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Anisotropy of Elementary Particle Fluxes in Primary Cosmic Rays measured with AMS on the ISS

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A measurement of the dipole anisotropy in the arrival directions of galactic cosmic positrons, electrons and protons has been performed with the Alpha Magnetic Spectrometer (AMS) onboard the International Space Station (ISS) using the first 6 years of data. Thanks to its wide field of view and to the inclination of the ISS orbit, AMS provides nearly full sky coverage in galactic coordinates, which allows to determine the three independent dipole components for each cosmic ray species. The results are consistent with isotropy for all three particle species and upper limits on the dipole amplitude have been derived. A 95% C.I. upper limit of $\delta < 0.020$ and $\delta < 0.005$ has been obtained for positrons and electrons, respectively, in the energy range 16 to 350 GeV, and $\delta < 0.008$ for protons for rigidities above 300 GV.

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1. Introduction

The precise measurements of the comic ray fluxes performed by AMS have revealed the existence of unexpected structures that can be hardly reconciled with our current understanding of galactic comic ray production and propagation. In particular, the positron spectrum shows distinctive features above $\sim$10 GeV[1], which are not consistent with a pure secondary origin and may indicate the presence of primary sources [2], whereas protons and nuclei show a progressive hardening above $\sim$100 GeV[3], which may also arise from the presence of local sources [4] or indicate a transition in their propagation regime [5]. In particular, the contribution of compact sources may induce some degree of large scale anisotropy in the arrival directions of the measured cosmic ray fluxes [6]. Therefore, the determination of the dipole component in galactic coordinates can help understand the origin of the observed features.

2. AMS detector

The AMS detector is a large acceptance magnetic spectrometer designed to carry out accurate measurements of charged cosmic rays in the GeV-TeV energy range. It was installed on 19 May 2011 onboard the ISS and has been continuously taking data since then. To date AMS has collected more than 10^{11} events in its long term mission, which will continue until the end ISS operations in 2024. A detailed description of the sub-detectors can be found in [7] and references therein.

3. Data selection

The measurement of anisotropies in the arrival directions of electrons, positrons and protons was carried out on the data sample corresponding to the first 6 years of AMS on the ISS. The selection of electrons and positrons follows the quality criteria described in [7] and [8]. The sample contains 9.2×10^4 positrons and 1.2×10^6 electrons between 16 and 350 GeV, with a negligible proton contamination. The proton selection follows the prescription in [9]. The selected sample contains more than 7×10^8 protons with negligible contamination from other cosmic ray species.

4. Determination of Large Scale Anisotropies

The analysis of anisotropies in the event sample is performed by comparing the observed distribution of arrival directions in galactic coordinates, (l,b), with a reference map. Two approaches can be used to determine the reference maps, which lead to either relative or absolute anisotropy measurements. Unlike relative anisotropies, where a data sample is used as reference, absolute anisotropies require the knowledge of the directional response of the detector. Systematic procedures have been developed to obtain the isotropic skymaps [10, 11]. The directional flux, resulting from the ratio of data over reference skymaps, is described by means of an spherical harmonic expansion

$$\Phi(l,b) = \Phi_0 \left(1 + \sum_{\ell>0} \sum_{m=-\ell}^{m=+\ell} a_{\ell m} Y_{\ell m}(l,b) \right)$$

where the multipolar coefficients, $a_{\ell m}$, are determined from a likelihood fit.

The dipole component, $\ell = 1$, is fully described by three orthonormal functions corresponding to three orthogonal axes: Y_{1+1} is aligned with the forward-backward direction, pointing to the galactic center; Y_{1+0} is aligned with the north-south direction, pointing to the north galactic pole; and Y_{1-1} is aligned with the east-west direction, contained in the galactic plane and completes the right-handed coordinate system. The dipole amplitude is defined as $\delta = \sqrt{\frac{3}{4\pi}\left(a_{1-1}^2 + a_{1+0}^2 + a_{1+1}^2\right)}$.

5. Results

The absolute anisotropy of the positron and electron samples is determined in 5 cumulative energy ranges, with minimum energies of 16, 25, 40, 65 and 100 GeV and a maximum energy of 350 GeV. Likewise, the measurement of the absolute anisotropy of the proton sample has been performed in reconstructed rigidity bins, with minimum rigidities ranging from 18 to 1000 GV.

For each particle species and energy range, the small geographical dependence of the detector efficiencies is estimated on data and introduced as a correction to its reference skymap. The validity of these corrections is verified with the determination of the amplitude of the multipolar expansion in geographic coordinates. The projection of the residual contributions into galactic coordinates is taken as a systematic uncertainty of the measurement. This uncertainty, together with the statistical error of the efficiency corrections constitute the dominant contribution to the systematic errors.

The amplitude of the dipole components in galactic coordinates is found to be consistent with isotropy for positrons, electrons and protons at all energies. The uncertainty of the measurement is dominated by the finite statistics of the selected data sample for positron and electrons in the complete energy range, and for protons above 80 GV. Upper limits to the dipole amplitude for each particle species and energy range have been derived following the procedure described in [12]. The upper limits to the dipole amplitude in galactic coordinates are displayed for positrons and protons in Fig.1. In particular, for positrons $\delta < 0.020$ (95% C.I.) in the energy range 16-350 GeV, whereas for protons $\delta < 0.008$ (95% C.I.) for rigidities above 300 GV. For electrons, the upper limit is $\delta < 0.005$ (95% C.I.) for energies 16-350 GeV.

