PROCEEDINGS OF SCIENCE

Dark matter signal from e^+ / e^- / $\bar{p}$ with the AMS-02 Detector on the International Space Station

Nikolas Zimmermann[*] **on behalf of the AMS collaboration**
Rheinisch-Westfälische Technische Hochschule (DE)
E-mail: `zimmermann@physik.rwth-aachen.de`

The excess of the antiproton flux and the antiproton-to-proton flux ratio beyond the prediction of the collision of ordinary cosmic rays is a unique signal from dark matter models of neutralino annihilation. This excess cannot come from pulsars. We present precision measurements by AMS-02 of the antiproton flux and the antiproton-to-proton flux ratio in the absolute rigidity range from 1 to 450 GV based on 3.49×10^5 antiproton events and 2.42×10^9 proton events. Comparison of our results with neutralino annihilation model shows good agreement.

We also present the latest results on 16.5×10^6 electron and 1.08×10^6 positron events measured by the Alpha Magnetic Spectrometer on the International Space Station. The measurement covers the energy range up to 1000 GeV. The measured positron flux and the positron fraction are in agreement with a specific dark matter model with a neutralino mass of 1 TeV.

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[*] Speaker.

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We present measurements of the electron flux, the positron flux and the antiproton/proton ratio in primary cosmic rays with the Alpha Magnetic Spectrometer (AMS-02) on the International Space Station (ISS).

AMS-02 is a multi-purpose magnetic spectrometer that was installed on the ISS in May 2011. AMS-02 has measured the electron flux, the positron flux and the antiproton/proton ratio with unprecedented accuracy. Modelling the fluxes and flux ratios simultaneously is a challenge in the field of astrophysics. The issues with a theoretical description will be briefly addressed in these proceedings.

1. The AMS-02 detector

The AMS-02 detector consists of a permanent magnet, nine planes of silicon tracker, a transition radiation detector (TRD), four planes of time-of-flight (TOF) counters, an array of anticoincidence counters, a ring imaging Čerenkov detector (RICH), and an electromagnetic calorimeter (ECAL). AMS operates continuously on the ISS and is monitored and controlled around the clock from the ground. A detailed description of the instrument is found in Ref. [5]. Monte Carlo (MC) simulated events were produced using a dedicated program developed by the collaboration based on the `Geant-4.10.1` package [7]. The program simulates electromagnetic and hadronic interactions of particles in the material of AMS and generates detector responses.

2. Electron/positron flux measurement

The isotropic flux of cosmic ray electrons ϕ_{e^-} and positrons ϕ_{e^+} in energy bins ΔE around energy E is given by

$$\Phi_{e^\pm}(E) = \frac{N_{e^\pm}(E)}{A_{\text{eff}}(E) \cdot \varepsilon_{\text{trig}}(E) \cdot T(E) \cdot \Delta E} \tag{2.1}$$

with the number of electrons N_{e^-} and positrons N_{e^+} in the bin around energy E. The trigger efficiency is denoted by $\varepsilon_{\text{trig}}$, and T is the exposure time. The effective acceptance is defined as

$$A_{\text{eff}} = A_{\text{geom}} \cdot \varepsilon_{\text{sel}} \cdot \varepsilon_{\text{id}} \cdot (1+\delta), \tag{2.2}$$

where ε_{sel} is the selection efficiency and ε_{id} is the identification efficiency for electrons and positrons. The product $A_{\text{geom}} \cdot \varepsilon_{\text{sel}} \cdot \varepsilon_{\text{id}}$ is determined from the MC simulation, and δ is a minor correction derived from comparing each cut between the MC simulation with ISS data in a control sample.

The analysis procedure is identical to the publication [2]. The used data set covers the data from May 2011 to May 2016, almost doubling the statistics that was used for the previous publication, reducing both the statistical and systematic uncertainties. This allows an extension of the energy range of the electron flux up to 1 TeV and up to 700 GeV for the positron flux. In total 16.5×10^6 events were identified as electrons and 1.08×10^6 events as positrons, as shown in Figure 1.

