Abstract: The PAMELA satellite-borne experiment was launched from the Baikonur cosmodrome on the 15th of June 2006. It has been collecting data since July 2006. The instrument is composed of a silicon-microstrip magnetic spectrometer, a time-of-flight system, a silicon-tungsten electromagnetic calorimeter, an anticoincidence system, a shower tail counter scintillator and a neutron detector. The primary scientific goal is the measurement of the antiproton and positron energy spectrum in order to search for exotic sources, such as dark matter particle annihilations. PAMELA is also searching for primordial antinuclei (anti-helium), and testing cosmic-ray propagation models through precise measurements of the energy spectra of light nuclei and their isotopes. Moreover, PAMELA is investigating phenomena connected with solar and earth physics. The first results obtained in the explored research fields and in particular for antiproton-proton and positron-electron ratios will be presented.
Dark Matter Indirect Research with the Pamela Space Experiment

Piergiorgio Picozza
INFN and University of Rome Tor Vergata

Colloquium
Perimeter Institute for Theoretical Physics
Waterloo, Canada
January 14th, 2009
The discovery of cosmic rays

- Victor Hess ascended to 5000 m in a balloon in 1912
- ... and noticed that his electroscope discharged more rapidly as altitude increased
- Not expected, as background radiation was thought to be terrestrial
- NPP 1936 (with Carl ‘e+’ Anderson)
~500 km

Smaller detectors but long duration.
PAMELA!

Top of atmosphere

Primary cosmic ray

~40 km

Large detectors but short duration. Atmospheric overburden ~5 g/cm

Almost all data on cosmic antiparticle from here.

~5 km

Ground

~0 m
COSMIC RAYS PRODUCTION MECHANISMS

- Primary particles: p, He, C, N, O
- Secondary production: e^+, e^-, p, He, C, N, O + Li, Be, B
- ISM gas: secondary production
- p, He, C, N, O + Li, Be, B
- Local bubble
- Solar modulation: lower the IS CR spectra

Synchrotron, bremsstrahlung, IC

CHANDRA

AGILE

GLAST

AMS

ACE

PAMELA
~500 km
Smaller detectors but long duration. PAMELA!
Top of atmosphere

~5 km
Large detectors but short duration. Atmospheric overburden ~5 g/cm
Almost all data on cosmic antiparticle from here.

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Primary cosmic ray

Primary Cosmic Rays
Primary cosmic ray

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Top of atmosphere

~500 km

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~40 km

~5 km

Ground
Fluxes of Cosmic Rays

- Knee: (1 particle per m²-year)
- Ankle: (1 particle per km²-year)

(1 particle per m²-second)
Fluxes of Cosmic Rays

- Knee: (1 particle per m²-year)
- Ankle: (1 particle per km²-year)

(1 particle per m²-second)
PARTICLE PHYSICS BIRTH WAS DUE TO COSMIC RAYS

1890  1900  1910  1920

1920  1930  1940  1950

1950  1960

Hesse, Wulf, Wilson, Anderson, Bothe, Kohlorster, Millikan, Blackett, Skobeltsyn, Rochester, Butler, Rossi, Pancini, Conversi, Powell, Occhialini

Advent of accelerators
The first historical measurements on galactic antiprotons

\[ p + p \rightarrow \bar{p} + \text{anything} \]

Robert L. Golden
ANTIMATTER

Collision of High Energy Cosmic Rays with the Interstellar Gas

Cosmic Rays Leaking Out of Antimatter Galaxies

Annihilation of Exotic Particles

Evaporation of Primordial Black Holes

Antimatter Lumps In the Milky Way

Pulsar’s magnetospheres
Search for the existence of Antimatter in the Universe

The Big Bang origin of the Universe requires matter and antimatter to be equally abundant at the very hot beginning.
Cosmic Diffuse Gamma

![Graph showing the diffuse gamma-ray flux as a function of photon energy](image)

