Constraining Decaying Dark Matter with FERMI LAT gamma-rays

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Multi3 meeting, Padova, 02.03.2010

Some (well known) basics

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

source function

propagation probability function

huge simplification

$$\frac{\partial N^i}{\partial t} - \nabla \cdot (D \nabla - v_c) N^i + \frac{\partial}{\partial p} \left(\dot{p} - \frac{p}{3} \nabla \cdot v_c \right) N^i - \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{N^i}{p^2} =$$

$$= Q^i(p, r, z) + \sum_{j>i} c\beta n_{\mathrm{gas}}(r, z) \sigma_{ji} N^j - c\beta n_{\mathrm{gas}} \sigma_{\mathrm{in}}(E_k) N^i$$

$$Q^i(p, r, z) = \quad \text{SNR distribution or} \quad \text{DM distribution}$$

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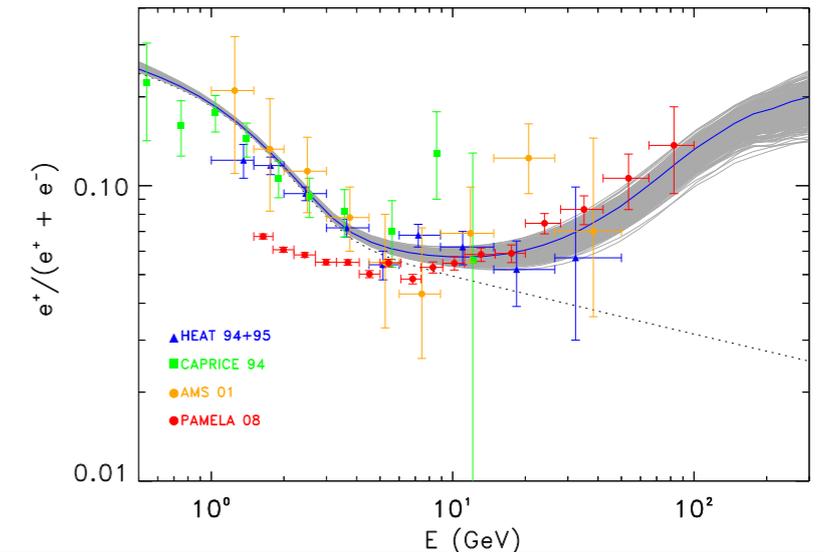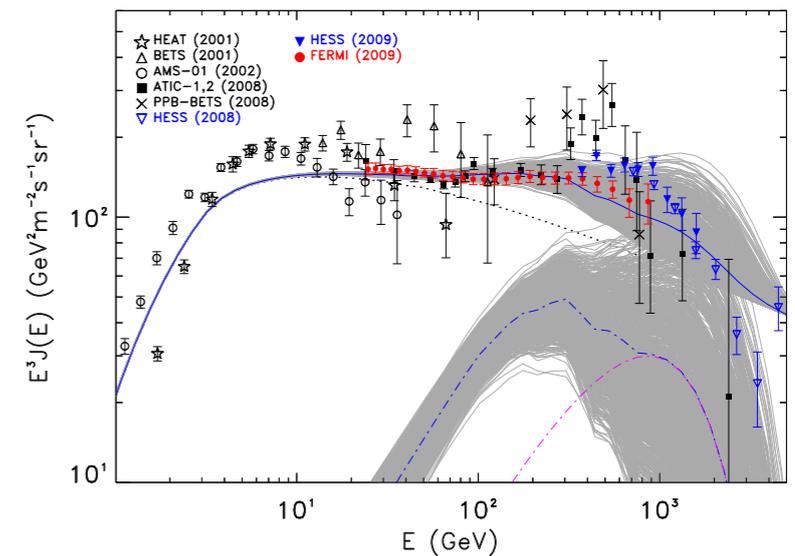
| Model	δ^1	D_0 $[10^{28}\text{cm}^2/\text{s}]$	R [kpc]	L [kpc]	V_c [km/s]	dV_c/dz km/s/kpc	V_a [km/s]	h_{reac} [kpc]
MIN	0.85/0.85	0.048	20	1	13.5	0	22.4	0.1
L1	0.50/0.50	4.6	20	4	0	0	10	4
MAX	0.46/0.46	2.31	20	15	5	0	117.6	0.1

γ-rays and decaying DM
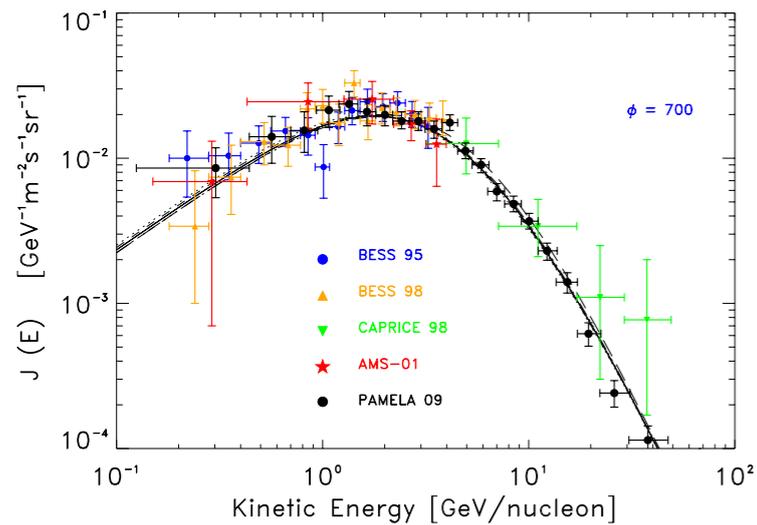
Antiprotons are well reproduced by only astrophysical models

