Particle identification with the AMS-02 RICH detector: D/p and $\bar{D}/\bar{p}$ separation

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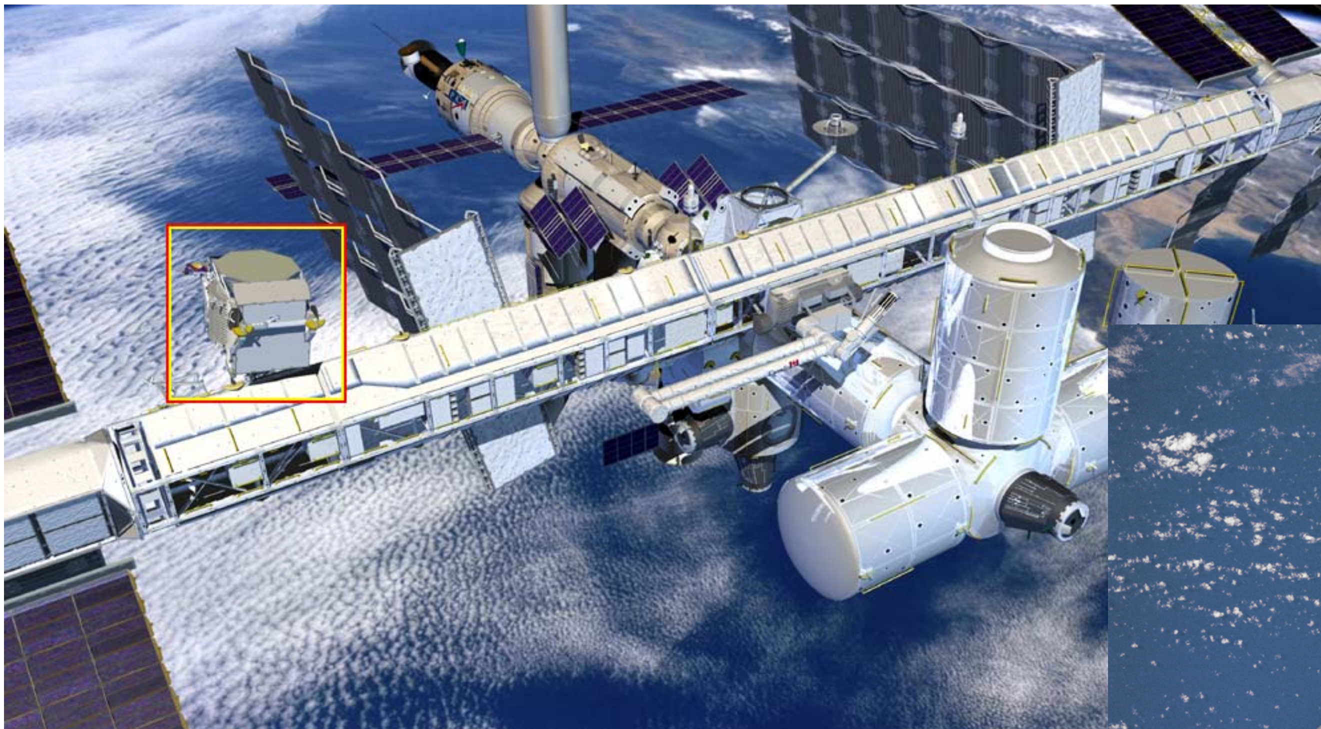
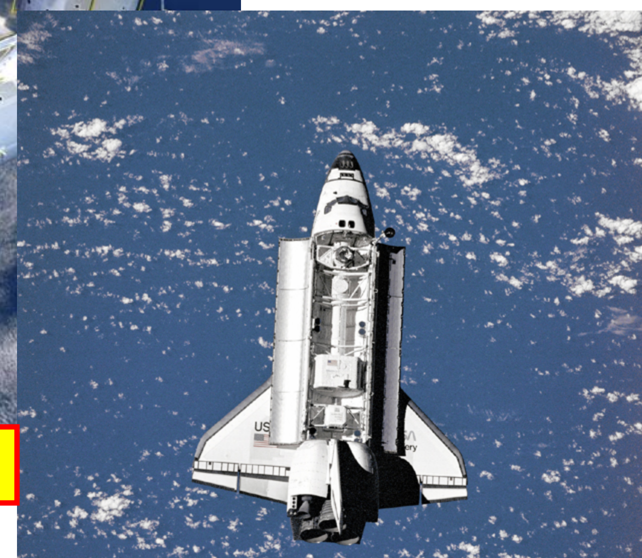
The AMS experiment

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



The AMS-02 detector on the International Space Station



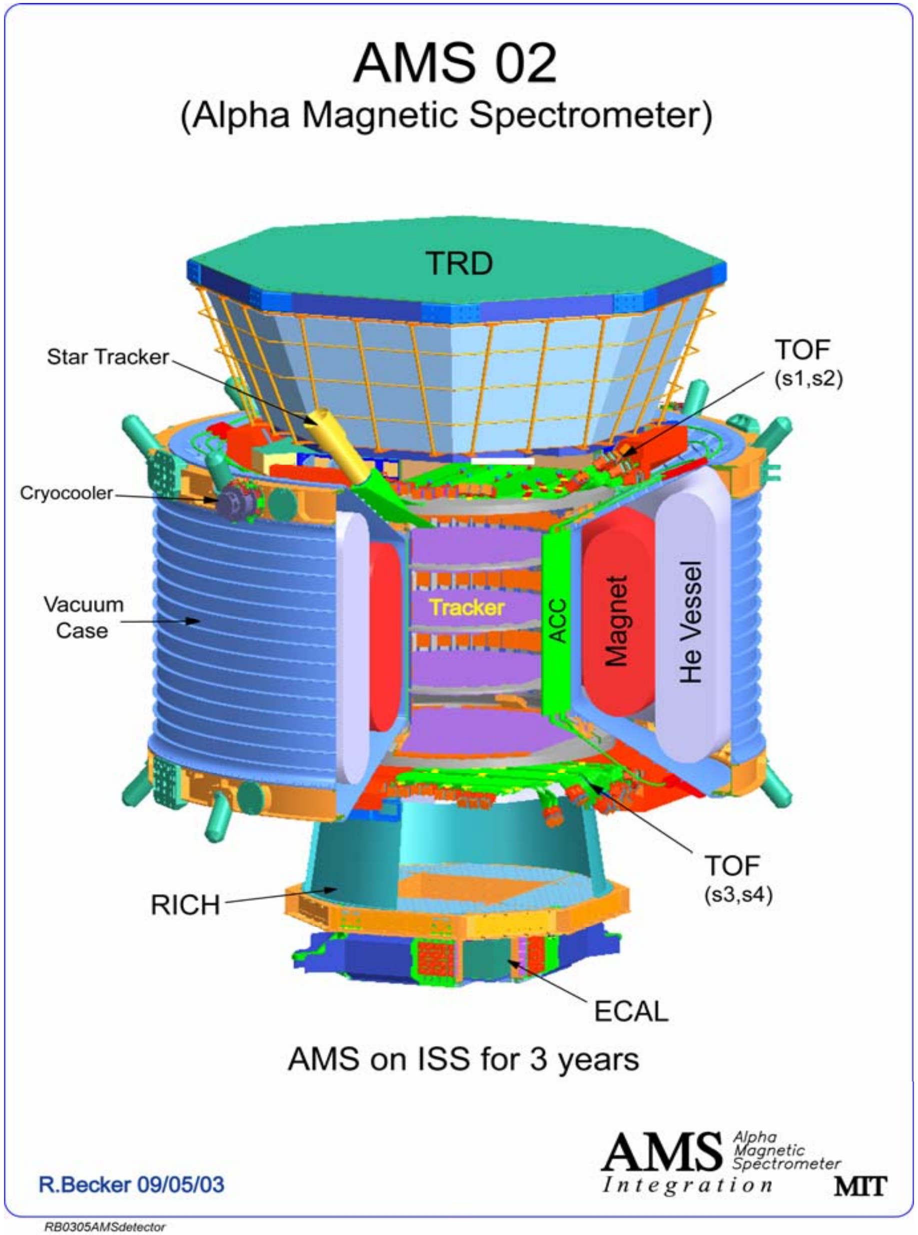
Prototype flight in space shuttle (1998)

