Constraining Decaying Dark Matter with FERMI LAT gamma-rays

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SciNeGHE 2010, Trieste, 10.09.2010

Some (well known) basics

$$n(E,\vec{r}_{\rm obs}) = \int_0^\infty dt \int d^3r_0 \int dE_0 \, \underbrace{\boxed{q(E_0,\vec{r}_0,t)}}_{\text{source function}} \, \underbrace{\boxed{f(E,\vec{r}_{\rm obs};E_0,\vec{r}_0,t)}}_{\text{propagation probability function}}$$

Some (well known) basics

$$n(E,\vec{r}_{\rm obs}) = \int_0^\infty dt \int d^3r_0 \int dE_0\, \boxed{q(E_0,\vec{r}_0,t)}\, \boxed{f(E,\vec{r}_{\rm obs};E_0,\vec{r}_0,t)}$$

source function

propagation probability function

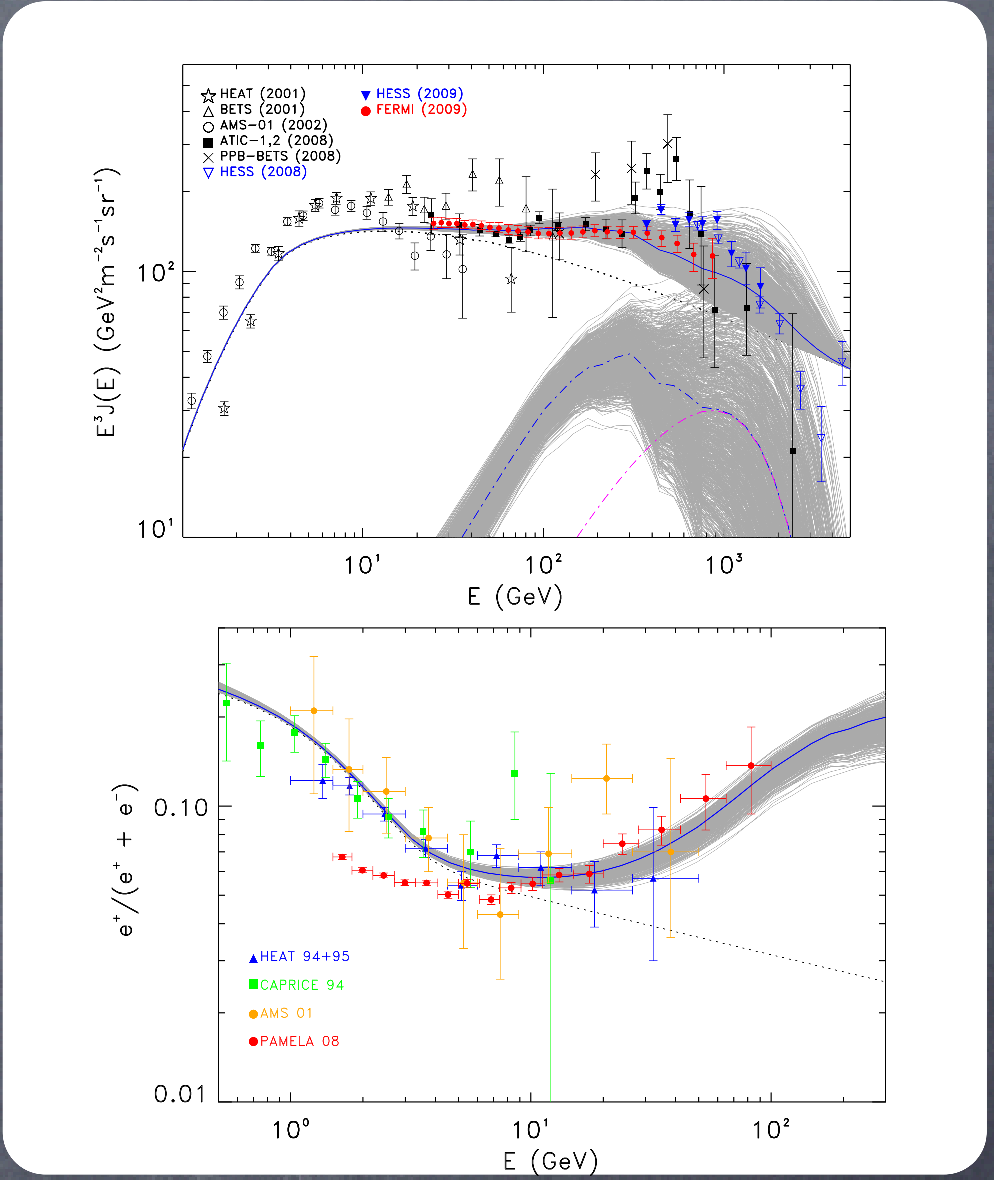
huge simplification

$$\frac{\partial N^i}{\partial t} - \nabla\cdot(D\,\nabla - v_c)\,N^i + \frac{\partial}{\partial p}\left(\dot{p} - \frac{p}{3}\nabla\cdot v_c\right)N^i - \frac{\partial}{\partial p}p^2 D_{pp}\frac{\partial}{\partial p}\frac{N^i}{p^2} =$$
$$= Q^i(p,r,z) + \sum_{j>i} c\beta n_{\rm gas}(r,z)\sigma_{ji}N^j - c\beta n_{\rm gas}\sigma_{\rm in}(E_k)N^i$$

$Q^i(p,r,z) =$ SNR distribution or DM distribution

Standard flow chart

- CRs diffuse for Myr in the Galaxy.
- Their observables depend much more on the details of propagation than on the source distribution
- Infer and "fix" propagation parameters from CR observations
- Use derived models to estimate DM contributions to observed fluxes and constrain/confirm DM models

