Interpretation of Fermi-LAT measurement of electron+positron spectrum from 7 GeV to 1 TeV

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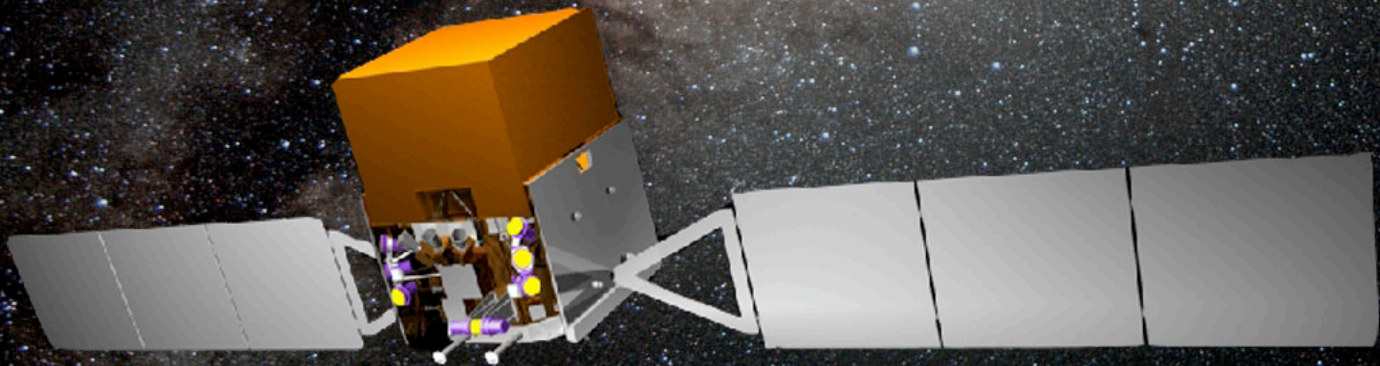
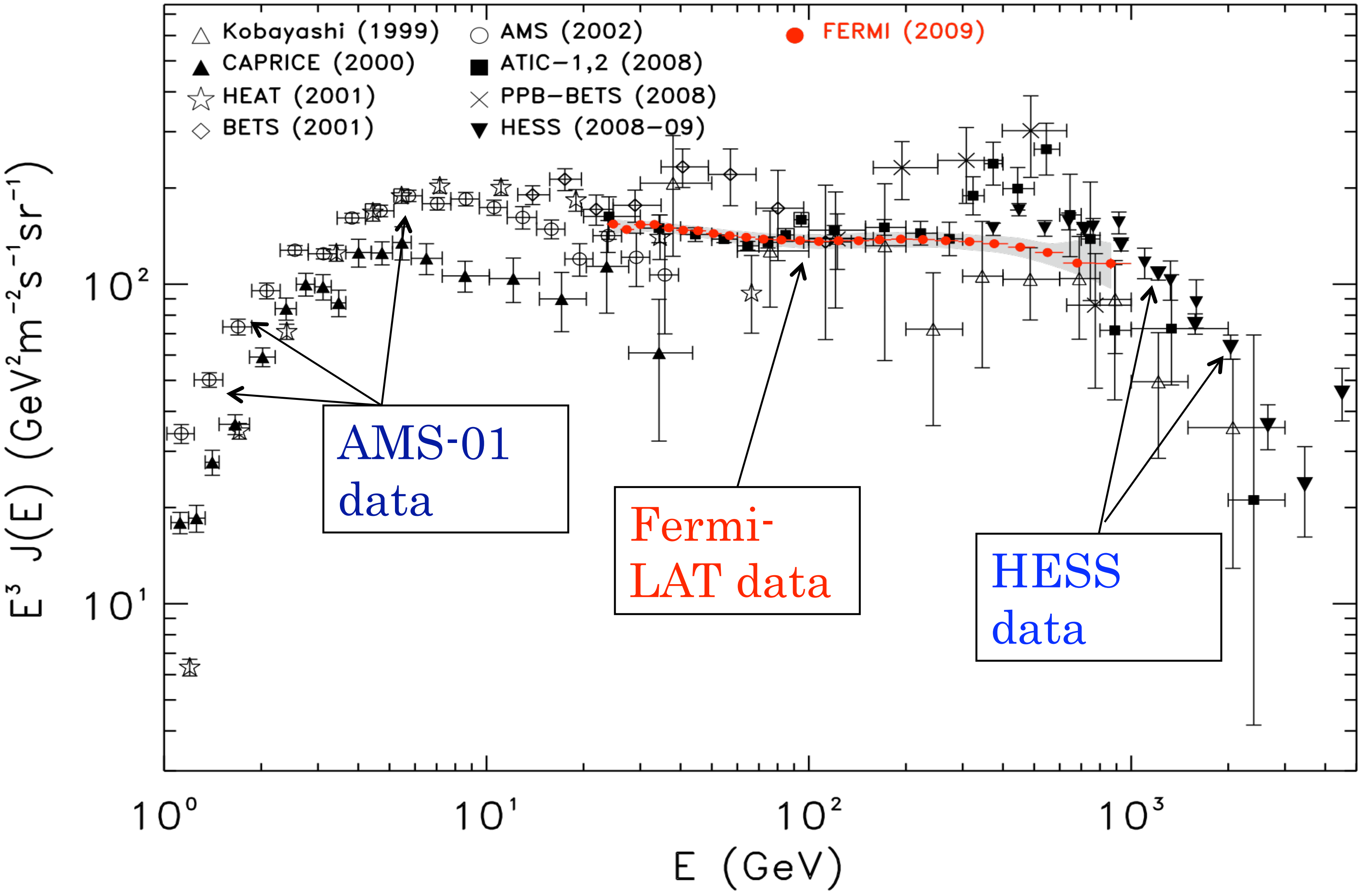
Member of Fermi collaboration



The electron+positron spectrum: the situation in 2009



Propagation models for CR leptons

CR electrons propagate in the turbulent galactic magnetic field and their motion is well described by a diffusion-loss equation of this kind:

$$\frac{\partial \psi(\vec{r},p,t)}{\partial t} = q(\vec{r},p,t) + \vec{\nabla}\cdot(D_{xx}\vec{\nabla}\psi - \vec{V}\psi) + \frac{\partial}{\partial p}p^2 D_{pp}\frac{\partial}{\partial p}\frac{1}{p^2}\psi - \frac{\partial}{\partial p}\left[\dot{p}\psi - \frac{p}{3}(\vec{\nabla}\cdot\vec{V})\psi\right] - \frac{1}{\tau_f}\psi - \frac{1}{\tau_r}\psi$$

This equation may be solved analitically (using simplified assumptions, i.e. on the spatial distribution of sources) or numerically (using numerical packages such as `GALPROP` or `DRAGON`)

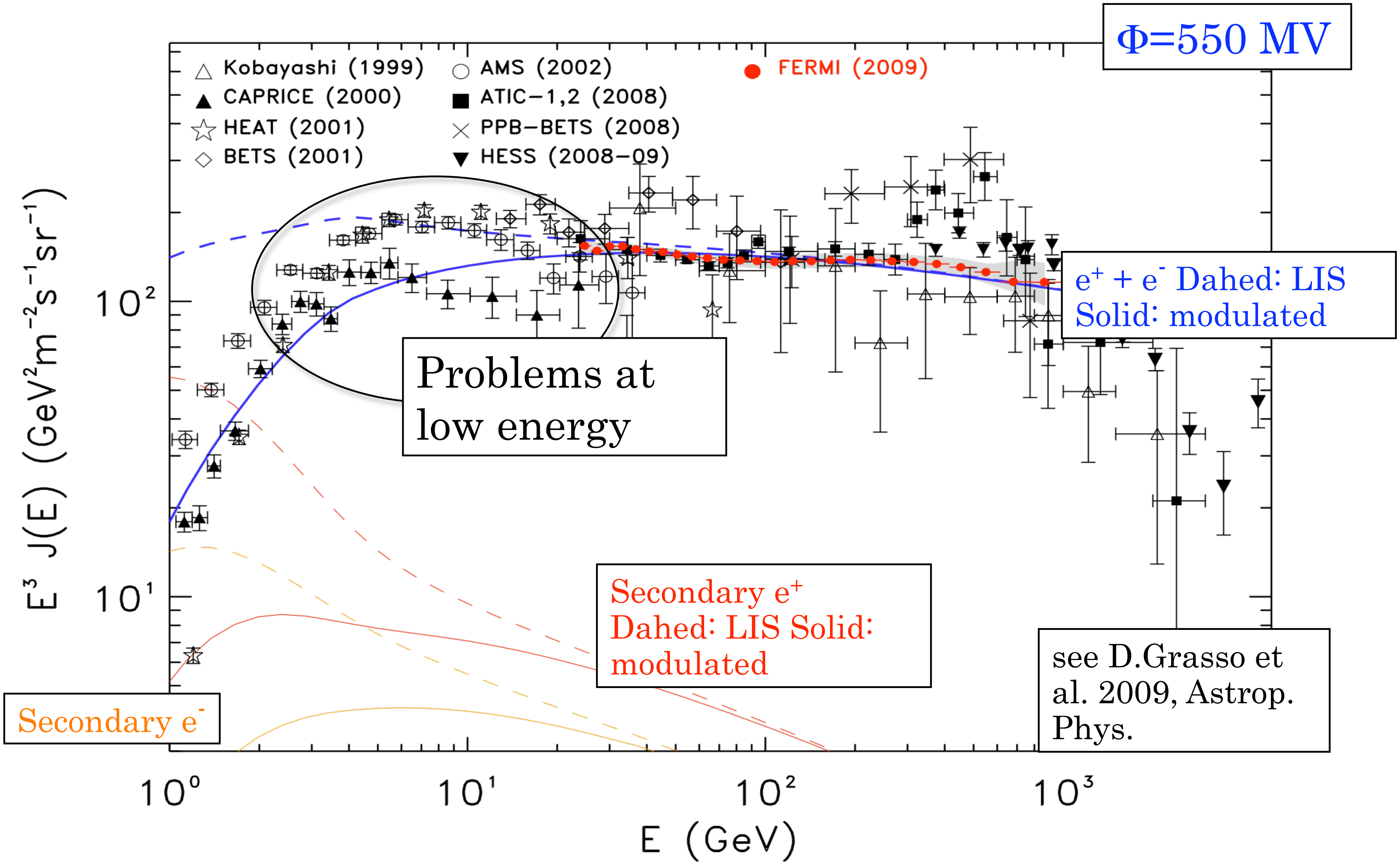
FREE PARAMETERS:

- Injection spectrum (usually a power law, with one or more breaks if necessary)

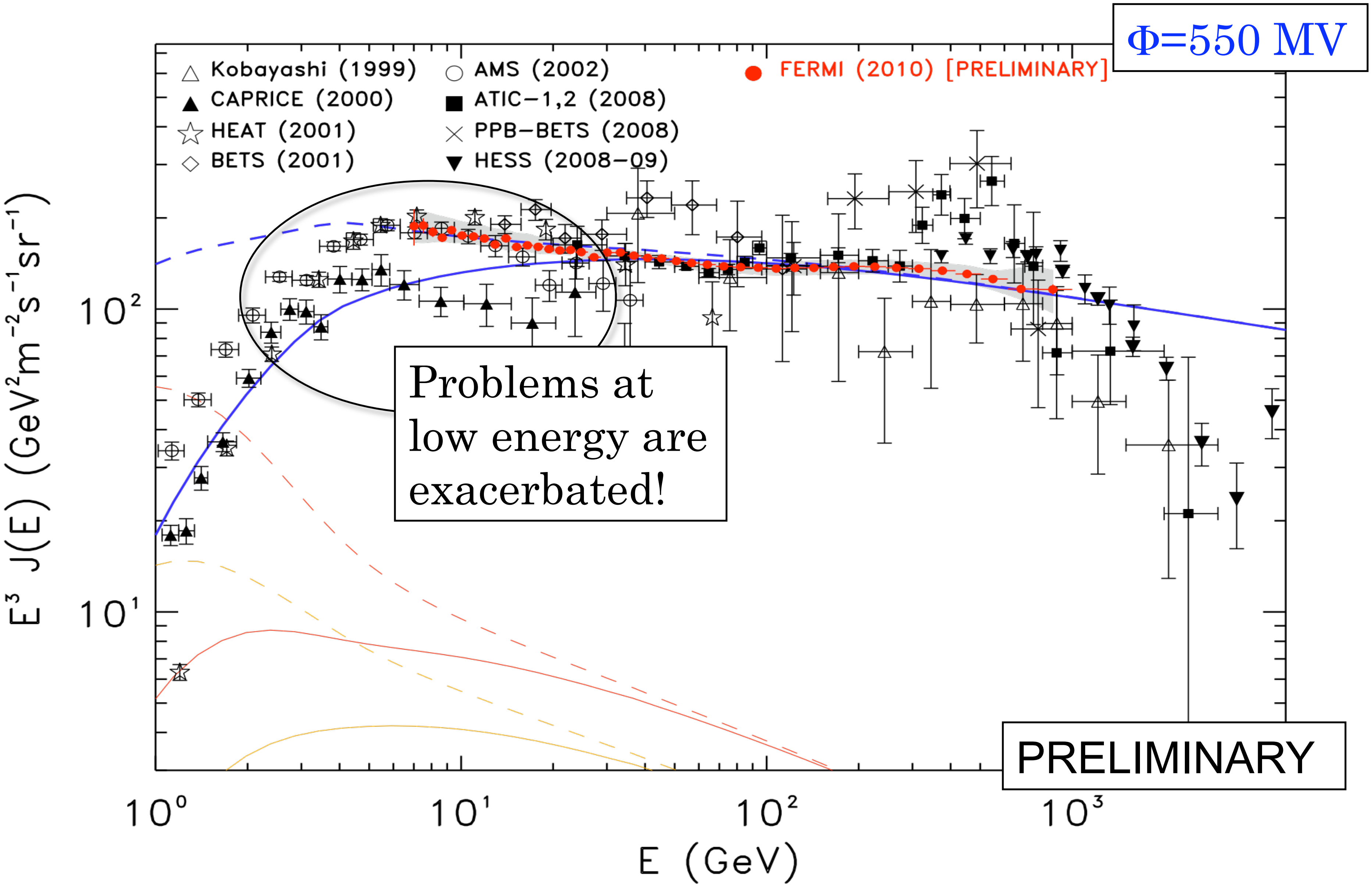
- Alfven velocity (the higher it is, the more reacceleration is effective)

