Collective RPV

work in progress with,
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November 9, 2011
Davis Hidden SUSY Party

what I told you yesterday about fine tuning in susy:

- If the squarks have a flavor symmetric boundary condition, then

$$m_{\tilde{q}} \gtrsim \text{TeV}$$

leads to ~1% fine tuning

- But if the squarks are split, the relevant (theorist-extrapolated) limits are:

$$m_{\tilde{H}} \gtrsim 100 \text{ GeV}$$
$$m_{\tilde{t}} \gtrsim 300 \text{ GeV}$$
$$m_{\tilde{g}} \gtrsim 700 \text{ GeV}$$

only ~1/3 fine tuning!

M. Papucci, JTR, A. Weiler 1110.6926

- so right now the situation isn't so bad!

  (except for flavor-symmetric theories)

- but if the LHC continues not to find SUSY, eventually the vanilla R-parity conserving scenario is going to look a lot less interesting

the plan:

1. review of regular RPV

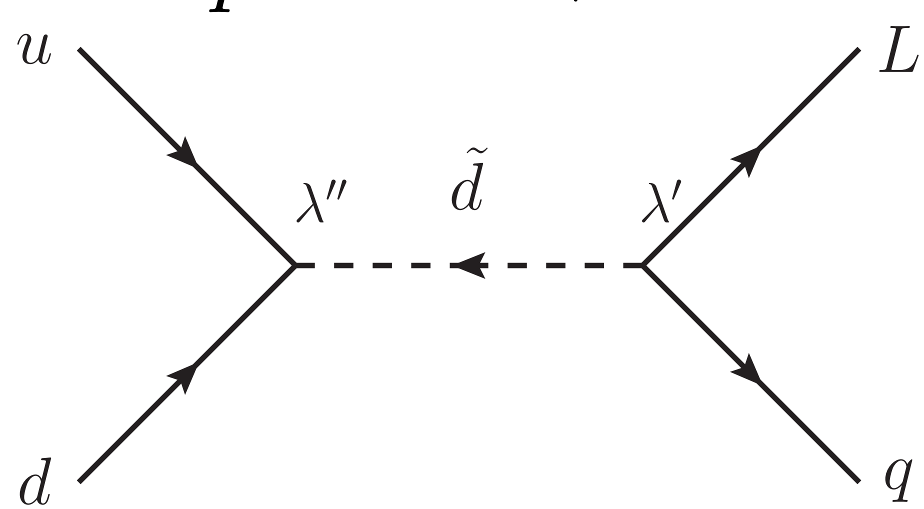
2. collective RPV

regular RPV

$$W \supset \kappa\, L H_u + \lambda\, L L e + \lambda'\, L Q d + \lambda''\, u d d$$

to avoid proton decay, we want baryon number violation or lepton number violation, but not both

$$p \to e^+ + \pi^0$$



$$\lambda'_{11k}\, \lambda''_{11k} \lesssim 10^{-27}$$

to hide SUSY, it makes sense to avoid leptons and focus on baryon number violation:

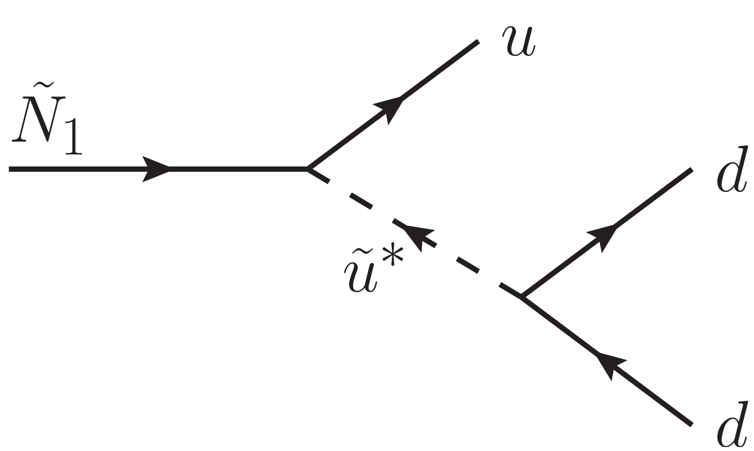
$$W \supset \lambda''_{ijk}\, u_i d_j d_k$$

$$W \supset \lambda'' udd$$

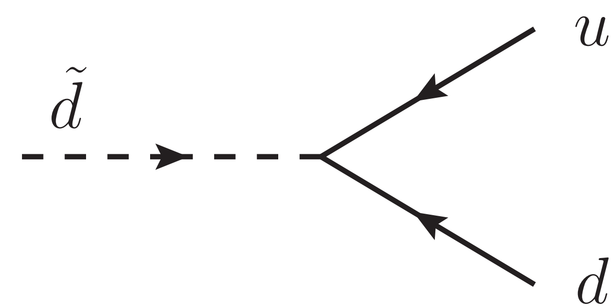
with udd, the final state involves a lot of jets.

