Effective Field Theories for Dark Matter

Snowmass Community Planning

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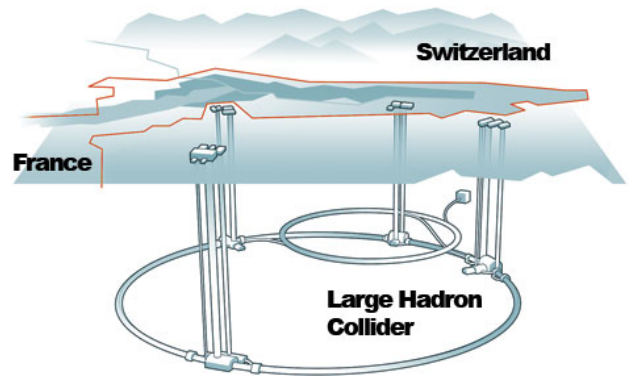
$$\Omega_M h^2 \neq \Omega_B h^2$$

0.1423 ± 0.0029 $\qquad$ 0.02207 ± 0.00033

H.E.S.S.



LUX

So far no definitive signals.

So why bother with precision tools?

Simple estimates can be off by orders of magnitude!

(EFTs also useful for parameterizing dark matter interactions, but will focus here on EFTs for precision)

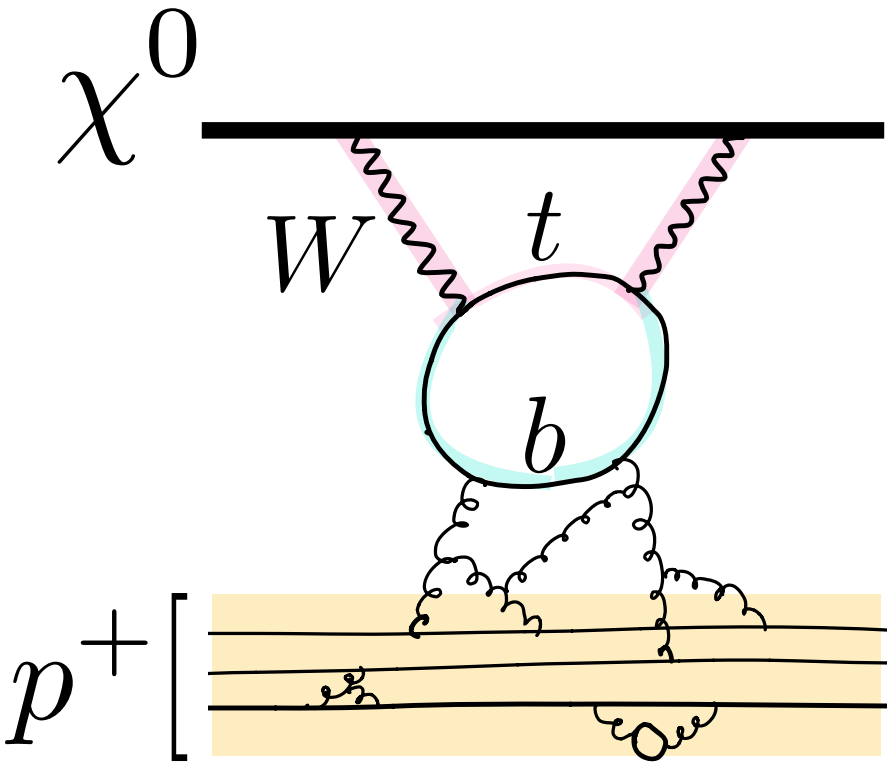
Particle Dark Matter

$$\chi$$

electroweak triplet

$$M_\chi \gg m_W$$

Direct Detection



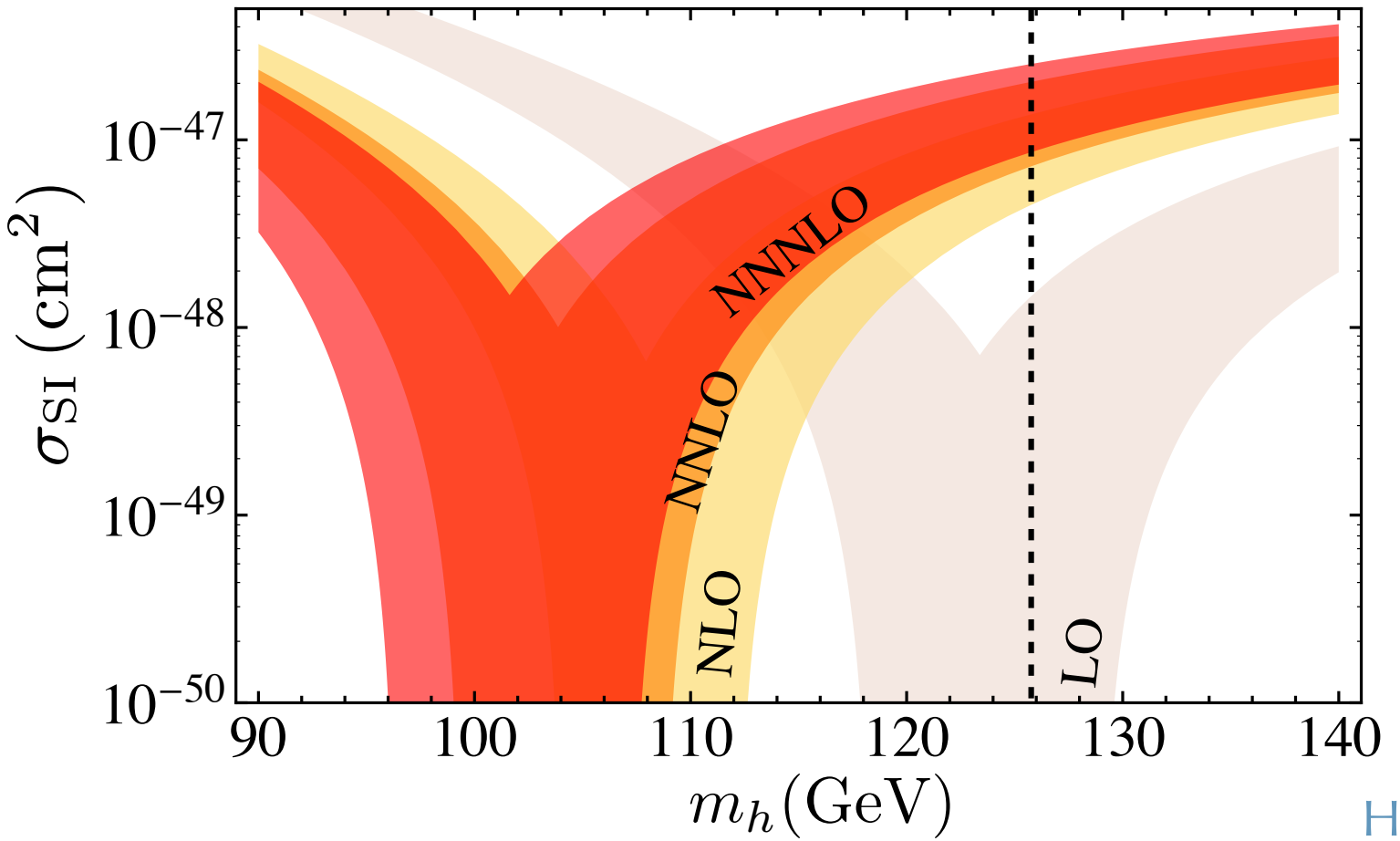
$M_\chi, m_W, m_b, m_N, \Lambda_{\rm QCD}$