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

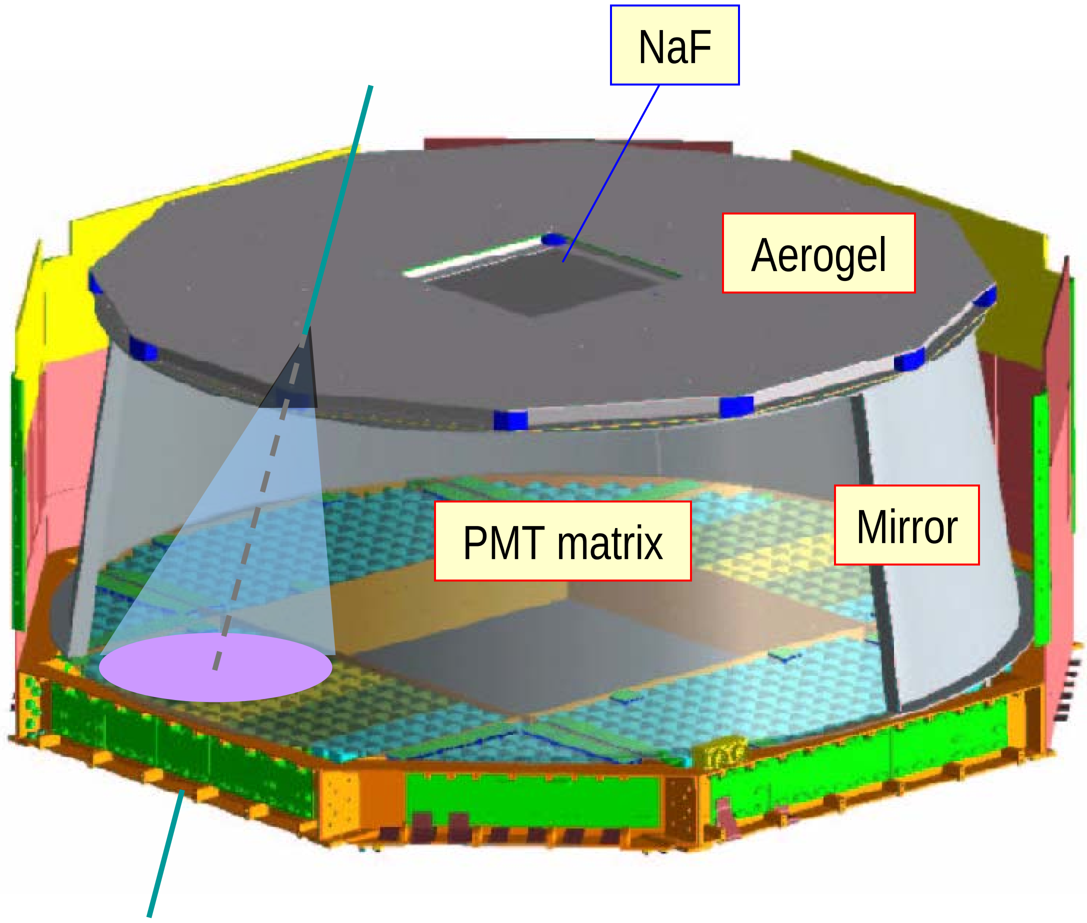
AMS-02 detector

- 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: $\sim 0.5\ m^2sr$



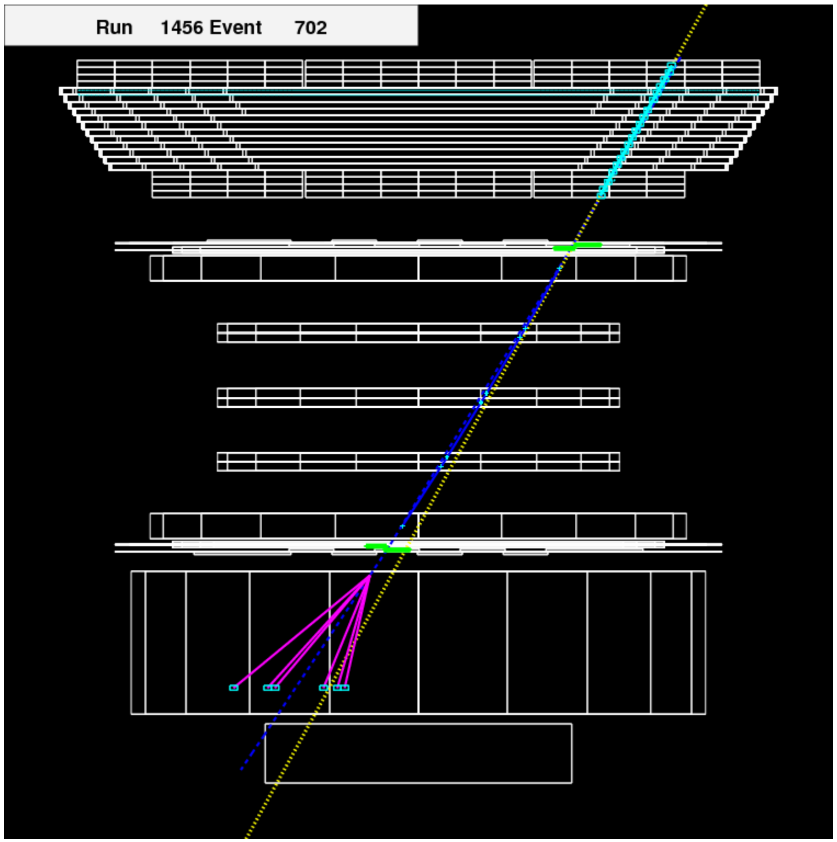
RICH detector

- 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*

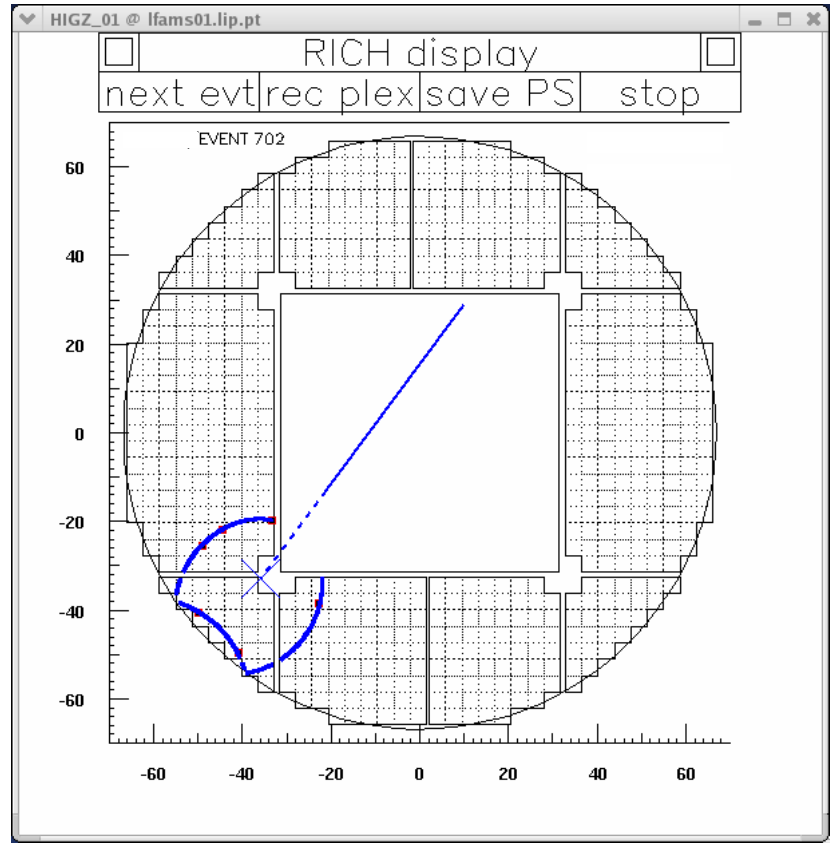


AMS event

