

Dark Matter and Pulsar Signals for PAMELA, Fermi and ACTs

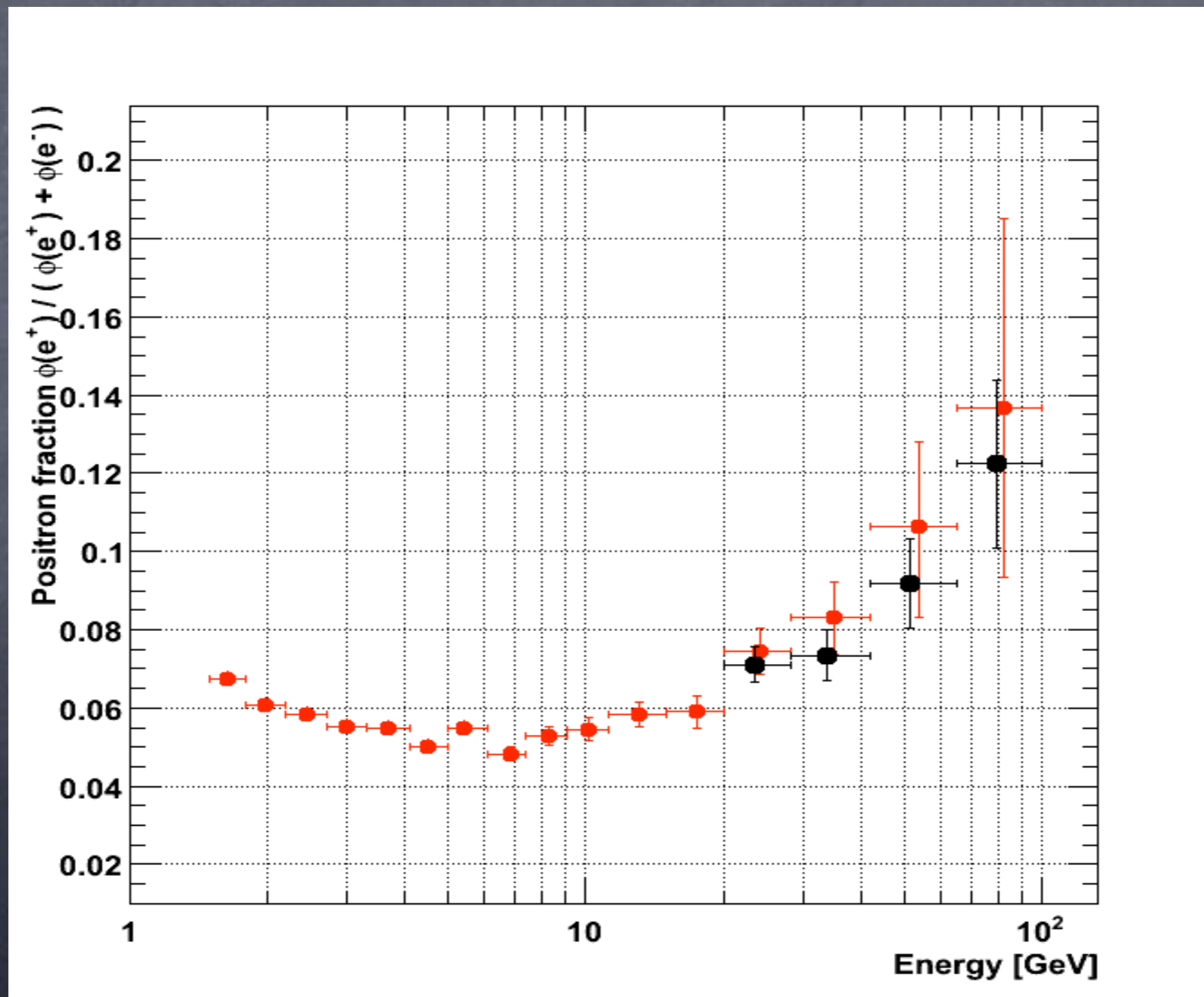
Danny Marfatia

with Barger, Gao, Keung, Shaughnessy 0904.2001

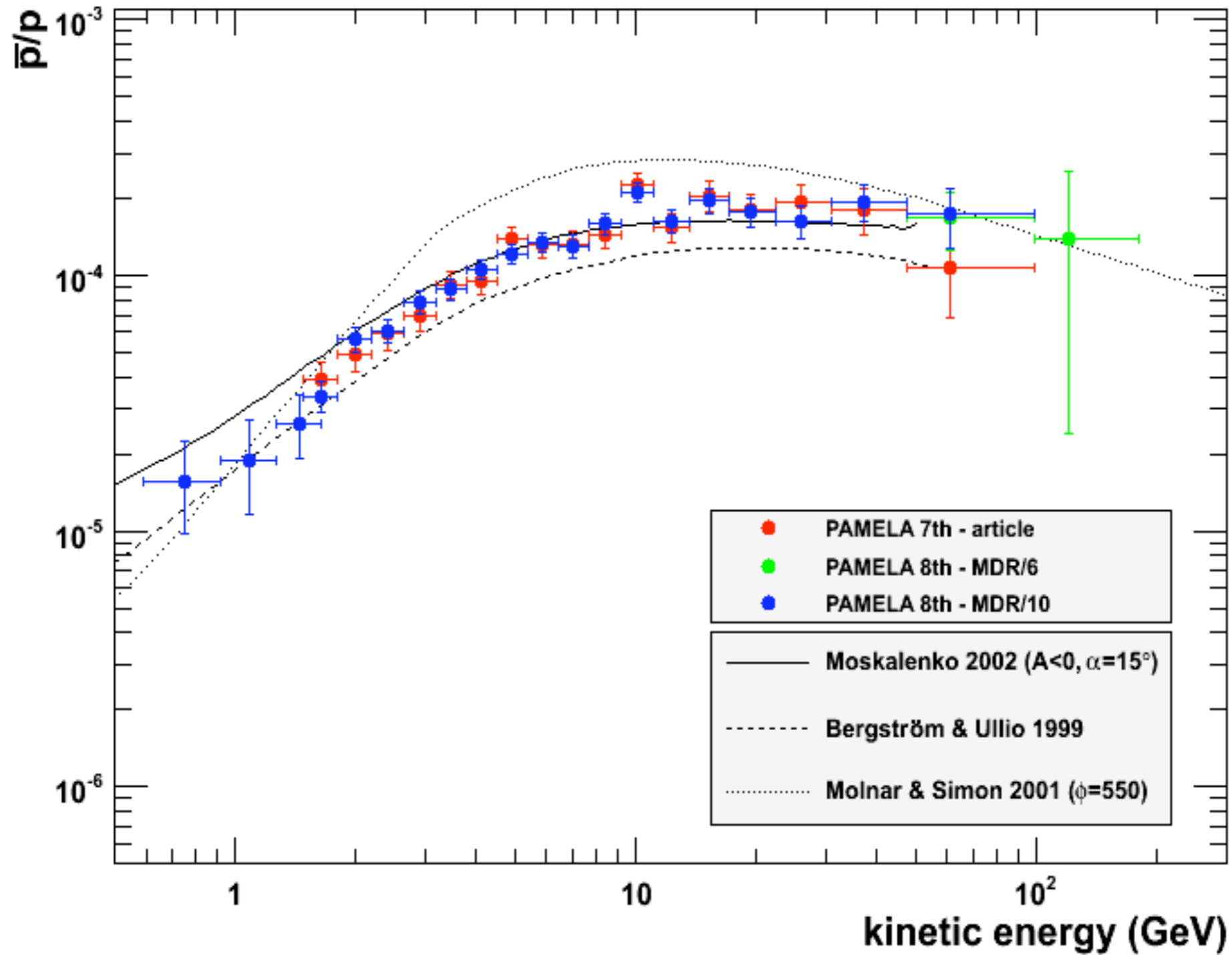
with Barger, Gao, Keung 0906.3009

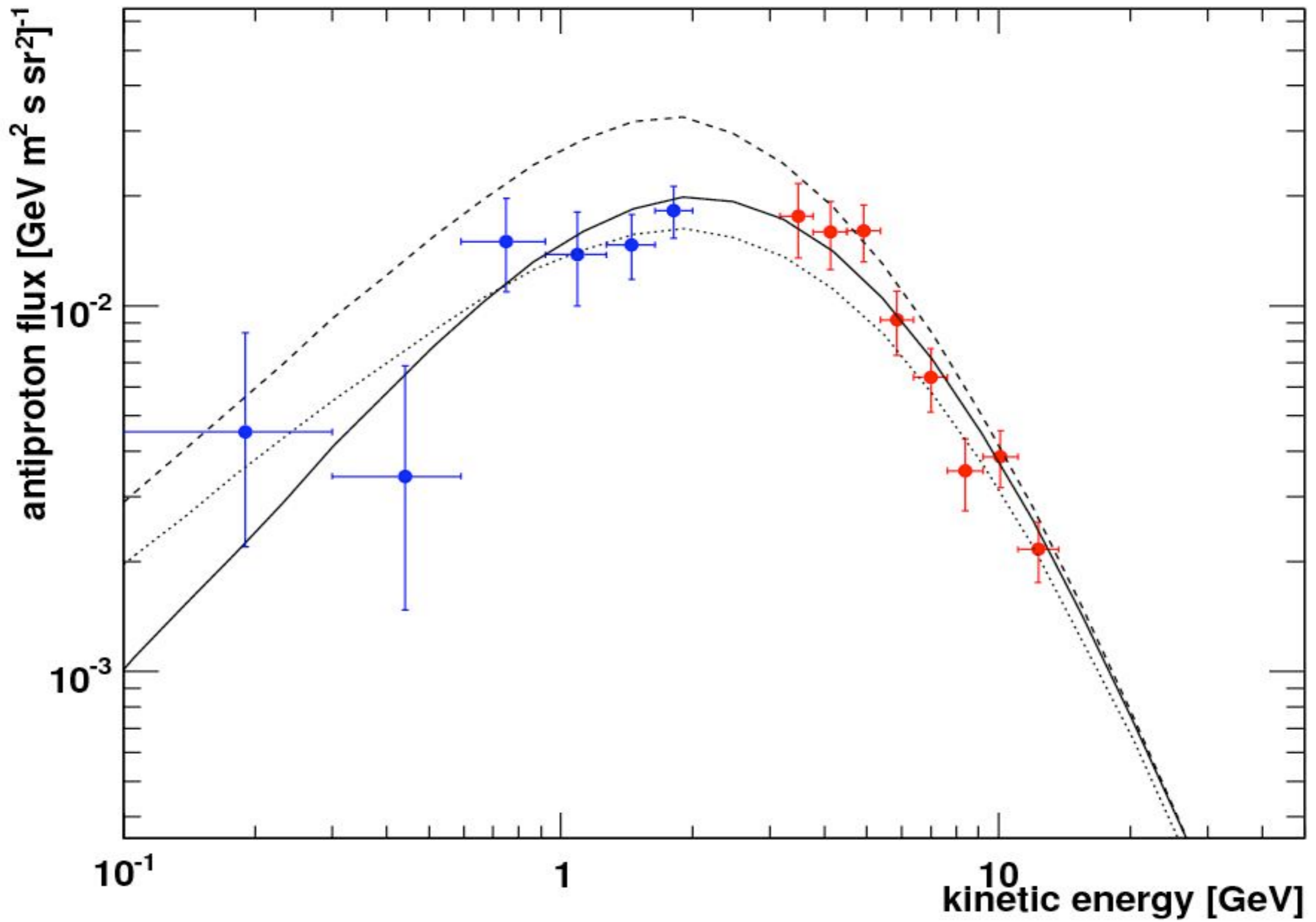
A brief history of recent cosmic ray data

