Dynamical R-Parity Violation

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We present a new paradigm for supersymmetric theories with R-parity violation (RPV). At high scale, R parity is conserved in the visible sector but spontaneously broken in the supersymmetry-breaking sector. The breaking is then dynamically mediated to the visible sector and is manifested via nonrenormalizable operators at low energy. Consequently, RPV operators originate from the Kähler potential rather than the superpotential, and are naturally suppressed by the supersymmetry-breaking scale, explaining their small magnitudes. A new set of nonholomorphic RPV operators is identified and found to often dominate over the standard RPV ones. We study the relevant low-energy constraints arising from baryon-number violating processes, proton decay, and flavor changing neutral currents, which may all be satisfied if a solution to the standard model flavor puzzle is incorporated. The chiral structure of the RPV operators implies new and distinct collider signatures, indicating the need to alter current techniques in searching for RPV at the LHC.

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Introduction.—Supersymmetry (SUSY) has long been considered to be the leading candidate for solving the hierarchy problem. However, searches in the first three years of the LHC have failed to uncover evidence for the existence of superpartners, thereby severely constraining the parameter space of the minimal supersymmetric standard model and pushing the masses of some of the superpartners to uncomfortably high scales. Thus, if supersymmetry is to remain natural, it must manifest itself differently than in standard scenarios.

The vast majority of SUSY searches studies events with significant missing energy, as typically follows from the implicit assumption of R-parity conservation. A way to evade many of the bounds is to consider theories in which R parity is violated [1]. Traditionally R-parity violation (RPV) models introduce the following holomorphic operators:

$$\mathcal{O}_{\rm hRPV} = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{e}_k + \lambda'_{ijk}L_iQ_j\bar{d}_k + \frac{1}{2}\lambda''_{ijk}\bar{u}_i\bar{d}_j\bar{d}_k,$$
$$\mathcal{O}_{\rm hBL} = \mu_i L_i H_u, \tag{1}$$

where $\mathcal{O}_{\rm hRPV}$ are the trilinear terms that do not contain dimensionful parameters, while $\mathcal{O}_{\rm hBL}$ are the holomorphic bilinear RPV terms, with dimensionful couplings μ_i. These operators are usually written in a superpotential $W_{\rm RPV} = \mathcal{O}_{\rm hRPV} + \mathcal{O}_{\rm hBL}$. The above couplings, however, are strongly constrained as they generically allow for rapid proton decay, dinucleon decays, neutron-antineutron oscillations, flavor changing processes, and cosmological depletion of any baryon asymmetries (for a review, see Ref. [2]). Thus RPV theories must incorporate extremely small and seemingly *ad hoc* couplings.

Recently, a proposal for an organizing principle that could explain the smallness and hierarchical nature of the RPV couplings above was introduced [3] (see also Refs. [4,5]), based on the minimal flavor violation principle, whereby the magnitude of the RPV couplings is related to the small Yukawa couplings of the flavor sector, naturally generating a hierarchy that leads to a viable pattern of RPV. Related models as well as recent studies on the LHC phenomenology of baryonic RPV models can be found in Refs. [6–9].

The main goal of this Letter is to present an alternative to the traditional approach summarized in Eq. (1), by postulating a dynamical origin of RPV. In particular, the visible sector is assumed to be R-parity conserving, while its breaking, which occurs in a hidden sector, is dynamically communicated to the visible sector. An immediate consequence is that RPV-inducing operators naturally appear in the Kähler potential, and are suppressed by the mediation scale, while they may or may not appear in the superpotential. As a result, under some quite general and natural circumstances, the terms in Eq. (1) are not the leading set of RPV operators and are insufficient to describe the low-energy dynamics of the model. In particular, new types of RPV operators with distinct phenomenology naturally arise and must be considered in any search for RPV supersymmetry.

