Status of PAMELA and Implications for New Physics

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On behalf of the PAMELA collaboration

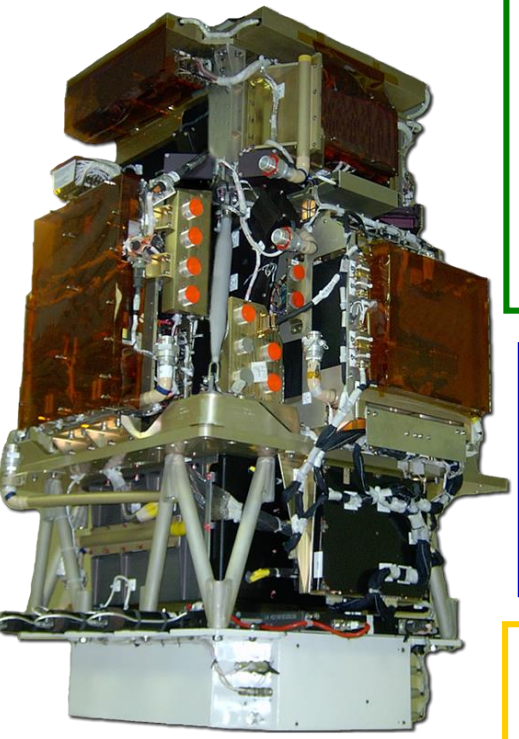
SLAC Cosmic Frontier Workshop

March 6th 2013

PAMELA apparatus

PAMELA detectors

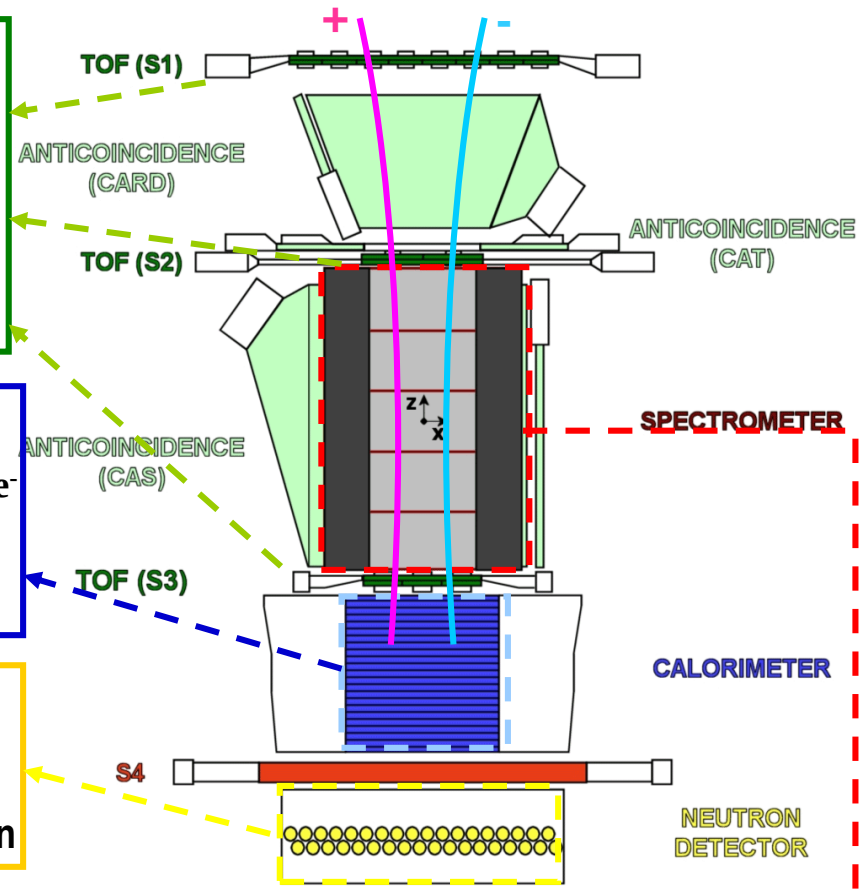
Main requirements → high-sensitivity antiparticle identification and precise momentum measure



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

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

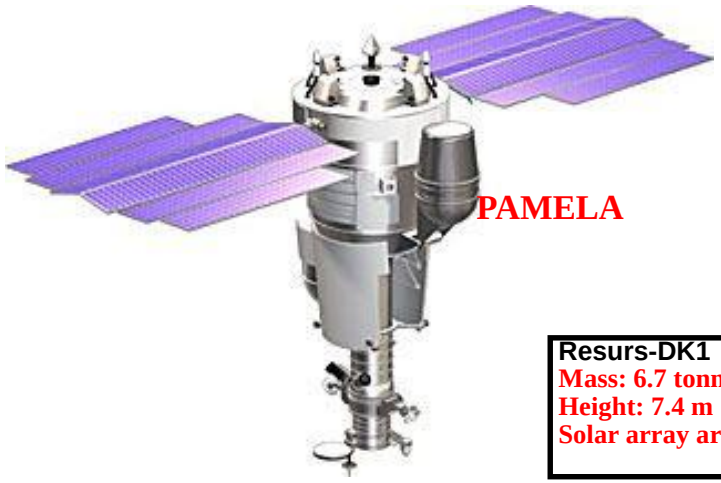
Neutron detector
^{3}He tubes + polyethylene moderator:
- High-energy e/h discrimination



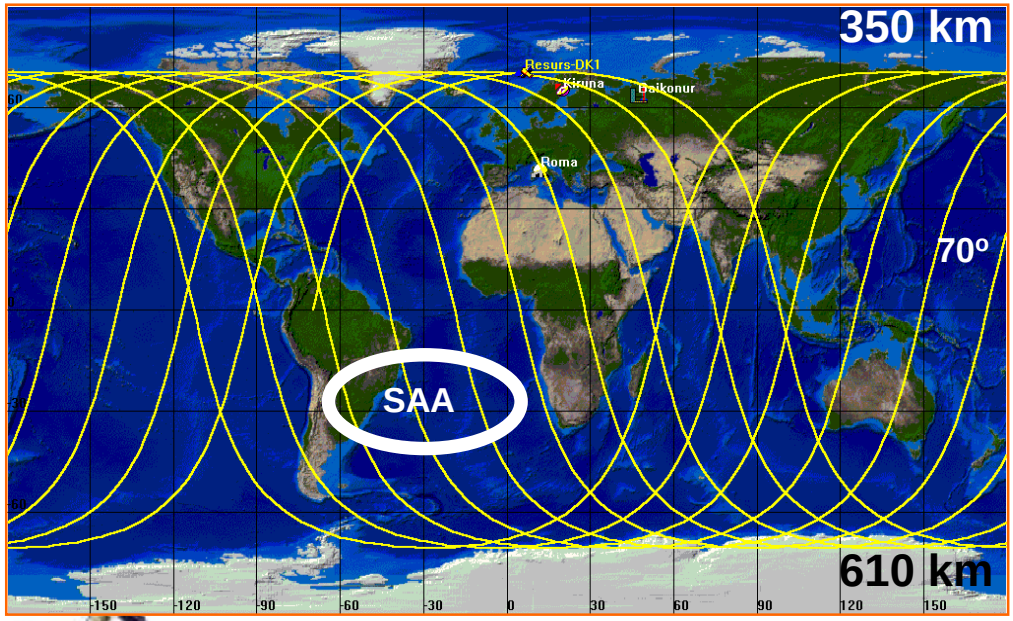
GF: 21.5 cm^2 sr
Mass: 470 kg
Size: 130x70x70 cm^3
Power Budget: 360W

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

Resurs-DK1 satellite + orbit



Resurs-DK1
Mass: 6.7 tonnes
Height: 7.4 m
Solar array area: 36 m^2



~90 mins

- **Resurs-DK1: multi-spectral imaging of earth's surface**
- **PAMELA mounted inside a pressurized container**
- **Lifetime >3 years (assisted, first time February 2009), extended till end of satellite operations**
- **Data transmitted to NTsOMZ, Moscow via high-speed radio downlink. ~16 GB per day**
- **Quasi-polar and elliptical orbit (70.0°, 350 km - 600 km) – from 2010 circular orbit (70.0°, 600 km)**
- **Traverses the South Atlantic Anomaly**
- **Crosses the outer (electron) Van Allen belt at south pole**

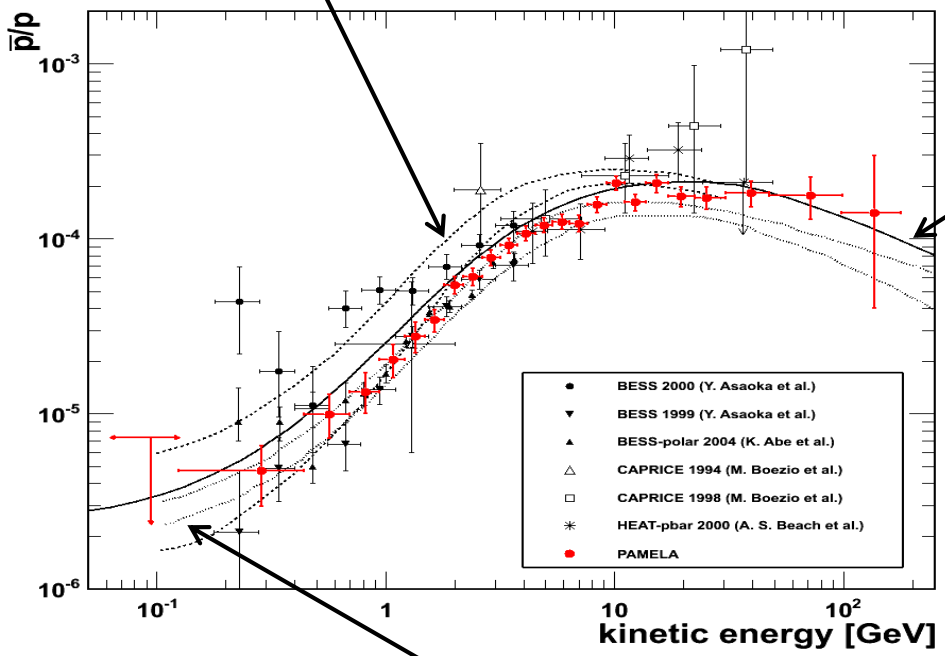
Antiprotons with PAMELA

Mirko Boezio, SLAC, 2013/03/06

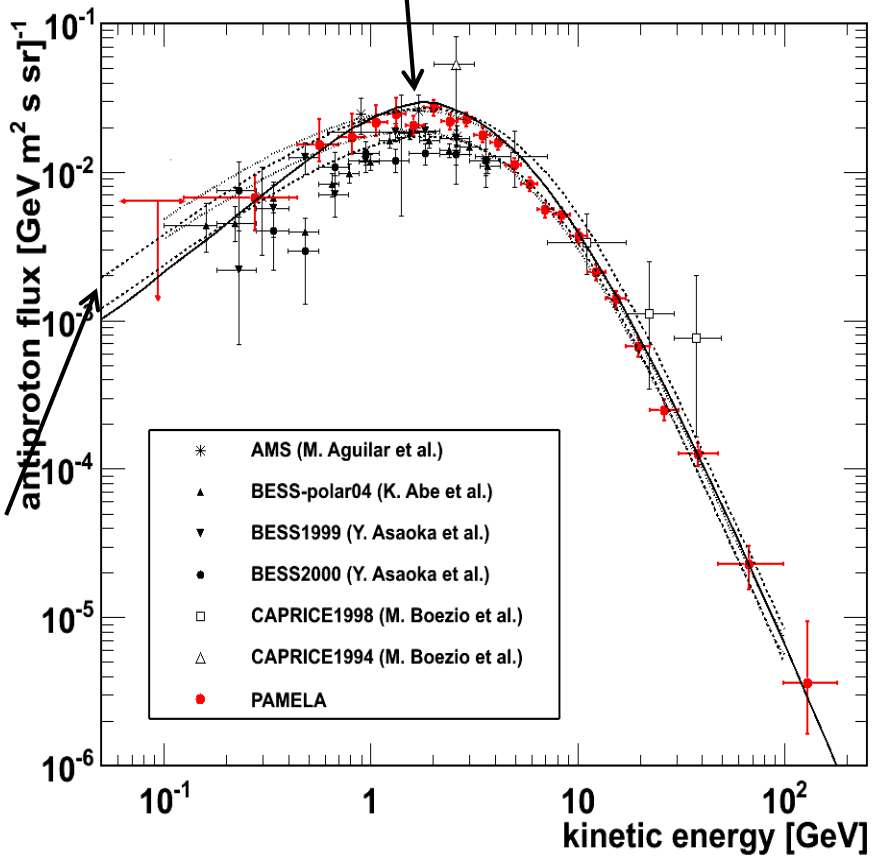
Antiproton Results

Simon et al. (ApJ 499 (1998) 250)

Ptuskin et al. (ApJ 642 (2006) 902)



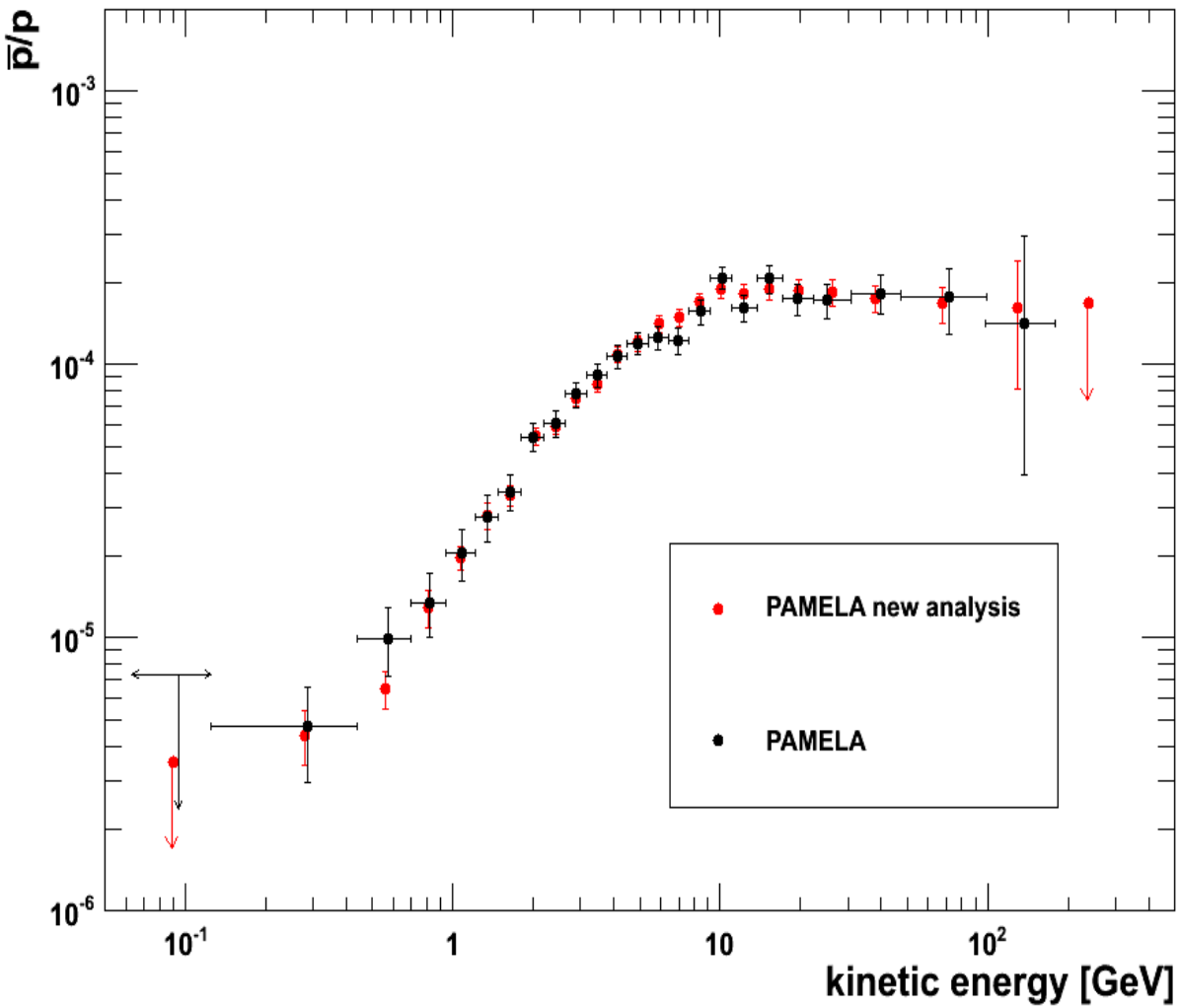
Donato et al. (PRL 102 (2009) 071301)



