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Cosmic ray Astrophysics with AMS-02 experiment

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The Alpha Magnetic Spectrometer (AMS-02) [1] is a detector designed to measure cosmic rays in space. The detector will be installed on International Space Station for at least a 3 year mission. It will provide measurements of cosmic rays in the rigidity range from 1 GV to a few TV, with unprecedented statistics and precision. The detector has capability to measure individual nuclei fluxes up to Z=26. It has also capability to distinguish isotopes and perform secondary-to-primary ratios measurements, for example d/p, He^3/He^4 and B/C. The AMS-02 experiment will provide important constraints on cosmic ray production and propagation models.

1. Introduction

Hadrons are the main component of cosmic rays. For energies below a few TeV the cosmic ray flux is composed mainly of protons (about 90%) and helium (about 9%). Part of them are believed to be of primary origin, however the exact production and acceleration mechanisms are not well determined. Secondary cosmic rays are generated by spallation of primary particles on the interstellar matter. Precise measurements of the primary and secondary cosmic ray fluxes are necessary to constrain the models of production and propagation in the Galaxy.

The models, constrained by primary and secondary cosmic ray measurements, are necessary to calculate backgrounds in the search of weak signals. For instance the antiproton signals from Dark Matter neutralino annihilation [2] would appear as a deformation of the spectrum of secondary antiprotons produced in spallation processes. The precise modelisation of the shape of the background is crucial in the search of the Dark Matter signal in this channel. The estimation of Galactic diffuse gamma background spectrum must also be done with use of such models. The lack of precise measurement of cosmic ray fluxes is one of the main sources of systematic errors in experiments which measure the solar and atmospheric neutrino deficits and oscillations [3].

AMS-02 is a large-acceptance superconducting magnet spectrometer which will be placed in space for at least 3 year mission on the International Space Station. A prototype of the detector has been tested during the NASA STS-91 Space Shuttle flight, and this test has already provided interesting cosmic ray data [4]. Since the precursor flight, the AMS-02 project has been upgraded with a superconducting magnet and additional subdetectors which were not present before [1].

2. Expected detector performance

The crucial detector performance for cosmic ray detection and identification is demonstrated by the mass resolution and charge identification capabilities. The charge of cosmic rays can be measured by three subdetectors independently: Time-of-Flight (TOF) system, Silicon tracker and Ring Imaging Cherenkov (RICH). Mass resolution is determined by the quality of the rigidity (tracker) and velocity (TOF and/or RICH) measurements.

In Figure 1 an example of beam test results of charge measurement with TOF system and RICH detectors is presented. The plots show a good separation between nuclei up to Z=26.

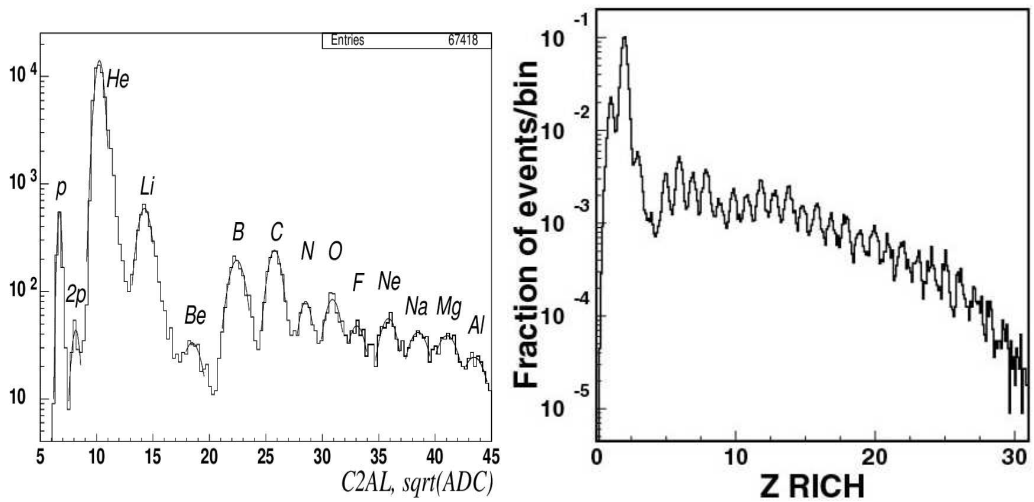

Figure 1. Example of beam test results of charge reconstruction in the Time-of-Flight system (left plot) and in Ring Imaging Cherenkov - RICH (right plot). In TOF the charge reconstruction is based on the energy loss measurement and in RICH on the Cherenkov radiation effect.

