GRAPPA

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Self-consistent velocity distributions for WIMPs explaining the Galactic Centre GeV excess

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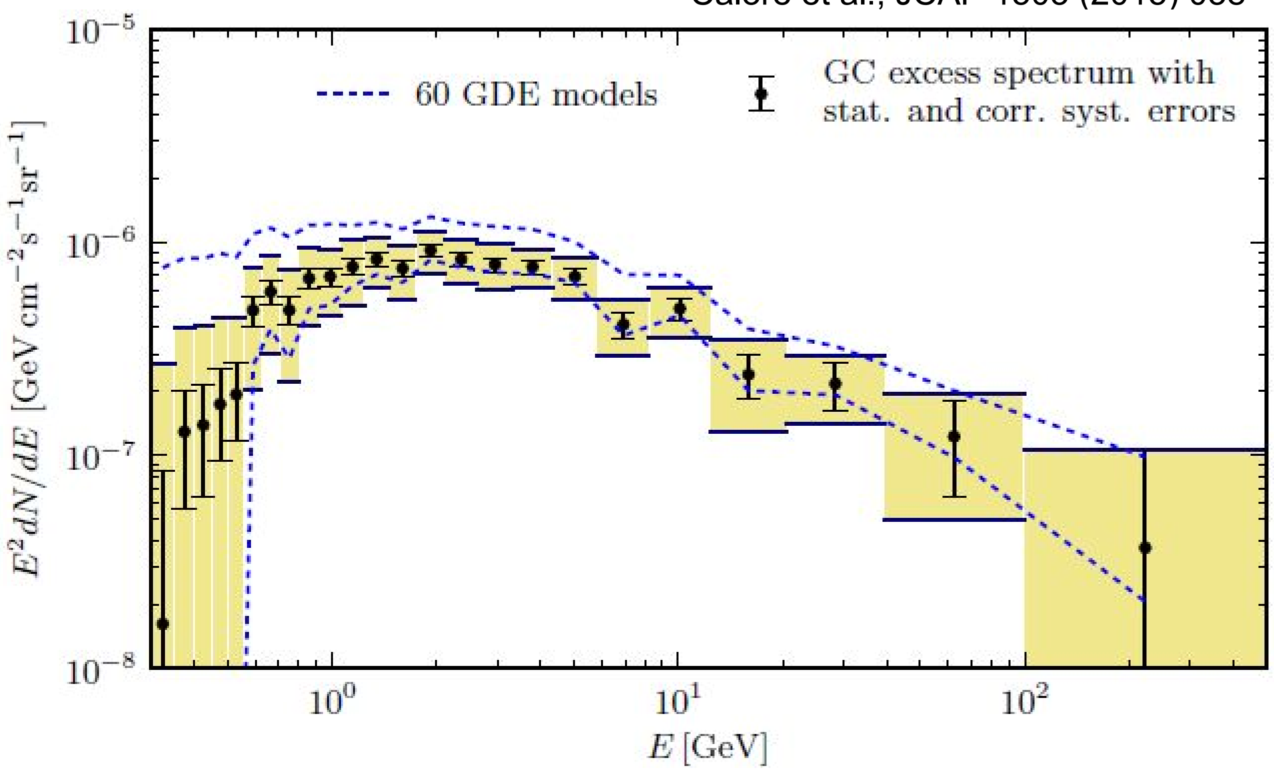
Galactic Centre GeV excess

- excess of gamma rays over the emission associated with cosmic rays
- it peaks at 2-3 GeV
- best-fit slopes for broken power-law: 1.42 and 2.63
- energy spectrum is universal over its extension
- spherical symmetric
- it extends until 7.4 degrees at 9.5 C.L.

Calore et al., JCAP 1503 (2015) 038



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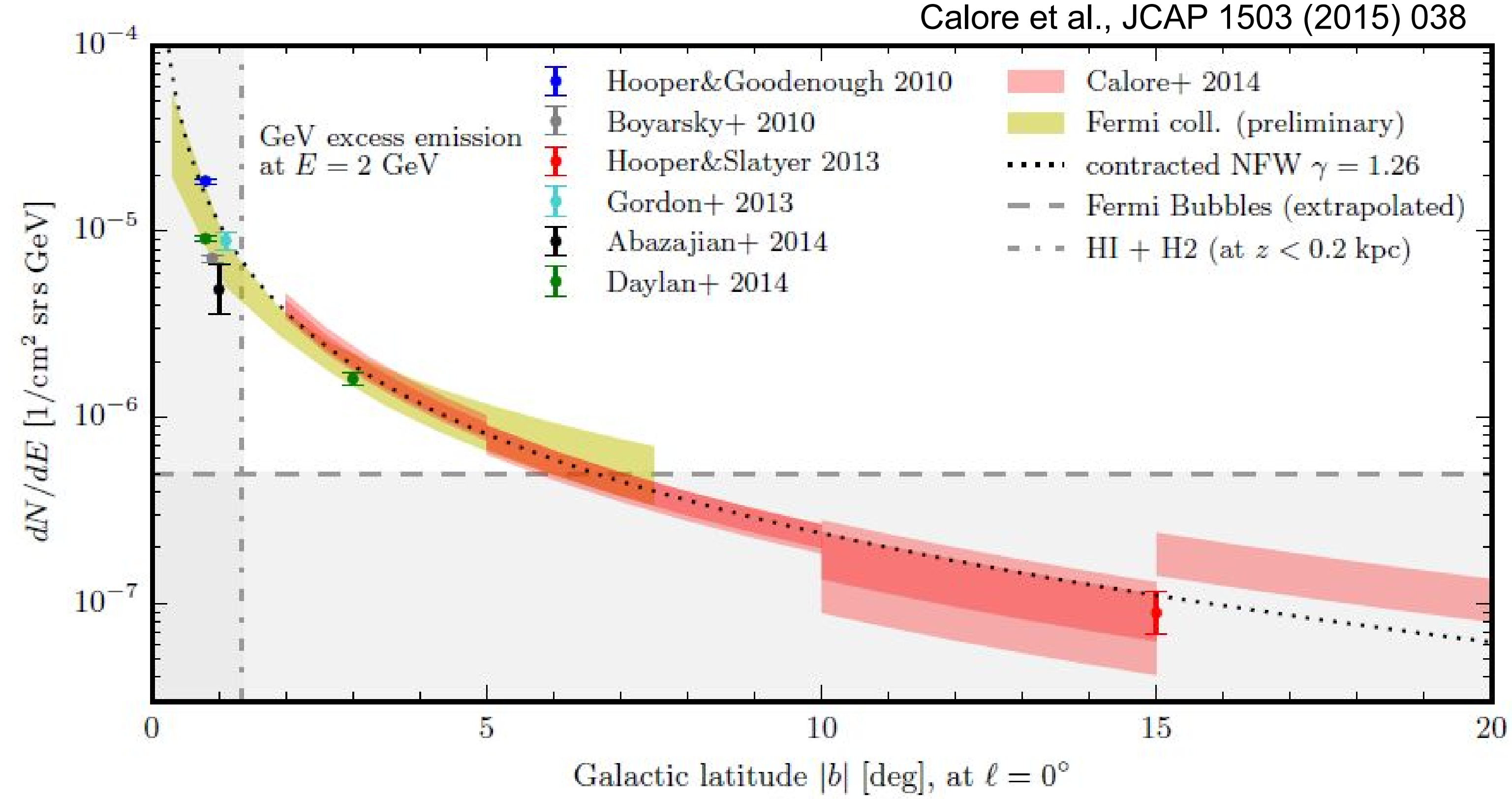


