m_h in MSSM with heavy Majorana neutrinos

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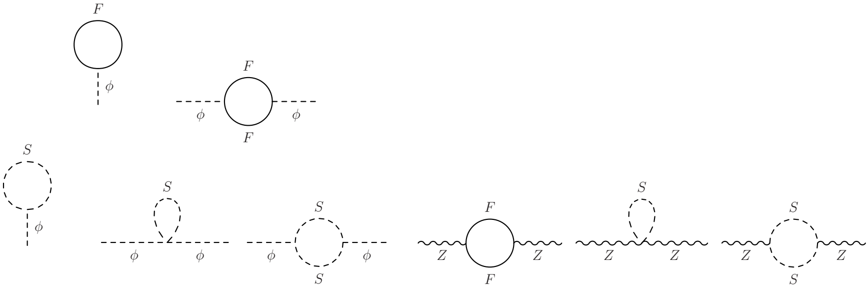
Rencontres de Moriond 2011

- S.Heinemeyer, M. J. Herrero, S.Penaranda and A.M. Rodriguez-Sanchez, [arXiv:1007.5512v2[hep-ph]]

OUR CALCULATION

- 1 loop radiative corrections to the lightest Higgs mass of the MSSM-seesaw type I model for 1 gen $\nu - \tilde{\nu}$. (3 gen work in progress)
- Corrections to m_h in the MSSM well known and crucial. They increase the bound of m_h up to 135 GeV
- Set of one-loop Feynman diagrams:

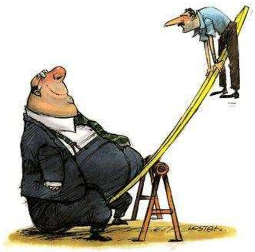


- New corrections neutrino/sneutrino sector $\rightarrow$ $\Delta m_h^{\nu/\tilde{\nu}} = M_h^{\nu/\tilde{\nu}} - M_h$

Seesaw type I

$$-\mathcal{L}_\nu = \frac{1}{2}\begin{pmatrix} \overline{\nu_L} & \overline{\nu_R^c} \end{pmatrix}\begin{pmatrix} 0 & m_D \\ m_D & m_M \end{pmatrix}\begin{pmatrix} \nu_L^c \\ \nu_R \end{pmatrix} .m_D = Y_\nu v_2;\ v_2 = v\sin\beta$$

$$m_{\nu,N} = \frac{1}{2}\left(m_M \mp \sqrt{m_M^2 + 4m_D^2}\right) \xrightarrow[m_D < m_M]{} \begin{cases} m_\nu \sim -\frac{m_D^2}{m_M} \text{ (light)} \\ m_N \sim m_M \text{ (heavy)} \end{cases}$$



If $m_M \sim 10^{14}$ GeV one can get $m_\nu \sim 0.1$ eV with $Y_\nu \simeq Y_t \sim \mathcal{O}(1)$

Sneutrino sector

SUSY preserving terms + SOFT susy breaking terms

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

New interactions in $\mathcal{L}_{\tilde\nu H}$ with respect to the Dirac case

$$\mathcal{L}_{\tilde\nu H} = \begin{cases} -\frac{g m_D m_M}{2M_W \sin\beta} [(\tilde\nu_L \tilde\nu_R + \tilde\nu_L^* \tilde\nu_R^*)(H \sin\alpha + h\cos\alpha)] \\ -i \frac{g m_D m_M}{2M_W \sin\beta} [(\tilde\nu_L \tilde\nu_R - \tilde\nu_L^* \tilde\nu_R^*) A \cos\beta] \\ + \text{usual int. terms } \tilde f \tilde f h_i,\ \tilde f \tilde f h_i h_i \end{cases}$$

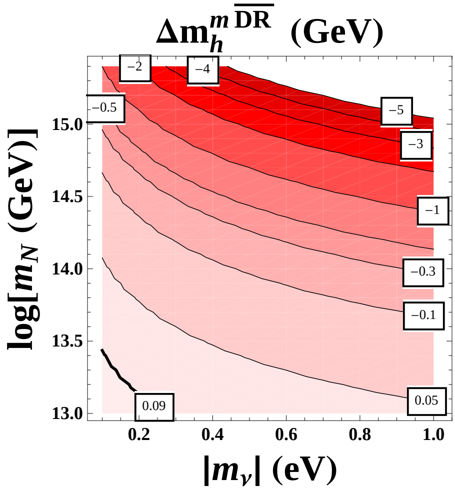
seesaw limit: $m_M >>$ all the other scales involved

