Decays $B \rightarrow \eta' K$ in $R$-parity violating supersymmetry

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In light of the recent experimental data from $B$ factories, We try to explain the large branching ratio (compared to the Standard Model prediction) of the decay $B^\pm \rightarrow \eta' K^\pm$ in the context of $R$-parity violating ($R_p$) supersymmetry. We investigate other observed $\eta'(0)$ modes and find that only two pairs of $R_p$ coupling can satisfy the requirements without affecting the other $B \rightarrow PP$ and $B \rightarrow VP$ decay modes except the mode $B \rightarrow \phi K$. We also calculate the CP asymmetry for the observed decay modes affected by the new couplings.

1. Introduction

Among the $B \rightarrow PP$ ($P$ denotes a pseudoscalar meson) decay modes, the branching ratio for the decay $B^\pm \rightarrow \eta' K^\pm$ is observed to be still larger than that expected within the Standard Model (SM). The SM contribution is about $3\sigma$ smaller than the experimental world average (Fig.1). Among the $B \rightarrow VP$ ($V$ denotes a vector meson) decay modes, the decay $B^\pm \rightarrow \phi K^\pm$ has been observed recently and the experimentally observed BR for the decay $B^0 \rightarrow \eta K^{(*)}$ has been found to be $2\sigma$ larger than the SM. The BR for the newly observed decay $B^\pm \rightarrow \eta K^{*\pm}$ is also available.

In this work, we address these large BR problems of $B^{\pm(0)} \rightarrow \eta(T) K^{\pm(0)}$ systems using $R$-parity violating ($R_p$) supersymmetric (SUSY) theories. The effects of $R_p$ couplings on $B$ decays have been investigated previously in the literature. Attempts were made to fit just the large BR for $B^\pm \rightarrow \eta' K^{\pm}$. At present, we have more results. Some of these results are concerned with decay modes involving $\eta'$ and these modes are influenced by the same $R_p$ coupling that affects $B^\pm \rightarrow \eta' K^\pm$. For example, the decay modes $B^\pm \rightarrow \eta K^{*\pm}$, $B^0 \rightarrow \eta K^{*0}$, $B^0 \rightarrow \eta' K^0$ are affected by the new couplings which cure the large BR problem of $B^\pm \rightarrow \eta' K^\pm$. Hence, it is natural to investigate these newly observed decay modes and try to see whether all the available data can be explained. We also need to be concerned about the other observed (not involving $\eta'$) $B \rightarrow PP$ and $B \rightarrow VP$ decay modes, which could be influenced by these new couplings. Our effort is not to affect the other modes as much as possible, since except for $B \rightarrow \eta(T) K^{(*)}$ decay modes, the other observed modes fit the available data well. Further, using the preferred values of different parameters (e.g., new couplings etc.), we also make predictions for CP asymmetry for these observed modes which will be verified in the near future.

2. $R_p$ SUSY effects to decay amplitudes

The $R_p$ part of the amplitude of $B^\pm \rightarrow \eta' K^\pm$ decay is

$$
M_{\eta'K}^{R_p} = \left( d_{121}^R - d_{112}^L \right) \xi A_{\eta'}^u + \left( d_{222}^L - d_{222}^R \right) \left[ \frac{m}{m_s} \left( A_{\eta'}^u - A_{\eta'}^s \right) - \xi A_{\eta'}^s \right]
$$
in three different experiments are \[6–8\], of Wilson coefficients given in Ref. \[5\].

3. Results

A replace \(A\) where placing a pseudoscalar meson by a vector meson, \(d\) expressions hold for \(BR\) in SM that we find is 42 average of them: \((in\ 10^{-6})\ 42\). The three results are close and we use the world average of them: \((in\ 10^{-6})\ 75\). The maximum BR in SM that we find is \(42 \times 10^{-6}\) (Fig. 1). In the \(R_p\) SUSY framework, we find that the positive values of \(d^{R}_{222}\) and negative values of \(d^{L}_{222}\) can increase the BR keeping most of the other \(B \to PP\) and \(B \to VP\) modes unaffected. The other \(R_p\) combinations are either not enough to increase in the BR or affect too many other modes. (An important role is played by the \(\lambda'_{321}\) -type couplings, the constraints on which are relatively weak.) We divide our results into two cases, Case 1: we use only \(d^{R}_{222}\) (positive values) and Case 2: we use a combination of \(d^{R}_{222}\) (positive values) and \(d^{L}_{222}\) (negative values).

\[
B(\pm) \to \eta' K^{\pm} \times 10^6 = 80^{+10}_{-10} \pm 7 \ (CLEO),
\]

\[
70 \pm 8 \pm 5 \ (BaBar), \ 79^{+12}_{-11} \pm 9 \ (Belle).
\]

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Figure 1. The BR for the decay \(B^\pm \to \eta' K^\pm\) vs \(\xi\). The solid line is for the SM. The dashed, dotted and dot-dashed lines correspond to \(|\lambda'_{323}| = |\lambda'_{322}| = 0.04, 0.06, 0.08,\) respectively. The bold solid lines indicate the experimental world average bound.