dimensional analysis (and previous work) $\sigma_{\rm SI} = 10^{-45}{\rm cm}^2$

$$\sigma_{\rm SI} = 1.3^{+1.2+0.4}_{-0.5-0.3} \times 10^{-47}\,{\rm cm}^2$$

Hill, Solon

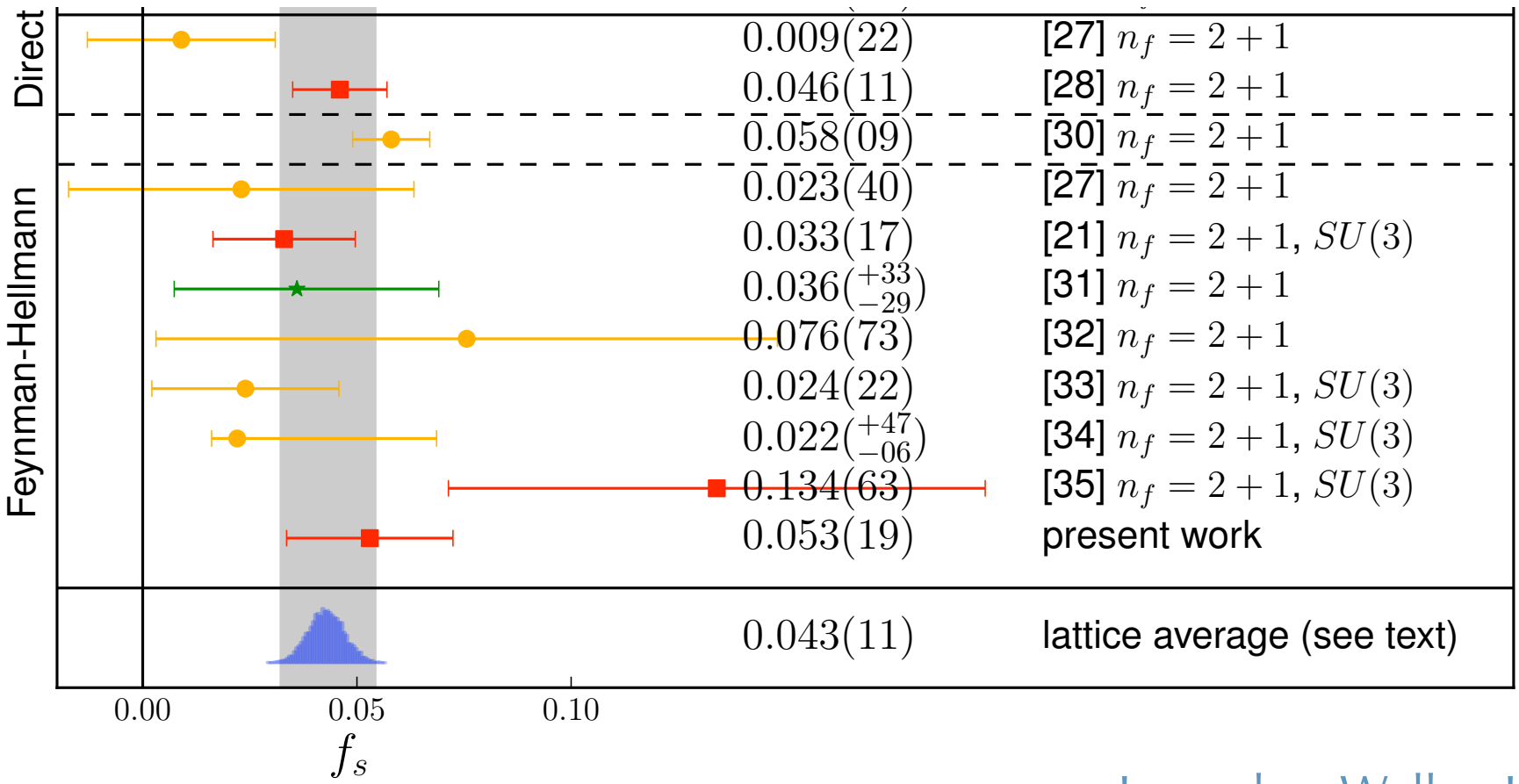
Perturbative QCD



Hill, Solon

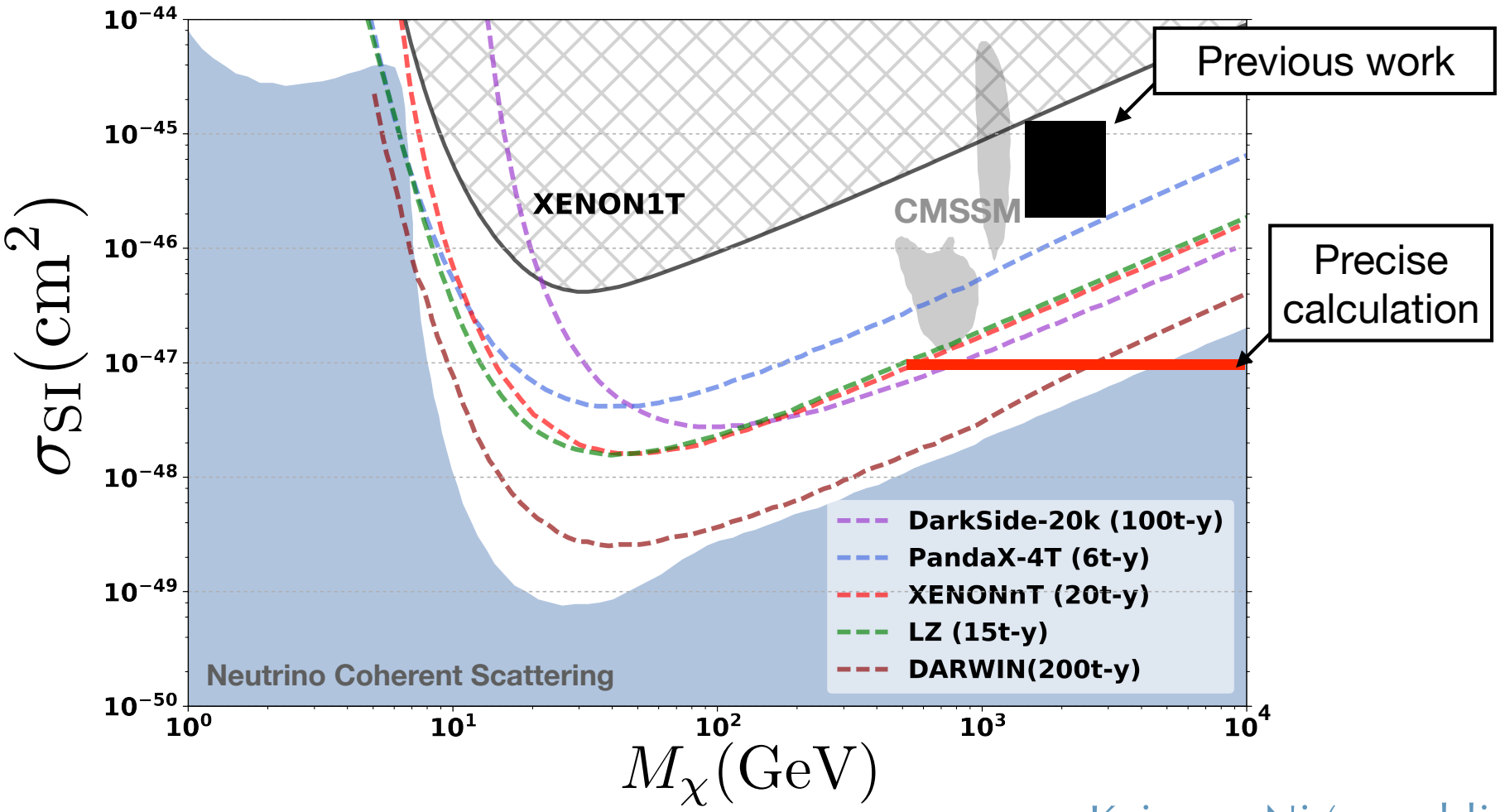
bands: hadronic and perturbative uncertainties

