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INDIRECT SEARCH FOR DARK MATTER WITH AMS EXPERIMENT*

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The Alpha Magnetic Spectrometer (AMS-02) is a large acceptance detector of cosmic rays which will be installed on International Space Station for a period of three years. It will provide precise measurements of spectrum and composition of cosmic rays in rigidity range from 1 GV to a few TV. These complex and precise data are expected to allow drawing interesting astrophysical conclusions. Particularly measurements of antiproton, positron, antideuteron and gamma fluxes will allow for search for Dark Matter component of the Universe.

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1. Introduction

About 83% of the matter in the Universe exists in the form of cold Dark Matter (DM) (see for instance [1] for the recent review). This matter is expected to be made of quasi-stable, non-baryonic, Weakly Interacting and Massive Particles (WIMPs). The nature of this major component remains unknown. One of the most popular hypothesis claims that Dark Matter is made of supersymmetric particles (possible candidate is neutralino). The models with extra-dimensions also provide candidates for WIMPs. In both cases it is possible that WIMP annihilates and produces signal which can be measured as anomaly in spectrum of charged cosmic rays or as a particular gamma-ray emission.

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The AMS detector with reduced experimental configuration (AMS-01) has successfully flown on Space Shuttle Discovery during STS-91 mission. It has not only tested the technology in space conditions but also collected about 10^8 of cosmic ray events [2].

2. AMS-02 detector

The Alpha Magnetic Spectrometer [3] consists of five subdetectors, a superconducting magnet and anti-coincidence counters. Transition Radiation Detector (TRD) allows for electron/hadron separation at the level 1:100 up to energies of 300 GeV. The Time-Of-Flight system (TOF) provides the main trigger and measures velocity of the particles. The superconducting magnet produces bending magnetic field which reaches 0.8 T close to the center of the Silicon Tracker (TRK). The Tracker is made of 8 layers of double-sided silicon sensors. The maximal detectable rigidity is 1 TV and the rigidity resolution is better than 2% up to 20 GV. The measurement of the charge deposited in tracker sensors allows for determination of particle charge. The Ring Imaging Cerenkov (RICH) provides further velocity and charge measurements. Electromagnetic Calorimeter (ECAL) is a three-dimensional sampling calorimeter with total length of $16X_0$. It allows to suppress protons at the level of 10^{-4}, and it also provides an independent gamma trigger.

Due to the Space Shuttle cargo specifications, International Space Station safety limits and environmental conditions in space, AMS has to fulfill various special requirements concerning weight (limited to 7 tons), vibration resistance, cosmic radiation, electromagnetic interference, power consumption and data communication.

3. Antiproton channel

The antiproton spectrum is presently measured between 200 MeV and 20 GeV. It is compatible with secondary production by interaction of primary cosmic rays with the interstellar medium. The prediction of antiproton spectrum for higher energies is sensitive to the details of cosmic ray propagation model. In this model the propagation can be determined from the ratio of abundances of secondary-to-primary isotopes. For instance boron-to-carbon (B/C) ratio is one of the most important parameters of the propagation model [4].

AMS-02 will measure both: antiproton spectrum in energy range from 0.5 to 200 GeV, and also B/C ratio with a great precision. It is expected that signal from DM annihilation could be observed for energies above 30 GeV. Such a signal can be generated by heavy DM particles, as presented on the left plot of Fig. 1 [5]. In most models high boost factors, *i.e.* enhancements of the signal due to local clumps of DM, are needed in order to observe the signal. For instance the flux from the model I (Fig. 1) was multiplied by boost factor of 4180 and model II by 1180.

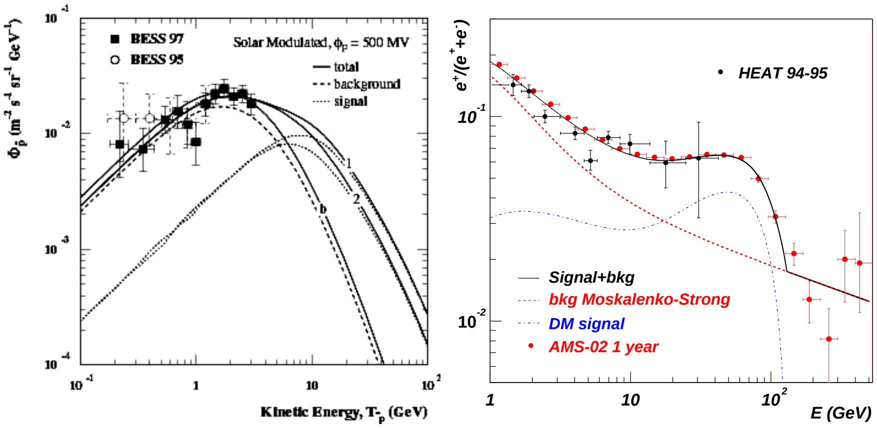

Fig. 1. Left plot: example of distortion of the primary antiproton flux (line b) at the Top Of the Atmosphere (TOA) due to neutralino annihilation signal for $m_\chi = 964\,\mathrm{GeV}/c^2$ (model I) and $777\,\mathrm{GeV}/c^2$ (model II). Right plot: the e^+ fraction in the case of a primary e^+ from annihilating neutralinos with mass $\mathrm{m}_\chi = 336\,\mathrm{GeV/c}^2$.