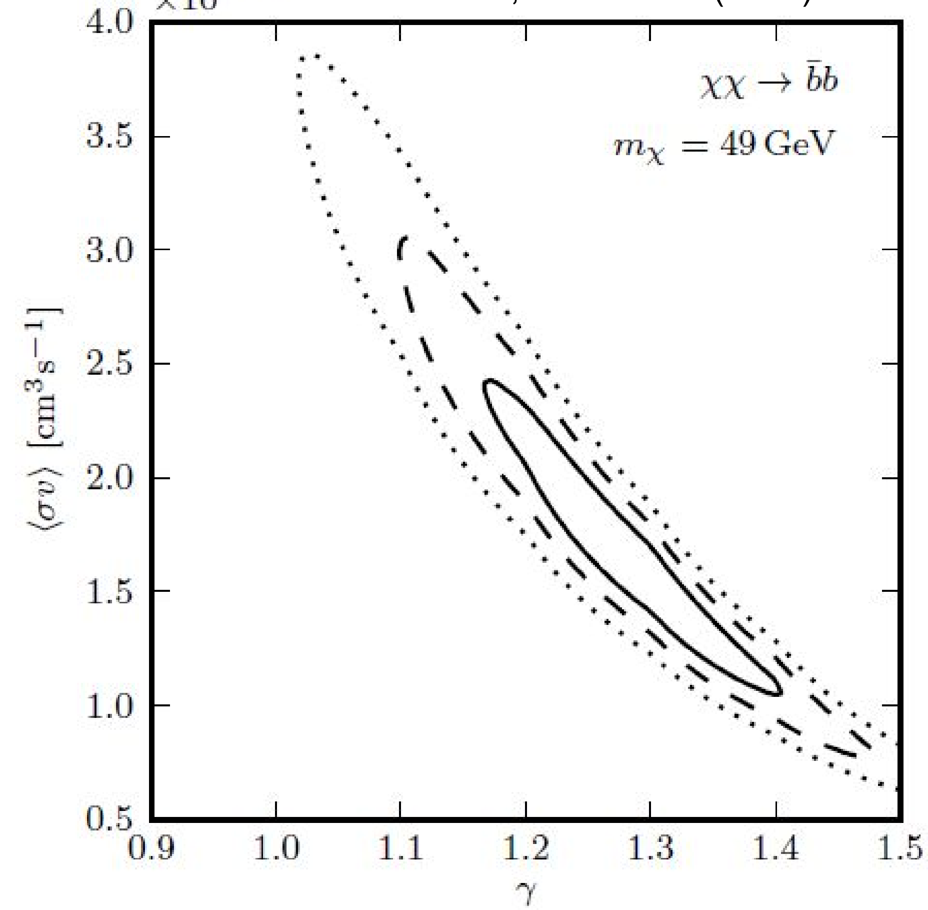
Galactic Centre GeV excess

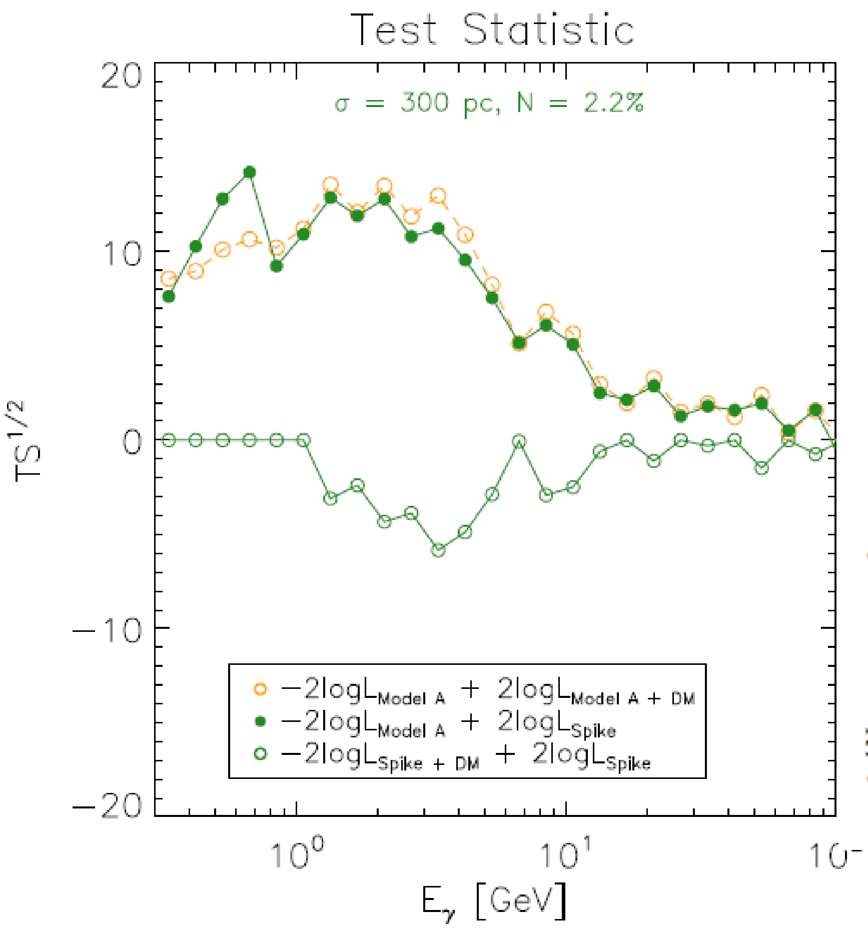
- generalised Navarro-Frenk-White (NFW) profile used in the fit

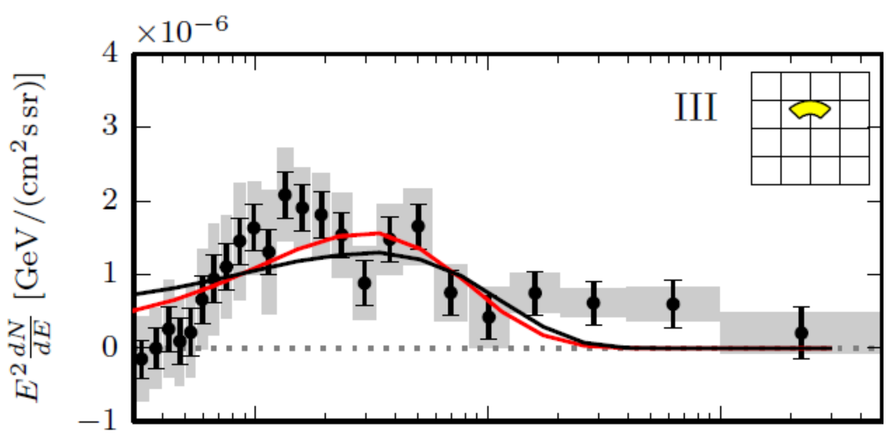
$$\rho_\chi(r) = \rho_s \left(\frac{r}{r_s}\right)^{-\gamma} \left(1 + \frac{r}{r_s}\right)^{\gamma-3}$$

- best-fit is γ=1.28
- we assume the excess is due to DM (other interpretations are possible)

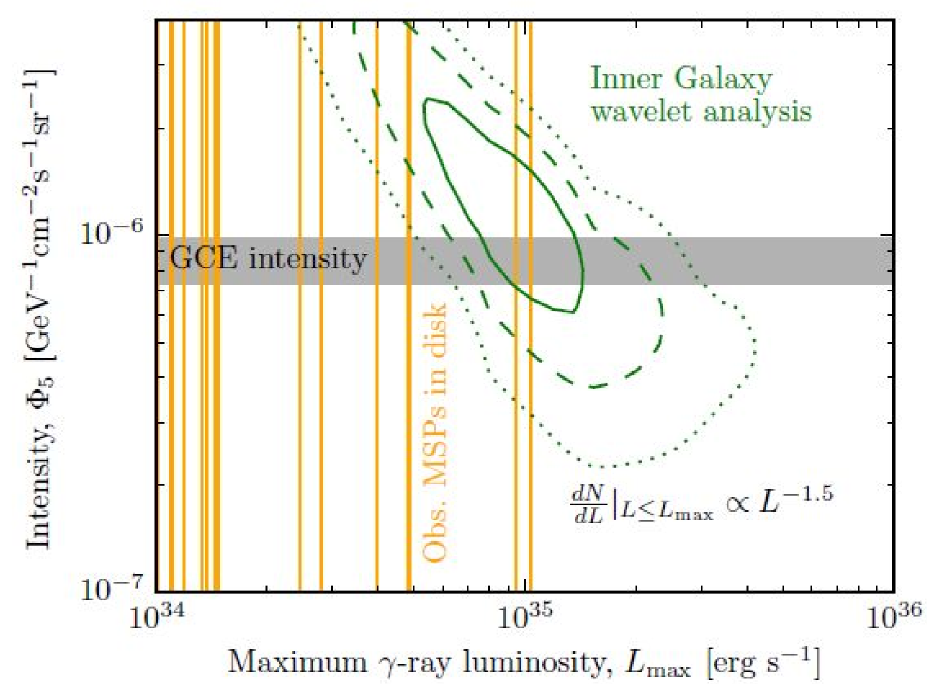
Calore et al., JCAP 1503 (2015) 038







Bartels et al., 1506.05104



Making predictions for direct detection

- upper limits on WIMP-nucleon cross section from LUX

$$\frac{\mathrm{d}R}{\mathrm{d}E_R} = \frac{\rho_0}{m_\chi m_\mathrm{N}} \int_{v_\mathrm{min}}^{\infty} v f_1(v) \frac{\mathrm{d}\sigma}{\mathrm{d}E_\mathrm{R}}\, \mathrm{d}v$$

