Constraining Dark Matter Properties with Fermi-LAT

based on NB and S. Palomares-Ruiz
ArXiv:1006.0477

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Bad Honnef, October 7th, 2010

Gamma-rays: general features

The differential intensity of the DM gamma-ray signal

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\Delta\Omega) = \left(\frac{d\Phi_\gamma}{dE_\gamma}\right)_{\rm prompt}(E_\gamma,\Delta\Omega) + \left(\frac{d\Phi_\gamma}{dE_\gamma}\right)_{\rm ICS}(E_\gamma,\Delta\Omega) + \left(\frac{d\Phi_\gamma}{dE_\gamma}\right)_{\rm synchrotron}(E_\gamma,\Delta\Omega)$$

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* Prompt gamma-rays produced by annihilation of DM particles:

$$\left(\frac{d\Phi_\gamma}{dE_\gamma}\right)_{\rm prompt}(E_\gamma,\Delta\Omega) = \frac{\langle\sigma v\rangle}{2\,m_\chi^2}\sum_i \frac{dN_\gamma^i}{dE_\gamma}\,{\rm BR}_i\,\frac{1}{4\,\pi}\int_{\Delta\Omega} d\Omega \int_{\rm los} \rho\big(r(s,\Omega)\big)^2\, ds$$

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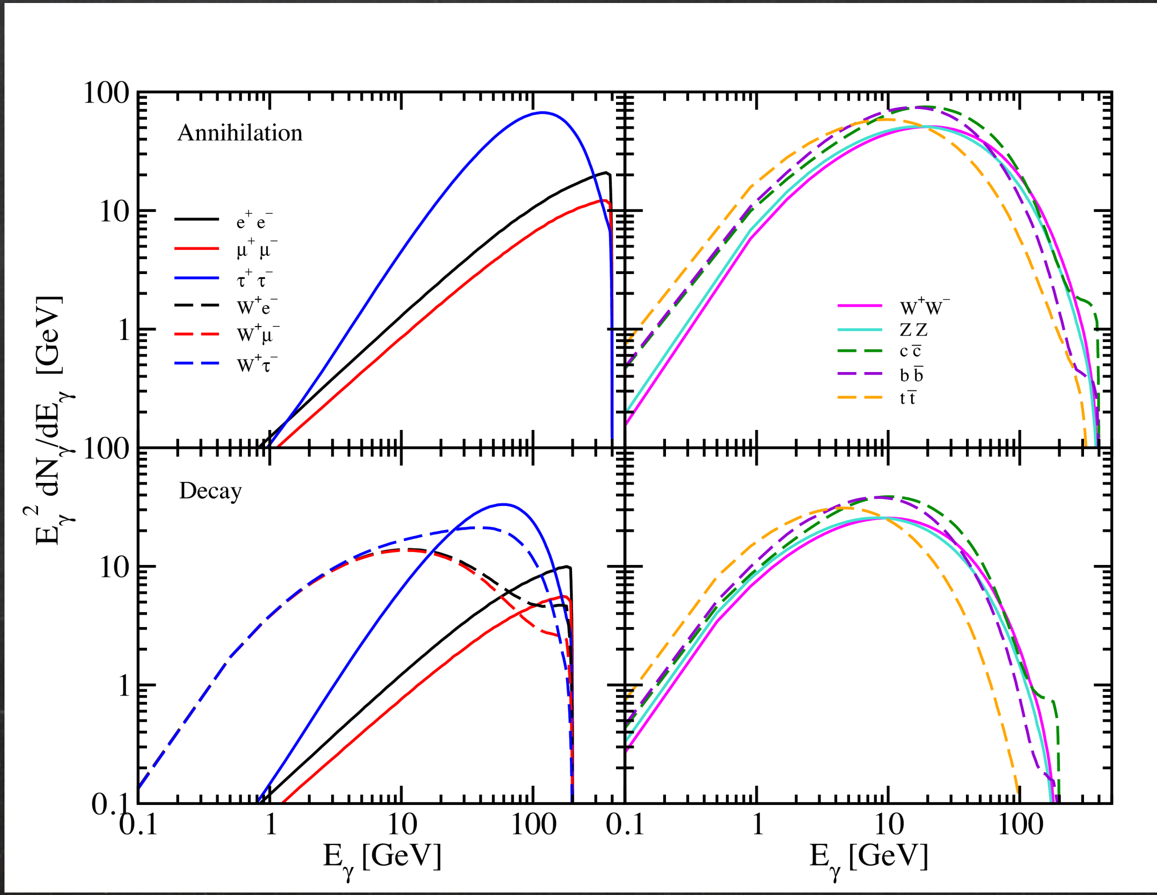
Particle P.

Gamma-ray spectra from DM annihilation

We assume DM annihilates into 2 SM particles and use Pythia.
Here only prompt photons are shown

Hard channels

Soft channels



S Palomares-Ruiz & JM Siegal-Gaskins arXiv:1003.1142

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Astro and Cosmo

DM halo profiles

From N-body simulations

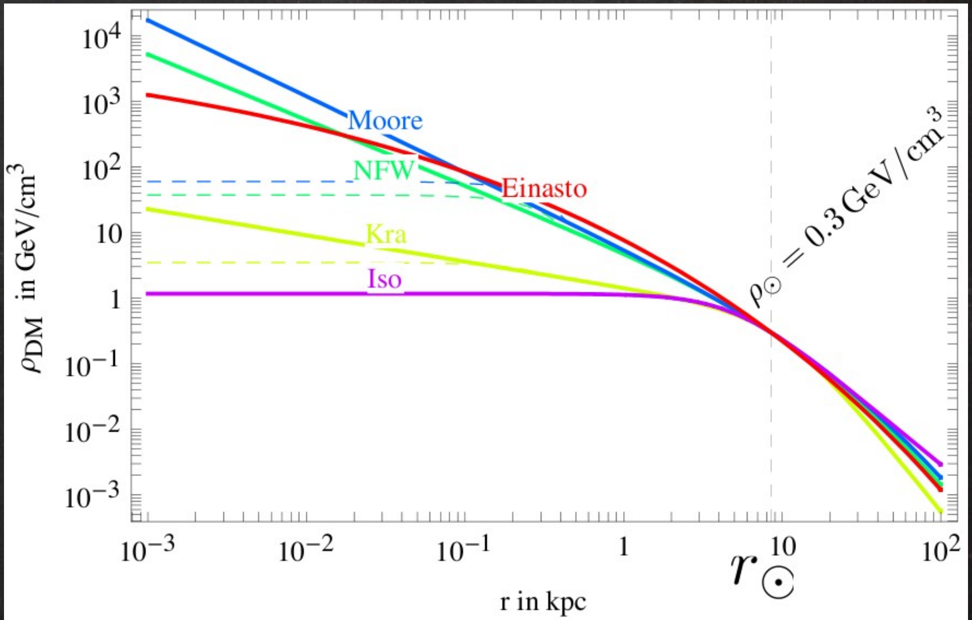
$$\rho(r) = \rho_\odot \frac{[1+(R_\odot/r_s)^\alpha]^{(\beta-\gamma)/\alpha}}{(r/R_\odot)^\gamma\,[1+(r/r_s)^\alpha]^{(\beta-\gamma)/\alpha}}$$

Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

At small r: $\rho(r)=1/r^\gamma$

$$\rho(r) = \rho_s \cdot \exp\left[-\frac{2}{\alpha}\left(\left(\frac{r}{r_s}\right)^\alpha - 1\right)\right]$$

Einasto | $\alpha = 0.17$ $r_s = 20\,\mathrm{kpc}$ $\rho_s = 0.06\,\mathrm{GeV/cm^3}$



Gamma-rays: general features

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* Gamma-rays from Inverse Compton Scattering:

- Electrons/Positrons could propagate in the ISM
- Gamma-rays production via ICS off the ambient photon background

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* Gamma-rays from Inverse Compton Scattering:
- Electrons/Positrons could propagate in the ISM
- Gamma-rays production via ICS off the ambient photon background

$$\left(\frac{d\Phi_\gamma}{dE_\gamma}\right)_{\text{ICS}}(E_\gamma, \Delta\Omega) = \frac{1}{E_\gamma}\frac{1}{4\pi}\int_{\Delta\Omega} d\Omega \int_{\text{los}} ds \int_{m_e}^{m_\chi} dE\, \mathcal{P}(E_\gamma, E)\, \frac{dn_e}{dE}(E, r_c(s,\Omega), z_c(s,\Omega))$$

Differential power emitted into photon of energy E_γ
by electrons/positrons of energy E

- Superposition of 3 blackbody spectra:
SL (T=0.3 eV), IR (T=3.5 meV), CMB (T=2.7 K)

Gamma-rays: general features

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* The gamma-ray synchrotron signal lies at radio frequencies (at least for typical WIMP DM masses) $\longrightarrow$ irrelevant

Overview of the analysis

* We consider the energy range [1, 300] GeV

* We select an 'optimal' angular window

* We add the ICS contribution to the DM-induced gamma-ray spectrum: crucial for some cases

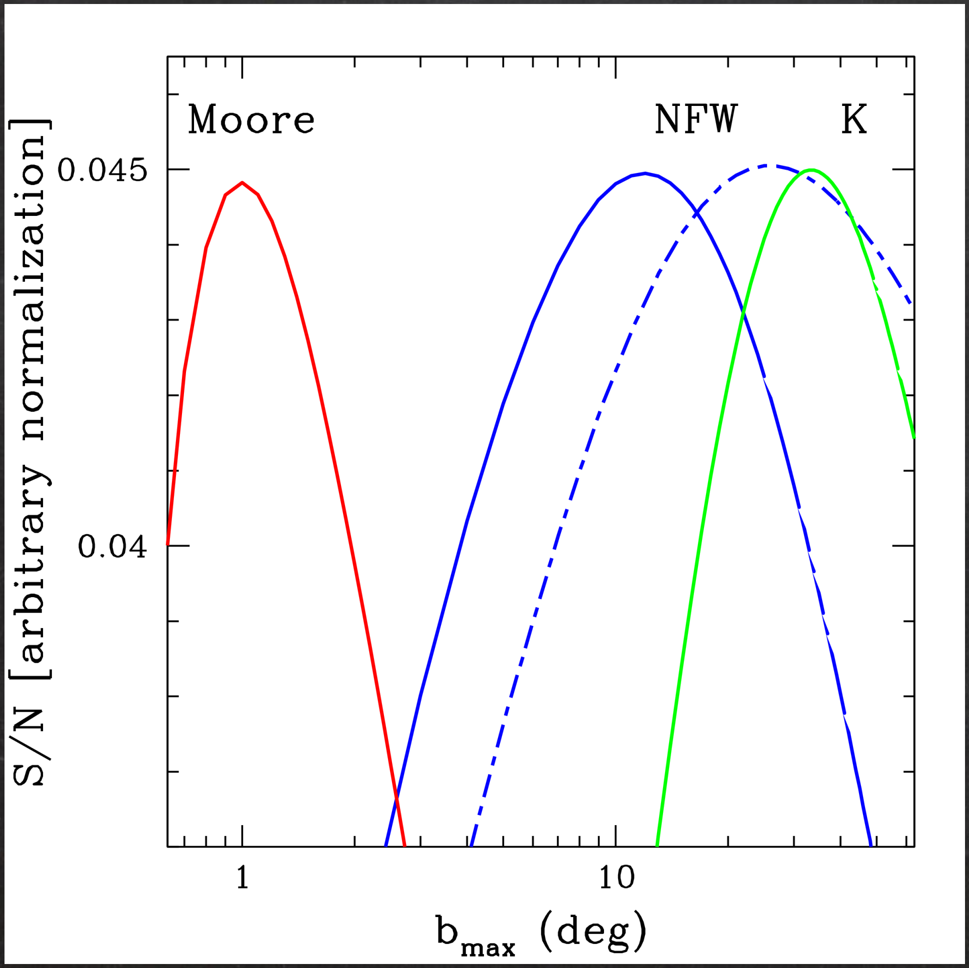
* We use Galprop + the latest Fermi measurements for the background around the GC

