Lifetime Difference in $D^0 - \bar{D}^0$ Mixing Within R-parity Violating Supersymmetry

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Wayne State University, Detroit, MI, USA

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Based on

A. A. Petrov, G. K. Yeghiyan, Phys. Rev. D 77, 034018 (2008)

Outline of the Talk:

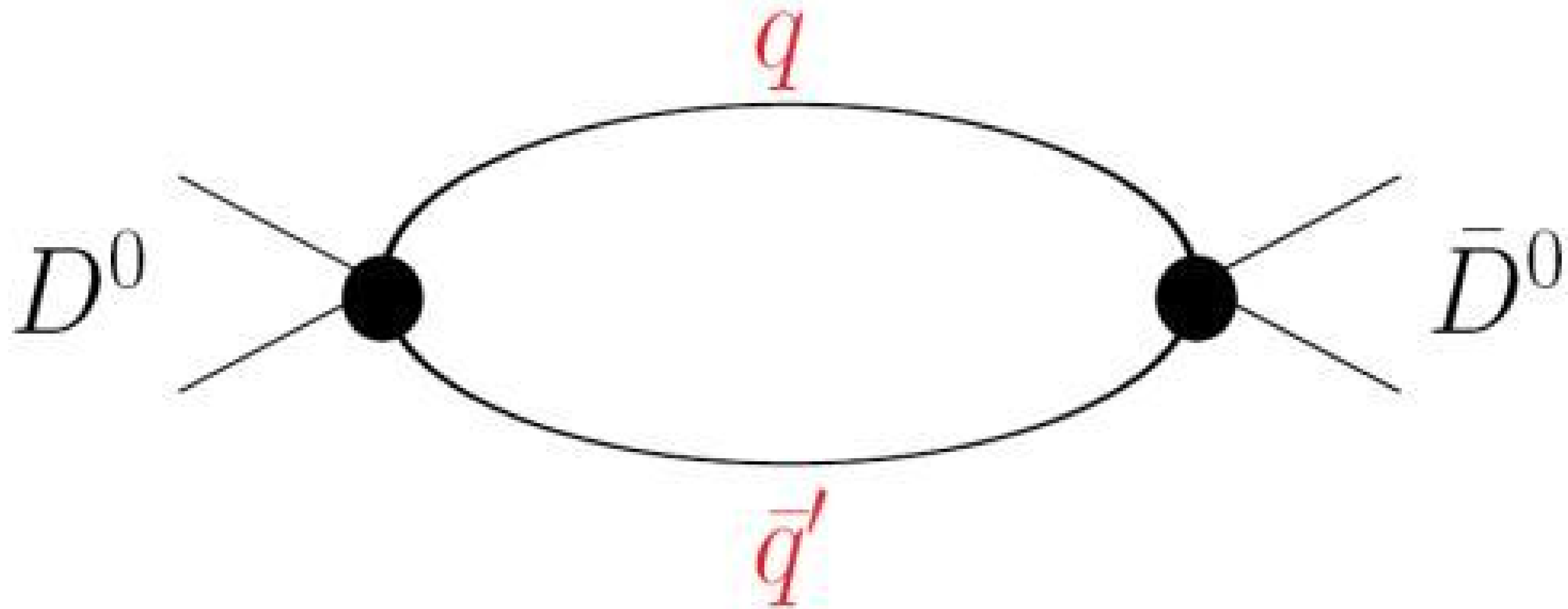
1. Issues of possible large NP contribution to $y_D = \Delta\Gamma_D / (2\Gamma_D)$

2. y_D within RPV SUSY models, subtleties of analysis

3. Numerical results

4. Conclusions

It is known that $\Delta\Gamma_D$ is driven by the physics of $\Delta C=1$ sector both in the SM and beyond.



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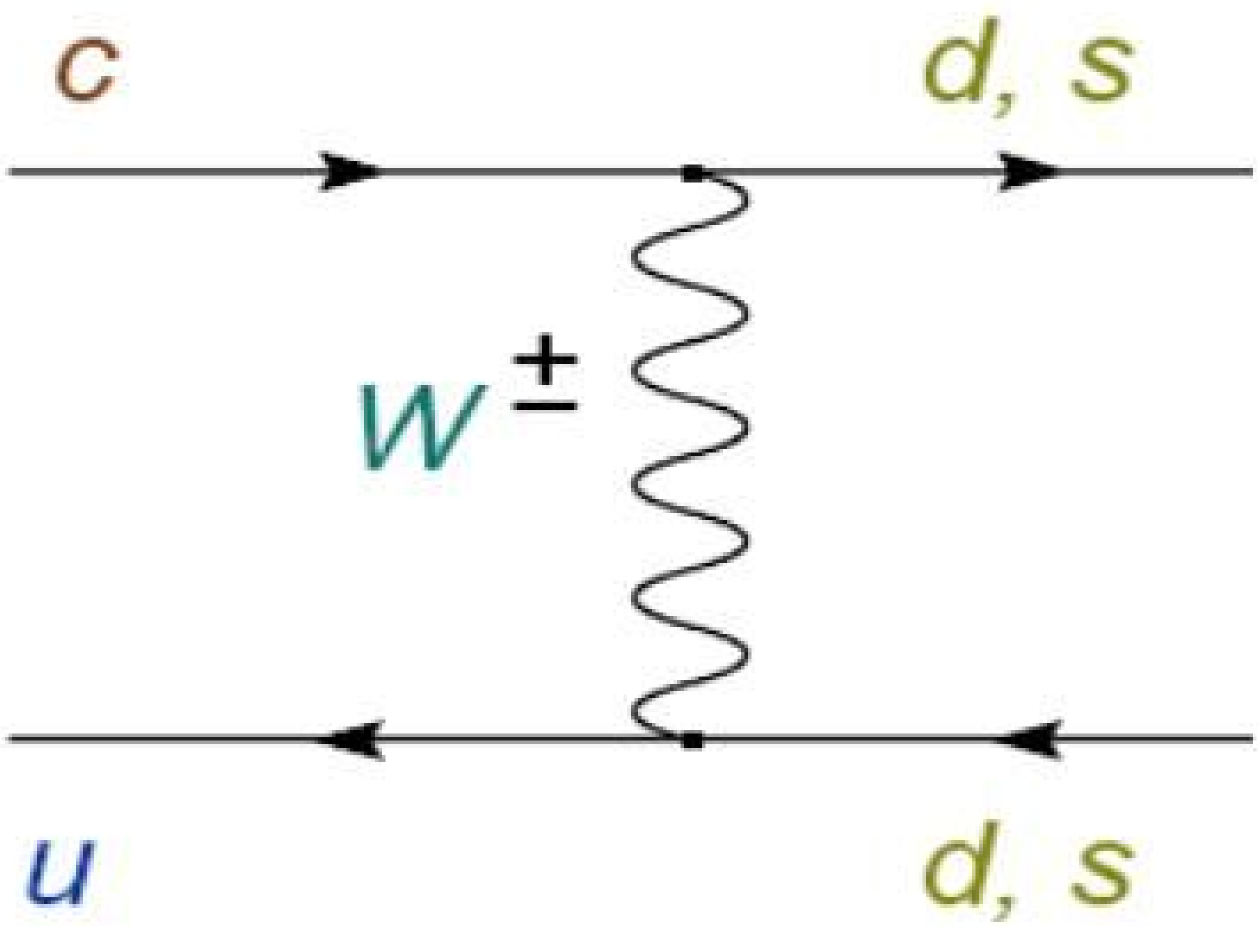

