Cosmic Ray Signals from Multiple Species of Dark Matter

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Outline

- *Multiple Dark Matter species annihilating into light bosons*
- *Implications on the observed positron and electron fluxes*
- *WMAP(Planck)-haze/Synchrotron radiation and one vs two DM species*

Motivation

- PAMELA positron fraction measurement and Fermi $e^+ + e^-$ spectra
- Possibility of explaining the INTEGRAL and DAMA results by the excited states of heavier ~TeV and lighter ~ 100GeV species
- Alleviate "some tension" between the suggested PAMELA and Fermi annihilation rates

- Possibility of having small “bumps” into the observed $e^{+} + e^{-}$ flux, (Pulsars and clumps of DM have been shown to provide such a case). New data from Fermi, AMS-02 can constrain such models.

Multiple DM annihilating species

Suppose multiple components of DM. Each DM species χ_i freezes out through annihilations into a new force carrier ϕ_i to which it couples with strength g. The cross section scales as:

$$\sigma_i v \sim \frac{\alpha^2}{M_{\chi_i}^2}.$$

DM density scales inversely proportional to the cross section:

$$\rho_i \sim \frac{1}{\langle \sigma \mid v \mid \rangle_i} \sim M_{\chi_i}^2$$

As the current annihilation rates scale as:

$$n^2_{\chi_i} \langle \sigma \mid v \mid \rangle_i \sim \left(\frac{\rho_i}{M_{\chi_i}} \right)^2 \frac{1}{M^2_{\chi_i}} \sim constant$$

So for cases where the DM species froze out through annihilations into light force carrier(s), their current annihilation rates are *equal* even though their contributions to the total DM density may differ by orders of magnitude.

Caveats

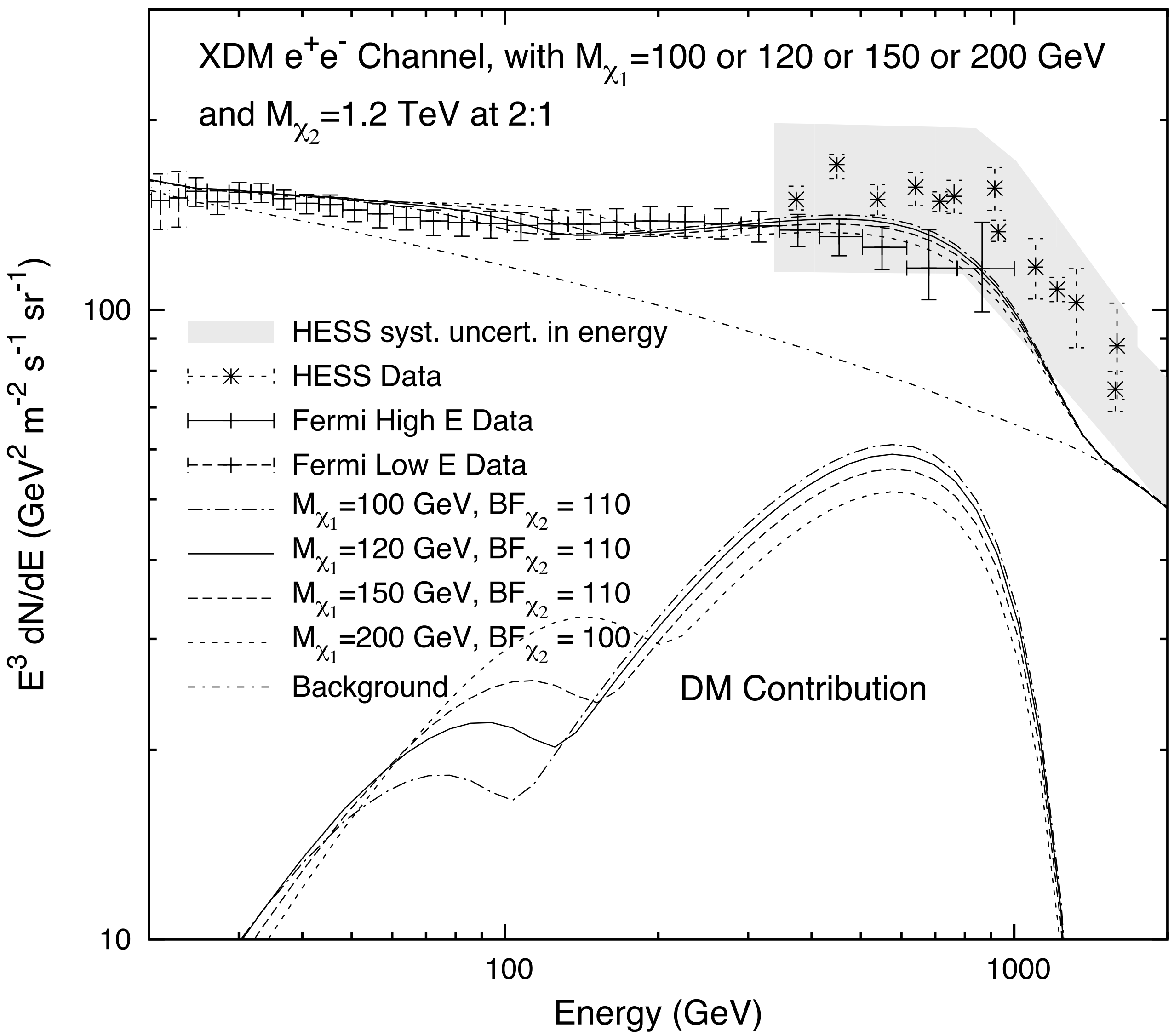
- Logarithmic corrections to the mass
- Injection spectra of the electrons/positrons, gammas originating from different species (different channels for the production of $e^{\pm}$ can arise from $m_{\phi_i} \neq m_{\phi_j}$)
- Multiplicities of the produced $e^{\pm}$
- Factors of 2 can arise from fermions vs scalars species
- Sommerfeld enhancement

