Electrons

- $\frac{\partial N}{\partial t} - \vec{\nabla} \cdot \left(D\vec{\nabla}N - \vec{u}N \right) + \frac{\partial}{\partial E}\left(b(E)N \right) + \frac{N}{\tau_{esc}} = Q(\vec{r}, E, t)$
  - $b(E) = A_1(3\ln\gamma + 19.8) + A_2\gamma + A_3\gamma^2, \gamma = \frac{E}{mc^2}$
  - $A_1 \cong 7.64 \cdot 10^{-9} n\ eV\ s^{-1}$, *ionization losses*;
  - $A_2 \sim 10^{-16} n\ eV\ s^{-1}$, *bremsstrahlung losses*;
  - $A_3 = \frac{4}{3}\sigma_T c\omega_0 \cong 2.66 \cdot 10^{-14}\omega_0 cm^3 s^{-1}$,

Inverse Compton and synchrotron losses

$$\sigma_T = \frac{8}{3}\pi r_e^2 \cong 6.65 \cdot 10^{-25} cm^2,$$

$$\omega_0 = \omega_B + \omega_{MBR} + \omega_{opt},$$

$$\omega_B \cong 0.2\frac{eV}{cm^3}, \omega_{MBR} \cong 0.265\frac{eV}{cm^3}, \omega_{opt} \cong 0.5\frac{eV}{cm^3}$$

- $\tau = \frac{E}{(dE/dt)_{IC}} \approx \frac{2.3 \cdot 10^{12}}{\gamma}\ years.$
- $E = 10\ GeV\ \rightarrow \tau \approx 1.2 \cdot 10^8 y$

Propagation models

- Leaky Box model:

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial E}(b(E)N) + \frac{N}{\tau_{esc}} = Q(\vec{r}, E, t)$$

Steady state:

- Low energies (less than a few GeV):

$$N \sim \left(Q_0 \tau_0 E_0^{\delta}\right) E^{-(p+\delta)},$$

$$Q = Q_0 E^{-p}, \tau_{esc} = \tau_0 \left(\frac{E}{E_0}\right)^{-\delta}, E_0 \approx 5\ GeV$$

- High energies:

$$N \sim \frac{Q_0}{a(p-1)} E^{-(p+1)}$$

$$a = \frac{A_3}{(mc^2)^2} \approx 1.4 \cdot 10^{-16}\ (GeV\ s)^{-1}$$

Propagation models

- Diffusive halo model:

$$\frac{\partial N}{\partial t} - \vec{\nabla} \cdot \left(D \vec{\nabla} N\right) + \frac{\partial}{\partial E}(b(E)N) = Q(\vec{r}, E, t)$$

Steady state:

– At energies of a few GeV):

$$N \sim Q_0 \frac{hH}{D_0} E^{-(p+\delta)},$$

$2h \equiv disk\ and\ 2H \equiv halo\ thickness, D_0 \approx 10^{29}\ cm^2/s$

– High energies (> 10 GeV):

$$N \sim \frac{Q_0}{a(p-1)} E^{-(p+1)}$$

Propagation models

- Diffusive halo model:
  - No losses: Green function for diffusion equation:

$$G(r,t) = \frac{1}{8(\pi D_0 t)^{3/2}} e^{-\frac{r^2}{4D_0 t}}$$

Probability for finding a particle, injected at the origin, at a position x after a time t:

$$\langle\lambda\rangle = \sqrt{\langle x^2\rangle} = \left[\int_{-\infty}^{\infty} x^2 G(r,t)dr\right]^{1/2} \approx \sqrt{2D_0 t}$$

IC and sync losses, e^- loses its energy time $2.3 \cdot 10^8/E$ (y · GeV)

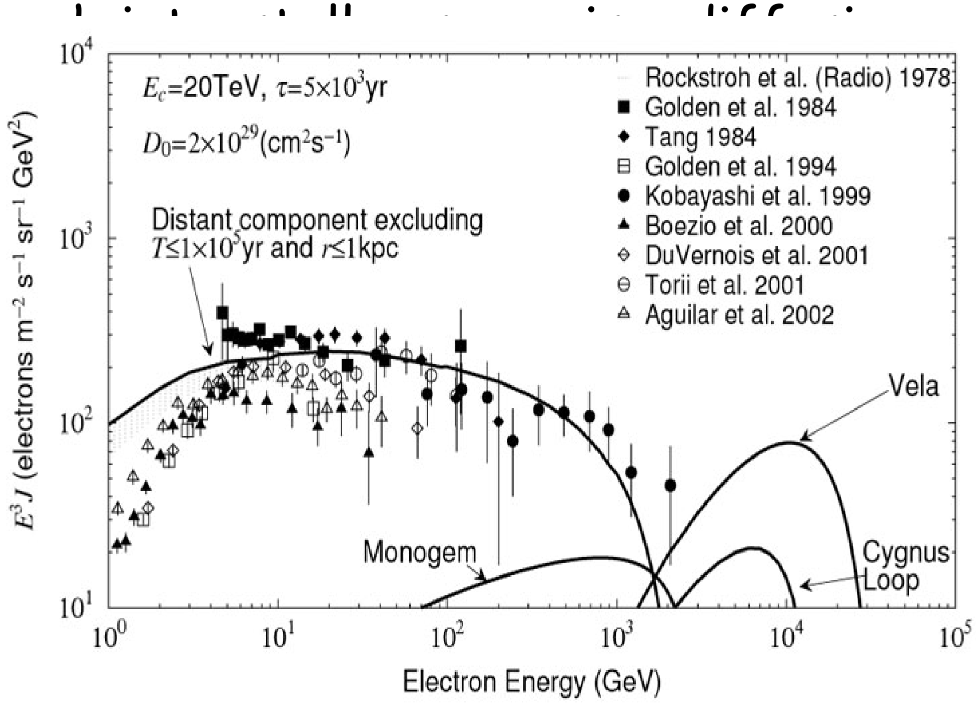
$$10\ GeV e^- \rightarrow \langle\lambda\rangle \approx 4\ kpc$$

Electrons can tell us about local GCR sources

- High energy electrons have a high energy loss rate ∝ E^2
  - Lifetime of ~10^5 years for >1 TeV electrons
- Transport of GCR thr

