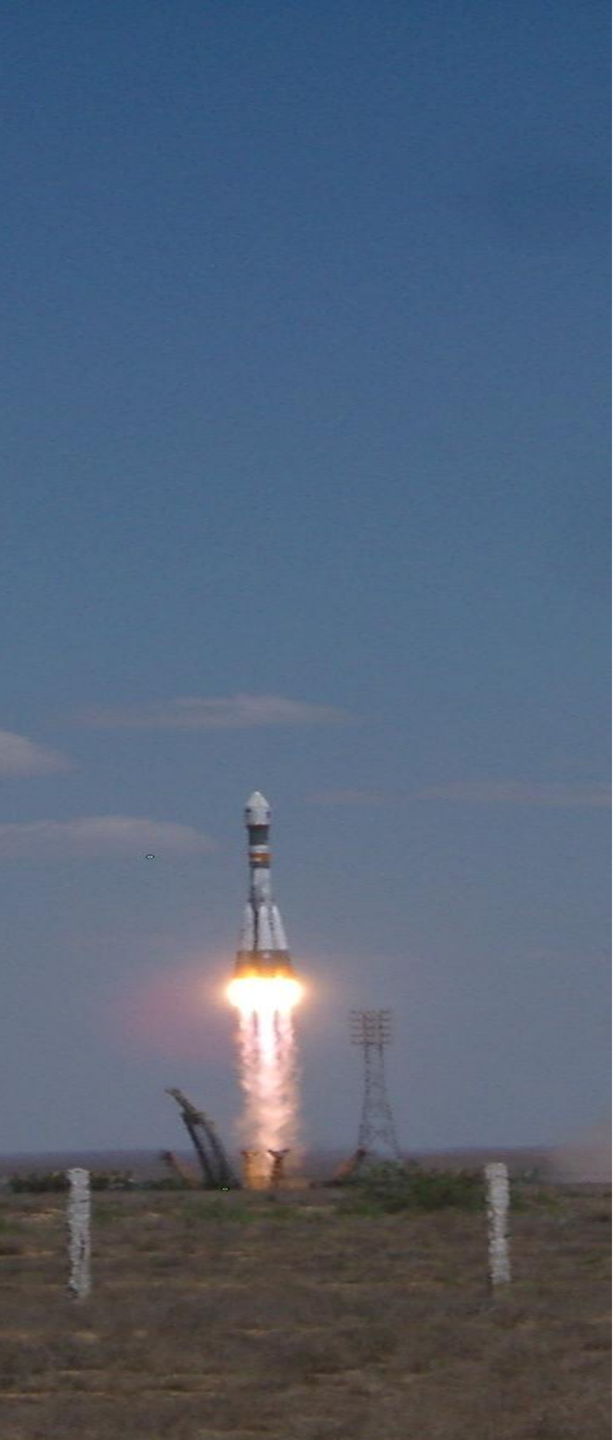


The PAMELA space Mission for Antimatter and dark Matter Searches in Space

Mirko Boezio

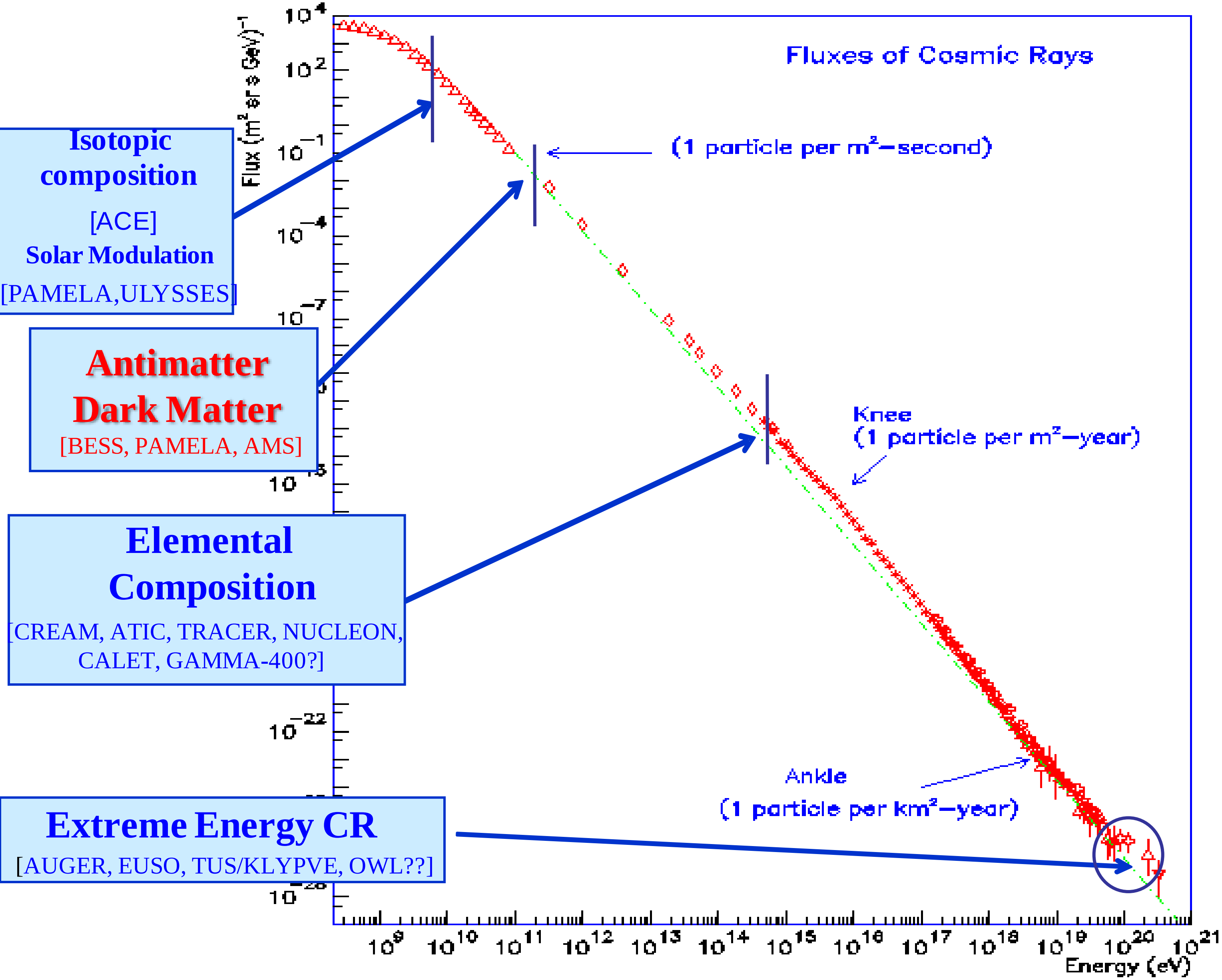
INFN Trieste, Italy

On behalf of the PAMELA collaboration

DMUH11- CERN

July 26th 2011

INFN Istituto Nazionale di Fisica Nucleare



Fluxes of Cosmic Rays
(1 particle per m²–second)
Knee
(1 particle per m²–year)
Ankle
(1 particle per km²–year)
Flux (m² sr s GeV)⁻¹
Energy (eV)
Isotopic composition
[ACE]
Solar Modulation
[PAMELA,ULYSSES]
Antimatter
Dark Matter
[BESS, PAMELA, AMS]
Elemental Composition
[CREAM, ATIC, TRACER, NUCLEON, CALET, GAMMA-400?]
Extreme Energy CR
[AUGER, EUSO, TUS/KLYPVE, OWL??]

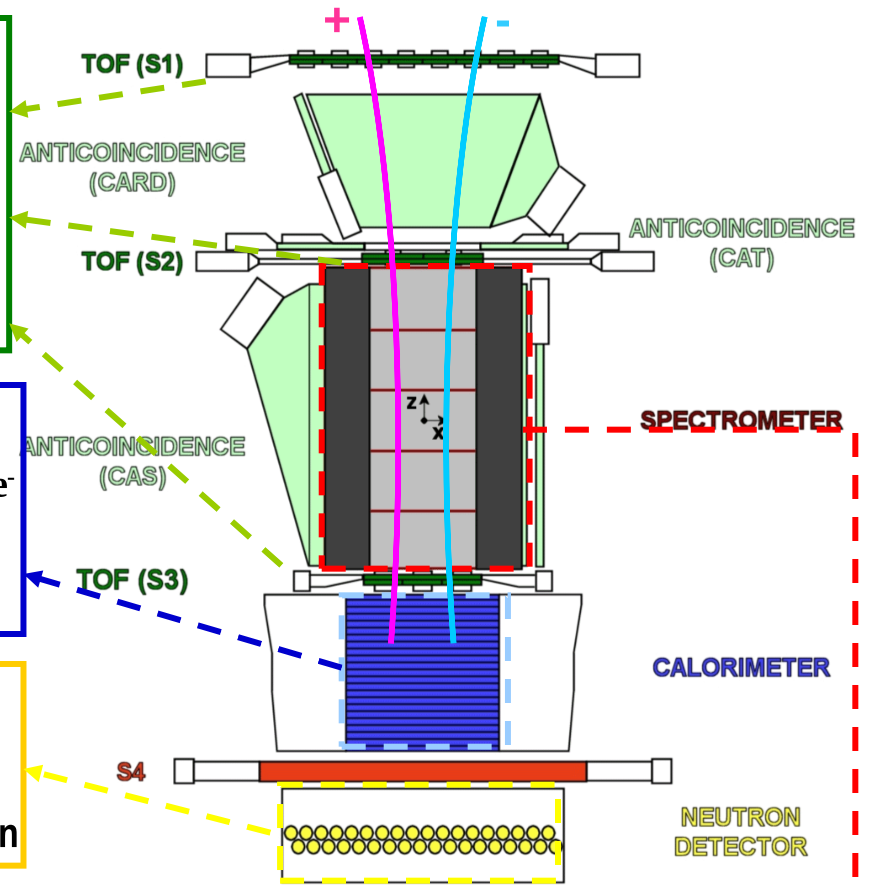
PAMELA detectors

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

<u>Time-Of-Flight</u>
plastic scintillators + PMT:
- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX.

<u>Electromagnetic calorimeter</u>
W/Si sampling (16.3 X_0, 0.6 λI)
- Discrimination e+ / p, anti-p / e^- (shower topology)
- Direct E measurement for e^-

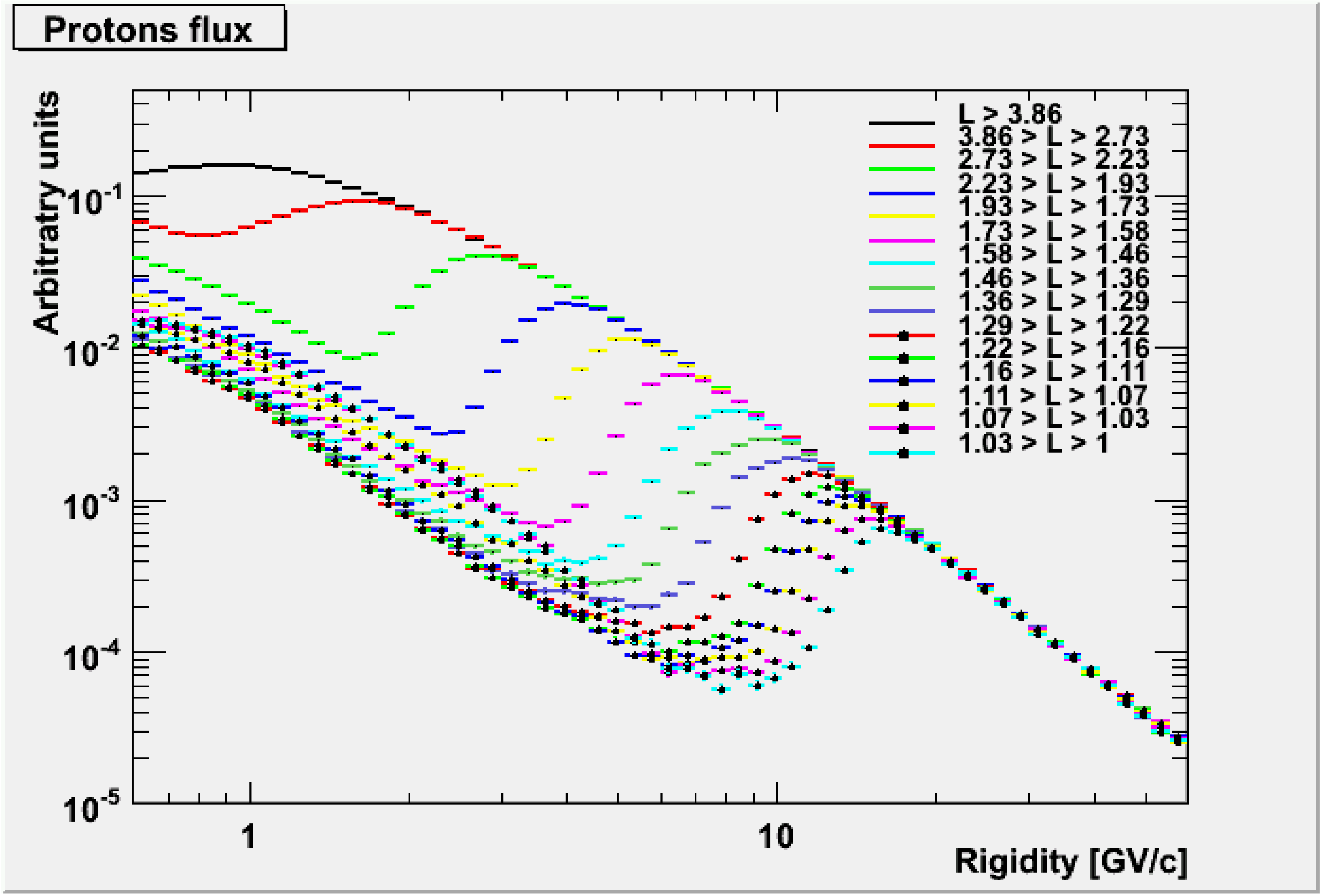
<u>Neutron detector</u>
^{3}He tubes + polyethylene moderator:
- High-energy e/h discrimination



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

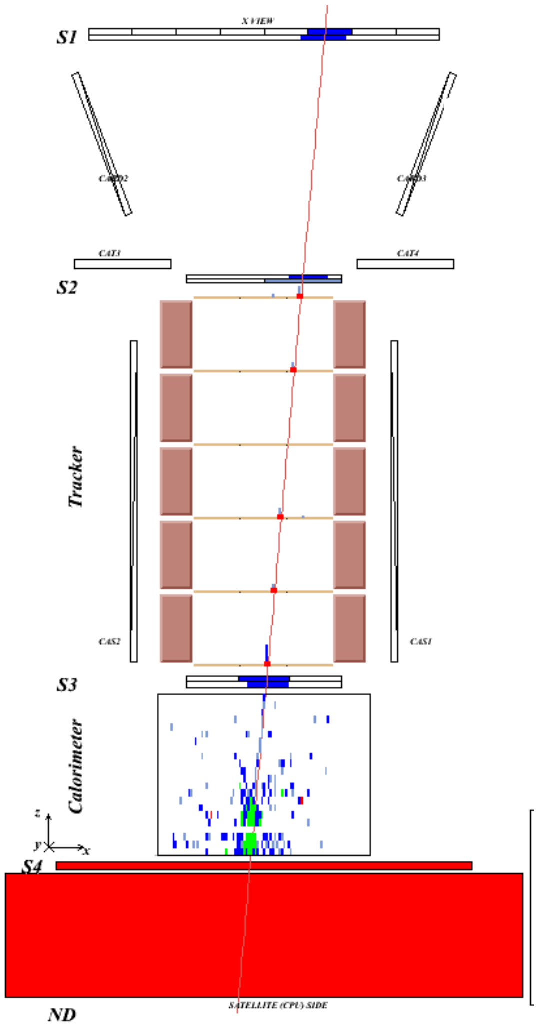
<u>Spectrometer</u>
microstrip silicon tracking system + permanent magnet
It provides:
- ***Magnetic rigidity*** → **R = pc/Ze**
- ***Charge sign***
- ***Charge value from dE/dx***

Subcutoff particles



Antiparticles with PAMELA

Antiproton/ positron identification

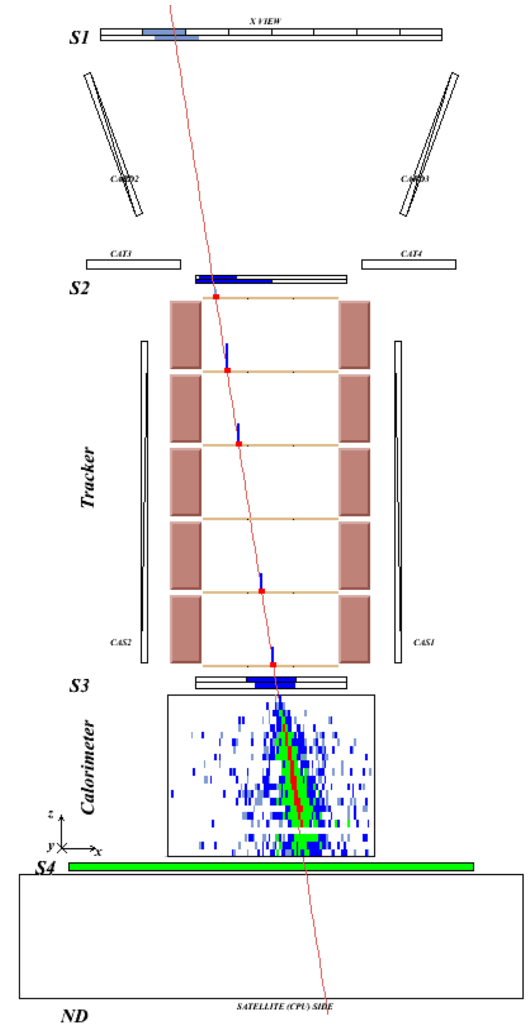


Time-of-flight:
trigger, albedo rejection, mass determination (up to 1 GeV)

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

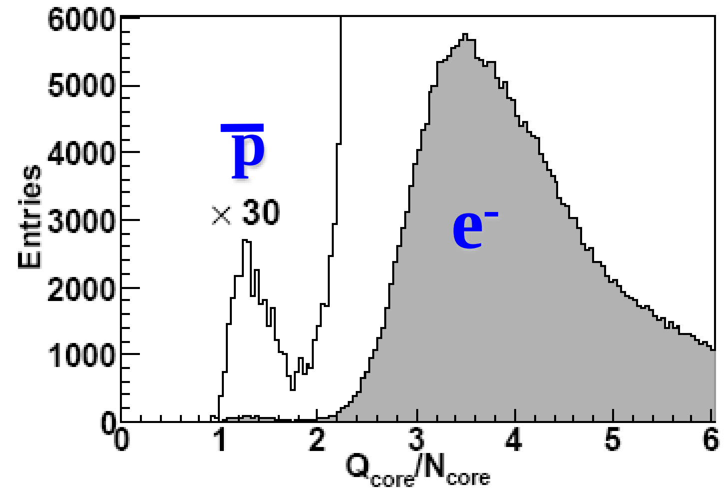


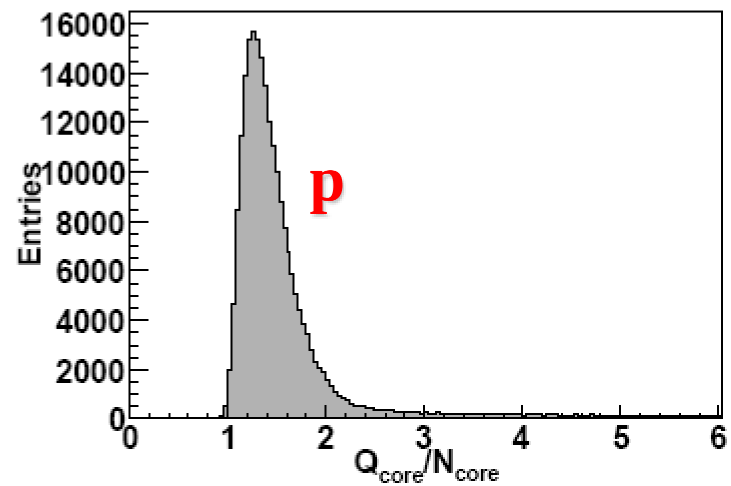
Antiproton
(NB: $e^-/\bar{p} \sim 10^2$)

