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Precision measurements of $e^+ e^-$ in Cosmic Ray with the Alpha Magnetic Spectrometer on the ISS

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ABSTRACT

One hundred years after their discovery by Victor Hess, Cosmic Rays are nowadays subject of intense research from space based detectors, able to perform for the first time high precision measurement of their composition and spectra as well as of isotropy and time variability. On May 2011, the Alpha Magnetic Spectrometer (AMS-02), has been installed on the International Space Station, to measure with high accuracy the Cosmic Rays properties searching for rare events which could be indication of the nature of Dark Matter or presence of nuclear Antimatter. AMS-02 is the result of nearly two decades of effort of an international collaboration, to design and build a state of the art detector capable to perform high precision Cosmic Rays measurement. In this paper I will briefly report on the first results of AMS-02 two years after the beginning of the operations in space.

1. The AMS-02 detector on the ISS

The Alpha Magnetic Spectrometer, AMS-02, is a general purpose high energy particle physics detector. It was installed on the International Space Station (ISS), on 19 May 2011 (Fig. 1) to conduct a unique long duration mission (~20 years) of fundamental physics research in space.

The layout of the AMS-02 detector is shown in Fig. 2 presenting the event display of a 369 GeV positron recorded by AMS. It consists of nine planes of precision Silicon Tracker, a Transition Radiation Detector (TRD), four planes of Time of Flight counters (ToF), a permanent magnet, an array of AntiCoincidence Counters (ACC) surrounding the inner tracker, a Ring imaging Cherenkov detector (RICH), and an Electromagnetic Calorimeter (ECAL).

The TRD is designed to use transition radiation to distinguish between electrons and protons, and dE/dx to independently identify nuclei. It consists of 5248 proportional tubes of 6 mm diameter with a maximum length of 2 m arranged side by side in 16-tube modules. The 328 modules are mounted in 20 layers. Each layer is interleaved with a 20 mm thick fiber fleece radiator (LRP375) with a density of 0.06 g/cm^3. There are 12 layers of proportional tubes along the y axis located in the middle of the TRD and, along the x axis, four layers located on top and four on the bottom. The tubes are filled with a 90:10 Xe:CO_2 mixture. In order to differentiate between electron and protons, signals from all the TRD layers are combined in a log-likelihood probability of the electron (TRD-LL$_e$) or proton (TRD-LL$_p$) hypothesis. The ratio of these probabilities has been used in the AMS-02 positron fraction as e/p discriminator.

The Silicon Tracker measures the particle rigidity ($R = p/Z$), its charge sign and evaluates the absolute charge magnitude (Z). Rigidity and sign are derived from the measurement of the curvature of the particle in the 1.4 kG AMS magnetic field. Particle trajectory is determined by the coordinate measurement along the 9 layers (L1, ..., L9) of 300 μm thick double-side micro-strip Silicon sensors. With a spatial resolution of about 7 μm ($2 < Z < 6$) and a maximum lever arm of about 3 m for $Z > 1$, the maximum detectable rigidity (MDR), i.e. R corresponding to $\Delta R/R = 100\%$, is estimated to be around 3 TV. Each Tracker layer delivers an estimation of the particle charge magnitude from the energy deposition measurement ($\propto Z^2$) in a wide charge range $1 < Z < 26$. The 7 independent measurement of charge in the Inner tracker (from L2 to L8) can be combined together achieving a charge resolution of 0.12 charge units (c.u.) for Carbon.

Two planes of TOF counters are located above and two planes below the magnet. Each plane contains eight or ten scintillating paddles. Each paddle is equipped with two or three photomultiplier tubes on each end for efficient detection of traversing particles. The average time resolution of each counter has been measured to be 160 ps, and the overall velocity ($\beta = v/c$) resolution of the system has been measured to be 4% for $\beta = 1$,

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1 For the complete list of the AMS Collaboration see Ref. [1].

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2212-6864/

Fig. 1. The Alpha Magnetic Spectrometer installed on the ISS.

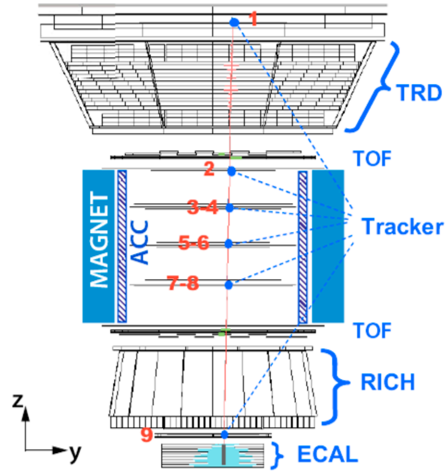

Fig. 2. A 369 GeV positron event as measured by the AMS detector on the ISS in the (y–z) plane. Tracker planes 1–9 measure the particle charge (+1) and momentum. The TRD identifies the particle as an electron/positron. The ToF measures the charge and ensures that the particle is downward-going. The RICH measures the charge and velocity. The ECAL independently identifies the particles an electron/positron and measures its energy.

