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

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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

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

Gauge Bosons

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

Higgs

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

Fermion Masses - Seesaw Mechanism

(Babu, Datta, Mohapatra, 2019)

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

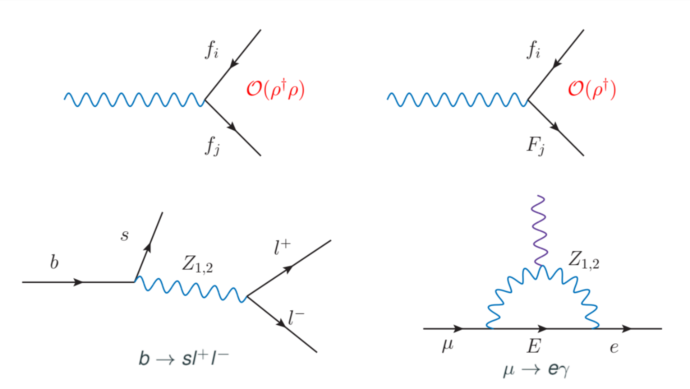
$$\mathcal{M}_{diag} = \mathcal{U}_L^{\dagger}\mathcal{M}\mathcal{U}_R$$

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

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

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

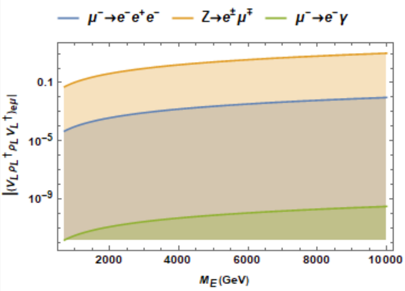
Under parity symmetry, $\rho_R = \frac{\kappa_R}{\kappa_L}\rho_L$

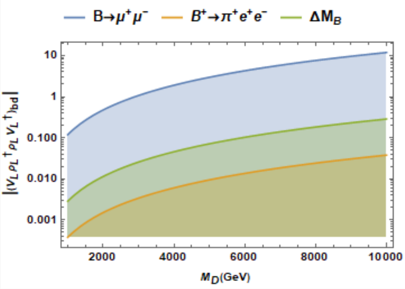


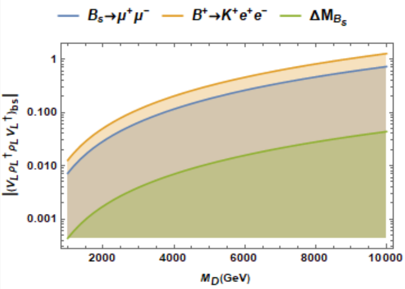
New contributions to gauge boson-fermion vertices and the resulting processes.

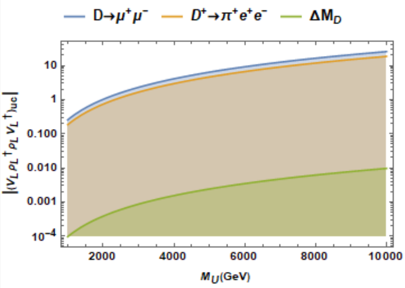
Constraints

- Computed under Parity symmetric case with $\kappa_R = 9.14$ TeV corresponding to $M_{Z_2} = 5$ TeV
- $M_{W_R} \gtrsim 2.5$ 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^*}

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

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

$B_s - \bar{B}_s$

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

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

$Z \to e^+e^-$

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

Best-fit

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

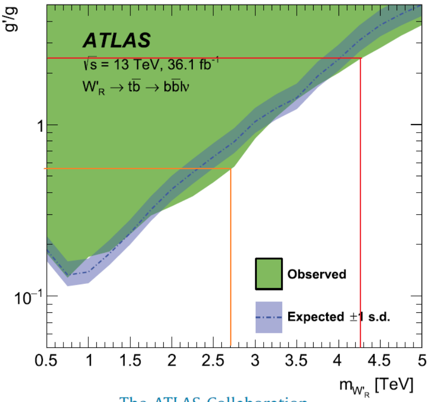
$M_{W_R} \simeq 2.7$ TeV
$g_R \simeq 1.6$

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

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

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

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



The ATLAS Collaboration
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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)

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

Under Parity symmetry & $\rho_R \simeq \mathcal{O}(1)$

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

Parity asymmetric case ✓

$$u\text{-}U \rightarrow \hat{M}_U \lesssim 6\text{ TeV}$$

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
- Slightly reduce the tension of neutral current B-anomalies under Parity asymmetric case
- Can explain the Cabibbo anomaly and give an upper bound on VLQ mass

Thank You