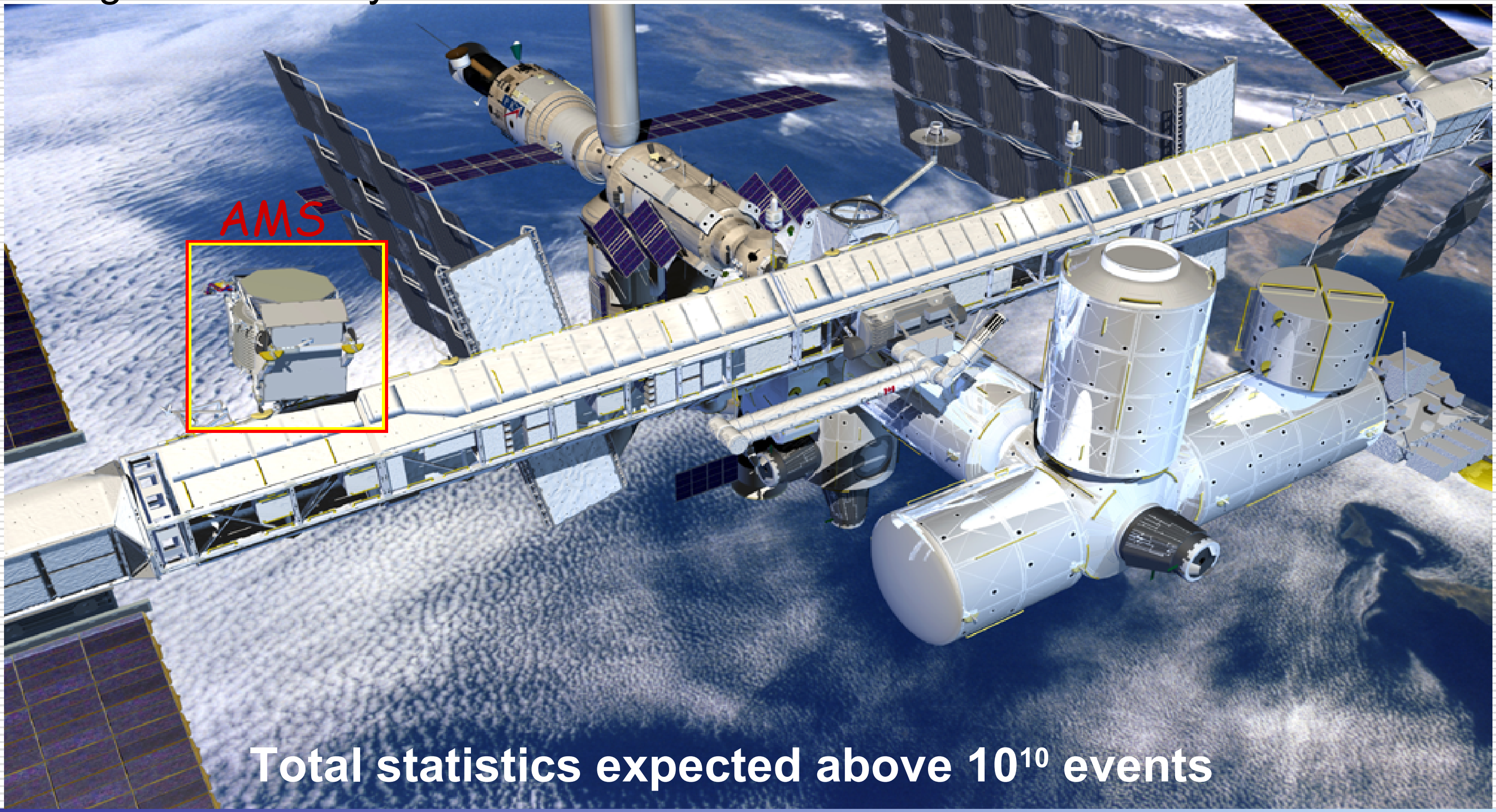
The Ring Imaging Cherenkov detector of the AMS experiment: test beam results with a prototype

Luísa Arruda

LIP - Lisbon

AMS-02 on the International Space Station

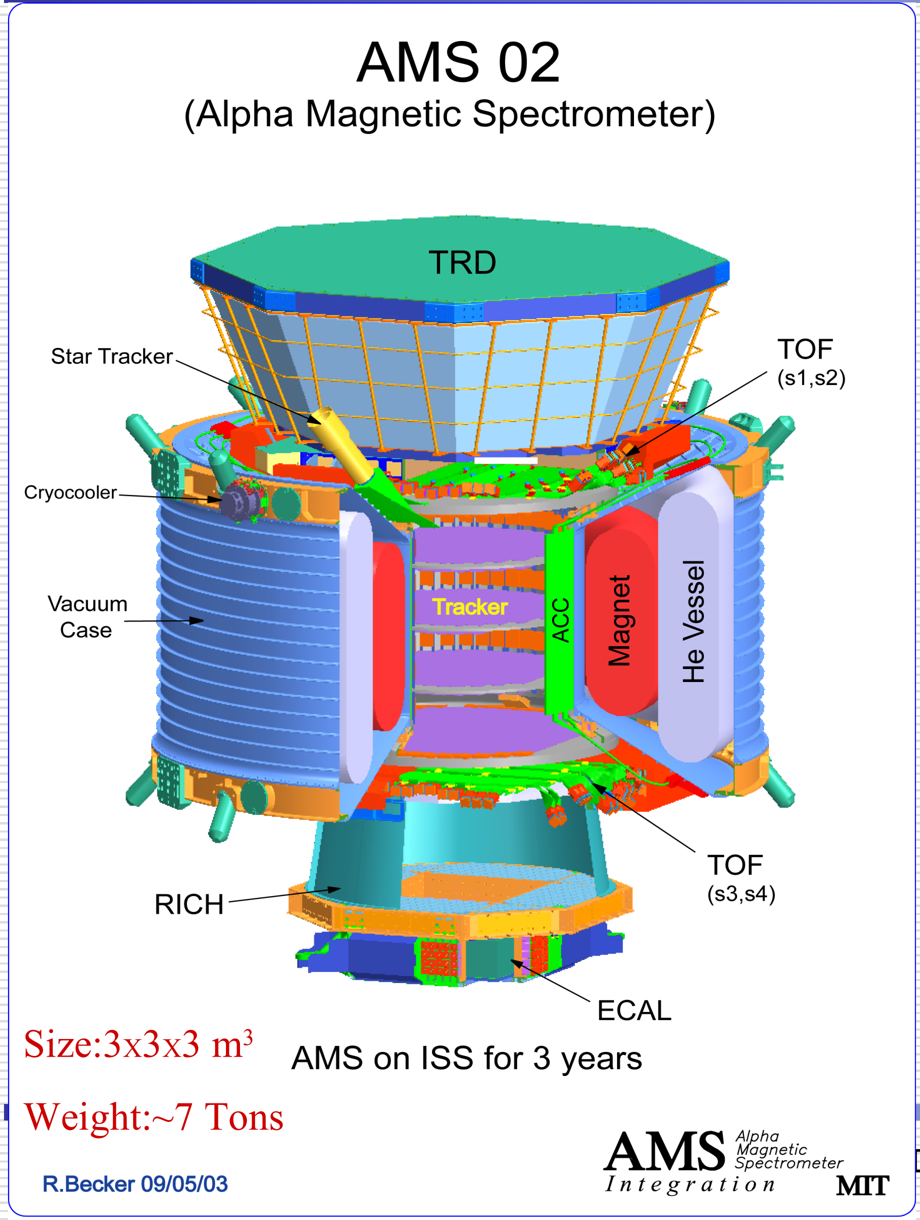
The Alpha Magnetic Spectrometer is a precision magnetic spectrometer scheduled to be installed in the International Space Station (ISS) with a data taking of at least 3 years.



