Measuring the $e^+ / e^-$ fluxes with AMS-02 on the ISS

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Motivation

![Graph showing positron fraction versus energy](image)

- AMS-02
- PAMELA
- Fermi

**Positrons:** $\chi + \chi \rightarrow e^+ + \ldots$

*Collision of Cosmic Rays*

L. Cholis et al., JCAP 0912 (2009) 007
AMS-02: A TeV precision multipurpose spectrometer

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

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

- TRD Identify $e^+$, $e^-$
- Silicon Tracker $Z$, $P$
- ECAL $E$ of $e^+$, $e^-$
- TOF $Z$, $E$
- Magnet $\pm Z$
- RICH $Z$, $E$
AMS-02 Transition Radiation Detector

- 20 layers (5248 tubes)
- Xe/CO₂ gas mixture

ISS data 83 - 100 GeV

Normalized probability

TRD Estimator

εₑ⁻ = 90%
AMS-02 Sillicon Tracker

- 9 tracker planes
- Coordinate resolution 10 $\mu$m
- Inner tracker alignment stability monitored using IR laser beam
- Outer tracker planes (1 / 9) aligned using cosmic-rays in 2 minute window
- MDR $\sim$ 2 TV for electrons

Residual in layer 1

![Residual in layer 1 graph]

$\sigma = 10 \, \mu$m
AMS-02 Electromagnetic Calorimeter

- 50,000 fibers, diameter of 1mm distributed uniformly inside 600 kg of lead
- $17X_0$ measurement of $e^{+/ -}$ energies up to TeV
- Calibration in CERN testbeam

![Calorimeter Image]

![Energy Resolution Graph]

$$\sqrt{\left(\frac{10.4}{E}\right)^2 + (1.4)^2}$$

Analysis flow: Prepare $e^+ / e^-$ sample

Geometric acceptance
\[ \sim 550 \text{ cm}^2 \text{ sr} \]

ECAL + Tracker provide $p^+$ rejection $\sim 10^4$

- ECAL / Tracker (E / P matching)
- ECAL shower shape

ISS data: 83-100 GeV

$\epsilon_{e^-} = 90\%$

Flux calculation

169.86 - 197.69 GeV

- Determine acceptance, efficiencies, measuring time —> calculate flux

\[
\Phi(E) = \frac{N_{\text{particle}}(E)}{dE \times A(E) \times \epsilon(E) \times T(E)}
\]
Correcting wrong measurements of the charge sign

- Full Geant4 detector simulation agrees with „charge-confusion“ obtained directly from ISS data using template fit in BDT using c.c-sensitive variables

Electron / Positron flux with 5 years data

- Electron flux extended up to 1 TeV
- Positron flux extended up to 700 GeV

Compared to PRL publication in 2014

- 16,500,000 Electrons
- 1,080,000 Positrons

2016 Data
- 17,600,000 e±

\[ E^3 \text{ Flux [GeV}^2/\text{s sr m}^2 \text{ GeV]} \]

\[ e^\pm \text{ energy [GeV]} \]
Between 20 and 200 GeV the positron spectral index is significantly harder than the electron spectral index and this causes the rise in the positron fraction.
Time-dependent electron flux

AMS Electron Flux: Jun 2011 – May 2016

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

\[ E \ (GeV) \]
Time-dependent electron / positron fluxes

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

- \( e^- \) June 2011 ... May 2016
- \( e^+ \) June 2011 ... May 2016

Energy [GeV]
Time-dependent electron / positron fluxes

2.0 - 2.3 GeV

Polarity reversal of solar magnetic field
Next polarity reversal expected in 2024

Electrons PAMELA

Electrons AMS

Positrons AMS
After the reversal of the solar magnetic field in 03/2013 it takes $(8 \pm 1.5)$ month till this has a visible effect on the $e^+/e^-$ ratio. It takes $(21 \pm 1)$ month to stabilize the $e^+/e^-$ ratio again.
Summary

- $e^- / e^+$ flux energy ranges were extended with the 5y dataset
- $e^- / e^+$ flux are significantly different in magnitude and energy dependance
- The differing behavior of the spectral indices versus energy is a new observation and provides important information on the origins of cosmic-ray electrons and positrons
- The reversal of the solar magnetic field polarity shows a drastic charge-sign dependency of the solar modulation

Stay tuned for upcoming results from AMS-02!
Backup Calibration
Extensive tests and calibration at CERN
# Test beam calibration @ CERN

## AMS in SPS Test Beam, 2010

<table>
<thead>
<tr>
<th>Particle</th>
<th>Momentum (GeV/c)</th>
<th>Positions</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>400 + 180</td>
<td>1,650</td>
<td>Full Tracker alignment, TOF calibration, ECAL uniformity</td>
</tr>
<tr>
<td>Electrons</td>
<td>100, 120, 180, 290</td>
<td>7 each</td>
<td>TRD, ECAL performance study</td>
</tr>
<tr>
<td>Positrons</td>
<td>10, 20, 60, 80, 120, 180</td>
<td>7 each</td>
<td>TRD, ECAL performance study</td>
</tr>
<tr>
<td>Pions</td>
<td>20, 60, 80, 100, 120, 180</td>
<td>7 each</td>
<td>TRD performance to 1.2 TeV</td>
</tr>
</tbody>
</table>
Backup
TRD
TRD performance on ISS

- ISS data
TRD lifetime on ISS

Xe storage: 49kg  CO2 Storage: 5kg

➤ Lifetime: 5000g / 0.44g/d = 11364d = 31y
Improved understanding of the operation of the detector, led to a factor $\sim 2$ improvement of the proton rejection.
Backup Tracker
Tracker alignment accuracy

Alignment accuracy of the 9 Tracker layers over 40 months

Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Layer 7
Layer 8
Layer 9
Backup
ECAL
ECAL energy resolution

**Absolute Energy Scale for $e^\pm$ (at the top of AMS)**

Verified using MIPs and $E/p$; compared to the test beam. In the test beam range (10-290 GeV) the uncertainty is 2%. It increases to 5% at 0.5 GeV and 1 TeV.

![Graph showing energy scale uncertainty vs energy](image)
ECAL angular resolution

\[ \Delta \theta_{68} = \sqrt{\left(\frac{5.8}{E}\right)^2 + (0.23)^2} \]
Proton rejection: 1. ECAL 3-D Shower Shape of $e^{\pm}$
2. $P$ from the Tracker = $E$ from ECAL
Backup
Physics Results
Electron / Positron flux

- Energy [GeV]
- Flux density [GeV$^2$ m$^{-2}$ sr$^{-1}$ s$^{-1}$]

**Electrons**

- Data from different experiments: AMS-02, PAMELA, Fermi-LAT.

**Positrons**

- Data from different experiments: AMS-02, PAMELA, Fermi-LAT, MASS, CAPRICE, AMS-01, HEAT.
All-electron flux

Energy Range: 0.5 GeV to 1 TeV

AMS-02
ATIC
BETS 97&98
PPB-BETS 04
Fermi-LAT
HEAT
H.E.S.S.
H.E.S.S. (LE)
Electron / positron flux table

For the positron flux, the statistical error dominates above ~50 GeV.

For the electron flux above ~200 GeV, the systematic error and the statistical error are compatible.
Positron fraction - low energies

![Graph showing positron fraction vs energy for different experiments: AMS-02, PAMELA, AMS-01, HEAT, TS93, CAPRICE94. The graph illustrates the variation of positron fraction with energy across different energy ranges.]
Positron fraction - high energies

![Graph showing positron fraction vs energy.](image)