New Contributions to Flavour Observables from Left-Right Symmetric Models with Universal Seesaw

DPF, 2021

Ritu D’cruz

In Collaboration with Dr. K. S. Babu
Department of Physics
Oklahoma State University

LRSM Model with Universal Seesaw

(Davidson and Wali,1987)

LRSM

- Parity symmetry
- $\nu_R \Rightarrow$ lightness of neutrino mass.

(Mohapatra and Senjanovic, 1975)
(Pati and Salam, 1974)

Motivation for the Model

- Universal seesaw to generate fermion masses
- Simple Higgs sector
- Mass hierarchy can be explained with $Y \in [10^{-3} - 1]$ as opposed to $Y \in [10^{-6} - 1]$ in standard LRSMs and SM
- Solution to strong CP problem without axions

Model Description

$SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

Quarks

$$q_{L_i}\,(3,2,1,+1/3)$$
$$q_{R_i}\,(3,1,2,+1/3)$$
$$U_i\,(3,1,1,+4/3)$$
$$D_i\,(3,1,1,-2/3)$$

Leptons

$$\psi_{L_i}\,(1,2,1,-1)$$
$$\psi_{R_i}\,(1,1,2,-1)$$
$$E_i\,(1,1,1,-2)$$
$$N_i\,(1,1,1,0)$$

Higgs

$$\chi_L\,(1,2,1,+1) \Rightarrow \langle\chi_L^0\rangle = \kappa_L \simeq 174 GeV$$
$$\chi_R\,(1,1,2,+1) \Rightarrow \langle\chi_R^0\rangle = \kappa_R$$

Gauge Bosons

$$M_{W_{L,R}} = \frac{1}{\sqrt{2}} g_{L,R}\kappa_{L,R}$$
$$M_{Z_1}^2 \simeq \frac{1}{2}(g_Y^2 + g_L^2)\kappa_L^2$$
$$M_{Z_2}^2 \simeq \frac{g_R^4\kappa_R^2 + g_Y^4\kappa_L^2}{2(g_R^2 - g_Y^2)}$$

Fermion Masses - Seesaw Mechanism

(Babu, Datta, Mohapatra, 2019)

$$\mathcal{M}_{U,D,E} = \begin{pmatrix} 0 & \mathcal{Y}_{U,D,E}\kappa_L \\ \mathcal{Y}'^{\dagger}_{U,D,E}\kappa_R & M_{U,D,E} \end{pmatrix}$$

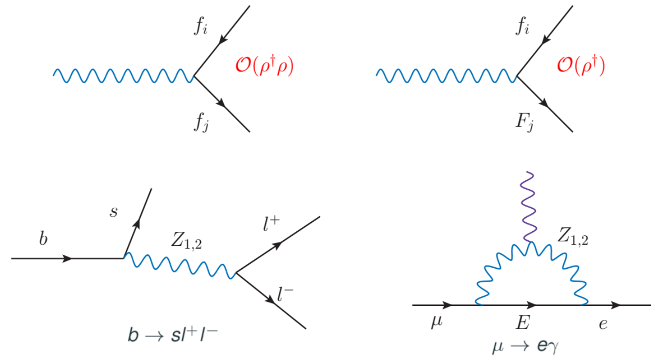
$$\mathcal{M}_{diag} = \mathcal{U}_L^{\dagger}\mathcal{M}\mathcal{U}_R$$

$$\mathcal{U}_{X=\{L,R\}} = \begin{pmatrix} \mathbb{1} - \frac{1}{2}\rho_X^{\dagger}\rho_X & \rho_X^{\dagger} \\ -\rho_X & \mathbb{1} - \frac{1}{2}\rho_X\rho_X^{\dagger} \end{pmatrix}$$

$$m_f = V_{L_f}\rho_L^{\dagger}M\rho_R V_{R_f}^{\dagger}$$

$$\rho_L = \kappa_L M^{-1\dagger}\mathcal{Y}^{\dagger} \qquad \rho_R = \kappa_R M^{-1}\mathcal{Y}'^{\dagger}$$

