Measurement of CR anisotropies with the AMS detector on the ISS

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on behalf of the AMS Collaboration
Origin of excess of positrons

Positron fraction shows an excess above 10 GeV that is not consistent with only the secondary production of positrons.

The observation requires the inclusion of primary sources whether from a particle physics or an astrophysical origin.

Astrophysical point sources of cosmic ray positrons and electrons may induce some degree of anisotropy on the measured $e^+/e^-$ ratio.

Preliminary data. Please refer to the AMS forthcoming publication in PRL.

Presented by Yuan-Hann Chang
Characterization of cosmic ray spectra
AMS measurements of the proton and helium cosmic ray spectra show that the flux deviates from a single power law and the spectral index progressively hardens at rigidities larger than 100 GV.

Analysis of anisotropy for high rigidity cosmic rays may help in understanding the origin of these unexpected phenomena.
Analysis of anisotropy

Measurement of the cosmic ray fluxes as function of the arrival direction in Galactic Coordinates

North-South direction

East-West direction

Forward-Backward direction

Solar System

Galactic Center
AMS sky coverage

Exposure time (s)

ISS Position (1 day)

AMS 5 years: Total Exposure time: $1.23 \times 10^8$ s
Positron to electron ratio anisotropy

Sample selection
Proton background is reduced to below the percent level with a selection based on cuts on $E/p$ and the TRD and ECAL estimators.

Event Sample: AMS 5 years
$8 \times 10^4$ e$^+$ and $10^6$ e$^-$ ($16 < E < 350$ GeV)
Build the sky map of the positrons and electrons arrival directions in galactic coordinates (b, l).

16 < E < 350 GeV

8x10^4 Positrons

10^6 electrons

Positron to electron ratio anisotropy
Positron to electron ratio anisotropy

Sky map of the relative fluctuation of the positron to electron ratio, \( r_e = \frac{e^+/e^-} \), in galactic coordinates \((b, l)\)

\[
\frac{r_e(b, l) - \langle r_e \rangle}{\langle r_e \rangle} \quad 16 < E < 350 \text{ GeV}
\]

The observed sky map shows no evident pattern
Positron to electron ratio anisotropy

The relative fluctuations of the positron to electron ratio are described by means of a spherical harmonics expansion

\[ \frac{r_e(\theta, \phi)}{<r_e>} = 1 + \sum_{\ell>1} \sum_{m=-\ell}^{m=\ell} a_{\ell m} Y_{\ell m}(\theta, \phi) \]

**Dipole components**

- **East-West**
  \[ \rho_{EW} = \sqrt{\frac{3}{4\pi}} a_{1-1} \]
- **North-South**
  \[ \rho_{NS} = \sqrt{\frac{3}{4\pi}} a_{10} \]
- **Forward-Backward**
  \[ \rho_{NS} = \sqrt{\frac{3}{4\pi}} a_{1+1} \]

**Dipole amplitude**

\[ \delta = \sqrt{\rho_{EW}^2 + \rho_{NS}^2 + \rho_{FB}^2} \]
Positron to electron ratio anisotropy

The fluctuations of the positron ratio are described by a spherical harmonic expansion

Selected events are grouped into 5 cumulative energy bins


Dipole components – Galactic Coordinates

Amplitude of the dipole anisotropy on the $e^+/e^-$ for $16 < E < 350$ GeV

$\delta < 0.02$ at the 95% C.L.
Positron to electron ratio anisotropy

The anisotropy analysis of the $e^+/e^-$ ratio is repeated for every season in the 5-year sample

The measured dipole amplitudes are consistent with the expectations from isotropy

Preliminary data. Please refer to the AMS forthcoming publication in PRL.
Positron absolute anisotropy

The arrival directions of positron events are compared with the expected map for isotropic flux

$16 < E < 350$ GeV

8x$10^4$ Positrons

Isotropic map
Positron absolute anisotropy

Computation of isotropic map requires detailed understanding of detector efficiencies at different geographical locations.

\[
\cos(\theta_M)
\]

Geographical Coordinates

Galactic Coordinates
Positron absolute anisotropy

Selected events are grouped into 5 cumulative energy bins 16-350, 25-350, 40-350, 65-350 and 100-350 GeV.

