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

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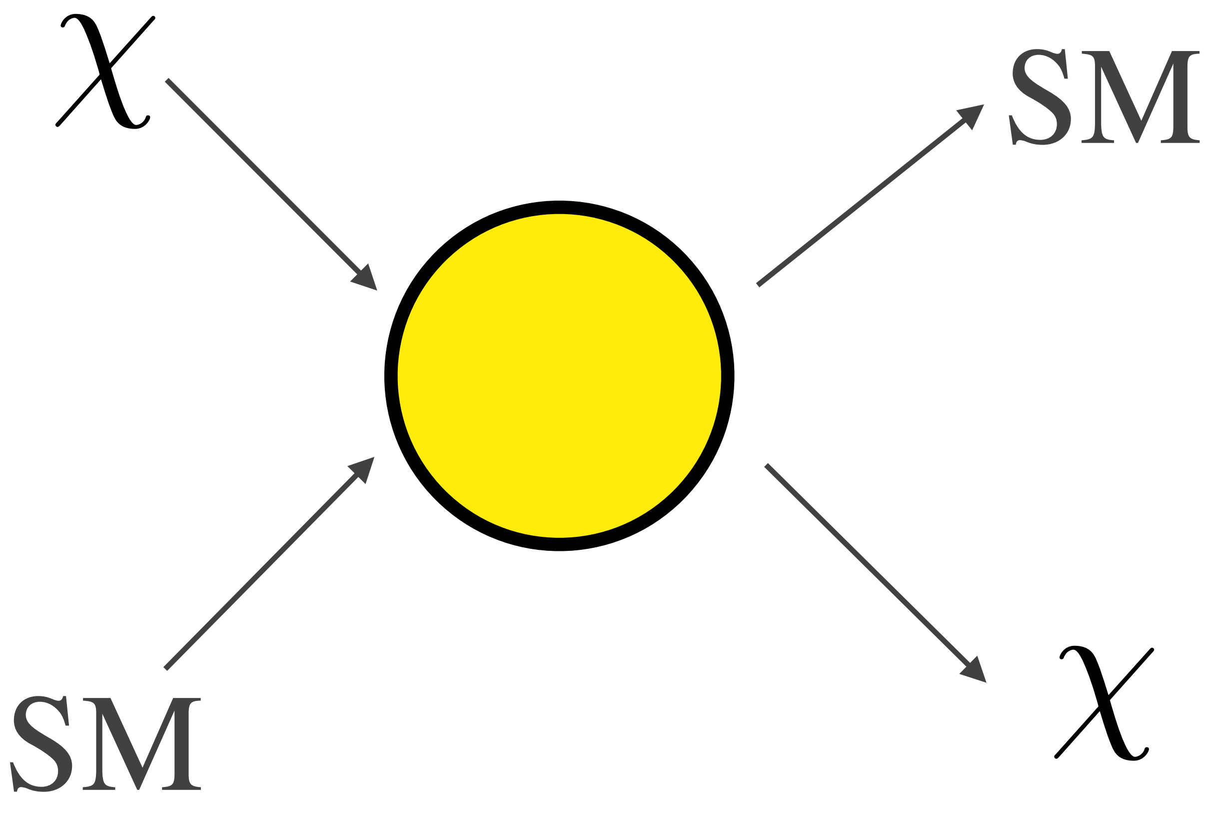
Introduction

Direct detection terrestrial experiments

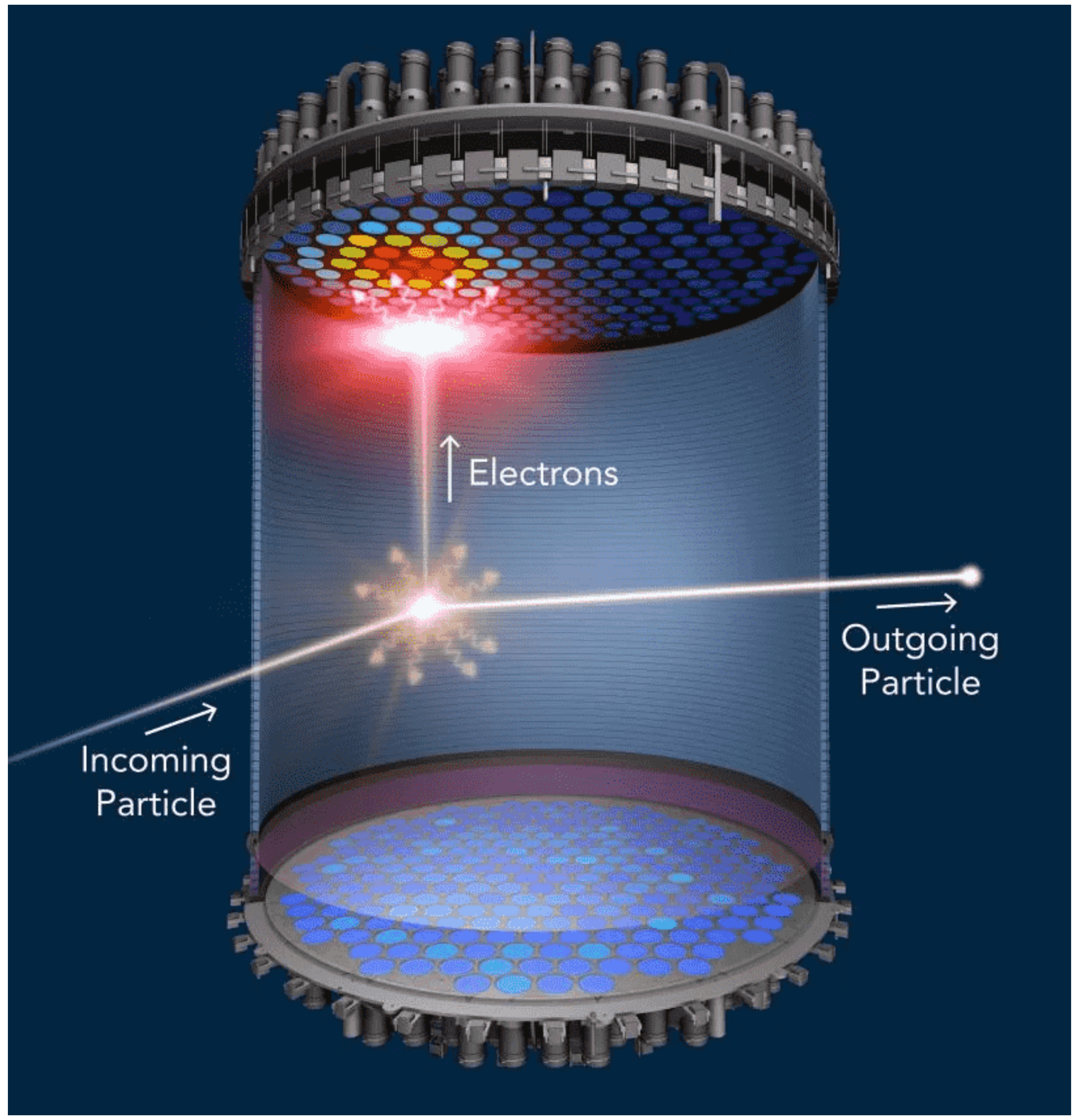


Differential event rate (per unit detector mass)

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

Particle physics

Astrophysics



Direct detection experiments
Event rate, astro components

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

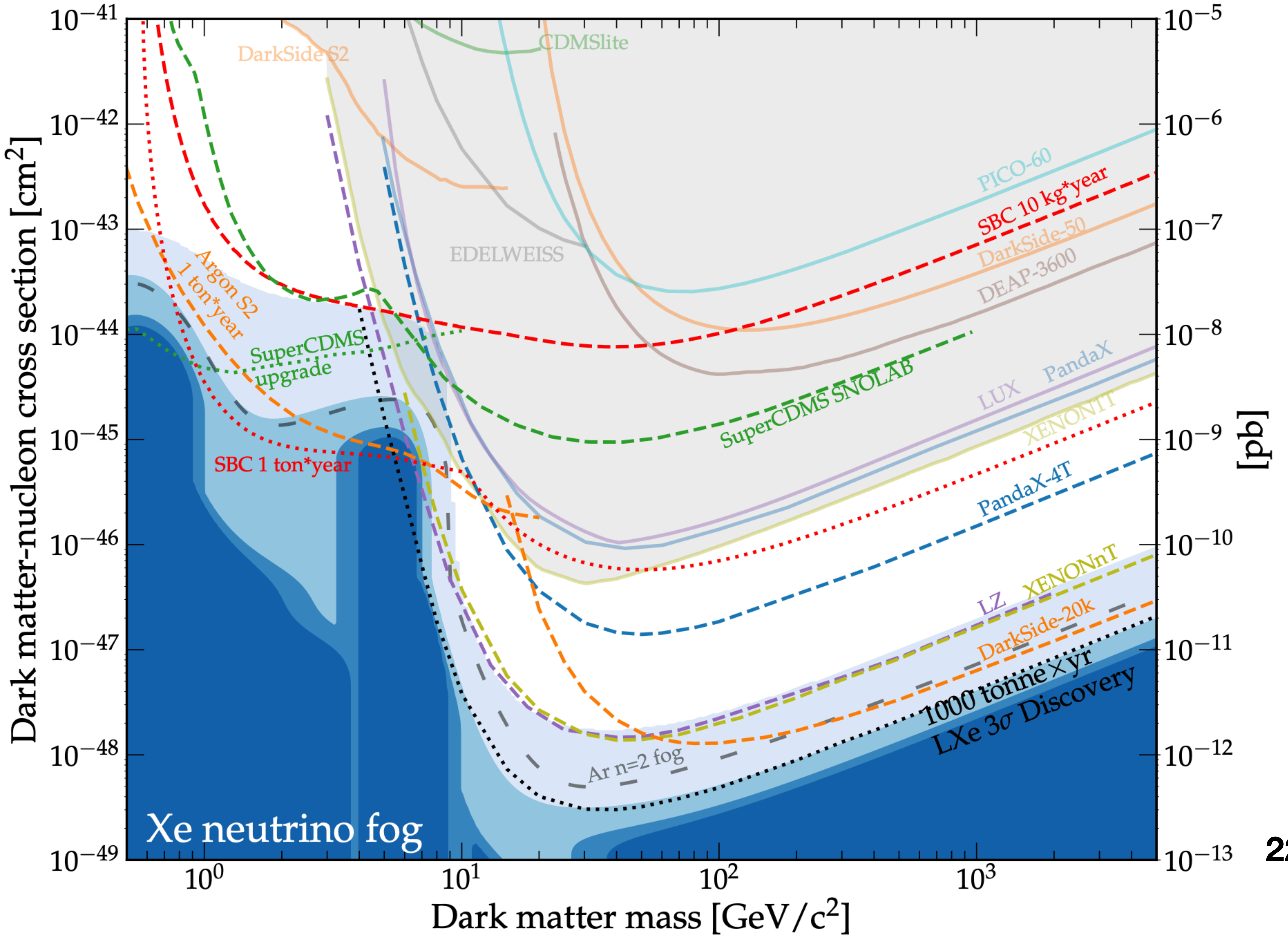
Direct detection limits

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

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

Usual assumption:

Maxwell Boltzmann distribution



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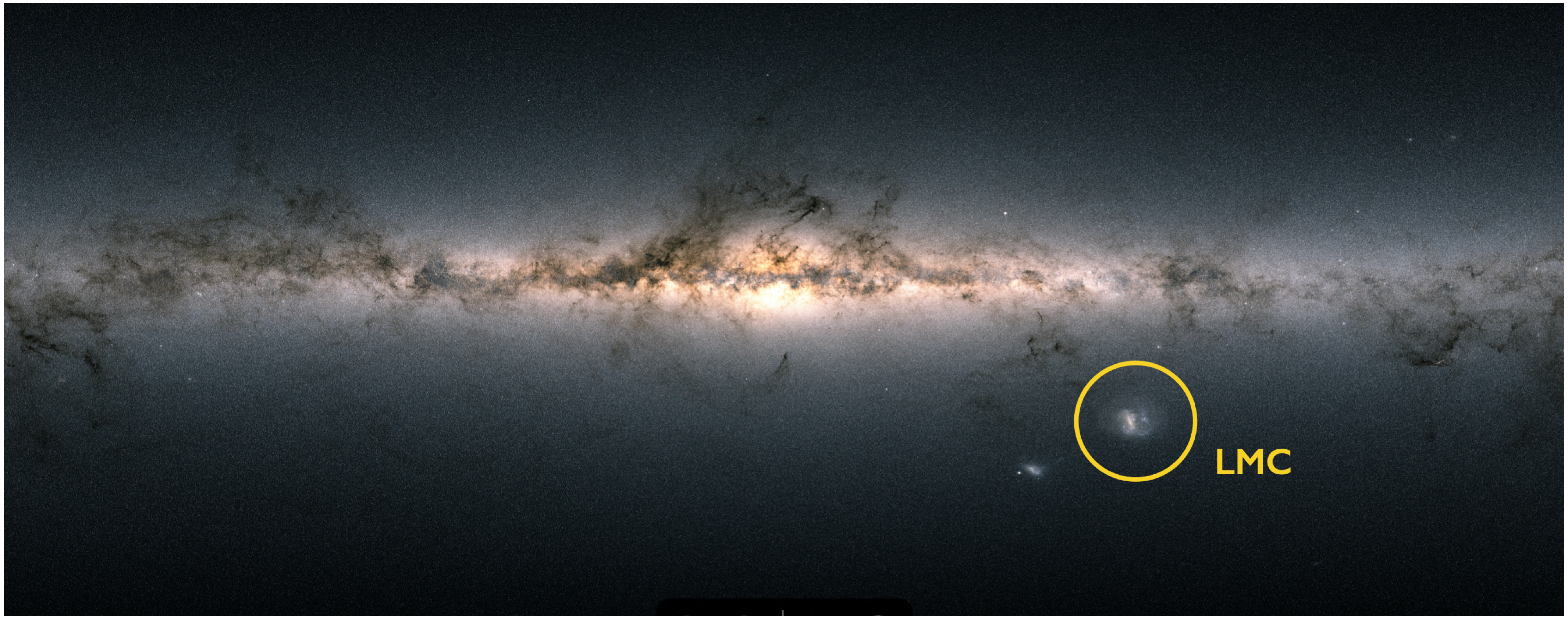
The Large Magellanic Cloud

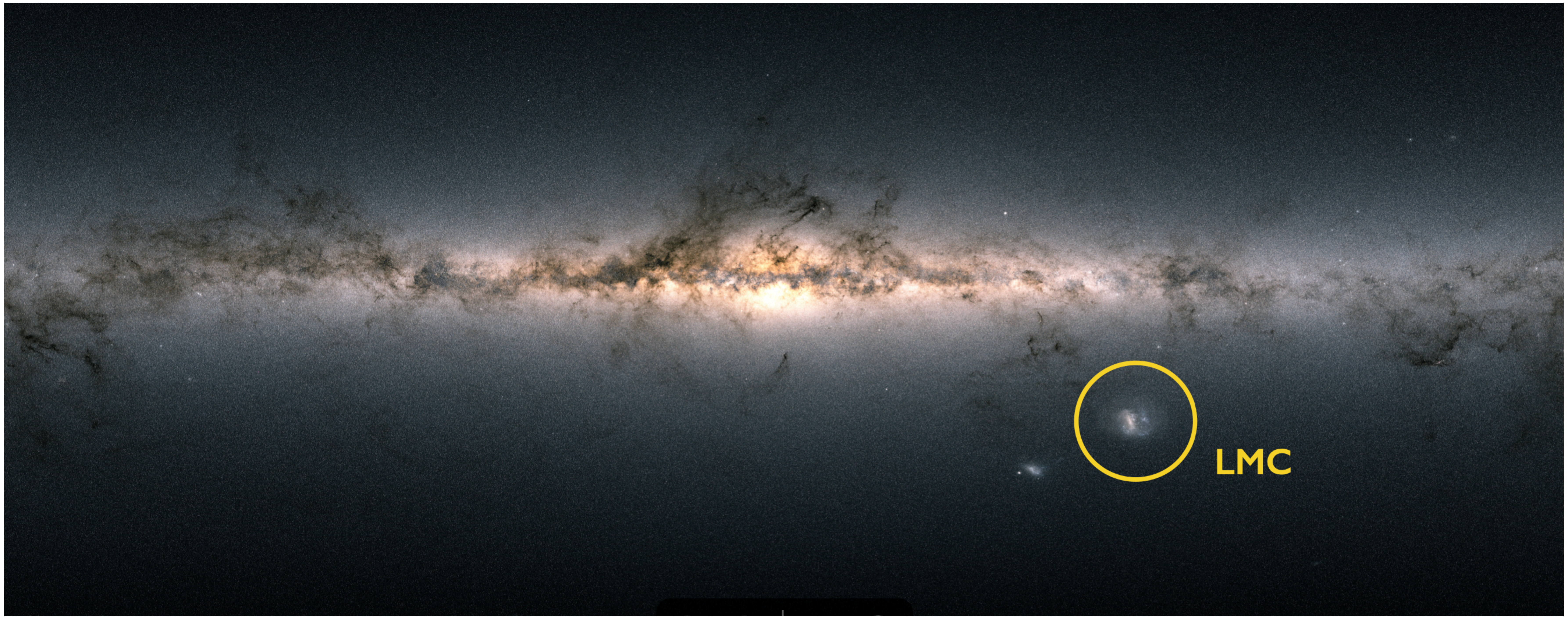


The LMC is the most massive satellite of the Milky Way ~

$$(1-3) \times 10^{11}\ M_{\odot}$$

First infall, pericenter ~ 50 Myr ago

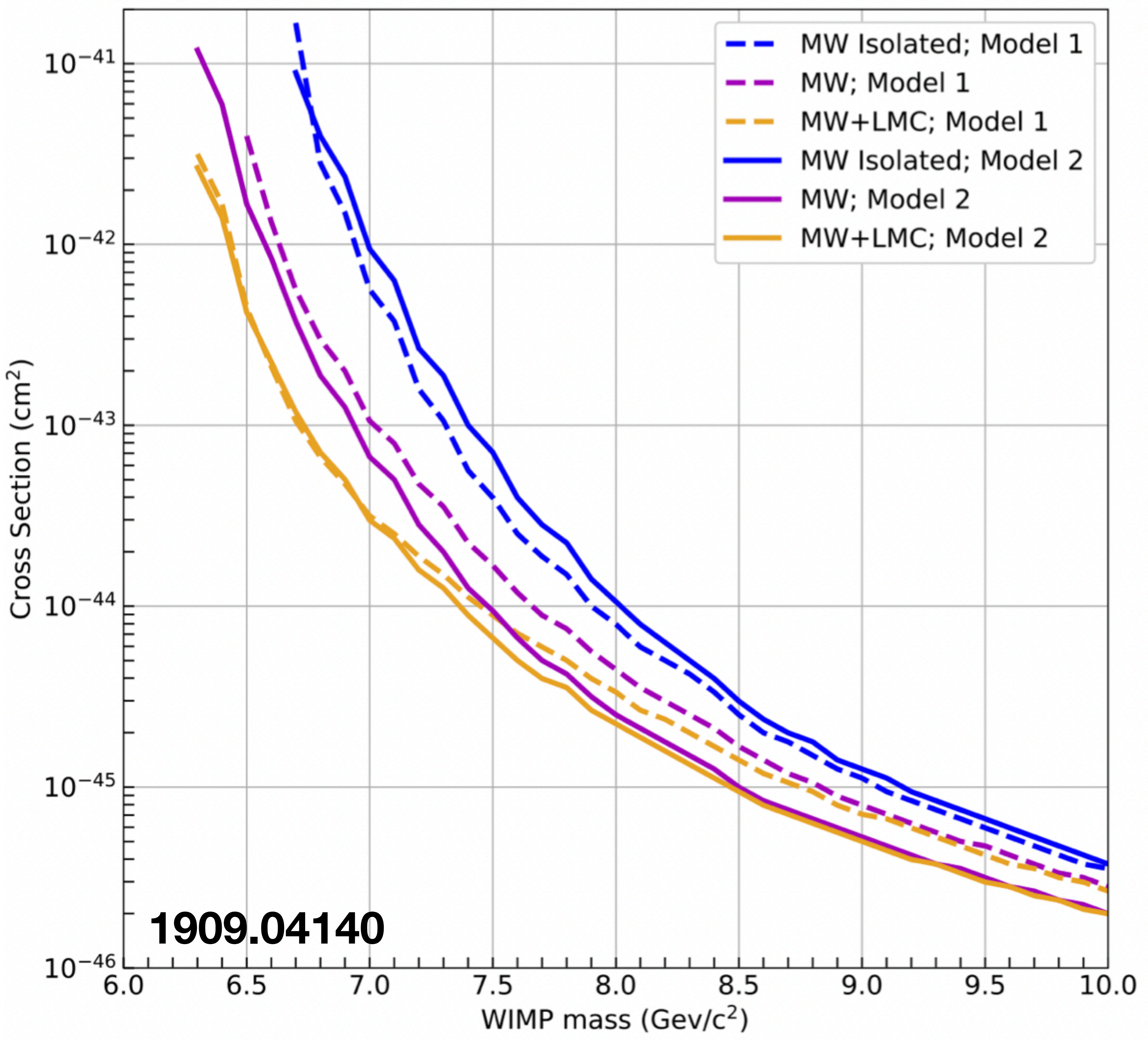
The Large Magellanic Cloud



The LMC contributes to the high speed tail through:

