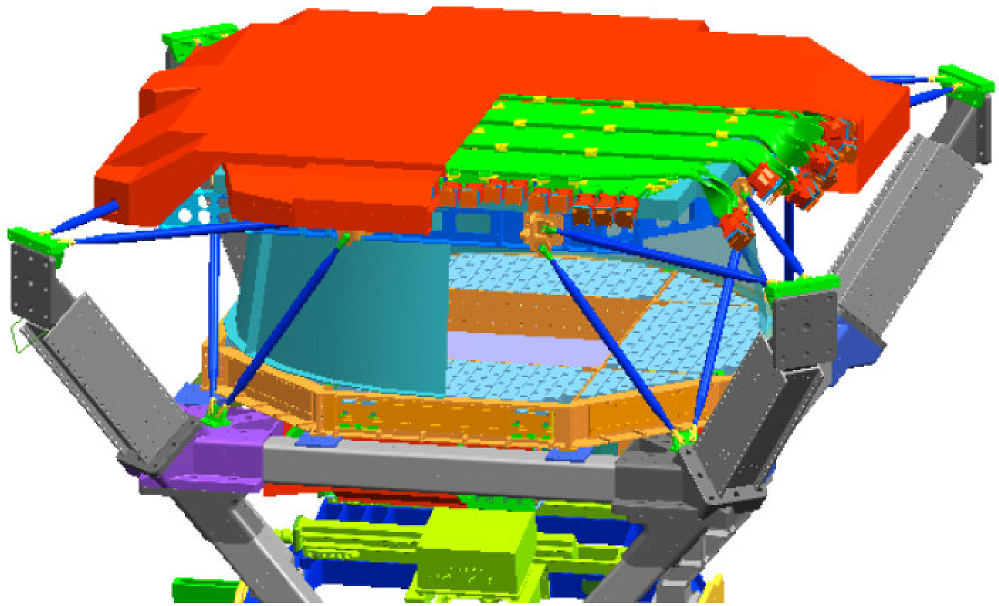
The Ring Imaging Cherenkov Detector (RICH) of the AMS Experiment



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Outline

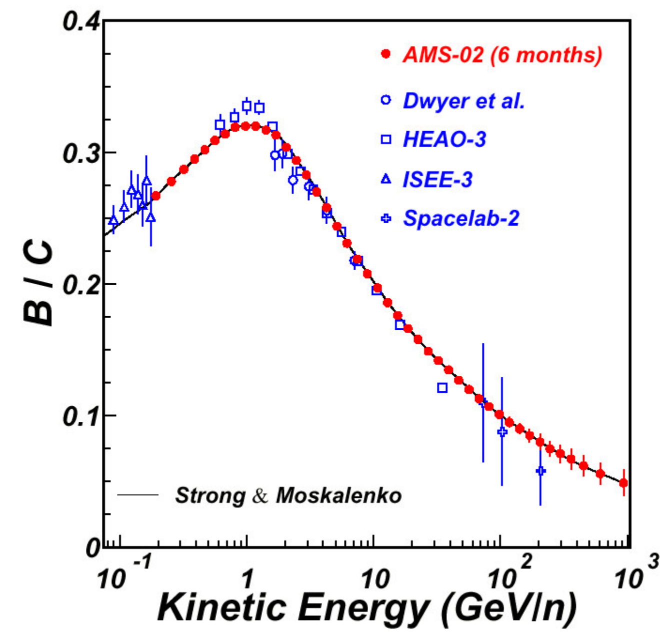
- Physics Motivations
- RICH goals
- RICH design principles
  - radiator, reflector, detection cells
- Velocity and Charge accuracy
- RICH Prototype beam test
  - aerogel choice and properties
  - velocity and charge reconstruction

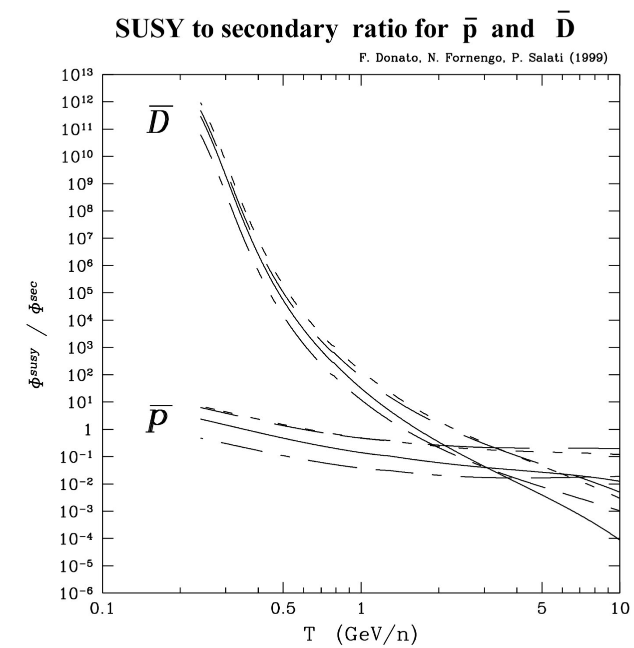
    aerogel and NaF radiators
  - mirror reflectivity
- Conclusions

Astrophysics motivations

- ✔ **Cosmic Rays Propagation**
  - ▶ The study of secondary species such as Li, Be and B which result essentially from CNO spallation provides information about propagation of cosmic-rays (CNO group) in galaxy (B/C)
    $Z > 2$ **abundance only** $\sim$ **1%**
  - ▶ The propagation history of the Helium nuclei can be probed by measuring the ratio $^3He/^4He$
    $^3\mathbf{He}$ **is essentially secondary** (from the $^4\mathbf{He}$ spallation)
- ✔ **Cosmic Rays Clocks**
  - ▶ The measurement of the ratio $^{10}Be/^9Be$ gives information about confinement of cosmic rays in the Galactic volume and is sensitive to different propagation models
    $\mathbf{T_{1/2}(^{10}Be) \sim 1.5 \times 10^6\ yrs}$
- ✔ **New Physics**
  - ▶ positrons, antiprotons, antideuterons : dark matter probe

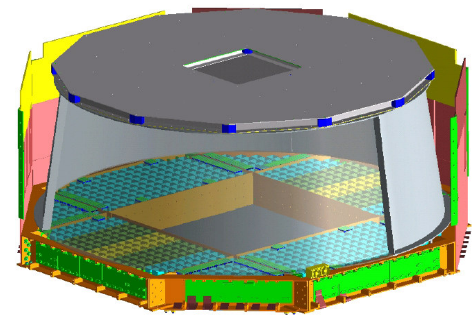
See Talk of M. Sapinski, *"Astrophysics with AMS02"*, OG.1.1





RICH goals

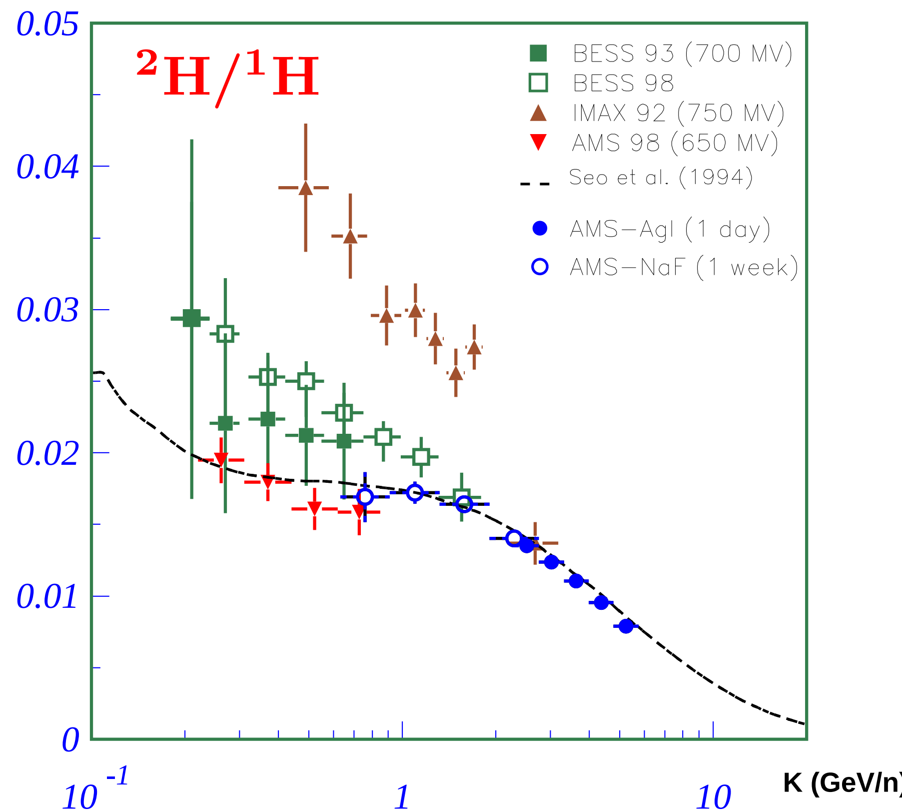
- ✔ Electric charge measurement over a wide range of Z's
  at least up to iron element (Z=26)
- ✔ High accuracy on velocity measurement
  $\Delta\beta/\beta \sim 0.1$ % for singly charged particles
- ✔ Contribution to AMS redundancy on albedo rejection



