From boost to brake: Dark Matter upscattering by the Diffuse Supernova Neutrino Background

Tim Herbermann

NOW 2024

2403.15367 (with A. Das, M. Sen & V. Takhistov)

2408.02721 (with M. Lindner & M. Sen)

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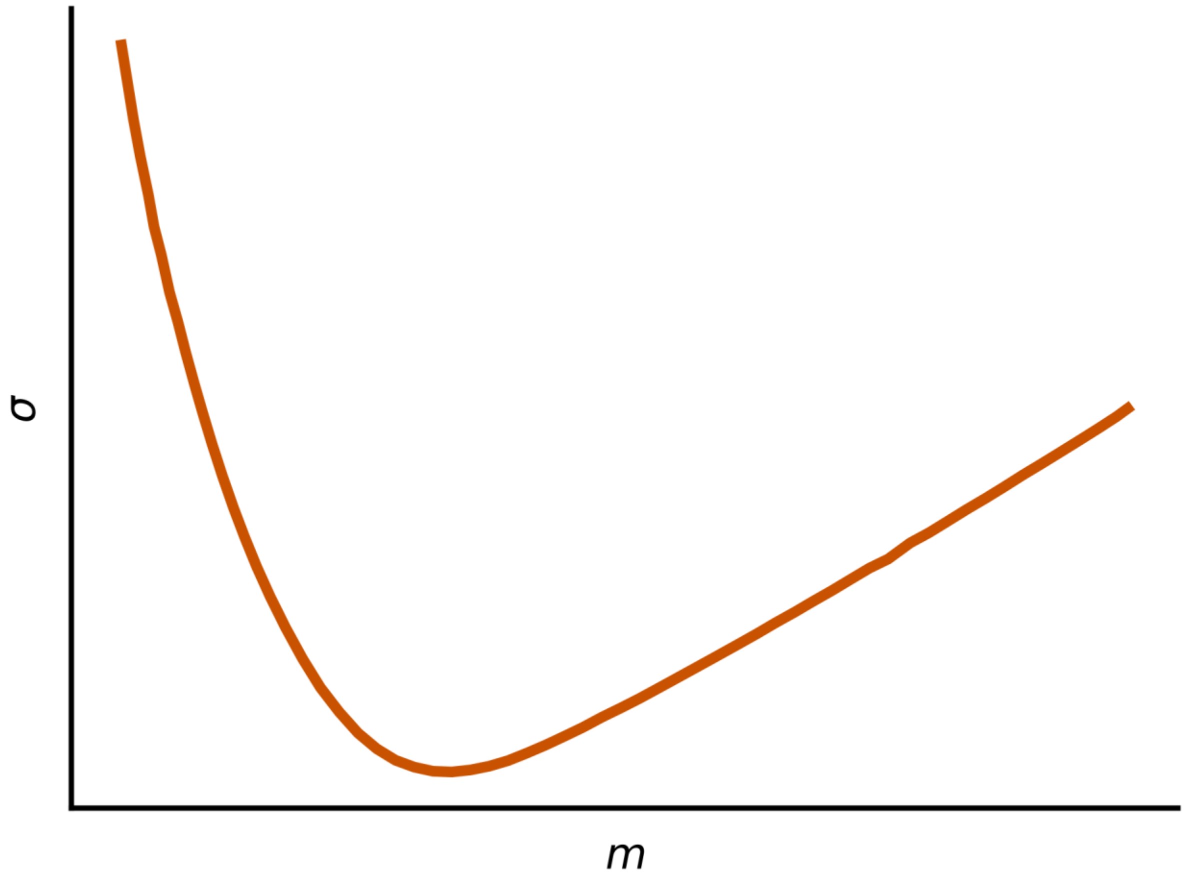
The problem in direct detection

$$E_{\text{recoil}}^{\text{max}} \propto m_{\text{DM}}^2$$



$$n_{\text{DM}} \propto m_{\text{DM}}^{-1}$$

Boosted DM to the rescue!

- Fraction of DM with boosted kinetic energies $T_\chi \gg m_\chi v_{\mathrm{gal}}^2$
- Recoil energy no longer mass suppressed
- Often irreducible, since we already assume interactions for detection → Comes for free!

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We use neutrinos from Diffuse Supernova Neutrino Background (DSNB) for upscattering of leptophilic DM

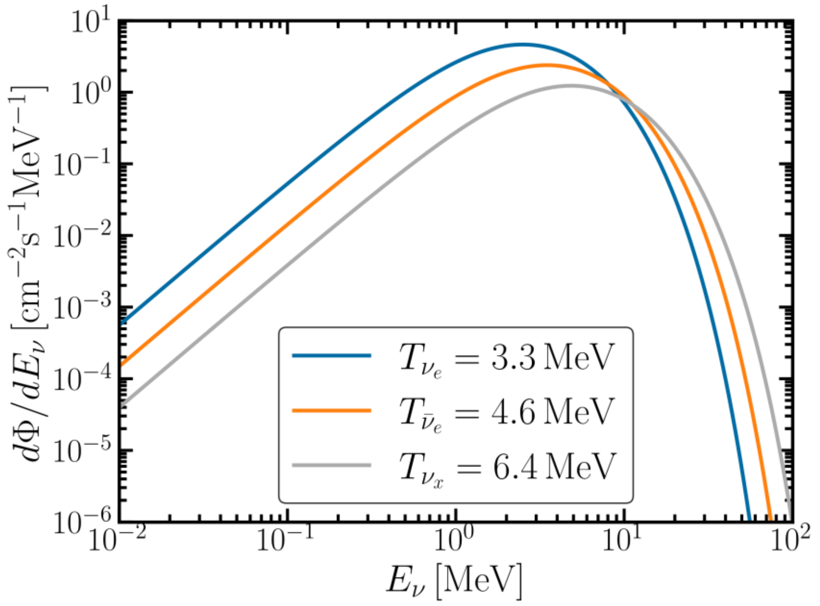
Why boosting with the DSNB?

