Velocity and Charge Reconstruction with the RICH detector of the AMS experiment

Isotopic Separation for helium and beryllium elements

Maria Luísa Arruda/ Fernando Barão

LIP (Laboratório de Instrumentação e Física de Partículas)

- Av. Elias Garcia, 14-1°,1000-149 Lisboa

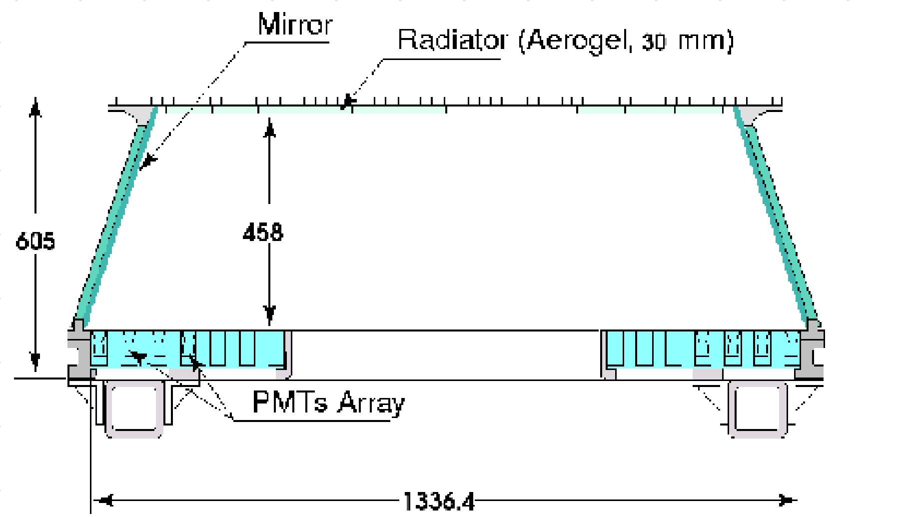
Outline

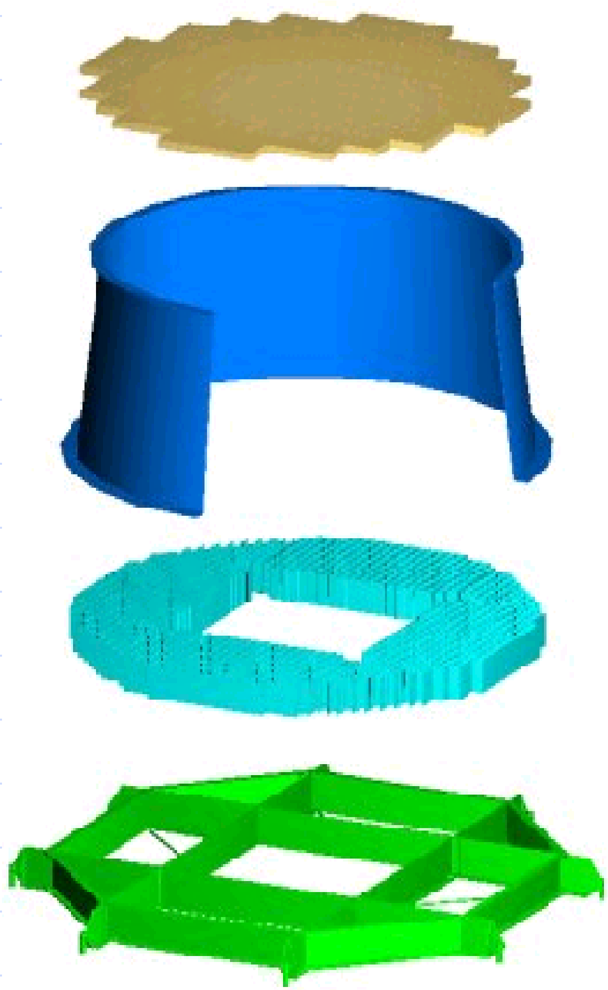
- The RICH detector
- Photon pattern tracing
- Velocity reconstruction
- Charge reconstruction
- Isotopic separation: $^{3}He/^{4}He$ and $^{10}Be/^{9}Be$
- Conclusions

RICH detector

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

- ✓ Velocity measurement $\frac{\Delta\beta}{\beta} = 0.1\%$
- ✓ Charge measurement Z~25 ΔZ~20%
- ✓ Redundancy on albedo rejection
- ✓ e/p separation



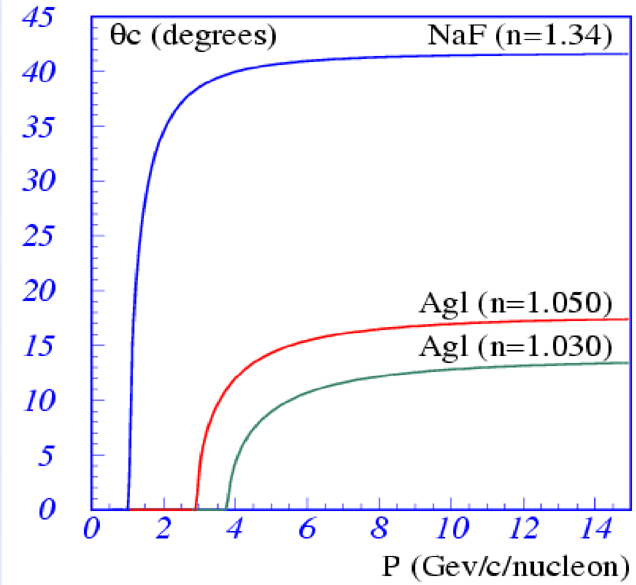


RICH Radiator

- Cerenkov radiation

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

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



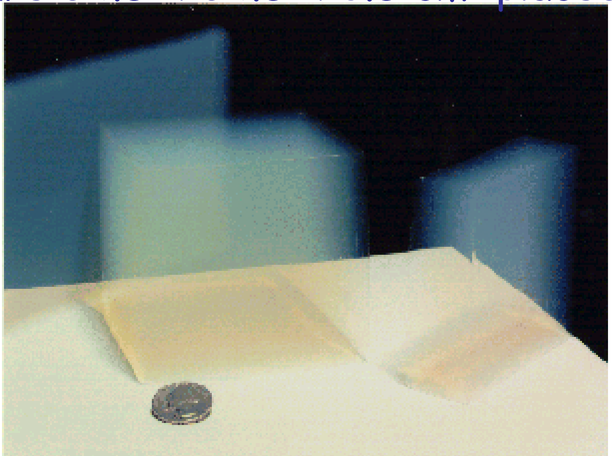
- Radiator

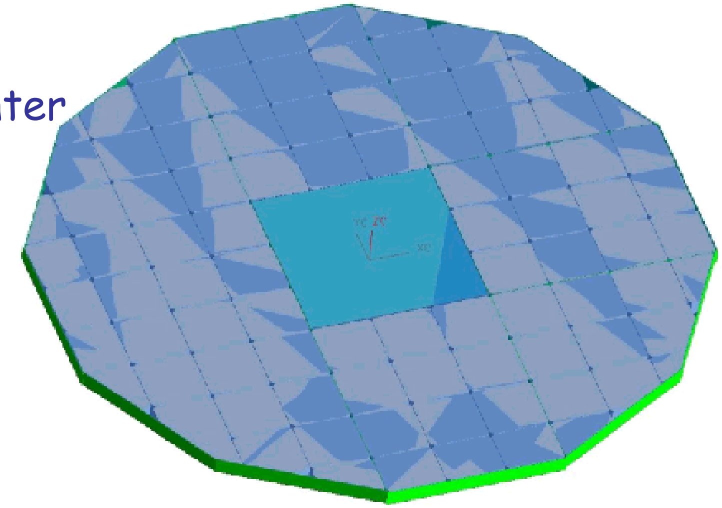
  Silica Aerogel n=1.03/1.05 3/2 cm of thickness

