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RECENT RESULTS FROM THE AMS-02 EXPERIMENT IN SPACE

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Abstract. The AMS-02 detector is a large acceptance magnetic spectrometer operating onboard the International Space Station since May 2011. The main goals of the detector are the search for antimatter and dark matter in space, and the measurement of cosmic rays composition and flux. The first publication of the AMS-02 Collaboration is a precision measurement of the positron fraction in primary cosmic rays in the energy range from 0.5 to 350 GeV, based on more than 6 million positron and electron detected events. AMS data confirm that the positron fraction is steadily raising from 10 to 250 GeV but, from 20 to 250 GeV, the slope decreases by an order of magnitude. Moreover, no anisotropy is observed on the positron fraction. In the present document, an overview of the AMS-02 detector will be given, the detection techniques of electrons and positrons in cosmic rays will be discussed, and the measurement of the positron fraction will be described.

Keywords: astroparticle, cosmic rays, positron fraction, AMS-02

1 Introduction

The Alpha Magnetic Spectrometer is a general purpose particle physics detector, operating in space since May 2011. It will achieve a unique long duration mission of about 20 years, aiming at performing antimatter and dark matter searches, as well as cosmic ray composition and fluxes measurements. The AMS detector is composed of several sub-detectors, as it can be seen in figure 1-left. The experiment is installed onboard the International Space Station (ISS), that follows a Low Earth Orbit at about 400 km altitude with respect to the Earth surface, well located to detect cosmic particles before they interact with the outer layers of the atmosphere. This makes the ISS one the most interesting environment to perform cosmic rays studies. AMS being a space-born detector, the data acquisition parameters change as a function of the detector position with respect to Earth, as it is shown in figure 1-right: the average trigger rate is 700 Hz, however several kHz are detected at the Poles and in the South Atlantic Anomaly, due to different geomagnetic cutoff values.

2 Measurement of the positron fraction with AMS-02

Electrons and positrons represent only a tiny fraction of the cosmic radiation reaching the Earth's atmosphere, however the understanding of their origin and production mechanisms is one of the hottest topics in astroparticle physics, especially because these particles are sensitive observables in the context of the indirect search for dark matter annihilation in our Galaxy. Due to their low mass, electrons and positrons experience severe energy losses during their propagation, so that their observation horizon is limited to few hundreds of pc: for this reason the study of these particles can let us explore the sources of cosmic rays in our Galaxy.
The first publication of the AMS-02 Collaboration is a precision measurement of the positron fraction, i.e. the ratio between the positron flux and the all-electron flux (electrons and positrons). The positron fraction is expected to be a decreasing function of energy, if positrons are only secondary particles, produced in the primary cosmic rays interactions with the interstellar medium. However, previous measurements [Adriani (2009)] [Ackermann (2009)] showed that above 10 GeV the positron fraction is not consistent with expectations from pure secondary origin, implying that a nearby source of positrons could be *hidden* in our Galaxy. The results reported in this proceedings are based on the data collected during the first 18 months of operation,

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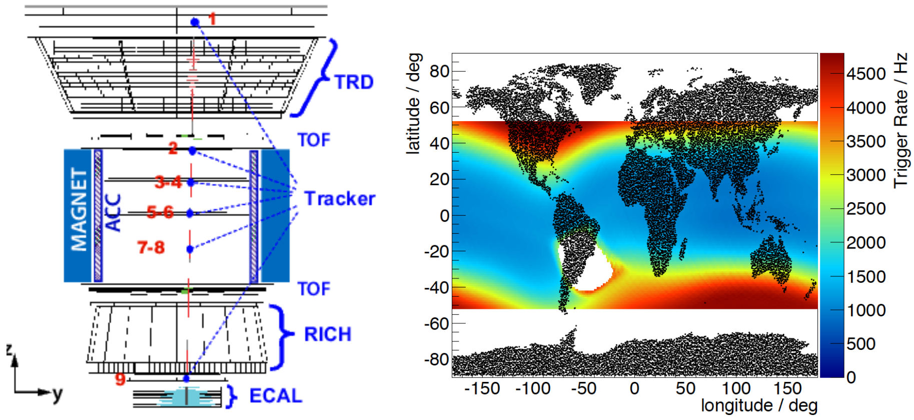

