Cosmic Rays and Diffuse Galactic Emission in a Self-Consistent model; Room for a DM Component

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Indirect DM Detection

Indirect DM detection is an approach to identify the properties of WIMPs through looking at their annihilation and/or decay products.

The imprints of WIMP annihilation/decay might be seen in the spectra of cosmic rays (CRs), such as positrons and anti-protons, diffuse gamma-rays and synchrotron radiation.

In none of these detection channels the DM contribution is expected to be dominant with respect to other, more standard, astrophysical components.

The study of astrophysical backgrounds is of great importance in constraining the WIMP annihilation/decay properties.

Primary Sources of CRs

Supernova Remnants:

CR primary sources up to energies of $\sim$100TeV, are mainly supernova remnants (SNRs).

$$q_i(r, z, E) = q_{0,i} f_s(r, z) \left(\frac{R(E)}{R_0}\right)^{-\gamma^i}$$

$f_s(r, z)$ traces the spatial distribution of SNRs. [Ferriere (2001)]

Pulsars:

Electrons and positrons accelerated between a pulsar and the termination shock of the wind nebula, may also contribute to the high energy $e^{\pm}$ spectrum.

$$Q_p(r, z, t, E) = J_0 f_p(r, z) E^{-n} e^{-E/M}$$

$f_p(r, z)$: Spatial distribution of middle aged pulsars in the Galaxy

[Giugere & Kaspi (2006)]

CR Propagation

The propagation of CRs in the Galaxy is described by:

$$\frac{\partial \psi(\vec{r},p,t)}{\partial t} = q(\vec{r},p,t) + \vec{\nabla}.(D_{xx}\vec{\nabla}\psi) + \frac{\partial}{\partial p}\left[p^2 D_{pp}\frac{\partial}{\partial p}(\frac{\psi}{p^2})\right]$$
$$- \frac{\partial}{\partial p}(\dot{p}\psi) - \vec{\nabla}.(\vec{V}\psi) + \frac{\partial}{\partial p}\left[\frac{p}{3}(\vec{\nabla}.\vec{V})\psi\right]$$
$$- \frac{\psi}{\tau_{frag}} - \frac{\psi}{\tau_{decay}}$$

We use the publicly available DRAGON code to numerically solve the propagation equation in the steady state approximation.

Diffusion and Magnetic Fields

The scattering of CRs on randomly moving magneto-hydro-dynamic (MHD) waves leads to diffusion in physical and momentum space.

The large scale Galactic magnetic field is generally assumed to be a bi-symmetrical spiral with small pitch angle.

We assume a purely azimuthal regular magnetic field with the form:

$$B_0 = B_h \exp\left(-\frac{r - r_\odot}{r_h}\right) \exp\left(-\frac{|z|}{z_h}\right)$$

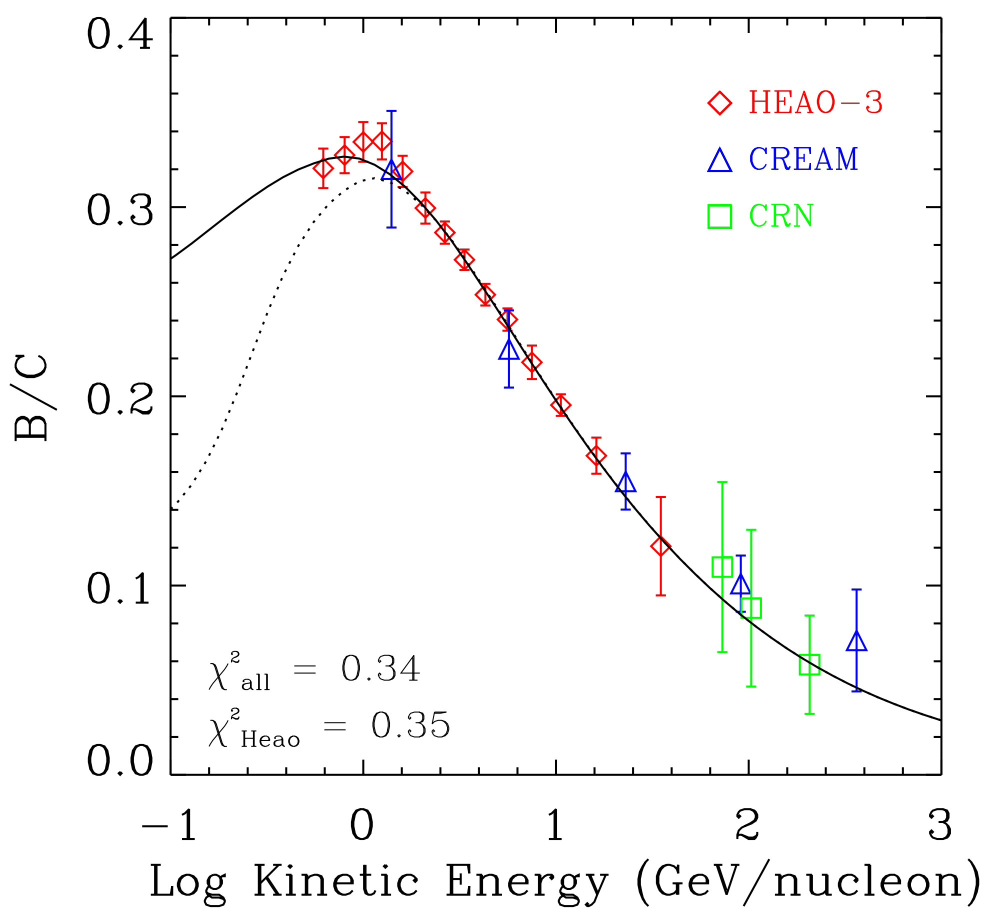
Phenomenologically, the weaker magnetic field, the stronger spatial diffusion.

$$D(r, z, R) = D_0 \beta^\eta (\frac{R}{R_0})^\delta \exp(\frac{r - r_\odot}{r_d}) \exp(\frac{|z|}{z_d})$$

$$D_{pp} \propto \frac{p^2 v_A^2}{D_{xx}}$$

CR Spectra

Secondary to Primary

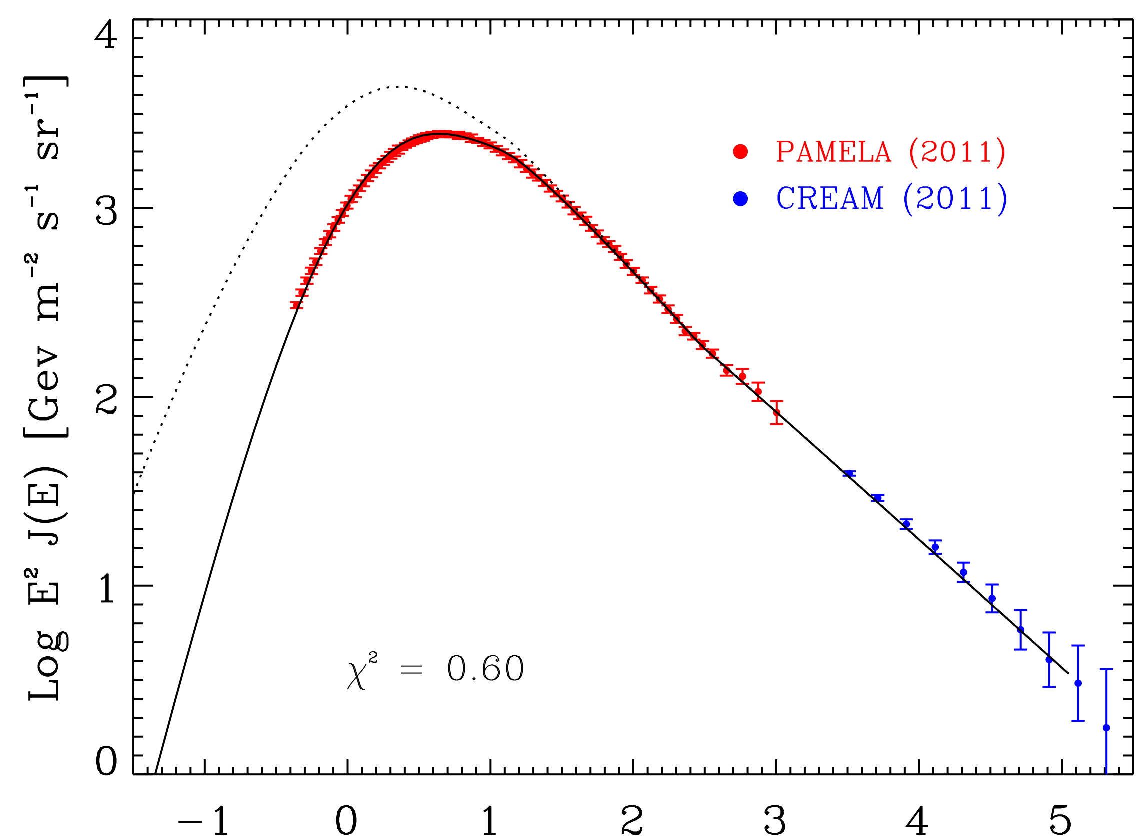


For the set of values of (δ, z_d, r_d) we derive the other propagation parameters (D_0, η, v_A) by minimizing the χ^2 of B/C data.

The injection spectral index of protons, γ^p, is fitted to the *PAMELA* and *CREAM* data.

