PAMELA results and challenges

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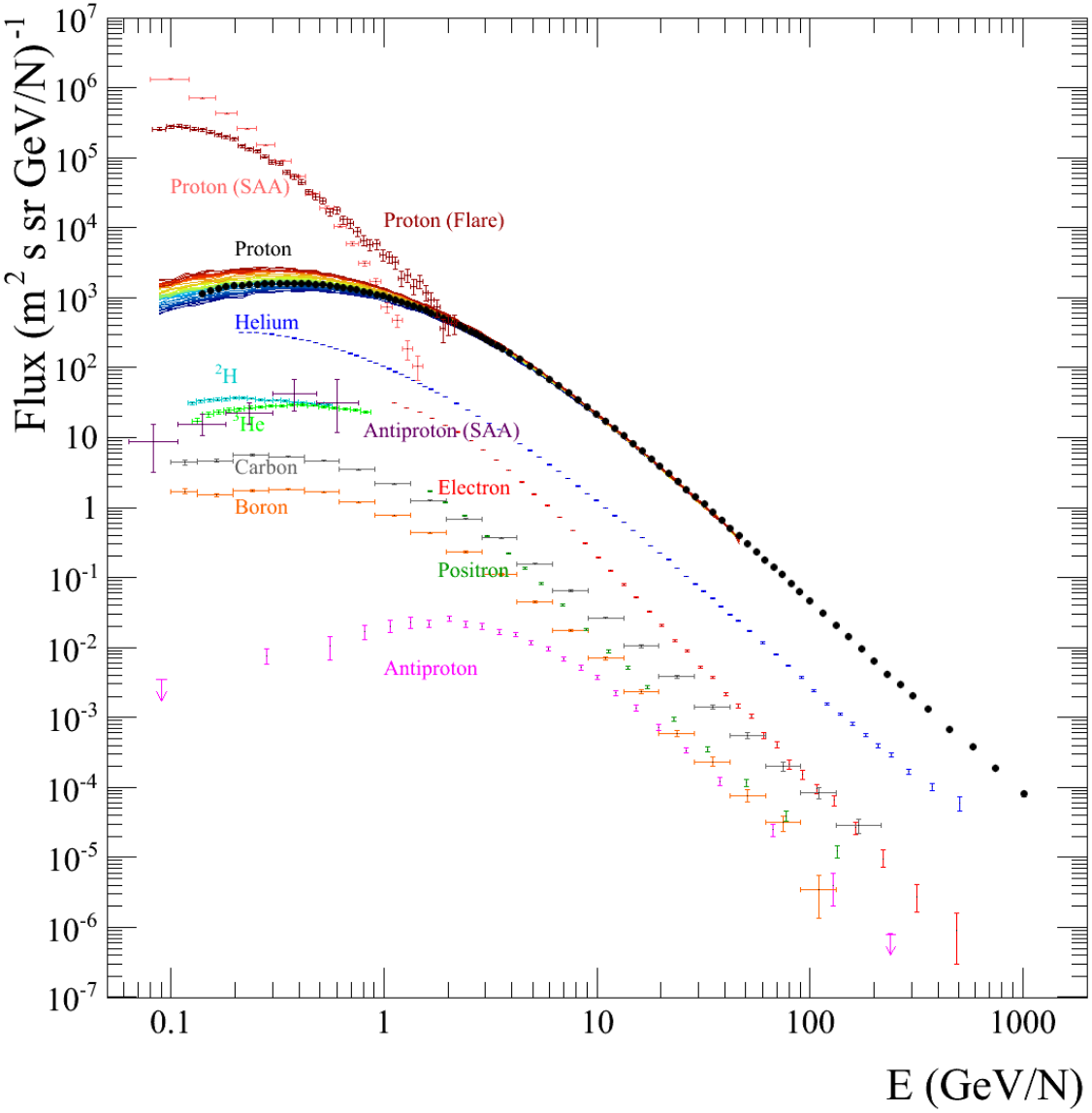
INFN and University of Rome Tor Vergata

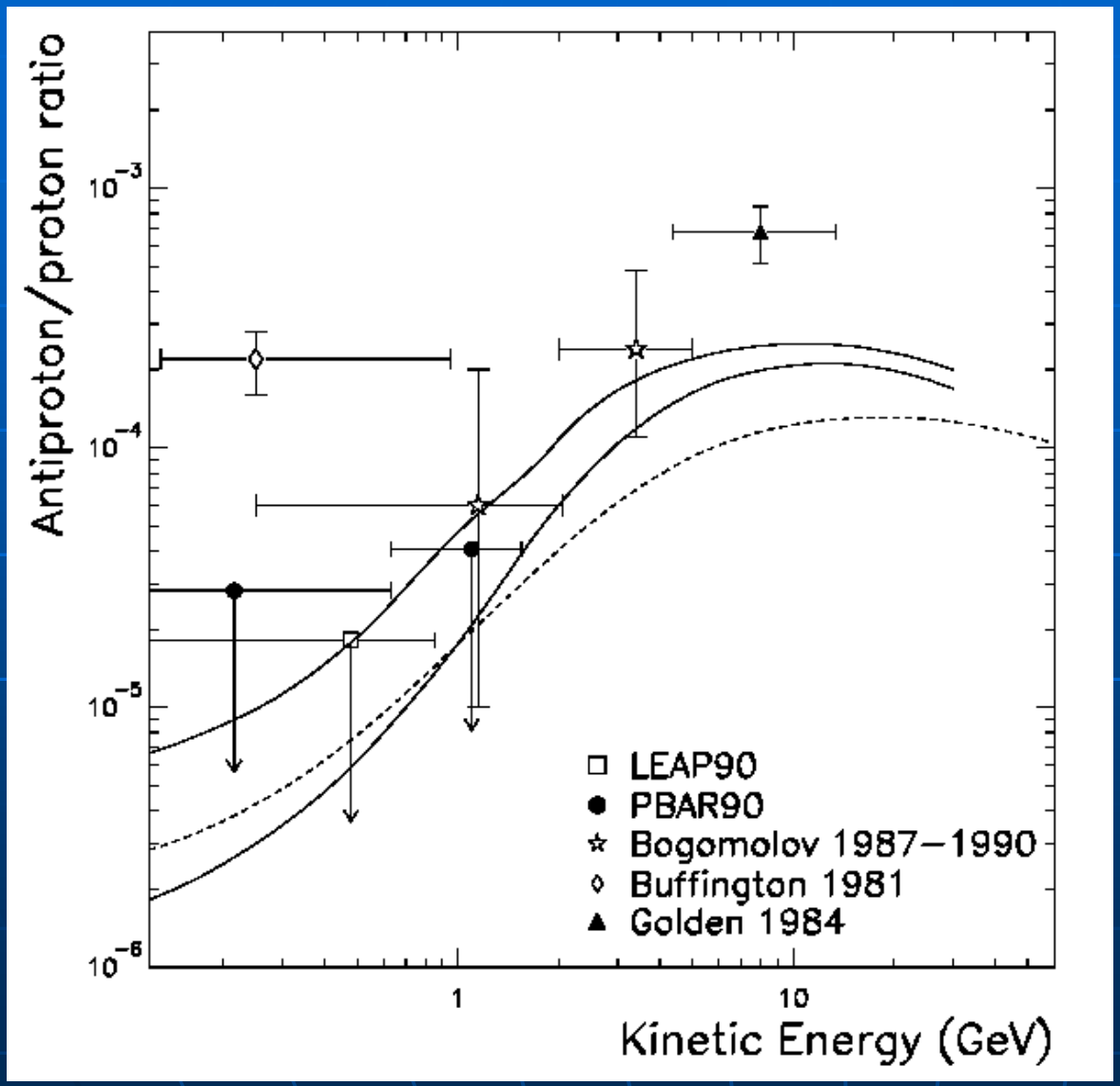
11th AGILE Science Workshop:
"Gamma-rays and Galactic Cosmic Rays", May 16-17, 2013

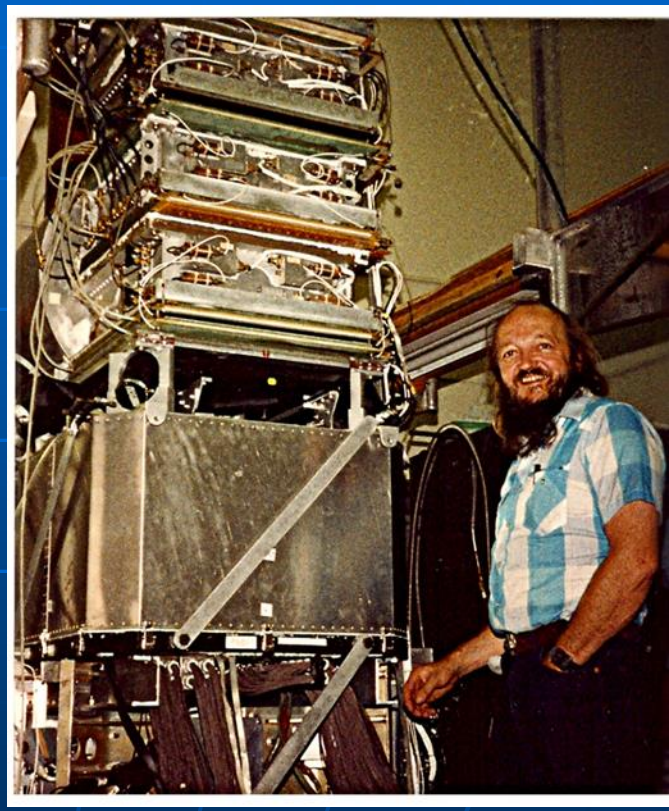
ASI Headquarters, Via del Politecnico, Rome

PAMELA

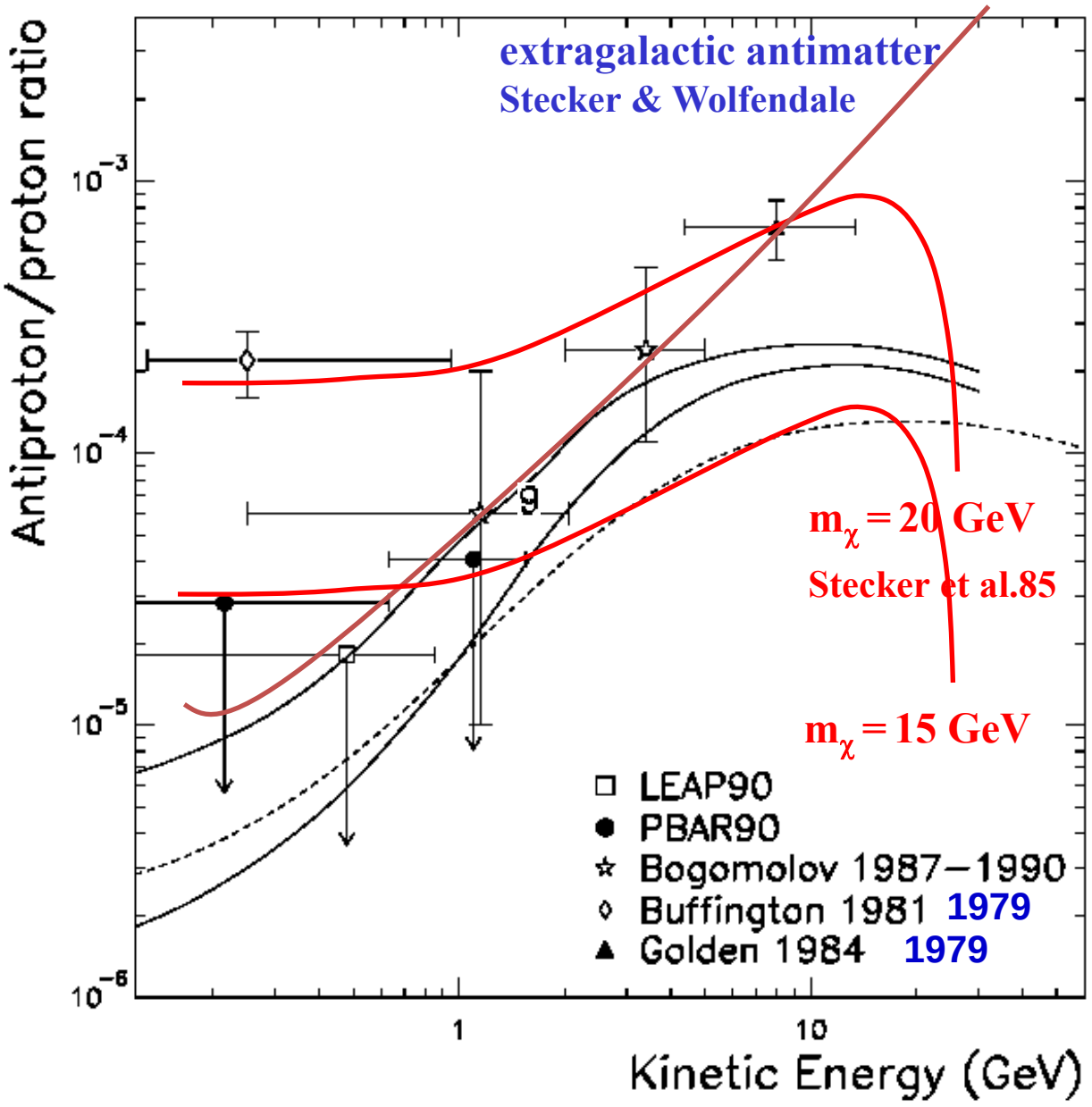

Flux (m^2 s sr GeV/N)$^{-1}$
E (GeV/N)
Proton (SAA)
Proton (Flare)
Proton
Helium
^{2}H
^{3}He
Antiproton (SAA)
Carbon
Boron
Electron
Positron
Antiproton

The Dawn of the Physics of PAMELA

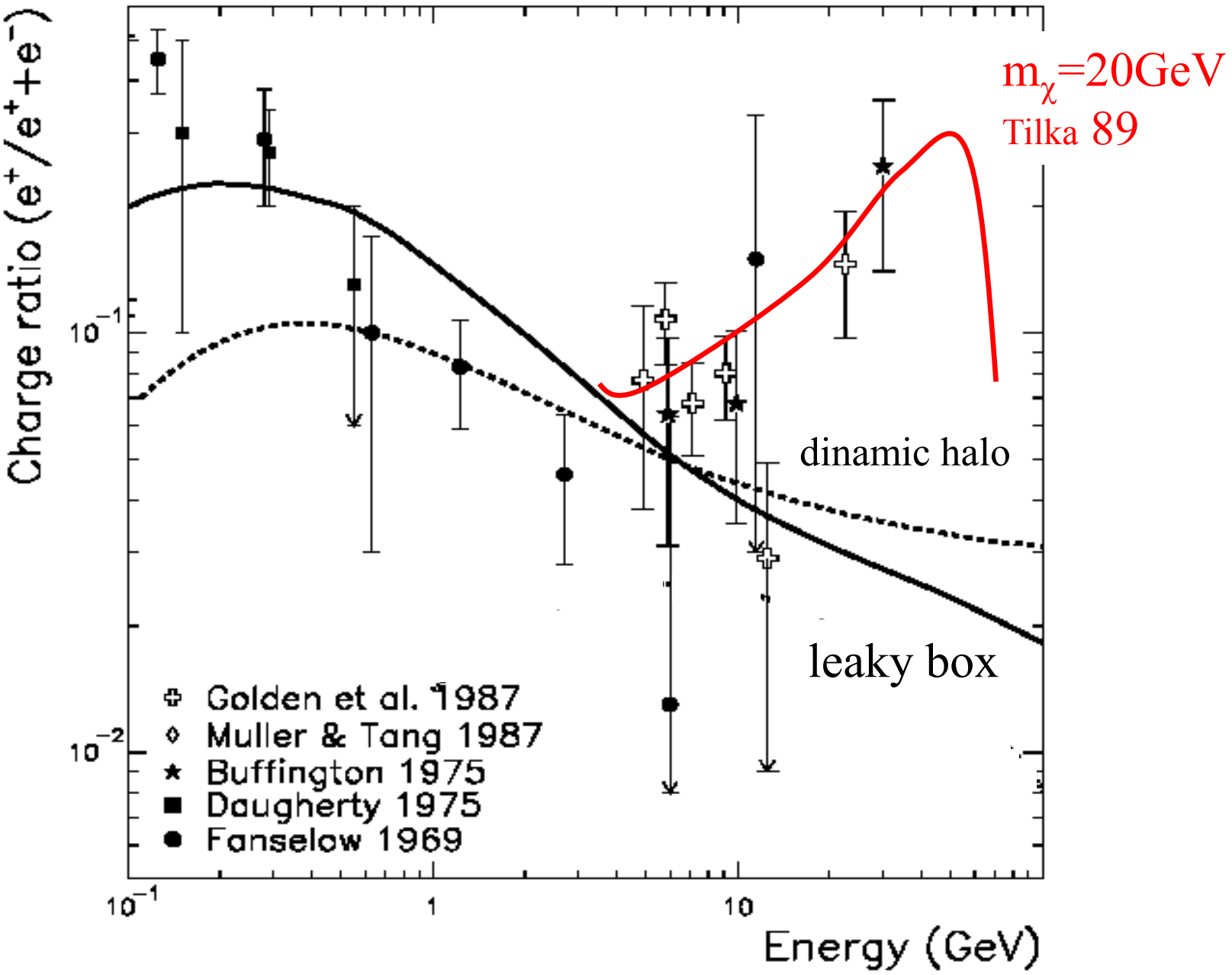




Antiproton/proton ratio before 1990



Balloon data : Positron fraction before 1990

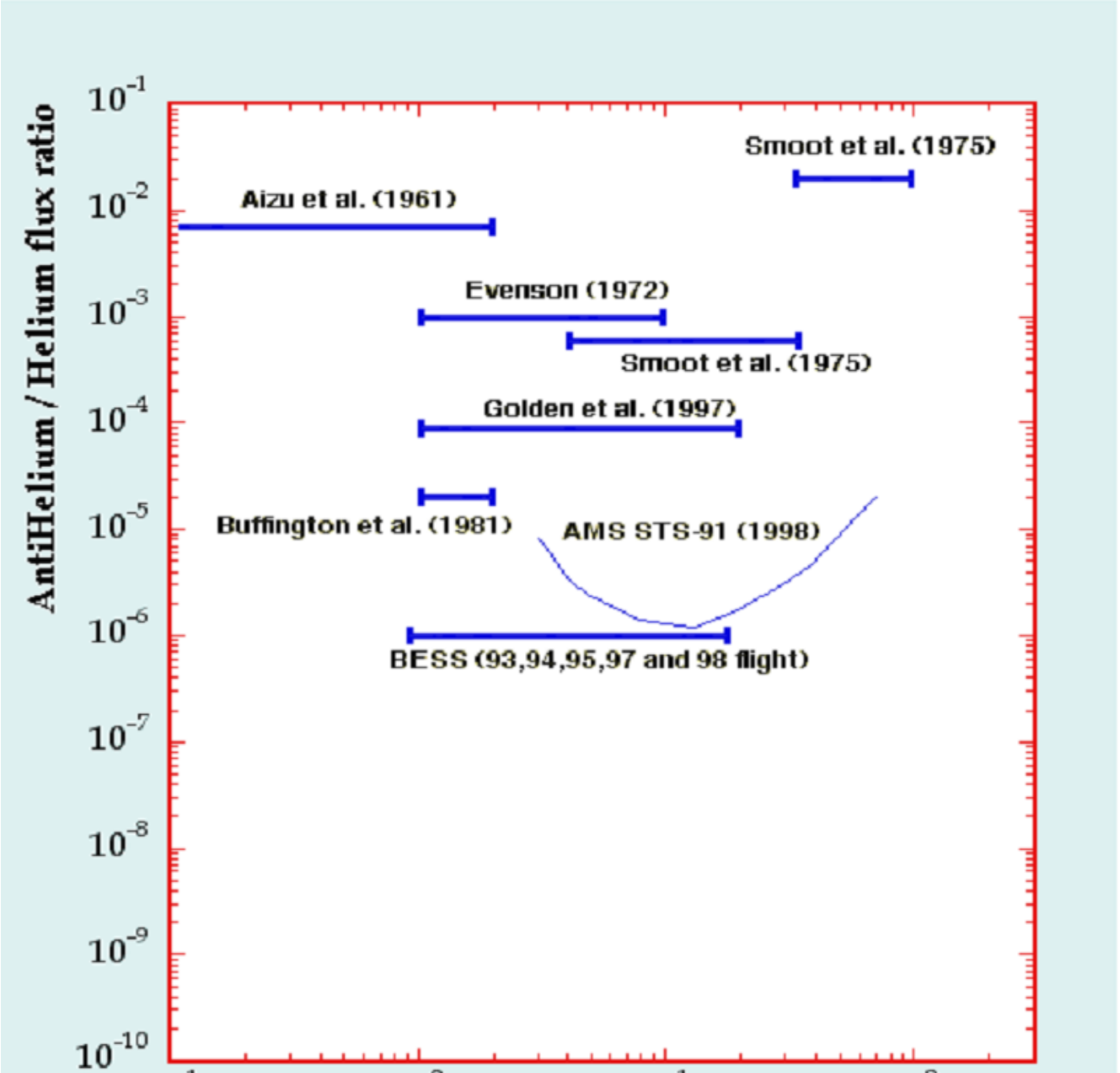


Antimatter Search

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)
- ✓ AMS-01 (1998)

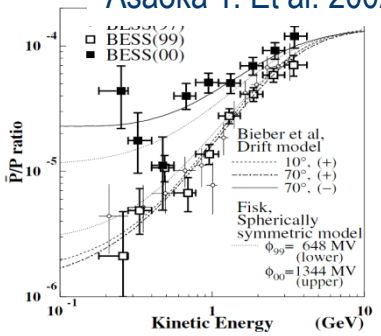
ANTIMATTER LIMITS



Cosmic Ray Antimatter

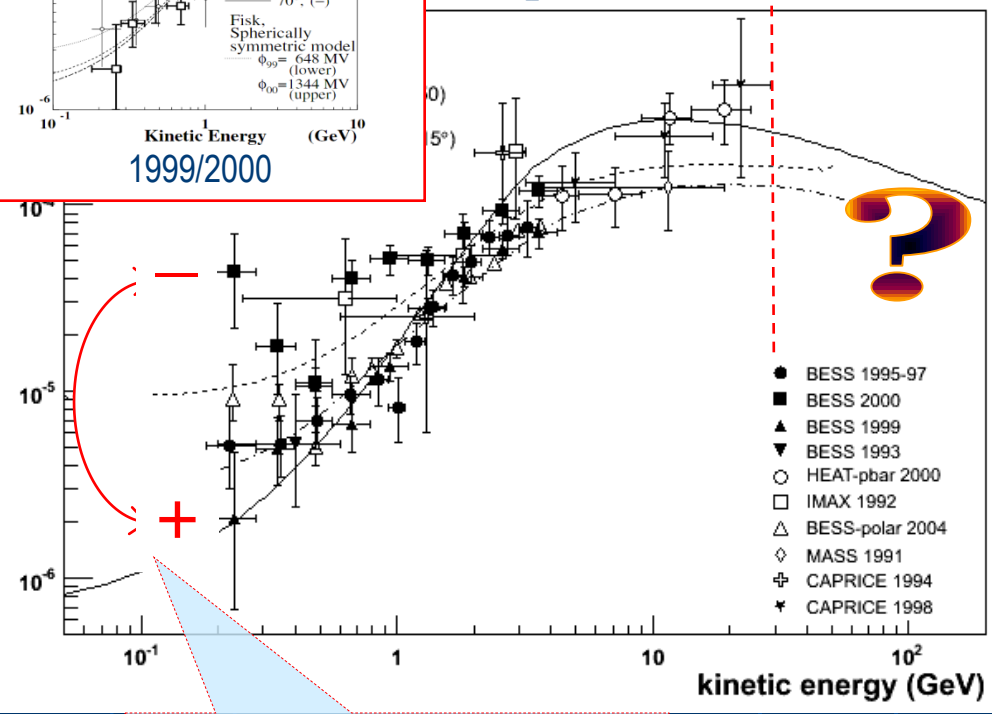
Charge-dependent solar modulation

Asaoka Y. Et al. 2002



1999/2000

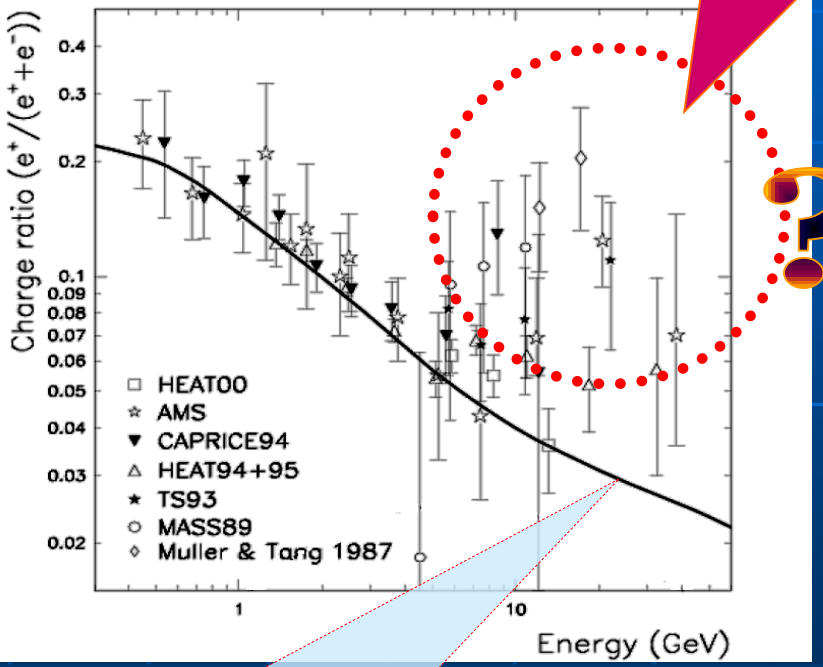
Antiprotons



Positrons

— Moskalenko & Strong 1998

Positron excess?



