Is m_h sensitive to the Majorana scale in a MSSM-seesaw model ?

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Our work

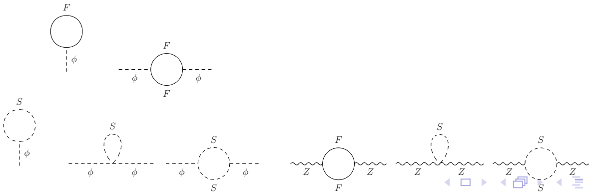
CALCULATION

- 1 loop radiative corrections to the lightest Higgs mass of the MSSM-seesaw model for 1 generation $\nu - \tilde{\nu}$. (3 gen work in progress)
- 1 loop corrected $M_h, M_H \rightarrow$ poles of the propagator matrix $\rightarrow$ solution of the eq:

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

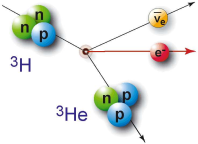
$$\hat{\Sigma}_{hh}(p^2) = \Sigma_{hh}(p^2) + \delta Z_{hh}(p^2 - m^2_{h,\mathrm{tree}}) - \delta m^2_h$$

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



Why Majorana neutrinos?

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



- 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)
- m_h precision observable $\rightarrow$ 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
  - $m_{h,\text{tree}} < M_Z$ (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 $Y_\nu \simeq Y_t$

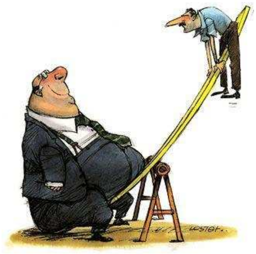
  $\rightarrow$ Do they affect Δm_h?
- In the SM:

$$V_{eff_{\nu heavy}} \simeq \frac{1}{64\pi^2} m_M^2 Y_\nu^2 H^2 \left(\log \frac{m_M^2}{\mu^2} - \frac{3}{2} + ...\right)$$

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 $Y_\nu \sim Y_t \sim \mathcal{O}(1)$

Sneutrino sector

SUSY preserving terms + SOFT susy breaking terms

$$W_{MSSM+\nu\tilde{\nu}} = \epsilon_{ij}\left[\mu H_1^i H_2^j + Y_\nu \hat{H}_2^i \hat{L}^j \hat{N}\right] + \frac{1}{2}\hat{N}\, m_M\, \hat{N}\,;\hat{N} = (\tilde{\nu}_R^*, (\nu_R)^c)$$

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

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

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

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

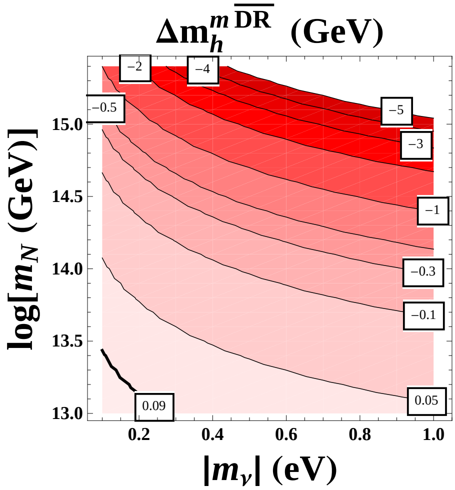
2 light $\tilde{\nu}$ and 2 heavy $\tilde{\nu}$

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

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

Contourplot of $\Delta m_h^{\mathrm{m\overline{DR}}}$ as a function of m_N and $|m_\nu|$

$A_\nu = B_\nu = m_{\tilde{L}} = m_{\tilde{R}} = 10^3$ 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)

The seesaw limit

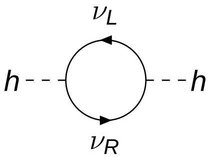
- expansion of $\hat{\Sigma}_{hh}^{m\overline{\mathrm{DR}}}$ in powers of the seesaw parameter $\xi = \frac{m_D}{m_M}$

$$\hat{\Sigma}(p^2) = \underbrace{\left(\hat{\Sigma}(p^2)\right)_{m_D^0}}_{\text{gauge-MSSM}} + \underbrace{\left(\hat{\Sigma}(p^2)\right)_{m_D^2} + \left(\hat{\Sigma}(p^2)\right)_{m_D^4} + \ldots}_{\text{Yukawa}} .$$

- 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 relevant Yukawa contributions come from the $\mathcal{O}(m_D^2)$ term

$$\left(\hat{\Sigma}_{hh}^{\overline{\mathrm{DR}}}(p^2)\right)_{m_D^2} = \left(\frac{g^2 m_D^2}{64\pi^2 M_W^2 \sin^2\beta}\right)\left[1 - \log\left(\frac{m_M^2}{\mu_{\overline{\mathrm{DR}}}^2}\right)\right]\left[-2M_A^2\cos^2(\alpha-\beta)\cos^2\beta\right.$$
$$\left.+2p^2\cos^2\alpha - M_Z^2\sin\beta\sin(\alpha+\beta)\left(2\left(1+\cos^2\beta\right)\cos\alpha - \sin 2\beta\sin\alpha\right)\right]$$

