R-Parity Conserving Minimal B-L Model

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Minimal SUSY B-L Model[1]

	$SU(2)_L$	$U(1)_Y$	$U(1)_{B-L}$
L_i	2	-1/2	-1
H_u	2	1/2	0
N_1^c	1	0	1
N_2^c	1	0	1
N_3^c	1	0	1

- Three N^c for anomaly free
- Gives Neutrinos Mass term via $W \supset Y_\nu L H_u N^c$
- Forbids R-Parity breaking terms

$$W_R = \epsilon L H_u + \lambda L L E^c + \lambda' Q L D^c + \lambda'' U^c D^c D^c$$

- When sneutrino develops a nonzero VEV, $U(1)_{B-L}$ is broken by $\langle N_i^C \rangle \neq 0$
- R-Parity is broken

[1] Barger, Perez, and Spinner Phys. Rev. Lett. 102, 181802, 2009

- Neutralino no longer DM candidate,
  Gravitino $\Psi_{3/2}$ has the longest lifetime for viable DM
- The neutralinos mix with the B-L gauginos and neutrinos in one mass matrix[2][3]:

$$
M = \begin{pmatrix}
0_{3\times3} & \frac{(Y_\nu)_{jI}\, v_u}{\sqrt{2}} & -\frac{g_{BL} v_{Lj}}{2} & -\frac{g_1 v_{Lj}}{2} & \frac{g_2 v_{Lj}}{2} & 0_{3\times1} & \frac{(Y_\nu)_{jK}\, v_{RK}}{\sqrt{2}} \\
\frac{(Y_\nu)_{Ji} v_u}{\sqrt{2}} & 0_{3\times3} & \frac{g_{BL} v_{RJ}}{2} & 0_{3\times1} & 0_{3\times1} & 0_{3\times1} & \frac{(Y_\nu)_{kJ} v_{Lk}}{\sqrt{2}} \\
-\frac{g_{BL} v_{Li}}{2} & \frac{g_{BL} v_{RI}}{2} & M_{BL} & 0 & 0 & 0 & 0 \\
-\frac{g_1 v_{Li}}{2} & 0_{1\times3} & 0 & M_1 & 0 & -\frac{g_1 v_d}{2} & \frac{g_1 v_u}{2} \\
\frac{g_2 v_{Li}}{2} & 0_{1\times3} & 0 & 0 & M_2 & \frac{g_2 v_d}{2} & -\frac{g_2 v_u}{2} \\
0 & 0 & 0 & -\frac{g_1 v_d}{2} & \frac{g_2 v_d}{2} & 0 & -\mu \\
\frac{(Y_\nu)_{Ki}\, v_{RK}}{\sqrt{2}} & \frac{(Y_\nu)_{Ik}\, v_{Lk}}{\sqrt{2}} & 0 & \frac{g_1 v_u}{2} & -\frac{g_2 v_u}{2} & -\mu & 0
\end{pmatrix}.
$$

[2] Barger, Perez, and Spinner, Phys. Lett. B 696:509-512, 2011
[3] Ghosh, Senjanovic, and Zhang, Phys.Lett. B 698:420-424,2011

Is there a way to preserve R-Parity while spontaneously breaking B-L?

R-Parity Conserving Minimal SUSY B-L Model

	$SU(2)_L$	$U(1)_Y$	$U(1)_{B-L}$	R-Parity
L_i	2	-1/2	-1	$-$
H_u	2	1/2	0	$+$
N_1^c	1	0	1	$-$
N_2^c	1	0	1	$-$
ϕ_{BL}	1	0	1	$+$

- Assign one N^c even R-Parity and call it ϕ_{BL}
- B-L radiatively broken by $\langle\phi_{BL}\rangle = v_{BL}$, while N_i^c will have a zero VEV
- Gauge anomaly still absent due to charge assignment not changing

Renormalization Group Equations

The approximate RGE's for B-L gauge sector and soft masses are[4]

$$16\pi^2 \frac{dg_{BL}}{d\ln\mu} = 16 g_{BL}^3$$

$$8\pi^2 \frac{dM_{BL}}{d\ln\mu} = 16 g_{BL}^2 M_{BL}$$

$$8\pi^2 \frac{dm^2_{\tilde{N}_i^c}}{d\ln\mu} = g_{BL}^2 \left[\left(m^2_{\tilde{N}_1^c} + m^2_{\tilde{N}_2^c} + m^2_{\phi_{BL}} \right) - 4 M_{BL}^2 \right].$$

$$8\pi^2 \frac{dm^2_{\phi_{BL}}}{d\ln\mu} = g_{BL}^2 \left[\left(m^2_{\tilde{N}_1^c} + m^2_{\tilde{N}_2^c} + m^2_{\phi_{BL}} \right) - 4 M_{BL}^2 \right].$$

