Higgs Decays in the Low Scale Type I See-Saw Model

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Based on ArXiv:1208.3654. It was done in collaboration with A. Ibarra, S. Petcov and E. Molinaro.

Description of the model

- One of the simplest extensions of the Standard Model is to include fermionic singlets under SM group.

$$\mathcal{L}_\nu = -\underbrace{M_D \overline{\nu_L} \nu_R}_{\text{Dirac Term}} - \underbrace{\tfrac{1}{2} M_N \overline{\nu^c}_L \nu_R}_{\text{Majorana Term}} + \text{h.c.} \tag{1}$$

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Dirac Term

Majorana Term

- $$|(m_\nu)_{\ell'\ell}| \simeq |\sum_k (R^*)_{\ell' k} \, (M_N)_k \, (R^\dagger)_{k\ell}| \lesssim 1 \text{ eV where} R \approx M_D \, M_N^{-1}. \tag{2}$$

  For Majorana masses M_N in the range (100 - 1000 GeV) this can be accomplished if there are two right handed neutrinos and:

$$R_{\ell 2} \quad \approx \quad \pm i \, R_{\ell 1} \sqrt{\frac{M_1}{M_2}} \, , \; \ell = e, \mu, \tau \, , \tag{3}$$

  This naturally occurs, for instance, if there exists an approximately conserved lepton charge. A. Ibarra, E. Molinaro and S. T. Petcov (2010)

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- Neutrino oscillations constrain the matrix R

$$|R_{\ell 1}|^2 = \frac{1}{2}\frac{y^2 v^2}{M_1^2}\frac{m_3}{m_2+m_3}\left|U_{\ell 3} + i\sqrt{m_2/m_3}U_{\ell 2}\right|^2 , \quad \text{NH} \qquad (4)$$

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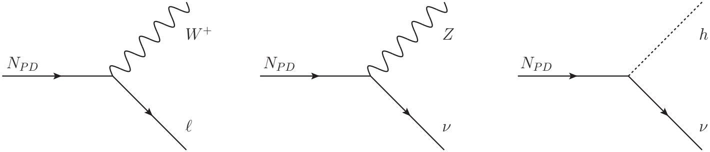
$$R_{\ell 2} = \pm i\, R_{\ell 1}\sqrt{\frac{M_1}{M_2}} , \; \ell = e, \mu, \tau , \qquad (6)$$

For our purposes, our model is described by two parameters: the yukawa coupling y and the heavy neutrino mass M_1.

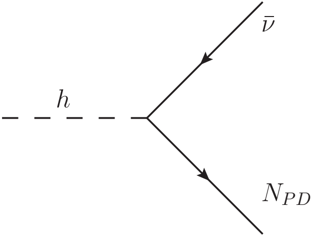
The matrix R determines the mixing between the Pseudo-Dirac Neutrino and the $W^{\pm}$, Z and H.

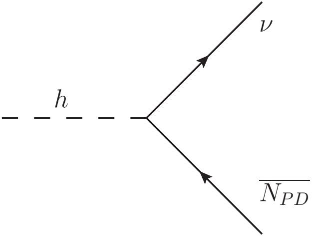
$$\mathcal{L}_{NP} = -\frac{gR_{\ell 1}}{\sqrt{2}}\left(\sqrt{2}W^{\alpha}\overline{\ell_{\ell L}}\gamma_{\alpha} + \frac{1}{c_W}Z^{\alpha}\overline{\nu_{\ell L}}\gamma_{\alpha} + \frac{M_k}{M_W}h\overline{\nu_{\ell L}}\right)N_{PD} + \text{h.c.} \qquad (7)$$



New Higgs Decay Channels

If $M_1 < m_h$ then it is possible that





$$\begin{aligned}
\Gamma(h \to \nu N) &\equiv \sum_{\ell=e,\mu,\tau} \left(\Gamma(h \to \nu_{\ell L}\, \overline{N_{PD}}) + \Gamma(h \to \overline{\nu_{\ell L}}\, N_{PD}) \right) \\
&= \frac{1}{16\pi} y^2\, m_h \left(1 - \frac{M_1^2}{m_h^2} \right)^2 ,
\end{aligned}$$

$$\mathrm{BR}(h \to \nu N) \equiv \frac{\Gamma(h \to \nu N)}{\Gamma(h \to \nu N) + \Gamma_{\text{tot}}^{\text{SM}}} = 1 - \frac{\mathrm{BR(obs)}}{\mathrm{BR(SM)}} , \tag{8}$$

