Some implications of Cosmic rays electron recent measurements

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The electron and positron spectra before 2008

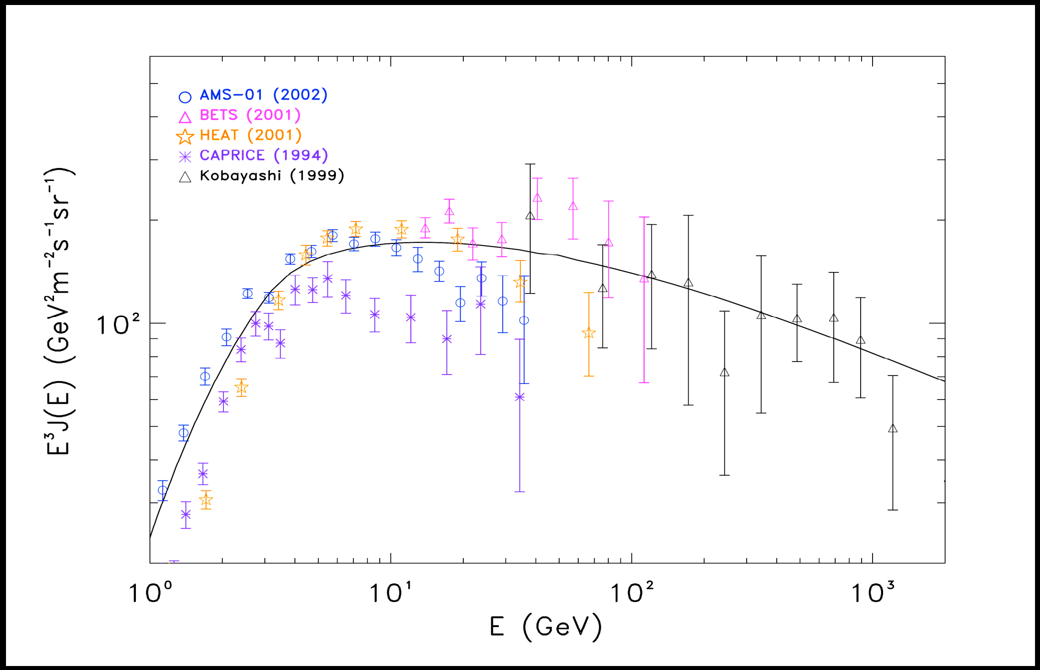
Electron + positron spectrum

Above few GeV the spectrum was fitted by a $\sim E^{-3.2}$ power-law (with large uncertainty)

in the figure GALPROP model with

$\delta = 0.33 \qquad \gamma_0 = 2.54$

(Alfven vel. V_A = 30 km/s , no convection)



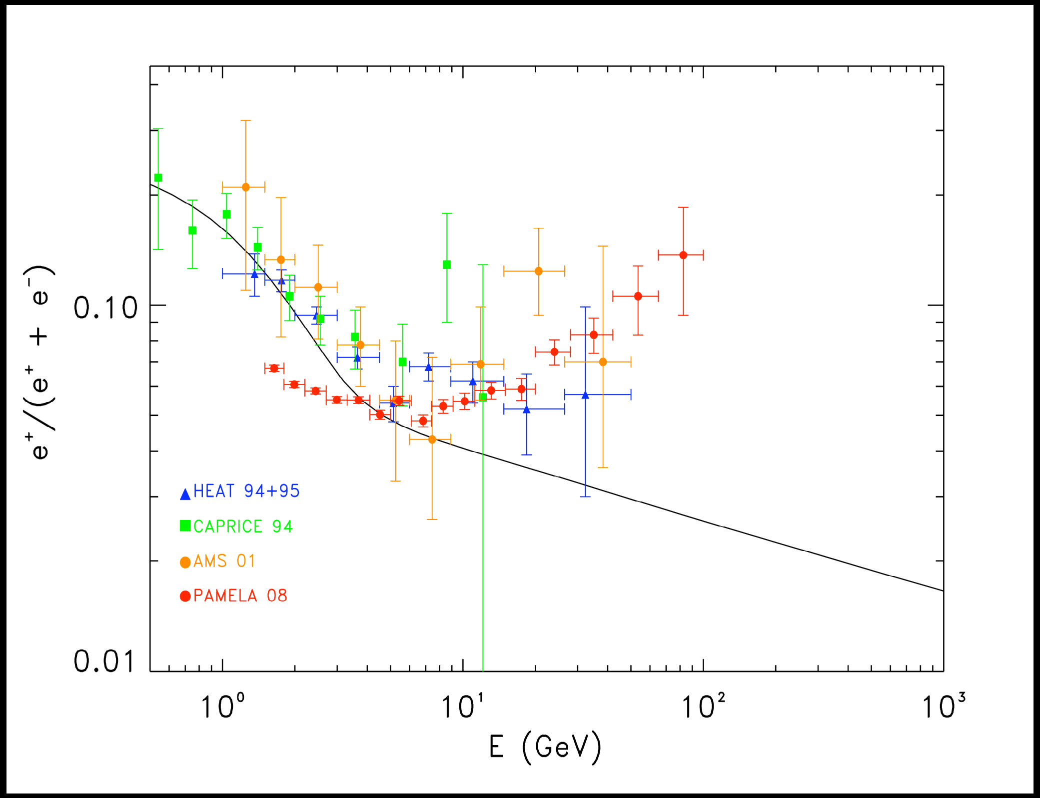
Positron fraction

tension with AMS-01 and HEAT

strong disagreement with PAMELA if positrons are only secondary products of CR p and nuclei

$$\frac{e^+}{e^- + e^+} \propto \frac{E^{-(\gamma_p+\delta/2+0.5)}}{E^{-(\gamma_0+\delta/2+0.5)}} = E^{-\gamma_p+\gamma_0}$$

it decreases if $\gamma_0 < \gamma_p \cong 2.7$

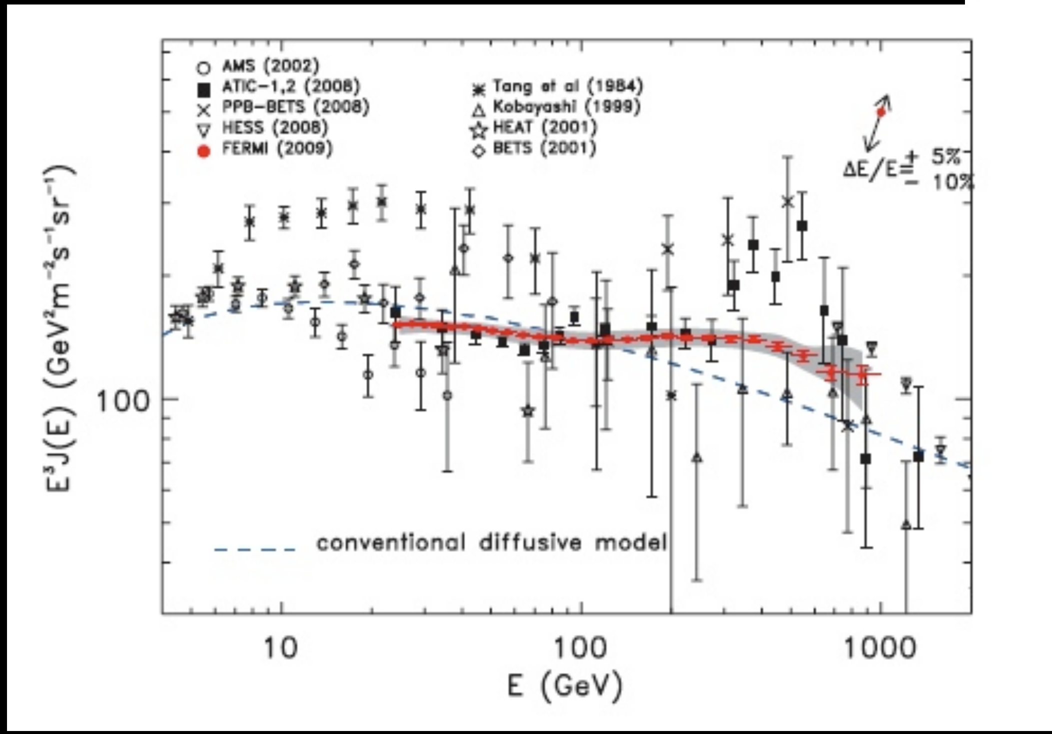


The Fermi-LAT + HESS CRE spectrum

Electron + positron spectrum published in PRL, May 2009 based on 6 months data

compared with most significant previous data and the conventional GALPROP model with

$$\delta = 0.33 \qquad \gamma_0 = 2.54$$

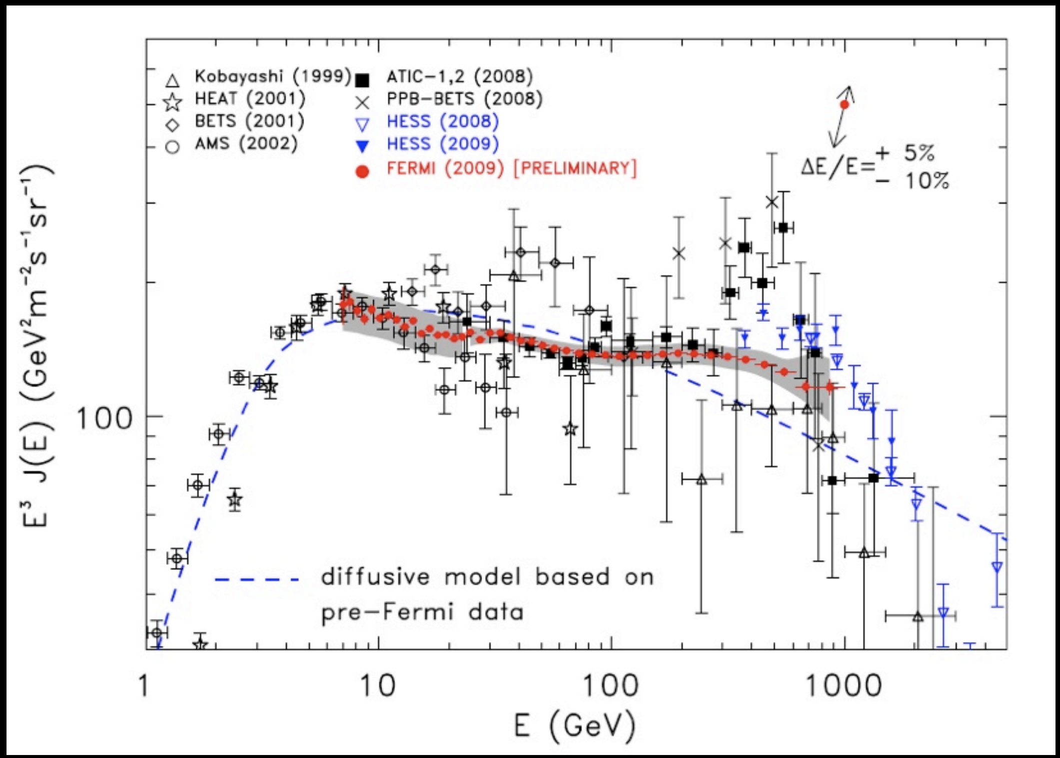


Fermi-LAT spectrum based on 1 yr data, extended down to 7 GeV

Latronico et al. - 2nd Fermi symp. 2009 [Fermi-LAT coll.] submitted to PRD

The spectrum is fitted by a E^(-3.08) power-law

with hints for a hardening at ~100 GeV and a steeping above 500 GeV



Propagation of CRE

For E > 10 GeV up to ~ 1 TeV solar modulation, CRE re-acceleration, convection are sub-dominant; only synchrotron + IC losses and plain diffusion play a relevant role.

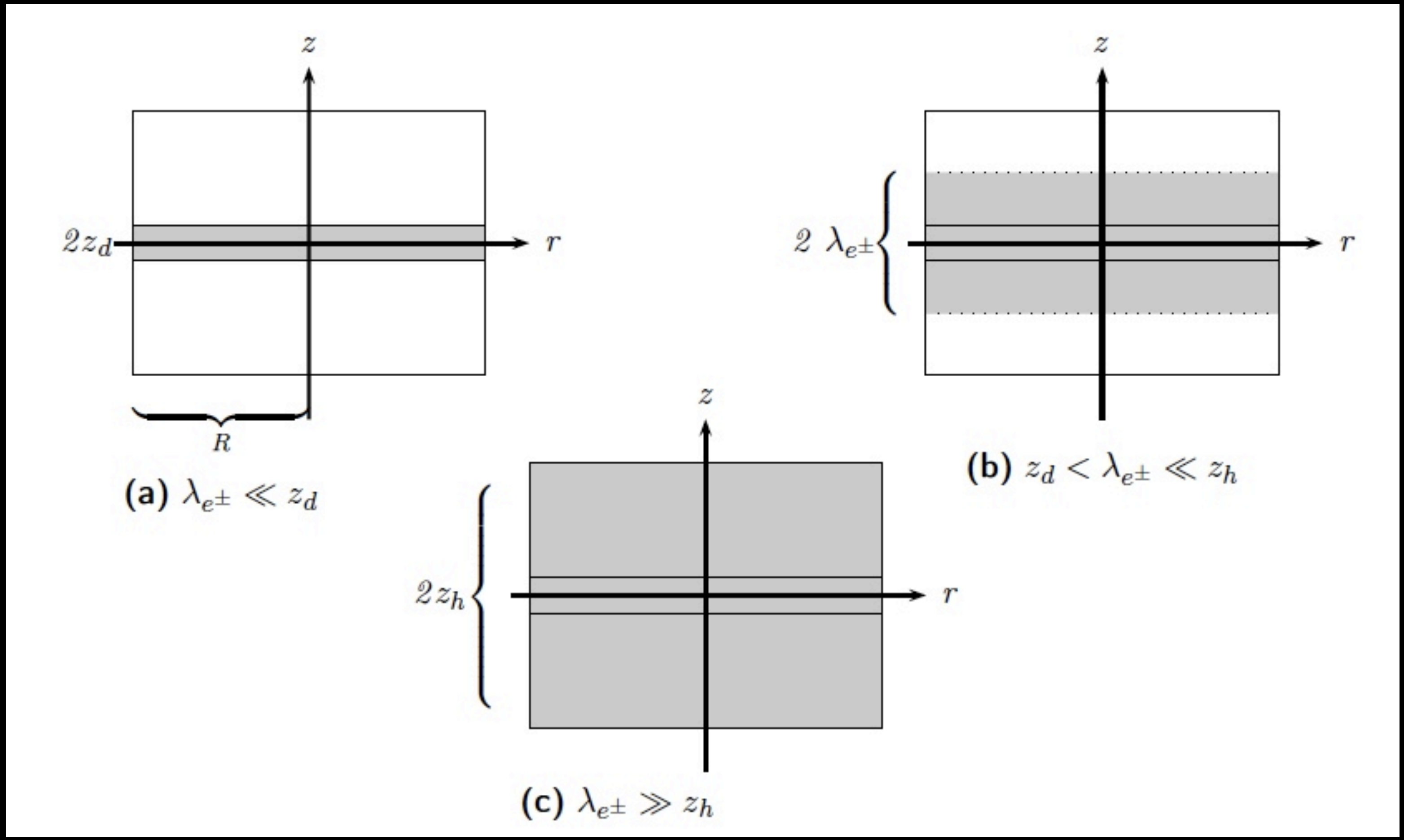
$$0 \simeq \frac{\partial n(E,\vec{x},t)}{\partial t} = q(E,\vec{x},t) + \nabla D(E,\vec{x})\,\nabla n(E,\vec{x},t) - \frac{\partial}{\partial E}\left[\beta(E)\,n(E,\vec{x},t)\right]$$

