The RICH detector of the AMS-02 experiment: status and physics prospects

Rui Pereira

(LIP - Lisbon)

on behalf of the AMS RICH collaboration

e-mail address: pereira@lip.pt

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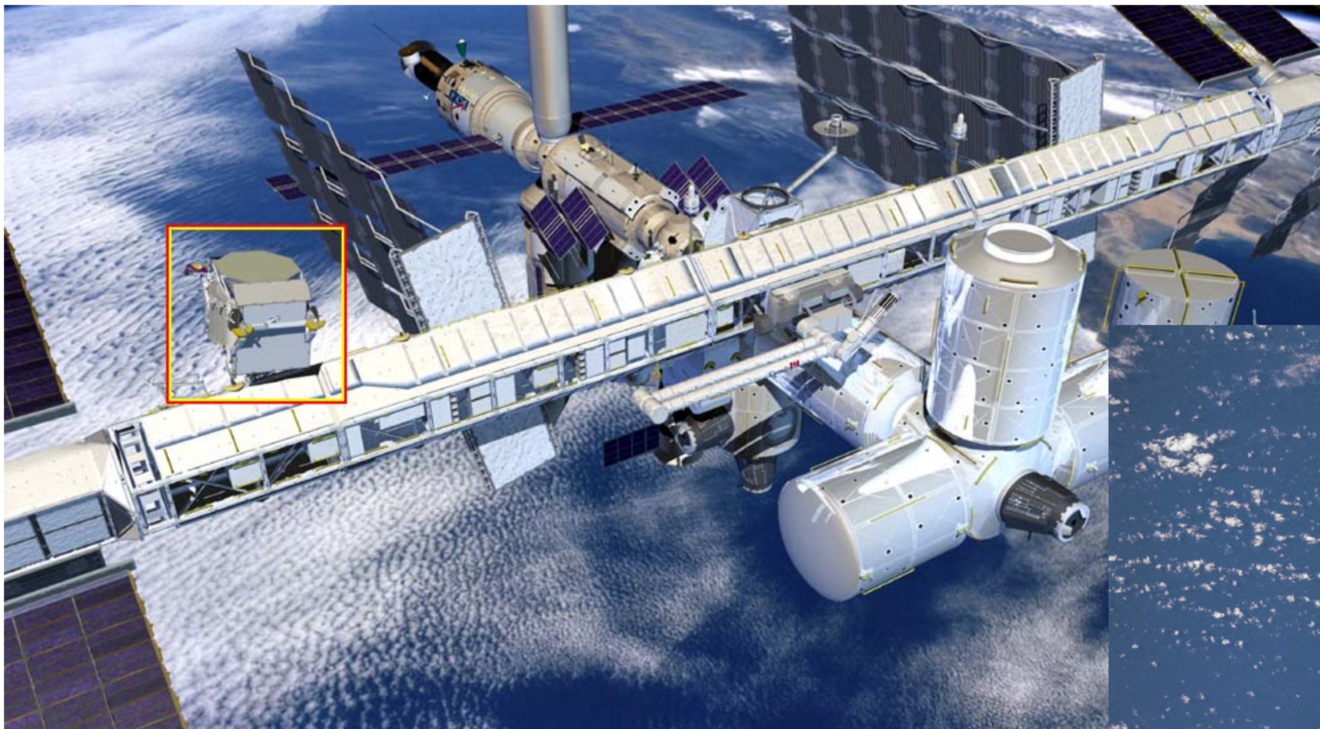
Outline

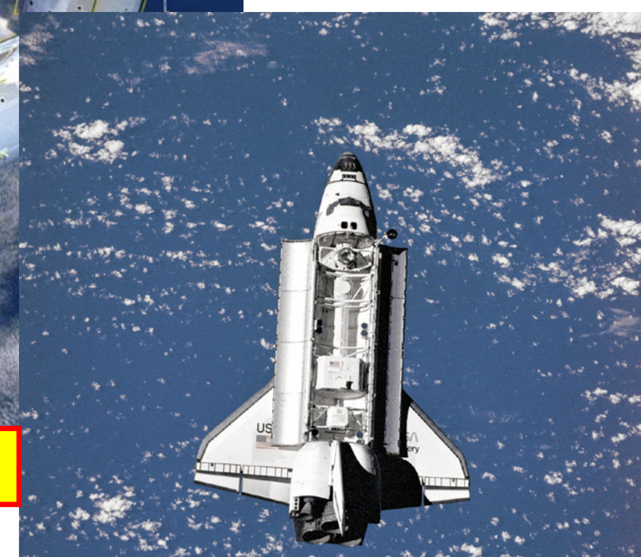
- The AMS experiment
- AMS-02 & RICH detector
- RICH physics
- Detector components
- RICH prototype tests
- System monitoring
- Pre-assembly tests
- Physics prospects
- Conclusions

The AMS experiment

- Broad international collaboration for the detection of primary cosmic rays in space



The AMS-02 detector on the International Space Station



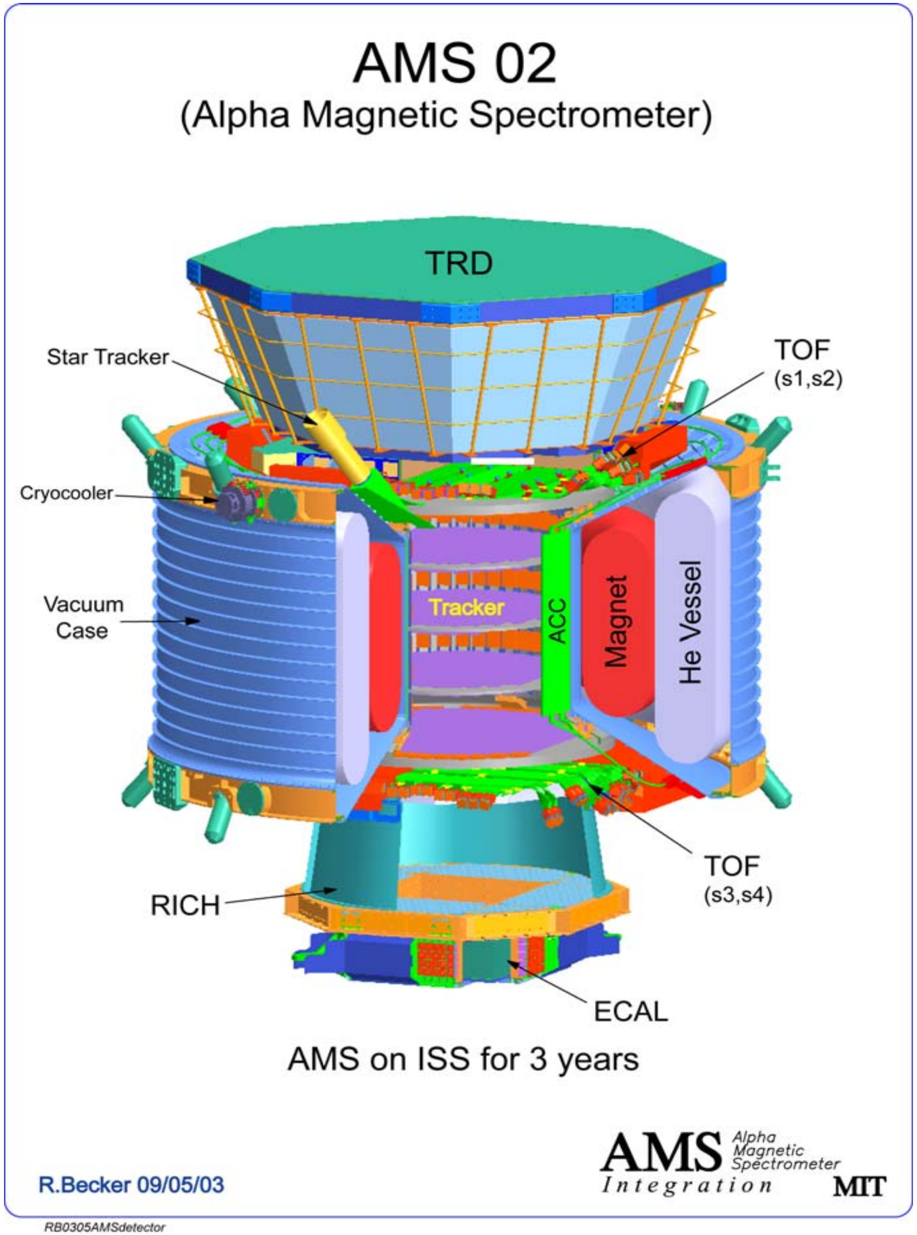
Prototype flight in space shuttle (1998)