- Particles
- Accelerate local MW DM particles

The Large Magellanic Cloud



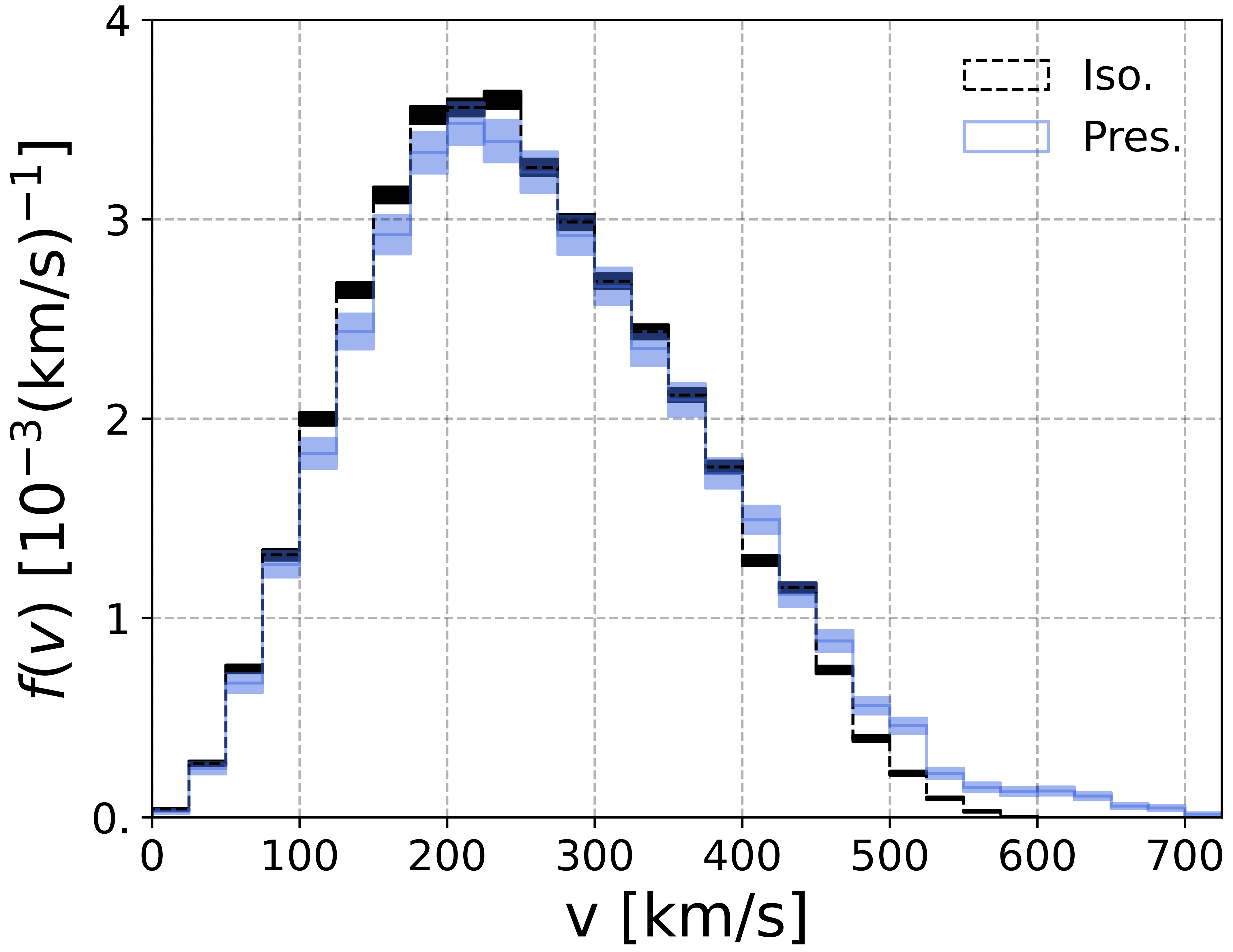
SI limits with Xe target

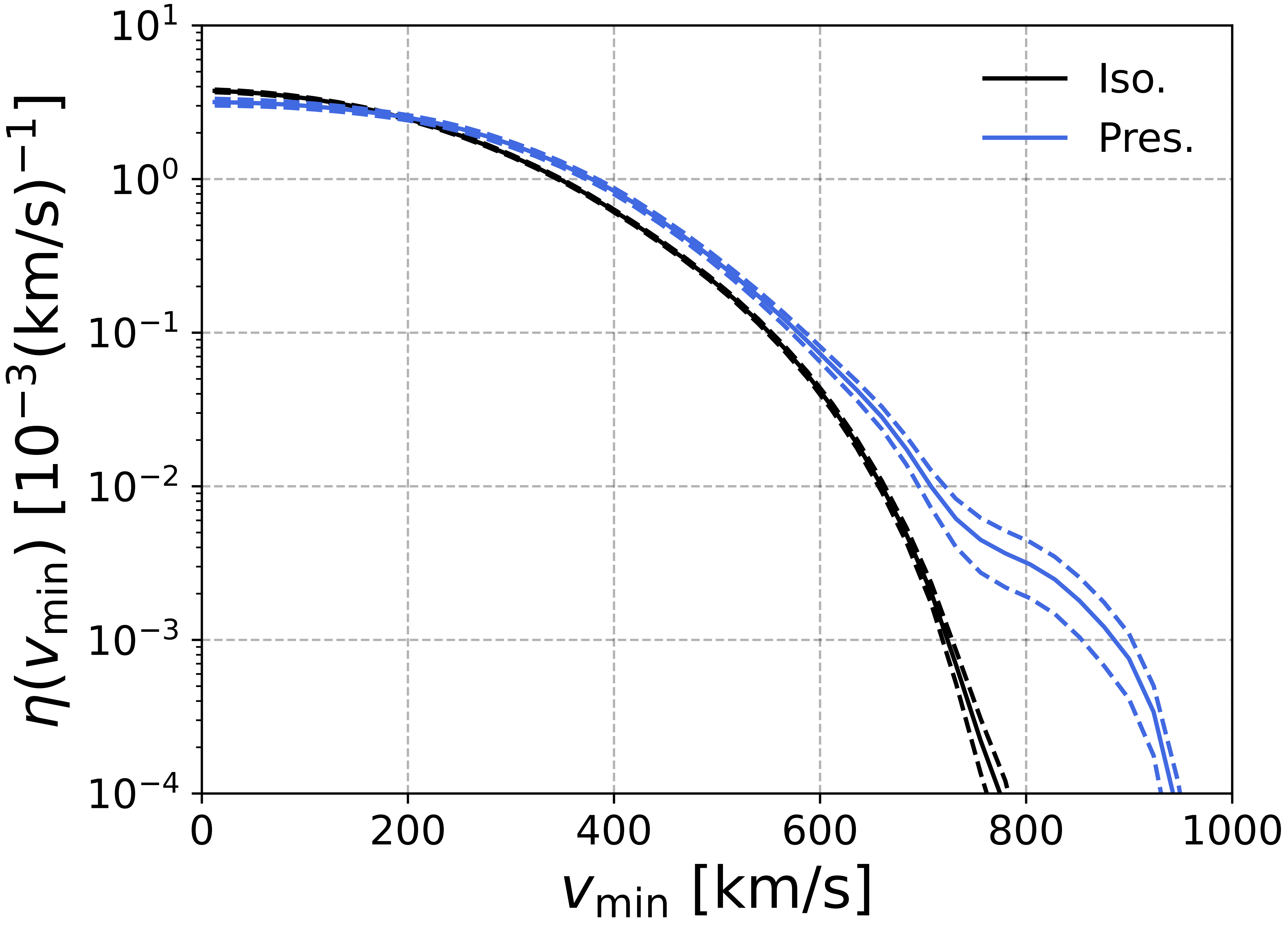
Lower limits for low DM mass regime

Dark Matter velocity distribution

This work: Auriga cosmological simulations

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





Non standard interactions

In the case of generalized non standard interactions

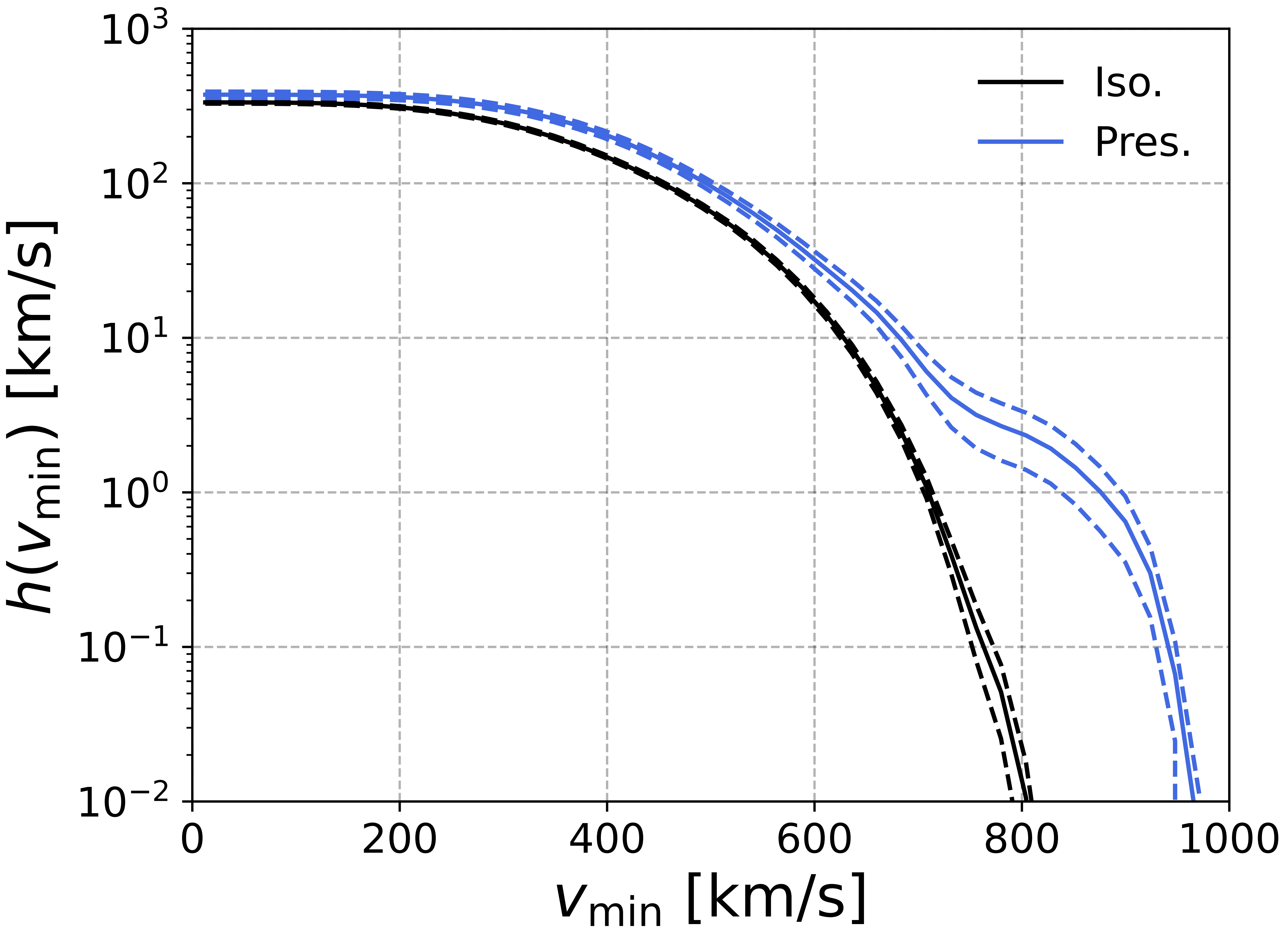
$$\frac{d\sigma_T}{dE_R} = \frac{d\sigma_1}{dE_R}\frac{1}{v^2} + \frac{d\sigma_2}{dE_R}$$

