Inverse Seesaw in NMSSM and 126 GeV Higgs Boson

Bin He

Bartol Research Institute
Department of Physics and Astronomy
University of Delaware

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in collaboration with Ilia Gogoladze and Qaisar Shafi.

Motivation

- Both ATLAS and CMS have reported the discovery of a scalar particle consistent with the SM Higgs boson of mass $m_h \approx 126$ GeV
- In MSSM it requires a very large stop quark mass to accommodate $m_h \sim 126$ GeV ("little hierarchy" problem).
- NMSSM can alleviate the "little hierarchy" problem due to a tree level contribution to the Higgs potential.
- However, the couplings (λ, κ, y_t) in NMSSM will be all of $\mathcal{O}(1)$ at the GUT scale.

NMSSM

The NMSSM is obtained by adding to the MSSM a gauge singlet chiral superfield S and including the following superpotential terms:

$$W \supset \lambda S H_u H_d + \frac{\kappa}{3} S^3$$

The upper limit on the lightest CP-even Higgs boson mass in the NMSSM is given by

$$\begin{aligned}\left[m_h^2\right]_{NMSSM} &= M_Z^2 \left(\cos^2 2\beta + \frac{2\lambda^2}{g_1^2 + g_2^2} \sin^2 2\beta\right) \left(1 - \frac{3}{8\pi^2} y_t^2 t\right) \\ &+ \frac{3}{4\pi^2} y_t^2 m_t^2 \sin^2\beta \left[\frac{1}{2}\widetilde{X}_t + t + \frac{1}{(4\pi)^2}\left(\frac{3}{2} y_t^2 - 32\pi\alpha_s\right)\left(\widetilde{X}_t + t\right) t\right]\end{aligned}$$

where

$$t = \log\left(\frac{M_S^2}{M_t^2}\right), \quad \widetilde{X}_t = \frac{2\widetilde{A}_t^2}{M_S^2}\left(1 - \frac{\widetilde{A}_t^2}{12 M_S^2}\right), \quad \widetilde{A}_t = A_t - \lambda \langle S \rangle \cot\beta$$

For comparison

$$
\begin{aligned}
\left[m_h^2\right]_{NMSSM} &= M_Z^2 \left(\cos^2 2\beta + \frac{2\lambda^2}{g_1^2 + g_2^2} \sin^2 2\beta \right) \left(1 - \frac{3}{8\pi^2} y_t^2 t \right) \\
&+ \frac{3}{4\pi^2} y_t^2 m_t^2 \sin^2\beta \left[\frac{1}{2} \widetilde{X}_t + t + \frac{1}{(4\pi)^2} \left(\frac{3}{2} y_t^2 - 32\pi\alpha_s \right) \left(\widetilde{X}_t + t \right) t \right] \\
\left[m_h^2\right]_{MSSM} &= M_Z^2 \cos^2 2\beta \left(1 - \frac{3}{8\pi^2} y_t^2 t \right) \\
&+ \frac{3}{4\pi^2} y_t^2 m_t^2 \left[\frac{1}{2} \widetilde{X}_t + t + \frac{1}{(4\pi)^2} \left(\frac{3}{2} y_t^2 - 32\pi\alpha_s \right) \left(\widetilde{X}_t + t \right) t \right]
\end{aligned}
$$

NMSSM

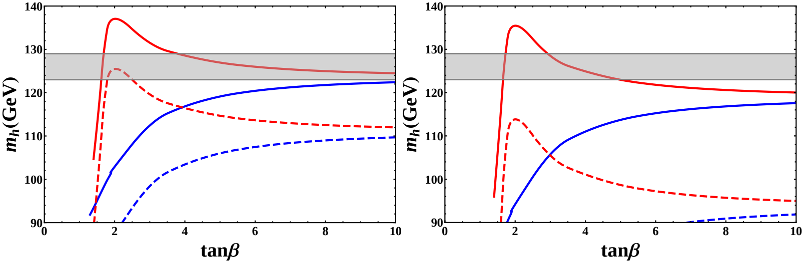
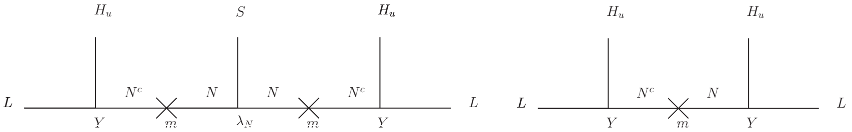


Figure: Upper bounds on the lightest CP-even Higgs boson mass versus $\tan\beta$, for $M_S = 1$ TeV (left panel) and $M_S = 200$ GeV (right panel). Maximum value of λ is used. Red lines correspond to the NMSSM, and blue lines correspond to the MSSM. The solid lines show the Higgs mass bounds for $\widetilde{X}_t = 6$, while the dashed lines show the bounds with $\widetilde{X}_t = 0$. The gray band shows the Higgs mass range of 126 ± 3 GeV.