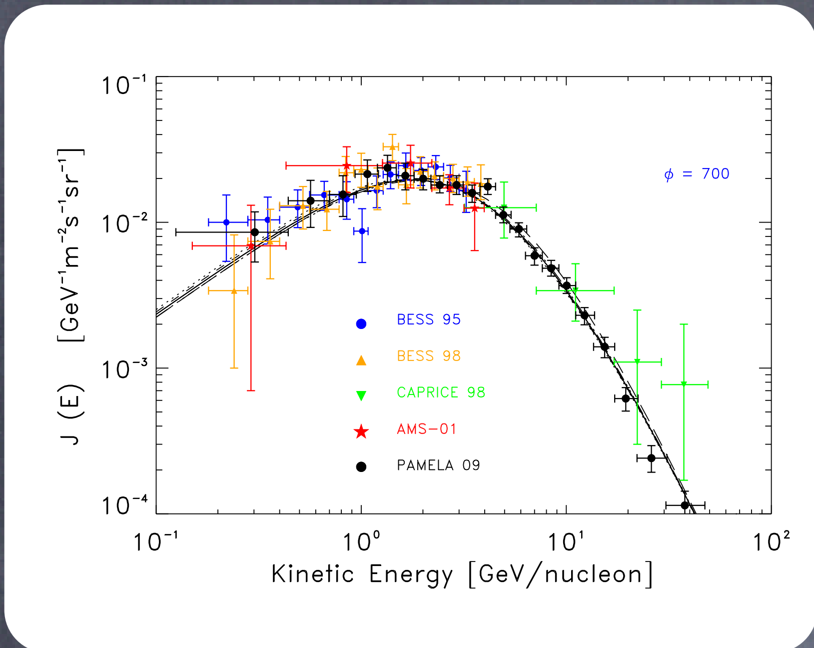


Caveats:

- this does not work perfectly with leptons
- there are anyway large uncertainties

Model	δ^1	D_0 $[10^{28}\text{cm}^2/\text{s}]$	R [kpc]	L [kpc]	V_c [km/s]	dV_c/dz km/s/kpc	V_a [km/s]	$h_{\rm reac}$ [kpc]
MIN	0.85/0.85	0.048	20	1	13.5	0	22.4	0.1
L1	0.50/0.50	4.6	20	4	0	0	10	4
MAX	0.46/0.46	2.31	20	15	5	0	117.6	0.1