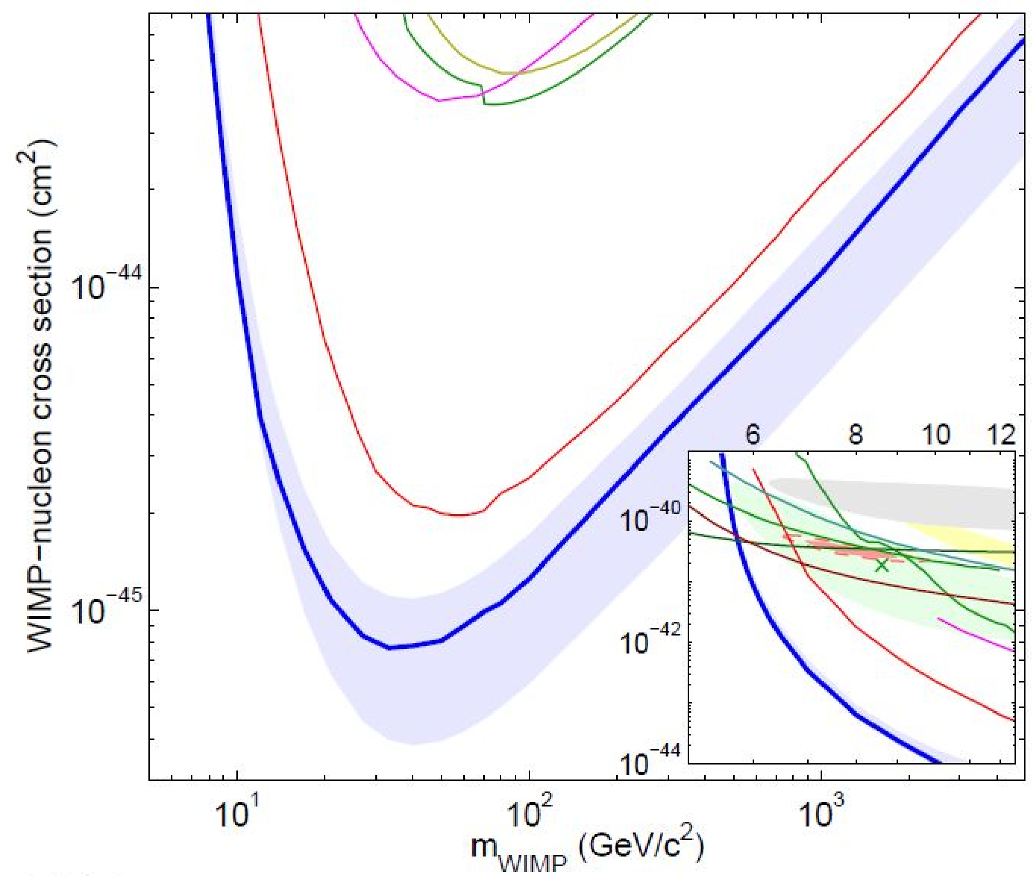
$$f_1(v) = \oint f_\mathrm{Gal}(\mathbf{v} - \mathbf{v}_\mathrm{lag}) v^2\, \mathrm{d}\Omega_\mathbf{v} \equiv v^2 f(v)$$

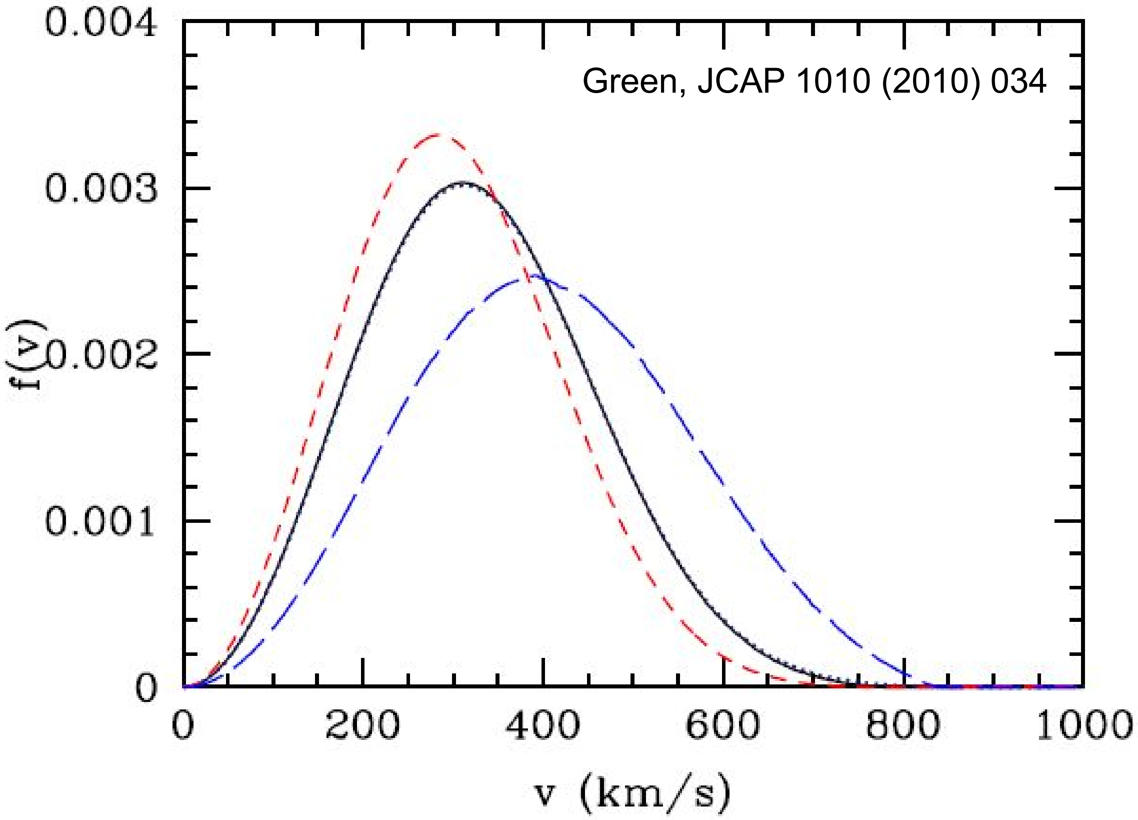
- Maxwell-Boltzmann velocity distribution

$$f_\mathrm{Gal}(\mathbf{v}) = \frac{1}{(2\pi\sigma_v^2)^{3/2}} \exp\left(-\frac{\mathbf{v}^2}{2\sigma_v^2}\right)$$

- a **consistent analysis** employs the speed distribution associated with the DM halo that reproduces the Galactic Centre GeV excess

Akerib et al., Phys.Rev.Lett. 122 (2013) 091303





Self-consistent speed distributions

- describing halo in terms of phase-space density $F(\mathbf{x},\mathbf{v})$

$$\rho(\mathbf{x}) = \int d^3\mathbf{v} F(\mathbf{x},\mathbf{v}) \qquad\qquad f(\mathbf{v}) = \frac{F(\mathbf{x},\mathbf{v})}{\rho(\mathbf{x})}$$

