

Electron and Positron Measurements in Space



Piergiorgio Picozza

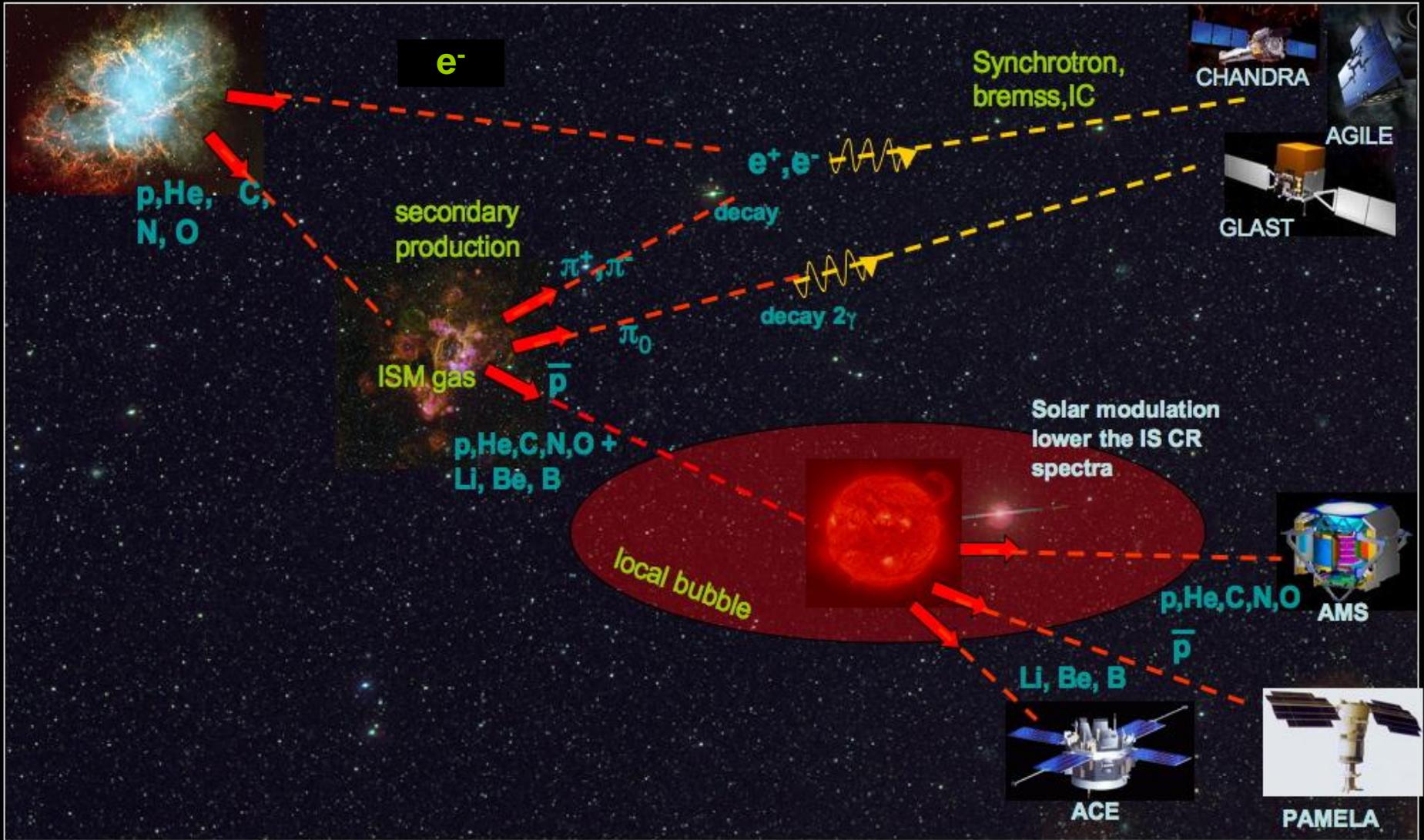
INFN and University of Rome Tor Vergata

100 Years Cosmic Rays

Anniversary of Their Discovery by V.F.Hess

5-8 August 2012, Die Bühne, Bad Saarow/Pieskow, Germany

COSMIC RAYS PRODUCTION MECHANISMS



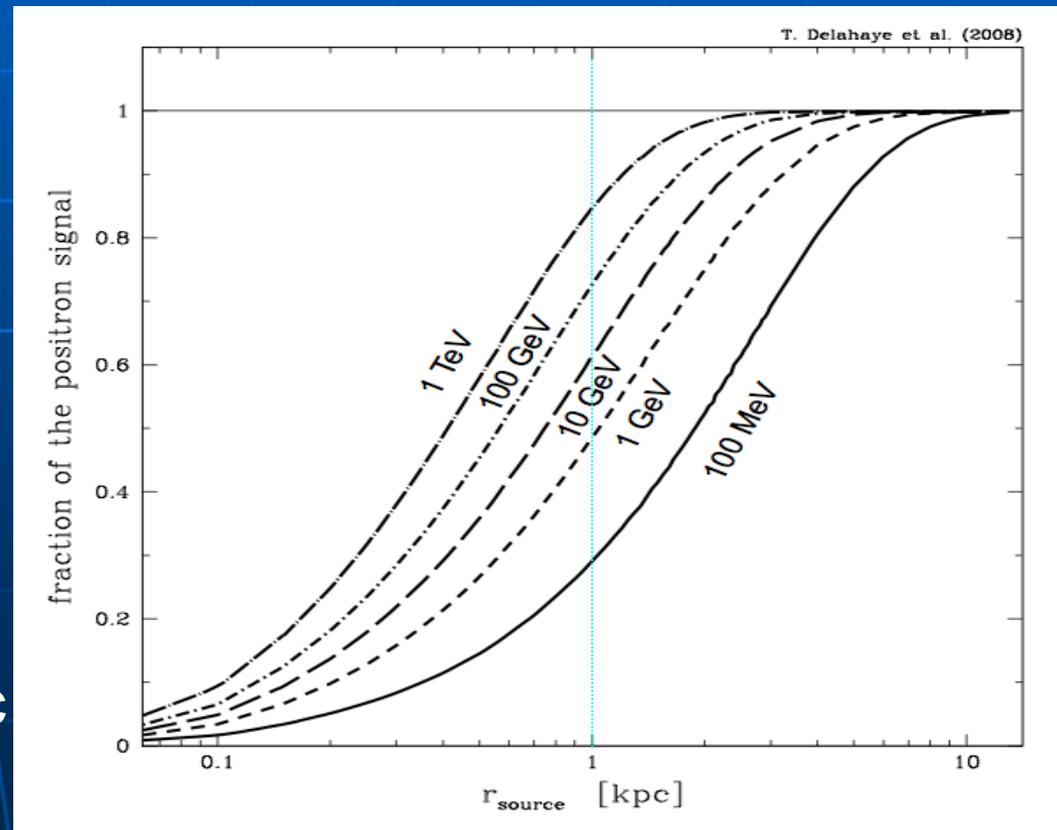
Where do **electrons** and **positrons** come from?

Mostly locally within 1 Kpc, due to the energy losses by Synchrotron Radiation and Inverse Compton

Typical lifetime

$$\tau \simeq 5 \cdot 10^5 \text{ yr} \left(\frac{1 \text{ TeV}}{E} \right)$$

Antiprotons within 10 Kpc



PRIMARY PROTONS:

$$n_{CR}(E) = N_{CR}(E) R \tau_{esc}(E) \propto E^{-\gamma} E^{-\delta}$$

PRIMARY ELECTRONS:

$$n_e(E) = N_e(E) R \text{Min}[\tau_{esc}(E), \tau_{loss}(E)] \propto E^{-\gamma_e} E^{-\beta}$$

b = d for diffusion

b = 1 for losses

SECONDARY POSITRONS INJECTION:

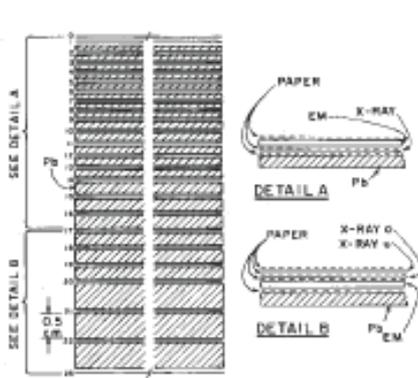
$$q_+(E') dE' = n_{CR}(E) dE n_H \sigma_{pp} c \propto E^{-\gamma-\delta}$$

SECONDARY POSITRONS EQUILIBRIUM:

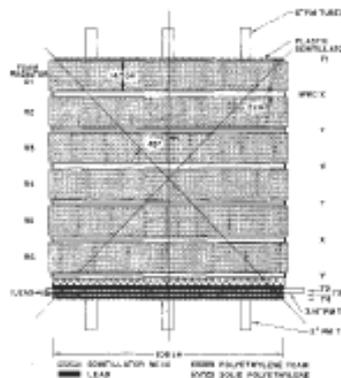
$$n_+(E) = q_+(E) \text{Min}[\tau_{esc}(E), \tau_{loss}(E)] \propto E^{-\gamma-\delta-\beta}$$

$$\frac{n_+}{n_e} \propto E^{-(\gamma-\gamma_e)-\delta}$$

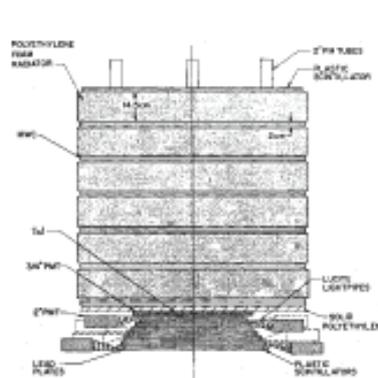
ALL ELECTRON INCLUSIVE SPECTRUM



Emulsion chambers (1968–79)
30 GeV–1.5 TeV [8.2 r. l.]



Hartman (1977)
9–300 GeV [8 r. l.]



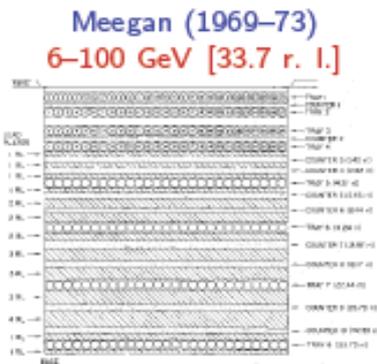
Tang (1980)
4–280 GeV [18.5 r. l.]



1970

1980

2000



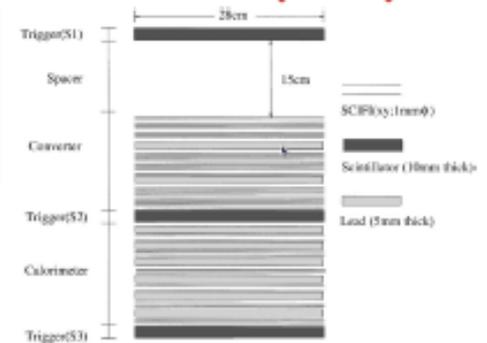
Meegan (1969–73)
6–100 GeV [33.7 r. l.]

Detector concepts

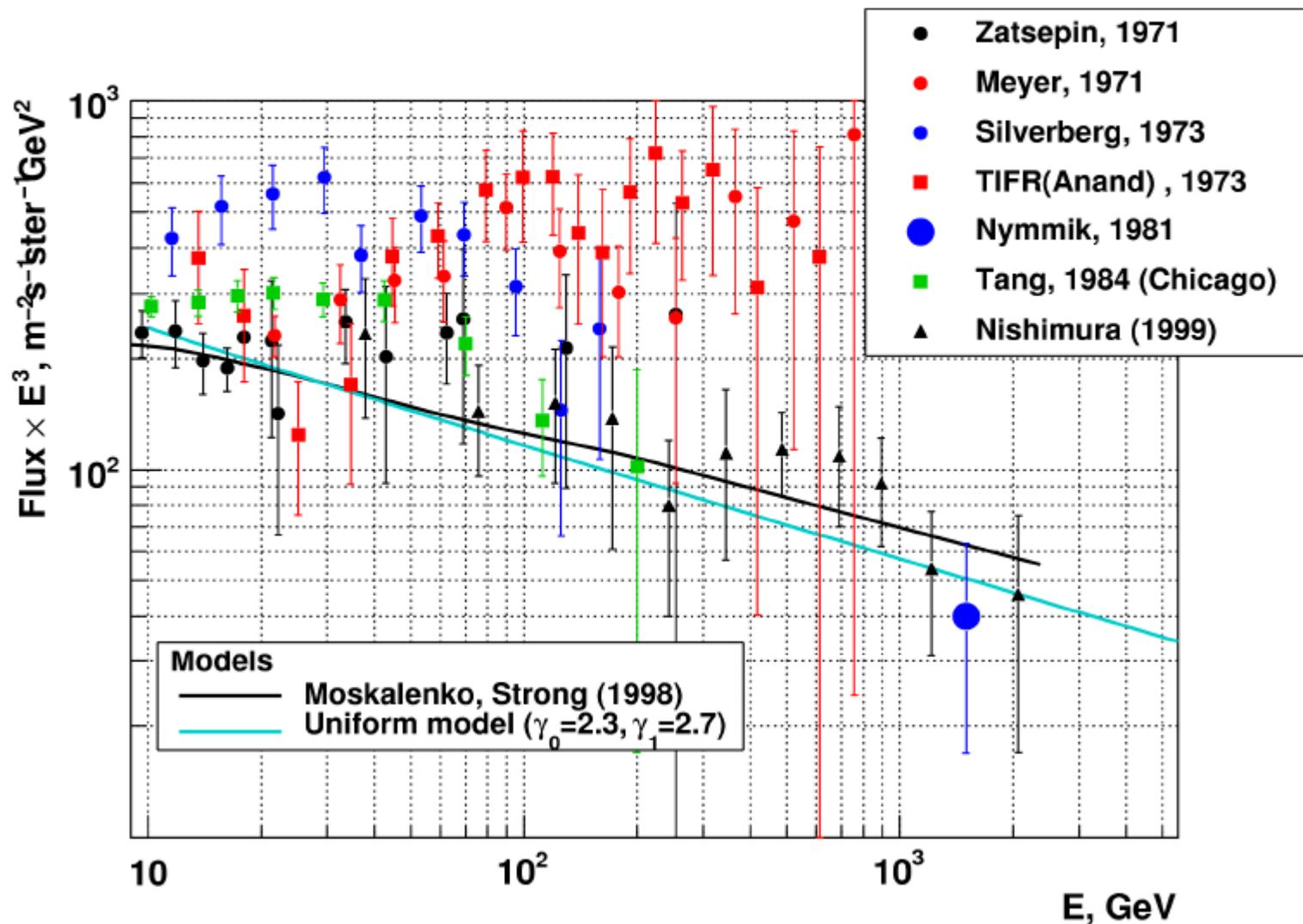
- ▶ Imaging calorimeters (energy measurement and background rejection).
- ▶ Many different implementations explored.

Courtesy of Luca Baldini

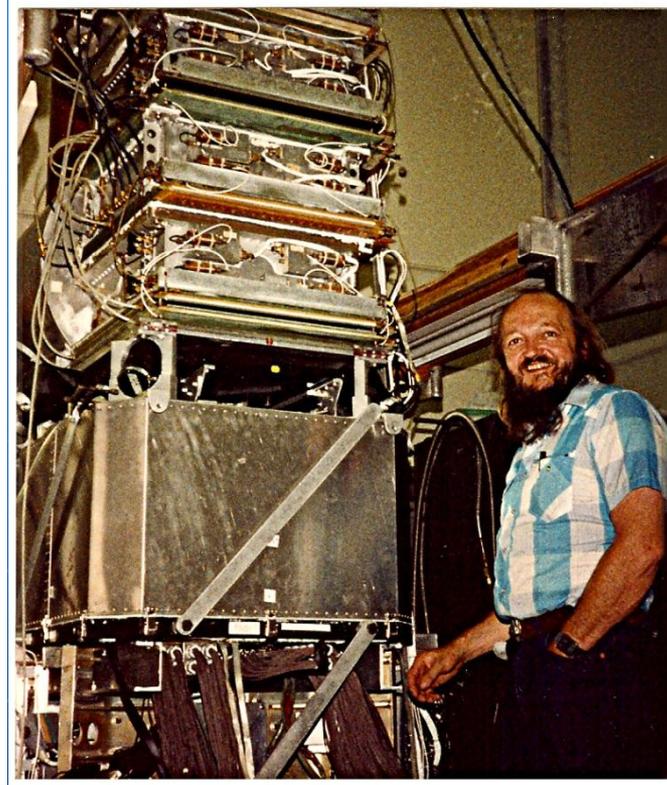
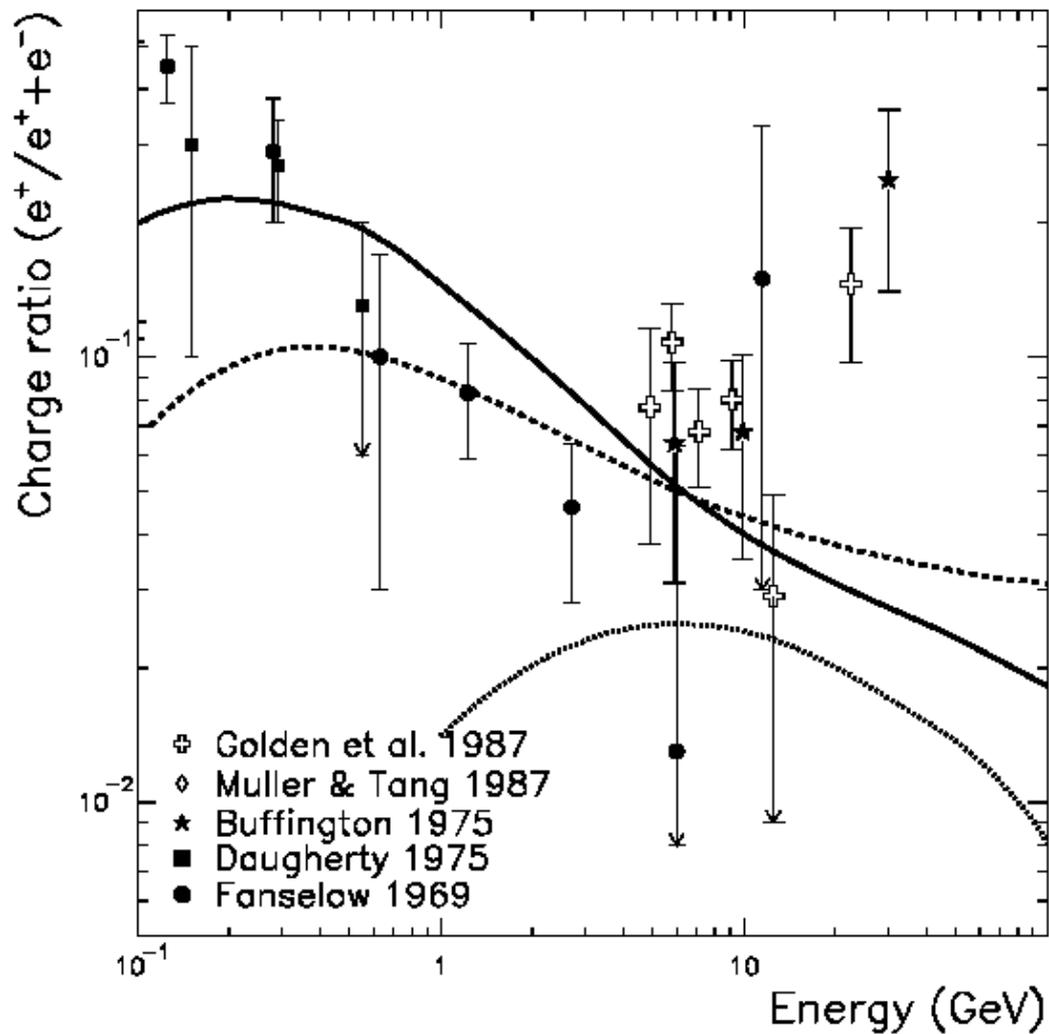
BETS (1997–98)
10–100 GeV [7.3 r. l.]