2 light $\tilde\nu$ and 2 heavy $\tilde\nu$

$$m^2_{\tilde\nu_+,\tilde\nu_-} = m^2_{\tilde L} + \frac{1}{2} M_Z^2 \cos 2\beta \mp 2m_D^2 (A_\nu - \mu\cot\beta - B_\nu)/m_M$$

$$m^2_{\tilde N_+,\tilde N_-} = m_M^2 \pm 2B_\nu m_M + m^2_{\tilde R} + 2m_D^2 \ .$$

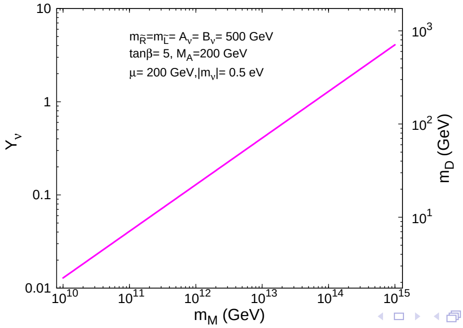
$A_\nu = B_\nu = m_{\tilde{L}} = m_{\tilde{R}} = 10^3$ GeV, $\tan\beta = 5$, $M_A = \mu = 200$ GeV



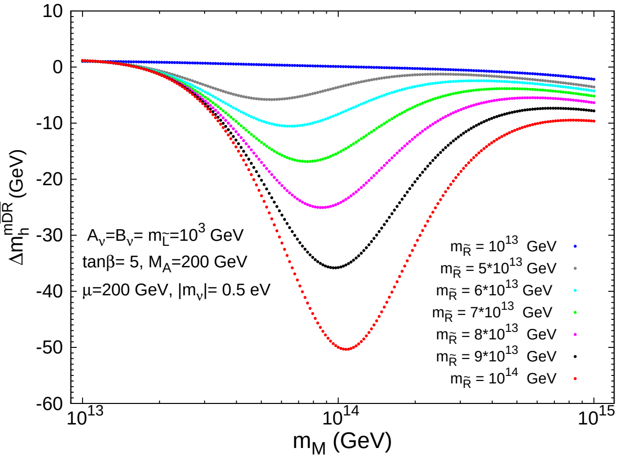
- $\Delta m_h^{\mathrm{m\overline{DR}}} < 0.1 GeV$ if 10^{13} GeV $< m_M < 10^{14}$ GeV (or, equivalently, 10^{13} GeV $< m_N < 10^{14}$ GeV) and 0.1 eV $< |m_\nu| <$ 1 eV
- $\Delta m_h^{\mathrm{m\overline{DR}}}$ change to negative sign and grow in size for larger m_M and/or $|m_\nu|$ values (up to ~ -5 GeV for $m_M = 10^{15}$ GeV and $|m_\nu| = 1$ eV)

Relevant contribution to $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}}$

- The gauge contribution dominates for $m_M < 10^{12}$ GeV $\Rightarrow$ contribution of Majorana neutrinos indistinguisable from Dirac neutrinos and from the MSSM without neutrino masses.
- The Yukawa contributions to $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}}$ are dominated by the $O(m_D^2)$
- growing of $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}}$ with m_M ONLY due to $Y_\nu \propto \frac{\sqrt{m_M |m_\nu|}}{v_2}$



$\Delta m_h^{\mathrm{m\overline{DR}}}$ dependence on m_M for different $m_{\tilde{R}}$



- The corrections are independent of $m_{\tilde{R}}$ when $m_{\tilde{R}} < 10^{13}$ GeV
- For $m_{\tilde{R}} \geq 10^{13}$ GeV $\Rightarrow \Delta m_h^{\mathrm{m\overline{DR}}}$ can be very big reaching its maximum at $m_{\tilde{R}} = m_M$

Conclusions

- The MSSM Higgs sector is sensitive to the heavy Majorana scale via radiative corrections due to the big Yukawa couplings as it happens in LFV observables such as $\tau \to \mu\gamma$.
- The radiative corrections to m_h can be relevant when $m_M > 10^{13}$ GeV, bigger than the anticipated experimental precision (LHC-0.2 GeV, ILC-0.05 GeV) $\Rightarrow$ they should be taken into account
- These corrections are negative $\Rightarrow$ they push down the lightest Higgs mass.

