PROCEEDINGS OF SCIENCE

New physics implications of COHERENT data

Valentina De Romeri[a,*]

[a] *Instituto de Física Corpuscular (CSIC-Universitat de València), Parc Científic UV C/ Catedrático José Beltrán, 2 E-46980 Paterna (Valencia) - Spain*

E-mail: deromeri@ific.uv.es

The observation of coherent elastic neutrino-nucleus scattering (CEνNS) has opened the window on many physics opportunities. In this talk I will discuss the implication of the observation of CEνNS by the COHERENT Collaboration using two different targets, CsI and argon, on new physics scenarios. These include neutrino generalised interactions, new light mediators, the production of a dark fermion through up-scattering and the sterile neutrino dipole portal.

XVIII International Conference on Topics in Astroparticle and Underground Physics (TAUP2023)
28.08 - 01.09.2023
University of Vienna

*Speaker

https://pos.sissa.it/

PoS(TAUP2023)169

1. Introduction

Coherent elastic neutrino-nucleus scattering (CEνNS) is a neutral-current process in which neutrinos scatter on a nucleus seeing it as a whole. CEνNS arises when the momentum transfer in the neutrino-nucleus interaction is smaller than or comparable to the inverse of the size of the nucleus: $|\vec{q}| \lesssim 1/\mathrm{R}_{\mathrm{nucleus}}$. The incoming neutrino energy E_ν is such that the amplitudes of the interactions with nucleons sum up coherently, thus leading to a cross section enhancement: $\sigma_{\mathrm{CE}\nu\mathrm{NS}} \propto$ (# scatter targets)^2. The upper limit on E_ν depends on the material of the target, but it is approximately $E_\nu \sim 100$ MeV for typical heavy nuclei used in CEνNS detectors. Due to the nature of SM couplings, the CEνNS differential cross section eventually scales with the number of neutrons squared: $\frac{d\sigma_{\mathrm{CE}\nu\mathrm{NS}}}{dE_r} \sim N^2$ (E_r being the recoil energy) and it can be quite large.
The CEνNS process was first theoretically proposed in the '70s [1], however, despite the magnitude of its cross section, it eluded detection for more than 40 years being the scattering product nuclear recoils of very low energy. In 2017, the COHERENT collaboration announced the detection of CEνNS [2] using a stopped-pion source with CsI detectors. In 2021, they have released up-dated data [3] using the same CsI detector, and meanwhile, in 2020 they observed the process also using an Ar target [4].
Going back to the CEνNS theory, its cross section is well-calculable in the SM and reads:

$$\left.\frac{d\sigma}{dE_r}\right|_{\mathrm{SM}} = \frac{G_F^2 m_N}{4\pi}\left(1 - \frac{m_N E_r}{2E_\nu^2} - \frac{E_r}{E_\nu}\right) Q_V^2 F_{\mathrm{W}}(|\vec{q}|^2)^2, \tag{1}$$

where G_F is Fermi's constant and m_N is the nuclear mass. The SM weak charge, Q_V, reads

$$Q_V = Z(1 - 4\sin^2\theta_W) - N\,. \tag{2}$$

Given the value of the weak mixing angle ($\sin^2\theta_W \sim 0.23$), it eventually encodes the typical N^2 dependence. The weak nuclear form factor F_W depends on the nuclear density distribution of protons and neutrons and it is approximated to 1 in the full-coherence limit $|\vec{q}| \to 0$.

2. Physics potential of CEνNS

The detection of CEνNS by COHERENT has opened the window on a plethora of possibilities in high-energy physics, from tests of the SM to inspiring new constraints on beyond the Standard Model (BSM) physics. Interestingly, the CEνNS process has important implications not only for high-energy physics, but also for astrophysics and nuclear physics. For a recent review of the topic including an extensive list of references, see [5].
The CEνNS process also has the potential to probe BSM physics. Some of the new physics scenarios that can be probed are those that include new interactions in the neutrino sector, like neutrino non-standard interactions (NSI) or neutrino generalised interactions (NGI), sterile neutrinos and non-trivial neutrino electromagnetic properties. In the following, I will discuss few examples extracted from Refs. [6, 7], where we have presented combined analyses of the COHERENT CsI [3] and LAr [4] data. In the analyses, we took into account experimental uncertainties associated to the efficiency as well as the timing distribution of neutrino fluxes, making the inferred constraints rather robust.

