Phenomenology of the minimal supersymmetric $U(1)_{B-L} \times U(1)_R$ extension of the standard model

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based on: arXiv:1206.xxxx (Martin Hirsch, Werner Porod, Florian Staub)

Motivation

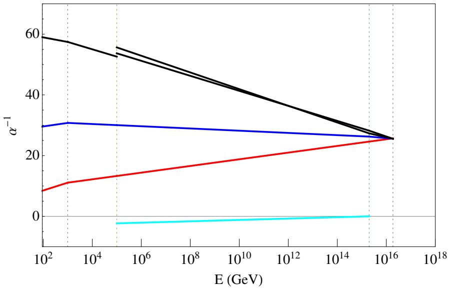
- unifies in the same way the MSSM does
- it can be easily embedded into a $SO(10)$ grand unified theory
- explains neutrino data
- allows Higgs masses significantly larger than the MSSM
- potentially leads to rich phenomenlogy at the LHC

Outline

- Model
- Higgs and SUSY masses
- LHC phenomenology
    - Lepton decays and LFV
    - Higgs physics
    - SUSY cascades
- Conclusions

Model

Gauge group: $SU(3)_c \times SU(2)_L \times U(1)_R \times U(1)_{B-L}$



Breaking:

$$\begin{aligned} SO(10) &\to SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} \\ &\to SU(3)_c \times SU(2)_L \times U(1)_R \times U(1)_{B-L} \\ &\to SU(3)_c \times SU(2)_L \times U(1)_Y \end{aligned}$$

Particle content

	Superfield	$SU(3)_c \times SU(2)_L \times U(1)_R \times U(1)_{B-L}$	Generations
	$\hat{Q}$	$(\mathbf{3}, \mathbf{2}, 0, +\frac{1}{6})$	3
	$\hat{d^c}$	$(\overline{\mathbf{3}}, \mathbf{1}, +\frac{1}{2}, -\frac{1}{6})$	3
	$\hat{u^c}$	$(\overline{\mathbf{3}}, \mathbf{1}, -\frac{1}{2}, -\frac{1}{6})$	3
	$\hat{L}$	$(\mathbf{1}, \mathbf{2}, 0, -\frac{1}{2})$	3
	$\hat{e^c}$	$(\mathbf{1}, \mathbf{1}, +\frac{1}{2}, +\frac{1}{2})$	3
	$\hat{\nu^c}$	$(\mathbf{1}, \mathbf{1}, -\frac{1}{2}, +\frac{1}{2})$	3
	$\hat{S}$	$(\mathbf{1}, \mathbf{1}, 0, 0)$	3
	$\hat{H}_u$	$(\mathbf{1}, \mathbf{2}, +\frac{1}{2}, 0)$	1
	$\hat{H}_d$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, 0)$	1
	$\hat{\chi}_R$	$(\mathbf{1}, \mathbf{1}, +\frac{1}{2}, -\frac{1}{2})$	1
	$\hat{\bar{\chi}}_R$	$(\mathbf{1}, \mathbf{1}, -\frac{1}{2}, +\frac{1}{2})$	1

Superpotential and soft terms

Superpotential:

$$W = W_{\rm MSSM} + W_S$$

$$\begin{aligned} W_{\rm MSSM} &= Y_u \hat{u^c} \hat{Q} \hat{H}_u - Y_d \hat{d^c} \hat{Q} \hat{H}_d - Y_e \hat{e^c} \hat{L} \hat{H}_d + \mu \hat{H}_u \hat{H}_d \\ W_S &= Y_\nu \hat{\nu^c} \hat{L} \hat{H}_u + Y_s \hat{\nu^c} \hat{\chi}_R \hat{S} - \mu_R \hat{\bar{\chi}}_R \hat{\chi}_R + \mu_S \hat{S} \hat{S} \end{aligned}$$

Soft terms:

$$\begin{aligned} V_{soft} &= \sum_a M_a \tilde{G}_a \tilde{G}_a + \sum_{ij} m^2_{ij} \phi^*_i \phi_j + T_u \tilde{u}^*_R \tilde{Q} H_u - T_d \tilde{d}^*_R \tilde{Q} H_d + T_\nu \tilde{\nu}^*_R \tilde{L} H_u \\ &\quad - T_e \tilde{e}^*_R \tilde{L} H_d + B_\mu H_u H_d - B_{\mu_R} \bar{\chi}_R \chi_R + T_s \tilde{\nu}^*_R \chi_R \tilde{S} + B_{\mu_S} \tilde{S} \tilde{S} \end{aligned}$$

