SUPERSYMMETRIC LEFT-RIGHT MODEL AND ITS PHENOMENOLOGICAL IMPLICATIONS

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ABSTRACT

We review here our study of a supersymmetric left-right model (SLRM). In the model the $\tilde{R}$-parity is spontaneously broken. Phenomenologically novel feature of the model is the occurrence of the doubly charged particles in the Higgs sector, which are possibly light enough to be seen in the next linear collider. Detection of the doubly charged higgsinos in the next linear collider is discussed.

1. Introduction

The left-right symmetric electroweak model based on the $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ symmetry has many attractive features. In particular, in the see-saw mechanism it offers a beautiful and very natural explanation for the lightness of the ordinary neutrinos. On the other hand, like in the Standard Model it has a hierarchy problem in the scalar sector, which can be solved by making the theory supersymmetric.

The left-right models are especially interesting, if the experiments on solar and atmospheric neutrinos continue to show deviation from the standard model, as well as the existence of the hot dark matter component explaining some features of the power spectrum of density fluctuations of the Universe persists. All these results seem to indicate that neutrinos indeed have a small mass.

To achieve the see-saw mechanism, the $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ symmetry has to be broken by scalar triplets of $SU(2)_R$. A novel feature of the model is that the triplet superfields contain among others also doubly charged particles.

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2. The model

The model is described by the superpotential

\[ W = h_{\phi Q} \hat{Q}_L^T \tau_2 \hat{\phi}^{c} \hat{Q}_R^c + h_{\chi Q} \hat{Q}_L^T i\tau_2 \hat{\chi} \hat{Q}_R^c + \mu_1 \text{Tr}(i\tau_2 \hat{\phi}^T i\tau_2 \hat{\chi}) + \mu_2 \text{Tr}(\hat{\Delta}), \]

(1)

where \( \hat{Q}_{L(R)} \) denote the left (right) handed quark superfield doublets and similarly for the leptons \( \hat{L}_{L(R)} \). The triplet and the bidoublet Higgs superfields of \( SU(2)_L \times SU(2)_R \times U(1)_{B-L} \) are given by

\[ \hat{\Delta} = \left( \begin{array}{cc} \hat{\Delta}^- / \sqrt{2} & \hat{\Delta}^0 \\ \hat{\Delta}^0 & \hat{\Delta}^- / \sqrt{2} \end{array} \right), \quad \hat{\delta} = \left( \begin{array}{cc} \hat{\delta}^+ / \sqrt{2} & \hat{\delta}^{++} \\ \hat{\delta}^{++} & -\hat{\delta}^+ / \sqrt{2} \end{array} \right) \]

\[ \hat{\phi} = \left( \begin{array}{cc} \hat{\phi}^0_1 \\ \hat{\phi}^0_2 \end{array} \right), \quad \hat{\chi} = \left( \begin{array}{cc} \hat{\chi}^0_1 \\ \hat{\chi}^0_2 \\ \hat{\chi}^+_2 \end{array} \right), \quad \hat{\nu} = \left( \begin{array}{cc} \hat{\nu} \end{array} \right), \]

(2)

where the different fields transform as \( \hat{\Delta} \sim (1, 3, -2), \hat{\delta} \sim (1, 3, 2), \hat{\phi} \sim (2, 2, 0), \) and \( \hat{\chi} \sim (2, 2, 0). \) Corresponding to each scalar multiplet with non-zero \( U(1) \) quantum number, one has to include another multiplet with an opposite \( U(1) \) quantum number in order to avoid chiral anomalies for the fermionic superpartners. Also another bidoublet Higgs superfield is added to get a nontrivial Kobayashi-Maskawa matrix.