Lattice QCD



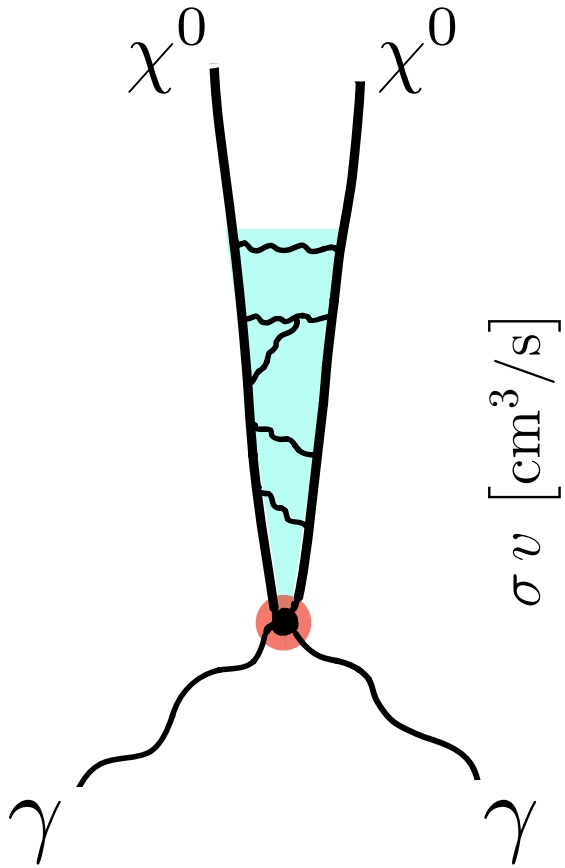
Junnarkar, Walker-Loud

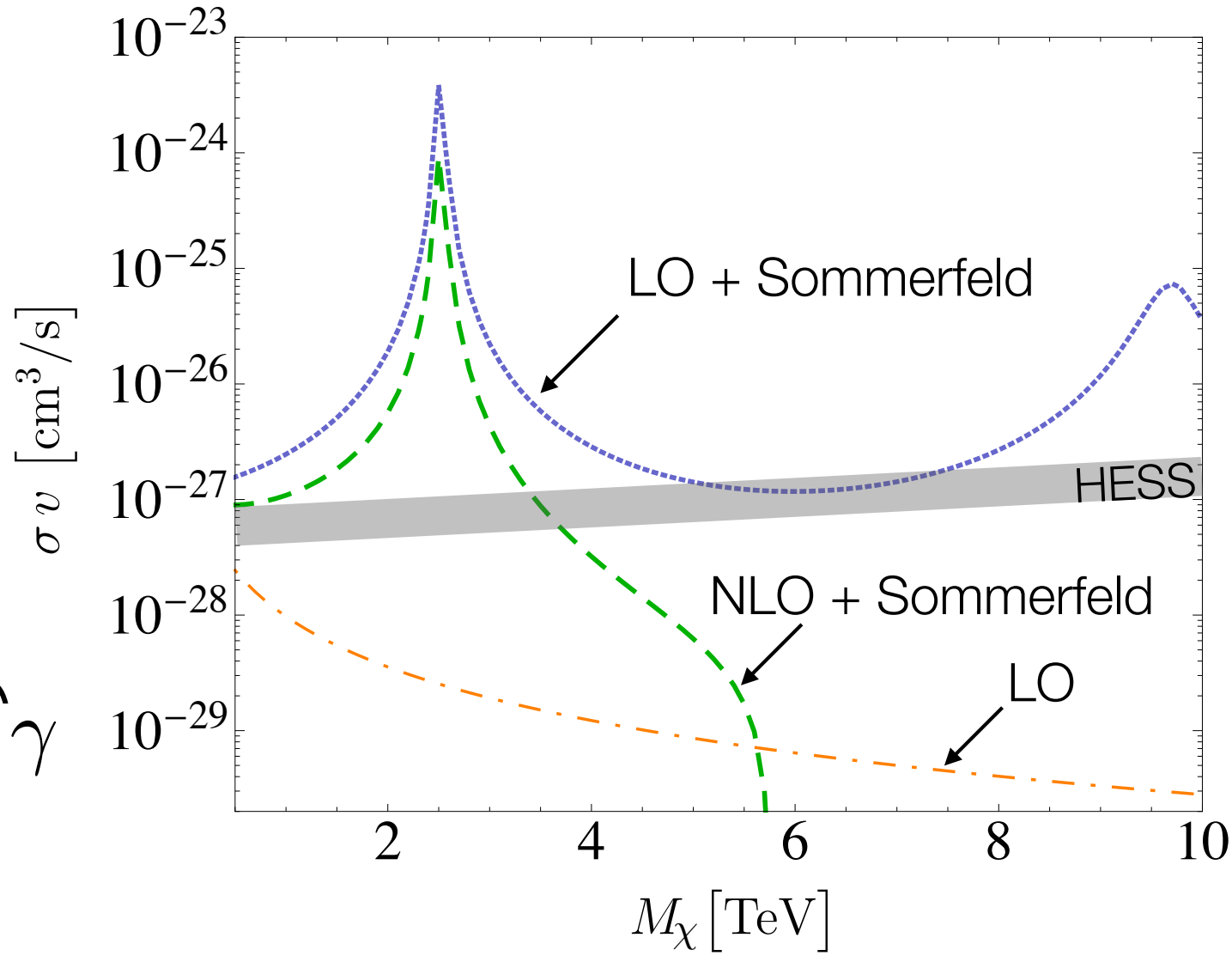
Direct Detection



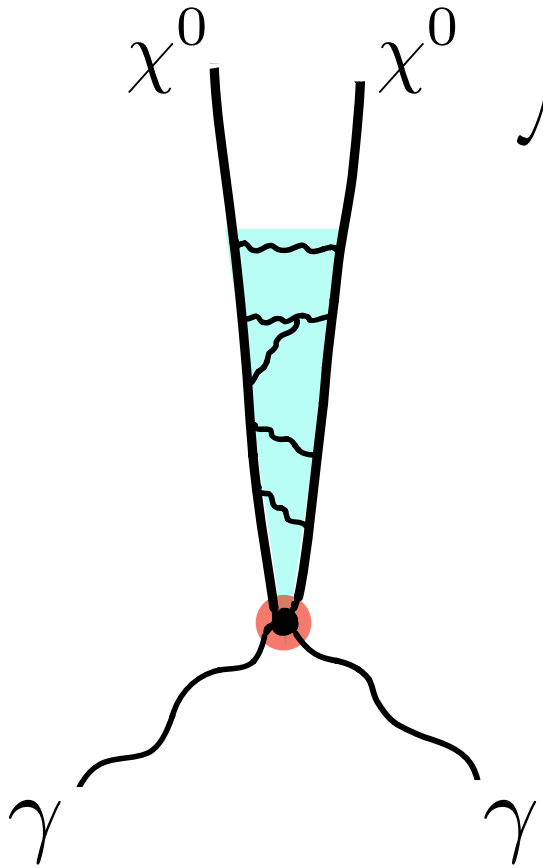
Kaixuan Ni (unpublished)

Indirect Detection





Two Large Effects



$$\mathcal{M} \supset \frac{e^2 g_2^2}{16\pi^2}\left[\frac{8\pi c_W^2 M_\chi}{m_Z} - 16\log^2\frac{m_W}{M_\chi}\right]$$

Sommerfeld

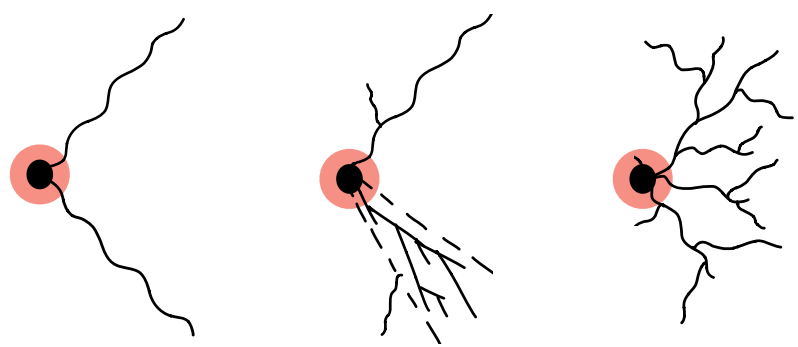
$$\left(\alpha_W \frac{M_\chi}{m_W}\right)^n$$