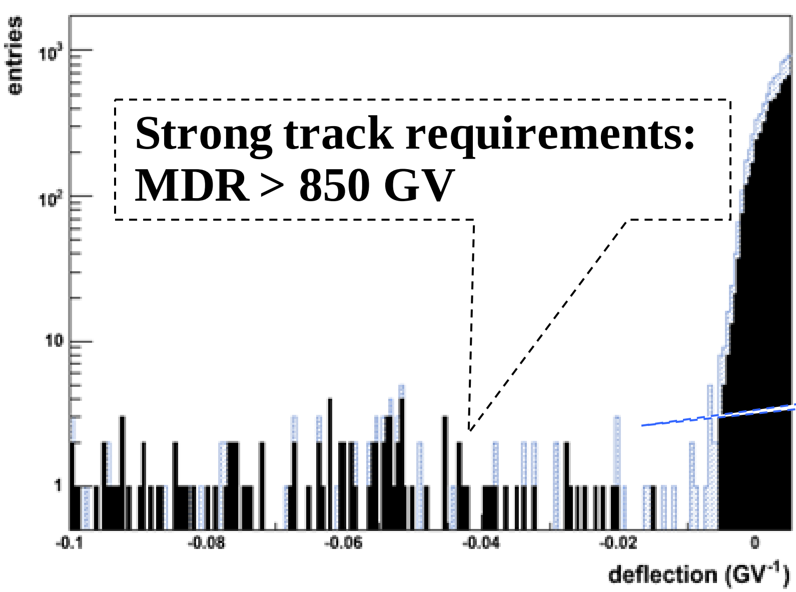
Positron
(NB: $p/e^+ \sim 10^{3\text{-}4}$)

ANTIPROTONS

Calorimeter selection







Minimal track requirements

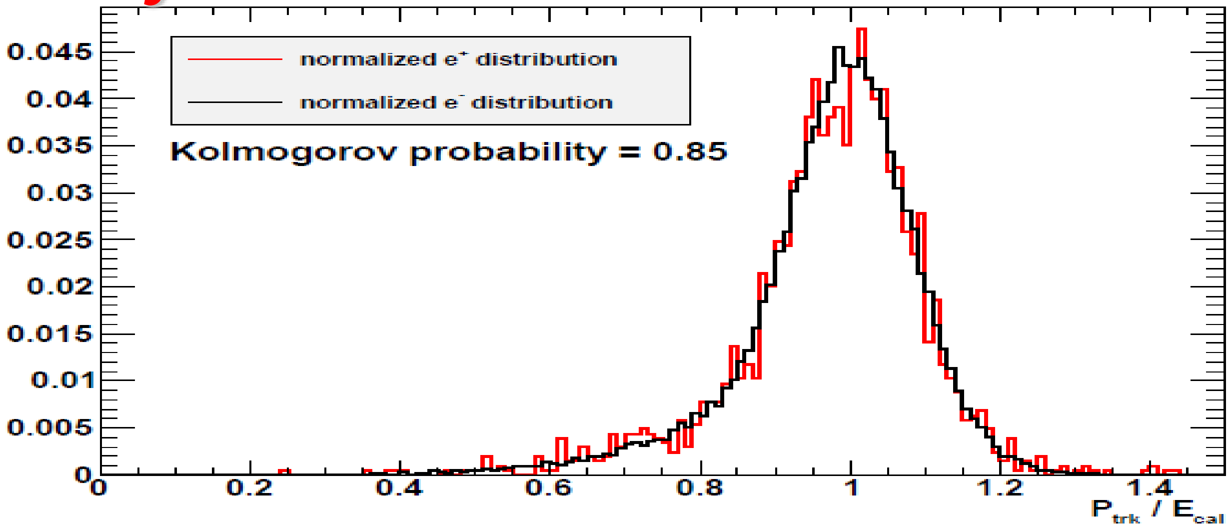
Protons (& spillover)

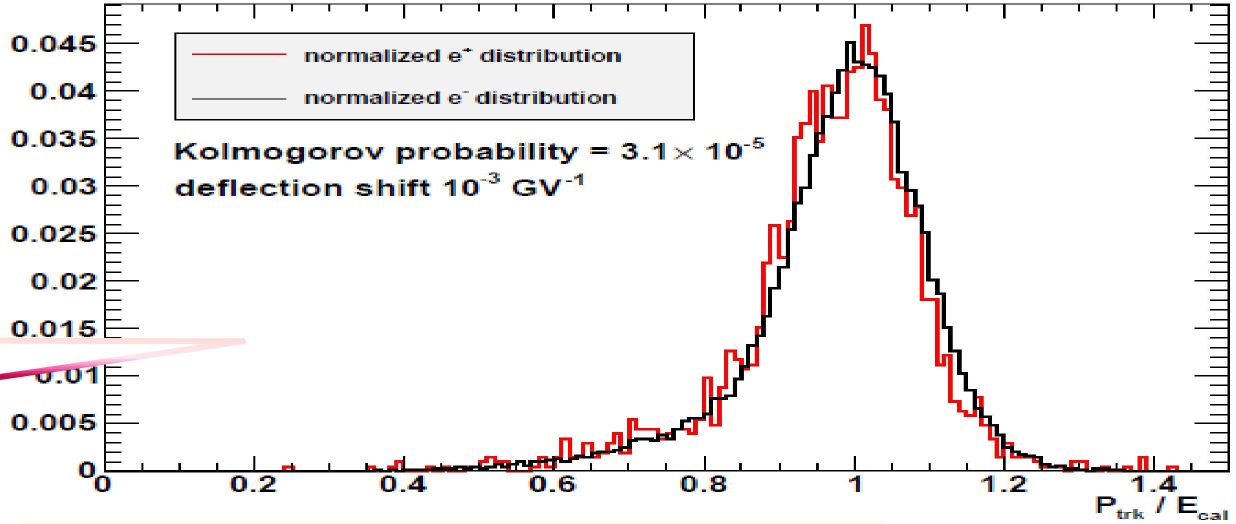
Spectrometer Systematic Uncertainties

With real data:

$$z = \frac{1}{E_C |\eta_S|} \longrightarrow \frac{1}{E_C(1+\varepsilon)\left(|\eta_S| \pm \Delta\eta\right)}$$

- The spectrometer may have a <u>charge-sign</u> dependent systematic
- A calorimeter systematic has <u>no such dependence</u>



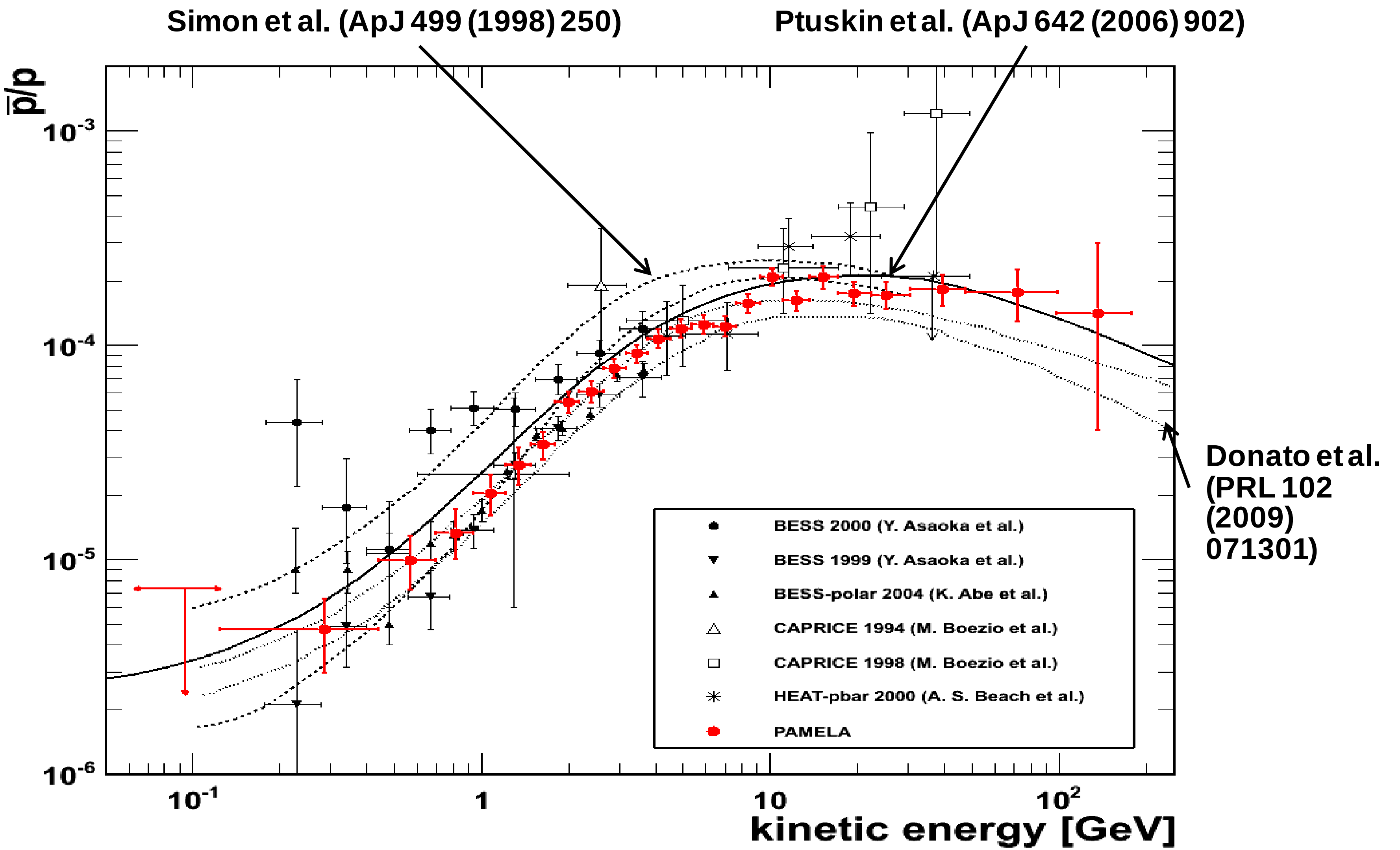


A systematic deflection shift causes an offset between e^- and e^+ distribution

Upper limit set by positron statistics:

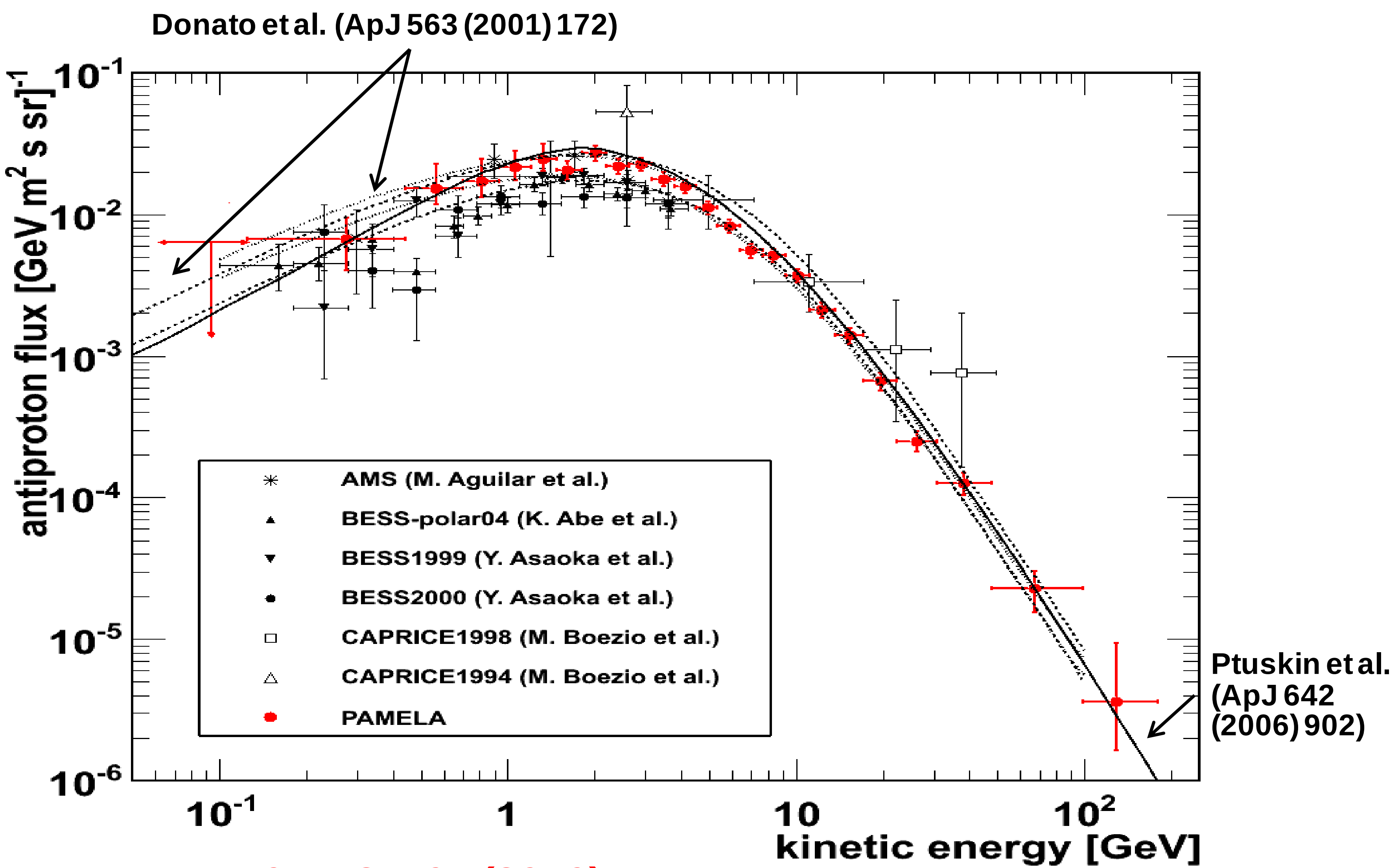
- <u>$\Delta\eta_{sys} \sim 1 \cdot 10^{-4}$ GV^{-1}</u>

Antiproton to proton ratio (0.06 GeV - 180 GeV)



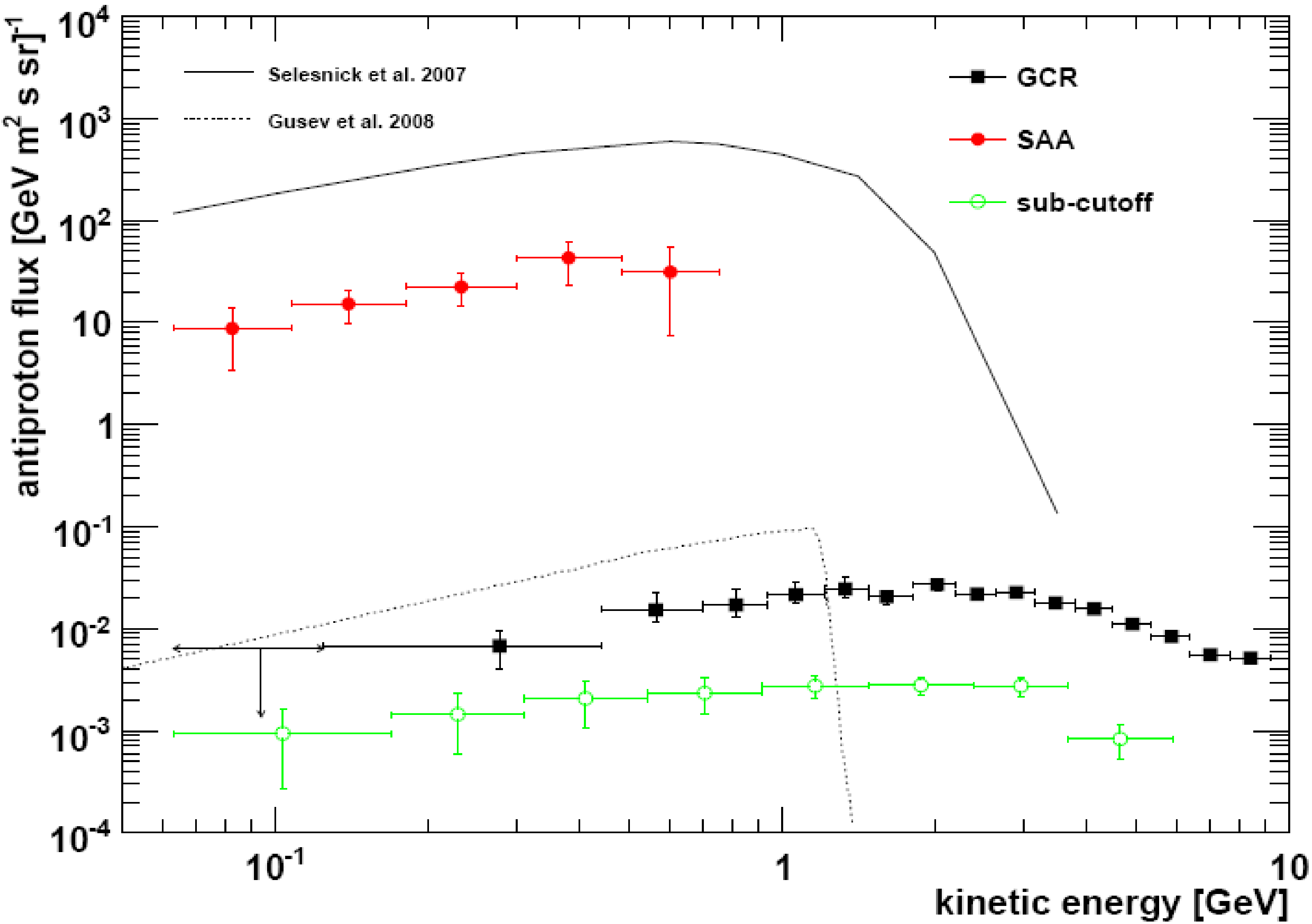
PRL 102, 051101 (2009) PRL. 105, 121101 (2010)

Antiproton Flux
(0.06 GeV - 180 GeV)



PRL. 105, 121101 (2010)

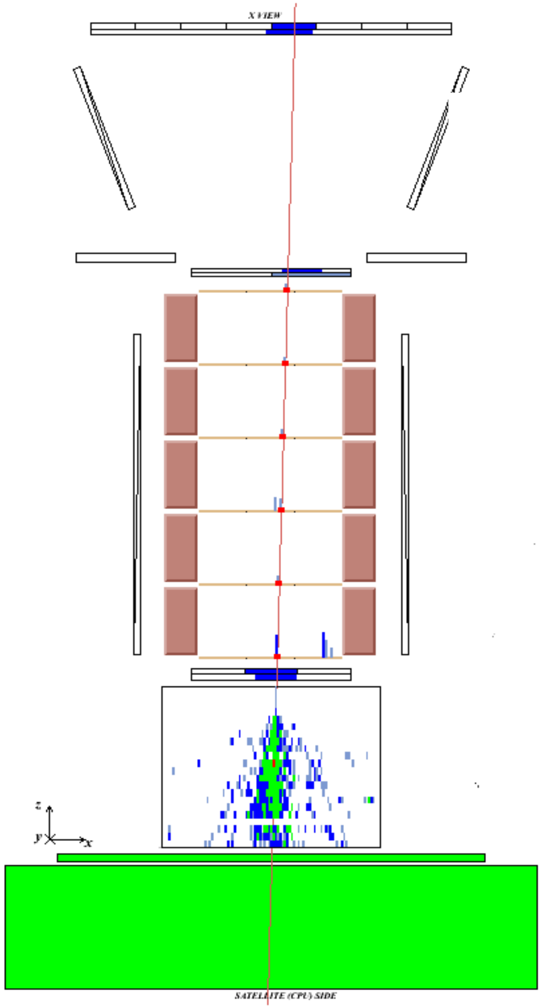
PAMELA trapped antiprotons



O. Adriani et al., to appear in Astrophys. J. Lett. (2011); arXiv:1107.4882

POSITRONS

Proton / positron discrimination



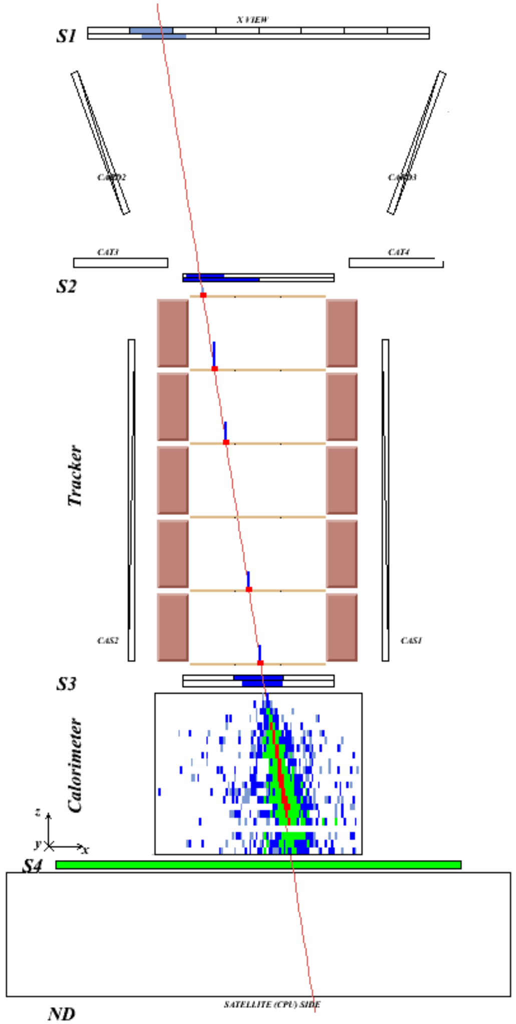
Proton

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

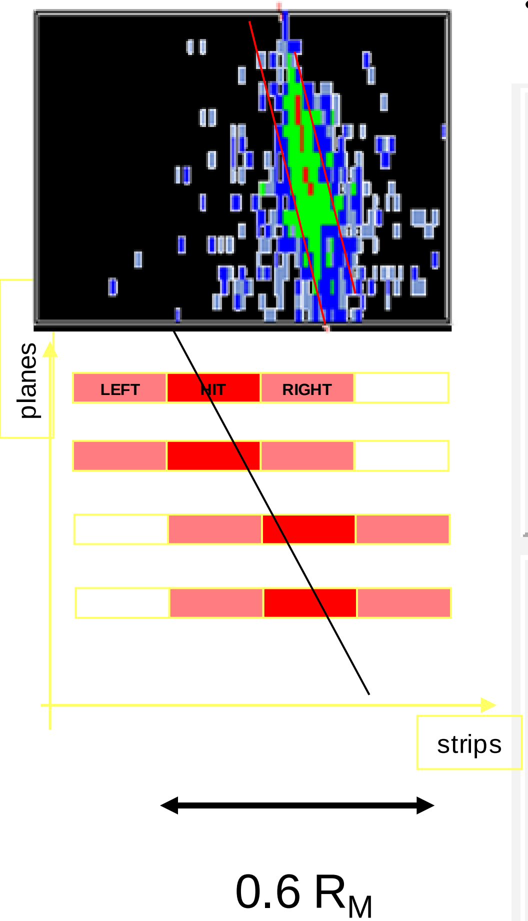
Interaction pattern in calorimeter:
electron-like or proton-like, electron energy