One can incorporate the observed solar and atmospheric neutrino oscillations in the NMSSM by introducing an effective dimension six operator:

$$\frac{L L H_u H_u S}{M_6^2}$$



NMSSM+gauge singlet field

		Q	U^c	D^c	L	E^c	H_u	H_d	S
case I	Z_3	1	ω^2	ω^2	1	ω^2	ω	ω	ω
case II	Z_3	1	ω	1	ω^2	ω	ω^2	1	ω
case III	Z_3	1	1	ω	ω	1	1	ω^2	ω

Table: Z_3 charge assignments of the NMSSM superfields corresponding to dimension six operators for neutrino masses. Here $\omega = e^{i2\pi/3}$.

NMSSM+gauge singlet field

The simplest way to generate this operator is to introduce the gauge singlet chiral superfields $(N_n^c + N_n)$ in the NMSSM.

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_3	Z_2
N_n^c	1	1	0	ω^2	$-$
N_n	1	1	0	ω	$-$

Table: Charge assignments of $N_n^c + N_n$ superfields. Here $\omega = e^{i2\pi/3}$.

NMSSM+gauge singlet field

The additional contribution to the lightest CP-even Higgs mass is given by

$$\left[m_h^2\right]_N \quad = \quad n \times \left[-M_Z^2 \cos^2 2\beta \left(\frac{1}{8\pi^2} Y_N^2 t_N\right) + \frac{1}{4\pi^2} Y_N^4 v^2 \sin^2\beta \left(\frac{1}{2}\widetilde{X}_{Y_N} + t_N\right)\right]$$

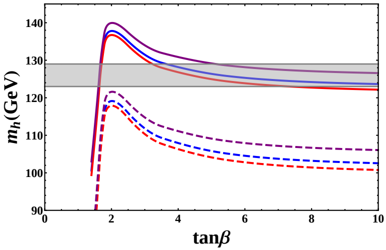
where

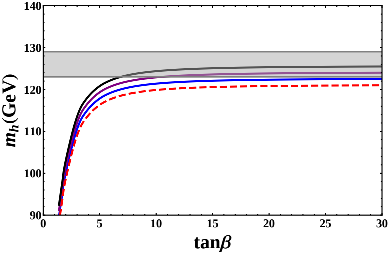
$$t_N = \log\left(\frac{M_S^2 + M_6^2}{M_6^2}\right), \quad \widetilde{X}_{Y_N} = \frac{4\widetilde{A}_{Y_N}^2\left(3M_S^2 + 2M_6^2\right) - \widetilde{A}_{Y_N}^4 - 8M_S^2 M_6^2 - 10M_S^4}{6\left(M_S^2 + M_6^2\right)^2},$$

and

$$\widetilde{A}_{Y_N} = A_{Y_N} - Y_N \langle S \rangle \cot\beta$$

NMSSM+gauge singlet field





(a) Upper bounds on the lightest CP-even Higgs boson mass versus tan β, with $M_S = 300$ GeV, $M_6 = 3$ TeV, $\widetilde{X}_{Y_N} = 4$. Maximum value of λ is used. Red lines correspond to NMSSM, while blue lines correspond to NMSSM with one additional pair of $(N_n^c + N_n)$ singlets. Purple lines correspond to NMSSM with 3 additional pairs of $(N_n^c + N_n)$ singlets. In both cases $Y_N = 0.7$. The solid lines show the Higgs mass bounds with $\widetilde{X}_t = 6$, while the dashed lines show the bounds with $\widetilde{X}_t = 0$.