AMS-02 astrophysics aims

- Search for cosmic antimatter, through the detection of antinuclei with $|Z| \geq 2$; for antihelium nuclei the upper limit of detection will be $\overline{He}/He < 10^{-9}$;
- Search for dark matter. Neutralino annihilations may contribute with anomalies on different spectra: e^{+}, $\overline{p}$, $\overline{d}$, γ
- Precision measurements on the relative abundance of different nuclei and isotopes of primary cosmic rays E<1 TeV
  - ⋆Secondary-to-primary ratios (B/C, $^{3}He/^{4}He$): test to propagation models
  - ⋆Confinement times ($^{10}Be/^{9}Be$): constraint to galactic halo models
  - ⋆Long period of observation will give information on solar cycle variations

The AMS-02 experiment



- 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 (Z)

  RICH, Tracker, Time-Of-Flight

- Trigger

  Time-Of-Flight, ECAL, Anti-Coincidence Counter

Ring Imaging Cherenkov Detector (RICH)

Physics Goals

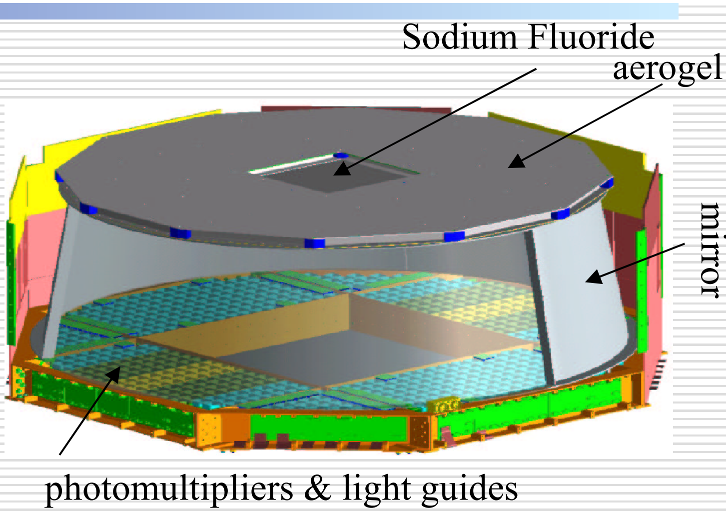
✓ High accuracy on velocity measurement

$\Delta\beta/\beta$~0.1% for singly charged particles

✓ Electric charge measurement over a wide range of Z's

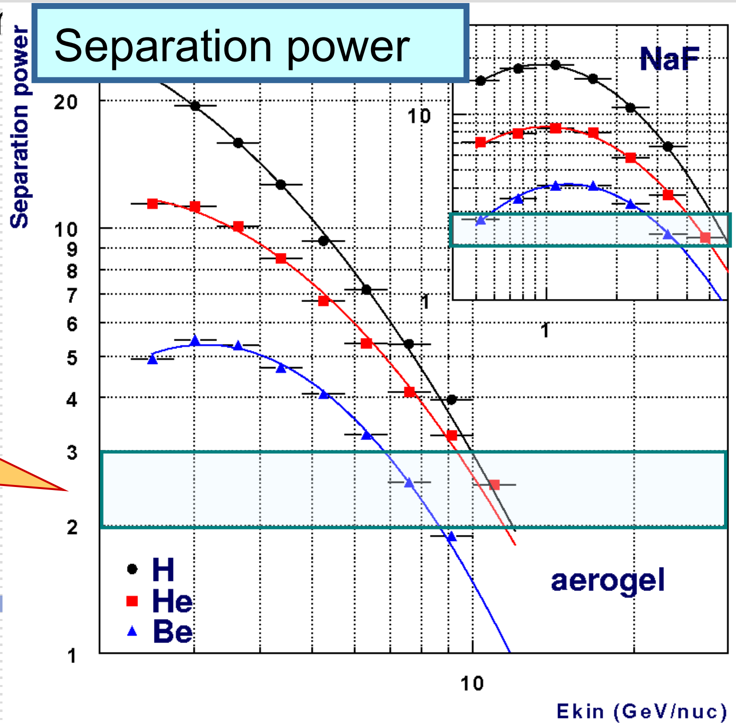
At least up to iron element (Z=26)

✓ Contribution to AMS redundancy on albedo rejection



Simulated data samples: p, He, Be

Separation criterium

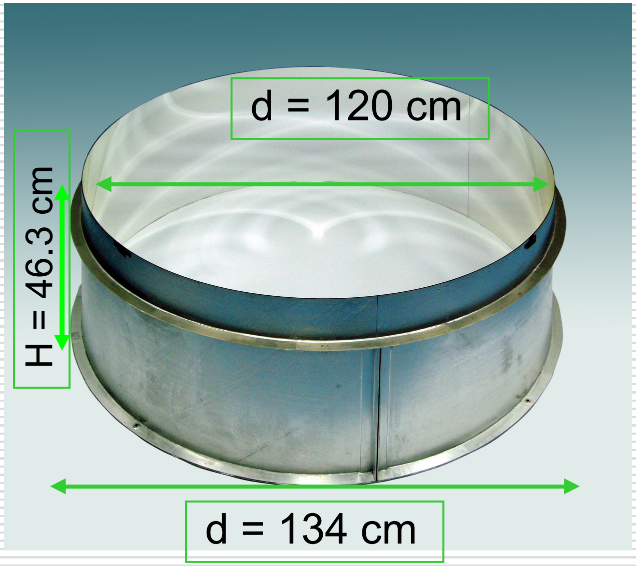


NaF can contribute at low energies but smaller acceptance!

RICH detector: radiator plane and reflector

- Radiator:
  - Dual solid radiator configuration
    - increases the detector acceptance
    - extends the kinematic coverage for lower energies

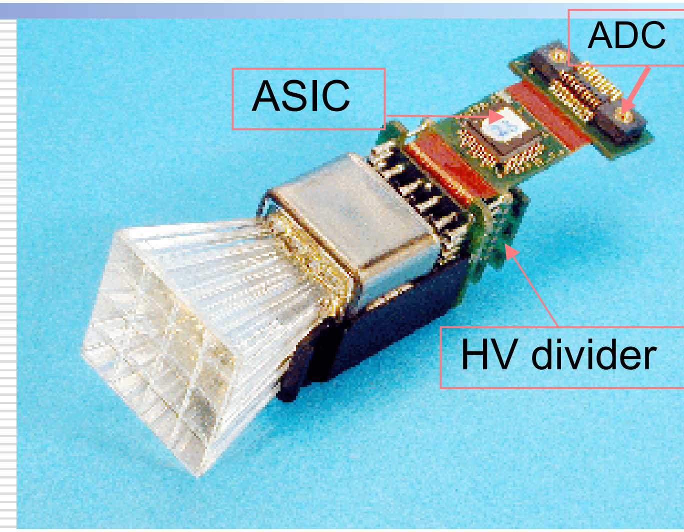
aerogel	1.050	2.5 cm	p_{th}~3 GeV/c/nuc
NaF	1.334	0.5 cm	p_{th}~1.1 GeV/c/nuc