$h(v_{\min})$ **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/XLZD (Xenon)

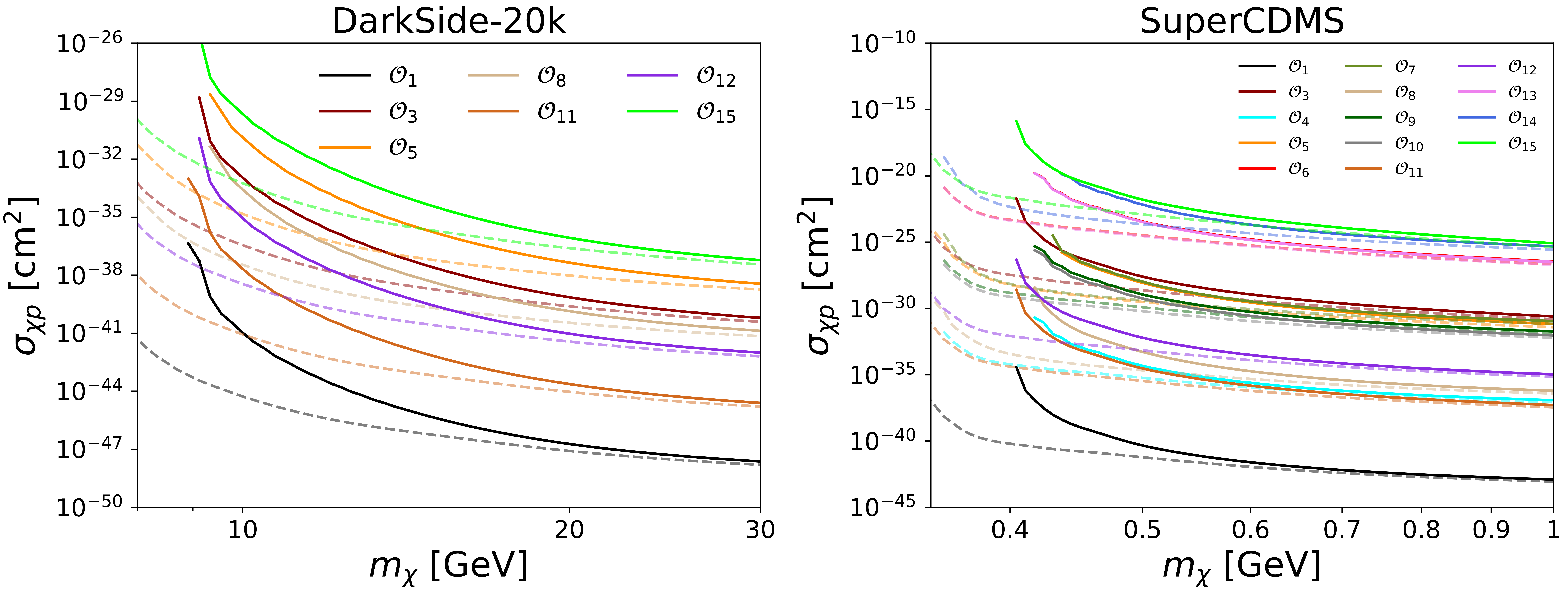
DarkSide-20k - SBC (Argon)

NEWS-G (Neon) **DarkSPHERE (Helium)**

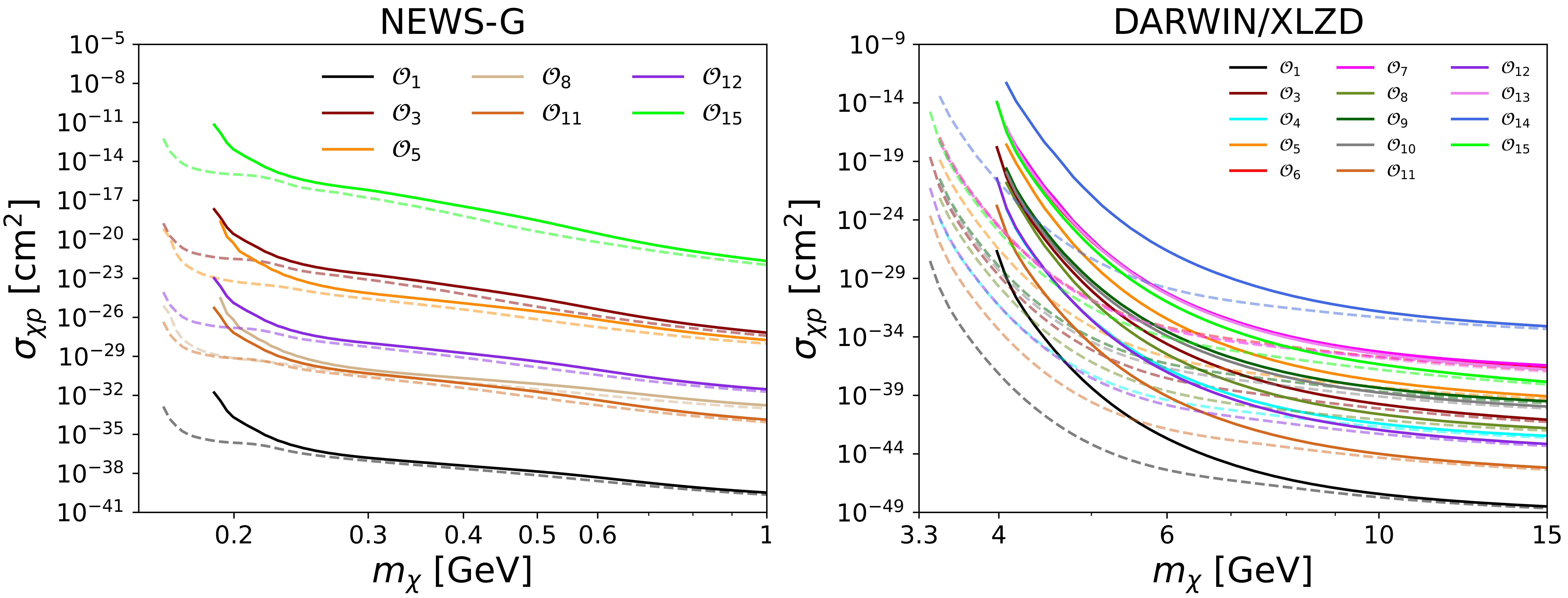
SuperCDMS (Germanium)

Experiment	Target Nucleus	Exposure [kg· day]	Energy range [keVnr]
DarkSide-20k	Ar	3.65×10^7	[30 – 200]
SBC	Ar	3.65×10^3	[0.1 – 10]
DARWIN/XLZD	Xe	7.3×10^7	[5 – 21]
SuperCDMS	Ge	1.6×10^4	[0.04 – 0.3]
NEWS-G	Ne	18	[0.03 – 1]
DarkSPHERE	^{4}He	7.4×10^3	[0.03 – 1]

