Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 4 (HE part 1), pages 765–768

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Cosmic Rays Antideuteron Sensitivity for AMS-02 Experiment

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Abstract: For energies less than 3 GeV/n, the Cosmic Rays Antideuteron component originated from spallation becomes very small due to kinematic reasons and the detection of even a single antideuteron will strongly suggest the existence of new sources, like neutralino Dark Matter. So far no antideuteron events have been detected in cosmic rays [1]. The AMS-02 detector, on board of ISS for a long duration mission (3 years), thanks to its large acceptance and very good particle identification capabilities, will be able to push down the current upper limit into the region where some new physics effects are expected. Using Monte Carlo simulation, the AMS-02 sensitivity for antideuterons has been estimated as of about 5–6$\times10^{-7}$ (m^2 sr sec)$^{-1}$ in the kinetic energy range between 0.2 and 1 GeV/n.

Introduction

In the last few decades the presence of antimatter in CR, namely antiprotons and positrons, has been confirmed through the measurement of their spectra with balloon-borne and space experiments. Indeed, light antinuclei, mostly antiprotons but also antideuterons, are produced in our galaxy as secondaries, mainly from the interaction of primary protons with the interstellar medium (ISM) of the Milky Way disc.

New exotic sources of these CR species could come from the annihilation of some Dark Matter (DM) candidates. A variety of experimental evidences, both from cosmology and astrophysics, points to the existence of "missing matter" in the Universe, but its nature is still a mistery. Recent results on Cosmic Microwave Background (CMB) measurements indicate that DM contributes to about 23% of the Universe energy density [2]. At the same time, strong arguments based on Big Bang nucleosysthesis, large structure formation, cosmological measurments and the observations of several rotational galactic curves essentially constrain the search to non-baryonic Cold Dark Matter.
No known particle in the Standard Model of particle physics (SM) can fulfil this role and so further candidates should be found in new theories. Going beyond the SM, among the different candidates, the most studied one is nowadays the Lightest Supersymmetric Particle (LSP), arising from the suspersymmetric extensions of the SM (SUSY models). If the DM was made of the neutralinos, the most favorite LSP particle, one could hope to detect them indirectly through their annihilation products by means of an excess of gamma rays, positrons, antiprotons and light antinuclei with respect to the known CR fluxes.

For kinematical reasons, antideuterons from neutralino annihilation are expected to populate mainly the low energy region, whereas antideuterons from standard astrophysical origin are produced with relatively higher energy. As a matter of fact, the fusion processes, which produce antideuterons from the merging of antiprotons and antineutrons, are favoured at low anergy, and this enhances the antideuteron formation from neutralino annihilation with regards to that from secondary CRs [3]. On the other hand, the existent antiprotons data are very well explained by secondary production in CRs, making the extraction of an

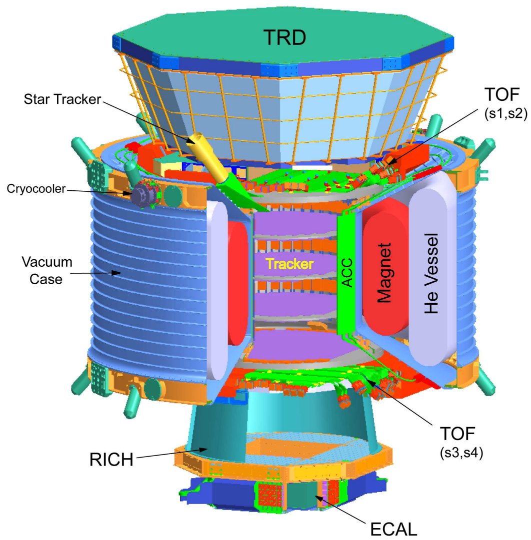

Figure 1: Schematic view of AMS-02 detector: all the main subdetectors are visible.

eventual supersymmetric signal much more difficult [4]. Therefore, antideuterons with kinetic energy below about 1 GeV/n are a much better probe for SUSY DM than antiprotons. Unfortunately, the antideuteron signal is very small in comparison with the primary cosmic rays fluxes and even with that of antiprotons [3]. A very large acceptance spectrometer in space, with long exposure time and good particle identification, like AMS-02, is therefore required.

AMS-02 detector

The *Alpha Magnetic Spectrometer* (AMS) experiment [5] is a space-borne high energy particle detector built to perform a high precision measurement of Cosmic Ray (CR) and gamma fluxes at low Earth orbit from few hundred MeV/n up to few TeV/n. AMS-02, developed by a world-wide international collaboration, will be ready at the end of 2008 to be installed on the International Space Station (ISS), where it will operate for at least three years.