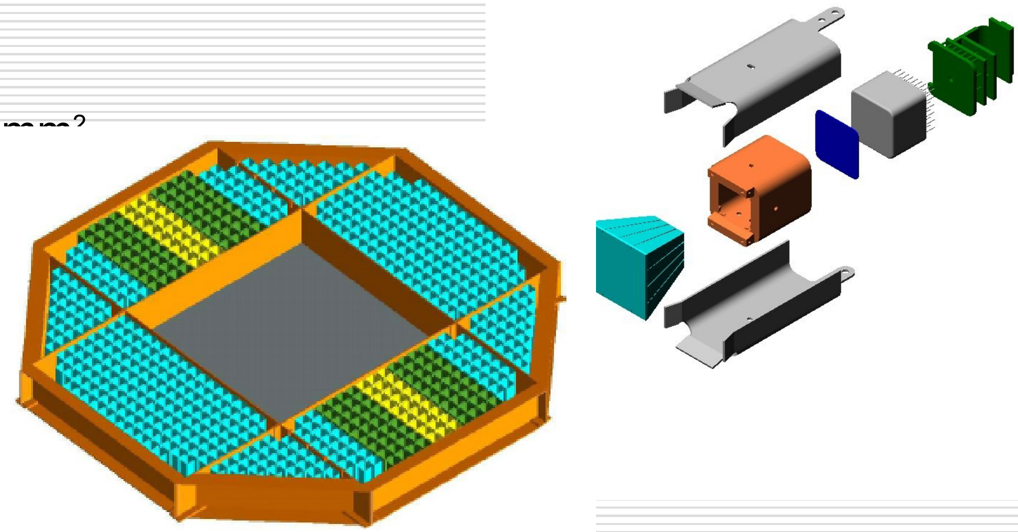


- Conical reflector
  - ~33% of the photons recovered
  - carbon fiber structure with multilayer coating ($Al+SiO_2$)
  - high reflectivity > 85% @ 420 nm

RICH detector: detection plane

- Photomultipliers
  - matrix of 680 PMTs
  - 4x4 multianode R7600-M16 (4.5 mm pitch)
  - single photoelectron response
  - spectral response 300-650 nm (λ_{max}~420 nm)
  - high B_{stray} (~300 G) on readout plane
    - magnetic shielding needed (0.8-1.3 mm)
- Light Guides: increase photon collection eff
  - Plexiglass (n=1.49) solid glass
  - Spatial pixel granularity: 8.5x8.5 mm²
- Readout Electronics
  - 16 channel ASIC developed
  - two amplification gains (x 1,5)
  - dynamic range from 1-100 pe





β and Z reconstruction algorithms

β reconstruction

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

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

$$P_i = \underbrace{(1-b)S(r_i)}_{P_{\text{signal}}} + \underbrace{B}_{P_{bkg}}$$

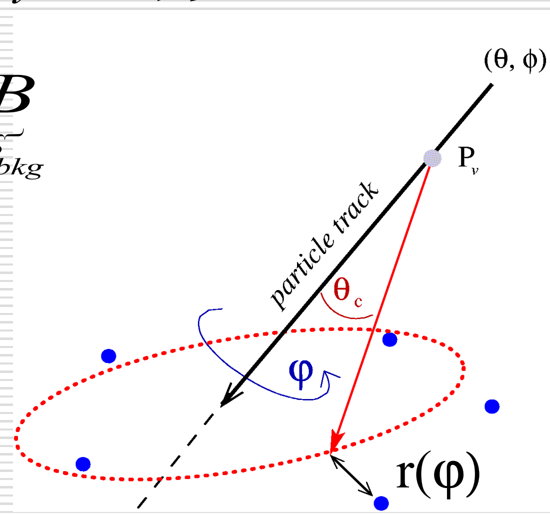
Z reconstruction

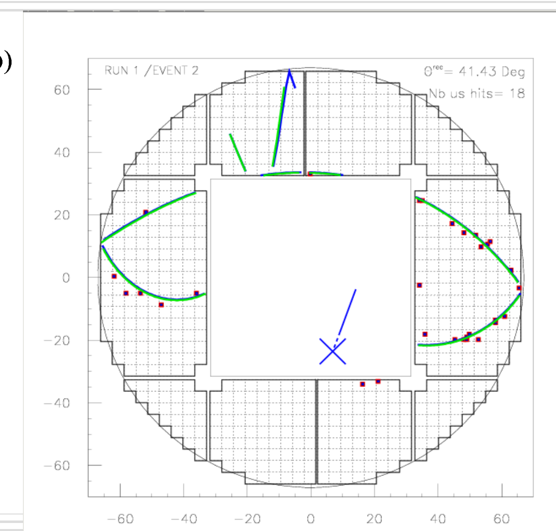
✓ A method based in

$$N_{pe} = N_0 Z^2$$

$$N_0 = N_{pe}(Z=1)$$

N_0 semi-analytically evaluated



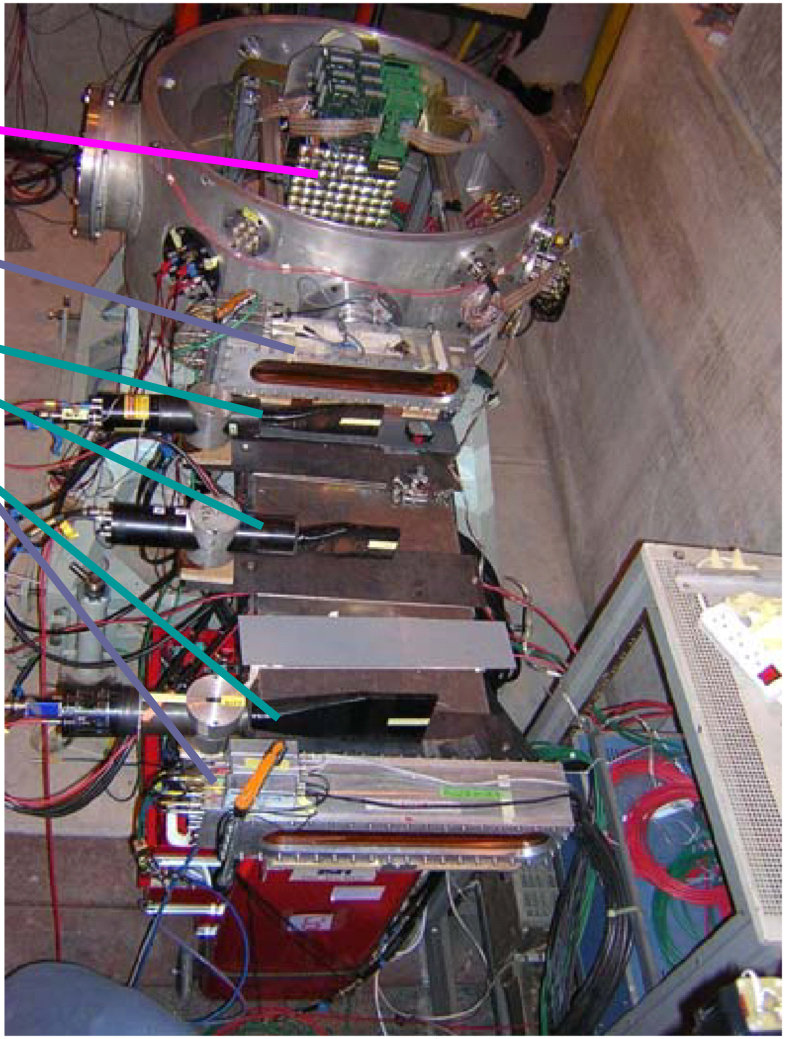


Test Beam 2003: experimental setup

RICH prototype

MWPC

Organic scintillators & Cherenkov counter



- Experimental area H8-SPS at CERN, October 2003
  - ***Primary Beam**: In*
  - ***Target**: Pb*
  - ***Momentum**: 158 GeV/c/nucleon*
- **Beam selection: A/Z=2, 2.25, 2.35**

