Implications on the UV from neutrino non-standard interactions in the $W^{\pm}I\nu$ 2021

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Based on Refs.[1], [2]

Abstract

The absence of any definite signals of new physics at colliders and/or from precision measurements has gradually changed our method in searching for new physics: from specific UV models to a model-independent study in the EFT framework. In light of the rich data from current terrestrial neutrino oscillation experiments and the precision measurements of Neff now and in the near future, in this talk, I will present our recent work on neutrino non-standard interactions and also discuss their implications on the UV physics in a model-independent approach.

FROM QM to QFT

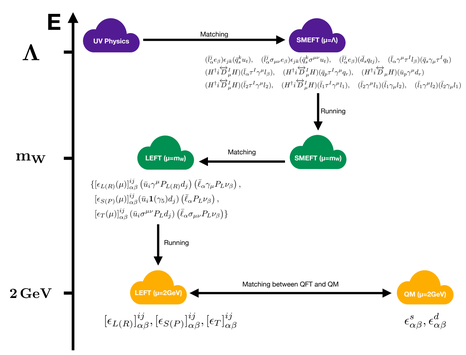
For neutrino oscillation experiments, neutrinos of different flavors at production and detection are usually parameterized in the following form in the quantum mechanical (QM) formalism:

$$|\nu^s_\alpha\rangle = \frac{(1+\epsilon^s)_{\alpha\gamma}}{N^s_\alpha}|\nu_\gamma\rangle,\ \ \langle\nu^d_\beta| = \langle\nu_\gamma|\frac{(1+\epsilon^d)_{\gamma\beta}}{N^d_\beta},$$

where ϵ^s and ϵ^d parameterize effects of new physics. On the other hand, since neutrino oscillation experiments are very low-energy ones, the system can also be parameterized in the quantum-field-theory (QFT) formalism as follows:

$$\begin{aligned}\mathcal{L}_{\rm CC} \supset -\frac{2V_{ud}}{v^2}\Big\{&[\mathbf{1}+\epsilon_L]^{ij}_{\alpha\beta}\left(\bar{u}_i\gamma^\mu P_L d_j\right)\left(\bar{\ell}_\alpha\gamma_\mu P_L\nu_\beta\right) + [\epsilon_R]^{ij}_{\alpha\beta}\left(\bar{u}_i\gamma^\mu P_R d_j\right)\left(\bar{\ell}_\alpha\gamma_\mu P_L\nu_\beta\right)\\ &+\frac{1}{2}\left[\epsilon_S\right]^{ij}_{\alpha\beta}\left(\bar{u}_i d_j\right)\left(\bar{\ell}_\alpha P_L\nu_\beta\right) - \frac{1}{2}\left[\epsilon_P\right]^{ij}_{\alpha\beta}\left(\bar{u}_i\gamma_5 d_j\right)\left(\bar{\ell}_\alpha P_L\nu_\beta\right)\\ &+\frac{1}{4}\left[\epsilon_T\right]^{ij}_{\alpha\beta}\left(\bar{u}_i\sigma^{\mu\nu}P_L d_j\right)\left(\bar{\ell}_\alpha\sigma_{\mu\nu}P_L\nu_\beta\right) + \text{h.c.}\Big\},\end{aligned}$$

where $\epsilon_{L,R,S,P,T}$ encode effects of new physics and "CC" stands for charge-current neutrino non-standard interactions (NSIs). To connect the parameters in the QM and the QFT formalisms, a consistent matching can be obtained following the procedure outlined in Ref.[3]. Once the connection is obtained, one can then readily connect NSIs in the QFT formalism to, for example, the Standard Model Effective Field Theory (SMEFT) through matching and running as depicted in the following graph:



In this way, constraints on ϵ^s and ϵ^d in the QM formalism can be translated onto those of the Wilson coefficients in the SMEFT, or equivalently, the UV scale.

