Distinctive Properties of Cosmic Electrons and Positrons Measured by AMS on ISS

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on behalf of the AMS Collaboration

July 6, 2018 ICHEP, Seoul
Electrons and Positrons in the Cosmos

- Electrons are produced and accelerated in SNR together with proton, Helium. They are primary cosmic rays that travel through the galaxy and detected by AMS.
- These particle interact with the interstellar matter and produce secondary source of anti-particle: positron, anti-protons etc. They are much less abundant in astrophysics process.
- New physics sources like Dark Matter produce both particles and antiparticles in equal amount.

Measuring antiparticles are much more sensitive to Dark Matter
Positron and electron fluxes before AMS

\[ \Phi_{e^+} E^3 \] [m\(^{-2}\)s\(^{-1}\)sr\(^{-1}\)GeV\(^{-1}\)] vs Energy [GeV]

- **Electron**
  - PAMELA
  - Fermi-LAT
  - MASS
  - CAPRICE
  - HEAT

- **Positron**
  - PAMELA
  - Fermi-LAT
  - MASS
  - CAPRICE
  - HEAT
Electrons and Positrons Identification

- Maximum Detectable Rigidity 2.0 TV for Z=1
- Independent Momentum and Energy measurement provide unique particle identification capability

- Electron charge confusion:
  - Large angle scattering,
  - Interaction with detector materials.
- Identified and measured from data using Charge confusion estimator $\Lambda_{CC}$
**Electrons and Positrons Identification**

- Identify $e^\pm$ from protons using transition radiation
- Combine 20 layers proportional tubes signal into TRD estimator $\Lambda_{TRD}$
- Reject protons with high efficiency

**Proton separation power @ 90% $e^\pm$ efficiency**

![Graph showing proton rejection vs. momentum (GeV/c)](image-url)

- 70%
- 90%
Electrons and Positrons Identification

- ECAL: $17 \times 0$, TeV Precision 3D measurement of the energy and shower development of electrons and positrons.
- ECAL proton separation power $> 10^4$: remove majority of the proton backgrounds.

TRD and ECAL are separated by the Magnet
They have independent particle identification: combined rejection $> 1$ in $10^6$
Measuring Positron and Electron

• For each bin, number of $e^+$ and $e^-$ are obtained from a fit to data sample in $(\Lambda_{TRD} - \Lambda_{CC})$ plane
• Precision determination of Signal and Background from Data
  • Positron Signal are clearly identified in the signal region of $\Lambda_{TRD}$ and $\Lambda_{CC}$
  • Proton: identified by TRD estimator $\Lambda_{TRD}$
  • Electron charge confusion measured from data using Charge confusion estimator $\Lambda_{CC}$

Fit to Data, Positive Rigidity, 237 – 290 GeV

In 6.5 Years: 28.1 million electrons, 1.9 million positrons
Electron, Positron Flux Measurement

\[ \Phi_{e^\pm}(E) = \frac{N_{e^\pm}(E)}{A_{\text{eff}}(E) \cdot \varepsilon_{\text{trig}}(E) \cdot T(E) \cdot \Delta E} \]

Major Systematic Errors:

- **Charge confusion:**
  - Measured directly from data. Good agreement between data and Monte Carlo. The difference is taken as systematic error.

- **Selection, Template definition:**
  - The measurement is stable over wide ranges of the selections.

- **Effective Acceptance:**
  - Estimated from MC, Small correction applied based on efficiency measured from Data. Systematic uncertainties: 2% ~ 3%

- **Energy Measurement:**
  - Uncertainty in the absolute energy scale: \(~2\% \text{ at } [10, 300] \text{ GeV}, \sim3\% \text{ at } 1\text{TeV}\)

Statistical error are larger than systematic error (> 30 GeV for e\(^+\), >200GeV for e\(^-\)
Latest result based on 30 million $e^+, e^-$

- The electron flux and positron flux are different in amplitude and energy behavior.
- Both spectra show change of behavior at $\sim30$GeV
- Positron shows drop-off at 300GeV
Latest result based on 30 million $e^+$, $e^-$

- Drop-off of $e^+$ at 300GeV does not correspond to the same behavior in $e^-$

Not a propagation effect: Additional source of cosmic ray positron and electron

Preliminary data, refer to upcoming AMS PRL publication
Additional source of cosmic ray Electron

AMS Electron flux disagree with conventional cosmic ray model expectation. Indicates additional primary source of electron starting ~30GeV

However, due to large background and its uncertainties from conventional cosmic ray electron, it is difficult to extract source contribution from electron flux alone.
Primary source of cosmic ray Positron

- 1.9 million positrons

The positron flux by far exceeds the prediction from collision of cosmic rays, requiring a primary source of $e^+$

Preliminary data, refer to upcoming AMS PRL publication
Models to explain the AMS Positron Flux

1) Particle origin: Dark Matter
2) Modified Propagation of Cosmic Rays
3) Astrophysics origin: Pulsars, SNRs

The AMS results appear to be in agreement 1.2 TeV Dark Matter Model

- 1.9 million positrons

Preliminary data, refer to upcoming AMS PRL publication
Positron excess also can be expressed in terms of the positron fraction

\[ \Phi_{e^+} / (\Phi_{e^+} + \Phi_{e^-}) \]

- 1.9 million positrons

Alternative Models to explain the AMS Measurements

• Modified Propagation of Cosmic Rays

Examples:

Explaining the AMS positron fraction (grey circle) as propagation effects.

