Observation of Complex Time Structures in the Cosmic-Ray Electron and Positron Fluxes by the Alpha Magnetic Spectrometer on the ISS
A precision, multipurpose, up to TeV spectrometer

**TRD**
Identify $e^+$, $e^-$

**Silicon Tracker**
$Z, P$

$Z, P$ are measured independently by the Tracker, RICH, TOF and ECAL

**ECAL**
$E$ of $e^+, e^-, \gamma$

**Magnet**
$\pm Z$

**TOF**
$Z, E$

**RICH**
$Z, E$
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Redundancy and Complementarity!
Thanks to the different energy deposits of light and heavy particles, the TRD is capable to achieve an e/p separation up to $10^4$. 

ISS Data

25/07/19

M. Duranti – ICRC2019
Exploring the shower topological differences between hadronic and electromagnetic particles, is possible to obtain an e/p separation up to $10^5$
Comparing the Energy measurement by the ECAL to the Rigidity one by the Tracker is possible to discriminate electromagnetic and hadronic particles. Given the natural abundances of $p^+$, $p^-$, $e^-$ and $e^+$, even a selection only based on the sign of the Rigidity is possible to obtain quite pure sample of $p^+$ and $e^-$. 

![ISS Data]

**e/p separation: Tracker+ECAL**
e/p separation: redundancy and complementarity

ISS Data

ECAL classifier vs. sign(R)*TRD LH(e/p)

- Electrons
- Positrons
- Anti-protons
- Protons

Normalized Entries

Electrons and positrons are clearly separated, indicating the effectiveness of the e/p separation technique. The ECAL classifier is used to distinguish between electrons and protons, while the sign(R)*TRD LH(e/p) parameter helps in separating positrons from anti-protons.
Solar modulation and $\pm$
Solar modulation of Cosmic Rays

1. Large time scale effects (~years):
   - change on intensity of CRs
   - charge-sign dependence:
     - at maximum: diffusive motion
     - at minimum: magnetic drift + diffusive motion

2. Small time scale effects (~days)
   - Forbush decrease & Solar Energetic Particles (SEP)

B~0.3\(\mu\)G

Galactic cosmic rays

Heliosphere

B>0.3\(\mu\)G

~ 11 years

AMS starts taking data

0 50 100 150 200 250
#sunspot


cycle 20 cycle 21 cycle 22 cycle 23 cycle 24
1. Large time scale effects (~years):
   - Change on intensity of CRs
   - Charge-sign dependence:
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2. Small time scale effects (~days)
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Solar modulation of Cosmic Rays

Image Credit & Copyright: Rainee Colacurcio
At low energies the flux behavior is strongly dependent on the local environment.

The effect of the solar wind and of the solar magnetic field is modifying the observed spectra with respect to the Local InterStellar ones.

For a perfect knowledge and understanding of the LIS spectra a detailed and predictive model of the solar modulation is needed.

* e⁺ and e⁻ up to TeV presented in next talk by W. Xu
Data analysis
Template fit to measure the number of electrons/positrons

Data driven background subtraction
Reference spectra for the signal and the background are fitted to data as a function of the TRD LH(e/p) once a ~ 100% efficiency cut is applied on the ECAL classifier.

The template fit is performed with reference spectra extracted from data, for each 27 days time period independently.

E=[4.12-4.54] GeV, Δt = 27 days

- data to fit
- fit result
- electrons: 13535.79 ± 116.49
  chi2/ndf: 1.55 (92.82/60)
- protons: 205.03 ± 16.36
  chi2/ndf: 0.41 (35.27/85)
- positrons: 754.50 ± 31.56
  chi2/ndf: 2.5 (63.53/60)
The flux measurement

\[ \Phi^i(E, E + \Delta E) = \frac{N^i_{obs}(E, E + \Delta E)}{A^i_{eff} \Delta T^i \varepsilon_{trig}(E) \Delta E} \]

**\( \Phi \)** = Absolute differential flux (m\(^{-2}\) sr \(^{-1}\) GeV\(^{-1}\))

**\( N_{obs} \)** = Number of observed events

**\( \Delta T \)** = Exposure time (s)

27 days (79 intervals, in May 2011-May2017)

**\( A_{eff} \)** = Effective acceptance (m\(^2\) sr)

**\( \varepsilon_{trig} \)** = Trigger efficiency

If the control of \( N_{obs} \) (i.e. rejection of the background) is important for the flux measurement, the control of the detector acceptance (geometrical one + efficiencies), \( A_{eff} \varepsilon_{trig} \), and its stability in time, is important at the same level.
Results
Short-term: prominent and distinct time structures visible in both the positron spectrum and the electron spectrum and at different energies (black dashed vertical lines)

Long-term:
- both positrons and electrons show the same trend (decrease and then increase)
- the end of the decrease phase, for the two fluxes, clearly happens at different times (green dashed vertical lines)
The 3871 independent $R_e$ measurements as a function of energy and time can be described well with a logistic function:

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

- Amplitude of the transition
- Midpoint of the transition
- Duration of the transition

$A < 0 \quad \downarrow \quad A > 0$

**Notes:**
- Not well-defined polarity
- $t_{rev}$: Reversal time
- $t_{1/2}$: Half-life
- $\Delta t$: Transition duration
- $\Delta t$ from 10% to 20%

**Table:**

<table>
<thead>
<tr>
<th>Energy Range</th>
<th>$R_e$ Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 - 2.31 GeV</td>
<td>0.15 - 0.10</td>
</tr>
<tr>
<td>5 - 5.49 GeV</td>
<td>0.07 - 0.05</td>
</tr>
<tr>
<td>10.32 - 11.04 GeV</td>
<td>0.06 - 0.04</td>
</tr>
<tr>
<td>20.04 - 21.13 GeV</td>
<td>0.02 - 0.01</td>
</tr>
</tbody>
</table>
The amplitude ($C$) and the midpoint ($t_{1/2}$) of transition are energy dependent:

- $C$ consistent with 0 for $E > 20$ GeV

The duration of transition is energy independent:

- The ratio exhibits a smooth transition over $830 \pm 30$ days from one value to another

* $t_{\text{rev}}=01/July/2013$, time of the solar magnetic field reversal
The redundancy and complementarity of AMS-02 and its large acceptance and long exposure time permitted an unprecedented measurement of the $e^+$ and $e^-$ fluxes as function of time.

For the first time, the charge-sign dependent modulation has been investigated in detail by leptons alone.

The high granularity and the large range of the time measurement permitted a detailed investigation of both the short-term and long-term characteristic structures of the fluxes.
More to come!

Solar magnetic field polarity reversal

11 years cycle

Solar magnetic field polarity reversal

A<0

A>0

Data already collected and being analyzed

Positron flux (m^{-2} sr^{-1} s^{-1} GeV^{-1})


1.01 – 1.22 GeV

2.00 – 2.31 GeV

5.00 – 5.49 GeV

Positron flux (m^{-2} sr^{-1} s^{-1} GeV^{-1})
Stay tuned!