How to constraint your favourite decaying DM model

(If such a thing exists...)

Javier Redondo (MPI München)

Based on:
JCAP 0909:012,2009 e-Print: arXiv:0905.4952 [astro-ph.GA] and
arXiv:0912.4504 [astro-ph.HE]

In collaboration with: Luca Maccione, Günter Sigl, Christoph Weniger, Le Zhang.

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but before ... DM facts and Hopes

- DM interacts gravitationally (if it is there...)
  (can we learn something else from this known property? See P. Sikivie's Talk)

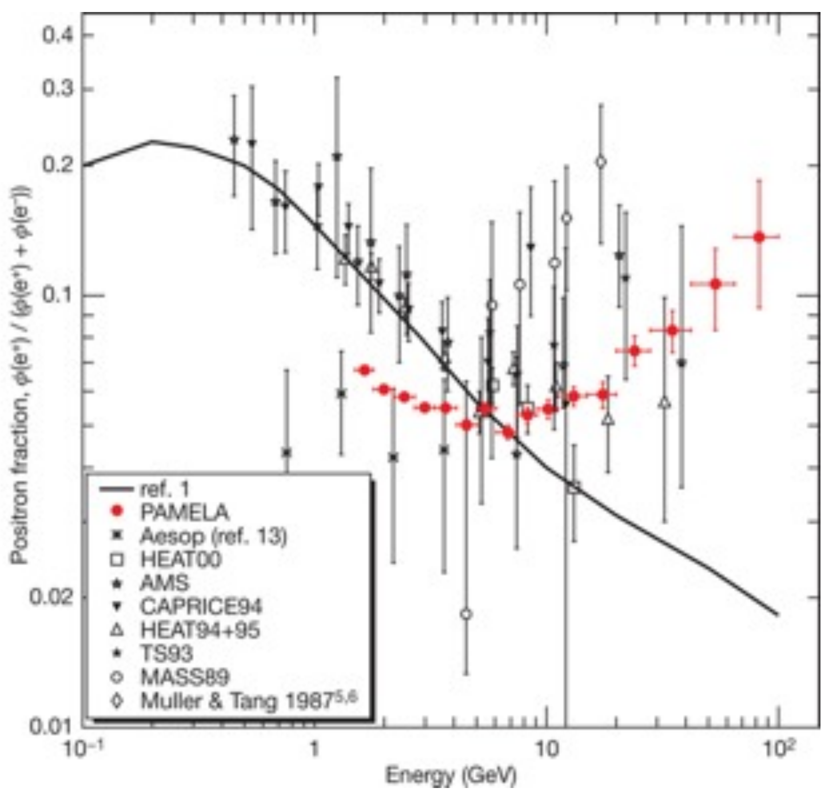
- We hope it participates in other interactions (aren't we mostly particle phsyicists?)

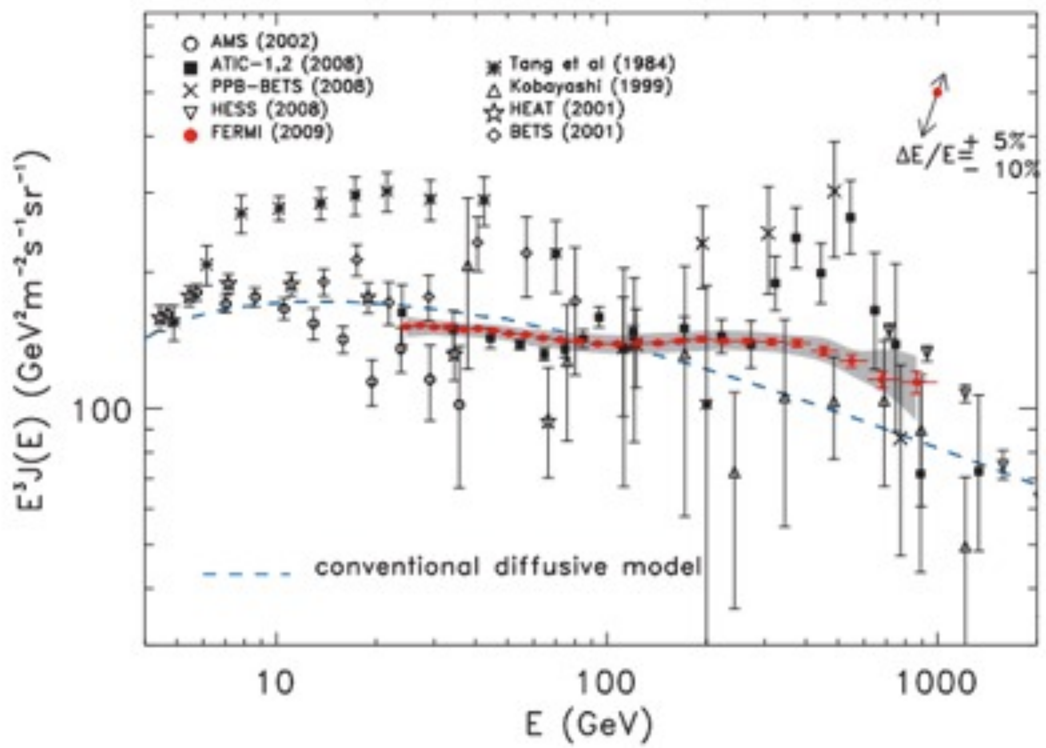
    -Allowing annihilation or decay into SM particles

    - We have plenty of Theories for Beyond the SM physics
      (usually predict only very very small observables)
        -WIMPs (R parity)
        -Gravitinos
        -Axions, Axinos
        -KK particles

what do we see?...

- Cosmic Ray "anomalies" : PAMELA, FERMI
(can be explained with DM but also by other standard mechanisms such as Pulsars, or solar system physics, ALL these hypothesis require confirmation)

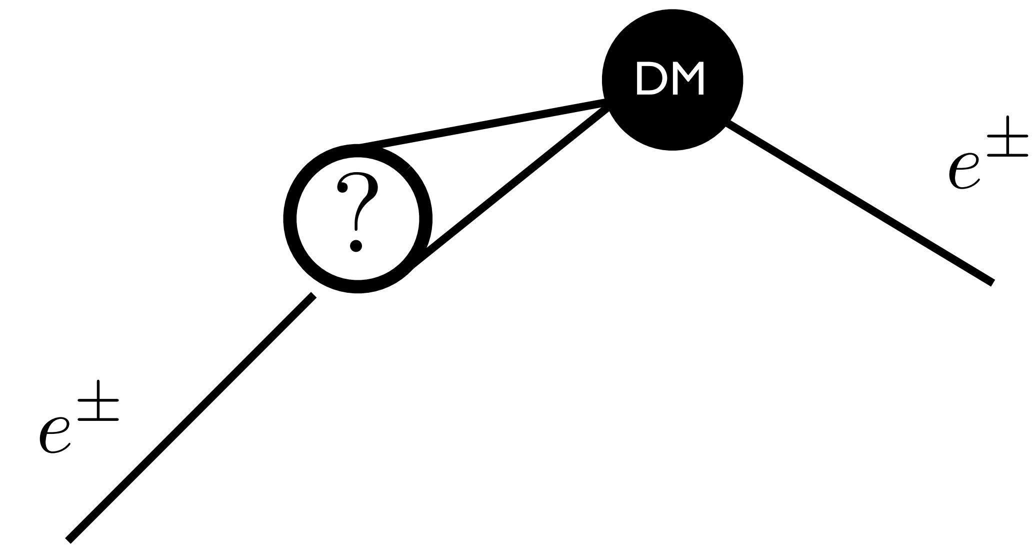


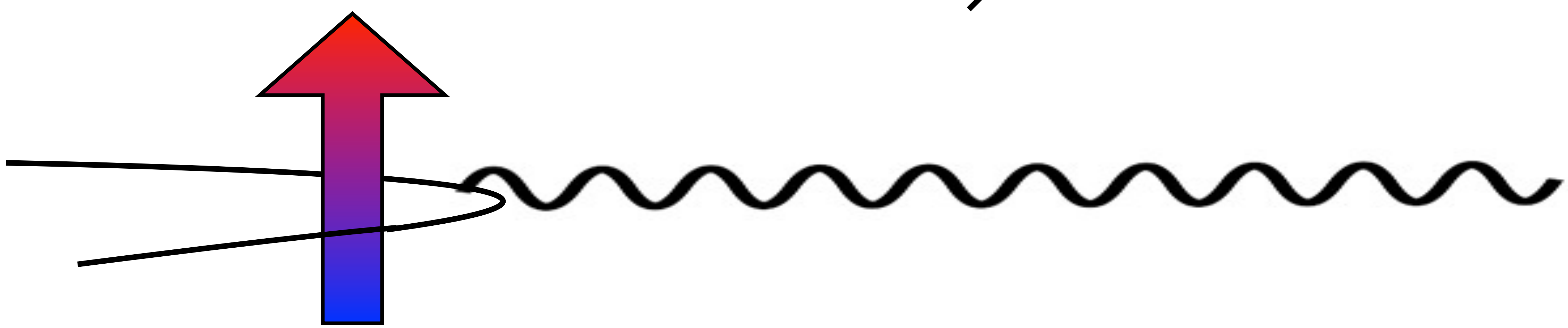


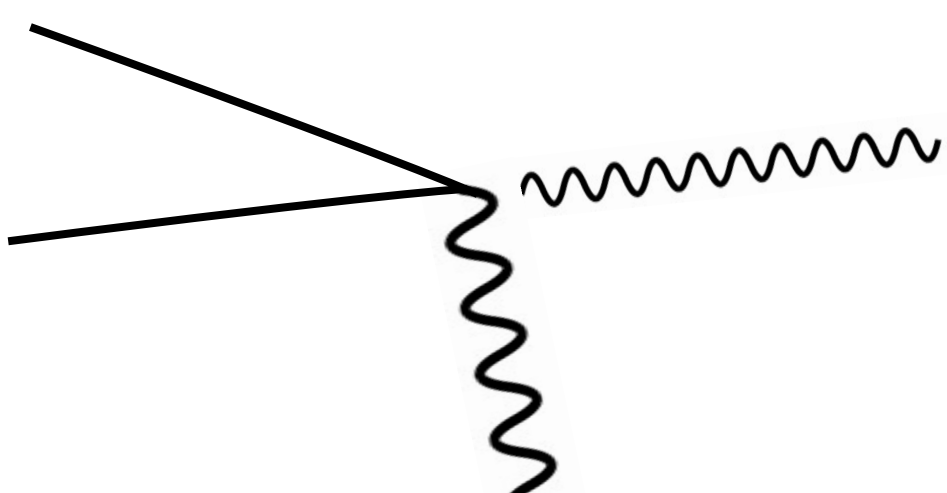
- If high energy electrons/positrons are emitted in DM decay they produce other signatures apart from local CR fluxes, In particular radio emission (from Synchrotron radiation) and gamma rays (prompt radiation and inverse compton scattering from CMB or intergalactic background light).

Signatures of electrons/positrons from DM origin

- electrons/positrons themselves
- Radio emission
- Inverse Compton Scattering







Computation

- (As far as we know) propagation of CRs through the galactic magnetic network and non-trivial plasma can be described as a diffusive process...

$$\cancel{\frac{\partial n}{\partial t}} - \mathcal{D}n = Q(\mathbf{r}, p)$$

sourced by std. mech. and DM decay

$$Q(\vec{r}, E_0) = \frac{\rho_X(\vec{r})}{m_X \tau_X} \frac{dn\pm}{dE_0}$$

($n = n(\vec{r}, p)$ electron/positron phase space density)

... with convection (stellar winds) and re-acceleration (Alfvèn waves)

$$\mathcal{D}n = \boldsymbol{\nabla} \cdot (D_{xx} \boldsymbol{\nabla} n - \mathbf{V_c} n) + \frac{\partial}{\partial p}\left(p^2 D_{pp} \frac{\partial}{\partial p} \frac{n}{p^2}\right) - \frac{\partial}{\partial p}\left[\dot{p}\, n - \frac{p}{3}(\boldsymbol{\nabla} \cdot \mathbf{V_c} n)\right].$$

$$D_{xx} = \beta D_0 \left(\frac{R}{\mathrm{GV}}\right)^{\delta} \qquad D_{pp} = \frac{4p^2 v_A^2}{3\delta(4-\delta^2)(4-\delta) w D_{xx}}$$

$\dot{p}$ energy loss from IC, synchrotron, bremsstrahlung, Coulomb sc, ionization...

Uncertainties...

- (As far as we know) propagation of CRs through the galactic magnetic network and non-trivial plasma can be nicely described as a <u>diffusive</u> process...

$$\cancel{\frac{\partial n}{\partial t}} - \mathcal{D}n = Q(\mathbf{r}, p)$$

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$\dot{p}$ energy loss from IC, synchrotron, bremsstrahlung, Coulomb sc, ionization...

$$n_\gamma(\vec{r}, \omega), \vec{B}(\vec{r}), n_{\mathrm{p,He^{+2},etc.}}(\vec{r}, p), n_{\mathrm{H,He,etc.}}(\vec{r}, p),$$

Uncertainties...

(Actually the whole picture works quite well...)

Propagation

- primary
  - positrons, ~ 5
  - antiprotons, ~ 100
  - antideuterium, ~ 100
- secondary
  - positrons, ~ 2, 4
  - antiprotons ~ 20%-30%
  - antideuterium, < 10

But there are even more uncertainties on our knowledge of <u>sources</u>.