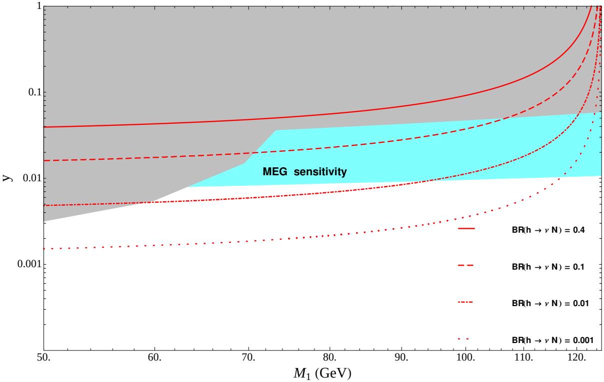


Figure: (a) Values of y probed by Higgs decays into N_{PD} for $m_h = 125$ GeV (solid lines). The gray region is excluded by LEP2 data and searches of lepton flavor violation. The cyan area represents the region of the parameter space which can be probed by the MEG experiment with the projected sensitivity to BR$(\mu \to e\gamma) = 10^{-13}$.

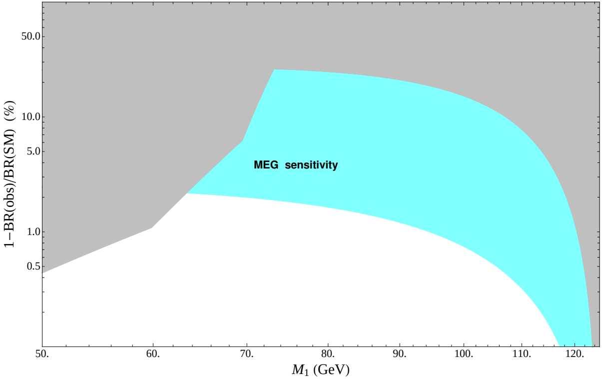


Figure: (b)Relative reduction of the Standard Model Higgs boson branching fraction to a generic channel for $m_h = 125$ GeV. The color convention is the same as in the previous plot.

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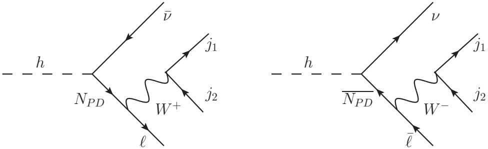

with only $\mu^{\pm}$ or $e^{\pm}$. And we use Madgraph to estimate the corresponding background.

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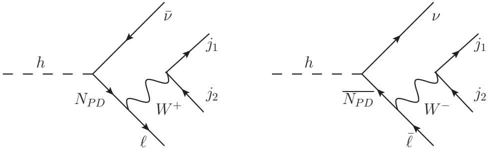

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$$
\begin{aligned}
p_T(\ell) &> 10\ \text{GeV}\,, \qquad p_T(j) > 15\ \text{GeV}\,, \qquad |\eta_\ell|, |\eta_j| < 2.5\,, \\
&\Delta R(jj) > 0.4\,, \qquad \Delta R(j\ell) > 0.4\,,
\end{aligned}
$$

$$
\begin{aligned}
80\ \text{GeV} &< m_{jj\ell} < 130\ \text{GeV}\,, \qquad m_W - 10\ \text{GeV} < m_{jj} < m_W + 10\ \text{GeV}\,, \\
110\ \text{GeV} &< m_T < 130\ \text{GeV} \qquad \not{E}_T > 10\ \text{GeV}\,,
\end{aligned}
$$

Branching Fractions

$$\begin{aligned} \mathrm{BR_{Total}} &= \mathrm{BR}(h \to e^- \bar{\nu} jj) + \mathrm{BR}(h \to \mu^- \bar{\nu} jj) + \mathrm{BR}(h \to e^+ \nu jj) + \mathrm{BR}(h \to \mu^+ \nu jj) \\ &= \mathrm{BR}(h \to \nu N)\, [\, \mathrm{BR}(N \to We) + \mathrm{BR}(N \to W\mu)\,]\, \mathrm{BR}(W \to jj)\,, \qquad (10) \end{aligned}$$

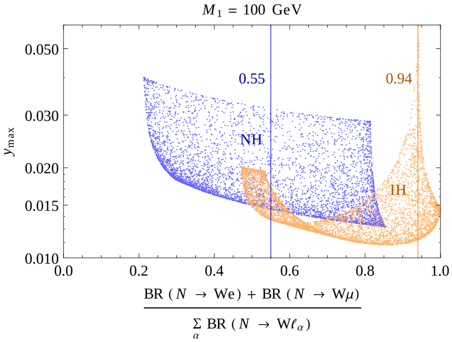


Figure: Upper limit on the Yukawa coupling for various values of the relative branching fraction for decays into e and μ for normal hierarchy (blue) and for inverted hierarchy (orange) and $M_1 = 100$ GeV. We also show in the plot the benchmark points taken in our analysis.