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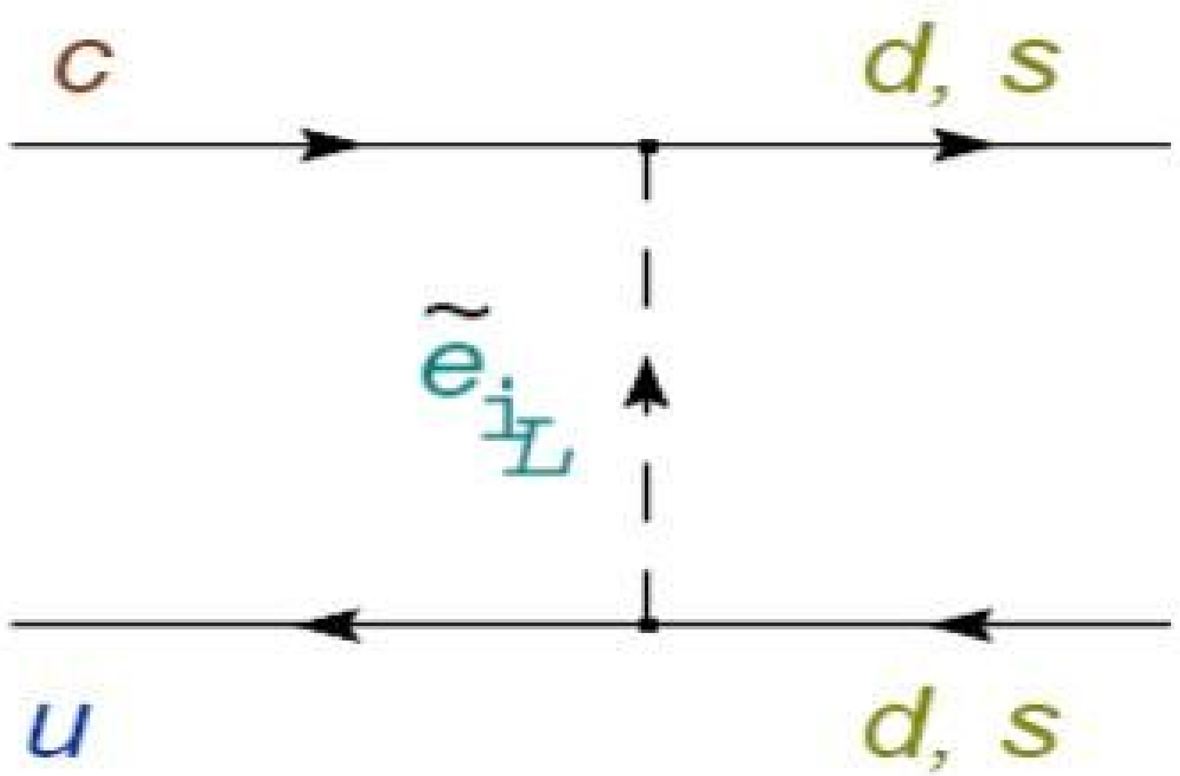

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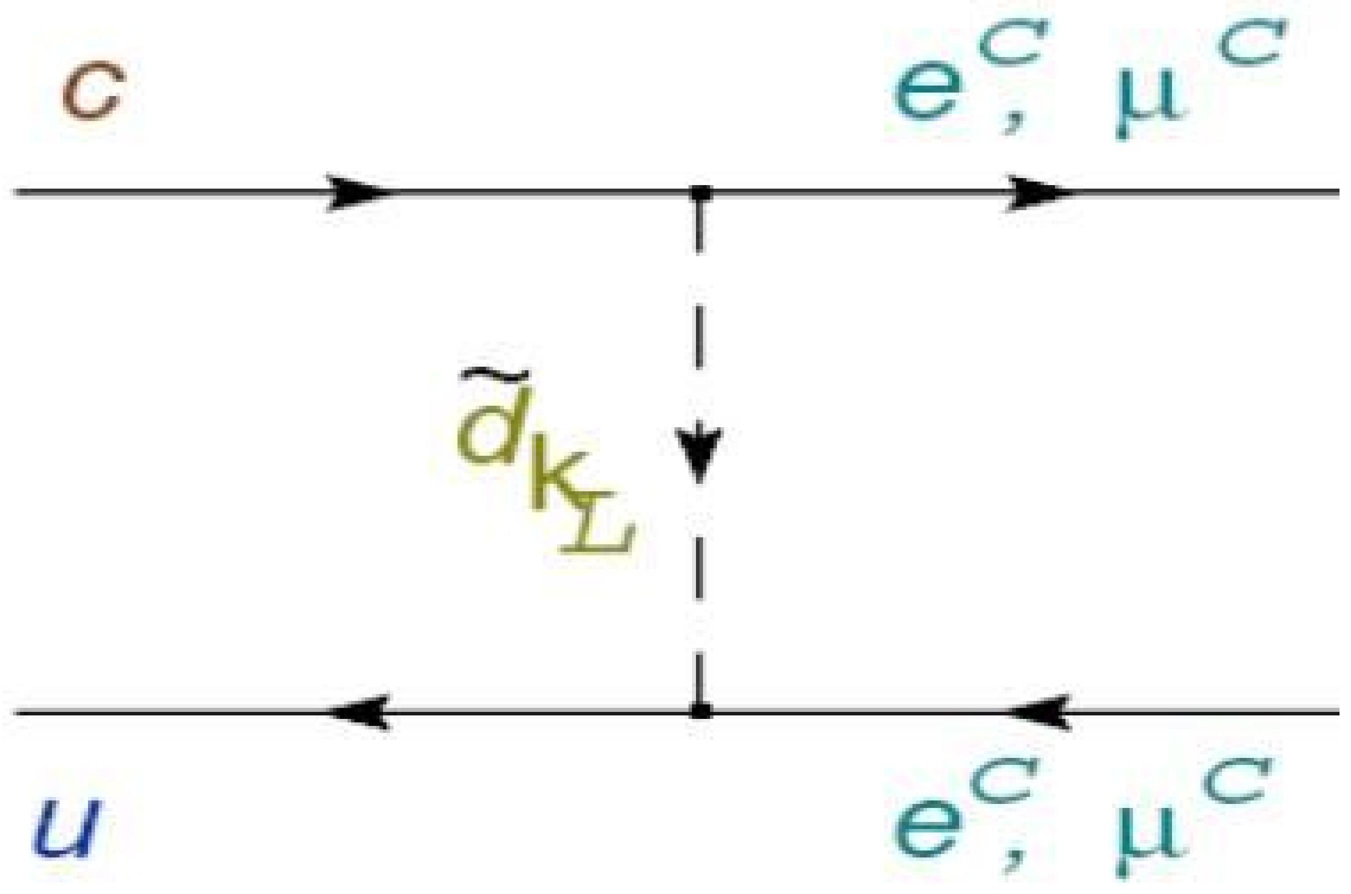

