# Interpretation of recent electron and positron data

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TeVPA ’09
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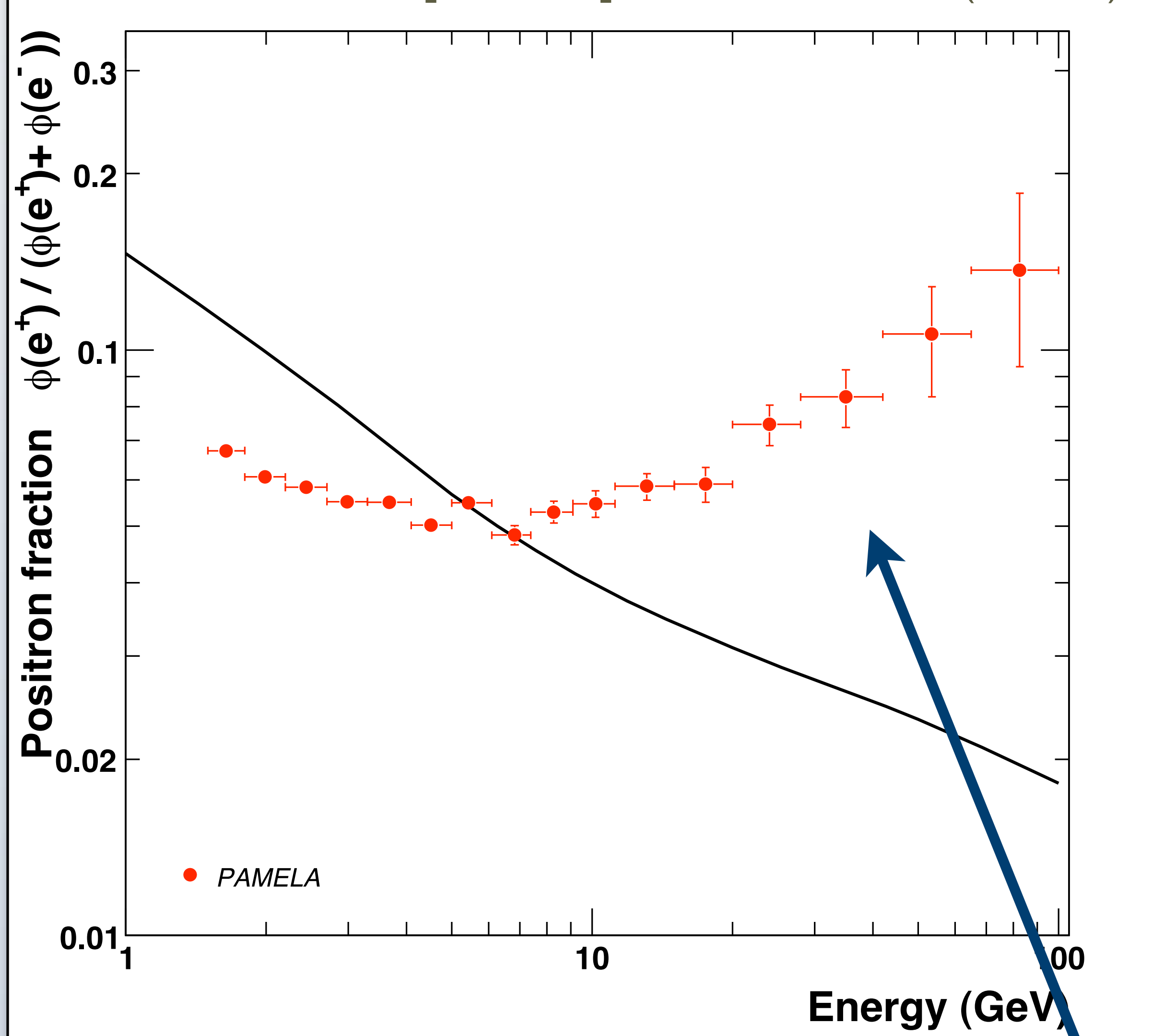
# Data and background expectations

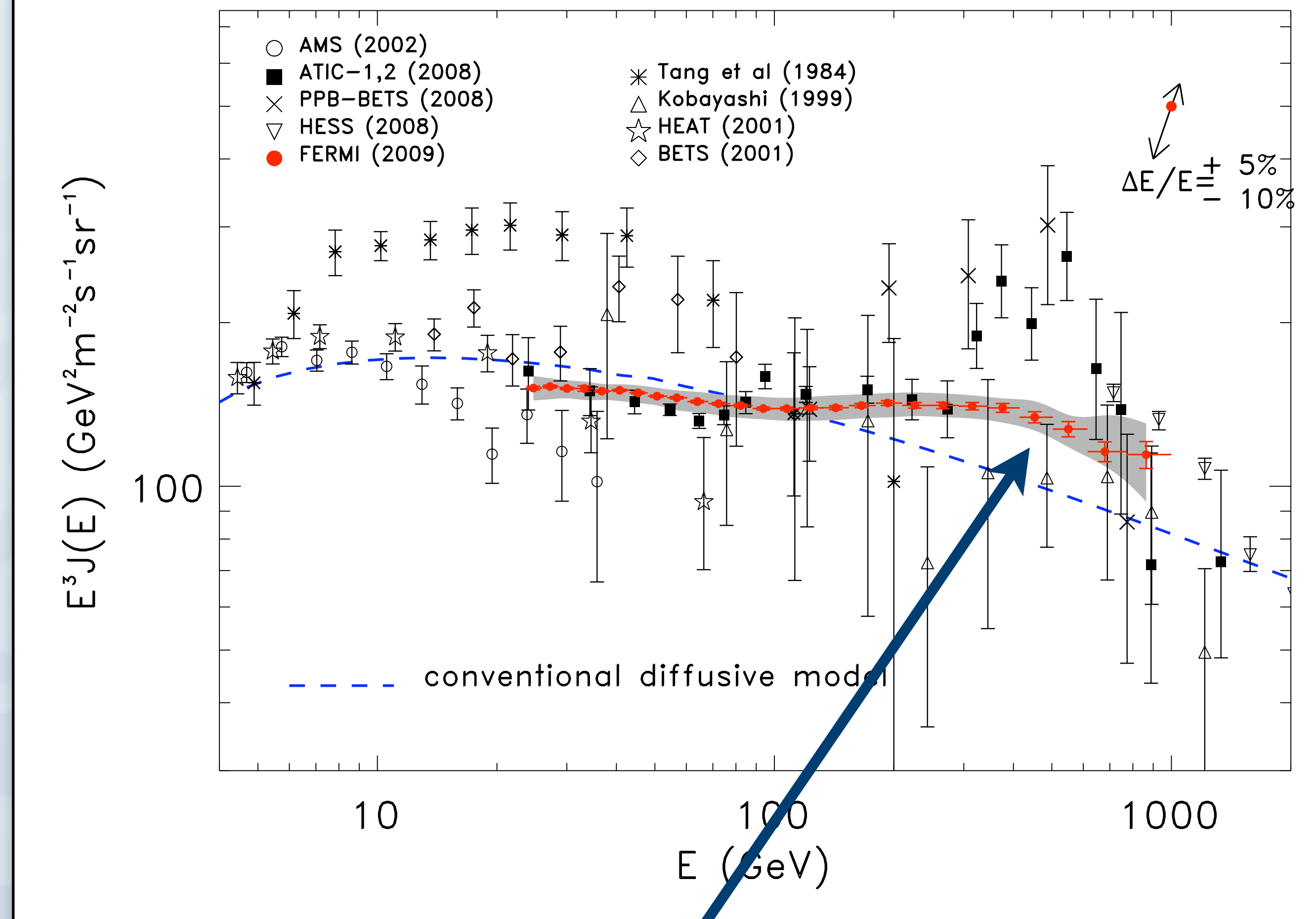
## Positron fraction

O. Adriani et al., [PAMELA], arXiv: 0810.4995 (Nature)




## e⁺+e⁻ spectrum

A.A. Abdo et al, [Fermi-LAT], arXiv: 0905.0025 (PRL)




**What are these excesses compared to the background?**

more than 275 papers written on Pamela since the fall...
...and 74 already citing the Fermi-LAT paper from early May...

# Possible explanations for the excess

- The diffuse background model is wrong?
- The local astrophysical sources (pulsars, reacceleration at SNR, localized SNR, ...) give a contribution?
- Dark matter annihilations give a contribution?
- There is no excess (non-standard diffusion)
- ...

# Is there an excess in $e^+/(e^++e^-)$?

- There are claims (see e.g. Waxman's talk Wednesday, arXiv:0907.1686) that there is no excess.
- It is certainly possible to be consistent with Pamela without primary sources, but we then need to give up the 'standard' diffusion model.
- Will here assume 'standard' diffusion, in which there is an excess

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# Electron and positron background

- The conventional diffuse background model is from Strong et al, 2004. It essentially contains
  - a primary electron and proton injection spectrum,
  - propagation and interactions, producing secondary electrons and positrons (and gammas)
- It needs input from other data and parameters need to be fit to all current cosmic ray data
- The current conventional model is from 2004 (pre-Fermi) and clearly needs updating

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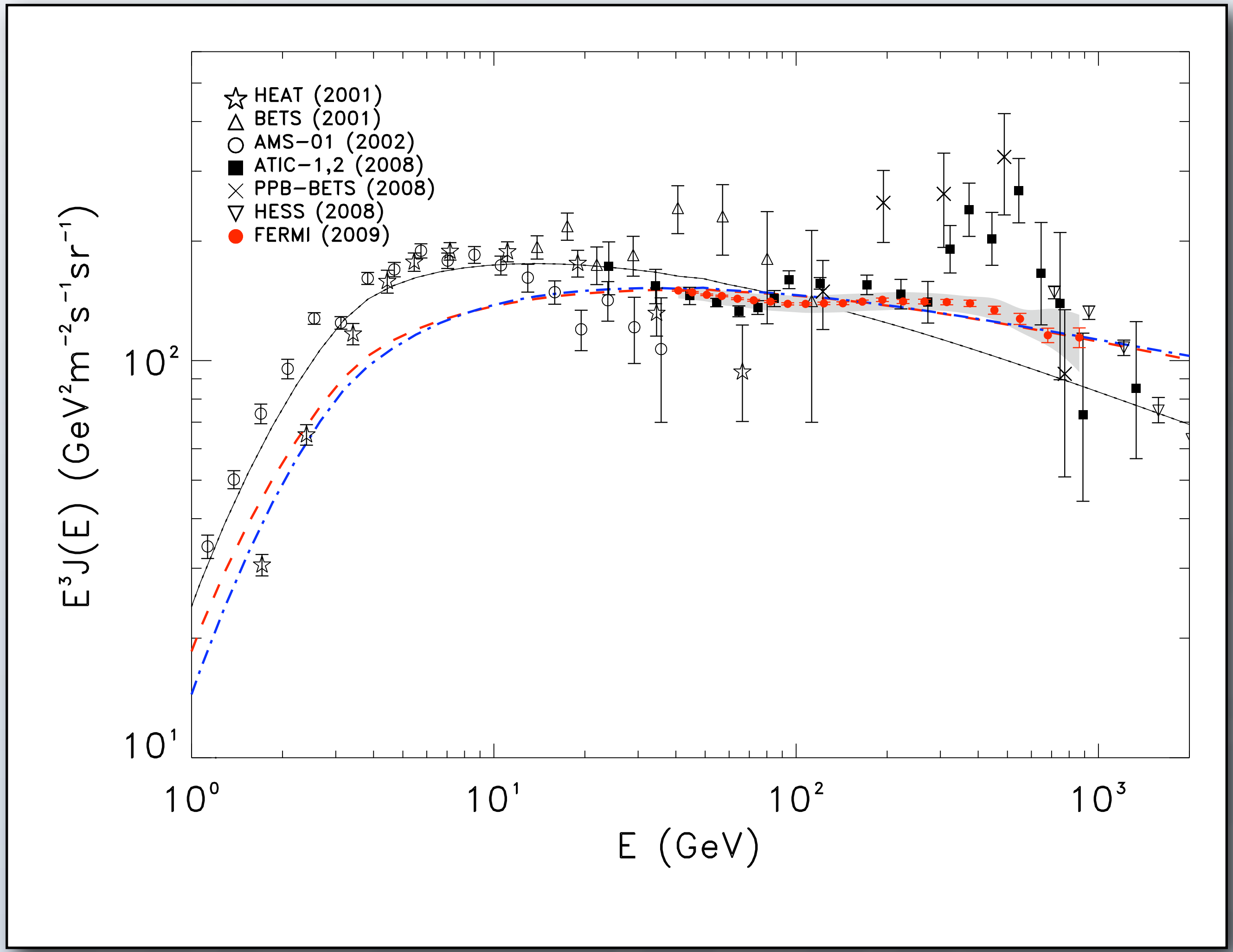
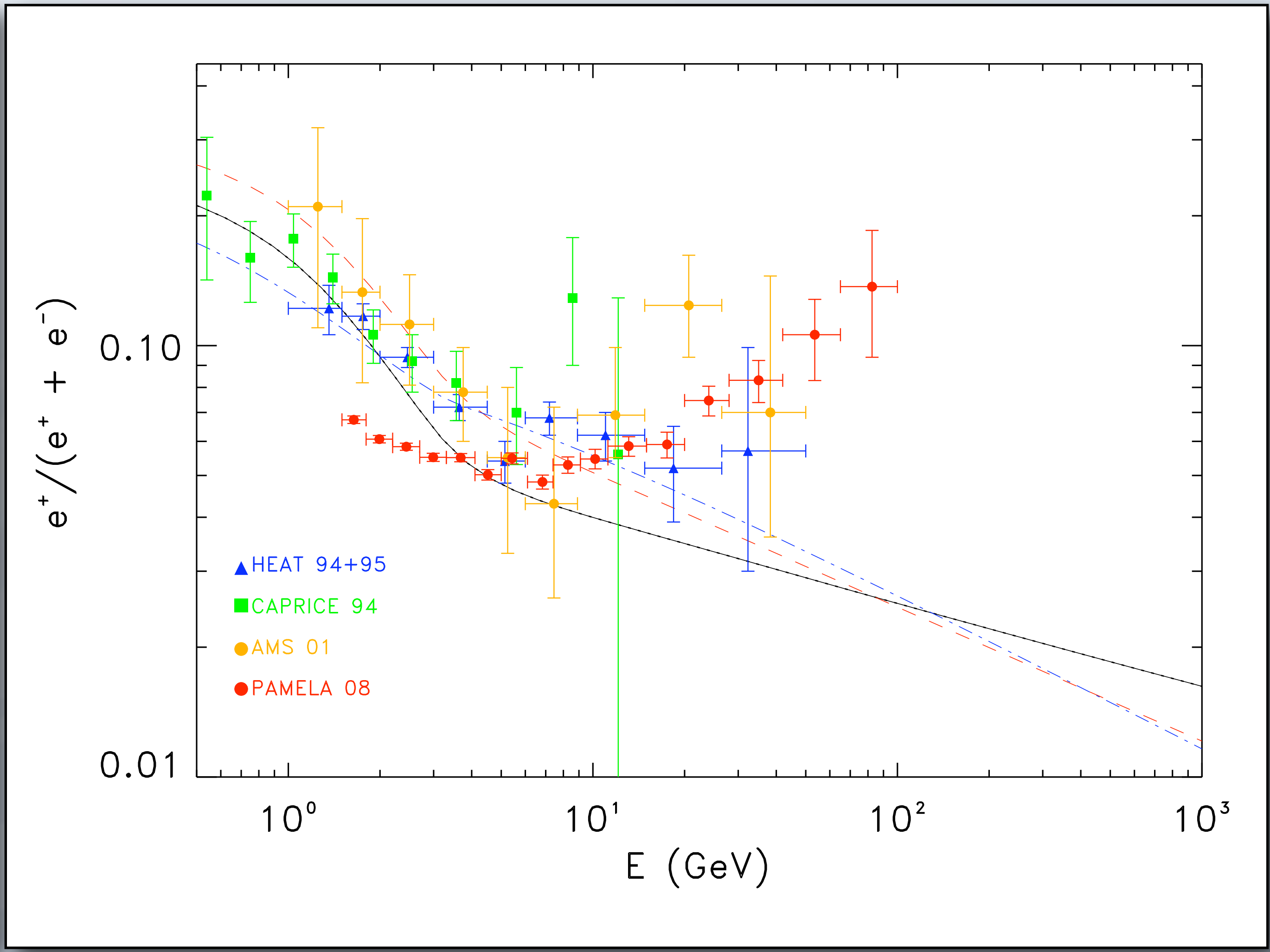
# Background fits

By changing the injection spectrum of electrons, we can get a better fit to the $e^{+}+e^{-}$ data