While not necessarily related, it is interesting to postulate a joint mechanism for breaking and mediating both supersymmetry and R parity (for related ideas see Ref. [7]). Since R parity in the visible sector is equivalent to $(-1)^{3(B-L)+2s}$, where s is the spin of the particle, the sector that triggers the breaking must be charged under that symmetry too. It is then also natural to consider a flavor-dependent mediation mechanism, such as the so-called flavor mediation models based on the Froggatt-Nielsen (FN) mechanism [10,11], or those which allude to partial compositeness. In such scenarios, additional suppression of the RPV terms is obtained, along the lines mentioned above. These suppressions will typically be present even if the flavor model is unrelated to the mediation scheme.

In what follows we make the following assumptions:

(I) Dynamical RPV (dRPV): RPV is broken dynamically in a hidden sector.

(II) RPV is related to SUSY breaking.

These assumptions then imply the appearance of novel nonholomorphic RPV operators

$$\mathcal{O}_{\rm nhRPV} = \eta_{ijk}\bar{u}_i\bar{e}_j\bar{d}_k^\dagger + \eta'_{ijk}Q_i\bar{u}_jL_k^\dagger + \frac{1}{2}\eta''_{ijk}Q_iQ_j\bar{d}_k^\dagger + \kappa_i\bar{e}_iH_dH_u^\dagger, \tag{2}$$

$$\mathcal{O}_{\rm nhBL} = \kappa'_iL_i^\dagger H_d, \tag{3}$$

which can show up in the Kähler potential, coupled to a SUSY-breaking spurion $X = M + \theta^2 F_X$. Here we define all the couplings to be dimensionless. The main consequence of these assumptions is that all RPV interactions will automatically be suppressed by, at least,

$$\epsilon_X \equiv F_X/M^2, \tag{4}$$

which may vary in size from $O(1)$ to $O(10^{-16})$ as in gravity mediation. Its smallness may explain why all of these terms are very small to start with.

We may further assume

(III) Dynamical solution to the standard model (SM) flavor hierarchy.

With this third assumption additional, flavor-dependent suppression factors arise. One then obtains a natural organizing principle that generates a hierarchy in the RPV couplings. Indeed any solution to the flavor hierarchy, such as the above mentioned FN model or partial compositeness, can be incorporated and would typically produce similar hierarchy in the RPV operators.

The RPV operators related to Eqs. (2) and (3) have not been studied before. We will argue below that the above three assumptions are sufficient to suppress any flavor-violating transitions, and in particular proton decay, without assuming lepton-number conservation. Moreover, the new operators predict novel and distinct LHC signatures. In this Letter we study the basic constraints and phenomenology of the above new operators, demonstrating their unique features, as well as the viability of this scheme. A more detailed LHC study and a UV complete model of dRPV will appear in upcoming publications [12].

Framework.—In accordance with assumptions I and II discussed above, we consider a two-scale scenario in which the single spurion X breaks both R parity and supersymmetry in a hidden sector, while providing the messenger mass scale. We will see below that $F_X/M^2 \ll 1$ is preferable, following constraints on RPV operators. We further assume that $M \ll M_{\rm Pl}$ for the mediator scale.

To derive constraints on dRPV, its low energy description must be understood. As is customary when studying supersymmetry breaking, the low energy SM Lagrangian is assumed to be accompanied by the above spurion X, parametrizing the effects of the hidden sector. Depending on the UV completion, X may be charged under various continuous and discrete symmetries, which will constrain its low-energy effective couplings. Nonetheless, a low-energy analysis suffices to restrict the form of the RPV operators that may show up. Indeed, one may assume that $B-L$ is preserved at low energy in the visible sector, as is typically the case. In order to break R parity, X must then be charged under $B-L$, while we will also consider the possibility that it is additionally charged under an unbroken $U(1)_R$ symmetry.