PAMELA: rising positron fraction from 10 – 100 GeV

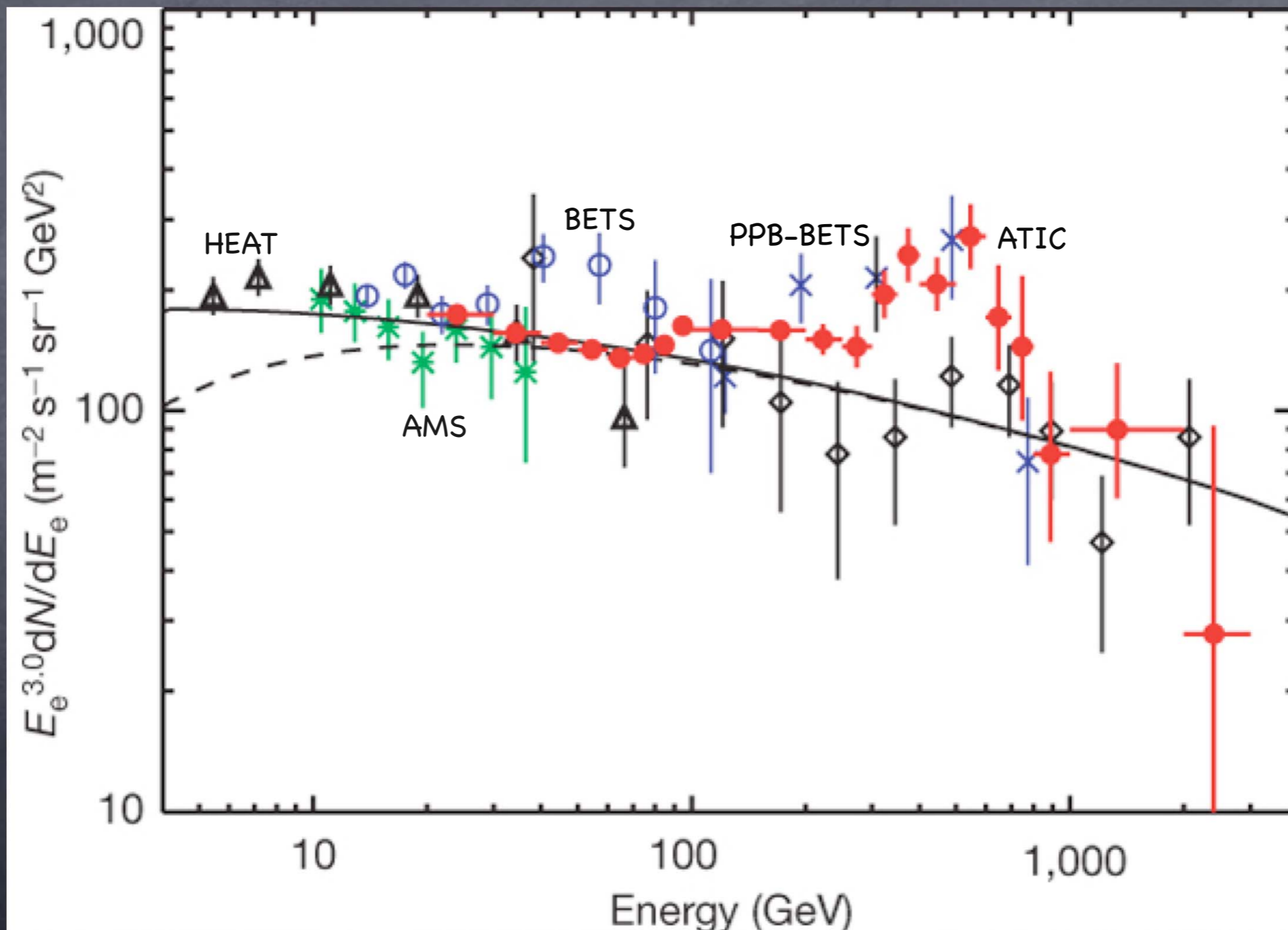


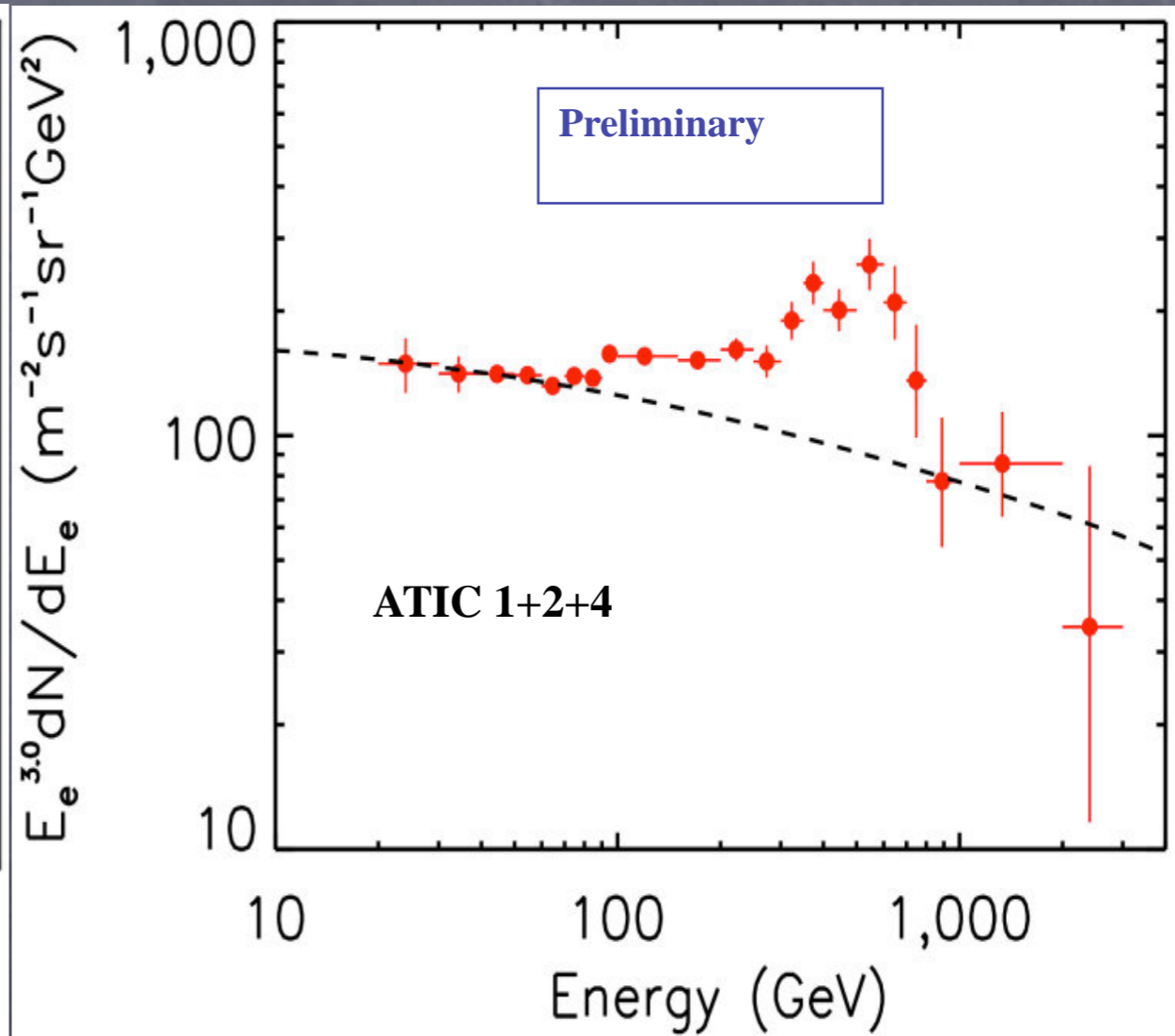
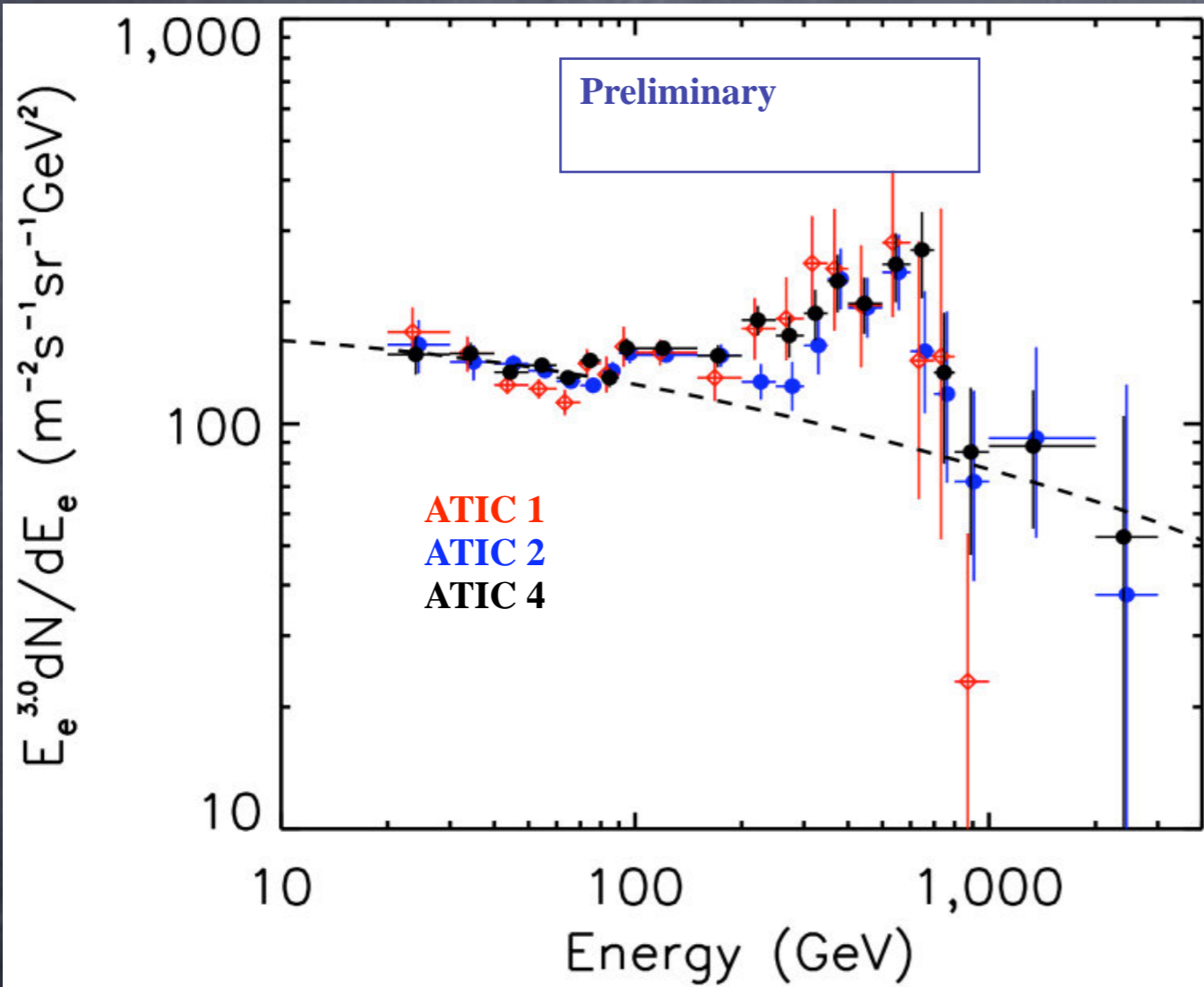
PAMELA: no excess in \bar{p}/p spectrum from 1 - 200 GeV



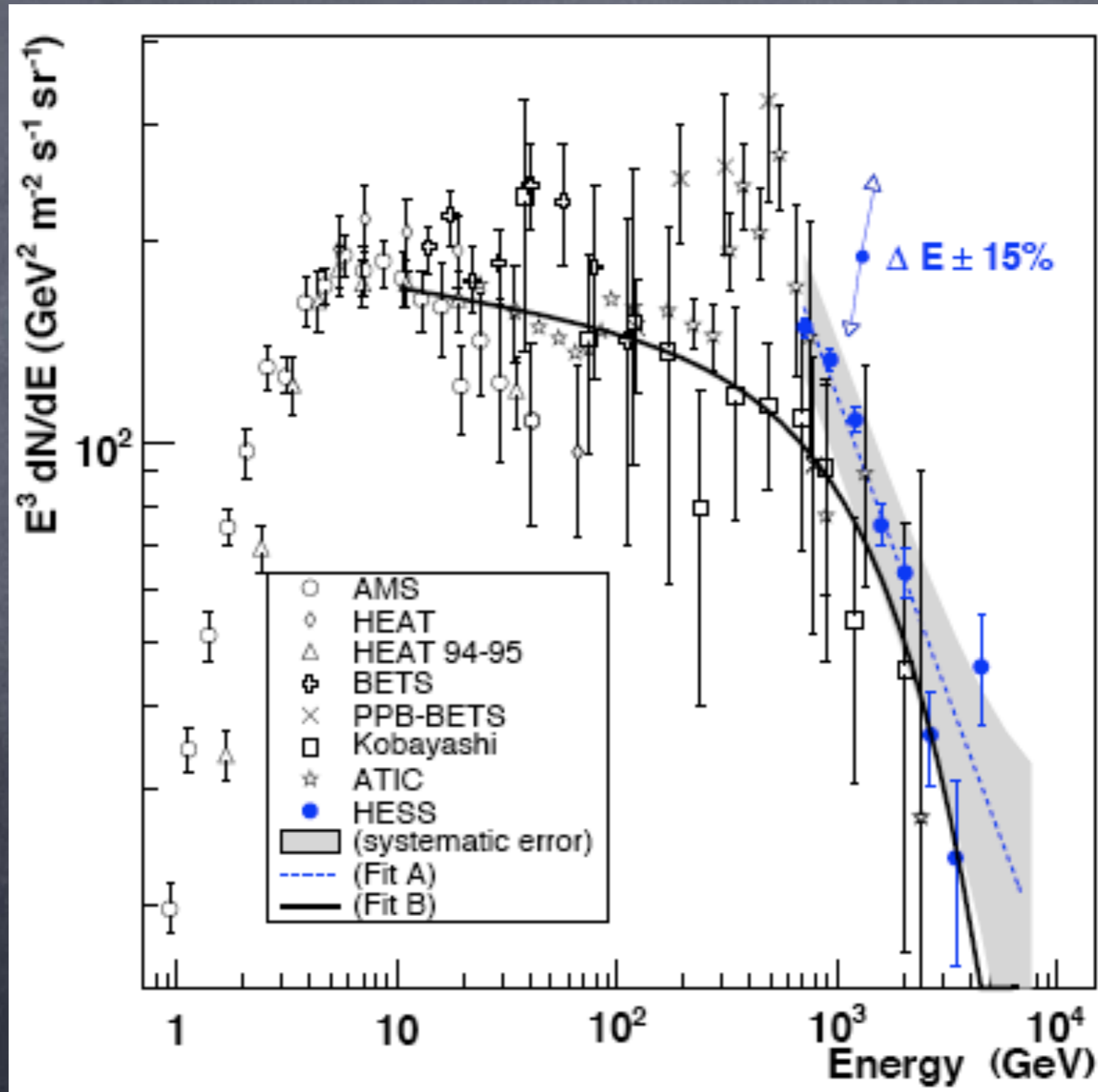


ATIC/PPB-BETS: - bump in $e^+ + e^-$ spectrum between 200 and 800 GeV
- ATIC excess is 70 events

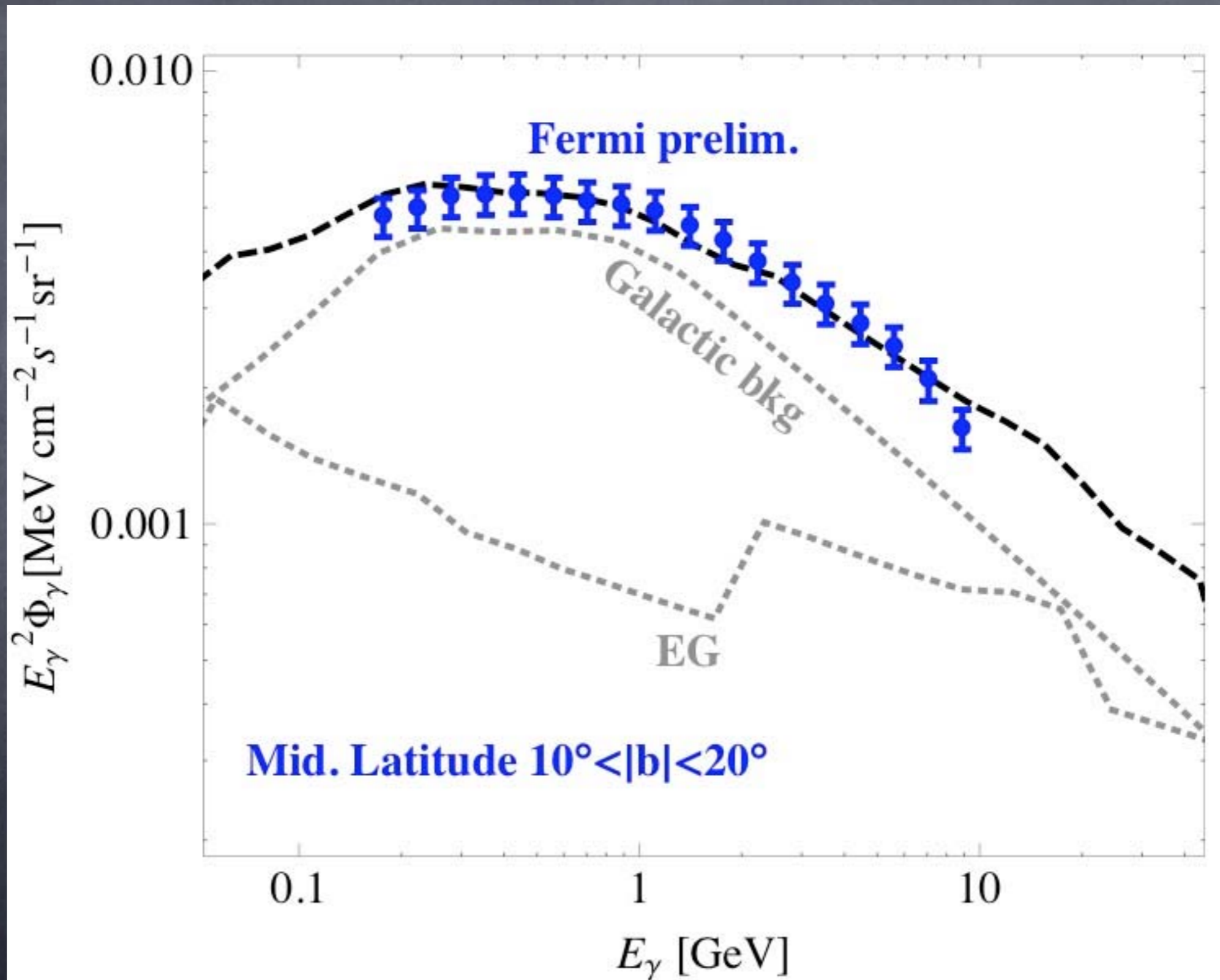




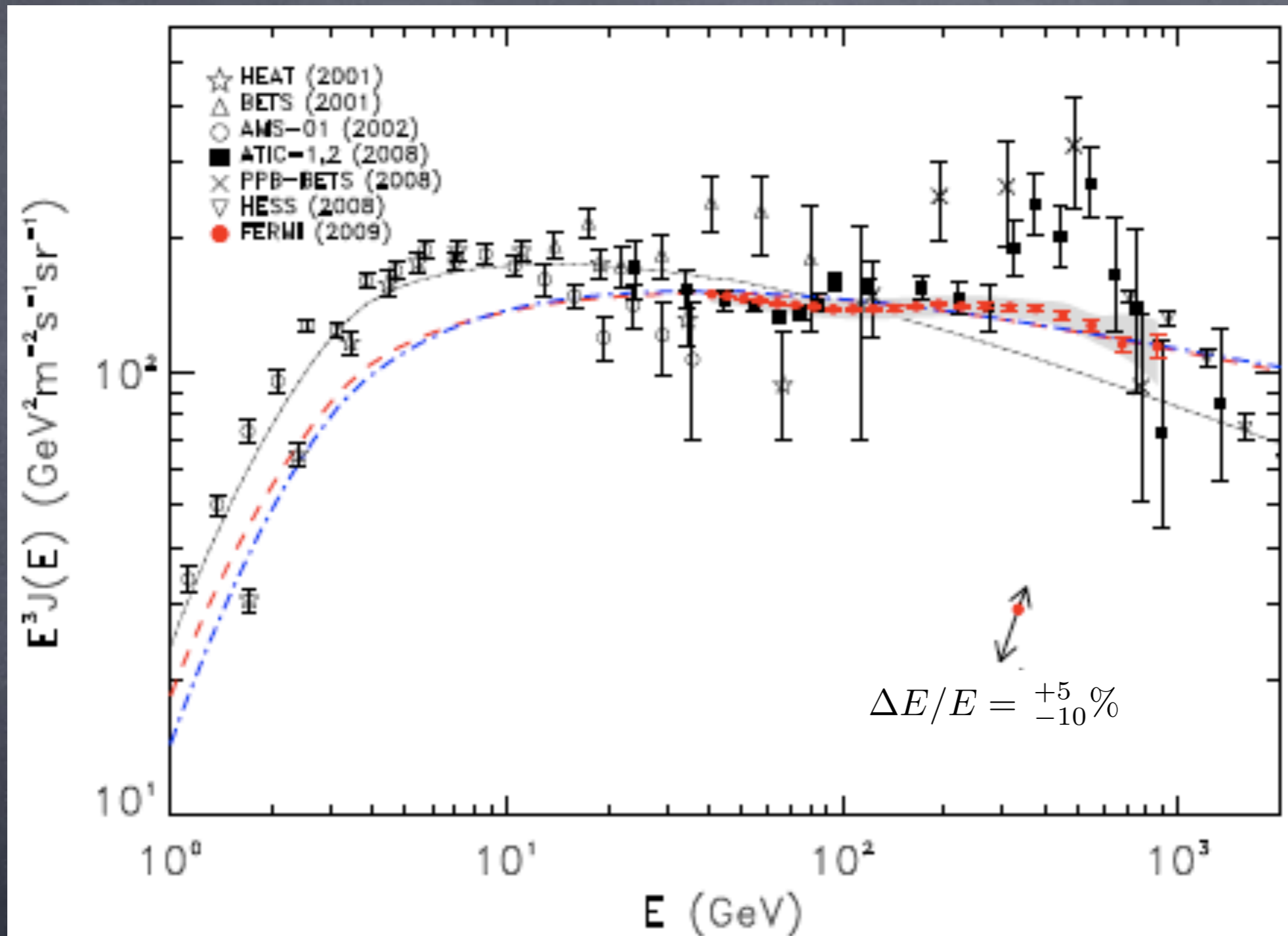
HESS: cutoff in $e^+ + e^-$ spectrum at about a TeV



