Published by Institute of Physics Publishing for SISSA

Received: *June 14, 2007*
Revised: *August 20, 2007*
Accepted: *August 30, 2007*
Published: *September 10, 2007*

SUSY R-parity violating contributions to the width differences for $D - \bar{D}$ and $B_{d,s} - \bar{B}_{d,s}$ systems

Shao-Long Chen, Xiao-Gang He, Artyom Hovhannisyan* and Ho-Chin Tsai

Department of Physics and Center for Theoretical Sciences,
National Taiwan University, Taipei, Taiwan
E-mail: shaolong@phys.ntu.edu.tw, hexg@phys.ntu.edu.tw, artyom@phys.ntu.edu.tw, hctsai@phys.ntu.edu.tw

Abstract: We study R-parity violating contributions to the mixing parameter y for $D^0 - \bar{D}^0$ and $B^0_{d,s} - \bar{B}^0_{d,s}$ systems. We first obtain general expressions for new physics contributions to y from effective four fermion operators. We then use them to study R-parity contributions. We find that R-parity violating contributions to $D^0 - \bar{D}^0$ mixing, and $B^0_d - \bar{B}^0_d$ to be small. There may be sizable contribution to $B^0_s - \bar{B}^0_s$ mixing. We also obtain some interesting bounds on R-parity violating parameters using known Standard Model predictions and experimental data.

Keywords: Supersymmetry Phenomenology, Beyond Standard Model.

*On leave from Yerevan Physics Institute, Yerevan, Armenia.

Contents

1. Introduction

Mixing between a neutral meson with specific flavor and its anti-meson provides powerful test for the Standard Model (SM) and new physics (NP) beyond. Mixing has been observed in [1] $K^0 - \bar{K}^0$, $B^0_d - \bar{B}^0_d$, and $B^0_s - \bar{B}^0_s$. Evidence for D^0 mixing has been recently reported by the BaBar [2] and Belle [3, 4] collaborations.

Two parameters, $x = \Delta M/\Gamma$ and $y = \Delta\Gamma/2\Gamma$, are often used to describe the mixing between a meson and its anti-meson. Here Γ is the life-time of the meson. $\Delta M = m_2 - m_1$, $\Delta\Gamma = \Gamma_2 - \Gamma_1$ with "1" and "2" indicating the CP odd and CP even states, respectively, in the limit of CP conservation. ΔM and $\Delta\Gamma$ are related to the mixing matrix elements M_{12} and Γ_{12} in the Hamiltonian by $\Delta M - i\Delta\Gamma/2 = 2\sqrt{(M_{12} - i\Gamma_{12}/2)(M^*_{12} - i\Gamma^*_{12}/2)}$.

If a new particle has flavor changing neutral current (FCNC) interaction, a non-zero contribution to M_{12} can be easily generated by exchanging this new particle in the intermediate state, tree or loop. The parameter Γ_{12} must come from the absorptive part which requires the intermediate states be light degrees of freedom to whom the meson can decay into. This fact severely constrains the contributions to Γ_{12} from NP. Due to this reason there is less theoretical work on new physics contributions to Γ_{12} than that for M_{12}. In this work, we study the Γ_{12} parameter in the present of NP, taking SUSY R-parity violating (RPV) interaction as an explicit example.

There are three types of R-Parity violating (RPV) terms [5]:

$$\frac{\lambda_{ijk}}{2} L_L^i L_L^j E_R^{ck} \;, \quad \lambda'_{ijk} L_L^i Q_L^j D_R^{ck} \;, \quad \frac{\lambda''_{ijk}}{2} U_R^{ci} D_R^{cj} D_R^{ck} \;, \tag{1.1}$$

where i, j and k are the generation indices: L_L, Q_L, E_R, D_R and U_R are the chiral superfields which transform under the SM gauge group $\mathrm{SU}(3)_C \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$ as $L_L : (1, 2, -1)$, $E_R : (1, 1, -2)$, $Q_L : (3, 2, 1/3)$, $U_R : (3, 1, 4/3)$ and $D_R : (3, 1, -2/3)$. The charge conjugated field ψ_R^c is defined as $\psi_R^c = C(\bar{\psi}_R)^T$. We will consider each of these R-parity contributions to $\Delta\Gamma_{12}$ for meson mixing separately. In that case, as the term proportional to λ_{ijk} involves only leptons, it will not contribute to meson mixing, since we are not considering pairs of λ_{ijk} and λ'_{ijk} couplings to be non-zero at the same time. We only need to consider the last two terms up to one loop level.

At the tree level, we have the following terms relevant to us by exchange s-fermions,

$$\begin{aligned}
\mathcal{L}_{\mathrm{eff}}(\lambda') = &\; \frac{\lambda'_{ijk}\lambda'^{*}_{i'j'k}}{2m^2_{\tilde{d}^k_R}} \bar{e}^{i'}_L \gamma^\mu e^i_L \bar{u}^{j'}_L \gamma_\mu u^j_L - \frac{\lambda'_{ijk}\lambda'^{*}_{ij'k'}}{2m^2_{\tilde{e}^i_L}} \bar{u}^{j'}_{L\beta} \gamma^\mu u^j_{L\alpha} \bar{d}^k_{R\alpha} \gamma_\mu d^{k'}_{R\beta} \\
&- \frac{\lambda'_{ijk}\lambda'^{*}_{ij'k'}}{2m^2_{\tilde{\nu}^i_L}} \bar{d}^{j'}_{L\alpha} \gamma^\mu d^j_{L\beta} \bar{d}^k_{R\beta} \gamma_\mu d^{k'}_{R\alpha} + \frac{\lambda'_{ijk}\lambda'^{*}_{i'j'k}}{2m^2_{\tilde{d}^k_R}} \bar{\nu}^{i'}_L \gamma^\mu \nu^i_L \bar{d}^{j'}_L \gamma_\mu d^j_L \\
&- \frac{\lambda'_{ijk}\lambda'^{*}_{i'jk'}}{2m^2_{\tilde{d}^j_L}} \bar{\nu}^{i'}_L \gamma^\mu \nu^i_L \bar{d}^k_R \gamma_\mu d^{k'}_R - \frac{\lambda'_{ijk}\lambda'^{*}_{i'jk'}}{2m^2_{\tilde{u}^j_L}} \bar{e}^{i'}_L \gamma^\mu e^i_L \bar{d}^k_R \gamma_\mu d^{k'}_R \\
\mathcal{L}_{\mathrm{eff}}(\lambda'') = &\; \frac{\lambda''_{ijk}\lambda''^{*}_{i'jk'}}{2m^2_{\tilde{d}^j_R}} (\bar{u}^i_{R\alpha} \gamma^\mu u^{i'}_{R\alpha} \bar{d}^k_{R\beta} \gamma_\mu d^{k'}_{R\beta} - \bar{u}^i_{R\alpha} \gamma^\mu u^{i'}_{R\beta} \bar{d}^k_{R\beta} \gamma_\mu d^{k'}_{R\alpha}) \\
&+ \frac{\lambda''_{ijk}\lambda''^{*}_{ij'k'}}{4m^2_{\tilde{u}^i_R}} (\bar{d}^j_{R\alpha} \gamma^\mu d^{j'}_{R\alpha} \bar{d}^k_{R\beta} \gamma_\mu d^{k'}_{R\beta} - \bar{d}^j_{R\alpha} \gamma^\mu d^{j'}_{R\beta} \bar{d}^k_{R\beta} \gamma_\mu d^{k'}_{R\alpha}) \,.
\end{aligned} \tag{1.2}$$

The first two terms in $\mathcal{L}_{\mathrm{eff}}(\lambda^{'('')})$ contribute to Γ_{12} for $D^0 - \bar{D}^0$ mixing. Except the first term in $\mathcal{L}_{\mathrm{eff}}(\lambda')$, all terms contribute to $B^0_{d,s} - \bar{B}^0_{d,s}$ mixing.

It is clear that from the above Lagrangian at the tree level, non-zero M_{12} can be generated. Constraints have been obtained using ΔM for various meson mixing. However, in order to generate a non-zero Γ_{12} additional loop corrections are needed from the above four fermion interactions.

There are short and long distance contributions to y or Γ_{12}. The calculations for long distance contributions are very difficult to handle due to our poor understanding of QCD at low energies. It is expected that long distance contributions become less and less important when energy scale becomes higher and higher, and perturbative short distance contributions will become the dominant one. We therefore will restrict ourselves to mesons containing a heavy c or b quark and to study the short distance contributions Γ_{12} for $D^0 - \bar{D}^0$ and $B^0_{d,s} - \bar{B}^0_{d,s}$ systems.