See talk by C. Volpe

- Abundant flux at MeV energies

$$T_\chi^{\max} = \frac{E_\nu^2}{E_\nu + m_\chi/2}$$

- ν-DM interactions can arise naturally in leptophilic models
- Probe of joint e-DM and ν-DM interaction



$$\Phi_\nu(E) = \int_0^{z_{\max}} \frac{dz}{H(z)} R_{\rm CCSN}(z) F_\nu(E')|_{E'=E(1+z)}$$

$$F_\nu(E) = \frac{E_\nu^{\rm tot}}{6} \frac{120}{7\pi^4} \frac{E^2}{T_\nu^4} \frac{1}{e^{E/T_\nu}+1}$$

$$E_\nu^{\rm tot} = 3 \times 10^{53} {\rm erg}$$

A. Das & M. Sen (2021), De Romeri et al (2024)

The boost…

Local upscattering rate of DM by DSNB

Integrate all lines of sight

$$\frac{d\Phi_\chi}{dT_\chi} = \int \frac{d\Omega}{4\pi} \int_{\mathrm{l.o.s.}} dl \int_{E_\nu^{\mathrm{min}}}^{E_\nu^{\mathrm{max}}} dE_\nu \frac{\rho_\chi(l)}{m_\chi} \frac{d\Phi_\nu}{dE_\nu} \frac{d\sigma_{\nu\chi}}{dT_\chi}$$

… and the brake

Underground direct detection sites

Energy loss from elastic scattering
before detection leads to flux attenuation

$$\frac{dT_\chi}{dx}(x) = -\sum_i n_i(x) \int_0^{T_i^{\max}} dT_i \, T_i \frac{d\sigma_{i\chi}}{dT_i}$$

Conservative: Purely elastic, no multiple
scattering, no deflection

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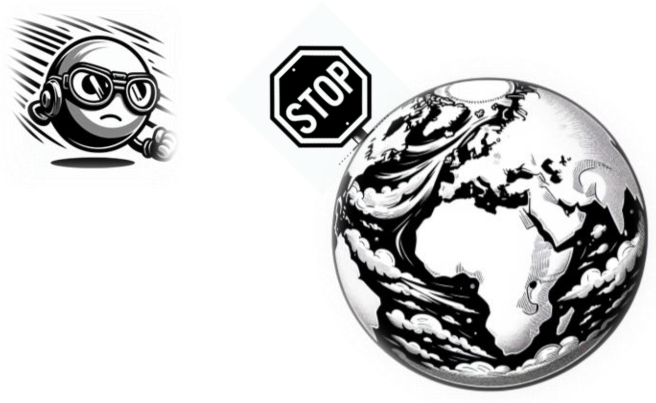

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Previously: Analytic approximation

- Constant cross section only
- Assumptions on kinematics

Does not apply here!

… and the brake

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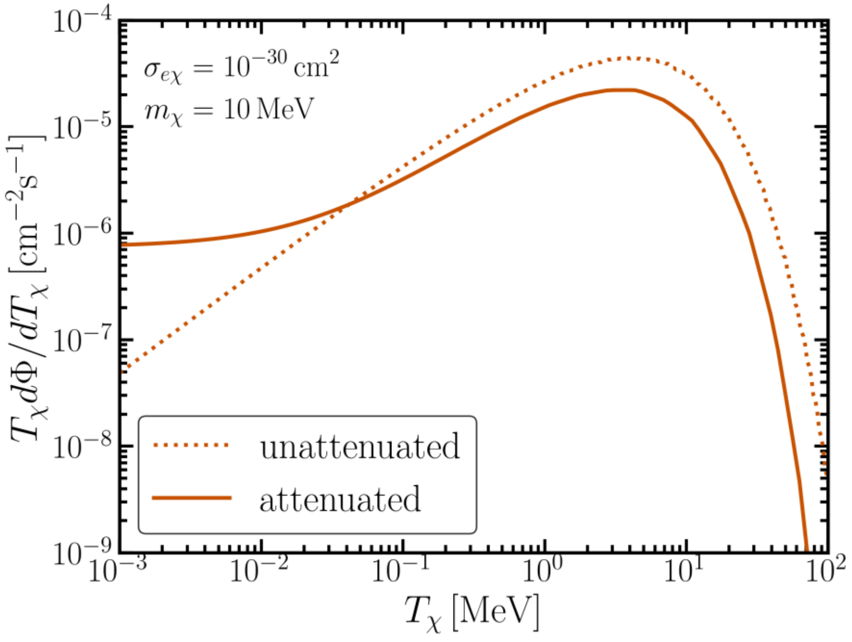
NEW: Full numerical solution
- No additional approximations
- Enables model dependent studies
- Numerically challenging