Figure 3 shows a schematic view of all the AMS-02 sub-detectors, that are listed below, starting from the top to the bottom.

- A twenty layers Transition Radiation Detector (TRD), which will ensure a rejection factor electrons (or positrons) against hadrons of 10^3 to 10^2 in the energy range from 1.5 to 300 GeV;
- Four layers Time of Flight (TOF) hodoscope, which provides primary trigger, measures time of flight ($\sim$ 120 ps of resolution) and particle charge.
- The superconducting magnet which provides a bending power of BL^2 = 0.86 Tm^2.
- Eight layers of double sided silicon detectors, which provide particle rigidity and charge resolution of nuclei up to iron (Z=26).
- Veto or Anti Coincidence counters (ACC), which ensure that only particles passing through the magnet aperture will be accepted.
- A Ring Imaging Cherenkov Counter (RICH), which measures the velocity (0.1% of resolution) and charge of particles or nuclei.
- A 3-D sampling calorimeter (ECAL), which measures the energy of gamma rays, electrons and positrons and distinguishes electrons and positrons from hadrons with a rejection power of 10^4 in the range between 1.5 GeV to 1 TeV.

The measurement of the particle velocity is provided by the TOF detector in the low energy region below about 1.5 GeV/n, where the exotic primary $\overline{\mathrm{d}}$ component is expected; the RICH detector will instead explore the region where the secondary flux coming from standard astrophysical sources is predicted.

Analysis

The antideuteron signal is very suppressed in CRs and its detection is a challenging task even for a large acceptance space detector like AMS-02. The goal of this analysis is to make an estimation of the sensitivity of the AMS-02 experiment to the antideuteron flux using simulated data.

Nuclear interactions of deuterons and antideuterons with the nuclei composing the AMS-detector are implemented in the Monte Carlo (MC) code. The universal parameterization proposed by Tripathi and co-workers, which gives the best fit to most of the measurements of nucleus-nucleus inelastic cross sections, has been introduced to describe deuteron interactions [6]. On the other hand, only few data are available on antideuteron cross sections particularly in the low energy range. Thus a phenomenological model has been built [7] and the $\overline{\mathrm{d}}$ inelastic cross section has been parametrized on the base of the existing experimental data on $\overline{\mathrm{p}}\mathrm{d}$ collisions [8]. The complete simulation of physical processes, as well as interactions of particles with detector material, has been done using GEANT3 framework [9].

Selection criteria

A set of selection criteria minimally dependent on MC has been studied and refined in order to maximize the AMS-02 acceptance to antideuteron signal and conversely minimize the background both in the low energy range where the velocity measurement is provided by the TOF and in the region where the RICH detector is operating. In order to select a clean sample of antideuterons, the information coming from all subdetectors are used to reject mis-reconstructed background events, which could mimic the signal. All the main possible sources of background for antideuterons have been considered: namely protons, deuterons, antiprotons and electrons.

Although protons have opposite charge sign and the probability to mix up their rigidity is very low, they can contaminate the $\overline{\mathrm{d}}$ sample because of their huge flux, about 10^{11} orders of magnitude greater than that of $\overline{\mathrm{d}}$. Similarly, the signal contamination due to deuterons, whose flux is expected to be about 2% of proton sample, has been evaluated. Specific cut are performed in order to optimize the rigidity reconstruction in the Tracker, whereas more general selection criteria are applied to suppress events spoiled by interactions inside the detector.

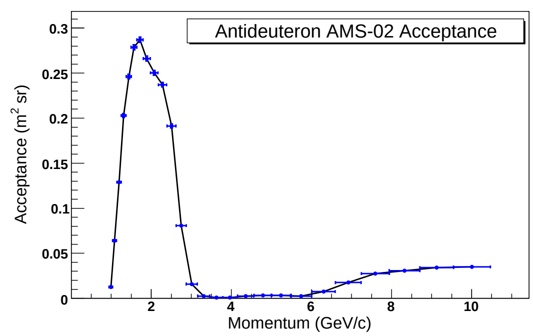

Figure 2: Final AMS-02 acceptance to $\overline{\mathrm{d}}$ signal.

Another source of background is rapresented by electrons, which have the same $\overline{\mathrm{d}}$ charge. Their rejection is based on the velocity measurement, thanks to the much lower electron mass compared to that of antideuterons. In addition, the AMS-02 TRD electron/hadron separation power, is crucial to reach the required suppression of the level of $10^8 - 10^9$. Finally, the antiproton background has to be taken into account, because they have the same momentum sign of antideuterons and so they could be rejected by mass measurement only. Tight quality cuts on velocity reconstruction are therefore required to improve the β measurement in the TOF and in the RICH according to the momentum range. After the application of this data selection, the AMS-02 acceptance to $\overline{\mathrm{d}}$ signal, shown in figure 2, is therefore obtained.

