Towards Understanding the Origin of Cosmic-Ray $e^+$
Nikolas Zimmermann on behalf of the AMS collaboration
1. Physikalisches Institut - RWTH Aachen - 11.07.2019 | EPS HEP 2019, Ghent
In 8 years, over 140 billion charged cosmic rays have been measured by AMS.
AMS: a unique TeV precision multi-purpose spectrometer in space

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

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

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

**Magnet**: $ \pm Z$

**TOF**: $Z$, $E$

**RICH**: $Z$, $E$

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

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

Charge-confusion:
Misidentification of rigidity sign

Identified and measured from data by multi-variate estimator $\Lambda_{cc}^e$
Transition Radiation Detector

**Single** TRD layer:
Fleece-Radiator and
Tubes filled with Xe/CO₂

Combining all 20 layers

\[ \text{TRD estimator} = -\ln\left(\frac{P_e}{P_e + P_p}\right) \]

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Electromagnetic Calorimeter

A precision, 17 $X_0$ three-dimensional measurement of the directions and energies of electrons and positrons up to the TeV regime.

Test Beam Results
TRD + ECAL Proton rejection

TRD > $10^2$

ECAL > $10^4$

Typically, 1 in 10,000 protons may be identified as a positron

TRD + ECAL are independent subdetectors.
Combined rejection power exceeds $10^6$
→ Allows to measure positron flux with sub-percent accuracy

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Example: Extraction of positron counts @ 290 – 370 GeV

In each energy bin, the number of positrons is extracted from a 2D template fit in the \((\Lambda_{\text{TRD}} - \Lambda_{\text{cc}})\) plane. Positrons are identified by both \(\Lambda_{\text{TRD}}\) and \(\Lambda_{\text{cc}}\). Protons are identified by \(\Lambda_{\text{TRD}}\) and charge-confused electron by \(\Lambda_{\text{cc}}\).
Results

1.9 Million positrons in 6.5 years data
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Model-independent interpretation

\[ \Phi^{e^+}(E) = \begin{cases} 
C(E/E_0)^\gamma & E \leq E_0 \\
C(E/E_0)^\gamma(E/E_0)^{\Delta \gamma} & E > E_0 
\end{cases} \]

\[ E_0 = 25.2 \pm 1.8 \text{ GeV} \]

Start of rise

\[ E_0 \text{ with its } 68\% \text{ C.L. band} \]

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Model-independent interpretation

\[ E_0 = 284^{+91}_{-64} \text{ GeV} \]

Start of fall

\[ \Phi_{e^+}(E) = \begin{cases} 
C(E/E_0)^\gamma & E \leq E_0 \\
C(E/E_0)^\gamma (E/E_0)^{\Delta\gamma} & E > E_0 
\end{cases} \]

AMS-02 data
Secondary production
→ Spectral breaks unrelated to solar modulation
(Time variation indicated by red band stops at > 20 GeV)
Minimal interpretation: two power laws, with exponential cut-off

\[ \Phi_{e^+}(E) = \frac{E^2}{\bar{E}^2} \left[ C_d (\hat{E}/E_1)^{r_d} + C_s (\hat{E}/E_2)^{r_s} \exp(-\hat{E}/E_s) \right] \]
Cut-off $E_s$ established with more than 4 sigma confidence

$E_s = 812^{+310}_{-180}$ GeV
Possible origin of the cut-off: dark-matter

DM self-annihilation would lead to a sharp cut-off in the flux (“kinematic edge”).

Models using astrophysical sources such as pulsar were constructed, leading to similar positron fluxes...

→ How to disentangle?
Possible origin of the cut-off: dark-matter

AMS-02 (2019)
Projection to 2024 based on DM model
DM model
J. Kopp, Phys. Rev. D 88 (2013) 076013

AMS-02 will continue to measure until the end of the ISS lifetime, at least 2024.

By 2024, the positron flux will extend past 1 TeV, giving the possibility to measure the flux past the cut-off.
Anisotropy

Astrophysical point sources will imprint a higher anisotropy on the arrival directions of energetic positrons than a smooth dark matter halo.

A large-acceptance analysis, with 4 times the positron statistics is under preparation. This will improve the limits by a factor 2, needed for sub-percent sensitivity.

Extending the positron flux measurement past 1 TeV and improving the anisotropy analysis is necessary to disentangle pulsar / DM hypothesis.

Stay tuned for new results!
Summary

- New positron flux results were published extending the energy range to 1 TeV
- Two spectral breaks were identified:
  - \( E_0 = 25.2 \pm 1.8 \) GeV  
    Start of rise  
  - \( E_0 = 284^{+91}_{-64} \) GeV  
    Start of fall
- First time report of a cut-off in the positron flux at 812 GeV, with more than 4 sigma confidence
  - \( E_s = 812^{+310}_{-180} \) GeV

Thanks for your attention!