2002
- ✓ October 2002 test beam at CERN with fragments from Pb ions 20 GeV/nuc
- ✓ October 2003 test beam at CERN with fragments of Indium beam 158 GeV/nuc

Test Beam 2003: experimental setup



Prototype &
RO electronics

- MWPC

- dE/dx
  - Scintillators
  - Cerenkov

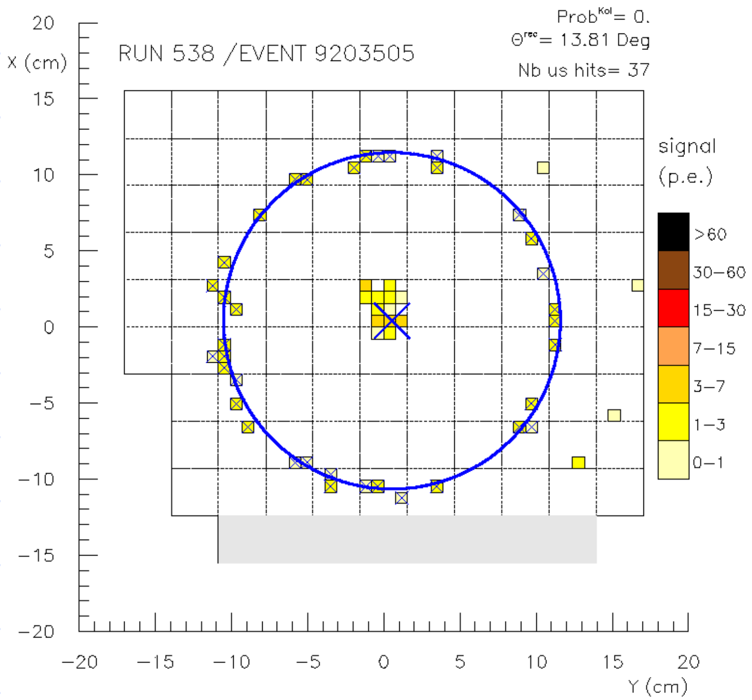
- MWPC

⊕ Tracker Prototype
⊕ TOF Prototype

Data characterization

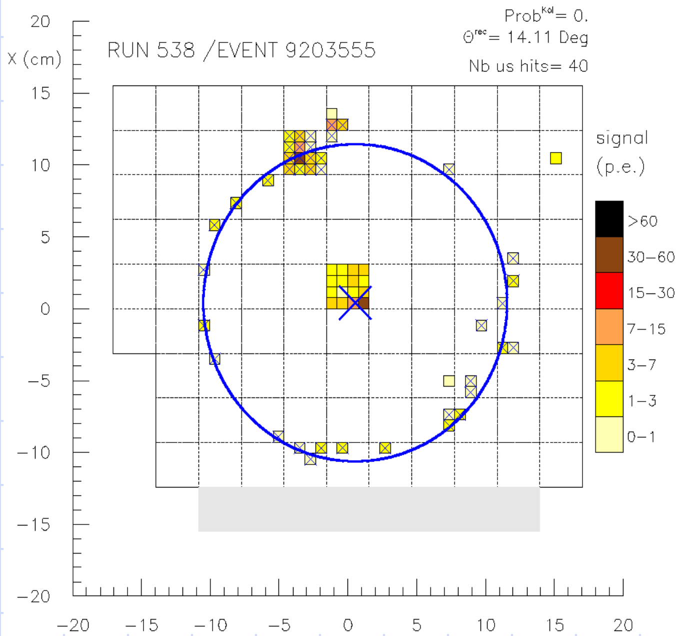
- RICH data ~10^7 events
- Very narrow beam (< 1 mm most of the time)
- Fully contained rings
- Different inclination of the matrix:

  0º, 5º, 10º, 15º, 20º
- Tested radiators: aerogel 1.03, 1.05, NaF
- readout: flight electronics

