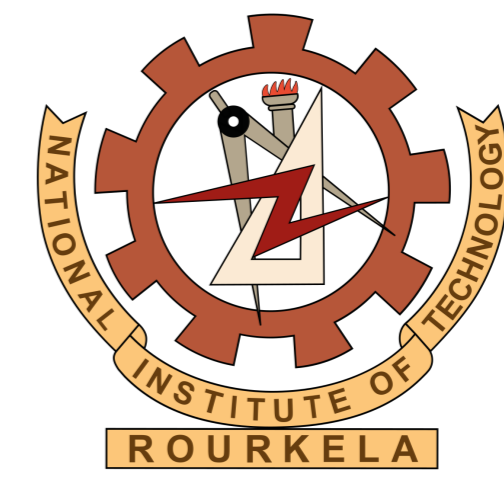# Flavoured Leptogenesis in a Minimal Type-I+II Seesaw Mechanism

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Abstract

Seesaw mechanism is a popular approach to give a viable explanation to the source of non-zero neutrino mass and to the cause of matter dominance of the Universe - two of the most important open problems that could not be answered in the Standard Model (SM) of Particle Physics. A minimal extension of the SM is studied, incorporating type-I+II seesaw mechanism with only one right-handed neutrino and one Higgs triplet scalar. Both of these heavy particles contribute to the generation of tiny neutrino mass, the contribution being inversely proportional to the corresponding heavy particle masses. Considering the leptogenesis is being achieved by the decay of the right-handed neutrino, the new source of CP violation is getting generated solely from the decay of the right-handed neutrino by one-loop vertex correction in the presence of the Higgs triplet scalar. The predictability of the model is further enhanced by introducing Fritzsch type 2-zero and 3-zero textures for the neutrino mass matrix and the non-diagonal charged lepton mass matrix, respectively. The parameter space study is executed following the latest neutrino oscillation parameter data and the phenomenological importance of this hybrid texture is analysed. Leptogenesis is successfully achieved in flavoured regime within the temperature range $T \subset [10^{10}, 10^{12}]$ GeV.

1. Model description

- One Right-handed Neutrino N_1 + One Higgs Triplet scalar Δ [1]

$$\Delta = \begin{pmatrix} \frac{\delta^+}{\sqrt{2}} & \delta^{++} \\ \delta^0 & -\frac{\delta^+}{\sqrt{2}} \end{pmatrix},$$

- Right-handed Neutrino's mass:
  $M_1 \sim [10^{10}, 10^{12}]$ GeV, $M_\Delta \gg M_1$

2. Neutrino mass generation

- The Lagrangian beyond SM,

$$-\mathcal{L} = M_\Delta^2 Tr\Delta^\dagger \Delta + \frac{1}{2} M_i \overline{N}_i N_i +,$$

$$g_{\alpha\beta} \overline{\psi^c}_{L_\alpha} i\tau_2 \Delta \psi_{L_\beta} - \mu \phi^T i\tau_2 \Delta \phi$$

$$+ Y_{\alpha i} \overline{\psi}_{L_\alpha} N_i \phi + h.c.$$

with $k = 1, 2$ and $i, j = e, \mu, \tau$.

- Lepton number breaking trilinear term $\mu \phi^T i\tau_2 \Delta \phi$

- Neutrino mass generation through the contributions by type-I+II seesaw mechanism [1]:

$$m_\nu = m_\nu^{(I)} + m_\nu^{(II)}$$

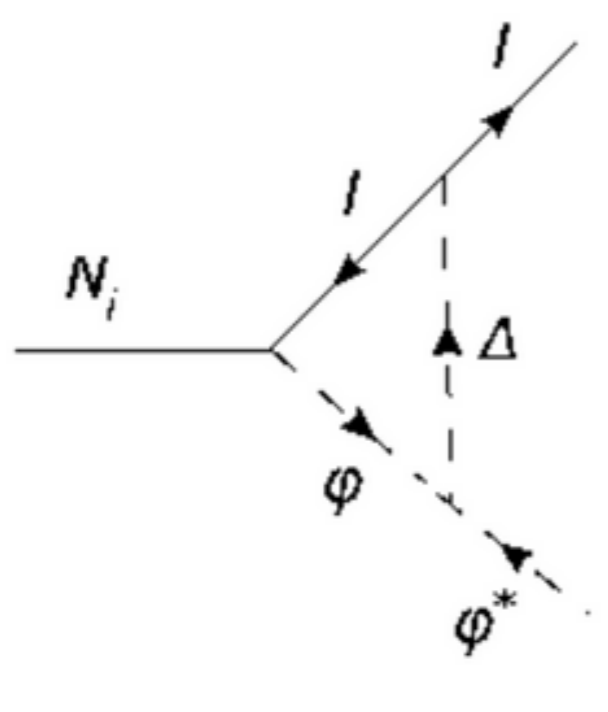$$= -Y^* \frac{1}{M} Y^\dagger v^2 + 2gv_\Delta$$

