PAMELA and Electrons

Emiliano Mocchiutti
(INFN - Trieste)

on behalf of the PAMELA collaboration
Presentation outline

• The PAMELA experiment
• Positron fraction measurement
• Electron (e-) flux measurement
• Summary
PAMELA
Time-Of-Flight
plastic scintillators + PMT:
- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX

Electromagnetic calorimeter
W/Si sampling (16.3 X0, 0.6 λ)
- Discrimination e+ / p, anti-p / e-
  (shower topology)
- Direct E measurement for e-

Neutron detector
plastic scintillators + PMT:
- High-energy e/h discrimination

Spectrometer
microstrip silicon tracking system + permanent magnet
It provides:
- Magnetic rigidity \( R = p c / Z e \)
- Charge sign
- Charge value from dE/dx

GF: 21.5 cm² sr
Mass: 470 kg
Size: 130x70x70 cm³
Power Budget: 360W
Positrons fraction
Positron identification

- Analyzed data July 2006 – February 2008 (~500 days)
- Collected triggers ~$10^8$
- Identified ~ $9 \times 10^3$ positrons between 1.5 and 100 GeV - 180 positrons above 20 GeV

Electron/positron identification:
- rigidity (R) $\rightarrow$ SPE
- $|Z|=1$ ($dE/dx$=MIP) $\rightarrow$ SPE&ToF
- $\beta=1$ $\rightarrow$ ToF
- $e-/e+ \text{ separation (charge sign)}$ $\rightarrow$ SPE
- $e+/p \text{ separation}$ $\rightarrow$ CALO

- Dominant background $\rightarrow$ interacting protons:
  - proton spectrum harder than positron
  - $p/e+$ increase for increasing energy ($10^3 \text{ @1GV}$, $10^4 \text{ @100GV}$)

$\rightarrow$ Strong CALO selection required
Positron selection with calorimeter

Methods:

Published results:
“background estimation” method

Data from test-beams and simulations were NOT USED in any step of flight data calibration, selection and analysis

This measurement is based purely on flight data

Background estimation:
• “weak” selection criteria
• p rejection factor ~O(10^4)
• estimate p contamination
• statistical analysis (parametric bootstrap analysis with maximum likelihood fitting, wavelets, spline…)

RESULTS
Positron selection

Fraction of energy released along the track (left, hit, right) in the calorimeter

Pre-selections:
- Energy-momentum match
- Starting point of shower

Rigidity: 20-30 GV

TRK trajectory

Aufgabe: e⁻, e⁺, negatives, positives

\[ \text{Fraction of energy along the track} \]

\[ \text{number of events} \]

\[ 0 \quad 0.6 \quad 1 \]

\[ 0 \quad 0.6 \quad R_M \]
Pre-selections:
- Energy-momentum match
- Starting point of shower

Neutrons detected by ND

Fraction of charge released along the track (left, hit, right) in the calorimeter

Rigidity: 20-30 GV
Energy loss in silicon tracker detectors:
- Top: positive (mostly p) and negative events (mostly e\(^{-}\))
- Bottom: positive events identified as p and e\(^{+}\) by transversal profile method

\[
\frac{-dE}{dx} = K z^2 Z \frac{1}{A \beta^2} \left[ \frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{\text{max}}}{l^2} - \frac{\delta(\beta \gamma)}{2} \right]
\]
Background estimation from data

Pre-selections:
- Energy-momentum match
- Starting point of shower

Rigidity: 28-42 GV

Fraction of energy released along the track (left, hit, right) in the calorimeter

- **Negatives**
- **Pre-sampler** p
- **Positives**

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PAMELA Positron Fraction

Nature 458, 607 (2009)

