Right Handed Neutrinos and Higgs Boson Decay

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(work in progress)

Motivation in Three Parts

New physics beyond the Standard Model

$$\Delta m^2_{\text{sun}} \simeq (9 \times 10^{-3}\text{eV})^2$$
$$\Delta m^2_{\text{atm}} \simeq (5 \times 10^{-2}\text{eV})^2$$

Dirac or Majorana?

Majorana: What is the mass scale? Presume that Majorana masses are at the weak scale. Related to Higgs mass?

$$\mathcal{L}_{\mathcal{R}} = \frac{1}{2} M_R \nu_R \nu_R + \lambda_\nu H^* L \nu_R + \lambda_l H L e^c$$

See-saw leads to :

$$m_{\nu_L} \simeq \lambda_\nu \frac{1}{M_R} \lambda_\nu^T v^2$$

Typically need

$$\lambda_\nu \simeq 2 * 10^{-7} \left(\frac{m_{\nu_L}}{1/10\text{eV}} \right)^{1/2} \left(\frac{M_R}{30\text{GeV}} \right)^{1/2}$$

Motivation (cont'd)

2. Baryogenesis from Leptogenesis

- CP violation, L number violation

- Tiny couplings $\Rightarrow$ out of equilibrium

Asaka and Shaposhnikov (2005) leptogenesis with $M_R \simeq 10$ GeV. Some lepton asymmetry converted to baryon asymmetry at the electroweak phase transition.

3. Higgs phenomenology

- Light states or higher dimension operators can drastically modify the production cross-section and/or introduce new decay processes Dermisek and Gunion (2005); Chang, Fox and Weiner (2005,2006); Strassler and Zurek (2006), Manohar and Wise (2006)

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  - $h \to aa,\ a \to b\bar{b}, gg, \gamma\gamma$

- Strassler and Zurek (2006):

  - $pp \to Z' \to \text{jets}, \tau's, b's$

  - Displaced vertices

- Manohar and Wise (2005) Higher dimension operator

$$\delta\mathcal{L} = \frac{H^\dagger H}{\Lambda} G^a_{\mu\nu} G_a^{\mu\nu}$$

  - Modifies Higgs boson production cross-section and decay ($g \to \gamma$)
  - Induced from couplings to light coloured scalars

Model

- Standard Model + 3 Right-handed Neutrinos

- More massive states interacting with both Higgs boson and Right-handed neutrinos

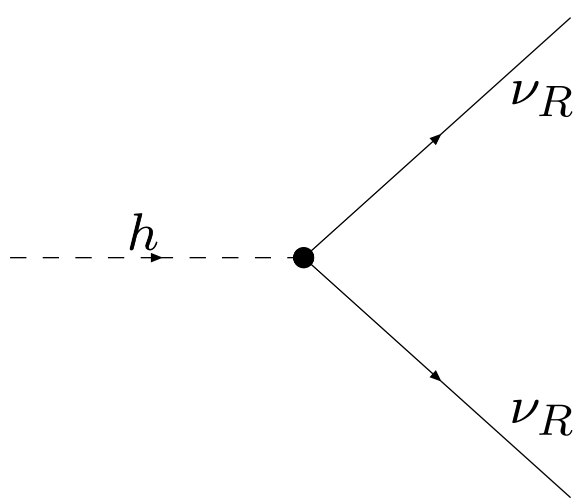
$$\Lambda \simeq \text{TeV} - 100's\text{TeV}$$

$$\delta\mathcal{L}_{eff} \ = \ \sum_i \frac{c_i^{(5)}.}{\Lambda}\mathcal{O}_i^{(5)} + \sum_i \frac{c_i^{(6)}.}{\Lambda^2}\mathcal{O}_i^{(6)} + \cdots + \text{h.c.}$$

$$\mathcal{O}^{(5)} = \frac{c^{(5)}}{2\Lambda} H^\dagger H \nu_R \nu_R$$

Electroweak symmetry breaking introduce coupling of higgs to right-handed neutrinos:

$$\delta\mathcal{L} = \frac{c^{(5)} v}{\sqrt{2}\Lambda} h \nu_R \nu_R$$



$m_h > 2m_R$ Higgs boson can decay into right-handed neutrinos. For light Higgs boson, this new decay can dominate over decays to $\bar{b}b$ and $\gamma\gamma$

- Compare SM rates with Higgs decays to 3 flavors of light Right-Handed neutrinos:

$$\mathcal{R}_{XY} \equiv \frac{\sum_i \Gamma[h \rightarrow \nu_L^{(i)} \nu_L^{(i)}]}{\Gamma[h \rightarrow XY]}$$

