Sensitivity of MSSM Higgs masses to Majorana neutrinos

A.M. Rodriguez-Sanchez

Departament of Theoretical Physics
UAM

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S.Heinemeyer, M. J. Herrero, Siannah Peñaranda, arXiv:1007.5512v2 [hep-ph]

Outline

1. Introduction
   - Motivations
   - MSSM-seesaw framework for one generation neutrinos/sneutrinos
   - Higgs boson sector
   - Renormalization prescription
2. Results: One Loop $\nu/\tilde{\nu}$ corrections to m_h
   - $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}} = M_h^{\nu/\tilde{\nu}} - M_h$
3. Conclusions

Relevance of Higgs mass corrections

- One of the main goal of the LHC $\rightarrow$ Higgs boson like particle
- The Higgs mass will be a precision observable
- Expected experimental accuracy in the meaurement of the SM-like Higgs mass
  - LHC: $\Delta m_h \approx 0.2$ GeV
  - ILC: $\Delta m_h \sim 0.05$ GeV
- In the MSSM, higher order corrections are crucial
  - Contrary to the SM, m_h is not a free parameter
  - MSSM tree-level bound:
    $m_{h,\text{tree}} < M_Z$, excluded by LEP Higgs searches
  - Large radiative corrections $\rightarrow \Delta m^2_{h_{1-loop}} \sim G_\mu m_t^4 \log \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}$
  - Higgs boson mass have been computed with very good precision at one, two loop level...$\rightarrow m_h < 135$ GeV
- Our work: How can the massive neutrinos affect m_h in an MSSM-seesaw framework?

Neutrino physics/ Seesaw type I

- neutrino oscillations $\Rightarrow$ at least two massive neutrinos
- tritium beta decay exp. $\Rightarrow m_{\nu_e} < 2.3\,\text{eV}$ (95%C.L.)
- New physics beyond the SM to explain the smallness of neutrino masses
- seesaw type I $\rightarrow$ introduction of 3 ν_R singlets
  - Dirac $\mathbf{m_D}\overline{\nu_L}\nu_R$ + Majorana $\mathbf{m_M}\overline{\nu_R^c}\nu_R$ terms allowed
  - L is violated $\rightarrow$ posible explanation of BAU via leptogenesis
  - large Y_ν couplings allowed
    Dirac $\Rightarrow Y_\nu \sim O(10^{-12})$ Majorana $\Rightarrow$ up to $Y_\nu \sim O(1)$
- Present work:

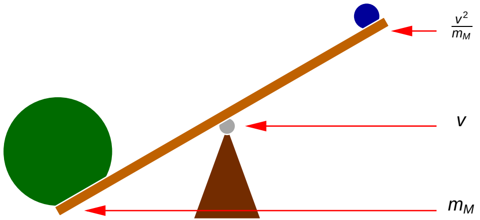
  For simplicity we restrict to the one generation neutrinos/sneutrinos case
  (three generations work in progress)

Seesaw model for one generation neutrinos

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

$$\nu = \nu^c = \cos\theta(\nu_L + (\nu_L)^c) - \sin\theta(\nu_R + (\nu_R)^c) \ ,$$
$$N = N^c = \sin\theta(\nu_L + (\nu_L)^c) + \cos\theta(\nu_R + (\nu_R)^c)$$

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



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

Sneutrino sector

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

$$\hat{N} = (\tilde{\nu}_R^*, (\nu_R)^c)$$

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

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

sneutrino masses

$$\tilde{M}^2_{\pm} = \begin{pmatrix} m^2_{\tilde{L}} + m^2_D + \frac{1}{2}M^2_Z \cos 2\beta & m_D(A_\nu - \mu \cot\beta \pm m_M) \\ m_D(A_\nu - \mu \cot\beta \pm m_M) & m^2_{\tilde{R}} + m^2_D + m^2_M \pm 2B_\nu m_M \end{pmatrix} .$$

4 mass eigenstates $\begin{cases} \tilde{\nu}_+, \tilde{N}_+ \to \text{CP even} \\ \tilde{\nu}_-, \tilde{N}_- \to \text{CP odd} \end{cases}$

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

$$\begin{aligned} m^2_{\tilde{\nu}_+,\tilde{\nu}_-} &= m^2_{\tilde{L}} + \frac{1}{2}M^2_Z \cos 2\beta \mp 2m^2_D(A_\nu - \mu\cot\beta - B_\nu)/m_M \ , \\ m^2_{\tilde{N}_+,\tilde{N}_-} &= m^2_M \pm 2B_\nu m_M + m^2_{\tilde{R}} + 2m^2_D \ . \end{aligned}$$

