The effect of the LMC on non-standard interactions on dark matter direct detection experiments

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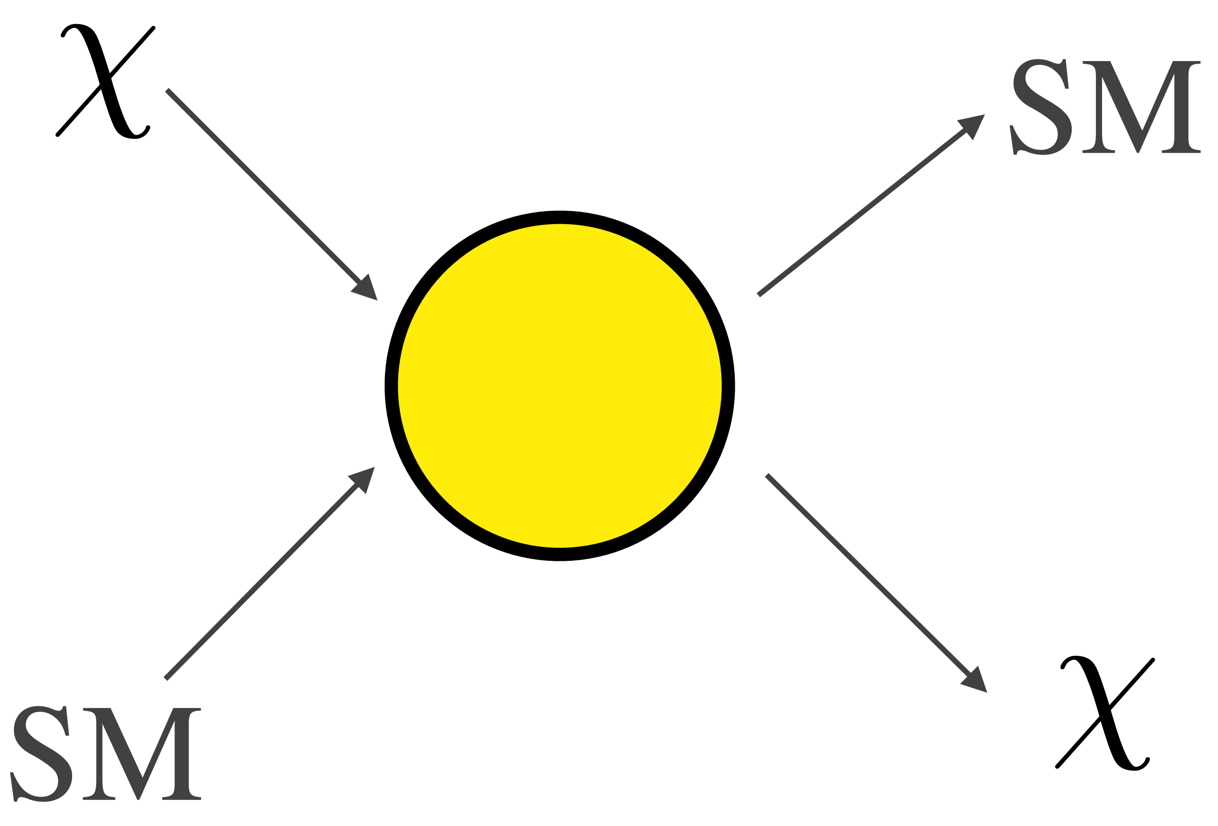
Introduction

Direct detection terrestrial experiments

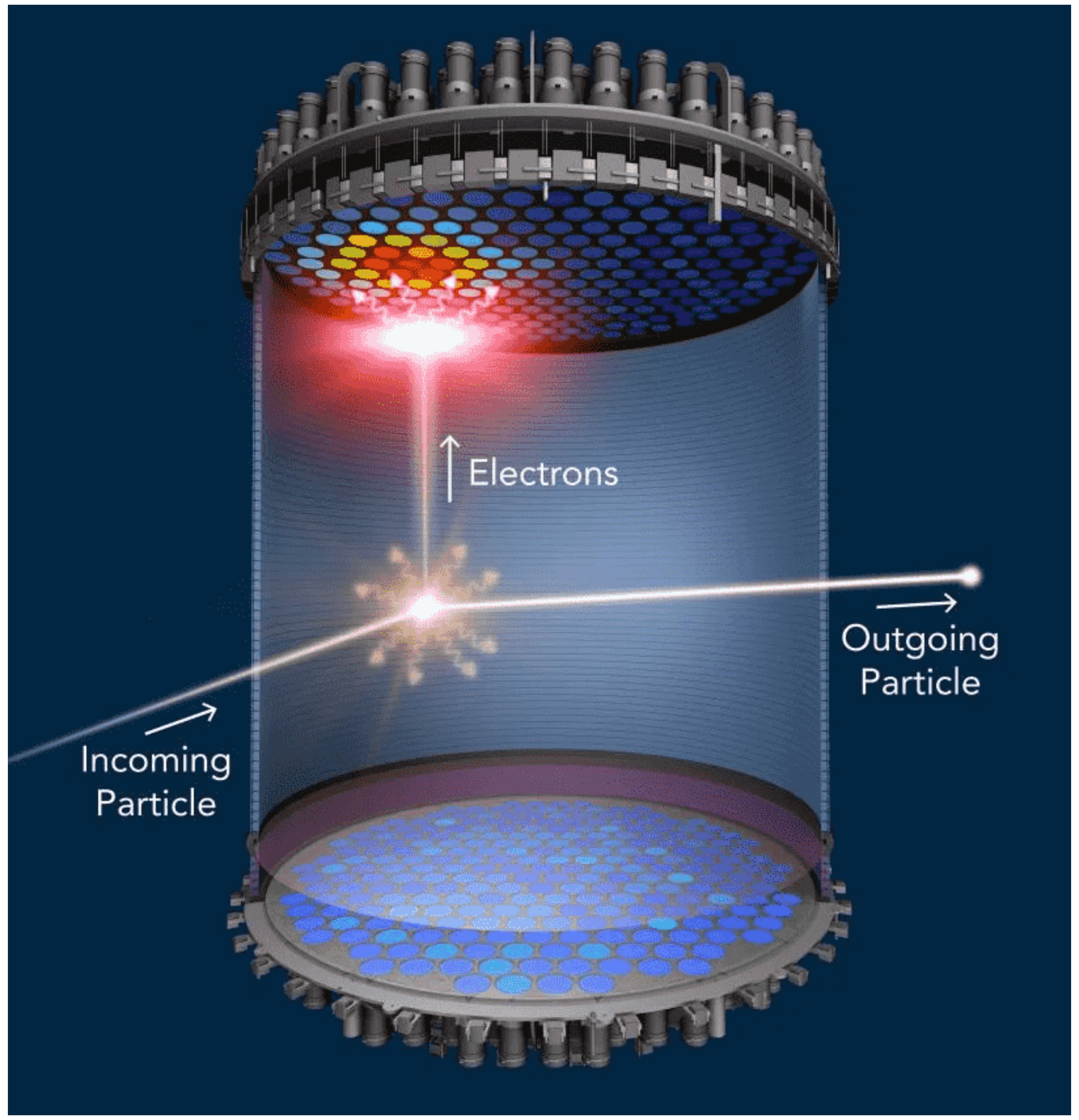


Differential event rate (per unit detector mass)

$$\frac{dR}{dE_R} = \frac{\rho_{\chi,0}}{m_\chi m_T} \int_{v>v_{\min}} d^3v \, \frac{d\sigma_{\chi N}}{dE_R} \, v \, f(\vec{v}, t)$$