For $B_{d,s}$ mesons, in the SM the short distance contributions are expected to be the dominant ones. The prediction for $\Delta\Gamma$ for $B^0_s - \bar{B}^0_s$ is [6]

$$\Delta\Gamma_s = (0.106 \pm 0.032)\ \mathrm{ps}^{-1}. \tag{1.3}$$

JHEP09(2007)044

which gives $y_{\rm SM} = 0.078 \pm 0.025$. The DØ experiment has measured this width difference [7] (see also [8]). Allowing the non-zero CP violation in mixing they obtained, $\Delta\Gamma_s = (0.17 \pm 0.09_{\rm stat} \pm 0.03_{\rm syst})$ ps^{-1} ($y = 0.125 \pm 0.066_{\rm stat} \pm 0.022_{\rm syst}$), and in the CP conserving limit, $\Delta\Gamma_s = (0.12 \pm 0.08_{stat}{}^{+0.03}_{-0.04 syst})$ ps^{-1} ($y = 0.088 \pm 0.059_{stat}{}^{+0.022}_{-0.030 syst}$). Within error bars, SM agrees with data. However, it is interesting to see if NP contributions can appear at the SM level.

For $B_d^0 - \bar{B}_d^0$ system the width difference in SM is known to be small [6] $\Delta\Gamma_d = (26.7 \pm 0.08) \times 10^{-4}$ ps^{-1}, corresponding to $y_{\rm SM} = (2.058 \pm 0.006) \times 10^{-3}$. There is no experimental data for the width difference yet. It is interesting to see whether the width difference can be much larger when going beyond the SM.

For the $D^0 - \bar{D}^0$ mixing in the SM as was shown in [9] x and y are generated only at the second order in SU(3) breaking, $x, y \sim \sin^2\theta_C \times [\text{SU(3) breaking}]^2$. Most of the studies give $x, y < 10^{-3}$, although large values are not excluded [10].

Recently, the parameter y for $D^0 - \bar{D}^0$ mixing has been measured. BaBar, assuming no CP violation in mixing, has analyzed the doubly Cabibbo suppressed (DCS) $D^0 \to K^+\pi^-$ mode [2], while Belle has studied singly Cabibbo suppressed (SCS) $D^0 \to K^+K^-, \pi^+\pi^-$ decays [3]. From these results the authors in [11] have fitted the mixing parameters and get the following result for y with 68% and 95% probability correspondingly

$$y = (6.1 \pm 1.9) \times 10^{-3}, \quad y \in [0.0023, 0.0102]. \tag{1.4}$$

In this work, we find that R-parity violating contribution to the parameter y is small for $D^0 - \bar{D}^0$ system, less than a few times 10^{-4}. The RPV contribution for $B_d^0 - \bar{B}_d^0$ system can be larger than the SM prediction. For $B_s^0 - \bar{B}_s^0$ system, the contribution to y can be as large as the SM contribution.

In the following sections, we provide the detailed calculations.

2. General expression for Γ_{12}

Before going into specific RPV model calculations, we summarize some general results for short distance NP contribution to Γ_{12} from four quark operators generated by SM and NP. The calculation is straightforward. Starting from tree level four quark interactions, one needs to obtain the absorptive part for figure 1. Let us take $D^0 - \bar{D}^0$ mixing for illustration. For the cases considered here, we can write the $\Delta C = -1$ interaction Lagrangian as

$$\begin{aligned} \mathcal{L}^{\Delta C=-1} &= \sum_{q,q'} \left\{ \mathbf{D}_{qq'} \left[\mathcal{C}_1(\mu) Q_1 + \mathcal{C}_2(\mu) Q_2 \right] + \mathbf{D}'_{qq'} \left[\mathcal{C}'_1(\mu) Q_3 + \mathcal{C}'_2(\mu) Q_4 \right] \right\} , \qquad (2.1) \\ Q_1 &= \overline{u}_i \Gamma_1 q'_j \, \overline{q}_j \Gamma_2 c_i \ , \quad Q_2 = \overline{u}_i \Gamma_1 q'_i \, \overline{q}_j \Gamma_2 c_j \ , \\ Q_3 &= \overline{u}_i \Gamma_3 q'_j \, \overline{q}_j \Gamma_4 c_i \ , \quad Q_4 = \overline{u}_i \Gamma_3 q'_i \, \overline{q}_j \Gamma_4 c_j \ . \end{aligned}$$

In the above we have omitted possible Lorentz indices for Γ_i which are contracted. The specific form of Γ_i depends on the nature of interaction generating the four quark operators. The notations here are that $\Gamma_{1,2(3,4)}$ and $\Gamma_{3,4(1,2)}$ should appear on the left and right four quark vertices in figure 1, respectively.

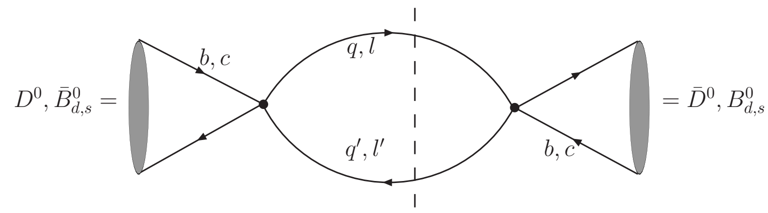

Figure 1: The one-loop Feynman diagram for meson mixing. The dashed line represents the cut for taking the absorptive part.

Evaluating the diagram in figure 1, one obtains the following general expression for Γ_{12},

$$\Gamma_{12} = -\frac{1}{2M_{\mathrm{D}}} \sum_{q,q'} \mathbf{D}_{qq'} \mathbf{D'}_{q'q} \left(K_1 \delta_{ik}\delta_{j\ell} + K_2 \delta_{i\ell}\delta_{jk}\right) \sum_{\alpha=1}^{5} I_\alpha(x,x') \, \langle \overline{D}^0 | \, \mathcal{O}_\alpha^{ijk\ell} \, | D^0 \rangle, \quad (2.2)$$

where

$$K_1 = \left(\mathcal{C}_1 \mathcal{C'}_1 N_c + \left(\mathcal{C}_1 \mathcal{C'}_2 + \mathcal{C'}_1 \mathcal{C}_2\right)\right), \;\; K_2 = \mathcal{C}_2 \mathcal{C'}_2. \quad (2.3)$$

The operators are defined as

$$\begin{aligned}
\mathcal{O}_1^{ijk\ell} &= \overline{u}_k \Gamma_3 \gamma_\nu \Gamma_2 c_j \; \overline{u}_\ell \Gamma_1 \gamma^\nu \Gamma_4 c_i, \quad & \mathcal{O}_2^{ijk\ell} &= \overline{u}_k \Gamma_3 \not{p}_c \Gamma_2 c_j \; \overline{u}_\ell \Gamma_1 \; \not{p}_c \Gamma_4 c_i, \\
\mathcal{O}_3^{ijk\ell} &= \overline{u}_k \Gamma_3 \Gamma_2 c_j \; \overline{u}_\ell \Gamma_1 \not{p}_c \Gamma_4 c_i, & \mathcal{O}_4^{ijk\ell} &= \overline{u}_k \Gamma_3 \not{p}_c \Gamma_2 c_j \; \overline{u}_\ell \Gamma_1 \Gamma_4 c_i, \\
\mathcal{O}_5^{ijk\ell} &= \overline{u}_k \Gamma_3 \Gamma_2 c_j \; \overline{u}_\ell \Gamma_1 \Gamma_4 c_i,
\end{aligned}$$

and the coefficients $I_\alpha(x,x')$ are given by

$$\begin{aligned}
I_1(x,x') &= -\frac{k^* m_c}{48\pi} \left[1 - 2\left(x + x'\right) + \left(x - x'\right)^2\right], \\
I_2(x,x') &= -\frac{k^*}{24\pi m_c} \left[1 + \left(x + x'\right) - 2\left(x - x'\right)^2\right] \\
I_3(x,x') &= \frac{k^*}{8\pi} \sqrt{x} \left(1 + x' - x\right), \\
I_4(x,x') &= -\frac{k^*}{8\pi} \sqrt{x'} \left(1 - x' + x\right), \\
I_5(x,x') &= \frac{k^* m_c}{4\pi} \sqrt{x x'} \;,
\end{aligned} \quad (2.4)$$

where $k^* \equiv (m_c/2)[1 - 2(x + x') + (x - x')^2]^{1/2}$ with $x \equiv m_q^2/m_c^2$ and $x' \equiv m_{q'}^2/m_c^2$. Replacing $D'_{qq'}$ with the SM couplings and $\Gamma_3 = \gamma^\mu(1-\gamma_5)/2$ and $\Gamma_4 = \gamma_\mu(1-\gamma_5)/2$, we obtain the formula presented in [12, 13] for SM and NP interference contribution. Note that when considering the contributions from the same operator, one should take $D'_{qq'} = D_{qq'}$, $\Gamma_{1,2} = \Gamma_{3,4}$ and the expression for Γ_{12} should be divided by 2.

