MeV gauge boson and secret interaction of sterile neutrinos*

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Abstract

Sterile neutrinos can have secret interactions that have consequences in cosmology and in laboratory experiments. We use the constrains from cosmology and from laboratory experiments: such as $g-2$ measurement and the MINOS neutrino experiment to found out the constrains on the existence of secret interactions of sterile neutrinos.

INTRODUCTION

Light sterile neutrinos did not fit in the simplest formulation to explain the neutrino oscillations observed in most of the experiments [1]. There are hints of sterile neutrino presence in the electron neutrino appearance in LSND and Mini-BooNe experiments [2] and for the electron neutrino disappearance in reactor experiments [3]. These hints can be fitted if we add one additional light sterile neutrino.

The existence of light sterile neutrino have deep consequences in cosmology in the nucleosynthesis, cosmic microwave background and large scale structure formation. Results from Planck [4] are compatible with three lightest neutrinos and with the total mass of neutrinos $\sum m_\nu < 0.17$ eV disfavouring the presence of light sterile neutrino with mass difference $\Delta m^2_{41} \sim 1$ eV^2.

We can evade the cosmological constraints on sterile neutrinos if we can effectively decouple it from evolution in early Universe. Recently it was proposed that a large coupling of sterile neutrino with MeV gauge boson can suppress the sterile neutrino oscillations decoupling from other neutrinos [5, 6].

We proposed to investigate the possibility of the sterile neutrino states interacting with a new gauge boson X, with mass $\sim$ MeV, which has couplings with the sterile neutrinos and the charged leptons in the SM [7]. This new interaction of the sterile neutrinos was first mentioned in [8]. The "ν_s ***Secret Interaction***" (ν_sSI) model produces a neutral current (NC) matter potential for the sterile states proportional to G_X, where G_X is the field strength of the new interaction. The NC matter potential in the ν_sSI model changes the oscillation probability of neutrinos and anti-neutrinos drastically. Therefore, using the data of a neutrino oscillation experiment such as the MINOS experiment [9], we can test the ν_sSI model.

Phenomenology of ν_sSI model

We enlarge the SM with one extra species of the sterile neutrinos which do not couple with the SM gauge bosons, but have interactions with a new $U_X(1)$ gauge symmetry (the ν_sSI model). The new gauge boson couples to the sterile neutrinos and charged leptons with coupling constants g'_s and g'_l, respectively, where for simplicity, we have assumed equal coupling constants for the changed leptons. The strength of this new interaction is given by

$$\frac{G_X}{\sqrt{2}} = \frac{g'_s g'_l}{4M_X^2}, \tag{1}$$

where M_X is the mass of the new gauge boson.

We are going to study the consequences of this model for

1. longbaseline neutrino experiments such as MINOS [9] that observe oscillations of neutrinos and antineutrinos
2. $(g-2)_\mu$ discrepancy: a light gauge boson with mass $\sim$ MeV can be used as a novel explanation for the 3.6 σ discrepancy between the experimental measurement and the SM prediction of the muon anomalous magnetic moment, $(g-2)_\mu$ [10].
3. CCFR experiment on measurement of the neutrino trident cross-section [11] can test the existence of light gauge bosons

To study the consequences for longbaseline experiments we should write down the neutrino evolution equation in the ν_sSI model,

$$i\frac{d}{dr}\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\\ \nu_s\end{pmatrix} = \left[\frac{1}{2E_\nu}UM^2U^\dagger + V^{\nu_s\mathrm{SI}}(r)\right]\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\\ \nu_s\end{pmatrix}, \tag{2}$$

where U is the 4×4 PMNS matrix [1], which is parametrized by the active-active mixing angles $(\theta_{12},\theta_{13},\theta_{23})$ as well as 3 active-sterile mixing angles $(\theta_{14},\theta_{24},\theta_{34})$. The matrix of the mass squared differences $M^2 = \mathrm{diag}\Big(0,\Delta\mathrm{m}^2_{21},\Delta\mathrm{m}^2_{31},\Delta\mathrm{m}^2_{41}\Big)$. The matter potential matrix in the ν_sSI model will be (after subtracting the constant $V_{NC}(r)\times\mathbb{I}$)

$$V^{\nu_s\mathrm{SI}}(r) \;= \sqrt{2}G_F N_e(r)\mathrm{diag}\Big(1,0,0,\tfrac{(1-\alpha)}{2}\Big). \tag{3}$$

