Particle identification with the AMS-02 RICH detector: search for dark matter with antideuterons

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The AMS-02 experiment

The Alpha Magnetic Spectrometer (AMS), whose final version AMS-02 is to be installed in the International Space Station (ISS) for at least 3 years, is a detector designed to study the cosmic ray flux by direct detection of particles above the Earth's atmosphere using state-of-the-art particle identification techniques. A preliminary version of the detector, AMS-01, was successfully flown aboard the US space shuttle Discovery in June 1998.

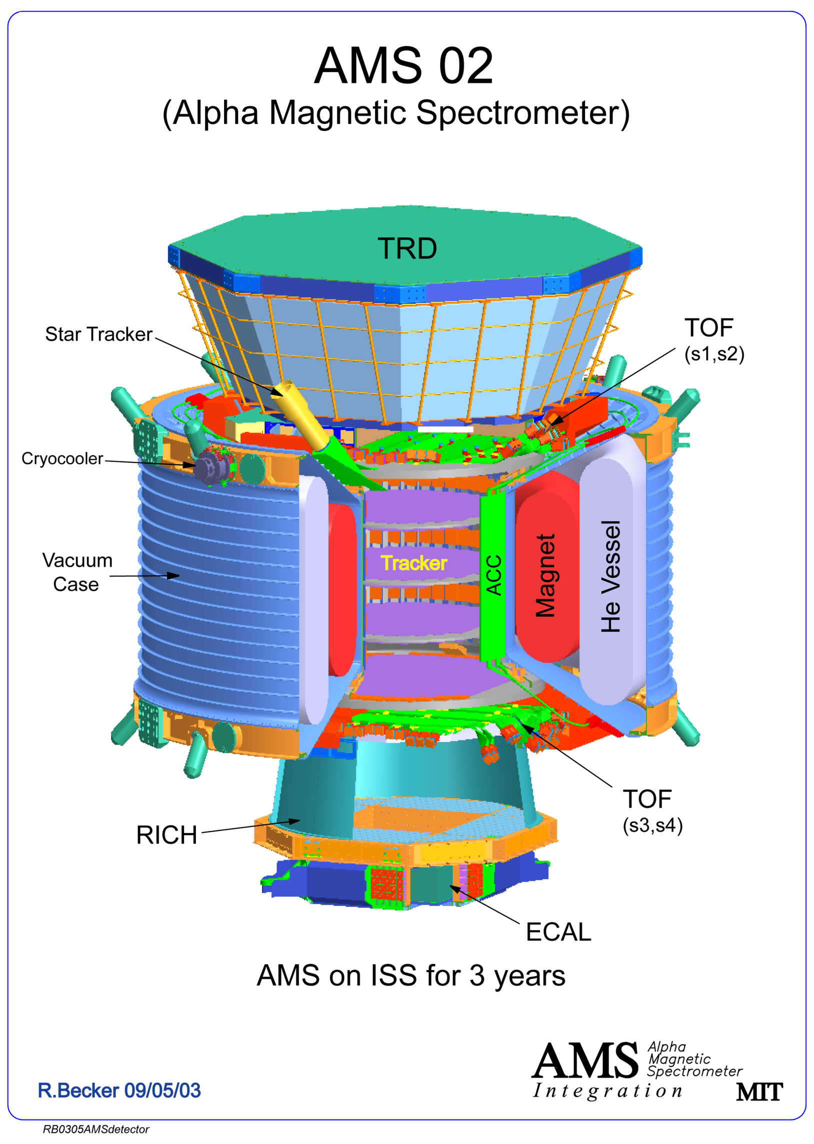
The main goals of the AMS-02 experiment are:

- A precise measurement of the cosmic ray spectrum between ~100 MeV and ~1 TeV;

- A search for heavy antinuclei (Z ≥ 2), which if discovered would signal the existence of cosmological antimatter;

- A search for dark matter constituents by examining possible signatures of their presence in the cosmic ray spectrum.

The long exposure time and large acceptance (0.5 m²sr) of AMS-02 will enable it to collect an unprecedented statistics of more than 10^{10} nuclei.