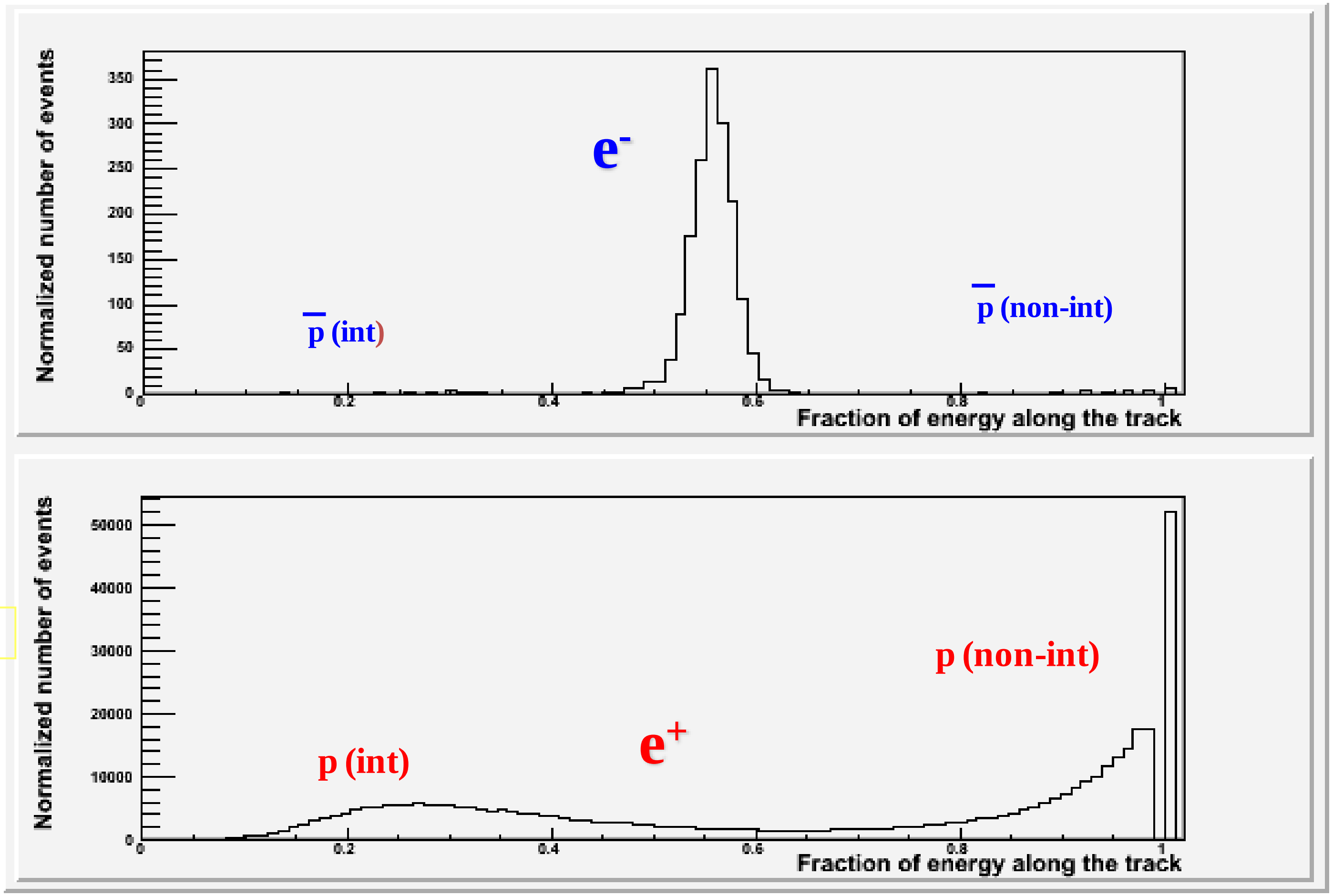
Positron

Positron selection with calorimeter

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



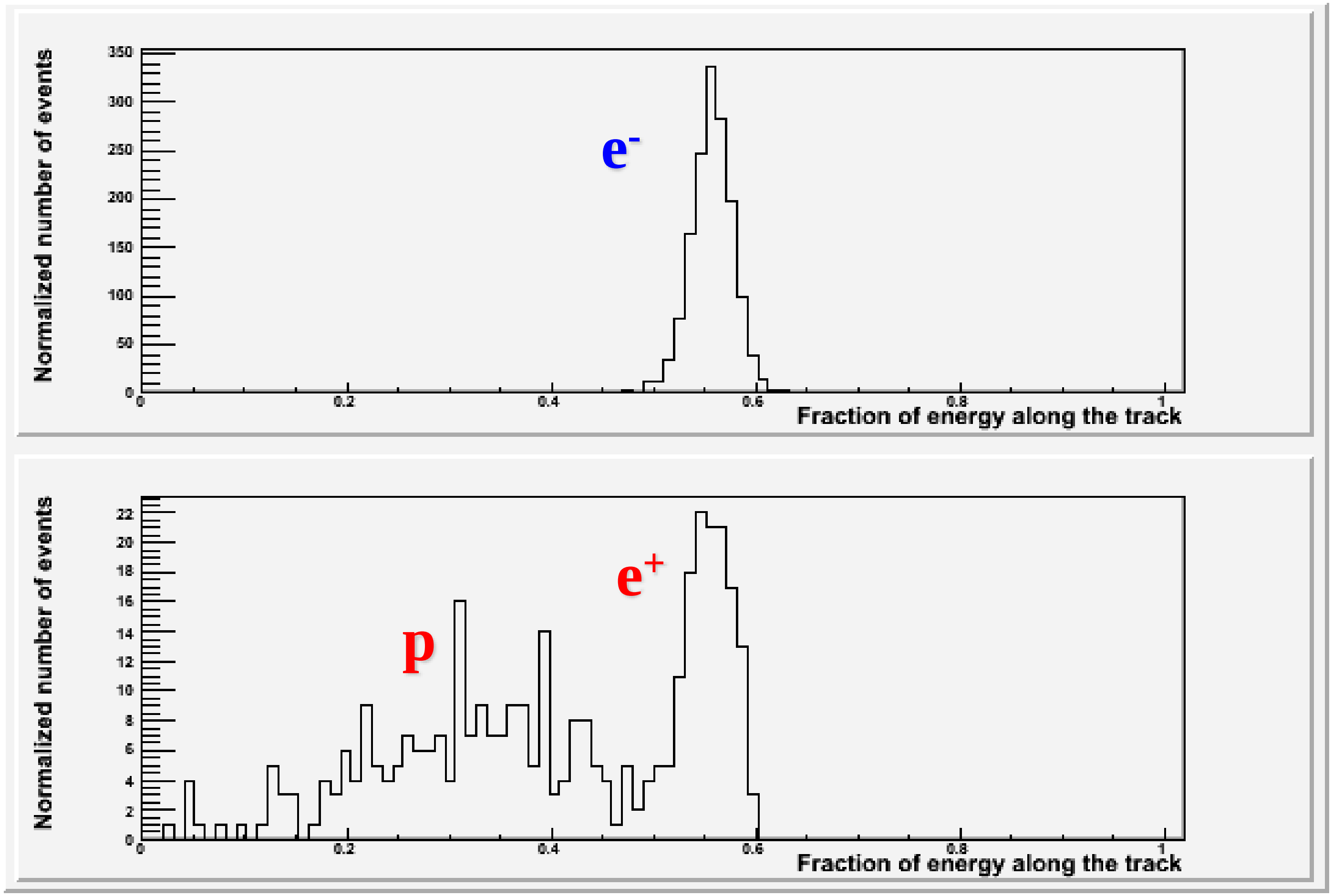
for em showers 90% of E contained in 1 R_M



Rigidity: 20-30 GV

Positron selection with calorimeter

Rigidity: 20-30 GV

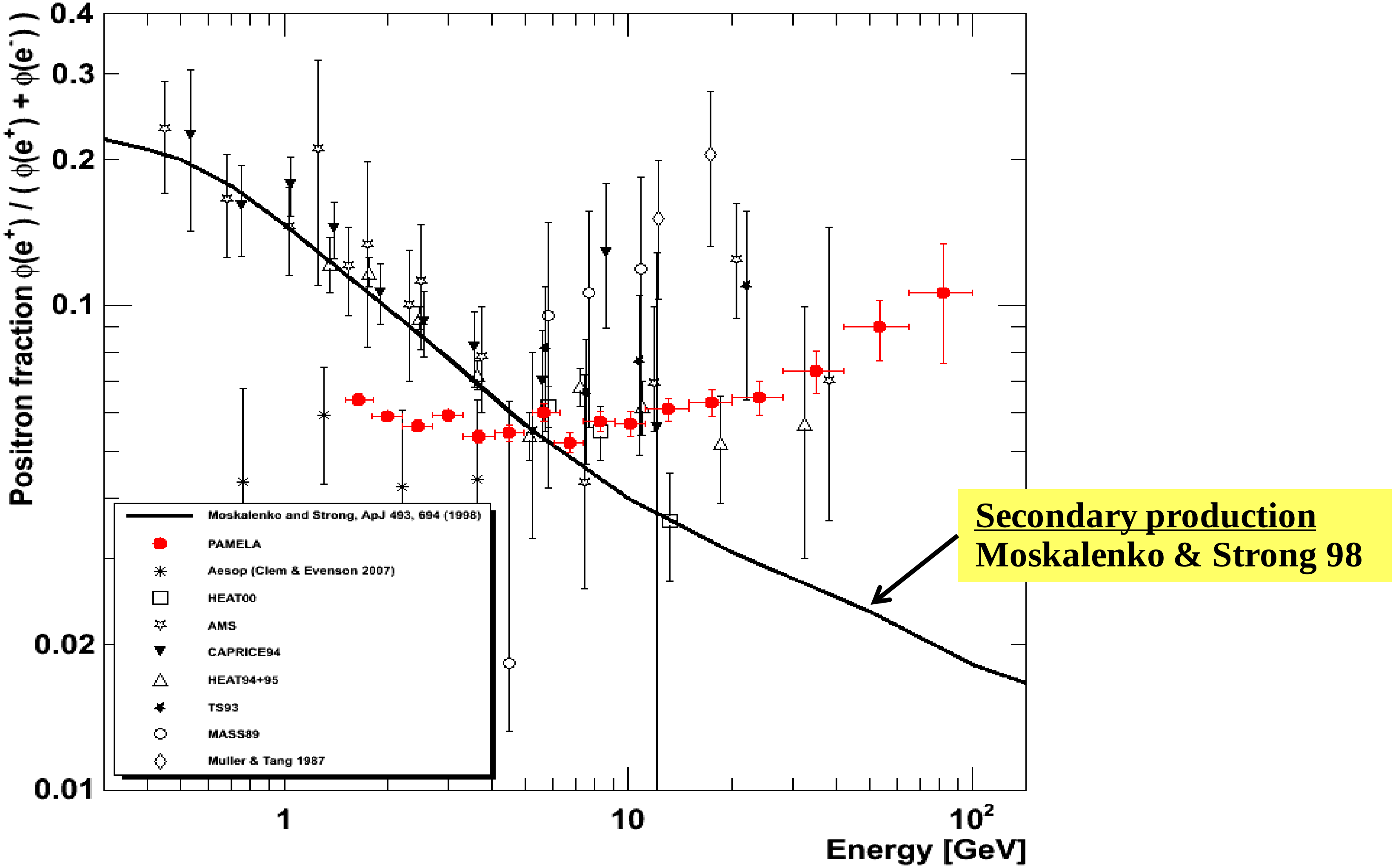


Fraction of charge released along the calorimeter track (left, hit, right)

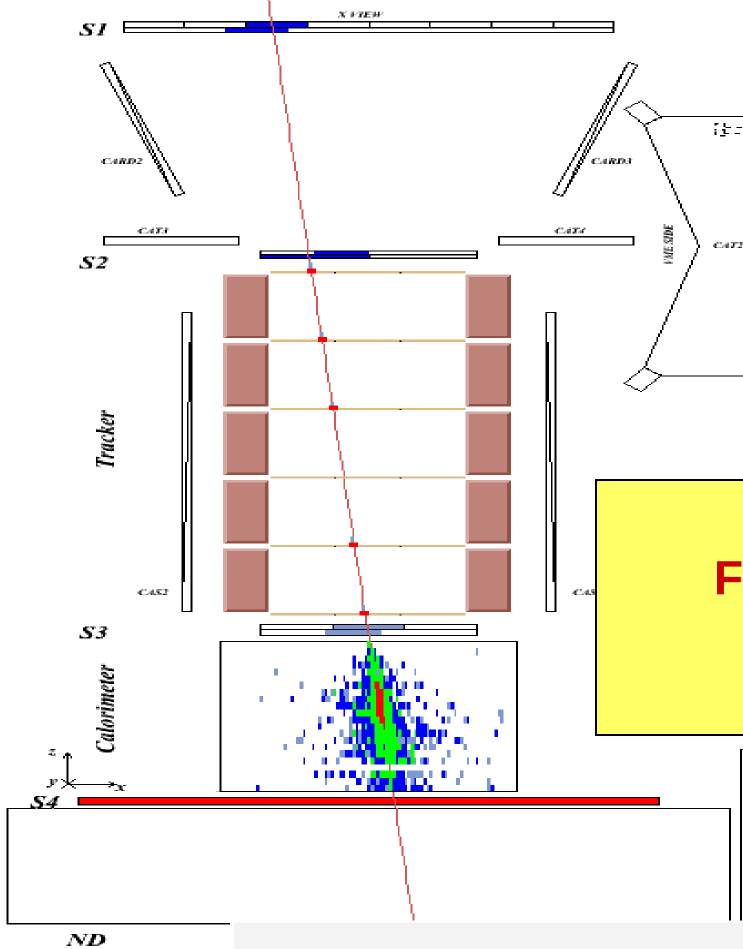
+

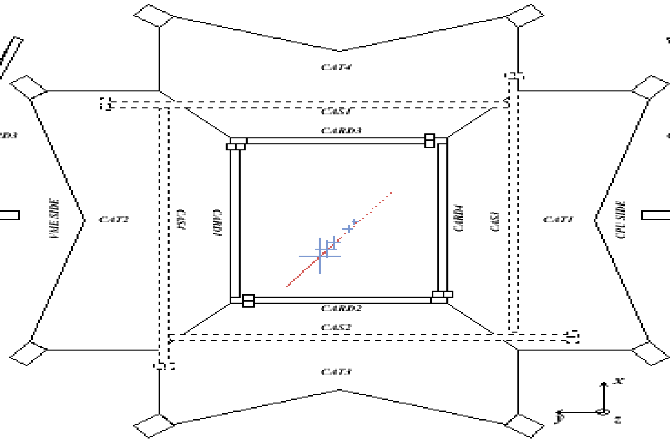
- **Energy-momentum match**
- **Starting point of shower**

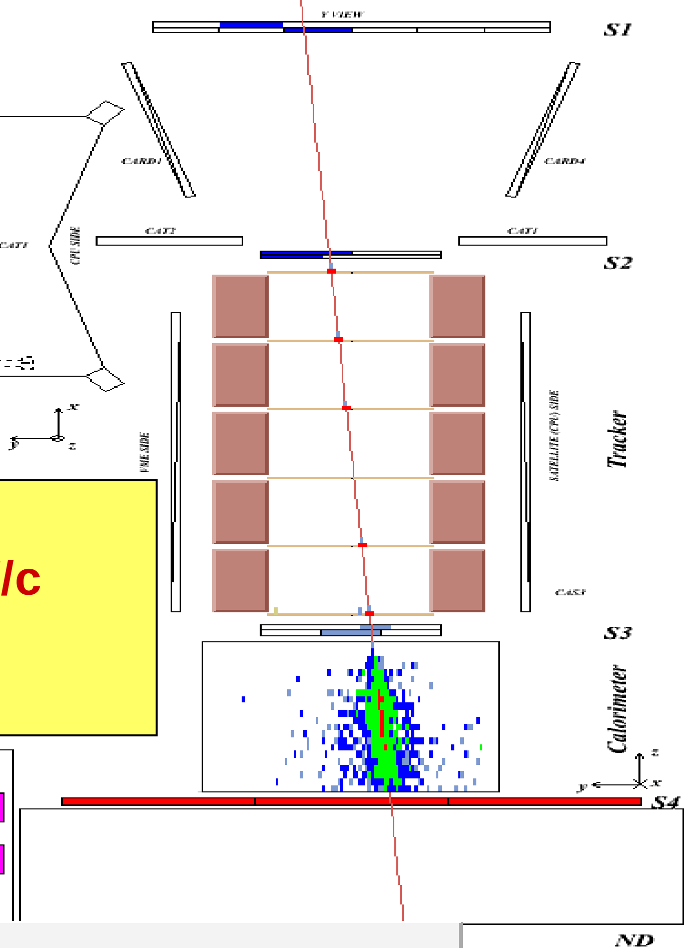
Positron to Electron Fraction



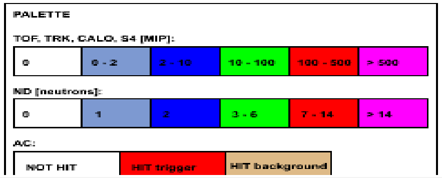
Astropart. Phys. 34 (2010) 1
Nature 458 (2009) 607

