27 or 30 september 2010
COSMO 2010 - Tokyo

Gamma ray and cosmological **constraints on DM** with large annihilation cross section

Marco Cirelli

(CERN-TH & CNRS IPhT Saclay)

in collaboration with:
A.Strumia (Pisa)
N.Fornengo (Torino)
M.Tamburini (Pisa)
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M.Raidal (Tallin)
M.Kadastik (Tallin)
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C.Bräuninger (Saclay)
P.Panci (Saclay)
F.Iocco (Saclay + IAP Paris)
P.Serpico (CERN)

0808.3867 [astro-ph]
Nuclear Physics B 813 (2009)
JCAP 03 009 (2009)
Physics Letters B 678 (2009)
Nuclear Physics B 821 (2009)
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0912.0663
and work in progress

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Gamma ray and cosmological constraints on DM

Why large annihilation cross section ?

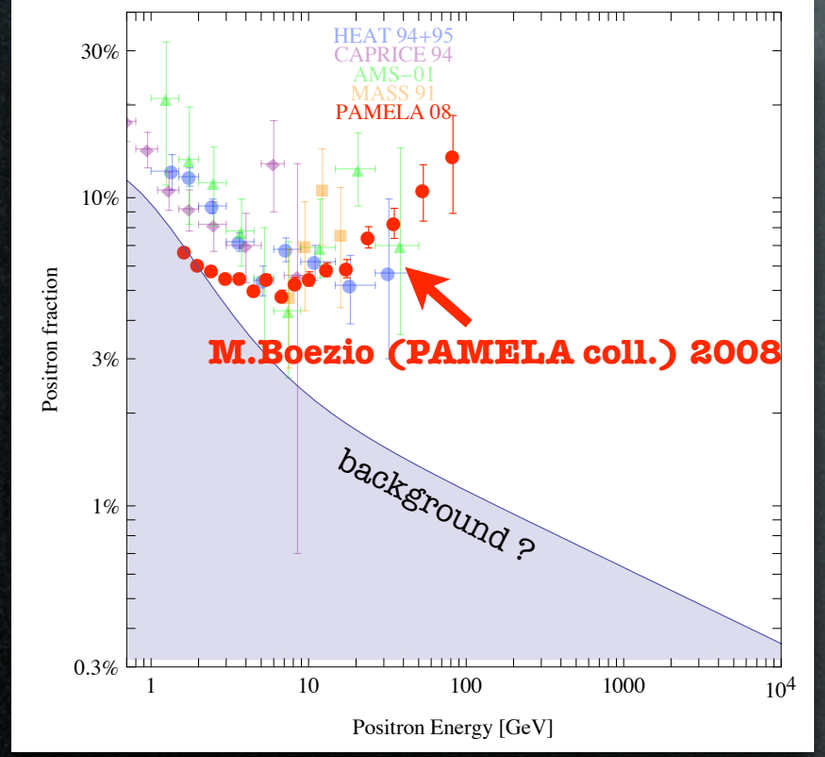
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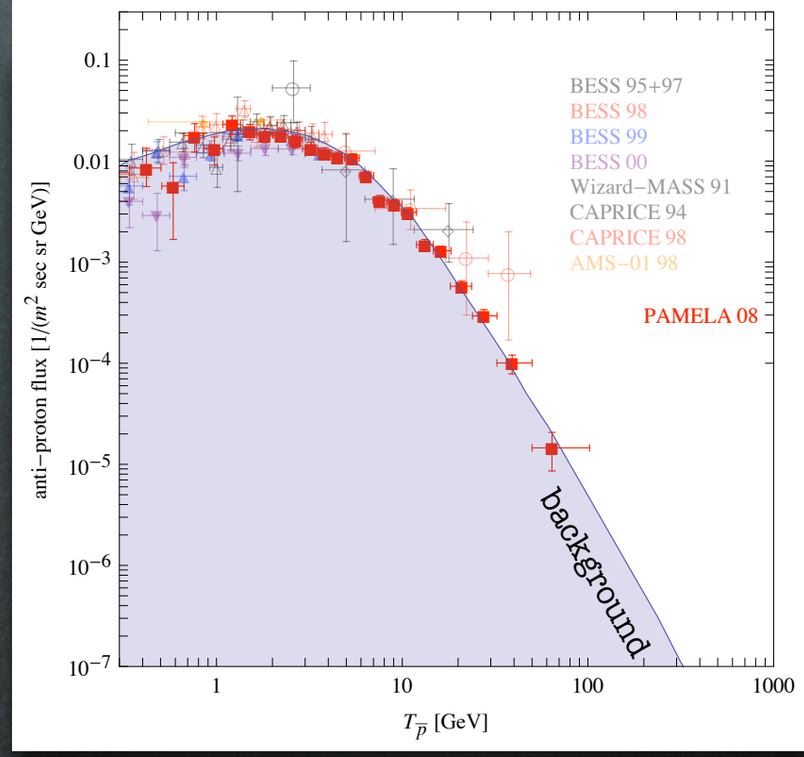
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Data

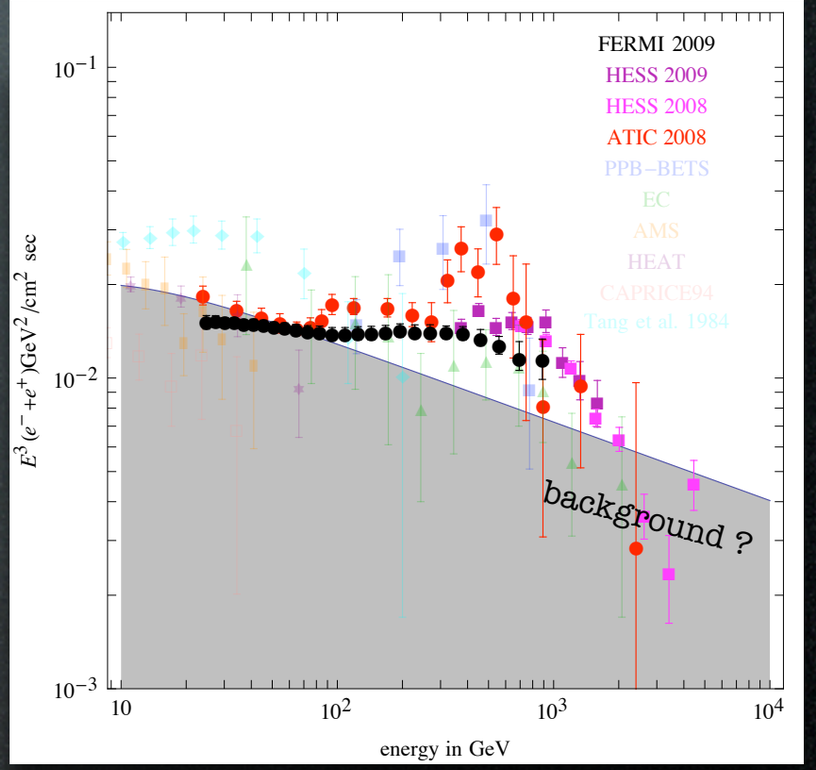
positron fraction



antiprotons



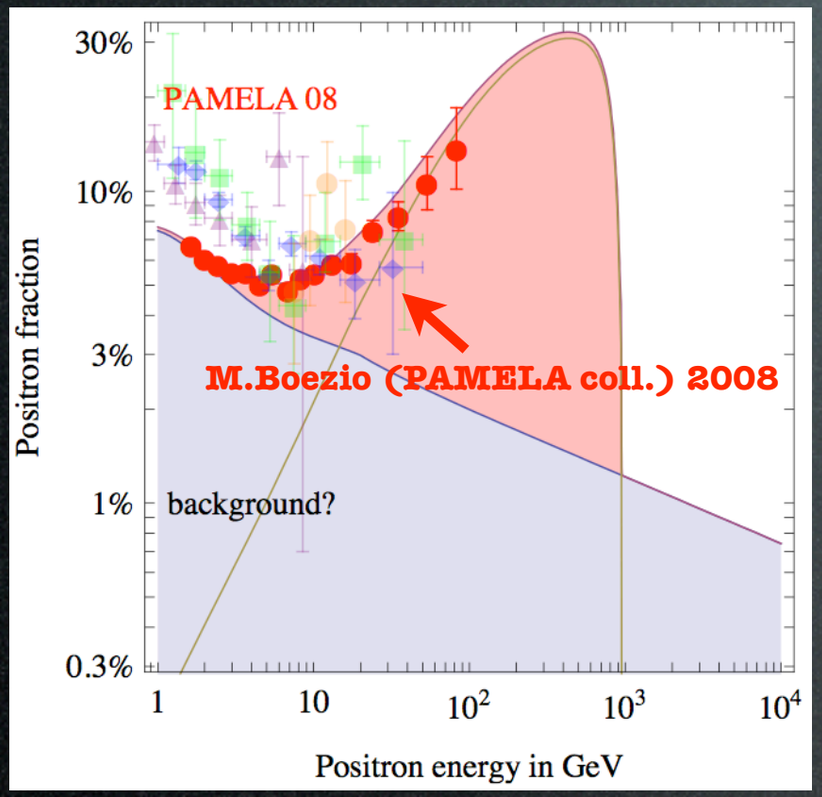
electrons + positrons



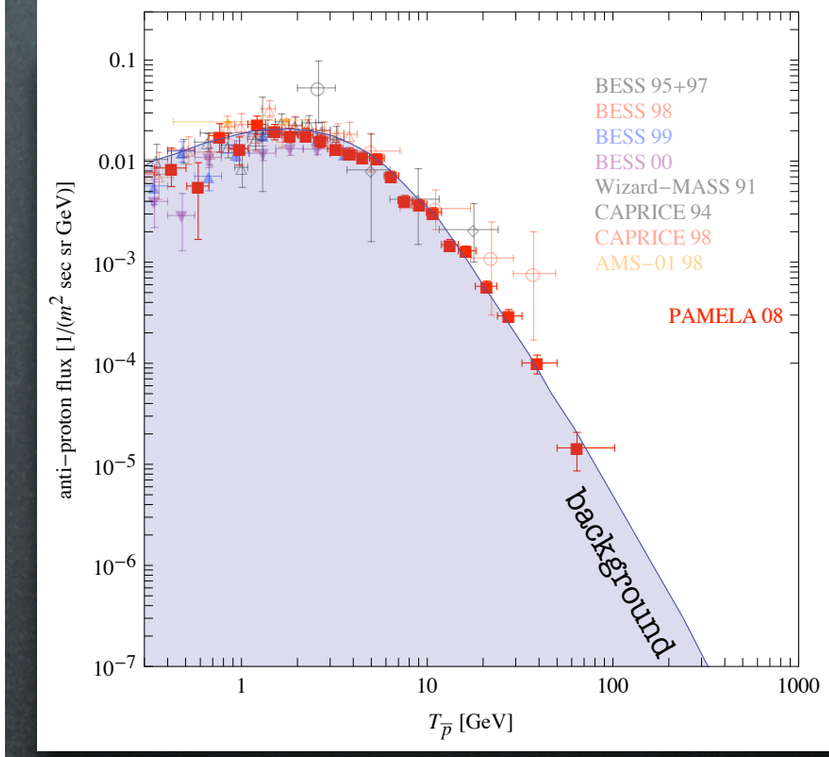
Are these signals of Dark Matter?

Data

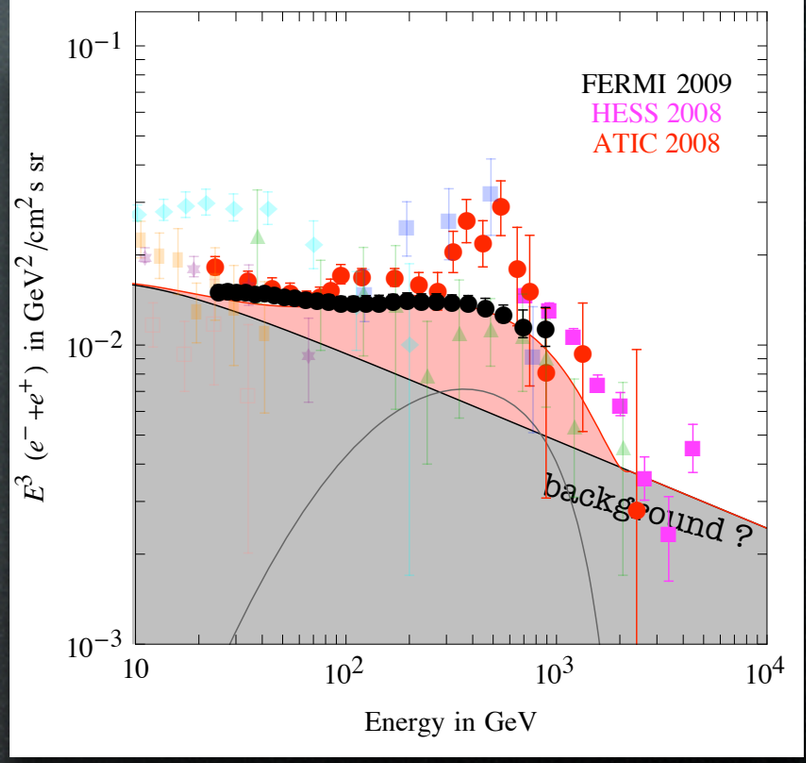
positron fraction



antiprotons



electrons + positrons

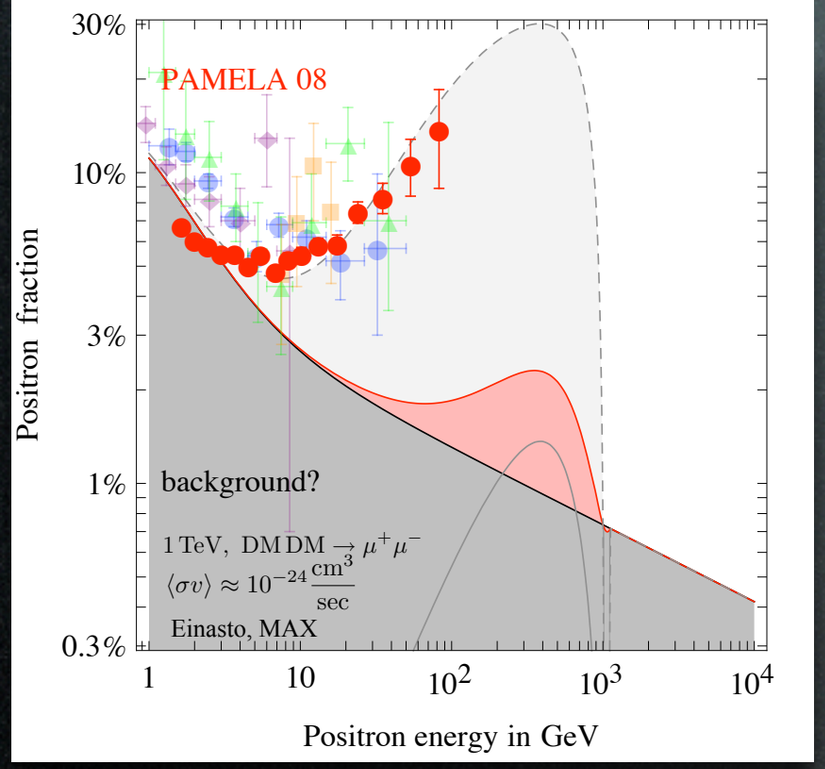


Are these signals of Dark Matter?

