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Cosmic positron spectrum measurement from 1 to 50 GeV with AMS-01

S. SCHAEL[1] FOR THE AMS COLLABORATION.
[1] *I. Physikalisches Institut B, RWTH Aachen University, Germany*
schael@physik.rwth-aachen.de

Abstract: As a prototype for the AMS-02 experiment, the AMS-01 particle spectrometer was flown on the Space Shuttle Discovery in near earth orbit for a ten day mission in June 1998. Concerning the identification of positrons, AMS-01 was limited to energies below 3 GeV due to the vast proton background and the characteristics of the subdetectors. In order to extend the sensitivity towards higher energies, positrons can be identified through the conversion of bremsstrahlung photons. Using the inverse quadratical proportionality of the bremsstrahlung cross section to the particle mass, a proton rejection in the order of 10^6 can be reached. This allows for the measurement of the positron fraction and the positron flux up to energies of 50 GeV.

Introduction

The observation of an anomaly in the cosmic-ray positron spectrum by various experiments [1, 2] has been suggested to originate from dark matter annihilations in the halo of the Galaxy. The most promising candidate for dark matter is a stable weakly interacting massive particle predicted by certain supersymmetric extensions to the standard model of particle physics [3], and called neutralino χ. Positrons and electrons will then be created in equal numbers as stable decay products of particles stemming from χ-χ-annihilations, for instance in the galactic halo. Such a process would constitute a primary source of positrons. Therefore, a measurement of the positron fraction is motivated by the prospect of indirect dark matter detection, especially if combined with other sources of information, such as antiprotons, diffuse γ-rays or – more challenging – antideuterons.

As a predecessor to the Alpha Magnetic Spectrometer AMS-02, which is to be operated on the International Space Station (ISS) for at least 3 years starting in 2009, the AMS-01 experiment was flown on the Space Shuttle *Discovery* from June 2nd to 10th, 1998 [4].

Positron Reconstruction

The main challenge of cosmic ray positron measurements is the suppression of the vast proton background. As it is known from previous measurements [4] [5], the flux of cosmic ray protons exceeds that of positrons by a factor of $10^3 - 10^4$ in the momentum range of 1 - 50 GeV/c. Hence, in order to keep the proton contamination of positron samples below 1%, a proton rejection of $10^5 - 10^6$ has to be reached. Since the AMS-01 detector provided a sufficient single track proton rejection only for energies below 3 GeV, a different approach has been chosen for this analysis [6] . It relies on the identification of bremsstrahlung emission through photoconversion. Due to the inverse quadratical dependence on the particle mass of the cross section, bremsstahlung emission is suppressed by a factor of more than $3 \cdot 10^6$ for protons with respect to positrons.

Fig. 1 shows the principle of a converted bremsstrahlung event signature. Here, a primary positron enters the detector volume from above and emits a bremsstrahlung photon in the first time of flight (TOF) scintillator layer. The photon then converts into an electron positron pair, for example, in the second TOF layer. Because of the low fraction of momentum which is typically carried away by the photon, the secondary particles have

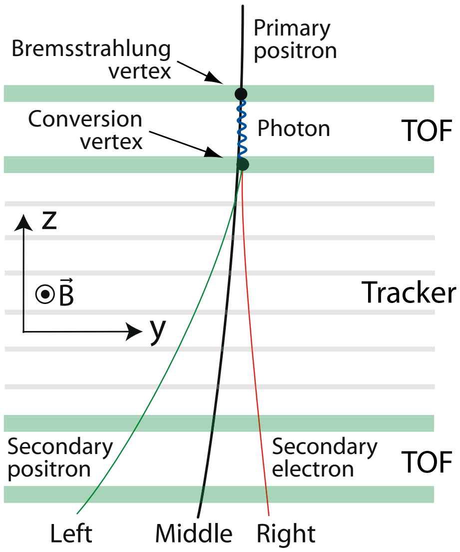

Figure 1: Schematic view of a converted bremsstrahlung event caused by a positron going top-down.

lower momenta than the primary. Therefore, in the bending plane projection, the secondaries tend to form the left and right tracks, while the primary remains in the middle.

The dominant background is caused by electrons with wrongly reconstructed momentum sign, as well as by protons undergoing hadronic reactions in the material distribution of the experiment. In the latter case mesons are produced, which mimic the 3-track signature of converted bremsstrahlung events. For example, in the reaction $pN \rightarrow pN\pi^{+}\pi^{-} + X$, beneath additional undetected particles X, the charged pions can be misidentified as an electron positron pair. Besides this, neutral pions produced in reactions of the type $pN \rightarrow pN\pi^{0} + X$ decay into two photons, one of which may escape undetected. If the remaining photon converts, the conversion pair forms a 3-track event together with the primary proton. However, the invariant mass of the mesons and primary protons is typically at the scale of the pion mass, leading to emission angles significantly larger than zero.