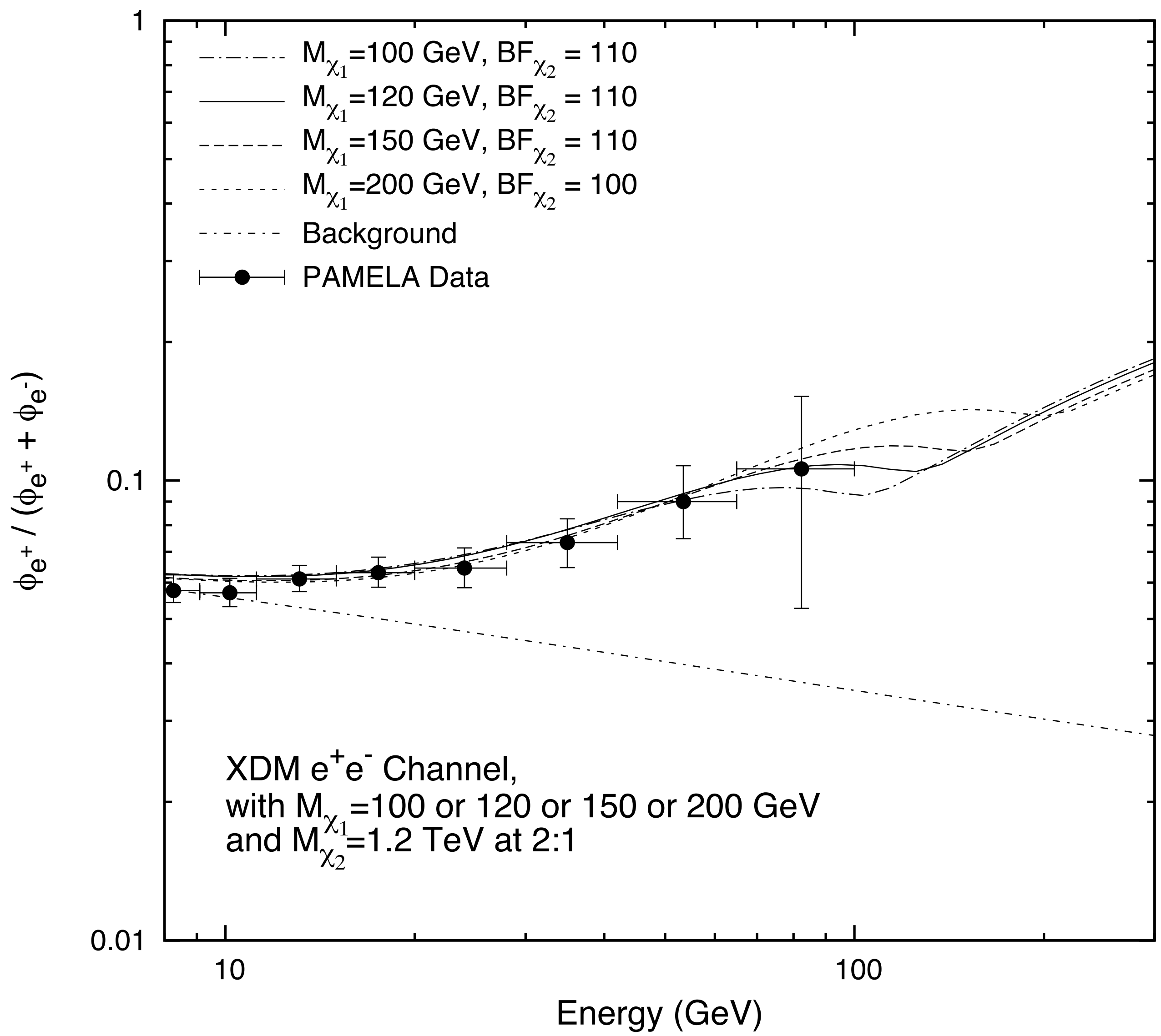
Two species

For $m_{\chi_1} \ll m_{\chi_2}$ and the B.F. can be defined as:

$$B.F._{\chi_2} \approx \frac{\langle \sigma \mid v \mid\rangle_{2_{fitted}}}{3 \times 10^{-26} cm^3 s^{-1}}$$

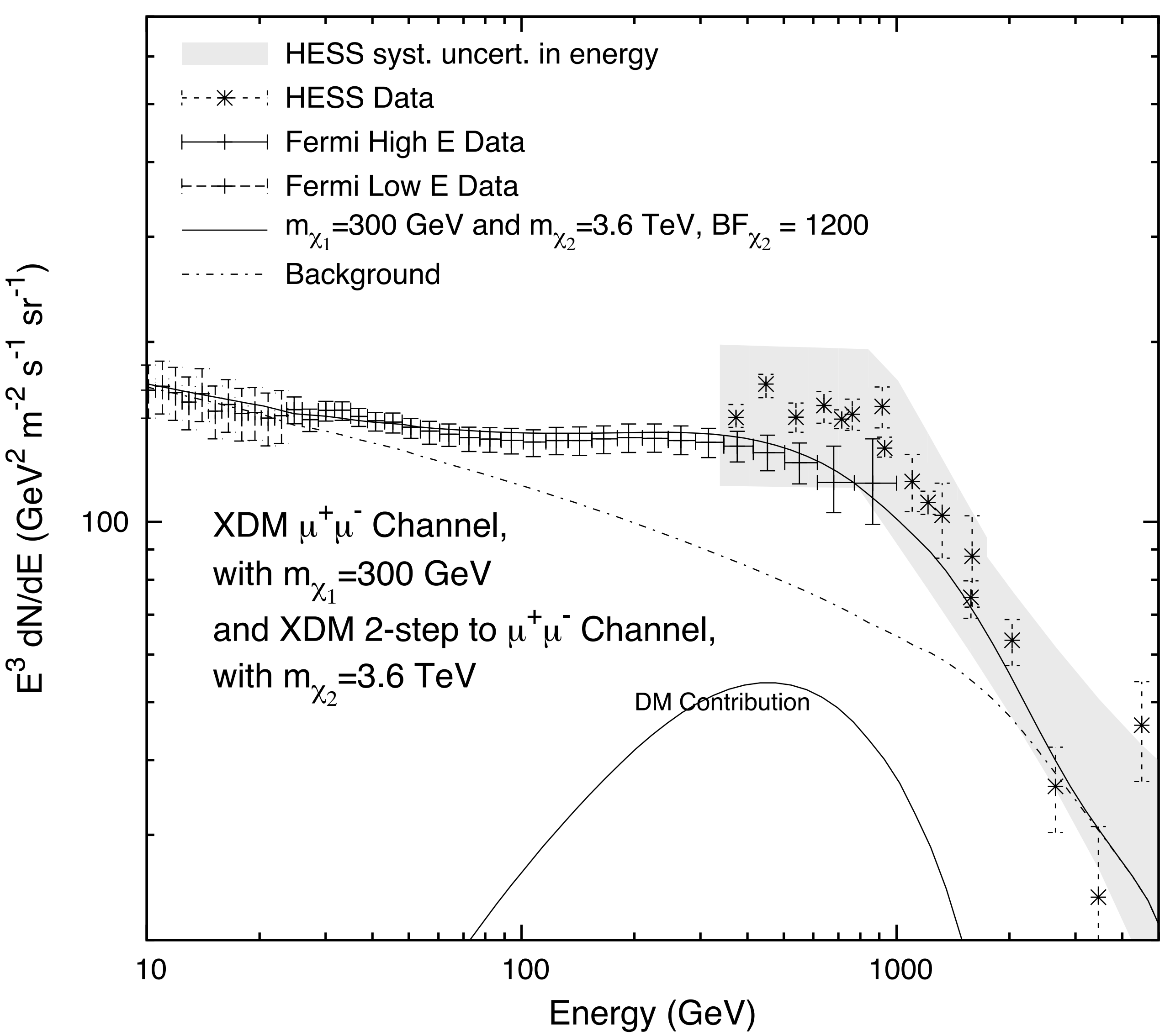
$$\chi\chi \to \phi\phi \qquad \phi \to e^+e^-$$