As a consequence, since $\mathcal{O}_{\rm nhRPV} + \mathcal{O}_{\rm nhBL}$ and $\mathcal{O}_{\rm hRPV} + \mathcal{O}_{\rm hBL}$ are charged $+1$ and -1 under $B-L$, respectively, they are distinguishable at low energy. If, for example, X is charged -1 under $B-L$, the Kähler potential and superpotential take the following form at leading order:

$$K_{\rm dRPV} = \frac{1}{X^\dagger}\mathcal{O}_{\rm nhRPV} + \frac{X}{M_{\rm Pl}}\mathcal{O}_{\rm nhBL} + \frac{X^\dagger}{M_{\rm Pl}^2}(\mathcal{O}_{\rm hRPV} + \mathcal{O}_{\rm hBL}) + \text{H.c.}, \tag{5}$$

$$W_{\rm dRPV} = \frac{X}{M_{\rm Pl}^2}(\rho_{ijk}H_dQ_iQ_jQ_k + \rho'_{ijk}H_dQ_i\bar{u}_j\bar{e}_k). \tag{6}$$

(The Lagrangian from a nonholomorphic RPV Kähler potential interaction is $\int d^4\theta(1/X^*)\Phi_j\Phi_k\Phi^{*i} = (F_X^*/M^{*2})\times[\psi_j\psi_k\phi^{*i} - (\phi_jF_k + \phi_kF_j)\phi^{*i}] + (1/M^*)[i(\phi_j\psi_k + \phi_k\psi_j)\times\sigma^\mu\partial_\mu\psi^{\dagger i} - \psi_j\psi_kF^{*i} + \phi_j\phi_k\partial_\mu\partial^\mu\phi^{*i} + (\phi_kF_j + \phi_jF_k)F^{*i}] +$ total derivatives). Note that the Kähler term $(1/X)\mathcal{O}_{\rm hRPV}$ is removed by a Kähler transformation, while the term $X\mathcal{O}_{\rm nhRPV}/M_{\rm Pl}^2$ is subleading. We thus find that in this case the holomorphic RPV operators, when generated dynamically, are highly suppressed in comparison to the new nonholomorphic cubic ones. Furthermore, the nonholomorphic bilinear terms are also suppressed and their effect is negligible as discussed below. (If the $B-L$ symmetry is a global symmetry, gravitational interactions are expected to break the symmetry, generating traditional RPV couplings of the form $(X/M_{\rm Pl})\mathcal{O}_{\rm hRPV}$ in the superpotential. In models of gauge mediation, these will be subdominant to the Kähler operators $(1/X^\dagger)\mathcal{O}_{\rm nhRPV}$ for a large portion of parameter space, corresponding to $M \lesssim 10^{11}$ GeV. It is also possible that the $B-L$ symmetry is a discrete gauge symmetry, and unbroken by gravitational interactions).

If instead X has charge $+1$ under $B-L$, then the leading holomorphic RPV operator is $(1/X^\dagger)\mathcal{O}_{\rm hRPV}$, while the leading nonholomorphic term is $(1/X)\mathcal{O}_{\rm nhRPV}$. At this stage the two terms appear to be of the same order; however, the nonholomorphic terms might still be suppressed due to their chiral structure. For instance, the $QQ\bar{d}^\dagger$ operator will induce couplings that are suppressed by m_d/M, compared with the F_X/M^2 suppression of

$\mathcal{O}_{\rm hRPV}$. Similar conclusions are obtained for other choices of charges under $B - L$.

We therefore conclude that in the absence of additional scales, dRPV allows for either the holomorphic or the nonholomorphic RPV operators to be generated, but the nonholomorphic ones should not be neglected. Given that previous studies consider exclusively holomorphic RPV, we will study below the case when only the nonholomorphic RPV terms appear.

