# Up-scattering production of a sterile fermion at neutrino and DM experiments

Based on *JHEP* 10 (2024) 032

in collaboration with Valentina De Romeri, Pantelis Melas, Dimitris Papoulias and Niki Saoulidou

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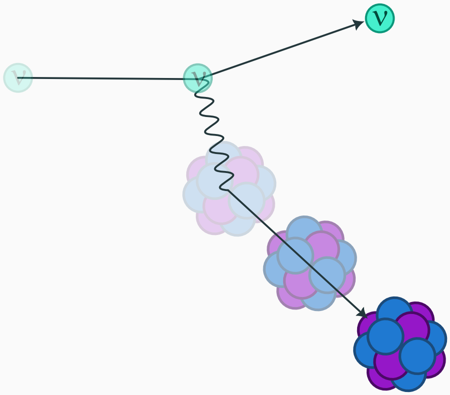
# Introduction

# What is CEvNS?




**C**oherent

**E**lastic

**ν** (neutrino)

**N**ucleus

**S**cattering

# A journey of 43 years

Predicted

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

**Coherent effects of a weak neutral current**

Daniel Z. Freedman†
*National Accelerator Laboratory, Batavia, Illinois 60510*
*and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790*
(Received 15 October 1973; revised manuscript received 19 November 1973)

First detected

*RESEARCH*

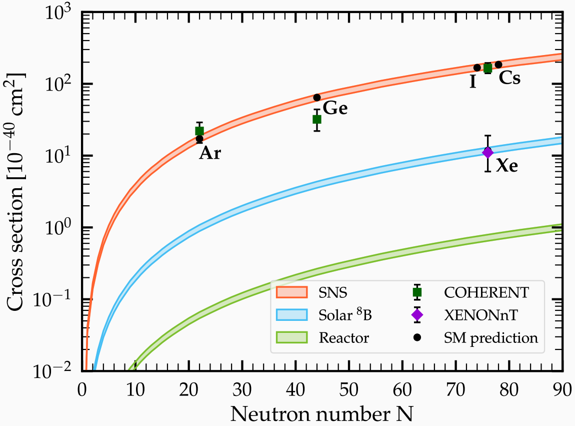
NEUTRINO PHYSICS

**Observation of coherent elastic neutrino-nucleus scattering**

[...]

Akimov *et al.*, *Science* **357**, 1123–1126 (2017) 15 September 2017

# The CEvNS cross section is enhanced by the number of neutrons




$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{4\pi} Q_W^2 F^2(|\mathbf{q}|^2)\left(1 - \frac{MT}{2E_\nu^2}\right)$$

- $Q_W^2 \approx N^2$ in the SM

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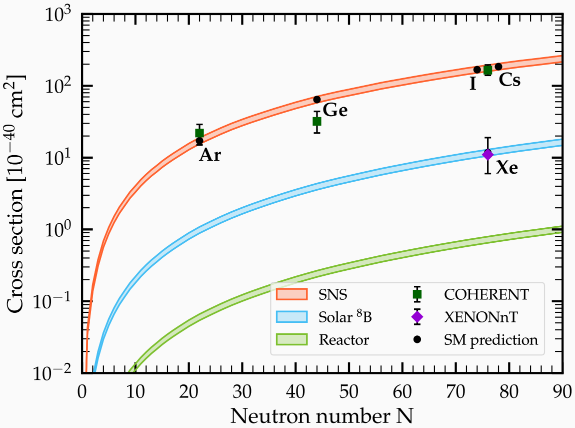



**References:**

COHERENT CsI 2021 measurement at **11.6$\sigma$**: D. Akimov *et al.* (COHERENT collaboration) Phys. Rev. Lett. **129**, 081801

COHERENT LAr 2020 measurement at **3.9$\sigma$**: D. Akimov *et al.* (COHERENT collaboration) Phys. Rev. Lett. **126**, 012002

COHERENT Ge 2024 measurement at **3.9$\sigma$**: S. Adamski *et al.* (COHERENT collaboration) Phys. Rev. Lett. **134**, 231801