$$\mathcal{R}_{b\bar{b}} = 1 \leftrightarrow \Lambda \simeq 17\text{TeV}$$

$$\mathcal{R}_{\gamma\gamma} = 10 \leftrightarrow \Lambda \simeq 200\text{TeV}$$

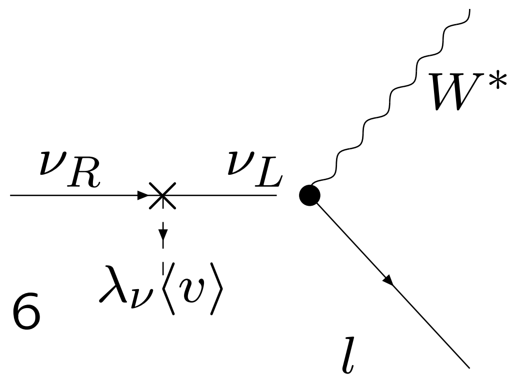
Decays of the Right-handed Neutrinos

Two Sources

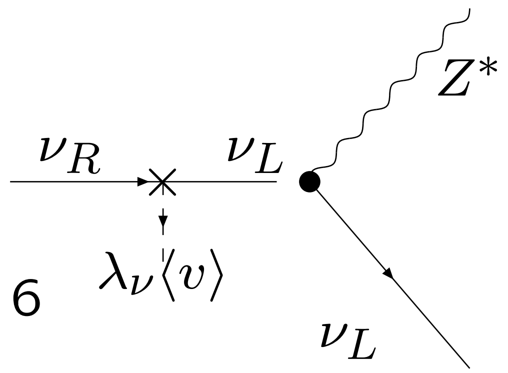
- Interactions with left-handed neutrinos

- Higher Dimension Operators

Renormalizable Interactions

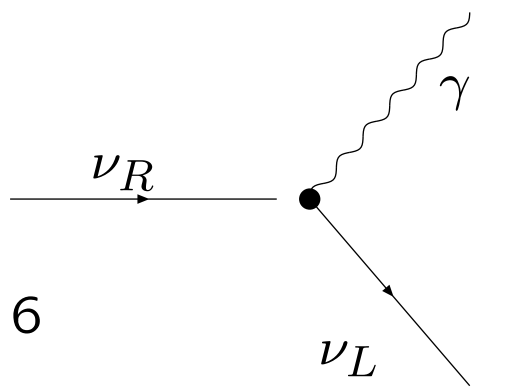


$BR \simeq 0.7$



$BR \simeq 0.3$

Higher dimension operators ($d = 6$)



$BR \propto \Lambda^{-2}$

Small neutrino couplings $\longrightarrow$ macroscopic decay lengths

- Universal right-handed neutrino masses and no CP violation in right-handed neutrino couplings

$$c\tau = 4\text{m}\left(\frac{30\text{GeV}}{M_R}\right)^4\left(\frac{10^{-1}\text{eV}}{m_{\nu_L}}\right)F\left(\frac{M_R^2}{m_W^2}\right)$$

$$F(0) = 1 \quad \beta\gamma \simeq \mathcal{O}(1)$$

- Right-handed neutrino masses M_R only completely unknown parameter

- Decay length insensitive to Λ

Experimental Limits

LEP

- Model-independent limit on Higgs mass (OPAL) : $m_h > 82$ GeV

- Invisible Limit ?

  - no limit if all 3 right-handed neutrinos decay within the detector; LEP detectors $R \simeq 6$m.

  - $m_h > 106$ GeV if one right-handed neutrino decays outside the detector $\leftrightarrow M_R <$ 20GeV or very light left-handed neutrino masses

  - can get neutrinos from Z^* but BF too low

- $\cdots$

Tevatron

- Diphoton search $p\bar{p} \to \gamma\gamma + X$
  - Limits $d = 6$ magnetic moment decay

    $$h \to \gamma\gamma\nu_L\nu_L$$

    $\Lambda > 500 GeV$ ....but analysis has missing $E_T >$ 40GeV cut
  - If right-handed neutrinos decay in the calorimeters
    - $l = \mu \Rightarrow$ 'trackless muon'
    - $l = e \Rightarrow$ 'photon'
      - Di-photon limit may apply. But

        $$h \to W^*W^*ee$$

        Six-body final state. To pass missing E_T cut need one or two neutrinos.

        $$E_{\nu_R} \simeq m_h/2 \simeq 40 - 50\text{GeV}$$

One neutrino probably doesn't pass E_T cut (or low acceptance). With two neutrinos $\sigma \cdot BR$ just below combined experimental limit of $\approx$ 0.07 pb, assuming same acceptance as in analysis

– D0 search for displaced di-muons

  * Analysis restricted to 5cm−20cm.

  * Required that di-muons reconstructed to a common vertex

  * Need $h \to N_2 N_2$, $N_2 \to \mu W^*$ and a μ from the W^*decay

$$\sigma \cdot BF \simeq 0.09\text{pb}$$

  * below experimental limit $\simeq$ 0.14 pb.

Conclusions

- Scenario with right-handed neutrinos at electroweak scale

- Higher dimension operators combining right-handed neutrinos and Standard Model Higgs boson

  - Possible new decay channel for Higgs boson

  - New decays can dominate $b\bar{b}$ up to tens of TeV, dominate $\gamma\gamma$ to hundreds of TeV

    * Macroscopic decays $\mathcal{O}(\mu\text{m} - \text{m})$

    * Decay length of right-handed neutrinos only dependent on their masses and is insensitive to scale of higher dimension operators