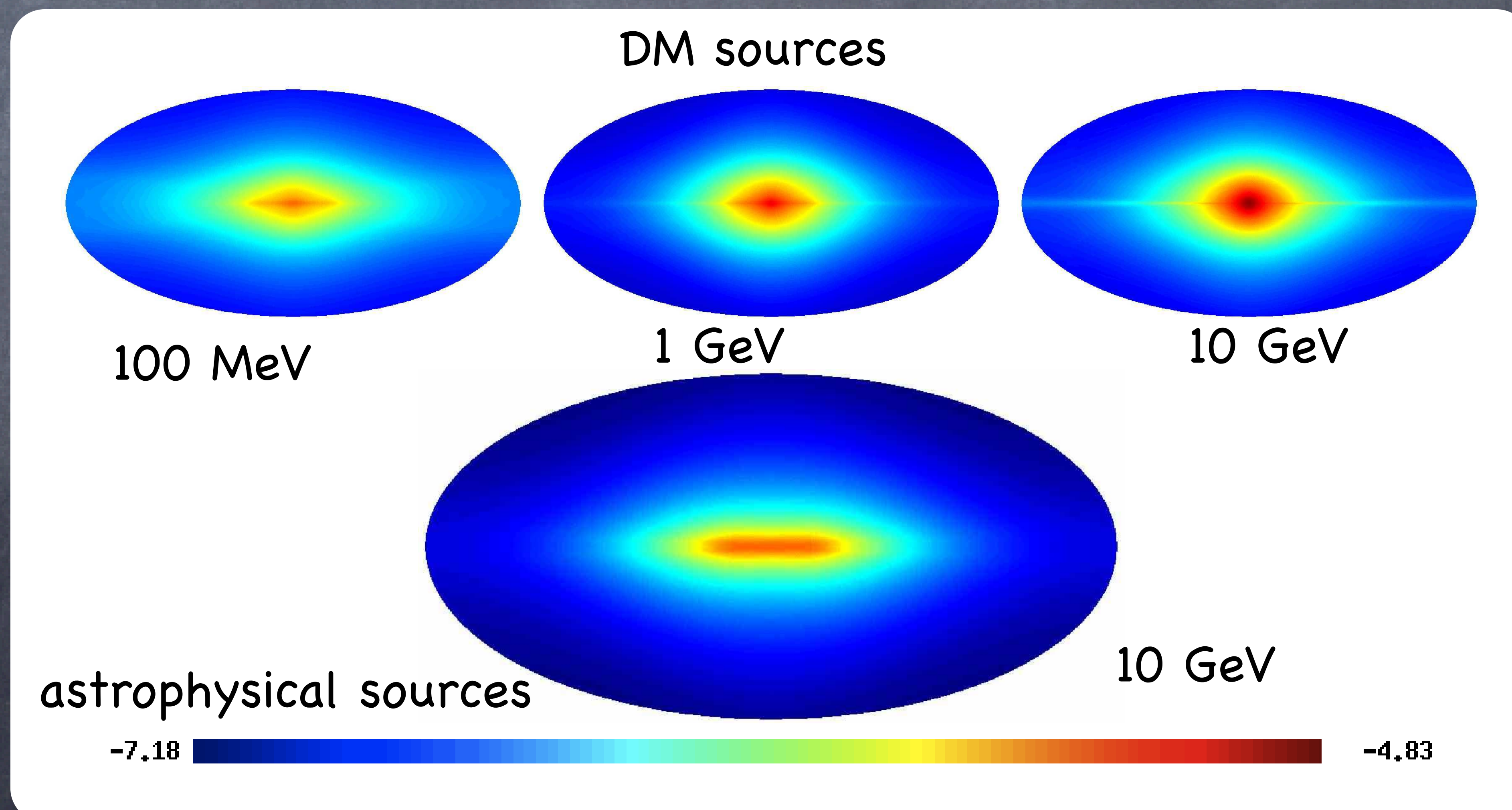
γ-rays and decaying DM



Antiprotons are well reproduced by only astrophysical models

We will consider prevalently leptonic (leptophilic) models...

... and on g-rays produced via IC scattering (bremsstrahlung is usually subdominant)



DM contribution extends at higher latitudes than astrophysical one

Response function

L. Zhang, C. Weniger, LM, J. Redondo, G. Sigl, JCAP 1006, 027 (2010)

see also L. Zhang, J. Redondo, G. Sigl, JCAP 09(2009), 12

$$\chi \to \cdots \to e^+ e^-$$

$e^+ e^- \to \gamma$ via IC scattering and Bremsstrahlung

$$-\mathcal{D} n_{\pm}^{E_0}(\vec{r}, E) = \boxed{\frac{\rho_\chi(\vec{r})}{m_\chi \tau_\chi}} \delta(E - E_0)$$

and compute the associated γ-ray flux $J^{E_0}(\Omega, E_\gamma)$

Define the response function

$$F(\Omega, E_\gamma; E_0) = \frac{J^{E_0}(\Omega, E_\gamma)}{J^{\mathrm{obs}}(\Omega, E_\gamma)} \left(\frac{\tau_\chi}{10^{26}\ \mathrm{s}}\right) \left(\frac{m_\chi}{100\ \mathrm{GeV}}\right)$$

independent of the actual particle physics model one wants to constrain!

plus the 2 sigma error

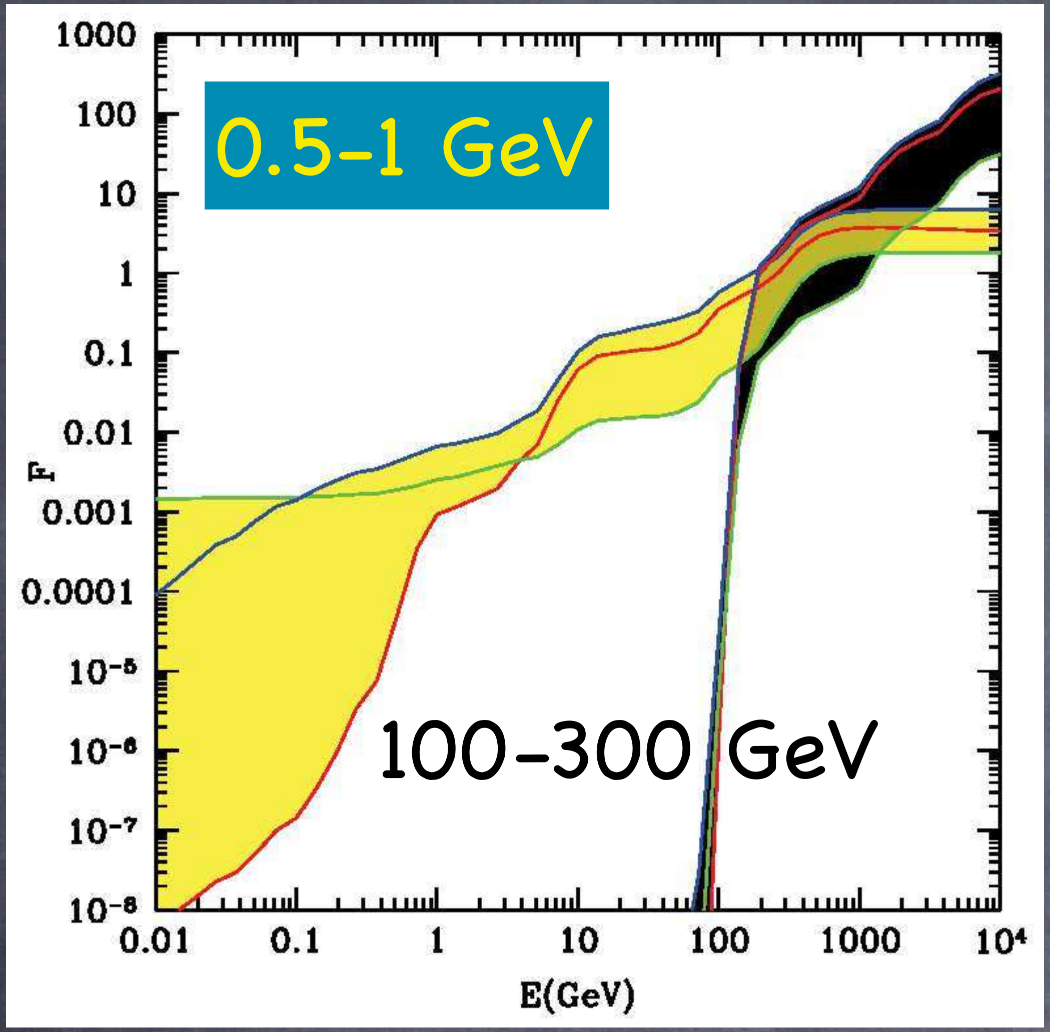
And compute constraints on DM models by asking

$$\int_{m_e}^{m_\chi} dE_0 F(\Omega, E_\gamma; E_0) \frac{dN_e}{dE_0} \leq \left(\frac{\tau_\chi}{10^{26}\ \mathrm{s}}\right) \left(\frac{m_\chi}{100\ \mathrm{GeV}}\right)$$