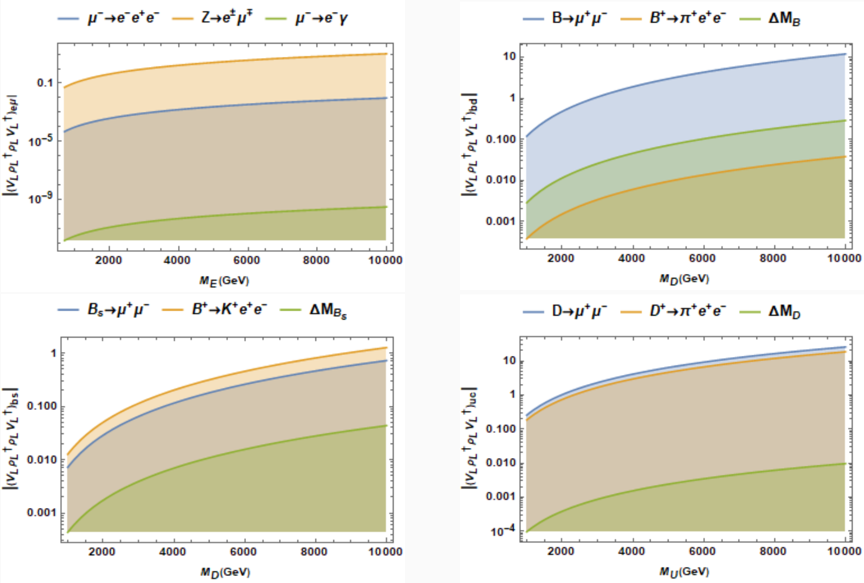
Under parity symmetry, $\rho_R = \frac{\kappa_R}{\kappa_L}\rho_L$



New contributions to gauge boson-fermion vertices and the resulting processes.

Constraints

- Computed under Parity symmetric case with $\kappa_R = 9.14$ TeV corresponding to $M_{Z_2} = 5$ TeV
- $M_{W_R} \gtrsim 2.3$ TeV from $K - \bar{K}$ mixing
- $M_H \gtrsim 6.6$ TeV for mixing angle between Higgs fields set to 0.



Most stringent constraints on the new couplings to neutral gauge boson.

Neutral Current B-anomalies

$b \to s\mu^+\mu^-$

R_K

R_{K^*}

$$\mathcal{L} = \frac{1}{2} M_{Z_i}^2 Z_{i\mu} Z_i^\mu - \frac{g_L}{\cos\theta_w}(C^i_{L_{bs}} \bar{s}_L \gamma^\mu b_L + C^i_{R_{bs}} \bar{s}_R \gamma^\mu b_R + C^i_{L_{ee}} \bar{e}_L \gamma^\mu e_L + C^i_{R_{ee}} \bar{e}_R \gamma^\mu e_R + C^i_{L_{\mu\mu}} \bar{\mu}_L \gamma^\mu \mu_L + C^i_{R_{\mu\mu}} \bar{\mu}_R \gamma^\mu \mu_R) Z_{i\mu}$$

$B_s \to \mu^+\mu^-$

$B_s - \bar{B}_s$

$Z \to \mu^+\mu^-$

$\frac{\Gamma(Z \to \mu^+\mu^-)}{\Gamma(Z \to e^+e^-)}$

$Z \to e^+e^-$

- $\chi^2_{SM} \simeq 25$
- Relax parity condition such that $\mathcal{Y}' \neq \mathcal{Y}$; $\rho_R \neq \kappa_R/\kappa_L \rho_L$.

Best-fit

$\chi^2_{NP} \simeq 7.5$

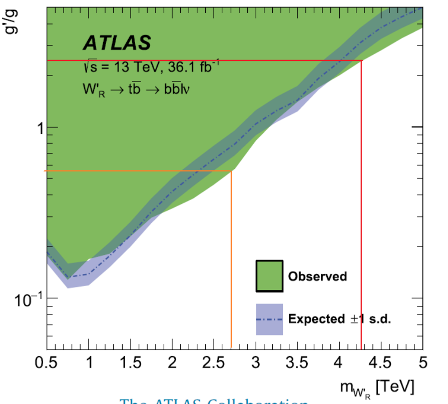
$M_{W_R} \simeq 2.7$ TeV
$g_R \simeq 1.6$