My conclusion is: compare DM predictions with observations, that's sufficiently uncertain. (To be continued)

Model Independent

Want to do something for now and forever

Something that every particle physicist can use to constrain a model

You want not to rely on our (pp's) knowledge on astrophysics
(separate the astro from the particle)

Green's functions and response functions

Diffusion eq. is LINEAR

$$\cancel{\frac{\partial n}{\partial t}} - \mathcal{D}n = Q(\mathbf{r}, p) \qquad Q_{\pm}(\mathbf{r}, E_0) = \frac{\rho_X(\mathbf{r})}{m_X \tau_X} \frac{dN_{\pm}}{dE_0}$$

$$\mathcal{D}n = \boldsymbol{\nabla} \cdot (D_{xx} \boldsymbol{\nabla} n - \mathbf{V_c} n) + \frac{\partial}{\partial p} \left(p^2 D_{pp} \frac{\partial}{\partial p} \frac{n}{p^2} \right) - \frac{\partial}{\partial p} \left[\dot{p}\, n - \frac{p}{3} (\boldsymbol{\nabla} \cdot \mathbf{V_c} n) \right] .$$

- Green's Function
  (In general impossible analitically)
  (But computable numerically once you define a model for the galaxy)
  (can be as complicated as you want as long as eq. is linear)

$$-\mathcal{D}\, n_{\pm}^{E_0}(\mathbf{r}, E) = \frac{\rho_X(\mathbf{r})}{m_X \tau_X} \delta(E - E_0) .$$

<u>Electron/positron flux</u>
(any component, e.g. DM electrons)

$$n_{\pm}(\mathbf{r}, E) = \int dE_0\, n_{\pm}^{E_0}(\mathbf{r}, E) \frac{dN_{\pm}}{dE_0} .$$

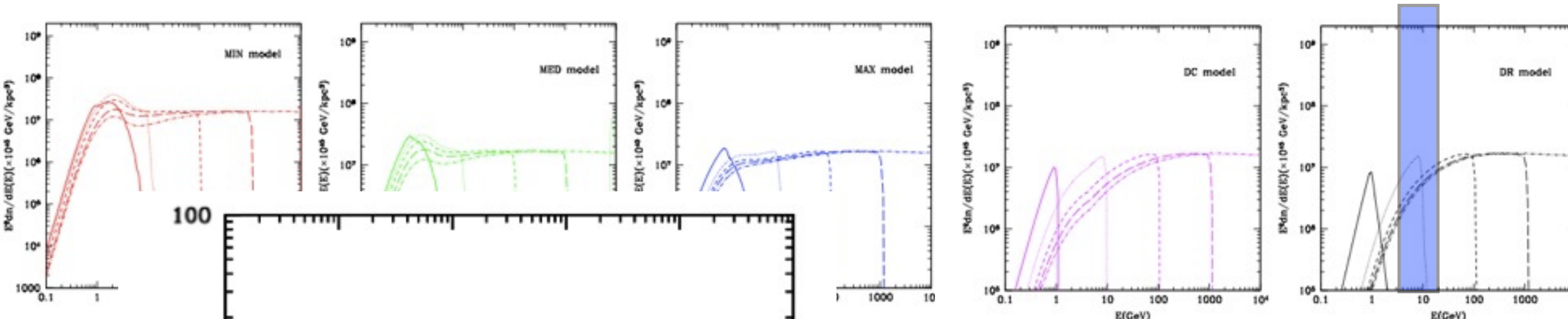
Normalise it to observations
(we call it a <u>response function</u>)

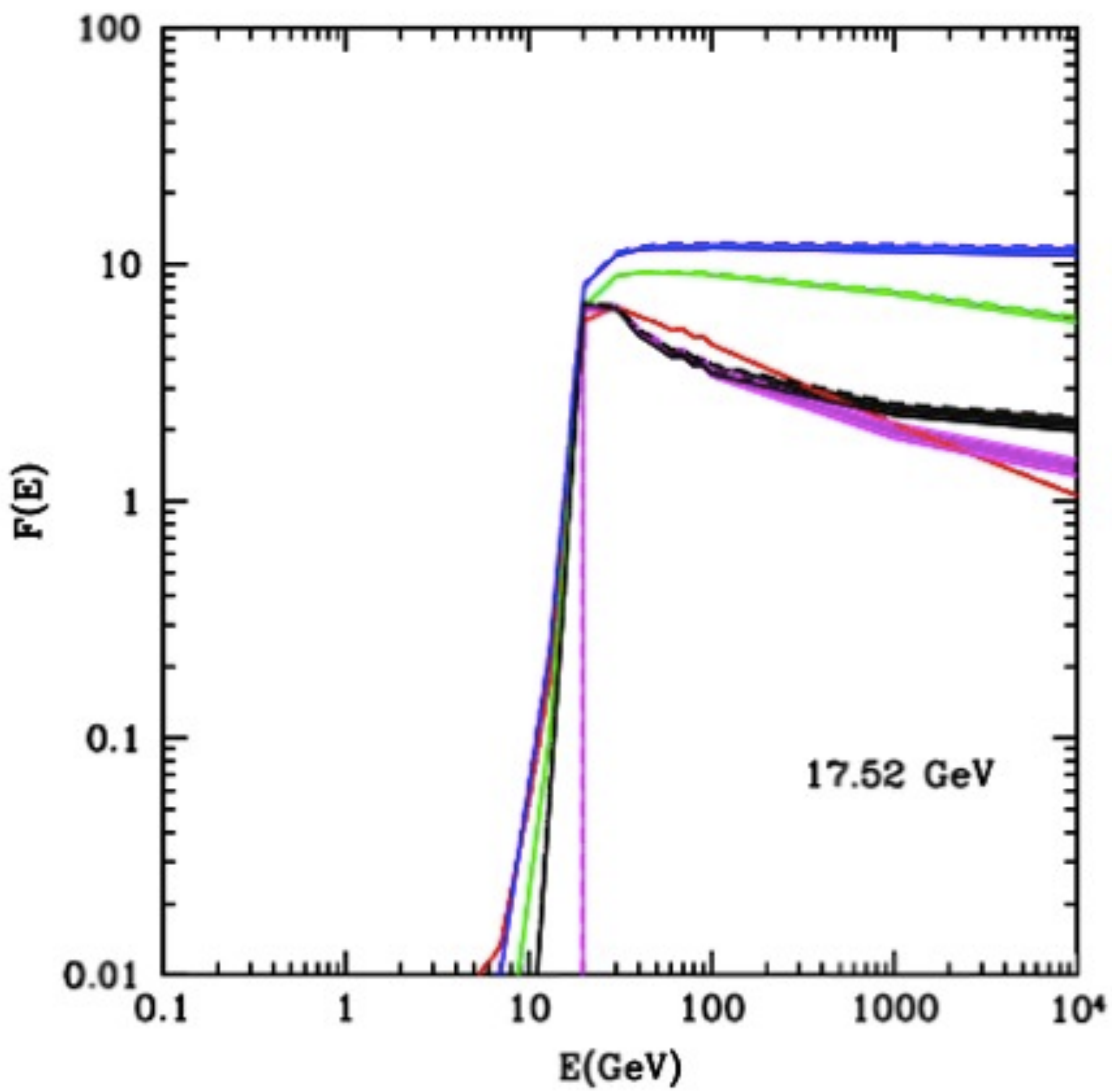
$$F_p(E; E_0) = \frac{n_{+}^{E_0}(\mathbf{r}_{\rm earth}, E)}{n_{+}^{\rm obs}(E)} \left(\frac{\tau_X}{10^{26}\,\mathrm{s}} \right) \left(\frac{m_X}{100\,\mathrm{GeV}} \right)$$

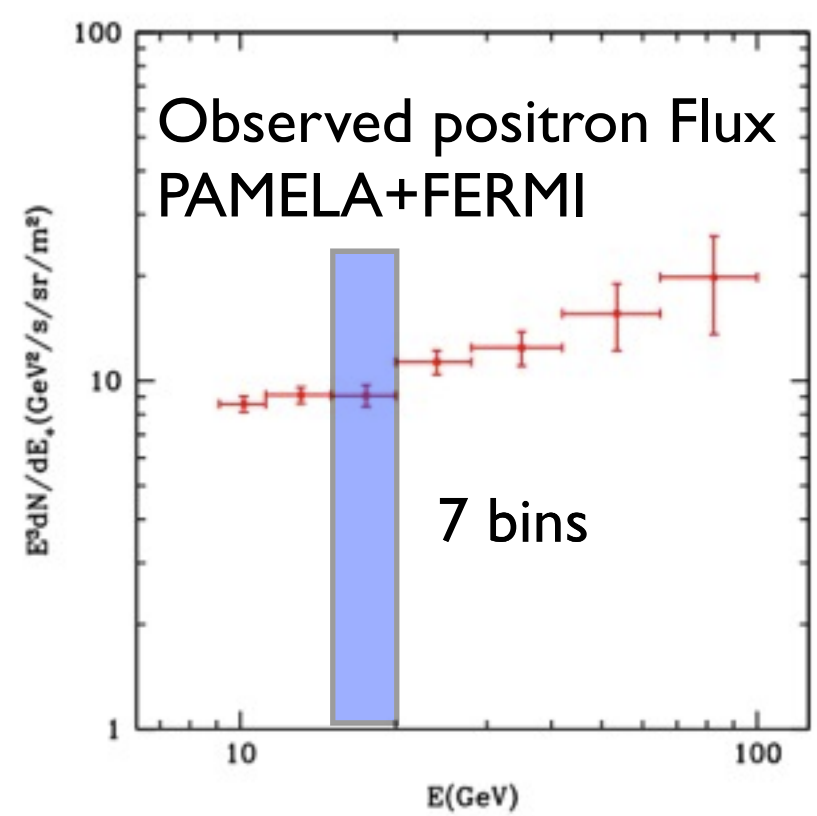
This is the normalization we used to compute

Positron Flux

We used 5 different propagation models, MIN, MED, MAX (Donato et at) DC, DR (Strong et al) to survey possible uncertainties