This requires a specific energy dependence of the B/C ratio ruled out by AMS B/C measurement

AMS: 11 million nuclei

The observed features of the AMS data cannot be explained by propagation effects
Alternative Models to explain the AMS Measurements
New Astrophysical sources (Supernova Remnants)

We have been trying (late last night) to get better fits to the new data but it is not easy… perhaps our model is too simple and some further refinements are necessary. This is justicied now that we have precision data from AMS.

<table>
<thead>
<tr>
<th>Model parameter tuned to fit the positron flux data</th>
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<tbody>
<tr>
<td>$e^+$</td>
</tr>
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<td>$E^3 I_{e^+} \text{[GeV}^2 \text{cm}^{-2} \text{s}^{-1}\text{sr}^{-1}]$</td>
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<td>Kinetic Energy [GeV/n]</td>
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HAWC rules out that the positron excess is from nearby pulsars

In addition, AMS Measurement of positron, electron anisotropy will distinguish and constrain Pulsar origin of high energy $e^\pm$
Measuring positron flux behavior at high energy is key to understanding their origin.

Combining last 3 points ($E > 370$ GeV), 2-sigma deviation from $\Phi \propto E^{-3}$

**Positron spectrum beyond the turning point**

- **1.9 million positrons**
  Preliminary data, refer to upcoming AMS PRL publication

**Graphical Elements**
- $\Phi_{e^+}E^3 \left( m^{-2} \text{sr}^{-1} \text{s}^{-1} \text{GeV}^2 \right)$
- Energy [GeV]
- 2-sigma

- 1.2 TeV Dark Matter + Collision of Cosmic Rays
- Collision of Cosmic Rays
By 2024, AMS will collect 4 million positrons.

By 2024, we will extend the measurements to 2 TeV and reaches 5 sigma significance.
Conclusion

• The individual positron and electron fluxes are measured to 1 TeV with 28.1 million electrons and 1.9 million positrons.
• The precision measurement indicates primary source of cosmic ray electron and positron
• Positron flux exhibits a cutoff at high energy: Above 370 GeV, Positron flux deviates from $\Phi \propto E^{-3}$ with 2 sigma significance.
• By continuing the measurement to 2024, we will be able to extend to higher energy and determine the origin of high energy positrons.
Separation of positive and negative charges

- **Electron charge confusion:** Large angle scattering, interaction with detector materials. Well reproduced by the Monte Carlo.

- **Identified and measured from data:** Evaluate charge sign measurement at high energy using **Charge confusion estimator**: Information from Tracker, TOF and ECAL, including Energy-Momentum matching

![Graph showing separation of positive and negative charges](https://via.placeholder.com/150)

- **Positron Signal**
- **Electron Background**
- **Reject**
A sample of papers on AMS data from more than 2000 publications

**Dark Matter**

1. J. Kopp, Phys. Rev. D 88, 076013 (2013);
10. Y. Zhao and K.M. Zurek, JHEP 1407 (2014) 017

*and many other excellent papers…*

**New Propagation Models**


*and many other excellent papers…*

**New Astrophysical Sources**


*and many other excellent papers…*
Starting from 30 GeV, electron flux require additional primary source. However, due to large background from conventional cosmic ray electron. It is difficult to extract source contribution from electron flux alone.

Preliminary data, refer to upcoming AMS PRL publication.

Additional source of cosmic ray Electron

\[ \Phi_e E^3 \text{[m}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{GeV}^2] } \]

Energy [GeV]

GARPROP parametrization

M. Boschini et al., APJ, 854, 94 (2018)
The Electron and Positron spectral indices

- Positrons and Electrons both show hardening from ~30GeV
- Positron shows softening/cut-off effect at 300GeV
- Softening of $e^+$ does not correspond to softening in $e^-$: Not a propagation effect.

Additional source of cosmic ray positron and electron
Measurements of electrons and positrons in AMS

TOF:
• Down-going particle $\beta>0.8$

TRD:
• TRD estimator identified as $e^\pm$

Tracker and magnet:
• Provide accurate momentum measurement
• Charge $|Z|=1$ particle

ECAL:
• Provide accurate energy measure
• Remove bulk of the proton.