Precision measurement of the positron fraction with the Alpha Magnetic Spectrometer

A. Kounine / MIT on behalf of the AMS Collaboration
AMS: A TeV precision, multipurpose spectrometer in space.

Positron fraction: 
\[ \frac{N^+}{N^+ + N^-} \]

Z, P are measured independently from Tracker, RICH, TOF and ECAL
Transition Radiation Detector.

Leak rate: CO2 ≈ 5 μg/s
Storage: 5 kg, >20 years lifetime

Identify e⁺, reject P

Fleece–Radiator
LRP 375 BK (ATLAS)
0.06 g/cm³

reported by H. Gast, ICRC
TRD performance on ISS

TRD estimator = -\ln(P_e/(P_e+P_p))
Proton rejection at 90% e⁺ efficiency

TRD performance on ISS

- ISS data

Rigidity (GV)
Silicon Tracker

Test Beam

MDR ~2.0 TV
E / |p| matching

Reported by P. Zuccon and by C. Delgado, ICRC
Electromagnetic Calorimeter

A precision, $17 \times X_0$, TeV, 3D measurement of the directions and energies of light rays and electrons

Test Beam Results

\[
\frac{\sigma (E)}{E} = \frac{10.4}{\sqrt{E}} + 1.4\%
\]

50,000 fibers, $\phi = 1$ mm distributed uniformly
Inside 1,200 lb of lead

Reported by S. Di Falco, ICRC
Separation of protons and electrons with ECAL

Boostered Decision Tree, BDT:
19 variables describing 3D shower shape combined
(B. Roe et al., NIM A543 (2005) 577)

ISS data: 83–100 GeV

fraction of events

\( \varepsilon_e = 90\% \)
Data from ISS: Proton rejection using the ECAL

![Graph showing proton rejection as a function of momentum in GeV/c.](image)
To date AMS collected over 35 billion events

25 billion events are used in the present analysis

25 month of AMS operations
Event selection.

- **DAQ:** efficiency > 50% (no SAA)

- **Geomagnetic cutoff:**
  \( E > 1.2 \cdot \text{max cutoff} \)

- **TRACKER:**
  - Track quality
  - geometrical match with ECAL shower

- **TRD:** at least 15 hits

- **TOF:** downgoing particle,
  \( \beta > 0.8, \quad 0.8 < Z < 1.4 \)

- **ECAL:**
  - shower axis within the fiducial ECAL volume
  - electromagnetic shape of the shower
Event selection: ECAL BDT

ISS data: 83–100 GeV

Selection: BDT > -0.8
Selection efficiency is high, ~90%, and uniform in a wide energy range, 2–400 GeV

\[ \text{Ne}^\pm \approx 6,800,000 \quad \text{Np} \approx 700,000 \]
Analysis: 2D fit to measure $\text{Ne}^{\pm}$ and $\text{Np}$

2D reference spectra for the signal and the background are fitted to data in the [TRD estimator - $\log(E/|P|)$] plane.

The method combines redundant information from TRD, ECAL, and Tracker; and provides much better statistical accuracy compared to cut-based analysis.
Results of the fit:
The TRD Estimator shows clear separation between protons and positrons with a small charge confusion background.

\[ \chi^2/\text{ndof} = 0.83 \]
Results of the fit: in the signal region only 1 % of protons

\[ \text{Data on ISS} \]

\[ \text{Fit} \]

\[ \text{Positron} \]

\[ \text{Proton} \]

\[ \text{Charge confusion} \]

\[ \chi^2/d.f. = 0.60 \]

TRD Estimator < 0.75

(83.2-100 GeV)
Systematic error on the positron fraction:
1. acceptance asymmetry

Difference between positron and electron acceptance due to known minute tracker asymmetry
The measurement is stable over wide variations of the cuts in the TRD identification, ECAL Shower Shape, \( E \) (from ECAL) matched to \(|P|\) (from the Tracker), ... For each energy bin, over 1,000 sets of cuts were analyzed.
Event migration effects are obtained by folding the measured spectra of positrons and electrons with the ECAL energy resolution.

Bin width: $2\sigma$ at 5 GeV; $4\sigma$ at 50 GeV; $8\sigma$ at 100 GeV; $19\sigma$ at 300 GeV.

