A Consistent Resolution of Possible Anomalies in $B^0 \to \phi K_S$ and $B^+ \to \eta' K^+$ Decays

B. Dutta$^1$, C. S. Kim$^2$ and Sechul Oh$^{2,3}$

$^1$Department of Physics, University of Regina, SK, S4S 0A2, Canada
$^2$Department of Physics and IPAP, Yonsei University, Seoul 120-479, Korea
$^3$Theory Group, KEK, Tsukuba, Ibaraki 305-0801, Japan

Abstract

In the framework of $R$-parity violating ($R_p$) supersymmetry, we try to find a consistent explanation for both recently measured CP asymmetry in $B^0 \to \phi K_S$ decay and the large branching ratio of $B^\pm \to \eta' K^\pm$ decay, which are inconsistent with the Standard Model (SM) prediction. We also investigate other charmless hadronic $B \to PP$ and $B \to VP$ decay modes whose experimental data favor the SM: for instance, recently measured CP asymmetries in $B^0 \to \eta' K_S$ and $B^0 \to J/\Psi K_S$. We find that all the observed data can be accommodated for certain values of $R_p$ couplings.
The main mission of $B$ factories, such as KEK−B and SLAC−B, is to test the Standard Model (SM) and further to find possible new physics effects in $B$ meson systems. For this goal, a variety of useful observables can be measured to be compared with theoretical expectations. One of the important observables is CP asymmetries in various $B$ meson decays, and another is branching ratios (BRs) for rare $B$ decay processes.

CP violation in $B$ system has been confirmed in measurements of time-dependent CP asymmetries in $B \to J/\Psi K_S$ decay. The world average of the asymmetry in $B \to J/\Psi K_S$ [1] is given by

$$\sin(2\beta)_{J/\Psi K_S} = 0.734 \pm 0.054,$$

which is consistent with the SM expectation. However, recent measurements of $\sin(2\beta)$ in $B^0 \to \phi K_S$ decay disagree with the above value. The measurements of time-dependent CP asymmetries in $B^0 \to \phi K_S$ have been recently reported by BaBar [2] and Belle [3], respectively:

$$\sin(2\beta)_{\phi K_S}^{\text{BaBar}} = -0.19^{+0.52}_{-0.50} \pm 0.09,$$

$$\sin(2\beta)_{\phi K_S}^{\text{Belle}} = -0.73 \pm 0.64 \pm 0.18.$$  

Both experimental results show (a tendency of) negative values of $\sin(2\beta)$.

Because within the SM the difference between the asymmetries in $B \to J/\Psi K_S$ and $B^0 \to \phi K_S$ is expected to be [4]

$$|\sin(2\beta)_{J/\Psi K_S} - \sin(2\beta)_{\phi K_S}| \lesssim O(\lambda^2)$$

with $\lambda \approx 0.2$, these results indicate 2.7 $\sigma$ deviation from the SM prediction and may reveal new physics effects.

The decay process $B^0 \to \phi K_S$ is a pure penguin process $b \to s\bar{s}s$, and in the SM the time-dependent CP asymmetry of this mode is expected to measure the same $\sin(2\beta)$ as in $B \to J/\Psi K_S$, as shown in Eq. (4). If there are any new physics effects in the measurements of time-dependent CP asymmetries, the effects can arise from new contributions to the
$B^0 - \bar{B}^0$ mixing amplitude and/or the decay amplitude of each mode. Because the new physics effects to the $B^0 - \bar{B}^0$ mixing would be universal to all the neutral $B^0$ meson decays, the discrepancy between the measured values of $\sin(2\beta)_{J/\Psi K_S}$ and $\sin(2\beta)_{\phi K_S}$ may indicate the possibility of new physics effects in the decay amplitude of $B^0 \to \phi K_S$. Supposing that the mode $B^0 \to \phi K_S$ reveals new physics effects [4,5], one might expect that other modes having the same internal quark level process $b \to s \bar{s} s$ (e.g., $B^0 \to \eta' K_S$) would reveal the similar effects. Interestingly, the recent measurements of CP asymmetries in $B^0 \to \eta' K_S$ by Belle [3] agree well with the results of $\sin(2\beta)_{J/\Psi K_S}$ given in Eq. (1) (see Table I). Therefore, any successful explanation invoking new physics should accommodate the data disfavoring the SM, such as $\sin(2\beta)_{\phi K_S}$, and simultaneously all the data favoring the SM, such as $\sin(2\beta)_{\eta' K_S}$ and $\sin(2\beta)_{J/\Psi K_S}$. Motivated by the recent measurements of $\sin(2\beta)_{\phi K_S}$, a few first analyses [1,6–9] have been done. But, all of them explain only the deviation of $\sin(2\beta)_{\phi K_S}$ from the SM prediction, or in addition, make (at most) qualitative statements on $\sin(2\beta)_{\eta' K_S}$ [1,6–9].