- **ASCA** (Gendreau 1995)
- **HEAO (LED)** (Gruber 1992)
- **HEAO (MED)** (Kinzer et al. 1996)
- **SMM** (Watanabe et al. 1997)
- **APOLLO** (Tombesi et al. 1997)
- **COMPTEL** (Kappadath et al. 1996)
- **SAS-2** (Thompson & Fichtel 1982)
- **EGRET** (This paper)
Antimatter Direct research

- **Antimatter** which has escaped as a cosmic ray from a distant antigalaxy
  \[\text{Sreitmatter, R. E., Nuovo Cimento, 19, 835 (1996)}\]

- **Antimatter** from globular clusters of antistars in our Galaxy as antistellar wind or anti-supernovae explosion
The peripheral stars of the galaxy M63 rotate around the center so fast that they would fly away in space without the presence of additional mass inside the galaxy. This is indirect evidence for the presence of dark matter.
Dark Matter

Evidence for the existence of an unseen, “dark”, component in the energy density of the Universe comes from several independent observations at different length scales:

- Rotation curves of galaxies
- CMB
- Large Scale Structure
- Galaxy clusters
- Lensing
- SN Ia

Matter in the Universe

Microwave Anisotropy

WMAP - NASA - Explorer Mission

\[ \Omega_{\text{total}} = \frac{\rho_{\text{total}}}{\rho_{\text{crit.}}} = 1 \]

(Universe is flat)

\[ \rho_{\text{crit.}} = \frac{3H^2(t)}{8\pi G} \]

\[ \Omega_{\text{total}} = \Omega_{\text{total, baryon.}} + \Omega_{\text{dyn.}} + \Omega_{\text{required}} \]

baryonic matter

4%

stars, galaxies

dark matter

23%

candidates:

- WIMPs
- Q-balls
- axions

dark energy

73%

quintessence

??

???
### The SUSY Particle Spectrum

#### Standard Model

<table>
<thead>
<tr>
<th>Particles</th>
<th>Symbol</th>
<th>Spin</th>
<th>Name</th>
<th>Symbol</th>
<th>Spin</th>
</tr>
</thead>
<tbody>
<tr>
<td>leptons</td>
<td>$l, \nu$</td>
<td>1/2</td>
<td>sleptons</td>
<td>$\tilde{l}_R, \tilde{l}_L, \tilde{\nu}_L$</td>
<td>0</td>
</tr>
<tr>
<td>quarks</td>
<td>$q_L, q_R$</td>
<td>1/2</td>
<td>squarks</td>
<td>$\tilde{q}<em>L, \tilde{q}<em>R$ ($\tilde{\bar{b}}</em>{1,2}, \tilde{\bar{t}}</em>{1,2}$)</td>
<td>0</td>
</tr>
<tr>
<td>photon</td>
<td>$\gamma$</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z boson</td>
<td>$Z$</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>light Higgs</td>
<td>$h$</td>
<td>0</td>
<td>neutralinos</td>
<td>$\tilde{\chi}^0_1, \tilde{\chi}^0_2, \tilde{\chi}^0_3, \tilde{\chi}^0_4$</td>
<td>1/2</td>
</tr>
<tr>
<td>heavy Higgs</td>
<td>$H$</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pseudoscalar Higgs</td>
<td>$A$</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W boson</td>
<td>$W^\pm$, $H^\pm$</td>
<td>1</td>
<td>chargeinos</td>
<td>$\tilde{\chi}^{\pm}_1, \tilde{\chi}^{\pm}_2$</td>
<td>1/2</td>
</tr>
<tr>
<td>gluon</td>
<td>$g$</td>
<td>1</td>
<td>gluino</td>
<td>$\tilde{g}$</td>
<td>1/2</td>
</tr>
<tr>
<td>graviton</td>
<td>$G$</td>
<td>2</td>
<td>gravitino</td>
<td>$\tilde{G}$</td>
<td>3/2</td>
</tr>
</tbody>
</table>

\[ \chi = N_1 \tilde{\gamma} + N_2 \tilde{Z}^0 + N_3 \tilde{H}^0 + N_4 \tilde{H}_2^0; \sum_{i=1}^{4} |N_i|^2 = 1 \]
Will distort the antiproton positron and gamma spectra from purely secondary production.