The AMS RICH detector

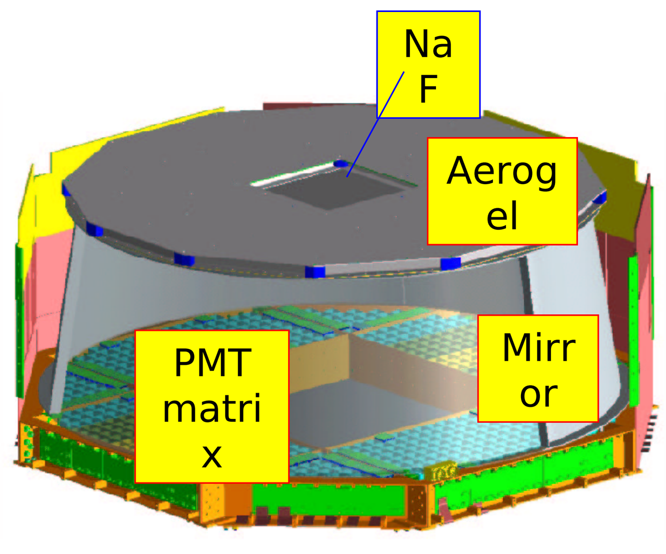
One of the subdetectors in AMS-02 is a proximity focusing Ring Imaging Čerenkov (RICH) detector. It is composed of a dual radiator with silica aerogel (n = 1.05) and sodium fluoride (n = 1.334), a high reflectivity lateral conical mirror and a detection matrix with photomultipliers coupled to light guides.

The RICH detector will provide a very accurate velocity measurement (in aerogel, $\Delta\beta/\beta \sim 10^{-3}$ for Z=1, $\Delta\beta/\beta \sim 10^{-4}$ for Z>10) and charge identification of nuclei up to iron (Z=26).

RICH data, combined with information on particle rigidity from the AMS Silicon Tracker, enable the reconstruction of particle mass. The RICH velocity measurement is essential due to the growth of relative errors when v → c:

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

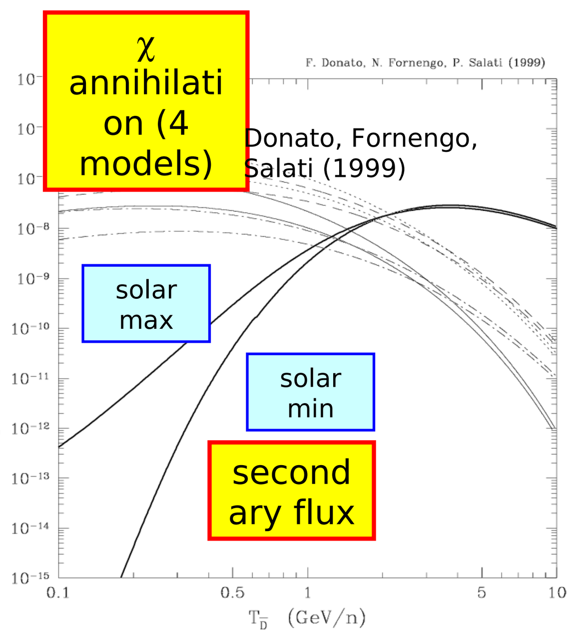
The assembly of the AMS RICH detector is currently underway at CIEMAT in Madrid. The integration of the RICH and the other subdetectors of AMS-02 will take place at CERN in 2007.



Dark matter and the antideuteron signal

The most recent cosmological data from WMAP indicate that baryons account for only a small fraction of the total matter density of the Universe ($\Omega_b \approx 0.04$, $\Omega_m \approx 0.24$). Non-baryonic dark matter should therefore be very abundant.

The neutralino (χ), a neutral, stable particle predicted by supersymmetric models, is one of the strongest dark matter candidates. The annihilation of neutralino pairs is expected to produce an effect on certain components of the cosmic ray spectrum (γ, e⁺, $\bar{p}$, $\bar{D}$). In particular, the low energy antideuteron flux resulting from neutralino annihilation is expected to be orders of magnitude higher than the secondary flux due to other interactions.