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Let

$A[D^0 \to n] = A_n^{(SM)} + A_n^{(NP)}$, $|n>$ is a charmless state

Then for $y_D=\Delta\Gamma_D/(2\Gamma_D)$

$$y_D = \sum_n \frac{\rho_n}{\Gamma_\mathrm{D}} A_n^{(\mathrm{SM})} \bar{A}_n^{(\mathrm{SM})} + 2\sum_n \frac{\rho_n}{\Gamma_\mathrm{D}} A_n^{(\mathrm{NP})} \bar{A}_n^{(\mathrm{SM})} + \sum_n \frac{\rho_n}{\Gamma_\mathrm{D}} A_n^{(\mathrm{NP})} \bar{A}_n^{(\mathrm{NP})}$$

$A_n^{(NP)}$ should be smaller than theoretical and experimental uncertainties in predictions for D-meson decays.

Is $y_D \approx y_{SM}$? y_{NP} may be essential as well!

Golowich, Pakvasa, Petrov, PRL 98, 181801 (2007)

$$y_D = \sum_n \frac{\rho_n}{\Gamma_D} A_n^{(SM)} \bar{A}_n^{(SM)} + 2 \sum_n \frac{\rho_n}{\Gamma_D} A_n^{(NP)} \bar{A}_n^{(SM)} + \sum_n \frac{\rho_n}{\Gamma_D} A_n^{(NP)} \bar{A}_n^{(NP)}$$

The SM contribution vanishes in the exact flavor SU(3) limit.

Short distance: LO $y_{SM} \sim m_s^6/m_c^6$ $y_{SM} \sim 10^{-8}$

NLO $y_{SM} \sim m_s^4/m_c^4$ $y_{SM} \sim 10^{-6}$

Long distance: $\sim m_s^2/m_c^2$, $y_{SM} \sim 10^{-4} \div 10^{-2}$

– **may explain** $y_D^{exp} = (7.3 \pm 1.8) \cdot 10^{-3}$

Key point:

- If non-vanishing in the exact flavor SU(3) limit

- Or if vanishing, but being (like long-distance SM contribution) $\sim m_s^2/m_c^2$ when SU(3) is broken,

NP contribution to y_D may be essential or even dominant (depending on M_{NP} and NP couplings)

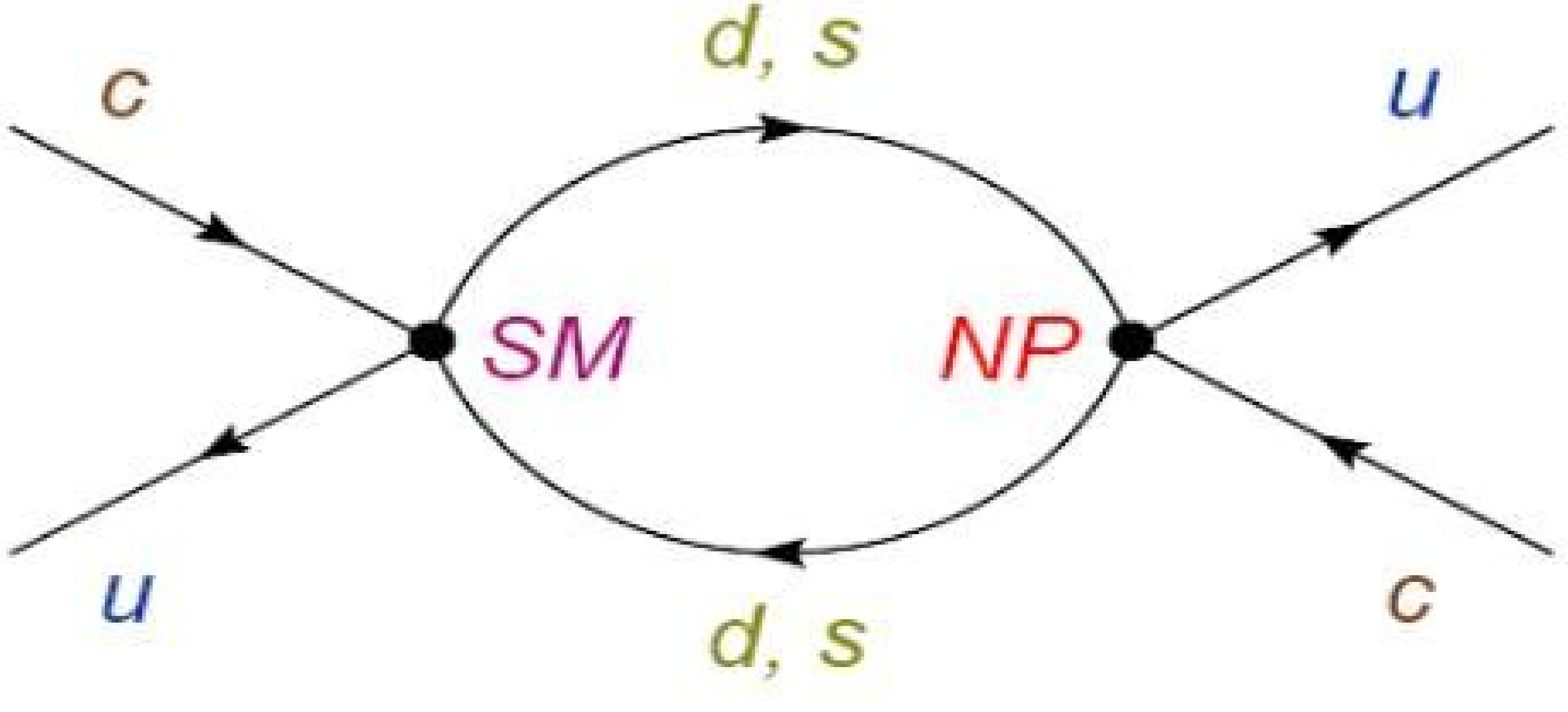
$$y_D = \sum_n \frac{\rho_n}{\Gamma_D} A_n^{(SM)} \bar{A}_n^{(SM)} + 2\sum_n \frac{\rho_n}{\Gamma_D} A_n^{(NP)} \bar{A}_n^{(SM)} + \sum_n \frac{\rho_n}{\Gamma_D} A_n^{(NP)} \bar{A}_n^{(NP)}$$

The second term (interference of the SM and NP $\Delta C=1$ transitions) –

within the most popular SM extensions

$y_{SM, NP} \leq 10^{-4}$ – fails to explain

$y_D^{exp} = (7.3 \pm 1.8) \cdot 10^{-3}$



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S. L. Chen, X. G. He, A. Hovhannissyan, H.S. Tsai JHEP 09, 044 (2007)

