$\mathrm{M_h}$ in MSSM with HEAVY MAJORANA NEUTRINOS

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We summarize the main results of the one-loop radiative corrections from the neutrino/sneutrino sector to the lightest Higgs boson mass, M_h, within the context of the so-called MSSM-seesaw scenario where right handed neutrinos and their supersymmetric partners are included in order to explain neutrino masses. For simplicity, we have restricted ourselves to the one generation case. We find sizable corrections to M_h, which are negative in the region where the Majorana scale is large ($10^{13} - 10^{15}$ GeV) and the lightest neutrino mass is within a range inspired by data ($0.1 - 1$ eV). For some regions of the MSSM-seesaw parameter space, the corrections to M_h are substantially larger than the anticipated Large Hadron Collider precision.

Introduction

The current experimental data on neutrino mass differences and neutrino mixing angles clearly indicate new physics beyond the so far successful Standard Model of Particle Physics (SM). In particular, neutrino oscillations imply that at least two generations of neutrinos must be massive. Therefore, one needs to extend the SM to incorporate neutrino mass terms.

We have chosen to work in the simplest version of a SUSY extension of the SM, the well known Minimal Supersymmetric Standard Model (MSSM), extended with three right-handed Majorana neutrinos and where the seesaw mechanism of type I is implemented to generate the small neutrino masses. The main advantage of working in a SUSY extension of the SM-seesaw is to avoid the huge hierarchy problem induced by the heavy Majorana scale.

On the other hand, it is well known that heavy Majorana neutrinos induce large LFV rates, due to their potentially large Yukawas to the Higgs sector. For the same reason, radiative corrections to Higgs boson masses due to heavy Majorana neutrinos could be relevant.

More specifically, our study has been focused on the radiative corrections to the lightest MSSM $\mathcal{CP}$-even h boson mass, M_h, due to the one-loop contributions from the neutrino/sneutrino sector within the MSSM-seesaw framework.

In the following we present a short summary of the main relevant aspects of the calculation of the mass corrections and the numerical results. For further details we address the reader to the full version of our work [1].

Our Calculation

The neutrino/sneutrino sector

The MSSM-seesaw model with one neutrino/sneutrino generation is described in terms of the well known MSSM superpotential plus the new relevant terms contained in:

$$W \,=\, \epsilon_{ij} \left[Y_\nu \hat{H}_2^i \, \hat{L}^j \hat{N} \,-\, Y_l \hat{H}_1^i \, \hat{L}^j \, \hat{R} \right] \,+\, \frac{1}{2} \, \hat{N} \, m_M \, \hat{N} \,, \tag{1}$$

where m_M is the Majorana mass and $\hat{N} = (\tilde{\nu}_R^*, (\nu_R)^c)$ is the additional superfield that contains the right-handed neutrino ν_R and its scalar partner $\tilde{\nu}_R$.

There are also new relevant terms in the soft SUSY breaking potential [2]:

$$V_{\rm soft}^{\tilde\nu} = m_{\tilde L}^2 \tilde\nu_L^* \tilde\nu_L + m_{\tilde R}^2 \tilde\nu_R^* \tilde\nu_R + (Y_\nu A_\nu H_2^2 \tilde\nu_L \tilde\nu_R^* + m_M B_\nu \tilde\nu_R \tilde\nu_R + {\rm h.c.})\ . \tag{2}$$

After electro-weak (EW) symmetry breaking, the charged lepton and Dirac neutrino masses can be written as

$$m_l \ = \ Y_l \ v_1\,, \qquad m_D \ = \ Y_\nu \, v_2\,, \tag{3}$$

where v_i are the vacuum expectation values (VEVs) of the neutral Higgs scalars, with $v_{1(2)} = v\ \cos(\sin)\beta$ and $v = 174$ GeV.

The 2×2 neutrino mass matrix is given in terms of m_D and m_M by:

$$M^\nu \ = \left(\begin{array}{cc} 0 & m_D \\ m_D & m_M \end{array} \right)\,. \tag{4}$$

Diagonalization of M^ν leads to two mass eigenstates, $n_i\,(i = 1, 2)$, which are Majorana fermions with the respective mass eigenvalues given by:

$$m_{\nu,N} = \frac{1}{2}\left(m_M \mp \sqrt{m_M^2 + 4 m_D^2} \right)\ . \tag{5}$$