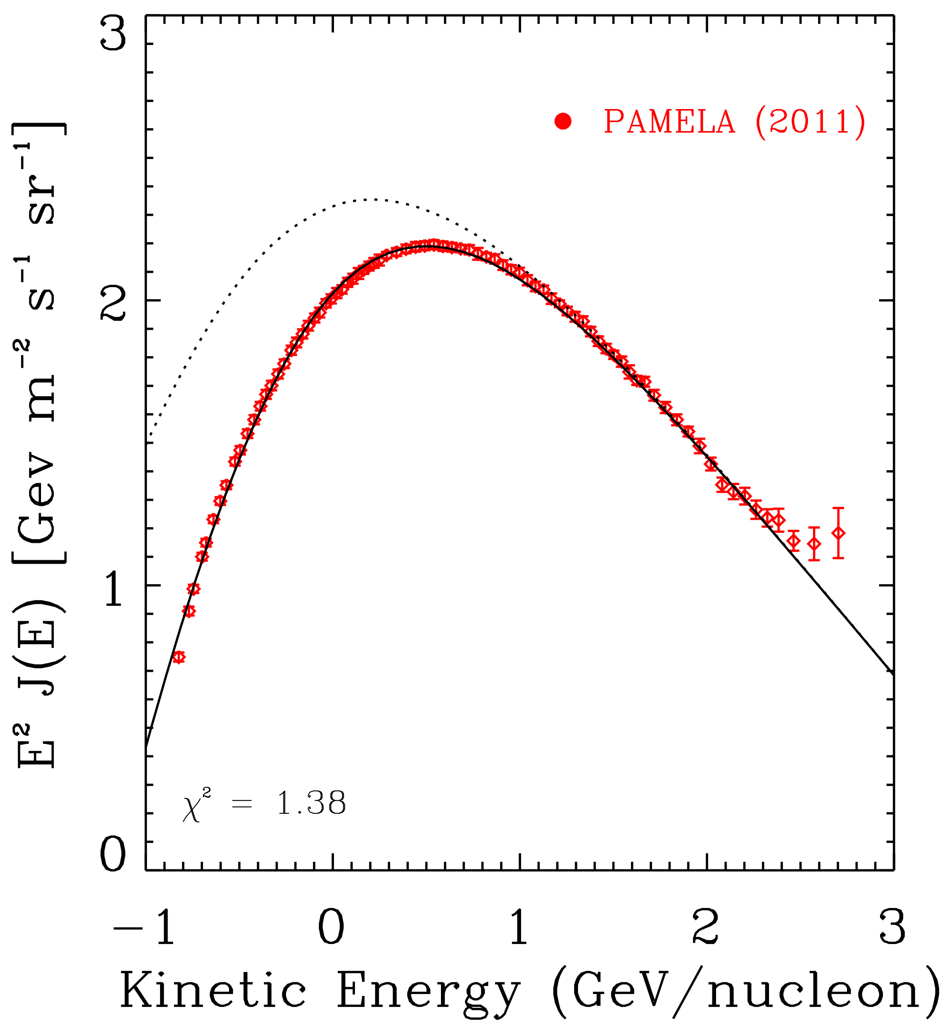
Proton flux has a broken power-law.

Protons

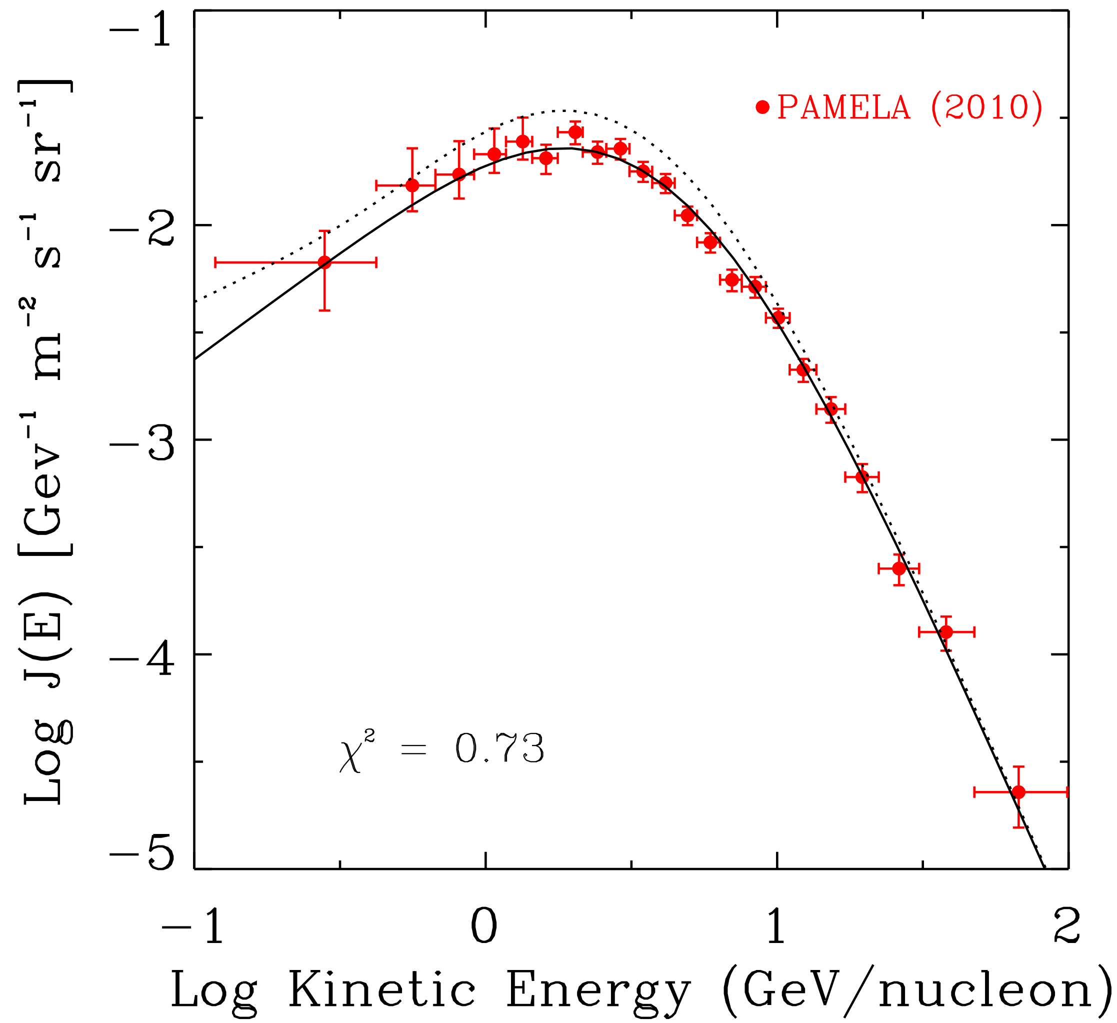


CR Spectra

Helium



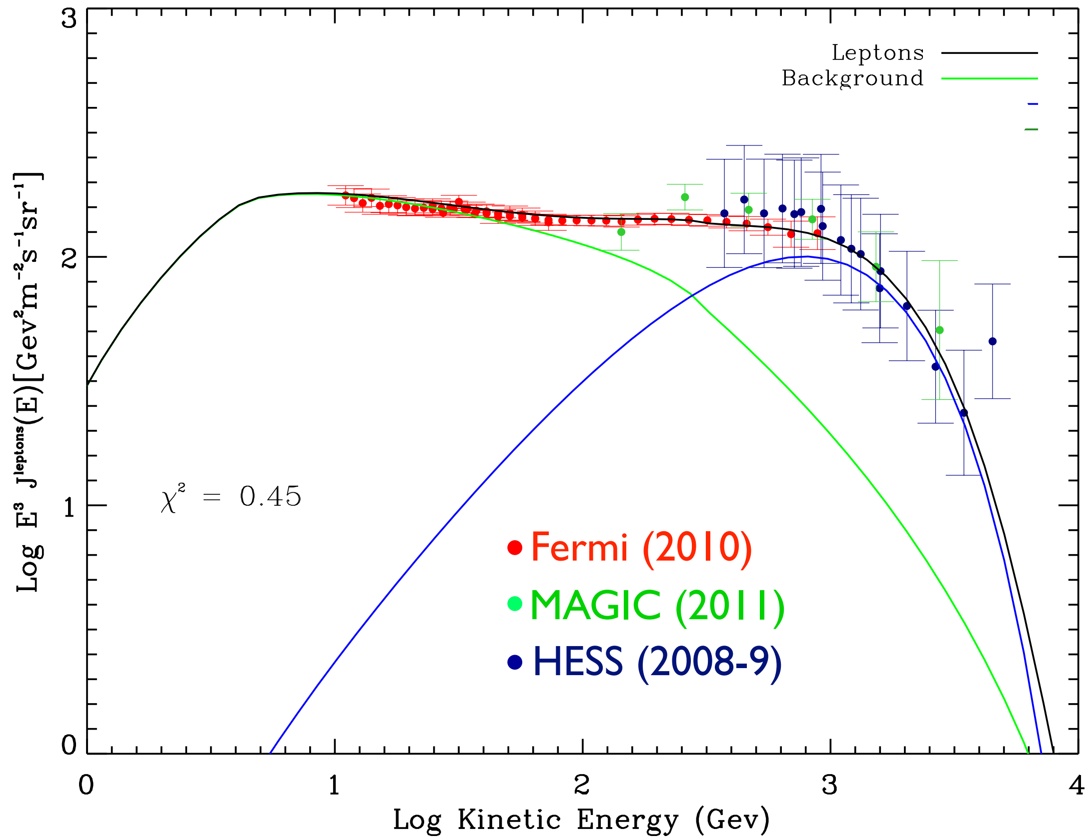
Anti-proton



The predicted Helium and anti-proton fluxes are consistent with local data.