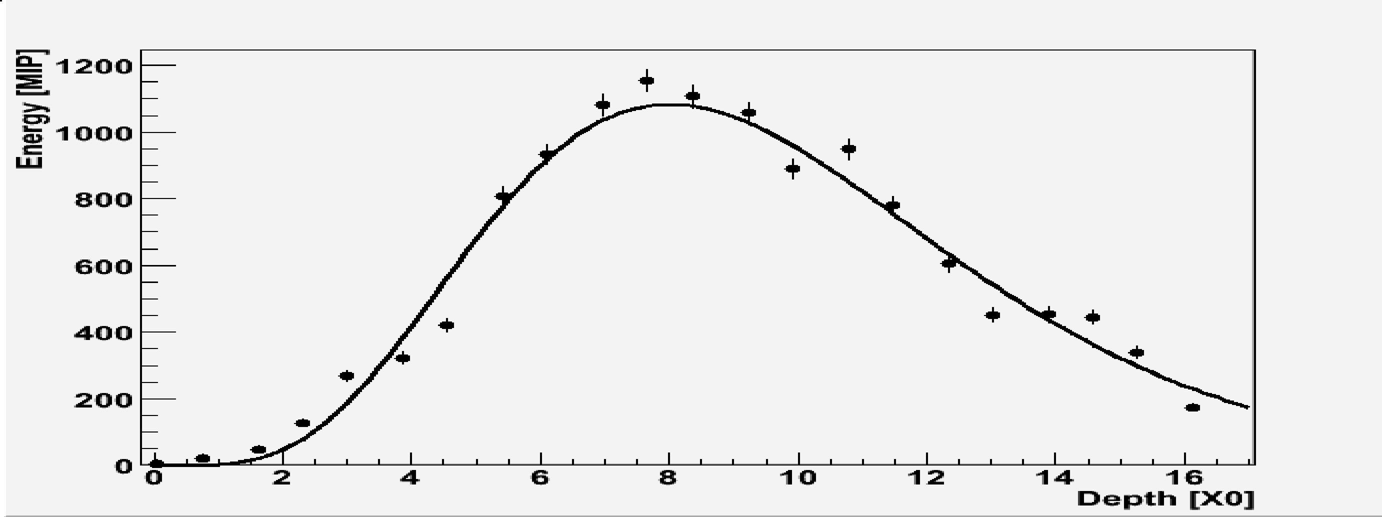






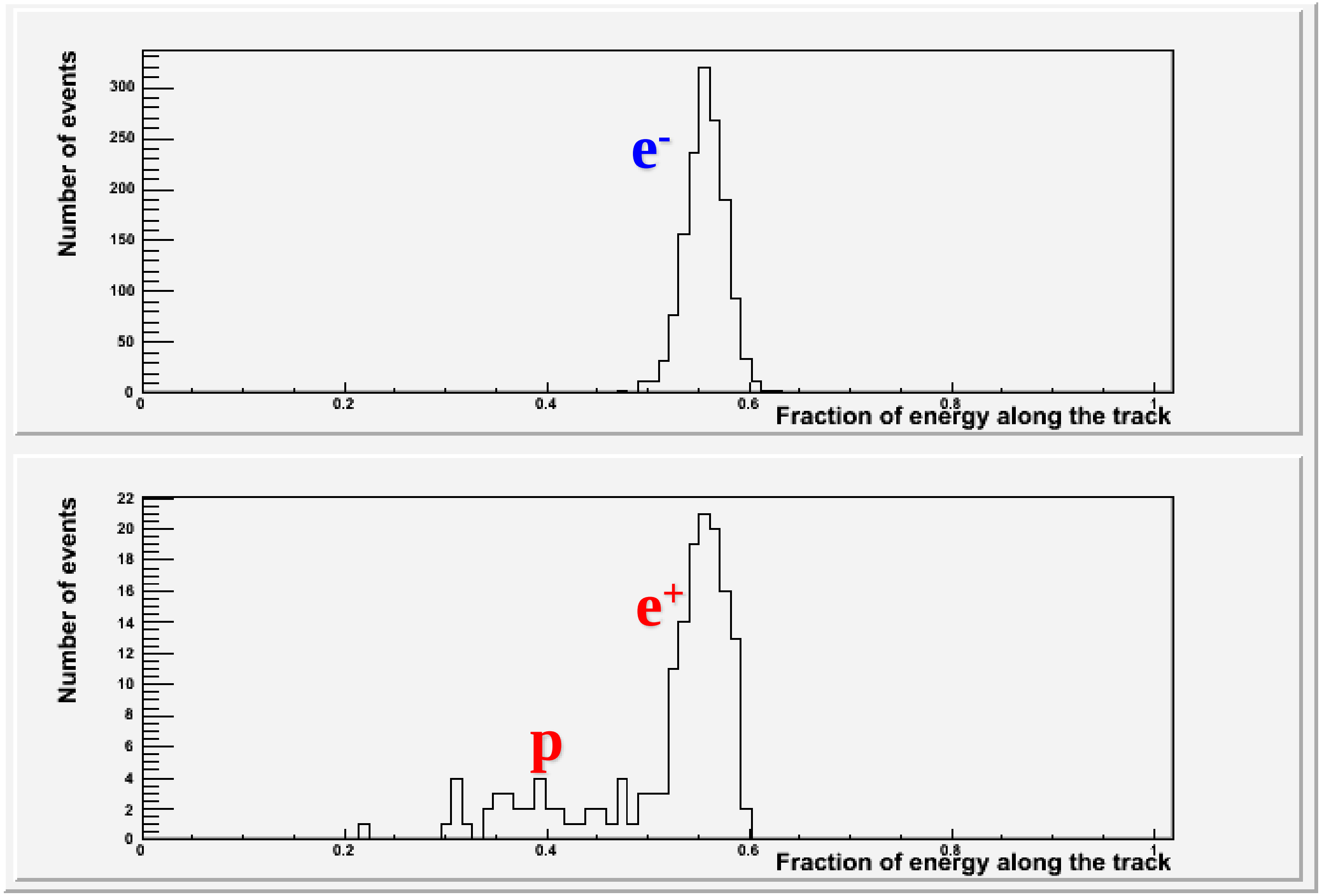
Flight data: 51 GeV/c positron





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 with calorimeter

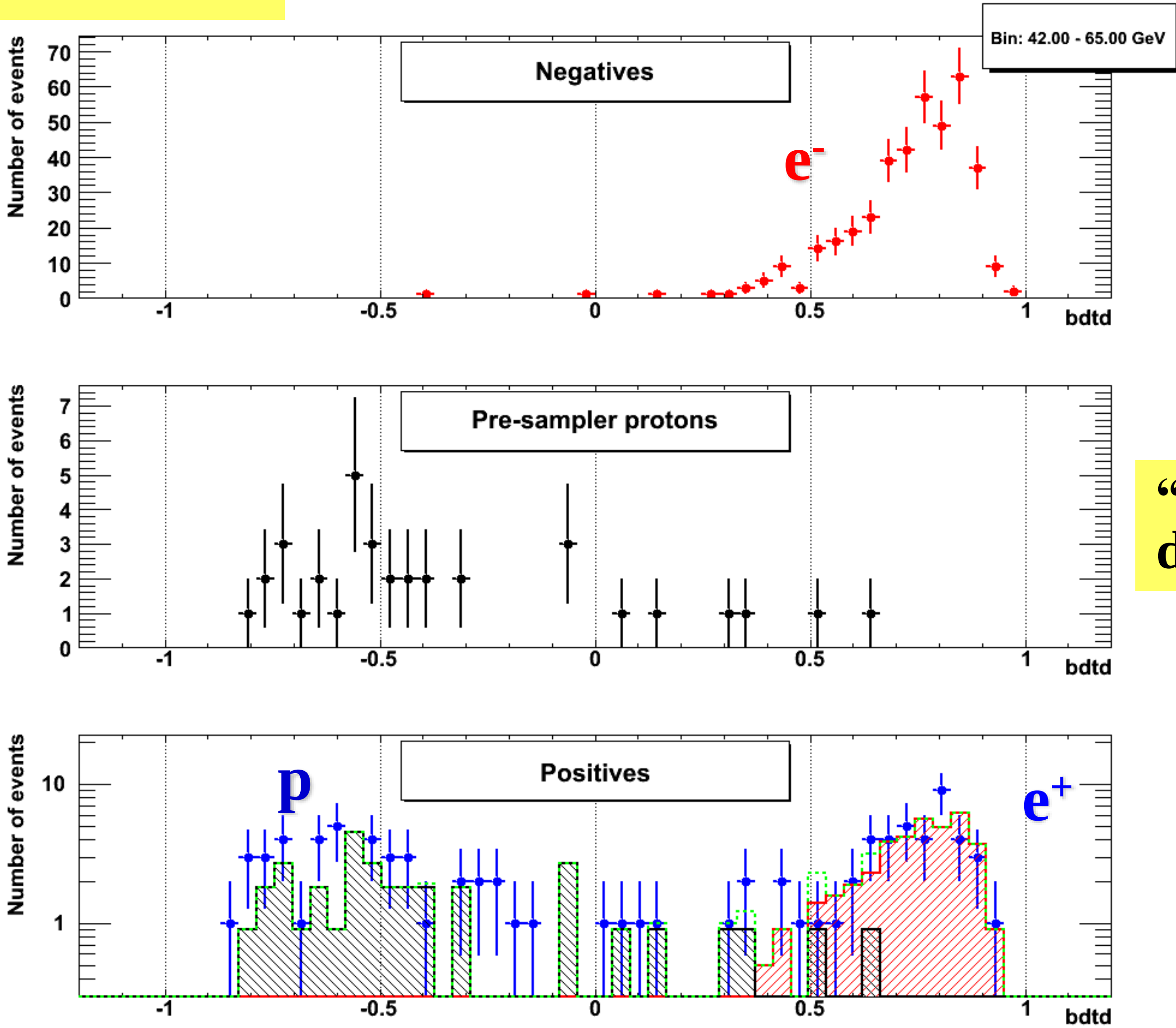
TMVA: Toolkit for MultiVariate data Analysis
http://tmva.sourceforge.net/

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

Training with "pre-sampler" data and simulation for the whole calorimeter.

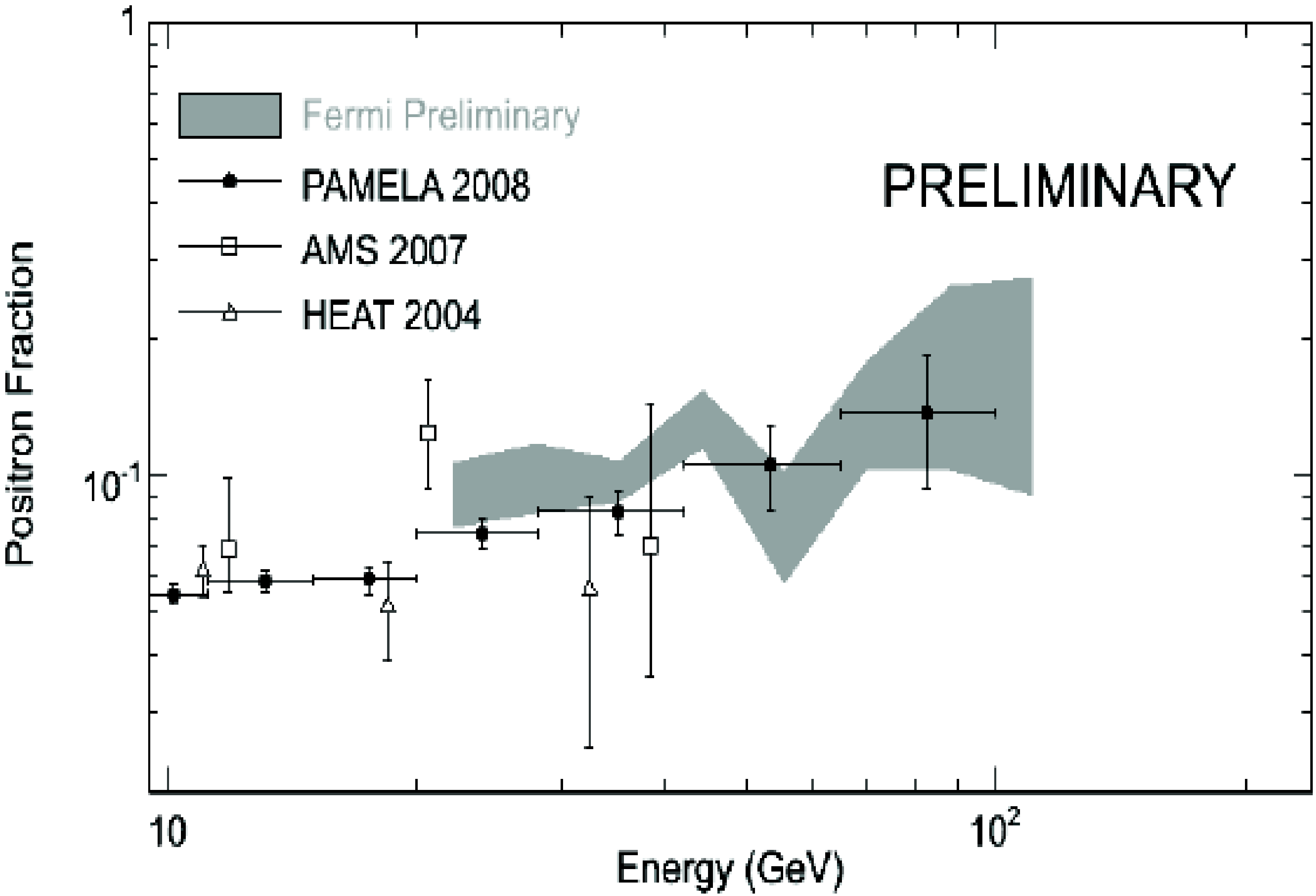
Positron selection with calorimeter

Rigidity: 42-65 GV
Boosted Decisional Trees



"Pre-sampler" data

PAMELA & Fermi Positron Fraction

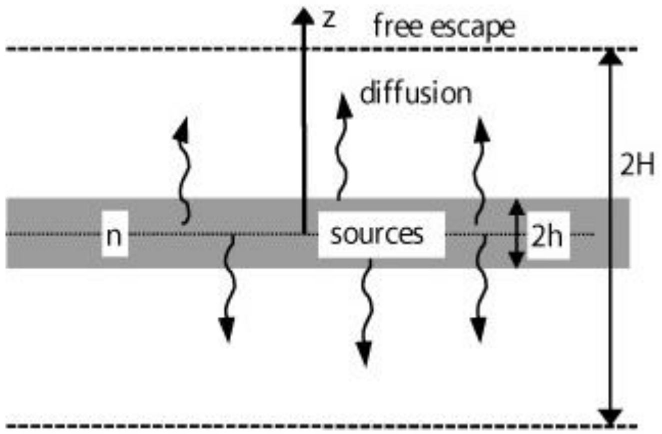


Fermi Symposium, May 9 2011

Cosmic Ray Spectra

Cosmic-Ray Acceleration and Propagation in the Galaxy

Diffusion Halo Model

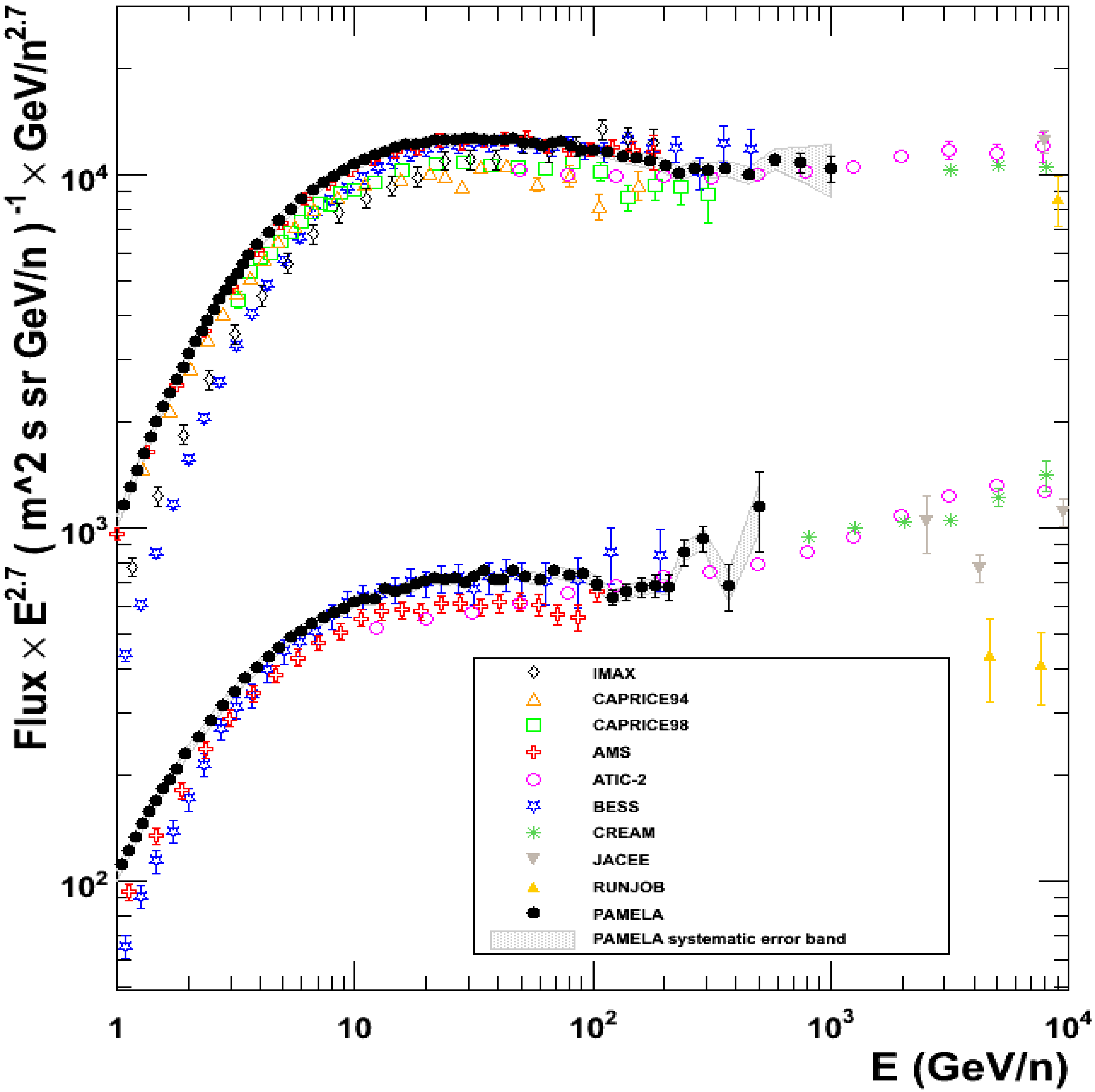


$$\frac{\partial N_i(E,z,t)}{\partial t} = \underbrace{D(E)\cdot\frac{\partial^2}{\partial z^2}N_i(E,z,t)}_{\text{diffusion}} - \underbrace{N_i(E,z,t)\left\{\frac{1}{\tau_i^{\text{int}}(E,z)}+\frac{1}{\gamma(E)\tau_i^{dec}}\right\}}_{\text{interaction and decay}}$$

$$+ \underbrace{\sum_{k>i}\frac{N_k(E,z,t)}{\tau_{\text{int}}^{k\to i}(E,z)}}_{\text{secondary production}} + \underbrace{Q_i(E,z)}_{\text{primary sources}}$$