CR + ISM → **p-bar** + …

kinematic threshold:

5.6 GeV for the reaction

$pp \rightarrow \bar{p}ppp$

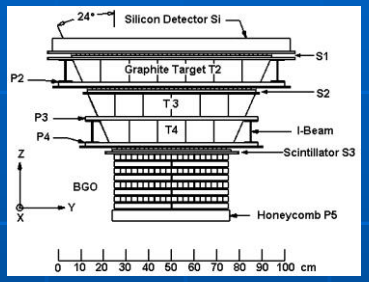
CR + ISM → $\pi^{\pm}$ + x → $\mu^{\pm}$ + x → **$e^{\pm}$** + x

CR ISM → π^0 + x → $\gamma\gamma$ → **$e^{\pm}$**

Space Missions and LDF

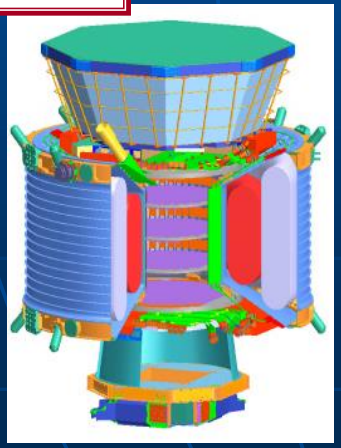
PAMELA
15-06-2006

ATIC
2002 - 2007



BESS
13-12-2004 23-12-2007

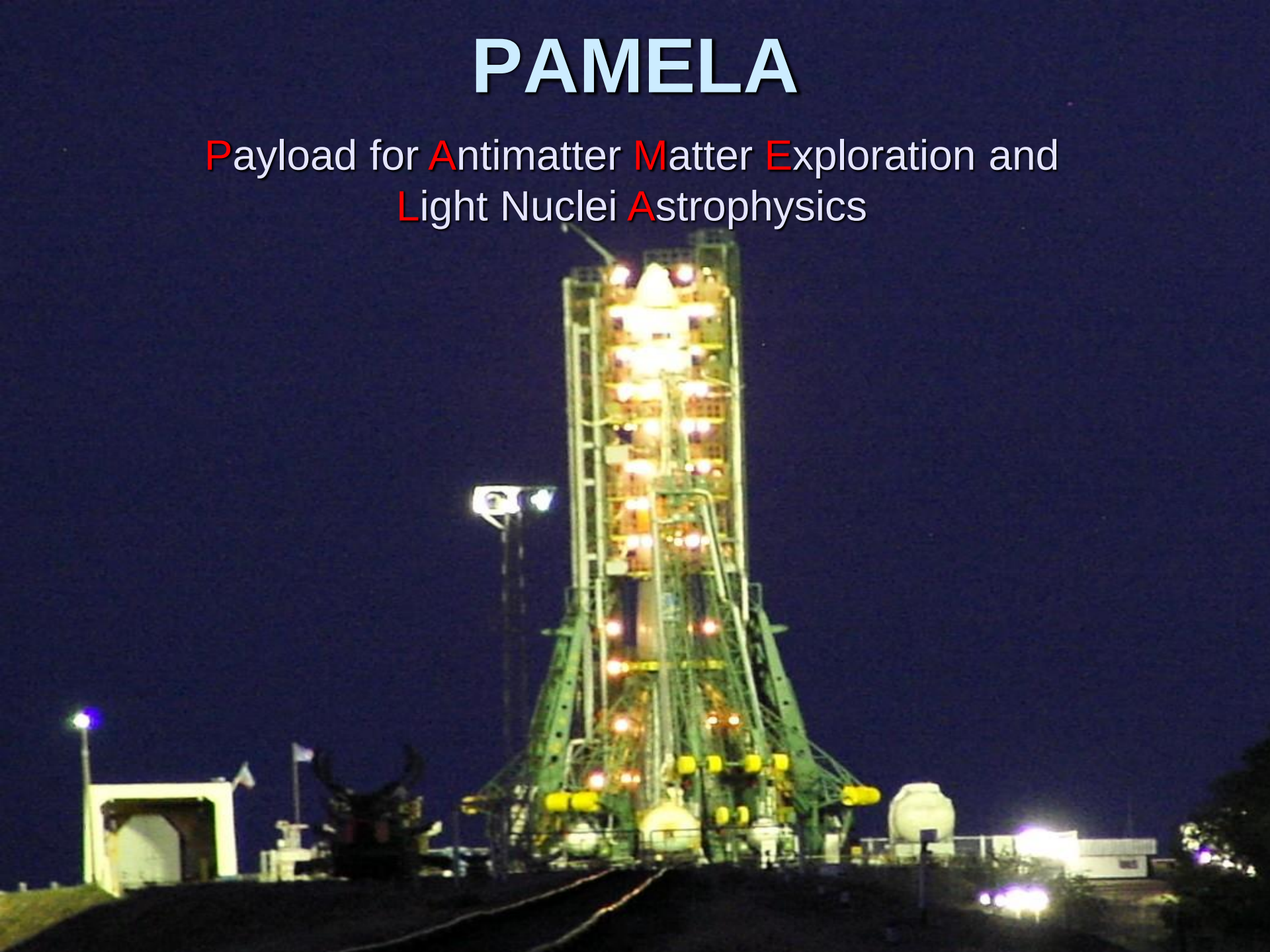
AMS-02
16 -5-2011



Fermi/GLAST
11-6-2008

PAMELA

Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics

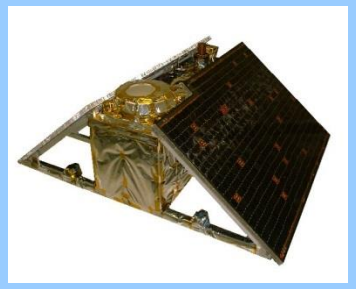


WiZard Space Program

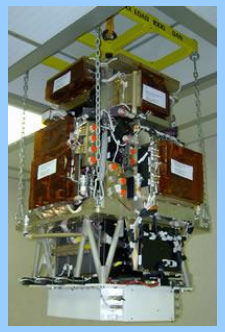
MASS-89, 91, TS-93, CAPRICE 94-97-98

NINA-1

NINA-2

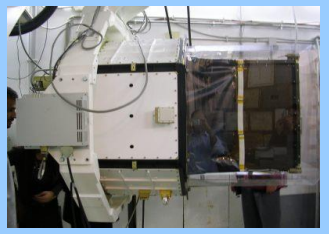


PAMELA



GLAST

AGILE



M 89 · M 91 · TS 93 · C 94 · C 97 · C 98

AGILE ⟵ ⟶ GLAST

PAMELA ⟵ ⟶

…1989 · 1990 · 1991 · 1992 · 1993 · 1994 · 1995 · 1996 · 1997 · 1998 · 1999 · 2000 · 2001 · 2002 · 2003 · 2004 · 2005 · 2006 · 2007..

SILEYE-1 ⟵ ⟶

NINA-1 ⟵ ⟶

NINA-2 ⟵ ⟶

Alteino-SILEYE-3 ⟵ ⟶

SILEYE-2 ⟵ ⟶

ALTEA-SILEYE-4 ⟵ ⟶

SILEYE-1

SILEYE-2

ALTEINO: SILEYE-3

ALTEA: SILEYE-4

LAZIO SIRAD

ARINA

PAMELA Collaboration

Italy:

Bari, Florence, Frascati, Naples, Rome, Trieste, CNR, Florence

Russia:

Moscow
St. Petersburg

Germany:

Siegen

Sweden:

KTH, Stockholm

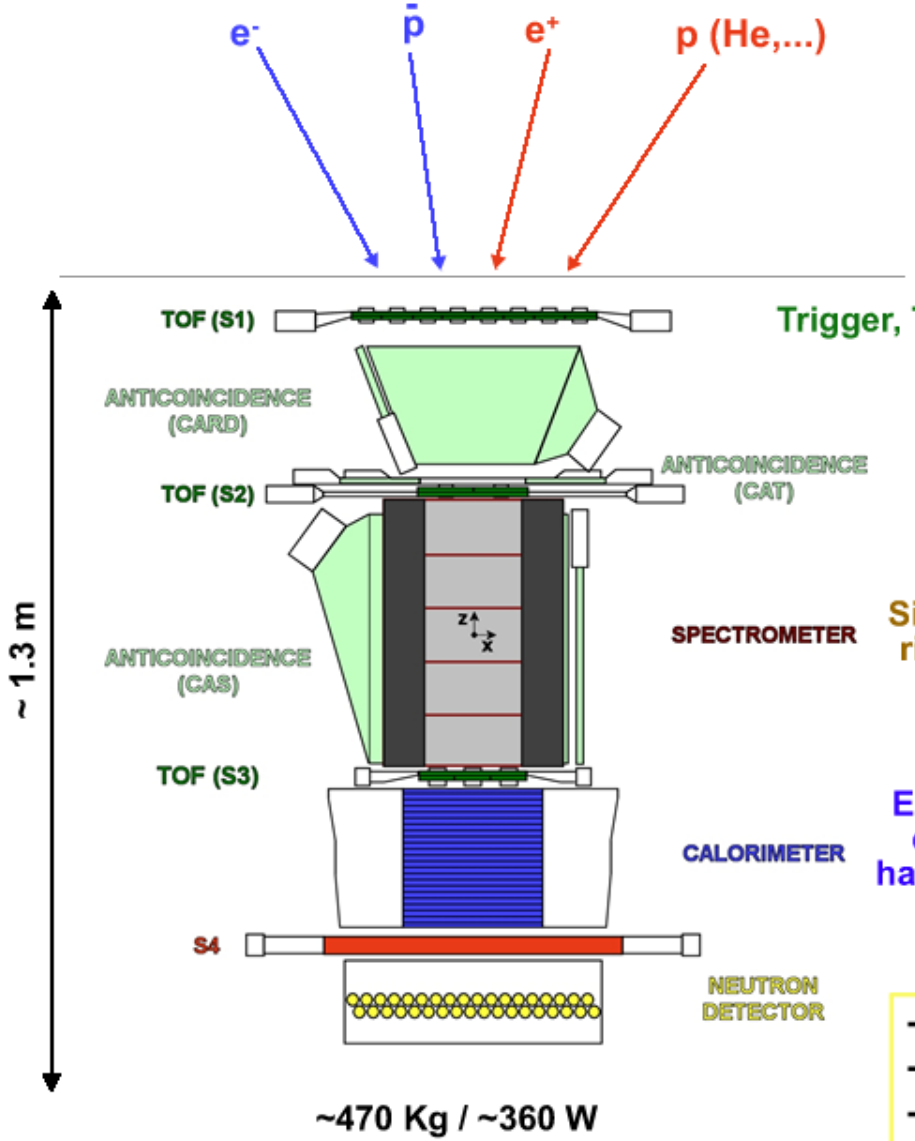
PAMELA Instrument

GF ~21.5 cm^2sr

Mass: 470 kg

Size: 130x70x70 cm^3

PAMELA Instrument



Trigger, ToF, dE/dx

- 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)

Sign of charge, rigidity, dE/dx

- Permanent magnet, 0.43 T
- 21.5 cm^2 sr
- 6 planes double-sided silicon strip detectors (300 μm)
- 3 μm resolution in bending view → MDR

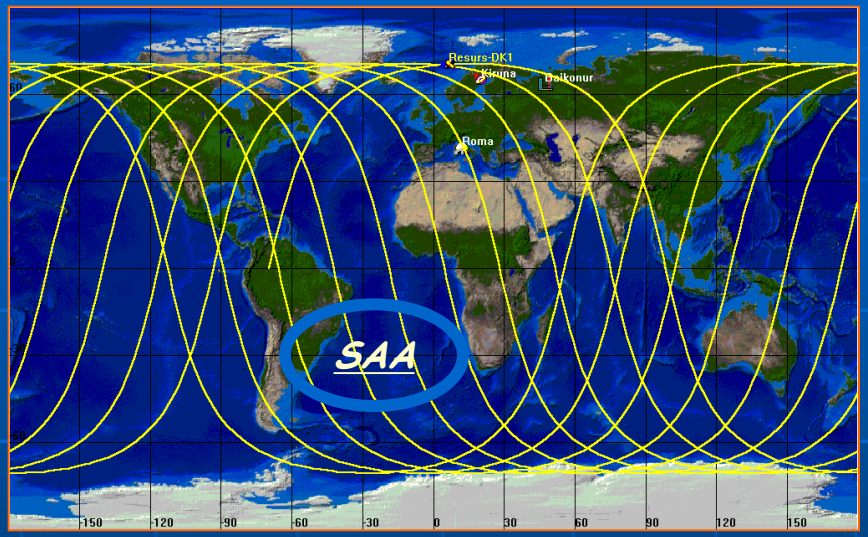
MDR 1.2 TeV

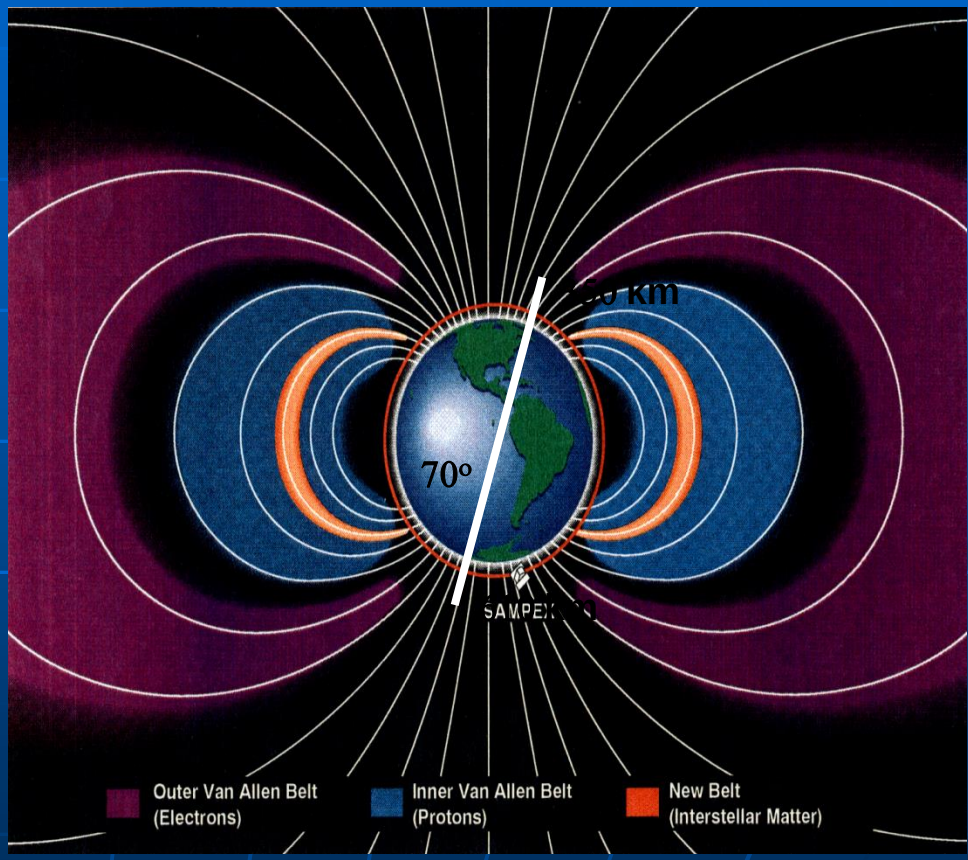
Electron energy, dE/dx, lepton-hadron separation

- 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 cm^2 sr

- 36 ^{3}He counters
- ^{3}He(n,p)T; E_p = 780 keV
- 1 cm thick poly + Cd moderator
- 200 μs collection

Orbit Characteristics



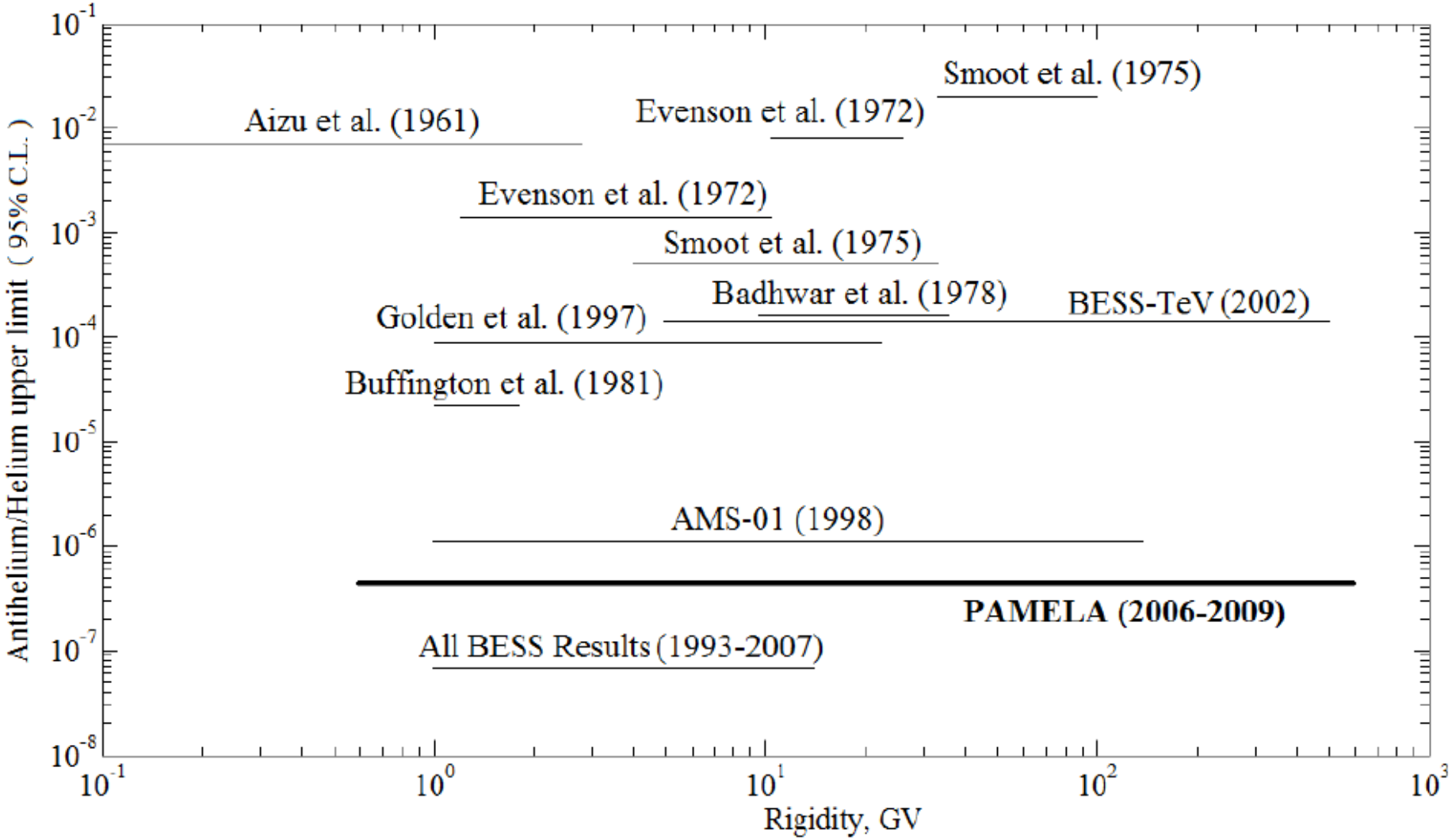


- Low-earth elliptical orbit
- 350 – 610 km
- Quasi-polar (70º inclination)
- SAA crossed

