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One-loop finite corrections to seesaw neutrino masses

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In the standard seesaw model, finite corrections to the neutrino mass matrix arise from one-loop self-energy diagrams mediated by heavy neutrinos. We discuss the impact that these corrections may have on the different entries of the tree-level effective neutrino mass matrix, paying special attention to their dependence with the seesaw model parameters. We also briefly comment on the implications these corrections might have on low-energy neutrino observables.

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1. Motivation

Among the plethora of models for Majorana neutrino masses present in the literature the standard seesaw [1] is certainly the most popular mechanism for neutrino mass generation. In this model, by extending the standard model Lagrangian with three fermionic electroweak singlets, the five dimensional effective operator $LLHH$ is realized via the exchange of the new states. The smallness of the light neutrino masses is determined by the suppression induced by the scale of lepton number violation which is assumed to be large $\mathscr{O}(\Lambda_{\rm GUT})$.

The seesaw parameter space depends upon 18 “coordinates”: 6 phases and 12 real parameters. Low-energy data implies -in principle- 9 constraints, provided the absolute light neutrino mass scale and the Dirac and Majorana CP violating phases are measured. Given the mismatch between the number of parameters and observables a unique region consistent with data [2] can not be fixed. The analysis of the available portions in parameter space is thus based on scans which in turn rely on parametrizations of the seesaw. All these parametrizations are based on the tree-level effective mass matrix, as the one-loop order corrections are assumed to be negligible. This however might not be the case if the corrections are finite [3, 4].

2. One-loop finite corrections

The fermionic electroweak singlets N_R induce new interactions that, in the basis in which the matrix of charged lepton Yukawa couplings and the singlet mass matrix $\boldsymbol{M_R}$ are diagonal, are described by the following Lagrangian

$$-\mathscr{L} = -i\bar{N}_{R_i}\gamma_\mu\partial^\mu N_{R_i} + \tilde{\phi}^\dagger\bar{N}_{R_i}\lambda_{ij}\ell_{Lj} + \frac{1}{2}\bar{N}_{R_i}CM_{R_i}\bar{N}_R^T + \text{h.c.} \tag{2.1}$$

Here $\phi^T = (\phi^+\phi^0)$ is the Higgs electroweak doublet, ℓ_L are the lepton $SU(2)$ doublets, C is the charge conjugation operator and $\boldsymbol{\lambda}$ is a Yukawa matrix in flavor space. In the seesaw limit that is to say, $M_R \gg v$ (with $v \simeq 174$ GeV) the effective neutrino mass matrix can be written according to

$$\boldsymbol{m_\nu}^{\text{(tree)}} = -v^2\boldsymbol{\lambda}^T\hat{\boldsymbol{M}}_{\boldsymbol{R}}^{-1}\boldsymbol{\lambda}\,. \tag{2.2}$$

Finite corrections to the above matrix arise from the one-loop self-energy diagrams shown in figure 1 and are given by [1]

$$\boldsymbol{m_\nu}^{\text{(1-loop)}} = v^2\boldsymbol{\lambda}^T\hat{\boldsymbol{M}}_{\boldsymbol{R}}^{-1}\left\{\frac{g^2}{64\pi^2M_W^2}\left[m_h^2\ln\left(\frac{\hat{\boldsymbol{M}}_{\boldsymbol{R}}^2}{m_h^2}\right)+3M_Z^2\ln\left(\frac{\hat{\boldsymbol{M}}_{\boldsymbol{R}}^2}{M_Z^2}\right)\right]\right\}\boldsymbol{\lambda}\,. \tag{2.3}$$

Notice that this correction is not suppressed with respect to the tree-level result by additional factors of $v\boldsymbol{\lambda}\boldsymbol{M_R}^{-1}$. Thus, it is expected to be smaller than the tree-level mass term solely by a factor of order $(16\pi^2)^{-1}\ln(M_R/M_Z)$, implying it might have sizable effects.

We evaluate the importance of the correction in (2.3) by using the Casas-Ibarra parametrization [5]:

$$\boldsymbol{\lambda} = \frac{\sqrt{\hat{\boldsymbol{M}}_{\boldsymbol{R}}}\boldsymbol{R}\sqrt{\hat{\boldsymbol{m}}_{\boldsymbol{\nu}}}\boldsymbol{U}^\dagger}{v}\,, \tag{2.4}$$

[1] For details see ref. [3] or the appendix in ref. [4].

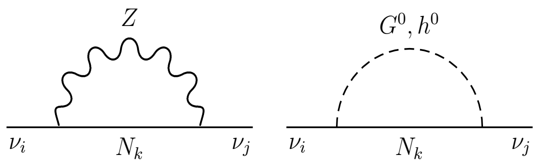

Figure 1: Self-energy diagrams accounting for $\delta\mathbf{M_L}$

where $\boldsymbol{R}$ is a general complex orthogonal matrix, and scanning the parameter space assuming a normal hierarchical spectrum and a real $\boldsymbol{R}$. The results for the 22, 23 and 33 elements of the mass matrix are displayed in figure 2.

An analysis of how the finite one-loop corrections may affect for example the neutrino mixing angles can be carried out by assuming a well motivated mixing scheme as an input. This has been done in ref. [4] (including also a study of the neutrino mass spectrum) where it has been shown that even in conservative scenarios the effects can be sizable. In conclusion, due to their relevance we argue these corrections must be taken into account in the study of the seesaw parameter space.

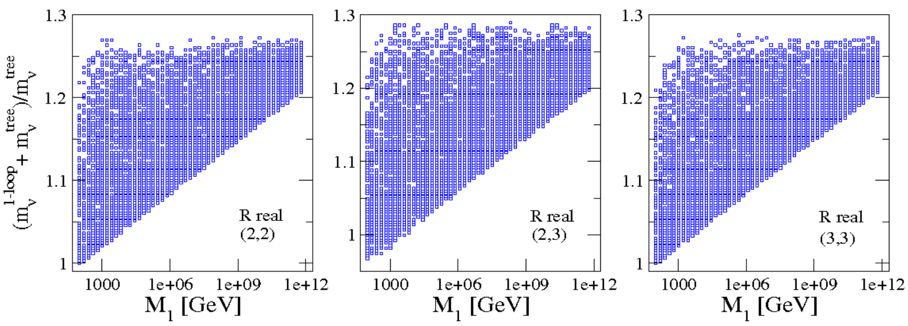

Figure 2: Relevance of the finite one-loop correction for the 22, 23 and 33 elements of the neutrino mass matrix in the case of a real $\boldsymbol{R}$ matrix.

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