... and background

\[ p_{CR} + p_{ISM} \rightarrow p + p + p + p + p \]

\[ p_{CR} + p_{ISM} \rightarrow \pi^+ \rightarrow \mu^+ \rightarrow e^+ \]

\[ \rightarrow \pi^0 \rightarrow \gamma \gamma \rightarrow e^+ e^- \]

Neutralino Annihilations

\[ \chi + \chi \rightarrow X + \gamma + \nu + \bar{p} + e^+ + \bar{D} \]
Antiproton flux (particle / (m^2 sr s GeV))

Secondary production (upper and lower limits)

from \( \chi \chi \) annihilation

Background from normal secondary production

Example of signal from neutralino annihilations

AMS98
BESS98
CAPRICE98
BESS95+97
MASS91
BE S00
CAPRICE94
MAX92

Kinetic Energy (GeV)
Another possible scenario: KK Dark Matter

Lightest Kaluza-Klein Particle (LKP): $B^{(1)}$

Bosonic Dark Matter: fermionic final states no longer helicity suppressed. $e^+e^-$ final states directly produced.

As in the neutralino case there are 1-loop processes that produces monoenergetic $\gamma\gamma$ in the final state.
Another possible scenario: KK Dark Matter

Lightest Kaluza-Klein Particle (LKP): $B^{(1)}$

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$e^+e^-$ final states directly produced.

As in the neutralino case there are 1-loop processes that produces monoenergetic $\gamma \gamma$ in the final state.
Another possible scenario: 

**KK Dark Matter**

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As in the neutralino case there are 1-loop processes that produces monoenergetic $\gamma \gamma$ in the final state.
Searches for WIMP Dark Matter

Accelerators

Direct

Indirect
Antimatter and Dark Matter Research

Wizard Collaboration

✓ MASS - 1,2 (89,91)
✓ TrampSI (93)
✓ CAPRICE (94, 97, 98)
✓ BESS (93, 95, 97, 98, 2000)
✓ Heat (94, 95, 2000)
✓ IMAX (96)
✓ BESS LDF (2004, 2007)
✓ AMS-01 (1998)
Cosmic Ray Antimatter
Present status

Antiprotons

Positrons

![Graphs of antiprotons and positrons with data from various sources.](image-url)
Cosmic Ray Antimatter

Present status

Antiprotons

CR + ISM $\rightarrow p\text{-}bar + \ldots$

kinematic threshold:
5.6 GeV for the reaction

$pp \rightarrow \bar{p}ppp$

Positrons

Moscalenko & Strong 1998
**Cosmic Ray Antimatter**

Present status

**Antiprotons**

\[ \text{CR + ISM} \rightarrow \bar{p} - \bar{p} + \ldots \]

kinematic threshold:

5.6 GeV for the reaction

\[ pp \rightarrow \bar{p}ppp \]

**Positrons**

Moskalenko & Strong 1998
"We must regard it rather an accident that the Earth and presumably the whole Solar System contains a preponderance of negative electrons and positive protons. It is quite possible that for some of the stars it is the other way about."

P. Dirac, Nobel lecture (1933)
What do we need?

- Measurements at higher energies
- Better knowledge of background
- High statistics
- Continuous monitoring of solar modulation

Long Duration Flights
PAMELA

Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics
Pamela as a Space Observatory at IAU

Search for dark matter annihilation
Search for antihelium (primordial antimatter)
Search for new Matter in the Universe (Strangelets?)
Study of cosmic-ray propagation
Study of solar physics and solar modulation
Study of terrestrial magnetosphere
Study of high energy electron spectrum (local sources?)
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Study of high energy electron spectrum (local sources?)
- S1, S2, S3; double layers, x-y
- plastic scintillator (8mm)
- ToF resolution ~300 ps (S1-3 ToF >3 ns)
- lepton-hadron separation < 1 GeV/c
- S1.S2.S3 (low rate) / S2.S3 (high rate)

- Permanent magnet, 0.43 T
- 21.5 cm² sr
- 6 planes double-sided silicon strip detectors (300 µm)
- 3 µm resolution in bending view → MDR ~800 GV (6 plane) ~500 GV (5 plane)