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

DM sources

100 MeV

1 GeV

10 GeV

astrophysical sources

10 GeV

-7.18   -4.83
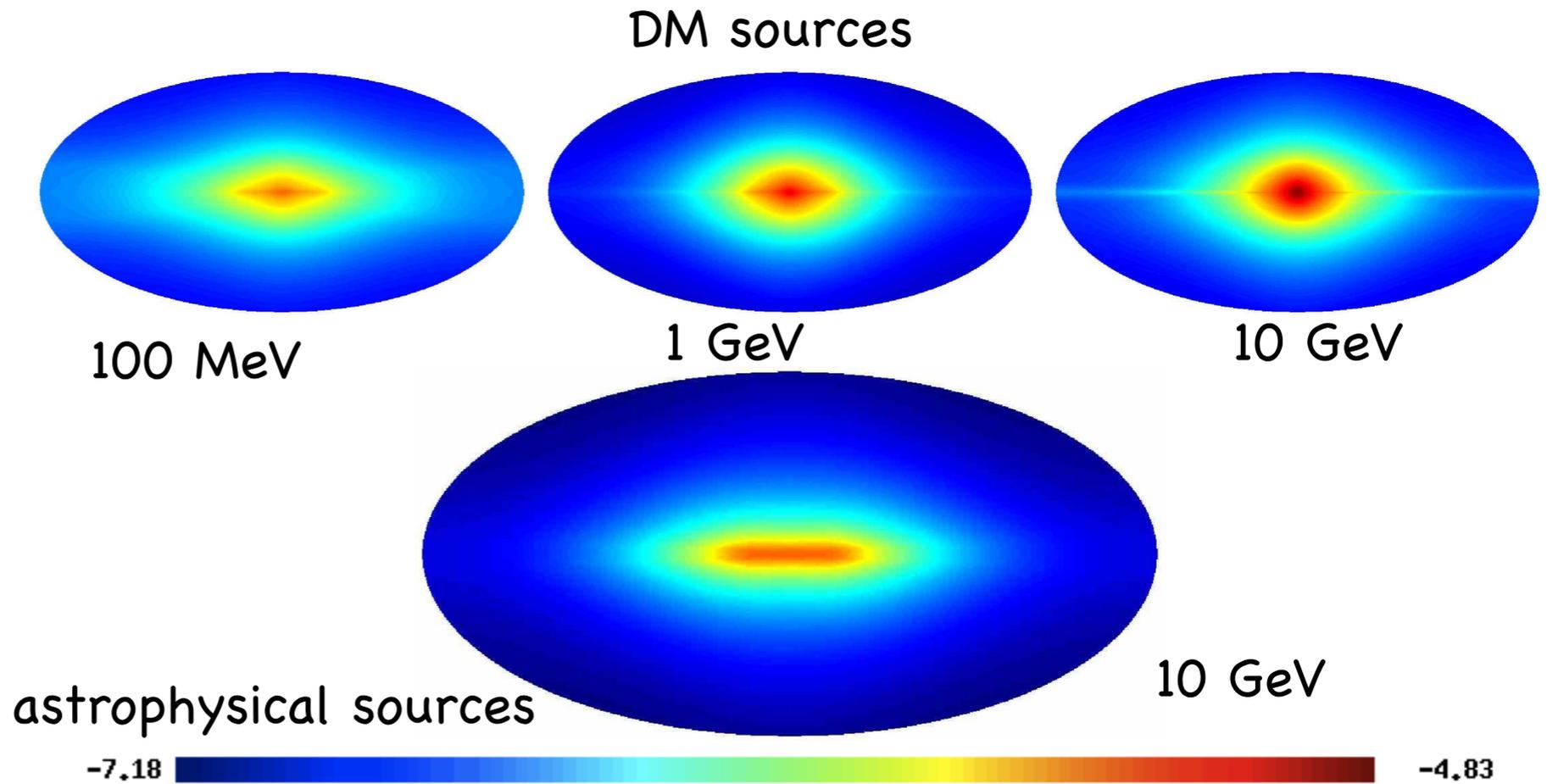
Response function

L. Zhang, C. Weniger, LM, J. Redondo, G. Sigl, 0912.4504

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

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

$$e^+ e^- \to \gamma \qquad \text{via IC scattering and Bremsstrahlung}$$

and compute the associated γ-ray flux J^{E_0} (Ω, E_γ)