The AMS experiment

- Data taking: > 3 years on the International Space Station
- Final detector AMS-02 currently being assembled, should be ready by the end of 2008
- Main goals:
  - *Detailed study of cosmic ray spectra*
    - AMS will provide an unprecedented statistics of charged cosmic ray measurements between ~100 MeV and ~1 TeV
    - Charge identification up to iron (Z=26)
    - Precise velocity measurement allows isotope separation in the GeV region
  - *Search for dark matter*
    - Anomalies in cosmic ray spectra may provide information on dark matter constituents
  - *Search for antinuclei*
    - The presence of heavy antinuclei ($Z \geq 2$) in cosmic rays may signal the existence of antimatter domains in the Universe

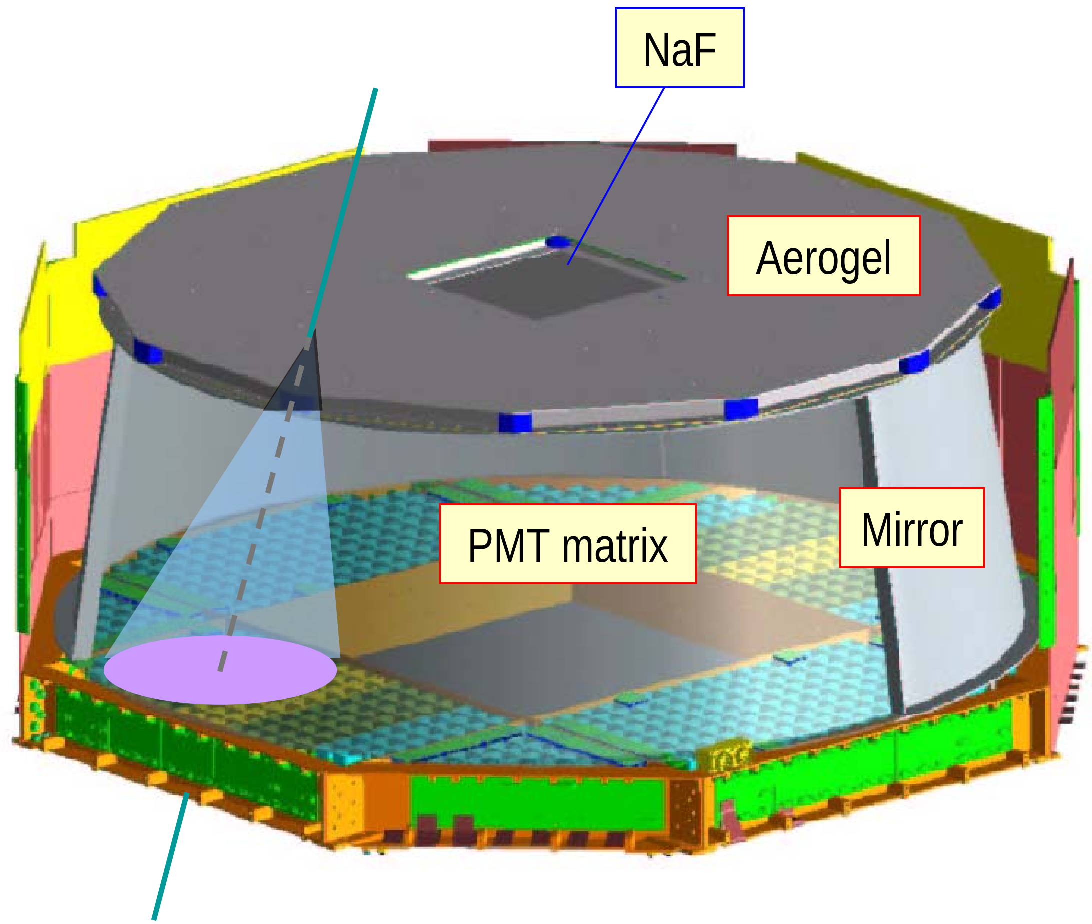
AMS-02 detector

- Has the following subdetectors:
  - *Transition Radiation Detector*
  - *Time-of-Flight detector*
  - *Silicon Tracker*
  - *Ring Imaging Cherenkov detector*
  - *Electromagnetic Calorimeter*
  - *Anti-Coincidence Counter*
- Detector capabilities:
  - *Particle bending*
    - Superconducting magnet (0.9 T)
  - *Measurements of particle:*
    - **Rigidity = p/Z** (Tracker)
    - **Direction** (ToF, Tracker, RICH)
    - **Velocity** (RICH, ToF, TRD)
    - **Charge** (RICH, Tracker, ToF)
  - *Trigger*
    - ToF, ECAL, ACC
- Total statistics: $>10^{10}$ events
- Acceptance: ~ 0.5 m^2sr



RICH detector

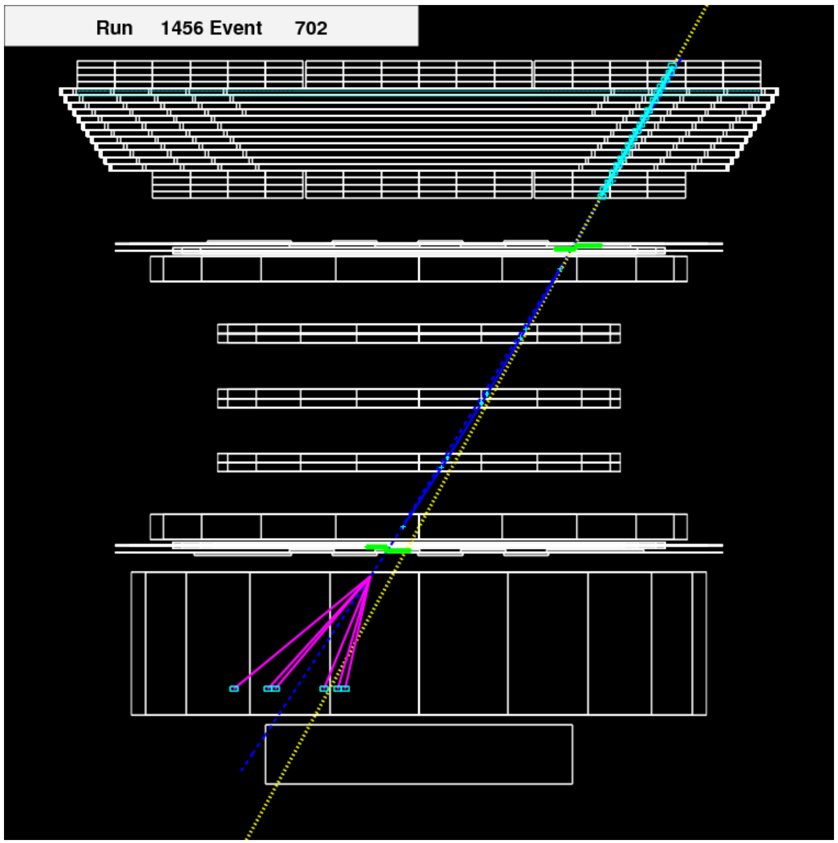
- Proximity focusing detector
- Two radiators
  - *NaF (n=1.334) – central square*
  - *Aerogel (n=1.05) – outer region*
- Ring acceptance increased with conical mirror (85% reflective)
- Detection matrix with 680 PMTs, each with 16 pixels
  - *Pixel size: 8.5 mm*



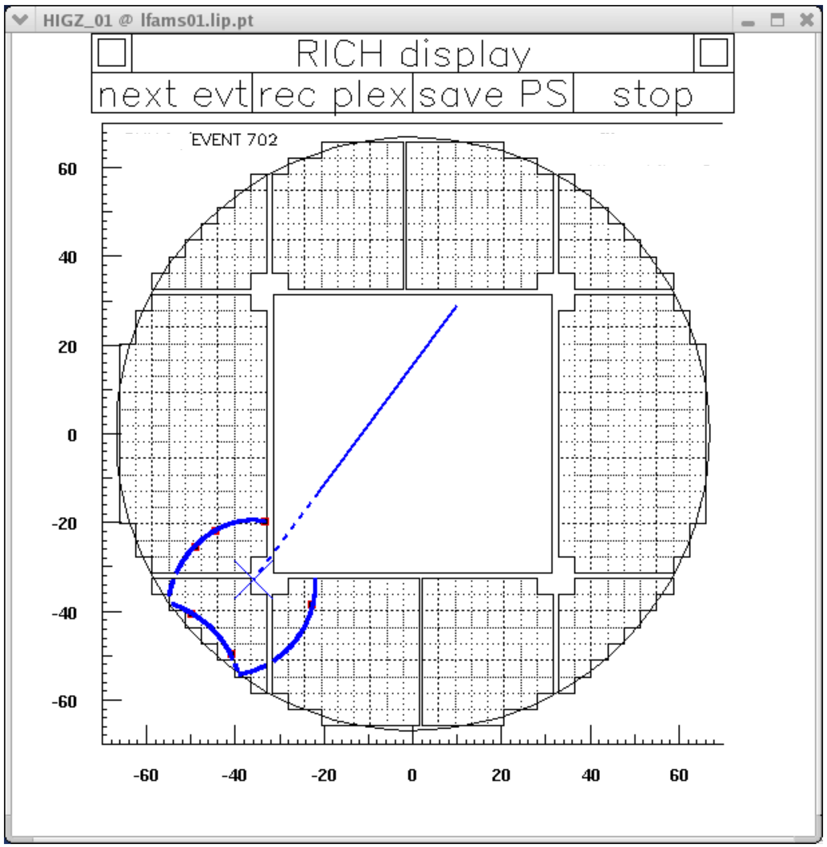
- Assembly of the RICH detector currently being finished at CIEMAT, Madrid
- AMS subsystems (including RICH) to be assembled at CERN