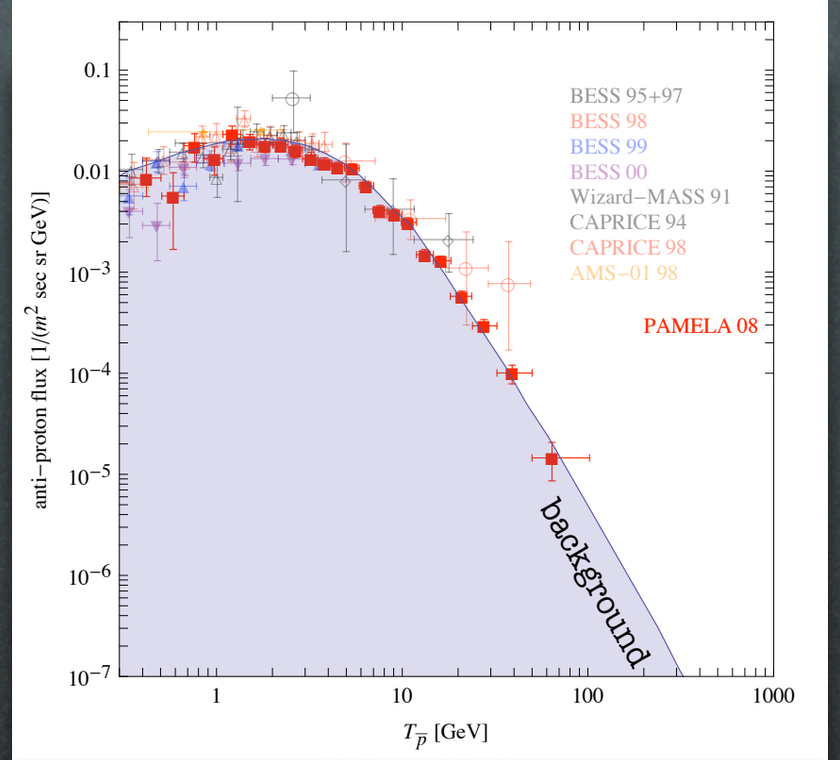
YES: few TeV, leptophilic DM
with huge $\langle \sigma v \rangle \approx 10^{-23}\,\mathrm{cm}^3/\mathrm{sec}$

Data

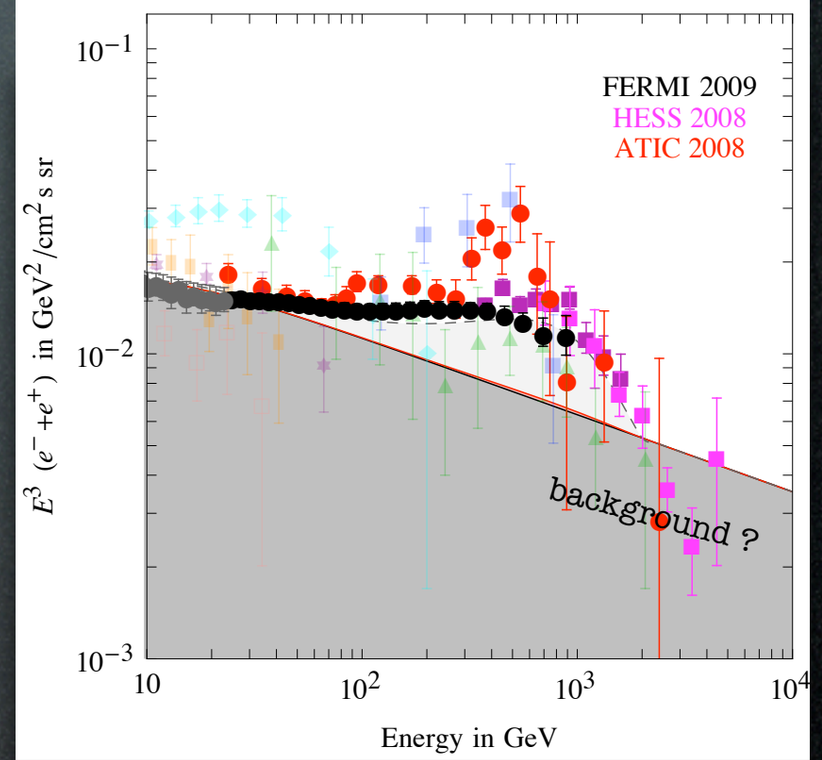
positron fraction



antiprotons



electrons + positrons



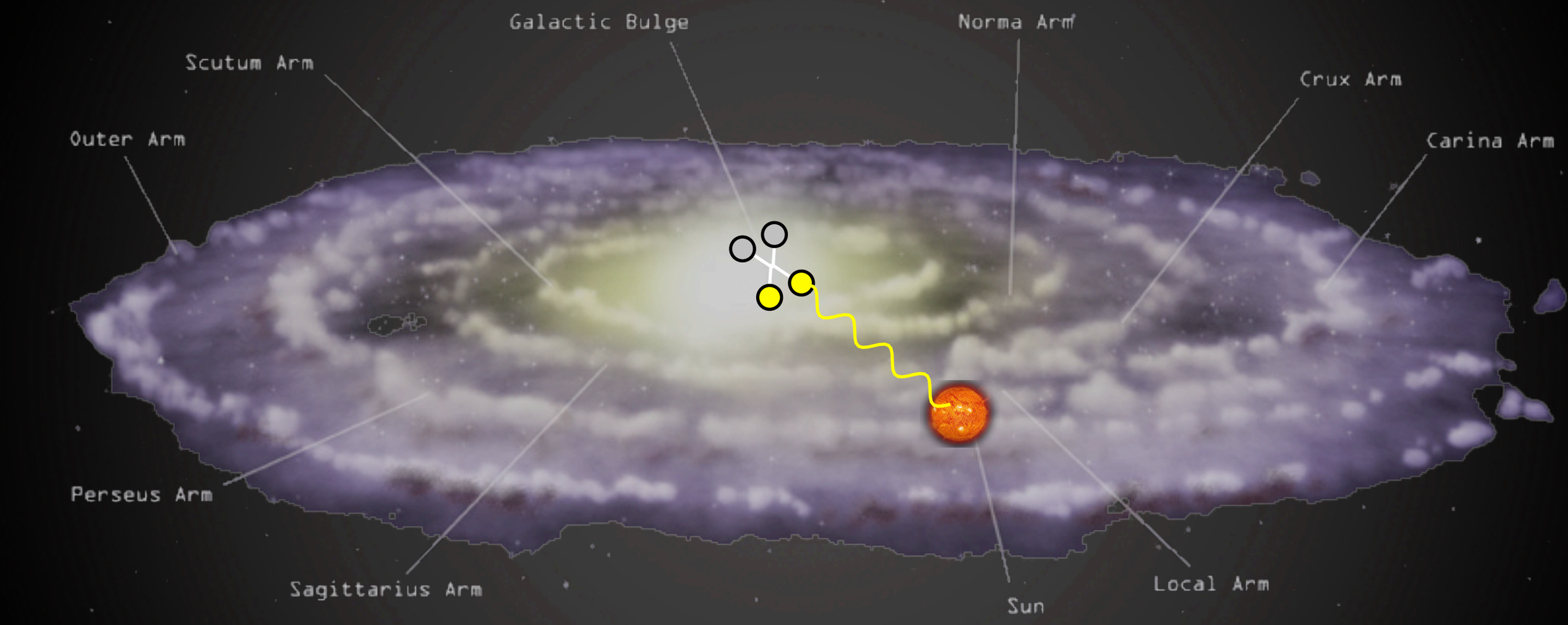
Are these signals of Dark Matter?

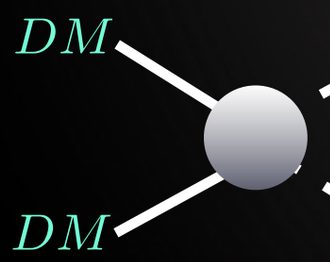
YES: few TeV, leptophilic DM
with huge $\langle\sigma v\rangle \approx 10^{-23}\,\text{cm}^3/\text{sec}$

NO: a formidable 'background' for future searches

Indirect Detection

γ from DM annihilations in galactic center



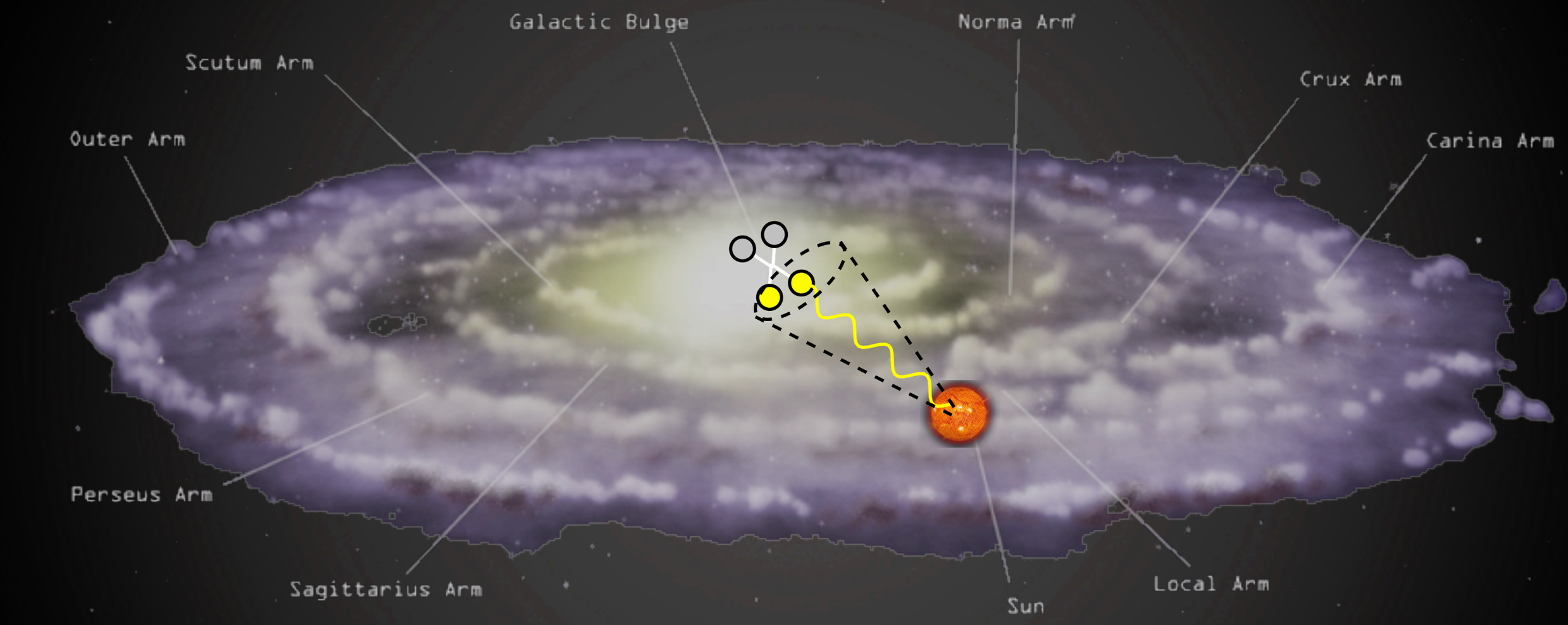


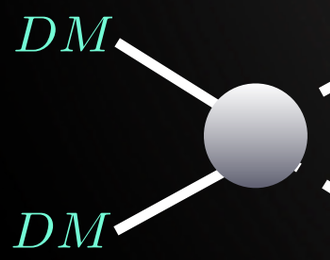
$$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^{\mp}, \overset{(-)}{p}, \overset{(-)}{D} \ldots \text{ and } \gamma$$

$$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^{\pm}, \overset{(-)}{p}, \overset{(-)}{D} \ldots \text{ and } \gamma$$

Indirect Detection

γ from DM annihilations in galactic center



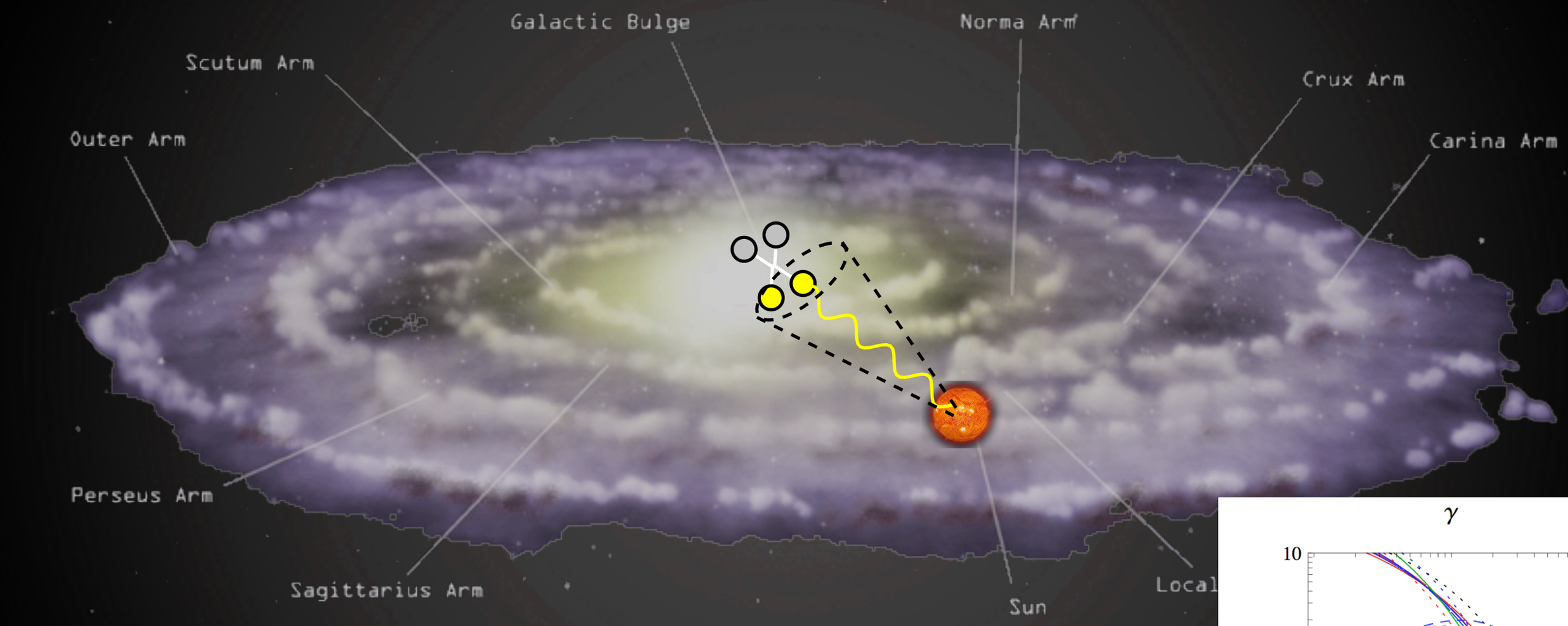


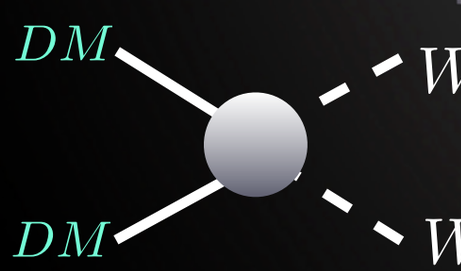
$$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^{\mp},\ \overset{(-)}{p},\ \overset{(-)}{D}\ \ldots \text{ and } \gamma$$

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Indirect Detection

γ from DM annihilations in galactic center

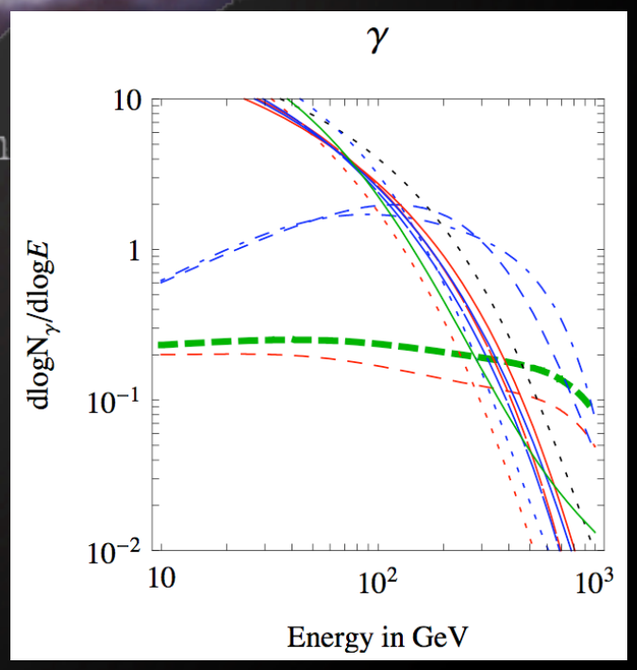




$$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^{\mp},\ \overset{(-)}{p},\ \overset{(-)}{D}\ \ldots \text{ and } \gamma$$

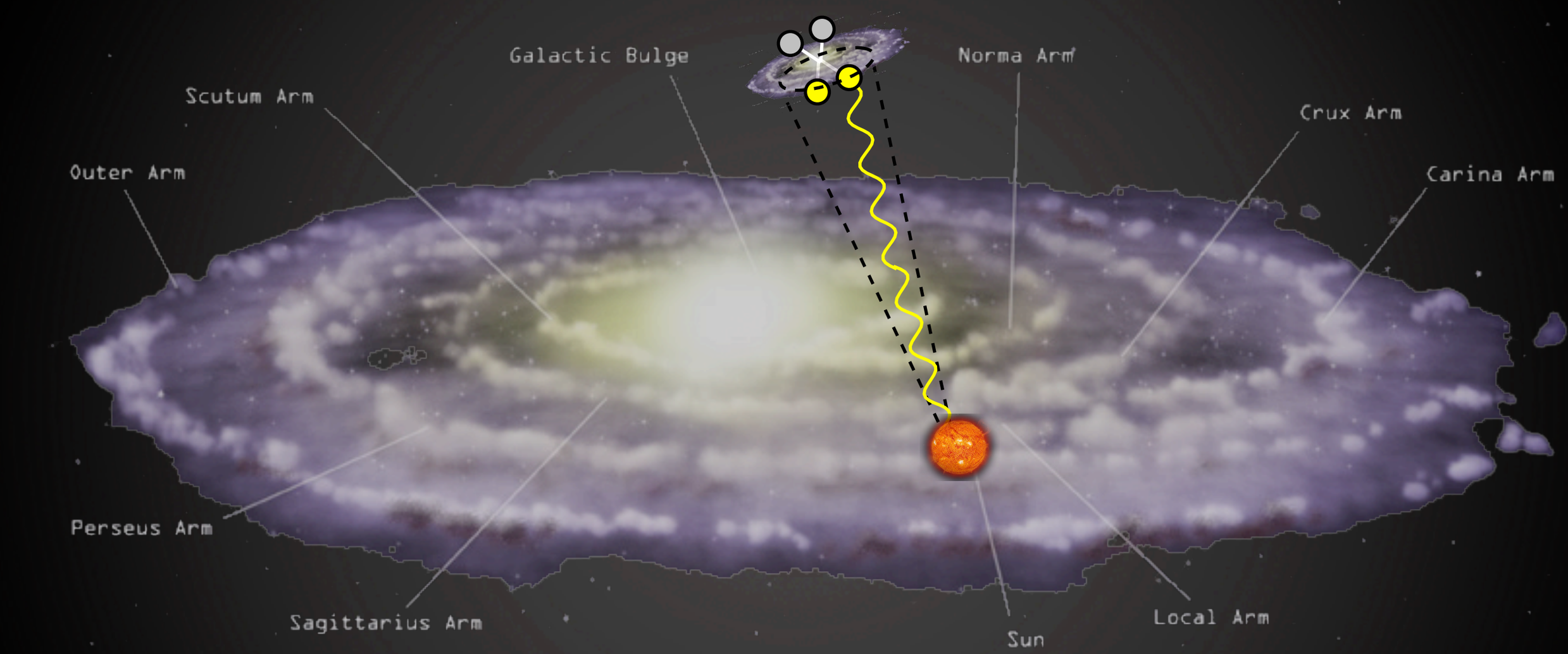
$$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^{\pm},\ \overset{(-)}{p},\ \overset{(-)}{D}\ \ldots \text{ and } \gamma$$

