Explaining neutrino phenomenology, leptogenesis and $(g-2)_{e,\mu}$ with U(1) symmetries in inverse seesaw framework, (Phys. Rev. D. 108, 035032 (2023), arXiv:2203.14536[hep-ph])

Papia Panda[1], Mitesh Kumar Behera[2], Priya Mishra[1], Rukmani Mohanta[1]

University of Hyderabad[1], Chulalongkorn University[2]

21st Lomonosov Conference on Elementary Particle Physics
Moscow State University, August 24-30, 2023

Outline

Outline

Particle Content

Table: Particles and their corresponding charge assignment under $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B-L} \times U(1)_{L_e-L_\mu}$ model.

Particles	$SU(3)_C \times SU(2)_L \times U(1)_Y$	$U(1)_{B-L}$	$U(1)_{L_e-L_\mu}$
$\ell_{\alpha \mathrm{L}}(\alpha = e, \mu, \tau)$	$(\mathbf{1}, \mathbf{2}, -1)$	-1	$1, -1, 0$
$\ell_{\alpha \mathrm{R}}(\alpha = e, \mu, \tau)$	$(\mathbf{1}, \mathbf{1}, -2)$	-1	$1, -1, 0$
$N_{\mathrm{R_i}}(i = 1, 2, 3)$	$(\mathbf{1}, \mathbf{1}, 0)$	-1	$1, -1, 0$
$S_{\mathrm{L_i}}(i = 1, 2, 3)$	$(\mathbf{1}, \mathbf{1}, 0)$	0	$1, -1, 0$
H	$(\mathbf{1}, \mathbf{2}, 1)$	0	0
χ_1	$(\mathbf{1}, \mathbf{1}, 0)$	1	0
χ_2	$(\mathbf{1}, \mathbf{1}, 0)$	0	1

$$SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{L_e-L_\mu} \times U(1)_{B-L} \xrightarrow{\langle \chi_1 \rangle} SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{L_e-L_\mu} \xrightarrow{\langle \chi_2 \rangle}$$
$$SU(3)_C \times SU(2)_L \times U(1)_Y \xrightarrow{\langle H \rangle} SU(3)_C \times SU(2)_L \times U(1)_{\mathrm{em}}$$

Lagrangian and mass matrices

$$\begin{aligned}\mathcal{L}_{\rm lepton} \supset \mathcal{L}_{SM}^{\rm lepton} &+ \left[y_D^e \bar{\ell}_{e\rm L}\tilde{H}N_{R_1} + y_D^\mu \bar{\ell}_{\mu\rm L}\tilde{H}N_{R_2} + y_D^\tau \bar{\ell}_{\tau\rm L}\tilde{H}N_{R_3}\right] \\ &+ \left[y_N^1 \bar{S}_{L_1} N_{R_1}\chi_1 + y_N^2 \bar{S}_{L_2} N_{R_2}\chi_1 + y_N^3 \bar{S}_{L_3} N_{R_3}\chi_1\right] \\ &+ \left[\mathcal{M}_{12}\bar{S}_{L_1}^c S_{L_2} + y_{13}\bar{S}_{L_1}^c S_{L_3}\chi_2^* + y_{23}\bar{S}_{L_2}^c S_{L_3}\chi_2 + \mathcal{M}_{33}\bar{S}_{L_3}^c S_{L_3}\right] + h.c.,\end{aligned}$$

Lagrangian and mass matrices

$$\mathcal{L}_{\rm lepton} \supset \mathcal{L}_{SM}^{\rm lepton} + \left[y_D^e \bar{\ell}_{e\rm L} \tilde{H} N_{R_1} + y_D^\mu \bar{\ell}_{\mu\rm L} \tilde{H} N_{R_2} + y_D^\tau \bar{\ell}_{\tau\rm L} \tilde{H} N_{R_3} \right]$$
$$+ \left[y_N^1 \bar{S}_{L_1} N_{R_1} \chi_1 + y_N^2 \bar{S}_{L_2} N_{R_2} \chi_1 + y_N^3 \bar{S}_{L_3} N_{R_3} \chi_1 \right]$$
$$+ \left[\mathcal{M}_{12} \bar{S}_{L_1}^c S_{L_2} + y_{13} \bar{S}_{L_1}^c S_{L_3} \chi_2^* + y_{23} \bar{S}_{L_2}^c S_{L_3} \chi_2 + \mathcal{M}_{33} \bar{S}_{L_3}^c S_{L_3} \right] + h.c.,$$