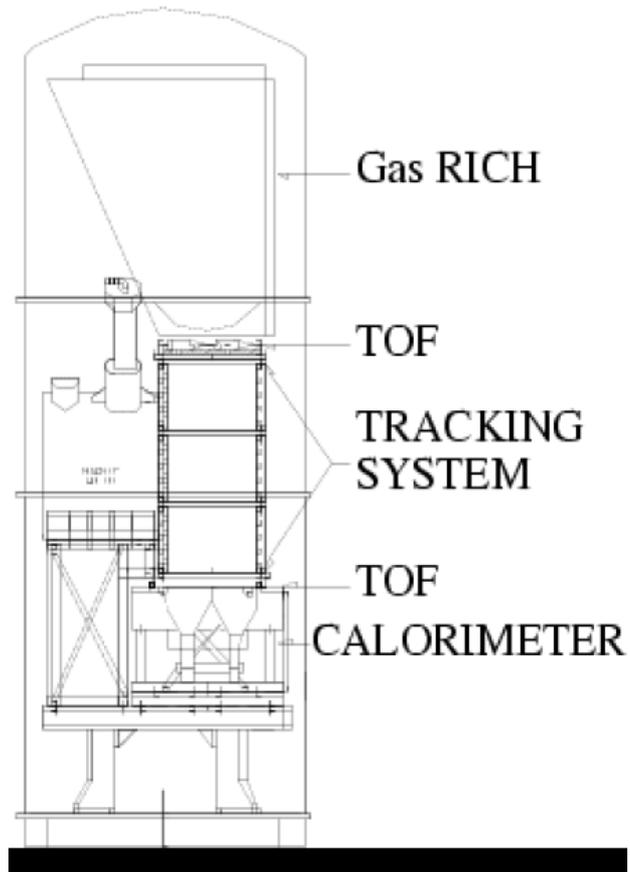
Electrons ($e^- + e^+$) - early experiments (1970-2000)



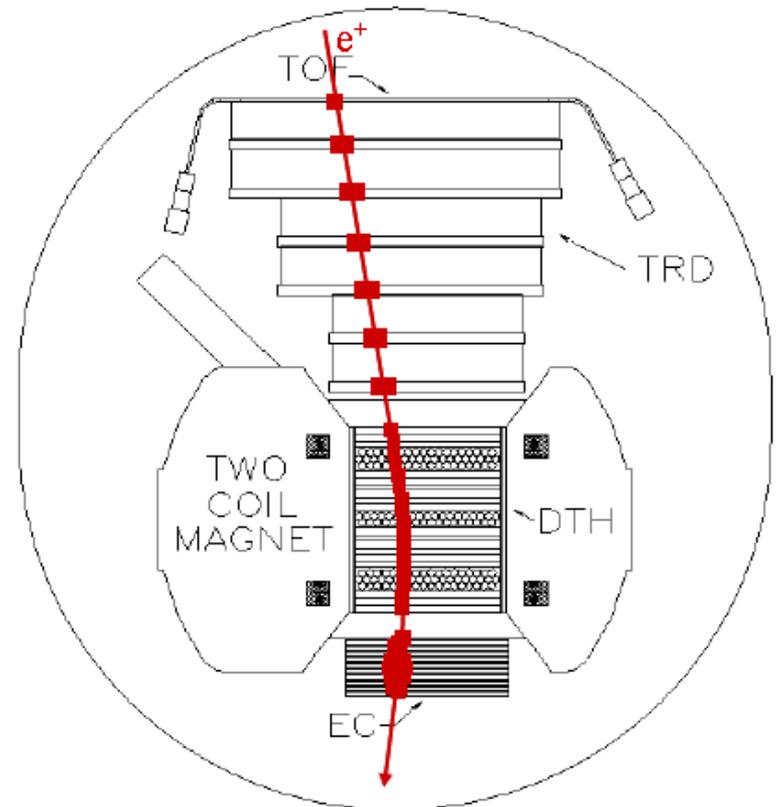
Balloon data : Positron fraction before 1990



CAPRICE



HEAT



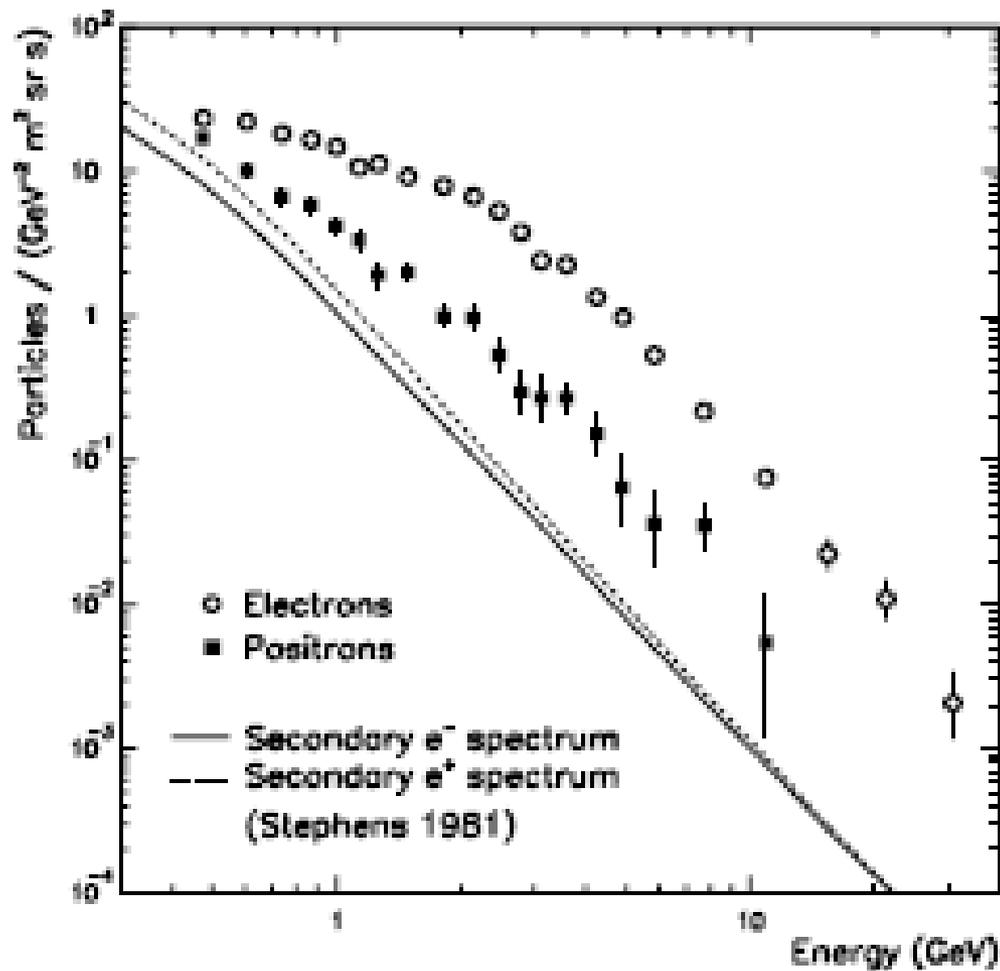
Antimatter Search

Wizard Collaboration

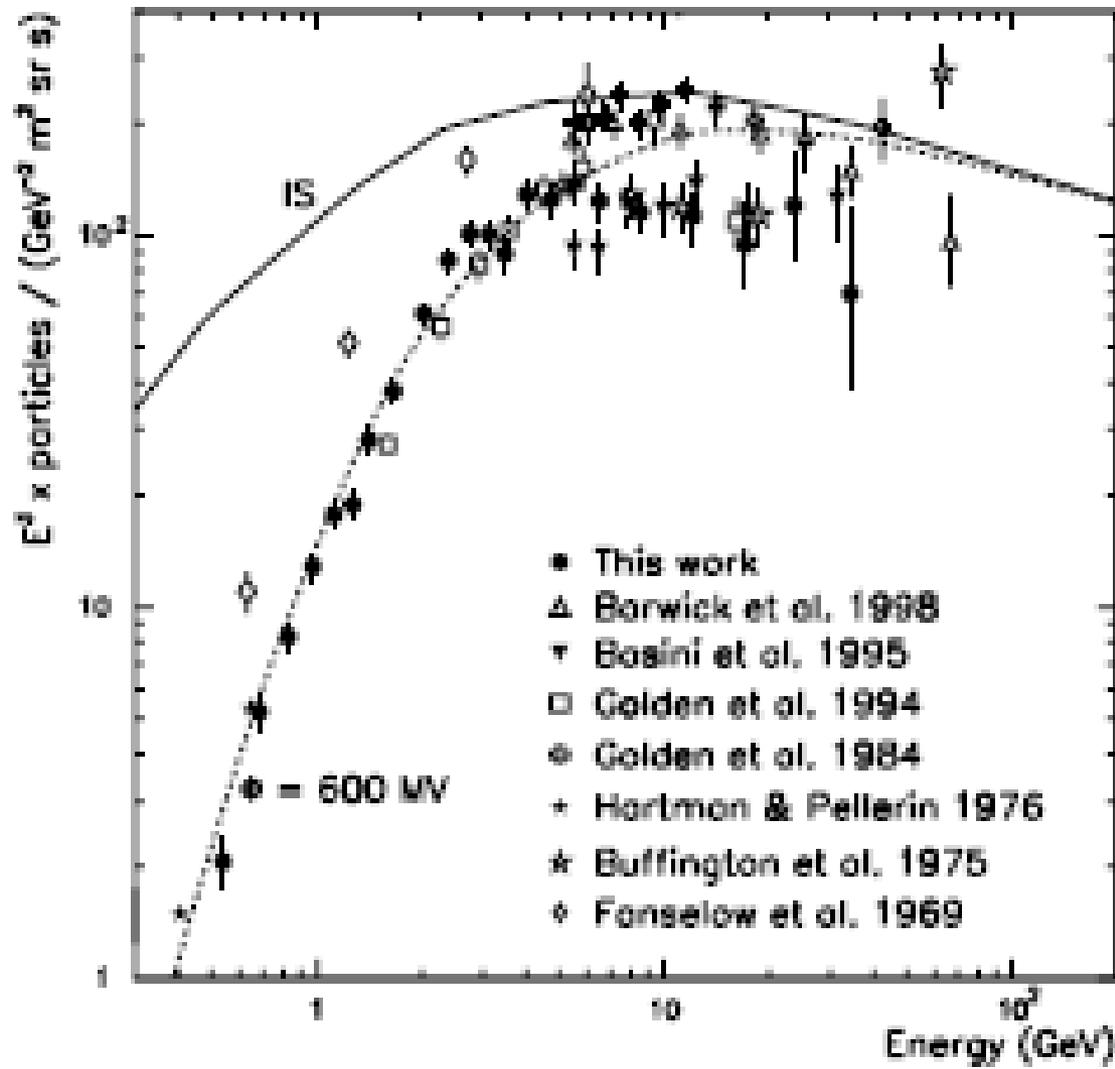
- ✓ MASS - 1,2 (89,91)
- ✓ TrampSI (93)
- ✓ CAPRICE (94, 97, 98)
- ✓ BESS (93, 95, 97, 98, 2000)
- ✓ Heat (94, 95, 2000)
- ✓ IMAX (96)
- ✓ AMS-01 (1998)