Conservative: Purely elastic, no multiple scattering, no deflection

Effect of attenuation

Attenuation for constant cross section



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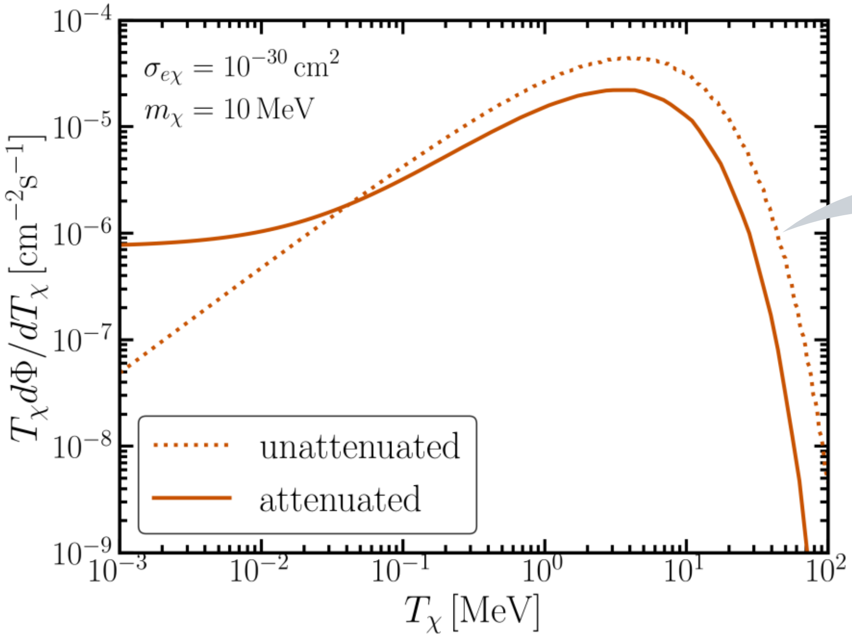

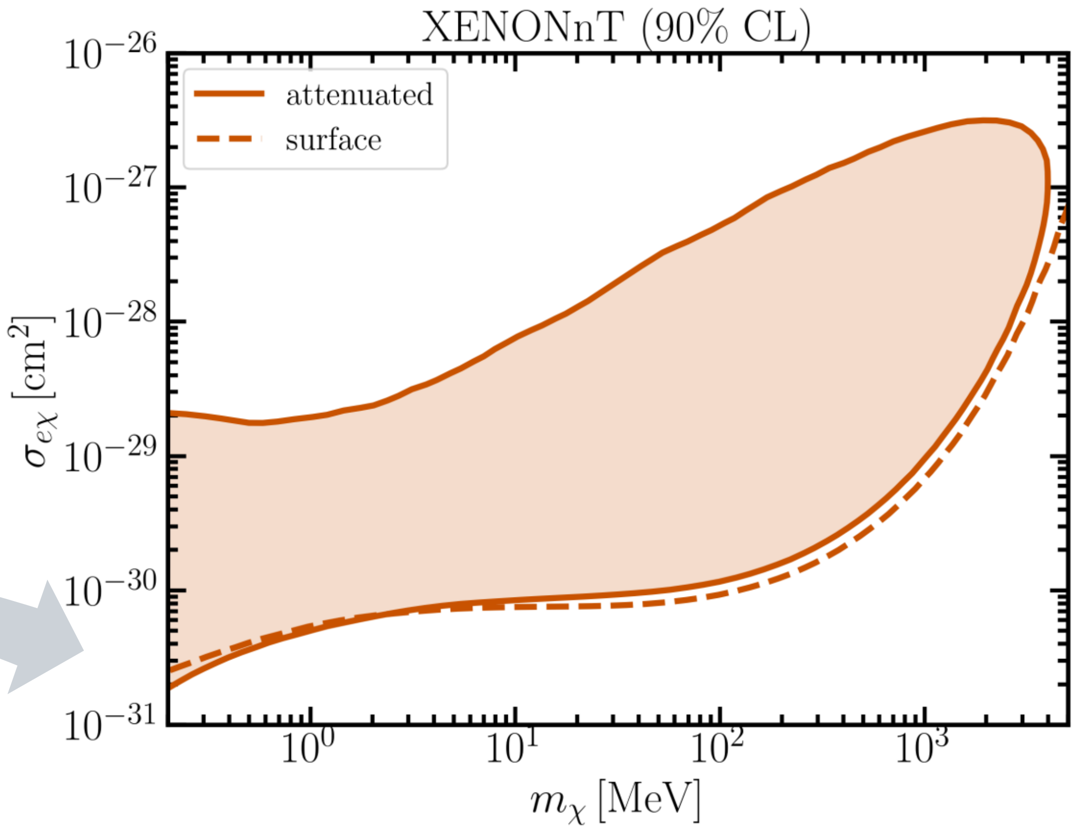

$$\frac{dR}{dT_e} = N_e \int dT_\chi \frac{d\Phi_\chi}{dT_\chi^z} \frac{d\sigma_{e\chi}}{dT_e}$$