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

Define the response function

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

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

And compute constraints on DM models by asking

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

Input from particle physics models

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

Response function: uncertainties
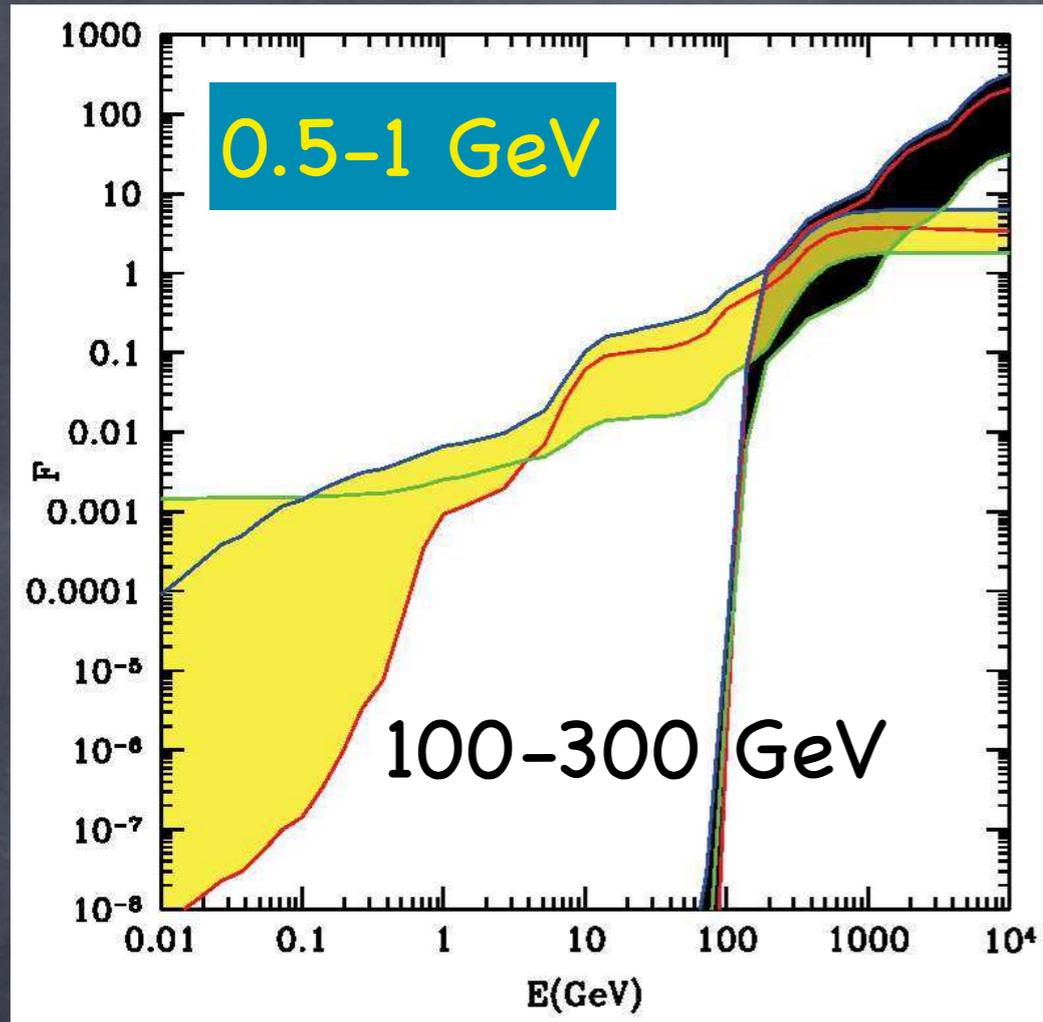

propagation model uncertainties
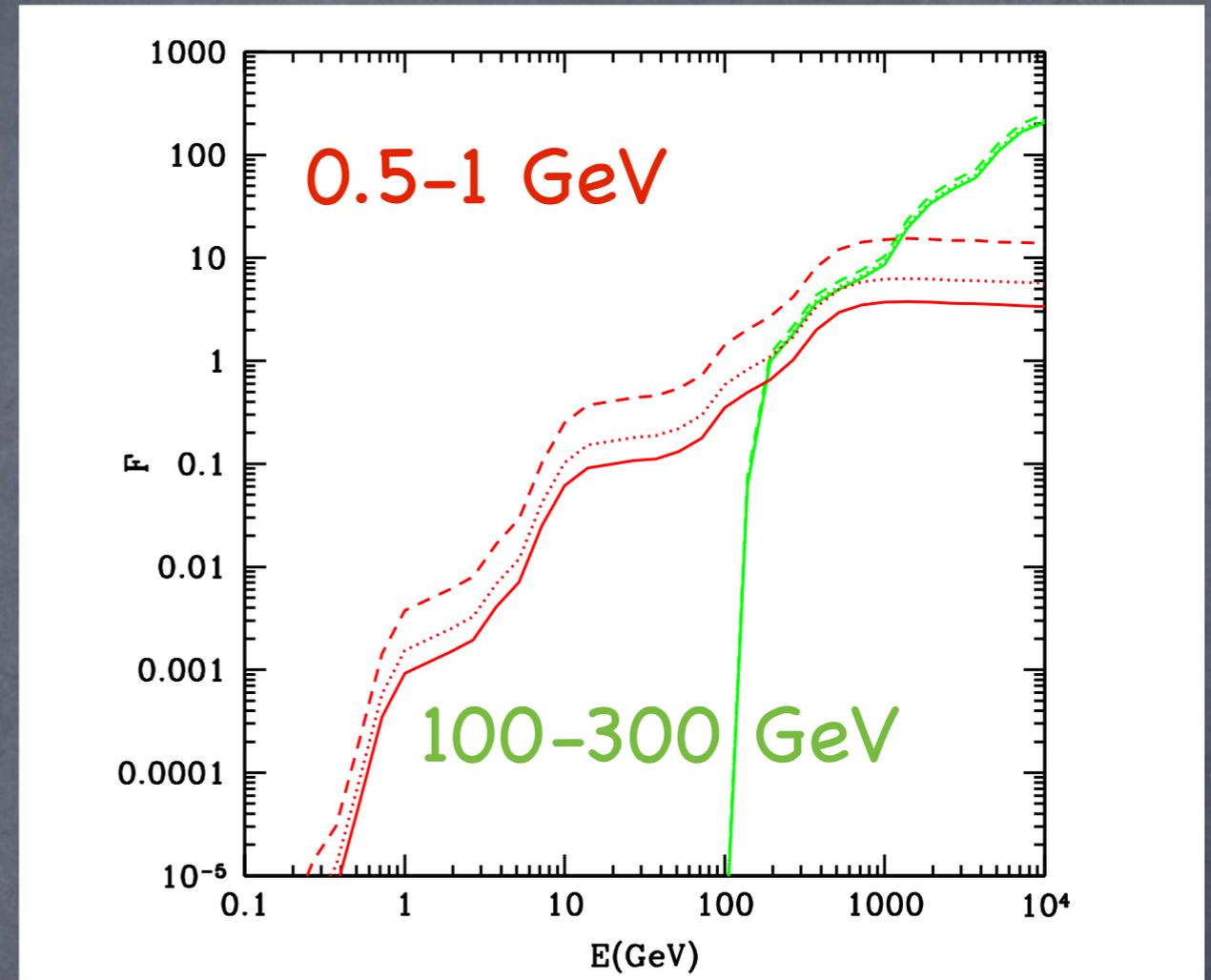
Solid: based on raw data
Dashed: pp gamma-rays subtracted

