THREE-LOOP NEUTRINO MASS MODEL

Sumit Ghosh[1,a], Bhaskar Dutta[1], Ilia Gogoladze[2] and Tianjun Li[3,4]

[1]Texas A&M University, [2]University of Delaware, [3] Chinese Academy of Sciences, [4] University of Chinese Academy of Sciences.

INTRODUCTION

- Discovery of the neutrino oscillations provide a solid evidence for new physics(NP) beyond SM(BSM).
- In BSM physics, tiny neutrino mass can be realised at tree level using Weinberg's dimension-5 operator

$$\mathcal{L}_5 = \frac{\ell\ell\phi\phi}{\Lambda} \tag{1}$$

where Λ is generally the GUT scale, which is inaccessible at experiments like LHC.
- To get a testable NP scale, one needs a new suppression mechanism such as the radiatively generated neutrino masses.
- At n-loop order, a dimension d diagram estimates the neutrino mass as,

$$m_\nu \sim c \times \left(\frac{1}{16\pi^2}\right)^n \times \frac{\langle v_0 \rangle^{2k}}{M^{2k-1}} \tag{2}$$

where c is a dimensionless quantity contains all the couplings and other mass ratios and the mass dimension of the corresponding effective operator is $d = 2k + 3$. We consider $n = 3$ and $k = 1$.

MODEL

- From a big picture perspective, the unification of the electromagnetic and weak forces, the cancellation of gauge anomalies, and the near intersection of the gauge couplings at high energies in the SM all hint at a Grand Unified Theory (GUT).
- We present a model with an additional $SU(2)_N$ gauge symmetry which can arise as a subgroup in the decomposition of the E6 GUT model.
- The low energy gauge symmetry of our model is $SU(3)_C \times SU(2)_L \times SU(2)_N \times U(1)_Y$. The $SU(2)_N$ has no component to the electric charge operator in our model, so the charge operator is defined as $Q = T3L + Y$.
- The fermion content of the model is :

$$Q_i \sim (3,2,1,\frac{1}{6});\;\; U_i^c \sim (\bar{3},1,1,-\frac{2}{3});\;\; D_i^c \sim (\bar{3},1,2,\frac{1}{3});\;\; D_i \sim (3,1,1,-\frac{1}{3})$$
$$L_i \sim (1,2,2-\frac{1}{2});\;\; E_i^c \sim (1,1,1,1);\;\; L_i' \sim (1,2,1,\frac{1}{2});\;\; N_i^c \sim (1,1,2,0);$$
$$F_i \sim (1,1,3,-1);\;\; F_i^c \sim (1,1,3,1)$$

- The scalar content is :

$$H_d \sim (1,2,2,-\frac{1}{2});\;\; H_u \sim (1,2,1,\frac{1}{2})$$
$$S^0 \sim (1,1,2,0);\;\; T \sim (1,2,2,\frac{3}{2})$$

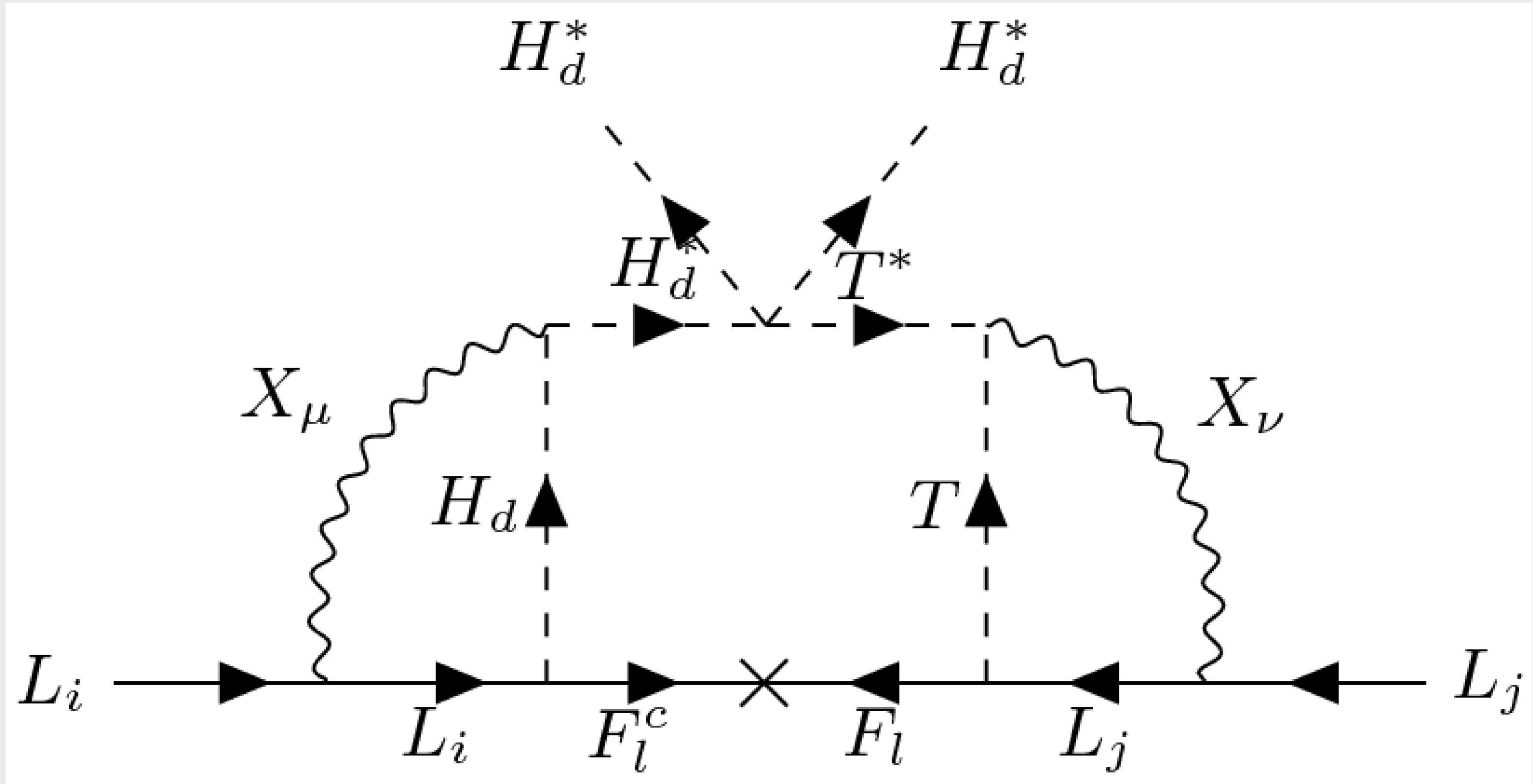
- We impose a discrete Z_2 symmetry such that only N_i^c is odd under the Z_2 symmetry while all the other particles are even. The lightest component of N_i^c is therefore stable and may contribute to the dark matter density.
- The important terms of the Lagrangian needed for the three-loop calculation are :