There also exist plenty of experimental data observed for charmless hadronic $B \to PP$ ($P$ denotes a pseudoscalar meson) and $B \to VP$ ($V$ denotes a vector meson) decay modes, which are well understood within the SM. However, among the $B \to PP$ decay modes, the BR of the decay mode $B^\pm \to \eta' K^\pm$ is found to be still larger than that expected within the SM\(^1\) [10–13]: the experimental world average is $B(B^\pm \to \eta' K^\pm) = (75 \pm 7) \times 10^{-6}$. The SM contribution is about $3\sigma$ smaller than the experimental world average [13]. Among the $B \to VP$ decay modes, the experimentally observed BR for the decay $B^0 \to \eta K^{*0}$ has been also found to be $2\sigma$ larger than the SM expectation [13].

In this letter we try to find a consistent explanation for all the observed data in charmless hadronic $B \to PP$ and $B \to VP$ decays in the framework of $R$-parity violating ($R_p$)

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\(^1\)Attempts to explain the large $B(B^\pm \to \eta' K^\pm)$ within the SM have been made: e.g., by using the anomalous $g - g - \eta'$ coupling [14].
supersymmetry (SUSY). In $R_p$ SUSY, the effects of $R_p$ couplings on $B$ decays can appear at tree level and can be in some cases comparable to the SM contribution. Our main focus is on the recent measurement of CP asymmetry in $B^0 \to \phi K_S$ and the large BR for $B^\pm \to \eta' K^\pm$: both data appear to be inconsistent with the SM prediction. In order to achieve this goal, we investigate all the observed $B \to PP$ and $B \to VP$ decay modes and explicitly show that indeed all the observed data can be accommodated in a consistent way for certain values of $R_p$ couplings.

The $R_p$ part of the superpotential of the minimal supersymmetric standard model (MSSM) can contain terms of the form

$$W_{R_p} = \kappa_i L_i H_2 + \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \lambda''_{ijk} U^c_i D^c_j D^c_k$$

(5)

where $E_i$, $U_i$ and $D_i$ are respectively the $i$-th type of lepton, up-quark and down-quark singlet superfields, $L_i$ and $Q_i$ are the SU(2)$_L$ doublet lepton and quark superfields, and $H_2$ is the Higgs doublet with the appropriate hypercharge. From the symmetry reason, we need $\lambda_{ijk} = -\lambda_{jik}$ and $\lambda''_{ijk} = -\lambda''_{ikj}$. The bilinear terms can be rotated away with redefinition of lepton and Higgs superfields, but the effect reappears as $\lambda_s$, $\lambda'$s and lepton-number violating soft terms [15]. The first three terms of Eq. (5) violate the lepton number, whereas the fourth term violates the baryon number. We do not want all these terms to be present simultaneously due to catastrophic rates for proton decay. In order to prevent proton decay, one set needs to be forbidden.

For our purpose, we will assume only $\lambda'$-type couplings to be present. Then, the effective Hamiltonian for charmless hadronic $B$ decay can be written as [16]

$$H_{eff}^{X'}(b \to \bar{d}_j d_k d_n) = d_{jkn}^{R}[\bar{d}_n \gamma^\mu_{L} d_j \bar{d}_k \gamma^\mu_R b_\alpha] + d_{jkn}^{L}[\bar{d}_n \gamma^\mu_{L} b_\beta \bar{d}_k \gamma^\mu_R d_j \alpha] ,$$

$$H_{eff}^{X'}(b \to \bar{u}_j u_k d_n) = u_{jkn}^{R}[\bar{u}_k \gamma^\mu_{L} u_j \bar{d}_n \gamma^\mu_R b_\alpha] ,$$