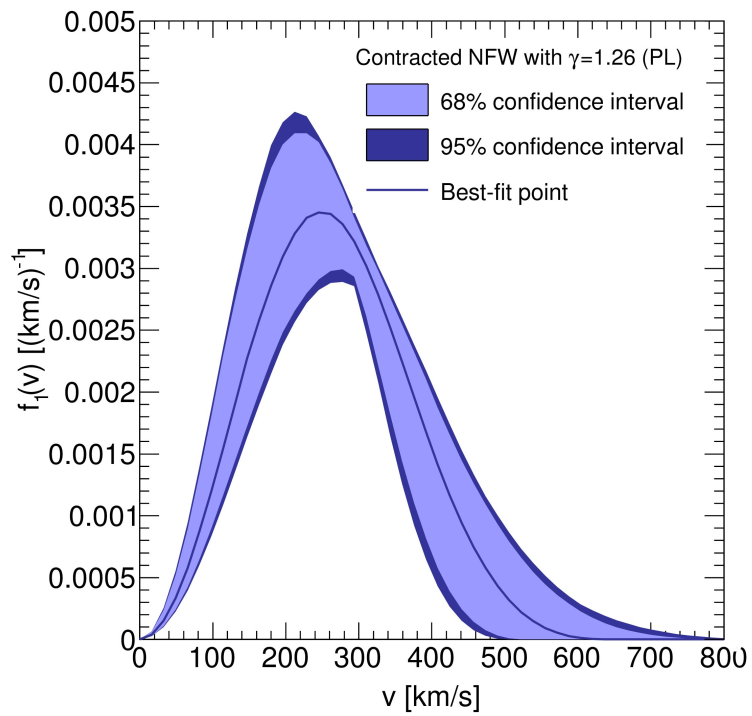
- self-consistent $f(\mathbf{v})$ comes from a $F(\mathbf{x},\mathbf{v})$ that reproduces a certain $\rho(\mathbf{x})$ and agrees with the gravitational potential $\Phi(\mathbf{x})$ of the system

- $\Phi(\mathbf{x}) \longleftrightarrow F(\mathbf{x},\mathbf{v})$: going from a mass model to a dynamic model of the Milky Way (MW)

- spherical steady-state: $F(\mathbf{x},\mathbf{v}) = F(E,L)$

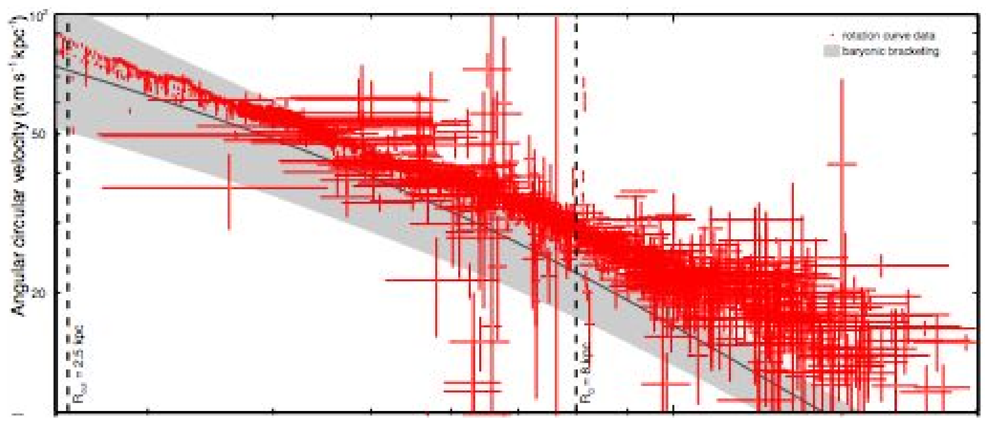
Constraining Φ(**x**) for the Milky Way

Model of matter components of the MW (Galactic parameters)