Using the above formula, one can easily work out the expressions contributing from the SM (taking SM operators for $Q_{1,2,3,4}$), the interference between the SM and NP (SM

JHEP09(2007)044

- NP) (taking $Q_{1,2}$ from SM (NP) and $Q_{3,4}$ from NP (SM)), and purely NP (NP - NP) (taking $Q_{1,2,3,4}$ from NP). New physics effects can show up in the later two cases. We will concentrate on these contributions.

We comment that the fermions in the loop are not necessary to be quarks. They can be leptons too. If one identifies q and q' to be leptons, the correct result can be obtained by setting $N_c = 1$ and $C_2^{(\prime)} = 0$ in eq. (2.3). One can easily generalize the above formula for $B^0_{d,s} - \bar{B}^0_{d,s}$ mixing cases with appropriate replacement of quark fields and couplings.

3. RPV contributions to Γ_{12} for $D^0 - \bar{D}^0$ mixing

In this section we give expressions for contributions to Γ_{12} with RPV interactions.

Contributions from λ' interaction to Γ_{12} are given by

$$\begin{aligned}
\Gamma_{12(SM-RPV)} &= \frac{\sqrt{2}G_F\lambda'_{i22}\lambda'^{*}_{i12}V_{us}V^{*}_{cs}}{8\pi m_D m^2_{\tilde{e}^i_L}} x_s m_c^2 (C_1 + C_2)\langle Q\rangle \ , \\
\Gamma_{12(RPV-RPV,l)} &= \frac{\lambda'_{i2k}\lambda'^{*}_{j1k}\lambda'_{j2k'}\lambda'^{*}_{i1k'}}{192\pi m^2_{\tilde{d}^k_R} m^2_{\tilde{d}^{k'}_R}} \frac{m_c^2}{m_D} \left(\langle Q\rangle + \langle Q_s\rangle\right) \ , \\
\Gamma_{12(RPV-RPV,d)} &= \frac{\lambda'_{i2j'}\lambda'^{*}_{i1j}\lambda'_{i'2j}\lambda'^{*}_{i'1j'}}{192\pi m^2_{\tilde{e}^i_L} m^2_{\tilde{e}^{i'}_L}} \frac{m_c^2}{m_D} \left(\frac{1}{2}\langle Q\rangle - \langle Q_s\rangle\right) ,
\end{aligned} \tag{3.1}$$

where

$$\langle Q\rangle = \langle \bar{D}^0|\bar{u}_\alpha\gamma^\mu P_L c_\alpha \bar{u}_\beta\gamma_\mu P_L c_\beta|D^0\rangle \ , \ \ \langle Q_s\rangle = \langle \bar{D}^0|\bar{u}_\alpha P_R c_\alpha \bar{u}_\beta P_R c_\beta|D^0\rangle \ ,$$

The first equation in eq. (3.1) is the leading order result in x_s. Depending on the internal lepton exchanges, in the expression for $\Gamma_{12(RPV-RPV,l)}$ the indices i, j take 1 and 2 indicating which charged leptons are in the loop. In principle, one can also have an electron and a tauon in the loop. However, the tauon mass is close to the D meson mass, the contribution is suppressed by phase space. We will neglect this contribution. In the expression for $\Gamma_{12(RPV-RPV,q)}$, j, j' take 1 and 2 indicating which of the down quarks are in the loop.

$\Gamma_{12(SM-RPV)}$ comes from SM interaction with the second term, $\Gamma_{12(RPV-RPV,l)}$ comes from the first term, and $\Gamma_{12(RPV-RPV,q)}$ comes from the second term, in $\mathcal{L}_{\rm eff}(\lambda')$, respectively. Note that the SM-RPV contribution is proportional to the internal quark masses and the dominant one comes from $s\bar{s}$ in the loop. This is due to the chiral structure of Γ_i which allow only O_5^{ijkl} to contribute and therefore proportional to the function $I_5(x, x')$. If x or x' takes the down quark mass $I_5(x, x')$ is negligibly small.

In obtaining the expression for $\Gamma_{12(SM-RPV)}$, we have used the SM $\Delta C = -1$ Lagrangian,

$$\mathcal{L}_{\rm SM} = -\frac{4G_F}{\sqrt{2}} V^*_{qc}V_{q'u}\left[C_1(m_c)Q_1 + C_2(m_c)Q_2\right], \tag{3.2}$$

with Γ_1 and Γ_2 in eq. (2.1) to be $\gamma_\mu(1-\gamma_5)/2$ and $\gamma^\mu(1-\gamma_5)/2$, respectively.

JHEP09(2007)044

The contributions from λ'' interaction come from the first term in $\mathcal{L}_{\rm eff}(\lambda'')$ and are given by

$$\begin{aligned}
\Gamma_{12(SM-RPV)} &= -\frac{\sqrt{2}G_F\lambda''_{1j2}\lambda''^*_{2j2}V_{us}V^*_{cs}}{8\pi m_D m^2_{\tilde{d}^j_R}} x_s m_c^2[(2C_1+C_2)\langle Q'\rangle - C_2\langle\tilde{Q}'\rangle] \,, \\
\Gamma_{12(RPV-RPV)} &= \frac{\lambda''_{1ji}\lambda''^*_{2ji'}\lambda''_{1j'i'}\lambda''^*_{2j'i}}{192\pi m^2_{\tilde{d}^j_R} m^2_{\tilde{d}^{j'}_R}}\frac{m_c^2}{m_D}\left(\frac{3}{2}\langle Q\rangle\right) \,.
\end{aligned} \tag{3.3}$$

where

$$\langle Q'\rangle = \langle\bar{D}^0|\bar{u}_\alpha\gamma^\mu P_L c_\alpha \bar{u}_\beta\gamma_\mu P_R c_\beta|D^0\rangle \,, \;\; \langle\tilde{Q}'\rangle = \langle\bar{D}^0|\bar{u}_\alpha\gamma^\mu P_L c_\beta \bar{u}_\beta\gamma_\mu P_R c_\alpha|D^0\rangle \,.$$

In first equation of eq. (3.3), as in the first equation of eq. (3.1), we only kept the leading order in x_s. The SM-RPV contribution is dominated by $s\bar{s}$ pair in the loop for the same reason as that for the λ' case for SM-RPV contribution explained earlier.

Here we should mention that recently in ref. [12] the authors have considered RPV with slepton and squark exchanges for SM-NP contributions. Our predictions in the first equations in eqs. (3.1) and (3.3), for the same measurable, do not agree with their eqs. (16) and (24), respectively.

4. RPV contributions to Γ_{12} for $B^0_{d,s} - \bar{B}^0_{d,s}$ mixing

In this case all terms except the first term in $\mathcal{L}_{\rm eff}(\lambda')$ contribute to Γ_{12}.

4.1 The λ' contribution

The expressions for Γ_{12} from various contributions are given by

$$\begin{aligned}
\Gamma_{12(SM-RPV)} &= \frac{\sqrt{2}G_F m_b^2 \lambda_{q'qk}}{48\pi m_B m^2_{\tilde{e}^i_L}}\left\{(2C_1(m_b)-C_2(m_b))\langle Q'\rangle + (2C_2(m_b)-C_1(m_b))\langle\tilde{Q}'\rangle\right\} \,, \\
\Gamma_{12(RPV-RPV,\nu)} &= \frac{m_b^2}{192\pi m_B}\left\{\frac{\lambda'_{j3i'}\lambda'^*_{j'ki'}}{m^2_{\tilde{d}^{i'}_R}}\frac{\lambda'_{j'3i}\lambda'^*_{jki}}{m^2_{\tilde{d}^i_R}}(\langle Q\rangle + \langle Q_s\rangle)\right. \\
&\qquad + \frac{\lambda'_{jik}\lambda'^*_{j'i3}}{m^2_{\tilde{d}^i_L}}\frac{\lambda'_{j'i'k}\lambda'^*_{ji'3}}{m^2_{\tilde{d}^{i'}_L}}(\langle Q\rangle + \langle Q_s\rangle) \\
&\qquad \left. -2\frac{\lambda'_{j3i'}\lambda'^*_{j'ki'}}{m^2_{\tilde{d}^{i'}_R}}\frac{\lambda'_{j'ik}\lambda'^*_{ji3}}{m^2_{\tilde{d}^i_L}}\left(\langle Q'\rangle - \frac{1}{2}\langle\tilde{Q}'\rangle\right)\right\} \,, \\
\Gamma_{12(RPV-RPV,l)} &= \frac{m_b^2}{192\pi m_B}\frac{\lambda'_{jik}\lambda'^*_{j'i3}}{m^2_{\tilde{u}^i_L}}\frac{\lambda'_{j'i'k}\lambda'^*_{ji'3}}{m^2_{\tilde{u}^{i'}_L}}(\langle Q_s\rangle + \langle Q\rangle) \,, \\
\Gamma_{12(RPV-RPV,u)} &= \frac{m_b^2}{192\pi m_B}\frac{\lambda'_{ijk}\lambda'^*_{ij'3}}{m^2_{\tilde{e}^i_L}}\frac{\lambda'_{i'j'k}\lambda'^*_{i'j3}}{m^2_{\tilde{e}^{j'}_L}}\left(\frac{1}{2}\langle Q\rangle - \langle Q_s\rangle\right) \,,
\end{aligned} \tag{4.1}$$

