High and low energy puzzles in the AMS-02 positron fraction results

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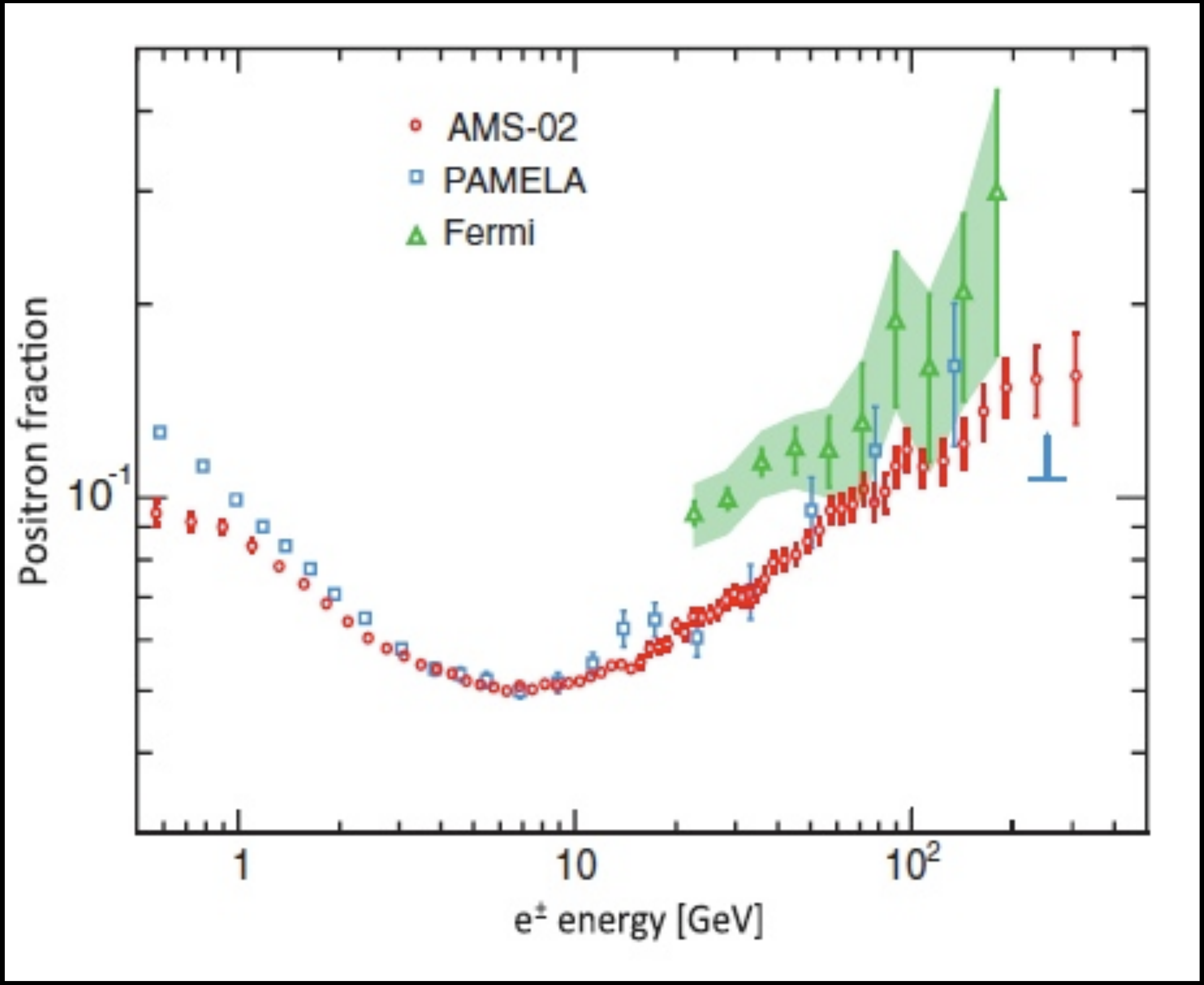
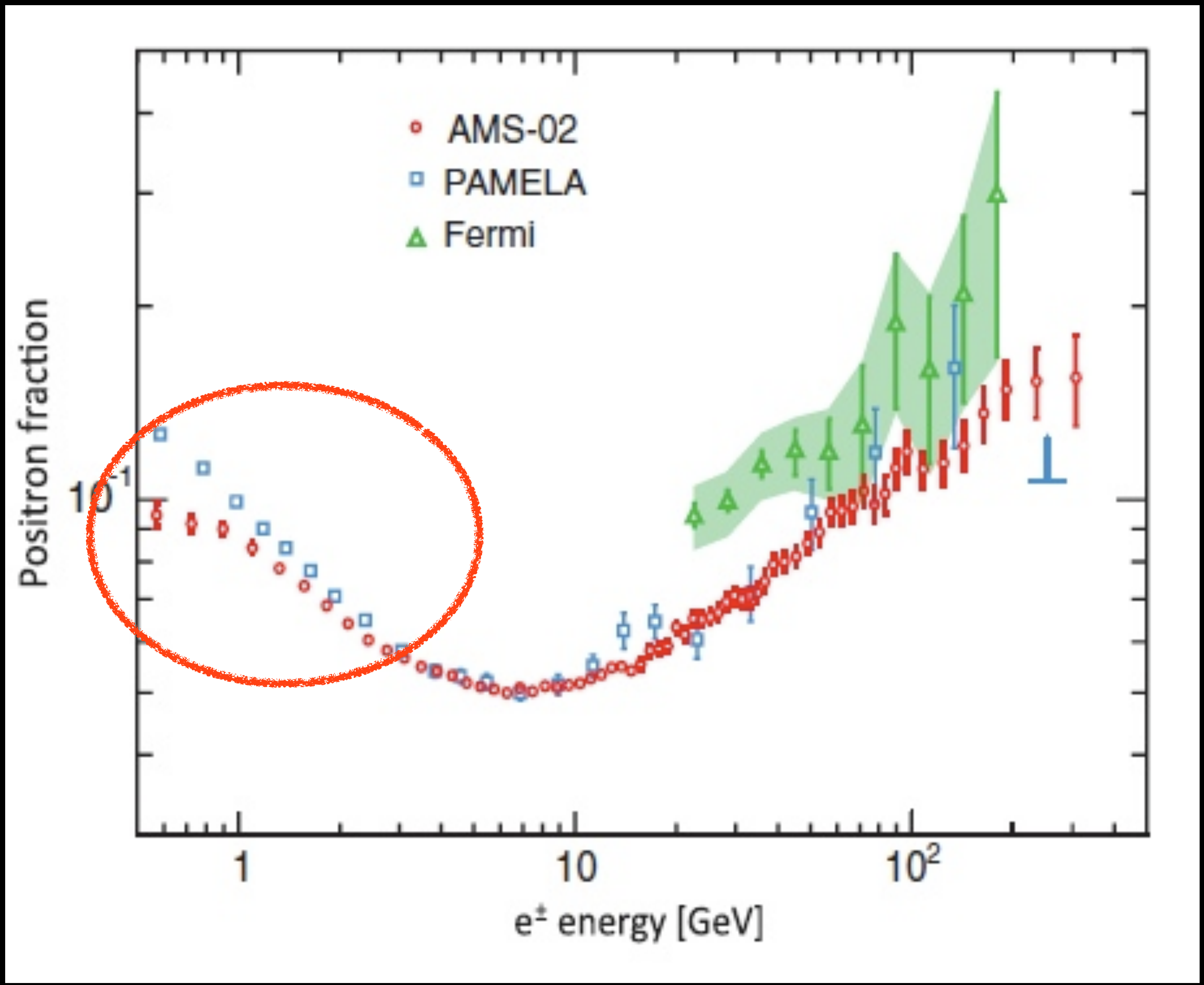
AMS-02 positron fraction (PF) results



PAMELA: new analysis, yet unpublished. Published results: Nature '08, APP '09
Fermi-LAT: *PRL* 2012

AMS-02 coll. - PRL 5 April 2013

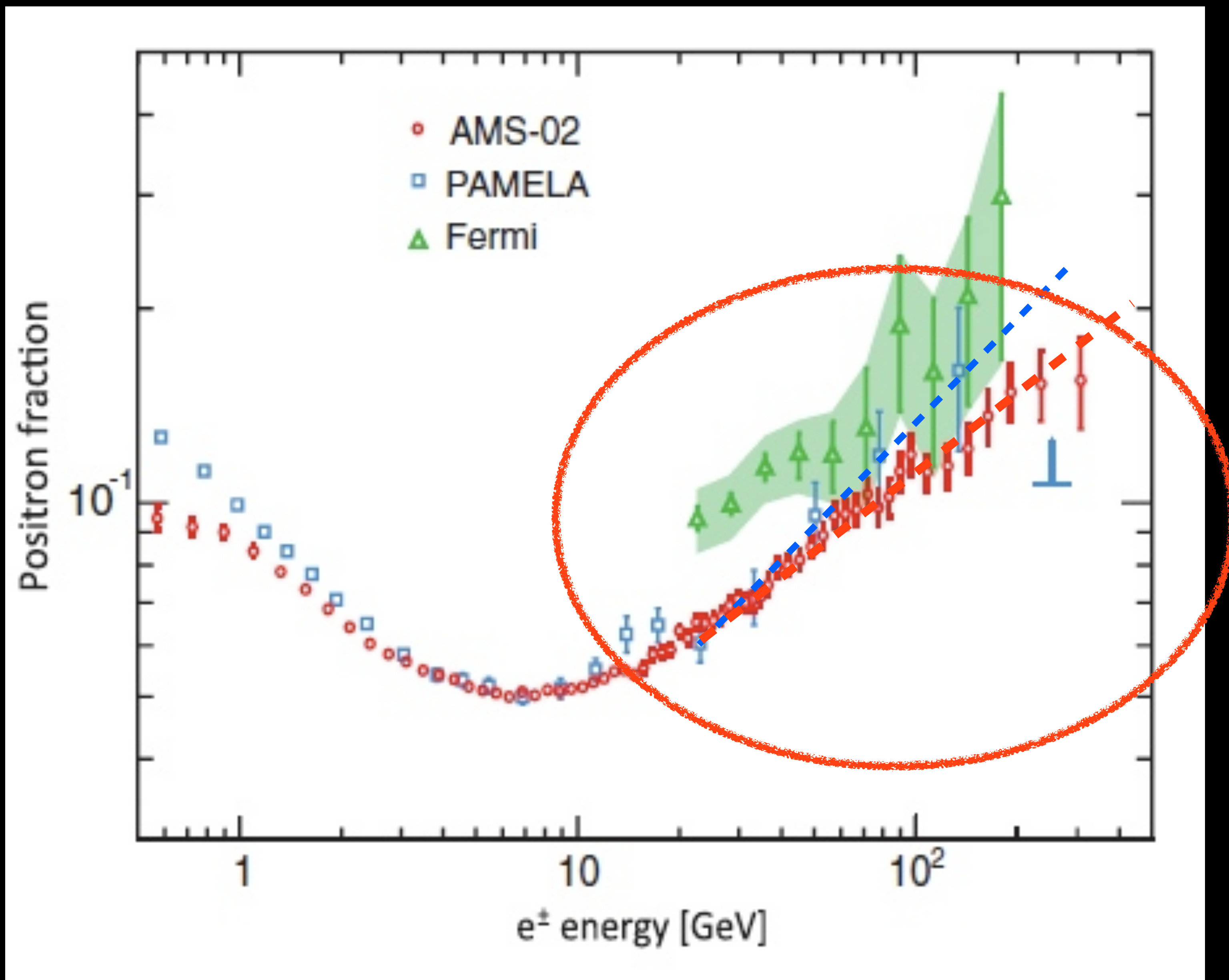
AMS-02 positron fraction (PF) results



- AMS-02 data taken from May '11-Dec '12
- PAMELA data taken from June'06-Dec '10
- lower than PAMELA below few GeV

AMS-02 coll. - PRL 5 April 2013

AMS-02 positron fraction (PF) results



- less steep than PAMELA between 20 - 250 GeV
- hints of a flattening above 250 GeV

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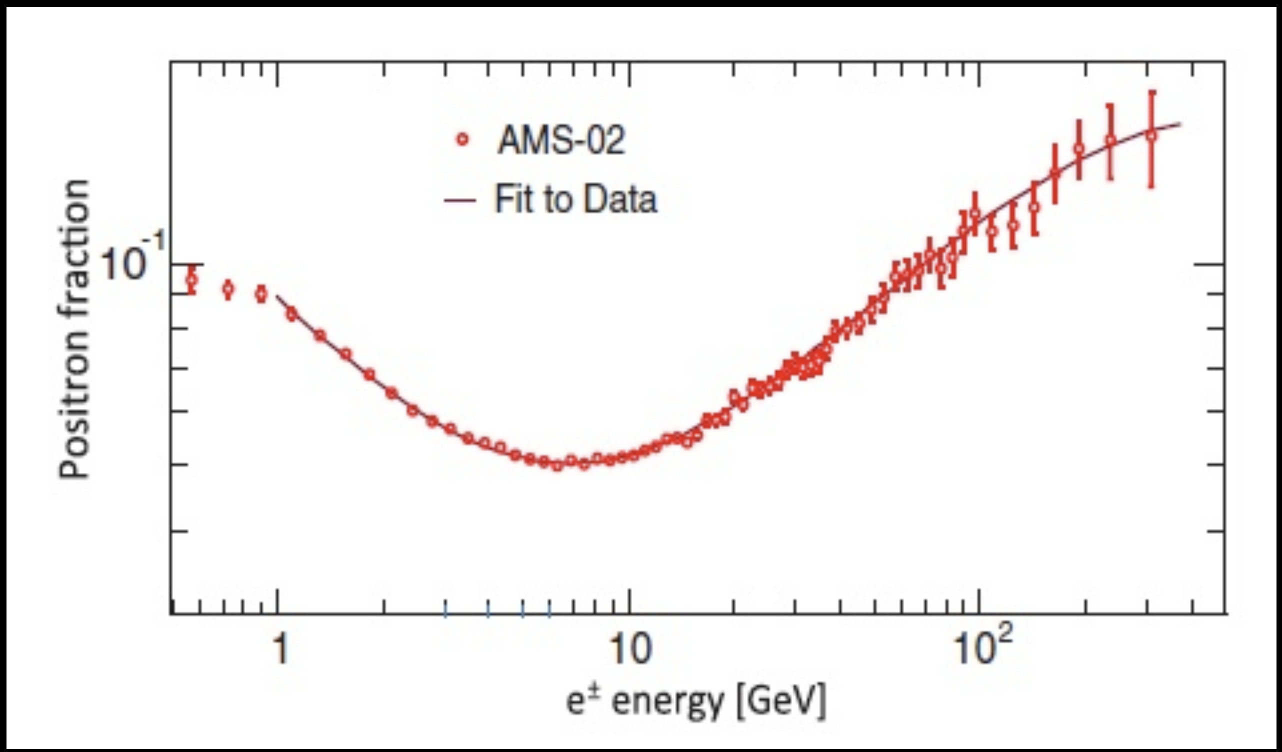
AMS-02 positron fraction (PF) results