$$\mathcal{M}_D = \frac{v_H}{\sqrt{2}} \begin{pmatrix} |y_D^e| e^{i\phi_1} & 0 & 0 \\ 0 & y_D^\mu & 0 \\ 0 & 0 & y_D^\tau \end{pmatrix}$$

$$\mathcal{M}_{NS} = \frac{v_1}{\sqrt{2}} \begin{pmatrix} |y_N^1| e^{i\phi_2} & 0 & 0 \\ 0 & y_N^2 & 0 \\ 0 & 0 & y_N^3 \end{pmatrix}, \quad \mathcal{M}_\mu = \begin{pmatrix} 0 & \mathcal{M}_{12} & y_{13}\frac{v_2}{\sqrt{2}} \\ \mathcal{M}_{12} & 0 & y_{23}\frac{v_2}{\sqrt{2}} \\ y_{13}\frac{v_2}{\sqrt{2}} & y_{23}\frac{v_2}{\sqrt{2}} & \mathcal{M}_{33} \end{pmatrix}$$

Outline

Numerical aspect and inverse seesaw

Parameters	ranges	Parameters	ranges
y_D^e	$[0.01, 2] \times 10^{-6}$	y_{23}	$[0.1, 1] \times 10^{-7}$
y_D^μ	$[0.1, 2] \times 10^{-3}$	v_1	$[1, 100] \times 10^3$ GeV
y_D^τ	$[1, 5] \times 10^{-2}$	v_2	$[0.3, 50] \times 10^2$ GeV
y_N^1	$[1, 2]$	$\mathcal{M}_{12}$	$[1, 3]$ keV
y_N^2	$[0.1, 2]$	$\mathcal{M}_{33}$	$[0.1, 3]$ keV
y_N^3	$[0.1, 2]$	ϕ_1	$[0, 2\pi]$ rad
y_{13}	$[0.7, 7] \times 10^{-7}$	ϕ_2	$[0, 2\pi]$ rad

Table: Allowed ranges of Yukawa couplings and VEVs for explaining neutrino phenomenology, electron and muon anomalous magnetic moment and leptogenesis.