- 44 Si-x / W / Si-y planes (380)
- 16.3 X0 / 0.6 L
- dE/E ~5.5 % (10 - 300 GeV)
- Self trigger > 300 GeV / 600 cm² sr

- 36 ³He counters
- ³He(n,p)T; E_p = 780 keV
- 1 cm thick poly + Cd moderator
- 200 µs collection
**Antiproton / positron identification**

- **Time-of-flight:** trigger, albedo rejection, mass determination (up to 1 GeV)
- **Bending in spectrometer:** sign of charge
- **Ionisation energy loss (dE/dx):** magnitude of charge
- **Interaction pattern in calorimeter:** electron-like or proton-like, electron energy

**Antiproton**  
(NB: $e^-/p \sim 10^2$)

**Positron**  
(NB: $p/e^+ \sim 10^{-4}$)
PAMELA Instrument

GF $\sim 21.5 \text{ cm}^2\text{sr}$

Mass: 470 kg

Size: 130x70x70 cm$^3$
# Design Performance

## Energy range

<table>
<thead>
<tr>
<th>Particle Type</th>
<th>Energy Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antiprotons</td>
<td>80 MeV - 150 GeV</td>
</tr>
<tr>
<td>Positrons</td>
<td>50 MeV – 300 GeV</td>
</tr>
<tr>
<td>Electrons</td>
<td>up to 500 GeV</td>
</tr>
<tr>
<td>Protons</td>
<td>up to 700 GeV</td>
</tr>
<tr>
<td>Electrons+positrons</td>
<td>up to 2 TeV (from calorimeter)</td>
</tr>
<tr>
<td>Light Nuclei (He/Be/C)</td>
<td>up to 200 GeV/n</td>
</tr>
<tr>
<td>AntiNuclei search</td>
<td>sensitivity of $3 \times 10^{-8}$ in $\overline{\text{He}}/\text{He}$</td>
</tr>
</tbody>
</table>

- Simultaneous measurement of many cosmic-ray species
- New energy range
- Unprecedented statistics
**Resurs-DK1 satellite**

- **Main task:** multi-spectral remote sensing of earth’s surface
- **Built by TsSKB Progress in Samara, Russia**
- **Lifetime:** >3 years (assisted)
- **Data transmitted to ground via high-speed radio downlink**
- **PAMELA mounted inside a pressurized container**

**Specifications:**
- Mass: 6.7 tonnes
- Height: 7.4 m
- Solar array area: 36 m²
PAMELA

Launch
15/06/06

16 Gigabytes trasmitted daily to Ground
NTsOMZ Moscow
Orbit Characteristics

- Low-earth elliptical orbit
- 350 – 610 km
- Quasi-polar (70° inclination)
- SAA crossed
Flight data:
0.171 GV positron

Flight data:
0.169 GV electron
Flight data: 0.632 GeV/c antiproton annihilation
Flight data: 0.763 GeV/c antiproton annihilation
PAMELA Status

- ~700 days of data taking (~73% live-time)
- ~12 TBytes of raw data downlinked
- >10⁹ triggers recorded and under analysis
Antiprotons
Flight data: 84 GeV/c interacting antiproton
PAMELA antiproton discrimination

Proton Spillover
Antiproton to proton ratio

Secondary Production Models

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

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

PAMELA

Kinetic energy (GeV)
Antiproton to proton ratio

astro-ph 0810.4994
Antiproton Flux

Secondary production

Primary production:
- Vaporation
- Mini black holes:
  - Oshimura et al.
  - Iaki et al.
Antiproton Flux
Antiproton Flux

Secondary production:

Secondary production:
F. Donato et al., 536 (2001) 172
Positrons
Proton / positron discrimination

Time-of-flight:
trigger, albedo rejection, mass determination (up to 1 GeV)

Bending in spectrometer:
sign of charge

Ionisation energy loss (dE/dx):
magnitude of charge

Interaction pattern in calorimeter:
electron-like or proton-like, electron energy

Proton

Positron
Positron selection with calorimeter

![Graph showing positron selection efficiency vs. energy](image-url)