- less steep than PAMELA between 10 - 250 GeV
- hints of a flattening above 250 GeV

$$E_S = 760^{+1000}_{-280}\ \mathrm{GeV}$$

The fit assumes

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

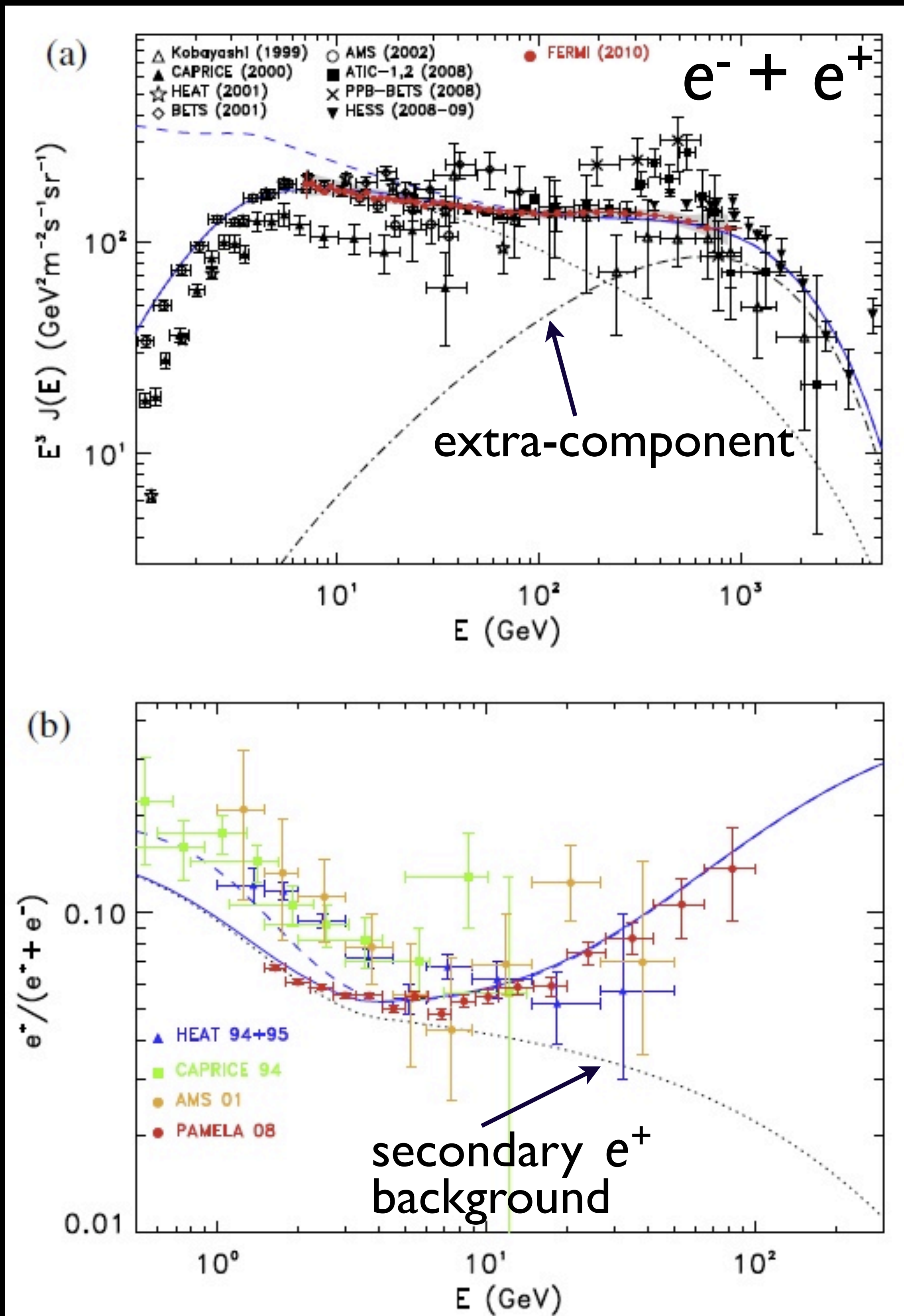
$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

the presence of a hard spectral e± component (S) is required

(though softer than what inferred from PAMELA)

AMS-02 coll. - PRL 5 April 2013

The extra-component scenario before AMS-02



- PAMELA (PF) + Fermi + HESS (e^- + e^+) require
  - a $e^{\pm}$ extra-component with source spectral index ~ 1.5 (pulsars, SNRs, DM)

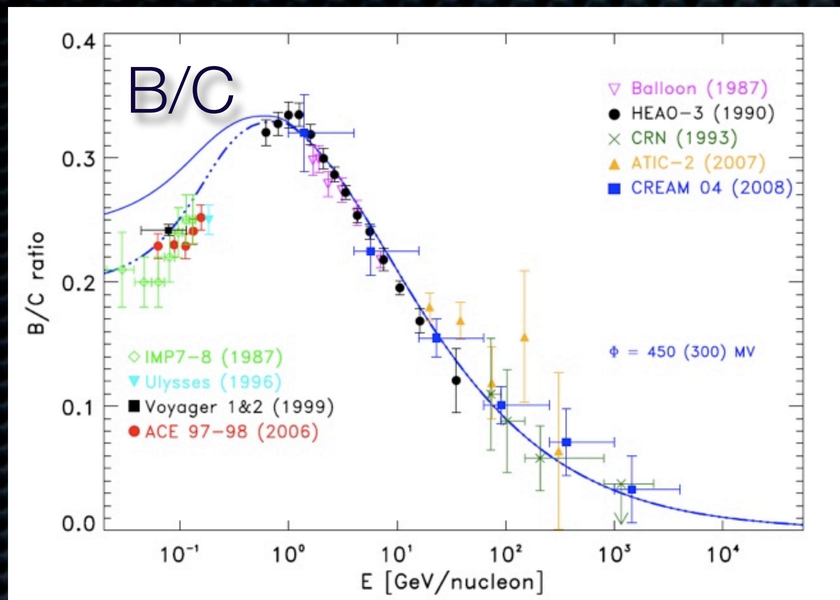
$$N_{\rm EC} \propto E^{-1.5} \exp(-E/1TeV)$$

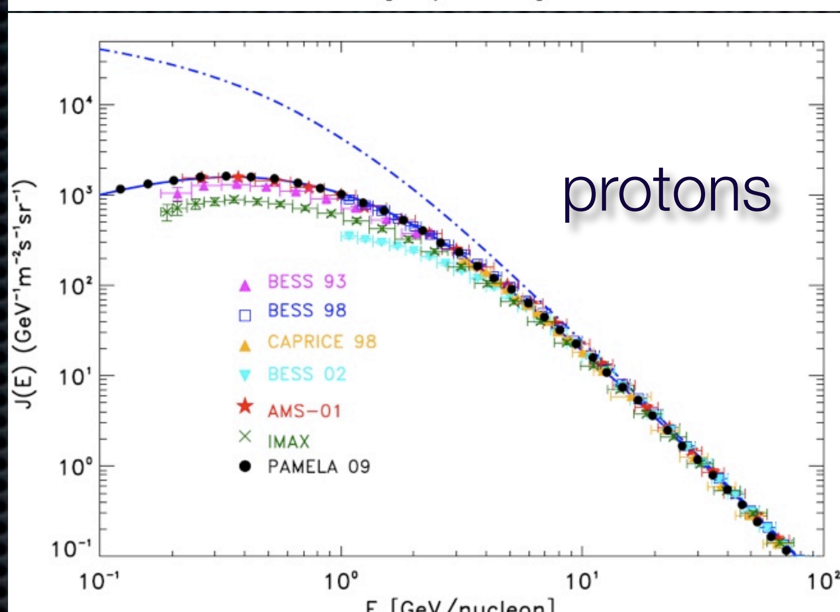
  - a e^- standard background with source spectral index
    ~ 2.6 ÷ 2.7 for E > 4 GeV
    ~ 2.0 for E < 4 GeV

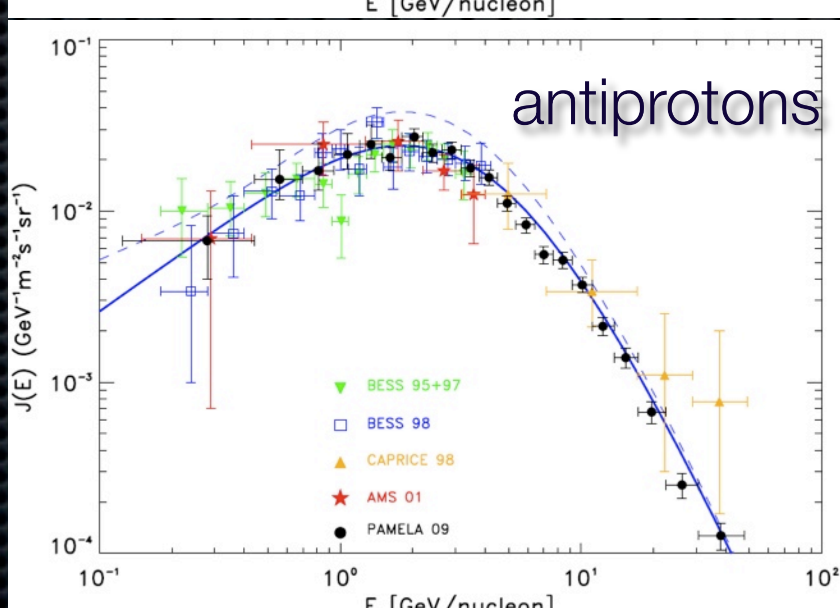
← *Di Bernardo et al. , APP 2011*
perfomed with DRAGON v2
see also Ackermann et al. 2010

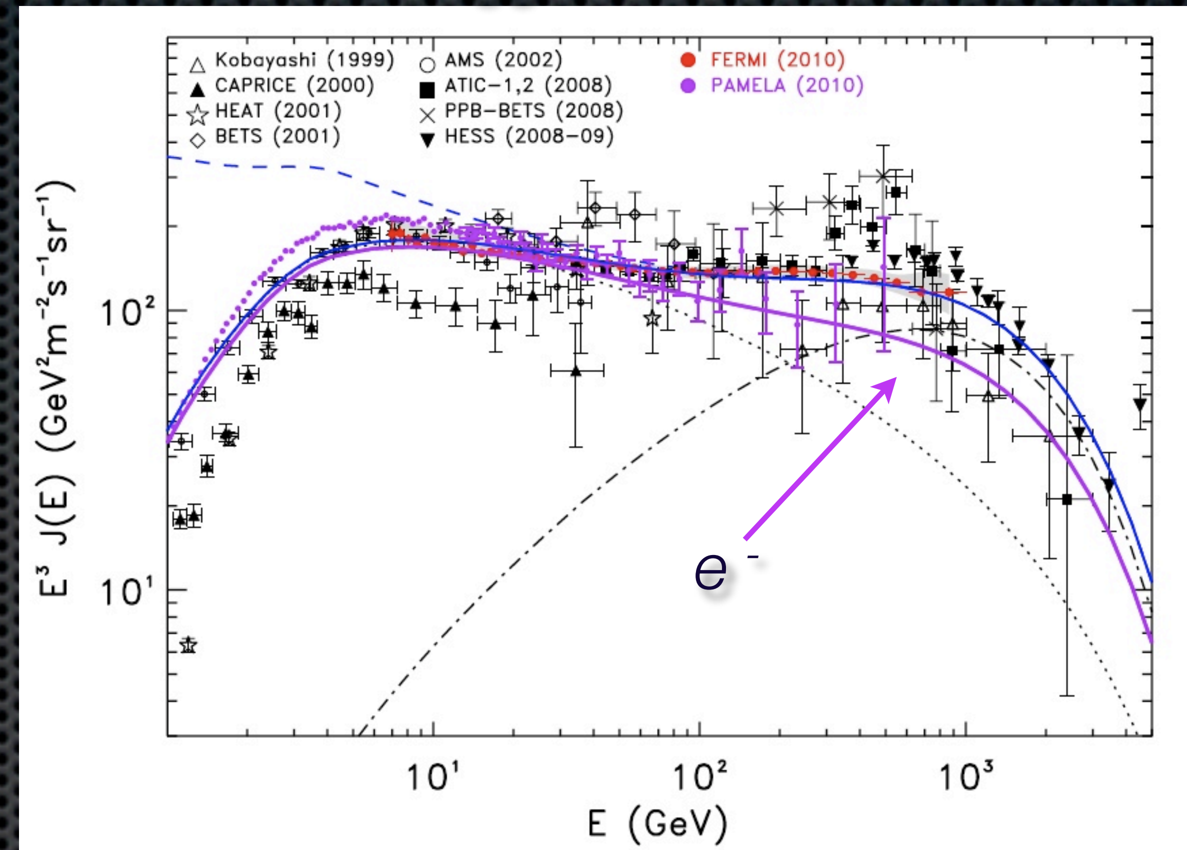
The extra-component scenario before AMS-02

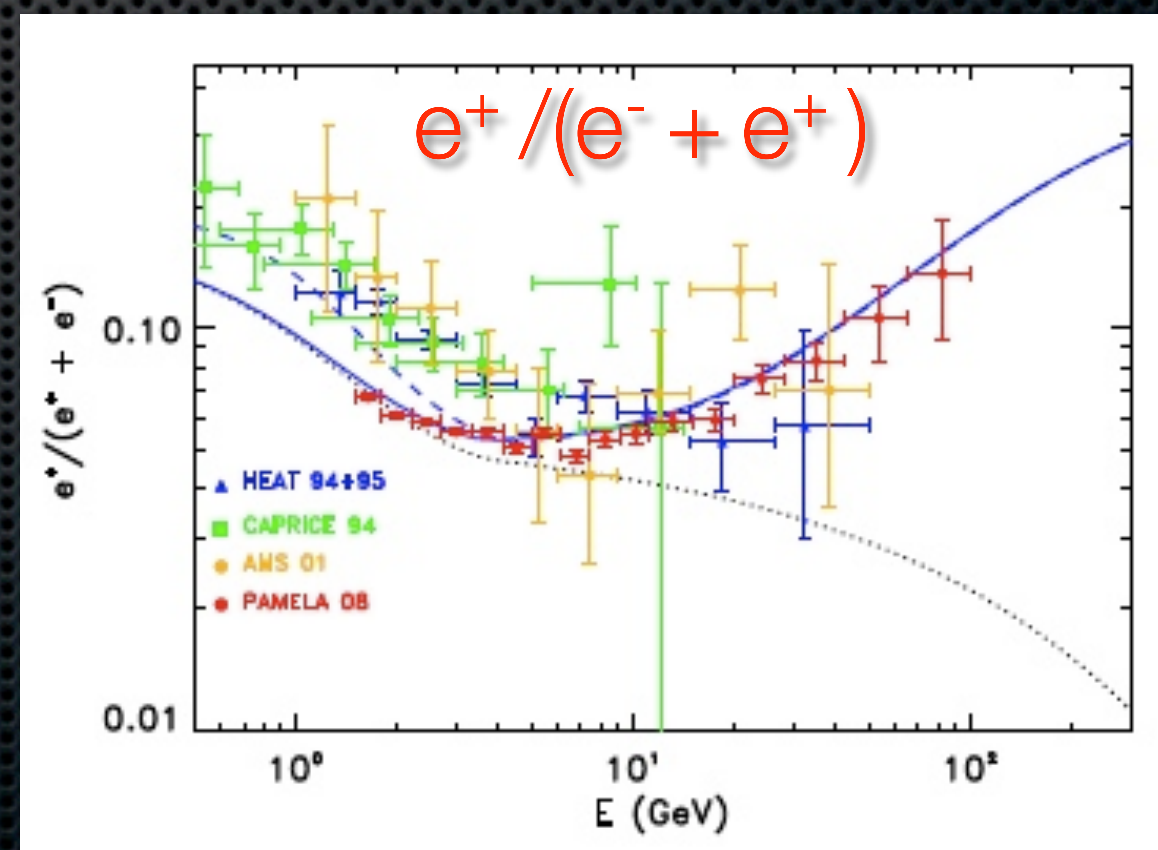
Di Bernardo, Evoli, Gaggero, D.G. Maccione, 2010