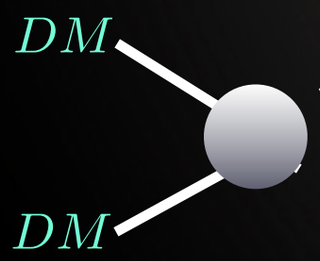
typically sub-TeV energies



Indirect Detection

γ from DM annihilations in Sagittarius Dwarf



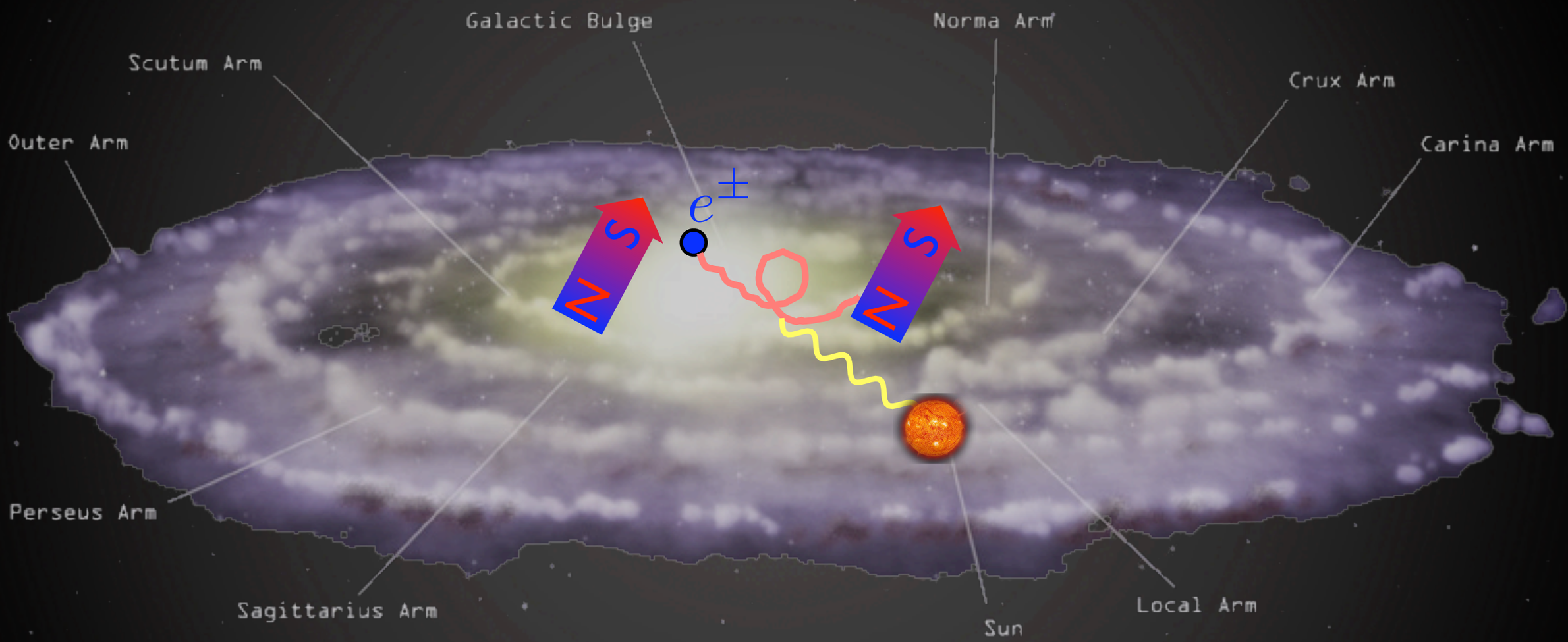


$$W^-, Z, b, \tau^-, t, h \ldots \rightsquigarrow e^{\mp}, \overset{(-)}{p}, \overset{(-)}{D} \ \ldots \ \text{and} \ \gamma$$

$$W^+, Z, \bar{b}, \tau^+, \bar{t}, h \ldots \rightsquigarrow e^{\pm}, \overset{(-)}{p}, \overset{(-)}{D} \ \ldots \ \text{and} \ \gamma$$

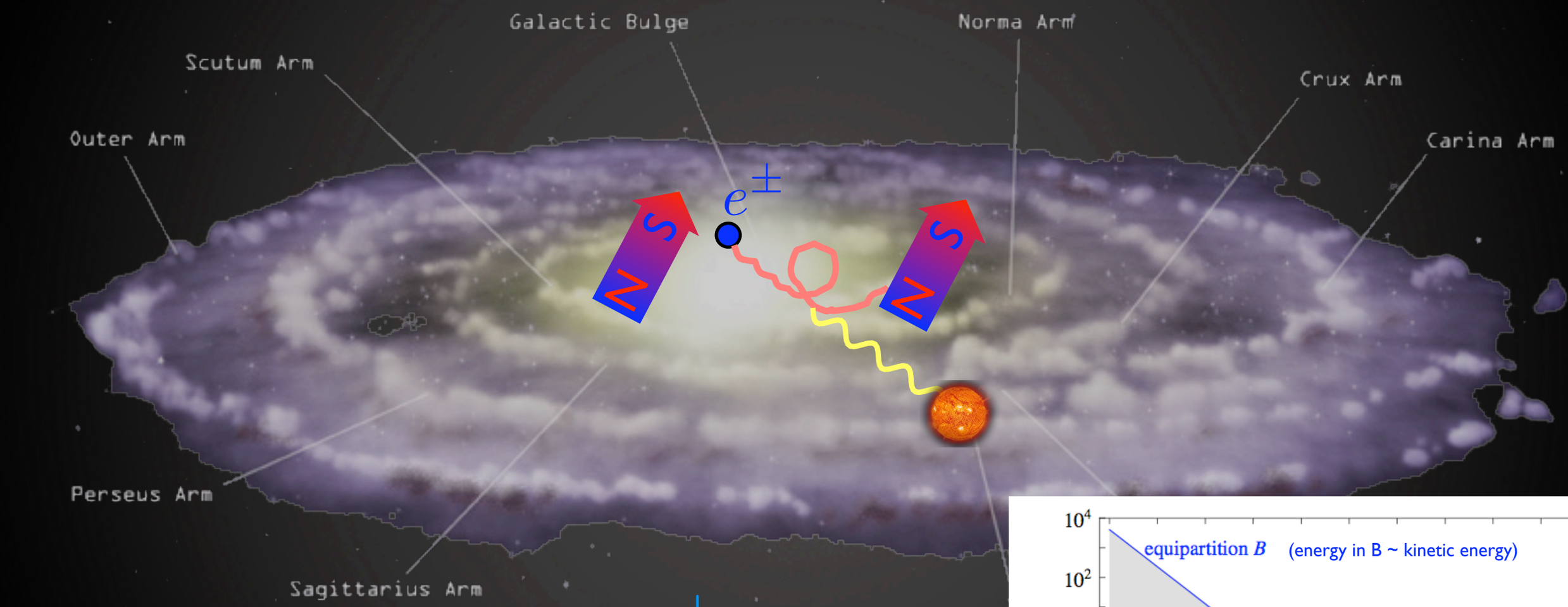
Indirect Detection

radio-waves from synchrotron radiation of $e^{\pm}$ in GC



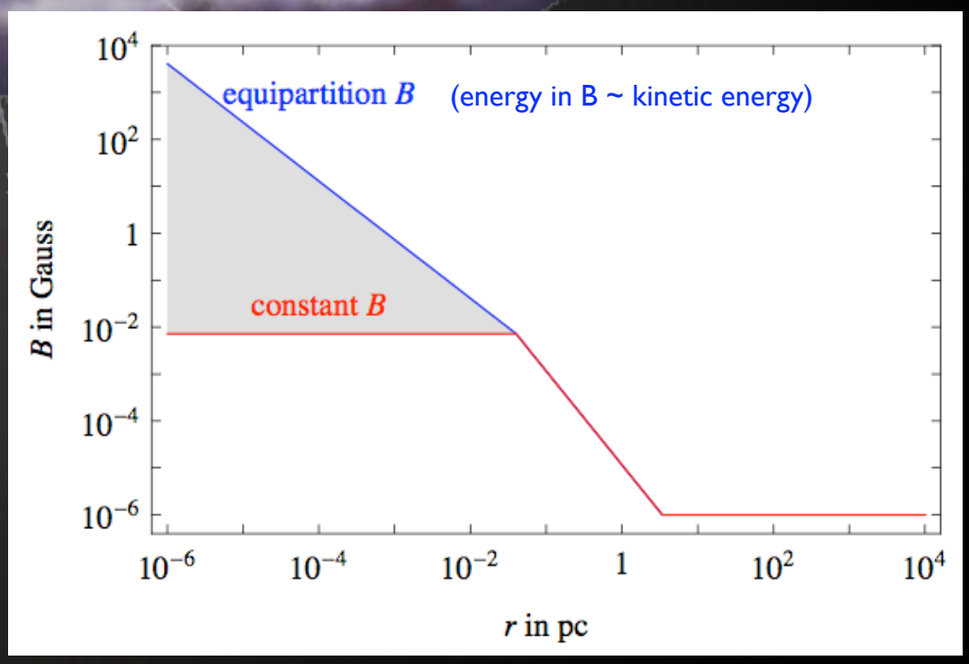
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radio-waves from synchrotron radiation of $e^{\pm}$ in GC



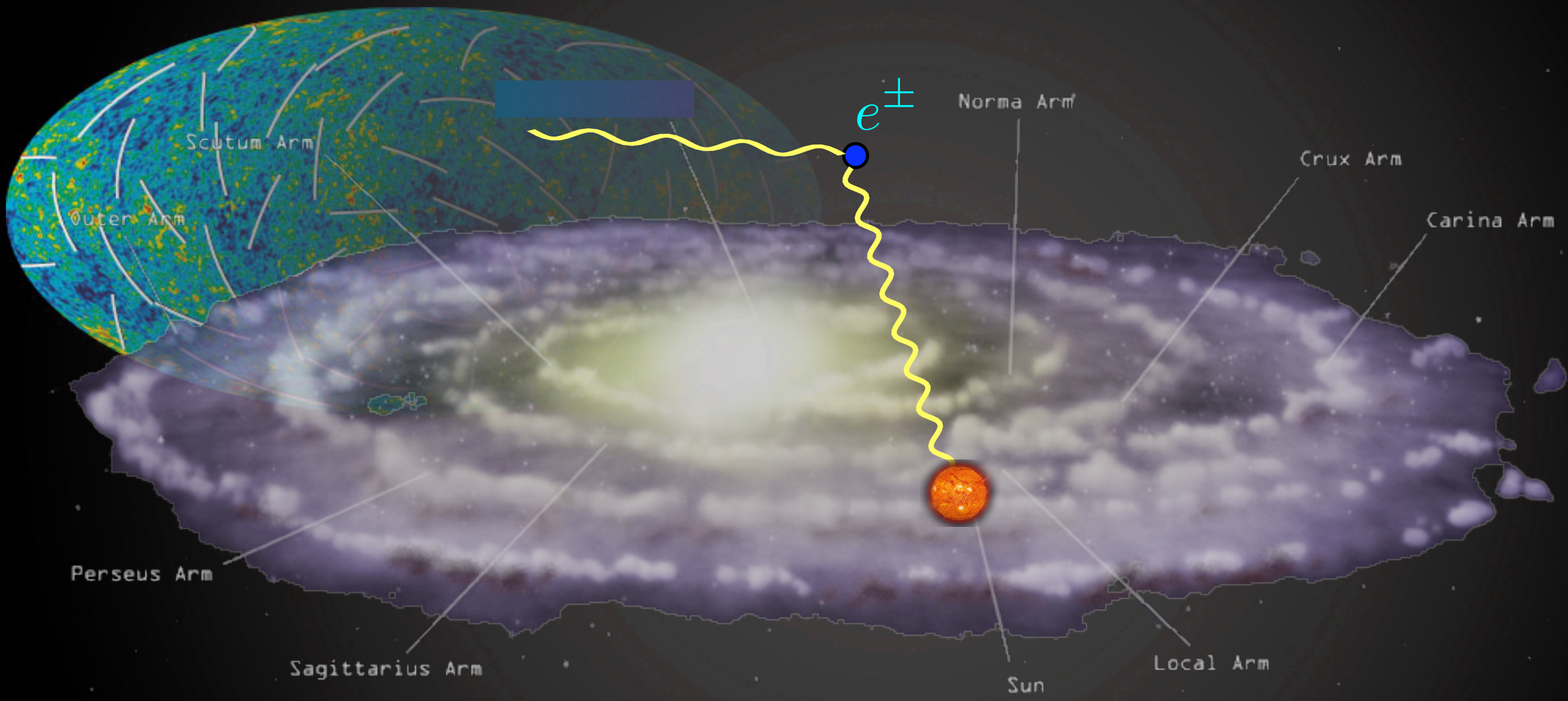
- compute the population of $e^{\pm}$ from DM annihilations in the GC
- compute the synchrotron emitted power for different configurations of galactic $\vec{B}$

(assuming 'scrambled' B; in principle, directionality could focus emission, lift bounds by O(some))



Indirect Detection

γ from Inverse Compton on $e^{\pm}$ in halo

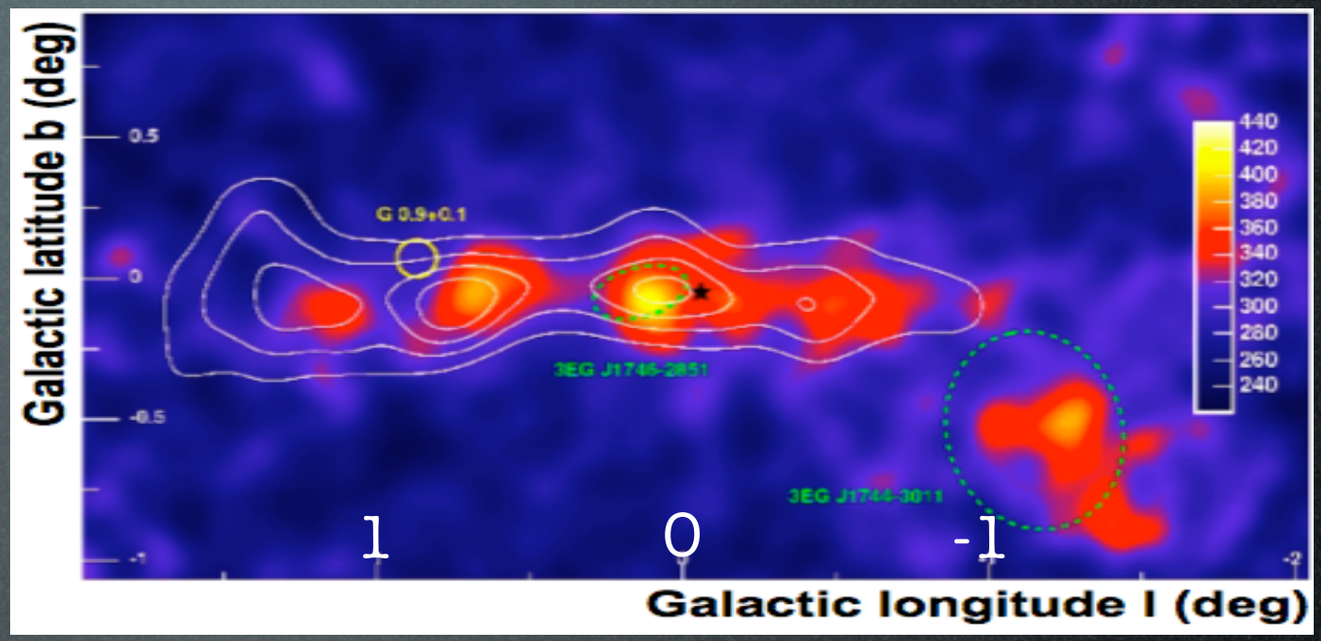


- upscatter of CMB, infrared and starlight photons on energetic $e^{\pm}$
- probes regions outside of Galactic Center

Comparing with data

Gamma constraints

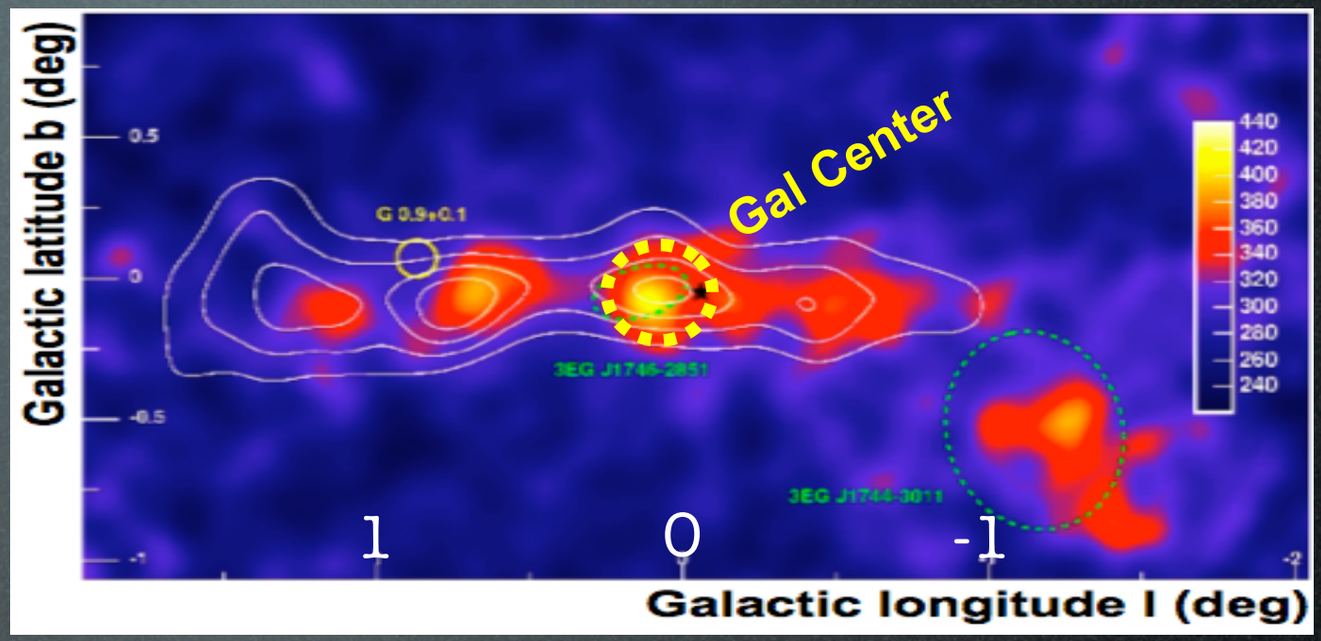
HESS has detected γ-ray emission from Gal Center and Gal Ridge. The DM signal must not excede that.