(6)

with
\[ d_{jkn}^R = \sum_{i=1}^{3} \frac{\lambda'_{ijk} \lambda^*_{imn}}{8m^2_{\tilde{\nu}_L}}, \quad d_{jkn}^L = \sum_{i=1}^{3} \frac{\lambda'_{3ik} \lambda^*_{iuj}}{8m^2_{\tilde{\nu}_L}}, \quad (j, k, n = 1, 2) \]
\[ u_{jkn}^R = \sum_{i=1}^{3} \frac{\lambda'_{ijn} \lambda^*_{ik3}}{8m^2_{\tilde{\nu}_L}}, \quad (j, k = 1, n = 2), \]

where \( \alpha \) and \( \beta \) are color indices and \( \gamma^\mu_{R,L} \equiv \gamma^\mu (1 \pm \gamma_5) \). The leading order QCD correction to this operator is given by a scaling factor \( f \approx 2 \) for \( m_{\tilde{\nu}} = 200 \text{ GeV} \).

The available data on low energy processes can be used to impose rather strict constraints on many of these couplings \([17–19]\). Most such bounds have been calculated under the assumption of there being only one non-zero \( \mathcal{R}_p \) coupling. There is no strong argument to have only one \( \mathcal{R}_p \) coupling being nonzero. In fact, a hierarchy of couplings may be naturally obtained \([18]\) on account of the mixings in either of the quark and squark sectors. In this work, we try to find out the values of such \( \mathcal{R}_p \) couplings for which all available data are simultaneously satisfied. An important role will be played by the \( \lambda'_{32i} \) -type couplings, the constraints on which are relatively weak. The BR of \( B \to X_s \nu \nu \) can put bound on \( \lambda'_{322} \lambda^*_{323} \) in certain limits. Using Ref. [20] and the experimental limit (BR < \( 6.4 \times 10^{-4} \)) on the BR of \( B \to X_s \nu \nu \) [21], we find that \( \lambda' \leq 0.07 \) (for \( m_{\tilde{q}} = 200 \text{ GeV} \)). However, if we go to any realistic scenario, for example grand unified models (with \( R \)-parity violation), we find a natural hierarchy among the sneutrino and squark masses. The squark masses are much heavier than the sneutrino masses and the bound does not apply any more for \( m_{\tilde{\nu}} = 200 \text{ GeV} \).

In our calculation, we use the effective Hamiltonian and the effective Wilson coefficients (WCs) for the processes \( b \to s\bar{q}q' \) and \( b \to d\bar{q}q' \) given in Ref. [22]. The decay amplitude of \( B^- \to \phi K^- \) decay mode is given by

\[ \bar{A}_{\phi K} = \bar{A}^{SM}_{\phi K} + \bar{A}^{R_p}_{\phi K}, \]

where the SM part of the amplitude is

\[ \bar{A}^{SM}_{\phi K} = -\frac{G_F}{\sqrt{2}} V_{tb} V^*_{ts} (a_3 + a_4 + a_5 - \frac{1}{2}a_7 - a_9 - \frac{1}{2}a_{10}) A_{\phi}, \]

and the \( \mathcal{R}_p \) part of the amplitude involves only \( d_{222}^L \) and \( d_{222}^R \):
\[ \mathcal{A}_{\phi K}^R = \left( d_{222}^L + d_{222}^R \right) [\xi A_{\phi}] , \]

with \( A_{\phi} = \langle K | \bar{s} \gamma^\mu (1 - \gamma_5) b | B \rangle \langle \phi | \bar{s} \gamma_\mu s | 0 \rangle \). This particular structure of \( A_{\phi} \) is obtained from the operators \( \bar{d}_{\alpha} \gamma^\mu_L d_{\beta} \bar{d}_{\kappa} \gamma_\mu R(L) b_\alpha \) given in Eq. (6), which are derived from the operators \( \bar{s}_L(R) \bar{s}_R(L) b_{\alpha} \) by Fierz transformation [23]. Here the effective coefficients \( a_i \) are defined as \( a_i = c_i^{eff} + \xi c_i^{eff} (i = \text{odd}) \) and \( a_i = c_i^{eff} + \xi c_i^{eff} (i = \text{even}) \) with the effective WCs \( c_i^{eff} \) at the scale \( m_b \) [22], and by treating \( \xi \equiv 1/N_c \) \((N_c \text{ denotes the effective number of color}) \) as an adjustable parameter.