Fig. 1. Left: A 369 GeV positron event as measured by the AMS detector on the ISS, in the (y-z) plane. Tracker planes 1-9 measure the particle charge and momentum [Delgado (2013)]. The Transition Radiation Detector (TRD) [Gast (2013)] identifies the particle as an electron/positron. The Time of Flight (TOF) [Quadrani (2013)] measures the charge and ensures that the particle is downward-going. The Ring Imaging CHerenkov detector (RICH) [Giovacchini (2013)] measures the charge and velocity. The Electromagnetic Calorimeter (ECAL) [Adloff (2013)] independently identifies the particle as an electron/positron and measures its energy. A permanent magnet provides a magnetic field of about 0.15 T. **Right**: Trigger rate as a function of orbital position. Variations are correlated with the geomagnetic cutoff rigidity.

corresponding to about 8% of the total expected AMS data sample, presented in [Aguilar (2013)].

The key of success for the detection of electrons and positrons relies on three factors: the detector high acceptance and the long duration of the AMS mission, the excellent energy resolution of the calorimeter [Adloff (2013)], parametrized as $\sigma(E)/E = \frac{10.4\pm0.2\%}{\sqrt{E[GeV]}} \oplus (1.4\pm0.1)\%$, and a very good background rejection. The main sources of background for this search come from lepton-hadron misidentification (protons identified as positrons) and from the charge confusion (electrons identified as positrons). This latter has two different sources. The first come from the finite resolution of the tracker and multiple scattering, and it is reduced by applying the requirement on the energy-momentum match as well as on the tracker track quality parameter. The second source of charge confusion is related to the production of secondary particles along the track of the primary electron (positron) in the tracker and it is reduced by requiring, for a given particle, a geometric match between the tracker track and the electromagnetic shower in the calorimeter. Both sources of charge confusion are found to be well reproduced in the Monte Carlo simulation. As an example, in the 82-100 GeV bin, the uncertainty on the number of positrons due to charge confusion is 1 %.

The main challenge for this kind of measurement comes from the fact that the data sample is dominated by the background, protons, that is $10^{3\div4}$ more abundant than signal (positrons). Three sub-detectors are used for signal identification and background rejection, namely the tracker, the transition radiation detector (TRD) and the electromagnetic calorimeter (ECAL). For the positron fraction measurement, the tracker is used to identify the sign of the charge, together with the absolute charge.

The TRD can distinguish between electrons (positrons) and protons by detecting the transition radiation, and independently identify nuclei by measuring dE/dx. Signals from 20 layers are combined in a TRD estimator formed from the log-likelihood probability of the electron (positron) hypothesis to the proton hypothesis. Using the TRD a rejection factor of $10^{3\div4}$ at 90% signal efficiency is achieved, as shown in figure 2a.

The electromagnetic calorimeter is an imaging detector, made of 98 lead foils and 50000 scintillating fibers, corresponding to 17 radiation lengths. The 3-dimensional capabilities of the detector are obtained by stacking alternate superlayers with fibers parallel to the x and y axis. An ECAL estimator, based on the a Bosted Decision Tree algorithm, has been developed to identify electrons (positrons) and to reject protons. The background rejection power of the ECAL estimator, when combined to the energy/momentum matching requirement, reaches about 10^4, as shown in figure 2b. A proton rejection of 10^6 can be reached by combining the three independent detectors.