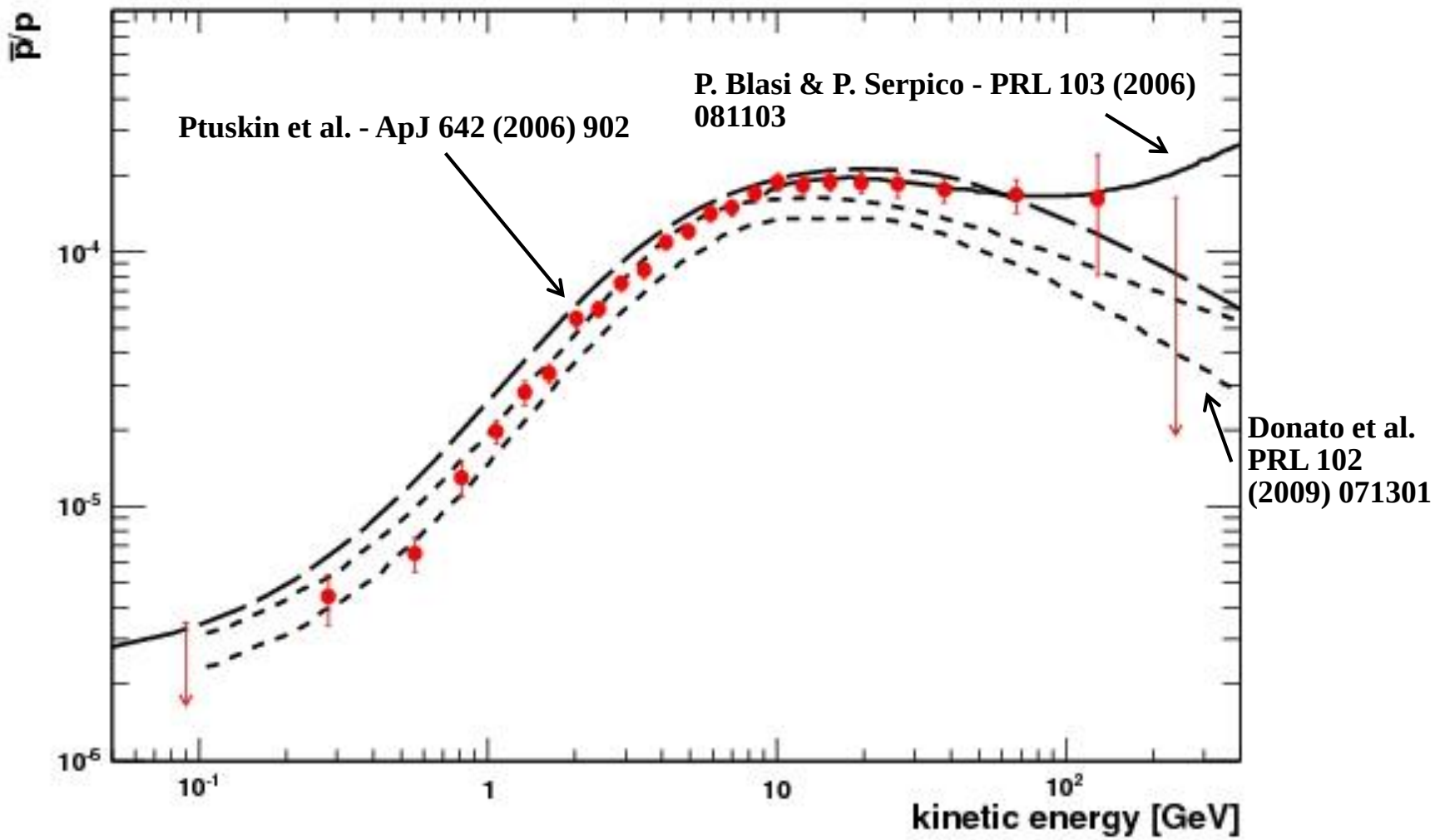
O. Adriani et al., PRL 102, 051101 (2009); PRL 105, 121101 (2010)

Antiproton to proton flux ratio

Using all data till 2010 and multivariate classification algorithms 20-50% increase in respect to published analysis

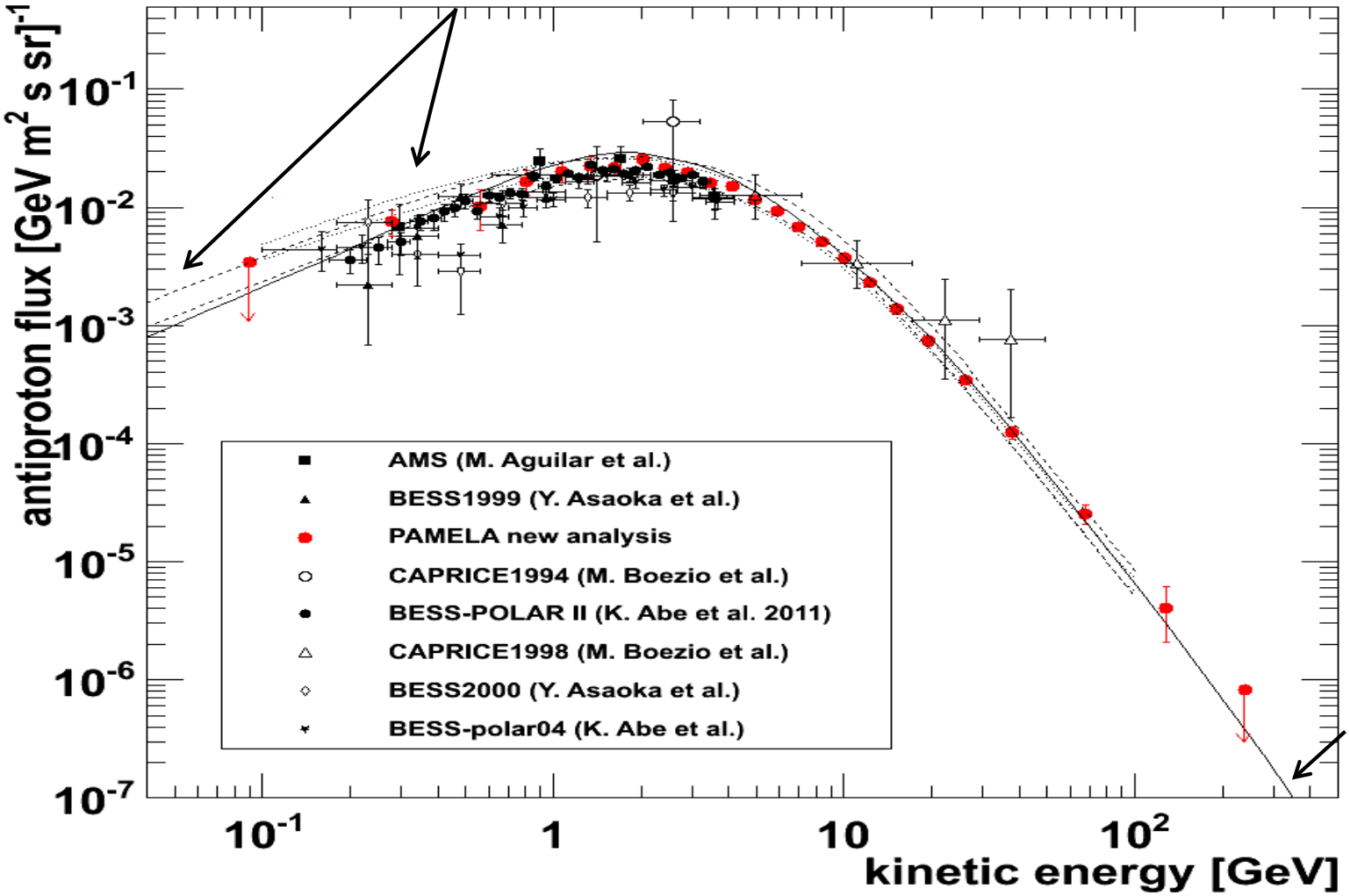


Antiproton to proton flux ratio



Antiproton flux

Donato et al. - ApJ 563 (2001) 172

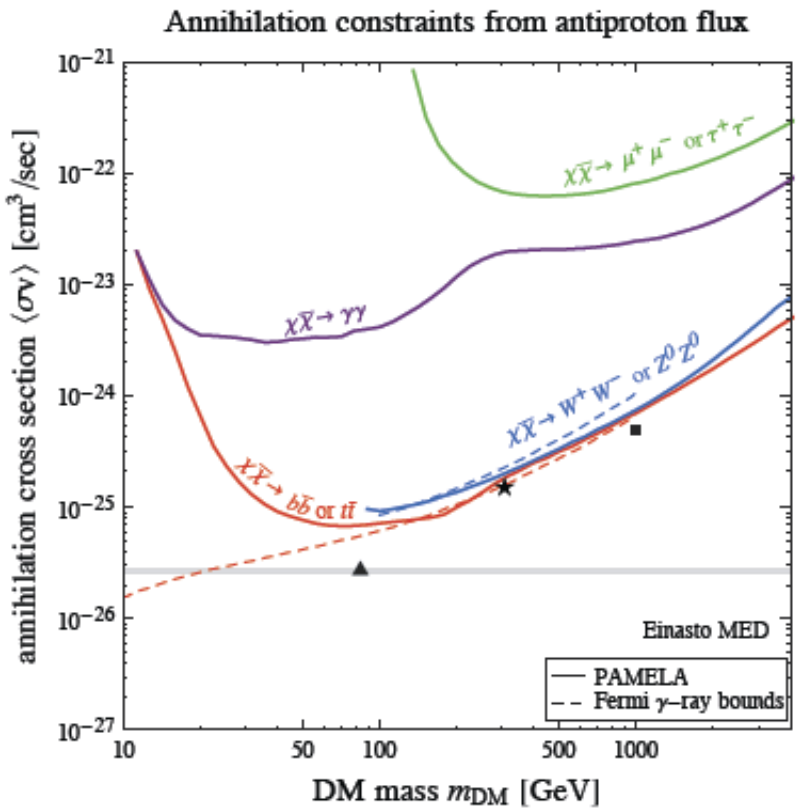


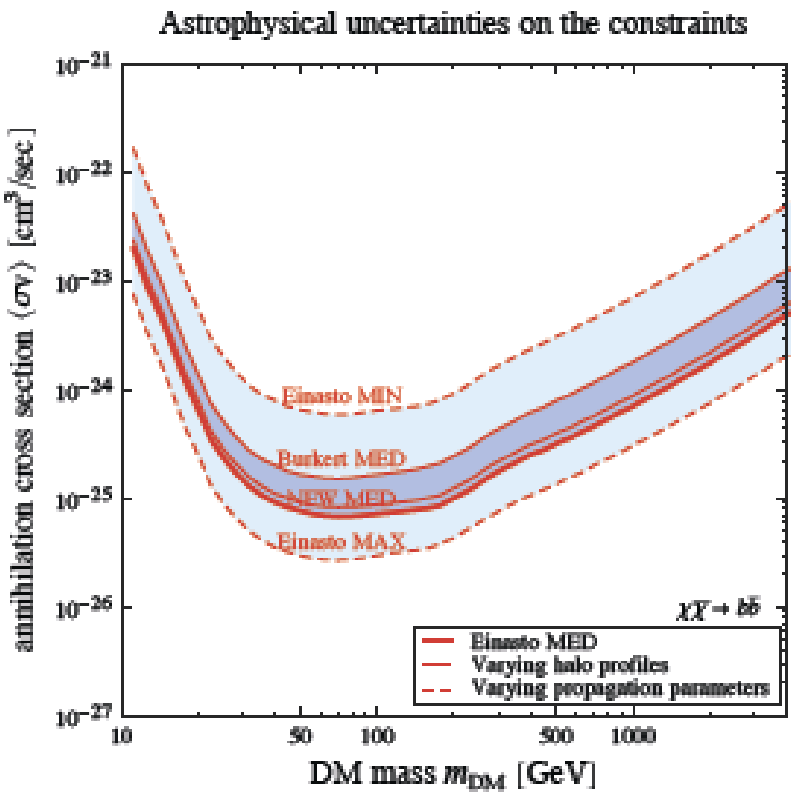
Ptuskin et al. ApJ 642 (2006) 902

Cosmic-Ray Antiprotons and DM limits

Mirko Boezio, SLAC, 2013/03/06

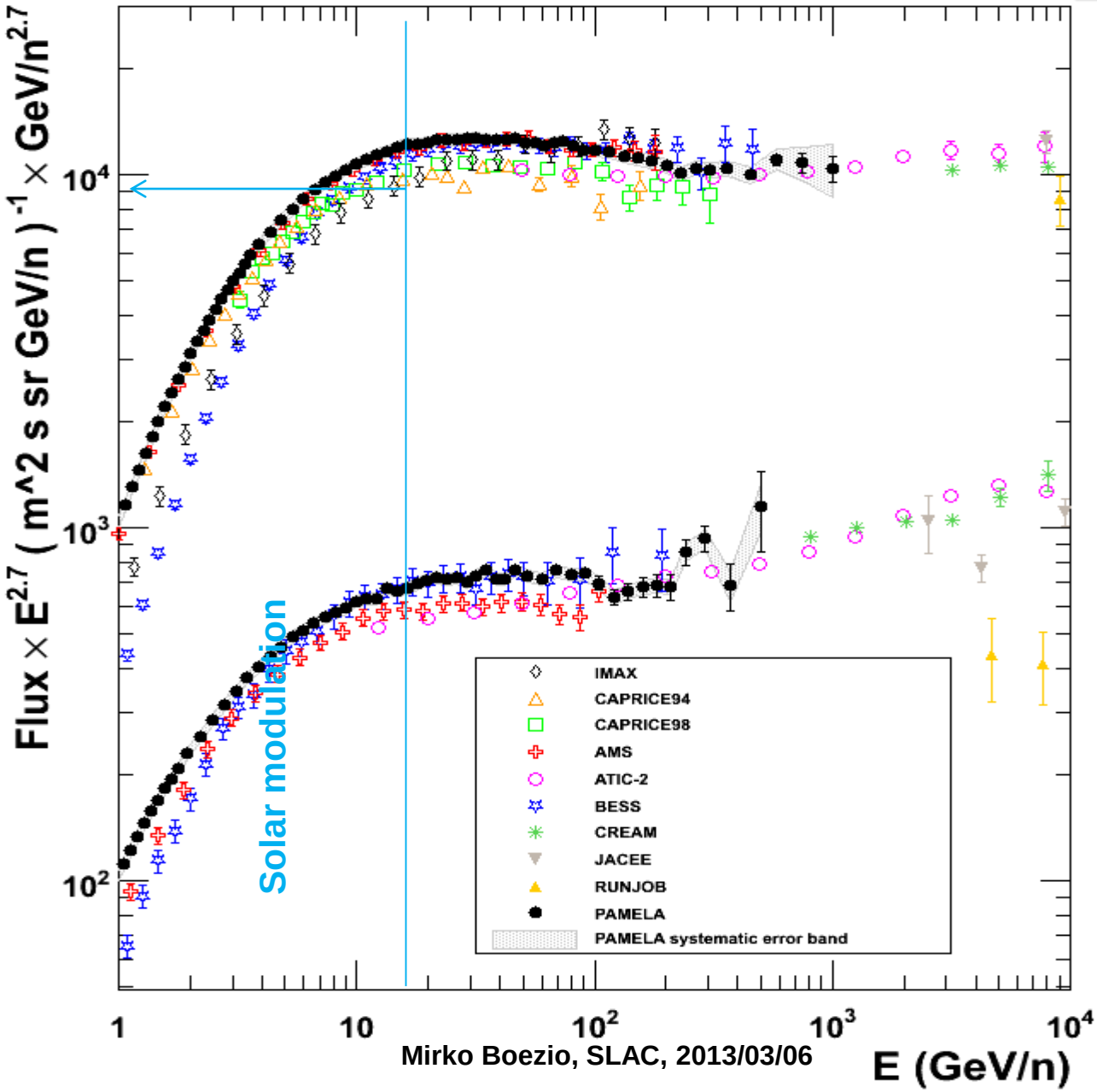
Cosmic-Ray Antiprotons and DM limits





M. Cirelli & G. Giesen, arXiv: 1301:7079
Antiprotons are a very relevant tool to constrain Dark Matter 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.

Proton and Helium Nuclei Spectra



H & He absolute fluxes @ high energy

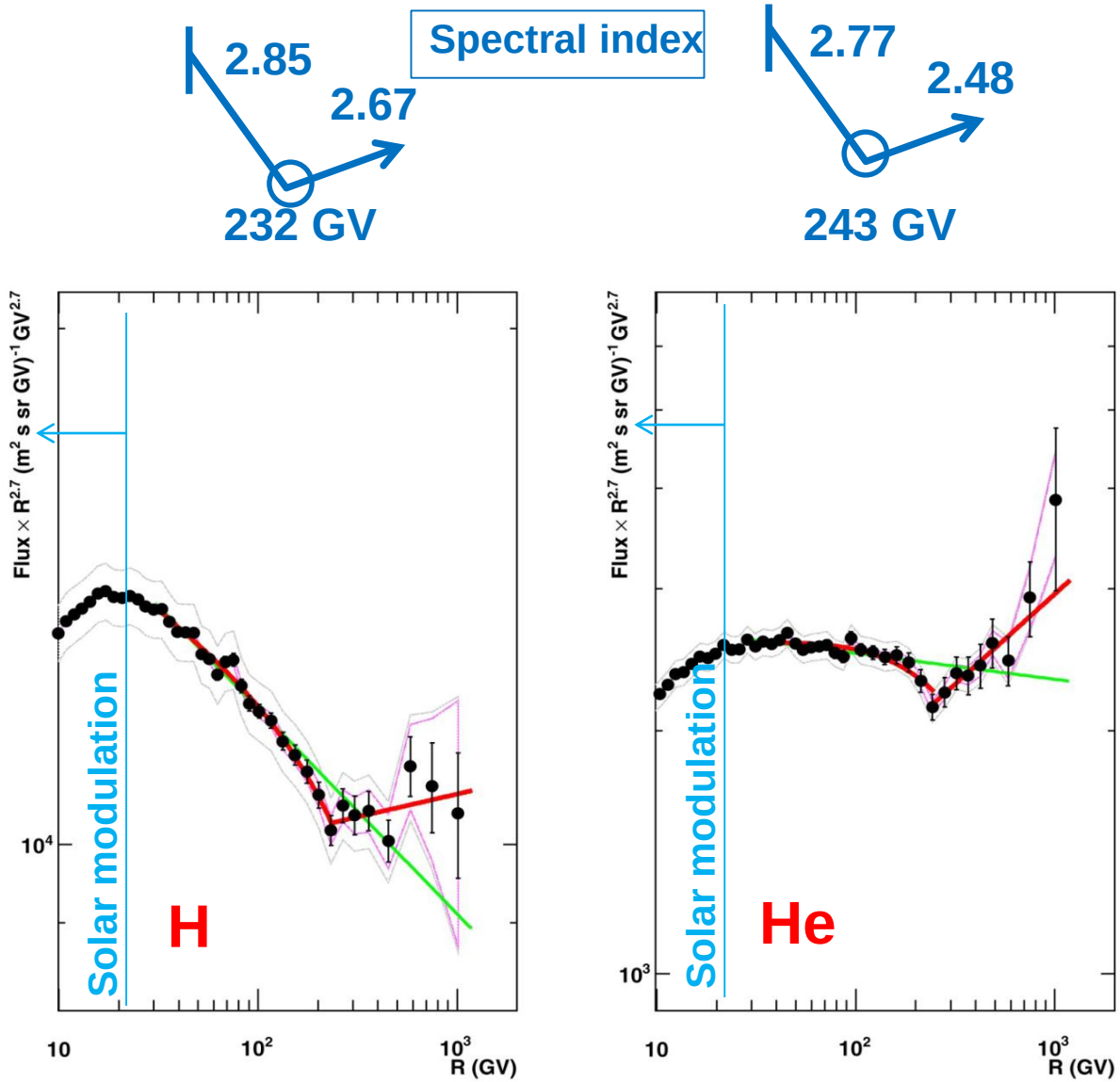
Deviations from single power law (SPL):

- Spectra gradually soften in the range 30÷230GV
- Spectral hardening @ R~235GV $\Delta\gamma$~0.2÷0.3

SPL is rejected at 98% CL

Origin of the structures?