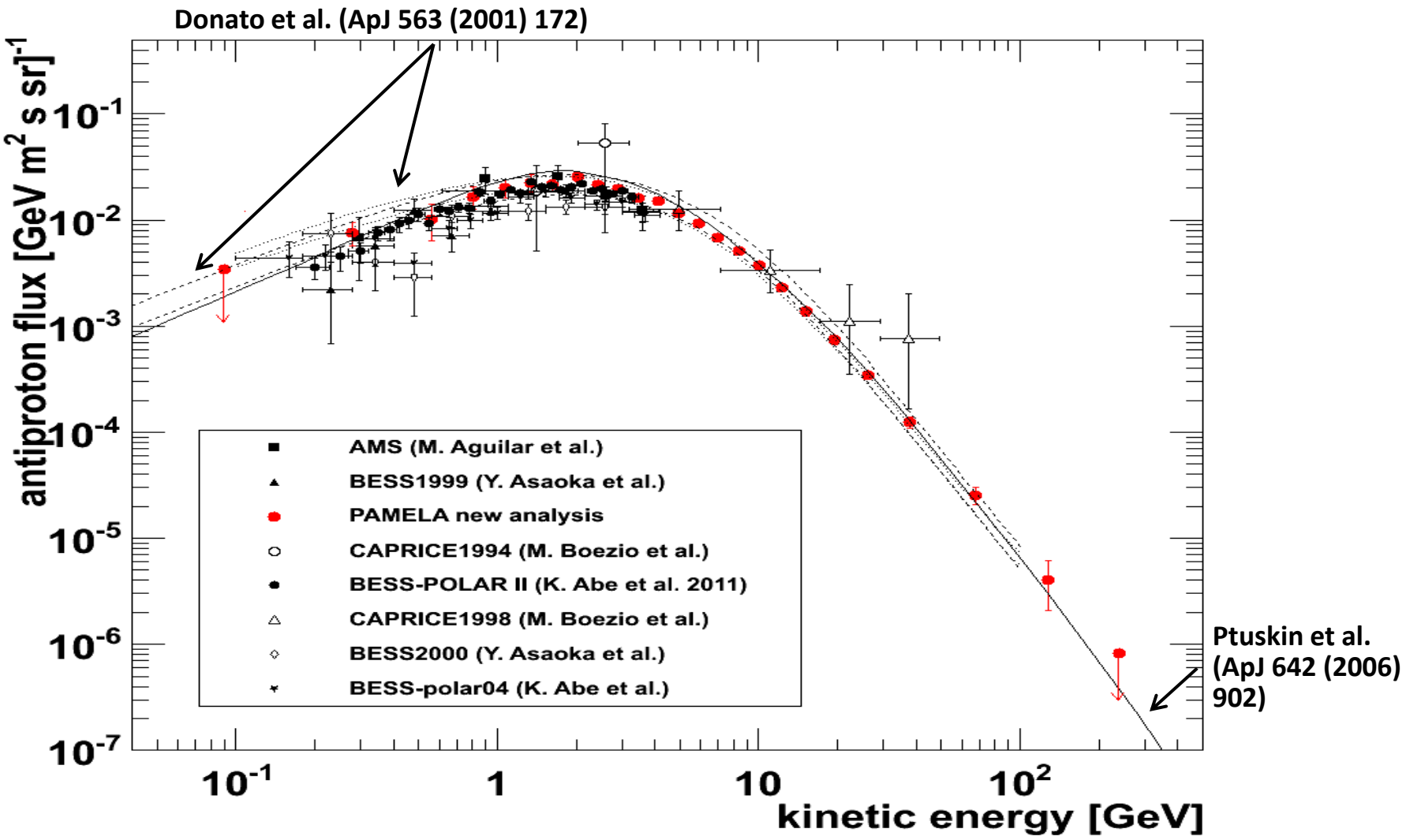
Antiparticles

Antimatter and Dark Matter Search

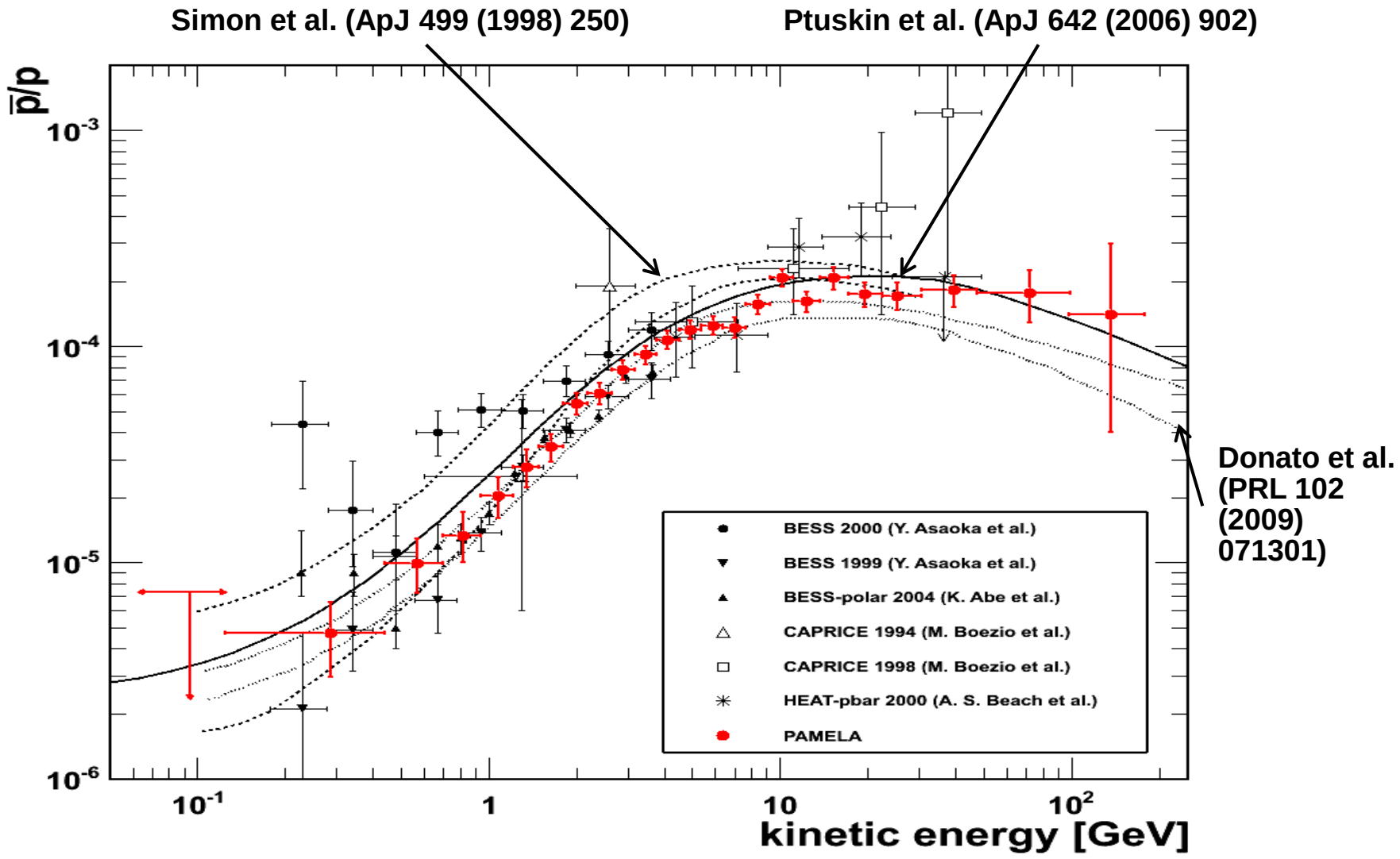
Antimatter limits



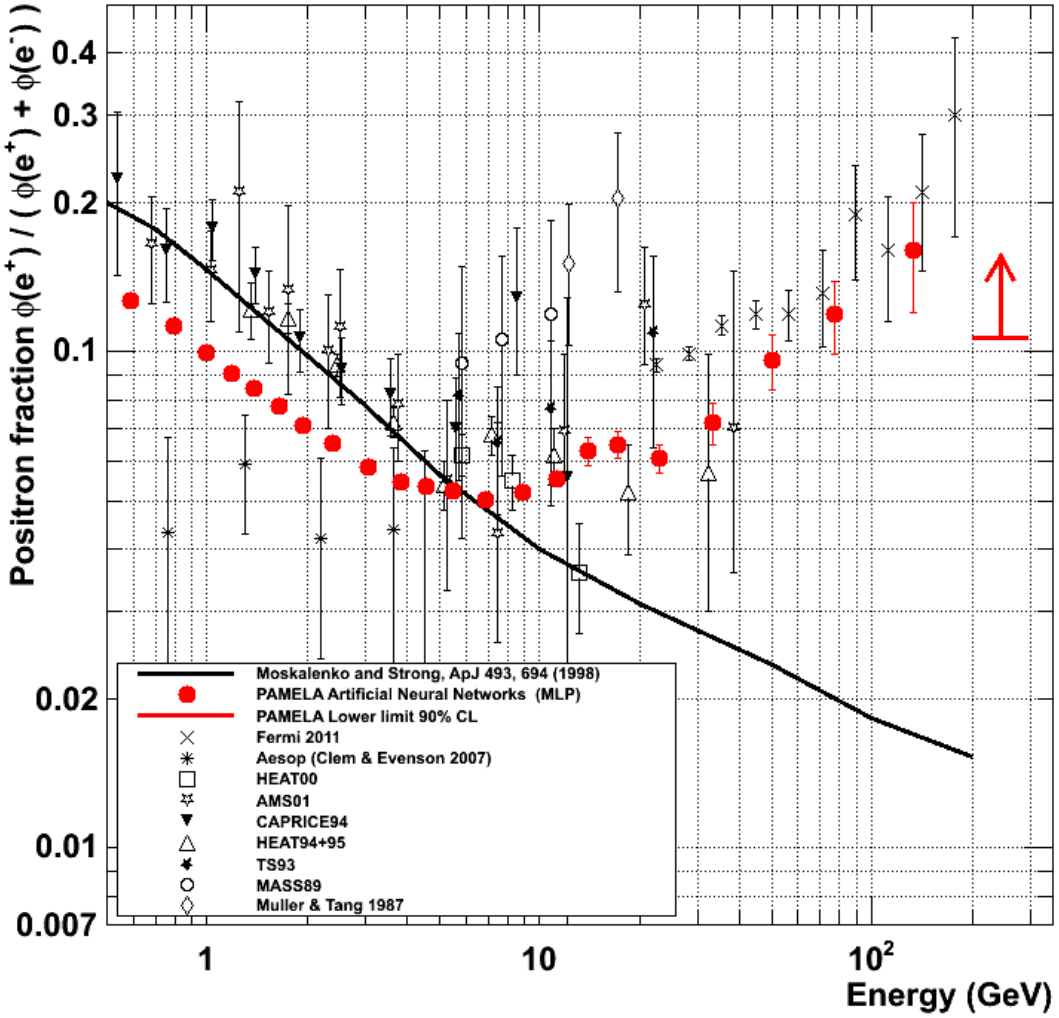
Antiproton Flux



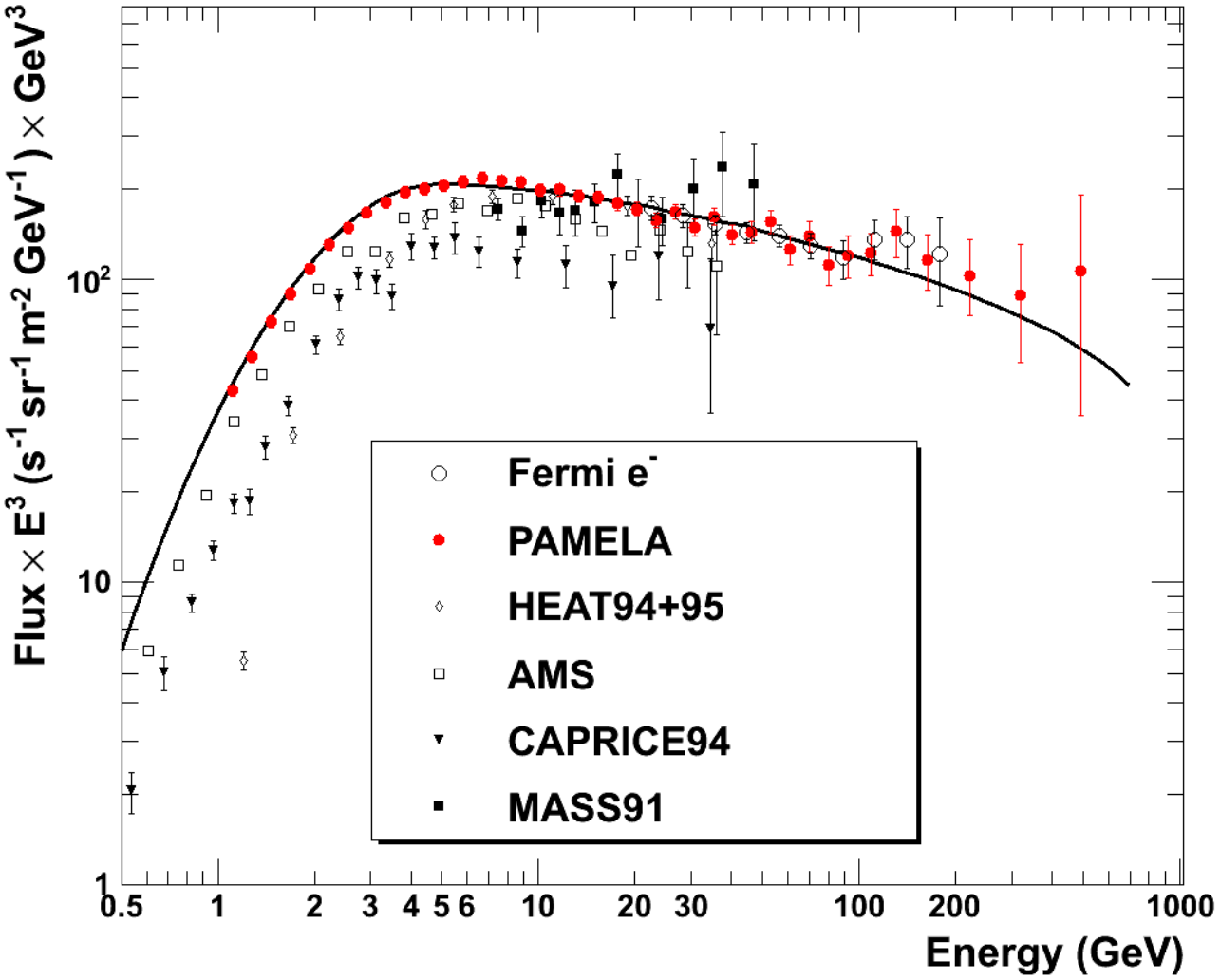
Antiproton to proton ratio (0.06 GeV - 180 GeV)



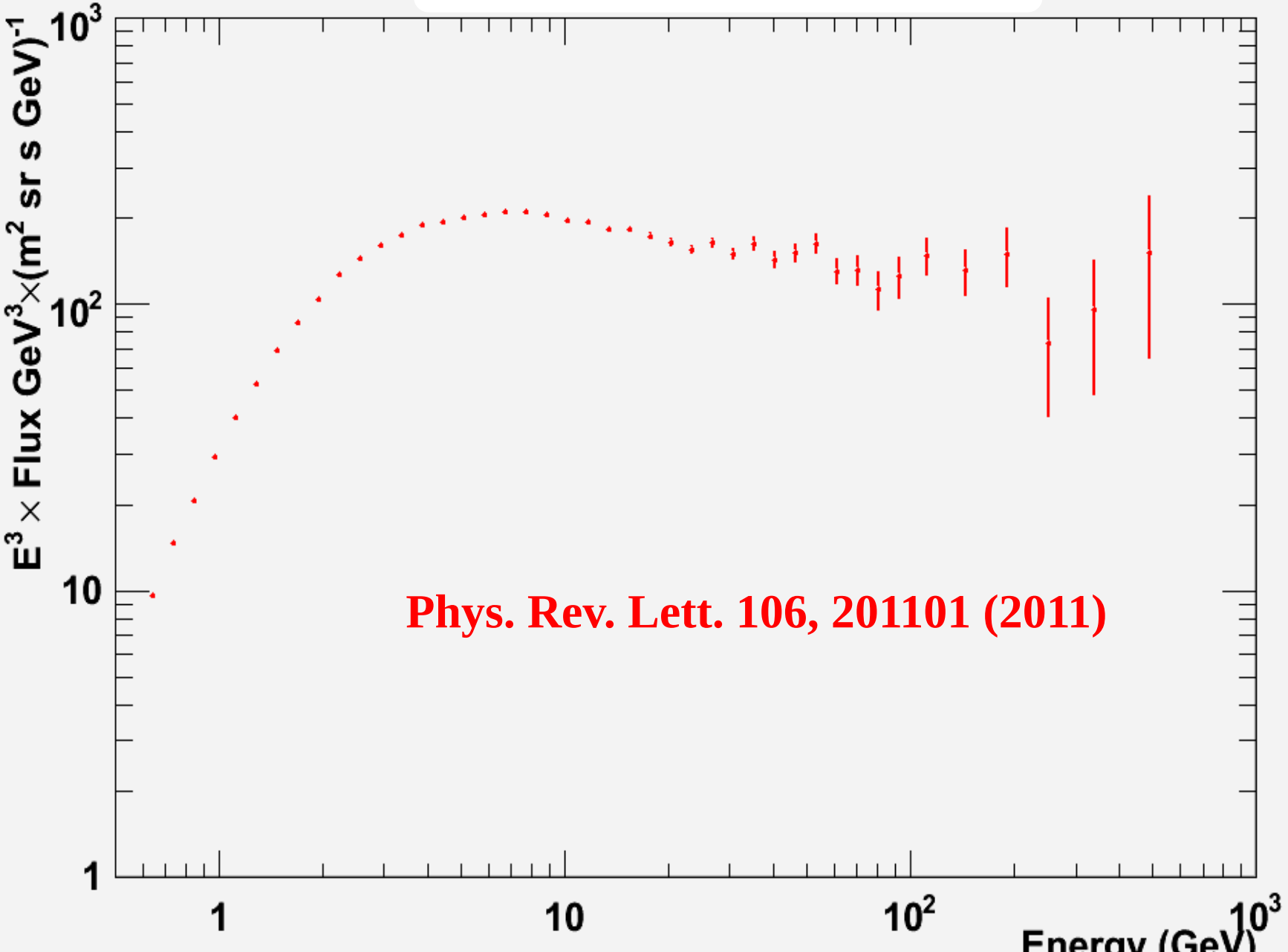
Positron ratio



Electron flux

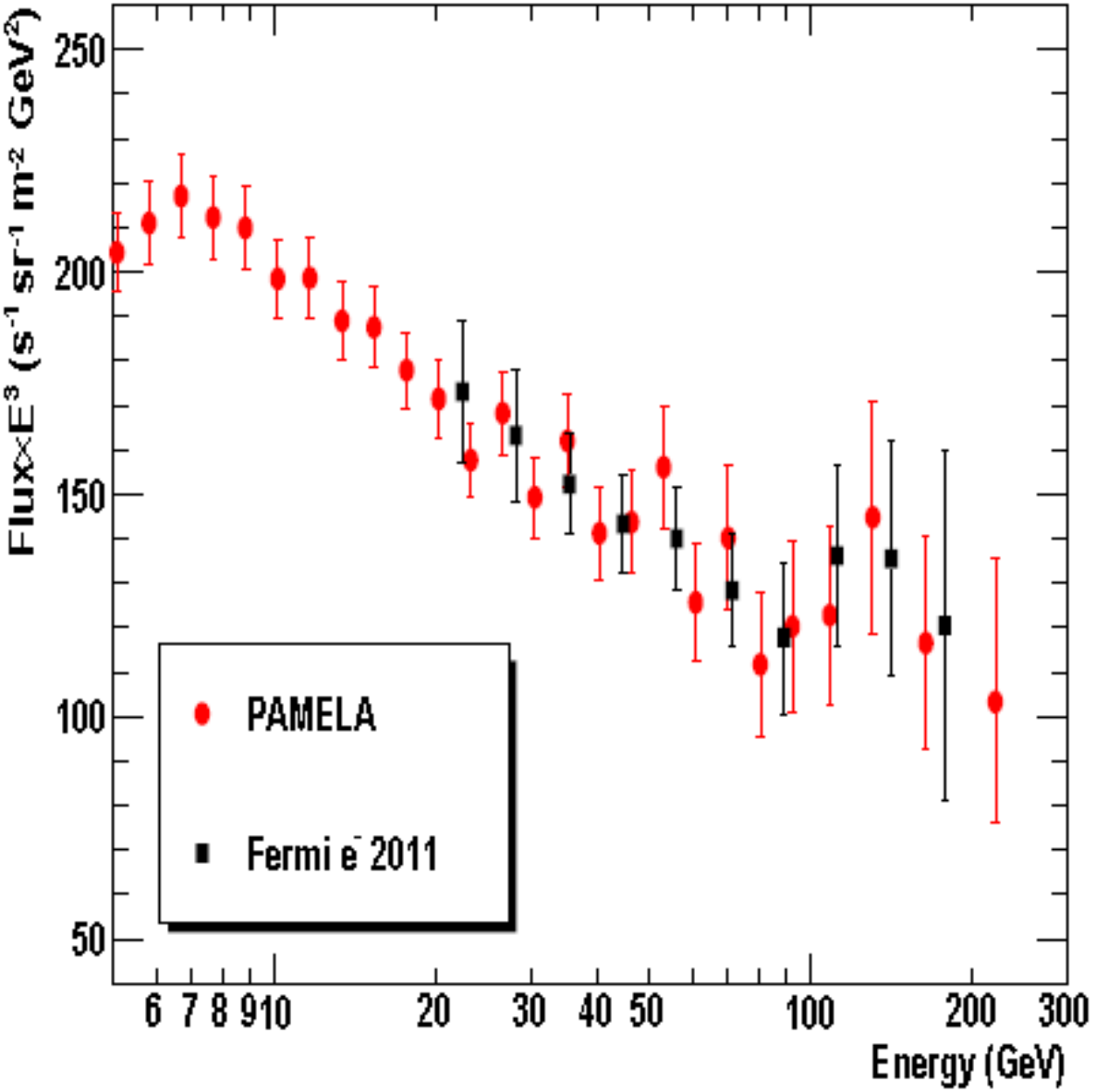


PAMELA Electron flux

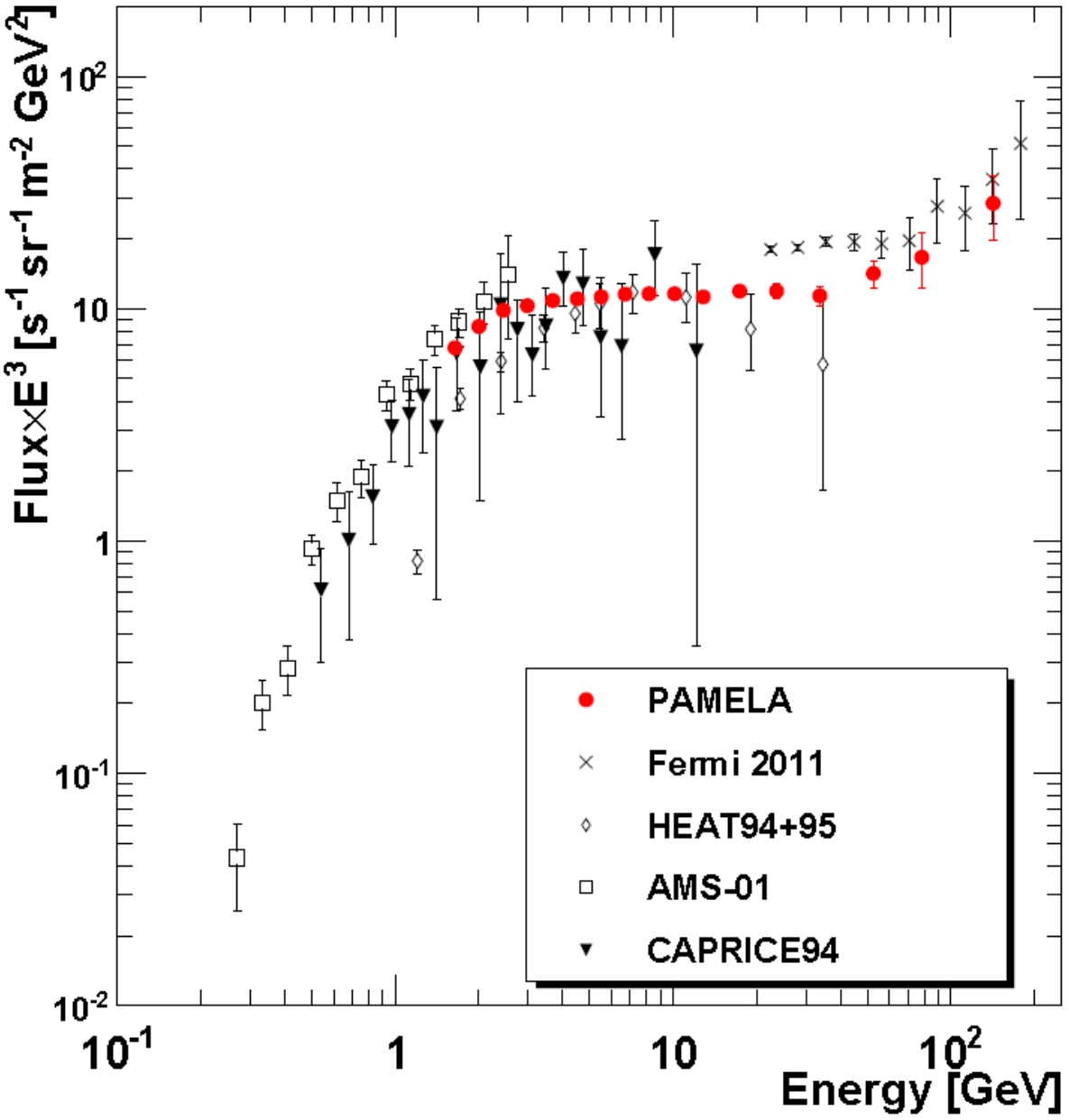


Phys. Rev. Lett. 106, 201101 (2011)

PAMELA and FERMI electrons

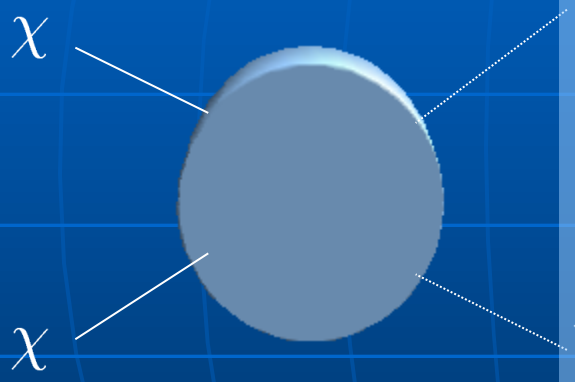


Positron flux



DM annihilations

DM particles are stable. They can annihilate in pairs.



$W^-, Z^0, b, \tau^-, t, h^0, \ldots$ → $e^\mp, p^{(-)}, D^{(-)}, \ldots$

$W^+, Z^0, \bar{b}, \tau^+, \bar{t}, h^0, \ldots$ → $e^\pm, p^{(-)}, D^{(-)}, \ldots$

Primary annihilation channels

Decay

Final states

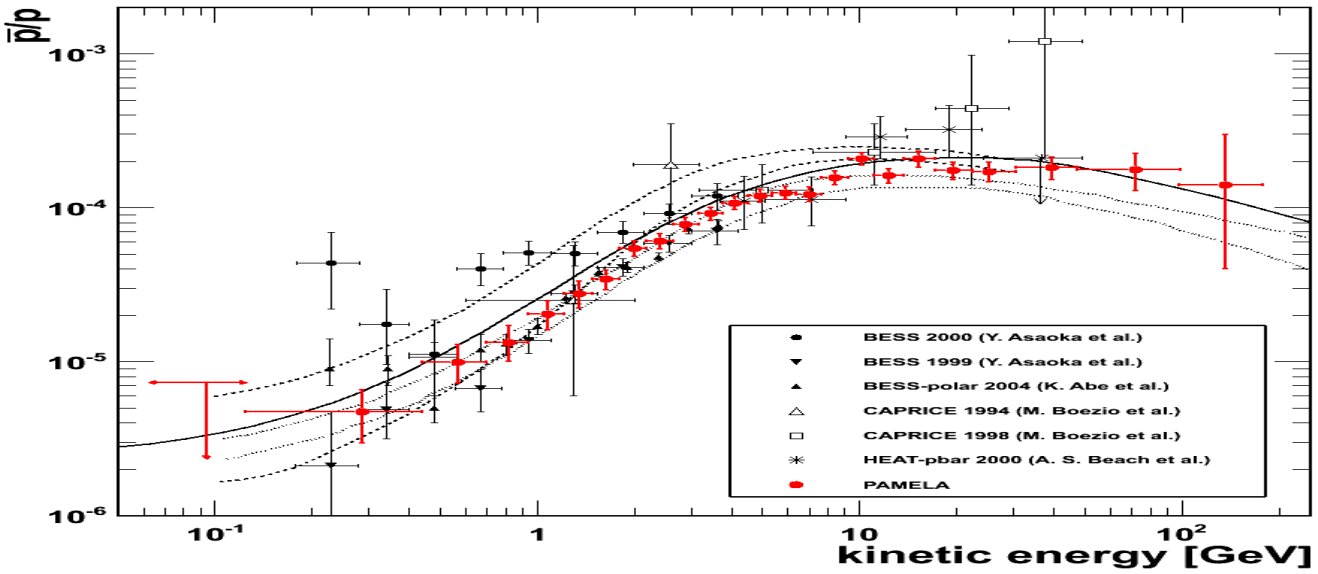
$\text{flux} \propto \underbrace{n^2}_{\text{astro\&cosmo}} \underbrace{\sigma_{\text{annihilation}}}_{\text{particle}}$

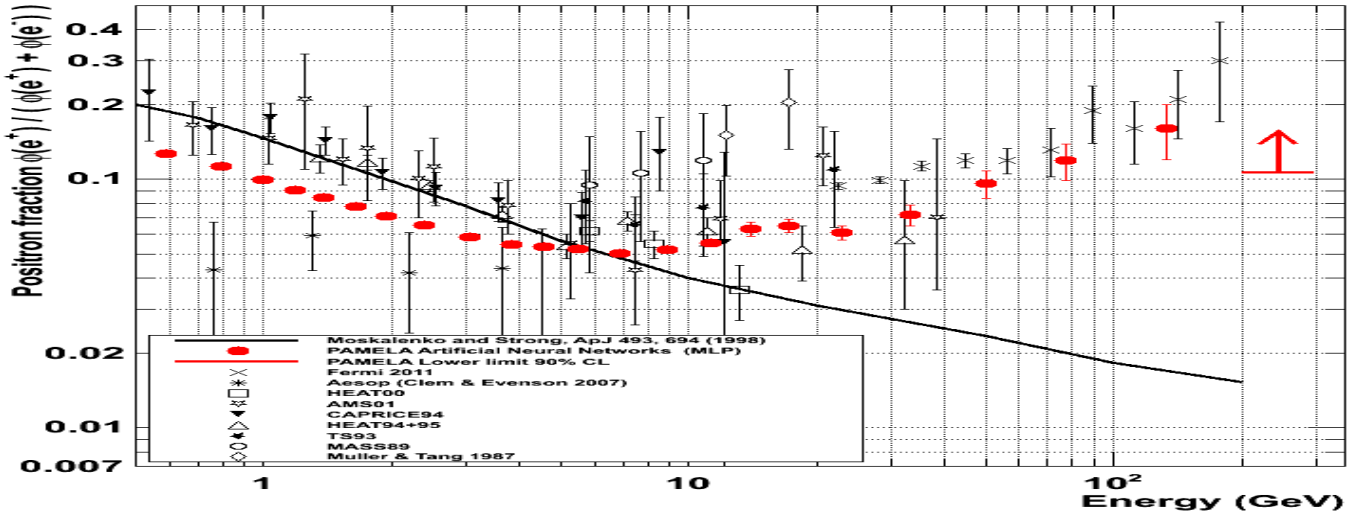
reference cross section:

$\sigma = 3 \cdot 10^{-26} \text{cm}^3/\text{sec}$

$\sigma_a = \langle \sigma v \rangle$

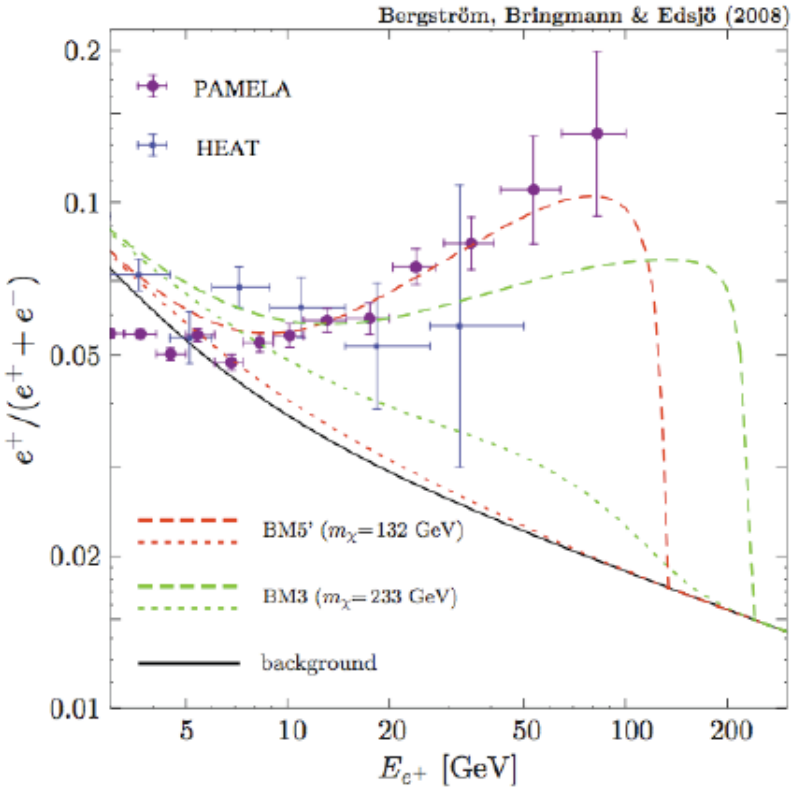
A Challenging Puzzle for Dark Matter Interpretation





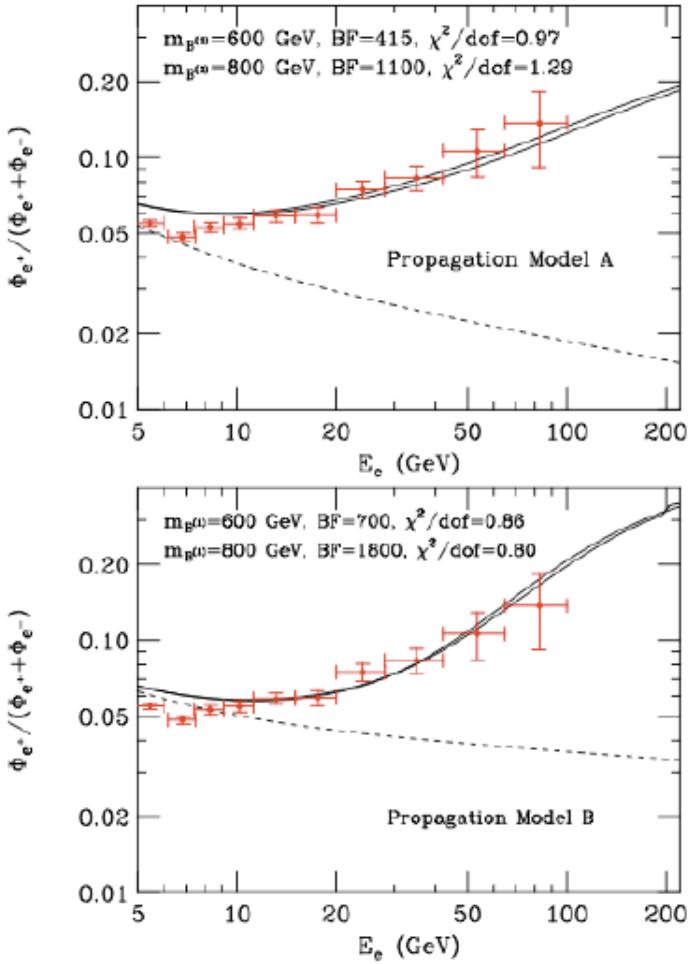
Example: Dark Matter

Phys.Rev.D8:103520,2008

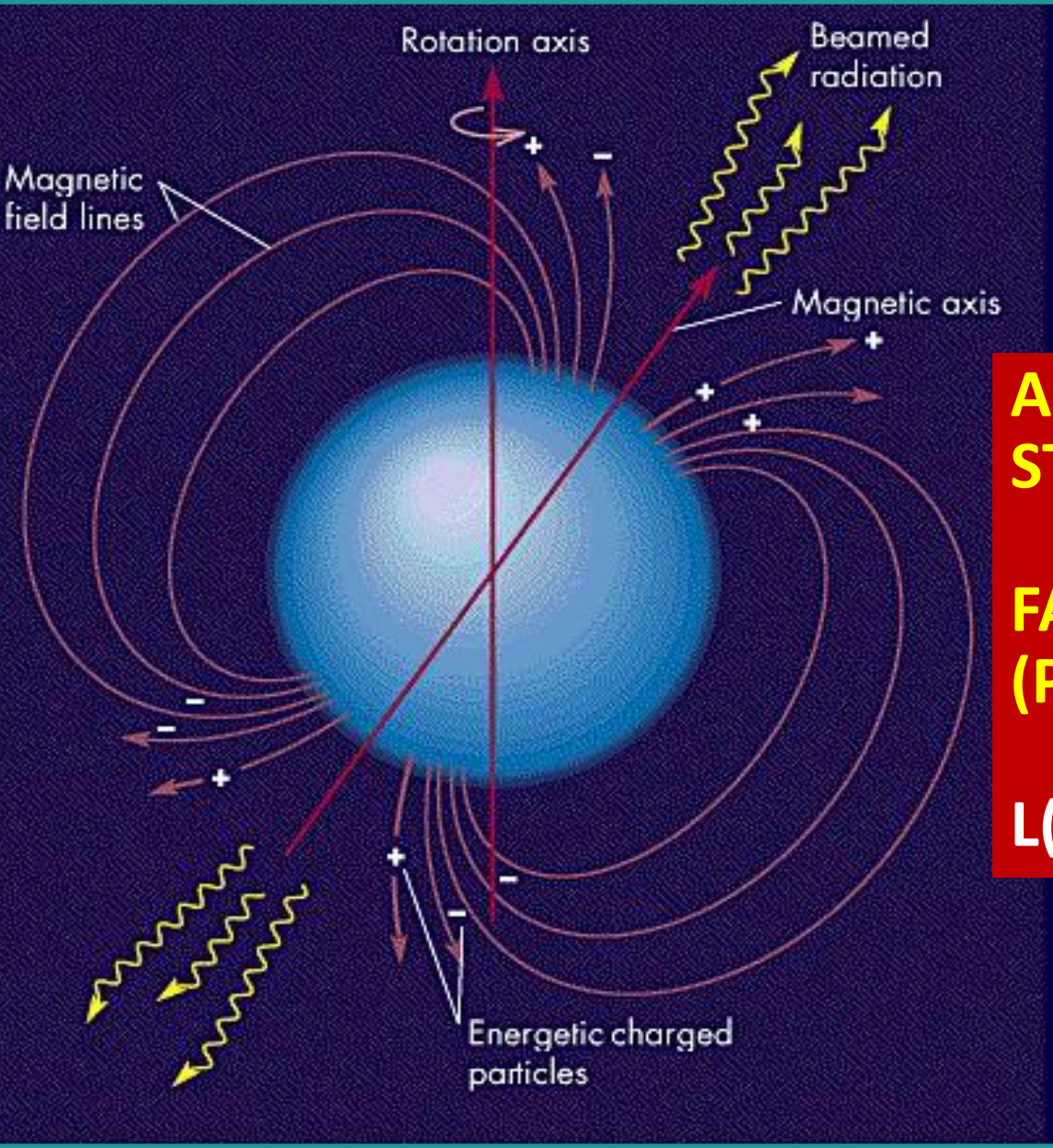


Majorana DM with **new** internal bremsstrahlung correction. NB: requires annihilation cross-section to be 'boosted' by >1000.