$\theta_\pm \propto m_D/m_M \to 0 \Rightarrow \tilde{\nu}_+, \tilde{\nu}_- \propto \tilde{\nu}_L, \tilde{\nu}^*_L$ and $\tilde{N}_+, \tilde{N}_- \propto \tilde{\nu}_R, \tilde{\nu}^*_R$

Higgs Boson Sector

- 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 ${M_A}^2 = -m_{12}^2(\tan\beta + \cot\beta)$

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

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

- Higher-order corrections to m_h

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

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

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

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

Renormalization conditions

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

Present work: One Loop Calculation to m_h

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

- One-loop $\nu/\tilde{\nu}$ corrections to $\hat{\Sigma}^{\nu/\tilde{\nu}}_{hh}$, $\hat{\Sigma}^{\nu/\tilde{\nu}}_{HH}$ and $\hat{\Sigma}^{\nu/\tilde{\nu}}_{hH}$ with Feynarts and FormCalc
- New Feynman rules neu/sneu sector in an available model file
- Cancellation of divergences in OS, $\overline{\mathrm{DR}}$, $\mathrm{m}\overline{\mathrm{DR}}$
- Yukawa and gauge contributions

$$\hat{\Sigma}(p^2)|_{\mathrm{full}} = \hat{\Sigma}(p^2)|_{\mathrm{gauge}} + \hat{\Sigma}(p^2)|_{\mathrm{Yukawa}}\ ;\ \hat{\Sigma}(p^2)|_{\mathrm{gauge}} = \hat{\Sigma}(p^2)|_{\mathrm{MSSM}}$$

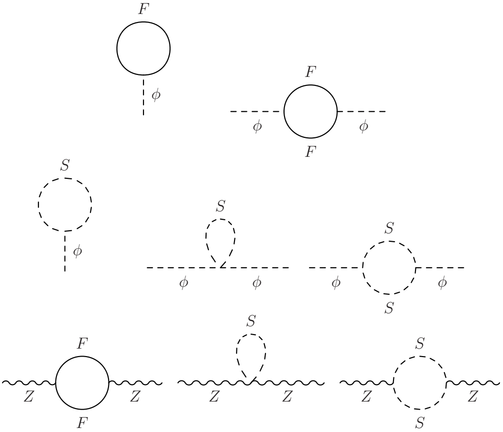
- Study seesaw limit $m_D << m_M$ and Dirac limit $m_M = 0$
- Calculation of the new Higgs corrections $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}}$ coming from the $\nu/\tilde{\nu}$ sector:

$$\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}} = M_h^{\nu/\tilde{\nu}} - M_h$$

Calculation of M_h and M_H in MSSM without $\nu/\tilde{\nu}$ with FeynHiggs

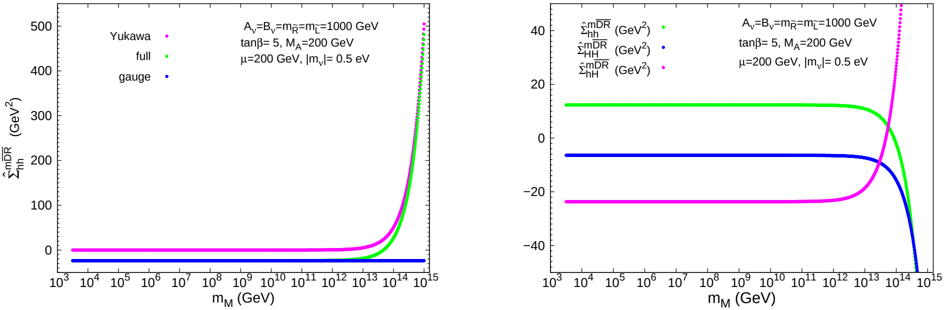
One Loop Calculation to m_h

- Set of one-loop Feynman diagrams:



- Parameters of the MSSM-Seesaw: m_M, $\tan\beta$, M_A, μ, A_ν, $m_{\tilde{L}}$, $m_{\tilde{R}}$, m_ν, B_ν and p

Results: Dependence of $\hat{\Sigma}_{hh}$ on m_M



- For $10^4 < m_M < 10^{12}$ GeV $\rightarrow \hat{\Sigma}^{m\overline{DR}}_{hh} = \hat{\Sigma}^{m\overline{DR}}_{hh}|_{\rm gauge} \rightarrow$ no sensitivity to m_M
- For $m_M > 10^{12}$ GeV $\rightarrow \hat{\Sigma}^{m\overline{DR}}_{hh}$ grow with m_M
- $\hat{\Sigma}^{m\overline{DR}}_{HH}$ and $\hat{\Sigma}^{m\overline{DR}}_{hH}$ show a similar dependence with m_M

