

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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IFIC (CSIC - UV), Valencia (Spain)

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XVII CPAN days

Valencia, Spain



Introduction

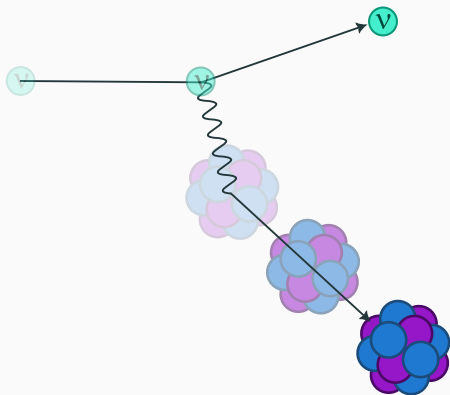
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- Elastic neutrino-electron scattering (EvES)

What is CEvNS?



Coherent
Elastic
 ν (neutrino)
Nucleus
Scattering

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

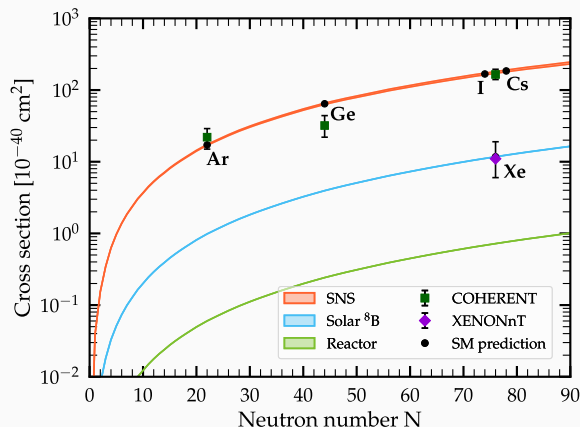
Observation of coherent elastic neutrino-nucleus scattering

[...]

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

15 September 2017

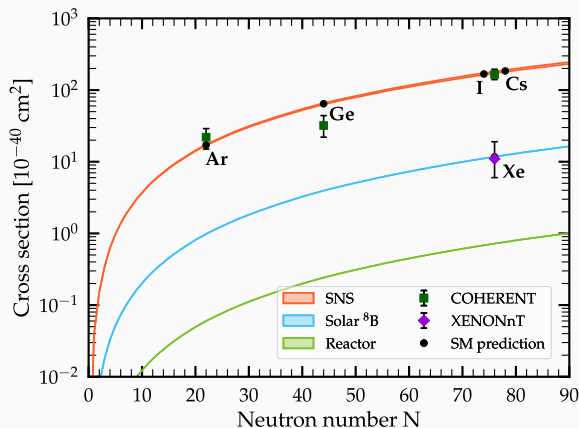
The CEvNS cross section is enhanced by the number of neutrons



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

$$\cdot Q_W^2 \approx N^2 \text{ in the SM}$$

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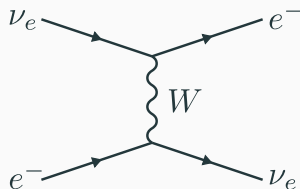
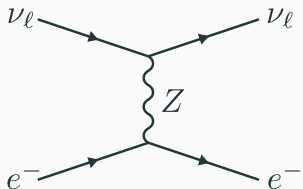


References:

- COHERENT CsI 2021 measurement at 11.6σ : D. Akimov *et al.* (COHERENT collaboration) Phys. Rev. Lett. **129**, 081801
- COHERENT LAr 2020 measurement at 3.9σ : D. Akimov *et al.* (COHERENT collaboration) Phys. Rev. Lett. **126**, 012002
- COHERENT Ge 2024 measurement at 3.9σ : S. Adamski *et al.* (COHERENT collaboration) Phys. Rev. Lett. **134**, 231801
- XENONnT Xe 2024 measurement at 2.73σ : E. Aprile *et al.* (XENONnT collaboration) Phys. Rev. Lett. **133**, 191002
- PandaX-4T Xe 2024 measurement at 2.64σ : Z. Bo *et al.* (PandaX collaboration) Phys. Rev. Lett. **133**, 191001
- CONUS+ Ge 2025 measurement at 3.7σ : 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