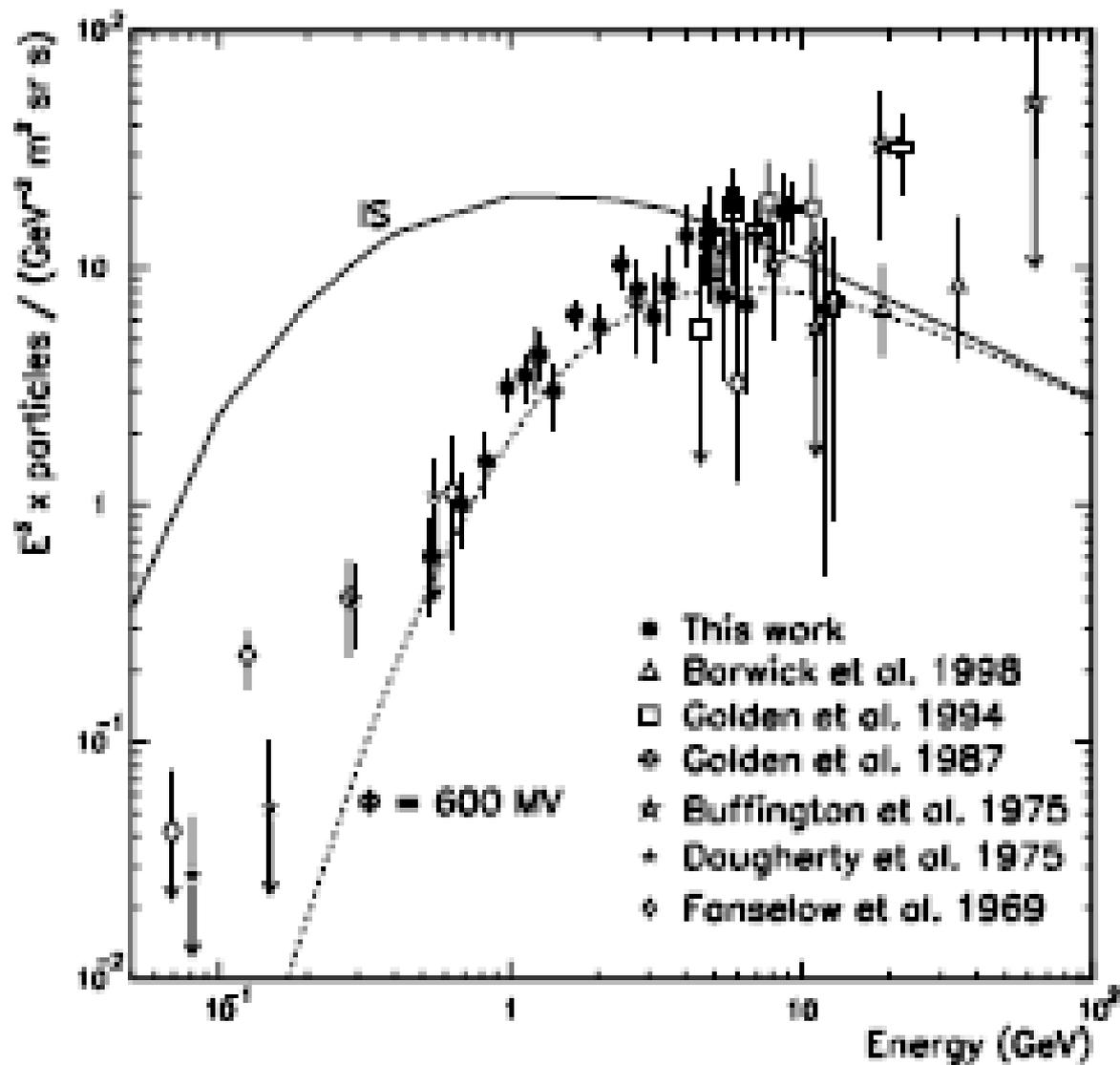
Caprice 94



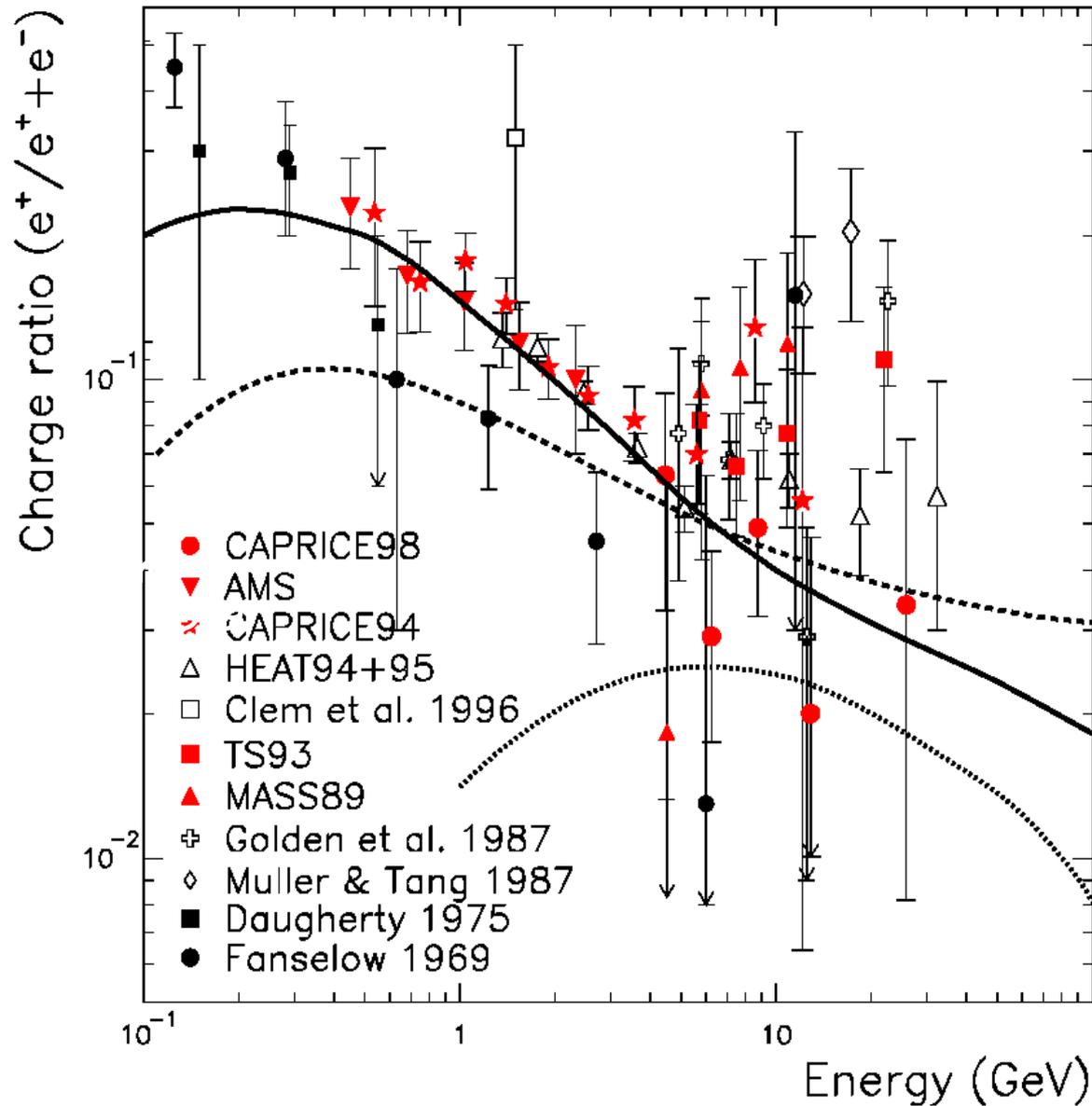
Electrons



Positrons



Positron Ratio

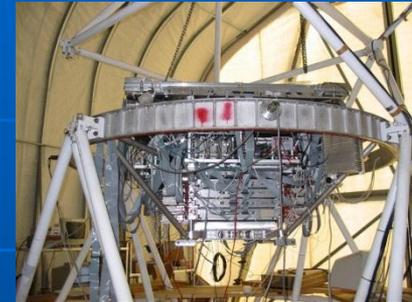


Space and LDF Missions

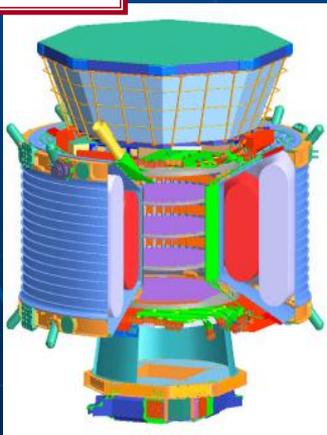
PAMELA
15-06-2006



ATIC
2002 - 2007



AMS-02
16 -5-2011

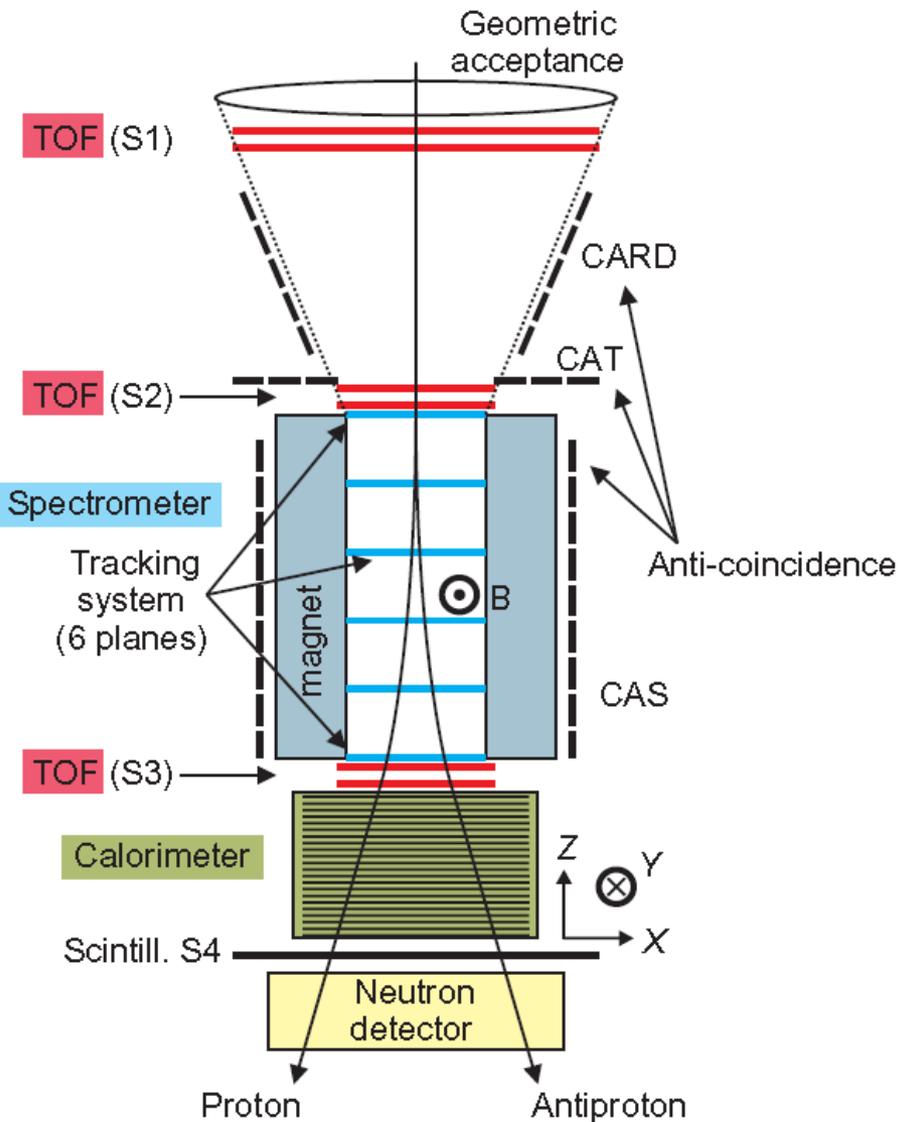


Fermi/GLAST
11-6-2008

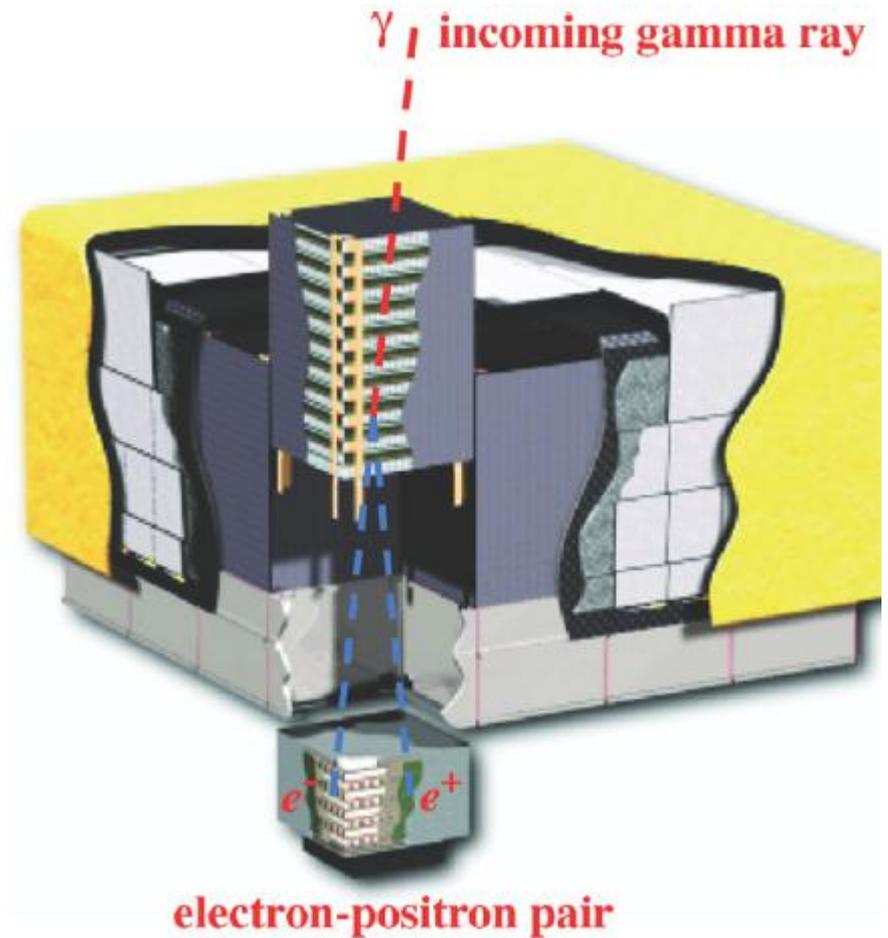


Electrons and Positrons

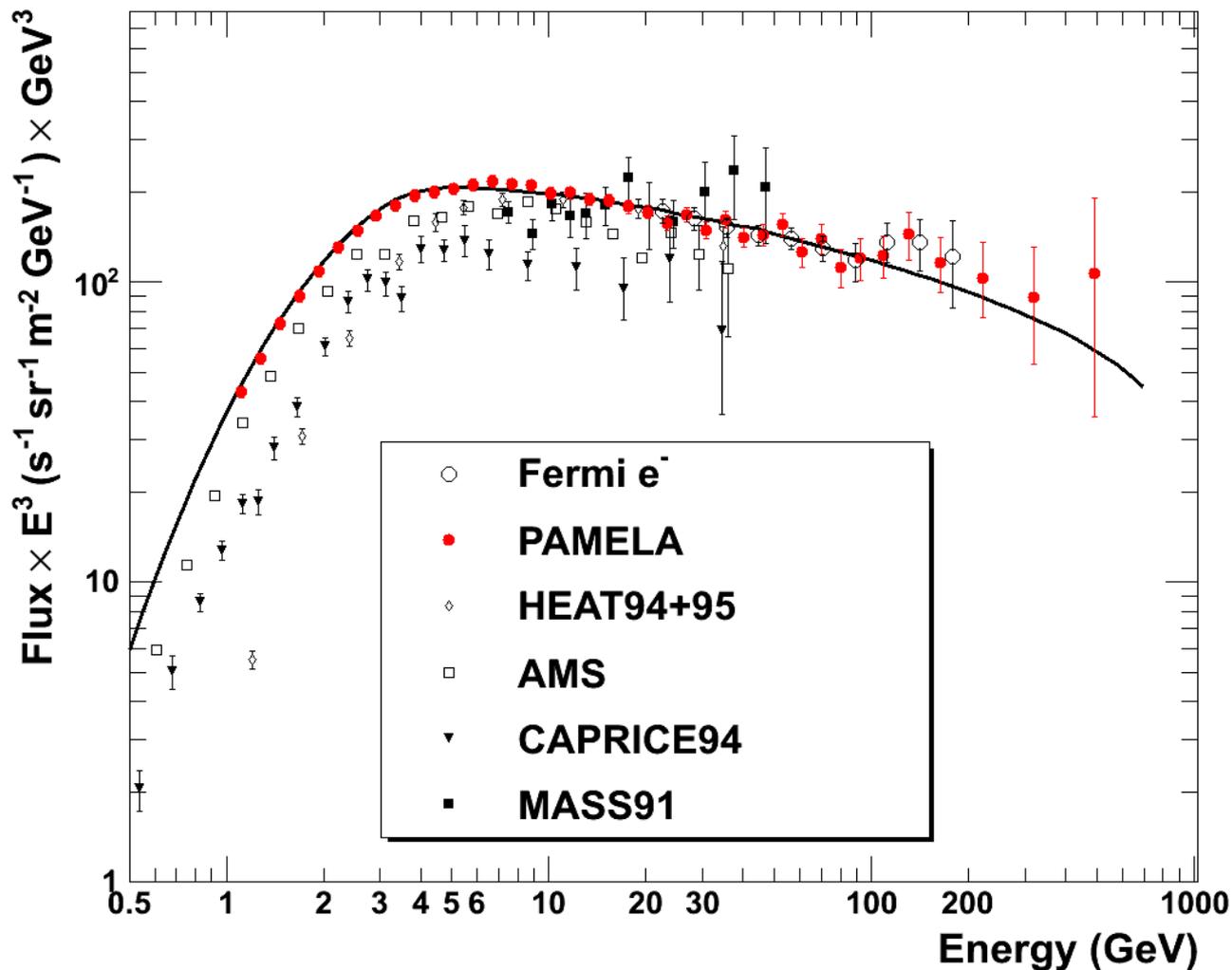
PAMELA



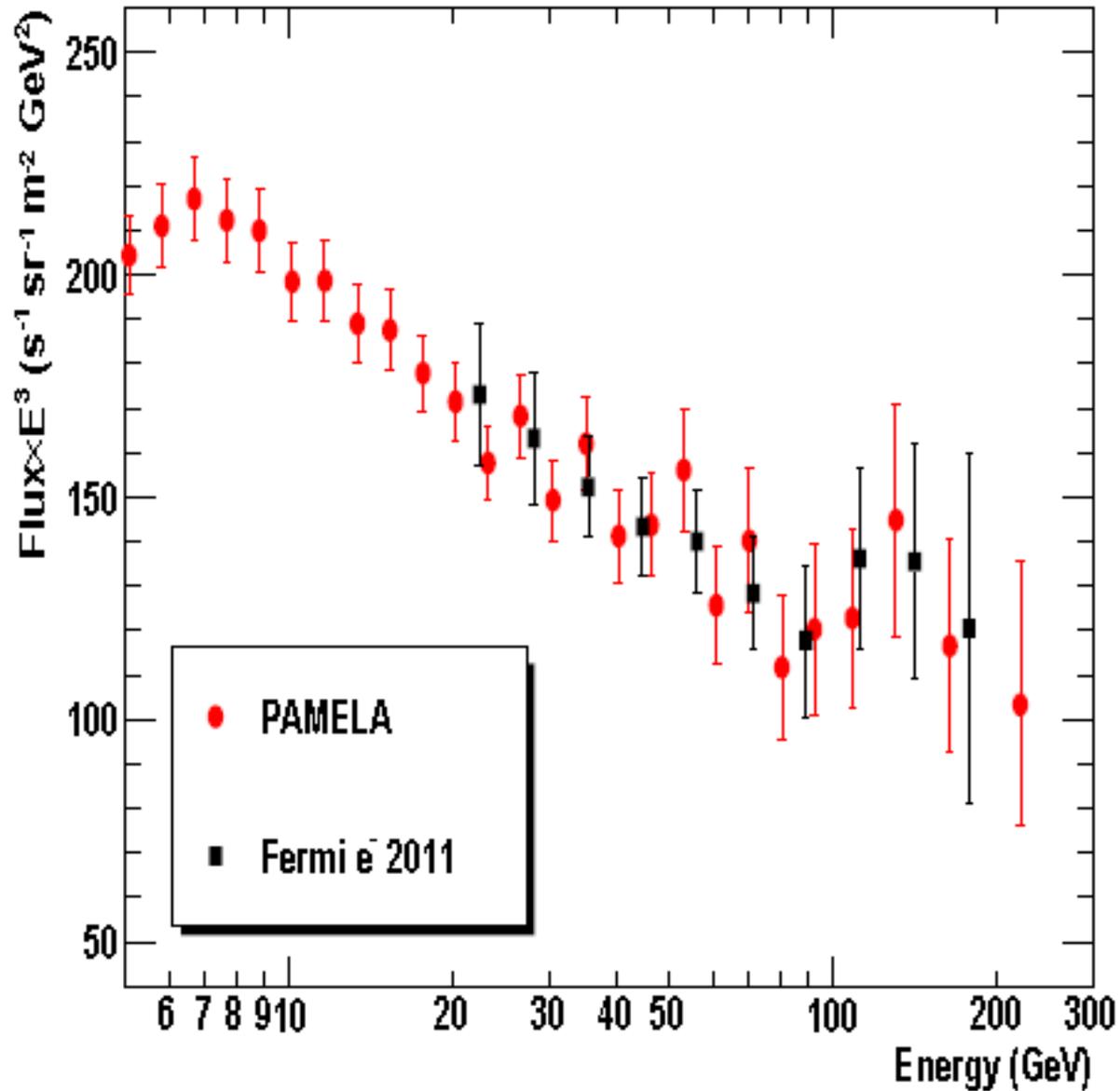
FERMI



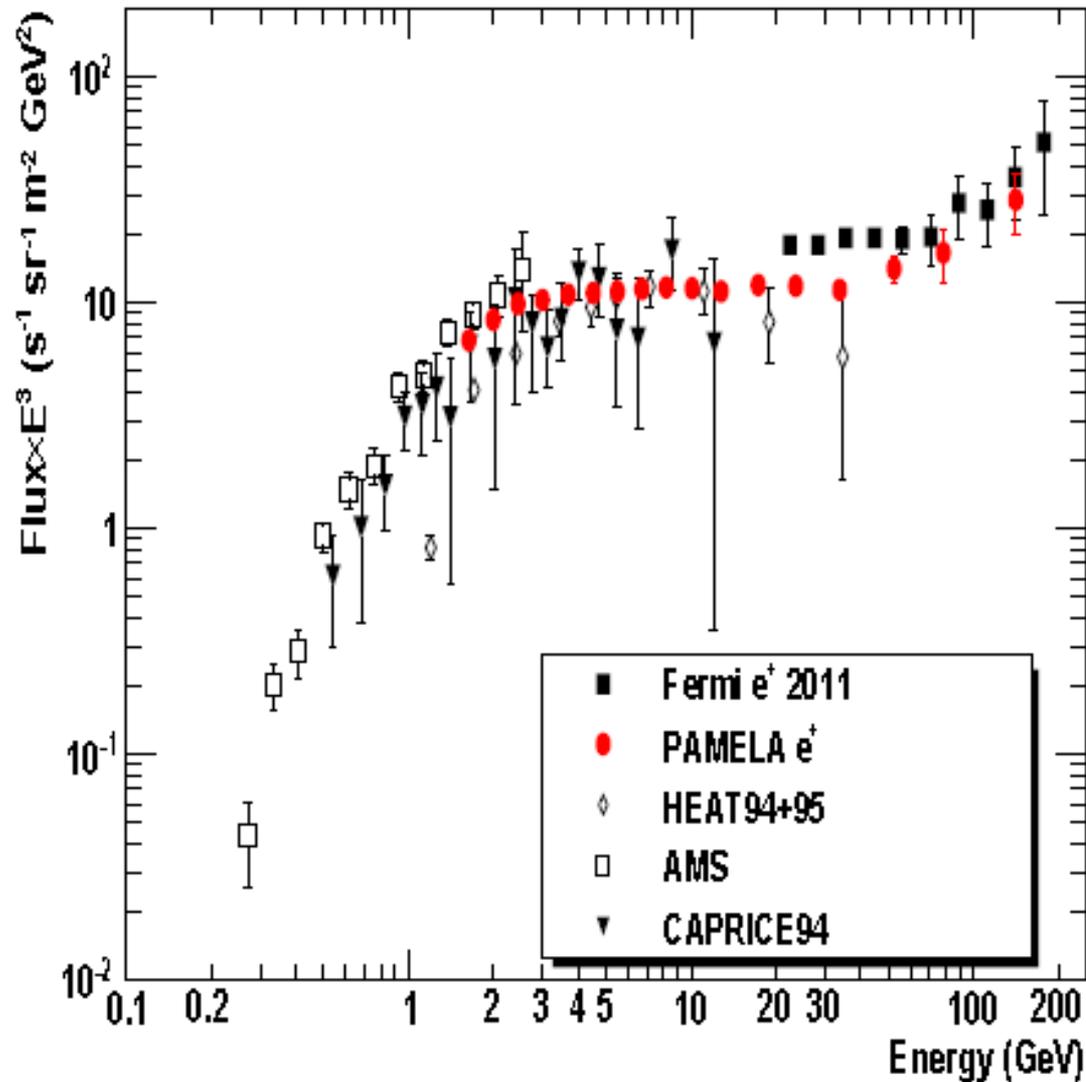
Electron flux



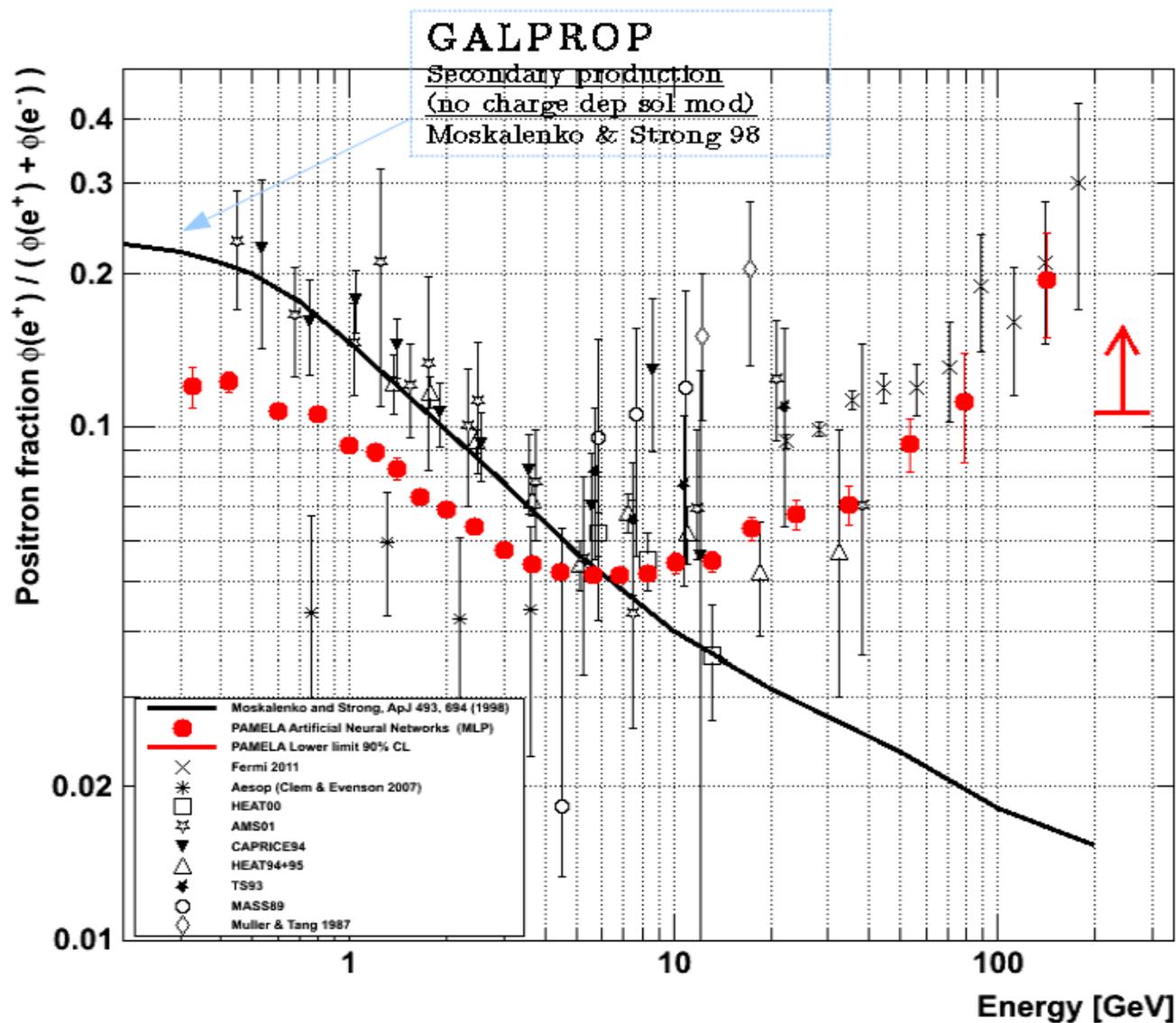
PAMELA and FERMI electrons



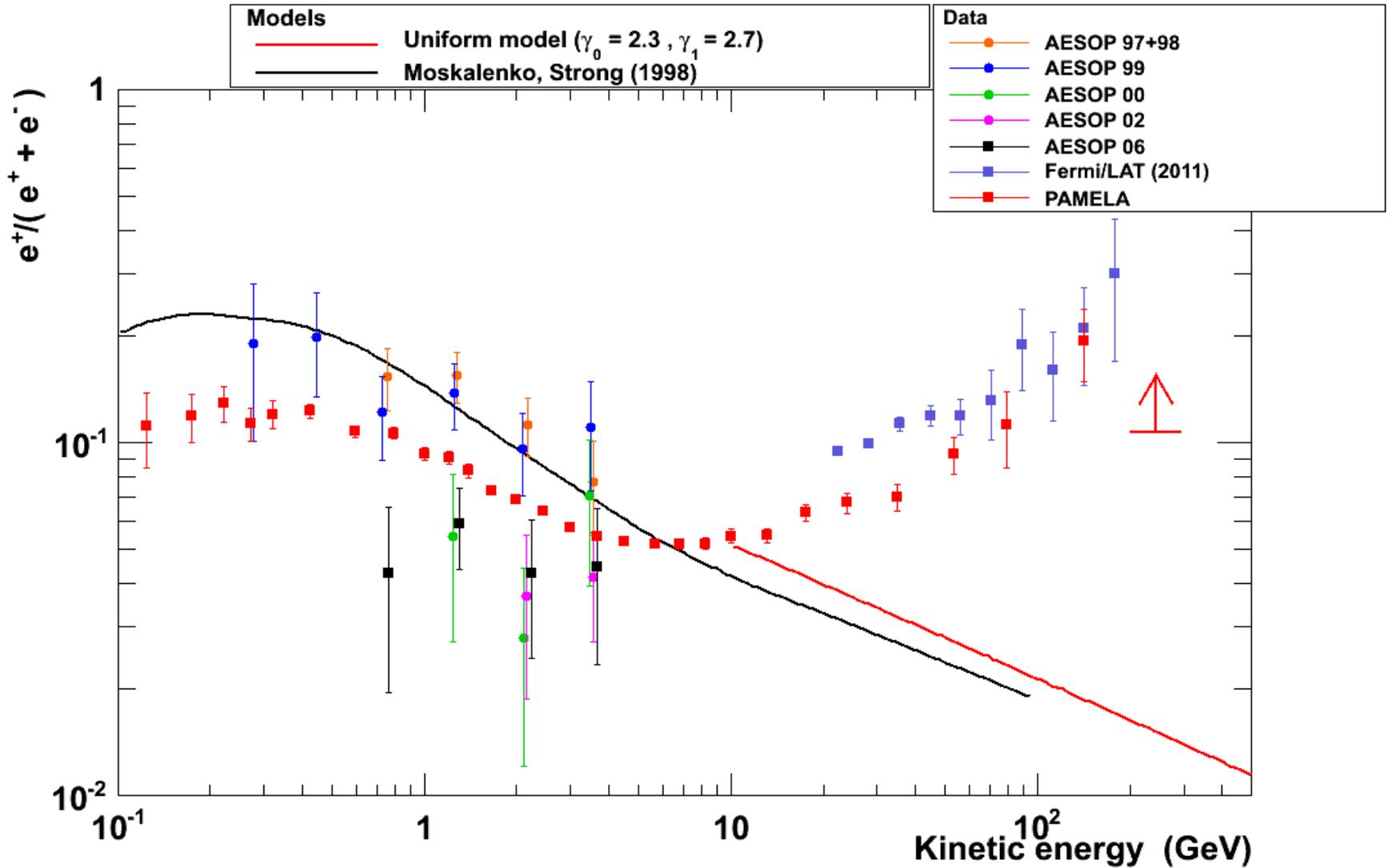
Positrons



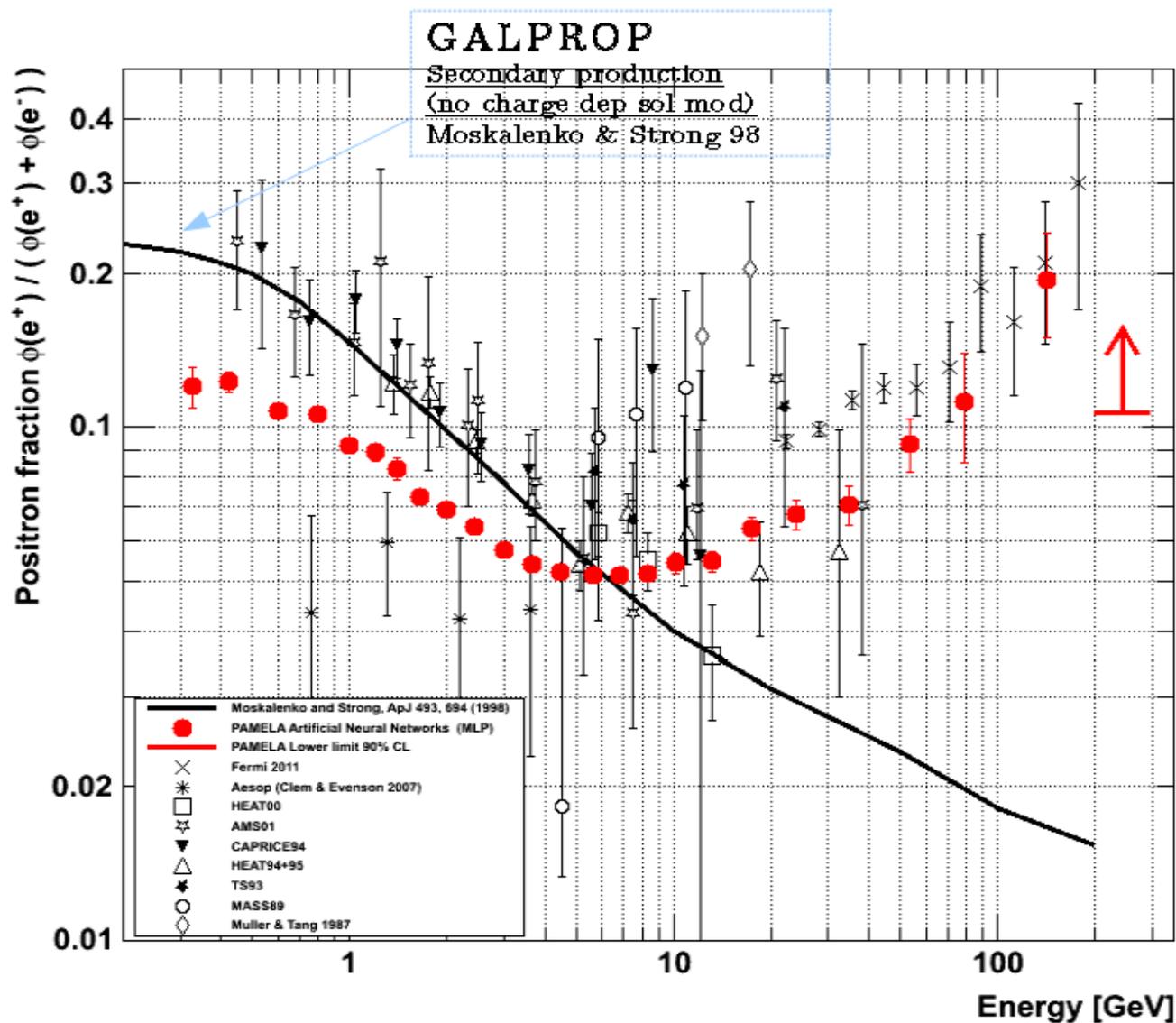
Positron fraction



PAMELA and AESOP DATA

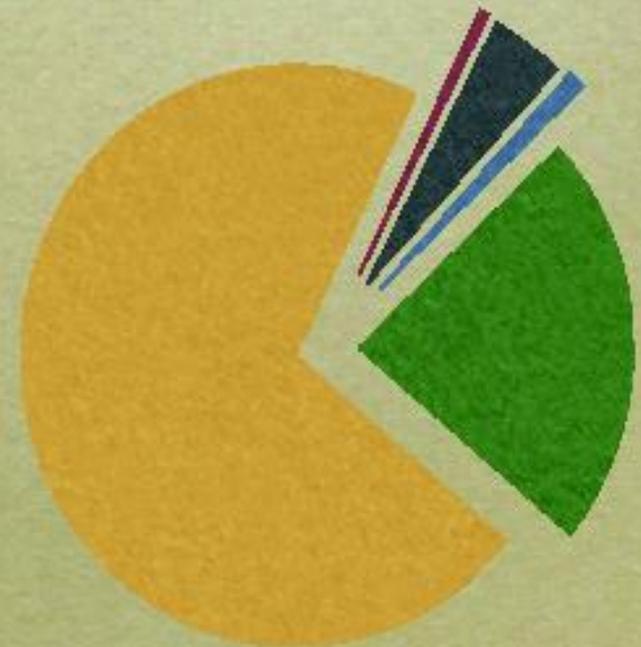


Positron fraction



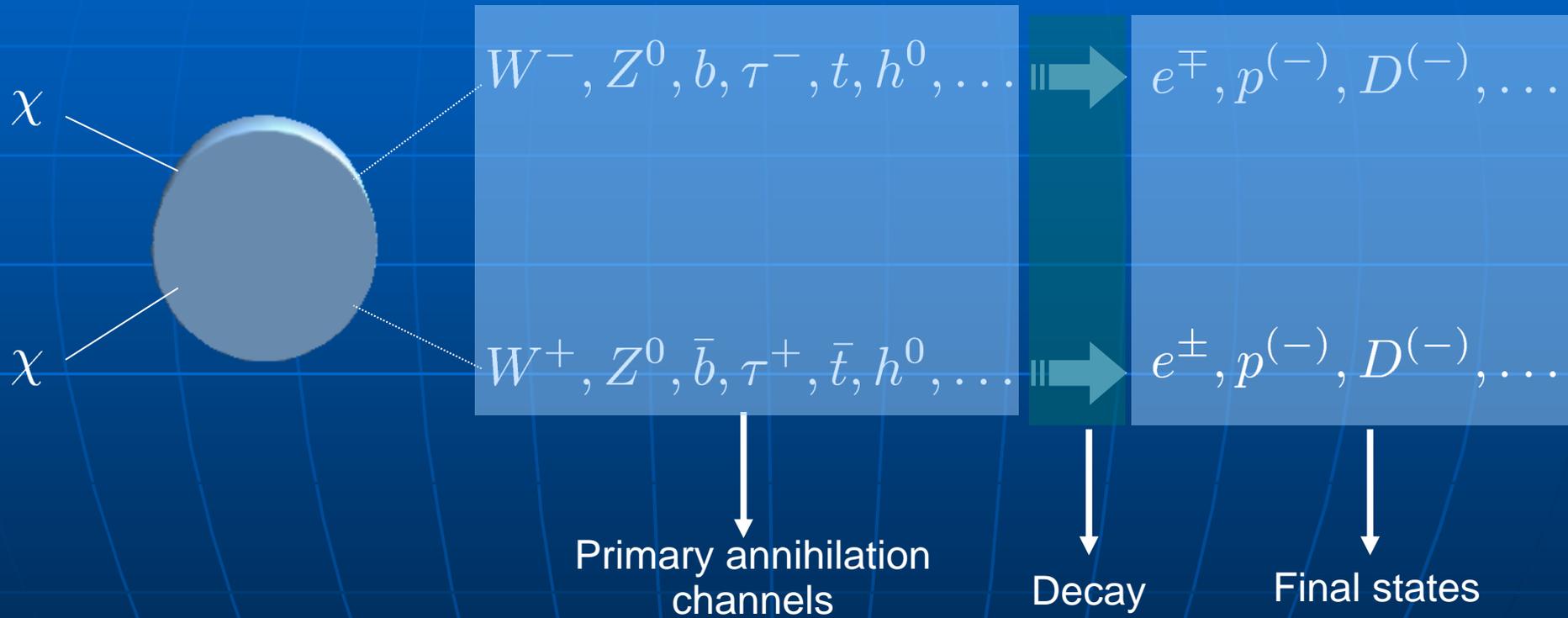
THE UNIVERSE ENERGY BUDGET

- *Stars and galaxies are only ~0.5%*
- *Neutrinos are ~0.1–1.5%*
- *Rest of ordinary matter
