Abstract

For neutrino phenomenology, we work in $A_4$ modular symmetry and $U(1)_{B-L}$ gauged symmetry with type-III seesaw mechanism. In type-III seesaw we add extra fermion triplet superfields to the Standard Model (SM). We show some interesting results of neutrinoless double beta decay mass parameter (NDBD) along with leptogenesis.

Introduction

- SM has no right handed neutrino, and hence fails to explain mass of neutrinos. So we need to go beyond SM.
- If we work in discrete flavour symmetry group for extension in SM symmetry, we need to handle several flavon field alignments.
- We particularly incorporate $A_4$ modular symmetry, in which Yukawa couplings are function of a complex modulus $\tau$ and transforms in particular manner under this symmetry.
- Modulus $\tau$ is defined in the upper half of the complex plane and transforms under modular group in the following manner

$$\tau \rightarrow \frac{a\tau + b}{c\tau + d}$$

where $a, b, c, d$ are integers and $cb - da = 1$.

NDBD ($0\nu\beta\beta$)

Expression for neutrinoless double beta decay is given as,

$$\langle m_{ee} \rangle = \sum m_i |U_{ei}|^2$$  \hspace{1cm} (1)

Fig 2: The green (red) band in both plots correspondence to the normal (inverted) mass hierarchy.

Results

- With the help of Chi-square minimization technique, we derived best fit values of model parameters.
- We find a strong correlation between neutrino oscillation observable.
- The model engenders neutrinoless double beta decay mass parameter ($m_{ee}$) between 0.0039 and 0.0087, which assures the limit coming from KamLAND-Zen experiment.
- Baryon and lepton asymmetry of the universe is also explained in this model.

Model Framework

- For symmetry extension we have used $A_4$ modular symmetry and $U(1)_{B-L}$ gauge symmetry.
- Since we work with type -III seesaw, we have taken extra hyperchargeless fermion triplet. The particle content of our model is given below,

<table>
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<th>Field</th>
<th>$L_i$</th>
<th>$R_i$</th>
<th>$N_i$</th>
<th>$y_1$</th>
<th>$y_2$</th>
<th>$y_3$</th>
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<td>$y_3$</td>
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<tr>
<td>$N_3$</td>
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<td>$0$</td>
<td>$0$</td>
<td>$y_1$</td>
<td>$y_2$</td>
<td>$y_3$</td>
</tr>
</tbody>
</table>

$$M_D = m_n \begin{pmatrix} \alpha_1 & 0 & 0 \\ 0 & \alpha_2 & 0 \\ 0 & 0 & \alpha_3 \end{pmatrix} \begin{pmatrix} y_1 & y_1 & y_2 \\ y_1 & y_1 & y_2 \\ y_2 & y_2 & y_2 \end{pmatrix}.$$  

$$M_R = \frac{1}{\sqrt{2}} \begin{pmatrix} 2y_1 & -y_1 & -y_1 \\ -y_1 & 2y_2 & -y_2 \\ -y_1 & -y_2 & 0 \end{pmatrix}.$$  

- Active neutrino mass matrix is given by, $m_{\nu} = M_D M_R^T M_D^T$.

Leptogenesis

The CP violating parameter is defined as,

$$\epsilon_{CP} = -\sum_{i,j} M_{\nu_{ei}} \left( \frac{\langle Y_{\nu_e} \rangle \langle Y_{\nu_{e}} \rangle_{ij}}{\langle Y_{\nu_{e}} \rangle_{ii}} \right) \frac{\text{Im} (\langle Y_{\nu_{e}} \rangle_{ij})}{\langle Y_{\nu_{e}} \rangle_{ii}}$$

Boltzmann Equation :

We use Boltzmann equation to plot number density in terms of yield.

$$\frac{dY_{\nu_e}}{dt} = -\frac{1}{H(M_D)} \left( \frac{Y_{\nu_e}}{T_e} - 1 \right) \gamma_D + \left( \frac{Y_{\nu_e}}{T_e} \right)^2 - 1 \gamma_\nu,$$

$$\frac{dY_{\nu_{e-L}}}{dt} = -\frac{1}{H(M_D)} \left( \frac{Y_{\nu_{e-L}}}{T_e} - \epsilon \tau \left( \frac{Y_{\nu_e}}{T_e} - 1 \right) \right) \gamma_D.$$  

Acknowledgement

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References

- Type III seesaw under $A_4$ modular symmetry with leptogenesis and muon $g - 2$, Priya Mishra, Mitesh K. Behera, P. Panda, R. Mohanta, e-Print: 2204.08338 [hep-ph]