PROCEEDINGS OF SCIENCE

Measurement of anisotropies in cosmic ray arrival directions with the AMS Detector on the Space Station

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A measurement of the dipole anisotropy in the arrival directions of galactic positrons, electrons and protons has been performed with the Alpha Magnetic Spectrometer onboard the International Space Station using the first 5 years of data taking. Relative anisotropies in the positron to electron ratio and in the high rigidity to low rigidity protons are presented together with the absolute anisotropy on positrons, electron and protons. Results are consistent with isotropy and upper limits on the true dipole amplitude are computed. A 95% C.L. upper limit of $\delta < 0.02$ and $\delta < 0.005$ was obtained for positrons and electrons respectively in the energy range 16 to 350 GeV, and $\delta < 0.01$ for protons in the rigidity range from 300 to 1800 GeV.

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1. Introduction

In the last years, the Alpha Magnetic Spectrometer (AMS-02) onboard the International Space Station (ISS) has provided precise measurements of Cosmic Ray fluxes, which have revealed many unexpected structures that cannot be fully explained within the current understanding of Cosmic Ray propagation.

In particular, a precise measurement of the positron fraction [1] shows an increase above $\sim$10 GeV, with a slope decreasing logarithmically with energy above 30 GeV. Many models have been proposed to describe this observation and, for the most cases, they required the inclusion of primary sources of positrons whether from a particle physics or an astrophysical origin [2, 3, 4], which may induce some degree of anisotropy on the measured e^+/e^- ratio [5].

On the other hand, precise measurements of proton and helium fluxes have been published [6, 7]. The results show that both fluxes deviate from a single power law and the spectral index progressively hardens at rigidities larger than 100 GV. The origin of this change in the spectral index may be connected to local sources (e.g.: supernova remnants [8]) or local structures in the Galactic Magnetic Field (GMF) [9] that may induce some degree of anisotropy in the high rigidity sample. Therefore, the analysis of anisotropy in CRs may help in understanding the origin of these unexpected phenomena.

2. AMS-02 detector

AMS-02 is a multipurpose particle physics detector designed to carry out accurate measurements of cosmic ray charged particles in the GeV-TeV range. It was installed on 19 May 2011 onboard the International Space Station and it continues taking data steadily since then. So far, AMS-02 has collected more than 10^{11} events of galactic CRs in a long term mission, which is supposed to continue during ISS lifetime until 2024.

The detector consists of nine layers of precision silicon tracker (STD), with a inner tracker (L2-L8) inside a permanent magnet and two outer layers (L1 and L9); a transition radiation detector (TRD); four planes of time of flight counters (TOF); an array of anti-coincidence counters (ACC) surrounding the inner tracker; a ring imaging Čerenkov detector (RICH); and an electromagnetic calorimeter (ECAL). More details on the sub-detectors can be found in [10].

3. Methodology

The analysis of anisotropies in a sample is performed by comparing the observed distribution of arrival directions in galactic coordinates, (l,b), with a reference map. Skymaps for both sample of study and reference are built using HEALPix scheme [11], which ensures a pixelization with an equal area isolatitude subdivisions of the sphere.

Two kind of studies can be done depending on the choice of the reference map: relative or absolute measurements. Unlike relative anisotropies, where a data sample is used as reference, absolute anisotropies require the knowledge of the directional response of the detector. Therefore, computation of isotropic skymaps for absolute anisotropies requires a precise understanding of

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detector's behavior. A systematic procedure, valid for all cosmic ray species, has been developed to obtain these isotropic skymaps. Details can be found in [12].

In both relative and absolute anisotropies, a likelihood fit is used to compare the distribution of events under study and the reference map, and takes into account the differences in the exposure for different energies or rigidities due to geomagnetic cutoff. This procedure proved to be stable against different map resolutions and sample statistics. A spherical harmonics expansion in terms of multipolar coefficients, $a_{\ell m}$, is used to described the flux or ratio of fluxes

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

The dipole for $\ell = 1$ 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 complets the right-handed coordinate system. Dipole components in each direction are defined as

$$\rho_{EW} = \sqrt{\frac{3}{4\pi}} a_{1-1} \quad ; \quad \rho_{NS} = \sqrt{\frac{3}{4\pi}} a_{1+0} \quad ; \quad \rho_{FB} = \sqrt{\frac{3}{4\pi}} a_{1+1} \tag{3.1}$$

