Higgs constraints on left-right supersymmetry

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M. Frank, D.K. Ghosh, K. Huitu, S.K. Rai, I. Saha, HW: arXiv 1408.2423

Outline

- Intro to left-right symmetry
- Properties of LRSUSY
- What does the 125 GeV Higgs imply on left-right supersymmetry?

Basics of left-right symmetry

- Left-right symmetric models assume that parity is a symmetry of nature which is spontaneously broken in weak interactions
- The gauge group of left-right symmetric models is $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
- Introduces right handed W– and Z–bosons, experimental searches excluded these below $\sim$ 2.5 TeV
- Both left-handed and right-handed fermions are in doublets $\Rightarrow$ right-handed neutrino always included
- Explicit R-parity violation is not possible

Higgs content of left-right symmetric models

- Fermion mass generation requires Higgs fields which are doublets under both $SU(2)_L$ and $SU(2)_R$
- In LRSUSY two bidoublets are needed to get the correct mass pattern (and to avoid mixing between W_L and W_R)
- Parity breaking needs fields which are singlets under $SU(2)_L$ but transform nontrivially under $SU(2)_R$
- Our choice is to include right-handed triplets with $B - L = \pm 2$ $\Rightarrow$ allow a mass term for right-handed neutrinos (other choices, see Babu, Patra 1412.8714)
- Usually also left-handed triplets are included to make the model fully left-right symmetric but this may lead to problems if even more fields are not included

The superpotential of the model

The superpotential

$$W = Y^u Q^T \tau_2 \Phi_1 \tau_2 Q^c + Y^d Q^T \tau_2 \Phi_2 \tau_2 Q^c + Y^\ell L^T \tau_2 \Phi_2 \tau_2 L^c$$
$$+ \mathrm{Y}^\nu L^T \tau_2 \Phi_1 \tau_2 L^c + if L^{cT} \tau_2 \Delta^c L^c + S[\lambda Tr(\Delta^c \bar{\Delta}^c)$$
$$+ \lambda' Tr(\Phi_1 \tau_2 \Phi_2 \tau_2) - M_R^2]$$

- $\Phi_{1,2}$ are bidoublets with $B-L=0$, Δ^c and $\bar{\Delta}^c$ are $\mathrm{SU}(2)_R$ triplets with $B-L=\mp 2$, S is a singlet and τ_2 is the Pauli matrix
- One could add the gauge invariant terms $W' = M_\Delta Tr(\Delta^c \bar{\Delta}^c) + \mu Tr(\Phi_1 \tau_2 \Phi_2 \tau_2) + M_s S^2 + \lambda_s S^3$ to the superpotential, but without them there is an additional R-symmetry

Babu, Mohapatra 0807.0481; Frank, Korutlu 1101.3601

VEV structure

We look for a stable minimum with the following VEV structure:

$$\Phi_1 = \begin{pmatrix} \phi_1^+ & \phi_2^0 \\ \phi_1^0 & \phi_2^- \end{pmatrix} \to \begin{pmatrix} 0 & 0 \\ v_u/\sqrt{2} & 0 \end{pmatrix}$$

$$\Phi_2 = \begin{pmatrix} \chi_1^+ & \chi_2^0 \\ \chi_1^0 & \chi_2^- \end{pmatrix} \to \begin{pmatrix} 0 & v_d/\sqrt{2} \\ 0 & 0 \end{pmatrix}$$

$$\Delta^c = \begin{pmatrix} \delta^{c-}/\sqrt{2} & \delta^{c0} \\ \delta^{c--} & -\delta^{c-}/\sqrt{2} \end{pmatrix} \to \begin{pmatrix} 0 & v_R/\sqrt{2} \\ 0 & 0 \end{pmatrix}$$

$$\bar{\Delta}^c = \begin{pmatrix} \bar{\delta}^{c+}/\sqrt{2} & \bar{\delta}^{c++} \\ \bar{\delta}^{c0} & -\bar{\delta}^{c+}/\sqrt{2} \end{pmatrix} \to \begin{pmatrix} 0 & 0 \\ \bar{v}_R/\sqrt{2} & 0 \end{pmatrix}$$

The vacuum of LRSUSY is often unstable

- The determinant of the tree-level doubly charged Higgs mass matrix is negative: the scalar potential is unstable

Several ways to make the potential stable:

- Spontaneous R-parity violation (sneutrino VEVs)
- Addition of triplets with $B - L = 0$
- Radiative corrections (our choice)

- One doubly charged Higgs will be light, since the mass comes from radiative corrections only (detailed study Basso et al 1503.08211)
- Experimental searches exclude a light doubly charged Higgs ($<$ 400 GeV) unless it decays to same sign taus

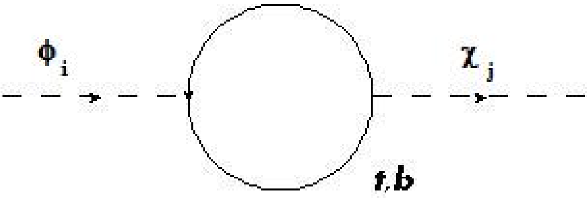
The Higgs mass is easier to achieve in LRSUSY