We find a region in the parameter space for which the scalar fields in the minimum have the following vacuum expectation values:

\[ \langle \Delta^0 \rangle = v_\Delta, \quad \langle \delta^0 \rangle = v_\delta, \quad \langle \phi^0_1 \rangle = \kappa_1, \quad \langle \chi^0_2 \rangle = \kappa_2, \quad \langle \nu \rangle = \sigma_R. \]

(3)

Applying the minimization conditions \( \partial V/\partial \kappa_1 = \partial V/\partial \kappa_2 = \partial V/\partial v_\Delta = \partial V/\partial v_\delta = \partial V/\partial \sigma_R = 0 \) one can find the scalar masses. In the minimum the mass\(^2\) of all the scalars in the Higgs sector must be positive. This requirement has fundamental consequences for the \( R \)-parity, \( R = (-1)^{3(B-L)+2s}. \) The \( R \)-parity is automatically conserved in Lagrangian in this type of models, but it may be broken spontaneously if \( \langle \nu \rangle \neq 0 \). In the case of conserved \( R \)-parity, i.e. \( \langle \nu_{R,L} \rangle = 0 \), the pseudoscalar mass matrix is given by four two by two blocks. One of the blocks contains the sneutrinos and we need not consider it here. Two of the blocks contain the Goldstone bosons which make two of the neutral gauge bosons massive. The physical pseudoscalar particles have the masses

\[ m_{A_1}^2 = m_{\phi \chi}^2 \left( \frac{\kappa_1}{\kappa_2} + \frac{\kappa_2}{\kappa_1} \right), \quad m_{A_2}^2 = m_{\Delta \delta}^2 \left( \frac{v_R}{v_\Delta} + \frac{v_\delta}{v_\Delta} \right), \]

\[ m_{A_{3,4}}^2 = \frac{1}{2} \left\{ m_{A_1}^2 \pm \left[ m_{A_1}^4 + 4(m_{W_R}^2 \cos 2\gamma - m_{W_L}^2 \cos 2\beta)^2 - 4(m_{W_R}^2 \cos 2\gamma - m_{W_L}^2 \cos 2\beta)m_{A_1}^2 \cos 2\beta \right]^{1/2} \right\}, \]

(4)
where it is defined \( \tan^2 \gamma = \left( \frac{v_\delta^2 + \frac{1}{2} \kappa_1^2}{v_\delta^2 + \frac{1}{2} \kappa_2^2} \right) \), \( \tan \beta = \frac{\kappa_2}{\kappa_1} \), and \( \tan \delta = \frac{v_\delta}{v_\Delta} \).

On the other hand the masses of the doubly charged scalars are given by

\[
m_{H_{1,2}^\pm}^2 = \frac{1}{2} \left\{ m_{A_2}^2 \pm \sqrt{m_{A_2}^4 + 8m_{W_R}^2 \cos 2\gamma [m_{A_2}^2 \cos 2\delta + 2m_{W_R}^2 \cos 2\gamma]} \right\}.
\]

(5)

It is easily seen that trying to make both pseudoscalar and doubly charged mass positive one ends in contradiction. Necessarily at least one of the \( \langle \tilde{\nu} \rangle \neq 0 \).

However, if the right-sneutrino has a vev, it is found that ranges of parameters exist, where all the squares of the Higgs masses are positive. Furthermore, one of the doubly charged Higgses turns out to be lighter than 500 GeV for \( h_\Delta \leq 0.8 \). The majority of the scalars are heavier than 1 TeV.

3. Testing SLRM in the colliders

Another particle of interest in the Higgs sector is the supersymmetric counterpart of the doubly charged Higgs. This particle is very suitable for experimental search for many reasons. It is doubly charged, which means that it does not mix with other particles. Consequently its mass is given by a single parameter, the susy Higgs mixing parameter \( \mu_2 \).

The next generation linear electron colliders will, besides the usual \( e^+e^- \) reactions, be able to work also in \( e^-e^-, e^-\gamma \) and \( \gamma\gamma \) modes. The high energy photon beams can be obtained by back-scattering an intensive laser beam on high energy electrons. The doubly charged higgsinos can be produced in any of these operation modes.

\[
e^+e^- \rightarrow \tilde{\Delta}^{++}\tilde{\Delta}^{--},
\]

(6)

\[
e^-e^- \rightarrow \tilde{\Delta}^{--}\tilde{\chi}^0,
\]

(7)

\[
\gamma e^- \rightarrow \tilde{l}^+\tilde{\Delta}^{--},
\]

(8)

\[
\gamma\gamma \rightarrow \tilde{\Delta}^{--}\tilde{\Delta}^{++}.
\]

(9)

We have chosen these reactions for investigation because they all have a clean experimental signature: a few hard leptons and missing energy. Furthermore, they all have very small background from other processes.