XENONnT Xe 2024 measurement at **2.73$\sigma$**: E. Aprile *et al.* (XENONnT collaboration) Phys. Rev. Lett. **133**, 191002

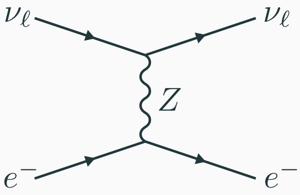
PandaX-4T Xe 2024 measurement at **2.64$\sigma$**: Z. Bo *et al.* (PandaX collaboration) Phys. Rev. Lett. **133**, 191001

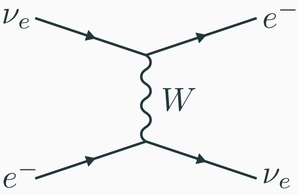
CONUS+ Ge 2025 measurement at **3.7$\sigma$**: N. Ackermann *et al.* (CONUS collaboration) Nature **643**, 1229–1233 (2025)

Dresden-II Ge 2022 (strong dependence on quenching factor): J. Colaresi *et al.* Phys. Rev. Lett. **129**, 211802

# Another detection channel: elastic neutrino-electron scattering (EνES)

In the Standard Model, the process is flavor-dependent (neutral and/or charged currents):



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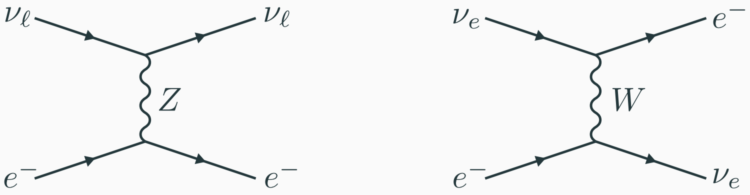
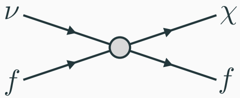



When the electron is bound to a nucleus, the cross section includes a term that indicates the amount of electrons that can be ionized by the energy deposited by the neutrino.

# Our phenomenological scenario

# New effective interactions are added to study the up-scattering of a sterile fermion $\chi$

$$\mathcal{L}^{a}_{\rm SF} \supseteq \frac{G_F}{\sqrt{2}}\,\varepsilon^{a}_{\ell}\left(\overline{\chi}\,\Gamma^{a}P_L\nu_{\ell}\right)\left(\overline{f}\,\Gamma_{a}f\right) + \text{H.c.},$$



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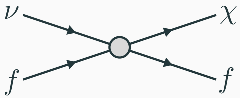
$$\Gamma^{a} = \{I,\, i\gamma^5,\, \gamma^{\mu},\, \gamma^{\mu}\gamma^5,\, \sigma^{\mu\nu}\}$$



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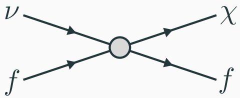


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On this talk we will consider only

- Scalar (S)

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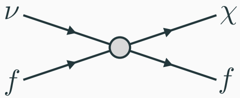


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On this talk we will consider only

- Scalar (S)
- Vector (V)

# We take the light mediator limit and consider the nuclear structure when computing cross sections

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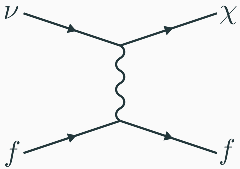


- Mediator mass comparable to momentum transfer

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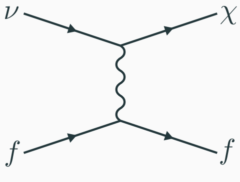


- Mediator mass comparable to momentum transfer

$$G_F^2 |\varepsilon_\ell^a|^2 \longrightarrow \frac{2g_a^4}{\left(m_a^2 + |\mathbf{q}|^2\right)^2}$$