3. Zero texture

Chosen neutrino mass matrix: $m_\nu = $

$$m_0 \begin{bmatrix} 0 & \hat{C}_\nu e^{i\alpha_\nu} & 0 \\ \hat{C}_\nu e^{i\alpha_\nu} & r^2 & r + \hat{B}_\nu e^{i\beta_\nu} \\ 0 & r + \hat{B}_\nu e^{i\beta_\nu} & 1 + \hat{A}_\nu e^{i\gamma_\nu} \end{bmatrix}.$$

Inverse Hierarchy $\longrightarrow$ disfavoured.
$\frac{m_1}{m_2} = [0.80 - 0.90]$, $\frac{m_2}{m_3} = [0.30 - 0.35]$

4. Triplet scalar decay mode:

One loop decay diagram: Right-handed neutrino N_i decaying into charged bi-lepton and SM Higgs, respectively in the presence of one Higgs triplet scalar Δ

5. Flavoured leptogenesis

- Temperature scale: $T \subset [10^{10}, 10^{12}]$ GeV "2-flavoured and 3-flavoured leptogenesis"

- Flavoured CP asymmetry parameter, generated through the decay of one heavy Right handed neutrino N_1, in the presence of one Higgs triplet scalar Δ:

$$\epsilon_{N_1,\alpha}^\Delta \simeq \frac{3}{16\pi} \frac{M_1}{v^2} \frac{\sum_\beta Im[Y_{1\alpha}^\dagger Y_{1\beta}^\dagger (m_\nu^{II*})_{\alpha\beta}]}{(Y^\dagger Y)_{11}}, \quad [Y = iy_0(0, r, 1)^T, r = \sqrt{m_2/m_0},$$

$$m_0 = v^2 \frac{y_0^2}{M_1}, v = 174 \text{ GeV, vacuum expectation value of the SM Higgs}]$$

- 2-flavoured CP asymmetry parameters, obtained from the neutrino mass model:

$$\epsilon_a = \frac{3}{16\pi} \frac{M_1}{v^2} r m_0 \frac{\hat{B}_\nu sin\beta_\nu}{1 + r^2}, \quad \epsilon_\tau = \frac{3}{16\pi} \frac{M_1}{v^2} m_0 \frac{(r\hat{B}_\nu sin\beta_\nu + \hat{A}_\nu sin\gamma_\nu)}{1 + r^2}.$$

- 3-flavoured CP asymmetry parameters, obtained from the neutrino mass model:

$$\epsilon_e = 0, \quad \epsilon_\mu = \frac{3}{16\pi} \frac{M_1}{v^2} r m_0 \frac{\hat{B}_\nu sin\beta_\nu}{1 + r^2}, \quad \epsilon_\tau = \frac{3}{16\pi} \frac{M_1}{v^2} m_0 \frac{(r\hat{B}_\nu sin\beta_\nu + \hat{A}_\nu sin\gamma_\nu)}{1 + r^2}.$$

6. Result

- Flavoured Boltzmann equations [2]:

$$\frac{dY_{N_1}}{dz} = -\frac{\gamma_D}{sHz}\left(\frac{Y_{N_1}}{Y_{N_1}^{eq}} - 1\right), \quad \frac{dY_{\Delta_i}}{dz} = -\frac{\gamma_D}{sHz}\left[\left(\frac{Y_{N_1}}{Y_{N_1}^{eq}} - 1\right)\epsilon_i + K_0^i \sum_j \frac{1}{2}(C_{ij}^l + C_j^H)\frac{Y_{\Delta_j}}{Y_l^{eq}}\right]$$

- After solving the set of Boltzmann equations we obtain the 2 & 3-flavoured lepton asymmetry plots, with $M_1 = 8 \times 10^{10}$ GeV, $\epsilon_i \sim 10^{-7}, 10^{-8}$