CR Spectra

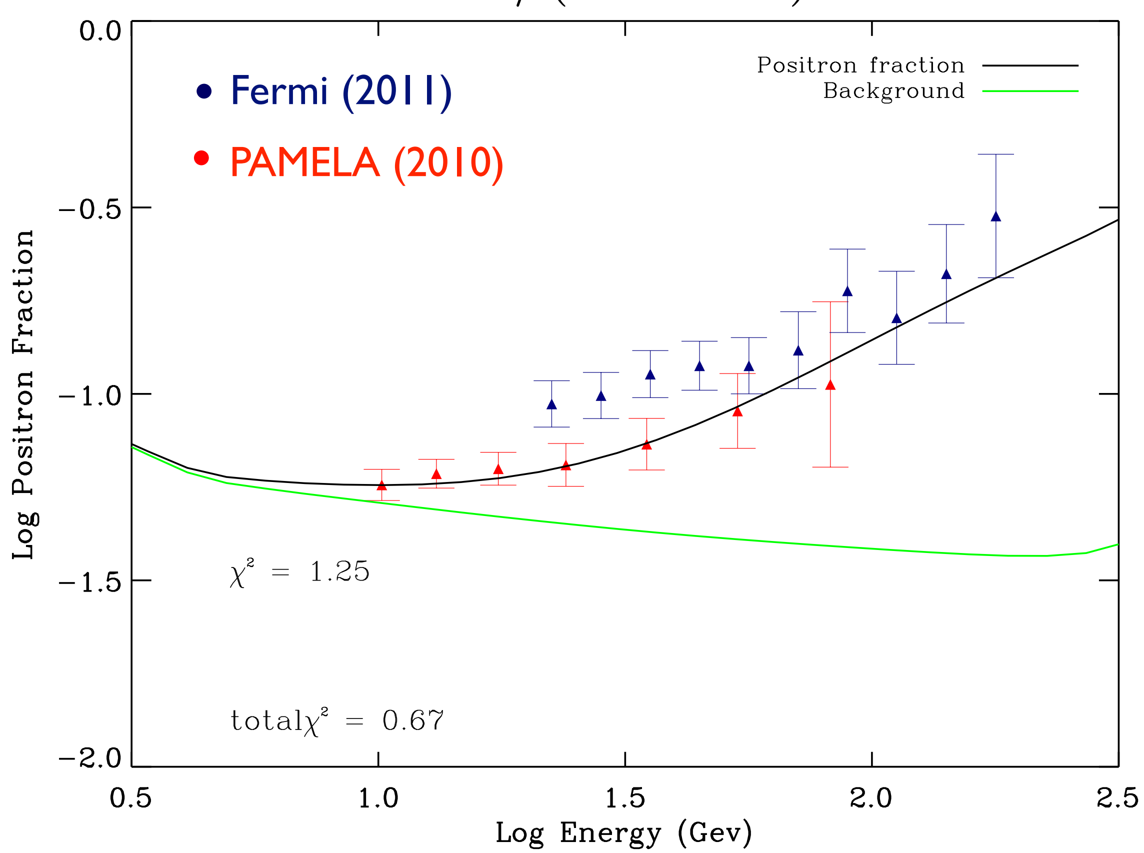
$e^- + e^+$



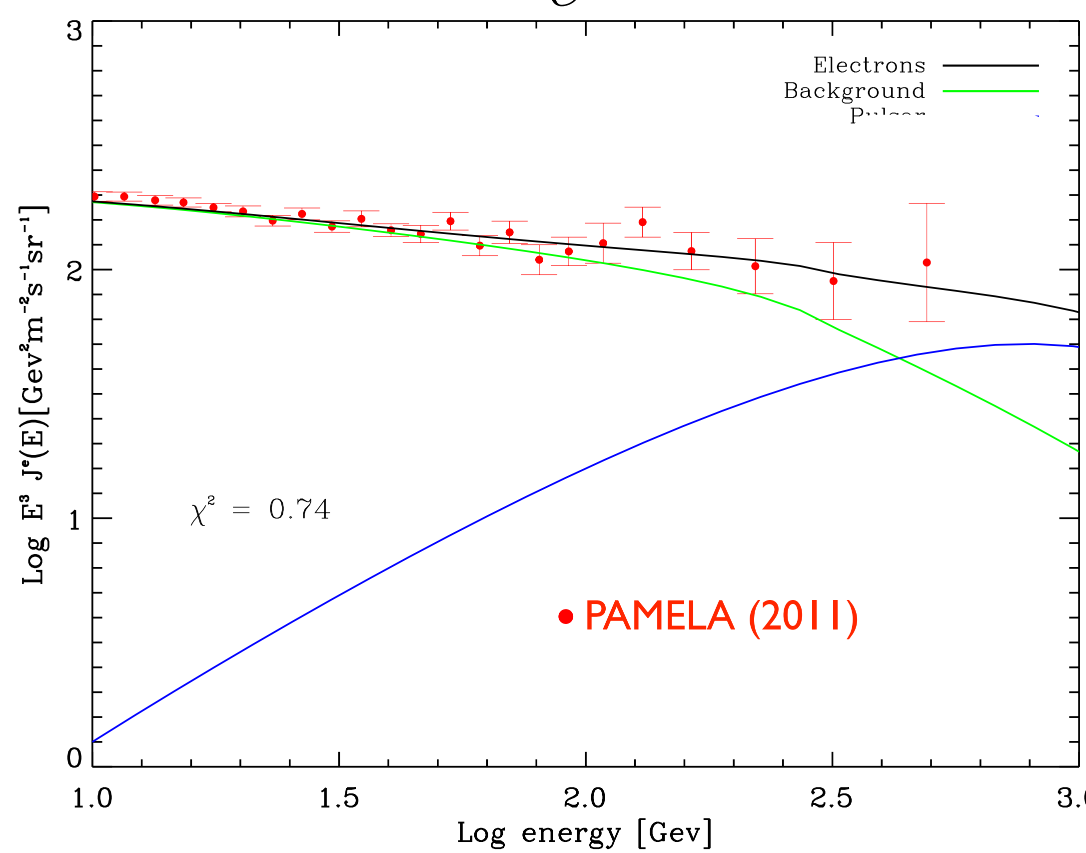
We fit the electron spectral index, γ^e, to the low energy $e^- + e^+$ spectrum.

The averaged properties of pulsars are determined by high energy spectrum.