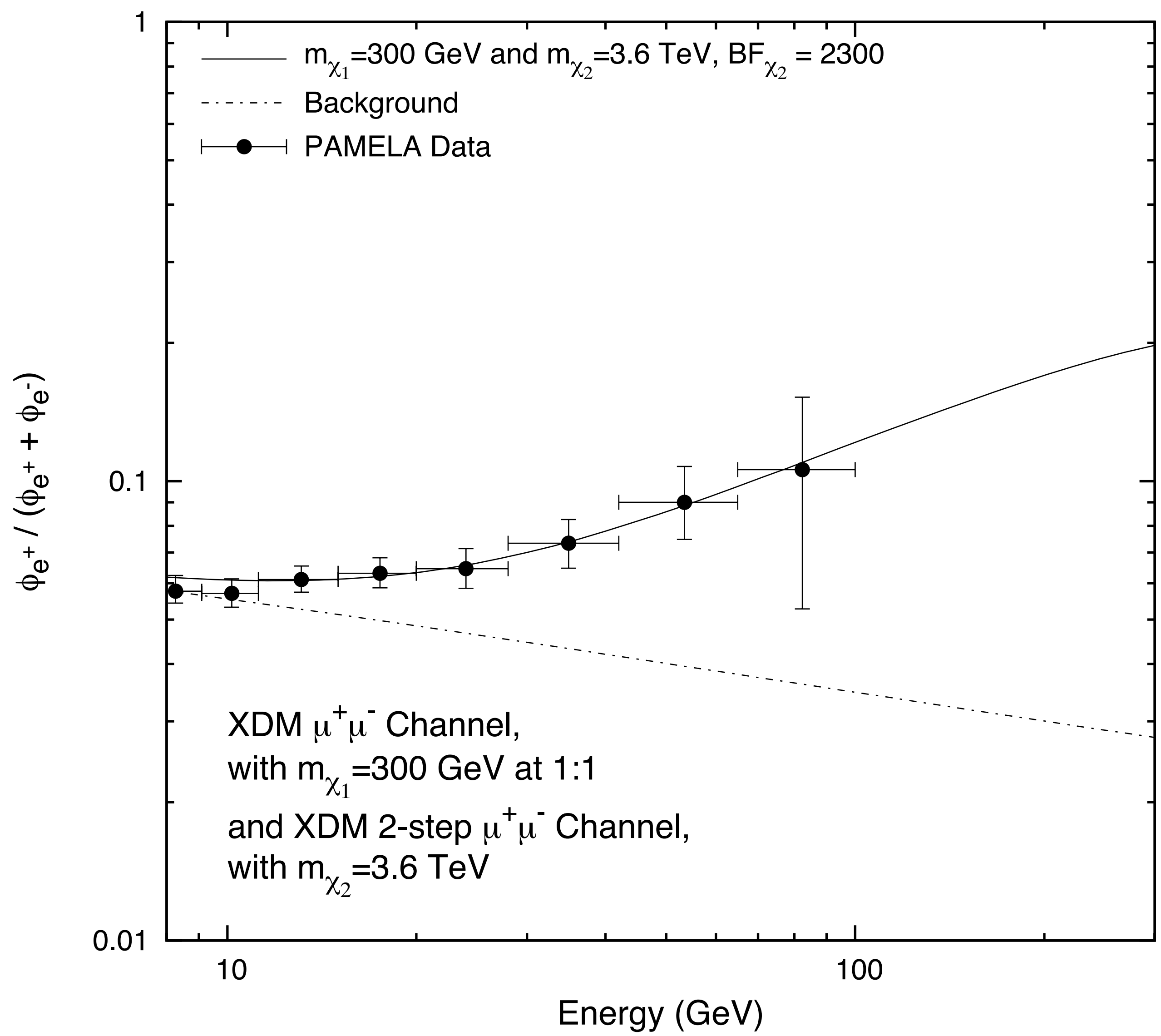




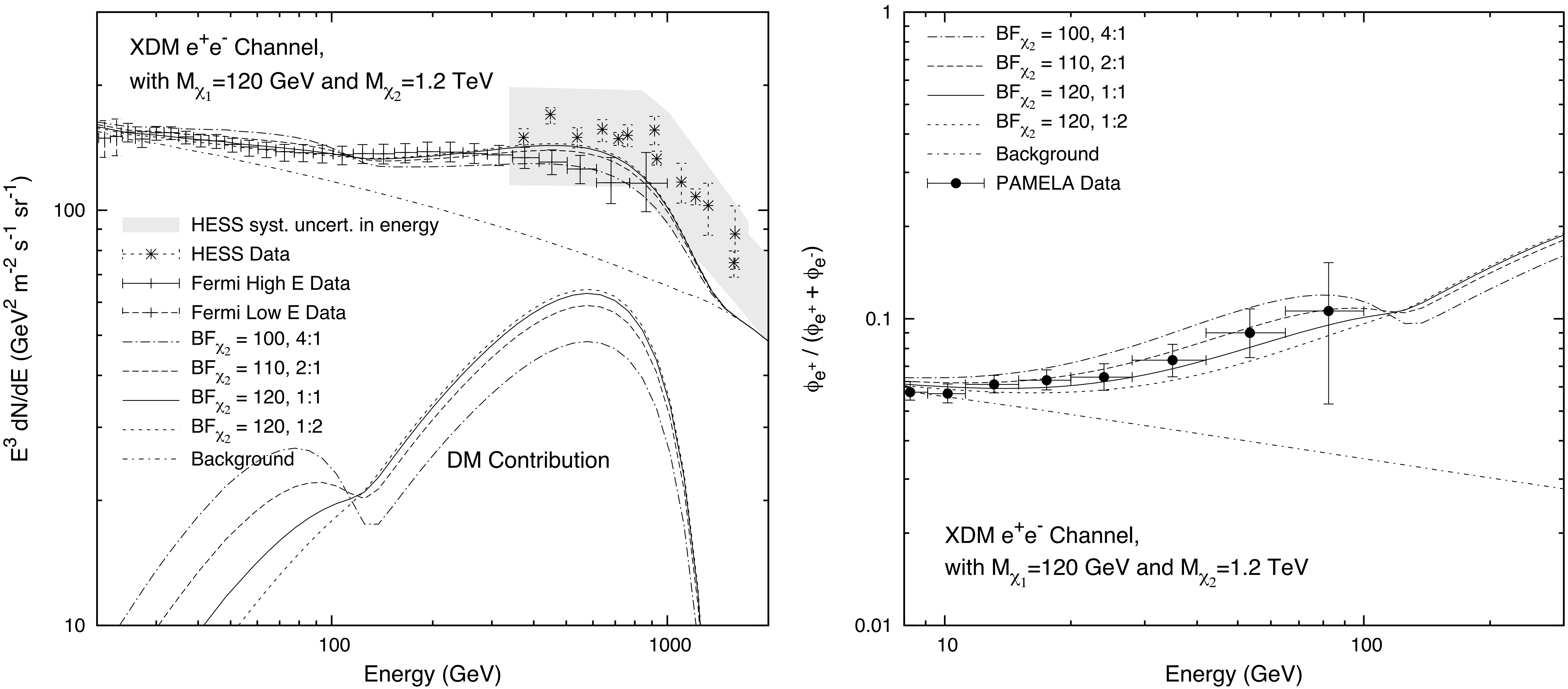
In the previous example there was good agreement to the Fermi data, a bump-change in the flux power law at E $\sim$200GeV within system.+stat. errors. Also there is better agreement between the implied annihilation rates from Fermi vs PAMELA.

An other case:





Allowing for greater deviations between the 2 species annihilation fluxes (due for instance to Sommerfeld enh. , scalars vs fermions)



Some cases already disfavored by the data.

