Solar Modulation of GCRs in the Heliosphere

Precise measurements of the time-dependent GCR spectra is important:

• to understand the propagation of GCRs in the heliosphere.

• to test solar modulation theories of particles diffusion and drift.

• to reduce the errors on theoretical models used for Dark Matter interpretation of the excess in the antimatter channels and in evaluation of the secondary background.

➢To understand significant sources of space radiation.
Cosmic rays entering the heliosphere are subject to diffusion, convection, adiabatic energy losses, and magnetic drift. Cosmic ray flux variation over time correlate with solar activity, which has several cycles.

Solar activity measured by AMS
AMS Proton and Helium time variation

Flux from May 2011 to May 2017
Minimum Flux February 2014

Published in PRL
August 1, 2018
AMS Monthly Proton and Helium time variation (Bartels rotation 27 days)

Minimum Flux February 2014
Flux increases starting from March 2015

Published in PRL August 1, 2018
The proton flux and the helium flux have time structures nearly identical in time and relative amplitude.
AMS Proton and Helium low energy structures

• For P and He structures are clearly present below 40 GV.

Published in PRL
August 1, 2018
AMS Proton /Helium ratio time dependence

The p/He flux ratio above 3 GV is time independent.

AMS Proton /Helium ratio time variation

Below 3 GV the ratio has a long-term decrease coinciding with the period during which the fluxes start to rise.

February 28, 2015 +/-42 days

Carbon analysis vs time is ongoing.
AMS electron and positron monthly time variation

Probe the drift process in the heliosphere

- At energies above 20 GeV, no time dependence.
- Prominent, distinct structures in both fluxes.
- Spectral indices soften with identical slope after April 2015.

Published in PRL August 1, 2018
AMS positron/electron ratio time variation

• Short-term variations largely cancel and clear overall trend revealed.

• Below 6GeV, smooth, long-term transition in e+/e- flux ratio after polarity reversal of solar magnetic field in 2013.

• Above 6GeV, e+/e- flux ratio is time independent.
Short term solar activity
Solar Energetic Particles

- Related to **flares** and **coronal mass ejections** (CME) at the Sun
- Solar Energetic Particles (SEP)
  - Temporary increase in particle flux
  - M- and X-class flares and high speed CMEs generate SEP events measured by AMS

**March 7, 2012**
Two Solar Flares of class X5.4 and X1.3 (XRT Flare catalog SDO UV light).
Two Coronal Mass Ejections with speeds of 2684 km/s and 1825 km/s (SOHO LASCO CME catalog).
Solar Energetic Particles Observed as an Excess above the GCR Background

Proton Flux [m$^2$ sr$^{-1}$ sec$^{-1}$ GV$^{-1}$]

- March 6, 2012
- March 7, 2012

Rigidity [GV]
Solar Energetic Particles Observed as an Excess above the GCR Background

Proton Flux [m$^{-2}$ sr$^{-1}$ sec$^{-1}$ GV$^{-1}$]

SEP over GCR background

- March 6, 2012
- March 7, 2012
- March 8, 2012

Rigidity [GV]
Solar Energetic Particles Observed as an Excess above the GCR Background

Proton Flux [m$^2$ sr$^{-1}$ s$^{-1}$ GV$^{-1}$]

- **SEP over GCR background**

- **March 6, 2012**
- **March 7, 2012**
- **March 8, 2012**
- **March 9, 2012**

Rigidity [GV]
Solar Energetic Particles Observed as an Excess above the GCR Background

[Graph showing the proton flux in $m^2 \cdot sr^{-1} \cdot sec^{-1} \cdot GV^{-1}$ as a function of rigidity in GV. The graph includes data points for different dates: March 6, 2012, March 7, 2012, March 8, 2012, March 9, 2012, and March 10, 2012.]
Solar Energetic Particles Observed by AMS

AMS SEP events from May 2011 to May 2016.

SEPs are typically associated with M- and X-class flares and fast CMEs.
AMS Multi-orbit Observations
SEP Time evolution

Average integration time about 20 minutes

May 17, 2012

Preliminary data. Please refer to the AMS forthcoming publication.
Multi-spacecraft Observation

AMS data, combined with other instruments at lower energy, provide a baseline for the modeling of SEP production.
Ellison-Ramatay PL*Exponential in Rigidity

Diffusive Shock Acceleration by CMEs

\[ \frac{dJ}{dR} = A R^{-\gamma} e^{-R/R_0} \]

Preliminary data please refer to the forthcoming publication in PRL.
Forbush Decreases

Temporary decrease in the galactic cosmic ray flux
Caused by a passing Interplanetary Coronal Mass Ejection or Corotating Interacting Regions

March 7, 2012
FD Relationship with Solar Wind
Identified 69 Forbush Decreases in AMS
FD Characteristics for Selected Events

<table>
<thead>
<tr>
<th>AMS-02 FD</th>
<th>Start Date</th>
<th>Date of Minimum</th>
<th>Duration (Days)</th>
<th>Max Rigidity (GV)</th>
<th>Amplitude 1.92 - 2.15 GV (%)</th>
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<tbody>
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<td>1</td>
<td>2011/06/23</td>
<td>2011/06/24</td>
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<td>19.5 - 21.1</td>
<td>8.5 ± 2.2</td>
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<td>14.1 - 15.3</td>
<td>16.6 ± 2.0</td>
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<td>20.6 ± 1.9</td>
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<td>28.8 - 31.1</td>
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<td>2012/02/27</td>
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<td>16</td>
<td>2013/12/15</td>
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<td>4</td>
<td>7.09 - 7.76</td>
<td>6 ± 1.8</td>
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• Precise time variation measurements of GCRs provide unique information to probe the dynamics of solar modulation diffusion and drift, and to improve the processes of galactic cosmic ray propagation in the heliosphere.

• The AMS experiment is measuring SEPs with high statistics at energies not accessible to current satellites attaining valuable information for the heliophysics and space radiation communities.

• 69 Forbush decreases were measured in space with very high accuracy.

• AMS can help to better understand and predict space radiation for future manned missions to the Moon and Mars.