Ch. H. Chen, Ch. Q. Geng, S. H. Nam, PRL 99, 019101 (2007)

G. K. Yeghiyan, PRD 76, 117701 (2007)

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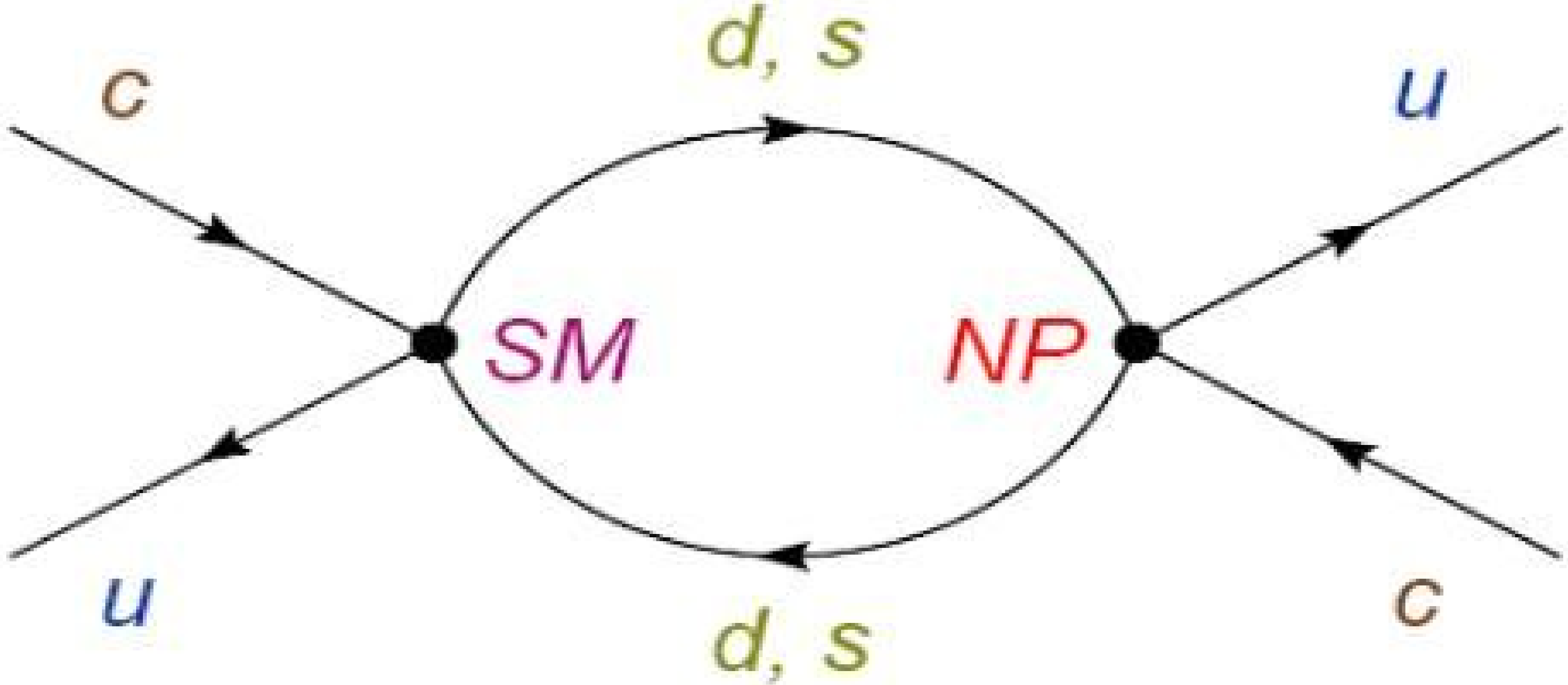

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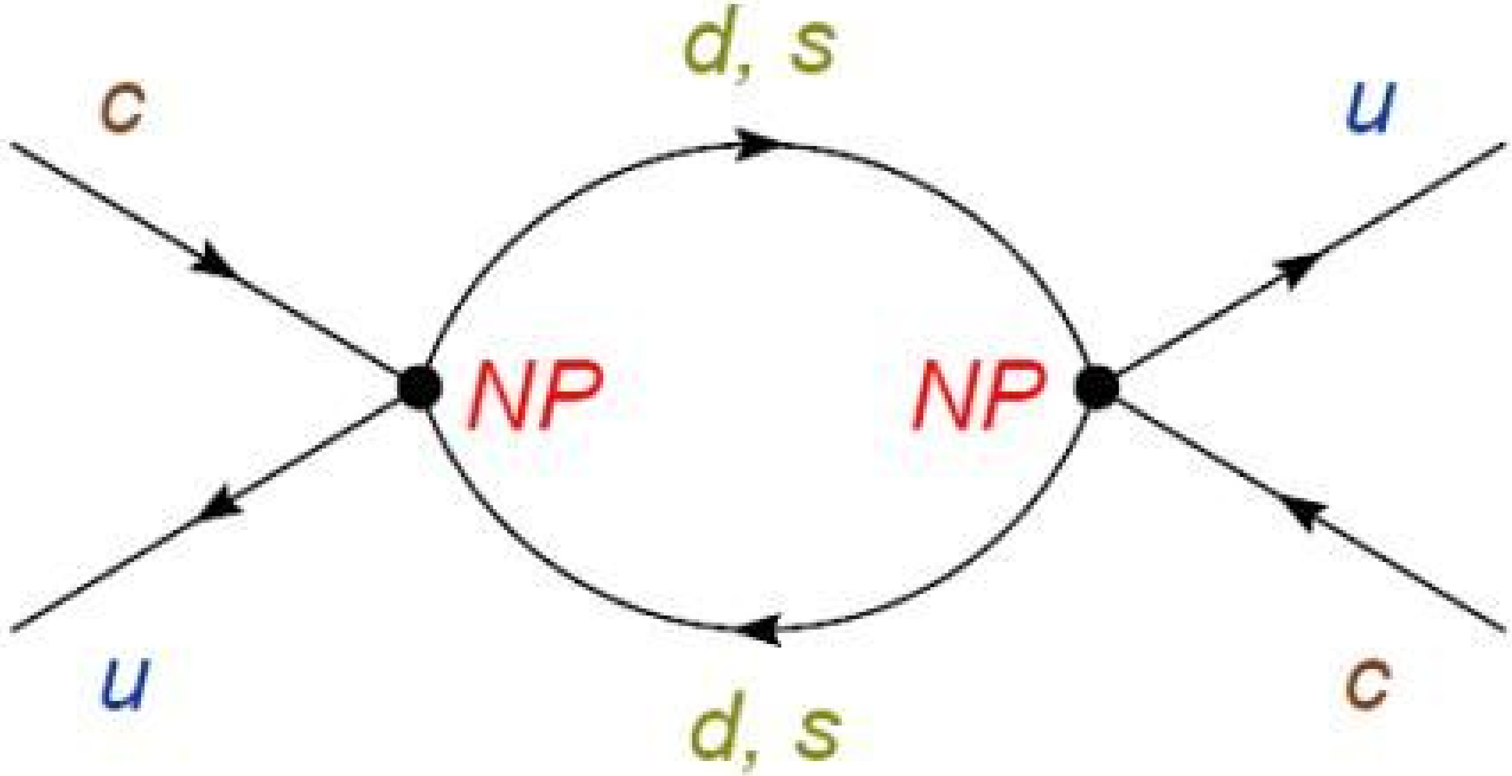