+ Tracker and TOF prototypes

beam

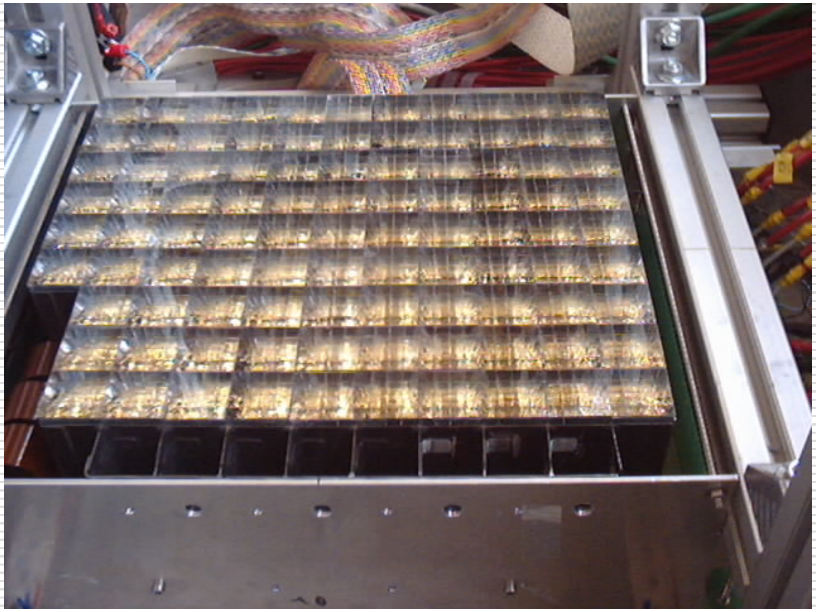
Test Beam 2003: experimental setup

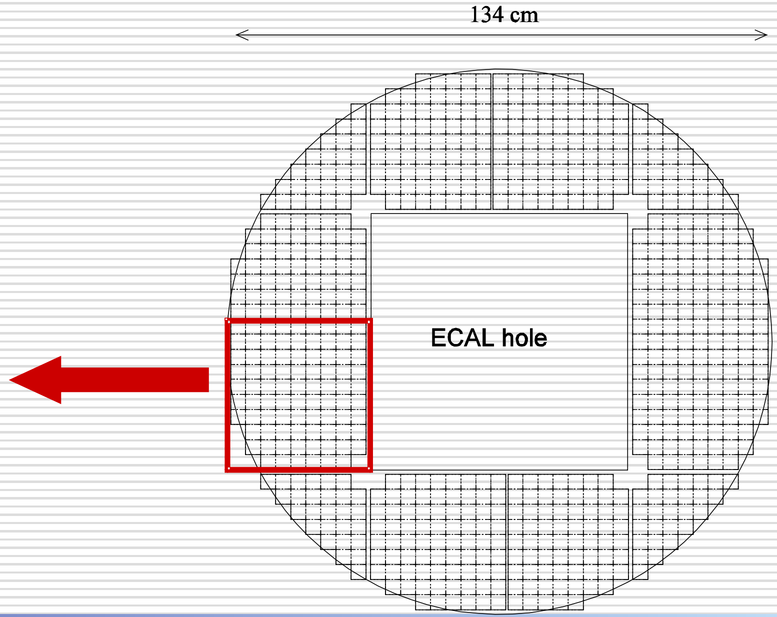
RICH Prototype:

- detection matrix with 96 PMTs
- radiator: several tiles of aerogel, NaF
- mirror prototype with 1/12 of the final azimuthal coverage

Aims:

- ✓ testing flight front-end electronics;
- ✓ characterization of the AGL and NaF radiators;
- ✓ estimation of the mirror reflectivity;
- ✓ evaluation of the prototype global performance.



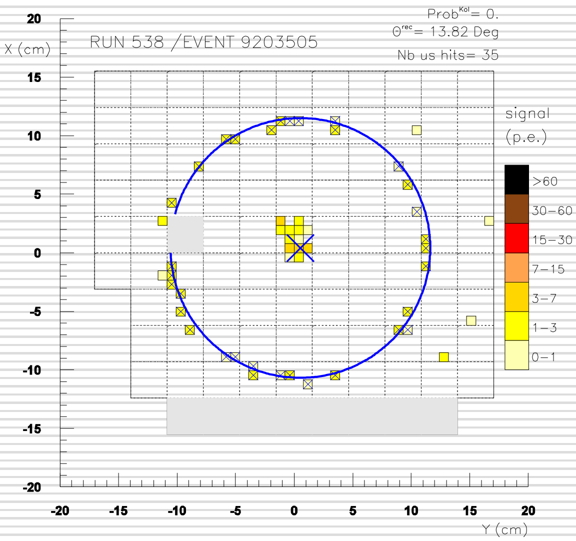


Final RICH PMT matrix (680 PMT's)

Test Beam 2003: analyzed data

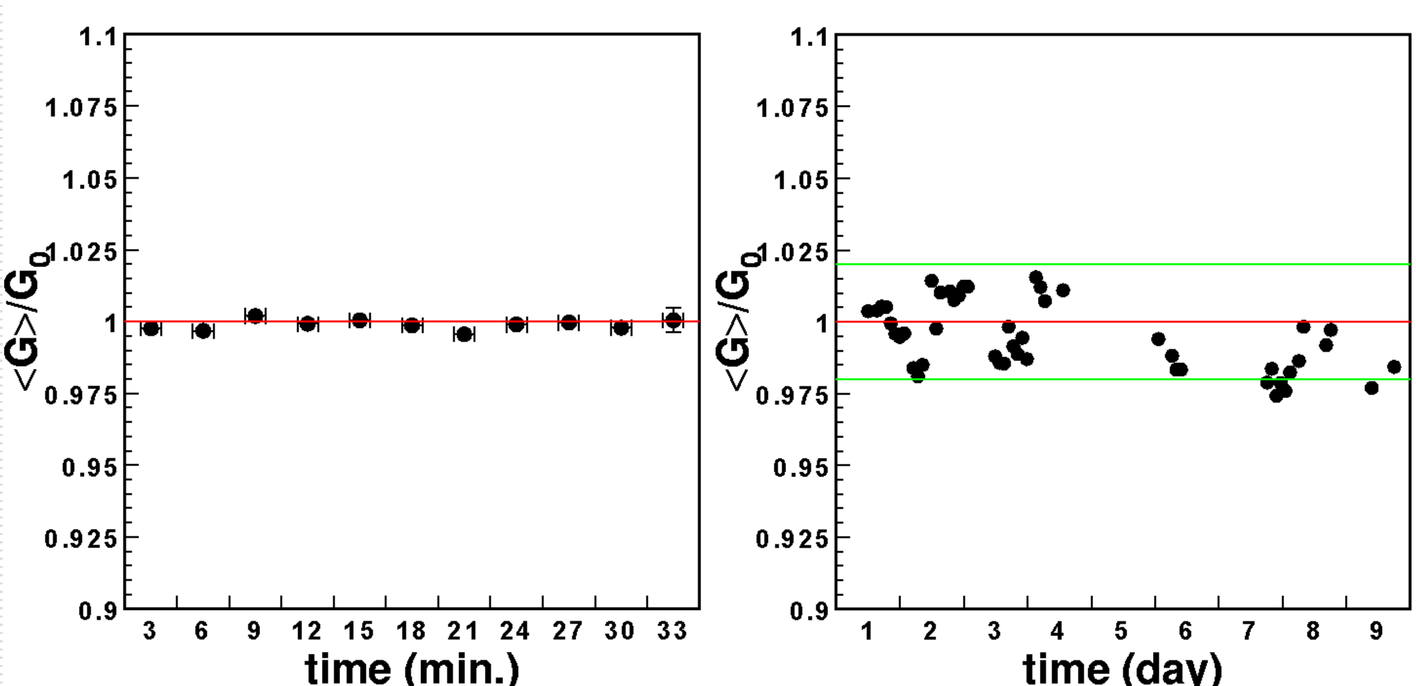
Radiators		
radiator	n	Thickness(cm)
Aerogel Novosibirsk (CIN103)	1.03	3
Aerogel Matsushita (MEC103)	1.03	3 X 1.1
Aerogel Novosibirsk (CIN105)	1.05	2.5
Sodium Fluoride	1.33	0.474