The CP asymmetry parameter \( \sin(2\tilde{\beta})_{XY} \) for \( B \to XY \) can be written as

\[ \sin(2\tilde{\beta})_{XY} = -\frac{2 \text{Im} \lambda_{XY}}{(1 + |\lambda_{XY}|^2)} , \]

where \( \lambda_{XY} = e^{-2i\beta} \left( \mathcal{A}_{XY}/A_{XY} \right) = e^{-i(2\beta + \theta)} \left| \mathcal{A}_{XY}/A_{XY} \right| \) with \( \mathcal{A}_{XY}/A_{XY} = e^{-i\theta} \left| \mathcal{A}_{XY}/A_{XY} \right| \). Here \( \beta \) denotes the CP angle in the SM and \( \tilde{\beta} \) denotes the effective CP angle given by \( 2\tilde{\beta} = 2\beta + \theta \) with a new weak phase \( \theta \) arising from new physics. \( A_{XY} = A_{XY}^{SM} + A_{XY}^R \) and \( \mathcal{A}_{XY} \) is its CP-conjugate amplitude. For \( B^0 \to \phi K_S \), in the SM, \( A_{\phi K_S}/A_{\phi K_S} = 1 \), so \( \tilde{\beta} = \beta \). But, in \( R_p \) SUSY, generally \( |A_{\phi K_S}/A_{\phi K_S}| \neq 1 \) and \( \theta \neq 0 \).

The \( R_p \) part of the amplitude of \( B^- \to \eta' K^- \) decay is

\[ \mathcal{A}_{\eta' K}^R = \left( d_{121}^R - d_{112}^L \right) \xi A_{\eta'}^u + \left( d_{222}^L - d_{222}^R \right) \left[ \frac{\bar{m}}{m_s} \left( A_{\eta'}^u - A_{\eta'}^d \right) - \xi A_{\eta'}^e \right] \]

\[ + \left( d_{121}^R - d_{112}^L \right) \frac{\bar{m}}{m_d} A_{\eta'}^u + u_{112}^R \left[ \xi A_{\eta'}^u - \frac{2m_K^2 A_K}{(m_s + m_u)(m_b - m_u)} \right] , \tag{12} \]

where \( \bar{m} \equiv m_{\eta'}^2/(m_b - m_s) \) and

\[ A_{\eta'}^{u(s)} = f_{\eta'}^{u(s)} F_{B \to K}(m_B^2 - m_K^2) , \]

\[ A_K = f_K F_{B \to \eta'}(m_B^2 - m_{\eta'}^2) . \]

\( F_{B \to K(\eta')} \) denotes the hadronic form factor for \( B \to K(\eta') \) and \( f_{K(\eta')} \) is the decay constant of \( K(\eta') \) meson\(^2\). Analogous expressions hold for \( B^\pm \to \eta K^\pm \) where we have to replace \( A_{\eta'}^u \)

\(^2\)The definition of \( f_{\eta'}^{u(s)} \) is given in Ref. [22], considering the \( \eta - \eta' \) mixing. The mixing angle \( \theta = -22^0 \) is used.
Case 1: We use the following input parameters: the CP angle $\gamma = 110^0$, the s quark mass $m_s$ (at $m_b$ scale) = 85 MeV, and the decay constants and the hadronic form factors used in Ref. [13]. We take $\beta = 26^0$ as our input, which corresponds to $\sin(2\beta)_{\phi/\psi K} = 0.78$ given in Eq. (1). We set $d_{222}^L = ke^{-i\theta'}$ and $d_{222}^R = -ke^{i\theta'}$, where $k = |d_{222}^L| = |d_{222}^R|$ and $\theta'$ is a new weak phase arising from $d_{222}^L \propto \lambda_{32}^s \lambda_{s22}^*, \text{ or } (d_{222}^R)^* \propto \lambda_{122}^s \lambda_{132}^*$. In this case, $\mathcal{A}_{\phi K}^{B_{s}}$ is purely imaginary and introduces a new weak phase to the decay amplitude of $B \rightarrow \phi K$ modes, which can cause non-zero direct CP asymmetries, different from the SM prediction. In contrast, $\mathcal{A}_{\psi K}^{B_{s}}$ introduces no new phase in this choice of $d_{222}^L$ and $d_{222}^R$. We find a constructive contribution to the SM part of the amplitude for $B^+ \rightarrow \psi K^+$ which helps to satisfy the experimental data.