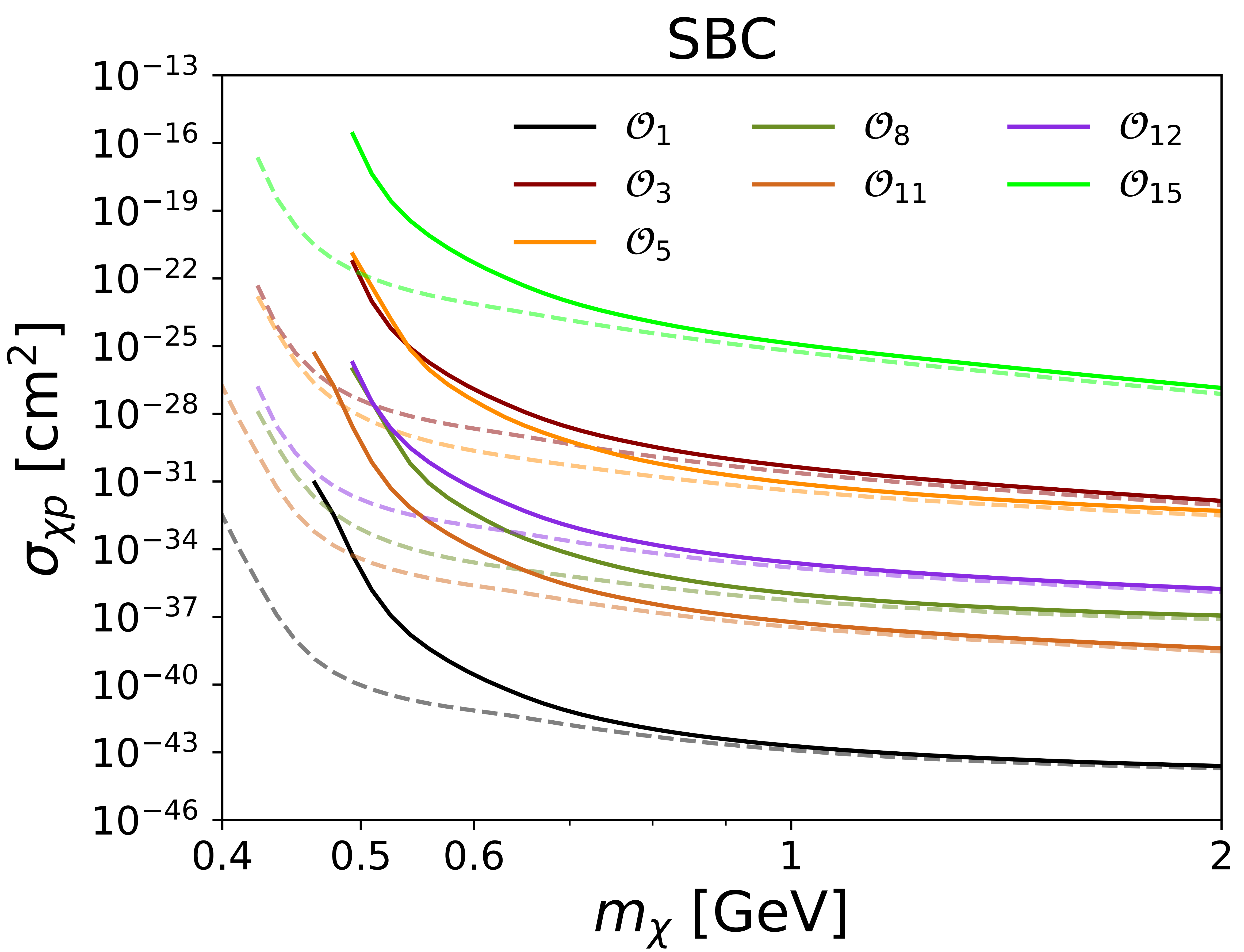
Results NREFT

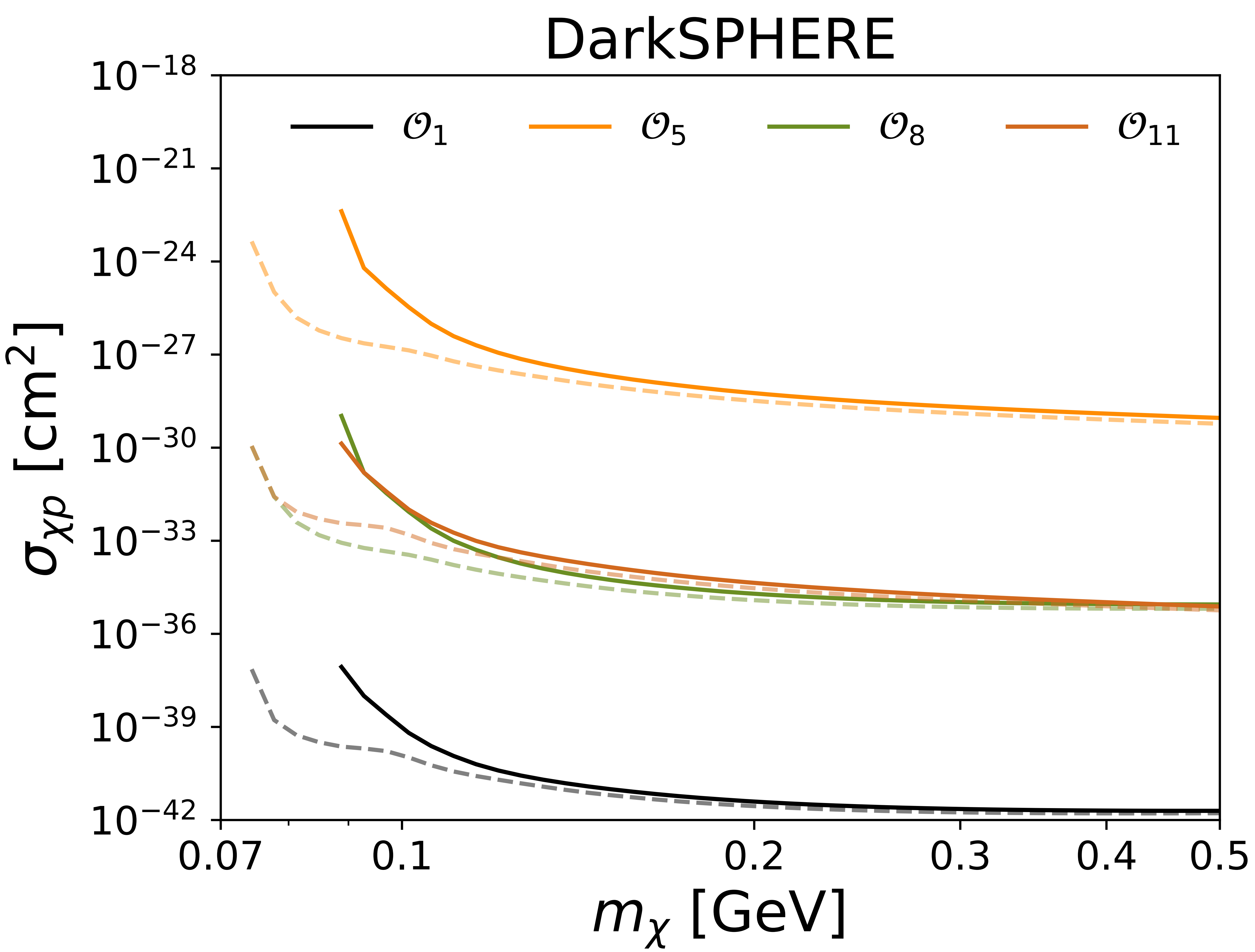


Results NREFT

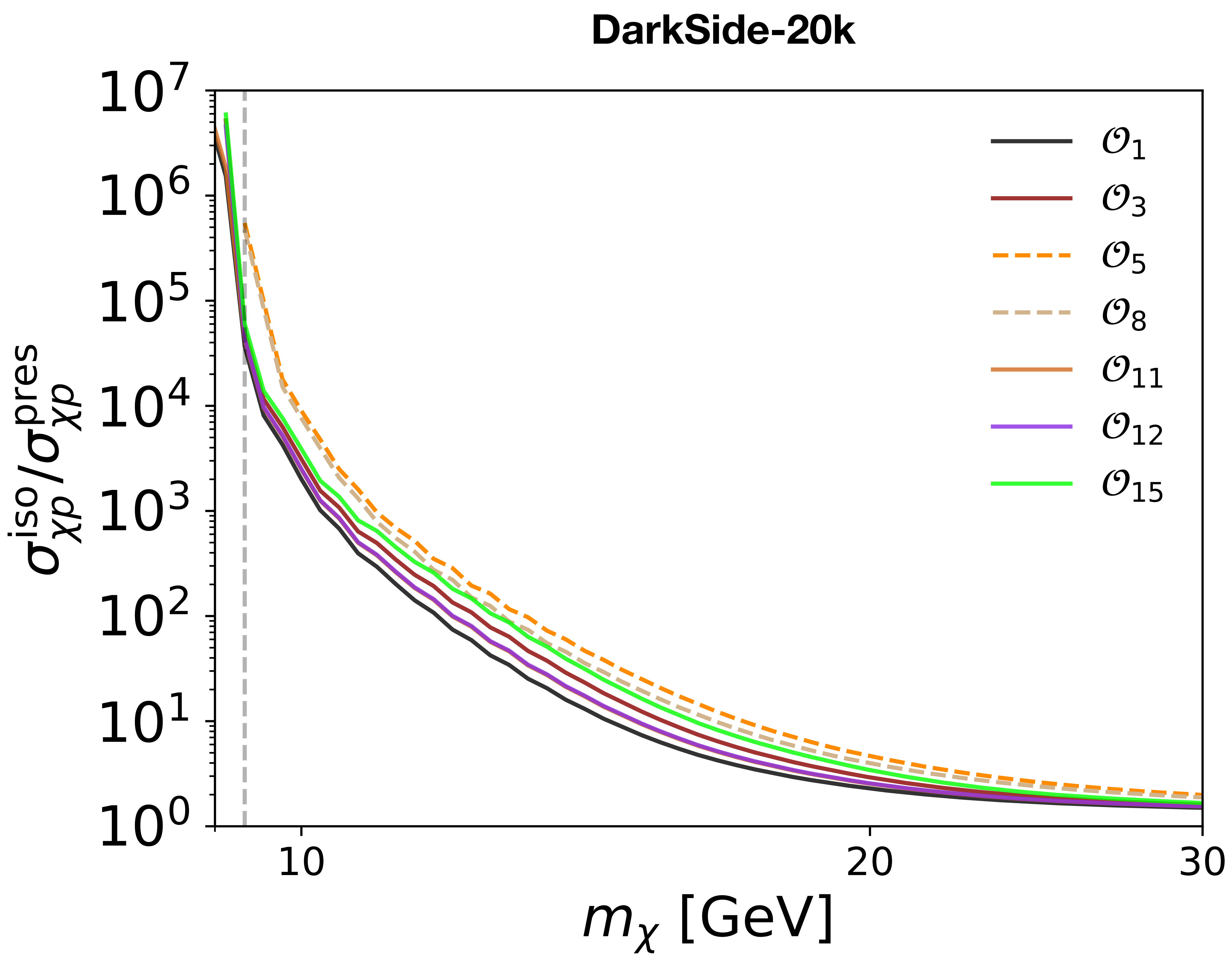


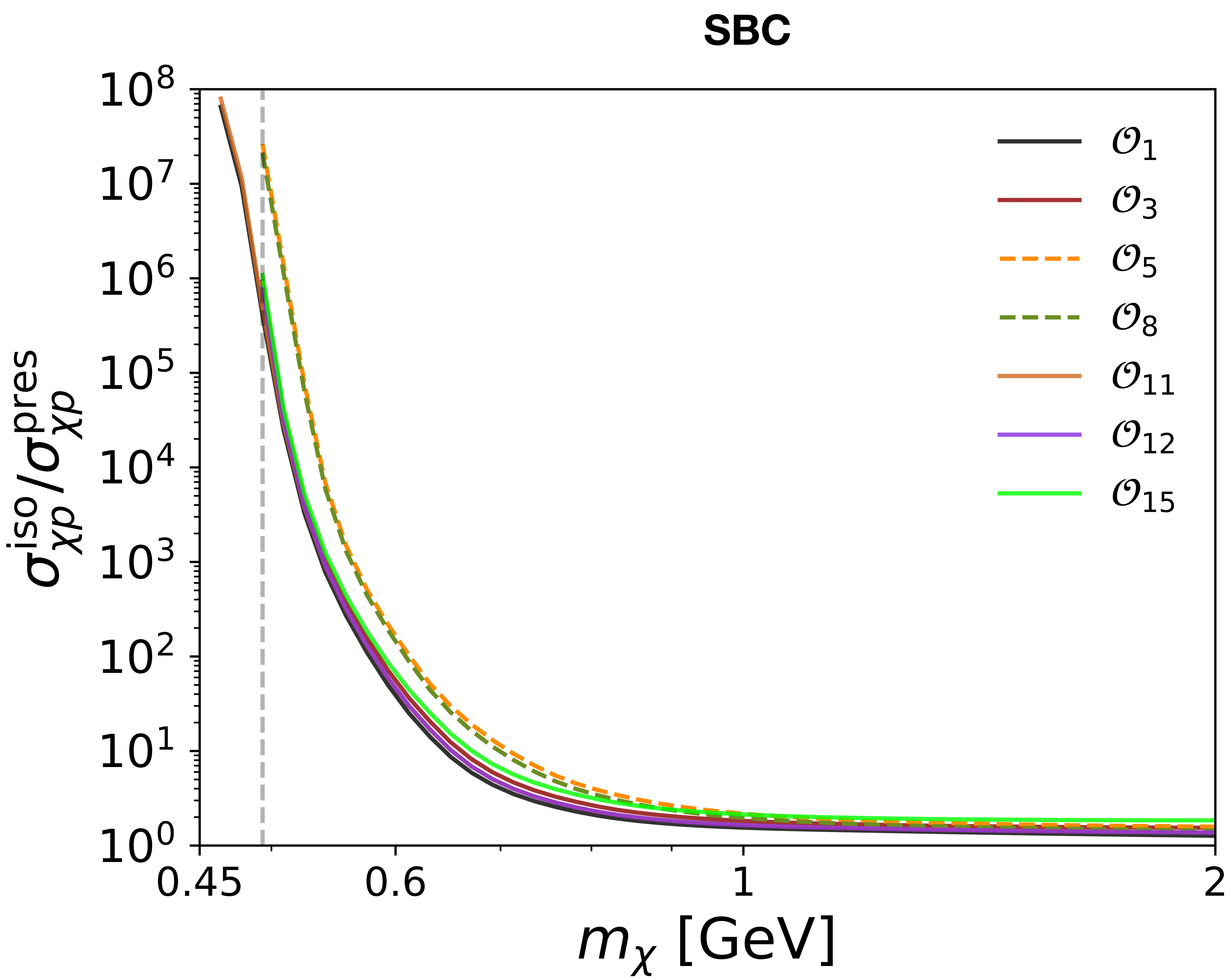
Results NREFT



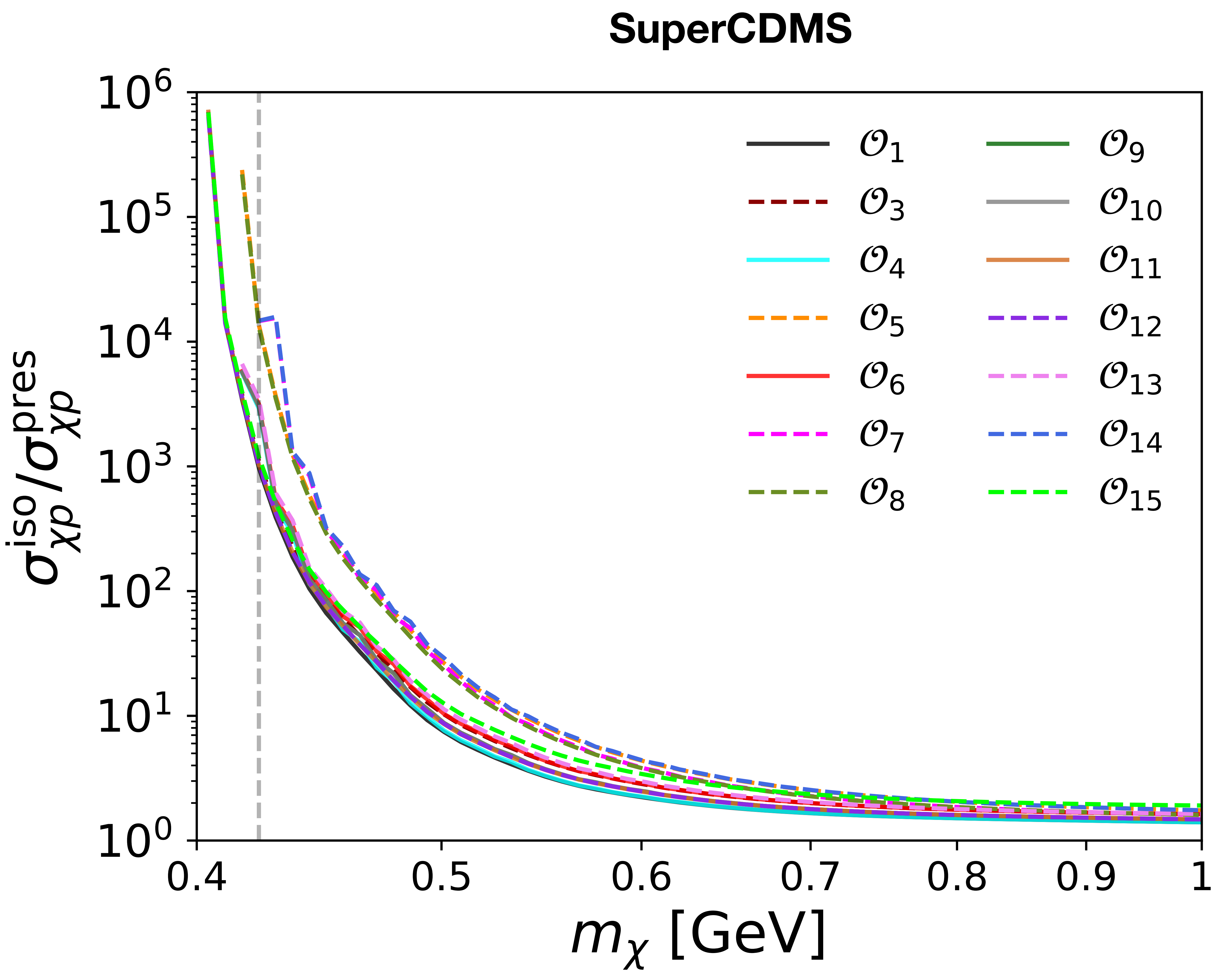