* We evaluate Fermi sensitivity to DM annihilations

* We evaluate Fermi abilities to constrain DM properties: annihilation cross section, mass and dominant annihilation channels

Optimal angular window

Significance of the signal: S/N

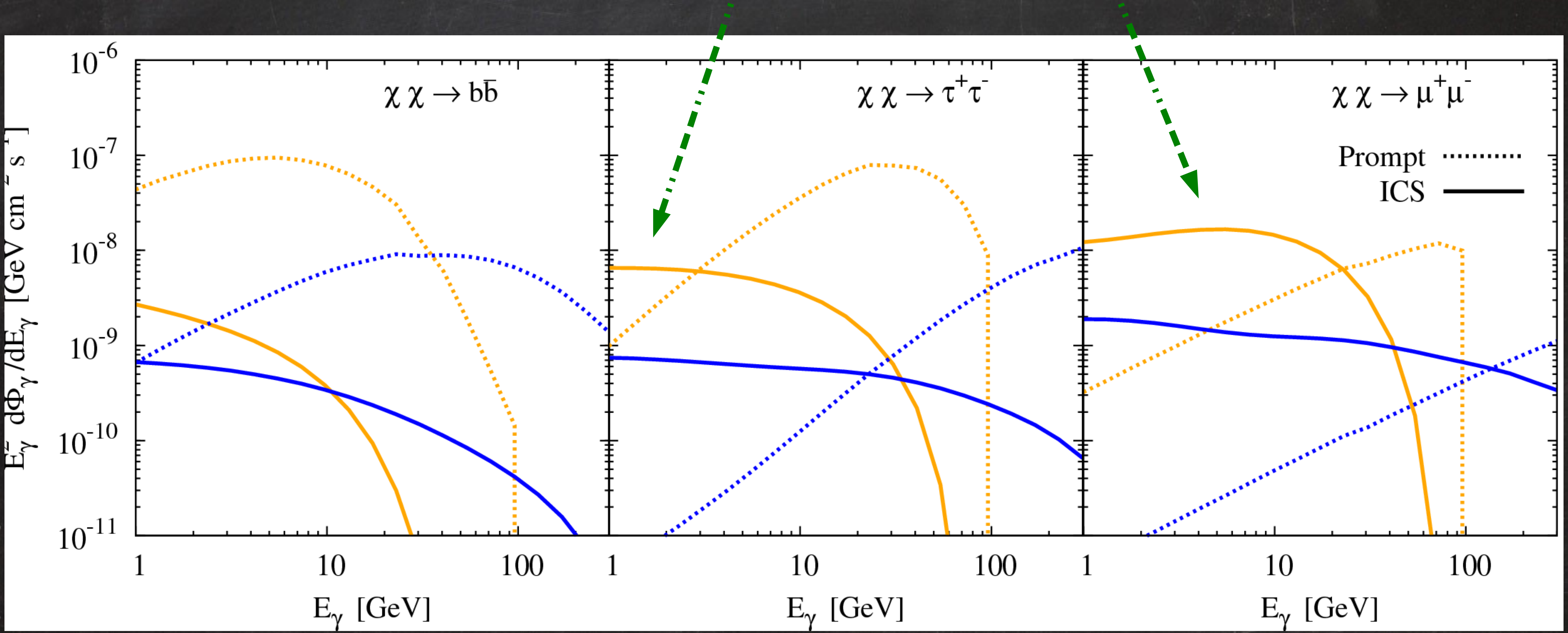


PD Serpico and G Zaharijas
Astropart. Phys. Rev. D 69 (2004)

Our selection:
10 degrees

Gamma-ray spectra from DM annihilation

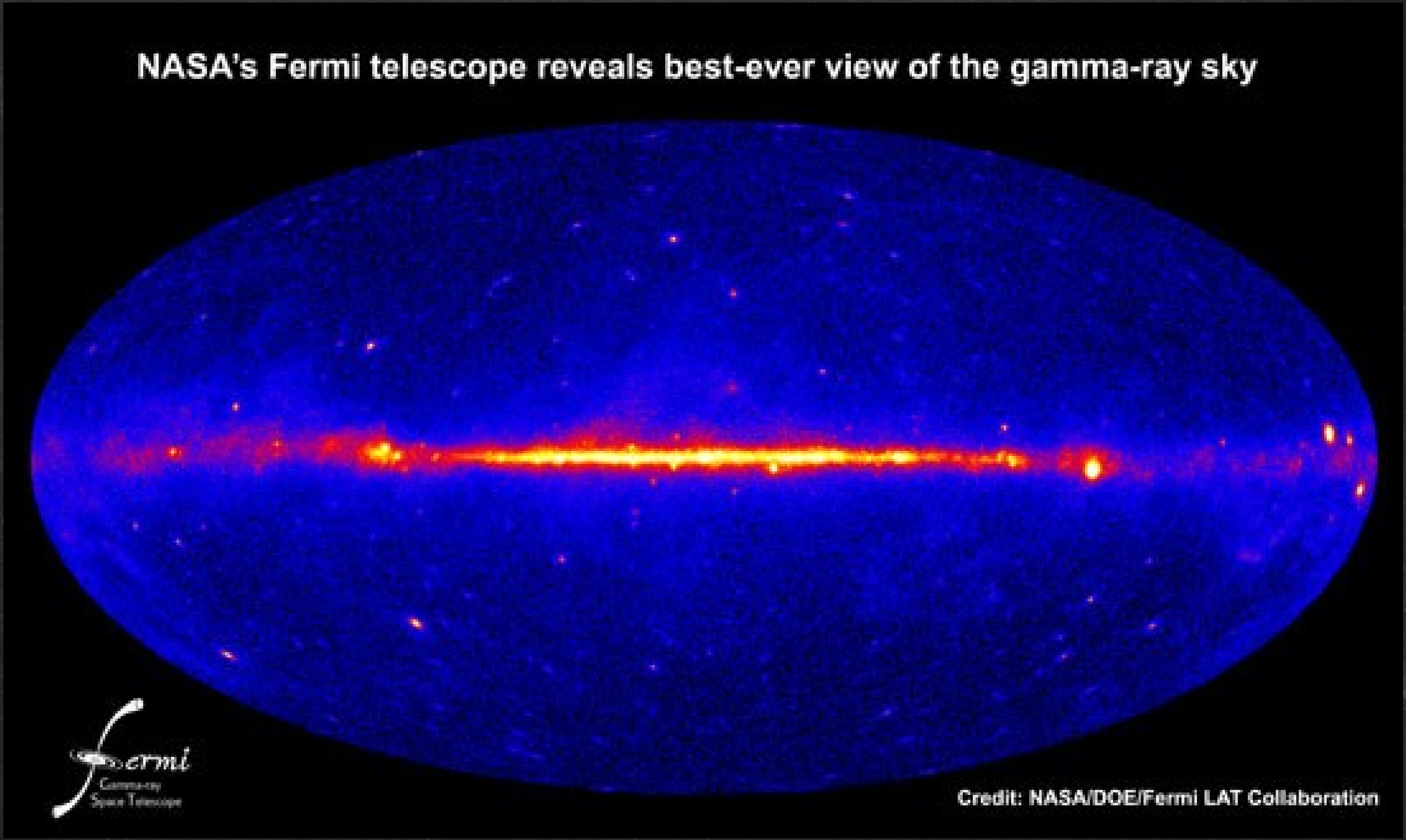
Important contribution from ICS at low energies!



NB and S Palomares-Ruiz arXiv:1006.0477

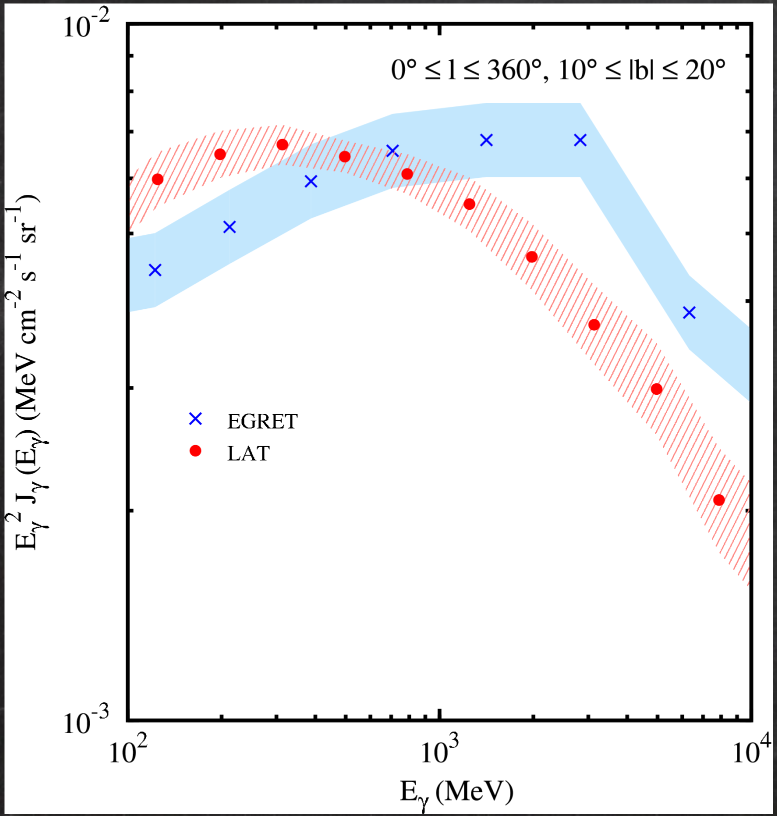
$<\sigma v> = 3 \times 10^{-26}$ cm^3 / s and NFW profile

Fermi-LAT sky map



AA Abdo [Fermi-LAT collaboration], Astrophys. J. Supp. 188:405, 2010

Galactic backgrounds: diffuse emission



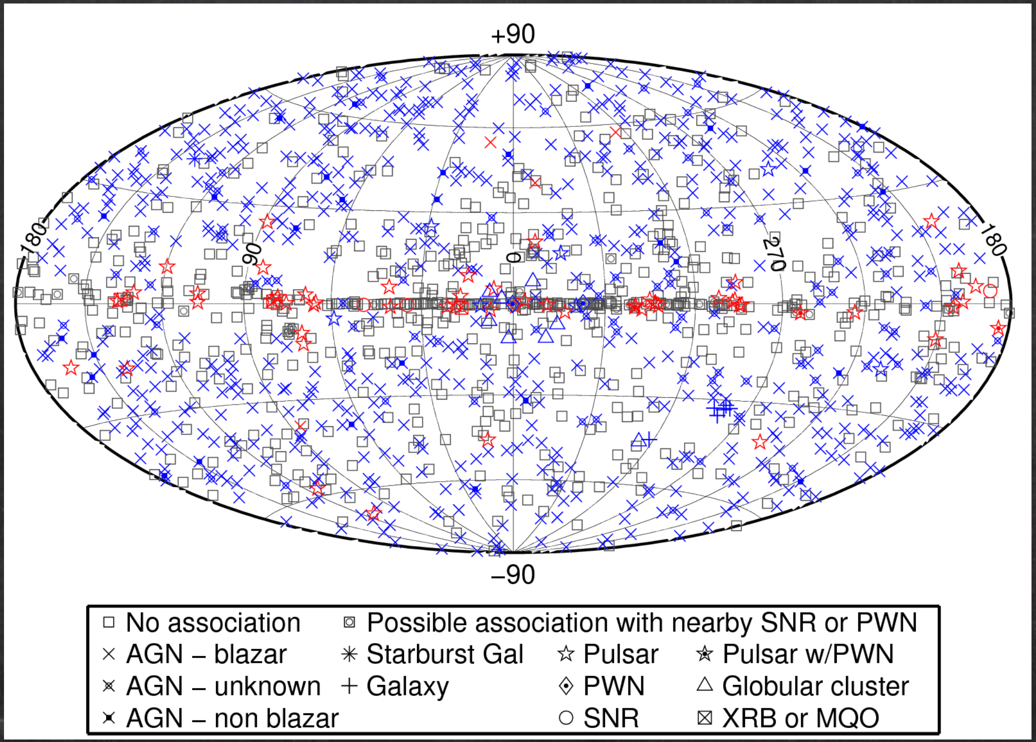
AA Abdo [Fermi-LAT Collaboration]
Phys. Rev. Lett. 103, 251101, 2009