For $|\lambda'_{322}| = |\lambda'_{332}| = |\lambda'_{323}| = 0.055$, $\tan \theta' = 0.52$, and $m_{\text{susy}} = 200$ GeV, we find $\sin(2\tilde{\beta})_{\phi K_S} = 0$ and $\sin(2\tilde{\beta})_{\psi K_S} = 0.73$ for $\xi = 0.45$, as shown in Table I. This result agrees well with the recently reported experimental data. Figures 1 and 2 show the BR versus $\xi$ for

| TABLE I. CP asymmetries in the decay modes $B^0 \rightarrow \phi K_S$ and $B^0 \rightarrow \psi K_S$. |
|-----------------|-----------------|-----------------|-----------------|
| $\sin(2\tilde{\beta})_{\phi K_S}$ | Case 1 | Case 2 | experimental data |
| $\sin(2\tilde{\beta})_{\psi K_S}$ | 0.73 | 0.72 | $-0.19^{+0.52}_{-0.50} \pm 0.09$ (BaBar), $-0.73 \pm 0.64 \pm 0.18$ (Belle) |

by $A_u^u$, $A_v^v$ by $A_u^s$ and $m_\eta'$ by $m_\eta$. Replacing a pseudoscalar meson by a vector meson, we also get similar expressions for the amplitudes of $B^{\pm(0)} \rightarrow \eta' K^{\pm(0)}$ modes.

In Eqs. (10) and (12), we note that $\mathcal{A}_{\phi K}^{B_{s}}$ includes the $(d_{222}^L + d_{222}^R)$ term only, while $\mathcal{A}_{\psi K}^{B_{s}}$ includes the $(d_{222}^L - d_{222}^R)$ term. Furthermore, in the $\mathcal{R}_p$ SUSY framework, we find that the positive values of $d_{222}^R$ and negative values of $d_{222}^L$ can increase the BR for the process $B^\pm \rightarrow \eta' K^\pm$, keeping most of the other $B \rightarrow PP$ and $B \rightarrow VP$ modes unaffected. The other $\mathcal{R}_p$ combinations are either not enough to increase in the BR for $B^\pm \rightarrow \eta' K^\pm$ or affect too many other modes. From now on, we will concentrate on contributions of $d_{222}^L$ and $d_{222}^R$ which are relevant to the process $b \rightarrow s\bar{s}s$. We divide our results into the following two cases.

Case 1: We use the following input parameters: the CP angle $\gamma = 110^0$, the s quark mass $m_s$ (at $m_b$ scale) = 85 MeV, and the decay constants and the hadronic form factors used in Ref. [13]. We take $\beta = 26^0$ as our input, which corresponds to $\sin(2\beta)_{\phi/\psi K} = 0.78$ given in Eq. (1). We set $d_{222}^L = ke^{-i\theta'}$ and $d_{222}^R = -ke^{i\theta'}$, where $k = |d_{222}^L| = |d_{222}^R|$ and $\theta'$ is a new weak phase arising from $d_{222}^L \propto \lambda_{32}^s \lambda_{s22}^*$, or $(d_{222}^R)^* \propto \lambda_{122}^s \lambda_{132}^*$. In this case, $\mathcal{A}_{\phi K}^{B_{s}}$ is purely imaginary and introduces a new weak phase to the decay amplitude of $B \rightarrow \phi K$ modes, which can cause non-zero direct CP asymmetries, different from the SM prediction. In contrast, $\mathcal{A}_{\psi K}^{B_{s}}$ introduces no new phase in this choice of $d_{222}^L$ and $d_{222}^R$. We find a constructive contribution to the SM part of the amplitude for $B^+ \rightarrow \psi K^+$ which helps to satisfy the experimental data.