Before analyzing the constraints, let us briefly discuss assumption III. The inclusion of flavor dynamics implies that the various operators discussed above are suppressed according to their flavor structure. Numerous models that introduce such suppressions exist, including, for example, theories with horizontal symmetries as in FN models [10], or ones with strong interactions [13–15]. Consequently, the low energy parameters, η, η', η'', κ, and κ' are suppressed in a flavor-dependent manner. For example, the η''_{ijk}'s can take the form

$$\eta''_{ijk} \sim \epsilon^{|q_{Q_i} + q_{Q_j} - q_{d_k}|}, \tag{7}$$

where $\epsilon = O(0.1)$ is a small parameter and q_α are the various charges of the SM fields under the FN symmetry. Similar expressions hold when q_α characterize the partial compositeness in the case of an RS-type scenario. While a comprehensive study is beyond the scope of this Letter, we stress that all the constraints discussed below are easily satisfied with, for example, a simple choice of FN charges. In particular, a straightforward extension of the alignment model of Ref. [16] to the lepton sector allows for a viable dRPV model, without any additional assumption such as the typically needed lepton-number conservation. A complete realization of this scenario will be discussed in an upcoming publication [12].

Finally a remark is in order. A complete model can introduce additional spurions into the low-energy effective action (such as the one responsible for breaking the FN symmetry). An additional spurion may modify the above discussion, which is based on the existence of just two scales X and $M_{\rm Pl}$, and as a result the suppression of the holomorphic and nonholomorphic bilinear RPV operators may naively be milder. Complete models, however, will typically include additional symmetries that can forbid or suppress the operators altogether [12].

Low energy constraints.—The operators in Eq. (2) violate baryon (B) and/or lepton-number (L), in addition to the non-Abelian $SU(3)^5$ flavor symmetries of the SM. As a result, low energy bounds exist, which we derive below. As mentioned above, all these bounds are easily satisfied with the inclusion of a simple flavor model.

$\Delta B = 2$ *processes:* The η'' term in Eq. (2) violates B number by one unit. Consequently it is important to check that the bounds on $\Delta B = 2$ processes, n-$\bar{n}$ oscillations, and dinucleon decay, obtained by two insertions of this vertex, are obeyed. The simplest way is to integrate out the squarks which will generate a dimension-9 operator. While the most general flavor index structure is allowed, we here display the subset necessary for the constraints. From the leading diagrams one finds

$$\frac{1}{\Lambda_{ijk}^5}(Q_i Q_i Q_j Q_j \bar{d}_k^\dagger \bar{d}_k^\dagger), \tag{8}$$

with the suppression scale

$$\frac{1}{\Lambda_{ijk}^5} = \pi\alpha_s \frac{\eta''_{iik}\eta''_{jjk}}{m_{\tilde{g}} m^4_{\tilde{d}_{R,k}}} \epsilon_X^2. \tag{9}$$

This leads to n-$\bar{n}$ oscillations and dinucleon decay $pp \to \pi^+\pi^+$ for $i, j, k = 1$ and $pp \to K^+K^+$ for $i, j = 1$; $k = 2$.

The n-$\bar{n}$ oscillation time is approximately given by

$$\tau_{n\text{-}\bar{n}} \simeq \frac{\Lambda_{111}^5}{2\pi\tilde{\Lambda}^6_{\rm QCD}}, \tag{10}$$

where $\tilde{\Lambda}_{\rm QCD}$ is the hadronic matrix element which we estimate at 200 MeV. We find

$$\tau_{n\text{-}\bar{n}} \simeq 3\times 10^8 \text{ s}\left(\frac{m_{\tilde{d}_{R1}}}{\rm TeV}\right)^4 \left(\frac{m_{\tilde{g}}}{\rm TeV}\right)\left(\frac{4\times 10^{-2}}{\eta''_{111}}\right)^2 \left(\frac{10^{-5}}{\epsilon_X}\right)^2, \tag{11}$$

to be compared with the experimental bound $\tau_{n-\bar{n}} > 2.44 \times 10^8$ s [17].

