R PARITY VIOLATION: CONSTRAINTS AND IMPLICATIONS

Anjan S. Joshipura
Dept. de Fisica Teorica, Univ. of Valencia,
461000, Burjassot, Valencia, Spain
E-mail: anjan@prl.ernet.in

The constraints on trilinear $R$ parity violating couplings $\lambda'_{ijk}$ following from (i) the neutrino mass resulting due to the induced vacuum expectation value for the sneutrino and (ii) the charm squark interpretation for the HERA anomalous events are discussed in this talk.

1 Introduction

The Baryon and the Lepton number symmetries enforced by the gauge interactions and particle content in the standard model get broken when it is extended to include supersymmetry. This violation is characterized in the minimal supersymmetric standard model (MSSM) by

$$W_R = -\tilde{\lambda}'_{ijk} L'_{i} Q'_{j} D'^{c}_{k} - \tilde{\lambda}''_{ijk} U'_{i} D'^{c}_{j} D'^{c}_{k} - \tilde{\lambda}_{ijk} L'_{i} L'_{j} E'^{c}_{k} + \epsilon_{i} L'_{i} H_{2},$$

where prime over the superfields indicates the weak basis and other notations are standard. The couplings in (1) can be forbidden by imposing $R$ symmetry. While the simultaneous presence of $\tilde{\lambda}''_{ijk}$ and any of the other couplings is constrained severely by proton stability, the lepton number violating couplings by themselves are not constrained as much. Their presence can lead to interesting signatures such as neutrino masses. We wish to discuss in this talk two topics related to the presence of the the trilinear couplings $\lambda'_{ijk}$ namely, neutrino masses and possible anomaly seen in the $e^p$ scattering at HERA.

We shall specifically consider the $\lambda'$-couplings related to the electron number violations as they are relevant for the description of HERA events. Moreover, they are also constrained more strongly than the others from the neutrino mass. We first discuss these constraints and their importance for the description of the HERA events and then specialize to the charm squark interpretation. As we will discuss, this interpretation needs significantly large $\lambda'_{121}$ coupling in many models including the minimal supergravity based scenario.

---

\*On leave from Physical Research Laboratory, Ahmedabad INDIA
2 Basis choice and definition of $\lambda'_{ijk}$

In order to meaningfully constrain the trilinear coupling, it is sometimes assumed that only a single coupling is non-zero at a time. While the physics implied by these couplings is basis independent, the said assumption makes the constraints on $\lambda'_{ijk}$ basis dependent since a non-zero $\lambda'$ in one basis may correspond to several non-zero $\lambda'$s in the other.

The relevant trilinear couplings in eq. (1) can be rewritten in the quark mass basis as follows:

$$W_R = \lambda'_{ijk} (-\nu_i d_l K_{lj} + e_i u_j) d^c_k$$

where $K$ denotes the standard Kobayashi Maskawa matrix. Even in the mass basis one could choose a different definition for the trilinear couplings:

$$\bar{\lambda}'_{ijk} \equiv K_{jl} \lambda'_{ilk}$$

and rewrite (2) as

$$W_R = \bar{\lambda}'_{ijk} (-\nu_i d_j + e_i K_{lj}^a u_l) d^c_k$$

With the first choice, a single non-zero $\lambda'_{ijk}$ can lead to tree level flavour violations in the neutral sector while this is not so if only one $\bar{\lambda}'_{ijk}$ ($j \neq k$) is non-zero. As an example of the basis dependence, let us note that the HERA results can be interpreted as production of charm squark either by assuming only $\lambda'_{121}$ or $\bar{\lambda}'_{121}$ to be non-zero. The first coupling is constrained severely by the neutrino mass but the second is not. We shall return to this in section (4).

3 Trilinear couplings and neutrino masses

The presence of trilinear couplings generate neutrino masses in two different ways. Firstly, eq. (2) directly leads to 1-loop diagrams generating neutrino masses. This is a well-known contribution. But there is an additional contribution which results from the following soft terms in the supersymmetry breaking part of the scalar potential

$$V_{soft} = -B_{\tilde{\nu}} \tilde{\nu}_i H_2^0 + m_{\nu_i H_1}^2 \tilde{\nu}_i^c H_1^0 + c.c + \cdots$$