$$y_{1ij} L_i F_j T + y_{2ij} L_i F_j H_d + \lambda T H_d^3 + \text{H.c.} \tag{3}$$

- We consider three nonzero vevs : $\langle H_d^0 \rangle$, $\langle H_u^0 \rangle$ and $\langle S^0 \rangle$.

NEUTRINO MASS

- Due to the particle content and the associated Z_2 symmetry, the Majorana neutrino mass in our model cannot be generated below the three-loop level.
- The dimension-5 effective Majorana neutrino mass operator $L_i L_j H_d^* H_d^* / M$, where M is some effective mass scale, can be realized at the three-loop level as



- The Neutrino mass matrix elements are estimated to be,

$$(M_\nu)_{ji} \sim \frac{g_2'^4}{(16\pi^2)^3} (y_1)_{jl} (y_2)_{li} \sin^2\beta \times I_{3-loop} \tag{4}$$

where, $j, i = 1, 2, 3$ and I_{3-loop} is the three loop integral, a function of the masses of the particles inside the loop.
- The Renormalization group evolution set $g_2' \simeq 0.35$ and we get a large suppression from $g_2'^4/(16\pi^2)^3 \simeq 10^{-11}$ which pushes the new scale to TeV.

PHYSICAL PARTICLE SPECTRUM

Brief descriptions of the physical scalars and fermions required for the calculations. The E^0 decays only to neutral fields leading to a missing energy signal at the LHC.

Particles	Mass values	Possible final states at LHC
Charged scalars : $h_1^\pm, h_2^\pm$ $H_1^\pm, H_2^\pm$	$m_{h_{1,2}} \sim \mathcal{O}(500)$ GeV $m_{H_1} \sim \mathcal{O}(5)$ TeV $m_{H_2} \sim \mathcal{O}(500)$ GeV	$h_{1,2}^+ \to u_i \bar{d}_j$+ MET $H_{1,2}^+ \to u_i \bar{d}_j$+ MET, $d_i \bar{d}_j + e_i^+$+MET
Charged vector-like leptons : $F_1^\pm, F_2^\pm$	$m_F \sim \mathcal{O}(100)$ GeV	$F_{1,2} \to u_i \bar{d}_j$ + MET, $d_i \bar{d}_j + e^+$+ MET
Neutral vector-like leptons : $E^0, \bar{E}^0$	$m_{s_1} = 500$ GeV, $m_{s_2} = 400$ GeV	$\bar{E}^0 \to e_i^+ e_i^-$ + MET, $E_i^0 \to \nu_i + n_1 \bar{n}_2$ n_1, n_2 dark matter
New gauge bosons $X_1^\mu, X_2^\mu, X_3^\mu$	$m_X \geq 3.6$ TeV	$X_3^\mu \to e_i^+ e_i^-, d_i \bar{d}_i$

NUMERICAL ANALYSIS

- The coupling constant g_2' of the new gauge group $SU(2)_N$ is taken to be $g_2' \simeq 0.35$.
- We take, $v_1/\sqrt{2} = 78$ GeV, $v_2/\sqrt{2} = 156$ GeV and $v_s/\sqrt{2} = 17$ TeV. Therefore, $v_1^2 + v_2^2 = 246^2$ GeV^2 and tan $\beta = v_2/v_1 = 2$.
- We consider one benchmark point(BP) to fit the neutrino oscillation data

Parameter	Benchmark value
m_{H_1}	5 TeV
m_{H_2}	500 GeV
m_{h_2}	268 GeV
m_T	500 GeV
m_X	5 TeV
m_F	(110,120,130) GeV
m_{E^0}	(115,125,135) GeV

- The values of the BP satisfy neutrino mass matrix for the Yukawa couplings : $y_1 \times y_2 \sim 10^{-3} - 10^{-4}$.
- The two most important factors that control the numerical calculation are the new gauge boson mass m_X and the loop suppression factor.
- The product of the coupling constants can be even larger by taking larger $v_s/\sqrt{2}$.

CONCLUSIONS

- E_6 GUT inspired model is proposed to accomodate tiny neutrino masses and mixing parameters with TeV scale physics.
- Such a low scalae is made possible by forbidding mass diagrams below 3-loop order.
- The typical masses of the new particles used in our 3-loop calculations are allowed by the current LHC data
- The flavor structure introduced in this work has the potential to explain the g-2 anomalies.
- Our model can be tested at the ongoing LHC and/or HE-LHC, FCC and SppC etc.

REFERENCES

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CONTACTS

[a]ghosh@tamu.edu