The same operator also contributes to the dinucleon decay process $pp \to \pi^+\pi^+(K^+K^+)$. The approximate expression for the width is given by [18]

$$\Gamma \simeq \frac{8}{\pi}\frac{\rho_N}{m_N^2}\frac{\tilde{\Lambda}^{10}_{\rm QCD}}{\Lambda^{10}_{pp}}, \tag{12}$$

where $\rho_N \simeq 0.25$ fm^{-3} is the nuclear matter density and $\Lambda_{pp} \equiv \min\{\Lambda_{11k}, \Lambda_{1k1}\}$ under the assumption that only one operator dominates the process. Here $k = 1$ or 2, depending on whether the decay is to pions or kaons. The bound on the lifetime is $\tau_{pp} \geq 1.7 \times 10^{32}$ years [19] while in our model we find

$$\tau_{pp} \simeq 5\times 10^{32} \text{ yr}\left(\frac{m^8_{\tilde{d}_{R,k}} m^2_{\tilde{g}}}{\rm TeV^{10}}\right)\left(\frac{10^{-1}}{\eta''_{pp}}\right)^4 \left(\frac{10^{-5}}{\epsilon_X}\right)^4, \tag{13}$$

where $\eta''_{pp} \equiv \max\{\eta''_{11k}, \eta''_{1k1}\}$.

$\Delta F = 2$ *processes:* Within the standard model, flavor-changing neutral currents (FCNC) are absent at tree level, and highly suppressed by the GIM mechanism at one loop. Thus, FCNC observables are extremely sensitive to new physics. In models of RPV, FCNC operators are generated at tree level, with the strongest constraints obtained from the $\Delta F = 2$ neutral meson-mixing processes. If either of the operators, $Q_i \bar{u}_j L_k^*$ or $Q_i Q_j \bar{d}_k^*$, is present, neutral meson mixing is generated once the squarks and sleptons are integrated out. The corresponding operators are

$$\mathcal{Q}_1^{q_i q_j} \equiv -\frac{1}{2\Lambda_{1,ij}^2}(Q_i^\alpha Q_i^\beta)(Q_j^{\alpha\dagger} Q_j^{\beta\dagger}), \tag{14}$$

$$\mathcal{Q}_4^{q_i q_j} \equiv \frac{1}{2\Lambda_{4,ij}^2}\bar{u}_j^\alpha Q_i^\alpha Q_j^{\beta\dagger}\bar{u}_i^{\beta\dagger}. \tag{15}$$

Here the suppressions are given by

$$\frac{1}{\Lambda_{1,ij}^2} = \frac{\eta''_{iik}\eta''^*_{jjk}}{m^2_{\tilde{d}_{R,k}}}\epsilon_X^2, \qquad \frac{1}{\Lambda_{4,ij}^2} = \frac{|\eta'_{ijk}|^2}{m^2_{\tilde{\nu}_{L,k}}}\epsilon_X^2. \tag{16}$$

Taking $m_{\tilde{f}} \simeq$ TeV the bounds from neutral meson mixing are [20]

$$\begin{aligned}
&\Delta m_K: \ |\eta''_{11k}\eta''^*_{22k}\epsilon_X^2| \lesssim 10^{-10},\\
&\Delta m_D: \ |\eta''_{11k}\eta''^*_{22k}\epsilon_X^2| \lesssim 10^{-8}, \quad |\eta'_{12k}\epsilon_X|^2 \lesssim 10^{-9},\\
&\Delta m_{B_d}: \ |\eta''_{11k}\eta''^*_{33k}\epsilon_X^2| \lesssim 10^{-7},\\
&\Delta m_{B_s}: \ |\eta''_{23k}\eta''^*_{33k}\epsilon_X^2| \lesssim 10^{-7}.
\end{aligned} \tag{17}$$

All of the dRPV operators are within the above limits for $\epsilon_X = O(10^{-5})$, with or without additional flavor suppressions. We note that the operator $\mathcal{Q}_4^{d_1 d_2}$, which is strongly constrained by K-$\bar{K}$ mixing, is not generated at tree level in nonholomorphic RPV, while it is in the standard holomorphic case.