- 11 days of data taking
- ~10^7 events accumulated
- fully contained rings



Detection matrix monitoring

- ✓ Photomultiplier gain stability monitored along the test beam.
- ✓ A gain stability within 2% was observed

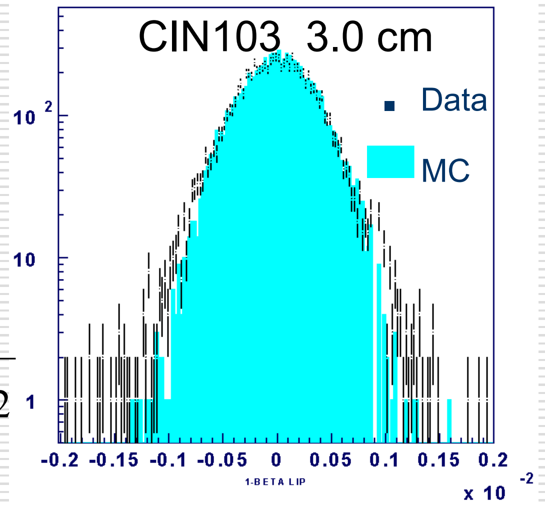


At single run level

At test beam level

β resolution with the aerogel radiators

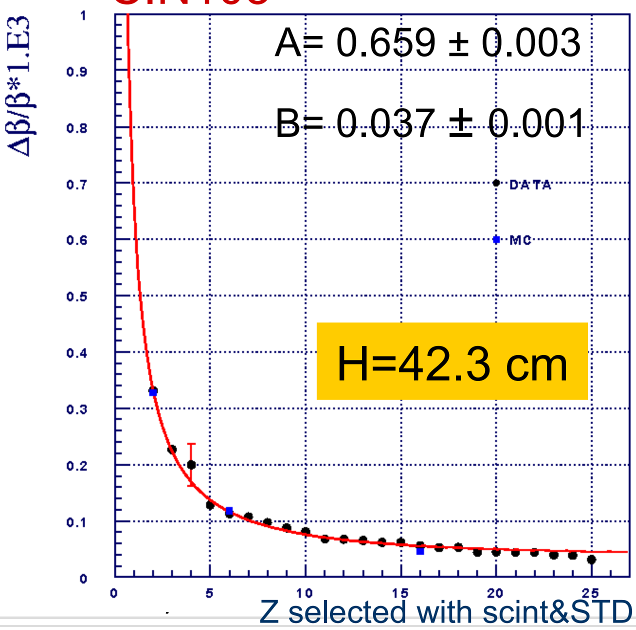
β resolution for Z=2, H=33.5 cm			
radiator	CIN103	MEC103	CIN105
$\sigma(\beta) X 10^3$	0.421±0.003	0.435±0.002	0.459±0.004



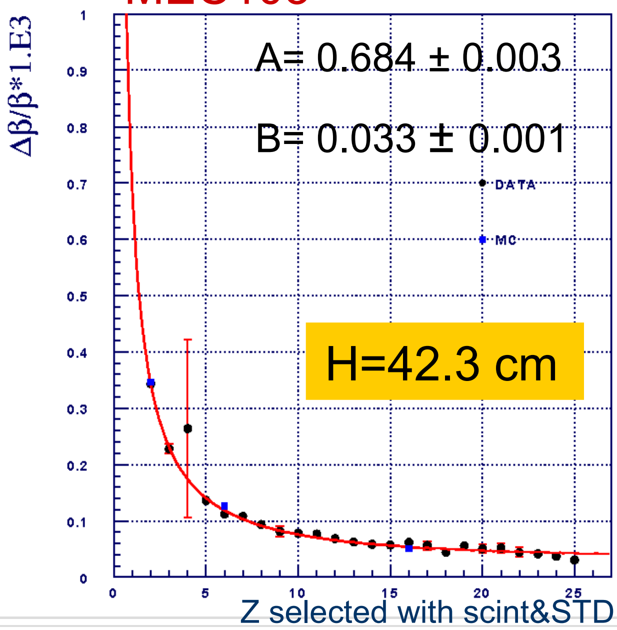
All radiators fulfill the RICH requirements for β measurement !!