- Fermi: - no excess in gamma-ray spectrum from 0.1 - 10 GeV
- contradicts EGRET data

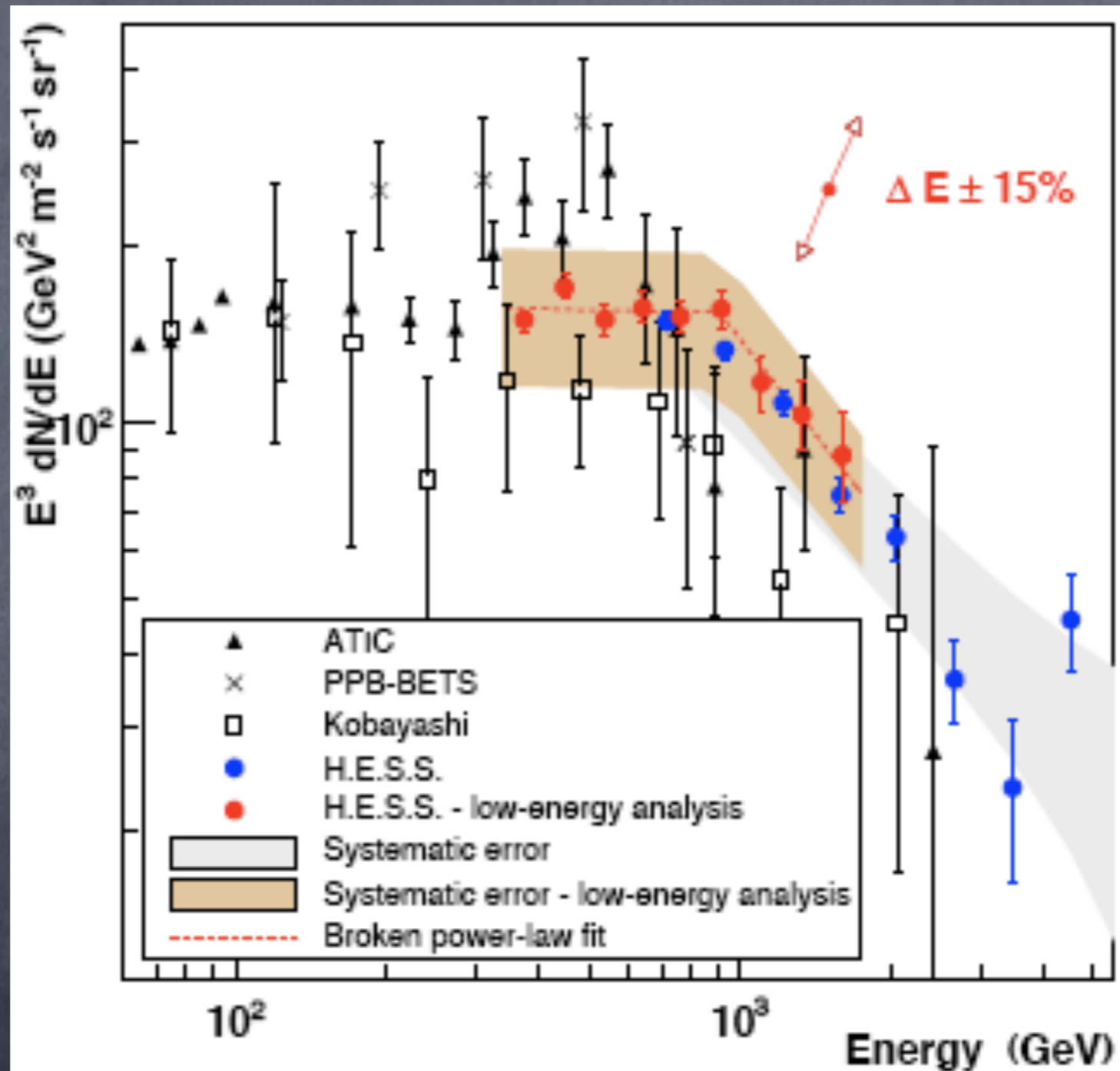


- Fermi: - no bump in $e^+ + e^-$ spectrum from 20 - 1000 GeV
- expected 7000 excess events to confirm ATIC



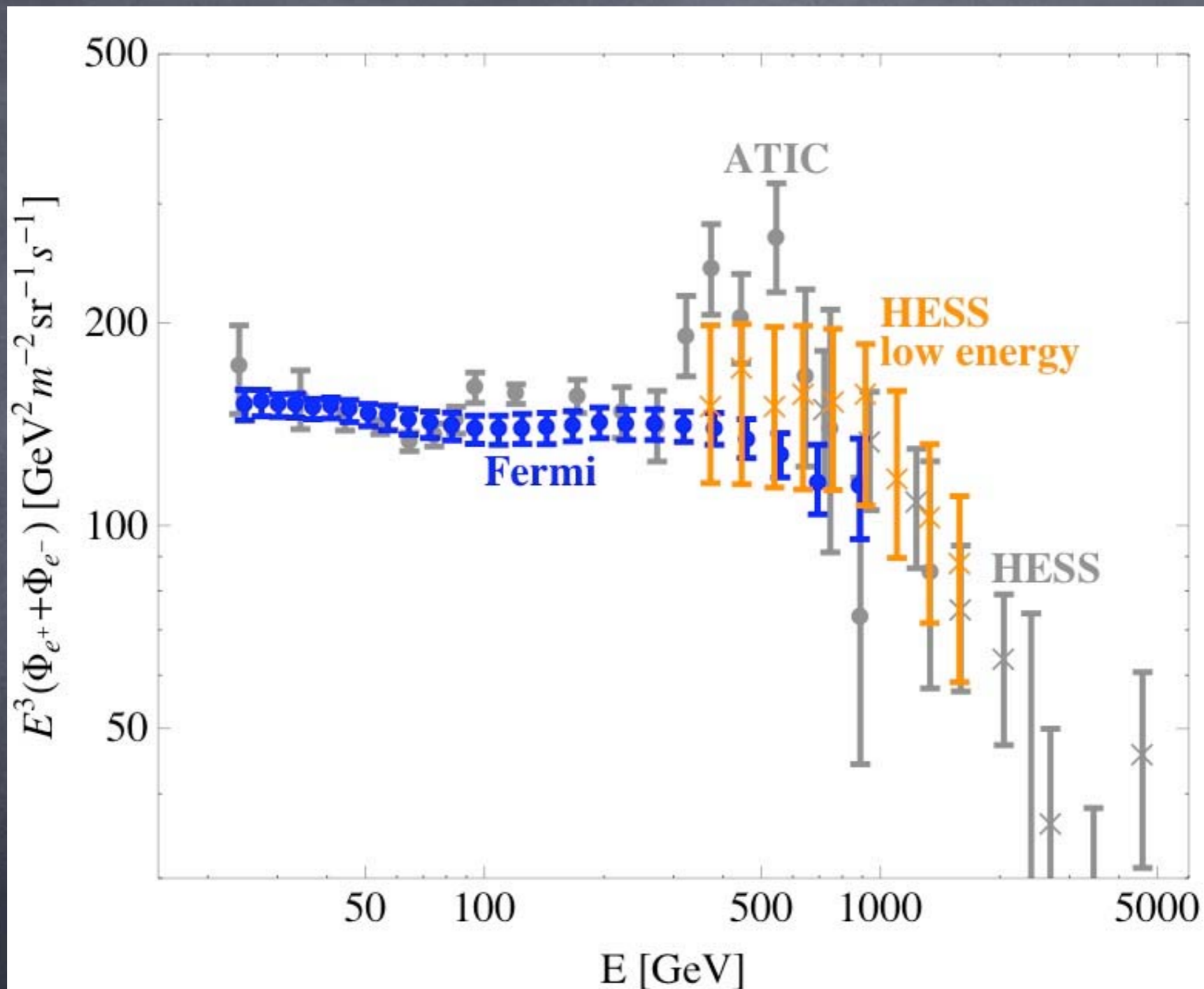
- excess from 200-1000 GeV subject to interpretation
- slight change in SN injection spectrum can reproduce data

- HESS: - no bump in $e^+ + e^-$ spectrum from 340 - 1000 GeV
- confirms falling spectrum above 1 TeV



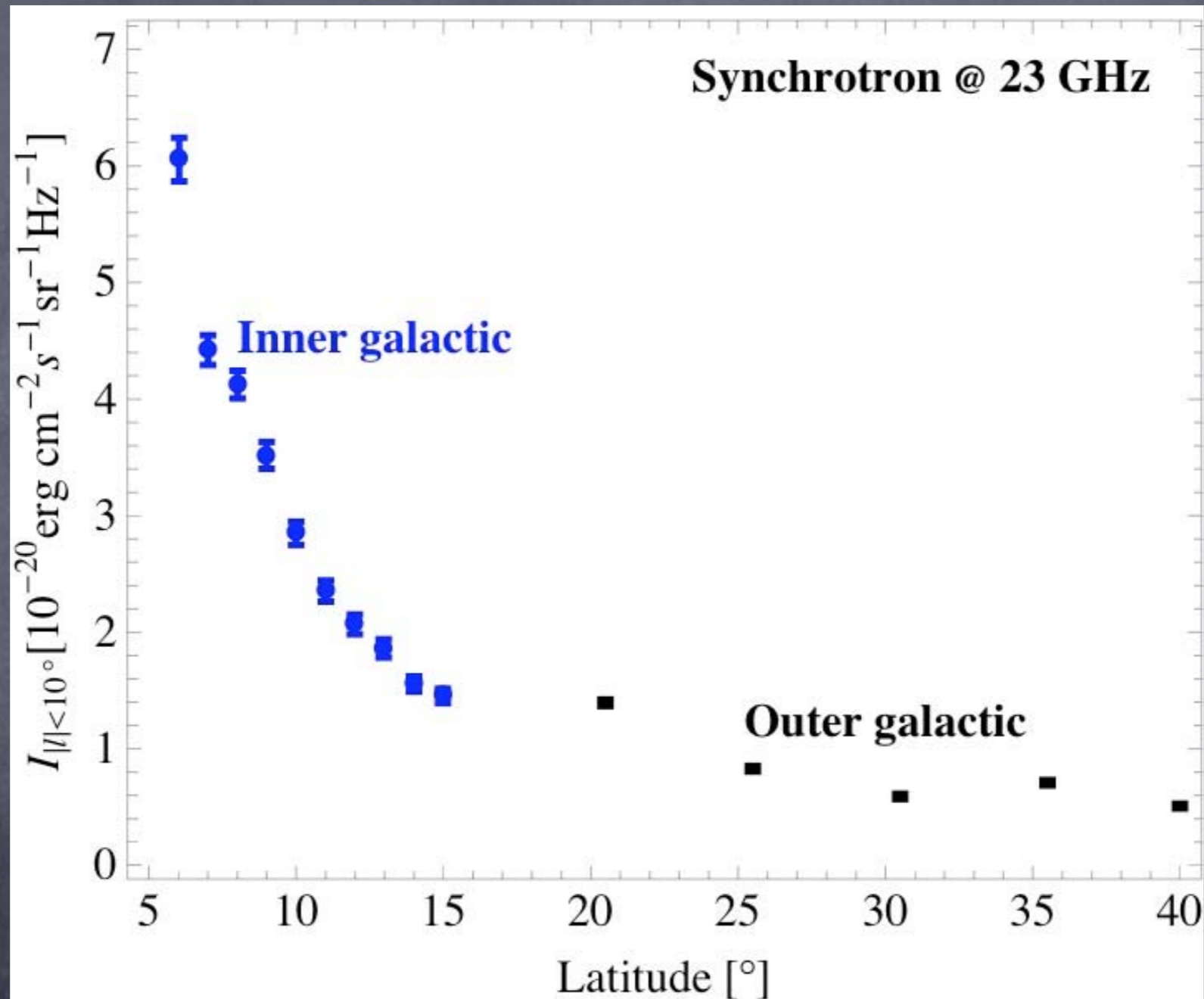
- statistically limited

Spectrum hardens slightly at 100 GeV and softens at 1 TeV



Statistical and systematic uncertainties added in quadrature for Fermi and HESS

WMAP Haze: residual microwave radiation between 23 - 94 GHz



Large and unknown systematic uncertainties, especially in the inner galactic region

- change in background injection spectrum can achieve agreement with Fermi electron data, but not PAM data: primary anomaly is PAM positron excess
- consider all data except ATIC
- need source that produces positrons but not antiprotons
- source must not produce a "feature" to be consistent with Fermi data
- spectrum must fall off rapidly above 1 TeV as per HESS
- possibilities are
 - dark matter annihilation
 - dark matter decay
 - pulsars

How these sources provide viable explanations:

DM annihilation/decay:

In the halo,

DM+DM \rightarrow SM particles \rightarrow decay/hadronize/shower to e^{\pm}, \bar{p}
or long-lived DM \rightarrow SM particles $\rightarrow e^{\pm}, \bar{p}$

e^{\pm}, \bar{p} interact with the galactic magnetic field, ISRF, ISM and lose energy via

- inverse compton scattering which produces gamma rays
- synchrotron radiation in the form of radiowaves
- spallation on heavy nuclei

e^{\pm}, \bar{p} eventually make it to the earth with scrambled trajectories

Gamma-rays produced as FSR, bremsstrahlung, in pion decay and IC essentially come directly to the earth

IC spectra will turn out to be the same for all scenarios since the e^{\pm} required by data is basically fixed

Main difference in gamma-ray spectra arises from FSR which is model-dependent and dominates IC close to the endpoint

Mature pulsars: ($0.01 < T < 1$ Myr)

e^\pm are confined to the pulsar wind nebula until it merges with the ISM. Merger process is fast so that pulsars can be treated as burst-like sources of e^\pm

Contribution could be from a few local pulsars

- Geminga: $d = 160$ pc, $T = 0.37$ Myr

- Monogem: $d = 290$ pc, $T = 0.11$ Myr

but pair conversion efficiency needs to be high (30 - 40%)

Contribution could be from a large number of pulsars, distant and local, with an assumed continuum distribution and injection spectrum

$$\frac{dN_{e^\pm}}{dE} \propto E^{-1.5} e^{-E/E_p}$$

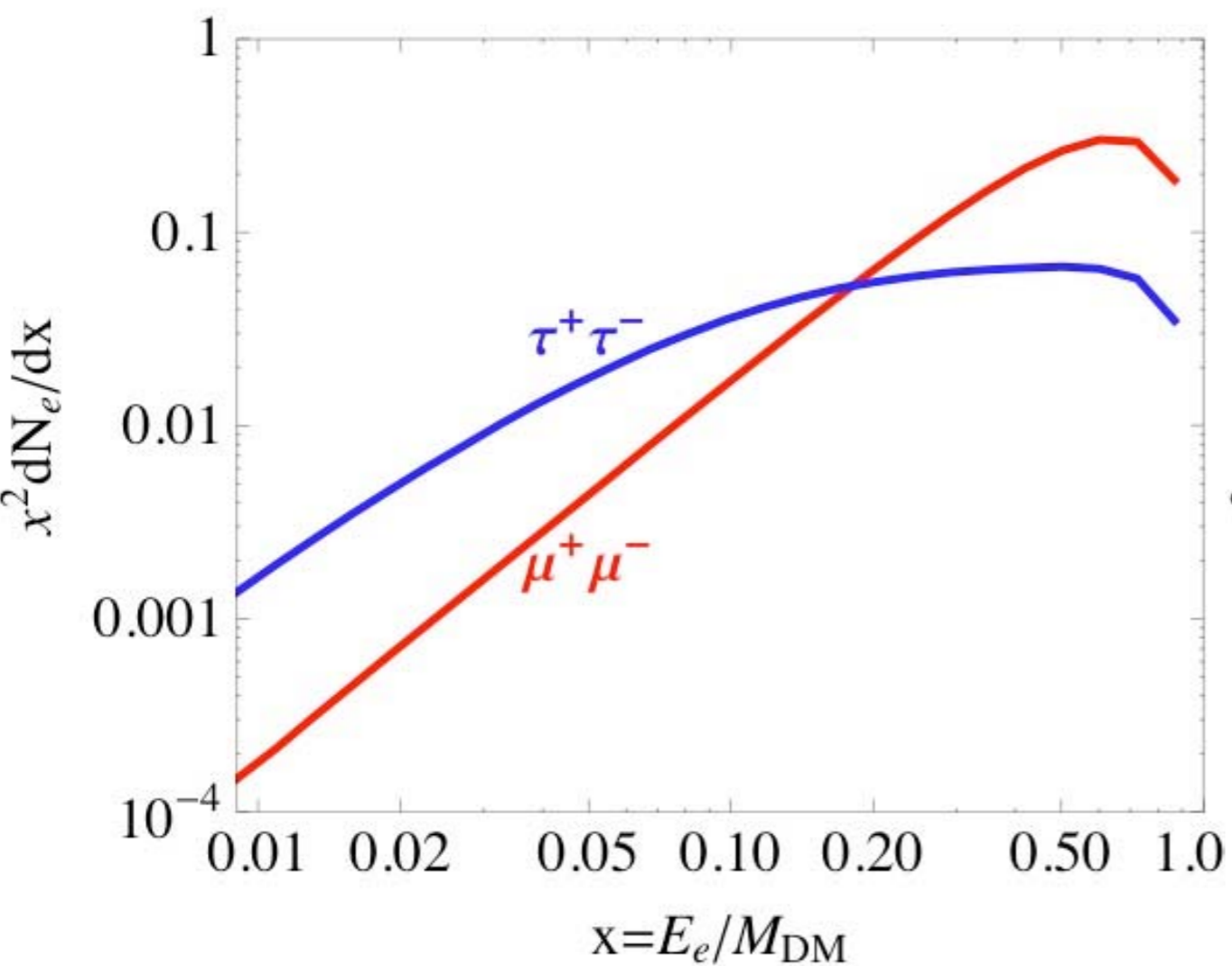
- absence of hadronic showers
 - > no antiprotons
 - > easily consistent with PAM antiproton data
- primary gamma-ray flux is negligible compared to the diffuse flux
 - > only contribution is from IC scattering
 - > easily consistent with Fermi gamma-ray data