- Normalization and energy dependence of diffusion coefficient $D = D_0\, R^{\delta}$

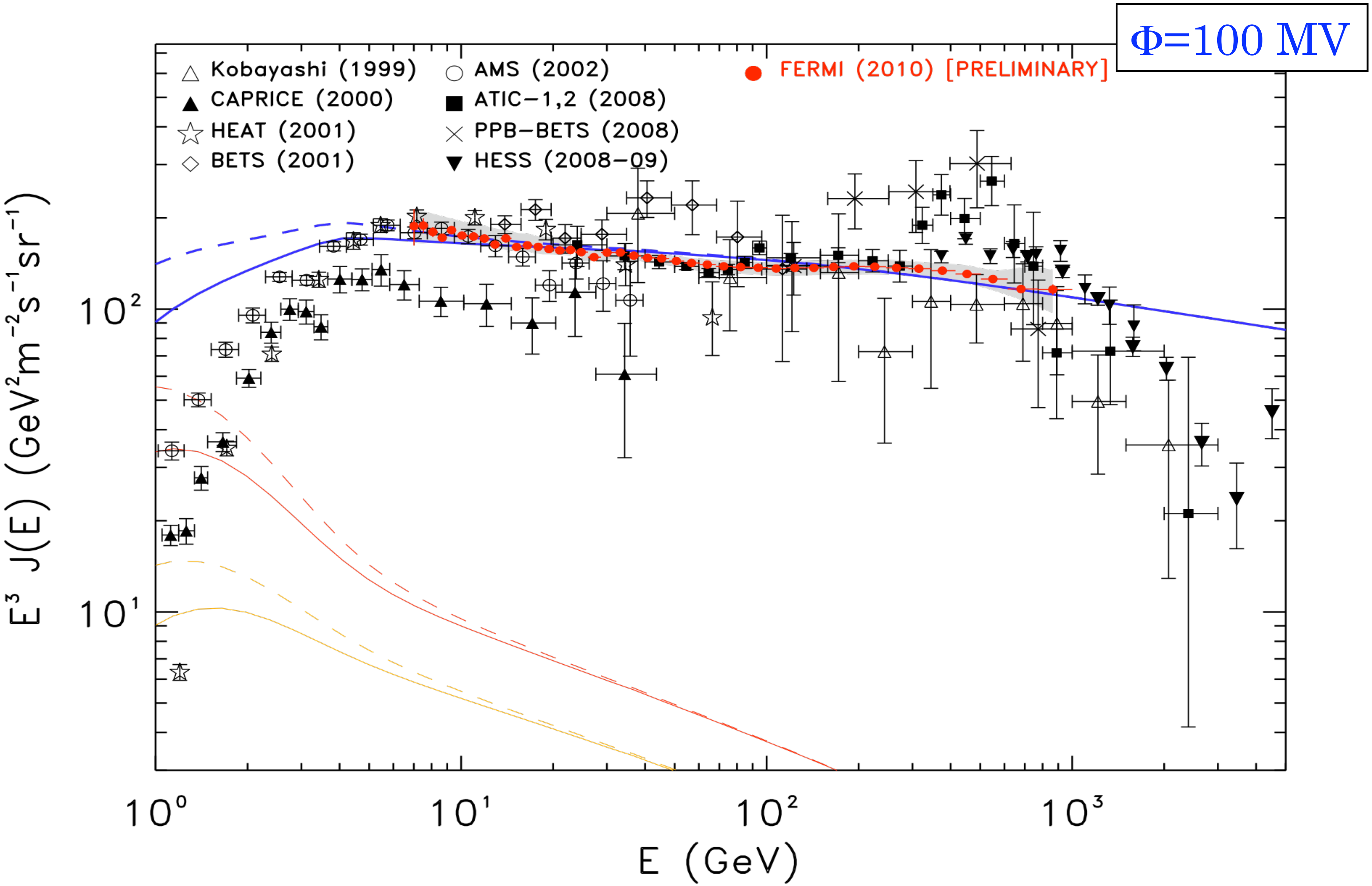
“Conventional” model with injection spectrum 1.60/2.42 (break at 4 GeV)



New Fermi-LAT data at low energy (preliminary)

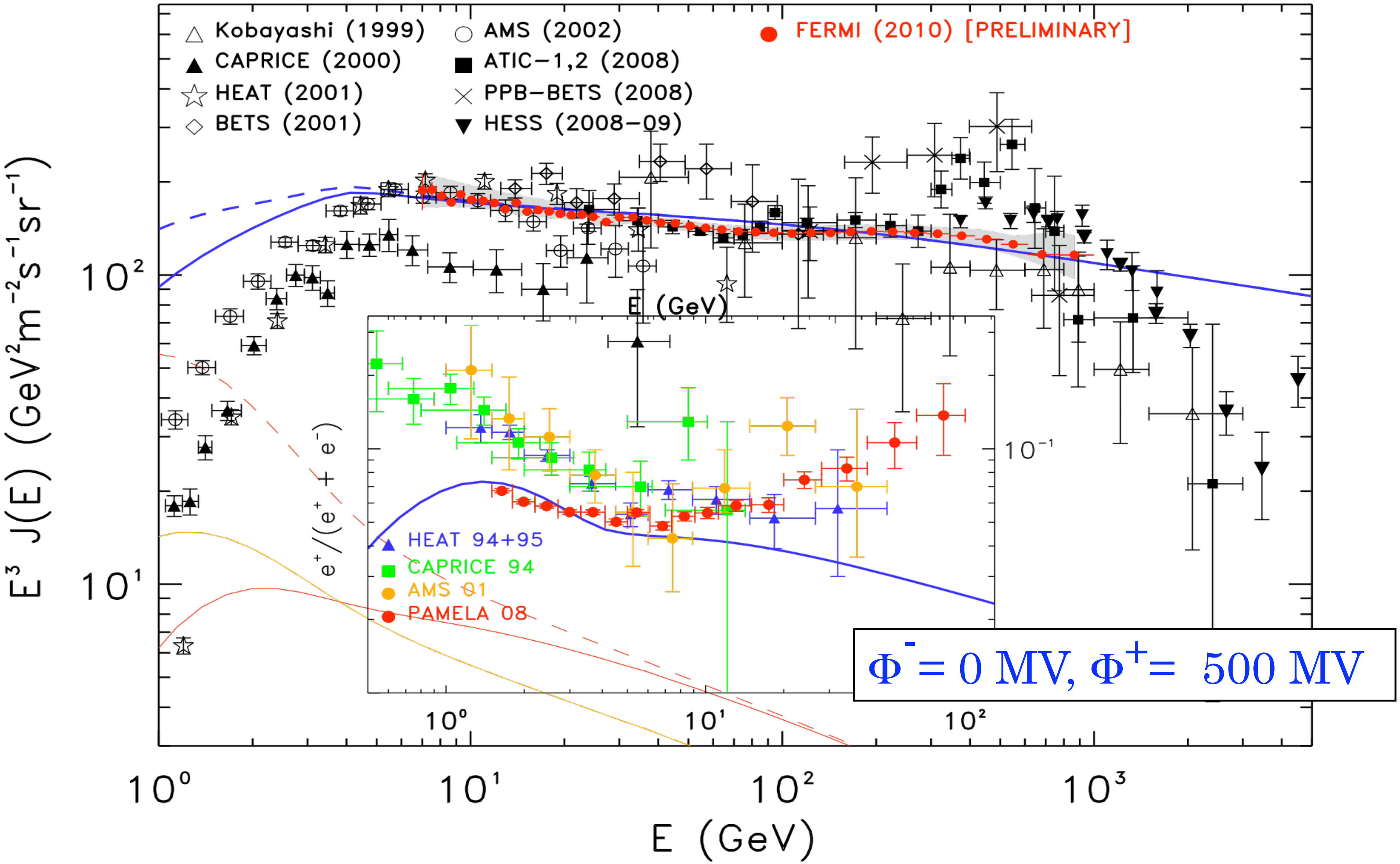


A possible solution: very low modulation potential (100 MV or less)

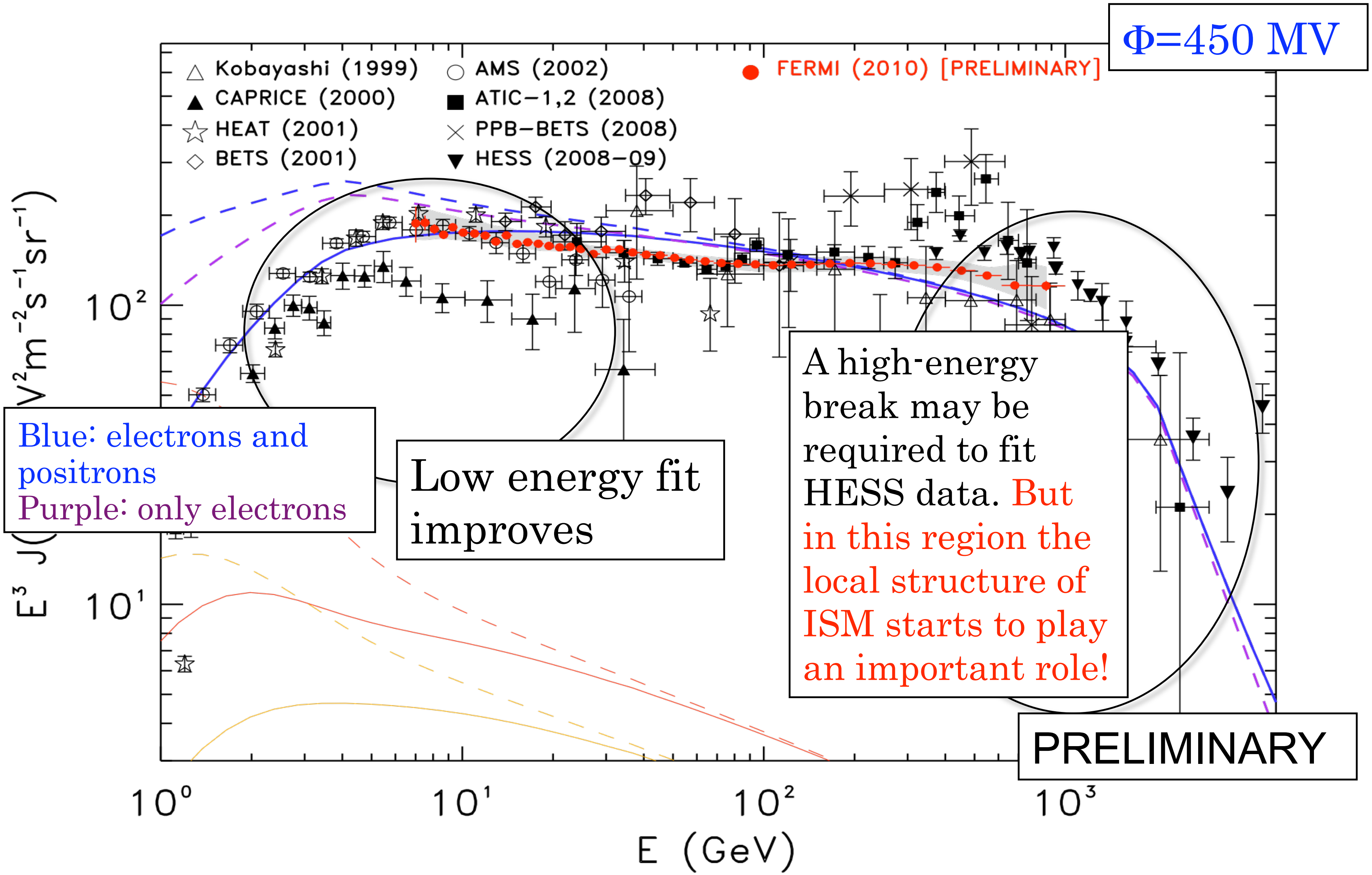


A low electron modulation potential is possible in the context of *charge-sign-dependent solar modulation* and also allows a good fit of low-energy PAMELA positron data