Breaking scenario

Higgs:

$$\chi_R = \frac{1}{\sqrt{2}}\left(\sigma_R + i\varphi_R + v_{\chi_R}\right)\ ,\ \bar{\chi}_R = \frac{1}{\sqrt{2}}\left(\bar{\sigma}_R + i\bar{\varphi}_R + v_{\bar{\chi}_R}\right)\ ,$$

$$H_d^0 = \frac{1}{\sqrt{2}}\left(\sigma_d + i\varphi_d + v_d\right)\ ,\quad H_u^0 = \frac{1}{\sqrt{2}}\left(\sigma_u + i\varphi_u + v_u\right)$$

VEVs:

$$v^2 = v_d^2 + v_u^2\ ,\quad \tan\beta = \frac{v_u}{v_d}$$

$$v_R^2 = v_{\chi_R}^2 + v_{\bar{\chi}_R}^2\ ,\quad \tan\beta_R = \frac{v_{\chi_R}}{v_{\bar{\chi}_R}}$$

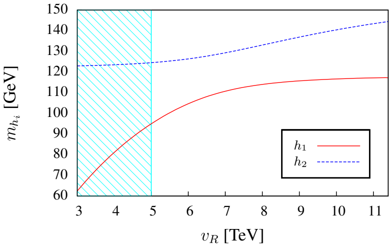
Gauge bosons

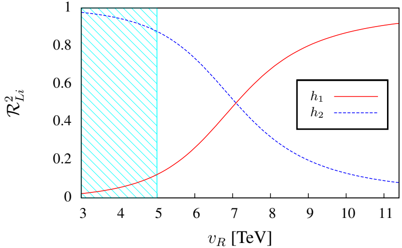
$$m_Z^2 = \frac{(g_{BL}^2 g_L^2 + g_{BL}^2 g_R^2 + g_L^2 g_R^2)v^2}{4(g_{BL}^2 + g_R^2)}\ ,\ m_{Z'}^2 = \frac{g_R^4 v^2}{4(g_{BL}^2 + g_R^2)} + \frac{1}{4}(g_{BL}^2 + g_R^2)\, v_R^2$$

$\rightarrow$ **lower limit on v_R from Z'-bounds**

Higgs

$$m_A^2 = B_\mu(\tan\beta + 1/\tan\beta)\,, \qquad m_{A_R}^2 = B_{\mu_R}(\tan\beta_R + 1/\tan\beta_R)$$



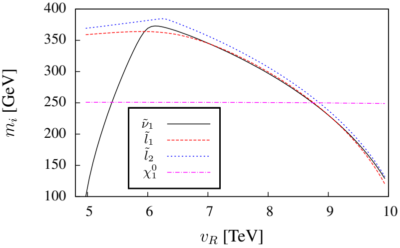


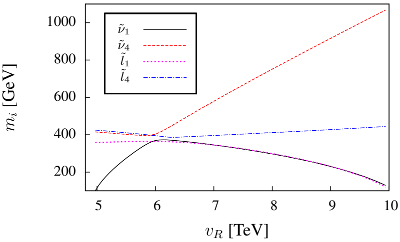
($m_0 = 250$ GeV, $M_{1/2} = 800$ GeV, $\tan\beta = 10$, $A_0 = 0$, $\tan\beta_R = 0.94$, $\mu_R = -800$ GeV, $m_{A_R} = 2350$ GeV)

Sleptons

- $\tan\beta_R > 1 \rightarrow$ left sparticles get lighter because of D-terms
- $\tan\beta_R < 1 \rightarrow$ right sneutrinos get lighter because of D-terms

$\rightarrow$ Limits on v_R and $\tan\beta_R$



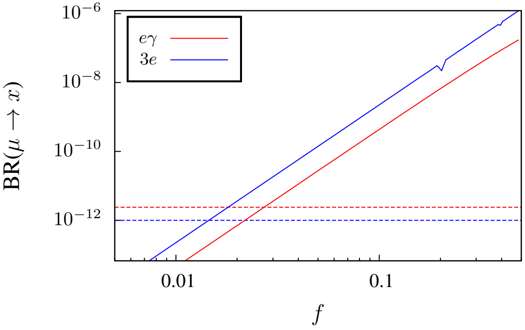


($m_0 = 220$ GeV, $M_{1/2} = 630$ GeV, $\tan\beta = 10$, $A_0 = 0$, $\tan\beta_R = 0.95$, $\mu_R = -850$ GeV, $m_{A_R} = 2200$ GeV)