- growing of $\Delta m_h^{m\overline{\mathrm{DR}}}$ with m_M ONLY due to $Y_\nu \propto \frac{\sqrt{m_M|m_\nu|}}{v_2}$



$$= -i\Sigma_{hh}^{\nu_L \nu_R},$$

$$-i\Sigma_{hh}^{\nu_L\nu_R} = (-1)(\mu)^{4-D} g^2_{h\nu_L\nu_R} \int \frac{d^Dk}{(2\pi)^D} Tr\left\{ \left(\frac{i}{\not{k} - m_{\nu_R}} \right) \left(\frac{i}{\not{p} + \not{k} - m_{\nu_L}} \right) \right\}$$

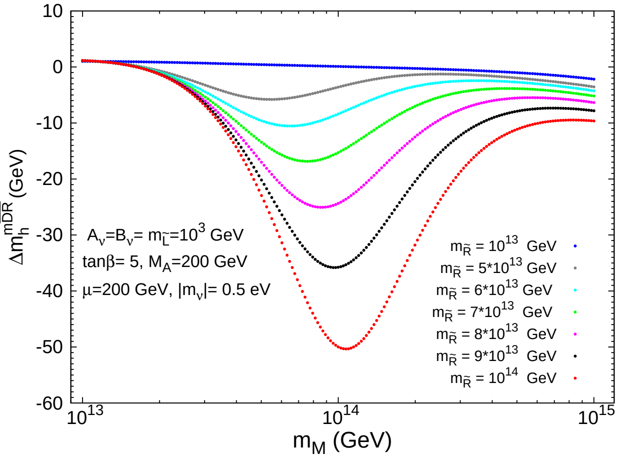
$$= 4 \frac{g^2 m_D^2}{s_\beta^2 4 M_W^2} \int \frac{d^Dk}{(2\pi)^D} \left\{ \frac{kp + k^2}{(k^2 - m^2_{m_M})((p+k)^2)} \right\}$$

using

$$\int \frac{kp}{\left[k^2 - m^2_{m_M}\right]\left[(k+p)^2\right]} = \frac{1}{2}\int \frac{1}{k^2 - m^2_{m_M}} - \frac{1}{2}\int \frac{1}{k^2} - \frac{m^2_{m_M} + p^2}{2} \int \frac{1}{\left[k^2 - m^2_{m_M}\right]\left[(k+p)^2\right]}$$

using the expression of the one loop integral $B_0(p^2, m_{m_M}, 0)$ in the limit $p << m_M$

$$-i\Sigma_{hh}^{\nu_L\nu_R} \simeq \frac{g^2 p^2 m_D^2}{16\pi^2 M_W^2 s_\beta^2} \left(1 - \log \frac{m_M^2}{\mu^2} - \frac{p^2}{m_M^2} \right)$$



- The corrections are independent of $m_{\tilde{R}}$ when $m_{\tilde{R}} < 10^{13}$ GeV
- For $m_{\tilde{R}} \geq 10^{13}$ GeV $\Rightarrow \Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}}$ 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.

Backup frames


¿Y ESTUM?
ERRARE HUMANUM EST

The Coleman- Weinberg MSSM effective potential (in the $\overline{DR}$ scheme which is the supersymmetric version of the $\overline{MS}$ with dimensional reduction):

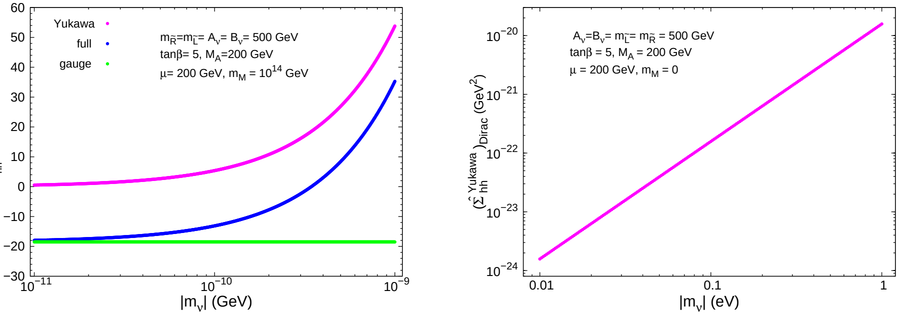
$$V\left(v_1, v_2; \mu\right) = V_0\left(v_1, v_2\right) + \frac{1}{64\pi^2} StrM^4 \left[\log\left(\frac{M^2}{\mu^2}\right) - \frac{3}{2}\right]$$

