Parameters of the Neutrino sector in tau decays

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1 Introduction

The smallness of the neutrino masses can be well understood within the see-saw mechanism (type I). After spontaneous symmetry breaking of the Standard Model gauge group one obtains a $(n_L + n_R) \times (n_L + n_R)$ Majorana mass matrix M_ν for neutrinos. The mixing between the n_R "right-handed" singlet fermions and the neutral parts of the n_L lepton doublets gives masses for the neutrinos which are of the size expected from neutrino oscillations.

The diagonalization of the mass matrix gives rise to a split spectrum consisting of heavy and light states of neutrinos given by $U^T M_\nu U = \mathrm{diag}(m_{n_L}^{\mathrm{light}}, m_{n_R}^{\mathrm{heavy}})$. For the case $n_R = 1$ we diagonalize M_ν with a rotation matrix determined by two angles, two masses, and Majorana phases. For the case $n_R = 2$ we diagonalize the mass matrix with a unitary matrix determined by complex parameters, four masses, and Majorana phases. In both cases we take $n_L = 3$.

We calculate the one-loop radiative corrections to the mass parameters which produce mass terms for the neutral leptons. In both cases we numerically analyse light neutrino masses as functions of the heavy neutrino masses.

2 Discussion

At the tree level the mass terms for the neutrinos can be written in a compact form as a mass term with a $(n_L+n_R)\times(n_L+n_R)$ symmetric mass matrix $M_\nu = \begin{pmatrix} 0 & M_D^T \\ M_D & \hat{M}_R \end{pmatrix}$, where M_D is $n_L \times n_R$ Dirac neutrino mass matrix and $\hat{M}_R$ is a diagonal matrix. M_ν can be diagonalized as $U^T M_\nu U = \hat{m} = \mathrm{diag}\,(m_1, m_2, \ldots, m_{n_L+n_R})$, where the m_i are real and non-negative. In order to implement the seesaw mechanism [1] we assume that the elements of M_D are of order m_D and those of M_R are of order m_R, with $m_D \ll m_R$. Then, the neutrino masses m_i with $i = 1, 2, \ldots, n_L$ are of order m_D^2/m_R, while those with $i = n_L + 1, \ldots, n_L + n_R$ are of order m_R.

One-loop corrections to the mass matrix, i.e. the self energies, are determined by the neutrino interactions with the Z boson, the neutral Goldstone boson G^0, and the Higgs boson h^0 [2]. Each diagram contains a divergent piece but when summing up the three contributions the result turns out to be finite [3].

First we consider the minimal extension of the standard model adding only one right-handed field ν_R to three left-handed fields contained in ν_L. We use the parametrization of $M_D = m_D \vec{a}^T$ with $|\vec{a}| = 1$. Working at tree level, we can construct the diagonalization matrix U from two diagonal matrices of phases and three rotation matrices $U = \hat{U}_\phi(\phi_i) U_{12}(\alpha_1) U_{23}(\alpha_2) U_{34}(\beta) \hat{U}_i$, where the angle β is determined by the masses of light and heavy neutrinos. The values of ϕ_i and α_i can be chosen to cover variations in M_D. The radiative corrections give mass to the second lightest neutrino. The third lightest neutrino remains massless.

If we add two singlet fields ν_R to three left-handed fields ν_L, the radiative corrections give masses to all three light neutrinos. Now we parametrize $M_D = \begin{pmatrix} m_{D_2}\vec{a}^T \\ m_{D_1}\vec{b}^T \end{pmatrix}$ with two vectors, which $|\vec{a}| = 1$ and $|\vec{b}| = 1$. The diagonalization matrix for tree level $U = U_{12}(\alpha_1, \alpha_2) U_{\text{egv}}(\beta_i) \hat{U}_\phi(\phi_i)$ is composed of a rotation matrix, an eigenmatrix of $M_\nu M_\nu^\dagger$ and a diagonal phase matrix, respectively.

The full results with discussions are presented in [4]. For the case $n_R = 1$ we can match the differences of the calculated light neutrino masses to $\Delta m^2_\odot$ and Δm^2_{atm} only for a mass of the heavy singlet of order 10^{17} GeV.

In the case $n_R = 2$ we obtain three non vanishing masses of light neutrinos for normal hierarchy. The numerical analysis shows that the values of light neutrino masses (especially of the lightest mass) depend on the choice of the heavy neutrino masses. The radiative corrections generate the lightest neutrino mass and have a big impact on the second lightest neutrino mass.

In future we plan to apply our parametrization to study the τ polarization coming from the decay of a W boson in the data of the CMS experiment at LHC and thus determine restrictions to the parameters of the neutrino sector.

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References

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