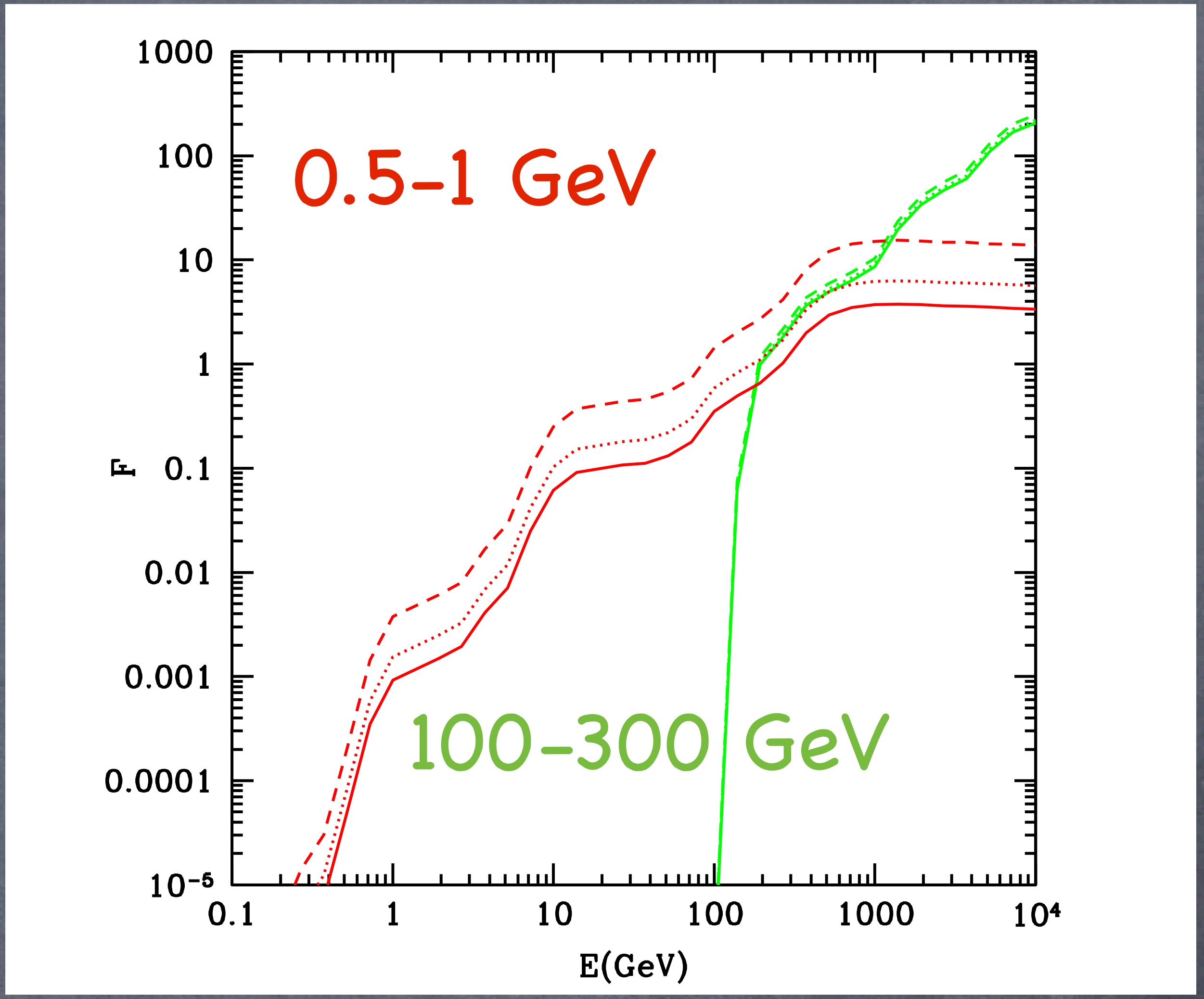
Input from particle physics models

Of course the response functions need to be updated whenever new data are available..