(electrons, protons & neutrons) are 4.4%*
- *Dark Matter 23%*
- *Dark Energy 73%*
- *Anti-Matter 0%*
- *Higgs Bose-Einstein condensate
~10⁶²%??*



DM annihilations

DM particles are stable. They can annihilate in pairs.

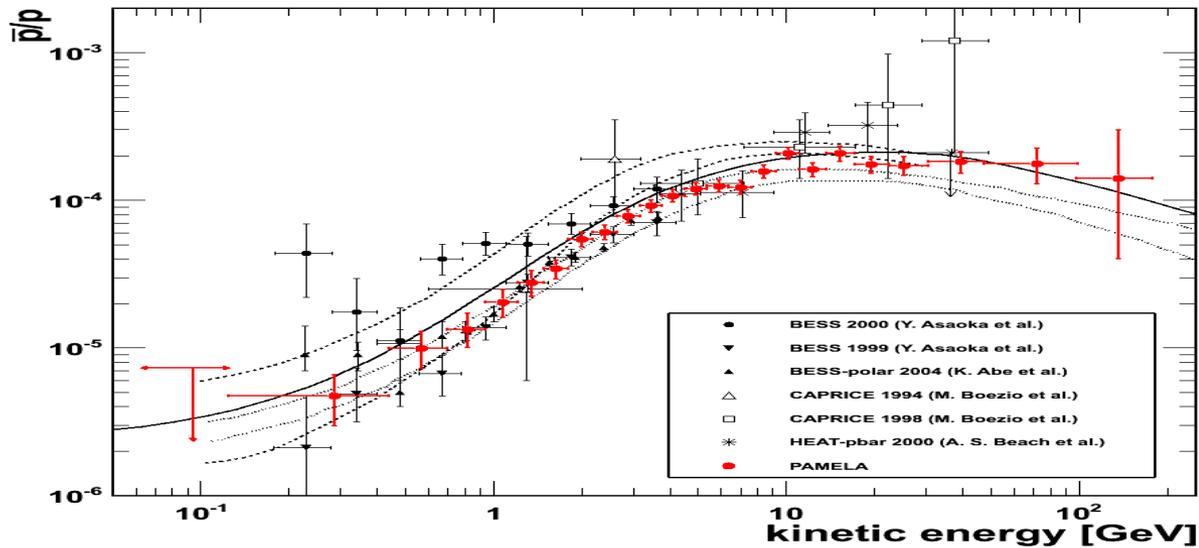
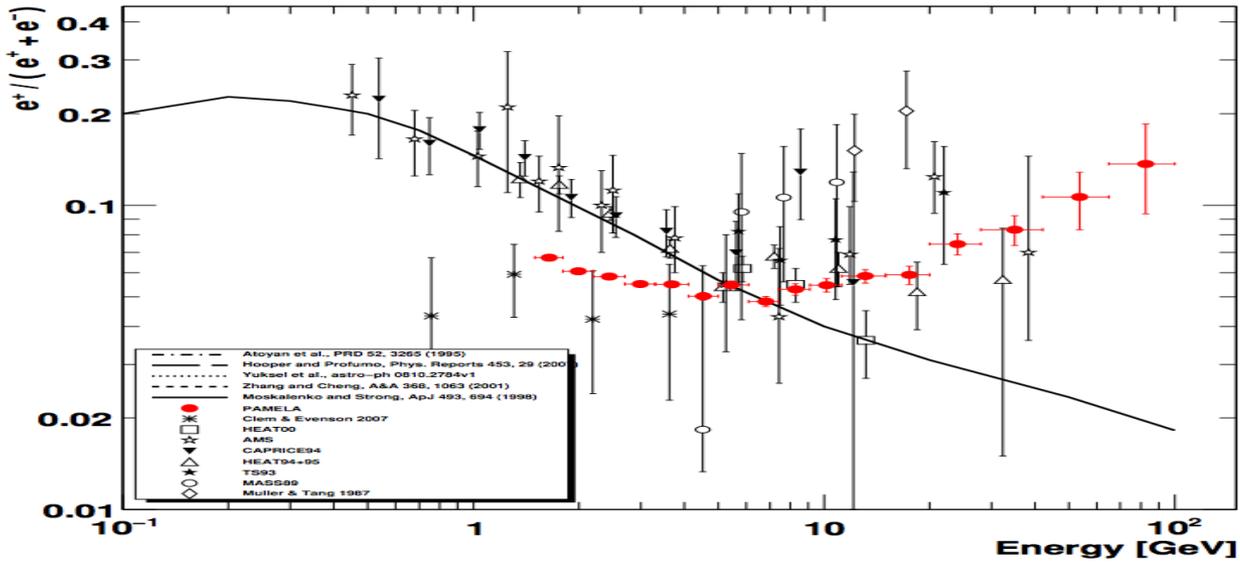


flux $\propto n^2 \sigma_{\text{annihilation}}$
 astro&cosmo particle

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

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

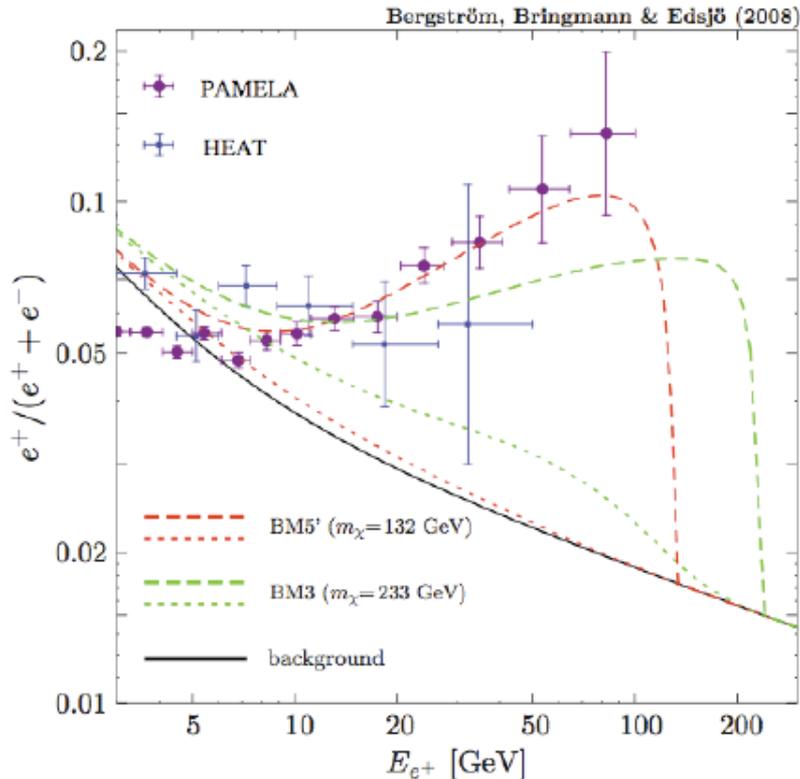
A Challenging Puzzle for CR Physics



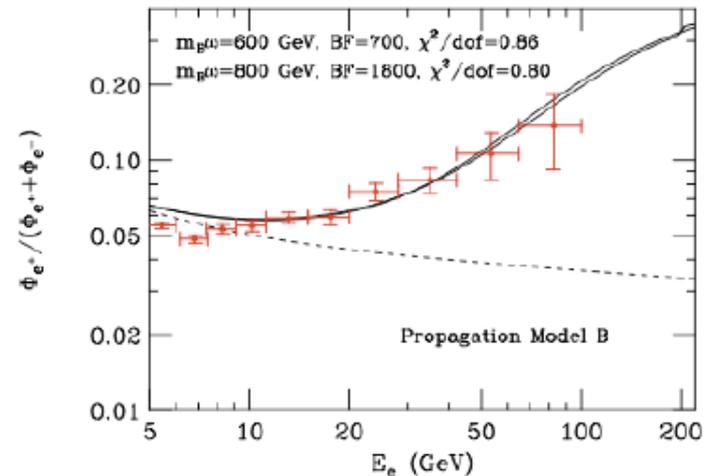
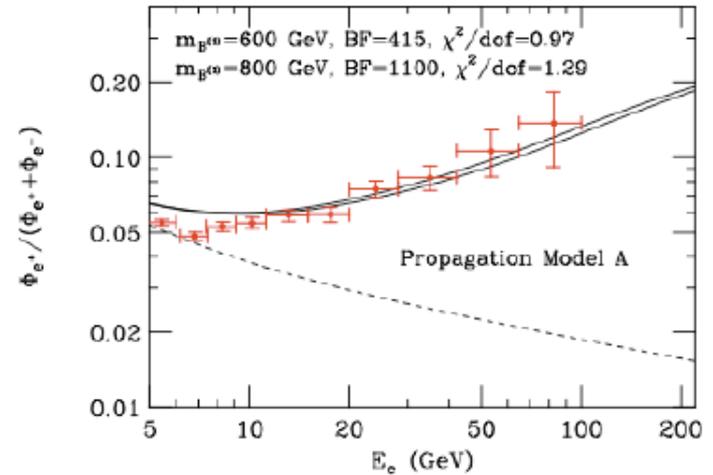
Example: Dark Matter

Phys.Rev.D79:103529,2009

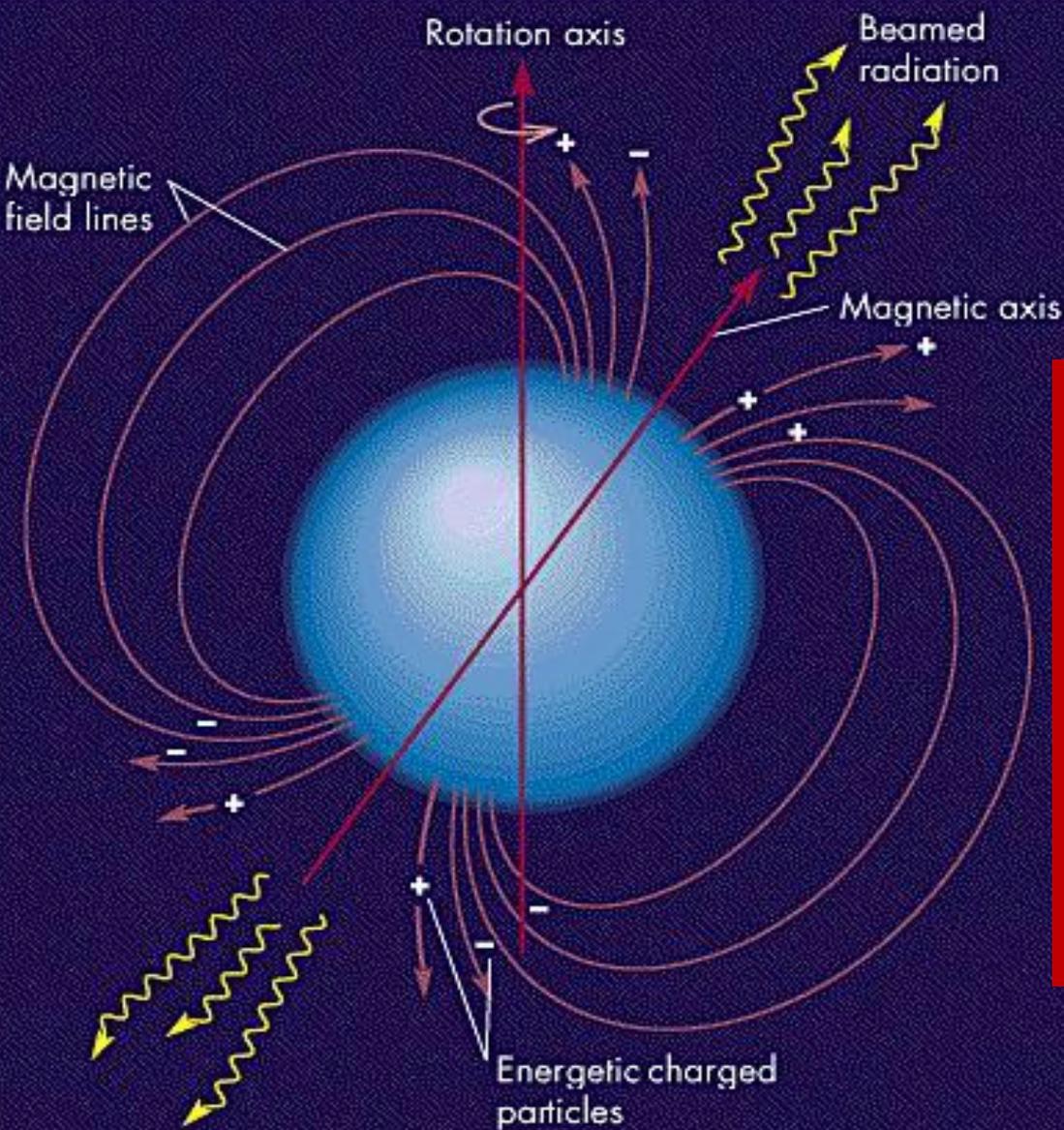
Phys.Rev.D8:103520,2008



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



Kaluza-Klein dark matter

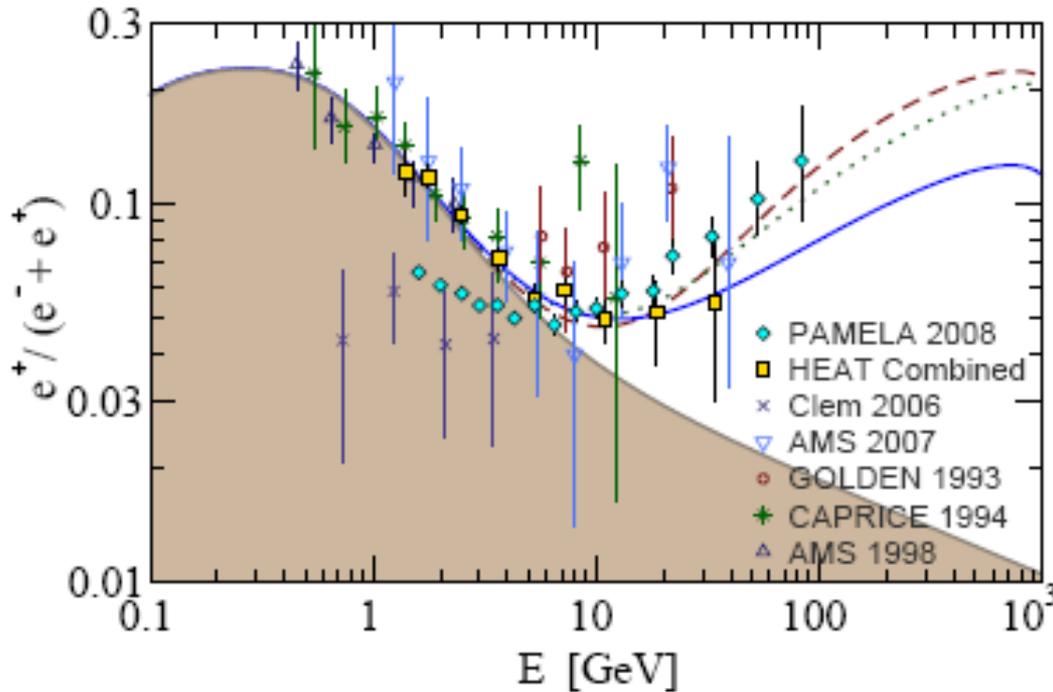


**A NEUTRON STAR WITH A
STRONG MAGNETIC FIELD:**

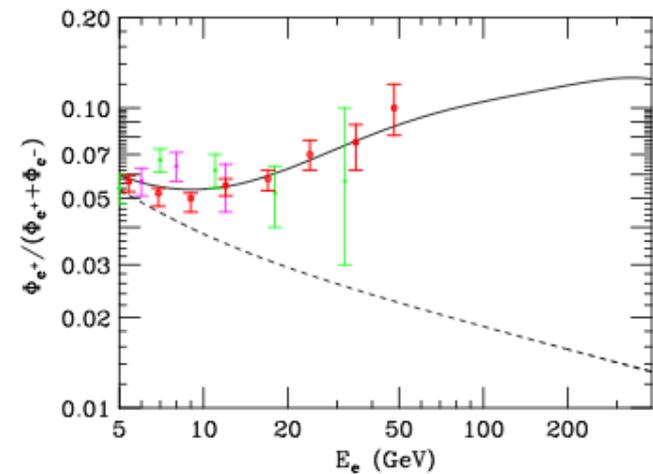
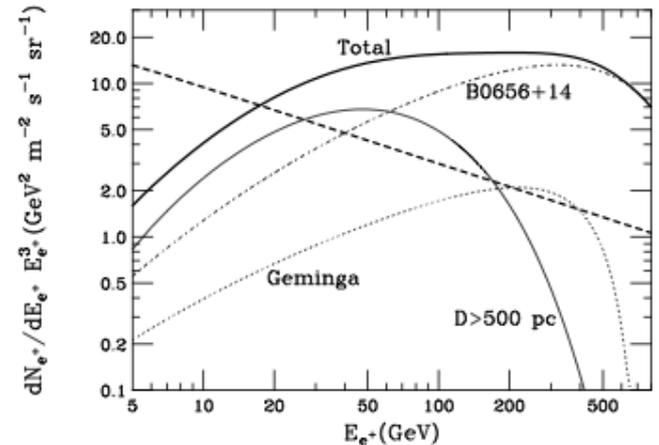
**FAST ROTATING PULSAR
(P = 33 msec)**