In large regions of the parameter space, the kinematically favoured decay mode of the triplet higgsino is \( \tilde{\Delta}^{++} \rightarrow \tilde{l}^+l^+ \). Which of the slepton decay modes is dominant, depends on kinematics, but one possibility is the decay to a lepton and the lightest neutralino: \( \tilde{l} \rightarrow l\tilde{\chi}^0 \). The experimental signature of the doubly charged higgsino could be then

\[
\tilde{\Delta}^{--} \rightarrow \tilde{l}^-l^- \rightarrow l^-l^-\tilde{\chi}^0,
\]

(10)

where \( l \) can be any of the \( e, \mu, \tau \) with practically equal probabilities. The experimental signal of reactions (8) and (9) would be then four leptons and missing energy. The total cross section of reaction (8) for the collision energy \( \sqrt{s} = 1 \) TeV and the slepton and higgsino masses in the range of 100–400 GeV is about 0.5 pb. The
reaction (9) is a model independent way to produce doubly charged higgsinos, since it depends only on the parameter $\mu_2$. For $\mu_2 \lesssim 300$ GeV its cross section is larger than 1 pb.

The slepton pair production

$$e^+e^- \rightarrow \tilde{\ell}^+\tilde{\ell}^-$$

(11)

tests also the Higgs sector of the theory since the process is mediated among others by the doubly charged higgsino $\tilde{H}_2$.

The selectron pair production in supersymmetric LR-model has a larger cross section than the corresponding process in the MSSM by about an order of magnitude. This is due to two factors, firstly the number of gauginos in t-channel is larger and secondly the triplet higgsino contribution in u-channel is large, though dependent on the unknown triplet higgsino coupling to the electron and selectron.

The u-channel exchange of the doubly charged higgsino occurs only for a right-handed electron and a left-handed positron ($P_{+-}$ polarization), whereas in s- and t-channel processes also other chirality combinations may enter. Use of polarized beams could therefore give us more information of the triplet higgsino contribution. For $P_{+-}$ polarization there is a peak in the backward direction in the angular distribution of the final state electron. Whether there is a forward peak, depends on the neutralino content. For gaugino dominated neutralinos, the peak exists, but for higgsino dominated neutralinos it is suppressed by the lepton Yukawa couplings.

The cross section of the pair production of smuons and staus are in general expected to be smaller than that of selectron pair production, since the neutralinos do not contribute. On the other hand the cross sections are in general larger than in the case of the MSSM because of the nondiagonal couplings of the triplet higgsinos.

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1. M. Gell-Mann, P. Ramond and R. Slansky, in *Supergravity*, eds. P. van Nieuwenhuizen and D.Z. Freedman (North Holland 1979); T. Yanagida, in Proceedings of *Workshop on Unified Theory and Baryon Number in the Universe*, eds. O. Sawada and A. Sugamoto (KEK 1979).

2. K. Lande et al., in Proc. XXVth Int. Conf. on High Energy Physics, eds. K.K. Phua and Y. Yamaguchi (World Scientific, Singapore, 1991); K.S. Hirata et al., Phys. Rev. Lett. 66 (1990) 1301; K. Nakamura, Nucl. Phys. B 31 (Proc. Suppl.) (1993); A.I. Abazov et al., Phys. Rev. Lett. 67 (1991) 3332; V.N. Gavrin, in Proc. XXVIth Int. Conf. on High Energy Physics (Dallas 1992), to appear.

3. K.S. Hirata et al., Phys. Lett. B 280 (1992) 146; D. Casper et al., Phys. Rev. Lett. 66 (1993) 2561.

4. M. Davis, F.J. Summers, D. Schlegel, Nature 359 (1992) 393; A. N. Taylor, M. Rowan-Robinson, ibid. 396.
5. R.N. Mohapatra, Phys. Rev. D34 (1986) 3457; A. Font, L.E. Ibanez, F. Quevedo, Phys. Lett. B 228 (1989) 79; S.P. Martin, Phys. Rev. D46 (1992) 2769.

6. K. Huitu, J. Maalampi, to appear in Phys. Lett. B.

7. K. Huitu, J. Maalampi, M. Raidal, Nucl. Phys. B 420 (1994) 449.

8. K. Huitu, J. Maalampi, M. Raidal, Phys. Lett. B 328 (1994) 60.