Neutrino Masses from Fine Tuning

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Outline

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- Phenomenology
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Background

- Seesaw mechanism introduces heavy right handed neutrinos to generate mass for neutrinos:

$$L = m_D \bar{\nu}_l N_R + \frac{m_R}{2} N_R^T C^{-1} N_R + h.c.$$

- Right handed neutrinos are usually very heavy ~10^{14} GeV

$$M_\nu = \begin{pmatrix} 0 & m_D \\ m_D & m_R \end{pmatrix}$$

$$\lambda_+ \approx m_R$$

$$\lambda_- \approx \frac{-m_D^2}{m_R}$$

$$m_R >> m_D$$

Motivations

- To explain why neutrinos have small mass with TeV scale physics
- To take the seesaw from 10^{14} GeV $\rightarrow$ 100 GeV
- To link neutrino physics to Higgs physics

The Model

- The standard model plus:
- 3 Higgs doublets (H, H_1, H_2) all with EW scale vev's
- 3 right handed neutrinos that mix with the light neutrinos
- Impose Z_2 symmetry that is softly broken by the Higgs potential
- All SM fields are even under Z_2
- N_R, H_1, and H_2 are odd under Z_2

The Model

New Components:

- Higgs Doublets H, H_1, and H_2
- 3 RHN's N_R
- Neutrino mass matrix M_ν
- Mixing angle θ~10^{-8} between heavy and light neutrinos

$$L_{Yukawa} = y_d^{ij}\bar{q}_L^i d_R^j H + y_u^{ij}\bar{q}_L^i u_R^j \tilde{H} + y_e^{ij}\bar{\ell}_L^i e_R^j H$$
$$+ y_{1\nu}^{ij}\bar{\ell}_L^i N_R^j \tilde{H}_1 + y_{2\nu}^{ij}\bar{\ell}_L^i N_R^j \tilde{H}_2$$

$$L_{mass} = \frac{M_R^{ij}}{2} N_R^{iT} C^{-1} N_R^j$$

$$M_\nu = \begin{pmatrix} 0 & m_D \\ m_D & m_R \end{pmatrix} \qquad m_\nu^{light} = \frac{m_D^2}{m_R}$$

$$m_\nu^{light} \sim 10^{-1}\,\text{eV and } m_R \sim 10^2\,\text{GeV} \Rightarrow$$
$$m_D = \sqrt{10^{-1}\,\text{eV} \times 10^{11}\,\text{eV}} = 10^5\,\text{eV}$$

The Model

$$m_D = \frac{1}{\sqrt{2}}\left(v_1 y_{1\nu} + v_2 y_{2\nu}\right) \sim 10^{-4}\,\mathrm{GeV}$$

- Since both $v_H \sim 100$ GeV there is fine tuning of 1 in 10^6 here
- By comparison, the cosmological constant has fine tuning of 1 in 10^{44}
- In Split SUSY, the Higgs mass is fine tuned
- Neutrino Mass from fine tuning instead of small Yukawa couplings

Higgs Sector

$$V_{\text{dim}=2}(H,H_1,H_2)=\mu_H^2 H^\dagger H+\mu_{11}^2 H_1^\dagger H_1+\mu_{12}H_1^\dagger H_1+\mu_{22}H_2^\dagger H_2+\mu_{H_1}H^\dagger H_1+\mu_{H_2}H^\dagger H_2+h.c.$$

- Z_2 is broken explicitly leading to mixing between Higgs fields
- All μ~100 GeV

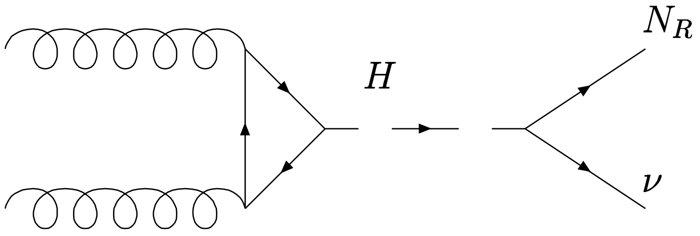
Experimental Constraints

- LEP searched for small mass N_R in the channel ee->Z->Nv
- N can decay to either W^+e^- or Zv
- Put limits on the mixing angle squared:
  $\sin^2\theta < 10^{-4}$ for 3 GeV < m_N < 80 GeV
  $\sin^2\theta < 0.1$ for m_N > 80 GeV
- LEP allows a very small mass for N_R