- Example of reconstructed event in AMS and RICH detector:



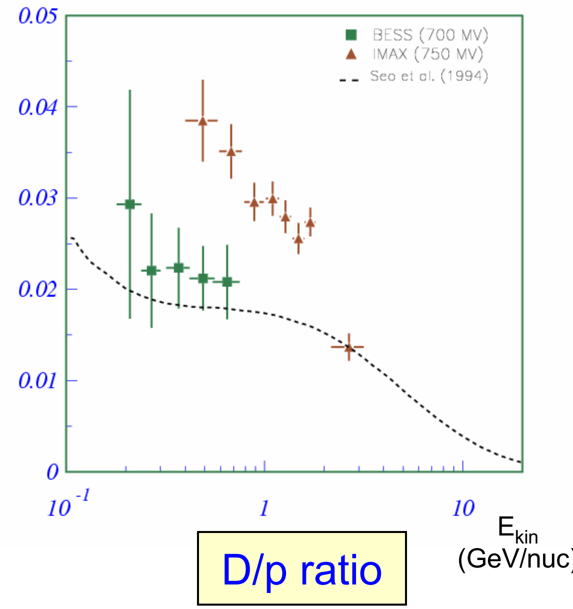
Simulated event on the AMS detector

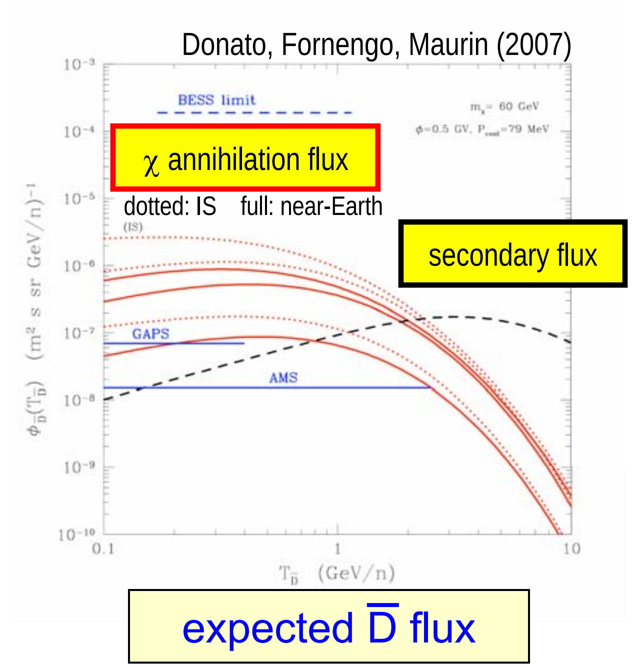


Same event on LIP RICH display

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
  - $\overline{D}$: possible dark matter signature, expected to be produced in neutralino annihilation
- ***Mass separation is needed!***