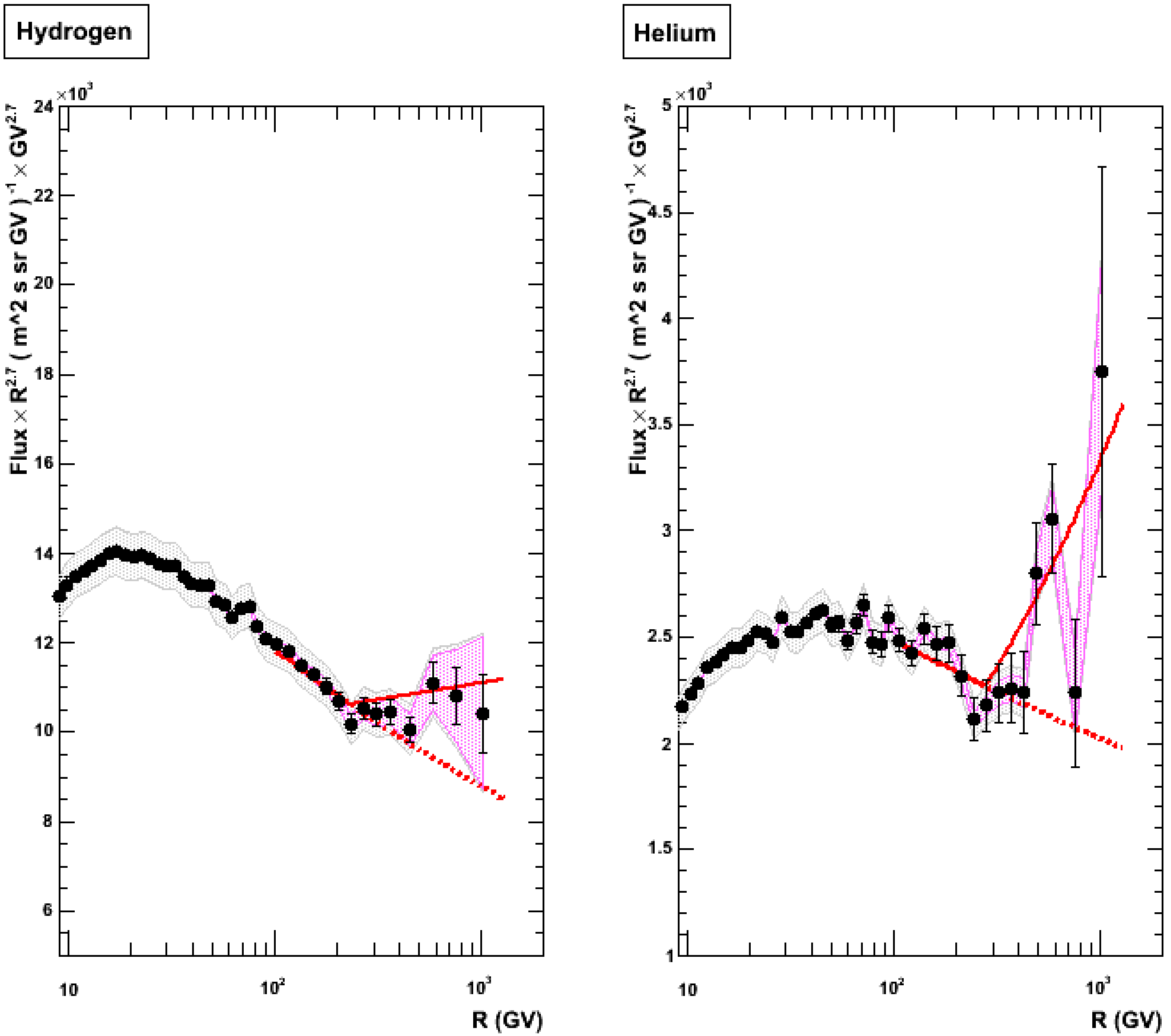
$$\underbrace{-\frac{\partial}{\partial E}\left\{\left\langle\frac{\partial E}{\partial t}\right\rangle\cdot N_i(E,z,t)\right\}+\frac{1}{2}\frac{\partial^2}{\partial E^2}\left\{\left\langle\frac{\Delta E^2}{\Delta t}\right\rangle\cdot N_i(E,z,t)\right\}}_{\text{energy changing processes (ionisation, reacceleration)}}$$

Proton and Helium Nuclei Spectra

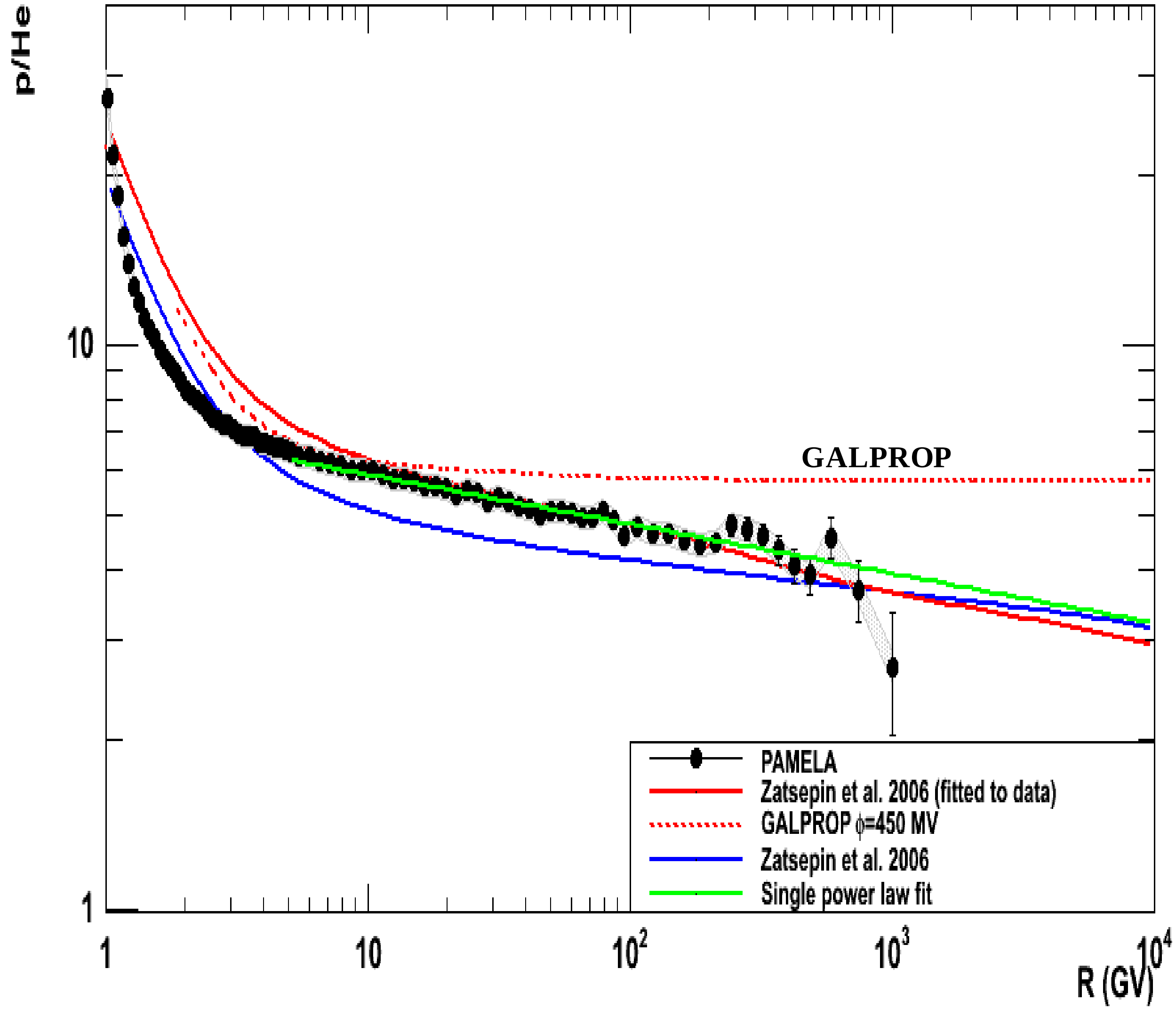


O. Adriani et al., Science 332 (2011) 69

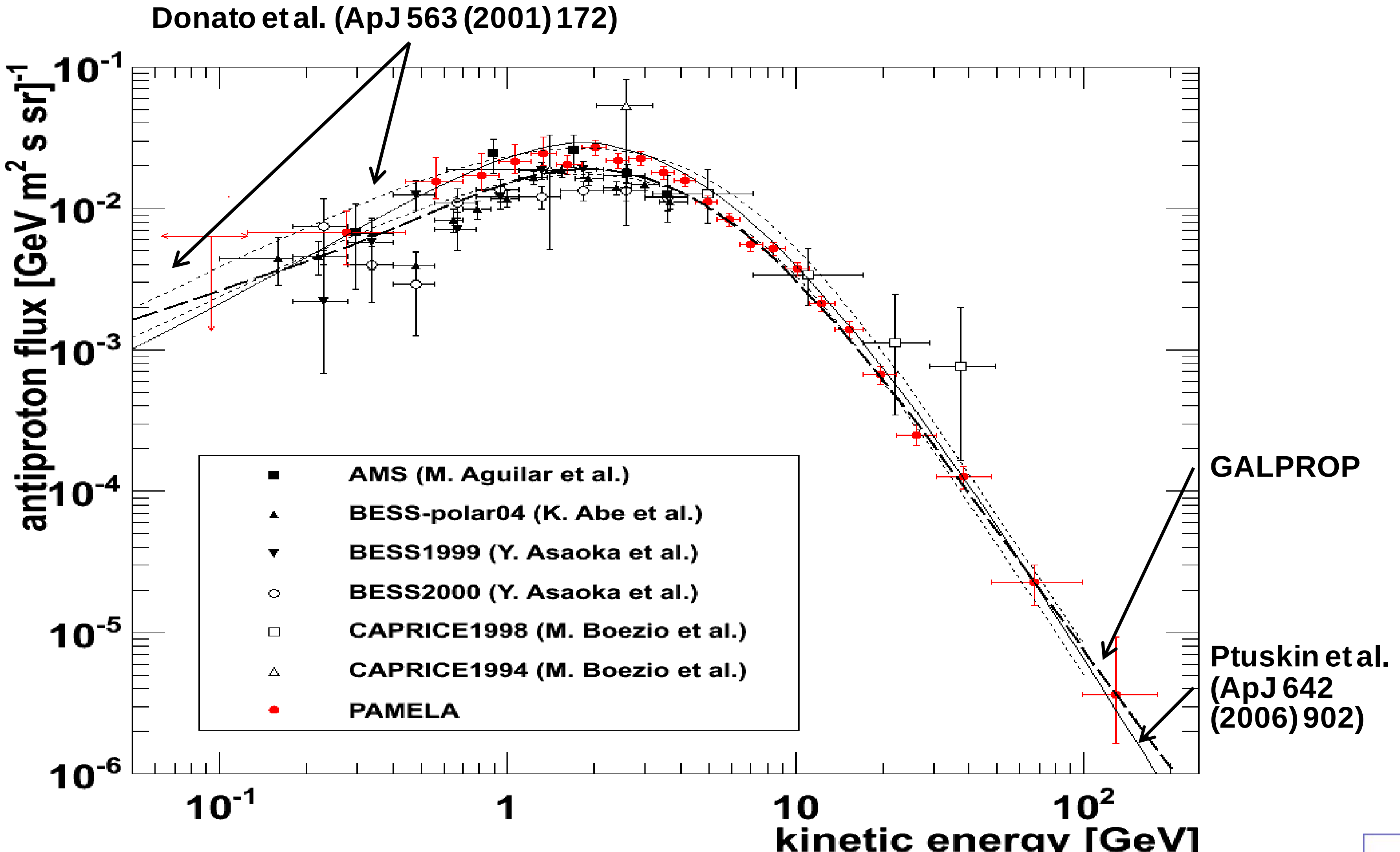
Proton and Helium Nuclei Spectra



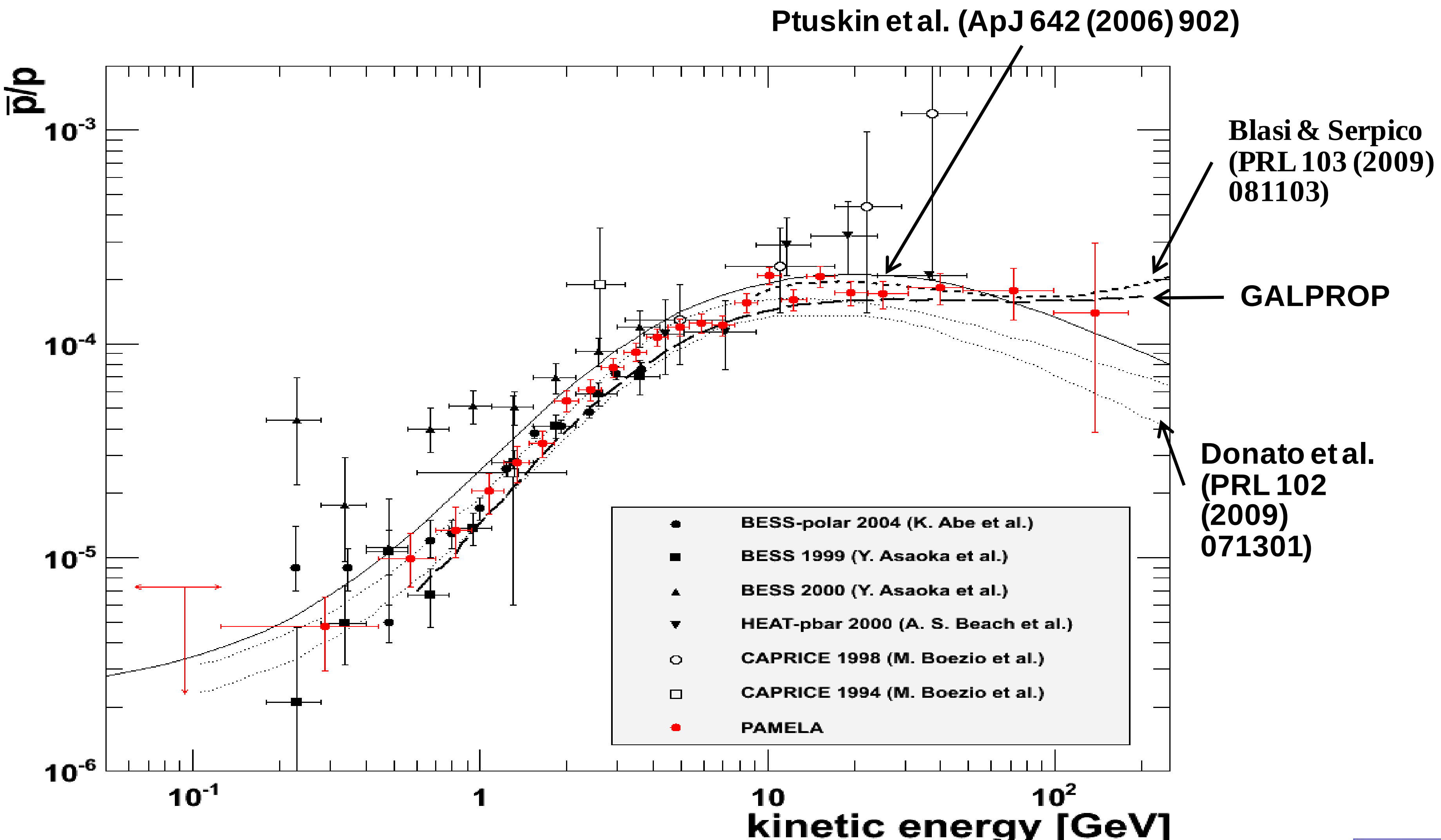
Proton and Helium Nuclei Spectra



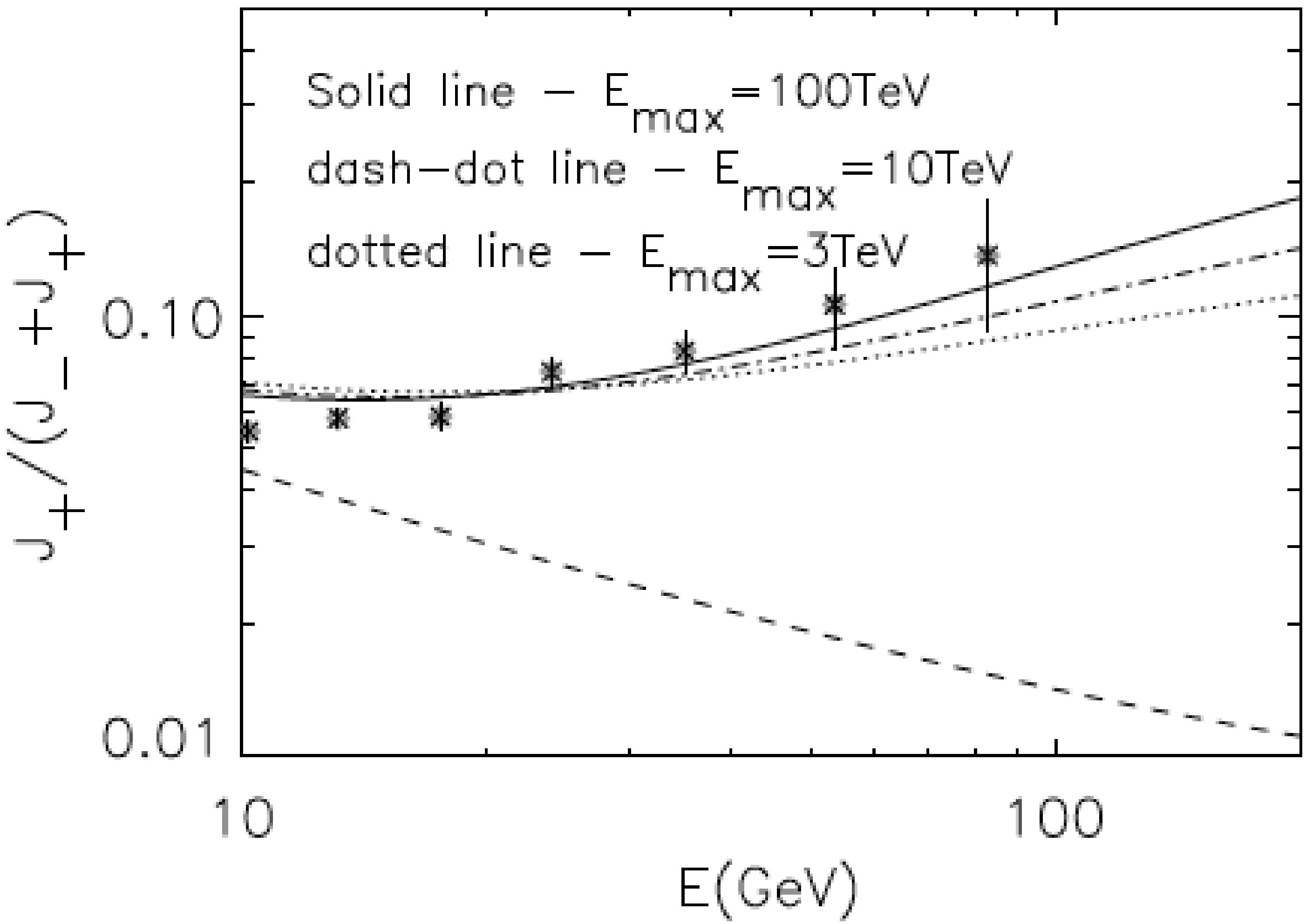
Antiproton Flux



Antiproton to proton flux ratio



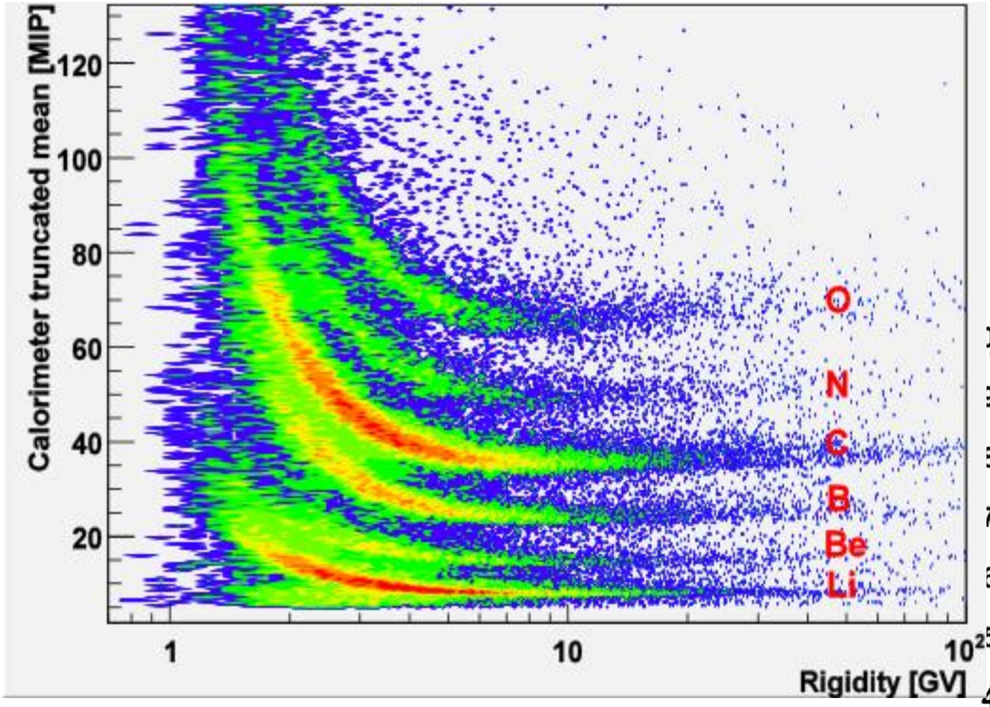
SNR as sources of secondaries e^+

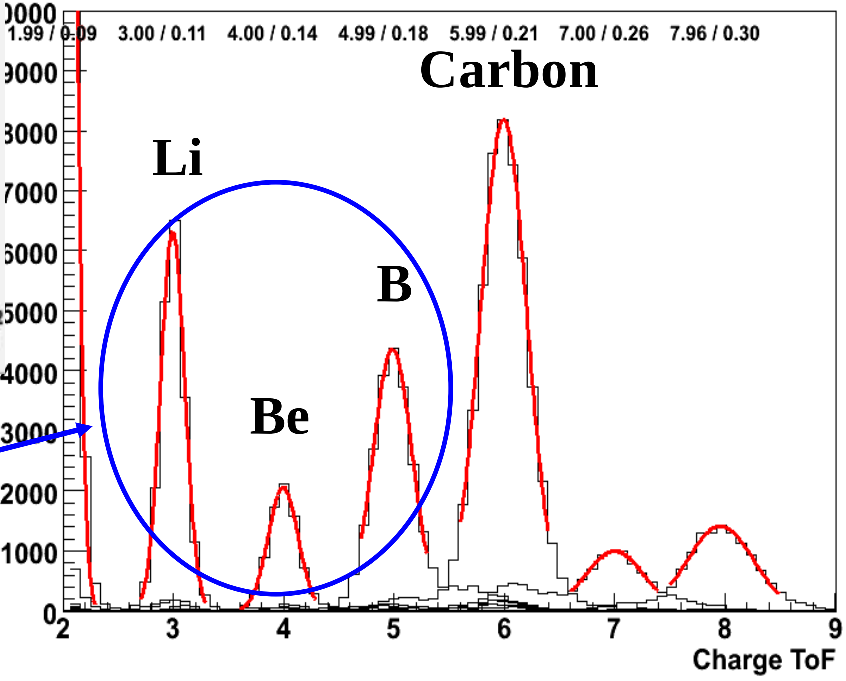


Positrons (and electrons) produced as secondaries in the sources (e.g. SNR) where CRs are accelerated.
But also other secondaries are produced: significant increase expected in the $\bar{p}$/p and B/C ratios.