Particle identification: the deuteron case

To evaluate the capabilites of AMS-02 for mass separation of antideuterons from other particles with the same charge, studies have been performed using the similar case of deuteron vs. proton separation. Additional studies focused on the separation of helium (Z=2) and beryllium (Z=4) isotopes.

In the study of D/p separation a full-scale simulation of the AMS detector was used. Particles were simulated as coming from the top plane of a cube, corresponding to an acceptance of 47.78 m²sr. Three data samples were chosen:

- Protons, low momentum (0.5-10 GeV/c), 3.1 × 10⁸ events

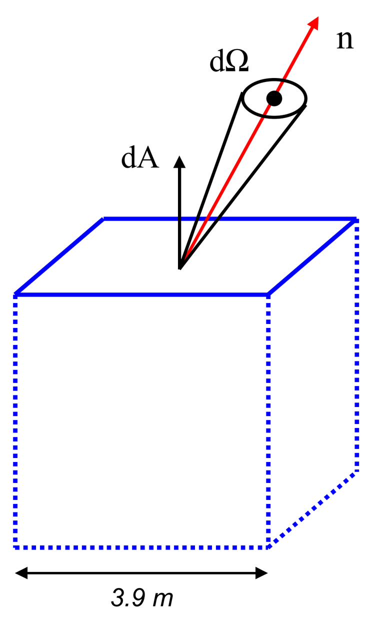
- Protons, high momentum (10-200 GeV/c), 1.3 × 10⁸ events

- Deuterons (0.5-20 GeV/c), 5.6 × 10⁷ events

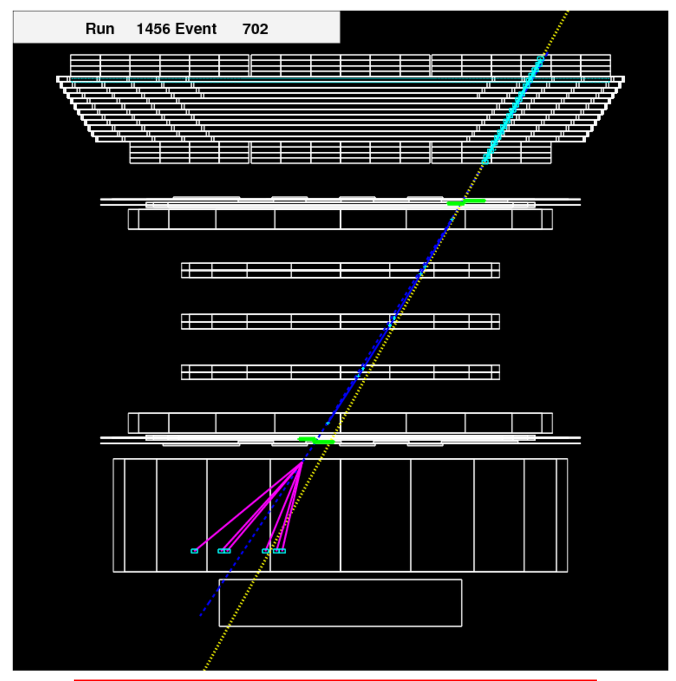
For all samples, dN/d(ln p) = constant. Variable weights were assigned to events in order to reproduce a realistic spectrum:

- For protons, $dN/dE \propto E^{-2.7}$;

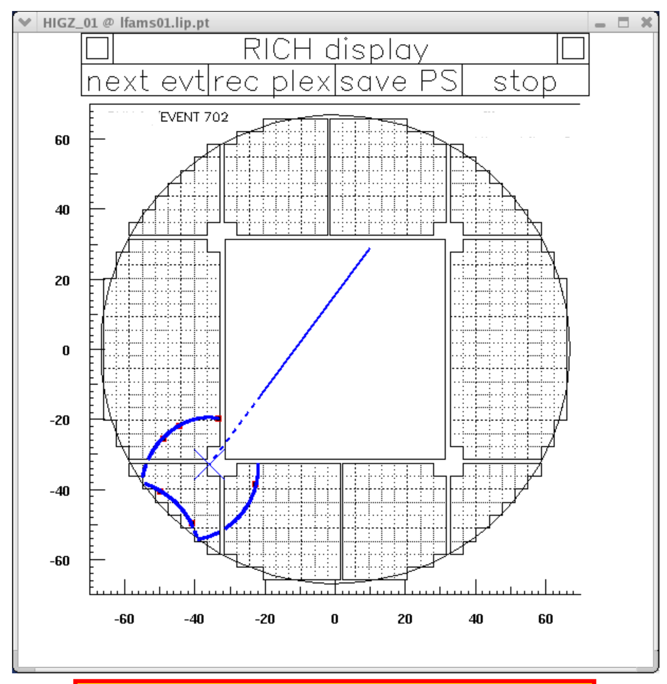
- For deuterons, D/p ratios from Seo et al. (1994) were used.