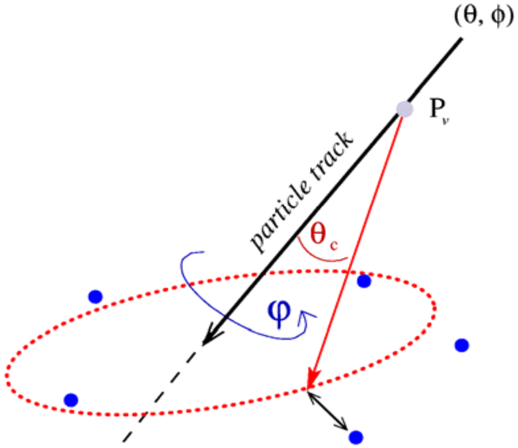


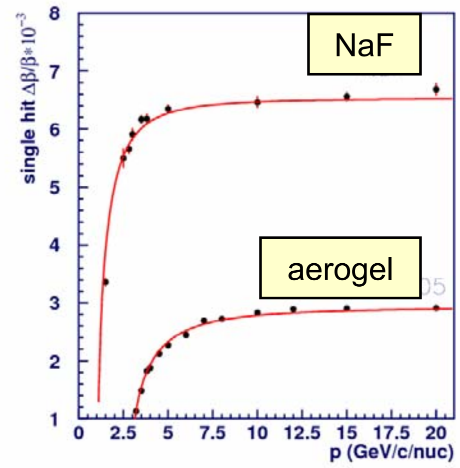
RICH velocity measurement

- Opening of Cherenkov cone is function of velocity:

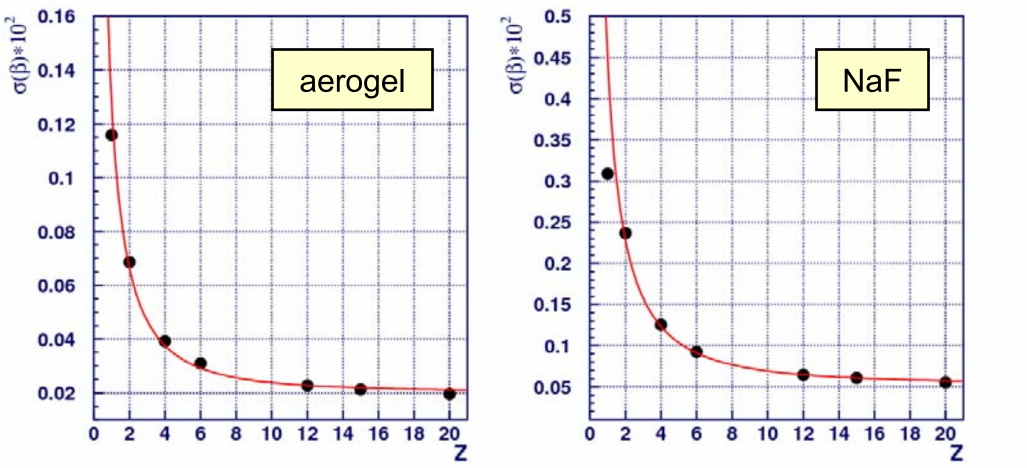
$$\cos\ \theta_c = \frac{1}{\beta\ n}$$

- Expected velocity resolution in aerogel events for $\beta \approx 1$:
  - *$\Delta\beta/\beta \sim 1.3\times10^{-3}$ for Z=1*
  - *$\Delta\beta/\beta \sim 2\times10^{-4}$ for Z>10*





single-hit resolution vs. momentum

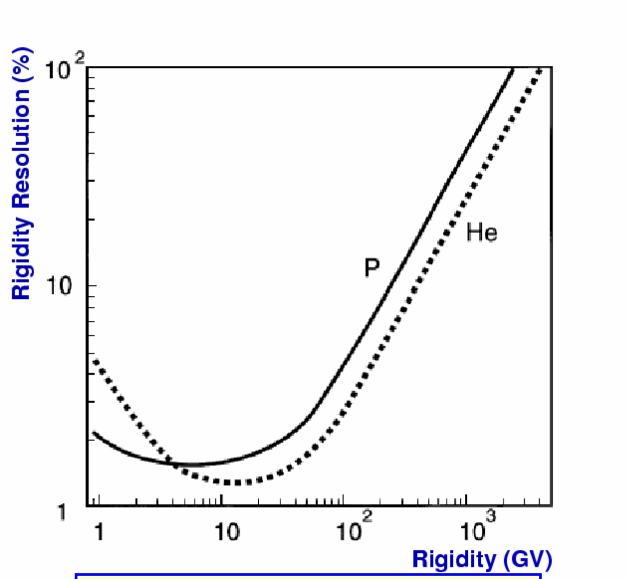


expected velocity resolution vs. charge: aerogel (left), NaF (right)

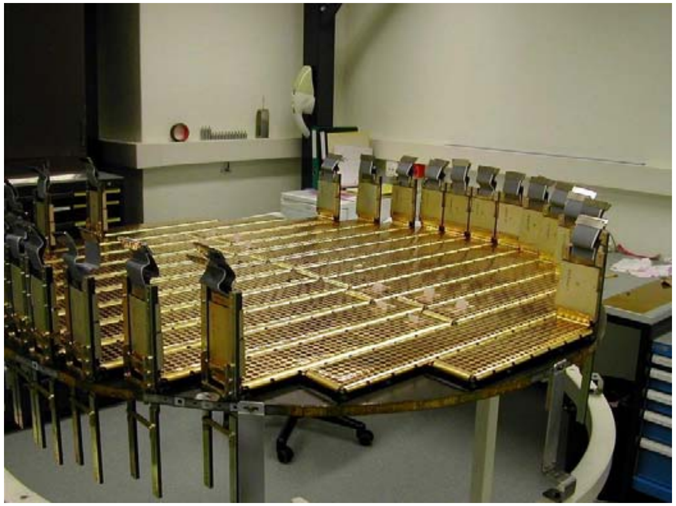
- Velocity resolution depends on:
  - Number of ring hits
  - Pixel size (8.5 mm)
  - Radiator thickness
  - Radiator chromaticity