Particle physics

Astrophysics



Direct detection experiments
Event rate, astro components

$$v_{\min} = \sqrt{\frac{m_T E_R}{2\mu_{\chi T}}}$$

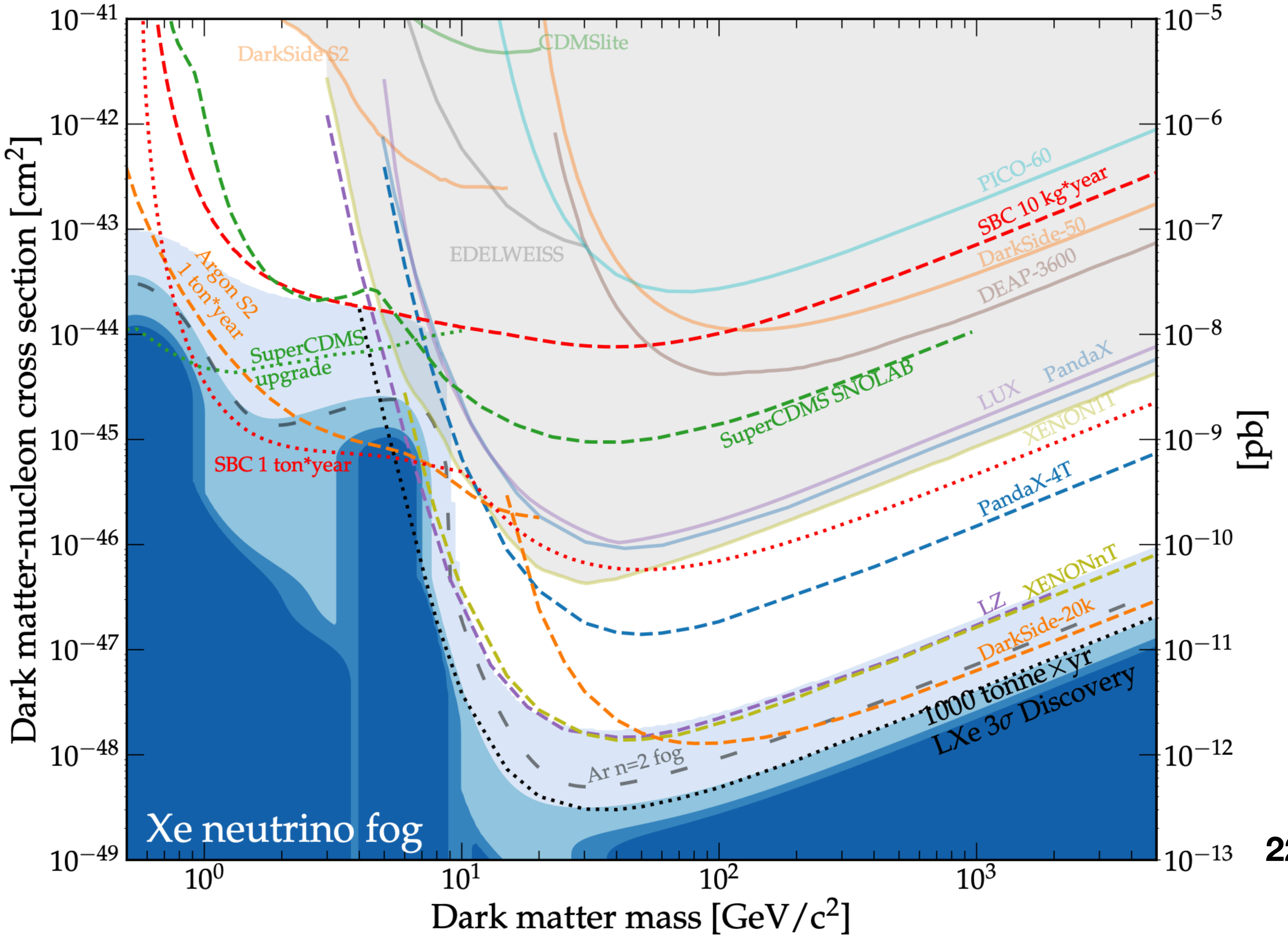
Direct detection limits

$$\eta(v_{\rm min}) = \int_{v>v_{\rm min}} d^3v \, \frac{f(\vec{v},t)}{v}$$

$$f(\vec{v},t)$$

Usual assumption:

Maxwell Boltzmann distribution



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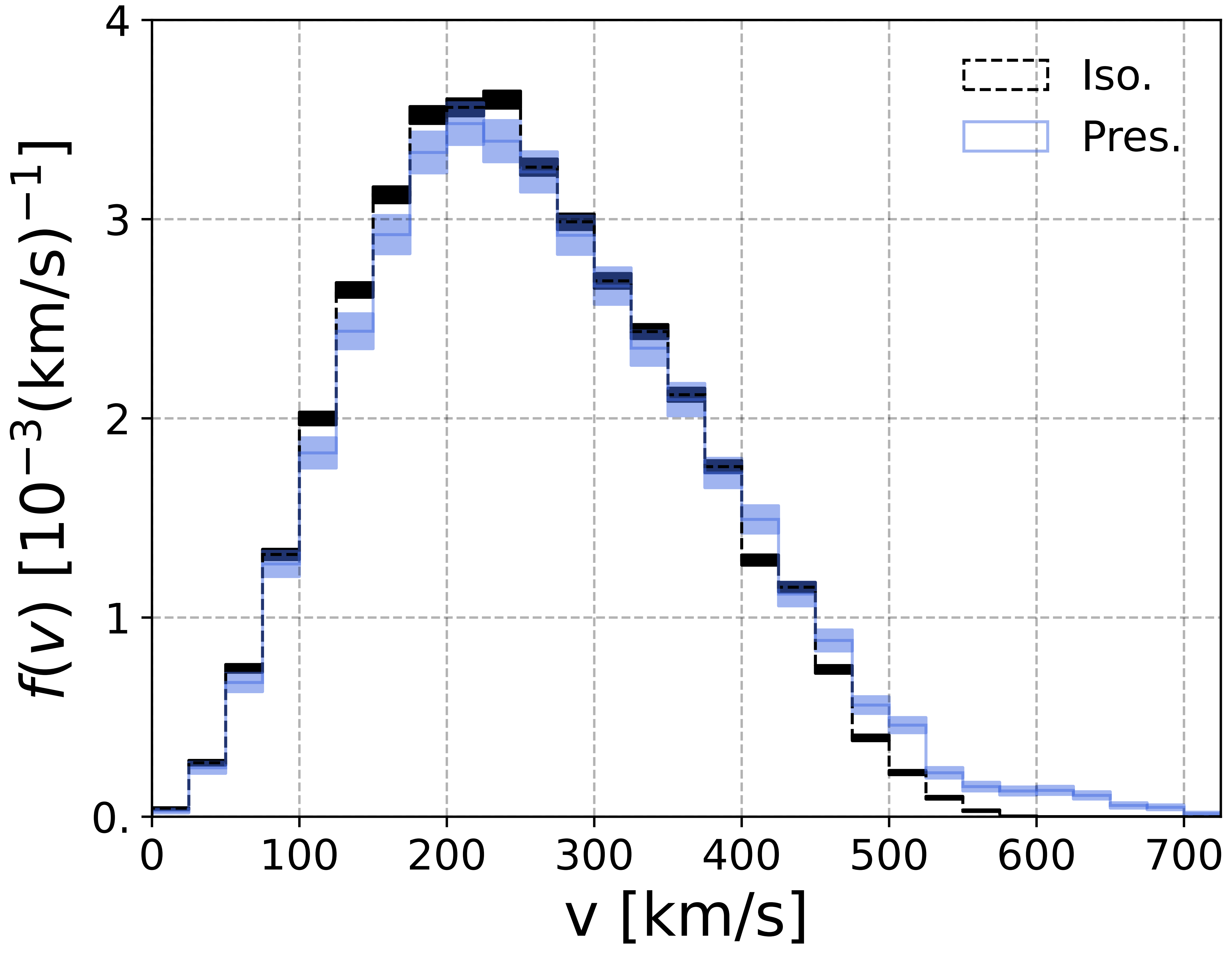
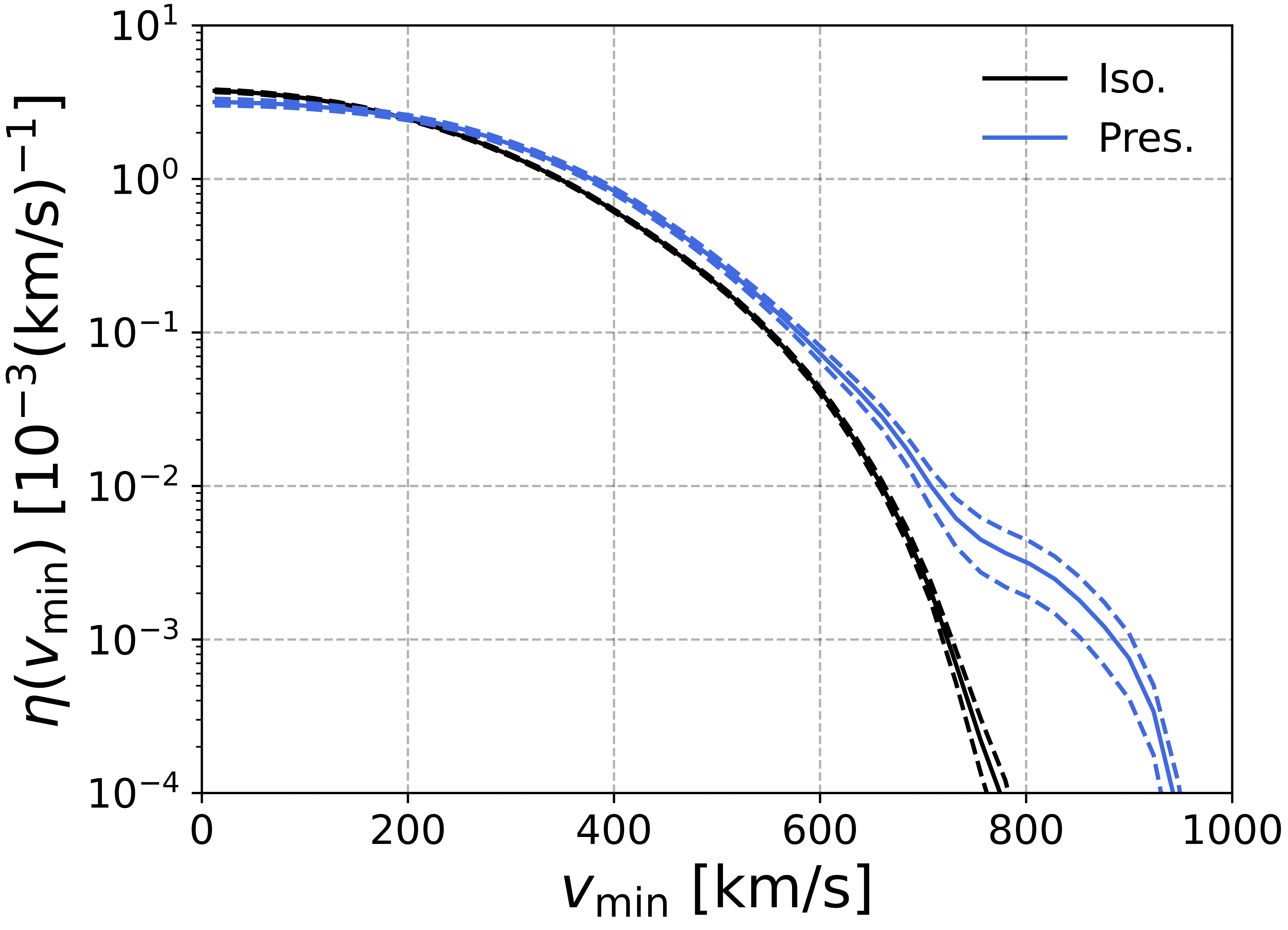
Dark Matter velocity distribution

Auriga cosmological simulations

The LMC dominates the high speed tail of the speed distribution

$$\eta(v_{\min}) = \int_{v>v_{\min}} d^3v \, \frac{f(\vec{v},t)}{v}$$





Non standard interactions

In the case of generalized non standard interactions

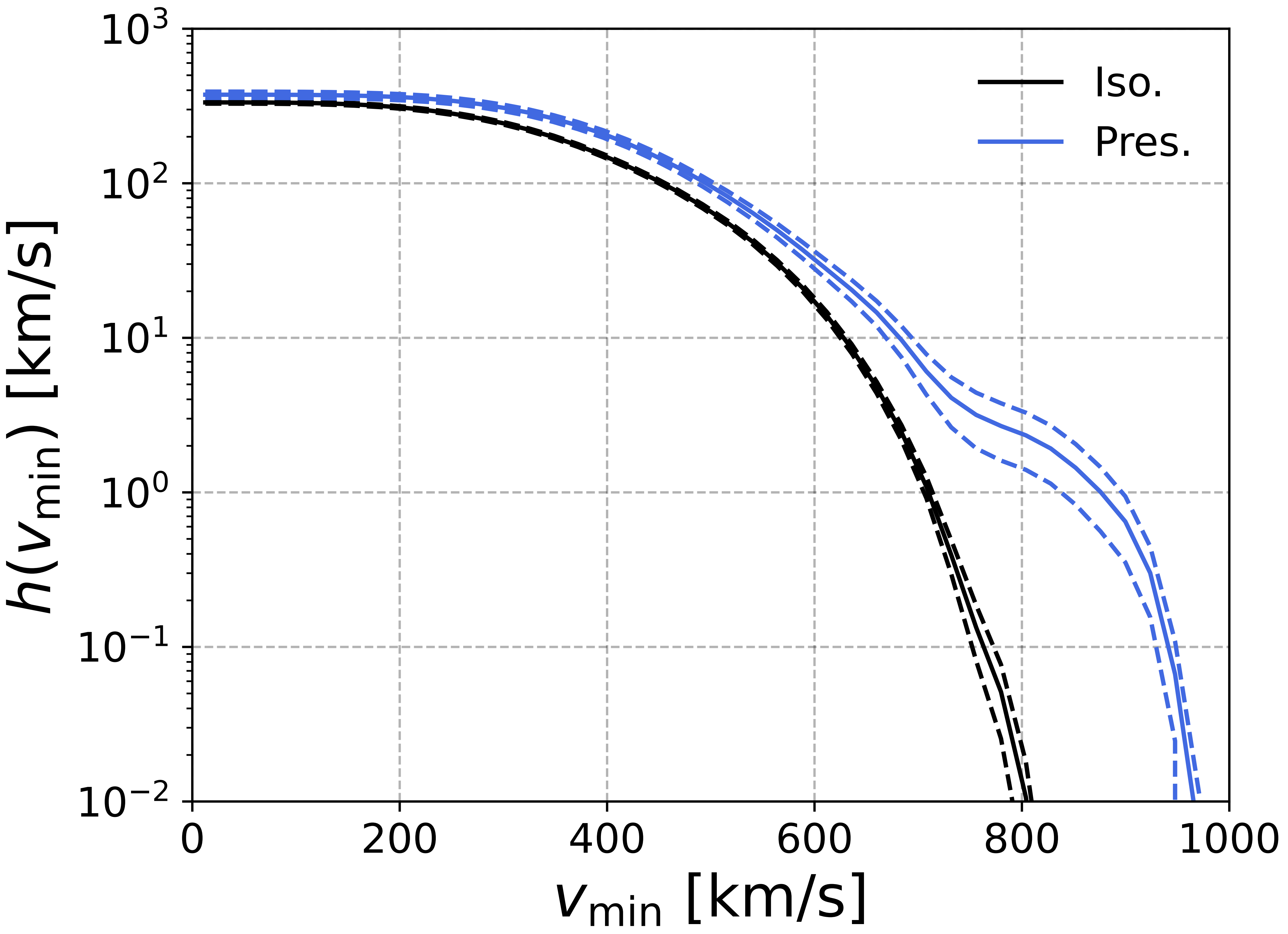
$$\frac{d\sigma_T}{dE_R} = \frac{d\sigma_1}{dE_R}\frac{1}{v^2} + \frac{d\sigma_2}{dE_R}$$