HESS coll.

Gamma constraints

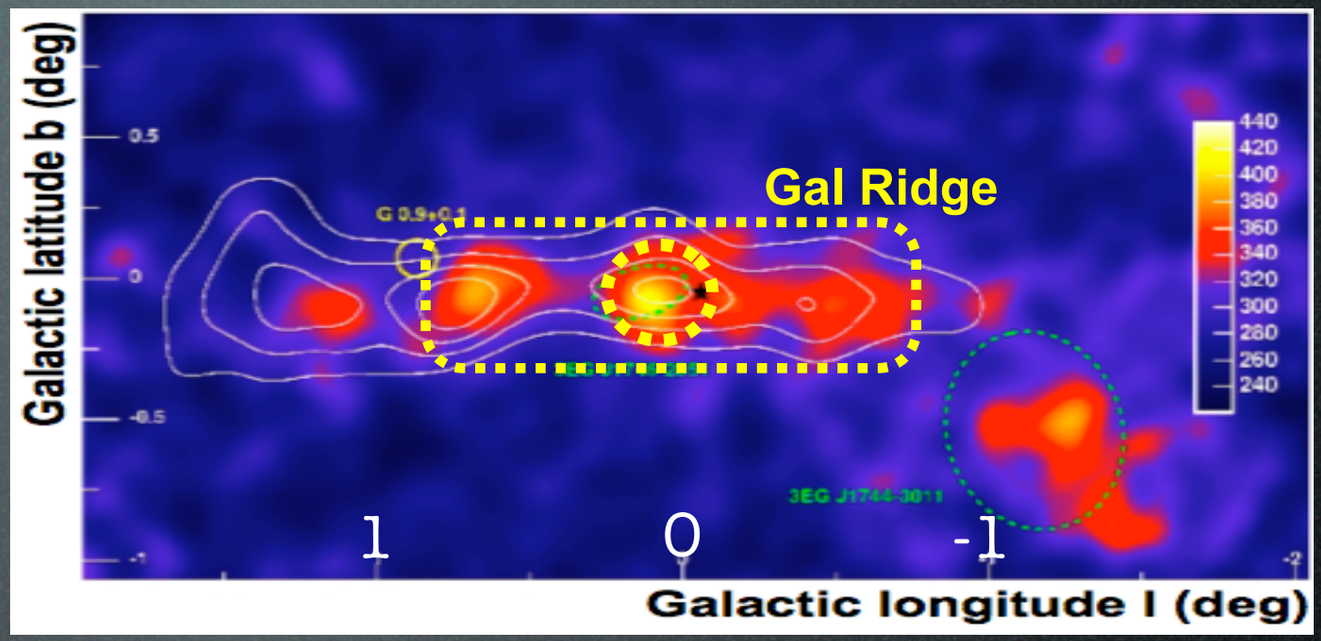
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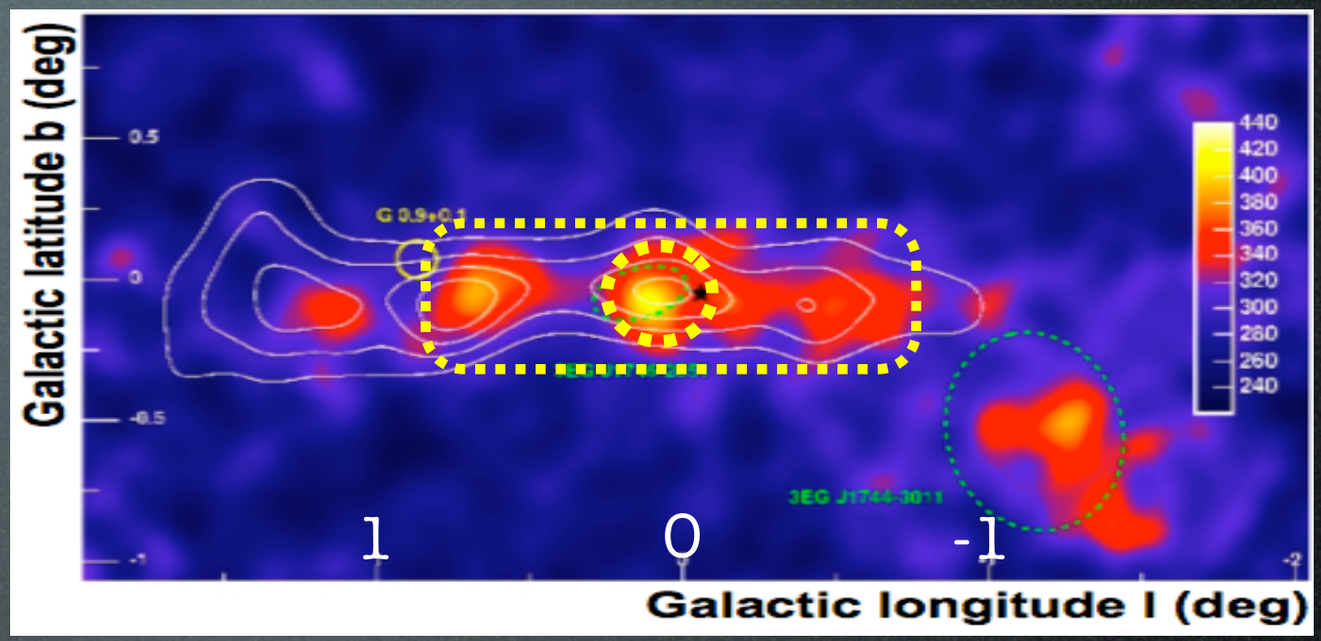
Gamma constraints

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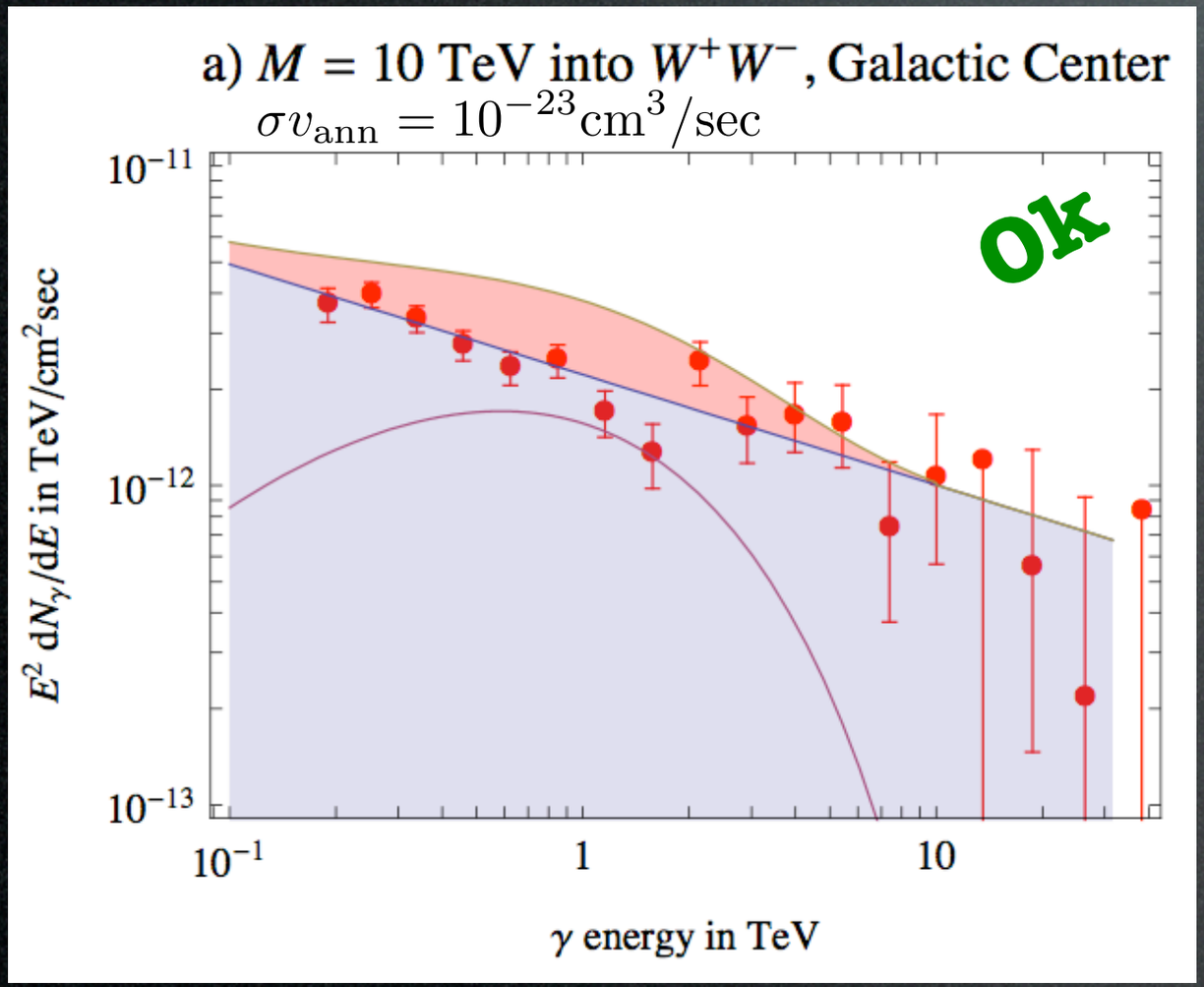


Gamma constraints

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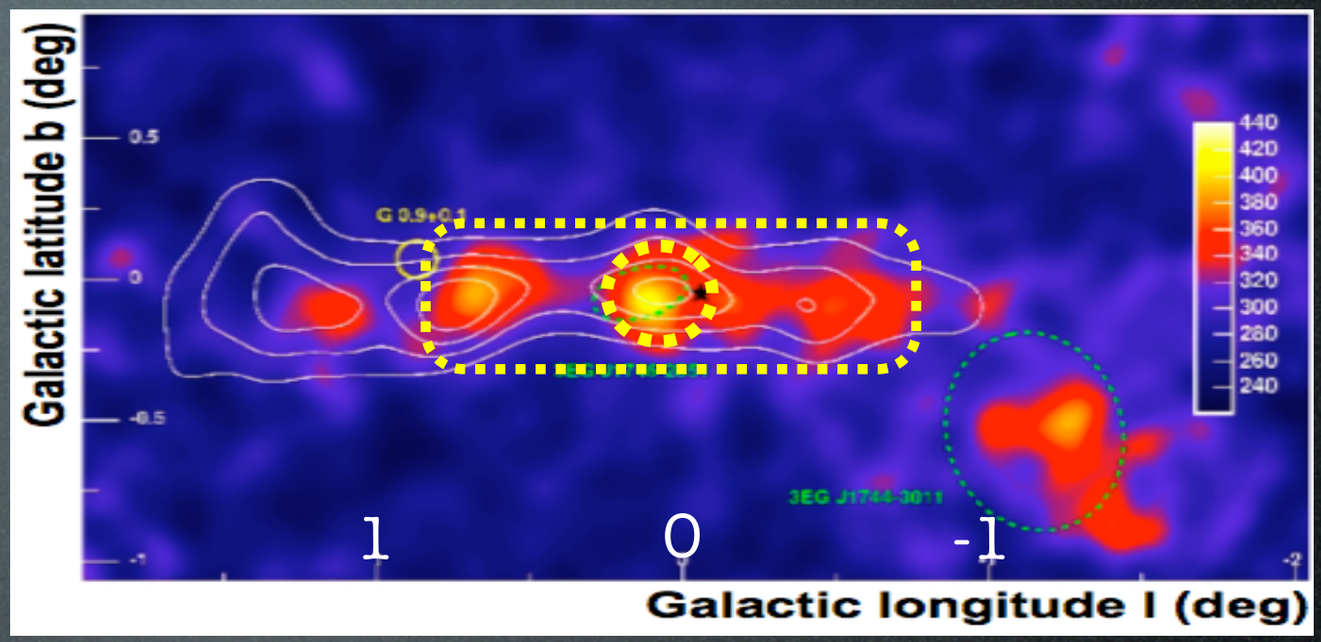
HESS coll.



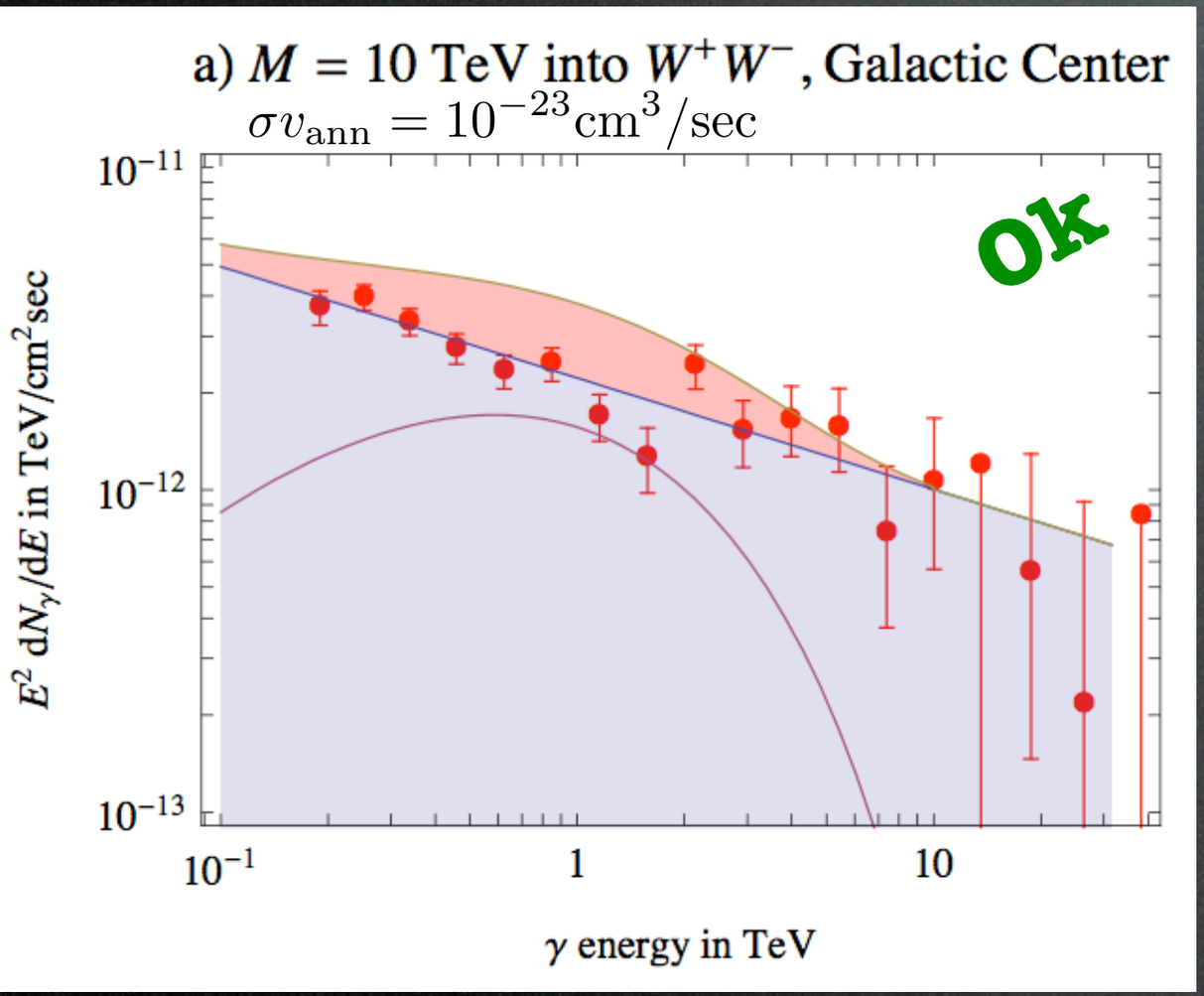
Data: HESS coll., astro-ph/0408145 and astro-ph/0610509