$$\frac{\Delta\beta}{\beta} = 10^{-3}\sqrt{\left(\frac{A}{Z}\right)^2 + B^2}$$

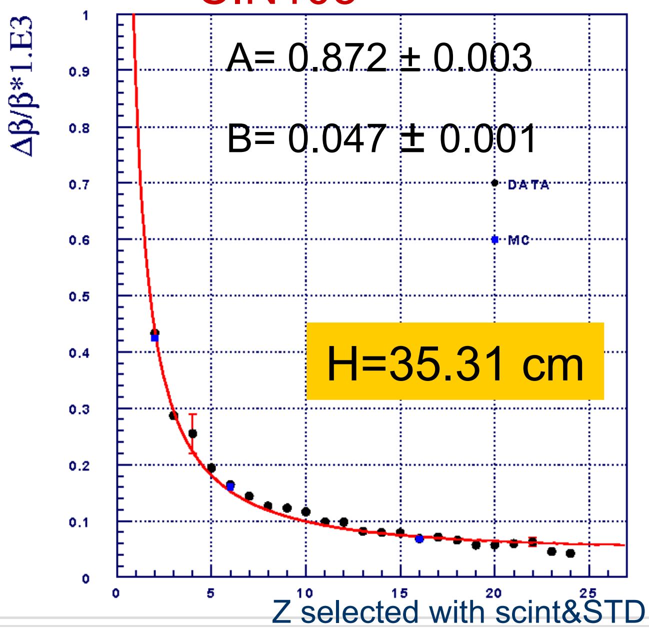
CIN103



MEC103



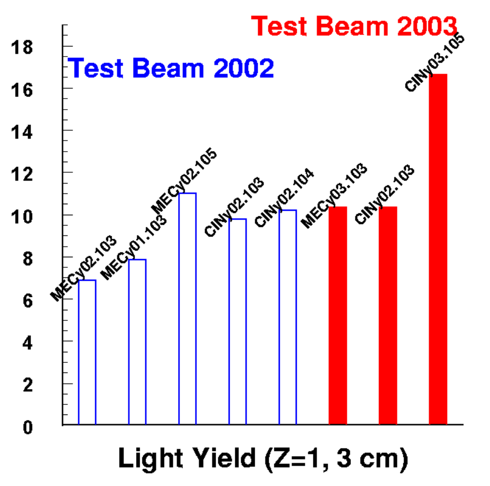
CIN105

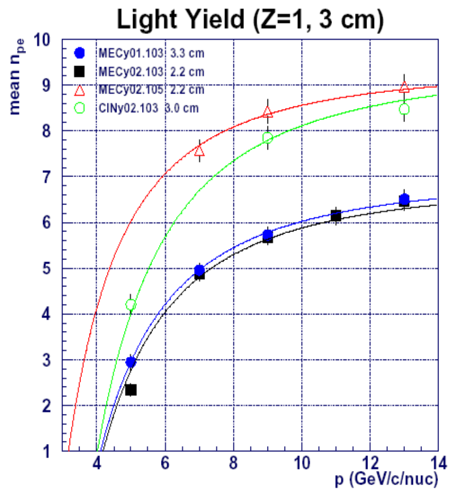


Photon yield and aerogel tile uniformity

Light Yield

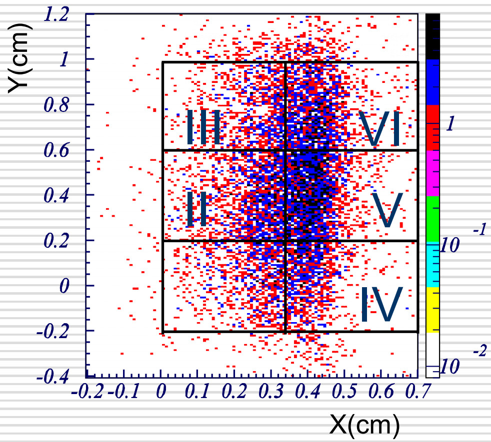
Tile Uniformity





Uniformity study based on data from a *wide beam*

Beam section ~ 0.7x1.2 cm^2



The aerogel of Novosibirsk 1.05 gives a significantly higher photon yield

✓ photon yield

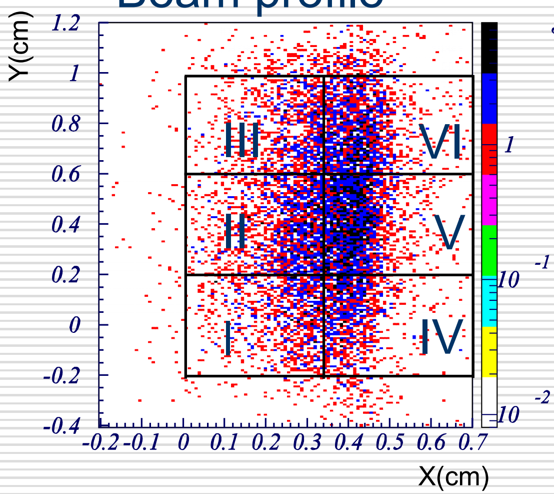
$\Delta n_{pe}/n_{pe} < 1\%$

Aerogel tile uniformity: refractive index

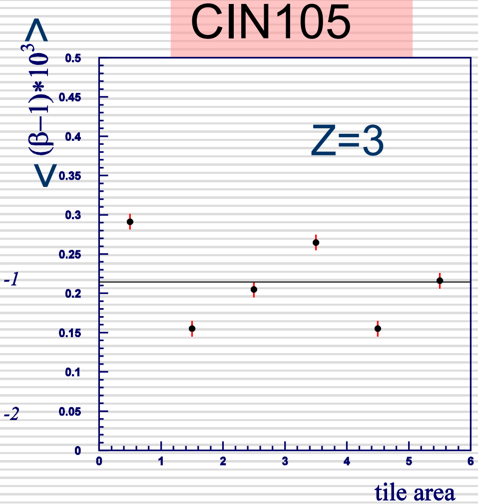
The study of bias in β mean value provides us with a direct estimation of the refractive index variation

$\Delta\beta/\beta=\Delta n/n$

Beam profile



CIN105



Radiator	Δnx10³ *Wide beam*
CIN105	0.06±0.02

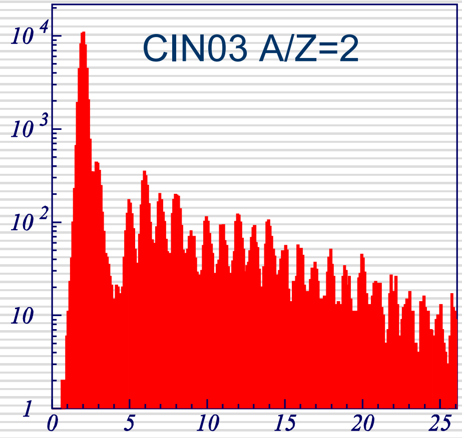
✓ refractive index

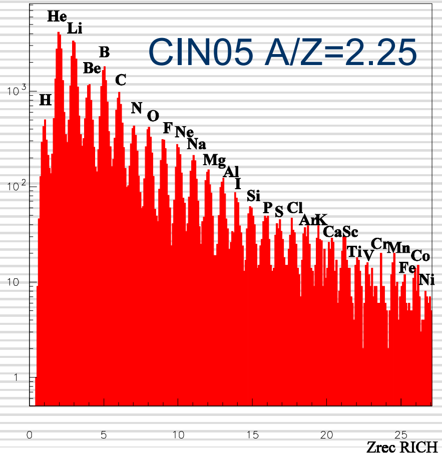
$\Delta n < 10^{-4}$

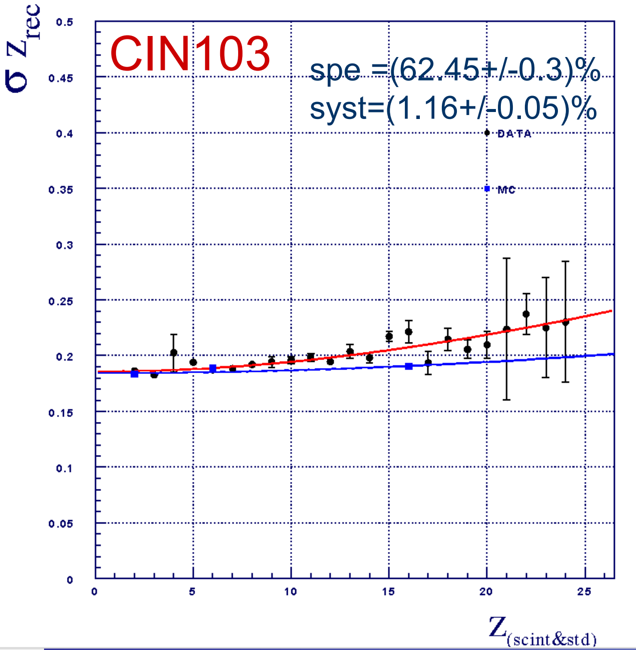
CIN105 shows negligible non-uniformities in the refractive index