PoS(TAUP2023)169

2.1 New neutrino interactions: light mediators and production of a dark fermion

NGI [6, 8–10] may appear mediated by a light particle. In such a case, the relevant parameters entering the scattering cross section are the mass of the mediator, m_X, and a coupling g_X, which, for the sake of simplicity, we define as $g_X = \sqrt{g_{\nu X} g_{f X}}$, $g_{\nu X}$ and $g_{f X}$ being the individual couplings of the mediator with neutrinos and fermions; $f = \{u, d\}$ for CEνNS. Fig. 1 shows the 90% C.L. (2 d.o.f.) exclusion regions for the universal light vector ($X = V$) model (left), superimposed over available constraints from other experimental probes. In such a model, a destructive interference with the SM is possible, thus leading to a tiny unconstrained band at $m_V \sim 0.05 - 1$ GeV and $g_V \gtrsim 10^{-4}$. We refer the reader to Ref. [6] for more details and a definition of the new interaction. Additionally, we consider the possible production of a new MeV-scale fermion χ at the COHERENT experiment. The new fermion, belonging to a dark sector, can be produced through the up-scattering process of neutrinos off the nuclei (and the atomic electrons) of the detector material, via the exchange of a light vector mediator. We show in Fig. 1 (right) the exclusion regions for this scenario, fixing m_χ and letting the mediator mass and the coupling vary. We choose several fixed values of m_χ ($m_\chi = 0.1, 10$ and 50 MeV, shown with darker to lighter shades).

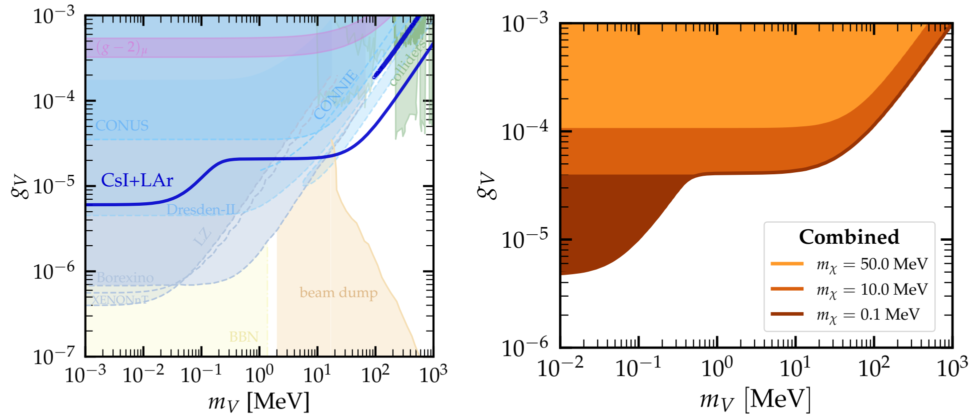

Figure 1: Left panel: 90% C.L. exclusion regions from our combined CsI+LAr analysis of vector (left) light mediators coupled universally to neutrinos and quarks, compared with other available experimental constraints. See [6] for more details. Right panel: 90% C.L. (2 d.o.f.) exclusion regions in the $m_V - g_V$ plane, for the vector-mediator case. Different fixed values of m_χ are considered. See [7] for more details.