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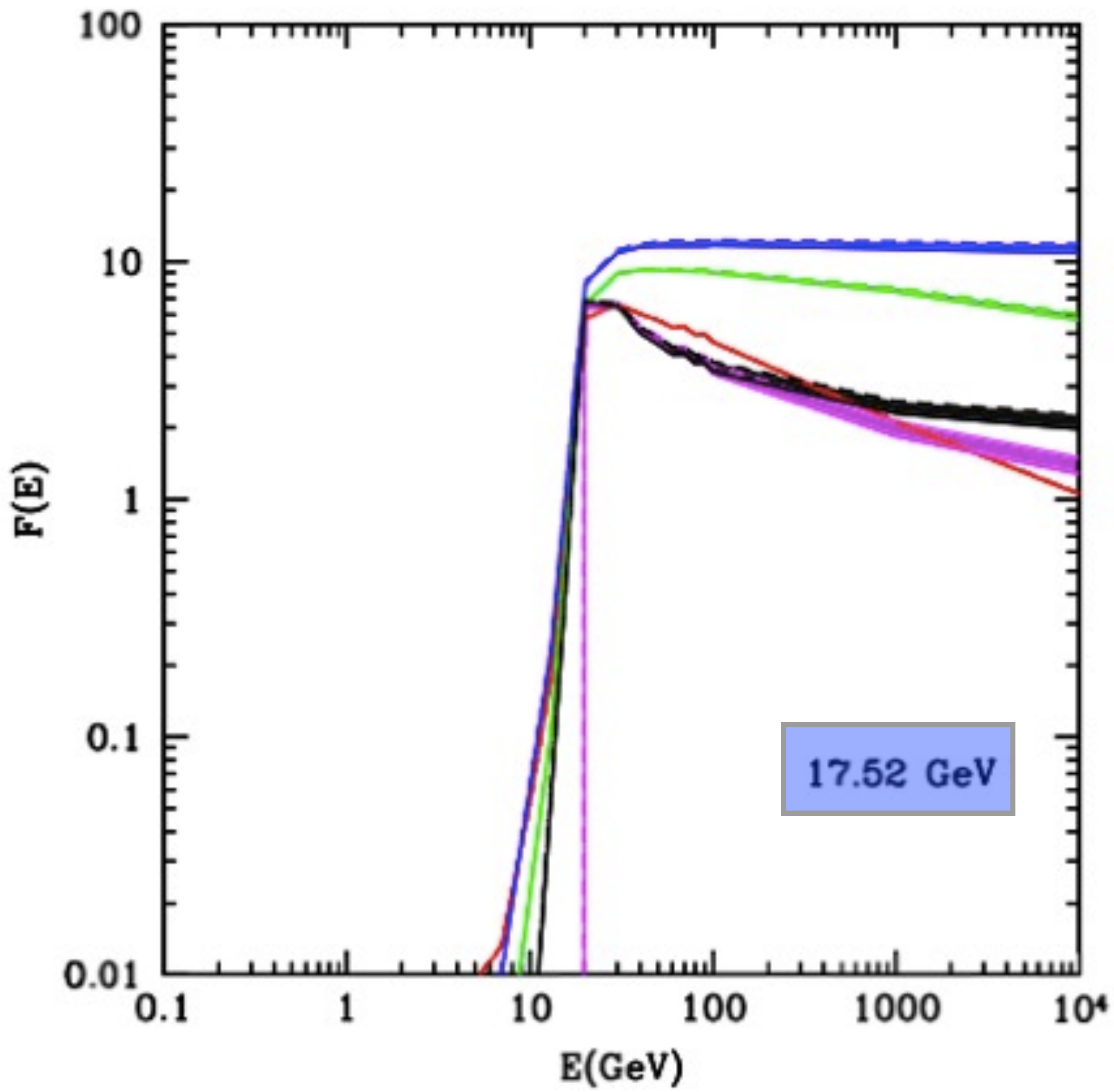
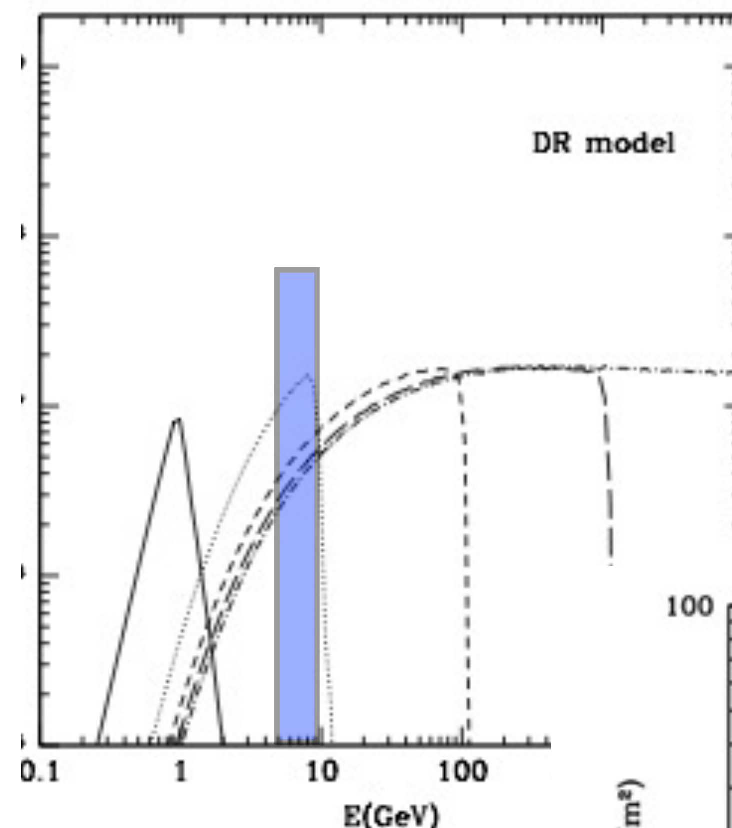
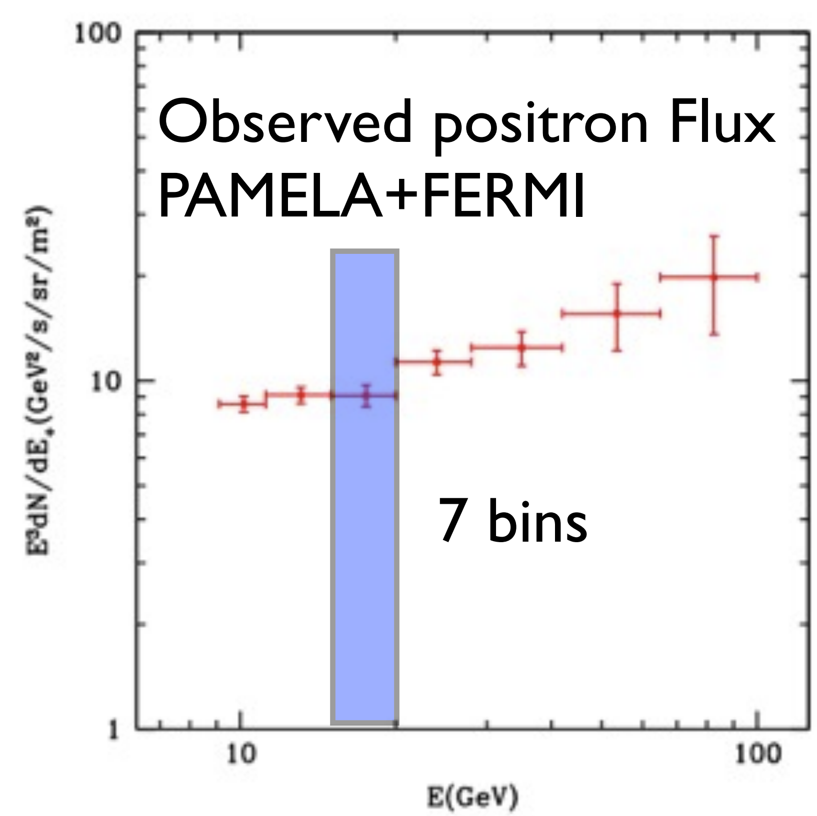
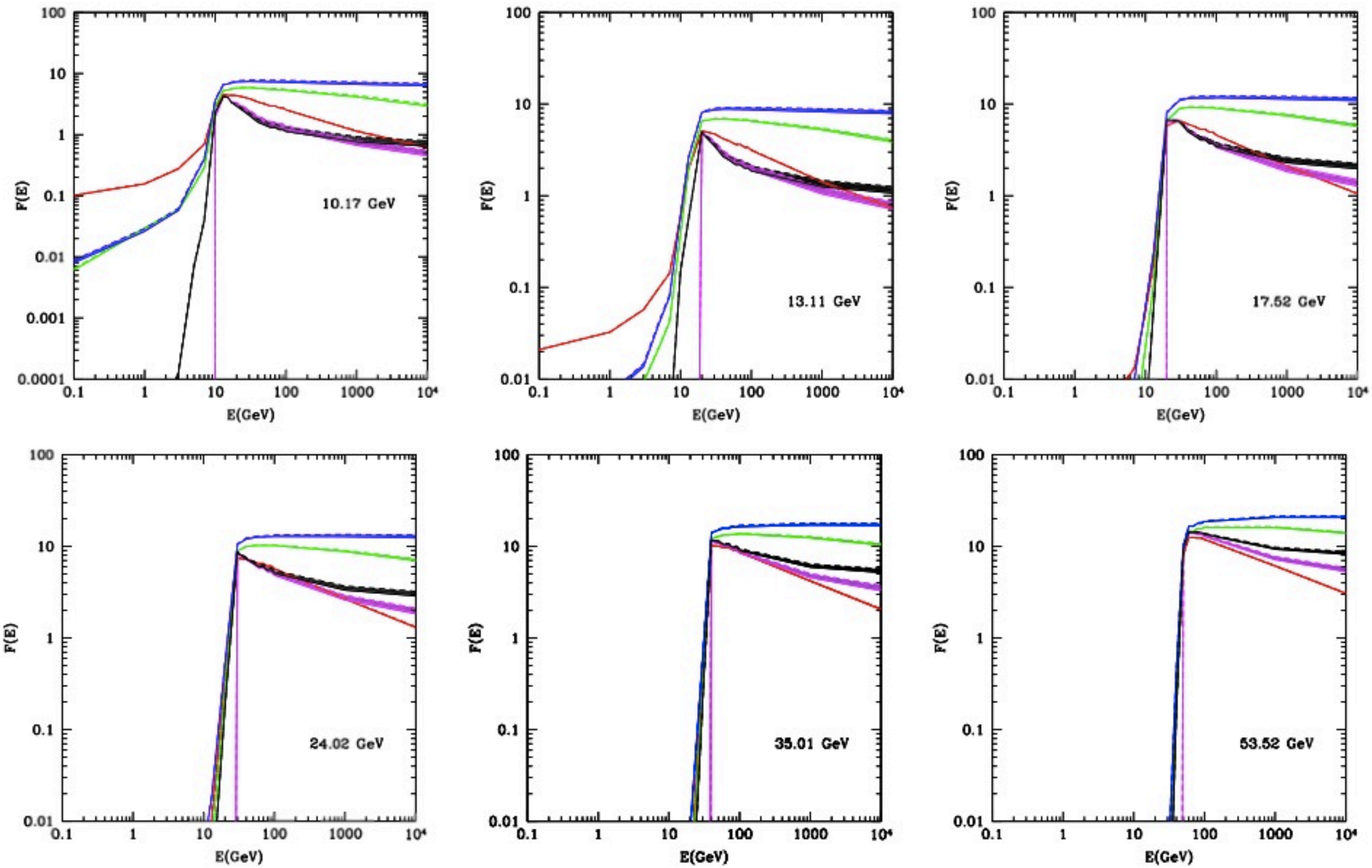






Positron Flux



Galactic models

Propagation models, MIN, MED, MAX (Donato et al) DC, DR (Strong et al)

Model	δ^1	D_0 $[\mathrm{kpc}^2/\mathrm{Myr}]$	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	0.0016	20	1	13.5	0	22.4	0.1
MED	0.70/0.70	0.0112	20	4	12	0	52.9	0.1
MAX	0.46/0.46	0.0765	20	15	5	0	117.6	0.1
DC	0/0.55	0.0829	30	4	0	6	0	4
DR	0.34/0.34	0.1823	30	4	0	0	32	4

Halo profiles

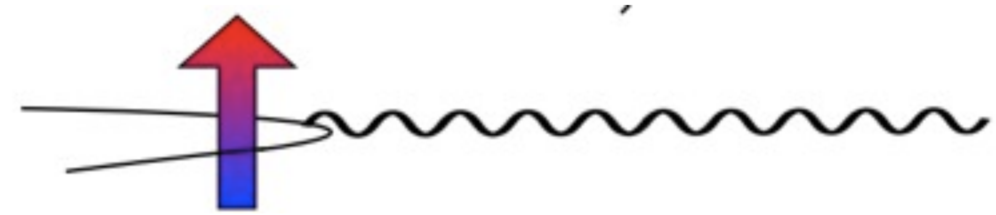
$$\rho_X(r) = \frac{\rho_0}{(r/r_0)^\gamma[1+(r/r_0)^\alpha]^{(\beta-\gamma)/\alpha}}$$

model	α	β	γ	r_0(kpc)
Kra	2	3	0.4	10
Iso	2	2	0	3.5
NFW	1	3	1	20

Magnetic Field

$$B(r,z) = 5\,e^{(-(r-8.5\mathrm{kpc})/10\mathrm{kpc})}e^{-|z|/2\mathrm{kpc}}\,\mu\mathrm{G}$$

Radio emission



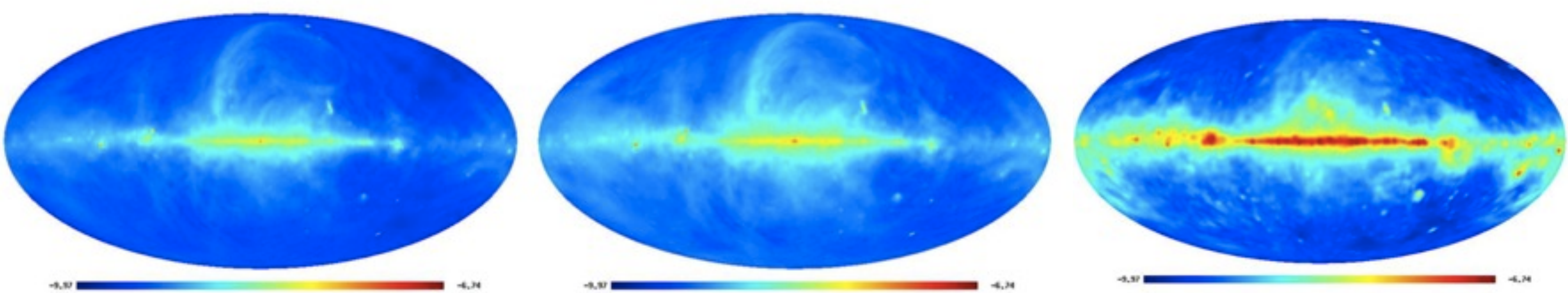
From the numerically computed Green's Function

$$-\mathcal{D}\, n_{\pm}^{E_0}(\mathbf{r}, E) = \frac{\rho_X(\mathbf{r})}{m_X \tau_X} \delta(E - E_0)\ .$$

Compute the Radio flux for each injection energy E_0

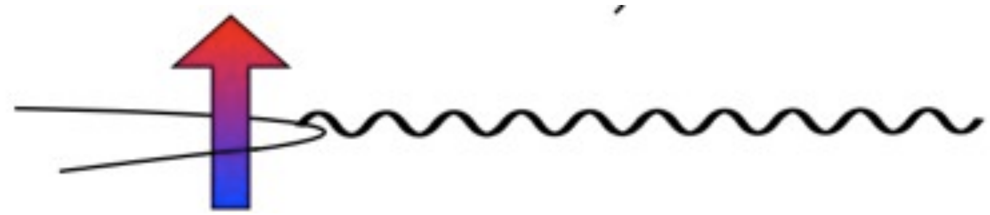
$$J^{E_0}(\Omega, \nu) = \frac{1}{4\pi} \int ds \int dE\, n_e^{E_0}(\mathbf{r}, E) P(\nu, E)\ .$$

We have very good observations at 408 MHz, 1.42 GHz, and 23 GHz,



Haslam et al, A&A Suppl. 47 1982 -- Reich et al, A&A Suppl. 347 2001 -- WMAP coll, PRD 74 2006

