Particle identification with the AMS-02 RICH detector

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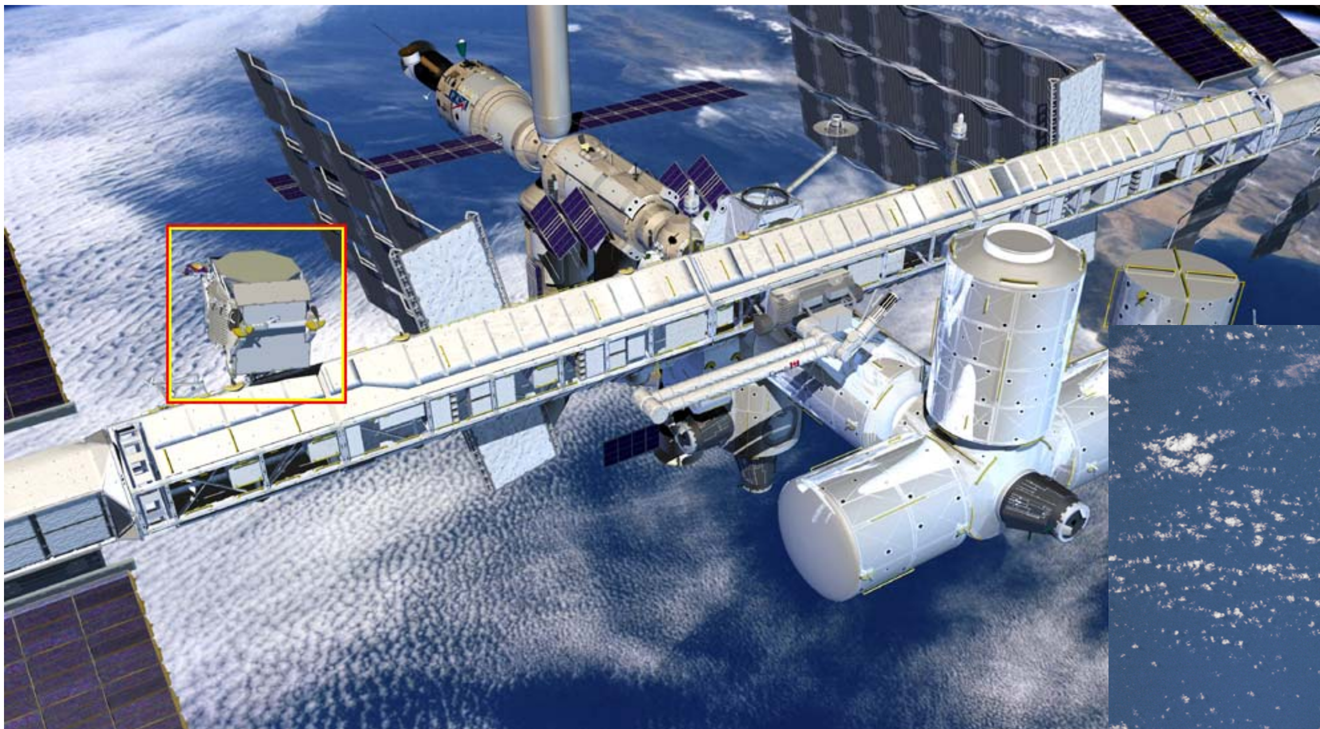
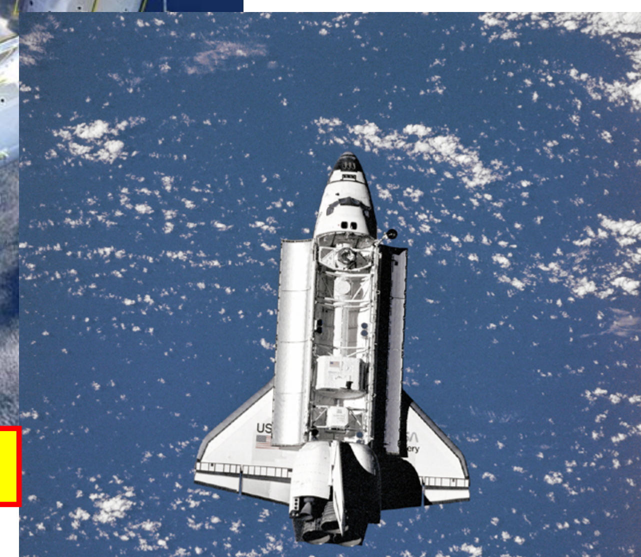
The AMS experiment

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



The AMS-02 detector on the International Space Station



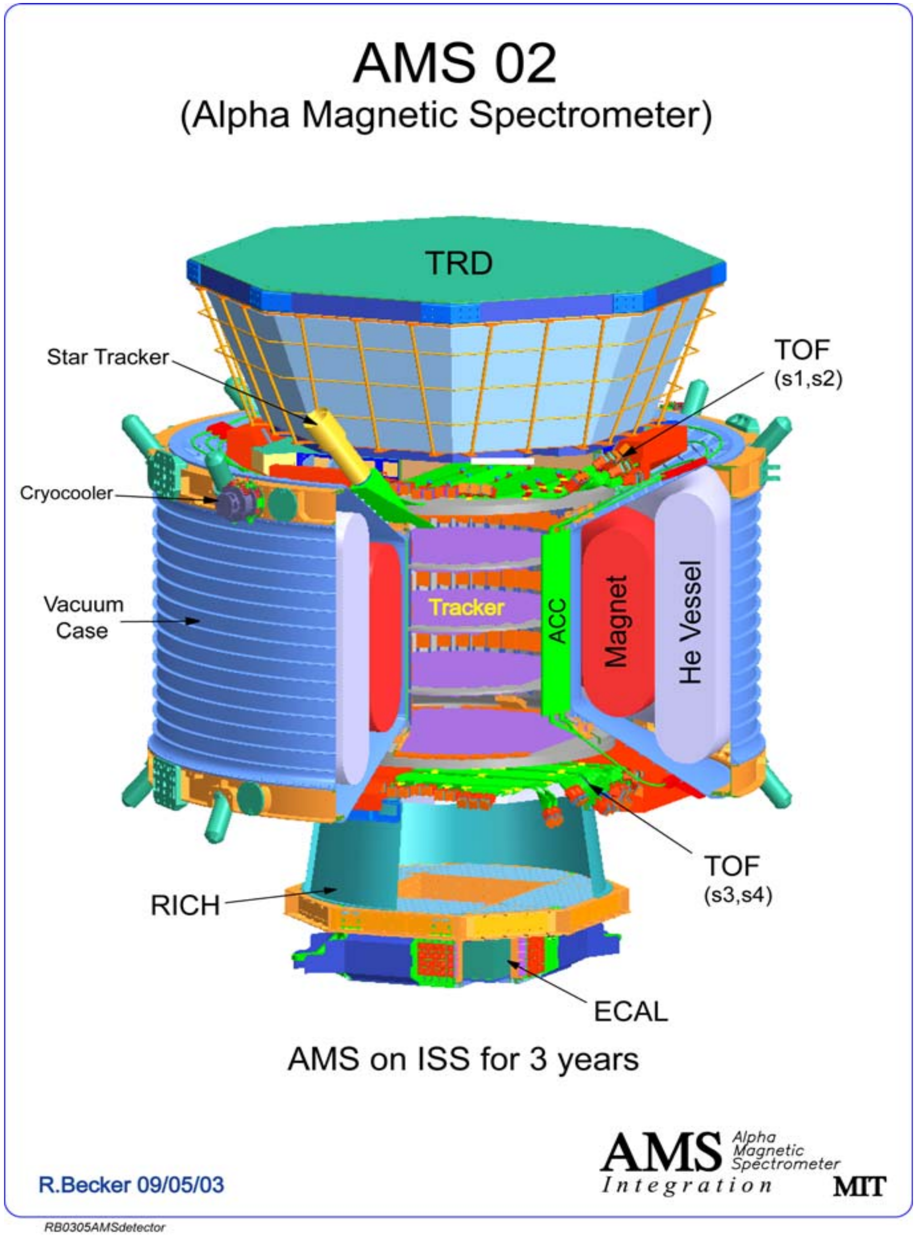
Prototype flight in space shuttle (1998)

