# 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)

luisa@lip.pt

# Outline

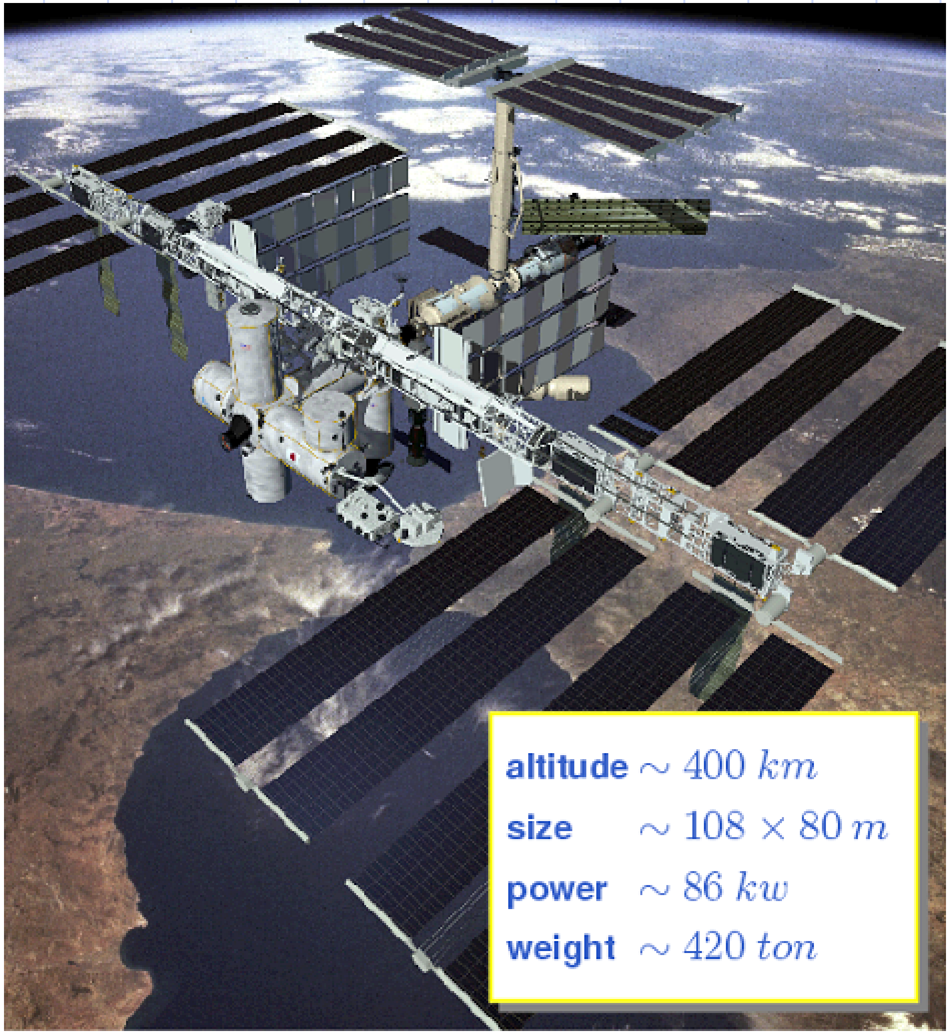
- The AMS experiment:
    - ✓ Physical aims
    - ✓ Spectrometer
- The RICH detector
- Photon pattern tracing
- Velocity reconstruction
- Charge reconstruction
- Isotopic separation: $^{3}He/^{4}He$ and $^{10}Be/^{9}Be$
- Conclusions

luisa@lip.pt

# AMS on the International Space Station

AMS 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 $He/He<10^{-9}$;
- Search for dark matter
- Precision measurements on the relative abundance of different nuclei and isotopes of primary cosmic rays E<1 TeV

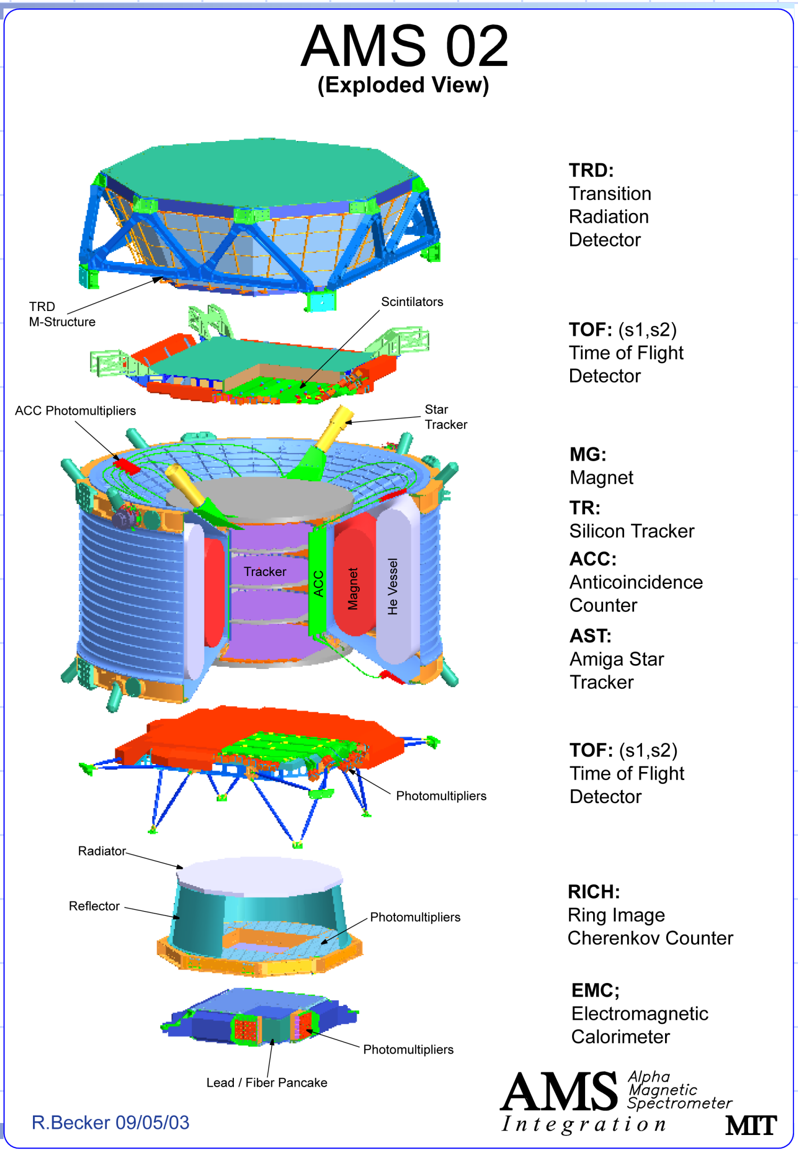


**altitude** $\sim 400\ km$
**size** $\sim 108 \times 80\ m$
**power** $\sim 86\ kw$
**weight** $\sim 420\ ton$

# AMS on the International Space Station

The AMS spectrometer will be composed by:

- a Transition Radiation Detector,
- a Time Of Flight detector,
- a microstrip silicon tracker,
- a superconducting magnet,
- an AntiCoincidence (veto) Counter,
- a Ring Imaging CHerenkov detector and
- an electromagnetic calorimeter.



RB0305AMSexpld

# AMS Spectrometer Capabilities

- Particle bending

  *Superconducting magnet*

- Particle direction of incidence

  *Time-of-Flight, Tracker*

- Rigidity (p/Z)

  *Silicon Tracker*

- Velocity (β)

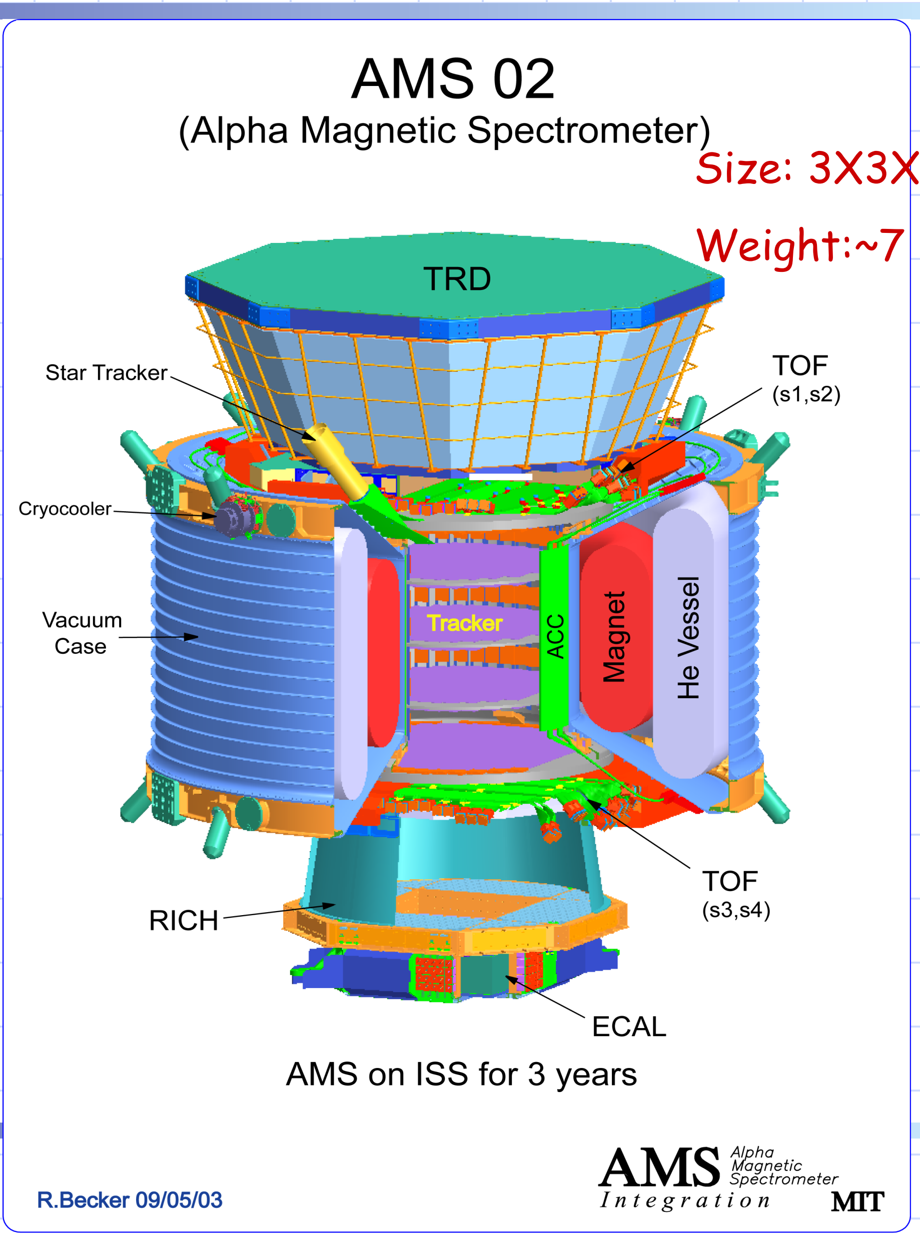
  *Time-of-Flight, RICH*

- Charge (Q)

