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Anisotropy of Positron and Electron Fluxes Measured with the Alpha Magnetic Spectrometer on the ISS

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A measurement of the cosmic ray anisotropy on the arrival directions of positrons and electrons has been performed in galactic coordinates by the Alpha Magnetic Spectrometer onboard the International Space Station. The analysis is based on the first 10 years of data taking. Results are consistent with isotropy and upper limits on the dipole amplitude (δ) at the 95% C.I. have been established. In particular, for energies above 16 GeV limits of $\delta < 1.50\%$ and $\delta < 0.33\%$ are obtained for positrons and electrons respectively.

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1. Introduction

As of today, AMS has provided the most precise measurements of the individual positron and electron fluxes in the GeV-TeV energy range. These results have revealed unexpected features that cannot be fully explained with the traditional models of cosmic rays.

On the one hand, the positron spectrum [1] shows a significant excess from ~ 25 GeV which is followed by a sharp drop above ~ 280 GeV. The flux can be described by the sum of a secondary and primary component. The first one contributes at low energies whereas the latter dominates at high energies with a finite energy cutoff around ~ 800 GeV. On the other hand, the electron spectrum [2] exhibits a significant excess starting from 42 GeV that is not consistent with the low energy trends. In addition, the nature of this excess has a contribution consistent with a positron-like source term. However, contrary to the positrons, the electrons do not present an energy cutoff below 1.9 TeV.

The origin of these features remains unclear, and a plethora of models have been proposed. In the case of positrons, the additional contribution cannot be explained by a pure secondary component and the inclusion of nearby primary sources is necessary, whether of astrophysical (pulsars) or a more exotic (dark matter) origin. Pulsars represent the leading astrophysical candidate as primary sources of positrons due to their capability to inject pairs of $e^{\pm}$ in the medium. Geminga and Monogem contributions are typically used to explain the observations and their predicted anisotropies with amplitudes between 10^{-3} and 10^{-2} [3–6]. Therefore, the measurement of a dipole amplitude in the positron spectrum would favor the astrophysical origin.

In this context, the measurement of the arrival directions of the cosmic ray positron and electron fluxes may help to understand the aforementioned observations. In particular, the impact that nearby sources imprint in the fluxes might be explored with these studies.

2. The AMS-02 Detector

AMS is a multipurpose particle physics detector installed onboard the ISS since May 19th 2011. The detector has been designed to carry out precise measurements of charged cosmic rays in the GeV-TeV energy range, and has continuously collected data since its installation, with more than 200 billion events for more than 11 years. The end of the ISS operation is currently scheduled for 2030 and AMS will continue taking data until that date.

The detector consists of different sub-detectors that measure the charge (Z), energy (E), and rigidity (R = p/Z) independently: a Silicon Tracker Detector (STD) with an inner tracker (L2-L8) inside a permanent magnet and two outer layers (L1 and L9), one at the top and the other at the bottom of the detector; a Transition Radiation Detector (TRD); a Time Of Flight (TOF); a Ring Imaging Cherenkov detector (RICH); and an Electromagnetic CALorimeter (ECAL). A detailed description can be found in [7, 8].

3. Positron and Electron Selection

Selected positron and electron events are required to be relativistic downward-going particles with measured velocity $\beta \sim 1$, to have a reconstructed shower in the ECAL, with a matched track in the tracker and the TRD, and charge consistent with Z = 1.

Positrons and electrons are separated from protons by means of a selection based on a cut in the ECAL estimator and a template fit to the TRD response. In particular, the positron identification ensures a proton background below the percent level.

In order to select cosmic rays above the geomagnetic cutoff, the measured rigidity is required to be greater than the maximum local geomagnetic rigidity cutoff within the AMS field of view.

For the anisotropy analysis, selected events are grouped into 5 cumulative energy ranges from 16 to 500 GeV with minimum energies E_{min}: 16, 25, 40, 65 and 100 GeV. The final sample corresponding to the first 10 years of data taking with AMS-02 in the lowest energy range, $E_{min} = 16$ GeV, contains 1.88×10^5 positrons and 2.54×10^6 electrons.

4. Methodology

The measurement of large scale anisotropies for different cosmic ray species is performed by comparing the skymap of measured events in galactic coordinates with an isotropic reference map. Both maps are created with the HEALPix scheme [9], which provides pixels of equal area in the sphere.

The reference map describes the directional response of the detector to an isotropic flux and its computation requires a detailed understanding of the detector's behavior. In particular, the precise understanding of the geographical dependences of the detector efficiencies is necessary in order to avoid possible spurious effects. More details on the construction of the isotropic reference maps can be found in [10].

In order to describe the directional dependence of the fluxes a spherical harmonic expansion is performed

$$\Phi(\theta, \phi) = \Phi_0 \left(1 + \sum_{\ell=1} \sum_{m=-\ell}^{m=+\ell} a_{\ell m} Y_{\ell m} \right) \tag{1}$$

where the $Y_{\ell m}$ are the real spherical harmonics of degree ℓ and order m, with $\ell = 0, 1, 2..$ and $m = 0, \pm 1, \pm 2, ..., \pm \ell$, and $a_{\ell m}$ are the coefficients of the expansion, which determine the degree of the anisotropy.