The mixing angle that defines the mass eigenstates is given by,

$$\tan\theta = -\frac{m_\nu}{m_D} = \frac{m_D}{m_N}\ . \tag{6}$$

In the seesaw limit, i.e. when $\xi \equiv \frac{m_D}{m_M} \ll 1$

$$\begin{aligned} m_\nu &= -m_D\xi + \mathcal{O}(m_D\xi^3) \simeq -\frac{m_D^2}{m_M}\ , \\ m_N &= m_M + \mathcal{O}(m_D\xi) \simeq m_M\ . \end{aligned} \tag{7}$$

Regarding the sneutrino sector, the sneutrino mass matrices for the $\mathcal{CP}$-even, $\tilde M_+$, and the $\mathcal{CP}$-odd, $\tilde M_-$, subsectors are given respectively by [2]:

$$\tilde M_\pm^2 = \left(\begin{array}{cc} m_{\tilde L}^2 + m_D^2 + \frac{1}{2} M_Z^2 \cos 2\beta & m_D(A_\nu - \mu\cot\beta \pm m_M) \\ m_D(A_\nu - \mu\cot\beta \pm m_M) & m_{\tilde R}^2 + m_D^2 + m_M^2 \pm 2 B_\nu m_M \end{array} \right)\ . \tag{8}$$

The diagonalization of these two matrices, $\tilde M_\pm^2$, leads to four sneutrino mass eigenstates, $\tilde n_i\,(i = 1, 2, 3, 4)$. In the seesaw limit, where m_M is bigger than all the other scales the corresponding sneutrino masses in this limit are given by:

$$\begin{aligned} m_{\tilde\nu_+,\tilde\nu_-}^2 &= m_{\tilde L}^2 + \frac{1}{2} M_Z^2 \cos 2\beta \mp 2 m_D(A_\nu - \mu\cot\beta - B_\nu)\xi\ , \\ m_{\tilde N_+,\tilde N_-}^2 &= m_M^2 \pm 2 B_\nu m_M + m_{\tilde R}^2 + 2 m_D^2\ . \end{aligned} \tag{9}$$

In the Feynman diagrammatic (FD) approach the higher-order corrected $\mathcal{CP}$-even Higgs boson masses in the MSSM, denoted here as M_h and M_H, are derived by finding the poles of the (h, H)-propagator matrix, which is equivalent to solving the following equation [3]:

$$\left[p^2 - m_h^2 + \hat\Sigma_{hh}(p^2)\right]\left[p^2 - m_H^2 + \hat\Sigma_{HH}(p^2)\right] - \left[\hat\Sigma_{hH}(p^2)\right]^2 = 0\,. \tag{10}$$

The one loop renormalized self-energies, $\hat\Sigma(p^2)$, in (10) can be expressed in terms of the bare self-energies, $\Sigma(p^2)$, the field renormalization constants δZ_{hh} and the mass counter terms δm_h^2. For example, the lightest Higgs boson renormalized self energy reads:

$$\hat\Sigma_{hh}(p^2) = \Sigma_{hh}(p^2) + \delta Z_{hh}(p^2 - m_h^2) - \delta m_h^2, \tag{11a}$$

Renormalization prescription

We have used an on-shell renormalization scheme for M_Z, M_W and M_A mass counterterms and T_h, T_H tadpole counterterms. On the other hand, we have used a m$\overline{\mathrm{DR}}$ scheme for the renormalization of the wave function and $\tan\beta$. The m$\overline{\mathrm{DR}}$ scheme is very similar to the well known $\overline{\mathrm{DR}}$ scheme but one avoids the renormalization scale dependence by taking a finite part proportional to the logarithms of the large Majorana scale divided by the renormalization scale. As studied in other works [4,5], this scheme minimizes higher order corrections when two very different scales are involved in a calculation of radiative corrections.

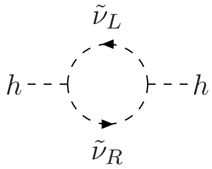
Results

Analytical results

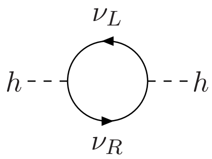
In order to check the analytical behavior of our full numerical results we have expanded the renormalized self-energies in powers of the seesaw parameter $\xi = m_D/m_M$:

$$\hat{\Sigma}(p^2) = \left(\hat{\Sigma}(p^2)\right)_{m_D^0} + \left(\hat{\Sigma}(p^2)\right)_{m_D^2} + \left(\hat{\Sigma}(p^2)\right)_{m_D^4} + \dots \,. \tag{12}$$