Response function: uncertainties



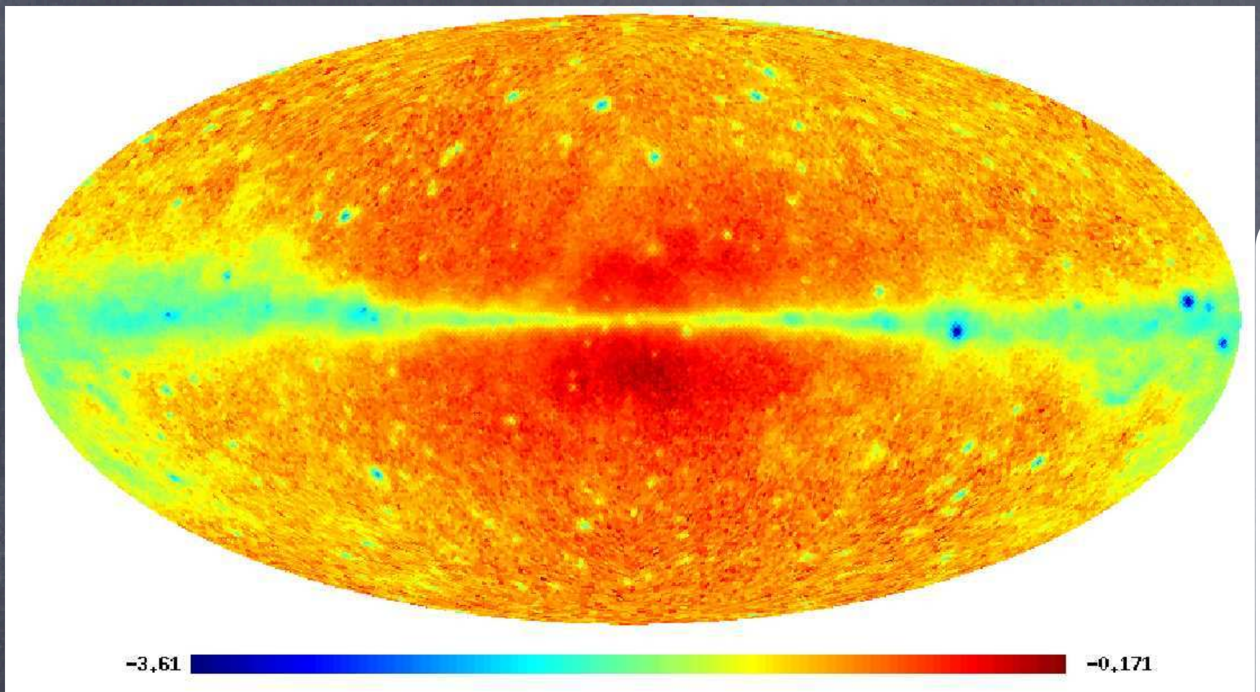
propagation model uncertainties

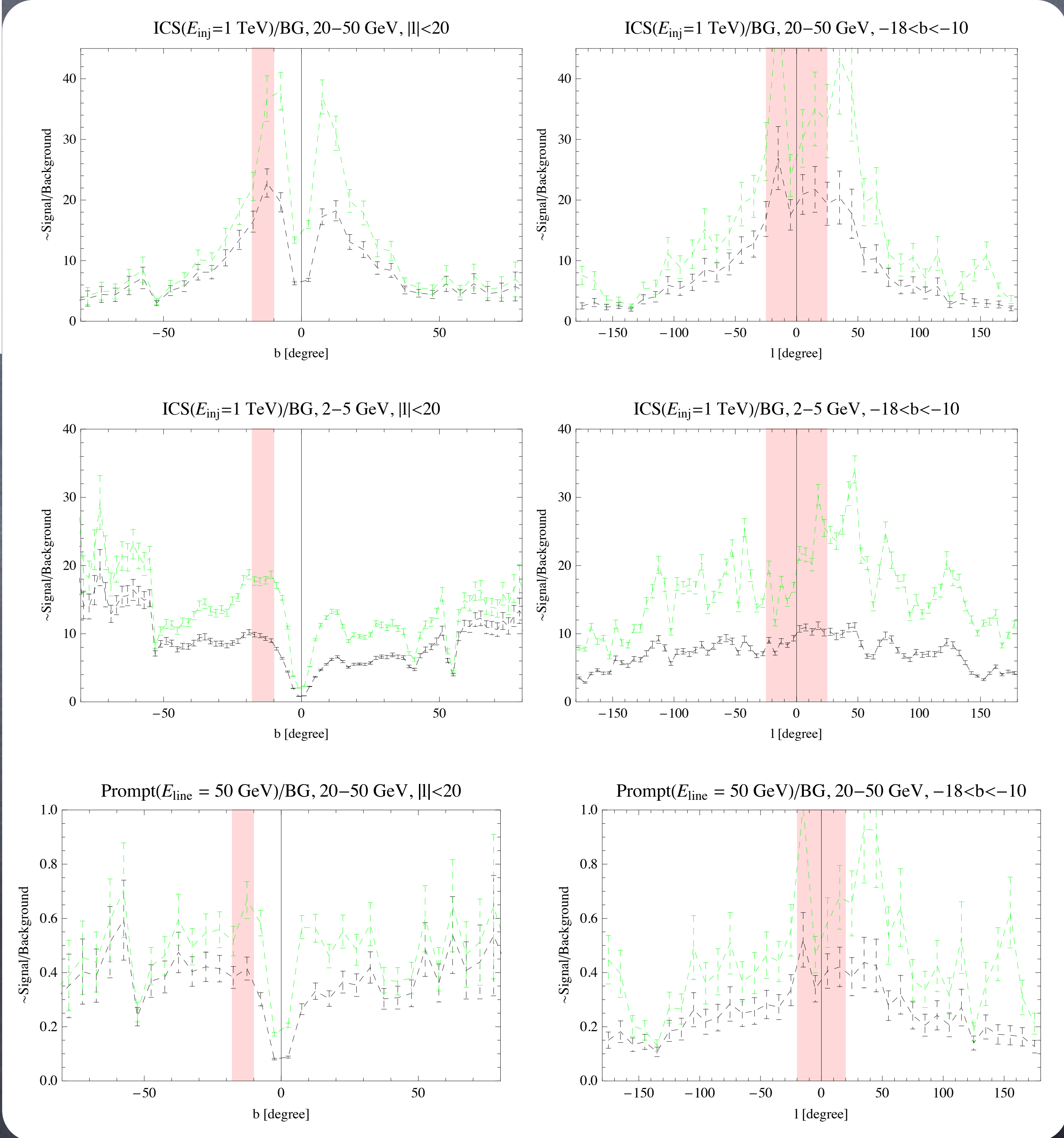


Solid: based on raw data
Dashed: pp gamma-rays subtracted

- ✓ Low energy data affected by large uncertainties
- ✓ High energy (> 100 GeV) data are "safer", BUT have less statistics
- ✓ Better knowledge of the background might improve constraints by a factor ~10.
- ✓ Uncertainties due to DM spatial distribution are negligible

Choosing the optimal patch...