GALPROP v54: 'conventional' model

- Pions decay
- Bremsstrahlung
- Inverse Compton scattering of CR

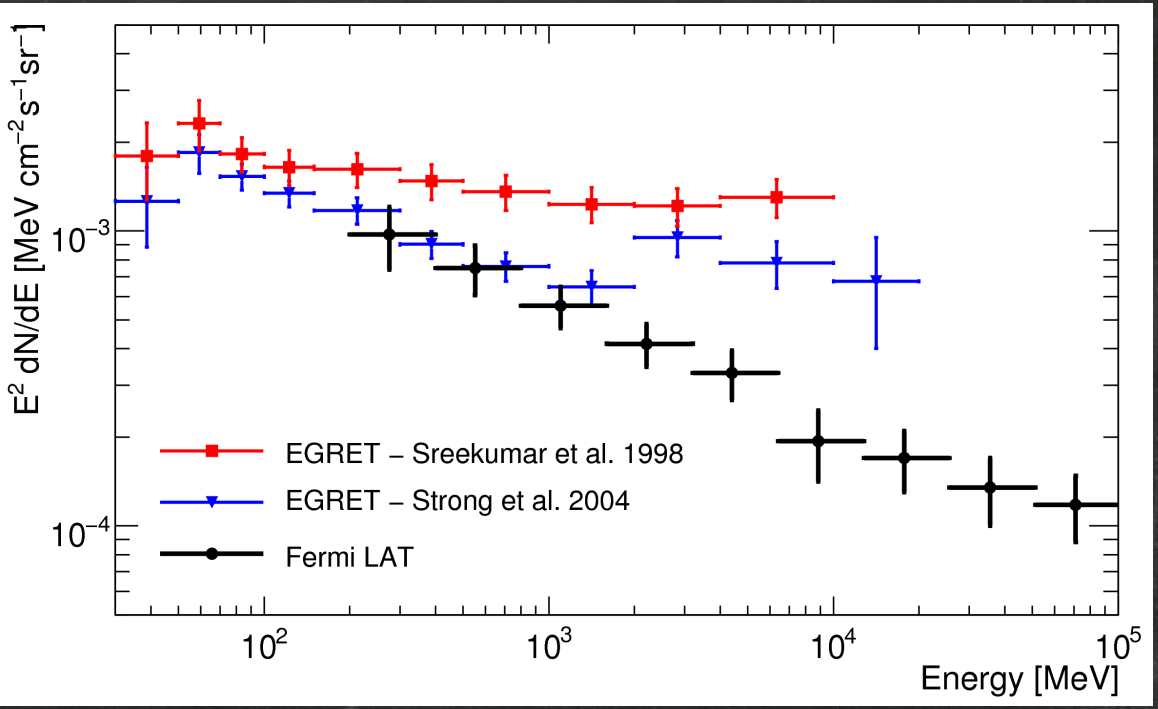
Galactic backgrounds: point sources

1451 point sources resolved at > 4 σ



AA Abdo [Fermi-LAT Collaboration], Astrophys. J supp . 188:405, 2010

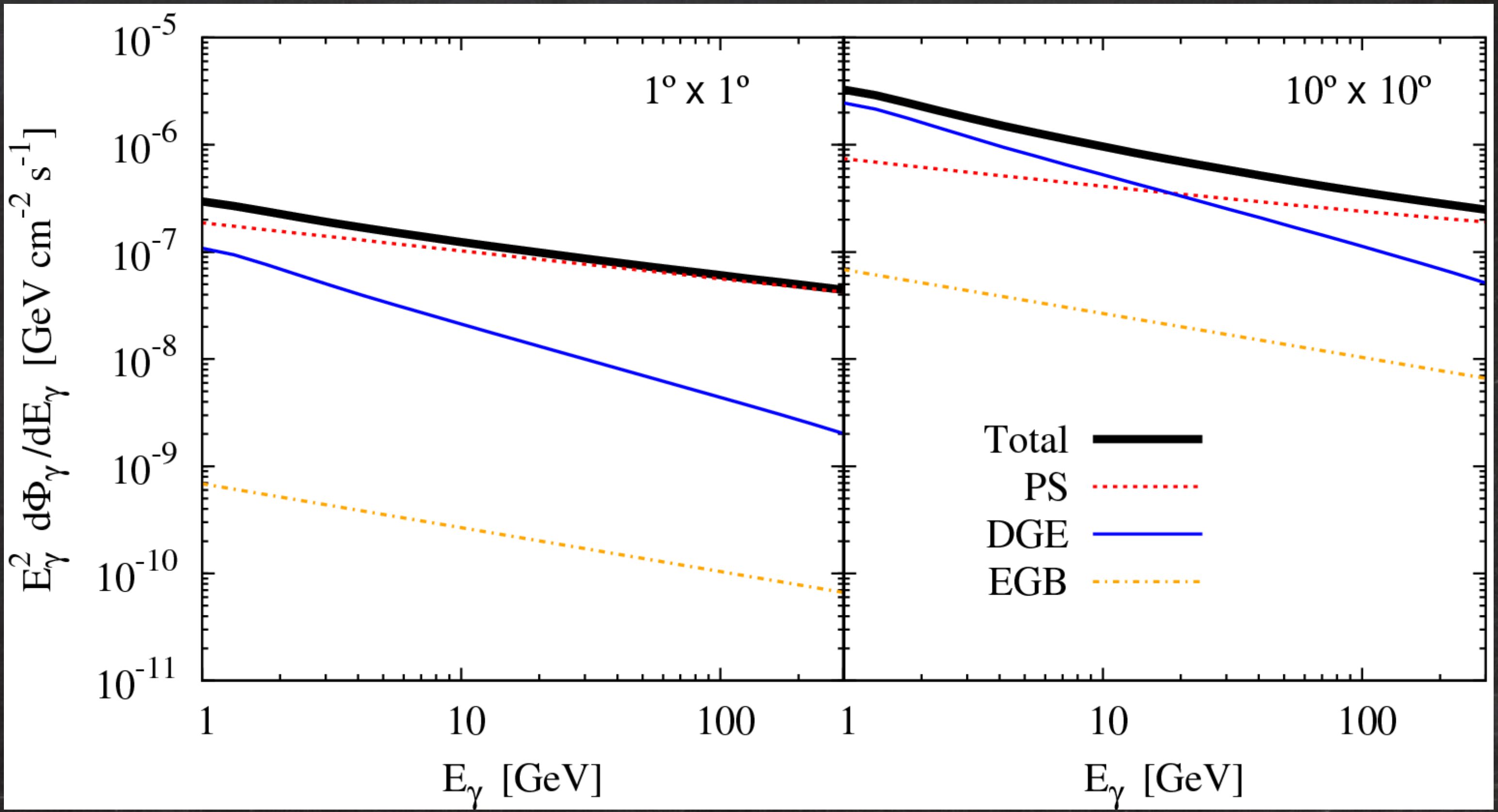
Galactic backgrounds: isotropic backg.



AA Abdo [Fermi-LAT Collaboration], Phys. Rev. Lett. 104,101101, 2010

$$\left(\frac{d\Phi}{dE_\gamma}\right)_{\rm IGRB}(E_\gamma) = 5.65\cdot 10^{-7}\cdot\left(\frac{E_\gamma}{\rm GeV}\right)^{-2.41} \quad {\rm GeV}^{-1}\,{\rm cm}^{-2}\,{\rm s}^{-1}\,{\rm sr}^{-1}$$

Galactic backgrounds



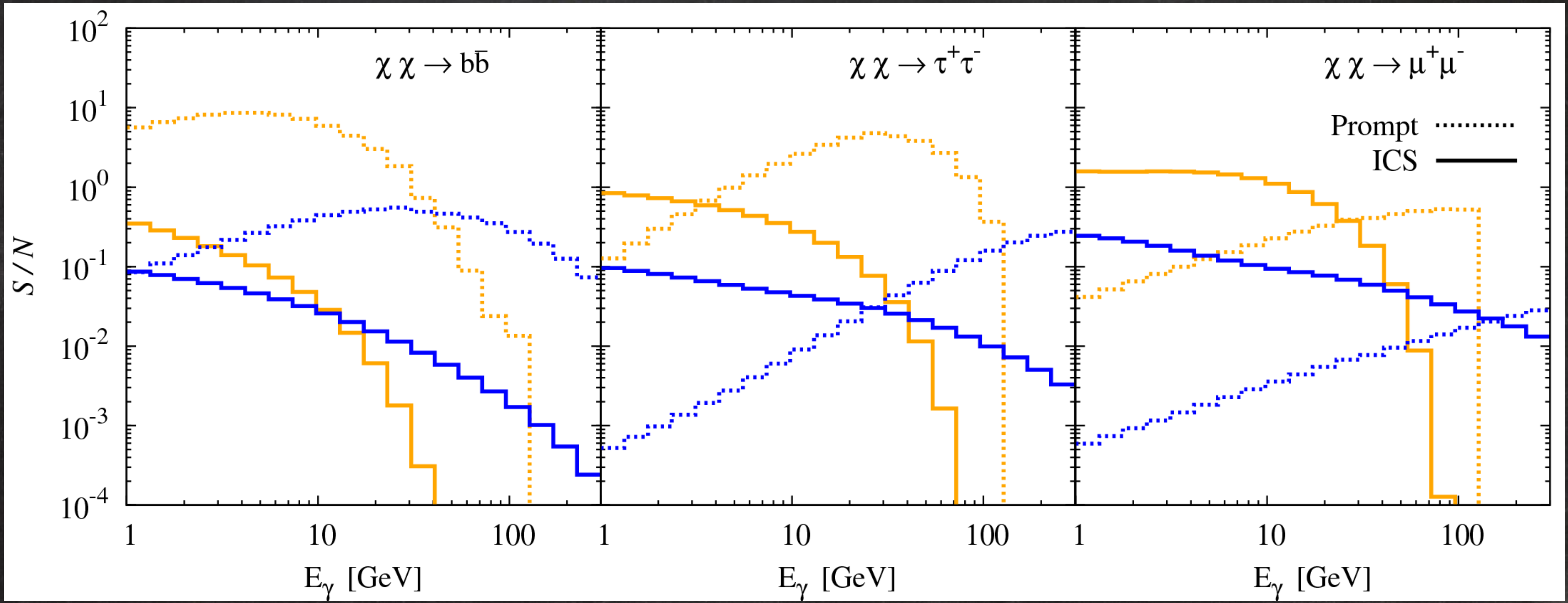
NB and S Palomares-Ruiz, arXiv:1006.0477