Phys.Rev.D79:103529,2009



Kaluza-Klein dark matter

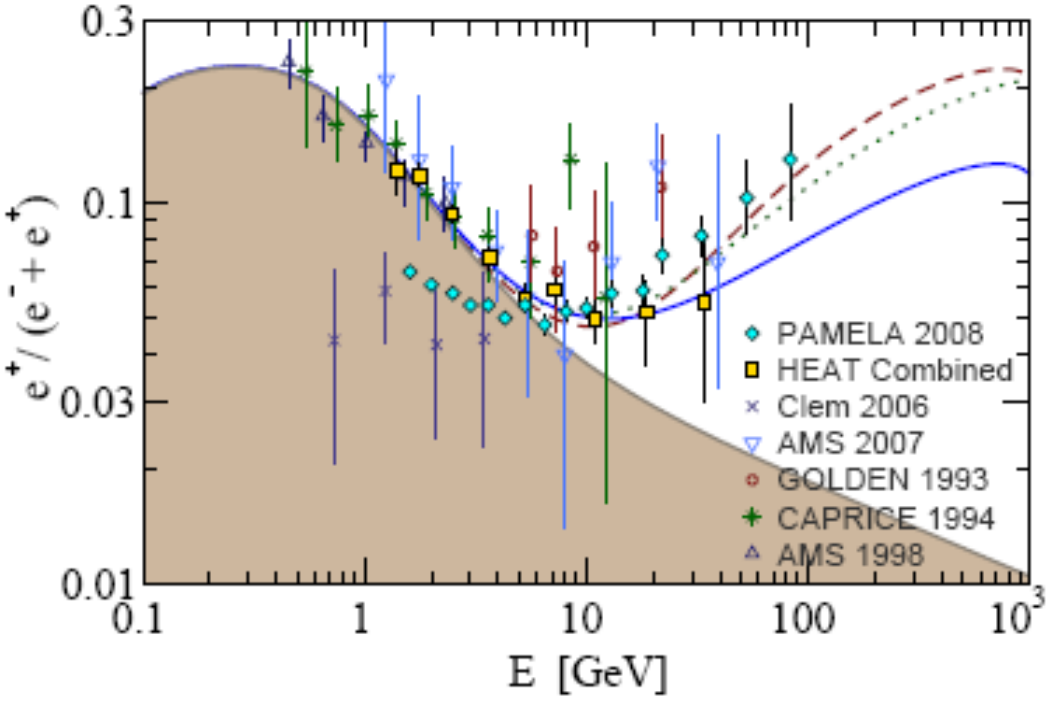


A NEUTRON STAR WITH A STRONG MAGNETIC FIELD:

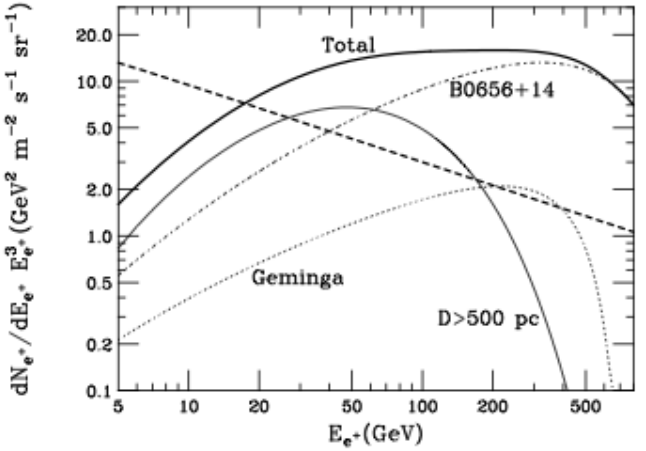
FAST ROTATING PULSAR (P = 33 msec)

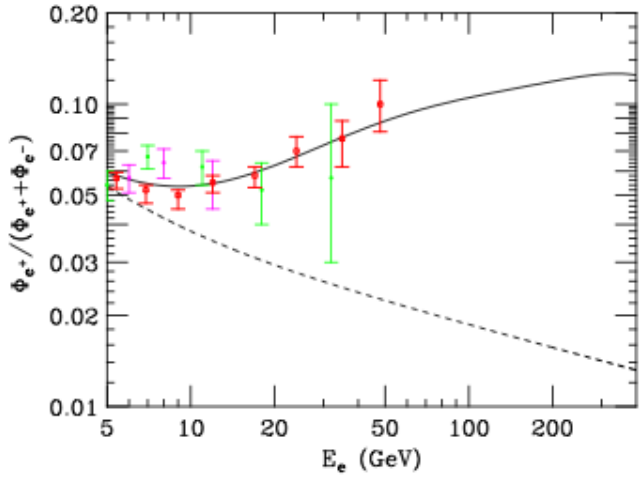
L(spindown) = 5 10^{38} erg/s

Example: pulsars



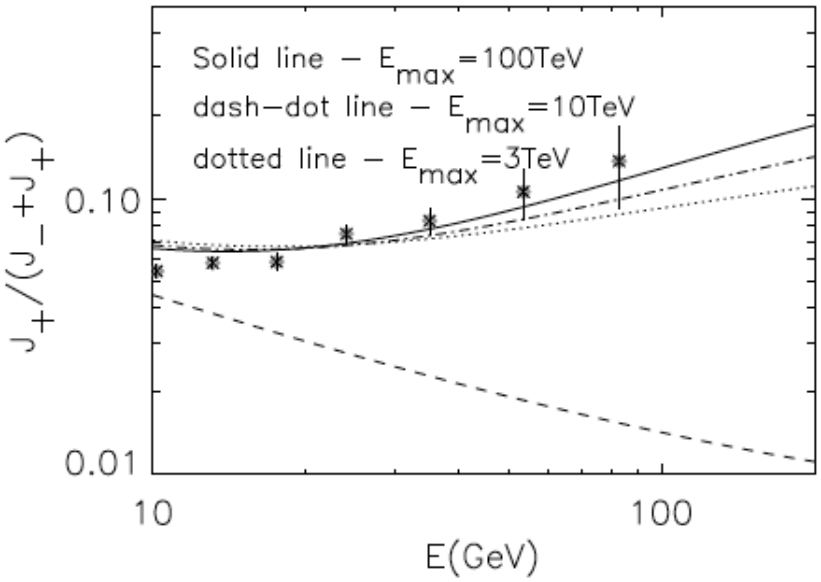
H. Yüksak et al., arXiv:0810.2784v2
Contributions of e- & e+ from Geminga assuming different distance, age and energetic of the pulsar





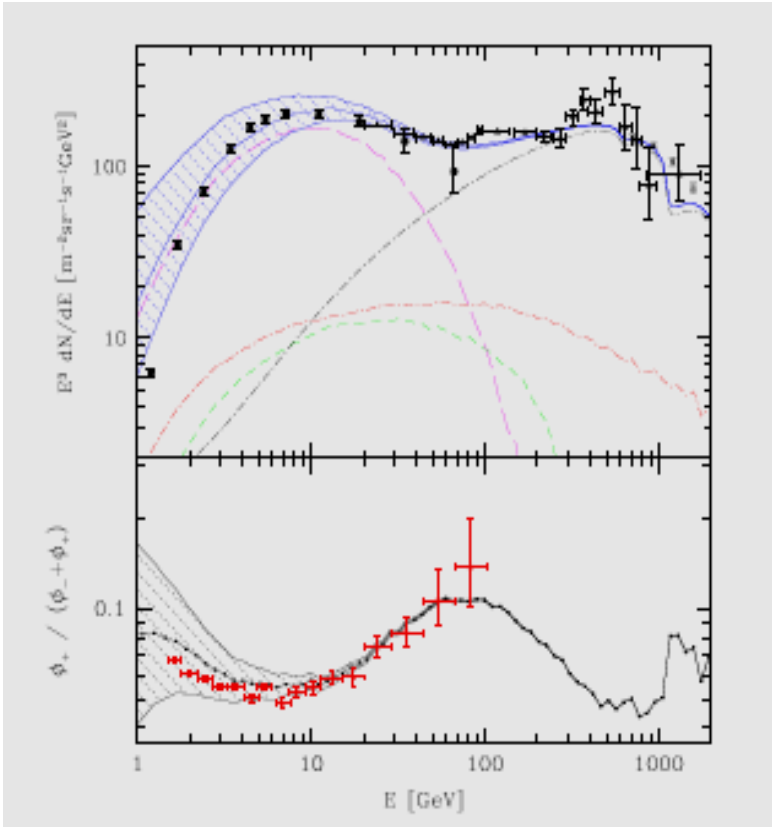
Hooper, Blasi, and Serpico
arXiv:0810.1527

A Challenging Puzzle for CR Physics



P.Blasi, PRL 103 (2009) 051104; 4
Positrons (and electrons) produced as secondaries in the sources (e.g. SNR) where CRs are accelerated.
S: Sarkar
Phys.Rev.Lett.103:081104,2009
arXiv:1108.1753. Nearby sources
But also other secondaries are produced: significant increase expected in the p/p and B/C ratios.

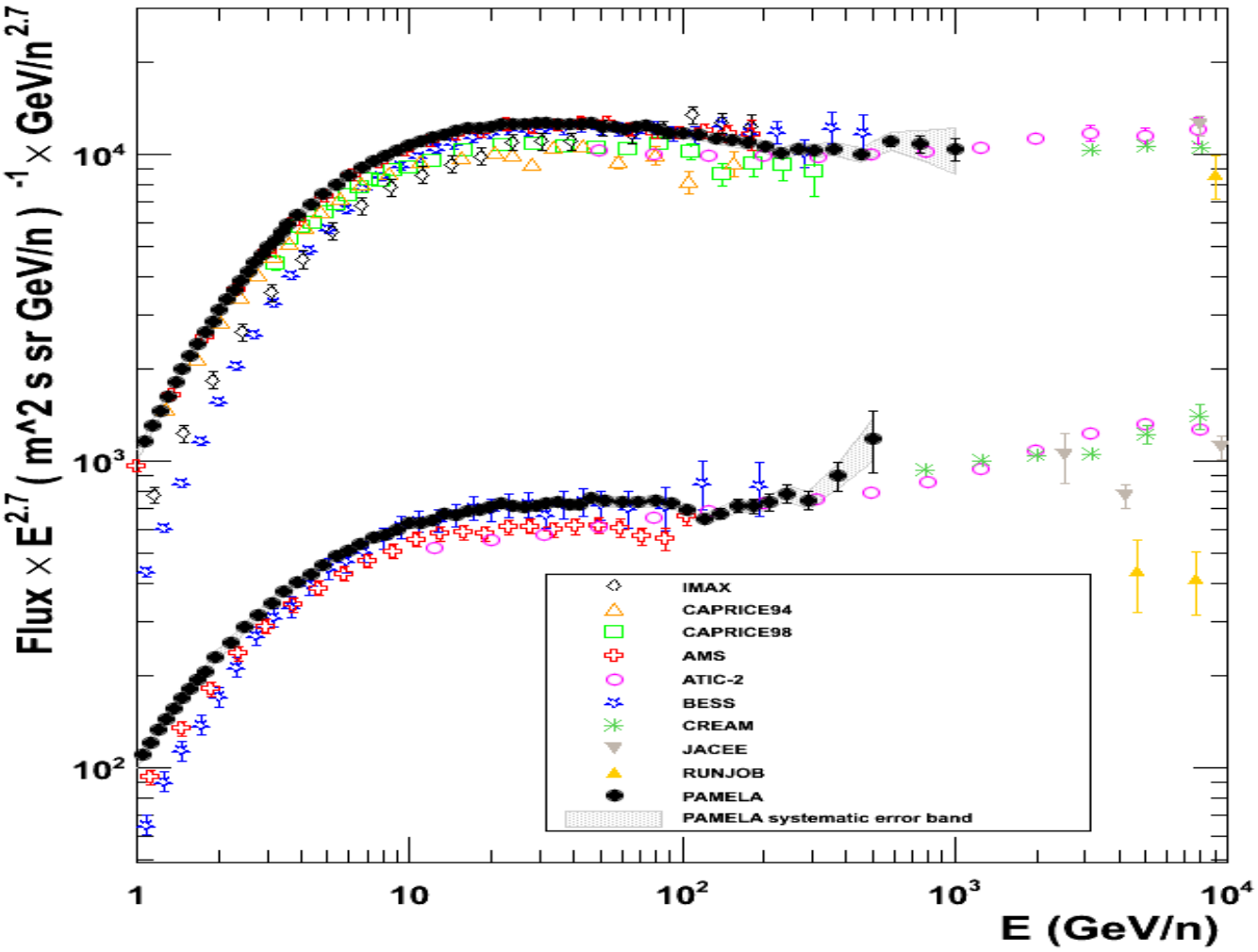
Y. Fujita
Phys.Rev.D80:063003,2009



N.J. Shaviv et al.,
PRL 103 (2009) 111302;

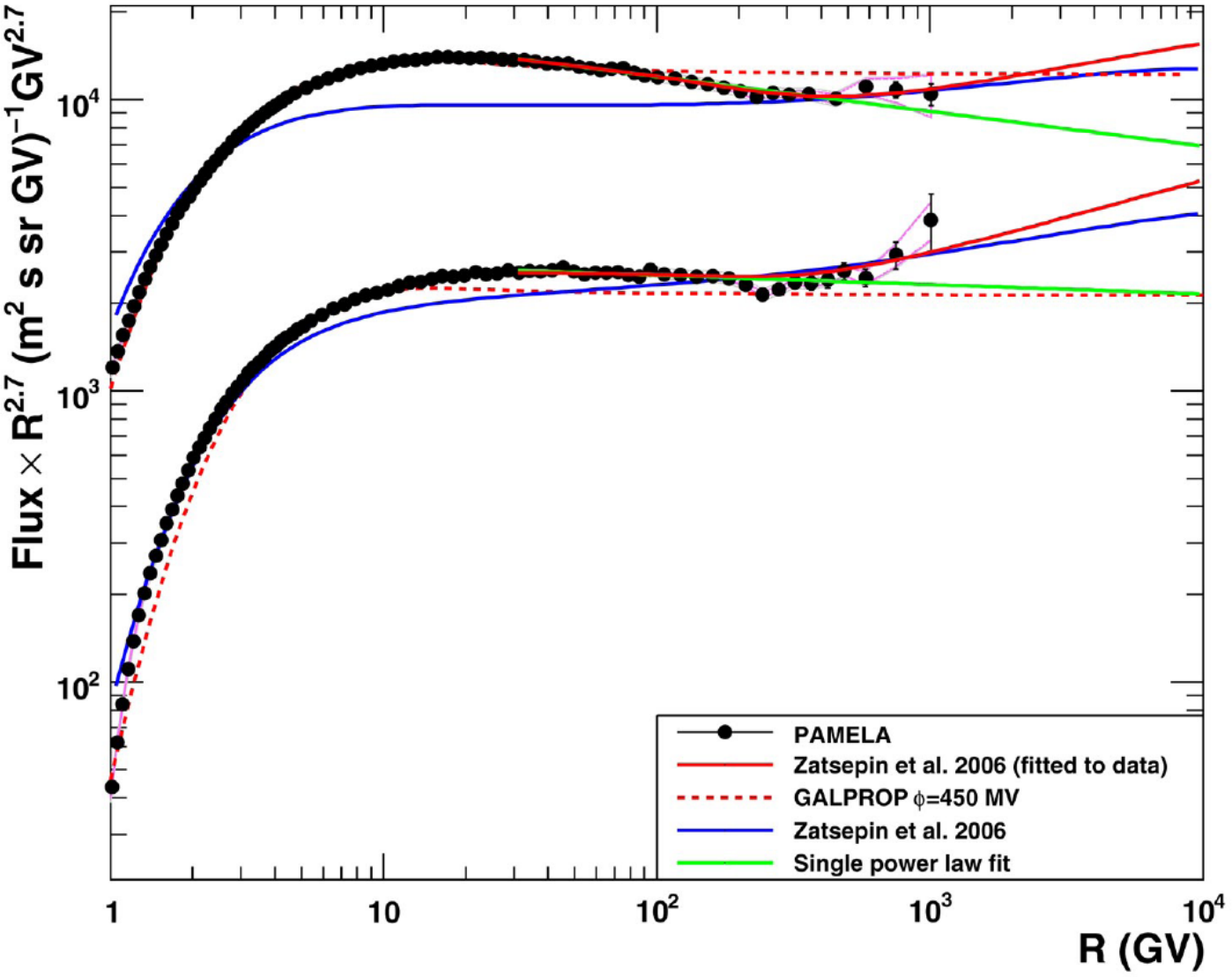
Proton and Helium Spectra

Proton and Helium fluxes

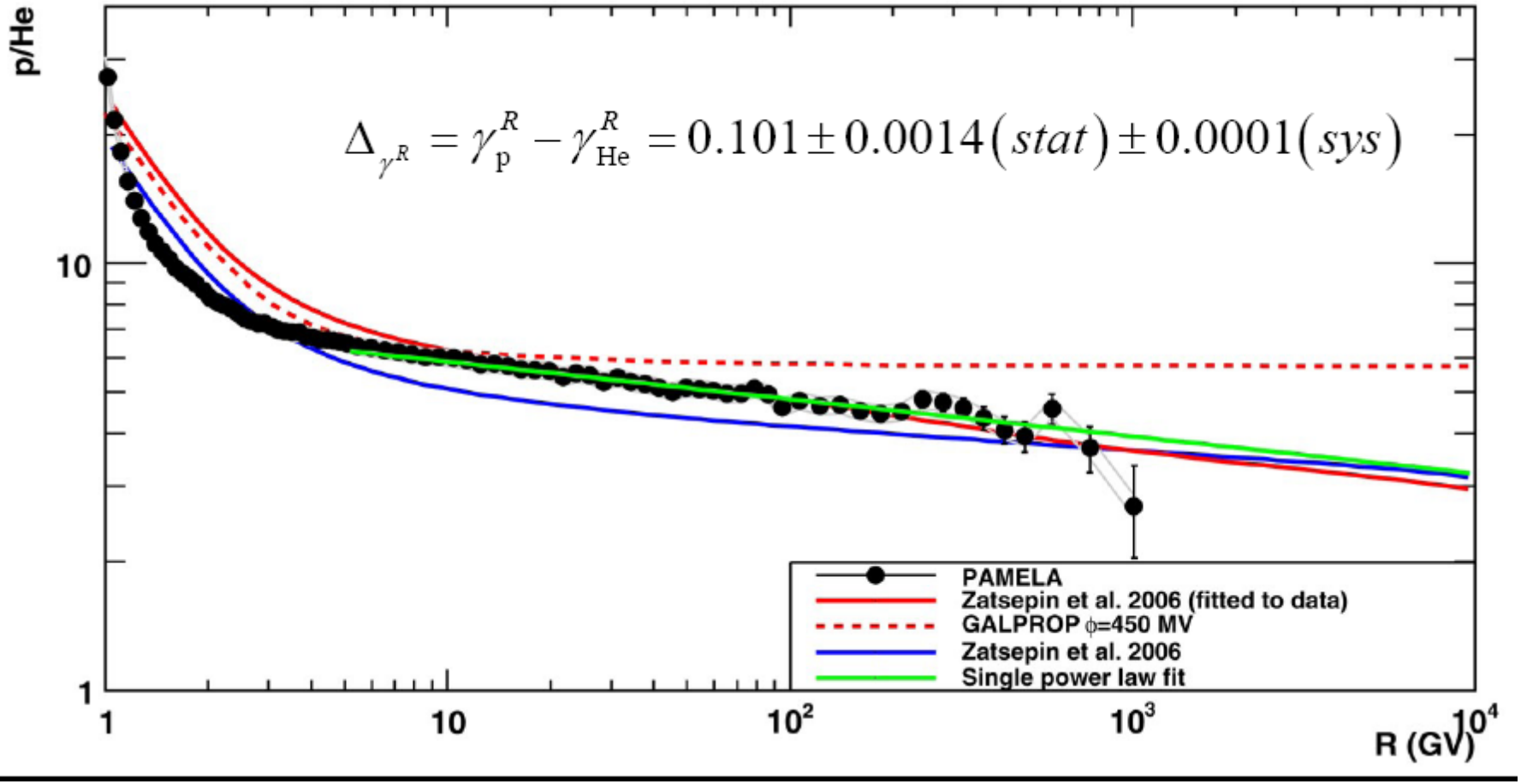


Science 332,69 (2011)

