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Precision Measurements of Electron Flux and Positron Flux in Primary Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station

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Precision measurements of the primary cosmic ray positrons and electrons are presented up to 1 TeV using the data sample of 1.9 million positrons and 28.1 million electrons collected by the Alpha Magnetic Spectrometer on the International Space Station. The positron flux and electron flux exhibit distinctly different and complex energy dependence. Both spectra show an excess staring from 30 GeV compared to the low energy trend. The most prominent feature of the positron flux is a sharp drop-off around 300 GeV. This feature is not present in the electron flux. These distinctive properties indicate a new source of high energy electrons and positrons. These experimental data on the behavior of the cosmic ray positrons and electrons at high energies provide unique information on their origin.

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There has been widespread interest and various explanations of the observed excess of high energy positrons [1]. Most of these explanations differ in their predictions for the behavior of cosmic ray positrons at high energies. The observation of distinctive properties of electron and positron fluxes at high energies are crucial for understanding the origin of high energy positrons in the cosmos and for providing insights into new physics phenomena.

We present precision measurements of the positron flux and electron flux up to 1 TeV measured with the Alpha Magnetic Spectrometer (AMS) on the International Space Station (ISS). The measurements are based on 1.9 million positron events and 28.1 million electron events collected by AMS from May 19, 2011 to Nov 26, 2017.

1. Positrons and Electrons measured by AMS-02 Detector

The full description of the AMS detector is presented in Ref. [1] and references therein. The key detector elements used for the present analysis are the transition radiation detector TRD, the time of flight counters TOF, the silicon tracker, the permanent magnet, and the electromagnetic calorimeter ECAL. Together with the magnet, the tracker accurately determines the particle trajectory and measures rigidity R (momentum/charge), and charge sign of cosmic rays. For $|Z| = 1$ particles the maximum detectable rigidity, MDR, is 2 TV over the 3 meters lever arm from L1 to L9. It also measure the particle charge $|Z|$. The TOF measures $|Z|$ and velocity with a resolution of $\Delta\beta/\beta^2 = 4\%$. The TRD separates electron (e^-) and positron (e^+) from protons (p). The ECAL has 17 radiation length. It's 3-dimensional imaging capability allows for an accurate measurement of the $e^\pm$ energy and of the shower shape. The entire detector has been extensively calibrated in a test beam at CERN with measurements in 18 different energies and particles at 2000 positions. A Monte Carlo program based on the GEANT4 10.1 package is used to simulate physics processes and signals in the detector. The combination of information from the TRD, tracker, and ECAL enables the efficient separation of the positron and electron signal events from background events, i.e. protons and charge confusion events, using a template fitting technique [1]. In total, 1.9 million positrons and 28.1 million electrons are identified in the energy range from 0.5 GeV to 1 TeV.

Detailed study of the systematic errors is the key part of the analysis. Systematic uncertainties for the positron flux and electron flux include: template definition, charge confusion determination, efficiency correction, bin-to-bin migration and energy scale. Most importantly, starting from 30 GeV for positron, and from 200 GeV for electorn, statistical error becomes dominating the total error. Therefore by continuing taking data, AMS will be able to improve the accuracy of the measurement and reach into uncharted high energy range.

2. Distinctive Properties of Positron Flux and Electron Flux

The measured positron spectrum (positron flux scaled by E^3) and electron spectrum (electron flux scaled by E^3) including statistical and systematic errors are presented in Figure 1. As seen, the electron spectrum and positron spectrum are different in amplitude and energy behavior. Both spectra show an excess staring from 30 GeV compared to the low energy trend. Importantly, the positron spectrum shows a significant drop-off at 300 GeV. This signals that the positron excess is coming to its end at higher energy. Meanwhile, the same drop-off behavior is not observed in the

