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The $B \to K\pi$ Puzzle and Supersymmetric Models

Richard Arnowitt[1*], Bhaskar Dutta[1†], Bo Hu[2‡] and Sechul Oh[3§]

[1]*Department of Physics, Texas A&M University, College Station, TX, 77845, USA*

[2]*Department of Physics, Nanchang University, Jiangxi 330047, China*

[3]*Natural Science Research Institute,*

Yonsei University, Seoul 120-479, Korea

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Abstract

In the light of new experimental results on $B \to K\pi$ decays, we study the decay processes $B \to K\pi$ in the framework of both R-parity conserving (SUGRA) and R-parity violating supersymmetric models. We find that any possible deviations from the Standard Model indicated by the current data for the branching ratios and the direct CP asymmetries of $B \to K\pi$ can be explained in both R-parity conserving SUGRA and R-parity violating SUSY models. However, there is a difference between the predictions of both models to the time-dependent CP asymmetry observable $S_{K_S\pi^0}$ whose current experimental results include large uncertainties. We demonstrate that this difference can be useful for testing both models with more accurate data for $S_{K_S\pi^0}$ and A_{CP}^{+-} in the near future.

* arnowitt@physics.tamu.edu

† dutta@physics.tamu.edu

‡ bohu@ncu.edu.cn

§ scoh@phya.yonsei.ac.kr

The quark level subprocesses for $B \to K\pi$ decays are $b \to sq\bar{q}$ $(q = u, d)$ penguin processes which are potentially sensitive to any new physics effects beyond the Standard Model (SM). All the $B \to K\pi$ modes have already been observed in experiment and their CP-averaged branching ratios (BRs) have been measured within a few percent errors by the BaBar and Belle collaborations [1, 2, 3, 4, 5, 6, 7]. The measurements of CP asymmetry observables for the $B \to K\pi$ modes had contained large errors so that the results have not led to any decisive conclusions until recently [1, 8, 9, 10, 11, 12, 13]. But, the direct CP asymmetry in $B^0 \to K^\pm\pi^\mp$ has been recently observed at the 5.7σ level by BaBar and Belle [10, 11, 12] whose values are in good agreement with each other: the world average value is

$$\mathcal{A}_{CP}^{+-} = -0.119 \pm 0.019 \ . \tag{1}$$

The direct CP asymmetry data for the other $B \to K\pi$ modes still involve large uncertainties: e.g., for $B^\pm \to K^\pm\pi^0$ modes, $\mathcal{A}_{CP}^{+0} = +0.04 \pm 0.04$.

The recent experimental data for the CP-averaged BRs of $B \to K\pi$ may indicate a possible deviation from the prediction of the SM:

$$R_c \equiv \frac{2\bar{\mathcal{B}}^{+0}}{\bar{\mathcal{B}}^{0+}} = 1.00 \pm 0.09 \ , \qquad R_n \equiv \frac{\bar{\mathcal{B}}^{+-}}{2\bar{\mathcal{B}}^{00}} = 0.79 \pm 0.08 \ , \tag{2}$$

where $\bar{\mathcal{B}}^{ij}$ denote the CP-averaged BRs of $B \to K^i\pi^j$ decays. It has been also claimed that within the SM, $R_c \approx R_n$ [14, 15]. The above experimental data show the pattern $R_c > R_n$ [14, 15], which would indicate the enhancement of the electroweak (EW) penguin and/or the color-suppressed tree contributions [16].

On the other hand, in the conventional prediction of the SM, $\mathcal{A}_{CP}^{+0}$ is expected to be almost the same as $\mathcal{A}_{CP}^{+-}$: in particular, they would have the *same* sign. However, the current data show that $\mathcal{A}_{CP}^{+0}$ differs by 3.5σ from $\mathcal{A}_{CP}^{+-}$. This is a very interesting observation with the new measurements of $\mathcal{A}_{CP}^{+-}$ by BaBar and Belle, even though the measurements of $\mathcal{A}_{CP}^{+0}$ still include sizable errors. This possible discrepancy from the SM prediction, together with the above one on R_c and R_n, has recently been called the "$B \to K\pi$ puzzle". One may need to explain on the theoretical basis how this feature can happen.