$e^+/(e^- + e^+)$



e^-



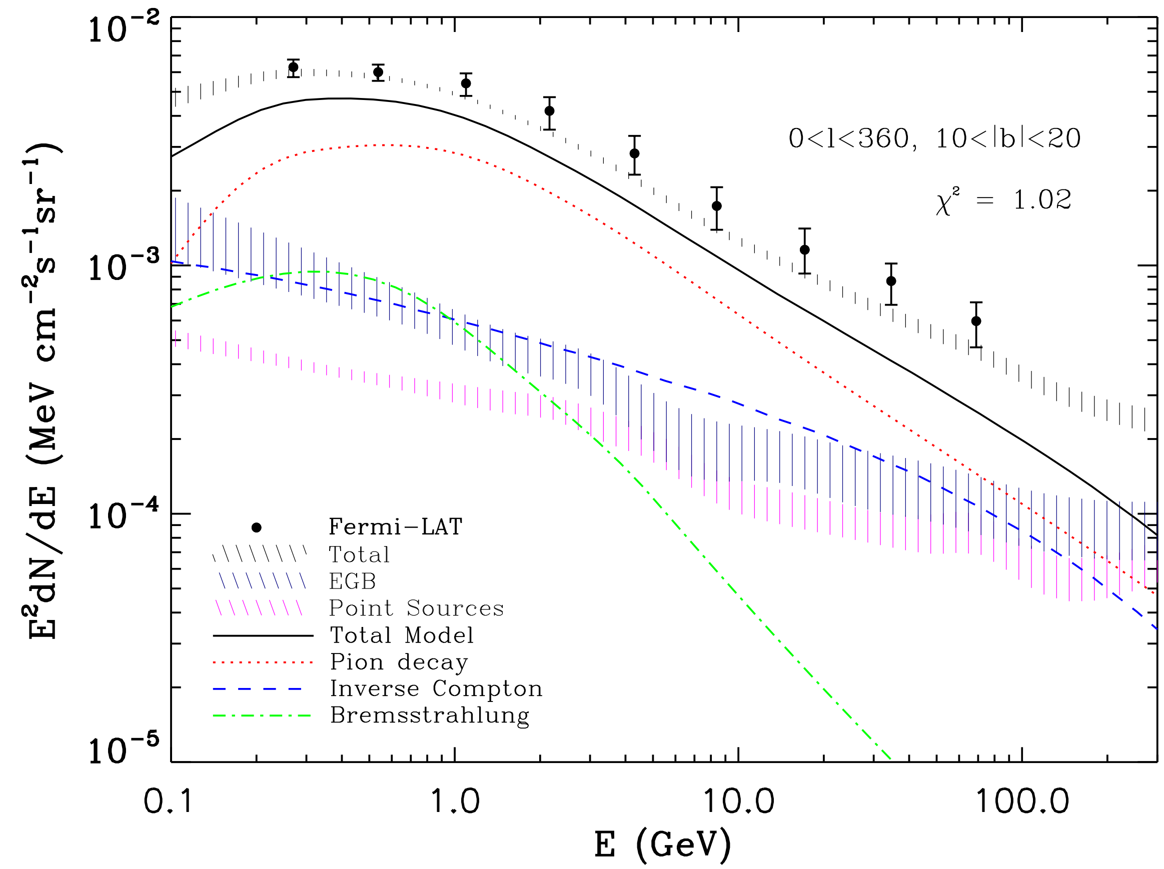
Diffuse Galactic Gamma Rays

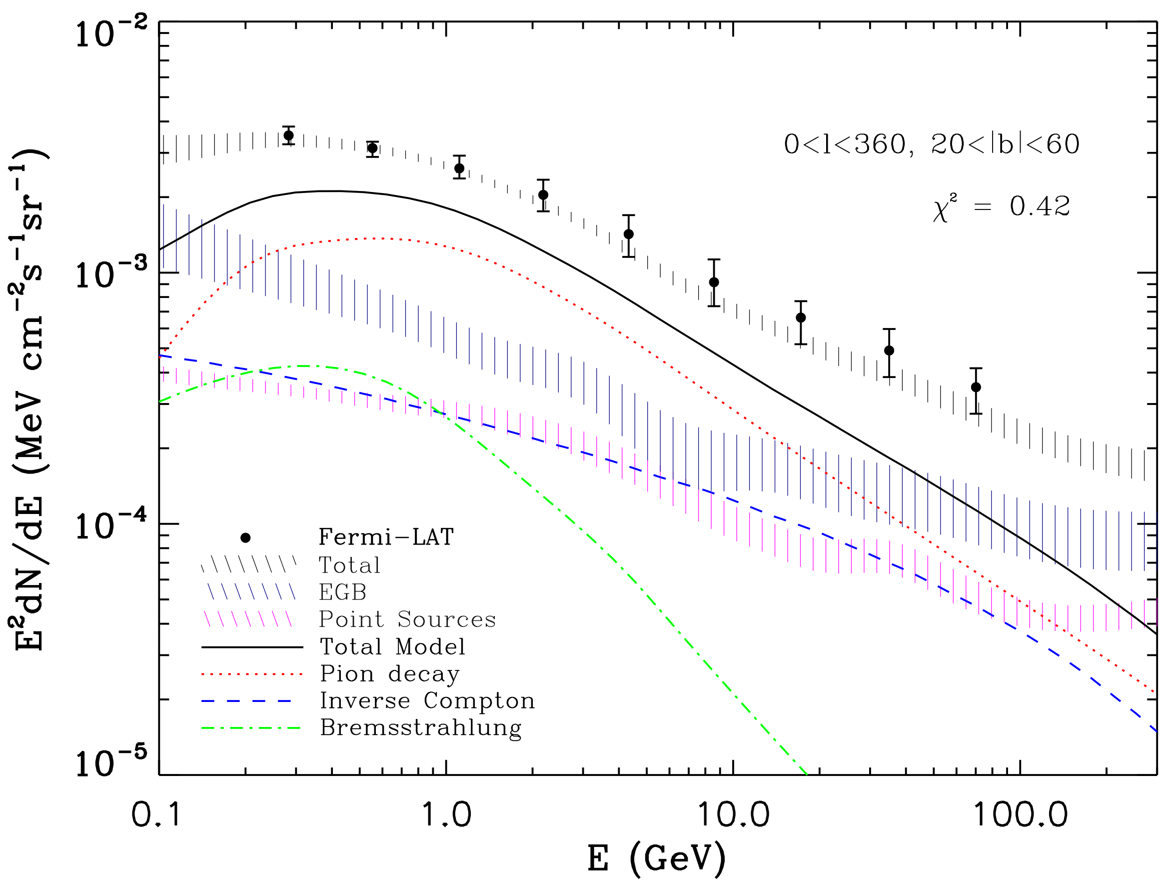
The Reference model :

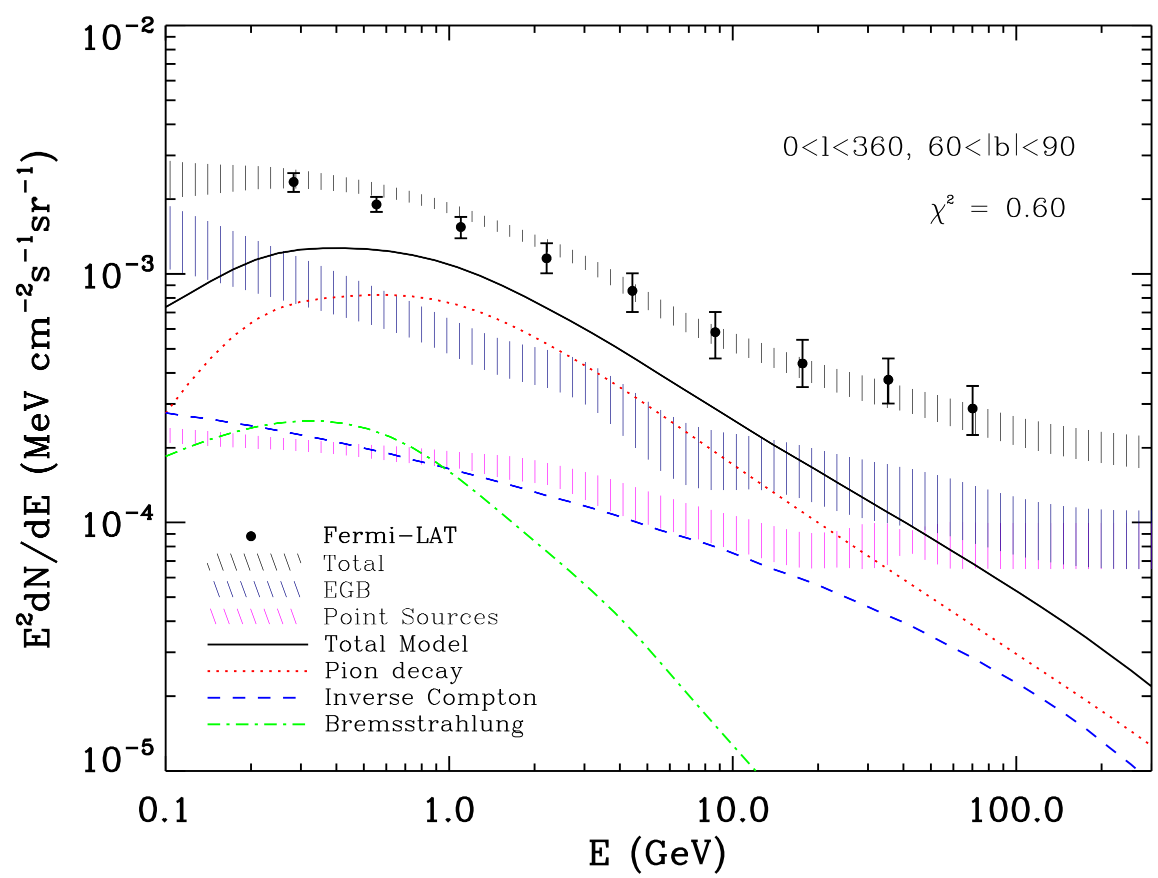
$$\delta = 0.5$$

$$z_d = 4\ kpc \quad r_d = 20\ kpc$$

A good combined fit to the local CR data and diffuse γ-ray.







DM Component

We consider generic DM candidates annihilating into quarks, charged leptons and charged gauge bosons.

We use PAMELA electrons, PAMELA and Fermi positron fraction, as well as Fermi, MAGIC and H.E.S.S $e^- + e^+$ spectra above 10 GeV.

We search for the maximum allowed DM annihilation rate fitting all of these data within 3σ.

For the distribution of DM in our Galaxy we take Burkert profile.

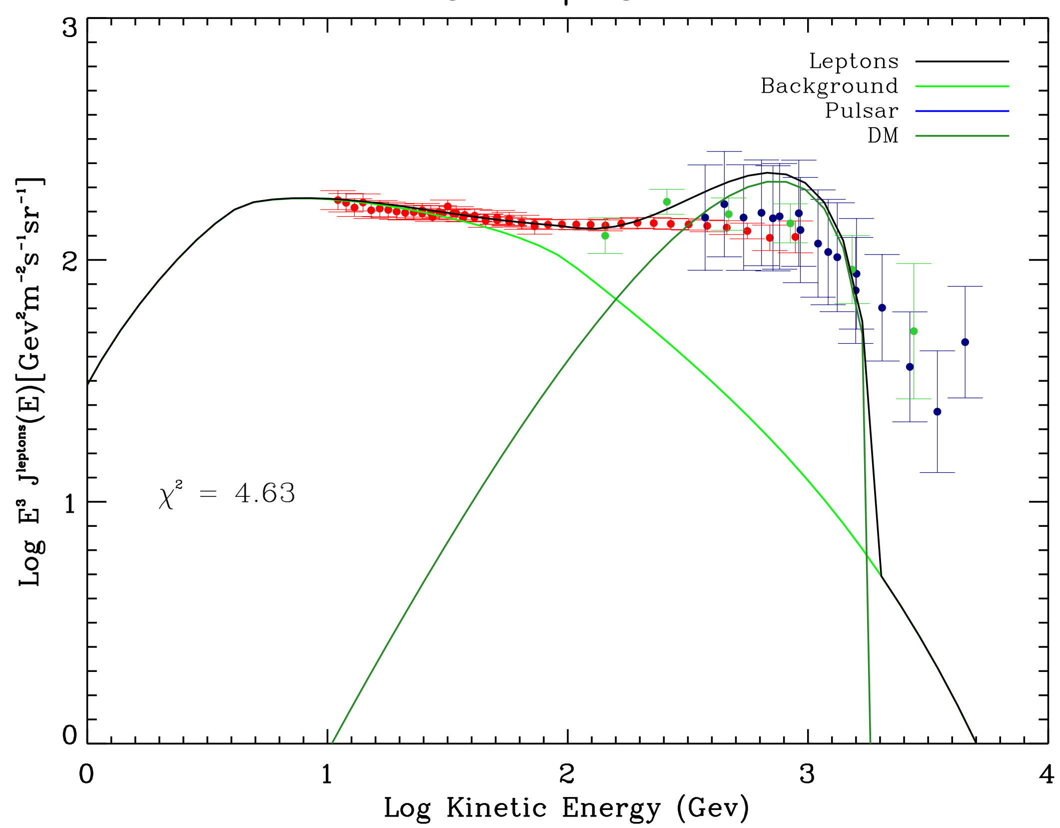
$$\rho_\chi(r) = \frac{\rho_0}{(1+x)(1+x^2)}, \quad x = \frac{r}{a_h}$$