Estimation of the sensitivity of the LHC to the coupling y vs M_1

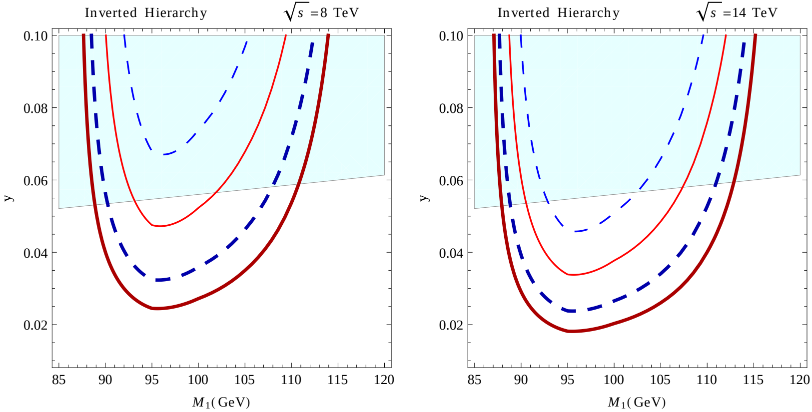
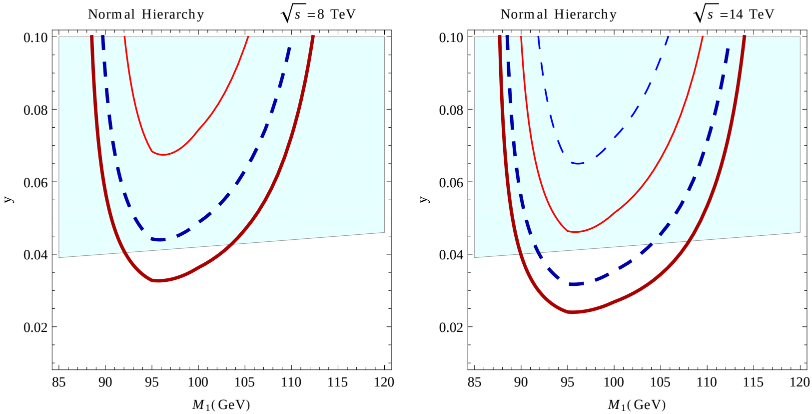


Figure: Sensitivity of the LHC to the coupling y vs M_1 at 3σ (continuous line) and 5σ (dashed line) and an integrated luminosity $\mathcal{L} = 1\ \text{fb}^{-1}$ (thin line) and $\mathcal{L} = 10\ \text{fb}^{-1}$ (thick line). The shaded region is excluded by the current experimental upper limit BR$(\mu \to e\gamma) \leq 2.4 \times 10^{-12}$.



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Conclusions

- The couplings of the low scale type I See-Saw model are severely constrained by the requirement of reproducing the correct neutrino mass and mixing parameters, by the non-observation of lepton number and charged lepton flavour violating processes and by electroweak precision data. We show that all these constraints still allow for the possibility of an exotic Higgs decay channel into a light neutrino and a heavy neutrino with a sizable branching ratio.
- We analyzed the prospects of revealing the existence of the pseudo-Dirac fermion N_{PD}, in the case in which the Higgs particle is heavier and decays with one charged lepton and two jets in the final state via the chain: $h \to \nu\, N \to \nu\, \ell\, W \to \nu\, \ell\, jj$.
- We find that if $y \gtrsim 0.02$ and 90 GeV $\lesssim M \lesssim$ 110 GeV, then the heavy pseudo-Dirac particle can be observed at LHC with a statistical significance in the range of 3 to 5 σ for a luminosity of 10 fb^{-1} and a center of mass energy of 14 TeV.
- The study of the properties of the Higgs boson observed at LHC might have important implications for the understanding of the origin of the neutrino masses and mixings.