PAMELA results, after more Than Six Years of Cosmic Rays Investigation.

F.S. Cafagna, INFN (Italian Institute for Nuclear Physics) Bari Unit

IXth Rencontres du Vietnam 2013
Cosmology in the Planck Era
Hot Topics in General Relativity and Gravitation
PAMELA results, after more than six years of cosmic rays investigation, and indirect DM searches.

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Cosmology in the Planck Era
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PAMELA results, after more than six years of cosmic rays investigation, and indirect DM searches. 

... an experimentalist point of view ...

F.S. Cafagna, INFN (Italian Institute for Nuclear Physics) Bari Unit

IX$^{th}$ Rencontres du Vietnam 2013
Cosmology in the Planck Era
Hot Topics in General Relativity and Gravitation
Why Anti(particle)matter matters?

- **Origin and Propagation of Cosmic Rays**
- **Nature of the Dark Matter**
- **Presence of Cosmological Antimatter**

*Collisions of High Energy Cosmic Rays With the Interstellar Gas*
Why Anti(particle)matter matters?

![Graph showing the ratio of \( \bar{\rho} / \rho \) vs. kinetic energy (GeV).]

- Golden 1979
- Bogomolov 1979
- Buffington 1981

R.L. Golden

31st July 2013
Why Anti(particle)matter matters?
Why Anti(particle)matter matters?
Why Anti(particle)matter matters?

F.S. Cafagna, Rencontres du Vietnam, 31st July 2013
DM particles are stable. They can annihilate in pairs.

Primary annihilation channels

$W^-, Z^0, b, \tau^-, t, h^0, \ldots$

$W^+, Z^0, \bar{b}, \tau^+, \bar{t}, h^0, \ldots$

Decay

$e^\pm, p^{(-)}, D^{(-)}, \ldots$

Final states

$e^\pm, p^{(-)}, D^{(-)}, \ldots$

$\sigma_a = \langle \sigma v \rangle$
Why Anti(particle)matter matters?

- Detecting antimatter in the cosmic rays, at «high» (>10GeV) energies not only helps you modelling propagation or in the indirect dark matter search but also ...
- Helps in having a better control of your detectors studying systematics that could be charge dependent (we need to measure absolute fluxes ...).
Why Anti(particle)matter matters?

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- Helps in having a better control of your detectors studying systematics that could be charge dependent (we need to measure absolute fluxes ...).
- $e^+ \& e^-$ in PAMELA are also used for that.
CR antimatter detector cookbook

- Charge identification. A magnet is needed.
- Good \( \frac{e}{h} > 10^{-5} \) particle identification (positron).

Positron/Proton rejection factor > 10\(^{-5}\)

Electron flux

Proton flux x 0.01

PDG (2010)
CR antimatter detector cookbook

- Charge identification. A magnet is needed.
- Good \( (e/h > 10^{-5}) \) particle identification (positron)
- Good \( (\geq 1\text{TV}) \) Maximum Detectable Rigidity (MDR) to defeat particle spillover (pbar)

The reconstructed rigidity for which the error is 100%
CR antimatter detector: the jargon

- We like to see spectra in Rigidity or Energy.
CR antimatter detector: the jargon

- We like to see spectra in Rigidity or Energy.
- We actually measure **deflection**: \( \eta = \frac{1}{R} \) (gaussian error in the measure), convoluted with a finite resolution (MDR).
CR antimatter detector cookbook

![Graph showing antiproton flux vs. kinetic energy]

- Ptuskin et al. 2006, $\Phi=550$ MV
- Donato et al. 2001, $\Phi=500$ MV

**Data Points:**
- BESS-polar04
- BESS1995-97
- CAPRICE1994
- CAPRICE1998
- IMAX1992
- MASS1991
- PAMELA

---

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CR antimatter detector cookbook

-1 ↔ Z → +1

\[ p (\pm e^\pm) \]

\[ p \]

\[ e^- (+ p-bar) \]

"spillover" p

Deflection:
\[ \eta = 1/R \]

\(|R| \geq 100\text{GV}\)