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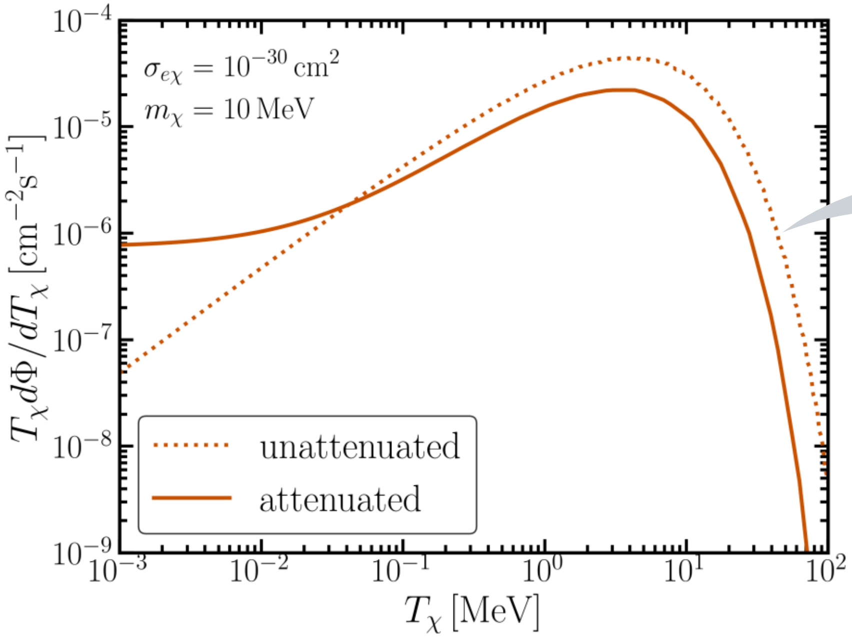

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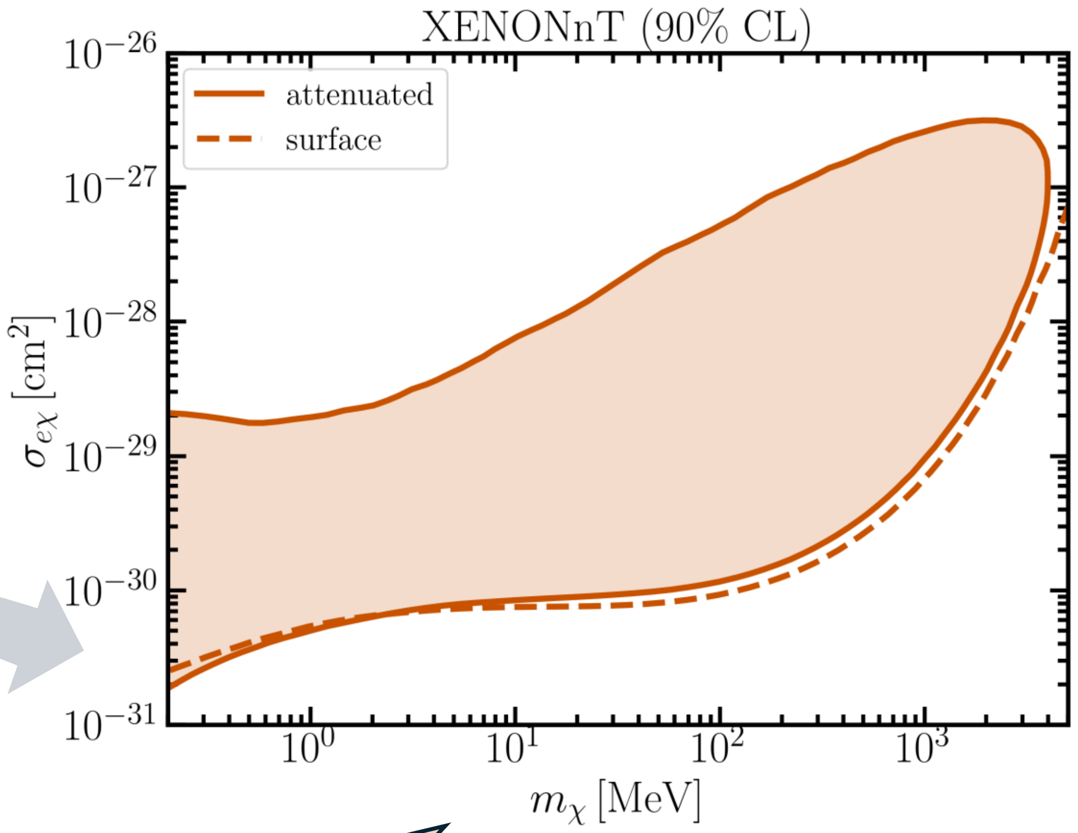
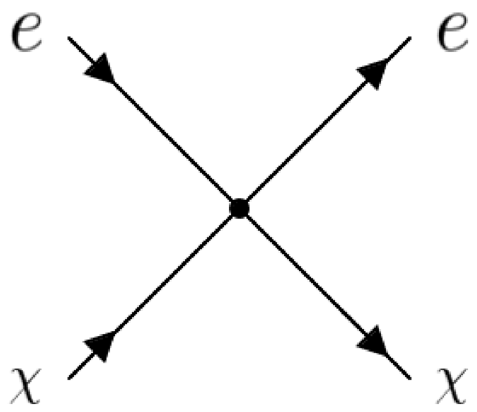


Attenuation ceiling in tension with approximate solutions highlighting the necessity of a full solution.