$$
\Gamma_{12(RPV-RPV,d)} = \frac{m_b^2}{192\pi m_B}\frac{1}{m^2_{\tilde{\nu}^i_L} m^2_{\tilde{\nu}^{i'}_L}}\Big\{18\lambda'_{ijj'}\lambda'^*_{ik3}\lambda'_{i'3k}\lambda'^*_{i'jj'}\langle\tilde{Q}'\rangle
$$
$$
+\left(\lambda'_{i3j'}\lambda'^*_{ikj}\lambda'_{i'3j}\lambda'^*_{i'kj'} + \lambda'_{ijk}\lambda'^*_{ij'3}\lambda'_{i'j'k}\lambda'^*_{i'j3}\right)\left(\frac{1}{2}\langle Q\rangle - \langle Q_s\rangle\right)\Big\}\ ,
$$

where j, j' take the values 1 and 2.

$$
\lambda_{cck} = V^*_{cq^k}V_{cb}\lambda'_{i2k}\lambda'^*_{i23}\ ,\quad \lambda_{cuk} = V^*_{cq^k}V_{ub}\lambda'_{i1k}\lambda'^*_{i23}\ ,
$$
$$
\lambda_{uck} = V^*_{uq^k}V_{cb}\lambda'_{i2k}\lambda'^*_{i13}\ ,\quad \lambda_{uuk} = V^*_{uq^k}V_{ub}\lambda'_{i1k}\lambda'^*_{i13}\ .
$$

and

$$
\langle Q'\rangle = \langle B^0_{q^k}|\bar{q}^k_\alpha\gamma_\mu P_L b_\alpha\ \bar{q}^k_\beta\gamma_\mu P_R b_\beta|\bar{B}^0_{q^k}\rangle\ ,
$$
$$
\langle \tilde{Q}'\rangle = \langle B^0_{q^k}|\bar{q}^k_\alpha\gamma_\mu P_L b_\beta\ \bar{q}^k_\beta\gamma_\mu P_R b_\alpha|\bar{B}^0_{q^k}\rangle\ .
$$

Here for B_d and B_s systems, k takes 1 and 2, respectively.

The five different contributions to Γ_{12} listed above come from the second, first and sixth, fourth and fifth, second and third terms in $\mathcal{L}_{\rm eff}(\lambda')$, respectively.

4.2 The λ'' Contribution

In this case we have

$$
\Gamma_{12(SM-RPV)} = -\frac{\sqrt{2}G_F x_c\sqrt{1-4x_c}\,m_b^2 V^*_{cq^k}V_{cb}\lambda''_{2ki}\lambda''^*_{23i}}{8\pi m_B m^2_{\tilde{d}^i_R}}
$$
$$
\times\Big\{(2C_1(m_b)+C_2(m_b))\langle Q'\rangle - C_2(m_b)\langle\tilde{Q}'\rangle\Big\}\ ,
$$
$$
\Gamma_{12(RPV-RPV,u)} = \frac{m_b^2}{192\pi m_B}\frac{\lambda''_{ijk}\lambda''^*_{i'j3}}{m^2_{\tilde{d}^j_R}}\frac{\lambda''_{i'j'k}\lambda''^*_{ij'3}}{m^2_{\tilde{d}^{j'}_R}}\left(\frac{3}{2}\langle Q\rangle\right)\ , \tag{4.2}
$$
$$
\Gamma_{12(RPV-RPV,d)} = \frac{m_b^2}{48\pi m_B}\frac{\lambda''_{j'ki}\lambda''^*_{j'3i'}}{m^2_{\tilde{u}^{j'}_R}}\frac{\lambda''_{jki'}\lambda''^*_{j3i}}{m^2_{\tilde{u}^j_R}}\left(\frac{3}{2}\langle Q\rangle\right)\ ,
$$

where i, i' take the values 1 and 2. The first two terms are due to the first term in $\mathcal{L}_{\rm eff}(\lambda'')$, and the last term is due to the second term in $\mathcal{L}_{\rm eff}(\lambda'')$.

The SM-RPV interference is dominated by $c\bar{c}$ exchange in the loop for the same reasons as that for the $s\bar{s}$ dominance for SM-RPV $D^0-\bar{D}^0$ mixing.

5. Numerical analysis

In this section, we carry out numerical analysis for RPV contributions to mixing parameter y for $D^0-\bar{D}^0$ and $B^0_{d,s}-\bar{B}^0_{d,s}$ systems.

In general RPV contribution to Γ_{12} has CP violating phases associated with the new couplings. The relation of Γ_{12} and y is not trivial. If CP violating effects can be neglected which is the case for the SM, they have a simple relation

$$
y \equiv \frac{\Gamma_{12}}{\Gamma}. \tag{5.1}
$$

JHEP09(2007)044

$\mu = 1.3\,\text{GeV}$ [6, 14]	$\mu = 4.8\,\text{GeV}$ [6, 14]	Masses (GeV) [1]	Decay cons. (GeV) [15]	Widths (GeV) [1]
$x_s = 0.006$	$x_c = 0.0841$	$M_D = 1.8645$	$f_D = 0.201$	$\Gamma_D = 1.6 \times 10^{-12}$
$C_1 = -0.411$	$C_1 = -0.272$	$M_{B_d} = 5.279$	$f_B = 0.216$	$\Gamma_{B_d} = 4.27 \times 10^{-13}$
$C_2 = 1.208$	$C_2 = 1.120$	$M_{B_s} = 5.368$	$f_{B_s} = 0.260$	$\Gamma_{B_s} = 4.46 \times 10^{-13}$

Table 1: The central values of input parameters and coefficients.

In our numerical analysis, we assume CP conservation for easy comparison with data and other constraints obtained in the literature.

To compare with data, one needs to evaluate various hadronic matrix elements in the expressions for Γ_{12}. We write them in the following form

$$\begin{aligned} \langle Q \rangle &= \frac{2}{3} f_P^2 m_P^2 B_Q \ , \qquad \langle Q_s \rangle = -\frac{5}{12} f_P^2 m_P^2 B_{Q_s} \ , \\ \langle Q' \rangle &= -\frac{5}{6} f_P^2 m_P^2 B_{Q'} \ , \ \ \langle \tilde{Q}' \rangle = -\frac{7}{6} f_P^2 m_P^2 B_{\tilde{Q}'} \ , \end{aligned} \tag{5.2}$$

where B_Q factors are the so called bag parameters [14]. This way of parameterizing the matrix elements was inspired by vacuum saturation approximation. In the vacuum saturation approximation, they are all equal to one, which we will use in our estimate.

In the table 1 we list the parameters and coefficients appearing in the equations above. The input CKM elements are [16]

$$\lambda \equiv |V_{us}| = 0.2248, \quad A\lambda^2 \equiv |V_{cb}| = 41.5 \times 10^{-3}. \tag{5.3}$$

The charm quark mass also comes into the calculations. In our numerical analysis we identify m_c and m_b with *pole* masses. Numerically we use [14] $m_{c,pole}/m_{b,pole} = \sqrt{x_c} = 0.29$, which is based on the mass difference $m_{b,pole} - m_{ct,pole} = 3.4\,\text{GeV}$ and $m_{b,pole} = 4.8\,\text{GeV}$.

To give some understanding of RPV contributions, in the following analysis we take the central values for the input parameters.