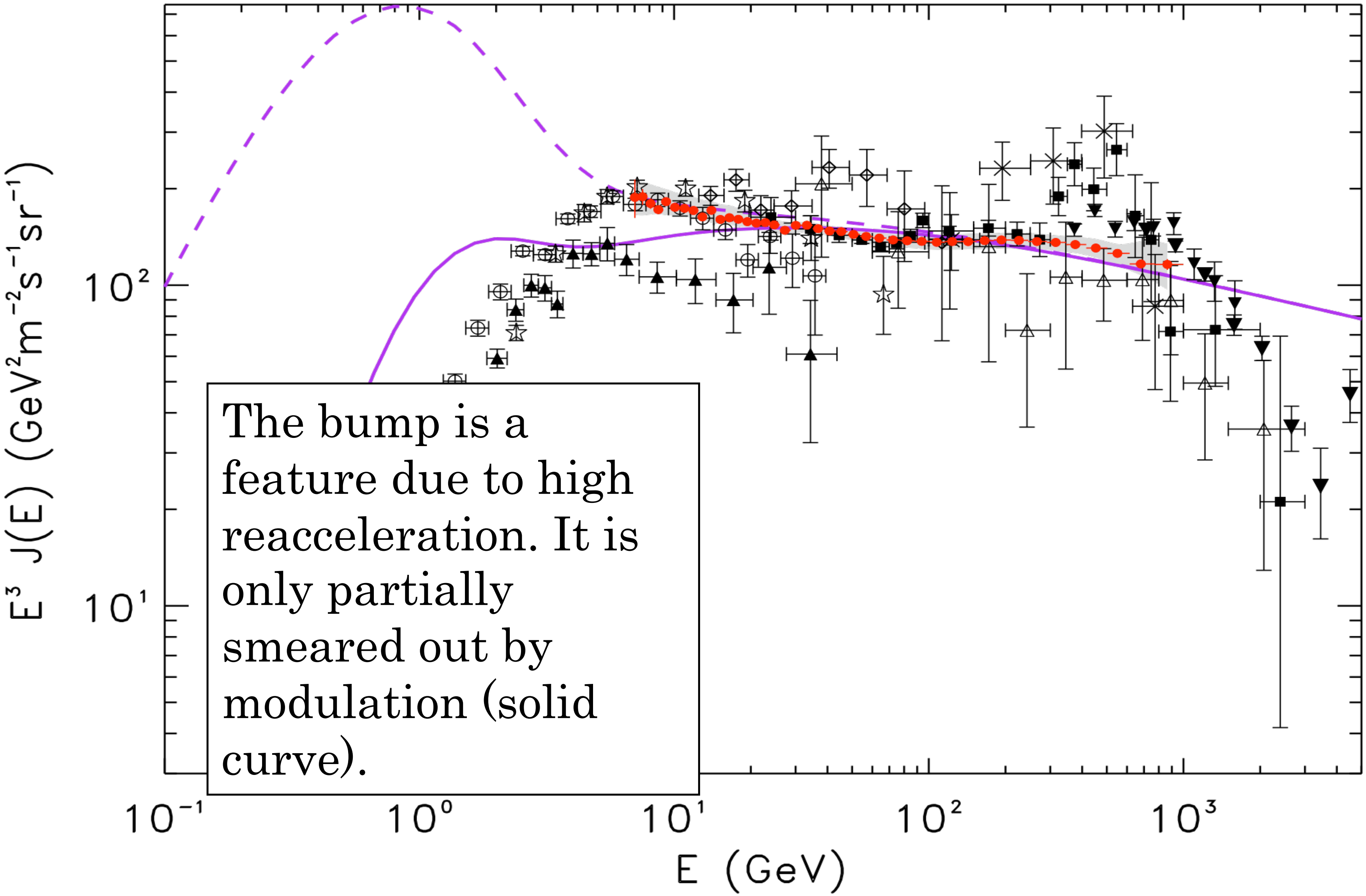
(see Gast and Schael 2009)



Or… a new "conventional" model with steeper injection index (1.60/2.50)



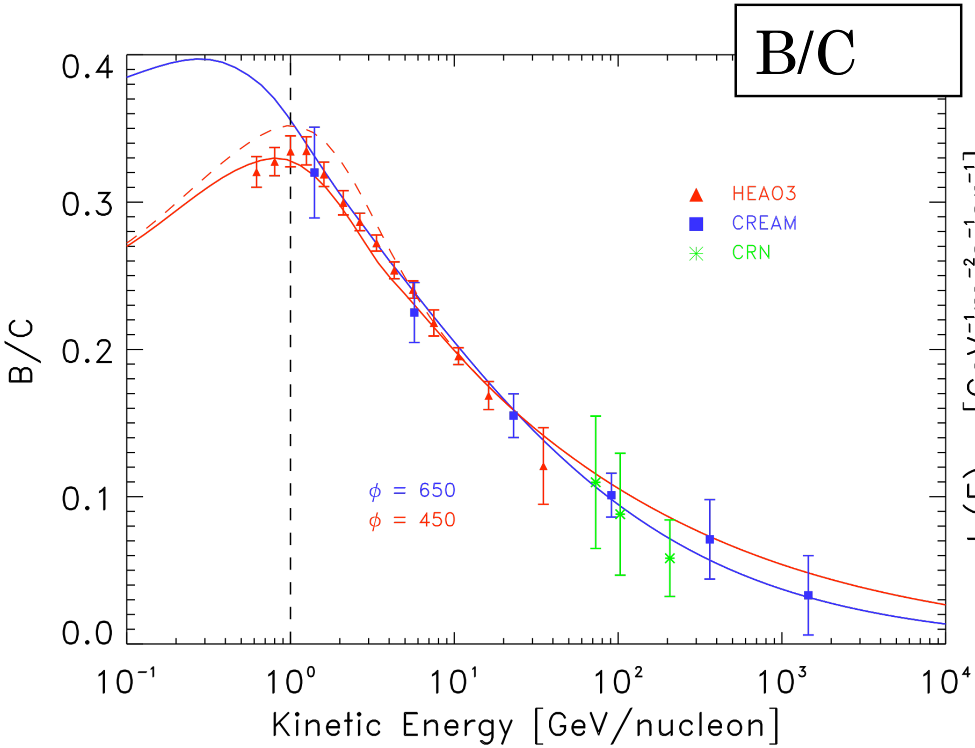
We can't avoid a low-energy break. With (2.45/2.45) a huge bump appears

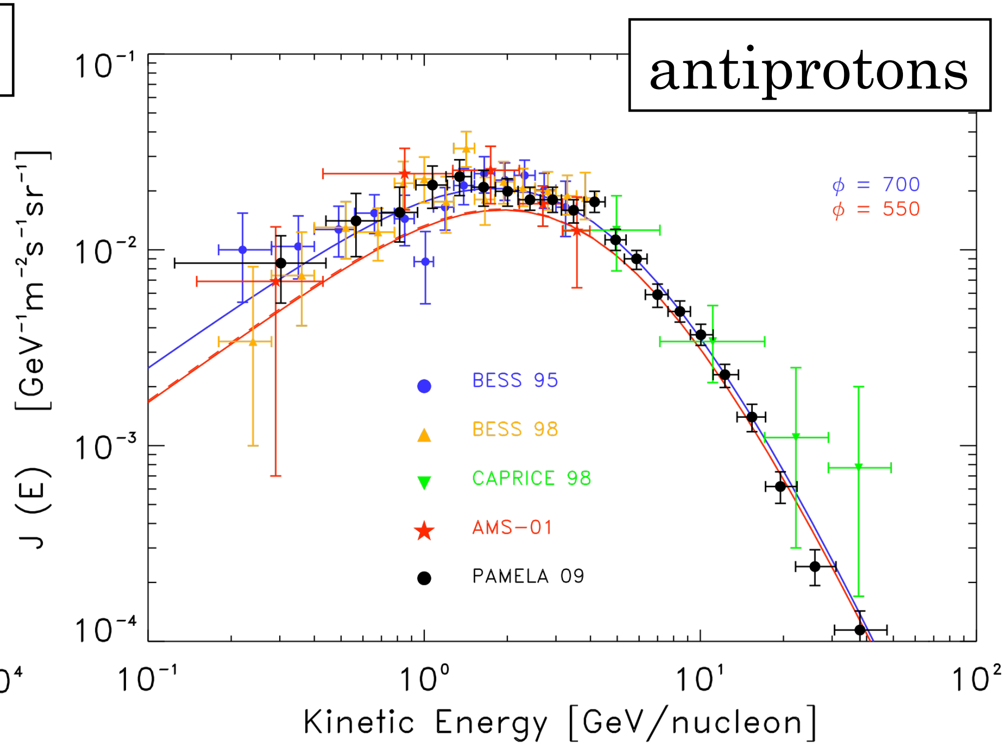


The bump is a feature due to high reacceleration. It is only partially smeared out by modulation (solid curve).

A new diffusion setup

Recently, we performed a maximum likelihood analysis on B/C data above 1 GeV and found a new set of diffusion parameters which give a better fit of all observables at E > 1 GeV *(as presented by LUCA MACCIONE)*

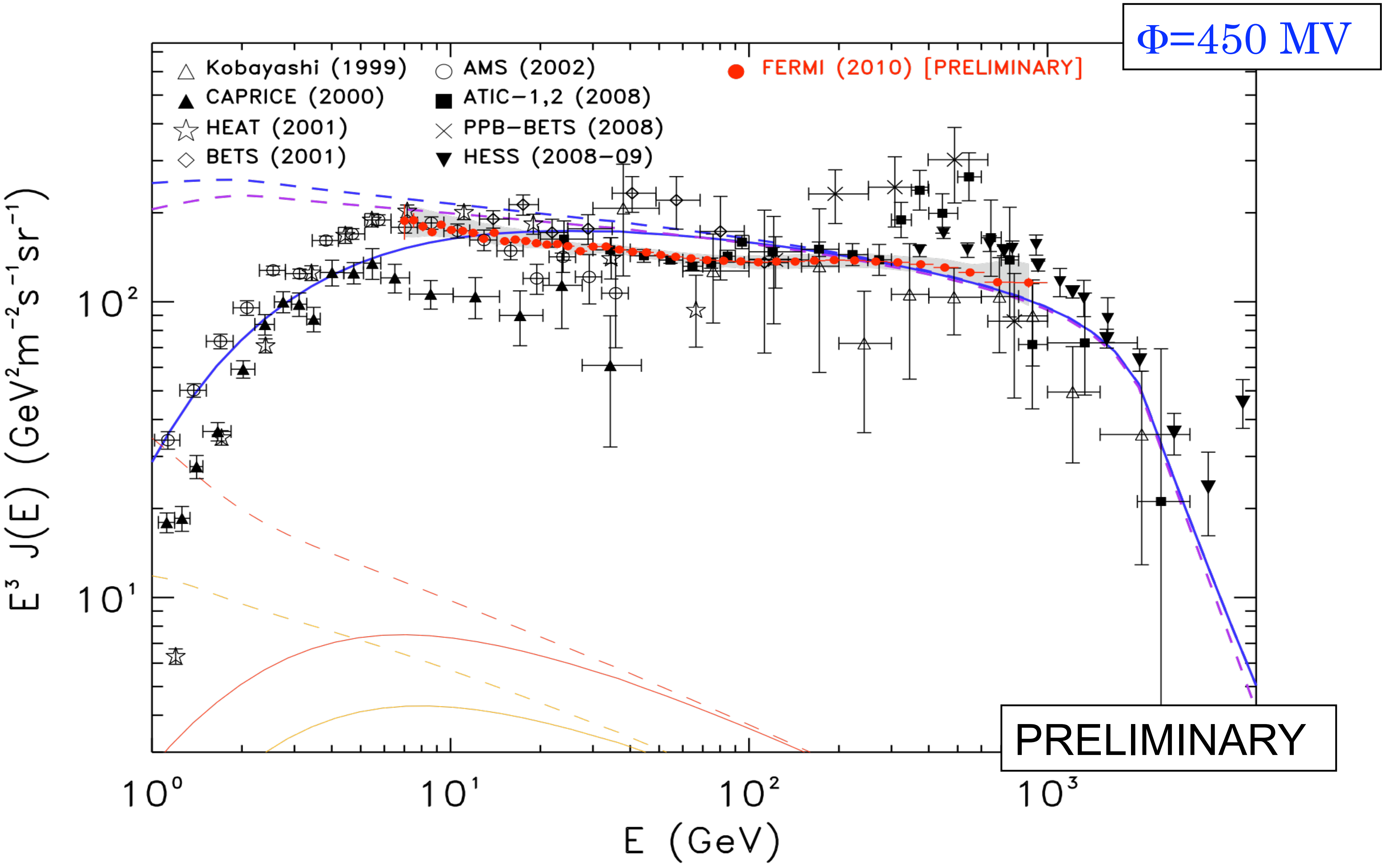




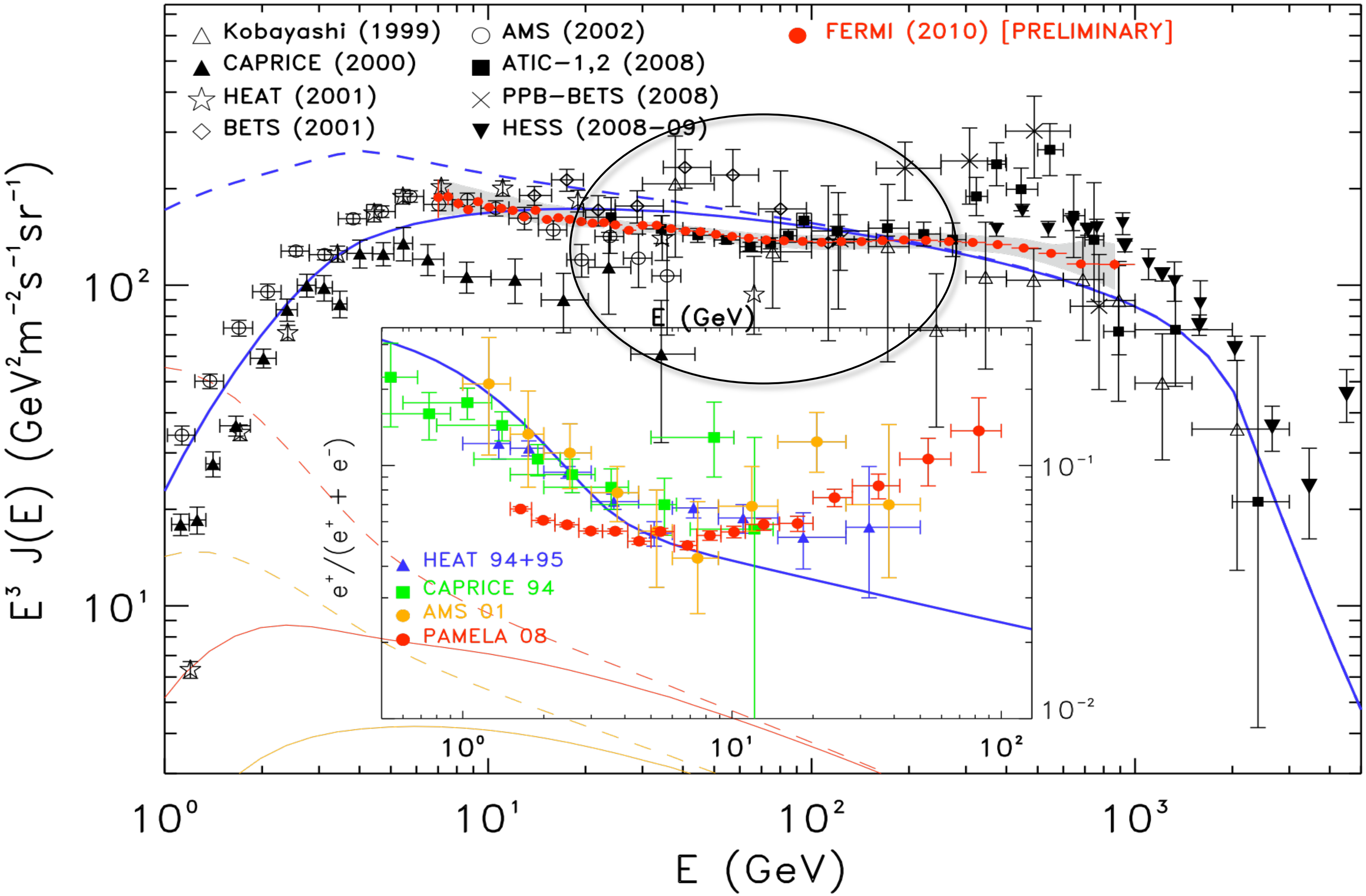
Blue line: new model. $\delta = 0.46$ (close to Kraichnan) Alfven speed = 15 km/s