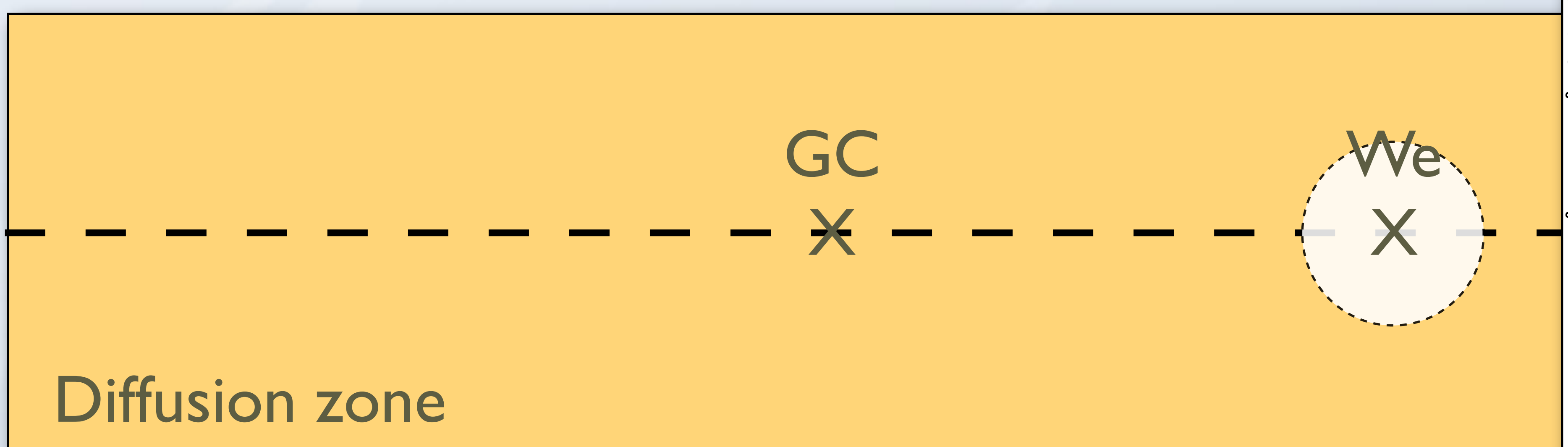

...but it does not fit the positron fraction at all (and does not fall off at ~1 TeV, probably due to how local sources are treated)

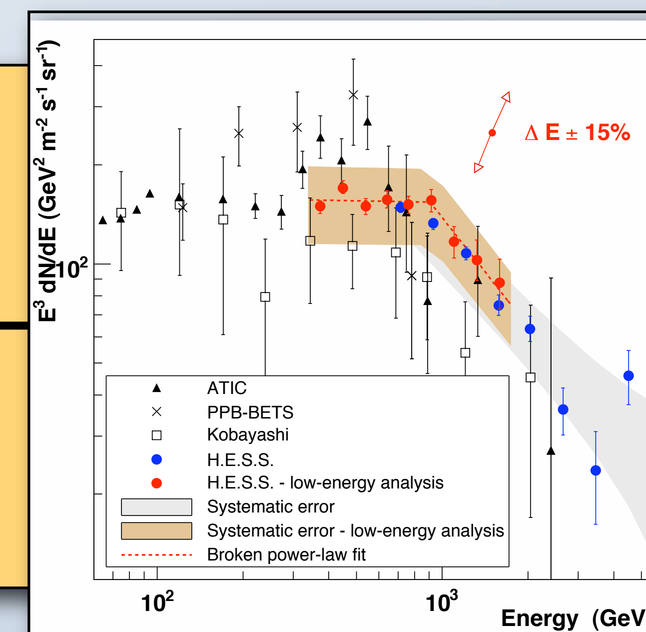
A primary positron source seems to be needed.

Figs from Grasso et al, arXiv:0905.0636

# Background model

- Remember though: the background model (galprop) is never intended to be OK at the highest energies. It includes assumptions that are not expected to hold at the highest energies, e.g. a continuous source distribution




- One should really cut away the local sources and repopulate with known SNRs, pulsars. The break at 1 TeV seen in HESS data tells us that there are no very nearby sources

$$f(r,t,\gamma) = \frac{N_0 \gamma^{-\alpha}}{\pi^{3/2} r^3} (1 - p_2\, t\, \gamma)^{\alpha-2} \left(\frac{r}{r_{\rm dif}}\right)^3 \exp\left(-\left(\frac{r}{r_{\rm dif}}\right)^2\right)$$

Sharp cut-off for distant sources

# Pulsar interpretation

- Many nearby pulsars known to exist
- Exact physical acceleration mechanisms not known, models exist though
- Accelerated electrons and positrons could be released into the ISM. Need mature pulsar to allow time for them to be released ($\sim 10^5$ years)

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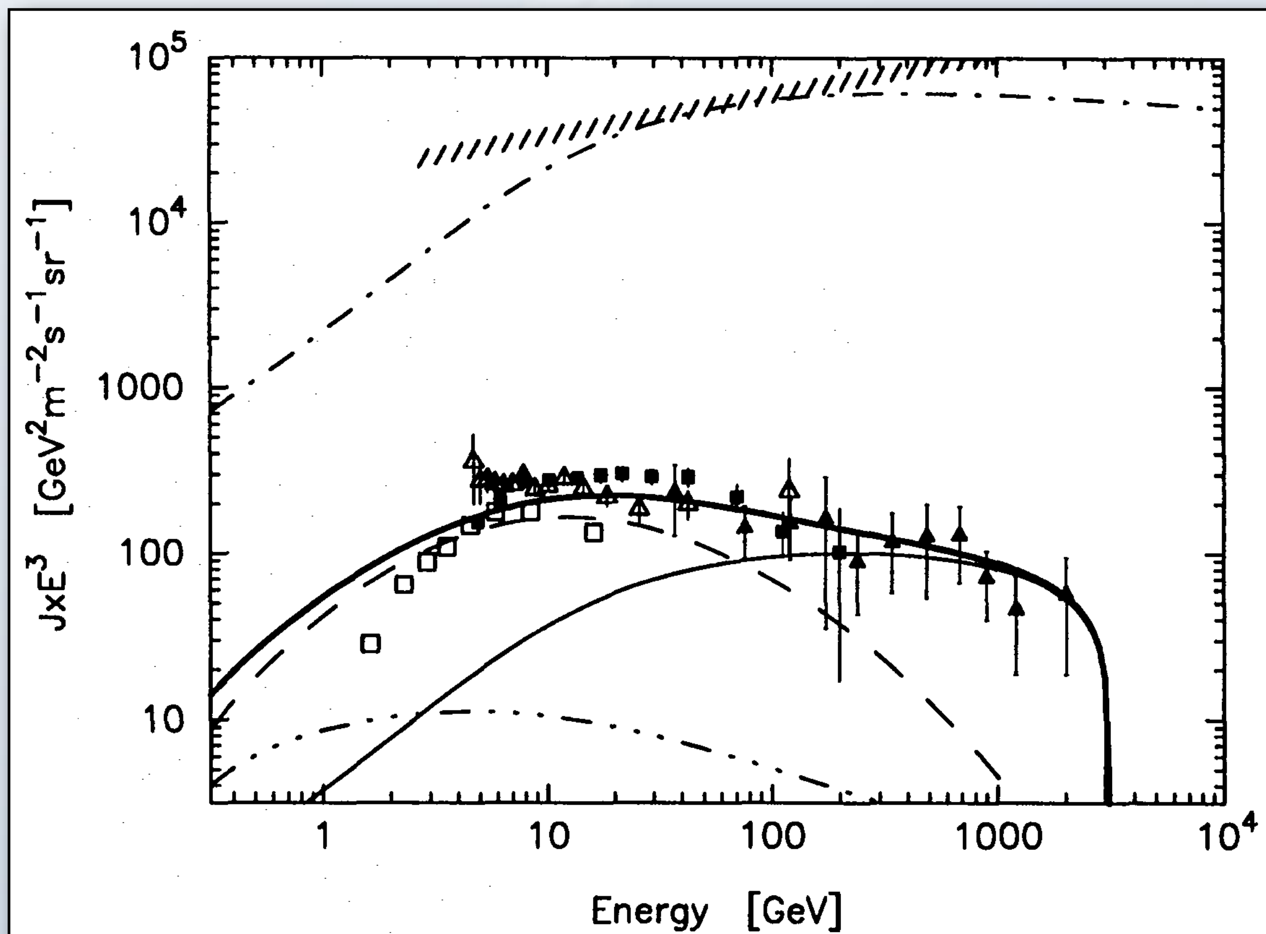
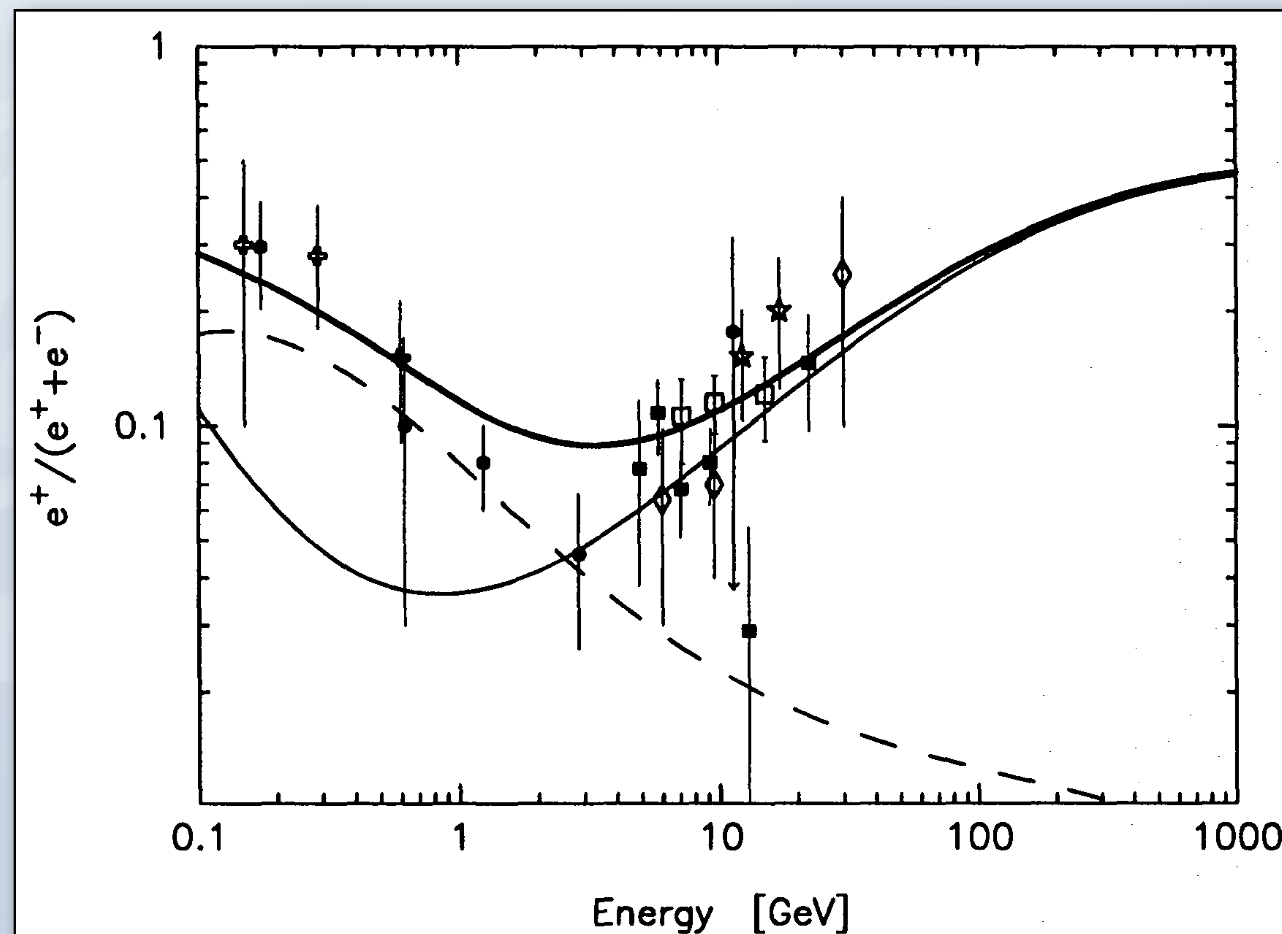
# Pulsars

Nearby pulsar (Geminga @ 100 pc) can give significant contribution to the electron and positron fluxes

**Electrons**




**Positron fraction**

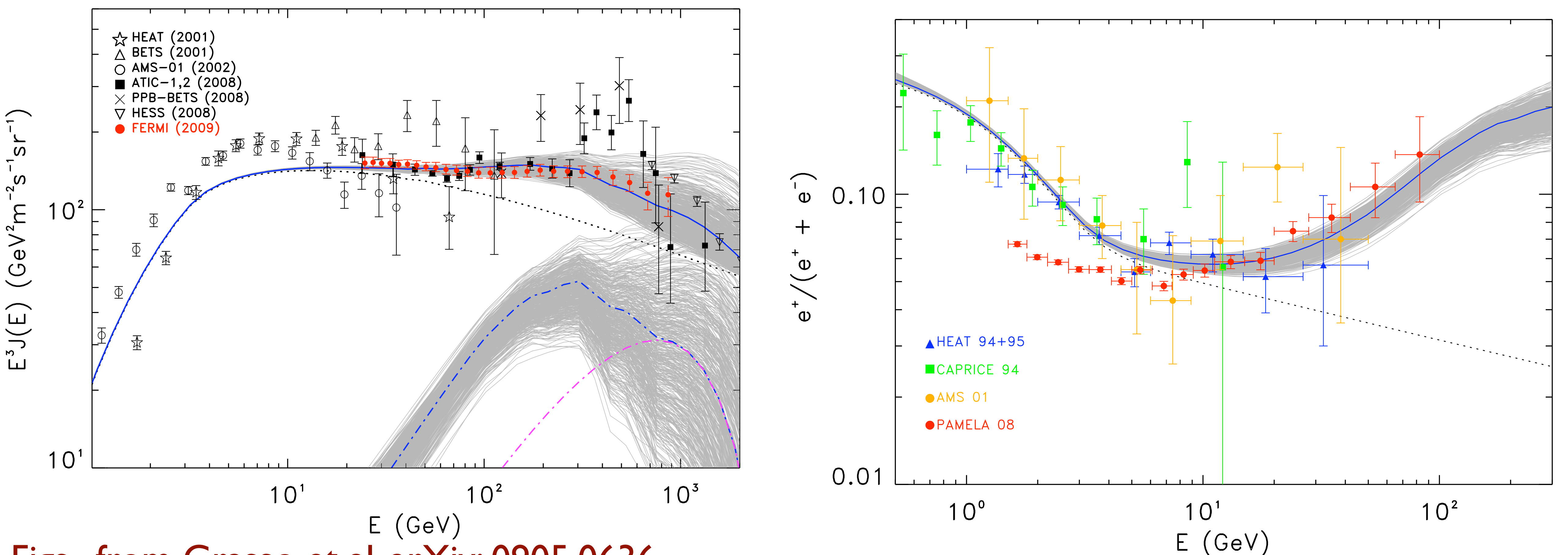



F.A. Aharonian, A.M. Atoyan and H.J. Völk, A&A 294 (1995) L41.

# Pulsar modelling

Nearby sources with hard injection spectrum, $E^{-(1.5-1.7)}$

$e^+ + e^-$ | $e^+$ fraction




Figs. from Grasso et al, arXiv: 0905.0636

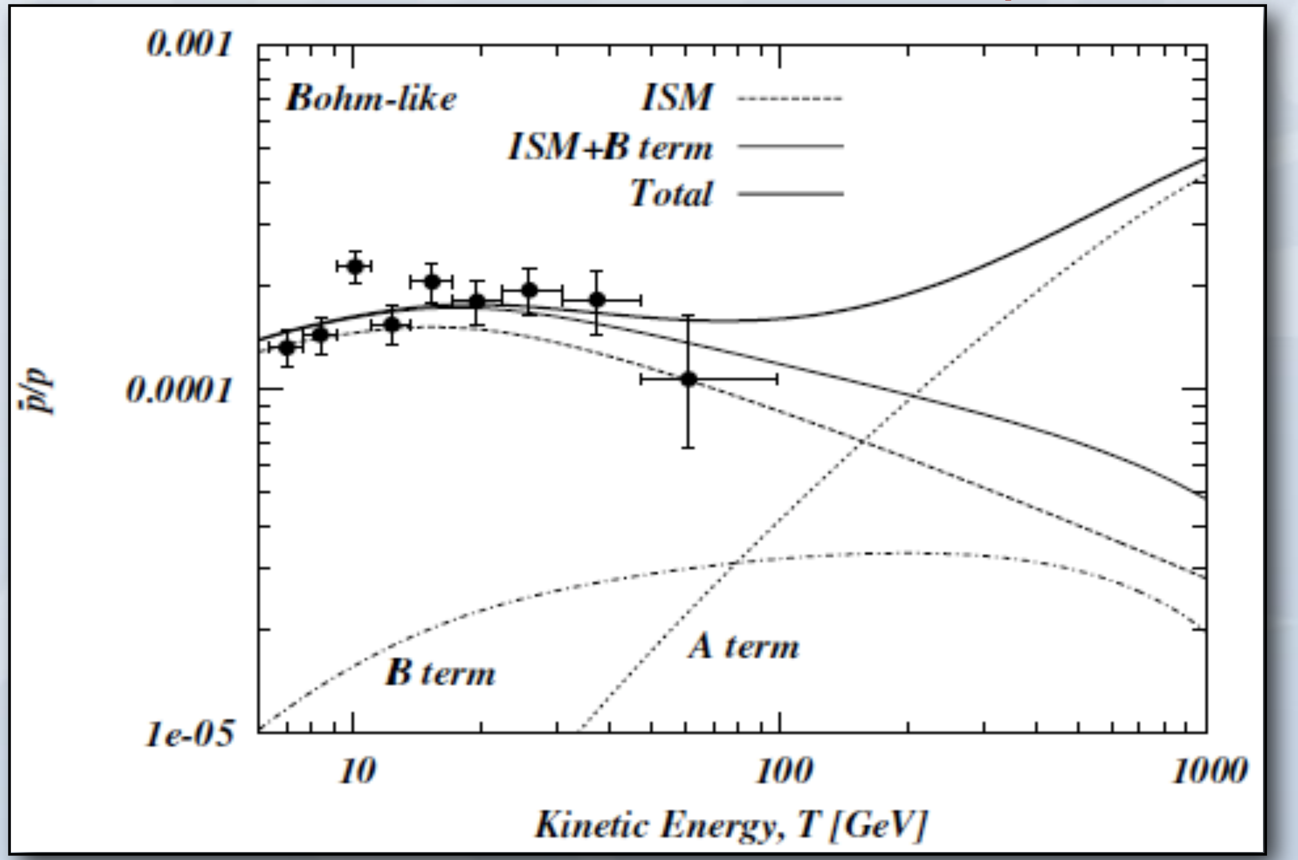
- Are pulsars with the hard spectral index (1.4–1.7) OK? How do we get the electrons and positrons out keeping the spetrum so hard?
- Are the properties of the nearby pulsars consistent with CRs and gammas elsewhere in the galaxy?