The seesaw limit

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

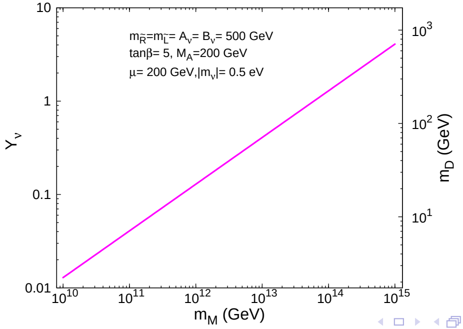
$$\hat{\Sigma}(p^2) = \underbrace{\left(\hat{\Sigma}(p^2)\right)_{m_D^0}}_{\text{gauge-MSSM}} + \underbrace{\left(\hat{\Sigma}(p^2)\right)_{m_D^2} + \left(\hat{\Sigma}(p^2)\right)_{m_D^4} + \dots}_{\text{Yukawa}} .$$

- $A_\nu = \mu = B_\nu = 0$ and universal SOFT SUSY masses $m_{\tilde{L}} = m_{\tilde{R}} = m_{\text{SUSY}}$
- expand in powers of $\frac{M_Z}{m_M}$, $\frac{M_A}{m_M}$, $\frac{p}{m_M}$ and $\frac{m_{\text{SUSY}}}{m_M}$
- The relevant Yukawa contributions come from the $\mathcal{O}(m_D^2)$ term

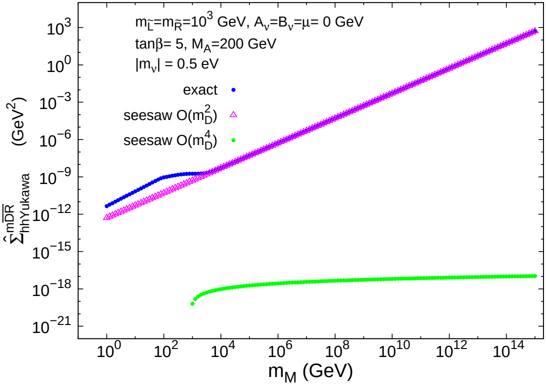
O(m_D^2) relevant term

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

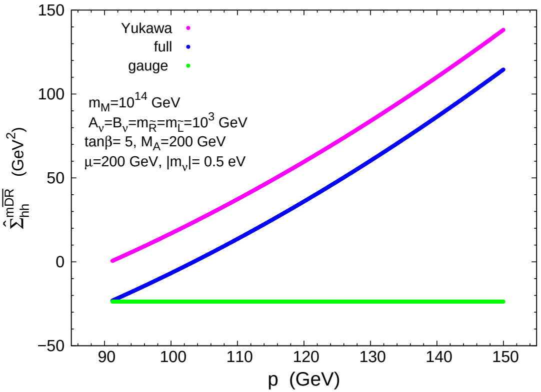
- growing of $\hat{\Sigma}_{hh}^{m\overline{\rm DR}}(p^2)$ with m_M ONLY due to Y_ν dependence on $m_M \to Y_\nu \propto \sqrt{m_M}$



EXACT versus SEESAW LIMIT $m\overline{\mathrm{DR}}$

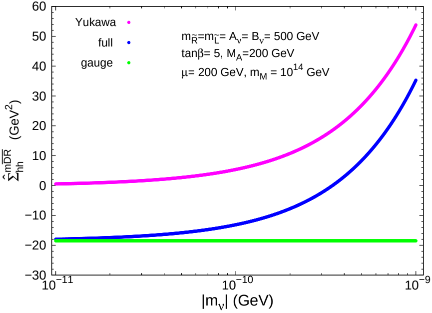


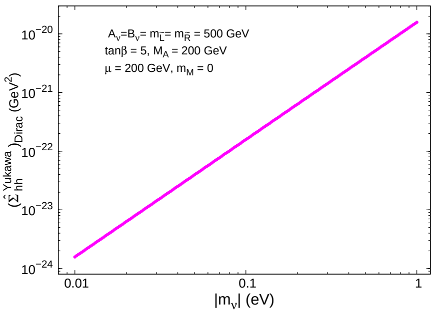
- seesaw limit OK with exact results for $m_M > M_{\rm EW}, m_{\rm SUSY}$
- $O(m_D^2)$ dominates the Yukawa contribution $\to m_D \propto \sqrt{m_M}$
- relevant size for $m_M \geq 10^{14}$ GeV
- $O(m_D^4)$ completely negliglible, suppressed by $\frac{1}{m_M^2}$