Signal events are identified by requiring a track in the TRD and in the tracker, a shower in the ECAL and a measured velocity in the TOF $\beta \simeq 1$, consistent with a down-going particle of charge one. In order to reject secondary electrons and positrons produced in the interaction of primary cosmic rays with the Earth atmosphere,

the energy measured with the ECAL is required to exceed by a factor of 1.2 the maximal Stoermer cutoff for either a positive or a negative particle at the geomagnetic location where the particle was detected.
The selection efficiency for electrons and positrons is about 90% in the acceptance of the ECAL: after the selection is applied, the remaining sample is composed of about 7 million primary electrons and positrons, and 700000 protons. The positron fraction is measured as a function of the ECAL energy, the binning being chosen according to the ECAL energy resolution. The number of signal events versus energy is determined using the TRD estimator as well as the energy-momentum matching. For every energy bin, the 2-dimensional reference spectrum for signal and background are fitted to data. The fit is performed separately to positive and negative momenta, providing the number of positrons and electrons respectively.

2.1 Results

The measured positron fraction is shown in figure 2-right, as a function of the energy measured by the ECAL. AMS data confirm the results from previous experiments [Adriani (2009)] [Ackermann (2009)], with high precision: below 10 GeV the positron fraction decreases with increasing energy, as expected if electrons and positrons are produced in the interaction of primary cosmic rays with the interstellar medium. From 10 to 250 GeV the

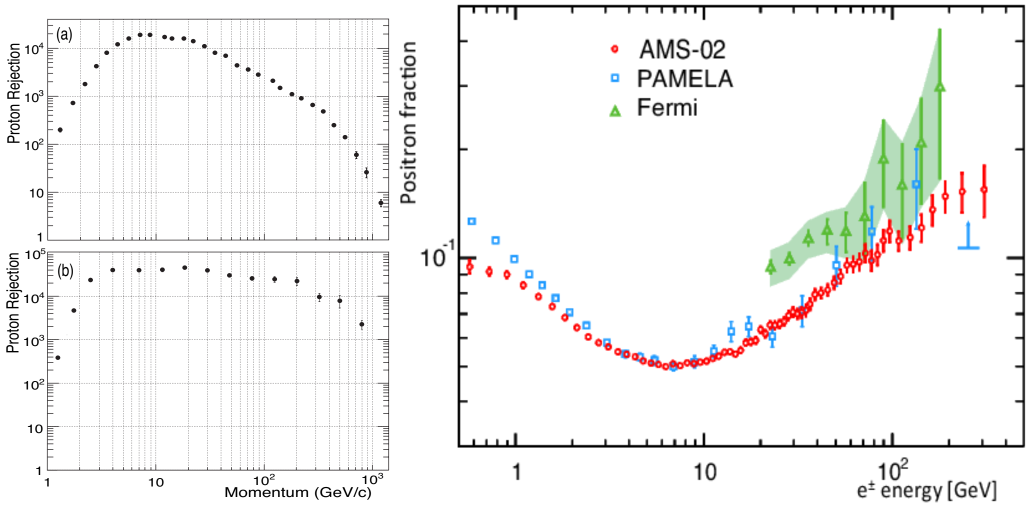

Fig. 2. Left: (a) the proton rejection measured by the TRD as a function of the tracker momentum, at 90% selection efficiency for e±. (b) the proton rejection measured by ECAL and the tracker, for 90% efficiency on the signal. **Right**: The positron fraction from AMS-02 [Aguilar (2013)], compared to the results of PAMELA[Adriani (2009)] and Fermi[Ackermann (2009)].

positron fraction is steadily increasing, in contrast with the pure secondary origin of positrons. AMS data are in good agreement with PAMELA data above 10 GeV, where the effects of the Solar Modulation start to be negligible. The slope of the positron fraction versus energy decreases by an order of magnitude from 20 to 250 GeV and no fine structure is observed.