See talk by Arons, Wed

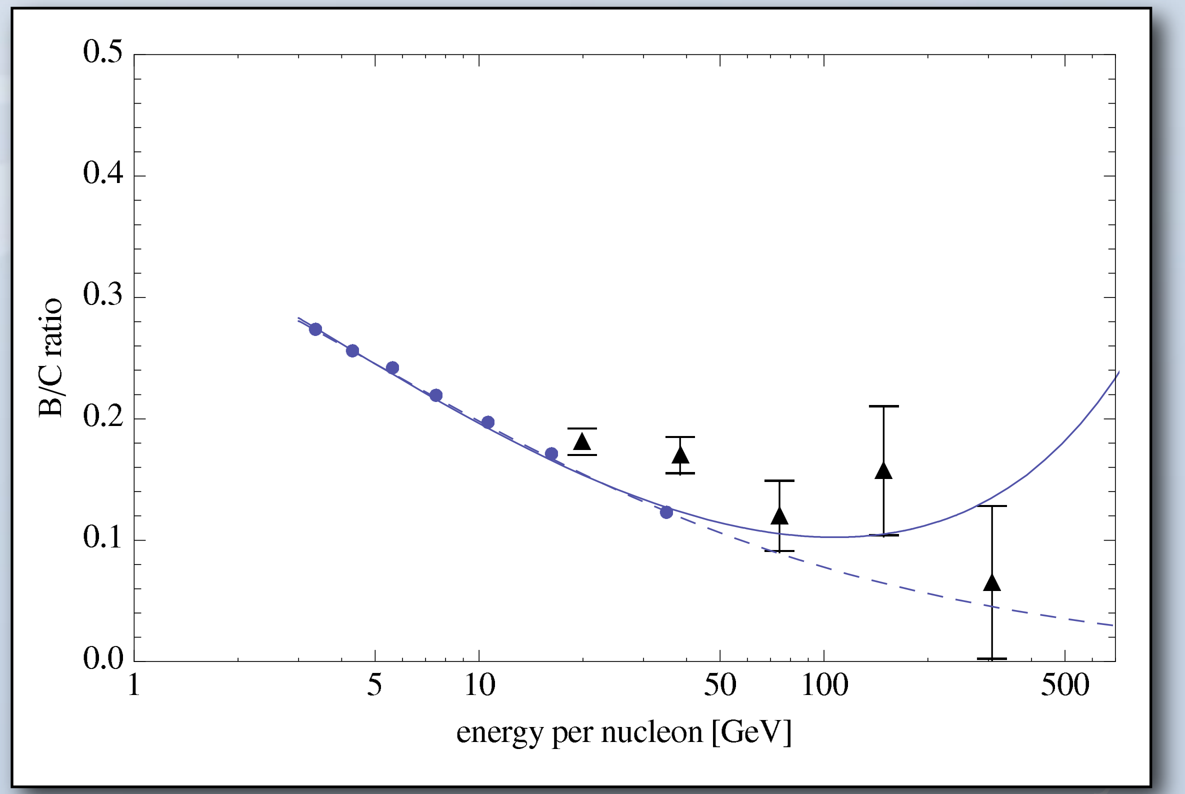
# Reacceleration at old SNRs

- Reacceleration at old SNRs could explain the data
- These models would predict rising antiproton/proton fractions and rather high fluxes of secondary nuclei (see Mertsch's talk, Wed)
- Can be tested with e.g. PAMELA

Blasi & Serpico 2009

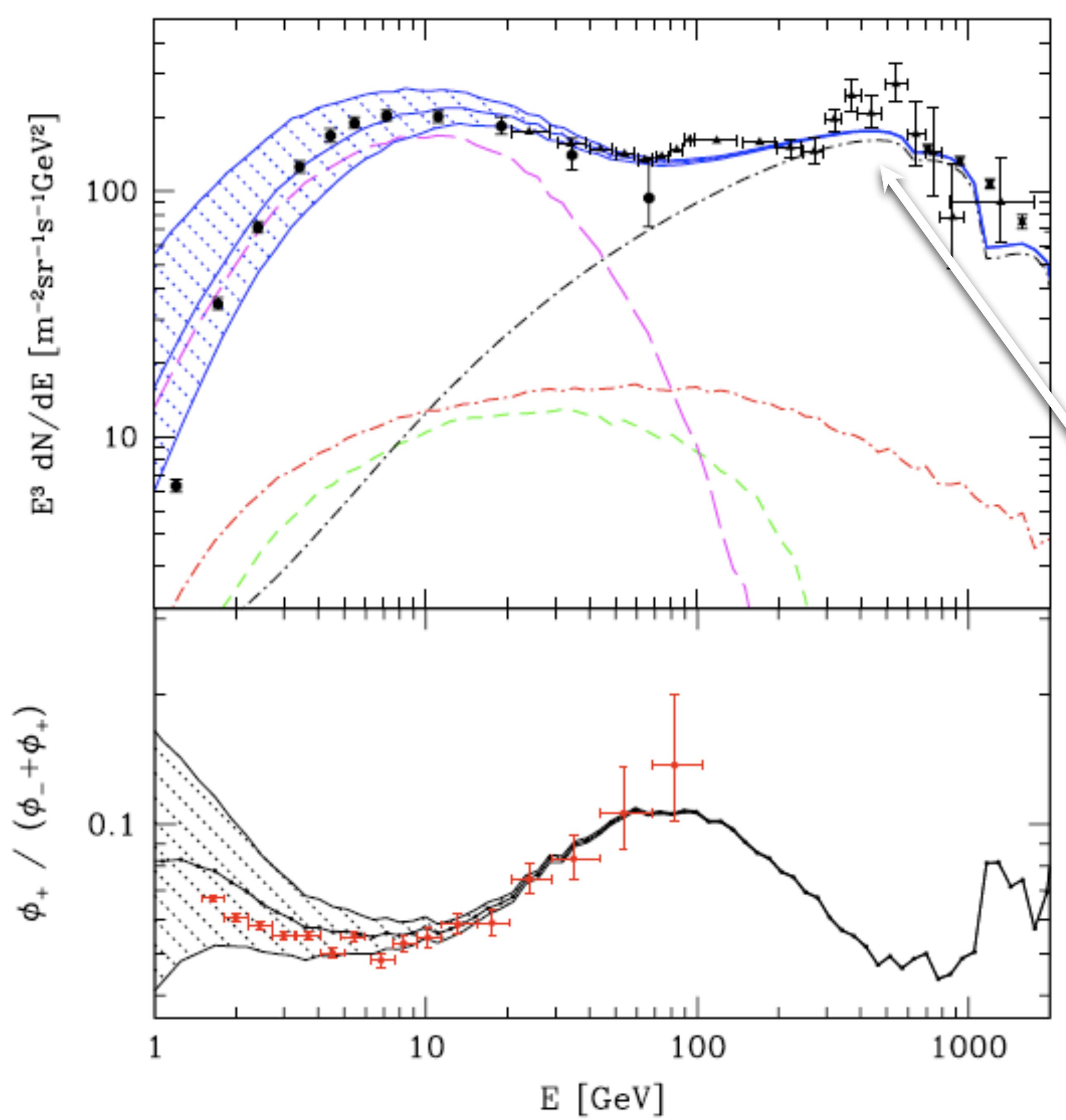



Mertsch & Sarkar, arXiv:0905.3152



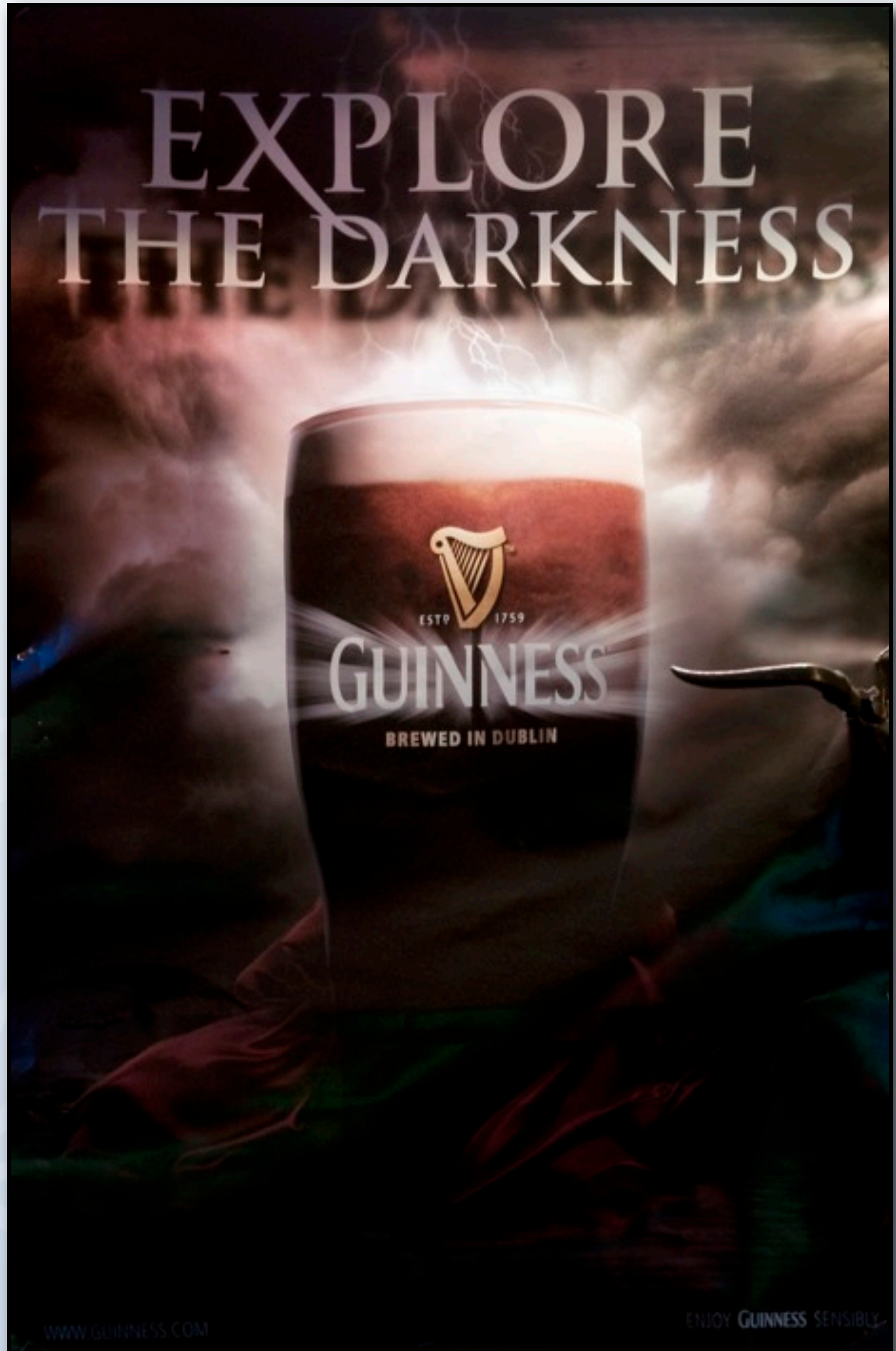
# Young (localized) SNRs

Piran et al, 2009




- Could explain current data
- Predicts that the positron fraction should peak at ~80 GeV. Can be tested with PAMELA.
- B/C could provide a test as well
- Electron and positron fluxes (separately) at higher energies should test these models as well.

**Contribution from nearby KNOWN young SNRs: Geminga, Monogem, Gela LoopI and Cygnus Loop**

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# Dark matter

- Many papers trying to explain the PAMELA and Fermi data (and before that PAMELA and ATIC data).
- Will not go through them all, but focus on simple leptonic models and see what the consequences would be if this interpretation is correct

See also e.g.
- Grasso et al, arXiv:0905.0636
- Meade et al, arXiv:0905.0480
- Kane's talk Monday
- ...

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# Dark Matter interpretation

L. Bergström, J. Edsjö & G. Zaharijas, arXiv:0905.0333, PRL, in press

- We have computed the electron and positron spectra from dark matter annihilations and fit to Fermi, HESS and Pamela data. Will focus on models that fit all of these.
- We have assumed a 'standard' halo model with an isothermal sphere
- We have assumed a 'standard' conventional diffusion model with best-fit parameters to other cosmic ray data (model MED in Delahaye et al, 2008)

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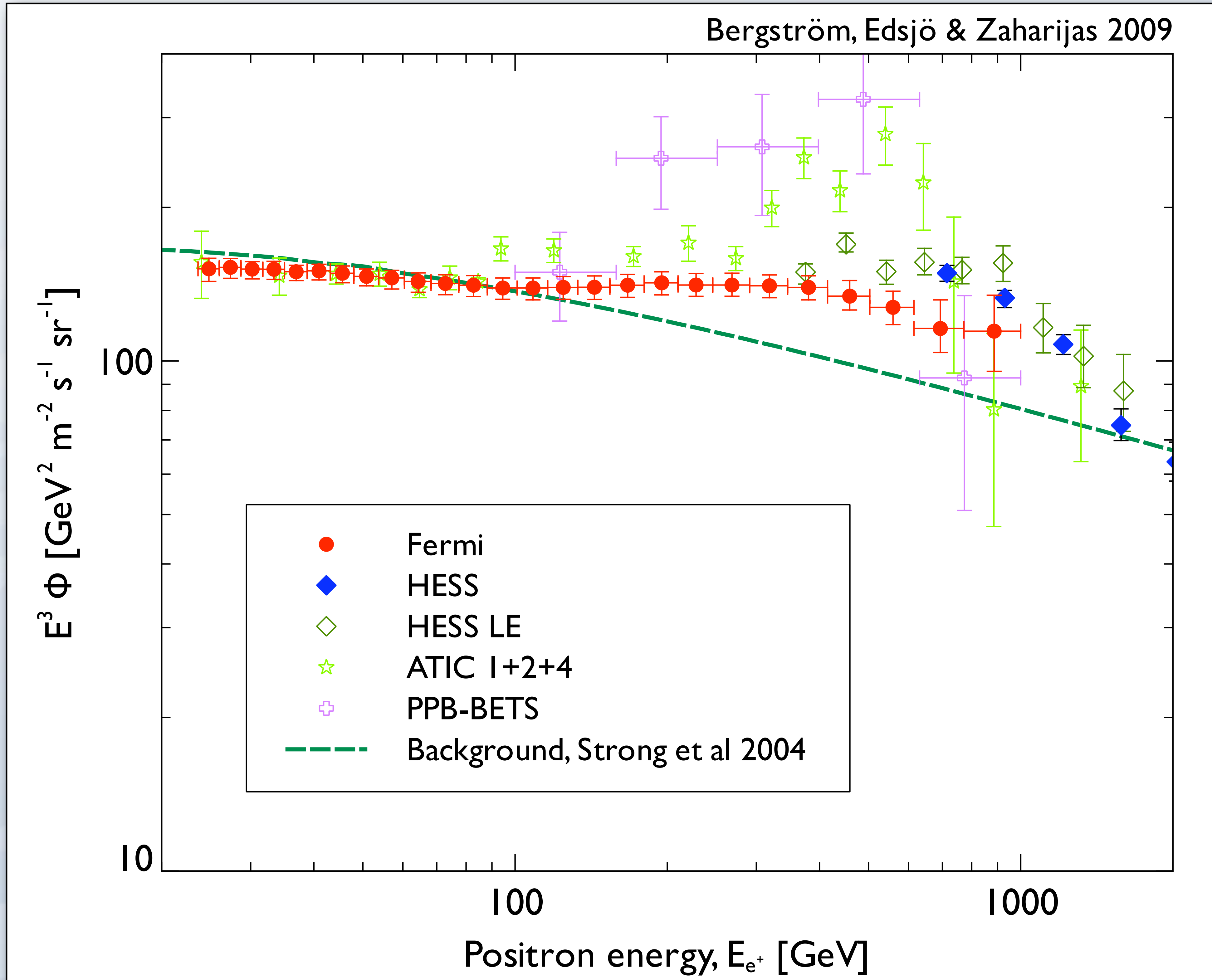
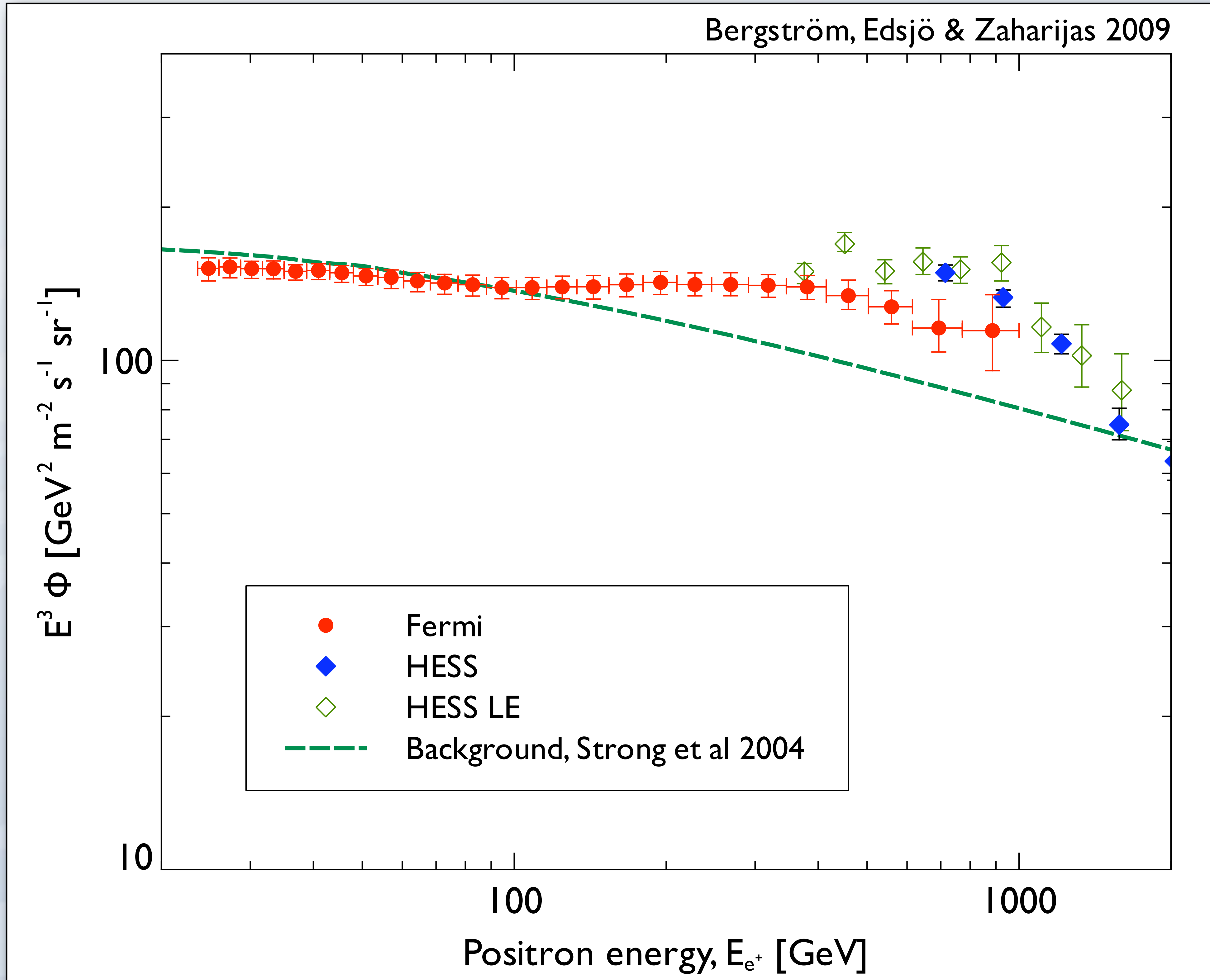
# Data and background - $e^+ + e^-$