In the light of those new data, *including the direct CP asymmetry in* $B^0 \to K^\pm\pi^\mp$, many works have been recently done to study the implications of the data [14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27]. However, most of those previous works have focused on finding out the $B \to K\pi$ puzzle itself and clarifying its implications through model-independent approaches, such as the topological quark diagram approach.

In this letter, we focus on how to resolve the $B \to K\pi$ puzzle with well-motivated new physics models: in the framework of R-parity conserving and R-parity violating supersymmetry (SUSY). We calculate the BRs and the direct CP asymmetries for all the $B \to K\pi$ modes in the SM and its SUSY extension with R-parity (SUGRA models) and without R-parity. Then, we present predictions of the different SUSY models to the mixing induced CP violating parameter $S_{K_S\pi^0}$ which has been observed *with large errors* through the time-dependent CP asymmetry measurement of $B^0 \to K_S\pi^0$ [5, 13]. In the recent work [16], it has been explicitly shown that the color-suppressed tree contribution is very sensitive to the observable $S_{K_S\pi^0}$, while in contrast, the EW penguin contribution is not sensitive to $S_{K_S\pi^0}$. As we shall see, the different SUSY models give different predictions to the time-dependent CP violating parameter $S_{K_S\pi^0}$ which can be tested by experiment.

For calculation of the relevant hadronic matrix elements, we adopt the QCD improved factorization (QCDF) [28]. This approach allows us to include the possible non-factorizable contributions, such as vertex corrections, penguin corrections, hard spectator scattering contributions, and weak annihilation contributions. The relevant end-point divergent integrals are parameterized as [28]

$$X_{H,A} \equiv \int_0^1 \frac{dx}{x} \equiv \left(1 + \rho_{H,A} e^{i\phi_{H,A}}\right) \ln\frac{m_B}{\Lambda_h} \ , \tag{3}$$

where X_H and X_A denote the hard spectator scattering contribution and the annihilation contribution, respectively. Here the phases $\phi_{H,A}$ are arbitrary, $0^0 \le \phi_{H,A} \le 360^0$, $\rho_{H,A}$ are free parameters to be of order one, typically $\rho_A \lesssim 2$, and the scale $\Lambda_h = 0.5$ GeV being the typical hadronic scale [28].

We first summarize the current status of the experimental results on $B \to K\pi$ modes in Table I, which includes the BRs, the direct CP asymmetries ($\mathcal{A}_{CP}$), and the mixing-induced CP asymmetry ($S_{K_s\pi^0}$). In order to exhibit the sign convention for CP asymmetries used in this work, let us specify the definition of CP asymmetries for $B \to K\pi$ as follows. The direct CP asymmetry for $B^\pm \to K^\pm\pi^0$ is defined as

$$\mathcal{A}_{CP}^{+0} \ \equiv \ \frac{\mathcal{B}(B^- \to K^-\pi^0) - \mathcal{B}(B^+ \to K^+\pi^0)}{\mathcal{B}(B^- \to K^-\pi^0) + \mathcal{B}(B^+ \to K^+\pi^0)} \ . \tag{4}$$

The definition of direct CP asymmetries for other $B \to K\pi$ modes becomes obvious. The time-dependent CP asymmetry for $B^0 \to K_S\pi^0$ is defined as

$$\mathcal{A}_{K_S\pi^0}(t) \ \equiv \ \frac{\Gamma(\bar{B}^0(t) \to K_S\pi^0) - \Gamma(B^0(t) \to K_S\pi^0)}{\Gamma(\bar{B}^0(t) \to K_S\pi^0) + \Gamma(B^0(t) \to K_S\pi^0)}$$

TABLE I: Experimental data on the CP-averaged branching ratios ($\bar{\mathcal{B}}$ in units of 10^{-6}), the direct CP asymmetries ($\mathcal{A}_{CP}$), and the mixing-induced CP asymmetry ($S_{K_s\pi^0}$) for $B \to K\pi$ modes. The $S_{K_s\pi^0}$ is equal to $\sin(2\phi_1)$ in the case that tree amplitudes are neglected for $B^0 \to K_s\pi^0$ [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13].