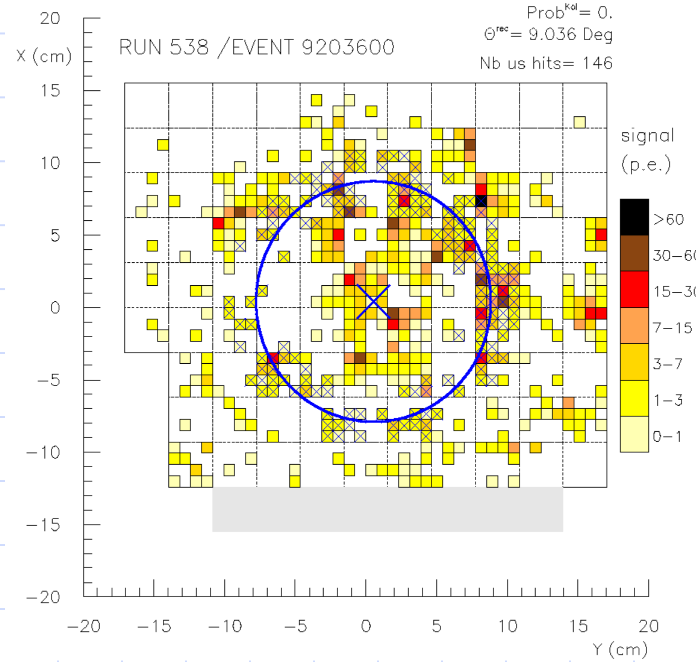


Data selection: background rejection

✓ Clustered events:



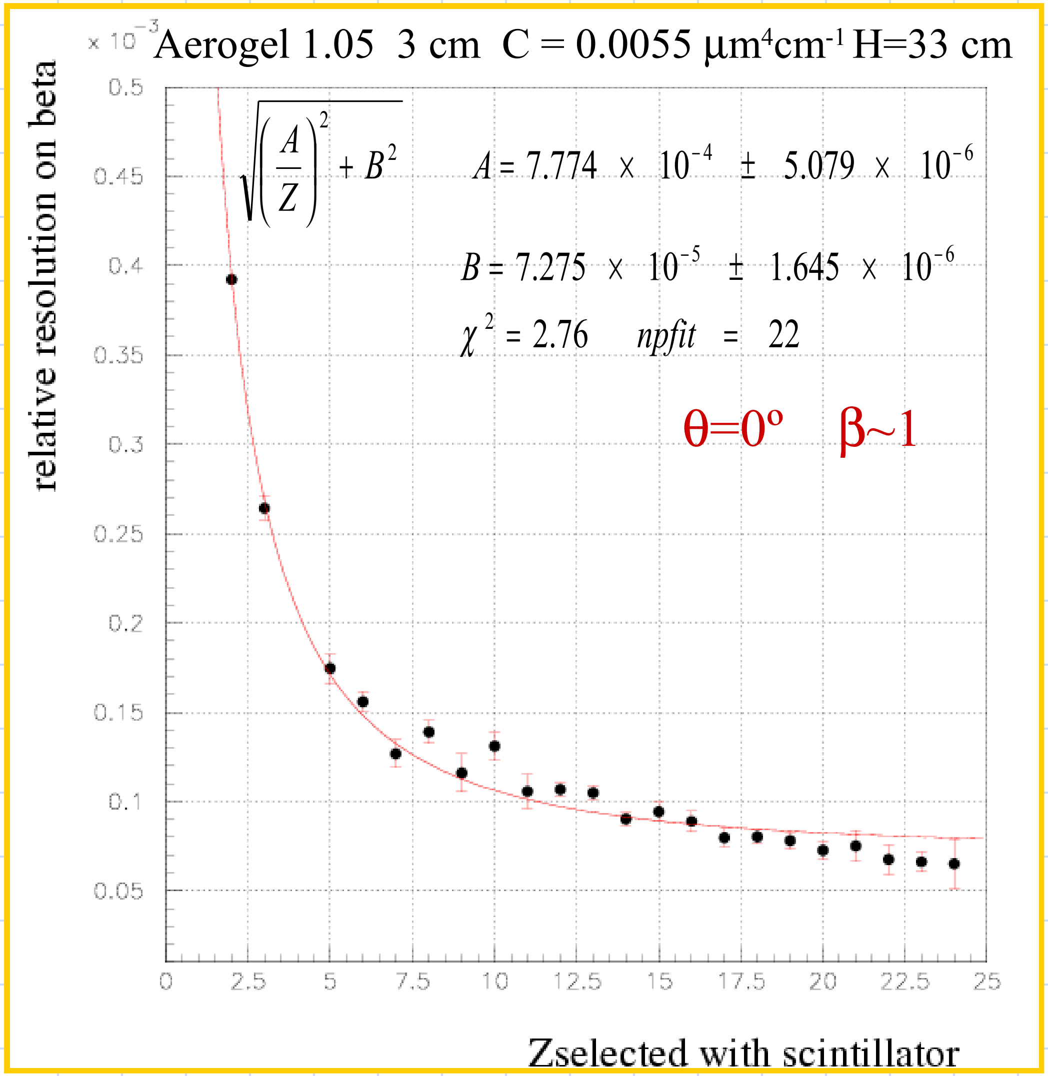
✓ Fragmented events:

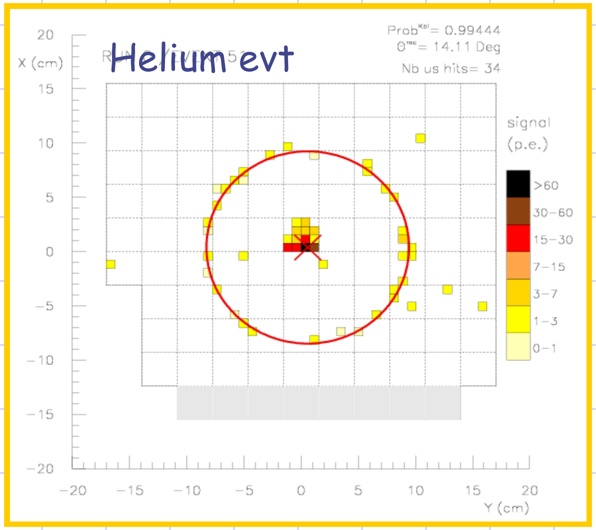


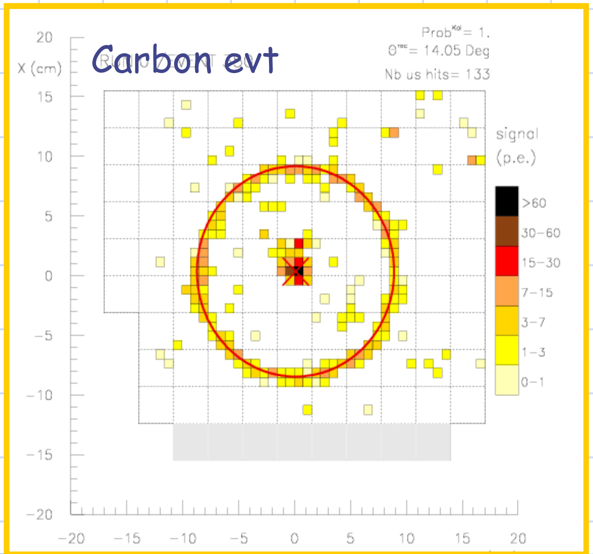
Cerenkov ring flatness - requirement of the hits azimuthal uniformity for particles with a perpendicular incidence

