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

Cheng ZHANG / IHEP
on behalf of AMS Collaboration

Daejeon, Korea 28 August 2018
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 particles interact with the interstellar matter and produce secondary source of anti-particle: positrons etc. They are much less abundant in astrophysics process.
- New physics sources like Dark Matter produce both particles and antiparticles.


Measuring antiparticles are much more sensitive to Dark Matter
**AMS: a unique TeV precision, magnetic spectrometer in space**

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

**Silicon Tracker:** Z, P

**ECAL:** E of $e^+$, $e^-$

**TOF:** Z, E

**Magnet:** $\pm Z$

**RICH:** Z, E

- Particles and nuclei are defined by their charge (Z) and energy (E or P).
- Z and P are measured independently by the Tracker, RICH, TOF and ECAL.
Silicon Tracker and Magnet

1.4 kG

Unique feature of AMS

Normalized entries

Protons

Electrons

L1 to L9: 3 m level arm;
single point resolution 10 μm;
Maximum Detectable Rigidity(MDR) 2.0 TV for Z=1
Positron identification in AMS

- Proton rejection $10^3$ to $10^4$ with TRD

- Proton rejection is above $10^4$ with ECAL and tracker

- TRD and ECAL is separated by magnet, they have independent proton rejection
Calibration of the AMS Detector

Test beam at CERN SPS: p, e\(^{\pm}\), \(\pi^{\pm}\), 10–400 GeV

Computer simulation: Interactions, Materials, Electronics

12,000 CPU cores at CERN

2000 positions
The measurement of electrons and positrons in AMS

Primary cosmic ray particle:
- $E > 1.2 \cdot \text{max cutoff}$

TOF:
- Down-going particle $\beta > 0.8$
- Charge $|Z| = 1$ particle

TRD:
- Provide proton rejection

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

ECAL:
- Provide accurate energy measurement.
- Provide proton rejection with 3D shower shape
Analysis method to determine the number of $e^+$

- ECAL selection to remove bulk of the proton background.
- For each bin, fit templates to positive data sample in $(\Lambda_{TRD} - \Lambda_{CC})$ plane
- Positron signal template from data using electrons
- Proton background template from proton data
- Charge confusion electron template from electron MC

![Data and Fit Graphs]

$149 < E < 170$ GeV

$\chi^2/df = 342.8/497$
With 28.1 million electrons and 1.9 million positrons, the study of systematic errors is crucial

1. Charge confusion
2. Template selection
3. Template statistical fluctuation
4. Acceptance (cancelled for positron fraction analysis)
   1) Data/MC efficiency correction
   2) ECAL selection efficiency

Statistical errors dominates above 60 GeV for positron flux
Positron and electron fluxes before AMS

These are very difficult measurements
AMS positron and electron fluxes

The magnitude and energy dependence are distinctly different between positrons and electrons.

Preliminary data. Please refer to the forthcoming publication in PRL.

28.1 million $e^{-}$

1.9 million $e^{+}$

The magnitude and energy dependence are distinctly different between positrons and electrons.
The origin of cosmic electrons

The AMS accurate data can not be explained by current models

AMS: 28.1 million $e^-$

Preliminary data. Please refer to the forthcoming publication in PRL

The AMS accurate data can not be explained by current models
The origin of cosmic positrons

The AMS positron flux exceeds the prediction from collision of cosmic rays, requiring a new source of high energy positrons.

- 1.9 million positrons

Preliminary data. Please refer to the forthcoming publication in PRL.
Models to explain the AMS Positron Flux

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

- **1.9 million positrons**

Preliminary data. Please refer to the forthcoming publication in PRL

AMS data appears to be in excellent agreement with the predictions from a 1.2 TeV Dark Matter model (J. Kopp, Phys. Rev. D 88, 076013 (2013))
Positron excess also can be expressed in terms of the positron fraction

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

- 1.9 million positrons

1.2 TeV
Dark Matter
+ Collision of Cosmic Rays

Collision of Cosmic Rays

Energy [GeV]

Positron fraction \( e^+ / (e^+ + e^-) \)

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)

Model parameter tuned to fit the positron flux data

\[ e^+ \]

Energy [GeV]

Model parameter tuned to fit the B/C data

\[ e^+ \]

Energy [GeV]

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 $e^\pm$. 

*Science 358, 911-914 (2017)
Combining last 3 points ($E > 370$ GeV), 2-sigma deviation from $\Phi \propto E^{-3}$

- 1.9 million positrons

Preliminary data. Please refer to the forthcoming publication in PRL
By 2024, AMS will collect 4 million positrons.

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

Dark Matter + Collision of Cosmic Rays
Conclusion

• The individual positron and electron fluxes are measured to 1 TeV with 28.1 million electrons and 1.9 million positrons.

• Both the amplitude and energy dependence are distinctly different between positron flux and electron flux.

• Positron flux hardens from 20 GeV and exhibits a cutoff at high energy.

• Above 370 GeV, Positron flux deviates from $\Phi \propto E^{-3}$ with 2 sigma significance. By 2024 we will reach 5 sigma.

By 2024
AMS will collect
4 million positrons

1.2 TeV
Dark Matter
+ Collision of
Cosmic Rays

Collision of Cosmic Rays
Complex energy dependence of positron and electron fluxes

The spectral indices and their energy dependence are distinctly different between positrons and electrons.

\[ \Phi_{e^+} = C_{e^+} E^{\gamma_{e^+}} \]
\[ \Phi_{e^-} = C_{e^-} E^{\gamma_{e^-}} \]

Preliminary data. Please refer to the forthcoming publication in PRL.