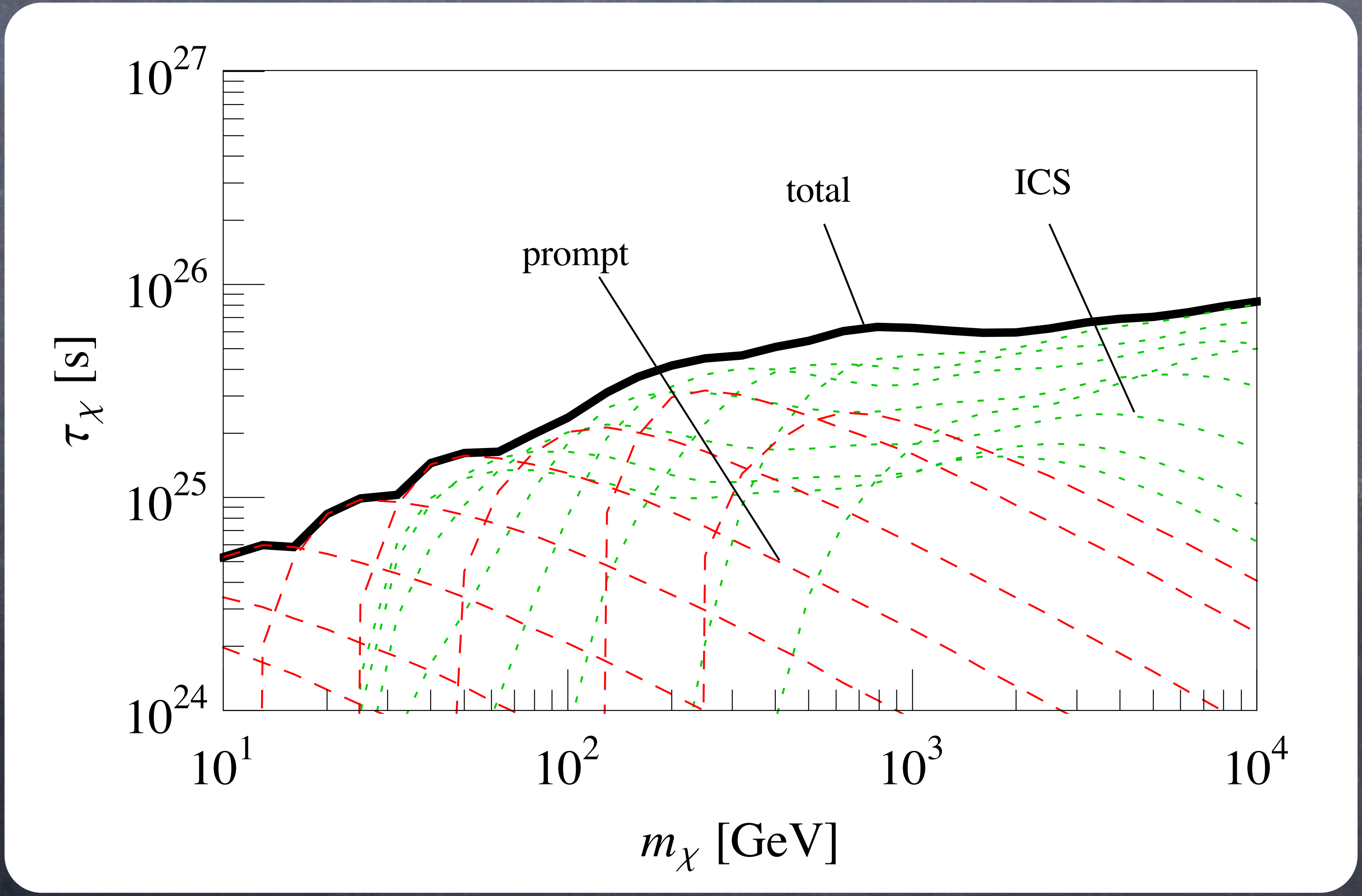


Signal/background map
Signal = DM g-rays
Background = FERMI data
in the range 0.5-1 GeV