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CR antimatter detector cookbook

- Charge identification
- Good ($\geq 1$TV) Maximum Detectable Rigidity (MDR) to defeat particle spillover ($\bar{p}$)
- Good ($e/h > 10^{-5}$) particle identification (positron)
- Redundancy to calculate efficiencies and systematic in flight (absolute fluxes)
- All other useful detectors ...
- Very low secondary background -> SPACE
PAMELA Design Performance

- **Antiprotons**: 80 MeV - 150 GeV
- **Positrons**: 50 MeV – 270 GeV
- **Electrons**: up to 400 GeV
- **Protons**: up to 700 GeV
- **Electrons + positrons**: up to 2 TeV (calorimeter alone)
- **Light Nuclei (He/Be/C)**: up to 200 GeV/n
- **AntiNuclei search**: sensitivity of $3 \times 10^{-8}$ in $^4$He/He

→ Simultaneous measurement of many cosmic-ray species
→ New energy range
→ Unprecedented statistics

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The PAMELA C.R. view

- Large flux range, from $10^{-7}$ to $10^7 \, (m^2 \cdot s \cdot sr \cdot GeV)^{-1}$
- "Large" energy range, from .5 to 1000 TeV.
- Several measurements with the same detector.
The PAMELA C.R. view

- Measurement of spectra from different particle families requires different approaches in systematics treatment and evaluation.
- Small features in spectra of high statistic particles fluxes, like H, He and e⁻, can be hint of new astrophysical effects.
- As well as distortions in the spectra of the more rare antiparticle can be indicators of not standard sources of antimatter.

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PAMELA Collaboration

Payload for Antimatter & Matter Exploration and Light nuclei Astrophysics

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

Germany: Universität Gesamthochschule Siegen
- Siegen

Sweden: KTH, Stockholm

Russia: Физический Институт им. П.Н. Лебедева / Институт ядерных проблем
- Moscow / St. Petersburg
Main requirements → high-sensitivity antiparticle identification and precise momentum measure
**PAMELA detectors**

**Main requirements** → high-sensitivity antiparticle identification and precise momentum measure

**Spectrometer**
- Microstrip silicon tracking system + permanent magnet
  - Magnetic rigidity ($R = p/c \cdot Z_e$)
  - Charge sign
  - Charge value from $dE/dx$

**Electromagnetic calorimeter**
- W/Si sampling ($16.3 \times X_0$, $0.6 \lambda_I$)
  - Discrimination $e^+/p$, $p\bar{p}/e^-$ (shower topology)
  - Direct E measurement for $e^-$

**Time-Of-Flight**
- Plastic scintillators + PMT
  - Trigger;
  - Albedo rejection;
  - Mass identification up to 1 GeV;
  - Charge identification from $dE/dX$

**GF:** 21.5 cm$^2$ sr  
**Mass:** 470 kg  
**Size:** 130x70x70 cm$^3$  
**Power Budget:** 360W

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PAMELA: the integration
The Resurs DK-1 spacecraft

- Multi-spectral remote sensing of earth’s surface
  → near-real-time high-quality images
- Built by the Space factory TsSKB Progress in Samara (Russia)
- Operational orbit parameters:
  - inclination ~70°
  - altitude ~ 350-600 km (elliptical)
- Active life >3 years
The Resurs DK-1 spacecraft

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From flight to parking position

Parking position

Satellite

PAMELA
• Launch from Baikonur: June 15th 2006, 0800 UTC. Power On: June 21\textsuperscript{st} 2006, 0300 UTC. Detectors operated as expected after launch

• PAMELA in continuous data-taking mode since commissioning phase ended on July 11\textsuperscript{th} 2006

- >6 year of data taking (~75\% live-time)
- >40 TByte of raw data downlinked
- >6x10\textsuperscript{9} triggers recorded and under analysis
Thanks to the PAMELA orbit we are able to measure different particle and antiparticle families.
Antiproton to Proton Ratio


Adriani et al., Phys. Rev. Lett. 105, 121101 (Published September 13, 2010)

Stat. & Sys. Errors plotted

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Antiproton to proton flux ratio

- Using all data till 2010 and multivariate classification algorithms about a $20\div 50\%$ of statistical increase in respect to published analysis

New results

Preliminary
Antiproton Flux

Secondary production

Stat. & Sys. Errors plotted

Adriani et al., Phys. Rev. Lett. 105, 121101
(Published September 13, 2010)
Antiproton flux predictions for a 12 GeV WIMP annihilating into different mass combinations of an intermediate two-boson state which further decays into quarks.