- **PAMELA**
- **AMS**
- **HEAT94+95**
- **TS93**

**Positron fraction** \( \frac{\phi(e^+)/\phi(e^+)}{\phi(e^-)/\phi(e^-)} \)

**Energy [GeV]**

**Secondary production**
Moskalenko & Strong 1998
ApJ 493, 694

**Wino (mass 200 GeV)**
Grajek et al. 2008
astro-ph 0812.4555

**KKDM (mass 300 GeV)**
Hooper & Profumo 2007
Phys. Reports 453, 29

**Supernovae Component**
Shaviv et al. 2009
astro-ph 0902.0376

**Pulsar Component**
Yüksel et al. 2008
astro-ph 0810.2784

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Positron fraction, test beam data

Fraction of energy released along the calorimeter track (left, hit, right)

Flight data: rigidity: 20-30 GV

Test beam data
Momentum: 50GeV/c
Positron fraction, calorimeter simulation

GEANT 3 (GHEISHA)

GEANT 4 (QGSP_BIC_HP)

Preliminary!
Positron selection with calorimeter

TMVA: Toolkit for MultiVariate data Analysis
http://tmva.sourceforge.net/

TMVA host large variety of multivariate classification algorithms (cut optimization with genetic algorithm, linear and non-linear discriminant and neural networks, support vector machine, boosted decision trees, ...)

Boosted decision tree output 42-65 GeV

REAL DATA

Simulated electrons

REAL DATA

Negatives

Simulated protons

REAL DATA

Positives

Bin: 42.00 - 65.00 GeV
Boosted decision tree output 42-65 GeV

REAL DATA

Negatives

Pre-sampler protons

Positives
Positron selection, Neural Networks (MLP)

TMVA probability for classifier: MLP

100-200 GeV p rejection \( \sim 5 \times 10^5 \)
Positron fraction, MLP+BDTD

statistics improved by $\sim 2.5 \div 3$

- Nature
- MLP+BDTD (+data, no pre-sampler, improved knowledge of detectors)
Electrons ($e^-$) flux
Electron identification

- Analyzed data July 2006 – February 2008 (~500 days)
- Collected triggers \( \sim 10^8 \)
- Identified \( \sim 1.5 \times 10^4 \) electrons between 1.5 and 100 GeV

Electron/positron identification:
- rigidity (R) \( \rightarrow \) SPE
- \(|Z|=1, (dE/dx=\text{MIP}) \rightarrow \) SPE&ToF
- \( \beta=1 \rightarrow \) ToF
- e-/e+ separation (charge sign) \( \rightarrow \) SPE
- \((e-/p\text{-bar separation} \rightarrow \) CALO)

\(~ \text{no background, issues:}~
- spillover protons at high energy
- spectrometer resolution
- selection efficiencies\)
Flight data: 131 GeV/c electron
Two independent energy measurements:

**Rigidity from Tracker**
- bremsstrahlung $\rightarrow$ propagation at top of payload

**Energy from Calorimeter**
- transversal and longitudinal leakage $\rightarrow$ energy corrections

$\Rightarrow$ possibility to cross-check fluxes and energy deconvolution
Energy reconstruction: calorimeter

Transversal and dead areas leakage:
- containment conditions
- energy recovered from a transversal fit (depends on energy)
- energy recovered from geometrical assumptions

Longitudinal leakage:
- Integrate a longitudinal fit of the shower
- use the calorimeter up to about the shower maximum (contained up to ~TeV)
PAMELA electron ($e^-$) flux

Demodulated spectrum

Power-law fit -- spectral index

<table>
<thead>
<tr>
<th>$\phi$=645 MeV</th>
<th>$\phi$=505 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 20 GeV</td>
<td>3.33±0.04</td>
</tr>
<tr>
<td></td>
<td>3.33±0.04</td>
</tr>
</tbody>
</table>

Demodulated with $\phi = 645$ MeV (July 2006)
Demodulated with $\phi = 505$ MeV (February 2008)
Spherical model (Gleeson & Axford 1968)

Very Preliminary!!!
Summary

- PAMELA has been in orbit and studying cosmic rays for ~35 months. >10^9 triggers registered, and >13 TB of data has been down-linked.