  *RICH, Tracker, TOF*

- Trigger

  *TOF, ECAL, AntiCounter*



AMS 02

(Alpha Magnetic Spectrometer)

Size: 3X3X3 $m^3$

Weight:~7 T

AMS on ISS for 3 years

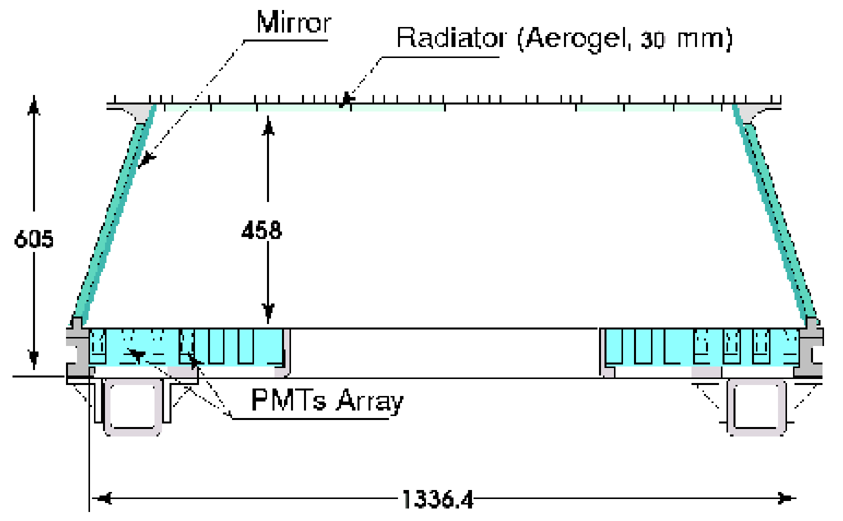
R.Becker 09/05/03

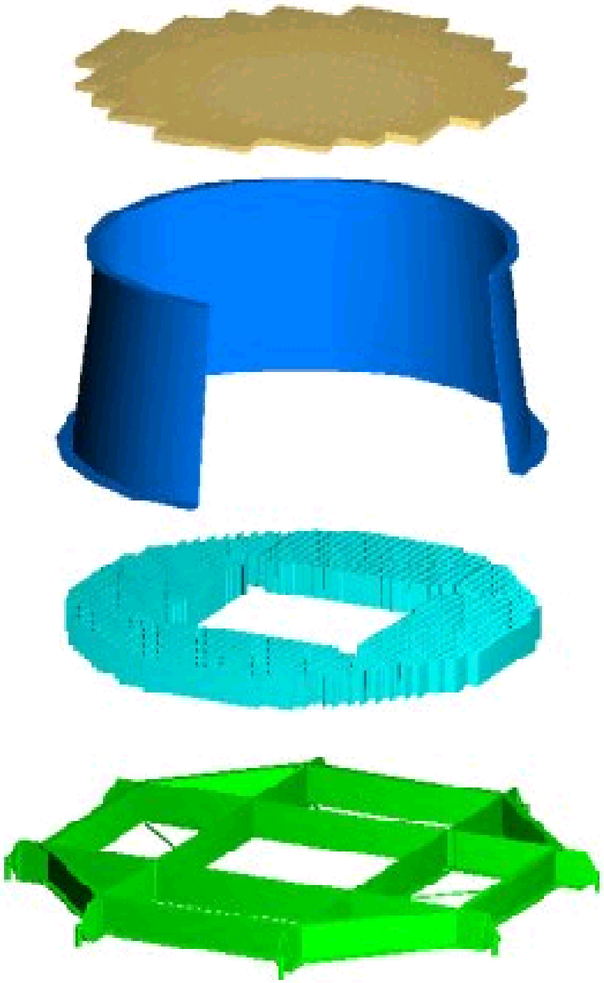
RB0305AMSdetector

# 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



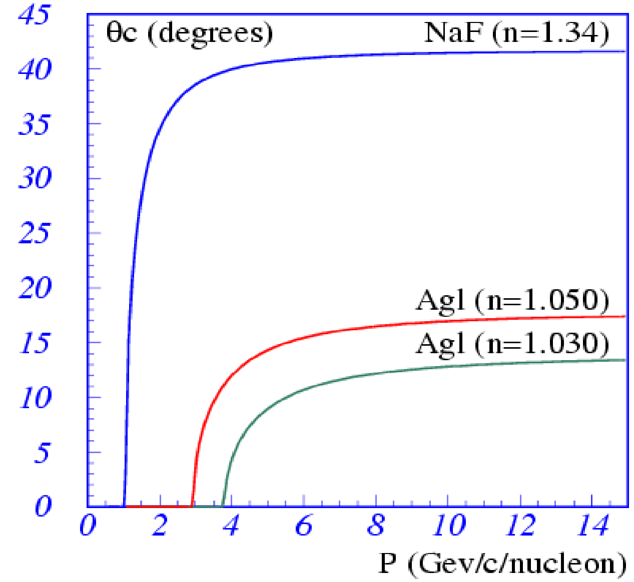


# RICH Radiator

- ✓ **Cerenkov radiation**

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

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



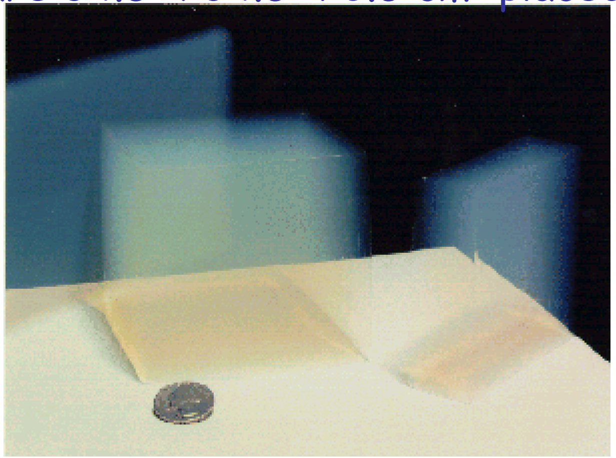
- ✓ **Radiator**

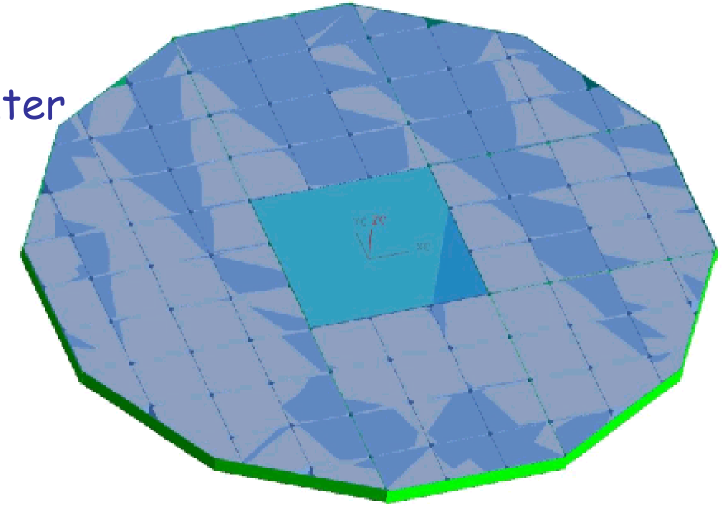
  Silica Aerogel n=1.03/1.05 3/2 cm of thickness