$h(v_{\min})$ **is a new velocity integral defined as:**

$$h(v_{\min}) = \int_{v>v_{\min}} d^3v\; v\, f(\overrightarrow{v}, t)$$

The rate can be expressed as

$$\frac{dR}{dE_R} = \frac{\rho}{m_\chi}\frac{1}{m_T}\left[\frac{d\sigma_1}{dE_R}\eta(v_{\min}, t) + \frac{d\sigma_2}{dE_R}h(v_{\min}, t)\right]$$



Non relativistic effective field theory (NREFT)

Parametrize all possible DM - nucleon interactions using the set of operators $\{\mathcal{O}_i\}$

Operator	Scaling factor
$\mathcal{O}_1 = 1_\chi 1_N$	1
$\mathcal{O}_3 = i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}_\perp\right)$	$q^2 v_\perp^2,\ q^4$
$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$	1
$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}_\perp\right)$	$q^2 v_\perp^2,\ q^4$
$\mathcal{O}_6 = \left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left(\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right)$	q^4
$\mathcal{O}_7 = \vec{S}_N \cdot \vec{v}_\perp$	$v_\perp^2$
$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}_\perp$	$v_\perp^2,\ q^2$
$\mathcal{O}_9 = i\vec{S}_\chi \cdot \left(\vec{S}_N \times \frac{\vec{q}}{m_N}\right)$	q^2
$\mathcal{O}_{10} = i\vec{S}_N \cdot \frac{\vec{q}}{m_N}$	q^2
$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}$	q^2
$\mathcal{O}_{12} = \vec{S}_\chi \cdot \left(\vec{S}_N \times \vec{v}_\perp\right)$	$v_\perp^2,\ q^2$
$\mathcal{O}_{13} = i\left(\vec{S}_\chi \cdot \vec{v}_\perp\right)\left(\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right)$	$q^2 v_\perp^2,\ q^4$
$\mathcal{O}_{14} = i\left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left(\vec{S}_N \cdot \vec{v}_\perp\right)$	$q^2 v_\perp^2$
$\mathcal{O}_{15} = -\left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left(\left(\vec{S}_N \times \vec{v}_\perp\right) \cdot \frac{\vec{q}}{m_N}\right)$	$q^4 v_\perp^2,\ q^6$

Contains momentum dependent and velocity dependent interactions

$$\frac{d\sigma_T}{dE_R} = \frac{2m_T}{v^2(2J+1)}\left[\sum_{k=M,\Sigma',\Sigma''} R_k(v_\perp^2, q^2)\, W_k(q^2) + \frac{q^2}{m_N^2}\sum_{k=\Phi'',\tilde{\Phi}',\Delta} R_k(v_\perp^2, q^2)\, W_k(q^2)\right]$$

Isoscalar interactions $c_i^p = c_i^n$

$$\sigma_{\chi p} \equiv \frac{\left(c_i^p \mu_p\right)^2}{\pi}$$

$\mathcal{O}_1$ corresponds to the standard spin-independent interaction but this is not true for the other operators

Experiments

We focus on different target materials

Darwin (Xenon)

DarkSide-20k (Argon)

NEWS-G (Neon + methane)

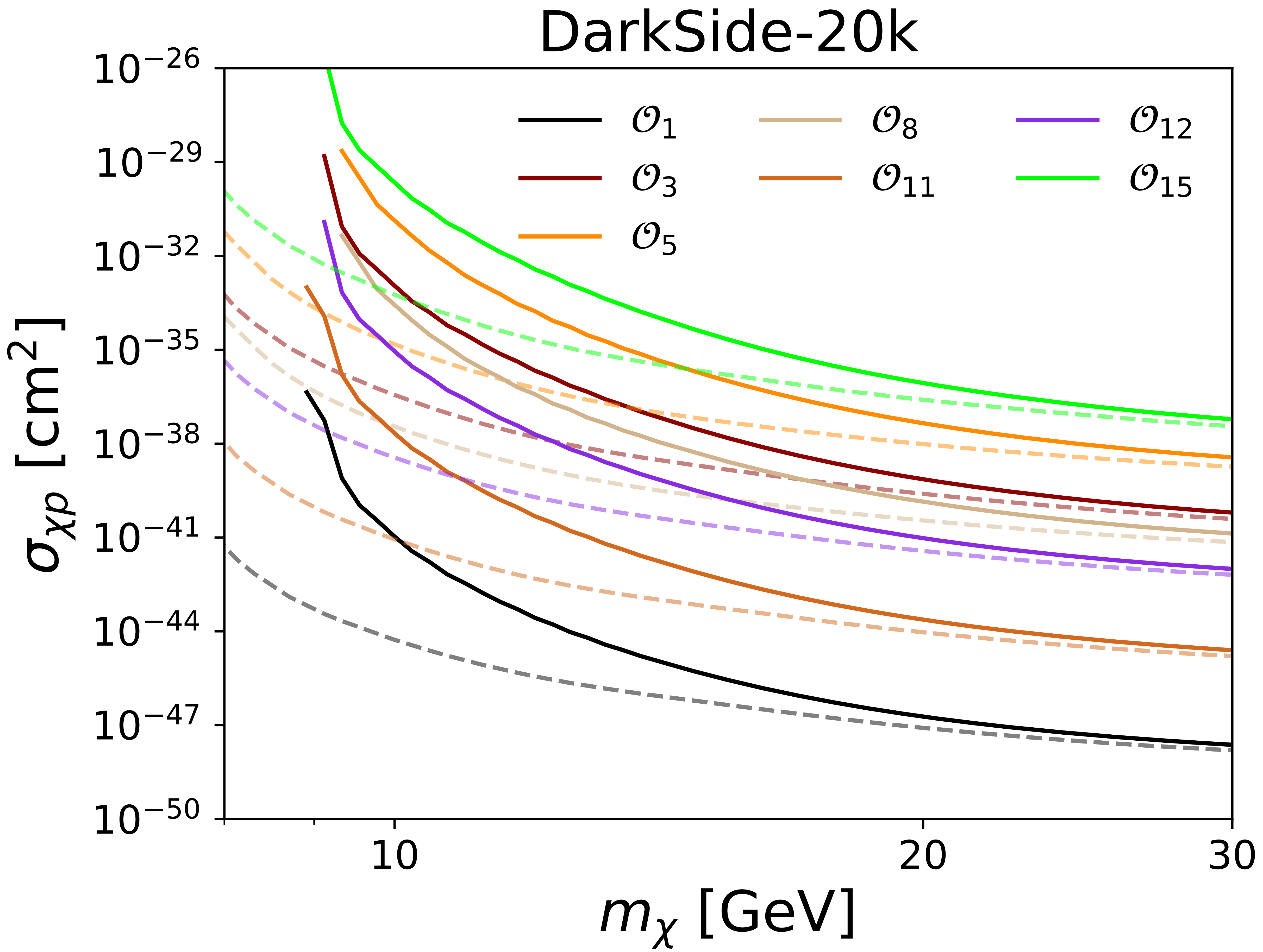
SuperCDMS (Germanium)

