Precision Measurement of the Monthly Cosmic Ray Fluxes with the Alpha Magnetic Spectrometer

Solar Energetic Particles (SEP), Solar modulation and Space Radiation: New Opportunities in the AMS-02 Era #3
Washington DC, April 23-26, 2018

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On behalf of the AMS Collaboration
AMS Period of Observation

AMS is a TeV precision, multipurpose, magnetic spectrometer, on the ISS since May 2011. AMS is measuring GCR fluxes and their time variation. AMS will study the solar modulation effect and the short-term solar activity in the present (24th) and next solar cycle for the live-time of the ISS.

NMDB database at [http://www.nmdb.eu](http://www.nmdb.eu)
AMS Contribution to Solar Modulation

- Simultaneous multi-particle measurements.
- Fine rigidity resolution.
- Total uncertainty at the percentage level.
- Short integration time.
- Continuous particle measurement over one solar cycle.

Detailed time evolution of GCR during both periods of maximum and minimum of solar activity.

AMS measurements will help to understand the propagation of charged particles in heliosphere and to test diffusion and drift models.
AMS Detector and Proton and Nuclei Identification

**Transition Radiation Detector**
- $e^+ e^-$ identification

**Time-of-Flight counter**
- Trigger
- Velocity
- Particle flight direction
- Charge

**Silicon Tracker + Magnet**
- Rigidity
- Charge & sign

**Ring Imaging Cherenkov detector**
- Velocity
- Charge

**Electromagnetic Calorimeter**
- $e^+ e^-$ identification
- $e^+ e^-$ Energy
In 7 year of operation, AMS has collected more than 117 billion events
AMS Proton and Helium Fluxes vs. Time & Rigidity

Proton

Helium

May 2011- May 2017
AMS Monthly Proton and Helium Fluxes (27 days, Bartels Rotation) Relative Variation

AMS Proton

AMS Helium
AMS Monthly Proton and Helium Fluxes
Time Profiles

Flux [GV·s⁻¹·sr⁻¹·m²⁻¹]


[1.92-2.15] GV

p

He
AMS Monthly Proton and Helium Fluxes
Time Profiles

Flux [GV⁻¹ s⁻¹ sr⁻¹ m²⁻¹]

[2.40-2.67] GV

p

He

AMS Monthly Proton and Helium Fluxes Time Profiles

Flux $[\text{GV}^{-1} \text{sr}^{-1} \text{m}^{-2}]$


[3.29-3.64] GV

p

He

Flux values for protons (p) and helium (He) over time from May 2011 to May 2017.
AMS Monthly Proton and Helium Fluxes
Time Profiles

Flux \([\text{GV}^{-1} \text{ sr}^{-1} \text{ m}^2]\)

---|---|---|---|---|---|---|---|---|---|---|---|---
80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200
AMS Monthly Proton and Helium Fluxes Time Profiles
AMS Monthly Proton and Helium Fluxes Time Profiles

Flux \( [\text{GV}^{-1} \text{ s}^{-1} \text{ Sr}^{-1} \text{ m}^{-2}] \)

- **p**
- **He**

- **[21.10-22.80] GV**
AMS Monthly Proton and Helium Fluxes Time Profiles

[Graph showing monthly time profiles of proton and helium fluxes from May 2011 to May 2017. The fluxes are given in units of $10^3$ cm$^{-2}$ s$^{-1}$ sr$^{-1}$ m$^{-2}$, with data points for each month plotted against time. The graph shows a fluctuating trend with a peak in 2013 and a noticeable difference in helium flux compared to proton flux.]
AMS Monthly Proton and Helium Fluxes

Time Profiles

Flux $[\text{GV}^{-1} \text{sr}^{-1} \text{m}^{-2}]$

- Protons ($p$)
  - [56.10-60.30] GV
  - Flux values range from 0.19 to 0.23

- Helium (He)
  - Flux values range from 0.04 to 0.048

Data points for each month from May 2011 to May 2017.
**AMS Proton and Helium Low Energy Structures**

- Detailed structures (green area) are clearly present below 40 GV.
- The amplitude of the structures decreases with increasing rigidity.
- Vertical dashed lines delimit boundaries of p and He structures (from I to X).
- The red vertical dashed lines denote structures that have also been observed by AMS in the electron and positron fluxes.
Above 3 GV the p/He flux ratio is time independent
Below 3 GV the p/He flux ratio has a long-term decrease.

- Differences in p and He diffusion coefficients.
- Differences in the local interstellar spectra of p and He.
- 3He and 4He isotopic composition.

See Claudio Corti presentation.
AMS Daily Proton & Helium Fluxes

The daily flux will give more details on the time evolution of the proton and Helium fluxes (ongoing analysis)

Forbush decreases (FD), Corotating Interaction Regions (CIR), Global Merged Interaction Region (GMIR), and Solar Energetic Particles (SEP) studies.