Radio emission



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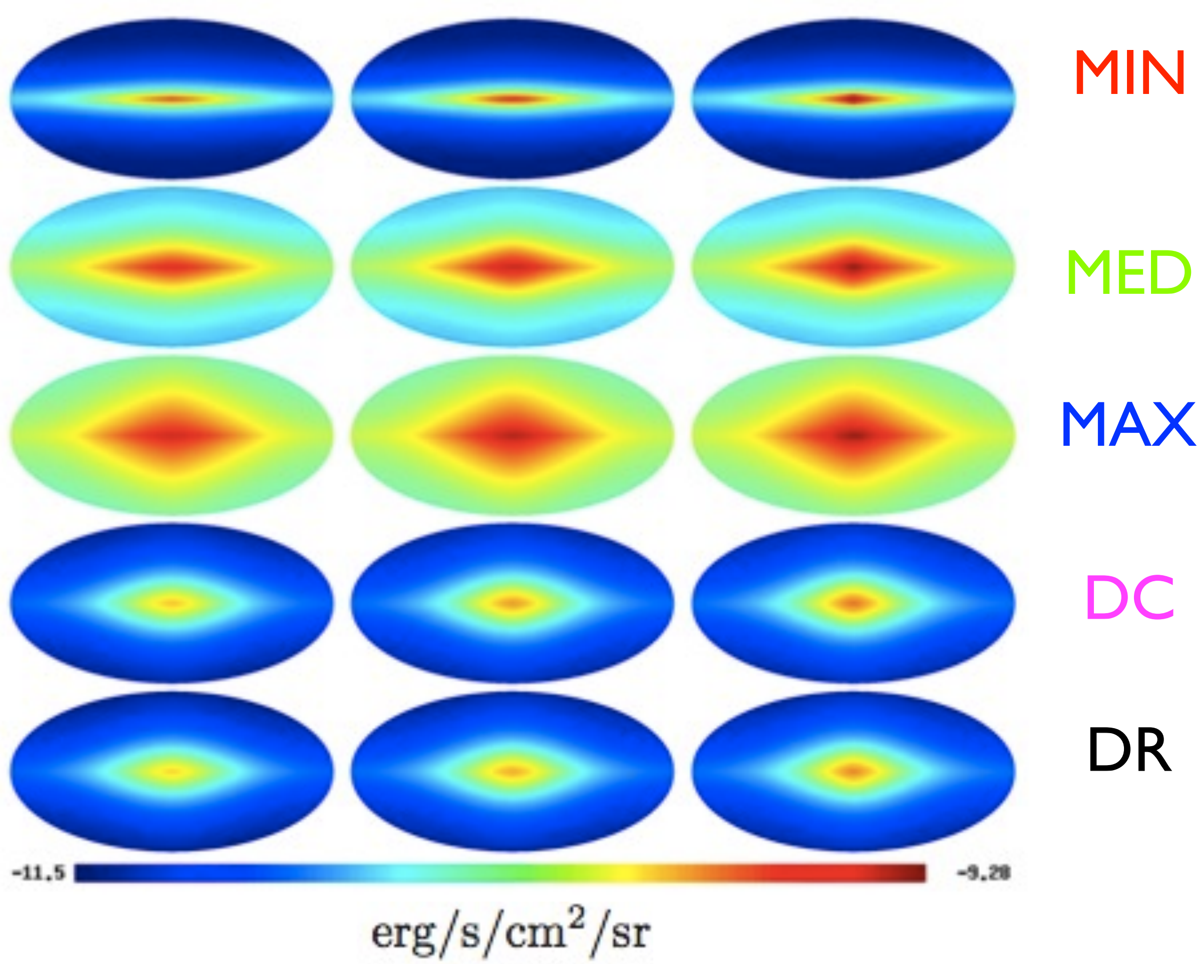
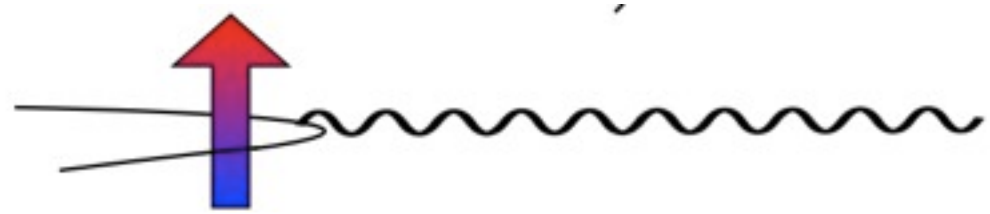


$$E_0 = 100\text{GeV}; \tau = 10^{26}\ \text{s}$$

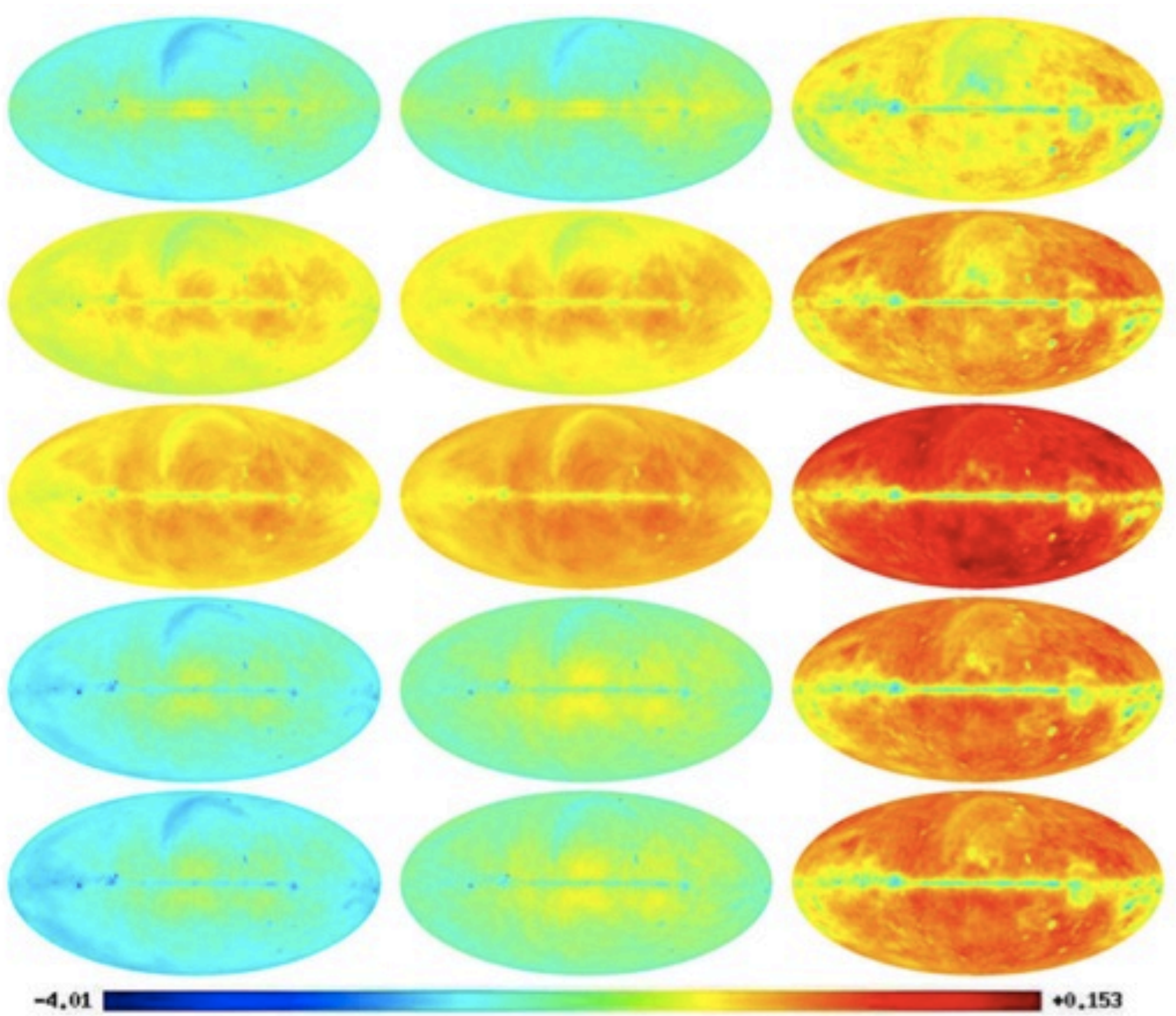
Radio emission



Define your signal/observation
'response' function

$$F_r(\Omega,\nu;E_0) = \frac{J^{E_0}(\Omega,\nu)}{J^{\rm obs}(\Omega,\nu)}\left(\frac{\tau_X}{10^{26}\,\rm s}\right)\left(\frac{m_X}{100\,\rm GeV}\right)$$

408 MHz, 1.42 GHz, and 23 GHz,



MIN

MED

MAX

DC

DR

$$E_0 = 100{\rm GeV}; \tau = 10^{26}\ {\rm s}$$

Make it simple and give only the response function in the most sensitive direction ...

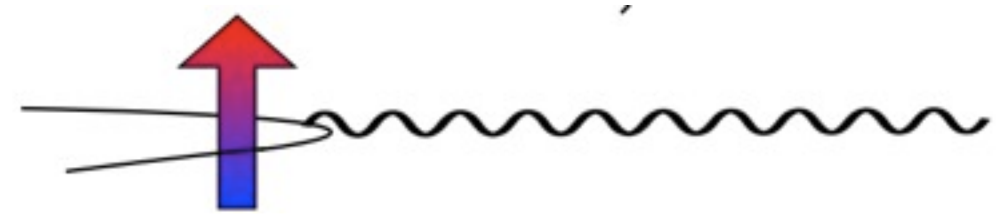
Of course, it depends on:

-E_0

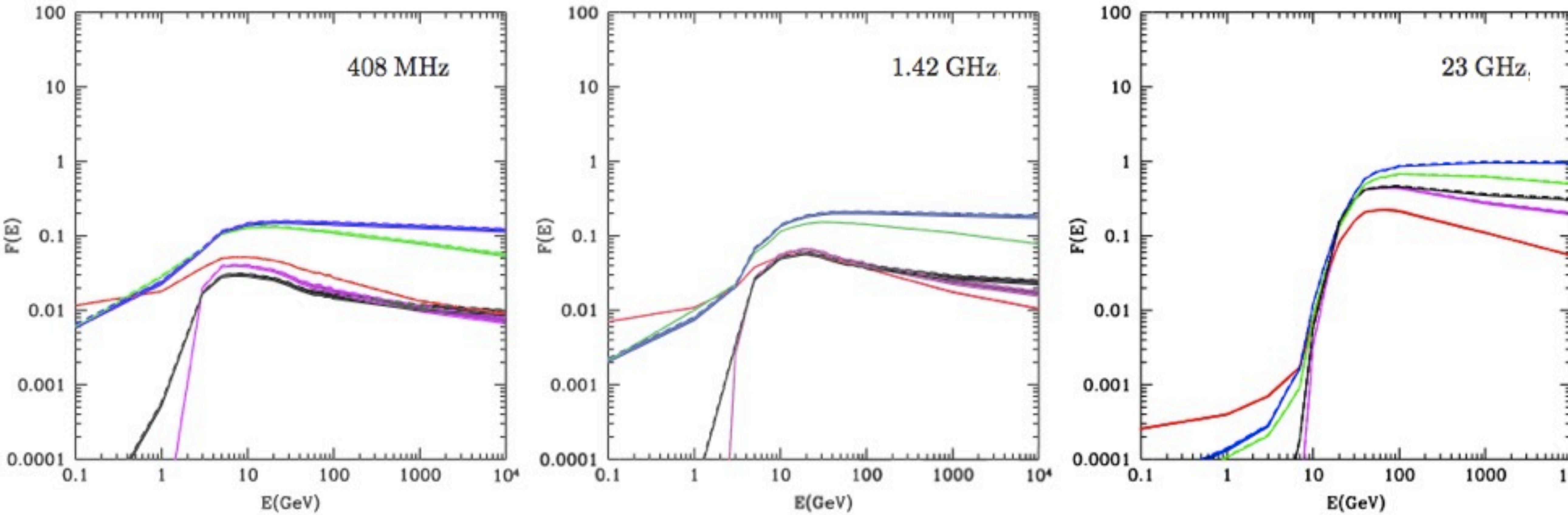
-galactic model

-observed frequency

Radio emission



Response Functions...



