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

Weiwei Xu / MIT
on behalf of AMS Collaboration

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Dark Matter search in space

- There are particles (protons, electrons) and antiparticles (positrons, antiprotons, anti-deuterons) in the cosmos.
- Particles are produced in many astrophysical sources.
- Antiparticles are much less abundant from astrophysical processes.
- Both particles and antiparticles can be produced by new physics sources, like Dark Matter.

Measuring antiparticles are more sensitive to Dark Matter, because the astrophysical background is much smaller.
AMS: a unique TeV precision, magnetic spectrometer in space

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

**Particles and nuclei**
are defined
by their charge ($Z$)
and energy ($E \sim P$)

**TOF:** $Z, E$

**Silicon Tracker:** $Z, P$

**Magnet:** $\pm Z$

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

**RICH:** $Z, E$

**Z and P**
are measured independently by the
Tracker, RICH, TOF and ECAL
L1 to L9: 3 m level arm;
single point resolution 10 μm;
Maximum Detectable Rigidity (MDR) 2.0 TV for Z=1

Unique feature of AMS

Protons
Electrons

Normalized entries

E_{ECAL}/P_{tracker}

Tracker
ECAL

Magnet

1.4 kG
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:
\[ p, e^\pm, \pi^\pm, \ 10-400 \text{ GeV} \]

2000 positions

12,000 CPU cores at CERN

Computer simulation:
Interactions, Materials, Electronics
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

$\chi^2/df = 342.8/497$
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
   1) Data/MC efficiency correction
   2) ECAL selection efficiency

Energy [GeV]

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.

1.9 million e$^+$

28.1 million e$^-$
Complex energy dependence of positron and electron fluxes

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

- AMS: 28.1 million $e^-$

Preliminary data. Please refer to the forthcoming publication in PRL

\[ \Phi_{e^-} \cdot E^3 [m^{-2} sr^{-1} s^{-1} GeV^2] \]

The AMS accurate data can not be explained by current models
The AMS positron flux exceeds the prediction from collision of cosmic rays, requiring a new source of high energy positrons.
The origin of cosmic positrons

- 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 spectrum beyond the turning point

- 1.9 million positrons

Preliminary data. Please refer to the forthcoming publication in PRL

Combining last 3 points (E > 370 GeV), 2-sigma deviation from $\Phi \propto E^{-3}$
By 2024, AMS will collect 4 million positrons.

By 2024, we will extend the measurements to 2 TeV and reaches 5 sigma significance.
The combined $(e^+ + e^-)$ flux measured by AMS

AMS-02
30 million $(e^+ + e^-)$
Preliminary data. Please refer to the forthcoming publication in PRL
AMS \((e^+ + e^-)\) data with a few non-magnetic detectors

Preliminary data. Please refer to the forthcoming publication in PRL.
(e^+ + e^-) data with AMS and with non-magnetic detectors

For \( \chi + \chi \rightarrow e^+, p, \gamma, \ldots \) measuring \( e^+ \) is the most sensitive way to identify \( \chi \), measuring \( (e^+ + e^-) \) is much less sensitive to \( \chi \) due to the large \( e^- \) background.
Conclusion

- The individual positron and electron fluxes are measured to 1 TeV with 28.1 million electrons and 1.9 million positrons.
- The combined (electron + positron) flux is measured to 2 TeV.
- Both the amplitude and energy dependence are distinctly different between positron flux and electron flux.
- Electron flux hardens from 30 GeV and is compatible with a single power law from 55 GeV to 1 TeV.
- 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

Collision of Cosmic Rays

1.2 TeV Dark Matter + Collision of Cosmic Rays

By 2024 we will reach 5 sigma.
Positron fraction

28.1 million $e^{-}$

1.9 million $e^{+}$

\[
\frac{\Phi_{e^{+}}}{\Phi_{e^{+}} + \Phi_{e^{-}}}
\]
Latest AMS Positron fraction results appears to be in excellent agreement with Dark Matter model.

- 1.9 million positrons

Positron fraction $= \frac{e^+}{e^+ + e^-}$

$\Phi e^+ \over \Phi e^+ + \Phi e^-$

Preliminary Data. Please refer to the AMS forthcoming publication in PRL.