P.Blasi, PRL 103 (2009) 051104
arXiv:0903.2794 [astro-ph]

Light Nuclei Selection

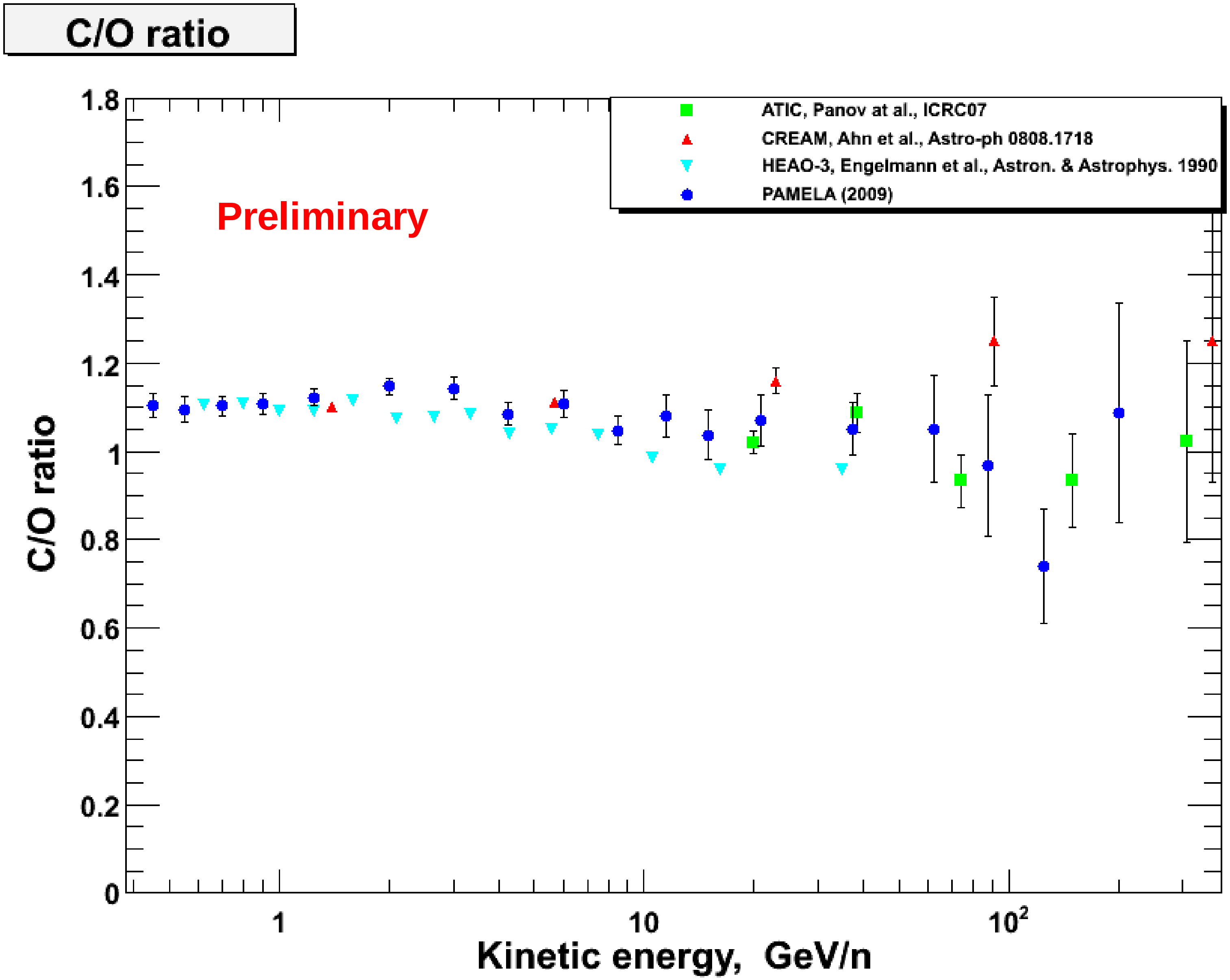




Produced as Secondaries

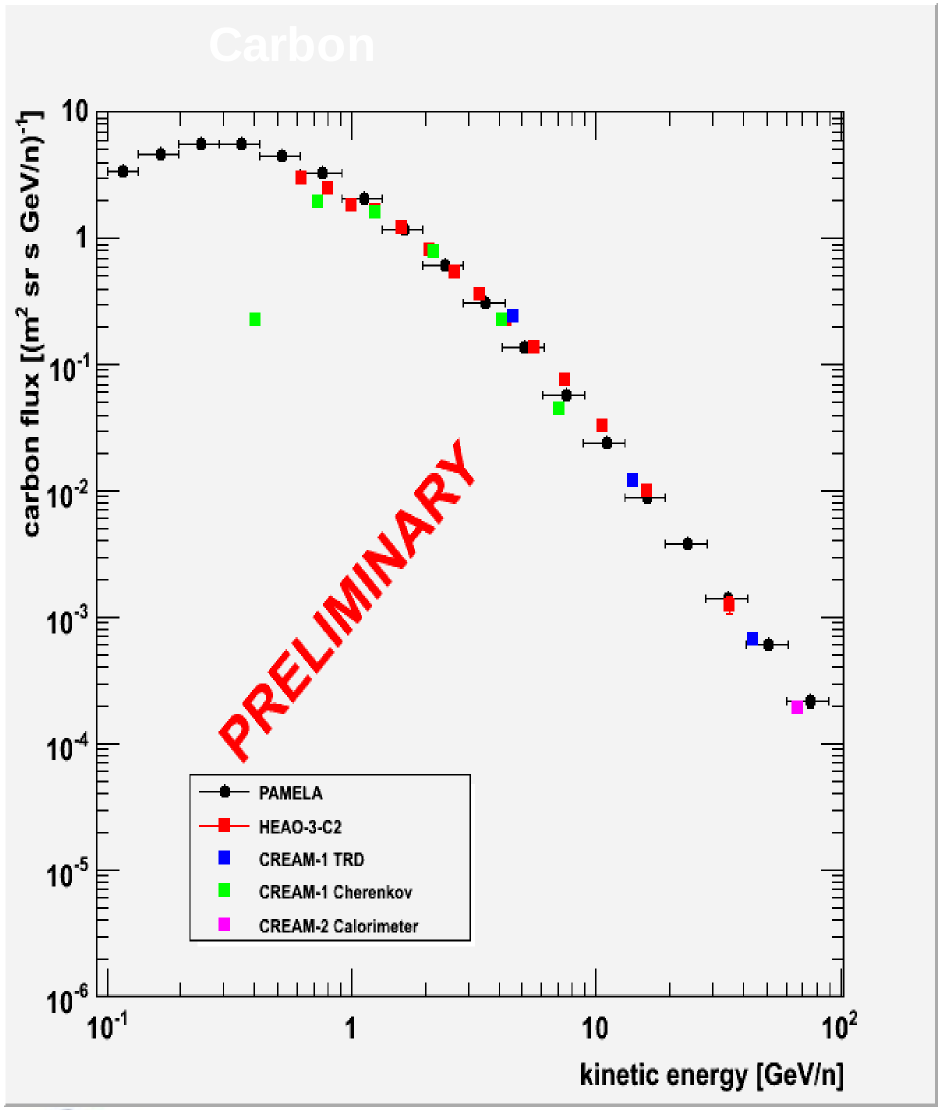
Information on Cosmic Ray Transport

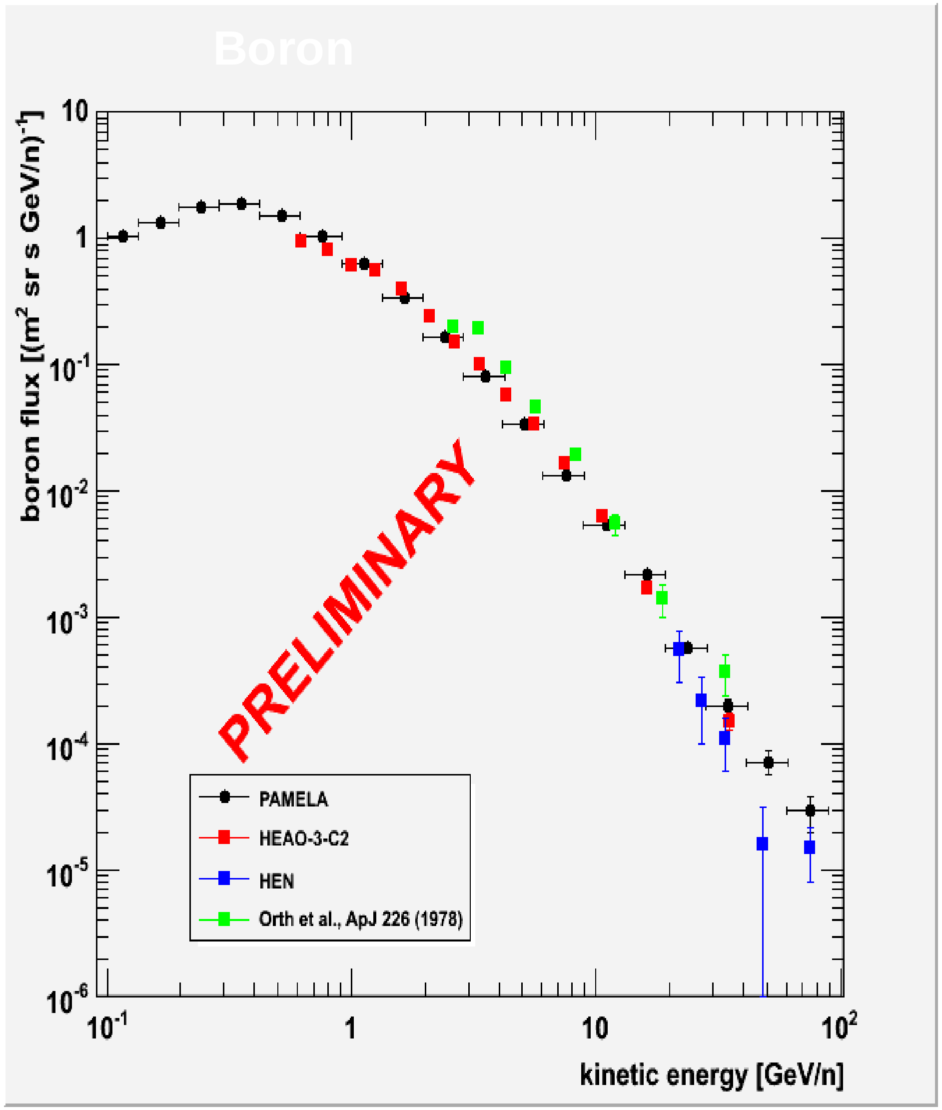
C/O ratio



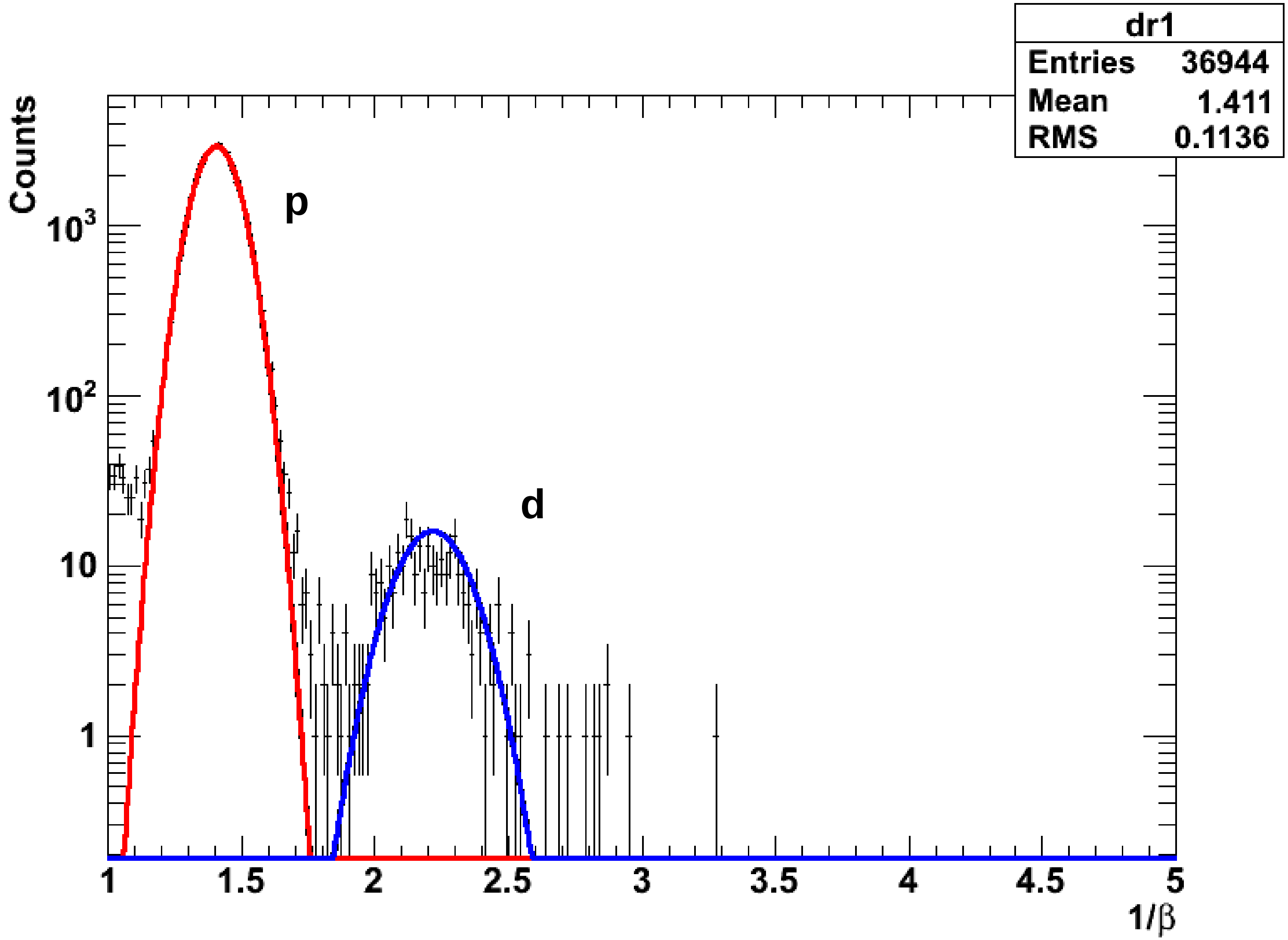
C/O ratio
Preliminary
ATIC, Panov at al., ICRC07
CREAM, Ahn et al., Astro-ph 0808.1718
HEAO-3, Engelmann et al., Astron. & Astrophys. 1990
PAMELA (2009)
C/O ratio
Kinetic energy, GeV/n
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
1
10
10^2

Boron and Carbon nuclei Spectra



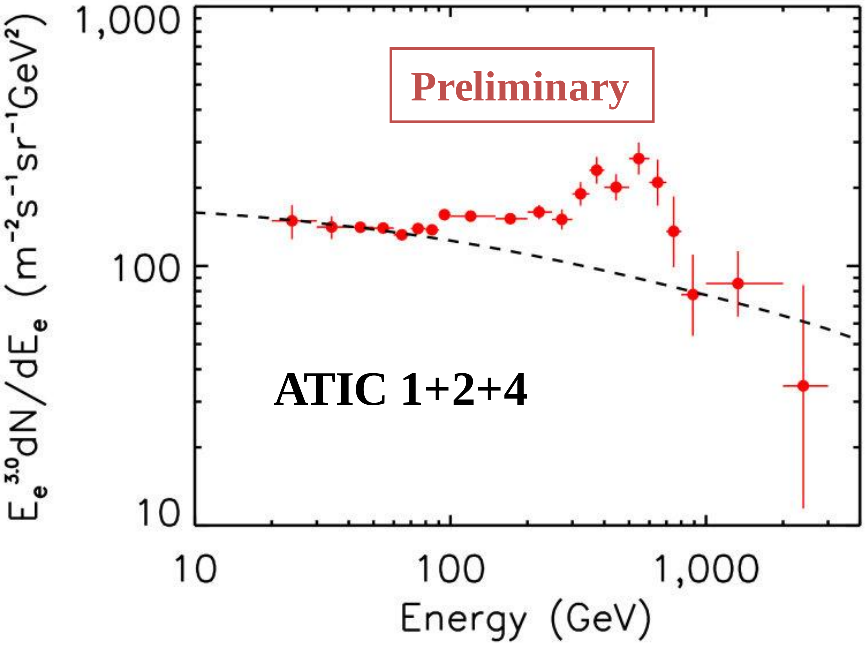


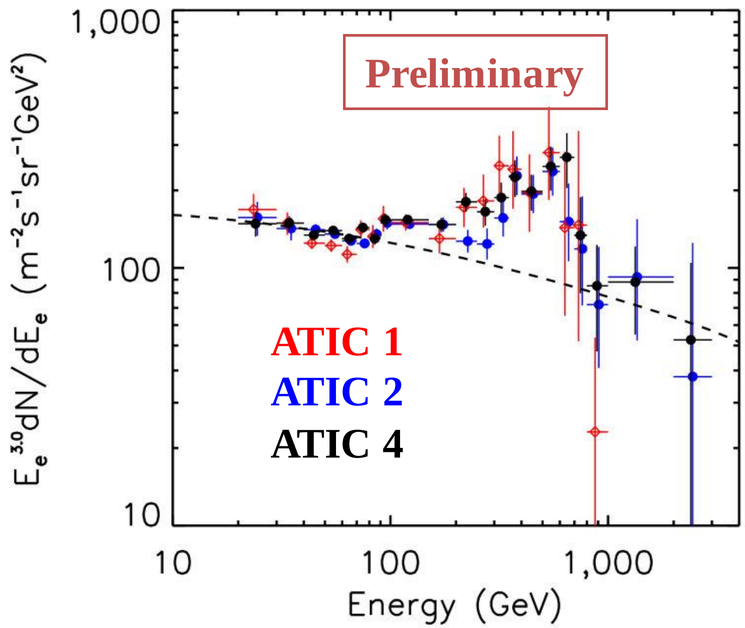
H isotopes separation



ELECTRONS

All three ATIC flights are consistent





"Source on/source off" significance of bump for ATIC1+2 is about 3.8 sigma

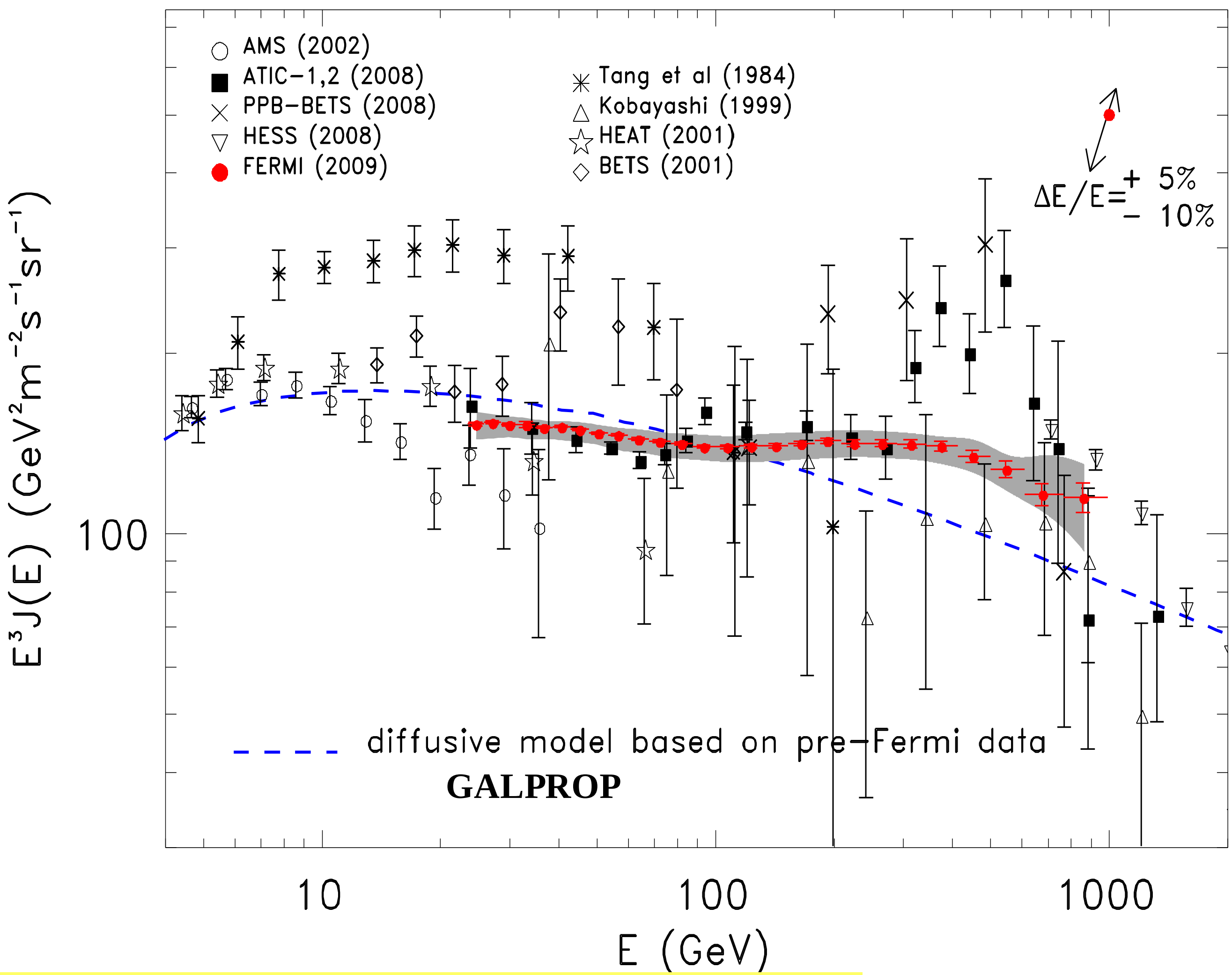
J Chang *et al. Nature* **456**, 362 (2008)