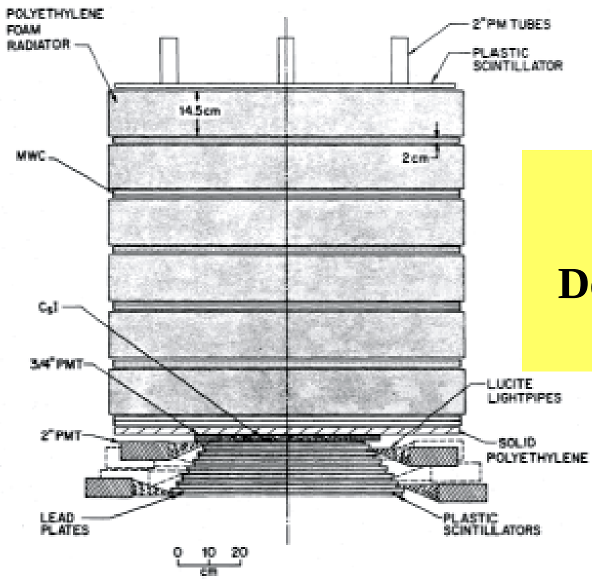
Only a handful of SNR meet the lifetime & distance criteria

Kobayashi et al., ApJ 601 (2004) 340 calculations show structure in electron spectrum at high energy

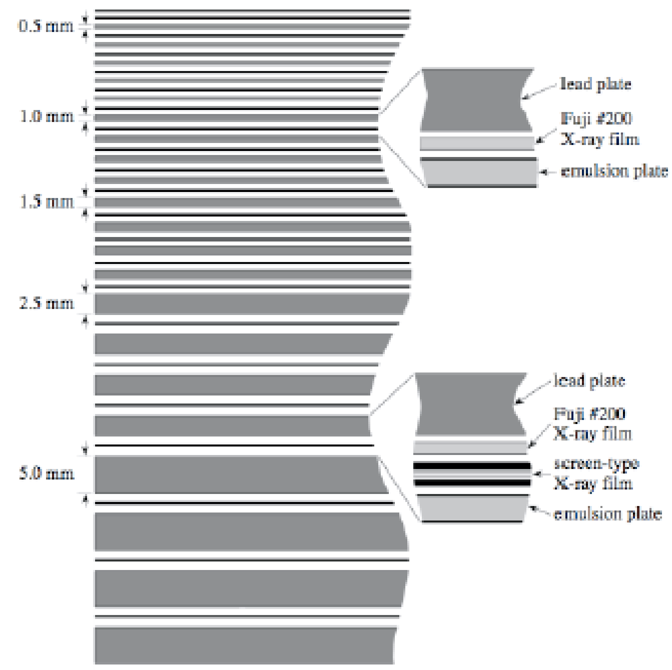


J. P. Wefel, TevPA 2011, Stockholm (2011)

Electron (e^- + e^+) Measurements



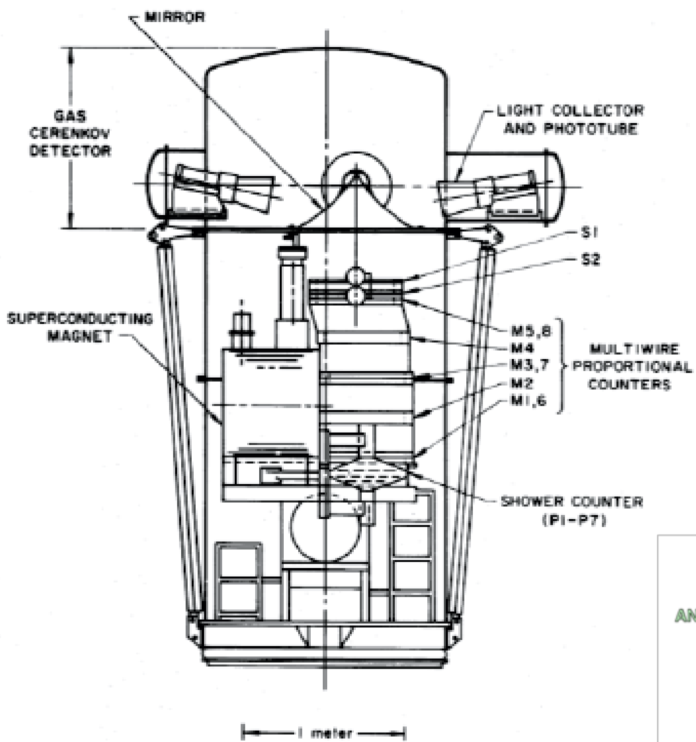
Transition Radiation Detector (Tang 1984)



Emulsion Chambers (Kobayashi et al. 1968-2001)

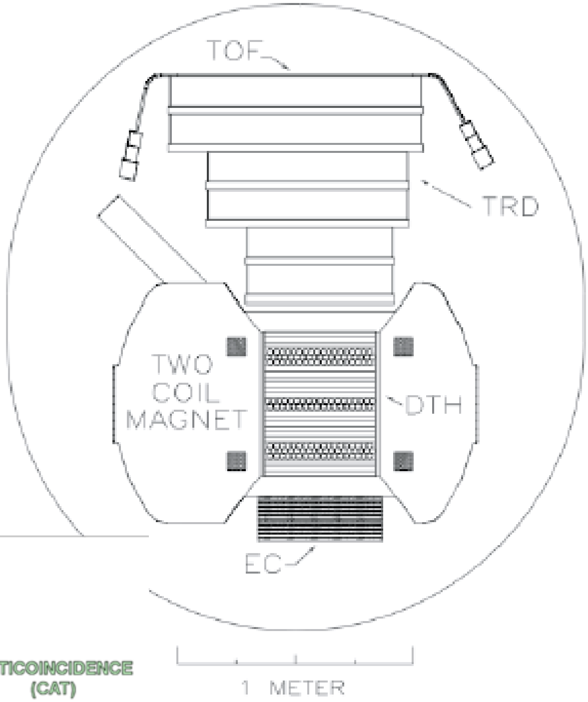
HESS Telescope-Array

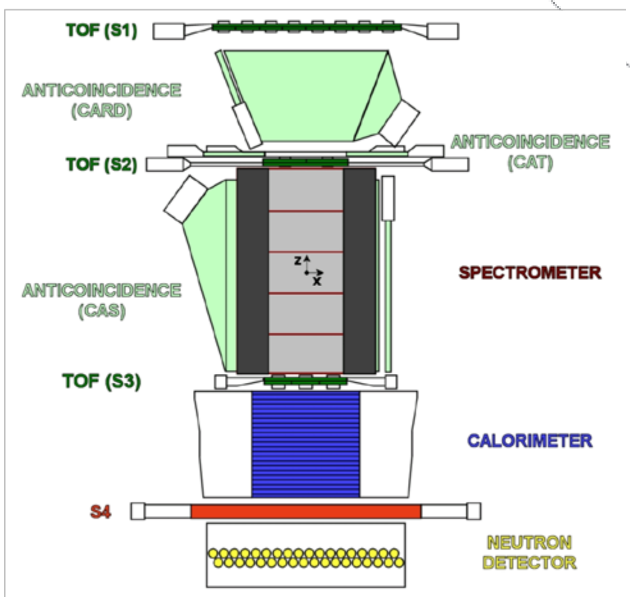
Electron (e^-) Measurements: Magnetic Spectrometer