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

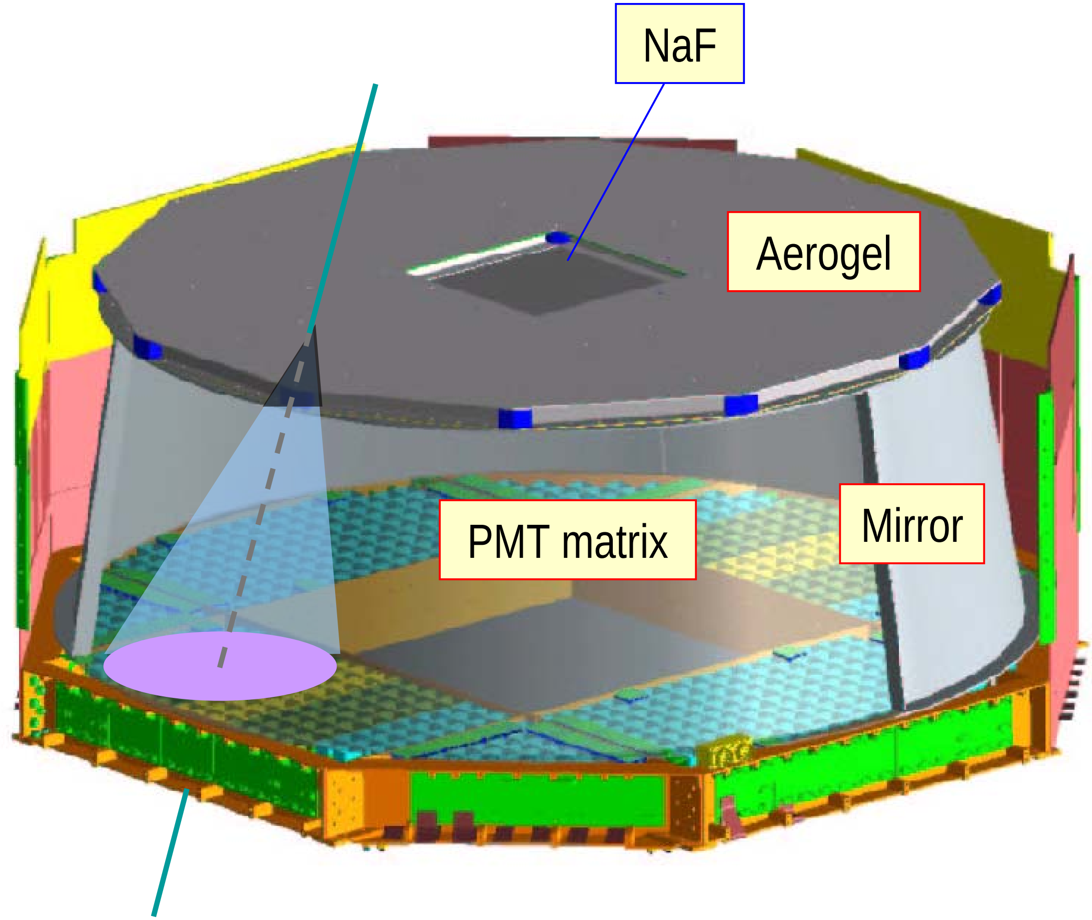
AMS-02 detector

- 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** (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

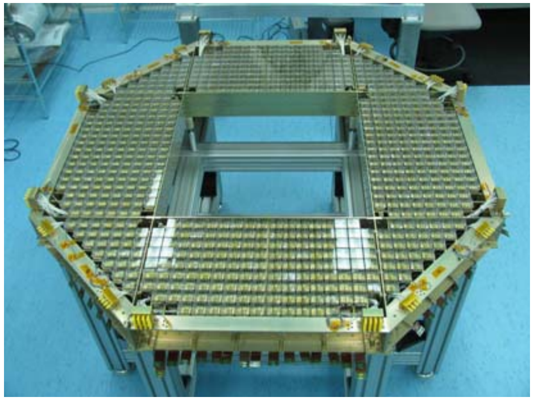
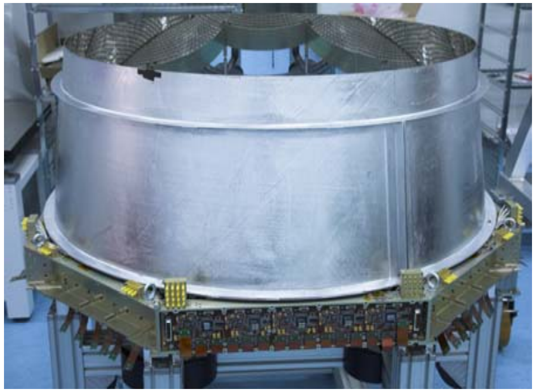
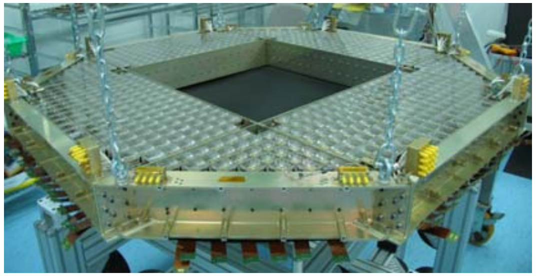
- Proximity focusing detector
- Two radiators
  - *NaF (n=1.334) – central square*
  - *Aerogel (n=1.05) – outer region*
- Ring acceptance increased with conical mirror (85% reflective)
- Detection matrix with 680 PMTs, each with 16 pixels
  - *Pixel size: 8.5 mm*



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

RICH detector: assembly

- A few images of the RICH assembly...

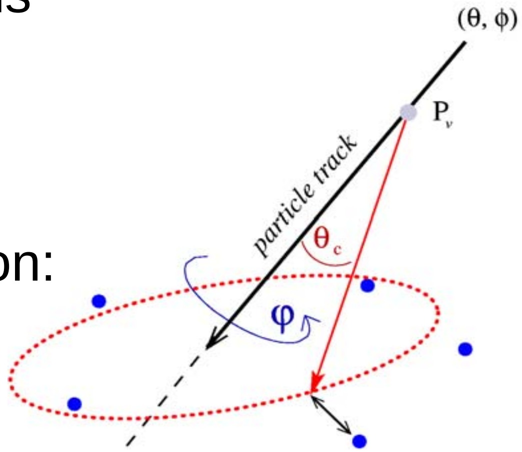





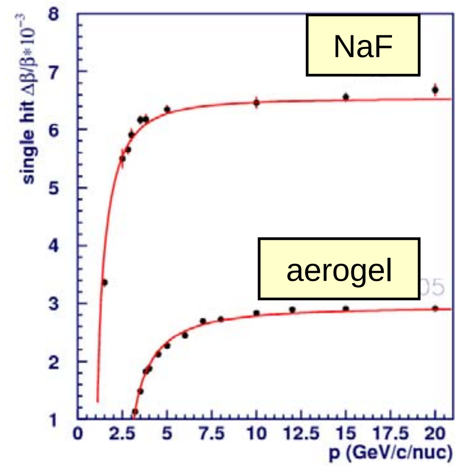
RICH physics: velocity measurement

- Opening of Cherenkov cone is function of velocity:

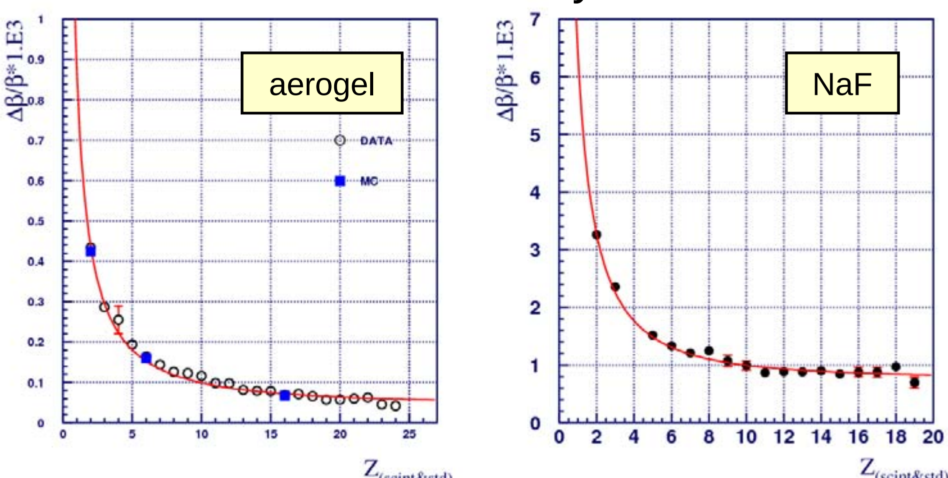
$$\cos\ \theta_c = \frac{1}{\beta\ n}$$

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





single-hit resolution vs. momentum (expected for final detector)



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

- Expected velocity resolution in aerogel events for β ≈ 1:

Z	Δβ/β
1	~10^{-3}
10-20	~10^{-4}

RICH prototype

- 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

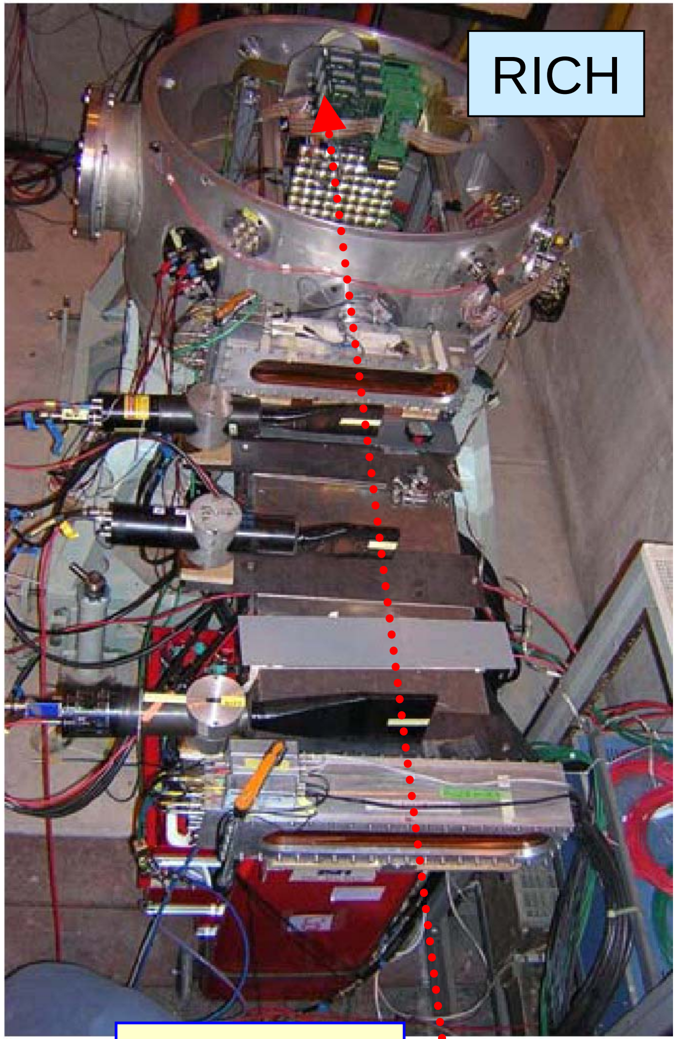
- Tests performed using prototype:
  - Cosmic ray test at LPSC, Grenoble
  - Two beam tests at CERN

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

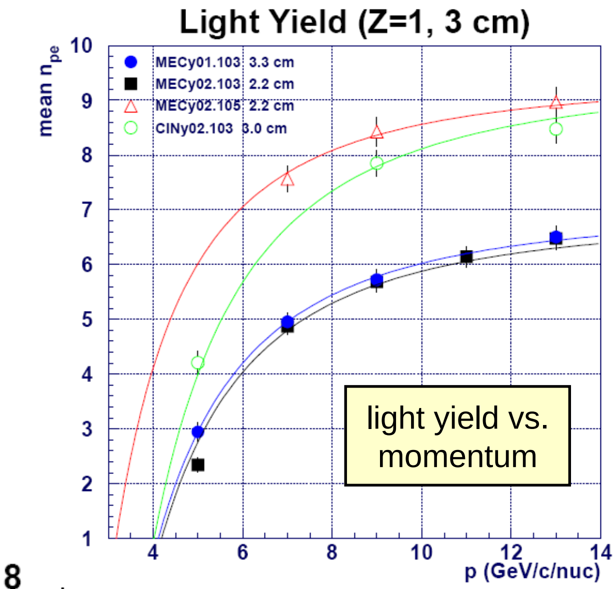


Setup for second beam test

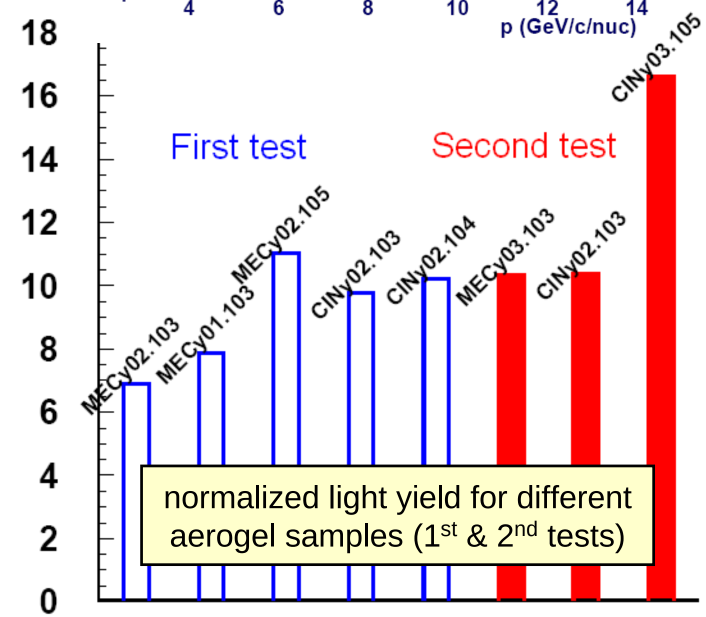
RICH prototype tests: analysis

- First test beam selection:
  - p = 5 to 13 GeV/c (protons)
  - Studies on aerogel light yield as function of momentum:

$$N_\gamma \propto 1 - \frac{1}{\beta^2 n^2}$$

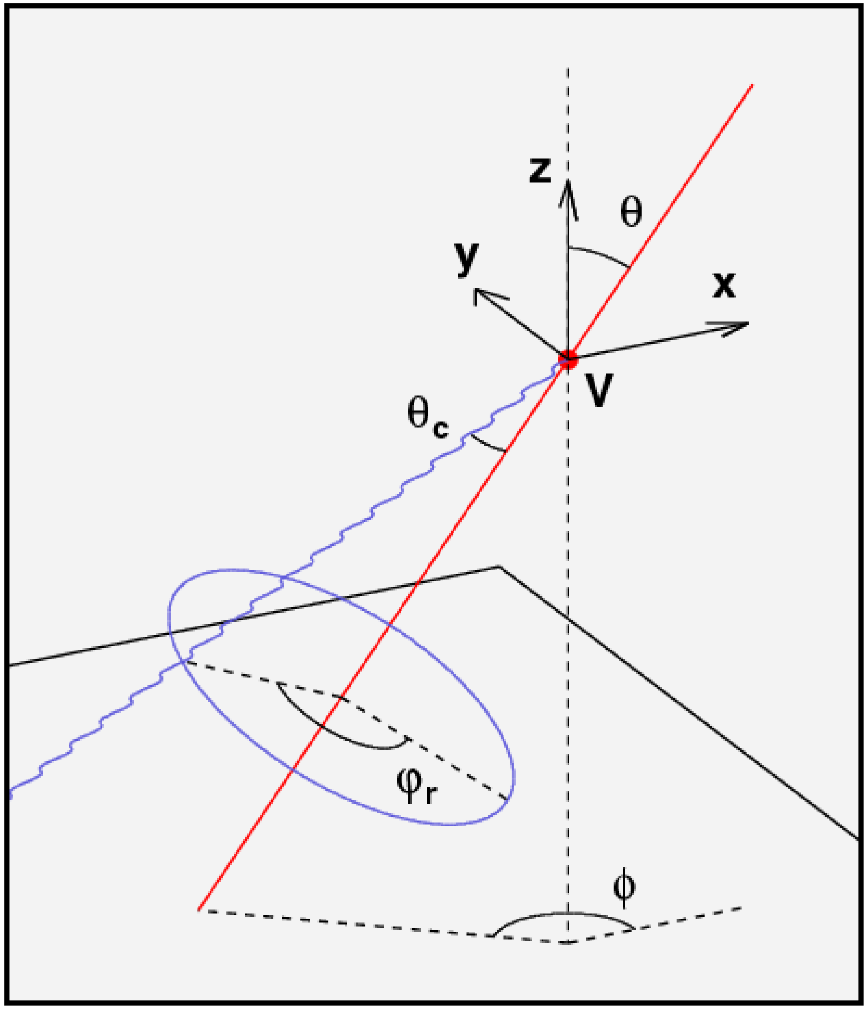


- Second test beam selection:
  - A/Z = 2, 2.25, 2.35
  - "Realistic" spectrum good for studies on charge separation
  - Several particle angles
  - Reflector tested
  - Studies on tile uniformity
  - Testing of readout electronics



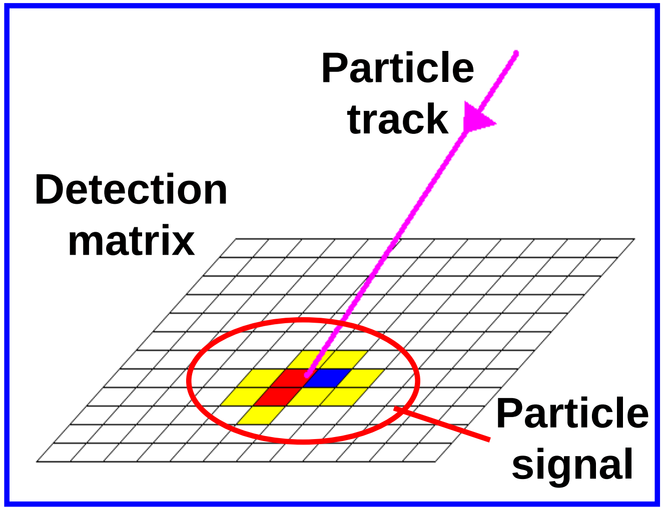
RICH standalone reconstruction

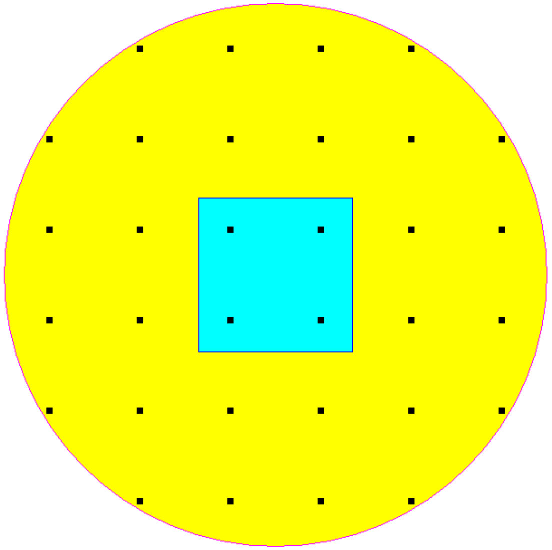
- Ongoing study using simulated proton events
- Goal: event reconstruction using only data from the RICH detector
  - No Tracker or TOF data used
- 5 parameters for reconstruction:
  - matrix impact point (x_{matrix}, y_{matrix}), Cerenkov cone angles (θ, ϕ, θ_c)
- Likelihood function used for ring fitting
- PMT matrix crossing point identified by strong signal in matrix (much stronger than ring hits)
- Quality cuts applied for hint



RICH standalone reconstruction

- Based on grid of hints in parameter space – combinations of emission points (in radiator), impact points (in PMT matrix), Cerenkov angles
- Large number of hints ⇒ minimization from all hints not possible in practice
- Our approach: likelihood calculated for all hints but minimization applied to the most promising ones only
- Several versions of hint grid procedure tested, looking for compromise between reconstruction quality and processing time
  - Version presented here uses 32 hints for emission point, 9 for impact point, 5 for Cerenkov angle; minimization applied for best 50 hints