  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



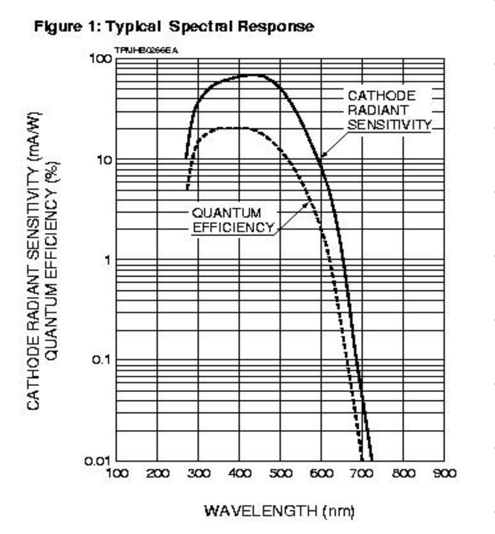


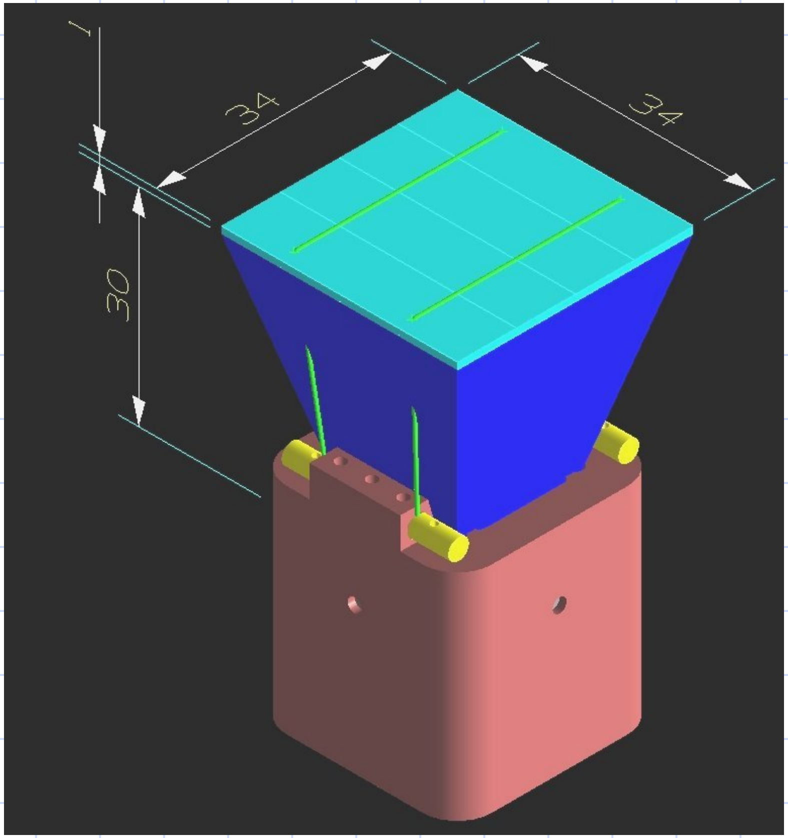
# Detection Matrix

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

    **4.5 mm pitch**
  - spectral response 300-650 nm

    **maximum at $\lambda$ = 420 nm**





- **Light Guides**

  Plexiglass (n=1.49) solid guides

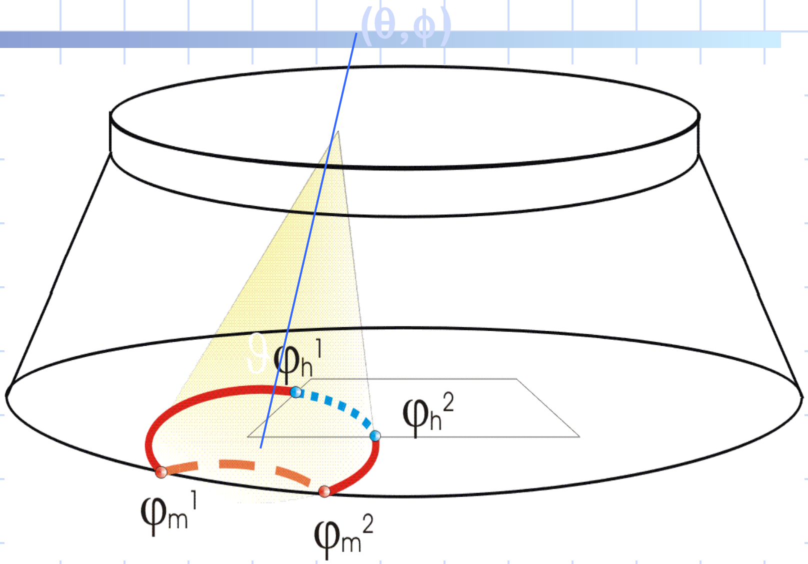
  Effective pixel size 8.5 mm

# Photon Pattern Tracing

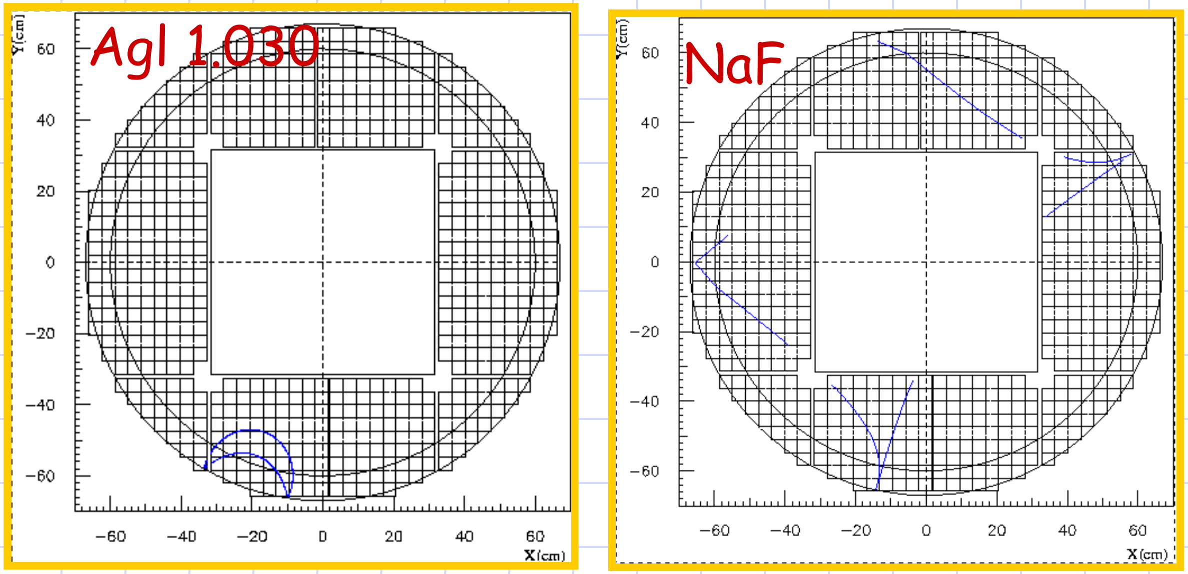
## Photon tracing includes:

Emission at a reference point with an opening angle $\theta_c$ and at a given azimuthal angle $\varphi$.

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

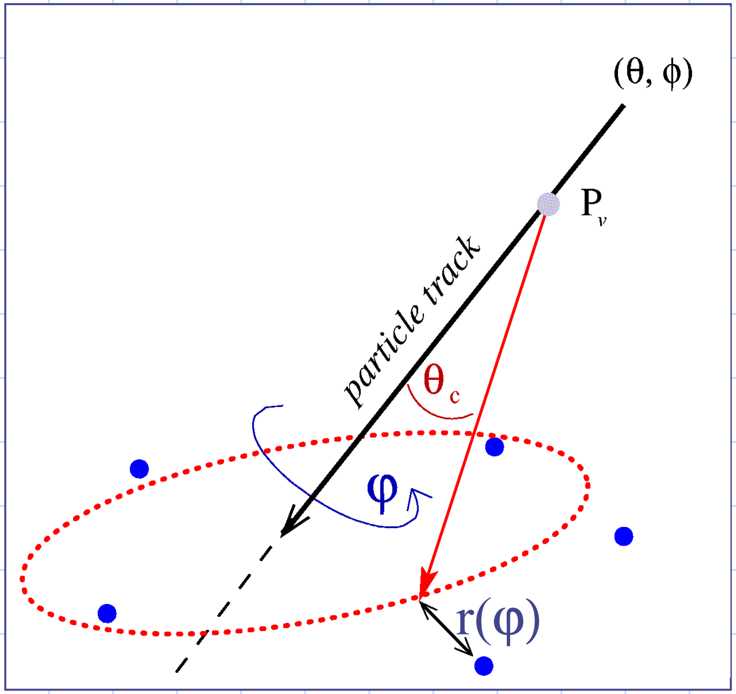


- ✓ escaping from radiator
- ✓ refracting at radiator boundary
- ✓ reflecting on mirror
- ✓ hitting detection plane



# $\theta_c$ 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 $\theta_c$
- ✓ The hits associated to the particle are excluded
- ✓ The maximization of a likelihood function provides the best $\theta_c$ angle



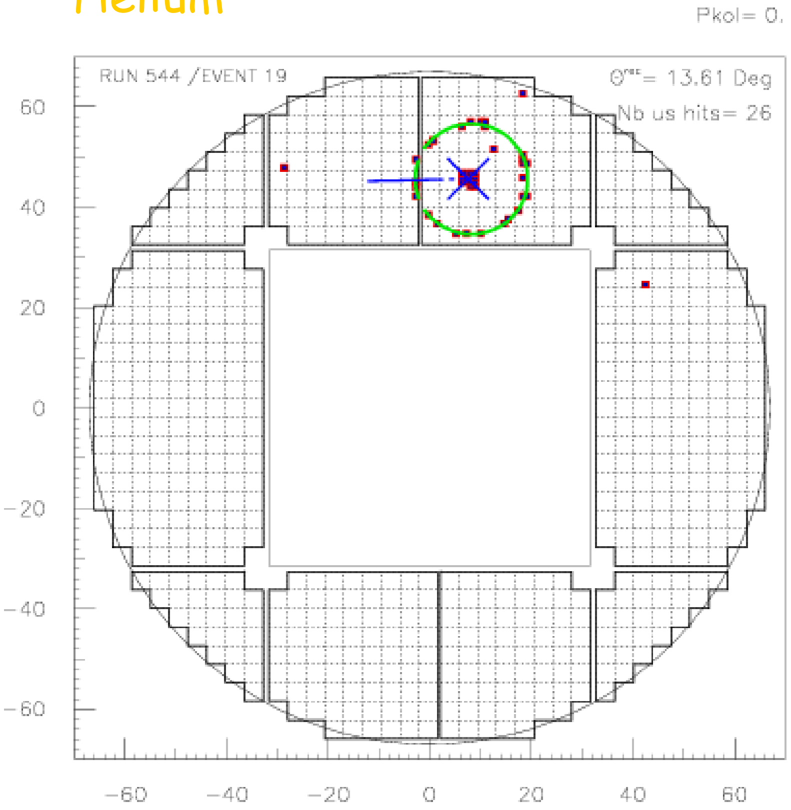
$$V(\theta_c) = \prod_{i=1}^{N_{hits}} P\{r_i(\varphi_i(\theta_c))\}$$