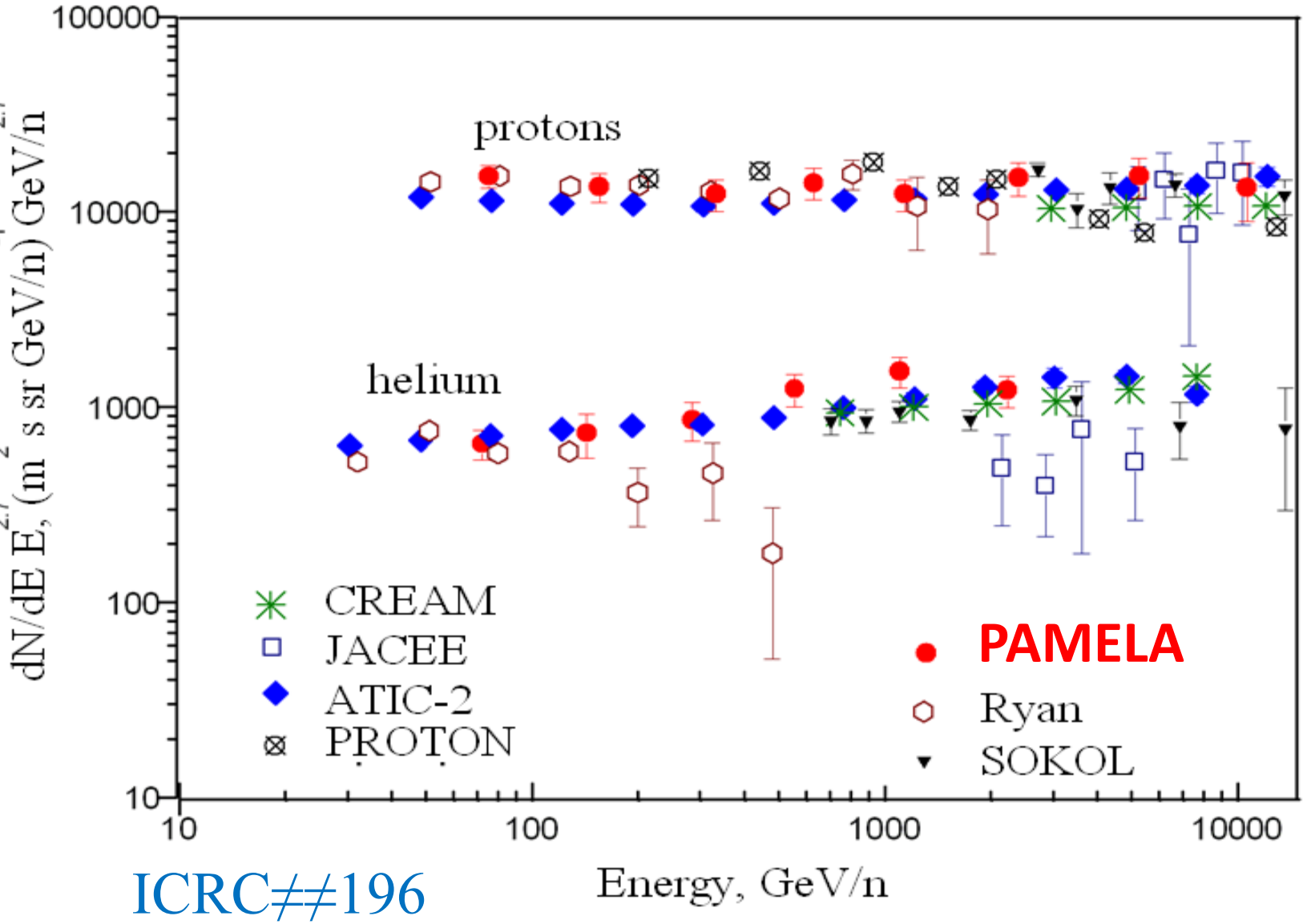
Proton and Helium fluxes



Proton to Helium ratio

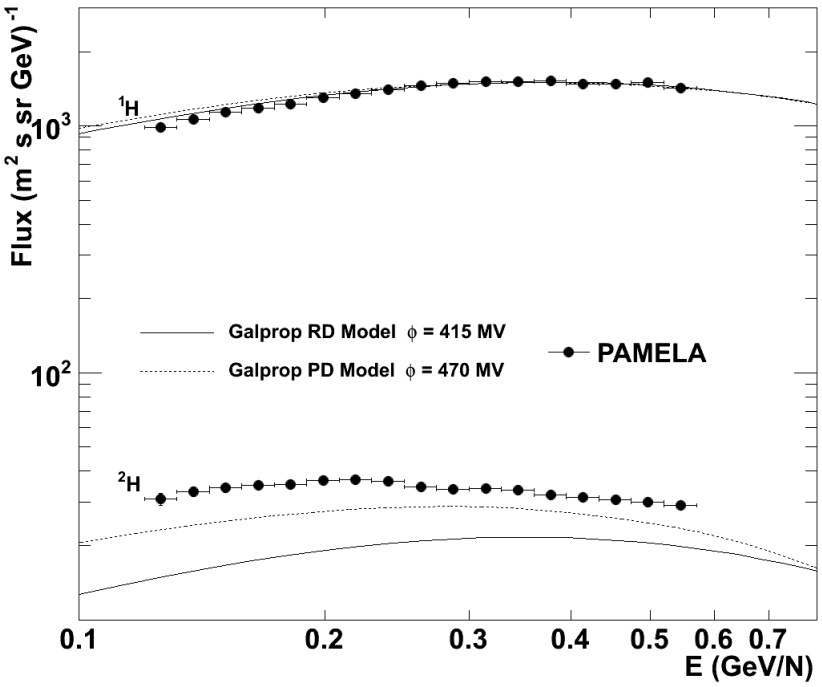


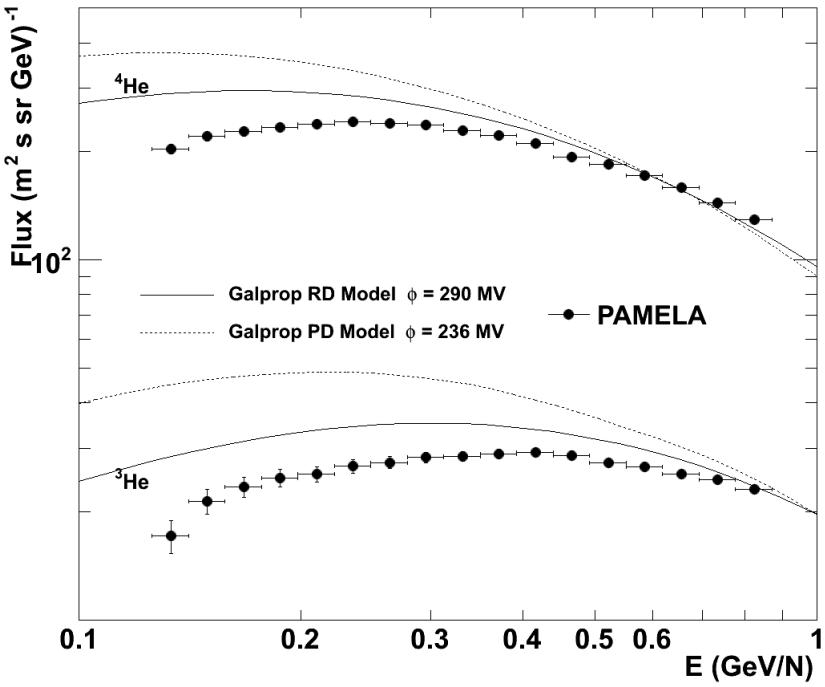
Proton and Helium fluxes



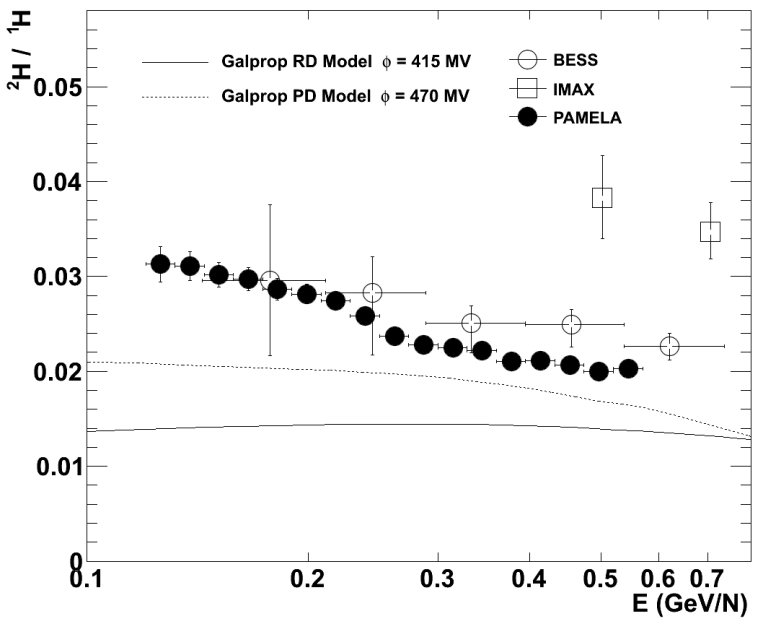
ICRC##196

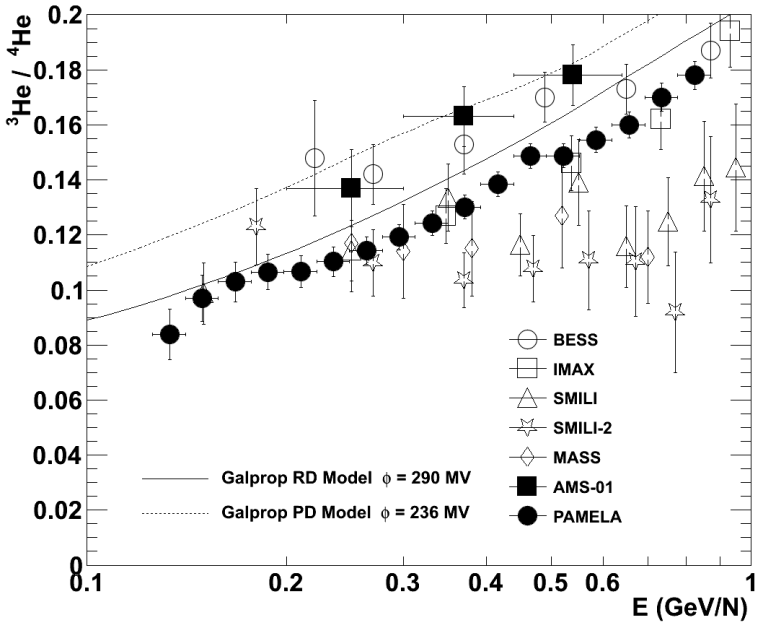
Hydrogen and Helium Isotopes



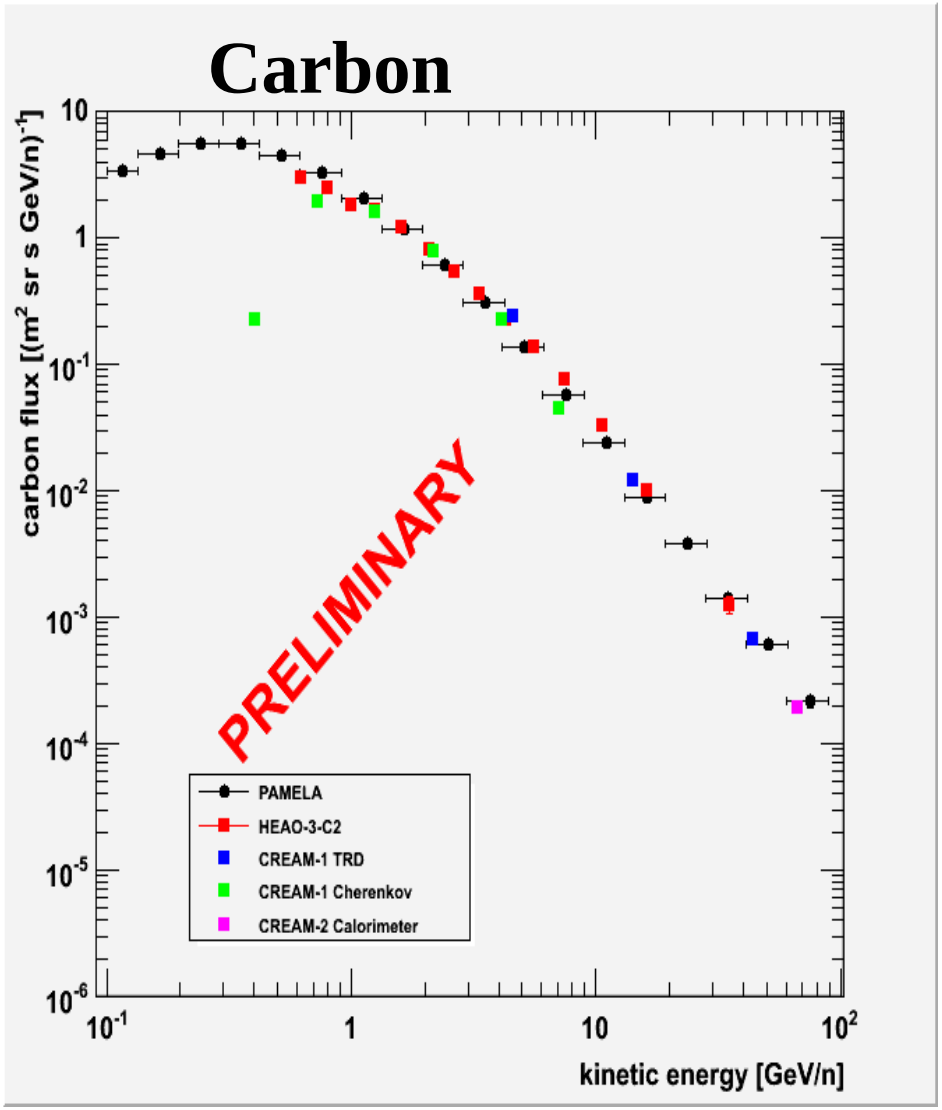


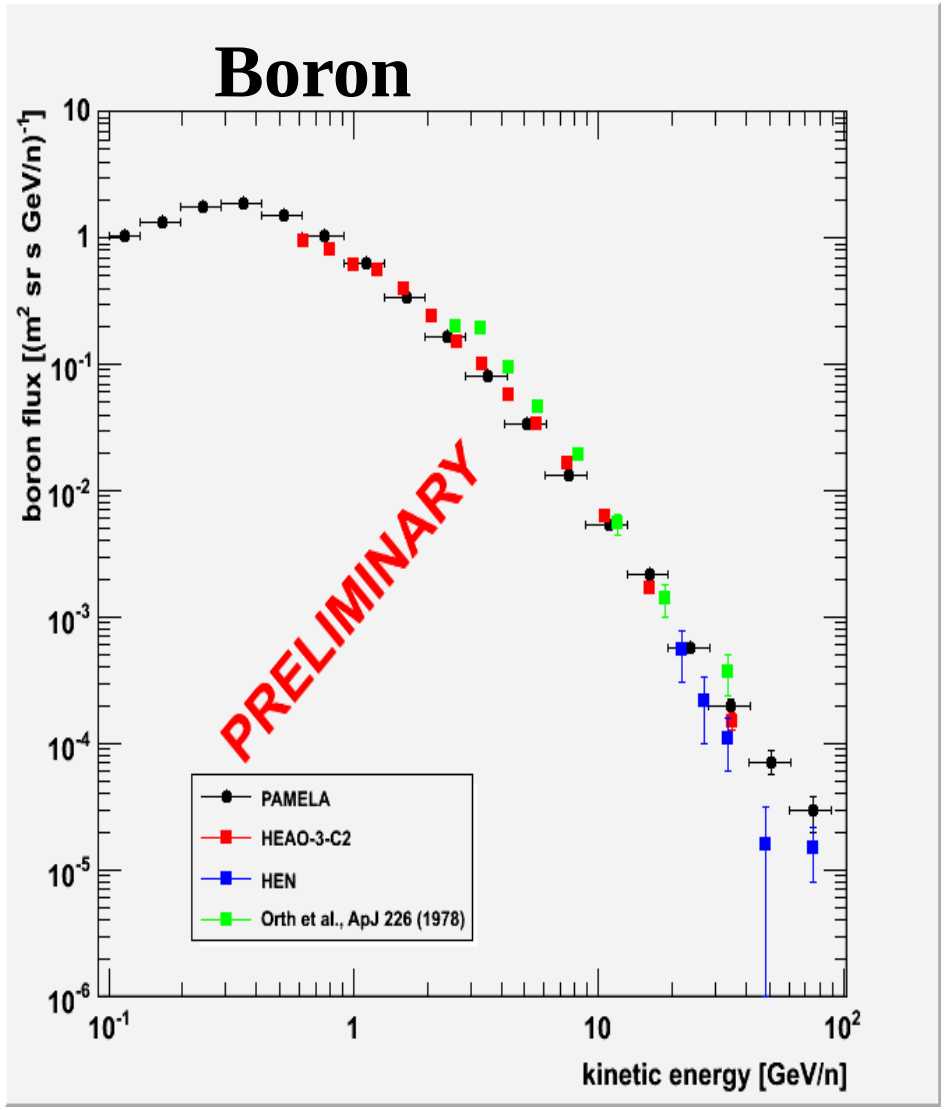
Ratios


^{2}H / ^{1}H
Galprop RD Model ϕ = 415 MV
Galprop PD Model ϕ = 470 MV
BESS
IMAX
PAMELA
0
0.01
0.02
0.03
0.04
0.05
0.1
0.2
0.3
0.4
0.5
0.6
0.7
E (GeV/N)


^{3}He / ^{4}He
Galprop RD Model ϕ = 290 MV
Galprop PD Model ϕ = 236 MV
BESS
IMAX
SMILI
SMILI-2
MASS
AMS-01
PAMELA
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.1
0.2
0.3
0.4
0.5
0.6
1
E (GeV/N)

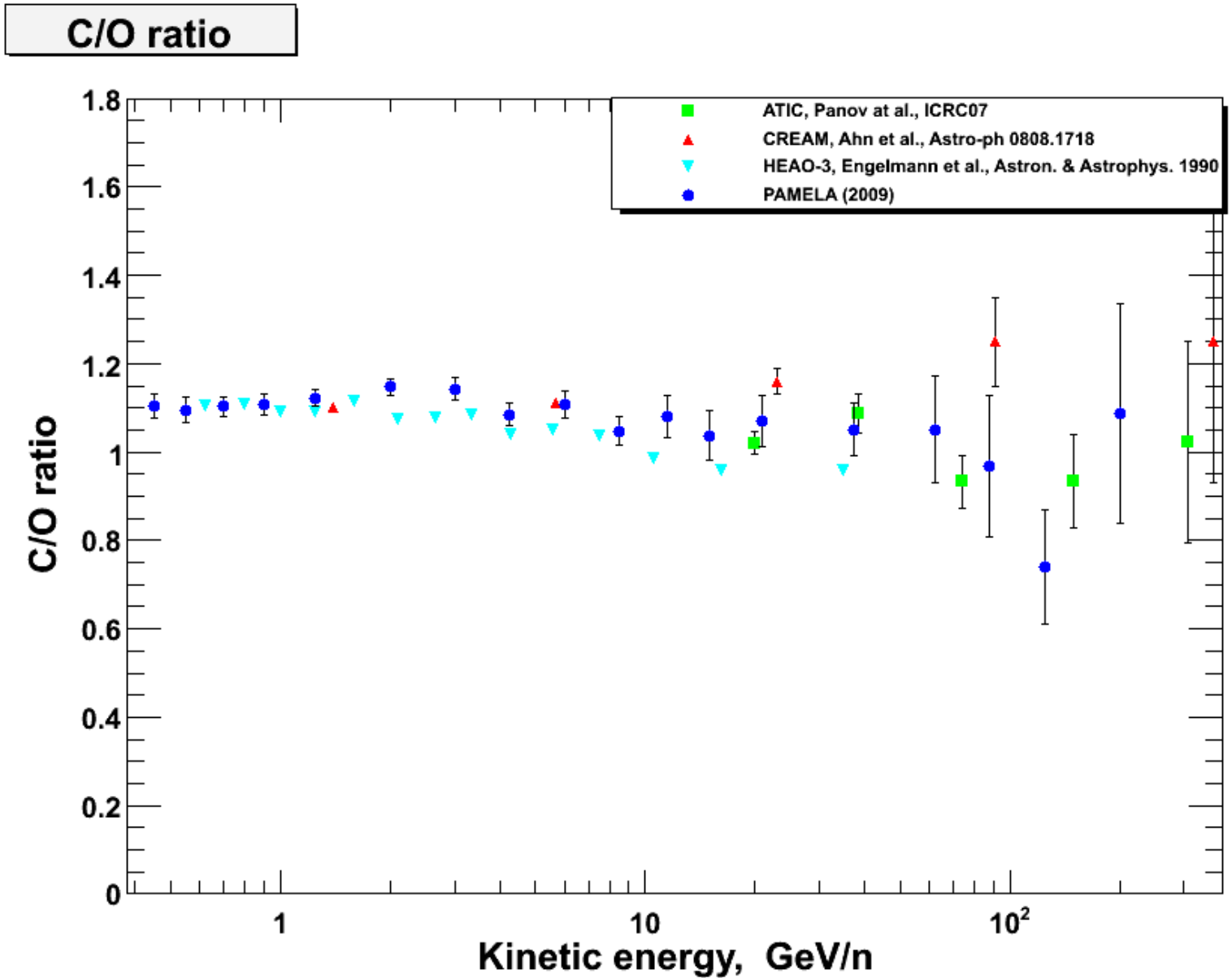
Boron and Carbon nuclei Spectra





ICRC#1079

C/O ratio


C/O ratio
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
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
10^2
Kinetic energy, GeV/n

Solar Modulation of galactic cosmic rays

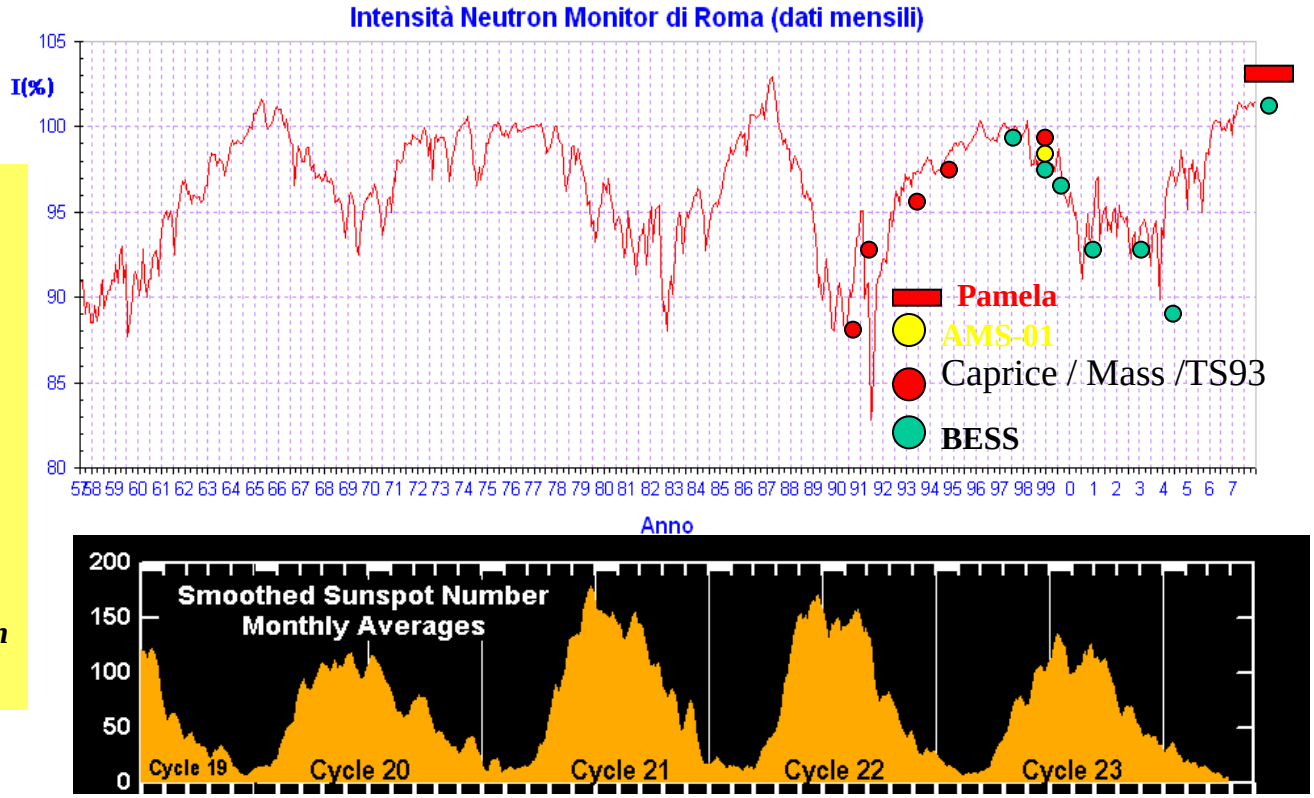
- **Study of solar modulation**
- **Study of charge sign dependent effects**

Asaoka Y. et al. 2002, Phys. Rev. Lett. 88, 051101),

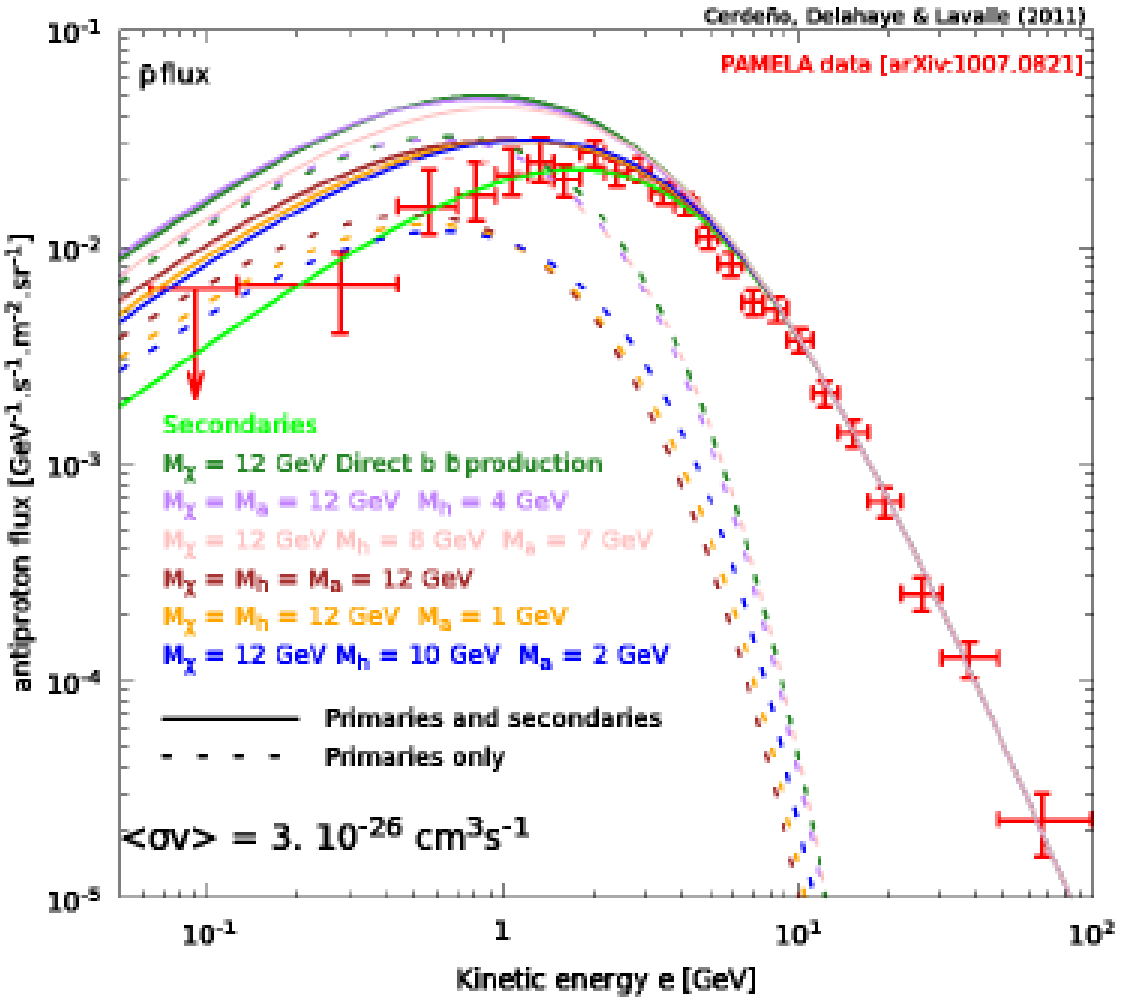
Bieber, J.W., et al. Physi-cal Review Letters, 84, 674, 1999.