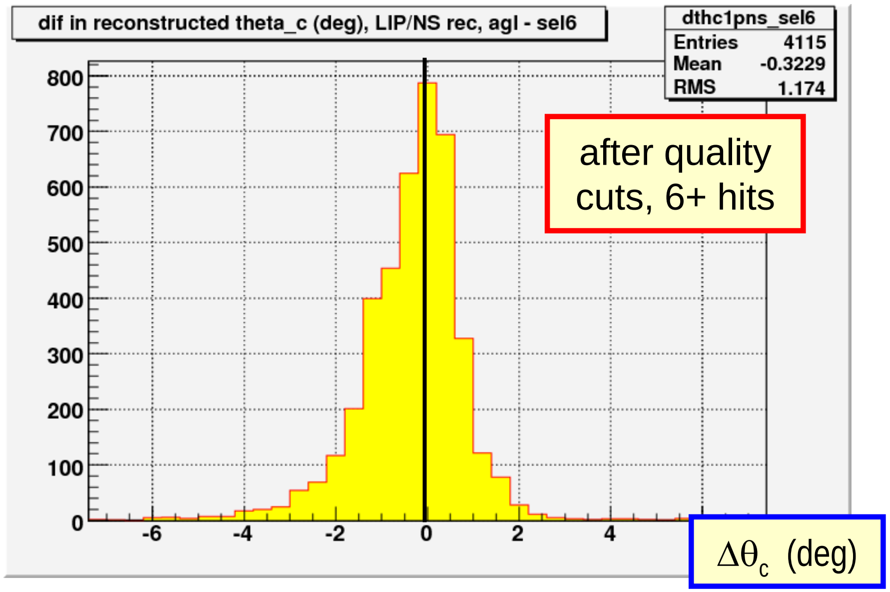


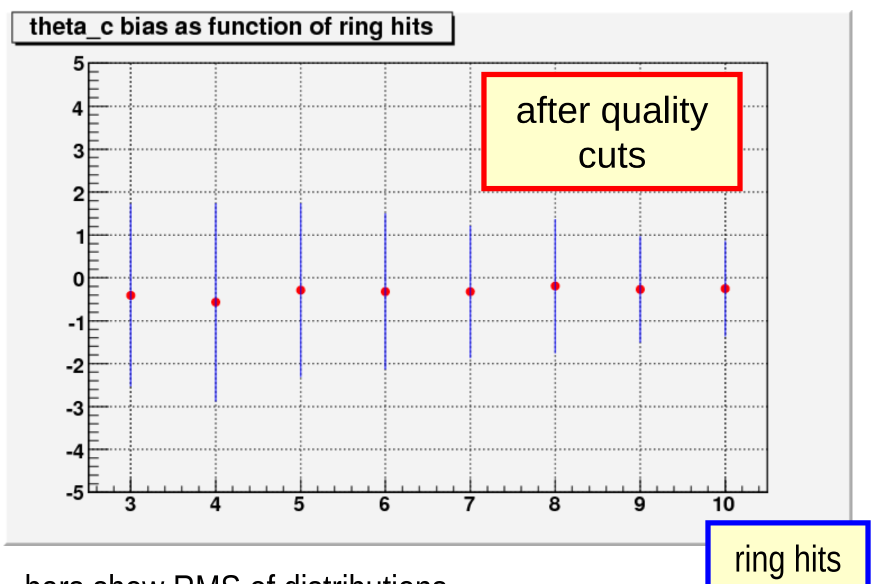


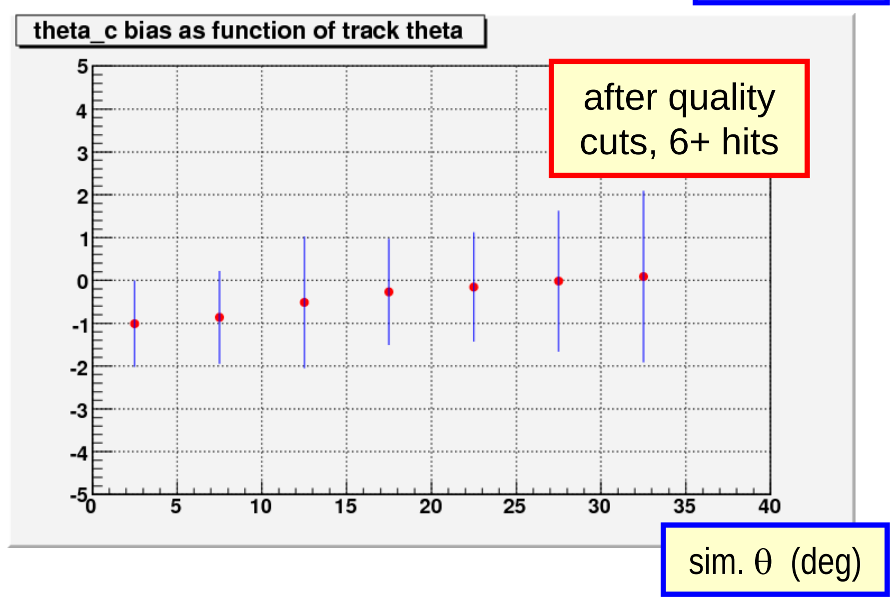
grid of hints for emission point

RICH standalone reconstruction

- Current results:
  - Reconstruction of Cerenkov angle ($\Rightarrow$ velocity) is feasible
  - Bias ~0.3º due to tail on left
    - Significant bias (~1º) for vertical events, no bias for high inclinations
  - No good track reconstruction $\Rightarrow$ external track data needed



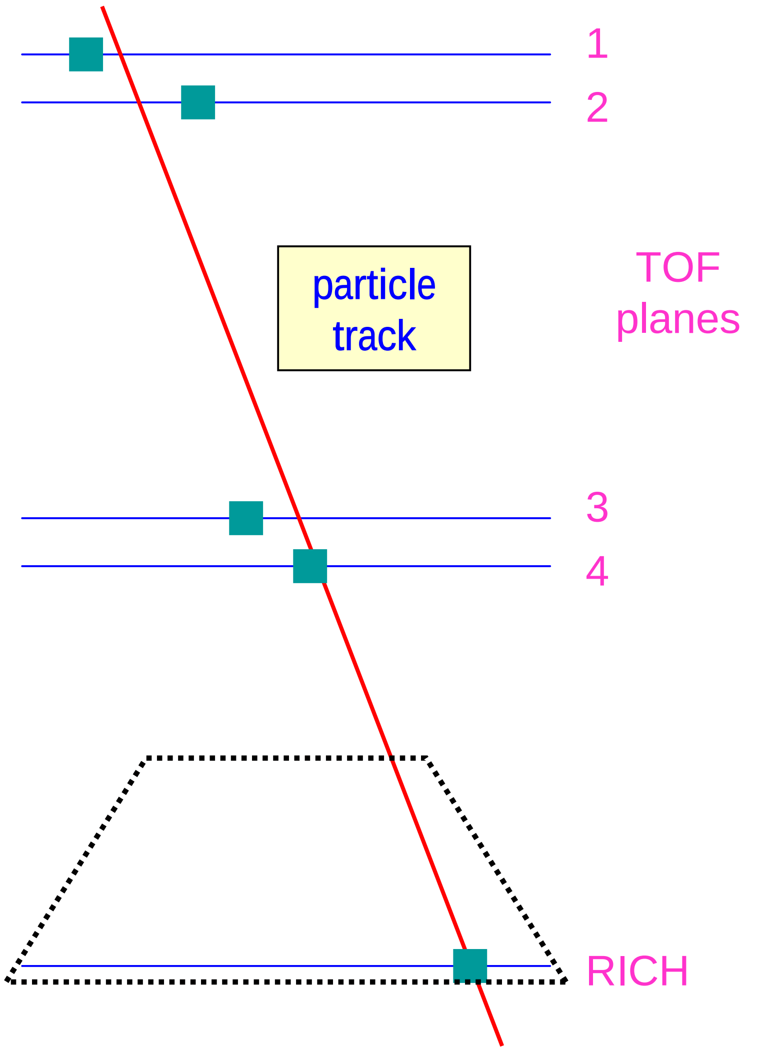




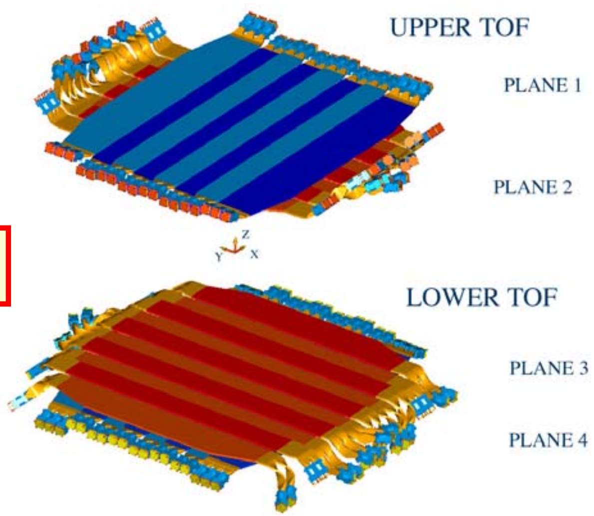
bars show RMS of distributions

RICH reconstruction using ToF data

- ToF clusters provide hint required for reconstruction without Tracker
- ToF has 4 planes, RICH may act as «5th ToF plane»
- Quality cuts applied for ToF, RICH data (clean signals, geometry)
- Track assumed to be straight line
  - Better for high energies (smaller bending)