DM annihilation/decay

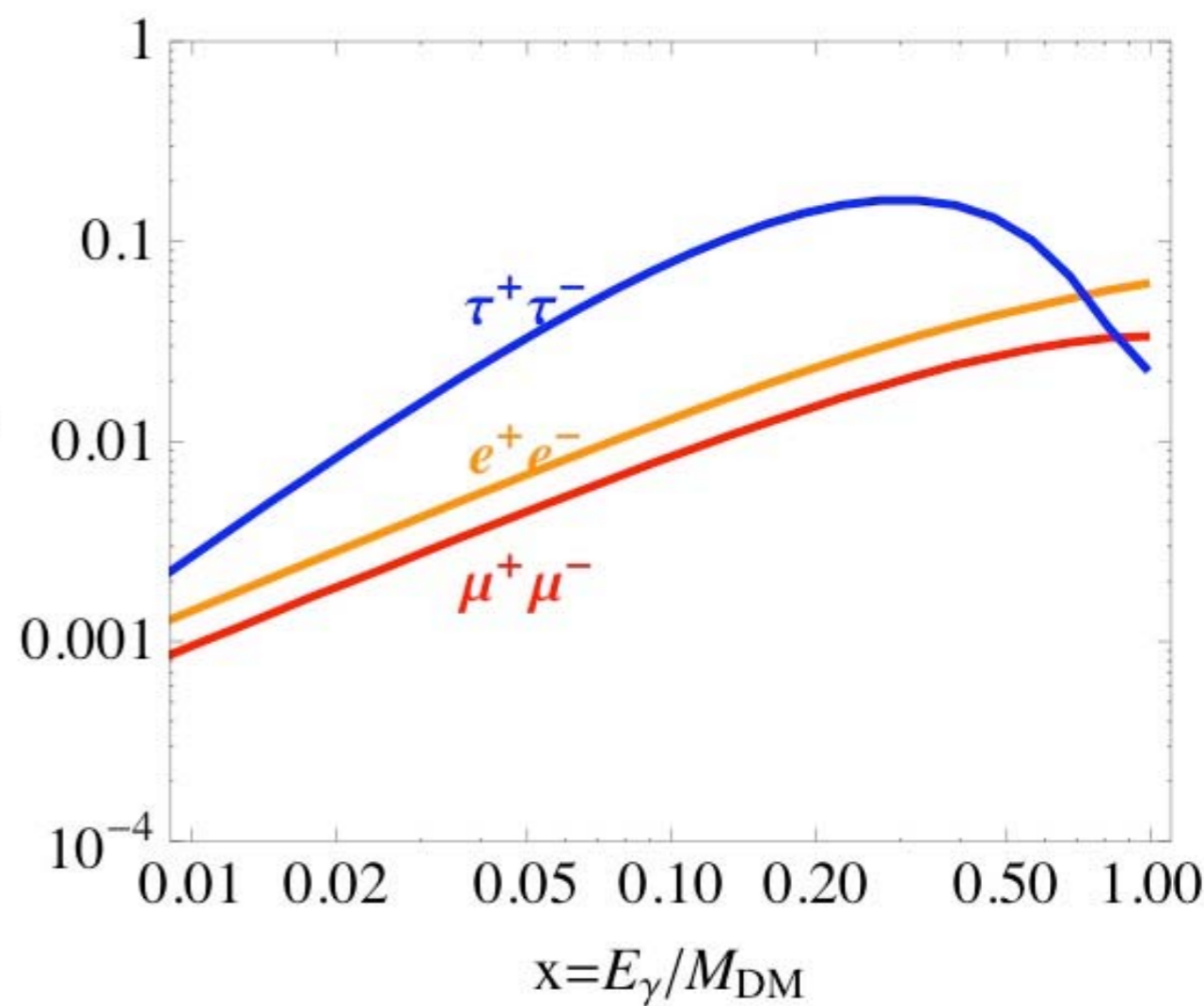
- Consider 2-body final states
- WW, ZZ, qq, hh are disfavored because of overproduction of antiprotons, or positron spec too flat
- Consider only $ee, \mu\mu, \tau\tau$, and to these channels with equal branching fractions
- For DM decay, effectively assuming that DM is a scalar
- Other channels, $Wl, Z\nu, ll\nu$ possible for fermion DM decay
 - $W\tau, Z\nu, \tau\tau\nu$ give too flat positron spectra

$$M_{DM} = 1 \text{ TeV}$$

line spectrum for ee

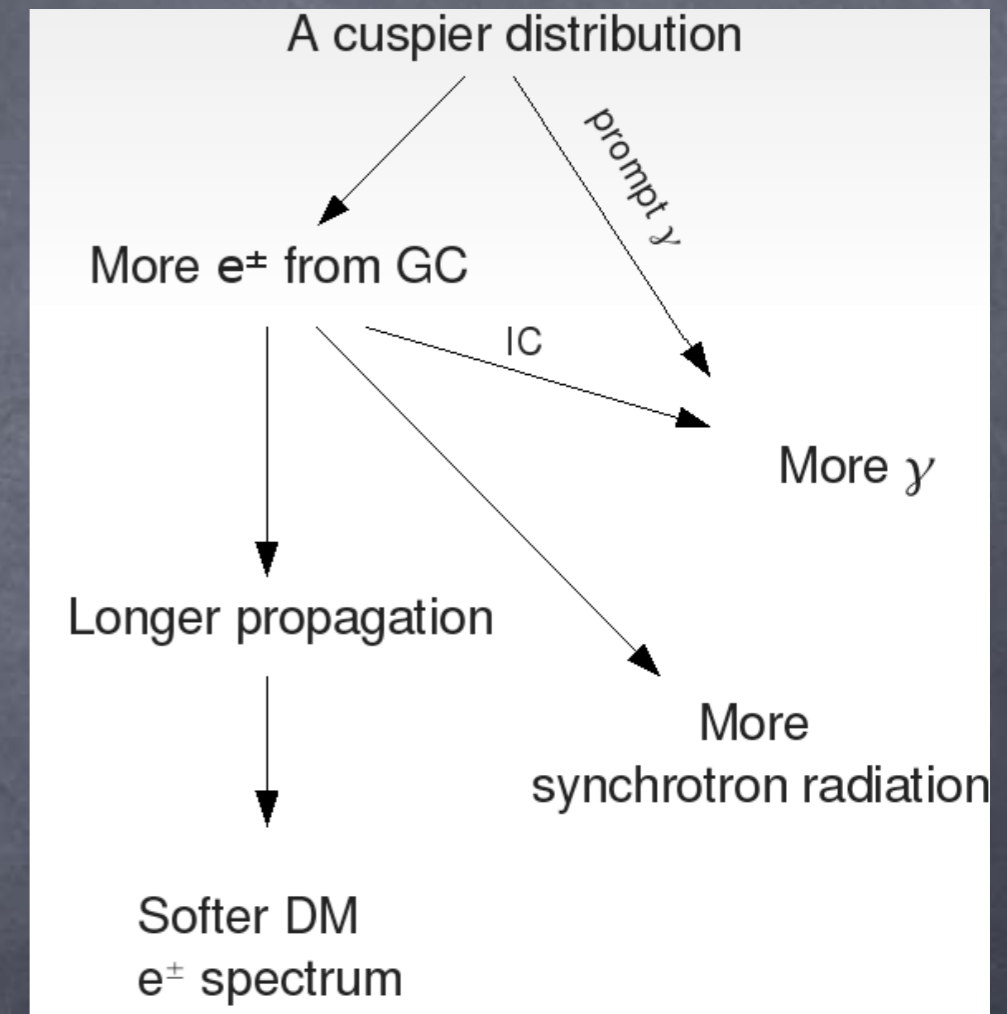
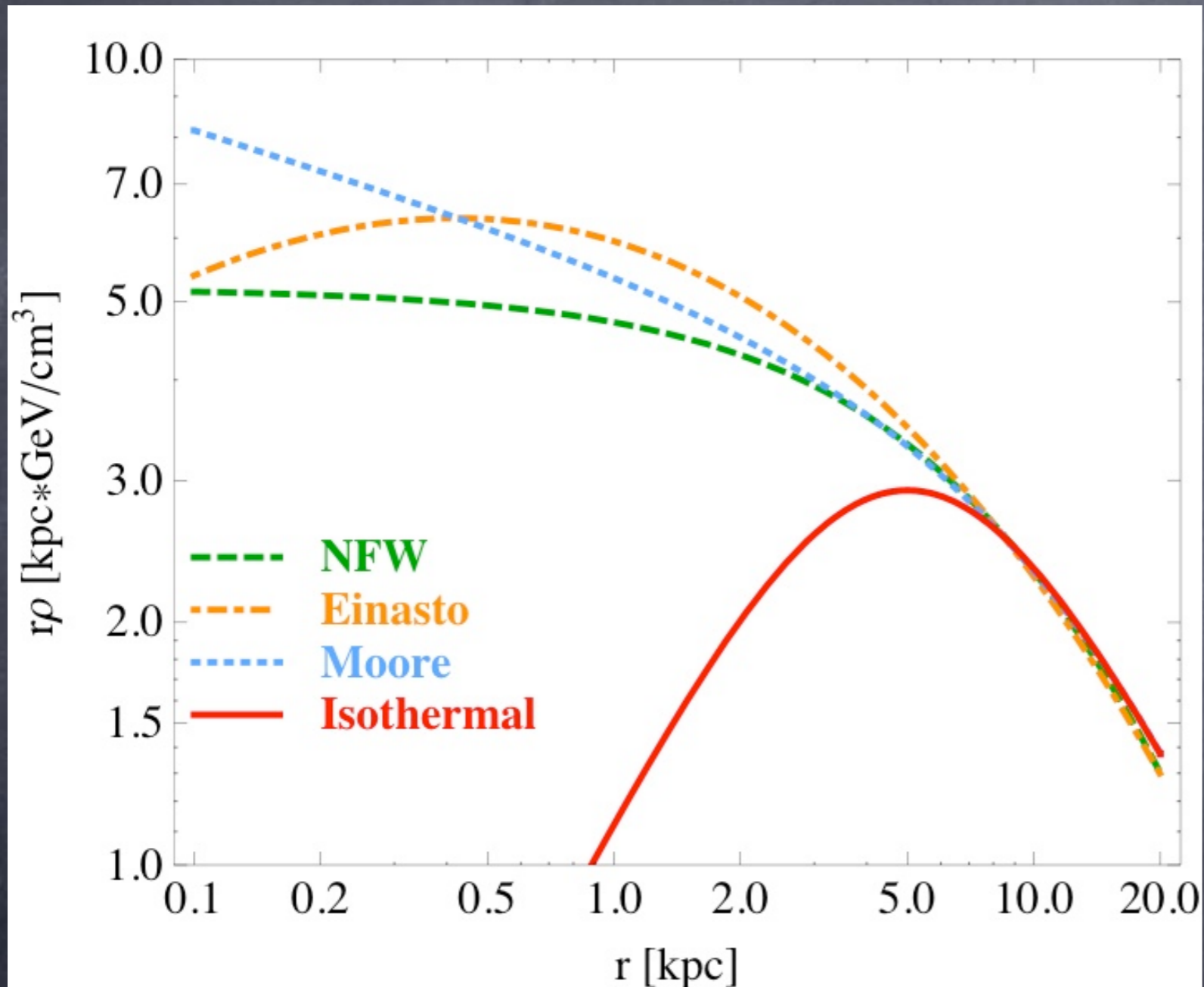


from MicrOMEGAs



from DMFIT

Dark matter halo profiles



Source terms: $\frac{d\Phi_i}{dE_i} \equiv \begin{cases} \frac{\text{BF}}{2} \frac{\rho^2}{M_{DM}^2} \langle \sigma v \rangle \frac{dN_i}{dE_i} & \text{DM ann.} \\ \frac{1}{T} \frac{\rho}{M_{DM}} \frac{dN_i}{dE_i} & \text{DM decay} \end{cases}$

Reference $\langle \sigma v \rangle = 3 \times 10^{-26} \text{cm}^3/\text{s}$ to obtain relic density

BF = "boost factor" from s-channel resonance, Sommerfeld effect, DM overdensities. Need large BF of order **100-10000**.

Need T of order **10^{26} s** (billion times the age of the universe)

Typical lifetime of a TeV-scale particle that decays via a dim-6 operator suppressed by the GUT scale is

$$T \sim 2 \times 10^{26} \text{s} \left(\frac{\text{TeV}}{M_{DM}} \right)^5 \left(\frac{M_{GUT}}{10^{16} \text{GeV}} \right)^4$$

Propagation with GALPROP

Allow variations of

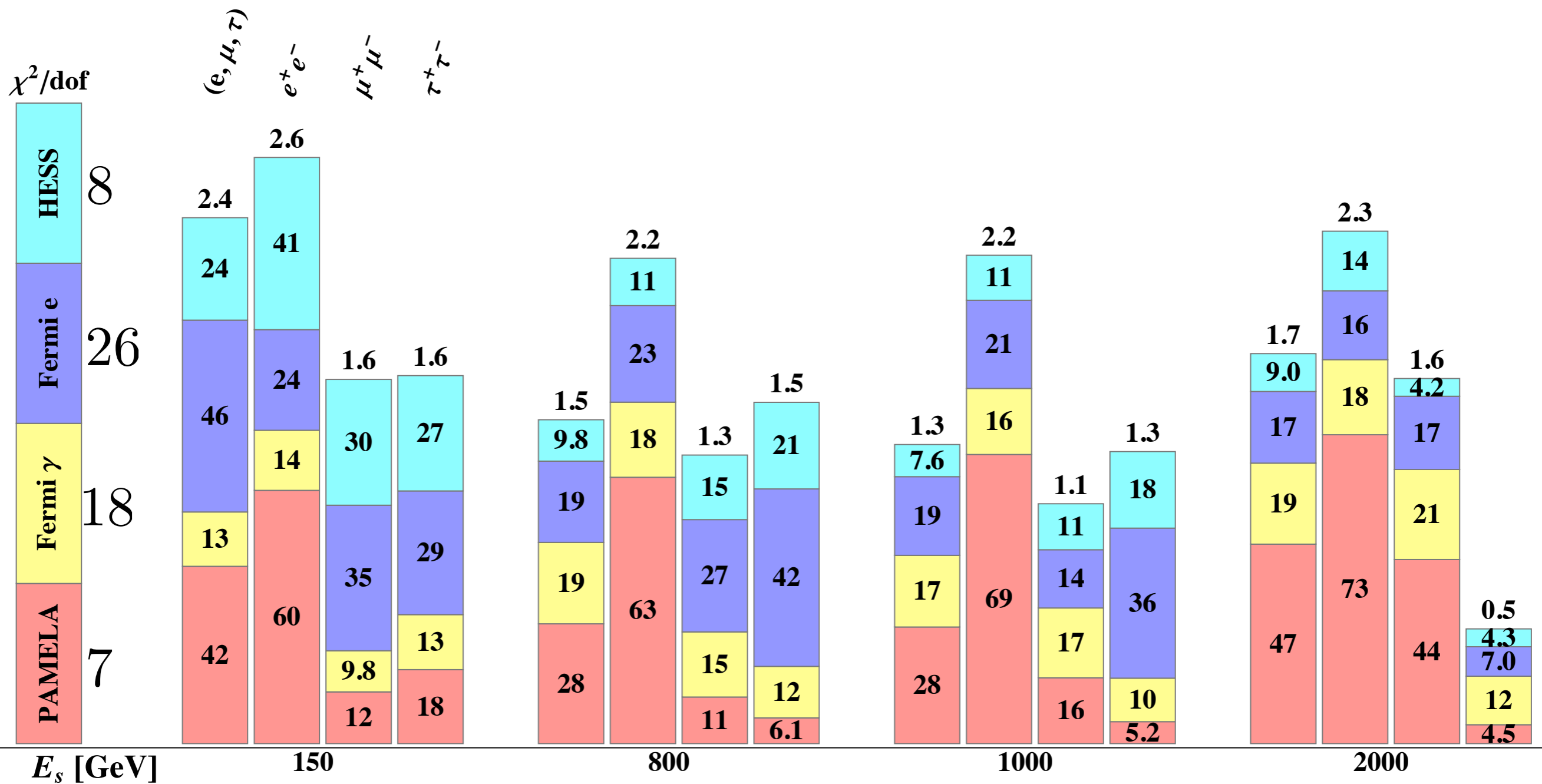
- background injection spectral index between 2.2 - 2.9
- overall normalization of the background
- 3 diffusion parameters within ranges consistent with nuclei data
- energy calibration scale for HESS and Fermi electron data

Define a generic energy scale of injected positrons:

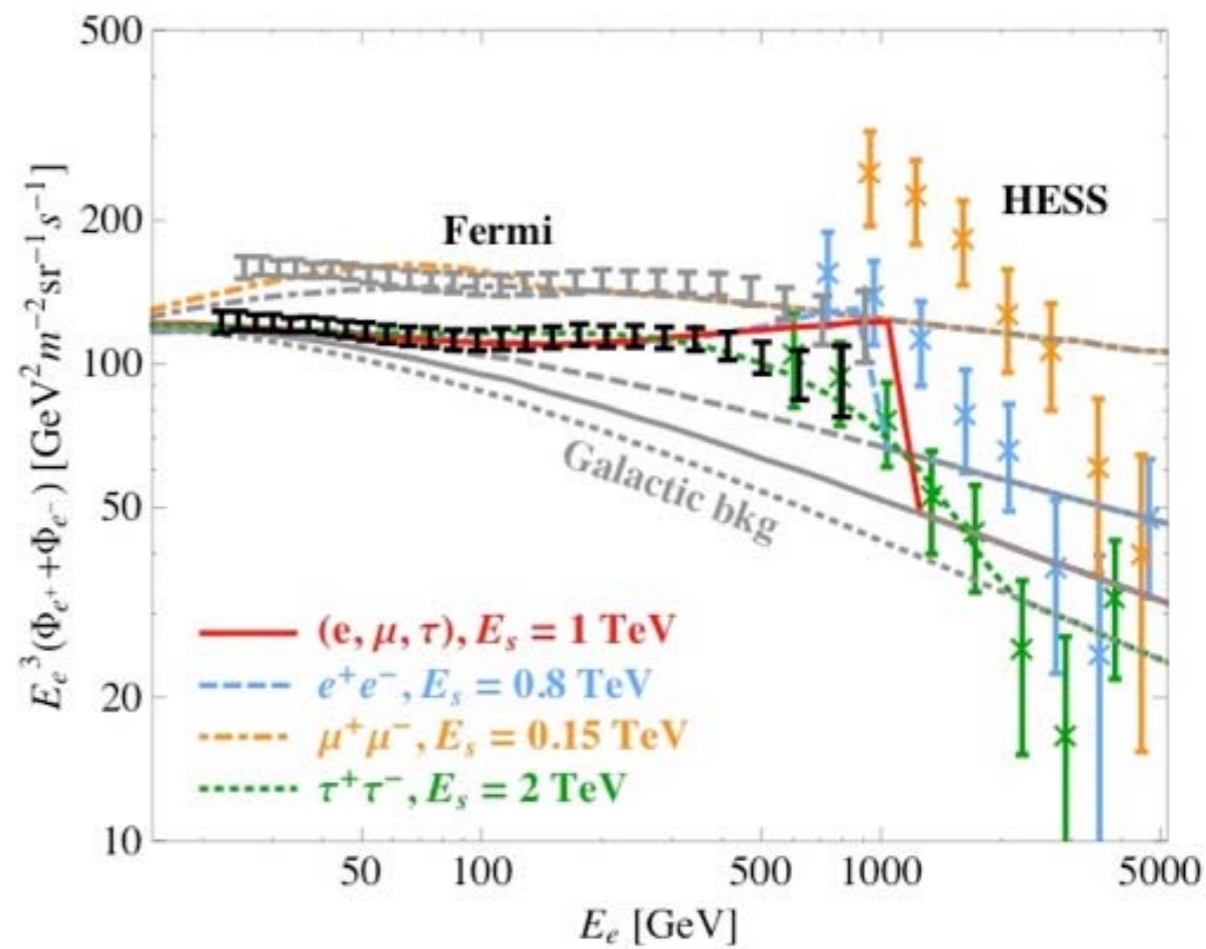
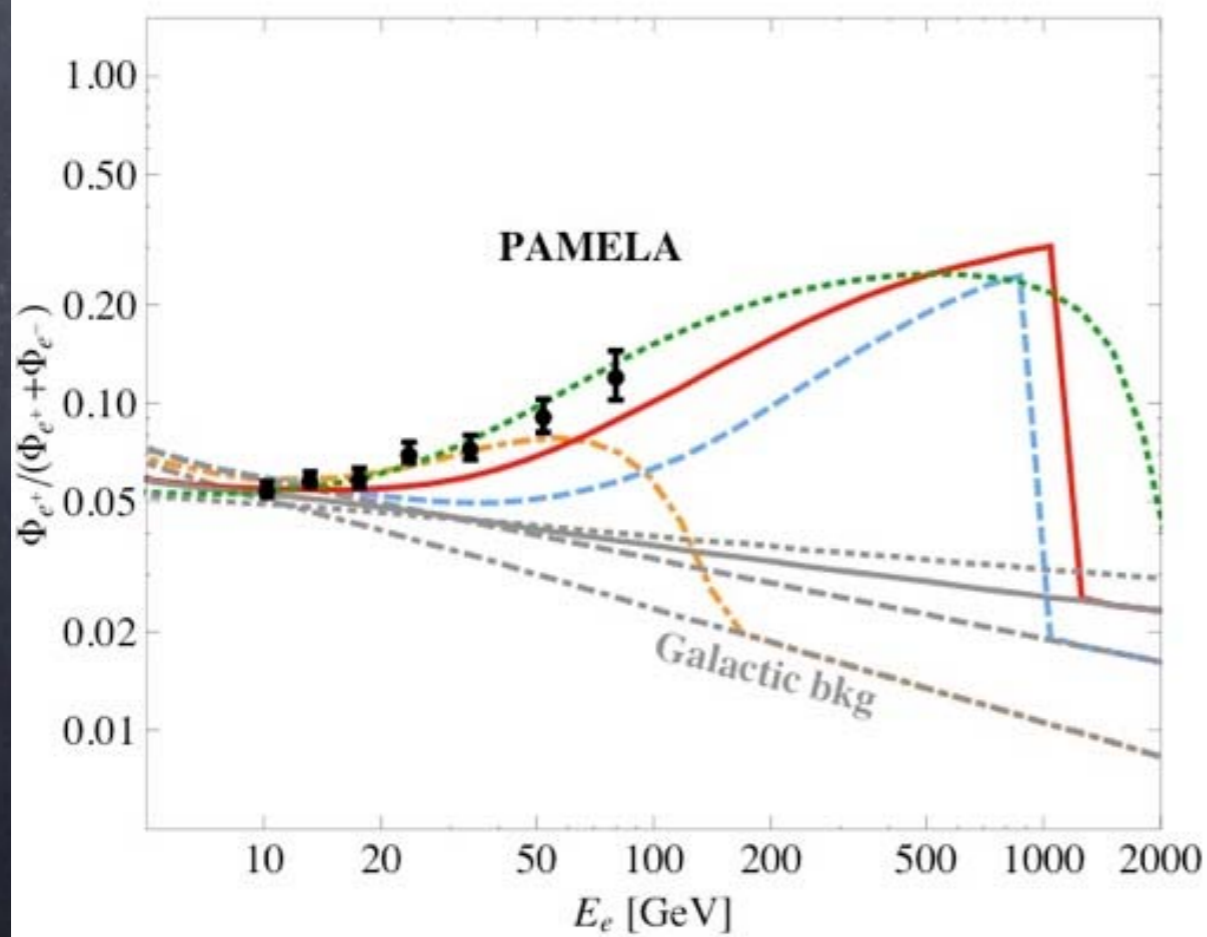
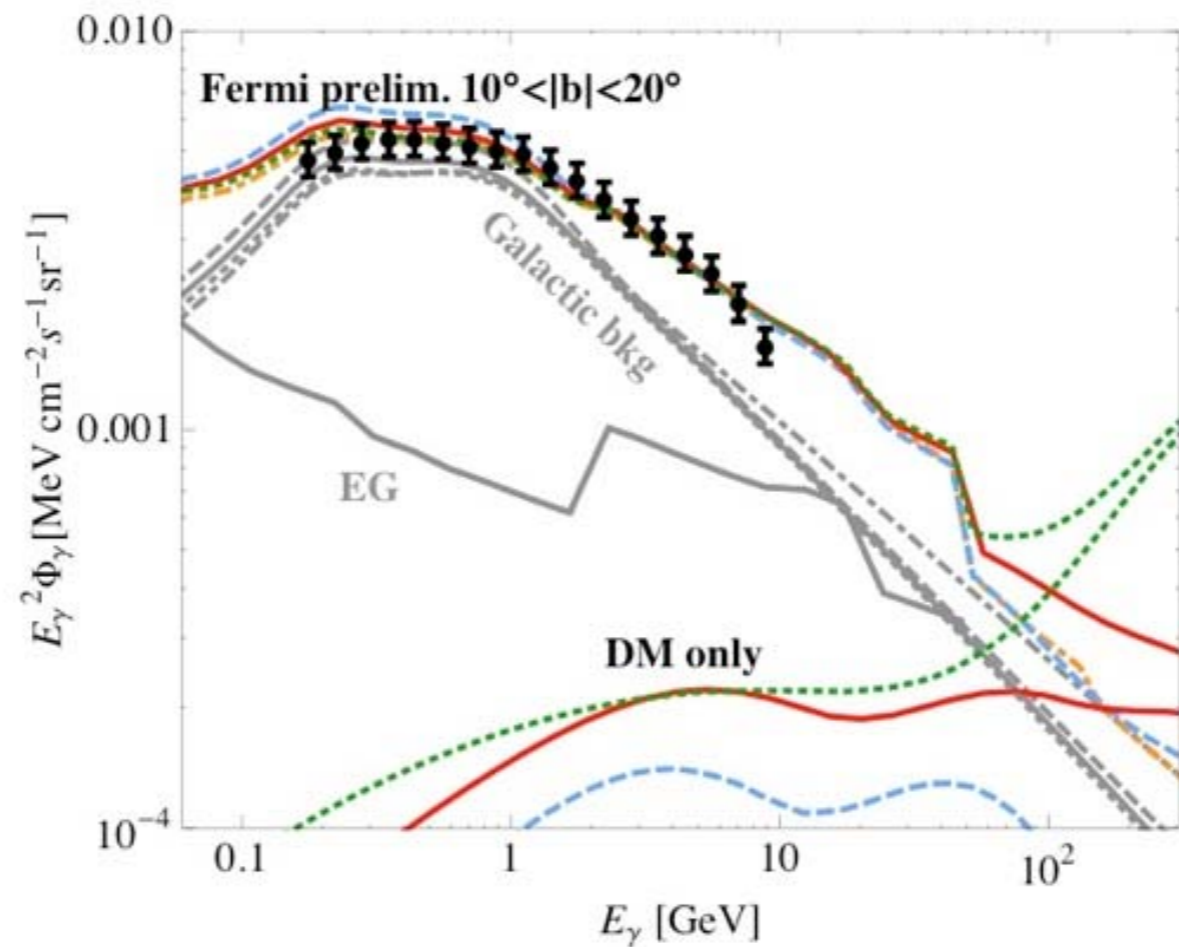
$$E_s \equiv \begin{cases} M_{DM} & \text{Annihilating DM} \\ \frac{M_{DM}}{2} & \text{Decaying DM} \\ E_p & \text{Pulsars} \end{cases}$$

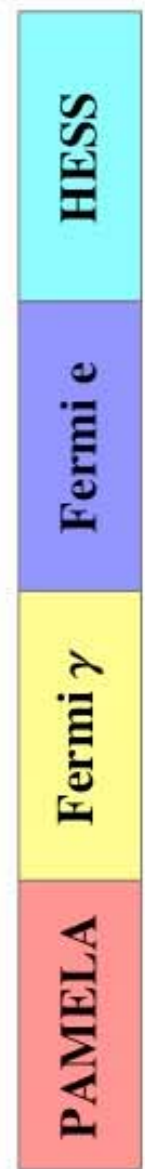
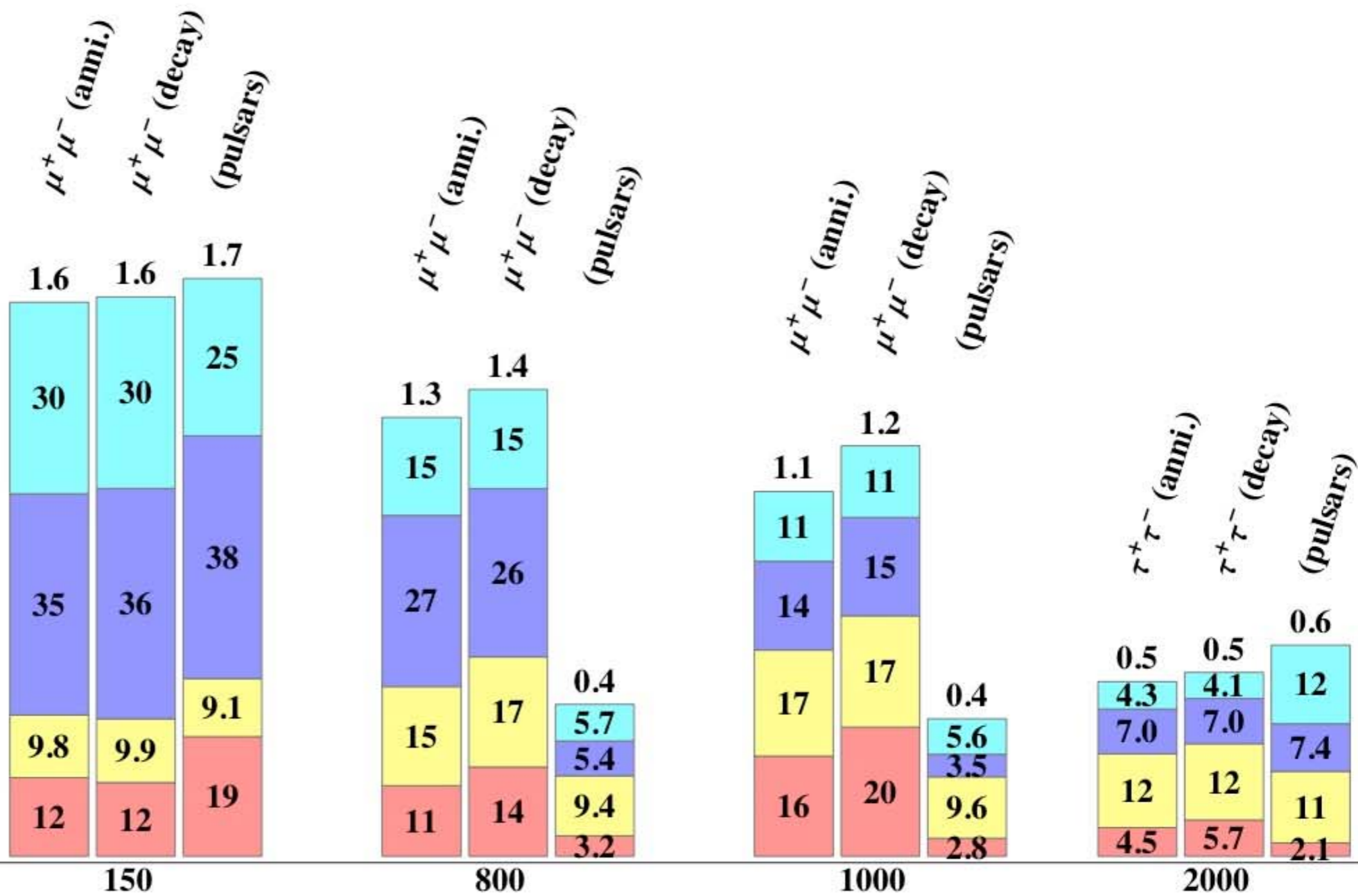
For a given E_s vary BF (for DM annihilation), T (for DM decay) and a spectrum normalization for pulsars