$$\rho_\chi(R_\odot) = 0.4\ GeV/cm^3, \quad a_h = \ 10.0\ kpc$$

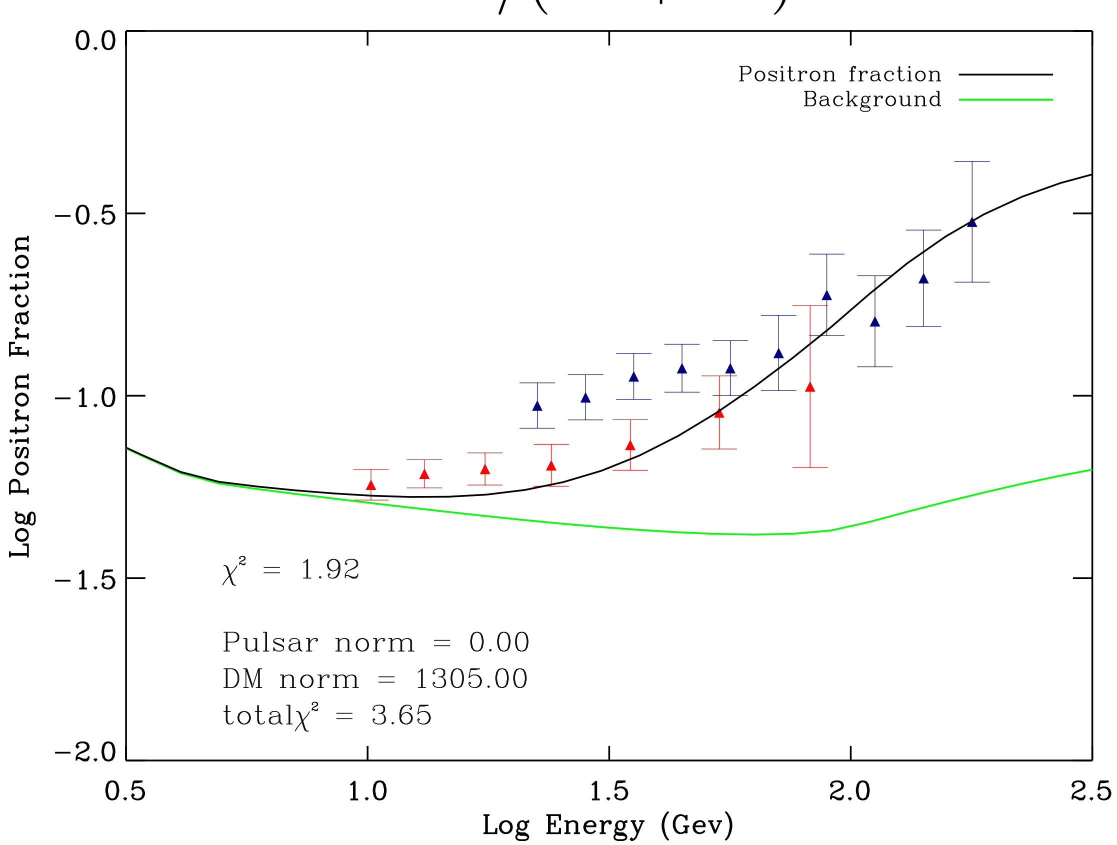
$\mu^+\mu^-$ Channel

For the leptophilic annihilation channels the lepton spectra induced by DM and pulsars are very similar.

