

Dynamical R-parity Violations from Exotic Instantons

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Abstract: We show how R-parity can be dynamically broken by non-perturbative quantum gravity effects. In particular, in D-brane models, Exotic instantons provide a simple and calculable mechanism for the generation of R-parity violating bilinear, trilinear and higher order superpotential terms. We show examples of MSSM-like D-brane models, in which one Exotic Instanton induces only one term among the possible R-parity violating superpotentials. Naturally, the idea can be generalized for other gauge groups. As a consequence, a dynamical violation of R-parity does not necessarily destabilize the proton, *i.e.* a strong fine tuning is naturally avoided, in our case. For example, a Lepton violating superpotential term can be generated without generating Baryon violating terms, and *viceversa*. This has strong implications in phenomenology: neutrino, neutron-antineutron, electric dipole moments, dark matter and LHC physics.

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1 Introduction

The possibility, that MSSM does not possess an R-parity has intriguing implications for phenomenology, in particular for LHC, baryon/lepton violations in low energy physics, neutrino mass and so on. This subject is rich with reviews and papers. See [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19], for a general overview in R-violating models.

However, as it is well known, MSSM without R-parity immediately destabilizes the proton, as well as the lightest neutralino. For the neutralino, one need not be particularly

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afraid: maybe, it could be substituted by another candidate. For example, gravitino is an alternative candidate for dark matter. On the other hand, proton destabilization is a serious problem: MSSM, without extra discrete symmetries, has to assume a very strong fine-tuning. For this reason, such a proposal seems farfetched without a deeper theoretical reason. On the other, we have learned several times in particle physics that, often, a mechanism of spontaneous or dynamical breaking of a symmetry is smarter than an explicit one. Can R-parity be spontaneously or dynamically broken, without proton destabilization?

As shown in [25, 26, 27, 30, 28, 29, 31, 32, 33, 41, 42, 34, 35, 36, 37, 38, 39], R-parity can be dynamically broken by *exotic instantons*. In particular, in intersecting D-brane models with open strings attached to D-brane stacks, exotic instantons are nothing but other Euclidean D-branes (or E-branes) wrapping differently the Calabi-Yau compactification ² (different n-cycles) with respect to physical D-branes (see [47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64] for D-brane models reproducing MSSM in the low energy limit) ^{3 4}.

In this paper, we discuss several different implications in phenomenology of exotic instantons, in the particular case of MSSM. We will show how, starting from an R-parity preserving model, one can generate specific operators in the superpotentials from exotic instantons, without generating all the possible R-violating terms! This leads to very interesting implications for LHC physics, Neutrino Physics, Dark Matter issues, Neutron-Antineutron physics, Electric Dipole moment physics, without proton decay.

2 Dynamical Generation of Bilinear and Trilinear Superpotential Terms

As first examples, let us consider a D-branes' model as the one in Fig. 1-(a)-(b)-(c). At low energy limit, these reproduce $\mathcal{N} = 1$ susy $G = U(3)_c \times Sp(2)_L \times U(1) \times U'(1) \times U''(1)$, embedding MSSM ⁵. We consider a Ω -plane in our construction. Let us remind that: i)

² However, another class of exotic instantons studied in [43, 44, 45] could lead to the same relevant effects. I would like to thank Parsa Ghorbani for useful discussions of these aspects.

³ An alternative mechanism for a dynamical R-parity violation is considered in [20, 21]. In this one, R-parity breaking is communicated from a hidden sector to our ordinary one. In this case, R-violating Kähler potentials are generated. On the other hand, another simple mechanism for a spontaneous R-parity breaking was proposed in [22, 23, 24]. This last seems intriguingly connected with our suggestion: usually, exotic instantons' effects are connected to a Stueckelberg mechanism for $U(1)_{B-L}$, as shown in publications cited above.

⁴ Let us comment that $SU(5)$ models can be embedded in D-brane models and that also in this case exotic instantons can generate R-parity violating terms. This can be an interesting reinterpretation of models like the one considered in [65]. Alternatively, one can construct 3-3-1 models, like the one in [66, 67, 68], from D-branes constructions, in which exotic instantons generate extra B/L-violating effective operators, not permitted at perturbative level. I would like to thank Luca Di Luzio and José Valle for inspiring conversations on these subjects.