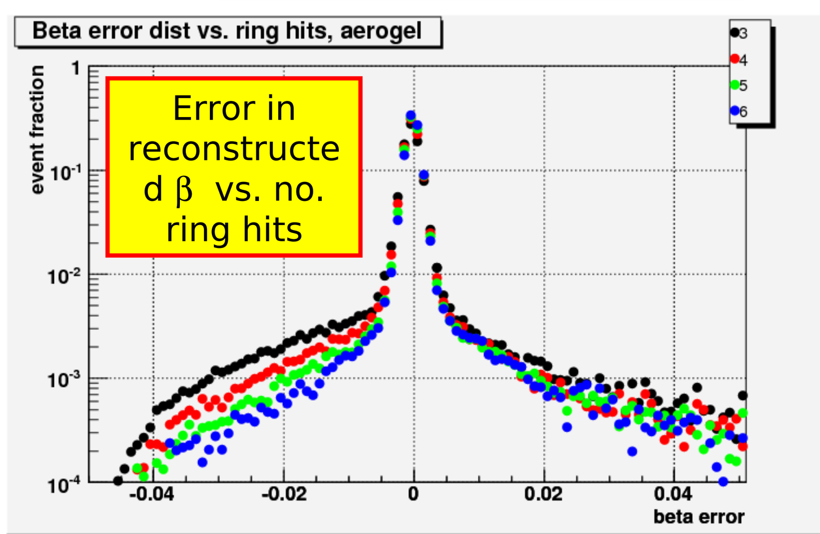
$$A = \int d\Omega \, n \, dA$$

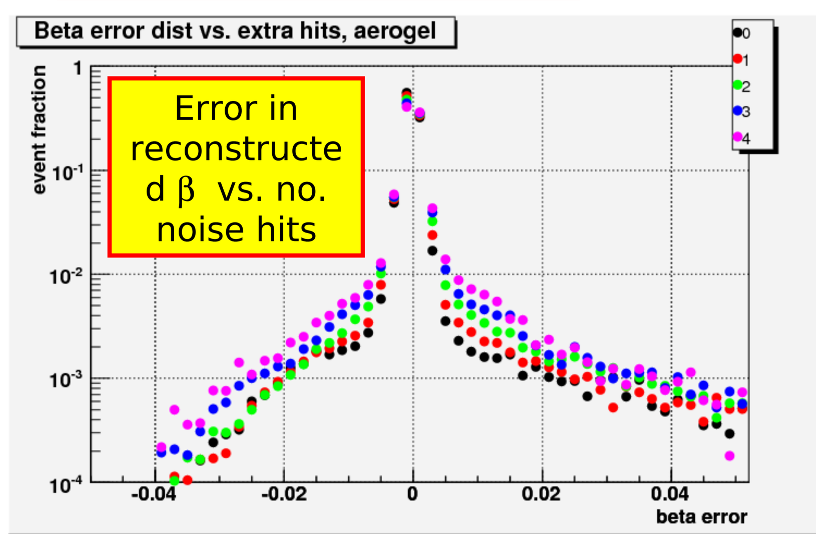


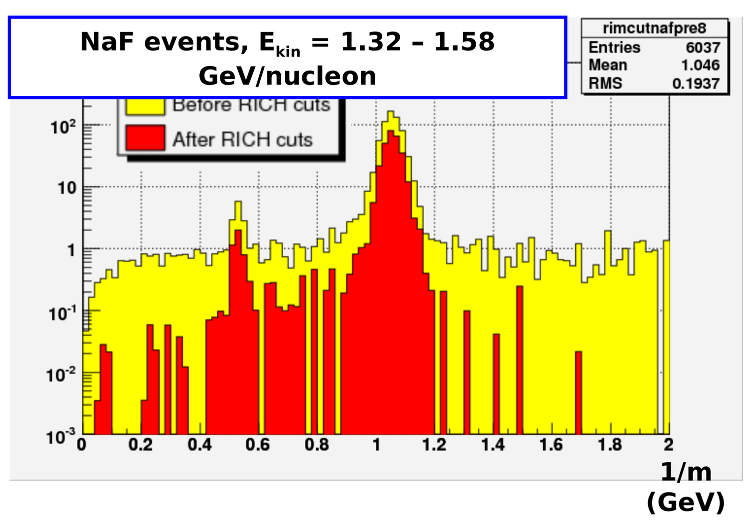
Simulated event on the AMS detector

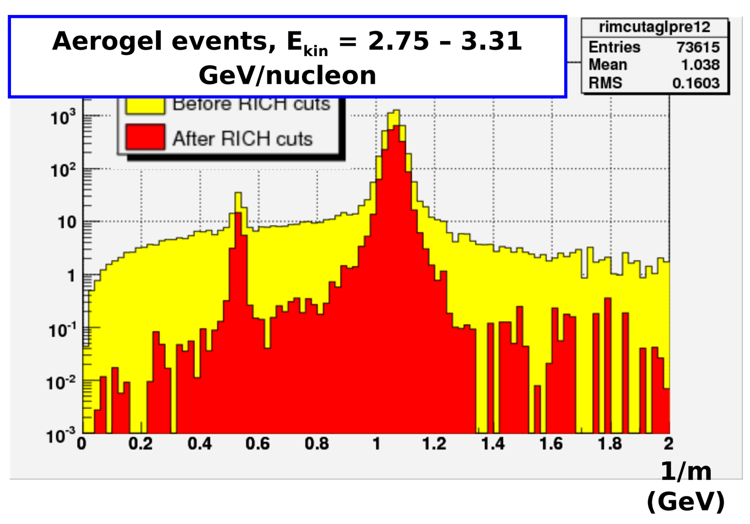


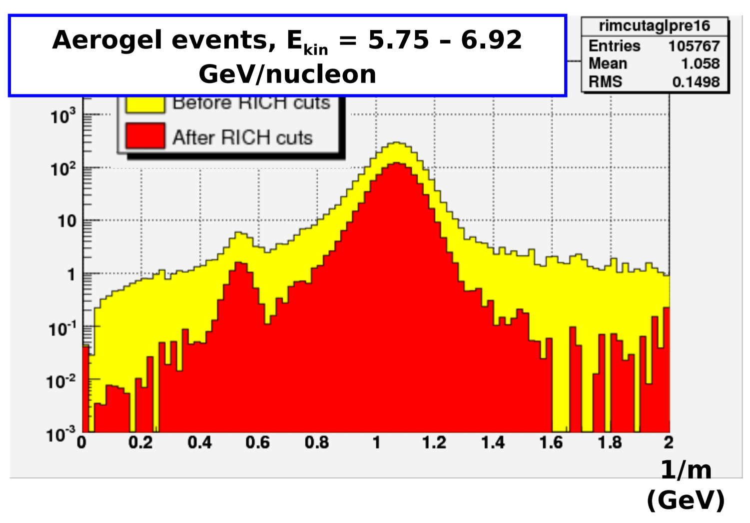
Same event on LIP RICH display





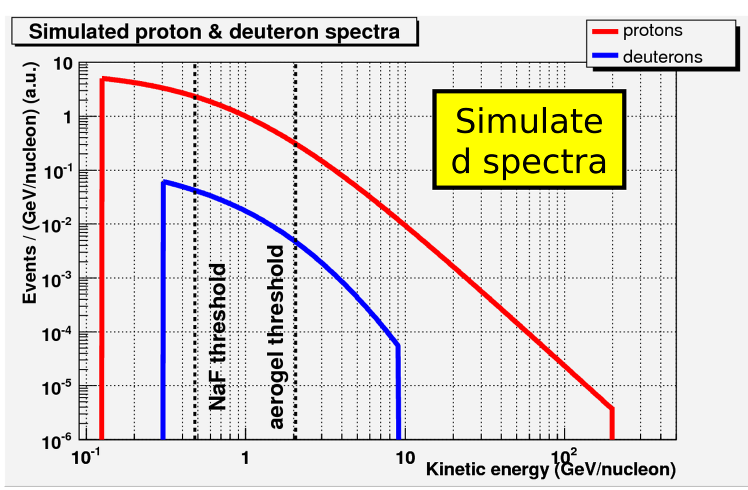






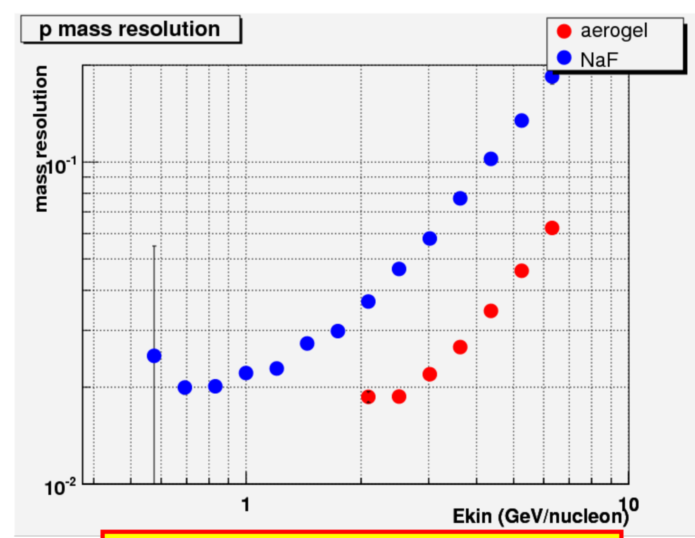
In each event a set of preliminary data selection cuts from different subdetectors was applied to exclude bad reconstructions. Data taken into consideration included the number of particles seen by the detector, the number of tracks in the Transition Radiation Detector, the number of hits used in the Silicon Tracker's rigidity reconstruction, the comparison of the rigidity values obtained by two different reconstruction algorithms, the comparison of rigidity measurements from the two halves of the Silicon Tracker, the Time-of-Flight reconstructed velocity and the number of TOF clusters used in its reconstruction.

AMS events that had a signal in the RICH detector and passed the preliminary selection were then studied in detail. A new set of cuts was applied to the RICH data to improve the quality of the sample. These included a minimum number of hits in the Čerenkov ring, a maximum number of noise hits, a limit on the total ring signal, a minimal photon ring acceptance (visible fraction), a good compatibility between the velocities calculated from two different algorithms, and a good reconstructed charge.