Optimal directions (not so optimal... same for each prop. model)

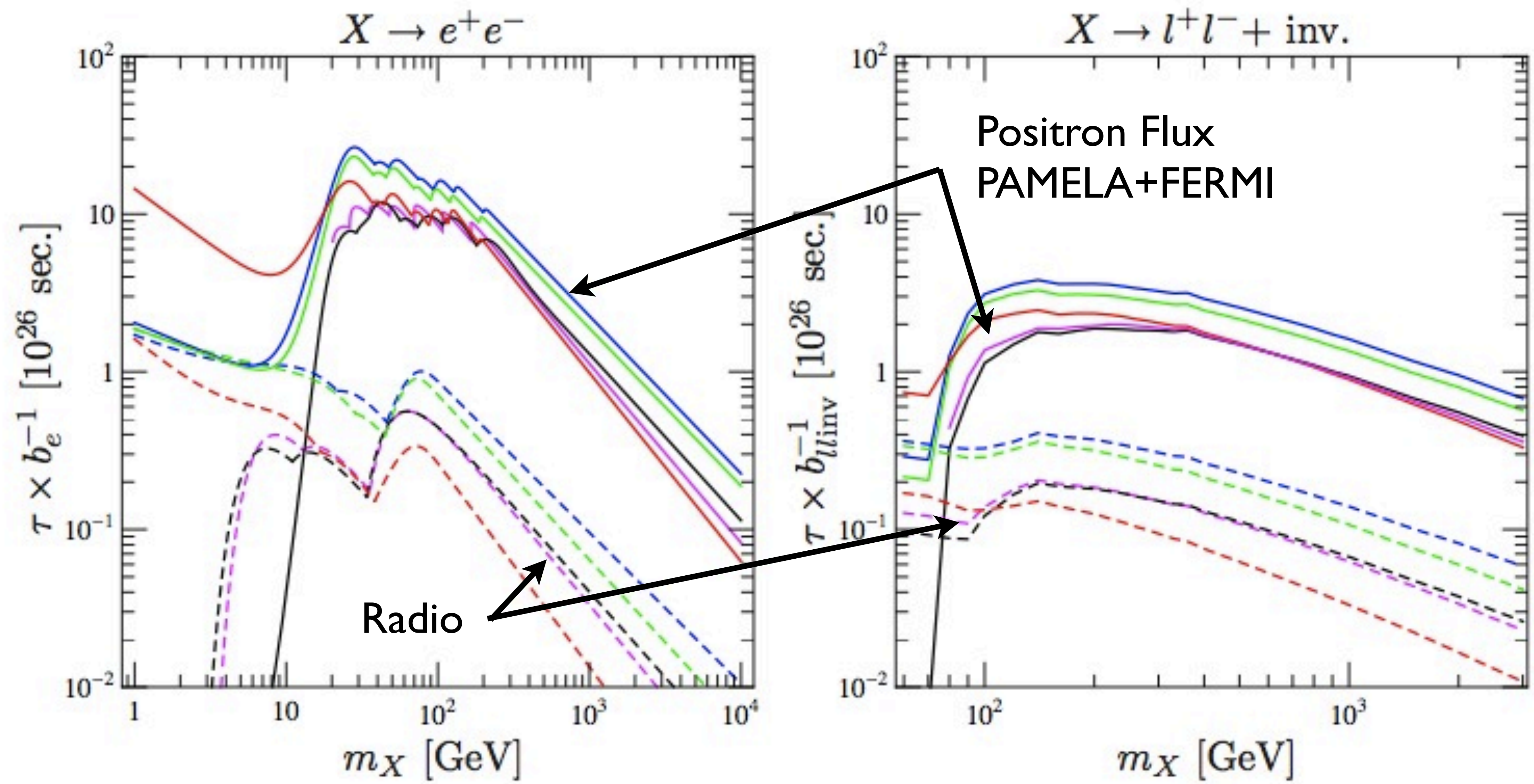
$$(\phi, \theta) = (291°, -13.9°), (291°, -13.9°), (233°, 25°)$$

(more than one order of magnitude smaller than positron flux)

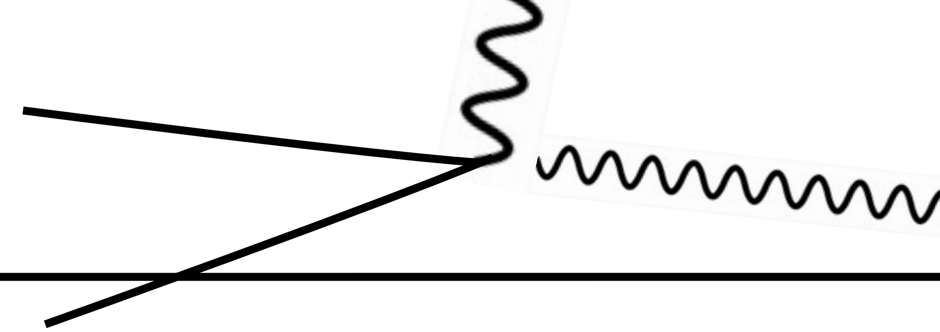
Conservative constraints

$$\int_{m_e}^{m_X} dE_0\, F_p(E; E_0) \frac{dN_+}{dE_0} \leq \left(\frac{\tau_X}{10^{26}\,\mathrm{s}}\right)\left(\frac{m_X}{100\,\mathrm{GeV}}\right)$$

$$\int_{m_e}^{m_X} dE_0\, F_r(\Omega, \nu; E_0) \frac{dN_e}{dE_0} \leq \left(\frac{\tau_X}{10^{26}\,\mathrm{s}}\right)\left(\frac{m_X}{100\,\mathrm{GeV}}\right)$$

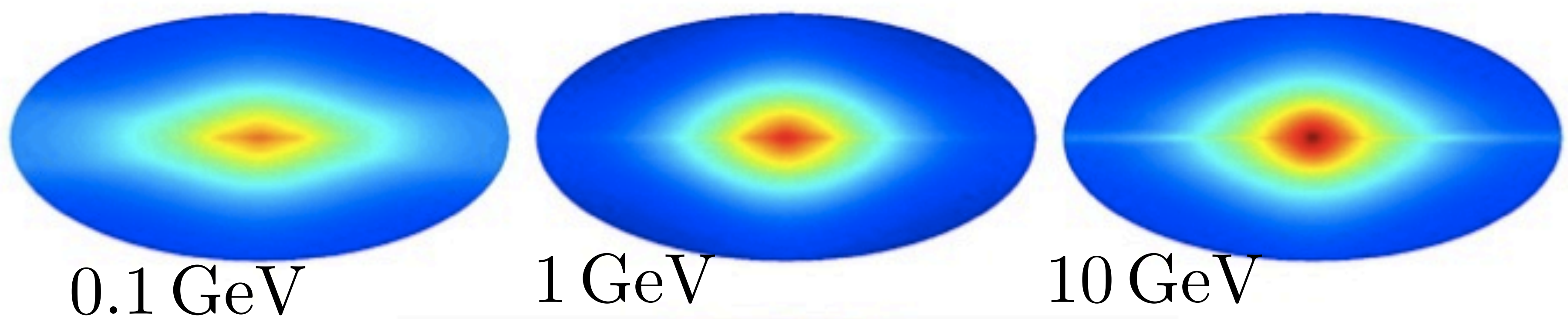


Inverse Compton Radiation

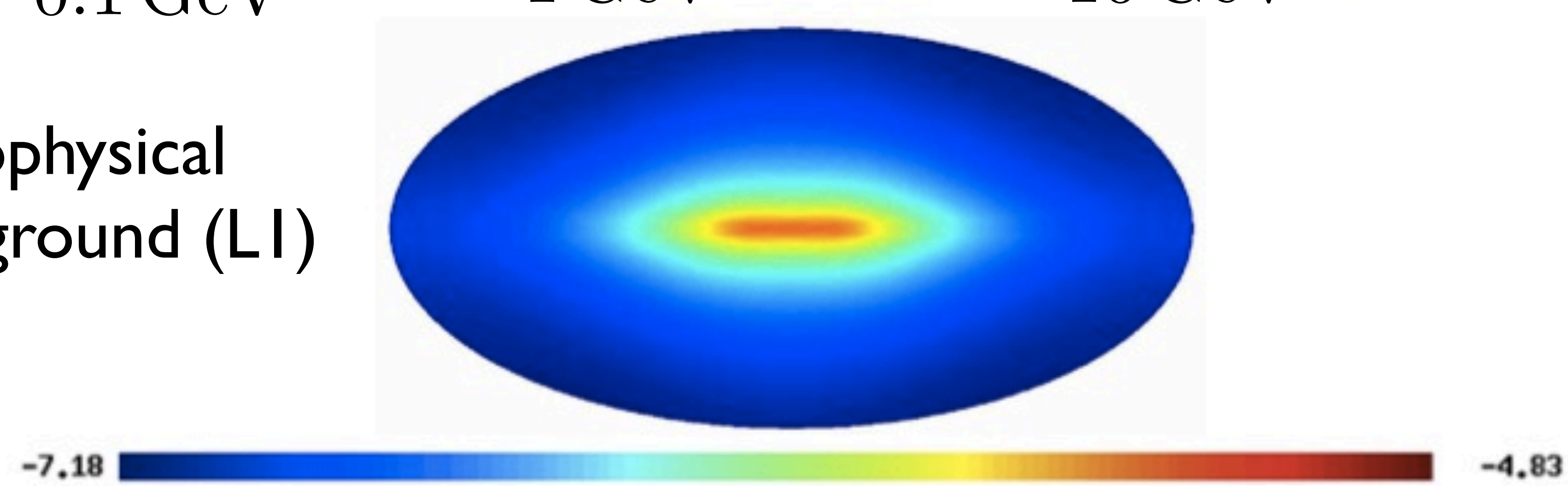


$$J_{\rm ICS}(\hat{\Omega}, E_\gamma; E_e) = \frac{1}{4\pi}\int_{\rm l.o.s.} ds \int_{m_e}^{\infty} dE\, P(E_\gamma, E)\, n_e^{E_0}(\mathbf{r}, E)$$

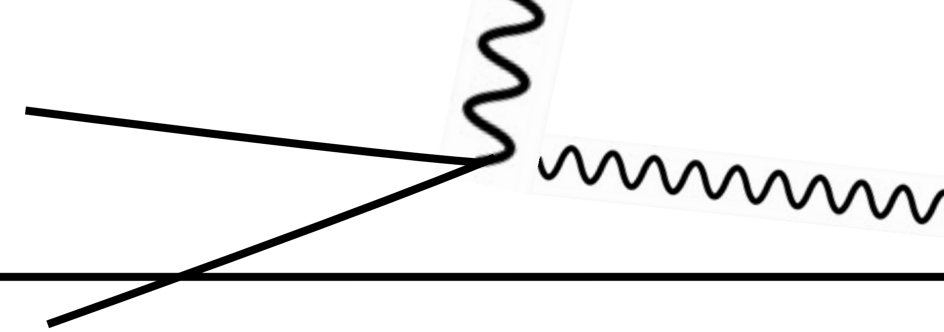
DDM prediction $E_0 = 100 \mathrm{GeV}; \tau = 10^{26}$ s



Astrophysical Background (L1)



Propagation models



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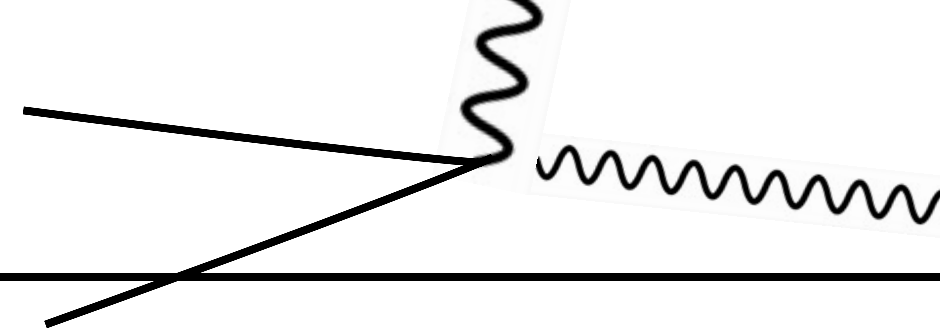
MIN	0.85/0.85	0.048	20	1	13.5	0	22.4	0.1
L1*	0.50/0.50	4.6	20	4	0	0	10	4
MAX	0.46/0.46	2.31	20	15	5	0	117.6	0.1

* Di Bernardo et al [DRAGON] arXiv:0909.4548 [astro-ph.HE]

Very similar to GALPROP DR

- NFW profile only (other profiles up to 30% difference)

Inverse Compton Radiation



Data to compare with:

FERMI 1-year data binned 0.5 -1- 2 - 5 - 10 - 20 - 50 - 100 - 300 GeV.

Dobler et al, arXiv:0910.4583 [astro-ph.HE].