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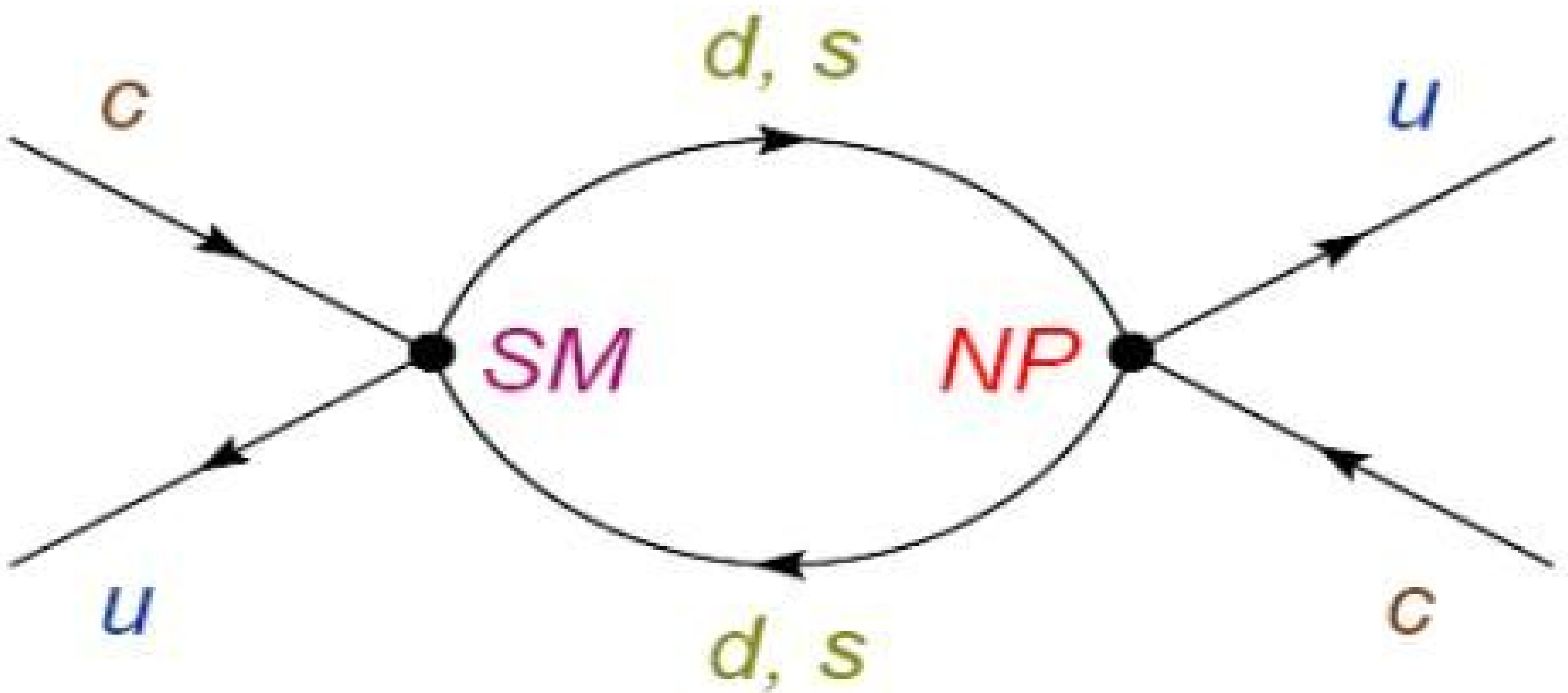

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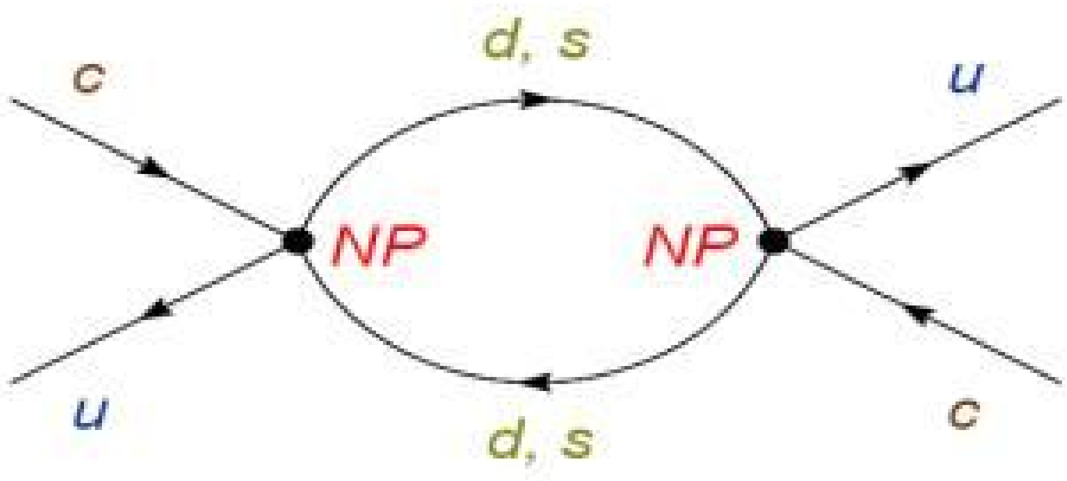

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Flavor SU(3) is broken: use power counting:

Powers of m_s/m_c vs. M_W^4/M_{NP}^4

Approximate rule: $M_W^4/M_{NP}^4 > m_s^2/m_c^2$

Purpose of our work:

1. Revisit the problem of the NP contribution to y_D within RPV SUSY models
2. Provide constraints on RPV couplings, insensitive or weakly sensitive to assumptions on R-conserving sector

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In contrast to studies of $x_D = \Delta m_D/\Gamma_D$ – have strong predictive power (Golowich, Hewett, Pakvasa, Petrov, PRD 76, 095009 (2007)), if only one may neglect R-conserving sector contribution

For y_D, R-conserving SUSY sector contributes at two-loop level, by dipenguin diagrams, and expected to be small

Revisit the problem within RPV SUSY:

- take into account the transformation of RPV couplings from the weak isospin basis to the quark mass eigenbasis

We considered a general low-energy SUSY scenario with no assumptions made on a SUSY breaking mechanism at unification scales.

