



## Search for Cosmic Ray Anisotropy with the Alpha Magnetic Spectrometer on the International Space Station

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### **Anisotropy Search in Galactic Cosmic Rays**



AMS-02 particle fluxes ( $e^{-}$ ,  $e^{+}$ , p, He) show structures that can not be explained within current models.

Features may be connected to **new phenomena** which might induce some degree of anisotropy in cosmic rays fluxes.

- No anisotropy expected: Change in CR diffusion, DM annihilation
- Might induce anisotropy: Local sources (pulsars for e<sup>+</sup> and e<sup>-</sup>, local SNRs or Stars)



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**Anisotropy Search With AMS-02** 

Large acceptance CR detector as external module aboard ISS orbiting earth at 400 km altitude since May 2011 taking data continuously.

- High precision measurement of particles above atmosphere
- Long time (*nearly*) full sky coverage (*orbit inclination* 51.6°)  $\frac{1}{2}$  <sup>80</sup>  $\rightarrow$  three-dimensional reconstruction of dipole signals
  - $\rightarrow$  three-dimensional reconstruction of dipole signals
- Inside magnetosphere
  - → deflection of particle trajectories (back-propagation)
  - $\rightarrow$  position dependent external particle rates
  - $\rightarrow$  rigidity cutoff (energy dependent exposure)







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ISS Orbi

#### **The Alpha Magnetic Spectrometer**







## Methodology For Anisotropy Search



#### **Reference Map:**

Best guess for an **image of an isotropic sky** measured by the detector in the respective data taking period to normalize exposure.

#### **Choices for reference maps:**

- (1) other cosmic ray species (e.g. Protons for Leptons)
- (2) same cosmic ray species (at different energies)

Any deviation from these reference maps might be detected as a signal.

A likelihood fit procedure is used to expand the normalized ratio of data and reference into a dipole.

Dipole amplitude: 
$$\delta = \sqrt{\rho_{NS}^2 + \rho_{FB}^2 + \rho_{EW}^2}$$
  
North-South: Forward-Backward: East-West:  
 $\rho_{NS} = \sqrt{\frac{3}{4\pi}}a_{10}$   $\rho_{FB} = \sqrt{\frac{3}{4\pi}}a_{11}$   $\rho_{EW} = \sqrt{\frac{3}{4\pi}}a_{1-1}$ 

Results are stated in the galactic coordinate system.

#### **Positrons Over Electrons – Dipole Components**







### **Back Tracing in Magnetosphere**



**Back-tracing** allows to reconstruct trajectories of cosmic rays detected by AMS-02 at ISS altitude in a deterministic way up to the border of the magnetosphere.

Internal Field: IGRF-12 model

Main earth magnetic field + annual changes

External Field: Tsyganenko 2005 model

Describes earths magnetosphere during quiet and active solar periods



### **Back Tracing in Magnetosphere**



The magnetosphere introduces a displacement with respect the asymptotic direction. This displacement decreases with rigidity.



#### **Positrons Over Protons – Dipole Components**





#### **Positrons Over Protons – Limit on Dipole**



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#### **Electrons Over Protons\* – Dipole Components**





#### **Electrons Over Protons\* – Limit on Dipole**



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#### NEW! **Protons Over Low Rigidity (LR) Protons**



- Minimum rigidity limit is given by the maximum geomagnetic cutoff (~32 GV)
- Use high rigidity selection already for low rigidities

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#### **Protons Over LR Protons – Dipole Components**







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#### **Seasonal Variation**



Divide the period of analysis (May 2011 – Nov 2015) in **seasons** (4 seasons per year)



- Check for time dependence of a signal (Galactic)
- Detect a possible signal as function of the position inside the Heliosphere or solar activity (GSE – Geocentric Solar Ecliptic)







# **Seasonal Variation – GSE Coordinates**



Search for solar effects.



### Conclusions



- Positron and Electron angular distributions are comparable with isotropy
  - for all energies
  - at ISS position and at magnetosphere border
- Proton sky at high rigidities is comparable with the Proton distribution at low rigidities
- No significant seasonal variation observed in any of the observables

#### **Positron Isotropy:**

$$\delta_{e^{+/e^{-}}}(>16 \text{ GeV}) < 2\% \text{ at } 95\% \text{ C.L.}$$

 $\delta_{e^{+/p}}(>16 \text{ GeV}) < 2\% \text{ at } 95\% \text{ C.L.}$ 

#### **Electron Isotropy:**

$$\delta_{e}$$
 (>16 GeV) < 0.6% at 95% C.L.

#### **Proton Isotropy:**

 $\delta_{p}$ (>80 GeV) < 0.3% at 95% C.L.

### Outlook



- Become independent of reference sample (absolute anisotropies)
- Extend analysis to other species (*He, Li, …*)
- Study other coordinate systems (full solar cycle  $\rightarrow$  GSE)

AMS-02 data-taking will continue until the end of the ISS mission allowing us to set stronger limits in the future.