Mass separation deals with :

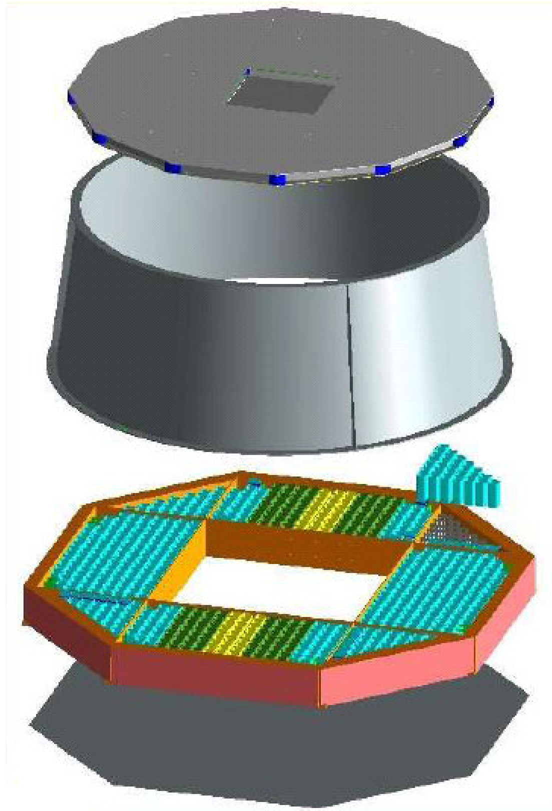
- ✔ momentum accuracy
  $\frac{\Delta p}{p} \sim 2\%$ **up to 10 GeV/c/n**
- ✔ velocity accuracy
  $\frac{\Delta\beta}{\beta} \sim \frac{0.1\%}{Z}$

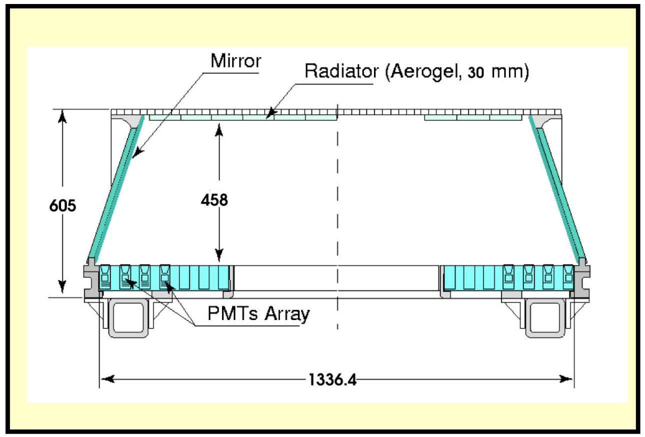
$$\frac{\Delta m}{m} = \frac{\Delta p}{p} \oplus \gamma^2 \left(\frac{\Delta\beta}{\beta}\right)$$



Ring Imaging Cerenkov Detector (RICH)

- ✔ proximity focusing Ring Imaging Detector
- ✔ dual solid radiator configuration
  - ▶ sodium fluoride in central region
    $n = 1.33$, 5 mm thick
  - ▶ low index material - aerogel - elsewhere
    $n = 1.05$, 27 mm thick
- ✔ conical reflector
- ✔ photomultiplier matrix
  680 multipixelized (4×4) unit cells





See C. LeLuc talk, *"The AMS-02 spectrometer"* OG.1.5

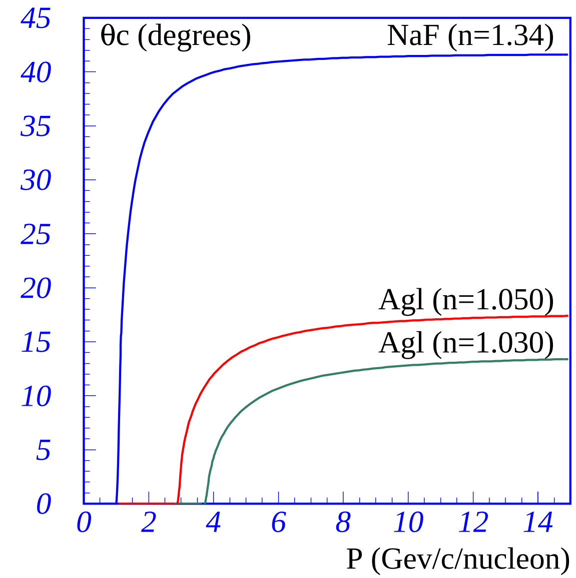
RICH radiator plane

- ✔ **Cerenkov radiation** $\boxed{\cos\theta_c = \frac{1}{\beta n}}$
- ✔ **Light Yield**
  the light yield increases with the radiator thickness (L), the charge (Z), the velocity (β) and refractive index (n) :

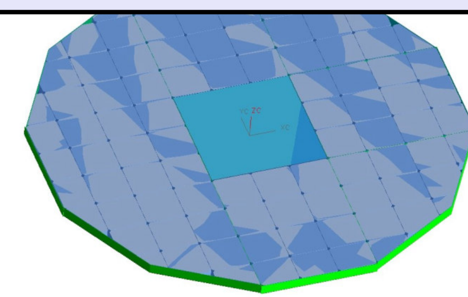
$$\boxed{N_{p.e} \propto Z^2\, L \left(1 - \frac{1}{\beta^2 n^2}\right) \int \varepsilon\, dE}$$

radiator	n	Z=1, $\beta \sim 1$	
		N_γ	$N_{p.e}$
aerogel	1.050	$\sim 75/cm$	$\sim$ 7
NaF	1.334	$\sim 375/cm$	$\sim$ 4

- ✔ **Aerogel : lowest refractive index solid material**
  - hygroscopic : pure gas pumped inside (N_2)
  - Rayleigh photon scattering $\frac{d\sigma}{d\Omega} \propto \frac{(1+\cos^2\theta_c)}{\lambda^4}$
    directionality of cerenkov photons lost
    transparency decreases for UVs $\Lambda_{int} = \frac{\lambda^4}{C}$
- ✔ **Ring acceptance**
  Sodium Fluoride (NaF) in the center increases the detector acceptance and extends the kinematic coverage (35×35 cm)