Systematic error on the positron fraction:

$$\frac{10.4}{\sqrt{E}} \pm 1.4$$
Systematic error on the positron fraction:

4. Reference spectra

Definition of the reference spectra is based on pure samples of electrons and protons of finite statistics.
Two sources: large angle scattering and production of secondary tracks along the path of the primary track. Both are well reproduced by MC. Systematic errors correspond to variations of these effects within their statistical limits.
### AMS Result: Measurement of the positron fraction

#### Positron events, positron fraction in each energy bin

<table>
<thead>
<tr>
<th>Energy [GeV]</th>
<th>$N_{e^+}$</th>
<th>Fraction</th>
<th>$\sigma_{\text{stat.}}$</th>
<th>acceptance</th>
<th>event selection</th>
<th>bin-to-bin migration</th>
<th>reference spectra</th>
<th>charge confusion</th>
<th>total systematic uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00-1.21</td>
<td>9335</td>
<td>0.0842</td>
<td>0.0008</td>
<td>0.0005</td>
<td>0.0009</td>
<td>0.0008</td>
<td>0.0001</td>
<td>0.0005</td>
<td>0.0014</td>
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<td>1.97-2.28</td>
<td>23893</td>
<td>0.0642</td>
<td>0.0004</td>
<td>0.0002</td>
<td>0.0005</td>
<td>0.0002</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.0006</td>
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<tr>
<td>3.30-3.70</td>
<td>20707</td>
<td>0.0550</td>
<td>0.0004</td>
<td>0.0001</td>
<td>0.0003</td>
<td>0.0000</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.0004</td>
</tr>
<tr>
<td>6.56-7.16</td>
<td>13153</td>
<td>0.0510</td>
<td>0.0004</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.0002</td>
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<tr>
<td>09.95-10.73</td>
<td>7161</td>
<td>0.0519</td>
<td>0.0006</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.0002</td>
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<tr>
<td>19.37-20.54</td>
<td>2322</td>
<td>0.0634</td>
<td>0.0013</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.0003</td>
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<tr>
<td>30.45-32.10</td>
<td>1094</td>
<td>0.0701</td>
<td>0.0022</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.0000</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0003</td>
</tr>
<tr>
<td>40.00-43.39</td>
<td>976</td>
<td>0.0802</td>
<td>0.0026</td>
<td>0.0002</td>
<td>0.0005</td>
<td>0.0000</td>
<td>0.0001</td>
<td>0.0004</td>
<td>0.0007</td>
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<tr>
<td>50.87-54.98</td>
<td>605</td>
<td>0.0891</td>
<td>0.0038</td>
<td>0.0002</td>
<td>0.0006</td>
<td>0.0000</td>
<td>0.0001</td>
<td>0.0004</td>
<td>0.0008</td>
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<tr>
<td>64.03-69.00</td>
<td>392</td>
<td>0.0978</td>
<td>0.0050</td>
<td>0.0002</td>
<td>0.0010</td>
<td>0.0000</td>
<td>0.0002</td>
<td>0.0007</td>
<td>0.0013</td>
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<tr>
<td>74.30-80.00</td>
<td>276</td>
<td>0.0985</td>
<td>0.0062</td>
<td>0.0002</td>
<td>0.0010</td>
<td>0.0000</td>
<td>0.0002</td>
<td>0.0010</td>
<td>0.0014</td>
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<tr>
<td>86.00-92.50</td>
<td>240</td>
<td>0.1120</td>
<td>0.0075</td>
<td>0.0002</td>
<td>0.0010</td>
<td>0.0000</td>
<td>0.0003</td>
<td>0.0011</td>
<td>0.0015</td>
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<tr>
<td>100.0-115.1</td>
<td>304</td>
<td>0.1118</td>
<td>0.0066</td>
<td>0.0002</td>
<td>0.0015</td>
<td>0.0000</td>
<td>0.0003</td>
<td>0.0015</td>
<td>0.0022</td>
</tr>
<tr>
<td>115.1-132.1</td>
<td>223</td>
<td>0.1142</td>
<td>0.0080</td>
<td>0.0002</td>
<td>0.0019</td>
<td>0.0000</td>
<td>0.0004</td>
<td>0.0019</td>
<td>0.0027</td>
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<tr>
<td>132.1-151.5</td>
<td>156</td>
<td>0.1215</td>
<td>0.0100</td>
<td>0.0002</td>
<td>0.0021</td>
<td>0.0000</td>
<td>0.0005</td>
<td>0.0024</td>
<td>0.0032</td>
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<tr>
<td>151.5-173.5</td>
<td>144</td>
<td>0.1364</td>
<td>0.0121</td>
<td>0.0002</td>
<td>0.0026</td>
<td>0.0000</td>
<td>0.0006</td>
<td>0.0045</td>
<td>0.0052</td>
</tr>
<tr>
<td>173.5-206.0</td>
<td>134</td>
<td>0.1485</td>
<td>0.0133</td>
<td>0.0002</td>
<td>0.0031</td>
<td>0.0000</td>
<td>0.0009</td>
<td>0.0050</td>
<td>0.0060</td>
</tr>
<tr>
<td>206.0-260.0</td>
<td>101</td>
<td>0.1530</td>
<td>0.0160</td>
<td>0.0003</td>
<td>0.0031</td>
<td>0.0000</td>
<td>0.0013</td>
<td>0.0095</td>
<td>0.0101</td>
</tr>
<tr>
<td>260.0-350.0</td>
<td>72</td>
<td>0.1550</td>
<td>0.0200</td>
<td>0.0003</td>
<td>0.0056</td>
<td>0.0000</td>
<td>0.0018</td>
<td>0.0140</td>
<td>0.0152</td>
</tr>
</tbody>
</table>
The data show that the positron fraction is steadily increasing from 10 to \(\sim250\) GeV, but, from 20 to 250 GeV, the slope decreases by an order of magnitude.