See also:
Antiprotons are a very relevant tool to constrain DM annihilation and decay, on a par with gamma rays for the hadronic channels. Current PAMELA data and especially upcoming AMS-02 data allow to probe large regions of the parameter space.
Positron to all electron fraction

- Using all data till 2010 and multivariate classification algorithms about a factor $2\div 3$ of statistical increase in respect to published analysis


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After April 2013, see W. Gillard talk
The latest (still) puzzling picture

Positron spectrum significantly harder than expectations from secondary production

But antiprotons in CRs are in agreement with secondary production

Preliminary


Donato et al. (PRL 102 (2009) 071301)
**Pulsar Explanation**

Contribution from diffuse mature & nearby young pulsars.

Contributions of e^- & e^+ from Geminga assuming different distance, age and energetic of the pulsar.

P. Blasi & E. Amato, arXiv:1007.4745
Contribution from pulsars varying the injection index and location of the sources.
Dark Matter Explanation

Contribution from DM annihilation.

Contribution from DM annihilation.

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Antiprotons & positrons from old SNR’s

- Positrons created as secondary products of hadronic interactions inside the sources
- Secondary production takes place in the same region where cosmic rays are being accelerated.
- Antiproton/proton and B/C increase for E > 100GeV

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Antiprotons & positrons from old SNR’s

F.S. Cafagna, Rencontres du Vietnam, 31st July 2013
Antiprotons & positrons from old SNR’s

Increase for $E > 100$ GeV/n?

B/C [unitless]

kinetic energy [GeV/n]

Preliminary

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Positron Fraction Theoretical Uncertainties

\[ \gamma = 3.54 \]  
\[ \gamma = 3.34 \]

Less significant

Most significant

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T. Delahaye et al., arXiv: 0809.5268v3
PAMELA Electron ($e^-$) flux


$\gamma = 3.18 \pm 0.05$
PAMELA $e^+$ spectra

PAMELA $e^+$ spectra

D. P. Finkbeiner et al., JCAP 1105, 002 (2011).
Secondary & primary production
(from dark matter annihilation)

T. Delahaye et al.,
Secondary & Primary productions
(from Astrophysical Sources)

Secondary production
Moskalenko & Strong 98
FERMI-GLAST

- No magnet
- Electromagnetic Imaging Calorimeter (8.5 $X_0$)
- Large Area Telescope (LAT), $\gamma$-ray detector
- 20 MeV ÷ 300 GeV
- 6500 cm$^2$ @ 1 GeV
- All sky survey instrument
- Launched: June 2008
Using the Earth magnetic field, they selected positrons and electrons and confirmed PAMELA positron fraction rise.
FERMI DM search: Dwarf galaxies

- For the first time, the WIMP cross section is reached in indirect detection.
- New promising method: Stacking data from many dwarf galaxies:
  - A. Geringer-Sameth and S. Koushiappas, PRL 2011

\[<\sigma v> \sim 3 \times 10^{-26}\text{cm}^3\text{s}^{-1}\]
FERMI DM search: Galactic Halo

\[ \langle \sigma v \rangle \sim 3 \times 10^{-26} \text{cm}^3 \text{s}^{-1} \]

Similar sensitivity as dwarf galaxy analysis for canonical DM particle annihilating to b quarks

Are the PAMELA and FERMI excess data excluded? (See fit in Cirelli et al. 2010, Nuclear Physics B, 840, 284)
FERMI DM search: Lines

- The smoking gun. A spectral line at 130 GeV.
- Confirmed in:
FERMI DM search: Lines

- FERMI do not confirm the line at 130 (133) GeV but do not completely ruled out a feature (See A. Ackerman: arXiv: 1305.5597).
- More analysis are needed with the new FERMI data release and more data from the «limb» were an effect was found.
A bright future for gamma-ray space telescopes?