Red line: conventional $\delta = 0.33$ (Kolmogorov) Alfven speed = 30 km/s

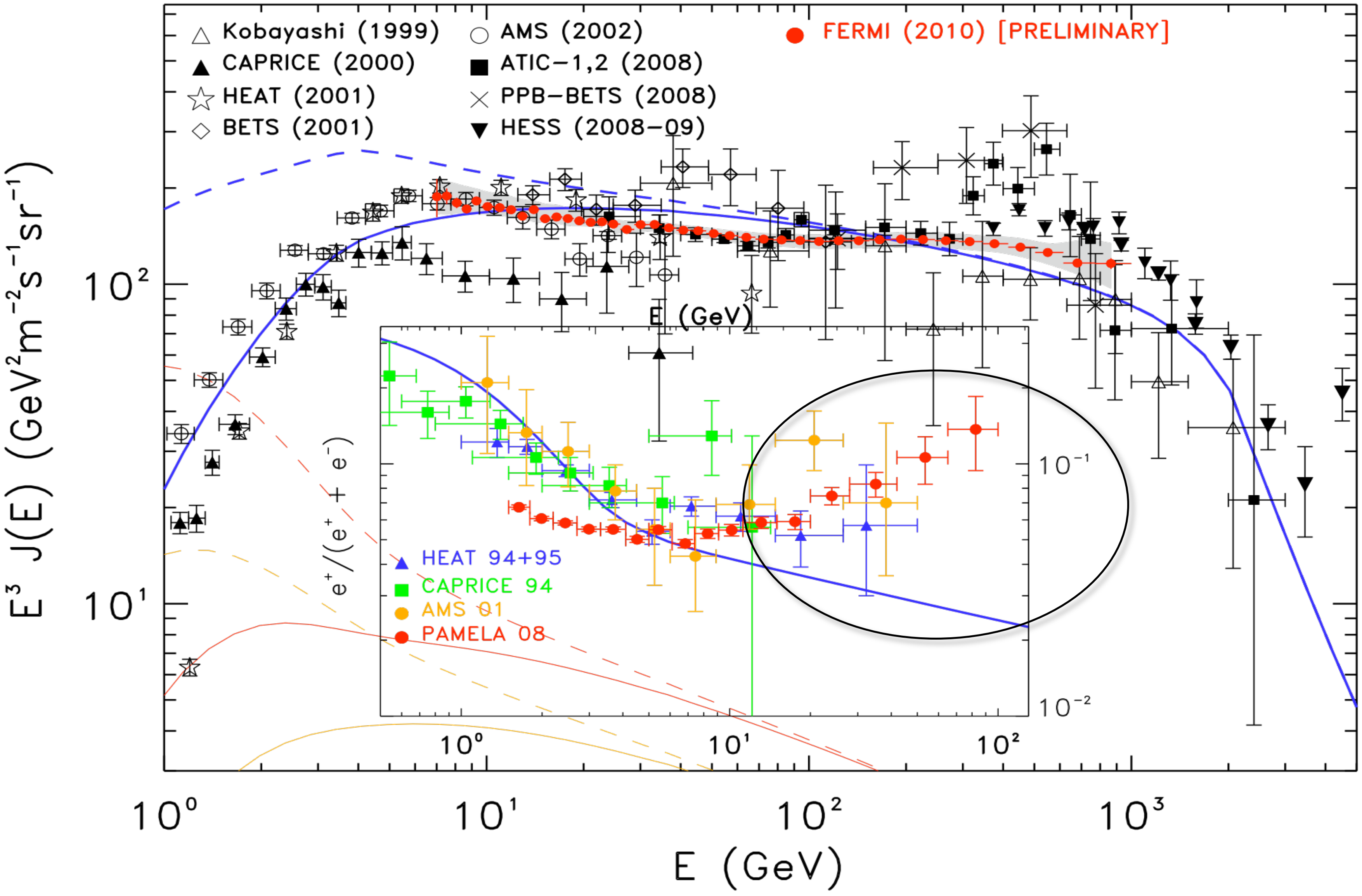
With the new diffusion setup a smoother break is required: (2.00/2.43)



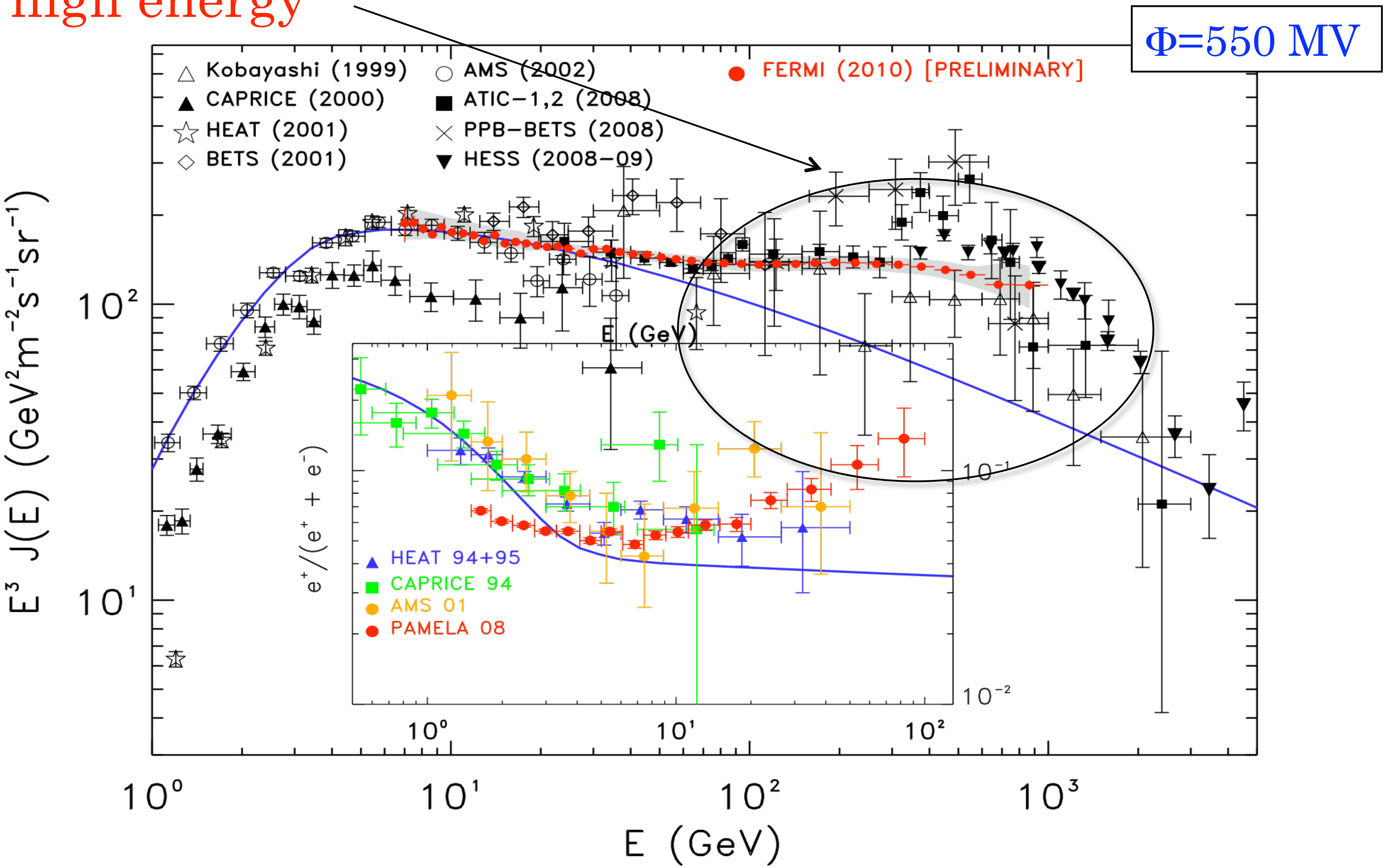
PROBLEM: These single-component models can't reproduce some features in FERMI spectrum



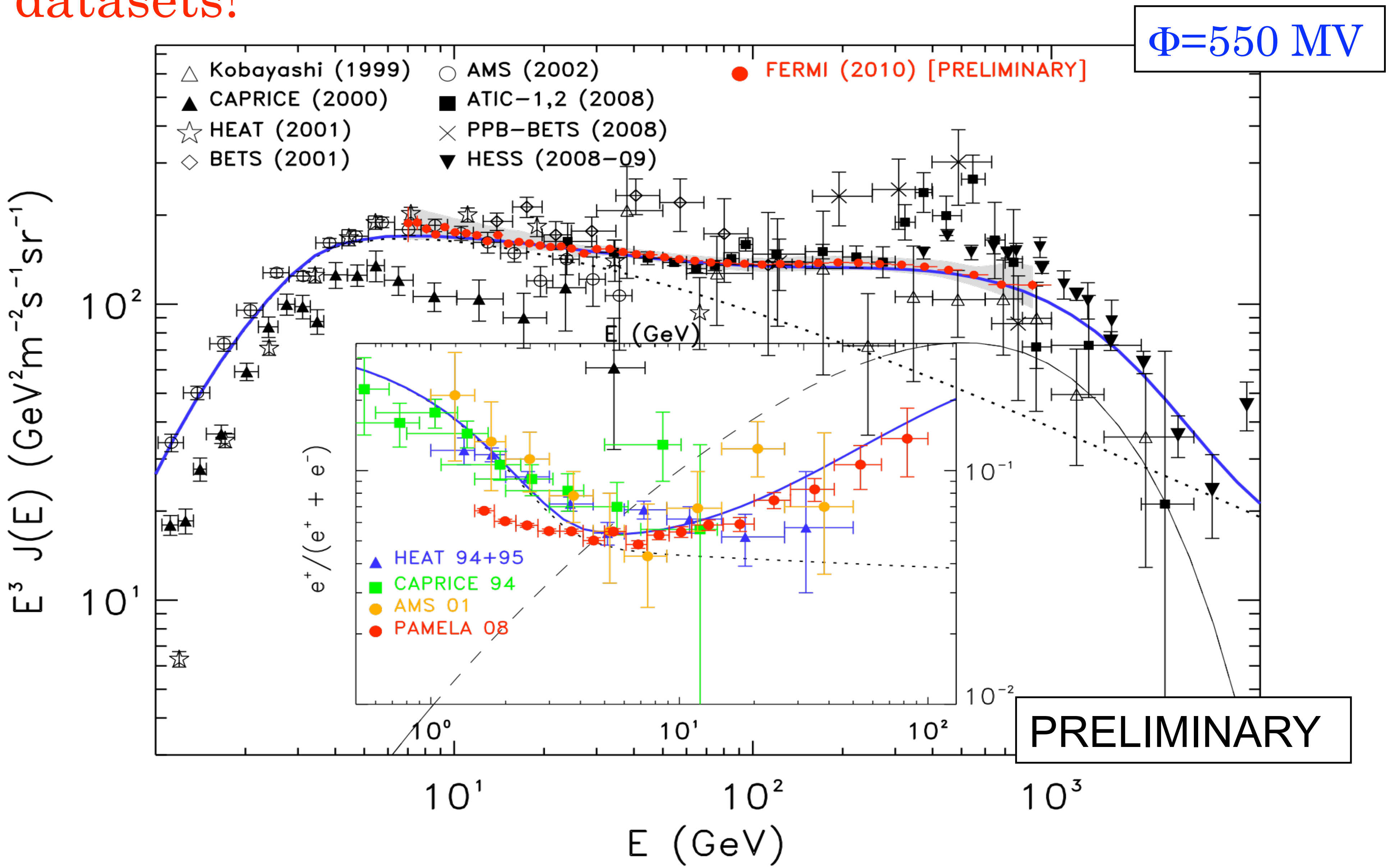
PROBLEM: These single-component models do not agree with PAMELA high-energy positron data…



… and if one wants to get a better fit of low-energy electron data, there is room for an extra source at high energy



An extra-component with injection index = 1.5 and an exponential cutoff at 1 TeV gives a good fit of all datasets!