- The tree-level bound for the square of the lightest Higgs mass is $m_Z^2[(g_L^2+g_R^2)/(g_L^2+{g'_{SM}}^2)]|\cos 2\beta| \Rightarrow$ If $g_R > g'_{SM}$ the bound is larger than in the MSSM, less fine-tuning
- The tree-level mass goes to zero with $\tan\beta$ close to one: a lower limit for $\tan\beta$, dependent on g_R and M_{SUSY}.
- The lower bound on $\tan\beta$ typically between $3\ldots6$

Babu, He, Ma PRD 36 (1987), 878; Huitu, Pandita, Puolamäki hep-ph/9708486

The coupling to bottoms can be strongly enhanced

- There is a neutral bidoublet field, which couples to bottom quarks via the top Yukawa coupling
- At tree-level these do not mix with the SM-like Higgs components but at loop-level there is mixing
- Mixing proportional to $y_t y_b \Rightarrow$ large at large values of $\tan\beta \Rightarrow$ constraining the Higgs-bottom coupling will constrain $\tan\beta$ from above

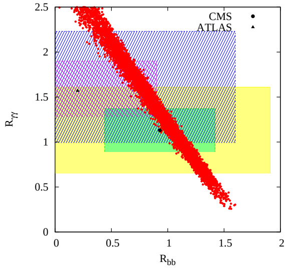


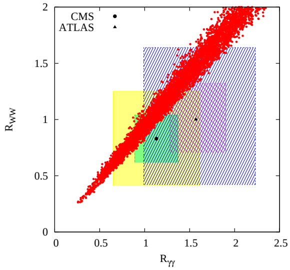
Numerical scan

- We did a random scan over all relevant parameters
- Three benchmark scenarios: only $H^{\pm\pm}$ light, additionally light charginos, light staus
- Requirements for the spectrum: $m_{H^{\pm\pm}} > 200$ GeV, $m_h \in [122, 128]$ GeV, $m_A > 300$ GeV
- Production computed in gluon fusion by a modification of HIGLU
- Spectrum and decays to $\gamma\gamma$ and $Z\gamma$ by our own codes, other decay modes with modified version of HDECAY

The $hb\bar{b}$ coupling dictates (anti)correlations of Higgs BRs

All signal strengths anticorrelated with $h \to b\bar{b}$, all other signal strengths correlated





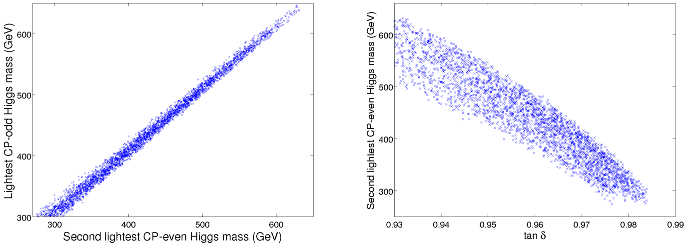
The doubly charged Higgs has a limited effect on $h \to \gamma\gamma$

- The coupling between the SM-like Higgs and the doubly charged Higgses is reduced at large (or even moderate) $\tan\beta$
- Since the 125 GeV Higgs needs at least a moderate value of $\tan\beta$, the effect is never too large
- The singly charged Higgs and charginos, if light, have a larger impact
- None of these are comparable to the effect of $\Gamma(h \to b\bar{b})$ to the total width

Bounds on the other MSSM-like states

- The second CP-even Higgs, lightest CP-odd Higgs and lightest charged Higgs have a mass roughly proportional to $\sqrt{|v_R^2 - \bar{v}_R^2|}$, where v_R and $\bar{v}_R$ are the triplet VEVs
- A similar term with both signs is also in the diagonal of the doubly charged Higgs mass matrix $\Rightarrow$ must be bounded or radiative corrections cannot overcome it
- Hence the MSSM-like states are usually lighter than $\sim$ 700 GeV
- CP-odd state also constrained at large $\tan\beta$ by $B_s \to \mu\mu$, charged Higgs by $b \to s\gamma$, essentially these need to be above 300 GeV
- The three states are nearly degenerate

MSSM-like Higgs masses



$$\tan\delta = \bar{v}_R / v_R$$

Conclusions

We studied a minimal supersymmetric left-right symmetric model.

- The minimal field content for the LRSUSY model has a light doubly charged Higgs which constrains the parameter space significantly
- There is a loop-generated coupling $\propto y_t$ between a part of the SM-like Higgs and b-quarks, this mixing is large at large $\tan\beta$
- Bounds on the SM-like Higgs mass and its coupling to b-quarks give lower and upper bounds for $\tan\beta$
- The other MSSM-like Higgs states are nearly degenerate with sub-TeV masses