GAMMA-400, 100 MeV – 3 TeV, an approved Russian γ-ray satellite. Planned launch 2017-18. Energy resolution (100 GeV) ~ 1%. Effective area ~ 0.4 m². Angular resolution (100 GeV) ~ 0.01°.


HERD: Instrument on the planned Chinese Space Station. Energy resolution (100 GeV) ~ 1%. Effective area ~ 1 - 2 m². Angular resolution (100 GeV) ~ 0.01°. Planned launch around 2020.

All three have detection of dark matter as one key science driver (and will build on the remarkable success of Fermi-LAT)

Ideal, e.g., for looking for spectral DM-induced features, like searching for γ-ray lines up to 1 TeV. If the 130 - 135 GeV structure exists, it should be seen with more than 10σ significance (L.B., G. Bertone, J. Conrad, C. Farnier & C. Weniger, JCAP, in press).

Otherwise, the parameter space of viable models will be probed with unprecedented precision – will follow the WIMP lead to the end...
Conclusions

• With PAMELA we are entered in the new era of precision measurements of (anti)particle fluxes in CR.
• PAMELA has been in orbit and studying particle and antiparticle in cosmic rays for more than 7 years. (>6x10^9 triggers registered and >35 TB of data has been down-linked).
• Antiproton-to-proton flux ratio and antiproton energy spectrum (~100 MeV - ~200 GeV) show no significant deviations from secondary production expectations.
• High energy positron fraction (>10 GeV) increases significantly with energy. It could be due to a primary source or is a DM signal?
• The e^- spectrum up to 600 GeV shows spectral features that may point to additional components.
• AMS will clarify the picture at higher energies and in the antiproton sector.
• First claim of lines in FERMI GC signal needs more investigation.
• FERMI measures already constrain part of the DM cross sections and mass.
• Exciting times are coming. Stay tuned !!!!

THANKS !!!!
Spare
DM annihilations

Resulting spectrum for positrons and antiprotons
$M_{\text{WIMP}} = 1 \text{ TeV}$

The flux shape is completely determined by:

1) WIMP mass
2) Annihilations channels

See Review talk by N. Weiner
The Fermi Gamma-ray Space Telescope

- Launched by NASA at Cape Canaveral June 11, 2008
- Routine science began August 2008
- Two instruments
  - Large Area Telescope: 20 MeV – 300 GeV
  - Gamma-ray Burst Monitor: 8 keV – 40 MeV
- Data publicly available since August 2009
- Orbit: 565 km, 25.6° inclination, circular
- Field of view = 2.4 sr (38% of 2π)
- Observe entire sky every 2 orbits = 3 hrs
- Expect thousands of sources, with spectra for hundreds
- ~0.1° resolution at 10 GeV, ~0.5° at 1 GeV, ~4° at 100 MeV

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$\text{Flux} \times E^{2.7}$

Deviations from single power law (SPL):
- Spectra gradually soften in the range $30 \div 230$ GV
- Spectral hardening @ $R \sim 235$ GV
  $\Delta \gamma \sim 0.2 \div 0.3$

SPL is rejected at 98% CL

Origin of the structures?
- At the sources: multi-populations, non-linear DSA.
- Propagation effects.

\[ \gamma_{80-232 \text{ GV}; p} = 2.85 \pm 0.015 \]
\[ \gamma_{>232 \text{ GV}; p} = 2.67 \pm 0.03 \]
\[ \gamma_{80-240 \text{ GV}; \text{he}} = 2.77 \pm 0.01 \]
\[ \gamma_{>240 \text{ GV}; \text{he}} = 2.48 \pm 0.06 \]
PAMELA Galactic H & He

\[ \gamma_{\text{CREAM}} = 2.58 \pm 0.02 \]

\[ \gamma_{\text{AMS}} = 2.74 \pm 0.01 \]

\[ \gamma_{< 200 \text{ GeV/n}} = 2.77 \pm 0.03 \]

\[ \gamma_{> 200 \text{ GeV/n}} = 2.56 \pm 0.04 \]
PAMELA Galactic H & HE

![Graph showing flux vs energy for various experiments.](image)