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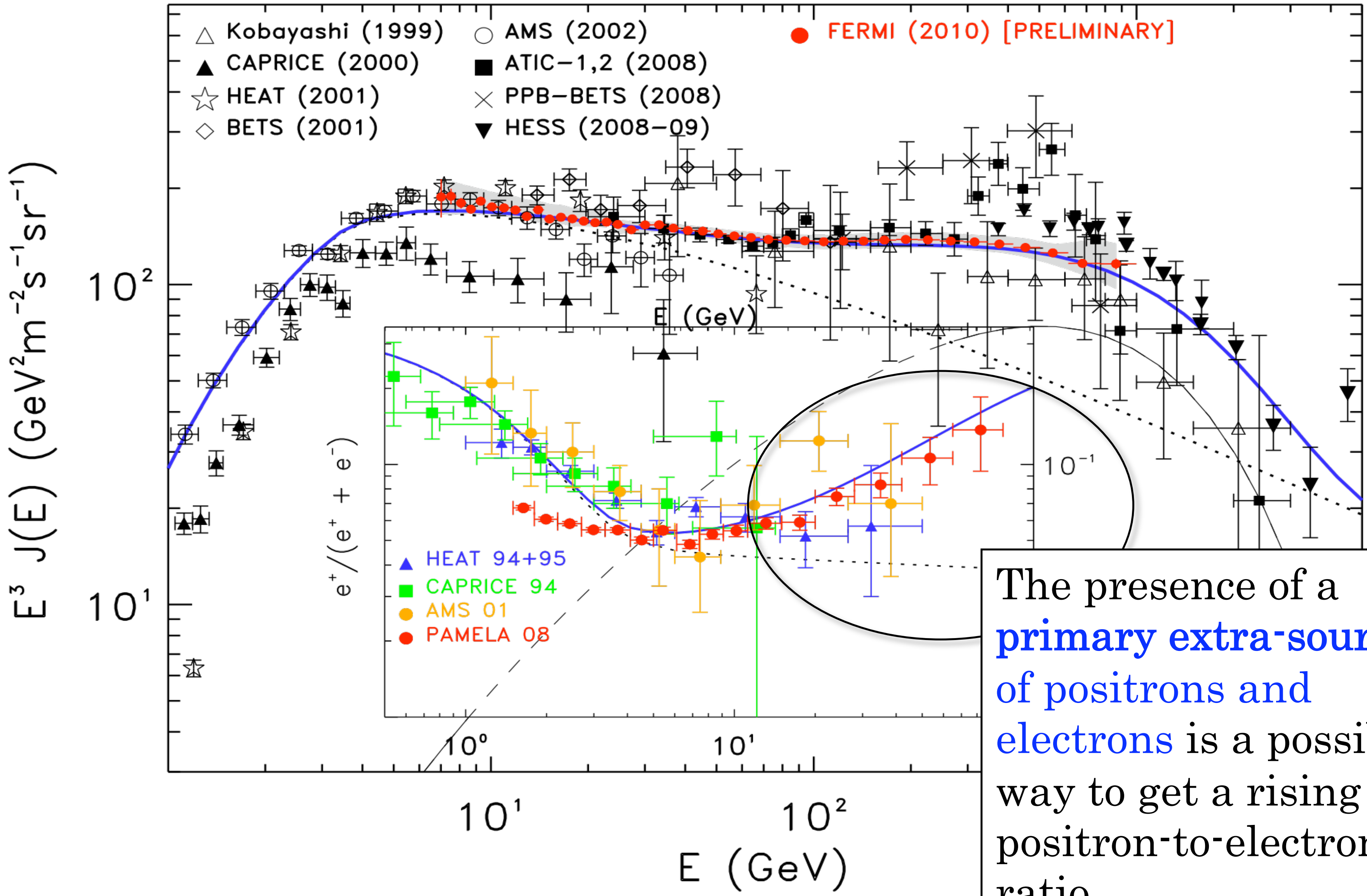
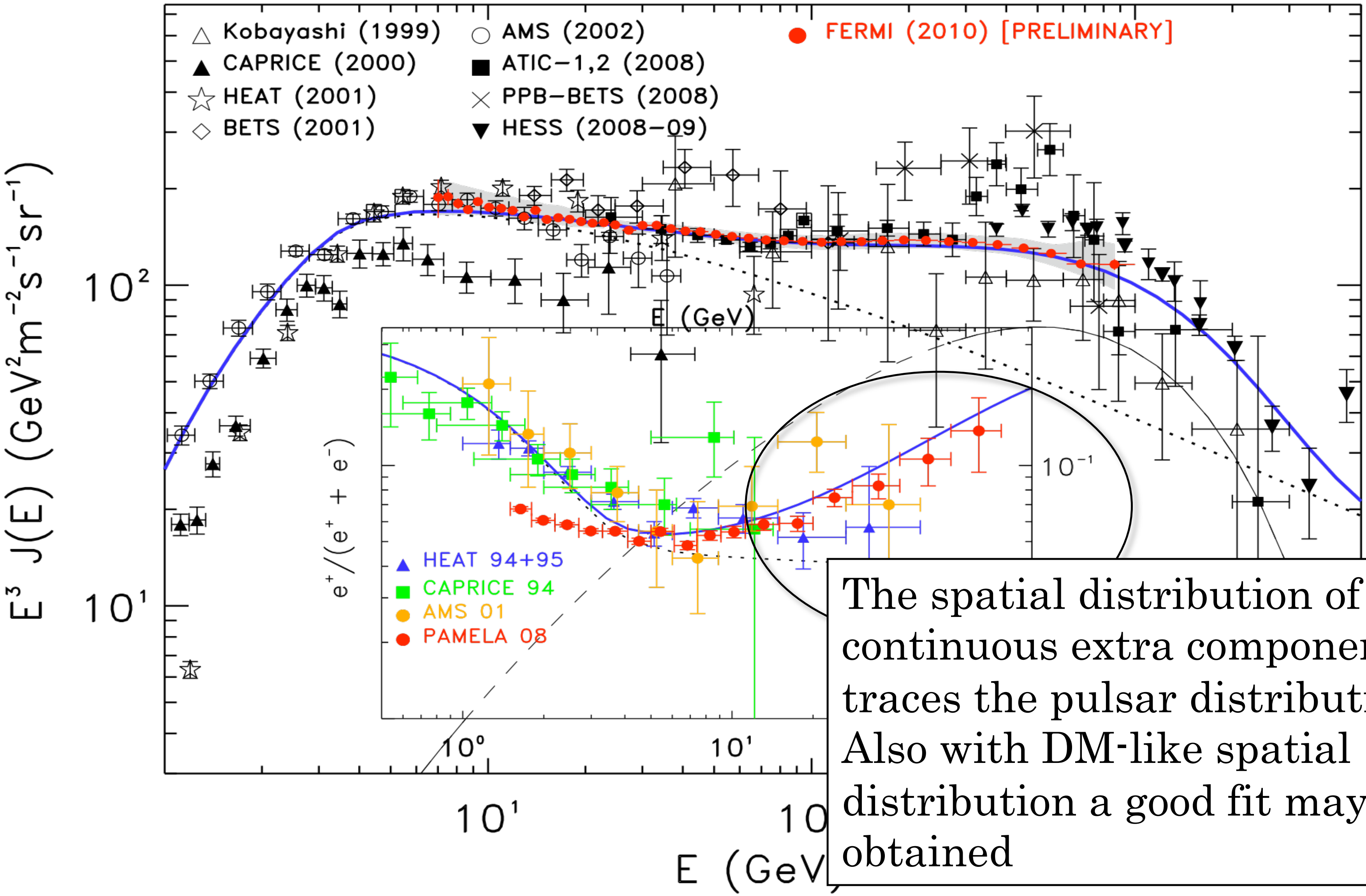


The presence of a **primary extra-source** of positrons and electrons is a possible way to get a rising positron-to-electron ratio

An extra-component with injection index = 1.5 and an exponential cutoff at 1 TeV gives a good fit of all datasets!



The spatial distribution of the continuous extra component traces the pulsar distribution. Also with DM-like spatial distribution a good fit may be obtained

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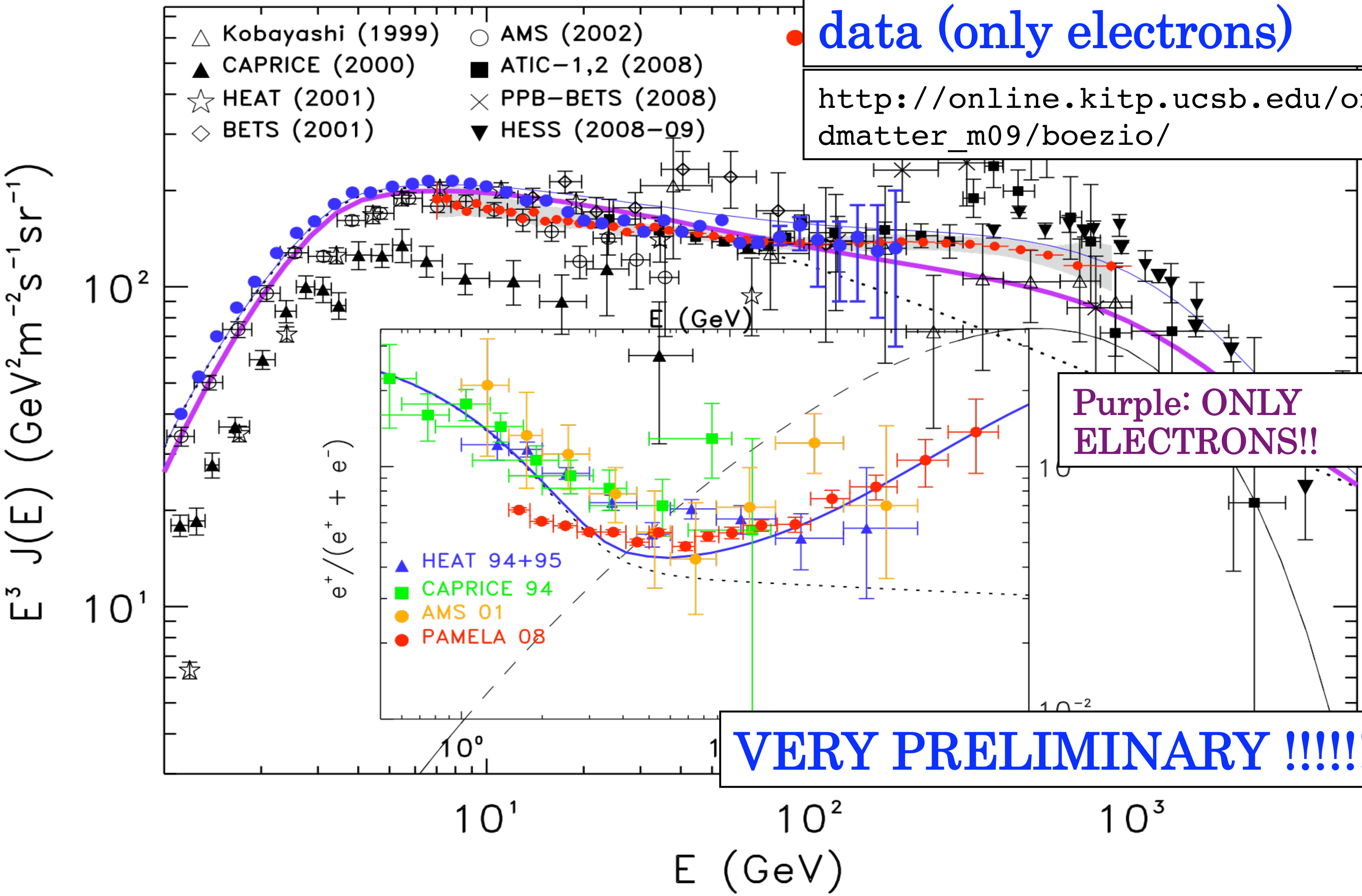


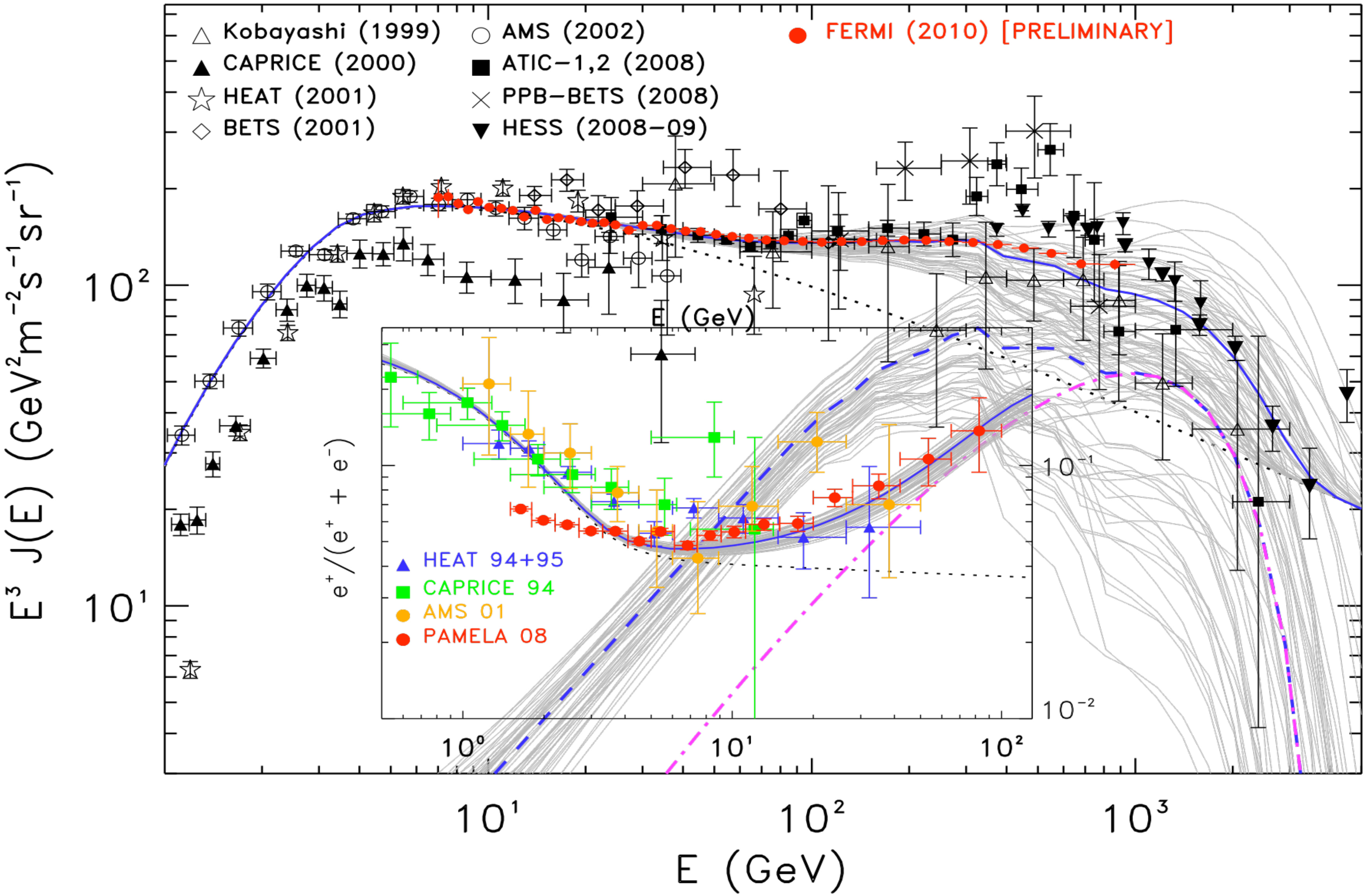
With PAMELA preliminary data (only electrons)

http://online.kitp.ucsb.edu/online/dmatter_m09/boezio/

Purple: ONLY ELECTRONS!!