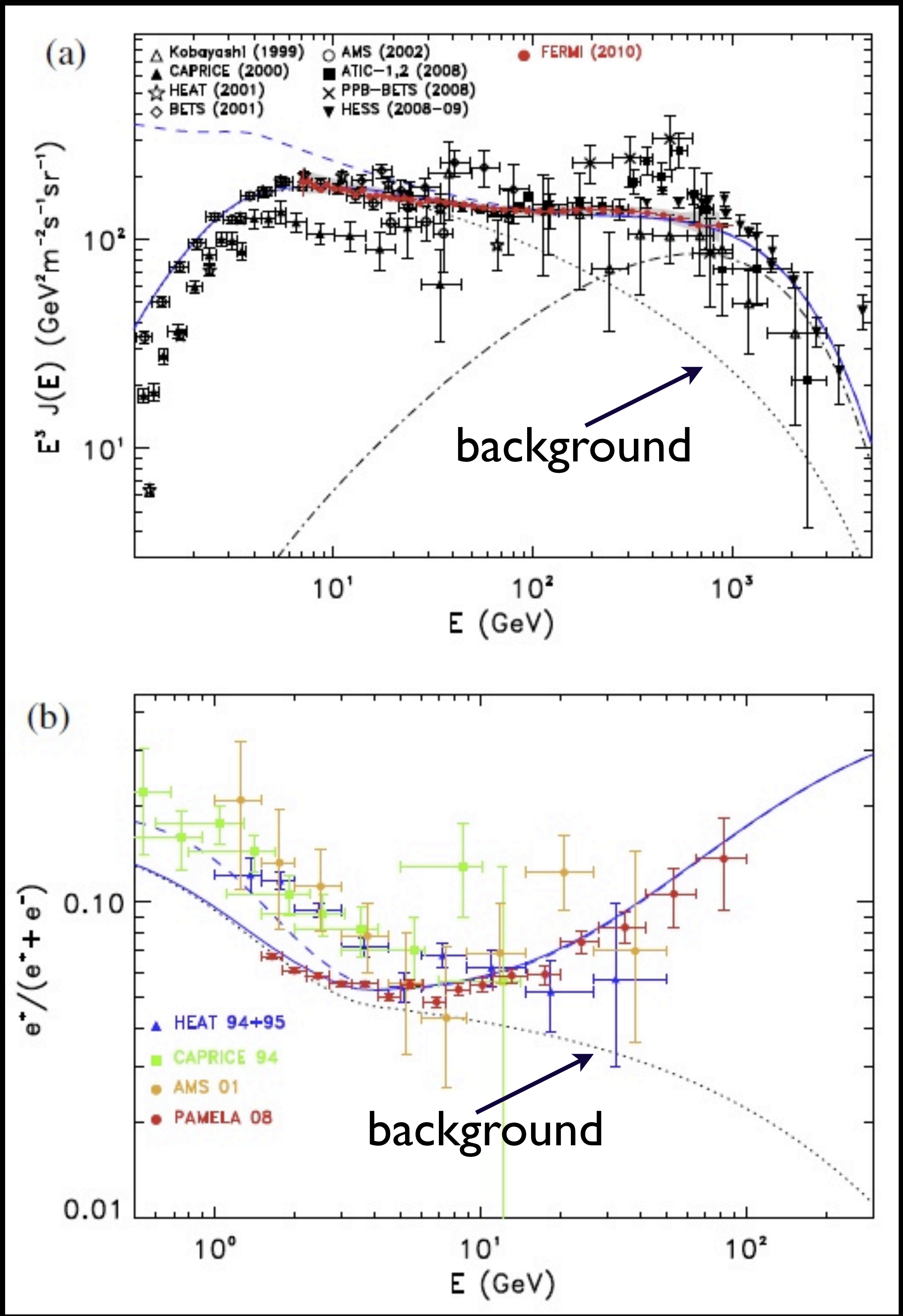








High Energy Puzzles before AMS-02



- PAMELA (PF) + Fermi (e^- + e^+) require
  - a $e^{\pm}$ extra-component with source spectral index ~ 1.5

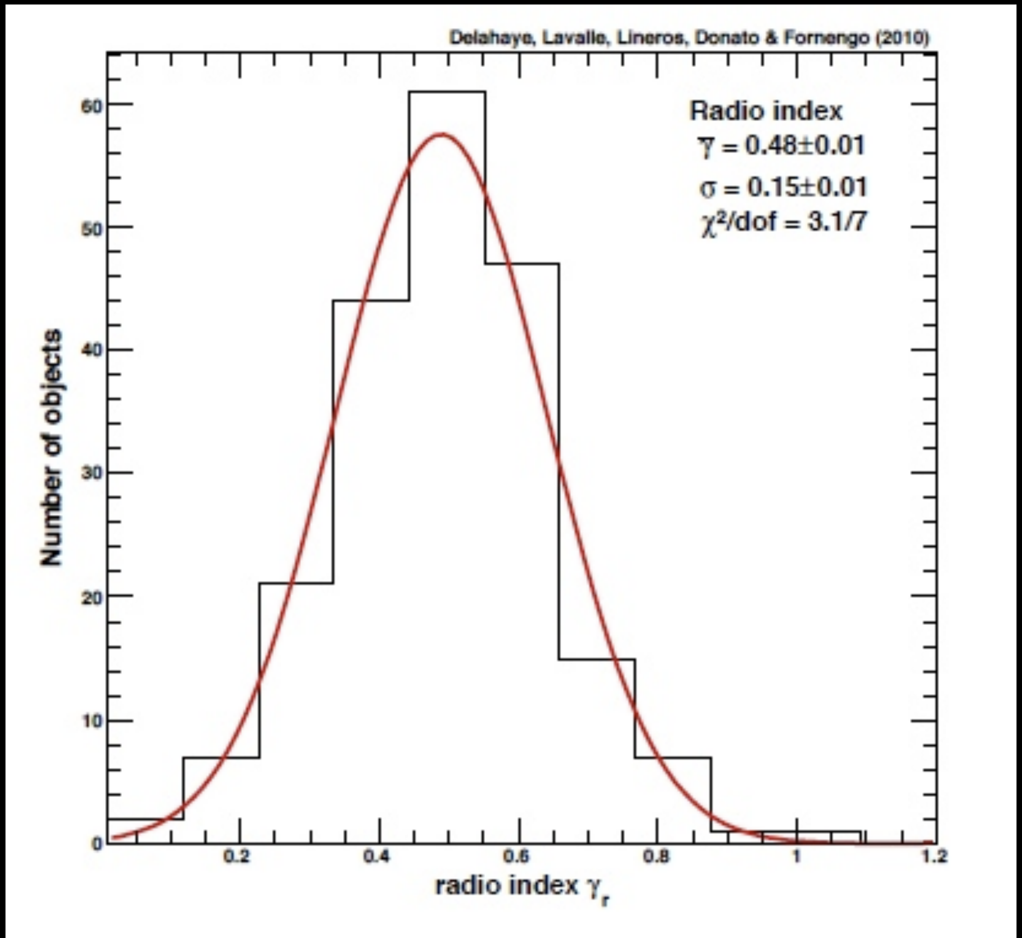
    hard to explain !

  - a e^- background with source spectral index

    ~ (2.6 ÷ 2.7) for E > 4 GeV
    even harder to explain !
    "Steepness problem"

Steepness problem

- Even accounting for non-linear effects, Fermi acceleration generally predicts
  $\Upsilon_{source}(e) \simeq \Upsilon_{source}(p) \lesssim 2.3$

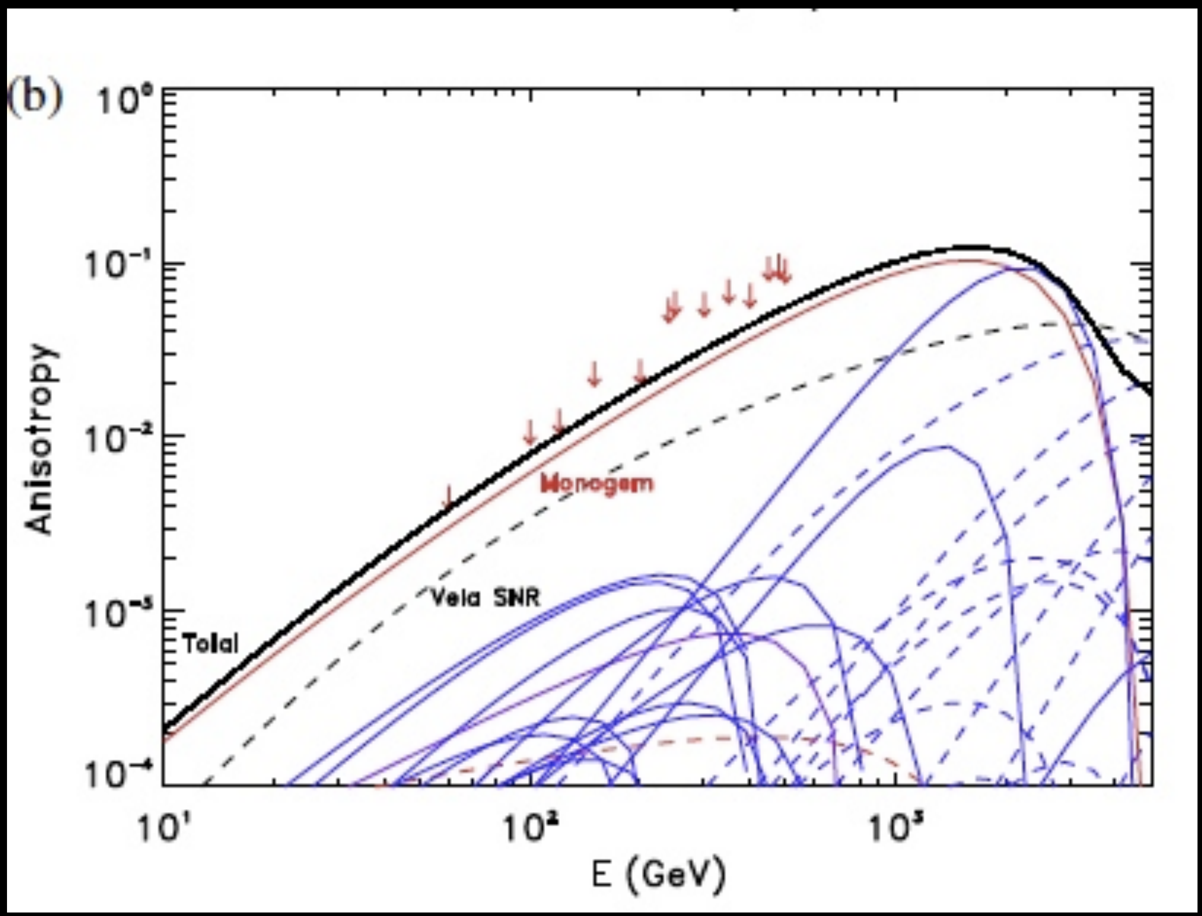


- Radio (synchrotron) emission of SNRs implies

  $<\Upsilon_{source}(e)> = 2<\Upsilon_{radio}> + 1 = 2.0 \pm 0.3$

  see e.g. Delahaye et al. 2009

No anisotropy problem (?)



Di Bernardo et al. 2011

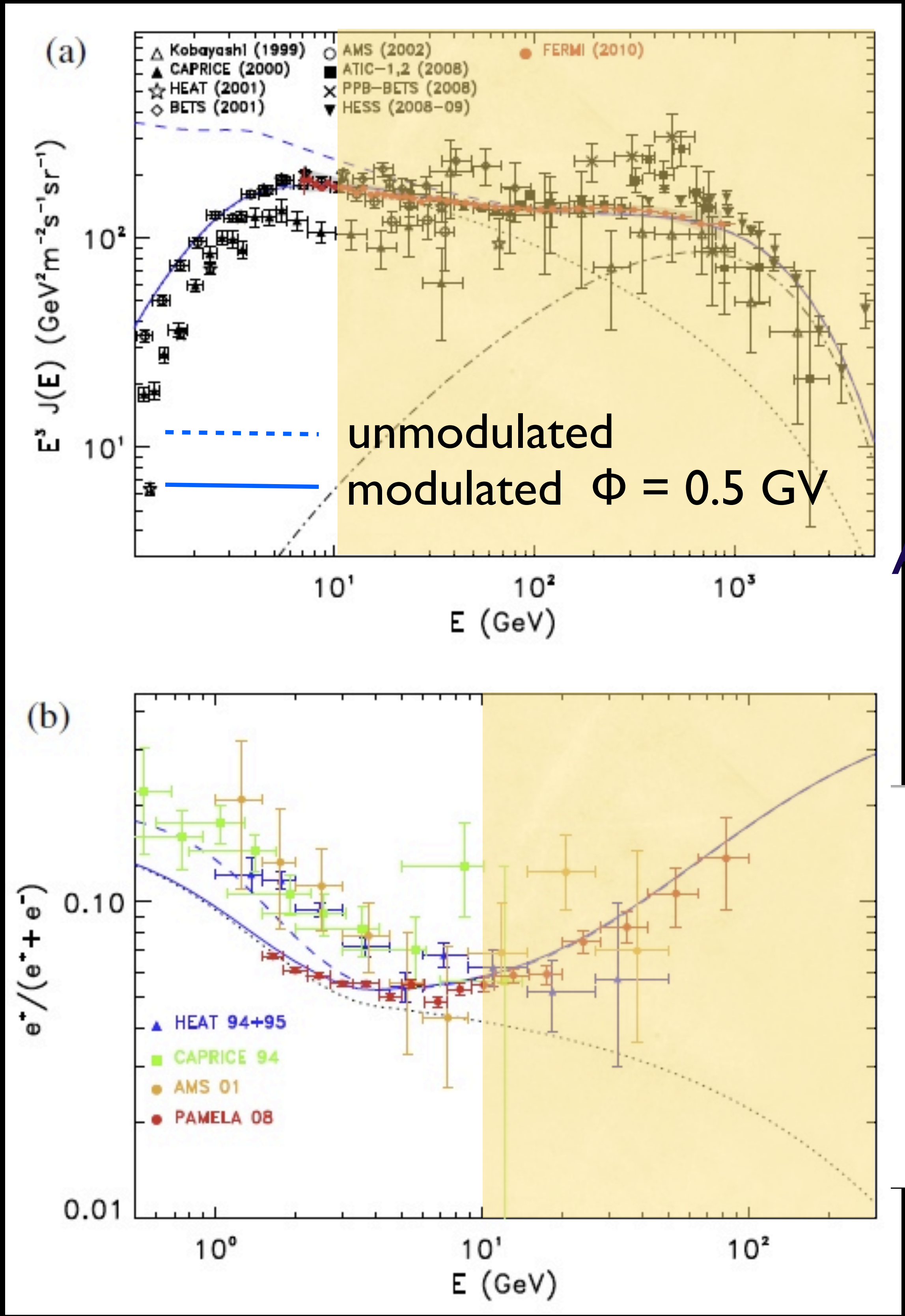
Propagating e^- observed SNRs and $e^\pm$ from observed SNR a dipole anisotropy is expected at a level marginally compatible with Fermi-LAT constraints ↓

Ackermann et al. PRD 2010

The AMS-02 constraint on the PF anisotropy (< 3.6% at 95% CL) is compatible with this scenario

May this be used to support the DM interpretation ?

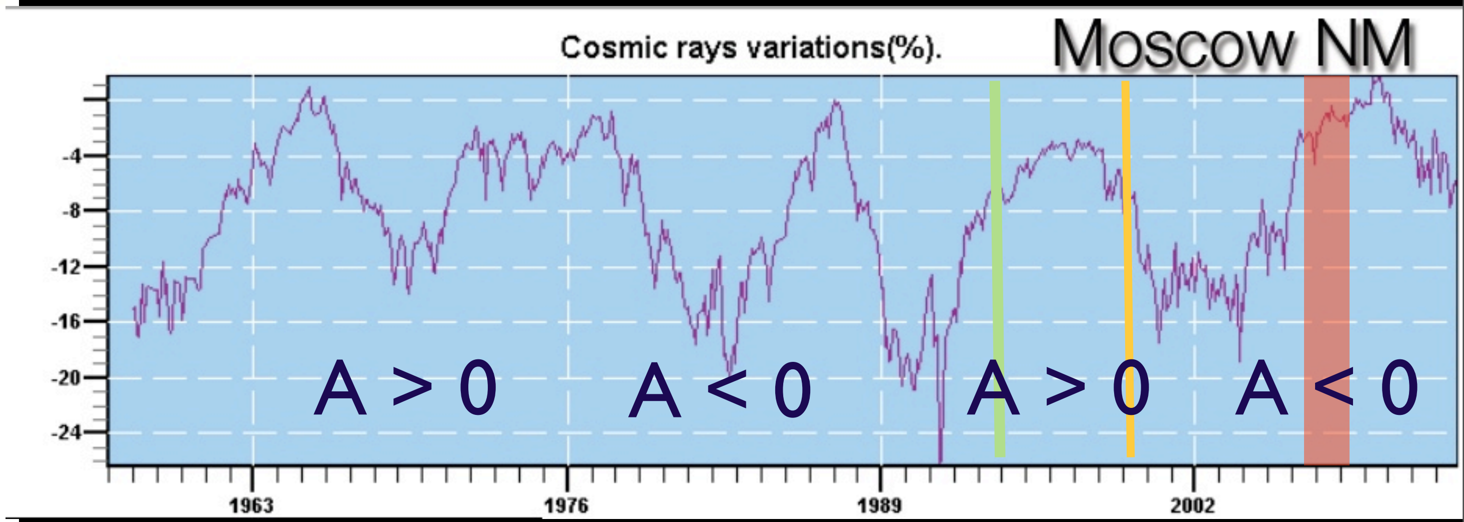
Low Energy Puzzles before AMS-02



Force-field (charge-sign independent) approximation for solar modulation can reproduce PAMELA PF (consistently with the proton spectrum)