Robert Golden's balloon-borne superconducting magnetic spectrometer 1984-1998

HEAT
1994-1995





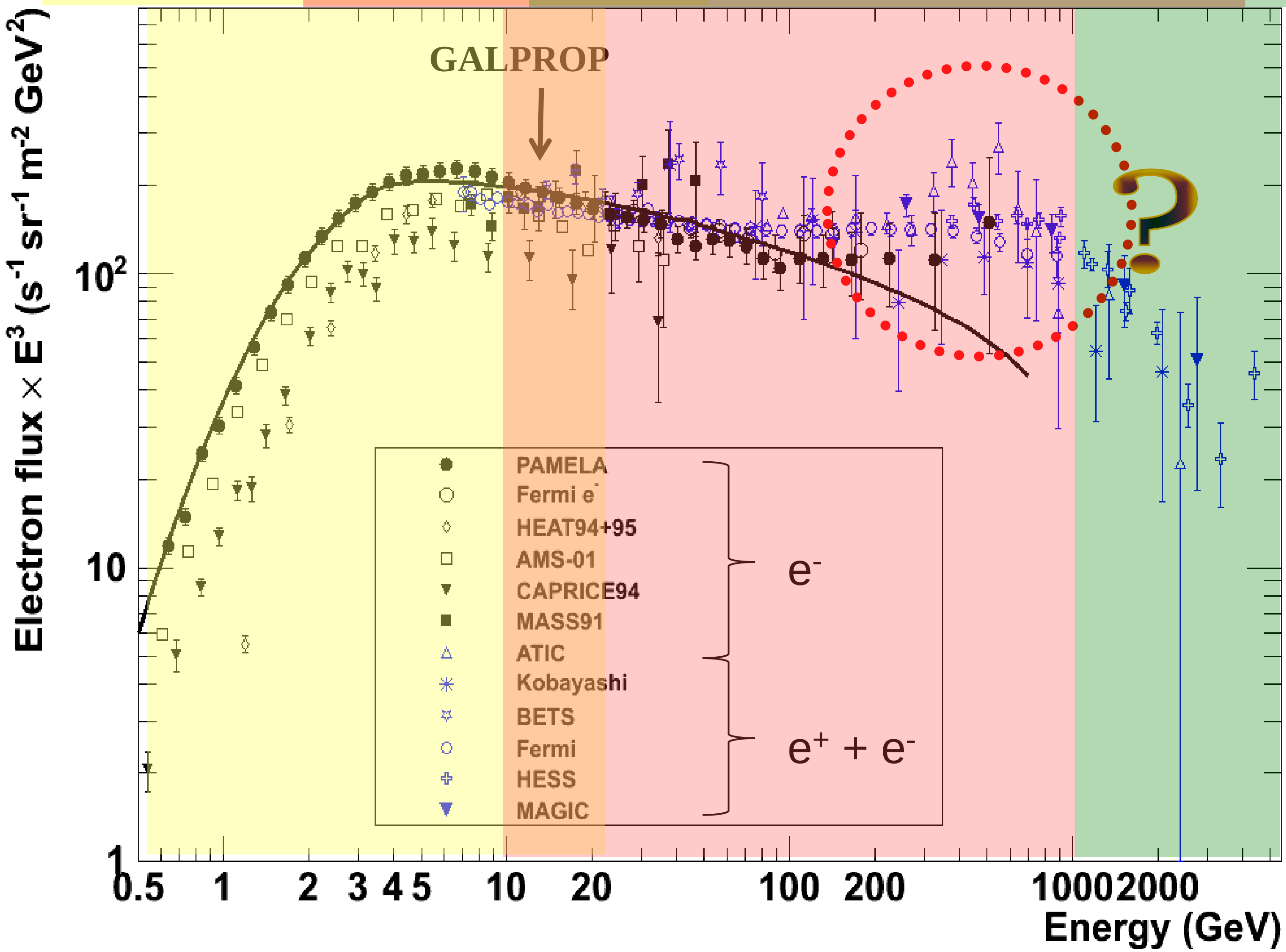
PAMELA
2006-

Electron Spectrum

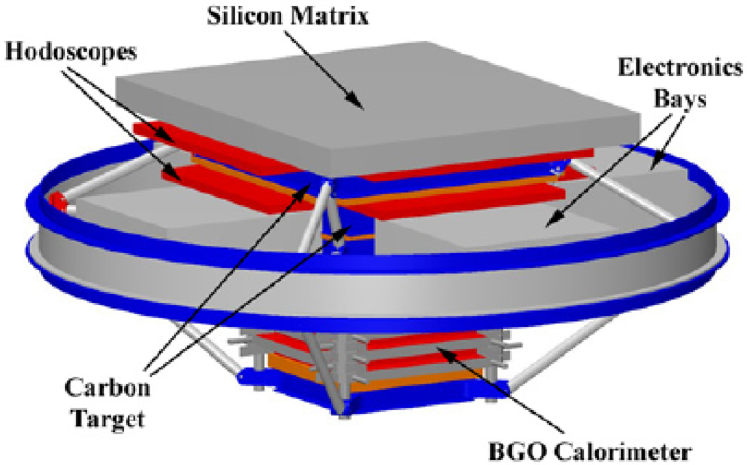
Observation of 1~20 GeV for st

Precise measurements of acceleration

Search for the signature of nearby HE electron sources (believed to be SNR) in the electron spectrum above ~ TeV

