Higgs Phenomenology in Minimal SUSY Left-Right Model

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OUTLINE

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MINIMAL SUPERSYMMETRIC LEFT-RIGHT MODEL

- The Gauge group is

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

- Quark and Lepton sector is

Q (3,1,2,1/3) = $\begin{bmatrix} u \\ d \end{bmatrix}$; Q^c (3^*,2,1,-1/3) = $\begin{bmatrix} d^c \\ -u^c \end{bmatrix}$

L (1,1,2,-1) = $\begin{bmatrix} \nu_e \\ e \end{bmatrix}$; L^c (1,2,1,1) = $\begin{bmatrix} e^c \\ -\nu_e{}^c \end{bmatrix}$

The Higgs sector is

$$\Delta(1,1,3,2) = \begin{bmatrix} \frac{\delta^{+}}{\sqrt{2}} & \delta^{++} \\ \delta^{0} & -\frac{\delta^{+}}{\sqrt{2}} \end{bmatrix} \qquad \bar{\Delta}(1,1,3,-2) = \begin{bmatrix} \frac{\bar{\delta}^{-}}{\sqrt{2}} & \bar{\delta}^{0} \\ \bar{\delta}^{--} & -\frac{\bar{\delta}^{-}}{\sqrt{2}} \end{bmatrix}$$

$$\Delta^{c}(1,3,1,-2) = \begin{bmatrix} \frac{\delta^{c-}}{\sqrt{2}} & \delta^{c0} \\ \delta^{c--} & -\frac{\delta^{c-}}{\sqrt{2}} \end{bmatrix} \qquad \bar{\Delta}^{c}(1,3,1,2) = \begin{bmatrix} \frac{\bar{\delta}^{c+}}{\sqrt{2}} & \bar{\delta}^{c++} \\ \bar{\delta}^{c0} & -\frac{\bar{\delta}^{c+}}{\sqrt{2}} \end{bmatrix}$$

$$\Phi_a(1,2,2,0) = \begin{bmatrix} \phi_1^{+} & \phi_2^{0} \\ \phi_1^{0} & \phi_2^{-} \end{bmatrix}_a \quad (a=1,2) \quad ; \quad S\,(1,1,1,0)$$

- Right-handed Higgs fields break $SU(2)_R \times U(1)_{B-L} \rightarrow U(1)_Y$
- The bidoublets are needed for quarks and lepton mass generation and for CKM mixings.

The Superpotential of the model is given by

$$W = Y_u Q^T \tau_2 \phi_1 \tau_2 Q^c + Y_d Q^T \tau_2 \phi_2 \tau_2 Q^c + Y_\nu L^T \tau_2 \phi_1 \tau_2 L^c + Y_l L^T \tau_2 \phi_2 \tau_2 L^c$$
$$+ i(f^* L^T \tau_2 \Delta L + f L^{cT} \tau_2 \Delta^c L^c)$$
$$+ S[Tr(\lambda^* \Delta\bar{\Delta} + \lambda \Delta^c \bar{\Delta}^c) + \lambda'_{ab} Tr(\phi_a^T \tau_2 \phi_b \tau_2) - M_R^2] + W'$$

where

$$W' = [M_\Delta Tr(\Delta\bar{\Delta}) + M_\Delta^* Tr(\Delta^c \bar{\Delta}^c) + \mu_{ab} Tr(\phi_a^T \tau_2 \phi_b \tau_2) - M_S S^2 + \lambda_S S^3$$

- If W′ is set to zero, there is an enhanced R symmetry
  - Helps to understand the μ term ($\langle S \rangle \approx m_{SUSY}$)

Parity Transformation

- ✓ Yukawa couplings are hermitian.
- ✓ M_R^2 are real

The model predicts

- A pair of right-handed light doubly charged higgs.
- A pair of right-handed light doubly charged higgsino.

The vacuum structure looks like

$$\langle \Delta^c \rangle = \begin{bmatrix} 0 & \mathrm{v}_{\mathrm{R}} \\ 0 & 0 \end{bmatrix} \qquad \langle \bar{\Delta}^c \rangle = \begin{bmatrix} 0 & 0 \\ \bar{\mathrm{v}}_R & 0 \end{bmatrix}$$

PROBLEMS

Two main problems with the model

- The Higgs Potential comes out to be lower for a charge non-conserving vacuum

$$\langle \Delta^c \rangle = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & v_R \\ v_R & 0 \end{bmatrix} \quad \langle \bar{\Delta}^c \rangle = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & \bar{v}_R \\ \bar{v}_R & 0 \end{bmatrix}$$

- The Doubly-charged Higgs squared mass comes out to be negative.