Significance of the signal: S/N

Prompt: dominant

Prompt: dominant high E
ICS: dominant low E

ICS: dominant



NB and S Palomares-Ruiz, arXiv:1006.0477

$\langle\sigma v\rangle = 3 \times 10^{-26}$ cm^3 / s and NFW profile

Constraining DM propertiess: default setup

* 10º x 10º

* DM profile: NFW

* $<\sigma v> = 3 \times 10^{-26}$ cm^3 / s

* Propagation model: MED

* "Real data": $\tau^+ \tau^-$ pairs

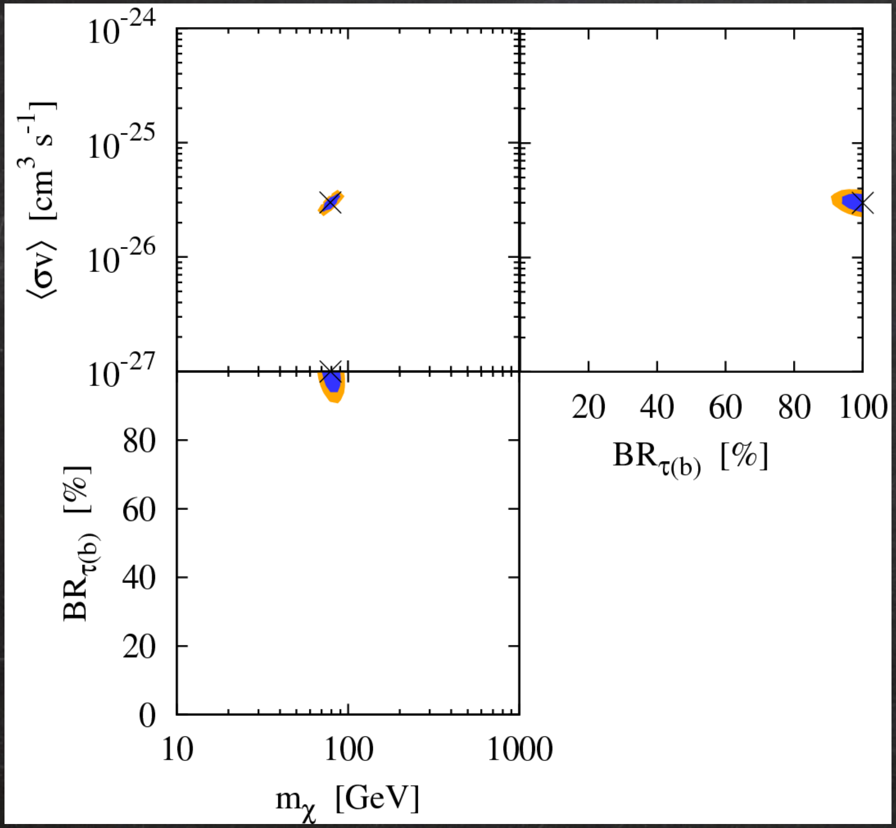
* Signal reconstructed with $\tau^+ \tau^-$ and bb pairs

* Fixed background

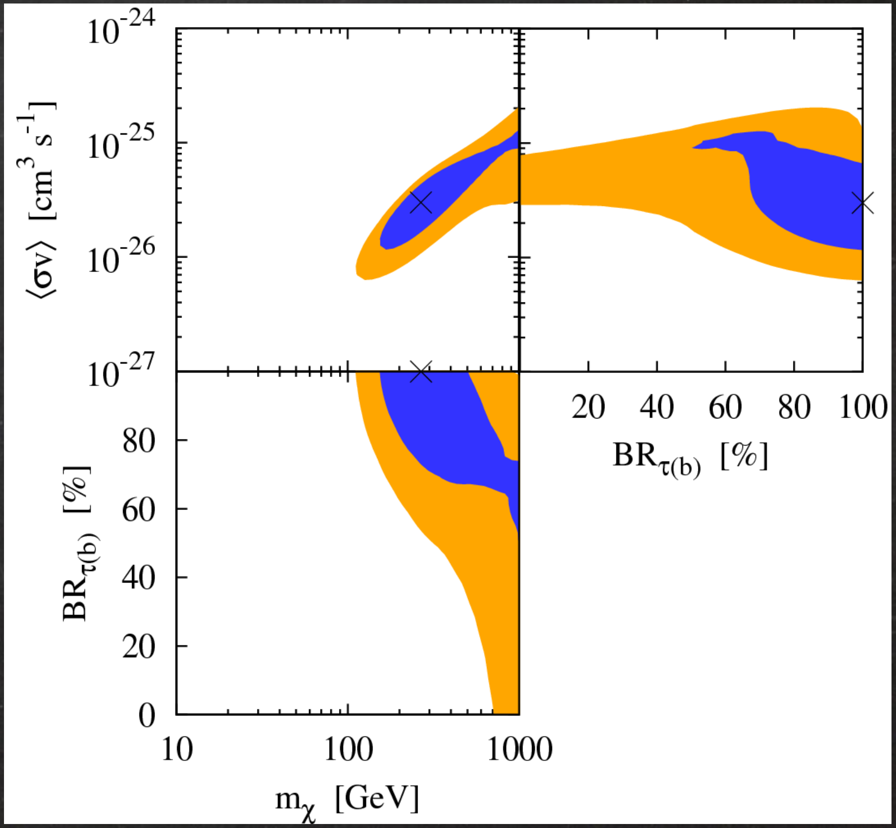
* 5 years of data taking

Default setup

m_χ = 80 GeV



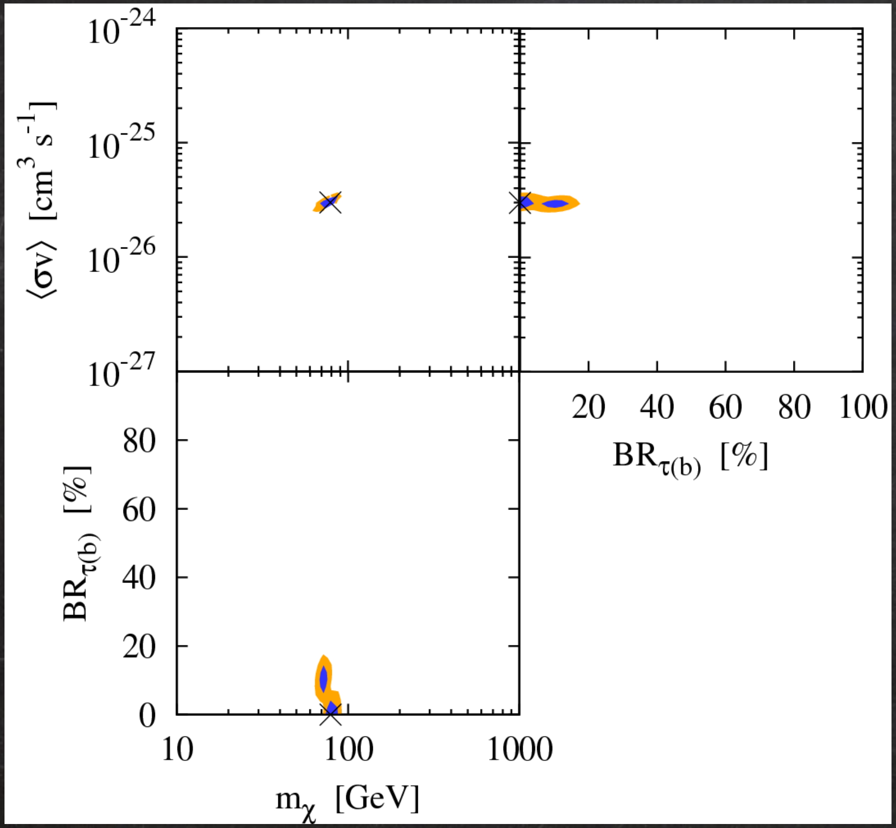
m_χ = 270 GeV



NB and S Palomares-Ruiz, arXiv:1006.0477

Data: bb

m_χ = 80 GeV



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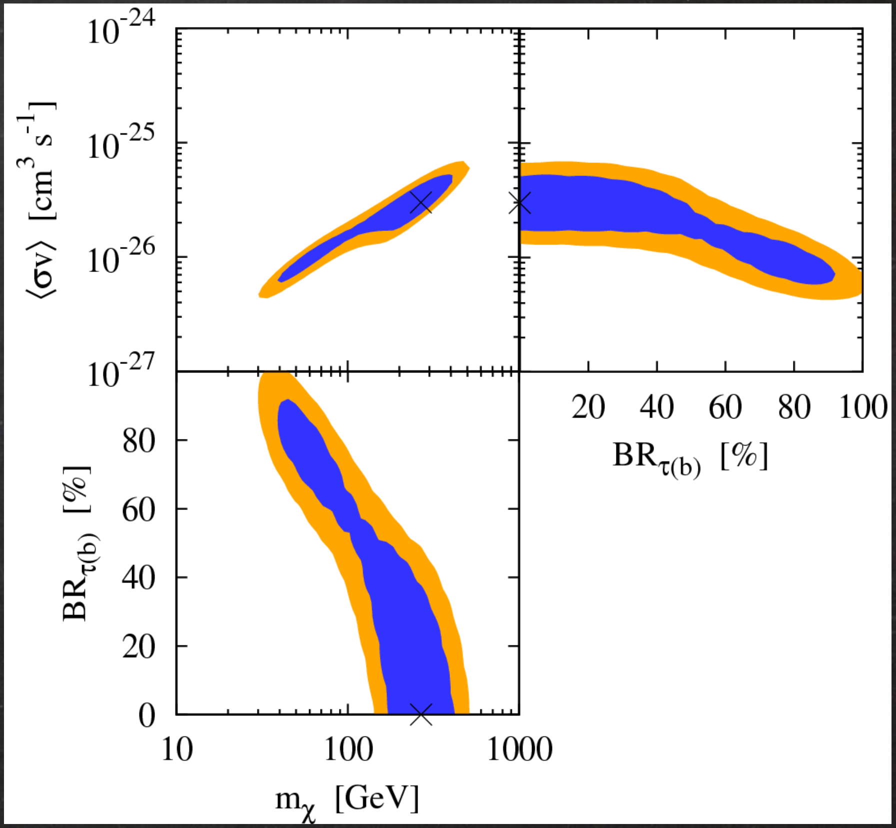
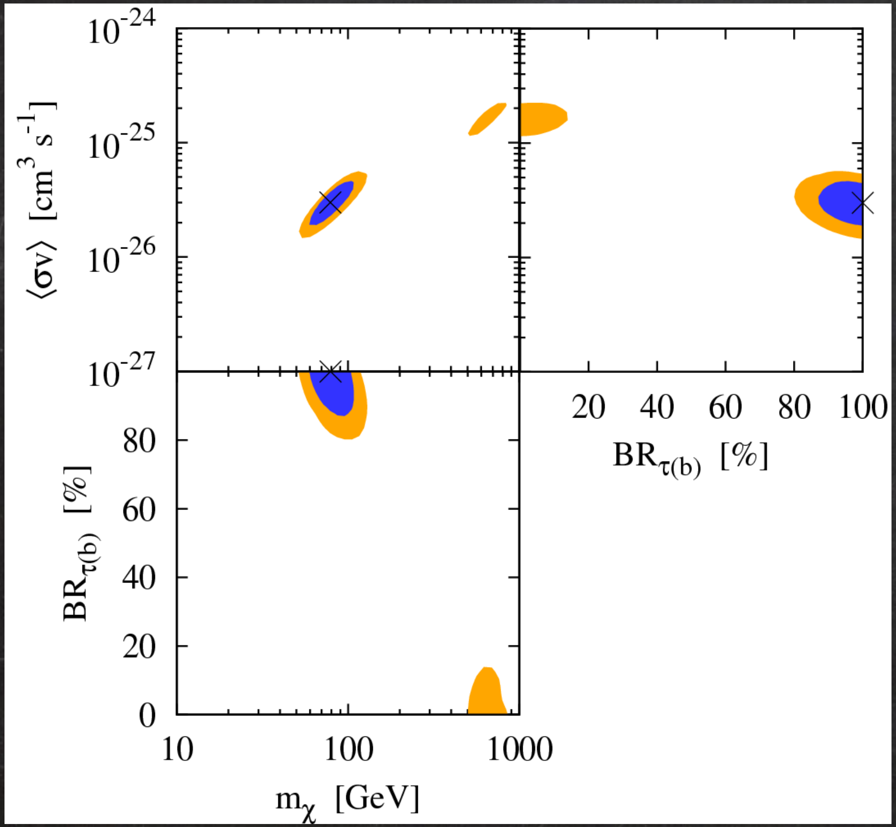