Gamma constraints

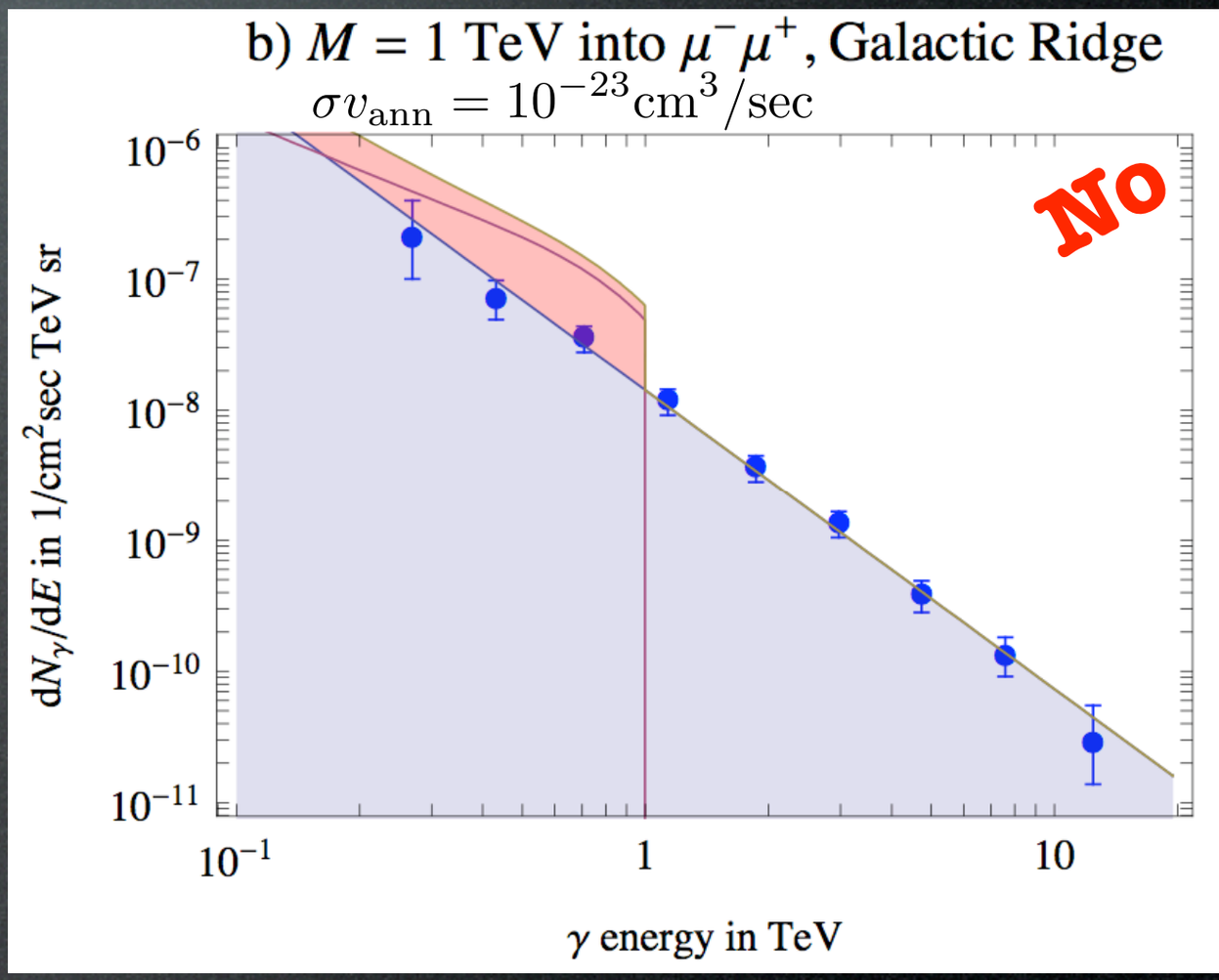
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HESS coll.



Data: HESS coll., astro-ph/0408145 and astro-ph/0610509

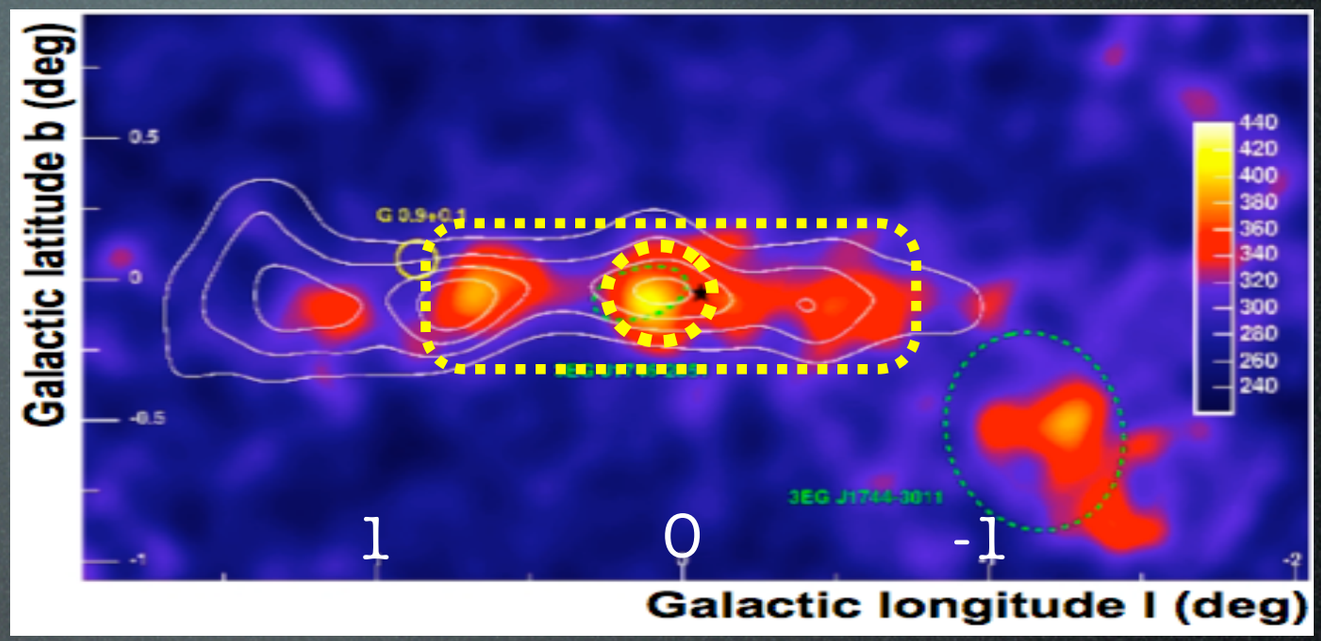


Data: HESS coll., astro-ph/0603021

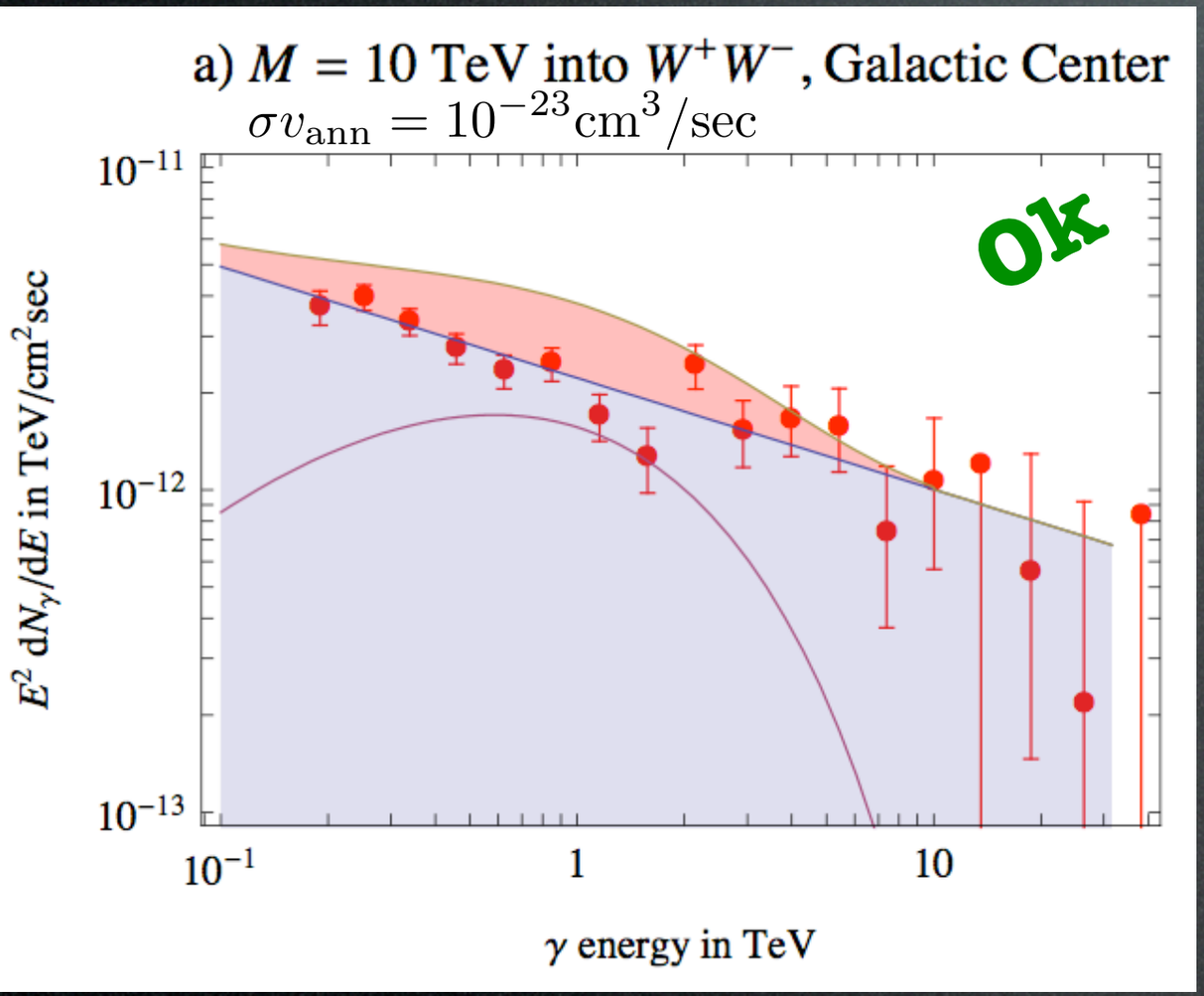
Gamma constraints

HESS has detected γ-ray emission from Gal Center and Gal Ridge. The DM signal must not excede that.

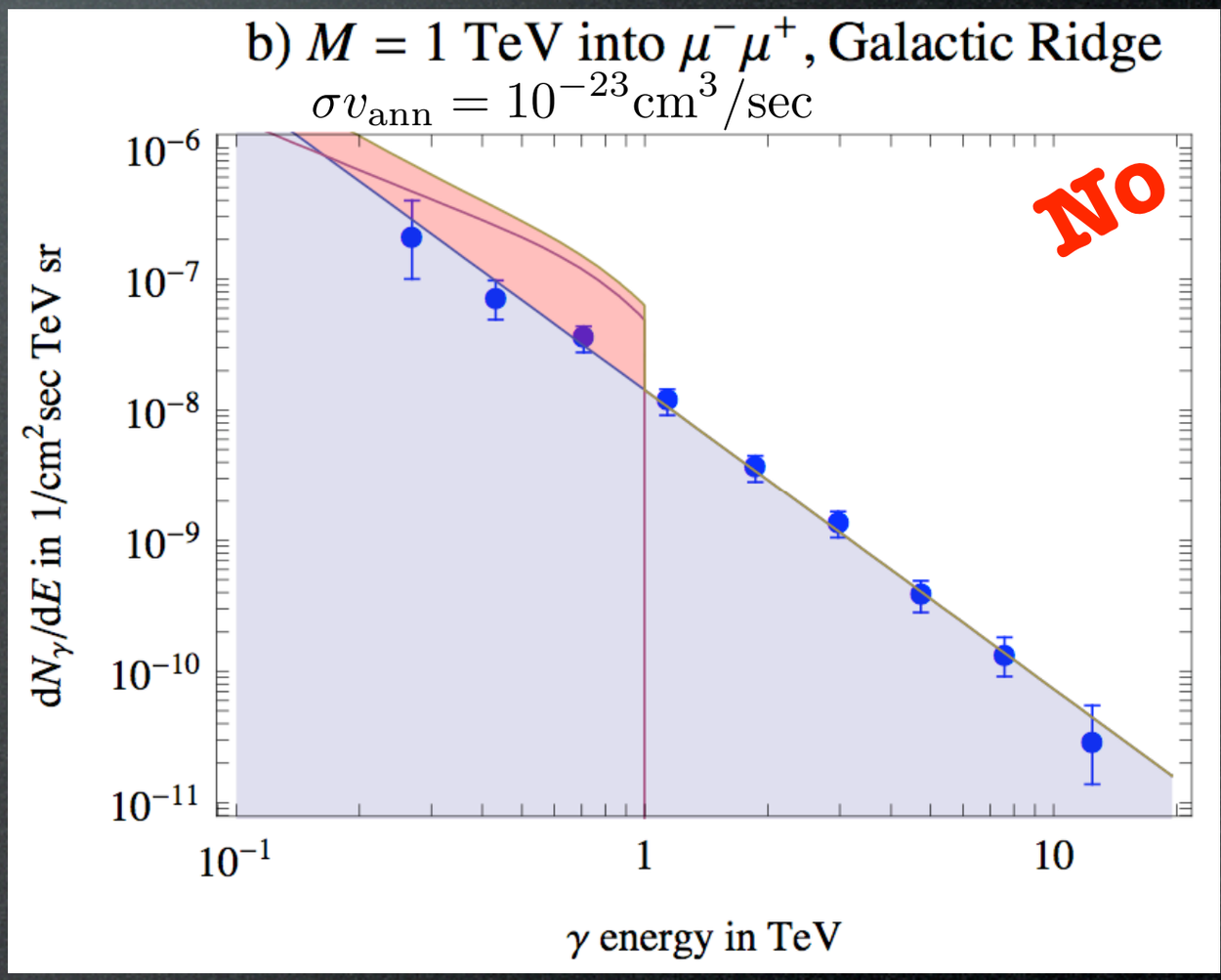
Moreover: no detection from Sgr dSph => upper bound.



HESS coll.