Fix model L1

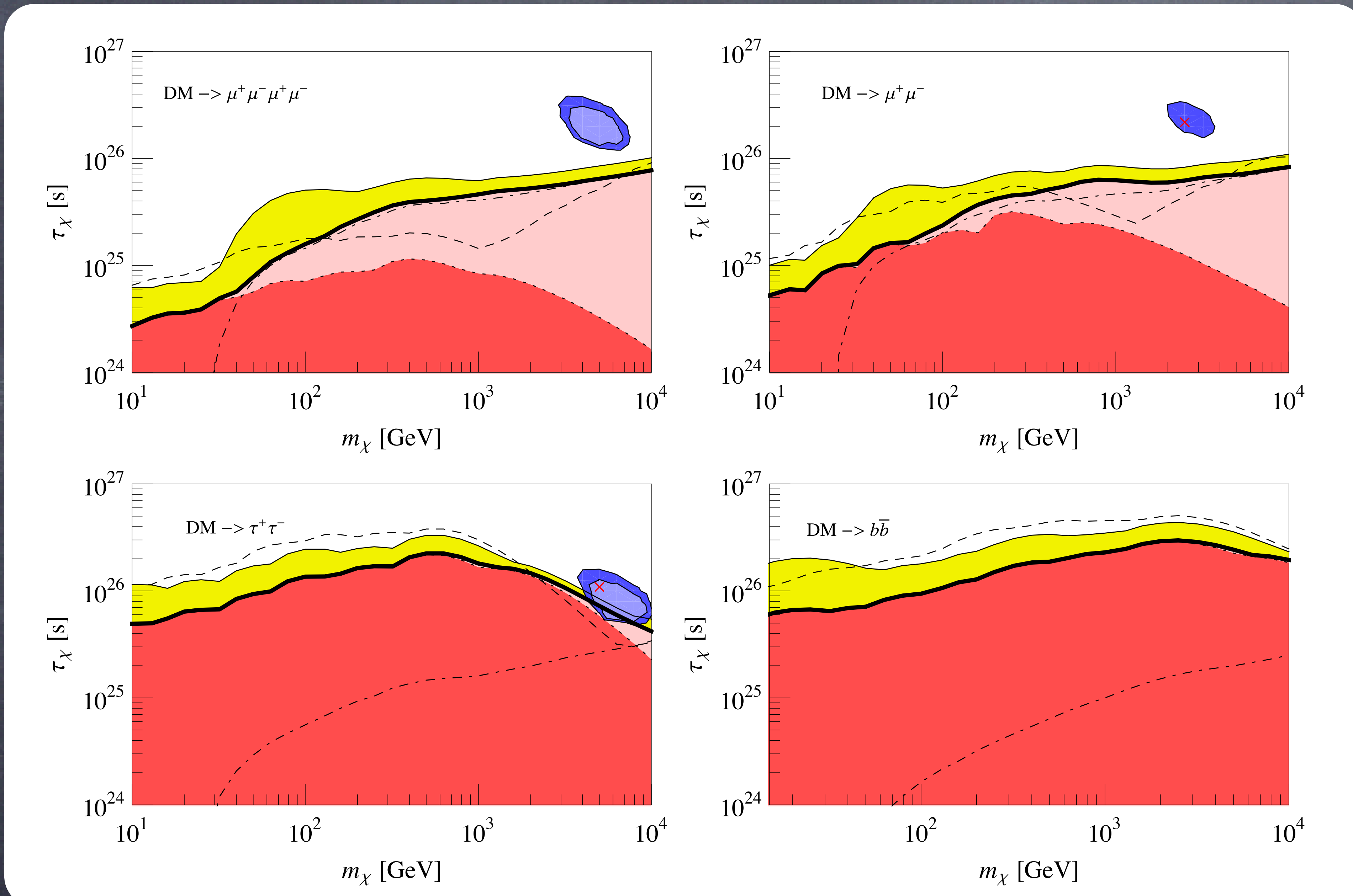
Response function: constraints

So far: particle physics model did not matter
Now: take some "definite" model and see the constraints. Need to include final state radiation specific for that model