Note that the $W_R$ in eq. (2) does not lead to the above soft terms at the GUT scale in conventional supergravity based models if $\epsilon_i$ are zero as assumed here. But terms in eq. (5) do get generated at the weak scale even in this case. This fact becomes clear from the following renormalization group equations satisfied by the soft parameters appearing in (5).
FCNC constraints on $\lambda_{121}^\prime$ for a) $m = 200$ GeV and b) $m = 50$ GeV for $\tan\beta = 40$. Neutrino mass constraints on $\lambda_{121}^\prime$ for c) $m = 50$ GeV, $\tan\beta = 15$; d) $m = 200$ GeV, $\tan\beta = 40$ and e) $m = 50$ GeV, $\tan\beta = 40$. f) $\lambda_{111}^\prime$ from neutrino less $\beta\beta$ decay. g) $\lambda_{111}^\prime$ from neutrino mass constraints for $m = 50$ GeV and $\tan\beta = 40$.

Neutrino mass constraints on $\lambda_{132}^\prime$ for a) $\tan\beta = 5$ and b) $\tan\beta = 25$; on $\lambda_{133}^\prime$ for $\tan\beta = 5$ c) considering only loop contributions and d) loop as well as sneutrino VEV contributions.

\[
\frac{d B_{\tilde{\nu}_i}}{dt} = -\frac{3}{2} B_{\tilde{\nu}_i} \left( Y^U_i - \tilde{\alpha}_2 - \frac{1}{9} \tilde{\alpha}_1 \right) - \frac{3 \mu}{16\pi^2} \lambda_{ijk}^\nu h_k^D \left( A_{ik}^\nu + \frac{1}{2} B_{\mu} \right),
\]

\[
\frac{dm_{\nu_{i,H_1}}^2}{dt} = -\frac{1}{2} m_{\nu_{i,H_1}}^2 \left( 3 Y^D_k + Y^E_k \right) - \frac{3}{32\pi^2} \lambda_{ijk}^\nu h_k^D \left( m_{H_1}^2 + m_{\nu_i}^2 \right) + 2 A_{ik}^\nu A_k^D + 2 m_{H_1}^Q + 2 m_{\nu_i}^{D^\nu}.
\]

where $\lambda_{ijk}^\nu \equiv K_{ik} \lambda_{ijk}^\nu$ and the terms on RHS are the standard soft supersymmetry breaking parameters. It is clear that a non-zero $\lambda_{ijk}^\nu$ generates non-trivial $V_{soft}$ at the weak scale even when the parameters $B_{\tilde{\nu}_i}, m_{\nu_{i,H_1}}^2$ are zero at the GUT scale. The $V_{soft}$ in eq. (3) invariably induces the vacuum expectation value (vev) for the sneutrino field and leads to a neutrino mass. It turns
out that due to additional logarithmic enhancement, this contribution to the neutrino mass dominates over the loop induced contribution in the supergravity based models. The constraints on $\lambda'_{ijk}$ following from this contribution are therefore stronger than from the loop induced contribution considered in the literature.

We have adopted the minimal supergravity based scenario to explicitly derive these constraints. Fig. 1a displays constraints on $\lambda'_{121}, \lambda'_{111}$ for some values of the MSSM parameters and compares them with the existing constraints. It follows that constraints coming from the neutrino mass are quite strong and complimentary to the similar existing constraints. Fig 1b shows similar constraints on parameters $\lambda'_{132}, \lambda'_{133}$. More details can be found in.

4 Charm squark interpretation of the HERA events

The interpretation of the HERA anomalies as due to resonant charm squark production requires

$$\lambda'_{121} \sim \frac{0.025 - 0.034}{B^{1/2}}$$

where $B$ is the branching ratio for the $R$ violating decay $\tilde{c}_L \rightarrow e^+d$. This equation implicitly depends upon the parameters of the MSSM through $B$. These parameters must be such that the charm squark has the right mass namely, around 200 GeV. Strictly speaking, charm squark mass can be treated as an independent free parameter as has been done in recent studies. However this is not so in a large class of models characterized by $m^2_{\tilde{c}_L}(M_{GUT}) > 0$ and hence also in the most popular minimal version of the supergravity based scenario. Assuming unification of the gauge couplings and gaugino masses at the GUT scale $M_{GUT} = 3 \times 10^{16}$ GeV, one has at a lower scale $Q_0 \sim 200$ GeV

$$m^2_{\tilde{c}_L}(Q_0) \approx m^2_{\tilde{c}_L}(M_{GUT}) + 8.83M^2_2 + 1/2 \ M_Z^2 \ \cos 2\beta (1 - 4/3 \sin^2\theta_W)^{1/2}$$