ATIC-4 with 10 BGO layers has improved e , p separation. **(~4x lower background)**

"Bump" is seen in all three flights.

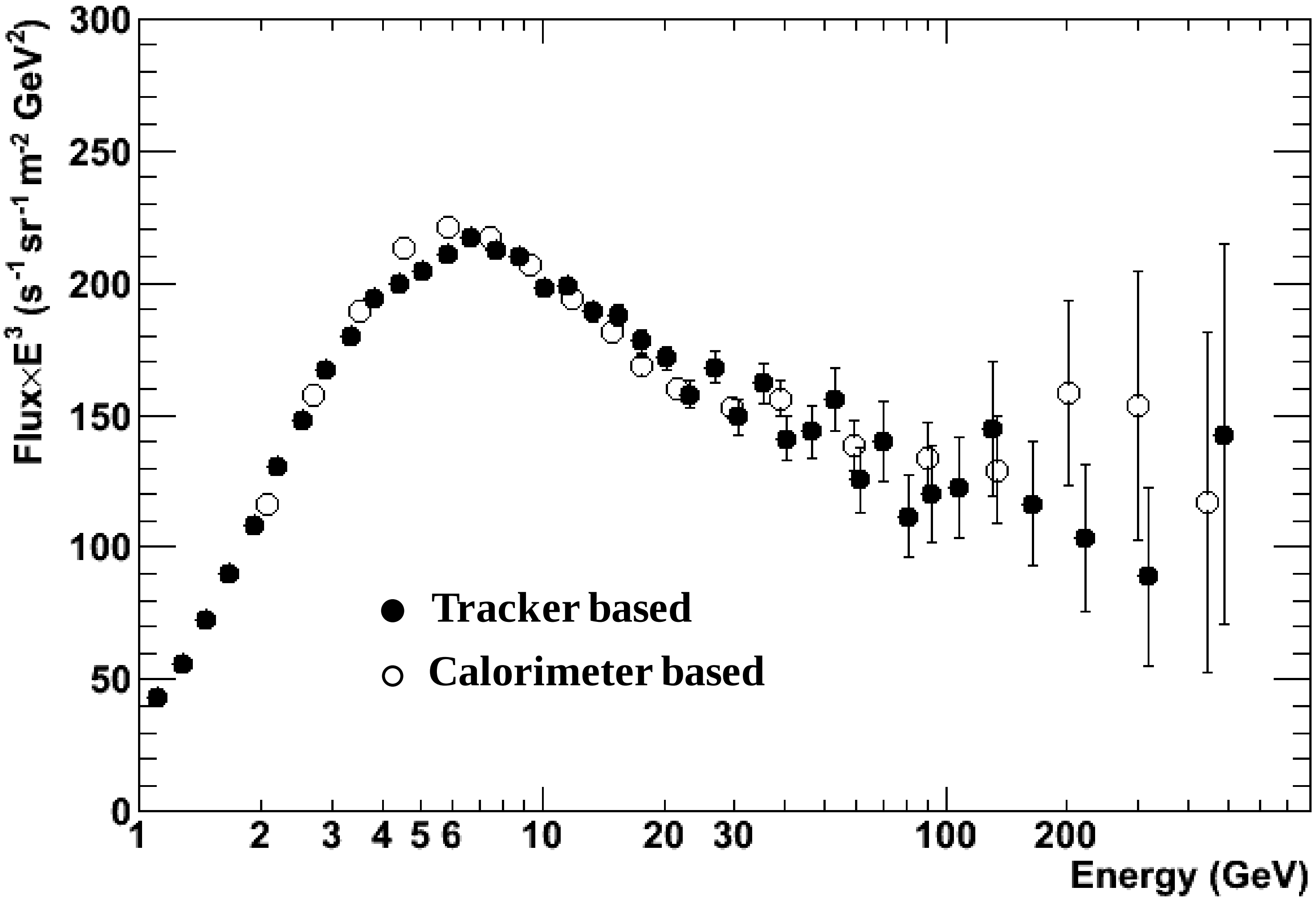
Significance for ATIC1+2+4 is 5.1 sigma

FERMI all Electron Spectrum

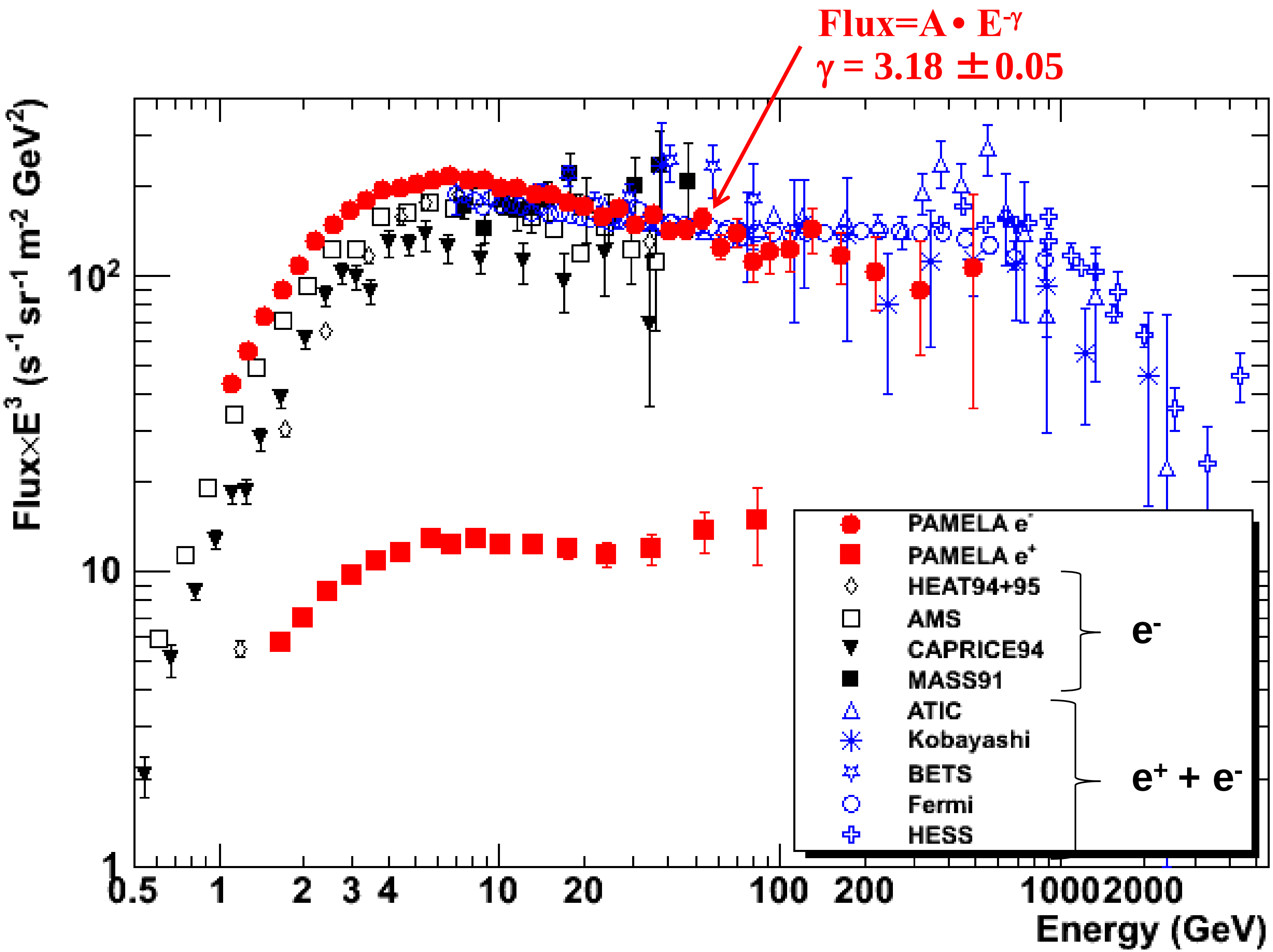


A. A. Abdo et al. (The Fermi LAT Collaboration), Phys. Rev. Lett. 102, 181101 (2009).

PAMELA electron (e^-) spectrum

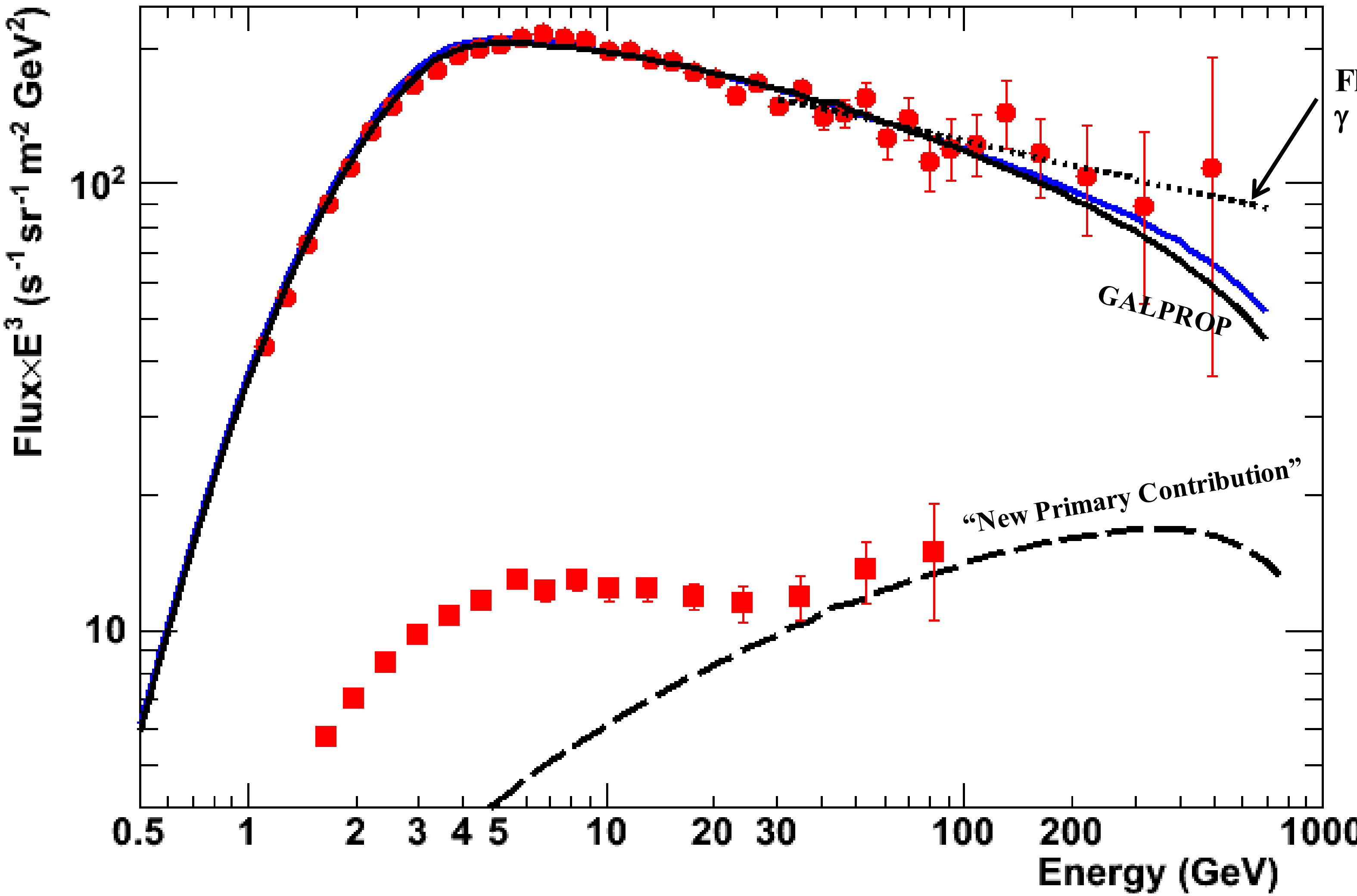


PAMELA e^- and e^+ spectra



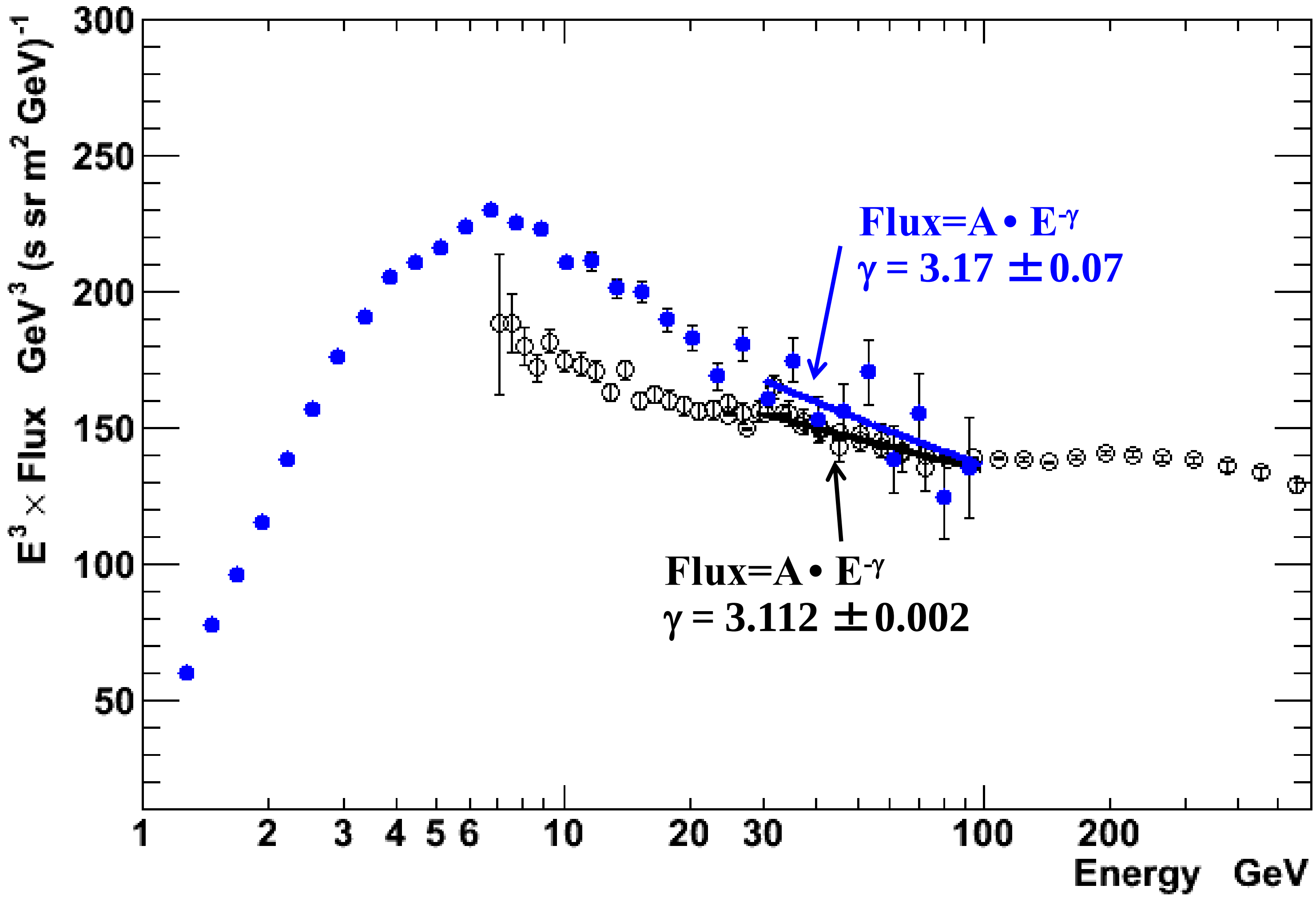
Mirko Boezio, DMUH11, 26-07-2011

PAMELA e^- and e^+ spectra

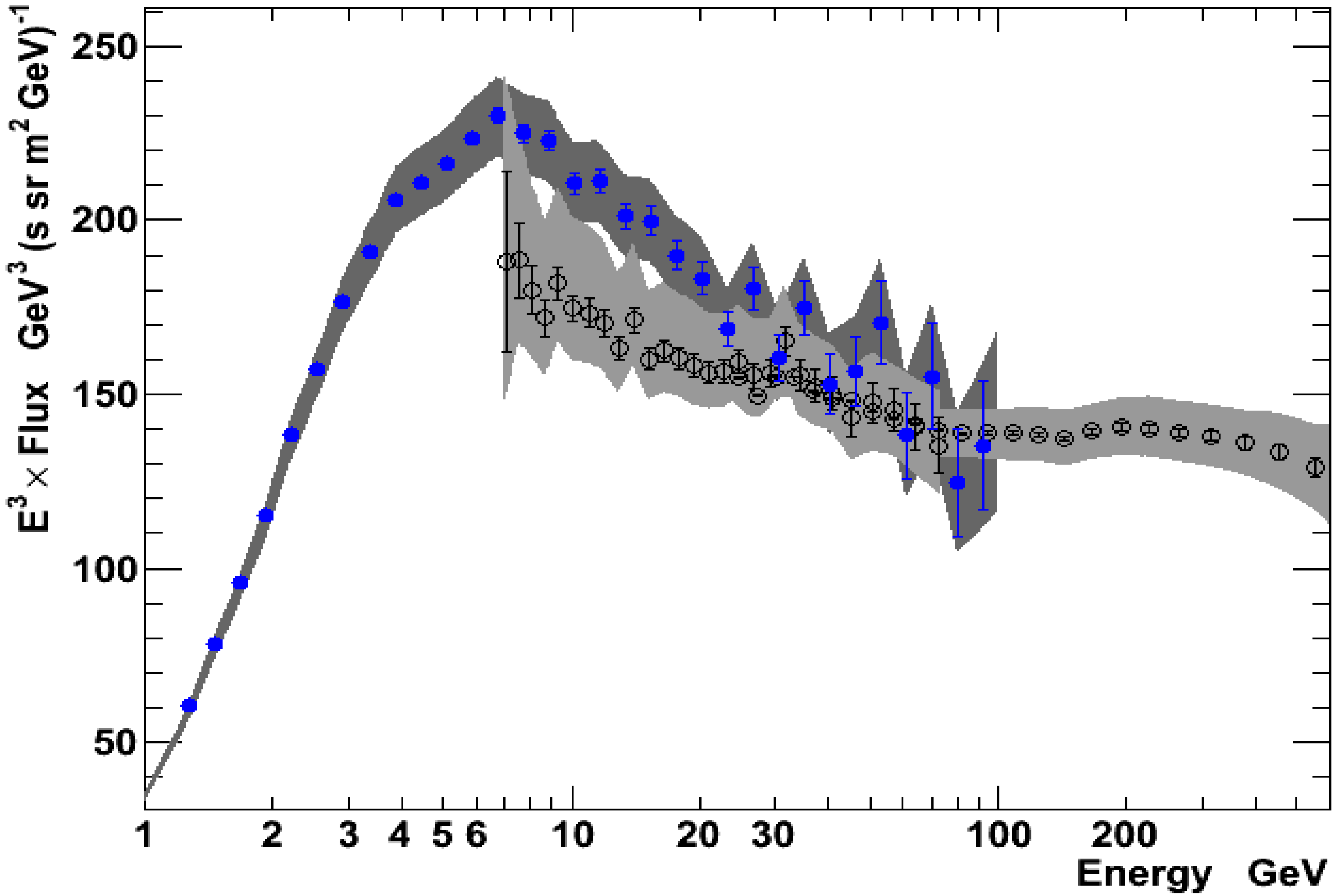


Mirko Boezio, DMUH11, 26-07-2011

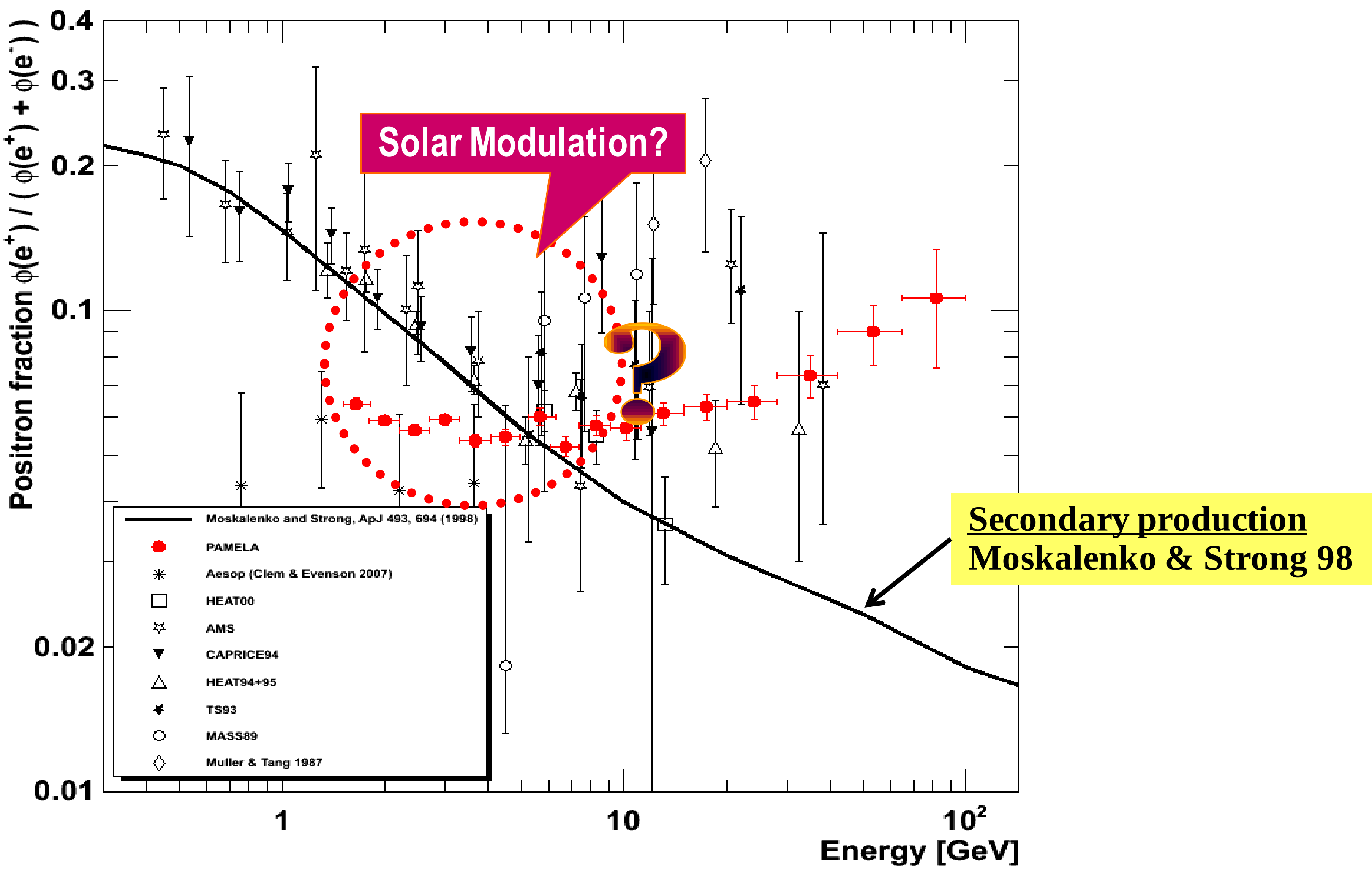
PAMELA & Fermi electron spectra



PAMELA & Fermi electron spectra

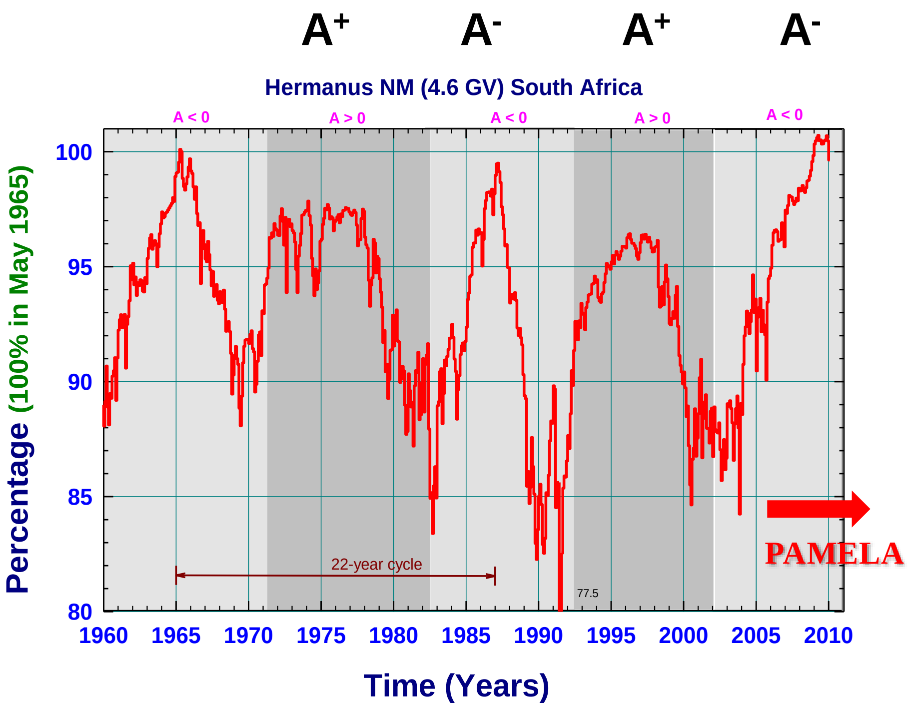


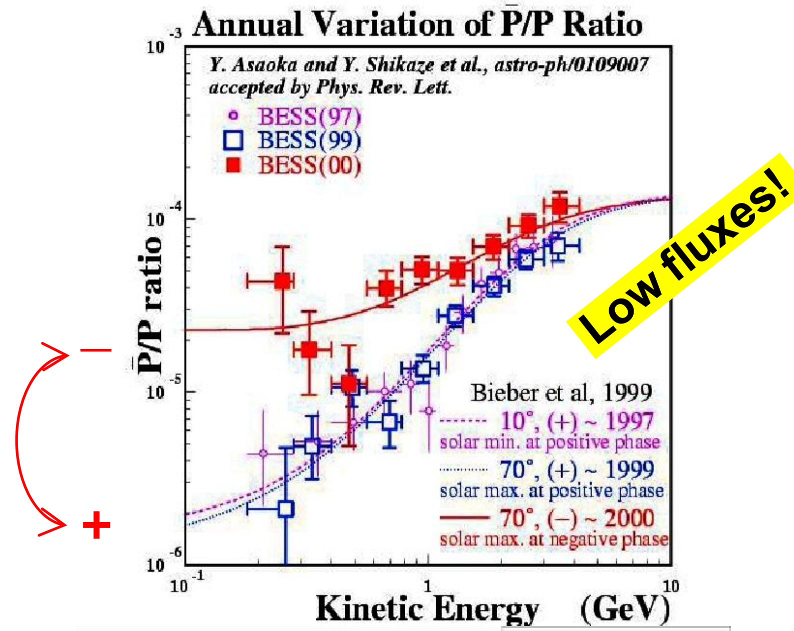
Positron to Electron Fraction



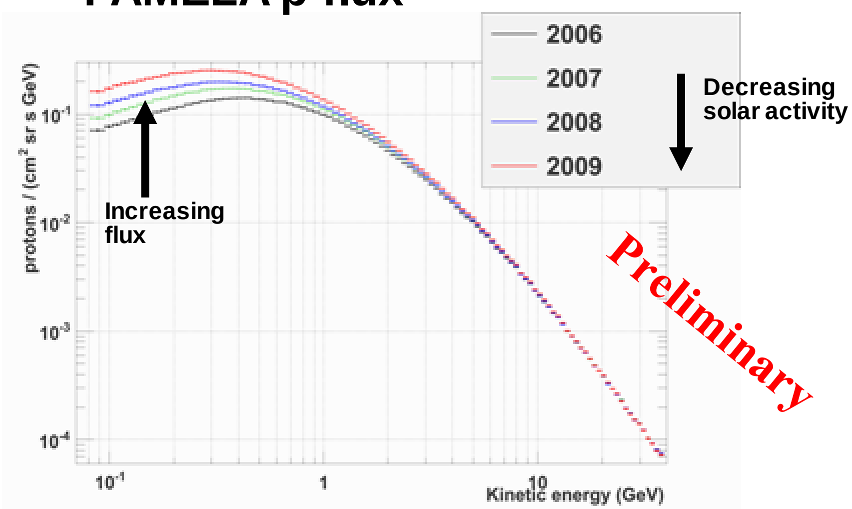
Adriani et al, Astropart. Phys. 34 (2010) 1
arXiv:1001.3522 [astro-ph.HE]