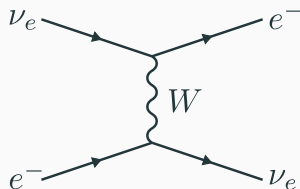
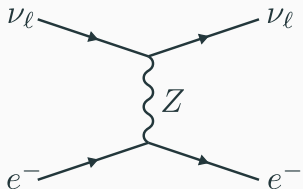
Elastic neutrino-electron scattering (EvES)

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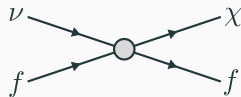


When the electron is bound to a nucleus, the cross section includes a term that indicates the amount of electrons that can be ionized by the energy deposited by the neutrino.

Our phenomenological scenario

New effective interactions are added to study the up-scattering of a neutrino into a sterile fermion χ

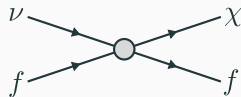
$$\mathcal{L}_{\text{SF}}^a \supseteq \frac{G_F}{\sqrt{2}} \varepsilon_\ell^a (\bar{\chi} \Gamma^a P_L \nu_\ell) (\bar{f} \Gamma_a f) + \text{H.c.},$$



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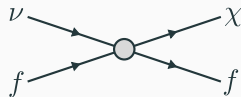
$$\Gamma^a = \{I, i\gamma^5, \gamma^\mu, \gamma^\mu \gamma^5, \sigma^{\mu\nu}\}$$



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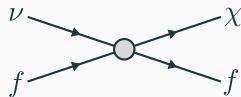
On this talk we will consider only

- Scalar (S)

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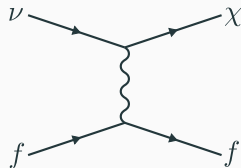
On this talk we will consider only

- Scalar (S)
- Vector (V)

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

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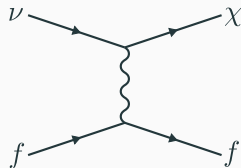


- Mediator mass comparable to momentum transfer

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- Mediator mass comparable to momentum transfer

$$G_F^2 |\varepsilon_\ell^a|^2 \longrightarrow \frac{2g_a^4}{(m_a^2 + |\mathbf{q}|^2)^2}, \quad |\mathbf{q}|^2 \approx 2m_{\mathcal{N}} T_{\mathcal{N}}$$

Up-scattering cross section (CEvNS)

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

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

References:

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

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

Up-scattering cross section (EvES)

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

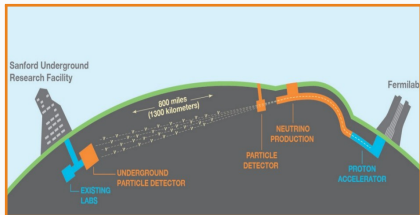
$$\left. \frac{d\sigma_{\nu\ell\mathcal{A}}}{dT_e} \right|_{\text{EvES}}^{\text{V}}(E_\nu, T_e) = \frac{m_e}{2\pi (m_V^2 + 2m_e T_e)^2} g_V^4 Z_{\text{eff}}^{\mathcal{A}}(T_e) \\ \times \left[\left(1 - \frac{m_e T_e}{2E_\nu^2} - \frac{T_e}{E_\nu} + \frac{T_e^2}{2E_\nu^2} \right) - \frac{m_\chi^2}{4E_\nu^2} \left(1 + \frac{2E_\nu}{m_e} - \frac{T_e}{m_e} \right) \right].$$

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We perform the analysis on several detectors



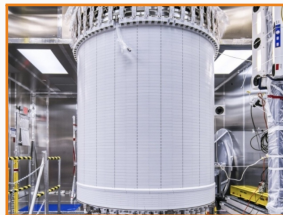
DUNE
(DUNE
collaboration)



XENONnT
detector
(XENON
collaboration)

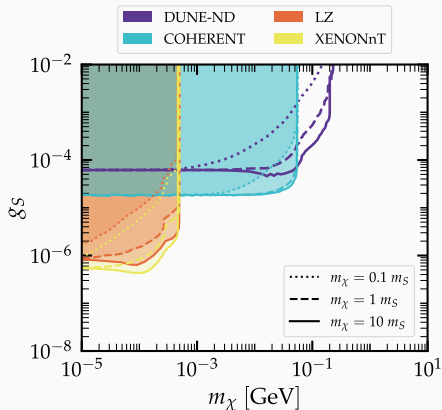


CsI detector
(COHERENT
collaboration)