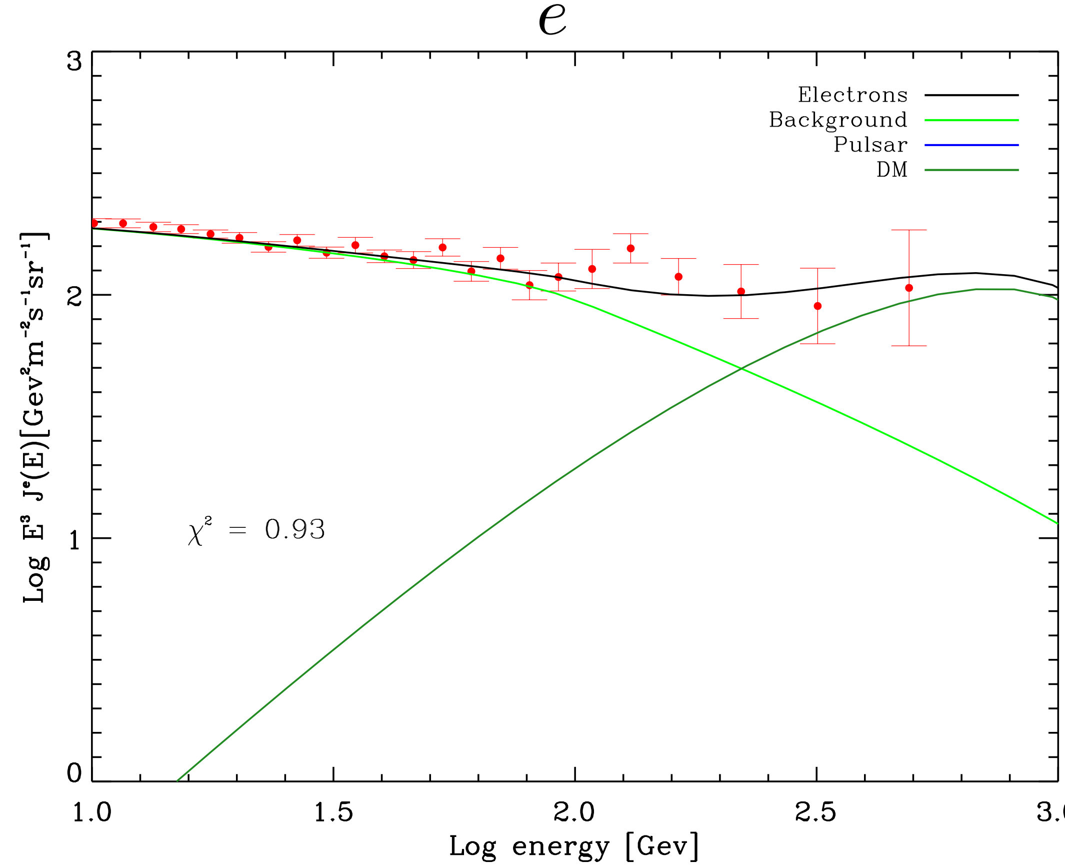
$e^- + e^+$



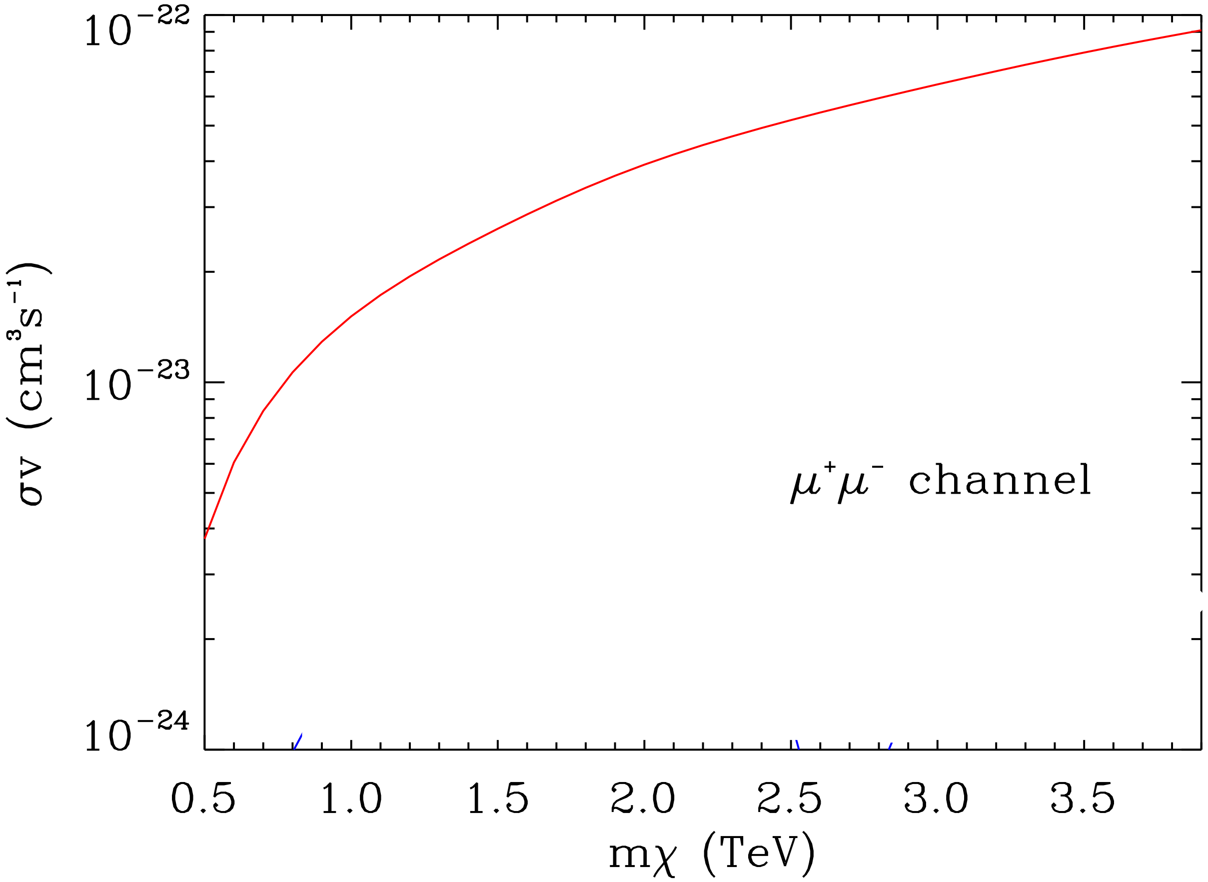
$e^+/(e^- + e^+)$

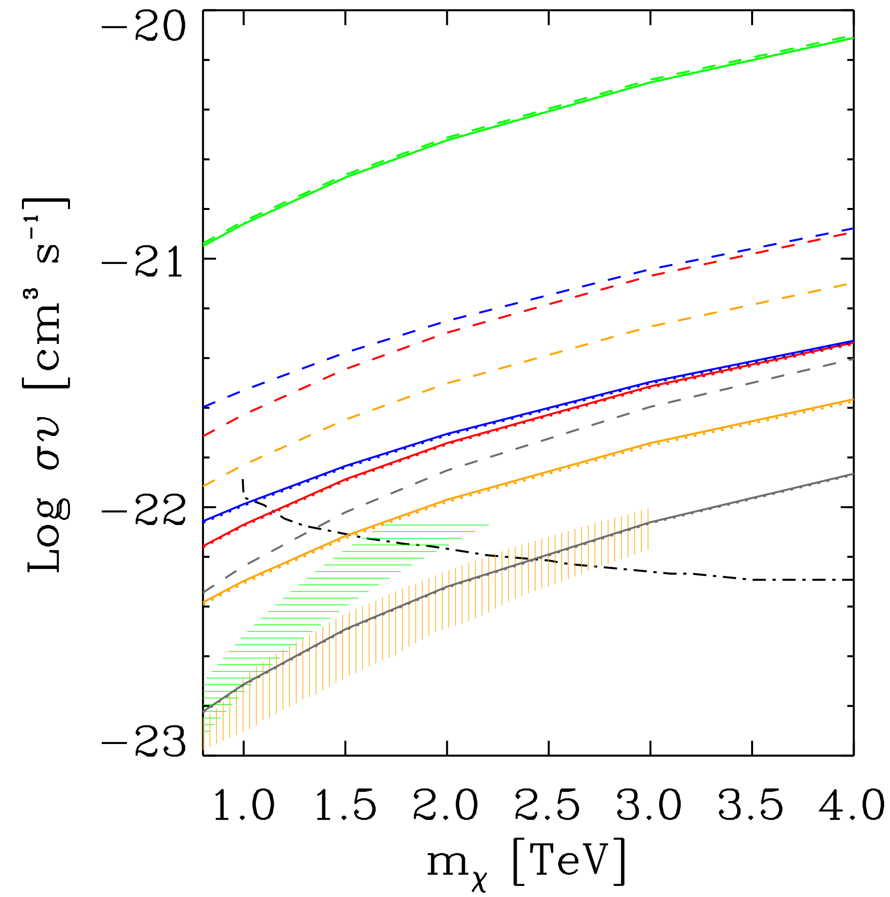


e^-

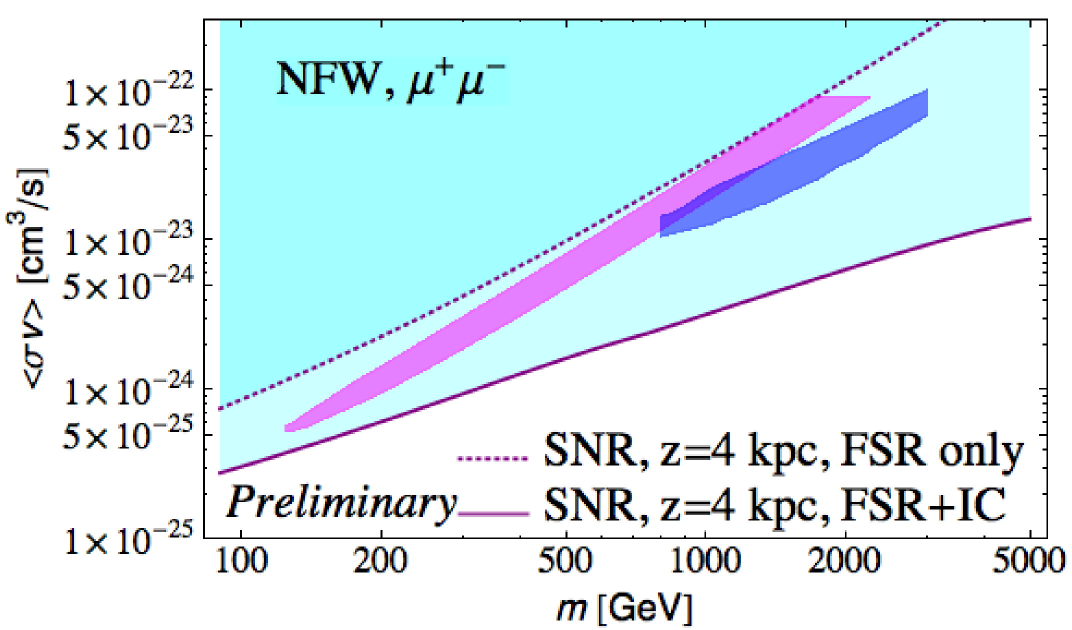


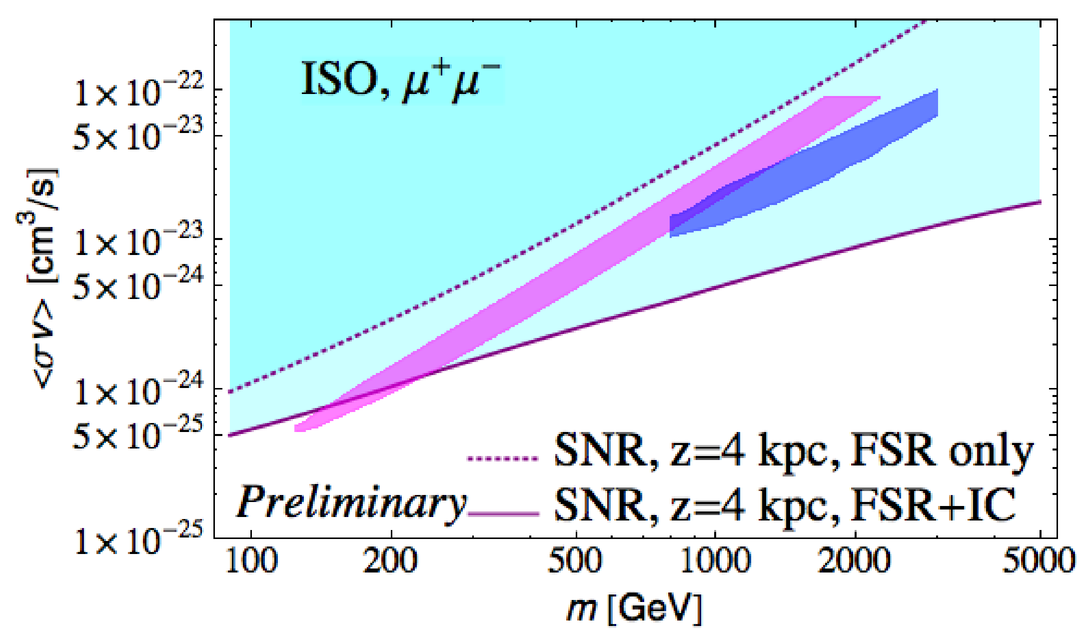
$\mu^+\mu^-$ Constraint





Evoli, Cholis, Grasso, Maccione, Ullio (arXiv:1108.0664)