  Aerogel tiles 11.5 X 11.5 X 1 cm^3

  NaF n=1.334, 0.5 cm thickness

  NaF square 34.5 x 34.5 x 0.5 cm^3 placed in the center



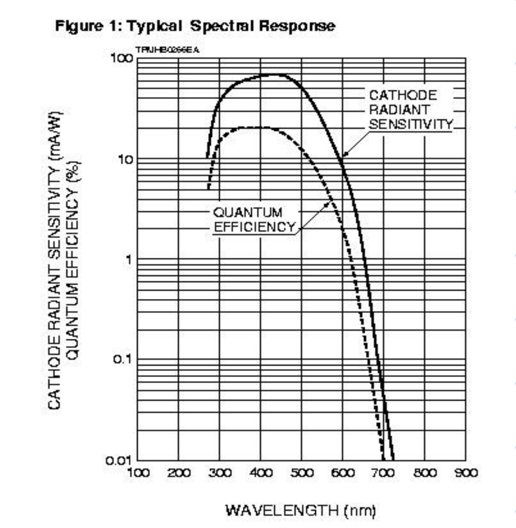


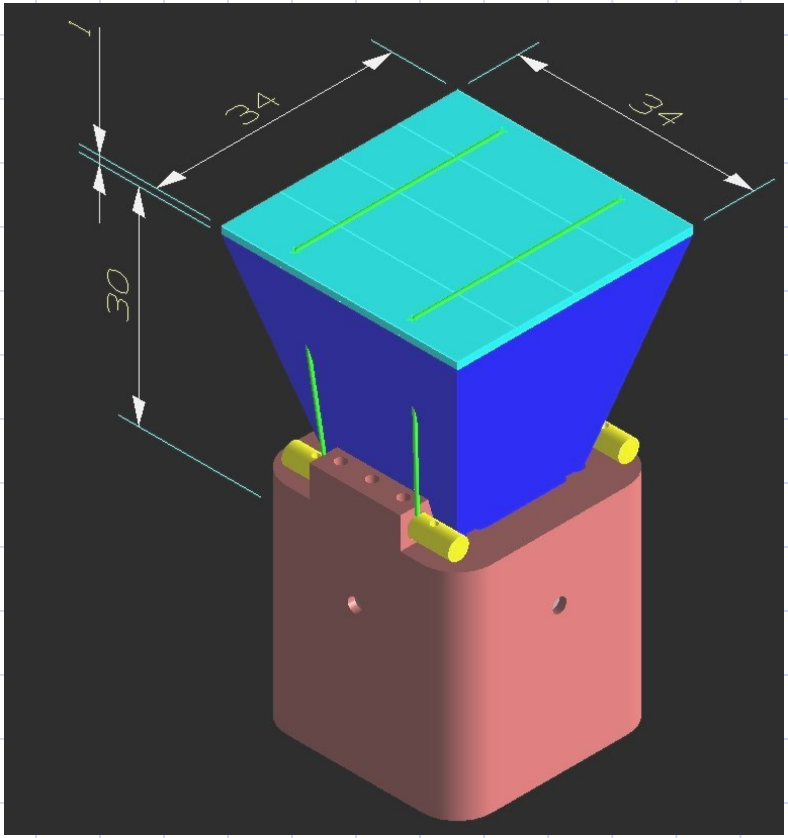
Detection Matrix

- Photomultipliers
  - matrix with 680 PMT's
  - 4 X 4 multianode R7600-M16

    4.5 mm pitch
  - spectral response 300-650 nm

    maximum at λ = 420 nm





- **Light Guides**

  Plexiglass (n=1.49) solid guides

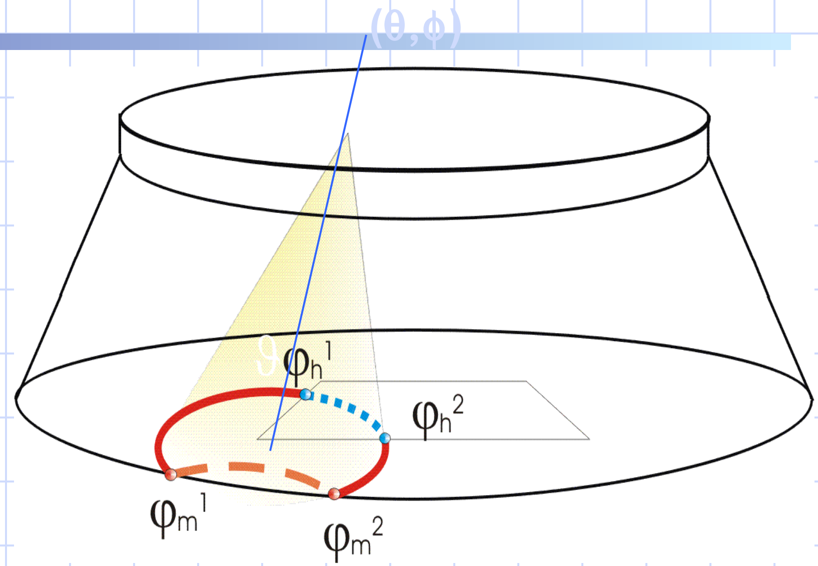
  Effective pixel size 8.5 mm

Photon Pattern Tracing

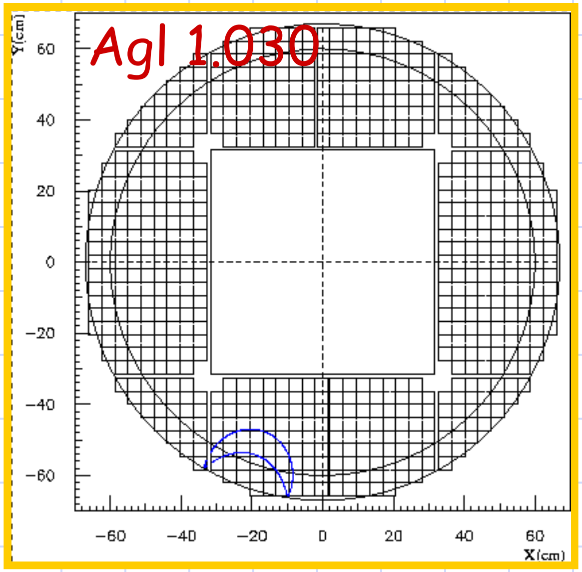
Photon tracing includes:

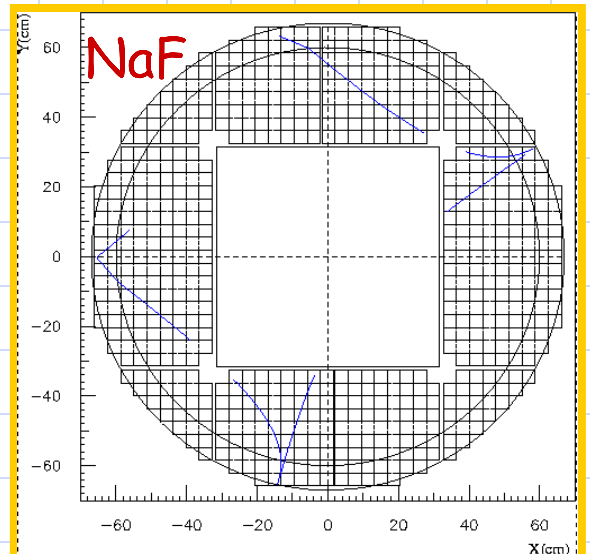
Emission at a reference point with an opening angle θ_c and at a given azimuthal angle φ.

$$\vec{g}'(\varphi;\ \theta_c) \xrightarrow{T(\theta,\phi)} \vec{g}(\varphi;\ \theta_c,\ \theta,\ \phi)$$

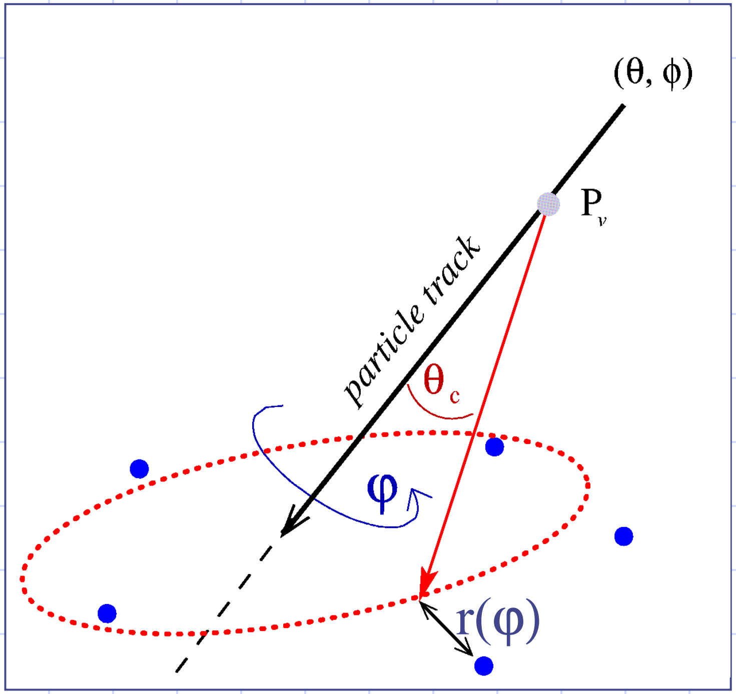


- ✓ escaping from radiator
- ✓ refracting at radiator boundary
- ✓ reflecting on mirror
- ✓ hitting detection plane