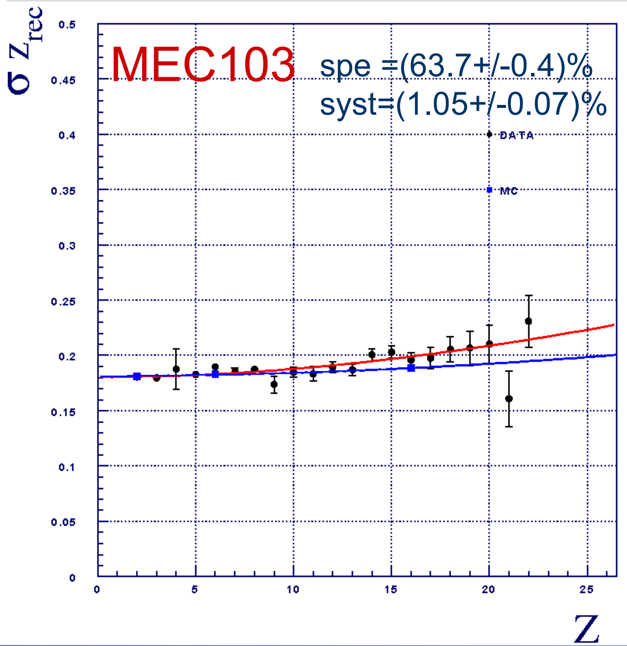
Z resolution with the aerogel radiators

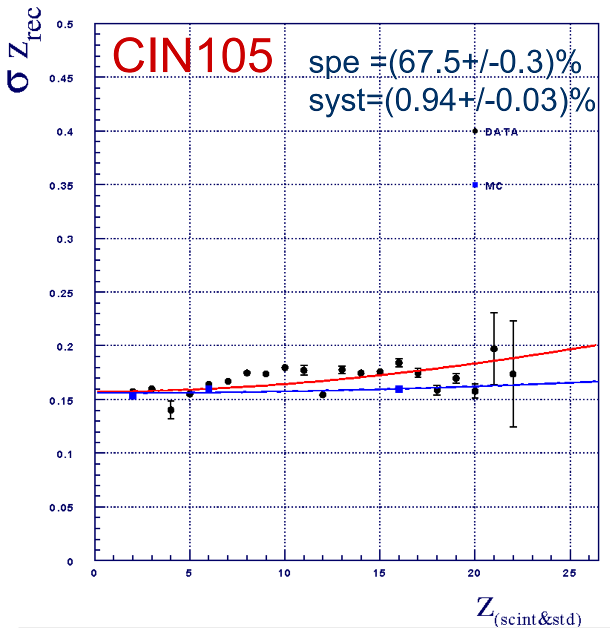
$$\sigma(Z) = \frac{1}{2}\sqrt{\underbrace{\frac{1+\sigma_{pe}^2}{N_0}}_{\text{stat}} + \underbrace{\left(\frac{\Delta N}{N}\right)_{syst}^2 Z^2}_{\text{syst}}}$$







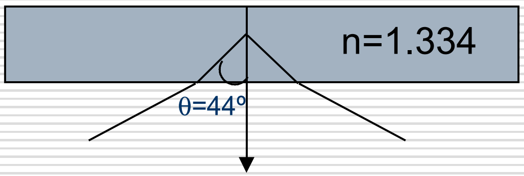




The best resolution is achieved with CIN 1.05 !!

β recontruction with the NaF radiator

NaF run 557 θ=0º

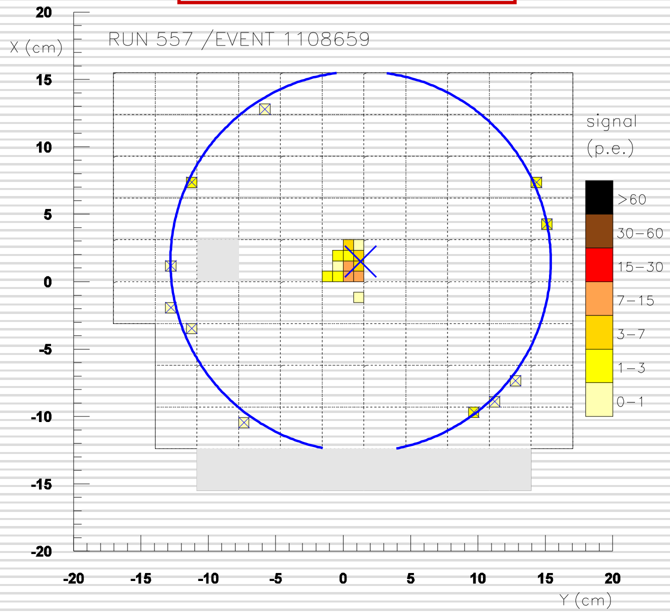


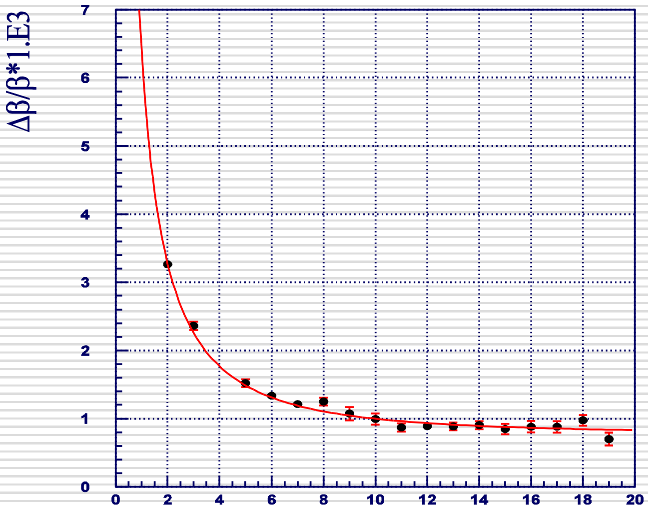
0.474 cm

$$\frac{\Delta\beta}{\beta} = 10^{-3}\sqrt{\left(\frac{A}{Z}\right)^2 + B^2}$$

Helium event

A=(6.19±0.04)
B=(0.61±0.02)