Used parameters:

$$L = \pm 4kpc$$

$$D_{xx}(R) = 5.3 \times 10^{28} \left(\frac{R}{4GV} \right)^{0.43} cm^2 s^{-1}$$

ISRF by arXiv:astro-ph/0507119v1 arXiv:astro-ph/0507119v1

$$B(\rho, z) = 5exp\left(\frac{R_{\odot} - \rho}{\rho_c} \right) exp\left(-\frac{z}{z_c} \right) \mu G$$

$\rho_c = 4.5kpc$ ***and*** $z_c = 2.0kpc$ ***B-field I***

$\rho_c = 10.0kpc$ $z_c = 2.0kpc$ ***B-field II***

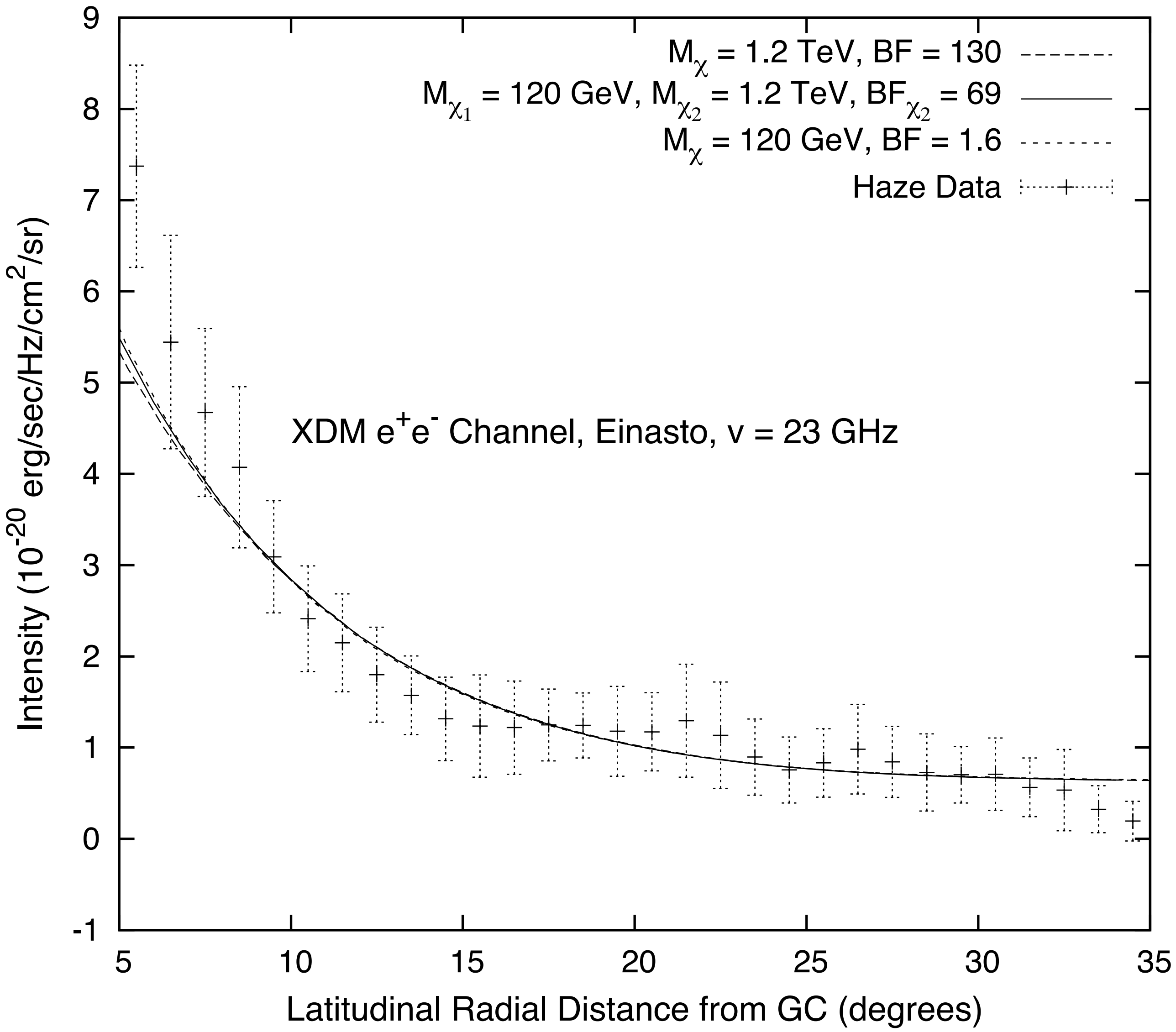
$\rho_c = 10.0kpc$ $z_c = 4.0kpc$ ***B-field III***