θ_c reconstruction: a likelihood approach



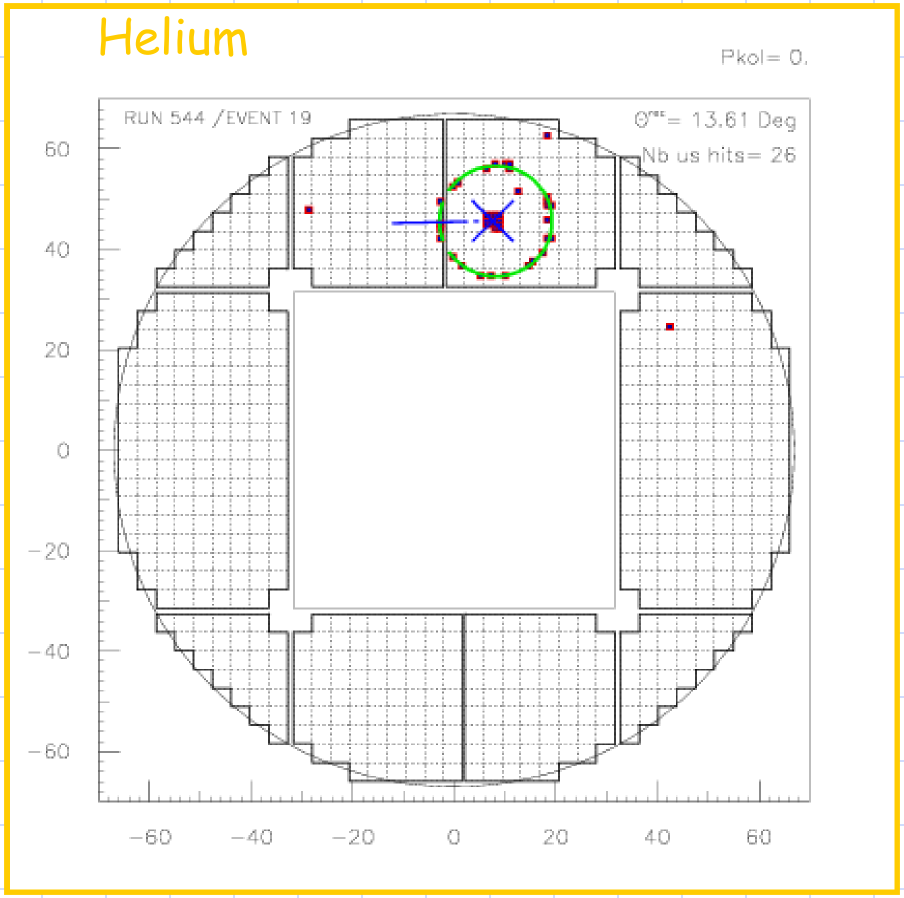
- The AMS tracker provide particle direction (θ,ϕ) and the impact point at the RICH radiator
- The photon pattern at the PMT matrix is derived as function of θ_c
- The hits associated to the particle are excluded
- The maximization of a likelihood function provides the best θ_c angle

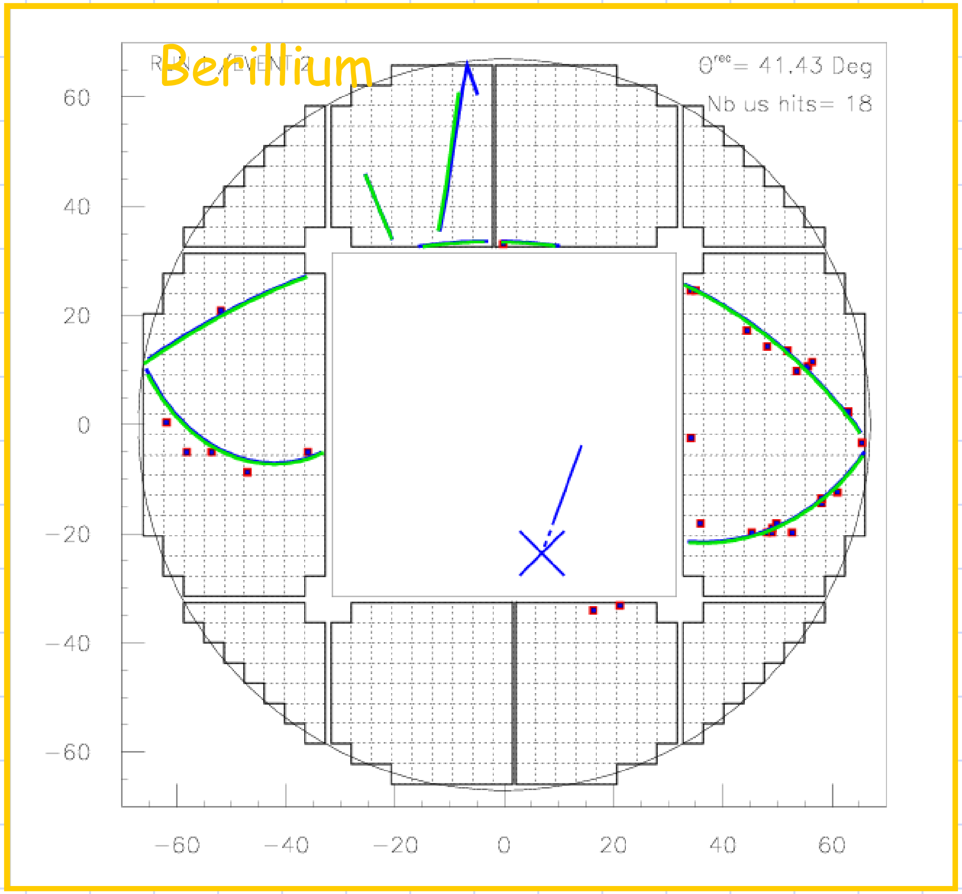
$$V(\theta_c) = \prod_{i=1}^{N_{hits}} P\{r_i(\varphi_i(\theta_c))\}$$

$r_i \equiv$ closest distance to the Cerenkov pattern

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

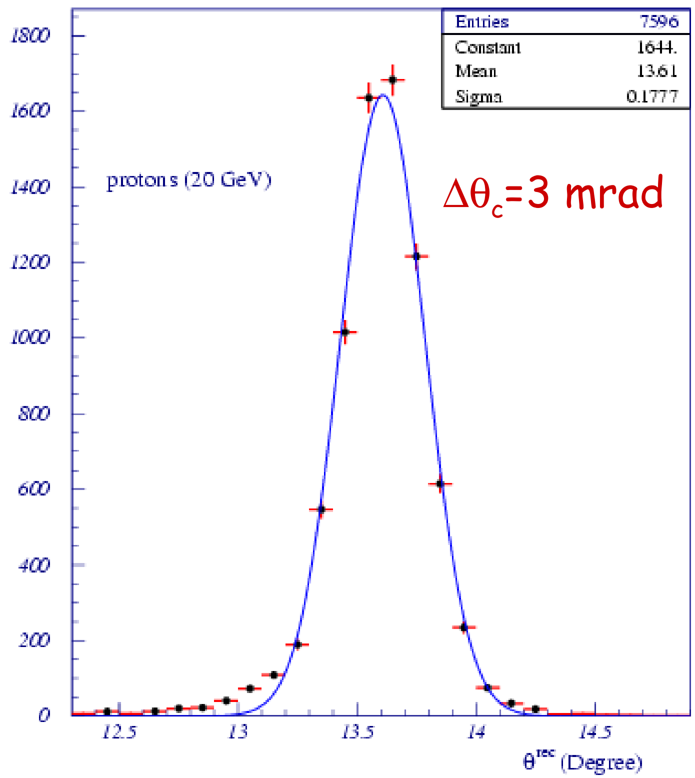
θc reconstruction: event displays

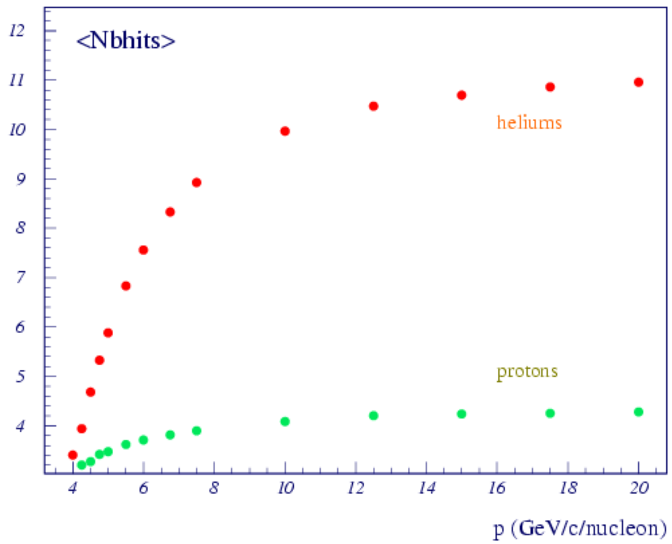


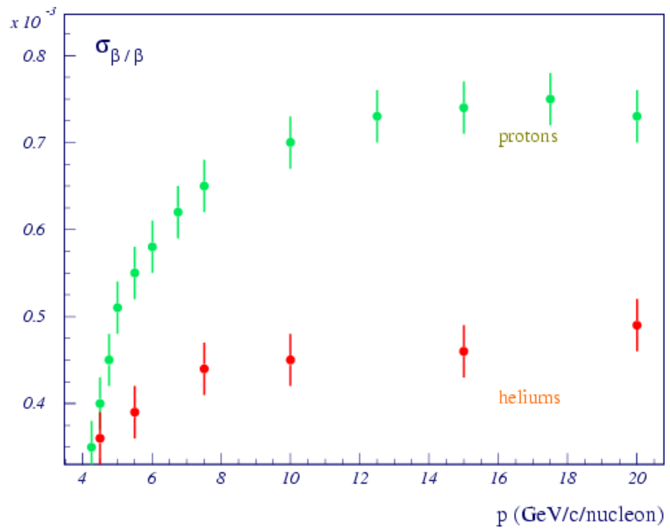


Simulated events: p=20 GeV/c/nucleon

θ_c reconstruction: β resolution scaling







The relative uncertainty of the velocity scales down with the number of hits

$$\frac{\Delta\beta}{\beta} = \tan\theta_c \frac{\Delta\theta_c}{\sqrt{N_{hits}}}$$