- High energy positron fraction (>10 GeV) increases significantly (and unexpectedly!) with energy. Primary source? Data at higher energies will help to resolve origin of rise (spillover limit ~300 GeV).

- Analysis ongoing to measure the e^- spectrum up to ~500 GeV, e^+ spectrum up to ~300 GeV and all electrum (e^- + e^+) spectrum up to ~1 TV.

• Antiproton-to-proton flux ratio (~100 MeV - ~180 GeV) shows no significant deviations from secondary production expectations
Positron fraction, beta - wavelets - MLP

- New data (beta)
- Nature
- New data (Wavelets)
- New data (Neural Network)
Fraction of charge released along the calorimeter track (left, hit, right) + Energy-momentum match Starting point of shower

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The “pre-sampler” method

CALORIMETER: 22 W planes: 16.3 $X_0$

2 W planes: $\approx 1.5 \ X_0$

20 W planes: $\approx 15 \ X_0$
NON-INTERACTING in the upper part

File: L2PAIM076506-tree.root - Pkt_num: 1350048
Progressive number: 3503
On Board Time: 61620249 [ms]
TRIGGER:
AC: CARD hit = 3, CAT hit = 0, CAS hit = 0
TRK: RIG = 80.5 [GV], CH12 = 1.63
CALO: NSTRP = 699, QTOT = 6861 [MIP]
S4: 84.9 [MIP], TOF: \( \beta = 6.891 \)
ND: Trig: 6 - Bckgr: upper = 3, lower = 9
File: L2PAM070506-tree.root - Pkt_num: 2216509
Progressive number: 35884  - S4 trigger -
On Board Time: 100664563 [ms]
TRIGGER: TOF4 CALO
AC: CARD hit = 0  CAT hit = 0  CAS hit = 2
TRK: RIG = -33.2 [GV] CH12 = 1.16
CALO: NSTRIP = 645  QTOT = 6921 [MIP]
S4: 72.2 [MIP]  TOF: β = 1.07
ND: Trig: 0  - Bckgr: upper = 11 lower = 3
Positron selection with calorimeter

test beam data
Neural network output 42-65 GeV

Negatives

Pre-sampler protons

Positives
Neural network output 42-65 GeV

Negatives

Pre-sampler protons

Positives
Positron selection with calorimeter

Rigidity: 42-65 GV

Fraction of charge released along the calorimeter track (left, hit, right)

Neutrons detected by ND

Energy-momentum match
Starting point of shower

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Background estimation from data

Rigidity: 20-28 GV

- Energy-momentum match
- Starting point of shower

![Graphs showing energy distribution for electrons and protons](image)
Positron selection

Energy loss in silicon tracker detectors:
- Top: positive (mostly p) and negative events (mostly e\textsuperscript{-})
- Bottom: positive events identified as p and e\textsuperscript{+} by trasversal profile method

\[
\frac{dE}{dx} = K Z^2 \frac{Z}{A} \beta^2 \left[ \frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{\text{max}}}{T^2} \right] \beta^2 - \frac{\delta(\beta \gamma)}{2}
\]

---

**Rigidity: 10-15 GV**

**Rigidity: 15-20 GV**

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The PAMELA Collaboration

Italy:
- Bari
- Florence
- Frascati
- Naples
- Rome
- Trieste
- CNR, Florence

Germany:
- Siegen

Sweden:
- KTH, Stockholm

Russia:
- Moscow
- St. Petersburg
<table>
<thead>
<tr>
<th></th>
<th>CAPRICE98</th>
<th>PAMELA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRACKER MDR</td>
<td>~350 GV</td>
<td>~1000 GV</td>
</tr>
<tr>
<td>CALO DEPTH</td>
<td>$7.2 X_0$</td>
<td>$16.3 X_0$</td>
</tr>
<tr>
<td>LONGITUDINAL SAMPLING</td>
<td>$0.9 X_0$</td>
<td>$0.7 X_0$</td>
</tr>
<tr>
<td>TRANSVERSAL SAMPLING (strip width)</td>
<td>$0.3 R_M$ (3.6 mm)</td>
<td>$0.2 R_M$ (2.44 mm)</td>
</tr>
<tr>
<td>PROTON REJECTION</td>
<td>$\sim 10^5$</td>
<td>$&gt;10^5$</td>
</tr>
</tbody>
</table>

Proton rejection power: C98 vs PAMELA

tested with RICH up to 50 GV

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Gamma-rays?