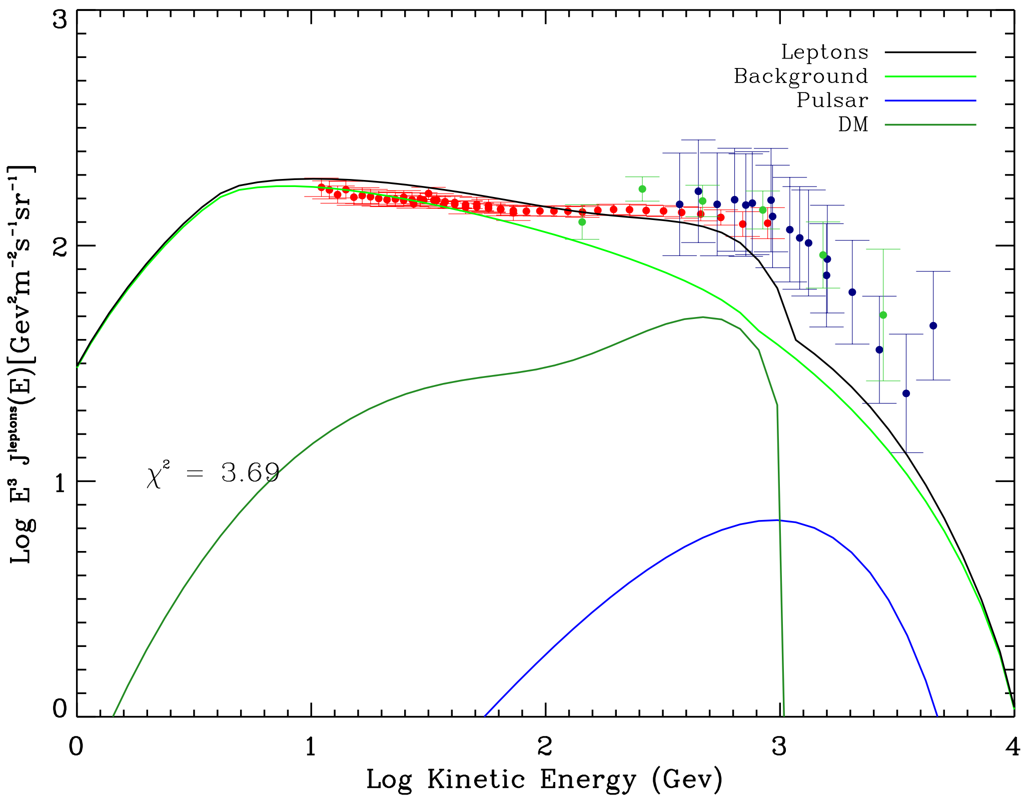




Zaharijas, Couoco, Yang, Conard
arXiv:1012.0588

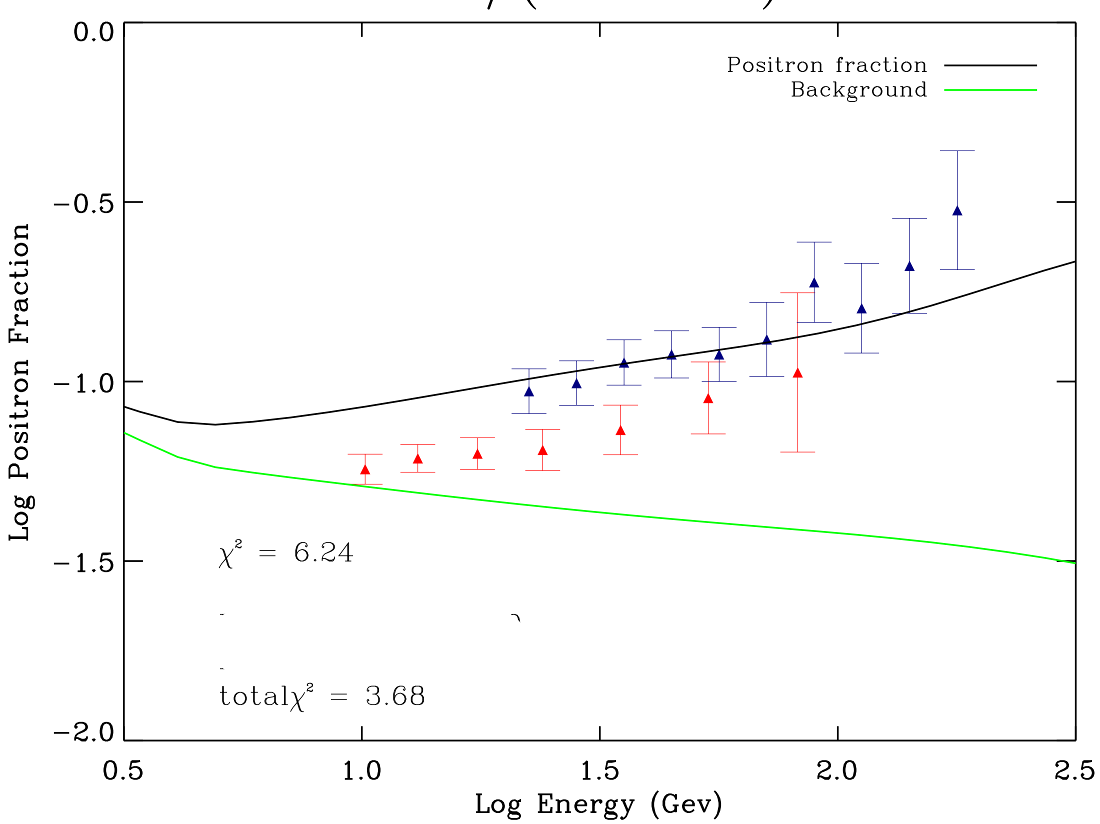
W^+W^- Channel

$e^- + e^+$

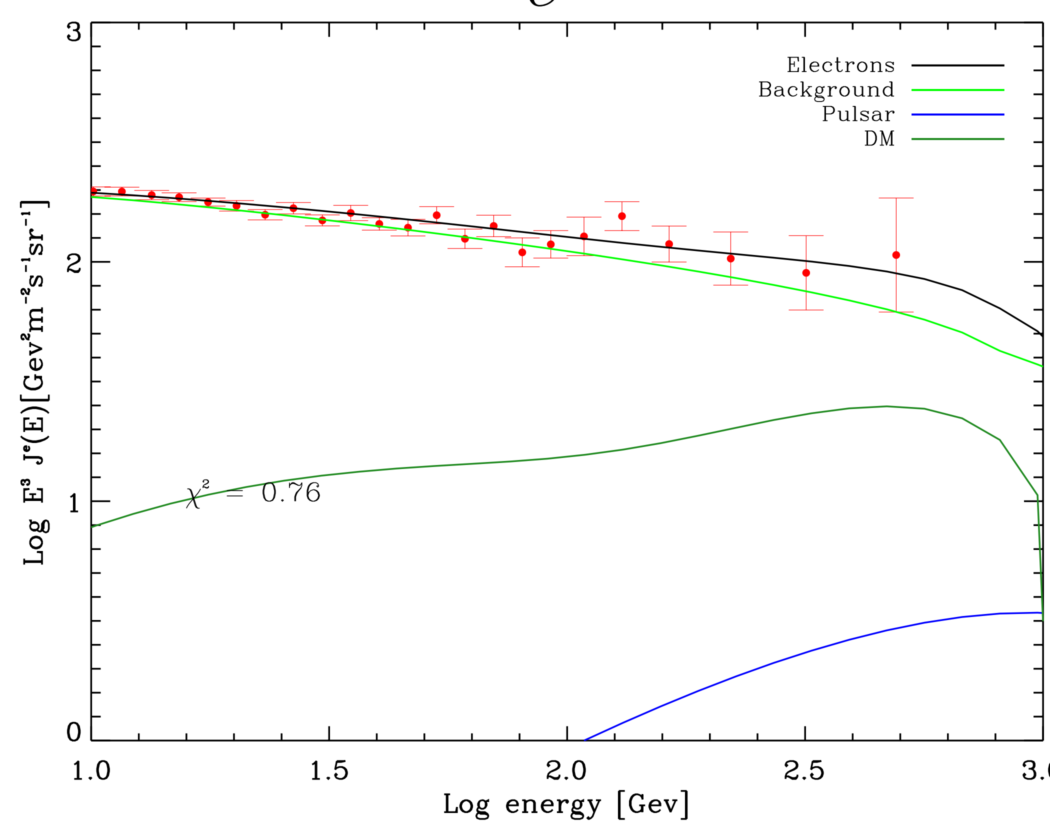


For WIMP masses below $\sim 1\ TeV$ in order to fit the data within 3σ a small contribution of pulsars is needed.