⁵ $U(1)_Y = -\frac{1}{3}U(1)_3 + U(1) + U(1)' - U(1)''$ for Fig.1-(c). However, following considerations are valid for a more general class of models with different hypercharge combinations.

extra anomalous $U(1)$ s contained in G are cured by the Generalized Chern-Simon mechanism, in string theory; ii) extra Z' bosons associated to extra $U(1)$ s get masses through a Stuckelberg mechanism ⁶, typically $m_{Z'} \sim M_S$, where M_S is the string scale. These aspects are extensively discussed in [69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79]. However, the presence of Euclidean D2-branes (usually also called E2-instantons), wrapping different 3-cycles with respect to ordinary D6-branes stacks, induce extra superpotential terms not permitted at perturbative level by R-parity. Which superpotential operators? It depends on intersections of the $E2$ -instanton with ordinary D6-branes. In particular, in cases of Fig.1-(a)-(b), $E2$ -instantons have a $O(1)$ Chan-Paton group ⁷. In Fig.1-(a), we consider an E2-instanton intersecting one time with the $U(1)$ -stack, one time with $U'(1)$ -stack, one time with $Sp_L(2)$ -stack ⁸. Now, although similar calculations were made several times in the literature cited above, we will show them again for our case, for completeness. The following interactions are generated in Fig.1-(a):

$$\mathcal{L}_1 \sim C^{(1)}\beta^{(1)}H_{uA}\tau_A^{(1)} + C_i^{\prime(1)}\gamma^{(1)}L_A^i\tau_A^{(1)} \tag{1}$$

where $\beta^{(1)}, \gamma^{(1)}, \tau^{(1)}$ are fermionic zero modes corresponding to excitations of open strings attached to $U(1) - E2, U'(1) - E2$ and $Sp_L(2) - E2$ respectively; i, j are $Sp_L(2)$ indices, $A; B$ are flavor indices; $C^{(1)}, C^{\prime(1)}$ are coupling constants, coming from the disk correlators. Integrating out fermionic zero modes, we obtain

$$\mathcal{W}_1 = \int d^2\tau^{(1)}d\beta^{(1)}d\gamma^{(1)}e^{\mathcal{L}_1} = M_S e^{-S_{E2}}(C^{(1)}C_i^{\prime(1)})H_uL^i \tag{2}$$

where M_S is the string scale, $e^{-S_{E2}}$ depends on geometric moduli parametrizing 3-cycles, wrapped by the $E2$ -instanton on the CY_3 . As a consequence, a R-parity violating superpotential $\mu'_i H_u L^i$ is generated by $E2$ -instanton in Fig.1-(a), with $\mu'_i = M_S e^{-S_{E2}}(C^{(1)}C_i^{\prime(1)})$. Note that $e^{-S_{E2}}$ can be in principle $e^{-S_{E2}} \sim 1$ as well as $e^{-S_{E2}} \sim 10^{-20}$: this depends on the particular geometry of 3-cycles wrapped by $E2$ -brane. The first case corresponds to small radii of 3-cycles, the second case to very large ones. From an effective theory point of view, μ' can be assumed as a free-parameter, attending for a realistic completion of this model. Now, let us consider another case, shown in Fig.1-(b), with a different $E2$ -instanton, that we call $E2'$. In fact, intersections of $E2'$ -brane with stacks are very different with respect to the previous case. In this case, we consider $U(3) - E2', U(1) - E2', U'(1) - E2'$ intersections. In particular, we can consider $E2$ intersecting two times $U(3)$, one times $U(1)$ and $U(1)'$, with orientations shown in Fig.1-(b). Effective interactions between fermionic modulini and ordinary fields are

$$\mathcal{L}_2 \sim C_i^{(2)}\beta^{(2)}U_A^i\tau_A^{(2)} + C_j^{\prime(2)}\gamma^{(2)}D_B^j\tau_B^{(2)} \tag{3}$$

⁶ We mention that another intriguing application of Stuckelberg mechanism is considered in Massive gravity. For a study of geodetic instabilities, for a class of these models, see [46].

⁷ Such an $E2$ -instanton has to stay on a Ω^+ -plane, while for ordinary D6-branes in Fig.1-(a)-(b) are projected by an Ω^- -plane. So, our Ω -plane in Fig.1-(a)-(b) "switches" from Ω^+ to Ω^- , compatible with our quiver.

⁸ Ω -planes are introduced for cancellations of stringy tadpoles. They are important for the construction of realistic models of particle physics from open string theories [80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 86, 87, 88, 92, 93].