long-distance potential

Sudakov

$$\alpha_W \log^2\left(\frac{M_\chi}{m_W}\right)$$

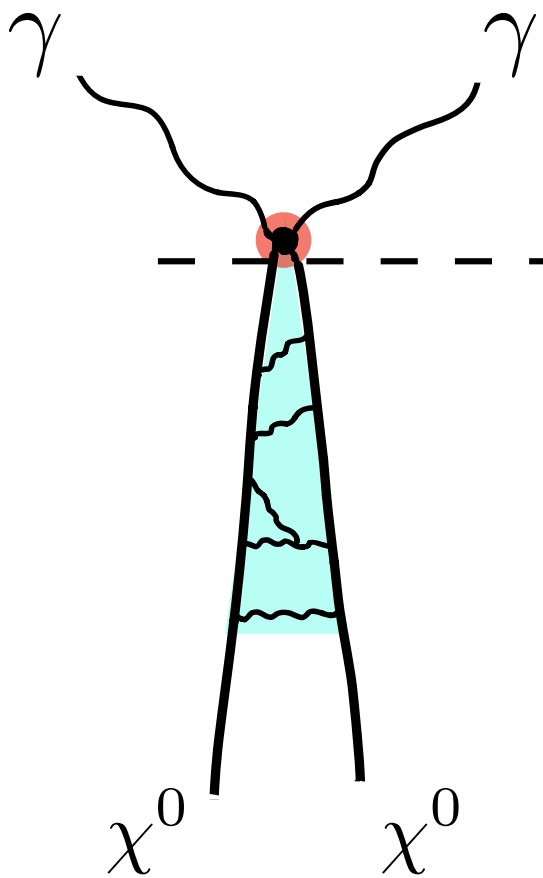
exclusive decay



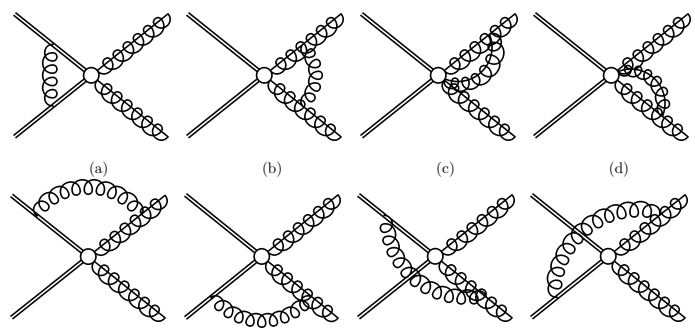
exclusive

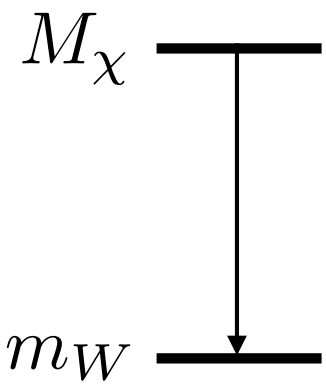
inclusive

Resummation



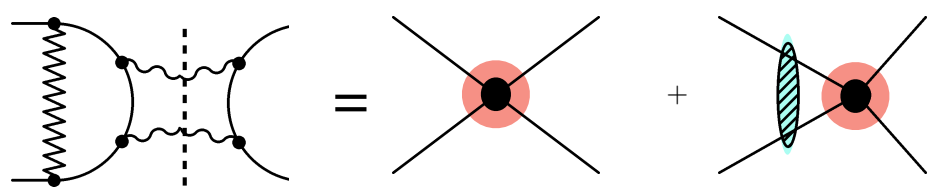
* electroweak Sudakov for collider physics