Doubly charged Higgs

$$M^2_{\delta^{++}} = \begin{pmatrix} -2g_R^2\left(|v_R|^2 - |\bar{v}_R|^2\right) - \dfrac{\bar{v}_R}{{v_R}^*}Y & Y^* \\ Y & 2g_R^2\left(|v_R|^2 - |\bar{v}_R|^2\right) - \dfrac{v_R}{\bar{v}_R^*}Y \end{pmatrix}$$

$$M^2_{\delta^{++}} = \frac{|Y|\left\{|v_R|^2 + |\bar{v}_R|^2\right\} \pm \left[\left(|Y|\left\{|v_R|^2 + |\bar{v}_R|^2\right\}\right)^2 + K\right]^{1/2}}{2|v_R||\bar{v}_R|}$$

where

$$K = 16g_R^2\left|v_R\bar{v}_R\right|^2\left\{|\bar{v}_R|^2 - |v_R|^2\right\} + 8g_R^2\left|\bar{v}_R Y v_R\right|\left\{|\bar{v}_R|^2 - |v_R|^2\right\} + 2\left|\bar{v}_R Y v_R\right|^2$$

$$Y = \lambda A_\lambda S + |\lambda|^2\left(v_R\bar{v}_R - \frac{M_R^2}{\lambda}\right)^*$$

There is a negative mass-squared eigenvalue.

SOLUTION USING EFFECTIVE POTENTIAL

The correction to the tree level potential.

Effective Potential (Coleman-Weinberg)

$$V^{eff}_{1-loop} = \frac{1}{64\pi^2}\sum_i (-1)^{2s}(2s+1)\, M_i^4 \left[\ln\left(\frac{M_i^2}{\mu^2}\right) - \frac{3}{2}\right]$$

So we need to calculate the mass spectrum.

Calculation of effective potential

Need to make some approximations

- Neglect EW scale.
- Right-handed symmetry breaking scale is much higher than SUSY breaking scale.
- Put the vacuum expectation value of neutral Higgs field.
- Keep the doubly charged Higgs fields and neglect the singly charged fields.

Masses of leptons, sleptons, charged gauge and gauginos were put in effective potential.

The corrected mass –squared matrix for the doubly charged higgs is

$$M^2_{\delta^{c--},\bar{\delta}^{c++}} = \begin{bmatrix} Z_1 - Z_2 & -Z_3 \\ -Z_3 & Z_4 + Z_2 \end{bmatrix}$$

Where,

$$Z_1 = \frac{|f|^2 |A_f|^2}{32\pi^2} + \frac{g_R^2\left[M_2^2 + |\lambda S|^2\right]}{512\pi^2}\left[\mathrm{Log}\left\{\frac{g_R^2 |v_R|^2}{\mu^2}\right\} - \frac{3}{2}\right] - \frac{\overline{v_R}}{v_R{}^*} Y$$

$$Z_2 = \frac{\left(g^4 - g_R^4\right)}{128\pi^2} a_2 m_{L_c}^2 \left[\mathrm{Log}\left\{ \frac{|f|^4 |v_R|^4}{\mu^4} \right\} - 3 \right]$$

$$- \frac{g_R^2 \left(M_2^2 + |\lambda S|^2\right)}{512\pi^2} \left[\mathrm{Log}\left\{ \frac{g_R^2 |v_R|^2}{\mu^2} \right\} - \frac{3}{2} \right] - 2g_R^2 \left[|\overline{v_R}|^2 - |v_R|^2 \right]$$

$$Z_3 = \frac{3|f|^2 |A_f \lambda S|}{128\pi^2} + Y$$

$$Z_4 = \frac{|f|^2 |A_f|^2}{32\pi^2} + \frac{g_R^2 \left[M_2^2 + |\lambda S|^2 \right]}{512\pi^2} \left[\mathrm{Log}\left\{ \frac{g_R^2 |v_R|^2}{\mu^2} \right\} - \frac{3}{2} \right] - \frac{v_R}{\overline{v}_R^{\,*}} Y$$