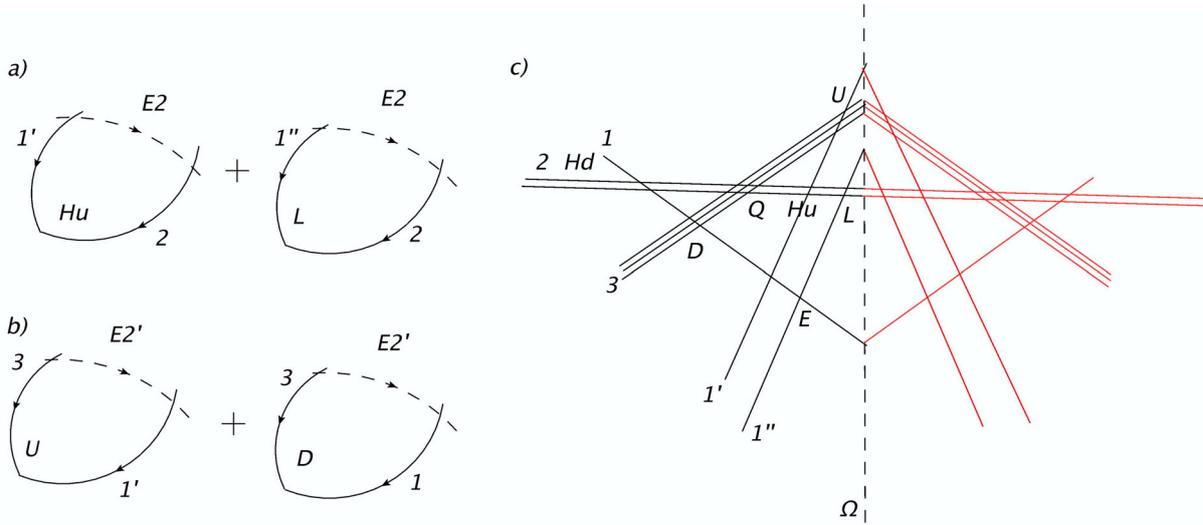


Fig. 1 a) Mixed Disk amplitude generating a bilinear term $\mu' H_u L$. b) Mixed Disk amplitude generating a trilinear term $\lambda'' U^c D^c D^c$. Notation in Figures: $U \equiv U^c$, $D \equiv D^c$, $E \equiv E^c$; 1, 2, 3 are stacks of one, two and three parallel D6-branes, with 3-cycles on the Calabi-Yau CY_3 ; in red the image of the D-branes system with respect to the Ω -plane.

and integrating out over moduli space we obtain

$$\mathcal{W}_2 = \lambda'' U^c D^c D^c \tag{4}$$

where $\lambda''_{ijk,ABC} = (C^{(2)} C'^{(2)} C''^{(2)})_{ijk} e^{-S_{E2'}} \epsilon_{ABC}$. Similarly, with other D-branes' models, we can produce other possible trilinear operators from $E2$ -branes with the appropriate intersections with ordinary $D6$ -branes. In particular, in R-violating MSSM, we can produce the following superpotentials

$$\mathcal{W}_{RPV} = \mathcal{W}_1 + \mathcal{W}_2 + \mathcal{W}_3 + \mathcal{W}_4 \tag{5}$$

with

$$\mathcal{W}_1 = \mu'_i L_i H_u \tag{6}$$

$$\mathcal{W}_2 = \lambda''_{ijk} U_i^c D_j^c D_k^c \tag{7}$$

$$\mathcal{W}_3 = \lambda_{ijk} L_i L_j E_k^c \tag{8}$$

$$\mathcal{W}_4 = \lambda'_{ijk} Q_i L_j D_k^c \tag{9}$$

where $i, j, k = 1, 2, 3$ are generation indices. One can find that $\lambda, \lambda' \sim e^{-S_{E2'', E2'''}}$, in generic MSSM D-brane models.

Let me conclude this section remarking that exotic instantons can be "not democratic" with flavors. In other words, mixed disk amplitudes like the ones generating (1)-(3), can have *i.e* matrices C, C' , parametrizing flavor hierarchies, easily reaching splitting of $10^{1\div 3}$ orders among different generations. Such a situation is possible if: i) 3-cycles (of $E2$ -instantons or of $D6$ -branes) have the same homologies but they are not identical ones; ii) 3-cycles have different homologies⁹. These aspects will have intriguing consequences for phenomenology as we will see in the next sections.

⁹ I would like to thank Massimo Bianchi for useful comments on these aspects.