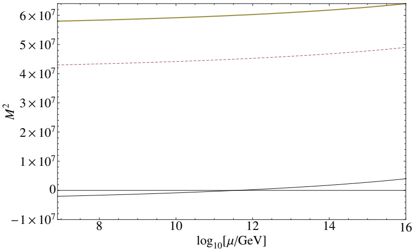
[4] M. Ambroso and B.A. Ovrut, JHEP 096 (2009) 011

Radiative Symmetry Breaking

- Setting $m_\phi^2 < m_{N^c}^2$ at the GUT scale drives m_ϕ^2 negative at low energies

$$m_\phi(\Lambda) = 2\,\mathrm{TeV}, \quad \mathrm{m}_{\tilde{\mathrm{N}}_1^c}(\Lambda) = 7\,\mathrm{TeV}, \quad \mathrm{m}_{\tilde{\mathrm{N}}_2^c}(\Lambda) = 8\,\mathrm{TeV},$$

$$M_{BL}(\Lambda) = 1\,\mathrm{TeV}, \quad \mathrm{g}_{\mathrm{BL}}(\Lambda) = \sqrt{\frac{4\pi}{30}}, \quad \Lambda = 2.0 \times 10^{16}\,\mathrm{GeV}$$



Neutrino Mass

- R-Parity conserved
- Neutrinos are Dirac

$$W \supset Y_{ij} L_i H_u N_j^c$$

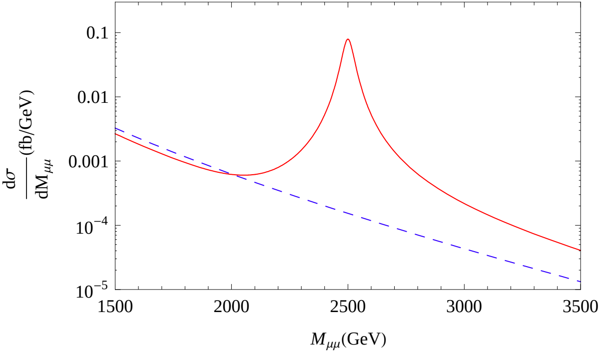
where i=1,2,3 and j=1,2

- lightest neutrino is massless
- $m_\nu = \frac{v_u Y_{ij}}{\sqrt{2}}$ (3x2 matrix)
- We may parameterize $m_\nu = U^\dagger_{MNS} D_{NH/IH}$, where

$$D_{NH} = \begin{pmatrix} 0 & 0 \\ m_2 & 0 \\ 0 & m_3 \end{pmatrix} \qquad D_{IH} = \begin{pmatrix} m_1 & 0 \\ 0 & m_2 \\ 0 & 0 \end{pmatrix}$$

Collider Phenomenology

- Z' resonance at $m_{Z'} = g_{BL} v_{BL} = \mathcal{O}(TeV)$ at LHC
- Invisible decay width of Z' due to 1 massless neutrino and 2 generations of Dirac neutrinos



Dark Matter

- LSP neutralino still DM candidate with an additional candidate of $\tilde{\phi}_{BL}$-λ_{BL} mixed state via

$$M = \begin{pmatrix} 0 & \mathrm{m}_{Z'} \\ \mathrm{m}_{Z'} & \mathrm{M}_{1/2} \end{pmatrix}$$

- For the new candidate the annihilation process $\tilde{\chi}\tilde{\chi} \to Z' \to q\bar{q}, l\bar{l}$
- Relic density $\Omega_{\tilde{\chi}} h^2 \approx 0.1$ is satisfied for[5,6] $m_{\tilde{\chi}} \approx \frac{1}{2} m_{Z'}$

[5] N. Okada and O. Seto, Phys. Rev. D **82**, 023507 (2010)

[6] Z.M. Burell and N. Okada, Phys. Rev. D **85**, 055011 (2012)

Conclusion

- Introducing gauged U(1) B-L to ensure R-Parity conservation
- Neutrinos are Dirac
- One massless neutrino
- B-L can be radiatively broken by a R-Parity even scalar by running of RGE's
- New LSP DM candidate
- LHC Z' gauge boson detection could probe right handed neutrino nature