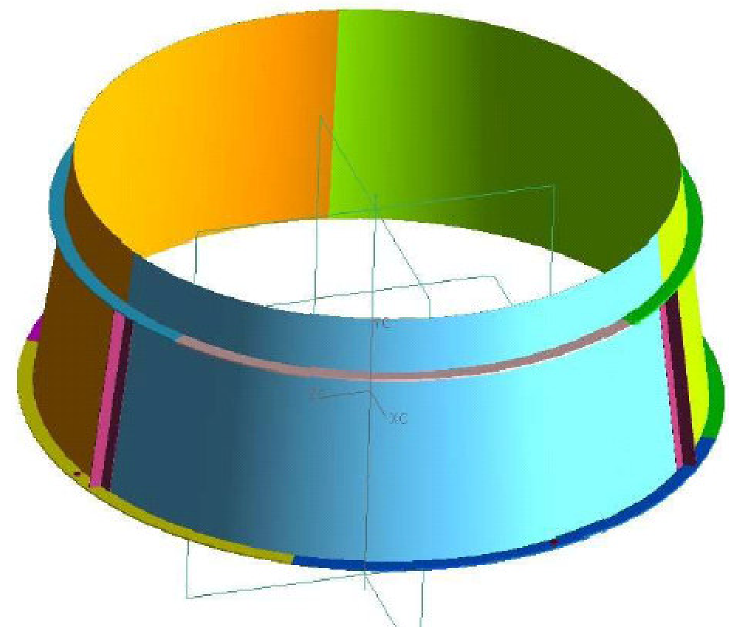


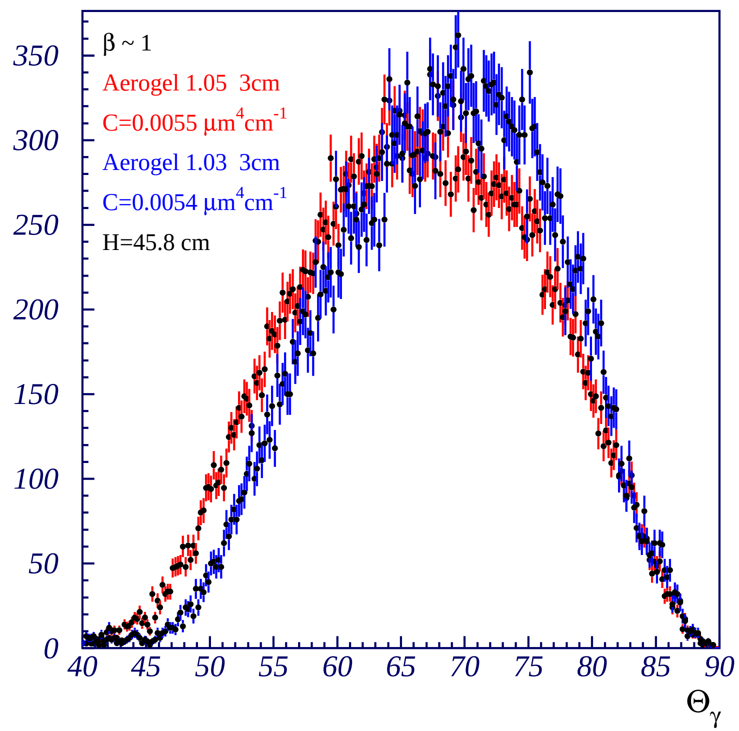
n=1.0.50 C $\sim 0.0055\, \mu m^4/cm$

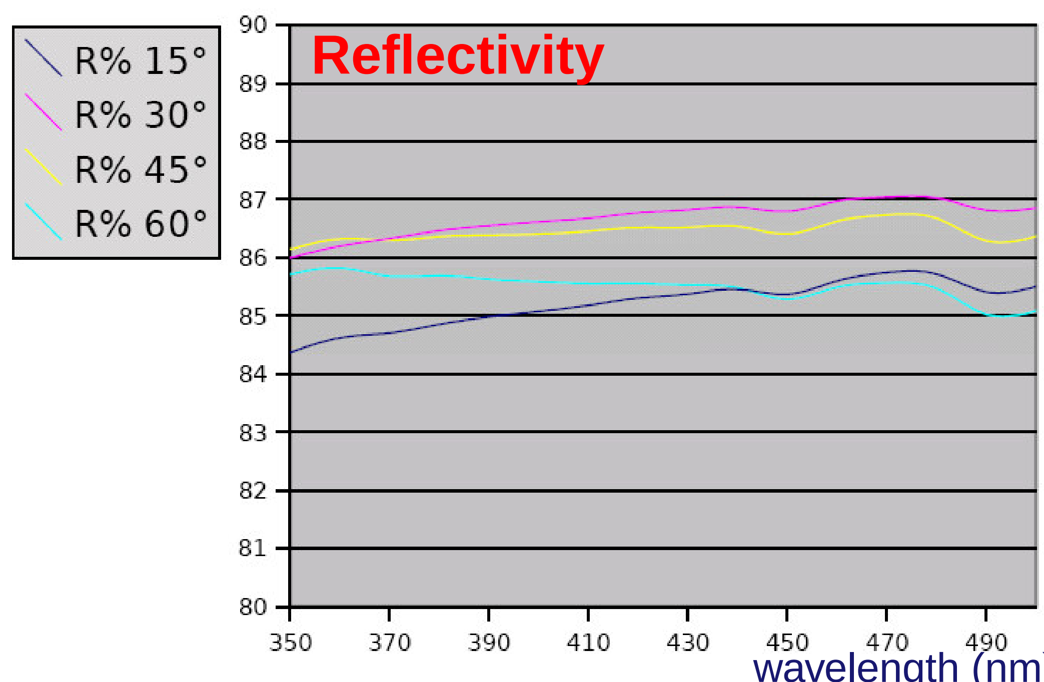


Rich detector : Reflector

- a significant fraction ($\sim 33\%$) of the photons emerging from the radiator point outside the detection matrix
- conical reflector made of carbon fiber structure with multilayer coating (Al + SiO2)
- high reflectivity $>$ **85% @ 420 nm**

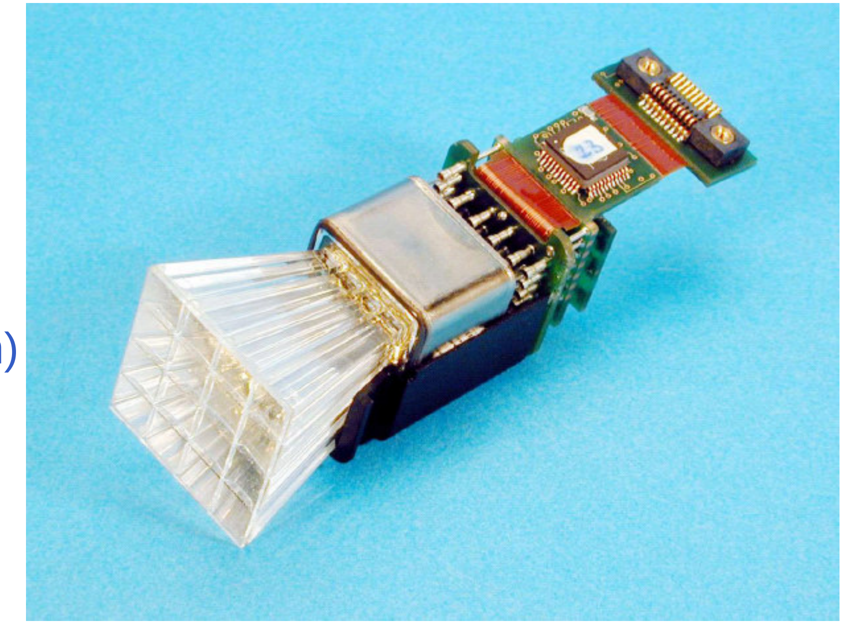


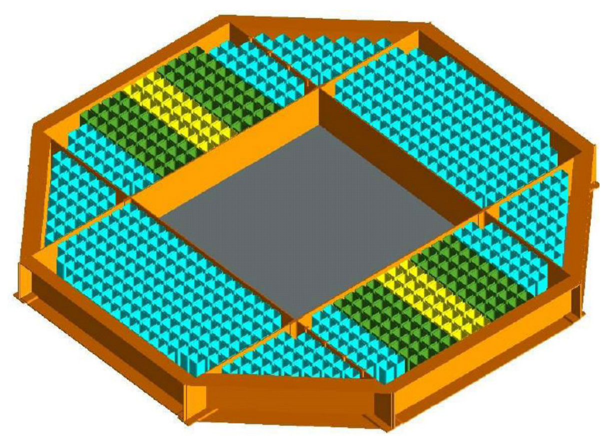




RICH photon detection

- **Photomultipliers**
  - matrix with 680 PMT's
  - 4x4 multianode R7600-M16 (4.5 mm pitch)
  - single photoelectron response
  - spectral response 300-650 nm ($\lambda_{max} \sim 420$ nm)
- **PMT shielding and Light Guides**
  - high stray magnetic field ($\sim 300G$) on readout plane
  - magnetic shielding of PMTs needed (0.8-1.3 mm)
  - increase photon collection eff with LGs
  - Plexiglass (n=1.49) solid guides
  - Effective pixel size 8.5 mm
- **Readout Electronics**
  - 16 channel ASIC developped
  - two amplification gains ($\times 1, 5$)
  - dynamic range from 1-100 pe
  - low consumption (~ 11 mW)