3 Phenomenology

With respect to explicit R-parity violations of MSSM, we would like to remark two important aspects for phenomenology: i) $\lambda, \lambda', \lambda''$ appear with factors $e^{-S_{E2}}$, geometrically understood as $E2$ -brane wrapping 3-cycles on CY_3 . $e^{-S_{E2}}$ can be $\ll 1$ (large 3-cycles), or ~ 1 (small 3-cycles). ii) $E2$ -brane of Fig.1-(a) generates one and only one R-parity violating superpotential term (6) among all the possible bilinear and trilinear terms. On the other hand, $E2'$ -brane of Fig.1-(b) generates only (7). In explicitly R-violating MSSM one has to consider in principle all superpotential terms, not avoided by R-parity. On the contrary, a dynamical breaking generates only one or at least a subclass of all the possible superpotential terms!

Because of a situation with more $E2$ -instantons complicate D-brane constructions, in our scenario, a model with one and only one superpotential term seems simpler than another one with all possible terms in (5). As a consequence, our point of view is "inverted" with respect a model without R-parity: a situation with all superpotential terms is more complicated to be obtained, in our case.

Finally, we would like to comment the rule of supersymmetry in these mechanism. In fact, non-renormalization theorem guarantees that also after R-parity breaking, other R-parity violating superpotential cannot be generated by quantum corrections. On the other hand, possible non-holomorphic terms in the Kähler potential, generated at quantum level, may be relevant in our analysis. In particular, extra R-parity violating terms can lead to proton decay. Unfortunately, to calculate such corrections is a difficult technical problem in a realistic D-branes model. However, as commented in [35], one can reasonable assume that such corrections will be absent or at least negligible, in a class of models as the one considered here.

3.1 Neutrino Physics

Let us discuss phenomenological implications of the mixed disk amplitude in Fig.1-(a), generating only one R-parity violating term $\mu' H_u L$. In this case, Lepton number is violated, but proton is not destabilized by any other superpotential terms, as well as no-baryon violating processes are generated. In this case, neutrino-neutralino mixings are induced by Sneutrino VEVs. This leads to a see-saw mechanism, giving, at three level, a mass to one neutrino; while the second neutrino mass scale is generated by loop corrections [94, 95]. The same VEVs enter in the lightest neutralino decays $\tilde{\chi}_1^0 \rightarrow \mu j j$ [96], and chargino decays $\tilde{\chi}_1^0 \rightarrow ll, \tau ll, \bar{l} b b, \tau b \bar{b}$ [97, 98, 99]. In our model, this scenario corresponds to large 3-cycles of the Exotic Instanton involved, *i.e.* $e^{-S_{E2}} \ll 1$, assuming string scale as $M_S \simeq 10^{19}$ GeV. For a recent discussion of implications for LHC, see [100]. This case is particularly interesting also because there are not other insidious bounds from low energy physics and cosmology. For instance, sphalerons and the bilinear term not wash-out all the initial Baryon/Lepton asymmetry [101]. On the other hand, present bounds on CP-violating phases from electric dipole moments are not in contradiction with

cosmological ones [101]. We also note that in this case, neutralino cannot be a stable WIMP. However, gravitino remains a good candidate for dark matter with good relic abundance. In RPV-models, gravitino can decay into $\tilde{G} \rightarrow \gamma\nu, Z\nu, Wl, h\nu$ (depending on its mass), with possible implications in indirect detection of dark matter. See [103, 104, 105, 106, 107, 108, 109, 110, 111, 112] for several papers in gravitino dark matter without R-parity.

Another possibility is to consider a model with two $E2$ -instantons generating $\mu' H_u L$ and $\lambda' Q L D^c$. This case is also more intriguing: Majorana masses for neutrini can be generated by squarks-quark radiative corrections, with intriguing signatures for LHC and $0\nu\beta\beta$ -decay [113, 114, 115, 116, 117, 118, 119]. However, this case has more insidious bounds to avoid: i) cosmological bounds for Baryon Asymmetry in our Universe (see Appendix A); ii) constrains from mesons physics, and in particular from tree-level $K - \bar{K}$, $B_d - \bar{B}_d$ and $B_s - \bar{B}_s$ mixings [120]. As regards the cosmological bound, we will discuss this one in Subsection 3.4. As regards tree-level $B_d - \bar{B}_d$ oscillations, $\lambda'_{i1(2)3}, \lambda'_{i31(2)}$ are restricted up to $8 \times 10^{-8} (m_{\tilde{t}}/100 \text{ GeV})^2$, approximately corresponding to 10^{-6} for 300 GeV [120]. As regards $K - \bar{K}$, one can get for $|\lambda'_{i12}\lambda'_{i21}| \simeq 10^{-9} (m_{\tilde{t}}/100 \text{ GeV})^2$. In principle, we can avoid this bound considering *ad hoc* only $\lambda'_{133}, \lambda'_{233}, \lambda'_{333}$ (only b-quark is involved). This seems not justified by MSSM-like D-brane models: the three generations of Q are attached to the same stacks, as well as for the three of L , the three of D^c and the three U^c . However, coefficients coming from mixed disk correlators are in general matrices with respect to flavors, as mentioned in Section 2. So, possible hierarchies originated by mixed correlators could also provide an intriguing motivation for direct channels at LHC avoiding "B,K-bounds"! The most promising channel for LHC is associated to λ'_{111} . In our model a hierarchy of this with respect to λ_{i12}, \dots can be considered. A resonant slepton productions in $pp \rightarrow eejj, ejj + \text{m.t.e}$ [121, 122] (m.t.e. is missing transverse energy) can be envisaged, not necessary related to other bounds for other flavors. This channel can be also tested in $0\nu\beta\beta$ -decays. Finally, neutrino laboratories and astrophysics provide other interesting tests [123], compatible with signals of opposite charged leptons $ee, \mu\mu, e\mu$ at LHC.