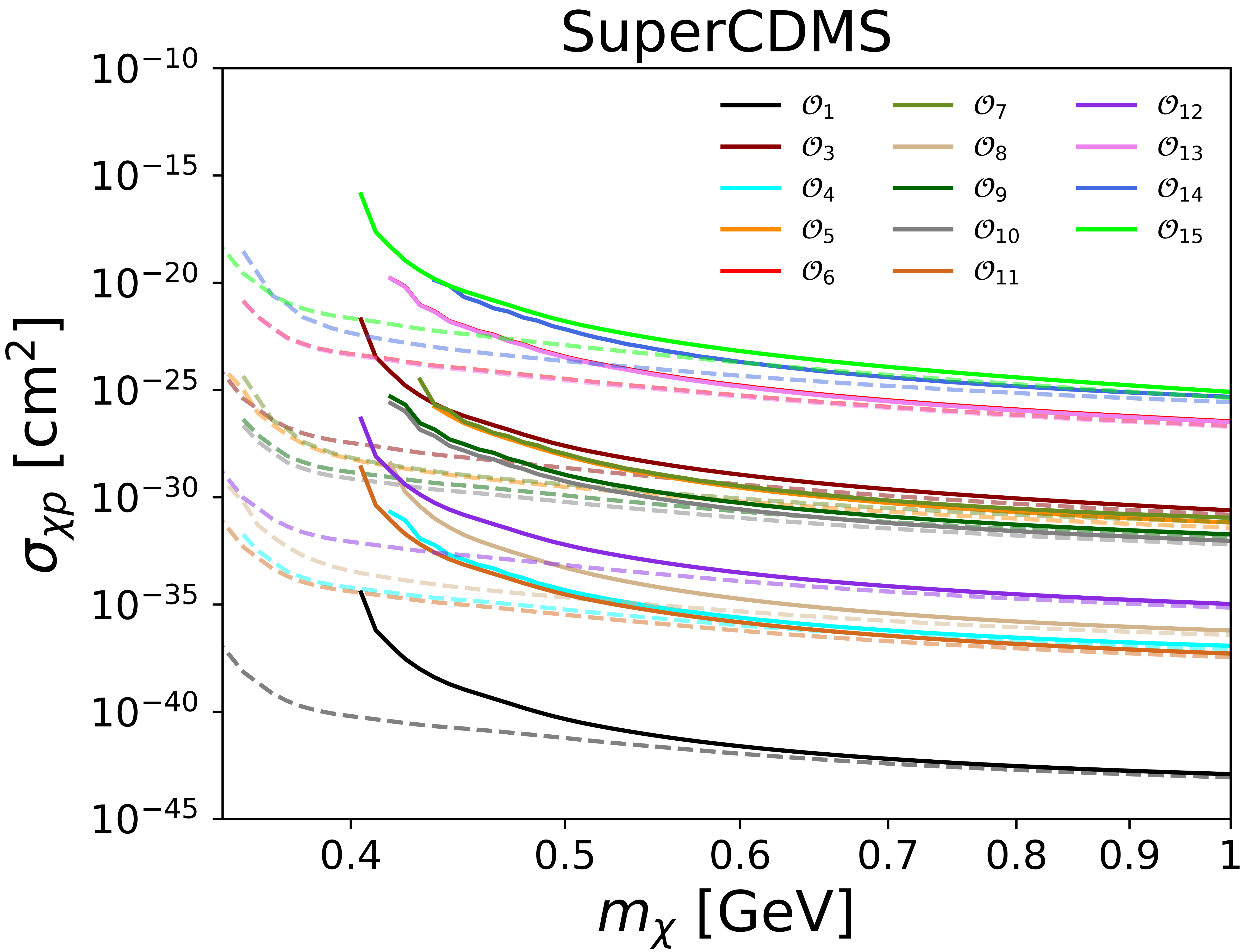
Experiment	Exposure [kg· d]	Energy threshold [keVnr]
DarkSide-20k	3.65×10^7	30
Darwin	7.3×10^7	1
NEWS-G	20	0.01
SuperCDMS	1.6×10^4	0.04

- We are also working to provide results for other experiments: SBC (Argon) and DarkSphere (Helium)