Synchrotron radiation as a handle to separate among 1 species vs 2 species scenarios

Need for a way-handle to distinguish among the one species and 2 species case. The synchrotron radiation from $e^{\pm}$ of DM origin can be used for that cause, *provided* there are data to compare it with.

So we could use the microwave haze

If we only use the 23 GHz band data then:



Morphologically identical, change in the boost factor by $\sim$2

The $e^{\pm}$ that emit synch. radiation at 23GHz have energies between $\sim$5 to 100GeV for a 10muG magnetic field.

Higher frequencies

The synchrotron emissivity of a single electron is given by:

$$j(\mathrm{v}) = \frac{\sqrt{3}e^3 B sin\alpha}{8\pi^2 \epsilon_0 c m_e} \frac{\mathrm{v}}{\mathrm{v}_c} \int_{\mathrm{v}/\mathrm{v}_c}^{\infty} K_{5/3}(z) dz$$

with

$$\mathrm{v}_c = \frac{3}{2}\gamma^2 \frac{eB}{2\pi m_e} sin\alpha$$

for a 50GeV electron at a 10muG mag. field $\mathrm{v}_c \approx$ 500GHz, emissivity peaks at $\approx$ 150GHz, while for a 1TeV electron, the $\mathrm{v}_c \approx$200THz and emissivity peaks at $\approx$ 60THz.

$J(\mathrm{v})$: the synchrotron emiss. of a distribution of $e^{\pm}$ of DM origin.

$$J_1(\mathrm{v}) \sim \mathrm{v}^{-\alpha_1}\ ,\ J_2(\mathrm{v}) \sim \mathrm{v}^{-\alpha_2} \text{ with } \alpha_1 > \alpha_2$$