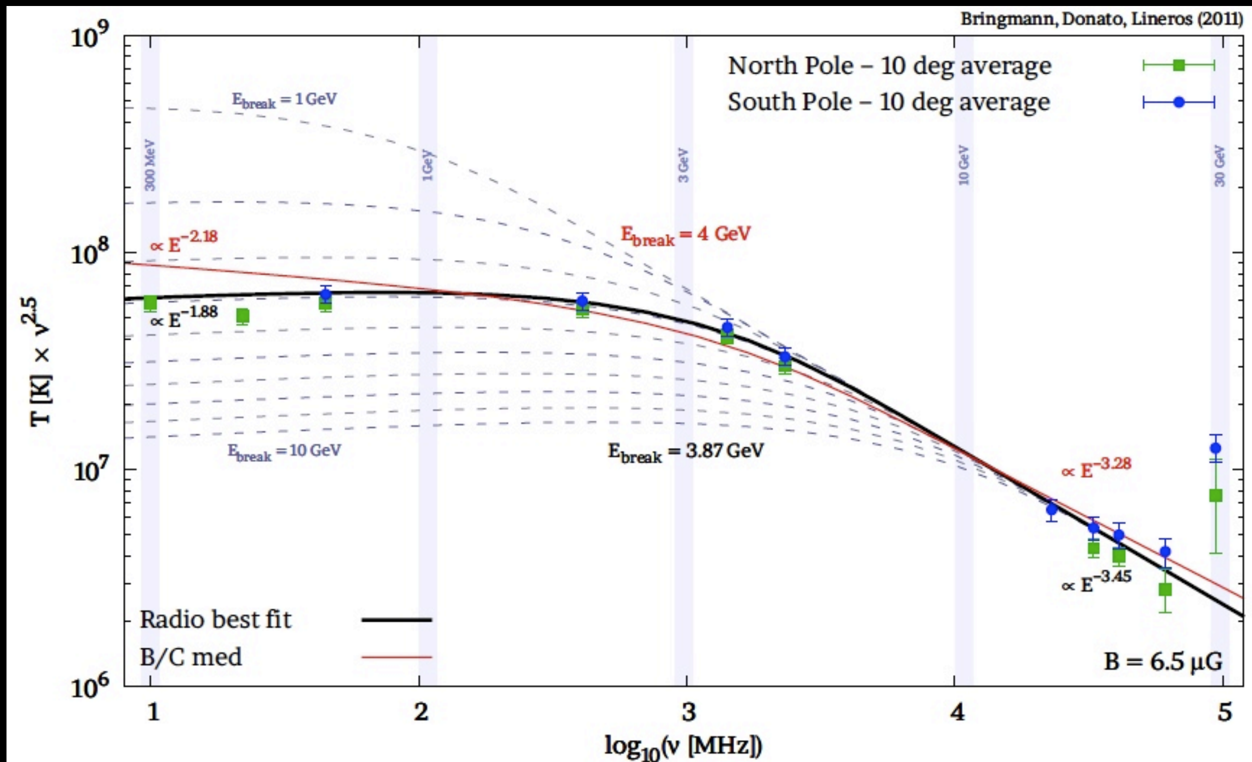
A > 0

but it cannot consistently match previous experiments

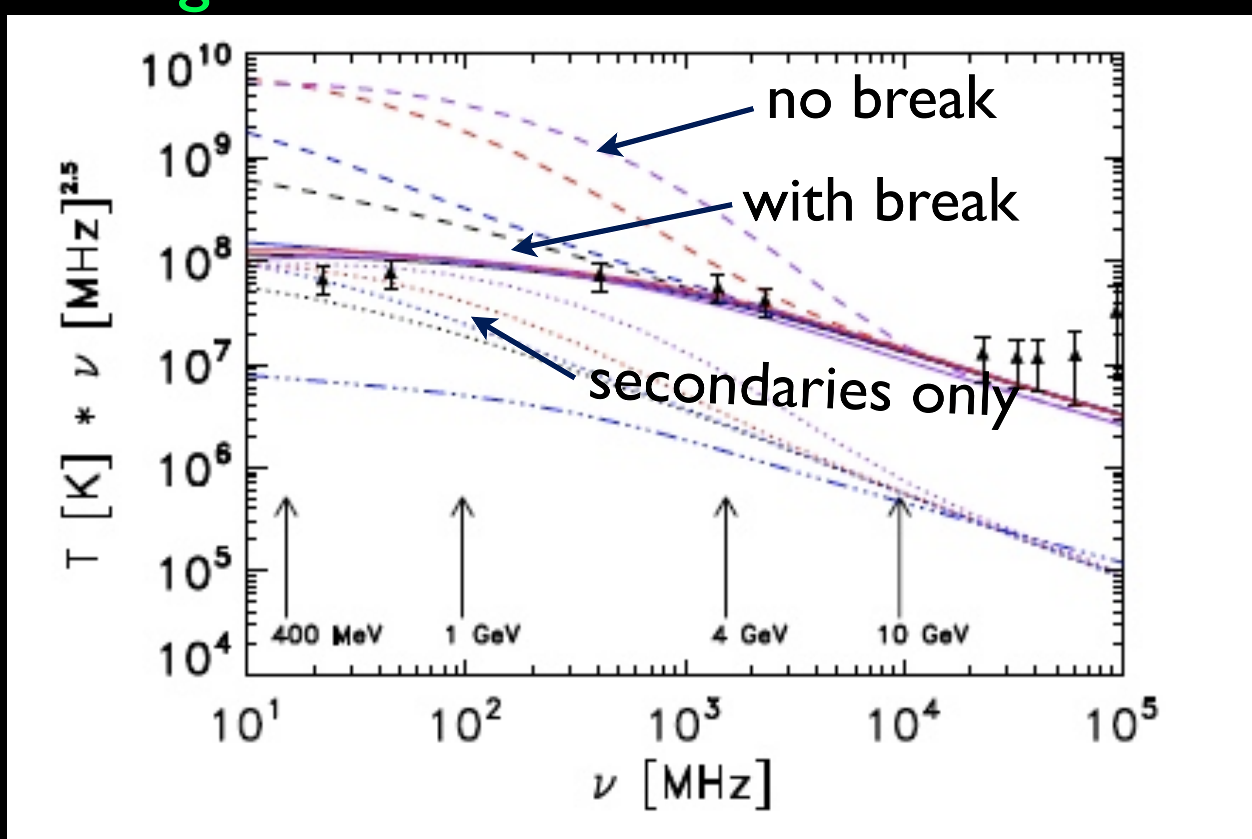


A: solar magnetic field polarity

The synchrotron spectrum



Bringmann & Donato 2012



It probes the $e^- + e^+$ interstellar spectrum (not affected by modulation !)

A strong break/cutoff is required at few GeV (for a PD model $\Upsilon_s(e) < 0.9$

(in contrast with $\Upsilon_s(e) = 2$)

Below few GeV the $e^- + e^+$ population is dominated by secondary particles

Di Bernardo et al. , JCAP 2013 perfomed with DRAGON v2

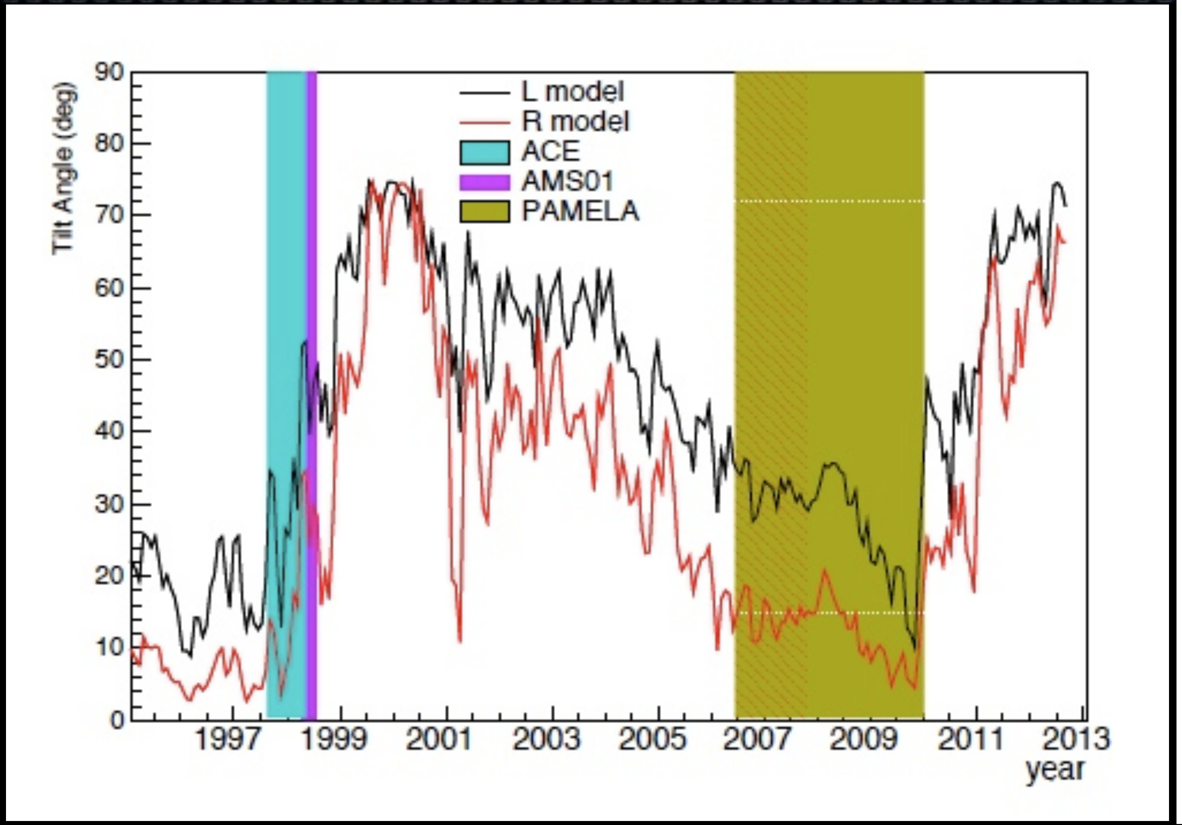
A realistic modulation treatment

Propagation equation

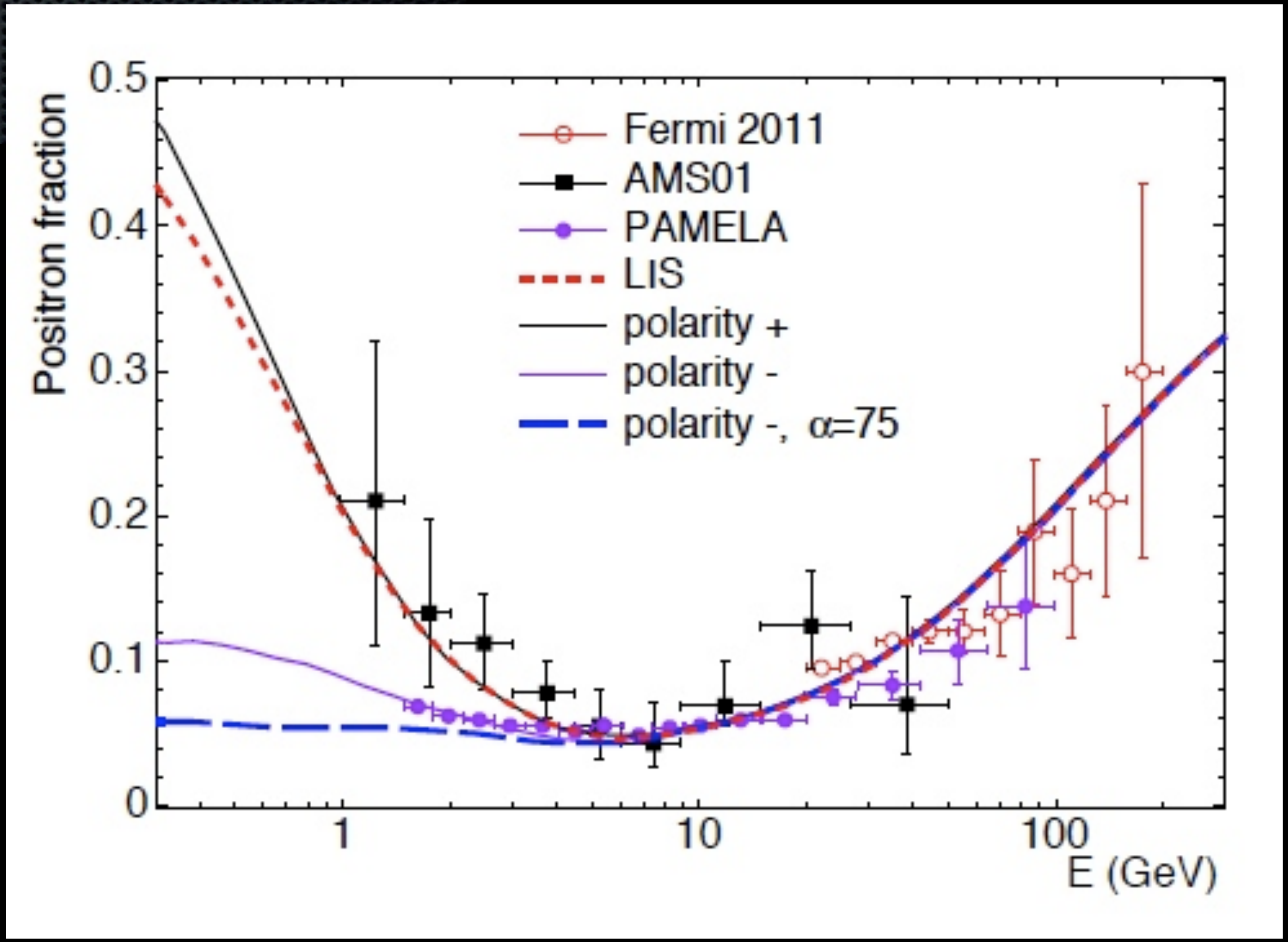
(notation from Strauss et al, 2012, eqn. dating back to Parker, Burger, Jokipii et al., 60/70's)

$$\frac{\partial f}{\partial t} = -(\vec{V}_{\rm sw} + \vec{v}_d) \cdot \nabla f + \nabla \cdot (\boldsymbol{K} \cdot \nabla f) + \frac{P}{3}(\nabla \cdot \vec{V}_{\rm sw}) \frac{\partial f}{\partial P}$$

$$\vec{v}_d = \frac{qv}{3} \nabla \times r_L \frac{\vec{B}}{B}$$



Maccione PRL 2013 - HELIOPROP



see also Gast & Shael 2009;
Della Torre et al. 2012

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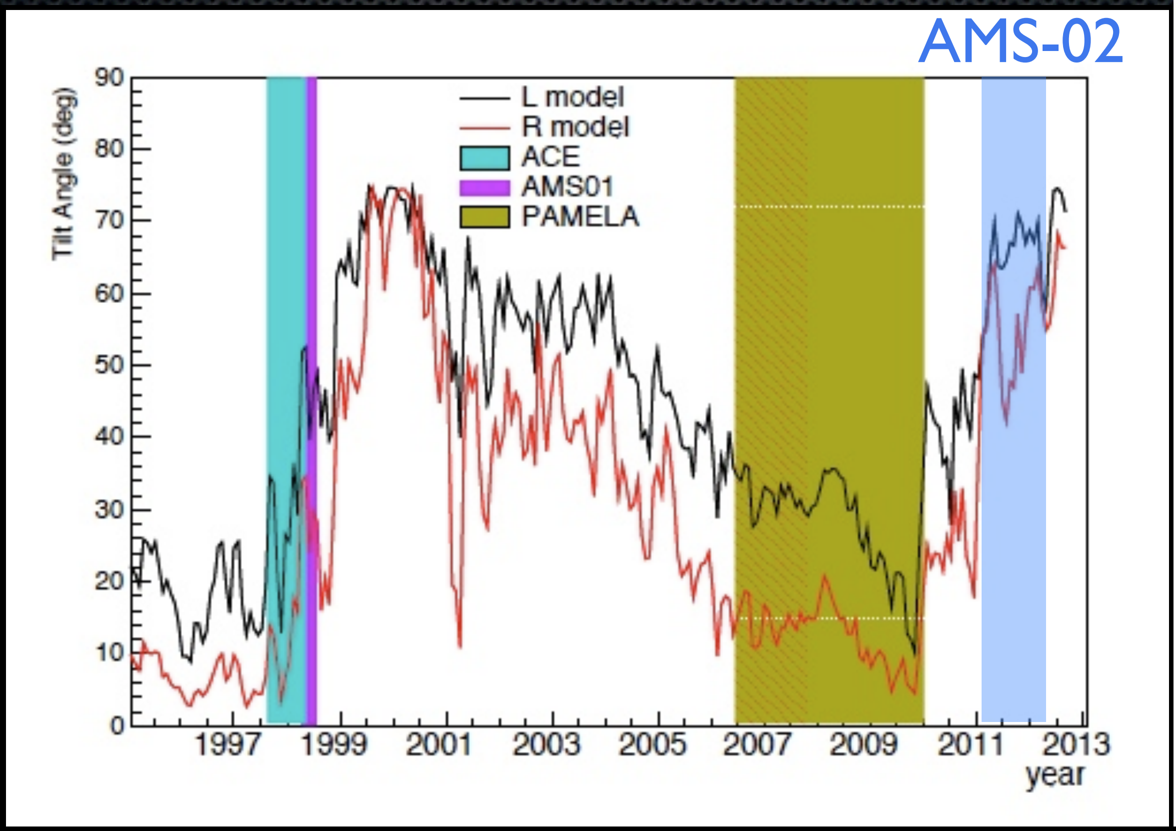