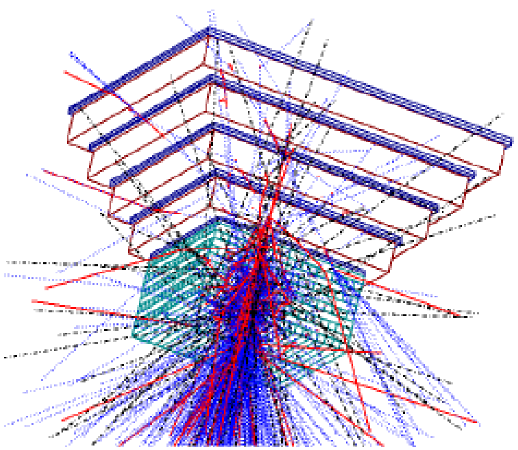


ATIC Instrument

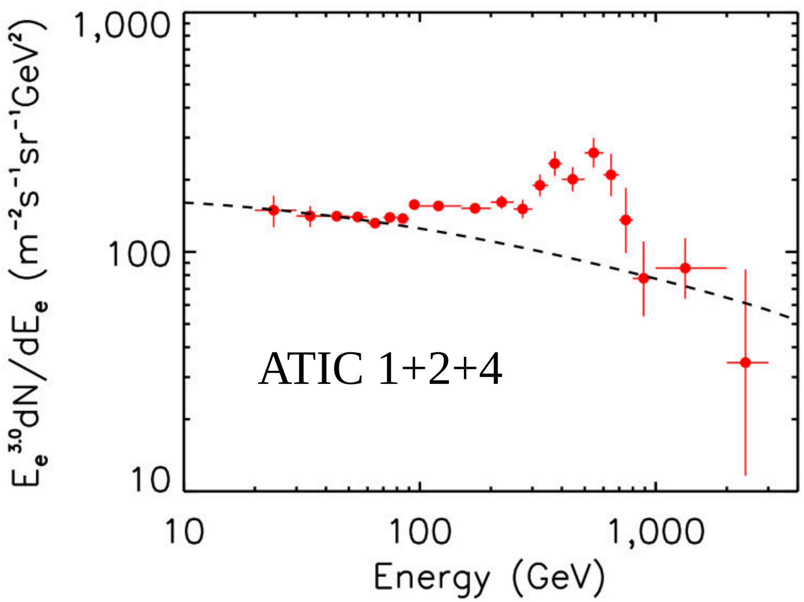


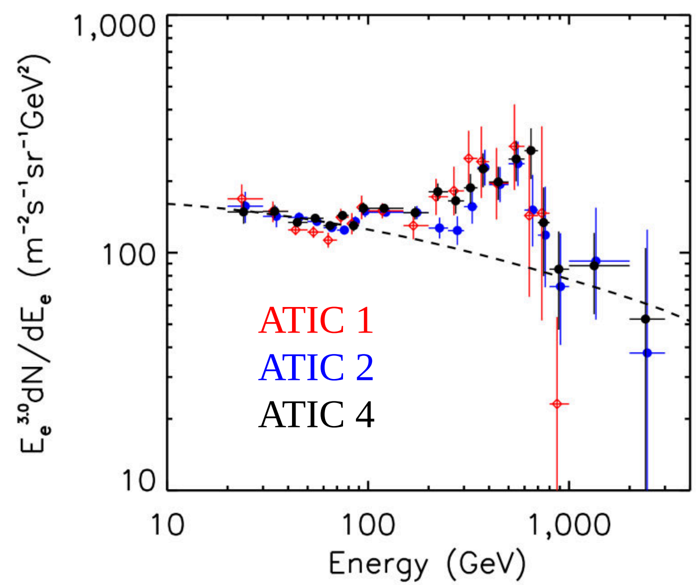
Antarctic Flights:

- 12/28/00 - 1/13/01
- 12/29/02 – 1/18-03
- 12/27/07 – 1/15/08



Results from three ATIC flights

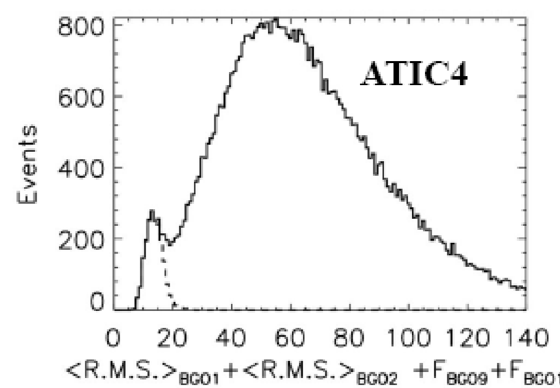




“Source on/source off” significance of bump for ATIC1+2 is about 3.8 sigma

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

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

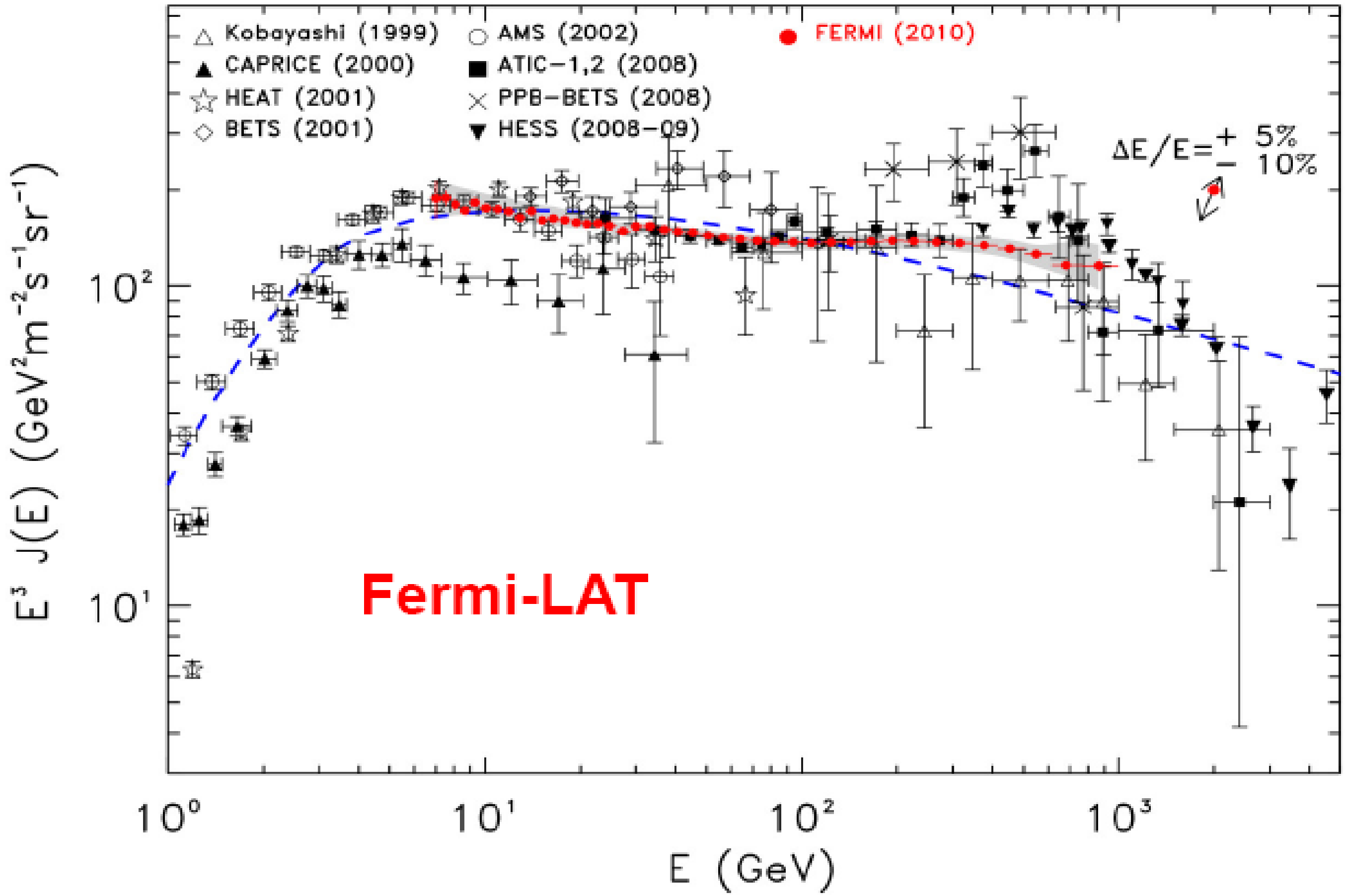


“Bump” is seen in all three flights.

Significance for ATIC1+2+4 is 5.1

J. P. Wefel, TevPA 2011, Stockholm (2011)

FERMI All Electron Spectrum

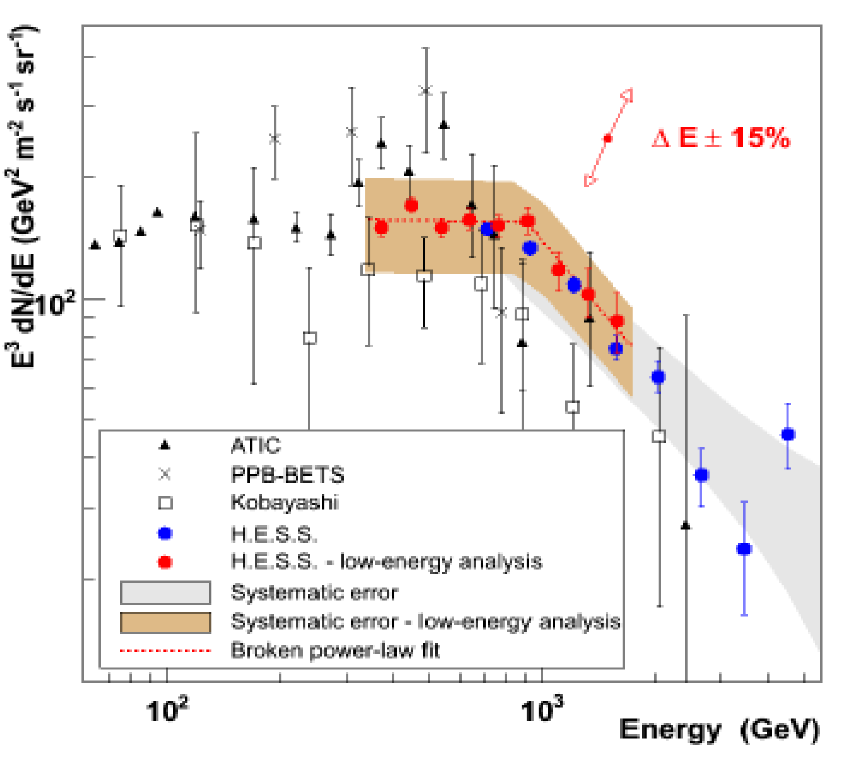


A. Abdo et al., Phys.Rev.Lett. 102 (2009) 181101
M. Ackermann et al., Phys. Rev. D 82, 092004 (2010)

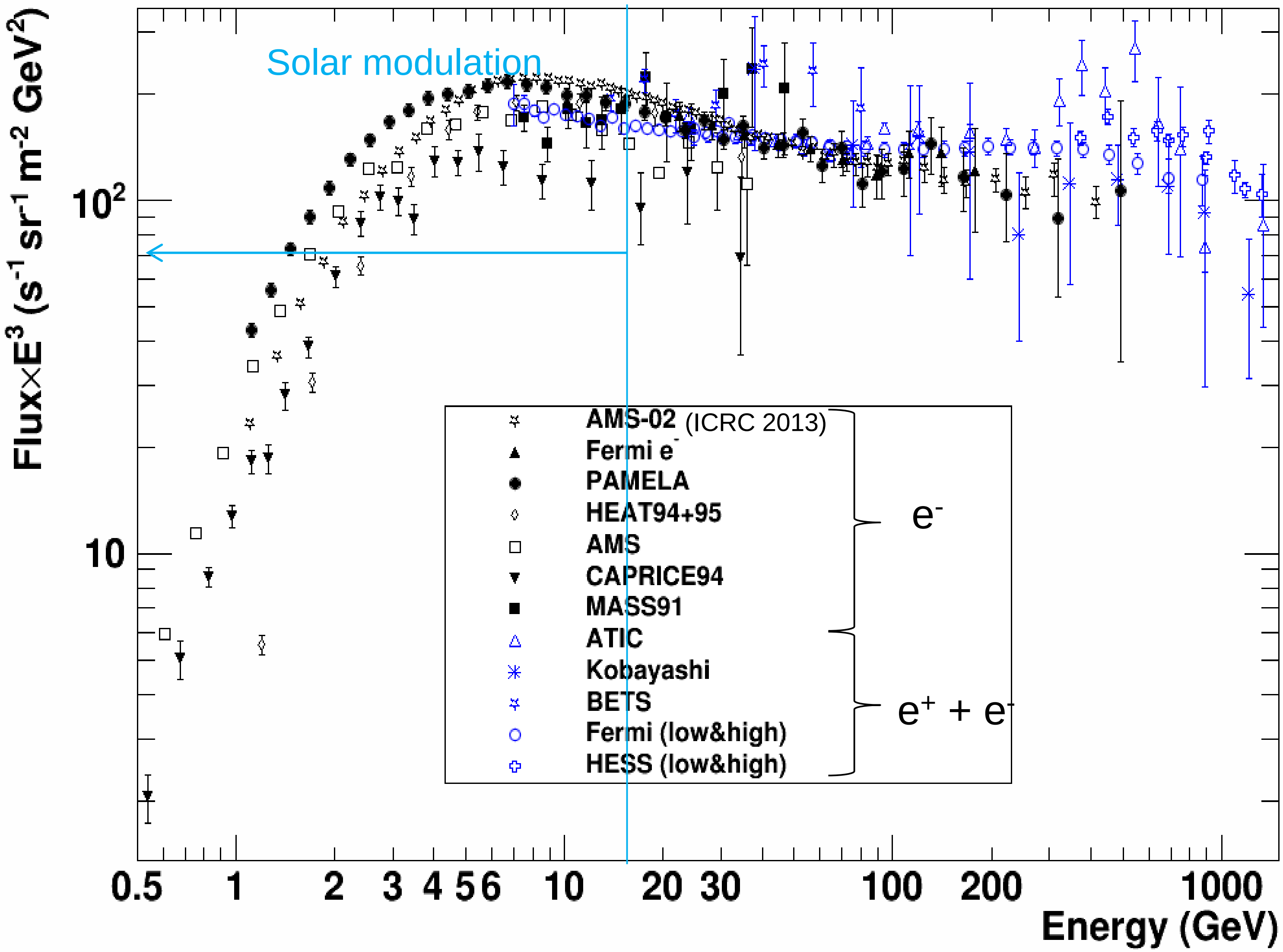
Electrons measured with H.E.S.S.