$L(\text{spindown}) = 5 \cdot 10^{38} \text{ erg/s}$

Example: pulsars

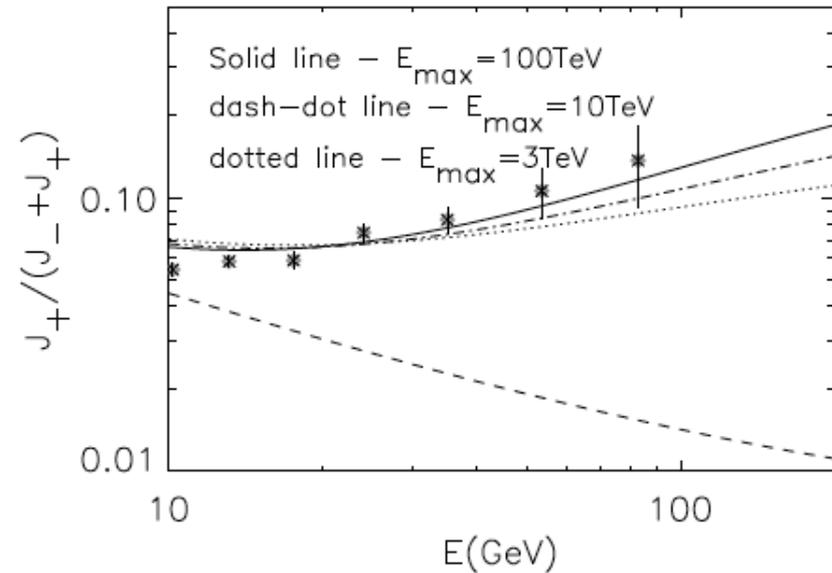


H. Yüksak et al., arXiv:0810.2784v2
Contributions of e^- & e^+ from
Geminga assuming different distance,
age and energetic of the pulsar



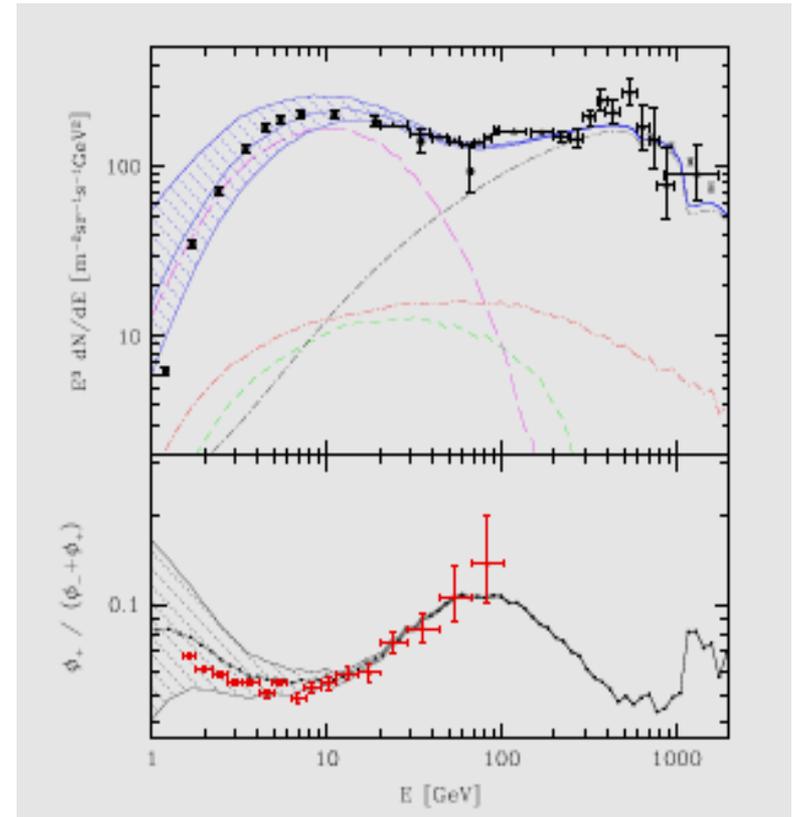
Hooper, Blasi, and Serpico
arXiv:0810.1527

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.

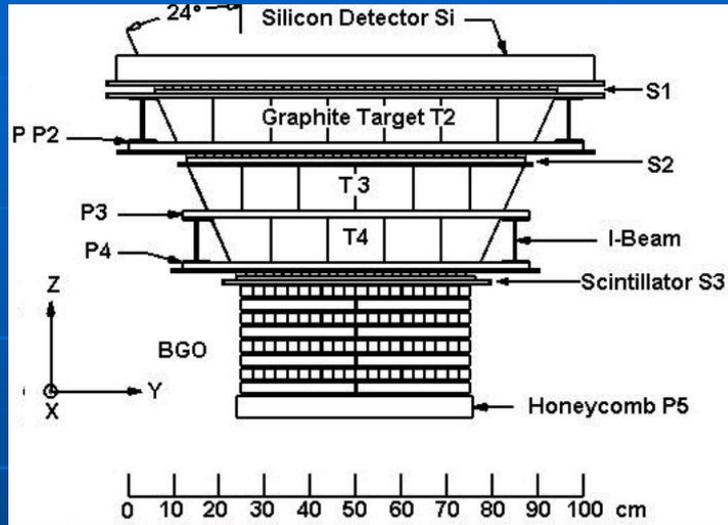
Y. Fujita
Phys. Rev. D 80:063003, 2009



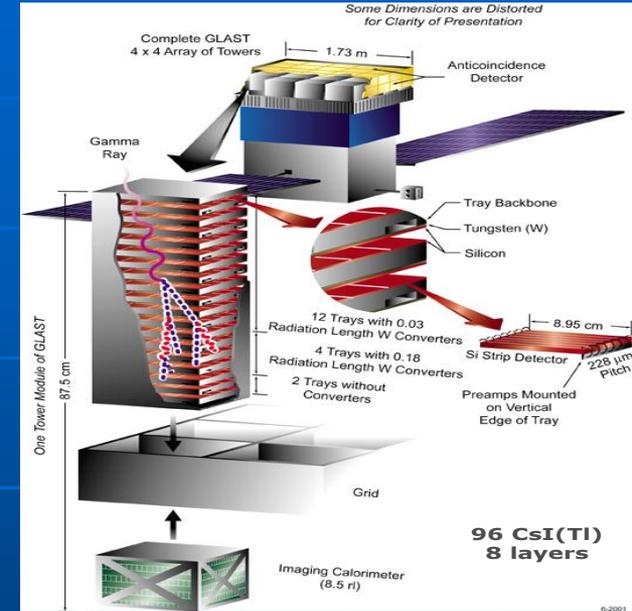
N.J. Shaviv et al.,
PRL 103 (2009) 111302;

All electron spectrum

ATIC



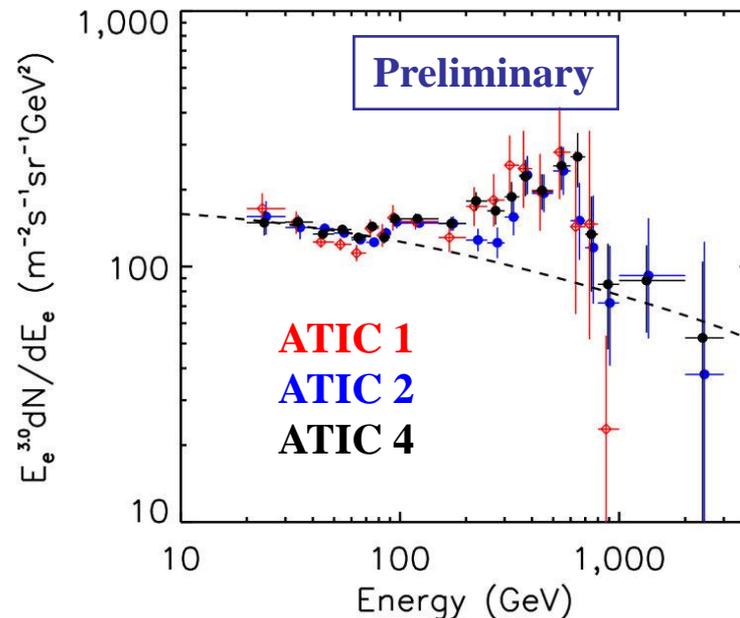
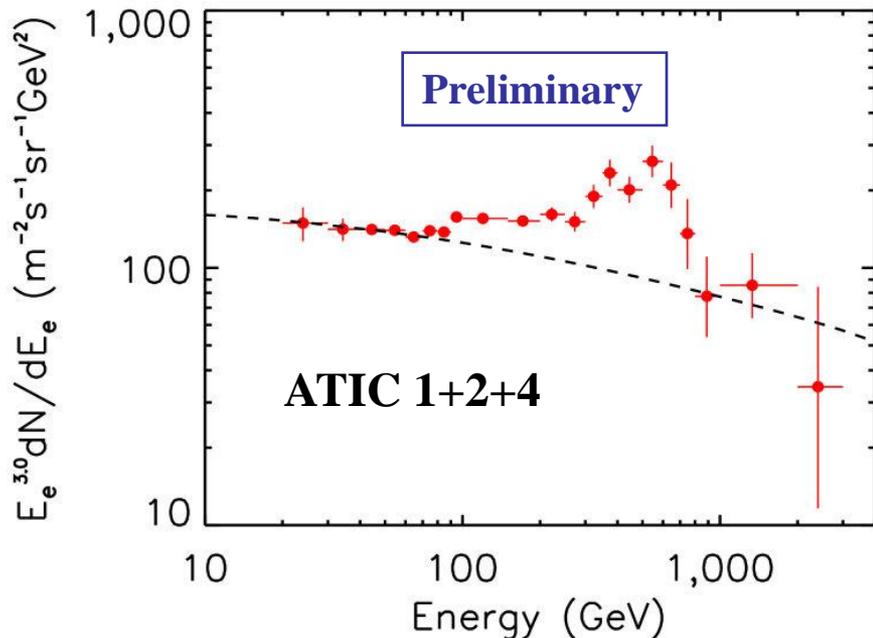
Fermi/LAT



HESS



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)

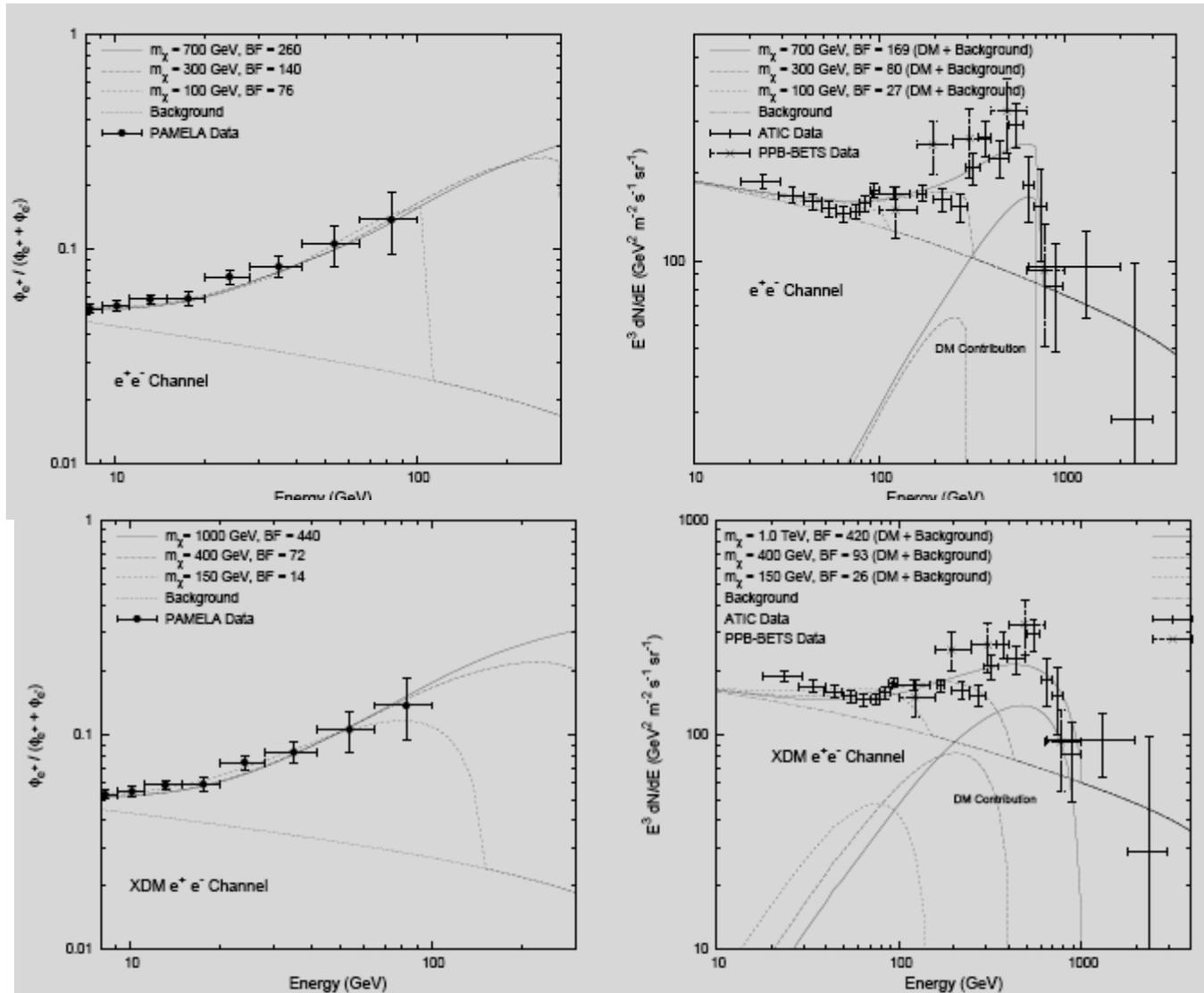
ATIC-4 with 10 BGO layers has improved e, p separation. (**~4x lower background**)

“Bump” is seen in all three flights.

Significance for ATIC1+2+4 is 5.1 sigma

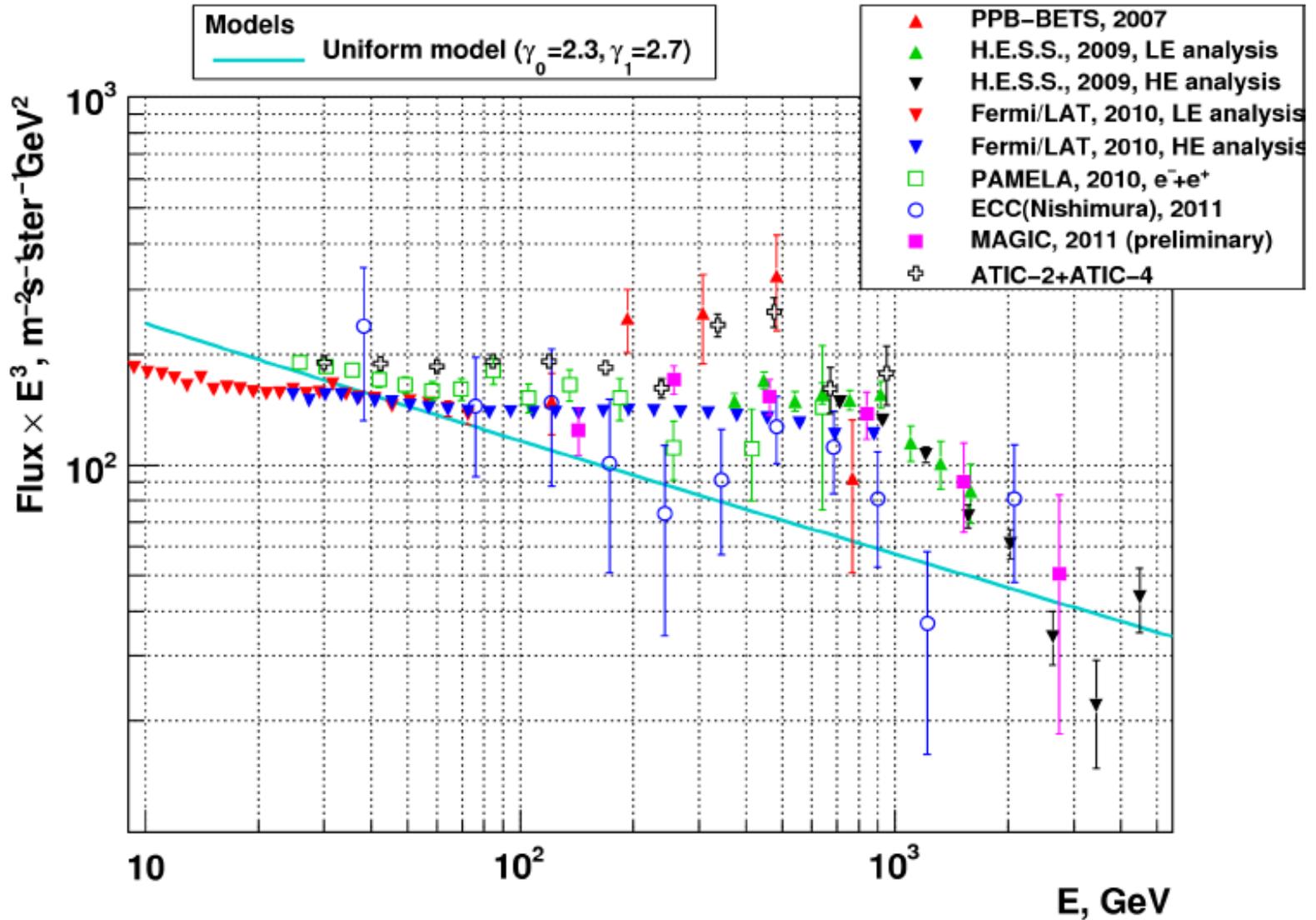
Example: DM

I. Cholis et al. arXiv:0811.3641v1



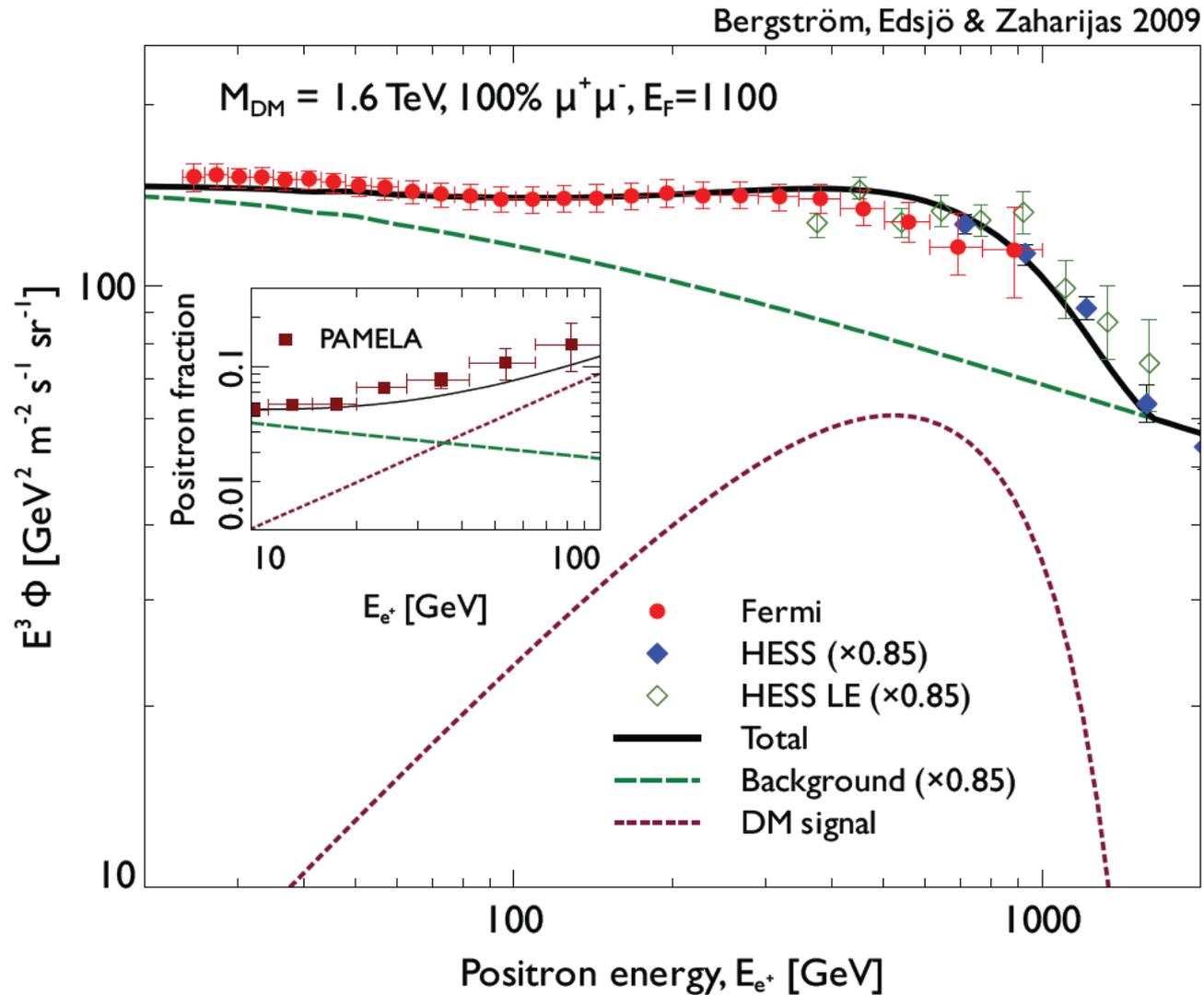
- Propose a new light boson ($m_\Phi \leq \text{GeV}$), such that $\chi\chi \rightarrow \Phi\Phi$; $\Phi \rightarrow e^+e^-, \mu^+\mu^-, \dots$
- Light boson, so decays to antiprotons are kinematically suppressed