$$\chi \to \mu^+ \mu^-$$

Response function: constraints



blue blob: models allowed by PAMELA positron fraction data

constraint from combined ICS and prompt

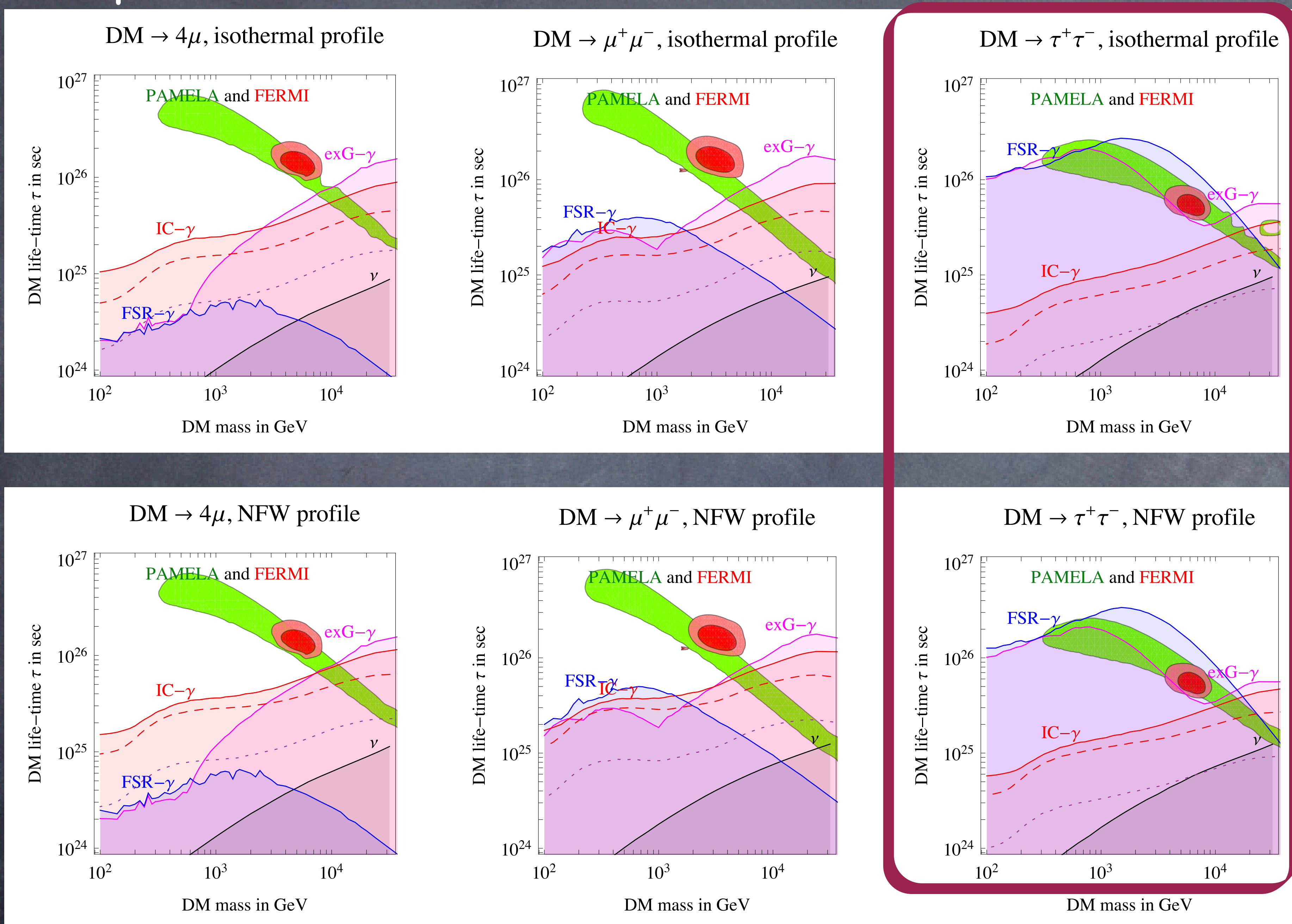
constraint from prompt alone

constraint from ICS alone

constraints from pp gamma-ray subtraction

Constraints: comparison

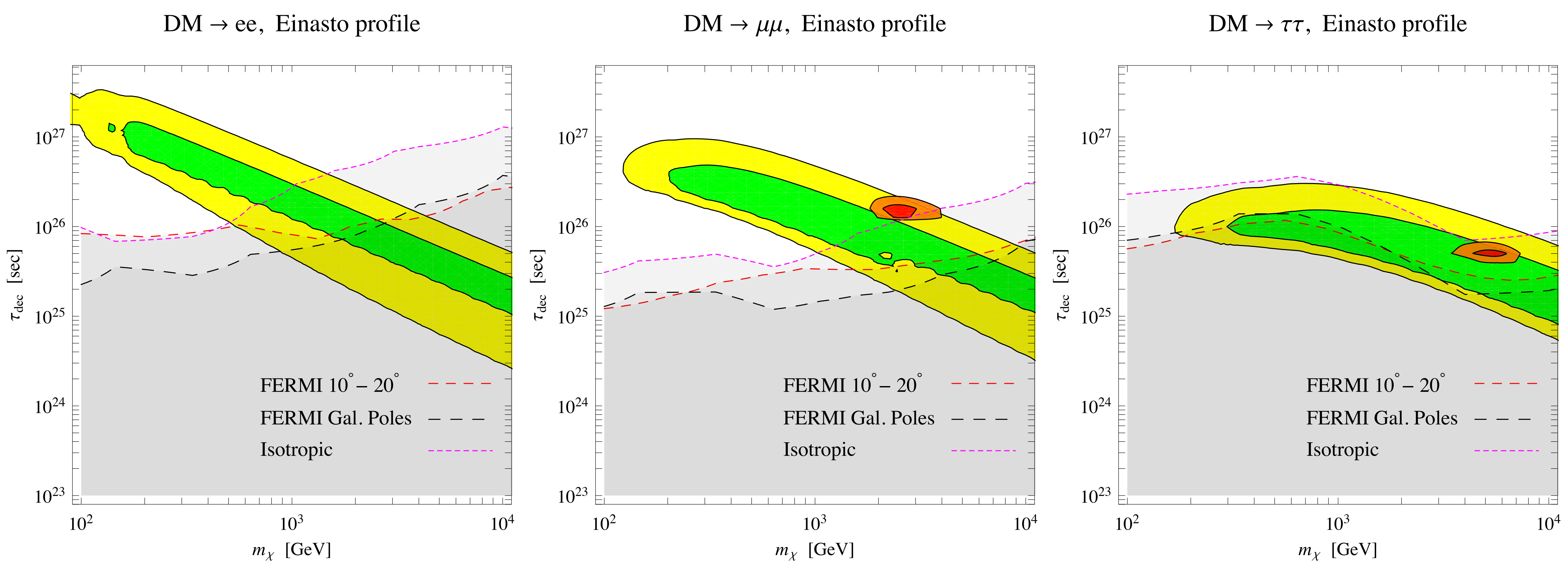
Papucci & Strumia, 0912.0742



Can exclude the tau channel, but constraint comes from higher energy data, with low statistics (a few events)

Constraints: comparison

Cirelli, Panci, Serpico, 0912.0663



Overall good agreement.
The tau channel is constrained only by the isotropic FERMI component, which again suffers from large uncertainties

Conclusions

- We computed response functions of DM originated gamma-rays versus data
- They are **independent of the underlying particle physics model**
- **Simple use**: once folded with an electron/positron spectrum from DM they provide immediately a constraint
- Analytical fits are ready and will be available soon
- Extremely useful for the decaying DM analysis: they do not depend on the DM distribution
- Optimal portion of the sky for the constraints: at intermediate latitudes, away from the Galactic Center
- Constraints: not conclusive yet. DM models fitting PAMELA data are still not in conflict with gamma-ray observations. More statistics at high energy (> 100 GeV) might solve the issue.