VERY PRELIMINARY !!!!!!

Nearby, observed middle aged pulsars are good candidates as extra-sources of electrons and positrons



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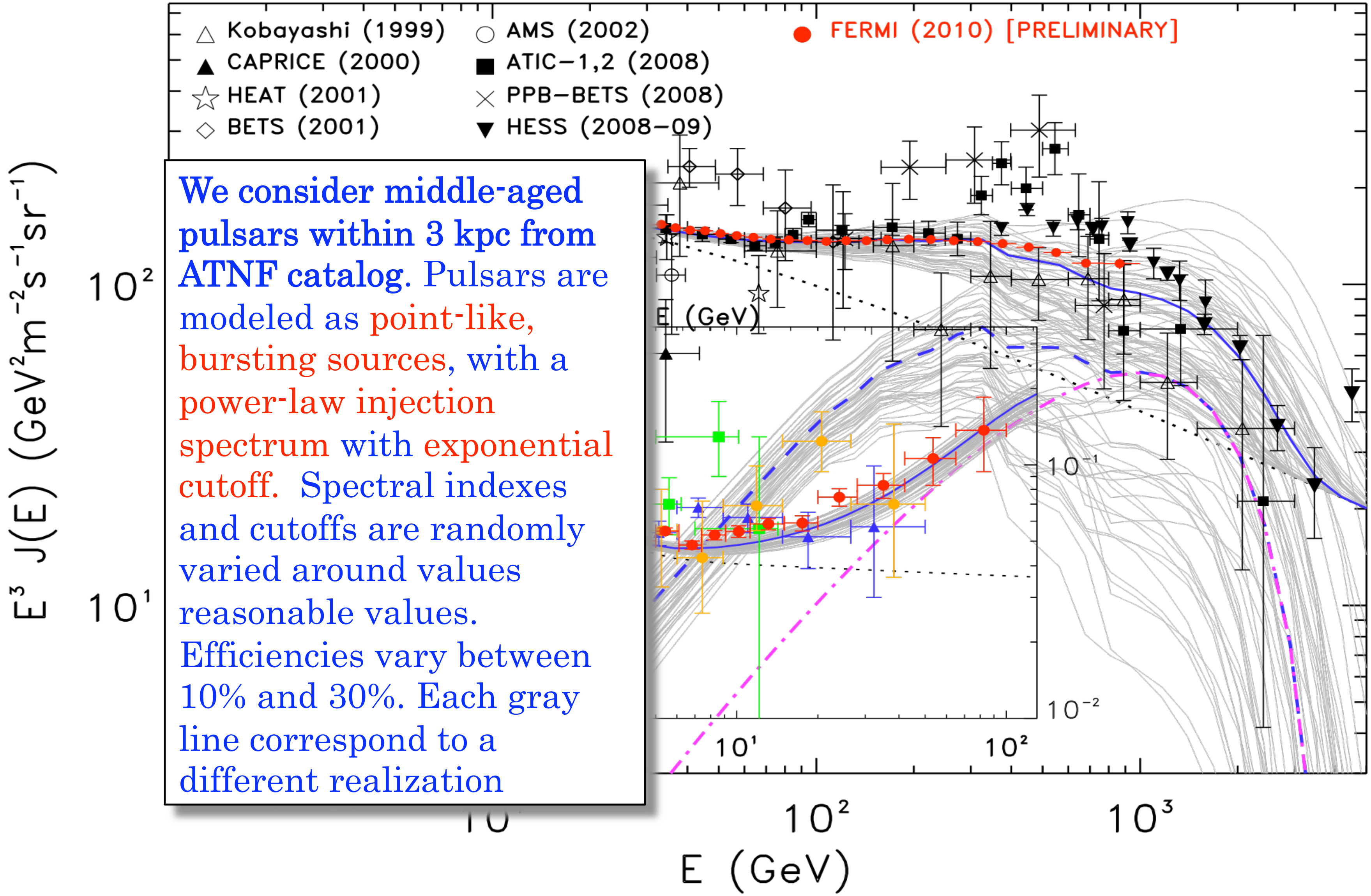
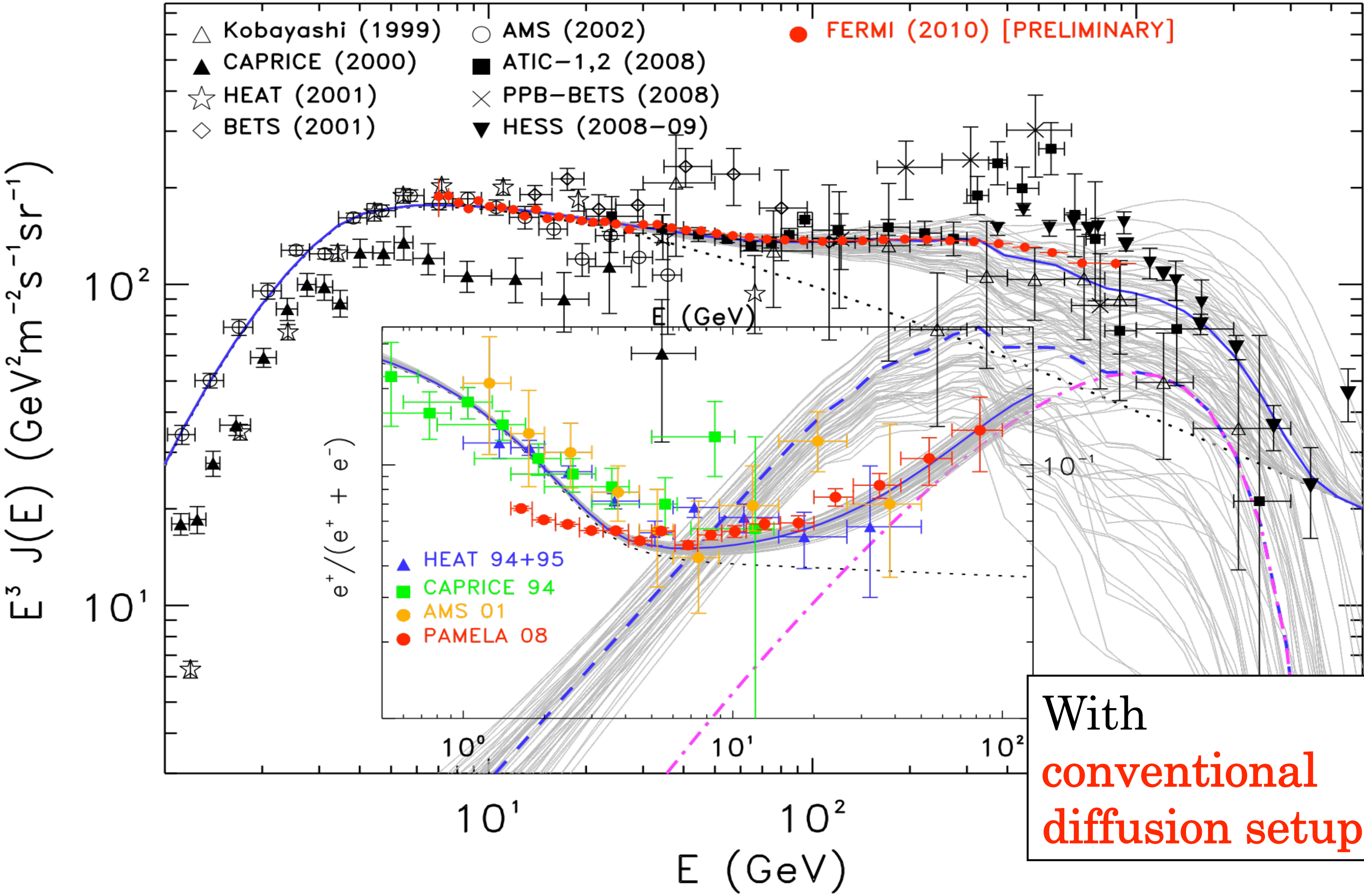


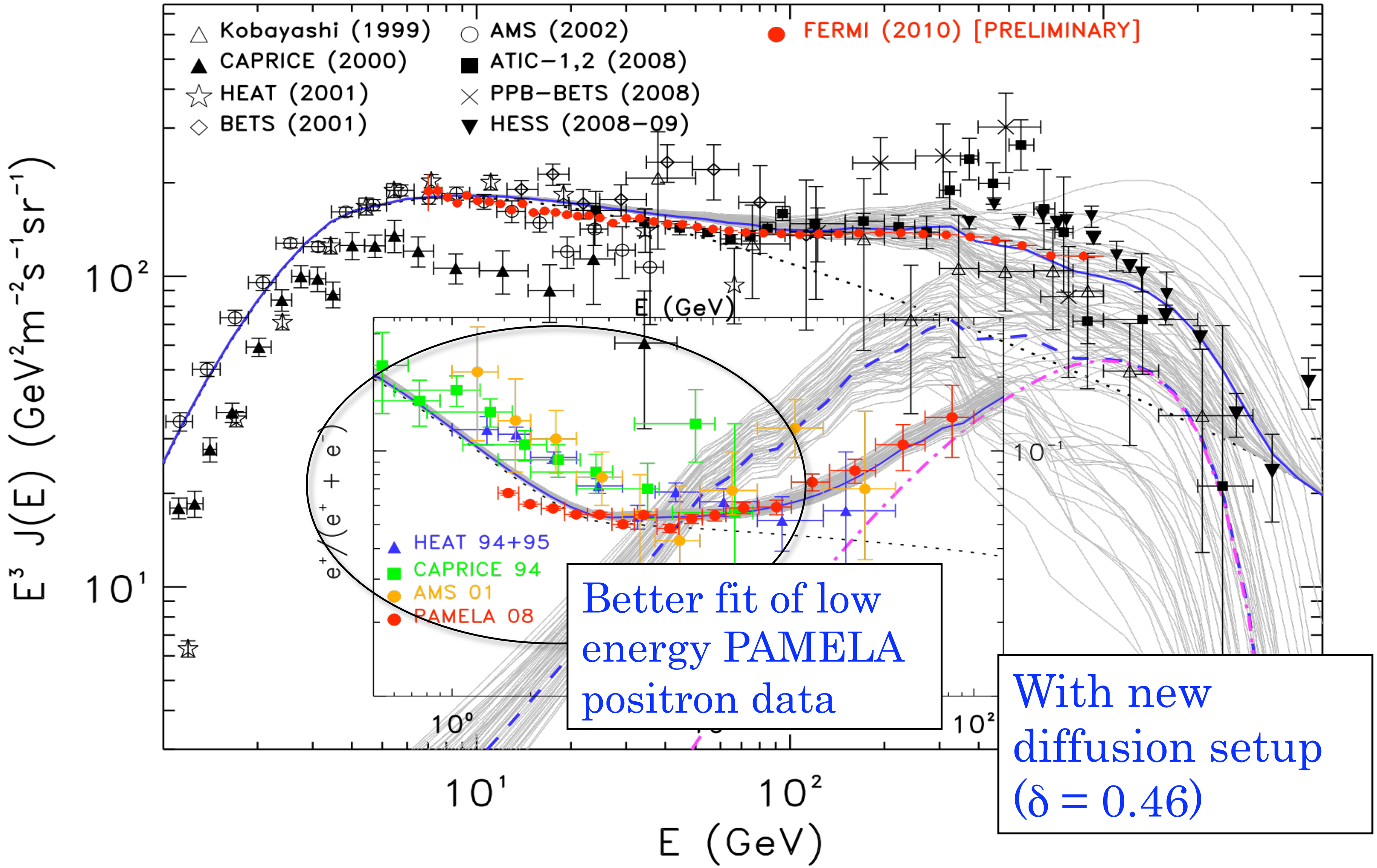
We consider middle-aged pulsars within 3 kpc from ATNF catalog. Pulsars are modeled as point-like, bursting sources, with a power-law injection spectrum with exponential cutoff. Spectral indexes and cutoffs are randomly varied around values reasonable values. Efficiencies vary between 10% and 30%. Each gray line correspond to a different realization

Nearby, observed middle aged pulsars are good candidates as extra-sources of electrons and positrons



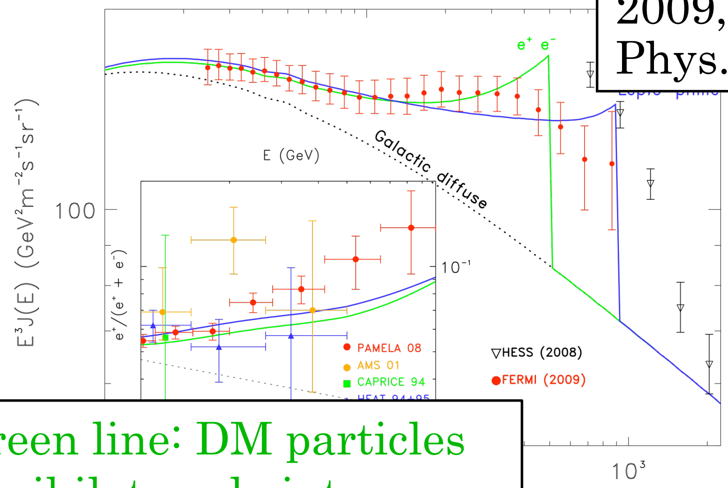
With **conventional diffusion setup**

Nearby, observed middle aged pulsars are good candidates as extra-sources of electrons and positrons



The extra-component may also be originated by annihilation or decay of Dark Matter particles

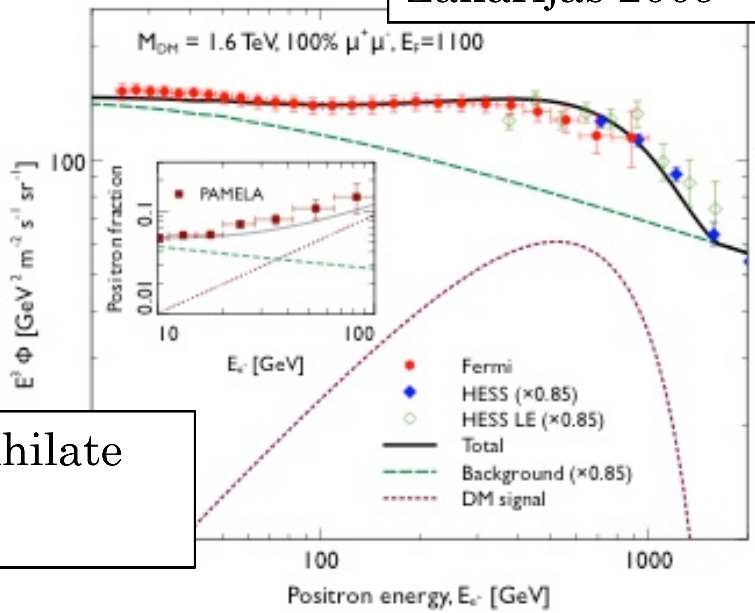
D.Grasso et al. 2009, Astrop. Phys.