2.2 Model for the interpretation of AMS data

To fit AMS data, the e^+ and e^- fluxes, Φ_{e^+} and Φ_{e^-}, have been parametrized as the sum of individual diffuse power law spectra and the contribution of a single common source of $e^\pm$:

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}; \tag{2.1}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}, \tag{2.2}$$

(with E in GeV) where the coefficients C_{e^+} and C_{e^-} correspond to relative weights of diffuse spectra for positrons and electrons, and C_s to the weight of the source spectrum; γ_{e^+}, γ_{e^-} and γ_s are the corresponding spectral indexes; and E_s is a characteristic cutoff energy for the source spectrum. With this parametrization the positron fraction depends on 5 parameters. A fit to the data in the energy range 1 to 350 GeV based on the number of events in each bin yields a $\chi^2/d.f. = 28.5/57$ and $\gamma_{e^-} - \gamma_{e^+} = -0.63 \pm 0.03$, *i.e.*, the diffuse positron spectrum is softer, that is, less energetic with increasing energy, than the diffuse electron spectrum; $\gamma_{e^-} - \gamma_s = 0.66 \pm 0.05$, *i.e.*, the source spectrum is harder than the diffuse electron spectrum; $C_{e^+}/C_{e^-} = 0.091 \pm 0.001$, *i.e.*, the weight of the diffuse positron flux amounts to ~10 % of that of the diffuse electron flux; $C_s/C_{e^-} = 0.0078 \pm 0.0012$, *i.e.*, the weight of the common source constitutes only ~1 % of that of the diffuse electron flux; $1/E_s = 0.0013 \pm 0.0007\,\mathrm{GeV}^{-1}$, corresponding to a source cutoff energy of $760^{+1,000}_{-280}$ GeV. The fit is shown in Figure 3 as a solid curve. The agreement between the data and the model

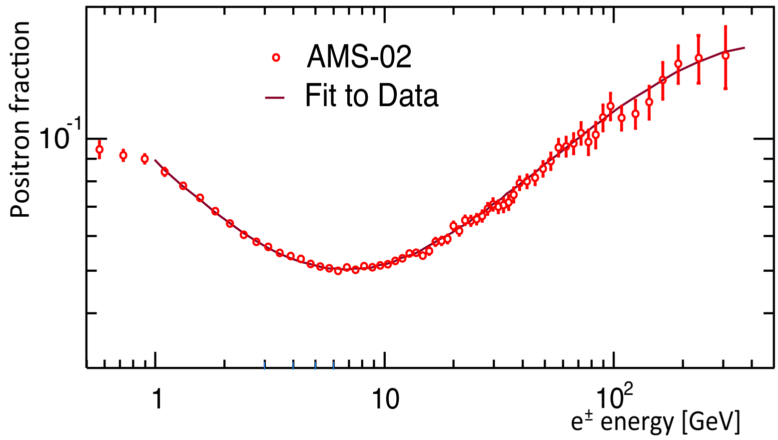

Fig. 3. The positron fraction measured by AMS, fit with the minimal model. For the fit, both the data and the model are integrated over the bin width [Aguilar (2013)].

reveals that the positron fraction is consistent with $e^\pm$ fluxes each of which is the sum of its diffuse spectrum and a single common power law source. The model has been shown to be insensitive to solar modulation effects during this period. Indeed, fitting over the energy ranges from 0.8–350 GeV to 6.0–350 GeV does not change the results nor the fit quality. Furthermore, fitting the data with the same model extended to include different solar modulation effects on positrons and electrons yields similar results.

3 Conclusions

AMS-02 is a particle physics experiment onboard the ISS since 2011, whose main physics goals are the search for antimatter and dark matter in space, as well as the precise measurement of cosmic rays composition and flux. The recently published positron fraction measurement was described. Above 10 GeV the positron fraction raises with increasing energy, being incompatible with the pure secondary production of positrons, and it shows no significant anisotropy. The data have been compared to a simple model, where both the electron and positron flux are described as the sum of individual diffuse power law spectra and a single common source. This model shows and excellent fit to the data, and it has been shown to be insensitive to the solar modulation. AMS-02 data confirm the results from previous experiments with unprecedented precision, giving evidence for the existence of new physical phenomena. AMS data will provide fundamental clues to understand the origin of those phenomena, as soon as more statistics is be available.

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