- **Electron selection efficiency** vs. **Energy [GeV]**
- **Proton contamination** vs. **Energy [GeV]**

- The graph shows a nearly constant efficiency for electron selection with a slight decrease as energy increases.
- Proton contamination increases significantly as energy increases.
Positron selection with calorimeter

![Graph showing positron selection efficiency and proton contamination as functions of energy. The graph includes data points labeled as 'Test Beam Data'.]
Positron selection with calorimeter

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

Rigidity: 20-30 GV
Positron selection with calorimeter

Rigidity: 20-30 GV

Fraction of charge released along the calorimeter track (left, hit, right) +
Energy-momentum match Starting point of shower
Positron selection with calorimeter

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

Flight data:
rigidity: 20-30 GV

Test beam data
Momentum: 50 GeV/c
Positron selection with calorimeter

Fraction of charge released along the calorimeter track (left, hit, right) + Energy-momentum match + Starting point of shower
Flight data: 51 GeV/c positron
Positron selection with calorimeter

Rigidity: 20-30 GV

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

- Energy-momentum match
- Starting point of shower
- Longitudinal profile
Positron selection

Rigidity: 20-30 GV

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

Neutrons detected by ND

Energy-momentum match
Starting point of shower
Positron to Electron Ratio

Secondary production
Moskalenko-Strong (1998)

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

Energy (GeV)
Positron to Electron Ratio

astro-ph 0810.4995
Positron to Electron Ratio

astro-ph 0810.4995
Positron to Electron Ratio

astro-ph 0810.4995

End 2007:
\[
\sim 10000 \ e^+ > 1.5 \ GeV \\
\sim 2000 > 5 \ GeV
\]
Positron Fraction

![Graph showing positron fraction vs energy.](image)
Solar Modulation of galactic cosmic rays

Study of charge sign dependent effects

Clem et al. 30th ICRC 2007

Solar modulation

protons/(cm$^2$ sr s GeV)

$10^{-2}$

$10^{-1}$

$10^{-1}$

kinetic energy (GeV)

July 2006
August 2007
February 2008
Solar modulation

Interstellar spectrum

July 2006
August 2007
February 2008

Preliminary

cos/sr s GeV

Increasing GCR flux

Ground neutron monitor

PAMELA

kinetic energy (GeV)

Cosmic rays variations (%)

sun-spot number

Cycle 22 Cycle 23

ka as: 09010005
Charge dependent solar modulation

Pamela 2006
(Preliminary!)
Comparison of $\overline{p}/p$ ratio with model

Time variation of $\overline{p}/p$ ratio at solar maximum

Observed data by BESS

Charge dependent model prediction (Bieber et al.)

Charge dependent solar modulation model well follows the suddenly increase of $\overline{p}/p$ ratio observed by BESS at the solar polarity reversal between 1999 and 2000
PAMELA Positron Fraction

- Pulsar Component: Yuksel et al. 08
- KKDM (mass 300 GeV): Hooper & Profumo 07
- Pulsar Component: Atoyan et al. 95
- Pulsar Component: Zhang & Cheng 01

Secondary production: Moskalenko & Strong 98
Secondary particles?

- Spectral feature in the proton flux responsible for secondaries
- Role of Helium nuclei in secondary production
- Difference between local and ISM spectrum of protons
- Anomalous energy-dependent behaviour of the diffusion coefficient
- Anomalous primary electron source spectrum
Galactic H and He spectra

- Flux (arbitrary units)
- Kinetic Energy (GeV/nucl)

Z = 1
- γ ≈ 2.73

Z = 2
- γ ≈ 2.73

Preliminary!!
Diffusion Halo Model

\[
\frac{\partial N_i(E, z, t)}{\partial t} = D(E) \cdot \frac{\partial^2}{\partial z^2} N_i(E, z, t) - N_i(E, z, t) \left\{ \frac{1}{\tau^\text{int}_i(E, z)} + \frac{1}{\gamma(E)\tau^\text{dec}_i} \right\}
\]

- **diffusion**
- **interaction and decay**

\[
\sum_{k > i} \frac{N_k(E, z, t)}{\tau^\text{int}_i(E, z)}
\]