Source Diffusion Energy Loss

if $Q(E) \propto E^{-\gamma_0} \quad D(E) \propto E^{\delta}$

the energy loss length is $\lambda_{loss} = \left(\int_E \frac{D(E')}{b(E')}\,dE'\right)^{1/2} \simeq 3\,\frac{D(E_0)}{10^{28}\ \mathrm{cm^2 s^{-1}}}\left(\frac{E}{E_0}\right)^{(\delta-1)/2}\ \mathrm{kpc}$

A simple approximate analytical solution can be found (see e.g. *Bulanov & Dogiel ASS (1974)*)



In the energy range 10 GeV - 1 TeV we are in the diffusion + losses dominated regime (case b). In that case

$$N_e(E) \propto \frac{Q(E)\ \tau_{\rm loss}}{\lambda_{\rm loss}} \propto E^{-\left(\gamma_0 + \frac{\delta}{2} + \frac{1}{2}\right)}$$

e.g. for Kraichnan diffusion $\delta = 0.5$ so that $N_e = 3.2\ (3.0) \rightarrow \gamma_0 = 2.45\ (2.25)$

The possible role of fluctuations/nearby sources

It was studied either by combining analytical propagation with Montecarlo generated sources

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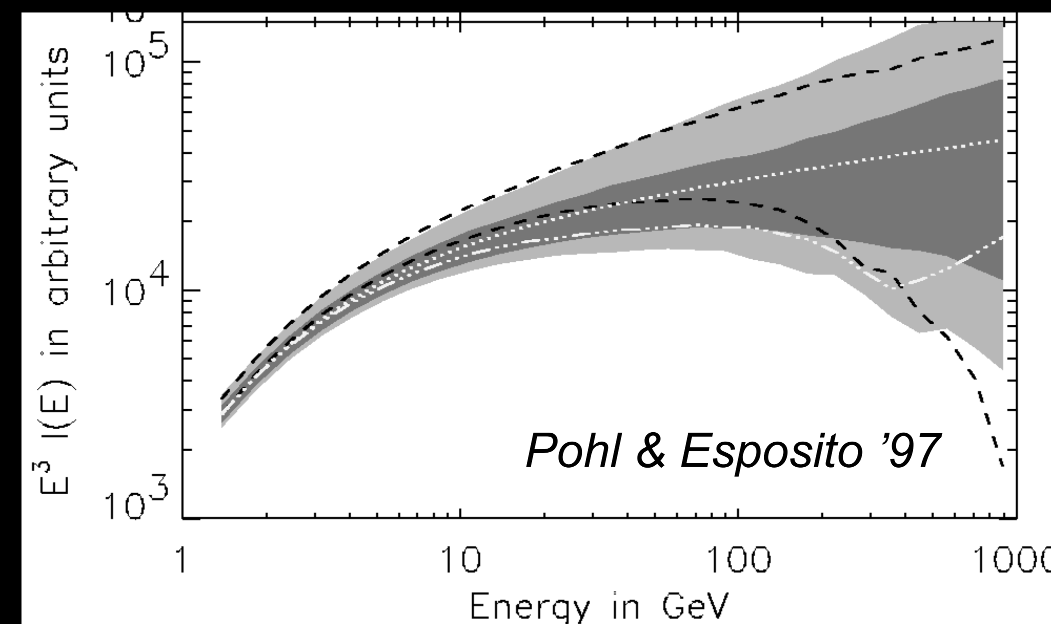

or by analytical propagation from a distribution of local sources

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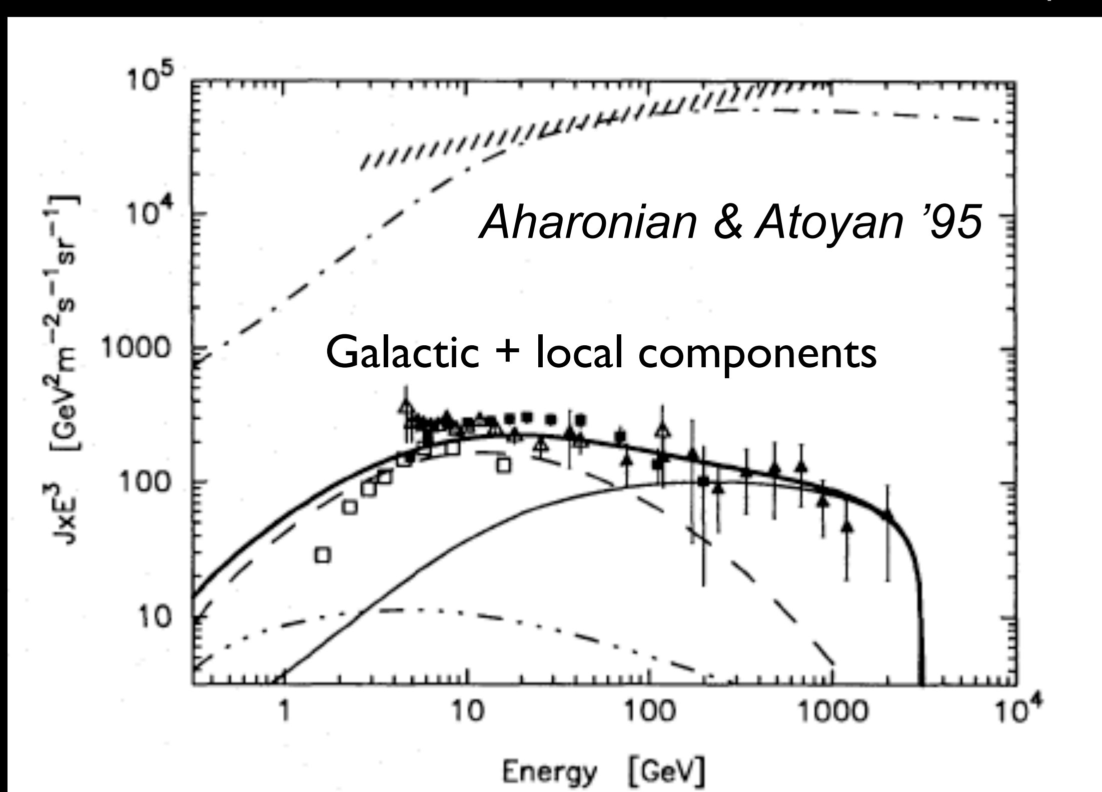

or by analytical propagation from actually observed candidate sources

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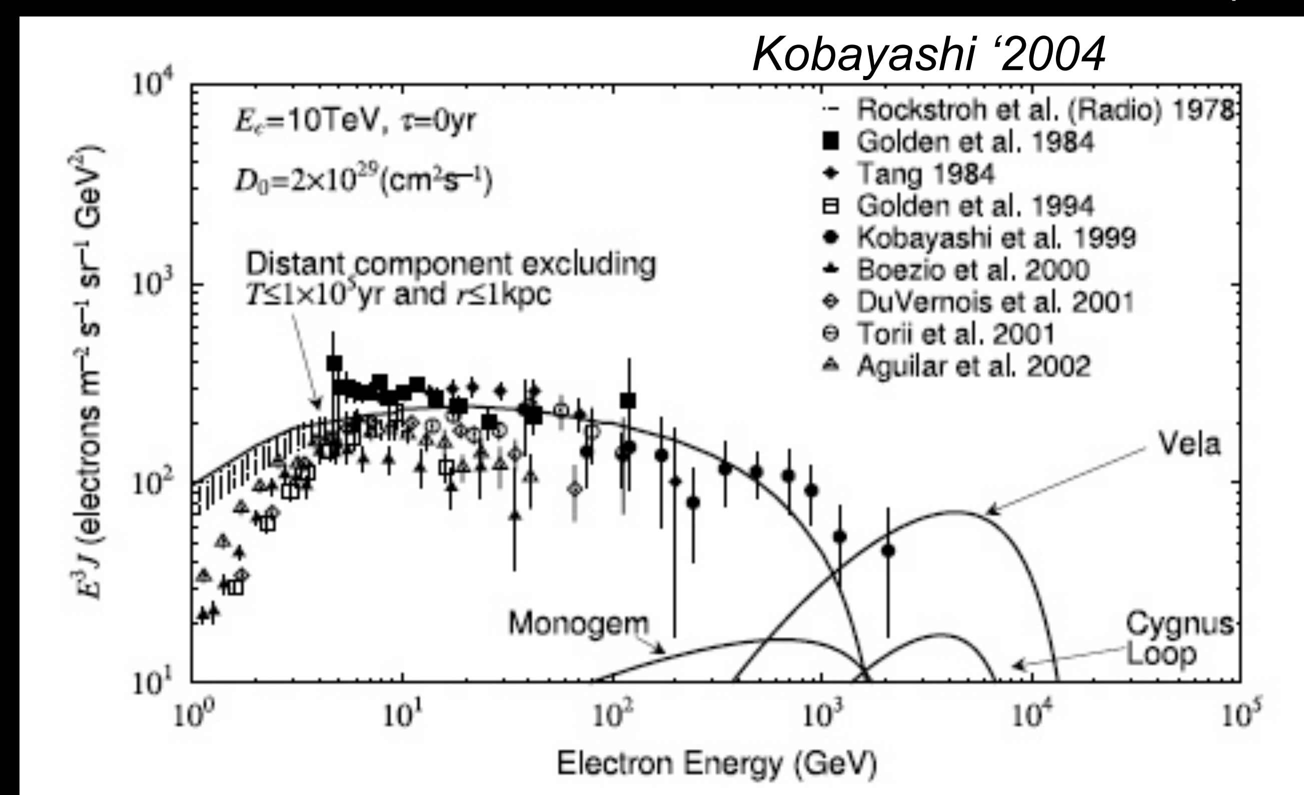
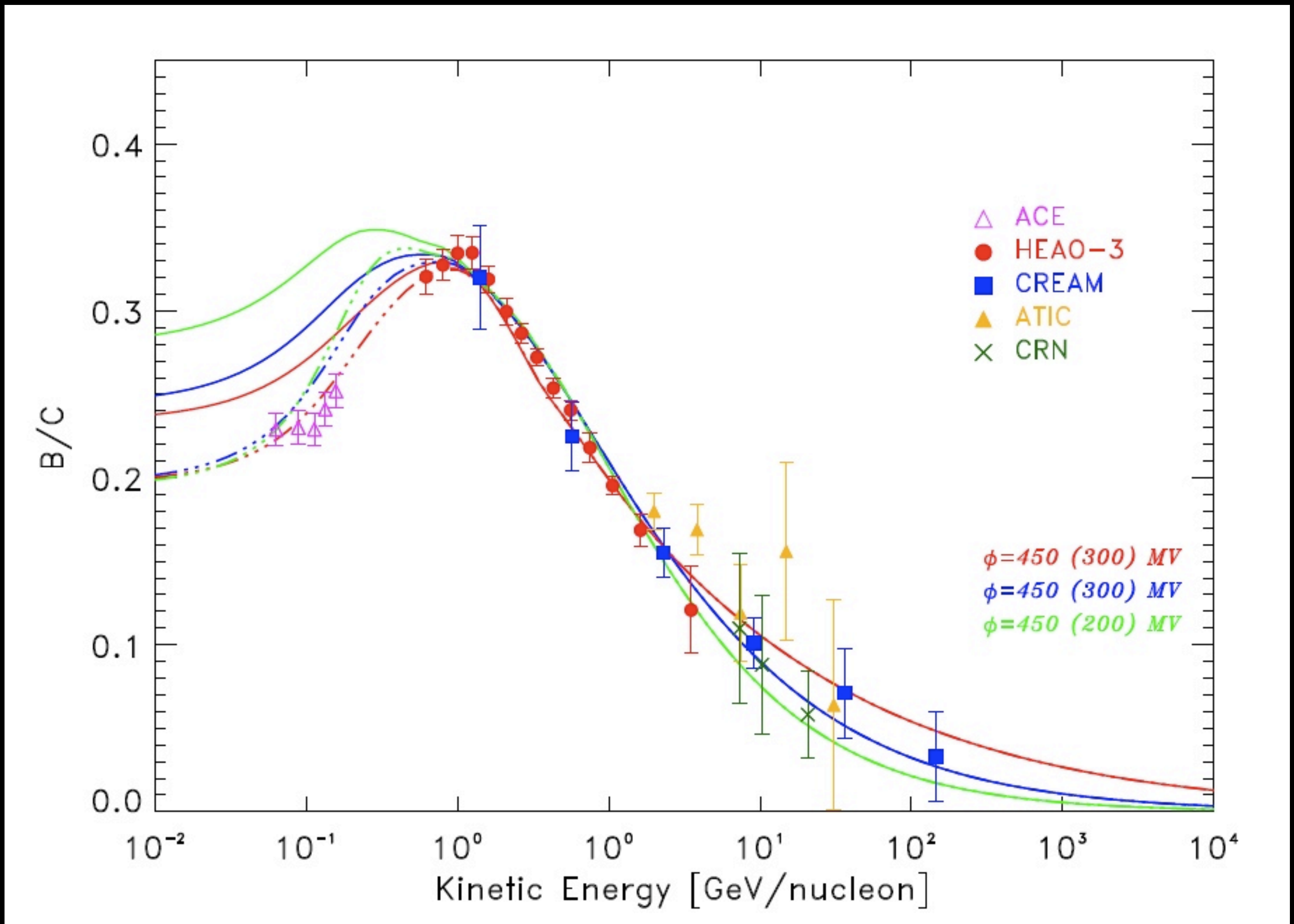


Fixing diffusion models against CR data (nuclear data)

Using either GALPROP (Strong & Moskalenko ....) or DRAGON



Plain diffusion (PD)
$\delta = 0.6$ $V_A = 0$

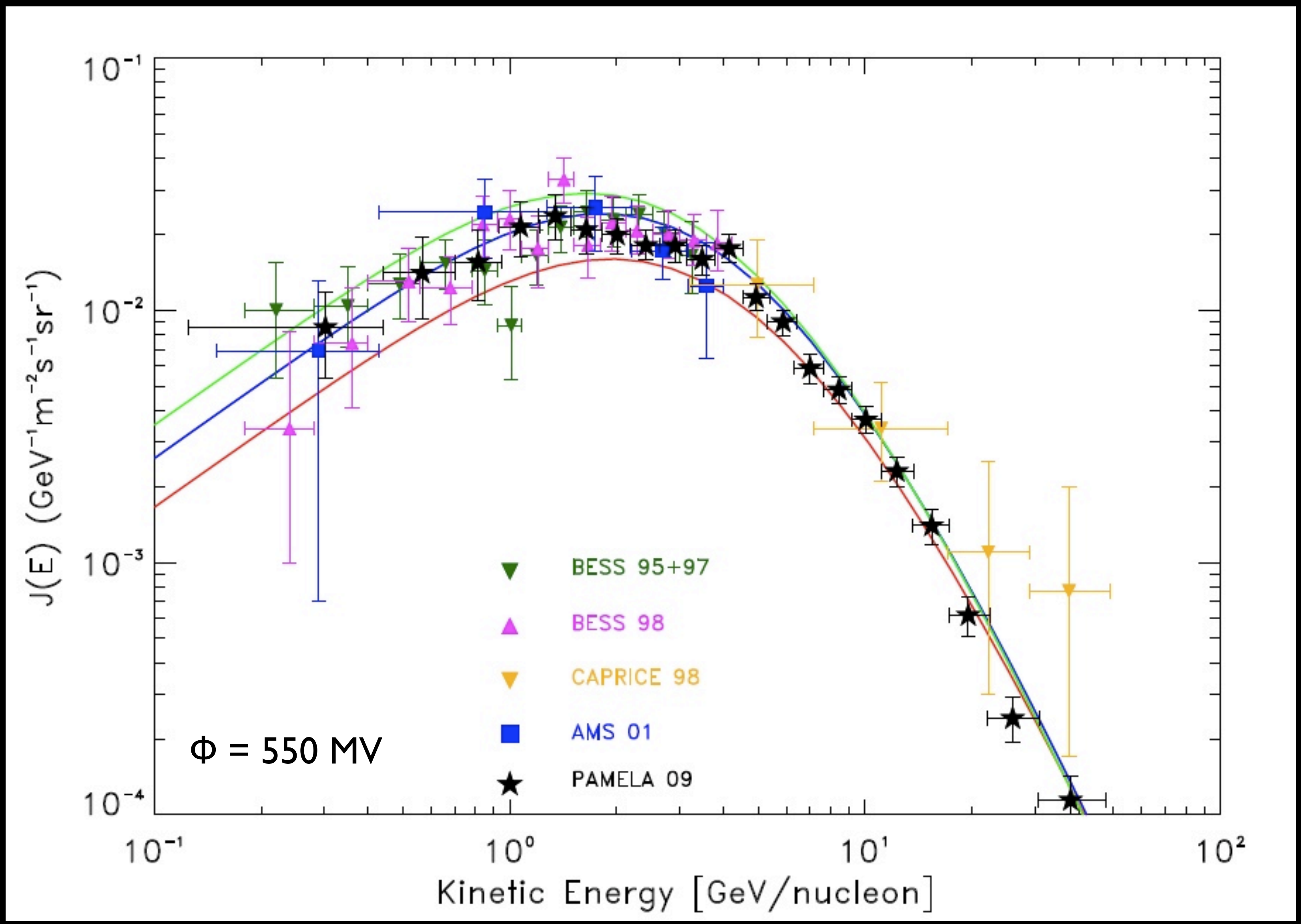
Kolmogorov diffusion
$\delta = 0.33$ $V_A = 30$ km/s