$Str = \sum_f (-1)^{2s_f} N_{C_f} N_{S_f}$. $N_{C_f}, N_{S_f} \rightarrow$ colour, spin degrees of freedom

$$\frac{\partial V_{eff}}{\partial \phi}|_{\phi=v} = 0, \quad \frac{\partial^2 V_{eff}}{\partial \phi^2}|_{\phi=v} = m_h^2,$$

$$\begin{aligned} \Delta m_h^{\nu/\tilde{\nu}} &\simeq -\frac{g^2 m_D^4}{32\pi^2 M_W^2 m_M^2}\left(m_{\tilde{R}}^2\left(1 + 2\log\frac{m_M^2 + m_{\tilde{R}}^2}{\mu^2}\right) - 2m_M^2 \log\frac{m_M^2 + m_{\tilde{R}}^2}{m_M^2}\right) \\ &\propto \frac{m_D^4}{m_M^2} \quad \text{if} \quad m_{\tilde{R}} << m_M \end{aligned}$$

Dependence of $\hat{\Sigma}^{m\overline{\rm DR}}_{hh}(p^2)$ on m_ν $\to$ Majorana versus Dirac



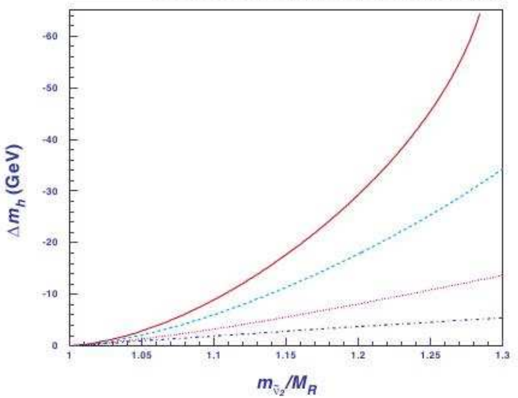
- In both cases $\hat{\Sigma}_{hh}$ grow with the neutrino mass, due to the Y_ν dependence on m_ν
  - Dirac case $\to Y_\nu = m_\nu/v_2 \to$ O(10^{-12})
  - Majorana case $\to Y_\nu = m_D/v_2 \sim \sqrt{|m_\nu| m_M}/v_2$

Renormalization conditions

- OS conditions for the mass counterterms $\Rightarrow \delta m_{ii} = \mathrm{Re}\,\Sigma_{ii}(m_{ii}^2)$
- 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

Previous works

PHYSICAL REVIEW D **71,** 111701 (2005)



- Neutrino/sneutrino contribution to m_h.The solid, dashed, dashed-dotted curve is for $m_{\tilde{R}} = 10^3, 10^7, 10^{11}, 10^{13} GeV$, respectively, $m_M = 10^{14}$ GeV
- J. Cao and J. M. Yang, *Phys. Rev.* **D 71** (2005) 111701

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

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

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

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

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

- Higher-order corrections to m_h

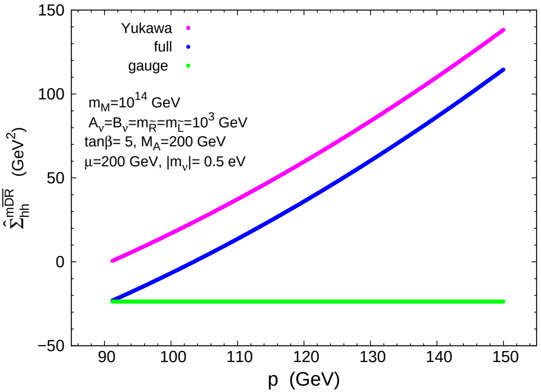
  M_h, M_H $\rightarrow$ poles of the propagator matrix $\rightarrow$ solution of the eq:

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

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

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

Dependence of $\hat{\Sigma}_{hh}^{m\overline{\mathrm{DR}}}(p^2)$ on p



- Strong dependence of $\hat{\Sigma}_{hh}$ with the external momentum $\rightarrow$ usual $p = 0$ aprrox not valid
- The gauge part is quasi insensitive to p $\rightarrow$ $\hat{\Sigma}_{hh}^{gauge} \sim p^2 M_Z^2 / m_{\mathrm{SUSY}}^2$
- The yukawa part increases with p $\rightarrow$ $\left(\hat{\Sigma}_{hh}^{\overline{\mathrm{DR}}}(p^2)\right)_{m_D^2} \sim Y_\nu^2 p^2$

Renormalization conditions

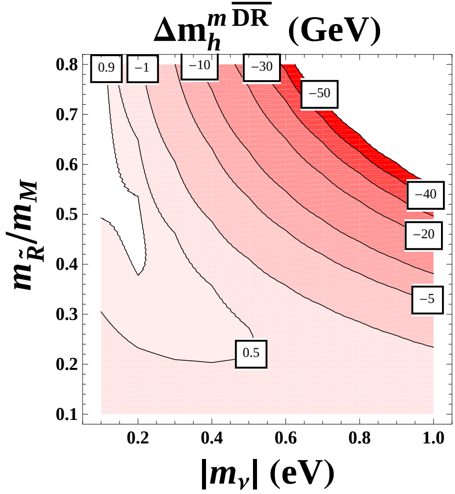
- OS conditions for the mass counterterms

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

- Different schemes adopted for field and tan β 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 $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}}$ 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:
  $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}} \sim -30$ GeV
  for $m_M = 10^{14}$ GeV,
  $m_{\tilde{R}}/m_M = 0.7$ and $|m_\nu| = 0.6$ eV