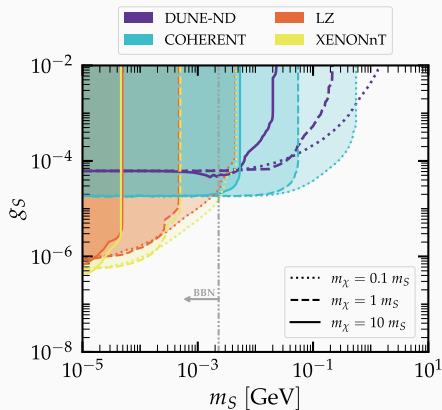


LZ detector
(LZ
collaboration)

Exclusion regions at 90% C.L. (in colour) change with different sterile fermion masses (m_χ) for the scalar interaction

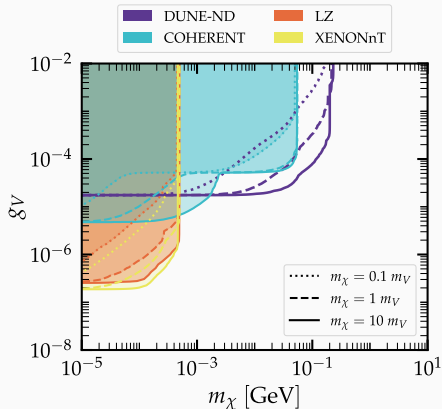


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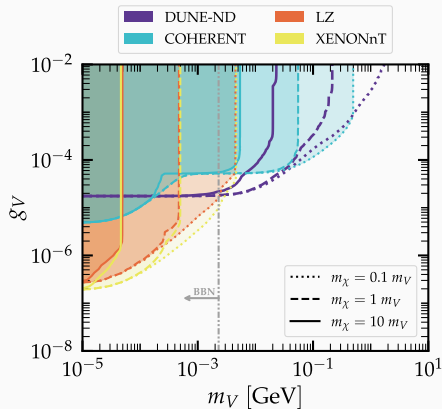


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Exclusion regions at 90% C.L. (in colour) change with different sterile fermion masses (m_χ) for the vector interaction



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Thank you!

Backup slides

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

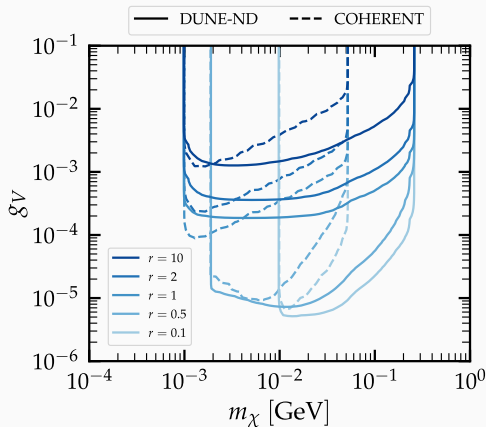
$$N_{ij}^{\text{th}} = (1 + \alpha_0 + \alpha_5) N_{ij}^{\text{CEvNS}}(\alpha_4, \alpha_6, \alpha_7) + (1 + \alpha_0) N_{ij}^{\text{ES}}(\alpha_6, \alpha_7) + (1 + \alpha_1) N_{ij}^{\text{BRN}}(\alpha_6) + (1 + \alpha_2) N_{ij}^{\text{NIN}}(\alpha_6) + (1 + \alpha_3) N_{ij}^{\text{SSB}}.$$

- σ_0 = 11% efficiency + flux
- σ_1 = 25% BRN
- σ_2 = 35% NIN
- σ_3 = 2.1% SSB
- σ_4 = 5% nuclear radius
 $R_A = 1.23 A^{1/3} (1 + \alpha_4)$
- σ_5 = 3.8% QF
- α_6 beam timing no prior
- α_7 CEvNS efficiency

Possible decay channels

Tree-level decays:

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



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