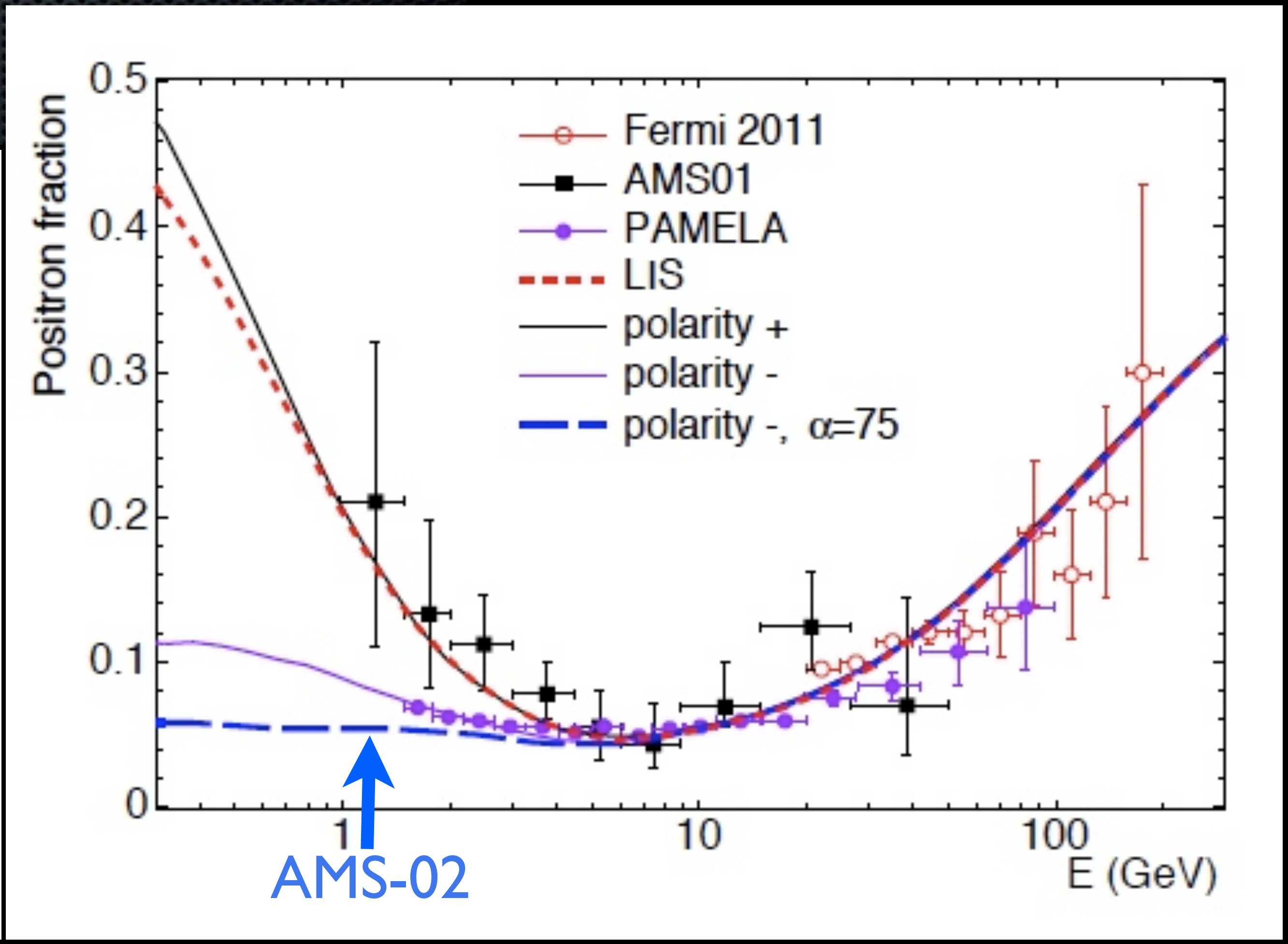

see also Gast & Shael 2009;
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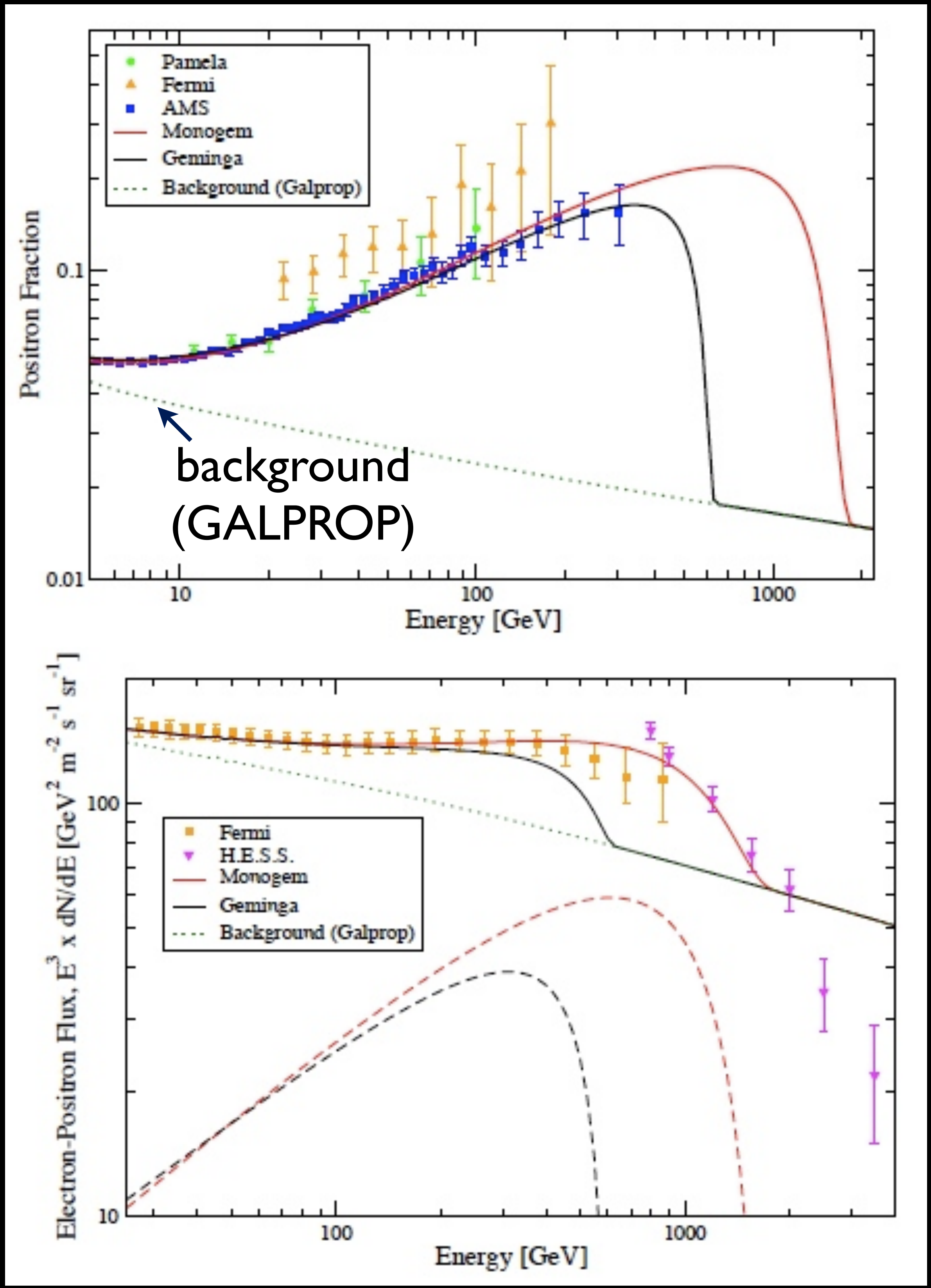
First attempts to interpret AMS-02 results

Linden & Profumo arXiv:1304.1791



Pulsar interpretation

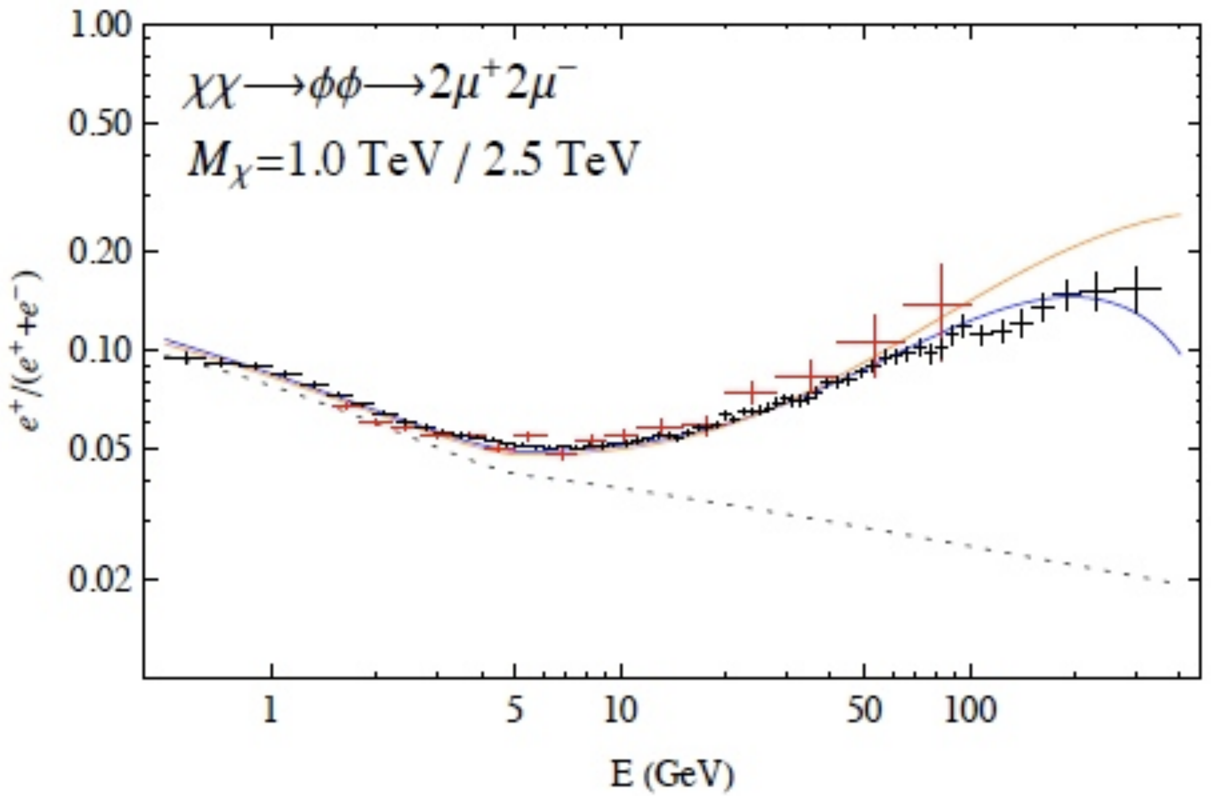
- a softer EC is required $1.8 < \gamma_{source}(e^{\pm}) < 2$
- best fit model for AMS-02 underproduces Fermi $e^- + e^+$

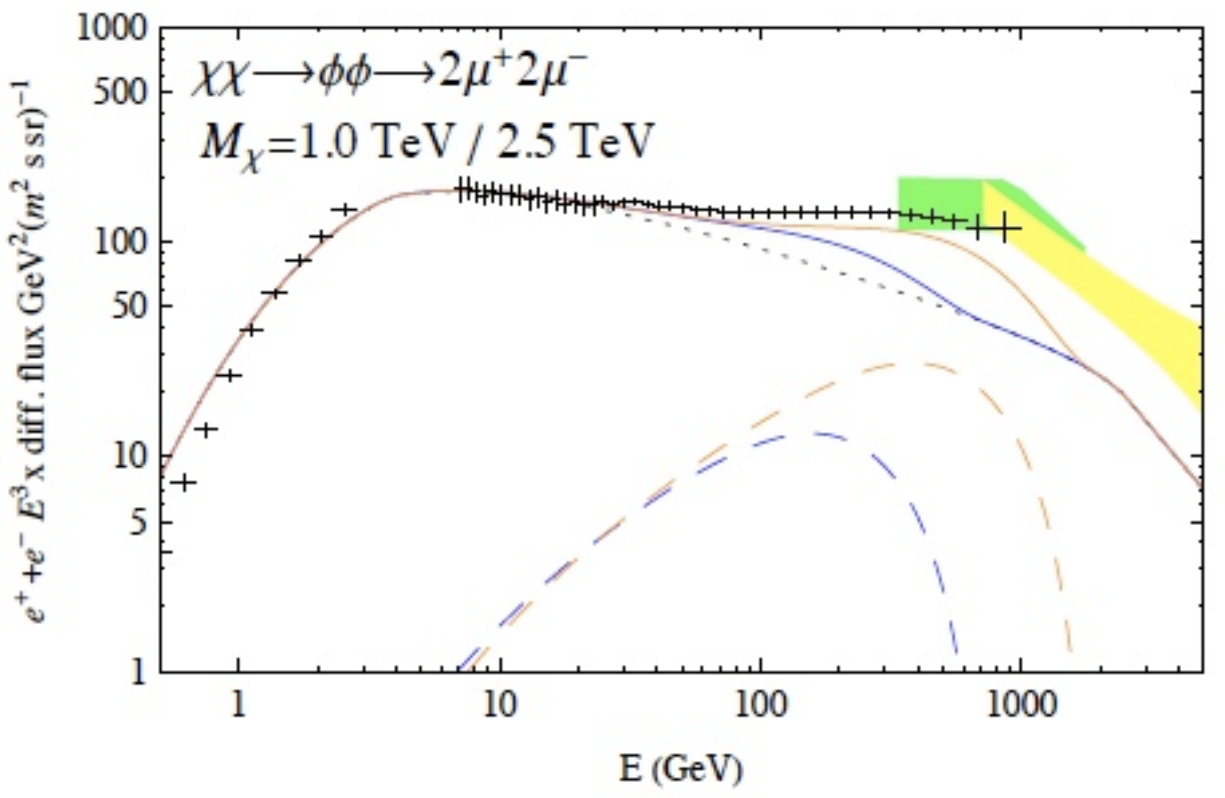
see *also* *Yin et al. arXiv:1304.4128*

- a softer EC implies a larger contribution from distant sources
- Those papers do not address the steepness problem