$r_i$ ≡ closest distance to the Cerenkov pattern

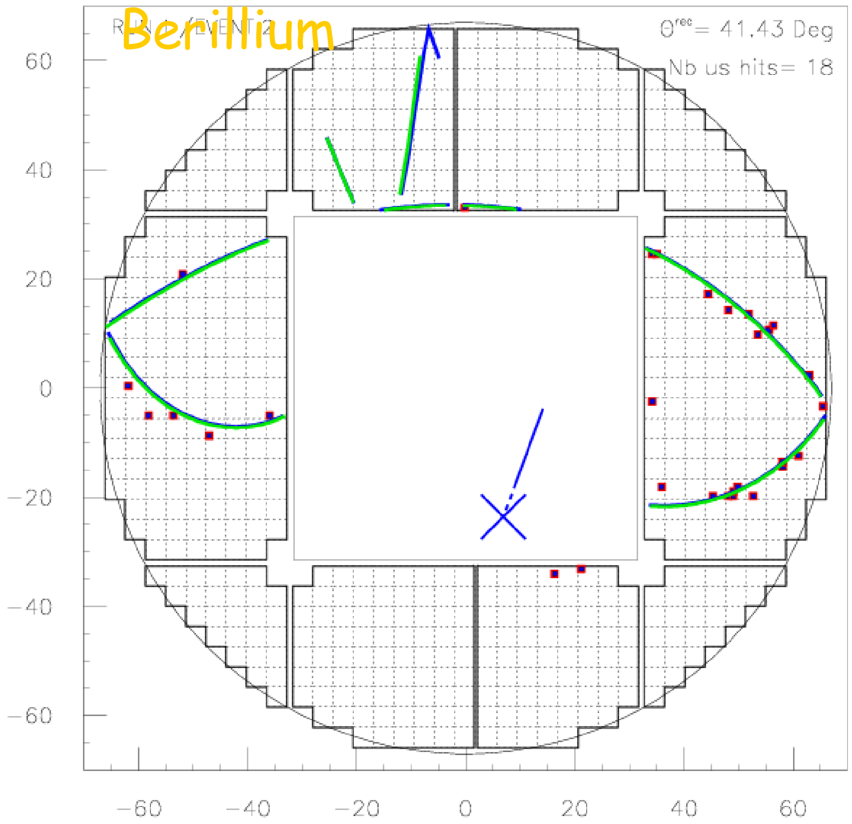
$P_i$ ≡ probability of a hit belong to the pattern

# $\theta_c$ reconstruction: event displays

Helium



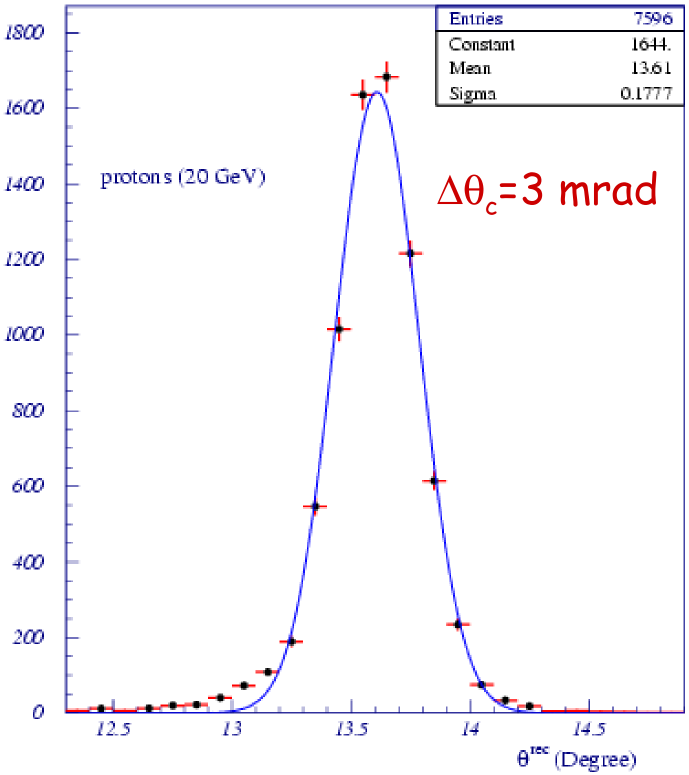
Berillium

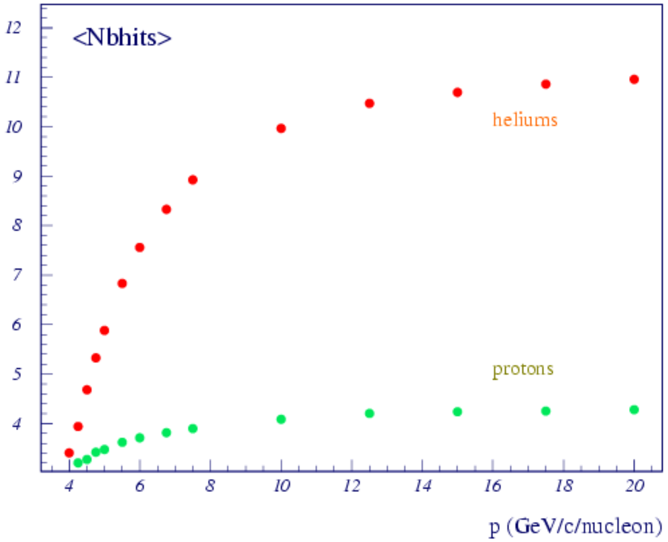


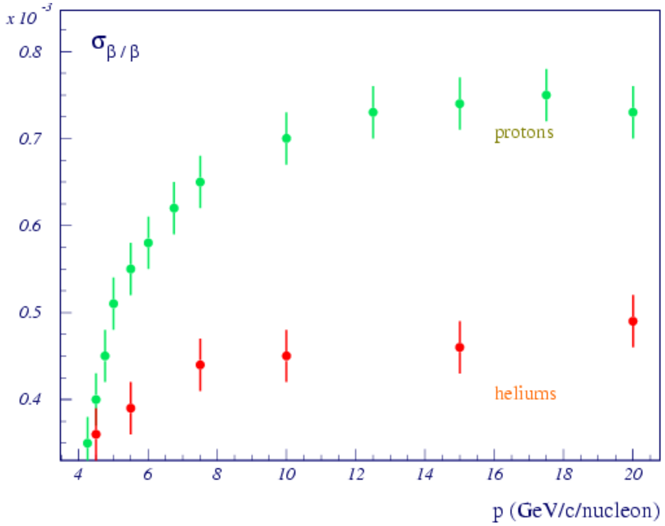
Simulated events: p=20 GeV/c/nucleon

luisa@lip.pt

# $\theta_c$ reconstruction: $\beta$ resolution scaling







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

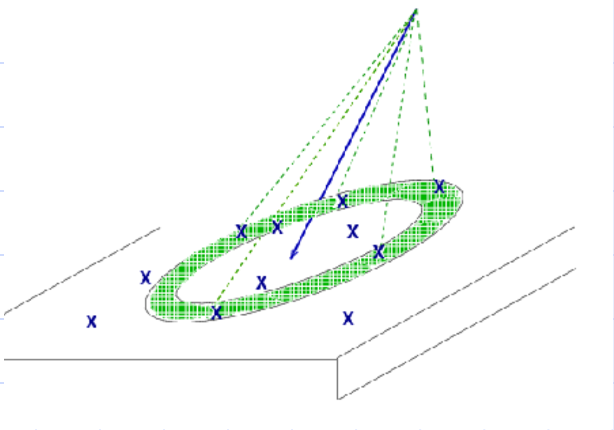
$$\frac{\Delta\beta}{\beta} = \tan\theta_c \frac{\Delta\theta_c}{\sqrt{N_{hits}}}$$

# 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:



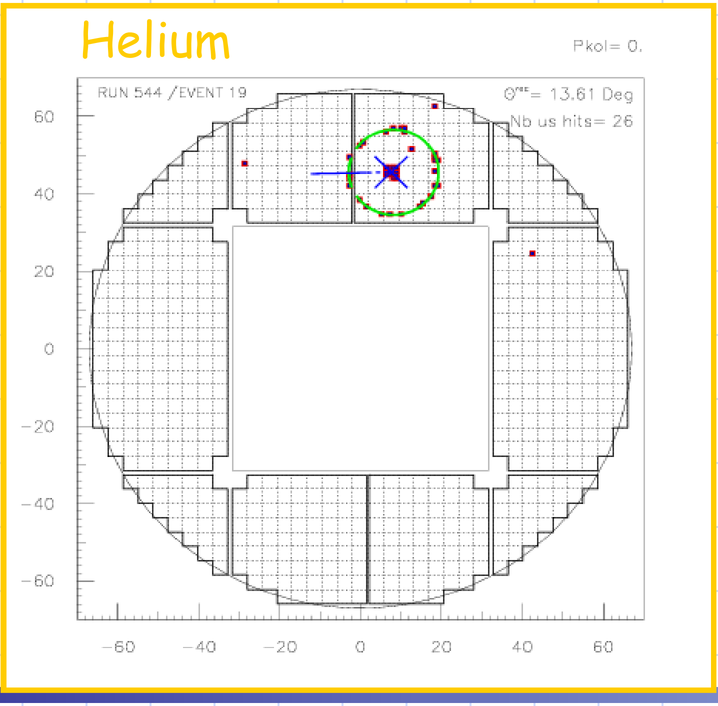
- radiator interactions ($\varepsilon_{rad}$) :
  - absorption and scattering
- geometrical acceptance ($\varepsilon_{geo}$) :
  - photons lost through the radiator lateral and inner walls
  - mirror reflectivity
  - photons falling into the non-active area
- light guide losses ($\varepsilon_{lg}$)
-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