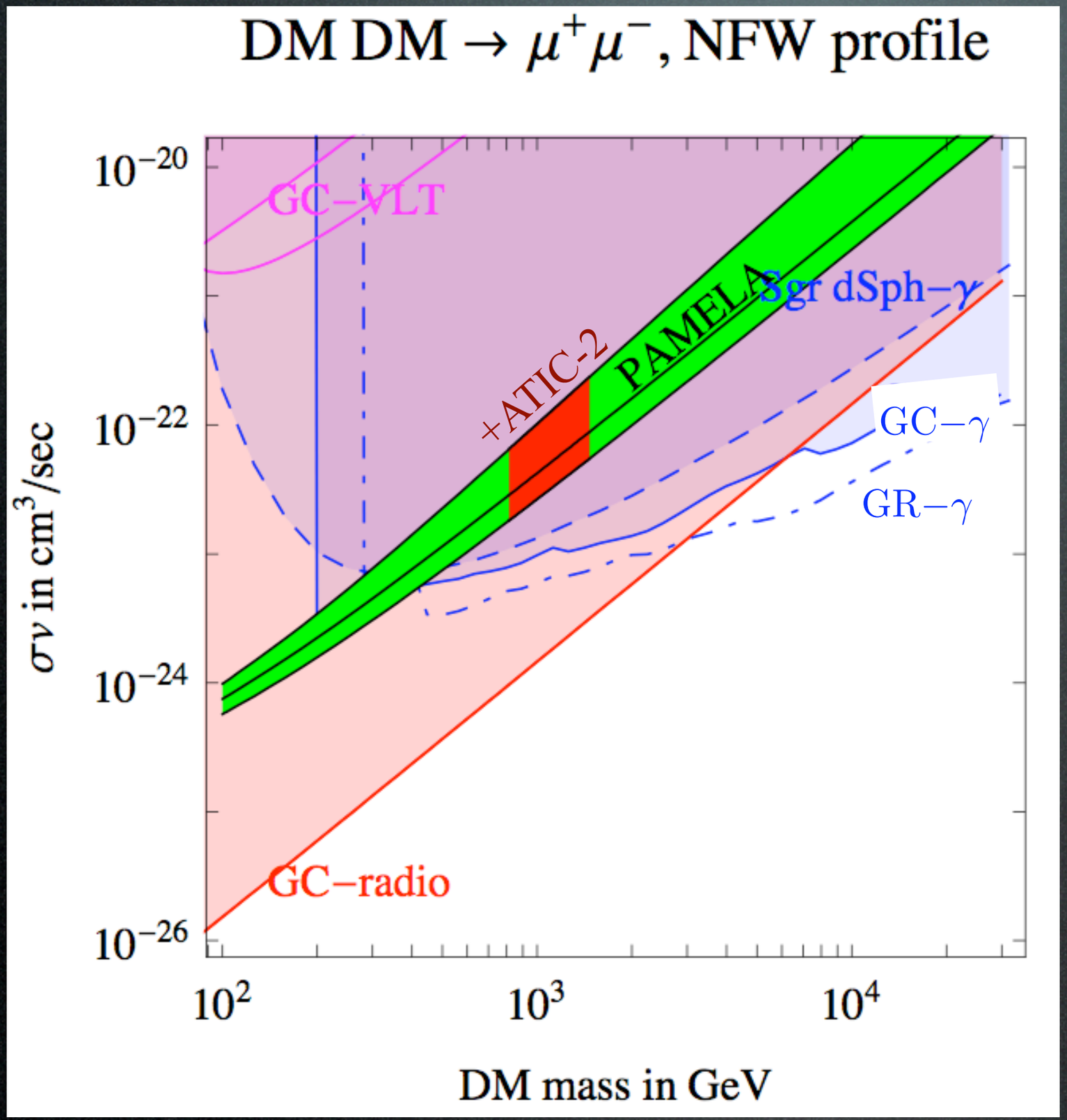


Data: HESS coll., astro-ph/0408145 and astro-ph/0610509



Data: HESS coll., astro-ph/0603021

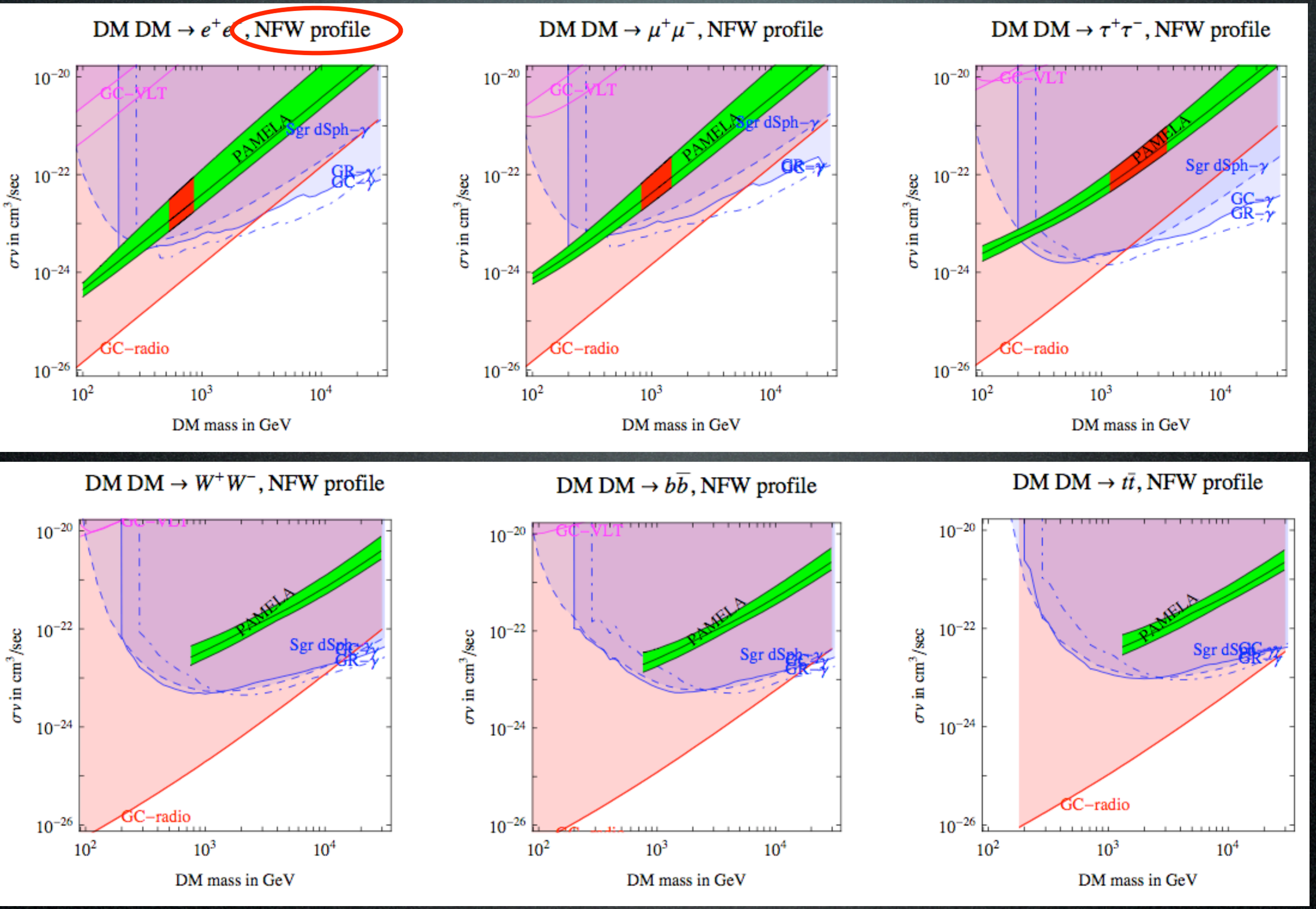
Gamma constraints



Bertone, Cirelli, Strumia, Taoso 0811.3744

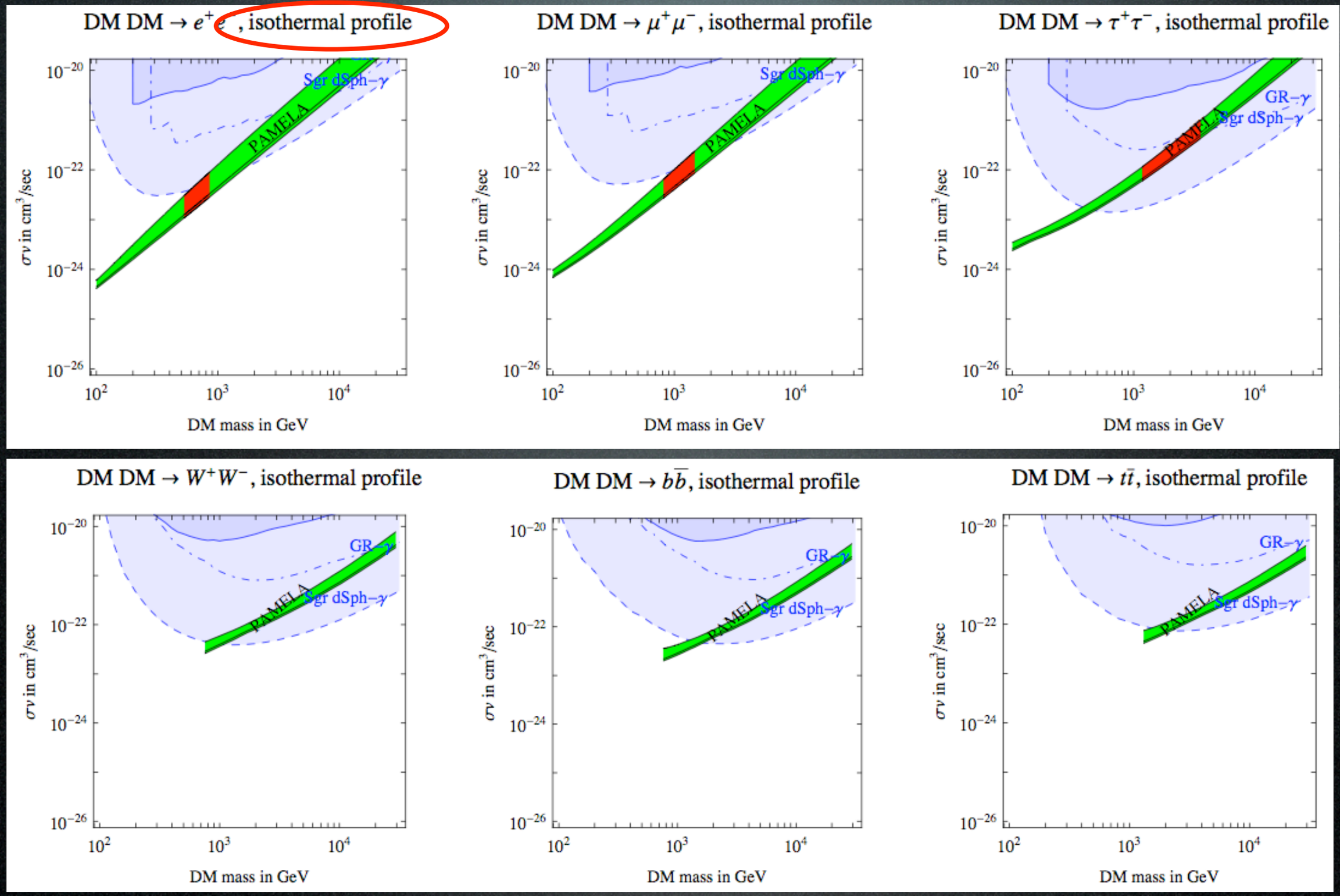
The PAMELA and ATIC regions are in conflict with gamma constraints, unless...

Gamma constraints



Bertone, Cirelli, Strumia, Taoso 0811.3744

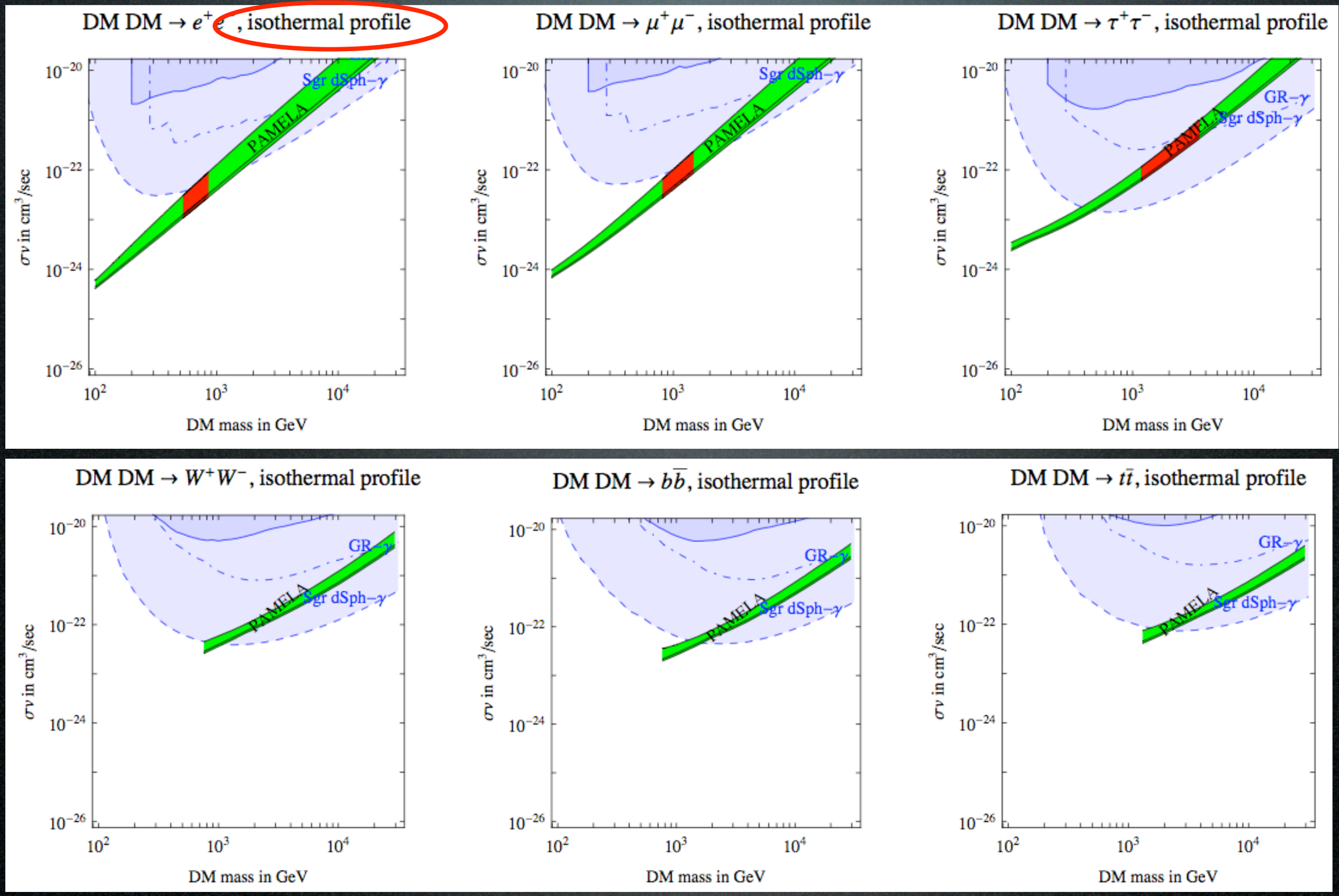
Gamma constraints



Bertone, Cirelli, Strumia, Taoso 0811.3744

...not-too-steep profile needed.

Gamma constraints



Bertone, Cirelli, Strumia, Taoso 0811.3744

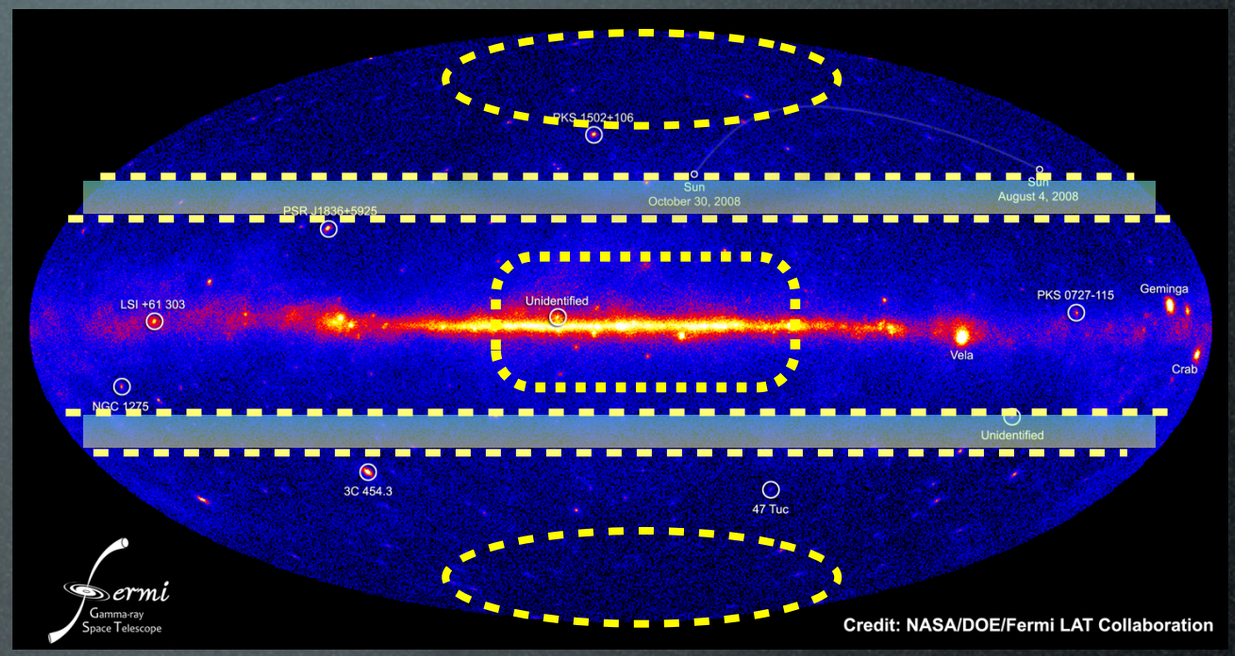
...not-too-steep profile needed.

Or: take different boosts here (at Earth, for e^+) than there (at GC for gammas).

Or: take ad hoc DM profiles (truncated at 100 pc, with central void..., after all we don't know).