Event Signal – requirement of a small noisy/ring signal ratio

Beta reconstruction in the test beam



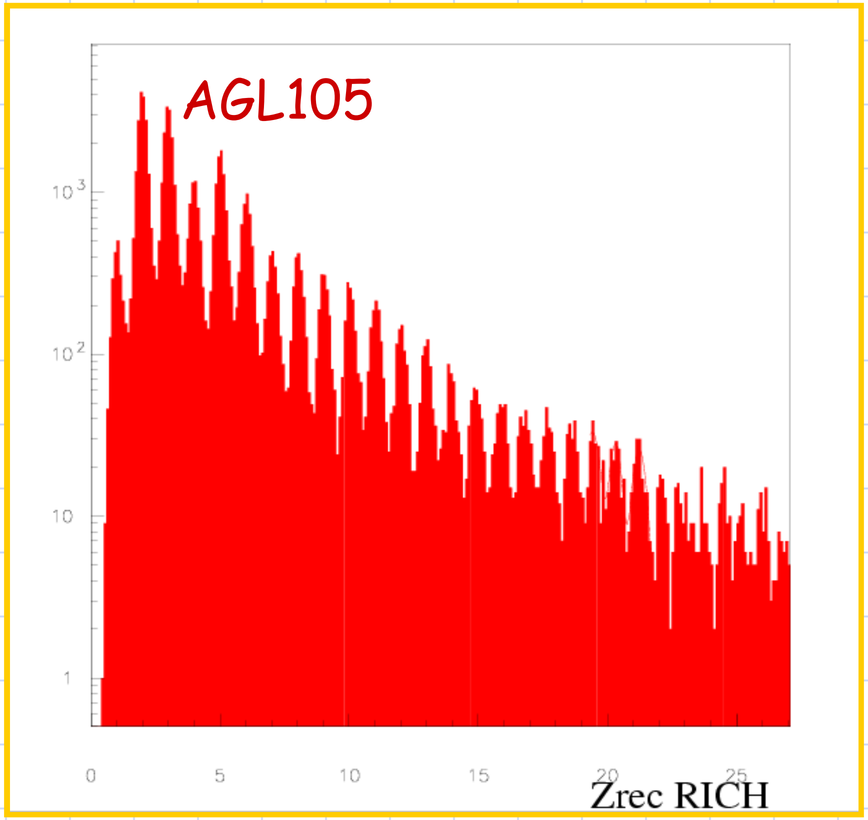


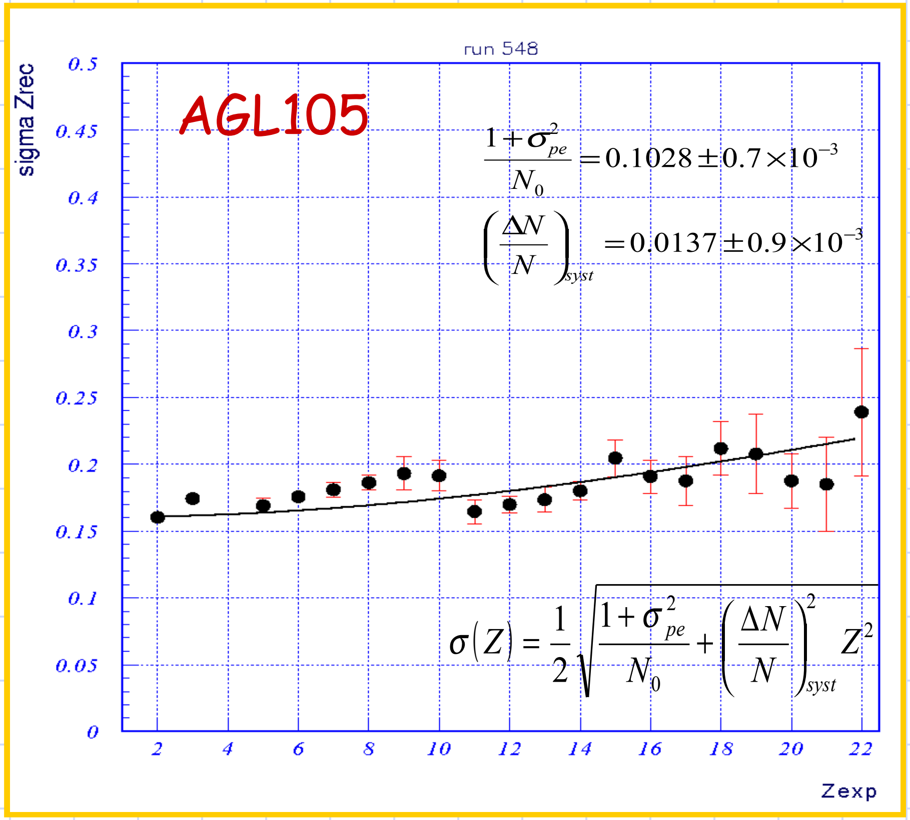


Charge reconstruction