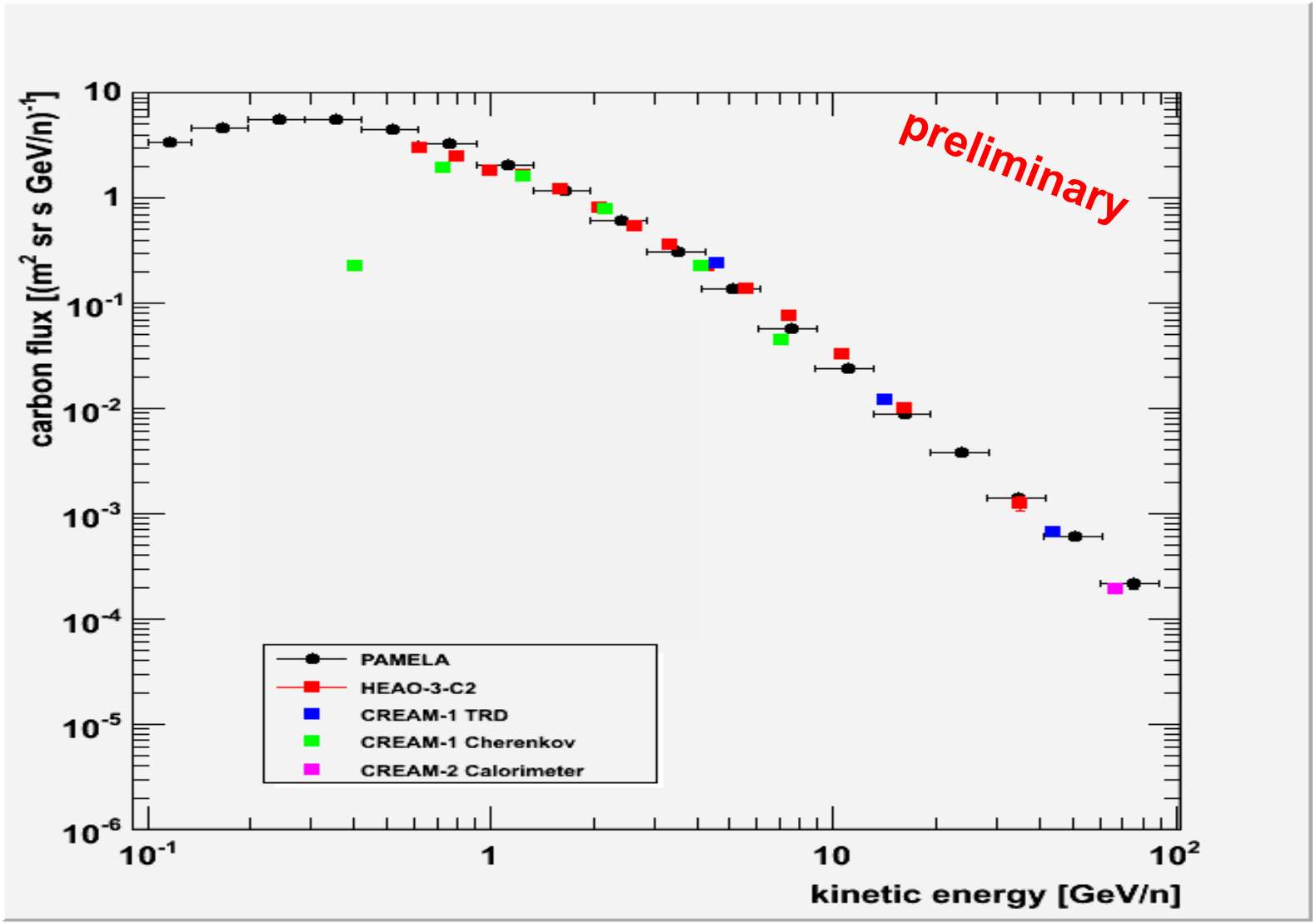
- At the sources: multi-populations, etc.?
- Propagation effects?



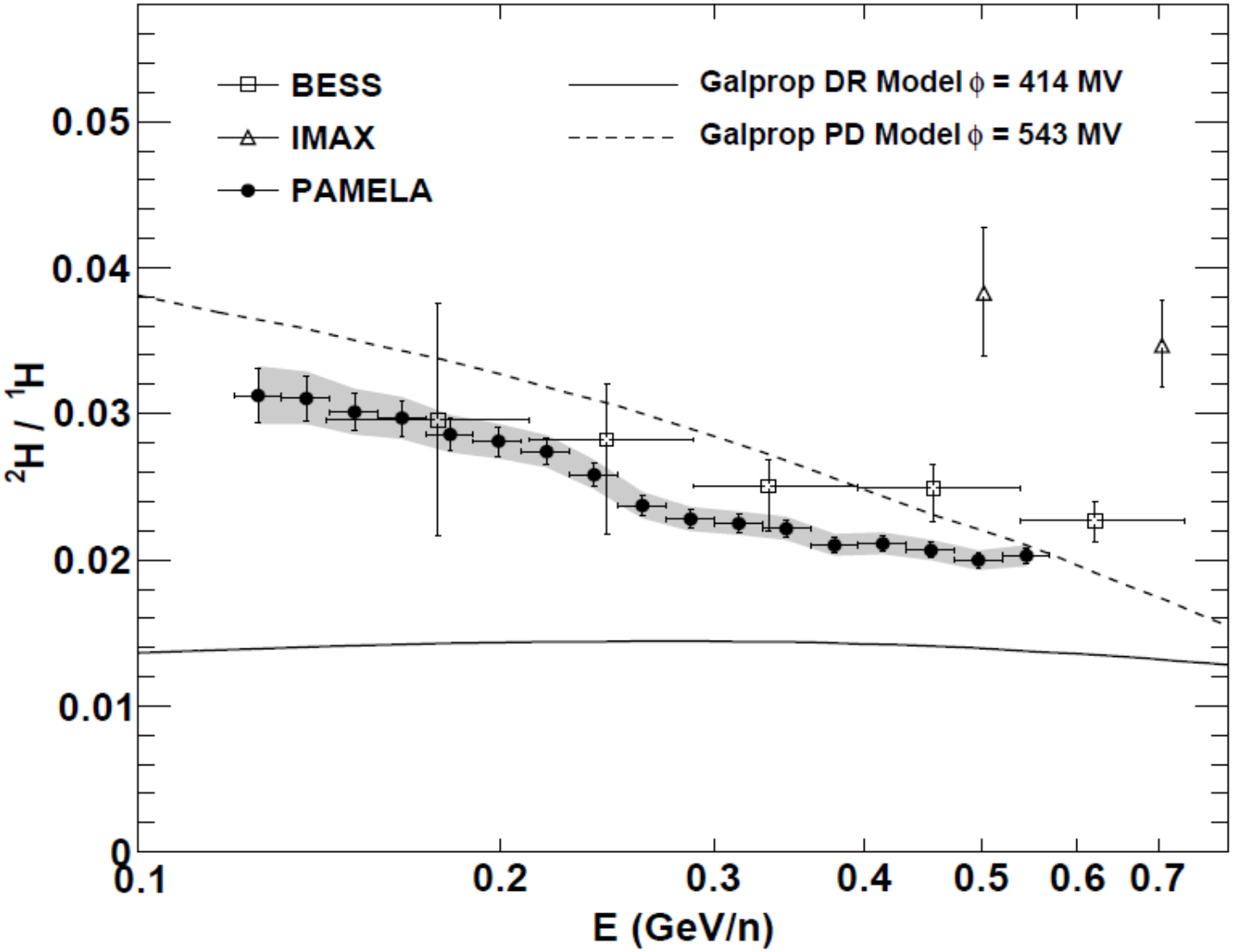
Mirko Boezio, SLAC, 2013/03/06

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

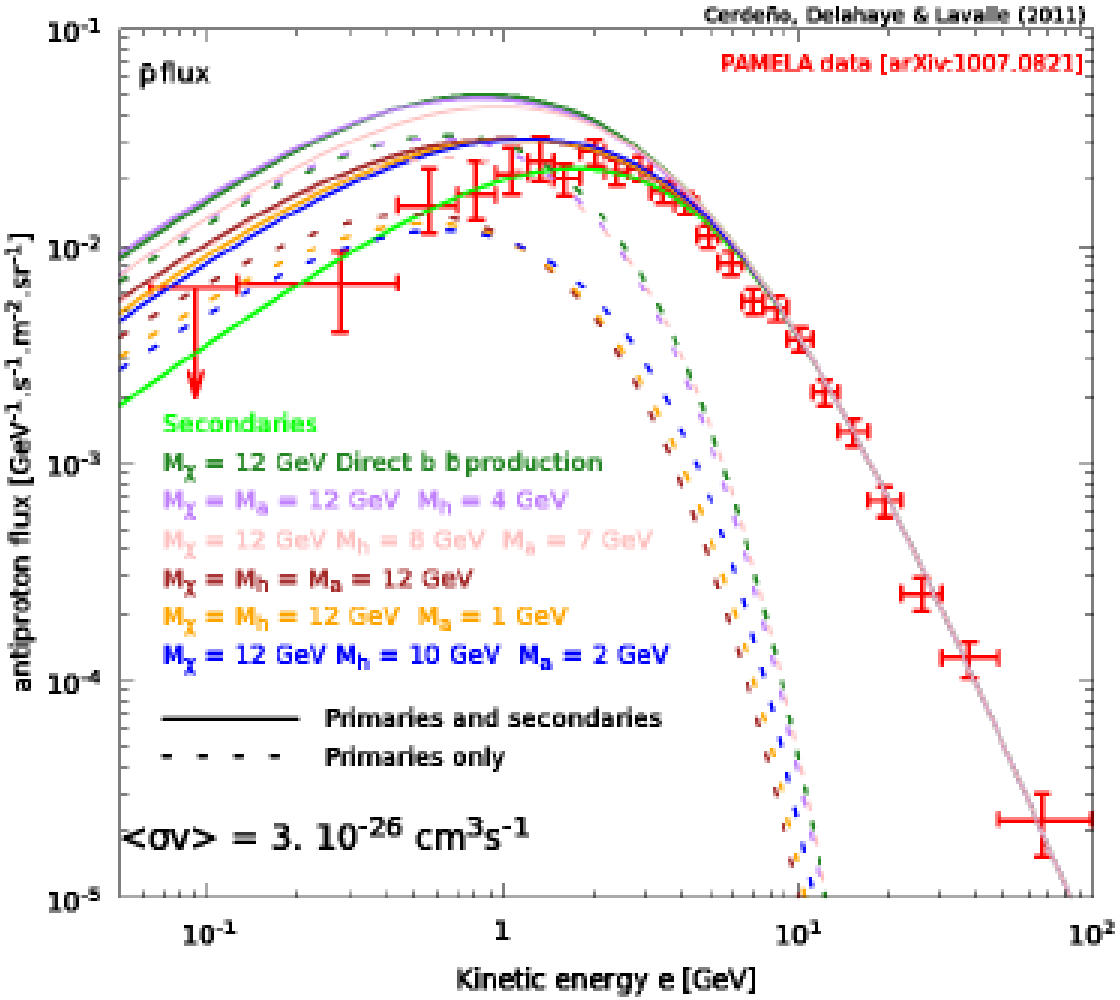
Carbon Nuclei Spectrum



PAMELA $^2H/^1H$


BESS
IMAX
PAMELA
Galprop DR Model ϕ = 414 MV
Galprop PD Model ϕ = 543 MV
0.05
0.04
0.03
0.02
0.01
0
$^2H / ^1H$
0.1
0.2
0.3
0.4
0.5
0.6
0.7
E (GeV/n)

Cosmic-Ray Antiprotons and DM limits



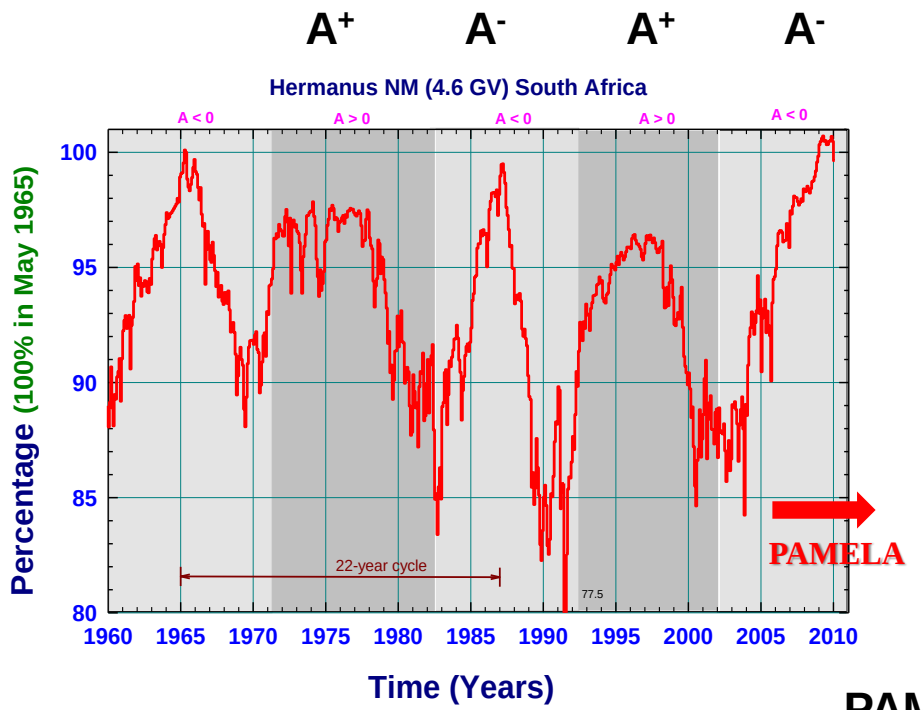
D. G. Cerdeno, T. Delahaye & J. Lavalle, Nucl. Phys. B 854 (2012) 738 Antiproton flux predictions for a 12 GeV WIMP annihilating into different mass combinations of an intermediate two-boson state which further decays into quarks.

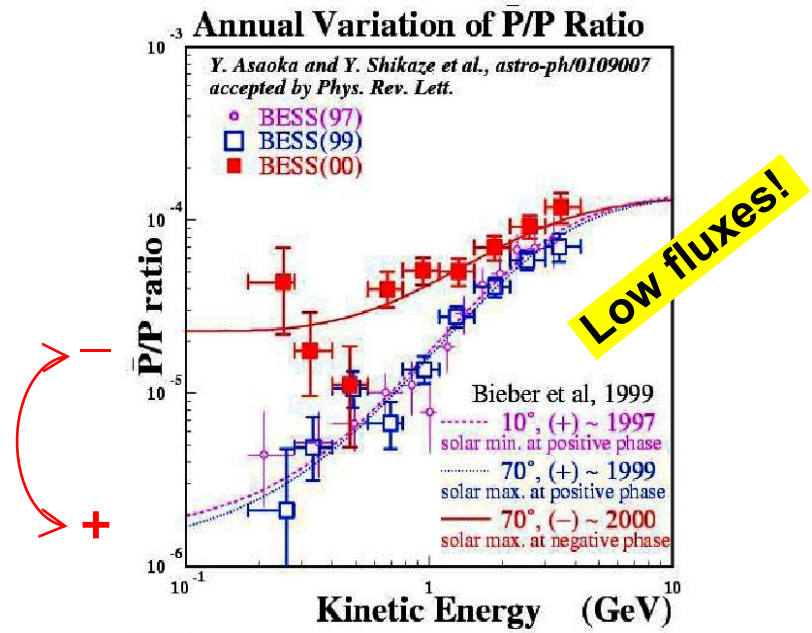
See also:
- **M. Asano, T. Bringmann & C. Weniger, Phys. Lett. B 709 (2012) 128.**
- **M. Garny, A. Ibarra & S. Vogl, JCAP 1204 (2012) 033**
- **R. Kappl & M. W. Winkler, PRD 85 (2012) 123522**