-'Diffuse' even class (background contamination at energies above the 100 GeV)
-No source substraction

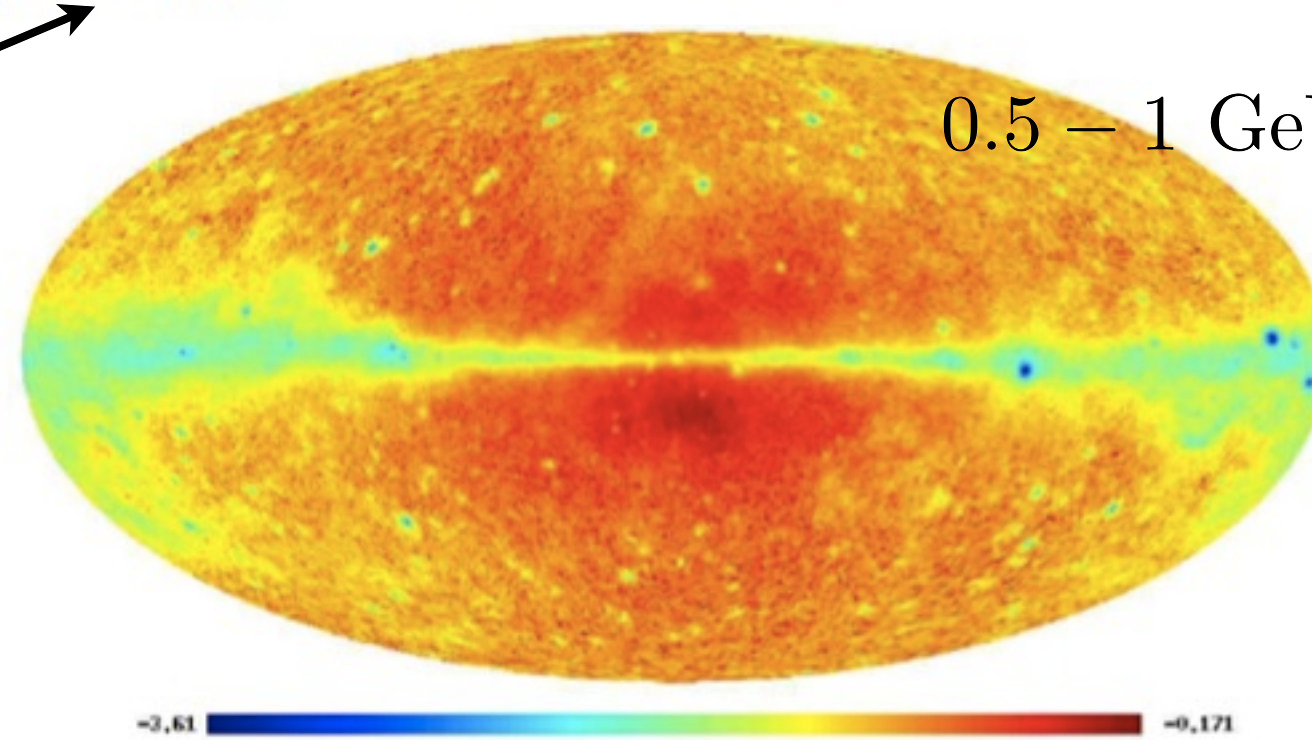
Response Function:

$$F_\gamma^{E_0:E_1}(\Delta\Omega; E_e) \equiv \frac{\int_{E_0}^{E_1} dE_\gamma \int_{\Delta\Omega} d\Omega J_{\rm ICS}(\Omega, E_\gamma; E_e)}{J_{\rm obs}^{E_0:E_1}(\Delta\Omega) + 2\cdot\delta J_{\rm obs}} \left(\frac{\tau_\chi}{10^{26}\,\rm s}\right)\left(\frac{m_\chi}{100\,\rm GeV}\right)$$

Included statistical error

Statistics is low so instead of a direction we can integrate signals in a patch.

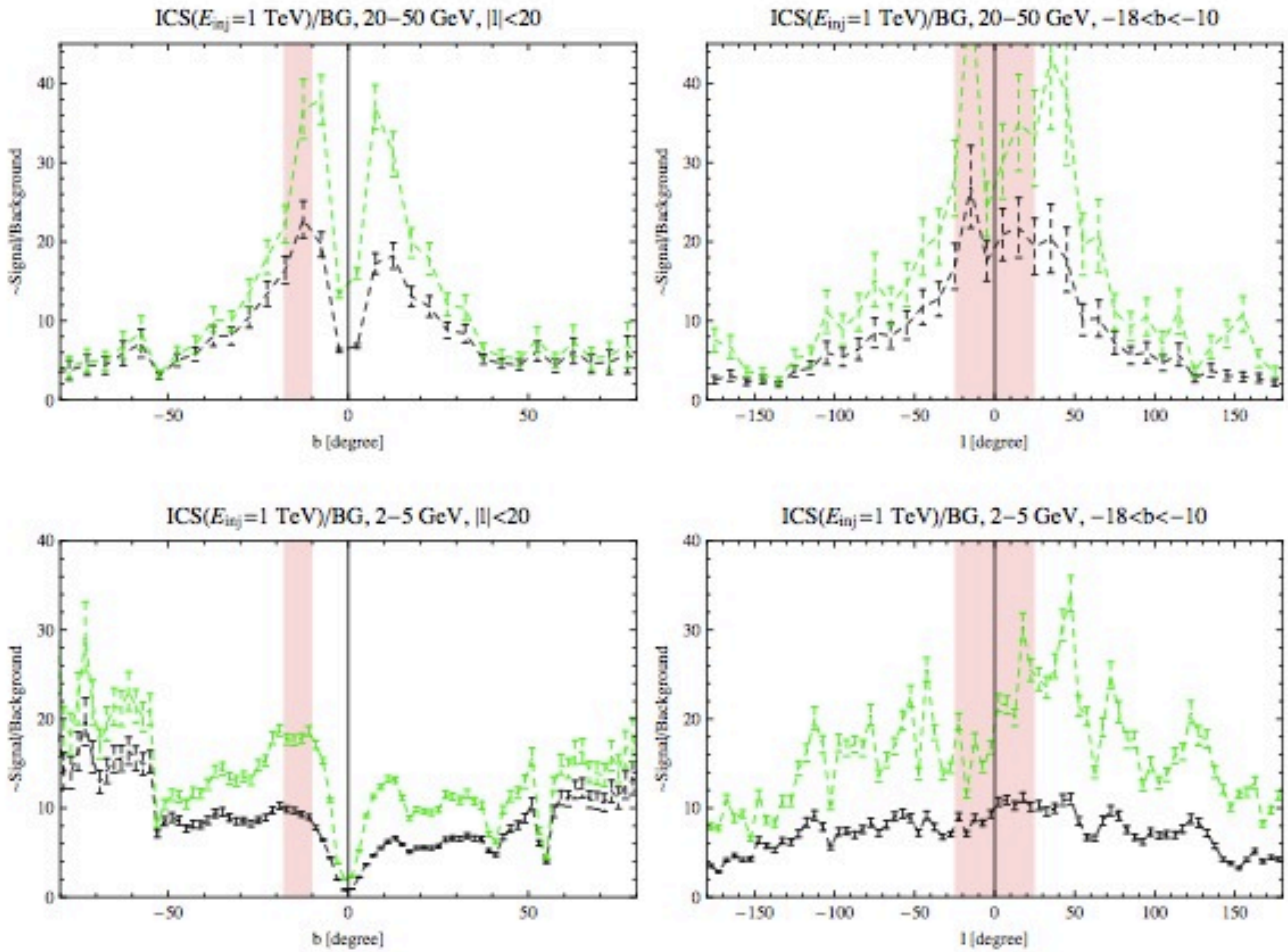
$0.5 - 1$ GeV



$E_0 = 100\text{GeV}; \tau = 10^{26}$ s

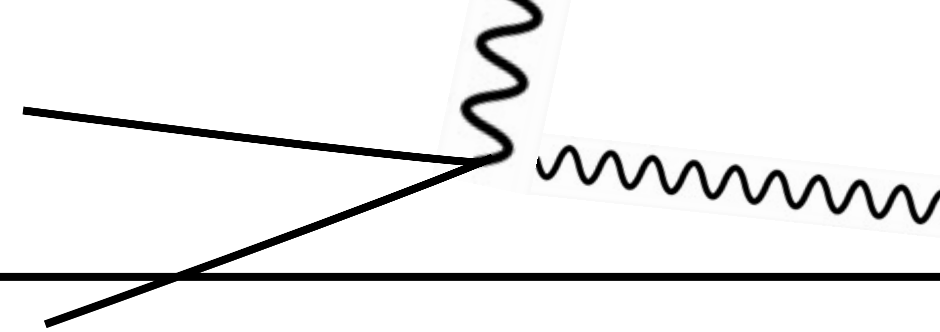
Optimal patch

$|l| \leq 20^\circ$ and $-18^\circ \leq b \leq -10^\circ$

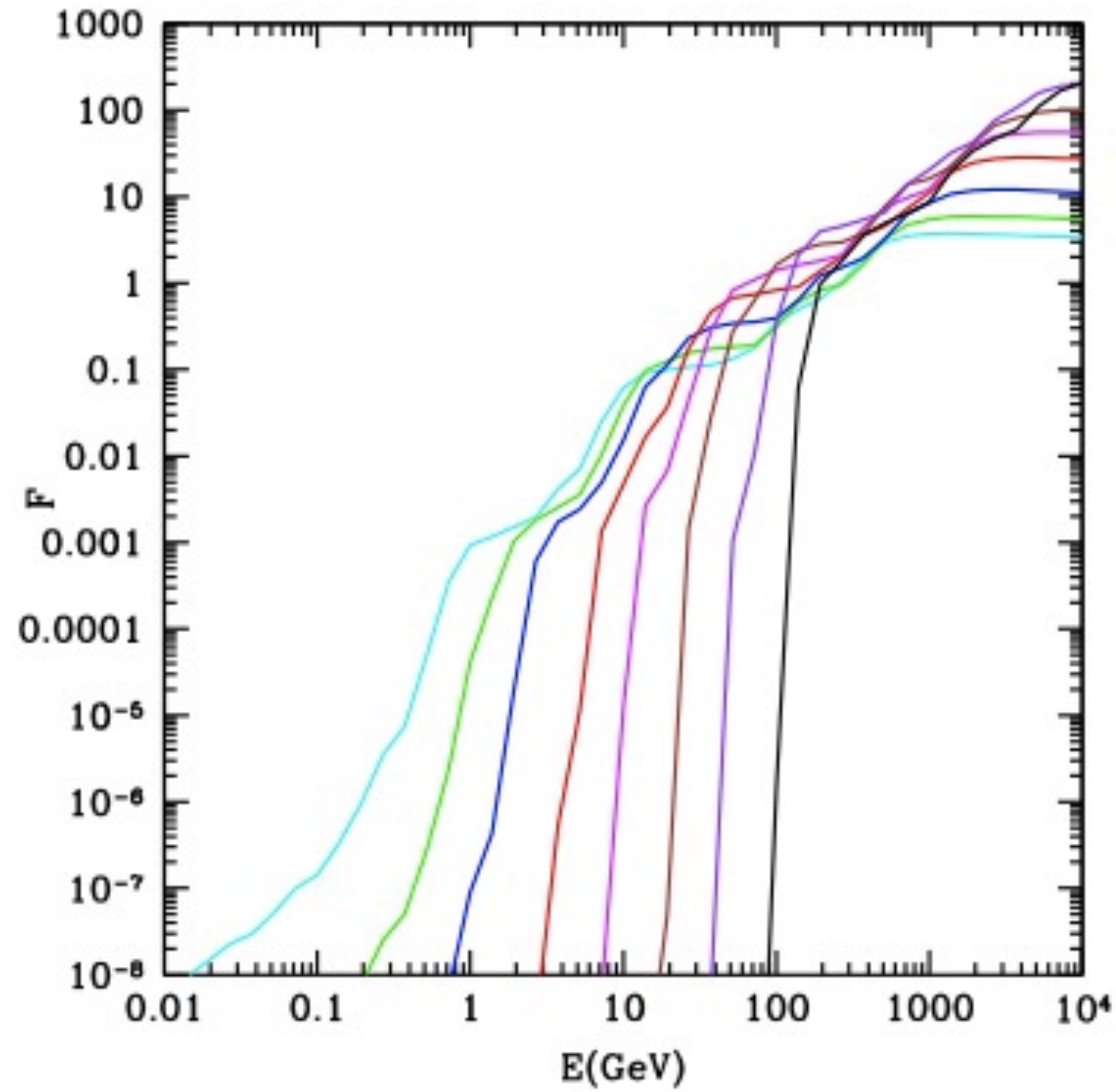


lattitude longitude

Inverse Compton Radiation

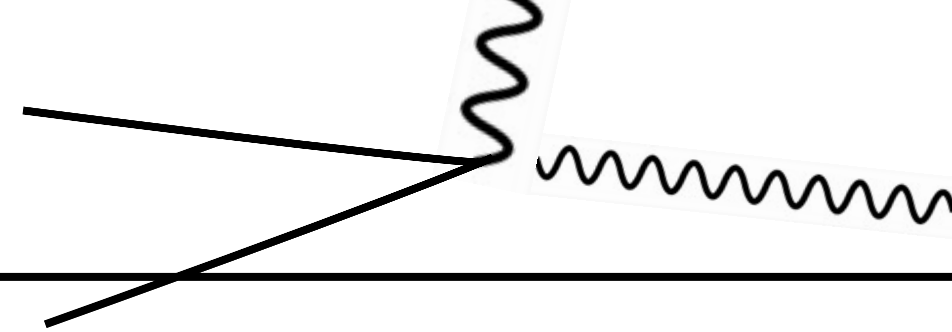


Response Functions (L1)