NB and S Palomares-Ruiz, arXiv:1006.0477

Dependence on the observational region

Observational region: 1ºx 1º around the GC

m_χ = 80 GeV



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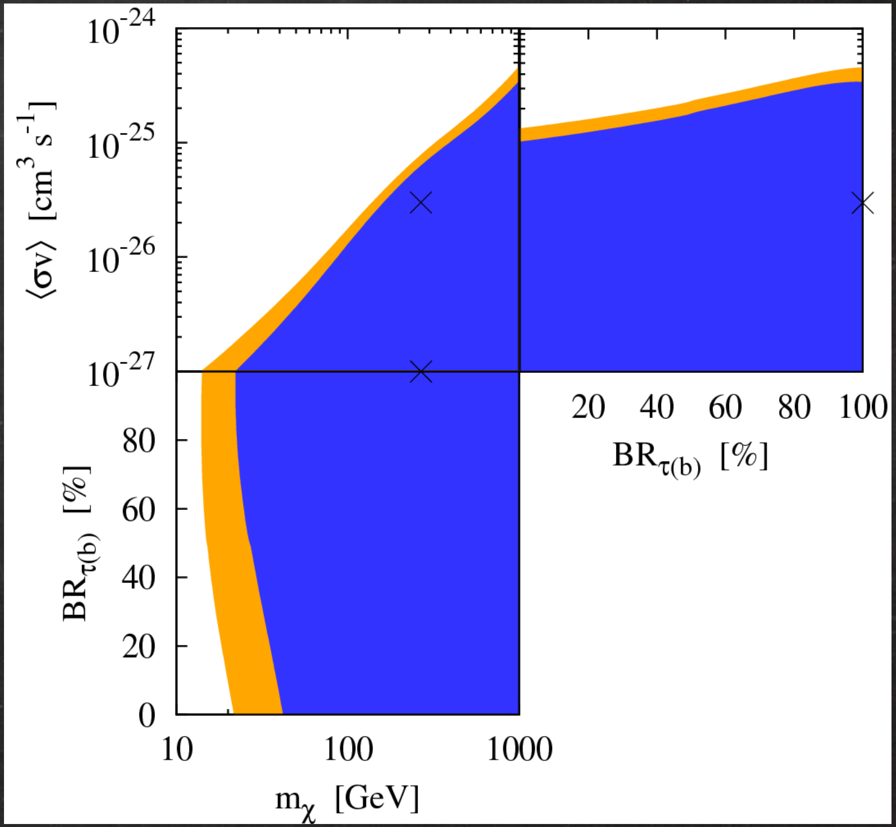
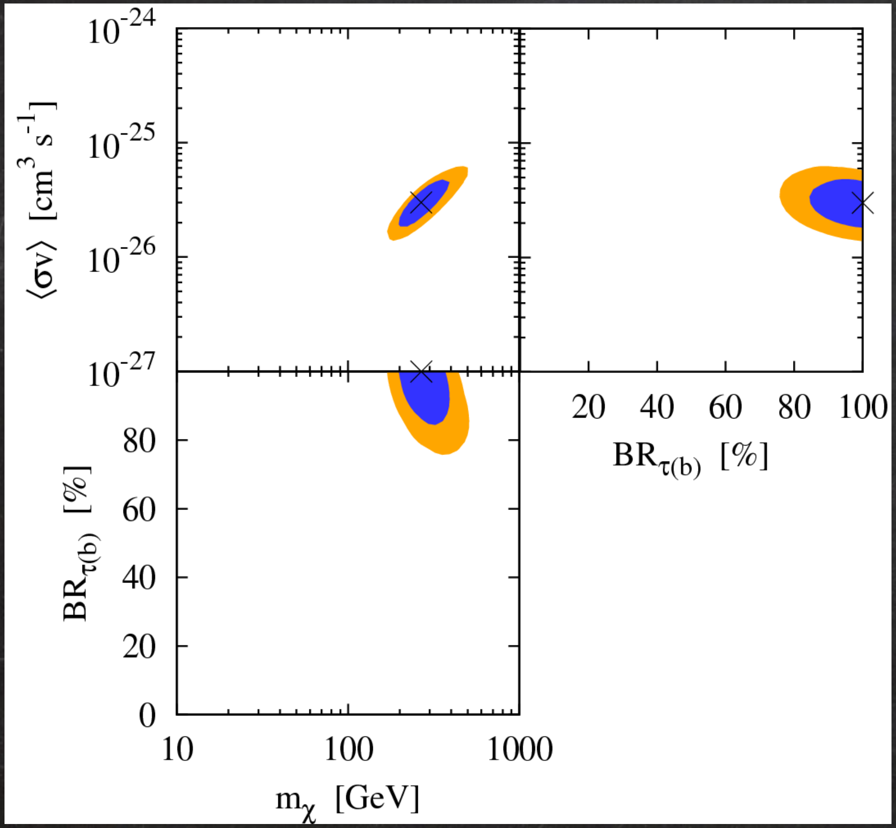