Solar modulation

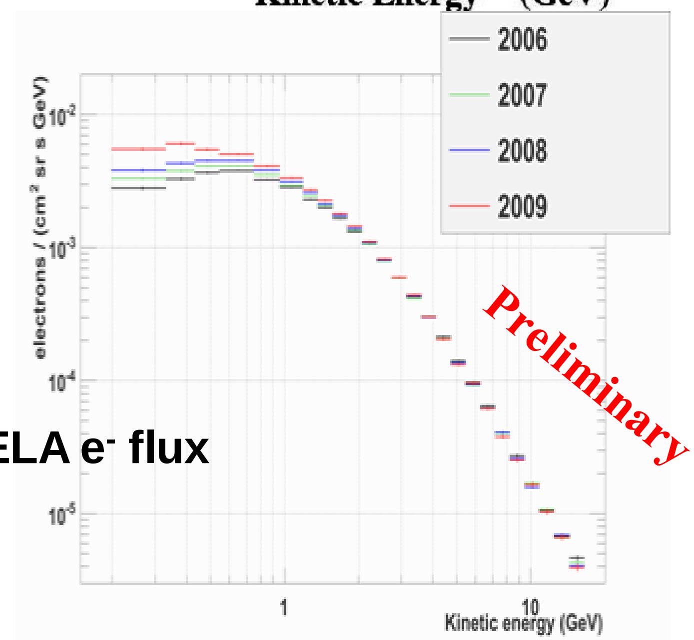




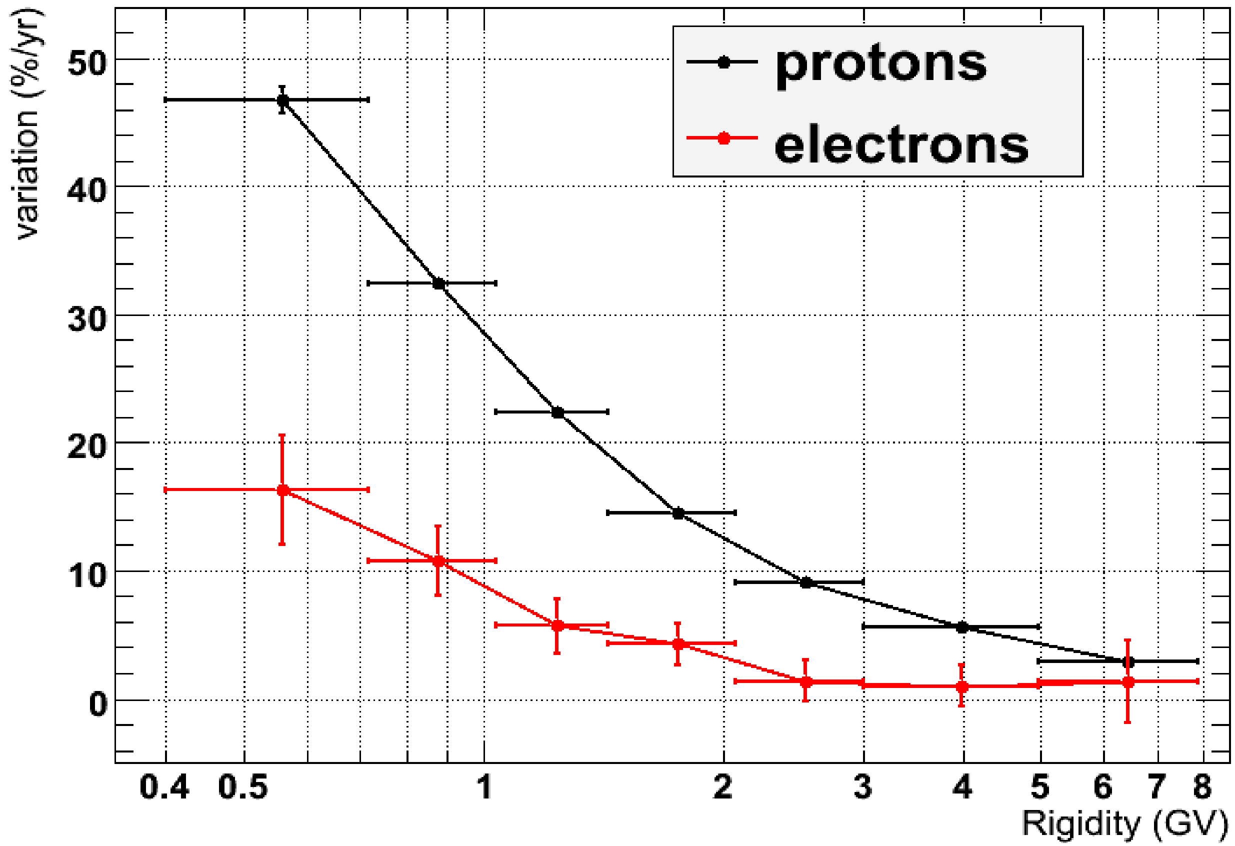
PAMELA p flux



PAMELA e⁻ flux

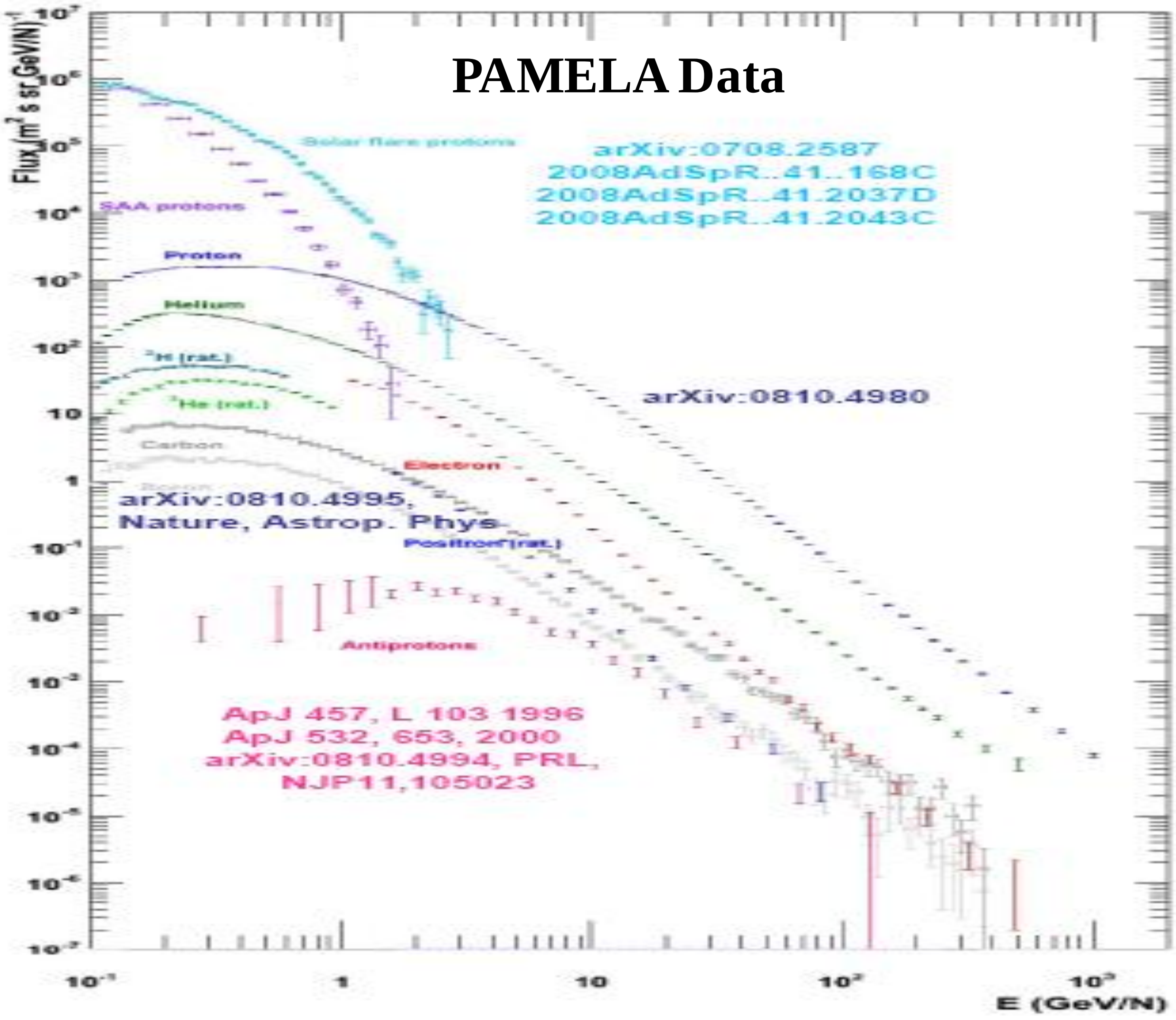


Time Dependence



Increase of the flux measured by PAMELA from July 2006 to December 2008

Summary PAMELA Results



Summary

- **PAMELA has been in orbit and studying cosmic rays for 5 years. >10^9 triggers registered and >20 TB of data have been down-linked.**

- **Antiproton-to-proton flux ratio and antiproton energy spectrum (~100 MeV - ~200 GeV) show no <u>significant</u> deviations from secondary production expectations.**
- **High energy positron fraction (>10 GeV) increases significantly (and unexpectedly!) with energy. Primary source?**

- **Analysis ongoing to finalize the antiparticle measurements (positron flux, positron fraction), continuous study of solar modulation effects at low energy.**

- **Waiting for AMS to compare contemporary measurements.**

Thanks!