PROCEEDINGS OF SCIENCE

Unique Properties of Twelve Years Electron and Positron Spectra measured by AMS

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We present the continuous daily electron and positron spectra over 12.5 years from 1 to 42 GV. The detailed time dependence measurements of these fluxes covering the major portion of solar cycle 24 and the first part of solar cycle 25 reveal variations on different timescales and rigidities associated to the solar activity. The simultaneous measurement of the electron and positron fluxes and the comparison with the proton flux over an extended time period offers a unique way to study charge-sign- and mass-dependent solar modulation effects at different timescales and provides critical information to the understanding of the propagation of charged particles in the heliosphere.

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1. Introduction

The fluxes of interstellar charged cosmic rays are thought to be stable on the timescale of decades [1–4]. Time-dependent structures in the energy spectra of galactic cosmic rays are expected from the solar modulation [5] only when they enter the heliosphere. Solar modulation involves convective, diffusive, particle drift, and adiabatic energy change processes. Only particle drift induces a dependence of solar modulation on the particle charge sign [6]. The simultaneous measurement of the electron and positron fluxes and the comparison with the proton flux over an extended time period offers a unique way to study charge-sign- and mass-dependent solar modulation effects at different timescales.

Previously, AMS has reported precision measurements of the daily fluxes of cosmic protons [7] and helium [8] over 9 years, and the daily fluxes of cosmic electrons [9] and positrons [10] over 11 years. We present the preliminary results of the electron and positrons fluxes obtained on 12.5 years covering the major portion of solar cycle 24 and the first part of cycle 25 approaching the maximum of solar activity.

2. AMS detector

The Alpha Magnetic Spectrometer (AMS) experiment is a magnetic spectrometer onboard the International Space Station (ISS) designed to provide precision measurements of charged cosmic rays of energies ranging from GeV up to a few TeV. AMS was installed on May 19, 2011 onboard the ISS and has taken data steadily since then. AMS has collected more than 240 billion galactic cosmic rays in a long-term mission that will continue during the ISS lifetime beyond 2030.

A detailed description of the AMS detector and its performances can be found in [11]. The main elements of AMS are the permanent magnet, the silicon tracker, four planes of time of flight scintillation counters, the array of anticoincidence counters, a transition radiation detector, a ring imaging Cherenkov detector, and an electromagnetic calorimeter.

Due to its capability to perform precision and redundant measurements, excellent particle identification including matter-antimatter separation, large acceptance and long-duration data taking in space, AMS is a unique experiment to perform accurate measurements of elementary particles and antiparticles in the cosmic rays.

3. Temporal Evolution of Electron Fluxes

We present the precision measurements of daily cosmic electron fluxes in the rigidity interval from 1.00 to 41.9 GV based on 2.4×10^8 electrons collected by AMS during the first 12.5 years of operation.

Figure 1 shows the daily electron fluxes, Φ_{e^-}, and the daily proton fluxes, Φ_p, for four rigidity bins from 1.00 to 11.0 GV measured from May 2011 to November 2023 [1]. As seen, Φ_{e^-} exhibits both short-term variations on the scale of days to months and long-term variations on the scale of years, and the relative magnitude of these variations decreases with increasing rigidity. The time-dependent behavior of the Φ_{e^-} and Φ_p is distinctly different, and the differences decrease

[1]The Φ_p measurements correspond to the 12.5-year extension of the previous AMS publication [7].

with increasing rigidity. From 2011 to 2014, Φ_{e^-} decreases faster with time than Φ_p. From 2015 to mid-2017, Φ_{e^-} increase more slowly than Φ_p below about 4 GV [Figs. 1(a) and 1(b)]. From mid-2020 to 2021, Φ_{e^-} decreases faster than Φ_p.

The new data collected since the previous AMS publication [9], covering the 2-year period from November 2021 to November 2023, show a fast decrease of Φ_{e^-} and Φ_p, which reach their minimum over the 12.5 years of operation coinciding with the maximum of solar activity in the current solar cycle.