3. Primary cosmic rays

The proton and helium (He^4) energy spectra measured by AMS-01 in its test flight in 1998 are the most accurate measurements in the kinetic energy range $1\ \mathrm{GeV/n} \leq \mathrm{E_k/n} \leq 100\ \mathrm{GeV/n}$ up to date. AMS-02 will increase the precision of this measurement and extend the rigidity range to about 2-3 TV. The proton and helium fluxes provide informations about the cosmic ray sources and primary acceleration mechanism. They are also important parameters for calculation of atmospheric neutrino fluxes and for estimation of secondary particle fluxes (antiprotons, positrons, etc.). The AMS-02 will collect an unprecedented statistics of proton events already after 6 hours of data taking, as shown on the left plot of Figure 2.

Other abundant nuclei are C, N, O and Fe. The abundance of these nuclei in cosmic rays is similar to what is observed in Solar System from meteoritic samples and solar spectroscopic measurements. It is widely believed that the sources of these nuclei are supernovae explosions and their spectra are related to the injection spectra.

The deuterium observed in cosmic rays was produced at the Big Bang and no known astrophysical processes lead to its destruction. Therefore, the $\mathrm{d/p}$ ratio is a parameter linked to the age of the Universe. Recent analyses [5] point on deuterium and He^3 abundances as important tests of the Big Bang nucleosynthesis predictions. AMS-02 will be able to perform these measurements.

Due to its small mass, the electron suffers from significant electromagnetic energy loss during propagation. The imprint of such losses on electron spectrum allows for interesting conclusions about contamination and source distribution of cosmic rays in the Galaxy. On the right plot of Figure 2 the wide variety of cosmic electron flux measurements performed up to now is presented. The situation for energies above a few GeV, where large discrepancies between experiments are observed, should be clarified after precise AMS-02 measurements in this region.

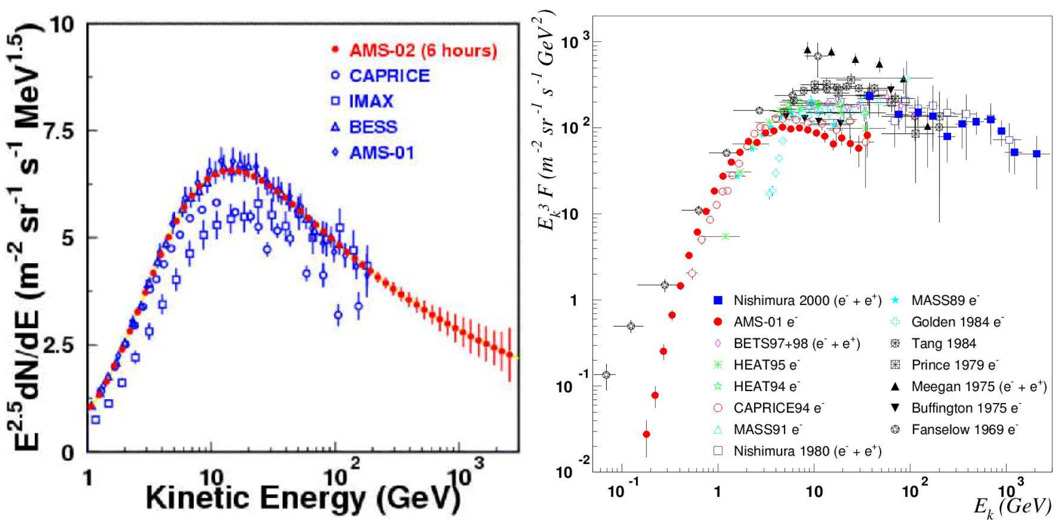

Figure 2. Left plot: example of AMS-02 sensitivity on proton flux after 6 hours of data taking. Right plot: electron flux measurements by different experiments.

