Left-Right Models Radiatively Broken by a Doublet

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Breaking Path

- The existing gauge symmetries at low energies, $SU(3)_c \times U(1)_{em}$, are vector-like.
- At higher energies ($\mu \sim \Lambda_{SM}$) there is a parity violation in nature due to the axial nature of $SU(2)_L$.
- Gauge parity can be restored at even higher energies using Left-Right Models, first proposed by Pati and Salam[1] $SU(4)_c \times SU(2)_L \times SU(2)_R$
- We choose to start at:

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

Which is broken down into the Standard Model.

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[1] Pati, J. C. and Salam, A., Phys. Rev. D 10, 275 (1974)

Particle Contents

To achieve realistic fermion masses, a 2nd higgs bidoublet is added.

	$SU(3)_c$	$SU(2)_L$	$SU(2)_R$	$U(1)_{B-L}$
Q	3	2	1	$1/3$
Q^c	$\bar{3}$	1	2	$-1/3$
L	1	2	1	-1
L^c	1	1	2	1
h	1	2	2	0
h'	1	2	2	0

(1)

The superpotential is

$$\begin{aligned} \mathcal{W} = {} & Y_q Q h Q^c + Y_q' Q h' Q^c + Y_e L h L^c + Y_e' L h' L^c \\ & + \alpha \mathrm{Tr} h h + \alpha' \mathrm{Tr} h' h' + \beta \mathrm{Tr} h h' + h.c. \end{aligned}$$

The soft mass terms are

$$V_{soft} = m_{L^c}^2 |\tilde{L}^c|^2 + m_L^2 |\tilde{L}|^2 + m_{Q^c}^2 |\tilde{Q}^c|^2 + m_Q^2 |\tilde{Q}|^2 + m_h^2 |h|^2 + m_{h'}^2 |h'|^2 + \mathcal{O}(hh') \tag{2}$$

In order to achieve radiative breaking, there needs to be a soft mass splitting at some higher energy, meaning this model does not have matter parity symmetry, only gauge parity symmetry.

Breaking Mechanism

Doublets were initially proposed[2], but after the seesaw was introduced [3] triplet models were introduced to achieve a seesaw mechanism without R-Parity breaking. However to achieve LRM breaking without Q_{em} violation, R-Parity has to be broken as well[4] leading to nonzero VEV of $\langle \tilde{L}^c \rangle = \frac{v_R}{\sqrt{2}}$.

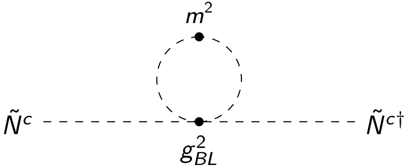

Figure: Soft mass insertions in D-term corrections must be larger than F-term and Gaugino corrections

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[2] Mohapatra, R. N. and Pati, J. C., Phys. Rev. D 11, 2558 (1975). ,Senjanovic, G. and Mohapatra, R. N., Phys. Rev. D 12, 1502 (1975)

[3] Minkowski, P., Physics Letters B 67, 421 (1977)

[4] Kuchimanchi, R. and Mohapatra, R. N., Phys. Rev. D 48, 4352 (1993)

Lepton RGEs

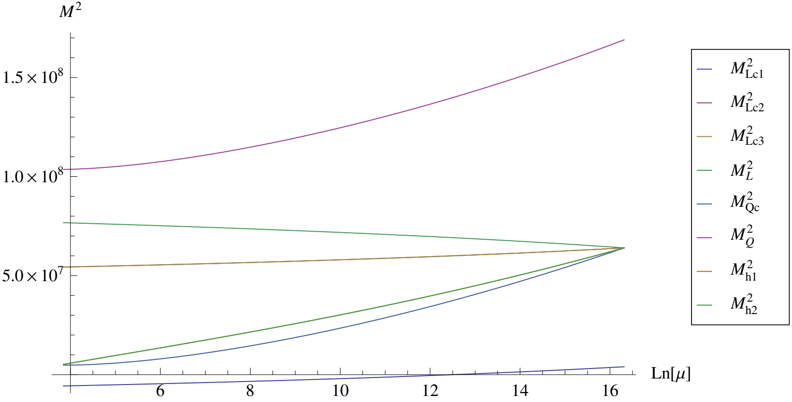
$$\begin{aligned}
8\pi^2 \frac{dm^2_{\tilde{L}_i}}{d\ln\mu} &= \sum_{j,k} |Y_L^{ijh}|^2 \left(m^2_{\tilde{L}_i} + m^2_{\tilde{L}^c_j} + m^2_h \right) - g^2_{BL} \mathrm{Tr}[\mathrm{Q_{BL}} \mathrm{m}^2] \\
&\quad - 4g^2_{BL} M^2_{BL} - 3g^2_L M^2_L \\
8\pi^2 \frac{dm^2_{\tilde{L}^c_i}}{d\ln\mu} &= \sum_{j,k} |Y_L^{ijh}|^2 \left(m^2_{\tilde{L}_i} + m^2_{\tilde{L}^c_j} + m^2_h \right) + g^2_{BL} \mathrm{Tr}[\mathrm{Q_{BL}} \mathrm{m}^2] \\
&\quad - 4g^2_{BL} M^2_{BL} - 3g^2_R M^2_R
\end{aligned} \tag{3}$$