5.1 $D^0 - \bar{D}^0$ mixing

Taking all λ' and λ'' to be real, and inserting known values for the parameters involved, for λ' contributions, we have

$$\begin{aligned} y_{(SM-RPV)} &= 0.0037 \times \lambda'_{i22}\lambda'^*_{i12} \frac{(100GeV)^2}{m^2_{\tilde{e}^i_L}} \ , \\ y_{(RPV-RPV,l)} &= 0.3298 \times \lambda'_{i2k}\lambda'^*_{j1k}\lambda'_{j2k'}\lambda'^*_{i1k'} \frac{(100GeV)^4}{m^2_{\tilde{d}^k_R} m^2_{\tilde{d}^{k'}_R}} \ , \\ y_{(RPV-RPV,q)} &= 0.9893 \times \lambda'_{i2j'}\lambda'^*_{i1j}\lambda'_{i'2j}\lambda'^*_{i'1j'} \frac{(100GeV)^4}{m^2_{\tilde{e}^i_L} m^2_{\tilde{e}^{i'}_L}} . \end{aligned} \tag{5.4}$$

RPV parameters	Bounds [Processes]	Estimate
$\lvert\lambda'_{i22}\lambda'^{*}_{i12}\rvert$	0.07 (see text)	$y_{(SM-RPV)} \simeq 2.6 \times 10^{-4}$
$\lvert\lambda'_{i2k}\lambda'^{*}_{j1k}\rvert$	5.28×10^{-6} $[K^+ \to \pi^+\nu\bar{\nu}]$	$y_{(RPV-RPV,l)} \simeq 9.2 \times 10^{-12}$
$\lvert\lambda'_{i2j}\lambda'^{*}_{i'1j}\rvert_{j=1,2}$	5.28×10^{-6} $[K^+ \to \pi^+\nu\bar{\nu}]$	$y_{(RPV-RPV,q)} \simeq 2.5 \times 10^{-11}$
$\lvert\lambda''_{132}\lambda''^{*}_{232}\rvert$	3.1×10^{-3} $[D\bar{D}]$	$y_{(SM-RPV)} \simeq 2.4 \times 10^{-5}$
$\lvert\lambda''_{132}\lambda''^{*}_{232}\rvert$	3.1×10^{-3} $[D\bar{D}]$	$y_{(RPV-RPV)} \simeq 1.3 \times 10^{-5}$

Table 2: The bounds on parameters from [17, 19, 18, 20, 21] and corresponding values for y.

The λ'' contributions are given by

$$y_{(SM-RPV)} = -0.0077 \times \lambda''_{1j2}\lambda''^{*}_{2j2}\frac{(100GeV)^2}{m^2_{\tilde{d}^j_R}} ,$$

$$y_{(RPV-RPV)} = 1.3191 \times \lambda''_{1ji}\lambda''^{*}_{2ji'}\lambda''_{1j'i'}\lambda''^{*}_{2j'i}\frac{(100GeV)^4}{m^2_{\tilde{d}^j_R} m^2_{\tilde{d}^{j'}_R}} . \tag{5.5}$$

There are constraints on the RPV parameters from various other processes [17, 19, 18]. Taking these constraints into account, we list in table 2 the corresponding values for the mixing parameter y.

For the contribution due to the λ' terms, using the constraint $|\lambda'_{i2k}\lambda'^{*}_{j1k}| \lesssim 5.28 \times 10^{-6}$, obtained from $K^+ \to \pi^+\nu\bar{\nu}$ [20] and taking the same bound for $|\lambda'_{i2j}\lambda'^{*}_{i'1j}|_{j=1,2}$ with the assumption that there is no accidental cancellation, we find $y_{(RPV-RPV,l)}$ and $y_{(RPV-RPV,q)}$ to be tiny $\lesssim 10^{-11}$. For the interference term due to the SM with λ' term, we have not found direct constraint on the appropriate combination of the λ' terms. We therefore use individual constraints from [18] $(\lambda'_{122}\lambda'^{*}_{112}, \lambda'_{222}\lambda'^{*}_{212}, \lambda'_{322}\lambda'^{*}_{312}) = (0.0009, 0.0124, 0.0572)$. This leads to $y_{(SM-RPV)} \simeq (3.3 \times 10^{-6}, 4.6 \times 10^{-5}, 2.1 \times 10^{-4})$. To see the largest possible value for y, we sum these three with the same sign to obtain an upper bound $y_{(SM-RPV)} = 2.6 \times 10^{-4}$. This contradicts with the result obtained in ref. [12], where y can be as large as $\simeq -3.7\%$.

As for the contributions from λ'', from the constraint $|\lambda''_{132}\lambda''^{*}_{232}| \lesssim 3.1 \times 10^{-3}$ [21] , $\lambda''_{112}, \lambda''_{121} \lesssim 2 \times 10^{-9}$ and $\lambda''_{131} < 10^{-4}$ [18], we find that λ'' contributions are small, less than 10^{-4}.

We conclude that R-parity violating contributions to y for $D^0 - \bar{D}^0$ mixing are small.

5.2 $B^0_d - \bar{B}^0_d$ mixing

Here we present the numerical results for the $B^0_d - \bar{B}^0_d$ mixing. For λ' contributions, we have

$$y_{(SM-RPV)} = -224.5 \times \lambda_{q'q1}\frac{(100GeV)^2}{m^2_{\tilde{e}^i_L}} ,$$

RPV parameters	Bounds [Processes]	Estimate
$\lvert\lambda'_{i21}\lambda'^*_{i13}\rvert$	1.2×10^{-5} $[B\bar{B}]$	$y_{(SM-RPV)_1}\simeq 1.1\times 10^{-4}$
$\lvert\lambda'_{i21}\lambda'^*_{i23}\rvert$	5.0×10^{-5} $[B\bar{B}]$	$y_{(SM-RPV)_2}\simeq 1.0\times 10^{-4}$
$\lvert\lambda'^*_{ij1}\lambda'_{i'j3}\rvert$, $\lvert\lambda'^*_{i1j}\lambda'_{i'3j}\rvert$	1.1×10^{-3} $[B^0\to X_q\nu\bar{\nu}]$	$y_{(RPV-RPV,\nu)}\simeq 2.7\times 10^{-4}$
$\lvert\lambda'^*_{ij1}\lambda'_{i'j3}\rvert$	1.1×10^{-3} $[B^0\to X_q\nu\nu]$	$y_{(RPV-RPV,l)}\simeq 0.67\times 10^{-4}$
$\lvert\lambda'_{ij1}\lambda'^*_{ij'3}\rvert\cdot\lvert\lambda'_{i'j'1}\lambda'^*_{i'j3}\rvert$	6.4×10^{-7} $[\bar{B}B]$	$y_{(RPV-RPV,u)}\simeq 1.1\times 10^{-4}$
$\lvert\lambda'_{ijj'}\lambda'_{i13}\rvert\cdot\lvert\lambda'_{ijj'}\lambda'_{i31}\rvert$	1.6×10^{-6} $[\bar{B}B]$	$y_{(RPV-RPV,d)}\simeq 7.2\times 10^{-3}$
$\lvert\lambda''_{212}\lambda''_{232}\rvert$	6×10^{-5} $[B\to\phi\pi]$	$y_{(SM-RPV)}\simeq 2.8\times 10^{-5}$
$\lvert\lambda''_{j21}\lambda''^*_{j23}\rvert$	6×10^{-5} $[B\to\phi\pi]$	$y_{(RPV-RPV,u)}\simeq 0.8\times 10^{-6}$
$\lvert\lambda''_{j12}\lambda''^*_{j32}\rvert$	6×10^{-5} $[B\to\phi\pi]$	$y_{(RPV-RPV,d)}\simeq 3.2\times 10^{-6}$

Table 3: The bounds on parameters from [17−19, 22, 24, 25] and corresponding values for y.

$$
\begin{aligned}
y_{(RPV-RPV,\nu)} &= 55.1\times(100\mathrm{GeV})^4\left\{\frac{\lambda'_{j3i'}\lambda'^*_{j'1i'}}{m^2_{\tilde{d}^{i'}_R}}\frac{\lambda'_{j'3i}\lambda'^*_{j1i}}{m^2_{\tilde{d}^{i}_R}}\right.\\
&\qquad\left.+\frac{\lambda'_{ji1}\lambda'^*_{j'i3}}{m^2_{\tilde{d}^{i}_L}}\frac{\lambda'_{j'i'1}\lambda'^*_{ji'3}}{m^2_{\tilde{d}^{i'}_L}}+2\frac{\lambda'_{j3i'}\lambda'^*_{j'1i'}}{m^2_{\tilde{d}^{i'}_R}}\frac{\lambda'_{j'i1}\lambda'^*_{ji3}}{m^2_{\tilde{d}^{i}_L}}\right\},\\
y_{(RPV-RPV,l)} &= 55.1\times\lambda'_{ji1}\lambda'^*_{j'i3}\lambda'_{j'i'1}\lambda'^*_{ji'3}\frac{(100GeV)^4}{m^2_{\tilde{u}^i_L}m^2_{\tilde{u}^{i'}_L}}, \qquad (5.6)\\
y_{(RPV-RPV,u)} &= 165.2\times\lambda'_{ij1}\lambda'^*_{ij'3}\lambda'_{i'j'1}\lambda'^*_{i'j3}\frac{(100GeV)^4}{m^2_{\tilde{e}^i_L}m^2_{\tilde{e}^{i'}_L}},\\
y_{(RPV-RPV,d)} &= 165.2\times\left(\lambda'_{i3j'}\lambda'^*_{i1j}\lambda'_{i'3j}\lambda'^*_{i'1j'}+\lambda'_{ij1}\lambda'^*_{ij'3}\lambda'_{i'j'1}\lambda'^*_{i'j3}\right. \qquad (5.7)\\
&\qquad\left.-28\lambda'_{ijj'}\lambda'^*_{i13}\lambda'_{i'31}\lambda'^*_{i'jj'}\right)\frac{(100GeV)^4}{m^2_{\tilde{\nu}^i_L}m^2_{\tilde{\nu}^{i'}_L}}.
\end{aligned}
$$