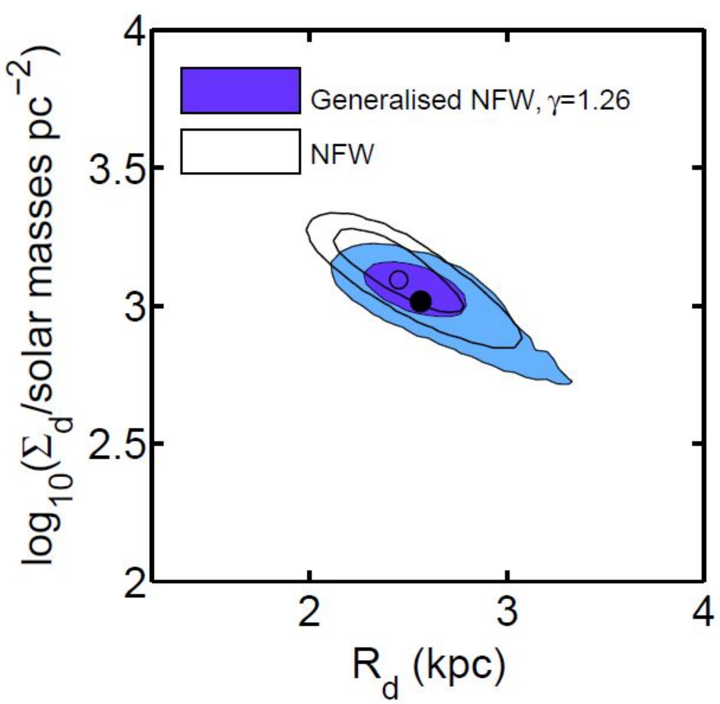


Self-consistent speed distribution

Likelihood with experimental data



Iocco, Pato and Bertone, Nature Phys. 11 (2015) 245

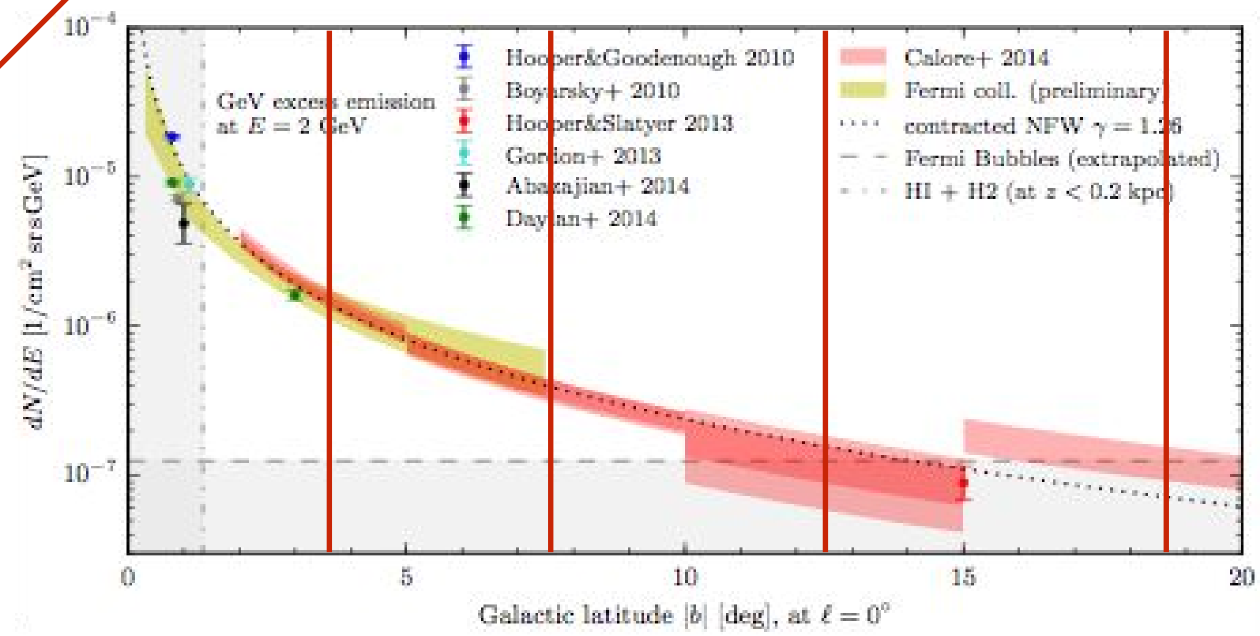


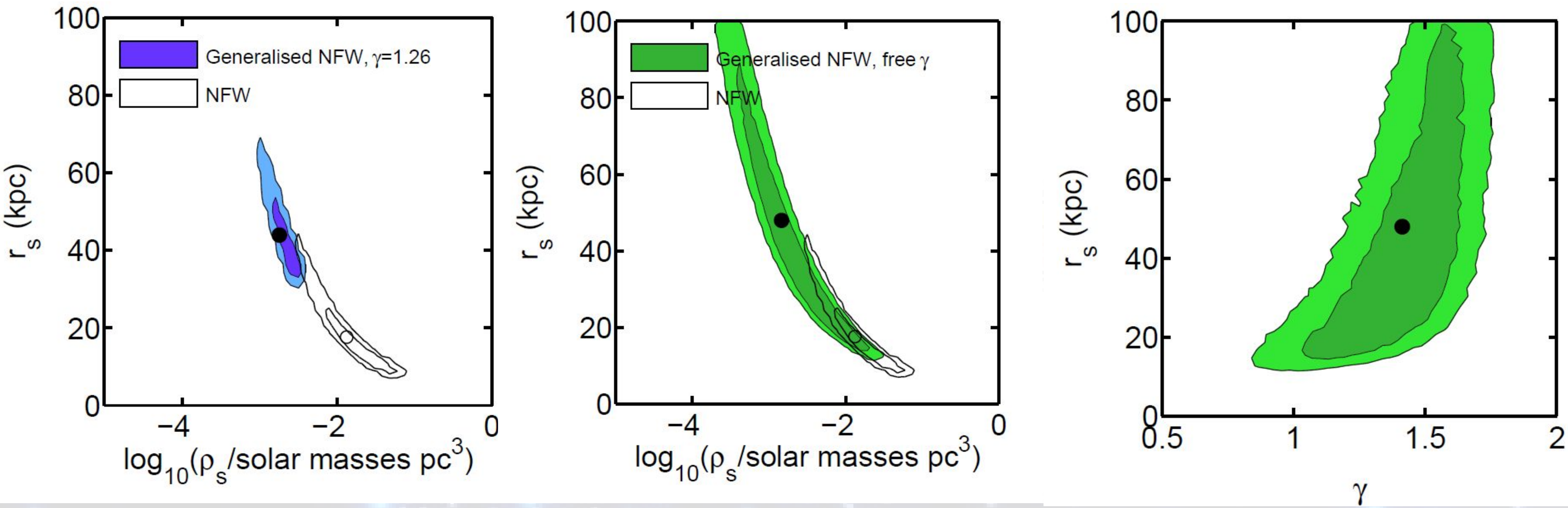
Parameter estimation

3 choices for the DM halos:

- original NFW with γ=1
- generalised NFW with γ=1.26
- generalised NFW with a free γ

additional term is included in the likelihood to reproduce the morphology of the Galactic Centre GeV excess



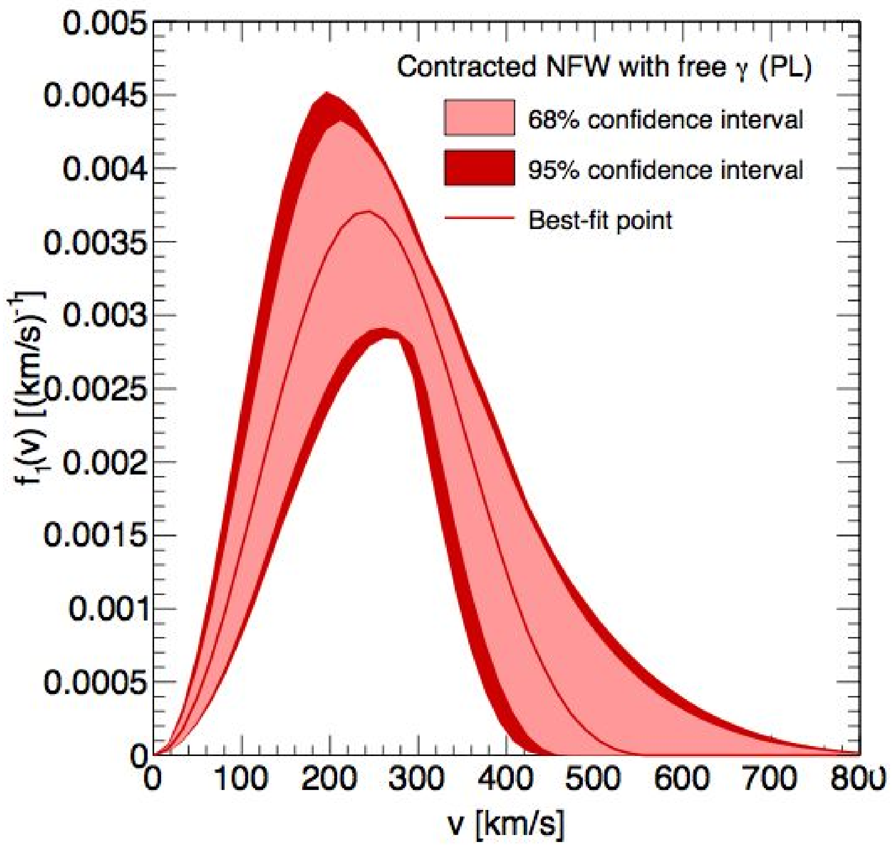


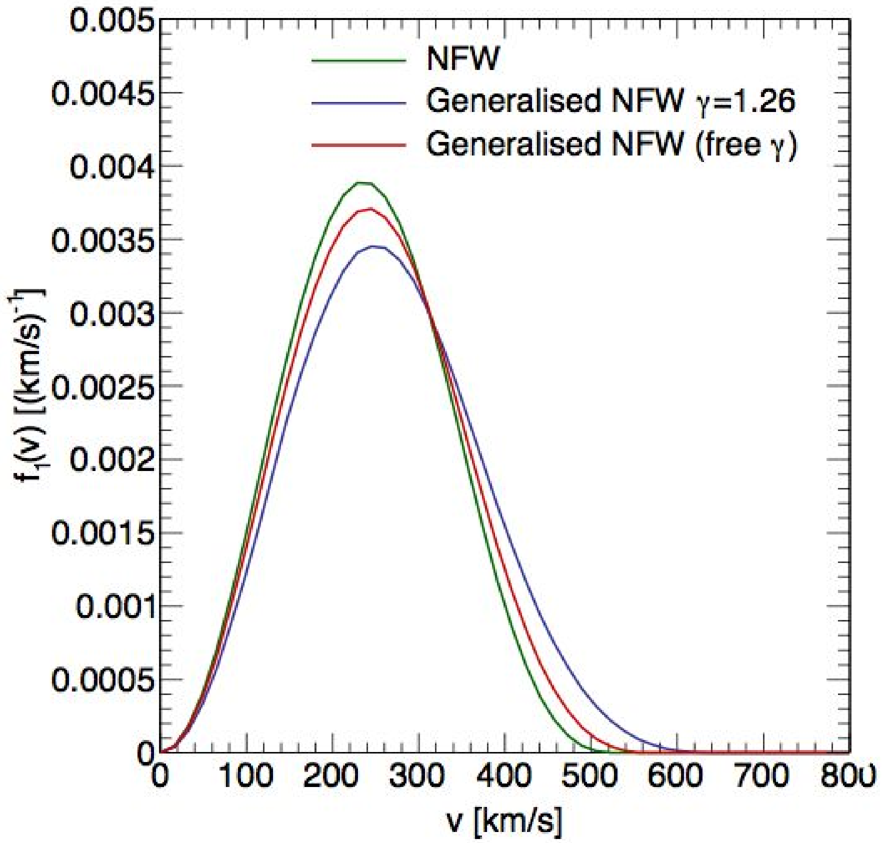
Spherical isotropic system (Eddington)

