COHERENT production of a dark fermion

Based on Phys. Rev. D 108, 055001

in collaboration with Valentina De Romeri and Dimitris Papoulias

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20th MultiDark Workshop

Gandía (Valencia), Spain

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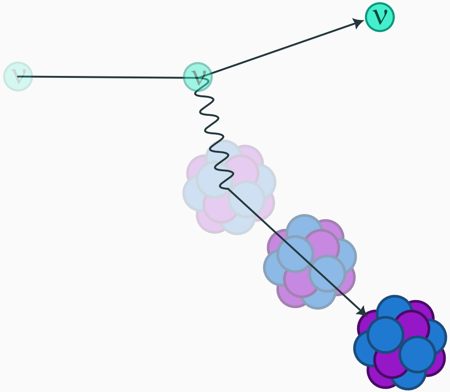
Introduction



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

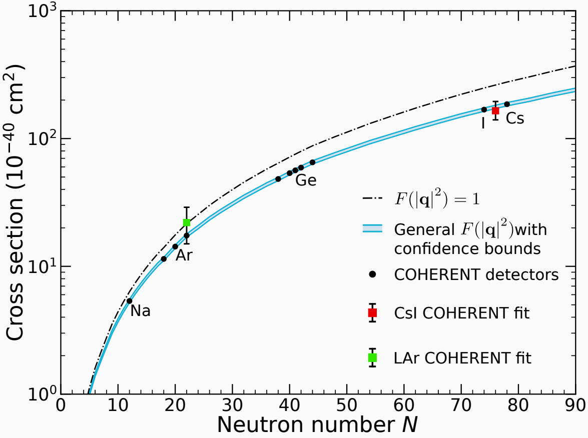
NEUTRINO PHYSICS

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



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

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

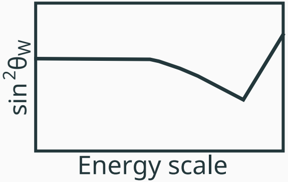
References:

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

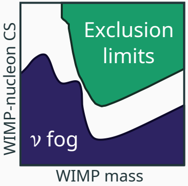
LAr 2020 measurement: D. Akimov *et al.* (COHERENT collaboration) Phys. Rev. Lett. 126, 012002

CEvNS has applications in the SM and beyond it

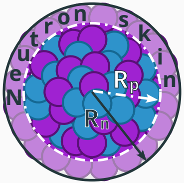
Weak mixing angle



Neutrino fog



Nuclear properties

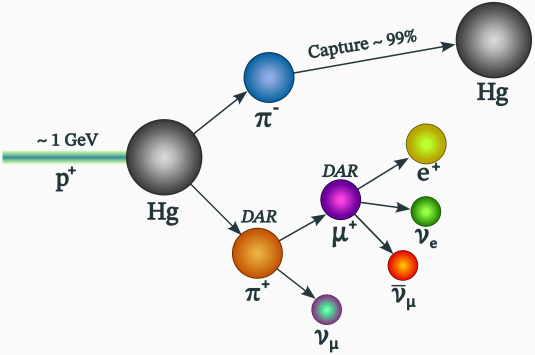


Sterile neutrinos

and more

(new dark sector particles)

The COHERENT experiment



Neutrino production at SNS

CsI detector
(COHERENT collaboration)

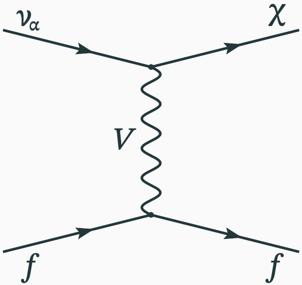
The COHERENT experiment

LAr detector
(COHERENT collaboration)

CsI detector
(COHERENT collaboration)