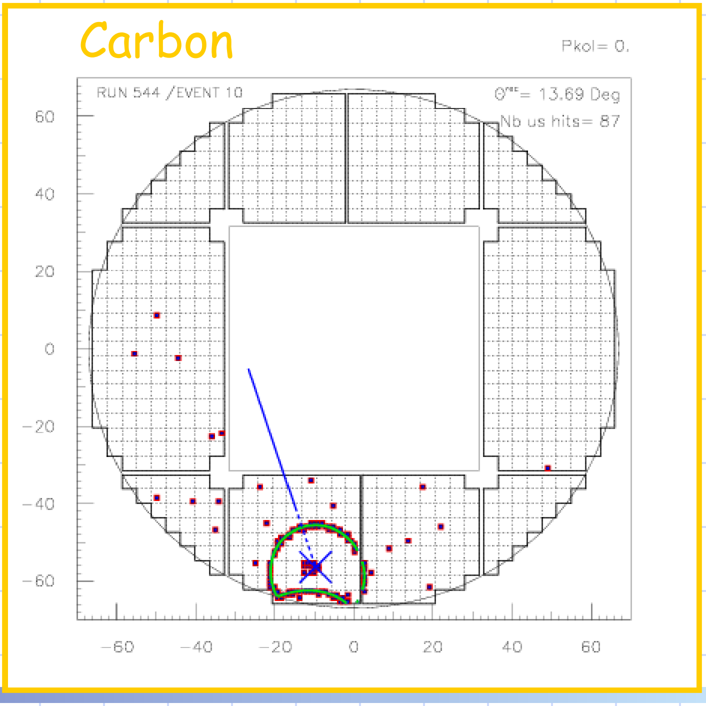
$$N_{pe} \propto Z^2 \Delta L \left(1 - \frac{1}{\beta^2 n^2}\right) \underbrace{\varepsilon_{rad}\,\varepsilon_{geo}\,\varepsilon_{lg}\,\varepsilon_{pmt}}_{\varepsilon_{tot}(\theta_c,\theta,\phi,P_I)}$$

# Charge reconstruction method

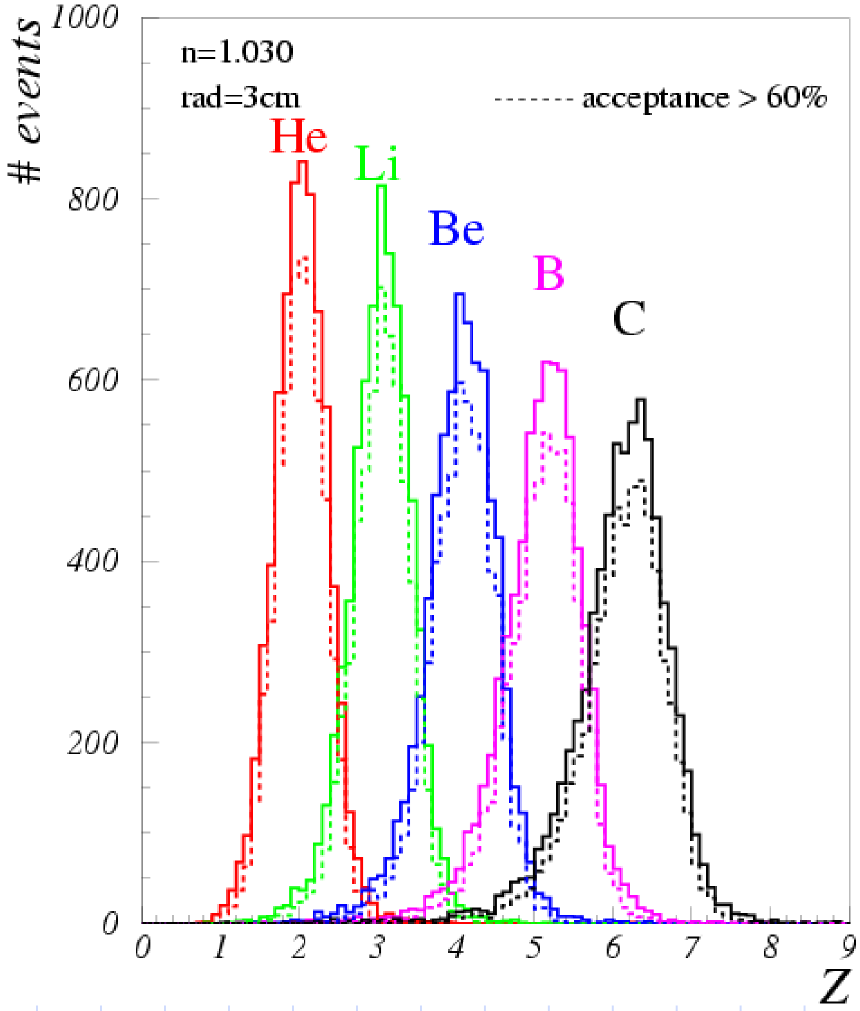
- ✓ Cerenkov angle reconstruction
- ✓ Photoelectron countage: the signal (p.e.) close to the reconstructed photon pattern is summed up $\Delta r < 1.3$ cm
- ✓ Photon detection efficiency
- ✓ Reconstruct electric charge

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

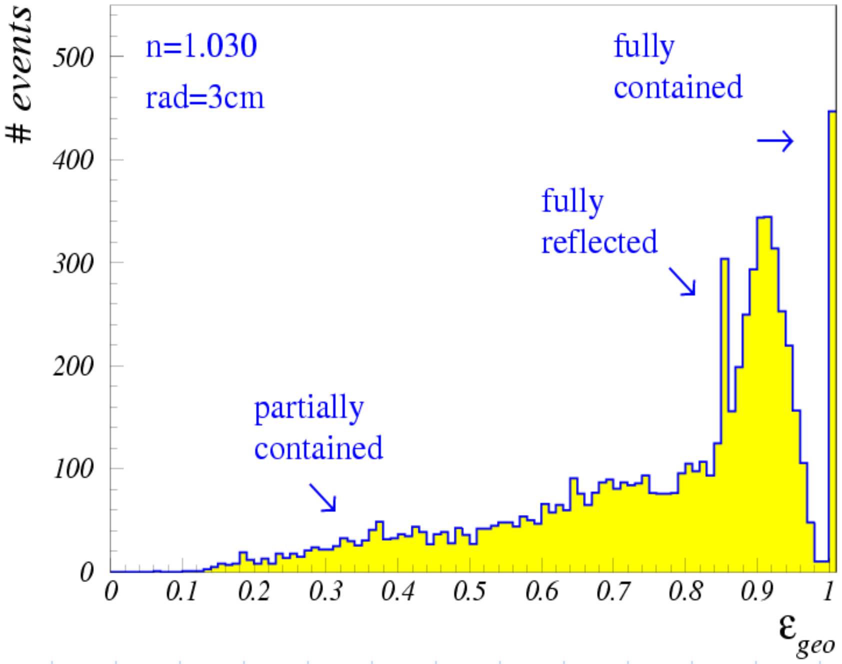

Helium


Carbon

# Charge reconstruction: simulated data



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



# RICH PROTOTYPE

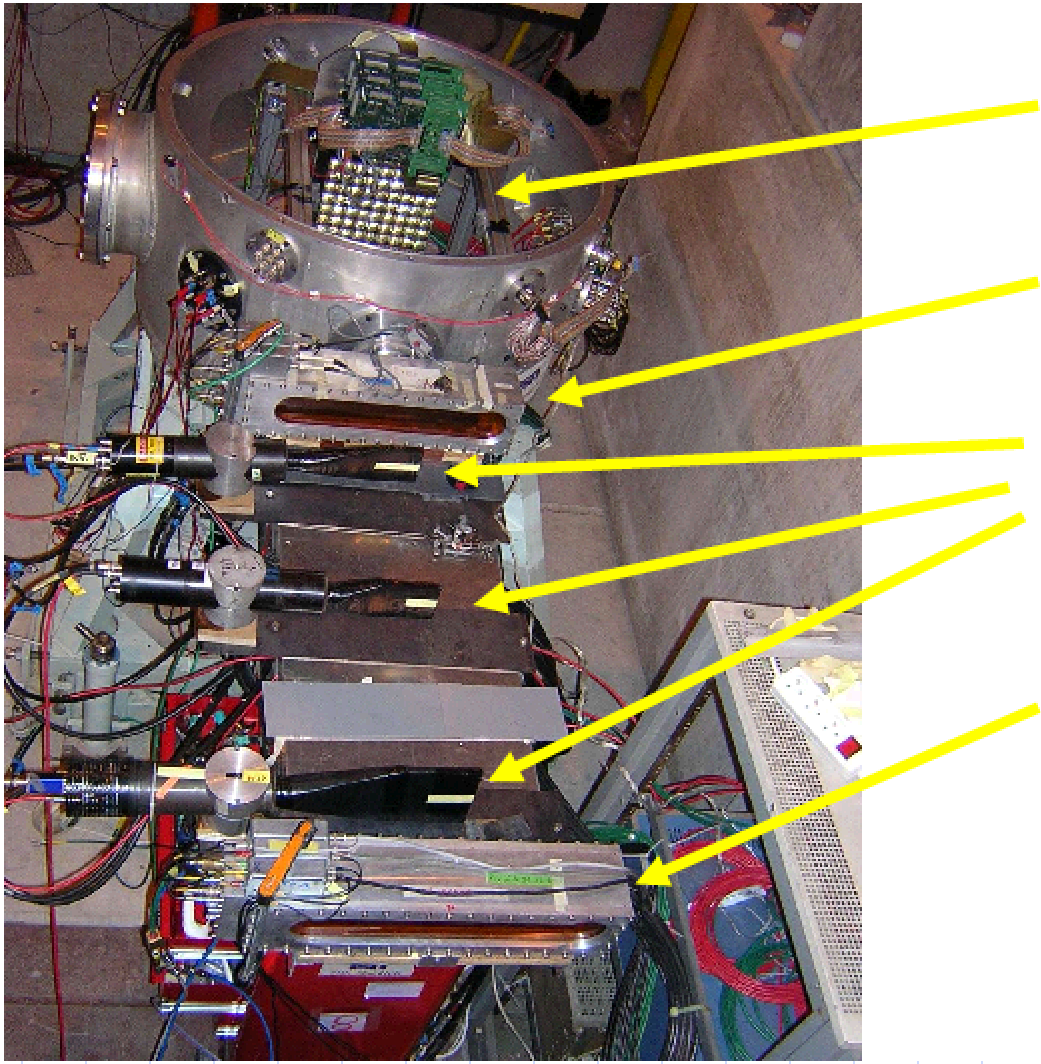
A small scale prototype with a detection matrix with 96 PMT's has been assembled:

- ✓ 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 158 GeV/nuc

# Test Beam 2003: experimental setup



Prototype &
RO electronics

- MWPC

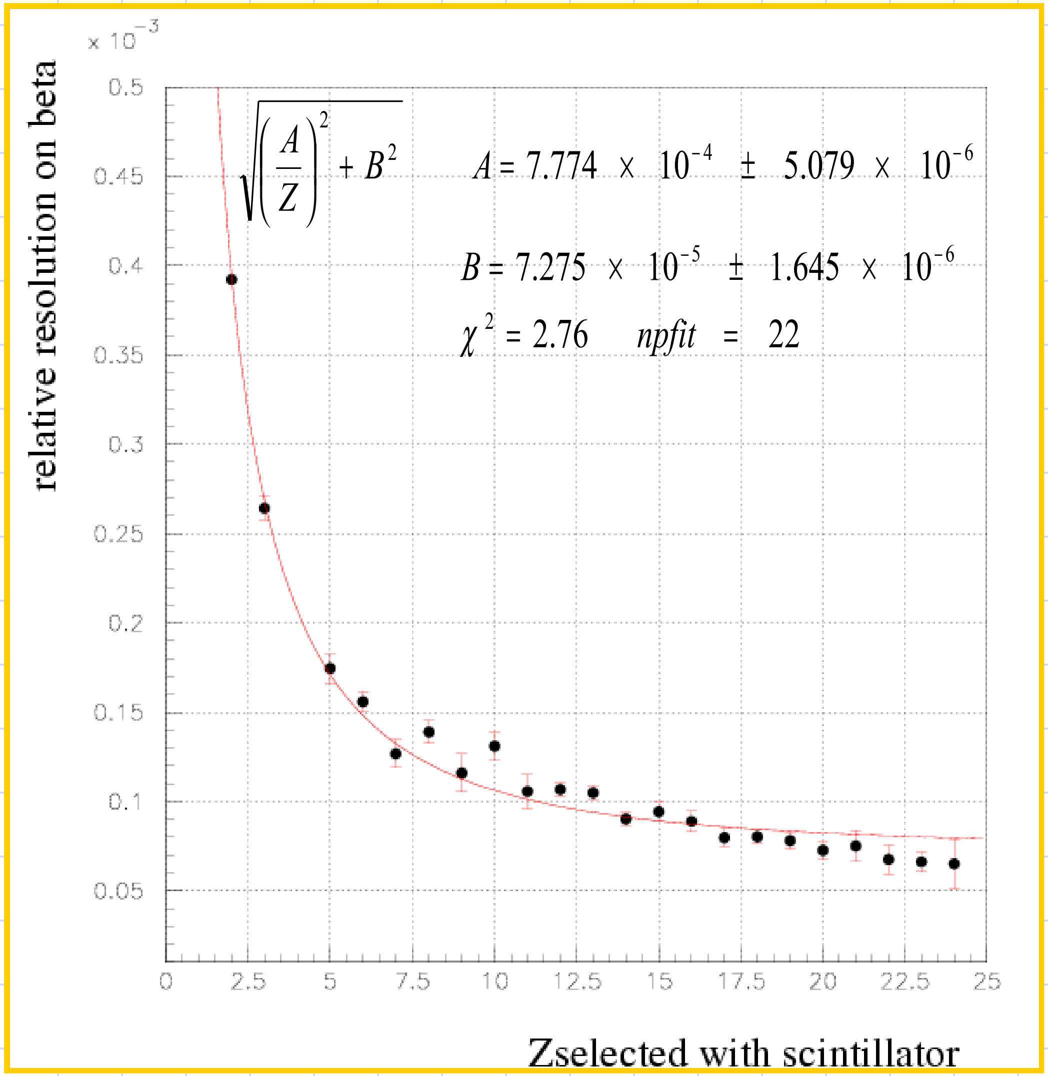
- dE/dx
    - Scintillators
    - Cerenkov

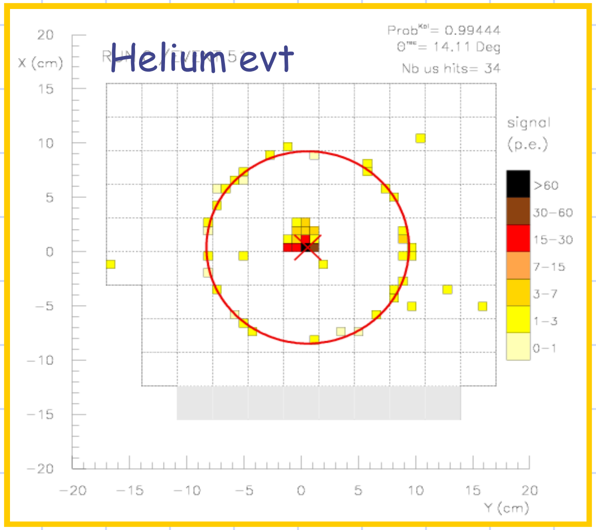
- MWPC

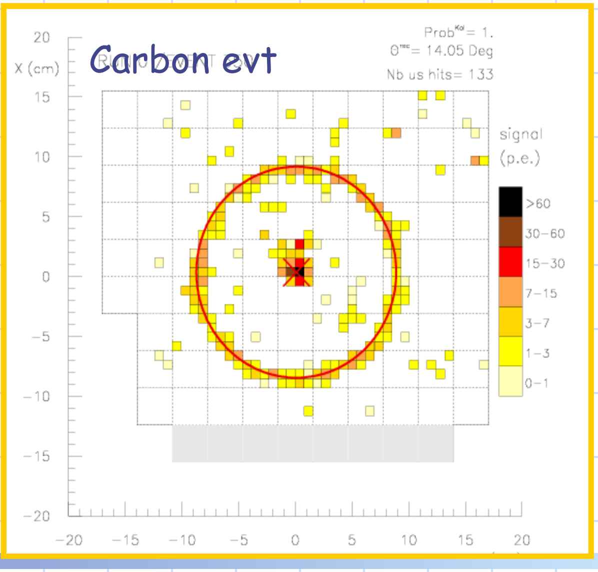
⊕ Tracker Prototype
⊕ TOF Prototype

luisa@lip.pt

# Beta reconstruction in the test beam

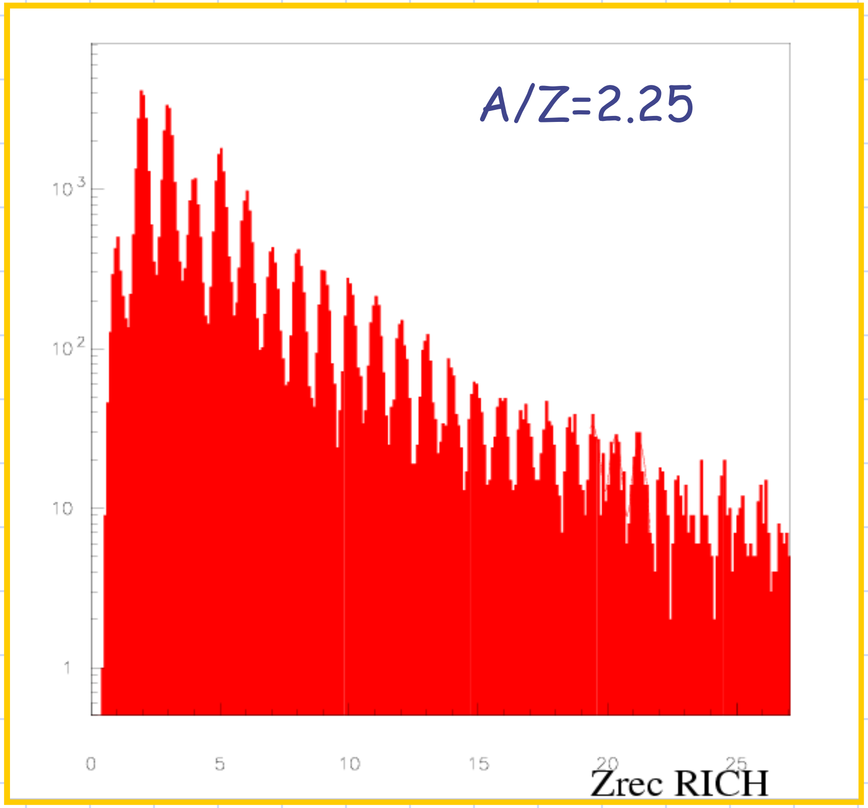


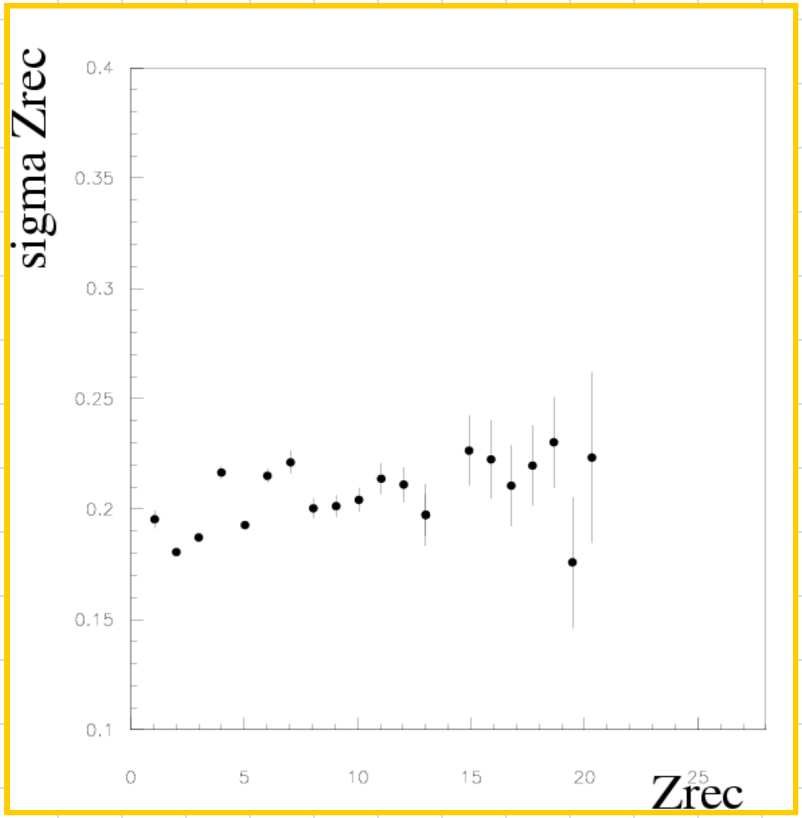




# Charge reconstruction

Charge separation up to Z~30





# Future Physics Prospects with RICH

- ✓ Dark matter search
  - ➢ $e^+$, $\bar{p}$ 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)