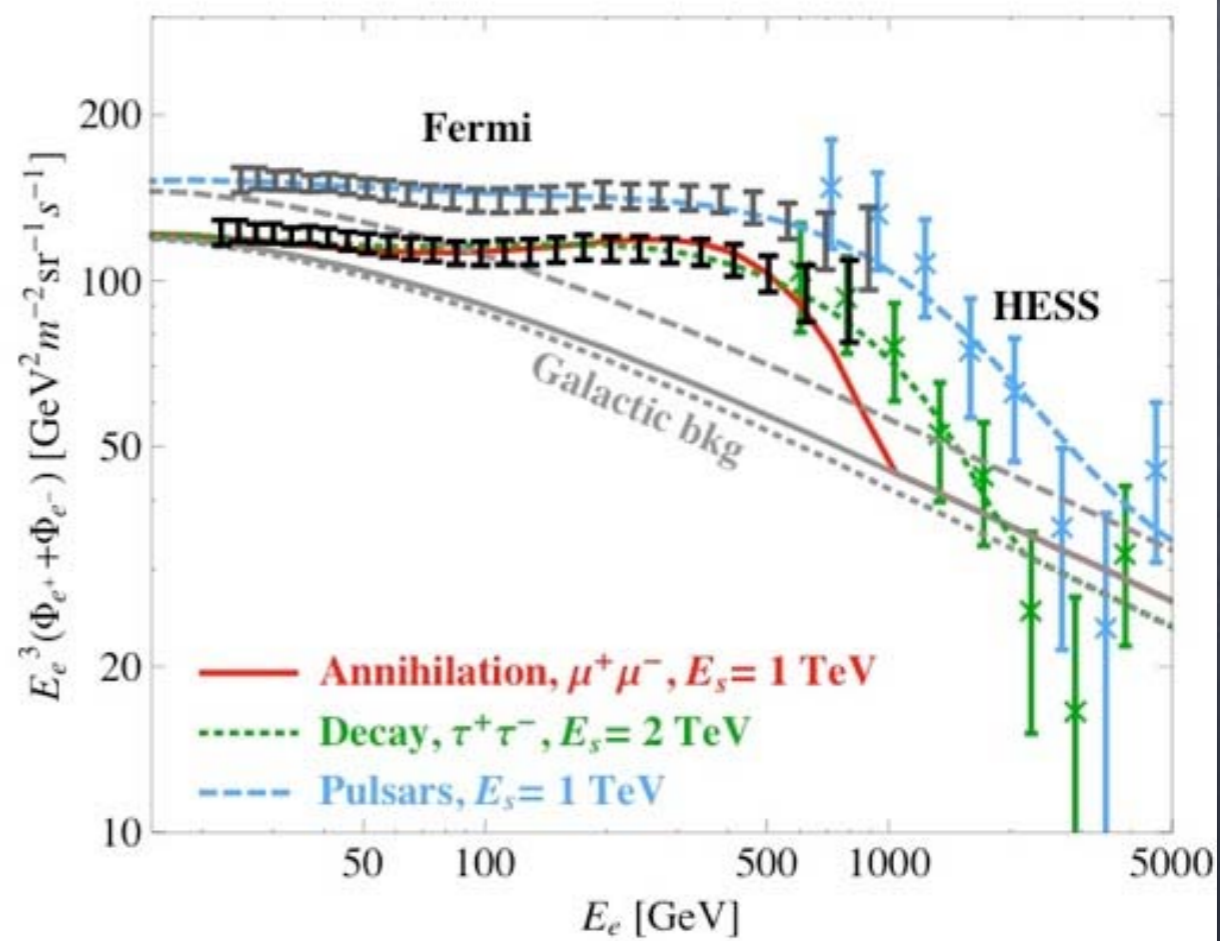
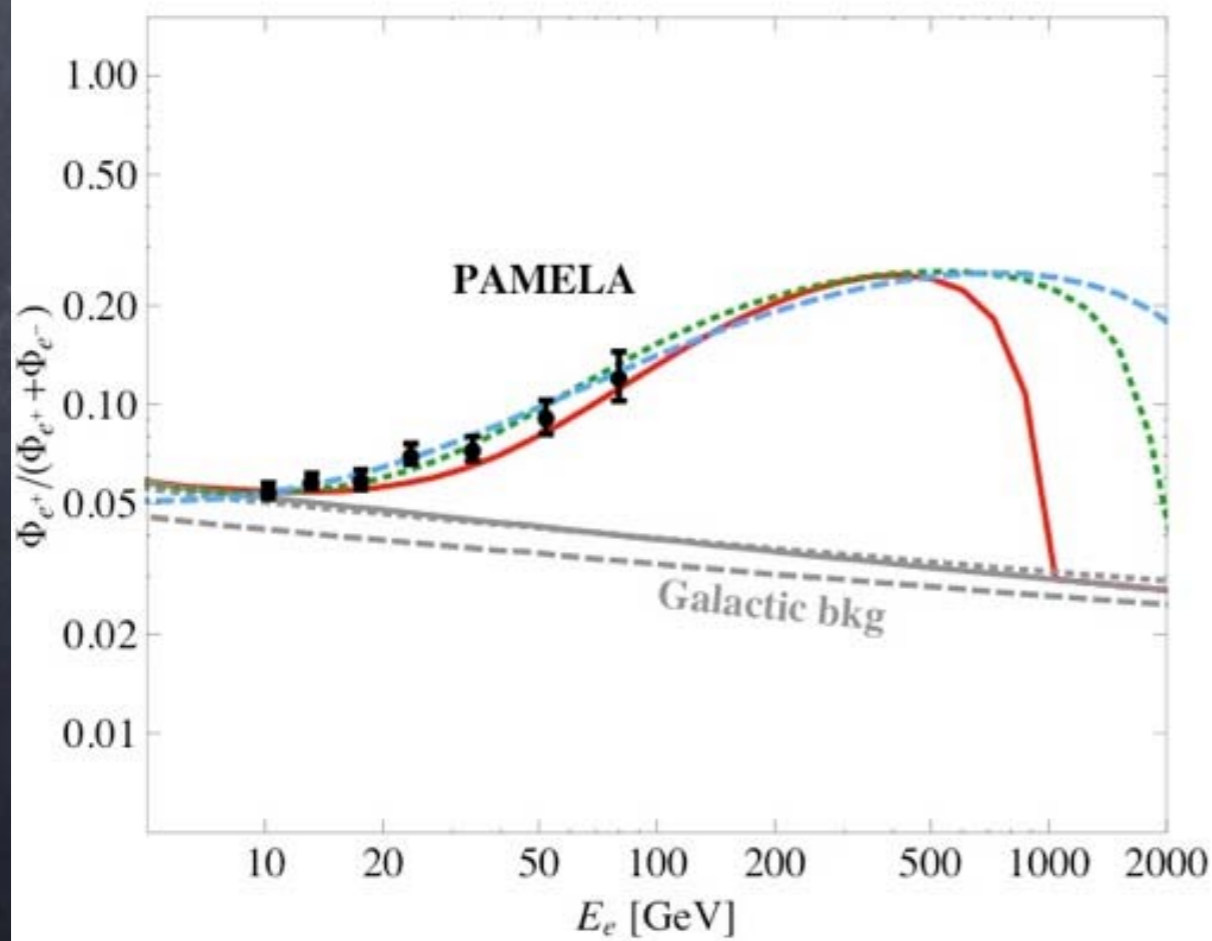
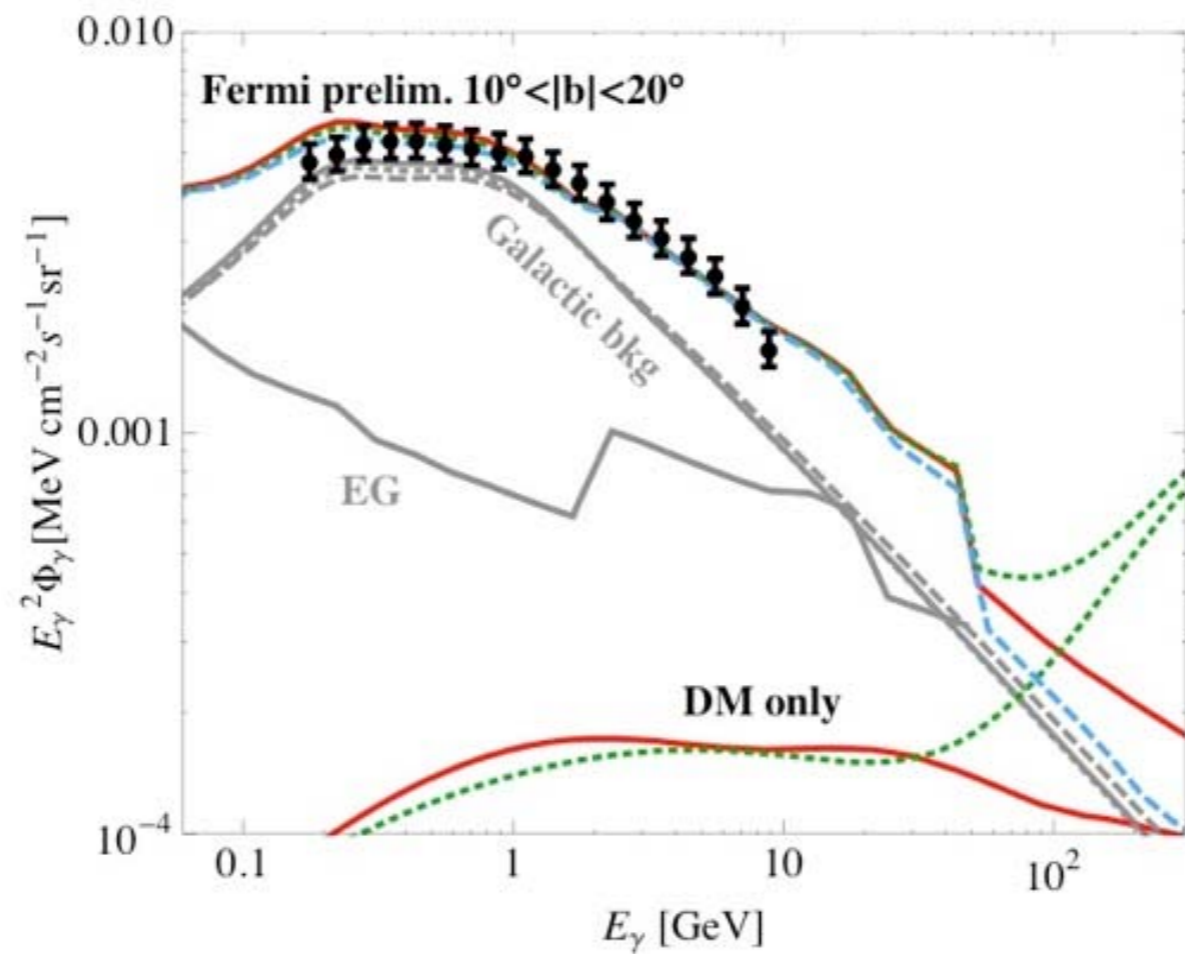
DM annihilation (isothermal profile)



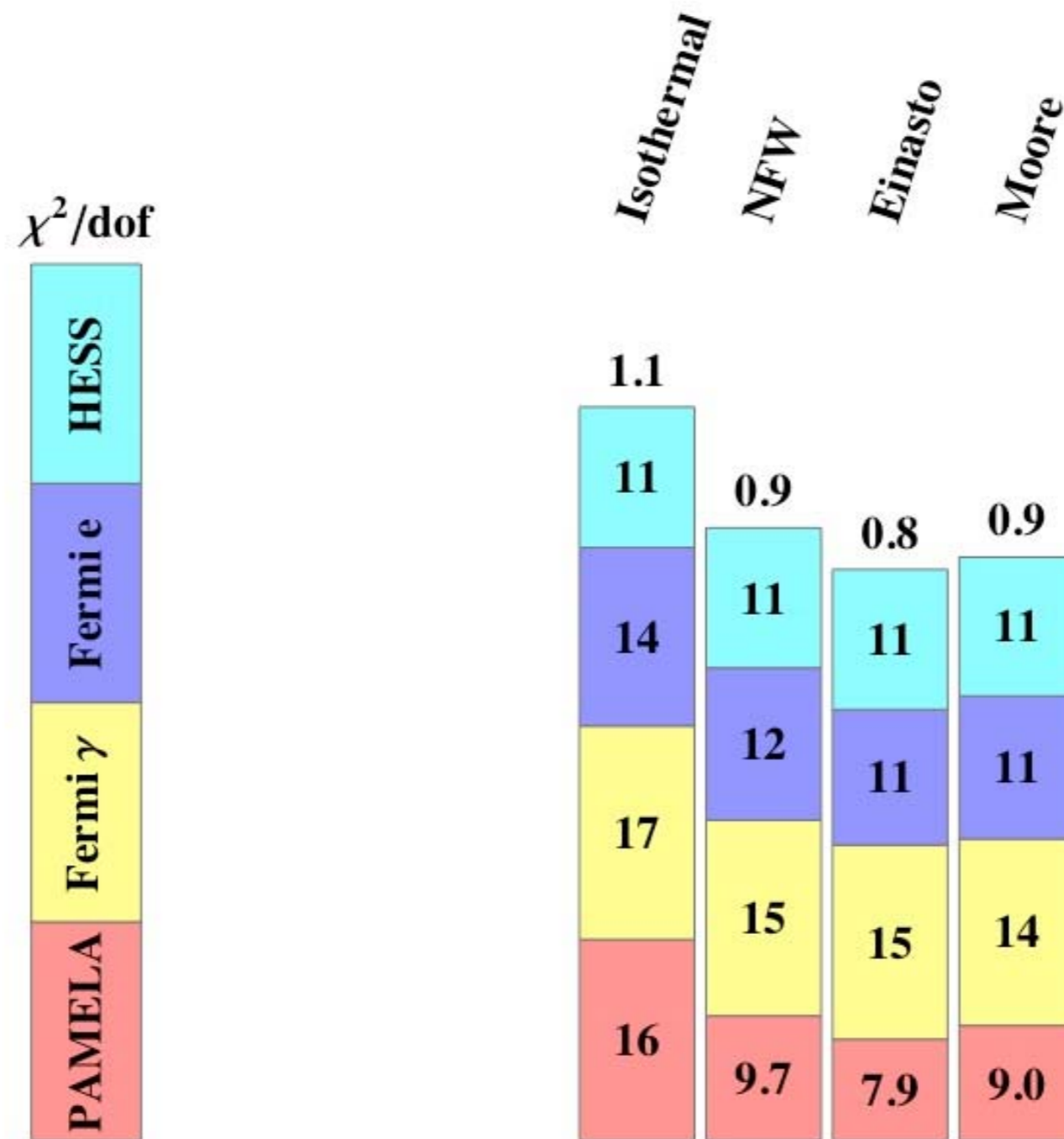
- Soft spectra preferred
- 1 TeV into $\mu\mu$ works well; 2 TeV into $\tau\tau$ works best