RICH velocity and charge determination

- Velocity obtained from θ_c measurement

$$\boxed{\beta = 1/n \ \cos\theta_c}$$

- β uncertainties :
  - pixel size (8.5 mm)
  - radiator thickness $(h \tan\theta_c)$

    photon emission point unknown
  - radiator chromaticity, $n(\lambda)$

$$\boxed{\frac{\Delta\beta}{\beta} = \frac{1}{N_{p.e}} \left(\tan\theta_c \Delta\theta_c \oplus \frac{\Delta n}{n}\right)}$$

		$\beta = 1, Z = 1$	
radiator	$\Delta n/n$	$\Delta\theta_c$	$\Delta\beta/\beta$
aerogel	$\sim$ 0.11%	4 mrad	$\sim 1.3\ 10^{-3}$
naf	$\sim$ 0.43%	4.1 mrad	$\sim 3.6\ 10^{-3}$

- Charge determination :

$$\boxed{Z^2 \propto \frac{N_{p.e}}{\varepsilon}}$$

$\varepsilon \equiv$ ring effi ciency

ring acceptance, γ absorption,...

- Z Uncertainties :
  - statistical :

    $$\Delta N_{p.e} = \sqrt{N_{p.e}\left(1 + \sigma^2_{p.e}\right)}$$
  - systematics from non-uniformities :
    - radiator : n, thickness, clarity, ...
    - detection : LG, PMT, temperature effects, ...

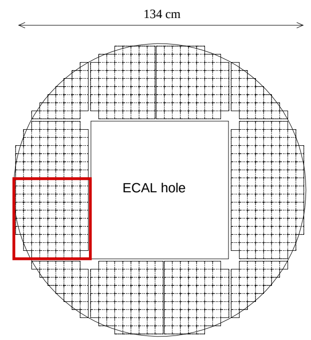
$$\boxed{\Delta Z = \frac{1}{2}\sqrt{\frac{1+\sigma^2_{p.e}}{N_0} + Z^2\left(\frac{\Delta\varepsilon}{\varepsilon}\right)^2}}$$

Aerogel tile uniformity requirements

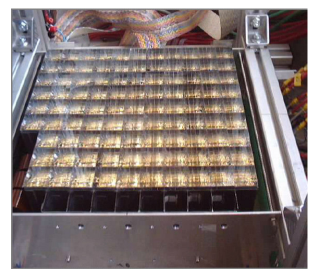
thickness $\sim$ 0.5 mm	refract index $\sim 10^{-4}$	• Clarity $\sim$ 5%

RICH prototype - Test Beam 2003

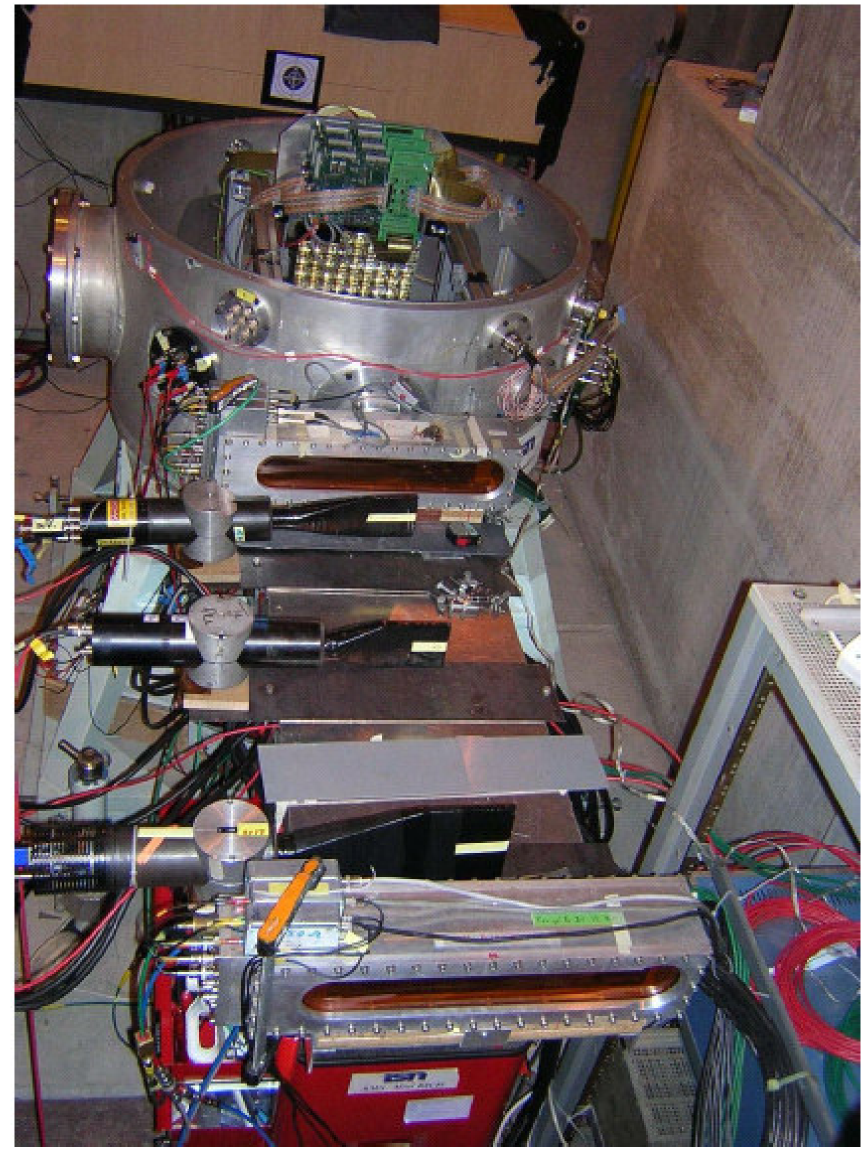
- ✔ CERN Indium (Z=49) primary beam with 158 GeV/c/n
- ✔ beam selection : $A/Z = 2,\ 2.25,\ 2.35$
- ✔ 8 days of data taking
- ✔ 10^7 events collected
- ✔ very narrow beam (< 1 mm most of time)
- ✔ many particle angles



Final RICH PMT matrix (680 PMT's)