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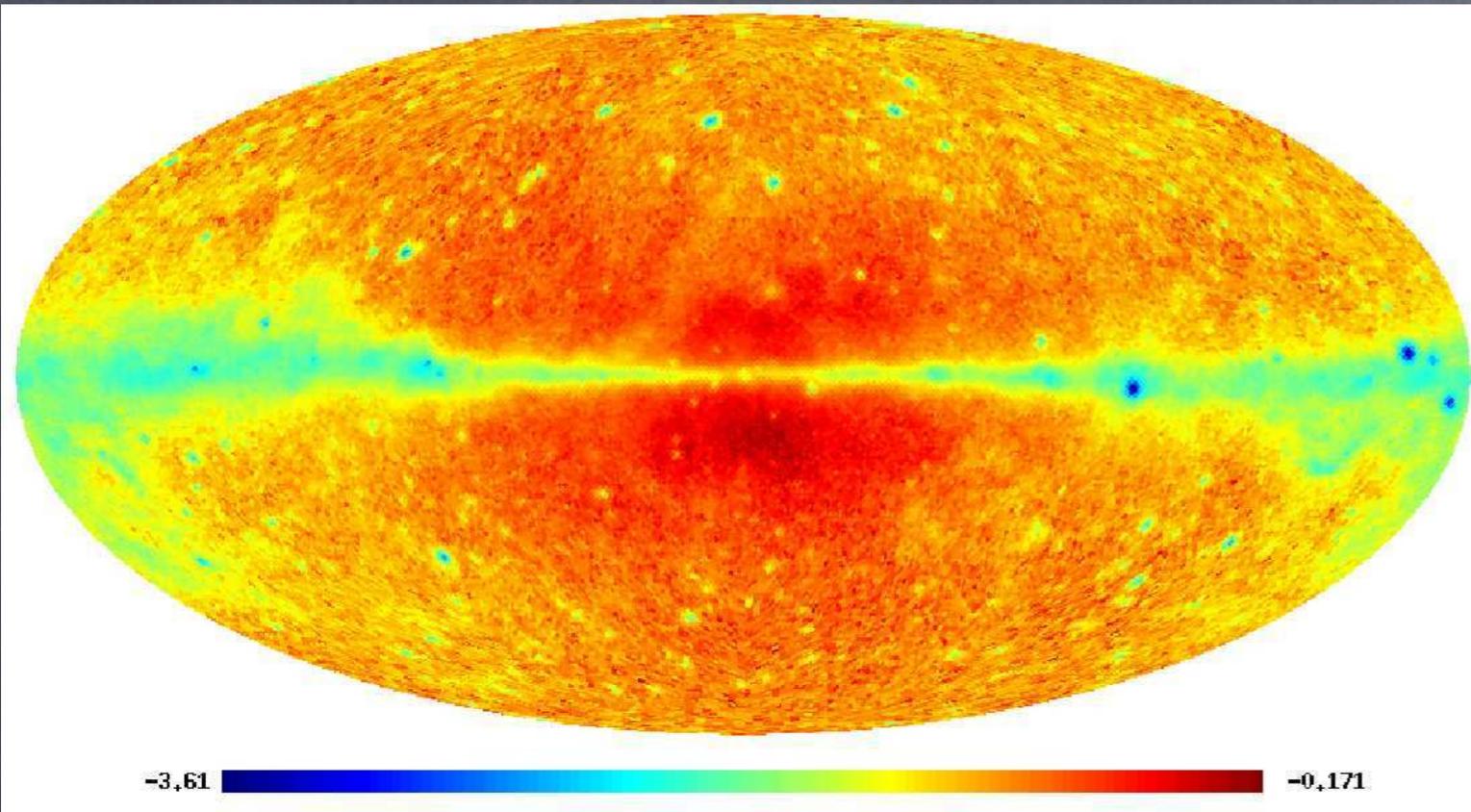
Signal/background map
Signal = DM g-rays
Background = FERMI data
in the range 0.5-1 GeV

Fix model L1
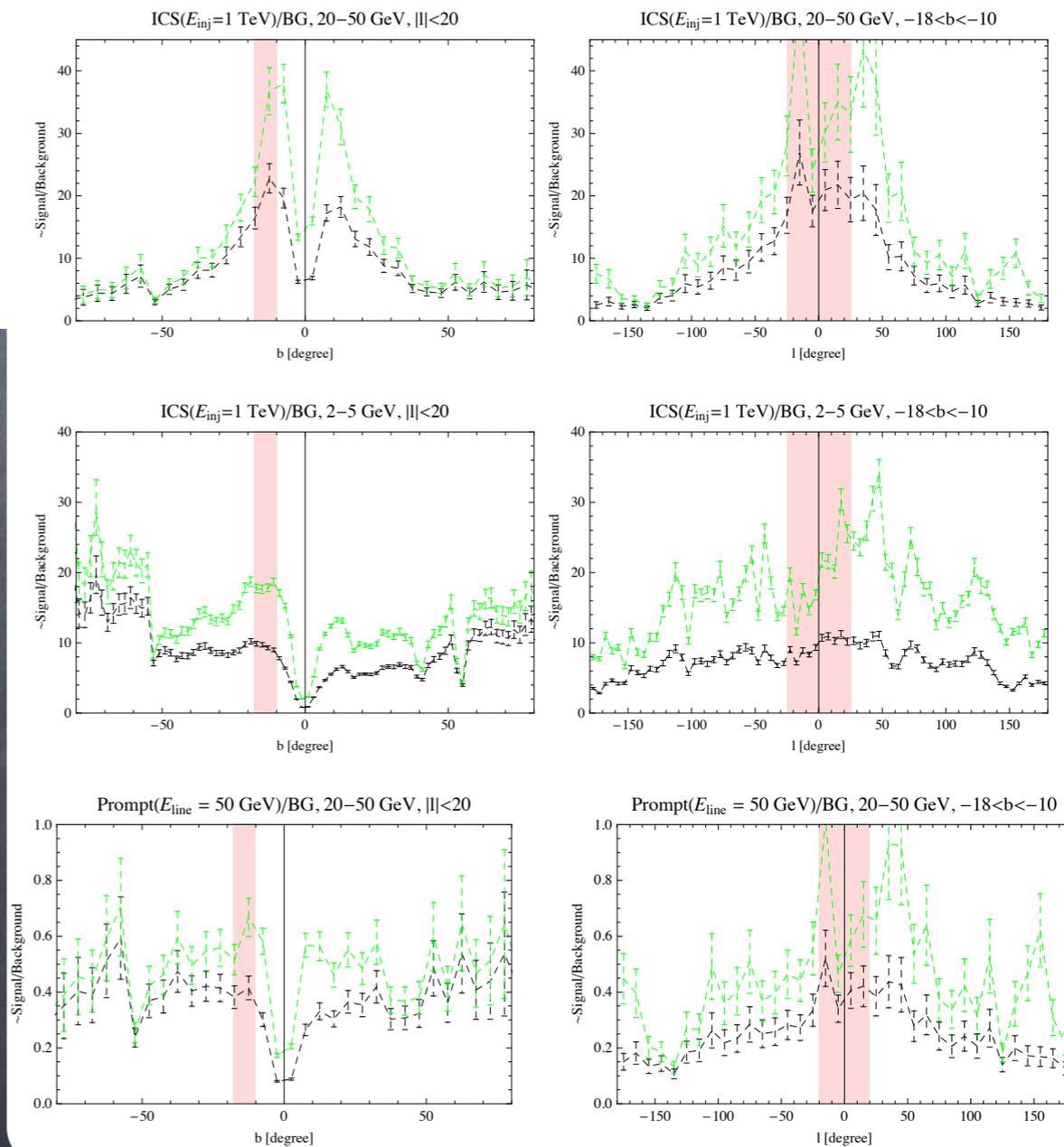
Response function: constraints