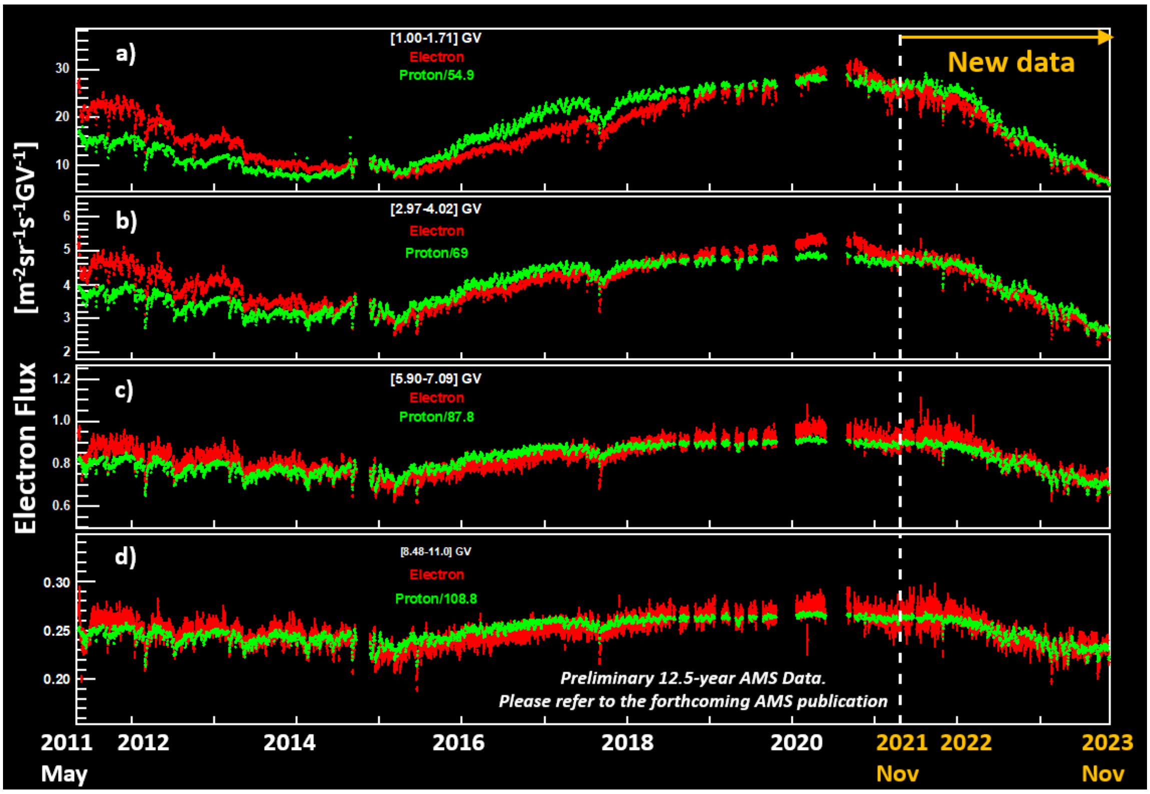

Figure 1: AMS daily electron fluxes, Φ_{e^-}, and daily proton fluxes, Φ_p, in units of [$m^{-2}sr^{-1}s^{-1}GV^{-1}$] for four rigidity bins from 1.00 to 11.0 GV measured from May 2011 to November 2023. The vertical dashed line indicates the new data period added since the latest AMS publication [9]. *[These are preliminary 12.5-year AMS data. Please refer to the forthcoming AMS publication for the final figures.]*

The detailed study of the temporal structures of the electron flux [9] shows that electron fluxes exhibit distinctly different time variations from the proton fluxes. The recurrent electron flux variations with periods of 27 days, 13.5 days, and 9 days are observed. The strength of all three periods of electron fluxes shows different rigidity and time dependence compared to protons. Remarkably, a significant hysteresis between the electron flux and the proton flux is observed at rigidities below 8.5 GV. Furthermore, structures in the electron-proton hysteresis are observed, corresponding to sharp variations in the fluxes likely caused by a series of interplanetary coronal mass ejections [12]. The clear deviation from the long-term trend implies a charge-sign-dependent modulation during those solar transients on the timescale of several Bartels rotations (BR: 27 days).

4. Temporal Evolution of Positron Fluxes

We present the precision measurements of daily cosmic positron fluxes in the rigidity range from 1.00 to 41.9 GV based on 4.0×10^6 positrons collected by AMS during the first 12.5 years.