- AMS-02 (6.8 million \(e^+, e^-\) events)
- 8\% of total Data to 2028

No fine structure in the spectrum
The agreement between the data and the model shows that the positron fraction spectrum is consistent with $e^\pm$ fluxes each of which is the sum of its diffuse spectrum and a single common power law source.

Physics Example: Comparing data with a minimal model.

\[
\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}
\]

\[
\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}
\]

$\chi^2/d.f. = 28.5/57$
A fit to the data in the energy range 1 to 350 GeV yields:

\[ \gamma_{e^-} - \gamma_{e^+} = -0.63 \pm 0.03, \ i.e., \ the \ diffuse \ positron \ spectrum \ is \ less \ energetic \ than \ the \ diffuse \ electron \ spectrum; \]

\[ \gamma_{e^-} - \gamma_S = 0.66 \pm 0.05, \ i.e., \ the \ source \ spectrum \ is \ more \ energetic \ than \ the \ diffuse \ electron \ spectrum; \]

\[ C_{e^+}/C_{e^-} = 0.091 \pm 0.001, \ i.e., \ the \ weight \ of \ the \ diffuse \ positron \ flux \ amounts \ to \ \sim 10\% \ of \ that \ of \ the \ diffuse \ electron \ flux; \]

\[ C_S/C_{e^-} = 0.0078 \pm 0.0012, \ i.e., \ the \ weight \ of \ the \ common \ source \ constitutes \ only \ \sim 1\% \ of \ that \ of \ the \ diffuse \ electron \ flux; \]

\[ 1/E_s = 0.0013 \pm 0.0007 \ \text{GeV}^{-1}, \]

\[ \text{corresponding \ to \ a \ cutoff \ energy \ of} \ 760^{+1000}_{-280} \ \text{GeV}. \]
Comparison at high energies

Positron fraction

Comparison at high energies

$e\pm$ energy [GeV]
In conclusion, the first 6.8 million primary positron and electron events collected with AMS on the ISS show:

I. At energies < 10 GeV, a decrease in the positron fraction with increasing energy.

II. A steady increase in the positron fraction from 10 to ∼250 GeV.

III. The determination of the behavior of the positron fraction from 250 to 350 GeV and beyond requires more statistics.

IV. The slope of the positron fraction versus energy decreases by an order of magnitude from 20 to 250 GeV and no fine structure is observed. The agreement between the data and the model shows that the positron fraction spectrum is consistent with $e^\pm$ fluxes each of which is the sum of its diffuse spectrum and a single common power law source.

These observations show the existence of new physical phenomena, whether from a particle physics or an astrophysical origin.
Electron $E=982$ GeV
Run/Event 1329775818/60709

Positron $E=636$ GeV
Run/Event 133119-743/56950

Front view
Side view

Energy (GeV)

z axis (cm)

y axis (cm)

x axis (cm)