Let us start with Case 1. We first discuss the case of \(\gamma = 110^0\). In Fig. 1, we plot the BR for the decay \(B^\pm \to \eta' K^\pm\) as a function of \(\xi\). We have used \(|\lambda'_{323}| = |\lambda'_{322}| = 0.04, 0.06, 0.08\) and \(m_{\text{susy}} = 200\ \text{GeV}\). We take \(d^{R}_{222}\) to be positive. The large branching ratio can be explained for \(\lambda' \geq 0.05\).

The \(B(B \to X_s \nu \nu)\) can put bound on \(\lambda'_{322}\lambda'_{323}\) in certain limits: \(\lambda' \leq 0.07\).

In another scenario we can use smaller value of \(\gamma\), e.g., \(\gamma = 80^0\) to fit the \(B \to \eta^{(*)} K^{(*)}\) data. In Table I, we present the BRs and the CP asymmetries for \(B \to \eta^{(*)} K^{(*)}\) and \(B \to \phi K\) for different values of \(\delta\) and \(\gamma\). Here the phase difference between \(\lambda'_{323}\) and \(\lambda'_{322}\), \(\delta\), is defined by

\[
\lambda'_{323}\lambda'_{322} = |\lambda'_{323}\lambda'_{322}| e^{i\delta}.
\]
Table 1
Case 1: for $|\lambda'| = 0.06$ and $\xi = 0.25$.

| mode       | $B \times 10^6$ | $A_{CP}$ | $B \times 10^6$ | $A_{CP}$ |
|------------|-----------------|----------|-----------------|----------|
| $B^+ \to \eta' K^+$ | 68.9            | 0.01     | 68.3            | 0.04     |
| $B^+ \to \eta K^{*+}$ | 36.4            | 0.03     | 36.4            | 0.04     |
| $B^0 \to \eta' K^0$    | 88.3            | 0.00     | 86.8            | 0.03     |
| $B^0 \to \eta K^{*0}$  | 14.0            | -0.39    | 14.6            | -0.42    |
| $B^+ \to \phi K^+$     | 7.11            | 0.00     | 6.97            | 0.04     |

The maximum values of $\delta$ allowed by the BR of $B^\pm \to \eta' K^\pm$ are $\delta = 15^\circ$ for $\gamma = 110^\circ$ and $\delta = 55^\circ$ for $\gamma = 80^\circ$.

Case 2: We now use the combination of $d_{222}^R$ and $d_{222}^L$ with $\gamma = 110^\circ$. We assume $d_{222}^R = -d_{222}^L$. In this scenario, the $R_p$ coupling part of the amplitude in $B \to \phi K$ decay mode canceled exactly (Eq. [3]). (In fact, our solution still works when the cancellation is incomplete by about 5%) But we still have contributions to $B^\pm \to \eta' K^\pm$ (Eq. [3]) and to increase the BR we choose $d_{222}^R$ to be positive. There is no $R_p$ contribution to the other $B \to PP$ and $B \to VP$ modes in this case as well.

In Table II, we calculate the BRs and the CP asymmetries for $B \to \eta' K^{(*)}$ and $B \to \phi K$ for different values of $\delta$. The maximum value of $\delta$ allowed by the BR for $B^\pm \to \eta' K^\pm$ is $\delta = 20^\circ$ for $\gamma = 110^\circ$.

| mode       | $B \times 10^6$ | $A_{CP}$ | $B \times 10^6$ | $A_{CP}$ |
|------------|-----------------|----------|-----------------|----------|
| $B^+ \to \eta' K^+$ | 69.3            | 0.01     | 68.0            | 0.05     |
| $B^+ \to \eta K^{*+}$ | 27.9            | 0.04     | 27.8            | 0.05     |
| $B^0 \to \eta' K^0$    | 107.4           | 0.00     | 104.5           | 0.05     |
| $B^0 \to \eta K^{*0}$  | 20.5            | -0.71    | 21.1            | -0.72    |
| $B^+ \to \phi K^+$     | 6.56            | 0.00     | 6.56            | 0.00     |

The maximum values of $\delta$ allowed by the BR of $B^\pm \to \eta' K^\pm$ are $\delta = 15^\circ$ for $\gamma = 110^\circ$ and $\delta = 55^\circ$ for $\gamma = 80^\circ$.

4. Conclusion

We have studied $B \to \eta' K^{(*)}$ modes in the context of $R_p$ SUSY theories. We have found solutions for both large and small values of $\gamma = 110^\circ, 80^\circ$ and two different values of $\xi \simeq 0.25, 0.45$ for two different scenarios. For our solutions, we need $|\lambda'| \sim 0.05 - 0.06$ for $m_{susy} = 200$ GeV.

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