The same evolution equation applies to anti-neutrinos with the replacement $V^{\nu_s\mathrm{SI}}(r) \to -V^{\nu_s\mathrm{SI}}(r)$. We consider the ν_sSI model with $\alpha > 0$.

Results

We put together all results in Fig. (1) . From the MINOS experiment we arrive to the the black dashed curve shown for the MINOS analysis and the purple shaded region ishows the favored 2σ region from $(g-2)_\mu$ discrepancy and red solid curve represents the results of the constrains from CCFR experiment on measurement of the neutrino trident cross-section [11].

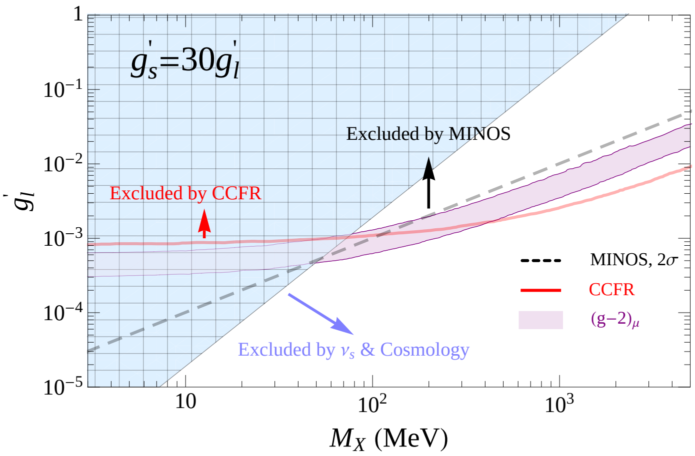

FIG. 1: We have shown the region of interest for the ν_sSI model with a light gauge boson with mass M_X and couplings g_l' and $g_s' = \gamma g_l'$. The result of the analysis of the ν_sSI model with the MINOS data is shown by the black dashed curve with 2σ C.L. (for $\gamma = 30$). The purple shaded region is the region favored by the $(g-2)_\mu$ discrepancy, while the red curve is the CCFR [11] measurement of the neutrino trident cross-section [12]. The blue shaded region is where the tension between the sterile neutrino and cosmology is relieved.

CONCLUSIONS

We have investigated the possibility that the light sterile neutrinos as suggested by the reactor anomaly have hidden interaction with an "MeV scale" gauge boson. In the Secret Interaction (ν_sSI) model, the sterile neutrinos have neutral current matter potential. Therefore, we can use the data of the neutrino experiments to constrain this model and probe other new physics scenarios. The field strength of this model is described by G_X. In this work we studied the ν_sSI model using the MINOS experiment and showed that the values above $G_X/G_F = 92.4$ are excluded.

One consequence of the ν_sSI model is constraining other new physics scenarios such as explaining the $(g-2)_\mu$ discrepancy with a light gauge boson. We showed that using the ν_sSI model, the $(g-2)_\mu$ region is entirely ruled out for $M_X \lesssim 100\sqrt{\gamma/30}$ MeV by the MINOS data. Also, the secret interaction of sterile neutrinos which is introduced in the literature to solve the tension between the sterile neutrinos and cosmology is excluded by MINOS for $g'_l > 5.3 \times 10^{-4}$ for any value of M_X. We can use the data of the future neutrino oscillation experiments such as DUNE [13] to further test the ν_sSI model and get a definite answer on the presence of the light gauge boson.

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