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

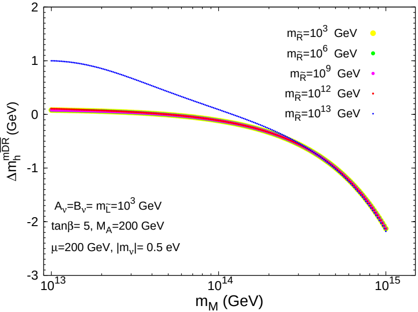
Dependence of $\hat{\Sigma}_{hh}^{m\overline{\mathrm{DR}}}(p^2)$ on $m_\nu \to$ Majorana versus Dirac

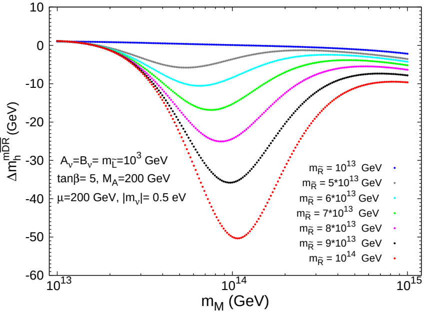




- In both cases $\hat{\Sigma}_{hh}$ grow with the neutrino mass, due to the Y_ν dependence on m_ν
  - Dirac case $\to Y_\nu = m_\nu / v_2 \to$ O(10^{-12})
  - Majorana case $\to Y_\nu = m_D / v_2 \sim \sqrt{|m_\nu| m_M} / v_2$

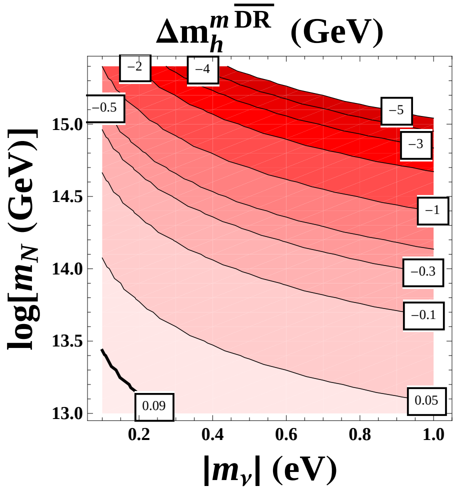
$\Delta m_h^{\overline{\rm mDR}}$ dependence on m_M for different $m_{\tilde{R}}$





- For $m_M \le 5 * 10^{13}$ GeV tiny positive corrections, $\Delta m_h^{\overline{\rm mDR}} < 0.1$ GeV
- For $m_M \ge 5 * 10^{13}$ GeV $\Rightarrow$ negative Higgs mass corrections, they increase with m_M up to a few GeV.
- The corrections are independent of $m_{\tilde{R}}$ when $m_{\tilde{R}} < 10^{13}$ GeV
- For $m_{\tilde{R}} \ge 10^{13}$ GeV $\Rightarrow \Delta m_h^{\overline{\rm mDR}}$ can be very big reaching its maximum at $m_{\tilde{R}} = m_M$

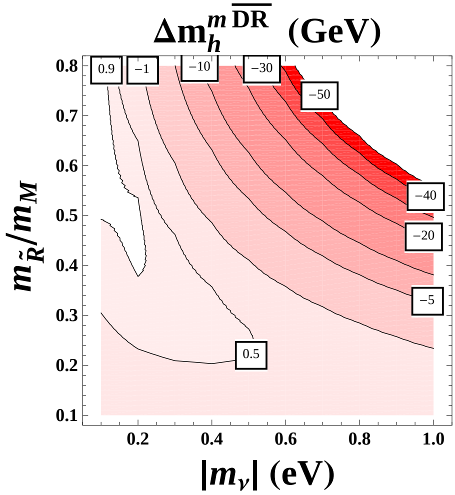
$A_\nu = B_\nu = m_{\tilde{L}} = m_{\tilde{R}} = 10^3$ GeV, $\tan\beta = 5, M_A = \mu = 200$ GeV



- $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}} < 0.1 GeV$ if 10^{13} GeV $< m_M < 10^{14}$ GeV and 0.1 eV $< |m_\nu| < 1$ eV
- $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}}$ 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)