Numerical aspect and inverse seesaw

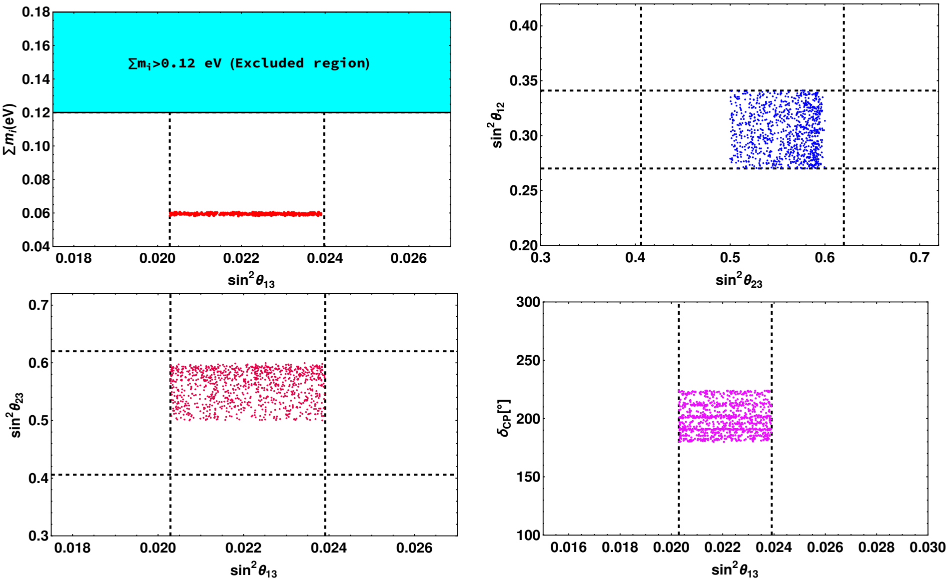
Parameters	ranges	Parameters	ranges
y_D^e	$[0.01, 2] \times 10^{-6}$	y_{23}	$[0.1, 1] \times 10^{-7}$
y_D^μ	$[0.1, 2] \times 10^{-3}$	v_1	$[1, 100] \times 10^3$ GeV
y_D^τ	$[1, 5] \times 10^{-2}$	v_2	$[0.3, 50] \times 10^2$ GeV
y_N^1	$[1, 2]$	$\mathcal{M}_{12}$	$[1, 3]$ keV
y_N^2	$[0.1, 2]$	$\mathcal{M}_{33}$	$[0.1, 3]$ keV
y_N^3	$[0.1, 2]$	ϕ_1	$[0, 2\pi]$ rad
y_{13}	$[0.7, 7] \times 10^{-7}$	ϕ_2	$[0, 2\pi]$ rad

Table: Allowed ranges of Yukawa couplings and VEVs for explaining neutrino phenomenology, electron and muon anomalous magnetic moment and leptogenesis.

- **Inverse seesaw condition:** $\mathcal{M}_\mu \ll \mathcal{M}_D < \mathcal{M}_{NS}$.
- The active neutrino mass matrix m_ν can be found from the expression

$$m_\nu = \mathcal{M}_D^T(\mathcal{M}_{NS}^{-1})^T\mathcal{M}_\mu\mathcal{M}_{NS}^{-1}\mathcal{M}_D \ . \quad (1)$$

Results (1): Neutrino phenomenology



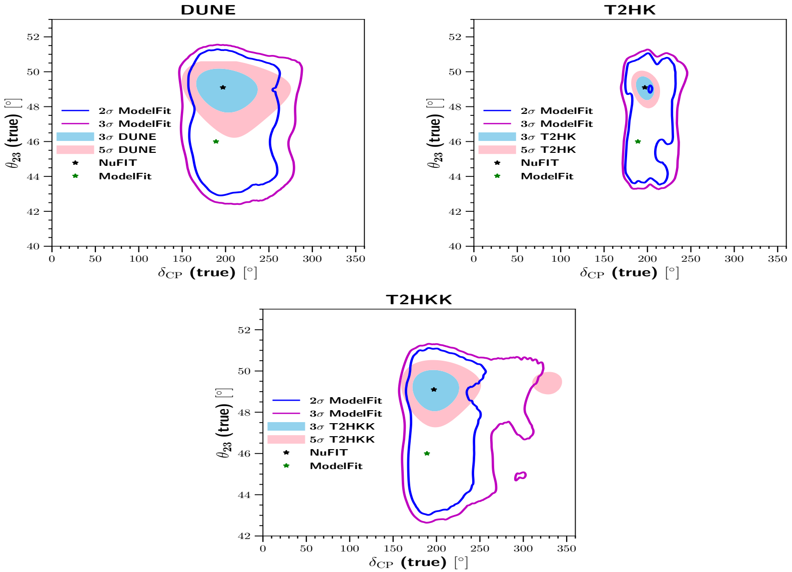
Outline

Probing the model in DUNE, T2HK, T2HKK

Details of DUNE and T2HK, T2HKK:

Experiment	DUNE	T2HK	T2HKK
Baseline	1300 km	295 km	295 km, 1100 km
detector volume	40 kt	374 kt (187 $\times$ 2)	187 kt, 187 kt
POT	1.1×10^{21}	2.7×10^{22}	2.7×10^{22}
Beam power	1.2 MW	1.3 MW	1.3 MW
Beam axis	on-axis	2.5° off-axis	2.5° off-axis, 1.5° off-axis
Runtime	$5\nu + 5\bar{\nu}$	$5\nu + 5\bar{\nu}$	$5\nu + 5\bar{\nu}$