Then, the large scale anisotropy is described at first order by a dipole ($\ell = 1$) and its projection onto 3 orthogonal directions (East-West, North-South and Forward-Backward). In galactic coordinates the North-South (NS) direction is perpendicular to the galactic plane, the Forward-Backward (FB) is pointing to the galactic center, and the East-West (EW) completes the right-handed coordinate system and is contained into the galactic plane. The three dipole components can be defined as

$$\rho_{EW} = \sqrt{\frac{3}{4\pi}} a_{1-1} \quad ; \quad \rho_{NS} = \sqrt{\frac{3}{4\pi}} a_{10} \quad ; \quad \rho_{FB} = \sqrt{\frac{3}{4\pi}} a_{1+1} \tag{2}$$

Finally, the dipole amplitude, which quantifies the magnitude of the dipole anisotropy, is computed as follows

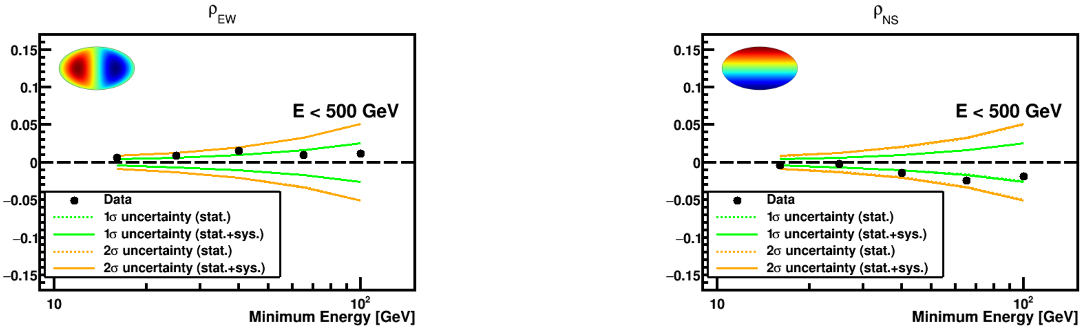
$$\delta = \sqrt{\rho_{EW}^2 + \rho_{NS}^2 + \rho_{FB}^2} \tag{3}$$

5. Positron and Electron Anisotropy

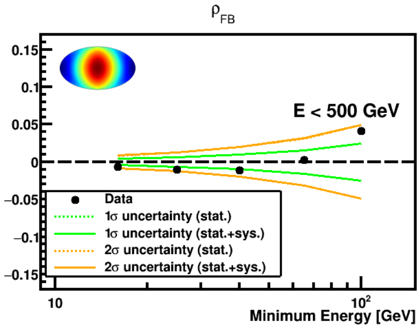
Results on the dipole components ρ_{EW}, ρ_{NS} and ρ_{FB} are shown in figures 1 and 2 for positrons and electrons respectively for the different energy ranges and with the 1 and 2 sigma deviations corresponding to the statistical and the statistical plus systematic uncertainties.

Results on the dipole amplitude are computed using the three dipole components, equation 3, and displayed as a function of the minimum energy in figures 3a and 4a. In particular, in the lowest energy range E_{min}= 16 GeV the positron and electron dipole amplitudes are $\delta_M^{e^+} = 0.97\%$ and $\delta_M^{e^-} = 0.19\%$.

The measurement of the anisotropy for positron and electron events for the first 10 years of operation with AMS-02 has been found to be consistent with isotropy and, therefore, the 95% C.I. upper limits on the dipole amplitude can be established (figures 3b and 4b). In the lowest energy range E_{min}= 16 GeV, the upper limits for positrons and electrons are $(\delta_{UL}^{95\%})^{e^+} = 1.50\%$ and $(\delta_{UL}^{95\%})^{e^-} = 0.33\%$.