Prototype RICH : 96 PMT's

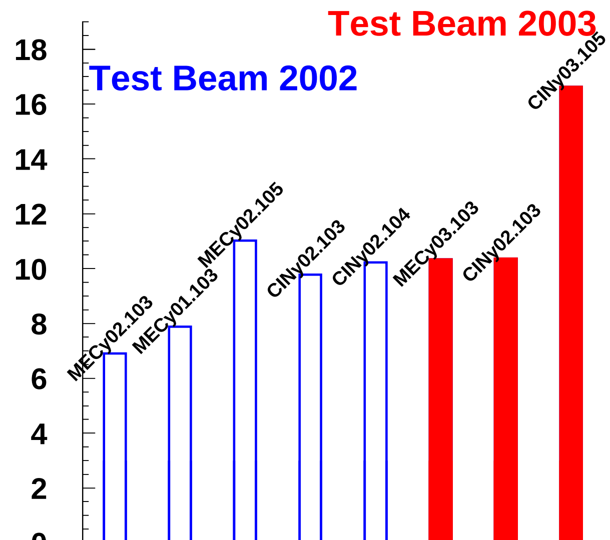


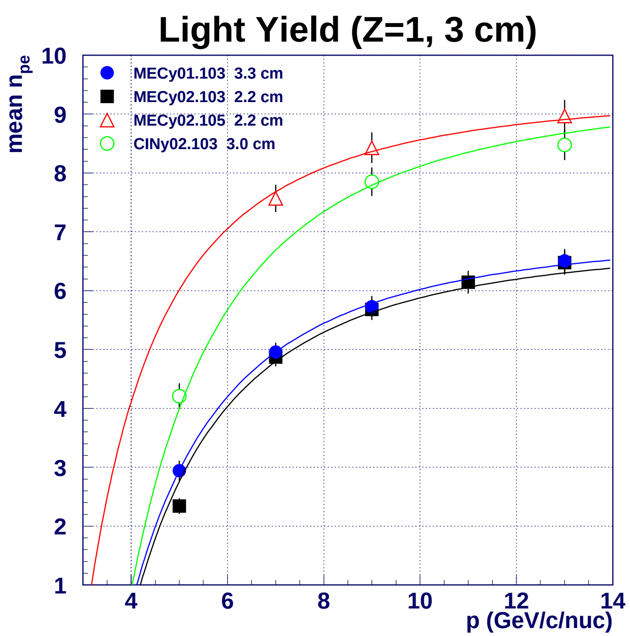
aims

- ✔ evaluate rich performance
- ✔ test readout electronics (flight model)
- ✔ test aerogel and NaF radiators
- ✔ evaluate mirror reflectivity

RICH - Test Beam 2003 : aerogel properties

Light yield

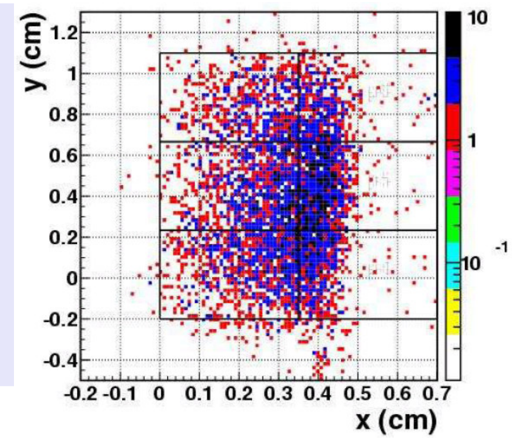


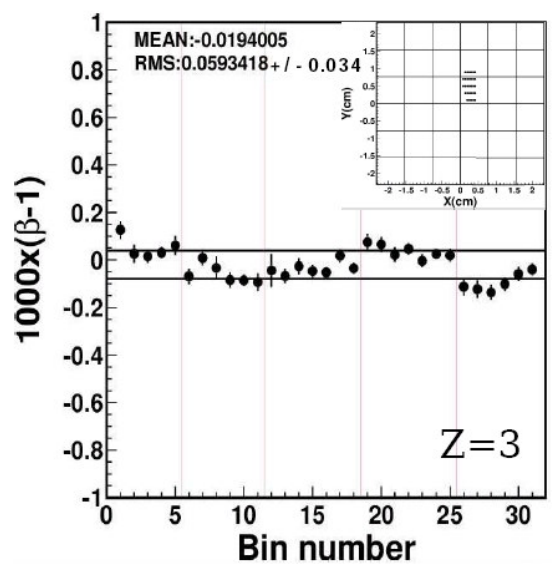


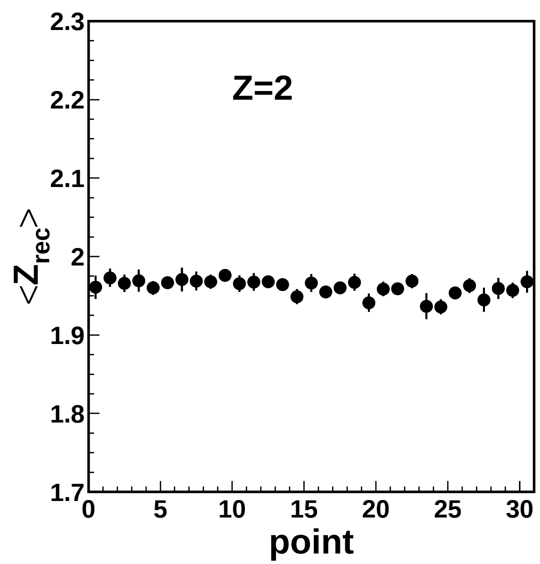
Tile uniformity

Scan of aerogel tile with a wide beam to evaluate its uniformity

- ✔ refractive index
  $\Delta n < 10^{-4}$
- ✔ photon yield
  $\frac{\Delta N_{p.e}}{N_{p.e}} < 1\%$