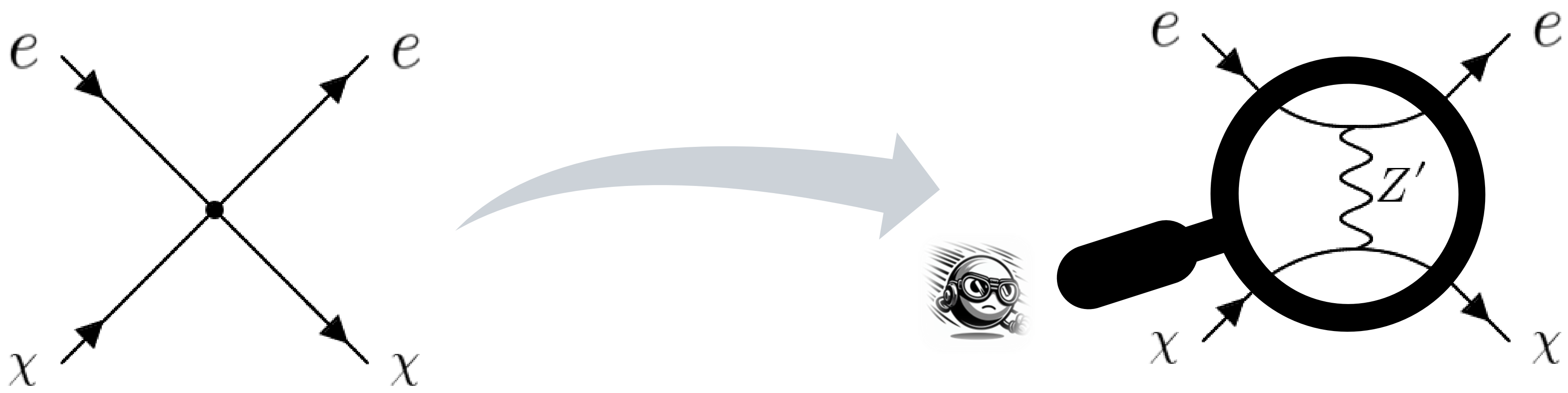
The role of energy dependence



Non relativistic DM mapped on effective cross section

$$\bar{\sigma}_{e\chi} = \frac{g_e^2 g_\chi^2}{\pi} \frac{\mu_{e\chi}^2}{\left(q_{\rm ref}^2 + M_{\rm med}^2\right)^2}\,, \quad q_{\rm ref} = \alpha m_e$$

The role of energy dependence



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Boosted DM (semi-)relativistic

$$q \gg \alpha m_e$$

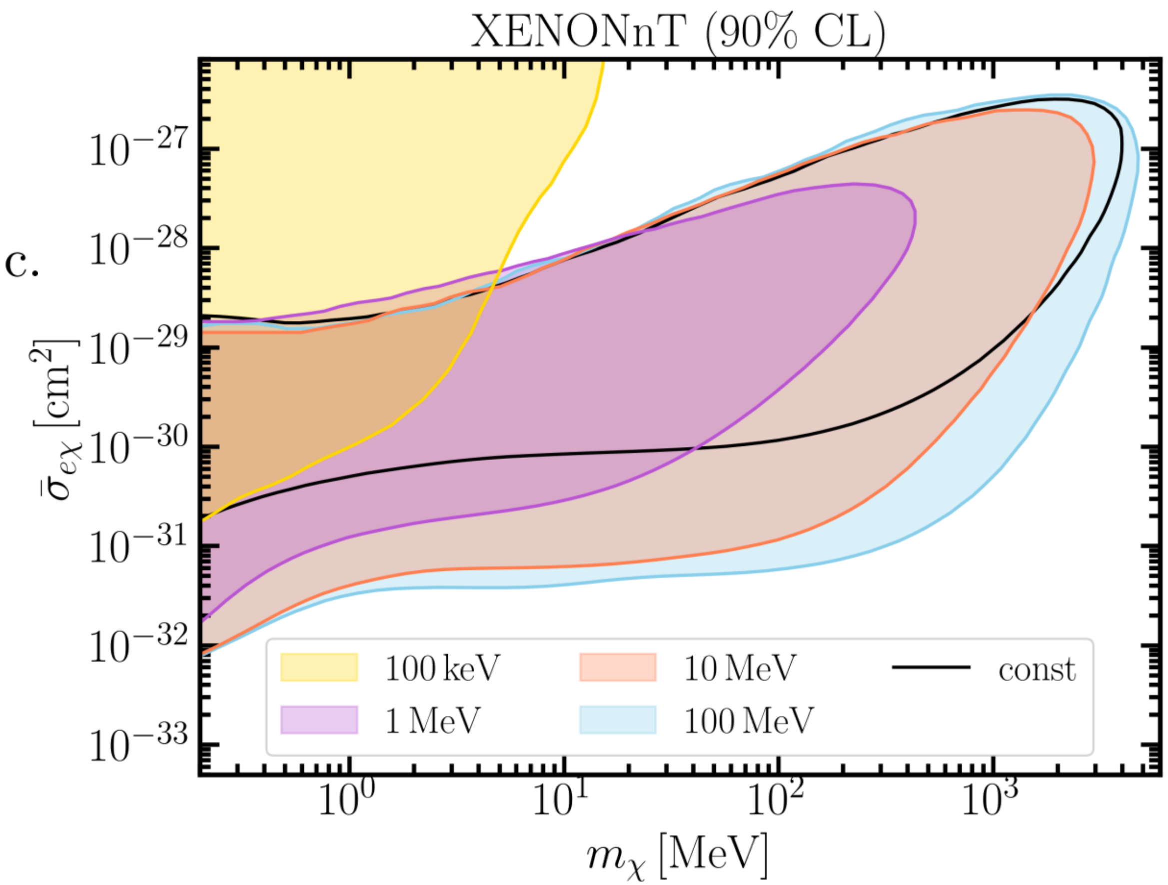
Are we sensitive to underlying interaction?