AMS event

- Example of reconstructed event in AMS and RICH detector:



Simulated event on the AMS detector



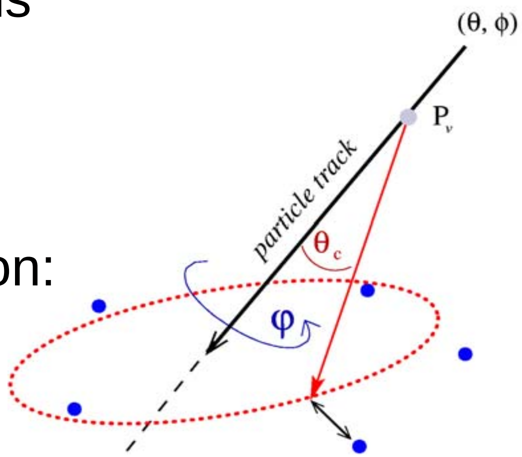
Same event on LIP RICH display

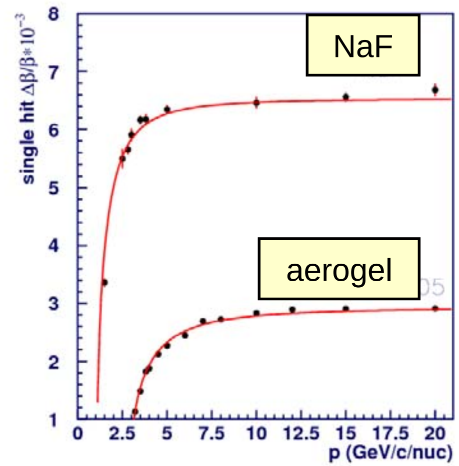
RICH physics: velocity measurement

- Opening of Cherenkov cone is function of velocity:

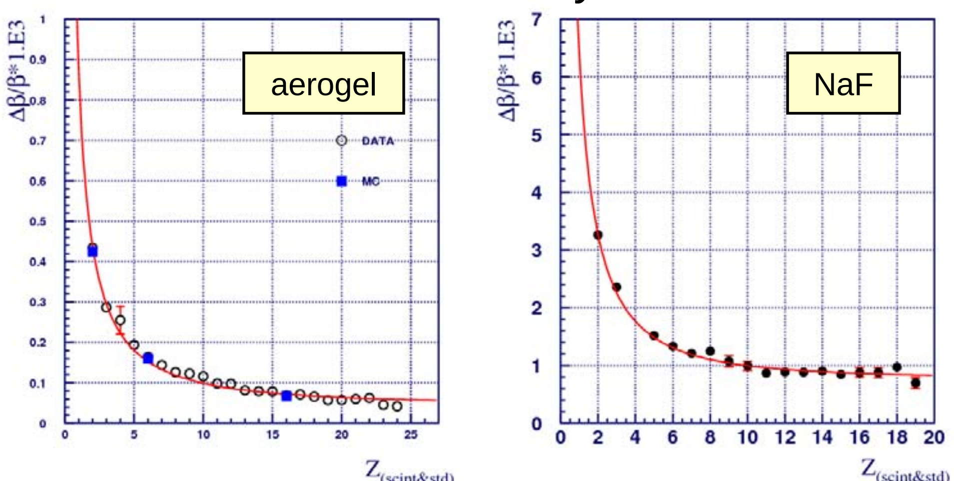
$$\cos\ \theta_c = \frac{1}{\beta\ n}$$

- Velocity resolution depends on:
  - Number of ring hits
  - Pixel size (8.5 mm)
  - Radiator thickness
  - Radiator chromaticity





single-hit resolution vs. momentum



velocity resolution vs. charge in RICH prototype: aerogel (left), NaF (right)

- Expected velocity resolution in aerogel events for $\beta \approx 1$:

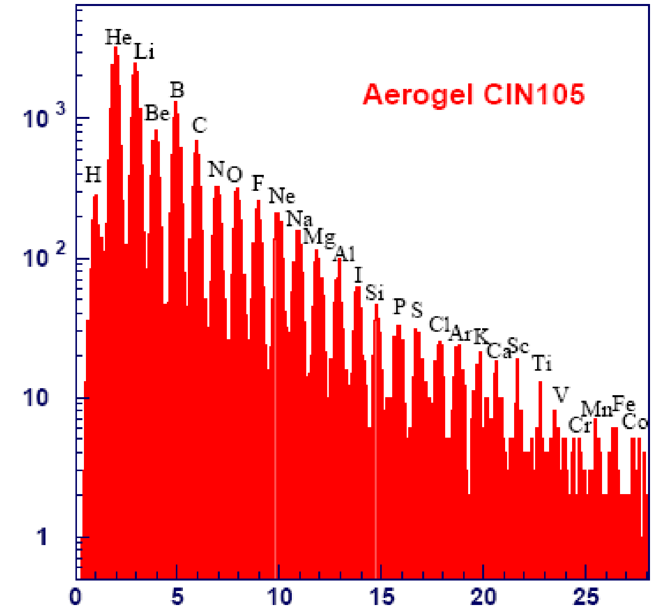
Z	$\Delta\beta/\beta$
1	$\sim 10^{-3}$
10-20	$\sim 10^{-4}$

RICH physics: charge measurement

- Cerenkov ring signal is proportional to Z^2
  - signal dependence on velocity must also be taken into account
- Ring acceptance ε (visible fraction) and photon absorption (both inside radiator and at mirror) must also be considered:

$$Z^2 \propto \frac{N_{pe}}{\varepsilon}$$

- Systematics from non-uniformities:
  - radiator: n, thickness, clarity...
  - detection: light guides, PMTs, temperature effects...
- Statistical error: $\Delta N_{pe} = \sqrt{N_{pe}(1+\sigma_{pe}^2)}$



reconstructed Z at CERN beam test

$$\Delta Z = \frac{1}{2}\sqrt{\frac{1+\sigma_{pe}^2}{N_0} + Z^2\left(\frac{\Delta\varepsilon}{\varepsilon}\right)^2}$$

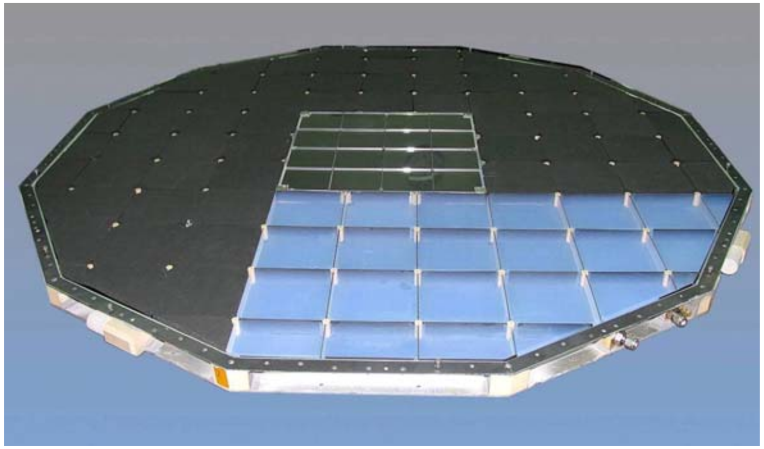
where N_0 is the average number of photoelectrons for a fully contained ring and Z=1

Charge separation feasible up to Z ~ 26

RICH detector: radiator

- Dual radiator configuration
- Silica aerogel: outer region
  - 92 tiles, n = 1.05
  - 11.3 cm × 11.3 cm × 2.5 cm
  - Aerogels have the lowest refractive indices of all solid materials
  - Threshold: E_{kin} > 2.1 GeV/nuc
- NaF: central region
  - 16 tiles, n = 1.334
  - 8.5 cm × 8.5 cm × 0.5 cm
  - High Cerenkov angle (~40º) reduces photon loss in central hole
  - Extends RICH range to lower energies (E_{kin} > 0.5 GeV/nuc)