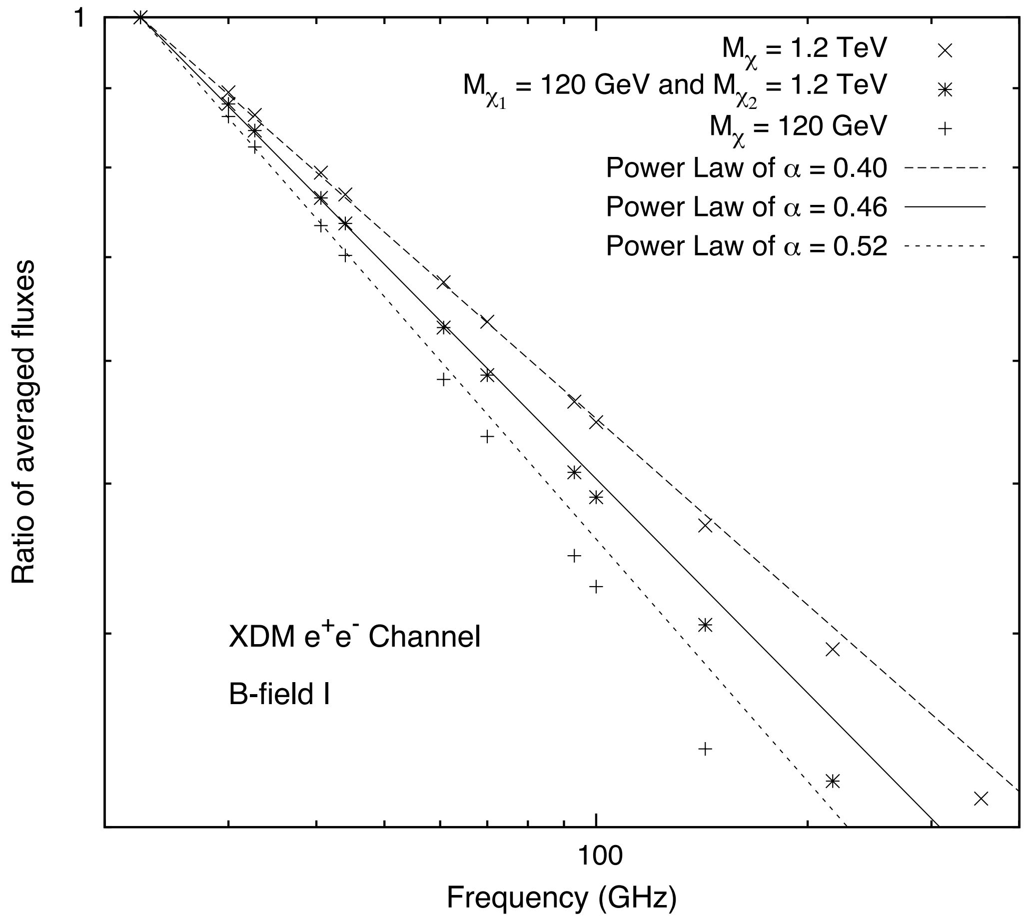
thus,

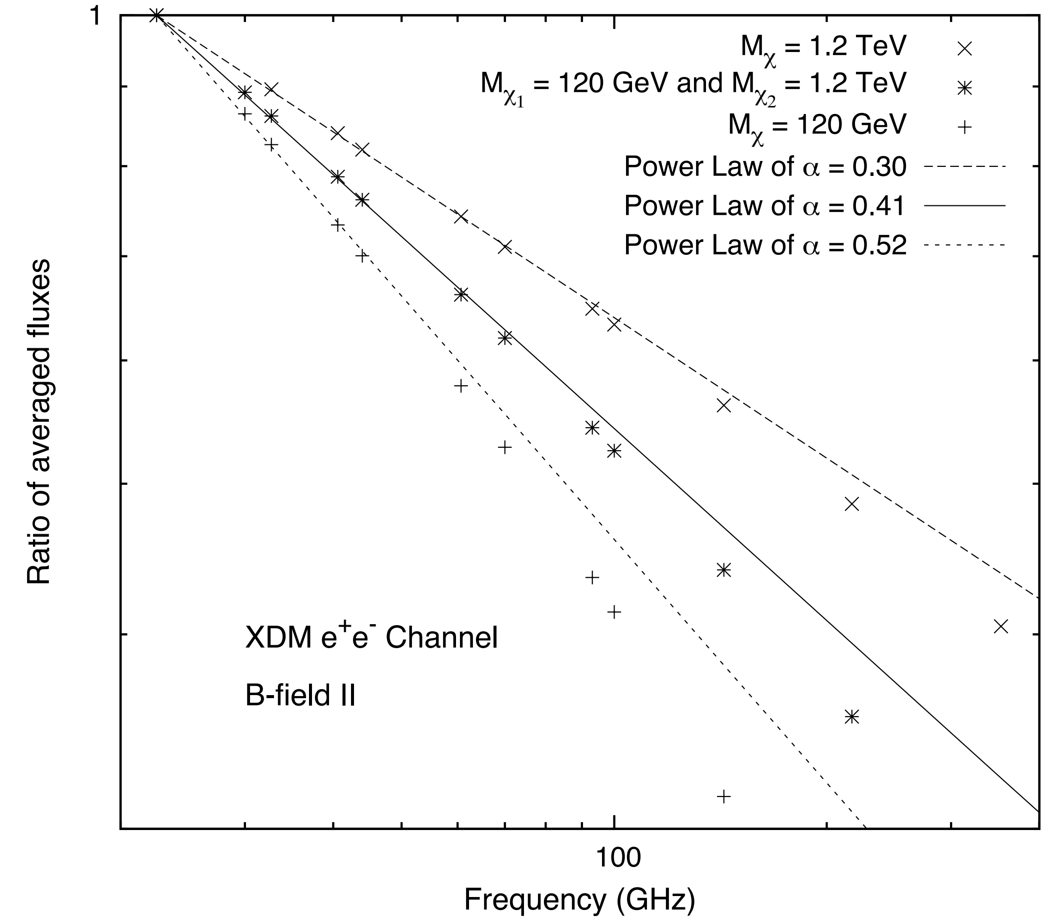
$$J_{comb}(\mathrm{v}) \sim \mathrm{v}^{-\alpha_{comb}} \text{ with } \alpha_1 > \alpha_{comb} > \alpha_2$$

Two reasons: i) different cut-off ($E_e < m_\chi$), ii) competing ICS mechanism.

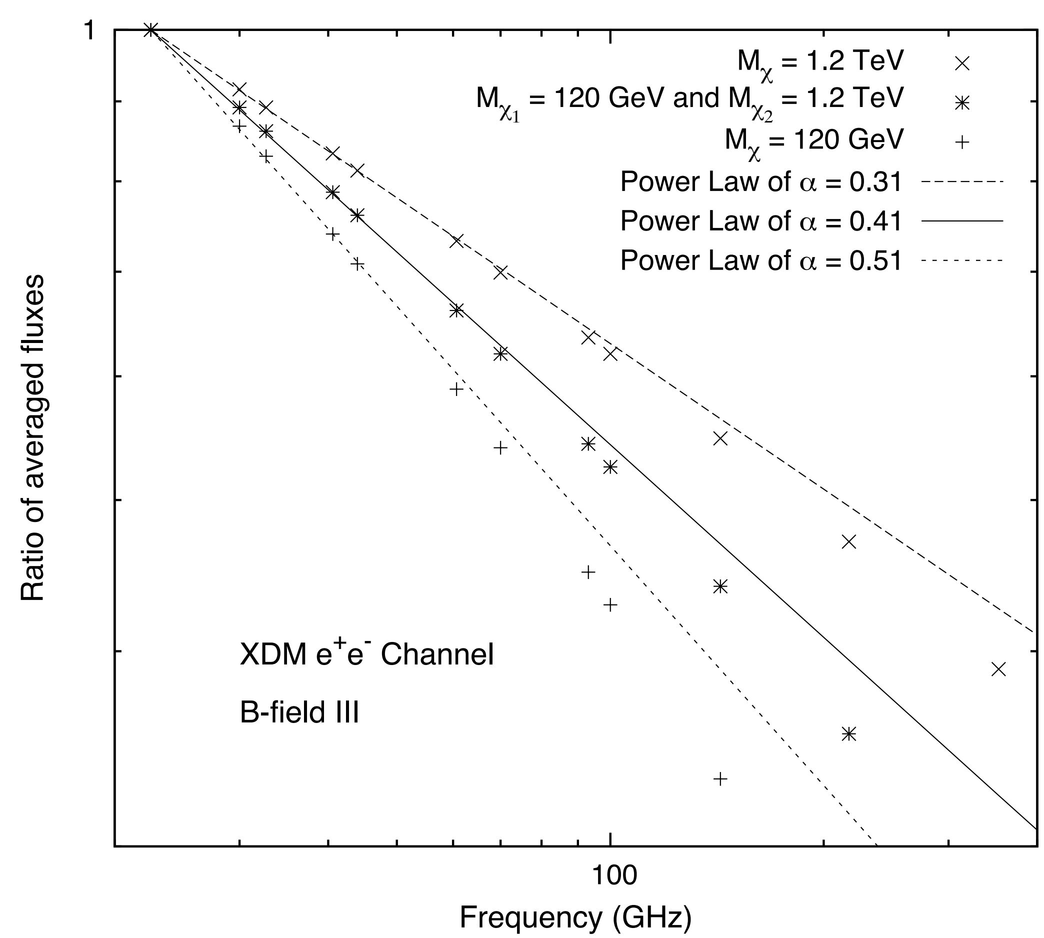
$$\sigma_{K-N} = \frac{3}{8}\sigma_T x^{-1}\left(ln(2x) + \frac{1}{2}\right) \qquad x = \frac{\hbar\omega}{m_e c^2}$$

ICS from starlight is less efficient at high energy electrons, more energy of the $e^{\pm}$ fractionwise is lost to synchrotron radiation.

