On the (neutral scalar sector of the) RPV-MSSM

(A lesson in linear algebra)

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A. Dedes, S. Rimmer, J. Rosiek, M. Schmidt-Sommerfeld (Physics Letters B 627, 161, 2005)

M. Nowakowski, A. Pilaftsis (Nuclear Physics B 461, 19, 1996)

H. Dreiner (hep-ph/9707435)

Motivating ...

Starting point: SM

It *is* very successful.

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So let's invent a symmetry (that is what theorists usually do, so nothing new here) that naturally leads to neutrino masses.

Such a symmetry is well-known, it is called

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So let's invent a symmetry (that is what theorists usually do, so nothing new here) that naturally leads to neutrino masses.

Such a symmetry is well-known, it is called ... supersymmetry.

R-parity violation

$$\mathcal{L}_{\alpha=0,\ldots,3} = (H_1, L_{i=1,\ldots,3}) \qquad \text{(same quantum numbers)}$$

$$\begin{aligned} \mathcal{W} \;=\; & \epsilon_{ab}[\frac{1}{2}\,\lambda_{\alpha\beta k}\,\mathcal{L}^a_\alpha\,\mathcal{L}^b_\beta\,\bar{E}_k + \lambda'_{\alpha jk}\,\mathcal{L}^a_\alpha\,Q^{b\,x}_j\,\bar{D}_{k\,x} - \mu_\alpha\,\mathcal{L}^a_\alpha\,H^b_2 \\ & +(Y_U)_{ij}\,Q^{a\,x}_i\,H^b_2\,\bar{U}_{j\,x}] + \frac{1}{2}\,\epsilon_{xyz}\,\lambda''_{ijk}\,\bar{U}^x_i\,\bar{D}^y_j\,\bar{D}^z_k \end{aligned} \tag{1}$$

- LSP unstable (Dark matter candidate ?)
- Proton stability $\Rightarrow$ $\lambda''_{ijk} = (\approx)0$
- Many new parameters and a new scale (μ_i)

Minimisation of the neutral scalar potential/Basis choice

$$V_{\text{neutral}} = \left(\mathcal{M}^2_{\tilde{\mathcal{L}}}\right)_{\alpha\beta} \tilde{\nu}^*_{L\alpha}\tilde{\nu}_{L\beta} + m_2^2\, h_2^{0*}\, h_2^0 - (b_\alpha \tilde{\nu}_{L\alpha} h_2^0 + \text{c.c.})$$

$$+ \frac{1}{8}(g^2 + g_2^2)[h_2^{0*}h_2^0 - \tilde{\nu}^*_{L\alpha}\tilde{\nu}_{L\alpha}]^2 \qquad (2)$$

$\Rightarrow$ Minimisation conditions:

$$[Z^T \left(\hat{\mathcal{M}}'^2_{\tilde{\mathcal{L}}}\right) Z]_{\alpha\beta} v_\beta - (b' Z)_\alpha v_u - \frac{1}{8}(g^2 + g_2^2)(v_u^2 - v^*_\gamma v_\gamma)\, v_\alpha = 0 \quad (3)$$

$$m_2^2 v_u - (b' Z)_\alpha v^*_\alpha + \frac{1}{8}(g^2 + g_2^2)(v_u^2 - v^*_\gamma v_\gamma)\, v_u = 0 \quad (4)$$

Determine Z such that $v_i = 0$:

$$[Z^T \left(\hat{\mathcal{M}}'^2_{\tilde{\mathcal{L}}}\right) Z]_{\alpha 0} v_0 - (b' Z)_\alpha v_u - \frac{1}{2}\, M_Z^2\, \frac{v_u^2 - v_0^2}{v_u^2 + v_0^2}\, v_0\, \delta_{0\alpha} = 0 \qquad (5)$$

Minimisation of the neutral scalar potential/Basis choice

$$\tan\beta = \frac{v_u}{v_0} \qquad\qquad Z_{\alpha 0} = \frac{b'_\alpha \tan\beta}{\left(\hat{\mathcal{M}}'^2_{\tilde{\mathcal{L}}}\right)_{\alpha\alpha} - \frac{1}{2} M_Z^2 \frac{\tan^2\beta - 1}{\tan^2\beta + 1}} \tag{6}$$

Determine $\tan\beta$ from the orthogonality condition:

$$\sum_{\alpha=0}^{3} Z_{\alpha 0} Z_{\alpha 0} \;=\; 1 \tag{7}$$

- Multiple solutions for $\tan\beta \Rightarrow$ Choose deepest minimum
- It is always possible to rotate into the basis with $v_i = 0$
- No CP-violation at tree level
- The freedom in the remaining columns can be used to diagonalise the sneutrino mass squared matrix.

Neutrino masses

$$\mathcal{M}_{neutralino} = \begin{pmatrix} 0 & m^T \\ m & M_4^{RPC} \end{pmatrix} \qquad m \sim \mu_i \tag{8}$$

- This matrix has two zero eigenvalues $\Rightarrow$ $m_{\nu_{1,2}}^{tree} = 0$
- m is L-violating and therefore small $\Rightarrow$ A seesaw type structure

$\Rightarrow$ The matrix can be approximatetely block-diagonalised using the matrix

$$\mathcal{V} = \begin{pmatrix} 1 & m^T (M_4^\dagger)^{-1} \\ -M_4^{-1} m & 1 \end{pmatrix} \tag{9}$$

- $m_{\nu_3}^{tree} \simeq -m^T M_4^{-1} m = \frac{|\mu_i|^2 c_\beta^2 M_Z^2 (M_1 c_W^2 + M_2 s_W^2)}{\det(M_4)}$
- All neutrinos acquire masses at loop level
- Normal hierarchy (Inverted at loop level ?)

Conclusions

- R-parity violating supersymmetry naturally incorporates neutrino masses.

- It is always possible to find the matrix that rotates the neutral scalar fields into the basis with vanishing sneutrino v.e.v.'s.

- The neutral scalar sector of the R-parity violating MSSM does not violate CP.