- Status as of July 2009 with
  - Fermi-LAT, 2009
  - HESS 2008
  - HESS LE 2009
  - PPB-BETS 2008
  - ATIC 1+2+4 2009
  - Conventional background, Strong et al 2004



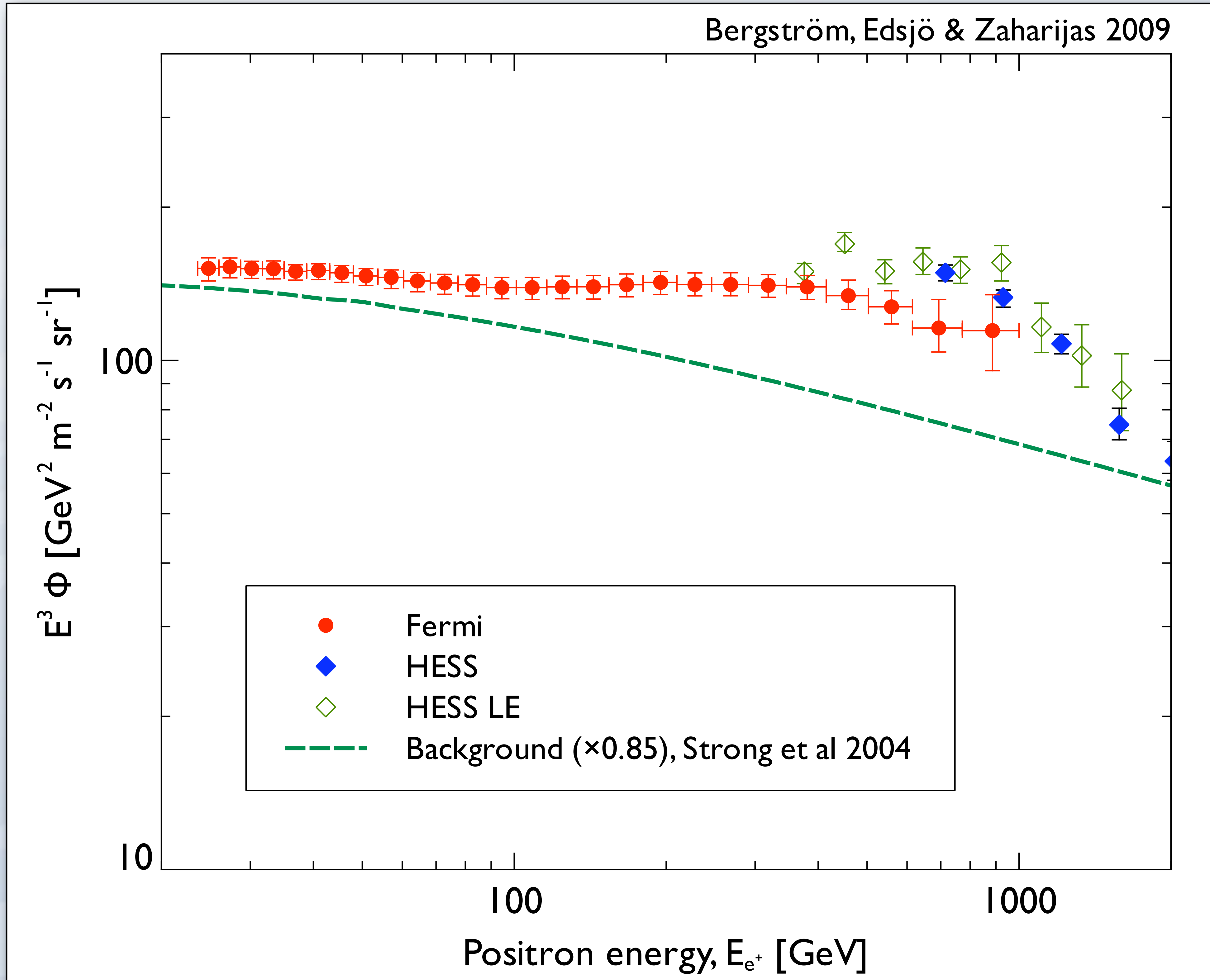
# Data and background - $e^+ + e^-$

- Remove ATIC and PPB-BETS for the moment (ATIC peak not seen by HESS and Fermi)



# Data and background - $e^{+}+e^{-}$

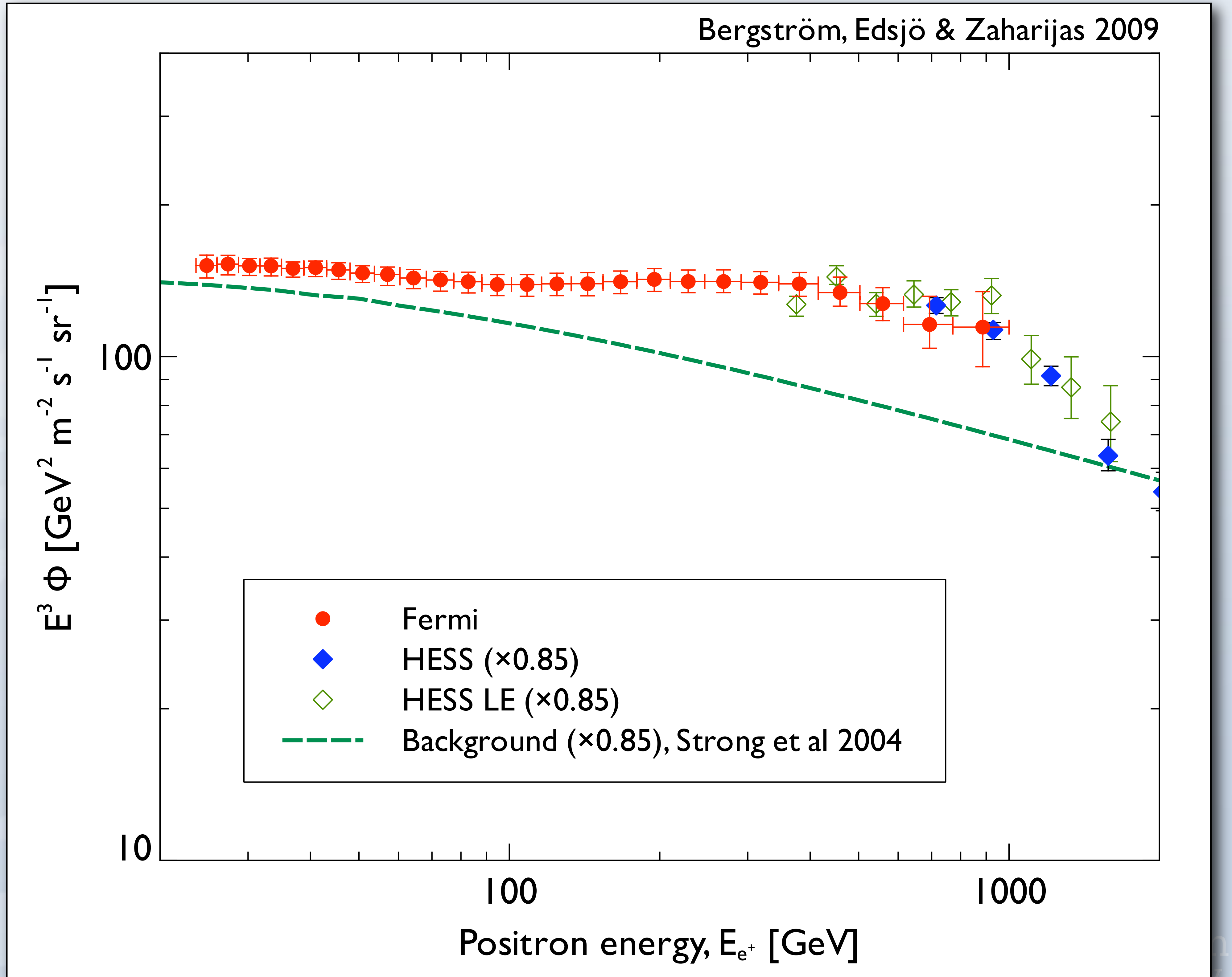
- Rescale background with factor 0.85 (within systematic uncertainties)



# Data and background - $e^+ + e^-$

- Rescale HESS with factor 0.85 (within systematic uncertainties)

- Good agreement between Fermi and HESS data.
- Background falls too steep.



# A note about propagation

- As we are mostly interested in the high-energy electrons/positrons, the exact details of the diffusion model does not matter too much. We then use a 'standard' setup and define an enhancement factor that includes the effects of changes to the model:

Local DM density

Energy loss parameter

Boost factor from Sommerfeld enhancement and/or substructure

$$E_F = \left( \frac{\rho_0}{0.3 \ \mathrm{GeV\,cm^{-3}}} \right)^2 \left( \frac{\tau_0}{10^{16} \ \mathrm{s\,GeV^{-2}}} \right) B_F$$

Default values: $\rho_0$ = 0.3 GeV/cm$^3$ $\tau_0$ = $10^{16}$ s/GeV$^2$
Note though:
$\rho_0$ could be higher (Ullio & Catena '09 find $\rho_0$ = 0.385±0.027 GeV/cm$^3$)
$\tau_0$ could be smaller due to higher local magnetic fields and ISRF

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# Dark matter models

- To explain the excess, we need to have a DM model that
  - gives reasonably hard electrons and positrons without producing too many photons or antiprotons
- Models giving mostly muons are then favoured. We will try to avoid too much theoretical prejudice and instead consider these three types of models:
  - Leptonic models with 100% annihilation to $\mu^+\mu^-$
  - Arkani-Hamed et al (AH) type of models with annihilation to light scalars that decay mostly to muons (Arkani-Hamed et al, arXiv:0810.0713)
  - Nomura & Thaler (N) type of models with annihilation to light pseudoscalars that decay to muons (Nomura & Thaler, arXiv: 0810.5397)
- The latter two also naturally have Sommerfeld enhancements
- We fit with mass ($M_{DM}$) and enhancement factor ($E_F$) as our two free parameters.