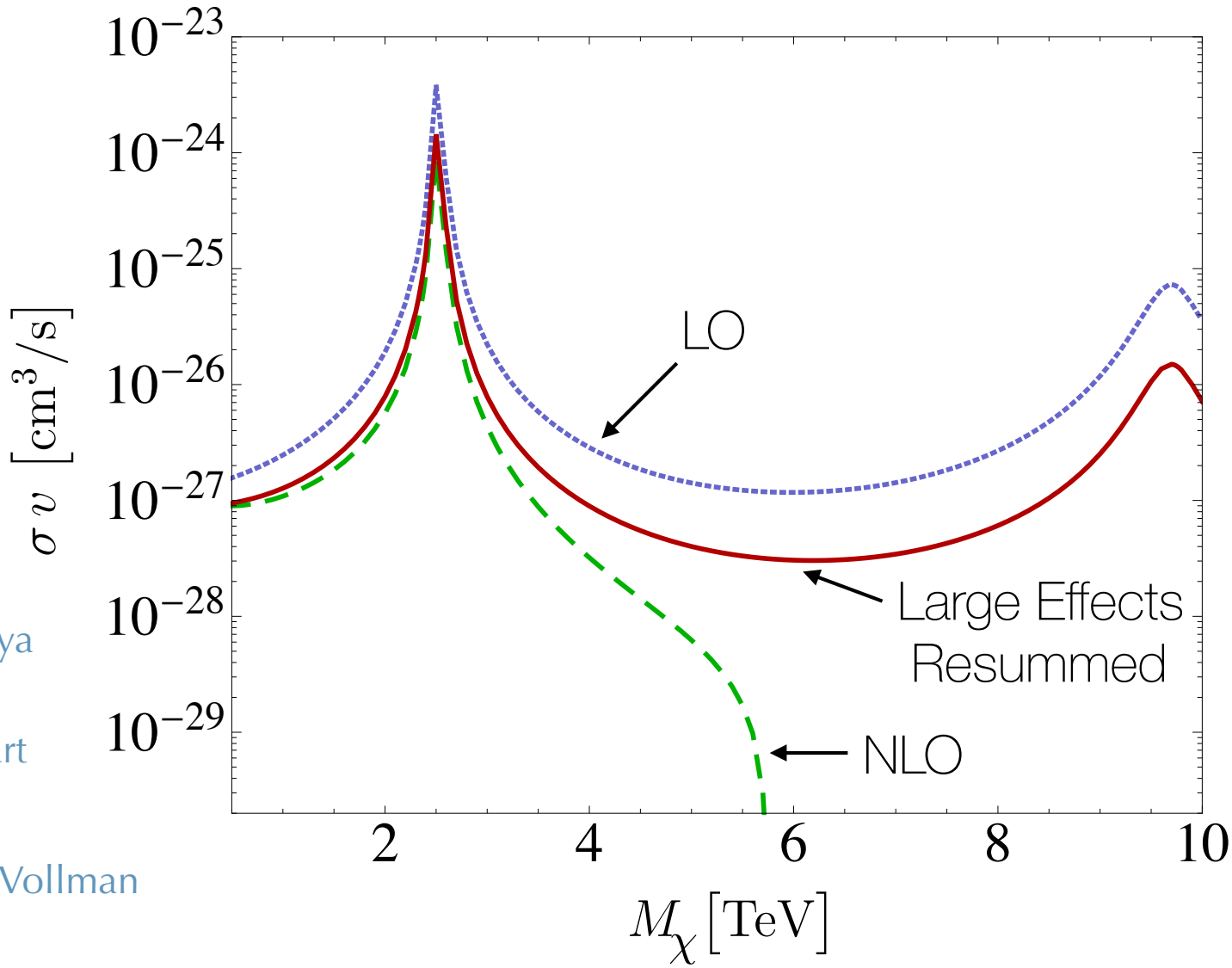


* solve Schrodinger equation

$$H = \frac{p^2}{2M_r} + \Delta + V + iW$$

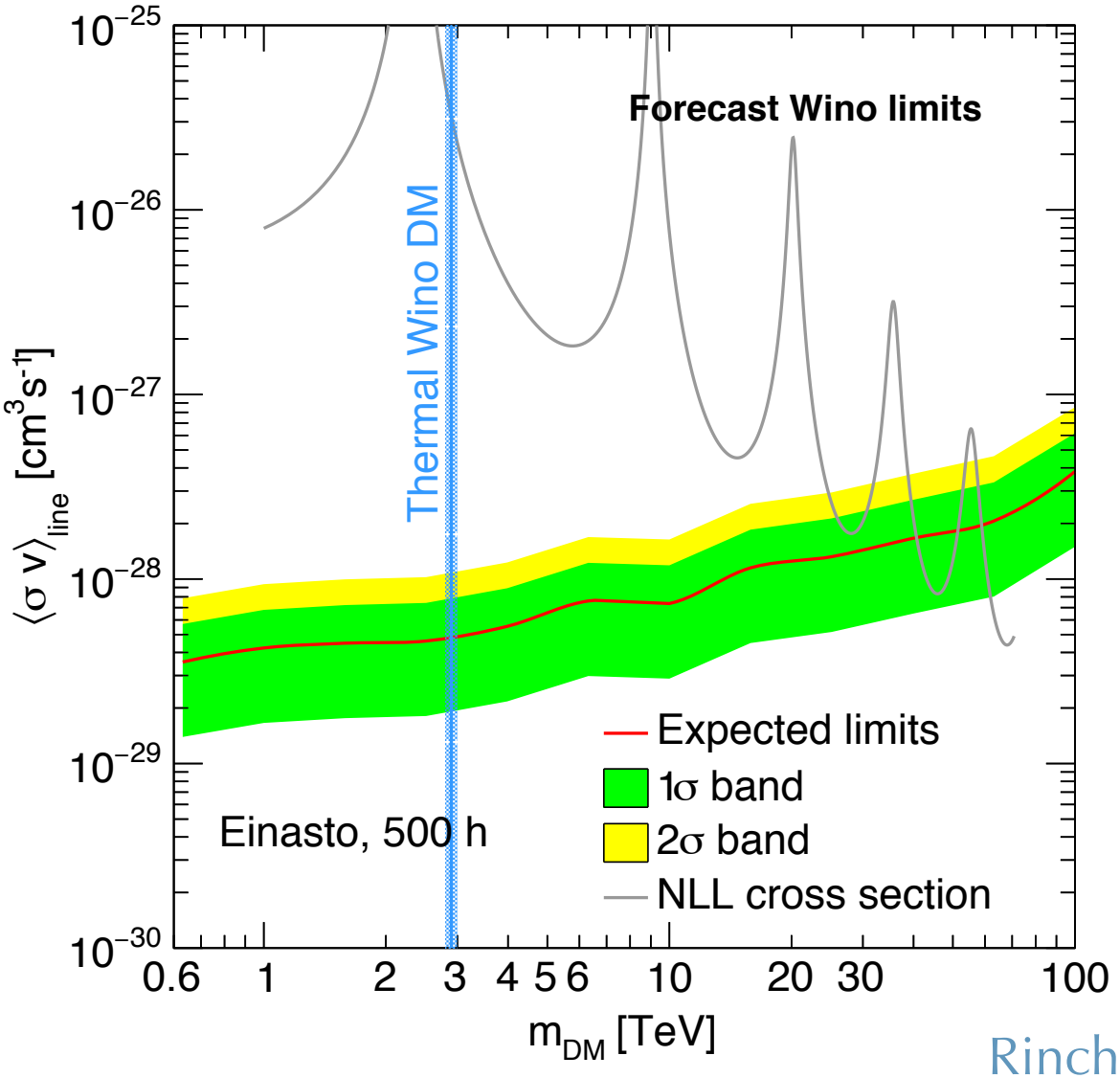


Indirect Detection



