Results from the First Five Years of Alpha Magnetic Spectrometer (AMS) Data on the ISS

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ABSTRACT

In 2016, the Alpha Magnetic Spectrometer (AMS) collaboration celebrated the fifth anniversary of AMS on the International Space Station (ISS). In this article, a few examples of the results from the first five years of data are presented and their physics implications are discussed.

INTRODUCTION

The ISS is the largest and most complex project ever flown in space. It has been providing a unique platform to conduct the physics missions of AMS since its installation in May, 2011. AMS is unique in physics research as it studies charged particles and nuclei from original sources in the cosmos before they interact in the Earth' s atmosphere. The improvements in accuracy, compared to previous measurements, have been achieved through AMS's long duration of observation in space, large acceptance, built in redundant system and its calibration at the accelerator beams at CERN. These features enable AMS to analyze cosmic-ray data to an accuracy of ~1% and discover many new phenomena [1-8].

Elementary Particles in Space

There are four elementary particles that are known to be stable and travel through the Galaxy; protons, electrons, positrons and antiprotons. Electrons and positrons have much smaller mass than protons and antiprotons so they lose more energy in the galactic magnetic field.

The precision measurement by AMS of positron fractions to 500 GeV has shown an excess over the expectation from the secondary products due to the collision of cosmic rays with interstellar medium [1,2]. This data generated wide spread interest in the cosmic-ray and particle physics community. Many theoretical models have been discussed to explain the positron excess, including annihilation/decay of dark matter, astrophysical sources and additional secondary productions. Simultaneous measurements of the energy spectra of these four elementary particles can provide a clue in understanding the origin and nature of positrons.

Antiprotons are very rare in cosmic rays. There is only one antiproton in about 10,000 protons. Therefore, a precision experiment requires a background rejection close to 1 in a million. It has taken AMS five years of operations to obtain a clean sample of 349,000 antiprotons [7]. Experimental data on cosmic ray antiprotons are crucial for understanding the origin of antiprotons in the cosmos and for providing insight into new physics phenomena.

Fig. 1 shows the comparison of the energy spectra of four elementary particles above 10 GV in rigidity, where rigidity is defined as the momentum per charge. Surprisingly, above 60 GV, positrons, protons and antiprotons display identical rigidity dependence, but electrons exhibit a totally different energy dependence [3,5,7].

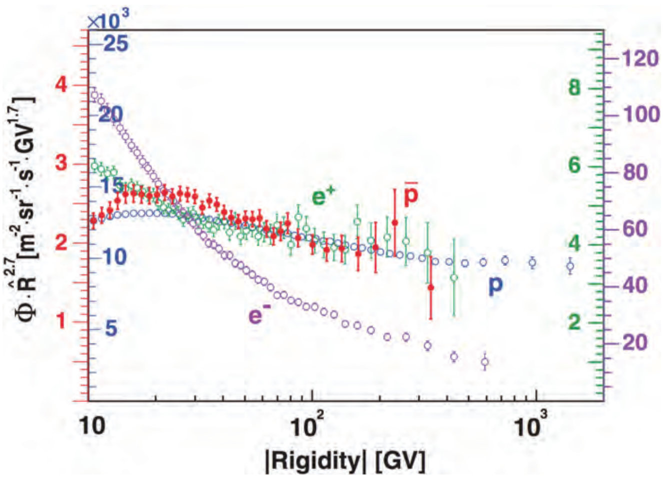

Fig. 1: Comparison of rigidity spectra for four elementary particles; antiprotons (red, left axis), protons (blue, left axis) [5], electrons (purple, right axis), and positrons (green, right axis) [3]. All the fluxes are multiplied by $R^{2.7}$ to show their detailed behaviors.

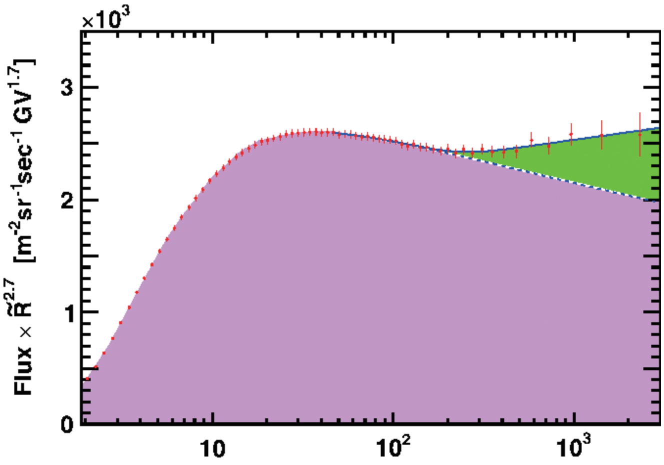

Fig. 2: Helium rigidity spectrum multiplied by $R^{2.7}$. The spectrum deviates from a single power law (purple shaded area) and is well fit with a double power law function (purple and green shaded area) [6].