Cosmic Rays in the Heliosphere

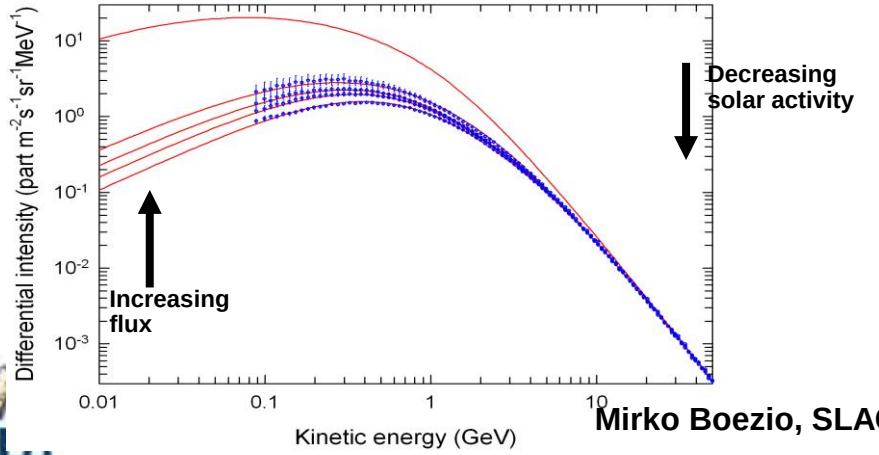
Mirko Boezio, SLAC, 2013/03/06

Solar modulation

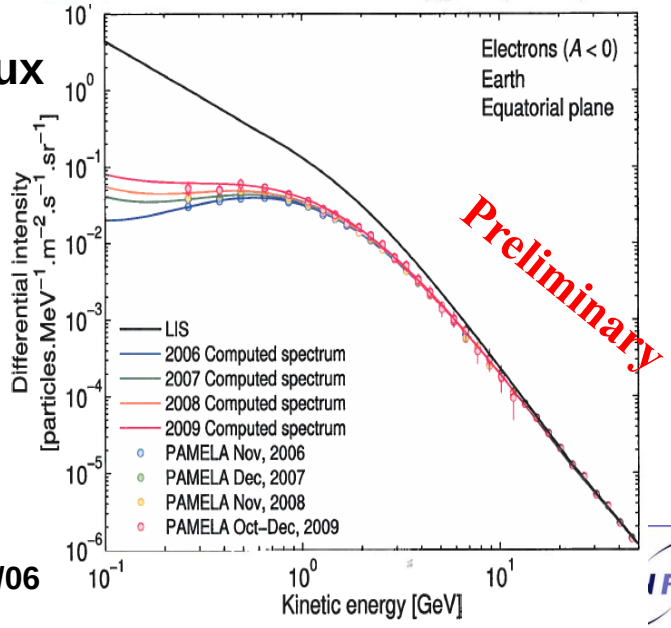




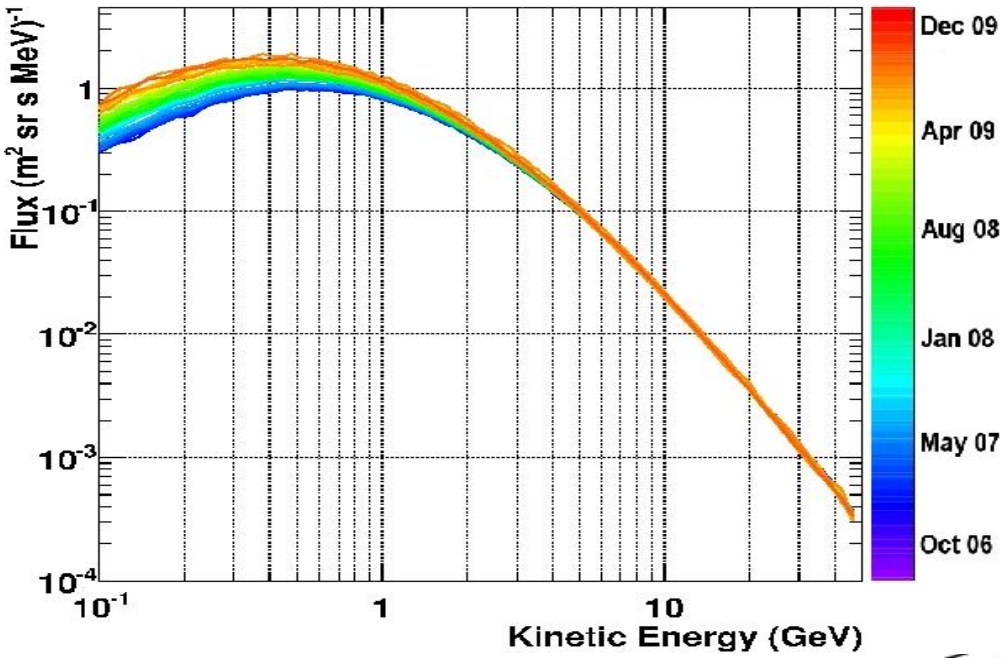
PAMELA p flux



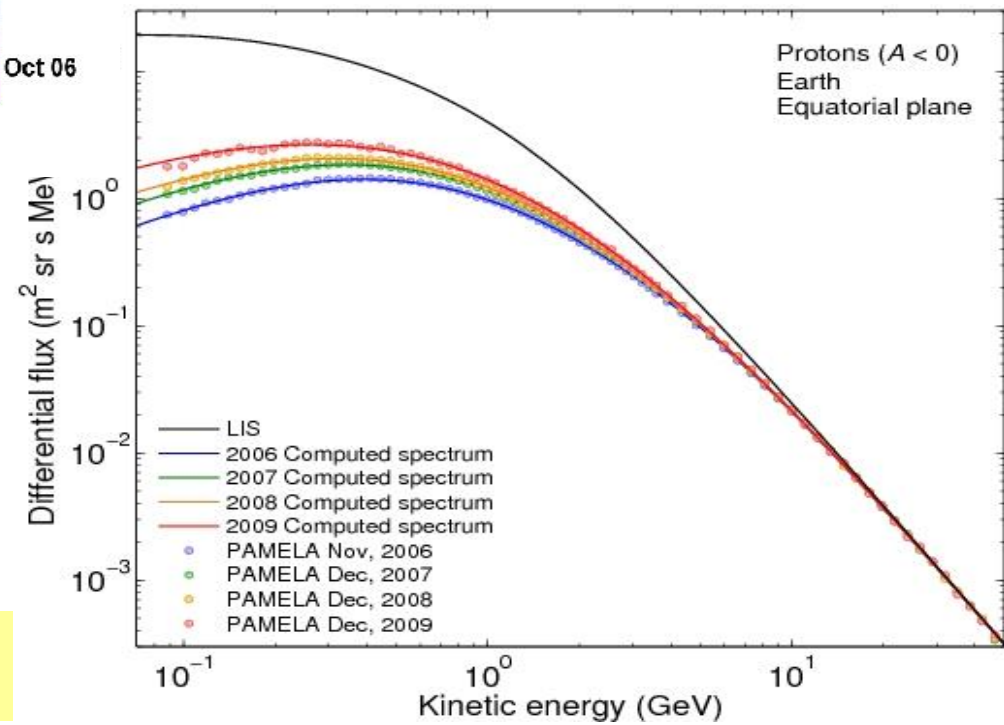
PAMELA e- flux



Time Dependance of the Proton Flux



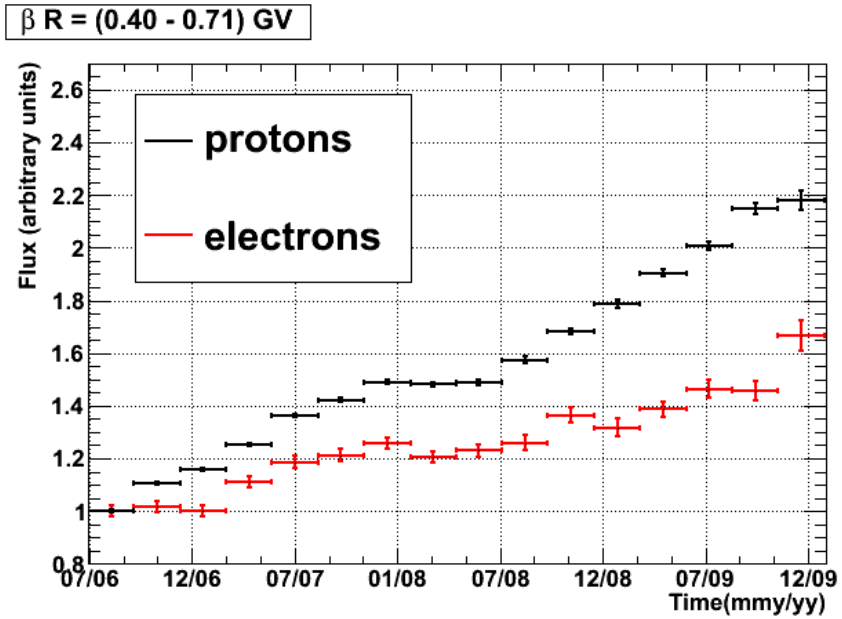
Evolution of the proton energy spectrum from July 2006 to Deember 2009

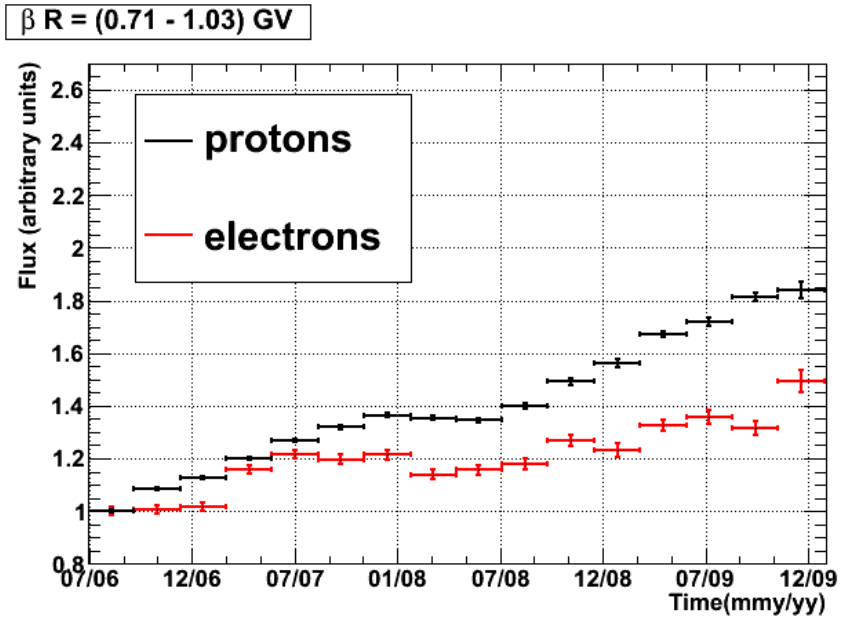


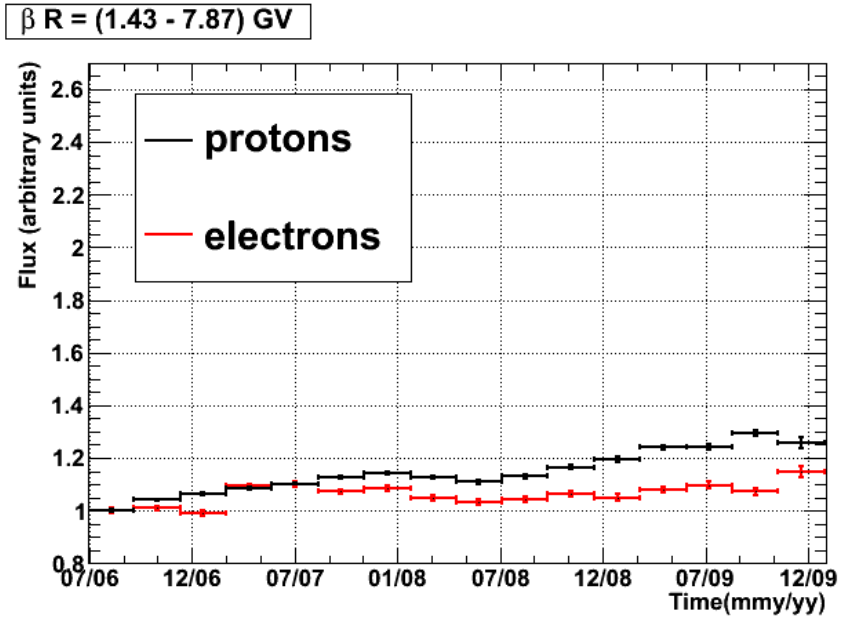
The PAMELA proton spectra over four months compared with the computed spectra

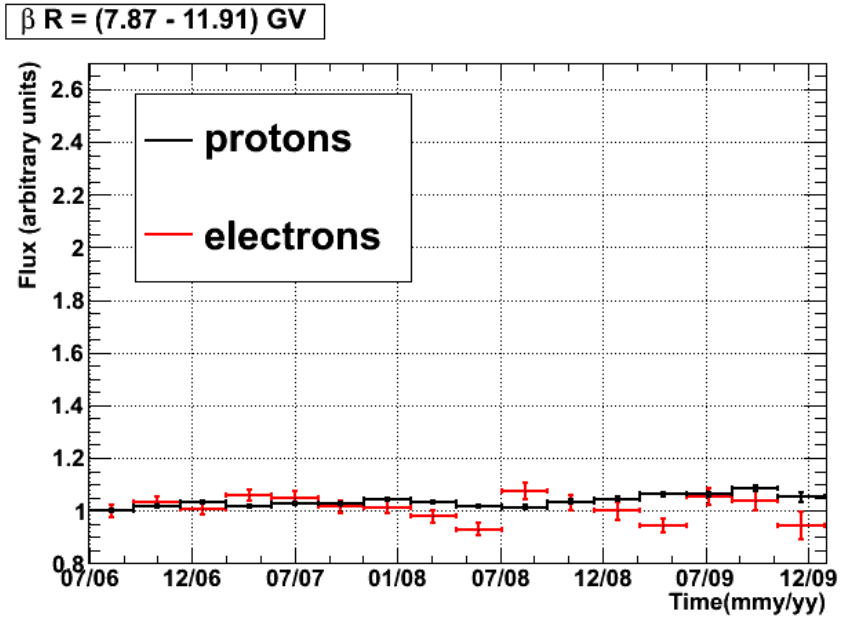
O. Adriani et al., ApJ 765 (2013) 91; arXiv:1301.4108

Time dependence: PAMELA p and e⁻(preliminary!)