Green line: DM particles annihilate only into electrons and positrons

Blue line: DM particles annihilate into e^+/e^- μ^+/μ^- τ^+/τ^-

Bergström, Edsjö & Zaharijas 2009



DM particles annihilate into μ^+/μ^-

An interpretation based on dark matter annihilation is still an open possibility

However DM interpretation seems disfavoured because:

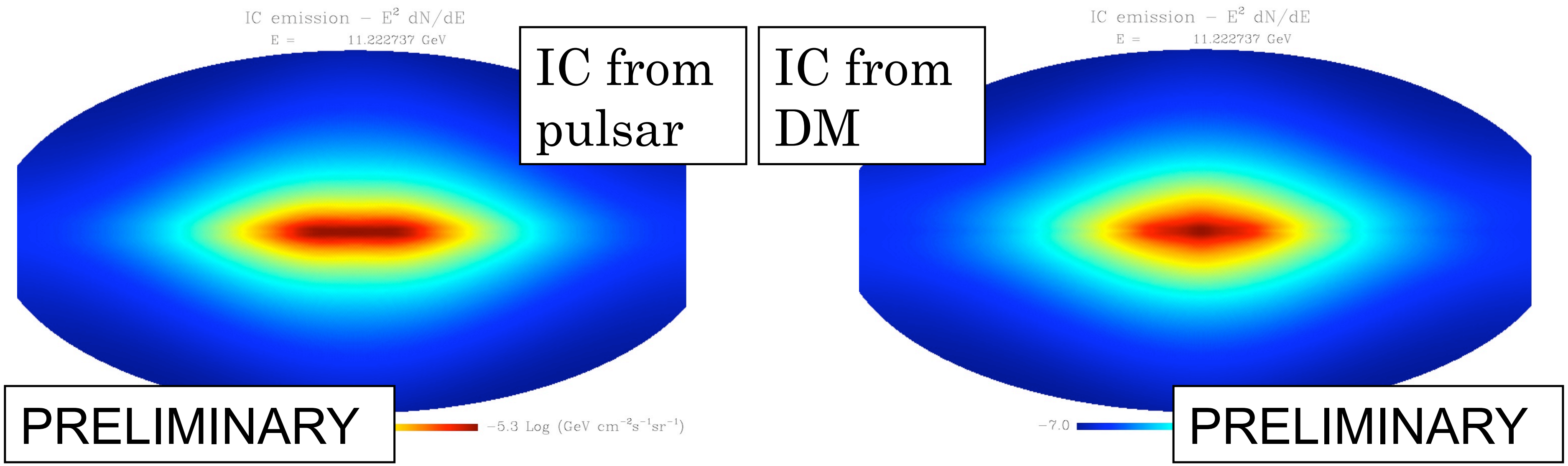
- Antiproton measurements rule out most annihilation modes, only "leptonic" models are allowed
- Large "boost factors" are needed (from 20 to 100) compared with expected annihilation rates

The extra-component may also be originated by annihilation or decay of Dark Matter particles

How do we distinguish between the two possibilities?

1) Study of ANISOTROPIES: pulsar model implies an anisotropy of order of 1 % in the direction of the closest middle-aged pulsar (Monogem)

2) Study of DIFFUSE GAMMA RAY sky. Both the DM extra-component and the pulsar component are expected to produce gamma rays via Inverse Compton. The γ ray map is expected to be different in the two cases



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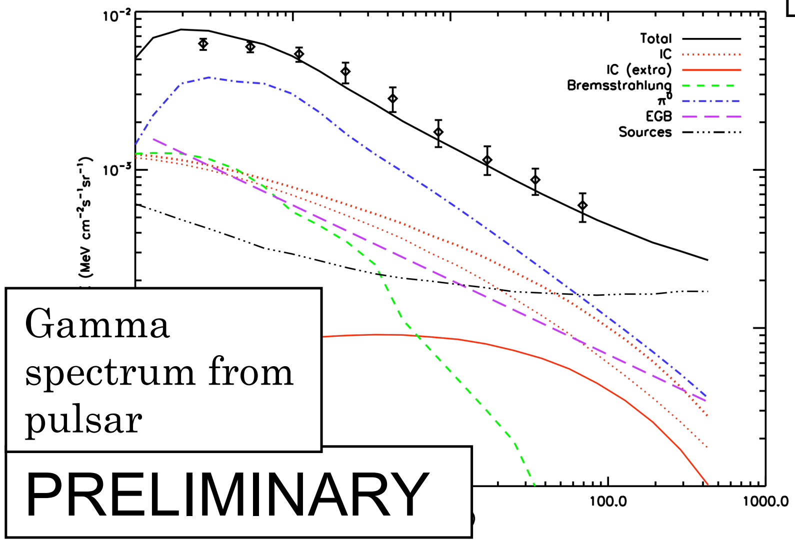
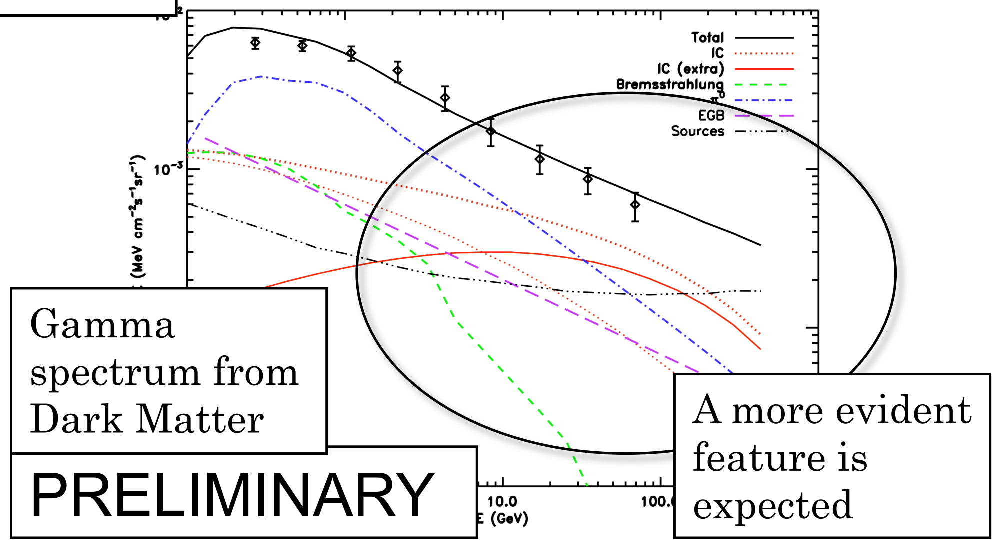
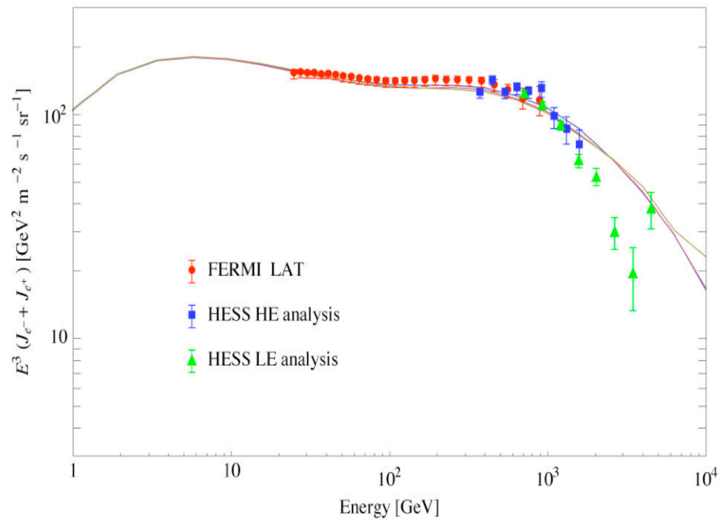
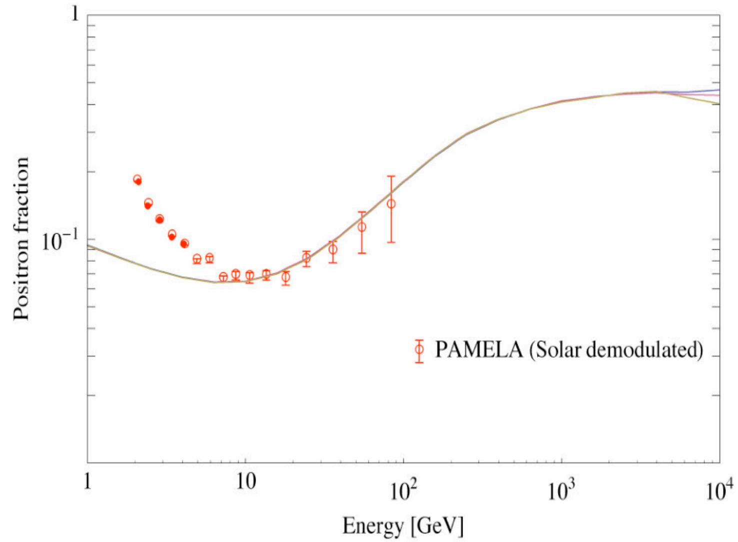
$-10° < b < 10°$





Another possible scenario: secondary production in the accelerator





It has been proposed that the observed rise in the positron fraction could be due to acceleration of secondary positrons in the same spatial region where primary species are accelerated (SNR shocks) [P.Blasi, 2009]

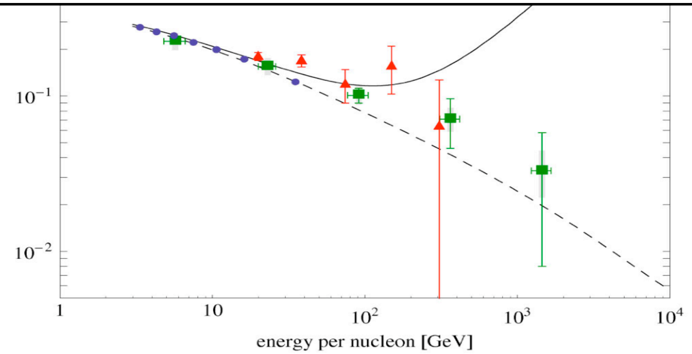
This scenario can account for Fermi and PAMELA datasets [P.Mertsch et al. 2009]

Summary of possible extra-components and their implications

PULSAR SCENARIO → Implies a 1% anisotropy at about 1 TeV in CR electron flux towards the nearest mature pulsars (in particular Monogem). Testable with Fermi-LAT with some years of data taking.

DM scenario → May imply an anisotropy in CR flux towards central region of Galaxy. May imply observable features in gamma-ray map of the Galaxy, different from those produced by pulsars. Testable with Fermi-LAT.

Secondary production in the accelerator → Predicts a boron-to-carbon ratio which starts to increase at high energy [Mertsch and Sarkar 2009]. This feature is compatible with ATIC data but in tension with CREAM data.



NEW DATA ARE NEEDED IN ORDER TO UNDERSTAND WHICH IS THE CORRECT INTERPRETATION!