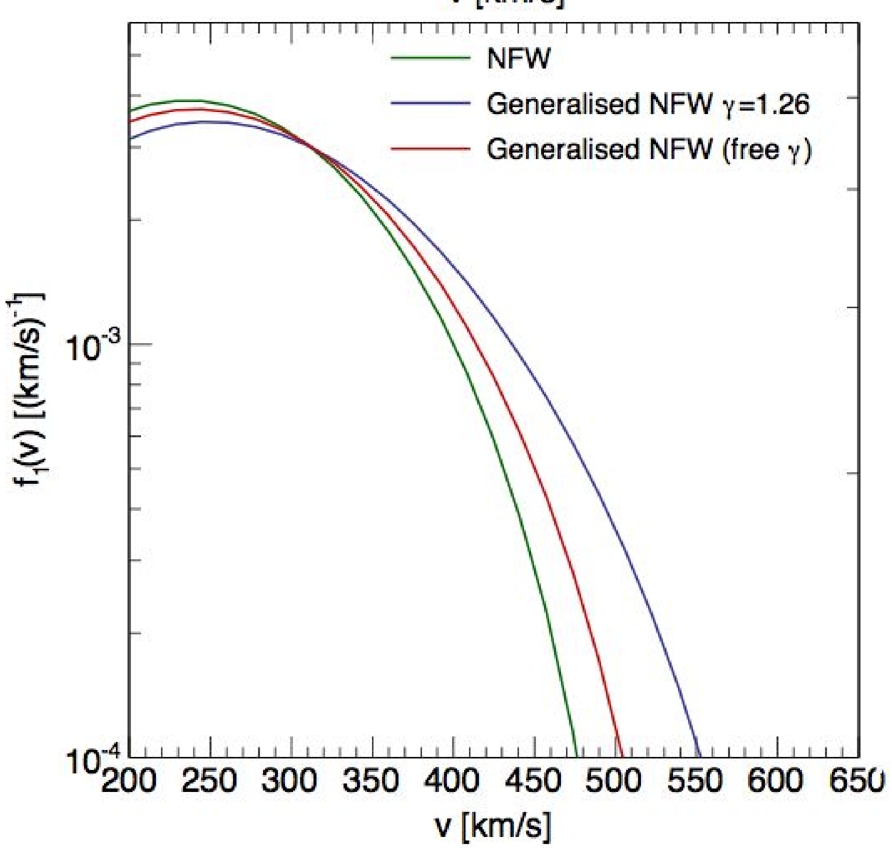
$$\rho(r) = 4\pi \int_0^{\Phi(r)} \sqrt{2(\Phi(r) - E)}\, F(E)\, dE$$

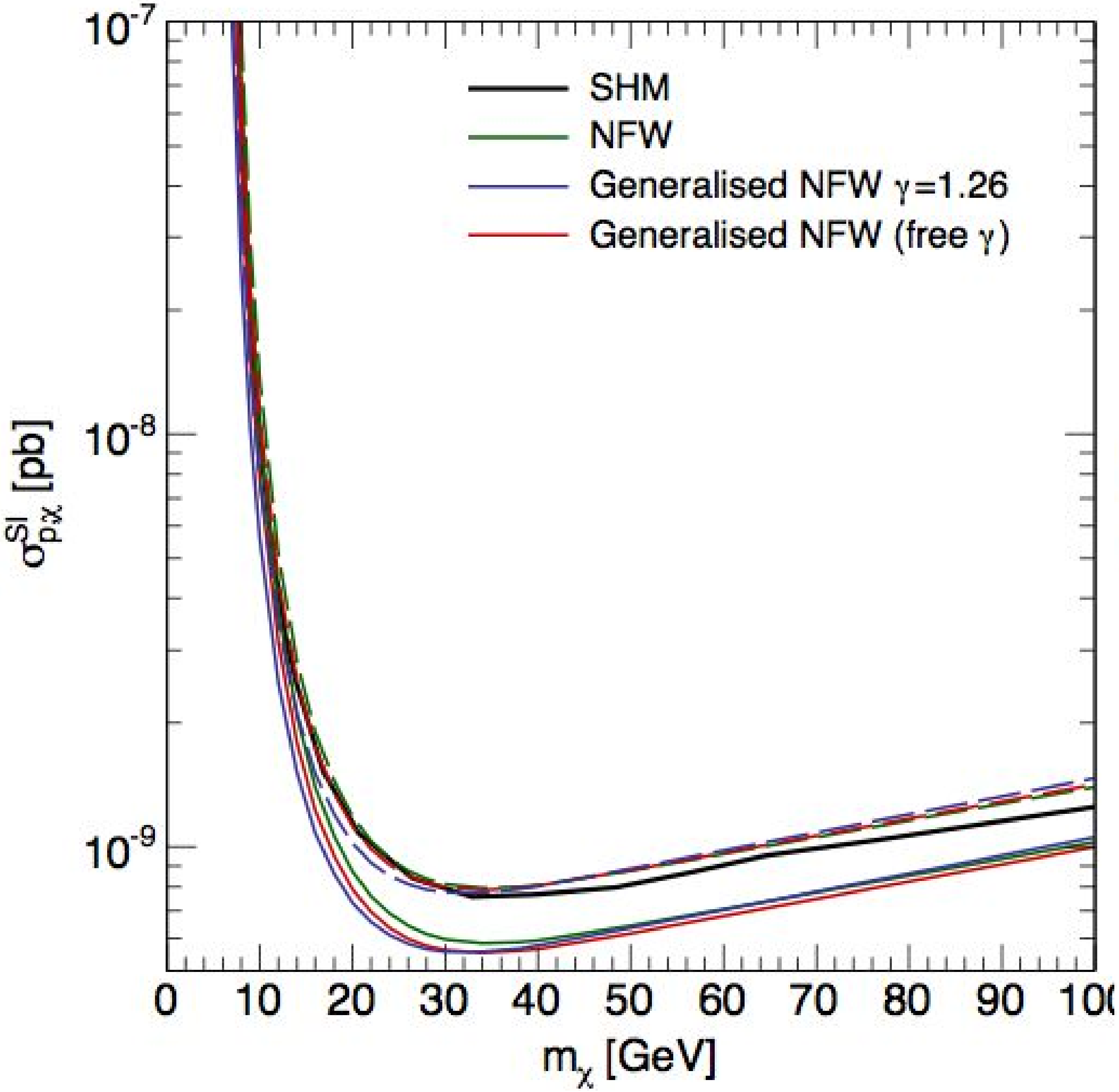
$$F(E) = \frac{1}{\sqrt{8}\pi^2} \left[\int_0^E \frac{d^2\rho}{d\Phi^2} \frac{d\Phi}{\sqrt{E - \Phi}} + \frac{1}{\sqrt{E}} \left(\frac{d\rho}{d\Phi} \right) \Big|_{\Phi=0} \right]$$

- original NFW with γ=1
- generalised NFW with γ=1.26
- generalised NFW with a free γ