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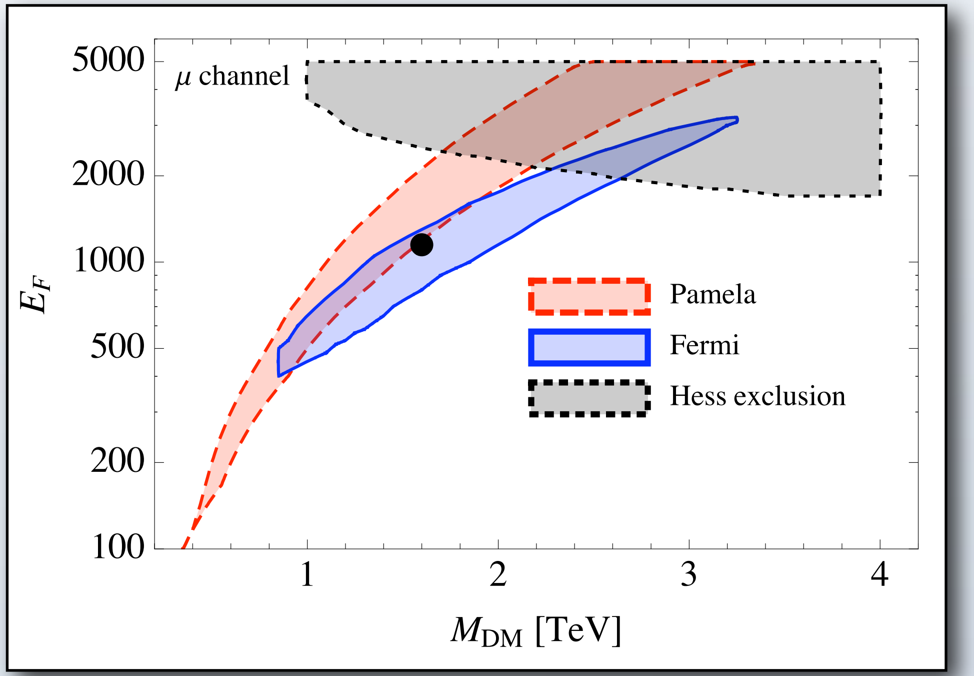
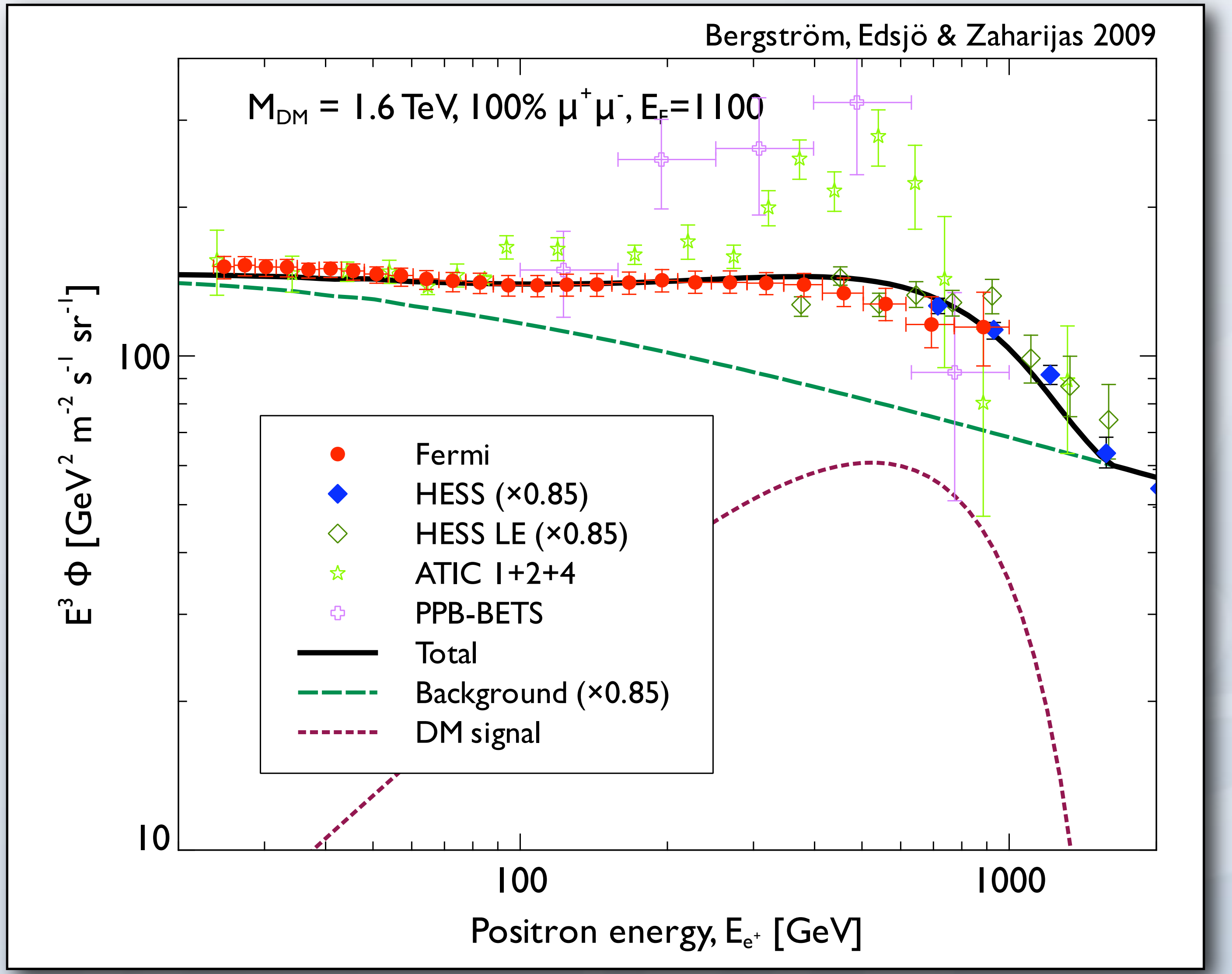
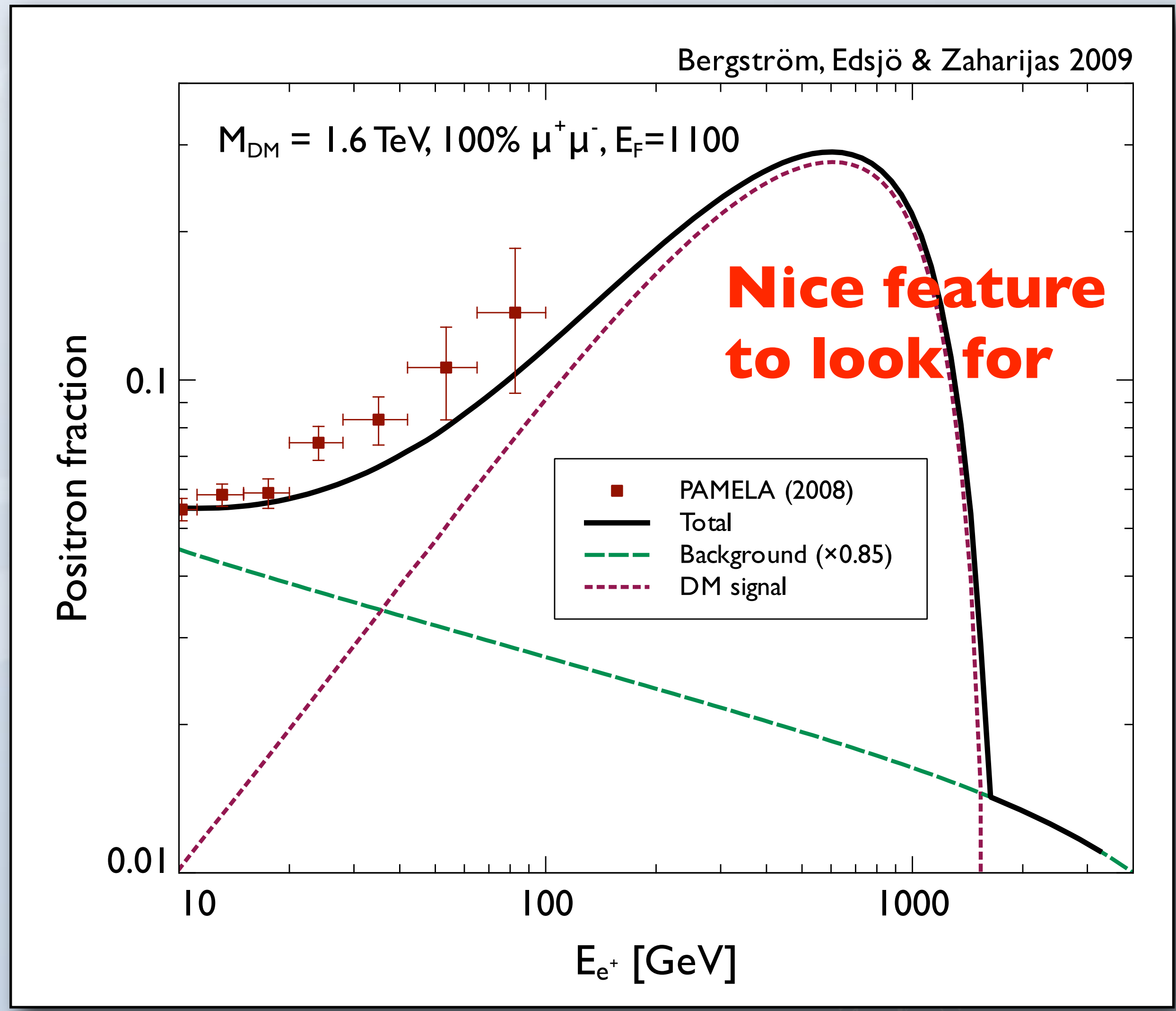
# Results – μ channel