R_K	0.9σ	$C_9^\mu = -C_{10}^\mu = -0.18(1-i)$
R_{K^*}	1.8σ	$C_9'^\mu = C_{10}'^\mu = -0.092(1+i)$
$Z_{\mu/e}$	2.3σ	$C_9'^e = C_{10}'^e = -0.57(1+i)$

$\chi^2_{NP} \simeq 15.3, C_{ee} = 0$

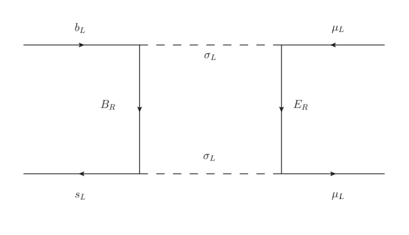
$M_{W_R} \simeq 4.3$ TeV
$g_R \simeq 1.6$

R_K	2.2σ	$C_9^\mu = -C_{10}^\mu = -0.14 + 0.11i$
R_{K^*}	2.3σ	$C_9'^\mu = C_{10}'^\mu = -0.06 - 0.07i$
$Z_{\mu/e}$	2.9σ	



The ATLAS Collaboration
Physics Letters B 788 (2019) 347–370

Alternate Approach to Resolving the Anomaly



Scalar mediated $b \to s\mu^+\mu^-$ box diagram.

- Parity asymmetric case
- Ignore mixing between scalars
- $\mathcal{Y} > \mathcal{Y}'$
- $C_9 = -C_{10} = -0.35 \pm 0.08$

(Altmannshofer,Stangl, 2021)

Mass Structures

$$\begin{pmatrix} 0 & \mathcal{Y}_\mu \kappa_L \\ \mathcal{Y}'_\mu \kappa_R & M_E \end{pmatrix}$$

$$\begin{pmatrix} 0 & 0 & \mathcal{Y}_s \kappa_L \\ 0 & 0 & \mathcal{Y}_b \kappa_L \\ \mathcal{Y}'^*_s \kappa_R & \mathcal{Y}'^*_b \kappa_R & M_B \end{pmatrix}$$

Bench-mark Point

- $C_9 = -C_{10} = -0.326$
- $\kappa_R \simeq 13.8$ TeV
- $\hat{M}_E = 994$ GeV
- $\hat{M}_B = 9.7$ TeV

Cabibbo Anomaly

Test on first-row unitarity of CKM matrix

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 \stackrel{?}{=} 1$$

$$\Downarrow$$

$$|V_{ud}|^2 + |V_{us}|^2 \stackrel{?}{=} 1 \Rightarrow \text{Cabibbo mixing}$$

- V_{CKM} is unitary
- $\Delta_{CKM} = (1.12 \pm 0.28) \times 10^{-3}$

(Kirk,2021)

$$\mathcal{L}_{W_L} \supset -\frac{g_L}{\sqrt{2}}\bar{u}_L\gamma^\mu W^+_{L\mu}\left(V_{L_u}V^\dagger_{L_d} - \overbrace{\frac{1}{2}(V_{L_u}\rho^\dagger_{L_D}\rho_{L_D}V^\dagger_{L_d} + V_{L_u}\rho^\dagger_{L_U}\rho_{L_U}V^\dagger_{L_d})}^{\text{non-unitarity}}\right)d_L$$

Parity symmetric case

- u-$T \rightarrow$ first row is unitary ✗
- u-$U \rightarrow$ extremely small Yukawa coupling to fit m_u ✗
- u-U, t-T ✗

Parity asymmetric case

u-$U \rightarrow \hat{M}_U \simeq 2.7$ TeV for $\kappa_R \simeq 9.3$ TeV

Concluding Remarks

- LRSM with universal seesaw mass mechanism has several advantages over the standard LR models
- FCNC and non-unitarity of charged current interaction at tree level
- Tree level FCNC cannot completely resolve B-anomalies
- Scalar mediated box diagram can explain the neutral current B-anomalies
- Can explain the Cabibbo anomaly and give an upper bound on VLQ mass

Thank You