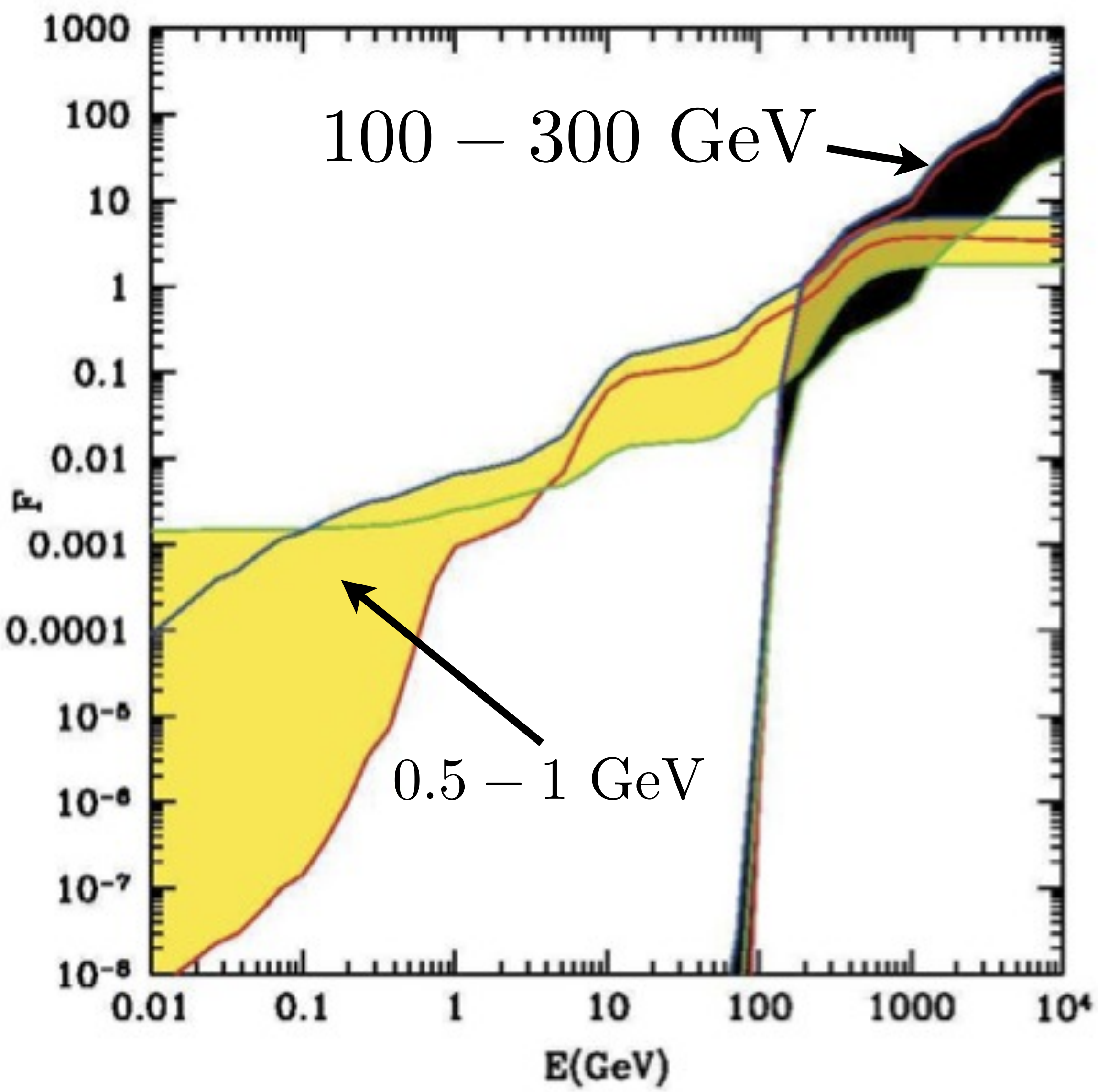


0.5 -1- 2 - 5 - 10 - 20 - 50 - 100 - 300 GeV.

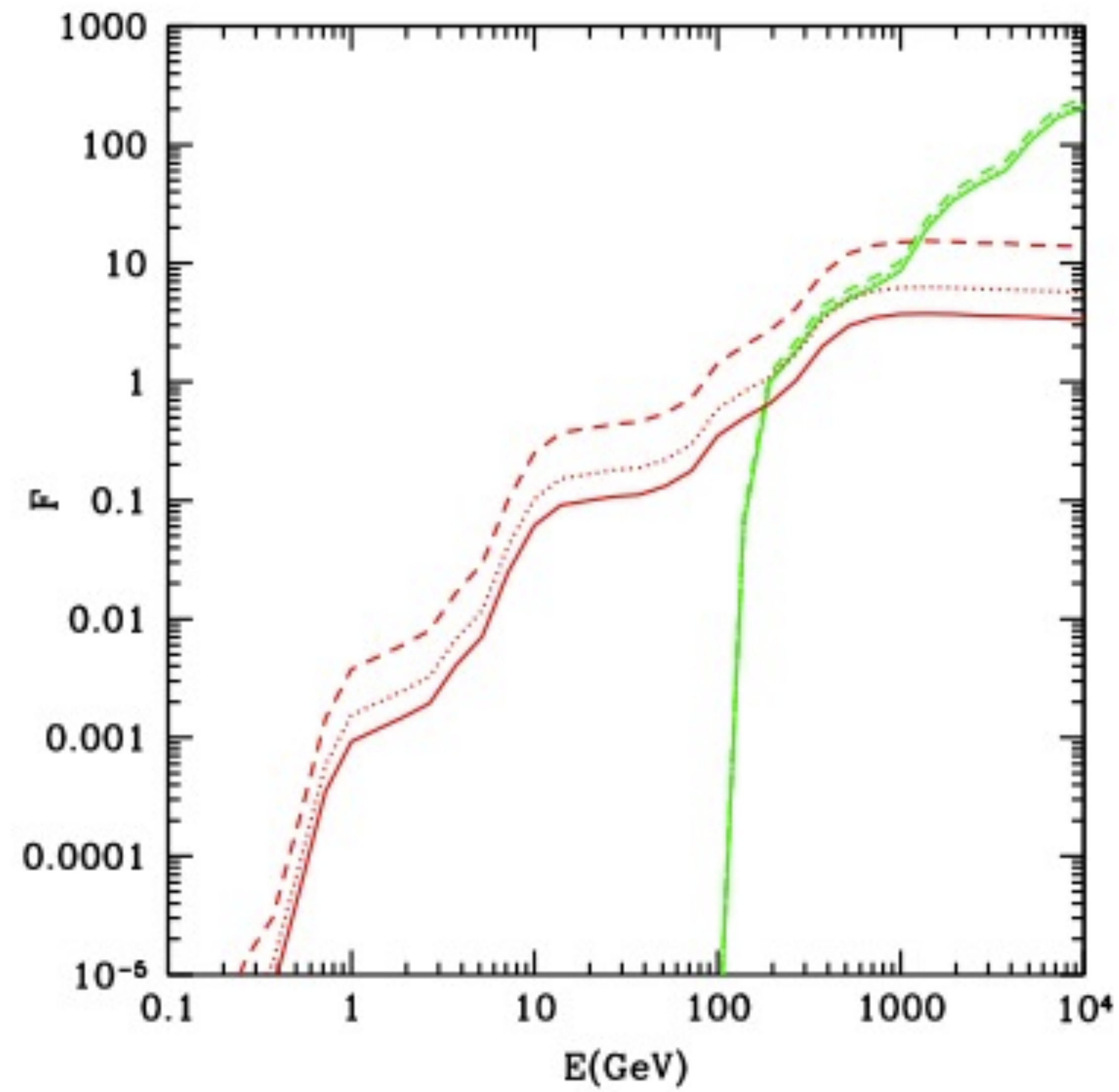
Inverse Compton Radiation



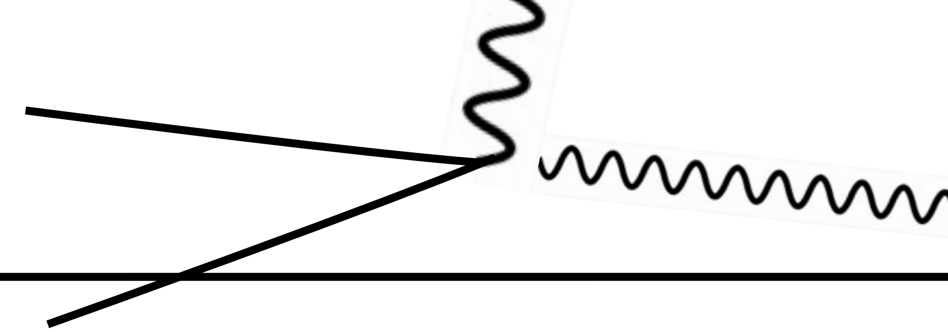
Response Functions
Model dependency on the propagation parameters