$\gamma/e^+ : \sim 0.1 @ 10\text{GeV}
\sim 0.2 @ 100\text{GeV}$

Positron selection requires:
A. 1 MIP (>0.2MIP) signal on S1/S2
B. no multiple paddle hit on S1/S2
C. no hit on CARD and CAT
D. clean track in TRK
(no spurious hits, no clusters not used in track fitting)

From simulations:
$\gamma/e^+$ after cuts A-B-C:
$< 4 \times 10^{-3} @ 10\text{GeV}
< 2 \times 10^{-3} @ 100\text{GeV}$
PAMELA Electron (e⁻) Flux

\[ \gamma \approx -3.28 \pm 0.05 \]

Very Preliminary!!!
Positrons with HEAT & PAMELA

Graph showing the charge ratio ($e^+/e^+$) against energy (GeV) with data points for PAMELA, HEAT00, and HEAT94+95.
Antiprotons
Antiproton identification

- Analyzed data July 2006 – February 2008 (~500 days)
- Collected triggers ~10^8
- Identified ~ 10^7 protons and ~ 10^3 antiprotons between 1.5 and 100 GeV - 100 p-bar above 20 GeV

- Antiproton/proton identification:
  - rigidity (R) → SPE
  - |Z|=1 (dE/dx vs R) → SPE&ToF
  - β vs R consistent with M_p → ToF
  - p-bar/p separation (charge sign) → SPE
  - p-bar/e⁻ (and p/e⁺) separation → CALO

- Dominant background → spillover protons:
  - finite deflection resolution of the SPE
  ⇒ wrong assignment of charge-sign @ high energy

→ Strong SPE selection required
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**Calorimeter selection**

- **Electron**
- **Hadron**

**Tracker Identification**

- **Protons (& spillover)**
- **Antiprotons**

**Strong track requirements:**

MDR > 850 GV

- Beta vs deflection graph showing e^- and p trajectories.
- Histogram showing deflection (GV^-1) with entries and MDR > 850 GV.
- Graph showing total detected energy (mip/GV) with 'Electron' and 'Hadron' regions.
- Statistics for 'hbetavsdef': Entries 2.962969*10^6, Mean = 0.4213.
PAMELA antiproton to proton ratio

Secondary Production Models

PRL 102:051101 (2009)

\[ \frac{\bar{p}}{p} \]

- Donato 2001 (DRC, \( \sigma = 500\text{MV} \))
- Moskalenko 2002 (A=0, \( \alpha = 15^\circ \))
- Ptuskin 2006 (PD, \( \sigma = 550\text{MV} \))

PAMELA

kinetic energy (GeV)
PAMELA Antiproton Flux

antiproton flux [GeV m$^{-2}$ s$^{-1}$ sr$^{-1}$]

kinetic energy [GeV]

P. Hofverberg's and A. Bruno's PhD theses

Preliminary

Bogomolov et al.
Buffington et al.
MASS 1991
BESS 1995-97
BESS 1998
BESS 1999
BESS 2000
BESS-polar 04
IMAX 1992
CAPRICE 1994
CAPRICE 1998
PAMELA (preliminary)
PAMELA (this work)
PAMELA Antiproton Flux

Preliminary

A. Bruno’s and P. Hofverberg’s PhD theses

Ptuskin et al. 2006
[Ap. J. 642 902]
PD model
DR model
DRD model

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