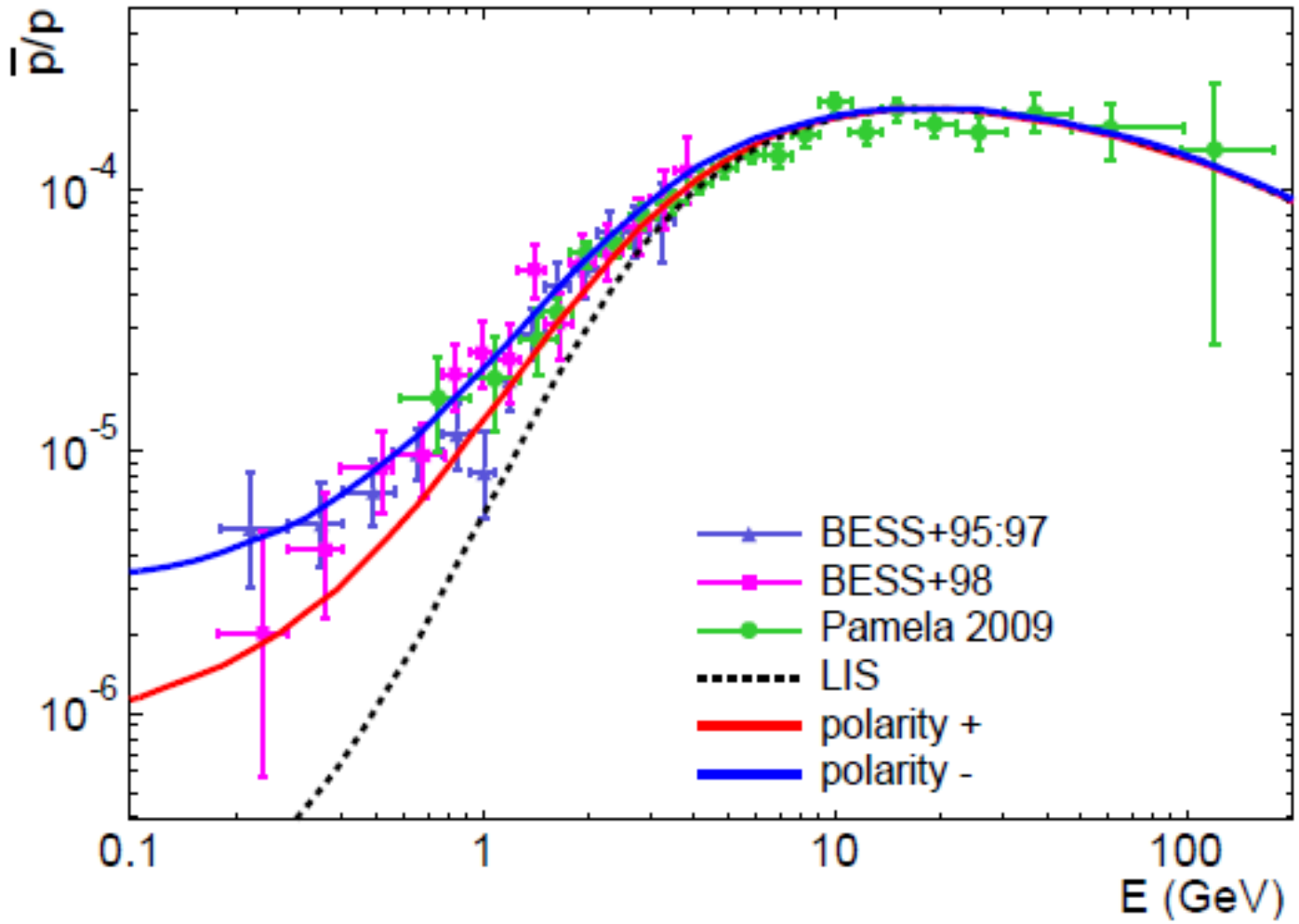








Charge-Sign Dependent Solar Modulation



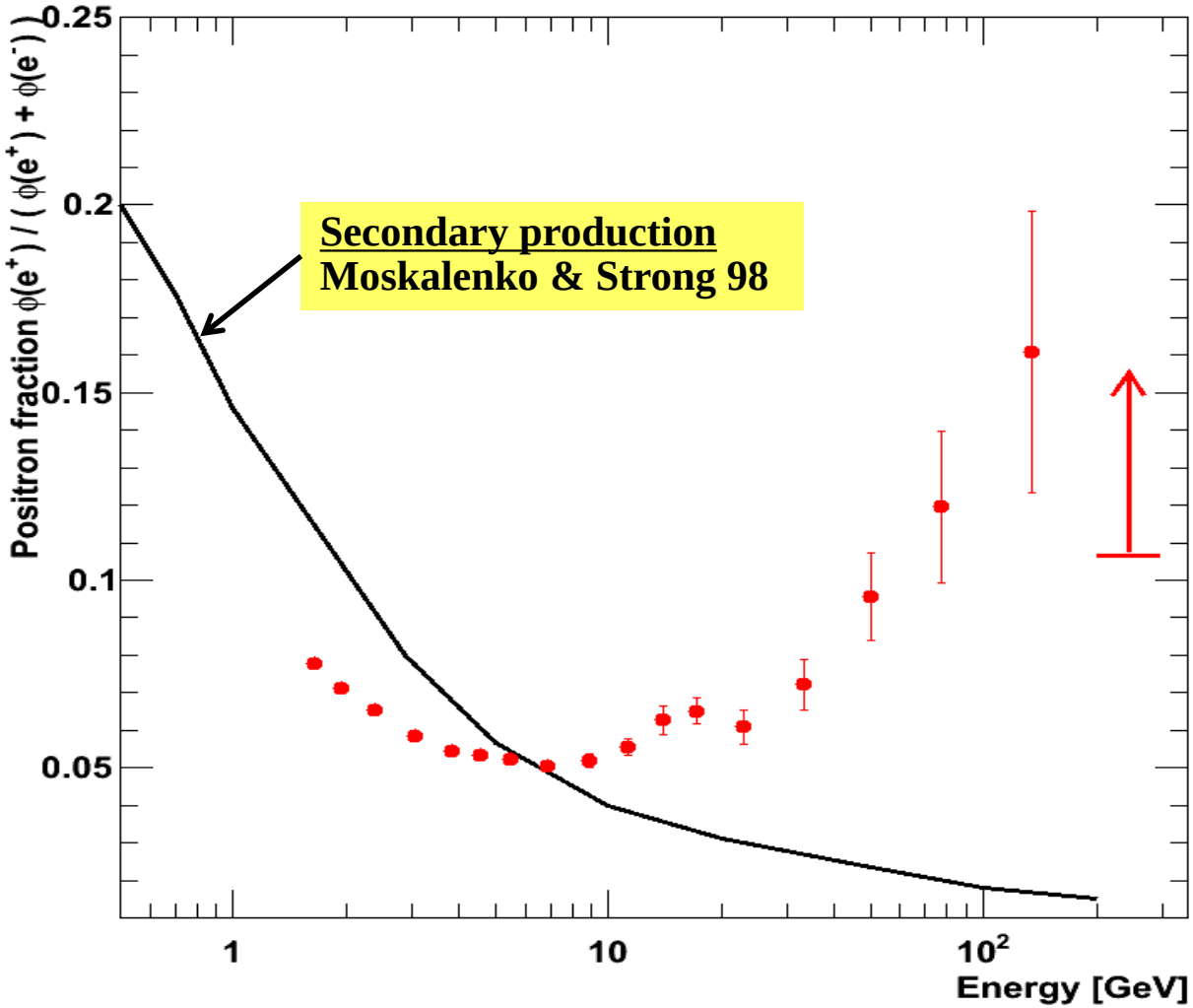
L. Maccione, PRL 110 (2013) 081101.

Electrons & Positrons with PAMELA

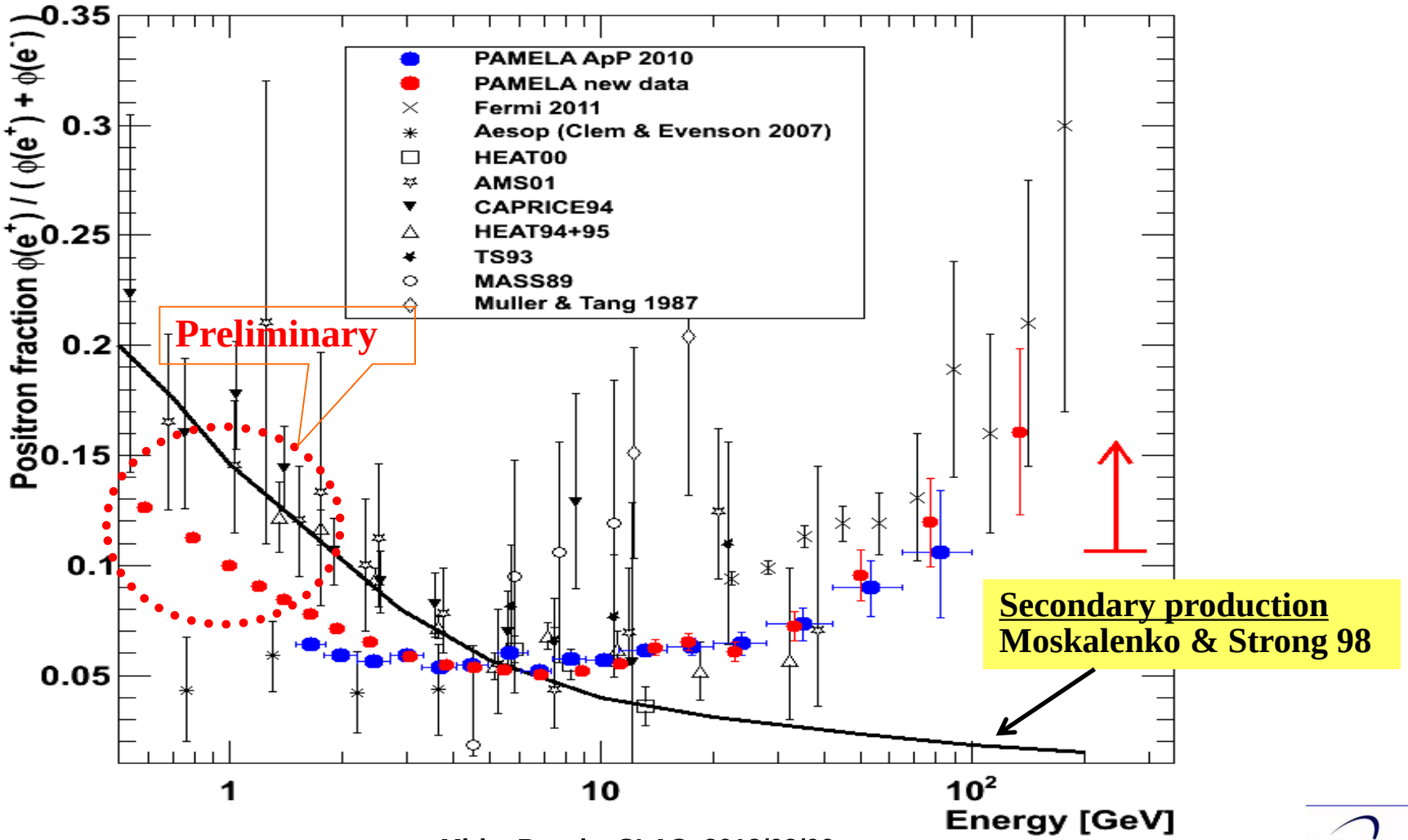
Mirko Boezio, SLAC, 2013/03/06

Positron to Electron Fraction

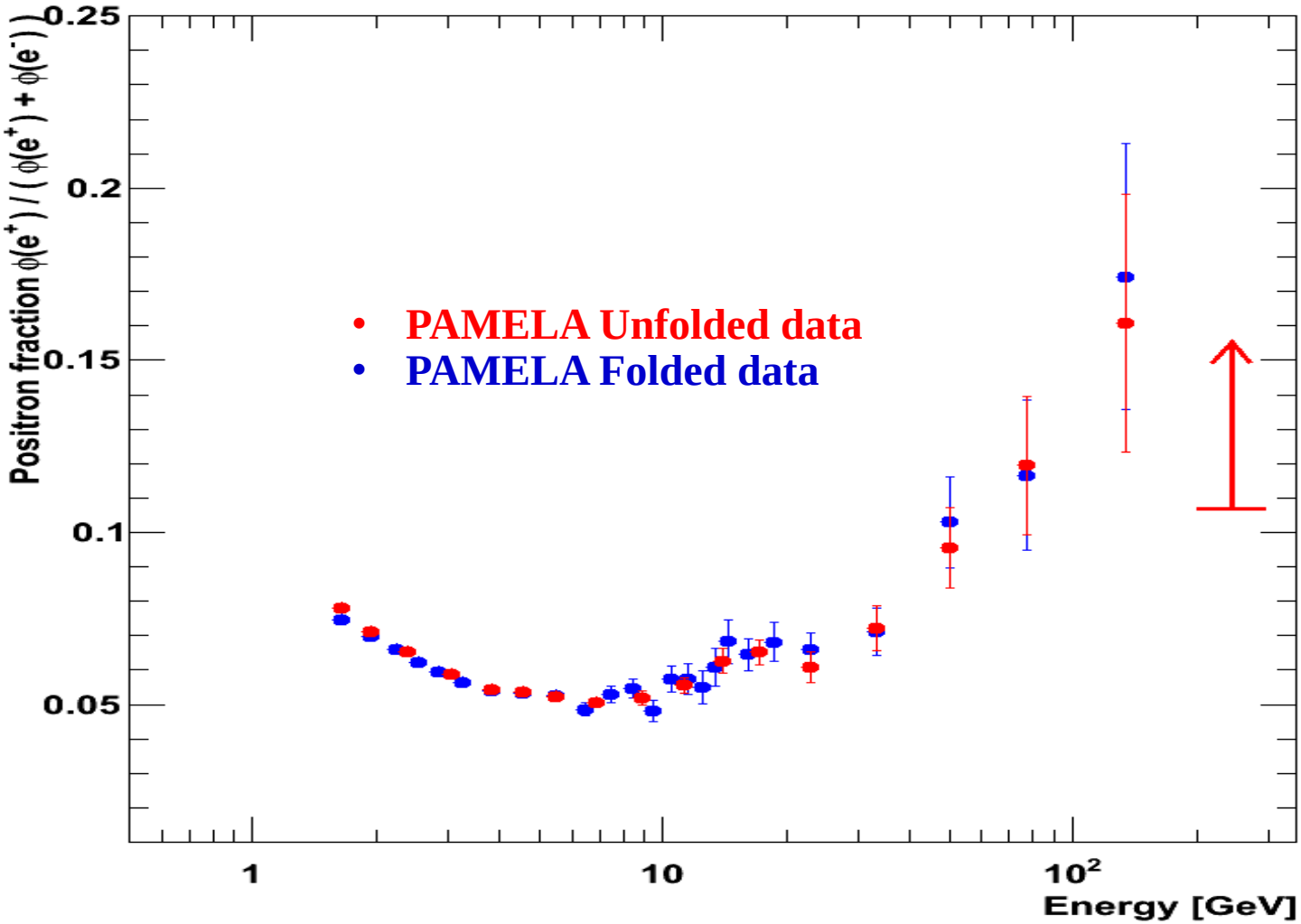
Using all data till 2010 and multivariate classification algorithms about factor 2-3 increase in respect to published analysis



