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Anisotropy of Particle Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the ISS

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An analysis of anisotropies in the arrival directions of galactic electrons and positrons, as well as protons, Helium, Carbon and Oxygen has been performed with the Alpha Magnetic Spectrometer on the International Space Station using the first 6.5 years (electrons and positrons) and the first 7.5 years (protons, Helium, Carbon, Oxygen) of data taking. Results on a dipole signal in Galactic coordinates are reported.

The arrival directions of all studied cosmic ray species are consistent with isotropy. For energies above 16 GeV a limit of $\delta < 0.019$ ($\delta < 0.005$) at the 95% confidence level is obtained for positrons (electrons). For rigidities above 200 GV a limit of $\delta < 0.0038$ ($\delta < 0.0036$, $\delta < 0.019$, $\delta < 0.017$) at the 95% confidence level is obtained for protons (Helium, Carbon, Oxygen). The quoted limits are based on a total of 9.9×10^4 (1.3×10^6, 2×10^6, 2.2×10^6, 6.1×10^4, 6.3×10^4) positron (electron, proton, Helium, Carbon, Oxygen) events.

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1. Introduction

The precise measurements of Cosmic Ray (CR) fluxes performed by the Alpha Magnetic Spectrometer (AMS-02) onboard the ISS, have revealed multiple unexpected features which cannot be explained in the standard paradigm of cosmic ray transport: for example, the spectra of primary cosmic rays like protons, Helium, Carbon and Oxygen [1, 2, 3] and secondary cosmic rays like Lithium, Berylium and Boron [4] as well as mixed species like Nitrogen [5] exhibit a hardening at rigidities of above 200 GV, which might be caused by the presence of a local CR accelerator dominating the local CR spectra above a few hundred GV. Further, the positron fraction shows a rise above a few GeV with a slope decreasing logarithmically with energy above 30 GeV and above 200 GeV the positron fraction is no longer increasing with energy [6]. This behaviour originates from the electron and positron fluxes dependence on energy [7, 8, 9]. Above around 20 GeV and up to 200 GeV the electron flux decreases more rapidly with energy than the positron flux, that is, the electron flux is softer than the positron flux [9]. Above 25 GeV the positron flux shows a significant excess compared to the low-energy power-law trend and above 284 GeV the positron flux shows a sharp dropoff [8]. The fluxes of electrons and positrons indicate the presence of a new source of energetic positrons, which dominates above the background of positrons produced in CR collisions at high energies.

These features cannot be explained within our current understanding of galactic cosmic ray transport. They may be related to the presence of unaccounted astrophysical sources, e.g. local supernova remnants or Wolf-Rayet stars might be the source of the hard proton and helium component, which dominates the respective CR spectra above a few hundreds of GV, pulsars might produce energetic electron-positron pairs in their strong rotating magnetic fields, which are able to explain the observed rise and flattening on the positron fraction.

If the observed features are indeed caused by a limited number of astrophysical point sources, such a point source needs to be relatively close by. Otherwise fast energy losses for electrons and positrons or escape from the galaxy for cosmic ray nuclei would significantly soften the CR spectra. A limited number of close-by point sources could induce some degree of anisotropy in the CR arrival directions. Therefore it is worth to measure and characterize the angular distribution of CR arrival directions. Anisotropy searches therefore provide complementary information to constrain the origin of the observed features and the propagation and production mechansims of CRs in the Galaxy.

In this study we analyzed a sample of electrons and positrons taken in the first 6.5 years of AMS-02 data taking between 16 GeV and 350 GeV and a sample of protons, Helium, Carbon and Oxygen nuclei above 18 GV taken in the first 7.5 years of AMS data taking. A search for absolute 3-dimensional dipole anisotropies in the arrival directions of these CR species was performed. Due to the page limit, this report focuses on the presentation of the results. A discussion of the AMS-02 detector, the data selection and the method can be found elsewhere [10].

2. Anisotropy in the arrival direction of protons, Helium, Carbon and Oxygen

Figure 1 shows the dipole components for proton arrival directions as a function of the minimum rigidities. No significant deviation from isotropy can be observed. The corresponding 95%

