Left-Right Symmetric Models (LRSM)

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LRSM $= SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$

Motivation: understand why and how parity or charge-conjugation are not good symmetries of the quantum world.

LR symmetric models have been extensively studied over the last 40 years. Usual picture: triplets $\Delta_R = (1,3,2)$ and $\Delta_L = (3,1,2)$

- $\langle \Delta_R^T \rangle = (0,\ 0,\ v_R)$ and $\langle \Delta_L^T \rangle = (0,\ 0,\ v_L)$
- Triplets introduce Majorana masses $\nu_R^T \gamma^2 \gamma^0 \sigma_2 \Delta_R \nu_R$
- Setting v_R at TeV and light m_{ν_L} requires large fine-tuning or new symmetries
- The VEV v_L is set to zero, otherwise $\rho \equiv M_W^2/(\cos^2(\theta_W) M_Z^2) \neq 1$ at tree-level

Doublets instead of triplets

Model considered: doublets $\chi_R = (1, 2, 1)$ and $\chi_L = (2, 1, 1)$

- $\langle \chi_R^T \rangle = (0,\ v_R)$ and $\langle \chi_L^T \rangle = (0,\ v_L)$
- Neutrinos are Dirac particles in this minimal picture
- $\rho = 1$ at tree-level
- The VEV v_L is a free parameter

Generalities

- Quarks: $Q_{L,R} = \begin{pmatrix} u_{L,R} \\ d_{L,R} \end{pmatrix}$, and leptons $L_{L,R} = \begin{pmatrix} \nu_{L,R} \\ \ell_{L,R} \end{pmatrix}$
- Electric charge: $Q = T_L^3 + T_R^3 + \frac{B-L}{2}$
- Yukawa interactions: $\overline{Q}_L Y \phi Q_R + \overline{Q}_L \tilde{Y} \tilde{\phi} Q_R + h.c.$,
  $\tilde{\phi} \equiv \sigma_2 \phi^* \sigma_2$.
  Bi-doublet scalar field, $\phi \to U_L \phi U_R^\dagger$.
  VEVs: $\langle \phi \rangle = \mathrm{diag}(\kappa_1, \kappa_2)$
- Mass matrices: $M_u = \kappa_1 Y + \kappa_2 \tilde{Y}$ and $M_d = \kappa_1 \tilde{Y} + \kappa_2 Y$.
  Mixing matrices: $V_L \equiv V^{CKM}$ and V_R
- Relate L to R w/ discrete sym. Under $\mathcal{P}$, $V_L \simeq S_u V_R S_d$; under $\mathcal{C}$, $V_L = K_u V_R^* K_d$

Breaking pattern

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

- g_L, g_R, g'

Breaking pattern

$$SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$$
$$\downarrow_{(v_R)}$$
$$SU(2)_L \otimes U(1)_Y$$

- $g_L,\ g_R,\ g'$
- $v_R \gtrsim \mathcal{O}(1)$ TeV
- New GBs: $W_R^{\pm}$, Z_R

Breaking pattern

$$SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$$
$$\downarrow_{(v_R)}$$
$$SU(2)_L \otimes U(1)_Y$$
$$\downarrow_{(\kappa_{1,2}, v_L)}$$
$$U(1)_{EM}$$

- g_L, g_R, g'
- $v_R \gtrsim \mathcal{O}(1)$ TeV
- New GBs: $W'^{\pm}$, Z'
- $\kappa \equiv \sqrt{\kappa_1^2 + \kappa_2^2 + v_L^2}$ set EWSB
- Known GBs: $W^{\pm} \sim W^{\pm}_{L\,/\,SM}$, $Z \sim Z_{SM}$
- $v_R \neq v_L$: vacuum is not $\mathcal{P}$ or $\mathcal{C}$-symmetric

Breaking pattern

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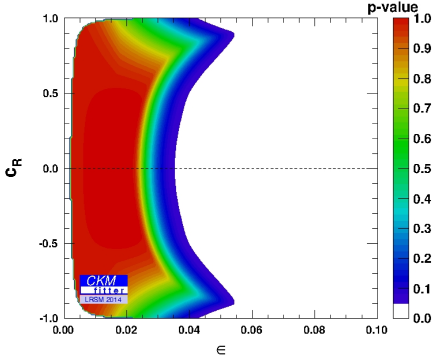
Higgs content: contains $h^0_{SM-like}$, 5 heavy ($\sim v_R$) neutral Higgs, 2 heavy ($\sim v_R$) charged Higgs

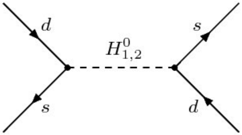
Preliminary fit: $SM_{EW@2-loop} + LR_{tree}$ and direct M_{W_R}

O	SM pull	LR pull
σ^0_{had}	-1.52	-0.91
R_e	-1.17	-1.36
R_μ	-1.20	-1.48
$A_{FB}(b)$	2.79	2.73
$A_{FB}(\tau)$	-1.41	-1.42
A_e^{SLD}	-1.76	-1.81
M_W	-0.85	-0.65
$Q_W(Cs)$	0.70	0.83
...	...	...



- $\epsilon \equiv \kappa/v_R$, $r \equiv \kappa_2/\kappa_1$, $w \equiv v_L/\kappa_1$, $t_R = \tan(\theta_R) \equiv g'/g_R$, $c_R = \cos(\theta_R)$
- pull $\equiv (O_{exp} - O_{fit}|_{w/o\ input})/\sigma_{exp}$
- Suppose $M_{W_R} \gtrsim 2$ TeV [CMS and ATLAS]
- r and w are not constrained by the fit

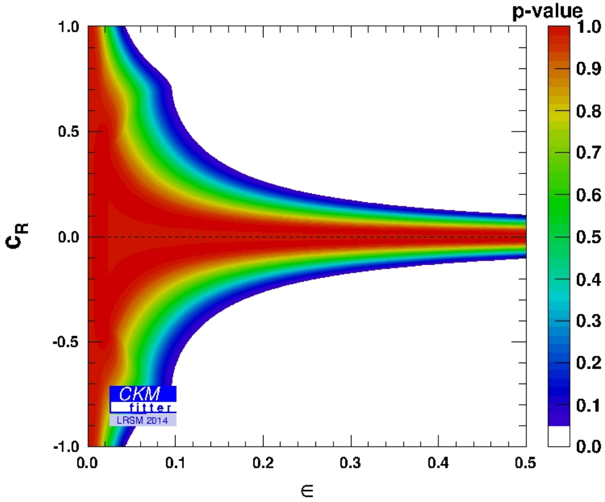
Flavour dynamics



- FCNC: Meson oscillations put severe constraints on H^0 when triplets are considered, $\mathcal{O}(15)$ TeV
- In the doublet case, preliminary studies indicate that one can bring it down to $\mathcal{O}(2)$ TeV
- However, a global fit still needs to be done
- Include fermion spectrum, $b \to s\gamma$, $b \to c\ell\nu$, ...
- Higgs potential and VEVs introduce new sources of CPV

Thank you for the attention

Preliminary fit: correlation w/o M_{W_R} as input



Preliminary fit: correlation σ^0_{had} − $Q_W(Cs)$