- The Higgs sector content in the MSSM-seesaw is as in the MSSM

$$\begin{aligned} \text{3 neutral bosons} &: \; h, H \; (\mathcal{CP} = +1), A \; (\mathcal{CP} = -1) \\ \text{2 charged bosons} &: \; H^+, H^- \end{aligned}$$

two ind parameters $\to \tan\beta = v_2/v_1$ and ${M_A}^2 = -m_{12}^2(\tan\beta + \cot\beta)$

$$m^2_{H,h \text{ tree}} = \frac{1}{2}\left[M_A^2 + M_Z^2 \pm \sqrt{(M_A^2 + M_Z^2)^2 - 4M_Z^2 M_A^2 \cos^2 2\beta}\right]$$

$$m^2_{h \text{ tree}} \leq M_Z|\cos 2\beta| \leq M_Z \qquad m^2_{h_{\text{SM}}} = \frac{1}{2}\lambda v^2$$

- Higher-order corrections to m_h

$M_h, M_H \to$ poles of the propagator matrix $\to$ solution of the eq:

$$\left[p^2 - m^2_{h \text{ tree}} + \hat{\Sigma}_{hh}(p^2)\right]\left[p^2 - m^2_{H \text{ tree}} + \hat{\Sigma}_{HH}(p^2)\right] - \left[\hat{\Sigma}_{hH}(p^2)\right]^2 = 0$$

$$\hat{\Sigma}_{hh}(p^2) = \Sigma_{hh}(p^2) + \delta Z_{hh}(p^2 - m^2_{h,\text{tree}}) - \delta m_h^2$$

$$\delta m_h^2 = f(\delta M_A^2, \delta M_Z^2, \delta T_H, \delta T_h, \delta\tan\beta)$$

Renormalization conditions

- OS conditions for the mass counterterms

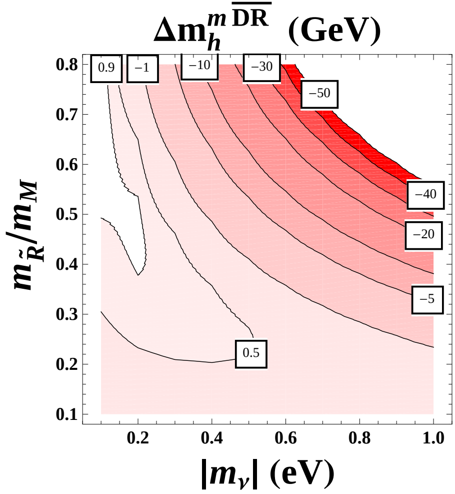
$$\delta M_Z^2 = \mathrm{Re}\,\Sigma_{ZZ}(M_Z^2),\ \delta M_W^2 = \mathrm{Re}\,\Sigma_{WW}(M_W^2),\ \delta M_A^2 = \mathrm{Re}\,\Sigma_{AA}(M_A^2).$$
$$\delta T_h = -T_h, \quad \delta T_H = -T_H\ .$$

- Different schemes adopted for field and $\tan\beta$ renormalization
  - OS
  - $\overline{\mathbf{DR}}$
  - m$\overline{\mathbf{DR}}$ $\rightarrow [\ ]^{\mathrm{div}}$ terms $\propto \Delta_m \equiv \Delta - \log(m_M^2/\mu_{\overline{\mathrm{DR}}}^2) \rightarrow \mu_{\overline{\mathrm{DR}}} = m_M$.

- m$\overline{\mathbf{DR}}$ $\rightarrow$best scheme to minimize higher order corrections $\rightarrow$ the large logarithms of the heavy scale are avoided

Contourplot of $\Delta m_h^{m\overline{DR}}$ as a function of $m_{\tilde{R}}/m_M$ and $|m_\nu|$

$m_M = 10^{14}$ GeV,
$A_\nu = B_\nu = m_{\tilde{L}} = 10^3$ GeV, $\tan\beta = 5, M_A = \mu = 200$ GeV



- Very large negative corrections for large m_M and $m_{\tilde{R}}$, of $\mathcal{O}(10^{14})$ GeV, and $|m_\nu|$ of $\mathcal{O}(1)$ eV: $\Delta m_h^{m\overline{DR}} \sim -30$ GeV for $m_M = 10^{14}$ GeV, $m_{\tilde{R}}/m_M = 0.7$ and $|m_\nu| = 0.6$ eV

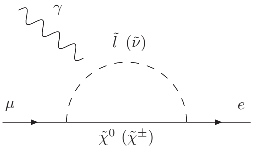
How to generate LFV via SUSY loops?

- Need non vanishing off diagonal slepton mass entries.
- The flavor off diagonal mass entries $M_{\tilde{l}}^{ij}$ and $M_{\tilde{\nu}}^{ij}$ $(i \neq j)$ at M_{EW} are generated via RGE-running of Y_ν.