Conclusions

1) New Fermi-LAT data on the electron+positron spectrum at low energy (between 7 and 20 GeV) forced us to reconsider the "conventional" model of propagation of CR leptons

2) Low energy Fermi-LAT data are consistent with a low-modulation scenario or with a conventional propagation model with injection index of 1.60/2.50 (above and below 4 GV respectively)

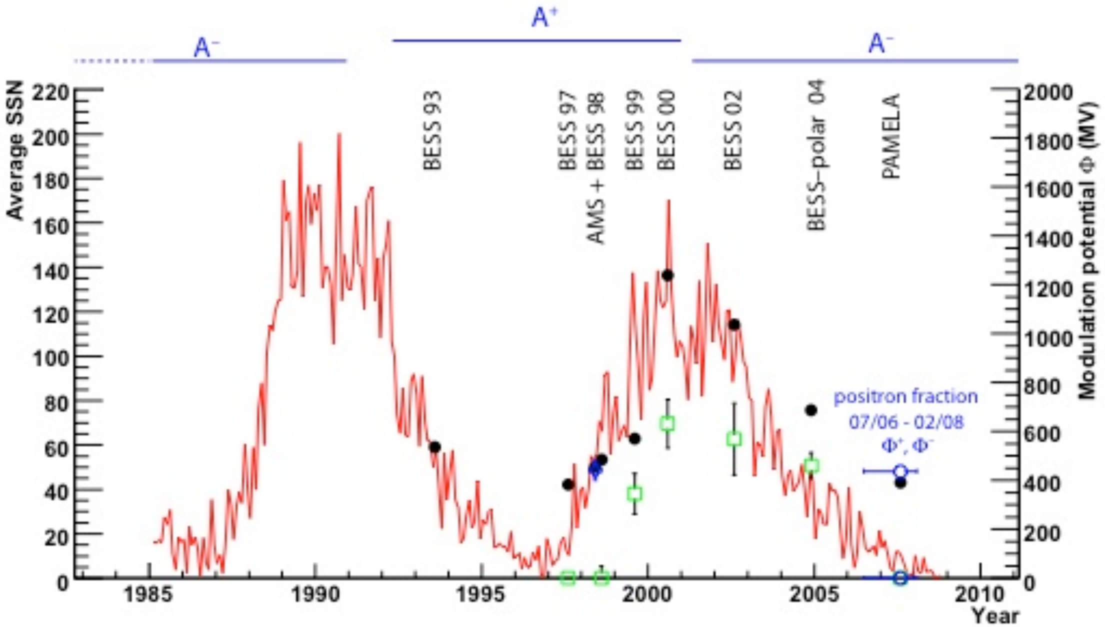
3) These single-component models cannot account for some features of Fermi-LAT spectrum and are in strong tension with high-energy PAMELA data on positron-to-electron ratio

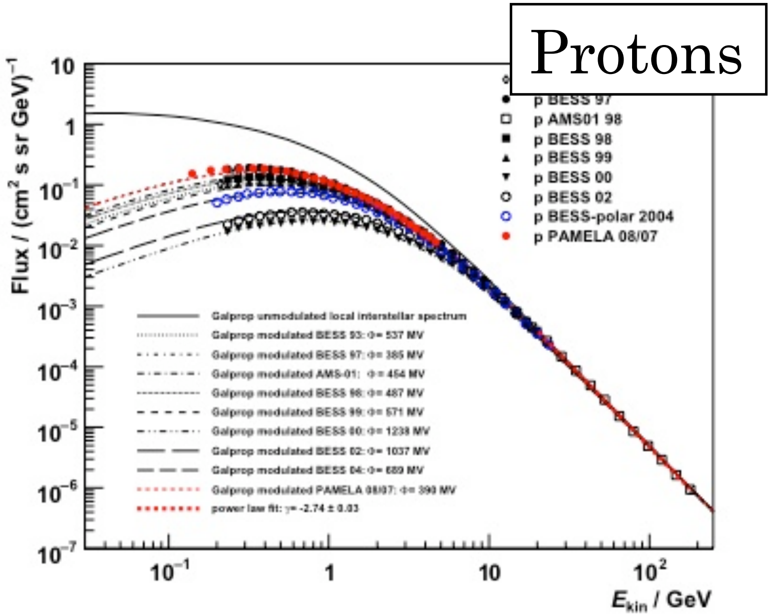
4) Models in which a primary extra-source of electrons and positrons is introduced give a good fit of alla datasets, with different choices of diffusion parameters

5) The nature of the extra-component (Pulsar origin? Dark Matter?) is still a matter of debate. New data from electron anisotropies and diffuse gamma rays will help to distinguish between different scenarios

Backup slides

A low electron modulation potential is possible in the context of ***charge-sign-dependent solar modulation***
(see Gast and Schael 2009)

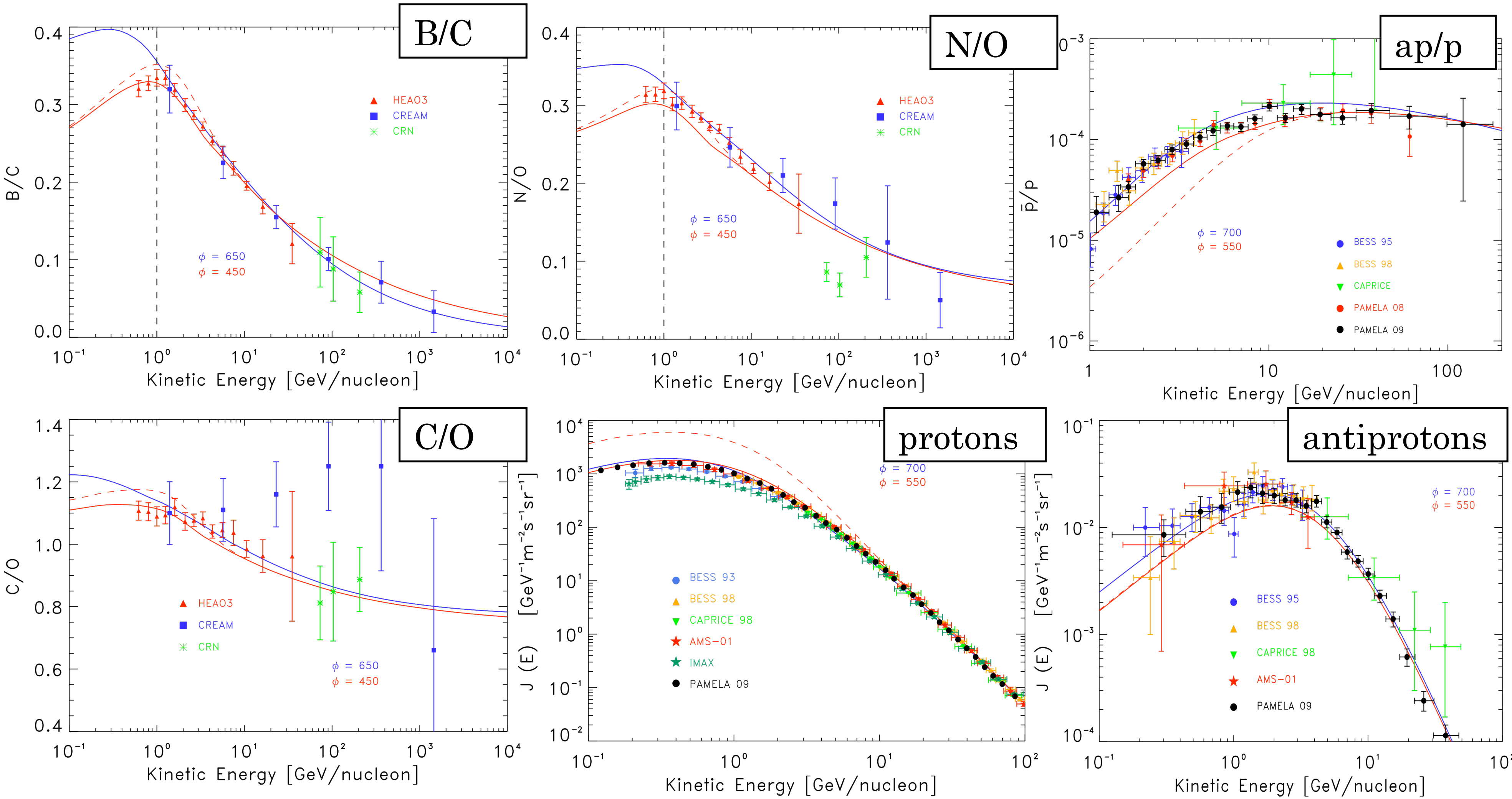




Experiment	Year	$\phi_{\rm p}^{+}$ (MV)	$\phi_{\bar{\rm p}}^{-}$ (MV)	$\phi_{\rm e^-}^{-}$ (MV)
BESS	1993	537		
BESS	1997	385	0	
AMS1	1998	454		442
BESS	1998	487	0	
BESS	1999	571	345	
BESS	2000	1238	632	
BESS	2002	1037	568	
BESS	2004	689	461	
PAMELA	2007	390	0	

In this scheme there are two free parameters because we allow negatively-charged particles (electrons, antiprotons) and positively-charged particles (protons, positrons) to be modulated by different potentials

Conventional model VS new model: all observables



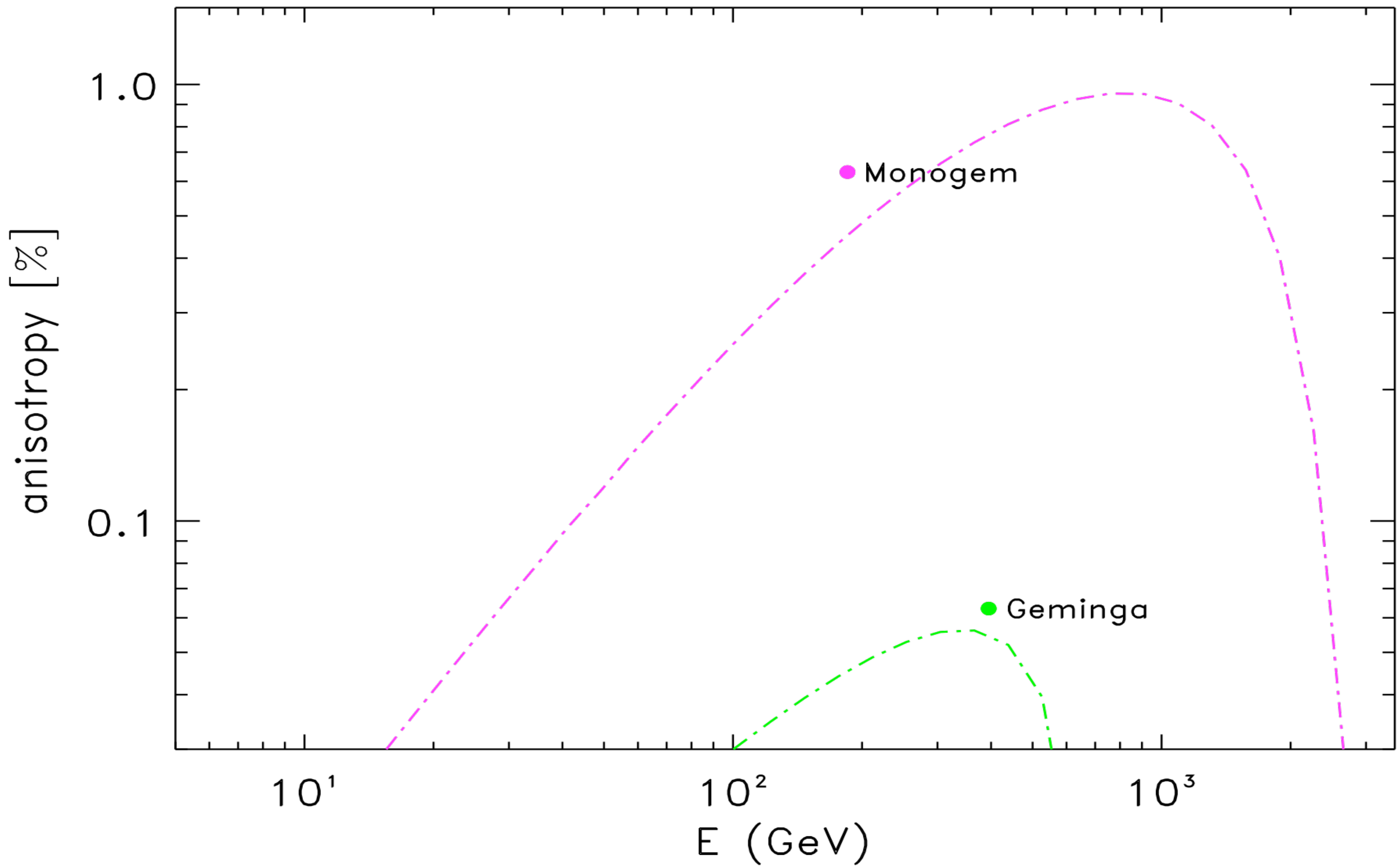
Blue line: new model. Red line: conventional model

Pulsar parameters

#	NAME		DIST kpc)	AGE (Yr)	EDOT (ergs/s)	
1	J0633+1746	hh92	0.16	3.42e+05	3.2e+34	Geminga
2	J1856-3754	tm07	0.16	3.76e+06	3.3e+30	
3	B0656+14	mlt+78	0.29	1.11e+05	3.8e+34	Monogem
4	J0720-3125	hmb+97	0.36	1.9e+06	4.7e+30	
5	B0823+26	cls68	0.36	4.92e+06	4.5e+32	
6	B1133+16	phbc68	0.36	5.04e+06	8.8e+31	
7	B1929+10	lvw68	0.36	3.1e+06	3.9e+33	
8	B2327-20	ll76	0.49	5.62e+06	4.1e+31	
9	J1908+0734	nft95	0.58	4.08e+06	3.4e+33	
10	B0906-17	mlt+78	0.63	9.5e+06	4.1e+32	
11	B2045-16	tv68	0.64	2.84e+06	5.7e+31	
12	J1918+1541	nft95	0.68	2.31e+06	2.0e+33	
13	J0006+1834	cnt96	0.70	5.24e+06	2.5e+32	
14	B0834+06	phbc68	0.72	2.97e+06	1.3e+32	
15	B0450+55	dth78	0.79	2.28e+06	2.4e+33	
16	B0917+63	dtws85	0.79	6.89e+06	3.7e+31	
17	B2151-56	mlt+78	0.86	5.15e+06	6.4e+31	
18	B0203-40	mlt+78	0.88	8.33e+06	1.9e+32	
19	B1845-19	mlt+78	0.95	2.93e+06	1.1e+31	
20	J0636-4549	bjd+06	0.98	9.91e+06	1.6e+31	
21	B0943+10	vazs69	0.98	4.98e+06	1.0e+32	

$$E_{e^\pm} \simeq \eta_{e^\pm} \, \dot{E}_{\rm PSD} \, \frac{T^2}{\tau_0} \, ,$$

Expected anisotropy in pulsar scenario



Dark Matter models in Fermi interpretation paper

$$\rho_{\rm DM}(r) = \rho_{\odot}\left(\frac{r}{R_{\odot}}\right)^{-1.24}\left(\frac{R_{\odot}+R_s}{r+R_s}\right)^{1.76}$$

DM profile, from Via Lactea II N-body simulation (Diemand et al. 2008); The simulation follows the growth of a Milky Way-size system from redshift 104.3 to the present

DM models parameters

Model	Ann. Final State	Mass (GeV)	$\langle\sigma v\rangle$ (cm^3/s)
e^+e^-	e^+e^-	500	9×10^{-25}
Leptophilic	$33\%(e^+e^-)+33\%(\mu^+\mu^-)+33\%(\tau^+\tau^-)$	900	4.3×10^{-24}