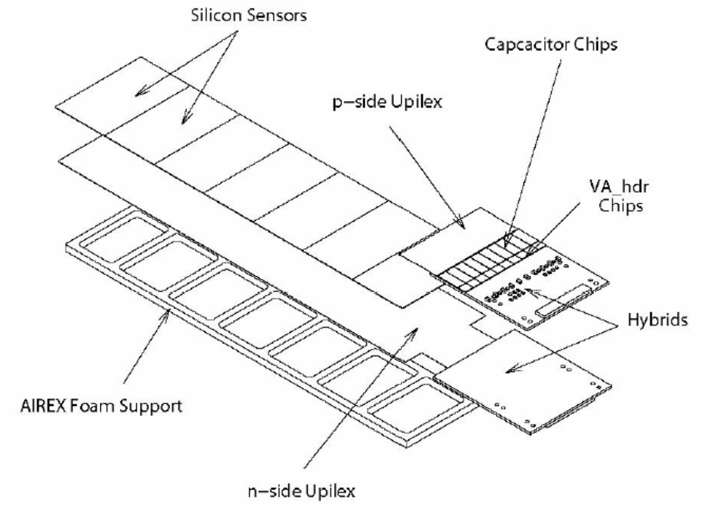
Tracker rigidity measurement

- Silicon Tracker: 5 planes, 8 layers of double-sided silicon microstrip sensors (total ~7 m^2)
- ~2500 sensors arranged on 192 ladders
- Accuracy of sensor relative position: better than 5 mm
- Spatial resolution for each measurement:
  - 10 μm on the bending plane
  - 30 μm on the non-bending plane
- Rigidity (R=pc/Z) measurement up to 1-2 TV



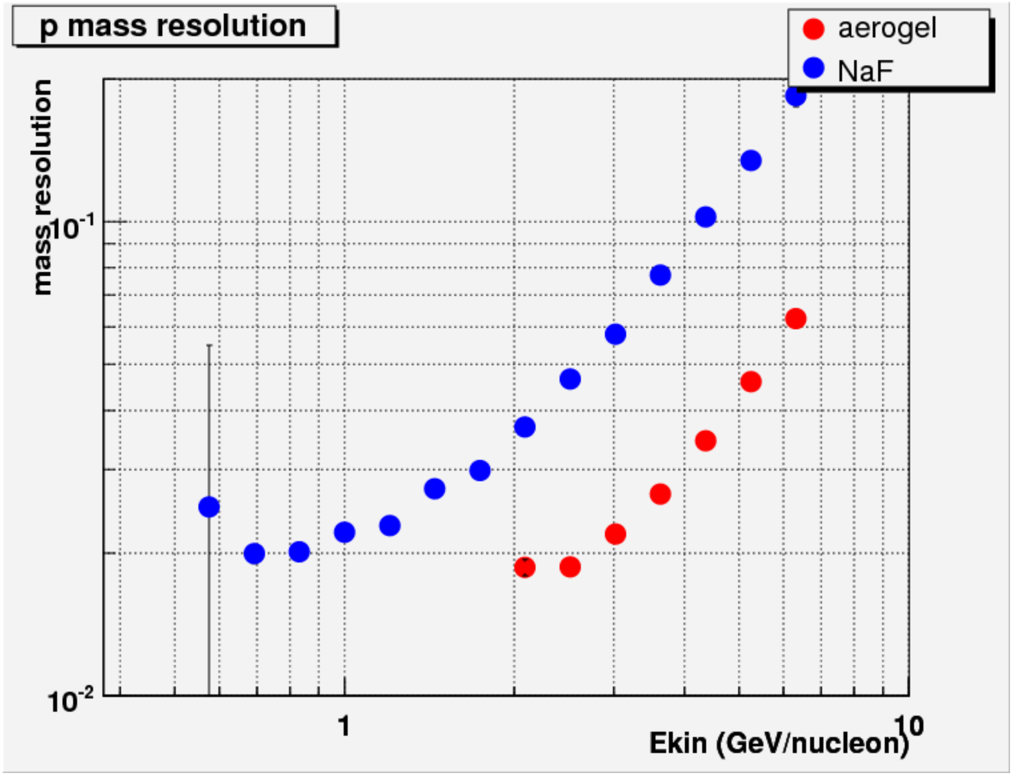
Tracker rigidty resolution





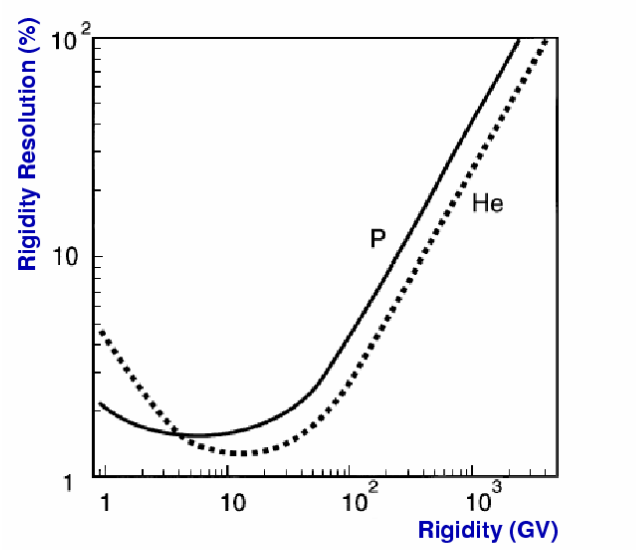
Mass resolution

- 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: procedure

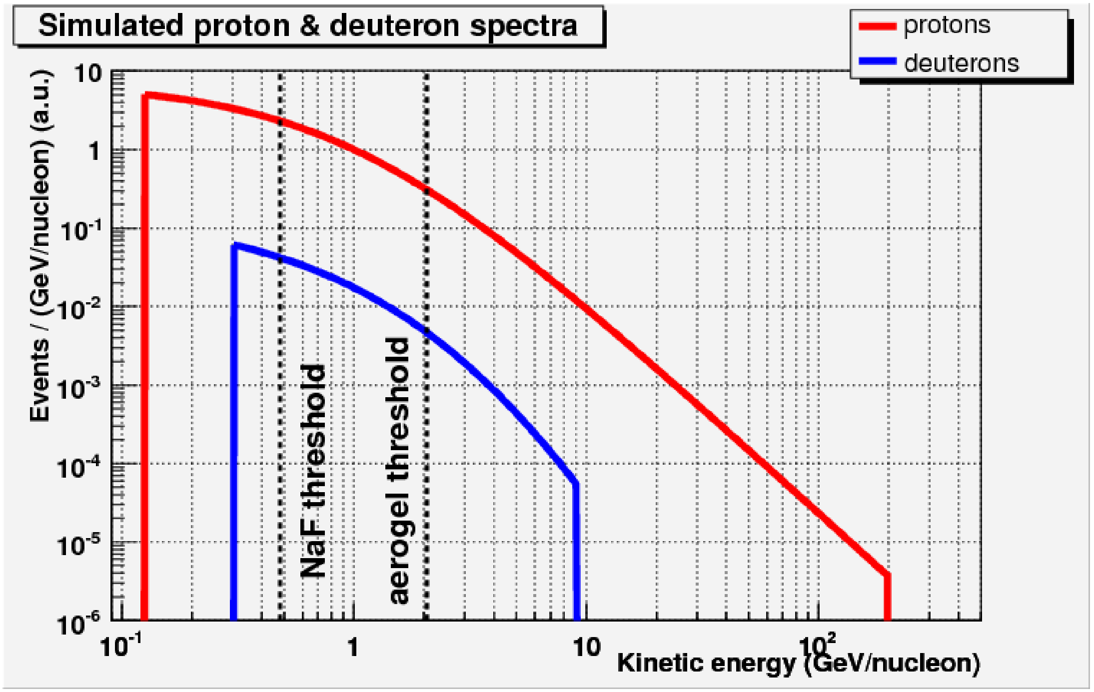
- Goal: realistic simulation of RICH performance on mass separation in the context of the AMS detector
  - Full simulation of the AMS-02 detector used