Cosmic-ray Nuclei

Primary cosmic-ray nuclei such as helium, carbon and oxygen are thought to be accelerated directly from sources in supernova remnants, whereas secondary cosmic-ray nuclei such as lithium, beryllium and boron are produced by the nuclear fragmentation of heavier primary nuclei with the interstellar medium during propagation. Thus, we can extract important information on cosmic rays by measuring both primary and secondary cosmic-ray spectra. The AMS spectrometer contains seven instruments to independently identify different elementary particles as well as nuclei.

Cosmic-ray Helium Spectrum

Helium is the second most abundant cosmic ray. Fig. 2 shows the helium rigidity spectrum. It deviates from a single power law and shows progressive hardening at rigidities larger than 100 GV. It can be well fit with a double power law function;

$$\Phi = C\left(\frac{R}{45GV}\right)^{\gamma}\left[1+\left(\frac{R}{R_0}\right)^{\Delta\gamma/s}\right]^{s}$$

with spectral index from γ for rigidities below the characteristic transition rigidity R0 to $\gamma+\Delta\gamma$ and s to quantify the smoothness of the transition [6]. The magnitude of the helium spectral index is different from that of the proton spectral index, but the rigidity dependence is similar for helium and protons [5,6].

The proton to helium flux ratio spectral index increases with rigidity up to about 45 GV and becomes constant for higher rigidities; i.e., the proton to helium flux ratio is well described by a single power law above 45 GV [6].

Boron to Carbon Ratio

The boron to carbon flux ratio (B/C) directly measures the average amount of interstellar material traversed by cosmic rays. In the propagation models, where cosmic rays are described as a relativistic gas scattering on a magnetized plasma, the B/C ratio is used to constrain the spatial diffusion coefficient D, as the B/C ratio is proportional to $1/D$ at high rigidities R. The diffusion coefficient dependence on rigidity is $D \propto R^{-\delta}$.

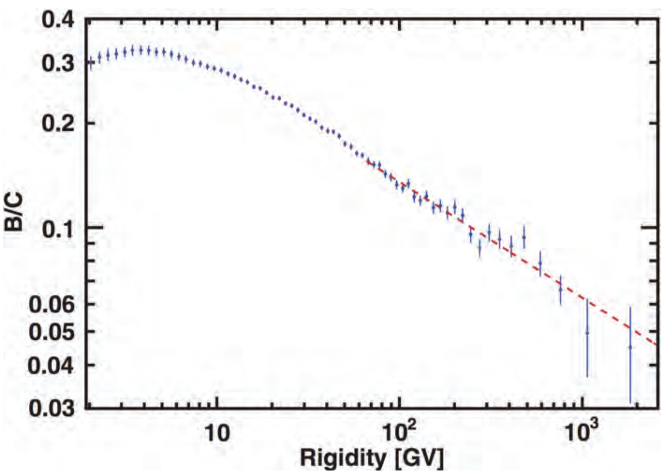

Fig. 3: Boron to carbon ratio (B/C) as a function of rigidity measured by AMS. The dashed line shows a single power law fit above 65 GV with an index of -0.333±0.015 [8].

Fig. 3 shows the B/C ratio as a function of rigidity measured by AMS [8]. The ratio increases with rigidity reaching a maximum at 4 GV, then decreases. The ratio does not show any significant structures and it is well fit with a single power law with an index of -0.333±0.015, which is in good agreement with the Kolmogorov theory of turbulence which predicts -1/3 asymptotically.

More importantly, many theoretical models that explain the positron excess with additional secondary production also require an excess of the B/C ratio over the single power law. These models can be constrained by the precision measurements by AMS of the B/C ratio.

Conclusion

Most of the results by AMS based on over 90 billion cosmic ray events during the first five-years of operation on the ISS are unexpected and provide new insight on particle physics phenomena in the Galaxy. The accuracy and characteristics of the data, simultaneously from many different species of cosmic rays, requires the development of comprehensive models. AMS will continue to collect and analyze data for the life time of the ISS, currently up to 2024.

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