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

$$\chi \to \mu^+ \mu^-$$
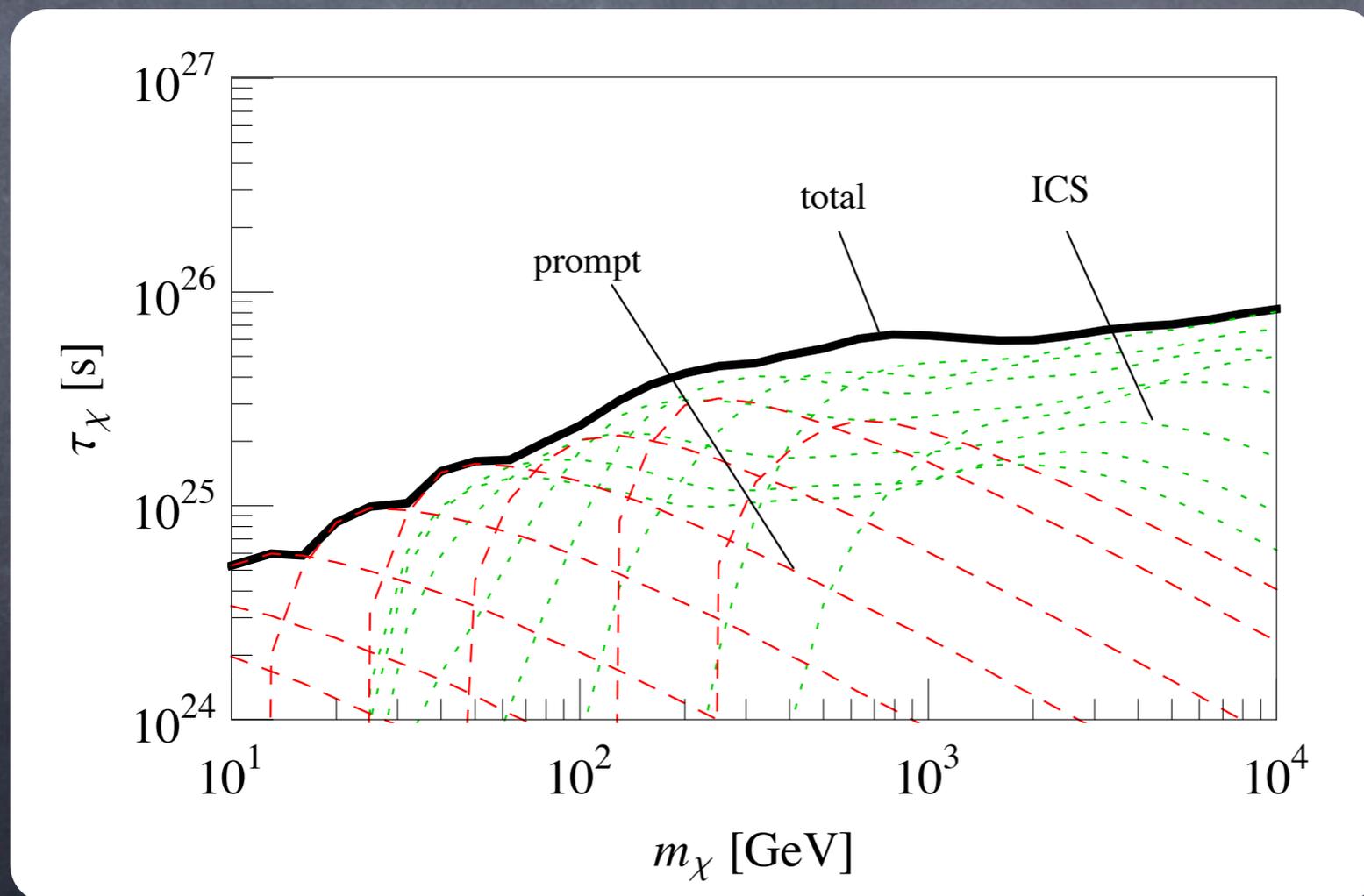
Response function: constraints
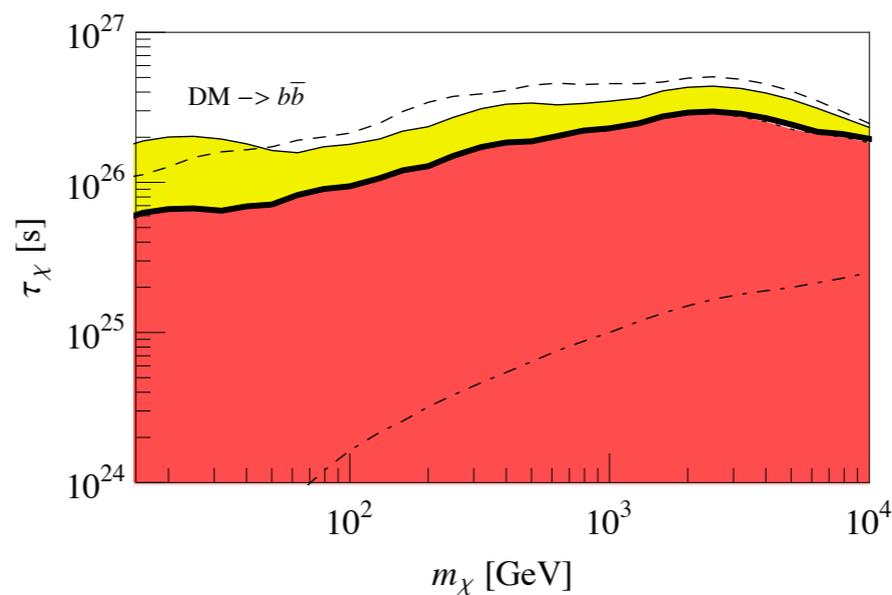