The electron flux and the positron flux are significantly different in their magnitude and energy dependence. The additional data point in the positron flux is lower than the previous data point

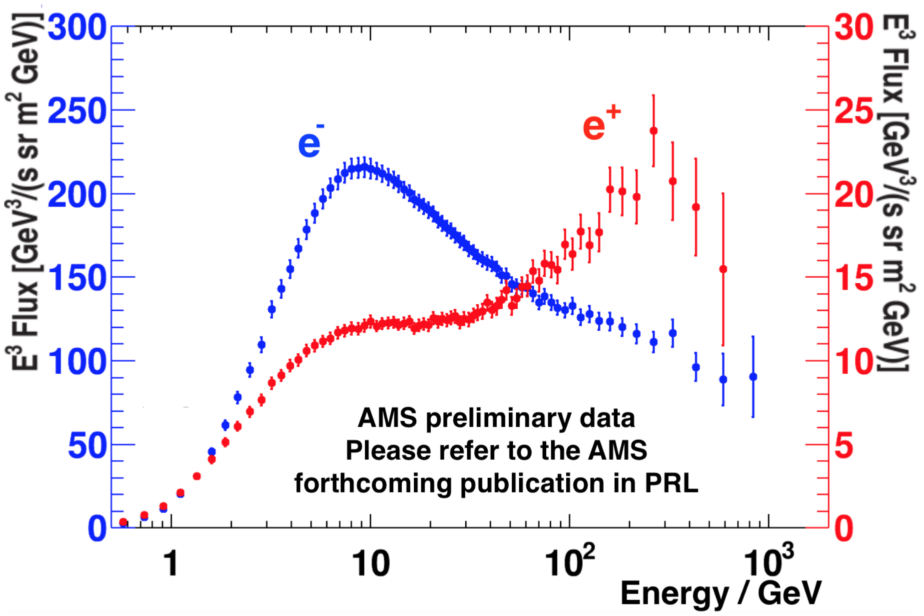

Figure 1: The AMS-02 electron and positron fluxes covering the data taking period from May 2011 to May 2016, multiplied by E^3.

supporting the trend that the positron flux continues to decrease towards higher energies. This is an important observation, making theoretical models unlikely that predict a rise of the positron spectrum towards higher energies.

3. Antiproton/proton ratio measurement

The antiproton flux and antiproton/proton flux ratio analysis is described in Ref. [4]. In total 2.42×10^9 events were identified as protons and 3.49×10^5 events as antiprotons. Figure 2 shows the measurement of the antiproton/proton flux ratio.

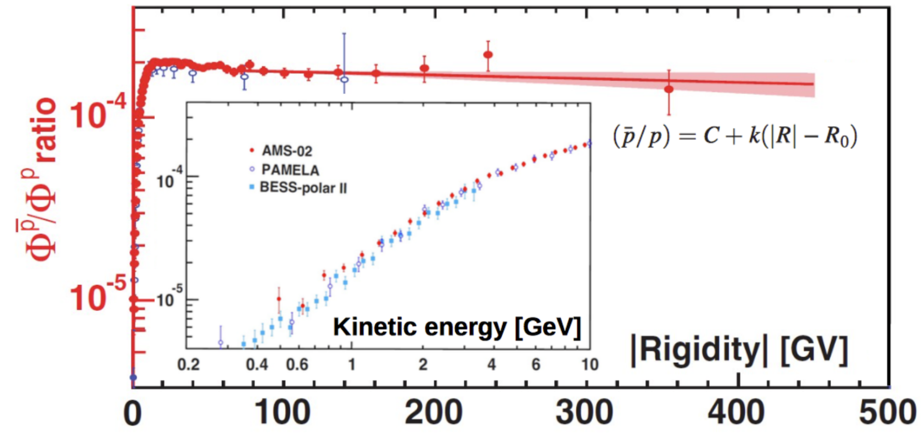

Figure 2: The AMS-02 antiproton / proton ratio [4] covering the data taking period from May 2011 to May 2015. The inlet shows a zoom of the low energy measurement compared to previous measurements.

The antiproton/proton ratio is flat above $\approx 60\,\mathrm{GeV}$ and does not decrease towards higher energies as it was predicted by theoretical models which describe antiprotons as secondary cosmic rays, produced via interactions of primary protons with the interstellar gas. This is an important observation, challenging the most common interpretation of antiprotons being pure secondary cosmic rays.