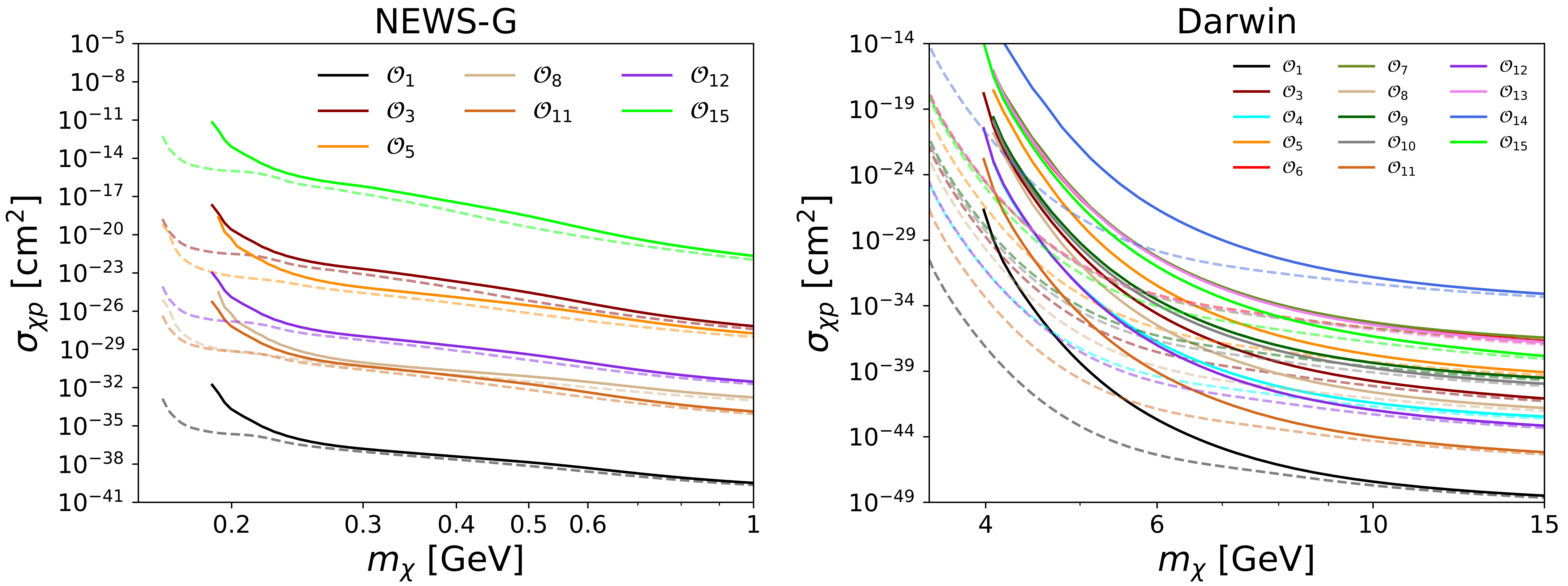
Results NREFT

Preliminary



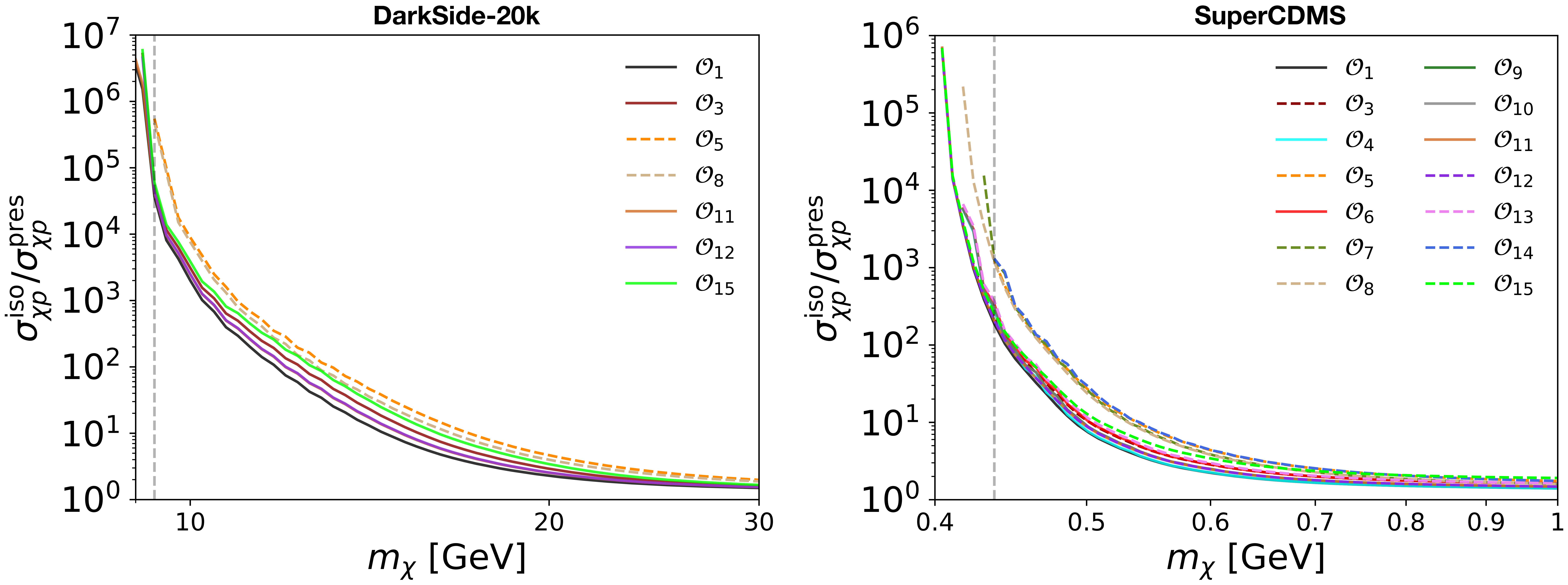


Results NREFT



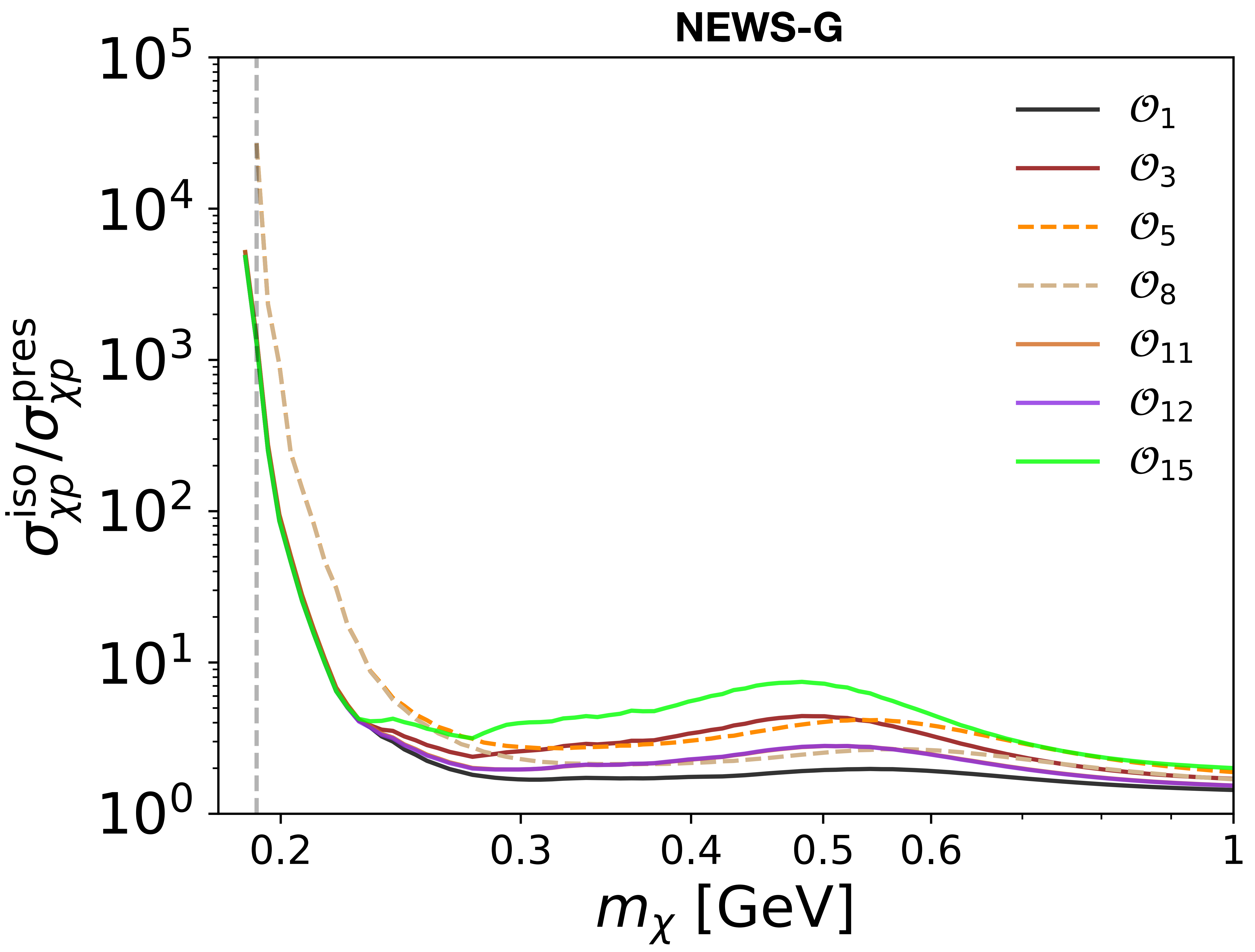
Results NREFT

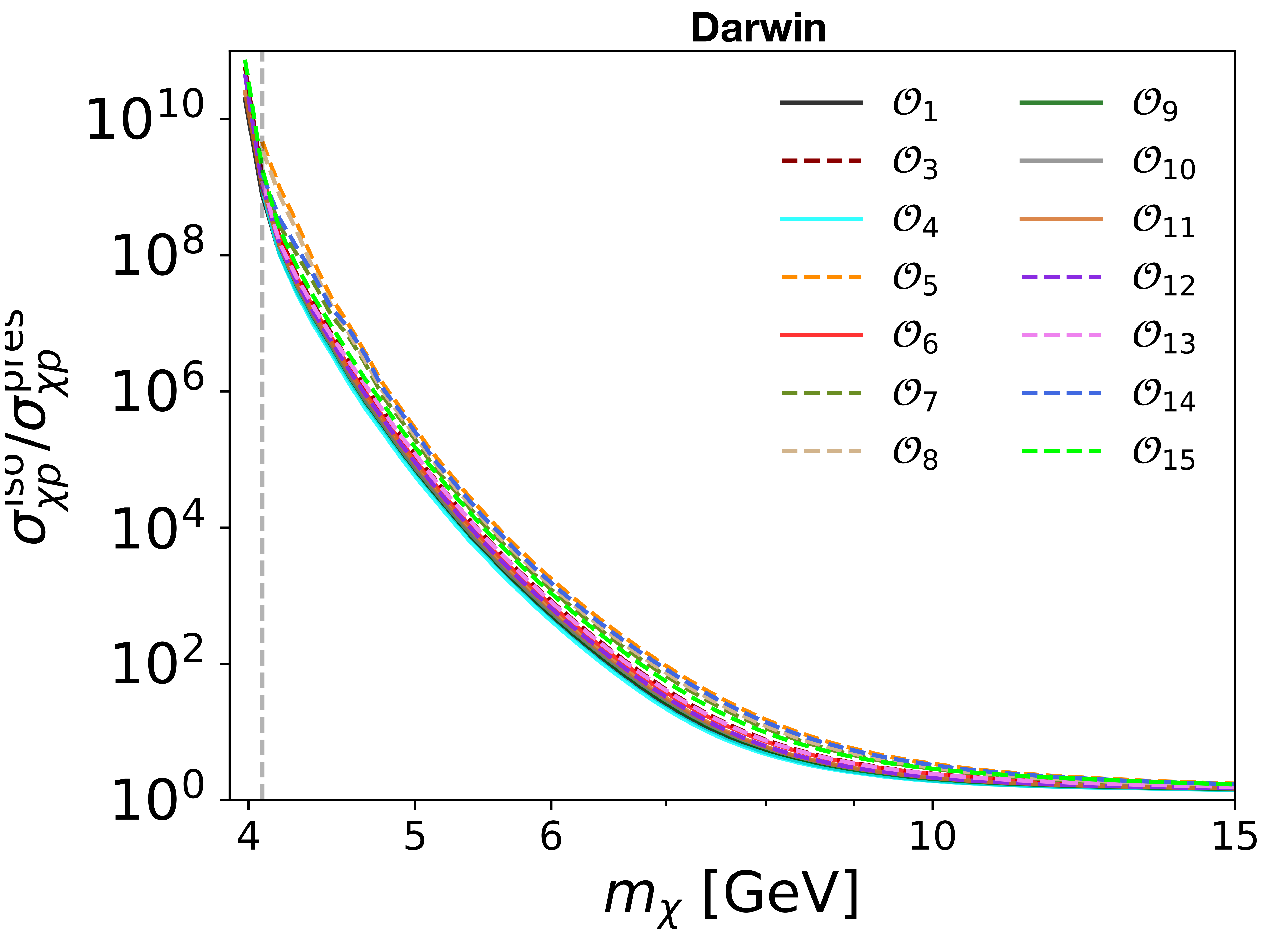
Preliminary



Results NREFT

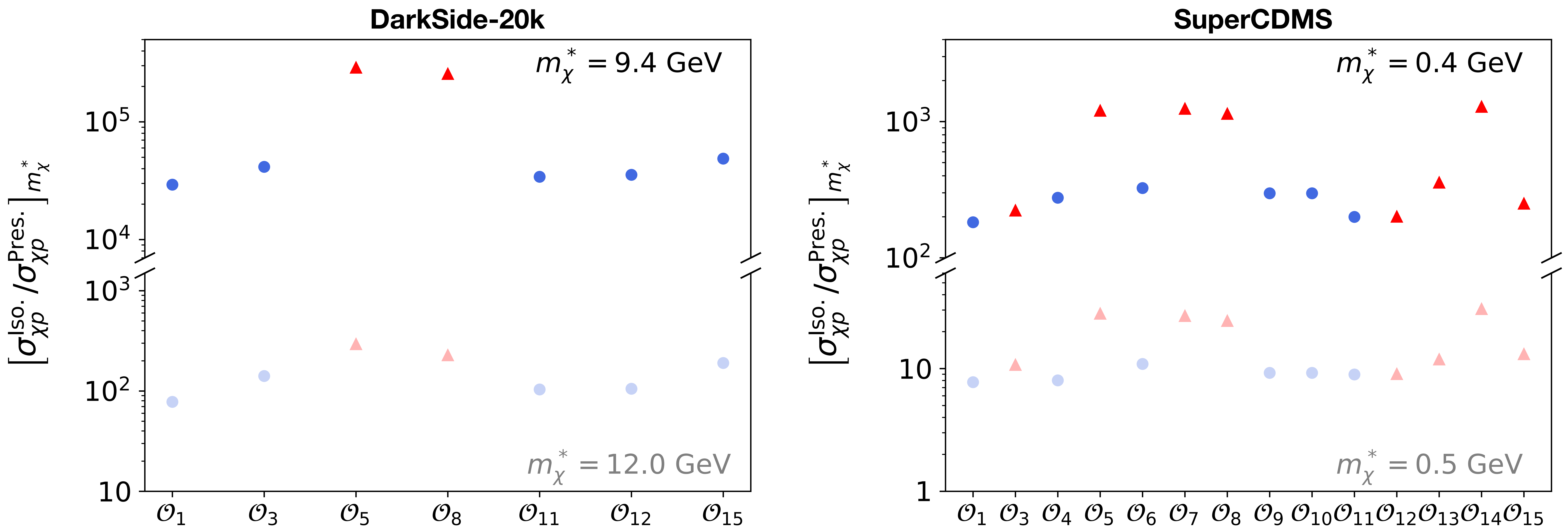
Preliminary





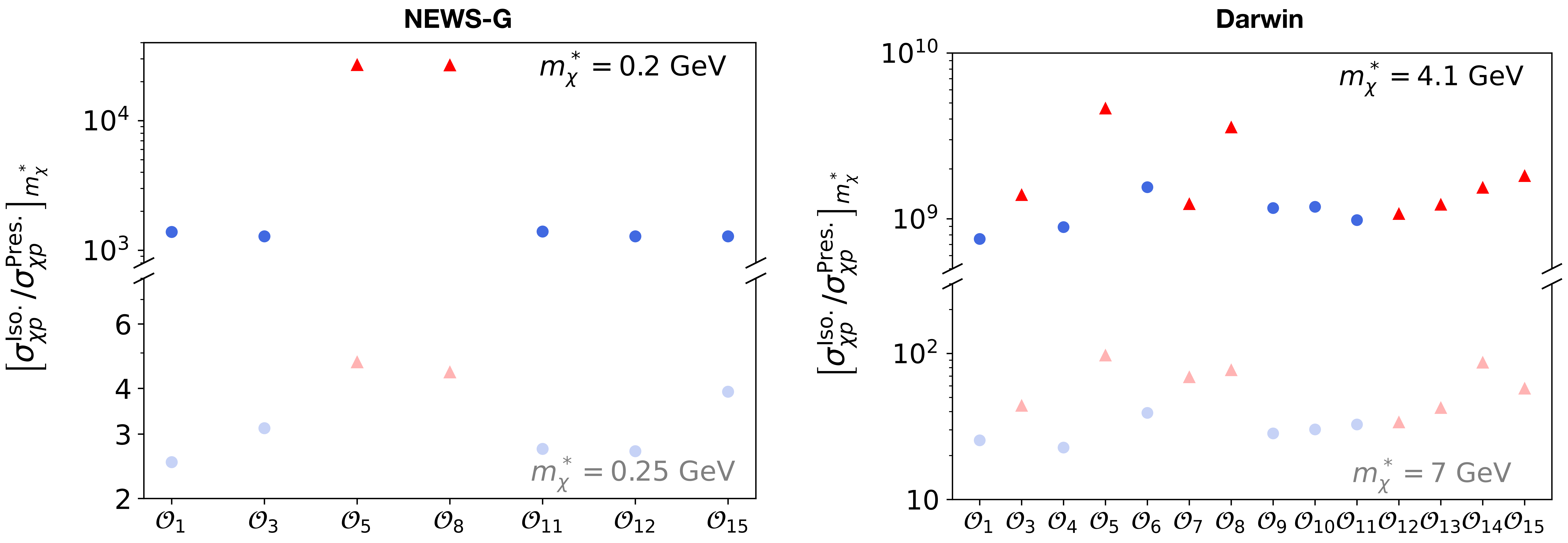
Results NREFT

Preliminary



Results NREFT

Preliminary

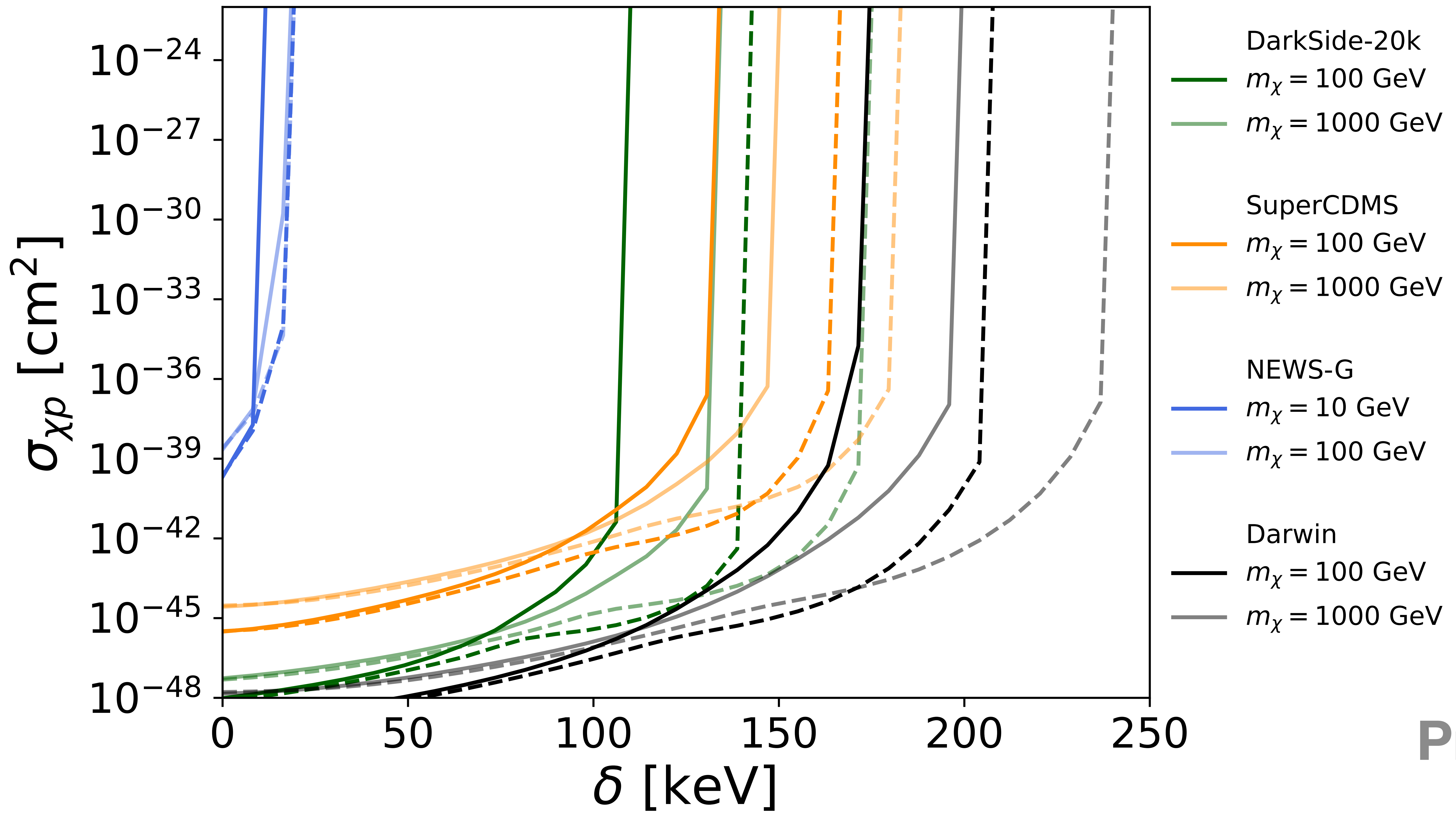


Inelastic scattering

Dark matter scattering to heavier mass state

$$\delta = m_\chi^* - m_\chi$$

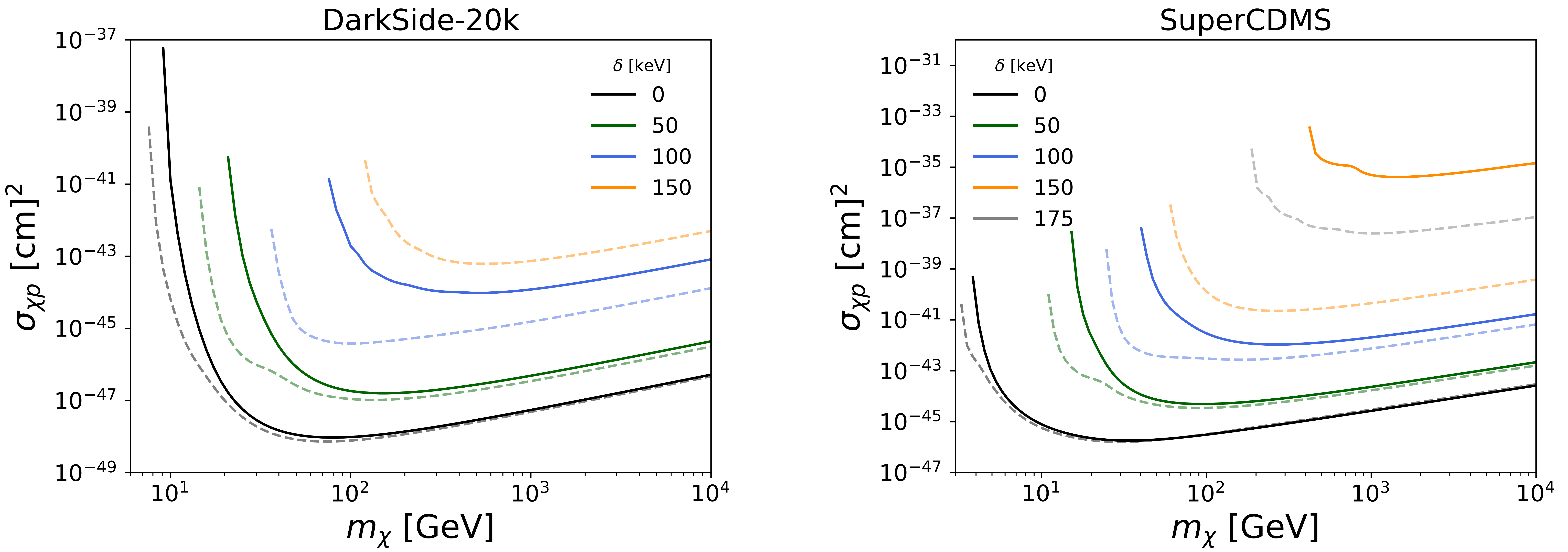
$$v_{\mathrm{min}} = \sqrt{\frac{1}{2m_T E_R}}\left(\frac{m_T E_R}{\mu_{\chi T}} + \delta\right)$$