depending on the LSP,

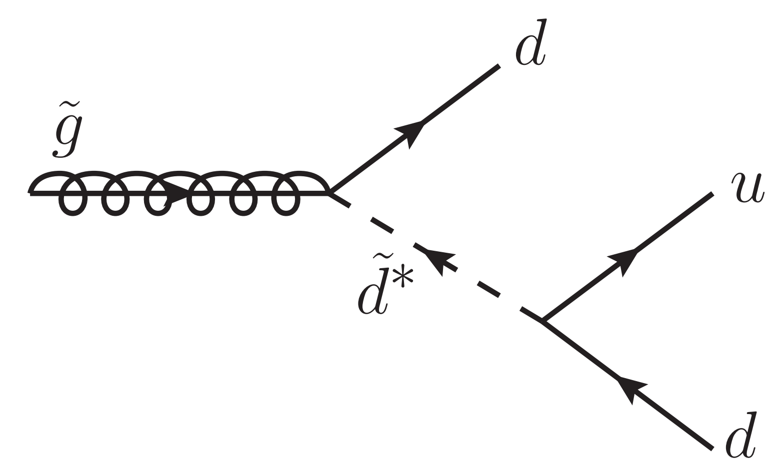
$\tilde{N}_1 \to 3j$



$\tilde{q} \to 2j$



$\tilde{g} \to 3j$

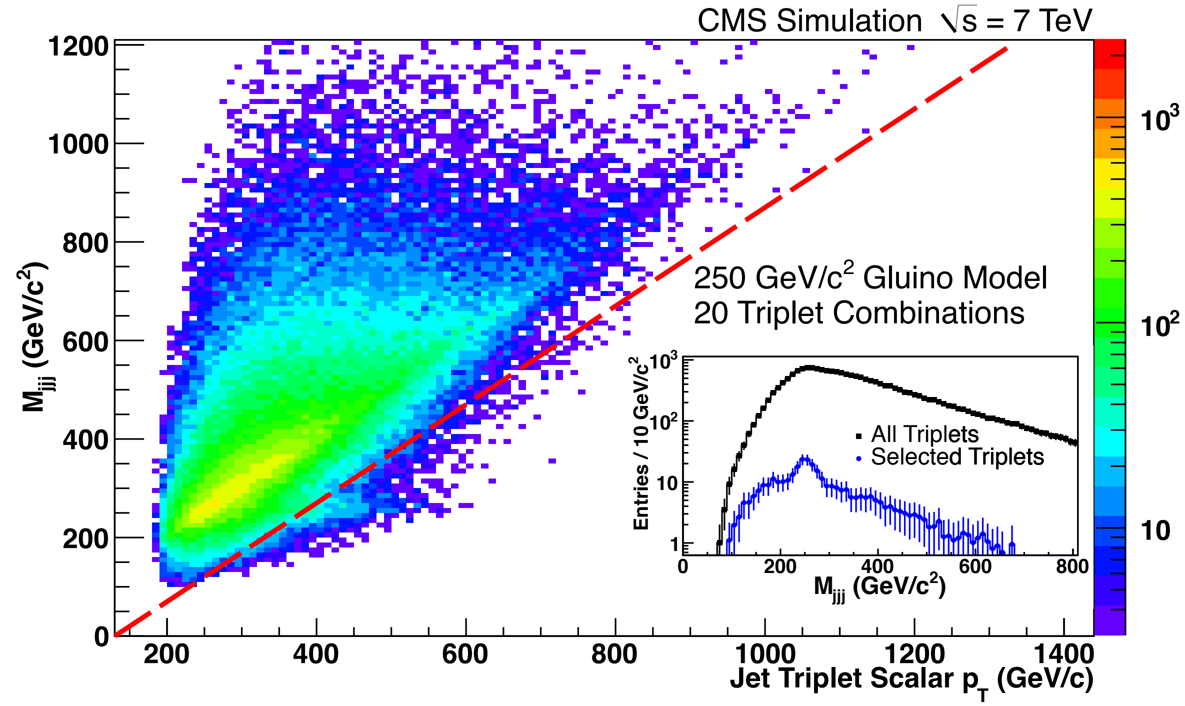


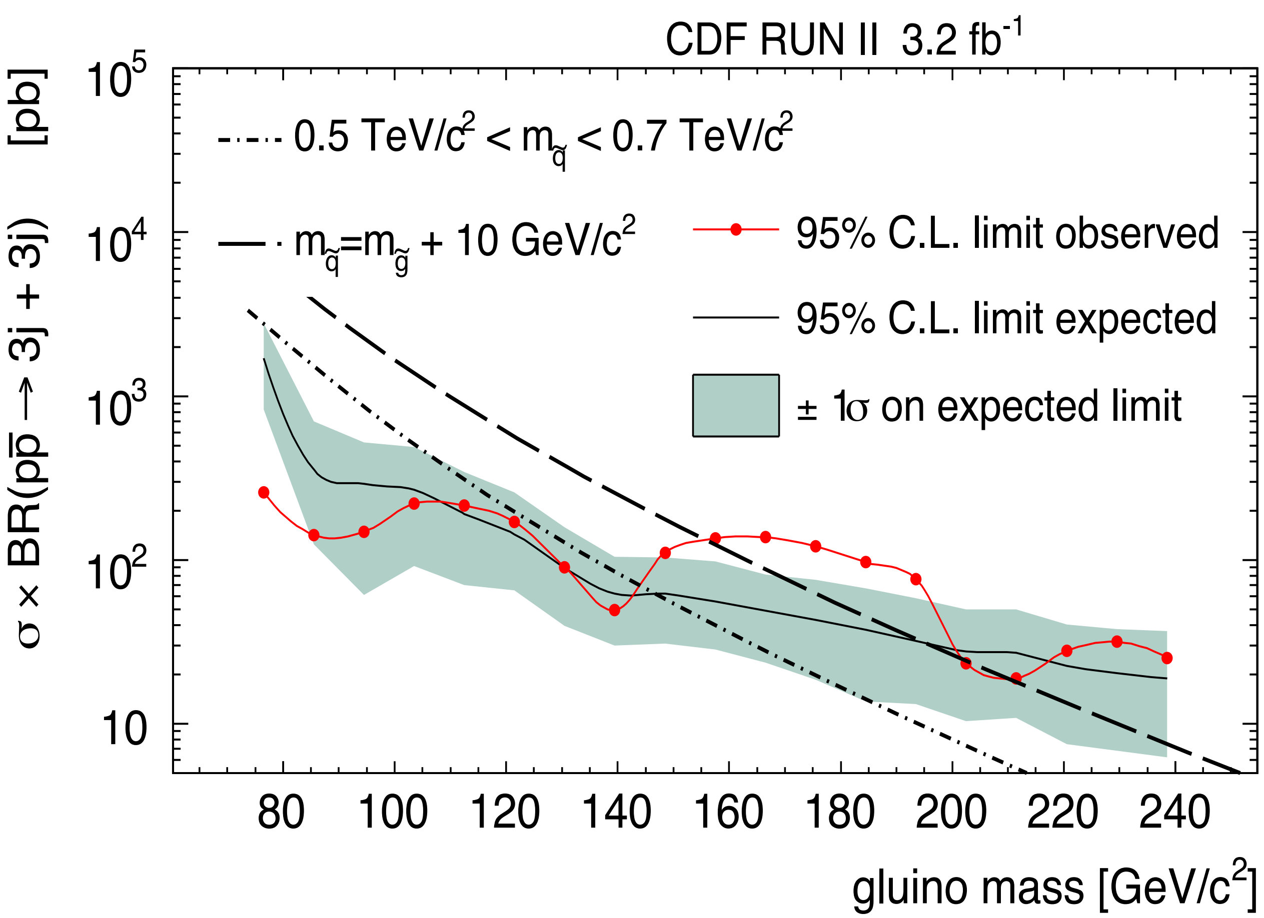
3j resonances have been searched for by CDF and CMS

