Future sensitivity on unitarity, light-sterile neutrinos and neutrino magnetic moment from low-energy experiments

O. G. Miranda[1], D. K. Papoulias[2], O. Sanders[1], M. Tórtola[3,4], and J. W. F. Valle[4]

[1]Departamento de Física, CINVESTAV IPN

[2]Division of Theoretical Physics, University of Ioannina

[3]Departament de Física Teórica, Universitat de Valencia

[4]AHEP Group, Insitut de Física Corpuscular

Abstract

We study the future sensitivities to a non-unitarity neutrino mixing matrix for different short-baseline coherent elastic neutrino-nucleus scattering (CEvNS) proposed experiments. We also identify the best configuration for measuring the oscillation parameters on the (3+1) scheme for light sterile neutrinos and find the estimated sensitivity for their parameters. Finally, we study the conversion to massive sterile neutrinos (in the keV-MeV energy mass) through transition magnetic moments and find the sensitivities for actual COHERENT results as well as future experiments of CEvNS and electron neutrino scattering with a proposed Cr-51 neutrino source experimental setup.

Introduction

We take into consideration three different cases:

A) We assume that there is extra singlet neutral heavy leptons that mediate light-neutrino mass generation. The presence of unitarity violation leads to the so called zero-distance effect, in which the oscillation probability at L=0 is:

$$P_{ee} = \alpha_{11}^4, \quad P_{\mu e} = \alpha_{11}^2|\alpha_{21}|^2, \quad P_{\mu\tau} \simeq \alpha_{22}^2|\alpha_{32}|^2,$$
$$P_{\mu\mu} = (|\alpha_{21}|^2 + \alpha_{22}^2)^2 \quad P_{e\tau} = \alpha_{11}^2|\alpha_{31}|^2,$$

B) We consider the simplest (3+1) scheme in which the new state is light enough to take part in oscillation this leads to the usual vacuum survival probability:

$$P_{ee}(E_\nu) \simeq 1 - \sin^2 2\theta_{14} \sin^2\left(\frac{\Delta m_{41}^2 L}{4E_\nu}\right),$$

C) Also, it is possible to study the transition magnetic moment in the presence of this light electroweak singlet neutrinos. For which the interaction Hamiltonian for Majorana particles is given by:

$$H_{em}^M = -\frac{1}{4}\nu_L^T C^{-1}\,\tilde{\lambda}\,\sigma^{\alpha\beta}\nu_L F_{\alpha\beta} + h.c.$$

Analysis

On analysis A) and B) we focus on three experiments aiming to deploy large liquid argon detectors to measure CEvNS signal at a π-DAR source. This is the case of CENNS detectors of COHERENT, CCM and ESS. For the case C) we focus on XENON1T, CsI and Lar detectors at COHERENT and TEXONO in which we also consider CR-51 neutrino sources.

The SM cross section for CEvNS is given by:

$$\left(\frac{d\sigma}{dT_A}\right)_{SM} = \frac{G_F^2 m_A}{2\pi}(Q_W)^2\left[2 - \frac{2T_A}{E_\nu} - \frac{m_A T_A}{E_\nu^2}\right]$$

We perform a χ^2 calculation for each experiment, with which we find the sensitivities to each of the beyond the standard model physics previously mentioned. In general, we can write this χ^2 function as:

$$\chi^2(\alpha_{11}, |\alpha_{21}|, \alpha_{22}) = \min_{\mathrm{a}}\left[\sum_i \frac{(N_{SM}^i - N_{new}^i[1+\mathrm{a}])^2}{(\sigma_{stat}^i)^2} + \left(\frac{\mathrm{a}}{\sigma_{sys}}\right)^2\right]$$

For A) and B), the zero-distance effect and the survival probability will affect the initial neutrino flux, while for C) we get that the cross-section will be:

$$\frac{d\sigma_{\nu\mathcal{N}\to\nu_s\mathcal{N}}}{dE_r} = \alpha_{em}\mu_{\nu,eff}^2 Z^2\left[\frac{1}{E_r} - \frac{1}{E_\nu} - \frac{m_4^2}{2E_\nu E_r M}\left(1 - \frac{E_r}{2E_\nu} + \frac{M}{2E_\nu}\right) + \frac{m_4^4(E_r - M)}{8E_\nu^2 E_r^2 M^2}\right]F_p^2(Q^2)$$

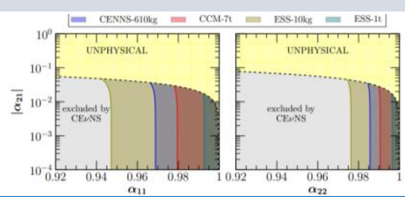
For the case of EvES(elastic neutrino-electron scattering) we make the corresponding substitution such as:

$$M \to m_e \text{ and } Z^2F_p^2(Q^2) \to 1$$

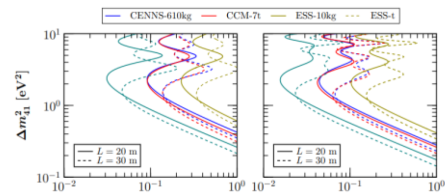
Results

Here we show the different curves obtained for each of the cases previously mentioned:

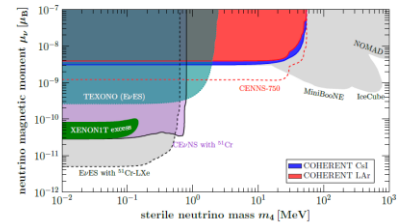
A)



B)



C)



Conclusions

We analyzed the potential of future CEvNS experiments in probe in new physics associated to the presence of heavy isosinglets neutrinos, light sterile neutrinos and to transition into a sterile massive neutrino state through a dipole moment interaction.

Future short-baseline experiments may be competitive and will test the region of interest for the different scenarios.

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References

[1] O. G. Miranda, D. K. Papoulias, O. Sanders, M. Tórtola and J. W. F. Valle, Phys. Rev. D102(2020), 113014doi:10.1103/PhysRevD.102.113014 [arXiv:2008.02759 [hep-ph]].

[2] In preparation