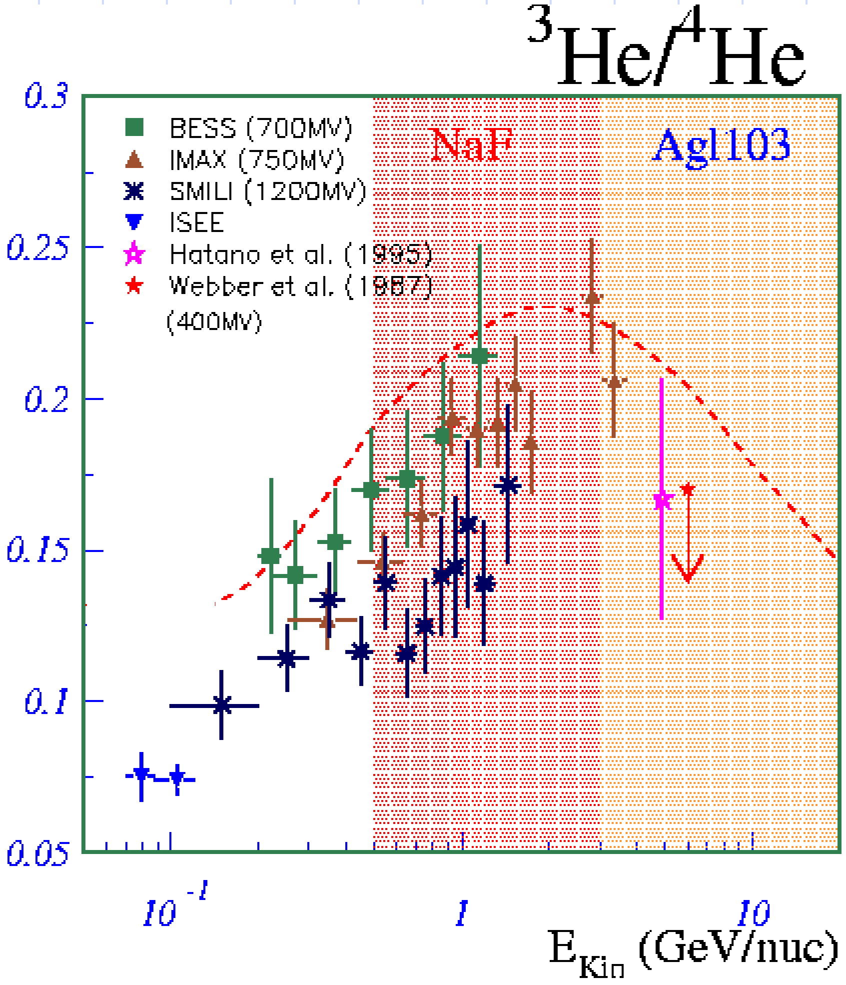
# Helium isotopic separation: Physical motivations

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 $E_{kin} \sim 3$ GeV/nuc

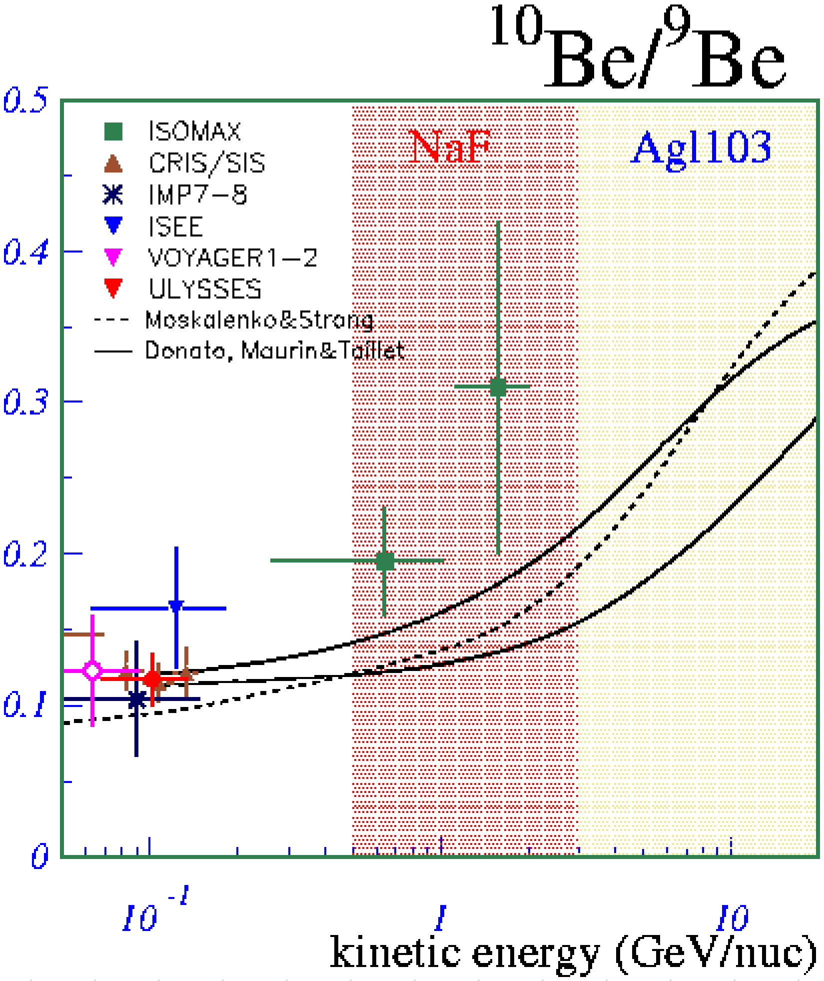
The integration of NaF in the RICH radiator will alow to measure isotopic ratios down to $E_{kin} \sim 0.5$ GeV/nuc



# 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

$\tau_{1/2}(^{10}Be) \sim 1.5\times10^{6}$ years



Light isotopic measurements before AMS:

- done at relatively low energies

  < 1.57 GeV/nuc (ISOMAX)

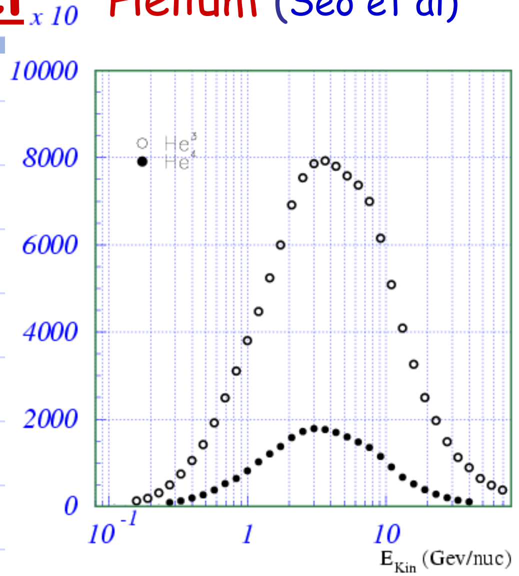
- based on a rather low statistics

# Simulation of helium and beryllium nuclei

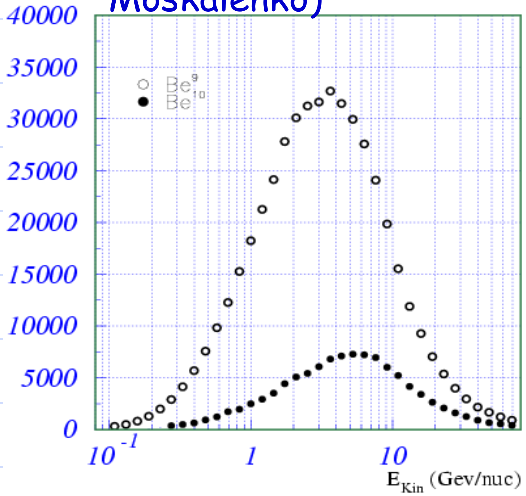
| Element | Statistics | Observation time |
|---|---|---|
| $^3$He | 3.4 x $10^5$ | 1 day |
| $^4$He | 1.7 x $10^6$ | |
| $^{10}$Be | 1.5 x $10^5$ | 1 year |
| $^9$Be | 7.0 x $10^5$ | |

- 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 Δp/p ~ 2%

Helium (Seo et al)



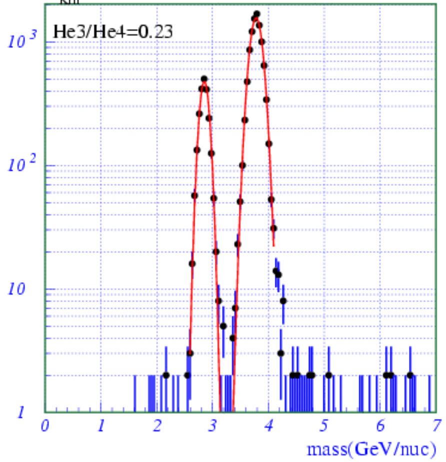
Beryllium (Strong & Moskalenko)



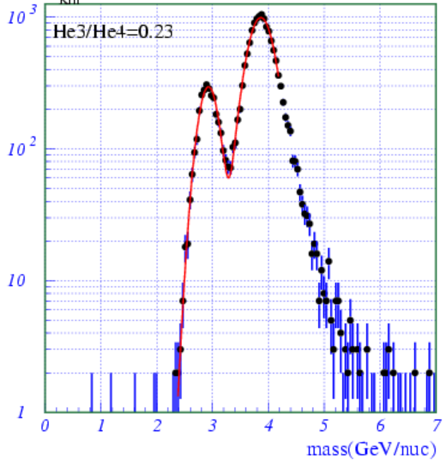
# Isotopic separation mass distribution (Helium)