J. Clem et al. 30th ICRC 2007

U.W. Langner, M.S. Potgieter, Advances in Space Research 34 (2004)



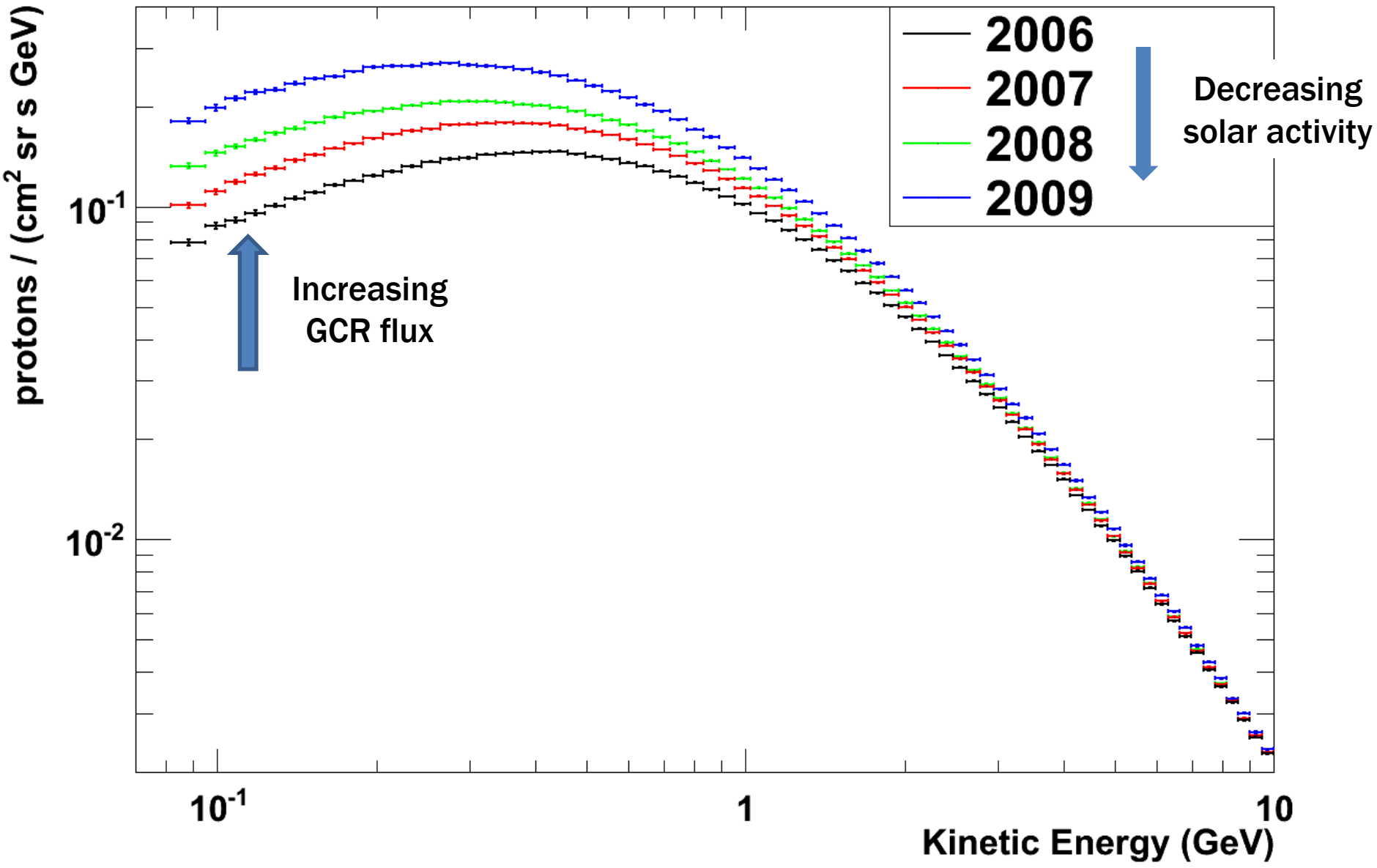
Cosmic-Ray Antiprotons and DM limits

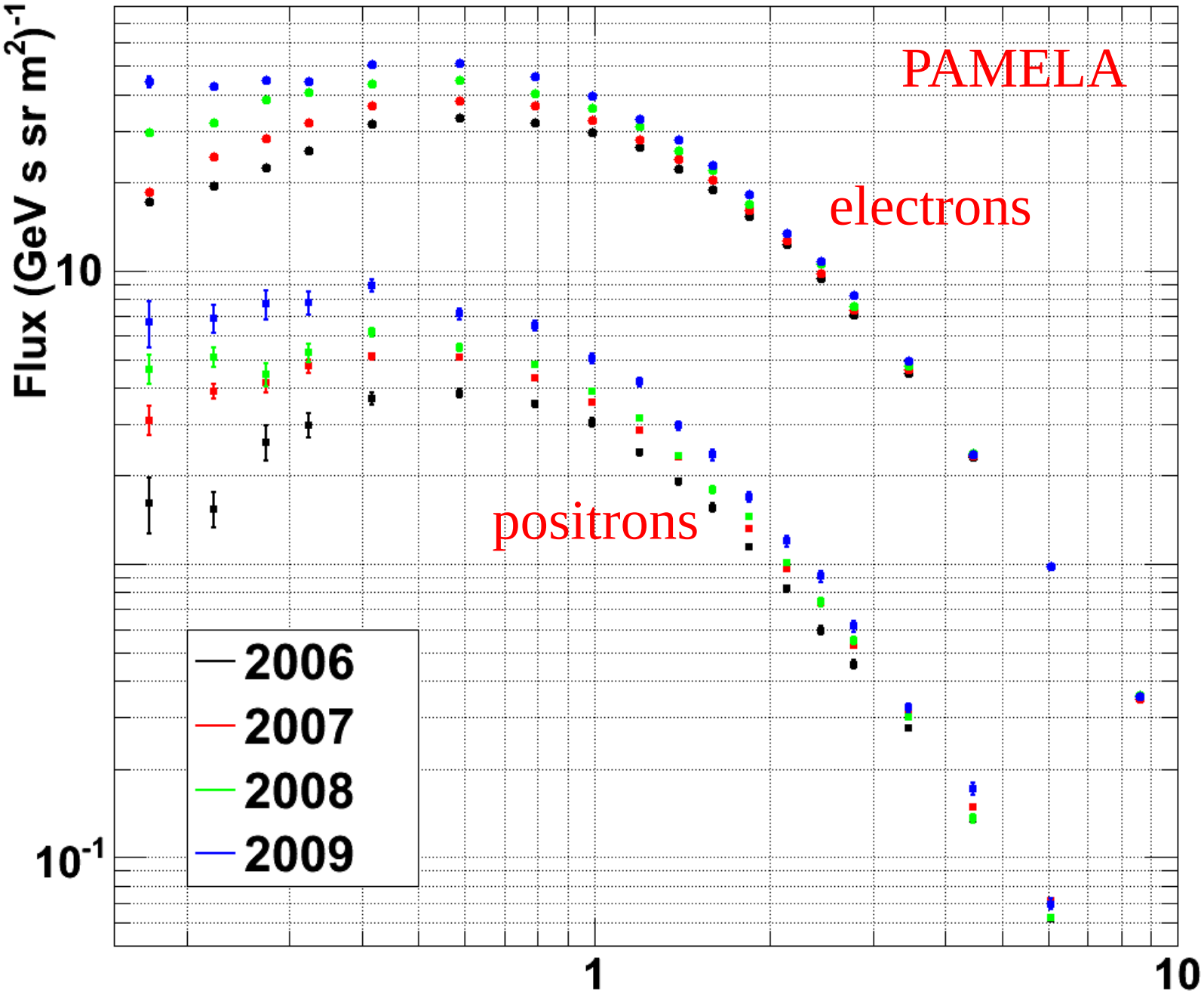


D. G. Cerdeno, T. Delahaye & J. Lavalle, arXiv: 1108:1128
Antiproton flux predictions for a 12 GeV WIMP annihilating into different mass combinations of an intermediate two-boson state which further decays into quarks.

See also:
- **M. Asano, T. Bringmann & C. Weniger, arXiv:1112.5158.**
- **M. Garny, A. Ibarra & S. Vogl, arXiv:1112.5155**
- **R. Kappl & M. W. Winkler, arXiv:1140.4376**

Time Dependence of PAMELA Proton Flux

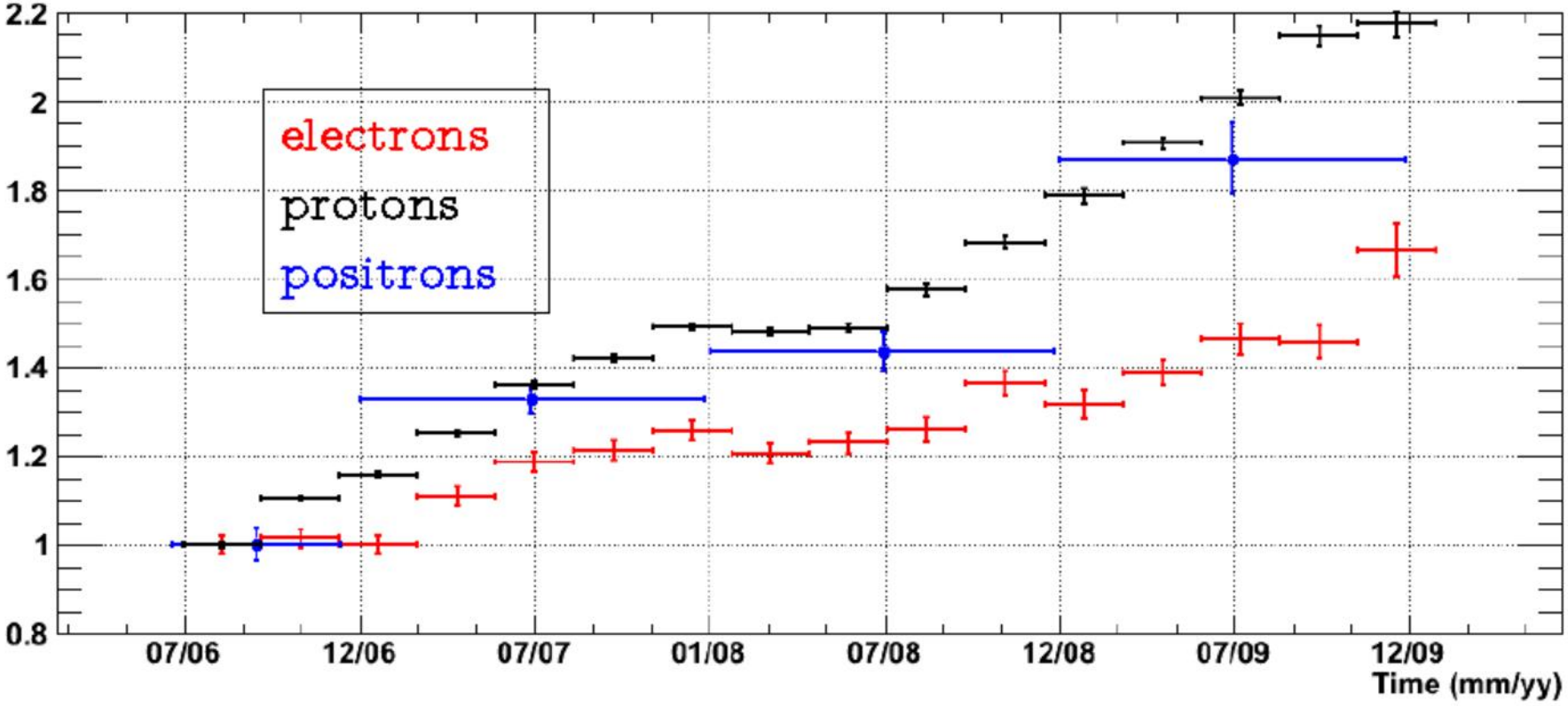



PAMELA
electrons
positrons
2006
2007
2008
2009
Flux (GeV s sr m^2)$^{-1}$
10
10^{-1}
1
10