For $|\lambda'_{322}| = |\lambda'_{332}| = |\lambda'_{323}| = 0.055$, $\tan \theta' = 0.52$, and $m_{\text{susy}} = 200$ GeV, we find $\sin(2\tilde{\beta})_{\phi K_S} = 0$ and $\sin(2\tilde{\beta})_{\psi K_S} = 0.73$ for $\xi = 0.45$, as shown in Table I. This result agrees well with the recently reported experimental data. Figures 1 and 2 show the BR versus $\xi$ for
$B^+ \rightarrow \phi K^+$ and $B^+ \rightarrow \eta' K^+$, respectively. In both figures, the shaded region represents the allowed region by the experimental results and the solid line corresponds the SM prediction. The SM BR of $B^+ \rightarrow \eta' K^+$ is far below the experimental lower bound. Our result in this case is denoted by the dotted line, which is clearly consistent with the experimental data: $B(B^+ \rightarrow \eta' K^+) = 69.3 \times 10^{-6}$ for $\xi = 0.45$. In Table II, we estimate the BRs and CP (rate) asymmetries $A_{CP}$ for $B \rightarrow \eta(0) K(\ast)$ and $B^+ \rightarrow \phi K^+$, where $A_{CP}$ is defined by

$$A_{CP} = \frac{B(\bar{b} \rightarrow \bar{f} \bar{s}s) - B(b \rightarrow f \bar{s}s)}{B(b \rightarrow f \bar{s}s) + B(b \rightarrow f \bar{s}s)}$$

with $b$ and $f$ denoting $b$ quark and a generic final state, respectively. The estimated BRs are well within the experimental limits. The BR of $B^0 \rightarrow \phi K^0$ has also been measured, $B(B^0 \rightarrow \phi K^0) = (8.1^{+3.1}_{-2.5} \pm 0.8) \times 10^{-6}$ [2]. The theoretical value for the BR of this mode is same as that of $B^+ \rightarrow \phi K^+$ and is allowed by the experimental data. Further, We note that $A_{CP}$'s for $B^+ \rightarrow \phi K^+$ and $B^0 \rightarrow \eta K^{*0}$ are large and have positive signs. This can be taken as a prediction of this model. It is hopeful that the CDF at Fermilab could measure the CP asymmetry of $B^+ \rightarrow \phi K^+$ mode using their two track trigger in the ongoing RUN II experiment [24].

So far we have assumed that the magnitudes and phases are same for $d_{222}^{L}$ and $d_{222}^{R}$. We can assume them to be different and still obtain good fits. For example, if we set $d_{222}^{L} = k_{L} e^{-i \theta'_{L}}$ and $d_{222}^{R} = -k_{R} e^{i \theta'_{R}}$ and choose: $k_{L} = 1.0 \times 10^{-8}$, $k_{R} = 8.0 \times 10^{-9}$ and $\tan \theta'_{L} = 0.4$, $\tan \theta'_{R} = 0.52$, we find $\sin(2 \tilde{\beta})_{\phi K_{S}} = 0.017$ and $B(B^{\pm} \rightarrow \phi K^{\pm}) = 7 \times 10^{-6}$. The BRs of $B \rightarrow \eta' K$ modes remain unchanged.

The other observed $B \rightarrow PP$ and $B \rightarrow VP$ decay modes without $\eta(0)$ or $\phi$ in the final state, such as $B \rightarrow \pi \pi$, $B \rightarrow \pi K$, $B \rightarrow \rho \pi$, $B \rightarrow \omega \pi$, and so on, are not affected in this scenario, because $d_{222}^{L}$ and $d_{222}^{R}$ are relevant to the process $b \rightarrow s \bar{s}s$ only. The estimated BRs for those modes by using the above input values are consistent with the experimental data for $\xi = 0.45$ [13].