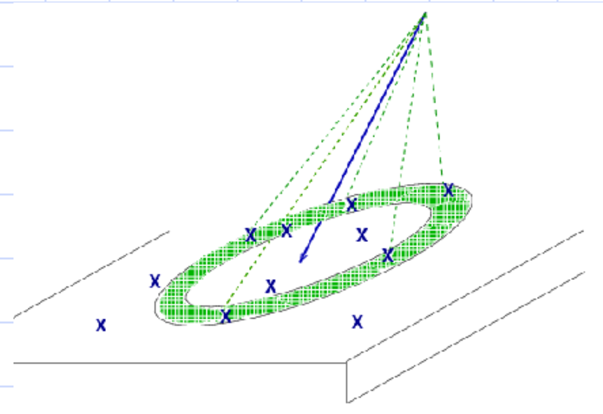
Charge reconstruction

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})

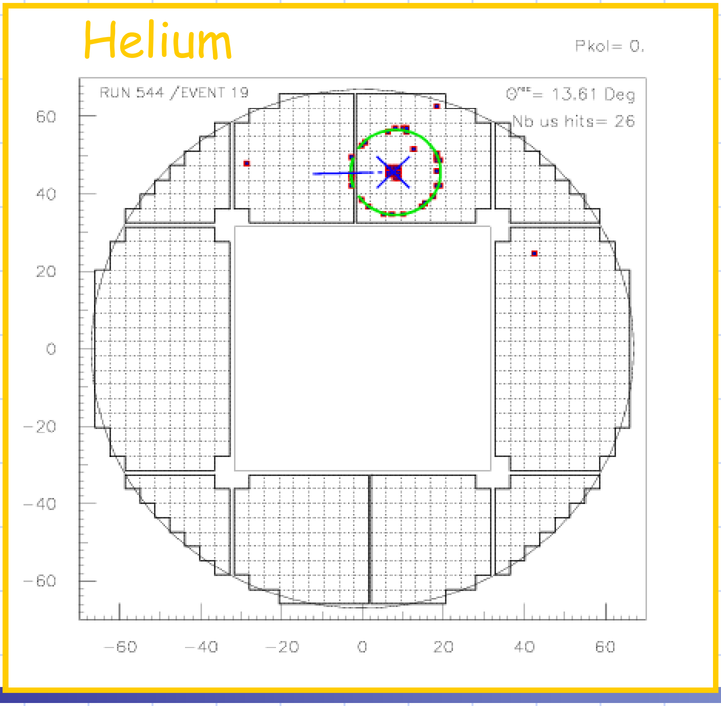


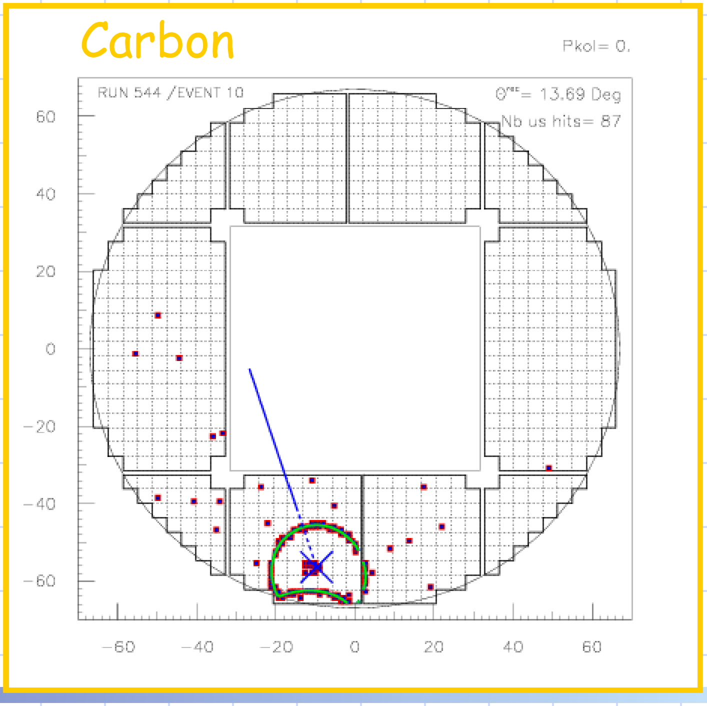
$$N_{pe} \propto Z^2 \Delta L \left(1 - \frac{1}{\beta^2 n^2}\right) \underbrace{\varepsilon_{rad}\,\varepsilon_{geo}\,\varepsilon_{lg}\,\varepsilon_{pmt}}_{\varepsilon_{tot}(\theta_c,\theta,\phi,P_I)}$$

Charge reconstruction method

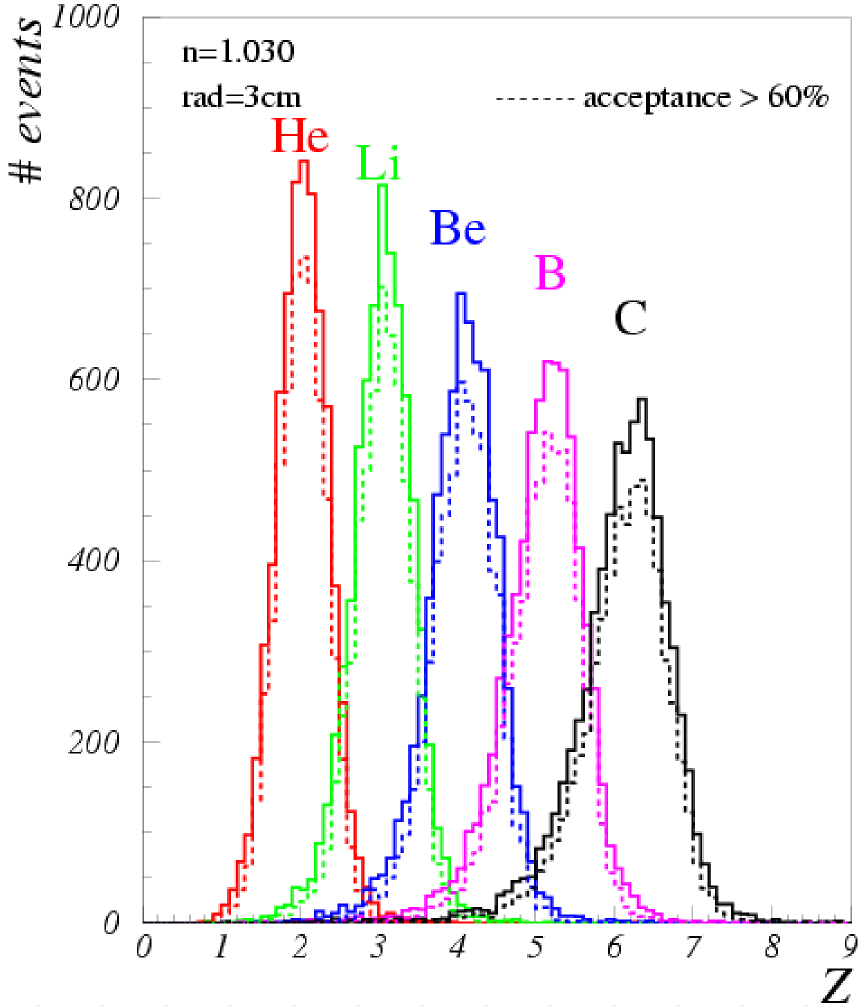
- ✓ Cerenkov angle reconstruction
- ✓ Photoelectron countage: the signal (p.e.) close to the reconstructed photon pattern is summed up Δr< 1.3 cm
- ✓ Photon detection efficiency
- ✓ Reconstruct electric charge

$$Z^2 \sim \frac{n_{p.e.}}{\varepsilon_{tot}} \frac{1}{\Delta L} \frac{1}{\sin^2 \theta_c}$$