Results

Accordingly to the current study, the AMS-02 experiment will be able to provide clean samples of antideuterons in the energy ranges between 0.2 and 1.2 GeV/n and from 2.1 up to 4.1 GeV/n.

As a result of this analysis, the minimum antideuteron detectable flux foreseen for AMS-02 is computed. In the energy range between 0.2 and 0.8 GeV/n and between 2.2 and 4.2 GeV/n, AMS-02 will detect primary antideuterons if their flux is greater than 4.5$\times 10^{-7}$ $(\mathrm{m}^2\ \mathrm{s\ sr\ GeV/n})^{-1}$ as

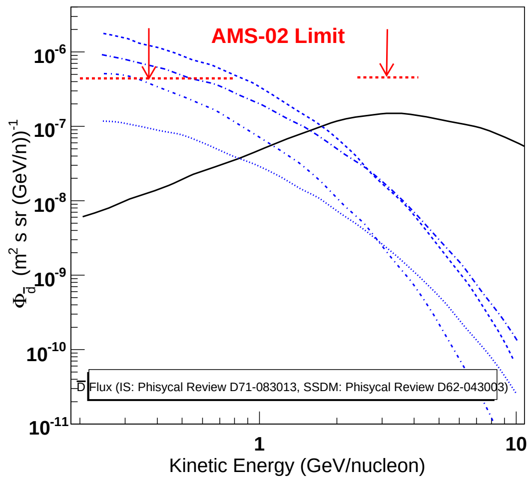

Figure 3: Extimated AMS-02 sensitivity limit for the antideuteron flux measurement compared to: the $\bar{d}$ secondary IS flux [4]; the $\bar{d}$ primary flux coming from the neutralino Dark Matter annihilation [3] for different points in the supersymmetric parameter space (labelled with a, b, c, d).

shown in figure 3 [7]. Taking into account the primary antideuterons fluxes published in literature [3], derived in the Minimal Super Symmetric Model framework, about 2 events of antideuterons below 1 GeV/n are expected to be collected by AMS-02 in three years of data taking, considering the $\bar{d}$ predicted flux corresponding to curve b in figure 3. It is important to underline that the present uncertanties related to computation of the antideuteron primary flux are substantial, mainly due to the fact that the sources of primary fluxes are located inside the diffusive halo, whose size is unknown.

Thanks to the predicted depletion of the secondary antideuteron spectrum below 1 GeV/n, even the detection of one antideuteron in this region would be a strong signal for the existence of new primary sources.

Conclusions

The capability of the AMS-02 experiment to reveal antideuteron signal in Cosmic Rays has been explored. The study of the AMS-02 sensitivity to the antideuteron signal has been performed on Monte Carlo (MC) data. To take into account the nuclear inelastic interactions of deuterons and antideuterons inside the detector, their relative cross sections have been implemented into the official AMS-02 MC code. The resulting minimum detectable flux for AMS-02 is comparable with the expected primary flux as predicted in literature, making AMS-02 sensible to this promising physics channel.

Acknowledgements

We wish to thank F. Donato and M. Buénerd for fruitful discussions.

References

[1] H. Fuke, Search of Cosmic-Rays Antideuteron, Physics Review Letters 95 (2005) 081101.

[2] W.-M. Y. et al., Review of Particle Physics, Nucl. Part. Phys. 33.

[3] F. D. N. F. and P. Salati, Antideuterons as a signature of supersymmetric dark matter, Physics Review D 62.

[4] R. D. et al., Flux of light antimatter nuclei near earth, induced by Cosmic Rays in the Galaxy and in the atmosphere, Physics Review D 71.

[5] V. Bindi, The Alpha Magnetic Spectrometer on the International Space Station, in: these proceedings.

[6] R. T. F. C. and J.W. Wilson, Medium modified nucleon-nucleon cross sections in a nucleus, Nuclear Instruments and Methods B 152 (1999) 425–431.

[7] F. Giovacchini, Cosmic Rays Anti-Deuteron Flux Sensitivity of the AMS-02 Detector., Phd thesis, Bologna University (2007).

[8] ttp://pdg.lbl.gov/ (2006).

[9] CERN Application Software Group, Computing and Networks Division, GEANT – Detector Description and Simulation Tool, cERN Program Library Long Writeup W5013 (1993).