For λ'' contributions, we have

$$
\begin{aligned}
y_{(SM-RPV)} &= 0.46\times\lambda''_{212}\lambda''^*_{232}\frac{(100GeV)^2}{m^2_{\tilde{d}^2_R}},\\
y_{(RPV-RPV,u)} &= 220.3\times\lambda''_{i21}\lambda''^*_{i'23}\lambda''_{i'21}\lambda''^*_{i23}\frac{(100GeV)^4}{m^2_{\tilde{d}^2_R}m^2_{\tilde{d}^2_R}}, \qquad (5.8)\\
y_{(RPV-RPV,d)} &= 881.3\times\lambda''_{j'12}\lambda''^*_{j'32}\lambda''_{j12}\lambda''^*_{j32}\frac{(100GeV)^4}{m^2_{\tilde{u}^{j'}_R}m^2_{\tilde{u}^{j}_R}}.
\end{aligned}
$$

We list various constraints on relevant RPV parameters and corresponding values for y in table 3.

For $y_{(SM-RPV)}$, we keep only the two terms proportional to λ_{cc1} and λ_{uc1} since the other two terms are proportional to V_{ub}. We obtain, $\lambda_{q'q1}=A\lambda^2\lambda'_{i21}\times[\lambda'^*_{i13}-\lambda\lambda'^*_{i23}]$. In table 3, $y_{(SM-RPV)_1}$ and $y_{(SM-RP)_2}$ indicate contributions from the first and the second term in

$\lambda_{q'q1}$. Using constraints from [22], we have $|\lambda'_{i21}\lambda'^*_{i13}| \lesssim 1.2\times10^{-5}$ and $|\lambda'_{i21}\lambda'^*_{i23}| \lesssim 5.0\times10^{-5}$, each gives $y \approx 1\times10^{-4}$. This value is much less than the SM prediction.

For $y_{(RPV-RPV,\nu(l))}$, using the constraints $|\lambda'^*_{ij1}\lambda'_{i'j3}|$, $|\lambda'^*_{i1j}\lambda'_{i'3j}| \lesssim 1.1\times10^{-3}$, from [19] we find that the corresponding upper bounds: $y_{(RPV-RPV,\nu)} \simeq 2.7\times10^{-4}$ and $y_{(RPV-RPV,l)} \simeq 6.7\times10^{-5}$.

As for the contribution $y_{(RPV-RPV,u)}$, there are four terms with j, j' take values 1 or 2. Taking the explicit constraints from ref. [22], $|\lambda'_{i11}\lambda'_{i13}| \lesssim 8.0\times10^{-4}$, $|\lambda'_{i11}\lambda'_{i23}| \lesssim 2.5\times10^{-3}$, $|\lambda'_{i21}\lambda'_{i13}| \lesssim 1.2\times10^{-5}$, and $|\lambda'_{i21}\lambda'_{i23}| \lesssim 5.0\times10^{-5}$, we find that the dominant contribution is from the case $j = j' = 1$ which gives the upper bound $y_{(RPV-RPV,u)} \simeq 1.1\times10^{-4}$. In the same way for the contribution $y_{(RPV-RPV,d)}$, taking the constraints from [22, 24], the dominant part is from $\lambda'_{ijj'}\lambda'^*_{i13}\lambda'_{i'31}\lambda'^*_{i'jj'}$ term with $j = j' = 1$. We find the value for $y_{(RPV-RPV,d)}$ can be as large as 7×10^{-3}. This is about three times larger than the SM contribution.

Contributions from λ'' are also constrained. ref. [25] considers the decay mode $B^- \to \phi\pi^-$ and drives the upper bound $\lambda''_{j21}\lambda''^*_{j32} < 6\times10^{-5}$. Taking the same bound for $|\lambda''_{j21}\lambda''^*_{j32}|_{j=2}$ and $|\lambda''_{j21}\lambda''^*_{j32}|_{j=1,2}$ under the assumption that there is no accidental cancellation, $y_{(SM-RPV)}$ and $y_{(RPV-RPV,u(d))}$ are constrained to be small as can be seen from table 3.

We conclude that if there is no accidental cancellations, for $B^0_d - \bar{B}^0_d$ mixing, R-parity contribution to y can be as large as 7×10^{-3} which is about three times larger than the SM prediction. This value is still difficult to be measured experimentally. However, if there is accidental cancellation, y could be bigger. Careful measurement of y for $B^0_d - \bar{B}^0_d$ can provide valuable information about new physics beyond the SM.

5.3 $B^0_s - \bar{B}^0_s$ mixing

For λ' contributions, we have

$$\begin{aligned}
y_{(SM-RPV)} &= -316.6\times\lambda_{q'q2}\frac{(100GeV)^2}{m^2_{\tilde{e}^i_L}}\,,\\
y_{(RPV-RPV,\nu)} &= 77.7\times(100\text{GeV})^4\left\{\frac{\lambda'_{j3i'}\lambda'^*_{j'2i'}}{m^2_{\tilde{d}^{i'}_R}}\frac{\lambda'_{j'3i}\lambda'^*_{j2i}}{m^2_{\tilde{d}^i_R}}\right.\\
&\qquad\left.+\frac{\lambda'_{ji2}\lambda'^*_{j'i3}}{m^2_{\tilde{d}^i_L}}\frac{\lambda'_{j'i'2}\lambda'^*_{ji'3}}{m^2_{\tilde{d}^{i'}_L}}+2\frac{\lambda'_{j3i'}\lambda'^*_{j'2i'}}{m^2_{\tilde{d}^{i'}_R}}\frac{\lambda'_{j'i2}\lambda'^*_{ji3}}{m^2_{\tilde{d}^i_L}}\right\}\,,\\
y_{(RPV-RPV,l)} &= 77.7\times\lambda'_{ji2}\lambda'^*_{j'i3}\lambda'_{j'i'2}\lambda'^*_{ji'3}\frac{(100GeV)^4}{m^2_{\tilde{u}^i_L}m^2_{\tilde{u}^{i'}_L}}\,, \qquad (5.9)\\
y_{(RPV-RPV,u)} &= 233.1\times\lambda'_{ij2}\lambda'^*_{ij'3}\lambda'_{i'j'2}\lambda'^*_{i'j3}\frac{(100GeV)^4}{m^2_{\tilde{e}^i_L}m^2_{\tilde{e}^{i'}_L}}\,,\\
y_{(RPV-RPV,d)} &= 233.1\times\left(\lambda'_{i3j'}\lambda'^*_{i2j}\lambda'_{i'3j}\lambda'^*_{i'2j'}+\lambda'_{ij2}\lambda'^*_{ij'3}\lambda'_{i'j'2}\lambda'^*_{i'j3}\right.\\
&\qquad\left.-28\lambda'_{ijj'}\lambda'^*_{i23}\lambda'_{i'32}\lambda'^*_{i'jj'}\right)\frac{(100GeV)^4}{m^2_{\tilde{\nu}^i_L}m^2_{\tilde{\nu}^{i'}_L}}\,.
\end{aligned}$$