Results: Low-Energy Spectrum

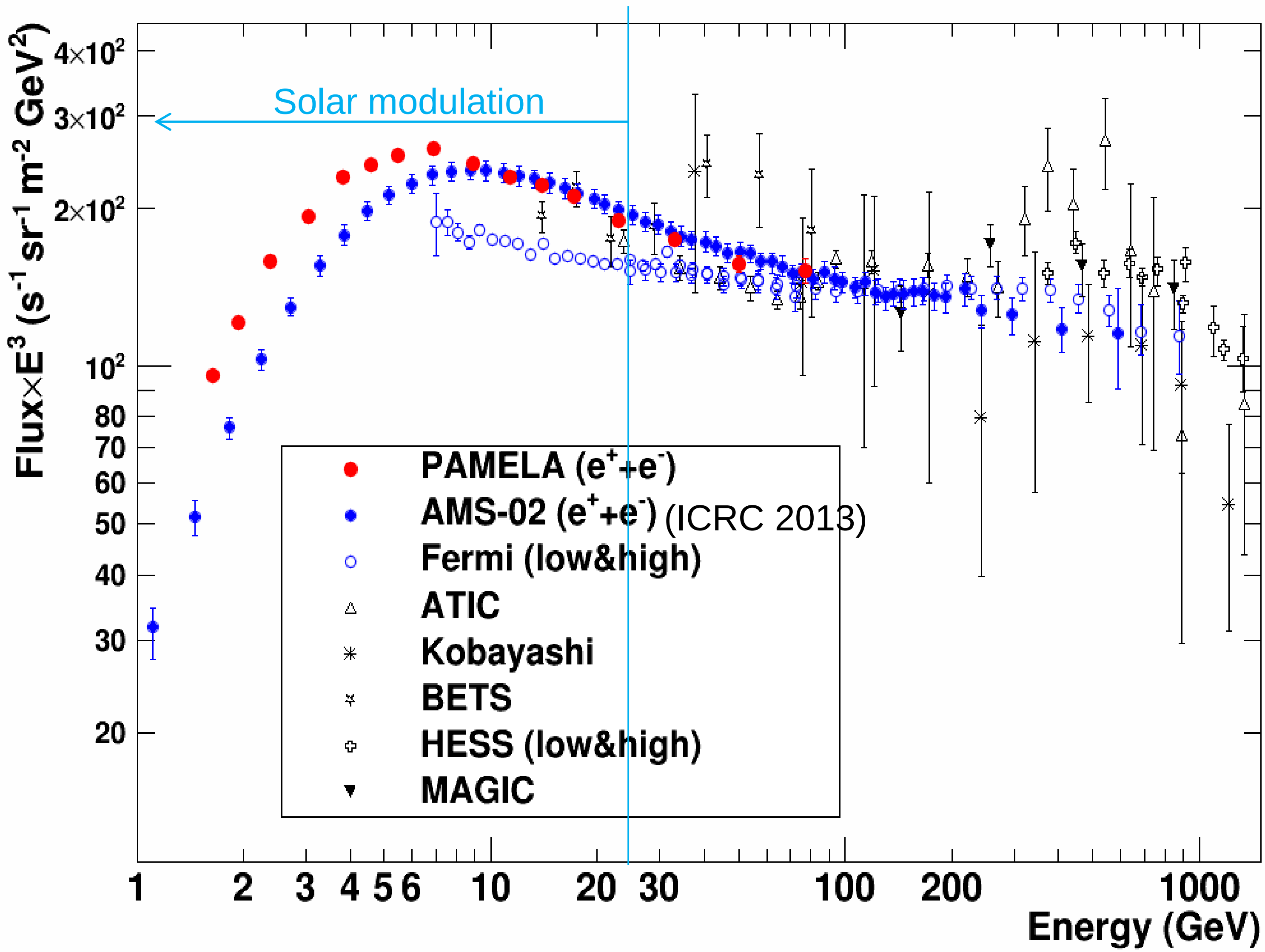
- Cuts:
  - impact distance < 100 m
  - image size in each camera > 80 photo electrons
  - Data set of 2004/2005
- Syst. uncertainty: atmospheric variations + model dependence of proton simulations (SIBYLL vs. QGSJET-II)
- Spectral index:
  $\Gamma_1 = 3.0 \pm 0.1(\text{stat}) \pm 0.3(\text{syst.})$
  $\Gamma_2 = 3.9 \pm 0.1(\text{stat}) \pm 0.3(\text{syst.})$