Our phenomenological model

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



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

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

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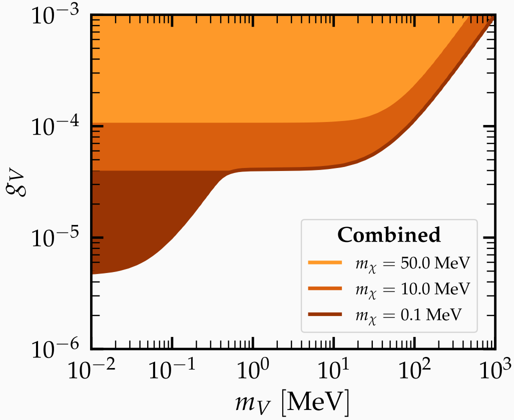
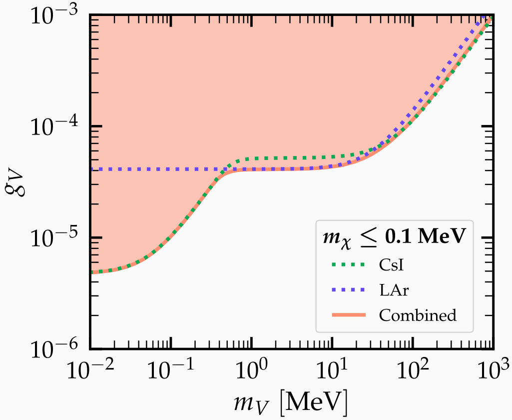
$$g_V \equiv \sqrt{g_{\chi_L} g_f}$$

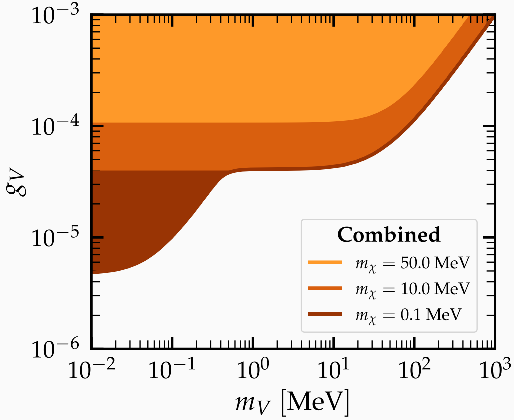
Results

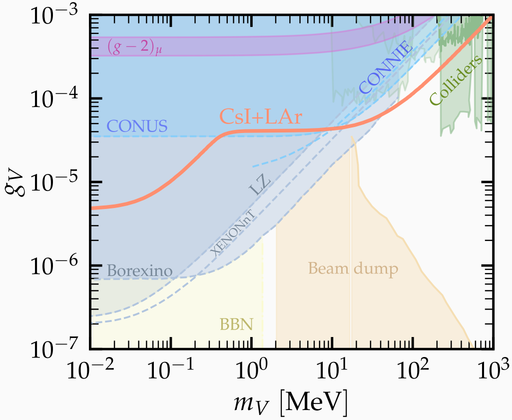
Exclusion regions at 90% C.L. (in colour) change with different dark fermion masses (m_χ)





The COHERENT experiment lowers existing bounds in the intermediate MeV region





Can this dark fermion be dark matter? Possible decay channels

- Two tree-level decay channels in our model:

$$\text{If } m_\chi > m_V, \text{ then } m_\chi \to V\nu_\alpha$$
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  - If χ is light enough ($m_\chi < 2m_e$), tree-level decay is forbidden $\cancel{m_\chi \to \nu_\alpha e^+ e^-}$

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- For heavier mediators ($m_V \gtrsim 1\ \mathrm{MeV}$), it depends:
    - If χ is light enough ($m_\chi < 2m_e$), tree-level decay is forbidden $m_\chi \to \nu_\alpha e^+ e^-$
    - Otherwise, χ decays

A more thoroughtful analysis is needed

Therefore, χ is stable if

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A more detailed analysis is needed

Conclusions

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- The generality of the model allows for an easy translation into more complete and specific models
- We analyzed the most recent data from the COHERENT experiment to study the production of a dark fermion via up-scattering
- CEvNS data from a stopped-pion source can provide competitive bounds on this scenario, along with other searches
- In some regions of the parameter space the Dark Fermion could be stable enough to be a Dark Matter candidate

Thank you!

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CsI statistical analysis

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

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

- $\sigma_0 = 11\%$ 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

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

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

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