The LL off-diagonal entry of the slepton mass matrix in the Leading-Logarithmic (LLog) approximation:

$$M_{LL}^{ij2} = -\frac{1}{8\,\pi^2}\,(3\,M_0^2 + A_0^2)\,(Y_\nu{}^\dagger\,L\,Y_\nu)_{ij}\ ;\ L_{kl}\ \equiv\ \log\left(\frac{M_X}{m_{M_k}}\right)\ \delta_{kl}$$

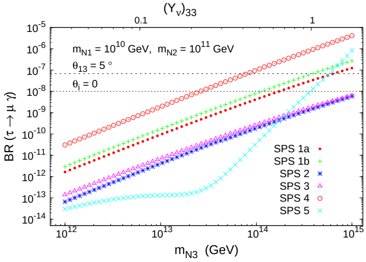
- Flavor changing sleptons propagators into loops then generate LFV

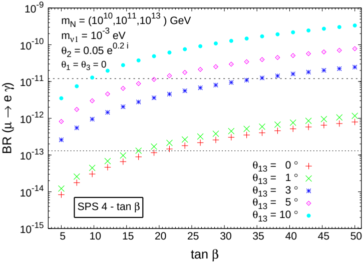


- δ_{LL}^{ij} useful phenomenologycal parameter that encodes the LFV in the i-j sector:

$$\delta_{LL}^{ij} = \frac{M_{LL}^{ij2}}{M_{SUSY}^2} \rightarrow \mathrm{BR}(\mu \rightarrow e\gamma) \simeq \frac{\alpha^3\ \tan^2\beta}{G_F^2\,M_{SUSY}^4}\ \left|\delta_{LL}^{21}\right|^2$$

Predictions for $\tau \to \mu\gamma$ and $\mu \to e\gamma$ in CMSSM-seesaw





- Most relevant seesaw param.: m_{N_3} if ν_R hierarchical (m_N if degenerate)
  BR $\sim |m_{N_3} \log m_{N_3}|^2$. Next θ_i; Ex.: BR $\times 10 - 100$ if θ_2: $0 \to 3e^{i\pi/4}$
- Relevant SUSY parameters: $\tan\beta$ and M_{SUSY} (explains $\mathrm{BR_{SPS}}$)
  $BR(\mu \to e\gamma) \simeq 0.1|\delta_{21}|^2 (\frac{100}{M_{SUSY}})^4 (\frac{\tan\beta}{60})^2$; $BR(\tau \to \mu\gamma) \simeq 0.015|\delta_{32}|^2 (\frac{100}{M_{SUSY}})^4 (\frac{\tan\beta}{60})^2$
  $BR(\mu \to e\gamma)/BR(\tau \to \mu\gamma)$ ratio nearly independent on SUSY parameters.
  It depends just on neutrino parameters: correlations fixed by seesaw
- BR($\mu \to e\gamma$), BR($\tau \to \mu\gamma$) reach exp. lim. at large (m_{N_3}, $\tan\beta$, θ_i)

Seesaw mechanism with 3 ν_R

For 3 generations $\Rightarrow$ 6 physical neutrinos: 3 ν light, 3 N heavy

$$U^{\nu T} M^{\nu} U^{\nu} = \hat{M}^{\nu} = diag(m_{\nu_1}, m_{\nu_2}, m_{\nu_3}, m_{N_1}, m_{N_2}, m_{N_3}).$$

$$m_D \ll m_M \Rightarrow m_\nu = -{m_D}^T {m_N}^{-1} m_D;\ m_N = m_M;\ m_D = Y_\nu < H_2 >$$

$$\begin{aligned} m_\nu^{\rm diag} &= {U_{\rm PMNS}}^T m_\nu U_{\rm PMNS} = {\rm diag}\,(m_{\nu_1}, m_{\nu_2}, m_{\nu_3})\,, \\ m_N^{\rm diag} &= m_N = {\rm diag}\,(m_{N_1}, m_{N_2}, m_{N_3})\,, \end{aligned}$$

Y_ν, m_D, m_M, $U_{\rm PMNS}$, are 3×3 matrices; $c_{ij} \equiv \cos(\theta_{ij})$, $s_{ij} \equiv \sin(\theta_{ij})$

$$U_{\rm PMNS} = \begin{pmatrix} c_{12}\, c_{13} & s_{12}\, c_{13} & s_{13}\, e^{-i\delta} \\ -s_{12}\, c_{23} - c_{12}\, s_{23}\, s_{13}\, e^{i\delta} & c_{12}\, c_{23} - s_{12}\, s_{23}\, s_{13}\, e^{i\delta} & s_{23}\, c_{13} \\ s_{12}\, s_{23} - c_{12}\, c_{23}\, s_{13}\, e^{i\delta} & -c_{12}\, s_{23} - s_{12}\, c_{23}\, s_{13}\, e^{i\delta} & c_{23}\, c_{13} \end{pmatrix} \times diag(1, e^{i\alpha}, e^{i\beta})$$