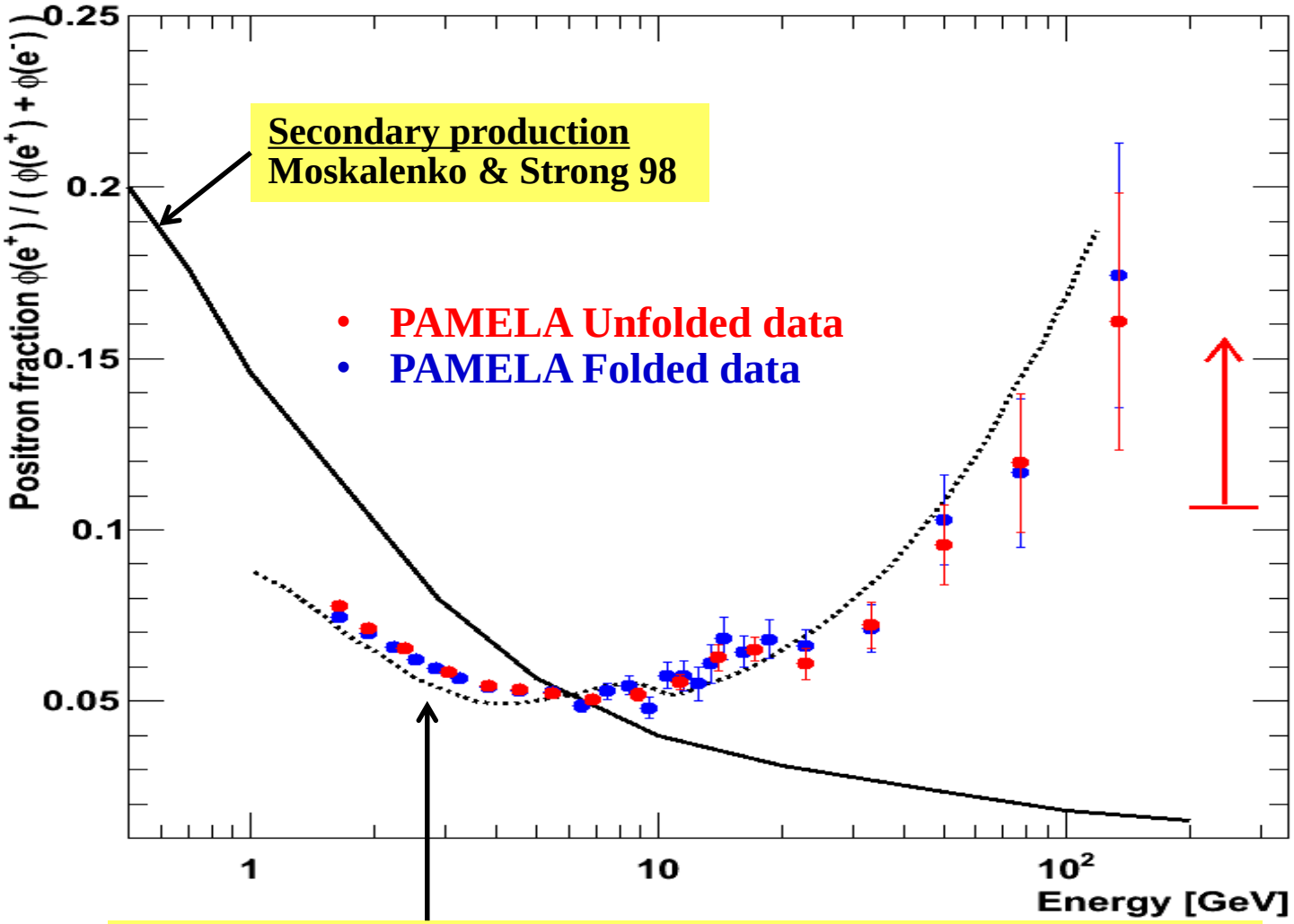
Positron to Electron Fraction



Positron to Electron Fraction

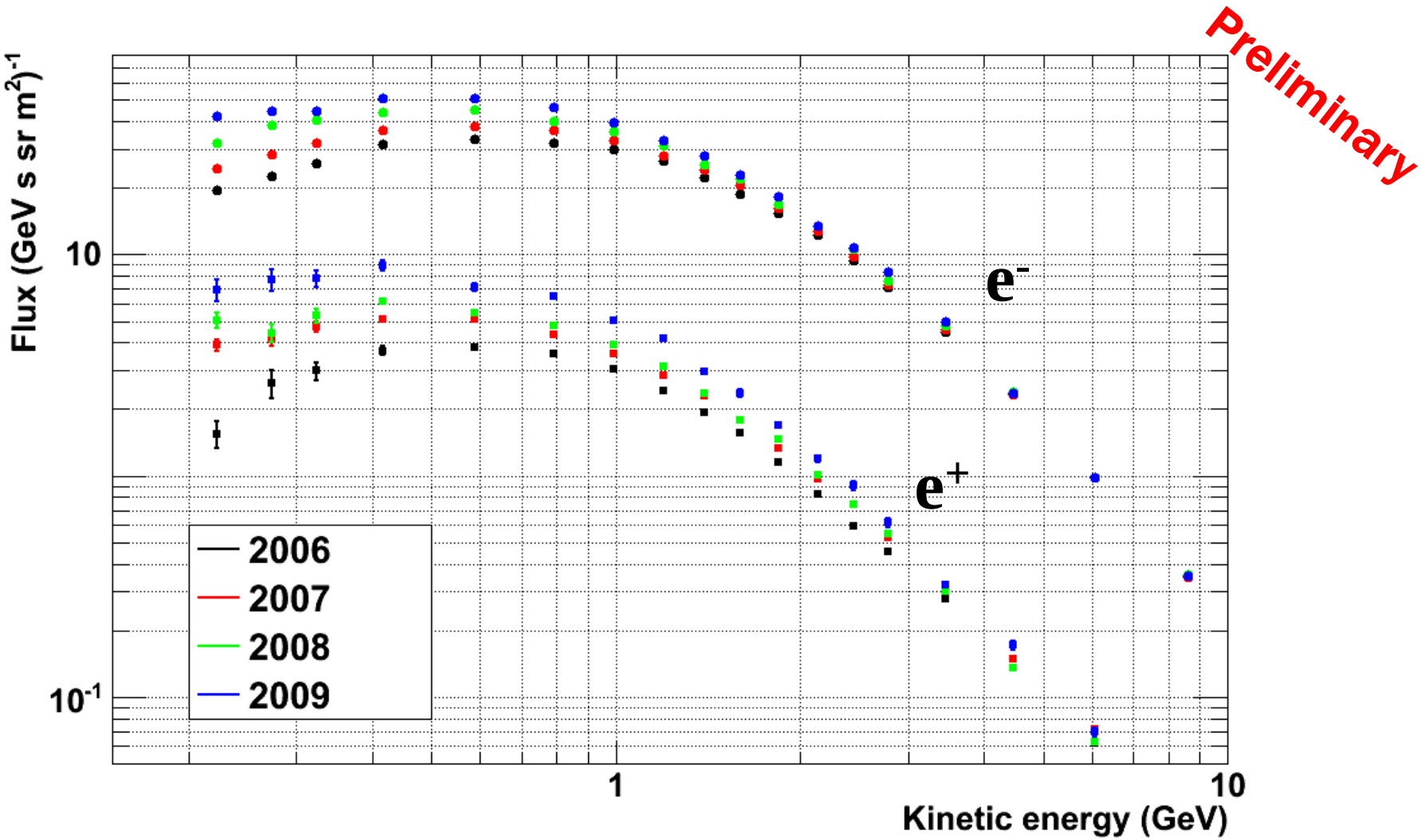


Positron to Electron Fraction

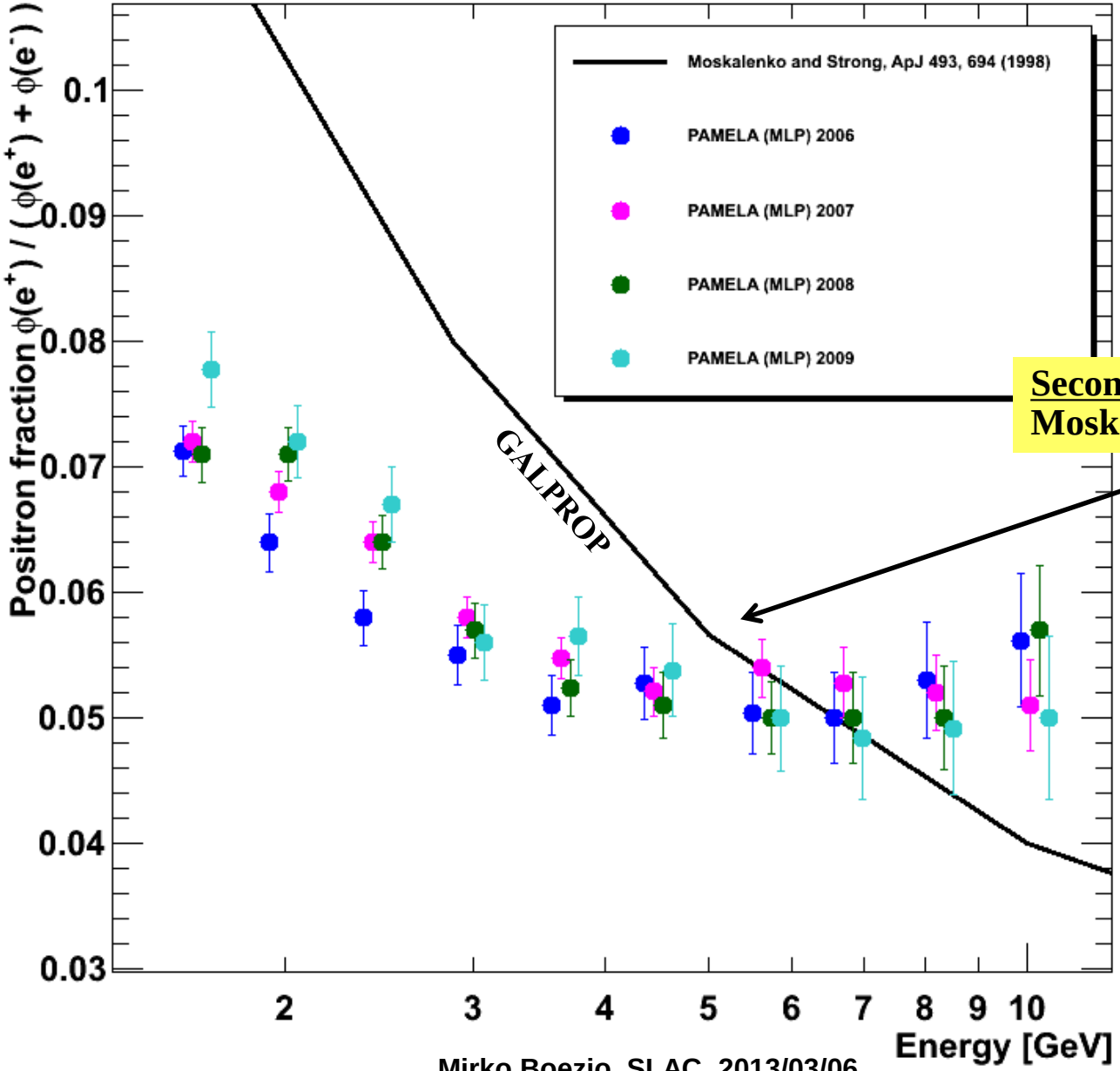


D. Hooper & W. Xue, PRL 110 (2013) 041302
Secondary production + primary production (pulsars and 10 GeV dark matter particle annihilating to charged lepton pairs)

PAMELA e^- e^+ Yearly Averages



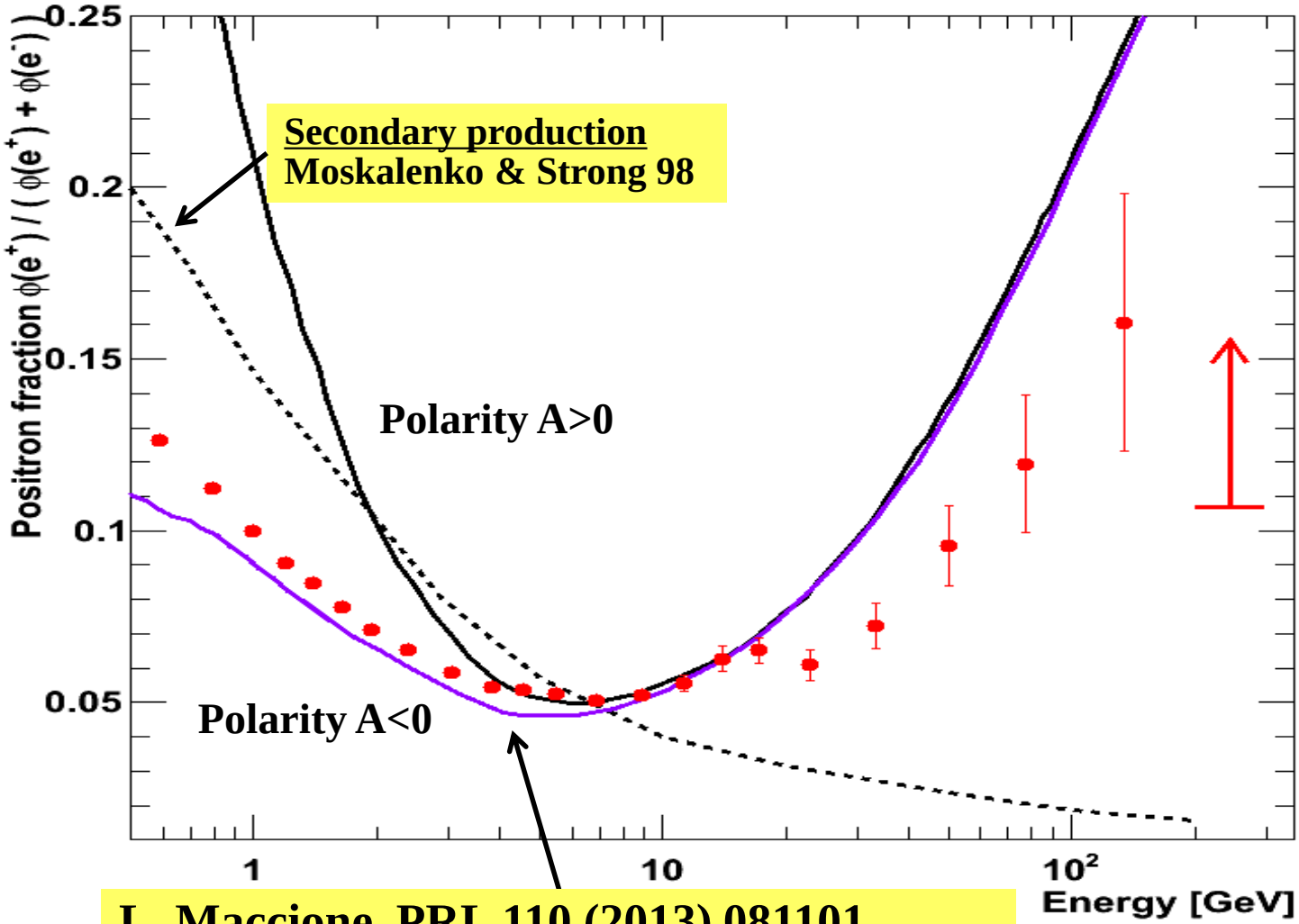
Time dependence: PAMELA Positron Fraction



Preliminary

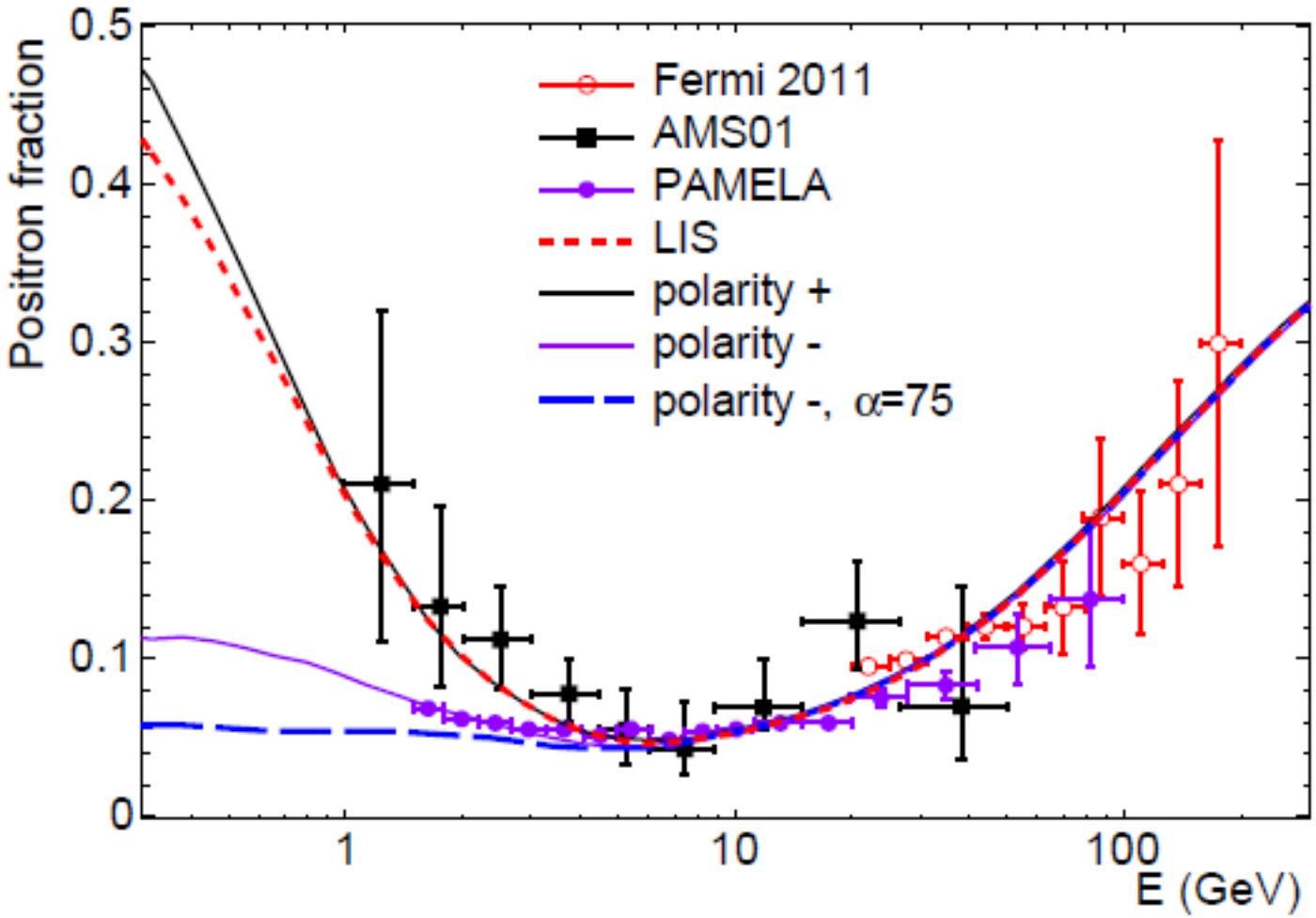
Secondary production
Moskalenko & Strong 98