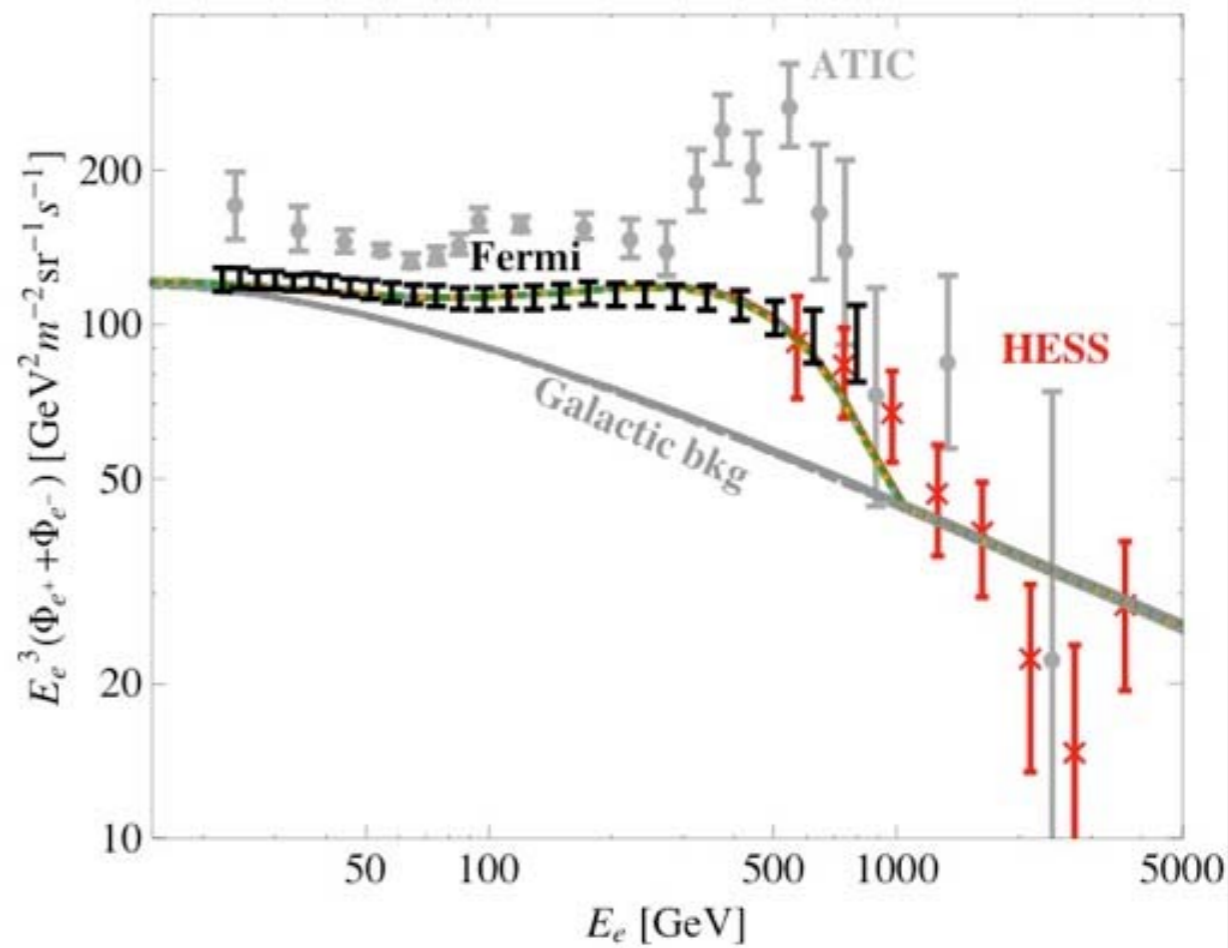
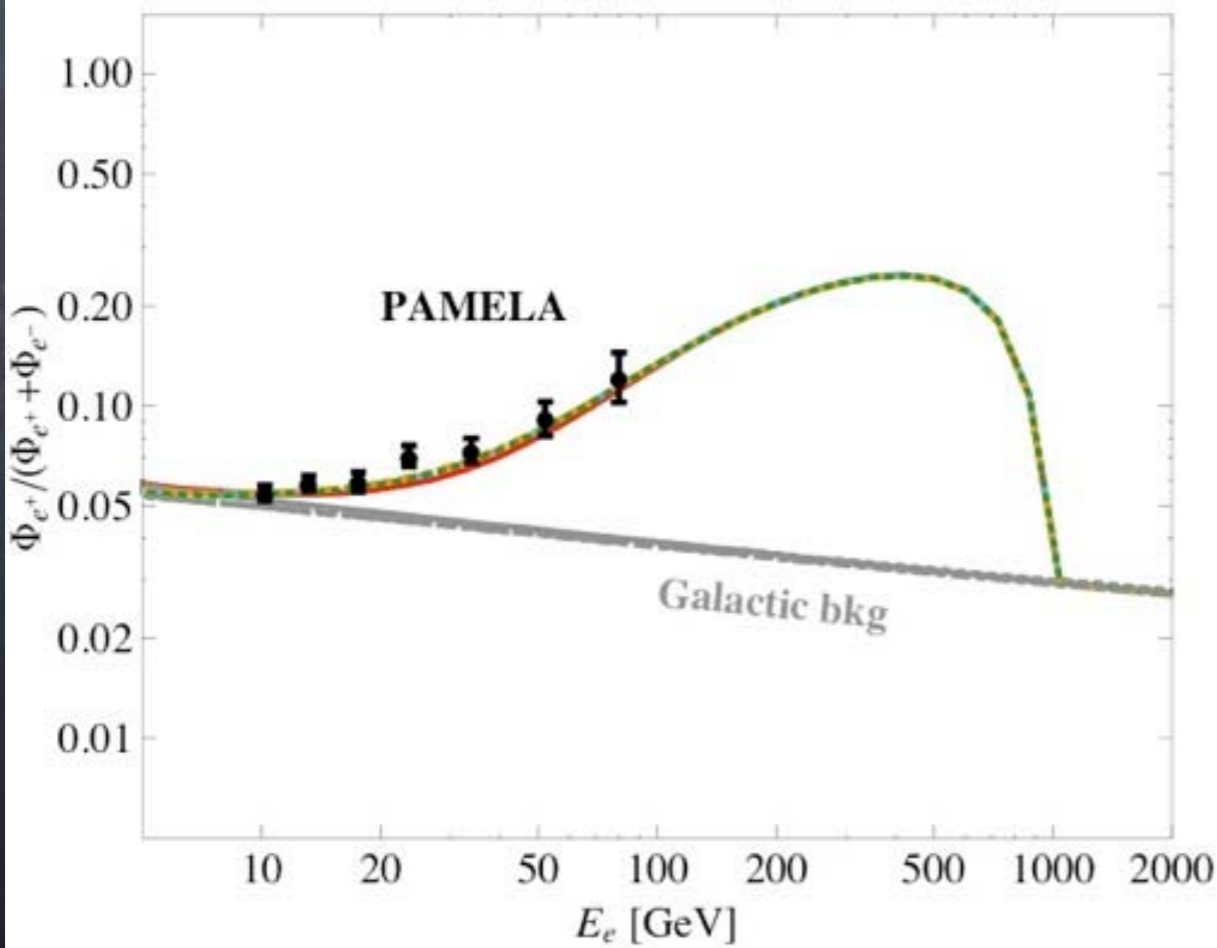
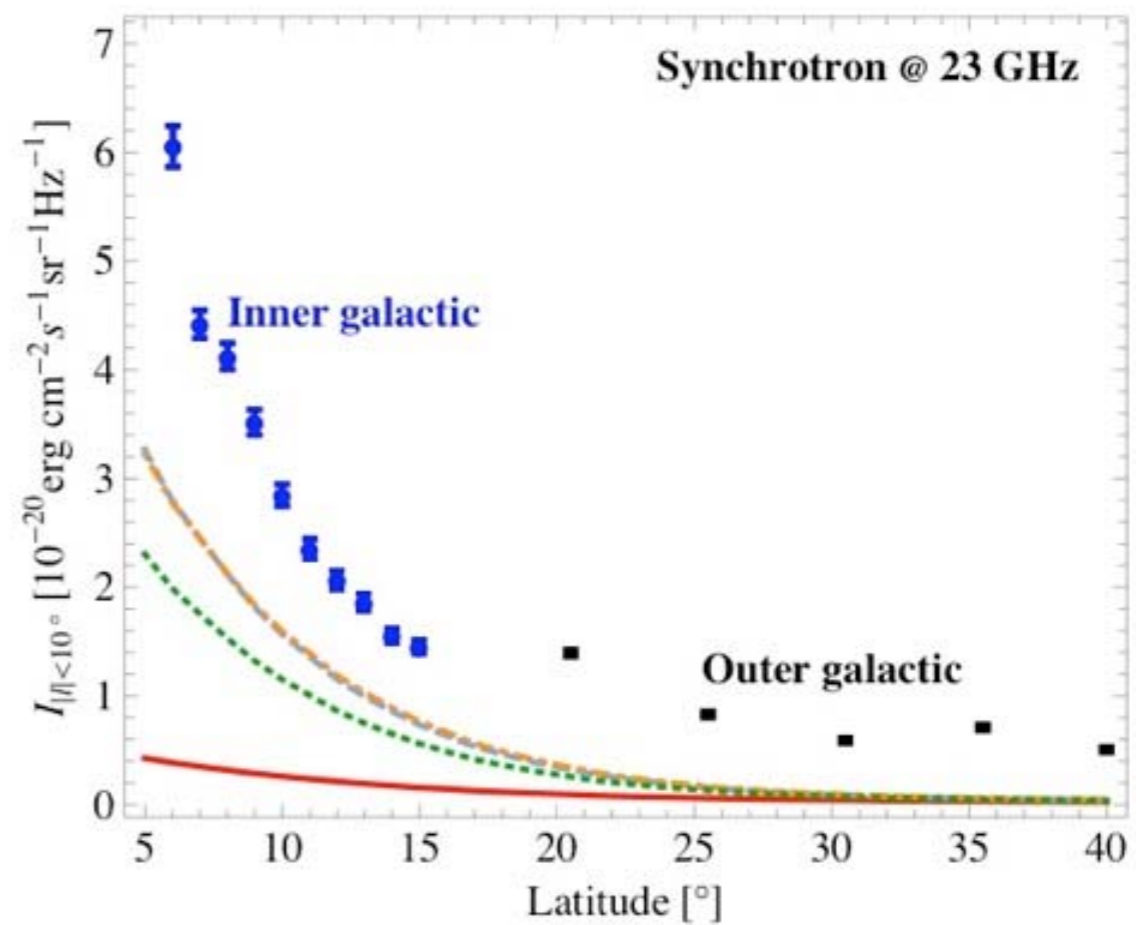
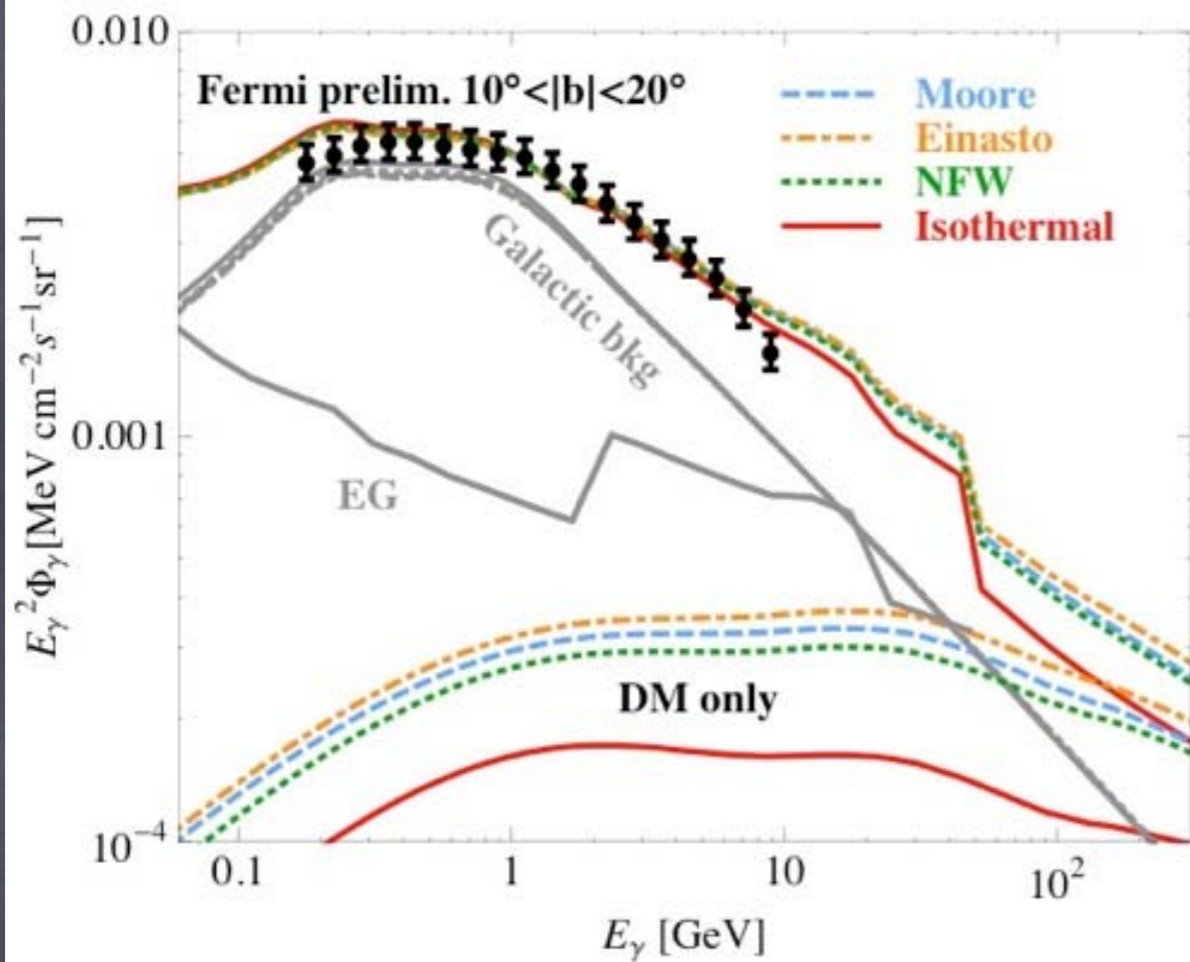
χ^2/dof  E_s [GeV]



Dependence on halo profiles (DM annihilation)



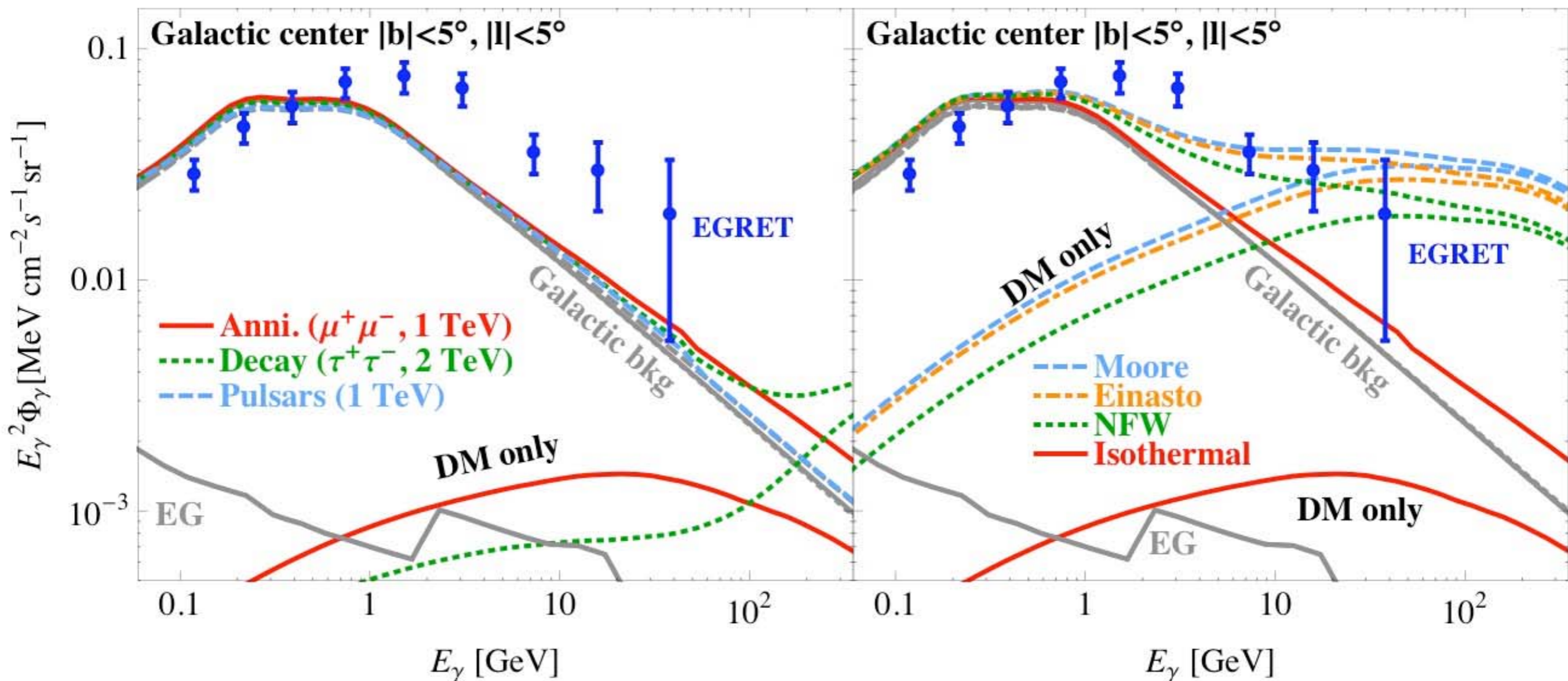
$$M_{DM} = 1 \text{ TeV into } \mu\mu$$



Gamma-ray predictions for Fermi

Isothermal profile

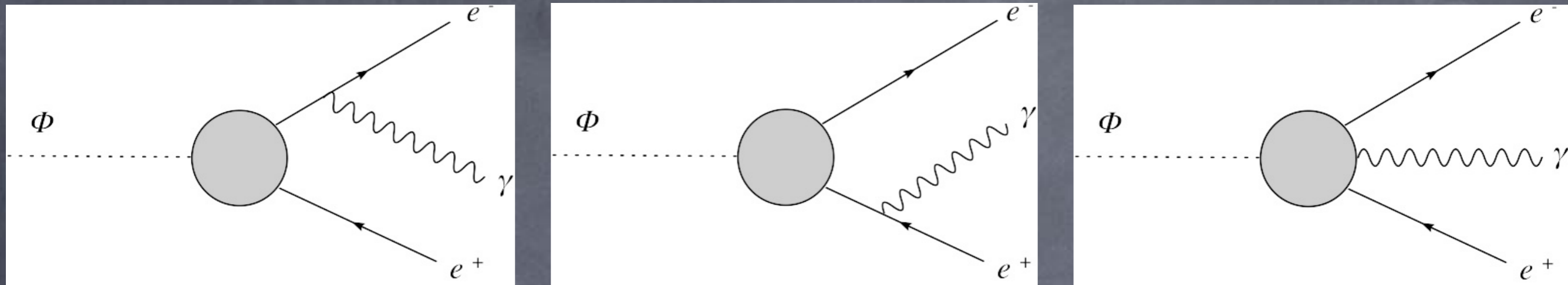
$M_{DM} = 1 \text{ TeV into } \mu\mu$



Summary

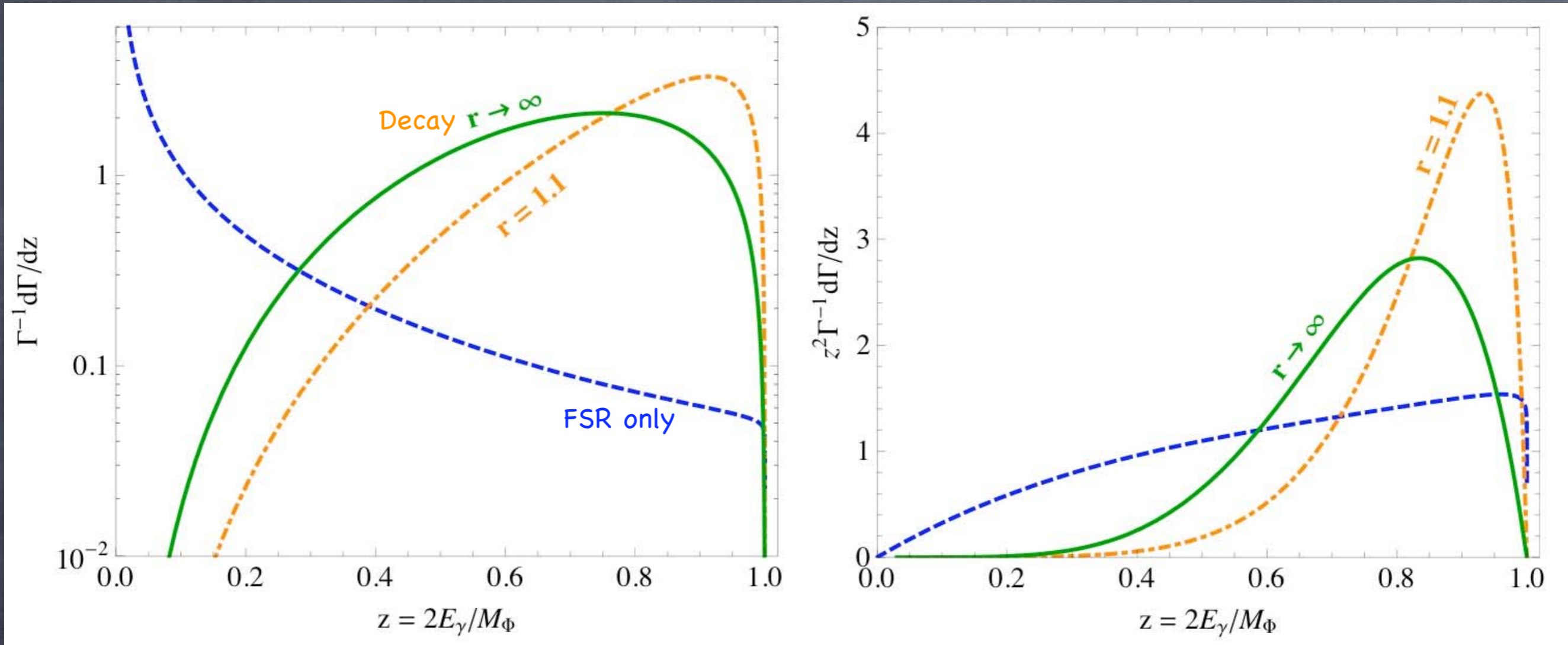
- Pulsars readily reproduce the data
- Simplest dark matter scenarios are strained
- Annihilation:
 - need huge cross section (PAM positron data)
 - lepton channels only (PAM antiproton data)
 - TeV and higher mass (HESS and Fermi electron data)
 - some gamma-ray data disfavor cusped halo profiles
- Decay:
 - need very long lifetime
 - lepton channels preferred
 - multi-TeV mass
- To invoke dark matter explanations, need to go from demonstrating consistency to seeing unique signals

Generic dark matter signatures?