First attempts to interpret AMS-02 results

Cholis & Hooper arXiv:1304.1840

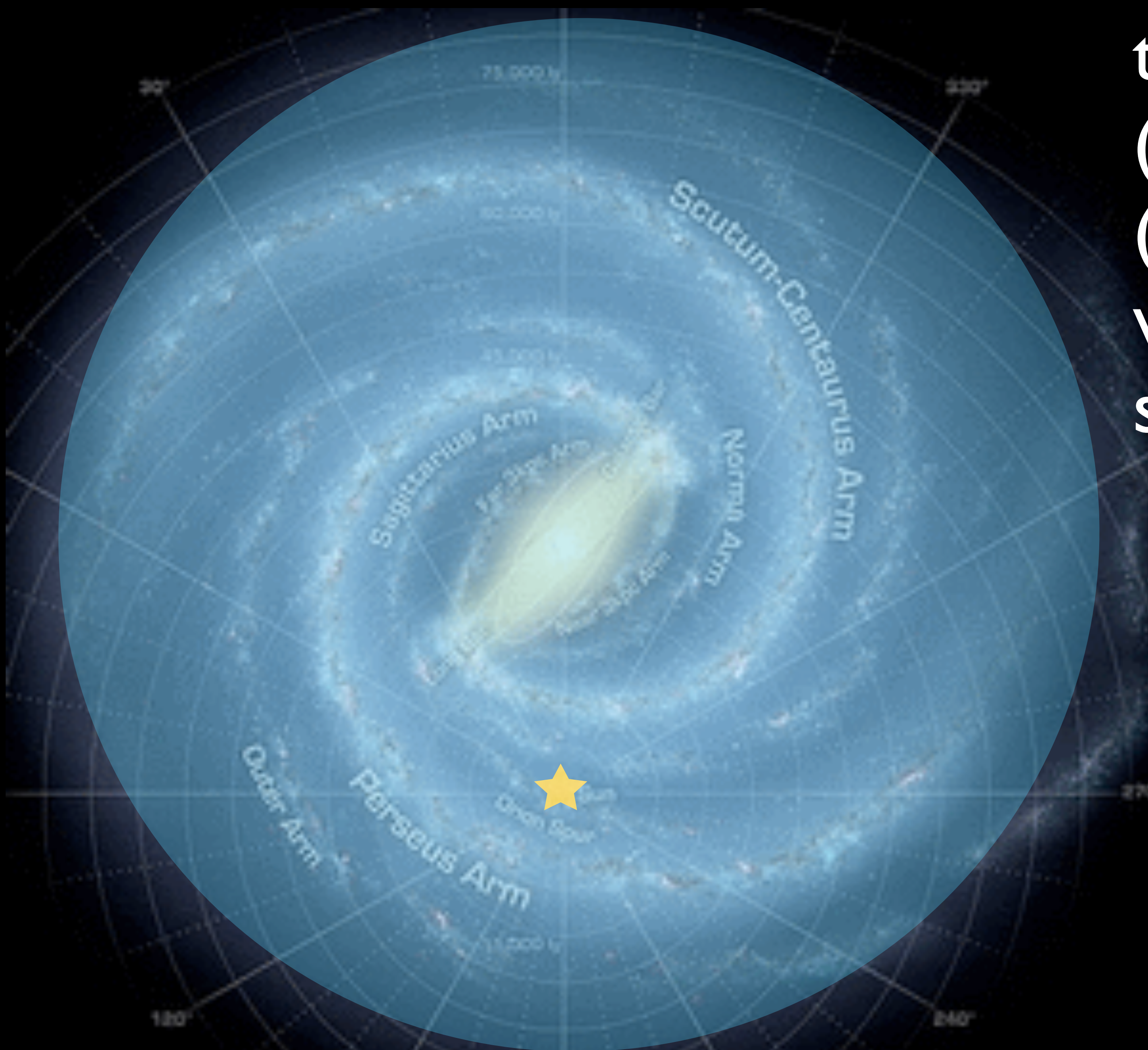




Dark matter interpretation

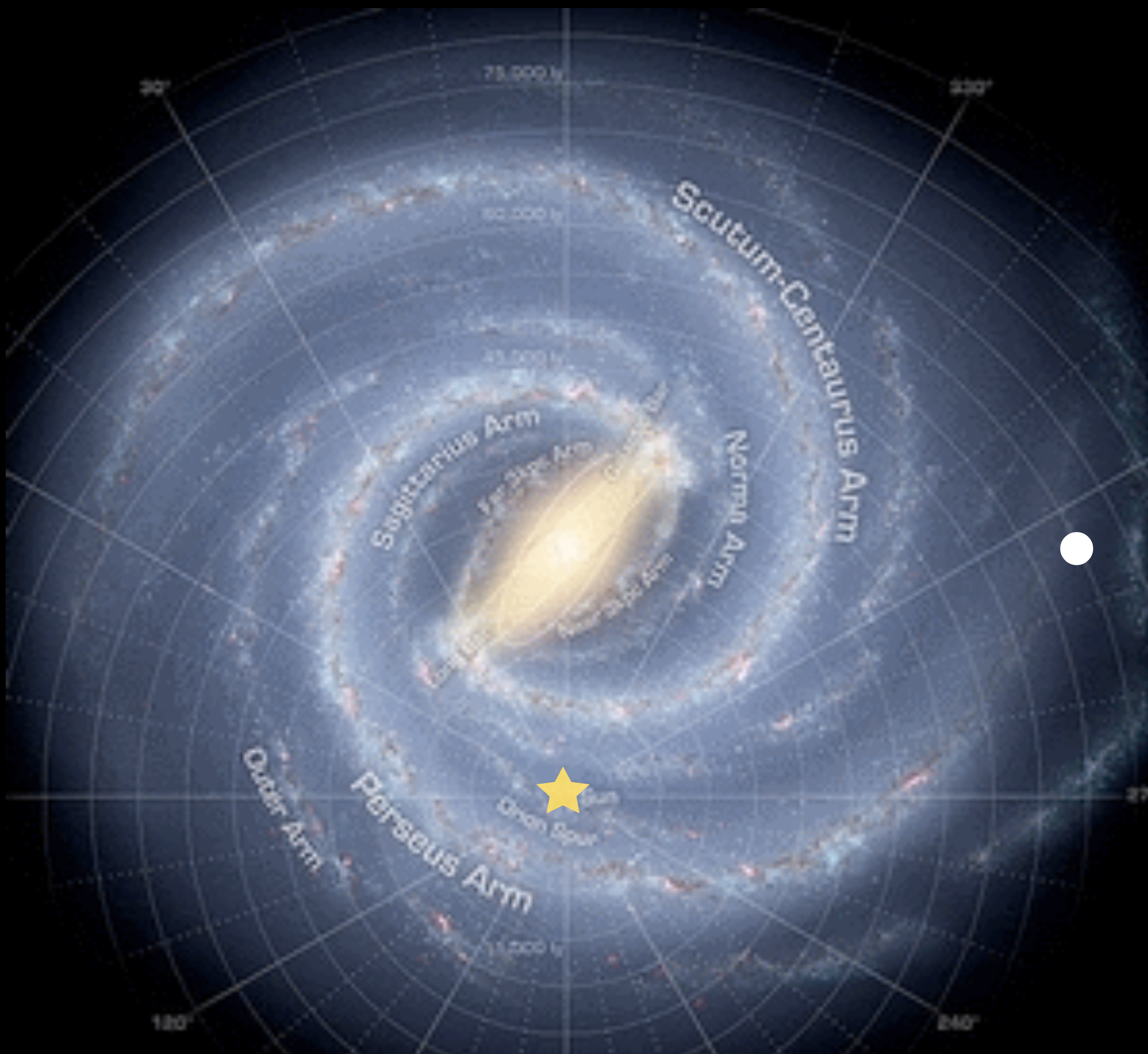
- best fit model for AMS-02 underproduces Fermi $e^- + e^+$
  see also Yin et al. arXiv:1304.4128
- either a break at ~ 200 GeV in the e^- source spectrum, or a local source, or a charge asymmetry in the DM sector
  Masina & Sannino arXiv: 1304.2800
- *background computed with GALPROP in 2D*

Why to consider a 3D model of CR propagation ?



- Cosmic ray propagation was treated with semi-analytical (e.g. USINE) or numerical (GALPROP and DRAGON v2) which assume azimuthal symmetry for CR sources

Why to consider a 3D model of CR propagation ?



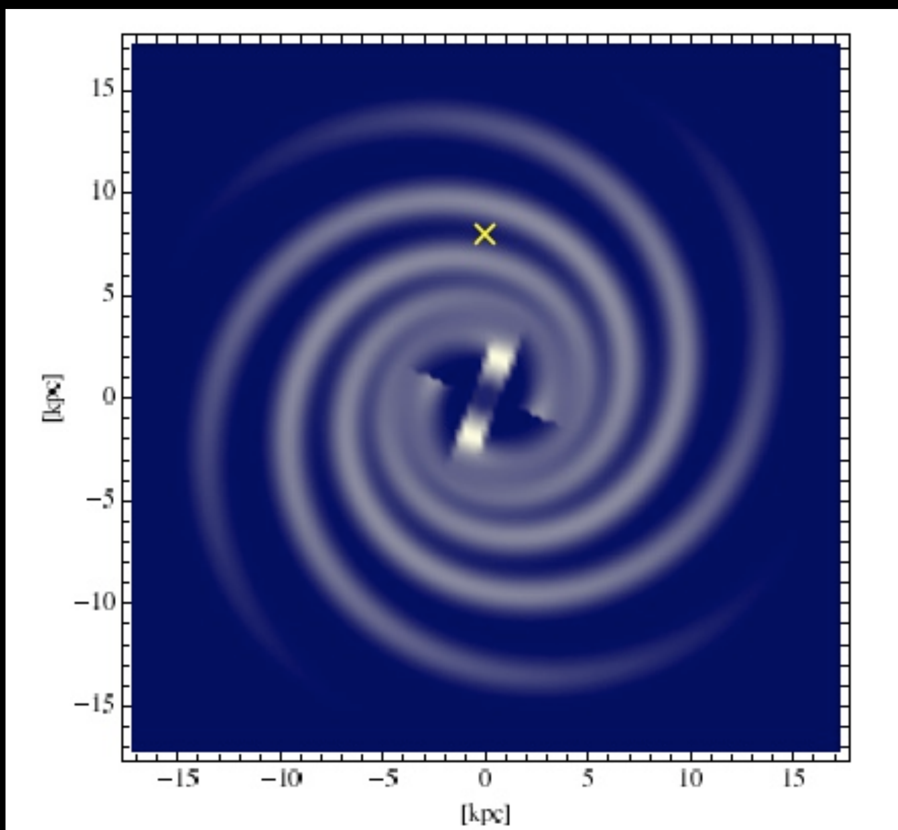
- Cosmic ray propation was treated with semi-analytical (e.g. USINE) or numerical (GALPROP and DRAGON v2) which assume azimuthal symmetry for CR sources
- This does not allow to account for energy losses in the interarm region. We are in an interarm region !

d(Sun-arms) ~ 1 kpc $\gtrsim L_{loss}$

for E > 100 GeV

DRAGON.v3 = 3D

Maccione, Evoli, Gaggero, Di Bernardo, DG
with contribution from I.Gebauer and coll. (KIT)
M.Tvakoli, P. Ullio (SISSA)

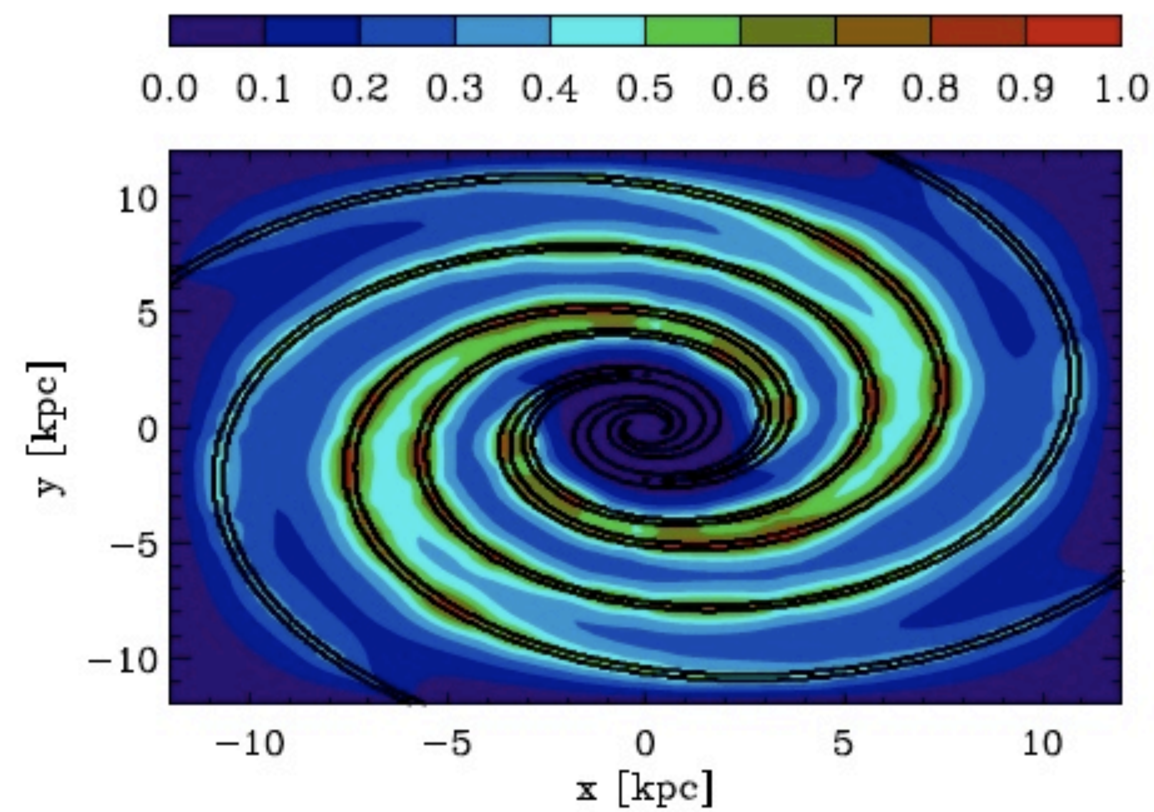


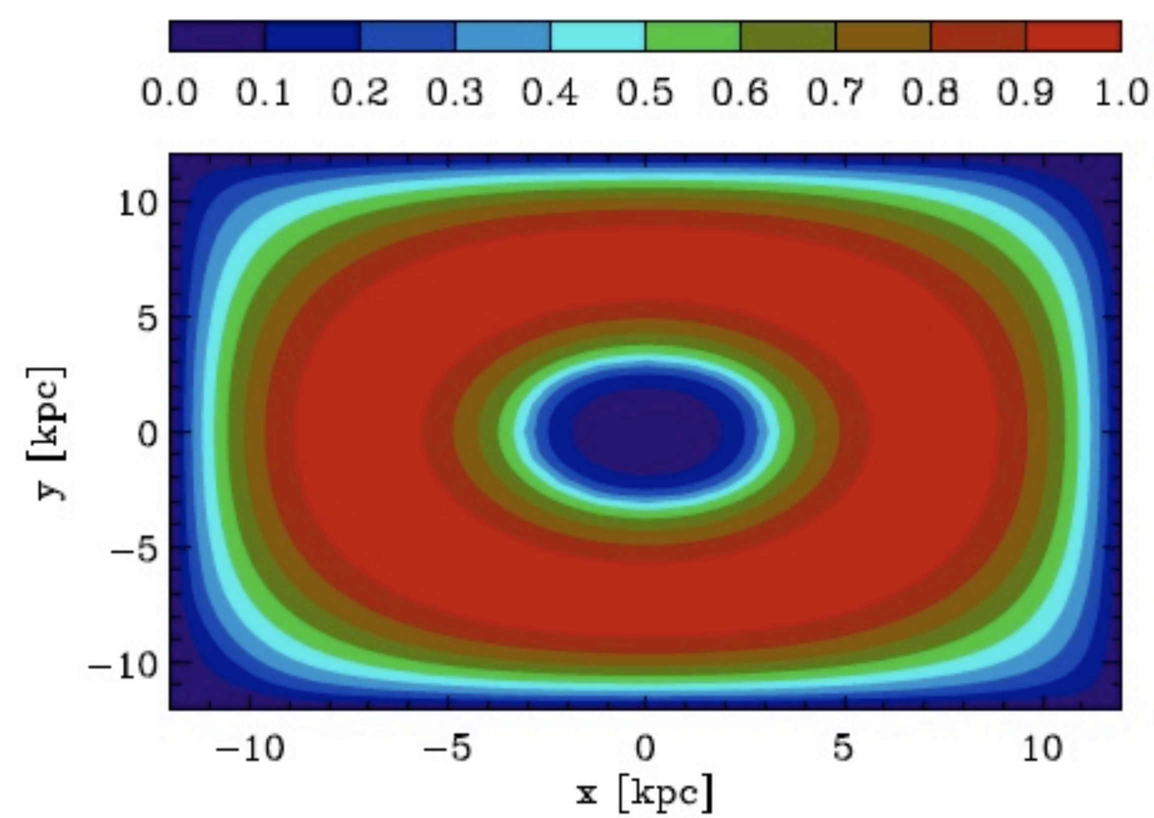
$$f(r) = A \sin\left(\frac{\pi r}{r_0} + \theta_0\right) \mathrm{e}^{-\beta r}$$