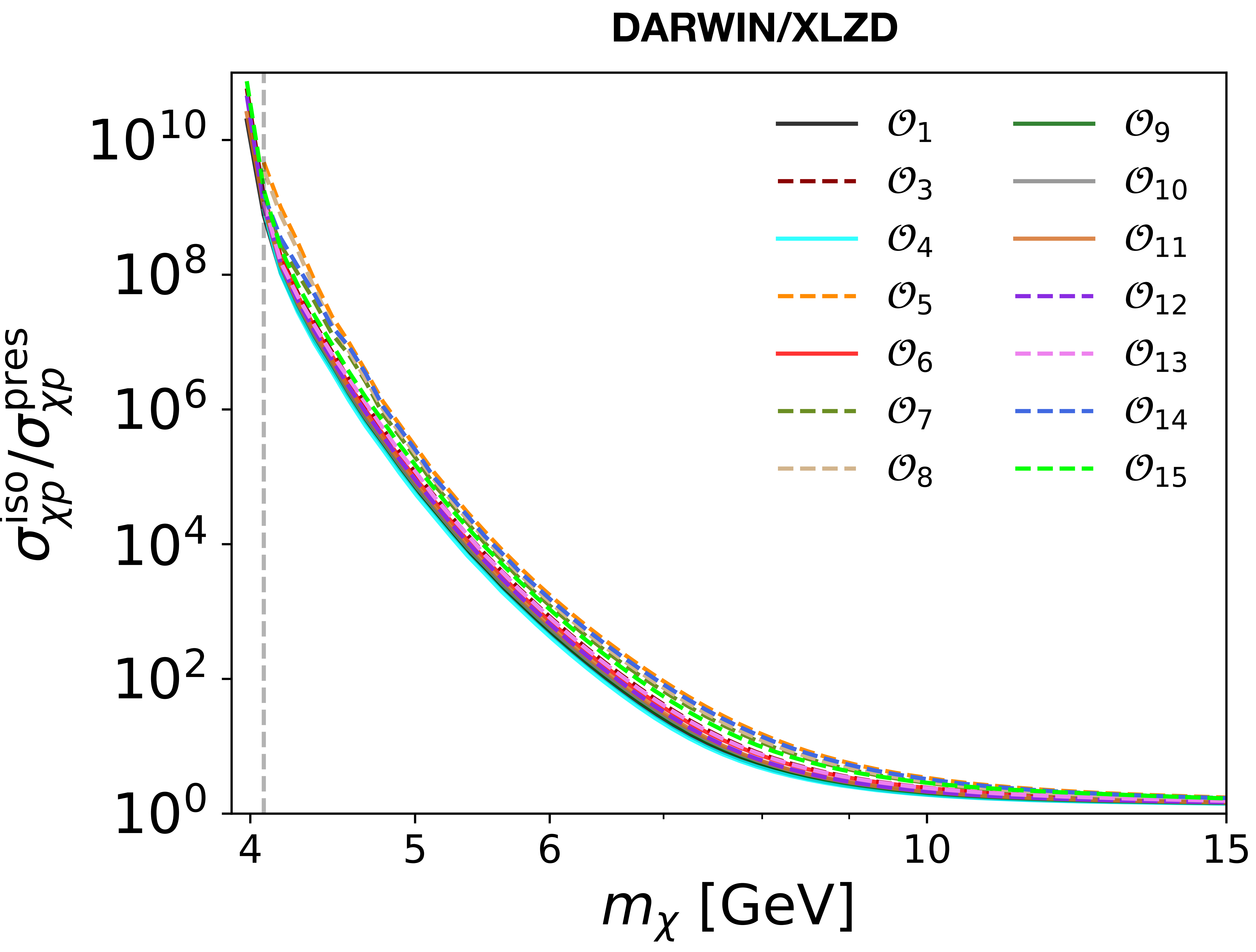
Results NREFT



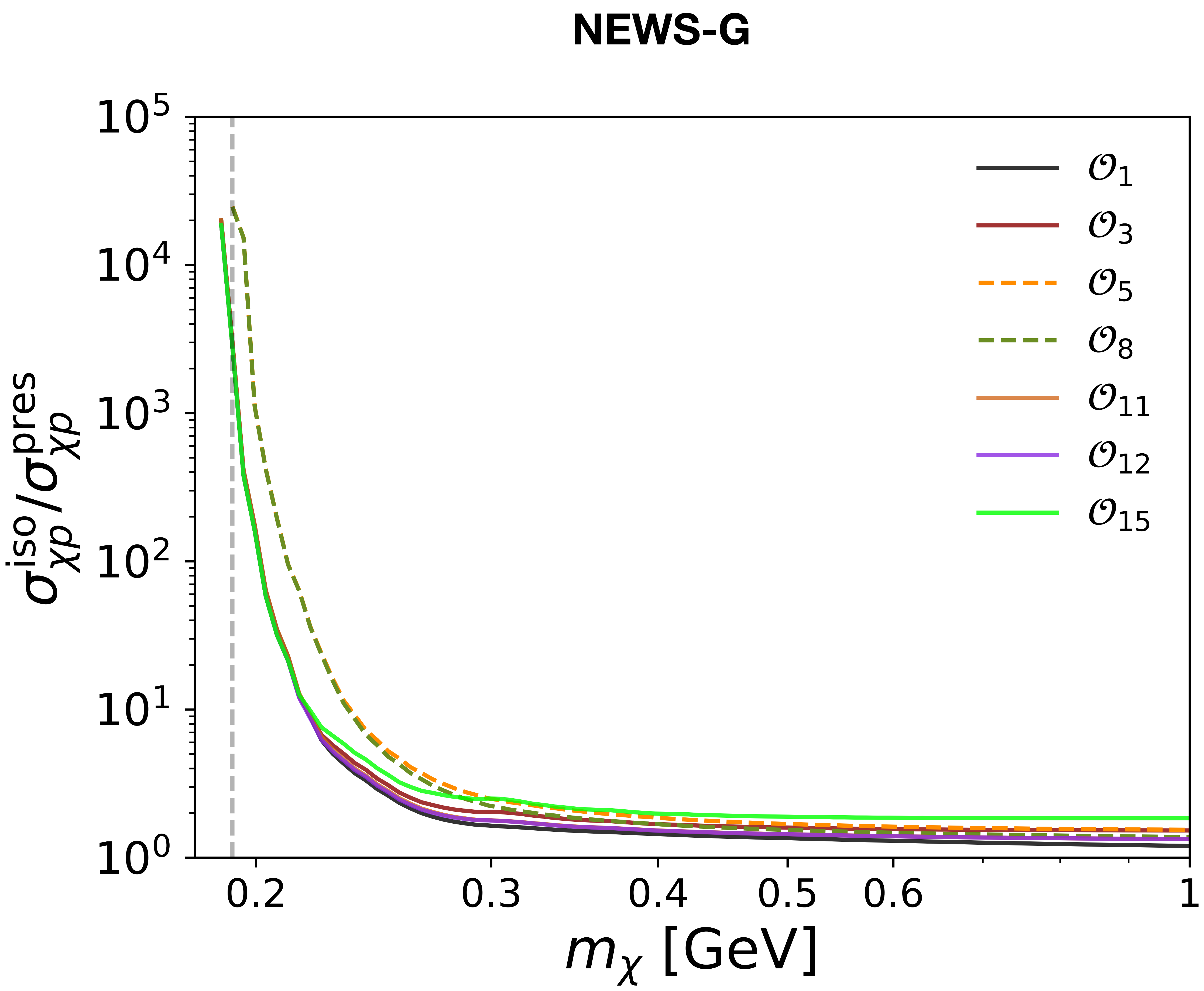


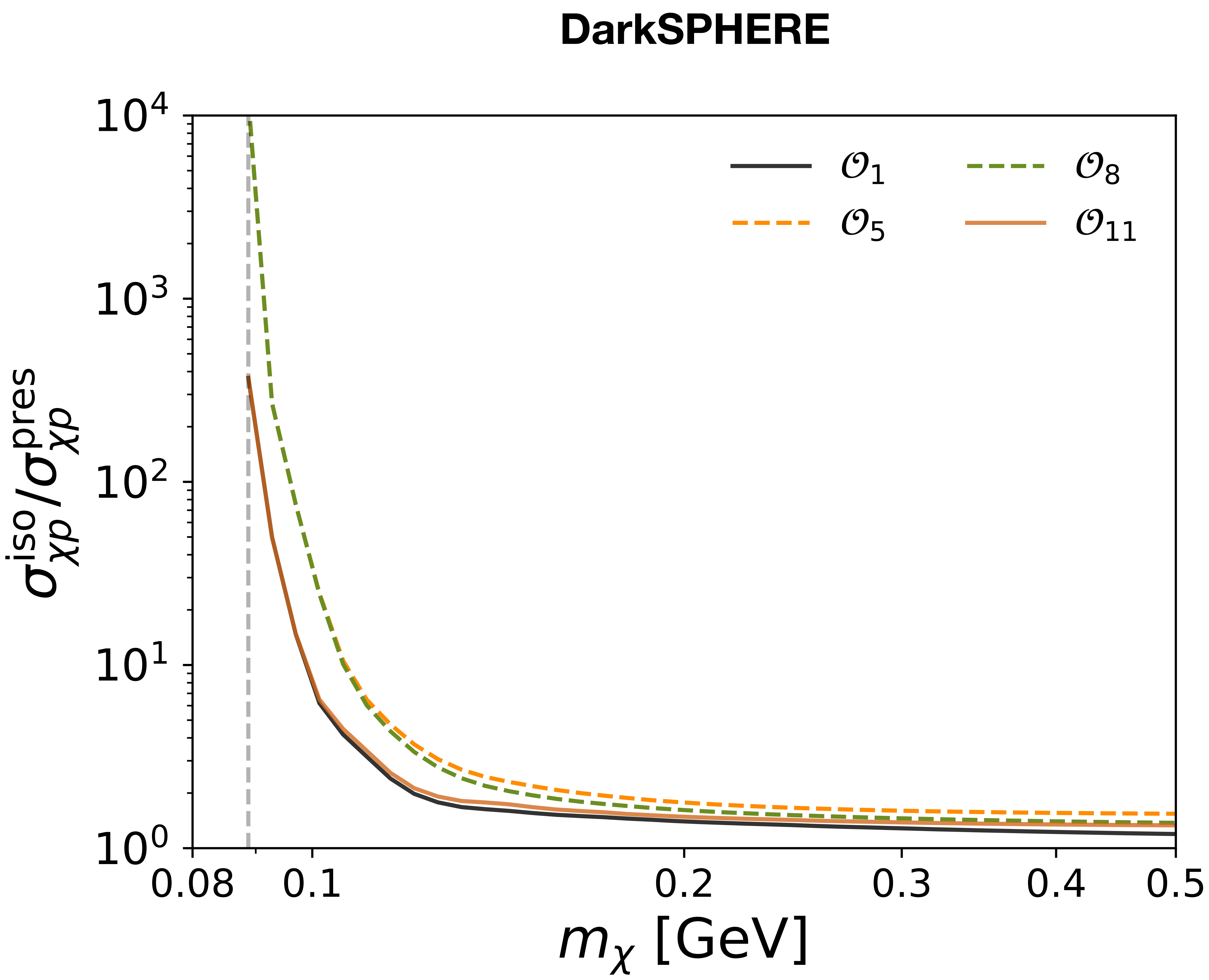
Results NREFT



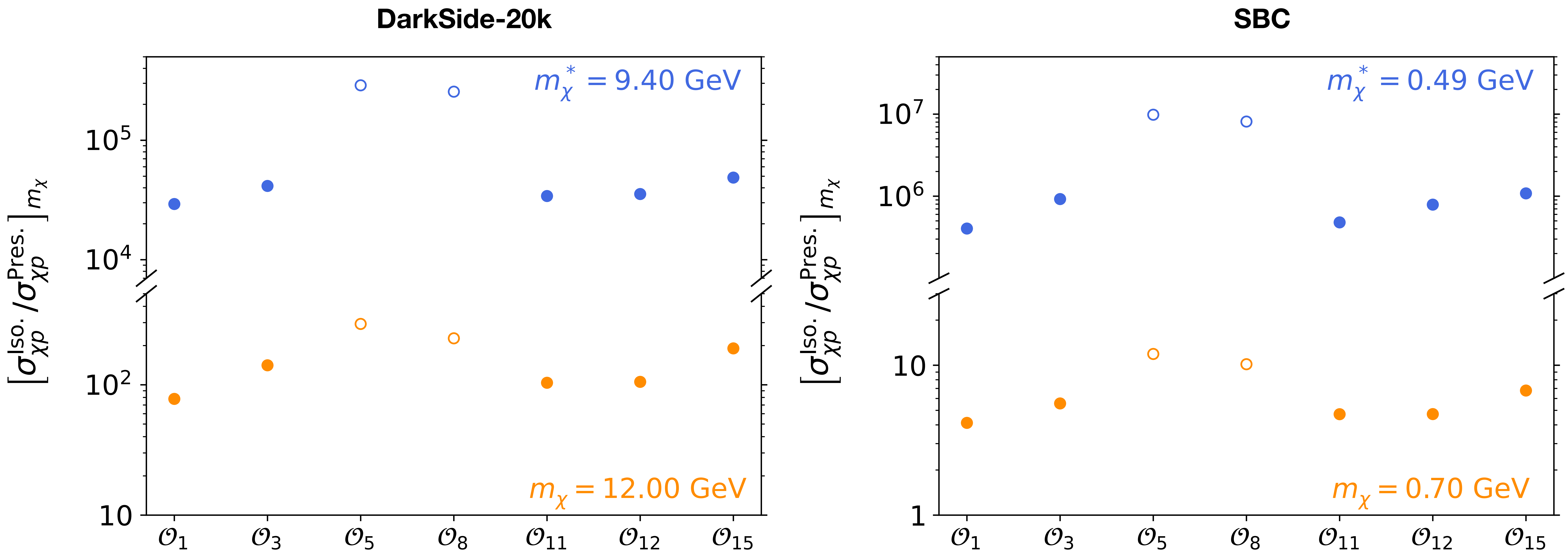


Results NREFT

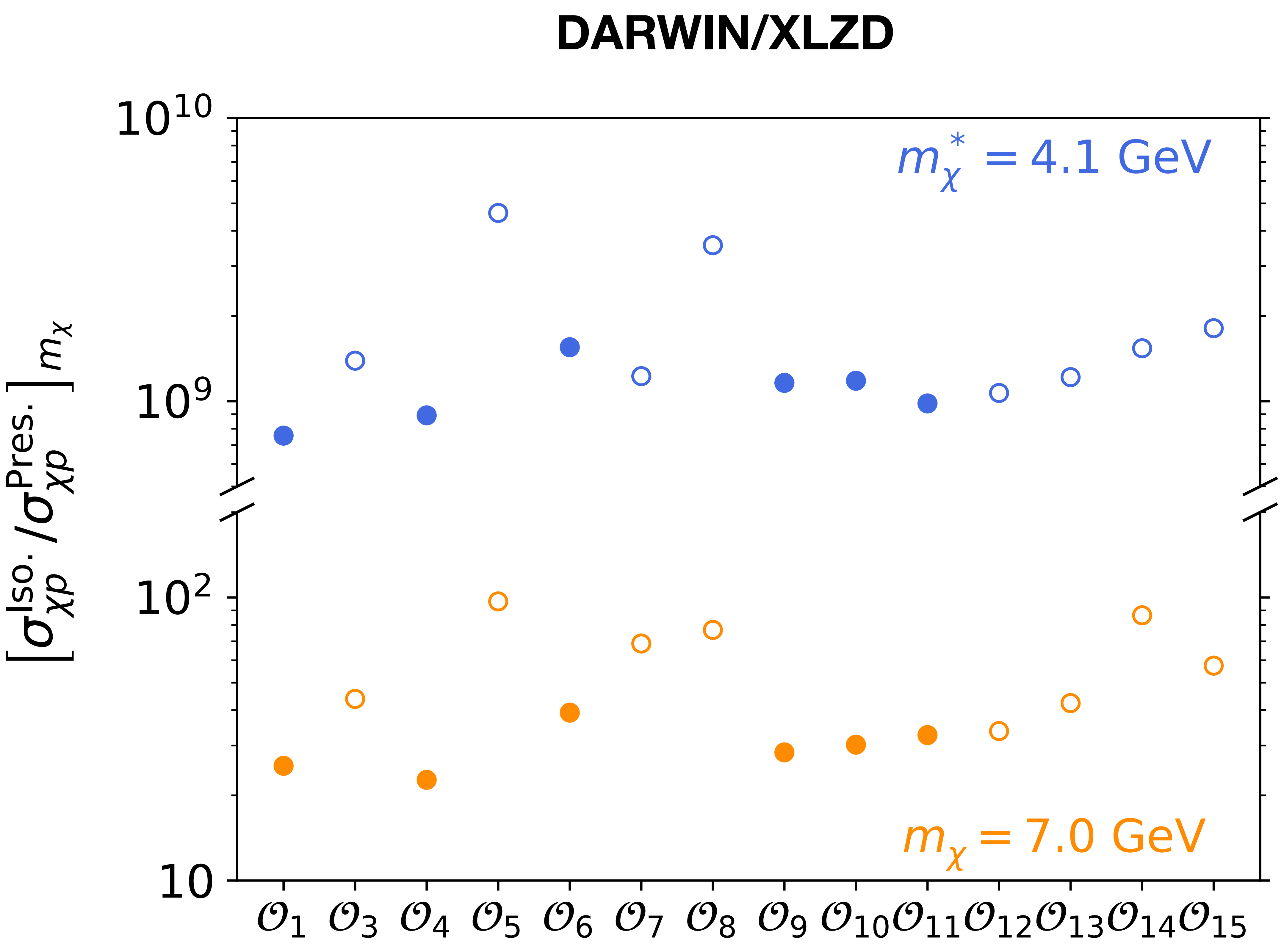


