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Low mass right-handed gauge bosons from minimal grand unified theories

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Abstract

Prediction of low-mass W_R and Z_R gauge bosons in popular grand unified theories has been the subject of considerable attention over the last three decades. In this work we show that when gravity induced corrections due to dim.5 operator are included the minimal symmetry breaking chain of $SO(10)$ and E_6 GUTs can yield $W_R^{\pm}$ and Z_R bosons with masses in the range $(3 - 10)$ TeV which are accessible to experimental tests at the Large Hordan Collider. The RH neutrinos turn out to be heavy pseudo-Dirac fermions. The model can fit all fermion masses and manifest in rich structure of lepton flavor violation while proton life time is predicted to be much longer than the accessible limit of Super-Kamiokande or palnned Hyper-Kamiokande collaborations.

Keywords: Grand unification, neutrino masses, gravity induced corrections, right-handed gauge bosons.

Left-right symmetric gauge theory [1, 2] originally suggested to explain parity violation as monopoly of weak interaction has also found wide applications in many areas of particle physics beyond the standard model including neutrino masses and mixings, lepton number and lepton flavor violations,CP-violation , $K - \bar{K}$ and $B - \bar{B}$ mixings and baryogenesis through leptogenesis. This theory is expected to make substantial new impact on weak interaction phenomenology if the associated $W_R^{\pm}$, Z_R bosons have masses in the TeV range. Finally the new gauge bosons can be detected at the Large Hardon Collider (LHC) where ongoing experimental searches have set the bounds $M_{W_R} \geq 2.5$ and $M_{Z_R} \geq 1.162$[3]. Over the years considerable attention has been focussed on the $SO(10)$ realisation of the left-right(LR) gauge symmetry, $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_C$, around the TeV scale with manifest LR symmetry which is always

accompanied by the left-right discrete symmetry $(g_{2L} = g_{2R})$ or without it $(g_{2L} \neq g_{2R})$ and this latter symmetry is denoted as G_{2213A}[4].

The purpose of this work is to show that these gauge boson masses can be realised quite effectively in the minimal symmetry breraking chain of $SO(10)$ or E_6 GUT:

$$
\begin{aligned}
SO(10), &E_6 \\
&\xrightarrow{M_U} SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_C \\
&\qquad\qquad (\equiv G_{2213A}) \\
&\xrightarrow{M_R} SU(2)_L \times U(1)_Y \times SU(3)_C (\equiv G_{213}). \quad (1)
\end{aligned}
$$

To accunt for tiny neutrino masses we use inverse seesaw formula [6] for which we include three additional singlet fermions $S_i (i = 1, 2, 3)$, one per each generation in case of $SO(10)$ but they are parts of standard fermion representations $\mathbf{27_{F_i}}$ of E_6.

We now give some details in $SO(10)$ by using Higgs representations Φ_{210} in the first step, χ_{16} in the second step, and H_{10} in the third step to achieve the low-energy symmetry. In addition to conventional renor-

malizable interactin, we also include the effect of non-renormalisable dim.5 operator [5] induced by gravity effects for which $M_C \sim M_{Planck}$

$$\mathcal{L}_{NR} = \frac{C}{M_C} Tr(F_{\mu\nu}\phi_{(210)}F^{\mu\nu}), \qquad (2)$$

leading to the GUT-scale boundary conditions on the two-loop estimated GUT-scale gauge couplings

$$\alpha_{2L}(M_U)(1 + \epsilon_{2L}) = \alpha_{2R}(M_U)(1 + \epsilon_{2R})$$
$$= \alpha_{BL}(M_U)(1 + \epsilon_{BL}) = \alpha_{3C}(M_U)(1 + \epsilon_{3C}) = \alpha_G, \quad (3)$$

where α_G is the effective GUT fine structure constant and

$$\epsilon_{2R} = -\epsilon_{2L} = -\epsilon_{3C} = \frac{1}{2}\epsilon_{BL} = \epsilon,$$
$$\epsilon = -\frac{CM_U}{2M_C}\left(\frac{3}{2\pi\alpha_G}\right)^{\frac{1}{2}}, \qquad (4)$$

here M_U = solution to the GUT scale that includes corrections due to dim.5 operator and the above boudary condition emerges by beaking the GUT symmetry through the VEVs of $< \eta(1,1,1) >, < \eta'(1,1,15) > \subset 210_H$ where the quantum numbers are under $SU(2)_L \times SU(2)_R \times SU(4)_C$. This implies that the $SO(10)$ and the Pati-Salam symmetry as well as the left-right discrete symmetry are broken at the GUT scale by 210 leading to G_{2213A} at lower scales.

Our solutions consistent with $\sin^2\theta_W(M_Z) = 0.23116 \pm 0.00013$, $\alpha(M_Z) = 1/127.9$, and $\alpha_S(M_z) = 0.1184 \pm 0.0007$ by including only one light bi-doublet $h(2,2,0,1)$ and one light right-handed doublet $\chi(1,2,-1,1)$ corresponding to $D_h = D_\chi = 1$ are shown in Table. 1. The right-handed doublet $\chi(1,2,-1,1)$ breaks the symmetry $G_{2213A} \longrightarrow G_{213}$ and also generates $N - S$ mixing mass term M which results in the inverse seesaw mechanism for neutrino masses. This also contributes significantly towards lepton flavor violation. The predicted proton life time for the decay $p \to e^+\pi^0$ in our model turns out to be in the range $\sim 10^{37} - 10^{38}$ yrs. which is beyond the accessible ranges of Super-Kamiokande ($\tau_p(p \to e^+\pi^0) \geq 1.4 \times 10^{34} yrs$) and proposed investigations at Hyper-Kamiokande ($\tau_p(p \to e^+\pi^0) \geq 1.3 \times 10^{35} yrs$).