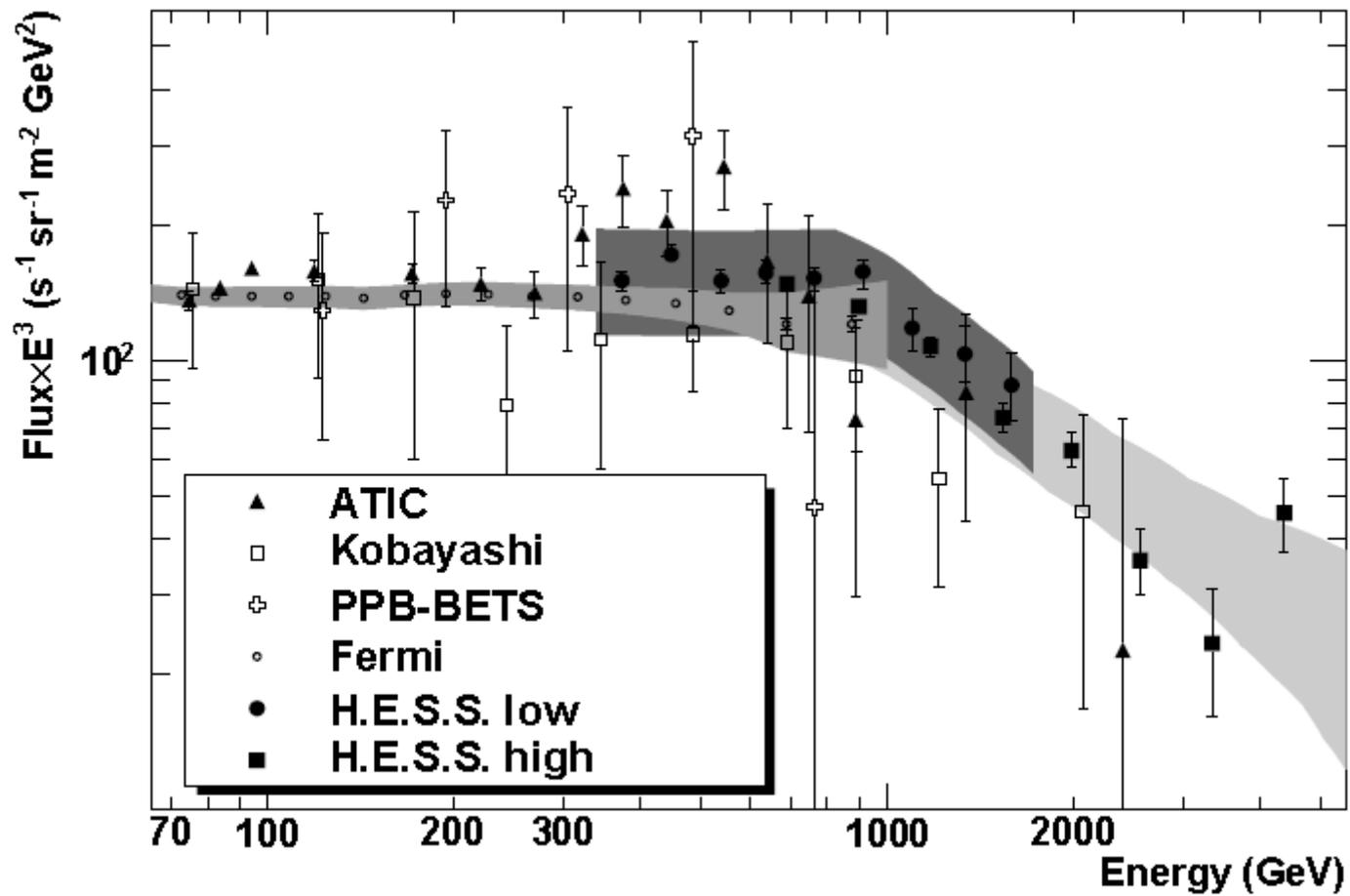
All Electron Spectrum



Fermi ($e^+ + e^-$) and PAMELA ratio

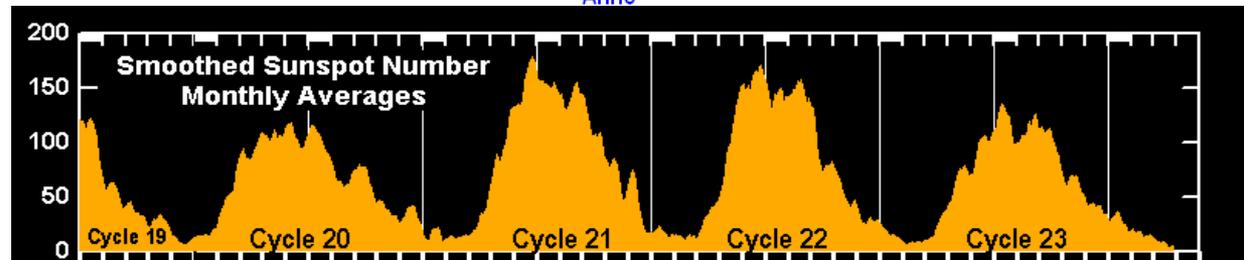
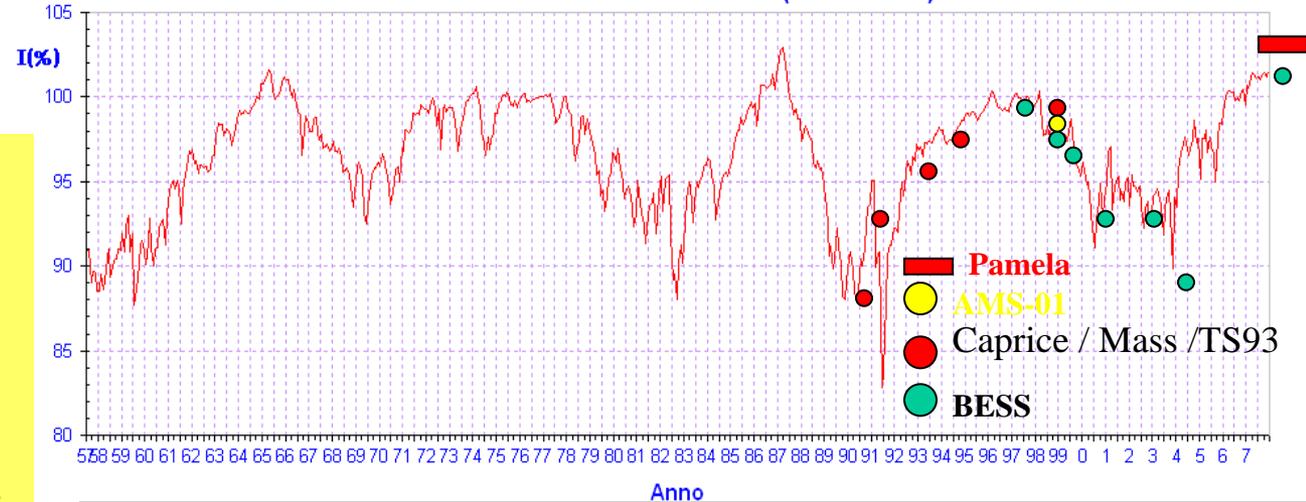
Bergstrom et al. Phys.Rev.Lett.103:031103,2009





Solar Modulation of galactic cosmic rays

Intensità Neutron Monitor di Roma (dati mensili)



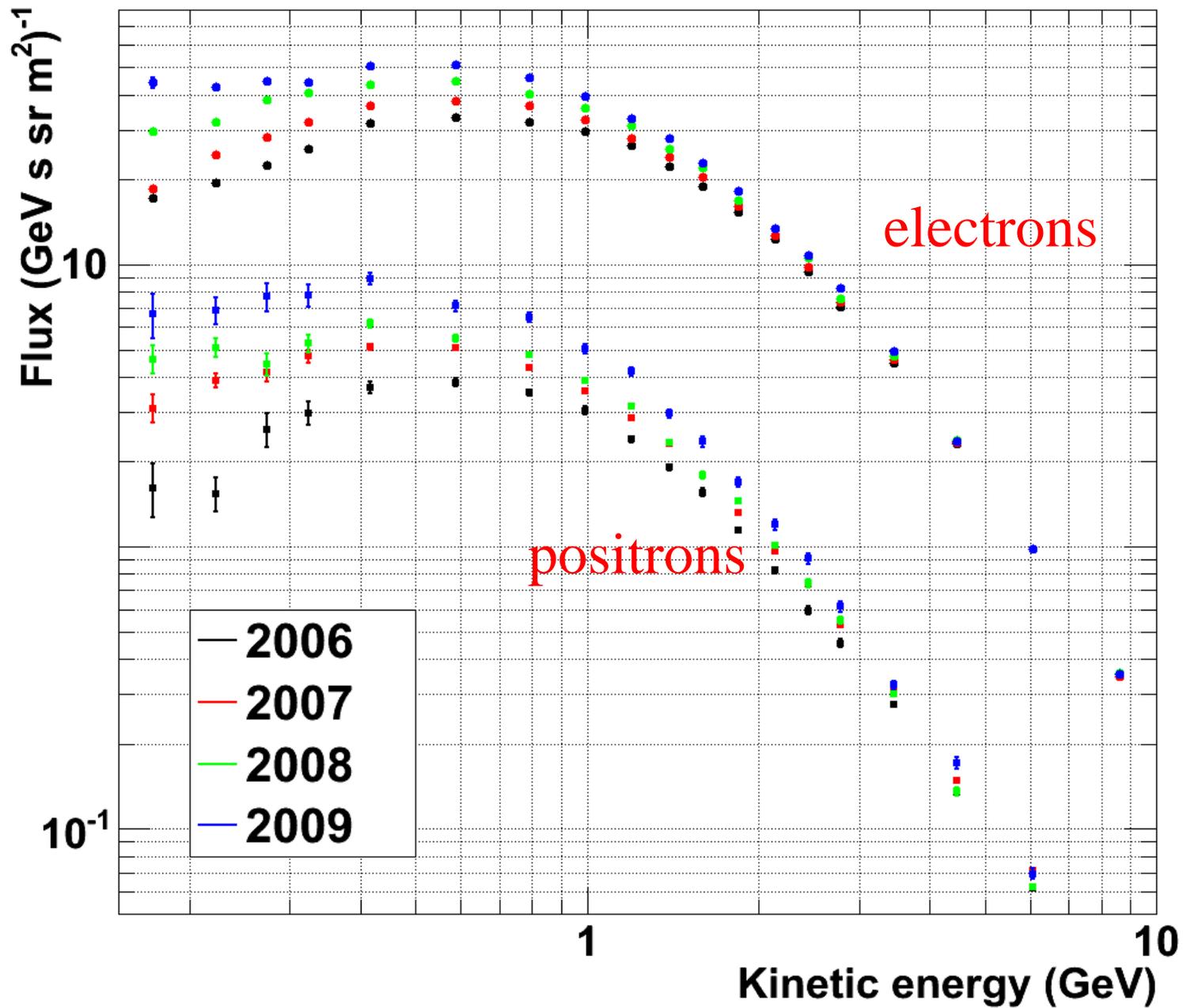
- Study of solar modulation
- Study of charge sign dependent effects

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

Bieber, J.W., et al. Physical Review Letters, 84, 674, 1999.