For example, in CEvNS up-scattering via a vector mediator the cross section reads

$$\left.\frac{\mathrm{d}\sigma_{\nu_\ell \mathcal{N}}}{\mathrm{d}T_\mathcal{N}}\right|_{\mathrm{CE}\nu\mathrm{NS}}^{\mathrm{V}}(E_\nu, T_\mathcal{N}) = \frac{9 m_\mathcal{N}}{2\pi (m_V^2 + 2 m_\mathcal{N} T_\mathcal{N})^2} g_V^4 A^2 F_W^2(|\mathbf{q}|^2) \times \left[\left(1 - \frac{m_\mathcal{N} T_\mathcal{N}}{2E_\nu^2} - \frac{T_\mathcal{N}}{E_\nu} + \frac{T_\mathcal{N}^2}{2E_\nu^2}\right) - \frac{m_\chi^2}{4E_\nu^2}\left(1 + \frac{2E_\nu}{m_\mathcal{N}} - \frac{T_\mathcal{N}}{m_\mathcal{N}}\right)\right].$$

References:

**Candela**, De Romeri, Melas, Papoulias, Saoulidou, JHEP 10 (2024) 032

**Candela**, De Romeri, Papoulias, Phys. Rev. D **108**, 055001

For example, in $\nu$–$e^-$ up-scattering via a vector mediator the cross section reads

$$\left.\frac{\mathrm{d}\sigma_{\nu_\ell \mathcal{A}}}{\mathrm{d}T_e}\right|_{\mathrm{E}\nu\mathrm{ES}}^{\mathrm{V}}(E_\nu, T_e) = \frac{m_e}{2\pi(m_V^2 + 2m_e T_e)^2}\mathrm{g}_V^4 Z_{\mathrm{eff}}^{\mathcal{A}}(T_e)$$
$$\times\left[\left(1 - \frac{m_e T_e}{2E_\nu^2} - \frac{T_e}{E_\nu} + \frac{T_e^2}{2E_\nu^2}\right) - \frac{m_\chi^2}{4E_\nu^2}\left(1 + \frac{2E_\nu}{m_e} - \frac{T_e}{m_e}\right)\right].$$

References:

**Candela**, De Romeri, Melas, Papoulias, Saoulidou, JHEP 10 (2024) 032

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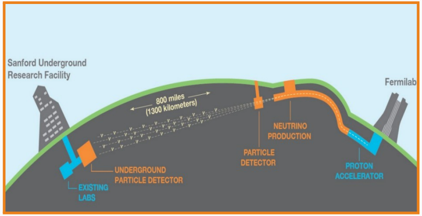
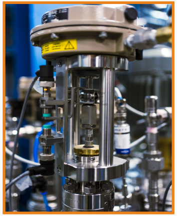
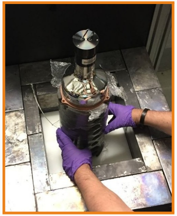
# We perform the analysis on several detectors




*DUNE*
(DUNE collaboration)



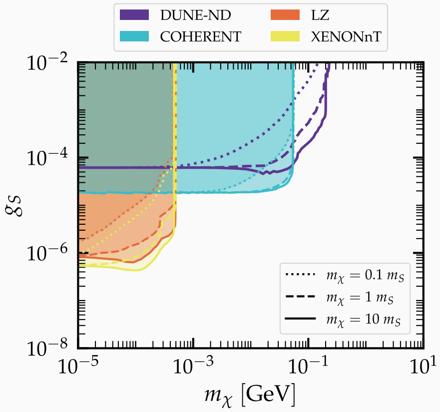
*XENONnT detector*
(XENON collaboration)



*CsI detector*
(COHERENT collaboration)

*LZ detector*
(LZ collaboration)

# Exclusion regions at 90% C.L. (in colour) change with different sterile fermion masses ($m_\chi$) for the scalar interaction

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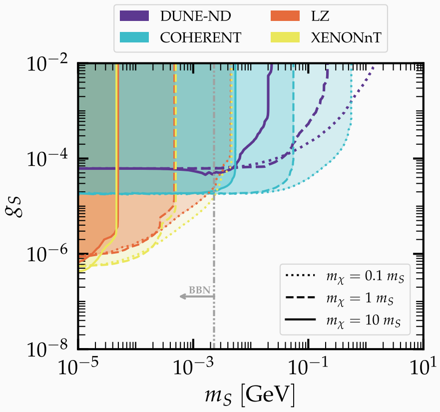


