Anisotropy of Cosmic Ray Fluxes Measured with the Alpha Magnetic Spectrometer on the ISS

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The proton and light nuclei fluxes cannot be described by a single power law; it shows a deviation above 200 GV.

The observation may require the inclusion of local sources of high rigidity protons or nuclei a modification of CRs transport models.

A nearby source of CR protons or light nuclei may induce some degree of anisotropy in the high rigidity sample.
Motivation: $e^+$

- The positron flux shows an excess above 25 GeV that is not consistent with purely secondary production.
- The excess is consistent with the existence of a source term of high-energy positrons with a characteristic cutoff energy (~800 GeV) with a significance of more than 4 sigmas.

Typically, the source term is classified in two scenarios: astrophysical sources and dark matter.

A local source of CR positrons may induce some degree of anisotropy.
- The **electron** flux shows an excess above 42 GeV that is not consistent with low energy trends
- The flux does not have an energy cutoff below 1.9 TeV

The origin of the electron excess comes from a different source than in positrons

A local source of CR electrons may induce some degree of **anisotropy**
Coordinate System of Analysis

Galactic Coordinates

North-South direction

East-West direction

Forward-Backward direction

Solar System

Galactic Center
Exposure of AMS-02

Position

Geographic Coordinates

Direction

Galactic Coordinates
Expansion of the CRs Flux

\[ \Phi(\theta, \varphi) = \Phi_0 \left( 1 + \sum_{\ell=1}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell m} Y_{\ell m}(\theta, \varphi) \right) \]

- Multipolar Components
- Real basis of spherical harmonics

**Dipole Components**

- East-West
  \[ \rho_{\text{EW}} = \sqrt{\frac{3}{4\pi}} a_{1-1} \]
- North-South
  \[ \rho_{\text{NS}} = \sqrt{\frac{3}{4\pi}} a_{1+0} \]
- Forward-Backward
  \[ \rho_{\text{FB}} = \sqrt{\frac{3}{4\pi}} a_{1+1} \]

**Dipole Amplitude**

\[ \delta = \frac{\Phi_{\text{max}} - \Phi_{\text{min}}}{\Phi_{\text{max}} + \Phi_{\text{min}}} = \sqrt{\rho_{\text{EW}}^2 + \rho_{\text{NS}}^2 + \rho_{\text{FB}}^2} \]
The arrival directions of Proton events for the first 7.5 years of data taking are compared to the expected map for an isotropic flux

# of protons \( (R > 18 \text{ GV}) \): 1.3 \times 10^8

Selected events are grouped into 9 cumulative rigidity ranges:

\( R > 18, 30, 45, 80, 150, 200, 300, 500, 1000 \text{ GV} \)
Computation of isotropic map requires detailed understanding of detector efficiencies at different geographical locations.

Geographical Coordinates

Galactic Coordinates

$R > 18$ GV

$\sim 3\%$

$\sim 2\%$
Corrections on individual components are computed for each selection efficiency to produce the corrected isotropic map.
Proton Anisotropy: Dipole Components

Galactic Coordinates

Dipole components are consistent with isotropy
Proton data is consistent with isotropy for all rigidity ranges

\[ \delta (R > 200 \text{ GV}) < 0.38\% \text{ at 95\% C.I.} \]

AMS 2019 preliminary data, refer to the upcoming AMS publication
The arrival directions of Helium events for the first 7.5 years of data taking are compared to the expected map for an isotropic flux.

# of Helium ($R > 18 \, GV$):

$1.0 \times 10^8$

Isotropic Map
Reduced amplitude of the **geographical** dependence of the detector efficiencies allows to use extended detector **acceptance**

![Graph showing relative L1 picking efficiency vs. \( \cos(\theta) \)](image)

- **Relative L1 Picking Eff.**
- **\( R > 18 \) GV**
- **0.5%**

**L1Inner**

- **Full Span**
- **(4 x more statistics)**
Helium data is consistent with isotropy for all rigidity ranges

\[ \delta (R > 200 \text{ GV}) < 0.36\% \text{ at 95\% C.I.} \]
• Same analysis as in Helium is applied for Carbon and Oxygen
• Carbon and Oxygen data are consistent with isotropy for all rigidity ranges

\( \# \) of Carbon \((R > 200 \text{ GV})\):

\[
6.1 \times 10^4
\]

\( \delta \) \((R > 200 \text{ GV})\) < 1.9\% at 95\% C.I.

\( \# \) of Oxygen \((R > 200 \text{ GV})\):

\[
6.3 \times 10^4
\]

\( \delta \) \((R > 200 \text{ GV})\) < 1.7\% at 95\% C.I.
The arrival directions of Positron and Electron events for the first 6.5 years of data taking are compared to the expected map for an isotropic flux.

# of $e^+$ (16 – 350 GeV) : $9.9 \times 10^4$

# of $e^−$ (16 – 350 GeV) : $1.3 \times 10^6$

Selected events are grouped into 5 cumulative energy ranges: $E > 16, 25, 40, 65, 100$ GeV
The positron and electron data are consistent with isotropy and limits to the dipole amplitude are set.

\[ \delta (16-350 \text{ GeV}) < 1.9\% \text{ at } 95\% \text{ C.I.} \]

\[ \delta (16-350 \text{ GeV}) < 0.5\% \text{ at } 95\% \text{ C.I.} \]
AMS measurements show new features in the positron, electron, proton and light nuclei fluxes which challenge the traditional propagation models.

The study of the anisotropy allows us to understand its origin.

Proton, Helium, Carbon and Oxygen are consistent with isotropy for \( R > 200 \) GV and upper limits to the dipole amplitude (95% C.I) can be set as:

- **Proton:** \( \delta < 0.38\% \)
- **Helium:** \( \delta < 0.36\% \)
- **Carbon:** \( \delta < 1.90\% \)
- **Oxygen:** \( \delta < 1.70\% \)

Positrons and electrons in the energy range of 16-350 GeV are also consistent with isotropy and upper limits to the dipole amplitude (95% C.I) \( \delta < 1.9\% \) and \( \delta < 0.5\% \) are obtained, respectively.

AMS will continue taking data until the end of ISS operation, currently 2024. By that time positron statistics will allow us to reach the 1% level predicted by pulsars models.