Kraichnan diffusion
$\delta = 0.5$ $V_A = 15$ km/s

all these models require some tuning of source spectrum / diffusion coeff. at low energy !

see also *Di Bernardo et al. 2009*

Fixing diffusion models against CR data (antiproton data)



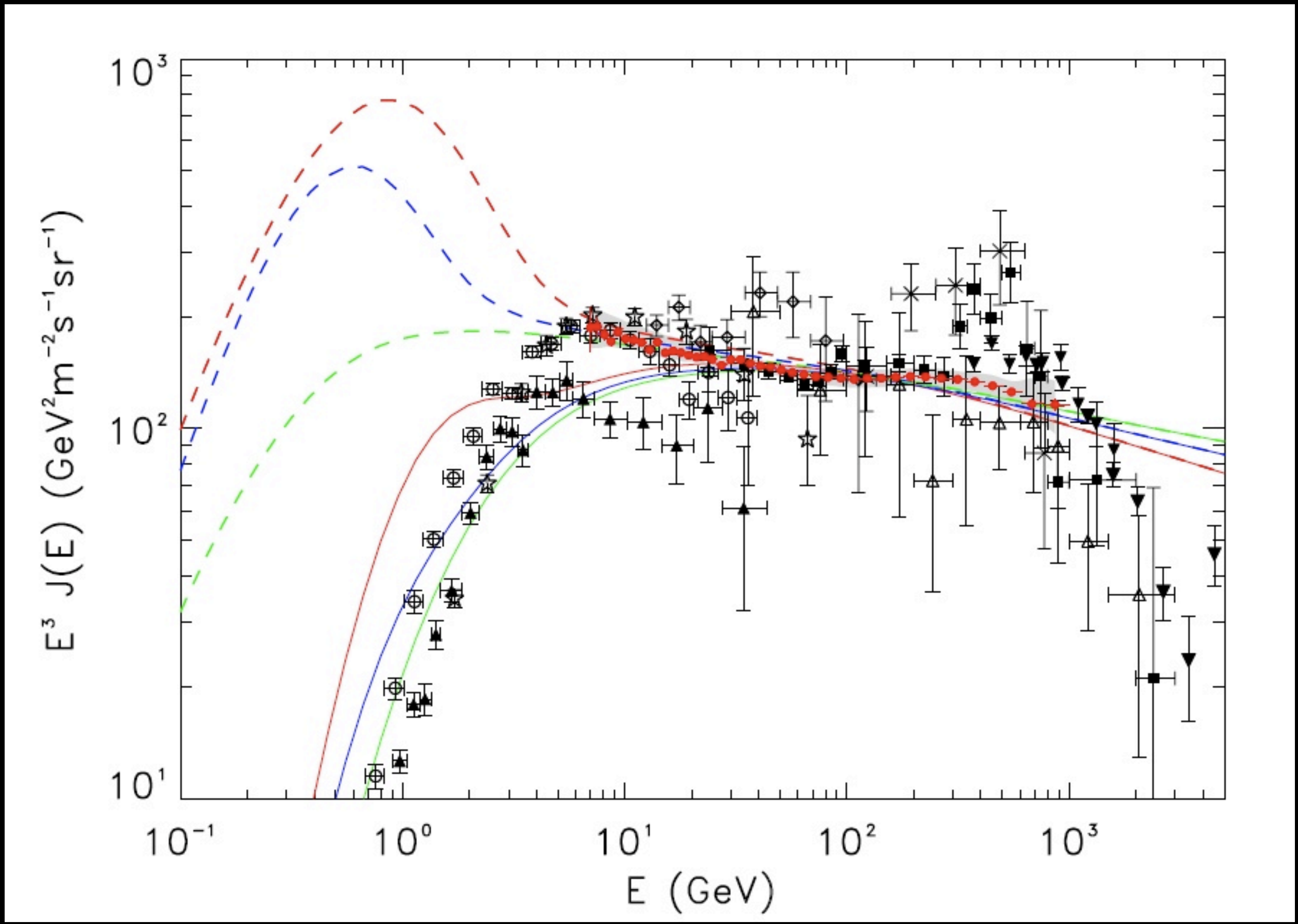
Plain diffusion (PD)
δ = 0.6 V_A = 0

Kolmogorov diffusion
δ = 0.33 V_A = 30 km/s

Kraichnan diffusion
δ = 0.5 V_A = 15 km/s

see also *Di Bernardo et al. 2009* where the constraint $0.3 < \delta < 0.6$ was derived

Single component interpretation of the Fermi-LAT CRE spectrum



Plain diffusion (PD)
$\delta = 0.6\ V_A = 0$
$\gamma_0 = 2.28$

Kolmogorov diffusion
$\delta = 0.33\ V_A = 30$ km/s
$\gamma_0 = 2.0/2.42$ $E_{break} = 4$ GeV

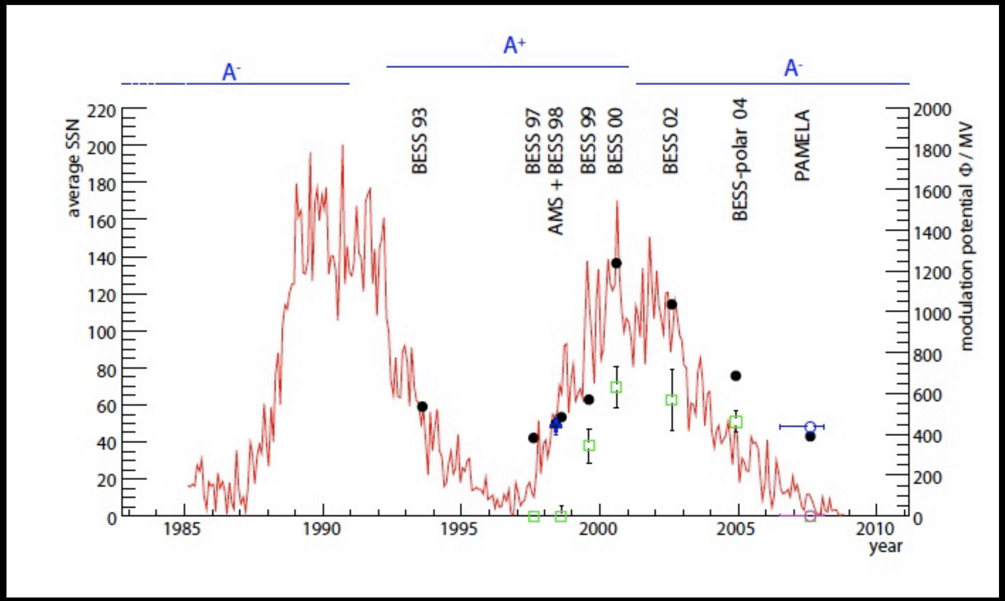
D. G. [Fermi-LAT coll.] APP 2009

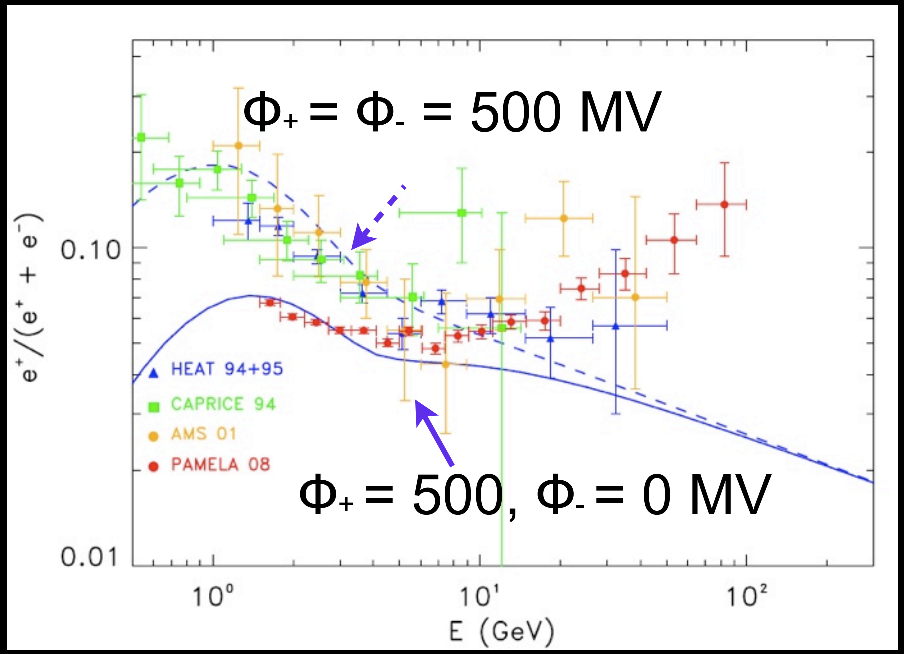
Kraichnan diffusion
$\delta = 0.5\ V_A = 15$ km/s
$\gamma_0 = 2.0/2.33$ $E_{break} = 4$ GeV

modulated with $\Phi = 500$ MV

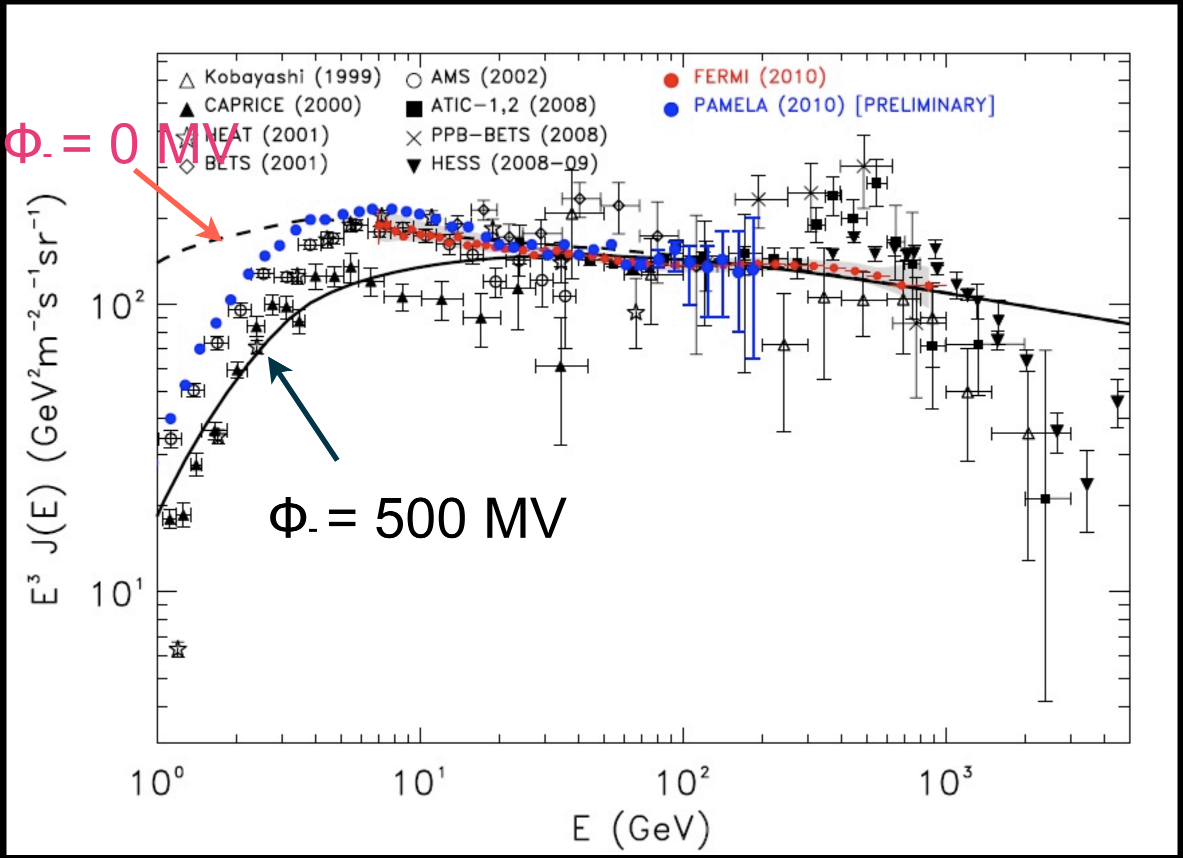
May charge asymmetric modulation account for the low energy discrepancy ?