3.2 R-violations with Very Light Neutralini

As remarked in [124, 125], a light neutralino is excluded as a Dark Matter candidate in R-parity preserving MSSM: such a stable neutralino gives an excessive quantity of dark matter as a thermal relic. However, it is not ruled-out in R-parity violating scenari. In this case a range of masses $0.7 \text{ eV} < m_{\chi_1^0} < 24 \text{ GeV}$ can be considered: the excessive part of neutralini can decay to other particles through R-violating operators, with couplings $O(10^{-6} \div 10^{-9})$. On the other hand, non-thermal processes of dark matter production, such as Q-balls' decays in Affleck-Dine scenari [126, 127, 128, 129], can strongly affect conventional calculations on DM production (thermal production). In particular, Q-balls will not disrupted by R-violating operators for a sufficient time, if the involved RPV couplings are $O(10^{-6} \div 10^{-9})$. This is an interesting range for future researches

in SHIP experiment [124, 125]. For these motivations, a scenario in which $m_{\chi_0^1} < m_{B,D}$ is intriguing. In particular, a superpotential term as $\lambda'_{i21} L_i Q_2 D_1^c$, can lead to $D^\pm \rightarrow \chi_0^1 + l_i^\pm$. On the other hand, decays like $\chi_0^1 \rightarrow \bar{K}_S^0 \nu^i, \bar{K}_L^0 \nu^i, K_S^0 \bar{\nu}^i, K_L^0 \bar{\nu}^i$ can be generated by the same operator. Analogous decays into charged Kaons can be considered, allowing $\lambda'_{i12} L_i Q_1 D_2^c$. These channels would be tested by SHiP experiment in next future [124, 125]. In fact, as mentioned above, SHIP experiment could test new RPV couplings up to 10^{-9} . We would like to stress again that the introduction of one and only one operator, among all possible R-violating ones, it is generically unnatural, while in our scenario is particularly simple to achieve as a dynamical R-parity breaking. This theoretical argument enforces motivations in favor of these kinds of RPV researches.

3.3 EDMs

Generically, a promising way to detect indirect effects of R-parity violating trilinear terms is through Electric Dipole Moments (EDMs). In fact, CP violating phases of $\mu', \lambda, \lambda', \lambda''$ have to contribute to EDMs of various baryons, nuclei, atoms and molecules. As extensively discussed in [130], Electric Dipole Moments (EDMs) of proton, deuteron, *He, Rn, Ra, Fr*, atoms, muons, and the R-correlation of neutron beta decay can constrain RPV superpotential operators (7)-(9). In fact, the imaginary parts of λ, λ' can contribute with CP violating phases to EDMs, through Barr-Zee type two-loop contributions, and four-fermion interactions. Let us define, as done in [130], relevant combinations

$$\begin{aligned} x_1 &= Im(\lambda_{311} \lambda_{322}^*) & x_2 &= Im(\lambda_{211} \lambda_{233}^*) \\ x_3 &= Im(\lambda_{(i=2,3)11} \lambda_{(i=2,3)11}) & x_4 &= Im(\lambda_{(i=2,3)11} \lambda'_{(i=2,3)22}^*) \\ x_5 &= Im(\lambda_{(i=2,3)11} \lambda'_{(i=2,3)33}^*) & x_6 &= Im(\lambda_{(i=1,2,3)22} \lambda'_{(i=1,2,3)11}^*) \\ x_7 &= Im(\lambda_{(i=1,2)33} \lambda'_{(i=1,2)11}^*) & x_8 &= Im(\lambda'_{(i=1,2,3)11} \lambda'_{(i=1,2,3)22}^*) \\ x_9 &= Im(\lambda'_{(i=1,2,3)11} \lambda'_{(i=1,2,3)33}^*) & x_{10} &= Im(\lambda'_{(i=1,2,3)22} \lambda'_{(i=1,2,3)33}^*) \end{aligned}$$