- solve the diffusion equation on a 4D (x,y,z, E) grid
- realistic distribution for sources which accounts the galactic arms
- position dependent, anisotropic diffusion (not used in this work)
- fast (linkable library)
- interfaced to DARKSUSY
- public: http://dragon.hepforge.org/

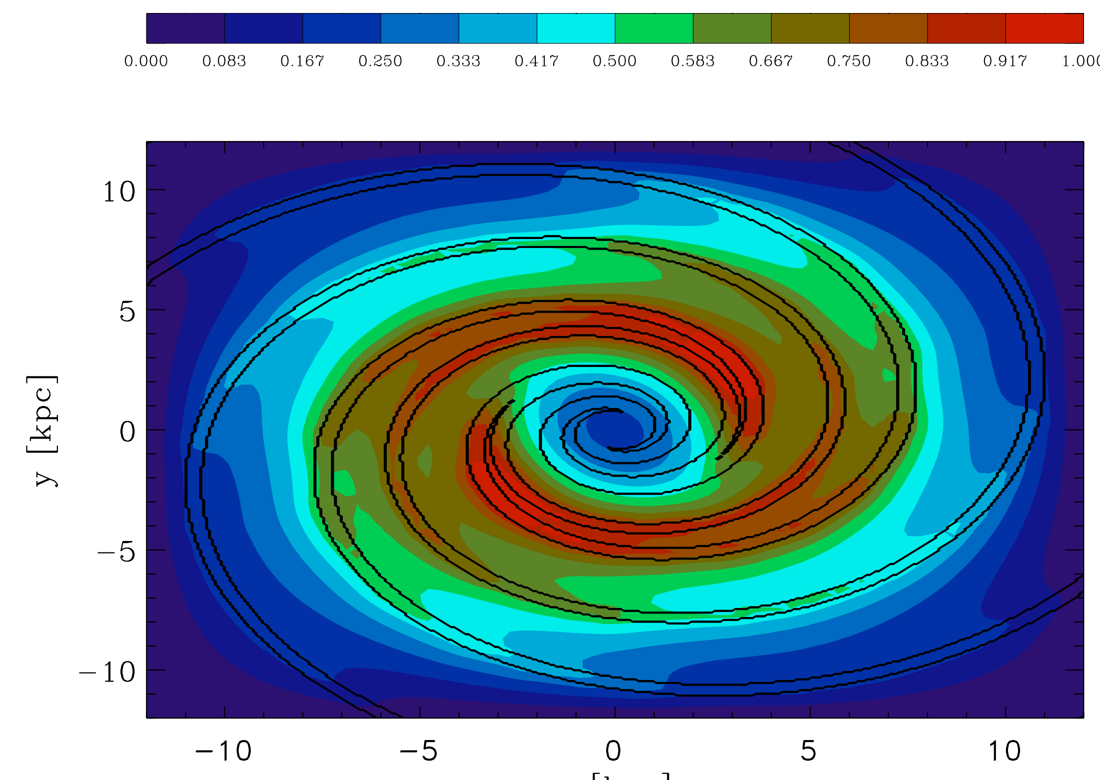
CRE distribution - 3D vs 2D

100 GeV





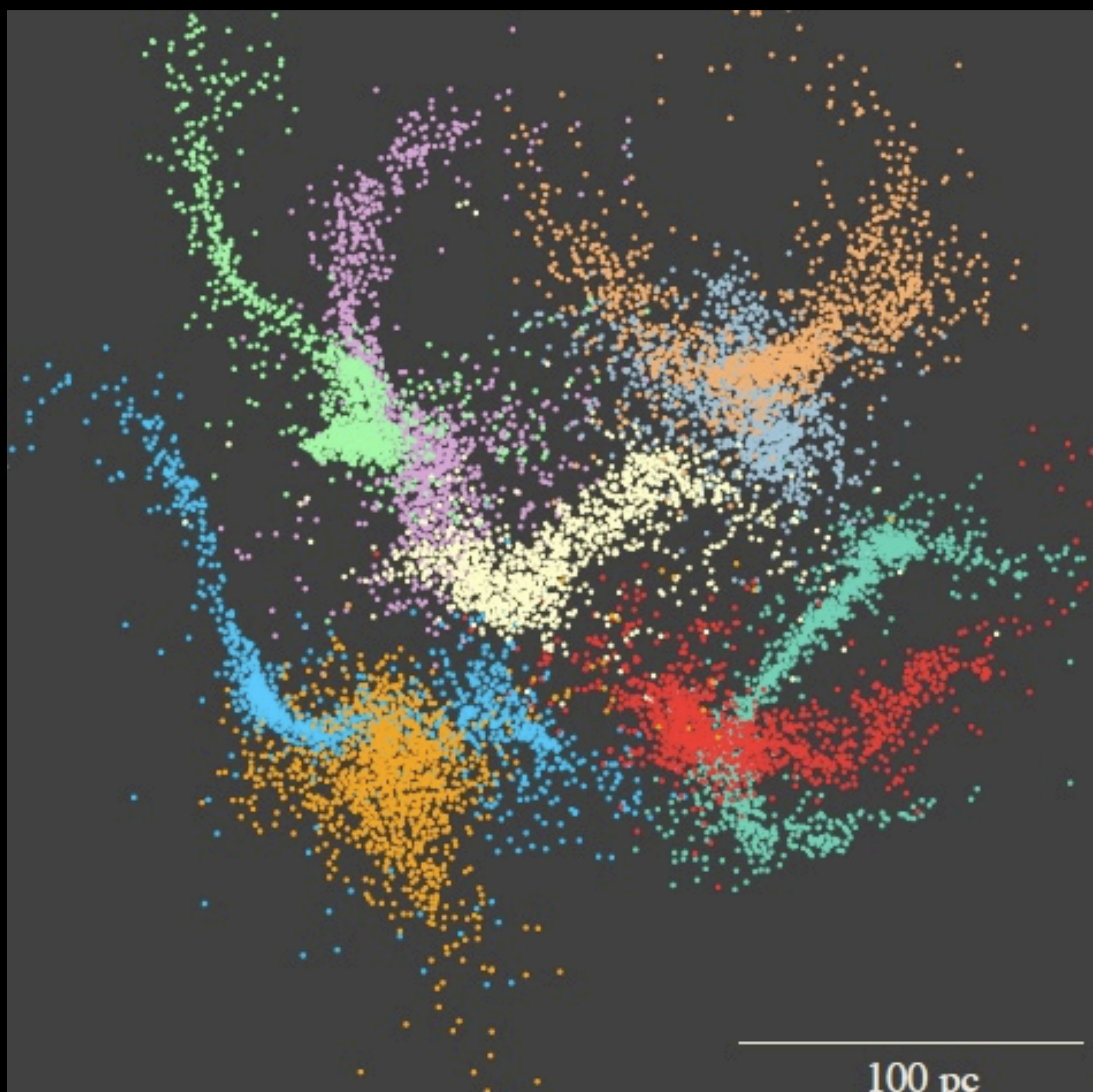
1 GeV



Gaggero, Maccione, Evoli, Di Bernardo, DG arXiv:1304.6718

➡ 2D
clearly unrealistic !!

Extra component in the Galactic arms only

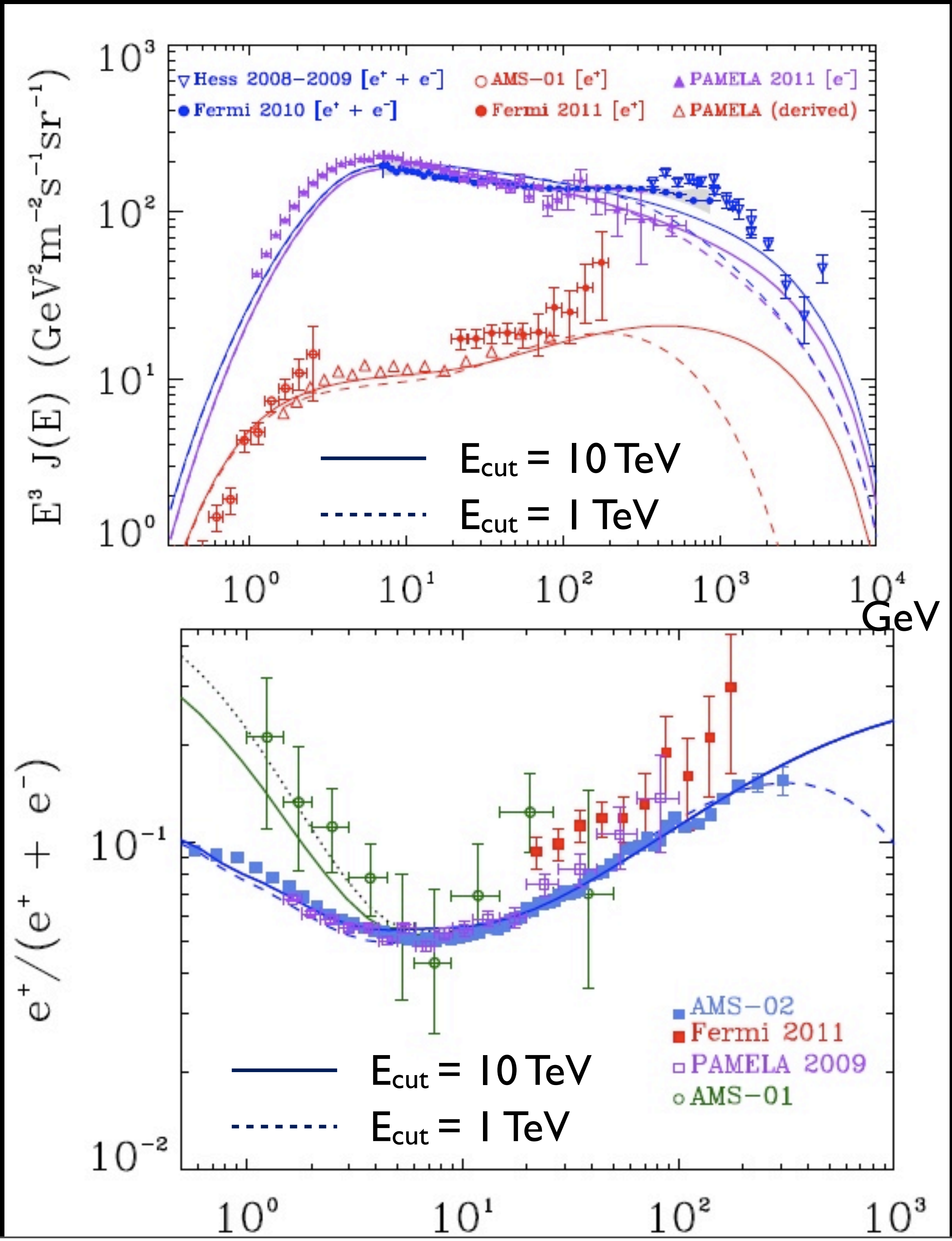


Kistler, Yuksel & Friedland 2012
Giacinti & Sigl PRL 2012

Motivations:

- AMS-02 PF needs a softer EC spectrum. The role of nearby source may be less relevant
- CRE from nearby sources may not reach us
- no-bumpiness and no-anisotropy naturally explained

Extra component in the Galactic arms only



same spatial distribution for the e^- background and the $e^\pm$ extra-component

$\gamma_{source}(p) = 2.28$

$\gamma_{source}(e^-) = 2.38 \quad E > 4$ GeV
(2.65 for the no-arm case)

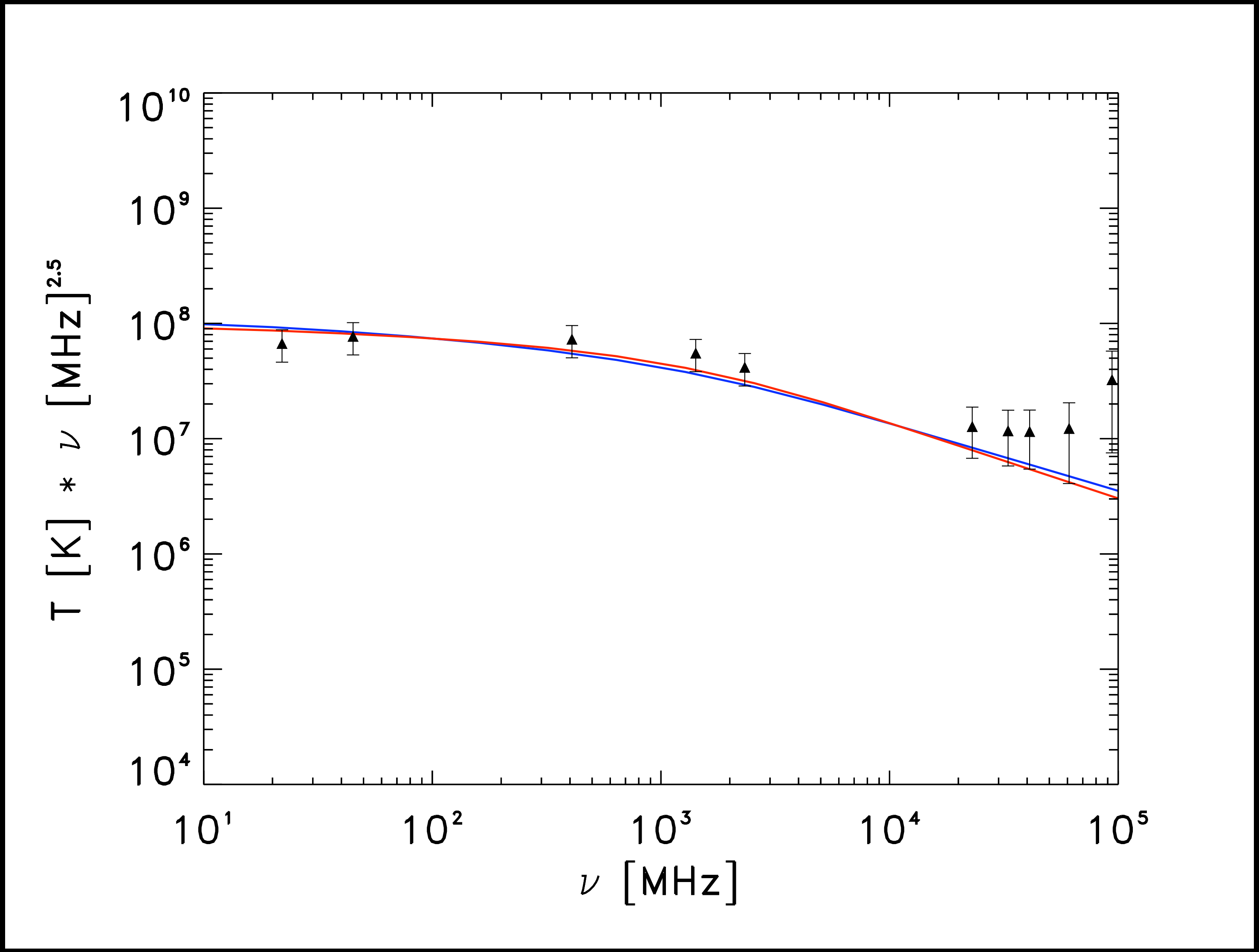
$\gamma_{source}(e^-) = 1.2 \quad E < 4$ GeV