- **Flux \( \times E^{-2.7} \) (m\(^2\) s sr GeV\(^{-1}\)) \times \text{GeV}^{-2.7}**
- **E (GeV)**
- **Symbols and Data Sets:**
  - PAMELA
  - CAPRICE94
  - AMS-01
  - BESS
  - JACEE (1994)
  - Ryan et al. (1972)
  - RICH2
  - GRAPES-3 (QGSJet)
  - Kascade (QGSJet)
  - Kascade (SHi)
  - IMAX
  - CAPRICE98
  - ATIC-2
  - CREAM
  - SOKOL
  - EASTOP
  - GRAPES-3 (Sibyll)
  - Kascade (Sibyll)
  - ARGO-YBJ
Proton flux
Comparison with past measurements

Flux $\times E^{2.7}$ (m$^{-2}$ sr$^{-1}$ s$^{-1}$ GeV$^{1.7}$)

Kinetic Energy (GeV)

S.L. Ting, ICRC2013

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Proton flux
Search for structures

AMS-02 Data
Pamela Data

Flux \times R^{2.7} (m^2 \cdot sr^{-1} \cdot s^{-1} \cdot GV^{1.7})

Rigidity (GV)

S.L. Ting, ICRC2013
Helium flux
Comparison with past measurements

S.L. Ting, ICRC2013

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Helium flux
Search for structures

AMS-02 Data
Pamela Data

Flux \times R^{2/7} (m^2 s sr Gy^{-1} GV^{-2/7})

R (GV)

10^3

10

10^2

10^3

S.L. Ting, ICRC2013

To be presented by V. Choutko (8 July, ICRC)
The GAPS Experiment

**Novel approach for antideuteron identification**

- antideuteron slows down and stops in material
- large chance for creation of an excited exotic atom \( E_{\text{kin}} \sim E_i \)
- deexcitation:
  - fast ionisation of bound electrons (Auger) → complete depletion of bound electrons
  - Hydrogen-like exotic atom (nucleus+antideuteron) deexcites via **characteristic X-ray transitions**
- nucleus-antideuteron annihilation: **pions and protons**
- exotic atomic physics understood (tested in KEK 2004/5 testbeam)
CALET Instrument

<table>
<thead>
<tr>
<th>CHD (Charge Detector)</th>
<th>IMC (Imaging Calorimeter)</th>
<th>TASC (Total Absorption Calorimeter)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Function</strong></td>
<td>Charge Measurement (Z=1-40)</td>
<td>Arrival Direction, Particle ID</td>
</tr>
<tr>
<td><strong>Sensor (+ Absorber)</strong></td>
<td>Plastic Scintillator: 2 layers Unit Size: 32mm x 10mm x 450mm</td>
<td>SciFi: 16 layers Unit size: 1mm(^2) x 448 mm Total thickness of Tungsten: 3(X_0)</td>
</tr>
<tr>
<td><strong>Readout</strong></td>
<td>PMT+CSA</td>
<td>64-anode PMT+ASIC</td>
</tr>
</tbody>
</table>

**Expected Performance**
(from Simulations and/or Beam Tests)

- **Geometric Factor**: 
  - 1200 cm\(^2\)sr for electrons, light nuclei
  - 1000 cm\(^2\)sr for gamma-rays
  - 4000 cm\(^2\)sr for ultra-heavy nuclei

- **\(\Delta E/E\)**: 
  - \(\sim 2\%\ (> 10 \text{ GeV})\) for e, \(\gamma\)'s
  - \(\sim 30\%\) for protons

- **e/p separation**: \(10^{-5}\)

- **Charge resolution**: 0.15 - 0.3 e

- **Angular resolution**: 0.1° for gamma-rays > ~50 GeV
Dark Matter Particle Explorer Satellite