Figure 2 shows the daily positron flux, Φ_{e^+}, in the rigidity range from 1.00 to 1.71 GV, measured from May 2011 to November 2023, together with (a) the daily electron flux, Φ_{e^-}, and (b) the daily proton flux, Φ_p, both measured by AMS in the same rigidity range and time period. As seen, Φ_{e^+} exhibits short-term variations on the scale of days to months, and long-term variations on the scale of years. Figure 2(a) shows that the long-term evolution of positron and electron fluxes is clearly different. On the contrary, Fig. 2(b) shows that positron and proton fluxes present a similar behavior over time.

The new data from November 2021 to November 2023 in Fig.2 show a fast decrease of Φ_{e^+}, which reaches its minimum over the 12.5 years of operation. The relative decrease of Φ_{e^+} is similar to the decrease observed in Φ_p and distinctly different from the evolution of Φ_{e^-} over this period.

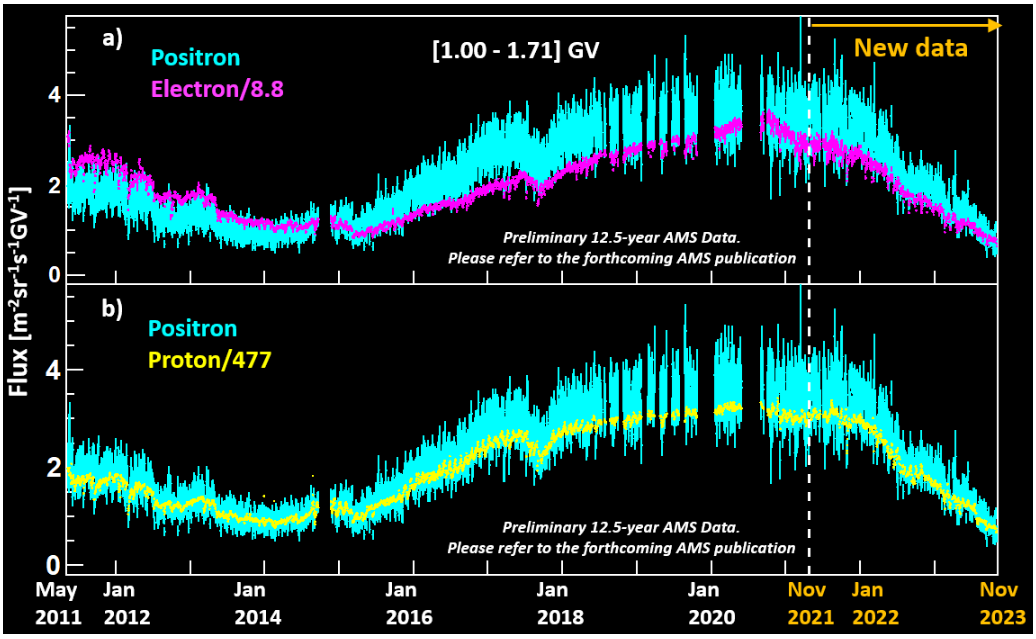

Figure 2: The daily positron fluxes, Φ_{e^+}, (light blue points) measured over the entire period for the rigidity range from 1.00 to 1.71 GV together with (a) the daily electron fluxes, Φ_{e^-}, (magenta points), and (b) the daily proton fluxes, Φ_p, (yellow points). Fluxes are in units of [$\text{m}^{-2}\text{sr}^{-1}\text{s}^{-1}\text{GV}^{-1}$]. The vertical dashed line indicates the new data period added since the latest AMS publication [10]. *[These are preliminary 12.5-year AMS data. Please refer to the forthcoming AMS publication for the final figures.]*

The detailed study of the temporal structures of the positron flux [10] shows that the positron fluxes exhibit distinctly different time variations from the electron fluxes at different time scales. A hysteresis between the electron flux and the positron flux is observed at rigidities below 8.5 GV, and structures in the electron-positron hysteresis are observed corresponding to sharp variations of both fluxes. On the contrary, positron and proton fluxes show nearly identical time variation. Remarkably, positron fluxes are more modulated than proton fluxes for rigidities below 7 GV.

5. Hysteresis in Electron and Positron Fluxes

To investigate in more detail the differences in the long-term modulation of electron and positron fluxes, figures 3(a,b) show the correlation of Φ_{e^-} and Φ_{e^+} with Φ_p in the rigidity range from 1.00 to 1.71 GV during 12.5 years calculated with a moving average of 14 BRs with a step of 1 day. Different colors indicate different years from 2011 to 2023.