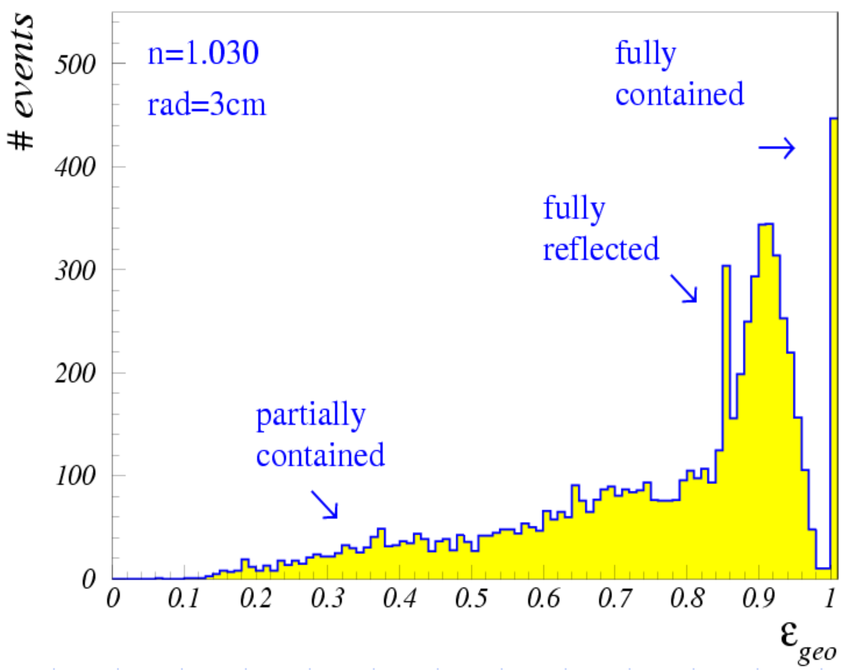




Charge reconstruction: simulated data



The number of p.e. is corrected according to the event efficiency



RICH PROTOTYPE

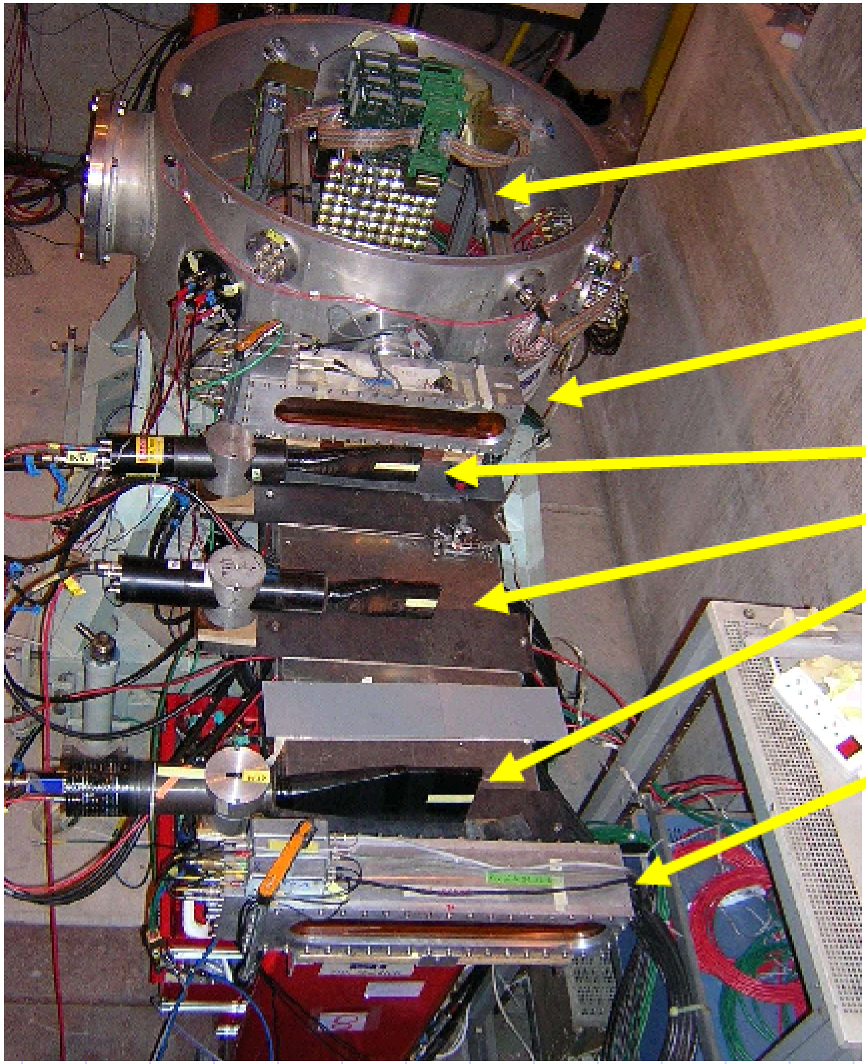
A small scale prototype with a detection matrix with 96 PMT's has been assembled:

- ✓ 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 156 GeV

Test Beam 2003: experimental setup

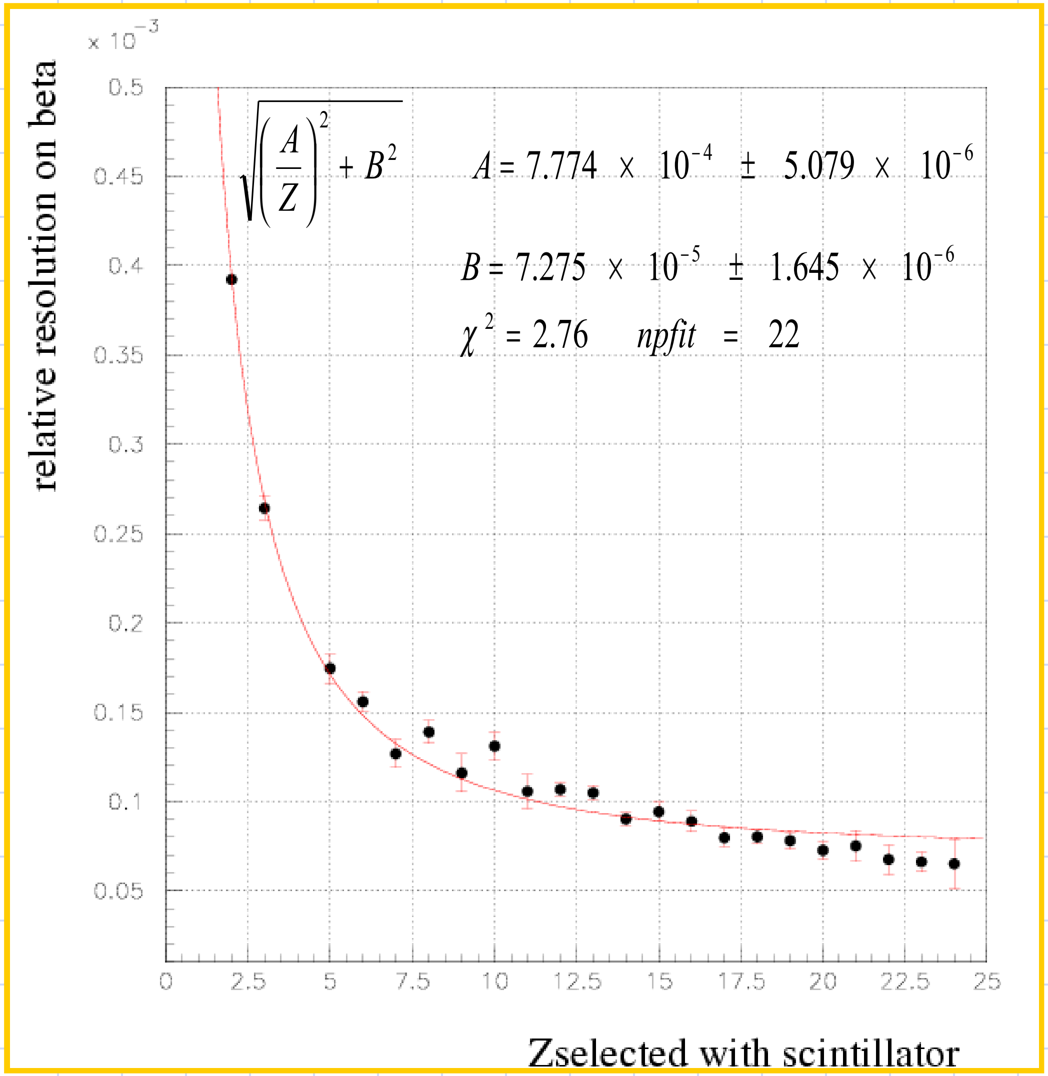


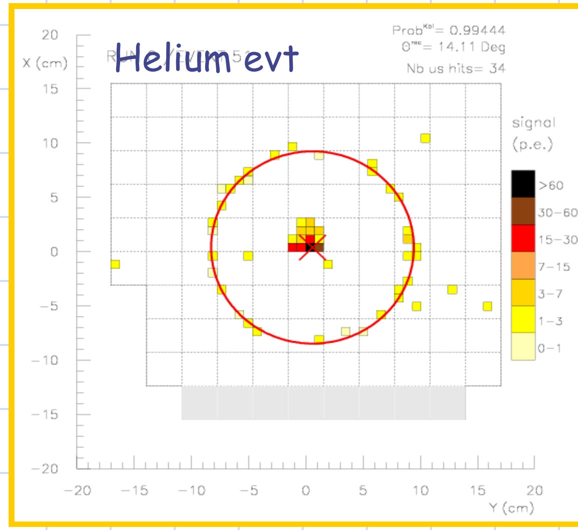
Prototype & RO electronics

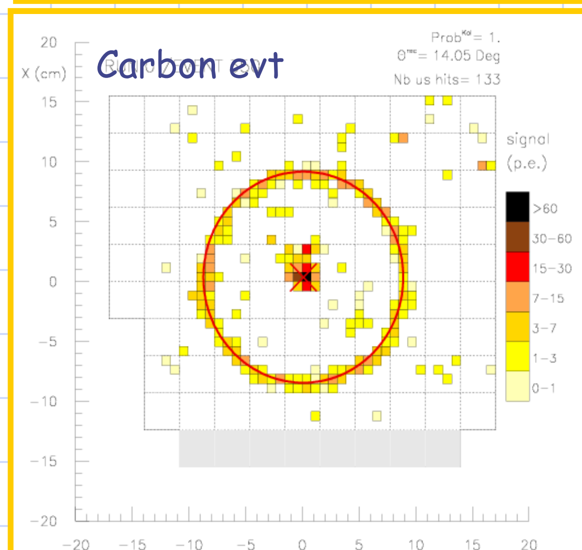
- MWPC
- dE/dx
  - Scintillators
  - Cerenkov
- MWPC