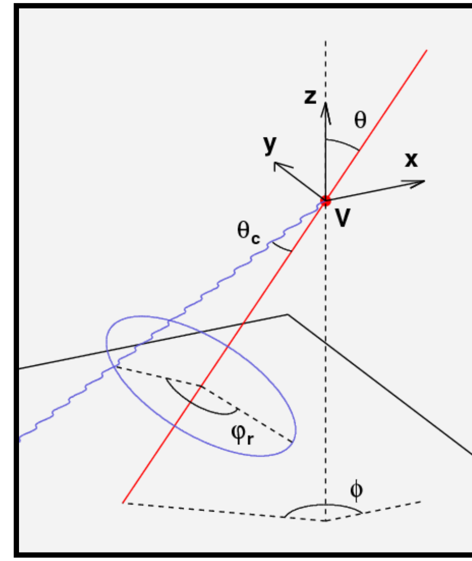


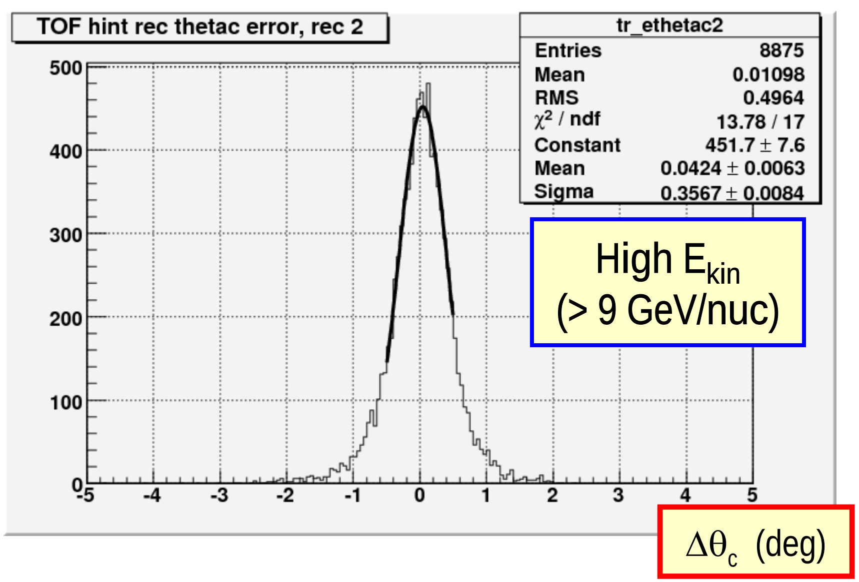
AMS ToF

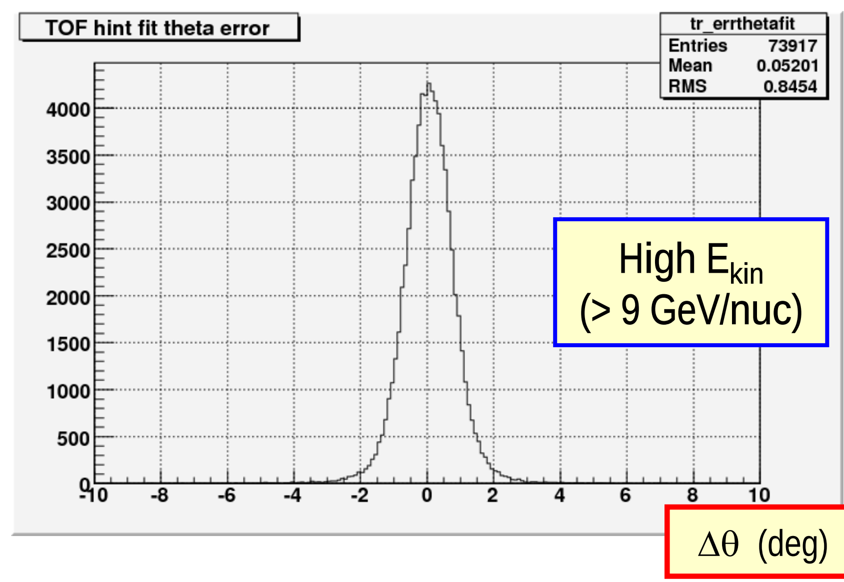


RICH reconstruction using ToF data

- Best results obtained using ToF and RICH data
- Error in Cerenkov angle from fit to peak:
  - $\sigma_{\theta c}$ = 0.36º for high E_{kin} (was $\sigma_{\theta c}$ = 0.21º using Tracker data)
- Good track reconstruction:
  - σ_{θ} = 0.85º for high E_{kin}
  - Larger uncertainty but no significant bias at lower energies
  - Resolution in θ is almost independent of inclination

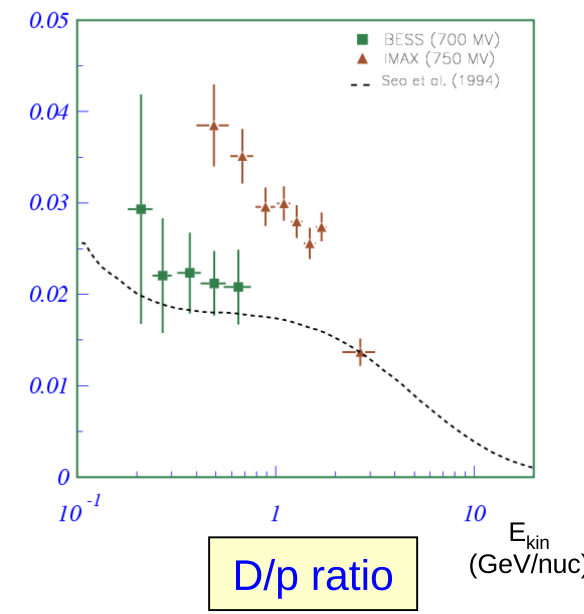




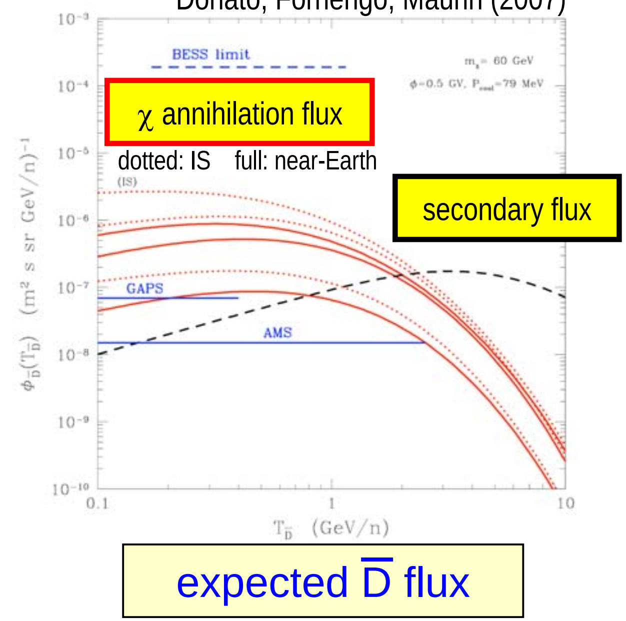


Mass separation

- Cosmic-ray spectrum is dominated by protons (~90%)
  - Other particles with the same charge (e^+, D) must be identified using mass-sensitive methods
  - Similar situation for negative-charged particles: high statistics of electrons and antiprotons, much smaller number of antideuterons
- Smaller components of cosmic-ray spectrum at each charge provide crucial information:
  - D/p: secondary vs. primary, data on secondary production, ISM properties
  - $^{10}Be/^{9}Be$: radioactive vs. stable, data on galactic confinement times
  - $\bar{D}$: possible dark matter signature, expected to be produced in neutralino annihilation
- ***Mass separation is needed!***



Donato, Fornengo, Maurin (2007)



Mass separation: procedure

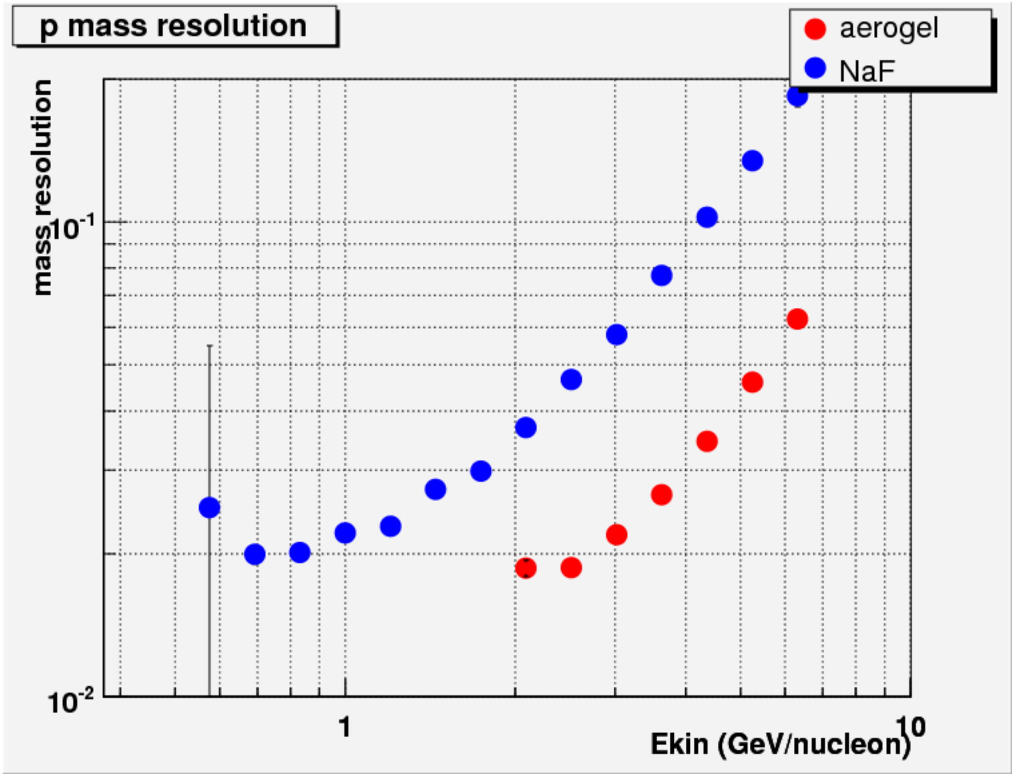
- Goal: realistic simulation of RICH performance on mass separation in the context of the AMS detector
  - Full simulation of the AMS-02 detector used