Gast & Schael 2010



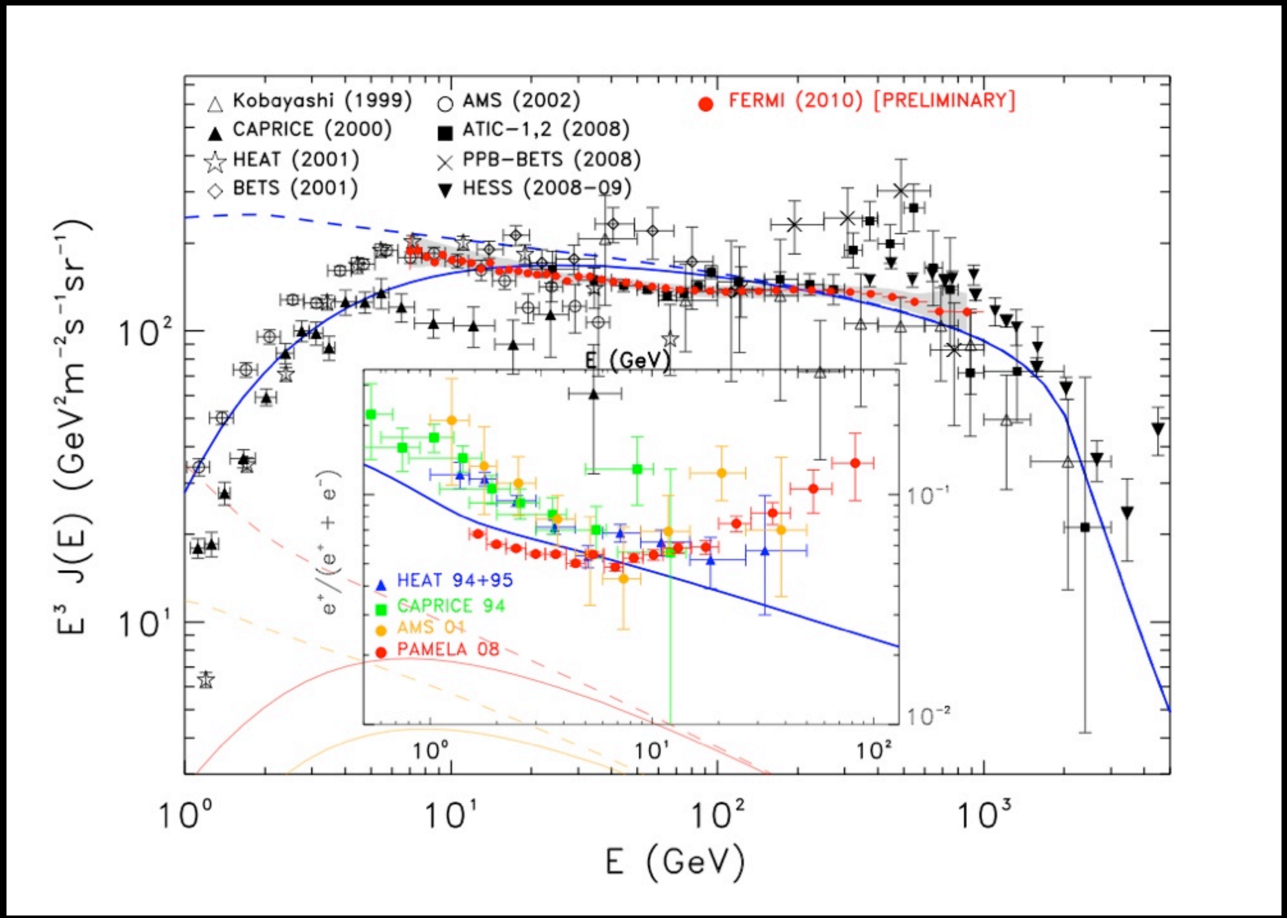


NO ! A low modulation potential such to account for the Fermi data and the pos. fraction below 10 GeV is at odd with the preliminary e^- *absolute spectrum* measured by PAMELA during the same solar phase FERMI is operating

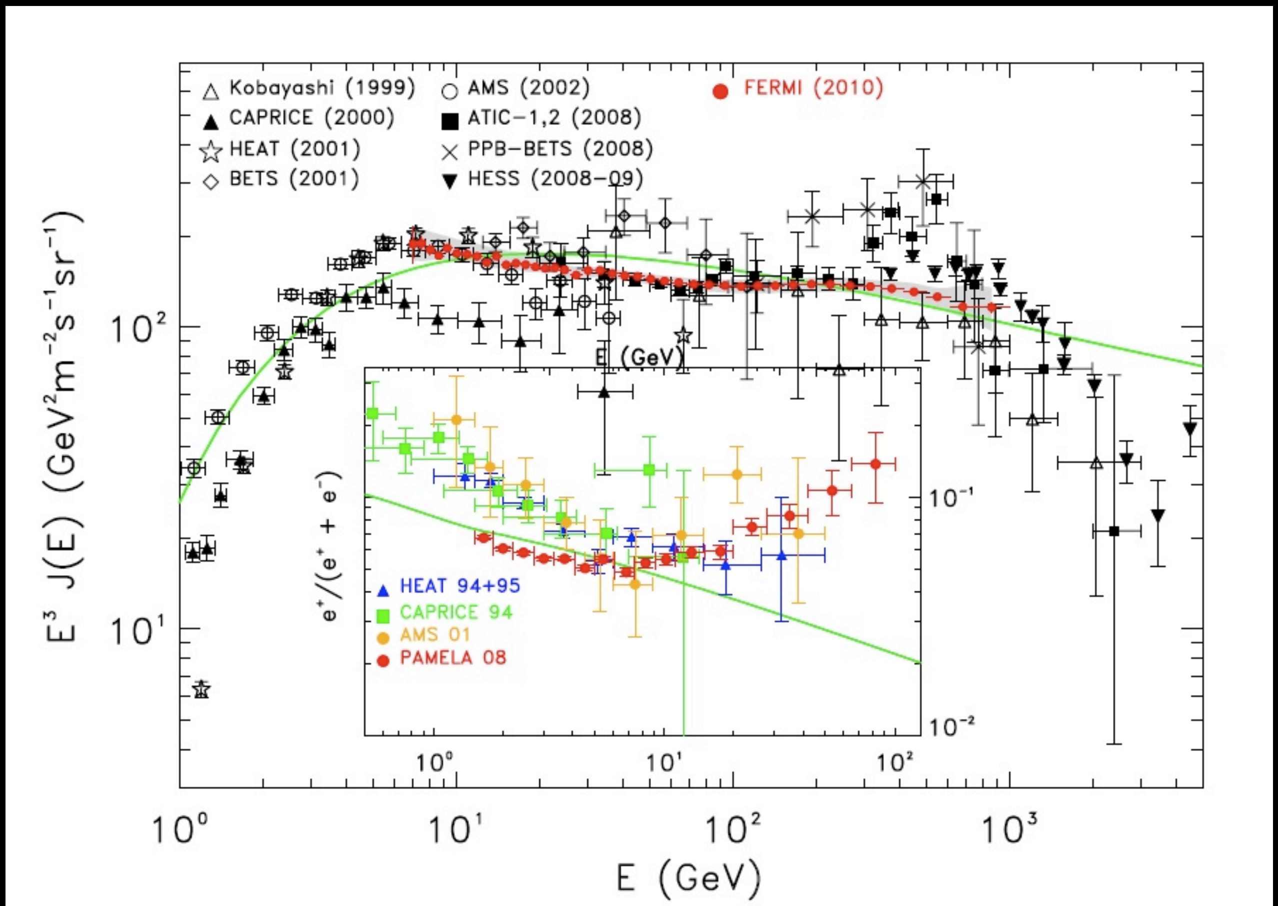


furthermore it is not needed !

Kraichnan diffusion



plain diffusion

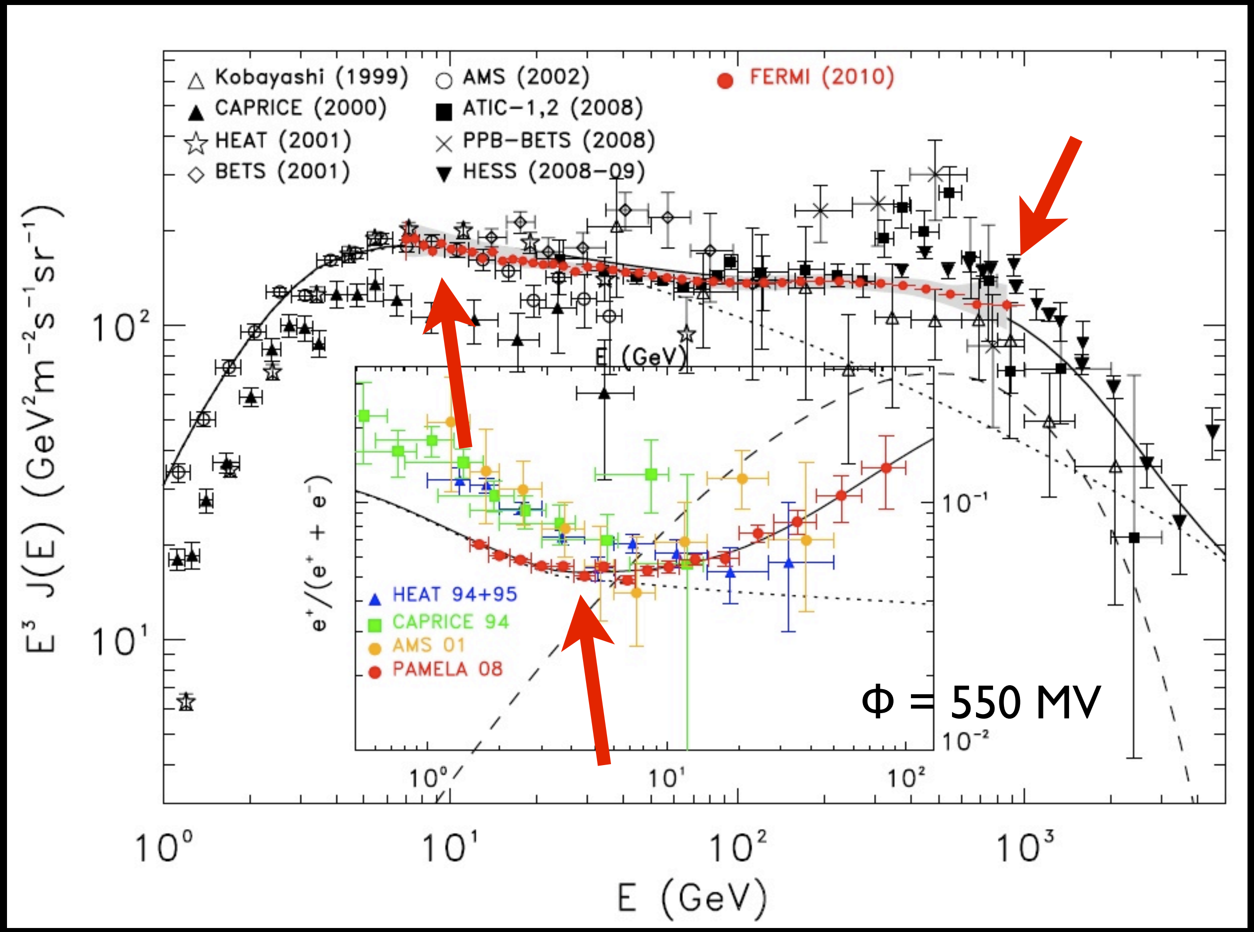


Hence, single component models face two major problems

- they cannot exactly reproduce the CRE spectrum
- they cannot reproduce the increasing positron fraction

Two components models: main motivations

Toy model with a Galactic $N_{\rm extra} \propto E^{-1.5}\ e^{-E/1\ {\rm TeV}}$ added to a conventional bkg with

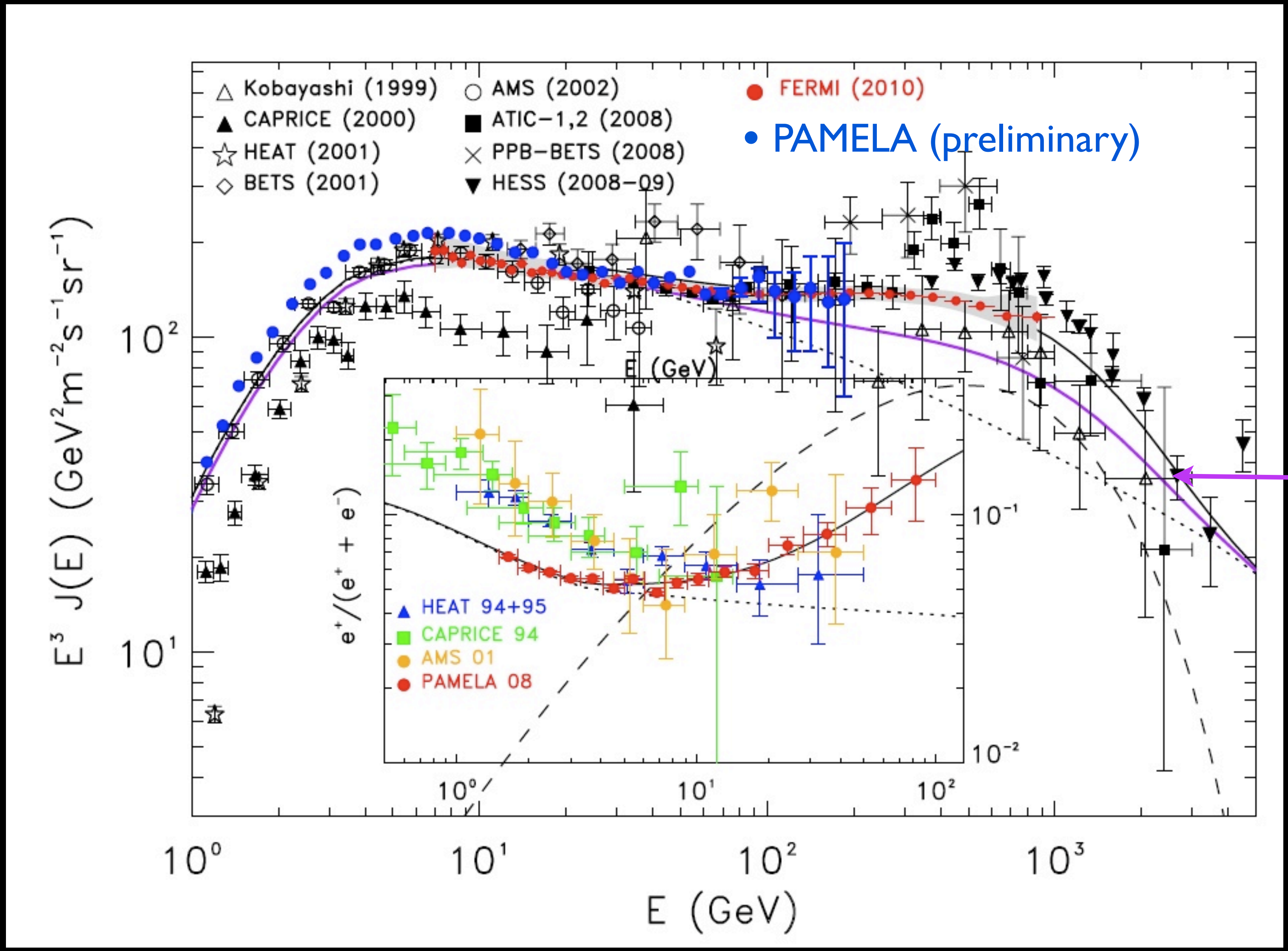


γ_0 = 2.0/2.65 above/below 4 GeV

δ = 0.5

- It allows to naturally fit the entire Fermi-LAT CRE spectrum as well as HESS
- It allows to consistently reproduce the entire PAMELA positron ratio even below 10 GeV

Two components scenario



All data can be reproduced by the same model within the simplest solar modulation scheme

A more realistic treatment of local sources

it can be obtained by a proper combination of numerical and analytical results

- The propagation of e± from local individual sources (SNR, pulsars, DM substructures..) can be treated analytically.

- A consistent approach requires to use the same conditions (propagation parameters, energy losses) as in the numerical code used to treat the large scale Galactic component

- In the case of astrophysical sources, actual observed properties of the source can be used

- GALPROP or DRAGON can be used in combination with analytical solutions from point-like sources implemented in the IDL package

The contribution of pulsars

- Energy source: rotational energy of the NS . The total $e^{\pm}$ energy release can be determined by pulsar timing (modulo an unknown efficiency factor $\eta_{e\pm}$) and can be as large as 10^{48} erg .