⊕ Tracker Prototype
⊕ TOF Prototype

Beta reconstruction in the test beam



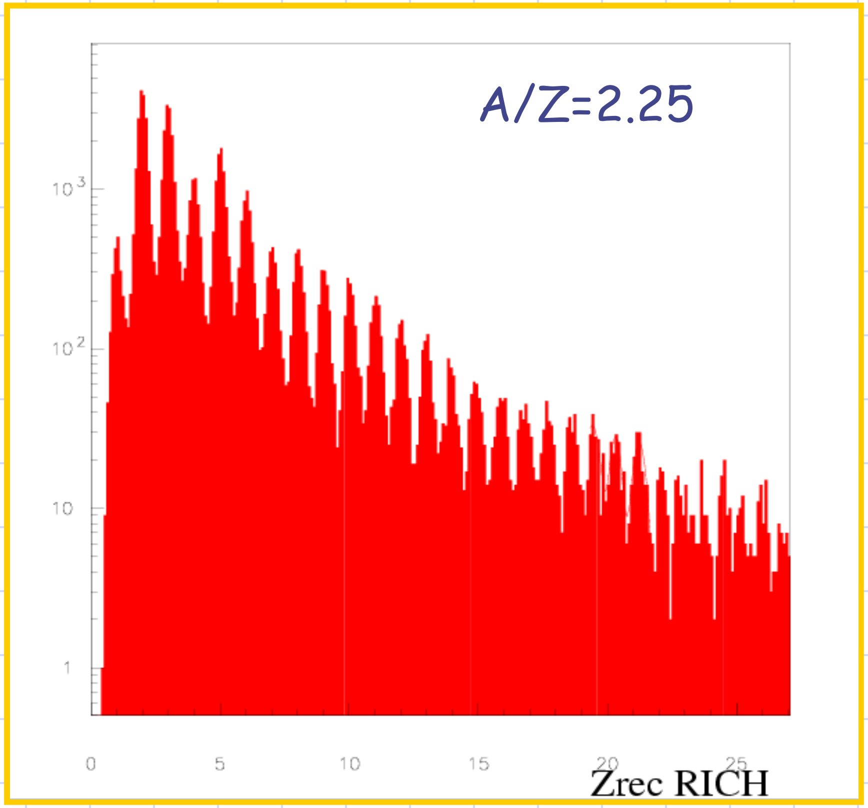


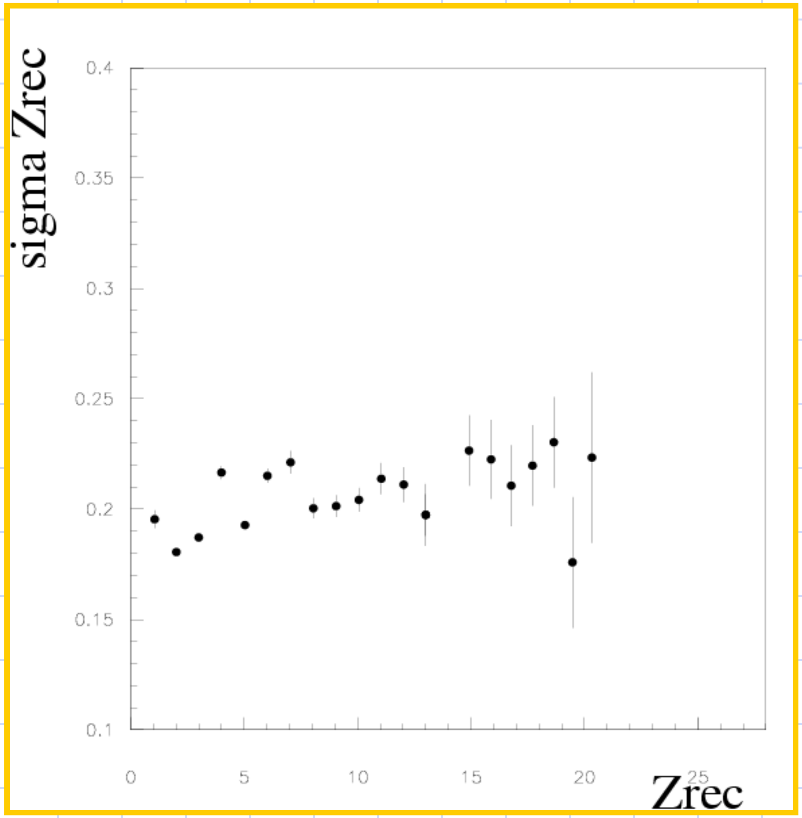


Charge reconstruction

RICH prototype test with data Pb (20 GeV/c/nuc) fragmented ion

Charge separation up to Z~30





Future Physics Prospects with RICH

- Dark matter search
  - e^+, p background rejection
- Detection of antimatter (antinuclei)
  - charge identification
  - albedo rejection
  - strong system redundancy
- Cosmic rays studies
  - confinement: radioactive isotopes ($^{10}Be/^{9}Be$)
  - propagation: isotopes $^{3}He/^{4}He$
- Detection of a large range of charged nuclei (Z)

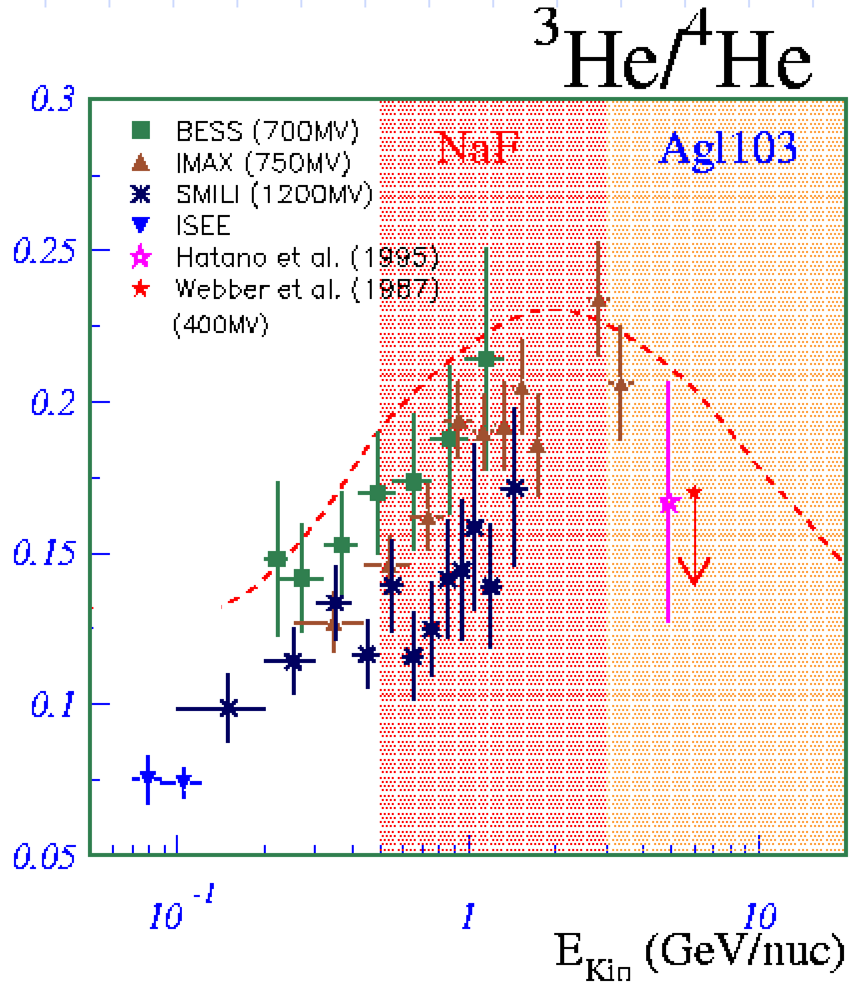
Helium isotopic separation: Physical motivations

The propagation history of the helium can be probed by measuring the isotopic ratio $^3He/^4He$