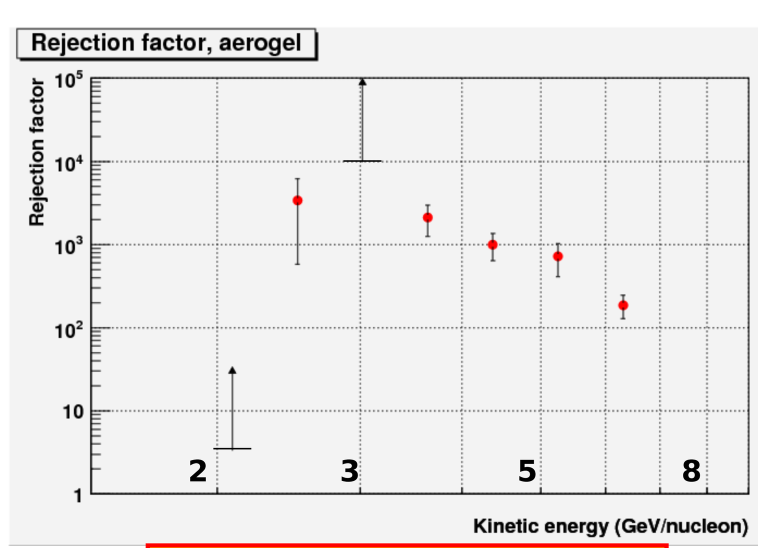


Analysis results

Results show that mass separation of particles with Z=1 is feasible even if one species is orders of magnitude more abundant than the other. D/p separation is possible up to ~ 8 GeV/nucleon. In the optimal region immediately above the aerogel radiation threshold (2.1 to 4 GeV/nucleon) rejection factors in the 10^3-10^4 region were achieved. The relative mass resolution for protons and deuterons is ~2% for both radiators in the regions above their respective thresholds.



Relative mass resolution for protons

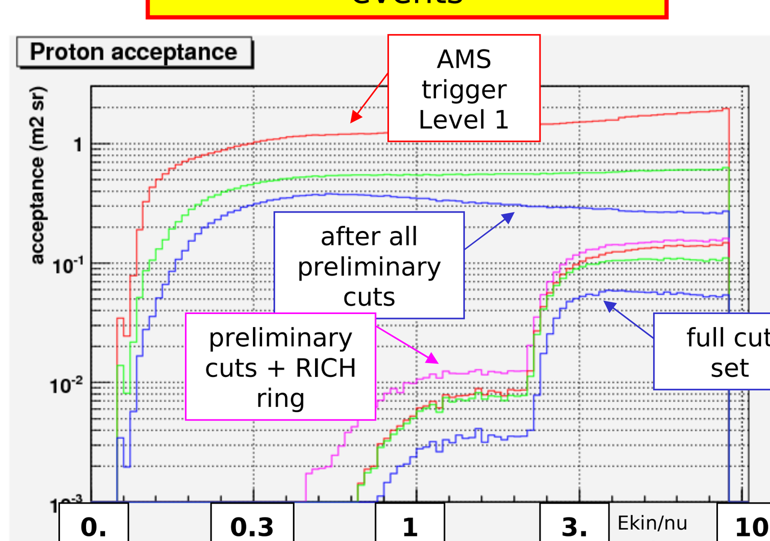


Rejection factor, aerogel events

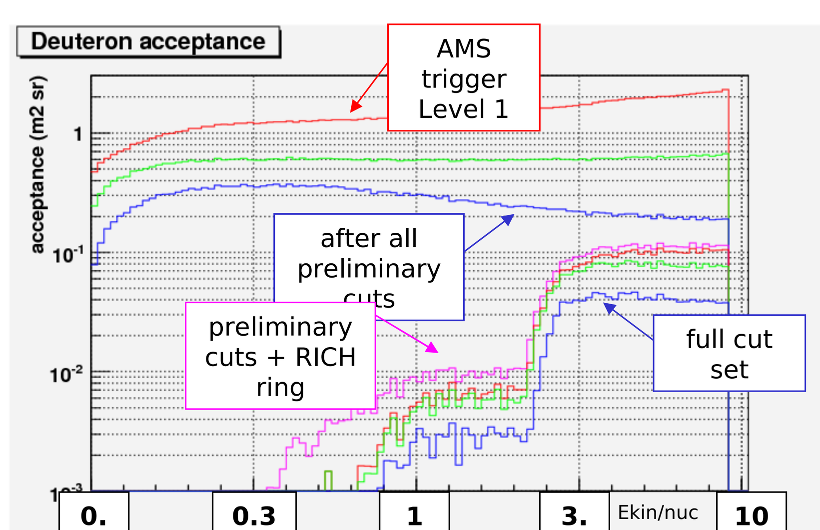
After all cuts, an acceptance of 0.05 m²sr was obtained for protons, and 0.04 m²sr for deuterons at kinetic energies above 3 GeV/nucleon.

The main background in the deuteron case comes from non-gaussian tails of proton events with a bad velocity reconstruction. Errors in rigidity reconstruction (ΔR/R ~ 2% in the GeV region) are not critical for in this case.

Rejection factors may be improved by applying stricter cuts, at the expense of a further acceptance reduction.



Proton acceptance, progressive cuts



Deuteron acceptance, progressive cuts