The zero order of this expansion corresponds to the gauge contribution and it does not depend on m_D or m_M. The rest of the terms of the expansion corrrespond to the Yukawa contribution. The leading term of this Yukawa contribution is the $O(m_D^2)$ term, it is the only one not suppressed by the Majorana scale. The relevant diagrams that are involved in this leading contribution are the following sunset diagrams:



$$\longrightarrow \quad g_{h\tilde{\nu}_L\tilde{\nu}_R} = -\frac{igm_Dm_M\cos\alpha}{2M_W\sin\beta}$$



$$\longrightarrow \quad g_{h\nu_L\nu_R} = -\frac{igm_D\cos\alpha}{2M_W\sin\beta},$$

Numerical results

In contour plot 1, we can check the main features of the extra Higgs mass corrections $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}}$ due to neutrinos and sneutrino loops in terms of the two physical Majorana neutrino masses, m_N and m_ν. For values of $m_N < 3\times 10^{13}$ GeV and $|m_\nu < 0.1 - 0.3|$ eV the corrections to m_h are positive and smaller than 0.1 GeV. In this region, the gauge contribution dominates. In fact, the wider black contour line with fixed $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}} = 0.09$ coincides with the prediction for the case where just the gauge part in the self-energies have been included. This means that 'the distance' of any other contour-line respect to this one represents the difference in the radiative corrections respect to the MSSM prediction.

However, for bigger values of m_N and m_ν the Yukawa part dominates and the radiative corrections become negative and larger in absolute value, up to values of -5 GeV in the right upper corner of plot 1. These corrections grow in modulus proportionally to m_M and m_ν, due to the fact that the seesaw mechanism impose a relation between the three masses involved, $m_D^2 = |m_\nu| m_N$. When any of the physical neutrino masses grows, m_ν or m_N, the Yukawa interactions become stronger, and therefore, the corrections become bigger.

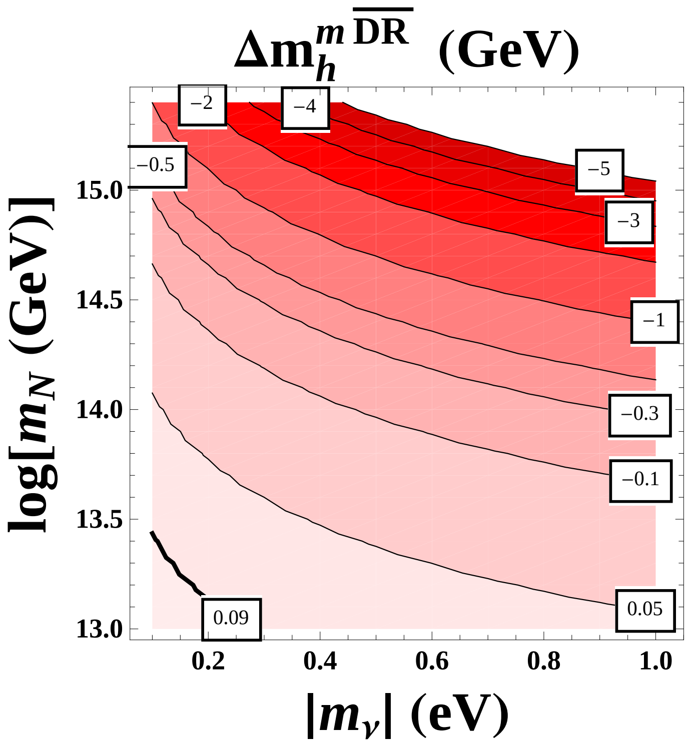


Figure 1: Contour-lines for the Higgs mass corrections from the neutrino/sneutrino sector as a function of the physical Majorana neutrino masses, light $|m_\nu|$ and heavy m_N. The other parameters are fixed to: $A_\nu = B_\nu = m_{\tilde{L}} = m_{\tilde{R}} = 10^3$ GeV, $\tan\beta = 5$, $M_A = 200$ GeV and $\mu = 200$ GeV.

Conclusions

We have used the Feynman diagrammatic approach for the calculation of the radiative corrections to the lightest Higgs boson mass of the MSSM-seesaw. This method does not neglect the external momentum of the incoming and outgoing particles as it happens in the effective potential approach . We have performed a full calculation, obtaining not only the leading logarithmic terms as it would be the case in a RGE computation but also the finite terms, that we have seen that can be sizable for heavy Majorana neutrinos ($10^{13} - 10^{15}$ GeV) and the lightest neutrino mass within a range inspired by data ($0.1 - 1$ eV). For some regions of the MSSM-seesaw parameter space, the corrections to M_h are substantially larger (up to -5 GeV) than the anticipated Large Hadron Collider precision (~ 200 MeV).

References

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