- Particles from the pulsar are re-accelerated at the pulsar wind/shock - power law spectrum with index $-1 < \Gamma < -2$

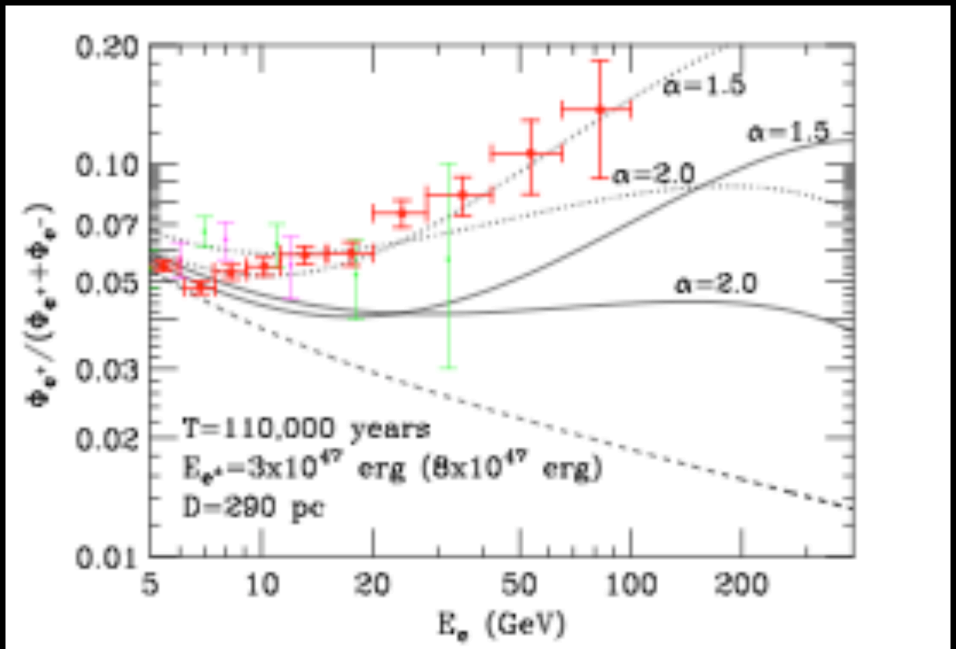
- PWN breakup $\Delta T \approx 10$ - 100 kyr after the birth of the pulsar, releasing the trapped $e^{\pm}$ ($Ne^{+} \approx Ne^{-}$)

- $E_{cut} \sim 10^3$ TeV for young PWN (T ~ 1 kyr) it is expected to decrease with the pulsar age/luminosity for middle-age pulsars (T ~ 10 - 100 kyr) $E_{cut} = 0.1 - 10$ TeV is a natural range

expected spectral shape at the source: $N_{e\pm}(E) = Q_0 \, (E/E_0)^{-\Gamma} \, \exp\{-E/E_{cut}\}$

It was shown that $e^{\pm}$ emission from nearby pulsars may account for the PAMELA e+ anomaly

see e.g. *Blasi & Serpico 2008* →

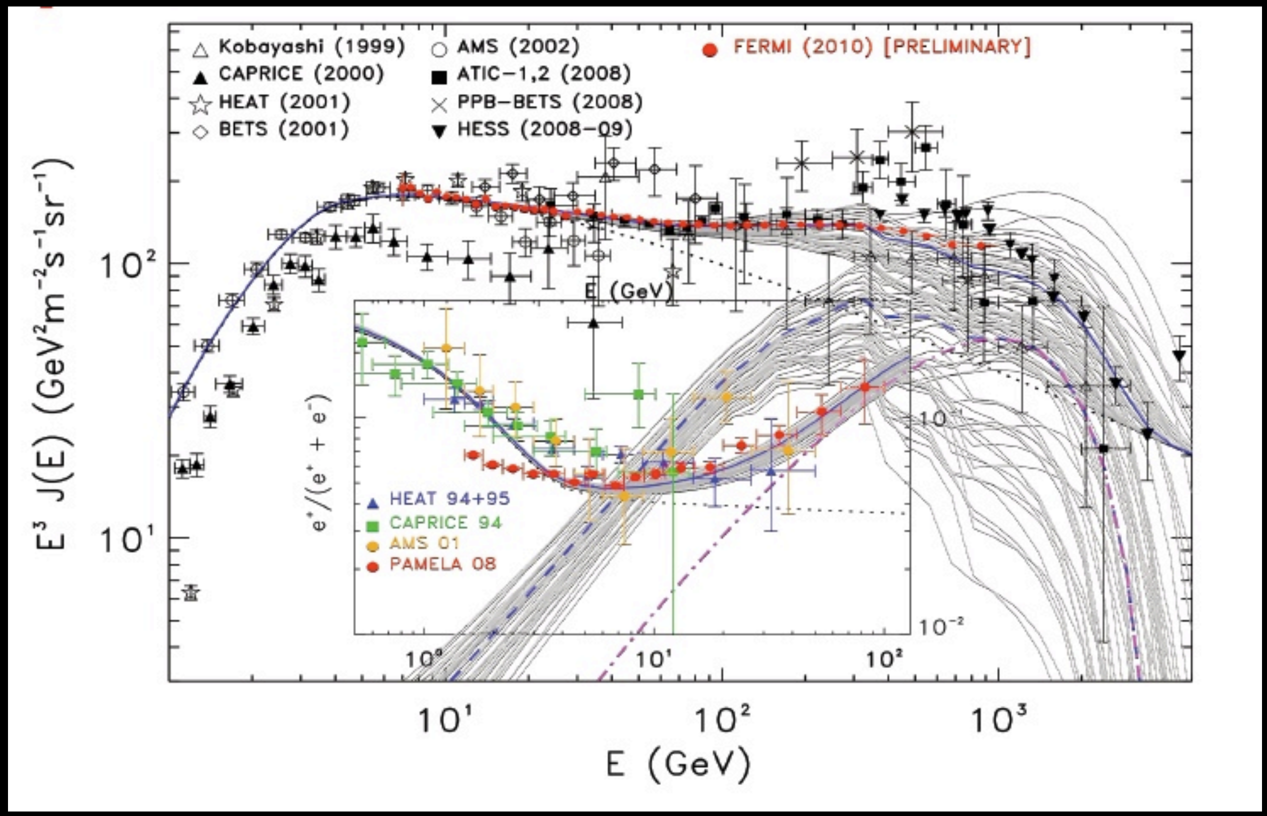


Pulsar interpretation

In *D.G. et al. [Fermi coll.] 2009*, the CRE background computed with GALPROP was summed to the analytically computed flux from actually observed pulsars taken from the ATNF radio catalogue

consistent choice of the propagation parameters and loss rates were used

Including the contribution of all observed pulsars with d < 3 kpc and allowing for the relevant pulsar parameters two vary in reasonable ranges, they got:

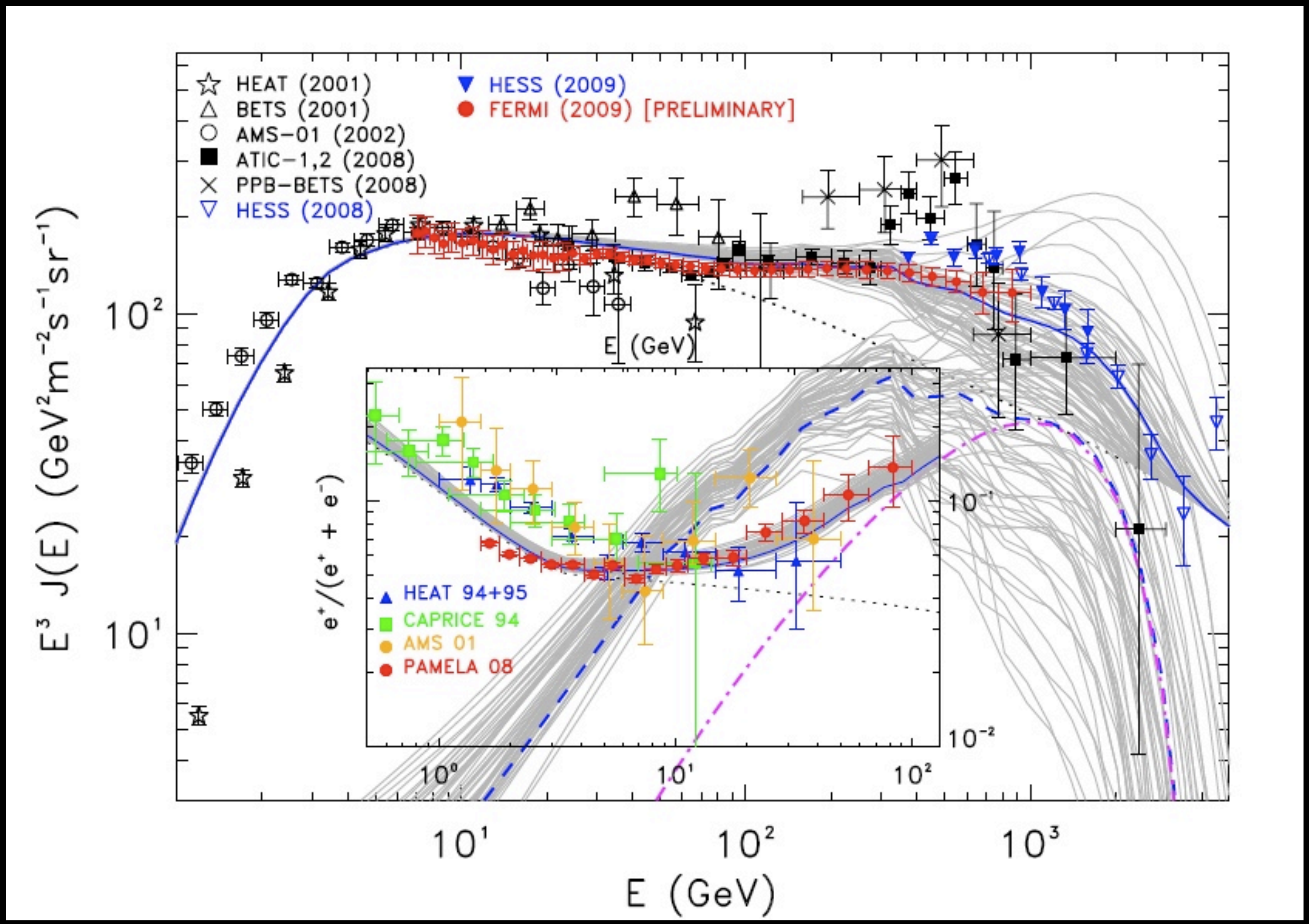


e± production efficiency: 10% - 30% ; 1.5 < Γ < 1.9 ; 800 < E_{cut} < 1400 GeV

background: conventional Kolmogorov with $\gamma_0 = 2.7$ (GALPROP)

Pulsar interpretation
using our propagation best-fit model

Modified background "DRAGON" model with $\gamma_0 = 2.65$ and $\delta = 0.5$ (and no break in the source proton spectrum) based on new analysis of CREAM (B/C) and PAMELA (proton and antiproton) recent data

