COHERENT production of a sterile fermion

Based on *Phys. Rev. D* 108, 055001 and *arXiv*:2404.12476 [hep-ph]

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

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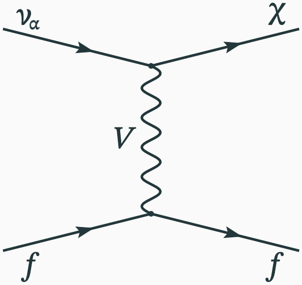
Our phenomenological scenario

We propose a new vector mediator. The sterile fermion is produced via up-scattering



$$\mathcal{L}_{\rm SF}^{\rm V} \supseteq V_\mu \overline{\chi}\gamma^\mu \left(g_{\chi_L} P_L + g_{\chi_R} P_R\right) \nu_\alpha + V_\mu \sum_f \overline{f}\gamma^\mu \left(g_{f_L} P_L + g_{f_R} P_R\right) f + \text{H.c.}$$

References:
V. Brdar, W. Rodejohann, and X.-J. Xu JHEP 12 (2018) 024
W.-F. Chang and J. Liao Phys. Rev. D 102, 075004
W. Chao, T. Li, J. Liao, and M. Su Phys. Rev. D 104 095017
Z. Chen, T. Li, and J. Liao JHEP 05 131
T. Li and J. Liao JHEP 02 (2021) 099

Let us simplify the analysis with some assumptions

$$\mathcal{L}_{\mathrm{SF}}^{\mathrm{V}} \supseteq V_\mu \, \overline{\chi} \gamma^\mu \left(g_{\chi_L} P_L + g_{\chi_R} P_R \right) \nu_\alpha + V_\mu \sum_f \overline{f} \gamma^\mu \left(g_{f_L} P_L + g_{f_R} P_R \right) f + \mathrm{H.c.}$$

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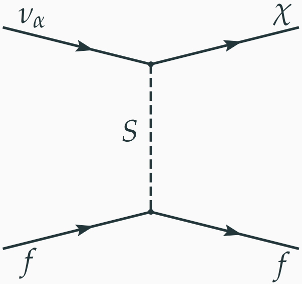
- Same with antiparticles

$$g_V \equiv \sqrt{g_{\chi_L} g_f}$$

We also propose a new scalar mediator. The procedure is the same



$$\mathcal{L}_{\mathrm{SF}}^{\mathrm{S}} \supseteq S\,\overline{\chi}\left(g_{\chi_L} P_L + g_{\chi_R} P_R\right)\nu_\alpha + S\sum_f \overline{f}\left(g_{f_L} P_L + g_{f_R} P_R\right) f + \mathrm{H.c.}$$

References:
V. Brdar, W. Rodejohann, and X.-J. Xu JHEP 12 (2012) 024
T. D. Lee and C.-N. Yang Phys. Rev. 104, 254

- After simplifications:

$$g_S \equiv \sqrt{g_{\chi_L} g_f}$$

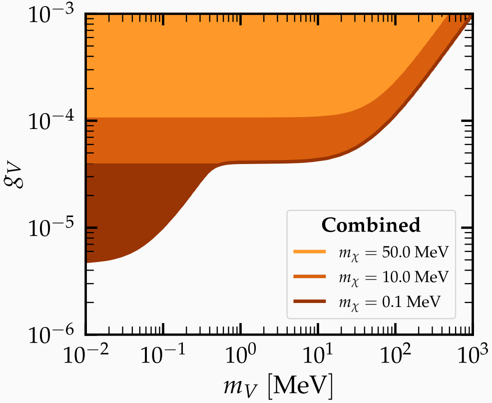
The COHERENT experiment (see Diana Parno's talk)

LAr detector
(COHERENT collaboration)

CsI detector
(COHERENT collaboration)

Results

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



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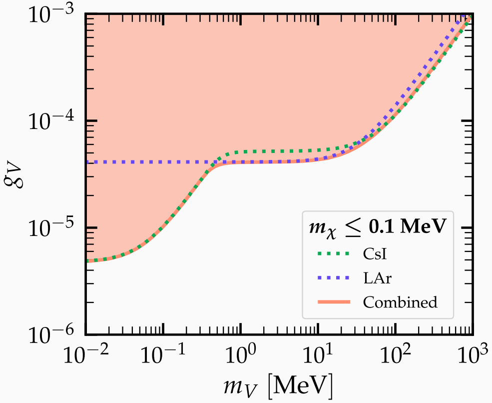

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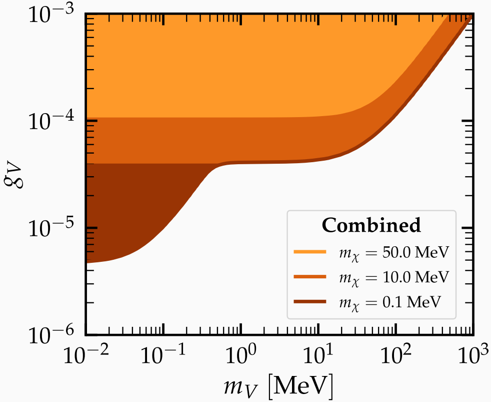
The COHERENT experiment lowers existing bounds in the intermediate MeV region