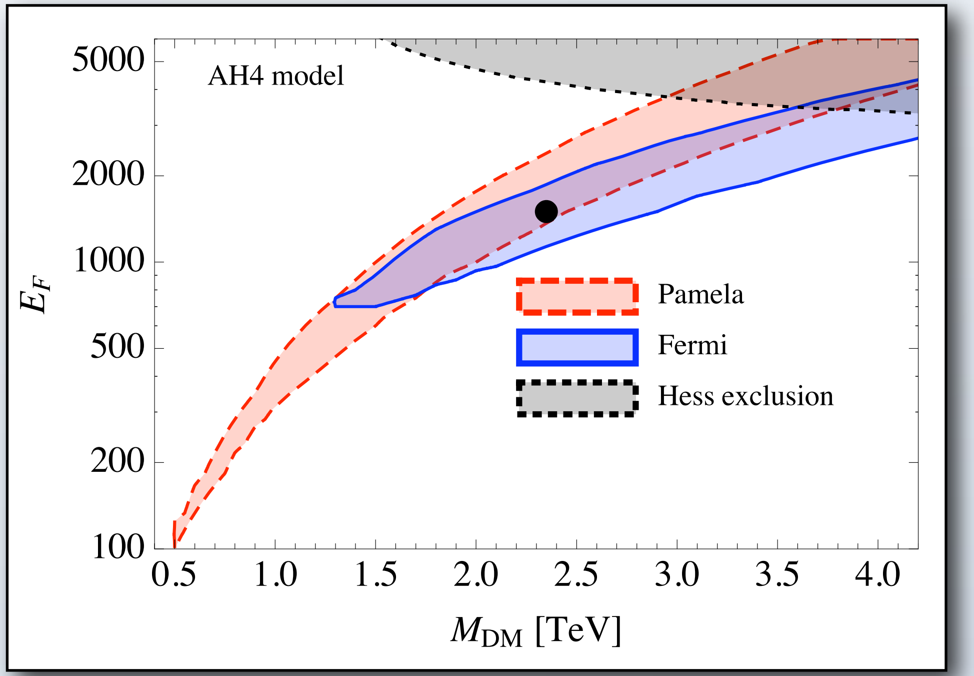


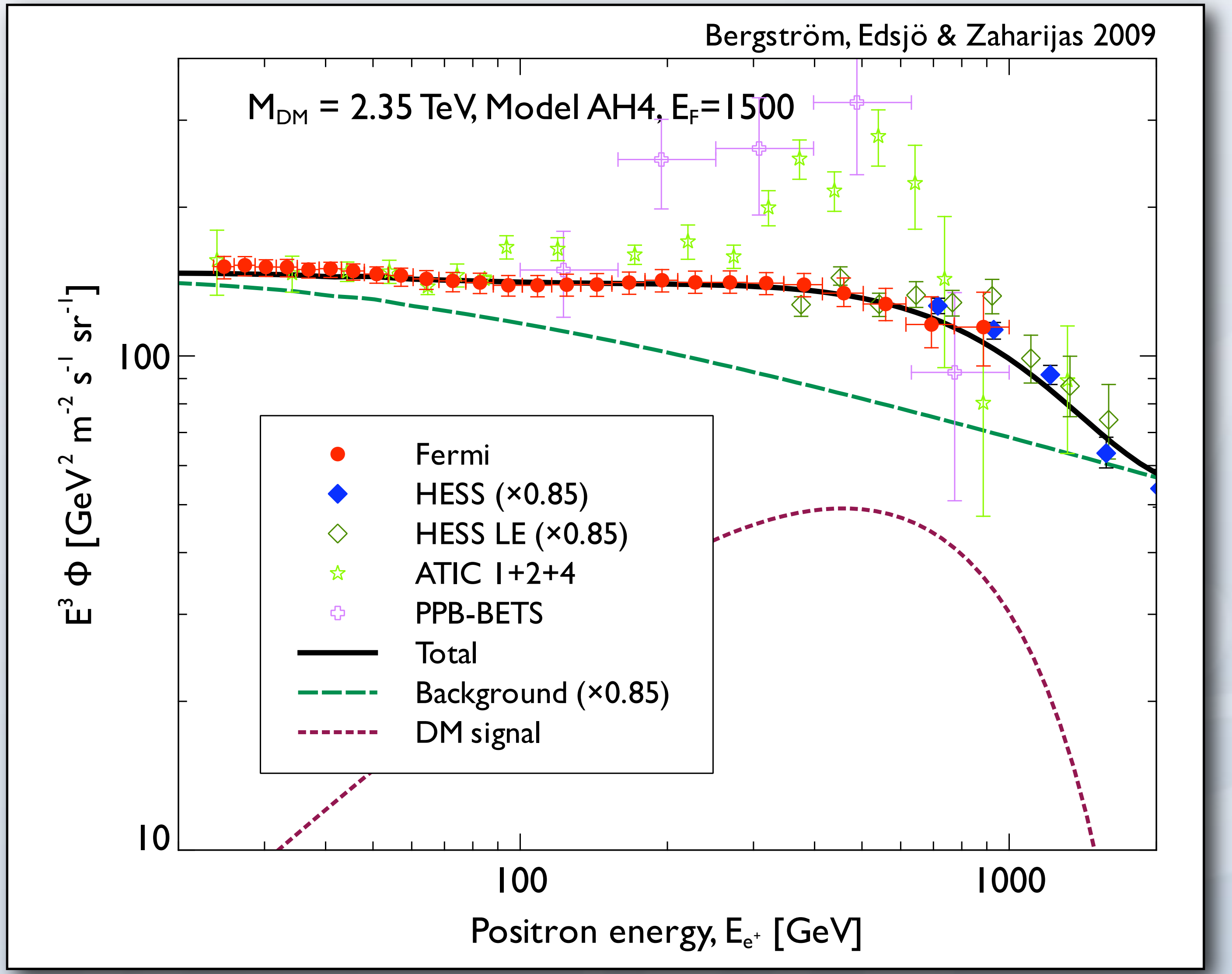



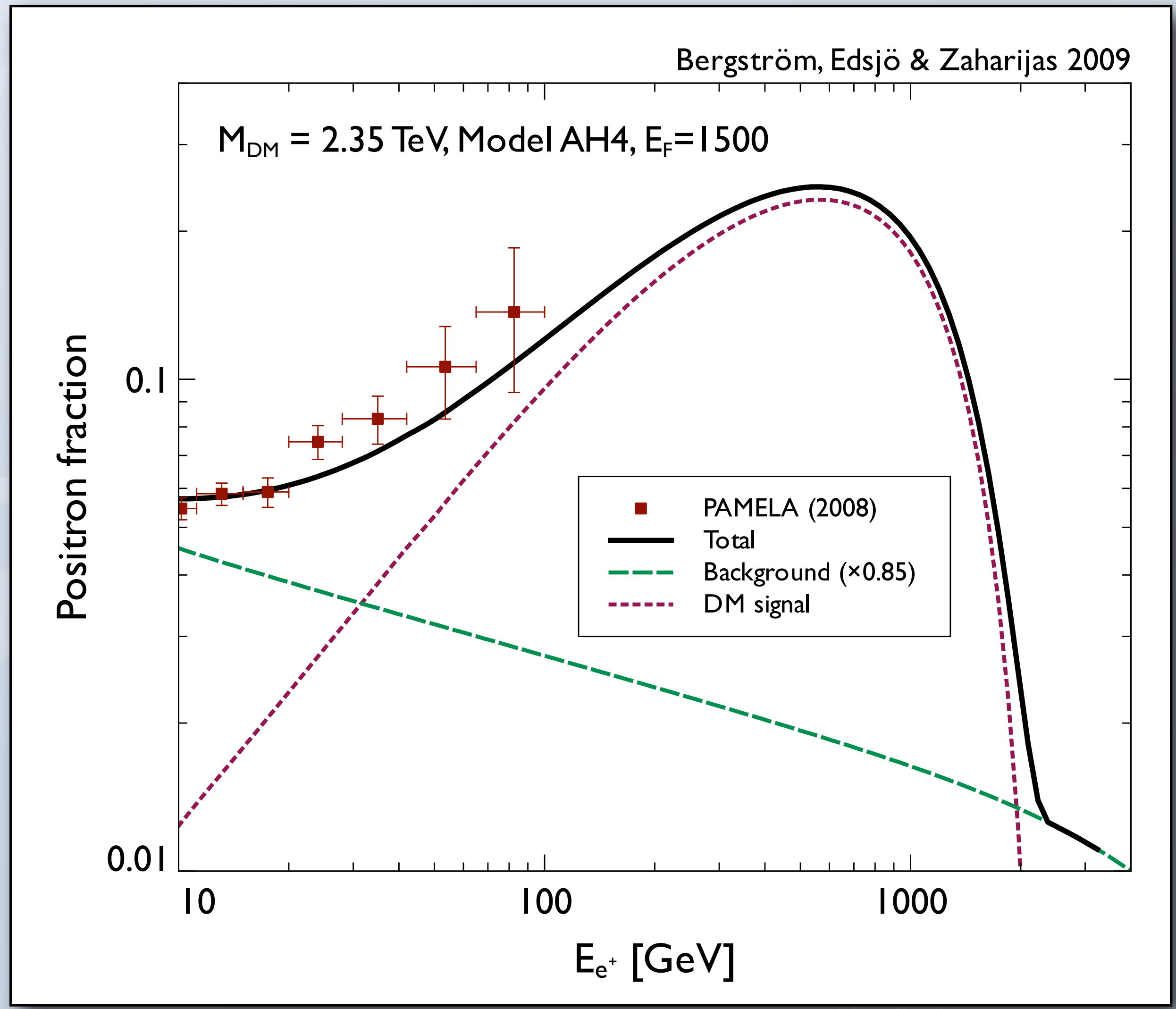




We get good fits to Fermi, HESS and PAMELA data

# Results – AH4 model



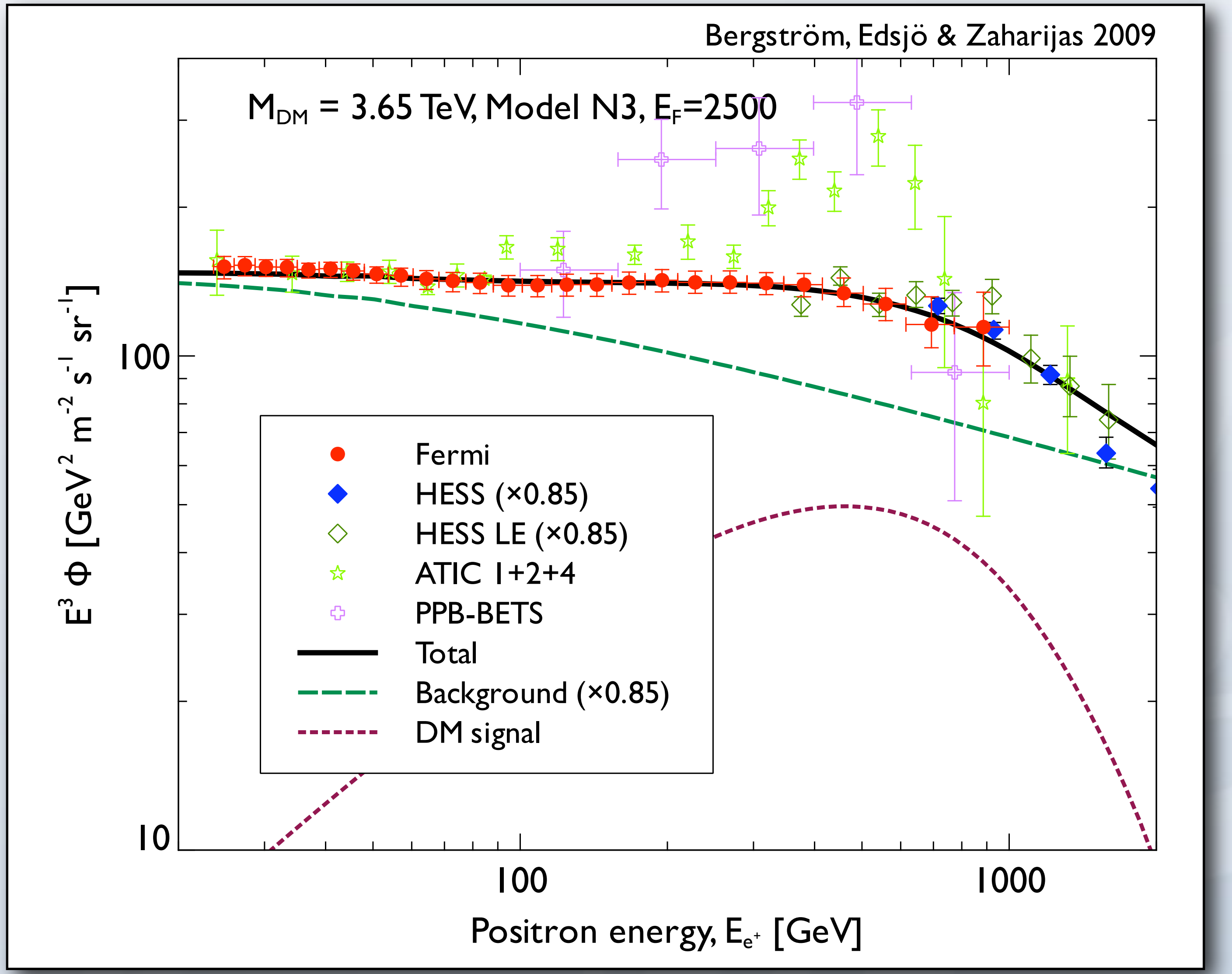



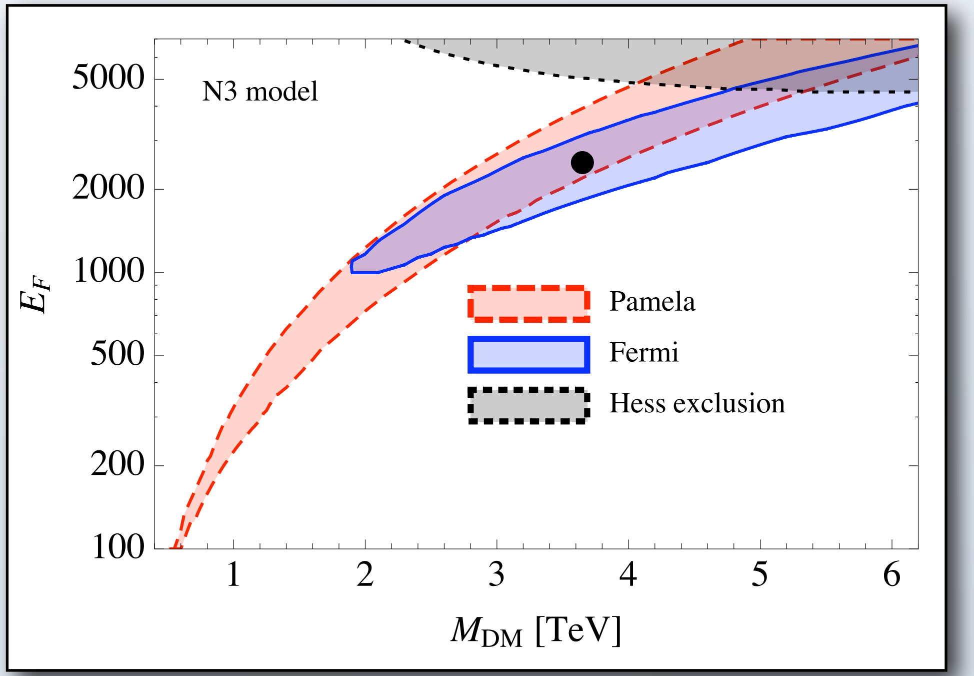



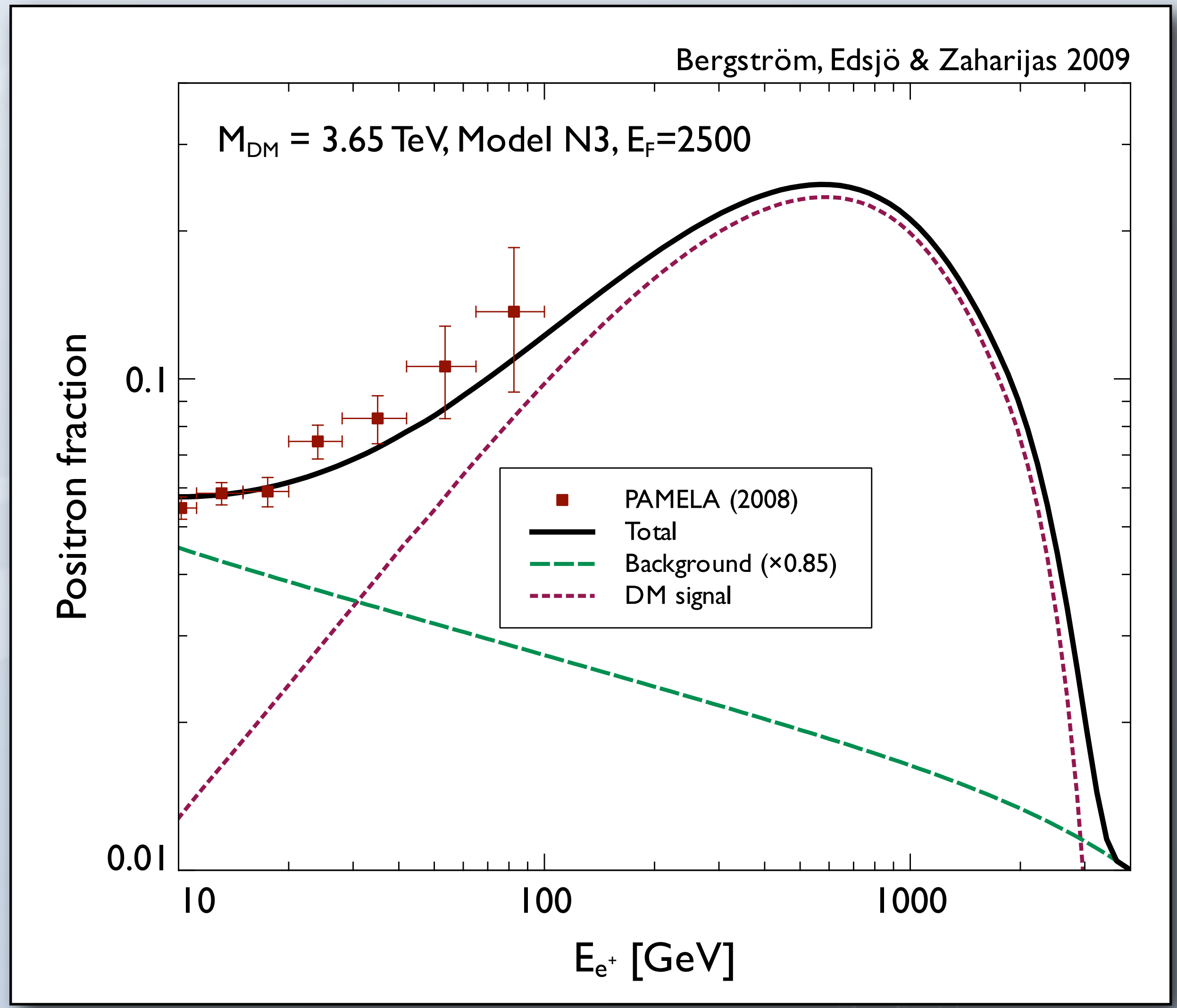

$$DM + DM \to \phi\phi, \phi \to \mu^+\mu^-$$

$$m_\phi = 0.25 \text{ GeV}$$

# Results – N3 model




$$DM + DM \to sa, a \to \mu^+\mu^-, s \to aa$$

$$m_s = 20 \text{ GeV} \qquad m_a = 0.5 \text{ GeV}$$

# Fits

- We can get very good fits to both Fermi, HESS and PAMELA data with 'off-the-shelf' halo, diffusion and background models
- Masses in the range 1–4 TeV fit well
- However, we need to assume enhancement factors of the order of 1000 (e.g. from Sommerfeld enhancements).
- Note: we have focused on muons as they give very good fits. Some electrons and tau leptons are certainly also possible though.

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# Constraints from the galactic centre and dwarf spheroidals

- These models just barely escape gamma and synchrotron constraints from the galactic centre and dwarf spheroidals (Bergström et al, arXiv:0812.3985)
- For a steeper halo profile than the isothermal sphere considered here, the models would be excluded (too much synchrotron radiation/gamma)

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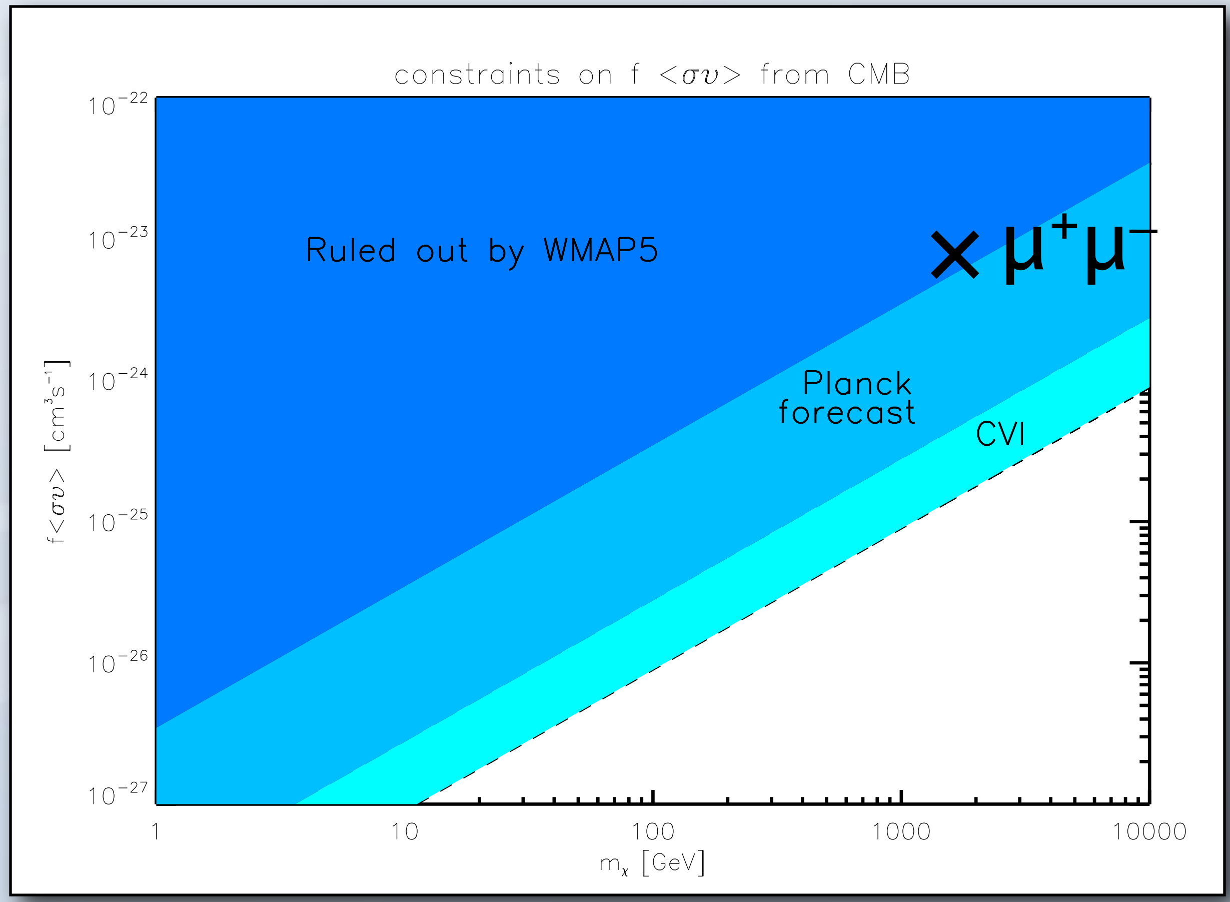
# Constraints from the CMB

See talks by Slatyer and Iocco, Tuesday!

- For Sommerfeld enhanced models (AH & N models), effects could also arise in the cosmic microwave background radiation. The models we have considered here are (just barely) OK with current constraints, but can be probed with Planck (launched May14!).

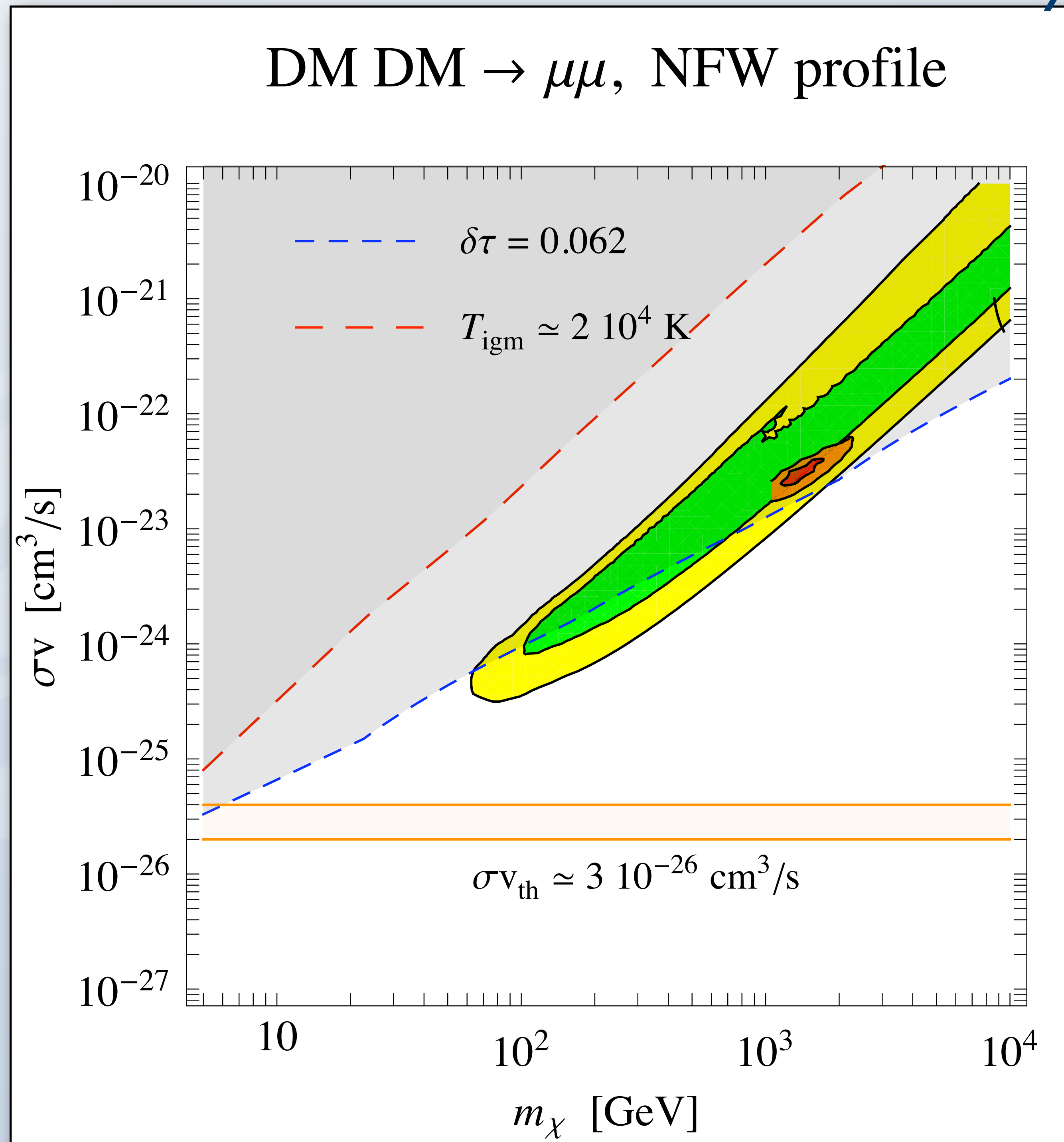



Galli et al, arXiv:0905.0003;
see also Slatyer et al, arXiv:0906.1197)