- 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 – ***this presentation***
  - Previous studies of D/p, $^{3}He/^{4}He$, $^{10}Be/^{9}Be$ cases with standalone simulation of RICH detector

D/p separation: Monte Carlo samples

- Data samples used:
  - Protons
    - Statistics: 4.4×10^8 events, p = 0.5-200 GeV/c/nucleon
    - Spectrum shape: $dN/dE_{tot} \propto E_{tot}^{-2.7}$
  - Deuterons
    - Statistics: 5.6×10^7 events, p = 0.25-10 GeV/c/nucleon
    - Spectrum shape: linear interpolation of D/p ratios from Seo et al.

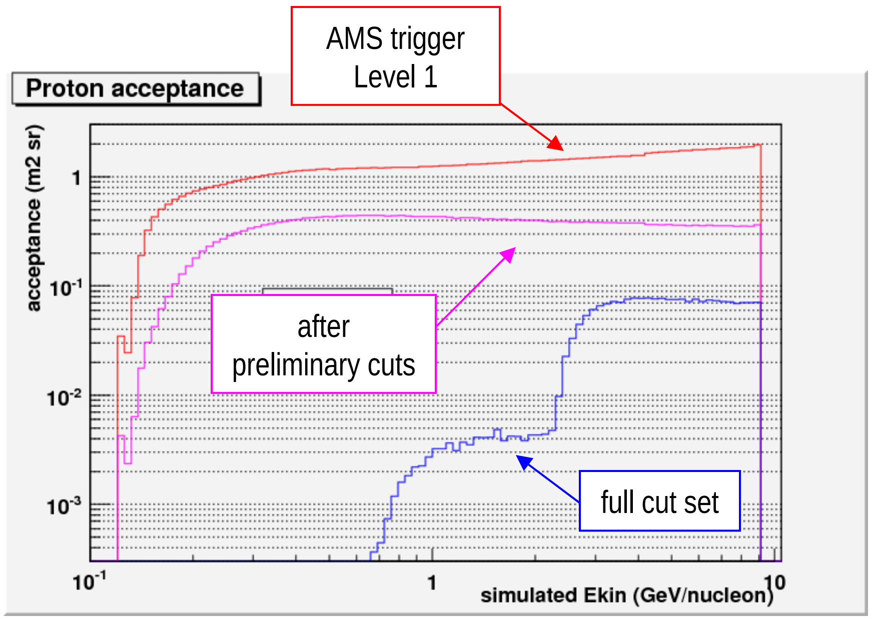


D/p separation: event quality cuts

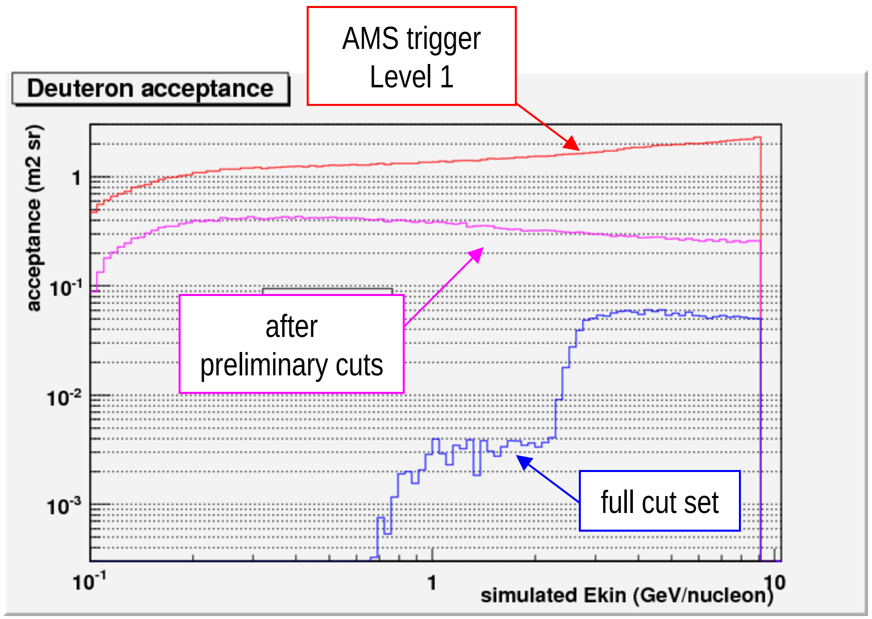
- Preliminary cuts include:
  - no. particles seen by the detector
  - no. tracks in the TRD
  - no. hits used in the Silicon Tracker's rigidity reconstruction
  - comparison of rigidity values from two different reconstruction algorithms
  - comparison of rigidity measurements from the two halves of the Silicon Tracker
  - ToF velocity measurement and no. clusters used in its reconstruction
- RICH cuts include:
  - minimum no. hits in the Čerenkov ring
  - maximum no. noise hits
  - limit on total ring signal
  - minimal photon ring acceptance (visible fraction)
  - compatibility between velocities calculated from two different algorithms
  - good reconstructed charge

Results: proton & deuteron acceptances

- Acceptance after all cuts (preliminary + RICH) for events having E_{kin} > 3 GeV/nucleon:
  - protons: ~ 0.07 $m^2 sr$
  - deuterons: ~ 0.05 $m^2 sr$