Superpotential:

$$W_{\not R} = \sum_{i,j,k} \left[\frac{1}{2}\lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \frac{1}{2}\lambda''_{ijk} U^c_i D^c_j D^c_k \right]$$

To avoid rapid proton decay, we put $\lambda''=0$. In the quark mass eigenbasis

$$\mathcal{L}_{\not R} = -\sum_{i,j,k} \widetilde{\lambda}'_{ijk} \left[\widetilde{e}_{i_L} \bar{d}_{k_R} u_{j_L} + \widetilde{u}_{j_L} \bar{d}_{k_R} e_{i_L} + \widetilde{d}^*_{k_R} \bar{e}^c_{i_R} u_{j_L} \right] +$$

$$+ \sum_{i,j,k} \lambda'_{ijk} \left[\widetilde{\nu}_{i_L} \bar{d}_{k_R} d_{j_L} + \widetilde{d}_{j_L} \bar{d}_{k_R} \nu_{i_L} + \widetilde{d}^*_{k_R} \bar{\nu}^c_{i_R} d_{j_L} \right] + h.c.$$

where

$$\widetilde{\lambda}'_{irm} \;=\; V^*_{rn}\; \lambda'_{inm}$$

Very often in the literature one neglects the difference between λ' and $\widetilde{\lambda}'$ based on

$$V_{jn} = \delta_{jn} + O(\lambda) \qquad \text{so} \qquad \widetilde{\lambda}_{ijk} \approx \lambda'_{ijk} + O(\lambda)$$

This is not always a good approximation.

Example: if for a given i, j, k, n, $\lambda'_{ijk} \neq 0$, $\lambda'_{ink} \neq 0$ and all other λ' couplings vanish,

$$\widetilde{\lambda}'_{ijk} \widetilde{\lambda}'^{*}_{ink} \approx \lambda'_{ijk} \lambda'^{*}_{ink} \quad \text{if} \quad \lambda'_{ijk} \sim \lambda'_{ink}$$

Otherwise, if $\lambda'_{ijk} >> \lambda'_{imk}$

$$\widetilde{\lambda}'_{ijk} \widetilde{\lambda}'^{*}_{ink} \approx \lambda'_{ijk} \lambda'^{*}_{ink} + V_{nj} \, | \lambda'_{ijk} |^2 \neq \lambda'_{ijk} \lambda'^{*}_{ink}$$

Or even

$$\widetilde{\lambda}'_{ijk} \widetilde{\lambda}'^{*}_{ink} \approx V_{nj} \, | \lambda'_{ijk} |^2 >> \lambda'_{ijk} \lambda'^{*}_{ink}$$

If one neglects the difference between λ' and $\widetilde{\lambda}'$

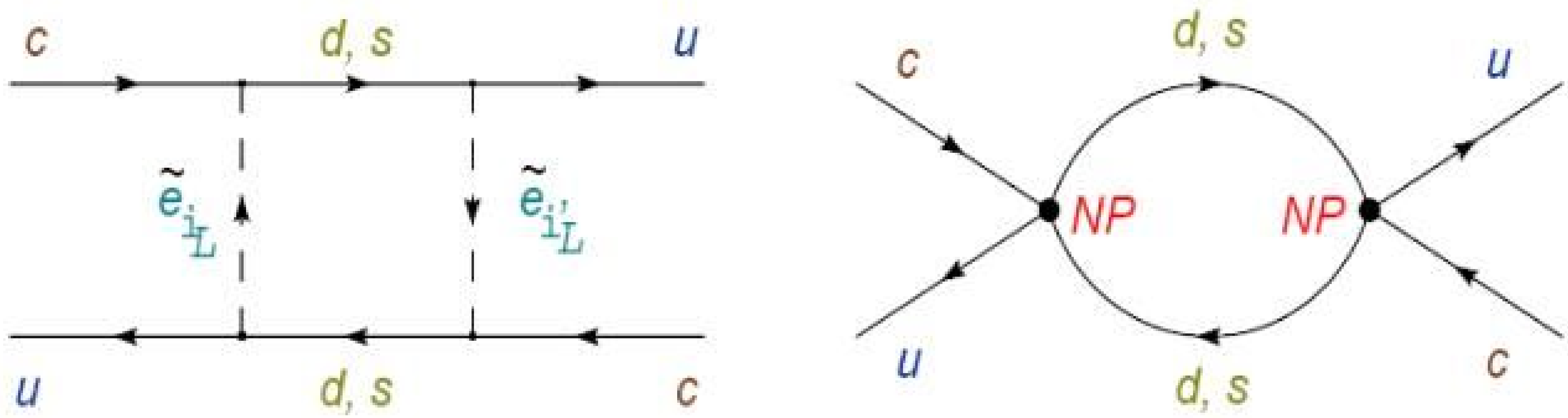
one may misuse the existing constraints on RPV couplings.

S. L. Chen, X. G. He, A. Hovhannissyan, H.S. Tsai JHEP 09, 044 (2007)-

RPV SUSY contribution to y_D is rather small –
true if only there is no hierarchy in the bounds (and hence the values) of the relevant RPV couplings

More generally, if the hierarchy is allowed, then….

The dominant diagrams.



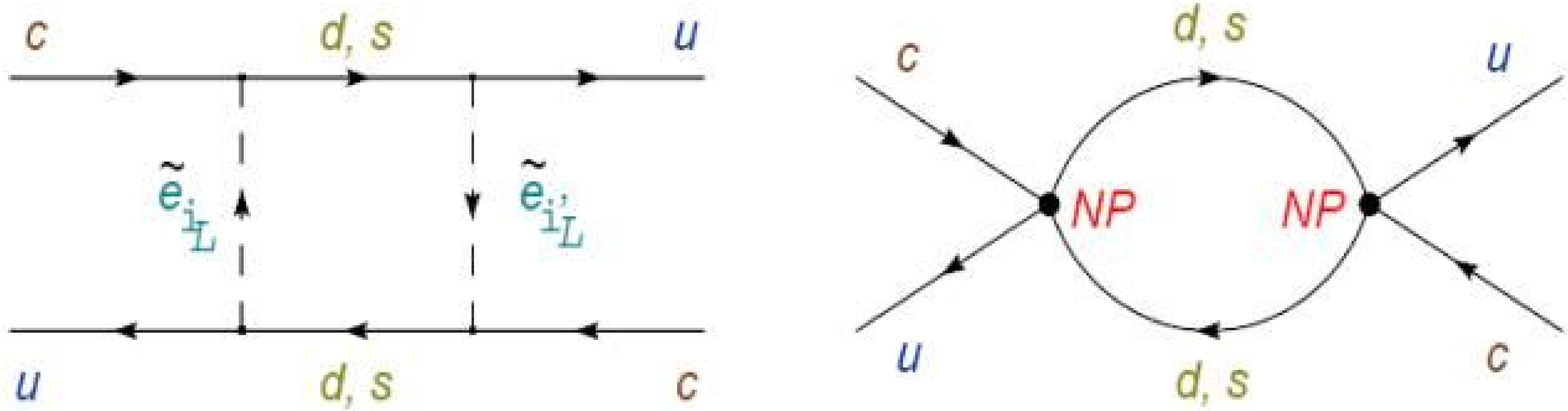
Neglecting numerically subdominant terms,

$$y_{\tilde{\ell}\tilde{\ell}} \approx \frac{-\,m_c^2\;f_D^2 B_D m_D}{288\pi\Gamma_D\;m_{\tilde{\ell}}^4}\left[\frac{1}{2}+\frac{5}{8}\frac{\bar{B}_D^S}{B_D}\right]\left[\,\lambda_{ss}^2+\lambda_{dd}^2\right]$$

$$\lambda_{ss} \equiv \sum_i \widetilde{\lambda}'^*_{i12}\widetilde{\lambda}'_{i22} \gg \sum_i \lambda'^*_{i12}\lambda'_{i22}$$

$$\lambda_{dd} \equiv \sum_i \widetilde{\lambda}'^*_{i11}\widetilde{\lambda}'_{i21} \gg \sum_i \lambda'^*_{i11}\lambda'_{i21}$$

The dominant diagrams.