BR	Average	CP asymmetry	Average
$\bar{\mathcal{B}}(B^\pm \to K^0\pi^\pm)$	24.1 ± 1.3	$\mathcal{A}_{CP}^{0+}$	-0.02 ± 0.04
$\bar{\mathcal{B}}(B^\pm \to K^\pm\pi^0)$	12.1 ± 0.8	$\mathcal{A}_{CP}^{+0}$	$+0.04 \pm 0.04$
$\bar{\mathcal{B}}(B^0 \to K^\pm\pi^\mp)$	18.9 ± 0.7	$\mathcal{A}_{CP}^{+-}$	-0.115 ± 0.018
$\bar{\mathcal{B}}(B^0 \to K^0\pi^0)$	11.5 ± 1.0	$\mathcal{A}_{CP}^{00}$	$+0.001 \pm 0.155$
		$S_{K_s\pi^0}$	$+0.34 \pm 0.29$

$$\equiv \; S_{K_S\pi^0} \sin(\Delta m_d \; t) - C_{K_S\pi^0} \cos(\Delta m_d \; t) \; , \tag{5}$$

where Γ denotes the relevant decay rate and Δm_d is the mass difference between the two B^0 mass eigenstates. The $S_{K_S\pi^0}$ and $C_{K_S\pi^0}$ are CP violating parameters. In the case that the tree contributions are neglected for $B^0 \to K_S\pi^0$, the mixing-induced CP violating parameter $S_{K_S\pi^0}$ is equal to $\sin(2\phi_1)$ [ϕ_1 ($\equiv \beta$) is the angle of the unitarity triangle]. Note that the measured value of $S_{K_S\pi^0}$ (Table I) is different from the well-established value of $\sin(2\phi_1) = 0.725 \pm 0.037$ measured through $B \to J/\psi K^{(*)}$ [1]. It may indicate that the EW penguin and the color-suppressed tree effects play an important role [16].

In the following two sections, we will discuss possible resolutions of the $B \to K\pi$ puzzles in the context of SUSY models.

[1] R-parity violating SUSY case

In the R-parity violating (RPV) minimal supersymmetric standard model, we will assume only l'−type couplings to be present [29]. The R-parity violating interaction introduces new operators. The relevant new operators are

$$\mathcal{L}_{eff} \;=\; -\frac{\lambda'_{i12}\lambda'^{*}_{i13}}{2m^2_{\tilde{e}_i}} \left(\bar{u}_\alpha \gamma_\mu L u_\beta\right) \left(\bar{s}_\beta \gamma_\mu R b_\alpha\right) - \frac{\lambda'_{i11(i32)}\lambda'^{*}_{i23(i11)}}{2m^2_{\tilde{\nu}_i}} \left(\bar{s}_\alpha \gamma_\mu L(R) d_\beta\right) \left(\bar{d}_\beta \gamma_\mu R(L) b_\alpha\right) \tag{6}$$

$$-\frac{\lambda'_{i12(i31)}\lambda'^{*}_{i13(i21)}}{2m^2_{\tilde{\nu}_i}} \left(\bar{d}_\alpha \gamma_\mu L(R) d_\beta\right) \left(\bar{s}_\beta \gamma_\mu R(L) b_\alpha\right) \; , \tag{7}$$

where $L(R) = (1 \mp \gamma_5)/2$, α and β are the color indices, and $m_{\tilde{f}}$ denotes the sfermion mass.

Note that the operators having the following chirality structure $(\bar{p}_\alpha \gamma_\mu L q_\beta)\,(\bar{r}_\beta \gamma_\mu R b_\alpha)$ do not exist in the SM effective Hamiltonian.

The RPV SUSY part of the decay amplitudes of $B \to K\pi$ modes are given by [30]