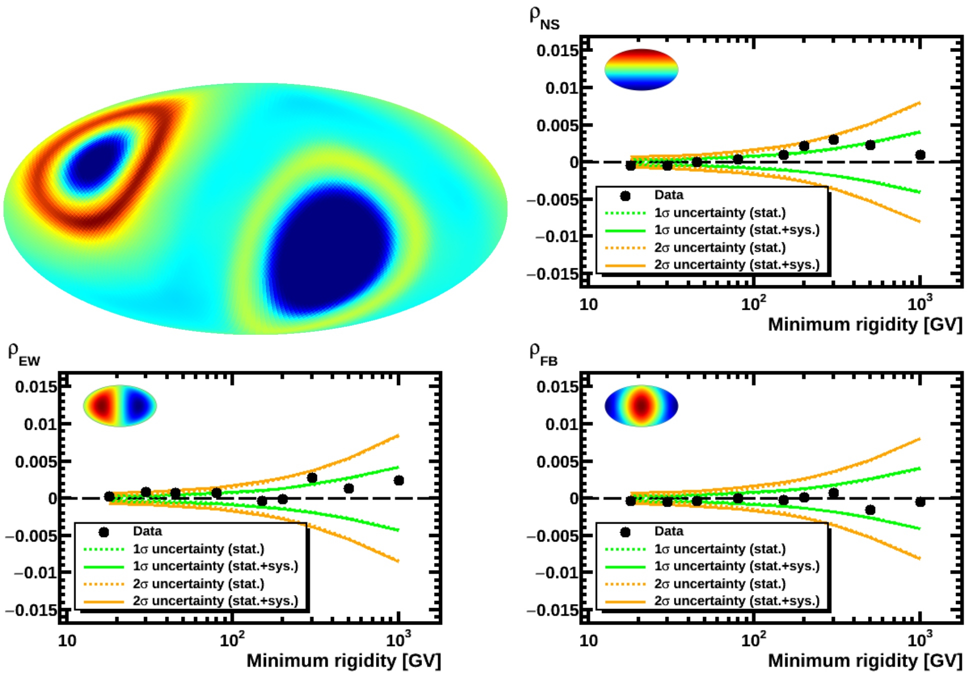

Figure 1: *Top left:* IsoSky map for protons above 40 GV in galactic coordinates. *Other figures:* Amplitudes of the ρ_{NS} (*top right*), ρ_{EW} (*bottom left*) and ρ_{FB} (*bottom right*) dipole components in the proton arrival directions obtained for different rigidity ranges. The black dots represent the fitted dipole components, the full green and orange lines represent the 1σ and 2σ statistical uncertainty. The efficiency corrections on the IsoSky map introduce systematics. The combined statistical and systematic uncertainties are shown as the green dashed and orange dashed line.

C.L. upper limits on the dipole amplitude for different rigidities are reported on the left side of the top panel of Fig. 2. The limit obtained for the rigidity range above 200 GV is $\delta < 0.0038$. For rigidities above 70 GV the measurement is limited by statistics, at low rigidities systematics on the efficiency corrections limit the sensitivity to 0.1%.

Fig. 2 also shows the 95% C.L. upper limits on the dipole amplitude for different rigidities for Helium, Carbon and Oxygen. The limit obtained at the 95% confidence level for the rigidity range above 200 GV is $\delta < 0.0036$ for Helium, $\delta < 0.019$ for Carbon and $\delta < 0.017$ for Oxygen.

To check for possible unknown systematics in the creation of the IsoSky maps similar analyses were performed using low energy proton, Helium, Carbon and Oxygen events as a reference for the respective high energy events, as described in [11]. The results obtained are consistent with the results reported here.

3. Anisotropy in the arrival directions of positrons and electrons

In Fig. 3 the 95% C.L. upper limits on the dipole amplitude for positrons (left) and electrons (right) are shown as a function of the minimum energy. No significant deviation from isotropy can be observed. The limit obtained for the energy range from 16 to 350 GeV is $\delta < 0.019$ for positrons and $\delta < 0.005$ for electrons as reported in [8, 9].