- One of the 5 satellite missions of the Chinese Strategic Priority Research Program in Space Science of CAS
  - Approved for construction (phase C/D) in Dec. 2011
  - Scheduled launch date 2015-2016

- Satellite < 1900 kg, payload ~1340kg
  - Power consumption 840W
  - Lifetime > 3 years
  - Launched by CZ-2D rockets

- Altitude 500 km
- Inclination 87.4065°
- Period 90 minutes
- Dawn/dusk (6:30 AM) sun-synchronous orbit

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• Scintillator strips, Silicon tracker, BGO calorimeter, neutron detector
• Combine a $\gamma$-ray space telescope with a deep imaging calorimeter
  – Silicon tracker/converter + BGO imaging calorimeter
  – Total $\sim 33 \; X_0 \rightarrow$ deepest detector in space
GAMMA-400 Mission
Russian Space Mission

**ORBIT EVOLUTION**

Initial orbit: 500 – 300000 km

Orbit after 5 months: 100000 – 200000 km
PAMELA $e^+$ fraction vs time

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

Energy [GeV]

New results

Secondary production Moskalenko & Strong 98

Preliminary
Boron and Carbon nuclei spectra

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Isotopes

$^2\text{H}/^4\text{He}$ ratio

$^3\text{H}/^4\text{He}$ ratio

O. Adriani et al., arXiv:1304.5420, accepted for publication on ApJ
Under cut-off (anti)particles

- Thanks to the semi-polar (70 deg inclination) and elliptical (350-610 km altitude) satellite orbit, PAMELA is able to perform energy spectra and particle composition measurements in different regions of the terrestrial magnetosphere.
- Clear separation of the trapped, untrapped and semi-trapped components in the lower magnetosphere and SAA.

Under-cutoff proton candidates distribution as a function of L-shell and geomagnetic field intensity B [G].
Antiproton trapped in the SAA

Sub-cutoff ($B > 0.23$ G), $R < 0.8 \times$ SVC. Nearly isotropic flux distribution was assumed.

Calculated for the PAMELA orbit

ApJL, 737:L29, 2011 August 20

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

Selesnick et al. 2007
Gusev et al. 2008

SAA
GCR
Sub-cutoff

kinetic energy [GeV]
Under cut-off protons
Under cut-off protons

Preliminary
Solar modulation

Drift Model

Positive particles

A > 0

A < 0
Solar modulation

Hermanus NM (4.6 GV) South Africa

Percentage (100% in May 1965)

Time (Years)


Increasing flux

Decreasing solar activity

Preliminary

Electrons ($A < 0$)
Earth Equatorial plane

PAMELA e$^-$ flux

Low fluxes!

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Flux time dependence

$\beta R = (0.40 - 0.71) \text{ GV}$

- protons
- electrons

$\beta R = (0.71 - 1.03) \text{ GV}$

- protons
- electrons

$\beta R = (1.43 - 7.87) \text{ GV}$

- protons
- electrons

$\beta R = (7.87 - 11.91) \text{ GV}$

- protons
- electrons
Gradients in the Heliosphere, PAMELA & ULYSSES

\[ \ln\left( \frac{I(t, R, \theta)}{I_{PAMELA}(t)} \right) = G_R R + G_\theta \theta \]

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Comparison of the proton flux measured between 1.97 and 2.07 GV by PAMELA and ULYSSES as a function of time.

\[ \frac{J_U}{J_P} = \exp(G_r \cdot \Delta r) \cdot \exp(G_\theta \cdot \Delta \theta) \]

\[ (2.51 \pm 0.1)\%/AU \quad (-0.025 \pm 0.002)\%/deg \]
Increase of low energy component from 2006-12-1 to 2006-12-4
from 2006-12-13 00:23:02 to 2006-12-13 02:57:46
from 2006-12-13 02:57:46 to 2006-12-13 03:49:09
from 2006-12-13 03:49:09 to 2006-12-13 04:32:56
from 2006-12-13 04:32:56 to 2006-12-13 04:59:16
from 2006-12-13 08:17:54 to 2006-12-13 09:17:34