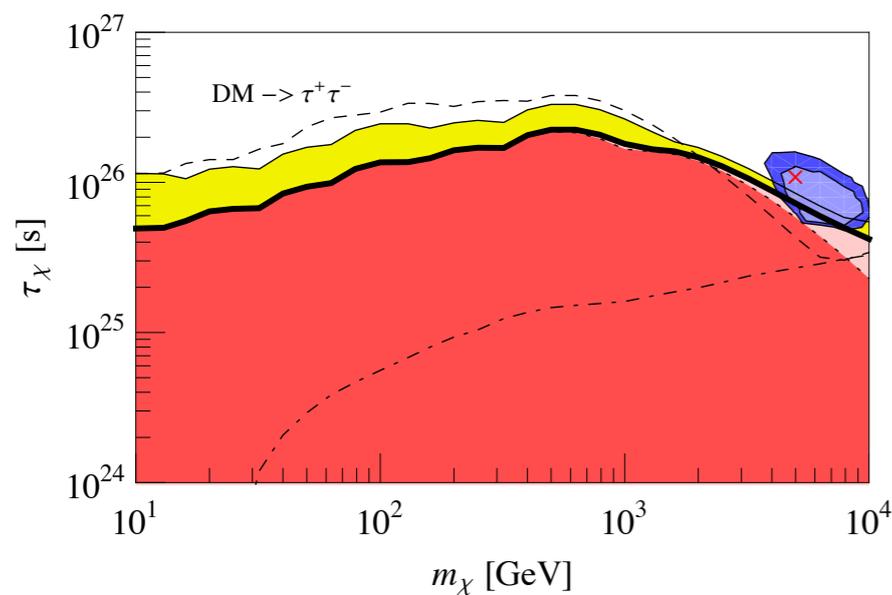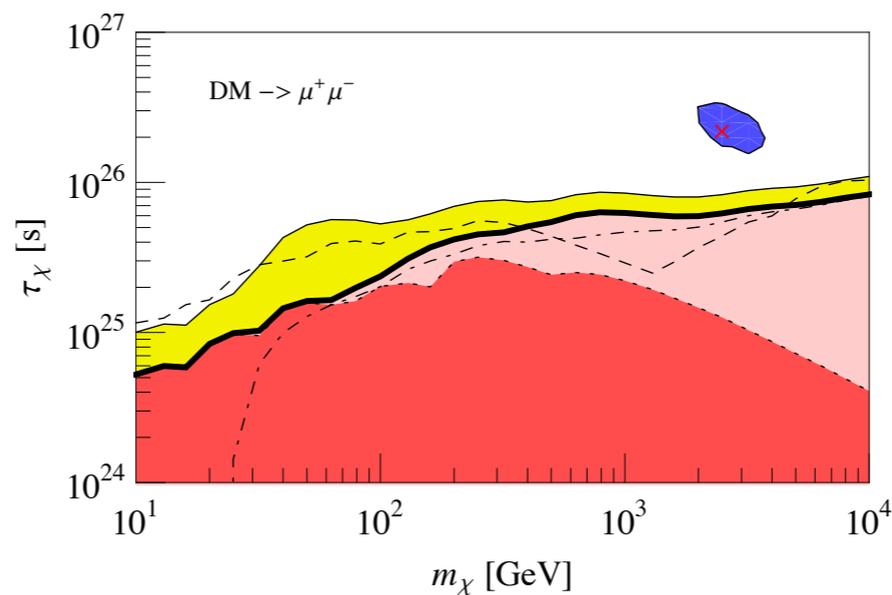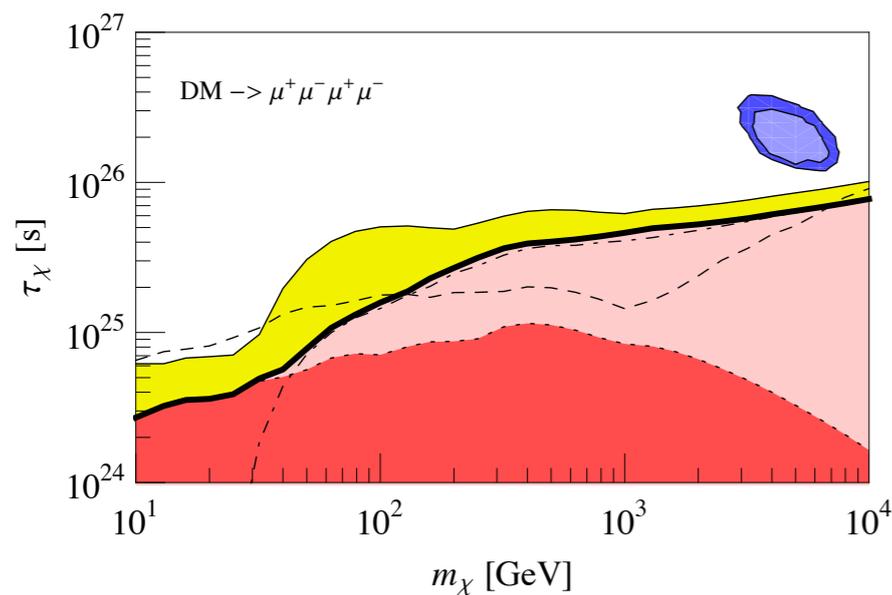
blue blob: models allowed by PAMELA positron fraction data