All these corrections are of order $M_{SUSY}^2 / 64\pi^2$

We expect $M_{++} \sim 100$ GeV

The masses come out to be

$$\frac{1}{2}(Z_1 + Z_4 \pm \sqrt{Z_1{}^2 - 4Z_1Z_2 + 4Z_2{}^2 + 4Z_3{}^2 - 2Z_1Z_4 + 4Z_2Z_4 + Z_4{}^2})$$

This gives the condition

$$\frac{|f|^4|A_f|^2}{64\pi^2}\left[\frac{4|A_f|^2 - \frac{9}{4}|\lambda S|^2}{64\pi^2} - 4\left(\frac{\overline{v_R}}{v_R^*} + \frac{v_R}{\overline{\overline{v_R^*}}}\right)Y\right] + \frac{|f|^2|A_f|^2 g_R^2\left[M_2^2 + |\lambda S|^2\right]}{2(64\pi^2)^2}\left[\mathrm{Log}\left\{\frac{g_R^2|v_R|^2}{\mu^2}\right\} - \frac{3}{2}\right] >$$

$$\left[\frac{(g^4 - g_R^4)a_2 m_{L_c}^2}{128\pi^2}\left\{\mathrm{Log}\left(\frac{|f|^4|v_R|^4}{\mu^4}\right) - 3\right\} - 2g_R^2\left(|\bar{v}_R|^2 - |v_R|^2\right) - \frac{g_R^2\left(M_2^2 + |\lambda S|^2\right)}{512\pi^2}\left\{\mathrm{Log}\left(\frac{g_R^2|v_R|^2}{\mu^2}\right) - \frac{3}{2}\right\}\right]$$

$$\left[\frac{(g^4 - g_R^4)a_2 m_{L_c}^2}{128\pi^2}\left\{\mathrm{Log}\left(\frac{|f|^4|v_R|^4}{\mu^4}\right) - 3\right\} - 2g_R^2\left(|\bar{v}_R|^2 - |v_R|^2\right) - \frac{g_R^2\left(M_2^2 + |\lambda S|^2\right)}{512\pi^2}\left\{\mathrm{Log}\left(\frac{g_R^2|v_R|^2}{\mu^2}\right) - \frac{3}{2}\right\} + \left(\frac{\overline{v_R}}{v_R^*} - \frac{v_R}{\overline{\overline{v_R^*}}}\right)Y\right]$$

- Need to find the parameter space to satisfy this contraint and find the mass.
- Recent paper by Mariana Frank and Beste Korutlu gave mass around 200 GeV.
- We are trying to do the calculation with the entire spectrum.
- All the masses need to be calculated to $\sim M_{SUSY}^2$

Summary and Outlook

- A pair of light doubly charged higgs and higgsino which may be seen at LHC.
- Effective potential calculation can help solve the problems of the model.
- Gives a limited parameter space which need to be calculated.
- A full calculation is needed for a better limit on the higgs mass.

Backup slides

$$M_{l_1} = \left| f v_R \right| \qquad M_{l_2} = \left| f \delta^{c--} \right|$$

$$M_{\tilde{l}_1}{}^2 = m_{L^c}{}^2 + \left|v_R\right|^2 \left|f\right|^2 + \left(\left|\overline{v}_R\right|^2 - \left|v_R\right|^2\right)(g^2 + gR^2) +$$

$$(g^2 - g_R^2)\left(\left|\overline{\delta}^{c++}\right|^2 - \left|\delta^{c--}\right|^2\right) \pm \left|f\right| \left|A_f v_R^* + \lambda^* S^* \overline{v}_R\right|$$

$$M_{\tilde{l}_2}{}^2 = m_{L^c}{}^2 + \left|\delta^{c--}\right|^2 \left|f\right|^2 + \left(\left|\overline{\delta}^{c++}\right|^2 - \left|\delta^{c--}\right|^2\right)(g^2 + gR^2) -$$

$$(g^2 - g_R^2)(\left|v_R\right|^2 - \left|\overline{v_R}\right|^2) \pm \left|f\right| \left|A_f \delta^{c--*} + \lambda^* S^* \overline{\delta}^{c++}\right|$$