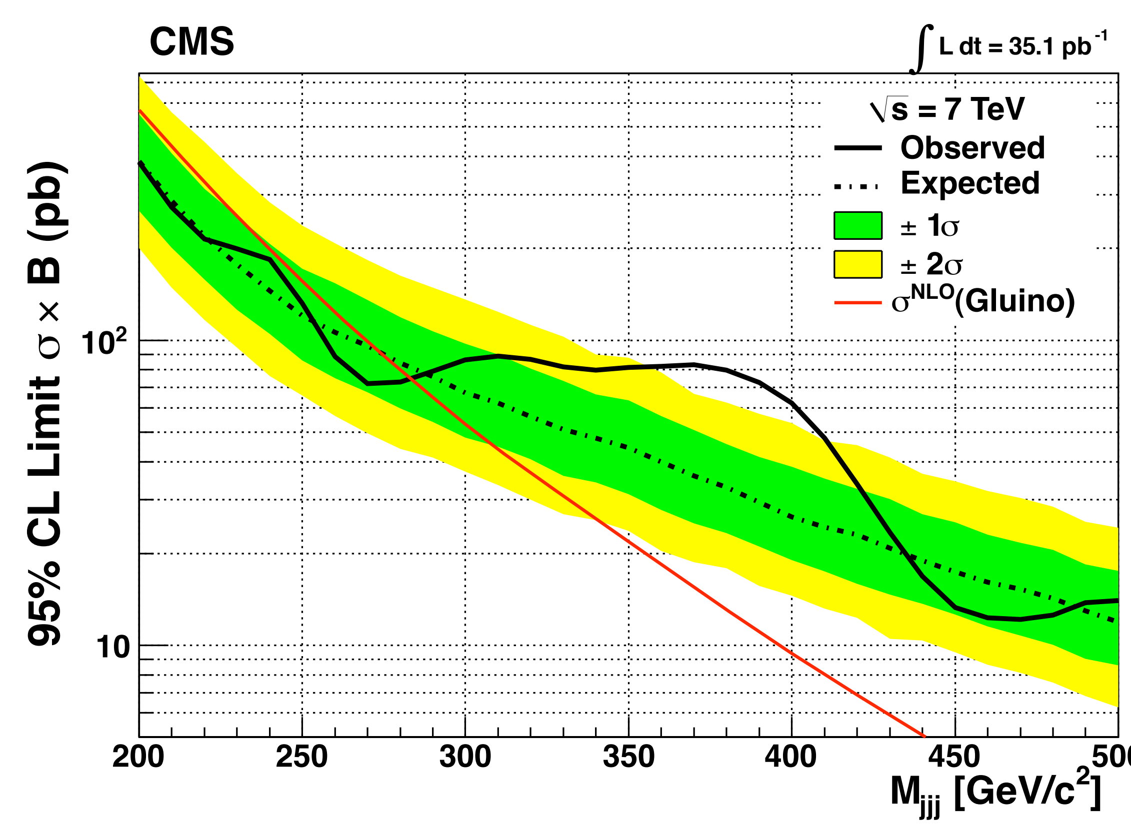
$$\tilde{g} \to 3j$$

using a technique suggested in Rouven Essig's thesis

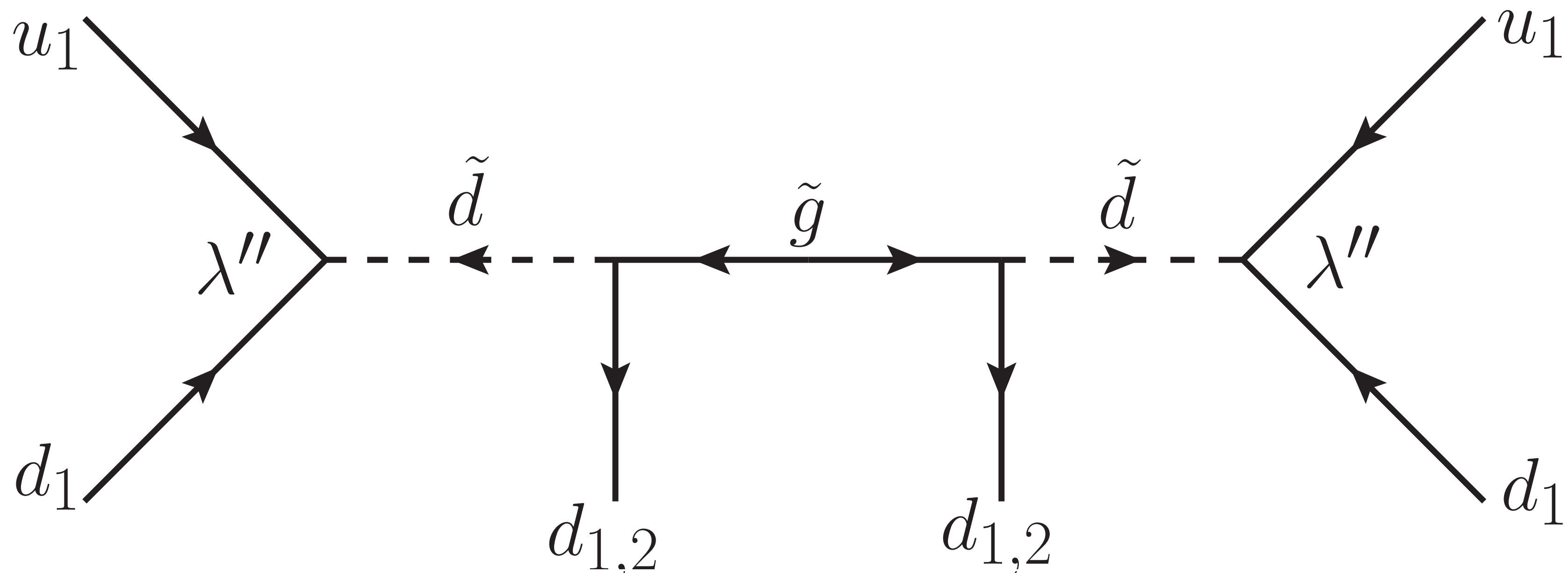
$$\Sigma_j |p_T| > M_{jjj} + c$$







there is a problem: baryon number violation is dangerous!



$N - \bar{N}$ oscillations:

$$\lambda''_{11k} \lesssim 10^{-8} \left(\frac{\tilde{m}}{100 \text{ GeV}} \right)^{5/2}$$

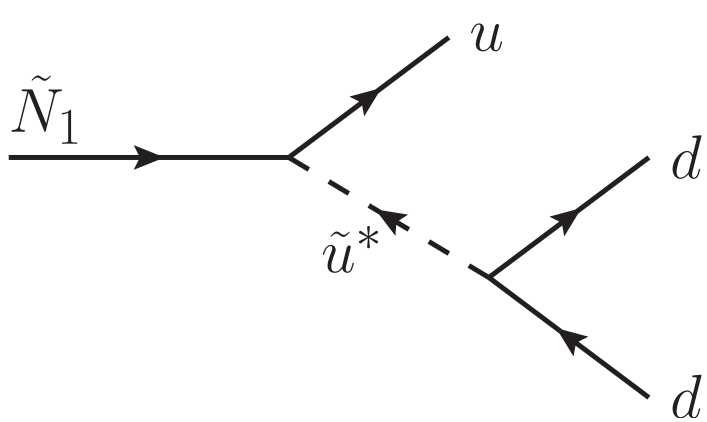
double nucleon decay:

$$p + p \to K^+ + K^+$$

$$\lambda''_{112} \lesssim 10^{-7} \left(\frac{\tilde{m}}{100 \text{ GeV}} \right)^{5/2}$$

from $^{16}O \to ^{14}C + K^+ + K^+$

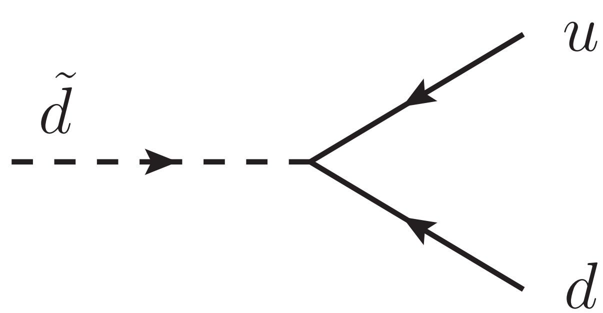
- there is tension between baryon number violation and keeping decays inside the collider



$$\Gamma_3 \approx \frac{g^2(\lambda'')^2}{(4\pi)^3}\frac{m_{N_1}^5}{m_{\tilde{q}}^4}$$

$$c\tau_3 \approx 30\ \text{cm}\left(\frac{\lambda''}{10^{-6}}\right)^2 \qquad \begin{aligned} m_{\tilde{N}} &= 100\ \text{GeV} \\ m_{\tilde{q}} &= 200\ \text{GeV}\end{aligned}$$

- the tension is ameliorated (but still present) if a right-handed squark is the LSP,



$$\Gamma_2 \approx \frac{(\lambda'')^2}{8\pi} m_{\tilde{q}} \qquad c\tau_2 \approx 30\ \text{cm}\left(\frac{\lambda''}{10^{-8}}\right)^2$$

- this means RPV needs a special flavor structure (can be MFV, see: Nikolidakis and Smith 2007, Ben's talk...), or something else...

collective RPV

- what if the MSSM preserves R-parity, and first learns about RPV by interacting with new fields?

- for example, let's add new vector-like quarks with the quantum numbers of the right handed quarks

$$W \supset M_D \, D\bar{D} + M_U \, U\bar{U}$$

- multiple interactions are needed to see that R-parity is violated:

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$$W \supset \lambda_1 \, udD$$

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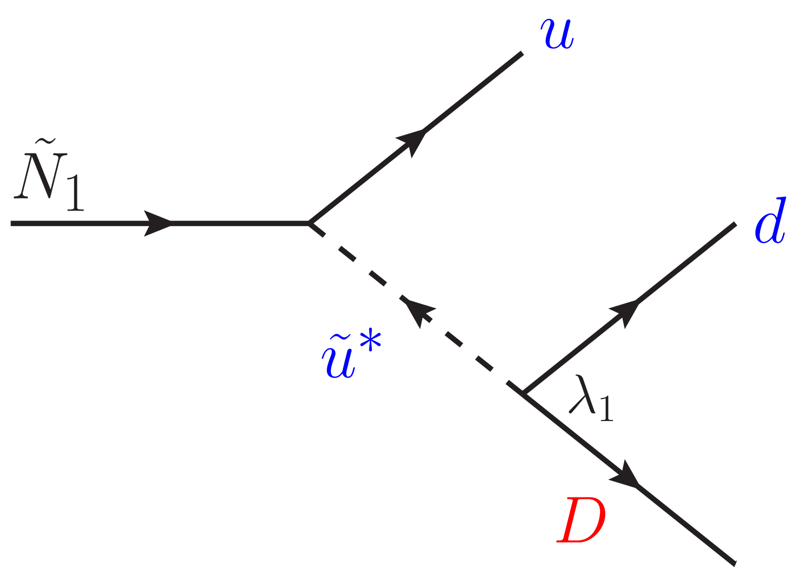
collective RPV

$$W \supset \lambda_1\, udD + \lambda_2\, UdD + \lambda_3 Udd$$

- any decay from a superpartner to SM fields must use all three couplings



- but only one couplings needs to be probed at a time, if the decays are sequential

$$m_{\tilde{N}_1} > m_D > m_{\tilde{U}}$$

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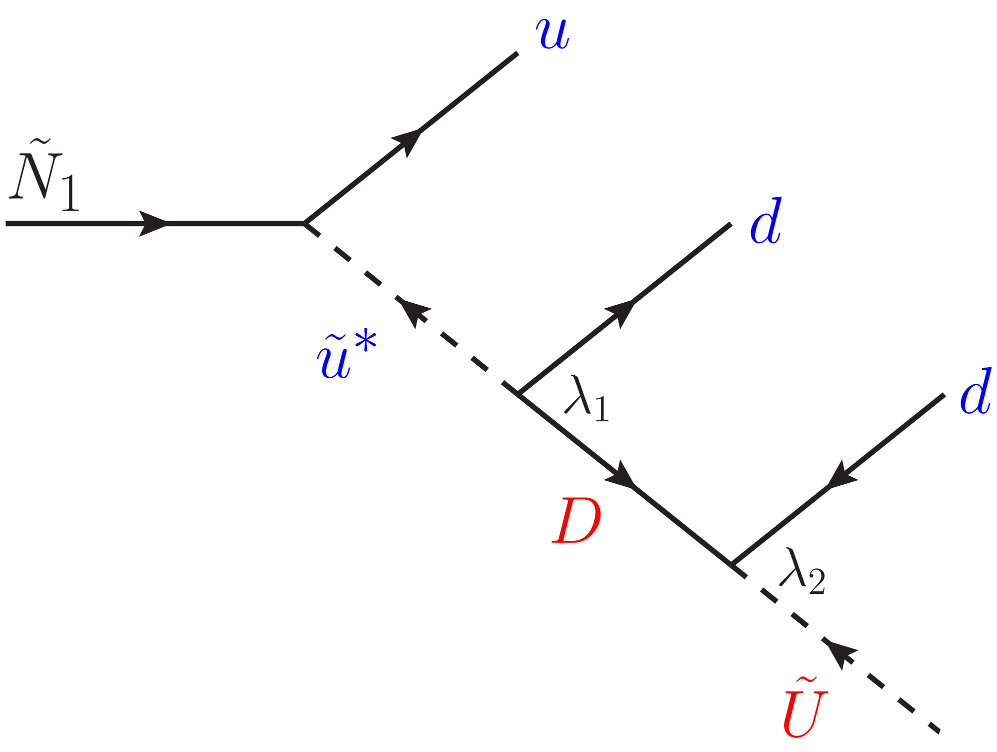