2.2 Sterile neutrino dipole portal

CEνNS can also probe non-trivial neutrino electromagnetic properties. We consider as for example the case of a transition of an active neutrino to a massive sterile state, induced by a magnetic coupling: $\nu_L + N \to F_4 + N$. In such a scenario, the scattering process induced by an ingoing active neutrino produces a sterile neutrino in the final state. From the combined analysis of the full COHERENT data, the 90% C.L. contours are expressed in terms of an effective magnetic moment as a function of the sterile state mass, and shown in Fig. 2. Given the nuclear recoil and neutrino energies typical of the COHERENT experiment, the maximum sensitivity to the sterile state mass is about 50 MeV due to kinematics. Let us highlight the complementarity of the COHERENT measurements with existing CEνNS reactor experiments, that can probe only the electron flavour.

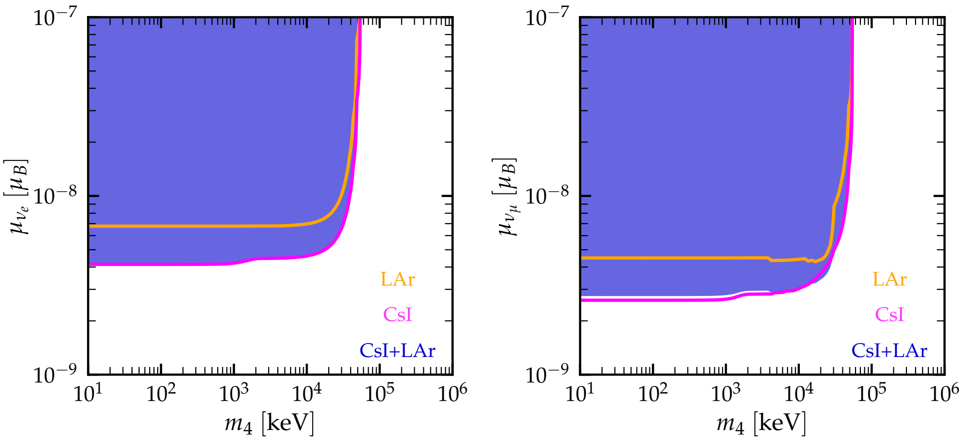

Figure 2: 90% C.L. (2 d.o.f.) exclusion regions for the neutrino magnetic moments concerning active-to-sterile transitions, from the analysis of CsI (magenta), LAr (orange) and CsI + LAr (blue) data. See [6] for more details.

3. Conclusions

In this talk, we have discussed the physics potential of the CEνNS process, focusing on BSM physics. First, we have presented the main features of CEνNS, and then we have listed some of the CEνNS extended physics potential, including new interactions, sterile neutrinos, and up-scattering production of a new fermion. We have presented results addressing some of these possible applications, from analyses of recent COHERENT data. To conclude, we want to stress that we can expect a wealth of information from forthcoming CEνNS data. These will have important implications for both precision tests of the SM and for probing new physics.

Acknowledgments

V.D.R. acknowledges financial support by the CIDEXG/2022/20 grant (project "D'AMAGAT") funded by Generalitat Valenciana and by the Spanish grant PID2020-113775GB-I00 (MCIN/AEI/ 10.13039/501100011033).

References

[1] D. Z. Freedman, Phys. Rev. D **9**, 1389-1392 (1974)

[2] D. Akimov *et al.* [COHERENT], Science **357**, no.6356, 1123-1126 (2017)

[3] D. Akimov *et al.* [COHERENT], Phys. Rev. Lett. **129**, no.8, 081801 (2022)

[4] D. Akimov *et al.* [COHERENT], Phys. Rev. Lett. **126**, no.1, 012002 (2021)

[5] M. Abdullah, *et al.* [arXiv:2203.07361 [hep-ph]].

[6] V. De Romeri, *et al.* JHEP **04** (2023), 035

[7] P. M. Candela, V. De Romeri and D. K. Papoulias, Phys. Rev. D **108** (2023) no.5, 055001

[8] D. Aristizabal Sierra, V. De Romeri and N. Rojas, Phys. Rev. D **98**, 075018 (2018)

[9] T. D. Lee and C. N. Yang, Phys. Rev. **104**, 254-258 (1956)

[10] M. Lindner, W. Rodejohann and X. J. Xu, JHEP **03**, 097 (2017)