RPV parameters	Bounds [Processes]	Estimate	Our bounds on RPV
$\lvert\lambda'_{i23}\lambda'^*_{i22}\rvert$	8.2×10^{-3} [$\bar{B}_s B_s$]	$y_{(SM-RPV)} \simeq 0.11$	7.4×10^{-3} (7.8×10^{-4})
$\lvert\lambda'_{j3i'}\lambda'^*_{j'2i'}\rvert$, $\lvert\lambda'^*_{ij2}\lambda'_{i'j3}\rvert$	1.5×10^{-3} [$B \to X_s\nu\bar{\nu}$]	$y_{(RPV-RPV,\nu)} \simeq 7\times10^{-4}$	-
$\lvert\lambda'^*_{ij2}\lambda'_{i'j3}\rvert$	1.5×10^{-3} [$B \to X_s\nu\bar{\nu}$]	$y_{(RPV-RPV,l)} \simeq 1.7\times10^{-4}$	-
$\lvert\lambda'_{ij2}\lambda'^*_{ij'3}\rvert_{j,j'\neq3}$	5.16×10^{-2} [$B_s\bar{B}_s$]	$y_{(RPV-RPV,u)} \simeq 0.06$	2.0×10^{-2} (6.6×10^{-3})
$\lvert\lambda'_{ijj'}\lambda'^*_{i23}\lambda'_{i'32}\lambda'^*_{i'jj'}\rvert_{j,j'\neq3}$	see text	$y_{(RPV-RPV,d),3} \simeq 0.26$	1.5×10^{-5} (1.6×10^{-6})
$\lvert\lambda''_{221}\lambda''^*_{231}\rvert$	1.01×10^{-2} [$B \to \bar{K}\pi$]	$y_{(SM-RPV)} \simeq 2.9\times10^{-2}$	3.3×10^{-2} (3.5×10^{-3})
$\lvert\lambda''_{i12}\lambda''^*_{i13}\rvert_{i\neq3}$	see text	$y_{(RPV-RPV,u)}$, see text	1.77×10^{-2} (5.7×10^{-3})
$\lvert\lambda''_{j'21}\lambda''^*_{j'31}\rvert$	1.2×10^{-3} [$B^+ \to \pi^+K^0$]	$y_{(RPV-RPV,d)} \simeq 1.8\times10^{-3}$	-

Table 4: Upper limits on parameters from [17−19, 22−24, 26] and corresponding values for y. The numbers in the brackets correspond to the case, when central values for $y_{\rm SM}$ and $y_{Exp.}$ are used to put the constraints. For each number see the text for the explanation.

For λ'' contributions, we have

$$\begin{aligned}
y_{(SM-RPV)} &= -2.9 \times \lambda''_{221}\lambda''^*_{231}\frac{(100GeV)^2}{m^2_{\tilde{d}^1_R}}, \\
y_{(RPV-RPV,u)} &= 310.8 \times \lambda''_{i12}\lambda''^*_{i'13}\lambda''_{i'12}\lambda''^*_{i13}\frac{(100GeV)^4}{m^2_{\tilde{d}^1_R}m^2_{\tilde{d}^1_R}}\ , \\
y_{(RPV-RPV,d)} &= 1243 \times \lambda''_{i'21}\lambda''^*_{i'31}\lambda''_{i21}\lambda''^*_{i31}\frac{(100GeV)^4}{m^2_{\tilde{u}^{i'}_R}m^2_{\tilde{u}^i_R}}\ .
\end{aligned} \tag{5.10}$$

We list the constraints on the RPV parameters from [17, 19] and the corresponding values for the mixing parameter y in table 4.

There are several terms contributing to y from λ'. For $y_{(SM-RPV)}$ case we again drop terms proportional to V_{ub}, and have, $\lambda_{q'q2} = A\lambda^2\lambda'_{i22} \times [\lambda'^*_{i23} + \lambda\lambda'^*_{i13}]$. We are using constraints from ref. [23] we have $|\lambda'_{i23}\lambda'^*_{i22}| \lesssim 8.2 \times 10^{-3}$ and from ref. [24] $|\lambda'_{i13}\lambda'^*_{i22}| \lesssim 2.48 \times 10^{-3}$. The first term dominates and gives $y_{(SM-RPV)} \simeq 0.1$, which is of order of SM prediction $y_{\rm SM} \simeq 0.078$ and may have measurable effect.

For $y_{(RPV-RPV,\nu)}$, we have three contributions. For first and second contributions using the following conditions on RPV parameters $|\lambda'_{j3i'}\lambda'^*_{j'2i'}|$, $|\lambda'^*_{ij2}\lambda'_{i'j3}| \lesssim 1.5 \times 10^{-3}$ [17], we get $y_{(RPV-RPV,\nu)} \simeq 1.7\times10^{-4}$. For the last term, we obtain $y_{(RPV-RPV,\nu)} \simeq 3.5\times10^{-4}$. If we simply add them together we will get $y_{(RPV-RPV,\nu)} \simeq 7 \times 10^{-4}$.

For $y_{(RPV-RPV,l)}$, the situation is the same as the second term of $(RPV - RPV, \nu)$ case.

In the case for $y_{(RPV-RPV,u)}$, if one uses the individual constraints from [19, 23, 24] $(\lambda'_{i12}\lambda'^*_{i13}, \lambda'_{i22}\lambda'^*_{i23}, \lambda'_{i12}\lambda'^*_{i23}, \lambda'_{i22}\lambda'^*_{i13}) = (1.63 \times 10^{-3}, 8.2 \times 10^{-3}, 5.16 \times 10^{-2}, 2.48 \times 10^{-3})$ can get for each contribution $y_{(RPV-RPV,u)} \simeq (6.2 \times 10^{-4}, 1.6 \times 10^{-2}, 6.0 \times 10^{-2})$. If we keep the dominant interference term we will get $y \simeq 0.06$.

For $y_{(RPV-RPV,d)}$ case we have three contributions. The contribution of the first term into y is small, about 1.6×10^{-3}. The dominant contributions here are coming from squares of $|\lambda'_{i31}\lambda'^*_{i21}| \simeq 1.29 \times 10^{-3}$ [$B^- \to K^-\pi_0$] [24] and $|\lambda'_{i32}\lambda'^*_{i22}| \simeq 2.3 \times 10^{-3}$ [$B^0 \to MM$] [19]. The second term is just the same as in $y_{(RPV-RPV,u)}$ case, considered above. So here we have $y_{(RPV-RPV,l)} \simeq 0.06$. The last term is enhanced with the large coefficient.

JHEP09(2007)044

Here the dominant contributions are coming from $|\lambda'_{i22}\lambda'^*_{i23}\lambda'_{i'32}\lambda'^*_{i'22}| \simeq 18.9 \times 10^{-6}$ and $|\lambda'_{i12}\lambda'^*_{i23}\lambda'_{i'32}\lambda'^*_{i'12}| \simeq 20.6 \times 10^{-6}$ [23, 24, 19, 22]. If we simply add them together, their contribution will be $y_{(RPV-RPV,d)} \simeq 0.26$. So, here we can conclude, that in $y_{(RPV-RPV,d)}$ case one also can expect large effects for y.

For λ'' contribution to $y_{(SM-RPV)}$, we have $|\lambda''_{221}\lambda''^*_{231}| \lesssim 1.01\times10^{-2}$ from $B \to \bar{K}\pi$ [24], which gives $y_{(SM-RPV)} \simeq 2.9 \times 10^{-2}$.

For the $y_{(RPV-RPV,u)}$ case no direct constraint on $|\lambda''_{i12}\lambda''^*_{i13}|_{i=1,2}$ exists. However, if one assumes that $|\lambda''_{i12}\lambda''^*_{i13}|_{i=1,2} \approx |\lambda''_{i12}\lambda''^*_{i13}| \lesssim 1.2 \times 10^{-3}$ [26], $y_{(RPV-RPV,u)} \simeq 4.5 \times 10^{-4}$.

For the last case of eq. (5.10) from [26] we have $|\lambda''_{j'21}\lambda''^*_{j'31}| \lesssim 1.2 \times 10^{-3}$, which gives $y_{(RPV-RPV,d)} \approx 1.8 \times 10^{-3}$.

We note that present constraints on the RPV parameters still allow large $y_{(SM-RPV)}$, $y_{(RPV-RPV,u)}$ and $y_{(RPV-RPV,u)}$ from λ' interaction. One can turn the argument around to constrain the relevant RPV parameters by requiring that the new contributions do not exceed the allowed range for the difference of SM prediction and experimental values. We have carried out an analysis, taking the one sigma range values $y_{\rm SM} = [0.054, 0.101]$ and $y_{Exp.} = [0.022, 0.151]$, and assumed constructive contributions between the SM and new contributions, to obtain the bounds for each individual terms. Similar analysis has been performed for λ'' cases. The bounds are listed in table 4 in the last column. These bounds are new ones.

6. Conclusion

In this paper we have explored the influence of SUSY R-parity violation contributions for the lifetime difference y on the $D^0 - \bar{D}^0$ and $B^0_{d,s} - \bar{B}^0_{d,s}$ systems. We have obtained general expressions for new physics contributions to y from effective four fermion operators including SM-NP interference and pure new physcis contributions. We find that in general R-parity violating contribution to $D^0 - \bar{D}^0$ mixing, and $B^0_d - \bar{B}^0_d$ to be small. There may be sizable contribution to $B^0_s - \bar{B}^0_s$ mixing. We also obtain some interesting bounds on R-parity violating parameters using known Standard Model predictions and experimental data.