Energy dependence matters!

Limits for leptophilic Z' toy-model

$$\mathcal{L} \supset \frac{1}{2} m_{Z'}^2 Z'_\mu Z'^\mu + g\bar{L}\gamma_\mu L Z'^\mu + g_\chi \bar{\chi}\gamma_\mu \chi Z'^\mu + \text{h.c.}$$

and map on effective cross section to compare



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JCAP 07 (2024), 045
(A. Das, TH, M. Sen & V. Takhistov)

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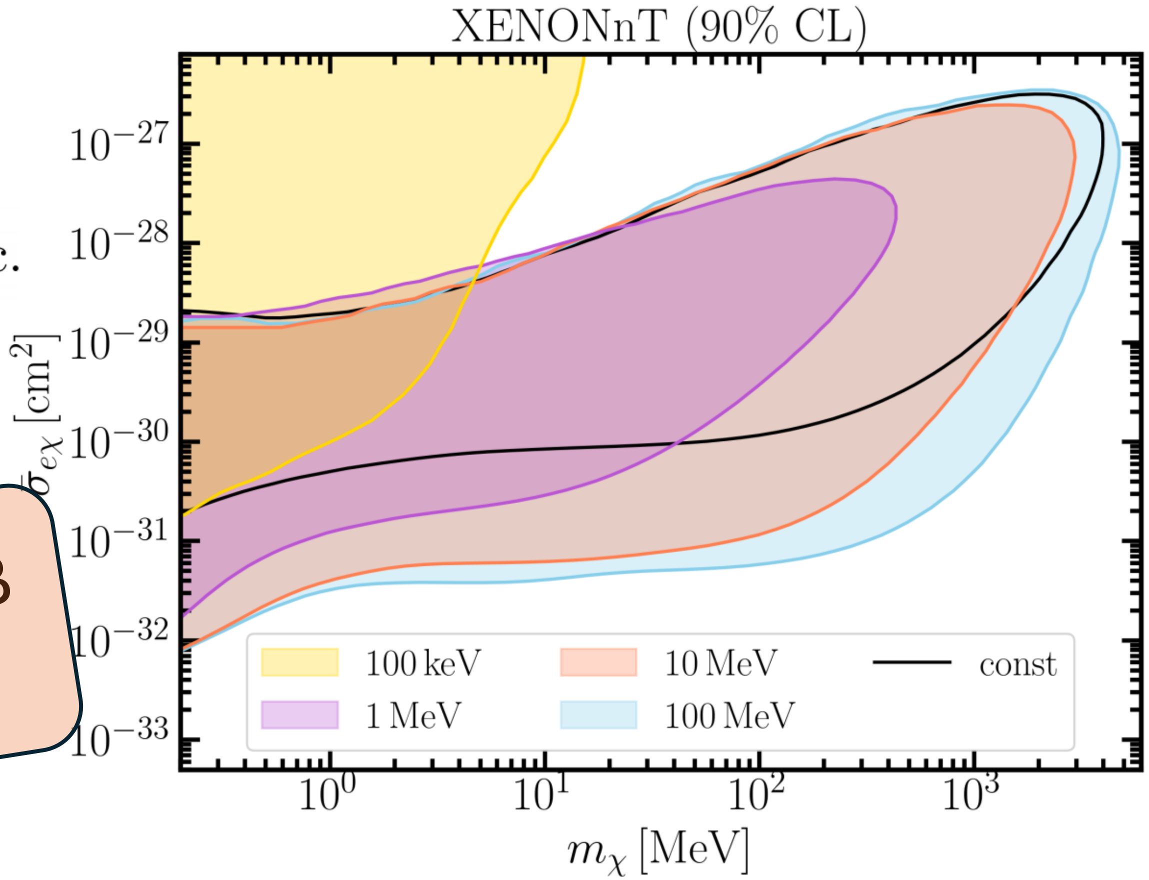
This also applies beyond DSNB boosted leptophilic DM