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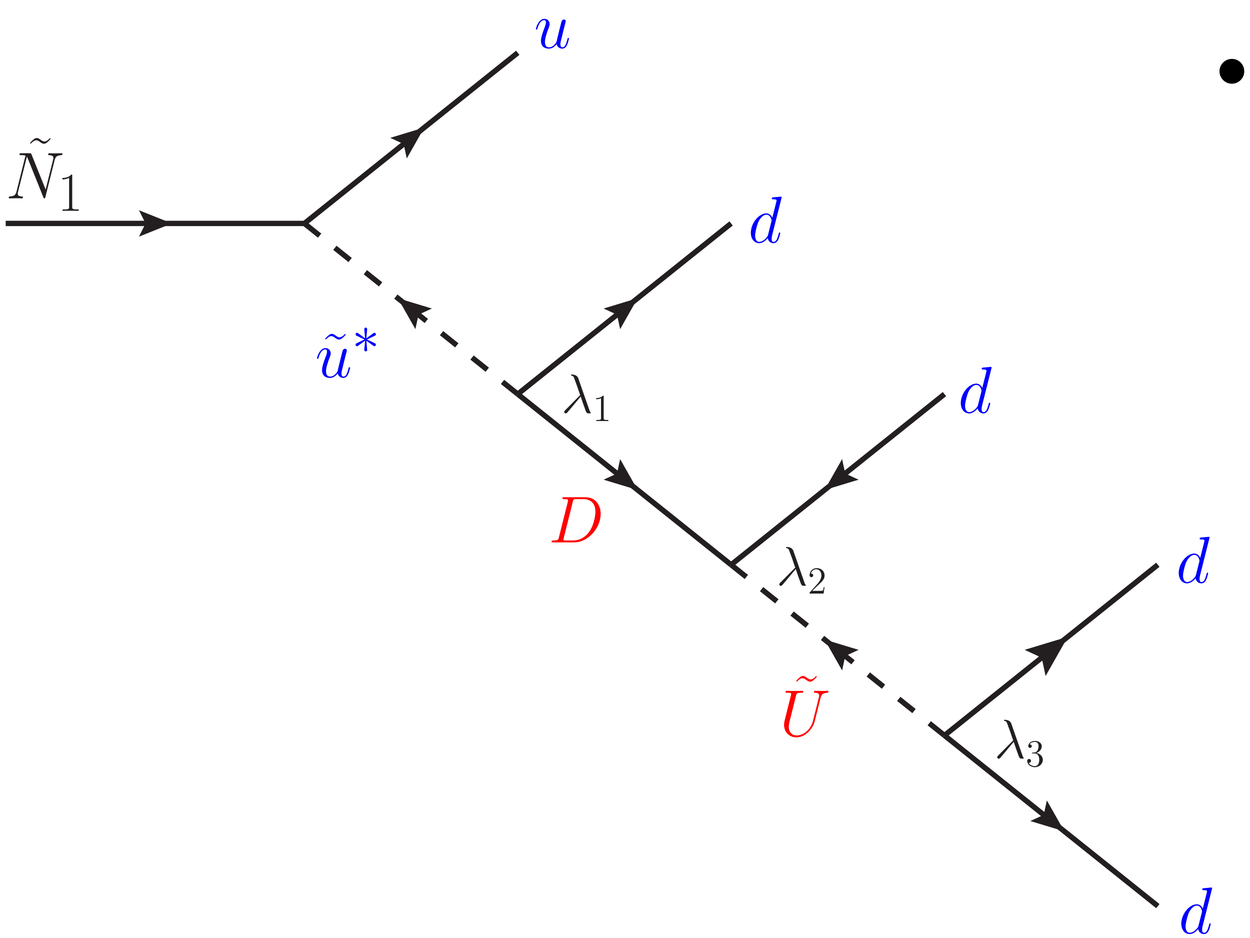

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$$m_{\tilde{N}_1} > m_D > m_{\tilde{U}}$$

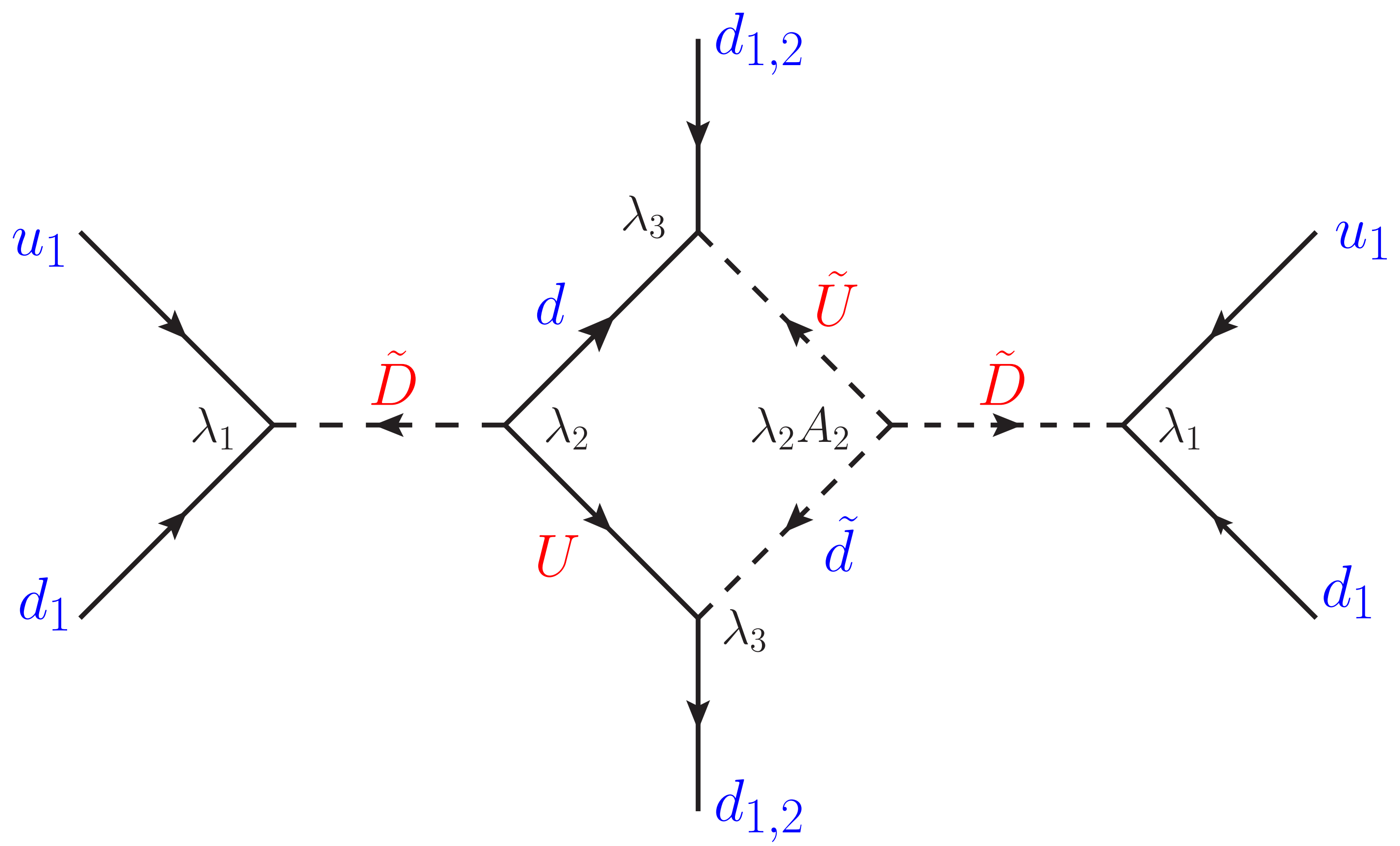
- probing more couplings means higher-multiplicity final states:

$$\tilde{N}_1 \to 5j$$

baryon-number violation

- the "collectivity" means that any baryon number violating process must use all three couplings at once.