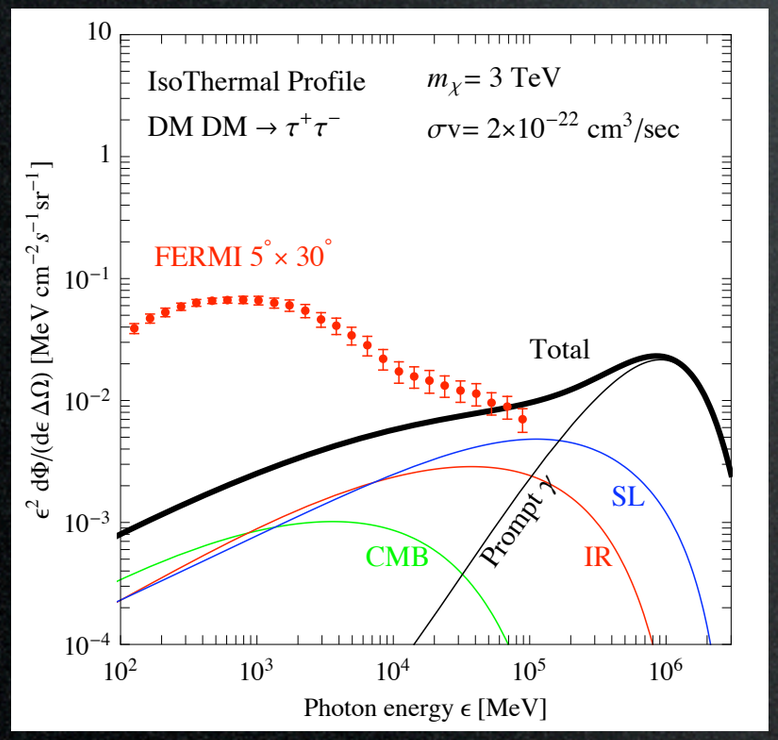
Gamma constraints

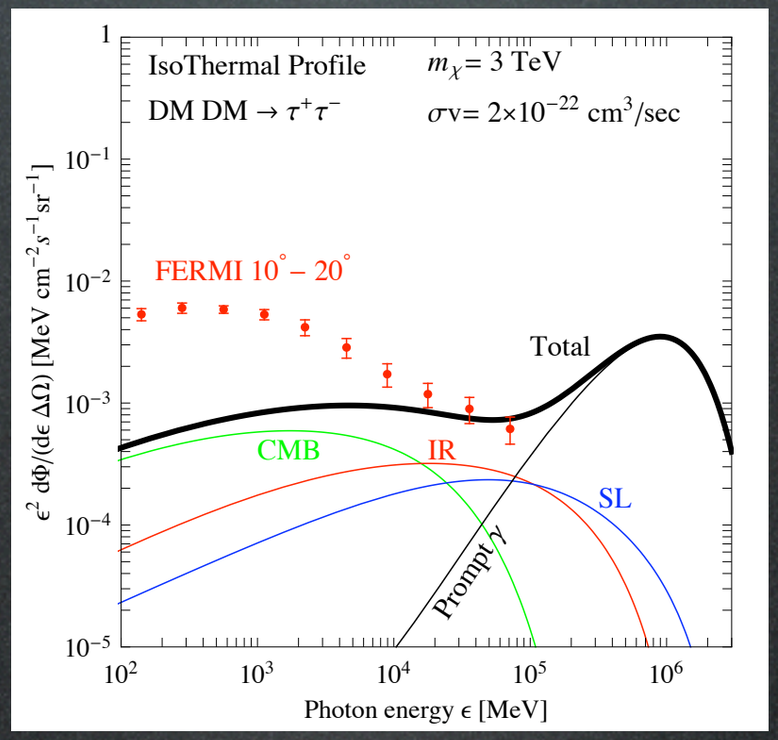
FERMI has measured diffuse γ-ray emission. The DM signal must not excede that.

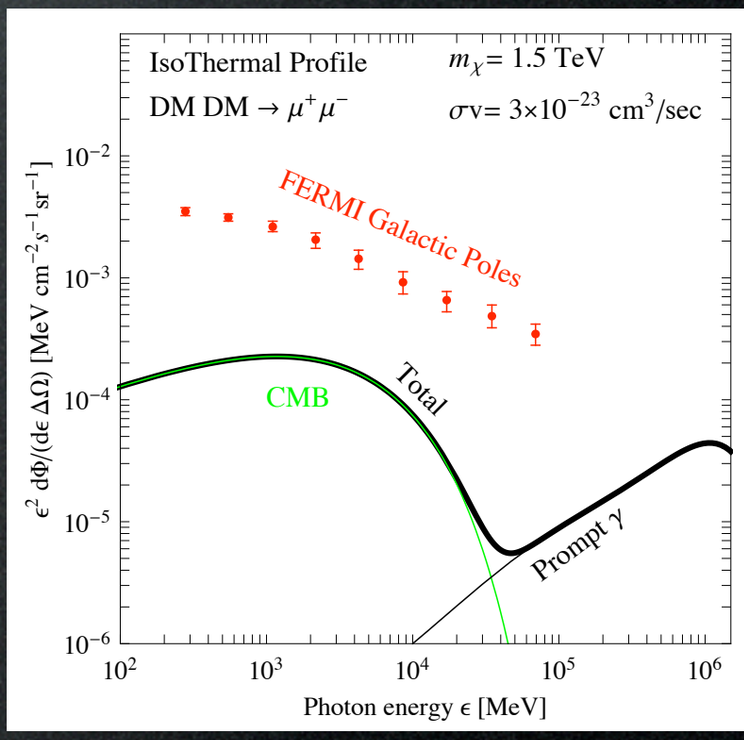


FERMI coll.

Data: FERMI coll., several talks and papers

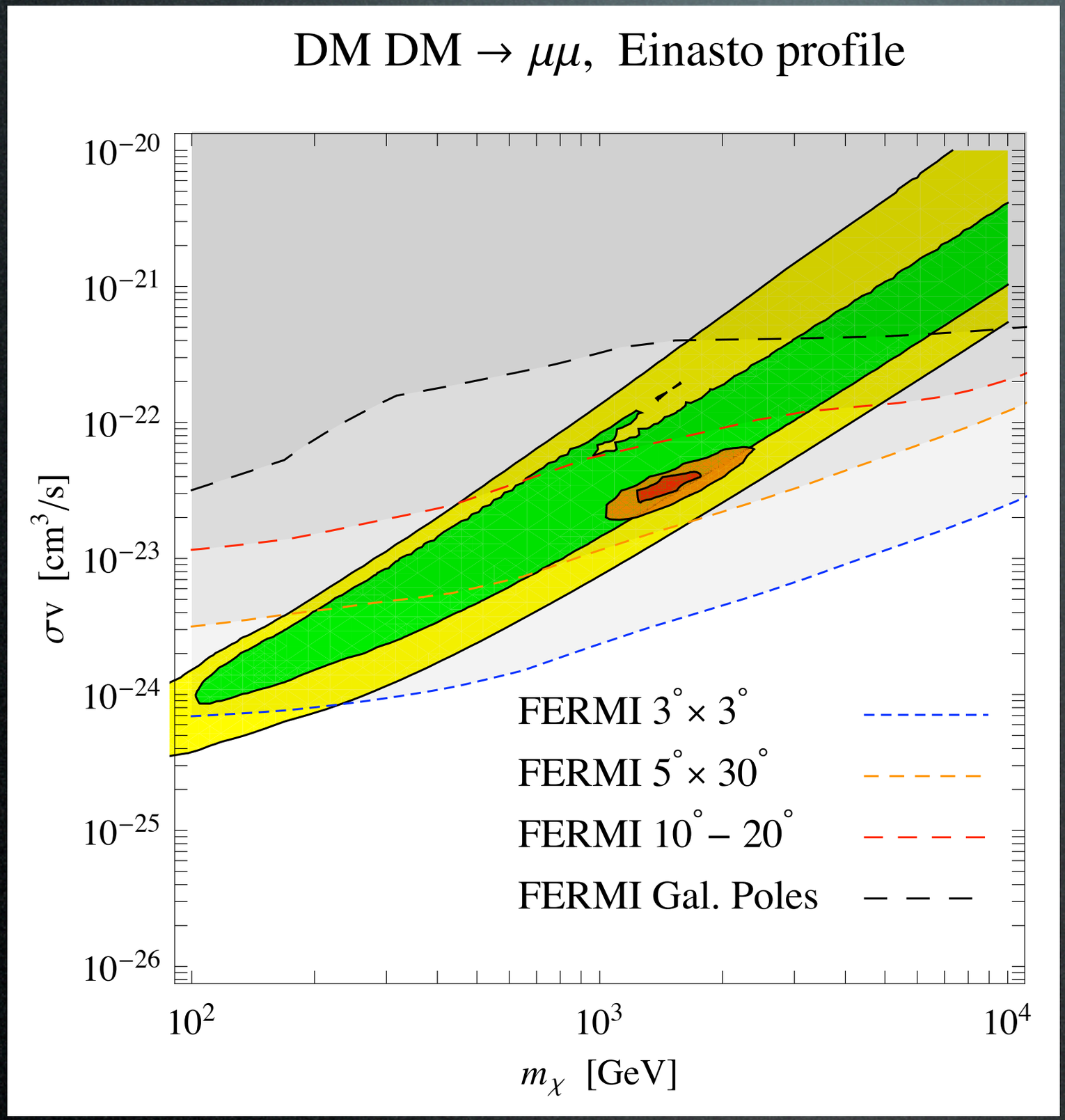






Cirelli, Panci, Serpico 0912.0663

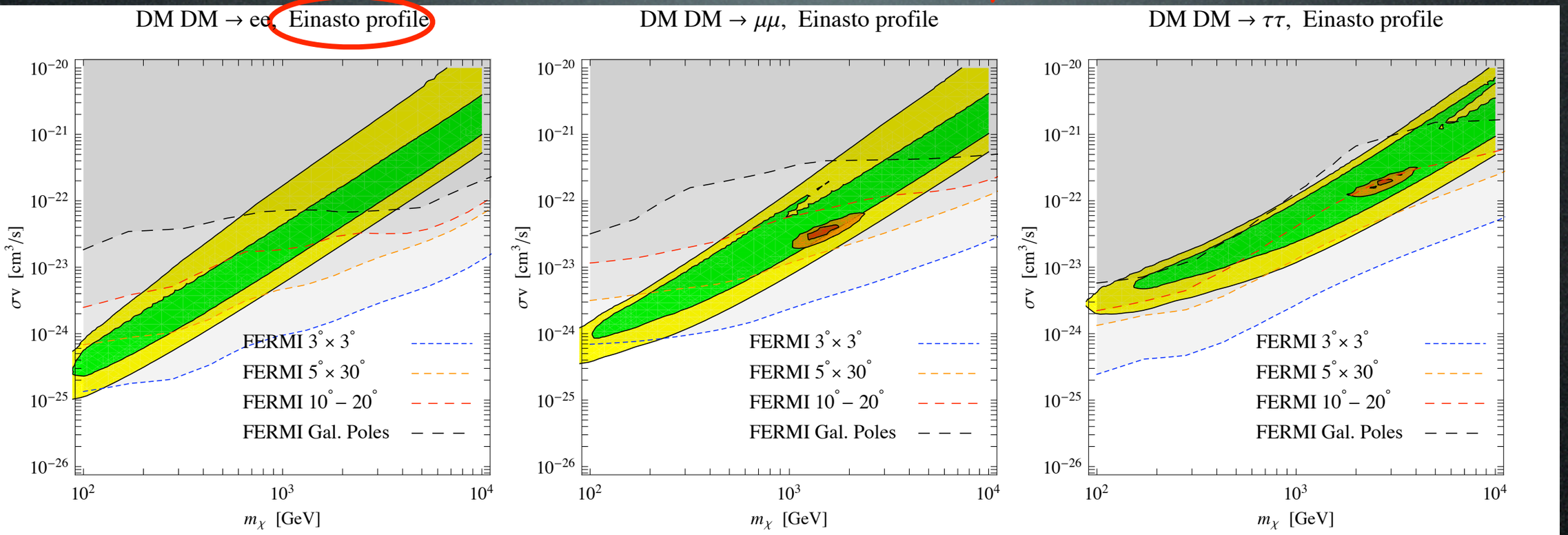
Inverse Compton γ constraints



Cirelli, Panci, Serpico 0912.0663

The PAMELA and ATIC regions are in conflict with these gamma constraints, and here...

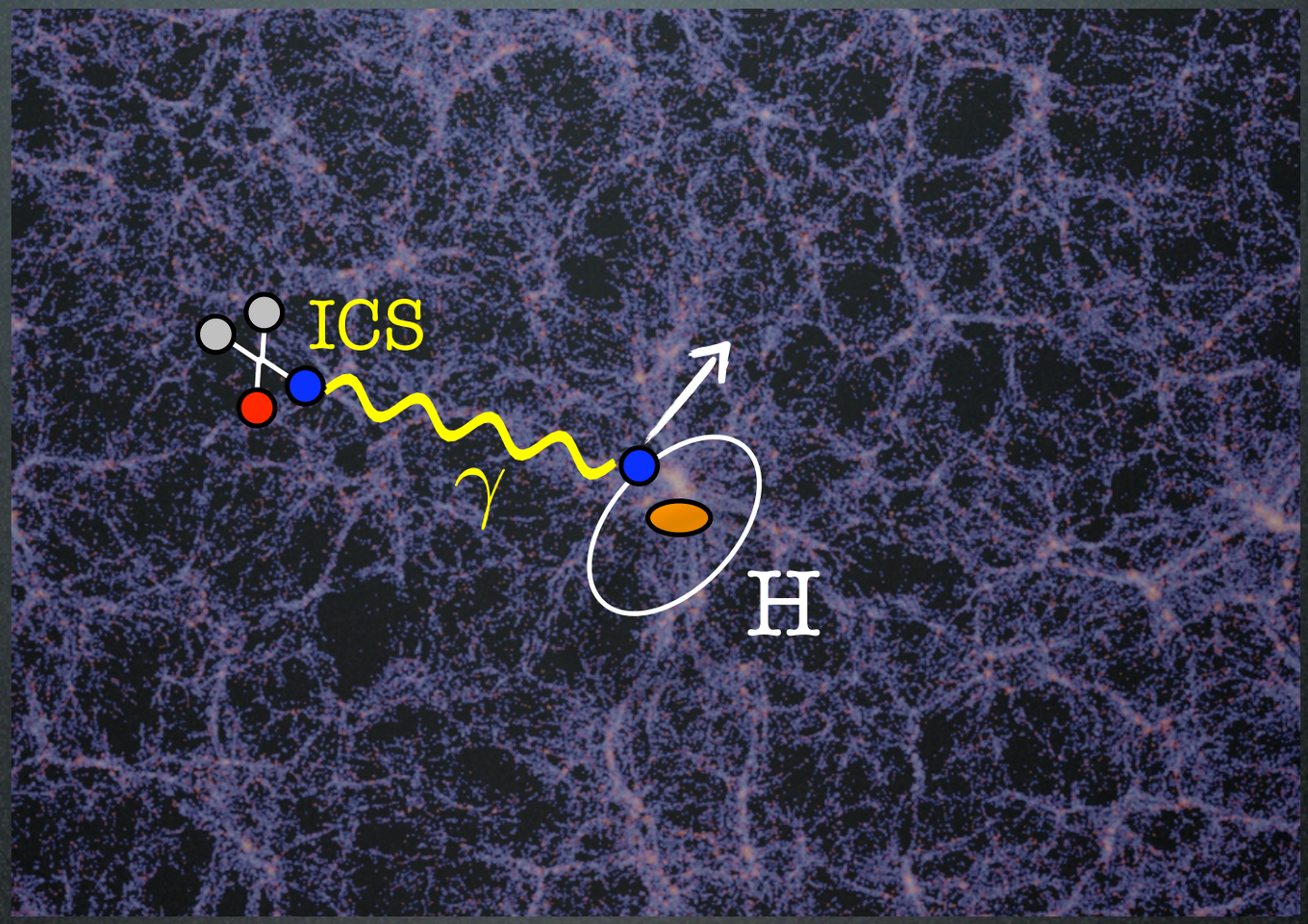
Inverse Compton γ constraints



Cirelli, Panci, Serpico 0912.0663

Cosmology: bounds from reionization

DM particle annihilations produce free electrons



$$-n_{\rm A} H_0 \sqrt{\Omega_{\rm M}} (1+z)^{11/2} \frac{dx_{\rm ion}(z)}{dz} = I(z) - R(z). \qquad I(z) = \int_{e_{\rm i}}^{m_\chi} dE_\gamma \, \frac{dn}{dE_\gamma}(z) \cdot P(E_\gamma, z) \cdot N_{\rm ion}(E_\gamma) \qquad P(E_\gamma, z) = n_{\rm A}(1+z)^3 \left[1 - x_{\rm ion}(z)\right] \cdot \sigma_{\rm tot}(E_\gamma),$$

$$N_{\rm ion}(E_\gamma) = \eta_{\rm ion}(x_{\rm ion}(z)) \; E_\gamma \left[\frac{n_{\rm H}}{n_{\rm A}} \frac{1}{e_{\rm i,H}} + \frac{n_{\rm He}}{n_{\rm A}} \frac{1}{e_{\rm i,He}} \right] = \eta_{\rm ion}(x_{\rm ion}(z)) \; \frac{E_\gamma}{\rm GeV} \, \mu \qquad \frac{dn}{dE_\gamma}(z) = \int_\infty^z dz' \, \frac{dt}{dz'} \, \frac{dN}{dE'_\gamma}(z') \, \frac{(1+z)^3}{(1+z')^3} \cdot A(z') \cdot \exp\left[\Upsilon(z, z', E'_\gamma)\right].$$