$\gamma_{source}(e^\pm) = 1.75$ EC

$E_{cut}(e^\pm) = 1 - 10$ TeV

Gaggero, Maccione, Evoli, Di Bernardo, DG arXiv:1304.6718

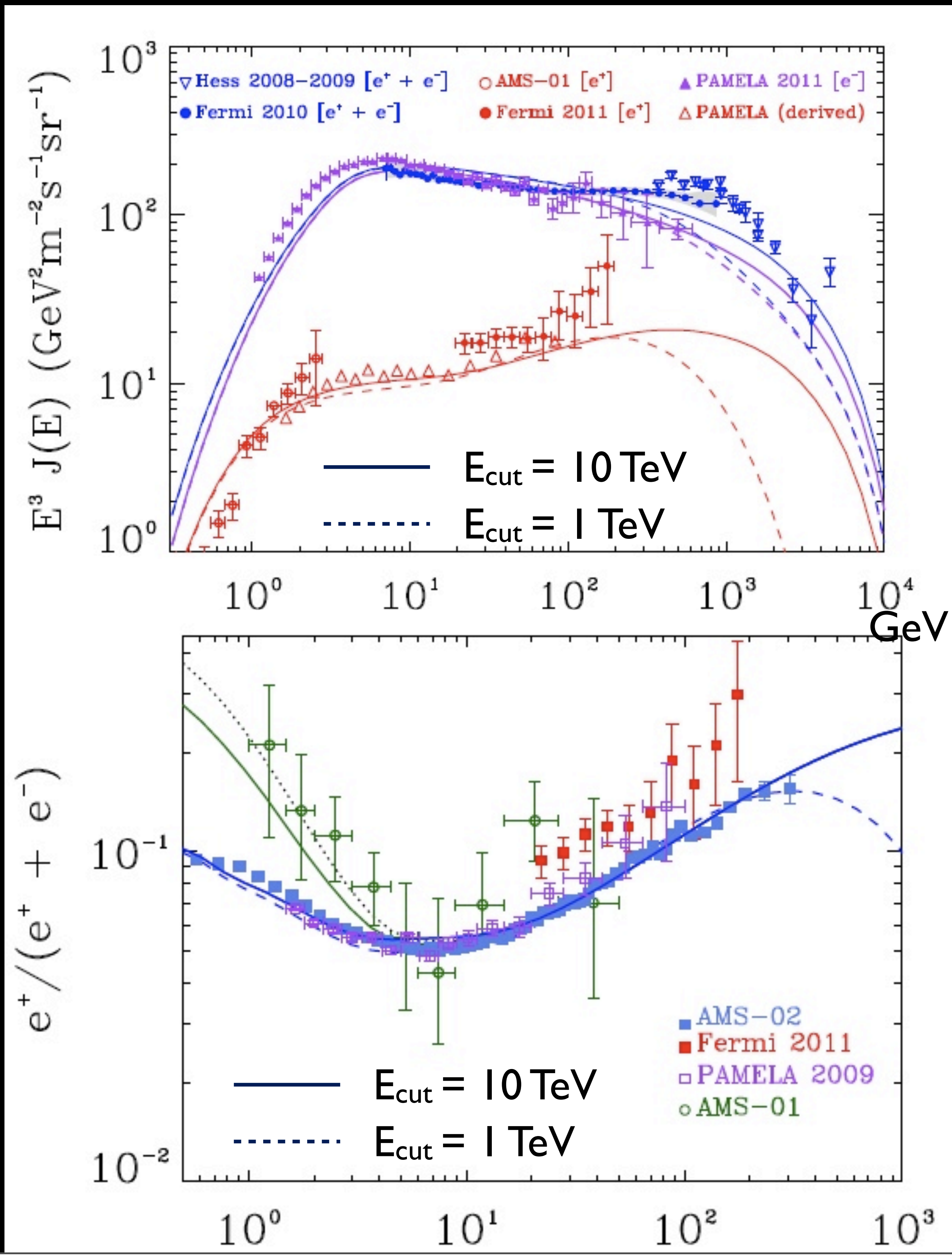
The synchrotron spectrum



- the radio spectrum, the time dependent PF and e^+ spectrum are consistently reproduced for the first time.

see Di Bernardo et al. JCAP 2013

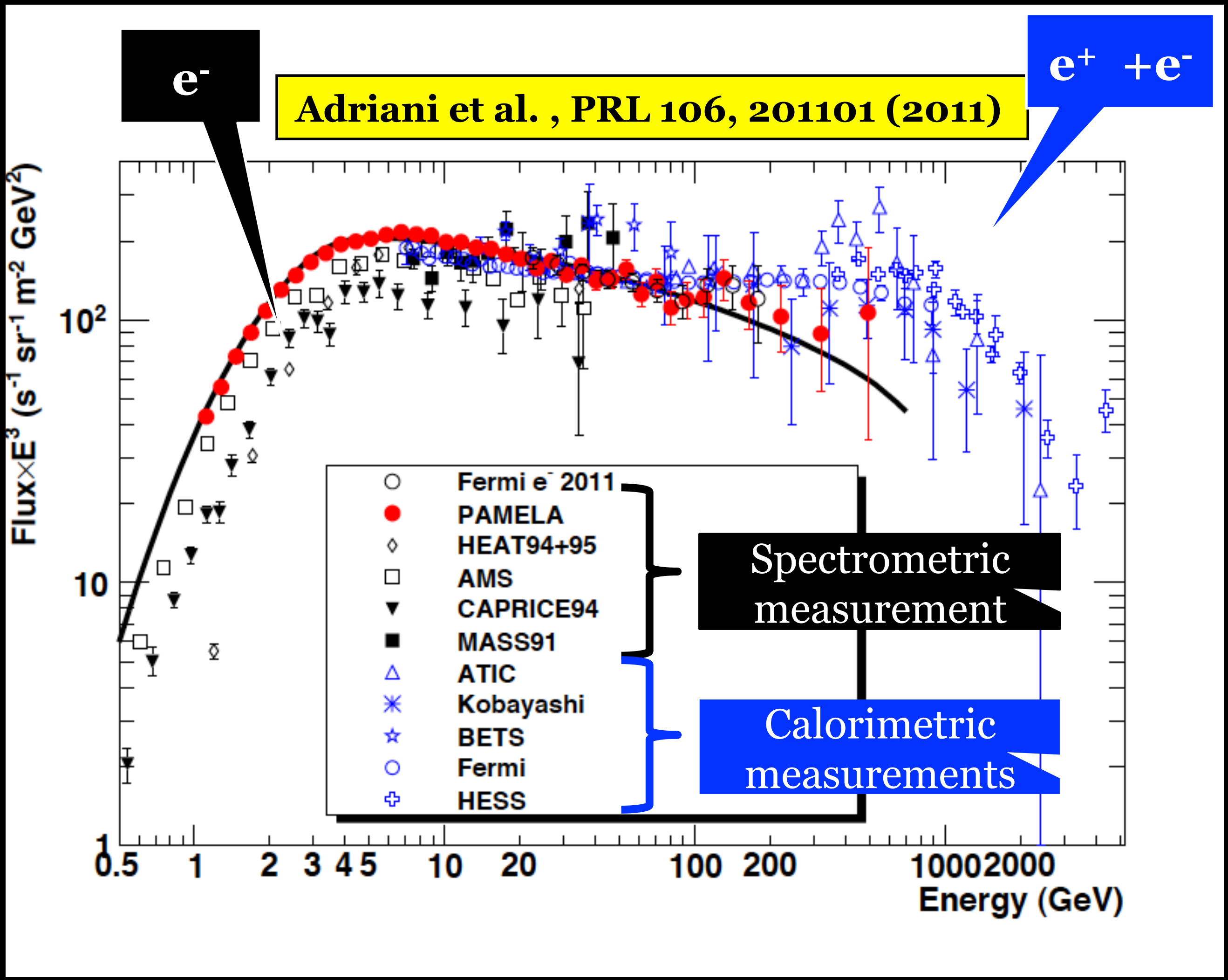
Extra component in the Galactic arms only



- steepness problem significantly ameliorated !
- AMS-01/02 low energy discrepancy explained !
- PAMELA e^- (e^+) *OK*
- PAMELA $e^-/e^- + e^+$ *OK*
- $e^- + e^+$ spectrum steeper respect to Fermi-LAT ! Quite serious discrepancy if E_{cut} ($e^{\pm}$) $\simeq$ 1 TeV

see also *Linden & Profumo 2013, Yin et al. 2013, Masina & Sannino*

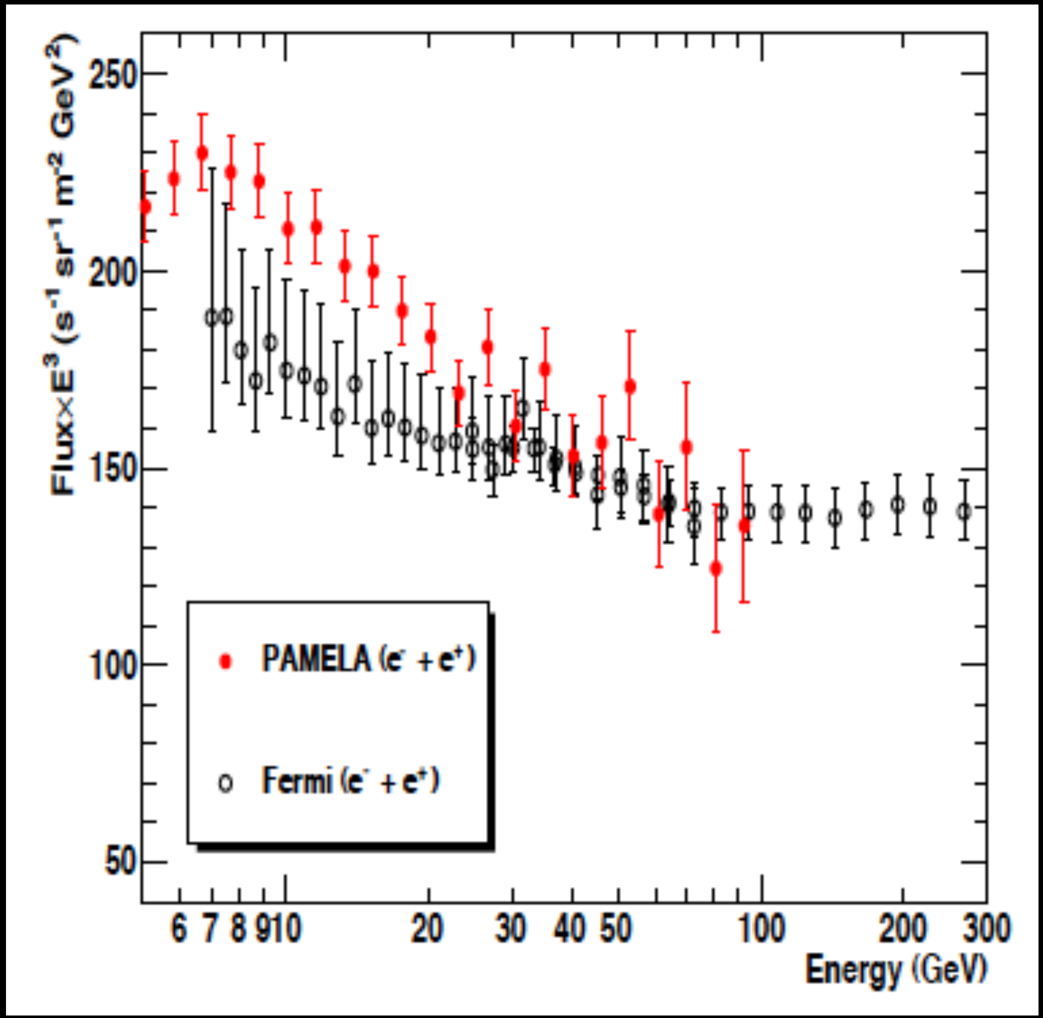
Is the e^- deficit real ?



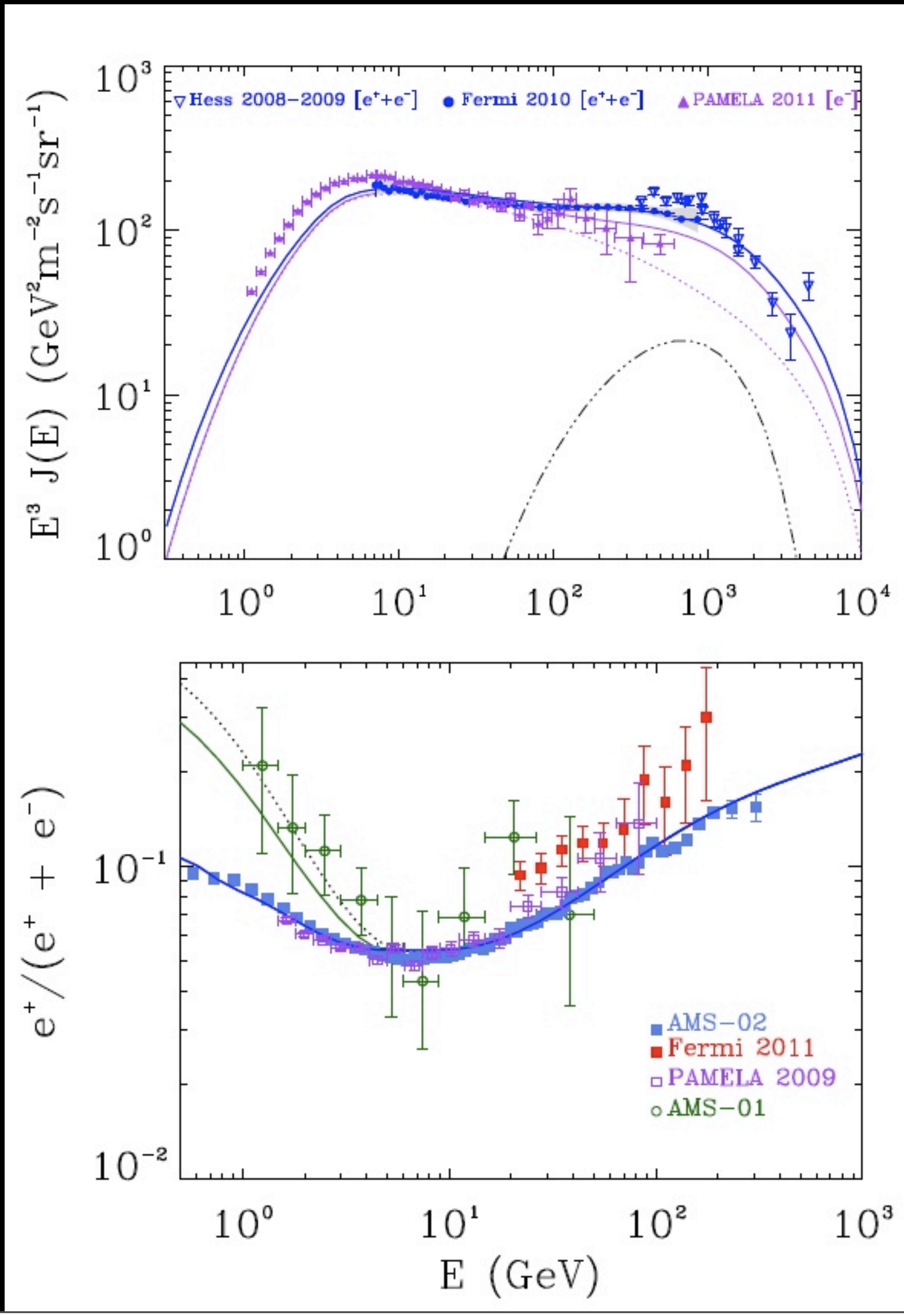
R. Sparvoli's talk, Paris Nov. 2012

May not be there if the $e^- + e^+$ spectral slope is closer to that inferred from PAMELA rather than Fermi-LAT !

would the deficit be real a break in the e^- spectrum at ~ 200 GeV or an extra source need to be introduced



The case of a nearby e⁻ accelerator (toy model)



e^- background:

$\gamma_{source}(e^-) = 2.38$ $E > 4$ GeV

$= 1.2$ $E < 4$ GeV

$e^\pm$ extra-component:

$\gamma_{source}(e^\pm) = 1.75$

$E_{cut}(e^\pm) = 10$ TeV

e^- nearby source

$\gamma_{source}(e^\pm) = 2.1$

$E_{cut}(e^\pm) = 1$ TeV

$E = 3.6 \times 10^{47}$ erg

$d = 290$ pc (Vela)

CONCLUSIONS

- a realistic modeling of CR e^- and e^+ propagation in the Galaxy requires to account for the spiral arm distribution of sources (both for the backgr. and the astroph. e^+ sources)
- DRAGON.v3 allows to built 3D numerical models which account for such structure reproducing a wide data set
- the steepening required to leave room to the extra-component to explain the PF anomaly is shown to be compatible with Fermi acceleration and radio-astronomical observations of SNRs
- diffuse radio and low energy CRE time dependent data are consistently reproduced using a realistic modulation setup

CONCLUSIONS

- AMS-02 results suggest that nearby sources may not be necessary to explain the positron excess.
- a cutoff in the PF above 350 GeV in the absence of a steepening of the $e^- + e^+$ spectrum would call for a nearby e^- source or for an hardening of the e^- spectrum (soon testable by AMS-02). This may favor the pulsar interpretation.
- the absence of a cutoff would favor the SNR (e.g. Blasi model) or DM interpretation of the positron anomaly.
- B/C and antiproton AMS-02 results will be crucial