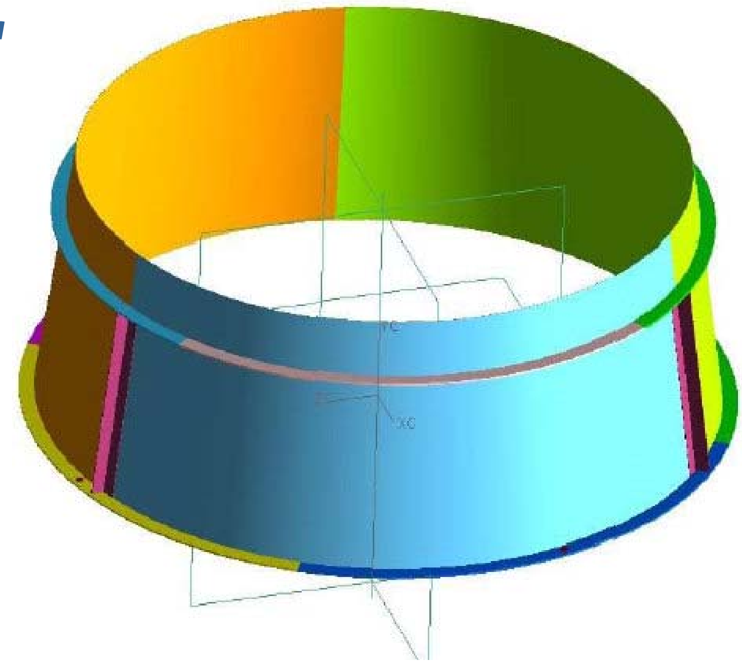
aerogel tile



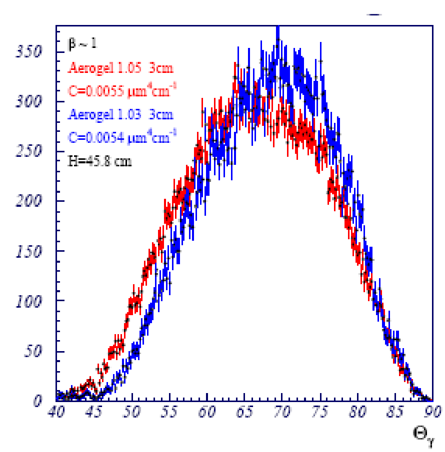
radiator container with all NaF and 1/4 of aerogel tiles

RICH detector: mirror

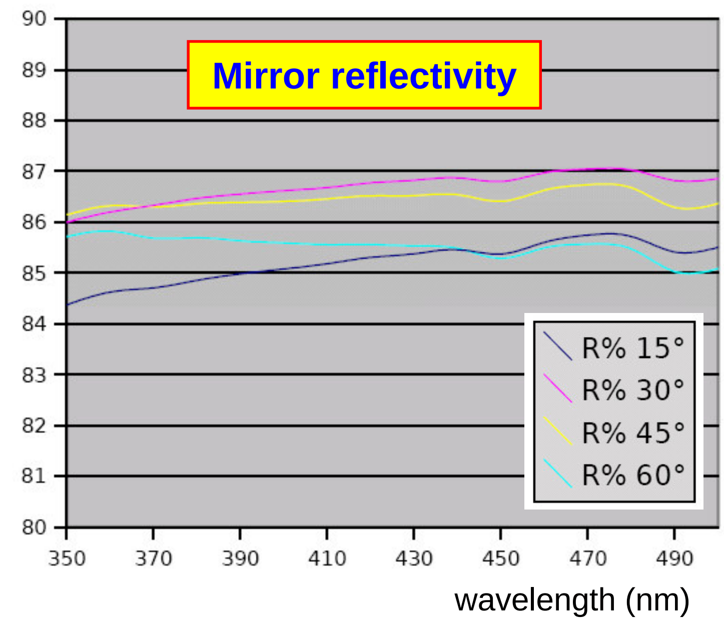
- ~33% of the photons emerging from the radiator point outside the detection matrix
- Conical mirror used for increased photon acceptance
- Structure: carbon fibre (3 segments)
- Reflector: 100 nm Al-Ni + 300 nm SiO_2



- Highly reflective (>85% at λ=420 nm)
  - Reflectivity must be known to ~1% for good charge reconstruction
- Dimensions
  - height: 46 cm
  - upper radius: 60 cm
  - lower radius: 67 cm

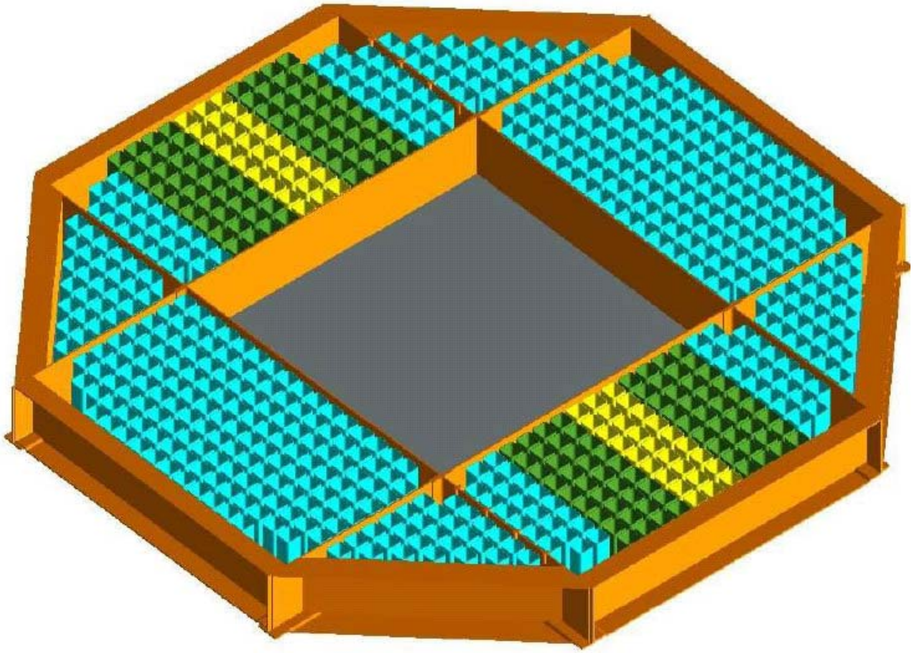


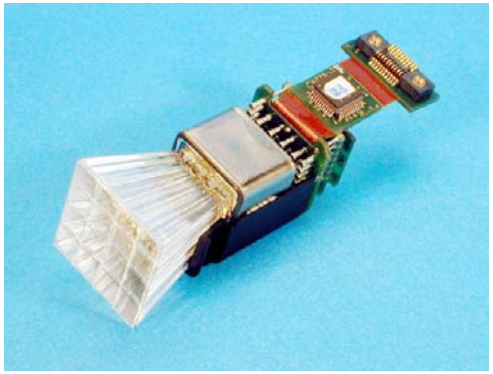
incidence angles in mirror (aerogel)



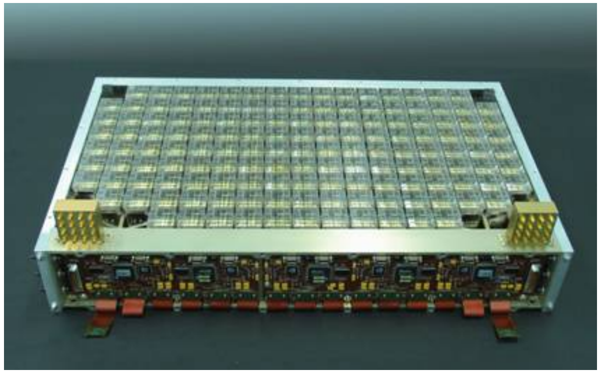
RICH detector: detection matrix

- 8 grids (4 rectangular + 4 triangular)
- 680 multianode PMTs coupled to light guides
- 16 pixels (4×4) in each PMT
- central hole due to insertion of electromagnetic calorimeter under the RICH