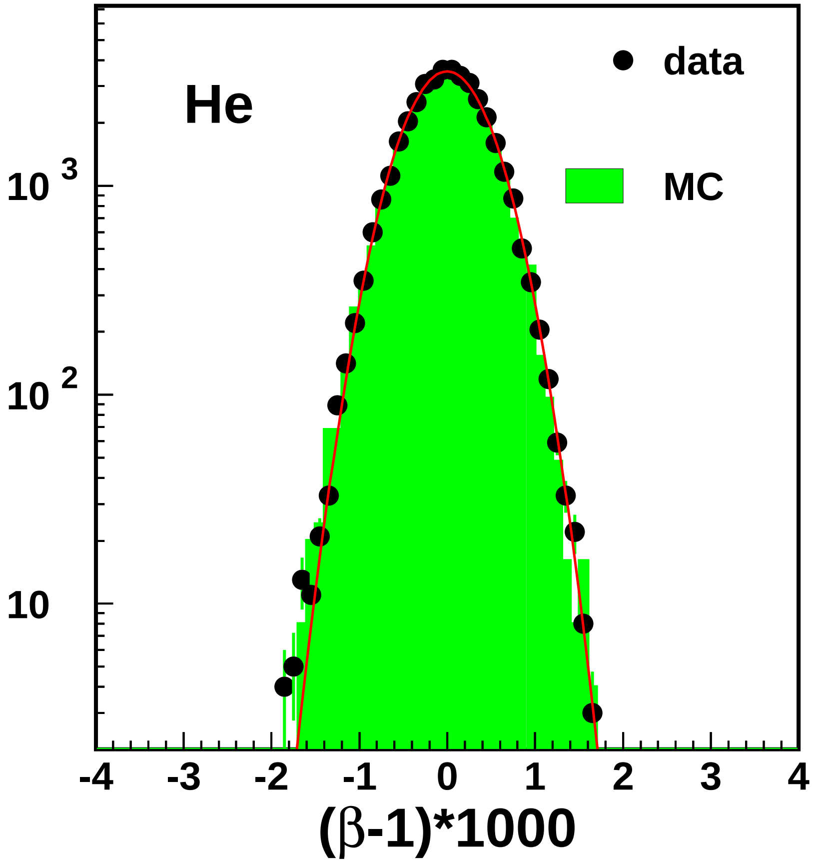




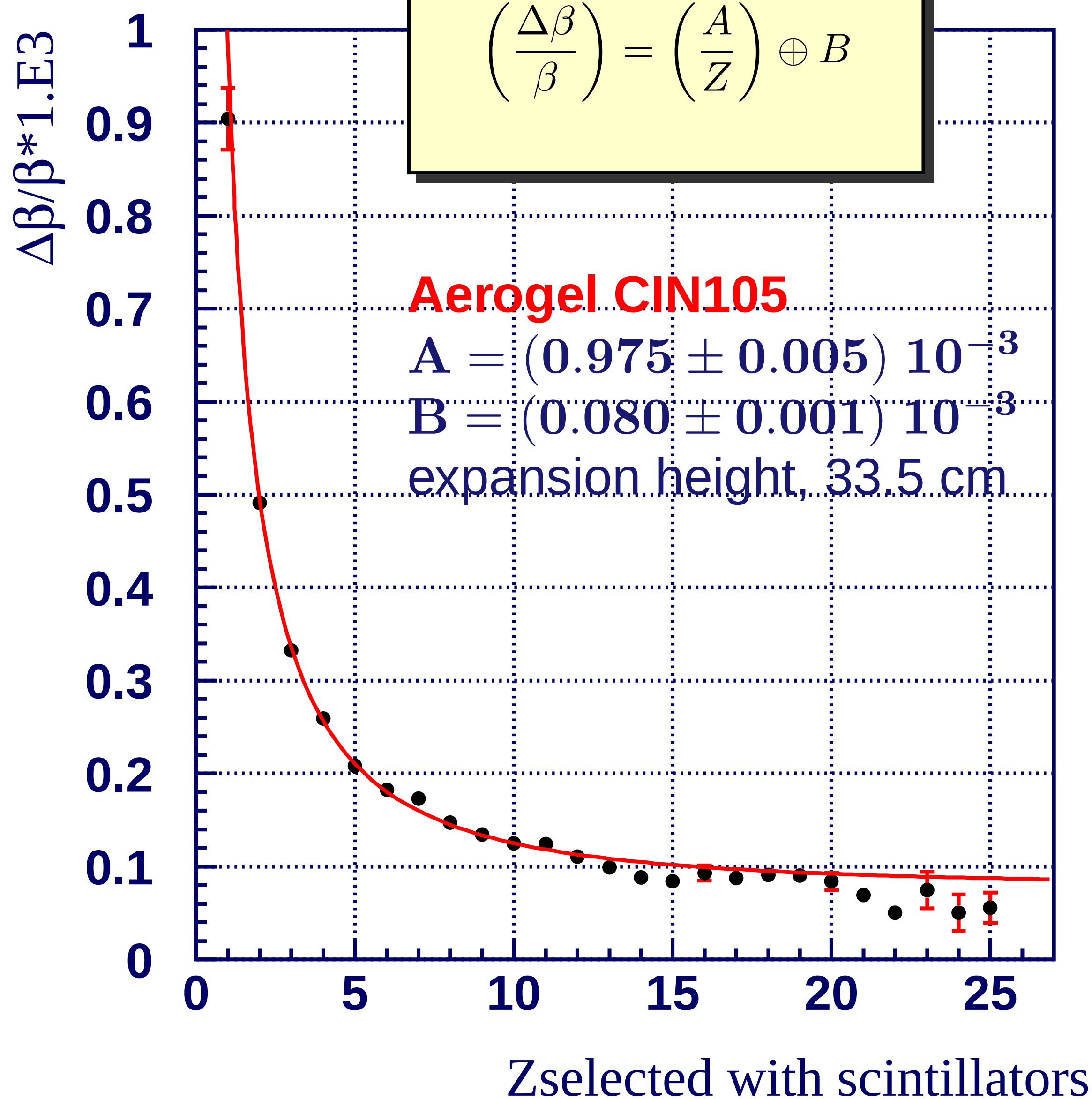


RICH - Test Beam 2003 : β reconstruction with agl

$$\frac{\Delta\beta}{\beta} \sim \frac{1}{\sqrt{N_{p.e}}} \left(\frac{\Delta\beta}{\beta}\right)_{hit}$$