Pontecorvo-Maki-Nakagawa-Sakata matrix: θ_{12}, θ_{13}, θ_{23}, δ, α, β

Seesaw mechanism with 3 ν_R versus neutrino data

SeeSaw Mechanism with 3 ν_R:$(m_{\nu_1}, m_{\nu_2}, m_{\nu_3}, m_{N_1}, m_{N_2}, m_{N_3})$

$m_\nu = -m_D^T m_N^{-1} m_D; m_N = m_M; m_D = Y_\nu < H_2 >$

Solution: $$m_D = i\sqrt{m_N^{diag}}\, R\, \sqrt{m_\nu^{diag}}\, U^\dagger_{\mathrm{PMNS}}$$ [Casas, Ibarra ('01)]

R is a 3×3 complex matrix and orthogonal

$$\mathbf{R} = \begin{pmatrix} c_2c_3 & -c_1s_3 - s_1s_2c_3 & s_1s_3 - c_1s_2c_3 \\ c_2s_3 & c_1c_3 - s_1s_2s_3 & -s_1c_3 - c_1s_2s_3 \\ s_2 & s_1c_2 & c_1c_2 \end{pmatrix}$$

$c_i = \cos\theta_i, \quad s_i = \sin\theta_i, \quad \theta_{1,2,3}$ complex

Parameters: θ_{ij},δ,α,β,m_{ν_i},m_{N_i},θ_i **(18)** ; m_{N_i}, θ_i drive the size of Y_ν.

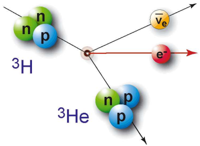
Hierarchical ν's : $m^2_{\nu_1} << m^2_{\nu_2} = \Delta m^2_{\mathrm{sol}} + m^2_{\nu_1} << m^2_{\nu_3} = \Delta m^2_{\mathrm{atm}} + m^2_{\nu_1}$

2 scenarios :

- Degenerate N's $\rightarrow m_{N_1} = m_{N_2} = m_{N_3} = m_N$
- Hierarchical N's $\rightarrow m_{N_1} << m_{N_2} << m_{N_3}$

Why Majorana neutrinos?

- neutrino oscillations $\Rightarrow$ at least two massive neutrinos
- tritium beta decay exp. (Mainz,Troitsk) $\Rightarrow$ $\mathbf{m_{\nu_e} < 2.3\,eV}$ (**95**%C.L.)



- simplest way to explain ν masses introduction of ν_R
  - Dirac terms $\mathbf{m_D \overline{\nu_L} \nu_R}$
  - Majorana terms $\mathbf{m_M \overline{\nu_R^c} \nu_R}$ allowed
- Majorana masses violate lepton number, possible explanation of BAU via Leptogenesis
- If heavy Majorana ν, one can have large Y_ν couplings $\rightarrow$ phenomenologically relevant
  - Dirac$\Rightarrow$ $Y_\nu \sim O(10^{-12})$ Majorana $\Rightarrow$ up to $Y_\nu \sim O(1)$

Why radiative corrections to m_h due to Majorana ν ?

- Indirect search of new physics via radiative corrections is a powerful tool for heavy particles that cannot be produced directly (such as LFV)
- The Higgs mass will be a precision observable
- Prospects in precision meaurements on SM-like Higgs boson mass
  - LHC $\sim$ 0.2 GeV
  - ILC $\sim$ 0.05 GeV
- In the MSSM, higher order corrections are crucial
  - $m_{h,\mathrm{tree}} < M_Z$ (free parameter in the SM)
  - Leading higher order correction $\rightarrow$ Yukawa sector

    $\Delta m_h^2 \sim G_\mu m_t^4 \log \frac{m_{\tilde{t}}^2}{m_t^2}$

  - 2-loop corrections: $m_h < 135$ GeV
- Majorana neutrinos can have large $Y_\nu \simeq Y_t \rightarrow$ Do they affect Δm_h?

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MODEL: MSSM + ν_R+$\tilde{\nu}_R$

- MSSM parameters: M_A and $\tan\beta$ (Higgs sector), $\tilde{m}$ (soft masses), A (trilinear couplings), μ parameter
- Neutrino sector: m_D and m_M
- Sneutrino sector: $m_{\tilde{\nu}_R}$, $m_{\tilde{\nu}_L}$, A_ν, B_ν

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