The soft slepton mass runnings at one-loop can easily be derived. The $U(1)_{B-L}$ charge dictates sign of the trace:

$$g^2_{BL} \mathrm{Tr}\left[Q_{BL} m^2 \right] = \sum_i^3 2g^2_{BL} \left(m^2_{\tilde{Q}_i} - m^2_{\tilde{Q}^c_i} - m^2_{\tilde{L}_i} + m^2_{\tilde{L}^c_i} \right). \tag{4}$$

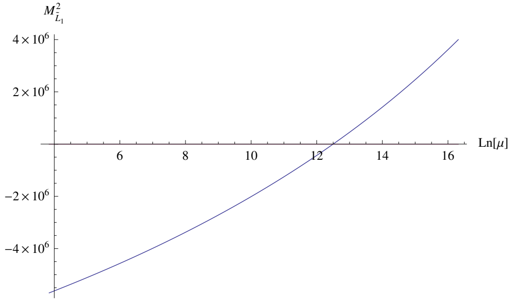
We only need a single large left handed scalar quark doublet to be large which would dominate over even the gaugino masses.

Inputs



- $\mu_{GUT} = 10^{16}$ GeV and the breaking is around 7 TeV
- Yukawas and g_y, for one heavy generation, were ran from low energy with $\theta_R \approx 50^\circ$
- At the GUT scale $M_{\frac{1}{2}} = 2$TeV, $m^2_{\tilde{Q}} = 13$ TeV, $m^2_{\tilde{L}^c_1} = 2$ TeV, and all else is 8 TeV

Breaking Relations



$$g_Y = g_R \sin\theta_R$$
$$\tan\theta_R = \frac{2g_{BL}}{g_R}$$
$$Y_W = \frac{Y_{BL}}{2} - (T_3)_R$$

$$\begin{aligned} M_{W_R} &= \frac{1}{2} g_R v_{\mathrm{R}} \\ M_{Z_R} &= \frac{1}{2} v_{\mathrm{R}} \sqrt{4g_{\mathrm{BL}}^2 + g_R^2} \\ M_{A_Y} &= 0 \end{aligned} \qquad (5)$$

Masses

- We define the VEV to be $v_R = \sqrt{\frac{-8m_{L^c}^2}{(g_R^2+g_{BL}^2)}} \sim 13$ TeV
- $M_{W_R} \sim 3$ TeV and $M_{Z_R} \sim 5$ TeV
- The mass matrix after the LRM breaking is

$$M_{\nu^c,\tilde{\lambda}_{BL},\tilde{\lambda}_R^3} = \begin{pmatrix} M_R & 0 & g_R v_R \\ 0 & M_{BL} & g_{BL} v_R \\ g_R v_R & g_{BL} v_R & 0 \end{pmatrix} \qquad (6)$$

- We still get a heavy neutrino but after EW breaking we can still induce a light neutrino spectrum via see-saw.

$$m_\nu \sim \frac{|\tilde{Y}_L|^2 \tilde{v}_u^2}{(2M_{\nu^c})} \qquad (7)$$

Conclusions

- The Left-Right Models offer great parity restoring phenomnology at higher energies
- Minimal LRMs without triplets can be broken via right-handed sneutrino radiatively.
- Radiative breaking can happen with just one order difference in squarks masses and all other sparticles.
- Small neutrino masses can still be produced via gaugino mixings
- Future parameter scans will be done to tune the inputs based on experimental constraints