Positron to Electron Fraction



L. Maccione, PRL 110 (2013) 081101.

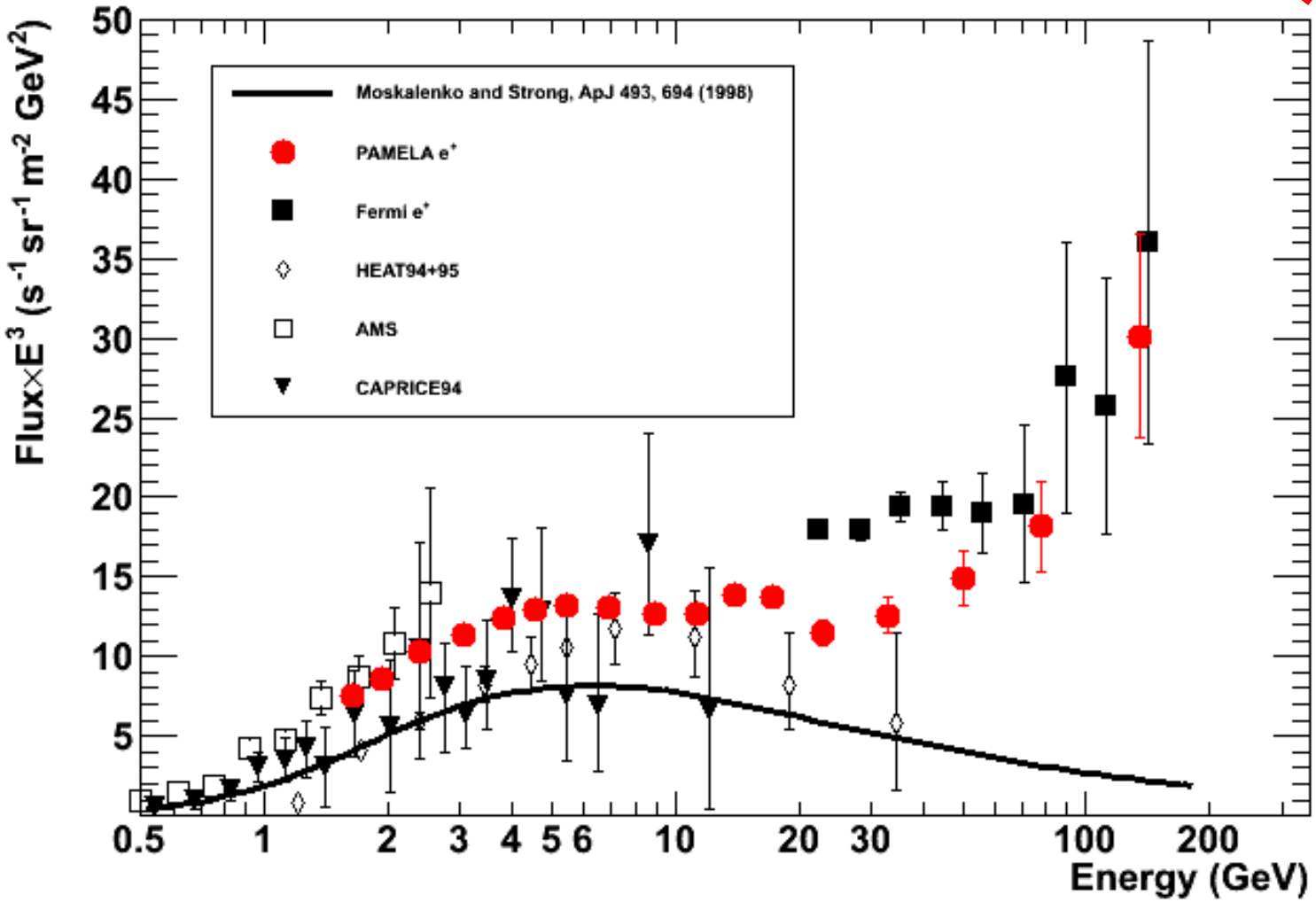
Charge-Sign Dependent Solar Modulation



L. Maccione, PRL 110 (2013) 081101.

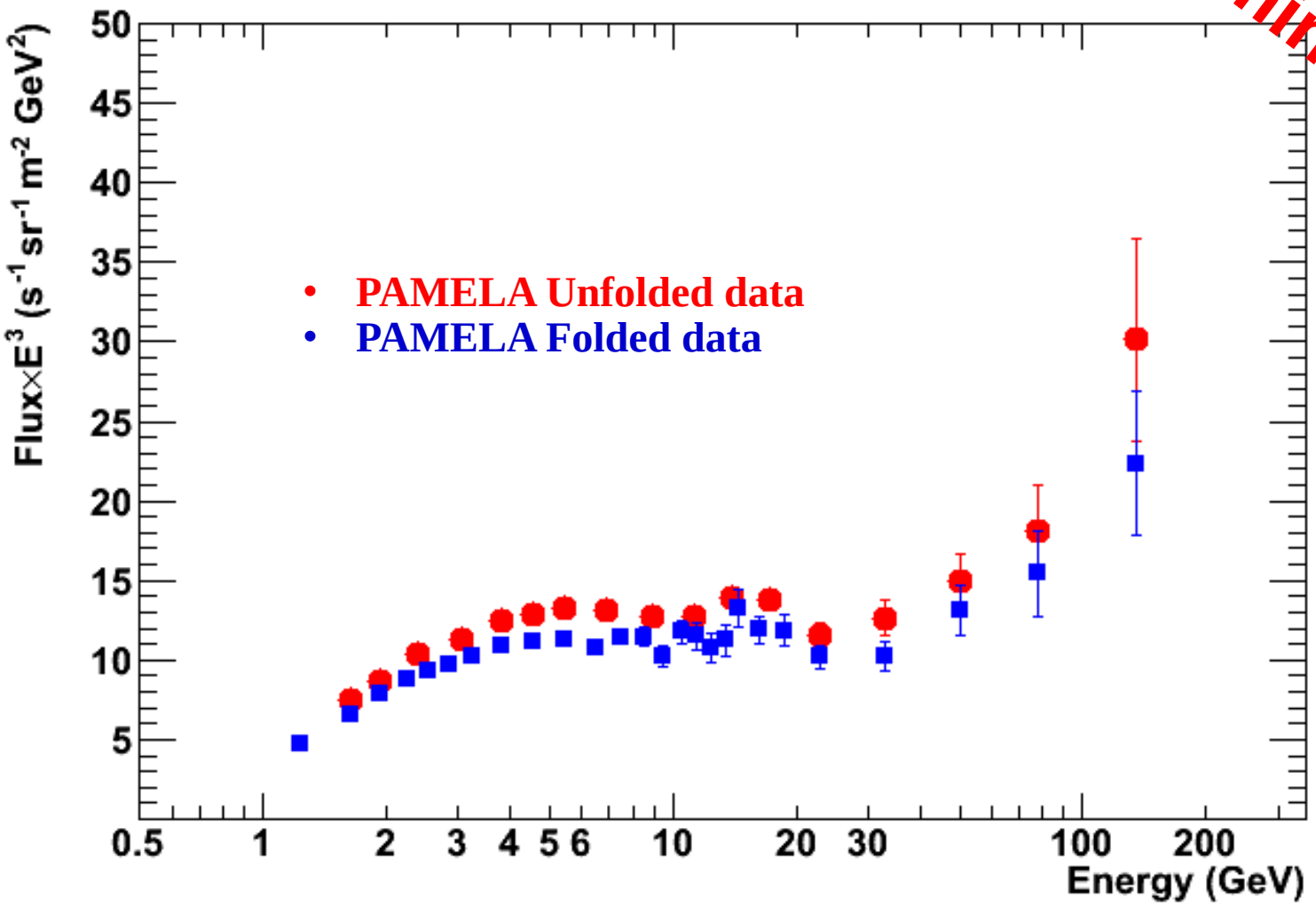
Positron Flux

Preliminary

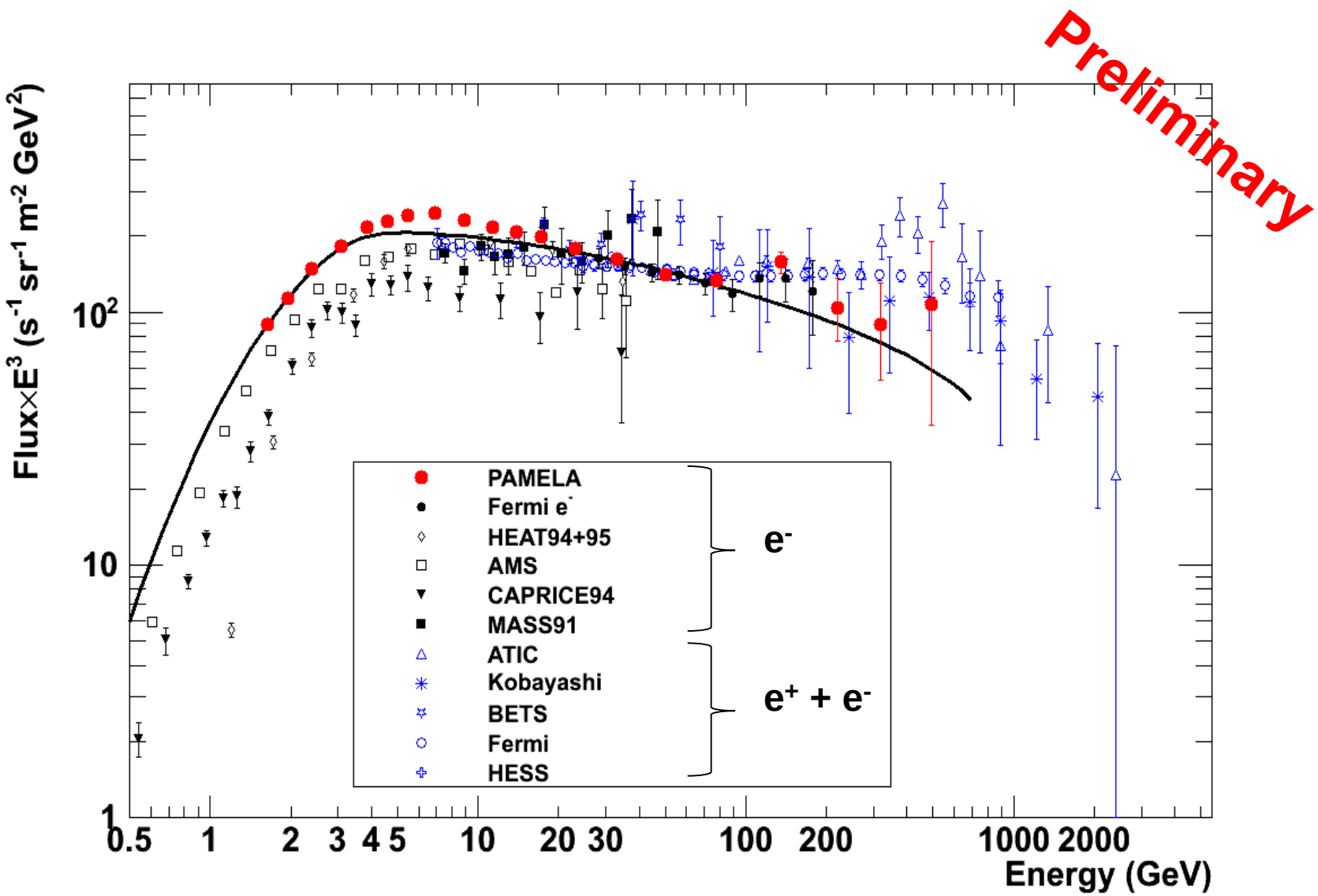


Positron Flux

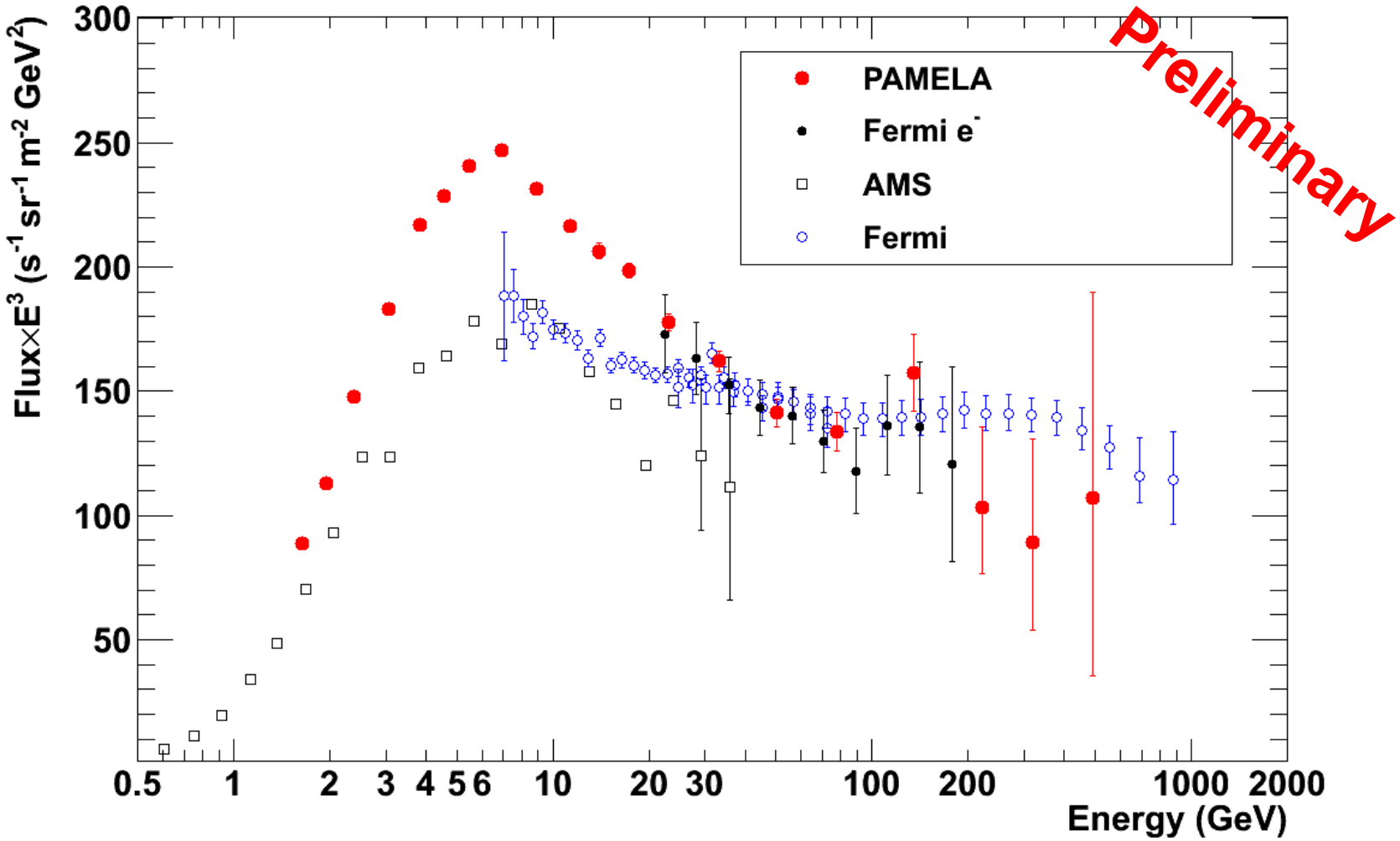
Preliminary



PAMELA electron (e^-) spectrum



PAMELA electron (e^-) spectrum

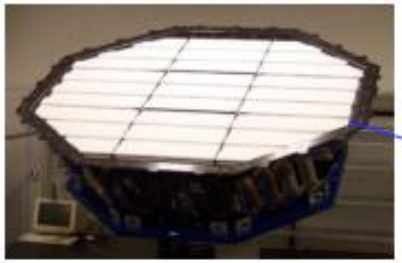


The Completed AMS Detector on ISS

AMS consitst of 5 sub-detetcors which provide reduandant information for particle identification

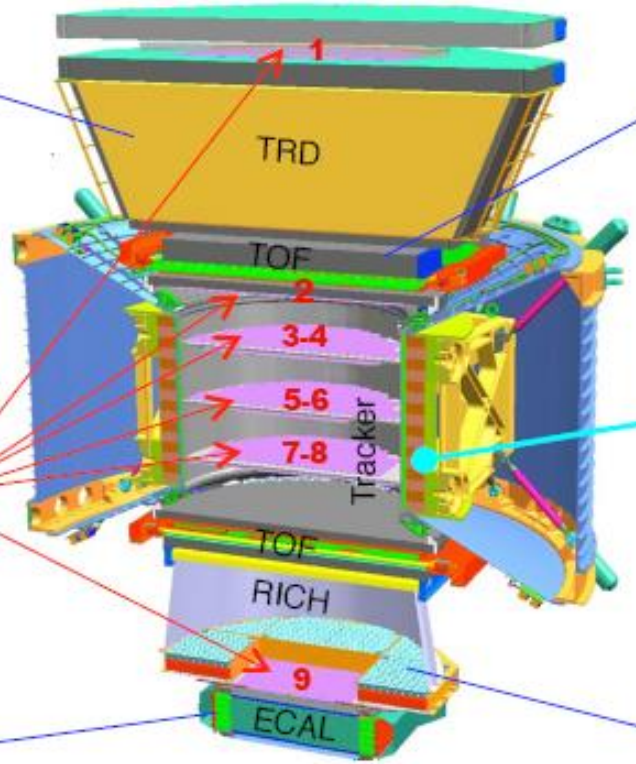
Particles and nuclei are defined by their charge (Z) and energy (E ~ P)