NB and S Palomares-Ruiz, arXiv:1006.0477

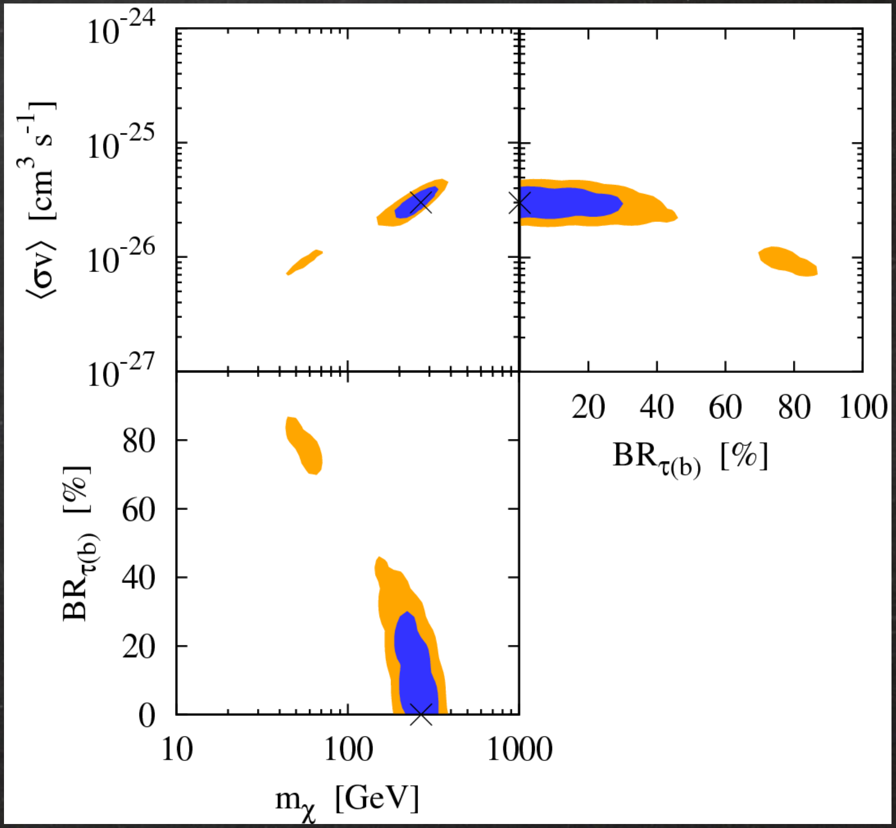
Dependence on the DM density profile

Einasto DM profile
m = 270 GeV

Data: $\tau^+ \tau^-$



Data: bb

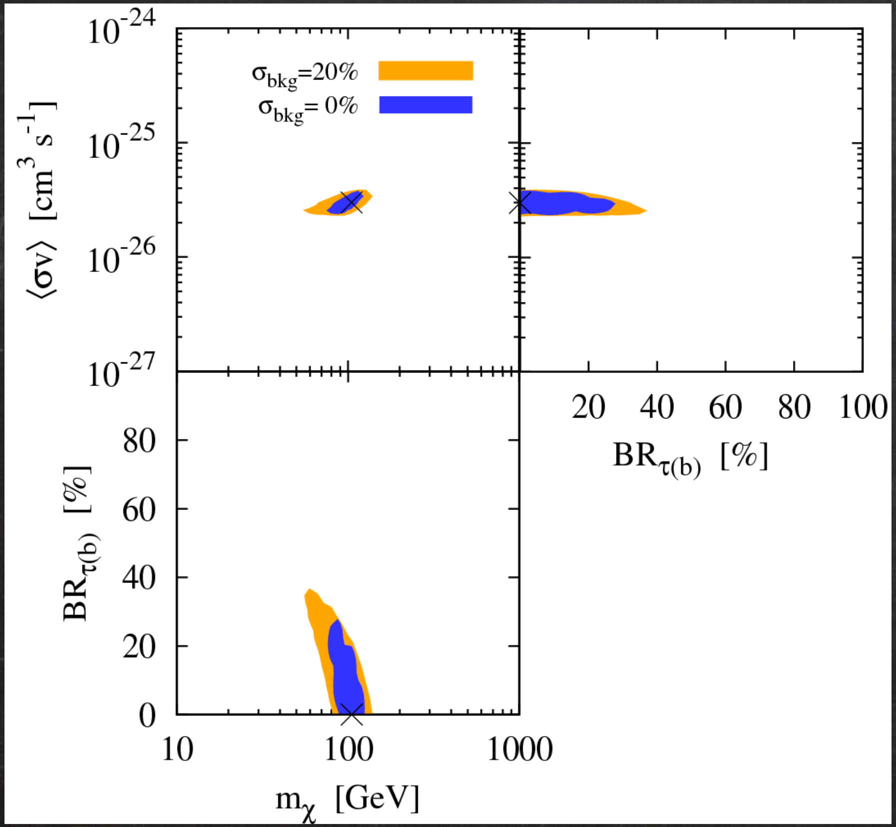


NB and S Palomares-Ruiz, arXiv:1006.0477

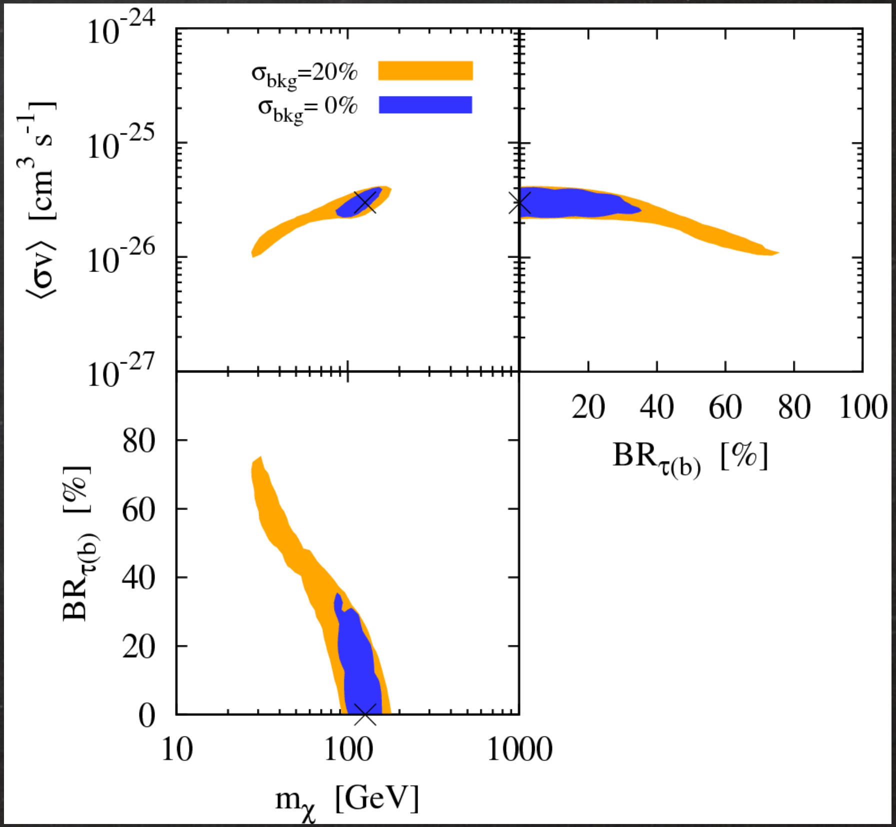
Dependence on systematic errors

Data: bb
Error background: 20%

m_χ = 105 GeV



m_χ = 125 GeV

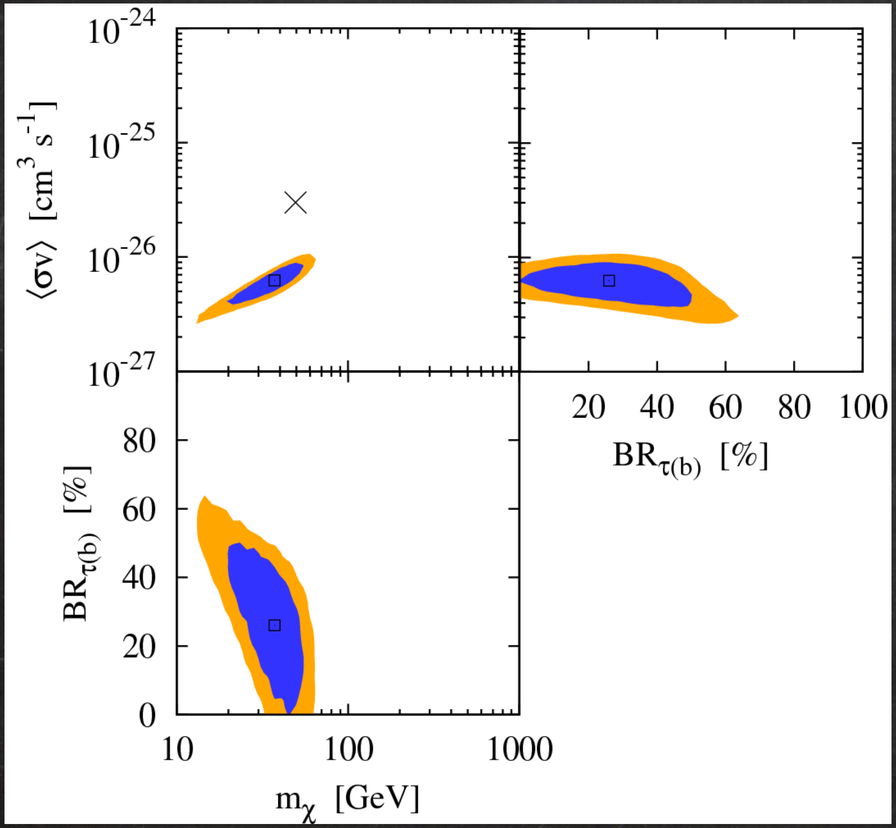


NB and S Palomares-Ruiz, arXiv:1006.0477

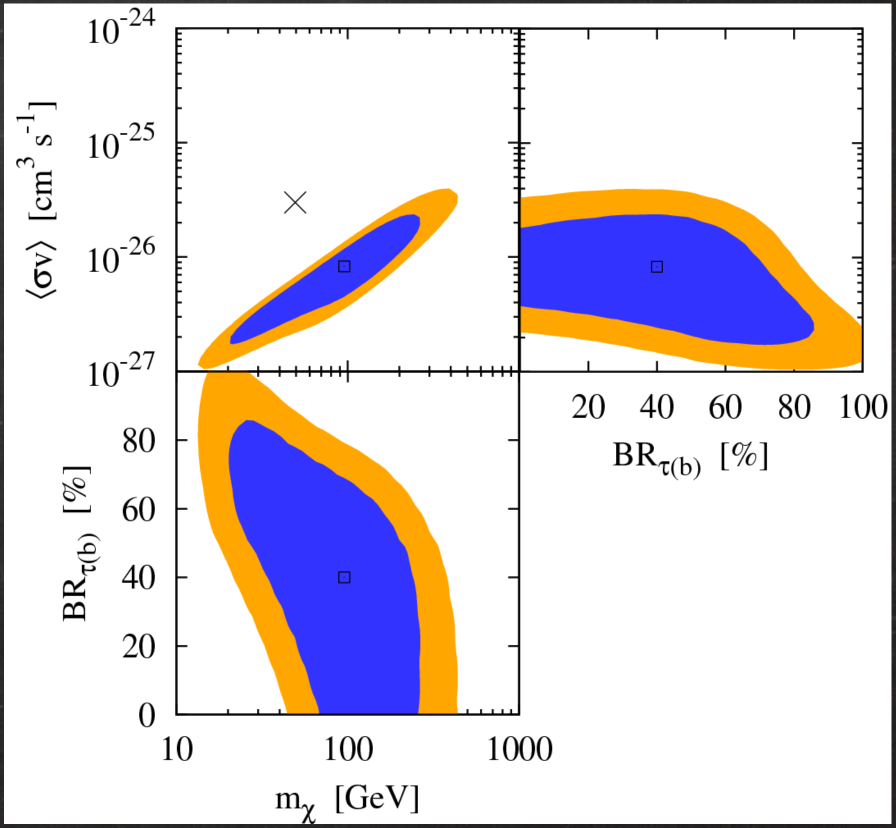
Dependence on the assumed DM model

Data: $\mu^+ \mu^-$

m_χ = 50 GeV



m_χ = 105 GeV

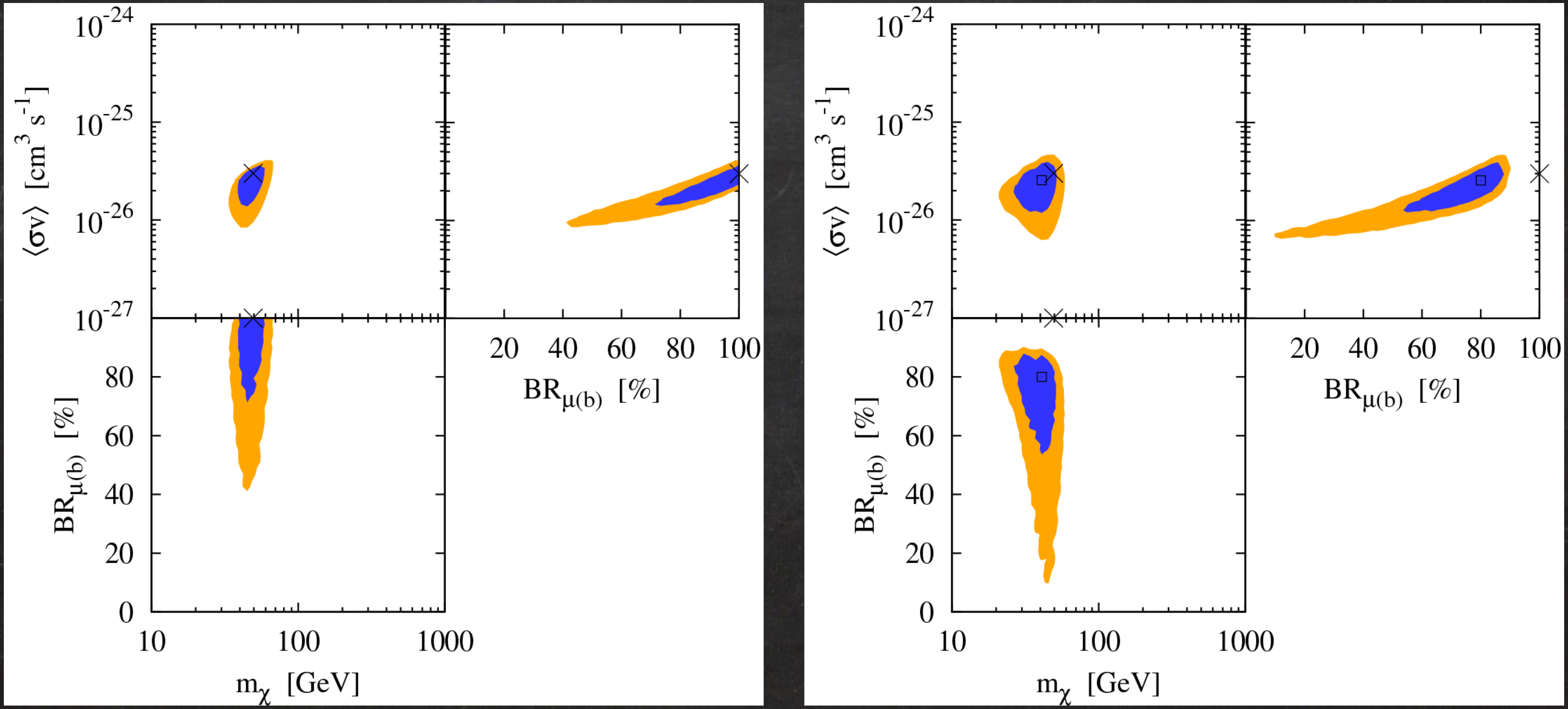


NB and S Palomares-Ruiz, arXiv:1006.0477

Data: $\mu^+ \mu^-$ Simulated: $\mu^+ \mu^-$ / bb
m= 50 GeV

Reconstruction with ICS

Reconstruction without ICS

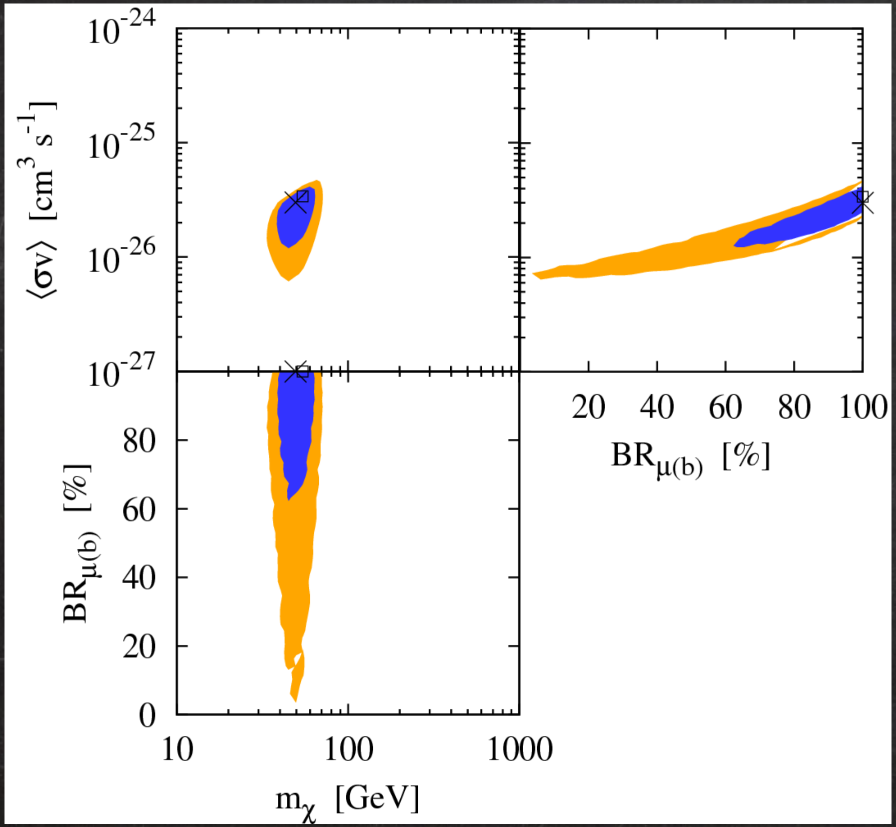


NB and S Palomares-Ruiz, arXiv:1006.0477

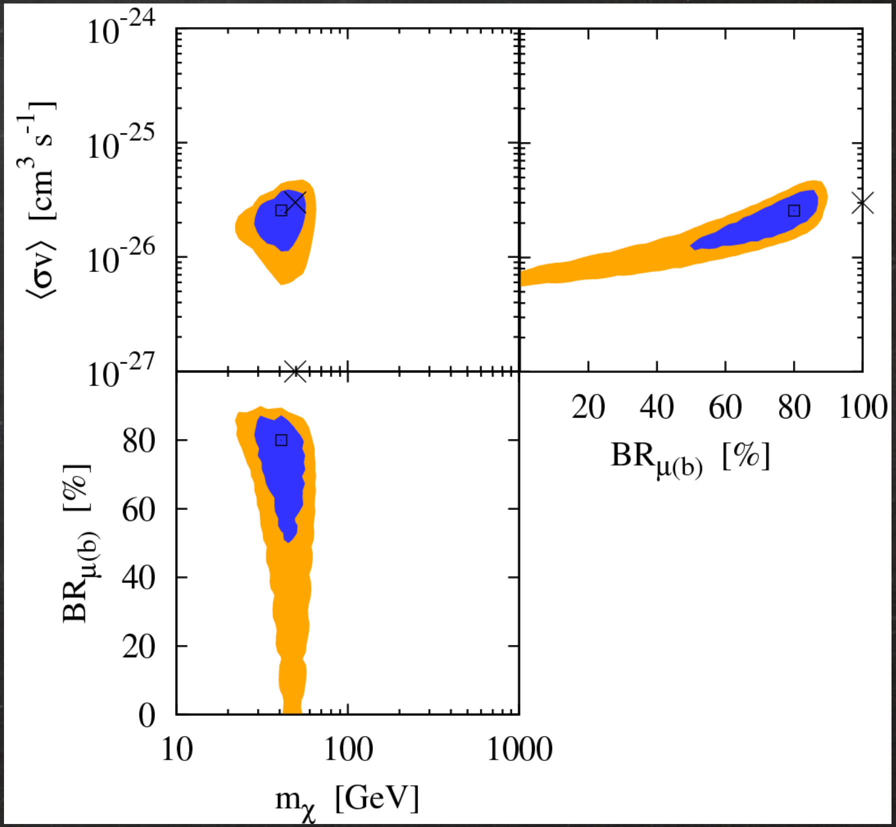
Dependence on the propagation model

Data: $\mu^+\mu^-$; MIN Simulated: $\mu^+\mu^-/bb$; MAX
m= 50 GeV

Reconstruction with ICS



Reconstruction without ICS



NB and S Palomares-Ruiz, arXiv:1006.0477

Conclusions