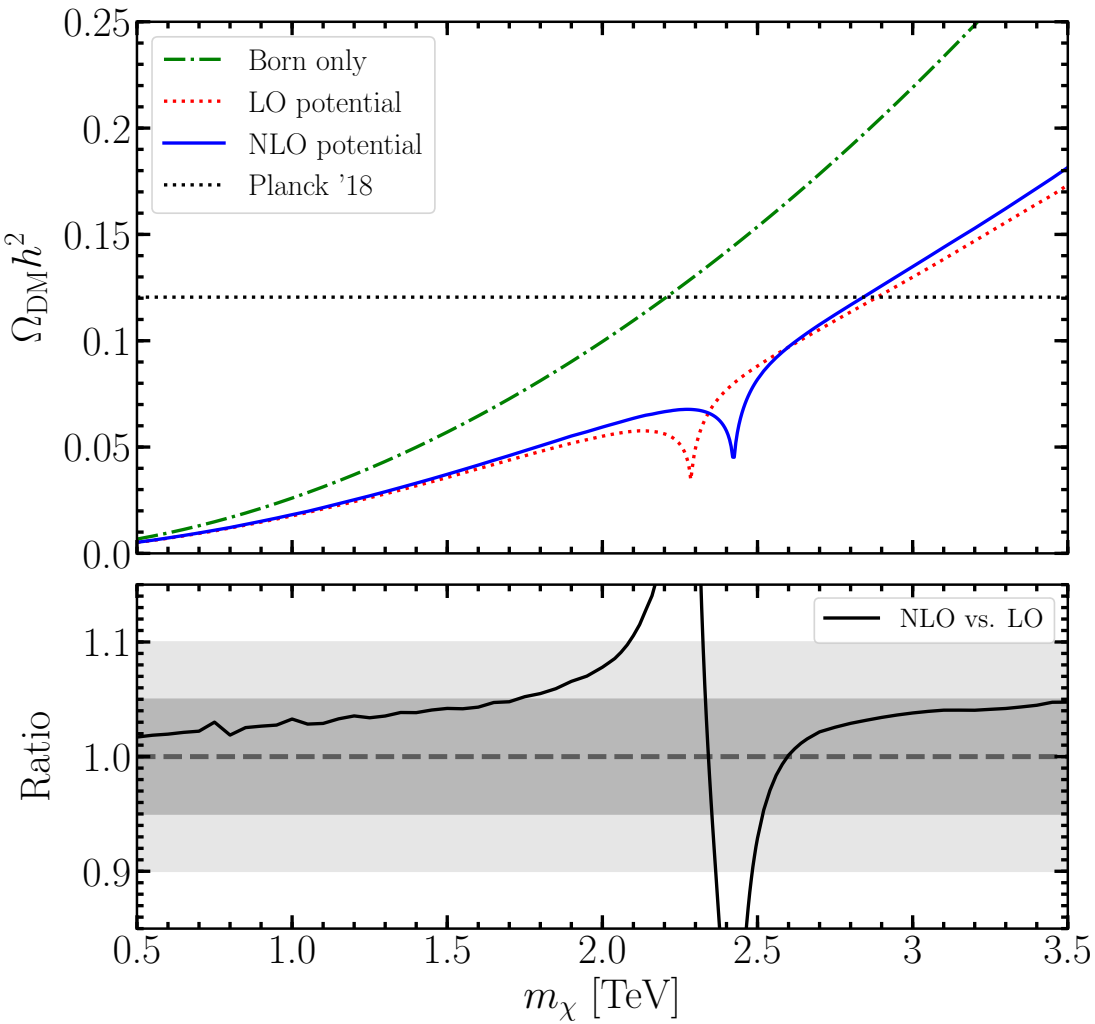
Baumgart, Rothstein, Vaidya
Bauer, Cohen, Hill, Solon
Ovanesyan, Slatyer, Stewart
Baumgart et al.
Beneke, Broggio, Hasner, Vollman
…