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$$y_{\tilde{\ell}\tilde{\ell}} < 0.$$

It is non-vanishing in the exact flavor SU(3) limit. Else, $|\lambda_{ss}| \leq 0.29$, $|\lambda_{dd}| \leq 0.29$ or $\lambda_{ss}^2 \leq 0.0841$ and $\lambda_{dd}^2 \leq 0.0841$, M_{NP}~100GeV, contribution of this type of diagrams is large.

Numerically

$$-0.12\left(\frac{100GeV}{m_{\tilde{\ell}}}\right)^4 \leq y_{\tilde{\ell}\tilde{\ell}} < 0$$

Compare to

$y_D^{exp} = (7.3 \pm 1.8) \bullet 10^{-3}$

Radical approach: place severe constraint on λ_{ss} and λ_{dd} to make NP contribution to y_D negligible

Moderate approach: demand a large positive contribution from the SM (to have a destructive interference of two contributions).

A. Falk et al., PRD 65, 054034 (2002): due do the long-distance effects, y_{SM} may be up to ~1%.

Thus, RPV SUSY contribution to y_D should be ~1% or less as well.

Impose $-0.01 \leq y_{new} \approx y_{\tilde{\ell}\tilde{\ell}}$ **then**

either $m_{\tilde{\ell}} > 185\mathrm{GeV}$

or if $m_{\tilde{\ell}} \leq 185\mathrm{GeV}$ **then**

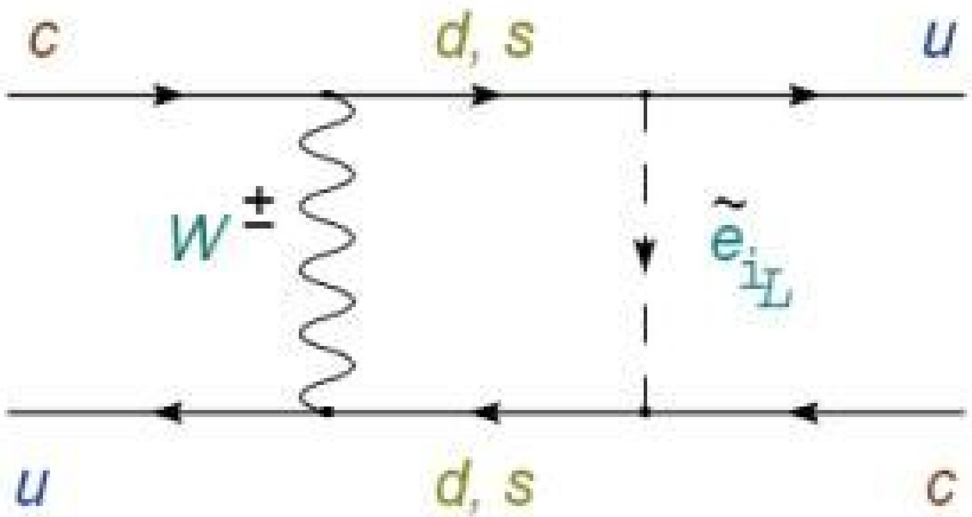
$$|\lambda_{ss}| \leq 0.082\left(\frac{m_{\tilde{\ell}}}{100GeV}\right)^2 \qquad |\lambda_{dd}| \leq 0.082\left(\frac{m_{\tilde{\ell}}}{100GeV}\right)^2$$

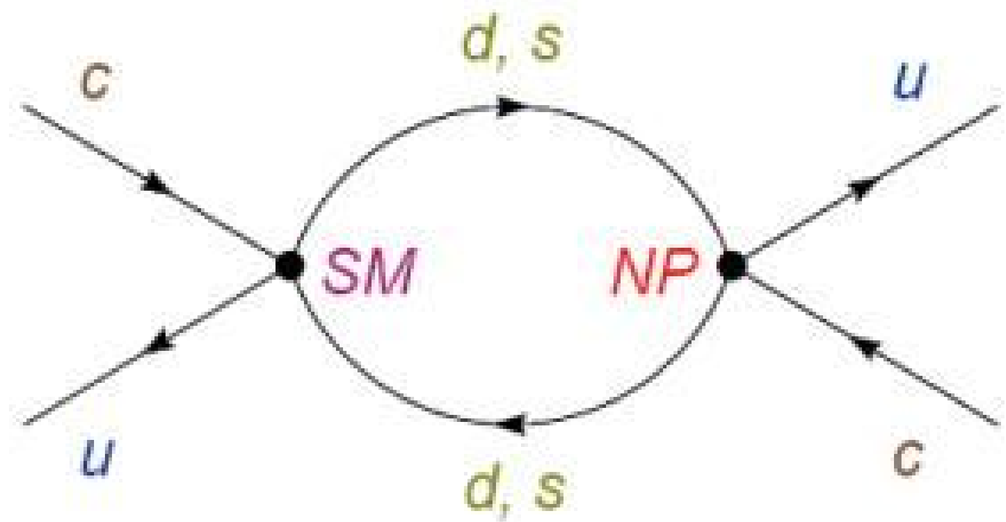
Our bounds are insensitive or weakly sensitive on the assumptions on R-conserving SUSY sector

Summary and conclusions

- Lifetime difference in $D^0 - \overline{D}^0$ mixing has been revisited within RPV SUSY models.
- NP contribution to y_D may be large in absolute value: it may exceed $y_D^{exp} = (7.3 \pm 1.8) \bullet 10^{-3}$ by an order of magnitude.
- When being large y_{NP} is negative in sign. The existing experimental data may be the result of destructive interference of the SM and RPV SUSY contributions.
- We derive new bounds on the RPV coupling pair products and/or supersymmetric particle masses. These bounds are insensitive or weakly sensitive to assumptions on the R-conserving sector of the theory.