* We have studied the abilities of Fermi-LAT, by using current and future observation of gamma-rays from the GC, to constrain some DM properties as annihilation cross section, mass and branching ratio into dominant annihilation channels

* We have included the ICS contribution to the signal spectra, which for some cases turns out to be crucial to get the correct results

* We have used the latest Fermi measurements to simulate the galactic backgrounds

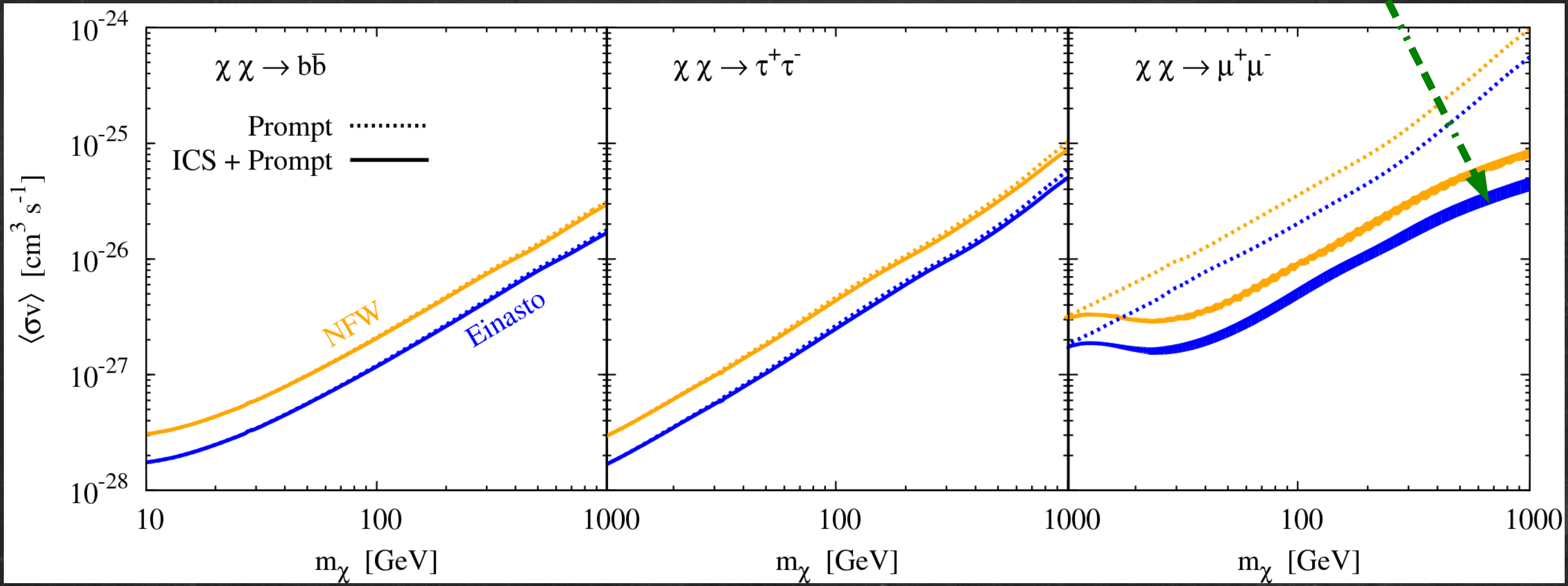
* We have evaluated the sensitivity to DM annihilations: after 5 years and for annihilations into hadronic channels, Fermi sensitivity is below the benchmark value for the annihilation cross section for thermal dark matter for $m_\chi < 1$ TeV

* We have also studied the dependence on different uncertainties and assumptions

Back up Slides

Fermi-LAT sensitivity to DM annihilations

Uncertanity on the propagation model



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Observational region: 1º around the GC
Data: bb

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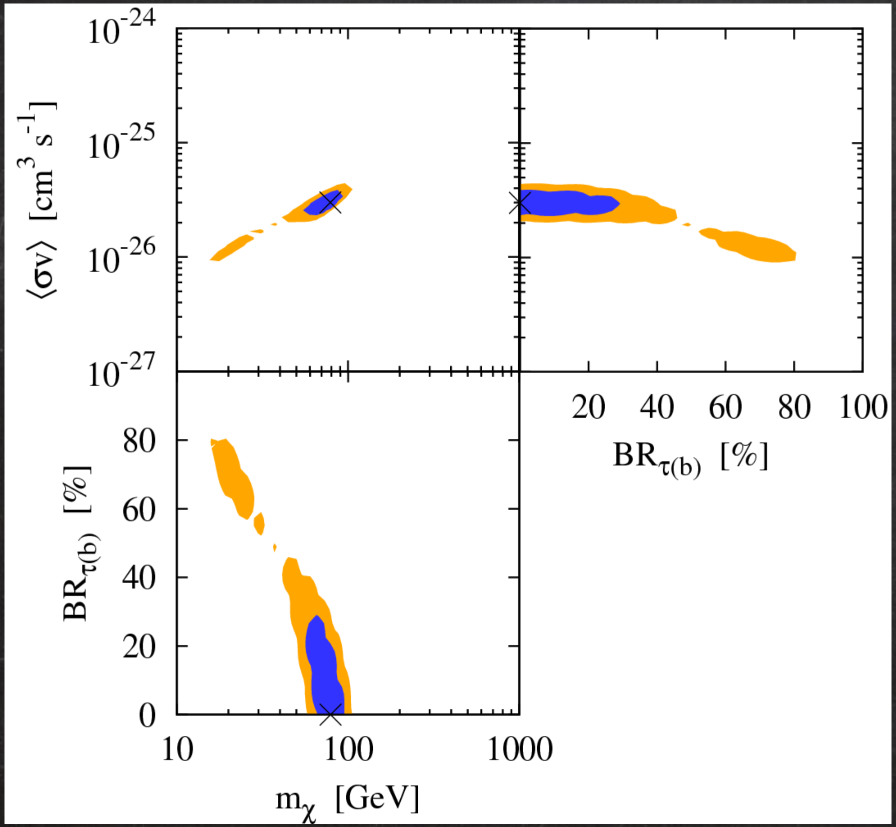

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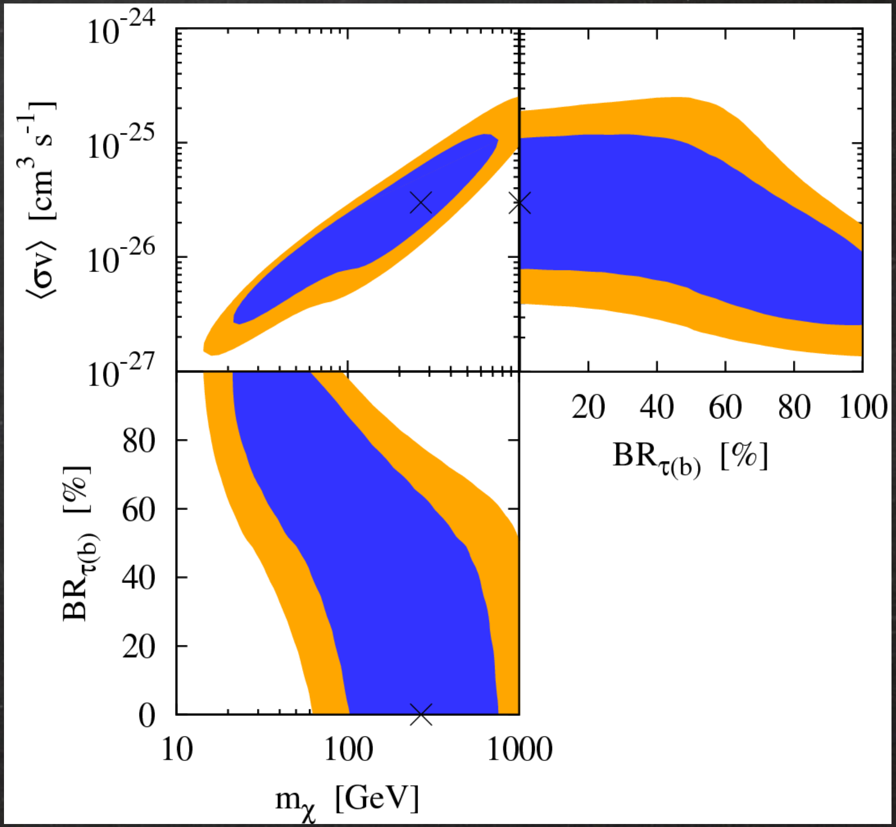

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Electron/Positron propagation in the halo