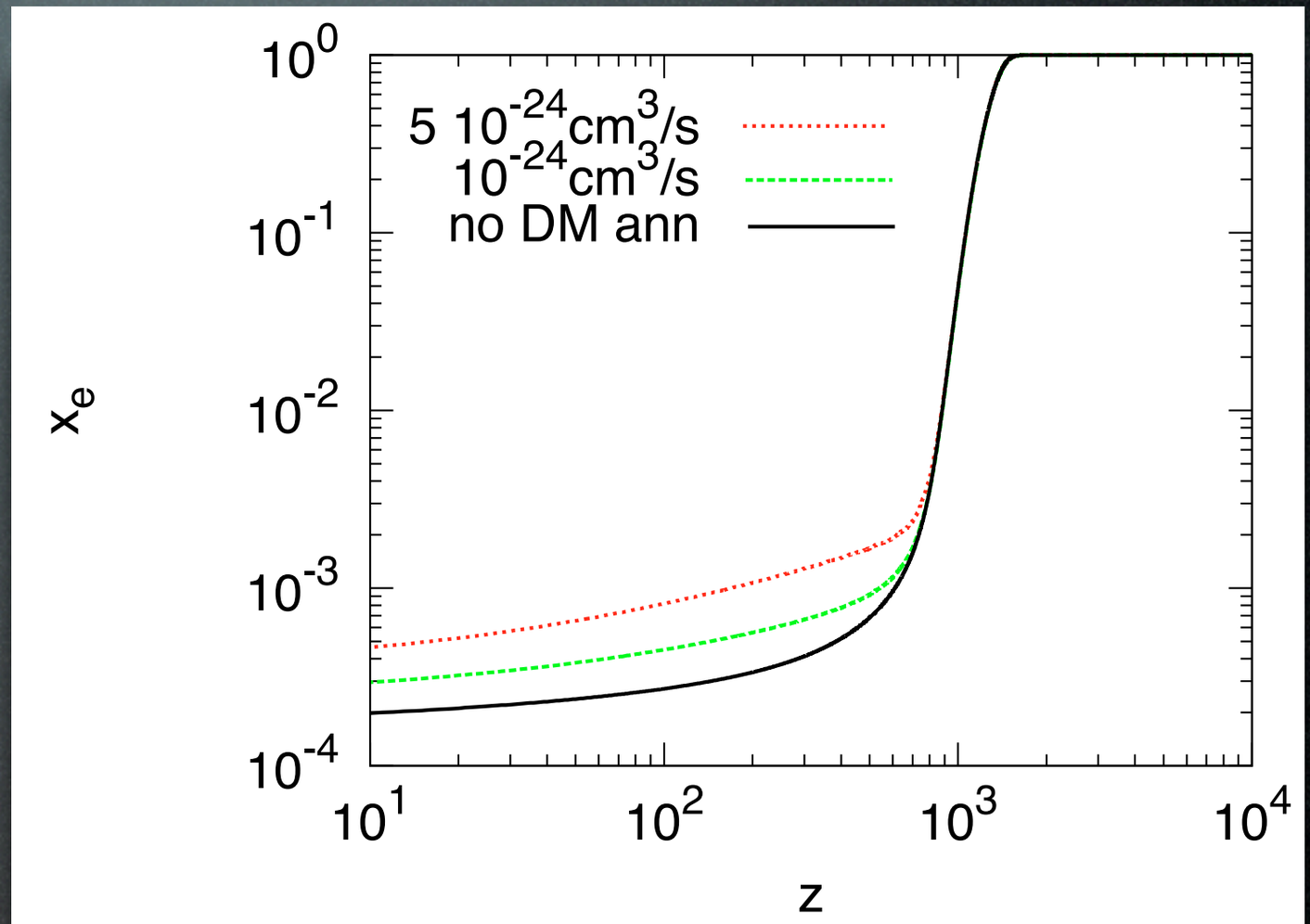
$$\Upsilon(z, z', E'_\gamma) \simeq - \int_{z'}^z dz'' \frac{dt}{dz''} n_{\rm A} (1+z'')^3 \sigma_{\rm tot}(E''_\gamma) \qquad \frac{dT_{\rm igm}(z)}{dz} = \frac{2\, T_{\rm igm}(z)}{1+z} - \frac{1}{H_0 \sqrt{\Omega_{\rm M}} \, (1+z)^{5/2}} \left(\frac{x_{\rm ion}(z)}{1 + x_{\rm ion}(z) + 0.073} \frac{T_{\rm CMB}(z) - T_{\rm igm}(z)}{t_{\rm c}(z)} + \frac{2\, \eta_{\rm heat}(x_{\rm ion}(z)) \, \mathcal{E}(z)}{3\, n_{\rm A} (1+z)^3} \right).$$

$$A(z) = \frac{\langle \sigma v \rangle}{2\, m_\chi^2} \rho_{\rm DM,0}^2 (1+z)^6 \left(1 + \mathcal{B}_i(z)\right), \qquad \mathcal{B}_i(z) = \frac{\Delta_{\rm vir}(z)}{3\, \rho_{\rm c} \Omega_{\rm M}} \int_{M_{\rm min}}^\infty dM \, M \frac{dn}{dM}(z, M) \, F_i(M, z), \qquad \frac{dn}{dM}(M, z) = \sqrt{\frac{\pi}{2}} \frac{\rho_{\rm M}}{M} \, \delta_{\rm c} \, (1+z) \frac{d\sigma(R)}{dM} \frac{1}{\sigma^2(R)} \exp\left(- \frac{\delta_{\rm c}^2 \, (1+z)^2}{2\sigma^2(R)} \right)$$

Cirelli, Iocco, Panci, JCAP 0910

Cosmology: bounds from reionization

DM particles that fit PAMELA+FERMI+HESS produce
free electrons

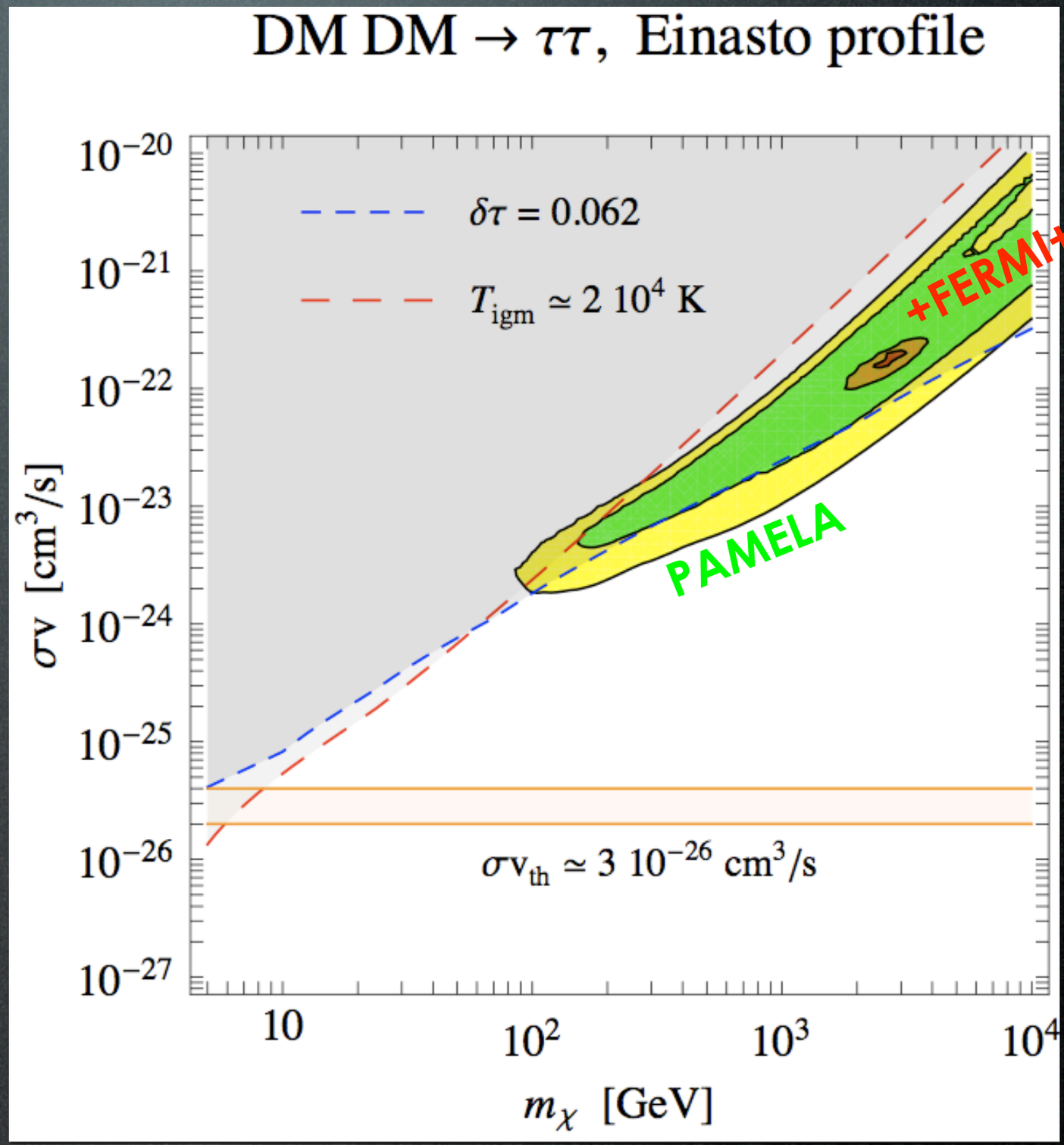


Kanzaki et al., 0907.3985

Cosmology: bounds from reionization

DM particles that fit PAMELA+FERMI+HESS produce too many free electrons: bounds on optical depth of the Universe violated

$\tau = 0.084 \pm 0.016$ (WMAP-5yr)



Cirelli, Iocco, Panci, JCAP 0910

see also:

Huetsi, Hektor, Raidal 0906.4550

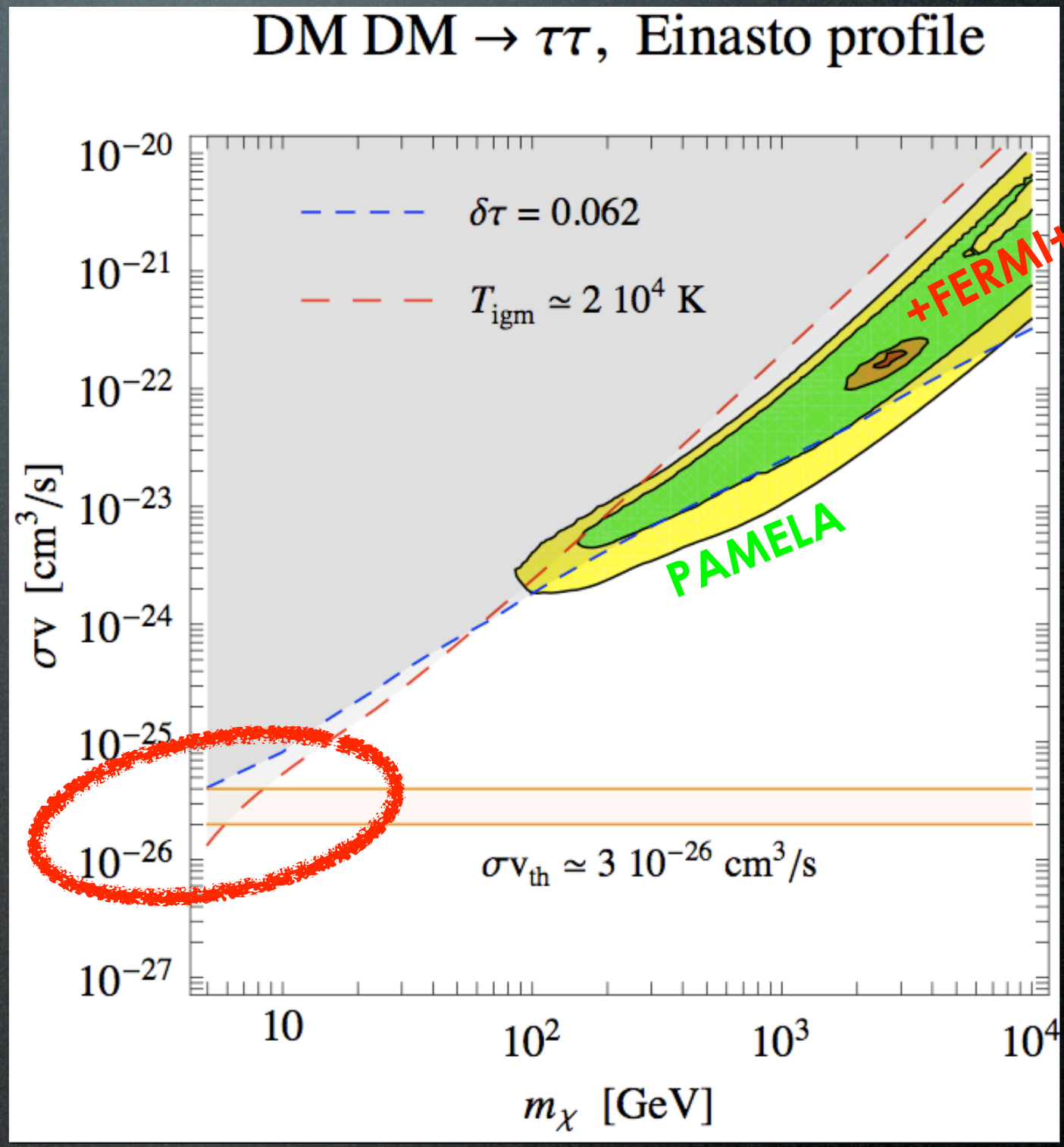
Kanzaki et al., 0907.3985

Cosmology: bounds from reionization

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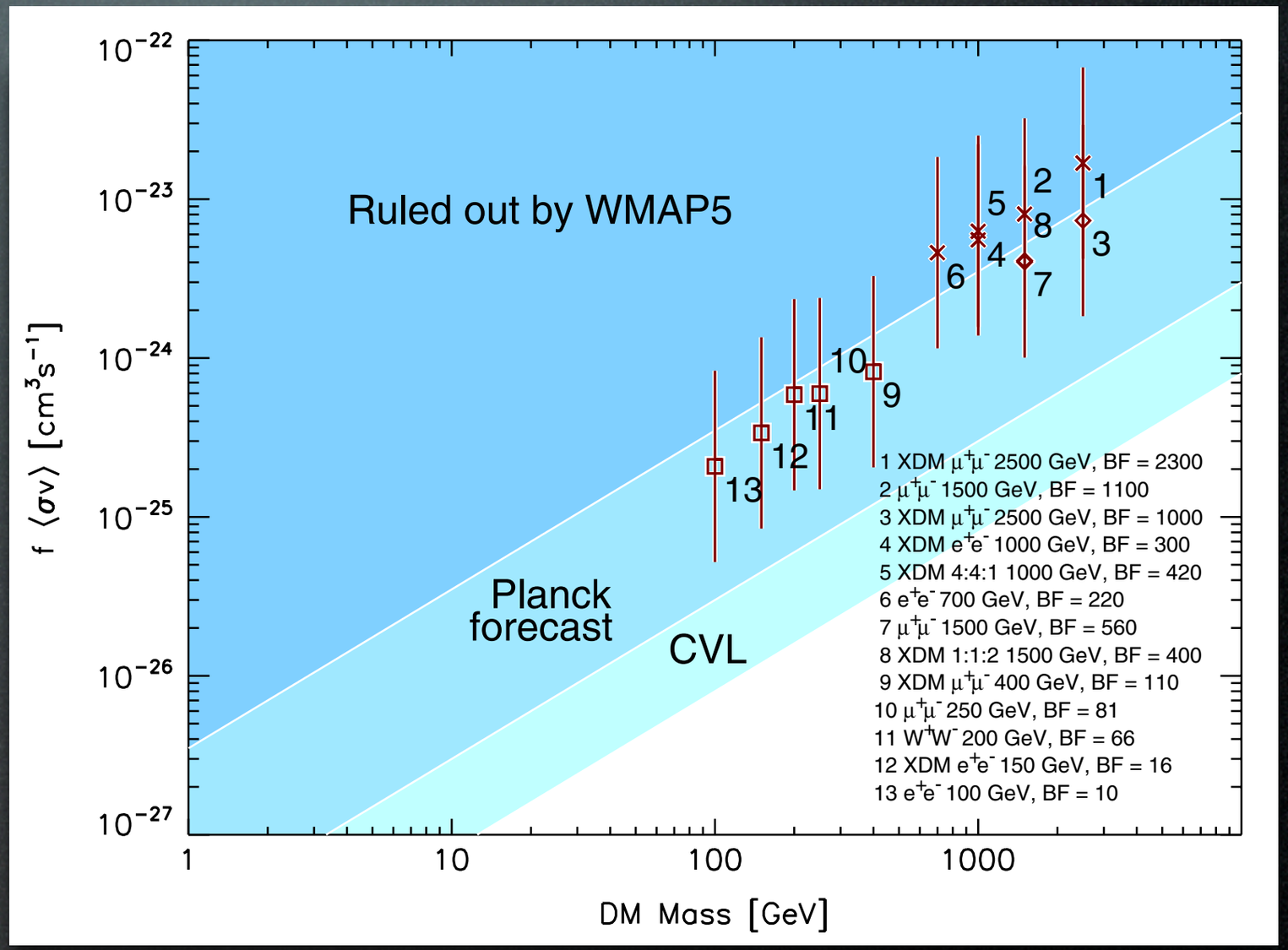
Starts constraining even thermal DM!



Cirelli, Iocco, Panci, JCAP 0910

Cosmology: bounds from CMB

Similar conclusion from global CMB fits



Galli, Iocco, Bertone, Melchiorri, PRD 80 (2009)

Slatyer, Padmanabahn, Finkbeiner, PRD 80 (2009)

Conclusions

Models with large DM annihilation cross section are popular.

Gamma ray constraints are severe:

- all cases excluded except:

  $\mathrm{DM}\,\mathrm{DM} \to \mu^+\mu^-$
  and
  galactic Isothermal profile (disfavored by N-body)

- in which case FERMI may soon see a spectacular signal

Cosmological constraints are even more severe:

- all cases excluded (albeit barely)
- starts to probe even thermal DM