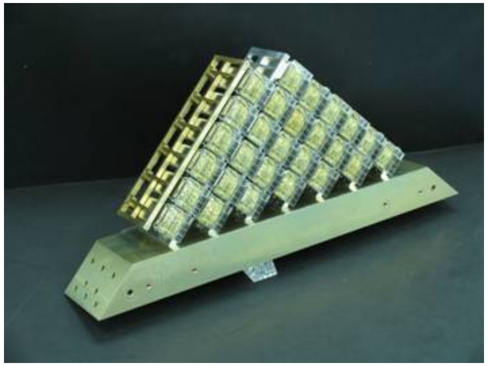




detection cell



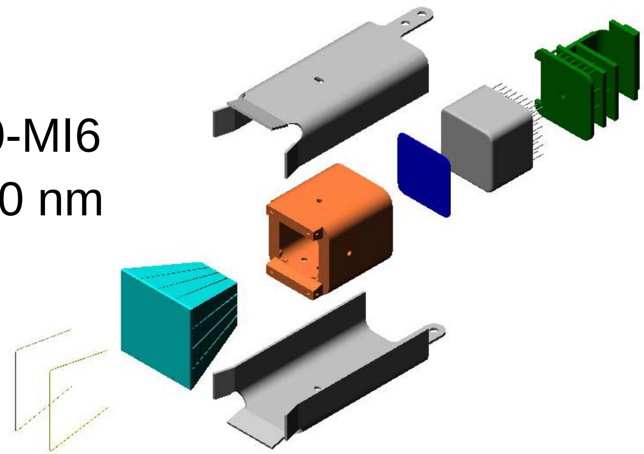
rectangular grid

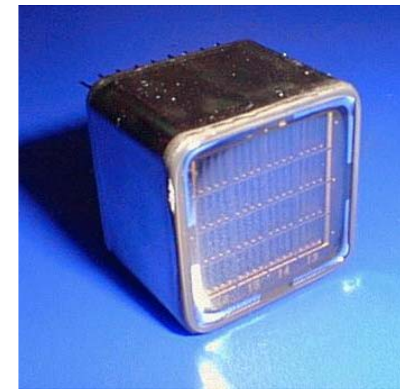


triangular grid

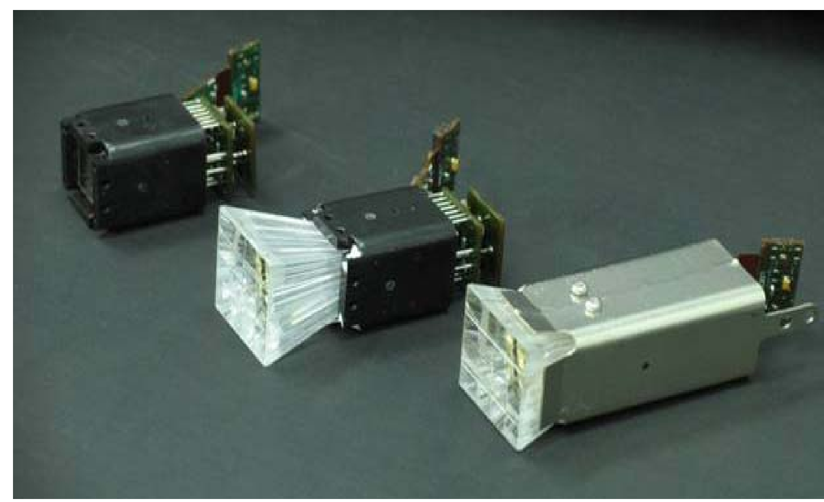
RICH detector: detection cell

- Photomultipliers
  - Model: Hamamatsu R7900-MI6
  - Spectral response: 300-650 nm (peak at 420 nm)
  - pitch: 4.5 mm





- Light guides
  - material: plexiglass (n=1.49)
  - increase on photon collection
  - effective pixel size: 8.5 mm
- Shielding
  - aluminium plate (0.8-1.3 mm)
  - needed due to high stray magnetic field on detection plane (~300 G)



RICH prototype / cosmic-ray test

- RICH prototype
  - Detection matrix: 96 PMTs (~1/7 of final detector)
  - Individual radiator tiles (NaF, several aerogel samples) tested in succession
  - Mirror segment: 30º (1/12 of total), used in second beam test only

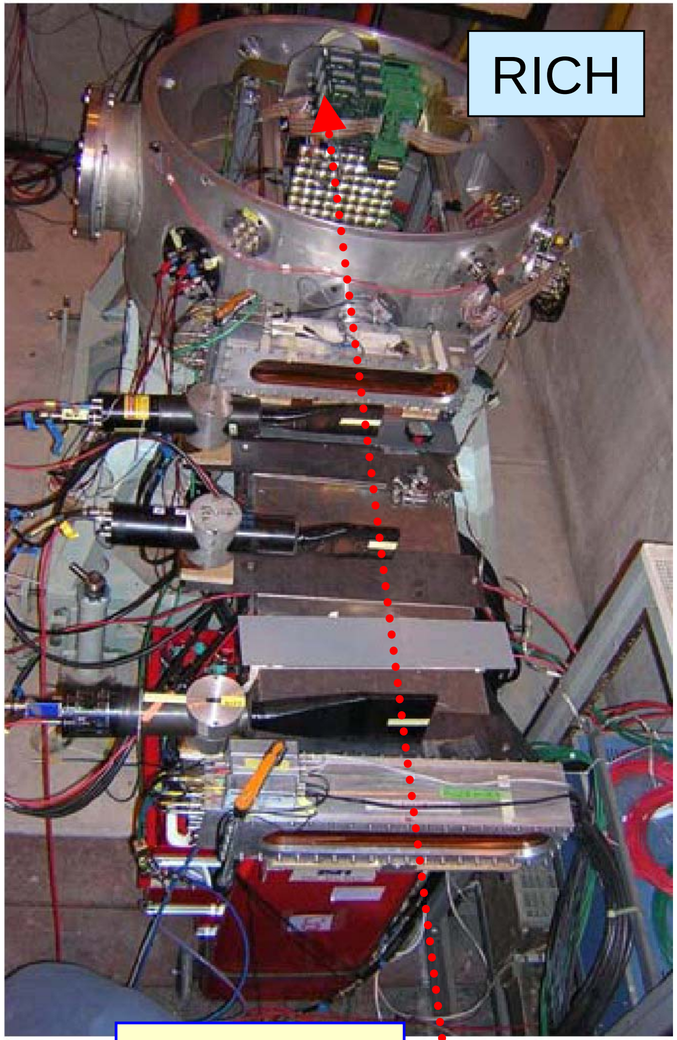
RICH prototype at cosmic-ray testing in Grenoble

- Cosmic-ray test at LPSC, Grenoble:
  - Prototype exposed to cosmic-ray flux at ground level

RICH prototype tests: setup

- First test:
  - Secondary beam produced from impact of primary 20 GeV/c lead beam on beryllium target
  - 5×10^6 events recorded
- Second test:
  - Secondary beam produced from impact of primary 158 GeV/c indium beam on lead target
  - 11×10^6 events recorded

RICH prototype with mirror segment

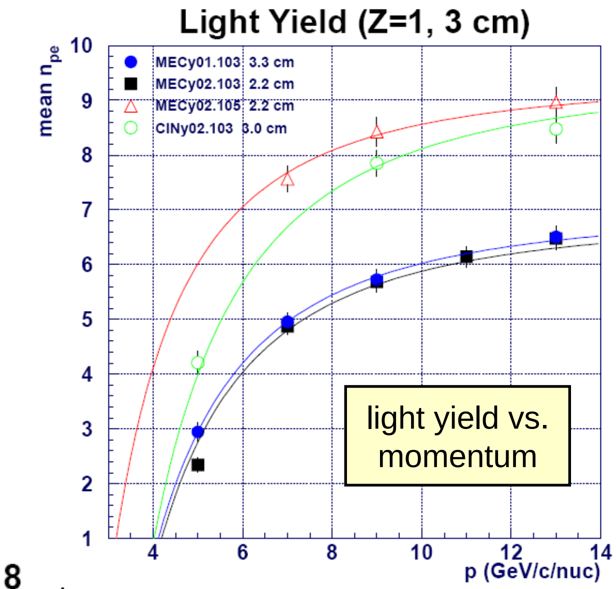


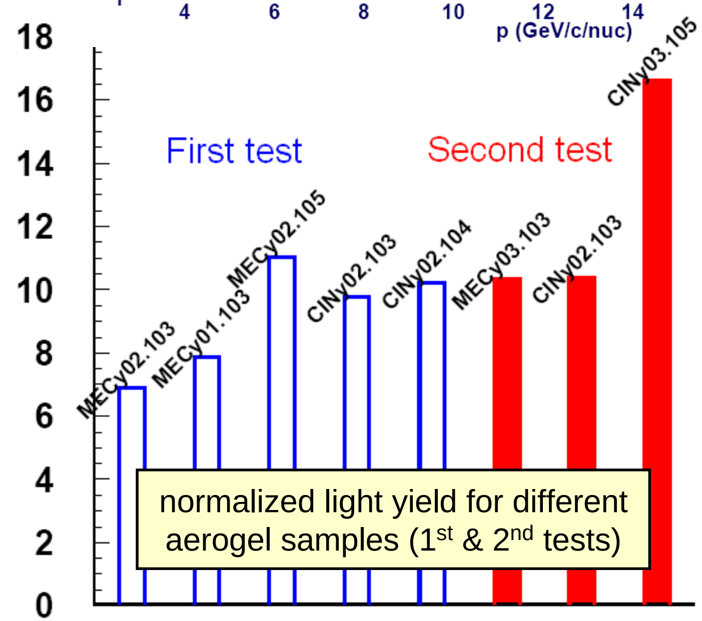
Setup for second beam test

beam

RICH prototype tests: analysis

- First test beam selection:
  - p = 5 to 13 GeV/c (protons)
  - Studies on aerogel light yield as function of momentum
- Second test beam selection:
  - A/Z = 2, 2.25, 2.35
  - "Realistic" spectrum good for studies on charge separation
  - Several particle angles
  - Reflector tested
  - Studies on tile uniformity
  - Testing of readout electronics