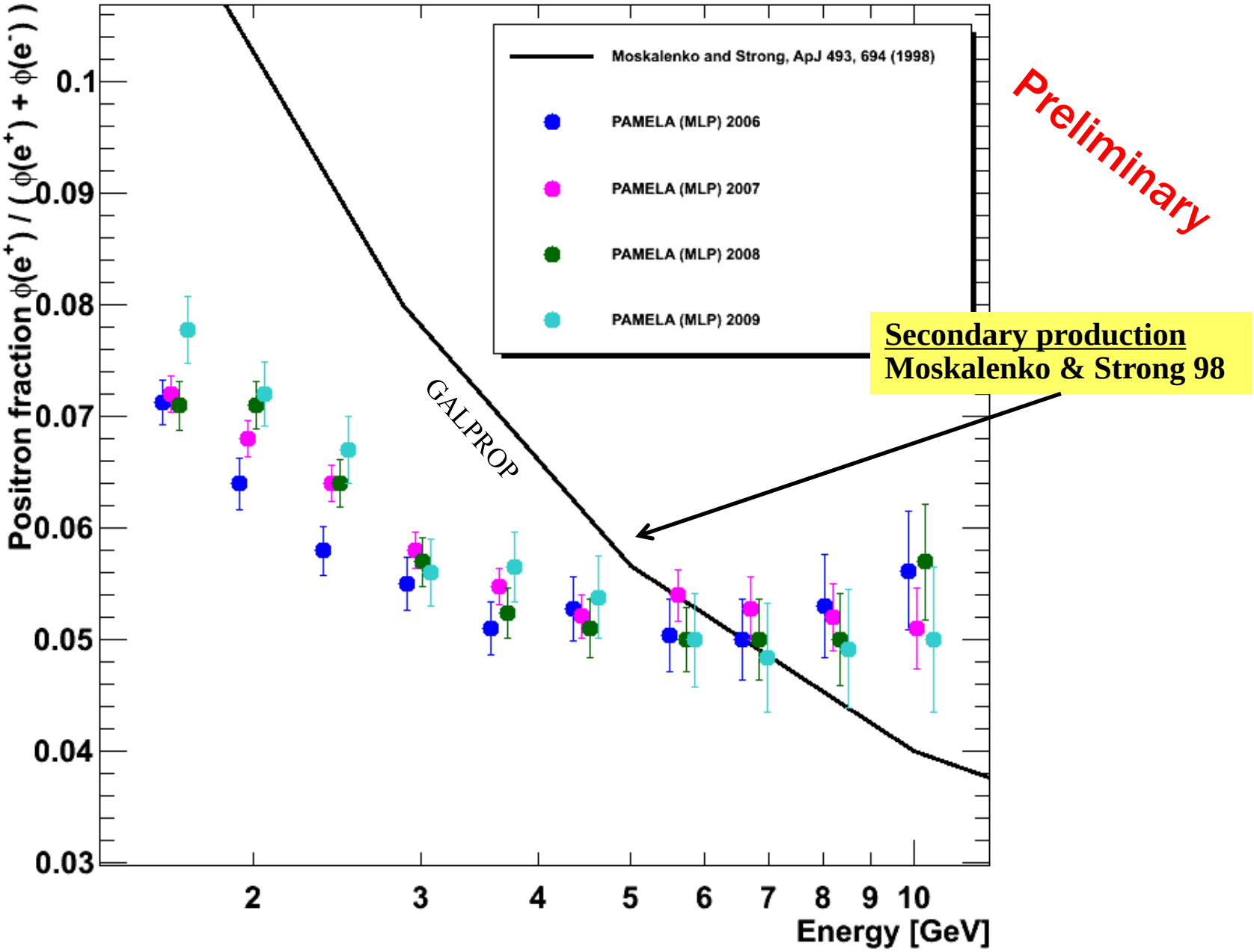
Fluxes in time

PAMELA

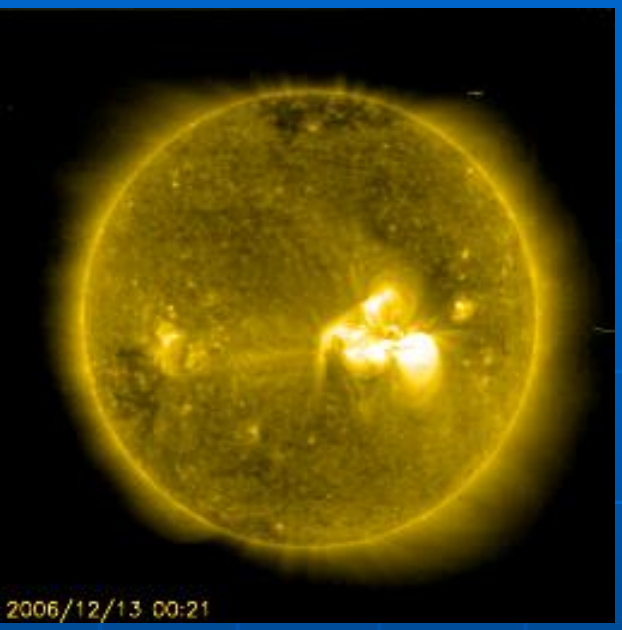
range: 0.4 – 0.71 GeV

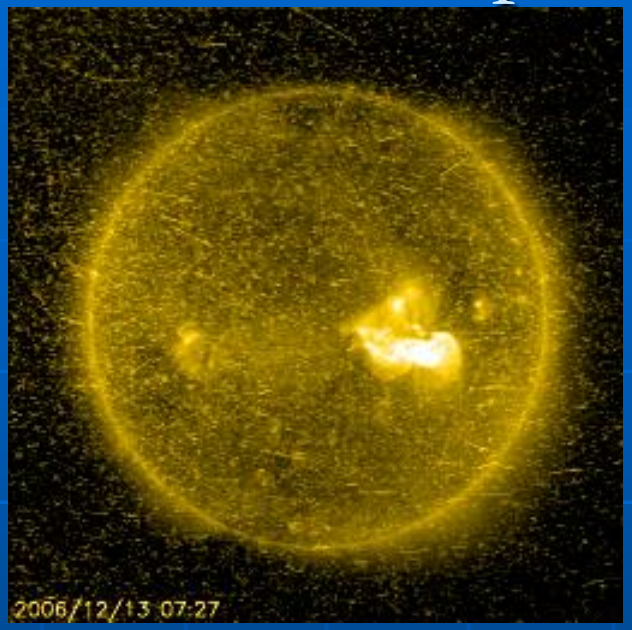


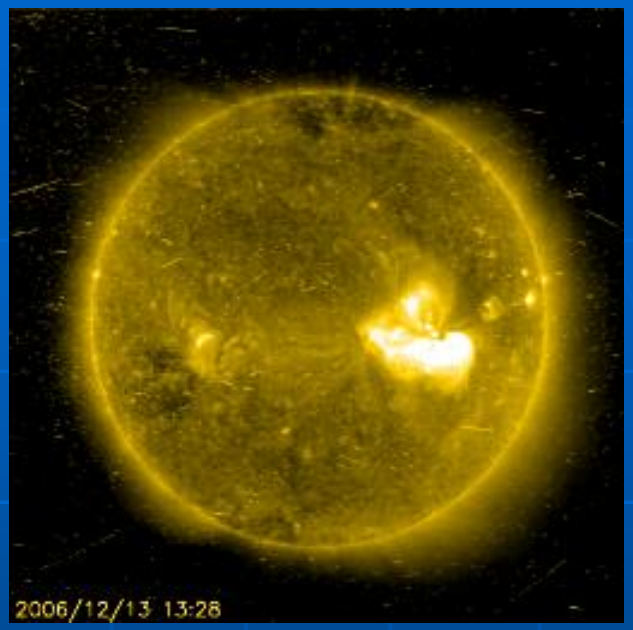
PAMELA Positron Fraction



December 2006 Solar particle events

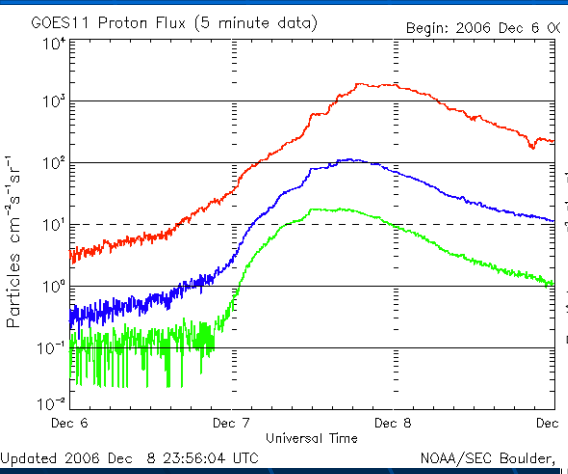


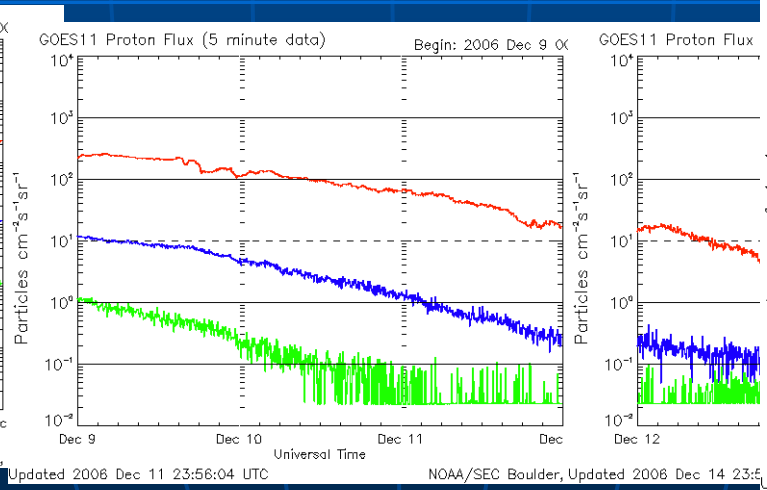


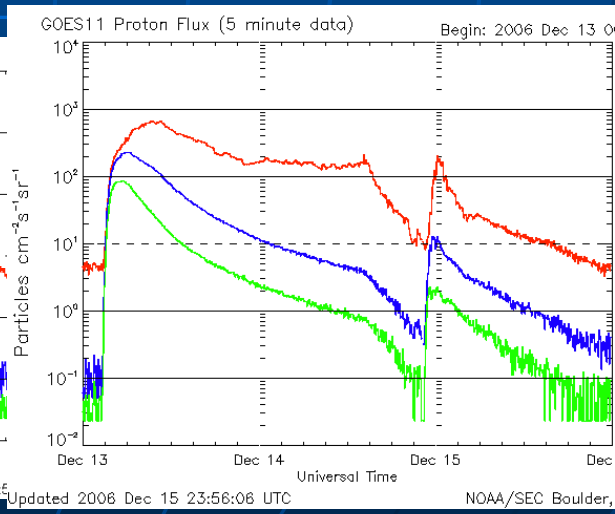


Dec 13th largest CME since 2003, anomalous at sol min

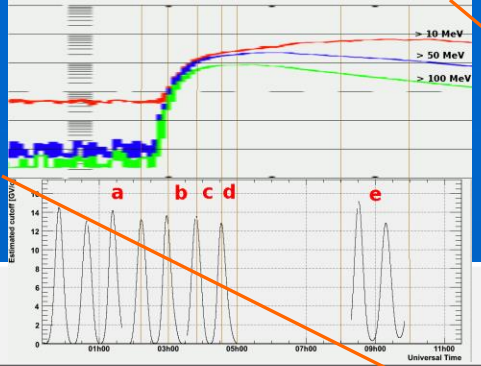
X3.4 solar flare,

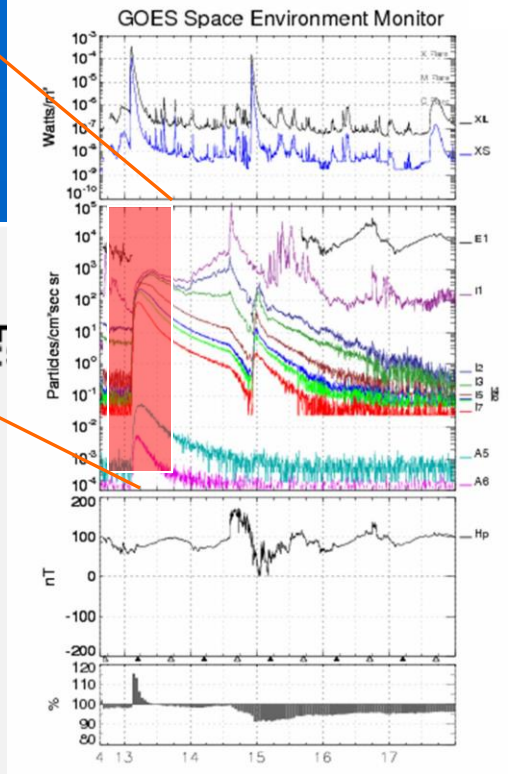


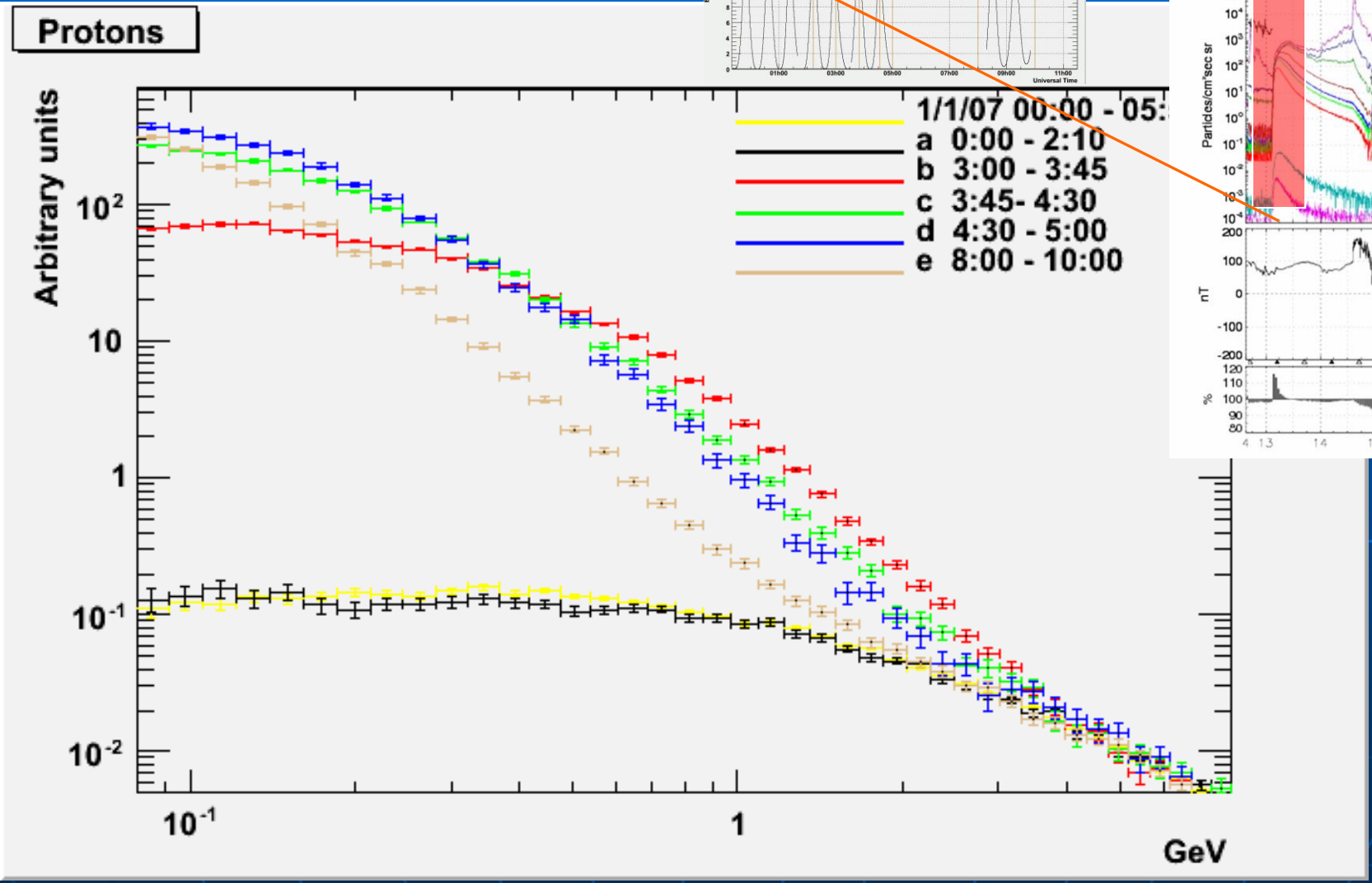




December 13th 2006 event

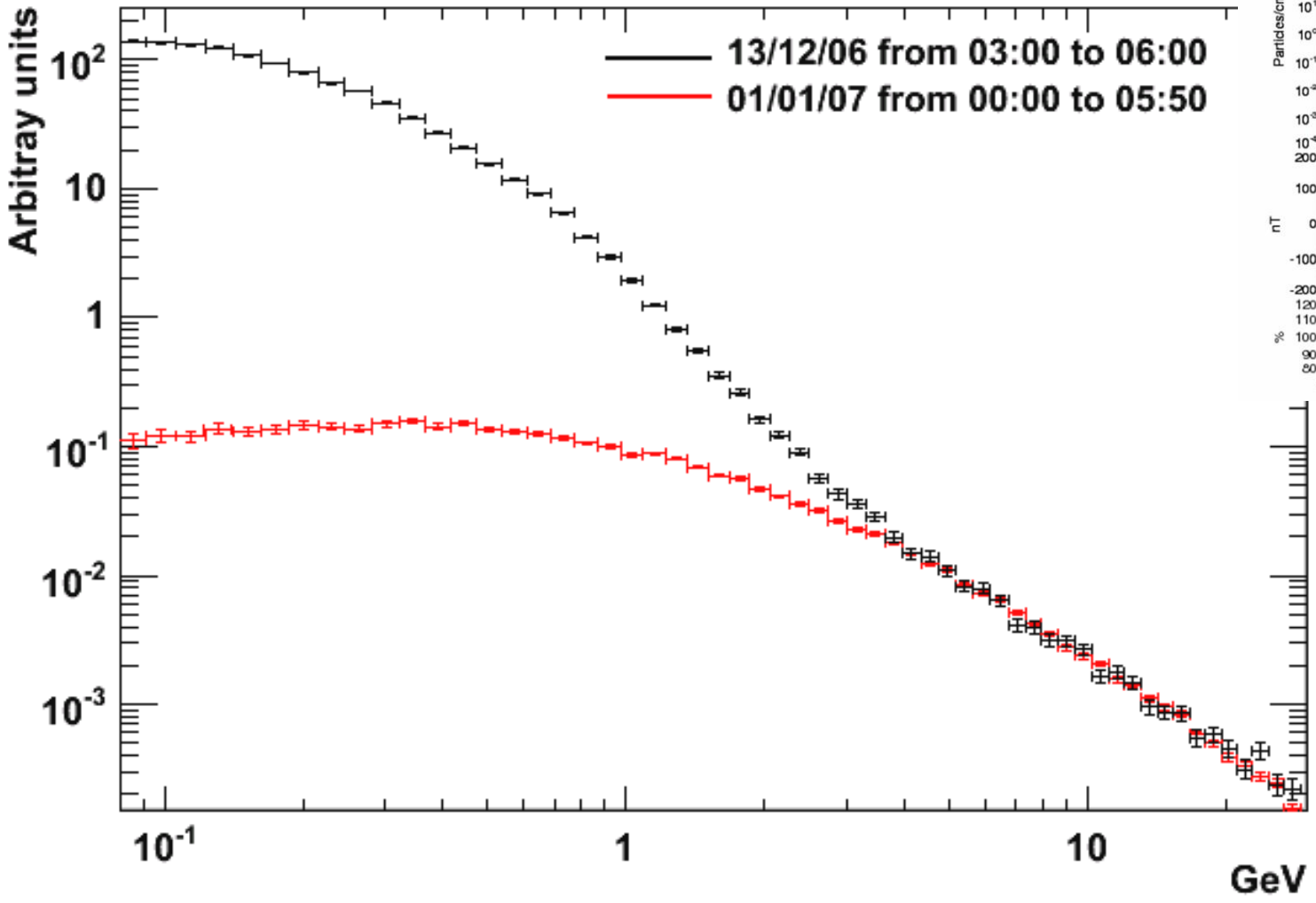


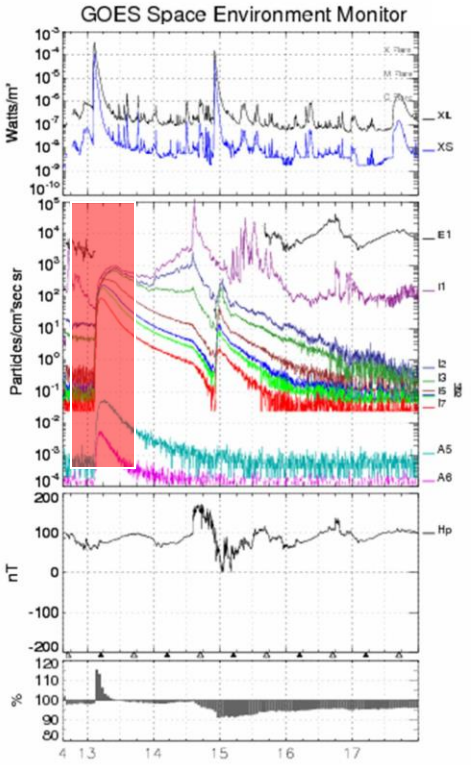




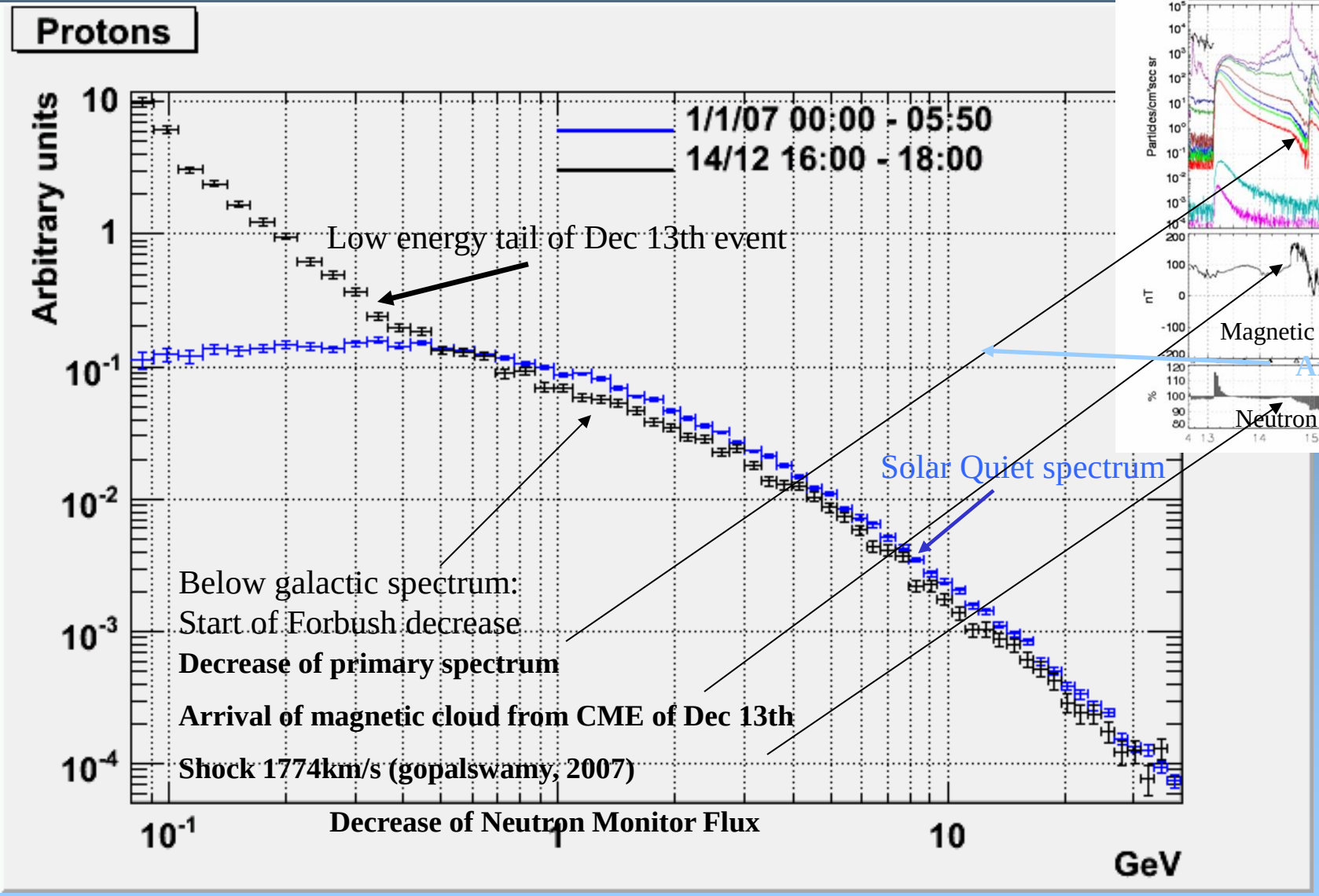
Preliminary!

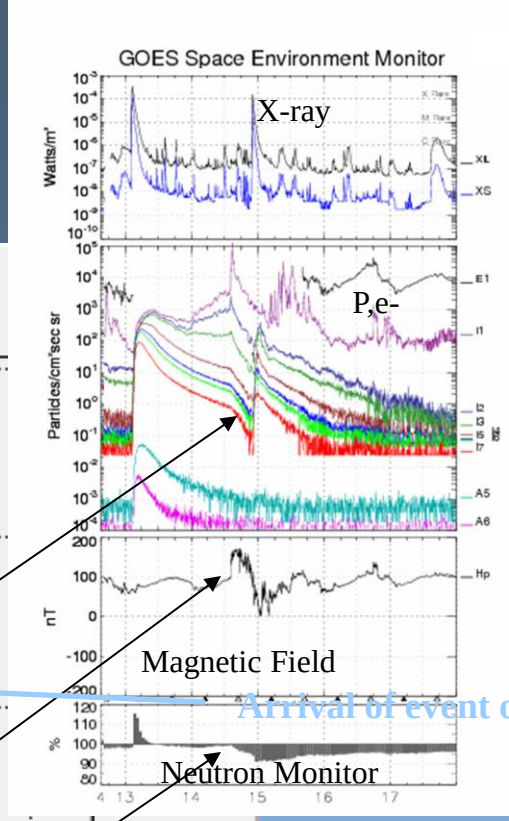
December 13th 2006 He differential spectrum



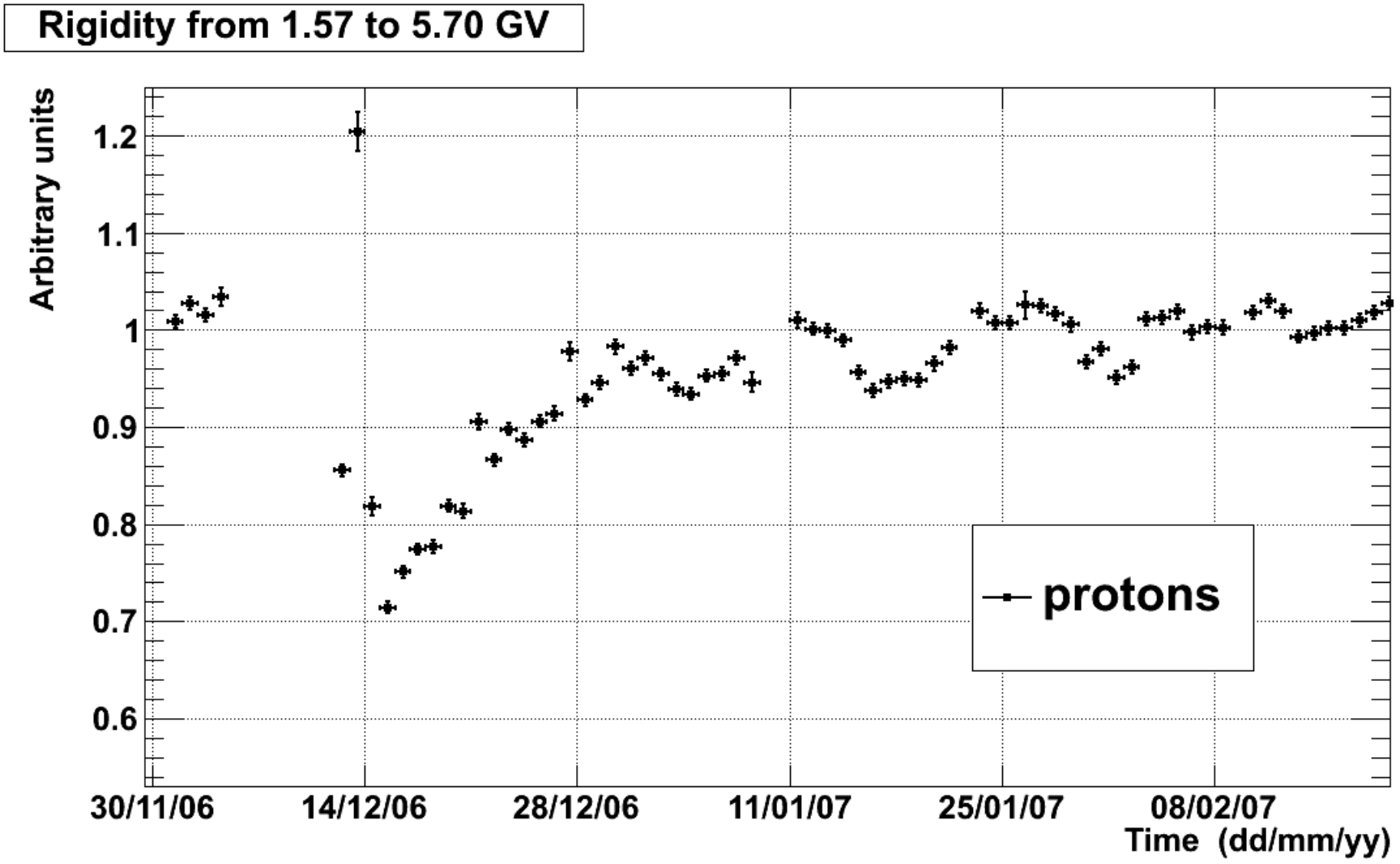


December 14th 2006: Forbush decrease

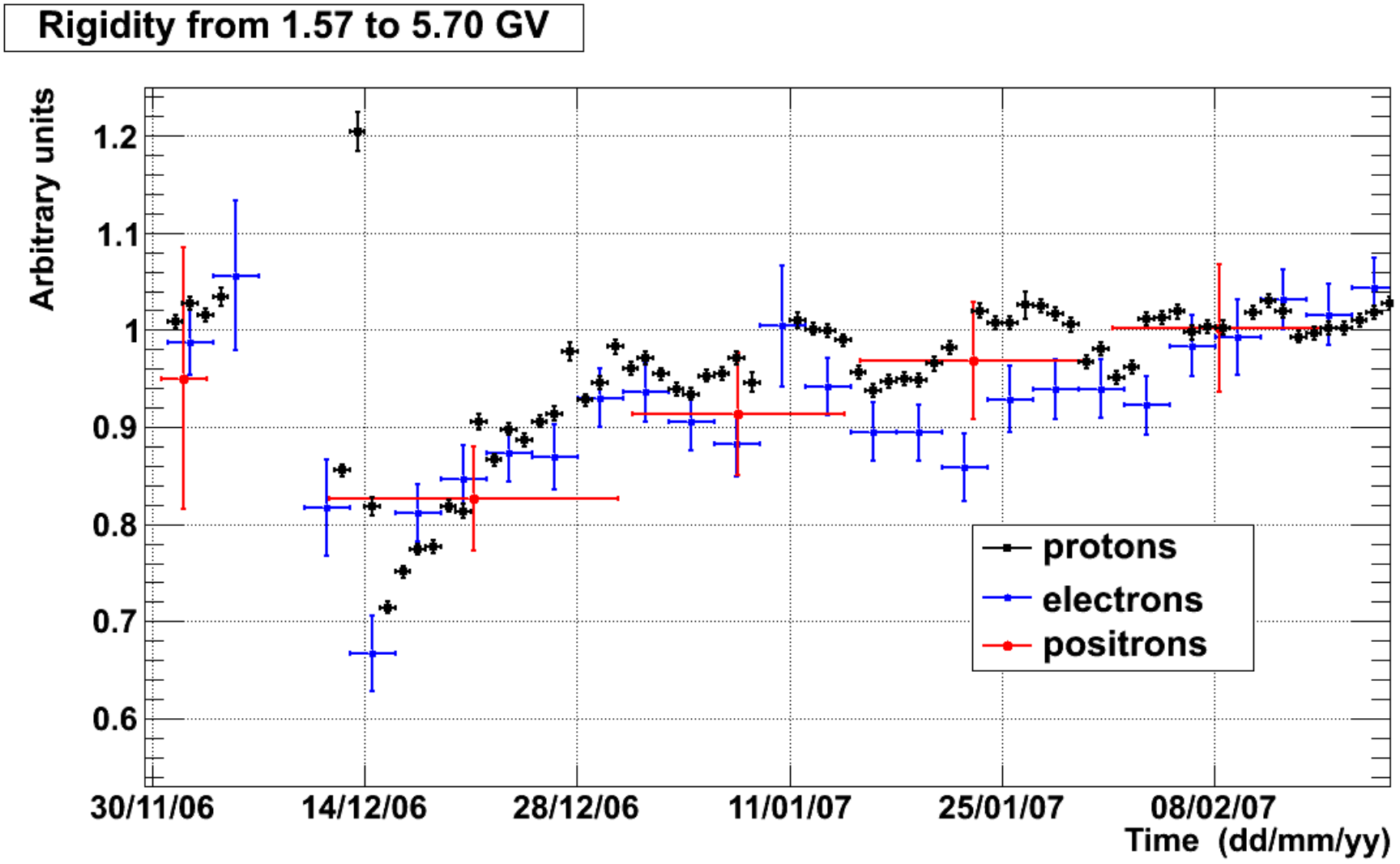




Forbush decrease – protons



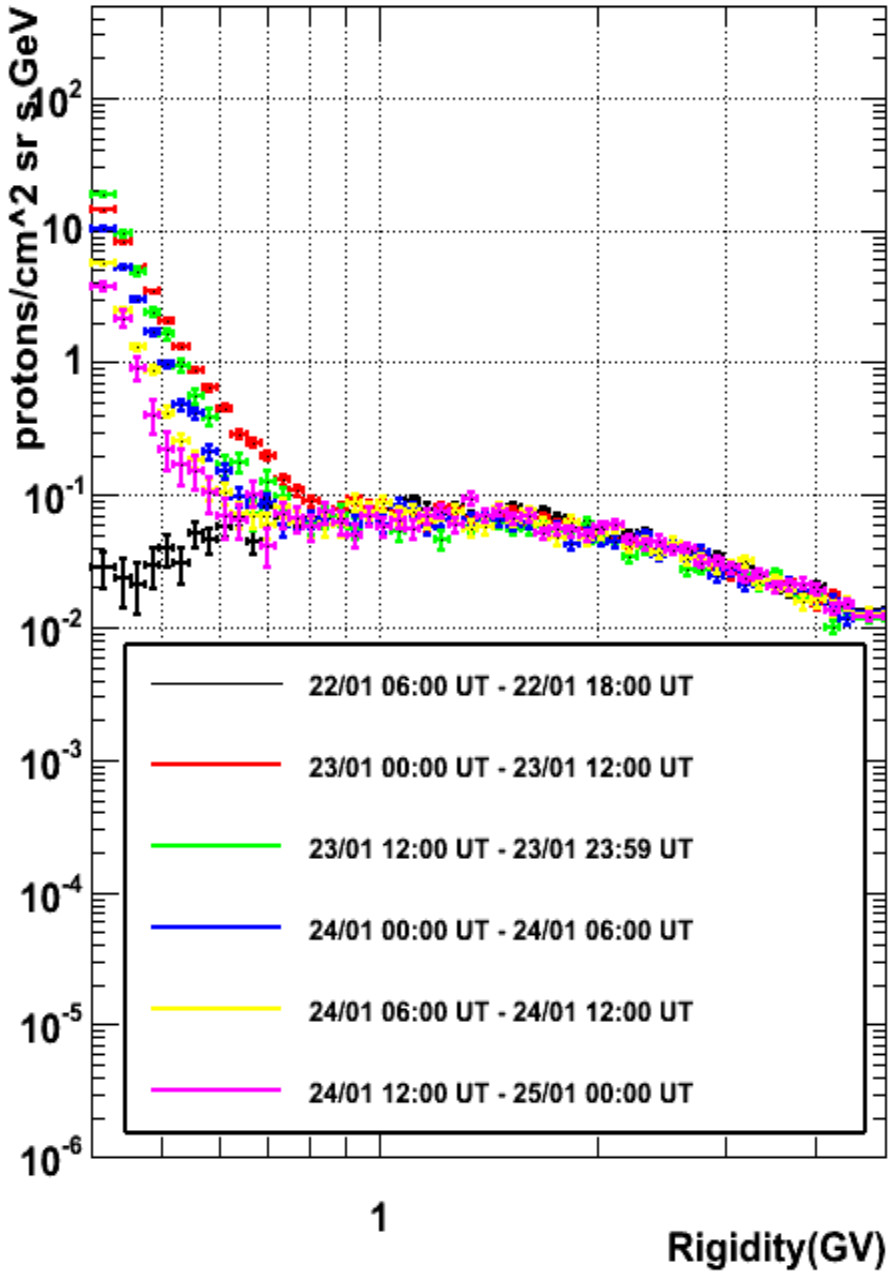
Forbush decrease – protons, electrons and positrons