NaF

$E_{Kin}$: 1.32-1.91 Gev/nuc

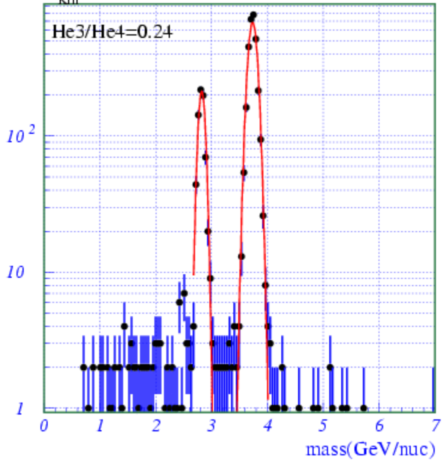


$E_{Kin}$: 2.75-3.98 Gev/nuc

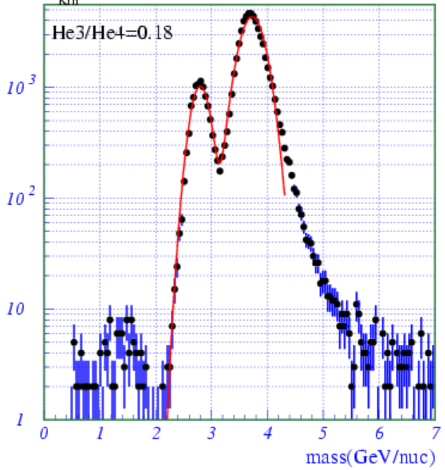


AgI

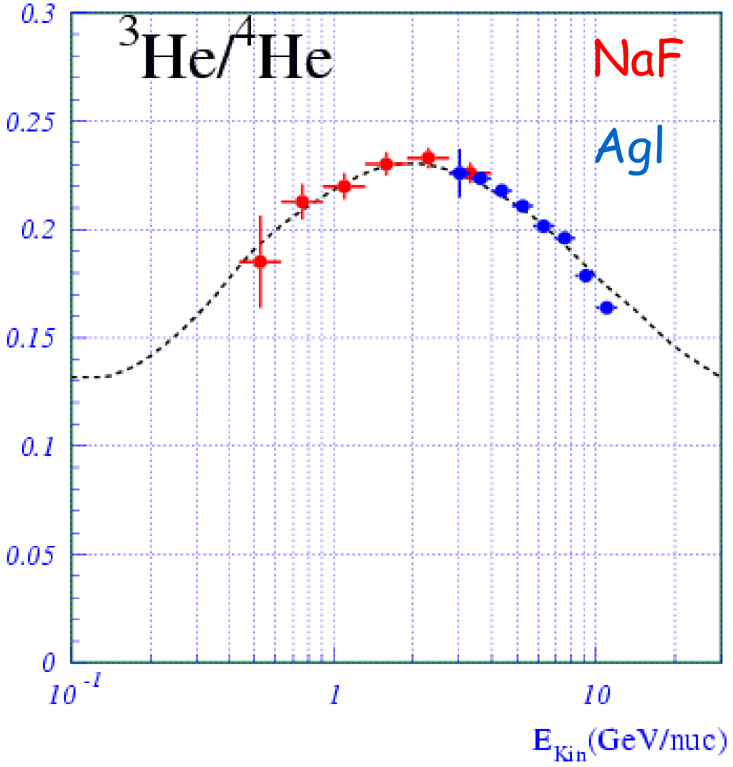
$E_{Kin}$: 2.75-3.31 Gev/nuc



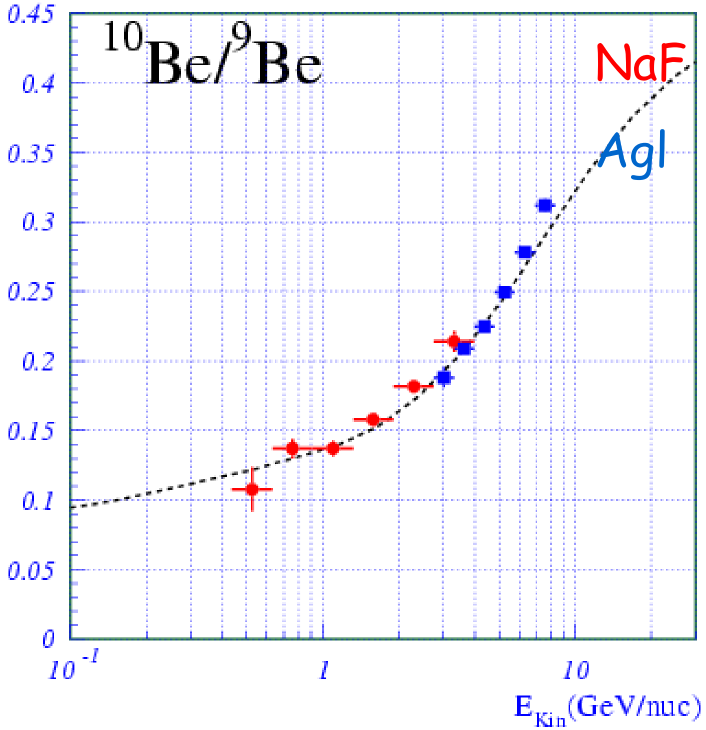
$E_{Kin}$: 8.32-10.00 Gev/nuc



# Reconstructed isotopic ratios for He and Be



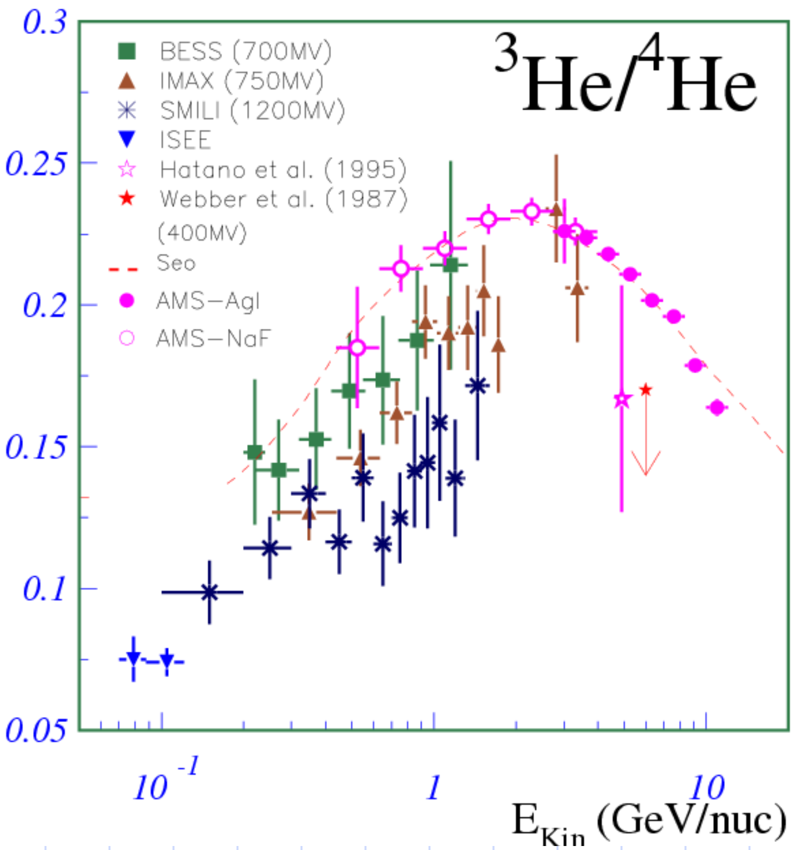
1 day

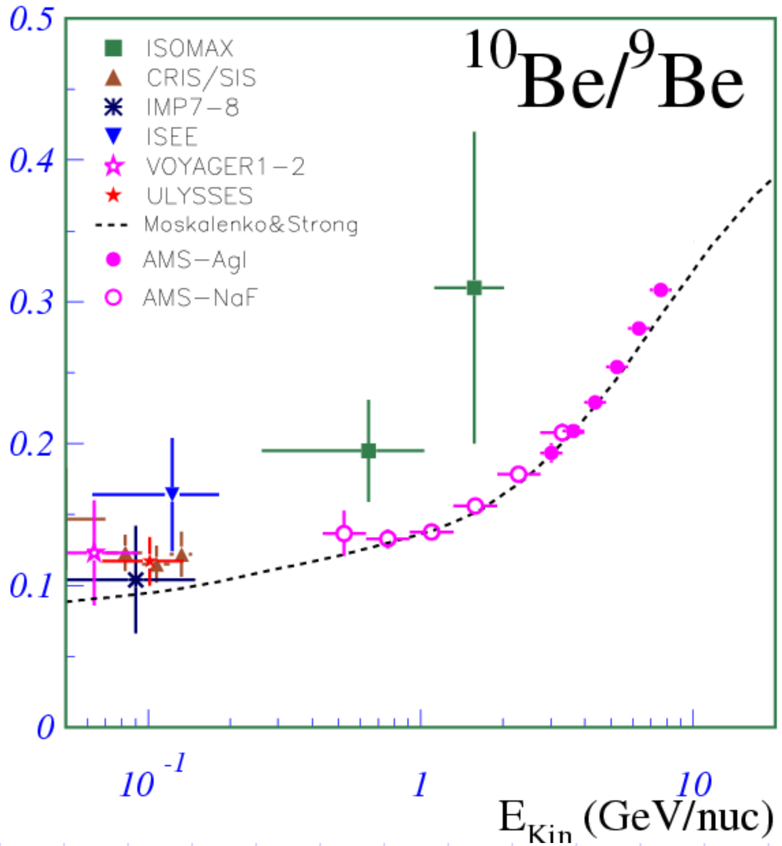


1 year

luisa@lip.pt

# AMS reconstructed isotopic ratios compared with previous experiments





# Conclusions

- ✓ AMS will be installed on the ISS in 2007 for three years for antimatter and dark matter search
- ✓ 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

luisa@lip.pt