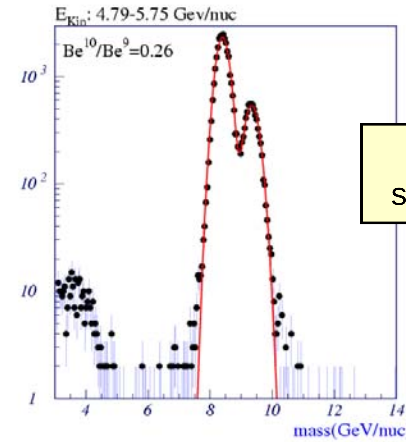




Why detailed monitoring is needed

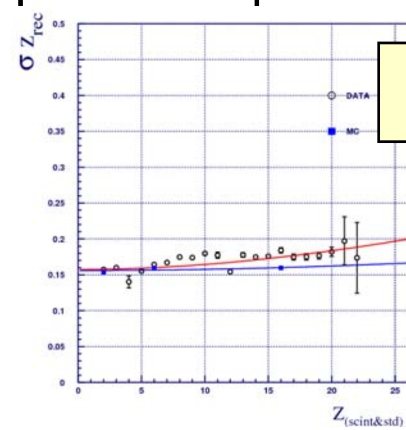
SYSTEM KNOWLEDGE REQUIREMENTS			
parameter	limited by		monitoring precision
	velocity	charge	
aerogel radiator			
ref. index	✓		~10^{-4}
thickness		✓	~0.4 mm
clarity		✓	~3%
reflector			
reflectivity		✓	~1%
detection matrix			
PMT gain		✓	~5%
cell eff.		✓	~5%

- Velocity requirement: separation of Be isotopes up to E_{kin} ~ 10 GeV/nuc



Be mass separation

- Charge requirement: separation up to Z ~ 26



charge resolution

Monitoring: aerogel properties

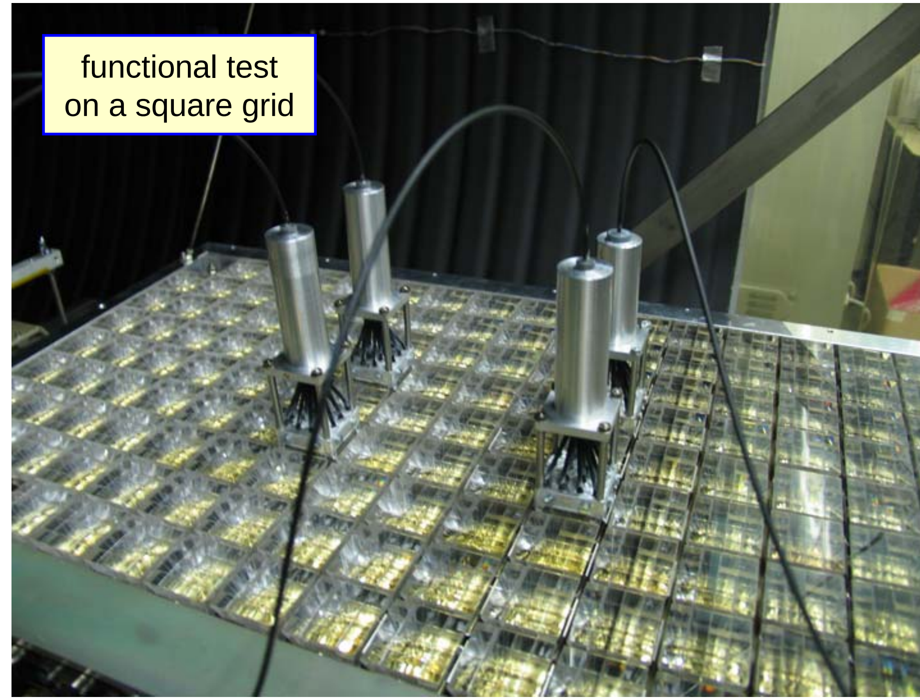
- Optical and geometrical characterization of aerogel tiles at LPSC, Grenoble with participation from LIP and UNAM
  - All tiles tested
  - Refractive index mapping: geometrical method using refraction of laser beam, step ~0.5 cm
  - Thickness mapping using comparator: step ~2 cm

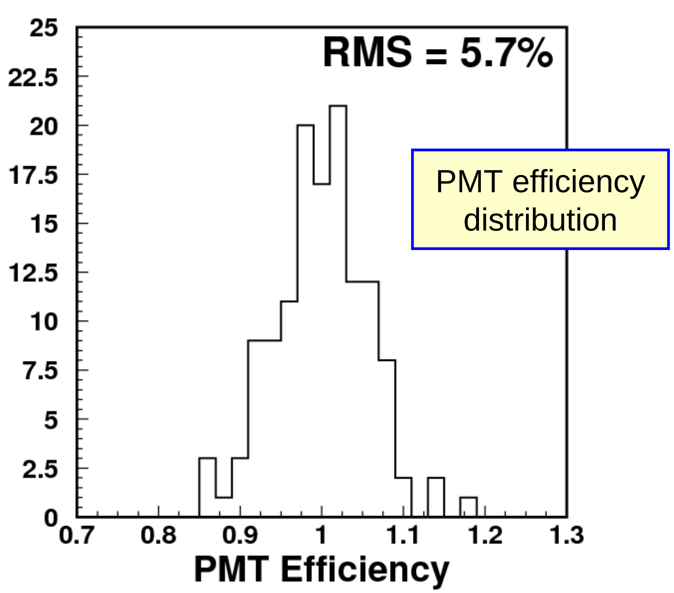
Precision requirements for data on aerogel properties	
refractive index	**10^{-4}**
clarity	**3%**
thickness	**0.4 mm**

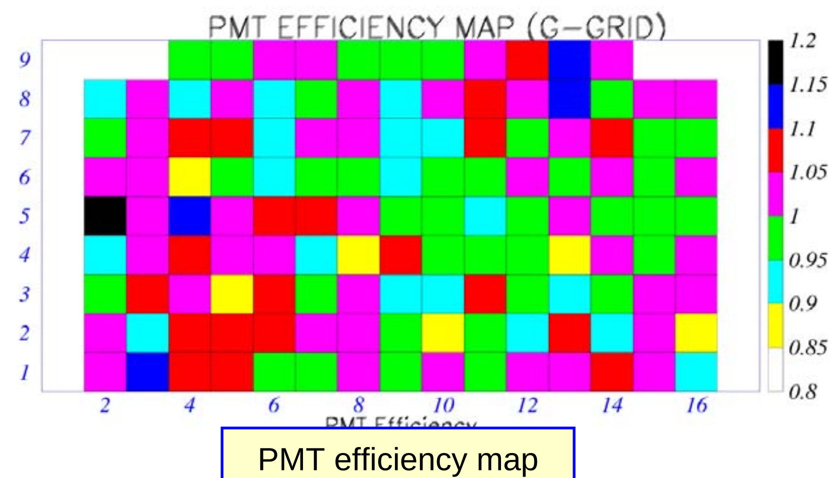
aerogel tile in optical bench

Monitoring: unit cell characterization

- Studies on unit cell characterization made at CIEMAT, Madrid
  - All PMTs tested
- PMT uniformity: photoelectron signal distribution measured, detection plane is uniform within 5-6%