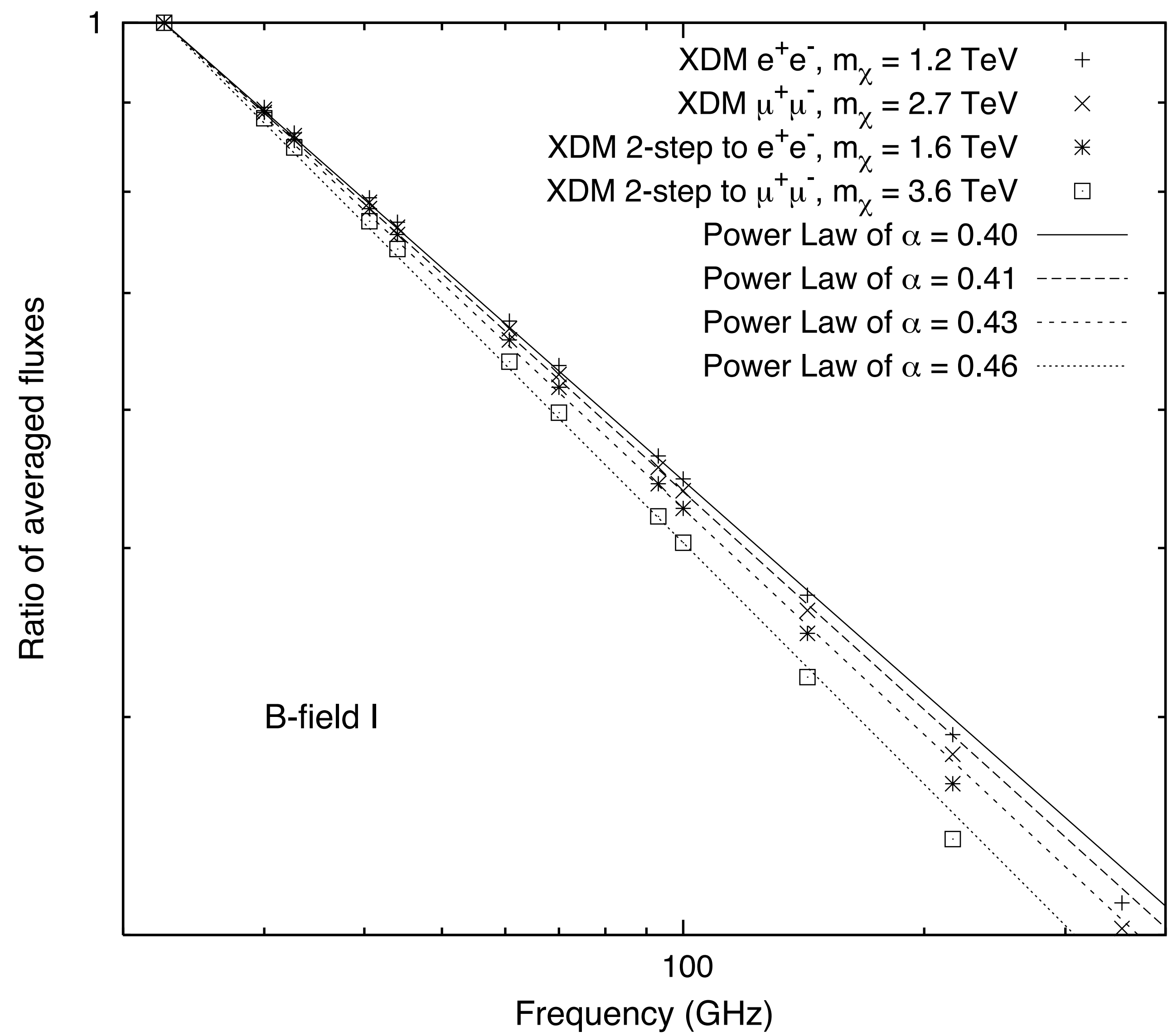




Stronger magnetic field:
i) steeper lower laws
ii) smaller difference of the power laws between the light vs heavy species

