Effective Potential in Minimal Supersymmetric Left-Right Model

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OUTLINE

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MOTIVATION

- The Gauge group is extended to

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

$$Q = I_{3L} + I_{3R} + \frac{B-L}{2}$$

- In Standard Model neutrino mass is not well motivated.

- Right-handed neutrino required to generate neutrino mass.

- The triplet scalars needed to break $SU(2)_R$ has the desired vacuum

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

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

Charge breaking vacuum

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

- Part of supersymmetric D-term vanishes for the charge breaking vacuum.
- The 1st order effective potential lowers the charge conserving vacuum. (Babu, Mohapatra, Phys. Lett. B668:404-409, 2008.)
- Calculated the contribution from the lepton and slepton sector.
- Need to calculate the full effective potential.
- A pair of doubly charged higgs and higgsino is expected to remain light.

Preliminary results…..

THE 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

2The effective potential is given as

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

MASS SPECTRUM

- Right-handed symmetry breaks at a high scale (seesaw).
- $M_{SUSY} << M_R$
- EW breaking gives very small corrections and hence neglected.

In the SUSY limit

$$|v_R| = |\bar{v}_R|$$

After SUSY breaking

$$|\bar{v}_R|^2 - v_R^2 \sim M_{SUSY}^2$$

Particle	Mass²
$\tilde{\nu}^c_\tau$	$\frac{1}{2}\left[\left(g'^2+g_R^2\right)\left\{\left\|\bar{v}_R\right\|^2-v_R^2\right\}+2m^2_{L^c}+2\left\|f\right\|^2 v_R^2 \pm 4\left\|f\right\|\left\|A_f v_R+\lambda^* S^* \bar{v}_R\right\|\right]$
$W_R^\pm$	$g_R^2\left\{v_R{}^2+\left\|\bar{v}_R\right\|^2\right\}$
Z'	$2\left(g_R^2+g'^2\right)\left\{v_R{}^2+\left\|\bar{v}_R\right\|^2\right\}$
$\Delta^{c0}, \bar{\Delta}^{c0}$	$4\left(g_R^2+g'^2\right)v_R^2\left[1+O(M_{SUSY}/v_R)\right]$ $2\left\|\lambda\right\|^2 v_R^2\left[1+O(M_{SUSY}/v_R)\right]$
S	$M^2_{S_1,S_2}=2\left\|\lambda\right\|^2 v_R^2\left[1+O(M_{SUSY}/v_R)\right]$
$\Delta^{c-}, \bar{\Delta}^{c+}$	$g_R^2\left\{v_R{}^2+\left\|\bar{v}_R\right\|^2\right\}-\frac{\left\|Y\right\|\left\{v_R{}^2+\left\|\bar{v}_R\right\|^2\right\}}{2v_R\bar{v}_R}$

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

Particle	Mass
ν_τ^c	$\lvert f\,\bar{v}_R \rvert$
$\tilde{\Delta}^{c0}, \tilde{\bar{\Delta}}^{c0}, \tilde{Z}, \tilde{\gamma}$	$\sqrt{2}\lvert\lambda\rvert v_R - \frac{1}{2}\left(M_S + S\lambda\right)$ $\sqrt{2}\lvert\lambda\rvert v_R + \frac{g_R^2\left(S\lambda - M_2\right) + g'^2\left(S\lambda - M_1\right)}{2\left(g_R^2 + g'^2\right)}$
$\tilde{\Delta}^{c-}, \tilde{\bar{\Delta}}^{c+}, \tilde{W}^{\pm}$	$\sqrt{2}g_R v_R + O(M_{SUSY}^2 / v_R)$

Particle	Mass^2
$\tilde{\tau}^c$	$\frac{1}{2}\left[\left(g'^2 - g_R^2\right)\left\{\lvert\bar{v}_R\rvert^2 - v_R^2\right\} + 2m_{L^c}^2\right]$
$\tilde{\Delta}^{c0}, \tilde{\bar{\Delta}}^{c0}, \tilde{Z}, \tilde{\gamma}$	$\left[\frac{g_R^2 M_1 + g'^2 M_2}{g_R^2 + g'^2}\right]^2$
$\tilde{\Delta}^{c--}, \tilde{\Delta}^{c++}$	$\lvert\lambda\langle S\rangle\rvert^2$
$\Delta^{c--}, \Delta^{c++}$	$\frac{\lvert Y\rvert\left\{v_R^2 + \lvert\bar{v}_R\rvert^2\right\} \pm \left[\left(\lvert Y\rvert\left\{v_R^2 + \lvert\bar{v}_R\rvert^2\right\}\right)^2 + K\right]^{1/2}}{2v_R\lvert\bar{v}_R\rvert}$

Doubly charged Higgs

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

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

where

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

and $\varepsilon \sim \frac{1}{3}M_1^2+\ldots$

SUMMARY AND OUTLOOK

- Right-handed neutrinos get mass in the high scale which makes seesaw a natural mechanism for neutrino mass generation.
- A pair of doubly charged higgs remains light and can be seen in future experiments.
- Doubly charged higgsinos are also light.
- A complete analysis of the effective potential needs to be done for both the cases.
- Parameter space for the desired vacuum has to be determined.