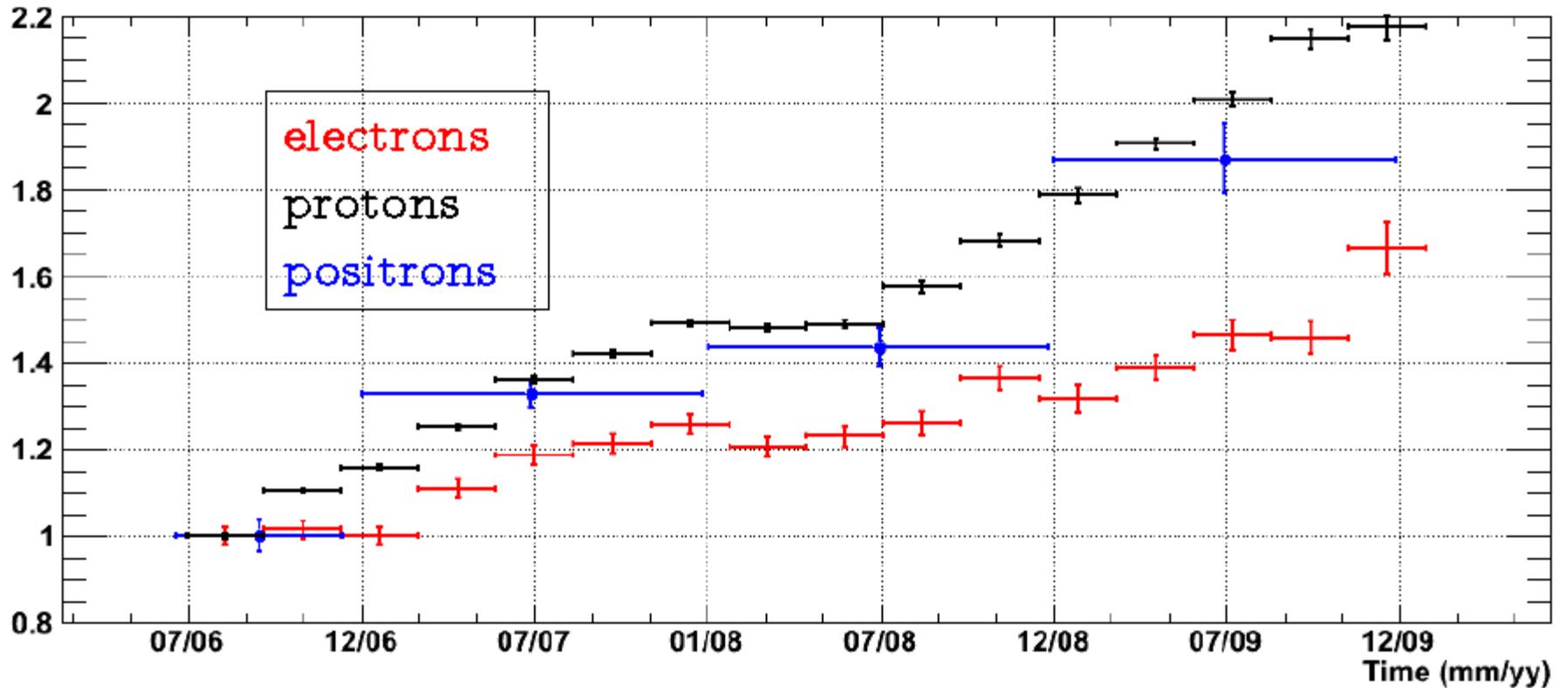
J. Clem et al. 30th ICRC 2007

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

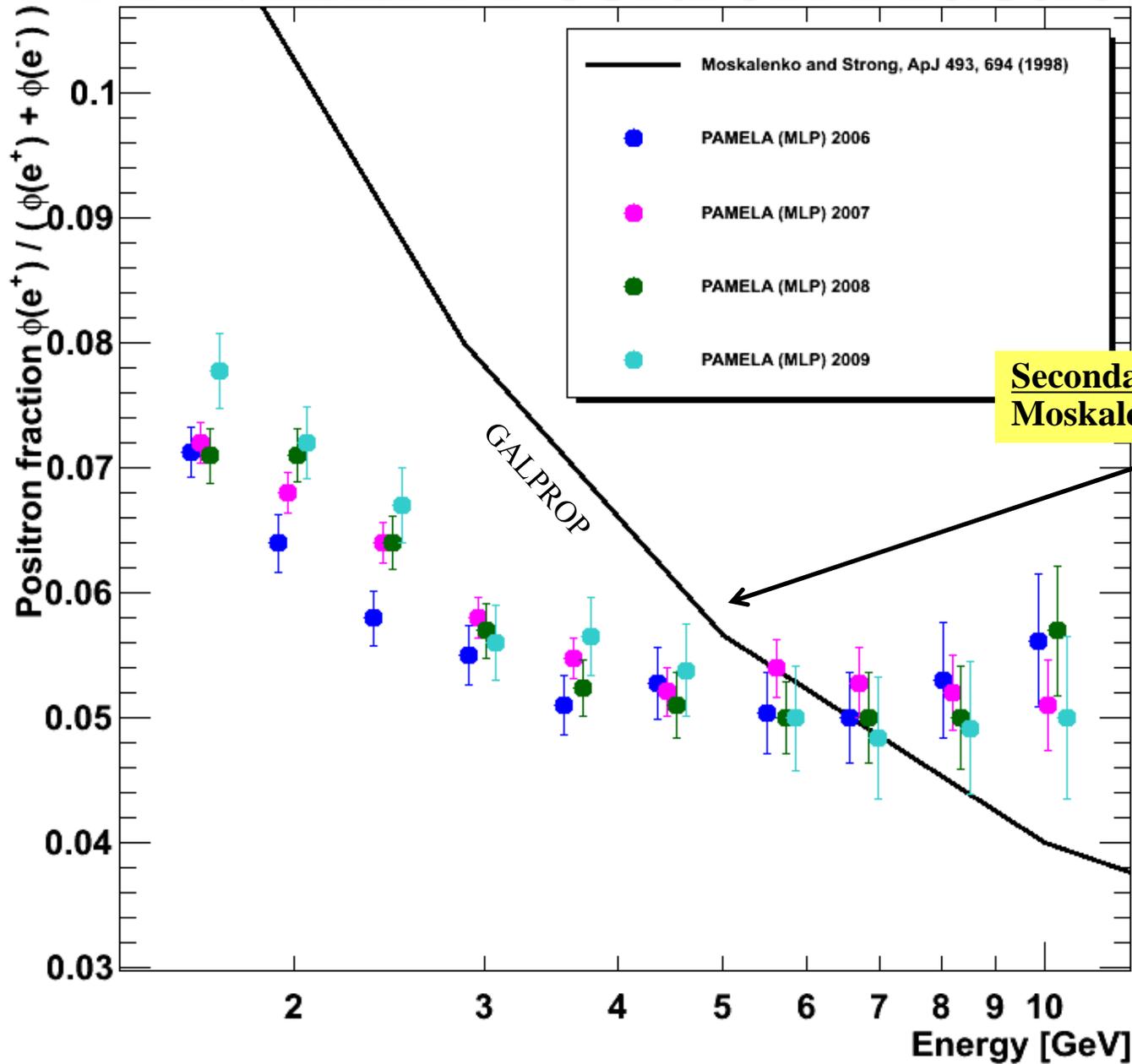


Fluxes in time

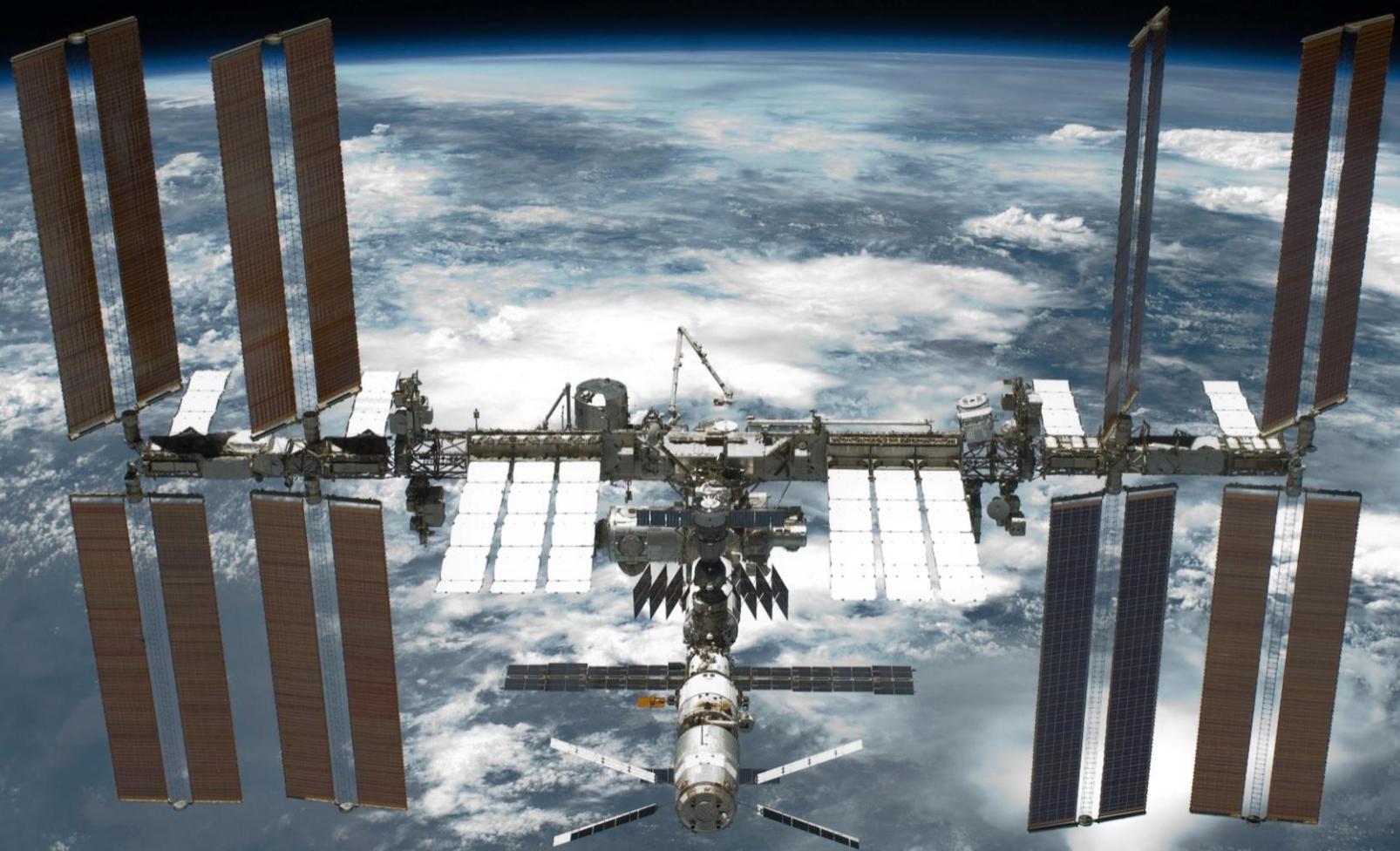
range: 0.4 – 0.71 GeV



PAMELA Positron Fraction

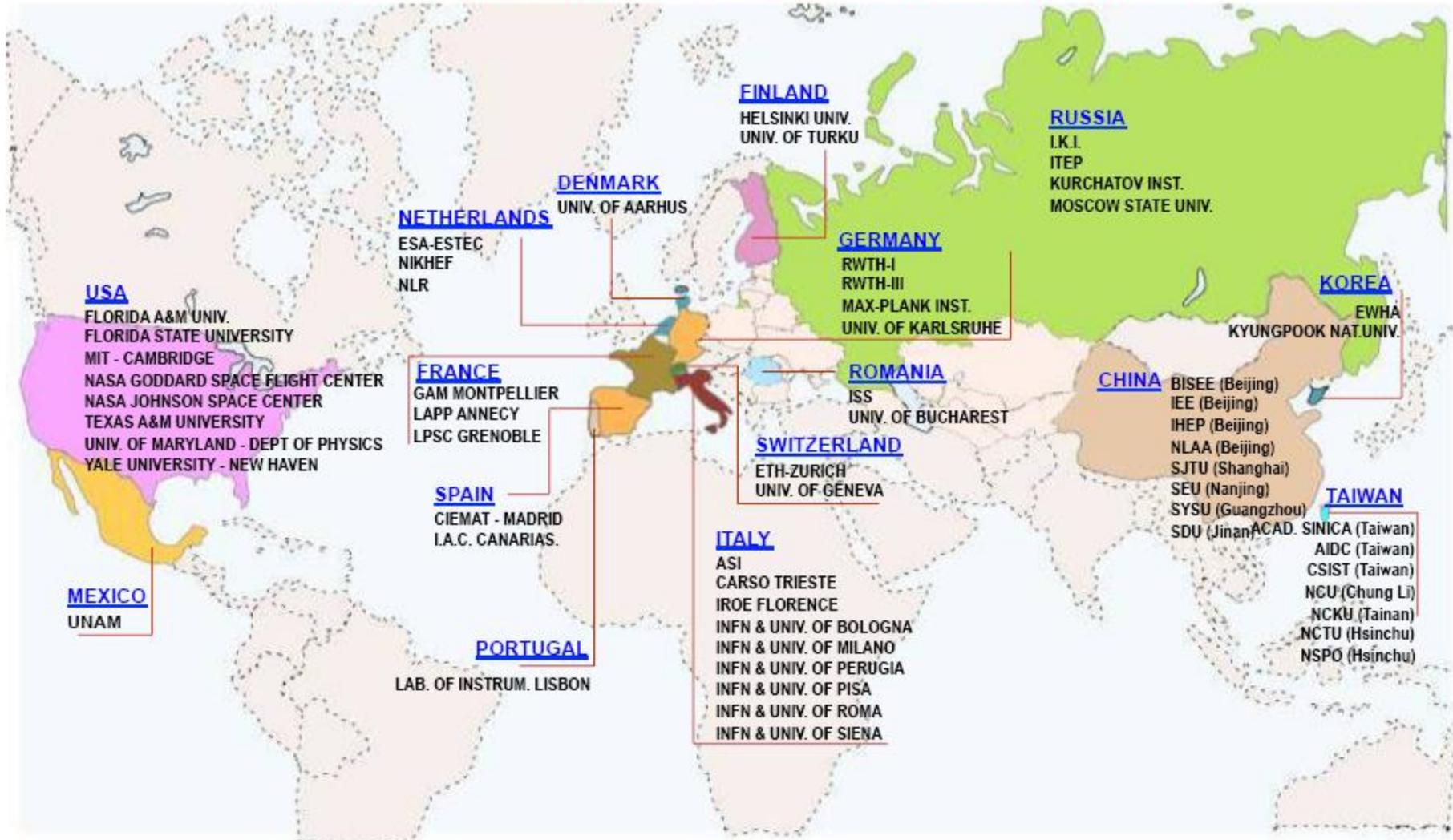


The Alpha Magnetic Spectrometer Experiment on the International Space Station



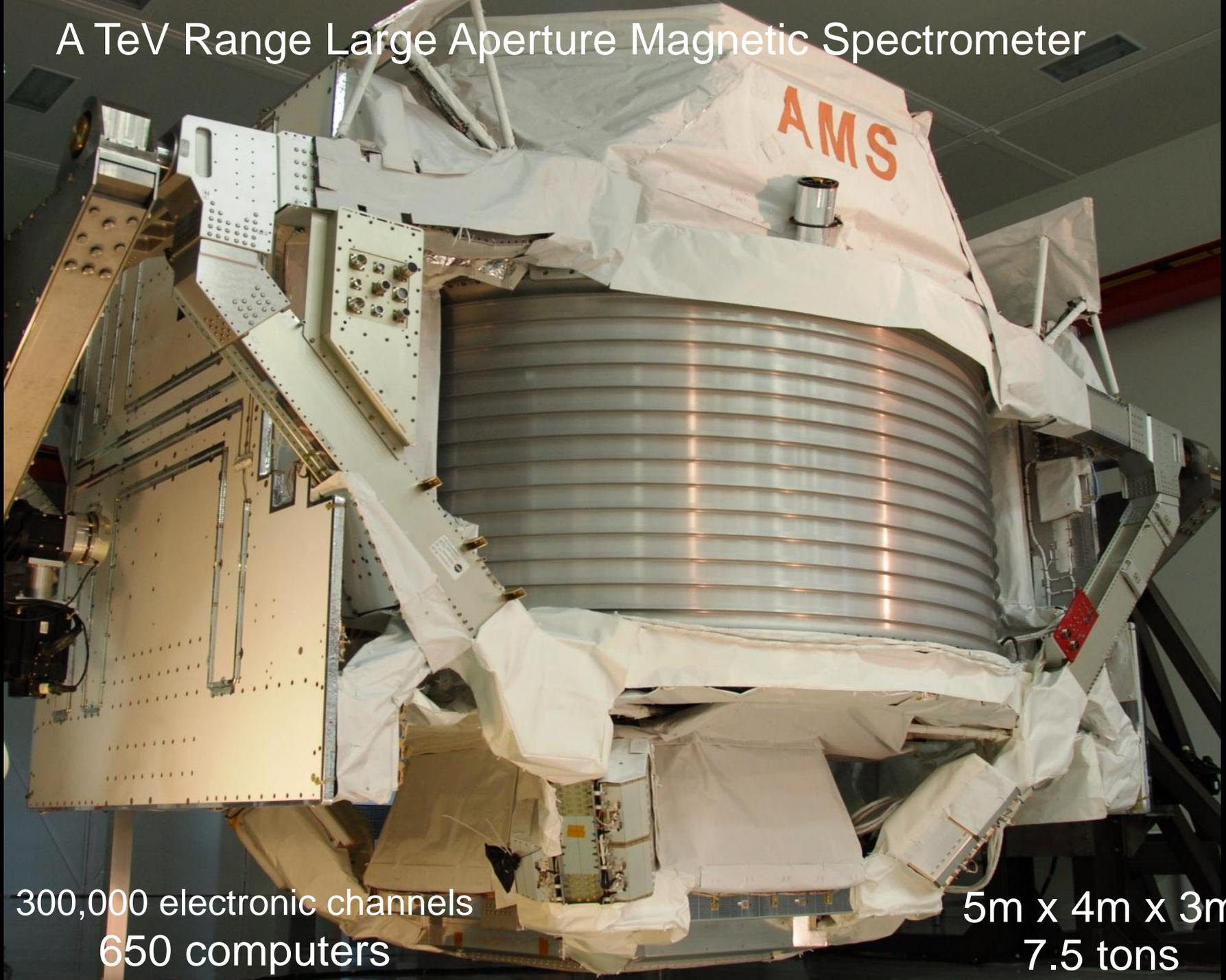
AMS is US Dept of Energy (DOE) led International Collaboration

16 Countries, 60 Institutes and 600 Physicists, 17 years



The detectors were built all over the world and assembled at CERN, near Geneva, Switzerland

A TeV Range Large Aperture Magnetic Spectrometer



300,000 electronic channels
650 computers

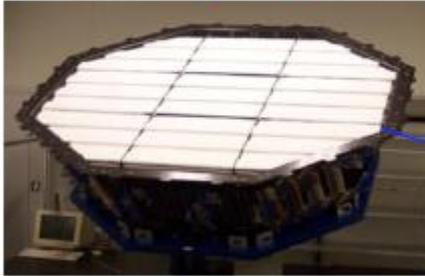
5m x 4m x 3m
7.5 tons

**AMS is installed on the ISS
Truss and fully operational
since May 19, 2011**



AMS consists of 5 sub-detectors which provide redundant information for particle identification

TRD
Identify e^+ , e^-



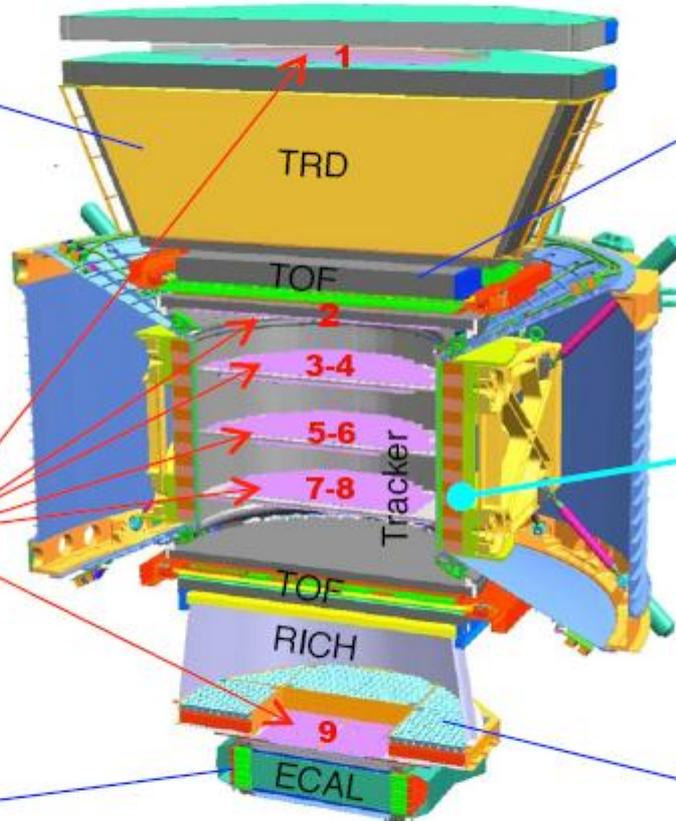
Silicon Tracker
 Z, P



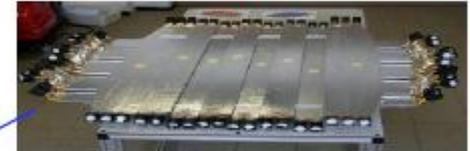
ECAL
 E of e^+ , e^- , γ



Particles and nuclei are defined by their charge (Z) and energy ($E \sim P$)



TOF
 Z, E



Magnet
 $\pm Z$



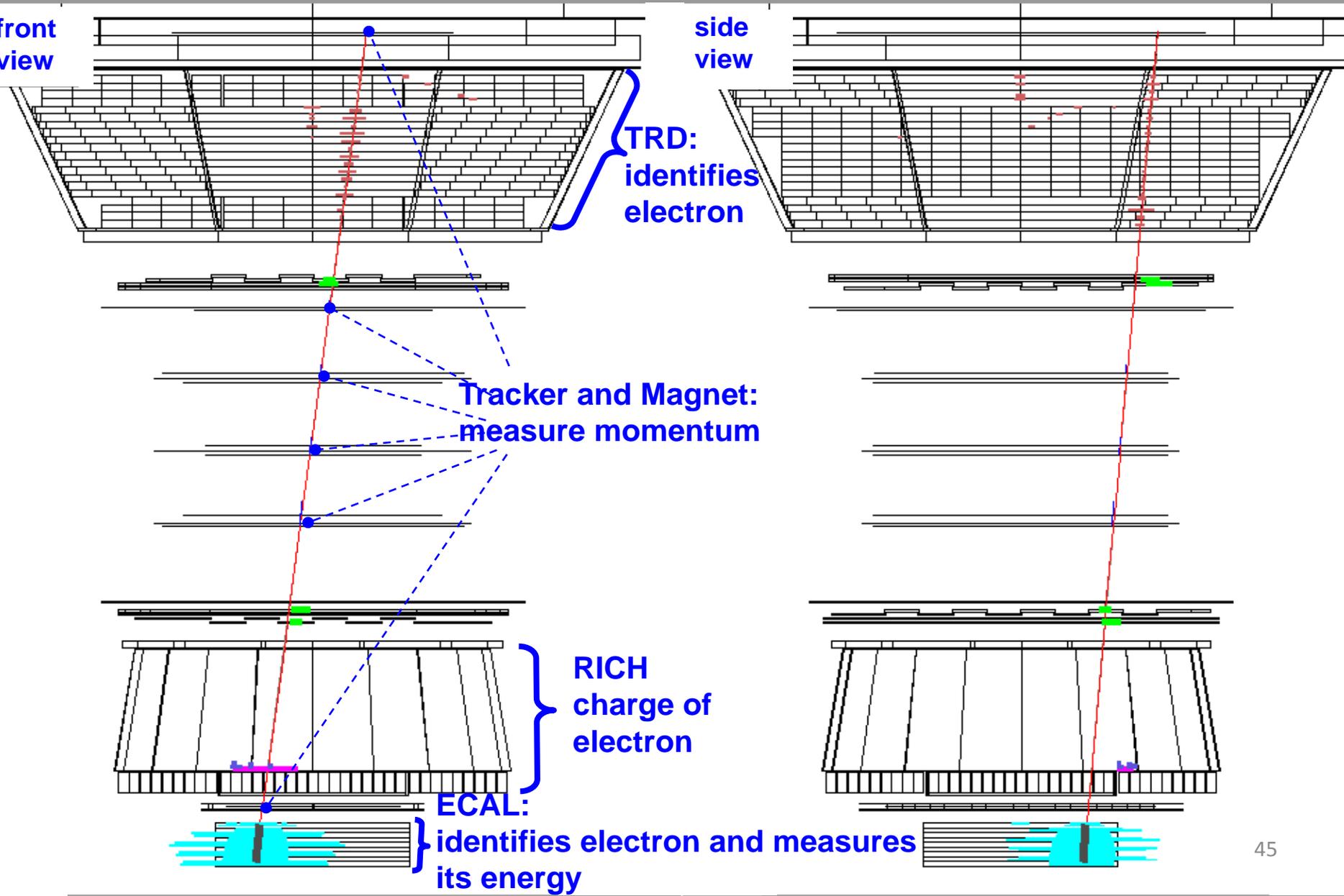
RICH
 Z, E



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

front view

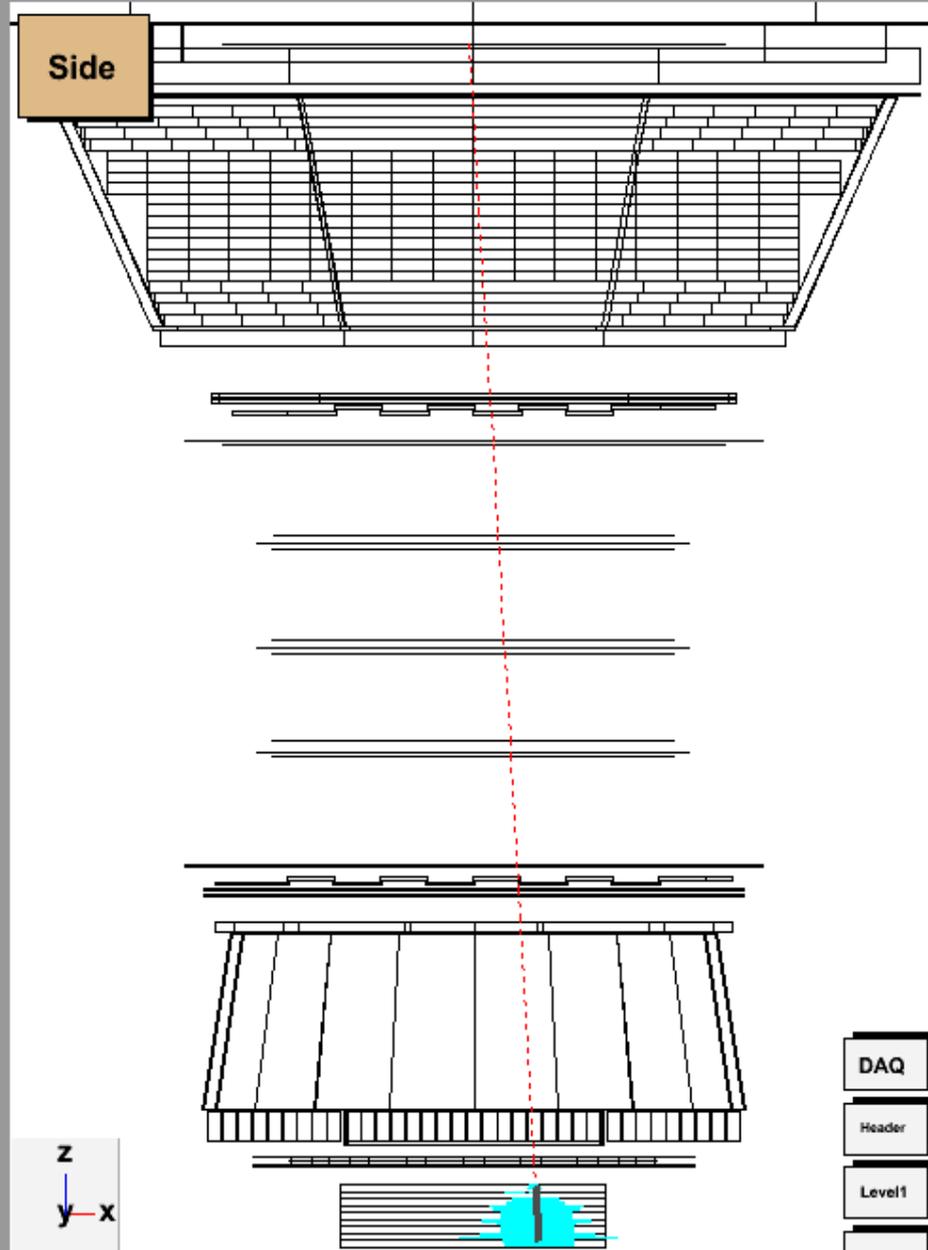
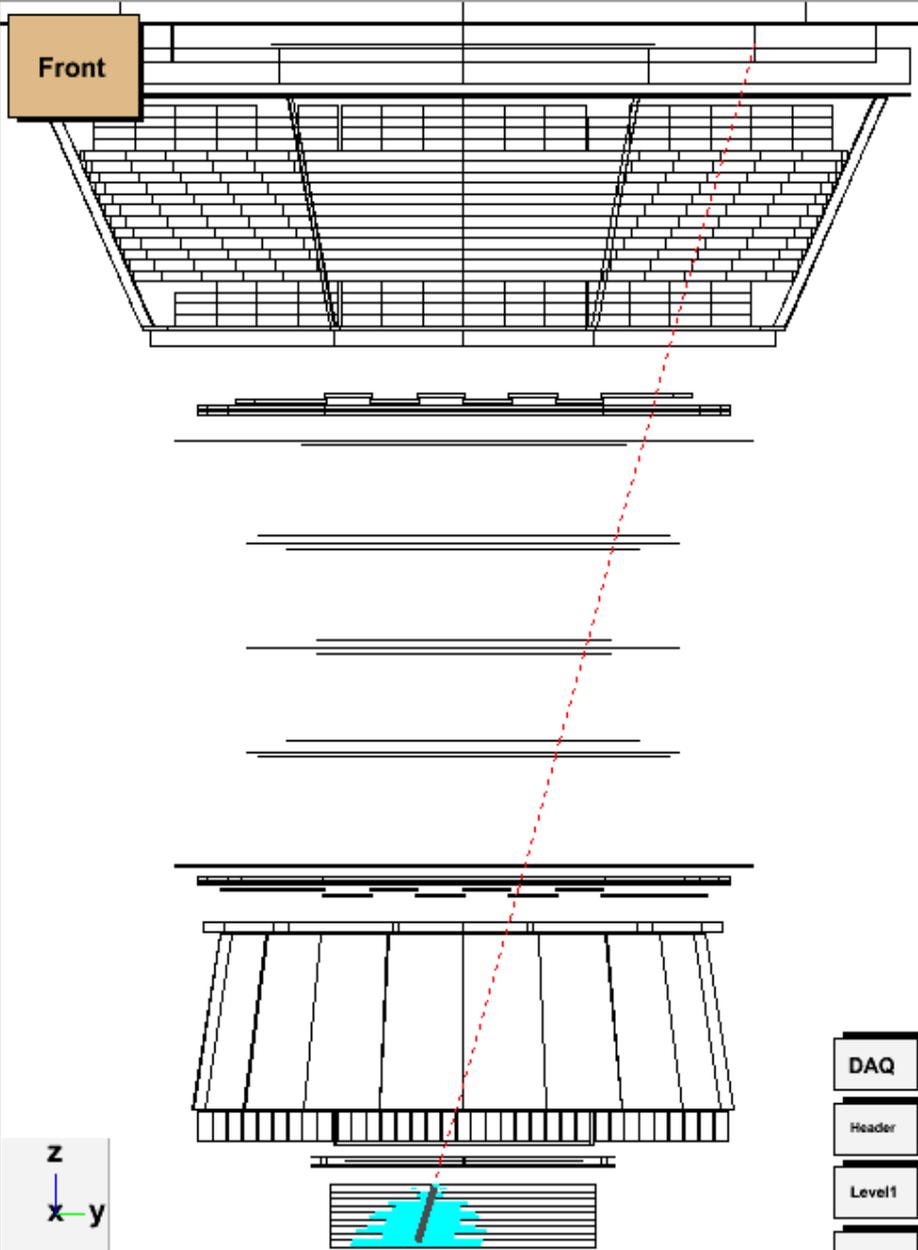
side view