4. Single charge particle spectra summary

Figure 3 shows a summary of the $|Z| = 1$ measurements performed using AMS-02.

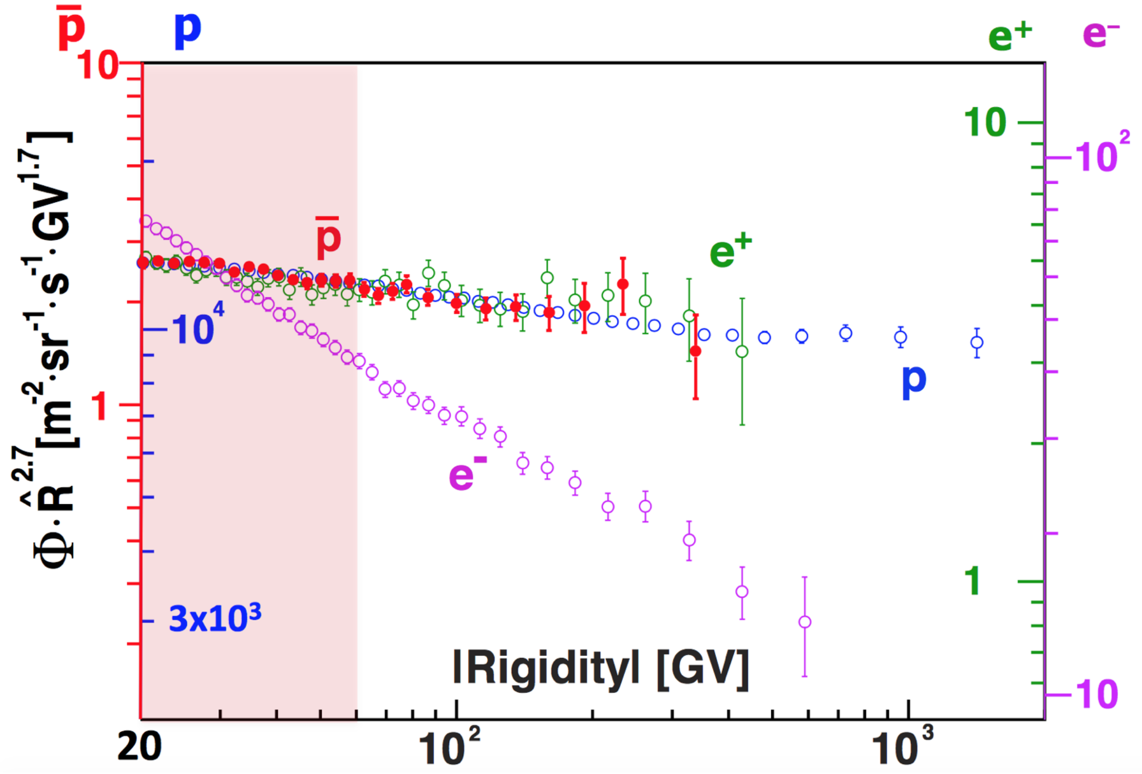

Figure 3: Overview of the published AMS-02 measurements for $|Z| = 1$. In red the antiproton flux [4], in green the positron flux [2], in magenta the electron flux [2] and in blue the proton flux [3] - all as function of rigidity.

In theory electrons and positrons in cosmic rays have different origins. Electrons are believed to be primary cosmic rays - particles accelerated at astrophysical sources such as supernovae, whereas a large fraction of positrons are thought to be secondary particles, produced in the interaction of the primaries with the interstellar gas. Because of this fundamental difference, the rigidity dependence of the electron and positron fluxes should be different, which the AMS-02 measurements clearly support, as shown in Figure 3.

Antiprotons are believed to be pure secondary particles, produced by proton interactions with the interstellar gas. In this scenario, the proton spectrum has already changed its spectral index due to propagation imprinting a different spectral index on the secondary antiprotons compared to the initial primary proton injection spectrum. This implies that the rigidity dependence of the antiproton flux should be different from the proton flux.