Indirect Detection



Rinchiuso et al

Relic Density



Beneke, Szafron, Urban

Multi-scale Problem

scattering

M

m_W EW corrections

m_b QCD corrections

m_N nucleon properties

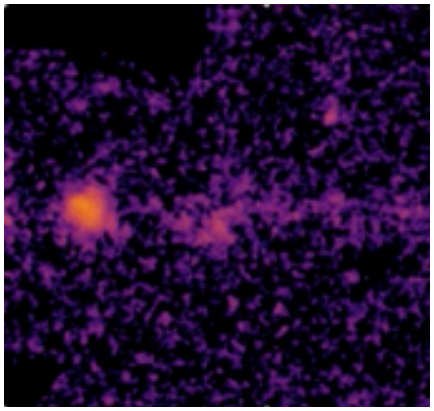
annihilation

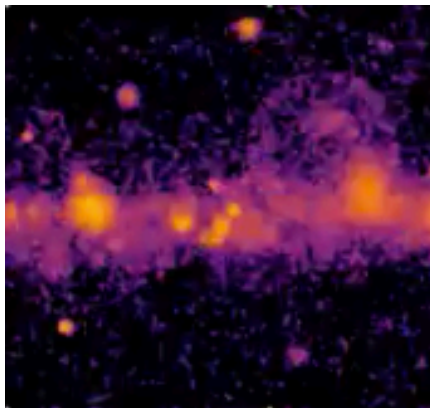
M

m_W

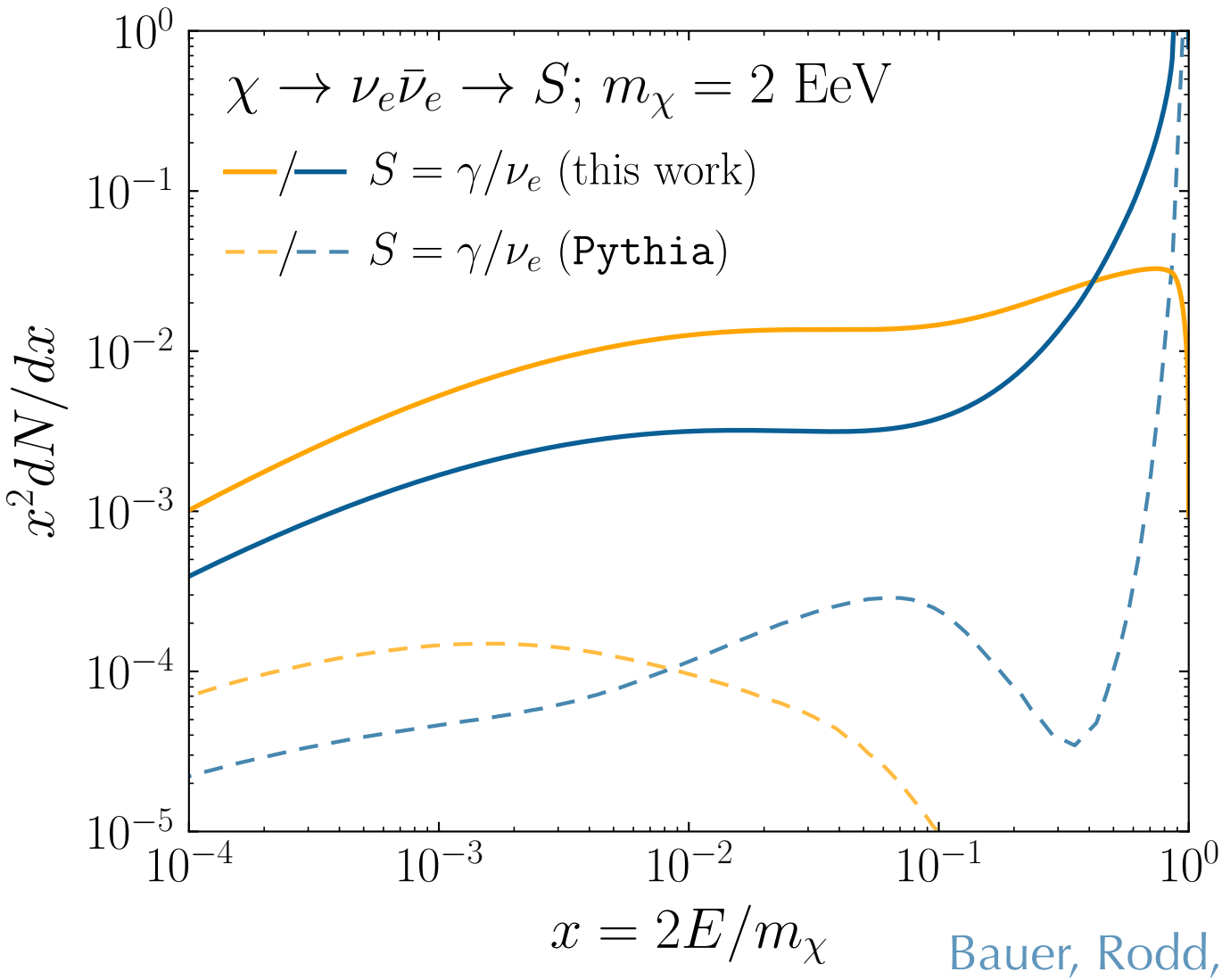
soft & collinear divergences

long-range forces



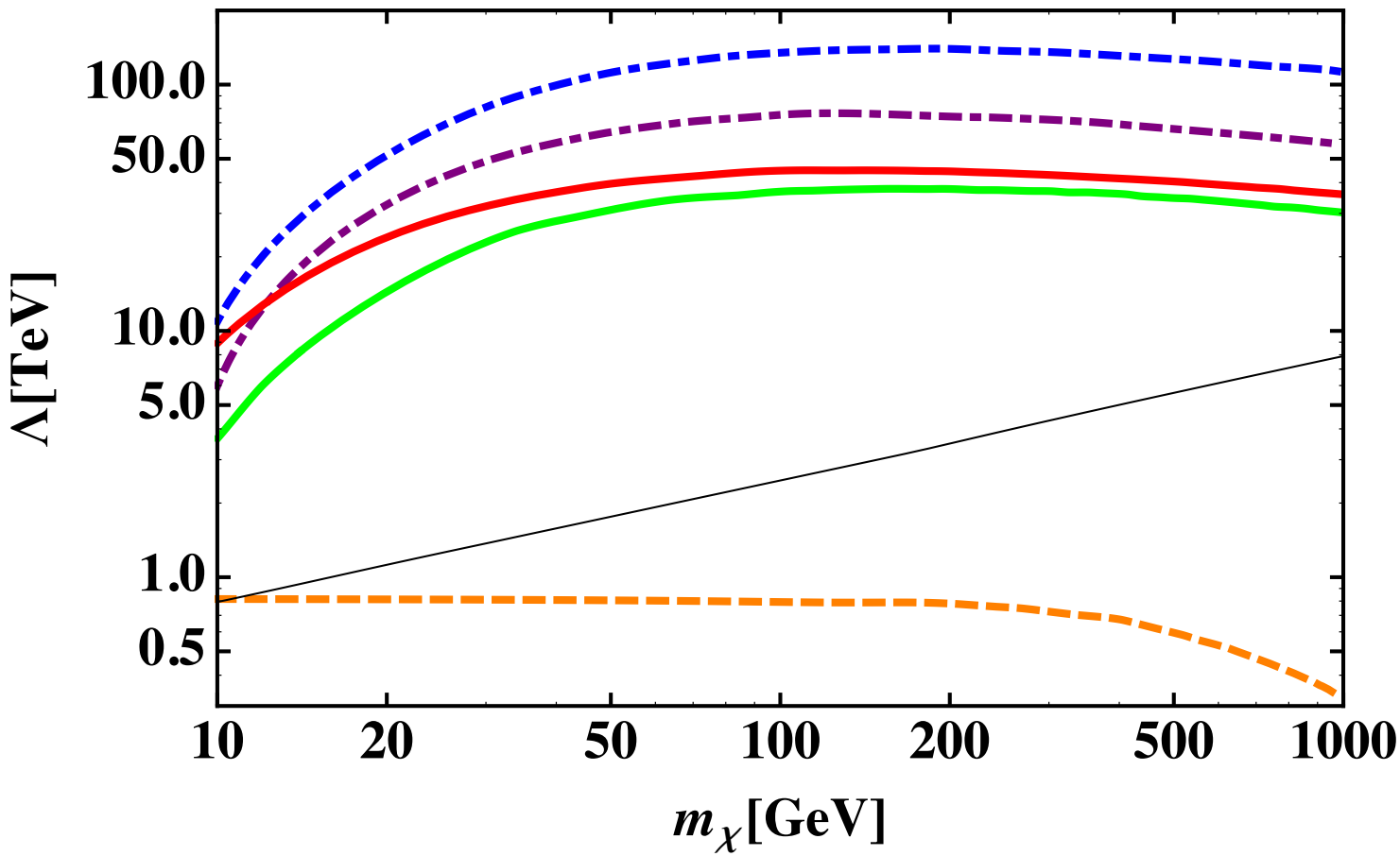


Heavy DM Indirect Detection



Bauer, Rodd, Webber 20

Renormalization Group Effects



Crivellin, D'Eramo, Procura

Precision tools (RG, HQET, SCET, lattice, perturbative QCD, …) are valuable for controlling large theoretical uncertainties in dark matter phenomenology.

We are planning to write a white paper on EFT for DM. Please contact me or Matthew Baumgart, Tim Cohen, Nicholas Rodd, or Tracy Slatyer if you're interested.