- **secondary production**
- **primary sources**

\[
- \frac{\partial}{\partial E} \left\{ \frac{\partial}{\partial t} \right\} N_i(E, z, t) + \frac{1}{2} \frac{\partial^2}{\partial E^2} \left\{ \frac{\Delta E^2}{\Delta t} \right\} N_i(E, z, t)
\]

- **energy changing processes**
  - (ionisation, reacceleration)
Charge identification capabilities (tracker)

Saturated clusters

Good charge discrimination of H and He
- Single-channel saturation at ~10MIP affects B/C discrimination
Charge identification capabilities (calorimeter)

Truncated mean of multiple dE/dx measurements in different silicon planes
Secondary nuclei

Preliminary
Secondary nuclei

\[ \frac{N_S}{N_p} \propto \lambda_{esc} \cdot \sigma_{p \rightarrow S} \]

- B nuclei of secondary origin:
  \[ \text{CNO + ISM} \rightarrow B + \ldots \]
- Local secondary/primary ratio sensitive to average amount of traversed matter \( \langle l_{esc} \rangle \) from the source to the solar system

Local secondary abundance:
\[ \Rightarrow \text{study of galactic CR propagation} \]

\( B/C \) used for tuning of propagation models
Secondary nuclei

![Graph showing B/C ratio vs kinetic energy.](image)

**Preliminary**
Secondary nuclei

\[ \frac{N_S}{N_p} \propto \lambda_{\text{esc}} \cdot \sigma_{p \rightarrow S} \]

- B nuclei of secondary origin:
  \[ \text{CNO + ISM} \rightarrow \text{B + ...} \]
- Local secondary/primary ratio sensitive to average amount of traversed matter \( (l_{\text{esc}}) \) from the source to the solar system

Local secondary abundance:
\[ \Rightarrow \text{study of galactic CR propagation} \]

\( (B/C \text{ used for tuning of propagation models}) \)
Theoretical uncertainties on “standard” positron fraction

T. Delahaye et al., arXiv: 0809.5268v3
Electron spectrum

\[ \approx E^{-3.28 \pm 0.05} \]
Positron to Electron Ratio

Secondary production
Moskalenko-Strong
(1998)

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

Energy (GeV)
During first week after PAMELA results posted on arXiv

- 0808.3725 DM
- 0808.3867 DM
- 0809.2409 DM
- 0810.2784 Pulsar
- 0810.4846 DM / pulsar
- 0810.5292 DM
- 0810.5344 DM
- 0810.5167 DM
- 0810.5304 DM
- 0810.5397 DM
- 0810.5557 DM
- 0810.4147 DM
- 0811.0250 DM
- 0811.0477 DM
Example: pulsars

H. Yüksak et al., arXiv:0810.2784v2
Contributions of e- & e+ from Geminga assuming different distance, age and energetic of the pulsar

Hooper, Blasi, and Serpico
arXiv:0810.1527
ATIC Results

$E_\theta^3 \frac{dN}{dE_\theta} \text{ (m}^{-2} \text{s}^{-1} \text{sr}^{-1} \text{GeV}^2)$

$1,000$

$100$

$10$

$10$ $100$ $1,000$

Energy (GeV)

Example: DM

L. Cholis et al. arXiv:0811.3641v1
Example: $e^-, e^- + e^+, \bar{p}$ with DM

DM with $M = 150$ GeV that annihilates into $\gamma\gamma$

DM with $M = 1$ TeV that annihilates into $\mu^+\mu^-$

DM with $M = 10$ TeV that annihilates into $W^+W^-$

M. Cirelli et al., arXiv: 0809.2409v3
Solar Physics with PAMELA

- Solar Modulation effects
- High energy component of Solar Proton Events (from 80 MeV to 10 GeV)
- High energy component of electrons and positrons in Solar Proton Events (from 50 MeV)
- Nuclear composition of Gradual and Impulsive events
- \(^3\text{He}\) and \(^4\text{He}\) isotopic composition
Future observations of electrons

Fermi GST: $\Phi_{e^\pm}$ up to $\sim 700$ GeV