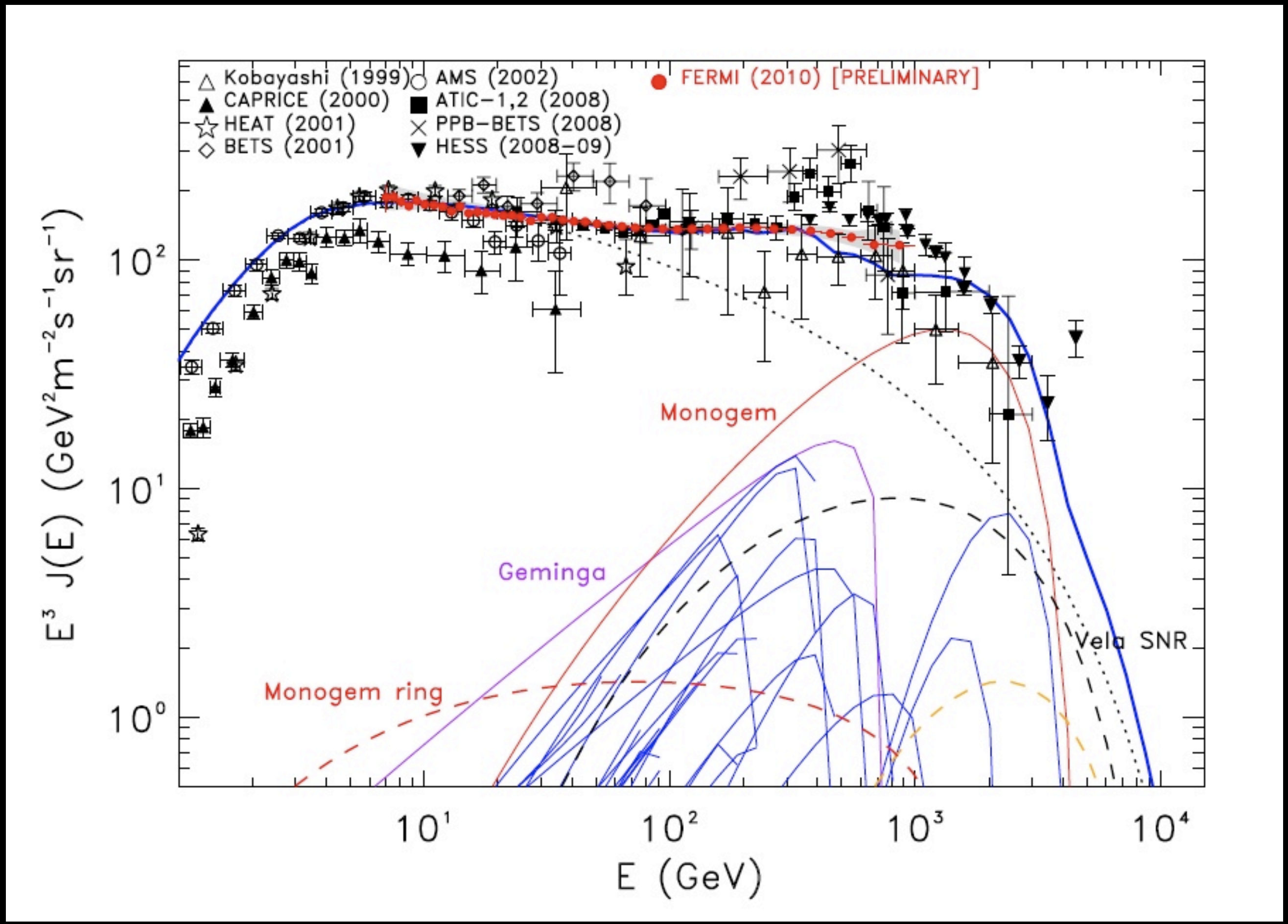


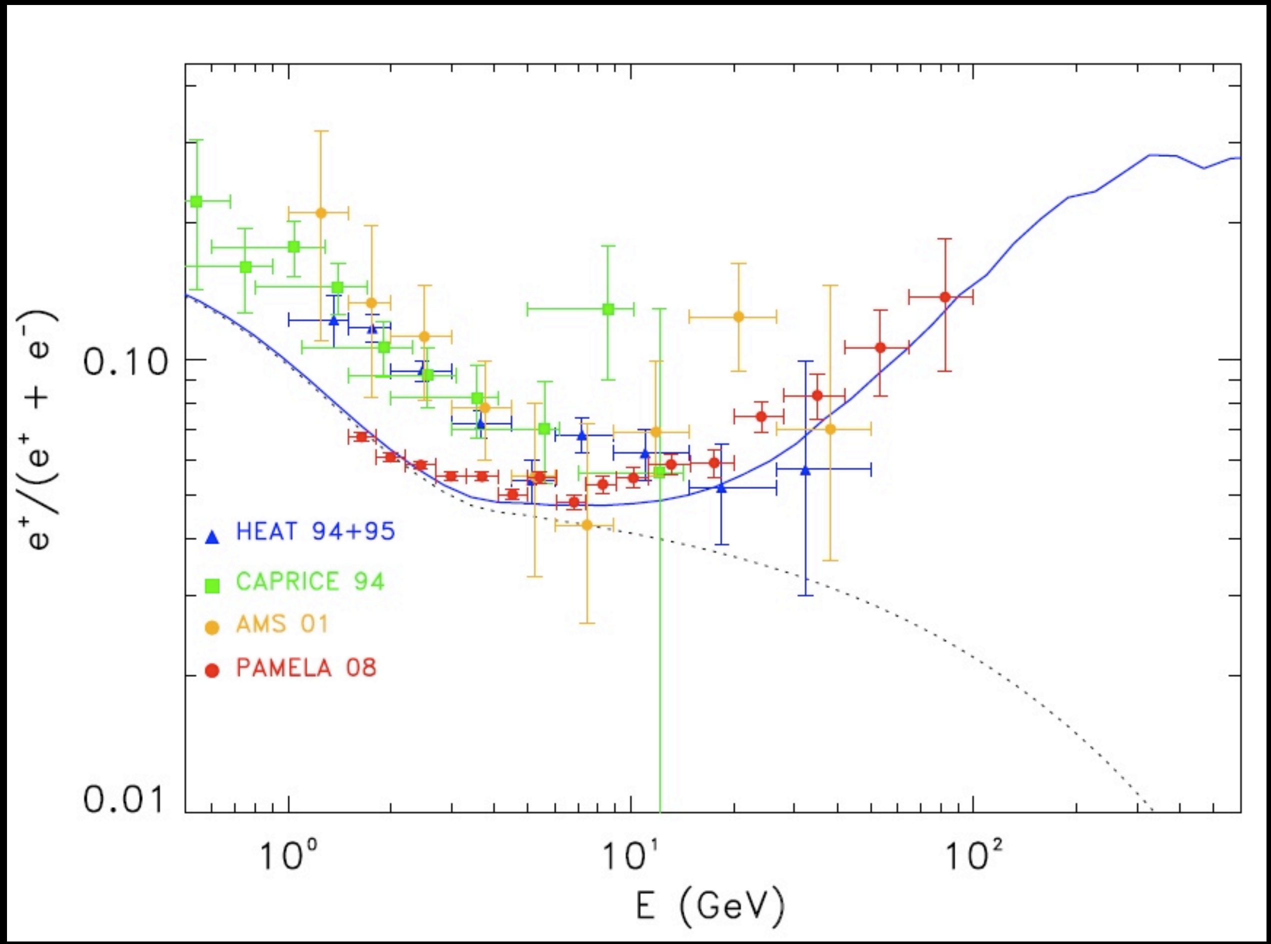
the inclusion of gamma-ray pulsars (see e.g. Profumo et al. 2010) does not modify significantly those results

Pulsars + SNRs local contribution

For illustrative purposes, we consider here all observed radio pulsars (dashed lines)+ SNRs (solid) with d < 2 kpc

Modified background model with $\gamma_0 = 2.4$ and $\delta = 0.5$ and $E_{cut} = 2$ TeV



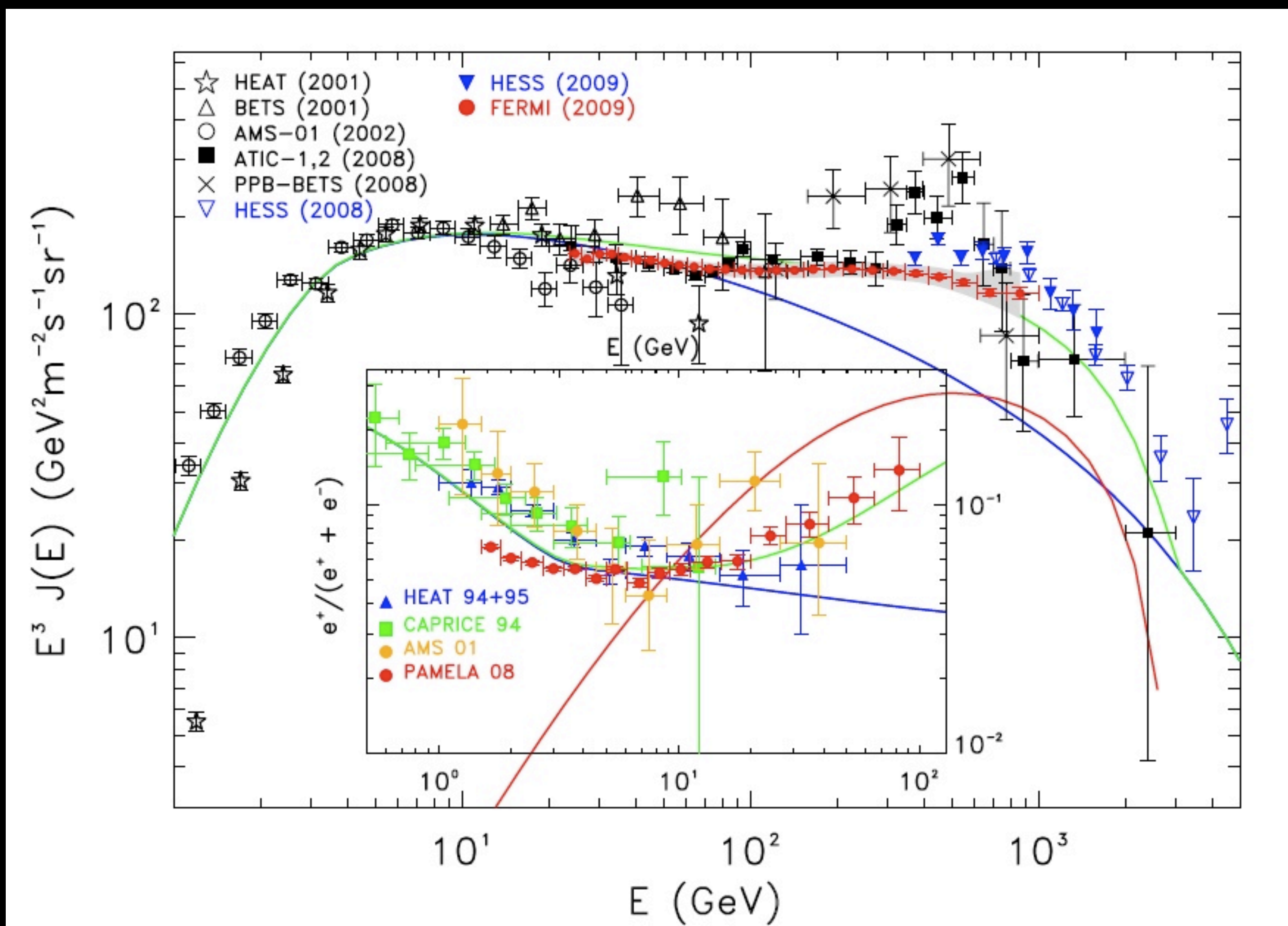


see also *Delahaye et al. 2010* *(PAMELA e+/e- was not reproduced)*

Dark matter annihilation interpretation

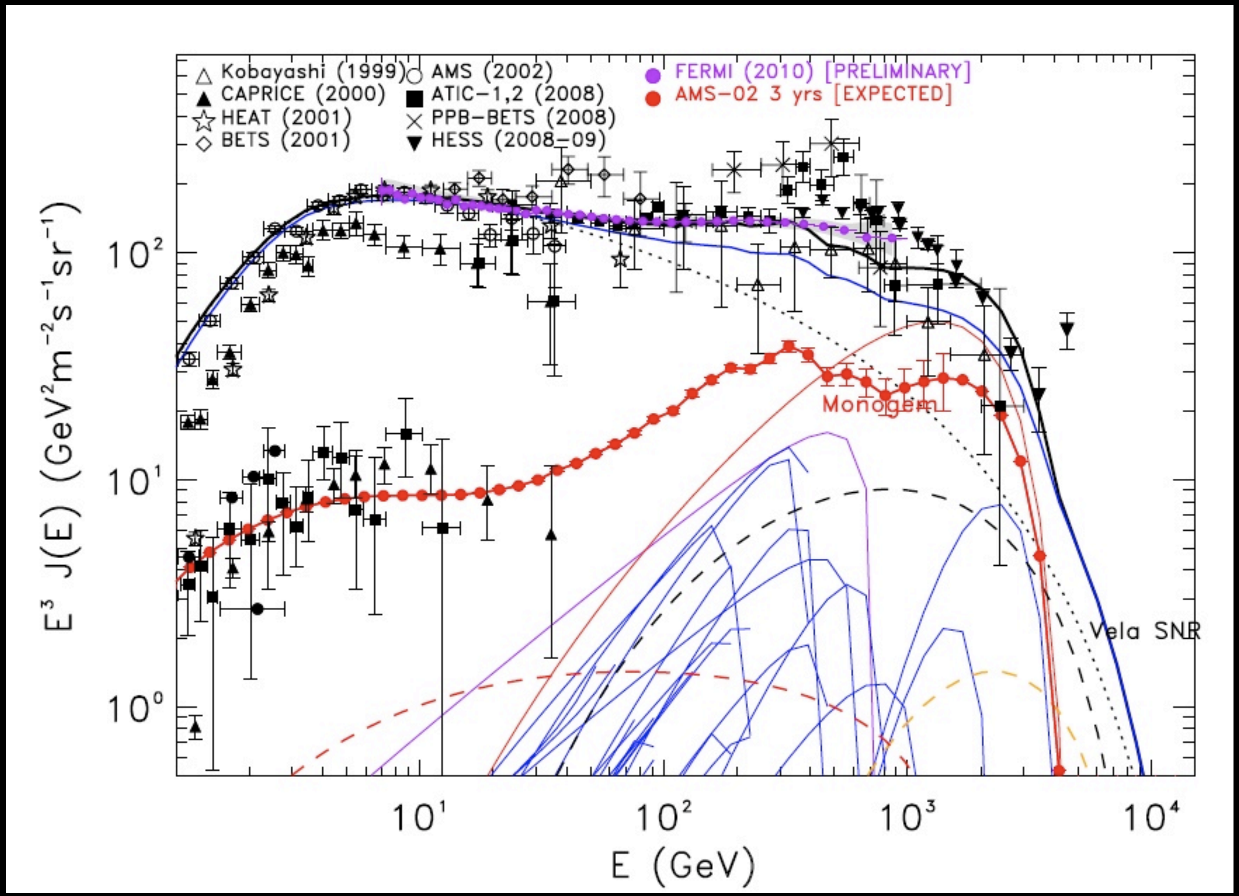
Several models invoke new (pseudo)scalar particle(s) which may decay mainly into leptons (such to avoid PAMELA antiproton constraints) and boost the annihilation cross above the value expected from standard cosmology due to the Born-Sommerfeld effect

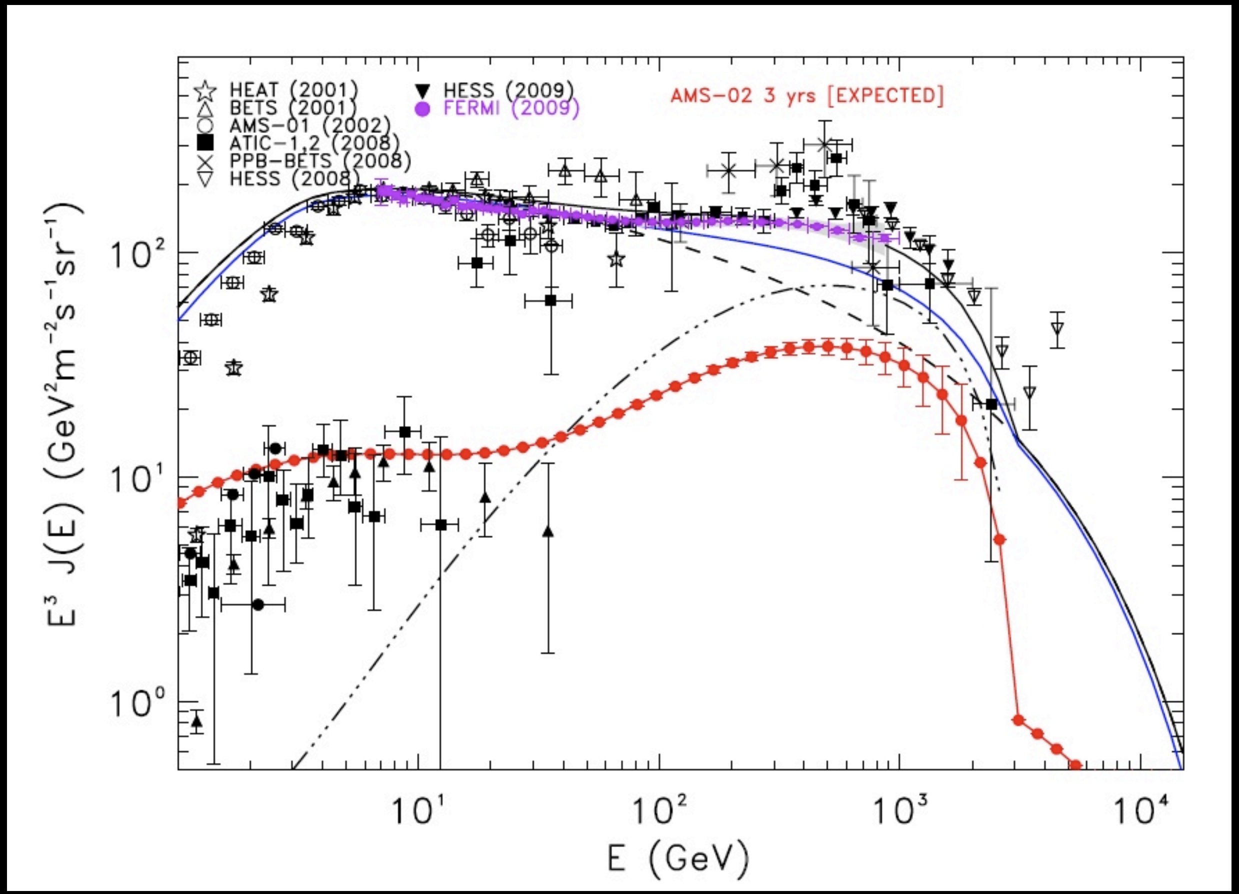
Computed with DRAGON + DARKSUSY



Benchmark DM model:
3 TeV DM annihilating mainly in $\tau^{\pm}$
see e.g. *Bergstrom et al. 2009*
and ref. therin