Study points

	BLRSP1	BLRSP2	BLRSP4
Sneutrinos and Sleptons			
$m_{\tilde{\nu}_1}$ [GeV]	102.3	797.0	542.3
$m_{\tilde{e}_1}$ [GeV]	484.1	1013.9	263.0
Higgs			
m_{h_1} [GeV]	59.6	125.4	102.6
m_{h_2} [GeV]	124.1	140.4	124.8
$\mathcal{R}^2_{L1}$	0.03	0.83	0.22
$\mathcal{R}^2_{L2}$	0.97	0.17	0.78
Neutralinos			
$m_{\chi^0_1}$ [GeV]	282.2	416.7	258.5

Lepton decays and LFV



$$Y_\nu = f \begin{pmatrix} 0 & 0 & 0 \\ a & a & -a \\ 0 & 1 & 1 \end{pmatrix}, \text{ with } a = \left(\Delta m^2_\odot / \Delta m^2_\mathsf{A}\right)^{\frac{1}{4}} \sim 0.4$$

Higgs physics

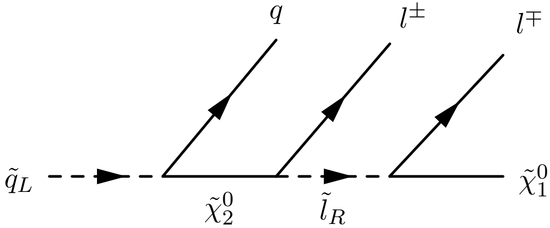
- A Higgs of 125 GeV can be easily produced due to "left-right"-mixing
- Due to the extended higgs sector slight excess at 140 GeV might be also explained
- MSSM-like higgs:
  - $\rightarrow$ non-standard decays:

$$
\begin{aligned}
h_2 &\rightarrow \nu_i \nu_k \rightarrow \nu_i l^{\pm} W^{\mp} \\
h_2 &\rightarrow \nu_i \nu_k \rightarrow \nu_i \nu_j Z \\
h_2 &\rightarrow h_1 h_1 \\
h_2 &\rightarrow \tilde{\nu}_i \tilde{\nu}_i
\end{aligned}
$$

- Singlet higgs:
  - $\rightarrow$ main production at LHC via SUSY cascades
  - $\rightarrow$ approximately same branching ratios into SM-fermions as SM-higgs but total widths are supressed

SUSY cascades

Typical decay chain in the MSSM:



For BLRSP1 we for example get:

$$\tilde{q}_R \rightarrow q\tilde{\chi}_1^0 \rightarrow q\nu_k\tilde{\nu}_1 \rightarrow q\nu_j Z\tilde{\nu}_1$$
$$\tilde{q}_R \rightarrow q\tilde{\chi}_1^0 \rightarrow q\nu_k\tilde{\nu}_1 \rightarrow ql^{\pm}W^{\mp}\tilde{\nu}_1$$
$$\tilde{q}_R \rightarrow q\tilde{\chi}_1^0 \rightarrow q\nu_k\tilde{\nu}_3 \rightarrow ql^{\pm}W^{\mp}\tilde{l}'^{+}l'^{-}\nu_1$$
$$\tilde{q}_R \rightarrow q\tilde{\chi}_5^0 \rightarrow ql^{\pm}\tilde{l}_i^{\mp} \rightarrow ql^{\pm}l^{\mp}\tilde{\chi}_1^0 \rightarrow ql^{\pm}l^{\mp}\nu_k\tilde{\nu}_1 \rightarrow ql^{\pm}l^{\mp}l'^{\pm}W^{\mp}\tilde{\nu}_1$$

$\rightarrow$ **new edges in the invariant mass spectra of the leptons**

Conclusions

Theoretical motivation

- Unification like in MSSM
- can be embedded in $SO(10)$

Phenomenology

- MSSM-like higgs at 125 GeV can be easily produced
- New edges in the invariant mass spectrum of leptons
- Sneutrino/higgsino-right can be a viable candidate for DM
- Singlet higgs can be produced in SUSY cascades

Thank you for your attention