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
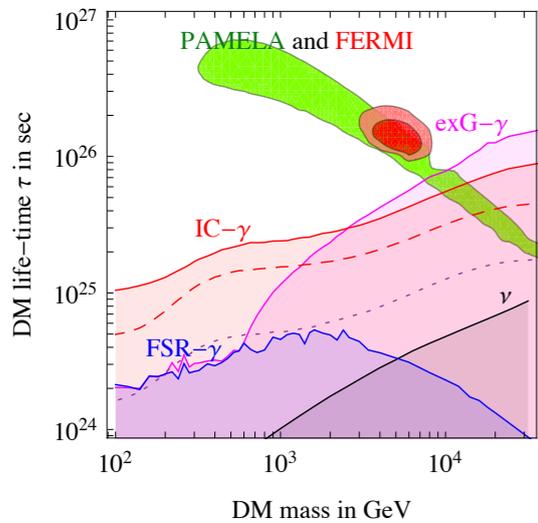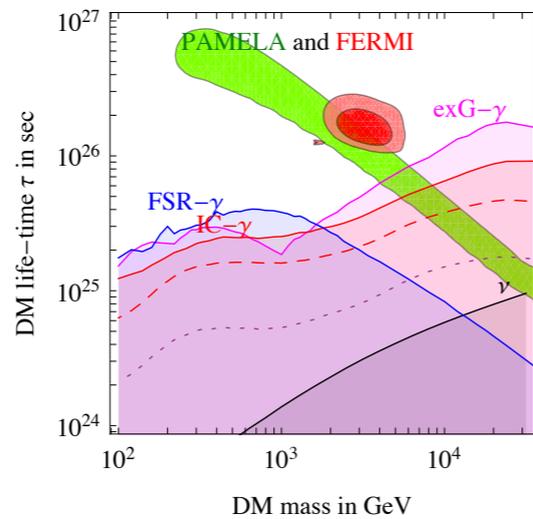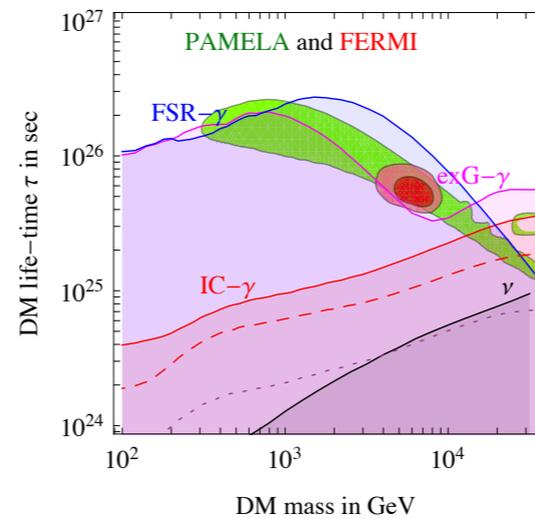
Can exclude the tau channel, but constraint comes from higher energy data, with low statistics (3 events)
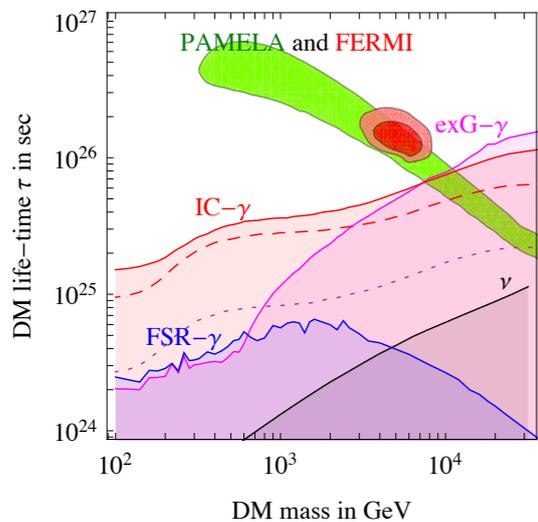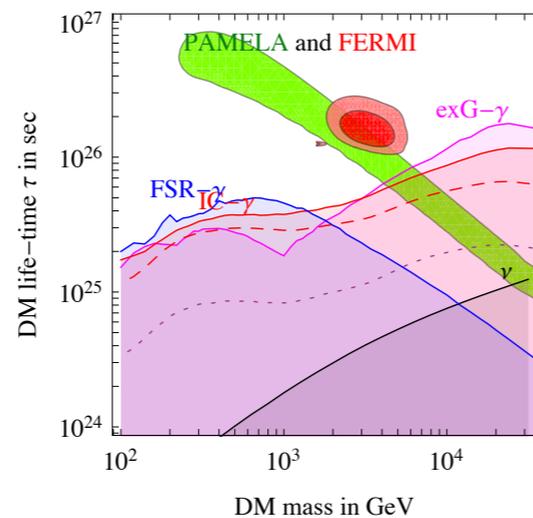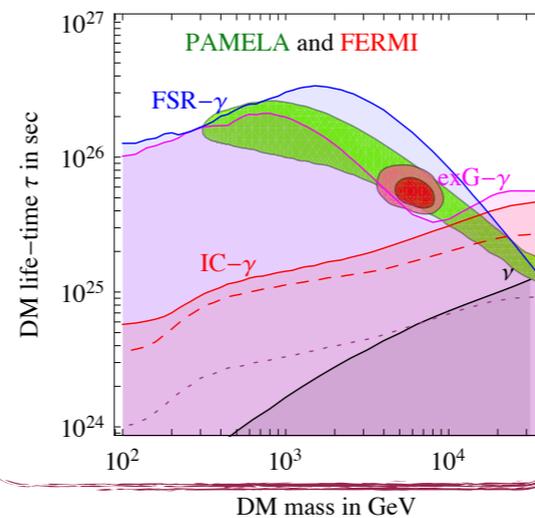
Constraints: comparison