Astrophysical vs dark matter interpretations
bumpiness signatures

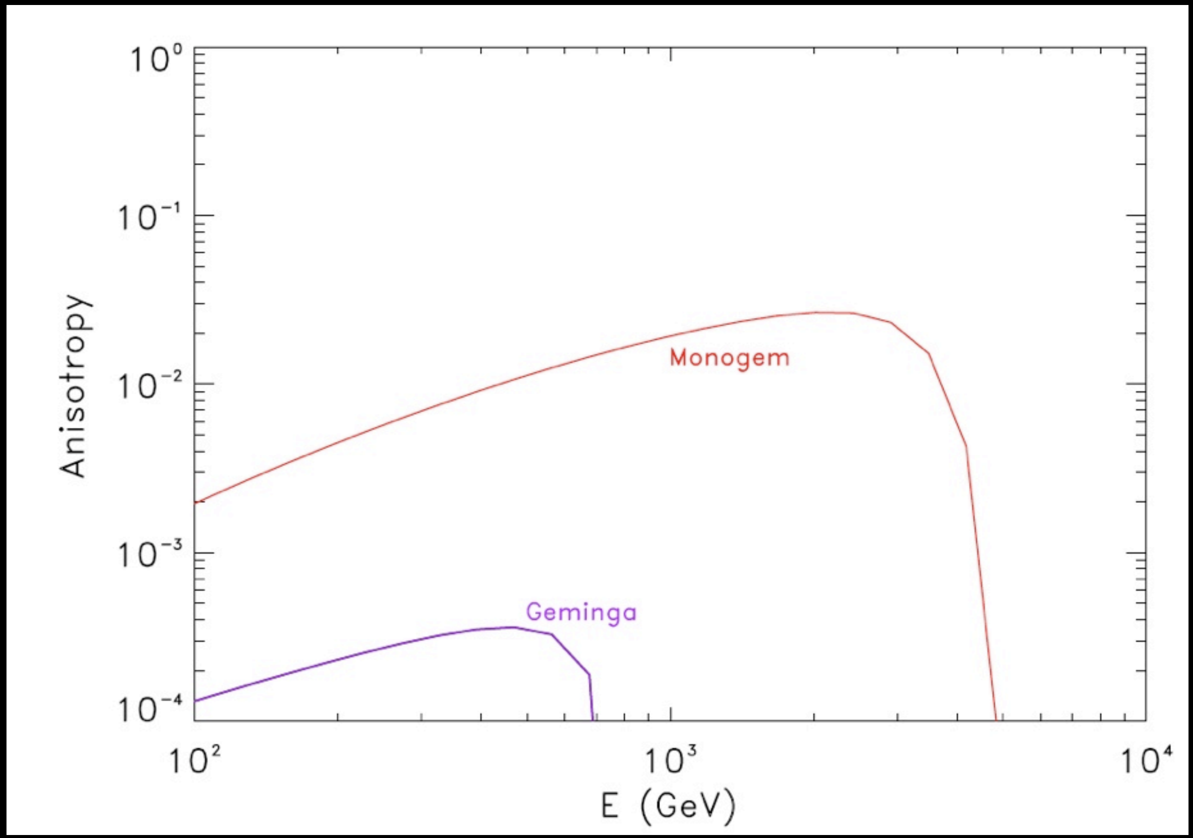


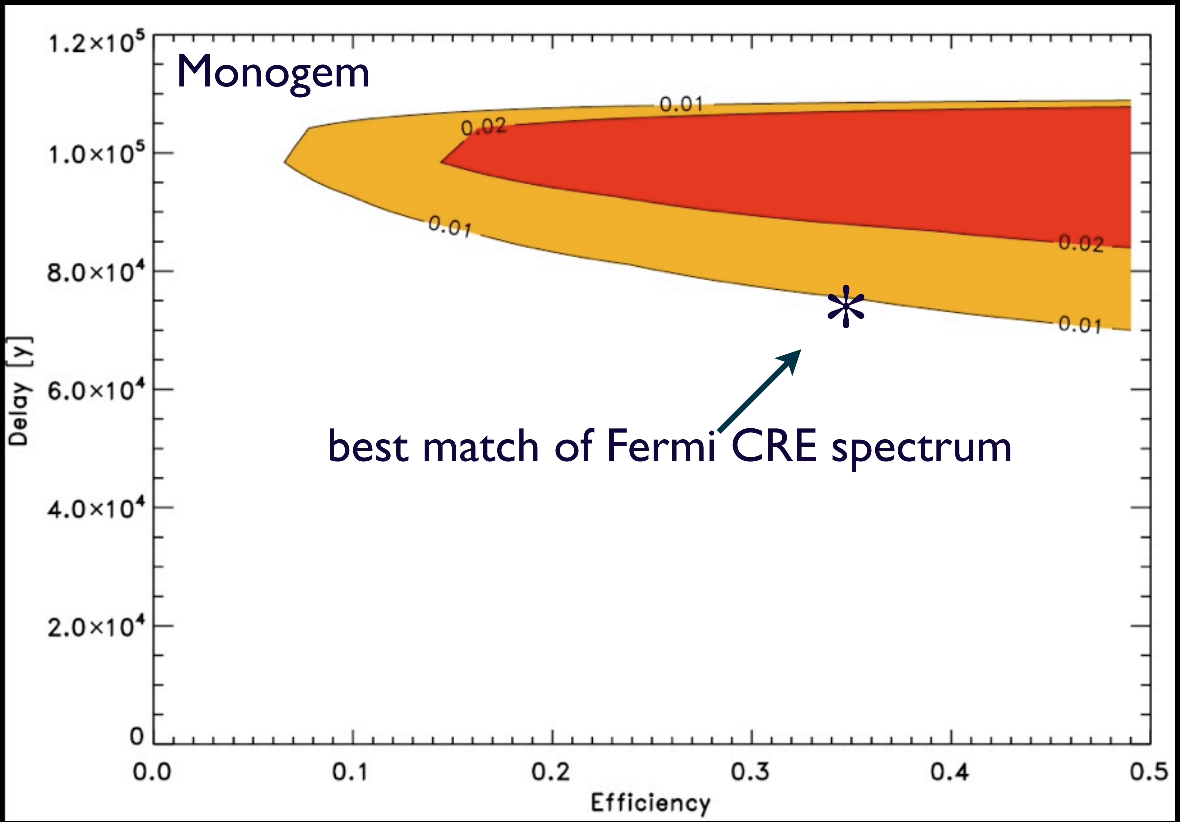


spectral features in the e^+ spectrum will be a target for AMS-02

Astrophysical vs dark matter interpretations
CRE anisotropy

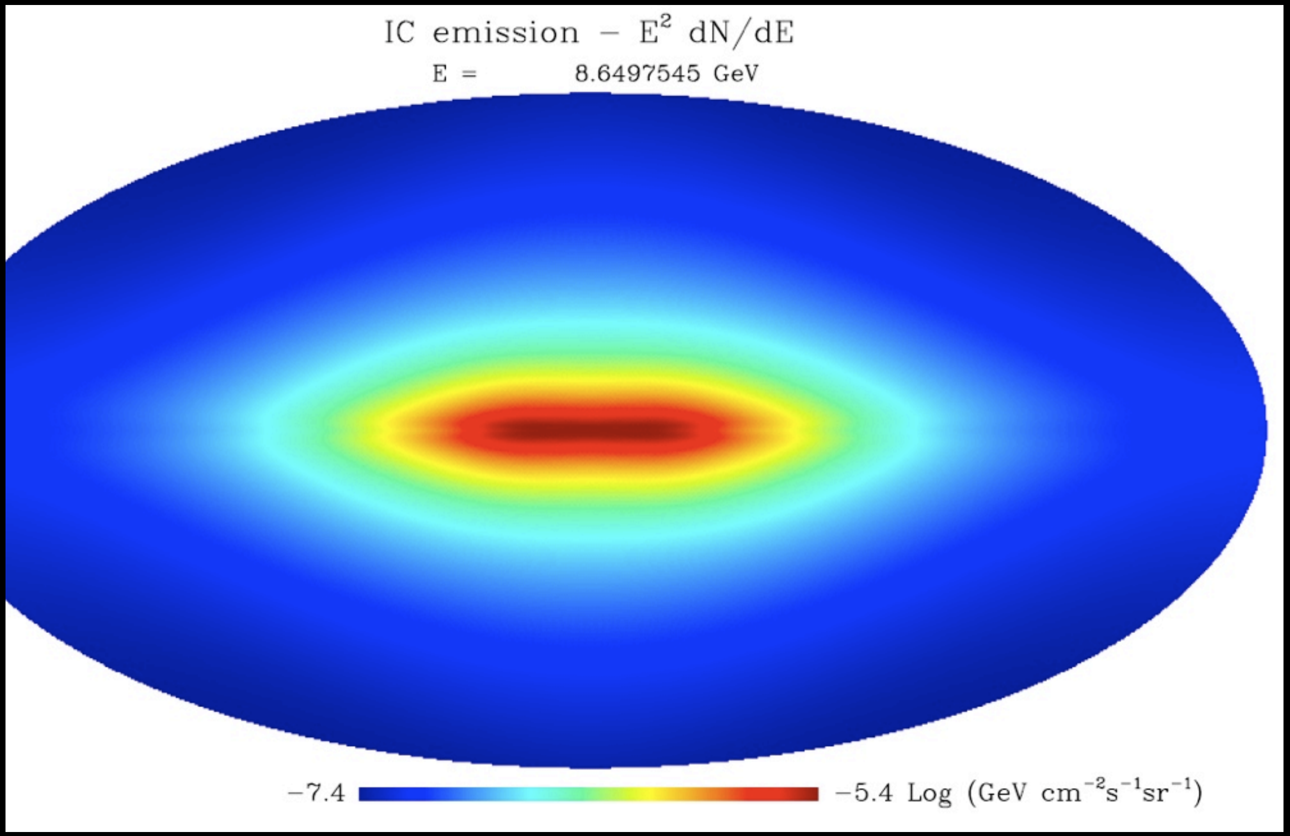
$$\text{Anisotropy} = \frac{3D}{c}\frac{\Delta N_e}{N_e} = \frac{3}{2c}\frac{r}{t-t_0}\left(\frac{1-(1-E/E_{max}(t))^{1-\delta}}{(1-\delta)E/E_{max}(t)}\right)^{-1}\frac{N_e^{\rm PSR}(E)}{N_e^{\rm tot}(E)}$$

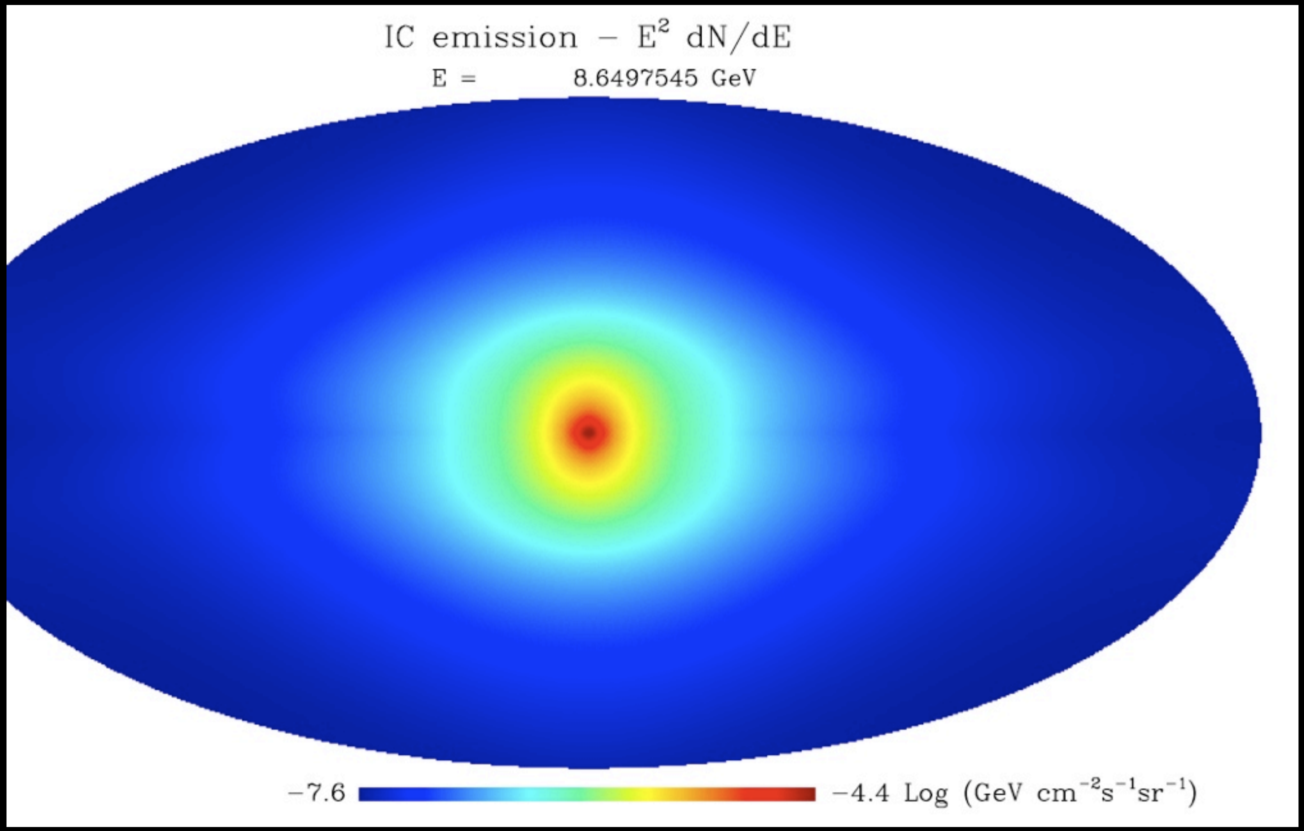




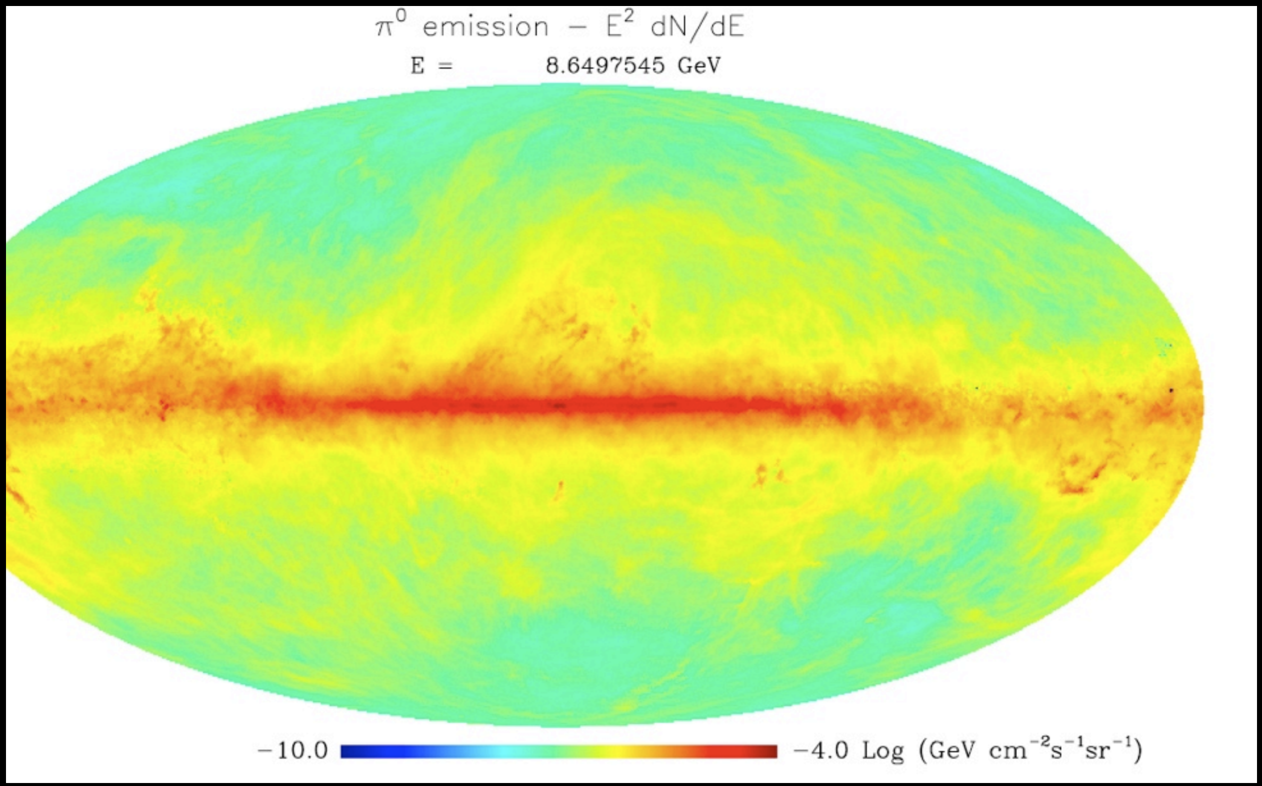
a positive detection in the Monogem direction would be a quite smoking gun !