Results (2): testing the model



Remarks

- 2σ and 3σ allowed regions of proposed model are compatible with 5σ parameter space of DUNE.
- 3σ allowed region of model can be tested by 5σ allowed region of T2HK.
- A small contour of parameter space which is excluded by 2σ C.L. of the model, is compatible with 3σ allowed region of T2HK. Thus, if this region is present in T2HK with the current best-fit values of NuFIT as true values, one can exclude the proposed model by 2σ C.L.
- 2σ allowed region is testable by 3σ allowed space of T2HKK. 3σ allowed region of model can be probed by 5σ C.L. of T2HKK.

Outline

Electron (g-2)

$$(\Delta a_e)_{\mathrm{Rb}} = (48 \pm 30) \times 10^{-14}$$

$$\mathcal{L} = g_{B-L}\ \bar{e}\gamma^{\mu} e\ (Z_{B-L})_{\mu} + g_{e\mu}\ \bar{e}\gamma^{\mu} e\ (Z_{e\mu})_{\mu}\ ,$$

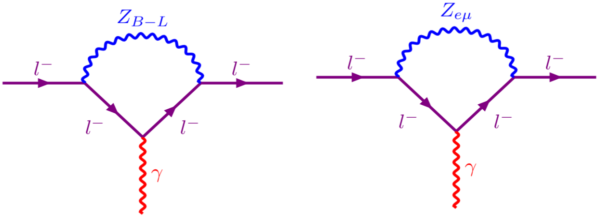
$$\Delta a_e = \int_0^1 \left(\frac{g_{B-L}^2}{4\pi^2} \frac{x^2(1-x)}{x^2 + \frac{m_{Z_{B-L}}^2}{m_e^2}(1-x)} + \frac{g_{e\mu}^2}{4\pi^2} \frac{x^2(1-x)}{x^2 + \frac{m_{Z_{e\mu}}^2}{m_e^2}(1-x)} \right) dx$$

Electron (g-2)

$$(\Delta a_e)_{\rm Rb} = (48 \pm 30) \times 10^{-14}$$

$$\mathcal{L} = g_{B-L}\ \bar{e}\gamma^{\mu} e\ (Z_{B-L})_{\mu} + g_{e\mu}\ \bar{e}\gamma^{\mu} e\ (Z_{e\mu})_{\mu}\ ,$$

$$\Delta a_e = \int_0^1 \left(\frac{g_{B-L}^2}{4\pi^2} \frac{x^2(1-x)}{x^2 + \frac{m_{Z_{B-L}}^2}{m_e^2}(1-x)} + \frac{g_{e\mu}^2}{4\pi^2} \frac{x^2(1-x)}{x^2 + \frac{m_{Z_{e\mu}}^2}{m_e^2}(1-x)} \right) dx$$



Muon (g-2)

$$\Delta a_\mu^{\mathrm{FNAL}} = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} = (25.1 \pm 5.9) \times 10^{-10}.$$

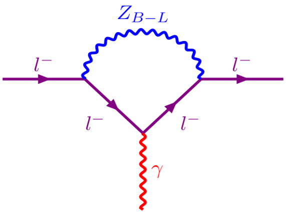
$$\Delta a_\mu^{\mathrm{BNL}} = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} = (26.1 \pm 7.9) \times 10^{-10}.$$

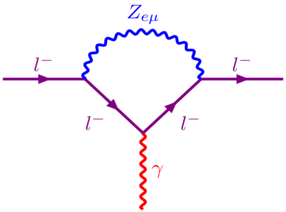
Muon (g-2)

$$\Delta a_\mu^{\rm FNAL} = a_\mu^{\rm exp} - a_\mu^{\rm SM} = (25.1 \pm 5.9) \times 10^{-10}.$$