θ=0º β~1

Charge separation up to Z~26

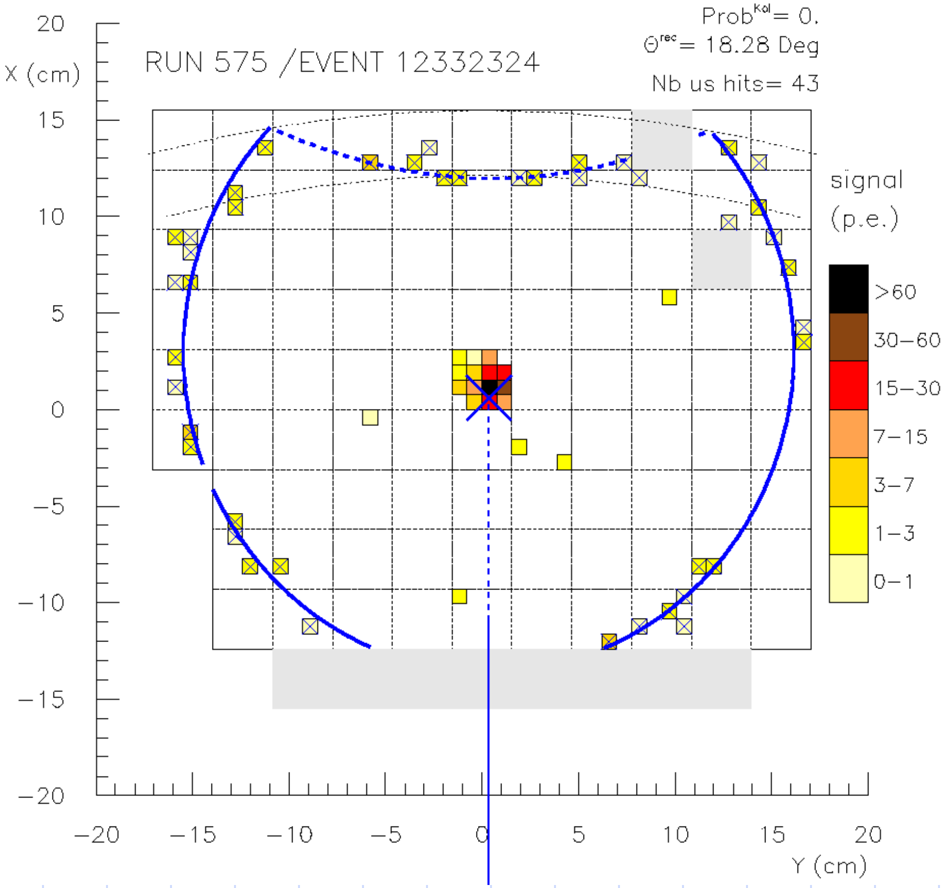




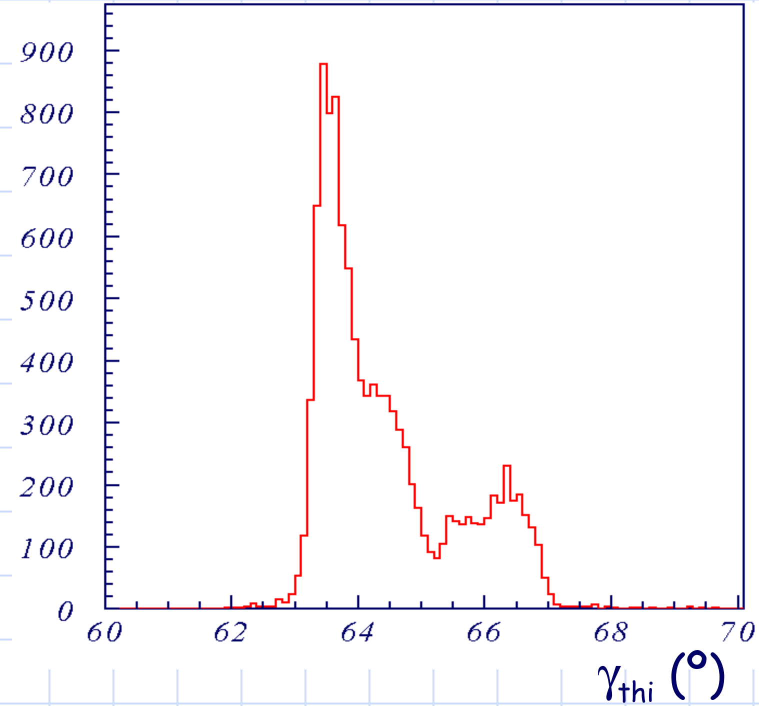
Mirror reflectivity evaluation with a run using AGL105 (θ=15°)