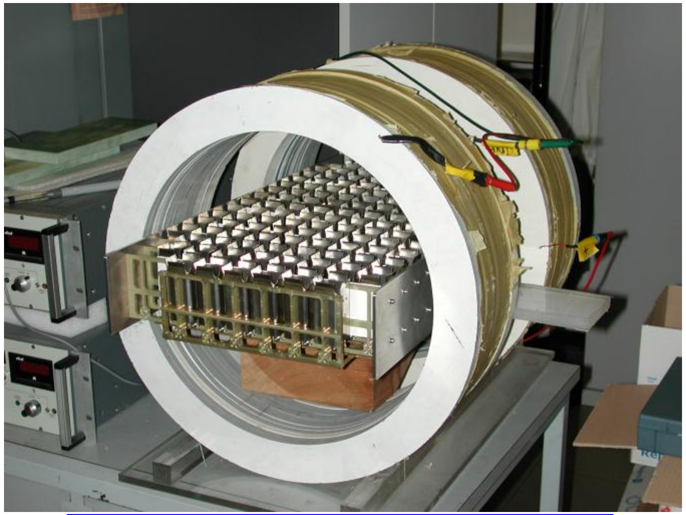




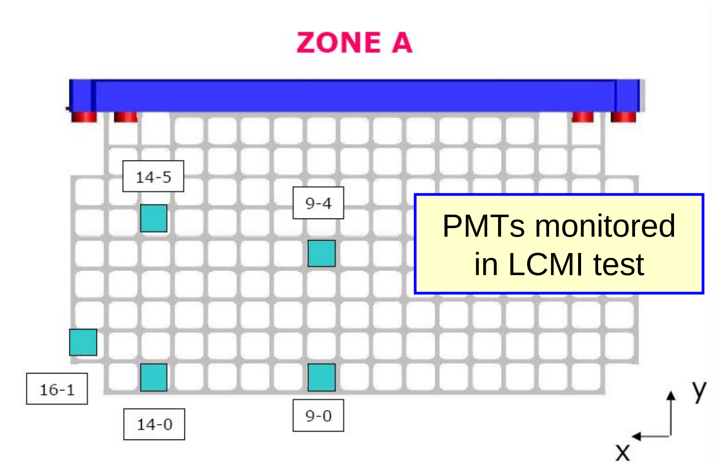


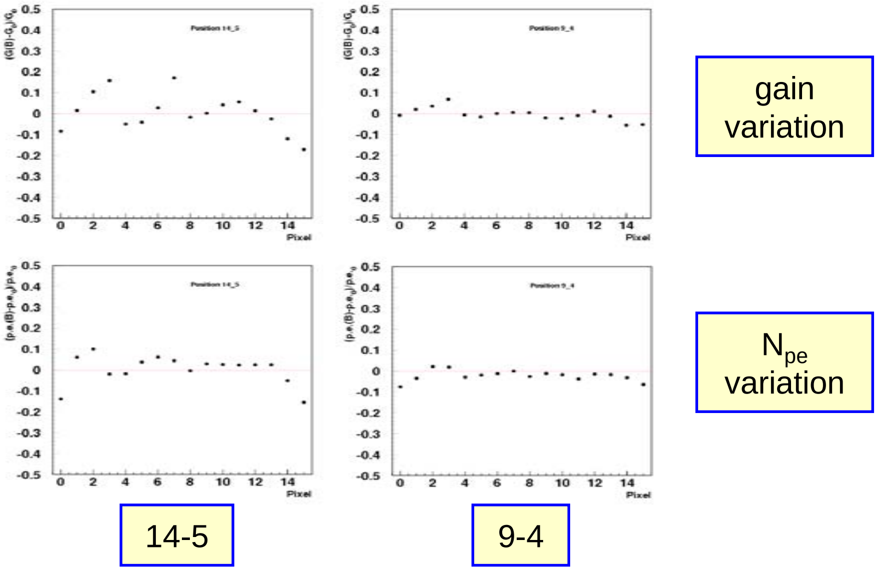
Pre-assembly tests: magnetic field

- Magnetic field tests performed at CERN and at LCMI, Grenoble
  - Expected stray field in PMT grid: up to ~ 300 G
- LCMI test: one rectangular grid, several PMTs monitored in all pixels
  - No significant change on average PMT gain
    - variation at pixel level observed
    - mean pixel gain variation below 10% in worst case
    - Magnetic field induces cross-talk between pixels



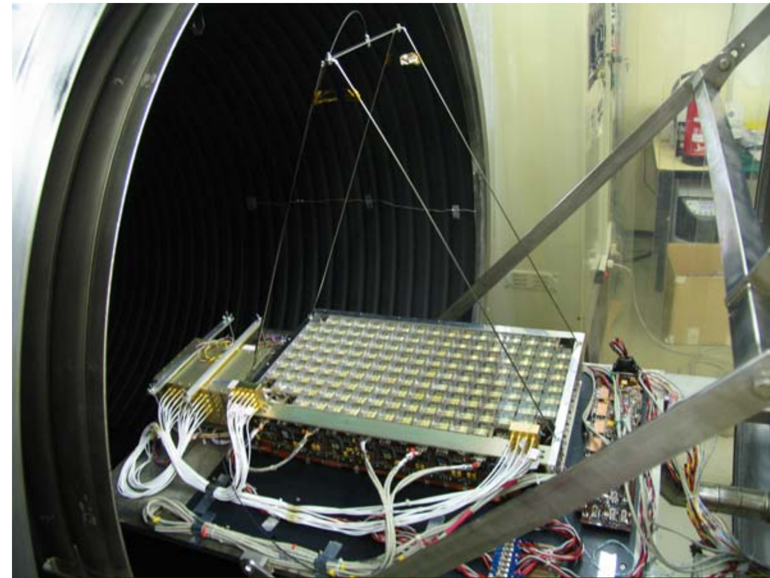
Shielded PMT grid in magnetic field



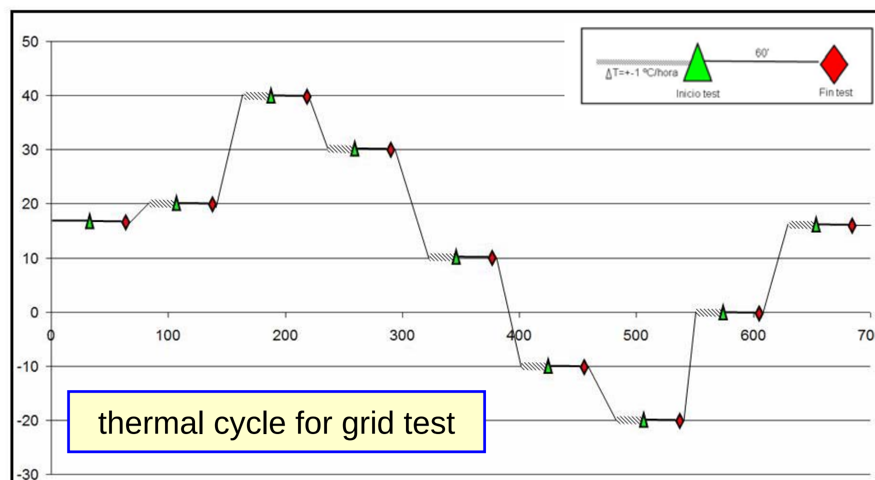


Pre-assembly tests: thermal & vacuum

- Thermal and vacuum testing performed at CIEMAT
- Thermal cycling performed on individual PMTs (–35ºC to 55ºC) and on rectangular grid (~1/5 of total matrix, –20ºC to 40ºC)
- Response to single photon measured in temperature range
- Vacuum test performed on rectangular grid



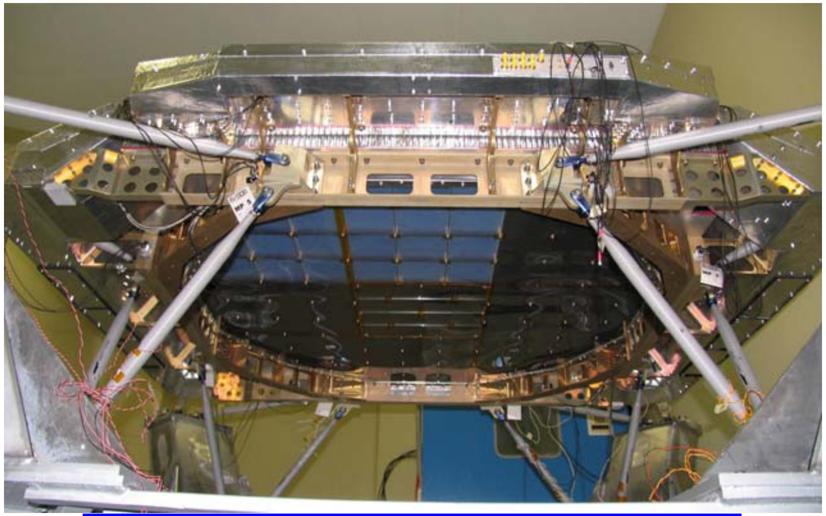
setup for thermal and vacuum tests with grid