# Constraints from heating and reionization of the intergalactic gas

See Iocco's talk Tuesday

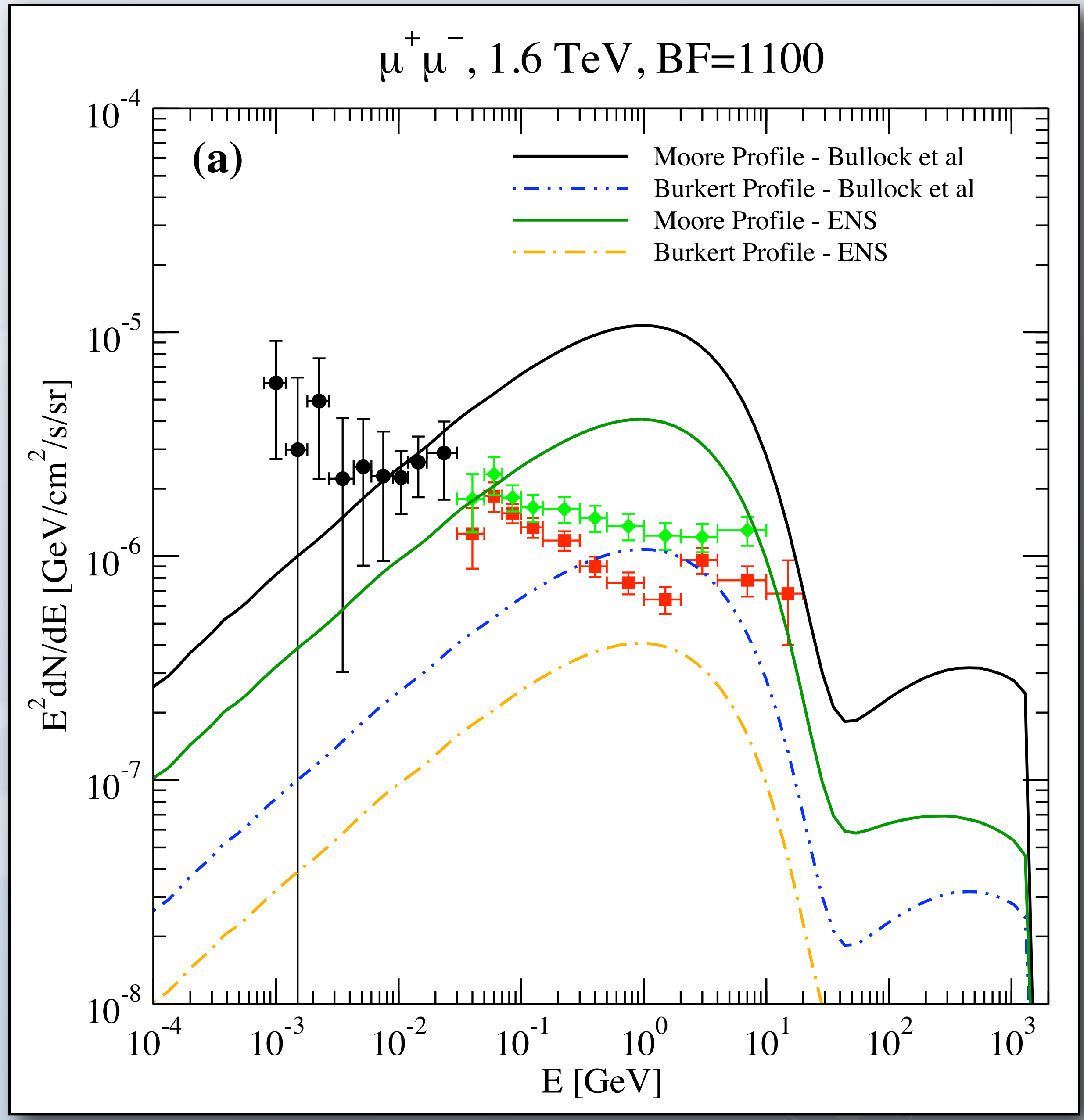
- DM annihilations would at time of structure formation heat and reionize the intergalactic gas
- Measurements of the optical depth constrain the amount of heating and reionization allowed
- Current models are (given the uncertainties) just barely OK with current constraints




Cirelli et al, arXiv:0907.0719; see also Hütsi et al, arXiv:0906.4550

# ICS on CMB also gives constraints

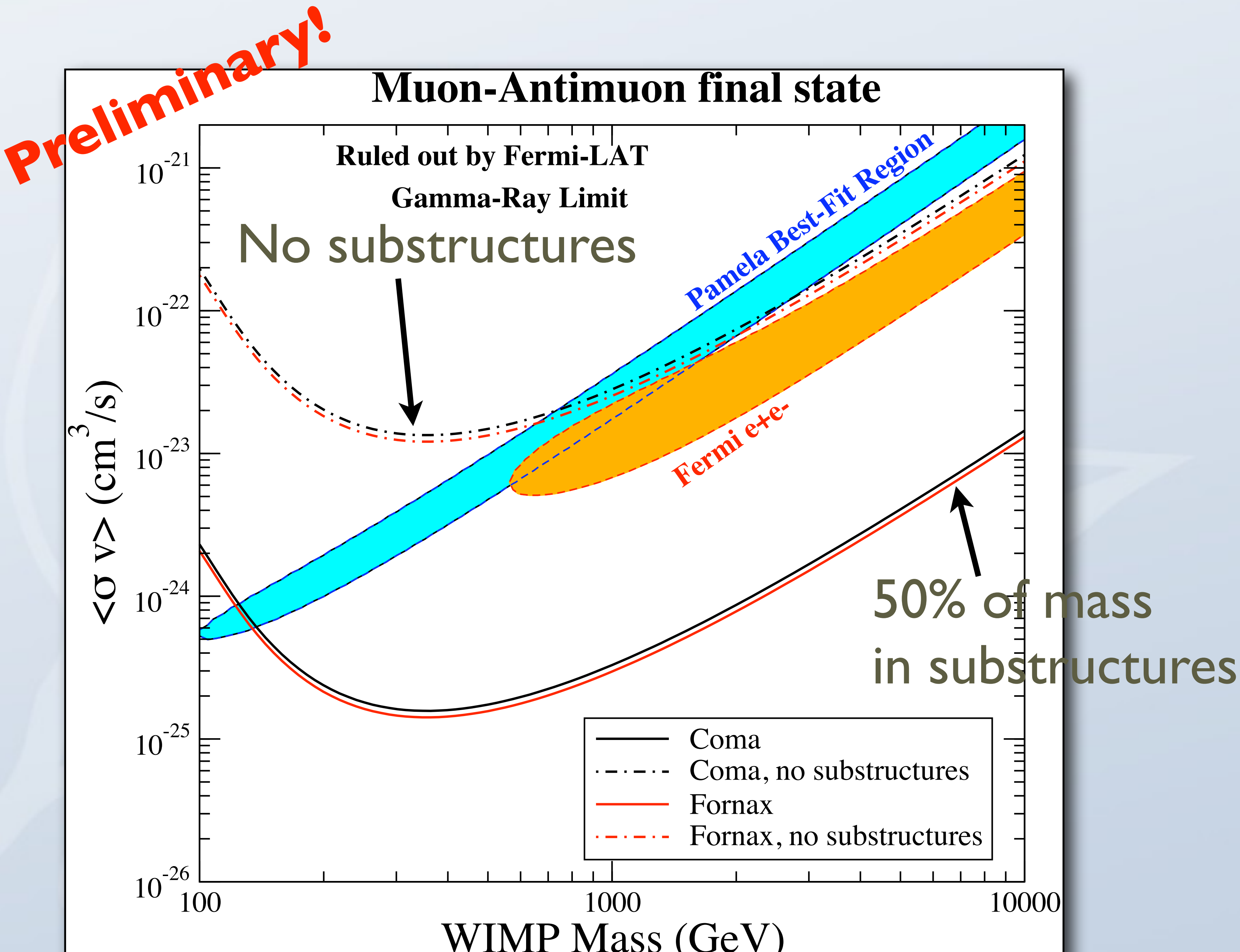
- Inverse Compton Scattering on the CMB in cosmological halos can give a contribution in gamma rays
- For optimistic halo models and structure formation setups, these models are excluded, but for more conservative models, these DM models are OK




Profumo & Jeltema, arXiv:0906.0001
See also Belikov & Hooper, arXiv:0906.2251

# Galaxy clusters give constraints

**Fermi preliminary galaxy cluster limits, from Jeltema's talk Tuesday**

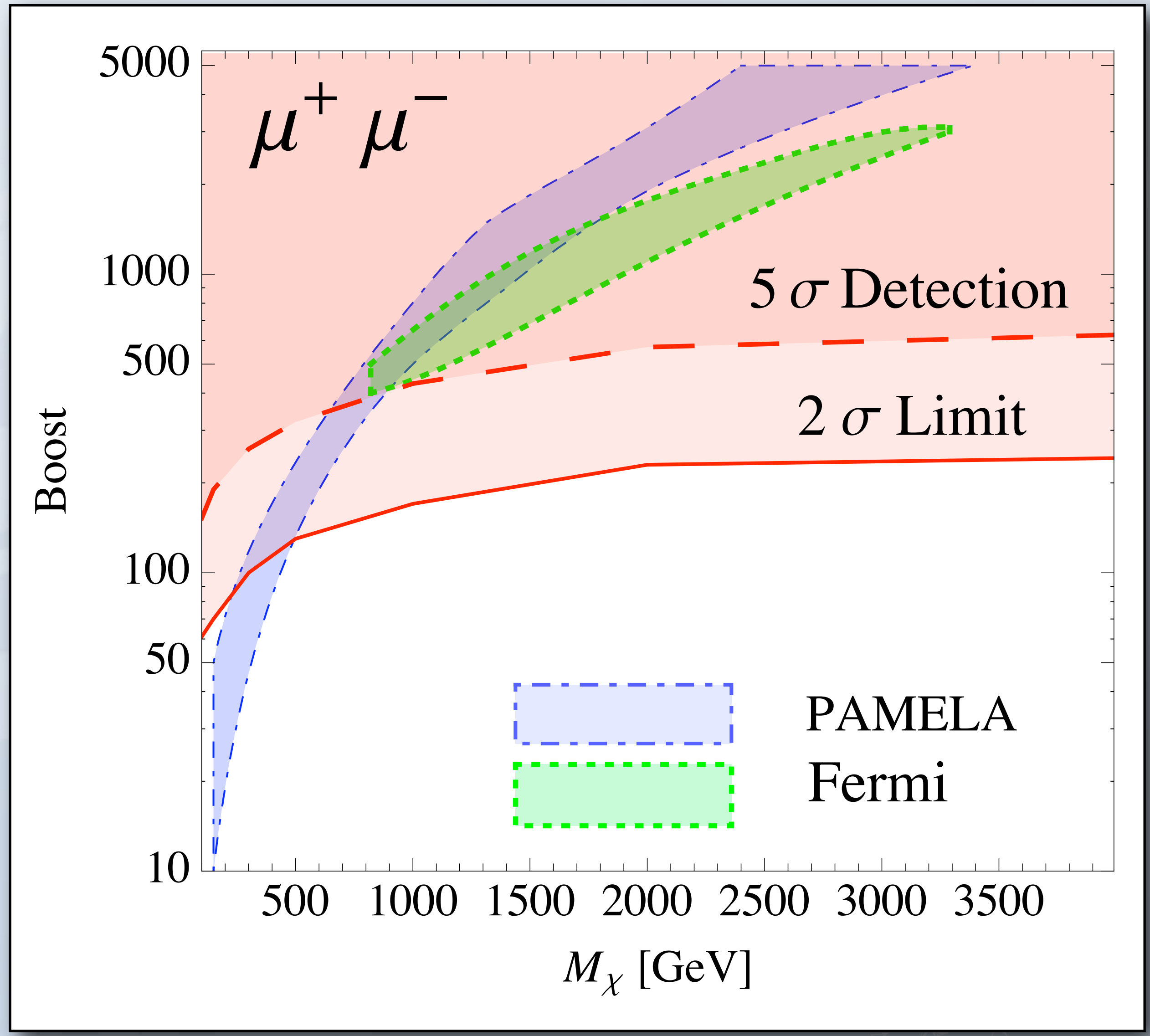



- Galaxy clusters also constrain these type of models.
- They are OK right now, but there is some tension, depending on how much of the mass is in substructure

# Constraints from neutrinos

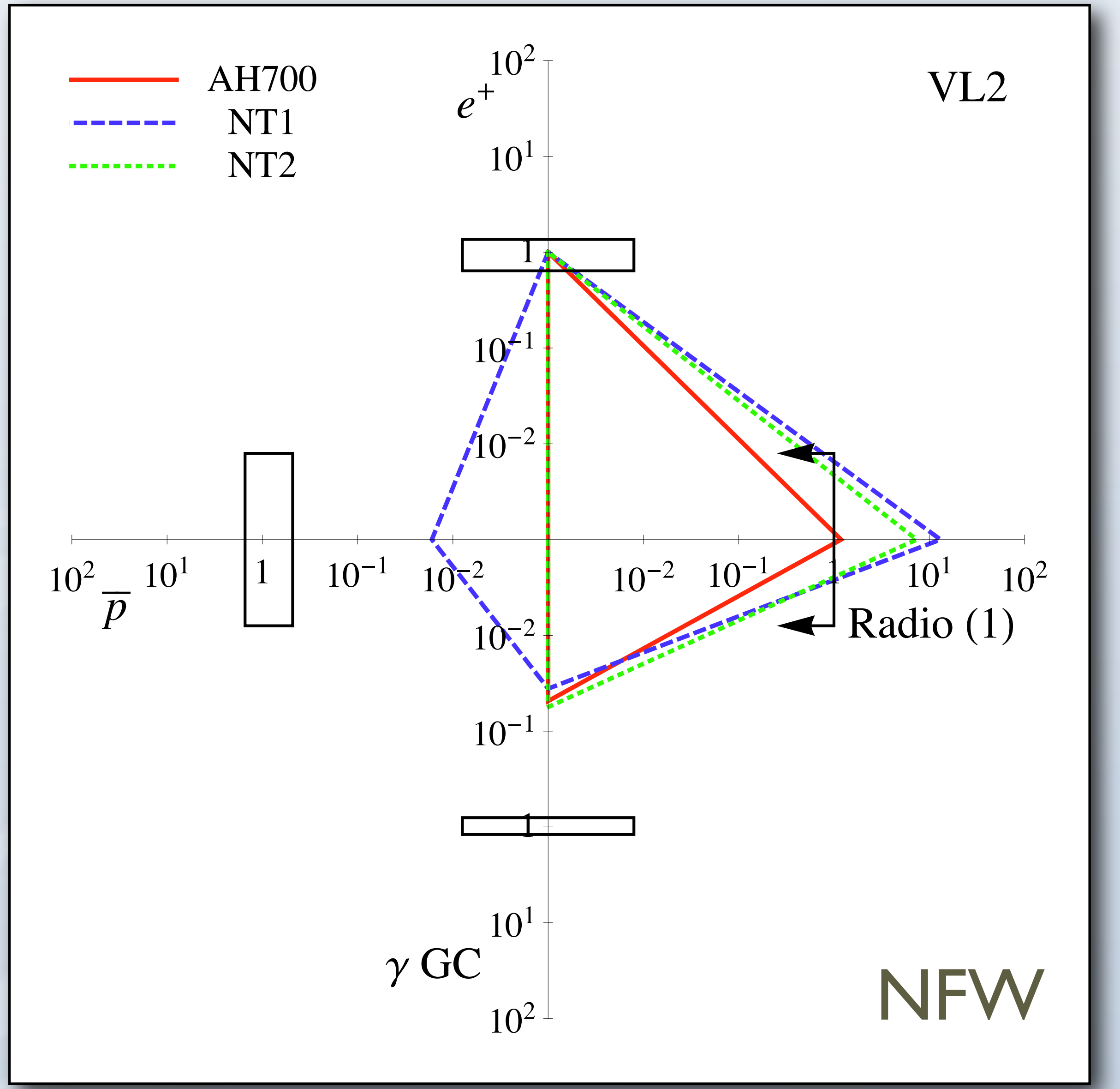
- DM annihilations at the galactic centre produce neutrinos that can be searched for with e.g. IceCube/DeepCore
- With a less steep profile, the sensitivity is very much reduced though

**Sensitivity for NFW and 5 years of IceCube/DeepCore operation**




Spolyar et al, arXiv:0905.4764

# Multimessenger constraints




Pato et al (arXiv:0905.0372),
see Pieri's talk Wednesday

# Additional features of the dark matter models

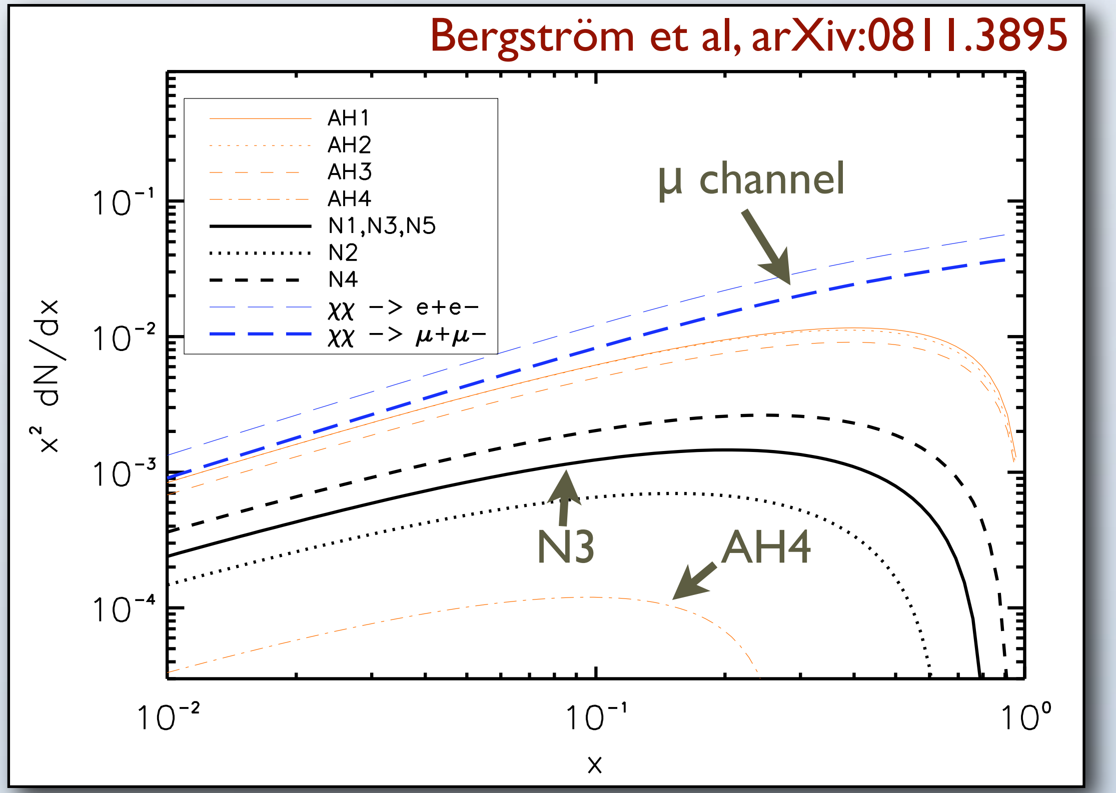
- As we produce many charged leptons, we expect final state radiation giving a