Response Functions
Substracted astrophysical foregrounds

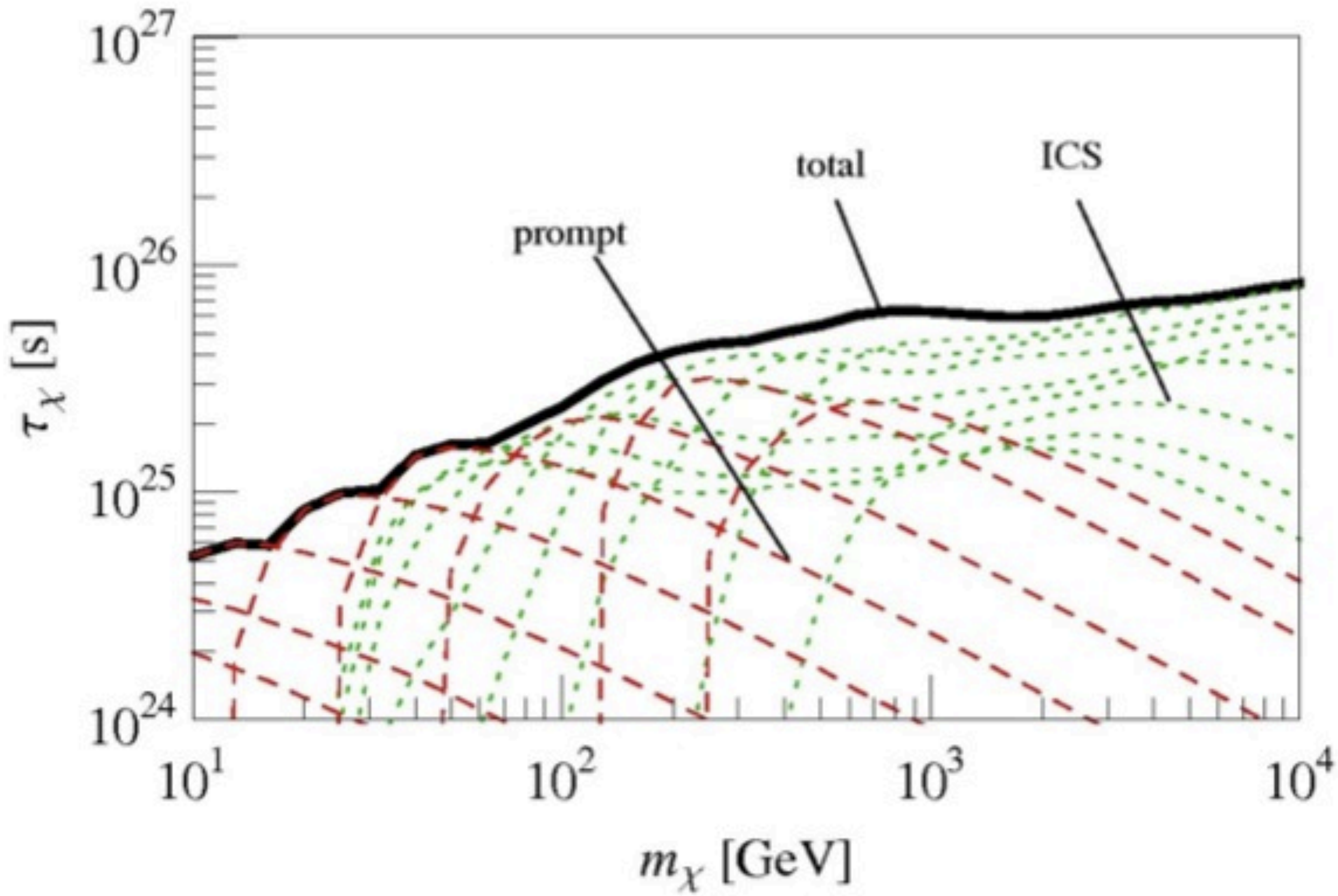


Bounds

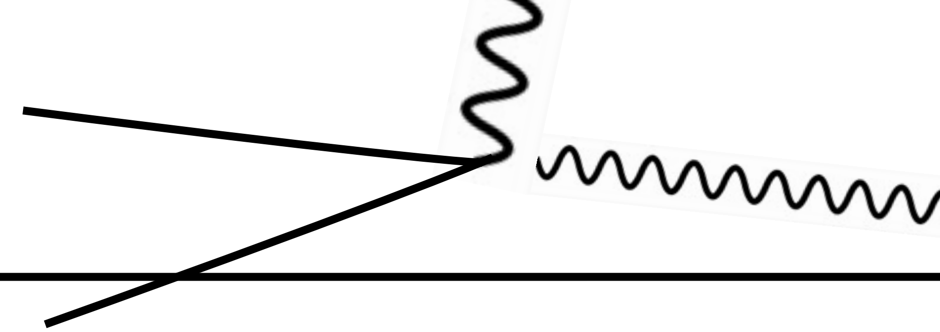


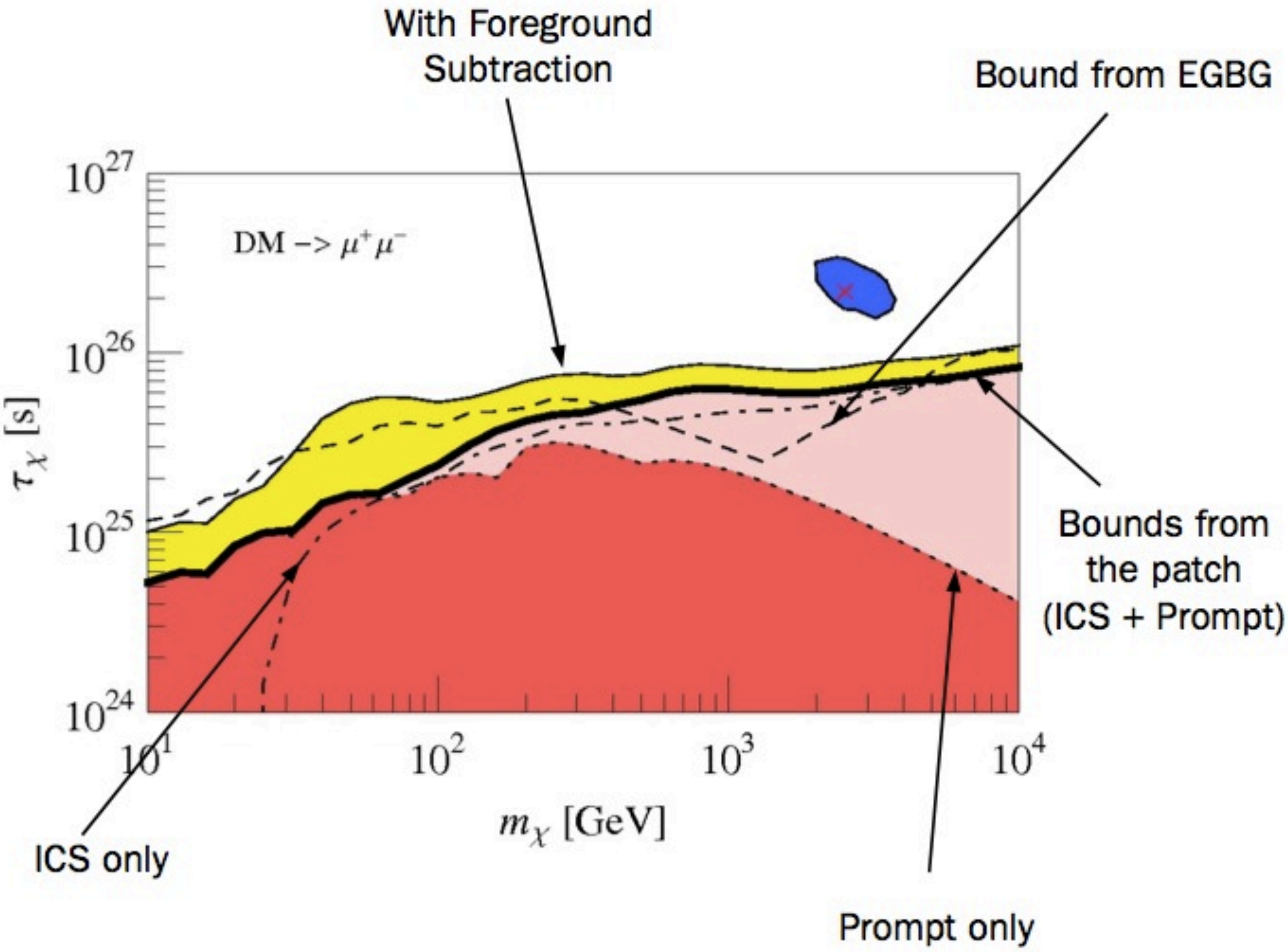
When it comes to bounds to a specific model one has to include prompt radiation as well (by hand)

$$\phi_{\rm dm} \rightarrow \mu^+ \mu^-$$

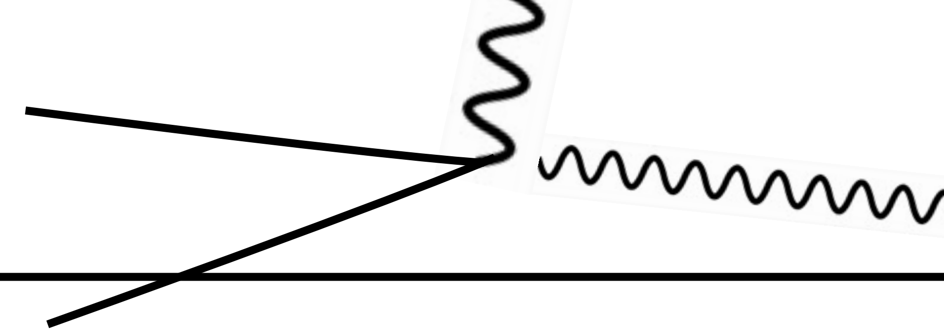


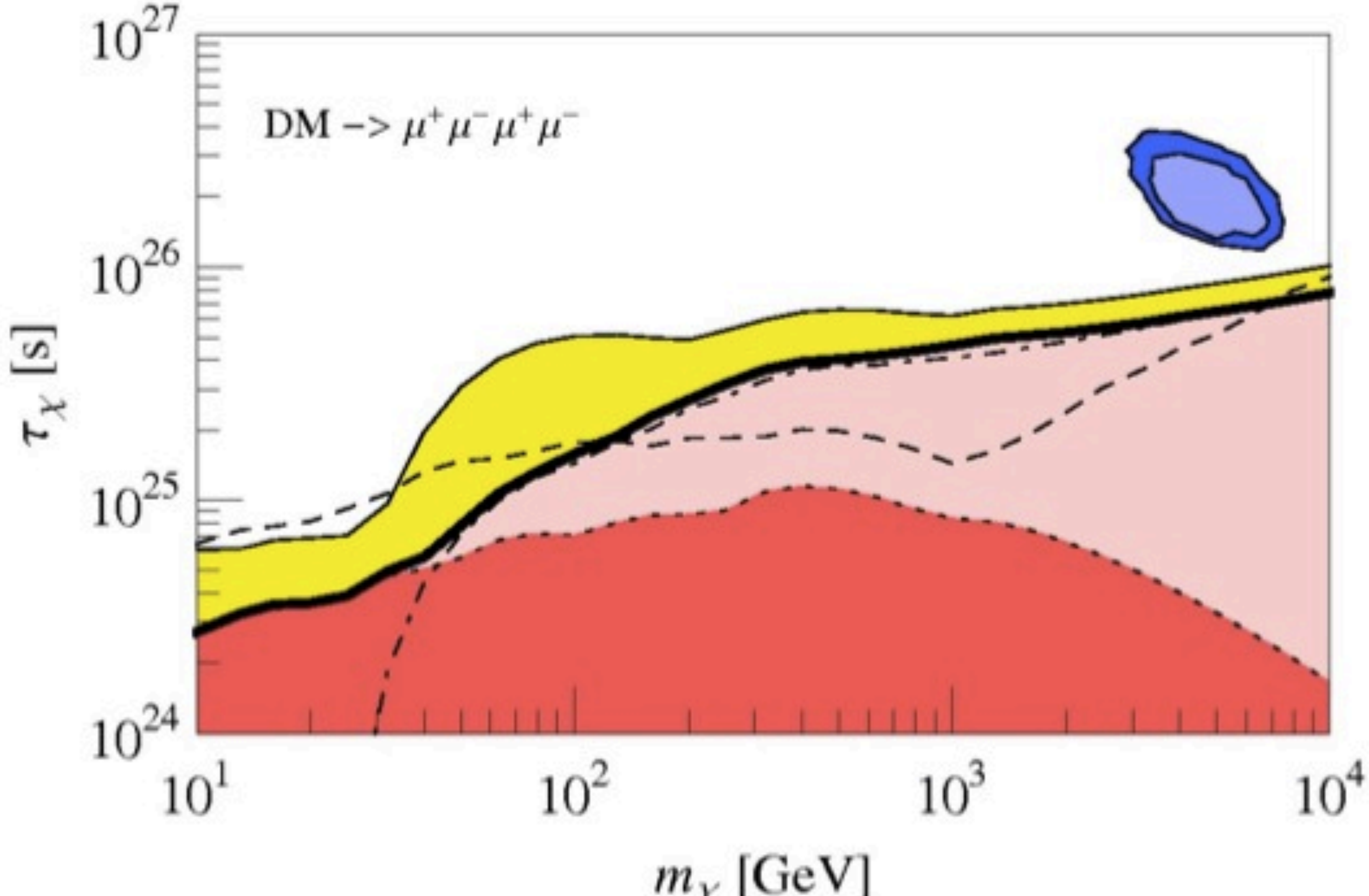
Bounds $\Phi \to \mu^+\mu^-$



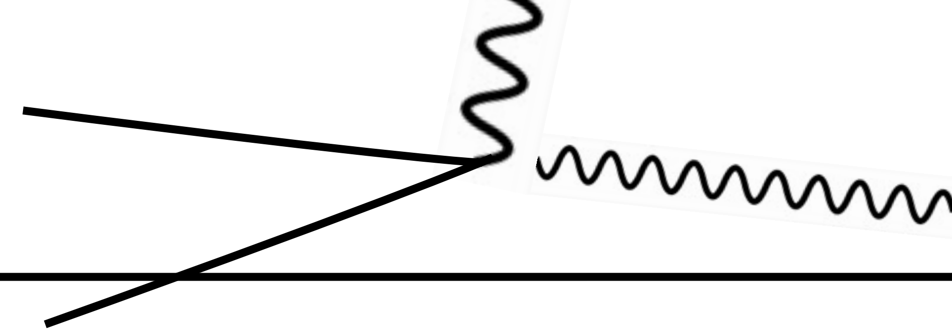


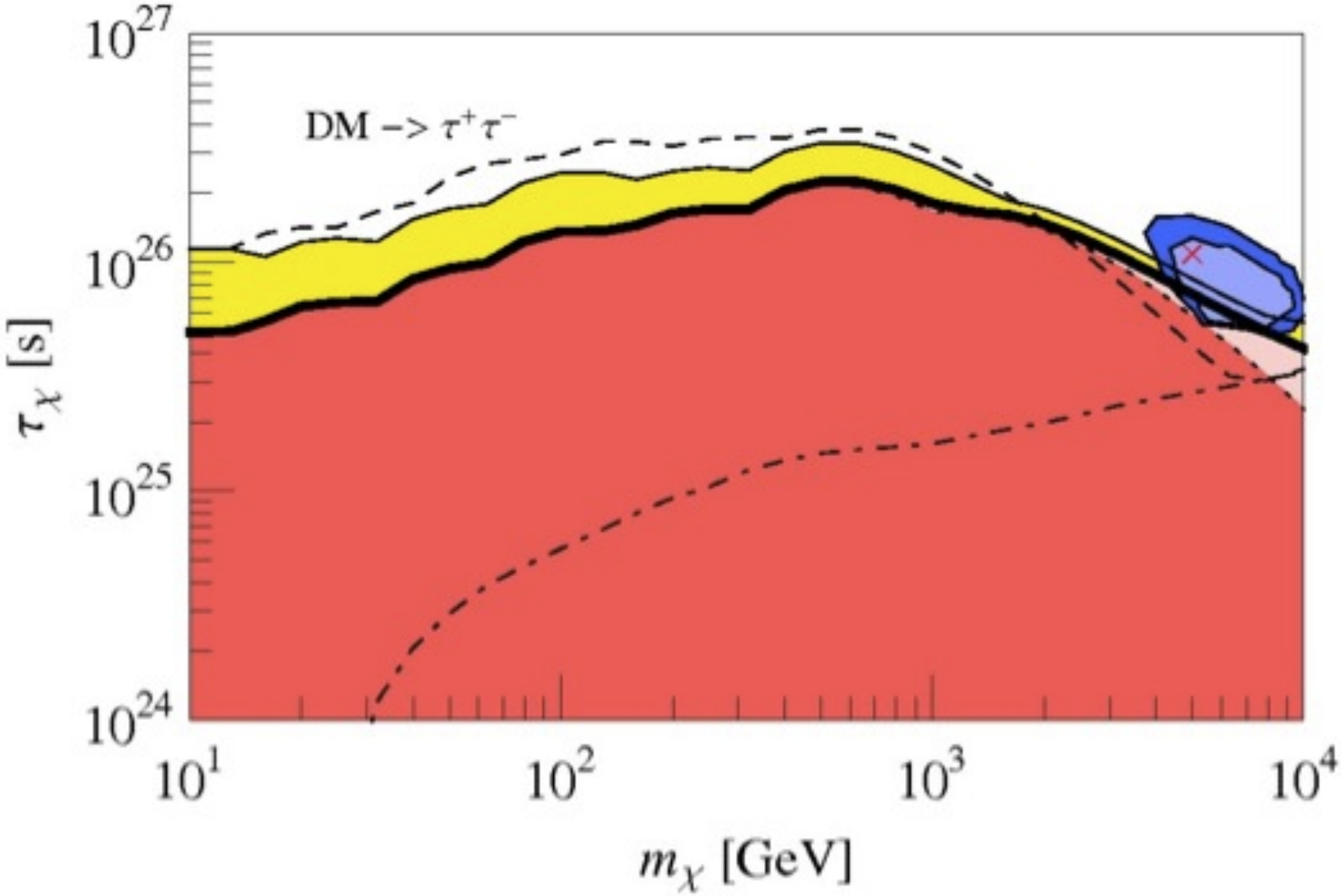
Bounds $\Phi \to \mu^+\mu^-\mu^+\mu^-$





Bounds $\Phi \to \tau^+\tau^-$





Conclusions

-we cannot rule out completely the DDM explanation of PAMELA, in some too simplistic scenarios (except maybe through common sense).

-we have provided a very easy way to test your DDM models against the observed positron/radio and gamma ray fluxes.

‘Convolution of electron/positron spectrum with very simple ‘Response Functions’ smaller than 1’

-In the future, much more developed CR propagation models can exist, and much more reliable response functions can be computed by astrophysicists, even with substraction of safe astrophysical foregrounds
(to then be used by lazy and conservative physicist like me)