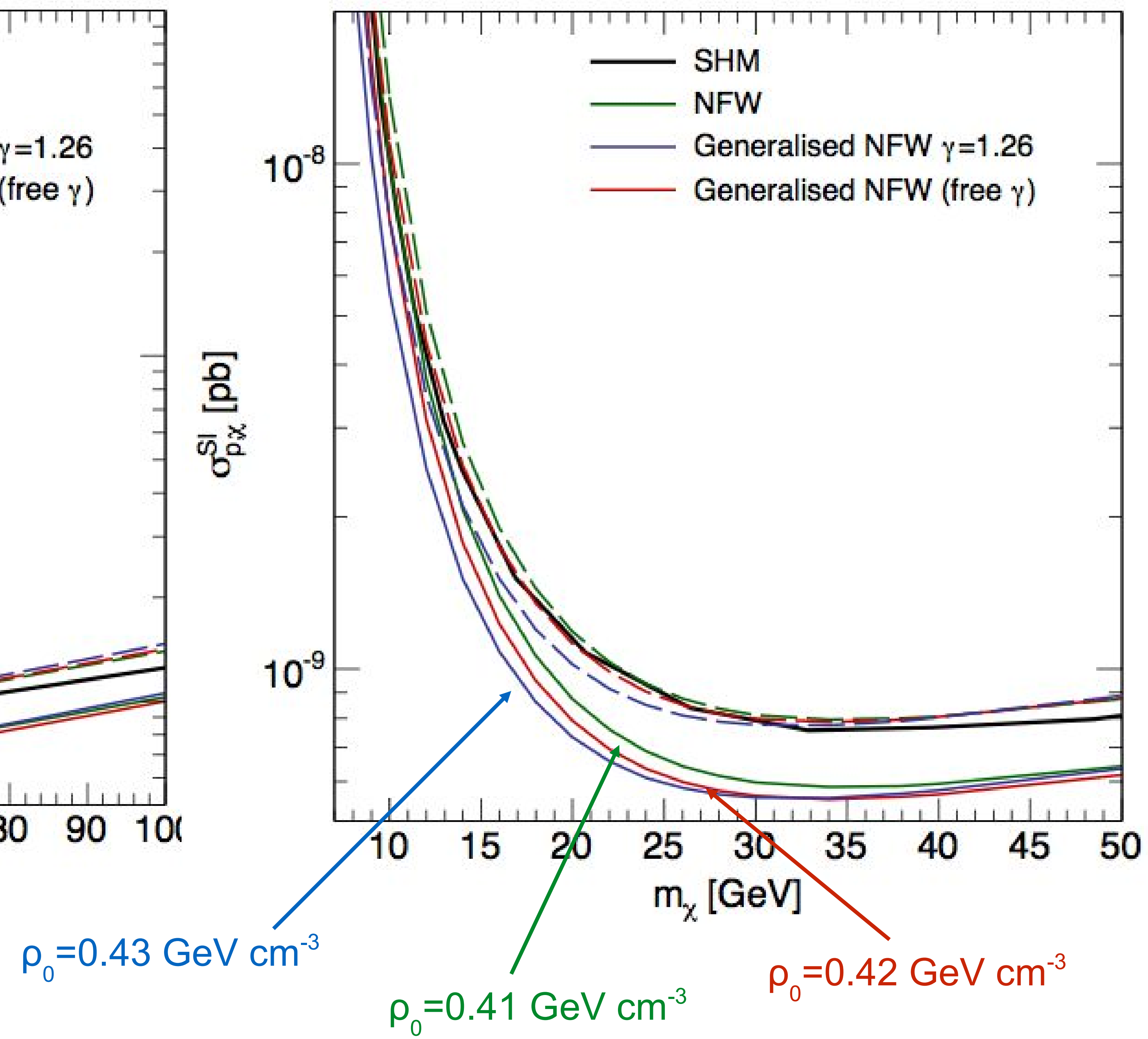








SHM
NFW
Generalised NFW γ=1.26
Generalised NFW (free γ)
$\sigma^{SI}_{p\chi}$ [pb]
m_χ [GeV]



SHM
NFW
Generalised NFW γ=1.26
Generalised NFW (free γ)
$\sigma^{SI}_{p\chi}$ [pb]
m_χ [GeV]
ρ_0=0.43 GeV cm^{-3}
ρ_0=0.41 GeV cm^{-3}
ρ_0=0.42 GeV cm^{-3}

Anisotropic systems

$$\rho(r) = 4\pi \int_0^{\Phi(r)} dE \int_0^{r\sqrt{2(\Phi(r)-E)}} dL \, \frac{F(E,L)}{r^2} \frac{1}{\sqrt{2(\Phi(r)-E)}} \frac{L}{\sqrt{1-\frac{L^2}{2r^2(\Phi(r)-E)}}}$$

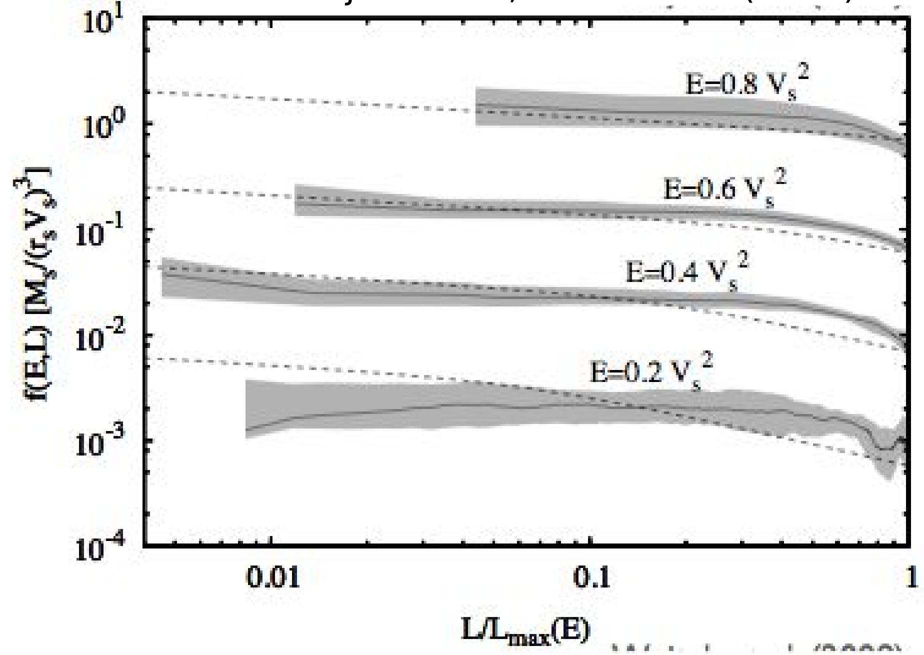
- $F(\mathbf{x},\mathbf{v})$ also depends on L and we take it to be separable: $F(E,L)=F_E(E)F_L(L)$
- $F_L(L)=L$k corresponds to a constant velocity anisotropy

$$\beta(r) = 1 - \frac{\langle v_T^2 \rangle}{2\langle v_r^2 \rangle}$$

- 3-parameter model of $F_L(L)$

$$F_L(L) = \left(1 + \frac{L^2}{2L_0^2}\right)^{-\beta_\infty+\beta_0} L^{-2\beta_0}$$