These can be constrained by current available EDM-data. For *TeV*-scale susy, the upper bounds, obtained among all data, are $|x_1| < 2 \times 10^{-4}$, $|x_2| < 2 \times 10^{-5}$, $|x_3| < 2 \times 10^{-8}$, $|x_4| < 10^{-6}$, $|x_5| < 7 \times 10^{-6}$, $|x_6| < 0.2$, $|x_7| < 2 \times 10^{-2}$, $|x_8| < 7 \times 10^{-4}$, $|x_9| < 3 \times 10^{-5}$, $|x_{10}| < 2 \times 10^{-4}$. In particular, $x_{1,2,3,4,5}$ are constrained by ThO molecule, while $x_{6,7,8,9,10}$ by neutron dipole moment.

As regards R-correlation, this can constrain $Im(\lambda_{i11} \lambda'_{i11}^*)$ up to 10^{-10} for *Hg* atom, if one assumes the dominance of only one "x".

Let us comment these results in the light of D-brane models discussed above. Simpler cases are the ones in which only one *E2*-instanton generate only one bilinear or trilinear operator. In this cases, mixed combinations as $x_{4,5,6,7}$ are previewed to be zero. As a consequence, D-brane models for λ -couplings seem to be disfavored with respect to λ' -models, by EDMs data.

3.4 B-violating Physics without Proton Decay

Now, let us discuss the class of models with only λ'' -terms. In this case, proton is not destabilized: lepton number is conserved, avoiding $p \rightarrow l^+\pi^0, K^+\bar{\nu}, \dots$. However, the strongest limits are placed by dinucleon decays $NN \rightarrow KK, n-\bar{n}$ transitions and $n \rightarrow \Xi$. In particular, assuming $M_{susy} = 1$ TeV, (or more precisely squarks masses around 1 TeV), we can get approximately: $|\lambda''_{112}| \sim |\lambda''_{11k}| \sim 10^{-6}$. Geometrically, this corresponds to an $E2$ -instanton with large 3-cycles. On the other hand, as discussed in the previous section, mixed disk amplitudes are not necessary "democratic" with generations: matrices with flavor indices emerge, and they can create hierarchies between $\lambda''_{ijk} \sim C_i^{(2)}C_j^{(2)}C_k^{(2)}$. For each coefficient of matrices $C^{(2)}$ and $C'^{(2)}$, hierarchies of $10 \div 10^3$ could be considered. As a consequence, researches of direct signatures at LHC as B-violating decays can be interesting. In particular, processes like $\tilde{t} \rightarrow \bar{d}_j\bar{d}_k$ can be searched and well constrained, especially under the hypothesis of Long-Lived superparticles. For example, as shown in [133], for $\lambda''_{312} \sim 10^{-8}$ and $c\tau \sim 10^{-1} \div 1$, limits on $m_{\tilde{t}}$ arrives to $\simeq 900$ GeV. Similar limits are obtained for λ''_{333} . Another possible decay channel in the case of a gluino LSP could be $\tilde{g} \rightarrow \tilde{q}q \rightarrow jjj$ where $U^cD^cD^c$ operator split one squark into two quarks. In this case, regions of the parameters are also more constrained than $\tilde{t} \rightarrow \bar{d}_i\bar{d}_j$ [133]. Alternatively, Higgsino three-body decays $\tilde{H} \rightarrow jjj$ can be also considered. In this case, limits are milder than the gluino-case [133].

3.5 Cosmological Bounds on Three Linear Superpotential Terms

In this section, we would like to briefly remind cosmological bounds on (7)-(8)-(9), from Baryogenesis and Leptogenesis. We also would like to mention possible ways-out. This can be important for direct researches at LHC.