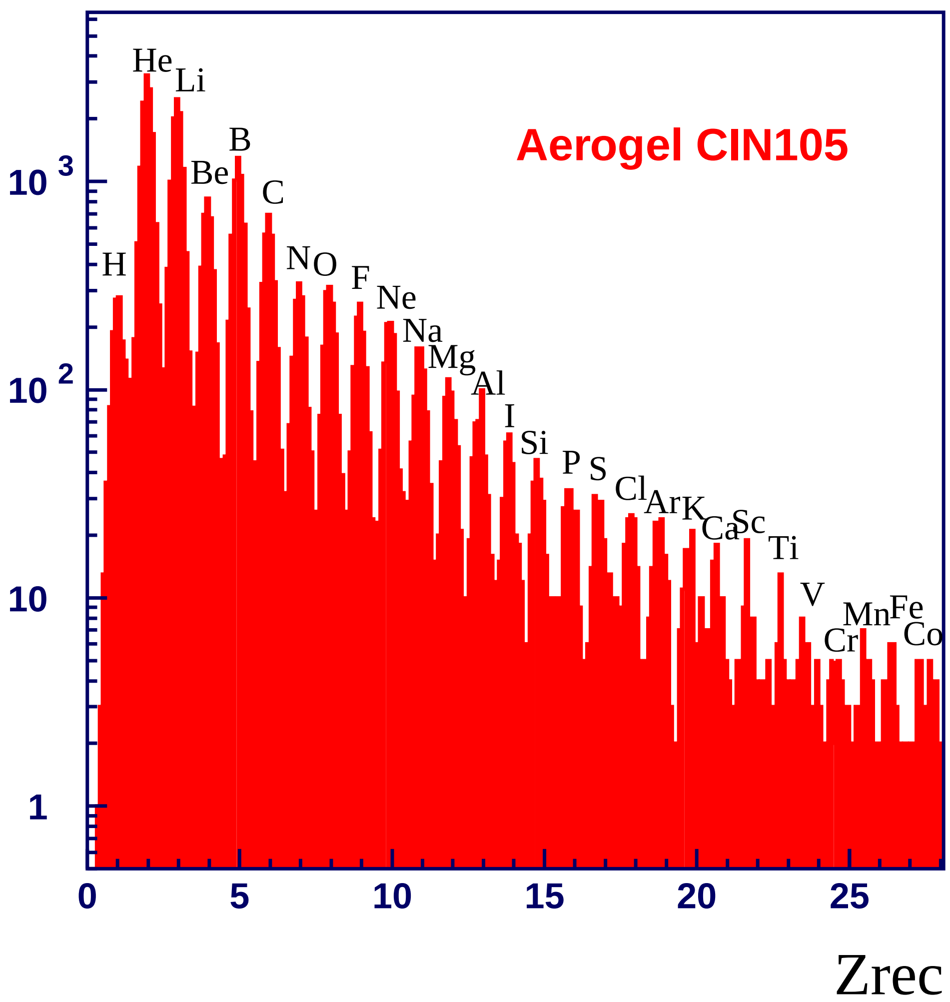


$$\left(\frac{\Delta\beta}{\beta}\right) = \left(\frac{A}{Z}\right) \oplus B$$

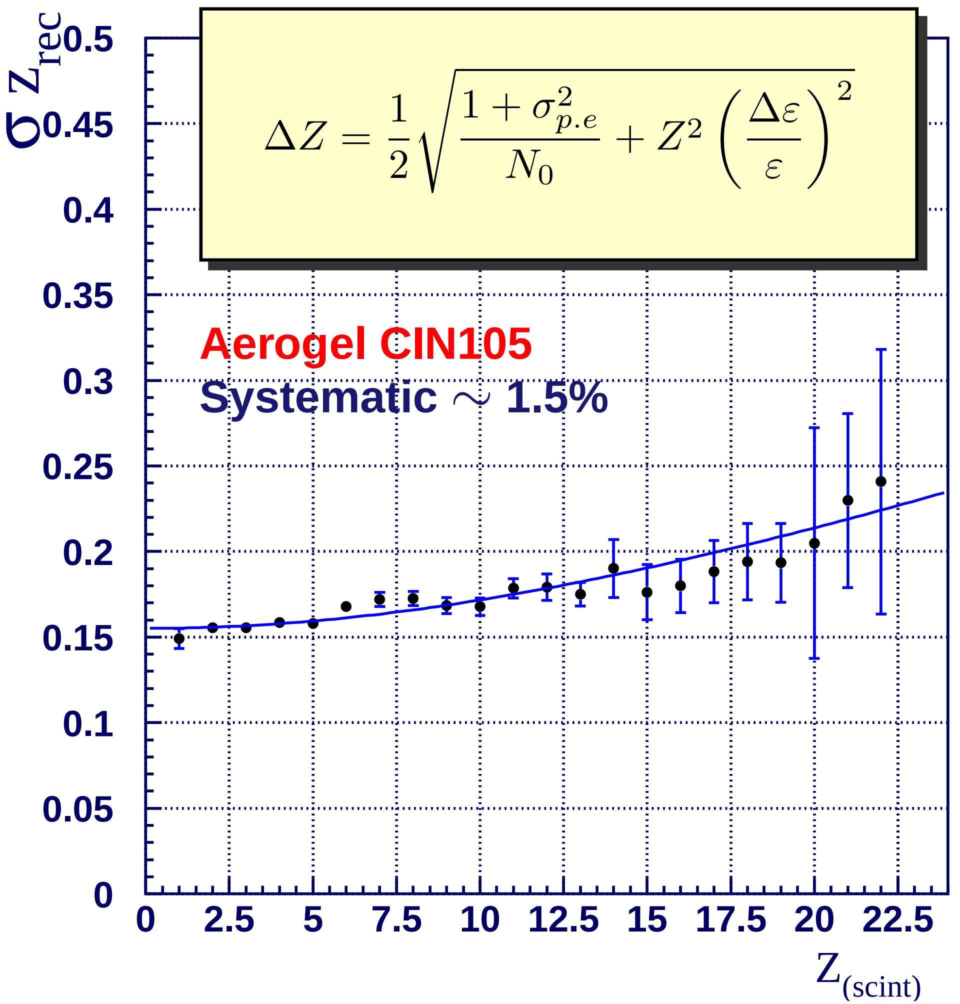


RICH - Test Beam 2003 : Z reconstruction with agl

Charge peaks

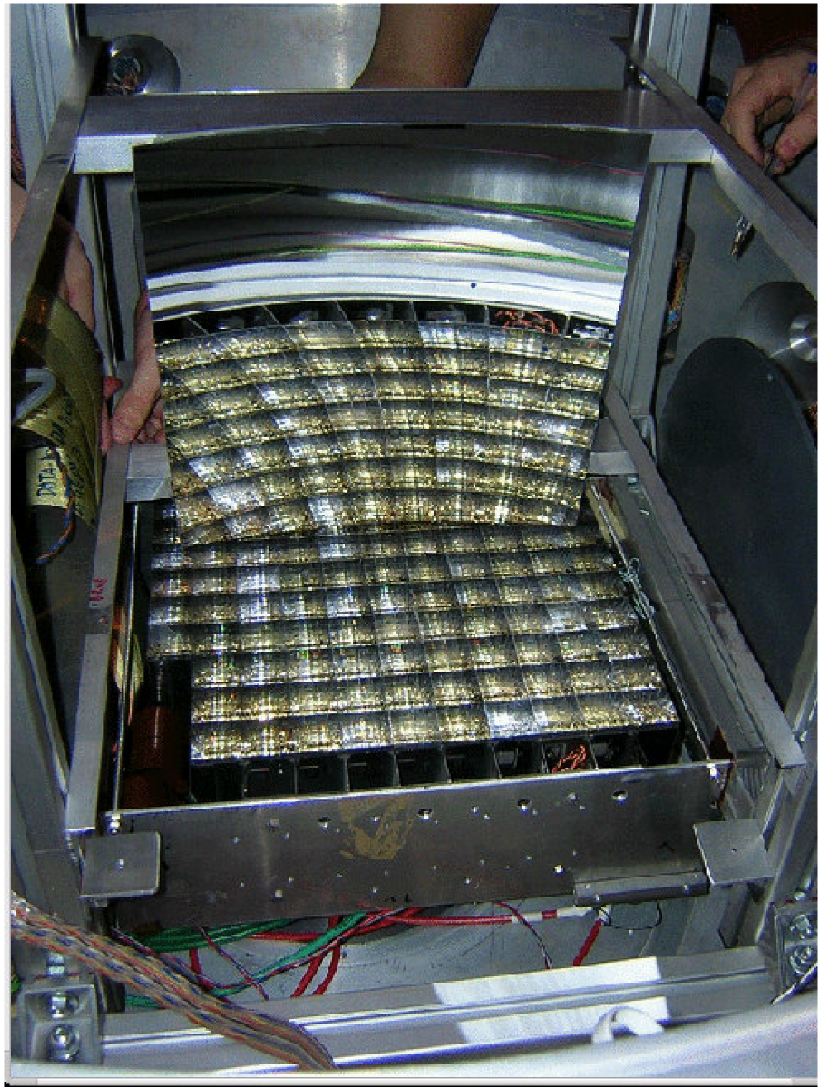


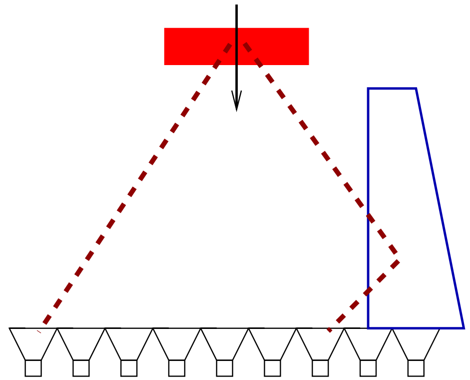
Charge uncertainty

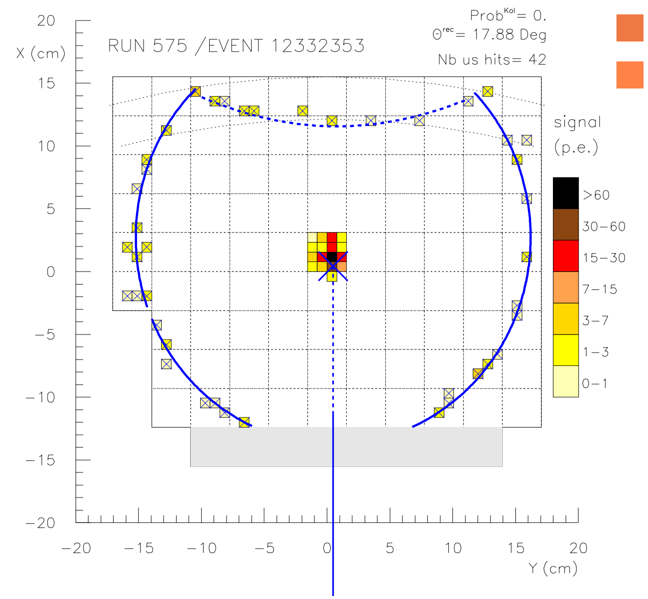


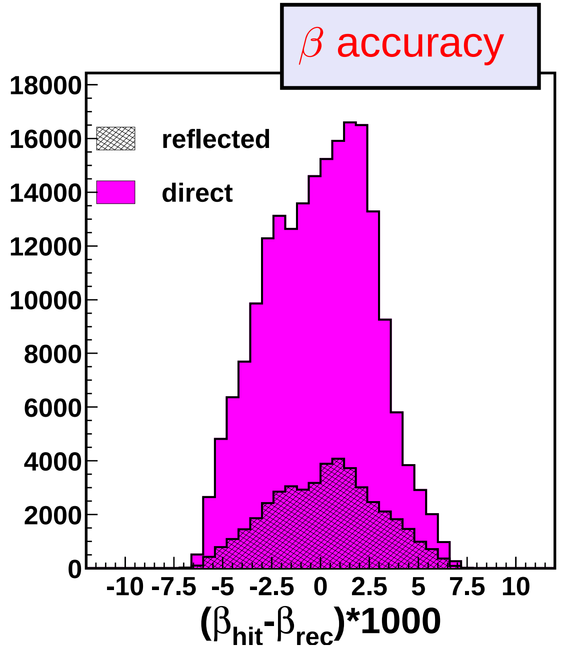
RICH - Test Beam 2003 : mirror reflectivity

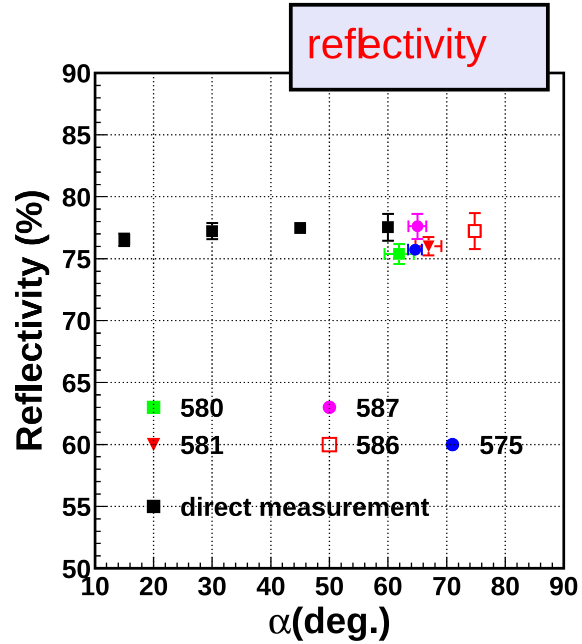
- ✔ A prototype mirror was tested
- ✔ Reflectivity measured from signal analysis of reflected and direct branches