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

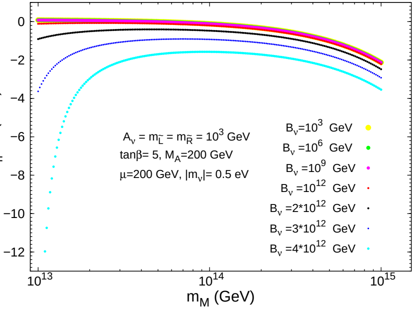
Conclusions

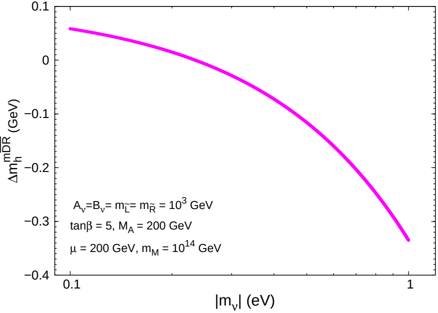
- The MSSM Higgs sector is sensitive to the heavy Majorana scale
- The radiative corrections to the higgs mass h_0 can be relevant when $m_M > 10^{13}$ GeV, bigger than the anticipated experimental precision (LHC-0.2 GeV, ILC-0.05 MeV) $\Rightarrow$ they should be taken into account
- The corresponding contribution of dirac neutrinos is negligible and completely indistinguisable of the MSSM with no masive neutrinos.
- The generalization to the realistic 3-neutrino-sneutrino case is appealing and could give extra contributions due to the big mixing angles as it happens in some LFV observables.(work in progress)

BACK UP SLIDES

Results for $\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}} = M_h^{\nu/\tilde{\nu}} - M_h$

$\Delta m_h^{\mathrm{m}\overline{\mathrm{DR}}}$ dependence on m_M for different B_ν and on m_ν





Dependence on $\tan\beta$, M_A, μ, A_ν

- $Y_\nu \propto \frac{\cos\alpha}{\sin\beta} \Rightarrow \hat{\Sigma}_{hh}^{m\overline{\rm DR}}(p^2) \downarrow$ when $\tan\beta \uparrow$.
  For $\tan\beta > 5 \rightarrow \hat{\Sigma}_{hh}^{m\overline{\rm DR}}(p^2) \sim$ constant
- For $M_A > 150$ GeV $\rightarrow \hat{\Sigma}_{hh}^{m\overline{\rm DR}}(p^2) \sim$ constant
- For $-1000\ {\rm GeV} < A_\nu < 1000\ {\rm GeV}$
  $\rightarrow \hat{\Sigma}_{hh}^{m\overline{\rm DR}}(p^2)$ independent of A_ν
- For $-1000\ {\rm GeV} < \mu < 1000\ {\rm GeV}$
  $\rightarrow \hat{\Sigma}_{hh}^{m\overline{\rm DR}}(p^2)$ independent of μ
- Reference chosen values:
  - $\tan\beta = 5$ GeV
  - $M_A = 200$ GeV
  - $A_\nu = 1000$ GeV
  - $\mu = 200$ GeV

Estimate of $\Delta m_h^{\overline{\rm mDR}} := M_h^{\nu/\tilde{\nu}} - M_h$

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

Simplification $\rightarrow$

- 1 step $\rightarrow$ Calculation of M_h and M_H in MSSM without $\nu/\tilde{\nu}$ with FeynHiggs. (T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak, G. Weiglein '98 - '10.
- 2 step $\rightarrow$ Solve the equation

$$\left[p^2 - M_h^2 + \hat{\Sigma}_{hh}^{\nu/\tilde{\nu}}(M_h^2)\right]\left[p^2 - M_H^2 + \hat{\Sigma}_{HH}^{\nu/\tilde{\nu}}(M_h^2)\right] - \left[\hat{\Sigma}_{hH}^{\nu/\tilde{\nu}}(M_h^2)\right]^2 = 0$$

  where, $\hat{\Sigma}_{hh,HH,hH}^{\nu/\tilde{\nu}}$ denote the corrections from $\nu/\tilde{\nu}$ sector

  The lightest pole $\rightarrow M_h^{\nu/\tilde{\nu}}$

- new correction to the lightest higgs mass $\nu/\tilde{\nu}$ sector $\rightarrow \Delta m_h^{\overline{\rm mDR}} = M_h^{\nu/\tilde{\nu}} - M_h$
- valid approach if $M_h^{\nu/\tilde{\nu}}/M_h$ is small