- Procedure for event selection:
  - Preliminary data selection cuts to exclude bad reconstructions
  - Cuts on RICH data to refine sample quality
  - Evaluate mass separation capability

- Physics channels:
  - D/p case used, ongoing study
  - Previous studies of D/p, $^{3}He/^{4}He$, $^{10}Be/^{9}Be$ cases with standalone simulation of RICH detector

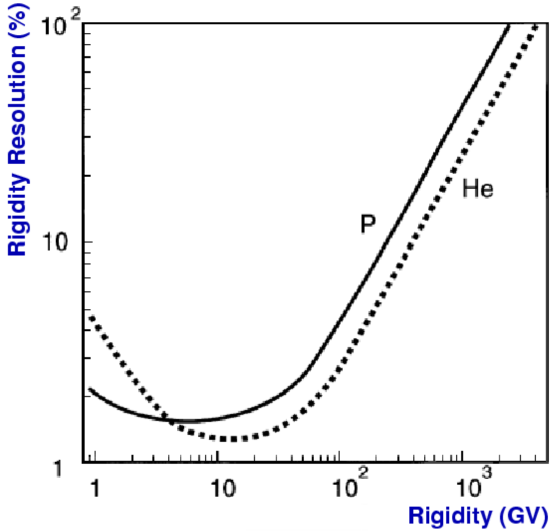
Mass resolution

- Key issue for mass separation, depends on velocity and rigidity data
- Best resolution for protons: σ_m/m ~ 2% at lower energies (< 1 GeV/n for NaF, 2-3 GeV/n for aerogel)
- Similar results obtained for deuterons



mass resolution for protons

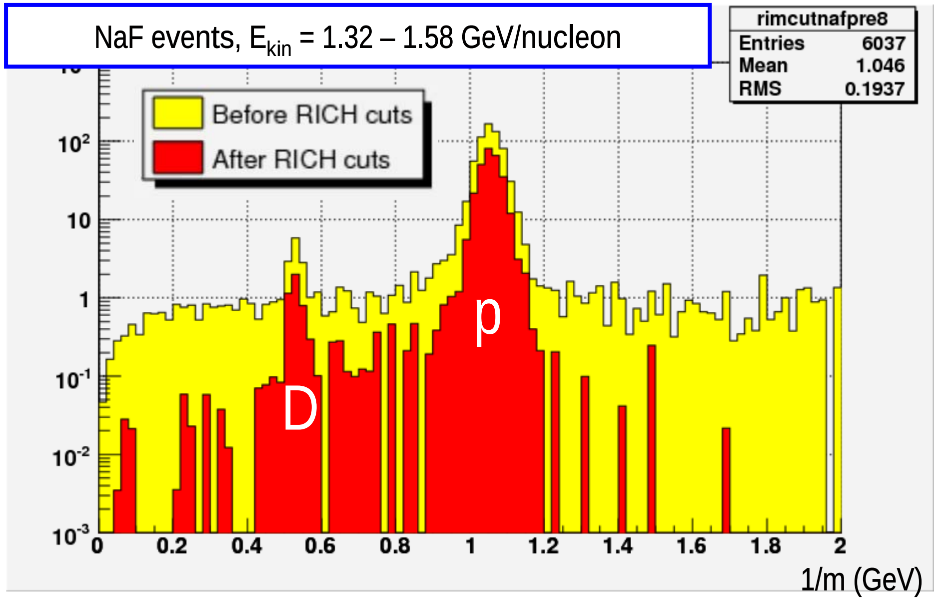
$$\frac{\Delta m}{m} = \frac{\Delta p}{p} \oplus \gamma^2 \frac{\Delta \beta}{\beta}$$

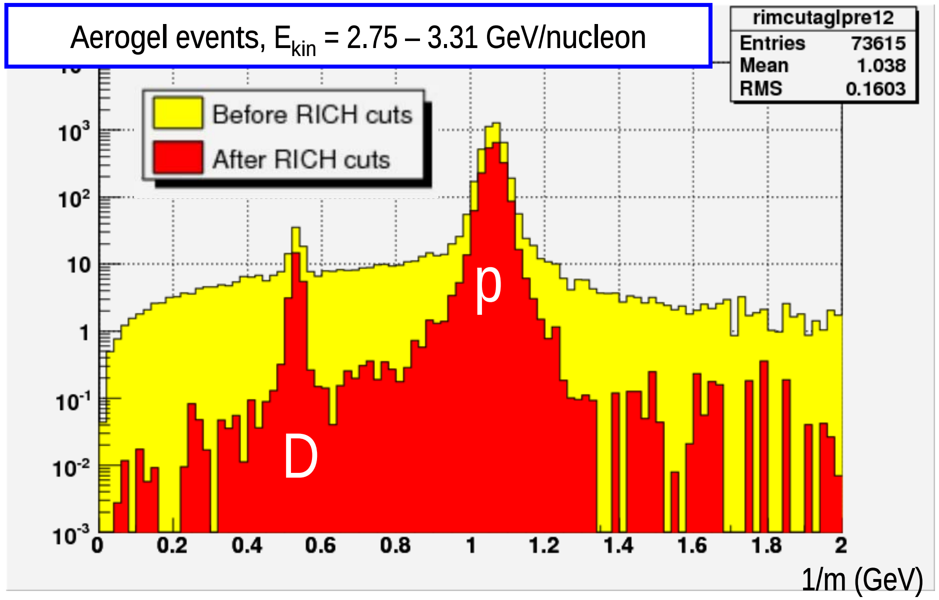


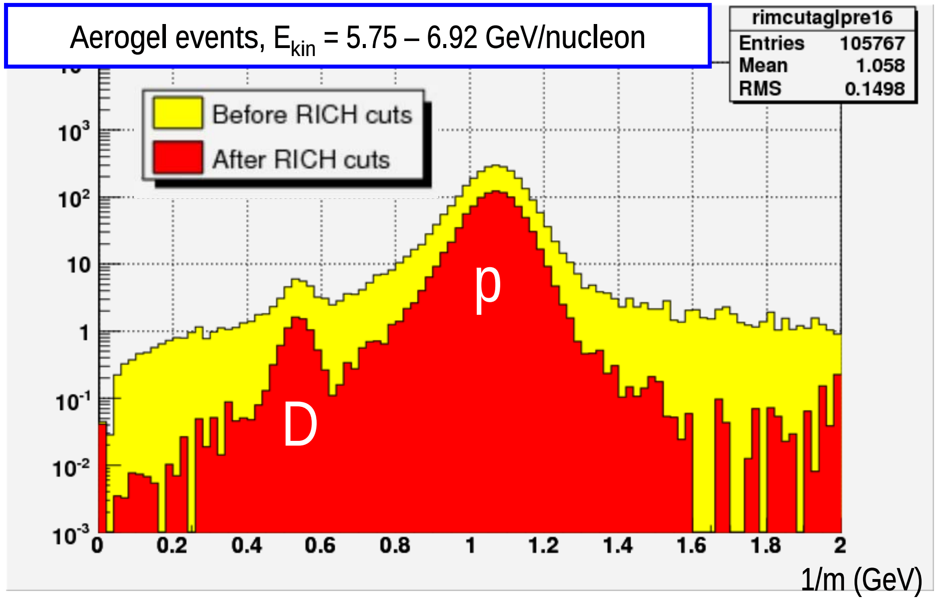
Tracker rigidty resolution

Mass separation

- Mass reconstructed using RICH velocity & Tracker rigidity
- Separation between proton and deuteron peaks visible up to ~ 8 GeV/nucleon
- RICH detector plays a major role in background reduction