Case 2: In Case 1, we have generated the very small value for $\sin(2 \tilde{\beta})_{\phi K_{S}}$. Let us now try to generate a large negative $\sin(2 \tilde{\beta})_{\phi K_{S}}$, since one experiment is preferring a small negative value and the other experiment is preferring large. We use the smaller value of $\gamma$ and $m_{s}$: $\gamma = 80^{0}$ and $m_{s}$ (at $m_{b}$ scale) = 75 MeV, keeping the other inputs unchanged. We also use
FIG. 1. BR vs $\xi$. The dotted and dot-dashed lines correspond to Case 1 and Case 2 respectively. The solid line corresponds to the SM (The SM BR is same for both cases). The shaded region is allowed by the experimental data.

TABLE II. The branching ratios ($B$) and CP rate asymmetries ($A_{CP}$) for $B \to \eta^(')K^{(*)}$ and $B \to \phi K$.

| mode            | Case 1  | $B \times 10^6$ | $A_{CP}$ | Case 2  | $B \times 10^6$ | $A_{CP}$ |
|-----------------|---------|-----------------|----------|---------|-----------------|----------|
| $B^+ \to \eta^(')K^+$ |         | 69.3            | −0.01    |         | 76.1            | −0.01    |
| $B^+ \to \eta K^{*+}$ |         | 27.9            | −0.04    |         | 35.2            | −0.03    |
| $B^0 \to \eta^(')K^0$  |         | 107.4           | 0.00     |         | 98.9            | 0.00     |
| $B^0 \to \eta K^{*0}$  |         | 20.5            | 0.71     |         | 11.7            | 0.15     |
| $B^+ \to \phi K^+$    |         | 8.99            | −0.21    |         | 8.52            | −0.25    |
FIG. 2. BR vs $\xi$. The dotted and dot-dashed lines correspond to Case 1 and Case 2 respectively. The solid lines correspond to the SM. The upper solid line is for Case 1 and the lower solid line is for Case 2. The shaded region is allowed by the experimental data.
the same form of $d_{22}^L$ and $d_{22}^R$ as in Case 1: the $R_p$ part of the decay amplitude introduces a new weak phase in the mode $B \to \phi K$, but no phase in the process $B^+ \to \eta'K^+$.

In this case, we find that a consistent explanation of all the observed data for $B \to PP$ and $B \to VP$ is possible for $|\lambda_{322}^\prime| = |\lambda_{332}^\prime| = |\lambda_{323}^\prime| = 0.069$, $\tan \theta' = 2.8$, and $m_{\text{susy}} = 200$ GeV. In this scenario, a large value of $\sin(2\tilde{\beta})$ with the negative sign is possible for $B^0 \to \phi K_S$: $\sin(2\tilde{\beta})_{\phi K_S} = -0.82$ for $\xi = 0.25$, as shown in Table I. The value of $\sin(2\tilde{\beta})$ for $B^0 \to \eta'K_S$ is similar to that of Case 1: $\sin(2\tilde{\beta})_{\eta'K_S} = 0.72$ for $\xi = 0.25$. The estimated BRs for $B^+ \to \phi K^+$ and $B^+ \to \eta'K^+$ are denoted by the dot-dashed lines in Figs. 1 and 2, respectively: $\mathcal{B}(B^+ \to \phi K^+) = 8.52 \times 10^{-6}$ and $\mathcal{B}(B^+ \to \eta'K^+) = 76.1 \times 10^{-6}$ for $\xi = 0.25$. The BRs of other $B \to PP, VP$ modes satisfy the experimental data for $\xi = 0.25$ [13].

In conclusion, we have shown that in $R_p$ violating SUSY it is possible to understand consistently both recently measured CP asymmetry $\sin(2\beta)$ in $B^0 \to \phi K_S$ decay and the large branching ratio of $B^{\pm} \to \eta'K^{\pm}$ decay, which appear to be inconsistent with the SM prediction. Experimental results imply that CP asymmetry for $B \to \phi K_s$ is different from the SM value, but for $B \to \eta'K_s$ it is same as in the SM. We have found that this tendency can be consistently understood in the framework of this model. We have searched for possible parameter space and found that all the observed data for $B \to PP$ and $B \to VP$ decays can be accommodated for certain values of $R_p$ couplings. Experimentally, these couplings can be observed through the direct production of SUSY particles at Tevatron (e.g., $\chi_{1}^\pm \chi_{2}^0$ production and their subsequent decays to final states with multiple b quarks) and other rare decays like $B_s \to \mu^+\mu^+$ [25].

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