- ^3He is essentially secondary and comes from the spallation of ^4He in the ISM

Aerogel 1.030 will provide isotopic ratios from E_{kin} ~ 3 GeV/nuc

The integration of NaF in the RICH radiator will alow to measure isotopic ratios down to E_{kin} ~ 0.5 GeV/nuc



Beryllium isotopic separation: Physical motivations

Measurement of the ratio $^{10}Be/^{9}Be$ gives us information about confinement time of cosmic rays in the Galactic volume and is sensitive to different propagation models

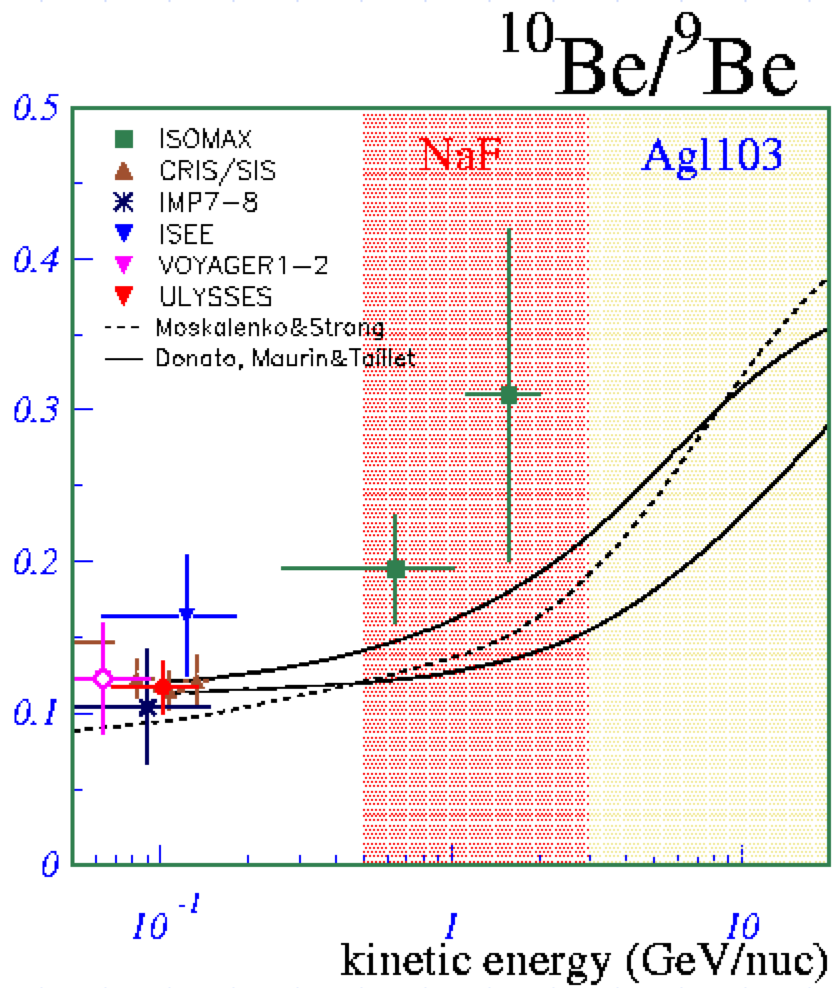
$\tau_{1/2}(^{10}Be) \sim 1.5 \times 10^{6}$ years

Light isotopic measurements before AMS:

- done at relatively low energies

  < 1.57 GeV/nuc (ISOMAX)

- based on a rather low statistics

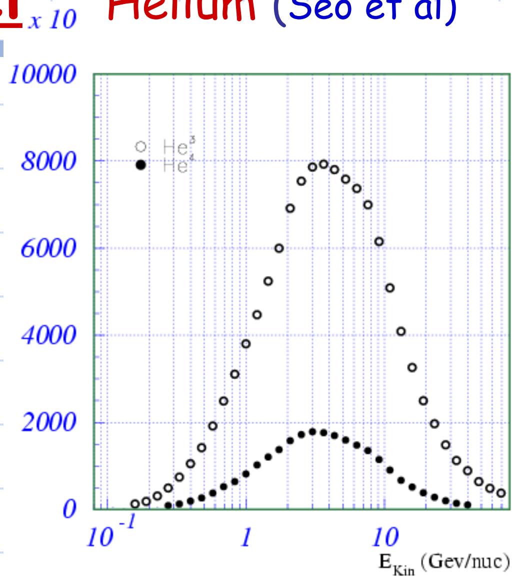


Simulation of helium and beryllium nuclei

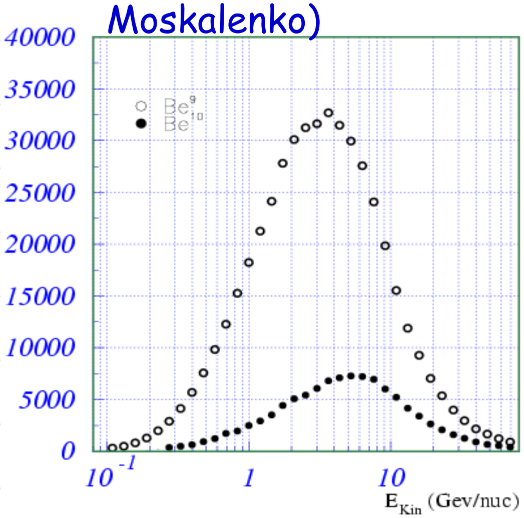
Element	Statistics	Observation time
^3He	3.4×10^5	1 day
^4He	1.7×10^6	
^{10}Be	1.5×10^5	1 year
^9Be	7.0×10^5	

- They were subject to the RICH acceptance
- Geomagnetic field taken into account: modulation of the nuclei energy with the ISS location
- Tracker momentum uncertainty folded $\Delta p/p \sim 2\%$

Helium (Seo et al)

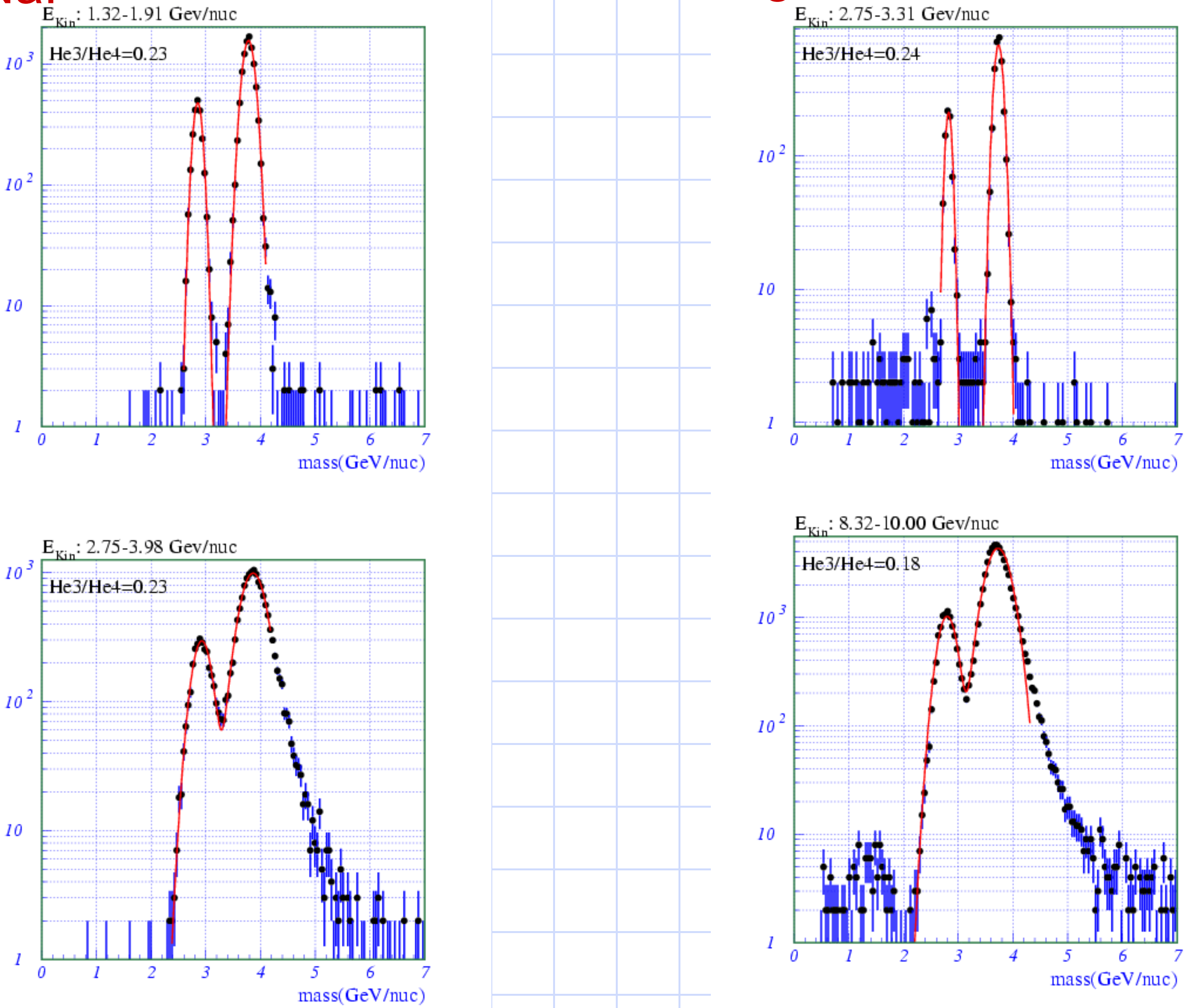


Beryllium (Strong & Moskalenko)