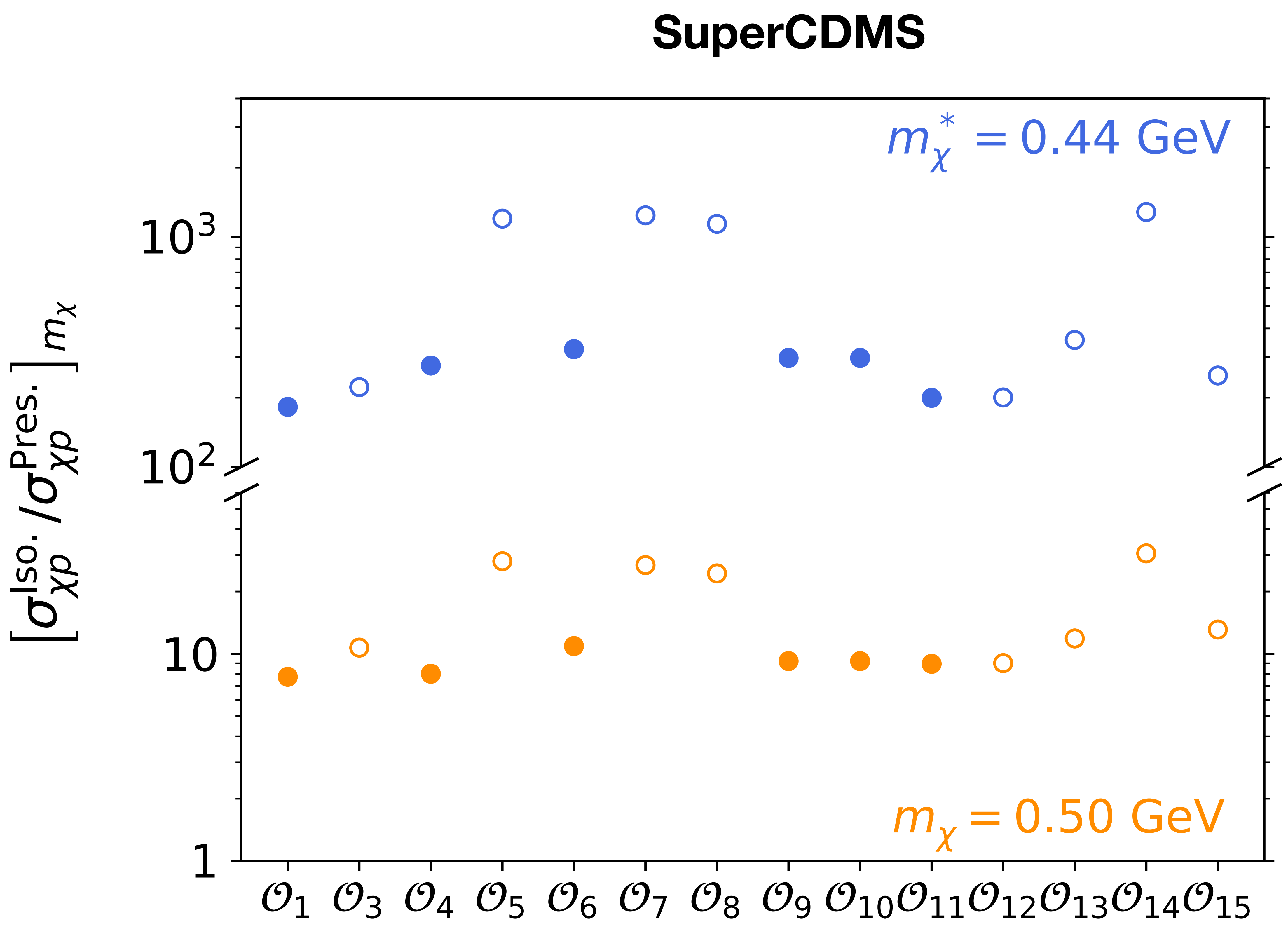


Results NREFT



Results NREFT



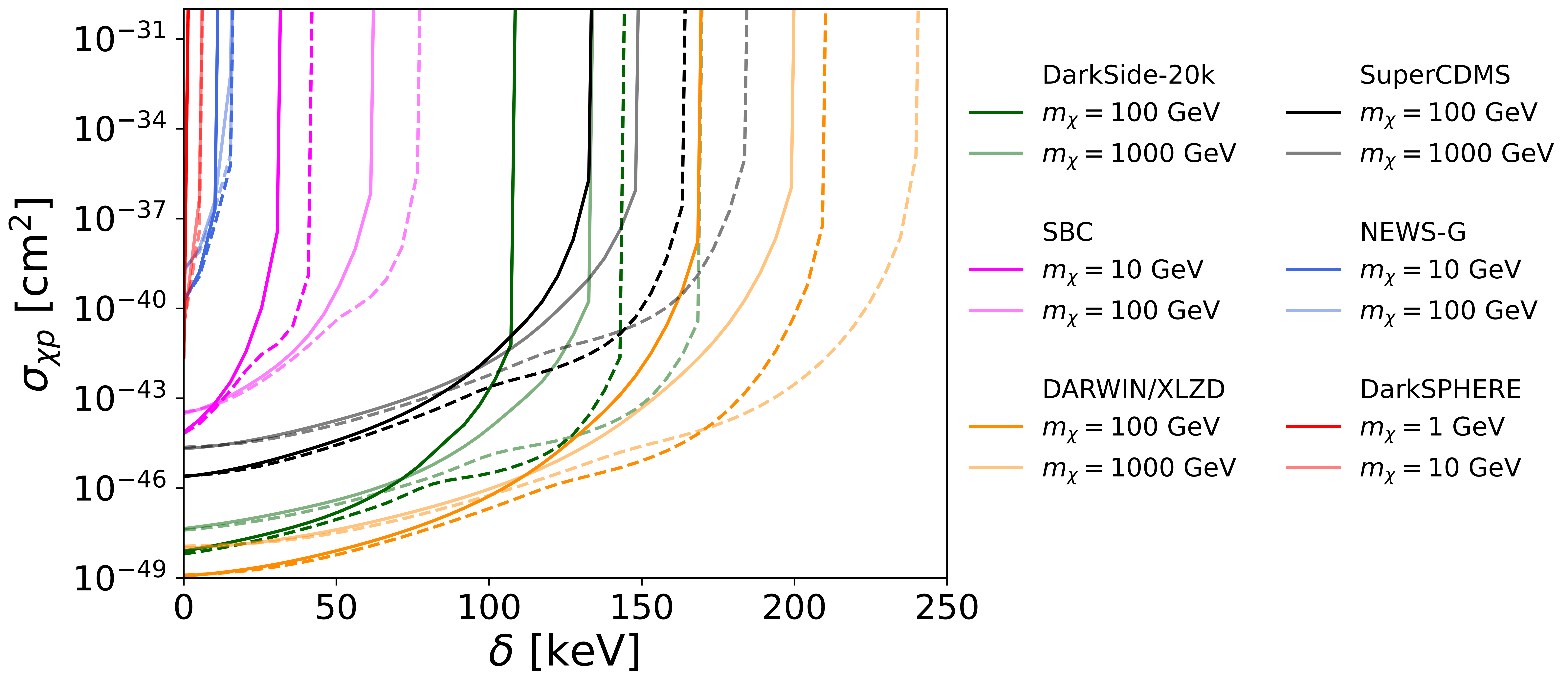


Inelastic scattering

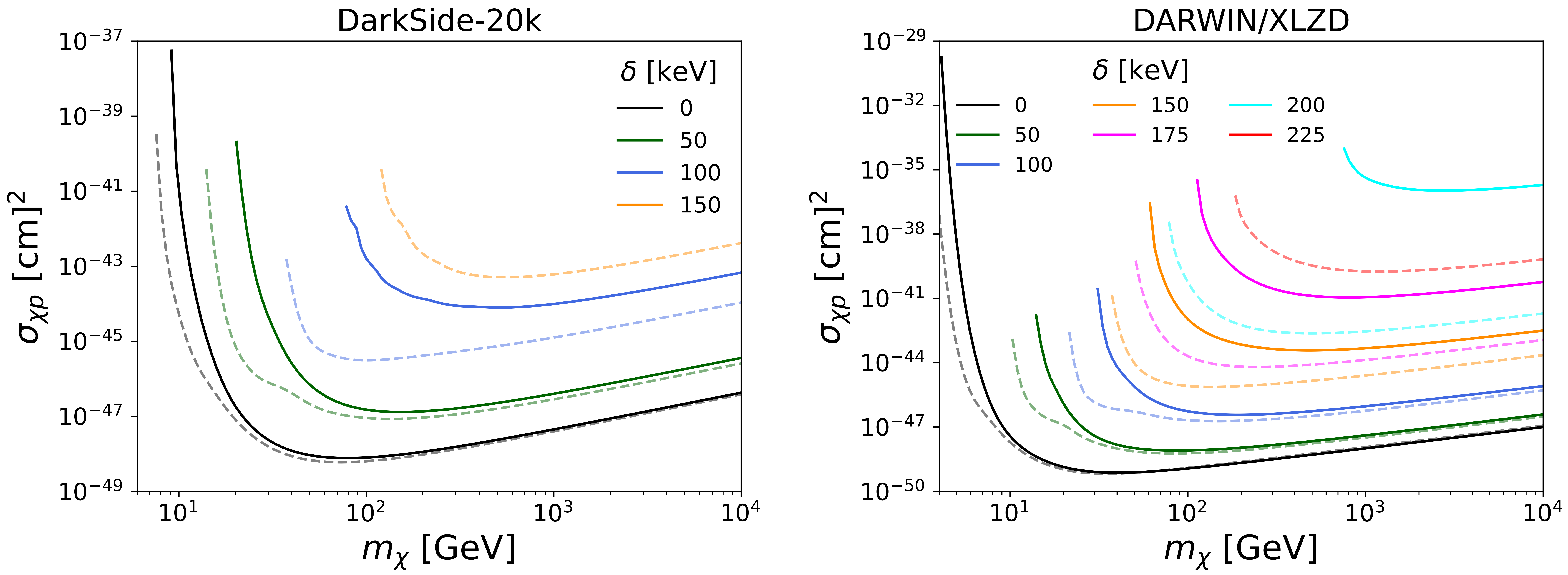
Dark matter scattering to heavier mass state

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

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



Results Inelastic scattering



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 masses
- 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