Suppose to generate a Baryon or Lepton asymmetry in the primordial Universe before the electroweak phase transition $E \gtrsim 100$ GeV. Under this quite generic hypothesis, we can put strong bounds on R-parity violating operators. In fact, they not conserve $B-L$. As a consequence, R-parity violating processes wash-out $B-L$ component, while sphalerons wash out the $B+L$ one; *i.e* any initial matter-antimatter asymmetry will be washed out! This leads to the upper bounds [134, 135, 136]

$$\lambda_{ijk}, \lambda'_{ijk}, \lambda''_{ijk} < 5 \times 10^{-7} \sqrt{\frac{M_{SUSY}}{1 \text{ TeV}}} \quad (10)$$

Clearly, these bounds have a possible way-out relaxing the initial assumption: one can assume a Post-Sphaleron mechanism for baryogenesis. However, here, we would like to suggest another possible idea as a sting-inspired way-out, alternative to Post-Sphalerons scenari: it is possible that λ' , has grown during the cosmological time as a "dynamical degree of freedom", from a small value $\lambda' < 10^{-7}$ up to a higher value reached in the present epoch $\lambda' \gg 10^{-7}$. In fact, in string-theories, all coupling constants depend on moduli, stabilized by non-perturbative effects like fluxes and instantons. But it is possible that λ' can be stabilized not as a constant value but as a "solitonic solution" $\lambda'(t)$ with

respect to the cosmological time t . The solitonic solution can connect two asymptotic branches $\lambda'(t < t_{early}) < 10^{-7}$ and $\lambda'(t \gg t_{early}) \gg 10^{-7}$. This hypothesis can be constrained by BBN bounds, strongly depending on the particular working hypothesis for the R-violating MSSM space of the parameters: sparticles decays could ruin the right ratio of nuclei. Conservatively, one can assume $\lambda'(t < t_{BBN}) \simeq \lambda'(t < t_{early}) < 10^{-7}$, in order to avoid any possible insidious constraints from BBN. However this issue deserves deeper investigations beyond the purposes of this paper.

4 Phenomenology for $M_{SUSY} \gg 1$ TeV

In our class of effective models, we cannot predict the susy breaking scale. It is undoubtable that MSSM is not in a good status after the first run of LHC. In TeV-scale susy, this favors R-parity violating MSSM with respect to R-preserving MSSM (more parameters). However, the next run of LHC will definitely test both MSSM scenarios. On the other hand, we cannot ignore the possibility that susy could be not linked to the hierarchy problem of the Higgs mass! In fact supersymmetry could be important for other fundamental issues such as neutrino masses, baryon and lepton violations and consistency of string theory^{10 11}. We would like to note that for $M_{susy} \gg 1$ TeV, R-parity violating MSSM remains still alive in phenomenology. For instance, assuming $\lambda \sim \lambda' \sim 1$ immediately we can put limits on M_{susy} around the Planck scale, from proton decay limits. In D-brane models, in which one $E2$ -instanton generate only one R-parity violating bilinear or trilinear superpotential, a $M_{susy} \gg 1$ TeV scenario can remain interesting. In these cases, proton decays will be avoided if $\lambda, \lambda', \lambda''$ are not contemporary generated by the D-brane models, *i.e* the correspondent three $E2$ -instantons are not contemporary introduced. In construction with one and only one among the possible bilinear and trilinear superpotentials, limits on sparticles masses are much smaller than $M_{Pl} \simeq 10^{19}$ GeV. As seen above, a situation in which $\lambda, \lambda', \lambda'' \sim 1$ is geometrically understood as $E2$ -instantons wrapping 3-cycles with small radii, on the CY_3 . For example, let us consider the case shown in Fig.1-(b), corresponding to a λ'' -model. Supposing for example all $\lambda'' \sim 1$, we can put an indirect bound on susy breaking scale from dinucleon decays, neutron-antineutron transitions and $n \rightarrow \Xi$, approximately corresponding to $M_{susy} \simeq 10^2 \div 10^3$ TeV (supposing squarks masses approximately equal to the susy breaking scale). The next generation of experiments in neutron-antineutron oscillations

¹⁰ Let us mention that in contest of non-local quantum field theories, supersymmetry seems an important element in order to cancel an infinite number of acausal divergences coming from F-terms [137]. In order to realize such a mechanism, susy can be broken at Λ_{NL} (effective Non-locality scale), supposed to be the Planck scale. On the other, divergences of D-terms remain uncured: susy is not a complete solution of the problem. In [138], we also would like to mention that, recently, we have shown how the formation of a classical configuration in ultra-high energy scatterings could unitarize and causalize a non-local QFT.

¹¹ In this case, an alternative dark matter candidate to neutralino could be provided from a parallel intersecting D-branes' world. If the vev scale of this world is different form the vev scale of our ordinary one, a non-collisional dark halo, composed of dark atoms, can be obtained. A discussion of theoretical aspects and direct detection implications can be found in [139].

promise to test the 10^3 TeV scale [148]. EDMs are other possible indirect test for this scenario. For example, the neutron electric dipole moment would be a good way to test PeV Scale Physics, in next future [132].