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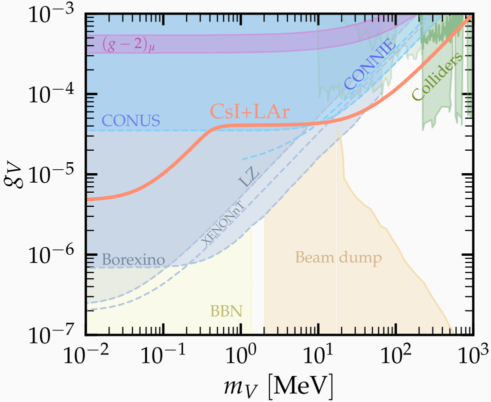

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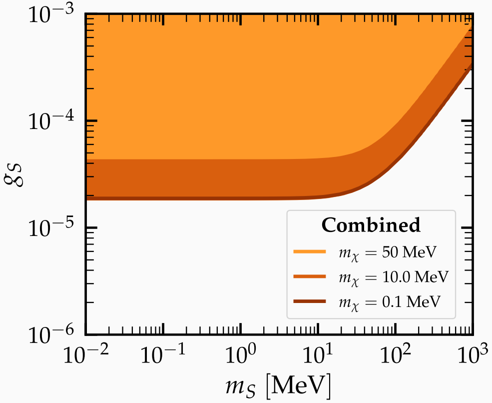
The scalar electron scattering contribution is suppressed with respect to the vector one



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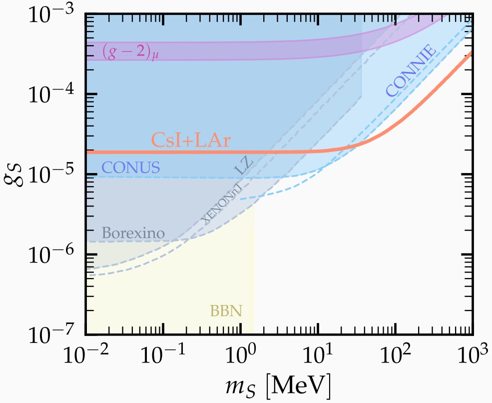

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Let us expand the analysis

We add new effective interactions

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

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

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- Scalar (S)

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- Scalar (S)
- Pseudoscalar (P)
- Vector (V)
- Axial (A)
- Tensor (T)

We take the light mediator limit

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

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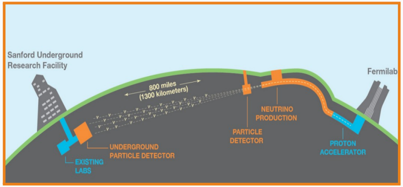
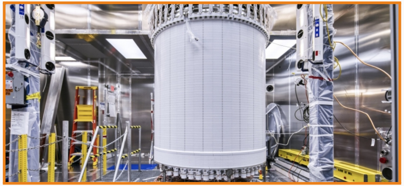
$$G_F^2 \varepsilon_\ell^a \longrightarrow \frac{2 g_a^4}{\left(m_a^2 + |\mathbf{q}|^2\right)^2}$$

- Recover previous vector and scalar cross sections of *Phys. Rev. D* **108**, 055001

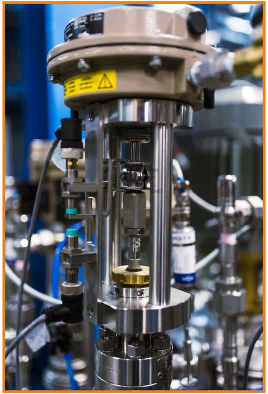
We also analyze LZ, XENONnT and DUNE-ND



Dune
(DUNE collaboration)

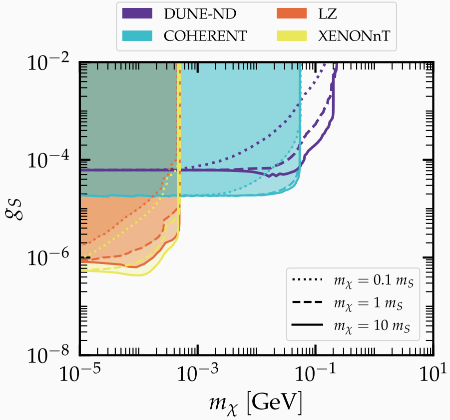


LZ detector
(LZ collaboration)

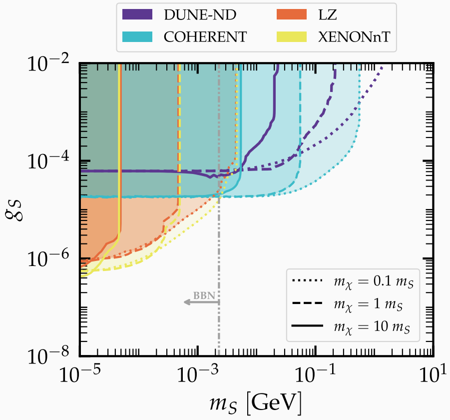


XENONnT detector
(XENON collaboration)