This allows to define the dipole amplitude as

$$\delta = \sqrt{\rho_{EW}^2 + \rho_{NS}^2 + \rho_{FB}^2} \tag{3.2}$$

4. Data selection

Measurement of anisotropy on arrival directions of electrons, positrons and protons has been carried out on the first 5 years of data taking. Quality criteria for selection of electrons and positrons follows [10] and [1]. Events are selected by requiring a track in the TRD and in the tracker, a cluster of hits in the ECAL, and a measured velocity $\beta \sim 1$ in the TOF consistent with a downward-going $Z = 1$ particle. Proton background is reduced to below the percent level by means of a cut based selection on TRD and ECAL estimators, and good energy-momentum matching.The remaining sample contains about 8×10^4 positrons and 10^6 electrons between 16 and 350 GeV, with negligible proton contamination.

Proton selection follows the one described in [6]. Preselected events include downward-going particles with velocity measured by four TOF layers and charge consistent with $Z = 1$. Events reconstructed by the 7 inner layers, passing through the outer layers 1 and 9, and satisfying additional track quality criteria are finally selected.

In addition, to select only primary CRs, well above the geomagnetic cutoff, the measured rigidity is required to be greater than 1.2 times the maximum geomagnetic cutoff within the AMS field of view.

5. Anisotropy in the positron to electron ratio

The anisotropy in the positrons to electron ratio is studied in 5 cumulative energy ranges, with a minimum energy of 16, 25, 40, 65 and 100 GeV, and a maximum energy of 350 GeV according to

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their measured energy in the ECAL. Fig. 1 shows the skymaps for positrons and electrons between 16 and 350 GeV in galactic coordinates.

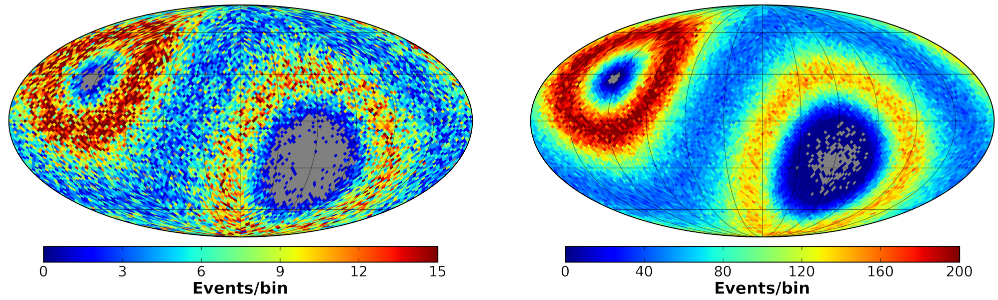

Figure 1: Skymaps for positrons (*left*) and electrons (*right*) in the energy range $16 < E < 350$ GeV (Galactic coordinates). The ISS orbit inclination of 51.6° relative to the Earth's equator combined with the position of AMS-02 on the ISS and its field of view leads to a non-uniform sky coverage, with a larger exposure in the regions around the Earth's north and south poles.

Fig. 2 shows the dipole components for the positron to electron ratio as a function of the minimum energy. No significant deviations from isotropy are found, which allows to set the corresponding 95% C.L. upper limits on the dipole amplitude for the different energy ranges. In particular, the upper limit for the first energy range, 16-350 GeV, is found to be $\delta < 0.02$ (95% C.L.).

To search for possible seasonal variations, the analysis of the anisotropy in the e^+/e^- ratio is repeated for every season in the 5 year sample. Results are consistent with expectations from isotropy and, therefore, no significant seasonal variation is observed.

6. Anisotropy in the high rigidity proton sample

The measurement of the anisotropy in the high rigidity proton sample has been performed in 5 cumulative rigidity ranges, with a minimum rigidity of 80, 150, 300, 500 and 1000 GV, and a maximum rigidity of 1800 GV according to their reconstructed rigidity in the tracker. Low rigidity protons, in the range 45-80 GV, are chosen as reference. No significant deviations from isotropy are observed for the different rigidity ranges, and 95% C.L. upper limits are computed. In particular, the upper limit obtained for the rigidity range 300-1800 GV is $\delta < 0.01$ (95% C.L.). Seasonal studies show no significant variation.