Analysis and suppression of background [7] [8] mainly rely on the evaluation of the topology and geometrical properties of the reconstructed events, and are therefore based on data from the tracker. Additionally, cuts on data from the TOF system are applied.

For the suppression of background, the fact is used that bremsstrahlung and photon conversion imply small opening angles of the particles at the vertices. The corresponding invariant mass is calculated according to

$$m_{inv}^{2} = 2 \cdot E_1 \cdot E_2 \cdot (1 - \cos\theta)\,, \qquad (1)$$

where θ, E_1 and E_2 denote the opening angle and the energies of the primary particle and the photon, or the conversion pair, respectively.

The distributions of the invariant masses are shown in fig. 2. For events with negative charge, which represent a largely clean electron sample, they reveal a narrow shape with a peak at zero. This is in perfect agreement with Monte Carlo results. In case of events with positive total charge, consisting of positrons and background, the distributions also show a peak at zero, but additionally a long tail towards higher invariant masses caused by the proton background. In order to discriminate against background events, cuts are applied on the invariant masses. The cuts are parameterized as ellipses in the invariant mass plane.

Energy spectra of cosmic rays are modulated by the geomagnetic field. Below a geomagnetic cutoff particles detected by AMS-01 must originate from within the magnetosphere. To discriminate against these secondaries, particle trajectories were individually traced back by numerical integration of the equation of motion [9]. A particle was rejected as a secondary if its trajectory once approached the surface of the Earth, and thus originated from an interaction with the atmosphere. Particles which did not reach a distance of 25 Earth radii within a reasonable time were considered as trapped and also rejected.

The remaining irreducible background from protons and electrons has to be corrected for using Monte Carlo simulations. Fig. 3 shows the total background correction as a function of momentum, separately indicating the contributions from protons and misidentified electrons. They amount to 24.9 and 6.4 events, respectively.

The measured positron fraction $e^{+}/(e^{+} + e^{-})$ is shown in fig. 4 in comparison with earlier results

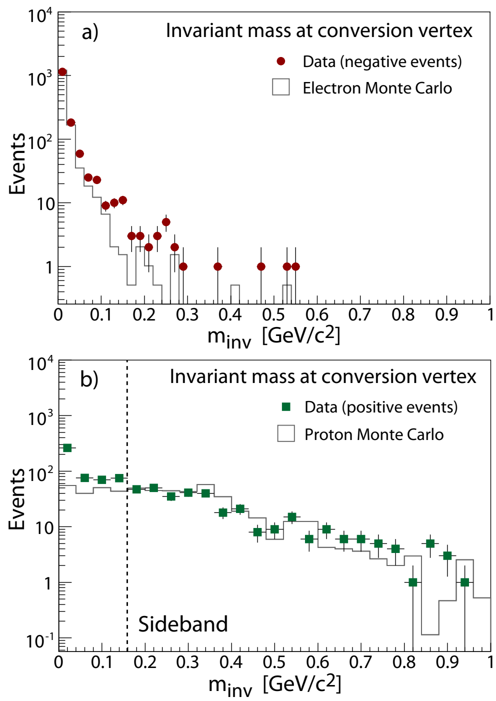

Figure 2: a) Invariant mass distribution at the conversion vertex for negatively charged data events (circles) and electron Monte Carlo (histogram). b) The same display for positively charged data events (squares) and proton Monte Carlo (histogram). The proton Monte Carlo distribution has been scaled to the data using the sideband. Below the sideband threshold of 0.16 GeV, the excess in the data due to the positron contribution is apparent.

and a model calculation based on purely secondary positron production.

As a crosscheck to the measurement of the positron fraction, presented above, the absolute incident fluxes of electrons and positrons can be calculated.

In fig. 5 the fluxes of downward going positrons and electrons, together with results published earlier by AMS-01 [10], and HEAT-e$^{\pm}$ [5], are displayed with their statistical errors. The fluxes are in very good agreement with previous measurements over the full momentum range, except for a slight discrepancy in the electron fluxes between 2 and 3 GeV. Here, at low momentum in combination

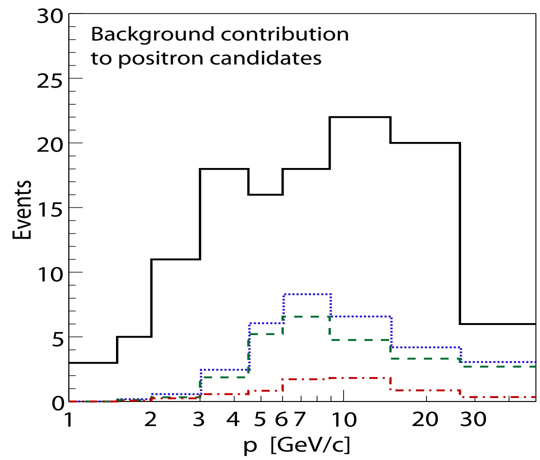

Figure 3: Momentum distribution of the positron candidates including background (solid line) and the total estimated background (blue dotted line), itemized into contributions from protons (green dashed line) and wrongly identified electrons (red dash-dotted line).