Electron Spectrum

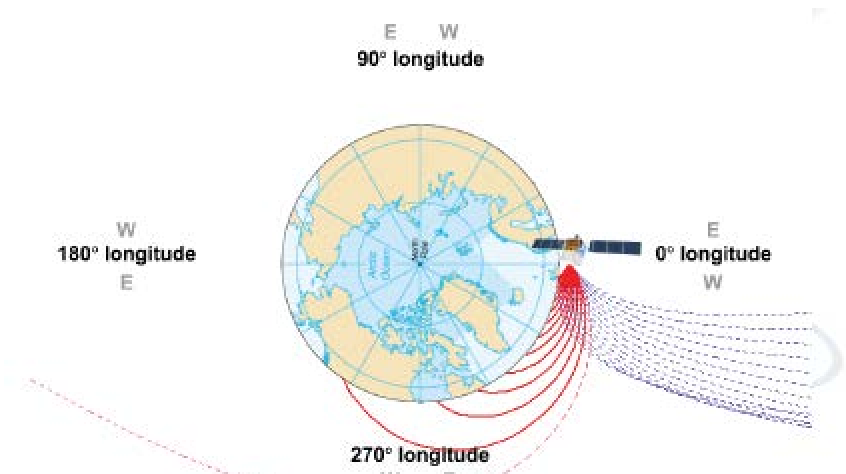


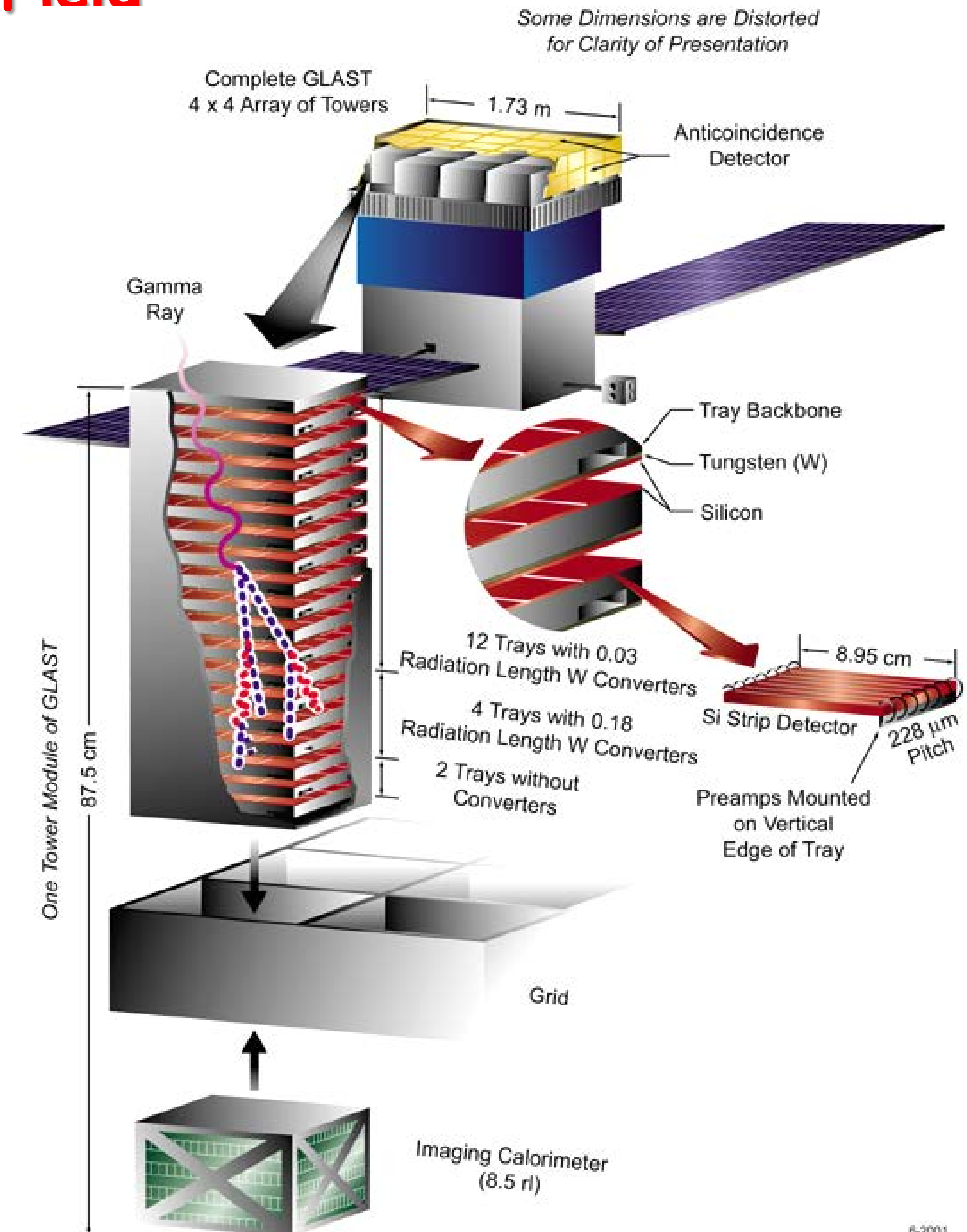
Electron (e^-+e^+) Spectrum



Electron (e^-) Measurements: using the Earth's Magnetic Field

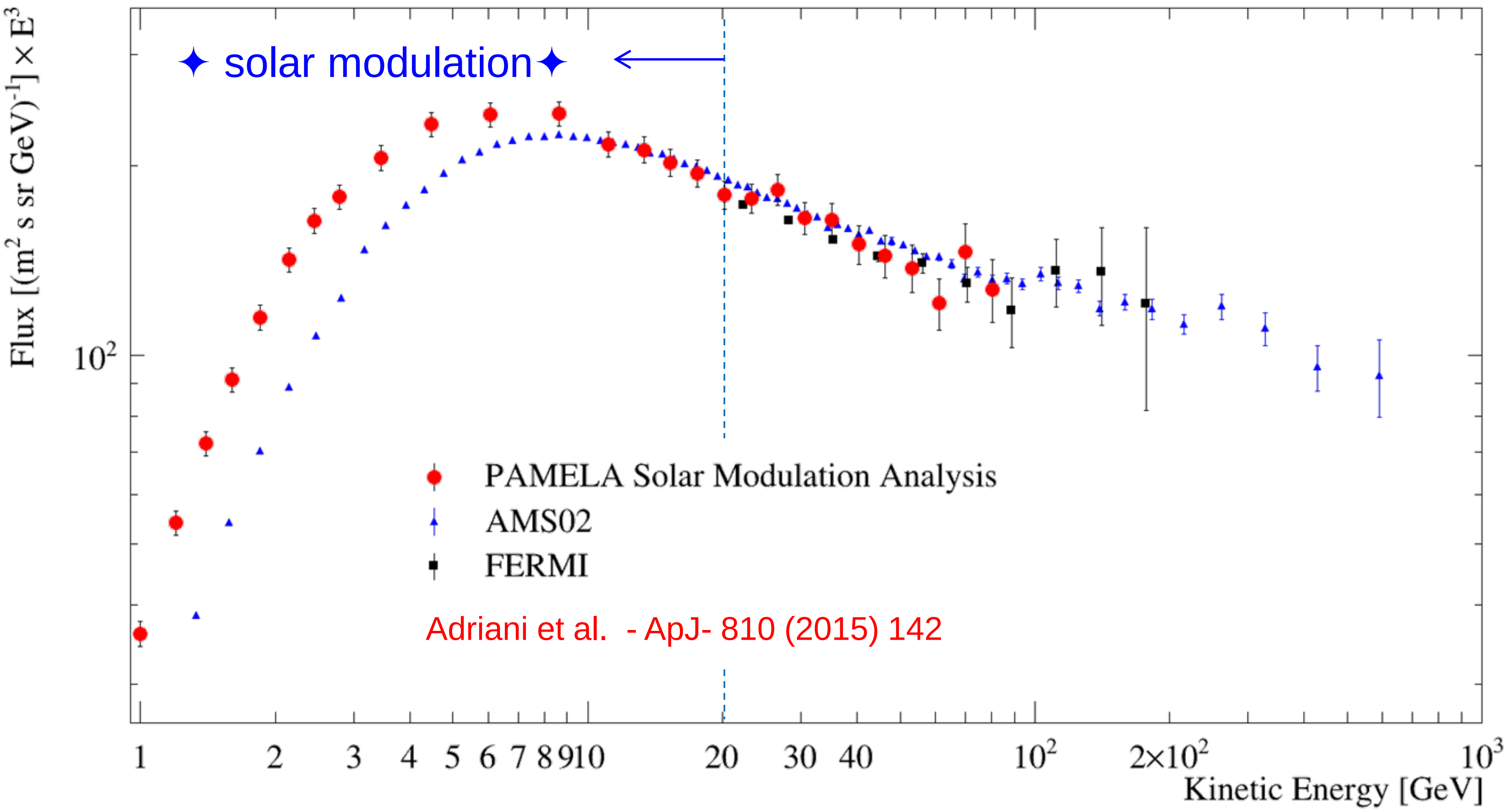
GLAST/ FERMI
Gamma-Ray
Large Area Space
Telescope