- AGL105 (θ=15°, β~1)

Z=2 event



Distribution of the photon incident angle on the mirror (related to the normal to the mirror surface)

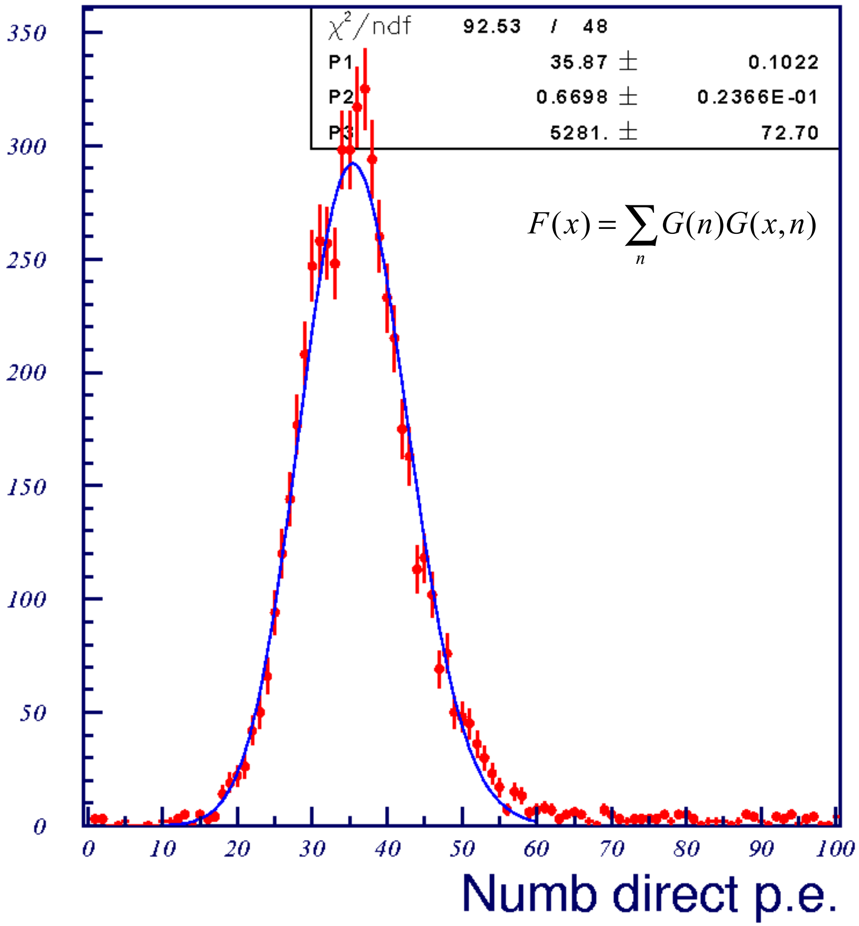


$$\varepsilon_{mir} = \frac{N_{pe}^{ref}}{N_{pe}^{dir}} \frac{\varepsilon_{geo}^{dir}}{\varepsilon_{geo}^{ref}} \frac{\varepsilon_{\lg}^{dir}}{\varepsilon_{\lg}^{ref}}$$

Evaluation of the number of photoelectrons coming from photons:

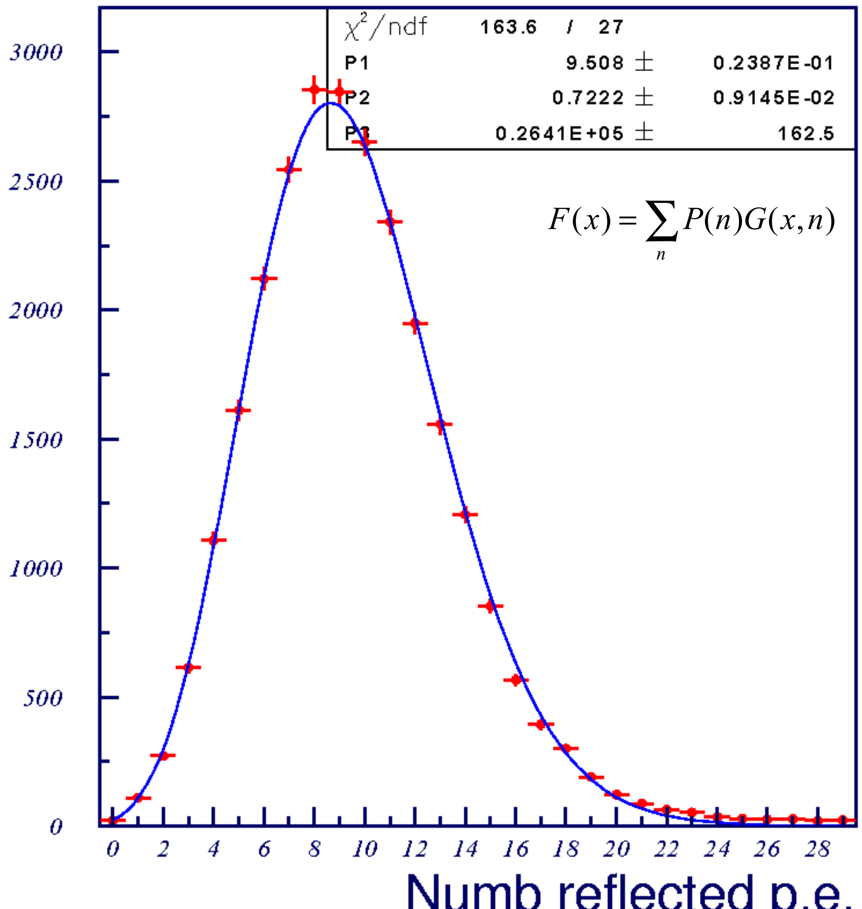
Helium events (Z=2) selected

without reflection



Direct photons: < Npe > = 35.9 +/- 0.1

with reflection



Reflected photons: < Npe > = 9.508 +/- 0.02

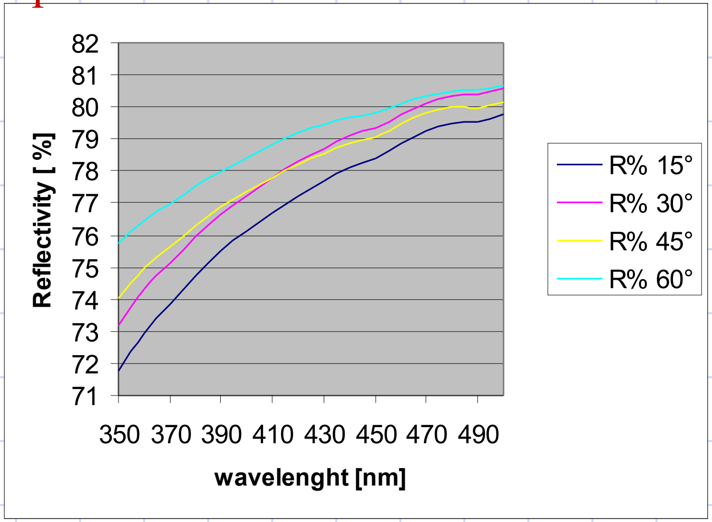
Mirror reflectivity evaluation with a run using AGL105 (θ=15°)

He events:

	Direct	Reflected
N_{pe}	35.9+/-0.1	9.51+/-0.02
ε_{LG}	0.7067+/-0.2E^{-4}	0.7709+/-0.3E^{-4}
ε_{geo}	0.6254+/-0.7E^{-4}	0.205+/-0.2E^{-4}

Reflectivity ~ (75.1 +/- 0.2) %

Optical measurement of the reflectivity



Conclusions

- The RICH detector was designed to provide AMS with very precise velocity measurement $\frac{\Delta\beta}{\beta} = 0.1\%$
- The RICH detector allows Zrec up to Z~26 (Iron)
- A RICH prototype has already been tested with cosmic ray events and with an heavy ion test beam at CERN Oct02/Oct03
  - Electronics validation
  - Reconstruction algorithms
  - Reflector monitoring

The construction of the full RICH detector will achieved at the end of this year