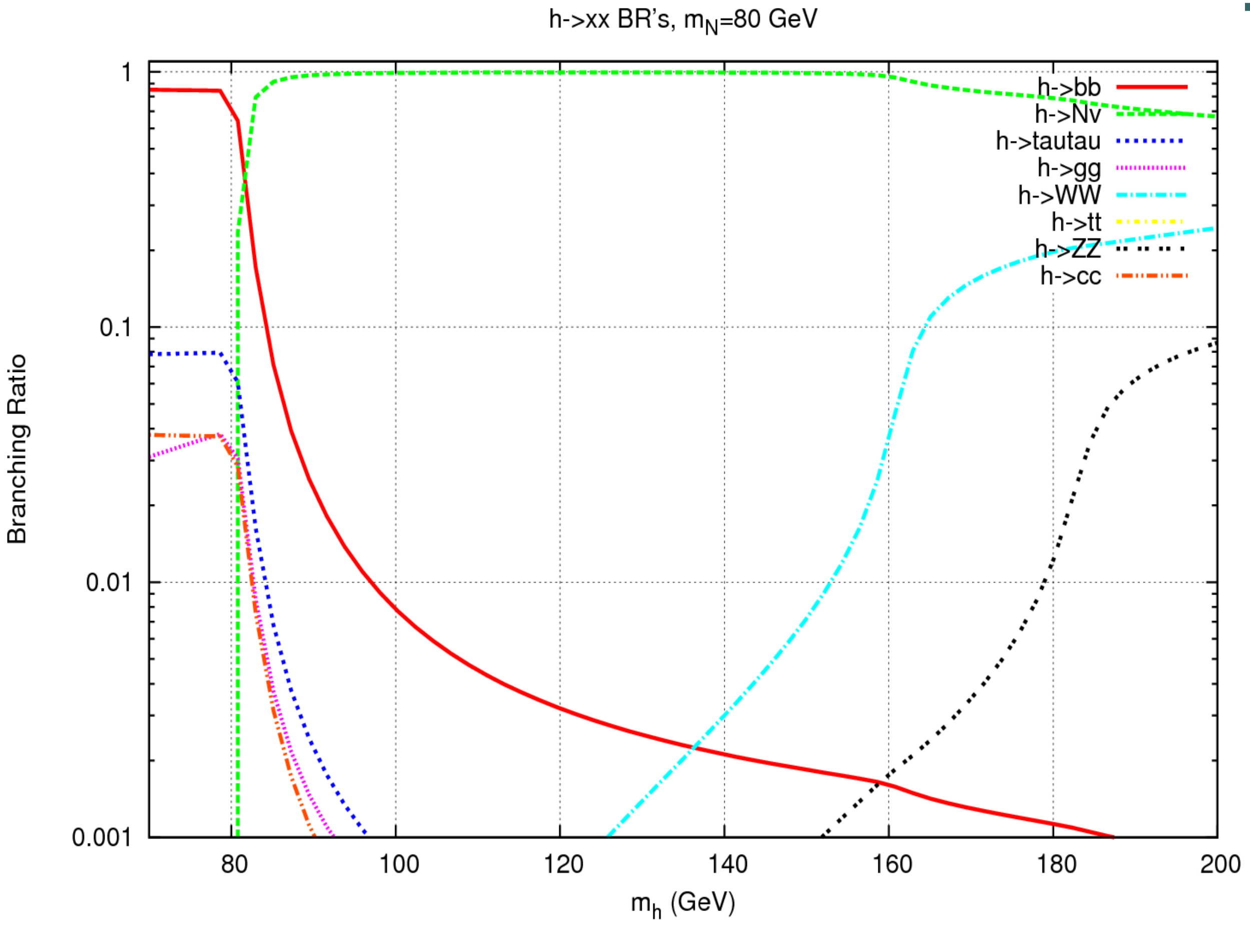
P.~Achard *et al.* [L3 Collaboration], Phys. Lett. B **517**, 67 (2001) [arXiv:hep-ex/0107014].

Phenomenology

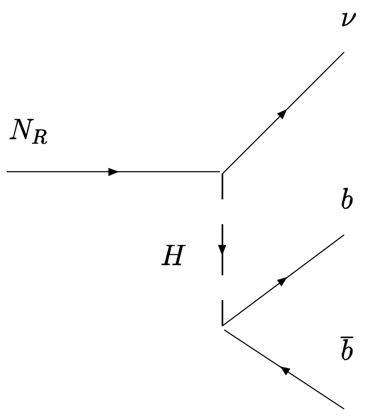
- N_R's only couple directly to the Yukawa sector
- If $M_N < M_H$, the Higgs will decay primarily to N_R and a ν
- Production mechanism is through the Higgs: $pp \rightarrow H \rightarrow N_R \nu$



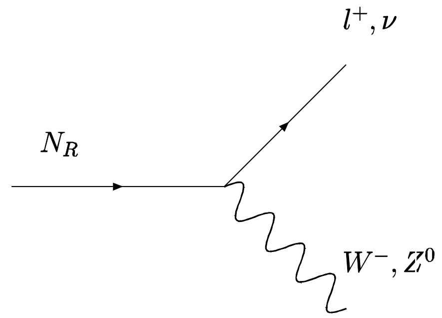
Higgs Decay Modes



N_R Decay Width



$\Gamma(N_R \to \nu b \bar{b}) \sim 10^{-7}$ GeV



$\Gamma(N_R \to l^+ W^- (\nu Z)) \sim 10^{-18}$ GeV

- Weak decays are suppressed by the mixing angle ($\theta \sim 10^{-8}$)
- 3 body decays to a neutrino and two b's are favored.

LHC Searches

- Using Madgraph, we generated events for pp$\rightarrow$vvbb in the SM for LHC @ 14 TeV
- Using MET > 30 GeV and pT for the b-jets > 20 GeV, the cross section is 13 pb.
- The cross section for Higgs production at the LHC ~ 50 pb
- The BR for H$\rightarrow$Nv is 100%, so pp-vvbb in our model should be much higher and observable at the LHC

Conclusions

- Presented a new model with weak scale right handed neutrinos
- Neutrino masses are generated from fine tuning
- Higgs decays are altered significantly
- The model is easily testable at the LHC

Backup Slides

Higgs Decay Modes: y=1 mixing = 1/50