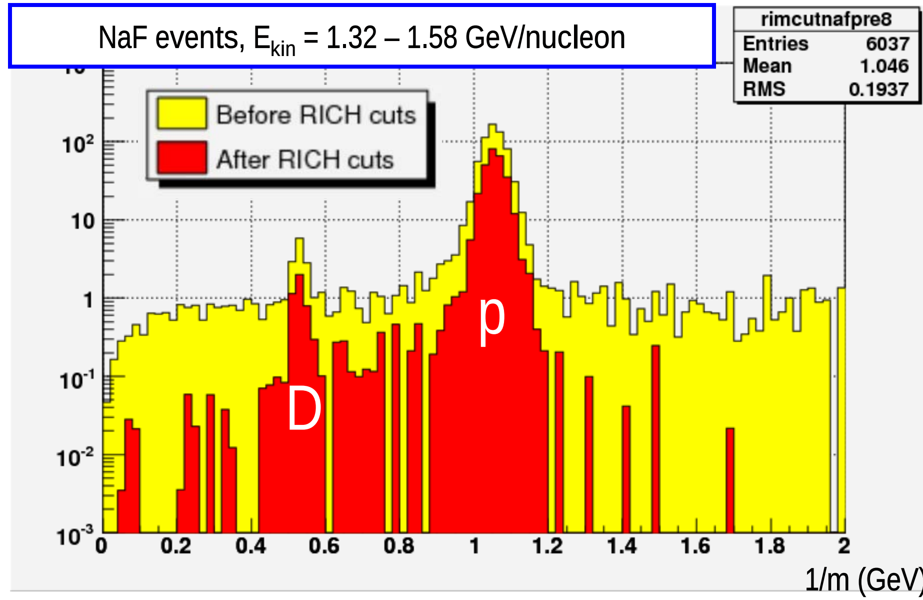
Proton acceptance as function of energy

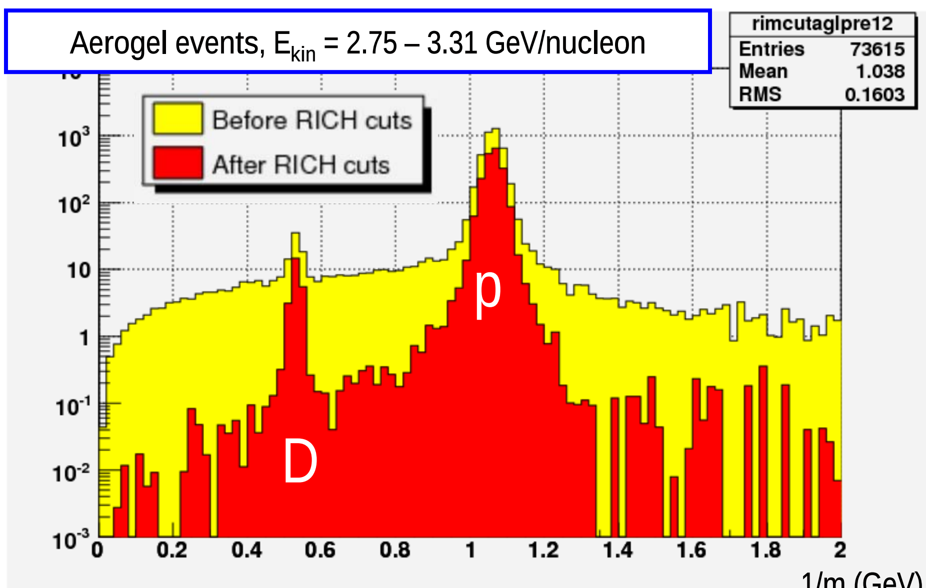


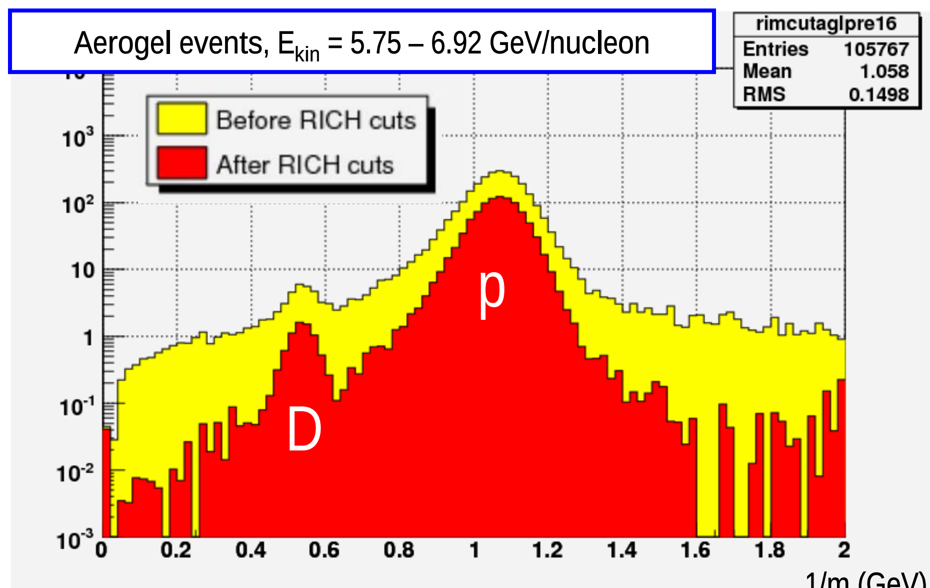
Deuteron acceptance as function of energy