Our measurement shows that the proton and antiproton spectra have identical rigidity dependence from ≈ 60 to 500 GeV, whereas the electron spectrum exhibits a totally different behavior, it decreases much more rapidly with increasing energy. Surprisingly both the proton and antiproton flux also share the same rigidity dependence with the positron flux. Positrons have much smaller mass than protons and antiprotons so they lose a lot more energy in the galactic magnetic field due to synchrotron radiation / inverse compton scattering, but still the rigidity dependence of the fluxes are identical. This observation challenges our current understanding of cosmic ray production and propagation.

5. Dark matter interpretation

There has been much interest over the last few decades in understanding the origin and nature of dark matter. In many dark matter models, collisions of dark matter particles produce energy that transforms into ordinary standard model particles, such as positrons and antiprotons. The characteristic signature of a dark matter particle in particle spectra is an increase of the fluxes with energy followed by a sharp drop off at the mass of dark matter particle as well as an isotropic distribution of the arrival directions of the excess positrons and antiprotons.

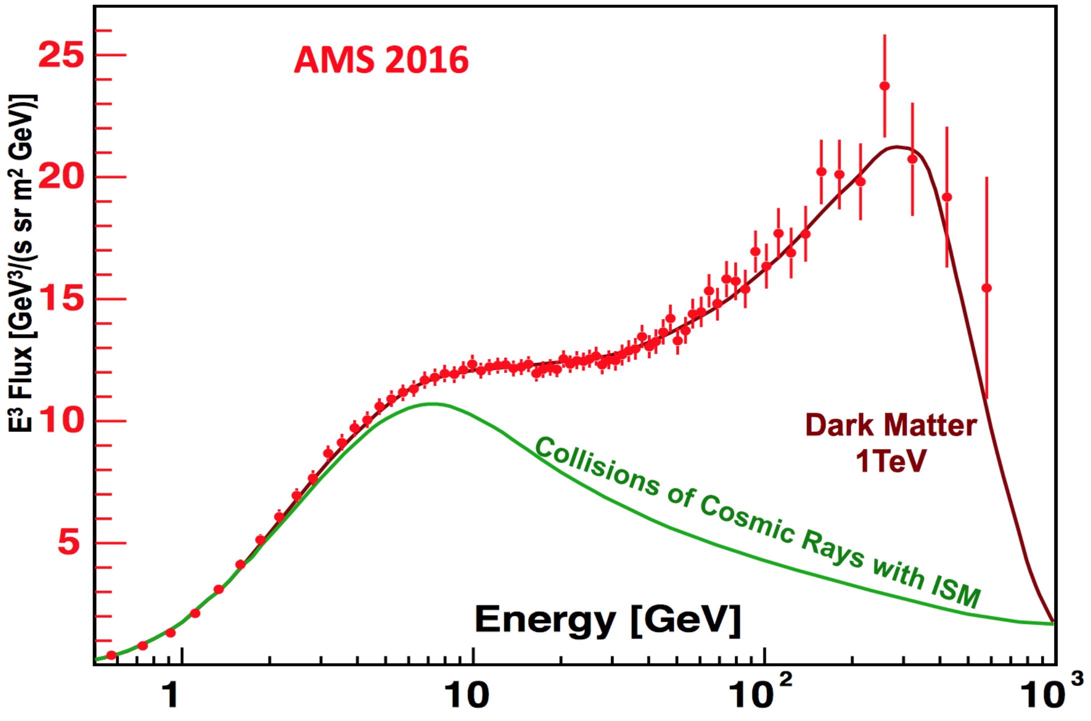

Figure 4: The AMS-02 positron flux measurement compared to a dark matter model [8] and a Galprop [9] simulation using pre-AMS data.

Figure 4 shows the latest results from AMS-02 on the positron flux. As seen from the figure, after rising from 8 GeV above the rate expected from cosmic ray collisions, the spectrum exhibits a sharp drop off at high energies in excellent agreement with the model of Ref. [8] utilizing a dark matter particle with a mass of 1 TeV. On the other hand this dark matter model cannot explain the observed antiproton/proton ratio. An alternative explanation for the positron spectrum is that this rise and drop off may come from ordinary astrophysical phenomena such as pulsars.

While pulsars might be an alternative description for the positron flux, the antiproton excess observed by AMS cannot be easily explained using pulsars. Further theoretical studies need to be carried out to find a suitable description of all elementary fluxes and flux ratios.

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