4. Positron channel

AMS-02 will be able to measure positron spectrum from 1 to 400 GeV with energy resolution of 3% above 10 GeV [6].

Neutralino annihilations into W^+W^- and Z^0Z^0 pairs lead to production of energetic positrons. This channel is very interesting, especially in the light of HEAT Collaboration [7] data, which shows excess of the positrons in cosmic ray spectrum for energies above 7 GeV. As positrons propagate on shorter distances than heavier particles, measurement in this channel is particularly sensitive for local properties of Dark Matter halo.

On the right plot of Fig. 1 an example of a supersymmetric model which might lead to positron flux excess is presented. The flux was multiplied by a boost factor of 11.7 in order to fit HEAT data. The simulated primary positron fluxes have been added to the Moskalenko and Strong [8] secondary positron spectrum. The reported error on AMS expected signal corresponds to 1 year of data taking. Details can be found in [6].

5. Antideuteron channel

Antideuterons have never been measured in cosmic rays. Standard processes of interactions of cosmic rays with interstellar medium — mainly spallation — lead to production of a very small flux (around $10^{-8}[\mathrm{m}^2\,\mathrm{s\,sr\,GeV}]^{-1}$) of antideuterons with kinetic energies above 1 GeV/nucleon [9]. This flux is a factor of a few below AMS-02 sensitivity.

The AMS sensitivity to $\bar{d}$ flux for low kinetic energy (0.15 GeV/nucleon – 0.65 GeV/nucleon) relays on the measurement of particle velocity by TOF. For energies above 2.2 GeV/nucleon the particle velocity is measured by RICH. Acceptance for low energies is a factor of a few higher than for high energies.

Neutralino annihilation might produce flux of a very low energy antideuterons. At kinetic energies below 1 GeV/nucleon this flux suffers from a small background of antideuterons produced in spallation process [10]. This situation, presented on the left plot of Fig. 2, is more comfortable than the case of antiprotons and positrons where the Dark Matter signal appears only as a distortion of a standard spectrum. The disadvantage of observations at such low energy is presence of geomagnetic cutoff which reduces cosmic antideuteron flux during a large fraction of the orbit.

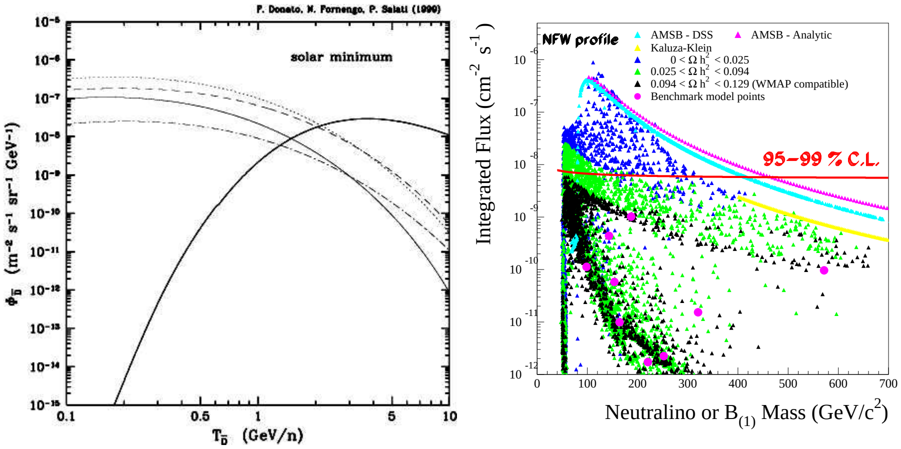

Fig. 2. Left plot: fluxes of secondary antideuterons (solid line) and antideuterons synthesized in Dark Matter pair annihilation [10]. Right plot: the integrated γ flux from the Galactic Center as a function of m_χ for the NFW halo profile parameterizations with the standard set of parameters. The considered models are the mSUGRA scheme, AMSB scenario and Kaluza–Klein Universal Extra-dimensions. The various selections were done by varying Ωh^2 cuts [13].

6. Gamma channel

Gamma ray identification in AMS-02 can be performed in two modes. In so called conversion mode the gammas are converted in TRD and the electron–positron pair is measured in tracker and other subdetectors. The second mode is when photon does not interact in any detector before ECAL, where it leaves characteristic signature of electromagnetic shower.

The objects which are expected to emit a significant γ flux due to DM annihilation are central parts of halos and local clumps. One of the most promising objects is the Galactic Center, which will be observed by AMS during about 400 hours per year. On the right plot of Fig. 2 the AMS-02 sensitivity to Dark Matter annihilation in Galactic Center is presented.

7. Conclusions

In conclusion, with optimistic astrophysical conditions, AMS will open new exclusion/discovery domain in the indirect Dark Matter searches. It will be the unique experiment performing these searches simultaneously in four channels.

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