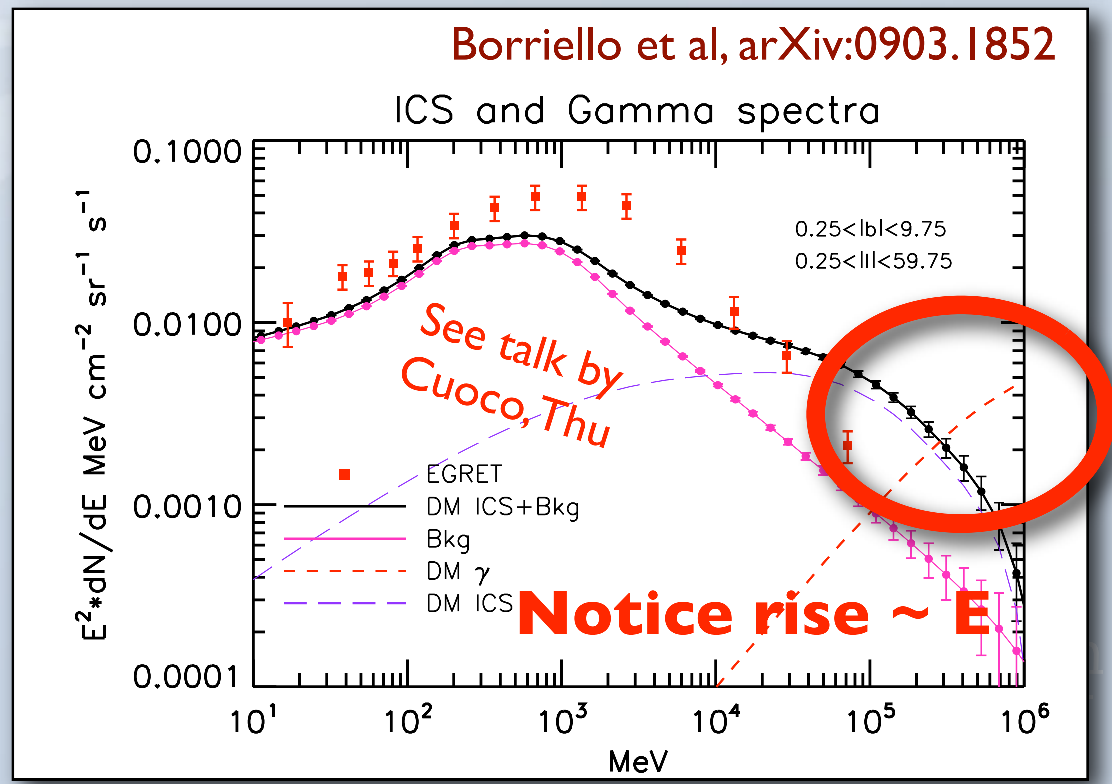
$$\frac{dN}{dE_\gamma} \propto E_\gamma^{-1}$$

spectrum of gamma rays

- These should provide a distinctive signature to search for from e.g. the galactic centre, especially for the muon channel model

- We would also get gammas from Inverse Compton Scattering (ICS) on the interstellar radiation field



# Other features

- The galactic diffuse emission will be more spherical from dark matter than from other sources (DM dominates at mid-high latitudes, $E_{\gamma}$>100 GeV)
- Discrimination between dark matter and astrophysical explanations possible with e.g. Fermi

**Inverse Compton from DM**

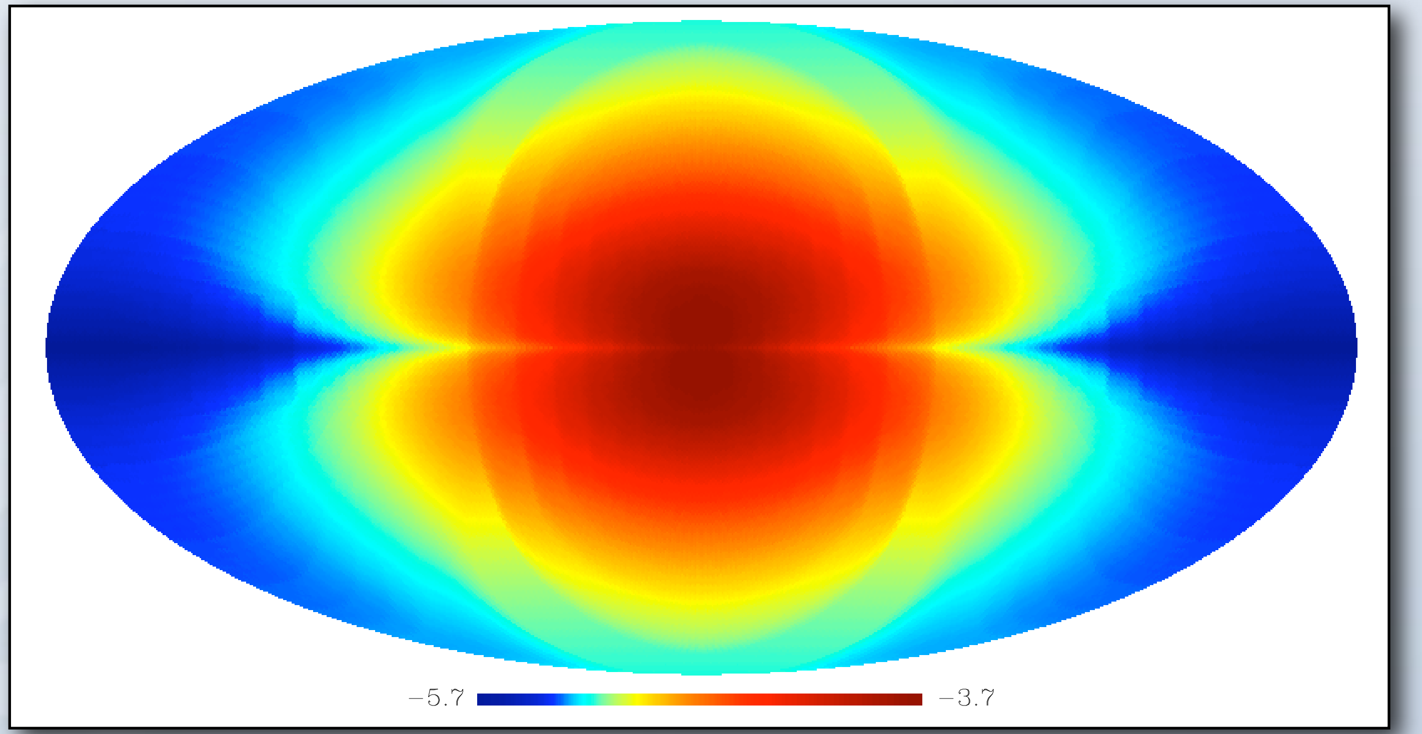
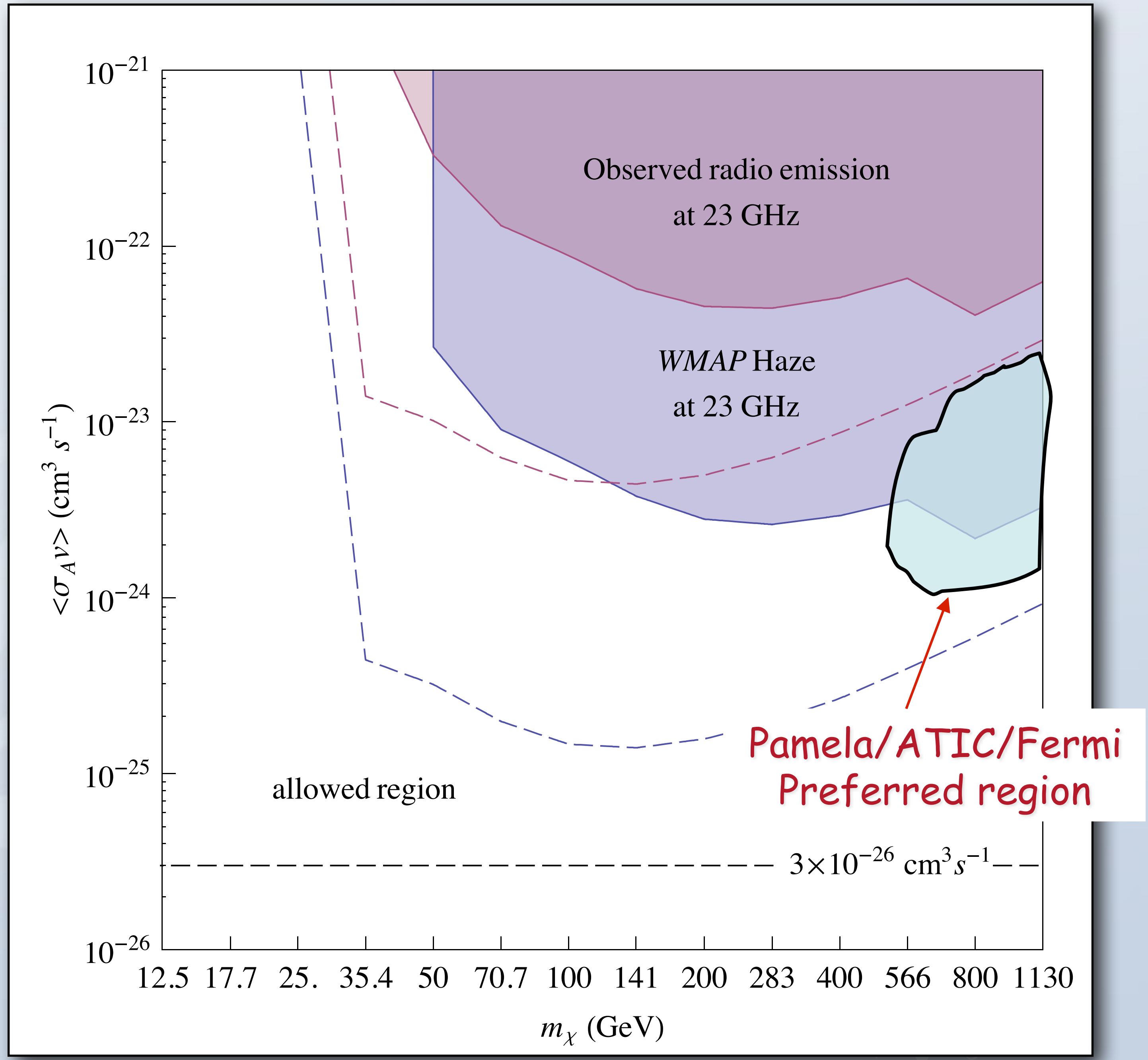



Fig. from Regis and Ullio, arXiv:0904.4645, see Regis' talk Wednesday

# WMAP haze

- Models explaining the Pamela/Fermi data, could also possibly explain the WMAP haze

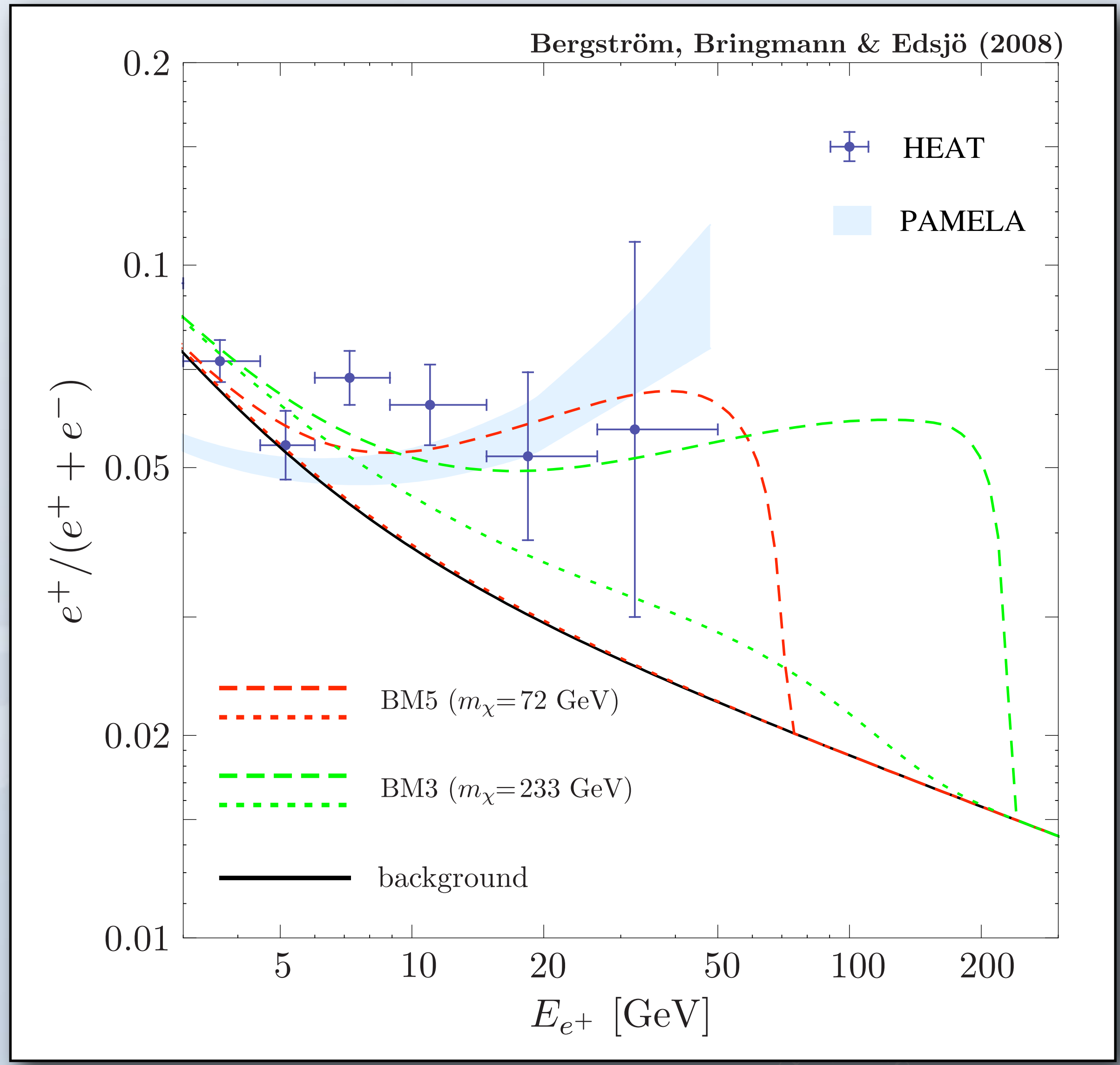
- WMAP haze can be tested with Planck




Boriello et al, arXiv:0809.2990, see Cuoco's talk Wednesday

# What about MSSM?

- Very hard to get enough leptons, without getting too many antiprotons (gammas) in MSSM
- Need very large (unrealistic) boost factors
- Given these caveats, it is though possible to get good fit to PAMELA with the help of internal bremsstrahlung
- Very hard to go to the high masses needed to fit Fermi data though




Bergström, Bringmann, Edsjö, PRD, arXiv:0808.3725

| Pulsars | New SNRs mechanisms (old SNR) | Localized SNR | Dark matter | ? |
|---|---|---|---|---|
| **Uncertainties** | | | | |
| • Acceleration model (polar cap, outer gap, ...)<br>• Injection spectrum $E^{-\alpha}$?<br>• Release into the ISM (when, how much?)<br>• Source locations, ages, ... | • Environmental parameters at SNR (production mechanism)<br>• Distance to closest source<br>• Cut-off energies<br>• ... | • Source properties<br>• Local environment<br>• Diffusion model<br>• ... | • Particle physics model<br>• Particle physics enhancement (Sommerfeld)<br>• Substructure enhancement (halo model)<br>• ... | ? |
| **Tests** | | | | |
| • Anisotropy of flux<br>• Fluctuations in spectrum (arXiv: 0903.1310)<br>• consistency checks (gamma, X-ray, ...) | • Antiproton fluxes<br>• Secondary nuclei | • Positron fraction down at several hundred GeV<br>• B/C, antiprotons<br>• Consistency checks | • FSR & IC photons<br>• Continuing positron fraction rise<br>• CMBR distortions<br>• LHC signatures | ? |

(0903.2794, ...) (0902.0376, ...)

+ need updated background model (with e.g. proper handling of local sources)

+ remember possibility of non-standard diffusion

# Conclusions

- Fermi excess can be explained with e.g.
  - A background model with less steep electron injection spectrum. Does not fit Pamela though.
  - Nearby astrophysical sources like pulsars, reacceleration at old SNRs, localized SNRs, ... Could explain Fermi and Pamela data.
  - Dark matter. Could explain Fermi and Pamela data. Prefer models that favour muons, like Sommerfeld enhanced Arkani-Hamed et al, or Nomura & Thaler models. These models give a rising positron fraction to high energies and possibly FSR and ICS photons. Could also give distortions in the CMB.
  - Or maybe there is no excess, the diffusion model is wrong.
- We need more data (Pamela, Fermi, AMS, Planck, ...) and understanding to distinguish these scenarios

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