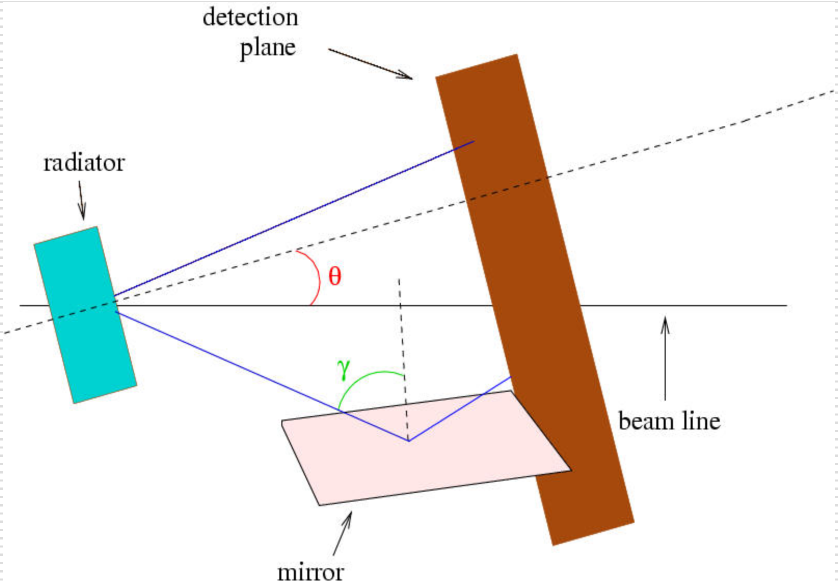


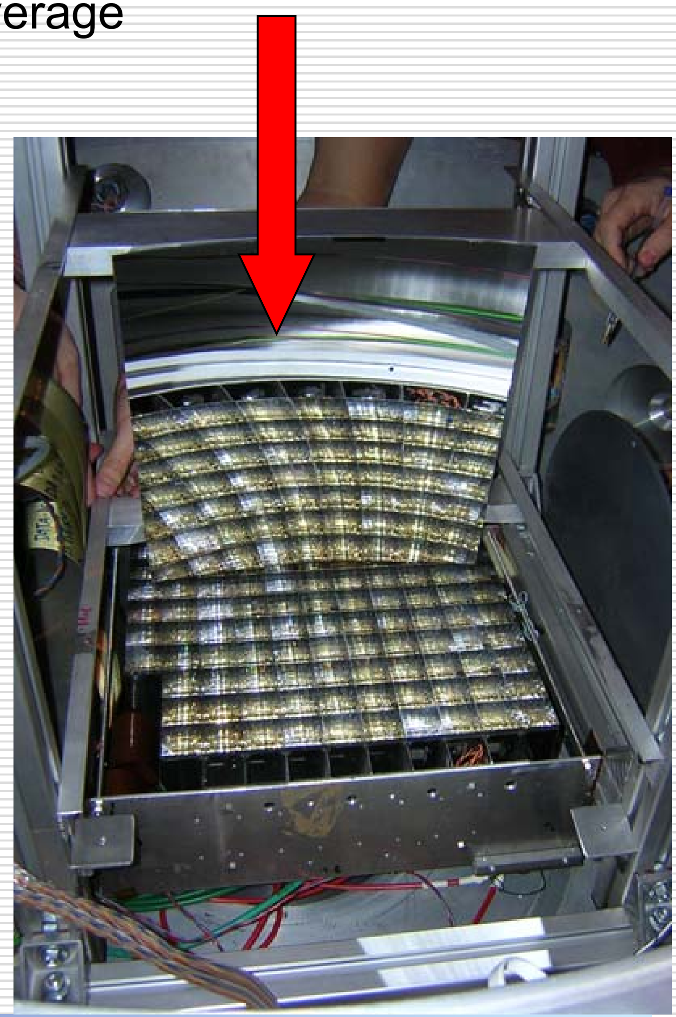


Z cintil & STD

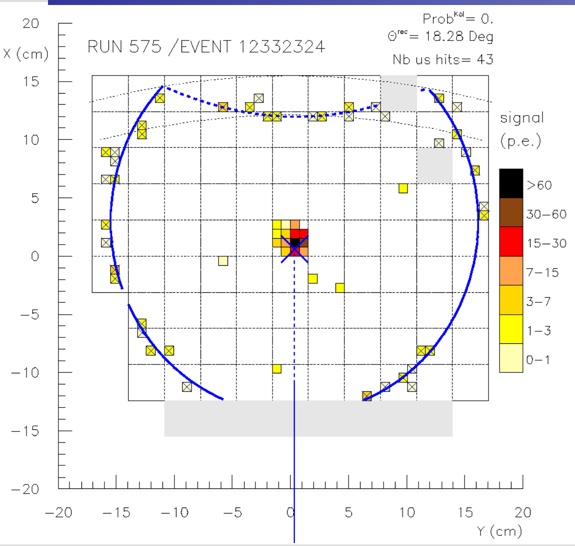
Mirror prototype

- Mirror segment with 1/12 of the total azimuthal coverage
- Data taken with different parameters:
  - refractive index (1.03, 1.05)
  - Different particle inclinations
  - Expansion heigh (42.3, 38.0 cm)





Mirror reflectivity



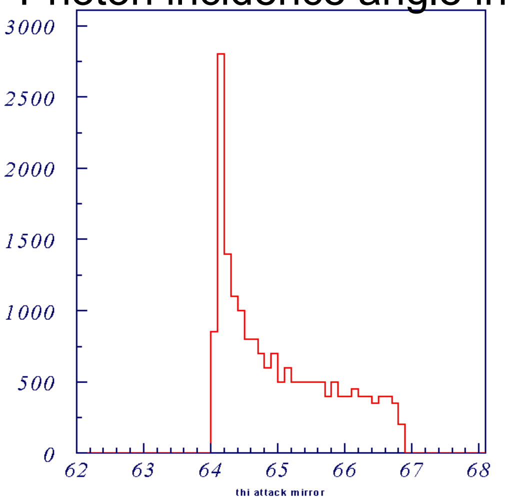
Helium events

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

	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) %

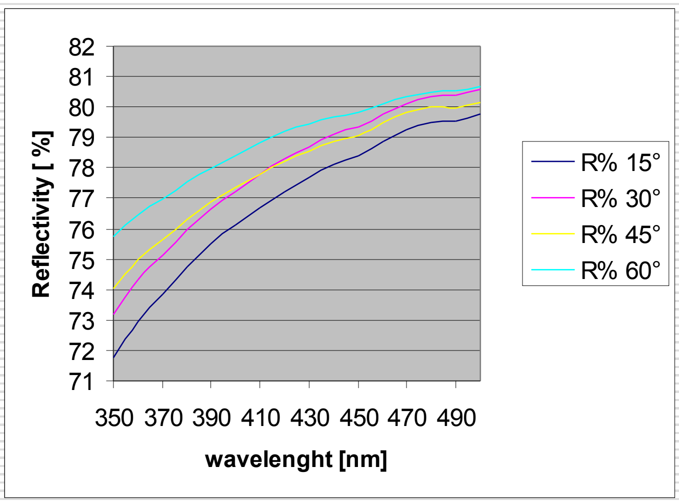
Photon incidence angle in the mirror



Mirror with a SiO coating not the final coating !!

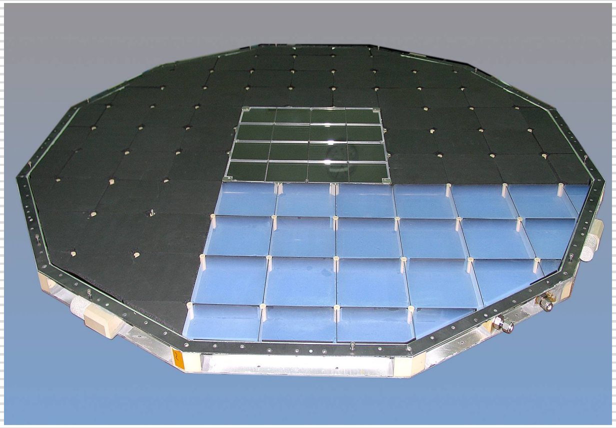
Final sample reflectivity of ~85%

Optical measurement of the reflectivity

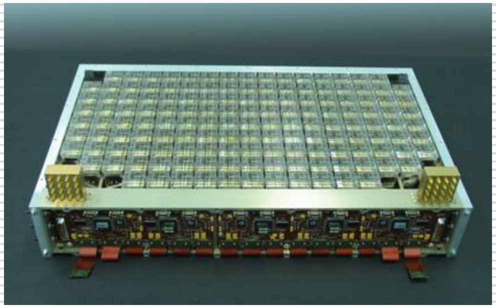


RICH status in October 2006

RICH Assembly has already started at CIEMAT, Madrid and is foreseen to be finished before July 2007



- Radiator:
  - aerogel tiles: optical characterization on going (@LPSC, Grenoble)
  - the aerogel container is ready (@CIEMAT, Madrid)
  - aerogel container + tiles: vibration starting today (@SERMS, Terni)
- Mirror: Prepared to be assembled. Already characterized with several measurements in LAB



- Detection plane:
  - 680 unit cells are finished and ready for grid assembly
  - 1st grid already assembled others are on going
  - functional tests of the unit-cells and full characterization done

Conclusions

- ✓ The AMS-02 experiment to be installed in the International Space Station will be equipped with a RICH which is foreseen to be completely assembled by July 2007
- ✓ The design of the RICH detector was validated through intensive tests of a prototype.
- ✓ Velocity and charge reconstruction algorithms were tested.
- ✓ Full agreement between the MC and data taken with the aerogel radiator.
- ✓ Mirror sample used in the test:
  - ✓ Reflectivity measurement with data in agreement with the measurements of the manufacturer.