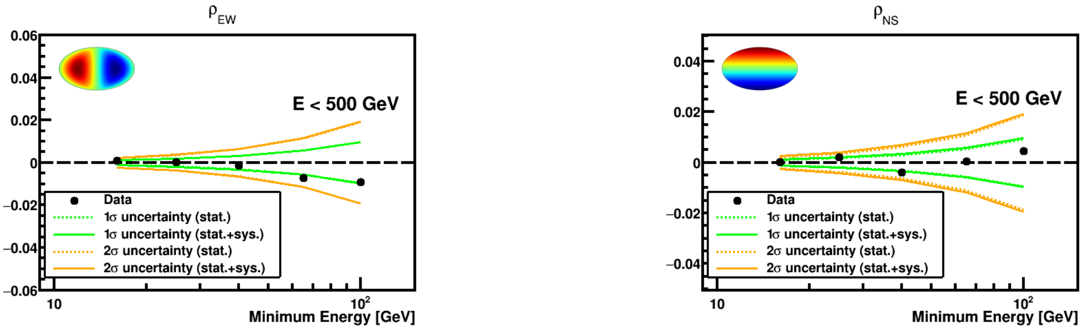


(a) East-West **(b)** North-South

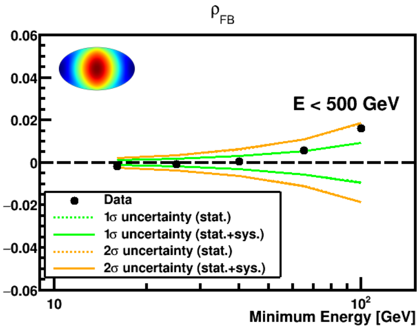


(c) Forward-Backward

Figure 1: Positron dipole components, ρ_{EW}, ρ_{NS} and ρ_{FB} in galactic coordinates where the 1 and 2 σ deviations from isotropy (green and yellow, respectively) corresponding to the statistical (dotted line) and total (solid line) uncertainties are shown.

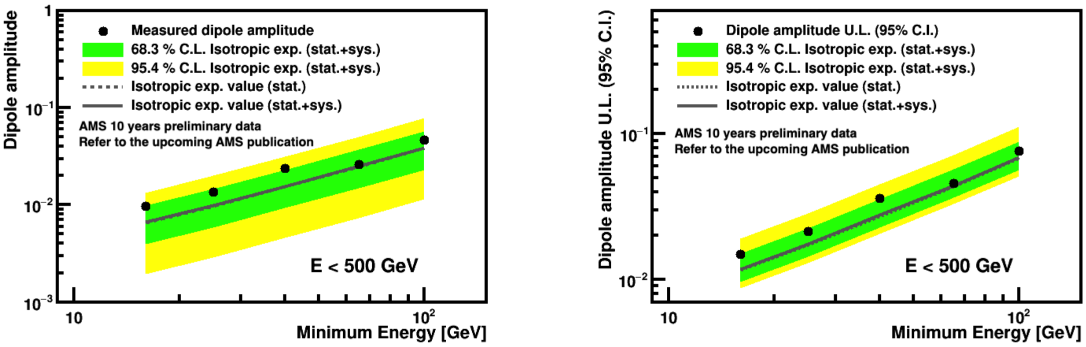


(a) East-West **(b)** North-South



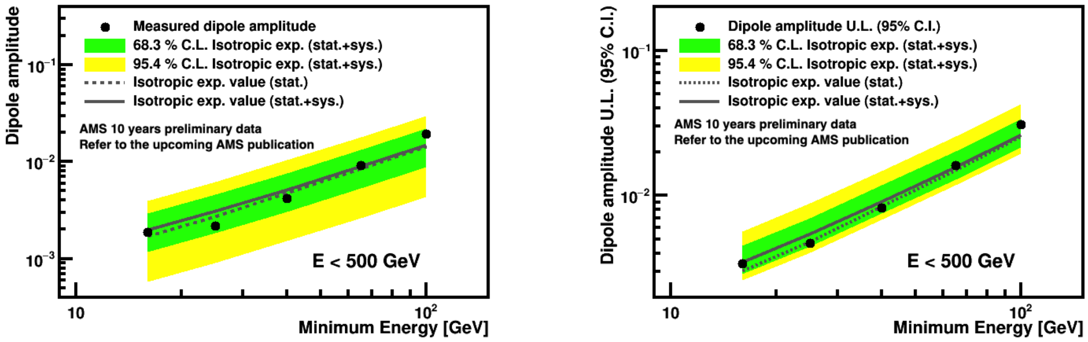
(c) Forward-Backward

Figure 2: Electron dipole components, ρ_{EW}, ρ_{NS} and ρ_{FB} in galactic coordinates where the 1 and 2 σ deviations from isotropy (green and yellow, respectively) corresponding to the statistical (dotted line) and total (solid line) uncertainties are shown.



(a) **(b)**

Figure 3: Positron measured dipole amplitude (a) and 95% C.I. upper limit (b) as a function of the minimum energy in galactic coordinates. The 1 and 2 σ total uncertainty bands are shown in green and yellow respectively. The expected value from isotropy considering the statistical (dotted line) and the statistical + systematic (solid line) uncertainties is also displayed.



(a) Dipole Amplitude **(b)** Upper Limit

Figure 4: Electron measured dipole amplitude (a) and 95% C.I. upper limit (b) as a function of the minimum energy in galactic coordinates. The 1 and 2 σ total uncertainty bands are shown in green and yellow respectively. The expected value from isotropy considering the statistical (dotted line) and the statistical + systematic (solid line) uncertainties is also displayed.

6. Conclusions

The measurement of the anisotropy in the arrival directions of cosmic ray positron and electron events in galactic coordinates has been performed with AMS-02. Results are presented for 10 years of data taking. No deviation from isotropy have been found and upper limits to the dipole amplitude (δ) are established. In particular, in the lowest energy range E_{min} = 16 GeV the limits are $\delta < 1.50\%$ and $\delta < 0.33\%$ for positrons and electrons respectively.

AMS will continue taking data until the end of the ISS operation, currently 2030. By that time AMS measurement will be sensitive to the positron anisotropy level predicted by pulsar models.

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