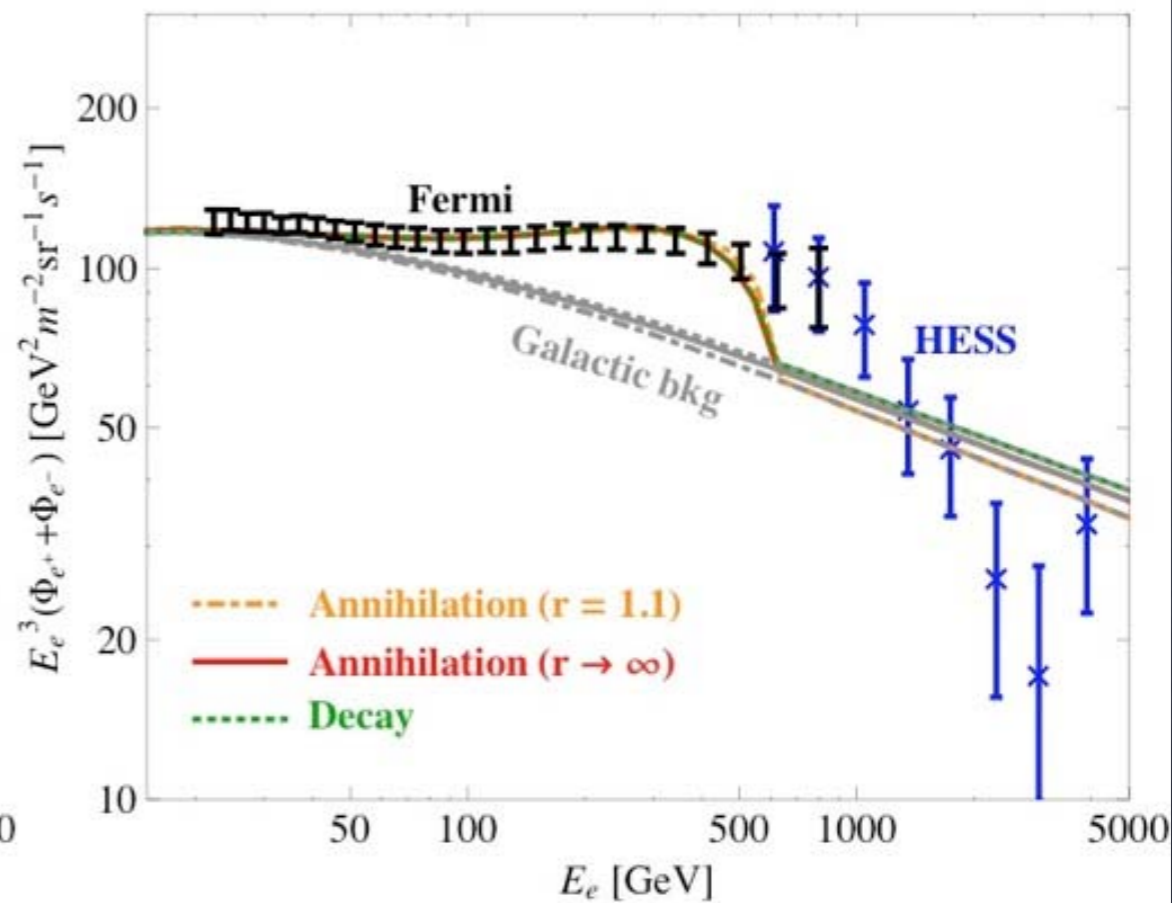
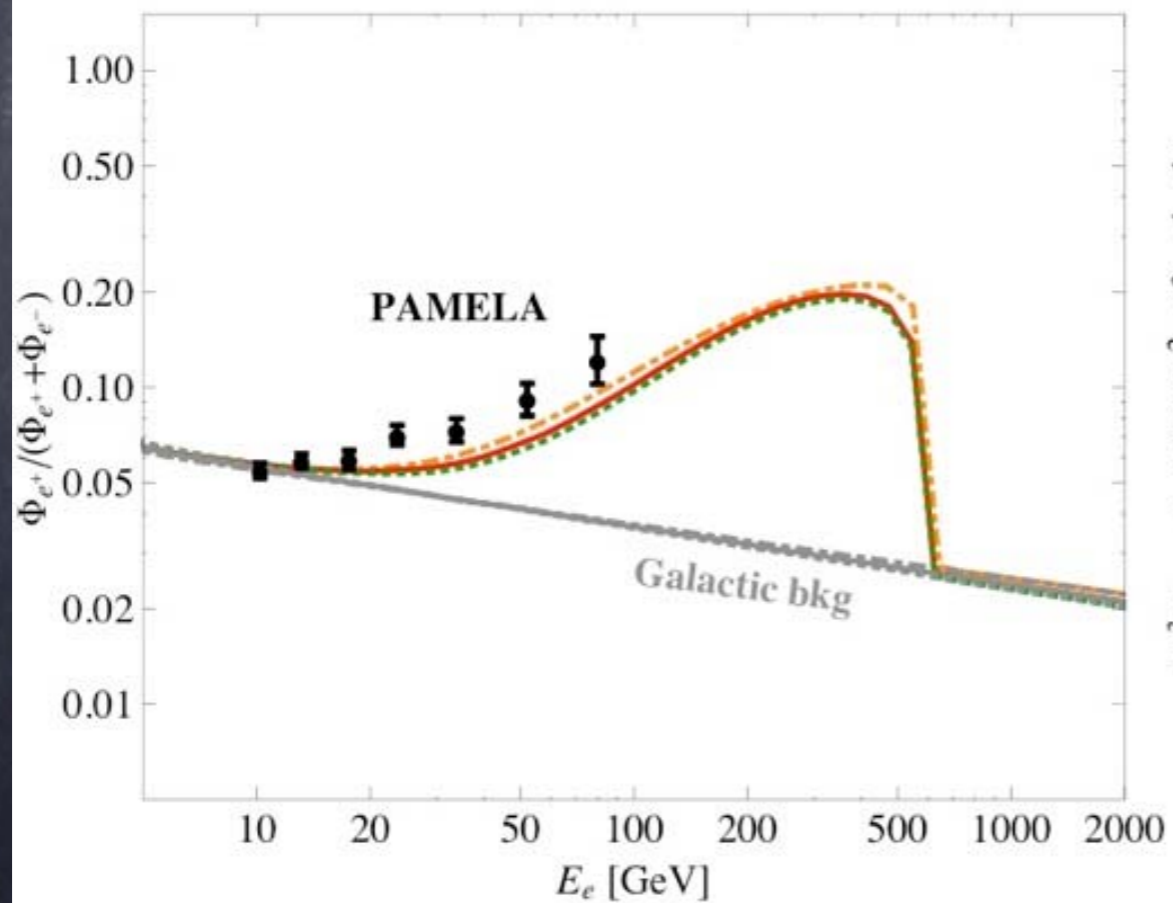
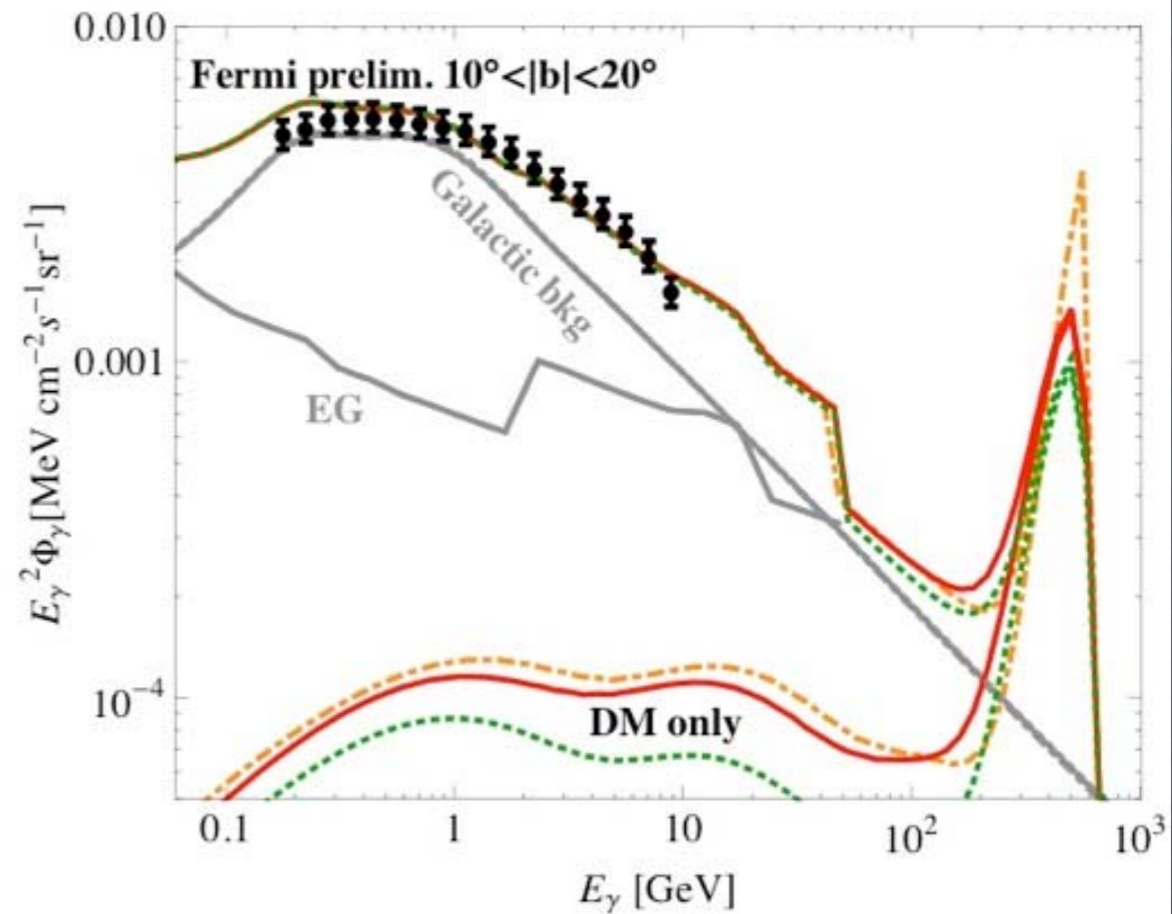
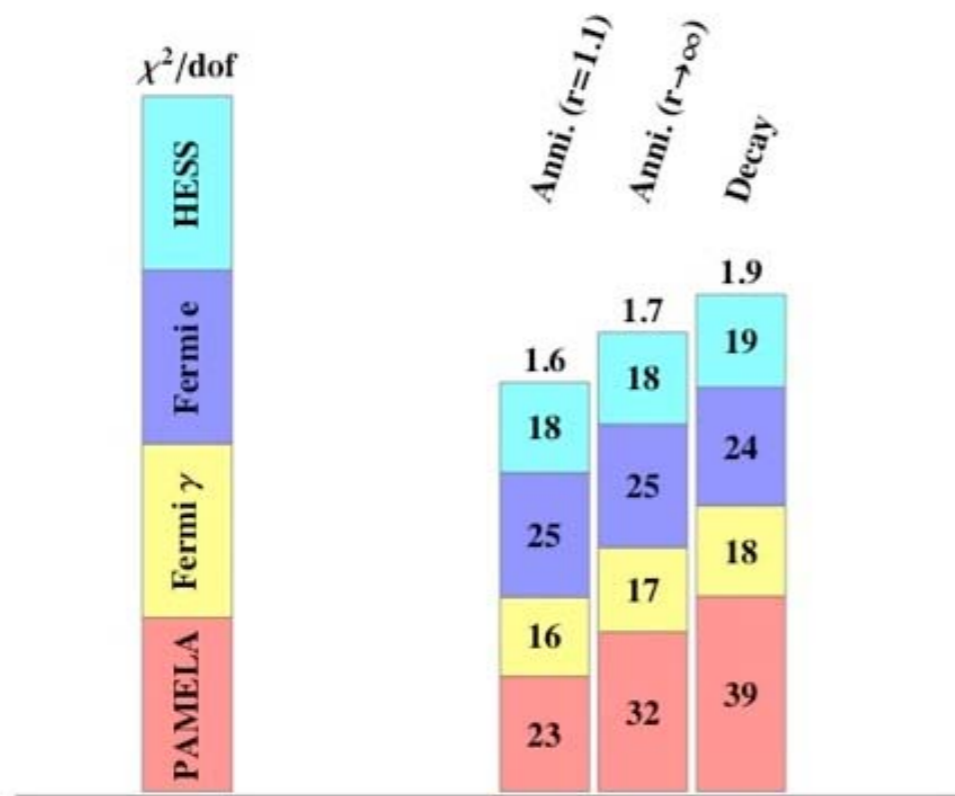
- Φ has zero total angular momentum
- helicity suppression prevents annihilation/decay to light fermion pairs
- suppression disappears if final state contains an additional photon
- Φ may be
 - annihilating Majorana fermions
 - annihilating self-conjugate scalars
 - a decaying scalar

Photon distributions

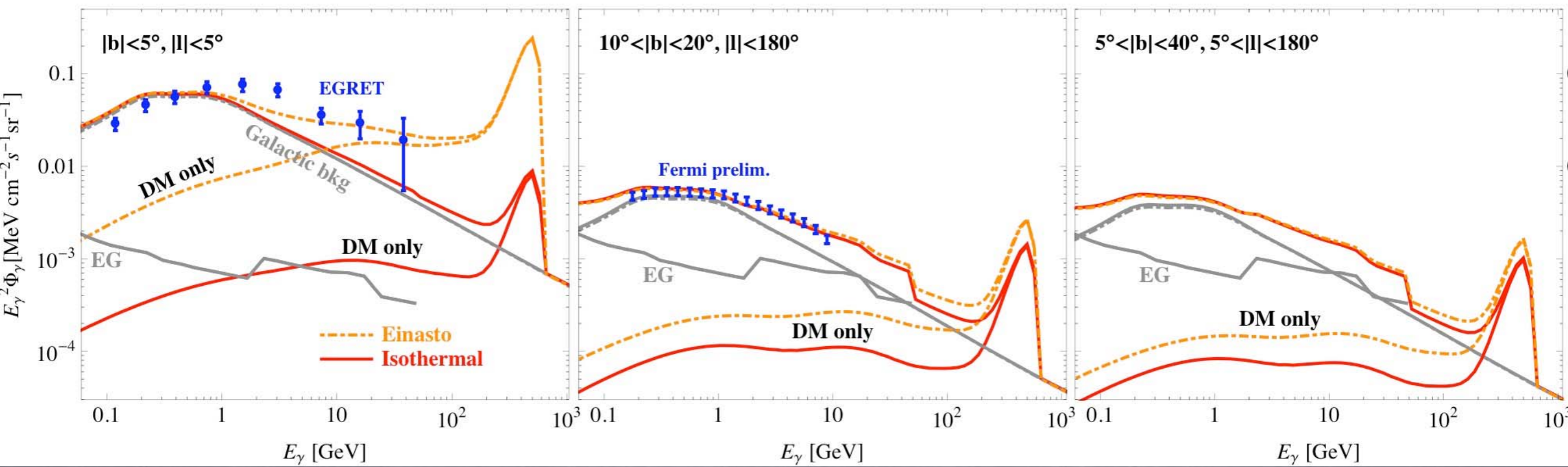


$$r = 4m_E^2/M_\Phi^2$$

$$M_\Phi = 1.2 \text{ TeV}$$



Gamma-ray predictions for Fermi and ACTs



Conclusion

We're excited, but clueless!