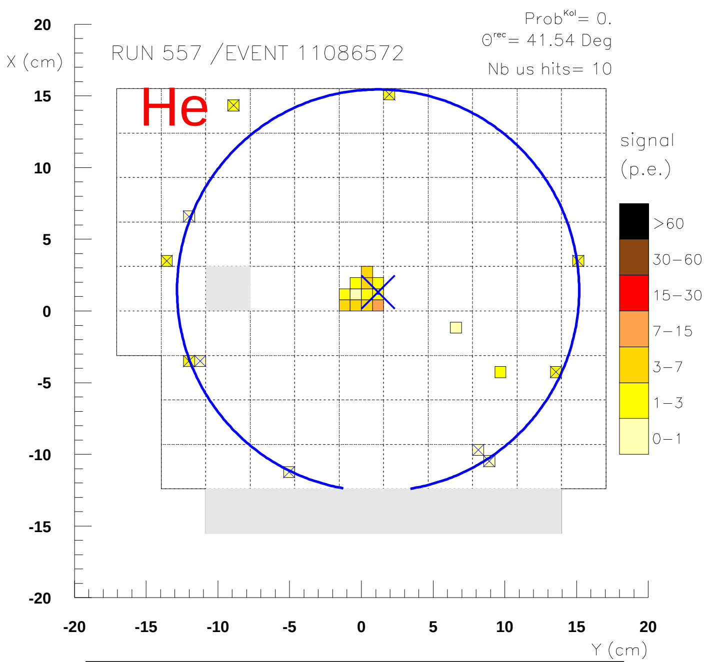


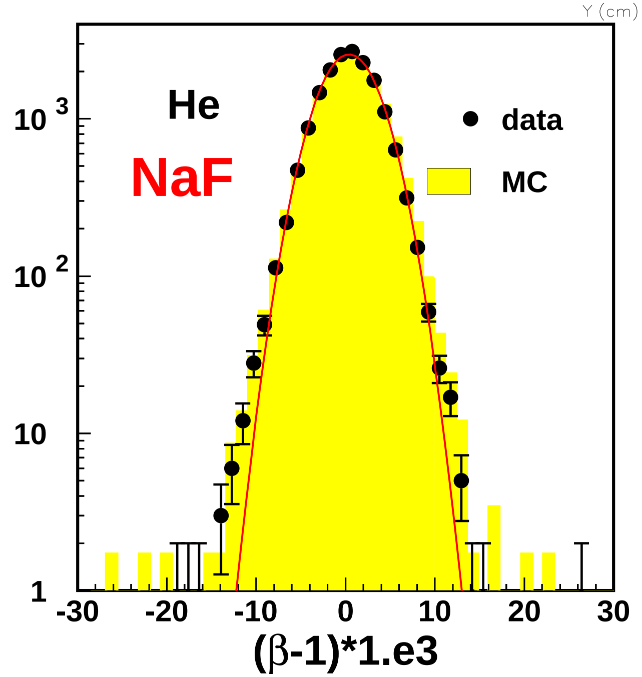


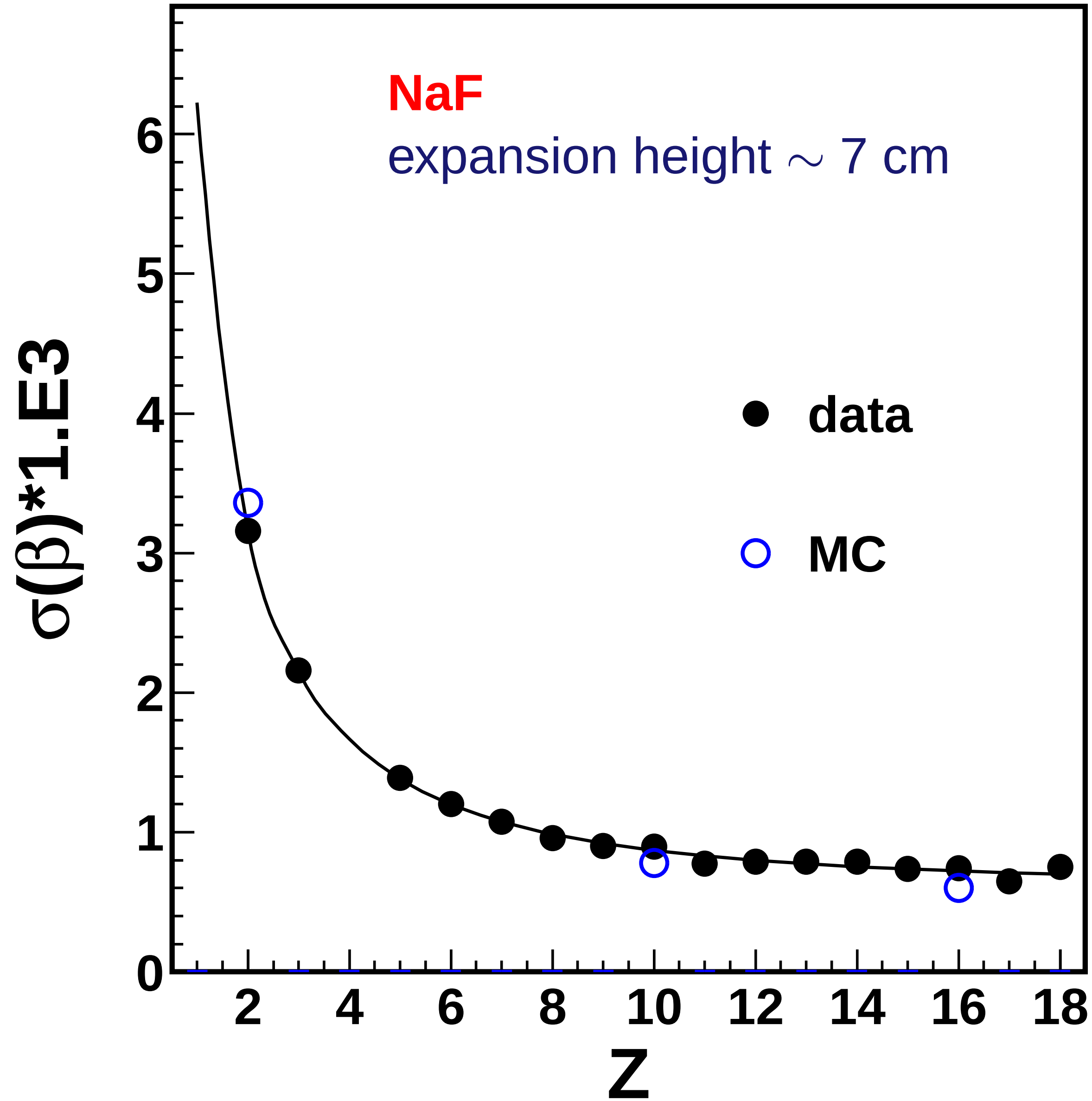




RICH - Test Beam 2003 : β reconstr with NaF







Conclusions

- ✔ The AMS experiment to be installed in the International Space Station in 2008 will be equiped with a RICH
  - ► key role in astrophysics studies
  - ► large range charge identifi cation
  - ► high accuracy in velocity
- ✔ Detector is being assembled
  - ► thermal and vibration tests performed
  - ► > 60 % of photon detection cells assembled
  - ► reflector ready by the end of 2005
- ✔ RICH design validated by intensive tests to a RICH prototype made of 96 photodetection cells
- ✔ RICH integration in AMS scheduled to July 2006