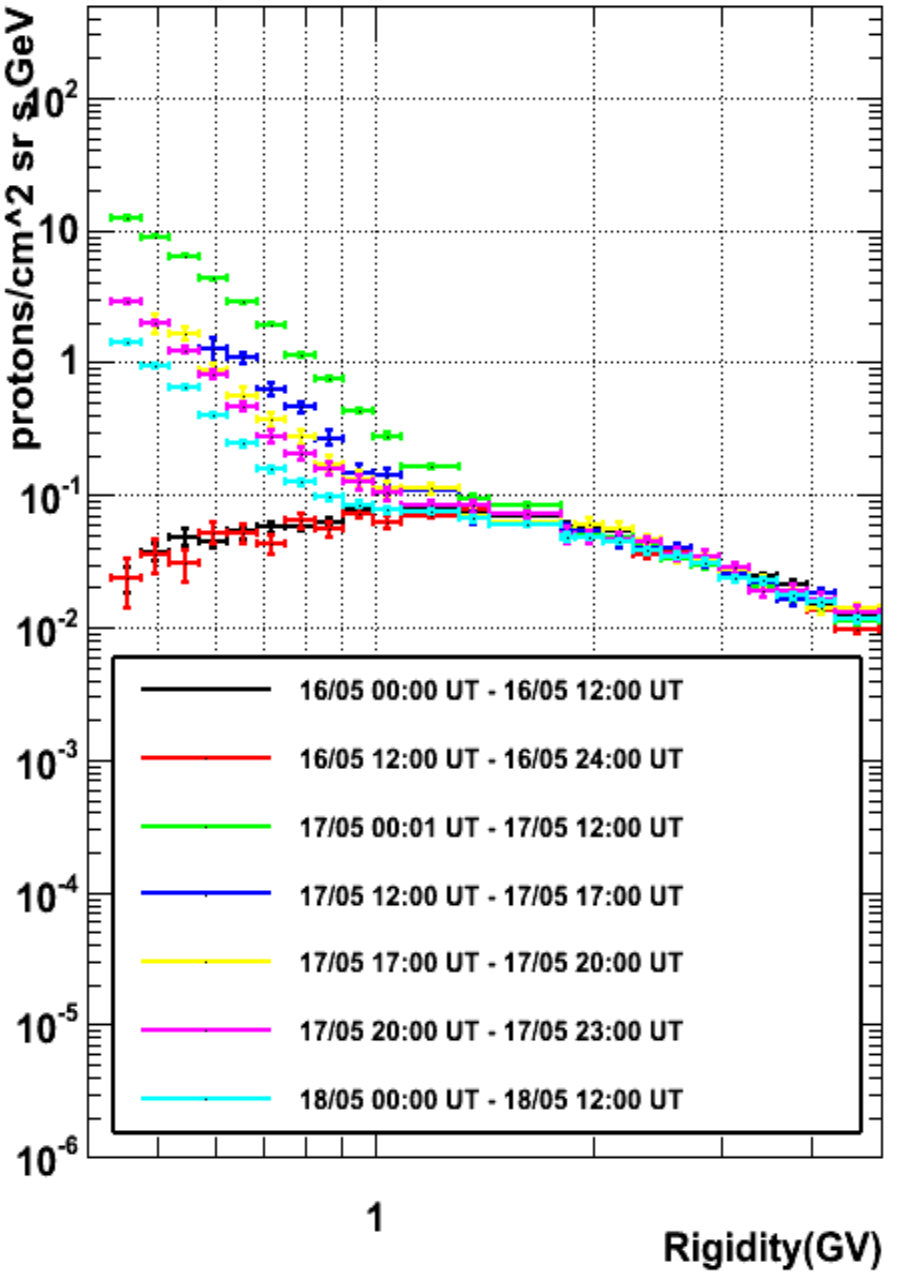


proton flux during the January 23rd flare

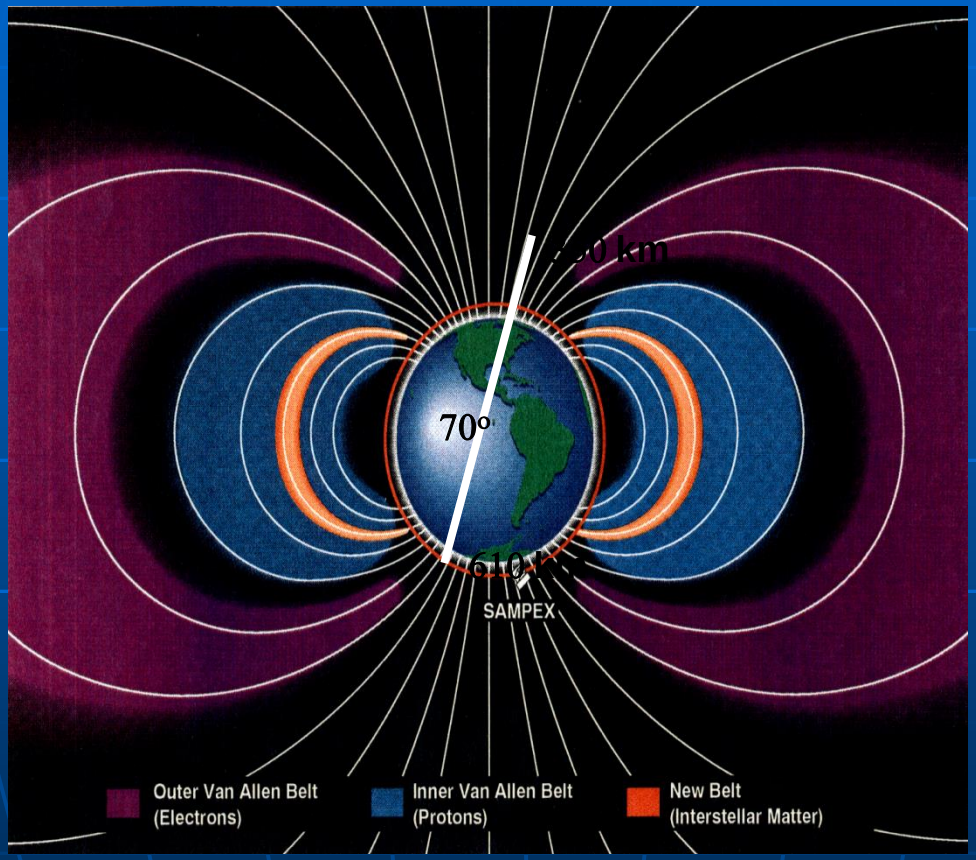
2012

proton flux during the May 17th flare

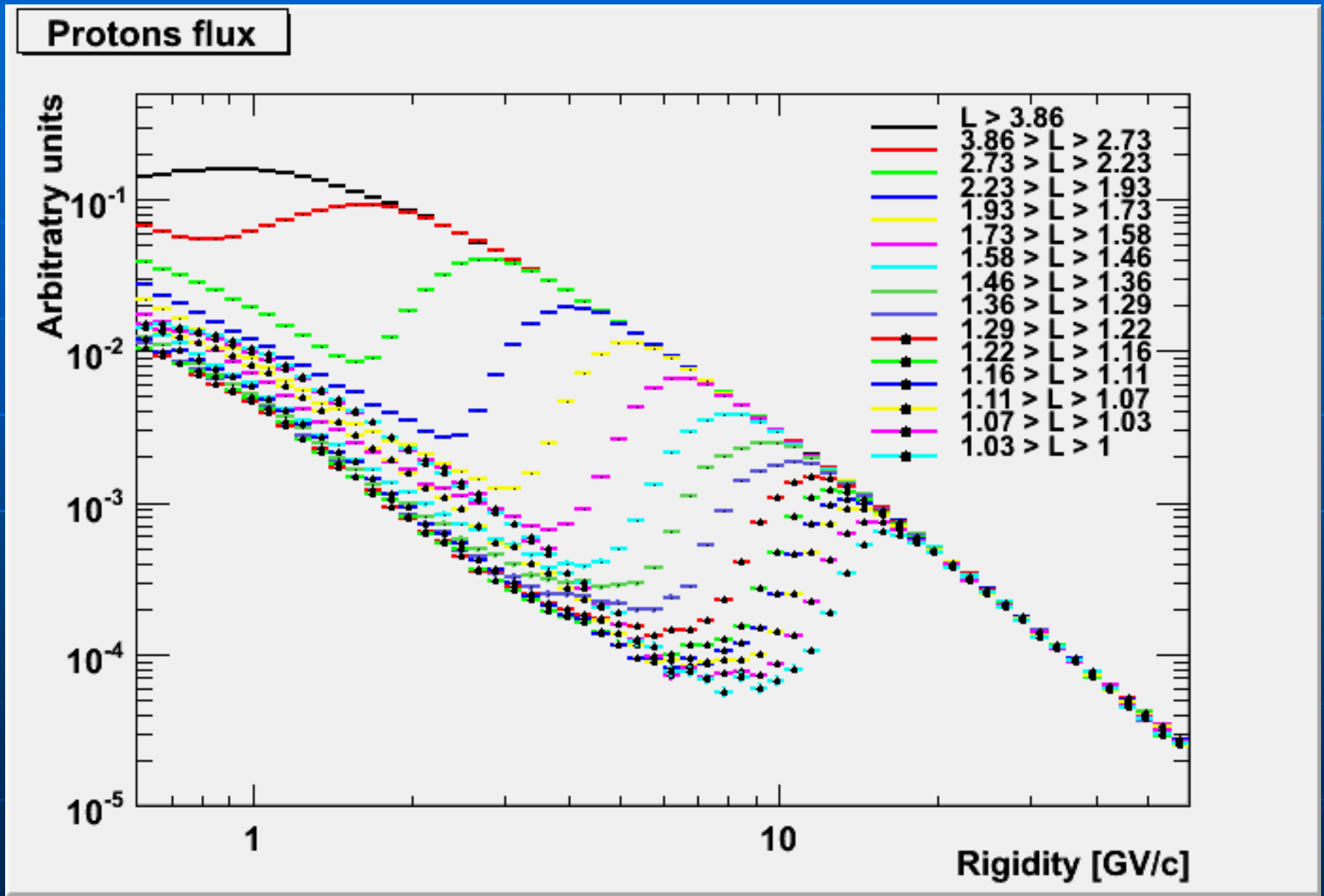




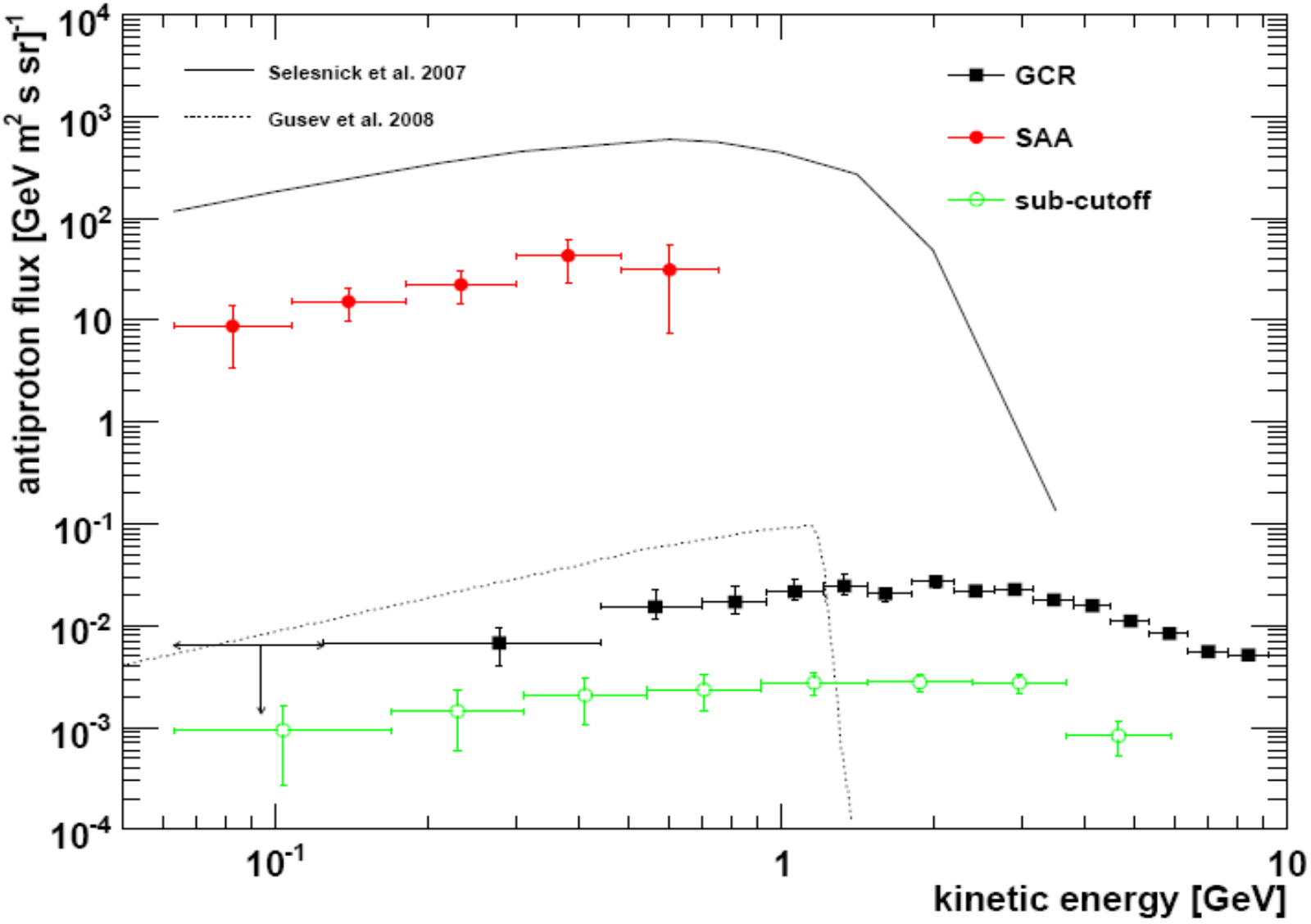
Radiation Belts



Proton flux over the PAMELA orbit

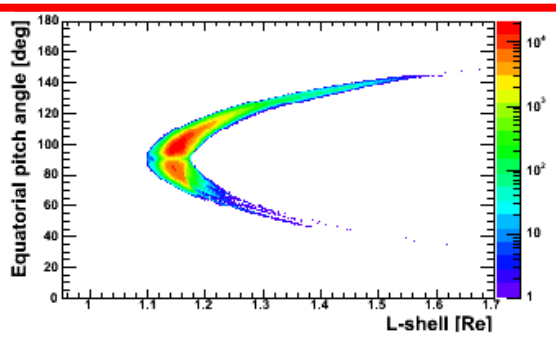
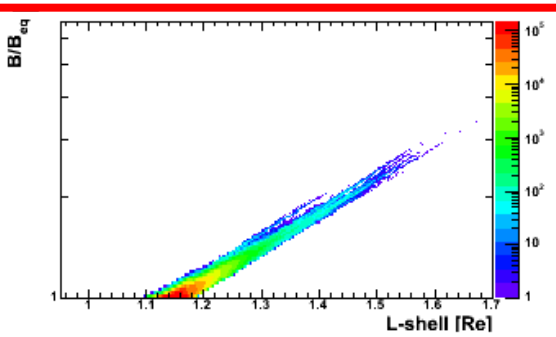
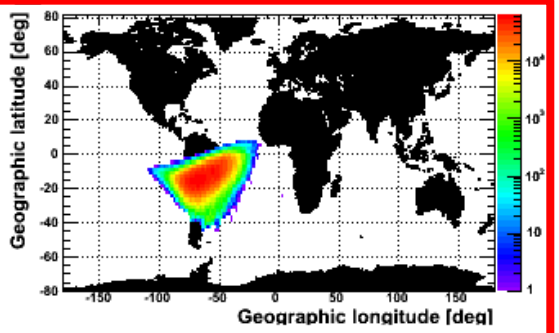
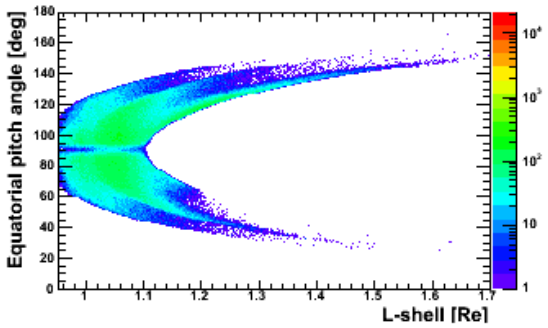
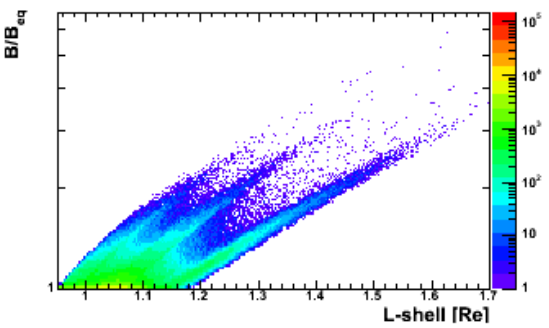
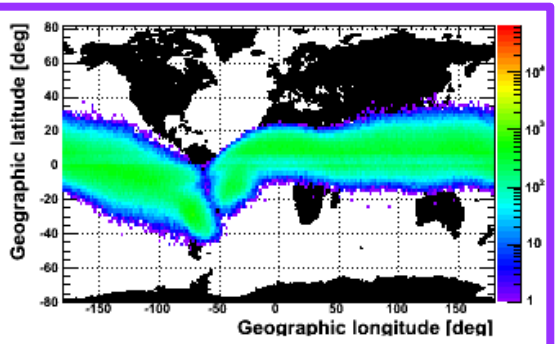
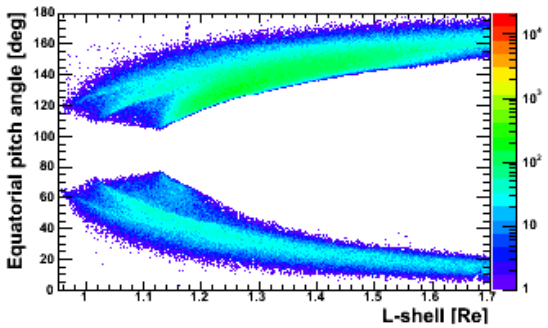
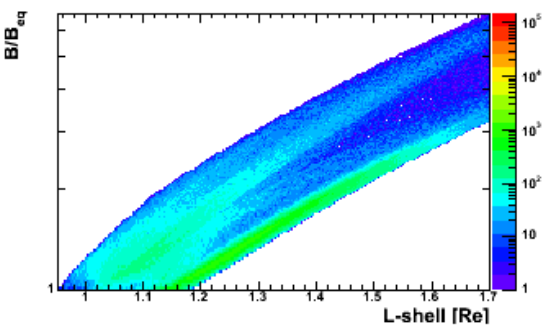
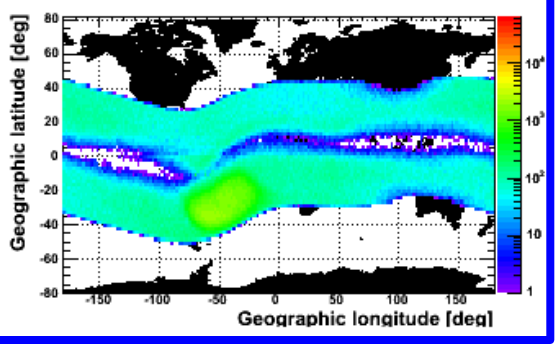


PAMELA trapped antiprotons

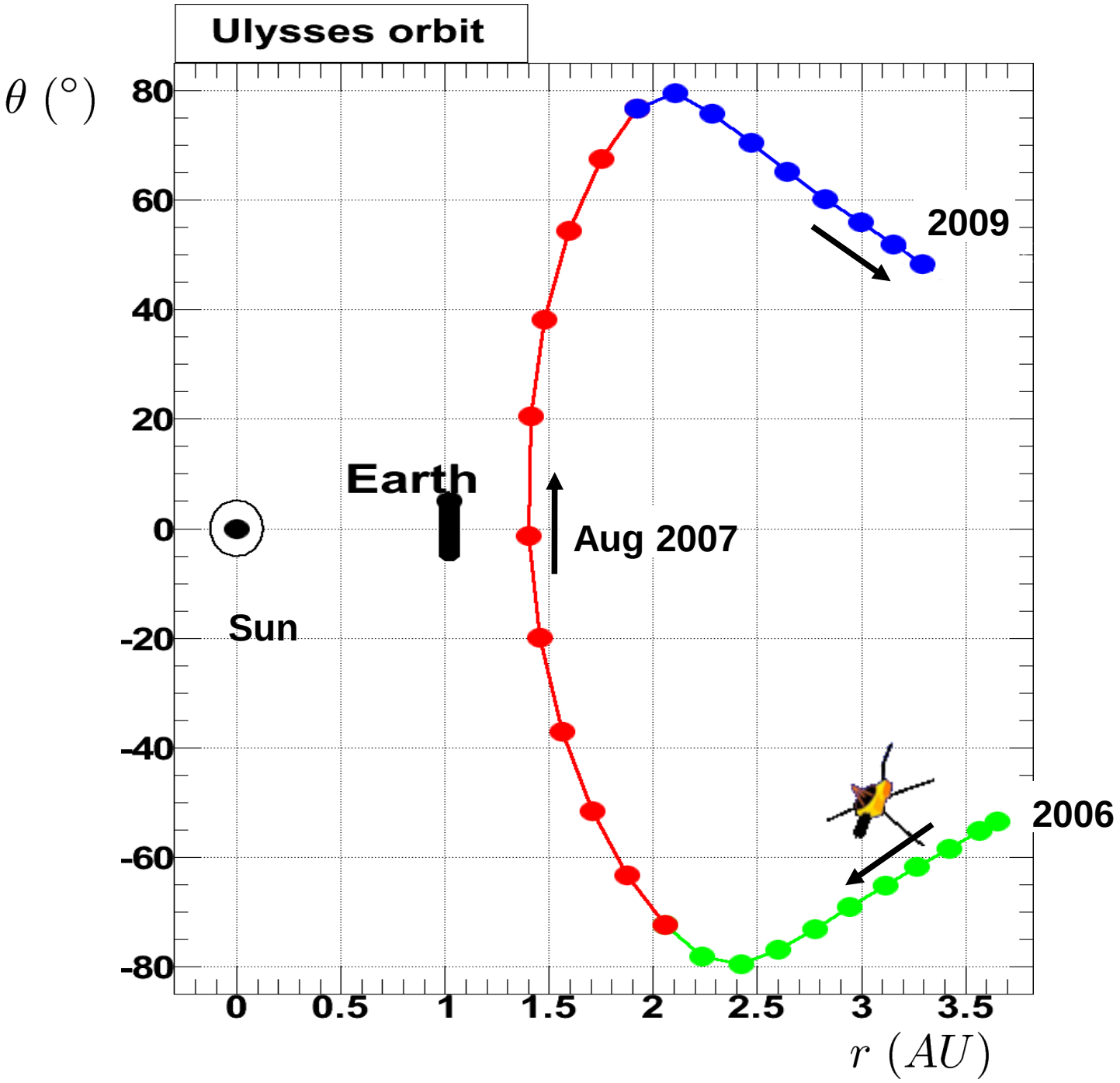


O. Adriani et al., APJL 737 L29 (2011); arXiv:1107.4882

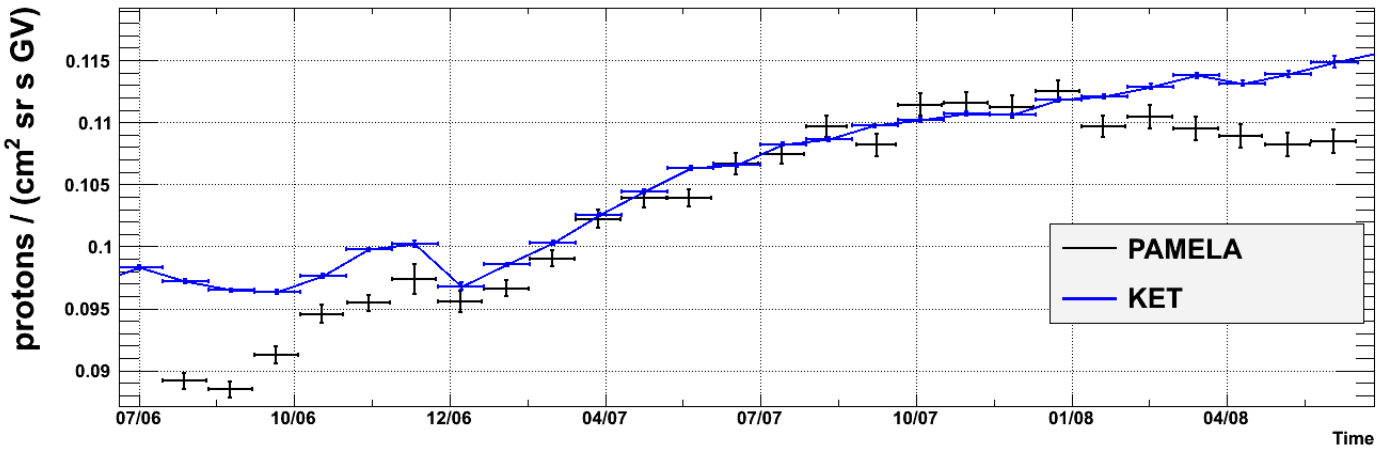
Distributions of sub-cutoff proton counts

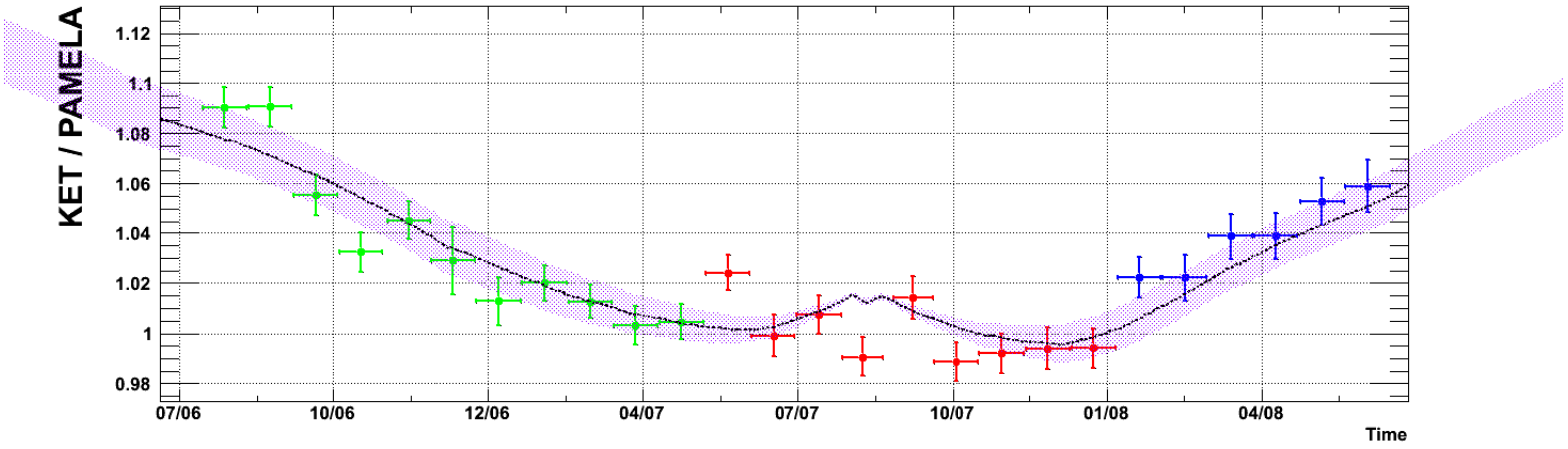
	α_{eq} vs L-shell	B/B_{eq} vs L-shell	Geo. Lat vs Long
Stably trapped			
Quasi trapped			
Reentrant albedo			

Proton gradients in the heliosphere – PAMELA and Ulysses


Ulysses orbit
θ (°)
80
60
40
20
0
-20
-40
-60
-80
0
0.5
1
1.5
2
2.5
3
3.5
r (AU)
2009
2006
Earth
Aug 2007
Sun

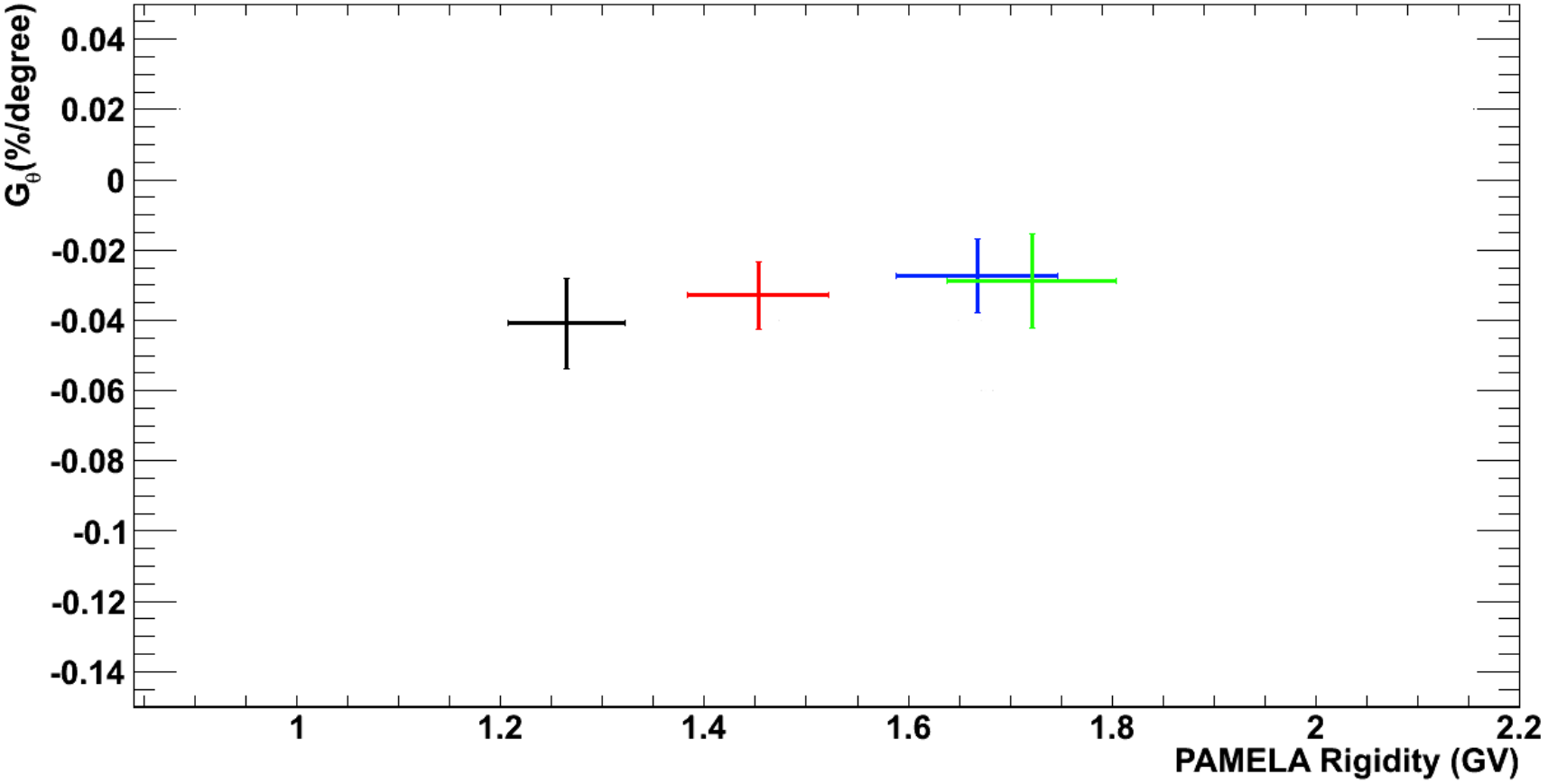
Gradients in the Heliosphere, PAMELA & ULYSSES



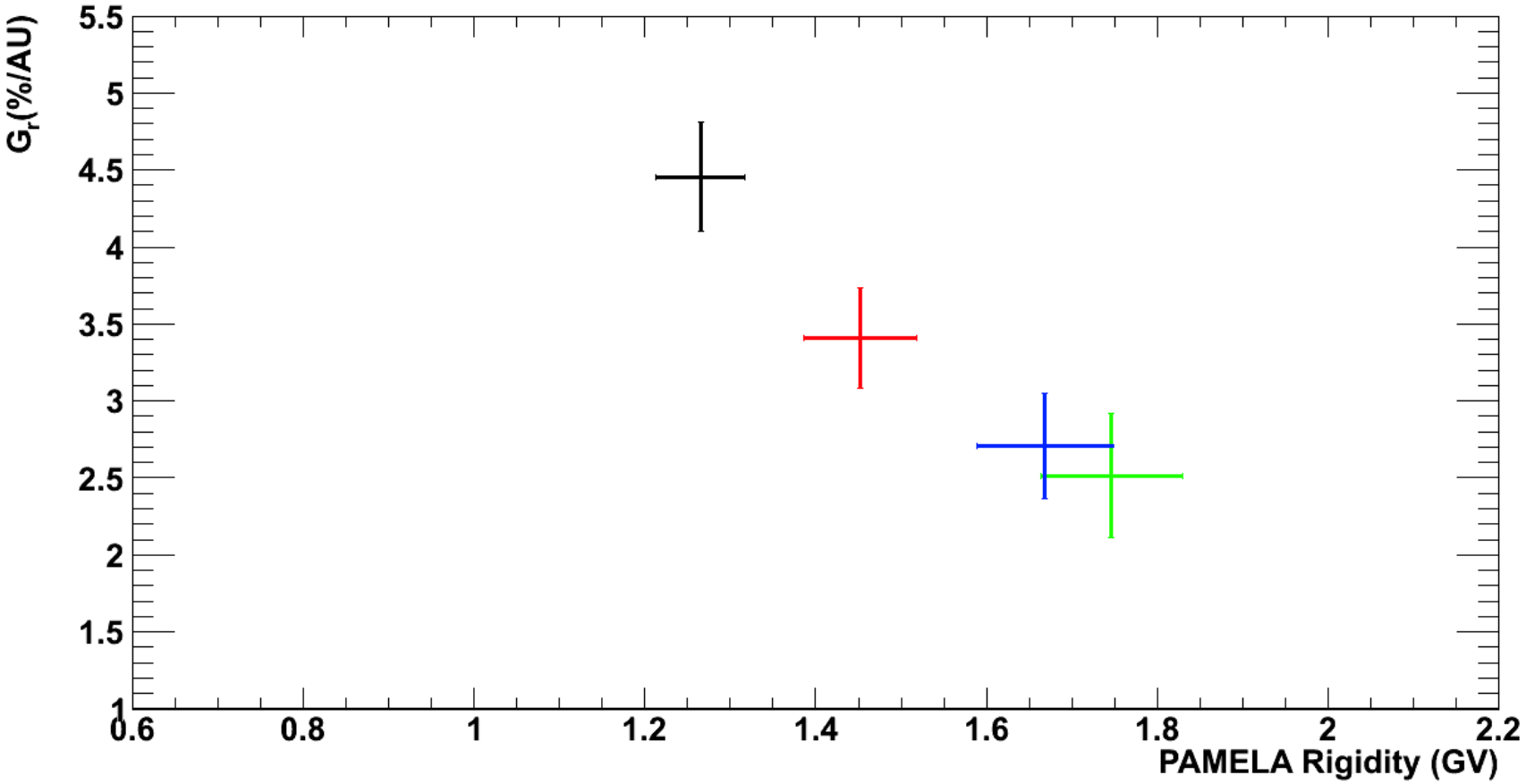


Comparison of the proton flux measured between 1.5 and 1.57GV by PAMELA and ULYSSES as a function of time

Latitudinal gradients



Radial gradients



Thanks!

http:// pamela.roma2.infn.it