Decrease of high energy component

December 13th 2006

31st May NASA press release: “PAMELA recorded the incoming solar particles up in space, providing one of the first in-situ measurements of the stream of particles that initiated a GLE. Only the early data has been seen so far, but scientists have high hopes that as more observations are relayed down to Earth, they will be able to learn more about the May 17 onslaught of solar protons, and figure out why this event triggered a GLE (Ground Level Enhancement) when earlier bursts of solar protons in January and March, 2012 didn't.”
Antiproton Selection

beta vs deflection

TOF & Spectrometer & Charge & Calo

beta vs deflection -- after Z1 & BETA sel -- no electrons

TOF & Spectrometer & Charge

Antiproton Selection

beta vs deflection -- after Z1 sel (Trk+ToF)
Spillover cut

MDR depends on:
- number and distribution of fitted points along the trajectory
- spatial resolution of the single position measurements
- magnetic field intensity along the trajectory

\[ MDR = \frac{1}{s_h} \] 
(evaluated event-by-event by the fitting routine)

\[ R < \frac{MDR}{10} \]
PAMELA e⁻ and e⁺ spectra

\[ \gamma = 3.18 \pm 0.04 \]

New results

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Positron selection with calorimeter

Fraction of charge released along the calorimeter track

Energy (calo) – Momentum (spectrometer) match

F.S. Cafagna,
**Positron selection with calorimeter**

- Tuning/check of selection criteria using:
  - test-beam data
  - simulation
  - flight data: $dE/dx$ from spectrometer & neutron yield from ND
- Selection of pure proton sample from flight data ("pre-sampler" method):
  - Background-suppression method
  - Background-estimation method
- Final results DON’T MAKE USE of test-beam and/or simulation calibrations.
Positron selection with calorimeter

51 GV Positron

80 GV Proton

Fraction of charge released along the calorimeter track

Energy (calo) – Momentum (spectrometer) match

Shower starting point

Longitudinal profile

F.S. Cafagna, Rencontres du Vietnam, 31st July 2013
Positron selection with calorimeter

Fraction of charge released along the calorimeter track

Z=-1

\( p\text{-bar (int)} \)

\( p\text{-bar (non-int)} \)

\( e^- \)

Z=+1

\( p\text{ (int)} \)

\( p\text{ (non-int)} \)

\( (e^+ ) \)

Rigidity: 20-30 GV

0.6 \( R_M \)

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e\(^+\) background estimation from data

Fraction of charge released along the calorimeter track

Constrains on:
- Energy momentum match
- Shower starting-point

Rigidity: 20-28 GV
What’s about ... antinuclei?
Ulysses orbit

\[ \theta \, (^\circ) \]

-20 -10 0 10 20 30 40 50 60 70 80

0 0.5 1 1.5 2 2.5 3 3.5

F.S. Cafagna, Rencontres du Vietnam, 31st July 2013

Earth

Aug 2007

2006

2009
Spectrometer Systematic Uncertainties

- Using real data calorimeter can be used to evaluate spectrometer charge-sign dependent systematic:

\[ z = \frac{1}{E_C|\eta_s|} \rightarrow \frac{1}{E_C(1+\varepsilon)(|\eta_s| \pm \Delta \eta)} \]

- Upper limit set by positron statistics:

\[ \Delta \eta^{\text{sys}} \sim 1 \cdot 10^{-4} \ \text{GV}^{-1} \]

A systematic deflection shift causes an offset between e- and e+ distribution.

F.S. Cafagna, Rencontres du Vietnam, 31st July 2013
H/He: Overall sys. uncertainties

- At Low R uncertainties due to the selection efficiencies dominate.
- Above 500GV is the tracking system misalignment (coherent) that dominates.
Check of systematics

- Check done evaluating fluxes by varying the selection conditions:
  - Flux vs time
  - Flux vs polar/equatorial
  - Flux vs reduced acceptance
  - Flux vs different tracking conditions (different response matrix)

\[ \text{Integral proton flux (} >50\text{GV)} \]

\[ 3\% \]

\[ \text{Time interval (2 months)} \]