(b) Upper bounds on the lightest CP-even Higgs boson mass versus tan β, with $M_S = 300$ GeV, $M_6 = 3$ TeV, $\widetilde{X}_t = 6$, $\widetilde{X}_{Y_N} = 4$, $Y_N = 0.7$ and $\lambda = 0.1$. Red dashed line corresponds to NMSSM. Blue, purple and black solid lines (from bottom to top) correspond to NMSSM+singlets with n=1, 2 and 3.

Another way for generating the dimension six operator is to introduce $SU(2)_L$ triplets $(\Delta_n^c + \Delta_n)$ with unit hypercharge .

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_3	Z_2
Δ_1	1	3	1	1	+
$\overline{\Delta}_1$	1	3	−1	1	+
Δ_2	1	3	−1	ω	+
$\overline{\Delta}_2$	1	3	1	ω^2	+

Table: Charge assignments of $(\Delta_n + \overline{\Delta}_n)$ superfields, where $n = 1, 2$. $\omega = e^{i2\pi/3}$ and Z_2 is matter parity.

NMSSM+triplets

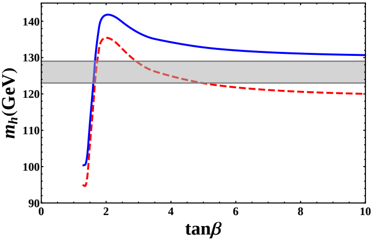
The additional contributions to the NMSSM superpotential in this case contain the following terms

$$W \supset \quad Y_{ij}(L_i \Delta_1 L_j) + Y_{H_u}(H_u \Delta_2 H_u) + \lambda_N S \,\mathrm{tr}\left[\bar{\Delta}_1 \bar{\Delta}_2\right] + m_1 \,\mathrm{tr}\left[\bar{\Delta}_1 \Delta_1\right] + m_2 \,\mathrm{tr}\left[\bar{\Delta}_2 \Delta_2\right]$$

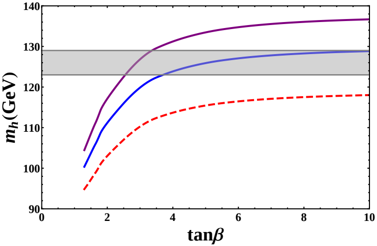
The coupling $Y_H(H_u \Delta H_u)$ will generate a tree level contribution to the lightest CP-even Higgs boson mass given by

$$\left[m_h^2\right]_\Delta = 4 Y_{H_u}^2 v^2 \sin^4 \beta$$

NMSSM+triplets



(c) Upper bounds on the lightest CP-even Higgs boson mass versus tan β, for $M_S = 200$ GeV, $\widetilde{X}_t = 6$, $Y_{H_u} = 0.15$, $m_1 = m_2 = 3$ TeV. Maximum value of λ is used. Red dashed line corresponds to NMSSM, and the blue solid line corresponds to NMSSM + $(\Delta_n + \overline{\Delta}_n)$.



(d) Upper bounds on the lightest CP-even Higgs boson mass versus tan β, with $M_S = 200$ GeV, $\widetilde{X}_t = 6$, $m_1 = m_2 = 3$ TeV, and $\lambda = 0.3$. Red dashed line corresponds to the NMSSM, and blue and purple solid lines correspond to NMSSM + $(\Delta_n + \overline{\Delta}_n)$, with $Y_{H_u} = 0.15$ and 0.2.

Conclusion

- We have considered extensions of the next-to-minimal supersymmetric model (NMSSM) in which the observed neutrino masses are generated through a TeV scale inverse seesaw mechanism.
- Introducing the gauge singlet superfields can yield a large contribution to the mass of the lightest CP-even Higgs.
- This new contribution makes it possible to have a 126 GeV Higgs with order of 300 GeV stop quarks mass and a broad range of $\tan\beta$ values.

Backup slide

The renormalizable superpotential terms involving only the new chiral superfields are given by

$$W \supset y^N_{ni} N^c_n (H_u L_i) + \frac{\lambda_{N_{nm}}}{2} S N_n N_m + m_{nm} N^c_n N_m$$

Following the electroweak symmetry breaking, the neutrino Majorana mass matrix is generated:

$$m_\nu = \frac{(Y_N^T Y_N) {v_u}^2}{M_6} \times \frac{\lambda_N \langle S \rangle}{M_6}.$$

This implies that even if $Y_N \sim \mathcal{O}(1)$ and $M_S \sim 1$ TeV, the correct mass scale for the light neutrinos can be reproduced by suitably adjusting λ_N.