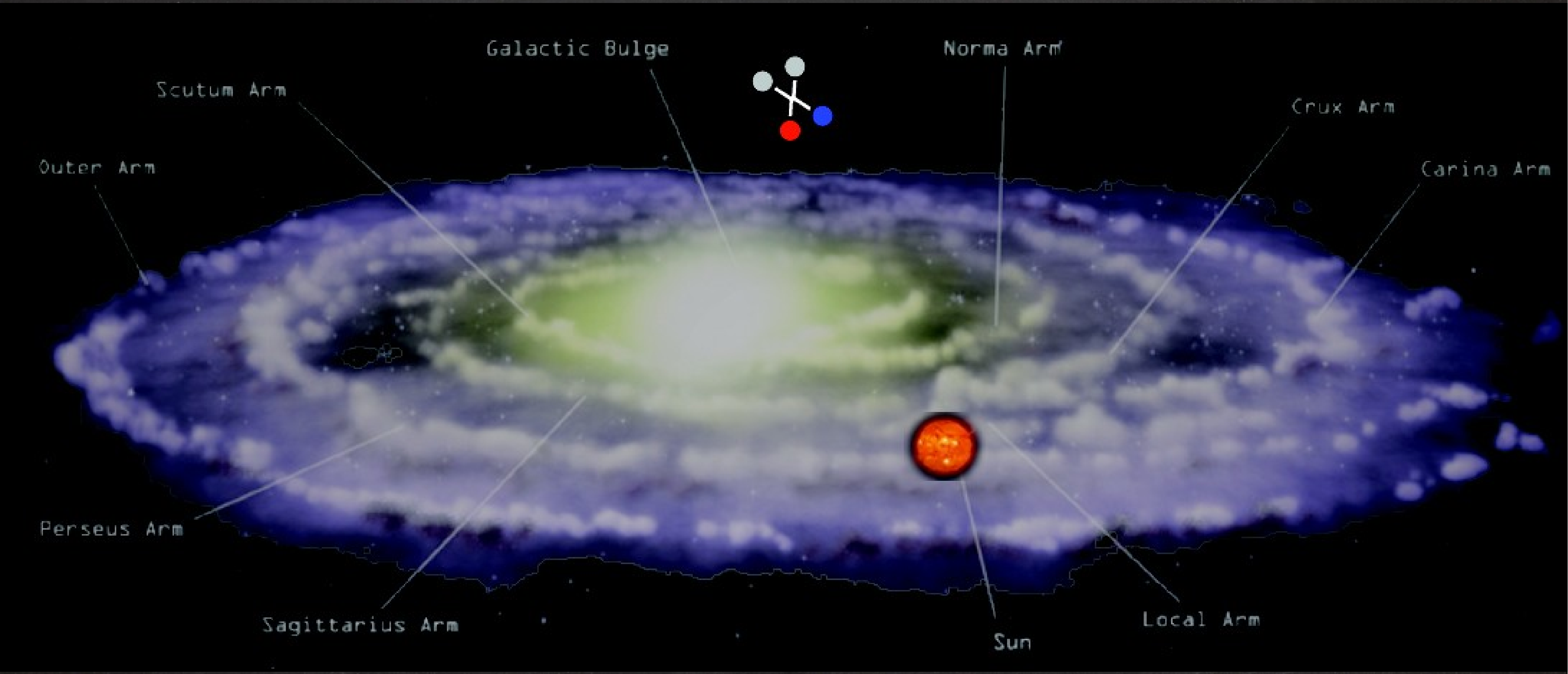
Three commonly used propagation models corresponding to the minimal, maximal and median primary *positron fluxes* that are compatible with the B/C data

	L [kpc]	K_0 [kpc^2/Myr]	α
MIN	1	0.00595	0.55
MED	4	0.0112	0.70
MAX	15	0.0765	0.46

$$\nabla\left(K(\vec{x},E)\,\nabla\frac{dn_e}{dE}(\vec{x},E)\right)+\frac{\partial}{\partial E}\left(b(\vec{x},E)\,\frac{dn_e}{dE}(\vec{x},E)\right)+Q(\vec{x},E)=0$$

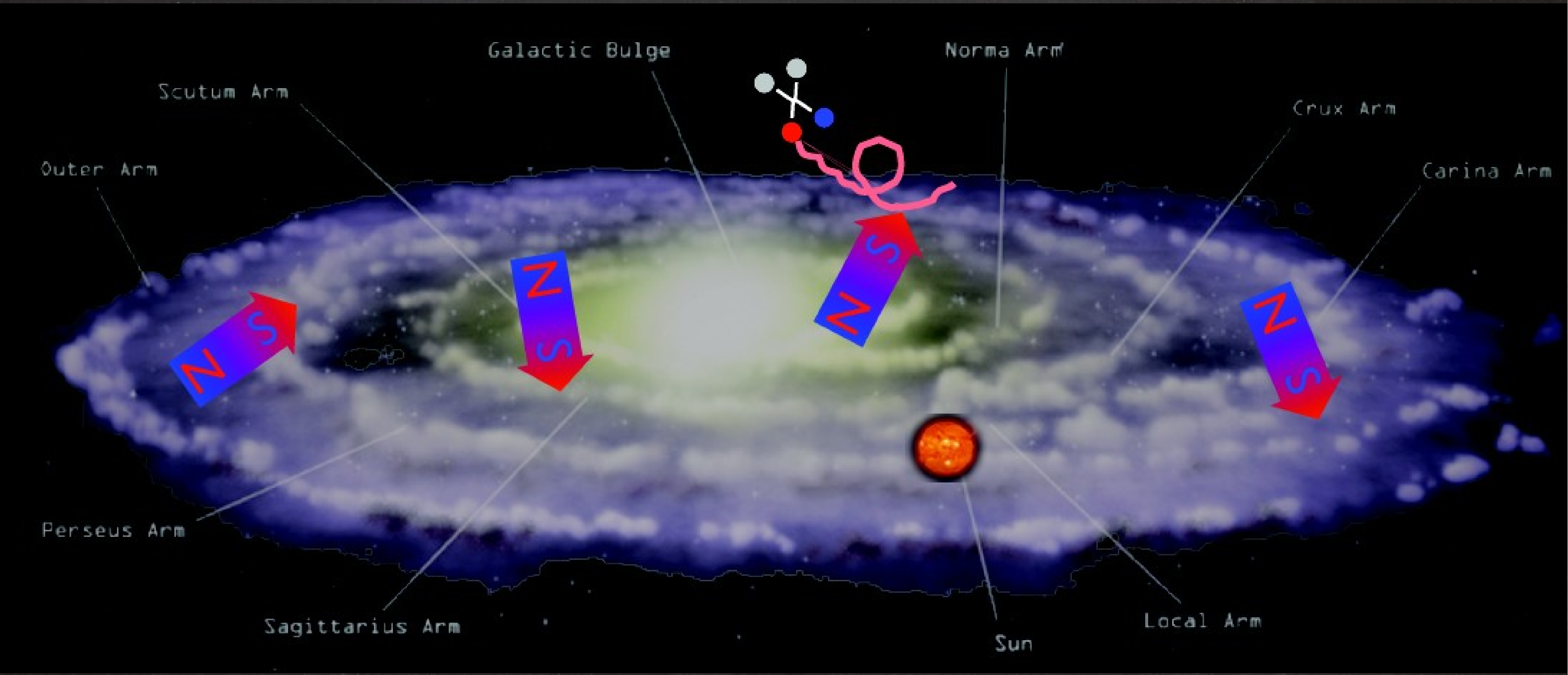
diffusion energy loss source

Electron/Positron propagation in the halo



Credit: M. Cirelli

Electron/Positron propagation in the halo

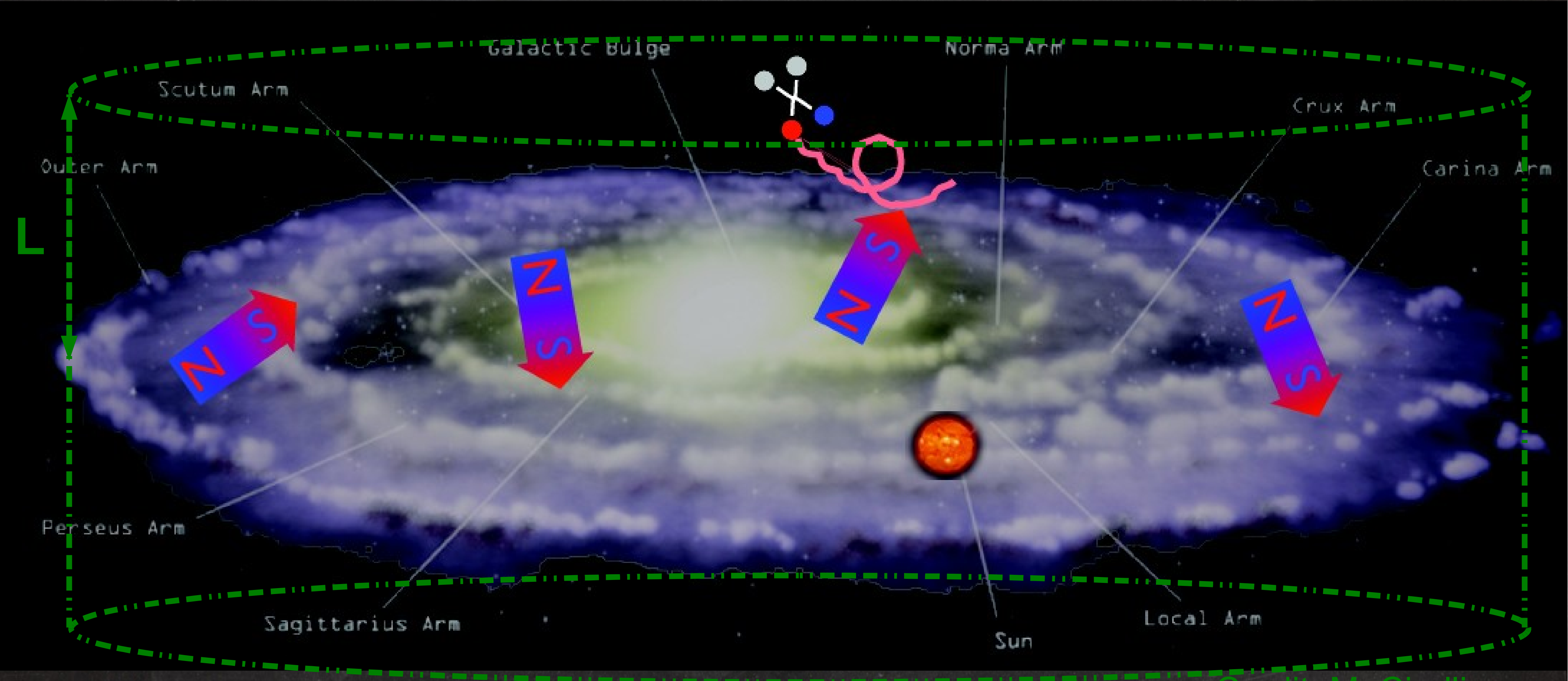


Credit: M. Cirelli

A plethora of tangled magnet fields, particles can jump to nearby field lines which will drastically alter their courses

→ Random walk

Electron/Positron propagation in the halo



Credit: M. Cirelli

$$\nabla\left(K(\vec{x},E)\,\nabla\frac{dn_e}{dE}(\vec{x},E)\right)+\frac{\partial}{\partial E}\left(b(\vec{x},E)\,\frac{dn_e}{dE}(\vec{x},E)\right)+Q(\vec{x},E)=0$$

diffusion energy loss source

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$$\frac{dn_{e^\pm}}{dE}(r_c, z_c, E) = \frac{\beta\,\langle\sigma v\rangle}{2}\left(\frac{\rho(r_c,z_c)}{m_\chi}\right)^2 \frac{E_0\,\tau_E}{E^2}\sum_i \mathrm{BR}_i \int_E^{m_\chi} \frac{dN^i_{e^\pm}}{dE_s}(E_s)\,\tilde{I}(\lambda_D, r_c, z_c)\,dE_s$$

I: all the dependence on the Astro and independent on Particle P.

$$\tilde{I}(\lambda_D, r_c, z_c) = \sum_{i,n=1}^{\infty} J_0\left(\frac{\alpha_i\, r_c}{R_{\rm gal}}\right)\varphi_n(z_c)\,\exp\left[-\left\{\left(\frac{n\,\pi}{2L}\right)^2 + \frac{\alpha_i^2}{R_{\rm gal}^2}\right\}\frac{\lambda_D^2}{4}\right] R_{i,n}(r_c, z_c)$$

Diffusion length: $\lambda_D^2(\epsilon,\,\epsilon_s) = 4\,K_0\,\tau_E\left(\frac{(E/E_0)^{\alpha-1} - (E_s/E_0)^{\alpha-1}}{1-\alpha}\right)$

Baltz & Edsjö Phys. Rev. D59 (1998)
Delahaye, Lineros, Donato & Fornengo Phys Rev. D77 (2008)

$$\underbrace{\nabla\left(K(\vec{x},E)\,\nabla\frac{dn_e}{dE}(\vec{x},E)\right)}_{\text{diffusion}} + \underbrace{\frac{\partial}{\partial E}\left(b(\vec{x},E)\,\frac{dn_e}{dE}(\vec{x},E)\right)}_{\text{energy loss}} + \underbrace{Q(\vec{x},E)}_{\text{source}} = 0$$