$Z = 1$ particles. The ToF also discriminates between downward and upward-going particles. The coincidence of signals from all four ToF planes provides the charged particle trigger.

The ECAL consists of a multilayer sandwich of lead and scintillating fibers with an active area of 648×648 mm^2 and a thickness of 166.5 mm corresponding to 17 radiation lengths. The calorimeter is composed of nine superlayers, each 18.5 mm thick. In each superlayer, the fibers run in one direction only. The 3D imaging capability of the detector is obtained by stacking alternate superlayers with fibers parallel to the x and y axes (five and four superlayers, respectively). The fibers are read out on one end by 1296 photosensors with a linearity of 1/105 per sensor. Signals from three superlayers in y view (superlayers 2, 4, 6) and in x view (superlayers 1, 3, 5) are used in the trigger logic to select events with a shower in the calorimeter.

In the measurement of electrons and positron particles, the ToF detector is used to select $Z = 1$ relativistic particles traversing the AMS-02 in the downward direction with respect the AMS-02 reference system. The different characteristics of the signal released by protons, nuclei and electrons in the TRD and ECAL detectors are used to identify the electron component. A track reconstructed at least in the inner tracker (planes 2 to 8) and matching the TRD and ECAL signals is used to select clean $Z = 1$ events in the apparatus. Specific calibration procedures of all sub-detectors have been developed in order to guarantee the stability of the AMS-02 performances over time and no significant degradation of the apparatus has been observed during two years of operation in space.

2. Precision $e^+ e^-$ physics with AMS

2.1. Positron to electron ratio

The AMS experiment collects about 1.5 billion Cosmic Ray during each month of operation. Results reported so far are based on the data collected during the initial 18 months of operations on the ISS, from 19 May 2011 to 10 December 2012. This constitutes 8% of the expected AMS data sample.

The first results published by the AMS Collaboration has been the precision measurement of the positron ratio from 0.5 to 350 GeV of energy [1]. The measured positron fraction is presented in Fig. 3 as a function of the reconstructed energy at the top of the AMS detector. As seen in the figure, below 10 GeV the positron fraction decreases with increasing energy as expected from the secondary production of cosmic rays by collision with the interstellar medium.

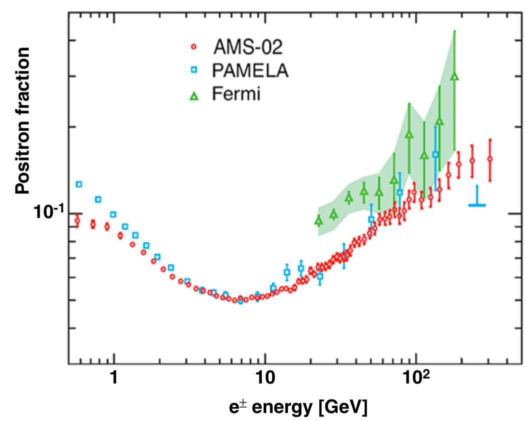

Fig. 3. The positron fraction compared with the most recent measurements from PAMELA [7] and Fermi-LAT [8]. The error bars for AMS are the quadratic sum of the statistical and systematic uncertainties and the horizontal positions are the centers of each bin.

The positron fraction is steadily increasing from 10 to ~250 GeV. This is not consistent with only the secondary production of positrons [2]. The behavior above 250 GeV will become more transparent with more statistics which will also allow improved treatment of the systematic.

The observation of the positron fraction increase with energy has been reported by earlier experiments: TS93 [3], Wizard/CAPRICE [4], HEAT [5], AMS-01 [6], PAMELA [7] and Fermi-LAT [8]. The most recent results are presented in Fig. 3 for comparison. The accuracy of AMS-02 and high statistics available enable the reported AMS-02 positron fraction spectrum to be clearly distinct from earlier work (see Fig. 4). The AMS-02 positron ratio spectrum has the unique accuracy and energy range to provide accurate information on new phenomena.

The accuracy of the data enables us to investigate the properties of the positron fraction with different models. We did compare our data with a minimal model, as an example. In this model the e^+ and e^- fluxes, Φ_{e+} and Φ_{e-}, are parameterized as the sum of individual diffuse power law spectra and the contribution of a single common source of $e^\pm$

$$\Phi_{e+} = C_{e+}E^{-\gamma_{e+}} + C_s E^{-\gamma_s} e^{-E/Es}; \quad (1)$$

$$\Phi_{e-} = C_{e-}E^{-\gamma_{e-}} + C_s E^{-\gamma_s} e^{-E/Es}, \quad (2)$$