Preliminary

Results Inelastic scattering

Preliminary



Conclusions

- We have studied the impact of the LMC on near-future direct detection experiments experiments using the Auriga simulations

- We have extended the standard SI (SD) interactions and consider non-standard interactions

- We have used different target materials

- We have found that the LMC has a greater impact on lower

- We have found that velocity-dependent operators tend to have greater impact when the LMC is considered in the velocity distribution (e.g $\mathcal{O}_5$, $\mathcal{O}_8$ for Ar and Ne)

- In the case of inelastic scattering, the presence of the LMC improves the sensitivity of the detector for greater values of the mass splitting parameter δ

Backup

$$\mathcal{L}_i(N_{\mathrm{p},i}|N_{\mathrm{o},i}) = \frac{(b_i + N_{\mathrm{p},i})^{N_{\mathrm{o},i}} \, e^{-(b_i+N_{\mathrm{p},i})}}{N_{\mathrm{o},i}!}$$

Poisson likelihood

DarkSide-20k: 0 events, 1 ν induced background event

Darwin: 1 observed event and 2.37 background events

NEWS-G: $1.67\ \mathrm{kg}^{-1}\ \mathrm{d}^{-1}\ \mathrm{keV}^{-1}$ **for the differential background with 0 expected events**

SuperCDMS: $10\ \mathrm{kg}^{-1}\ \mathrm{yr}^{-1}\ \mathrm{keV}^{-1}$ **differential background rate with 0 expected events**