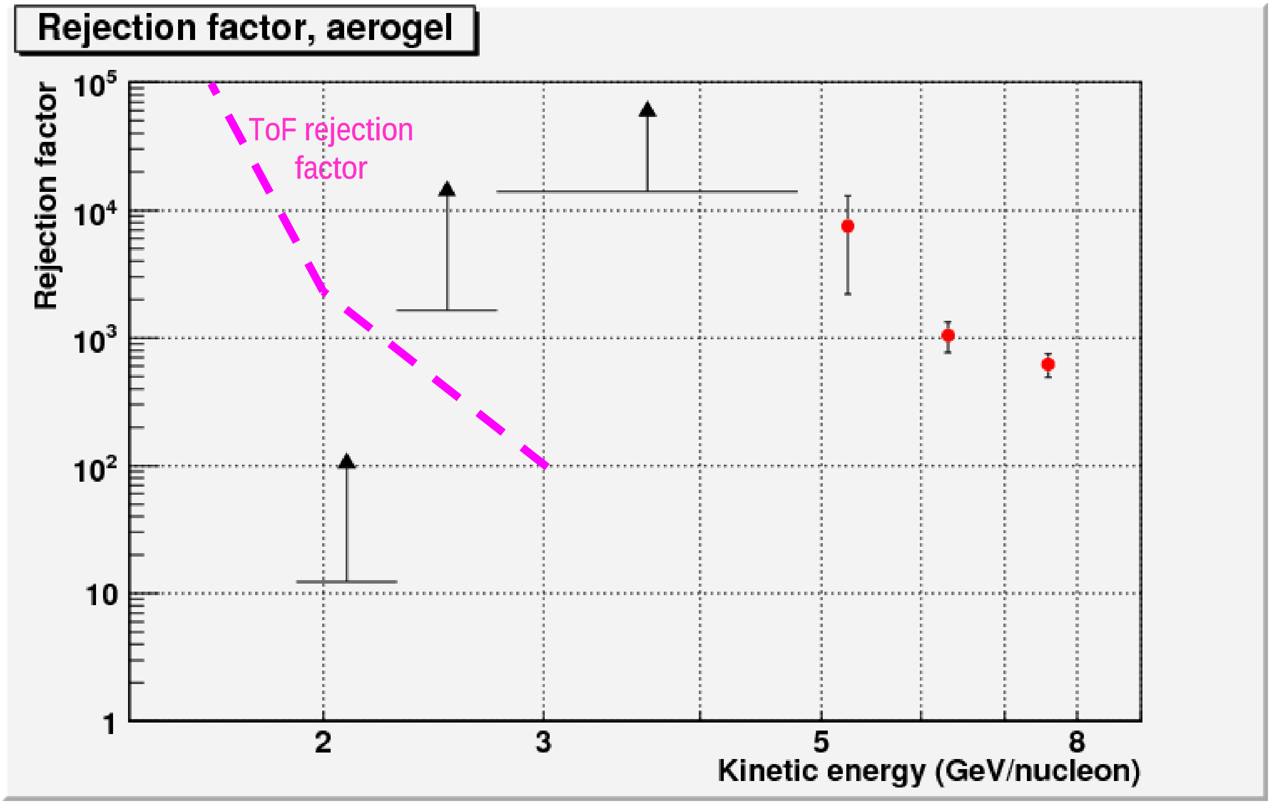






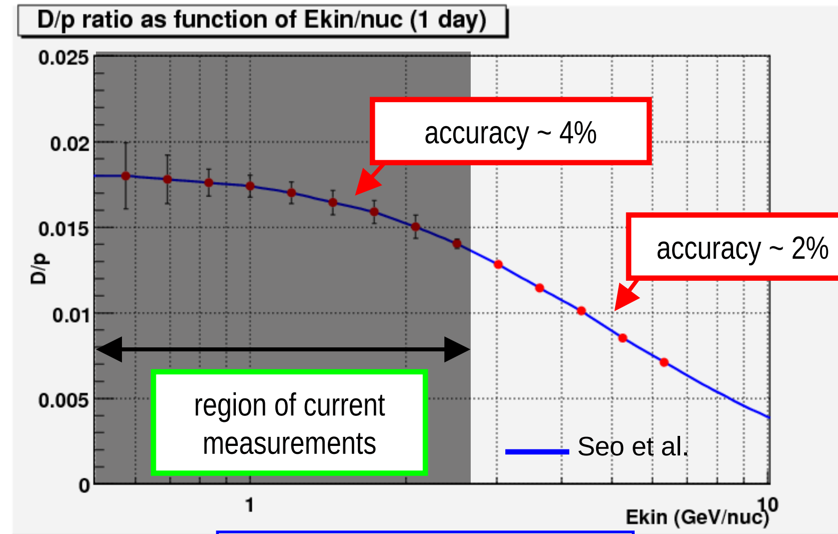
D/p rejection factor

- Rejection factor higher than 10^4 obtained for D/p separation in optimal region (E_{kin} ~ 3-5 GeV/nucleon) using aerogel radiator
- Estimate is currently limited by simulation statistics
- Results expected to be similar for antideuteron case

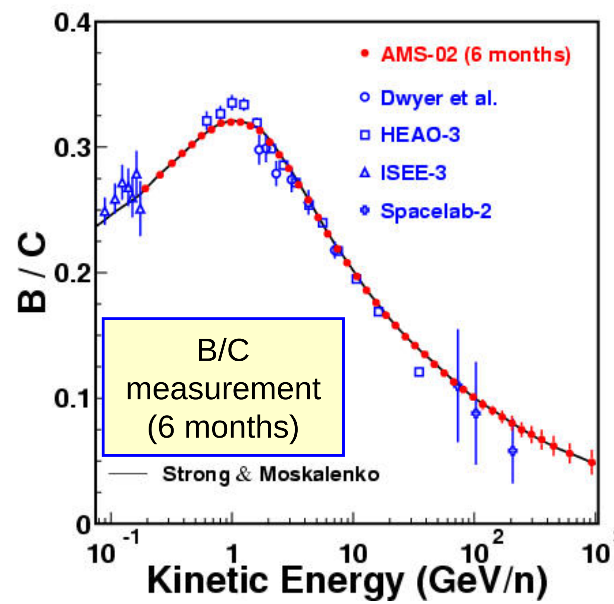


Physics prospects

- 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, ^{3}He/^{4}He, B/C: information on cosmic ray propagation*
  - *^{10}Be/^{9}Be: confinement times, galactic halo models*



D/p measurement (1 day)



B/C measurement (6 months)

Conclusions

- RICH detector plays major role in AMS-02 particle identification and track reconstruction
  - Prototype tests confirm design principles:
    - $\Delta\beta/\beta \sim 10^{-3}$ for Z=1, 10^{-4} for Z>10, charge separation up to Z~26
  - Mass separation is essential to address several physics issues
    - Based on RICH velocity & Tracker rigidity
    - Separation of light isotopes (H, He, Be) possible in GeV region
  - Standalone reconstruction:
    - Reconstruction of Cerenkov angle is feasible, with some bias
    - Track reconstruction not possible
  - Using TOF data:
    - Good reconstruction of Cerenkov angle, although not as good as using Tracker data
    - Track reconstruction is possible
- AMS-02 will provide a major improvement on existing cosmic ray data
  - Assembly of RICH detector being finished at CIEMAT, Madrid
  - Integration of the global AMS-02 detector taking place at CERN, should be finished by the end of 2008