5 Higher Order Superpotential Terms and Further Implications in $n - \bar{n}$ Oscillations

In previous sections, we have discussed R-parity violating bilinear and trilinear superpotentials. However, Exotic instantons can generate higher order superpotential terms without generating at all bilinear and trilinear superpotential terms! Examples are the ones considered in Fig.1-(a)-(b). The first one, as suggested in [26], can directly generate a Weinberg operator for neutrino masses $\mathcal{W}_4 = H_u L H_u L / \Lambda_4$. In fact, in the case of fig.1-(a), we can consider the same mixed disk amplitudes, but with an $E2$ -instanton intersecting two times relevant D-brane stacks. Here, we suggest Fig.1-(b) can generate $\mathcal{W}_5 = (U^c D^c D^c)^2 / \Lambda_5^3$, and consequently a Majorana mass for neutrons. However, there is an important difference with respect to previous cases: $\Lambda_{4,5} \sim e^{+S_{E2^{(IV)}, E2^{(V)}}} M_S \geq M_S$. As a consequence, superpotentials like $\mathcal{W}_{4,5}$ are too much suppressed for phenomenology if, as usual, M_S is only slightly smaller than the Planck scale. However, they can become interesting in low string scale scenario [140, 141, 142, 143, 144]¹². For example we can envisage a $\Lambda_5 \simeq M_S \simeq 10^3$ TeV (small 3-cycles of $E2^{(V)}$ -instanton). Also in this case, exotic instantons generate a neutron-antineutron transition testable in the next future [148, 149]. As an alternative, one can generate analogous superpotentials like $\mathcal{W}_6 = Q Q D^c Q Q D^c / \Lambda_6^3$, also leading to a neutron-antineutron transition. In particular, from $\mathcal{W}_{5,6}$ we obtain the relevant New Physics (NP) scale $\mathcal{M}_{5,6}^5 = \Lambda_{5,6}^3 m_{\tilde{g}}^2$, where $m_{\tilde{g}}$ is the gaugino mass (gluino, zino or photino) for operators $\mathcal{O}_{n\bar{n}} = (u_R d_R d_R)^2 / \mathcal{M}_5^5$ and $\mathcal{O}_{n\bar{n}} = (q_L q_L d_R)^2 / \mathcal{M}_6^5$. As a consequence, neutron-antineutron bounds can be satisfied, for example, for $m_{\tilde{g}} \simeq M_S \simeq 1000$ TeV, for $e^{+S_{E2}} \sim 1$ (small 3-cycles of $E2$ -instanton on CY_3). Alternatively, compatible with TeV-scale susy, $m_{\tilde{g}} \simeq 1$ TeV and $\Lambda_{5,6} \simeq 10^5$ TeV can also satisfy neutron-antineutron bounds¹³.

6 Conclusions and Remarks

In this paper, we have shown how R-parity can be dynamically broken by Exotic Instantons in a simple, calculable and controllable way, in a class of D-brane models. We have discussed explicit examples of intersecting D-branes, generating a RV bilinear or trilinear terms in the superpotential. We have stressed how one $E2$ -instanton generates one and only one bilinear or trilinear term, without generating the other ones. In this sense, a dynamical breaking of R-parity is radically different with respect to an explicit one. In fact, in explicitly R-violating models, in principle one has to consider all possible

¹² See [145, 146, 147] for recent papers about the case of $1 \div 10$ TeV quantum gravity.

¹³ Neutron-Antineutron oscillation could be also a probe for CPT symmetry [150] and new fifth force interactions [151].

R-violating operators in the superpotential, *i.e.* a strong fine-tuning is necessary in order to avoid proton decay. This unnatural situation is avoided in an elegant way in D-brane models. Another important feature of Exotic instantons is that they are not necessary "democratic" with flavors, depending on the particular topology of the mixed disk amplitude. This can enforce reasons for direct tests at LHC, avoiding a lot of indirect bounds from meson physics, FCNCs and so on. In addition, we have also commented the possible generation of higher dimensional operators in the superpotential, dynamically breaking R-parity, without generating bilinear or trilinear ones. In several different scenarios, we have discussed phenomenological implications in neutrino physics, neutron physics, EDMs, Dark Matter and LHC. We conclude that string theory provides powerful tools for phenomenology of Baryon and Lepton number violations: exotic instantons could be key elements for the understanding of many aspects of fundamental physics.

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