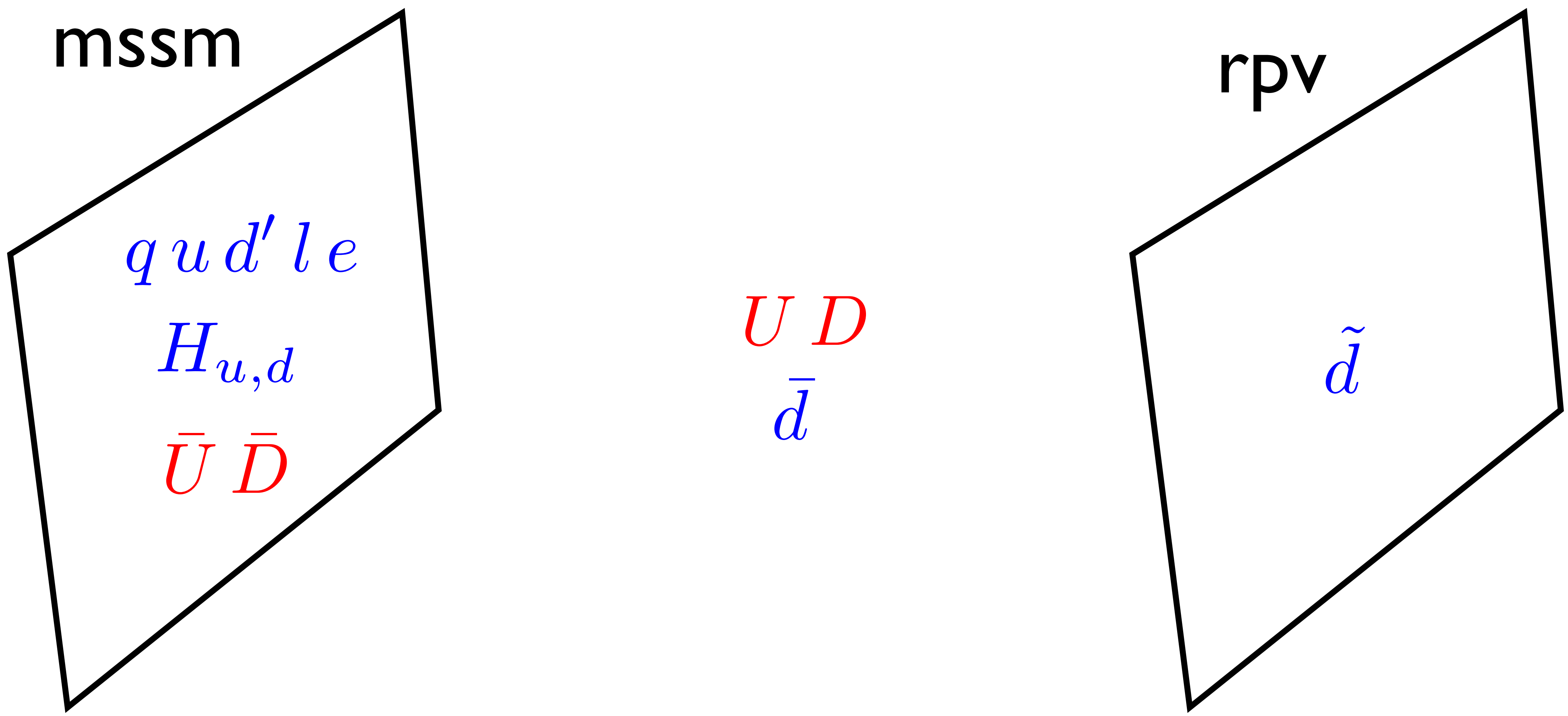
$$iM_{\Delta B} \propto (\lambda_1\lambda_2\lambda_3)^{|\Delta B|}$$



$$\lambda_1\lambda_2\lambda_3 \lesssim 10^{-7}\left(\frac{\tilde{m}}{100\ \text{GeV}}\right)^{5/2}\left(\frac{100\ \text{GeV}}{A_2}\right)$$

- easy to satisfy with flavor-generic couplings and prompt decays

geometrical origin: can originate from an RPV-brane



$$W_{MSSM} \supset udD + Udd + M_U U\bar{U} + M_D D\bar{D} + m_1 d\,\bar{d}$$

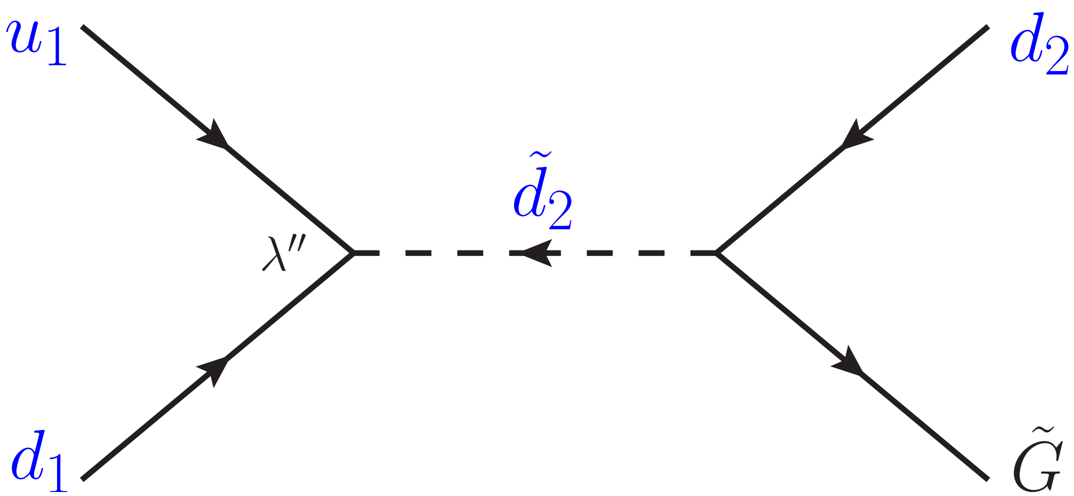
$$W_{RPV} \supset UD\tilde{d} + m_2\,\tilde{d}\bar{d}$$

- one linear combination of $(d', \tilde{d})$ remains massless and will be d

- integrating out the orthogonal mode gives: $W \supset udD + Udd + UdD$

Normally, hadronic RPV is a disaster for low-scale SUSY breaking,

$$p \to K^+ + \tilde{G}$$



$$\lambda''_{112} \lesssim 6 \times 10^{-17} \left(\frac{m_{3/2}}{\text{eV}}\right) \left(\frac{m_{\tilde{d}}}{100\ \text{GeV}}\right)^2$$

Choi, Chun, Lee 1996

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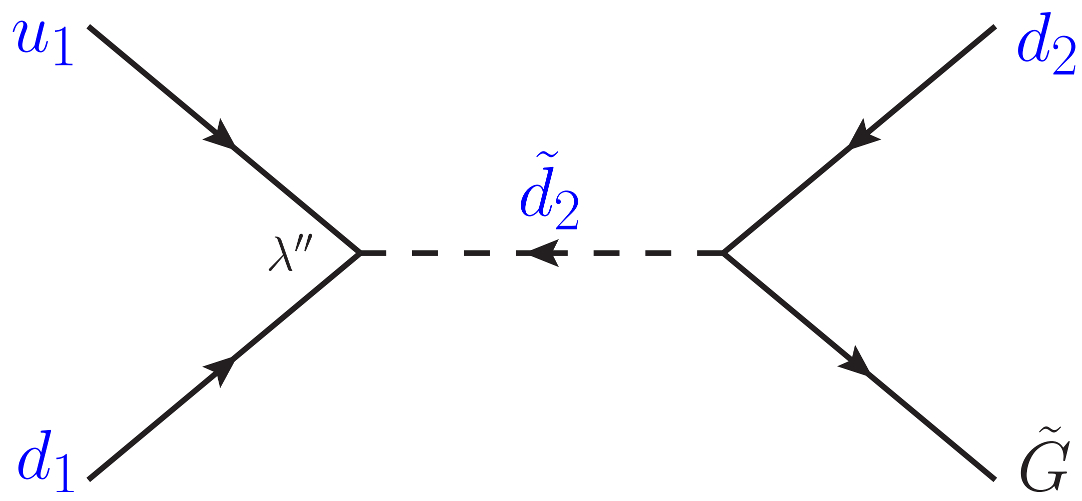