Wojtak et al., MNRAS 288 (2008) 815



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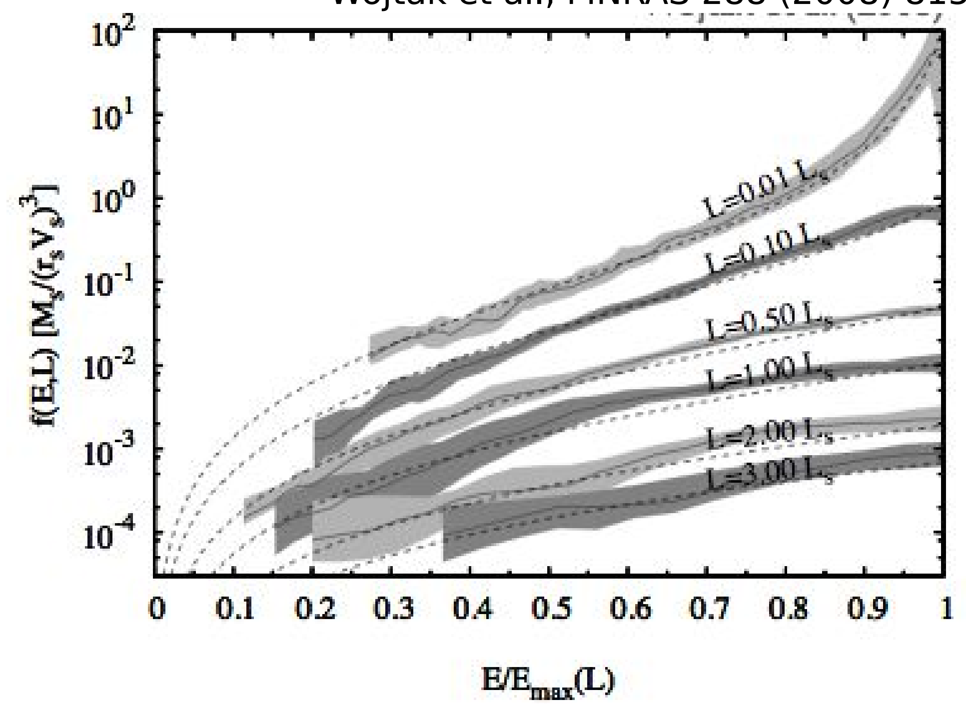
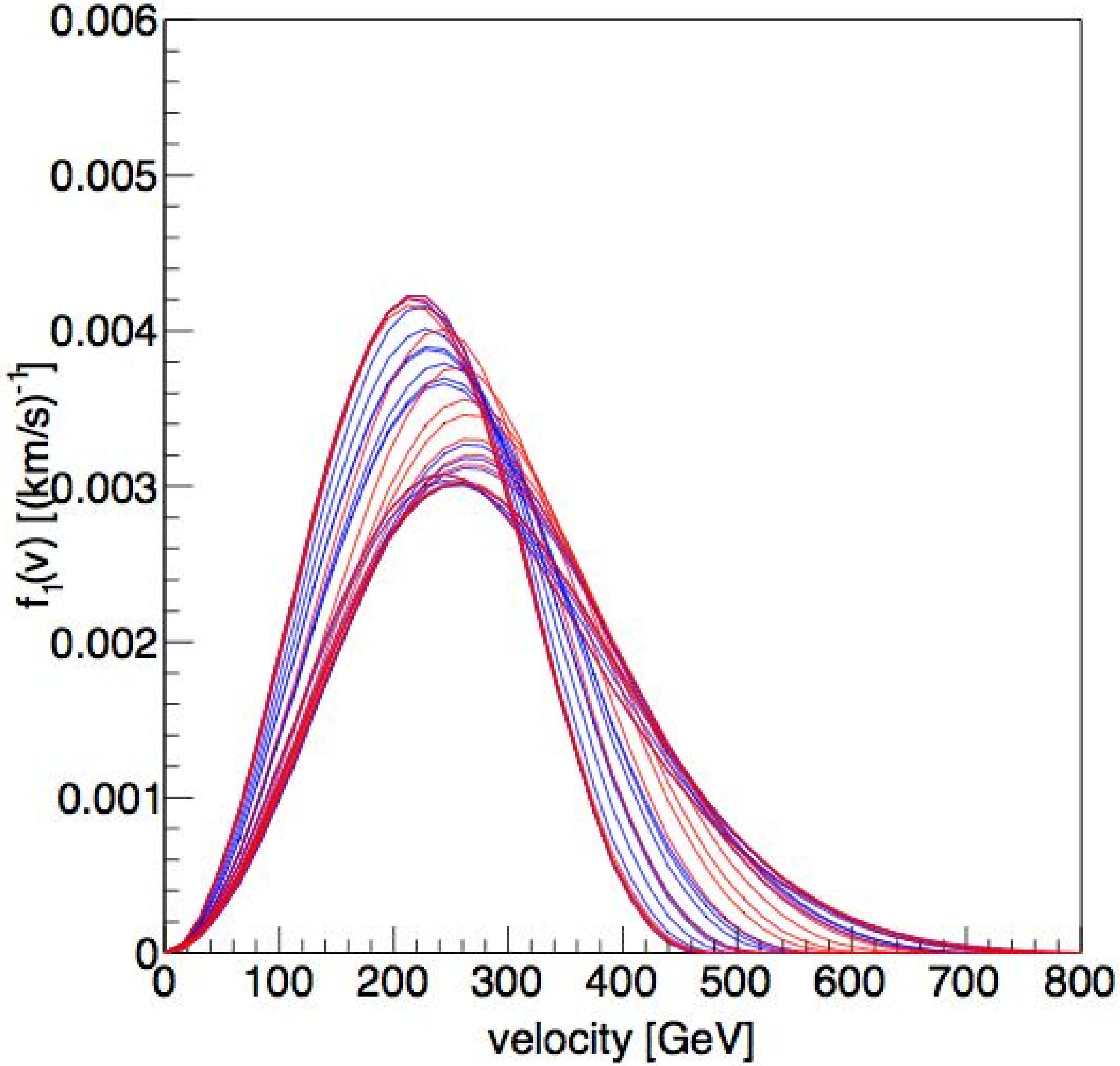
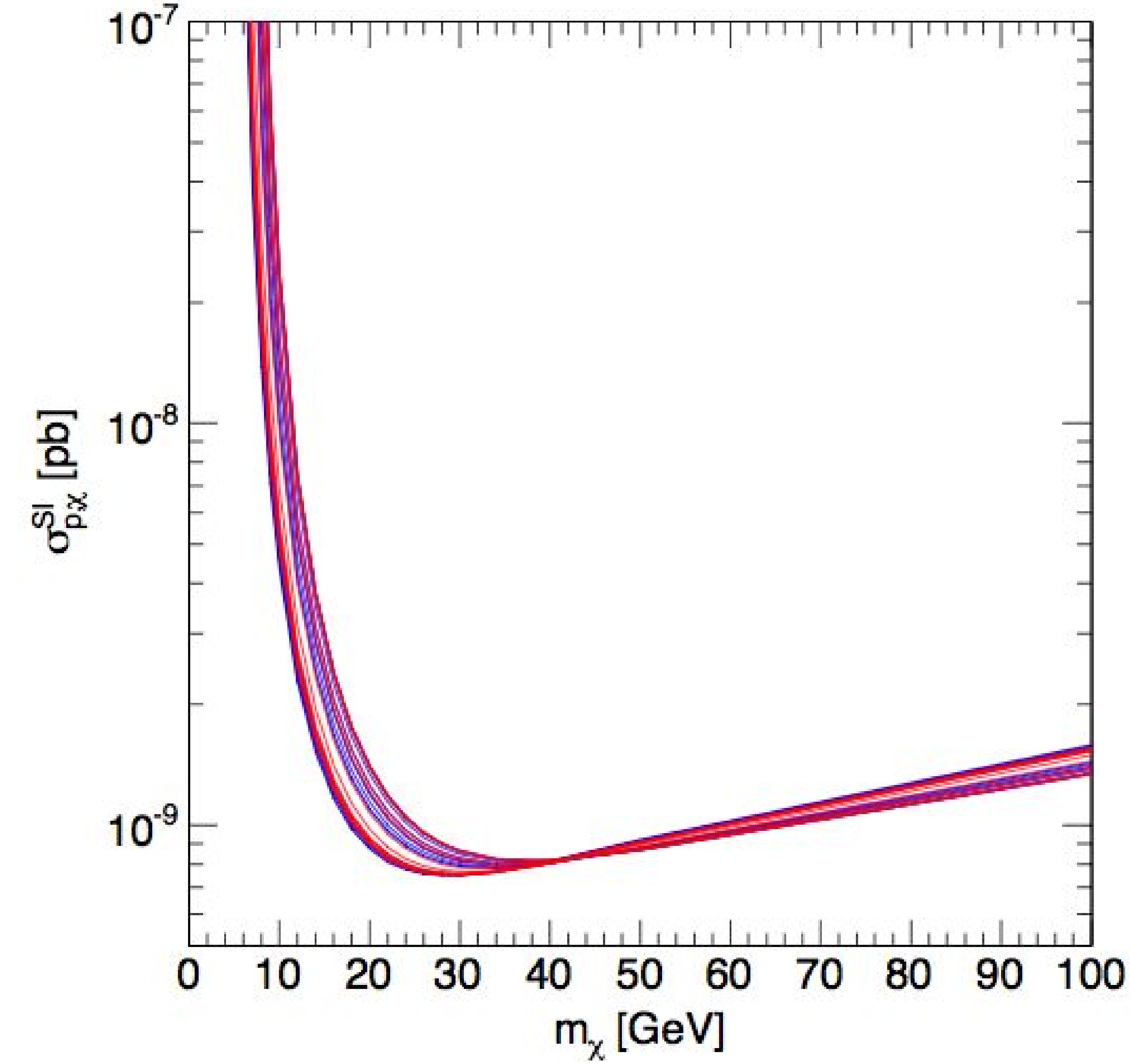


Conclusions

- take care of using consistent assumptions when combining results/predictions from different DM detection strategies
- impact of consistent halo description in LUX upper limits can be as large as a factor of 2
- it comes mainly from the value used for the local DM density
- it is possible to derive self-consistent $f1(v)$, at least for velocity-anisotropic spherical systems

Alternative way of estimating uncertainties





- Generalised NFW with free γ
- all upper limits have the same local DM density
- minimal and maximal *f*1(*v*) for different *v*, for all models inside the 95% C.L. region