4. Secondary cosmic rays

The largest discrepancies between abundances in cosmic rays and in Solar System are observed for the light nuclei as Li, Be and B. This is because light nuclei are easily produced in spallation processes - collisions of primary heavy nuclei with the interstellar gas. Thus, most of the light nuclei present in cosmic rays are of secondary origin. The spectra helps to understand the propagation of cosmic rays in the Galaxy.

One of the most widely used observables is boron-to-carbon ratio [6]. Boron nuclei are exclusively of secondary origin while carbon is mainly from primary production. The ratio gives information about the amount of matter traversed by the cosmic ray, therefore about the confinement volume. On the left plot of Figure 3 the most recent B/C measurements are confronted with the estimated AMS-02 precision after 6 months of data taking. The solid line is an estimation from model [7].

5. Unstable isotopes

Among the unstable isotopes present in cosmic rays, Be^{10} is the lightest having a half-life time comparable with the confinement time of cosmic rays in the Galaxy. The ratio Be^{10}/Be^{9}, where Be^{9} is a stable isotope, can be used to estimate the mean age of the cosmic rays which reach the Earth vicinity. On the right plot of Figure 3 the present measurements are shown and the expected AMS-02 data points are aligned along the line representing model expectations [7].

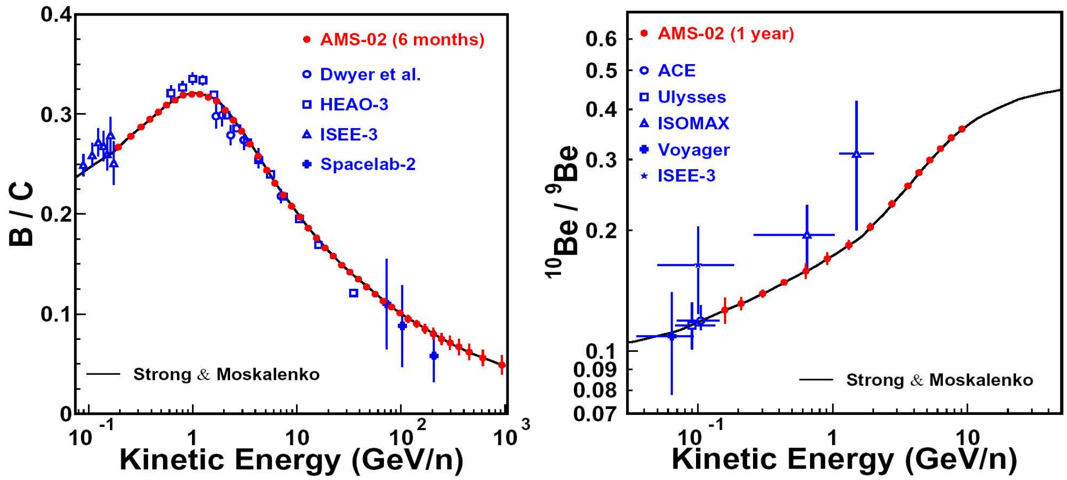

Figure 3. Status of the B/C measurements (left plot) and Be^{10}/Be^{9} measurements compared to the AMS-02 estimations as derived from the Strong-Moskalenko model [7].

6. Conclusions

AMS-02 is a magnetic spectrometer designed for cosmic ray measurement on Earth orbit. Due to its large acceptance and long duration of data taking it will provide precise data on various cosmic ray fluxes. This data will help to constrain models of cosmic ray production, acceleration and propagation.

7. Acknowledgments

We want to thank the many organizations and individuals listed in the acknowledgments of ref [1].

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