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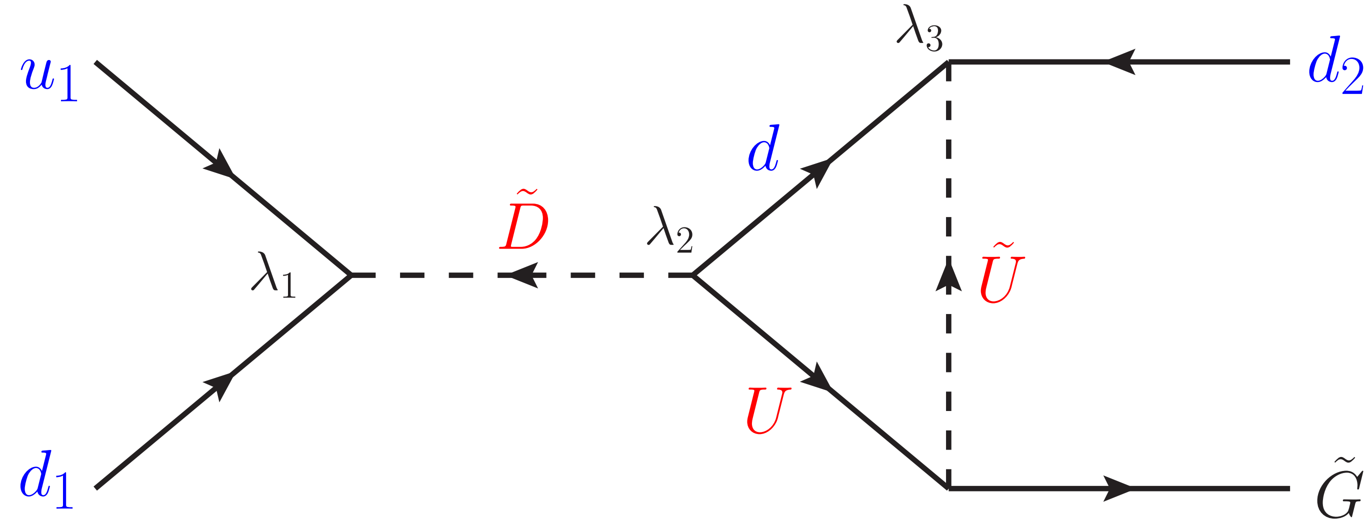
Choi, Chun, Lee 1996

but collectivity saves the day!



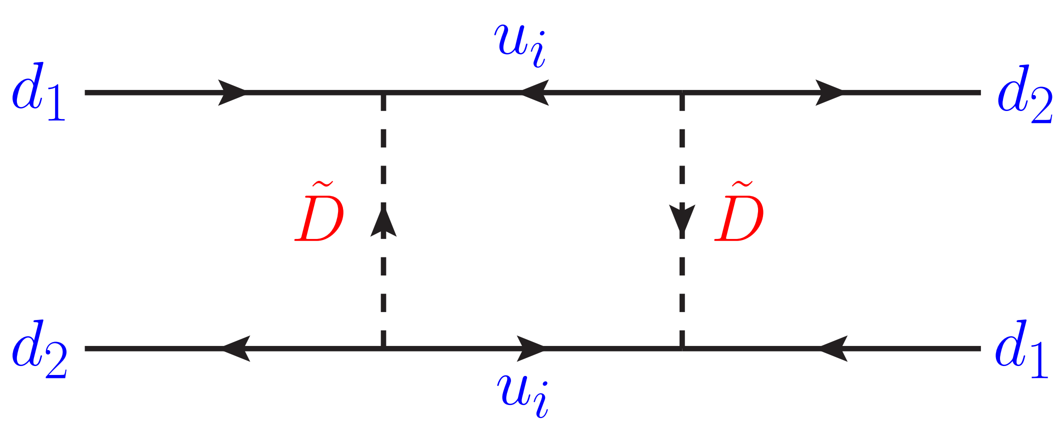
$$\lambda_1 \lambda_2 \lambda_3 < 10^{-16} \left(\frac{m_{3/2}}{\text{eV}}\right) \left(\frac{6}{\log \Lambda/\tilde{m}}\right) \left(\frac{\tilde{m}}{100\ \text{GeV}}\right)^2$$

flavor

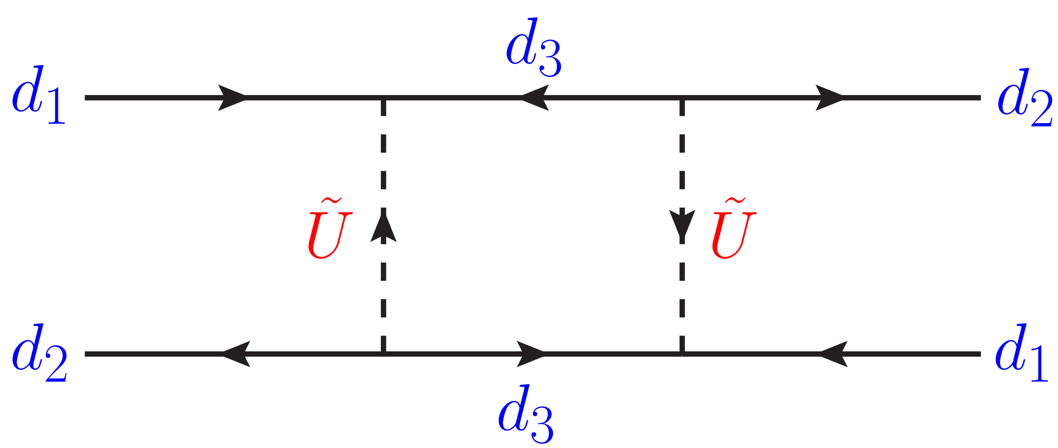
$$W \supset \lambda_1\, udD + \lambda_2\, UdD + \lambda_3 Udd$$

- The strongest constraints on the individual couplings λ_1, λ_3 come from flavor

$K - \bar{K}$ mixing:



$$\lambda_1^{1i}\lambda_1^{2i} \lesssim 10^{-4}$$

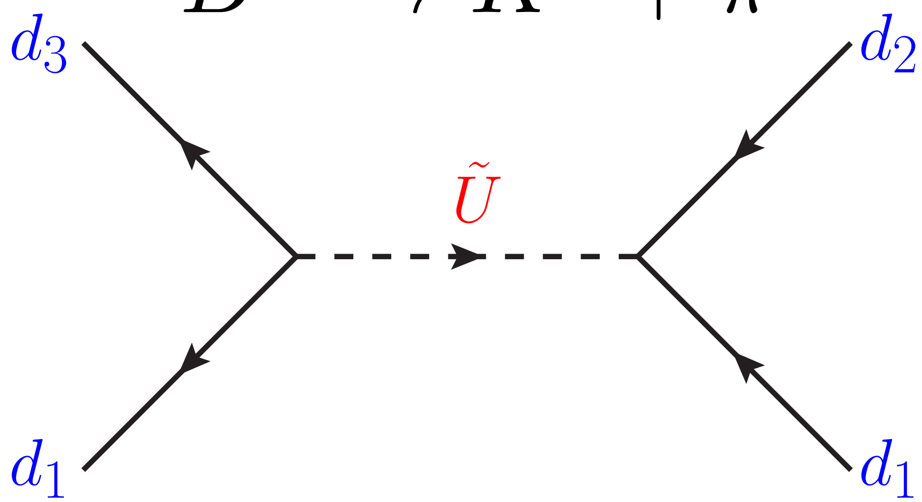


$$\lambda_3^{13}\lambda_3^{23} \lesssim 10^{-4}$$

flavor

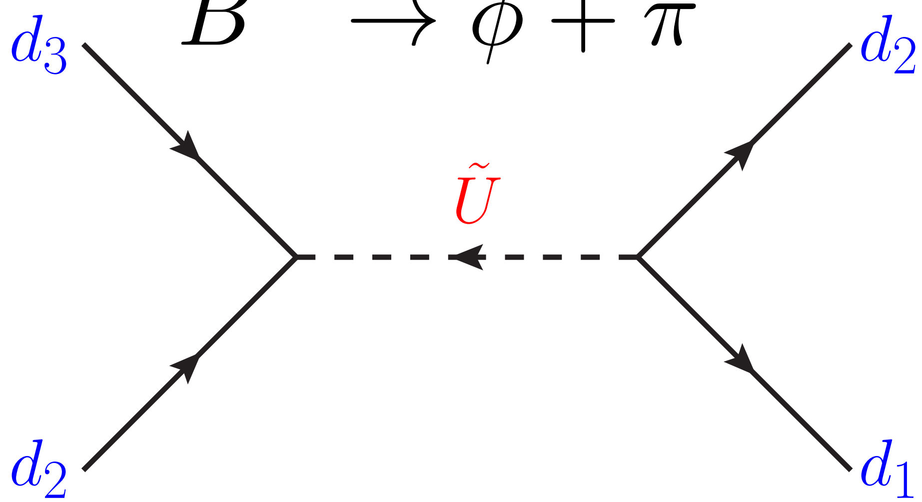
- There are also relevant limits from rare B-meson decays