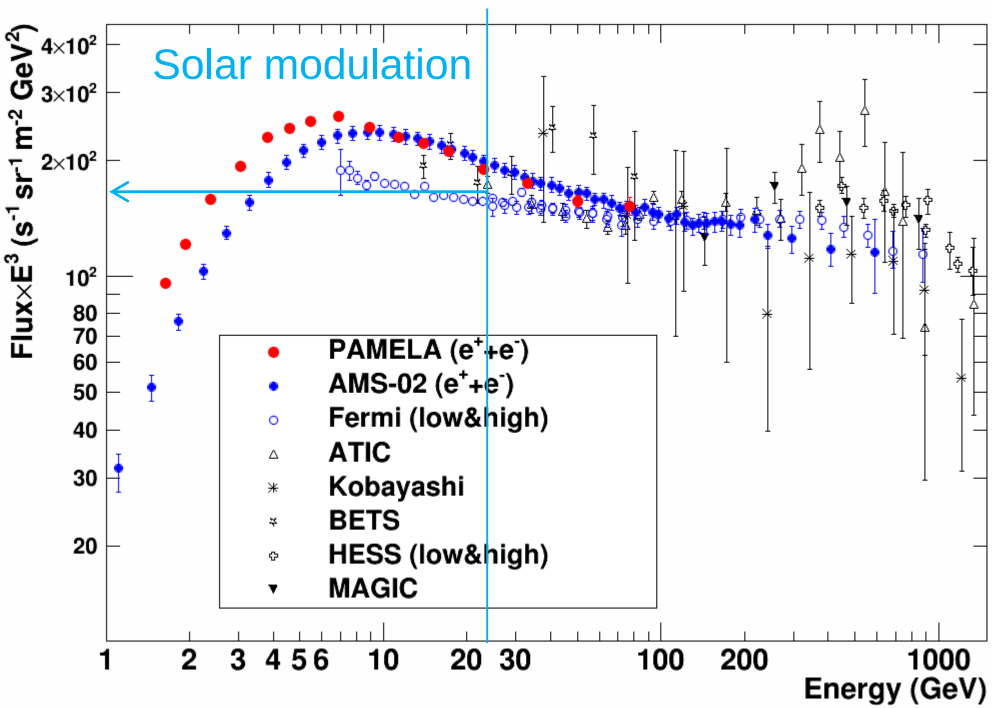


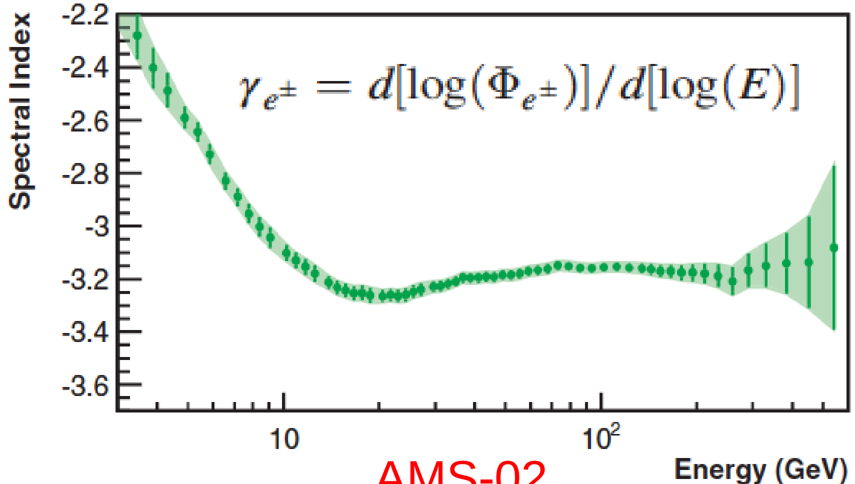
Electron Spectrum

PAMELA data → Jul 2006 ÷ Dec 2009
AMS02 data → May 2011 ÷ Nov 2013

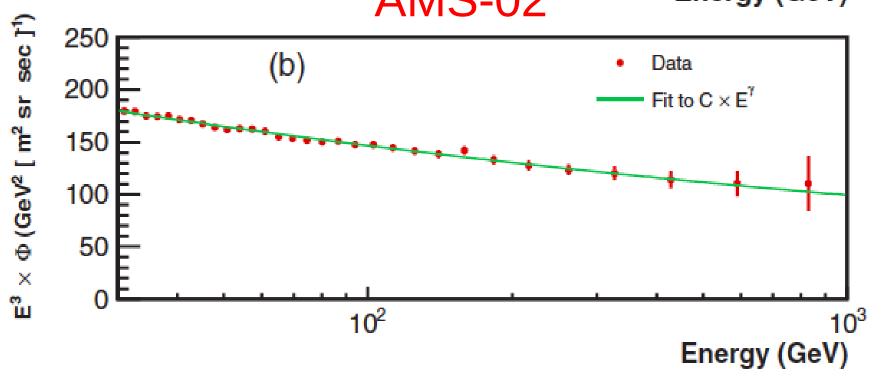


AMS-02, Fermi & PAMELA ($e^- + e^+$) Spectrum





AMS-02



M. Aguilar et al., PRL 113 (2014) 221102

Electron (e^-+e^+) Spectrum