Dipole components – Galactic Coordinates

Amplitude of the dipole anisotropy on the positrons for $16 < E < 350$ GeV

$\delta < 0.02$ at the 95% C.L.
Anisotropy on $e^+$ : Projected dipole amplitude

In 2024, AMS will collect above 200,000 positron events in the energy range $16 \text{ GeV} < E < 350 \text{ GeV}$

Pulsar Model:
D. Hooper, P. Blasi & P. D. Serpico, JCAP 0901(2009)
Test of systematics for an anisotropy measurement on a sample of 200,000 positrons

Electron absolute anisotropy (AMS 5 years: $10^6$ events)

Selected events are grouped into 5 cumulative energy bins 16-350, 25-350, 40-350, 65-350 and 100-350 GeV.

Dipole components – Galactic Coordinates

Measurements are compatible with isotropy
Amplitude of the dipole anisotropy on electrons ($16 < E < 350$ GeV)
$\delta < 0.005$ at the 95% C.L.
High rigidity proton anisotropy

Search for anisotropies in the high rigidity proton sample using the low rigidity proton events (45-80 GV) as reference

\[ r_p = \frac{p_{\text{high}}}{p_{\text{low}}} \]

Sample selection: 5 years

high rigidity protons:
\[ p \ (300-1800 \text{ GV}): 0.6 \times 10^6 \text{ events} \]

low rigidity protons:
\[ p \ (45-80 \text{ GV}): 11 \times 10^6 \text{ events} \]
proton anisotropy

Relative fluctuation of the high rigidity to low rigidity ratio,

\[ r_p = \frac{p_{\text{high}}}{p_{\text{low}}} \]

in galactic coordinates \((b,l)\)

\[ r_p(b, l) - < r_p > \quad < r_p > \]

Rigidity: 300-1800 GV (0.6 x 10^6 events)

The observed sky map shows no evident pattern
Proton absolute anisotropy

Fluctuations of the proton arrival directions are described by a spherical harmonic expansion

The selected events are grouped into 8 cumulative rigidity bins


Dipole components – Galactic Coordinates

Amplitude of the dipole anisotropy on protons (Rig: 300-1800 GV)

δ < 0.01 at the 95% C.L.
Summary

The new features measured by AMS on high energy cosmic rays for \( e^+ \), \( e^- \), \( p \), \( He \), ... are new phenomena. The study of their anisotropy is a way to understand their origin.

AMS has measured the \( e^+ \) anisotropy in the energy range from 16 GeV to 350 GeV as being consistent with isotropy. An extended data taking, up to 2024, will allow to explore anisotropies of 1\% on the positron cosmic ray sample.

No significant deviation from isotropy has been found in the analysis of the arrival directions of the high energy protons.

A limit on the amplitude of the dipole anisotropy for protons in the rigidity range between 300 and 1800 GV of \( \delta < 0.01 \) at the 95\% C.L. has been obtained.

AMS will provide large sky coverage anisotropy measurements in the GeV-TeV energy range for individual cosmic ray particles.
BACKUP SLIDES
Positron to electron ratio anisotropy

Dipole Strength Vs Energy – Galactic Coordinates

![Dipole Strength Diagram](image)
Positron absolute anisotropy

Dipole Strength Vs Energy – Galactic Coordinates

- Measured dipole strength
- Isotropic exp. (68.3 % C.L.)
- Isotropic exp. (95.4 % C.L.)

E < 350 GeV

Minimum Energy [GeV]
Electron absolute anisotropy

Dipole Strength Vs Energy – Galactic Coordinates
Proton absolute anisotropy

Dipole Strength Vs Energy – Galactic Coordinates

![Graph showing dipole strength vs. energy with Galactocentric coordinates. The graph includes measured dipole strength data and two isotropic expectations with confidence levels.]