Supplementary slide N1

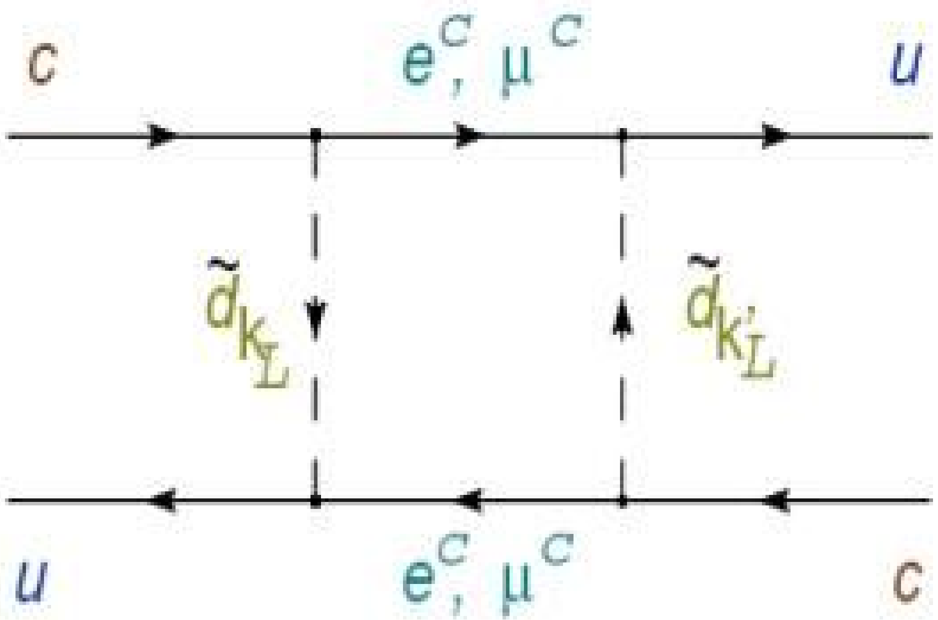


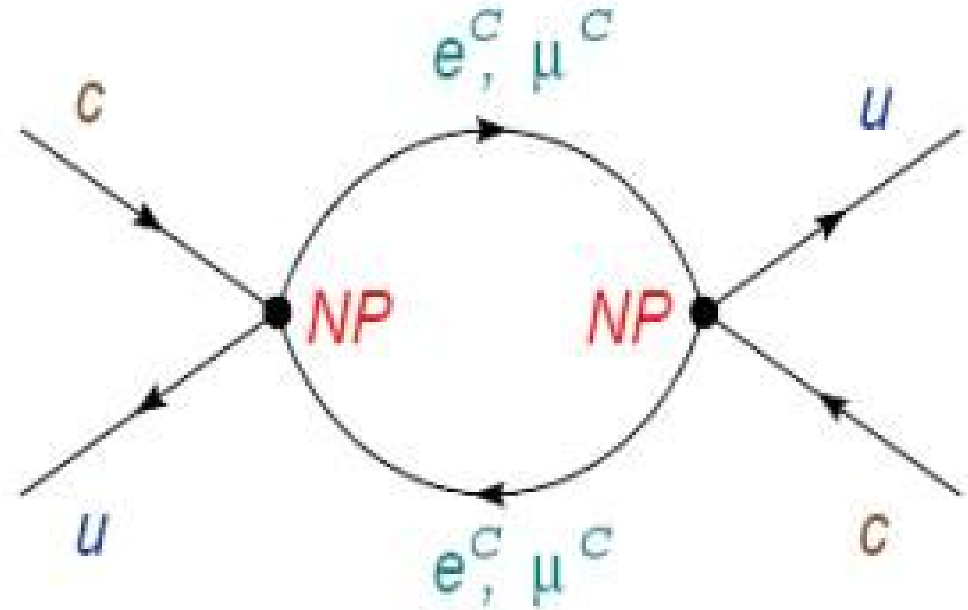


$$y_{SM,NP} = \frac{-G_F}{\sqrt{2}} \frac{f_D^2 B_D m_D}{6\pi\Gamma_D} \left(\frac{m_c^2}{m_{\tilde{\ell}}^2}\right) [C_1(m_c) + C_2(m_c)] \Big[\lambda_{sd}\sqrt{x_s x_d} + $$
$$+ \lambda(\lambda_{ss} x_s - \lambda_{dd} x_d) - \lambda^2 \lambda_{ds}\sqrt{x_s x_d}\Big]$$

Contribution of this type of diagrams vanishes in the exact flavor SU(3) symmetry limit. As flavor SU(3) is broken $y_{SM,NP}$ is suppressed as $x_s = m_s^2/m_c^2$ or $x_d = m_d^2/m_c^2$. It is not hard to show that contribution of this type of diagrams is rather small.

Supplementary Slide N2





$$y_{\tilde{q}\tilde{q}} = \frac{m_c^2\ f_D^2 B_D m_D}{288\pi\Gamma_D\ m_{\tilde{q}}^4}\left[\ \frac{5}{8}\frac{\bar{B}_D^S}{B_D} - 1\ \right]\left[\ \lambda_{\mu\mu}^2 + \lambda_{ee}^2 + 2\ \lambda_{\mu e}\lambda_{e\mu}\ \right]$$

Contribution of this type of diagrams does not vanish in the exact flavor SU(3) limit, however it is numerically subdominant :

$$y_{\tilde{q}\tilde{q}} \leq 5.34 \cdot 10^{-5}$$

because of the stringent bounds on the RPV coupling products

Supplementary slide N3

$$\lambda_{ss} \equiv \sum_i \tilde{\lambda}'^*_{i12}\, \tilde{\lambda}'_{i22} = \sum_i \lambda'^*_{i12}\, \lambda'_{i22} + \lambda\Big[\sum_i |\lambda'_{i22}|^2 - \sum_i |\lambda'_{i12}|^2\Big]$$

$$+ A\lambda^2 \sum_i \lambda'^*_{i12}\, \lambda'_{i32} + A\lambda^3(1+\rho-i\eta)\sum_i \lambda'^*_{i32}\, \lambda'_{i22}$$

$$+A^2\lambda^5(\rho - i\eta)\sum_i |\lambda'_{i32}|^2$$

$$|\lambda'^*_{i12}\, \lambda'_{i22}| \leq 6.3 \cdot 10^{-5}\left(\frac{m_{\tilde{q}}}{300GeV}\right)^2 \quad \Bigg| \quad |\sum_i \lambda'^*_{i12}\, \lambda'_{i22}| \leq 2.7 \times 10^{-3}\left(\frac{m_{\tilde{\ell}}}{100GeV}\right)^2$$

For $m_{\tilde{q}} \geq 300\text{GeV}$, $|\lambda_{322}| \ \leq \ 1.12$ | $|\lambda'_{312}| \leq 0.33(m_{\tilde{q}}/300GeV),$

$$|\lambda_{312}| \leq 1.12$$

$$-0.025\left(\frac{m_{\tilde{q}}}{300GeV}\right)^2 \leq \lambda_{ss} \leq 0.29, \quad \text{if} \quad m_{\tilde{q}} \leq 1TeV,$$

$$-0.29 \leq \lambda_{ss} \leq 0.29, \quad \text{if} \quad m_{\tilde{q}} \geq 1TeV$$