Proton decay: Perhaps the strongest constraint in RPV theories occurs in the case where both B and L are violated (or only B is violated but the gravitino is light), and as a consequence, the proton becomes unstable. The leading contribution to proton decay comes from integrating out the gluinos and gives the decays $p^+ \to (\pi^0 \text{ or } K^0)\ (e^+ \text{ or } \mu^+)$. The matrix element for the process is

$$\mathcal{M} \simeq 2\eta^*_{m\ell k}\eta''_{11k}\epsilon_X^2 \frac{\tilde{\Lambda}^2_{\rm QCD}}{m^2_{\tilde{d}_{R,k}}}, \tag{18}$$

where $m = 1(2)$ for a pion (kaon) and $\ell = 1(2)$ for electron (muon). Taking, as before, $\tilde{\Lambda}_{\rm QCD} = 200$ MeV, one finds a lifetime of order

$$\tau_p \simeq 5\times 10^{33}\ {\rm yr}\left(\frac{m_{\tilde{d}_{Rk}}}{\rm TeV}\right)^4\left(\frac{10^{-14}}{|\eta_{m\ell k}\eta''_{11k}|}\right)^2\left(\frac{10^{-5}}{\epsilon_X}\right)^4. \tag{19}$$

The above result should be compared to the relevant limit. The strongest is found for the $p \to e^+\pi^0$ decay mode, $\tau_p > 8.2\times 10^{33}$ yr [21].

Another channel for proton decay can appear if the gravitino is light, leading to the decays $p \to (\pi, K) + \tilde{G}$. The matrix element is estimated to be

$$|\mathcal{M}|^2 \sim \frac{1}{3}|\eta''_{11i}|^2\epsilon_X^2 \frac{m_p^4\tilde{\Lambda}^4_{\rm QCD}}{m^4_{\tilde{d}_i} m^2_{3/2} M^2_{\rm Pl}}, \tag{20}$$

and the corresponding lifetime is

$$\tau_p \sim 2\times 10^{33}\ {\rm yr}\left(\frac{m_{\tilde{d}_i}}{\rm TeV}\right)^4\left(\frac{M}{10^8\ {\rm GeV}}\right)^4\left(\frac{10^{-8}}{|\eta''_{11i}|}\right)^2\left(\frac{F}{F_X}\right)^2. \tag{21}$$

Here $F = \sqrt{3}m_{3/2}M_{\rm Pl}$, while F_X denotes, as above, the F term for X. In the case of a single SUSY-breaking sector one has $F = F_X$; more generally, additional sources of SUSY breaking can exist and will relax the constraint. In this case, the strongest constraint is obtained from a search for $p \to \nu K$, which gives [21] $\tau_p > 2.3\times 10^{33}$ yr.

Finally, proton decay may also result from the lepton-number-violating operators parametrized by κ, κ'. These will induce mass and kinetic mixing between the charged leptons and the charginos (via their charged higgsino components). The decay amplitude is given by

$$\mathcal{M} \simeq \eta''_{11k}\kappa_k^{\rm eff}\epsilon_X \frac{\tilde{\Lambda}^2_{\rm QCD}}{m^2_{\tilde{d}_{R,k}}}, \tag{22}$$

where $\kappa_k^{\rm eff} = \kappa_k(v_d/M) + \kappa_k\epsilon_X(m_{e_k}v_u/m_{\tilde{C}}) + \kappa'_k(M/M_{\rm Pl})$ defines the effective mixing between the electron and the chargino. The resulting proton lifetime is

$$\tau_p \simeq 3\times 10^{33}\ {\rm yr}\left(\frac{m_{\tilde{d}_{Rk}}}{\rm TeV}\right)^4\left(\frac{3\times 10^{-20}}{|\kappa_k^{\rm eff}\eta''_{11k}|}\right)^2\left(\frac{10^{-5}}{\epsilon_X}\right)^2. \tag{23}$$

Cosmology: Rapid B and L violating interactions induced by RPV operators may wash out any preexisting baryonic or leptonic asymmetry. Consequently, such processes should be highly suppressed at low temperatures. Since sphalerons, active above the weak scale, violate $B + L$, it is typically required that the RPV-induced rates are sufficiently slow above that scale. The bounds on the dRPV operators are similar to those in standard holomorphic RPV. One finds $\epsilon_X\eta \lesssim 10^{-7}$ and $\kappa_i^{\rm eff} < 10^{-6}$ where η stands for any η_{ijk}, η'_{ijk}, or η''_{ijk} [2,22,23].