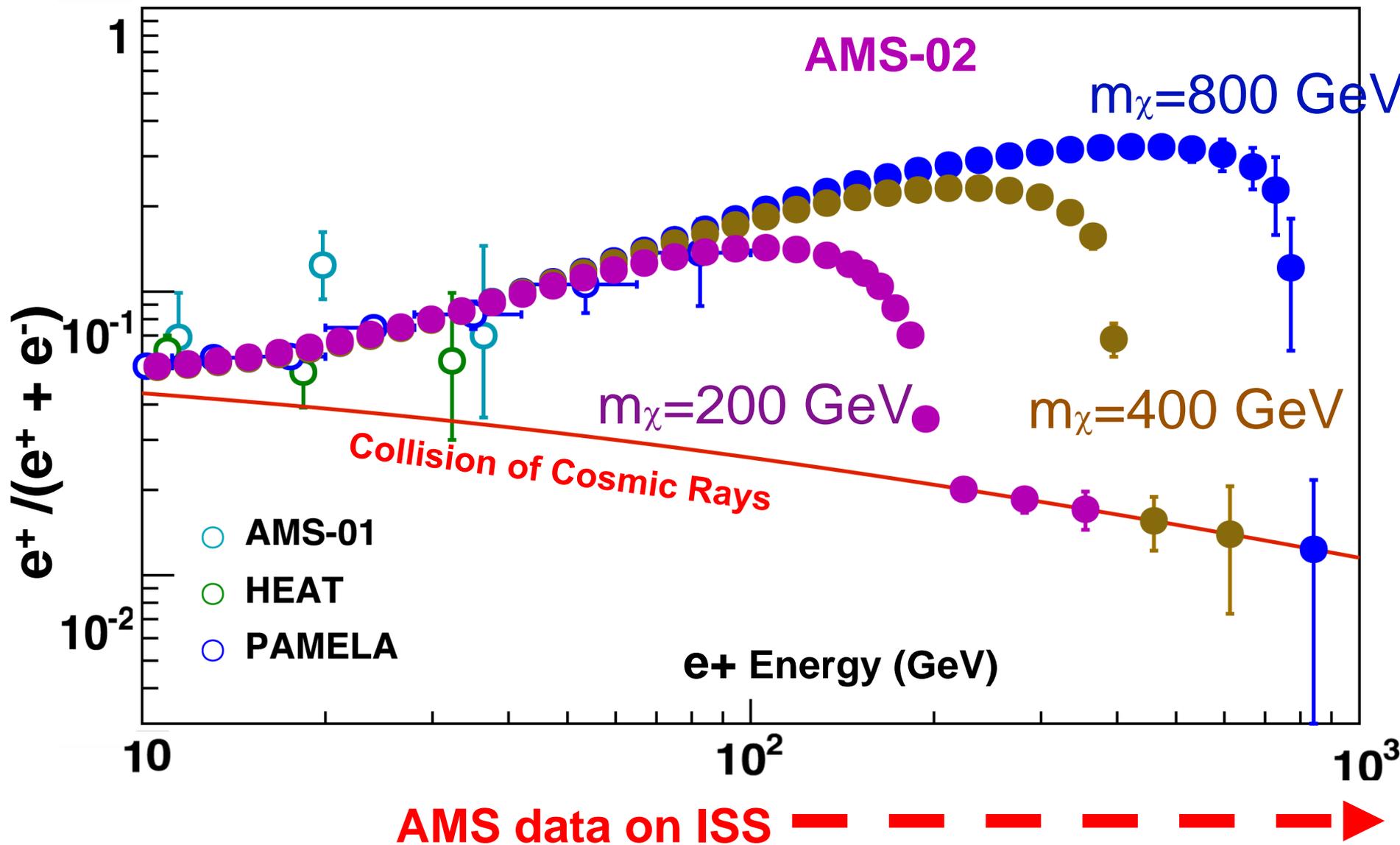
AMS data: 120 GeV photon

AMS Event Display

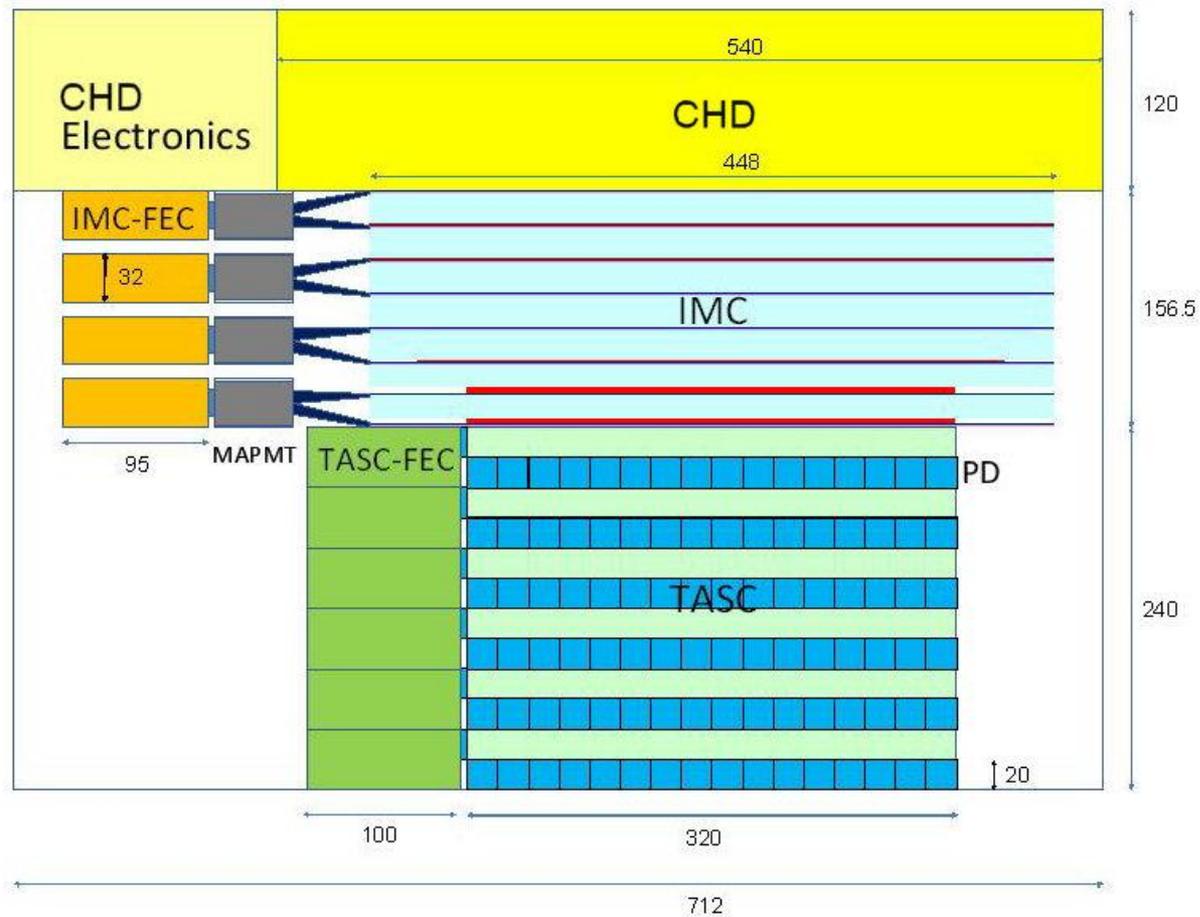
Run/Event 1315471502 / 47441 GMT Time 2011-251.08:48:55



Detection of High Mass Dark Matter from ISS

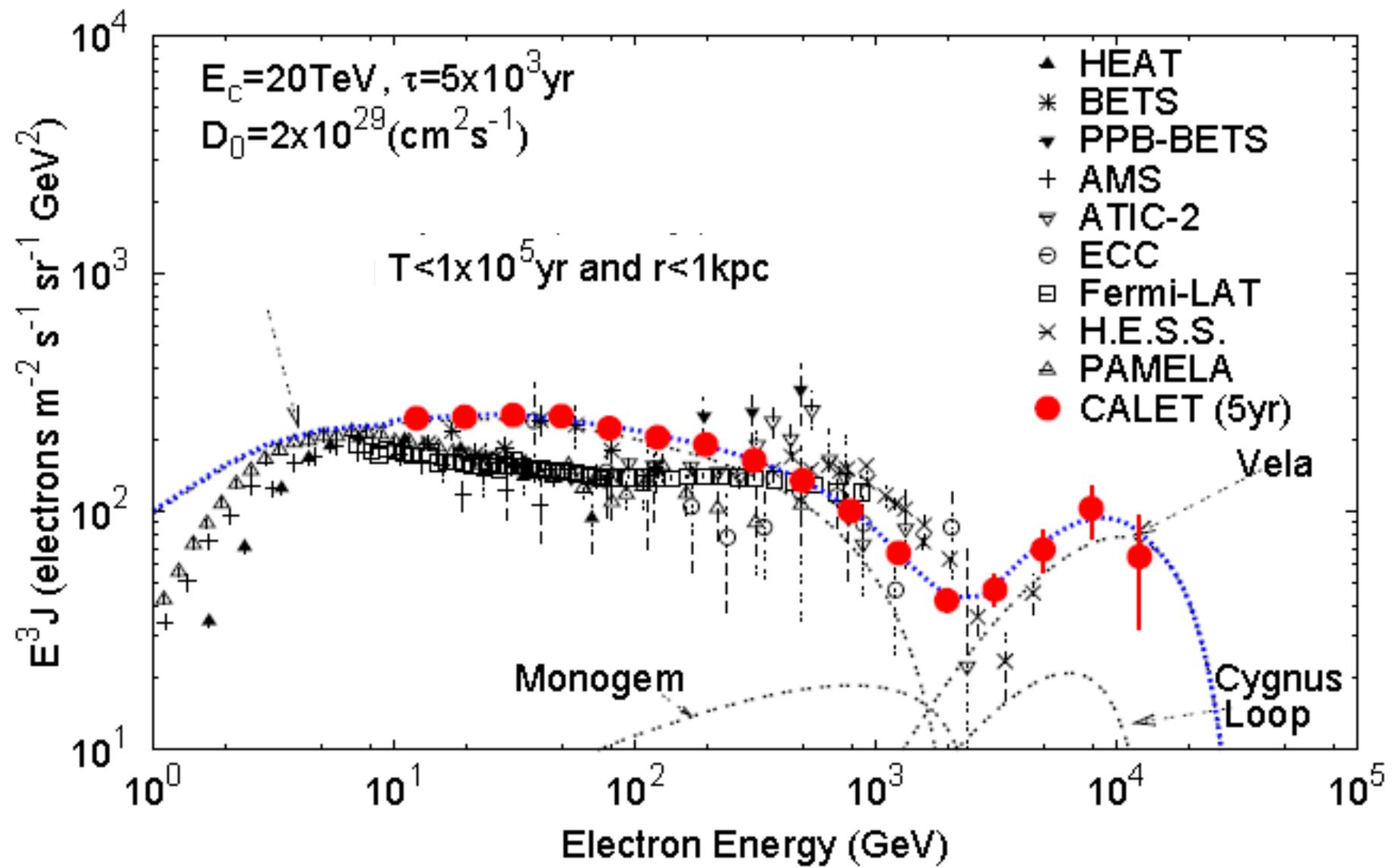


CALET KIBO-ISS



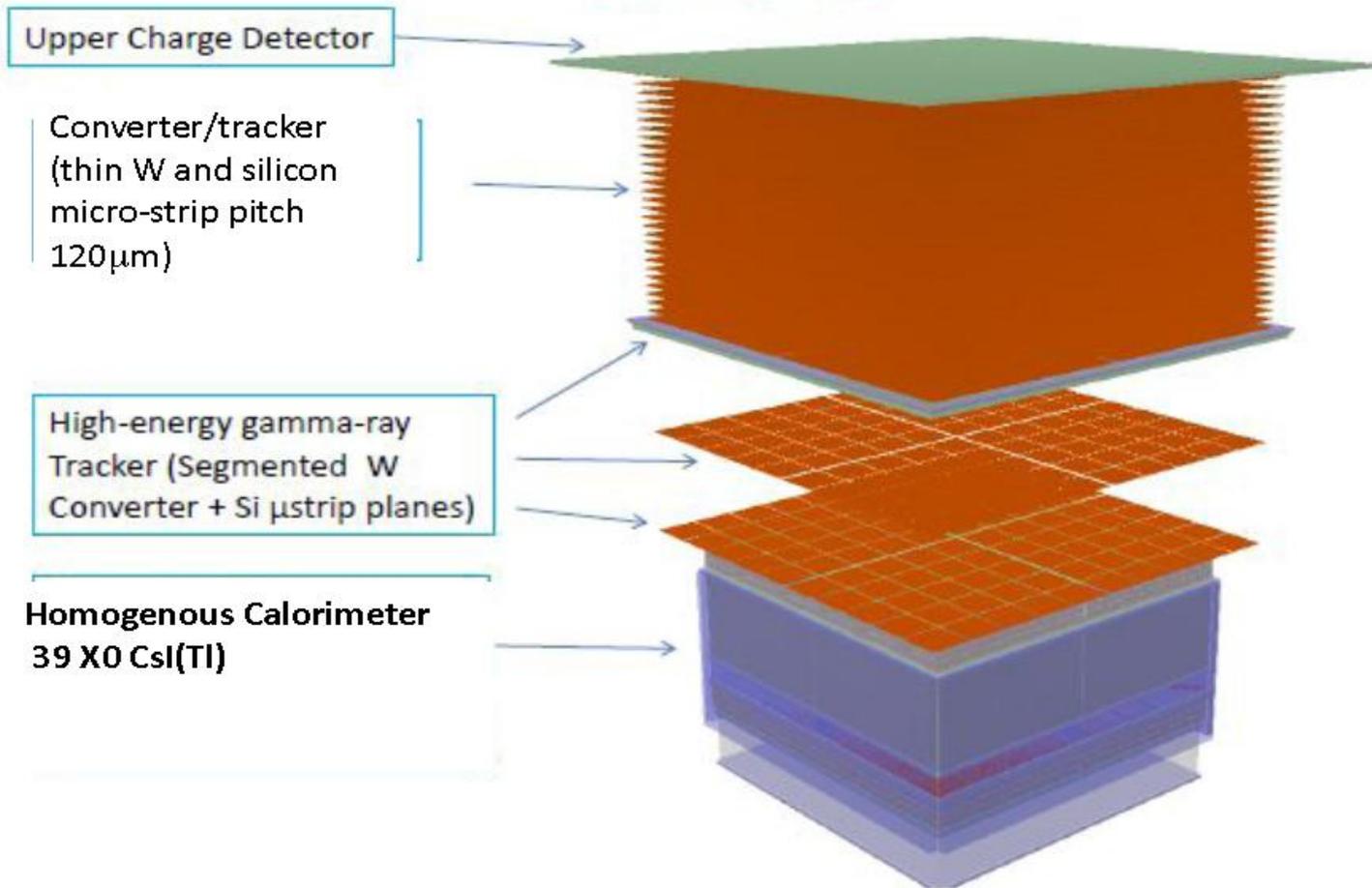
**Electrons up to 20 TeV
Launch 2015**

CALET 5 years



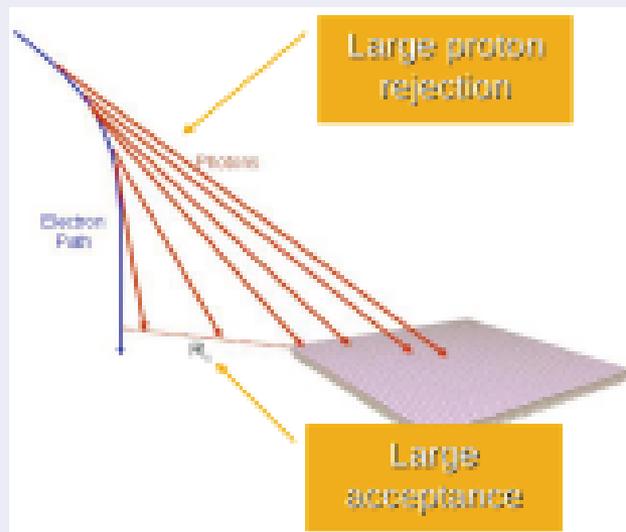
Gamma-400

Satellite



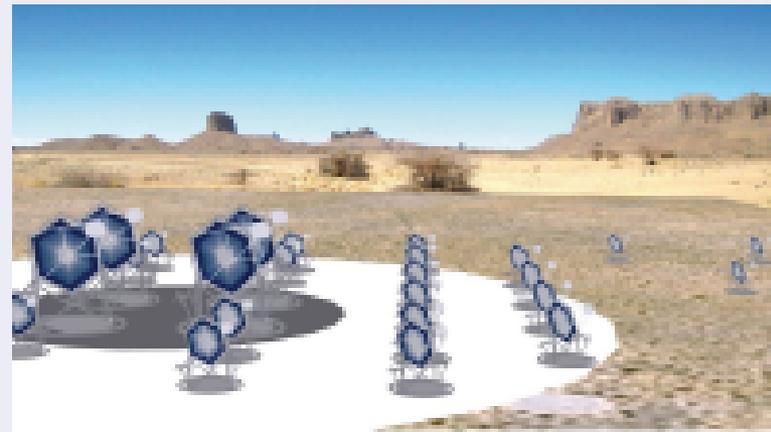
- *Launch foreseen by end 2018*
- **gamma-rays from 30 MeV up to 300GeV energies**
- **electrons/positrons in the TeV energy range and beyond**
- **proton/ion cosmic-rays up to the "knee"**

CREST (Cosmic Ray Electron Synchrotron Telescope)



- ▶ Two Antarctic LDBFs
- ▶ **All electrons from 2 TeV to 50 TeV.**
- ▶ Detect synchrotron radiation of primary electron as it passes through Earth's magnetic field: 1024 BaF₂ crystal with hermetic ACD.
- ▶ Signal: line of photons arriving nearly simultaneously (mean energy 10 keV–5 MeV, related to the primary electron energy).

CTA,



- ▶ Planning for the next-generation ground-based gamma-ray observatories started.
- ▶ Sensitivity improved by one order of magnitude.
- ▶ **All electrons up to ≈ 10 TeV.**

Thanks!

[http:// pamela.roma2.infn.it](http://pamela.roma2.infn.it)