As noted above,this model admits inverse seesaw formula for light neutrino masses [6]

$$m_\nu = \frac{M_D}{M}\mu_S\left(\frac{M_D}{M}\right)^T \qquad (5)$$

where $M = Y_\chi V_\chi$ (Y_χ=Yukawa coupling,V_χ is the VEV of χ_R^0)=diag(M_1, M_2, M_3) $>> M_D$ and μ_S is small $SO(10)$-singlet-fermion mass term that violates a SM global symmetry .

The Dirac neutrino mass matrix M_D is determined by fitting the extrapolated values of all charged fermion masses at the GUT scale and running it down to the TeV scale following top-down approach [7, 8]. We may have to use $D_h = 2$ for this purpose but to achieve near TeV scale G_{2213A} symmetry $D_h = D_\chi = 1$ is sufficient

$$M_D(M_R^0)(GeV) =$$

$$\begin{pmatrix} 0.0151 & 0.0674 - 0.0113i & 0.1030 - 0.2718i \\ 0.0674 + 0.0113i & 0.4758 & 3.4410 + 0.0002i \\ 0.1030 + 0.2718i & 3.4410 - 0.0002i & 83.450 \end{pmatrix}.$$

The heavy neutrinos in this model are three pairs of pseudo-Dirac fermions which mediate charged lepton flavor violating decays with predictions on branching ratios shown in Table.2. The present experimental limits on branching ratios are $Br(\mu \to e\gamma) \leq 2.4 \times 10^{-12}$ [9], $Br(\tau \to e\gamma) \leq 1.2 \times 10^{-7}$ and $Br(\tau \to \mu\gamma) \leq 4.5 \times 10^{-8}$ [10]. For verification of model predictions, improved measurements with accuracy upto $3 - 4$ orders are needed.

Table 2: Nonunitarity Predictions of branching ratios for lepton flavor violating decays $\mu \to e\gamma$, $\tau \to e\gamma$ and $\tau \to \mu\gamma$ as a function of singlet fermion masses

$M(GeV)$	$BR(\mu \to e\gamma)$	$BR(\tau \to e\gamma)$	$BR(\tau \to \mu\gamma)$
(50, 200, 1711.8)	1.19×10^{-16}	4.13×10^{-15}	5.45×10^{-13}
(100, 100, 1286)	1.07×10^{-15}	2.22×10^{-14}	2.64×10^{-12}
(100, 200, 1702.6)	1.14×10^{-16}	4.13×10^{-15}	5.52×10^{-13}
(500, 500, 1140)	1.35×10^{-16}	1.25×10^{-14}	1.77×10^{-12}

The inverse seesaw formula fits the neutrino oscillation data quite well for all the three types of light neutrino mass hierarchies. All corresponding Higgs representations being present in E_6 GUT, the same approach leads to identical results but now the three $SO(10)$ fermion singlets are in $\mathbf{27_{F_i}}$ each of which has 10 non-standard fermions compared to $16_F + 1_F$.

We have discussed a novel method of realising low mass RH gauge bosons in minimal GUTs accessible to LHC using gravitational corrections through dim.5 operator. The model successfully accounts for the neutrino oscillation data through inverse seesaw mechanism. The heavy fermions in the model are pseudo Dirac particles which are also verifiable by their trilepton signatures at LHC. We have obtained similar solutions with $D_h = D_\chi = D_T = 1$ where

Table 1: Predictions for RH gauge bosons in $SO(10)$ model with gravity induced corrections for $D_h = D_\chi = 1$.

ϵ	α_G^{-1}	M_R(GeV)	M_U(GeV)	$\sigma = \left(\frac{g_{2L}}{g_{2R}}\right)^2$	M_C(GeV)	$C = -\frac{\kappa}{8}$	τ_p(yrs)
0.082	49.6	2.32×10^4	2.77×10^{16}	1.274	1.12×10^{18}	-1.36	1.04×10^{38}
0.083	49.6	1.9×10^4	2.75×10^{16}	1.277	1.1×10^{18}	-1.37	1.01×10^{38}
0.084	49.7	1.6×10^4	2.73×10^{16}	1.280	1.09×10^{18}	-1.38	9.84×10^{37}
0.085	49.8	1.31×10^4	2.70×10^{16}	1.284	1.08×10^{18}	-1.4	9.55×10^{37}
0.087	49.9	9.08×10^3	2.66×10^{16}	1.290	1.05×10^{18}	-1.41	9.02×10^{37}

T = a RH triplet $\subset 126 \subset SO(10)$ but, in this case, heavy fermions are Majorana particles with interesting experimental signatures. Deatils of this approach would be reported elsewhere [11].

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