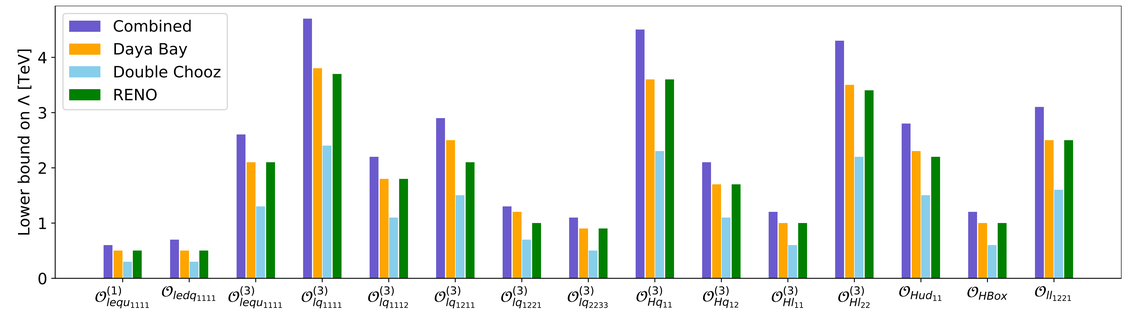
On the other hand, for Neutral-Current (NC) NSIs, we consider contact interactions between neutrinos and electrons, neutrinos and photons, as well as neutrino self-interactions in the EFT framework. All possible operators up to dimension-7 are listed in the table below:

Dimensions	Operators	Wilson coefficients
dimension-5	$\mathcal{O}^{(5)}_1 = \frac{e}{8\pi^2}\left(\bar{\nu}_\beta\sigma^{\mu\nu}P_L\nu_\alpha\right)F_{\mu\nu}$	$C^{(5)}_1$
dimension-6	$\mathcal{O}^{(6)}_{1,f} = \left(\bar{\nu}_\beta\gamma_\mu P_L\nu_\alpha\right)\left(\bar{f}\gamma^\mu f\right)$	$C^{(6)}_{1,f}$
	$\mathcal{O}^{(6)}_{2,f} = \left(\bar{\nu}_\beta\gamma_\mu P_L\nu_\alpha\right)\left(\bar{f}\gamma^\mu\gamma_5 f\right)$	$C^{(6)}_{2,f}$
	$\mathcal{O}^{(6)}_3 = \left(\bar{\nu^c}_\beta P_L\nu_\alpha\right)\left(\bar{\nu^c}_{\beta'}P_L\nu_{\alpha'}\right)^\clubsuit$	$C^{(6)}_3$
	$\mathcal{O}^{(6)}_4 = \left(\bar{\nu}_\beta\gamma_\mu P_L\nu_\alpha\right)\left(\bar{\nu}_{\beta'}\gamma_\mu P_L\nu_{\alpha'}\right)^\clubsuit$	$C^{(6)}_4$
	$\mathcal{O}^{(6)}_5 = \left(\bar{\nu^c}_\beta\sigma^{\mu\nu}P_L\nu_\alpha\right)\left(\bar{\nu^c}_{\beta'}\sigma^{\mu\nu}P_L\nu_{\alpha'}\right)^\clubsuit$	$C^{(6)}_5$
dimension-7	$\mathcal{O}^{(7)}_1 = \frac{\alpha}{12\pi}\left(\bar{\nu}_\beta P_L\nu_\alpha\right)F^{\mu\nu}F_{\mu\nu}$	$C^{(7)}_1$
	$\mathcal{O}^{(7)}_2 = \frac{\alpha}{8\pi}\left(\bar{\nu}_\beta P_L\nu_\alpha\right)F^{\mu\nu}\tilde{F}_{\mu\nu}$	$C^{(7)}_2$
	$\mathcal{O}^{(7)}_{5,f} = m_f\left(\bar{\nu}_\beta P_L\nu_\alpha\right)\left(\bar{f}f\right)$	$C^{(7)}_{5,f}$
	$\mathcal{O}^{(7)}_{6,f} = m_f\left(\bar{\nu}_\beta P_L\nu_\alpha\right)\left(\bar{f}i\gamma_5 f\right)$	$C^{(7)}_{6,f}$
	$\mathcal{O}^{(7)}_{7,f} = m_f\left(\bar{\nu}_\beta\sigma^{\mu\nu}P_L\nu_\alpha\right)\left(\bar{f}\sigma_{\mu\nu}f\right)$	$C^{(7)}_{7,f}$
	$\mathcal{O}^{(7)}_{8,f} = \left(\bar{\nu}_\beta i\overleftrightarrow{\partial}_\mu P_L\nu_\alpha\right)\left(\bar{f}\gamma^\mu f\right)$	$C^{(7)}_{8,f}$
	$\mathcal{O}^{(7)}_{9,f} = \left(\bar{\nu}_\beta i\overleftrightarrow{\partial}_\mu P_L\nu_\alpha\right)\left(\bar{f}\gamma^\mu\gamma_5 f\right)$	$C^{(7)}_{9,f}$
	$\mathcal{O}^{(7)}_{10,f} = \partial_\mu\left(\bar{\nu}_\beta\sigma^{\mu\nu}P_L\nu_\alpha\right)\left(\bar{f}\gamma_\nu f\right)$	$C^{(7)}_{10,f}$
	$\mathcal{O}^{(7)}_{11,f} = \partial_\mu\left(\bar{\nu}_\beta\sigma^{\mu\nu}P_L\nu_\alpha\right)\left(\bar{f}\gamma_\nu\gamma_5 f\right)$	$C^{(7)}_{11,f}$