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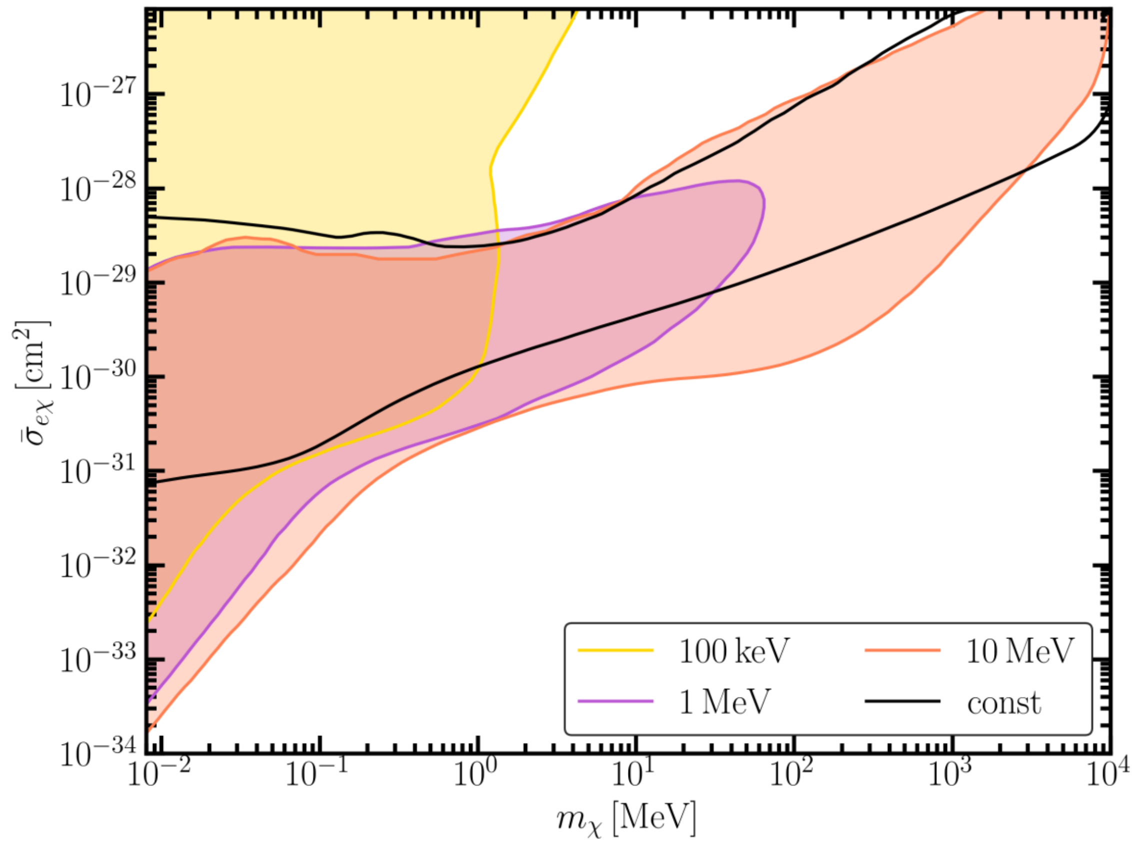
Beyond DSNB?

Energy depence and attenuation general features of (boosted) DM

Indeed, we found similar results for cosmic ray electron boosted DM!



arXiv: 2408.02721
(**TH**, M. Lindner, M. Sen)

Summary

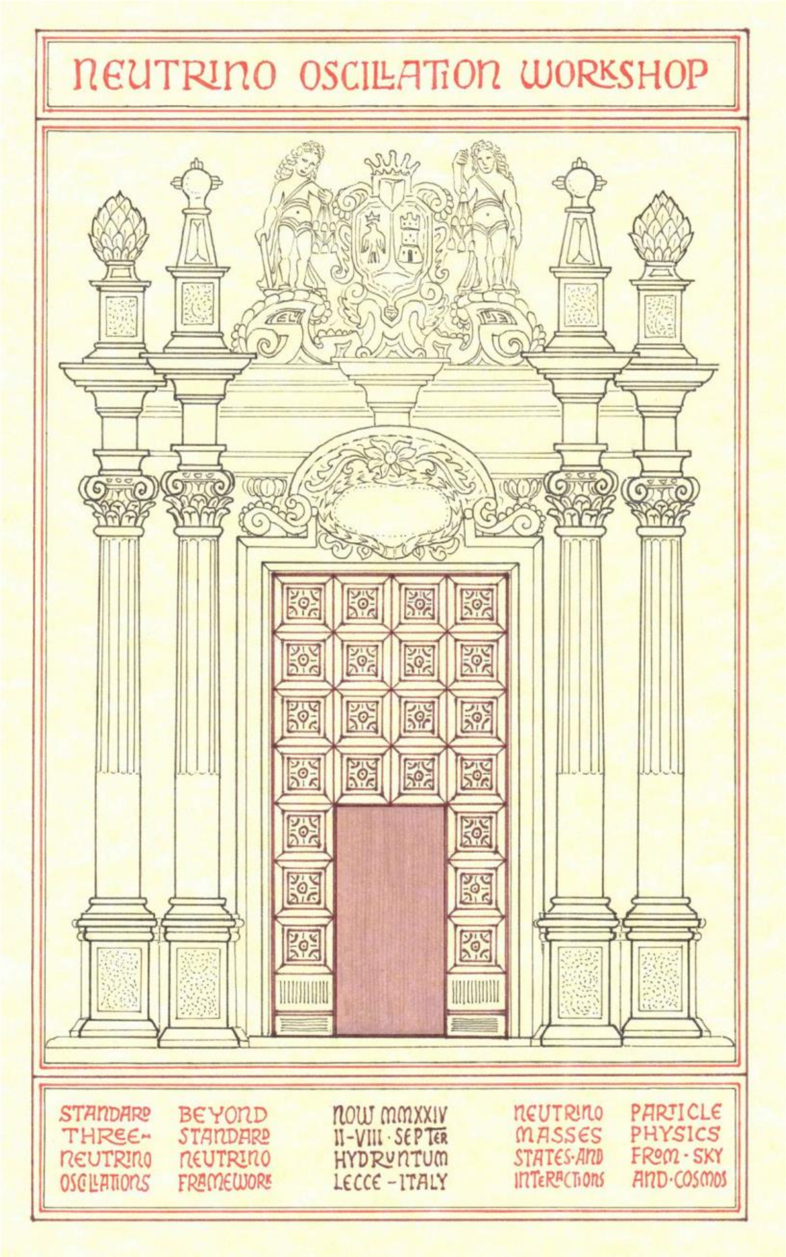
Unique testing ground for DM-lepton interactions complementing other ν-DM probes.