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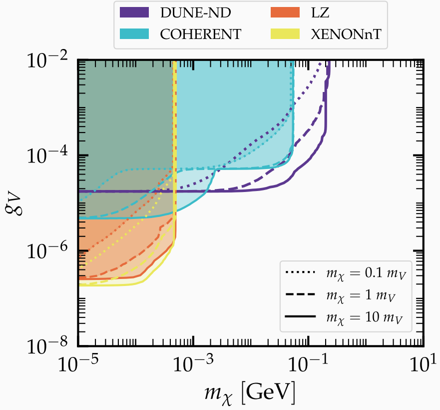
# Exclusion regions at 90% C.L. (in colour) change with different sterile fermion masses ($m_\chi$) for the vector interaction

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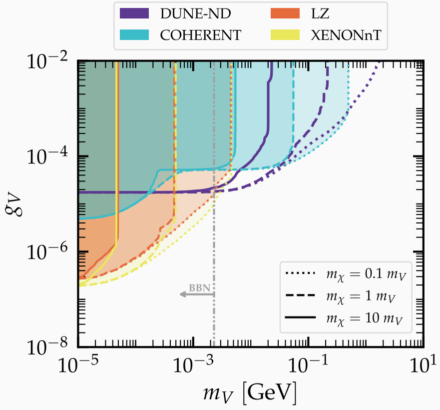


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Thank you!

# Backup slides

# CsI statistical analysis

$$\chi^2_{\text{CsI}}\Big|_{\text{CE}\nu\text{NS+ES}} = 2\sum_{i=1}^{9}\sum_{j=1}^{11}\left[N_{ij}^{\text{th}} - N_{ij}^{\text{exp}} + N_{ij}^{\text{exp}} \ln\left(\frac{N_{ij}^{\text{exp}}}{N_{ij}^{\text{th}}}\right)\right] + \sum_{k=0}^{5}\left(\frac{\alpha_k}{\sigma_k}\right)^2 ,$$

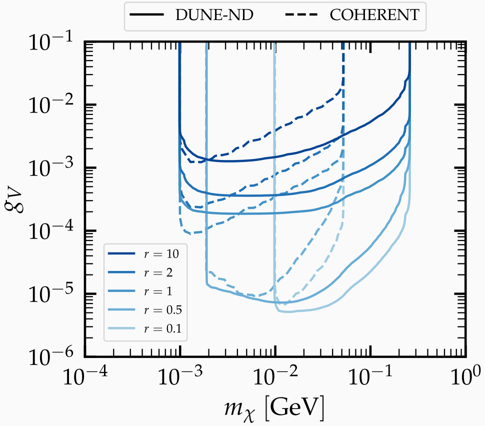
$$N_{ij}^{\text{th}} = (1+\alpha_0+\alpha_5) N_{ij}^{\text{CE}\nu\text{NS}}(\alpha_4,\alpha_6,\alpha_7) + (1+\alpha_0) N_{ij}^{\text{ES}}(\alpha_6,\alpha_7) + (1+\alpha_1) N_{ij}^{\text{BRN}}(\alpha_6) + (1+\alpha_2) N_{ij}^{\text{NIN}}(\alpha_6) + (1+\alpha_3) N_{ij}^{\text{SSB}} .$$

- $\sigma_0 = 11\%$ efficiency + flux
- $\sigma_1 = 25\%$ BRN
- $\sigma_2 = 35\%$ NIN
- $\sigma_3 = 2.1\%$ SSB
- $\sigma_4 = 5\%$ nuclear radius $R_A = 1.23 A^{1/3}(1+\alpha_4)$
- $\sigma_5 = 3.8\%$ QF
- $\alpha_6$ beam timing no prior
- $\alpha_7$ CEvNS efficiency

# Possible decay channels

Tree-level decays:

- If $m_\chi > m_V$, then $m_\chi \to V\nu_\ell$
- If $m_\chi < m_V$, then $m_\chi \to \nu_\ell f\bar{f}$

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