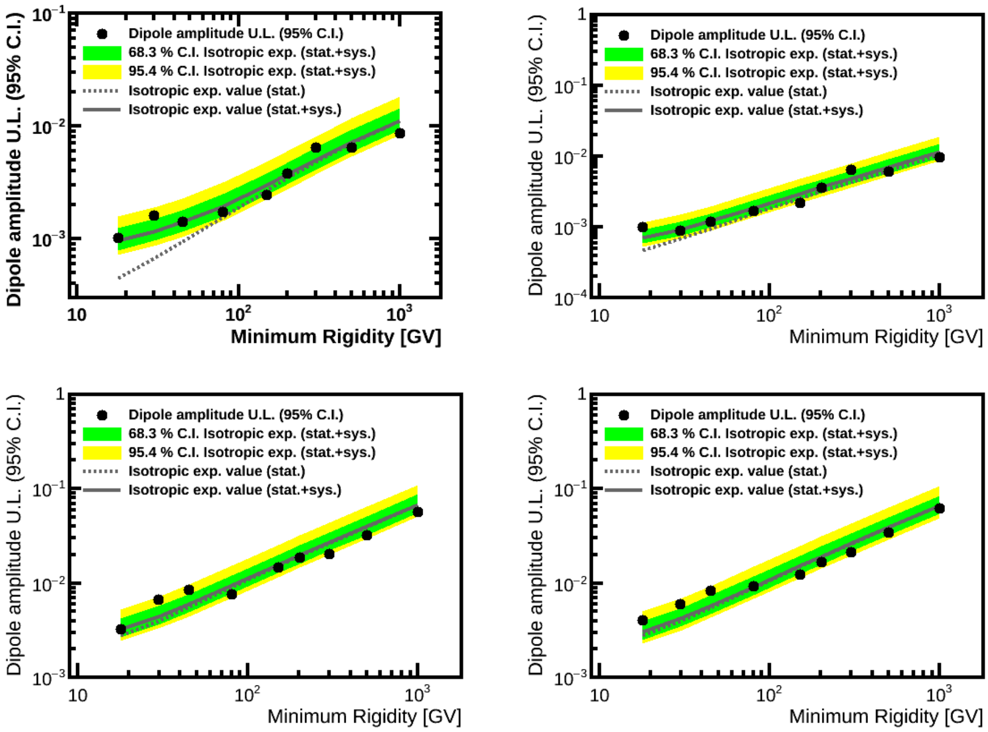

Figure 2: The 95% C.L. upper limit for the omnidirectional dipole amplitude for protons (*top left*), Helium (*top right*), Carbon (*bottom left*) and Oxygen (*bottom right*). The upper limit is calculated from monte carlo using simulated dipoles and isotropic reference maps. A bayesian 95% C.L. is computed from the distribution of true dipole strengths for the dipole strength measured on data. Also shown is the isotropic expectation calculated from a simulated isotropic signal. The gray dashed line indicates the isotropic expectation value based on only statistical uncertainties, the gray full line indicated the isotropic expectation value based on statistical and systematic uncertainty. The isotropic expectation is quoted as the 68.3% C.L. (green) and 95.4% C.L. (yellow) of the reconstructed δ distribution.

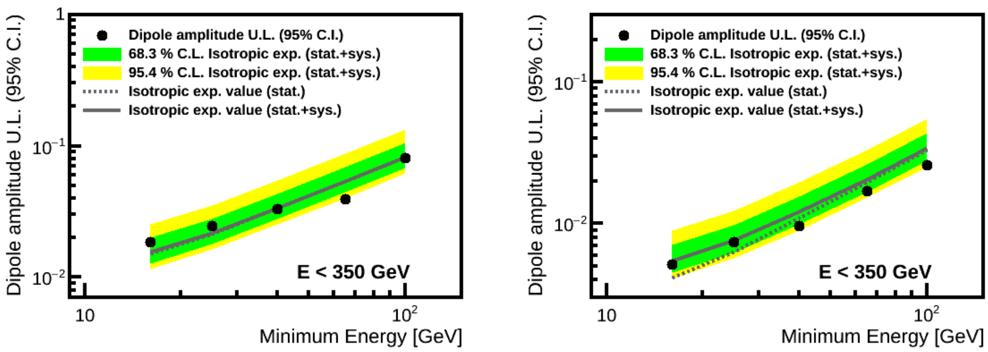

Figure 3: The 95% C.L. upper limits on the omnidirectional dipole amplitude for positrons (*left*) and electrons (*right*) as a function of the minimum energy. See caption of Fig. 2 for details.

To check for possible unknown systematics in the creation of the IsoSky maps a similar analysis was performed using protons and electrons as a reference for positrons and protons as a reference for electrons. The results obtained are consistent with the results reported here.

4. Conclusions

A search for a dipole signal in the arrival directions of positrons, electrons, protons, Helium, Carbon and Oxygen was performed using 6.5 years of data (positrons and electrons) and 7.5 years of data (protons, Helium, Carbon, Oxygen) taken with the AMS-02 detector onboard the ISS. No significant deviation from isotropy was observed. A 95% confidence level upper limit of $\delta < 0.019$ and $\delta < 0.005$ was obtained for the energy range 16 to 350 GeV for positrons and electrons, respectively. For protons (Helium, Carbon, Oxygen) a 95% confidence level upper limit of $\delta < 0.0038$ ($\delta < 0.0036$, $\delta < 0.019$, $\delta < 0.017$) was obtained for the rigidity range above 200 GV. Each analysis was performed using independent references maps. The results obtained are consistent.

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