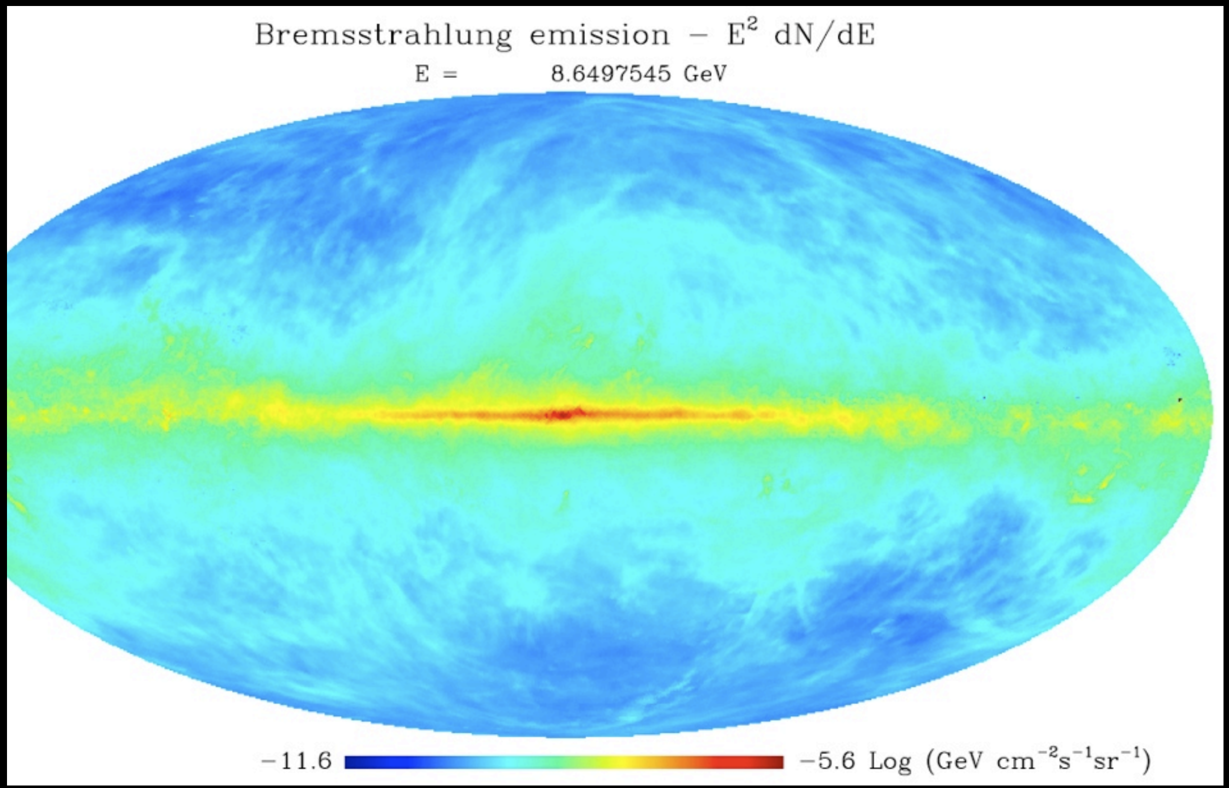
Astrophysical vs dark matter interpretations
Gamma-ray diffuse emission (1)
work in progress





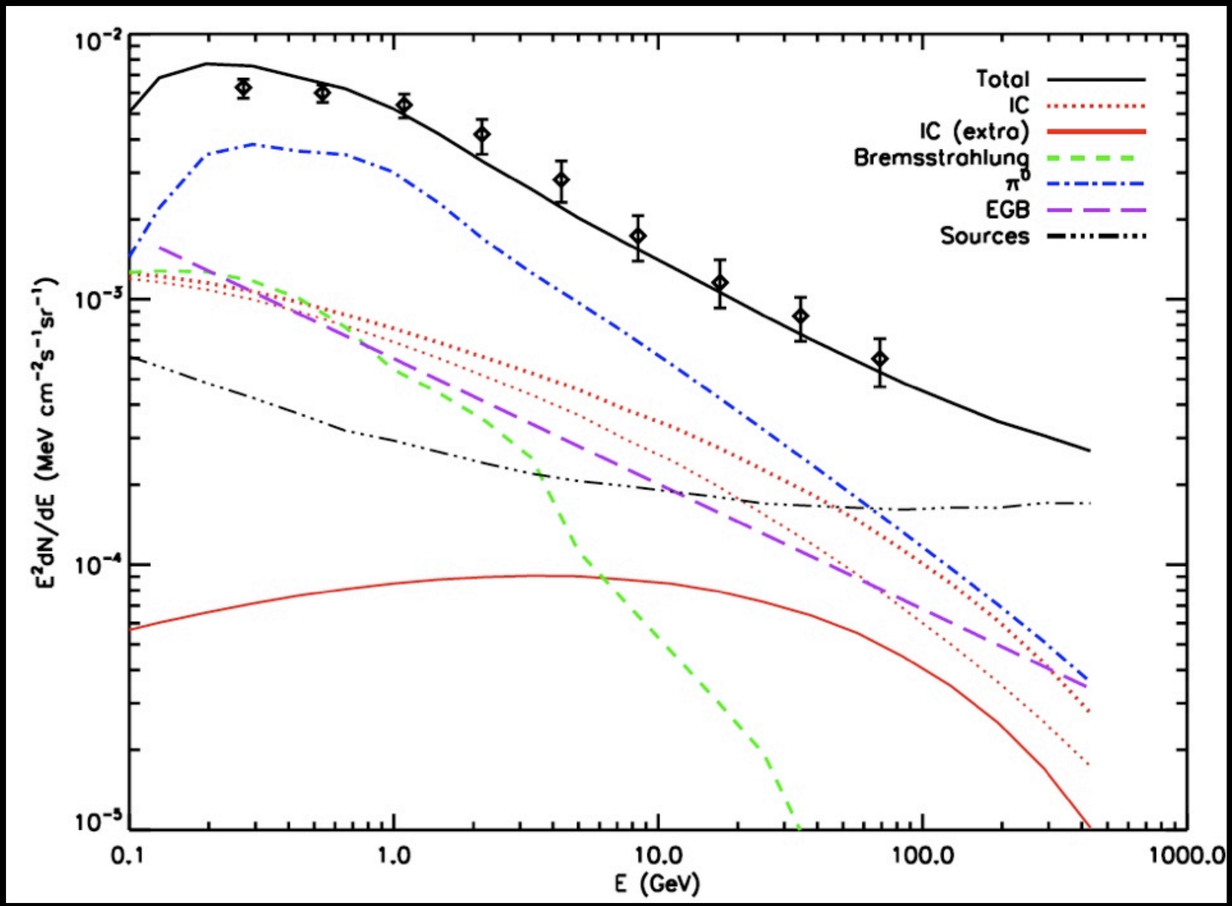
Astrophysical vs dark matter interpretations
Gamma-ray diffuse emission (2)



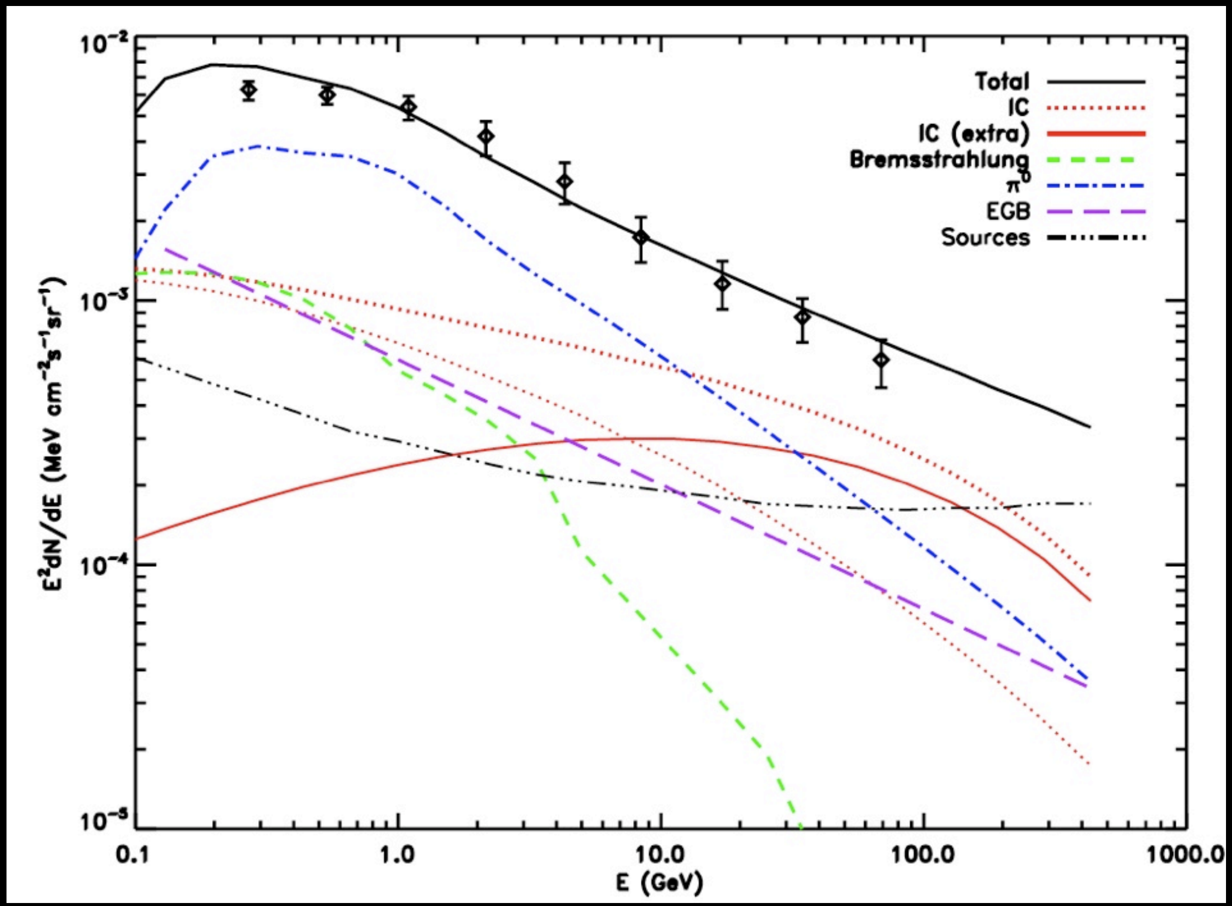


Astrophysical vs dark matter interpretations
Gamma-ray diffuse emission (3)

pulsar like distribution of extra-comp.

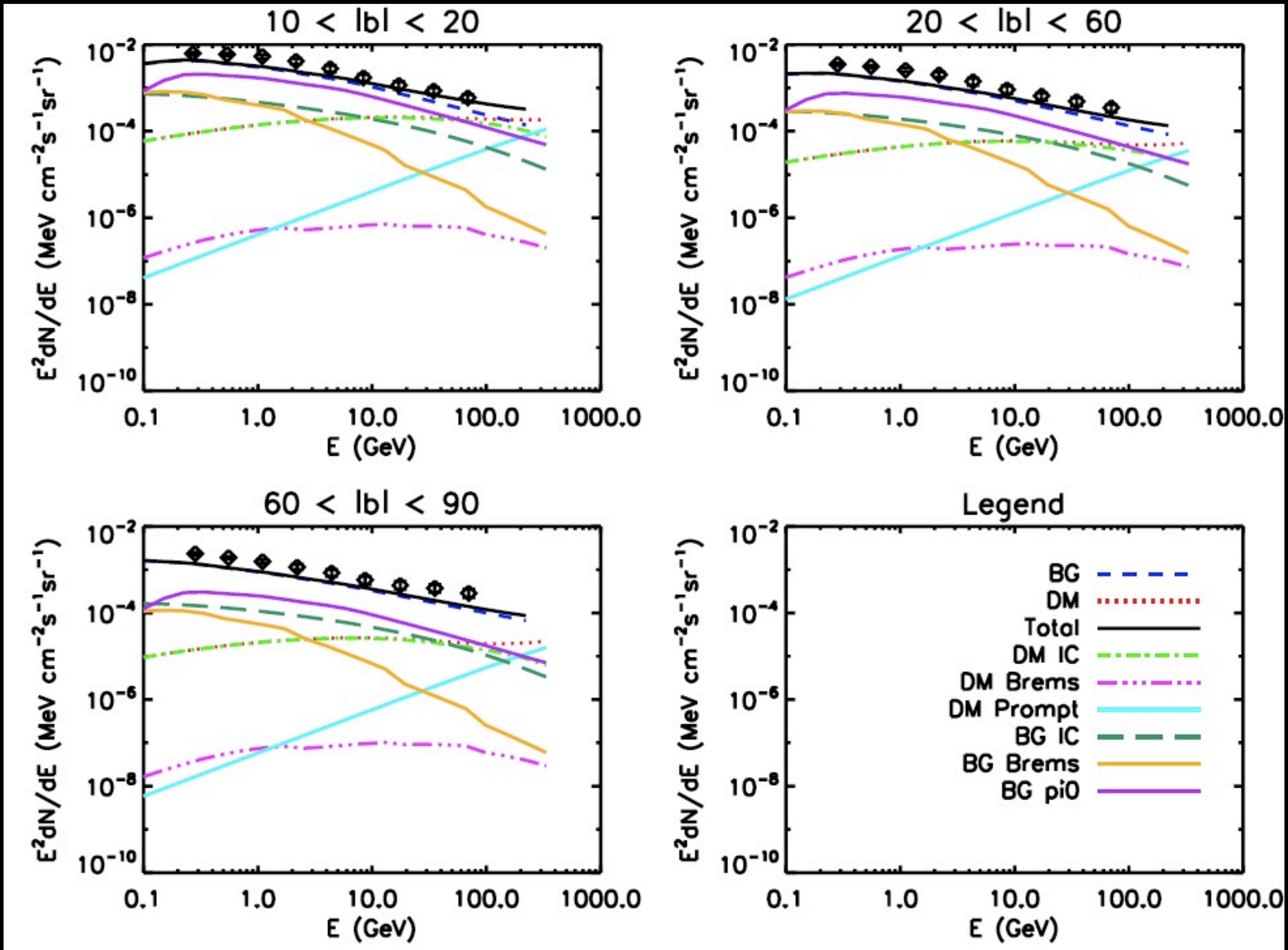


ann. DM like distribution of extra-comp.



$10° < |b| < 20°$

Astrophysical vs dark matter interpretations
Gamma-ray diffuse emission (4)



Benchmark DM model:
3 TeV DM annihilating mainly in $\tau^{\pm}$
see e.g. *Bergstrom et al. 2009*
and ref. therin

DRAGON + DARKSUSY

Conclusions

• Propagation models with low values of δ and strong re-acceleration are disfavored by antiproton and CRE data

• Even disregarding the PAMELA anomaly above 10 GeV, a combined fit of PAMELA and Fermi-LAT low energy data with single component models is highly problematic

• An excellent fit of all available data is possible invoking an $e^{\pm}$ extra-component harder than the conventional one

• Pulsars can naturally provide such extra-component

• Dark matter annihilation (decay) remains an open possibility

- spectral features in both e^- $e+$
- anisotropies in the CRE flux
- features in the gamma-ray spectrum and angular distribution
- features in the synchrotron spectrum and angular distribution

are very promising tools but none of them may be enough if taken by itself