$$B^+ \to K^0 + \pi^+$$



$$\lambda_3^{12}\lambda_3^{13} \lesssim 5 \times 10^{-3} \left(\frac{m_{\tilde{U}}}{100 \text{ GeV}}\right)^2$$

$$B^- \to \phi + \pi^-$$



$$\lambda_3^{12}\lambda_3^{23} \lesssim 2 \times 10^{-5} \left(\frac{m_{\tilde{U}}}{100 \text{ GeV}}\right)^2$$

limit summary

$$W \supset \lambda_1 \, udD + \lambda_2 \, UdD + \lambda_3 Udd$$

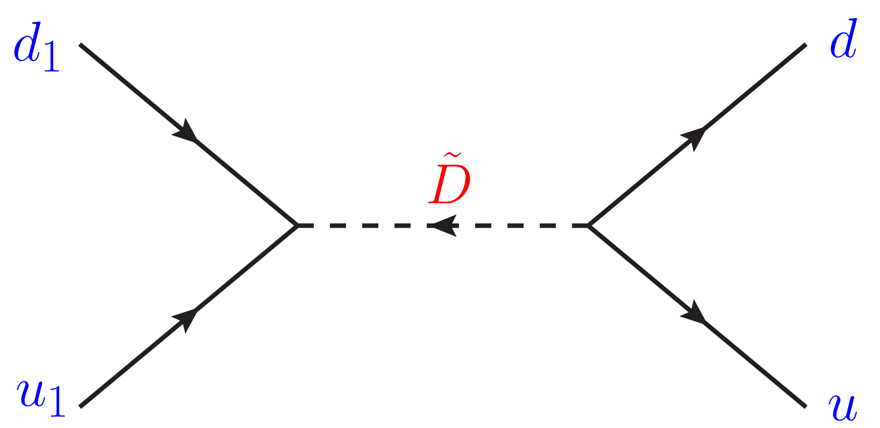
process	limit
$\Delta B = 2$	$\lambda_1\lambda_2\lambda_3 \lesssim 10^{-7}$
$p \to \tilde{G}$	$\lambda_1\lambda_2\lambda_3 \lesssim 10^{-16} \left(\frac{m_{3/2}}{\text{eV}}\right)$
flavor	$\lambda_1, \lambda_3 \lesssim 10^{-2}$

s-channel production

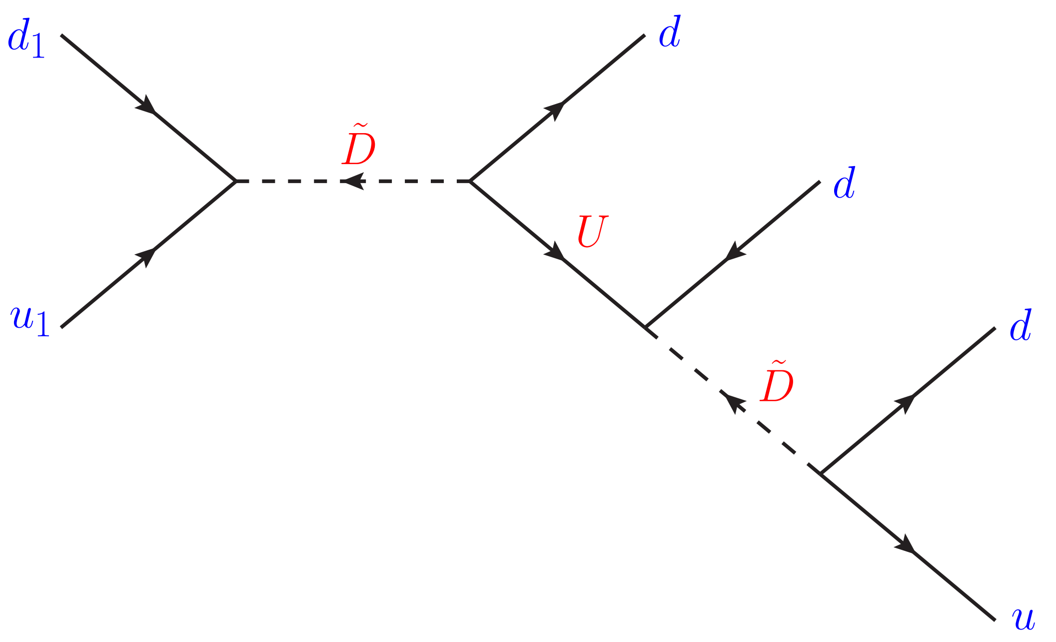
- for vanilla RPV, s-channel production must rely on the strange quark PDF because of the strong constraint on λ''_{11i}

- but collective RPV can include a large coupling to valence quarks

λ_1^{11} large



$\lambda_1^{11}, \lambda_2$ large



there are many other ways to implement cRPV

$$W \supset \lambda_1 \, llE + \lambda_2 \, LlE + \lambda_3 LlE$$

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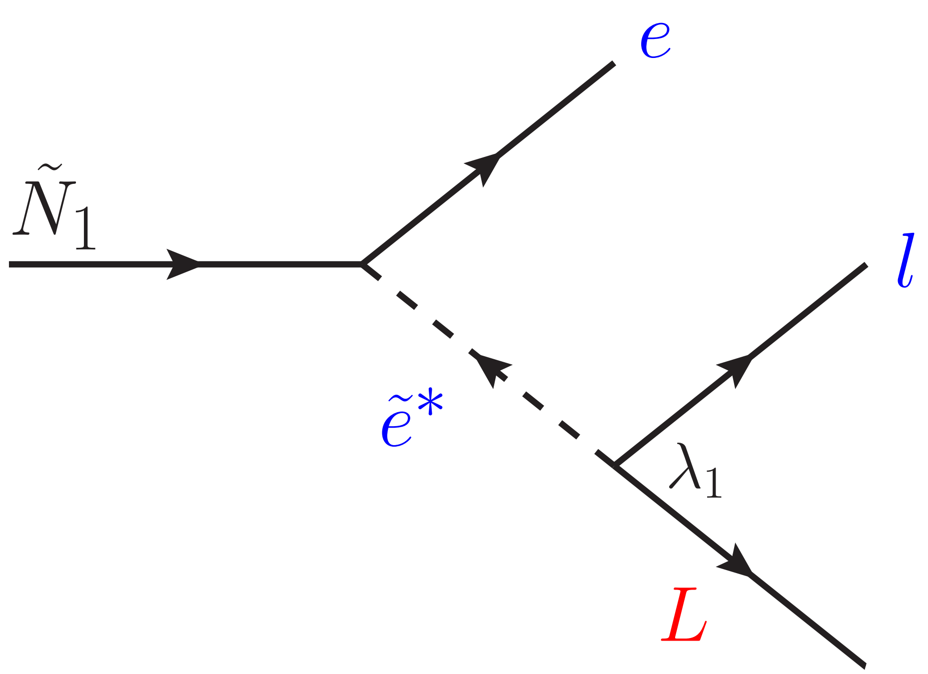
$$W \supset \lambda_1 \, llE + \lambda_2 \, LlE + \lambda_3 Lle$$