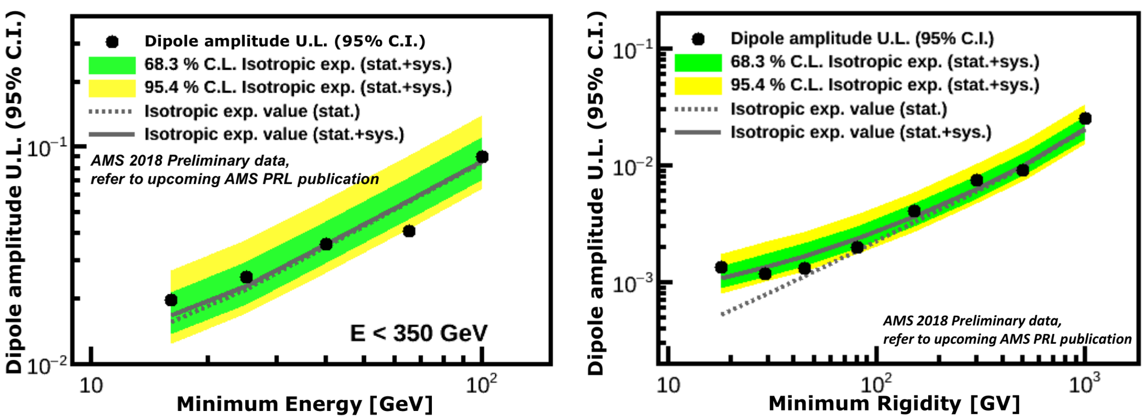

Figure 1: Upper limits on the dipole amplitudes of positrons (*left*) and protons (*right*). The points show the AMS measurement, the solid(dashed) lines correspond to the isotropic expectation with(without) systematic uncertainties, and the bands display the 68.3% and 95.4% C.L. regions.

The absence of significant dipole anisotropy in positrons above $\sim$10 GeV can be used to constrain source models. By the end of its operation on the ISS, AMS expects to reach the sensitivity to test the pulsar origin of this excess. The results for electrons, where the relative source contribution and thus the expected anisotropy should be much smaller, confirm the absence of systematics beyond the few per mil level. On the other hand, the absence of a large dipole component in protons above $\sim$100 GeV can be used to constrain models that make use of local sources to explain the proton spectral hardening. Finally, the results obtained on both protons and electrons confirm that the anisotropy of the diffuse component of cosmic rays is below the per mil level in the energy range where the positron excess is observed and, in particular, below the expectation from pulsar models for its origin.

References

[1] Z. Weng *et al.* [AMS Collaboration], *Precision Measurement of Electron and Positron Fluxes in Primary Cosmic Rays with the Alpha Magnetic Spectrometer on the International Space Station*, in these proceedings.

[2] M. Di Mauro, F. Donato, N. Fornengo, A Vittino, *Dark matter vs. astrophysics in the interpretation of AMS-02 electron and positron data*, *JCAP*, **1605**, 031 (2016) [arXiv:1507.07001 [astro-ph.HE]]

[3] Z. Weng *et al.* [AMS Collaboration], *Observation of the Identical Rigidity Dependence of the Primary Cosmic Rays Helium, Carbon and Oxygen fluxes by the Alpha Magnetic Spectrometer on the International Space Station*, in these proceedings.

[4] P. Blasi, E. Amato, *Diffusive propagation of cosmic rays from supernova remnants in the Galaxy. II: anisotropy*, *JCAP*, **2012**, 011 (2012) [arXiv:1105.4529 [astro-ph.HE]].

[5] P. Blasi, E. Amato, P. D. Serpico, *Spectral breaks as a signature of cosmic ray induced turbulence in the Galaxy*, *Phys.Rev.Lett.* **109**, 109, 061101 (2012) [arXiv:1207.3706 [astro-ph.HE]].

[6] S. Manconi, M. Di Mauro, F. Donato, *Dipole anisotropy in cosmic electrons and positrons: inspection on local sources*, *JCAP*, **1701**, 006 (2017) [arXiv:1611.06237 [astro-ph.HE]].

[7] M. Aguilar *et al.* [AMS Collaboration], *First Result from the Alpha Magnetic Spectrometer on the International Space Station: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–350 GeV*, *Phys.Rev.Lett.* **110**, 141102 (2013).

[8] L. Accardo *et al.* [AMS Collaboration], *High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station*, *Phys.Rev.Lett.* **113**, 121101 (2014).

[9] M. Aguilar *et al.* [AMS Collaboration], *Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station*, *Phys.Rev.Lett.* **114**, 171103 (2015).

[10] M.A. Velasco, *Ph.D. thesis*, *Universidad Complutense de Madrid (2018)*, [https://cds.cern.ch/record/2640369].

[11] S. Zeissler, *Ph.D. thesis*, *Karlsruher Institut für Technologie (2018)*, [http://ekp-invenio.physik.uni-karlsruhe.de/record/48952].

[12] C. Maña. *Probability and Statistics for Particle Physics.* UNITEXT for Physics. Springer International Publishing, 2017. ISBN 9783319557380.