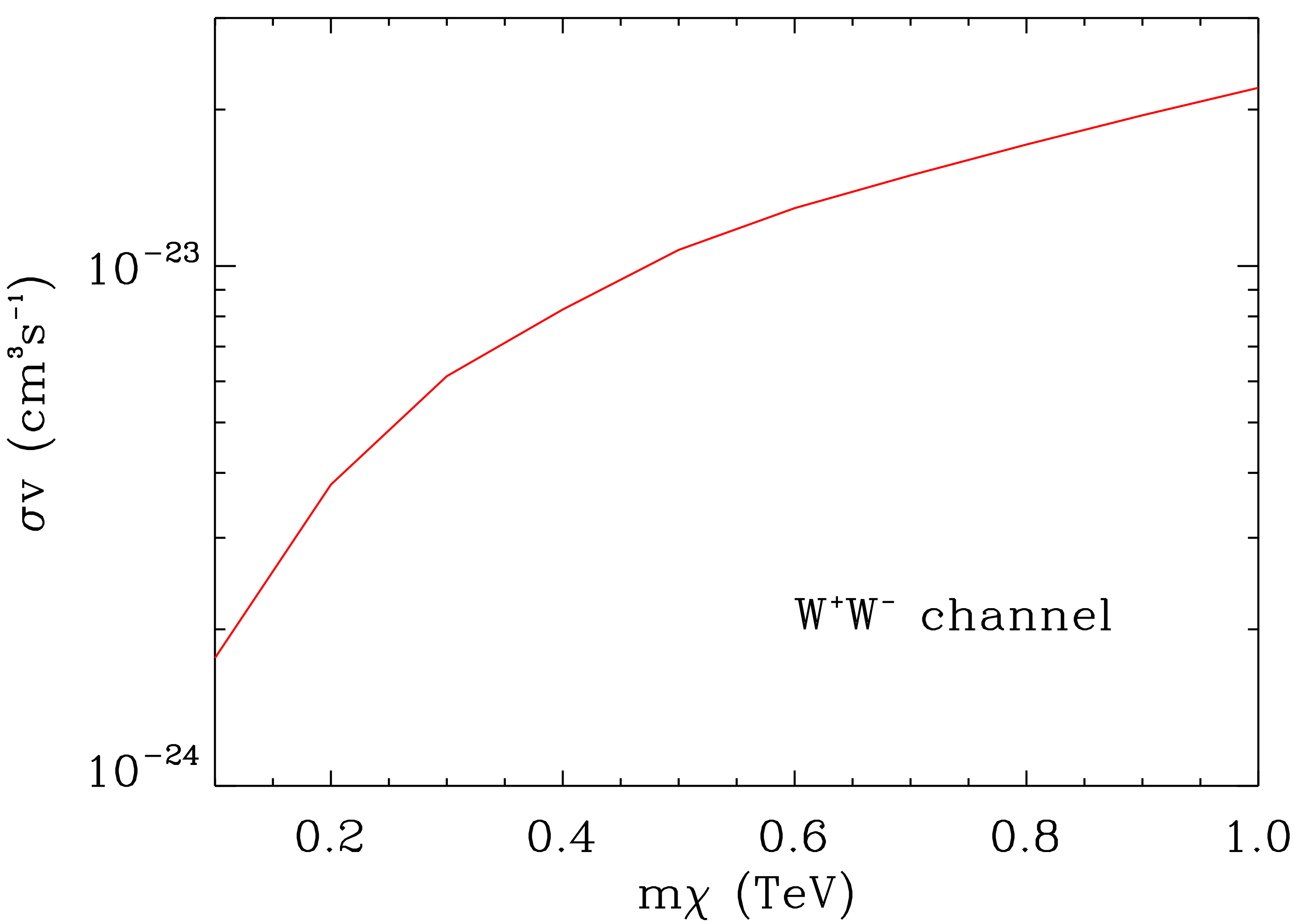
$e^+/(e^- + e^+)$

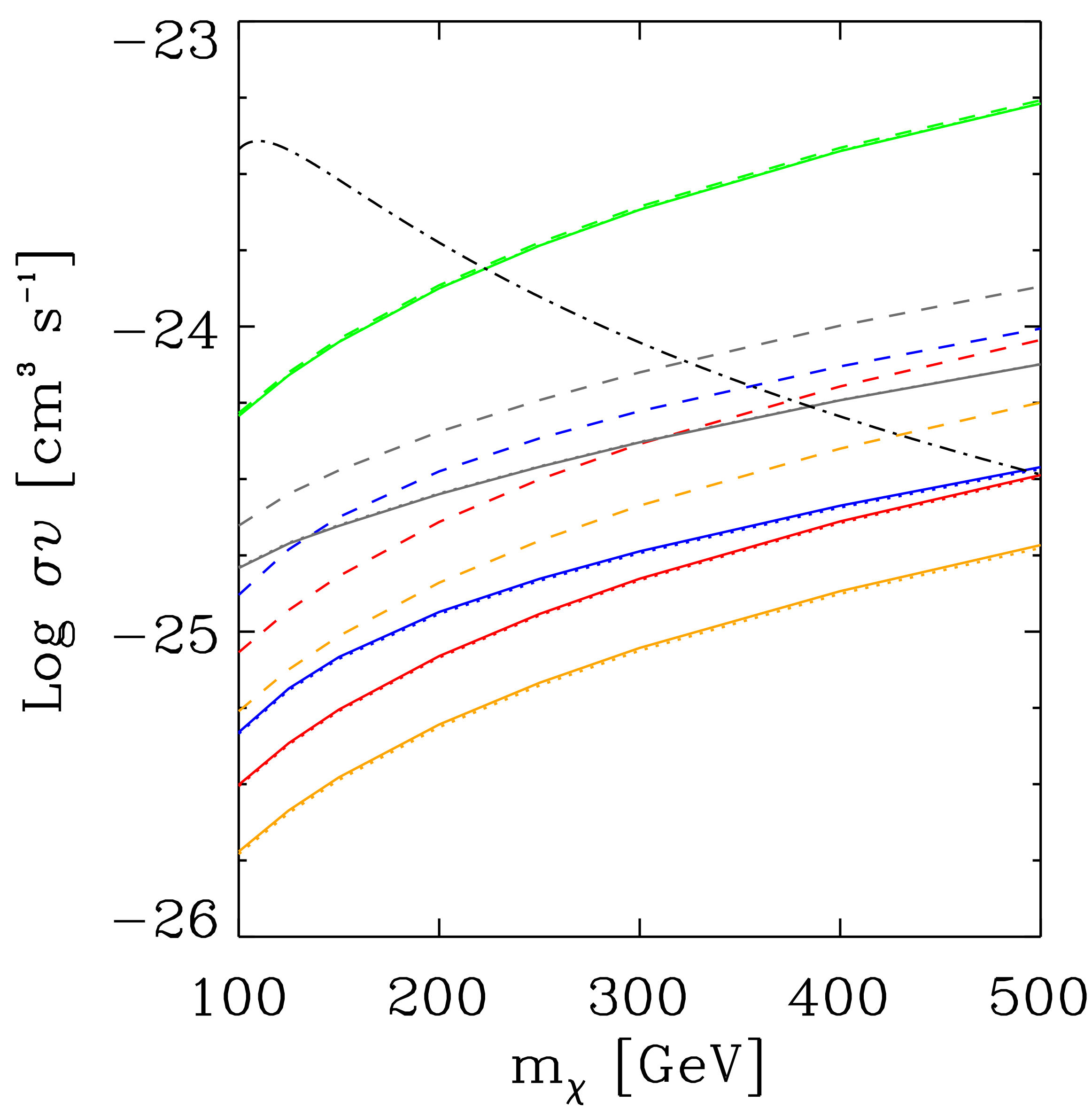


e^-



W^+W^- Constraint



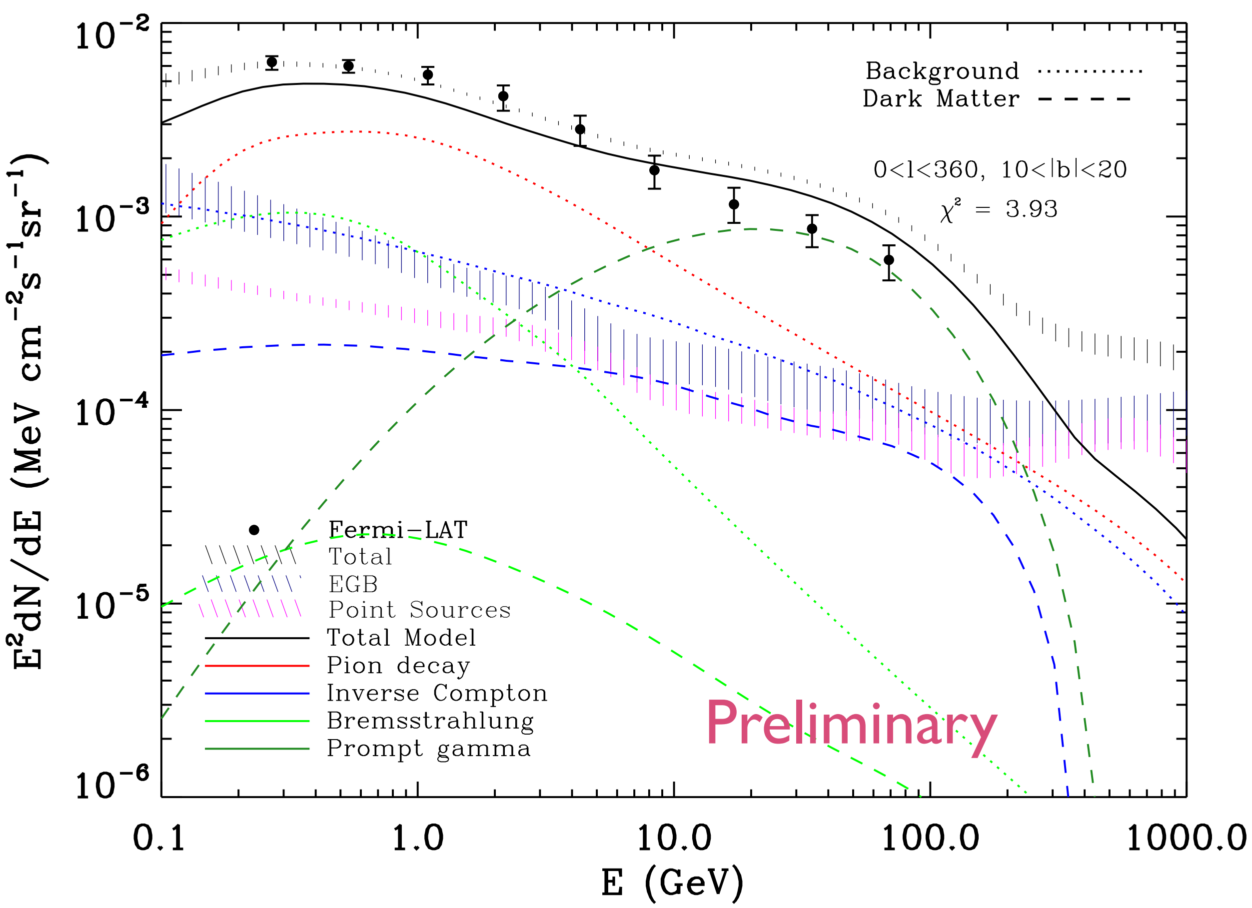


Anti-protons put more stringent constraints on WIMP annihilation cross section with respect to leptons.

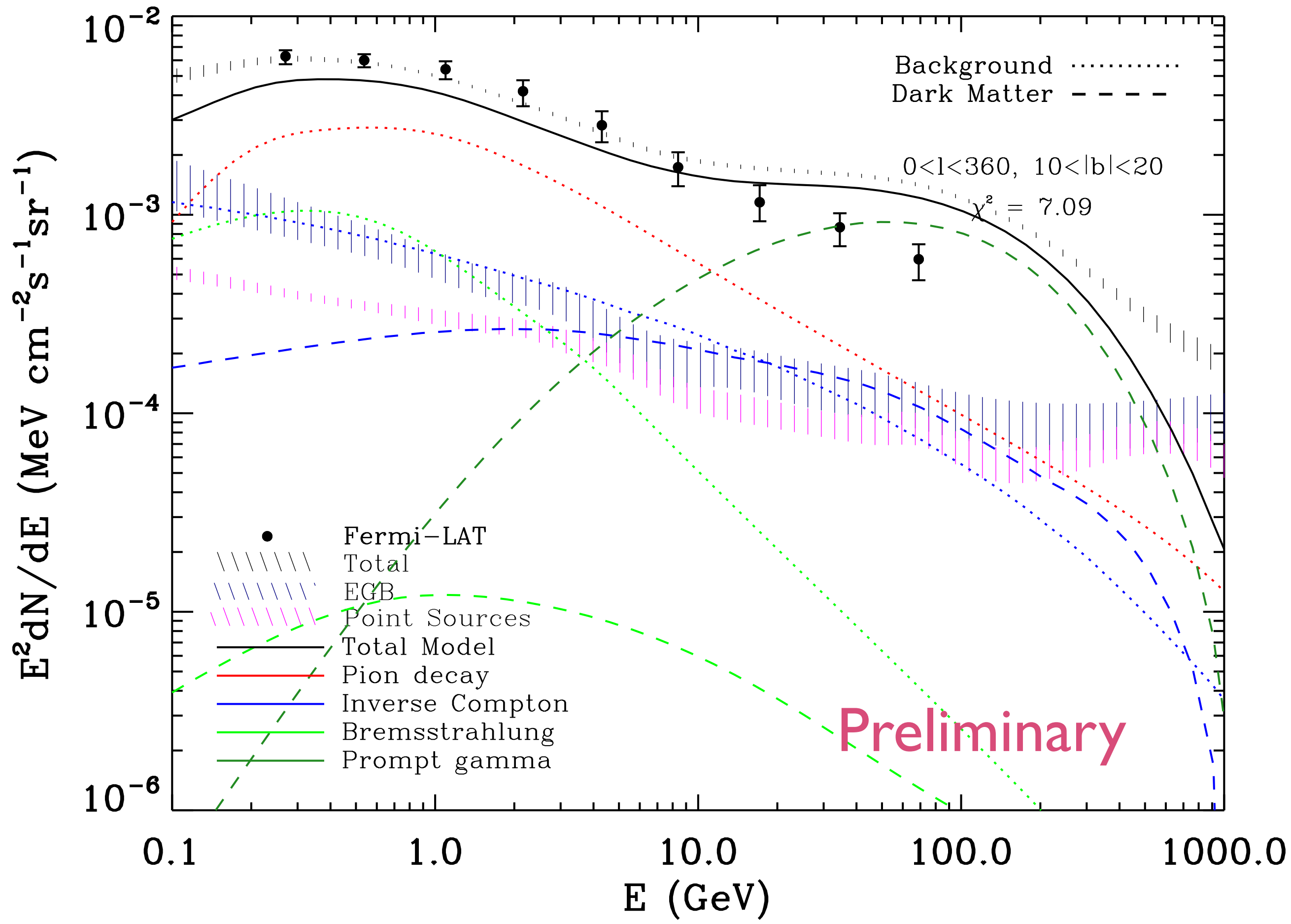
Evoli, Cholis, Grasso, Maccione, Ullio (arXiv:1108.0664)

W^+W^- Constraint

$m_\chi = 400\ GeV \quad \sigma v = 8.25 \times 10^{-24}$



$m_\chi = 1000\ GeV \quad \sigma v = 2.2 \times 10^{-23}$



WIMP models with large mass and cross section annihilating to W gauge bosons, which are allowed by leptons data, are excluded by diffuse gamma-ray data.

Summary

- A model of CR propagation and interstellar medium which is consistent with CRs and diffuse gamma spectral data is used as a background.
- Electrons, positron fraction and total electrons spectra are used to constrain the WIMP annihilation properties.
- The limits on the leptophilic DM annihilating to muons are the most tight ones in this analysis.
- Adding a new piece of information, by using diffuse gamma emissions in different regions of the sky, we can constraints further the DM annihilation/decay properties. (work in prep)