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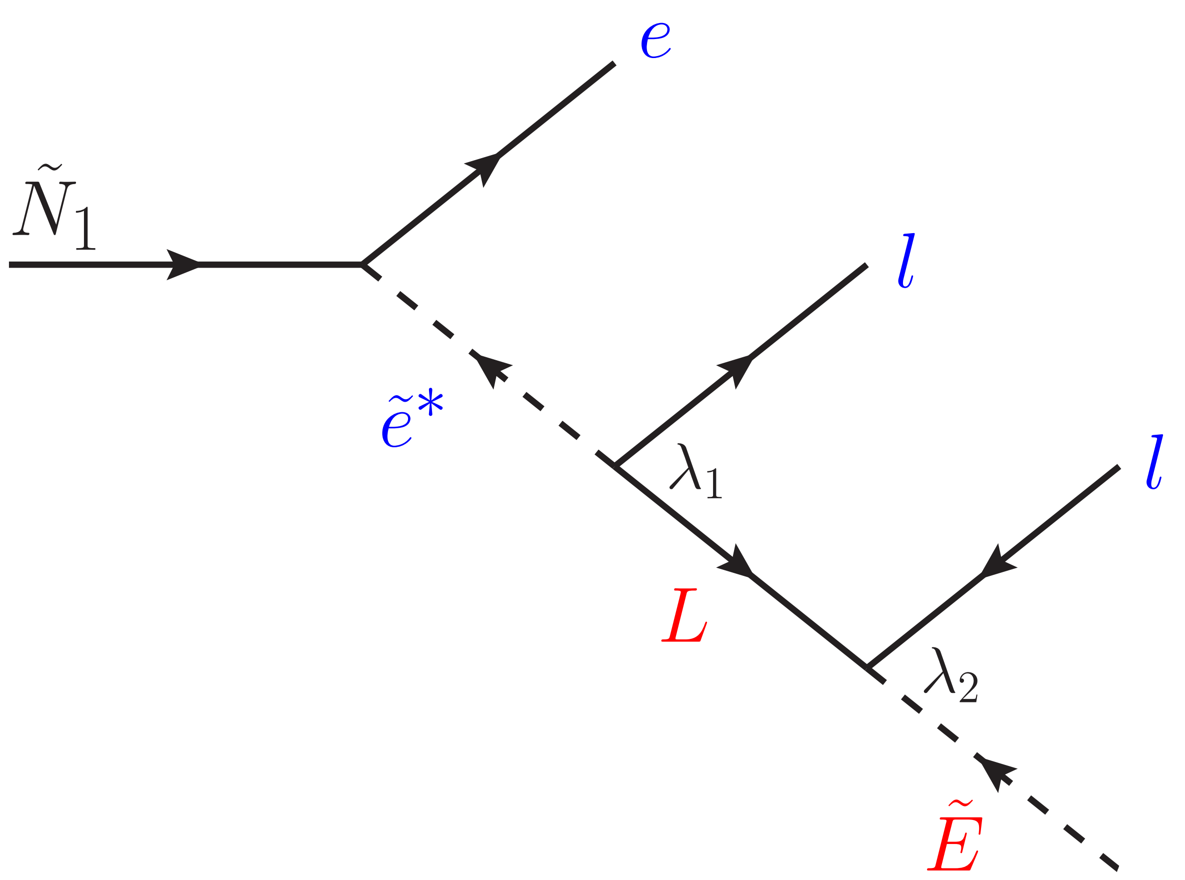

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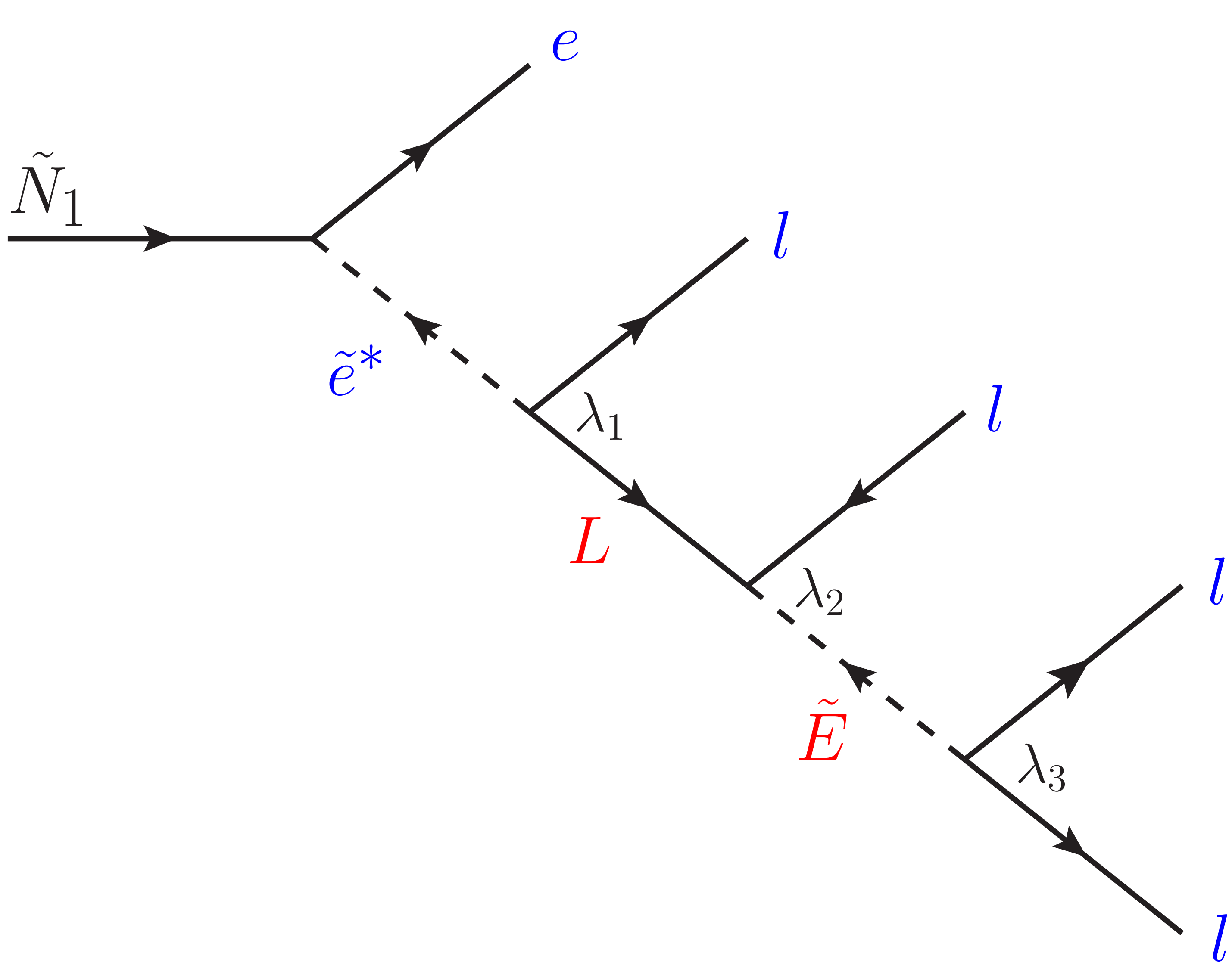


a lepton factory!

$$\tilde{N}_1 \to 4l + 1\nu$$
$$2l + 3\nu$$

4, 6, 8 leptons per event

summary

- hadronic RPV may hide susy, but there is tension between baryon number violation and keeping decays inside the detector
- collective RPV: several couplings are needed to violate baryon number
- but sequential decays only probe one coupling at a time, so generic/anarchic flavor couplings are OK.
- collider pheno of cRPV includes higher-multiplicity final states and, potentially, larger s-channel production cross-sections

backup slides

kinetic/mass mixing

$$W \supset \lambda_1\, udD + \lambda_2\, UdD + \lambda_3 Udd$$

- there is kinetic mixing between d and D (and between u and U)

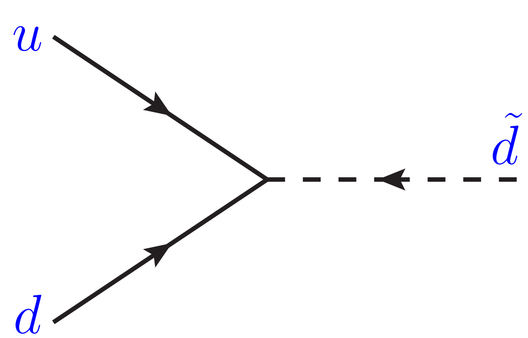
$$\int d^2\theta\ d^\dagger d + D^\dagger D - \epsilon(d^\dagger D + h.c.)$$

- it can be removed above the scale of susy breaking by a superfield redefinition, $d \to d + \epsilon D$

- below the scale of SUSY breaking, there is kinetic mixing and mass mixing,

$$\epsilon \sim \frac{\lambda_2\lambda_3}{(4\pi)^2}\log\left(\frac{\Lambda}{\tilde{m}}\right) \qquad m^2_{dD} \sim \frac{\lambda_2\lambda_3}{(4\pi)^2}\tilde{m}^2\log\left(\frac{\Lambda}{\tilde{m}}\right)$$

- removing the mixings, the residual effect is the vertex:



$$\sim \frac{\lambda_2\lambda_3}{(4\pi)^2}\log\left(\frac{\Lambda}{\tilde{m}}\right)$$