TRD
Identify e+, e-



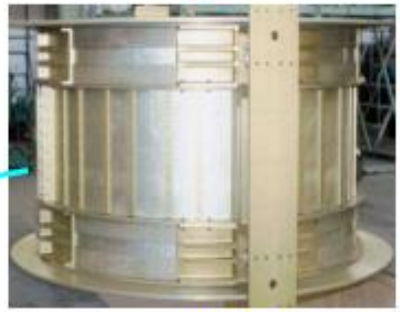
Silicon Tracker
Z, P

ECAL
E of e+, e-, γ

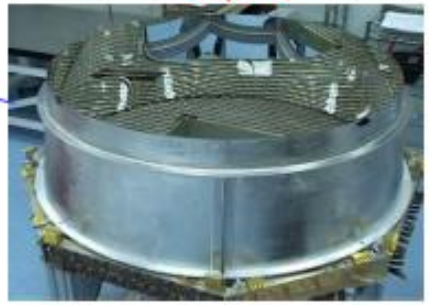


TOF
Z, E

Magnet
±Z

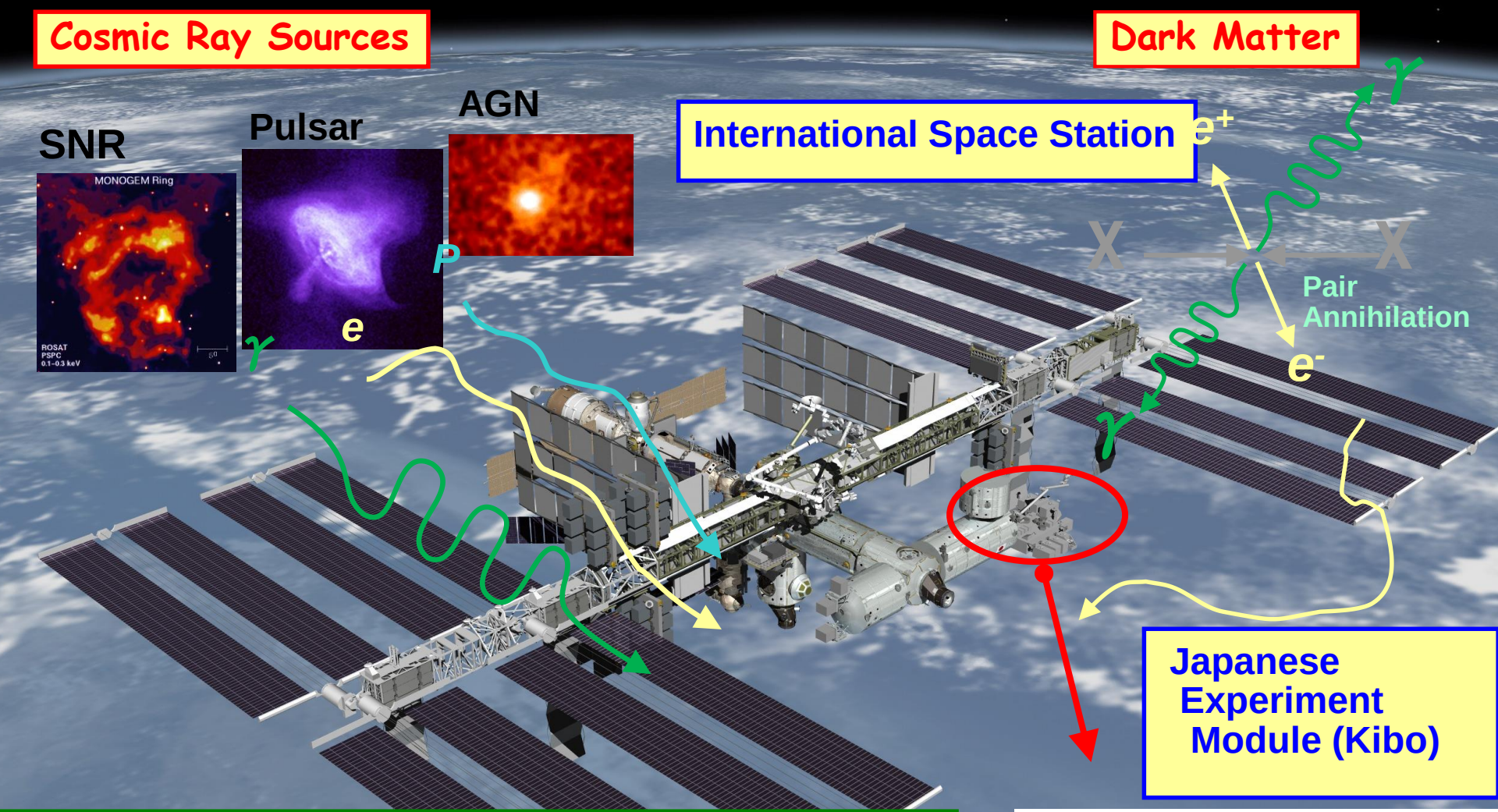


RICH
Z, E



Z, P are measured independently by the Tracker, RICH, TOF and ECAL

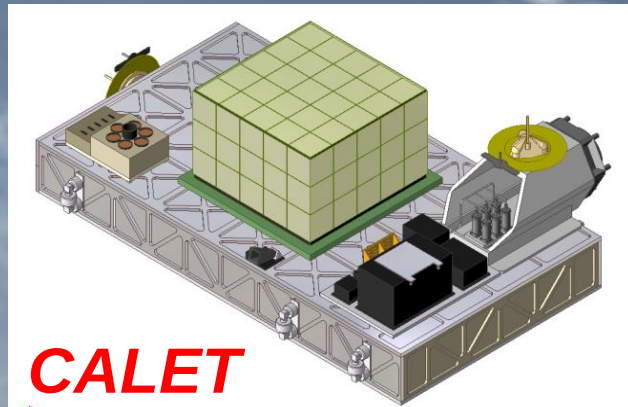
See talk by V. Bindi in CF6 on 7th



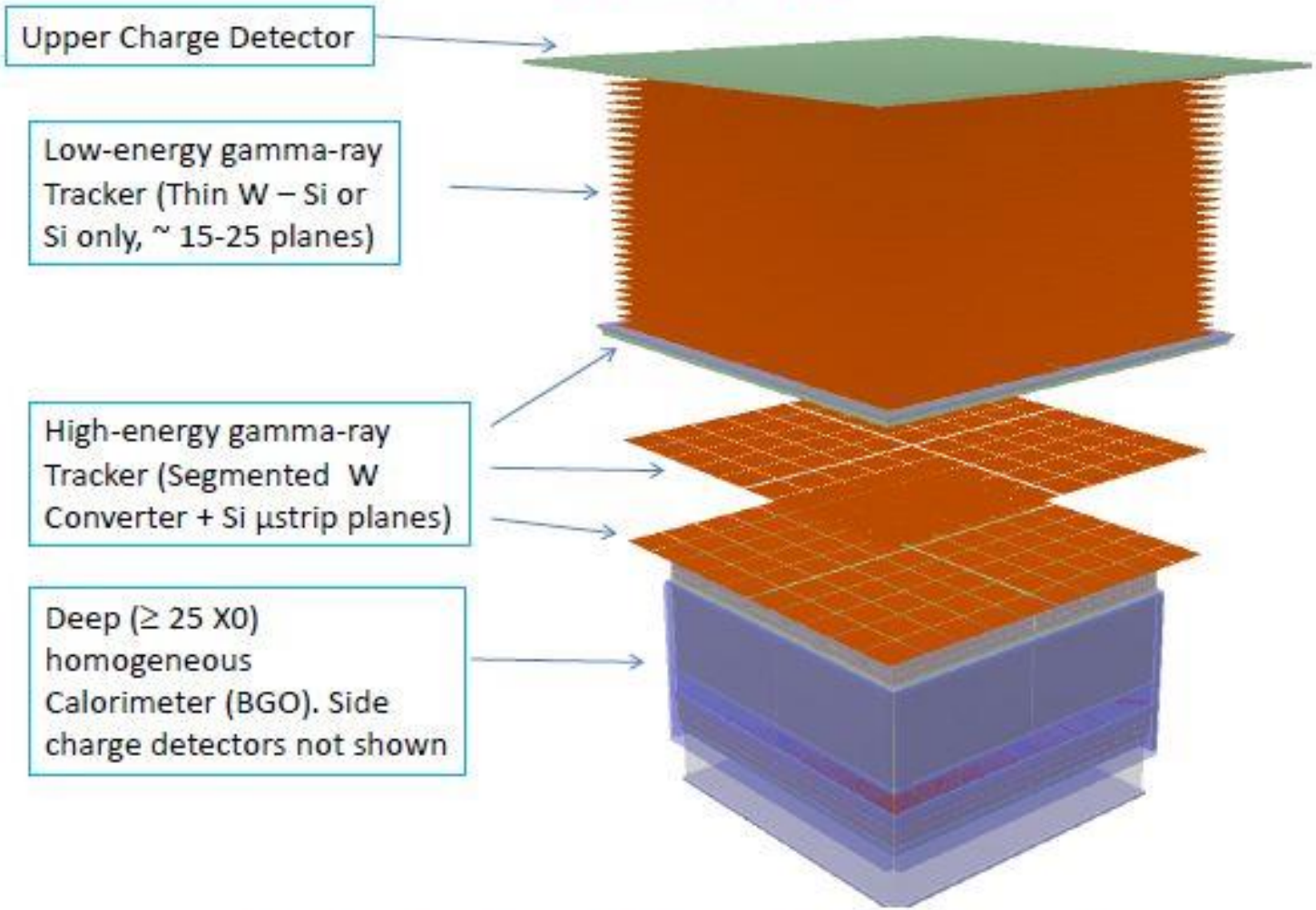
CALorimetric Electron Telescope

A Dedicated Detector for Electron Observation in 1GeV – 10,000 GeV

See talk by A. Moiseev in CF2 on 7th



Gamma-400



apparatus versions used in one of the preliminary simulations.

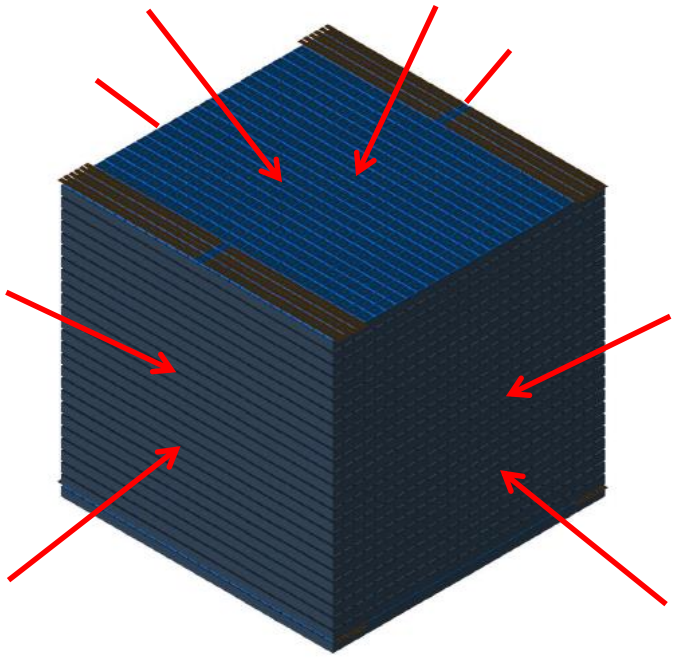
See talk by A. Moiseev in CF2 on 7th

Gamma-400: Calorimeter Geometry

- **Homogeneous calorimeter**
- **Symmetric, to maximize the Geometric Factor:**

  78x78x78 cm^3 (39X_0x39X_0x39X_0)
- **Total weight < 1600 kg**
- **Very high dynamic range**
- **Finely segmented in every direction**

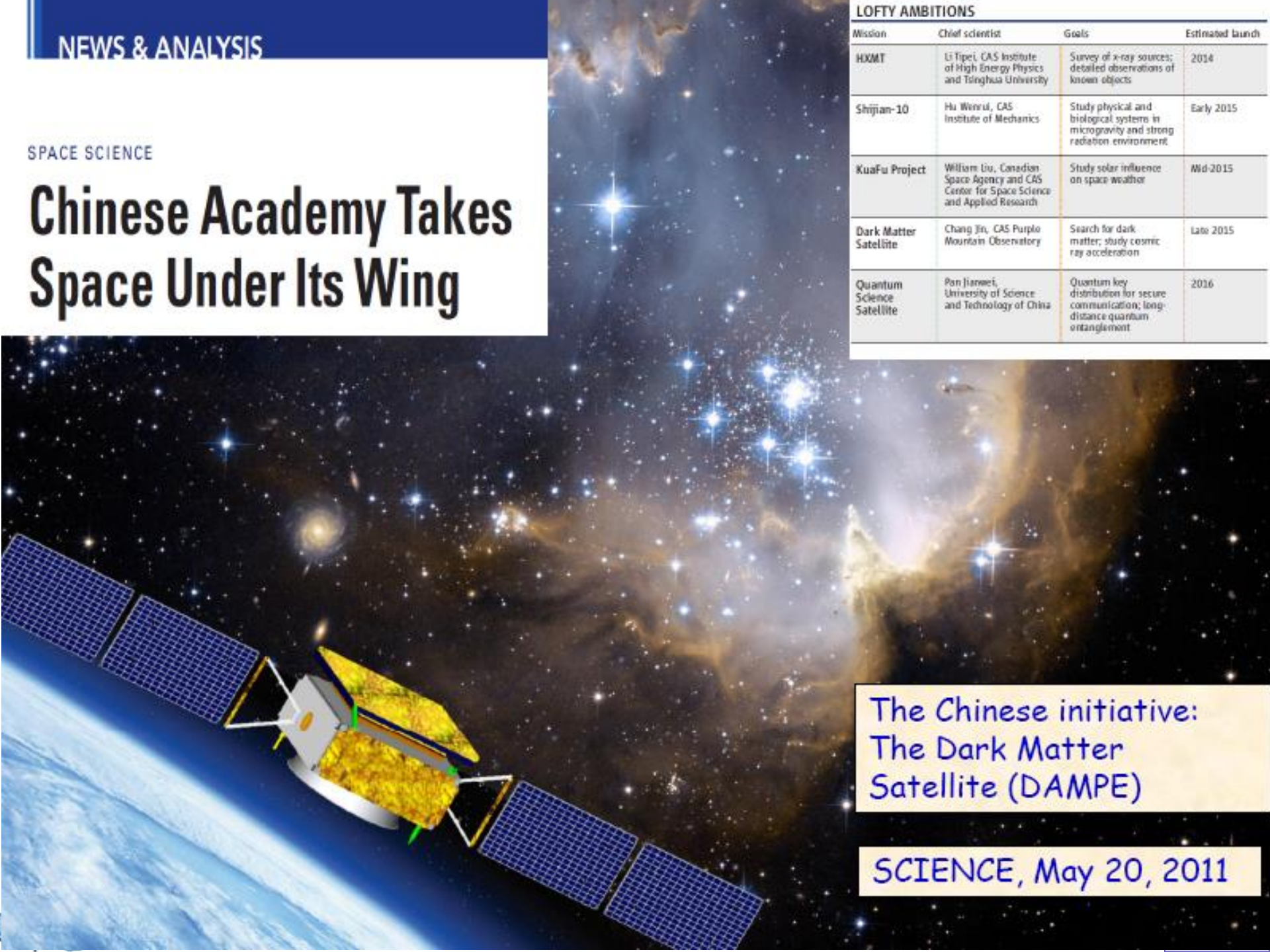
  1 R_M x 1 R_M x 1 R_M small CSI crystals, cubic shape
- **Few mm gap between crystals**



NEWS & ANALYSIS

SPACE SCIENCE

Chinese Academy Takes Space Under Its Wing



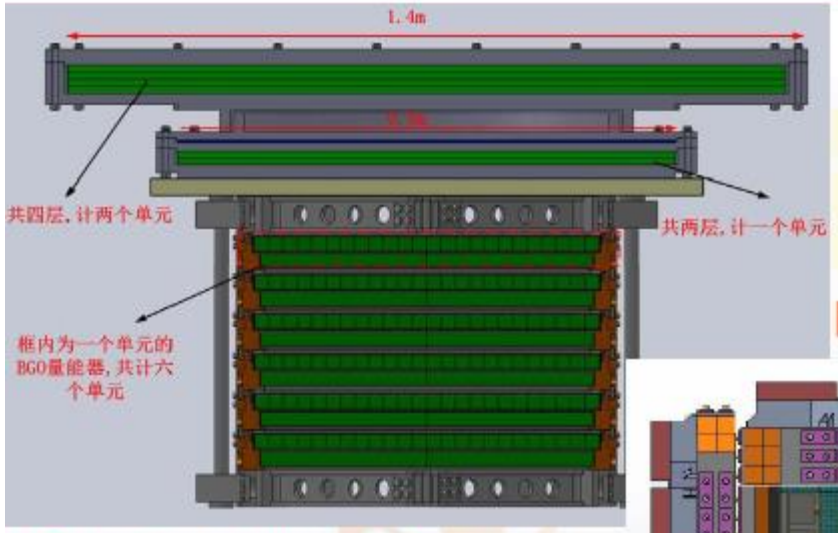
LOFTY AMBITIONS

Mission	Chief scientist	Goals	Estimated launch
HXMT	Li Tipei, CAS Institute of High Energy Physics and Tsinghua University	Survey of x-ray sources; detailed observations of known objects	2014
Shijian-10	Hu Wenrui, CAS Institute of Mechanics	Study physical and biological systems in microgravity and strong radiation environment	Early 2015
KuaFu Project	William Liu, Canadian Space Agency and CAS Center for Space Science and Applied Research	Study solar influence on space weather	Mid-2015
Dark Matter Satellite	Chang Jin, CAS Purple Mountain Observatory	Search for dark matter; study cosmic ray acceleration	Late 2015
Quantum Science Satellite	Pan Jianwei, University of Science and Technology of China	Quantum key distribution for secure communication; long-distance quantum entanglement	2016

The Chinese initiative:
The Dark Matter Satellite (DAMPE)

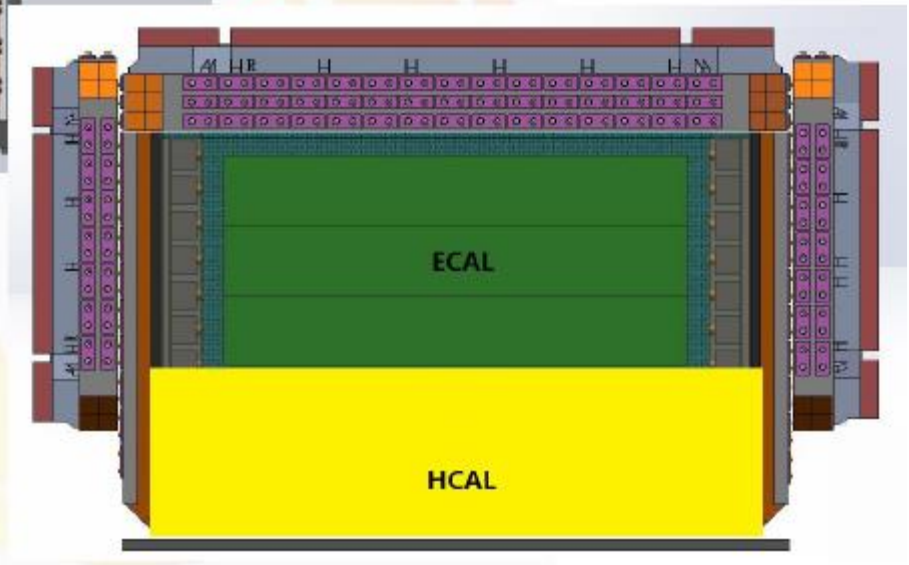
SCIENCE, May 20, 2011

Two Dark Matter Detection Experiments



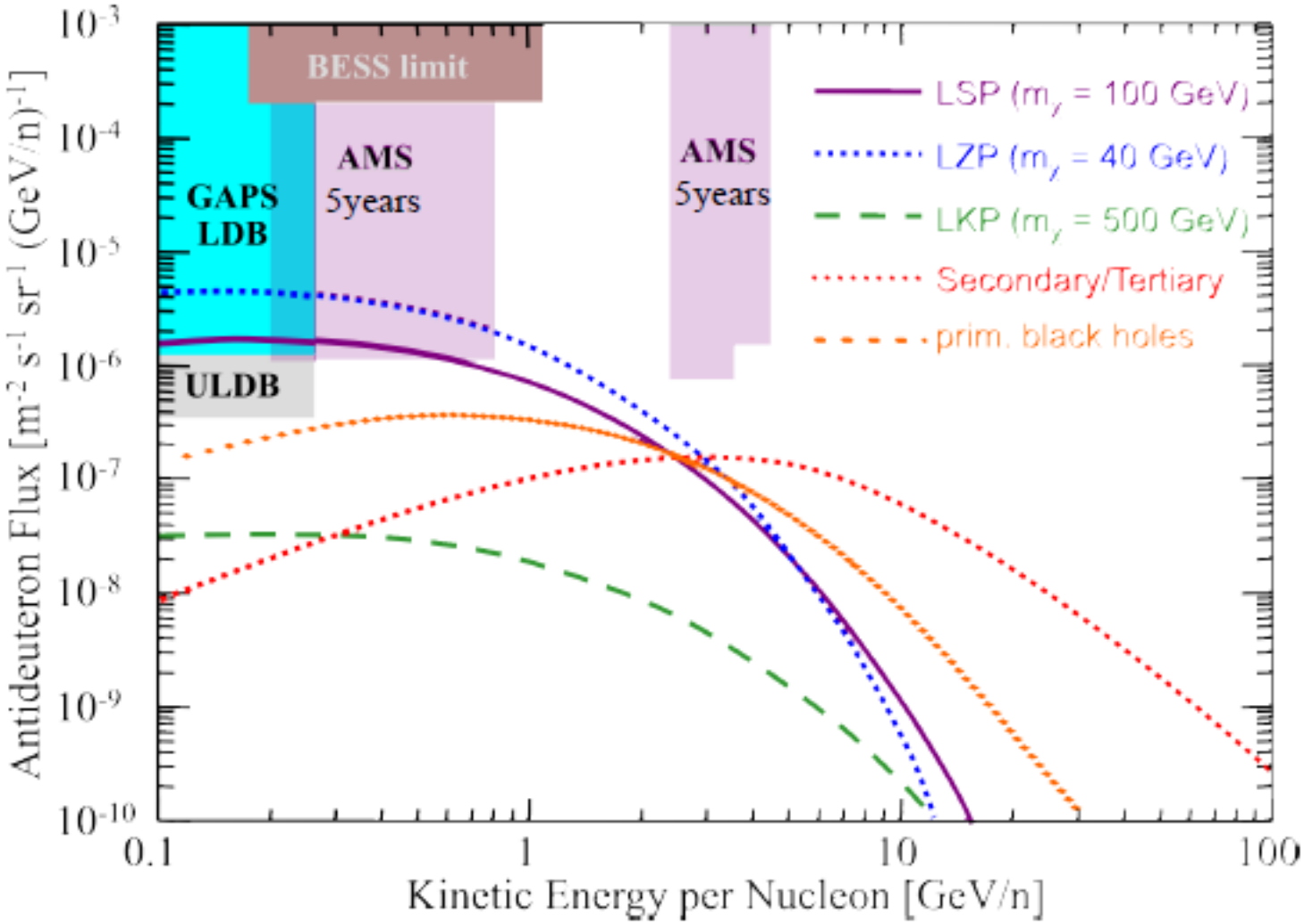
High Energy cosmic Radiation Detection facility (HERD) onboard China's space station: ~2000 kg payload. Launch time ~2020

China's dark matter detection satellite experiment: 1200 kg payload. Expected launch time ~2015



Antideuterons

P. Von Doetinchem, UCLA Dark Matter 2012



See talk by P. Von Doetinchem in CF2+CF4 on 7th

Summary

- PAMELA has been in orbit and studying cosmic rays for ~6 years. >10^9 triggers registered and ~30TB of data has 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?

- The e^- spectrum up to 600 GeV shows spectral features that may point to additional components.

- The proton and helium nuclei spectra have been measured up to 1.2 TV. The observations challenge the current paradigm of cosmic ray acceleration and propagation.

- 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!