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

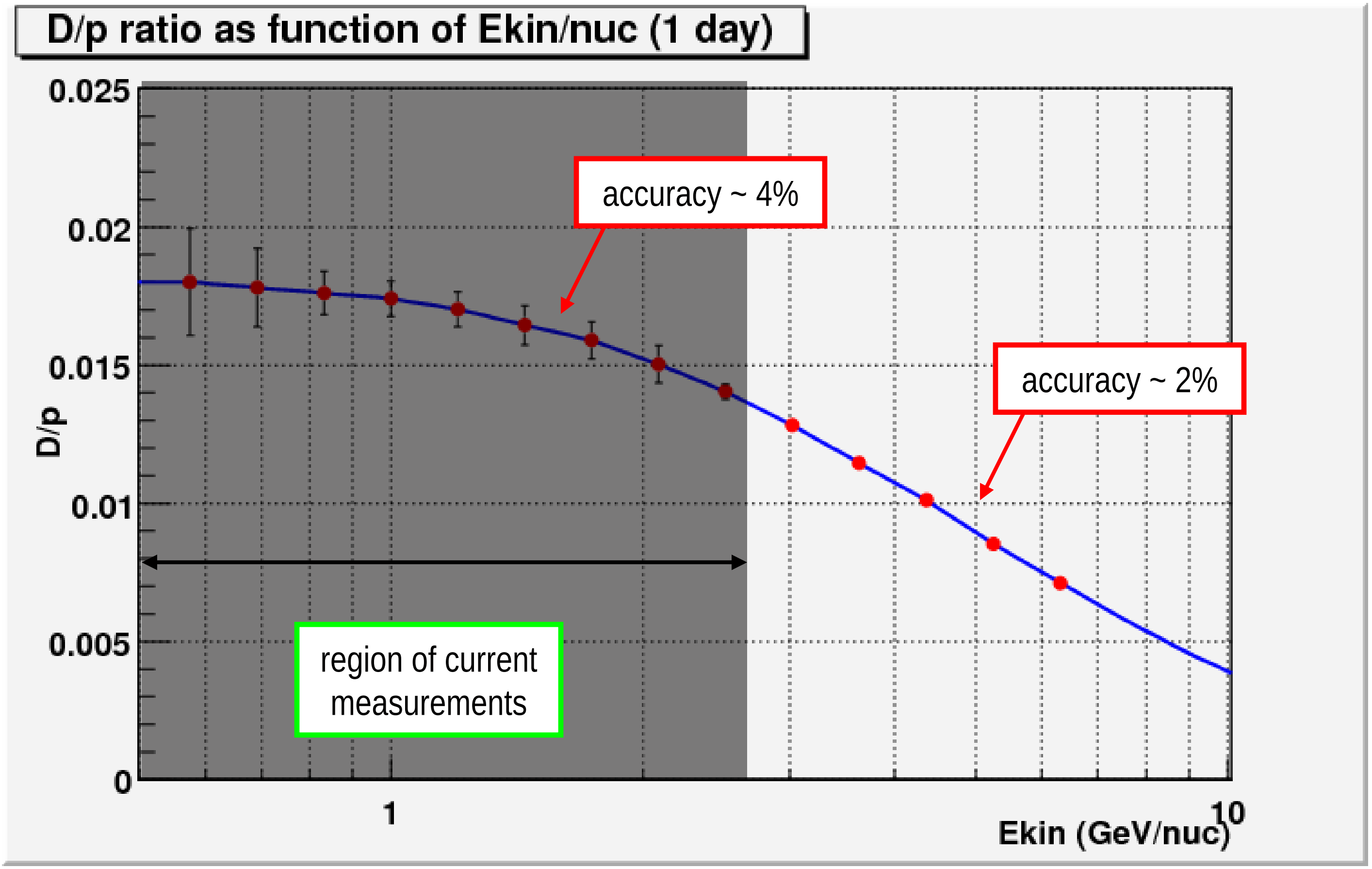






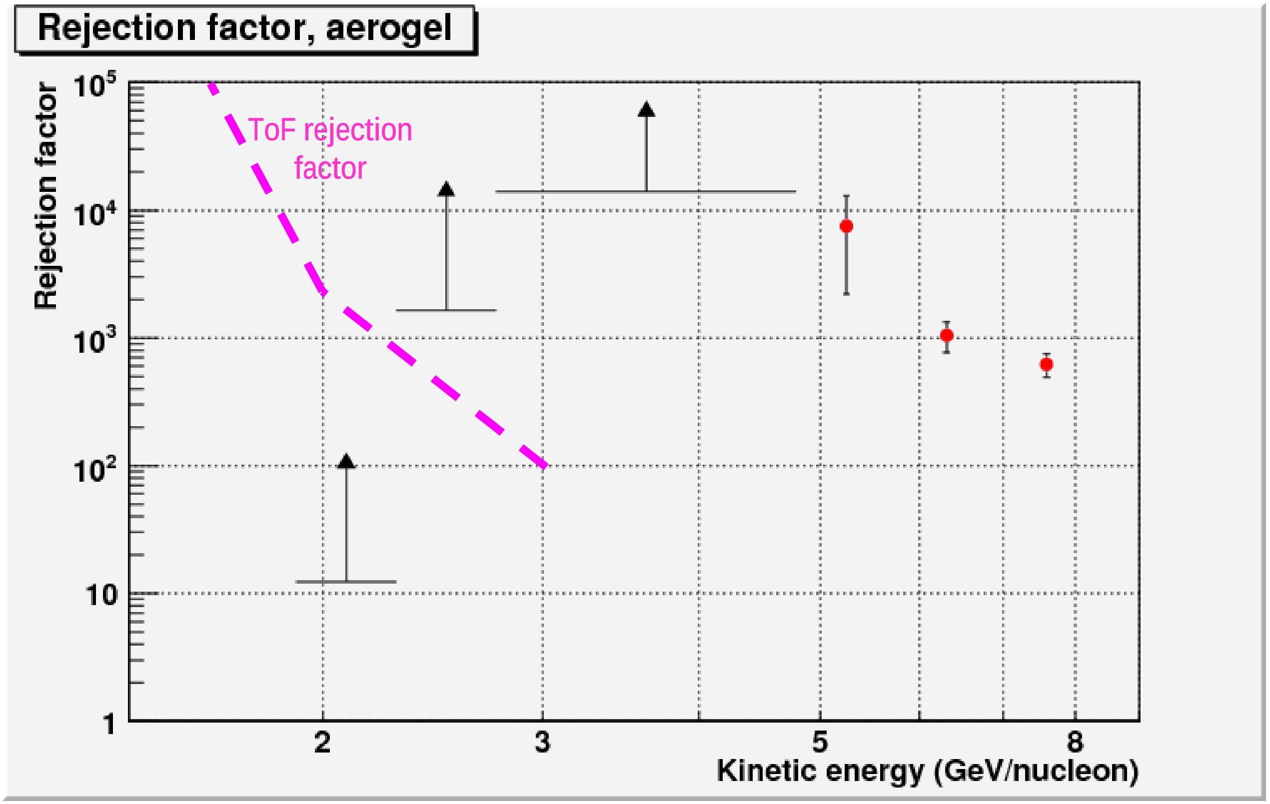
Results: D/p ratio

- Even after a single day of data taking, AMS will be able to improve on the existing results for the D/p ratio:



Results: 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



Conclusions

- AMS-02 will provide a major improvement on existing cosmic-ray data
- Mass separation is essential to address several physics issues (cosmic-ray propagation, dark matter signals...)
- Quality of mass separation for D/p has been studied in the context of the full AMS-02 simulation
  - Full set of cuts using both non-RICH and RICH data has been established
  - Mass separation possible up to ~8 GeV/nucleon
  - Mass resolution ~2% in optimal regions above Cerenkov thresholds
  - Reliable estimate of D/p ratio up to ~6 GeV/nucleon after a single day of data taking
  - Current rejection factor $>10^4$ in optimal region (up to 5 GeV/nuc)
  - Results expected to be similar for anti-D/anti-p separation