Boosted DM comes for free - we should exploit it.

Energy dependence and correct treatment of attenuation matter.

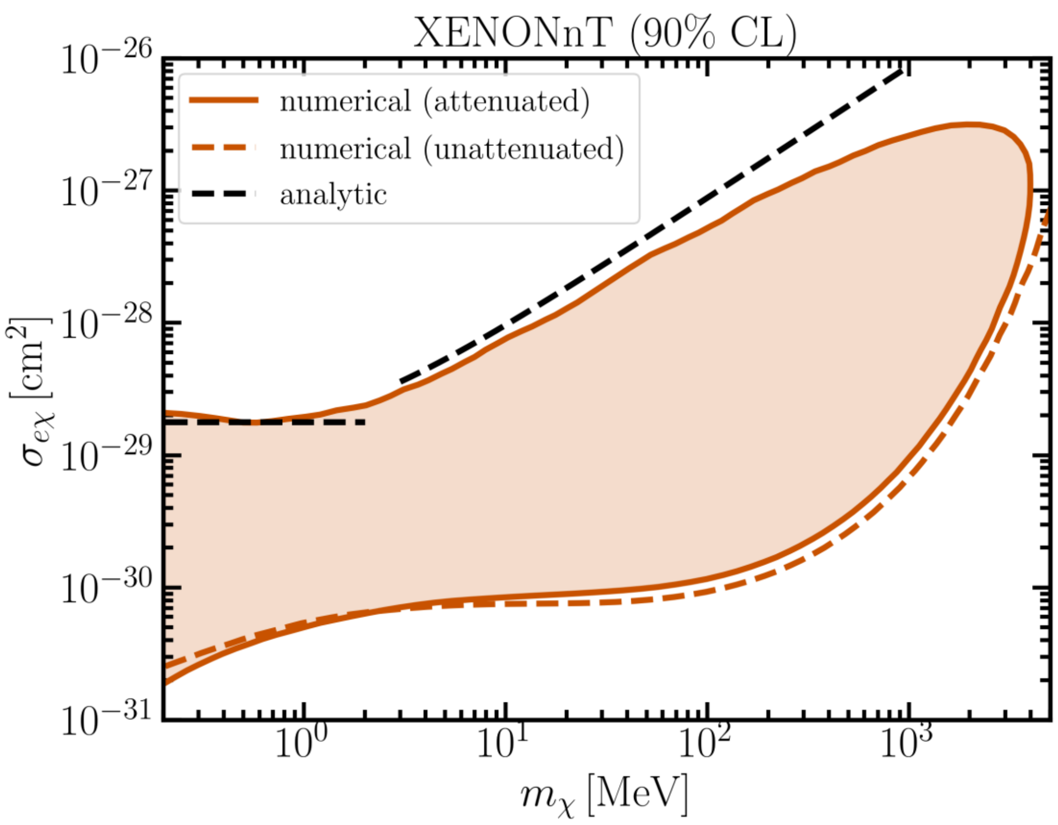
Implications beyond DSNB boosted DM.

Thank you!



NEUTRINO OSCILLATION WORKSHOP
STANDARD THREE-NEUTRINO OSCILLATIONS
BEYOND STANDARD NEUTRINO FRAMEWORK
NOW MMXXIV II-VIII · SEPTER HYDRUNTUM LECCE - ITALY
NEUTRINO MASSES STATES · AND INTERACTIONS
PARTICLE PHYSICS FROM · SKY AND · COSMOS

Understanding attenuation



Approximate for constant cross section and detector at depth d

i. $m_\chi \gg m_e$

$$\frac{dT_\chi}{dx} = -\frac{1}{2m_\chi \lambda_{\rm eff}}(T_\chi^2 + 2m_\chi T_\chi)\,, \quad \lambda_{\rm eff}^{-1} = 4\,n_e \bar{\sigma}_{e\chi} m_e m_\chi/(m_e + m_\chi)^2 \propto m_\chi^{-1}$$

$d/\lambda_{\rm eff} \approx 1 \;\Rightarrow\; \sigma_{e\chi} \propto m_\chi$

ii. $m_\chi \sim m_e$

$$\frac{dT_\chi}{dx} \approx -\frac{1}{2} n_e \bar{\sigma}_{e\chi} T_\chi\,.$$

$\Rightarrow\; \sigma_{e\chi} \approx \text{const}$