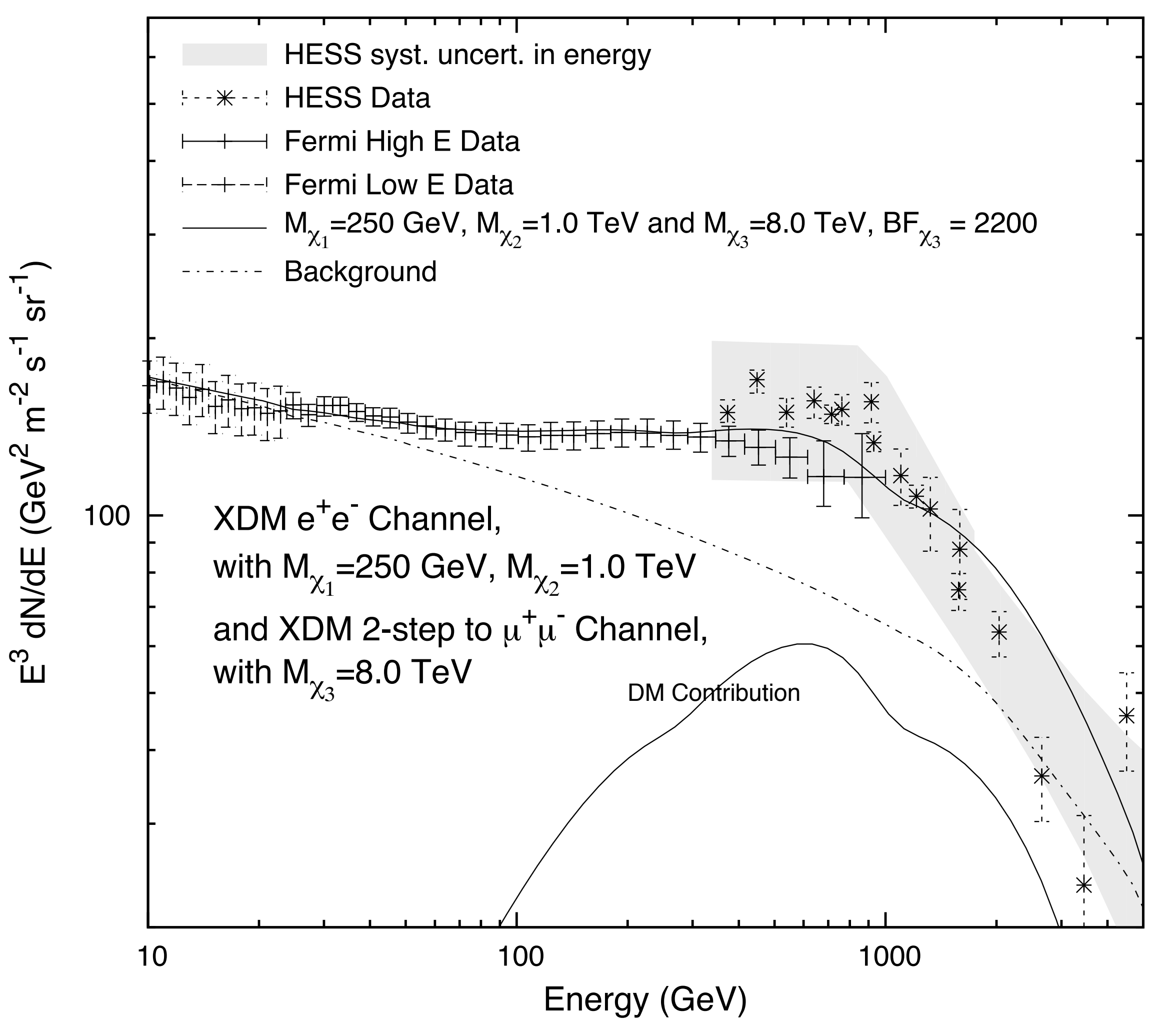


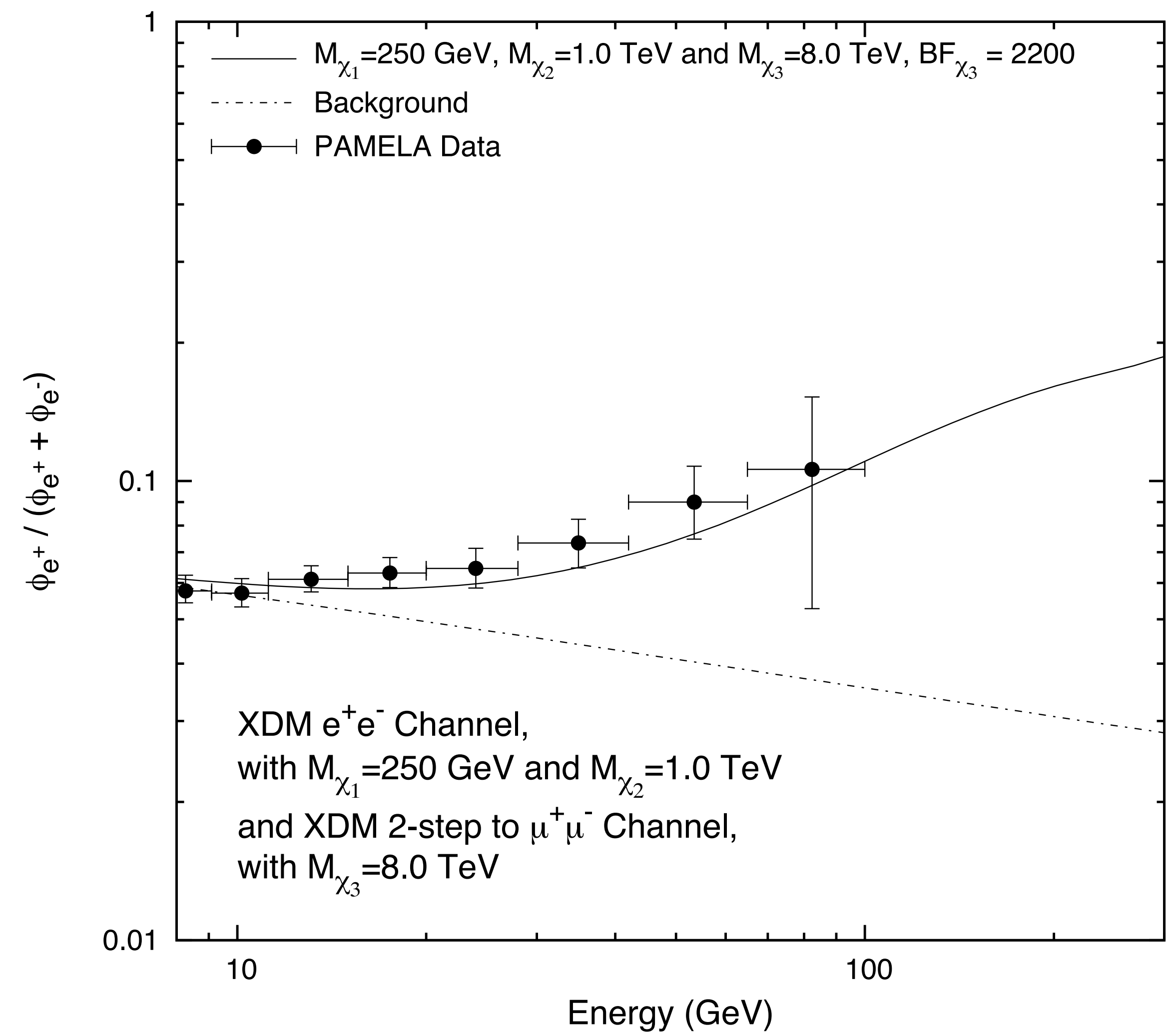
DM channel dependence



Can't distinguish yet between the annihilation "channels". Also magnetic field dependence.

3 species





HESS upper bounds put "some" constrain the mass of the heaviest species. Astrophysical background dominated by PWNs, recent supernovae explosions. Also need for better understanding of the diffusion of ~10TeV electrons.

Summary

- Possibility that the Dark sector contains two or more stable DM species annihilating through light force carriers.

- Similar contributions to the $e^{\pm}$ fluxes at energies smaller than the lightest DM species can be obtained.

- Existence of bumps or changes in the power-law in the $e^{\pm}$ flux, that can still be in agreement with the Fermi $e^{+} + e^{-}$ flux measurements.

- Better agreement for XDM models between Fermi and PAMELA, "suggested" annihilation rate, with the HESS upper bounds restricting the heaviest species.

- Synchrotron radiation from electrons/positrons of DM at frequencies up to ~100GHz, may be used as a tool for discriminating between 1 vs 2 species case.

- Current uncertainties in the particle physics and galactic astrophysics (Diffusion, ISRF, B-field) are still too great.

Thank you