Deuteron-proton separation with the RICH detector of the AMS-02 experiment

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Abstract

The Alpha Magnetic Spectrometer (AMS), whose final version AMS-02 is to be installed on the International Space Station (ISS) for at least 3 years, is a detector designed to measure charged cosmic ray spectra with energies up to the TeV region and with high energy photon detection capability up to a few hundred GeV, using state-of-the-art particle identification techniques.

Among several detector subsystems, AMS includes a proximity focusing RICH enabling precise measurements of particle electric charge and velocity. The combination of both these measurements together with the particle rigidity measured on the silicon tracker endows a reliable measurement of the particle mass.

The main topics of the AMS-02 physics program include the search for indirect signatures of dark matter and detailed measurements of the nuclear component of the cosmic-ray spectrum. Mass separation of singly charged particles, and in particular the separation of deuterons and antideuterons from massive backgrounds of protons and antiprotons respectively, is essential in this context. Detailed Monte Carlo simulations of AMS-02 have been used to evaluate the detector's performance for mass separation at different energies. The obtained results and physics prospects are presented.

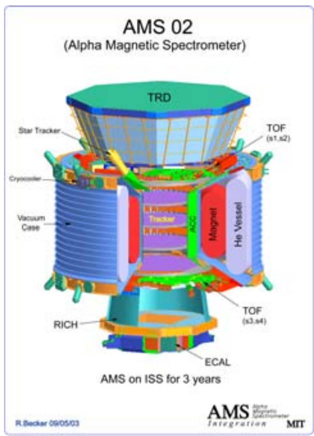
The AMS-02 experiment

The Alpha Magnetic Spectrometer, whose final version AMS-02 is to be installed in the International Space Station 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 ($Z \geq 2$), 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 m^2sr) of AMS-02 will enable it to collect an unprecedented statistics of more than 10^{10} nuclei.



The AMS RICH detector

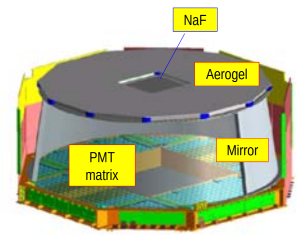
One of the subdetectors in AMS-02 is a proximity focusing Ring Imaging Čerenkov (RICH) detector. It is composed of a dual radiator with silica aerogel (n = 1.05) and sodium fluoride (n = 1.334), a high reflectivity lateral conical mirror and a detection matrix with photomultipliers coupled to light guides.

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 $v \to c$:

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

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. The full detector is expected to be ready by the end of 2008.



Aerogel tile

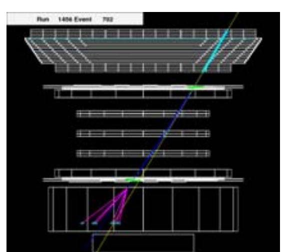
Particle identification

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

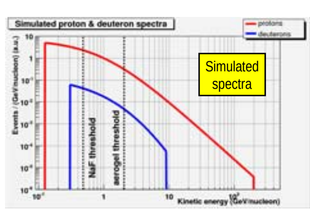
In the study of D/p separation a full-scale simulation of the AMS detector was used with a realistic particle spectrum: for protons, $dN/dE \propto E^{-2.7}$; for deuterons, D/p ratios from Seo et al. (1994) were used.

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.



Simulated event in the AMS detector



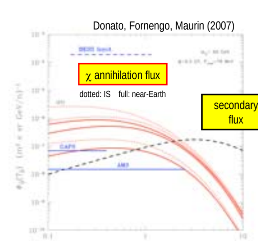
Simulated spectra

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^+, $\overline{p}$, $\overline{D}$). 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.

The identification of this antideuteron flux will only be possible if methods of particle identification can separate it from the huge flux of other single-charged particles.



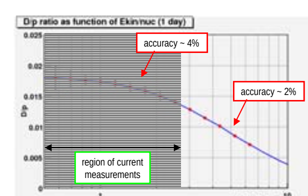
Analysis results

Current 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 in a large range, extending the region where measurements are currently available up to ~ 8 GeV/nucleon. In the optimal region above the aerogel radiation threshold (3 to 5 GeV/nucleon) rejection factors higher than 10^4 are attainable. The relative mass resolution for protons and deuterons is ~ 2% for both radiators in the regions above their respective thresholds. Good estimations of the D/p ratio at different energies may be obtained from a few days of data.

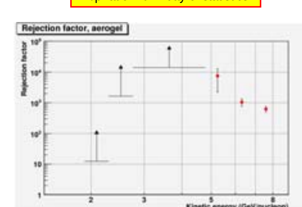
After all cuts were applied, an acceptance of ~ 0.07 m^2sr was obtained for protons, and ~ 0.05 m^2sr for deuterons at kinetic energies above 3 GeV/nucleon.

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

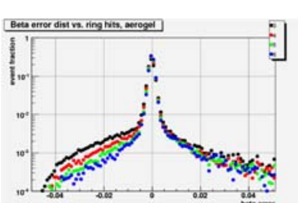
Rejection factors may be improved by applying stricter cuts, at the expense of a further acceptance reduction.



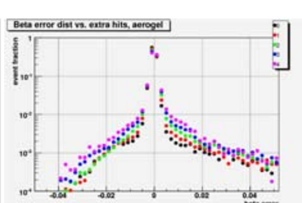
D/p ratio with 1 day of statistics



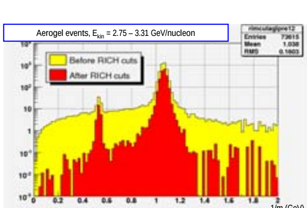
Rejection factor for aerogel events

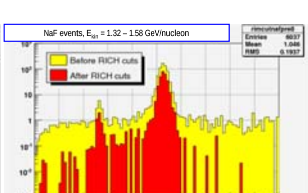


Error in reconstructed β vs. no. ring hits

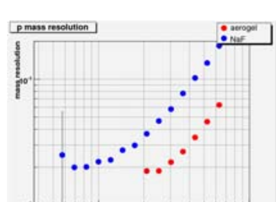


Error in reconstructed β vs. no. noise hits



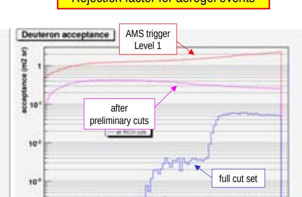


Examples of reconstructed mass distribution: aerogel (left) and NaF (right)



Relative mass resolution for protons

Proton acceptance as function of energy



Deuteron acceptance as function of energy