Now $m^2_{\tilde{c}_L}(M_{GUT}) > 0$ implies

$$M_2 \leq 74.04 \text{ GeV} \left( \frac{m_{\tilde{c}_L}}{220 \text{ GeV}} \right) \left( 1 - 0.06 \cos 2\beta \left( \frac{220 \text{ GeV}}{m_{\tilde{c}_L}} \right)^2 \right)^{1/2}$$

This bounded value for $M_2$ results in light chargino to which charm squark decays dominantly reducing $B$ to a very small value and hence $\lambda'_{121}$ to a large value through (8). This is quantitatively displayed in Fig.2 where we plot contours of constant $\lambda'_{121}$ satisfying eq.(8). It is seen that the bound (10) does not allow $\lambda'_{121}$ to be small. The required large value of $\lambda'_{121}$ is severely constrained from the atomic parity violation, neutrino mass and the decay
Figure 2. The contours (continuous lines) of constant $\lambda'_{121}$ obtained by imposing HERA constraint, eq.(8). The contours are for values 0.05, 0.08, 0.12, and 0.13. The horizontal dashed line represents the bound on $M_2$ coming from requiring $m_{\tilde{\epsilon}_L} = 220 \text{ GeV}$. The vertical dash-dot lines represent the bounds on the chargino mass, the upper one for a mass of 85 GeV and the lower one for a mass of 45 GeV. All the above are computed for $\tan \beta = 1$.

$K \rightarrow \pi \nu \nu$. One may try to avoid the last two bounds by choosing basis given in (3) and requiring that only $\tilde{\lambda}'_{121}$ is non-zero. But then one has the following constraint coming from the neutrinoless double beta decay in this case.

$$K_{12}^{12} \tilde{\lambda}_{121} \leq 2.2 \times 10^{-3} \left( \frac{m_{\tilde{\epsilon}_L}}{200 \text{ GeV}} \right)^2 \left( \frac{m_{\tilde{\nu}}}{200 \text{ GeV}} \right)^{1/2}$$

(11)

This too does not allow $\tilde{\lambda}_{121} \sim O(0.1)$. One needs to allow more than one non-zero $\lambda'_{121}$ and fine tune them to satisfy the neutrinoless double beta decay constraint.

5 Summary

We have underlined in this talk the phenomena of the generation of the sneutrino vev and the resulting neutrino mass in the presence of trilinear $R$ violating couplings. This additional contribution is shown to restrict the trilinear
coupling much more strongly than the corresponding loop contribution. We have systematically derived these constraints. We also discussed the charm squark interpretation of the HERA events. It was shown that such interpretation requires large trilinear coupling in a wide class of models which include the minimal supergravity based model. Such a large coupling by itself is ruled out from other constraints but one may allow it by invoking new physics and postulating more than one non-zero couplings and fine tuning them.

Acknowledgments

I thank my collaborators V. Ravindran and Sudhir Vempati for many interesting discussions. Thanks are also due to D. Chaudhury, S. Raychaudhuri and J.W.F. Valle for helpful remarks. This work was supported under DGICYT grant no. SAB-95-0627.

References

1. G. Farrar Phys. Lett. 76B (1978) 575; S. Weinberg, Phys. Rev. D26 (1982) 287.
2. ZEUS Coll., Z. Phys. C74 (1997) 207; H1 Coll., Z. Phys. C74 (1997) 191; talk presented by B. Straub at the Lepton-Photon Symposium, paper contributed to the Lepton-Photon Symposium, Hamburg, 1997.
3. A.S. Joshipura, V. Ravindran and S.K. Vempati, hep-ph/9706482.
4. B. de Carlos and P.L. White, Phys. Rev. D54 (1996) 3427. E. Nardi, Phys. Rev. D55 (1997) 5772.
5. A.S. Joshipura, V. Ravindran and S.K. Vempati, hep-ph/9712219. This also contains a detailed list of original references on the theoretical interpretations of the HERA events.
6. K. Agashe and M. Graesser, Phys. Rev. D54 (1996) 4445.
7. L.J. Hall and M. Suzuki, Nucl. Phys. B231 (1984) 419.
8. R. Godbole, P. Roy and X. Tata, Nucl. Phys. B401 (1993) 67.
9. M.Guchait and D.P.Roy, hep-ph/9707277.
10. V.Barger,K.Cheung,D.P.Roy and D.Zeppenfeld, hep-ph/9710353.
11. M. Hirsch, H.V. Klapdor-Kleingrothaus and S.G. Kovalenko, Phys. Rev. Lett. 75 (1995) 17.