In Fig. 3(a), the hysteresis between Φ_{e^-} and Φ_p is clearly observed; that is, from 2011 to 2018 at a given electron flux, the proton flux shows two distinct branches with time, one before 2014–2015 and one after. Both electron and proton fluxes peak in 2020, after which the hysteresis curve starts to trace the earlier behavior backwards. Remarkably, the new data after 2021 showing the fast decrease of both fluxes confirm this behavior, which is consistent with the differences in electron and proton modulation being symmetric with respect to the minimum solar modulation. On the contrary, as seen in Fig. 3(b), there is a nearly linear correlation between Φ_{e^+} and Φ_p in the entire time period. In particular, the new data after 2021 provide a striking confirmation of the linear correlation over the complete range of variation of the positron and proton fluxes.

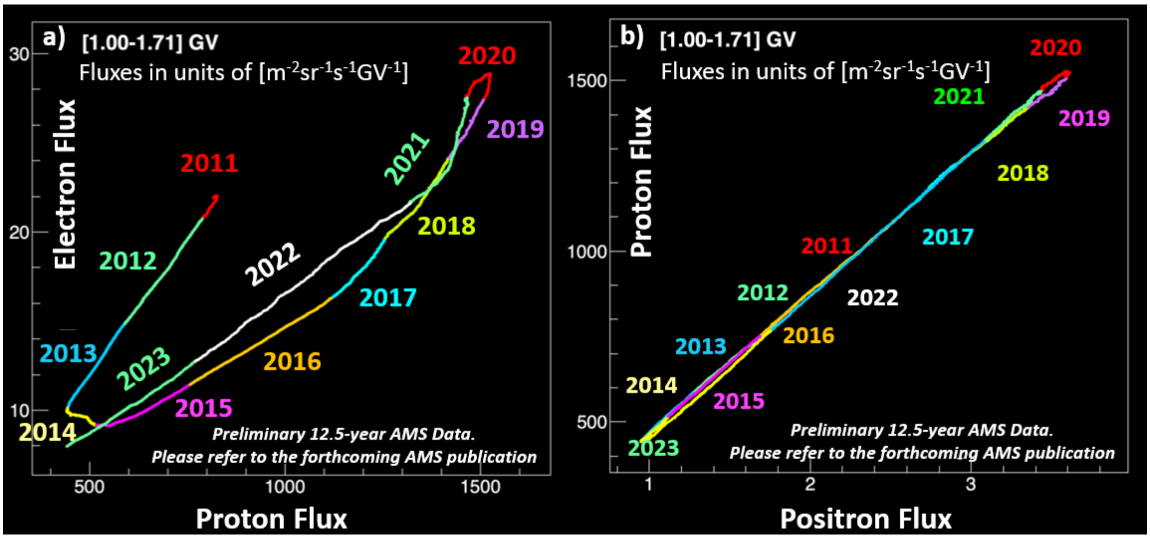

Figure 3: In the rigidity range from 1.00 to 1.71 GV, (a) electron flux, Φ_{e^-}, versus proton flux, Φ_p, and (b) proton flux, Φ_p, versus positron flux, Φ_{e^+} calculated with a moving average of 14 BRs and a step of 3 days. Fluxes are in units of [$\mathrm{m^{-2}sr^{-1}s^{-1}GV^{-1}}$]. Different colors indicate different years. *[These are preliminary 12.5-year AMS data. Please refer to the forthcoming AMS publication for the final figures.]*

6. Conclusions

The measurement of the daily electron and positron fluxes by AMS in the rigidity interval from 1 to 42 GV spanning over 12.5 years have been presented. The set of data covers the major portion of solar cycle 24 and the first part of solar cycle 25 approaching its maximum. The electron and positron fluxes exhibit distinctly different time variations at short and long timescales. Remarkably, the latest AMS data covering the 2-year period from November 2021 to November 2023 provide a precise confirmation the complex hysteresis between the electron flux and the positron flux and the nearly identical time variation of positron and proton fluxes over the complete time period. These continuous daily data and their comparison with the proton flux offer a unique input to study charge-sign- and mass-dependent solar modulation effects at different timescales and provides critical information to the understanding of the propagation of charged particles in the heliosphere.

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