As we show below, these cosmological bounds typically imply displaced decays at the LHC. Nonetheless these bounds can be easily evaded in several ways (see Ref. [2] and references therein). For example, the bounds are irrelevant if the baryon asymmetry is generated at or below the electroweak scale. Conversely, as discussed in Refs. [9,23], when a single lepton flavor number is approximately conserved the bounds can be significantly weaker.

LHC phenomenology.—The phenomenology of models with dRPV can be very different from those with R-parity conservation and even from those with traditional RPV described by Eq. (1). The details depend greatly on the identity of the lightest supersymmetric particle (LSP). Here we briefly comment on three interesting possibilities that crucially differ in their collider phenomenology from standard RPV: stop LSP, gluino LSP, and sneutrino LSP, with the first two most relevant for naturalness. Further details on these and other interesting possibilities will be given in Ref. [12].

Consider first the stop LSP. In all of the nonholomorphic operators of Eq. (2), stop decays are induced from SUSY-conserving interactions in which the stop is extracted from one of the chiral fields. As a consequence, the resulting operators in the Lagrangian all have derivative couplings and, hence, the decay rate is chirally suppressed. One finds that the dominant decay mode is typically $\tilde{t} \to \bar{b}\,\bar{b}$, with a decay length

$$c\tau_{\tilde{t}} \simeq 1 \text{ mm}\left(\frac{300 \text{ GeV}}{m_{\tilde{t}}}\right)\left(\frac{M}{10^8 \text{ GeV}}\right)^2\left|\frac{1}{\eta''_{333}}\right|^2. \quad (24)$$

Thus the stop LSP case may manifest itself uniquely as four displaced b's, where each pair reconstructs to a single displaced vertex, and the two pairs have a similar invariant mass. We stress that such decays do not exist in the holomorphic RPV scenario. The collider search for a stop LSP should be significantly altered in order to discover dRPV.

Next consider the case of a sneutrino LSP, where the LSP decay is governed by the η' couplings that induce the operators $u_{Li}u^\dagger_{Rj}\tilde{\nu}_k + d_{Li}u^\dagger_{Rj}\tilde{e}^\dagger_{Lk}$. Since the 3rd generation couplings are typically least suppressed, the leading decay mode will be $\tilde{\nu} \to t_L t^\dagger_R$ with a decay length

$$c\tau_{\tilde{\nu}} \simeq 1 \text{ mm}\left|\frac{10^{-2}}{\eta'_{331}}\right|^2\left(\frac{10^{-5}}{\epsilon_X}\right)^2\frac{165 \text{ GeV}}{\left(1-2\frac{m_t^2}{m_{\tilde{\nu}}^2}\right)\sqrt{m_{\tilde{\nu}}^2-4m_t^2}}. \quad (25)$$

For $\eta'_{331} \lesssim 10^{-2}$ this vertex will be displaced, leading to the interesting LHC signal of four displaced top quarks in the final state.

Finally, a gluino LSP decays via an off-shell stop to two bottoms and a top, $\tilde{g} \to tbb$. The decay length here is estimated at

$$c\tau_{\tilde{g}} \simeq 1 \text{ mm}\left|\frac{1}{\eta'_{333}}\right|^2\left(\frac{m_{\tilde{t}}}{400 \text{ GeV}}\right)^4\left(\frac{350 \text{ GeV}}{m_{\tilde{g}}}\right)^5\left(\frac{M}{10^6 \text{ GeV}}\right)^2. \quad (26)$$

A late decaying gluino is less constrained than a promptly decaying one. This possibility may allow for a lighter gluino to be produced at the LHC [12].

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