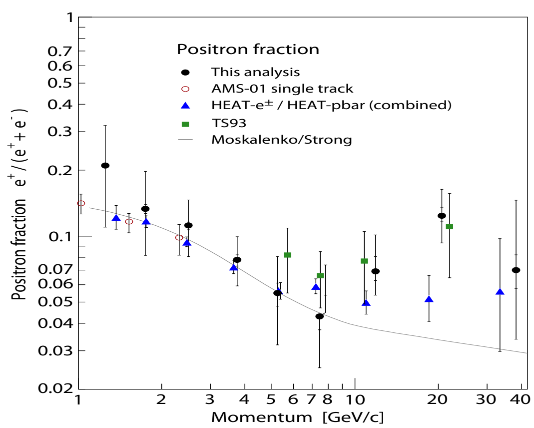

Figure 4: The positron fraction $e^+/(e^+ + e^-)$ measured in this analysis (filled circles), compared with earlier results from AMS-01 (open circles) [10], TS93 (squares) [2], the combined results from HEAT-$e^{\pm}$ and HEAT-pbar (triangles) [1], together with a model calculation for purely secondary positron production from [11] (solid line). The total error is given by the outer error bars, while the inner bars represent the systematic contribution to the total error.

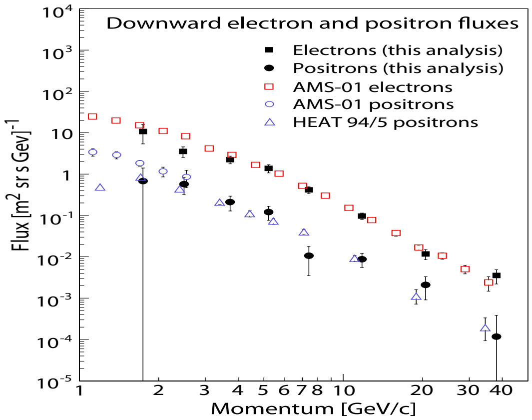

Figure 5: The fluxes of downward going positrons (filled circles) and electrons (filled squares) measured in this analysis, compared with earlier results from AMS-01 (open circles and squares) [10] and HEAT-$e^{\pm}$ (triangles) [5]. Error bars denote statistical errors only.

with low statistics, we expect the inaccuracies of the backtracing through the geomagnetic field to become the dominant source of systematic error to the fluxes. However, for the positron fraction as a ratio of particle counts, this effect widely cancels out.

Outlook: AMS-02

The successor to AMS-01, the AMS-02 experiment is currently under construction by the collaboration [12]. The expected precision of the AMS-02 measurement is shown in figure 3 (statistical errors only). Up to positron energies of $100\,GeV$, the statistical errors will be completely negligible due to the large combined geometrical acceptance of TRD, Tracker and ECAL of $800\ cm^2 sr$ at 100 GeV. The yellow band indicates an estimate of the systematic uncertainty of the background predictions from the GALPROP [11] model. It has been obtained from a variation of the spectral index of the power spectrum at the source using the measured cosmic ray proton and electron spectrum as a constraint. The present statistical significance of a possible SUSY dark matter signal is already at the 5σ level as indicated by the signal boost factor of 93 ± 17 which accounts for the expected local clumpiness of dark matter. Such a signal could only be established by measuring the return to the background above 100 GeV which AMS-02 would clearly be able to do.

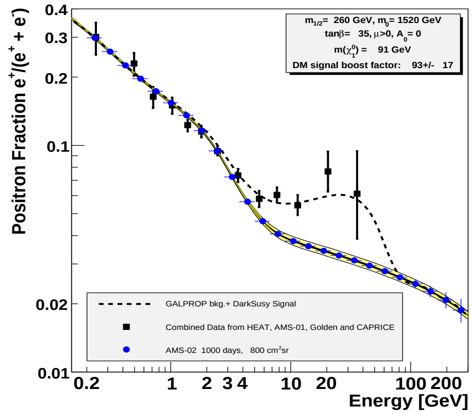

Figure 6: Expected positron fraction measurement from AMS-02 (blue circles, statistical errors only).

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