Acknowledgments

This work was supported in part by the NSC and NCTS.

References

[1] Particle Data Group collaboration, W.M. Yao et al., *Review of particle physics*, *J. Phys.* **G 33** (2006) 1.

[2] BABAR collaboration, B. Aubert et al., *Evidence for D^0-$\bar{D}^0$ mixing*, *Phys. Rev. Lett.* **98** (2007) 211802 [hep-ex/0703020].

[3] Belle collaboration, M. Staric et al., *Evidence for D^0-$\bar{D}^0$ mixing*, *Phys. Rev. Lett.* **98** (2007) 211803 [hep-ex/0703036].

[4] Belle collaboration, M. Staric, *Measurement of D^0-$\bar{D}^0$ mixing in $D^0 \to K_s^0\pi^+\pi^-$ decays*, talk given at the *XLII Rencontres de Moriond*, La Thuile, Italy, 10-17 March (2007) [arXiv:0704.1000].

[5] C.S. Aulakh and R.N. Mohapatra, *Neutrino as the supersymmetric partner of the Majoron*, *Phys. Lett.* **B 119** (1982) 136;
F. Zwirner, *Observable $\Delta B = 2$ transitions without nucleon decay in a minimal supersymmetric extension of the standard model*, *Phys. Lett.* **B 132** (1983) 103;
L.J. Hall and M. Suzuki, *Explicit R-parity breaking in supersymmetric models*, *Nucl. Phys.* **B 231** (1984) 419;
I.-H. Lee, *Lepton number violation in softly broken supersymmetry.* 2, *Nucl. Phys.* **B 246** (1984) 120;
J.R. Ellis, G. Gelmini, C. Jarlskog, G.G. Ross and J.W.F. Valle, *Phenomenology of supersymmetry with broken r-parity*, *Phys. Lett.* **B 150** (1985) 142;
G.G. Ross and J.W.F. Valle, *Supersymmetric models without R-parity*, *Phys. Lett.* **B 151** (1985) 375;
S. Dawson, *R-parity breaking in supersymmetric theories*, *Nucl. Phys.* **B 261** (1985) 297;
R. Barbieri and A. Masiero, *Supersymmetric models with low-energy baryon number violation*, *Nucl. Phys.* **B 267** (1986) 679.

[6] A. Lenz and U. Nierste, *Theoretical update of B_s-$\bar{B}_s$ mixing*, *JHEP* **06** (2007) 072 [hep-ph/0612167];
M. Beneke, G. Buchalla, C. Greub, A. Lenz and U. Nierste, *Next-to-leading order QCD corrections to the lifetime difference of B_s mesons*, *Phys. Lett.* **B 459** (1999) 631 [hep-ph/9808385];
M. Ciuchini, E. Franco, V. Lubicz, F. Mescia and C. Tarantino, *Lifetime differences and CP-violation parameters of neutral B mesons at the next-to-leading order in QCD*, *JHEP* **08** (2003) 031 [hep-ph/0308029].

[7] D0 collaboration, V.M. Abazov et al., *Measurement of the CP-violation parameter of B^0 mixing and decay with $p\bar{p} \to \mu\mu x$ data*, *Phys. Rev.* **D 74** (2006) 092001 [hep-ex/0609014].

[8] CDF collaboration, D. Acosta et al., *Measurement of the lifetime difference between B_s mass eigenstates*, *Phys. Rev. Lett.* **94** (2005) 101803 [hep-ex/0412057].

[9] A.F. Falk, Y. Grossman, Z. Ligeti, Y. Nir and A.A. Petrov, *The D^0-$\bar{D}^0$ mass difference from a dispersion relation*, *Phys. Rev.* **D 69** (2004) 114021 [hep-ph/0402204].

[10] T. Ohl, G. Ricciardi and E.H. Simmons, *D-$\bar{D}$ mixing in heavy quark effective field theory: the sequel*, *Nucl. Phys.* **B 403** (1993) 605 [hep-ph/9301212];
I.I.Y. Bigi and N.G. Uraltsev, *D^0-$\bar{D}^0$ oscillations as a probe of quark-hadron duality*, *Nucl. Phys.* **B 592** (2001) 92 [hep-ph/0005089];
J.F. Donoghue, E. Golowich, B.R. Holstein and J. Trampetic, *Dispersive effects in D^0-$\bar{D}^0$ mixing*, *Phys. Rev.* **D 33** (1986) 179;
T.A. Kaeding, *D meson mixing in broken* SU(3), *Phys. Lett.* **B 357** (1995) 151 [hep-ph/9505393];
P. Colangelo, G. Nardulli and N. Paver, *On D^0-$\bar{D}^0$ mixing in the standard model*, *Phys. Lett.* **B 242** (1990) 71;
F. Buccella, M. Lusignoli and A. Pugliese, *Charm nonleptonic decays and final state interactions*, *Phys. Lett.* **B 379** (1996) 249 [hep-ph/9601343];
E. Golowich and A.A. Petrov, *Can nearby resonances enhance D^0-$\bar{D}^0$ mixing?*, *Phys. Lett.* **B 427** (1998) 172 [hep-ph/9802291].

[11] M. Ciuchini et al., *D-$\bar{D}$ mixing and new physics: general considerations and constraints on the MSSM*, hep-ph/0703204.

[12] E. Golowich, S. Pakvasa and A.A. Petrov, *New physics contributions to the lifetime difference in D^0-$\bar{D}^0$ mixing*, *Phys. Rev. Lett.* **98** (2007) 181801 [hep-ph/0610039].

[13] E. Golowich, J. Hewett, S. Pakvasa and A.A. Petrov, *Implications of D^0-$\bar{D}^0$ mixing for new physics*, arXiv:0705.3560.

[14] M. Beneke, G. Buchalla and I. Dunietz, *Width difference in the $B_s - \bar{B}_s$ system*, *Phys. Rev.* **D 54** (1996) 4419 [hep-ph/9605259].

[15] M. Okamoto, *Full determination of the CKM matrix using recent results from lattice QCD*, PoS(LAT2005)013 [hep-lat/0510113].

[16] CKMfitter Group collaboration, J. Charles et al., *CP-violation and the CKM matrix: assessing the impact of the asymmetric B factories*, *Eur. Phys. J.* **C 41** (2005) 1 [hep-ph/0406184].

[17] R. Barbier et al., *R-parity violating supersymmetry*, *Phys. Rept.* **420** (2005) 1 [hep-ph/0406039].

[18] B.C. Allanach, A. Dedes and H.K. Dreiner, *Bounds on R-parity violating couplings at the weak scale and at the GUT scale*, *Phys. Rev.* **D 60** (1999) 075014 [hep-ph/9906209].

[19] M. Chemtob, *Phenomenological constraints on broken r parity symmetry in supersymmetry models*, *Prog. Part. Nucl. Phys.* **54** (2005) 71 [hep-ph/0406029].

[20] A. Deandrea, J. Welzel and M. Oertel, *$K \to \pi\nu\bar{\nu}$ from standard to new physics*, *JHEP* **10** (2004) 038 [hep-ph/0407216];
N.G. Deshpande, D.K. Ghosh and X.-G. He, *Constraints on new physics from $K \to \pi\nu\bar{\nu}$*, *Phys. Rev.* **D 70** (2004) 093003 [hep-ph/0407021].

[21] C.E. Carlson, P. Roy and M. Sher, *New bounds on R-parity violating couplings*, *Phys. Lett.* **B 357** (1995) 99 [hep-ph/9506328].

[22] A. Kundu and J.P. Saha, *Constraints on R-parity violating supersymmetry from neutral meson mixing*, *Phys. Rev.* **D 70** (2004) 096002 [hep-ph/0403154].

[23] S. Nandi and J.P. Saha, *B_s-$\bar{B}_s$ mixing, B decays and R-parity violating supersymmetry*, *Phys. Rev.* **D 74** (2006) 095007 [hep-ph/0608341].

[24] D.K. Ghosh, X.-G. He, B.H.J. McKellar and J.-Q. Shi, *Constraining R-parity violating couplings from $B \to pp$ decays using QCD improved factorization method*, *JHEP* **07** (2002) 067 [hep-ph/0111106].

[25] S. Bar-Shalom, G. Eilam and Y.-D. Yang, *$B \to \phi\pi$ and $B_0 \to \phi\phi$ in the standard model and new bounds on R parity violation*, *Phys. Rev.* **D 67** (2003) 014007 [hep-ph/0201244].

[26] D. Chakraverty and D. Choudhury, *B physics constraints on baryon number violating couplings: grand unification or R-parity violation*, *Phys. Rev.* **D 63** (2001) 112002 [hep-ph/0012309].

JHEP09(2007)044