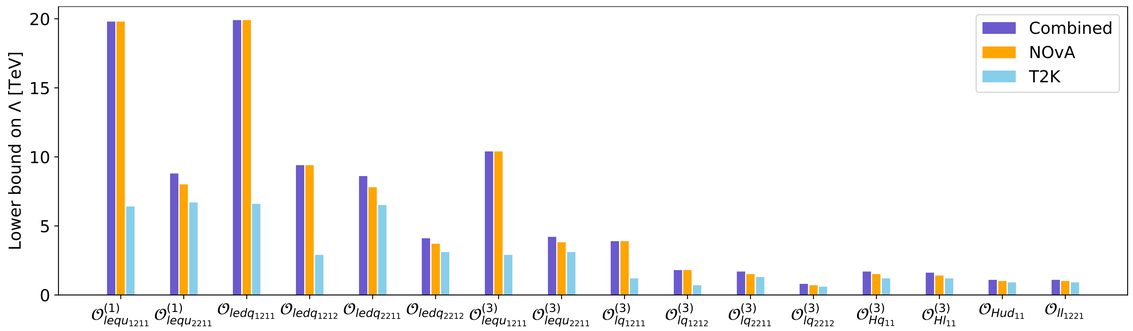
Each type of interactions in the table above could affect neutrino decoupling in the early Universe, thus altering the prediction of Neff. Since Neff has been precisely measured by Planck as well as CMB-S4 in the future at the percent level, these operators would be constrained from precision measurements of Neff.

Results: CC NSIs

Constraints for reactor neutrino oscillation experiments Daya Bay, Double Chooz and RENO are summarized below with their Wilson coefficients fixed at one and considering only one operator to dominate at a time [1]:

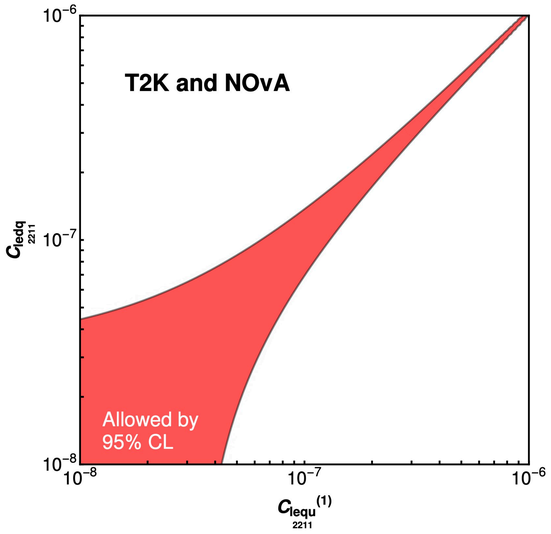


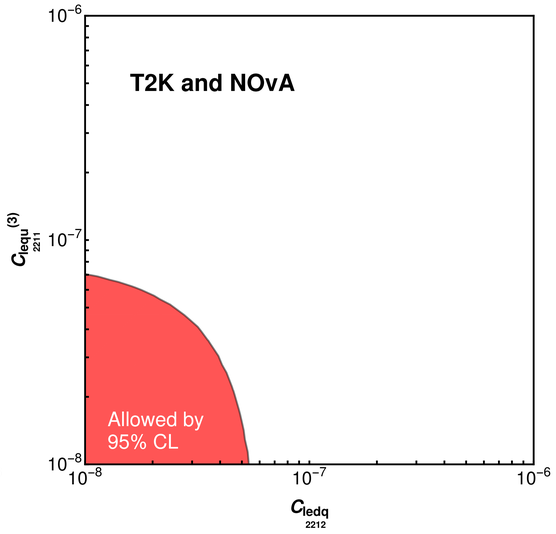
Similarly, constraints for acceleration neutrino oscillation experiments T2K and NOvA are summarized below with their Wilson coefficients fixed at one



Note that reactor and accelerator type neutrino oscillation experiments are complementary to each other in probing different subsets of SMEFT operators.

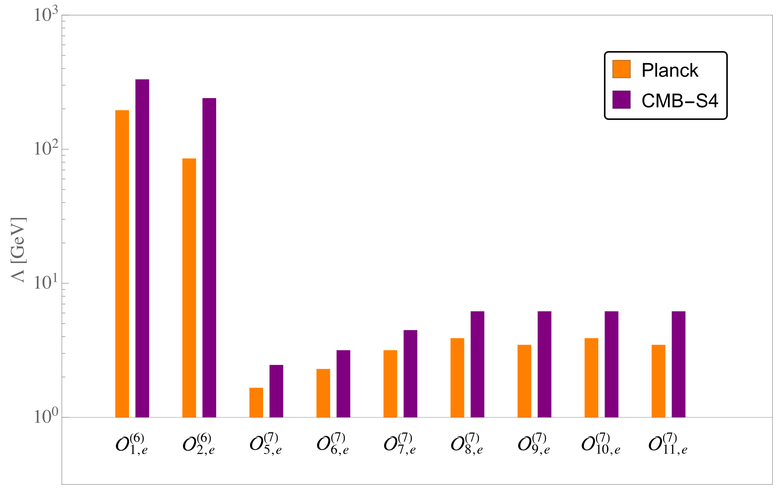
Correlation among multiple operators could change the constraints by orders of magnitudes, examples are given below, where the left plot represents a weaker constraint on each operator from the correlation, and the right for a stronger one.





Results: NC

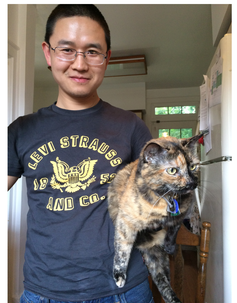
Constraints on NC NSIs (operators shown in the previous table) are shown below from considering precision measurements of Neff at Planck and CMB-S4 [2]:



Conclusions

1. Reactor and accelerator type neutrino experiments are already sensitive to new physics at ~ 5 TeV and ~ 20 TeV, they are complementary to each other in probing different subsets of SMEFT operators.
2. Correlation among multiple operators could change constraints on new physics by orders of magnitude.
3. Precision measurements of Neff from Planck and CMB-S4 put stringent constraints on NC NSIs, dimension-6 neutrino-electron contact interactions are most stringently constrained to be above O(100GeV). Results on dimension-7 operators are mostly firstly obtained from our work.

References

[1] *JHEP* 03 (2021) 019 • e-Print: 2011.14292 [hep-ph]
[2] *JHEP* 05 (2021) 058 • e-Print: 2101.10475 [hep-ph]
[3] *JHEP* 11 (2020) 048 • e-Print: 1910.02971 [hep-ph]

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