2-flavoured lepton asymmetries

3-flavoured lepton asymmetries
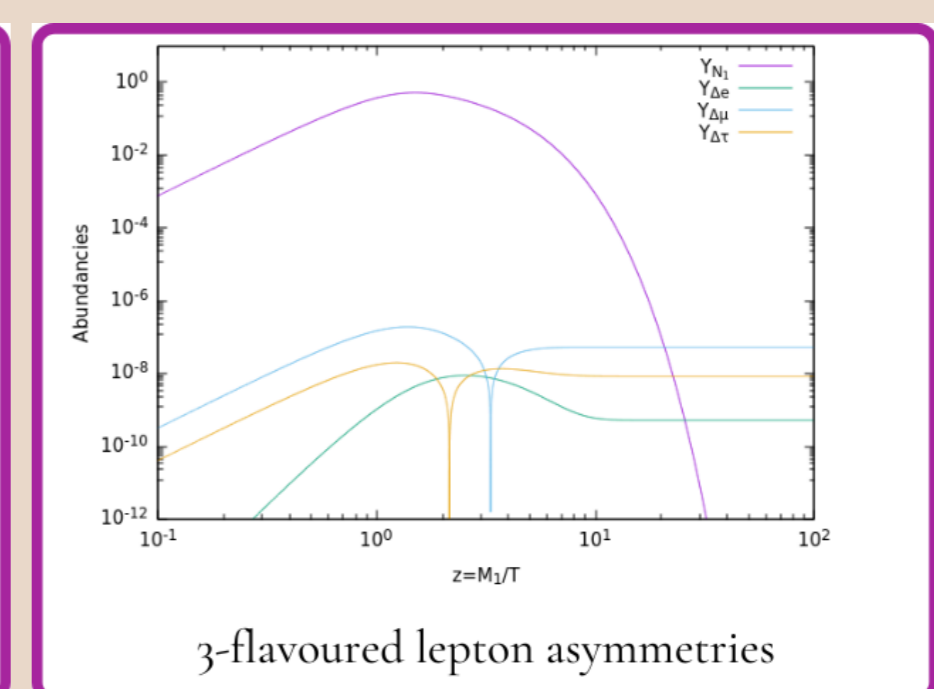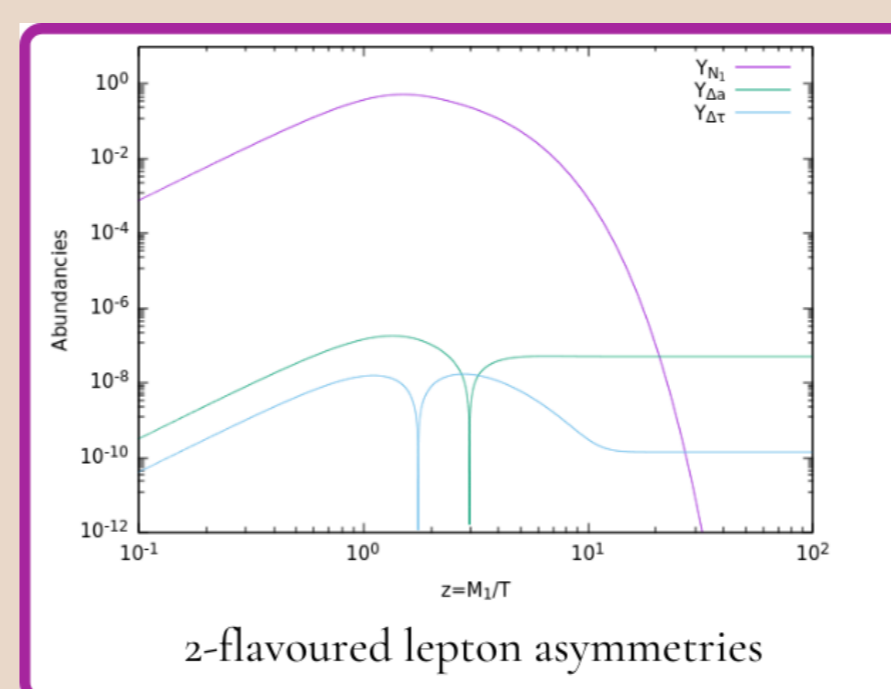
The finally obtained baryon asymmetry is given by[3]: $\eta_B = 7.04 \times 1.38 \times 10^{-3} \sum_i Y_{\Delta_i}(z \gg 1)$

η_B(2-flavoured leptogenesis) $= 4.94 \times 10^{-10}$, η_B(3-flavoured leptogenesis) $= 5.98 \times 10^{-10}$

References

[1] Pei-Hong Gu, He Zhang, and Shun Zhou. A Minimal Type II Seesaw Model. *Phys. Rev. D*, 74:076002, 2006.

[2] Y. H. Ahn, Sin Kyu Kang, C. S. Kim, and Jake Lee. Leptogenesis in a seesaw model with Fritzsch type lepton mass matrices. *Phys. Rev. D*, 77:073009, 2008.

[3] Enrico Nardi, Yosef Nir, Esteban Roulet, and Juan Racker. The Importance of flavor in leptogenesis. *JHEP*, 01:164, 2006.