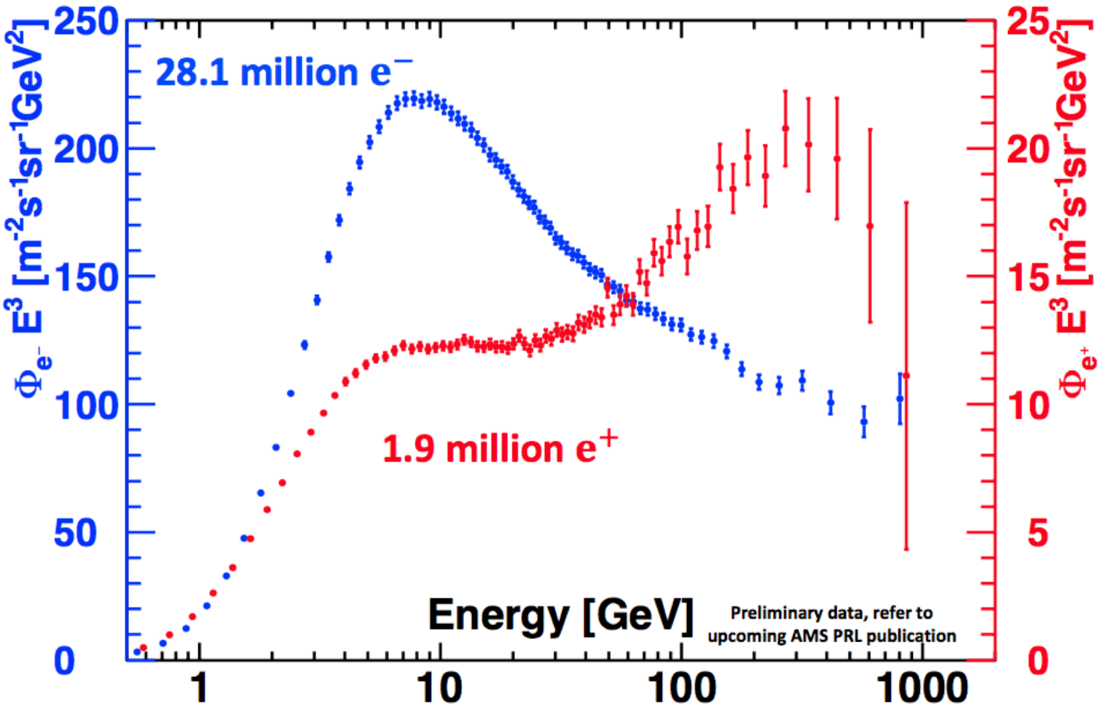

Figure 1: AMS e^+ spectrum and e^- spectrum from 0.5 GeV to 1 TeV. They are different in magnitude and energy dependence. The e^+ spectrum shows a significant drop-off at 300 GeV.

electron spectrum, which indicates that the drop-off of positron spectrum at around 300 GeV is not a propagation effect.

The AMS positron flux by far exceeds the standard prediction from secondary origin produced from collision of cosmic rays with the interstellar gas, this is illustrated in Figure 2(Left). Additional source of positrons is needed to describe the observed positron excess starting from around 30 GeV. Models to explain the excess in positron flux includes 3 classes. The first class is annihilation of Dark Matter particles [2], As illustrated in Figure 2, the AMS positron spectrum is in good agreement with a Dark Matter particle with mass 1.2 TeV on top of the small contribution from positrons of secondary origin. The second class is acceleration of positrons in astrophysical objects like super nova remnants or pulsars [3]. However, it was shown by HAWC collaboration that nearby pulsar is not the source for high energy positrons excess observed by AMS [4]. AMS measurement of the anisotropy of the arrival direction of positrons and electrons will furthur constrain and distinguish Pulsar origin of high energy positrons and electrons. The third class of models require modification of the standard propagation of cosmic-rays [5] and predicts higher flux of secondary cosmic rays, including positrons, from interactions of cosmic ray nuclei with interstellar gas. Many of these predictions are already ruled out by high accuracy B/C flux ratio measrement from AMS[6]. Currently, the observed features of the AMS data cannot be explained by propagation effects.

Comparison of the AMS electron flux with two model predictions is shown in Figure 2(Right). As seen, the AMS electron spectrum disagree with conventional cosmic ray model [7]. High accuracy measurement from AMS provide invaluable input for the understanding of the electron flux in

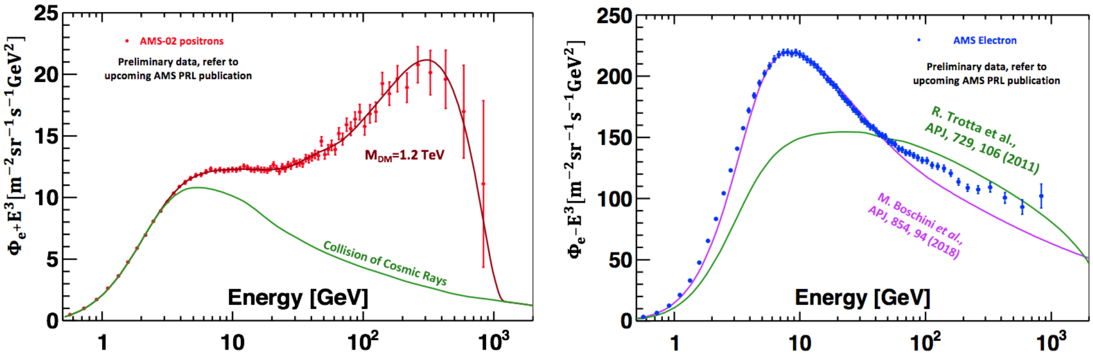

Figure 2: (Left) The AMS positron spectrum is in good agreement with a Dark Matter particle with mass 1.2 TeV on top of the small contribution from positrons of secondary origin. (Right) The AMS electron spectrum also disagree with conventional cosmic ray model expectation.

the galaxy. Recent model [8] taking as input the previous AMS measurement already provide much better description of the electron flux. Intriguingly, it is also worth noting that a primary source of electron identical to that of the positrons is consistent with the electron flux behavior. However, due to modeling uncertainties and significant contribution from conventional primary cosmic ray electron, it is currently not possible to extract source contribution from electron flux alone.

3. Conclusion and Outlooks

Precision measurements of the primary cosmic ray positrons and electrons are presented up to 1 TeV. The positron and electron fluxes exhibit distinctly different and complex energy dependence. Both spectra show an excess staring from 30 GeV compared to the low energy trend. The most prominent feature of the positron flux is a sharp drop-off around 300 GeV. This feature is not present in the electron flux. These distinctive properties indicate a new source of high energy electrons and positrons. AMS will continue the precision measurements on positron flux and electron flux toward higher energy with the goal to determine the origin of high energy positrons.

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