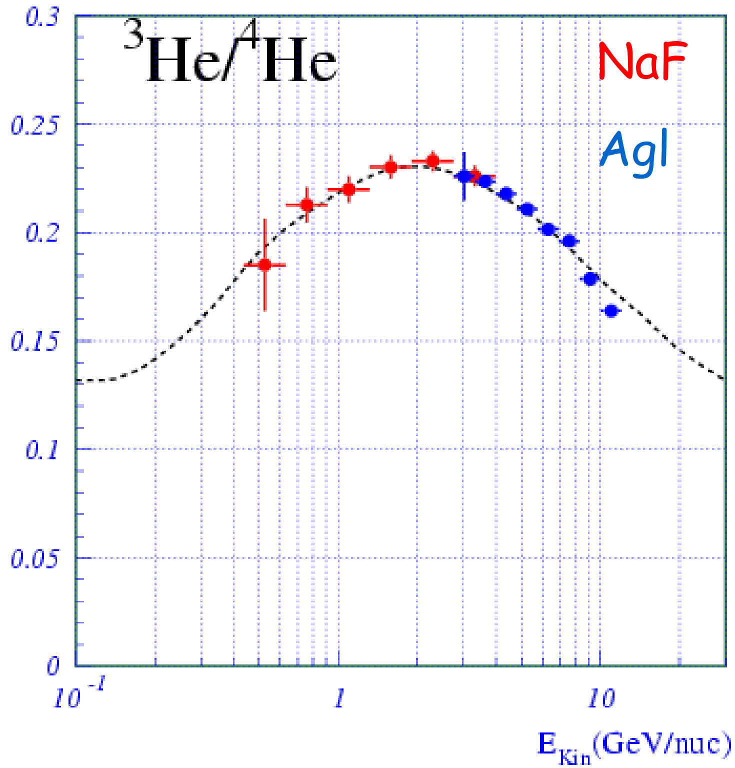


Isotopic separation mass distribution (Helium)

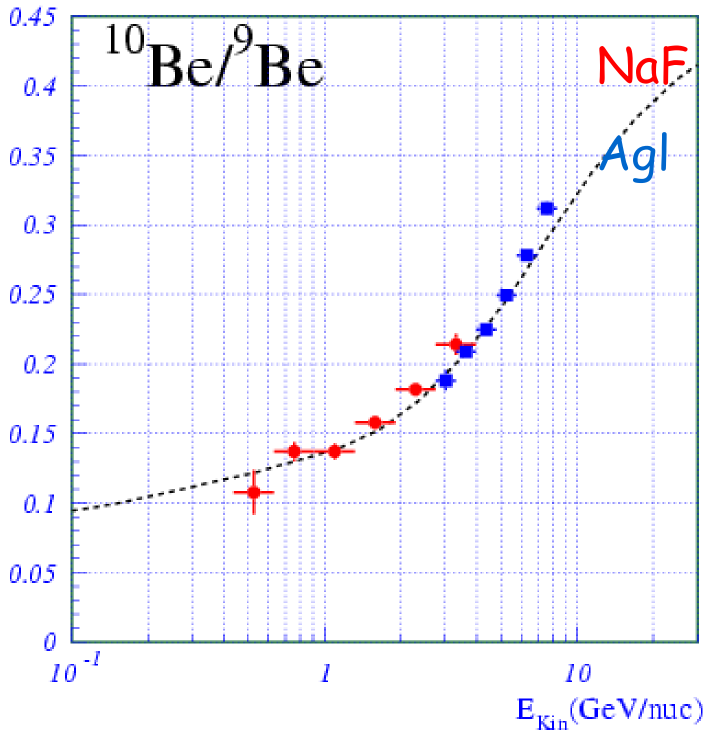
NaF AgI



Reconstructed isotopic ratios for He and Be

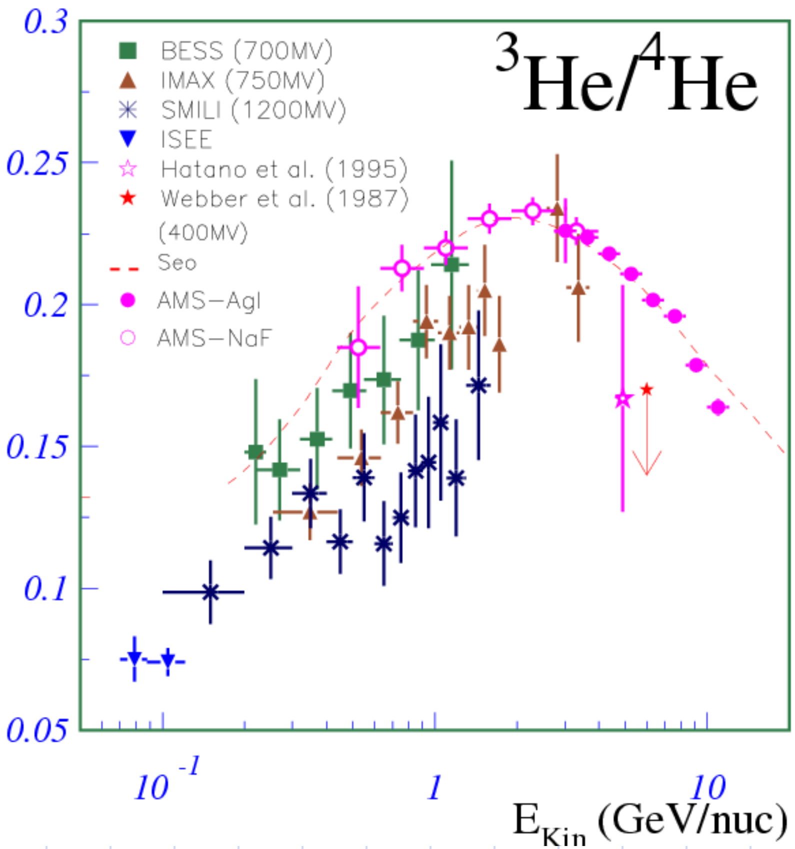


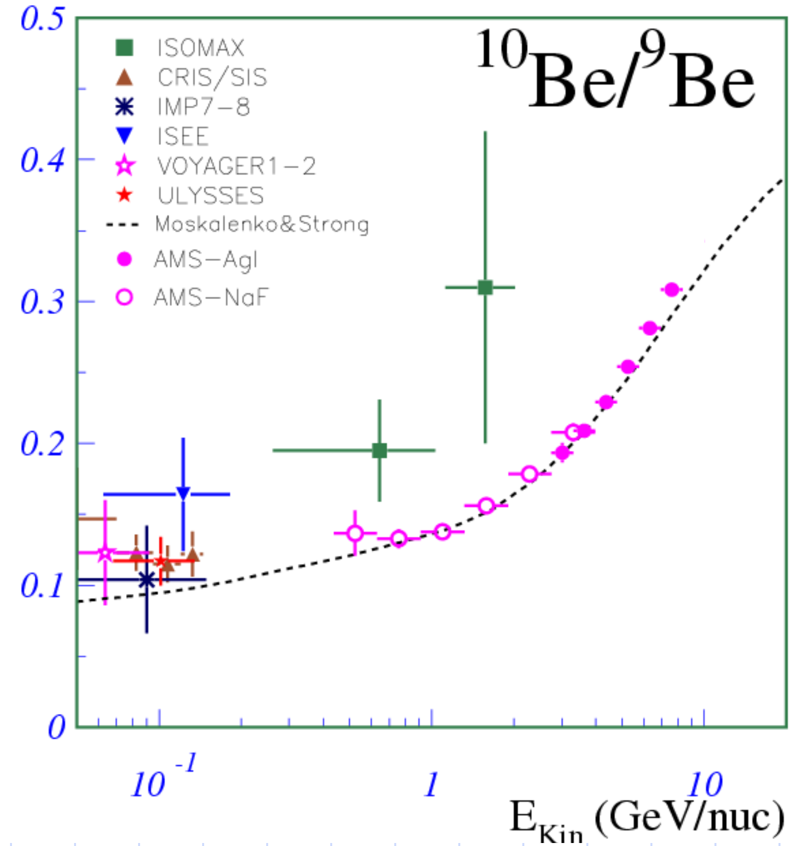
1 day



1 year

AMS reconstructed isotopic ratios compared with previous experiments





Conclusions

- The RICH detector was designed to provide AMS with very precise velocity measurement $\frac{\Delta\beta}{\beta} = 0.1\%$ in order to
  - Perform isotopic mass separation in an wider energy range 0.5 GeV/nuc up to 10 GeV/nuc
  - Contribute to e/p separation
- 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