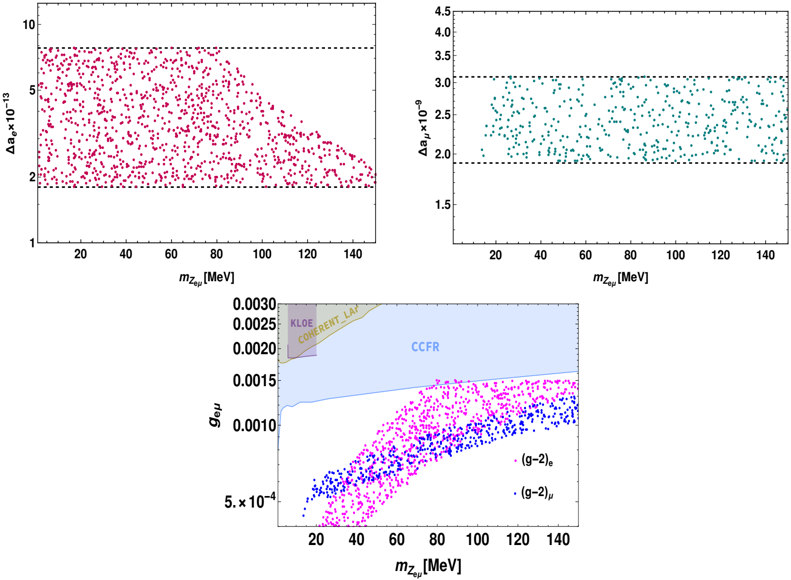
$$\Delta a_\mu^{\rm BNL} = a_\mu^{\rm exp} - a_\mu^{\rm SM} = (26.1 \pm 7.9) \times 10^{-10}.$$

$$\Delta a_\mu = \int_0^1 \left(\frac{g_{B-L}^2}{4\pi^2} \frac{x^2(1-x)}{x^2 + \frac{m_{Z_{B-L}}^2}{m_\mu^2}(1-x)} + \frac{g_{e\mu}^2}{4\pi^2} \frac{x^2(1-x)}{x^2 + \frac{m_{Z_{e\mu}}^2}{m_\mu^2}(1-x)} \right) dx.$$





Results (3): Electron and muon (g-2)



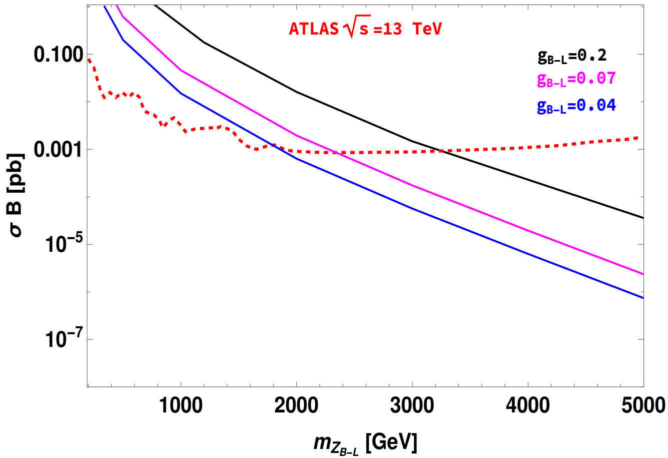
Outline

Collider search

Remark

- Collider analysis is the experimental procedure to search new heavy gauge boson.
- There is a strong bound on $\sigma B - m_{Z_{B-L}}$ parameter space given by past and current running collider experiments.

Results (4): collider search



Outline

Conclusion

Remarks

- Proposed model is able to explain small non-zero mass of neutrino.
- It can be tested in future long longbaseline experiments: DUNE, T2HK , T2HKK with 5σ C.L.
- Electron and muon (g-2) has been explained by the model.
- The acceptibility of the model increases by the results with collider search.
- Proposed model has also explained “baryogenesis” through “leptogenesis” (not discuss here due to time constrain).

Thank you!