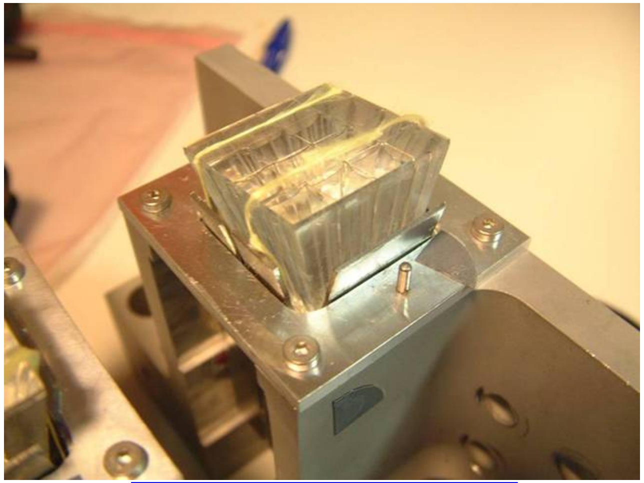
thermal cycle for grid test

Pre-assembly tests: vibration

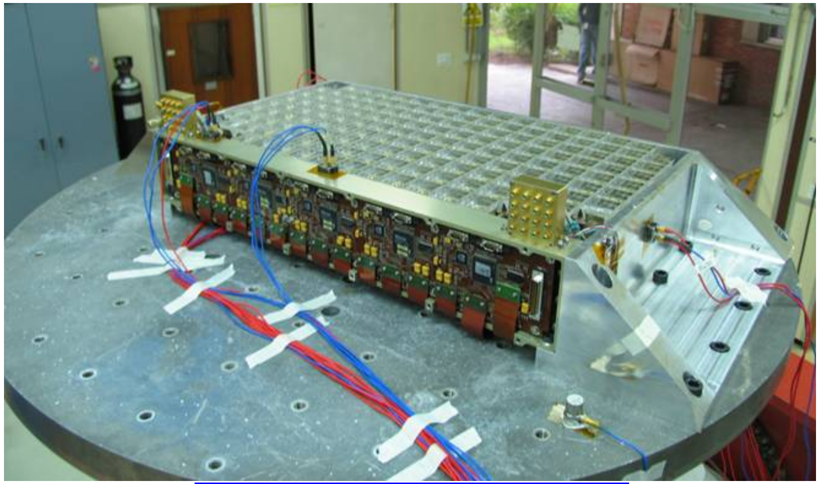
- Test of radiator container at SERMS, Terni
  - All NaF + 1/4 of aerogel tiles vibrated with lower ToF
- Test of PMT grid at INTA, Madrid
  - One rectangular grid tested (~1/5 of total matrix)
- Vibration tests also performed on individual unit cells



setup for RICH radiator + ToF vibration test



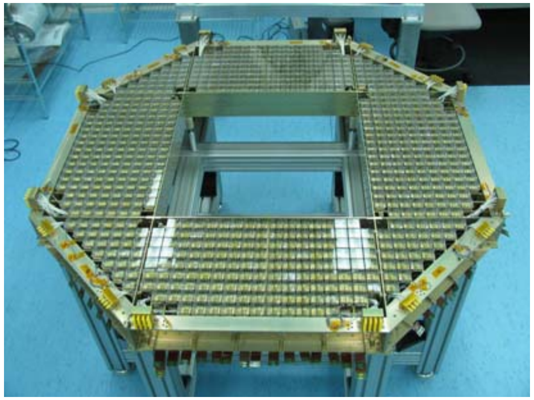
unit cell in vibration test

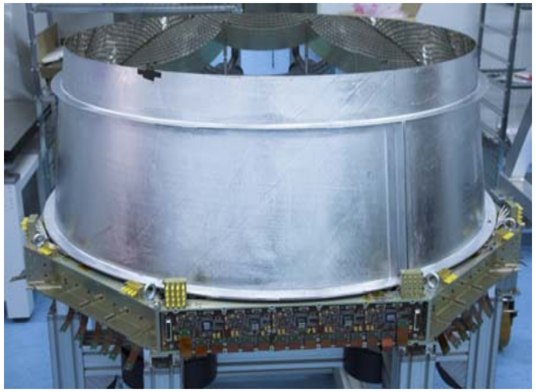


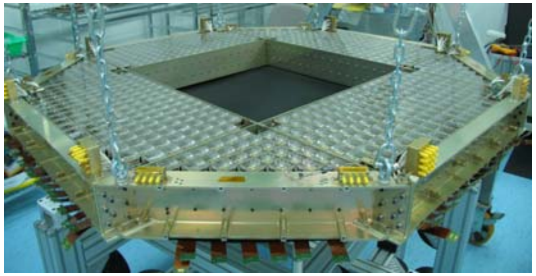
setup for grid vibration test

RICH assembly: current status

- A few recent images of the AMS-02 RICH...

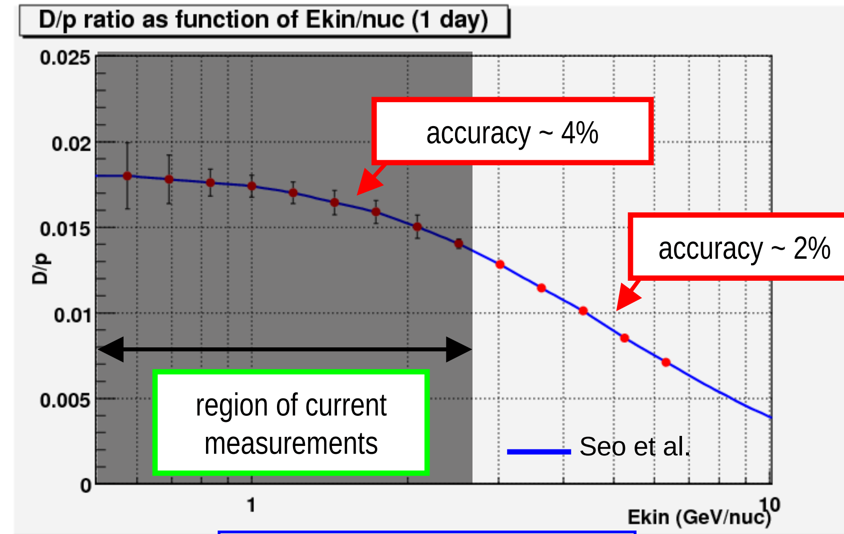




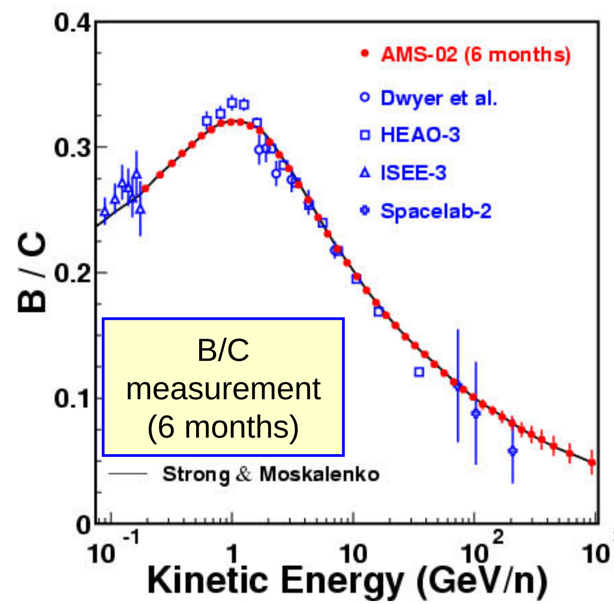


Physics prospects

- RICH data are essential for particle identification
  - *RICH separates charges up to Z ~ 26*
  - *Mass measurement (from RICH velocity+Tracker data) allows isotope separation*
  - *Improvement in albedo rejection*
- Expected in AMS-02
  - *Isotope separation of H, He, Be up to ~ 10 GeV/nucleon: major improvement on current data*
- AMS data to provide insight on cosmic ray physics
  - *D/p, $^3He/^4He$, B/C: information on cosmic ray propagation*
  - *$^{10}Be/^9Be$: confinement times, galactic halo models*



D/p measurement (1 day)



Conclusions

- AMS-02 will provide a major improvement on existing cosmic-ray data

- The RICH detector will play a key role in velocity, charge and mass reconstruction
    - Detector assembly is being finished at CIEMAT, Madrid
    - Extensive testing (mechanical, electrical, ...) has been performed on the detector's components
    - Prototype tests confirm design principles:
        - $\Delta\beta/\beta \sim 10^{-3}$ for Z=1, 10^{-4} for Z>10
        - $\Delta Z \sim 0.16$ for low Z, charge separation up to Z ~ 26
        - Separation of light isotopes is possible

- Integration of the global AMS-02 detector will take place at CERN, should be finished by the end of 2008