See Alexis Popkow, Christopher Light, Metteo Palermo presentations.
AMS Leptons: Electron & Positron

Transition Radiation Detector
- e+ e- identification

Time-of-Flight counter
- Trigger
- Velocity
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Silicon Tracker + Magnet
- Rigidity
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Ring Imaging Cherenkov detector
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Electromagnetic Calorimeter
- e+ e- identification
- e+ e- Energy
AMS Electron and Positron Monthly Fluxes
AMS Positron/Electron Flux Ratio

\[ R_e = \frac{\text{positrons}}{\text{electrons}} \]

- **A<0**
  - 1.01 - 1.22 GeV
  - 2 - 2.31 GeV
  - 5 - 5.49 GeV

- **A>0**
  - 10.32 - 11.04 GeV
  - 20.04 - 21.13 GeV

Polarity reversal of solar magnetic field in 2013.
AMS Positron/Electron Transition Parametrization

\[ R_e(t, E) = R_0(E) \left[ 1 + \frac{C(E)}{\exp \left( -\frac{t-t_{1/2}(E)}{\Delta t(E)/\Delta_{80}} \right) + 1} \right] \]

- \( t_{\text{rev}} \): relative amplitude of transition
- \( t_{1/2} \): midpoint of transition
- \( \Delta t \): from 10% to 90%
- \( R_e \): relative amplitude of transition
- \( R_0 \): initial relative amplitude
- \( C(E) \): function of energy
- \( \Delta t(E) \): duration of transition depending on energy
- \( \Delta_{80} \): duration at 80% transition
AMS Positron/Electron Transition Parametrization

\[ R_e(t, E) = R_0(E) \left[ 1 + \frac{C(E)}{\exp\left(-\frac{t-t_{1/2}(E)}{\Delta t(E)/\Delta 80}\right) + 1} \right] \]

- **Relative amplitude of transition**
  - Graph showing the relative amplitude of transition against energy (E) in GeV.

- **Duration of transition**
  - Graph showing the duration of transition against energy (E) in GeV.
  - Duration is 830 ± 30 days.

Midpoint of transition changes by (260 ± 30) days from 1 to 6 GeV.
Drift Effect on Opposite Charged Particles

A<0 negative particles are less modulated than positive particles
A>0 negative particles are more modulated than positive particles

Polarity Inversion:
Nov2012-Mar2014

Drift direction of positrons in A>0 epochs or electrons A<0
Drift direction of positrons in A<0 epochs or electrons A>0

A<0 negative particles are less modulated than positive particles
A>0 negative particles are more modulated than positive particles

Sun's Magnetic field data from Wilcox Solar Observatory http://wso.stanford.edu/
p&He and e+ e- Submitted for Publication on PRL

Observation of Fine Time Structures in the Cosmic-ray Proton and Helium Fluxes with the Alpha Magnetic Spectrometer on the International Space Station

AMS particle and antiparticle: Proton & Anti-proton

Transition Radiation Detector
- to separate anti-p and p from e+ and e-

Time-of-Flight counter
- Trigger
- Velocity
- Particle flight direction
- Charge

Silicon Tracker + Magnet
- Rigidity
- Charge & sign

Ring Imaging Cherenkov detector
- Velocity
- Charge
- to separate anti-p and p from other |Z|=1

Electromagnetic Calorimeter
- to separate anti-p and p from e+ and e-
AMS Proton/Anti-proton Flux Ratio

From May 2011 to Nov 2016, each point is 81 days of integration

11.0-12.6 GV

Preliminary
AMS Proton/Anti-proton Flux Ratio

From May 2011 to Nov 2016, each point is 81 days of integration.
AMS Proton/Anti-proton Flux Ratio

From May 2011 to Nov 2016, each point is 81 days of integration.
AMS Proton/Anti-proton Flux Ratio

From May 2011 to Nov 2016, each point is 81 days of integration

4.1-5.0 GV

Preliminary
AMS Proton/Anti-proton Flux Ratio

From May 2011 to Nov 2016, each point is 81 days of integration
Summary & Conclusions

- AMS p, He, e+, e-, anti-p monthly fluxes were measured during the ascending phase of solar cycle 24 through its maximum and toward its minimum.

- Fluxes at low rigidity show sub-structures related to the short-term solar activity.

- Above 3 GV the p/He flux ratio is time independent while below 3 GV the p/He flux ratio has a long-term decrease.

- AMS e+/e- and anti-p/p ratio clearly shows the charge-sign dependence of solar modulation.

- AMS is measuring all nuclei, particle and anti-particle fluxes in the present and next solar cycle.
Backup
Time Evolution of Spectral Indices at 10GV

Spectral indices for both positrons and electrons harden until April 2015, then soften with identical slope.