7. Absolute anisotropies

Absolute anisotropies of positrons, electrons and protons are obtained using exposure maps as reference, which are built following the method described in [12]. Absolute analysis on positrons provides consistent results with those obtained in the positron to electron ratio, in particular, the upper limit for the first energy range is found to be $\delta < 0.02$ (95% C.L.). By the end of the data taking in 2024, AMS-02 will collect about 2×10^5 positrons. Since electrons have a larger sample size, absolute anisotropy on electrons constitutes a test of possible systematics that might compromise the measurement. Results on the electron absolute anisotropy are found to be compatible

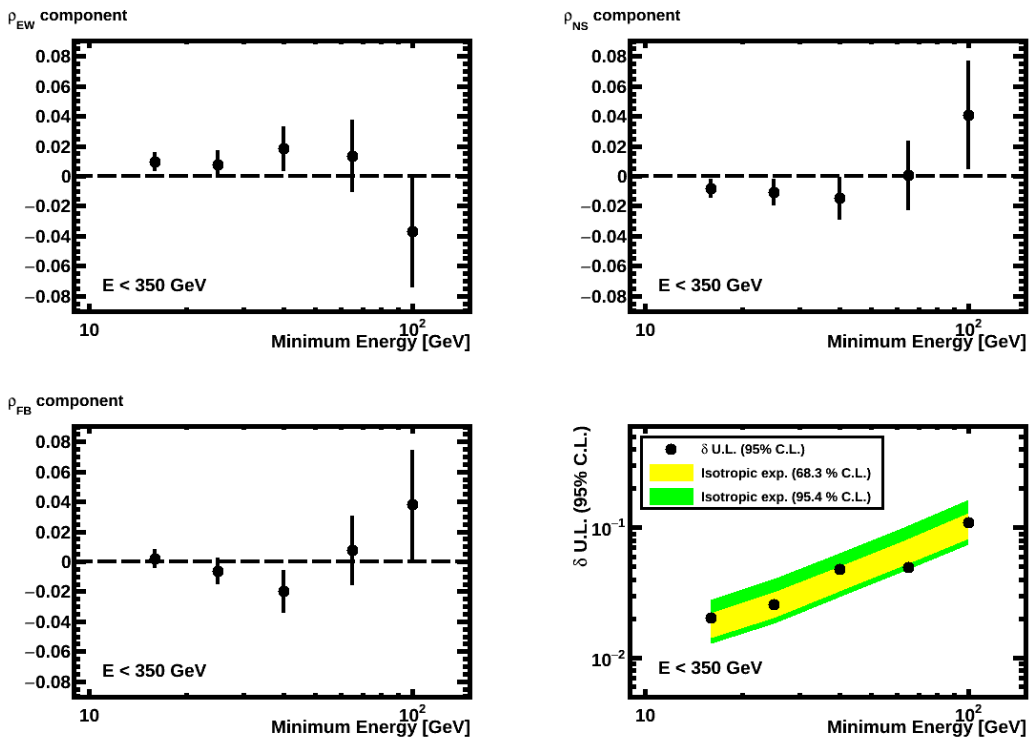

Figure 2: Amplitudes of the dipole components: east-west (*top left*), north-south (*top right*) and forward-backward (*bottom left*) as a function of the minimum energy for the positron to electron anisotropy. 95% C.L. upper limits on the dipole amplitude (*bottom right*) are obtained from bayesian inference. Bands corresponding to isotropic expectation at 68.3% and 95.4% C.L. are also displayed.

with isotropy, and upper limits are set. For the first energy range, 16-350 GeV, the obtained limit is $\delta < 0.005$ (95% C.L.). Measurement of absolute anisotropy on protons yields consistent results to those obtained in the relative analysis. In particular, for protons in the rigidity range between 300 and 1800 GV the upper limit is found to be $\delta < 0.01$ (95% C.L.). No significant seasonal variation is observed in galactic coordinates.

8. Conclusions

A systematic measurement of dipole anisotropies in the arrival directions of electrons, positrons, protons has been performed in the first 5 years of data taking with AMS-02 onboard the ISS. No significant deviation from isotropy was observed, which allows to set limits on the dipole amplitude. A 95% C.L. upper limit of $\delta < 0.02$ and $\delta < 0.005$ was obtained for positrons and electrons in the energy range 16 to 350 GeV, and $\delta < 0.01$ for protons in the rigidity range from 300 to 1800 GeV. Both relative and absolute measurements yield consistent results. No significant seasonal variation of the anisotropy is observed.

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