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



arXiv:2404.12476 [hep-ph]



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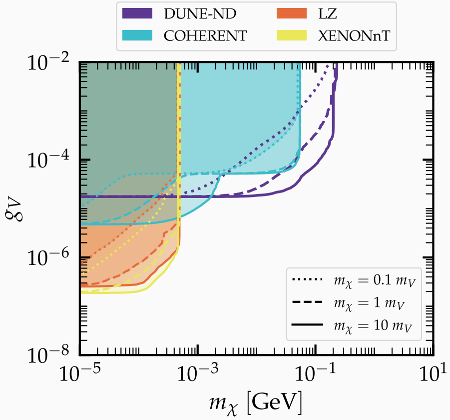

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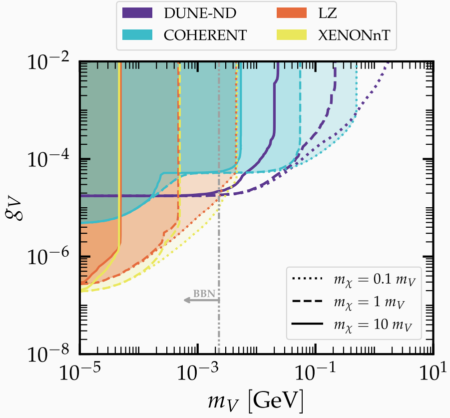

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- We have analyzed existing data from LZ, XENONnT and COHERENT experiments and computed DUNE-ND sensitivities
- CEvNS data from a stopped-pion source can provide competitive bounds on this scenario, along with other searches, in the intermediate MeV region
- LZ and XENONnT dominate at low energies
- DUNE will be able to provide the strongest constraints in the intermediate and high MeV region for most of the interactions

Thank you!

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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 $R_A = 1.23A^{1/3}(1+\alpha_4)$
- $\sigma_5 = 3.8\%$ QF
- α_6 beam timing no prior
- α_7 CEvNS efficiency

LAr statistical analysis

$$\chi^2_{\rm LAr} = \sum_{i=1}^{12}\sum_{j=1}^{10}\left(\frac{N_{ij}^{\rm th} - N_{ij}^{\rm exp}}{\sigma_{ij}}\right)^2 + \sum_{k=0,3,4,8}\left(\frac{\beta_k}{\sigma_k}\right)^2 + \sum_{k=1,2,5,6,7}(\beta_k)^2 \,,$$

$$\begin{aligned} N_{ij}^{\rm th} = &\left(1 + \beta_0 + \beta_1\Delta^{F_{90+}}_{\rm CE\nu NS} + \beta_1\Delta^{F_{90-}}_{\rm CE\nu NS} + \beta_2\Delta^{t_{\rm trig}}_{\rm CE\nu NS}\right) N_{ij}^{\rm CE\nu NS} \\ &+ (1+\beta_3)\, N_{ij}^{\rm SSB} \\ &+ \left(1 + \beta_4 + \beta_5\Delta^{E_+}_{\rm pBRN} + \beta_5\Delta^{E_-}_{\rm pBRN} \right. \\ &\quad \left. + \beta_6\Delta^{t^+_{\rm trig}}_{\rm pBRN} + \beta_6\Delta^{t^-_{\rm trig}}_{\rm pBRN} + \beta_7\Delta^{t^{\rm w}_{\rm trig}}_{\rm pBRN}\right) N_{ij}^{\rm pBRN} \\ &+ (1+\beta_8)\, N_{ij}^{\rm dBRN} \,. \end{aligned}$$

Normalization uncertainties:

- $\sigma_0 = 13\%$ CEvNS
- $\sigma_3 = 0.79\%$ SS
- $\sigma_4 = 32\%$ prompt BRN
- $\sigma_8 = 100\%$ delayed BRN

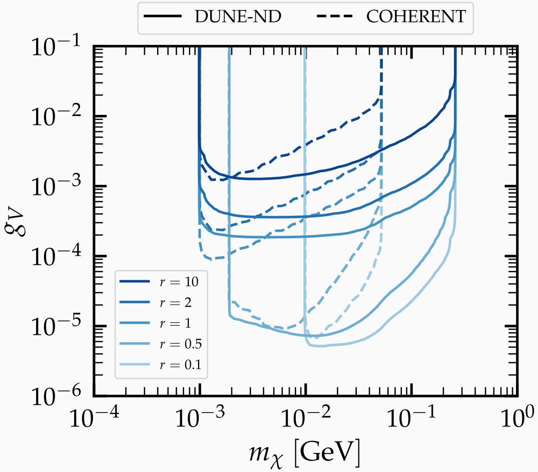
Shape uncertainties:

- β_1 and β_2 CEvNS
- β_5, β_6 and β_7 prompt BRN

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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