Cirelli, Panci, Serpico, 0912.0663
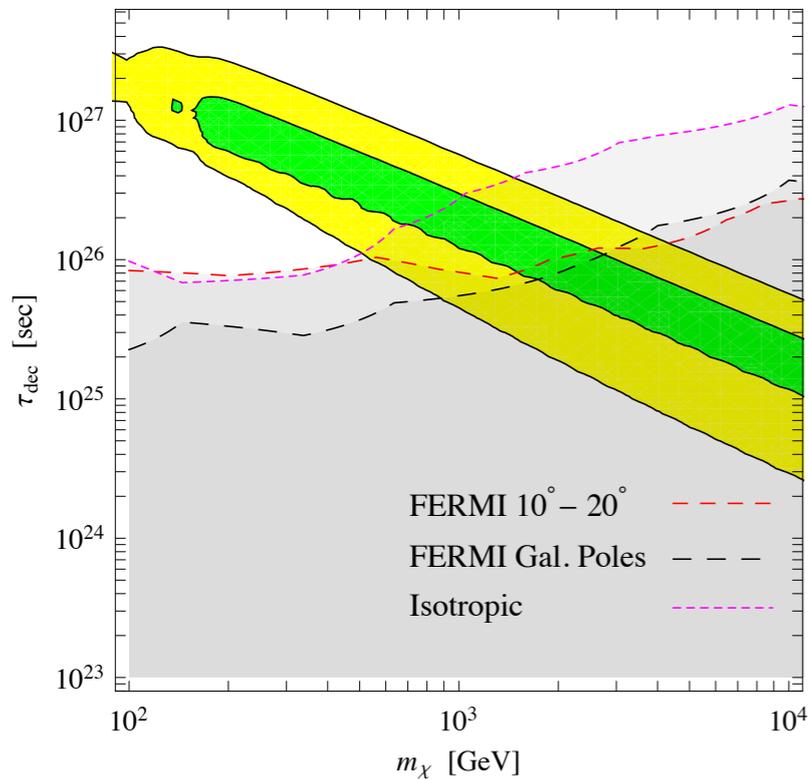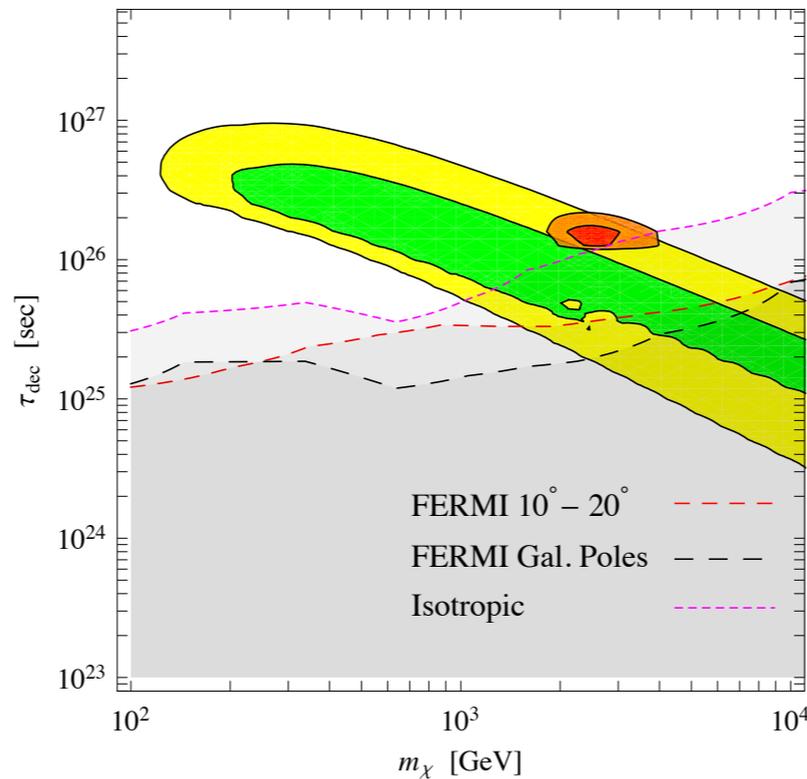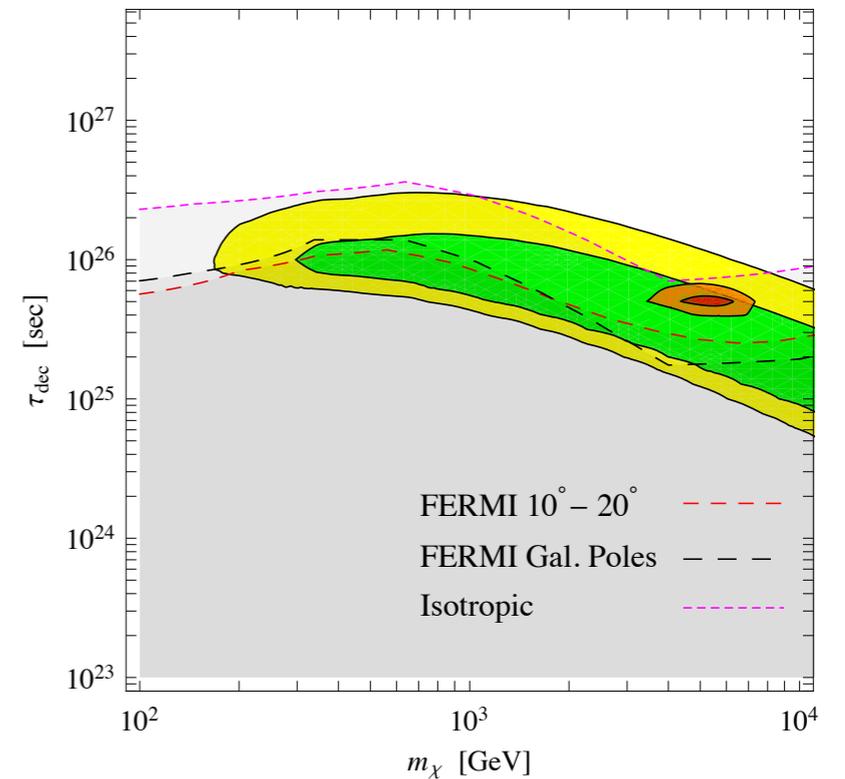
Overall good agreement.
The tau channel is constrained only by the isotropic FERMI component, which again suffers from large uncertainties

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.