$$
\begin{aligned}
A^{\rm RPV}(\bar{B}^0 \to K^-\pi^+) &= -if_K F_0^{B\to\pi}(0)\left(m_B^2 - m_\pi^2\right) u_{112}^R R_K c_A + A_{ann}^{\rm RPV}(K^-\pi^+)\ , &(8)\\
A^{\rm RPV}(B^- \to K^-\pi^0) &= if_\pi F_0^{B\to K}(0)\left(m_B^2 - m_K^2\right)\left[u_{112}^R \frac{1}{\sqrt{2}}(-r_{K\pi} R_K c_A + a')\right.\\
&\quad \left. + \left(d_{112}^R - d_{121}^L\right)\frac{1}{\sqrt{2}} R_\pi c_A - \left(d_{121}^R - d_{112}^L\right)\frac{1}{\sqrt{2}} a'\right]\\
&\quad + A_{ann}^{\rm RPV}(K^-\pi^0)\ , &(9)\\
A^{\rm RPV}(B^- \to \bar{K}^0\pi^-) &= if_K F_0^{B\to\pi}(0)\left(m_B^2 - m_\pi^2\right)\left[\left(d_{112}^R - d_{121}^L\right) a' - \left(d_{121}^R - d_{112}^L\right) R_K c_A\right]\\
&\quad + A_{ann}^{\rm RPV}(\bar{K}^0\pi^-)\ , &(10)\\
A^{\rm RPV}(\bar{B}^0 \to \bar{K}^0\pi^0) &= if_\pi F_0^{B\to K}(0)\left(m_B^2 - m_K^2\right)\\
&\quad \times\left[u_{112}^R \frac{1}{\sqrt{2}} a' - \left(d_{112}^R - d_{121}^L\right)\frac{1}{\sqrt{2}}(-R_\pi c_A + r_{K\pi} a')\right.\\
&\quad \left. - \left(d_{121}^R - d_{112}^L\right)\frac{1}{\sqrt{2}}(-r_{K\pi} R_K c_A + a')\right] + A_{ann}^{\rm RPV}(\bar{K}^0\pi^0)\ , &(11)
\end{aligned}
$$

where the annihilation contributions are given by

$$
\begin{aligned}
A_{ann}^{\rm RPV}(K^-\pi^+) &= -\sqrt{2} A_{ann}^{\rm RPV}(\bar{K}^0\pi^0) = -if_B f_\pi f_K \left[\left(d_{112}^R - d_{121}^L\right) b_4' + \left(d_{121}^R - d_{112}^L\right) b_3'\right], &(12)\\
A_{ann}^{\rm RPV}(\bar{K}^0\pi^-) &= \sqrt{2} A_{ann}^{\rm RPV}(K^-\pi^0) = -if_B f_\pi f_K\ u_{112}^R b_3'\ . &(13)
\end{aligned}
$$

The u_{jkn}^R and $d_{jkn}^{L,R}$ are defined as $u_{jkn}^R = \sum_{i=1}^3 \frac{l'_{ijn} l'^*_{ik3}}{8m^2_{\tilde{e}_{iL}}}$, $d_{jkn}^R = \sum_{i=1}^3 \frac{l'_{ijk} l'^*_{in3}}{8m^2_{\tilde{\nu}_{iL}}}$, $d_{jkn}^L = \sum_{i=1}^3 \frac{l'_{i3k} l'^*_{inj}}{8m^2_{\tilde{\nu}_{iL}}}$. We refer to Refs. [29] for the relevant notations. Here f_i and $F_0^{B\to i}$ denote decay constants and form factors, respectively. The parameters a', R_i, r_i are defined as

$$
\begin{aligned}
a' &= \frac{c_A}{N_c}\left[1 - \frac{C_F \alpha_s}{4\pi} V'_{P_2}\right] - \frac{c_A}{N_c}\frac{C_F \pi \alpha_s}{N_c} H'_{P_2 P_1}\ , &(14)\\
R_K &= \frac{2m_K^2}{\bar{m}_b(\mu)(\bar{m}_q(\mu) + \bar{m}_s(\mu))}\ , \quad (q = u\ (d)\ \text{ for }\ K^-\ (\bar{K}^0)) &(15)\\
R_\pi &= \frac{2m_\pi^2}{\bar{m}_b(\mu)(\bar{m}_u(\mu) + \bar{m}_d(\mu))}\ , &(16)\\
r_{K\pi} &= \frac{f_K F_0^{B\to\pi}(0)(m_B^2 - m_\pi^2)}{f_\pi F_0^{B\to K}(0)(m_B^2 - m_K^2)}\ , &(17)
\end{aligned}
$$

where N_c $(= 3)$ is the number of colors and $C_F = (N_c^2 - 1)/(2N_c)$. V'_{P_2} and $H'_{P_1 P_2}$ come from the vertex corrections and the hard spectator scattering contributions, respectively. For their explicit expressions, we refer to [31]. P_1 is the final state meson absorbing the

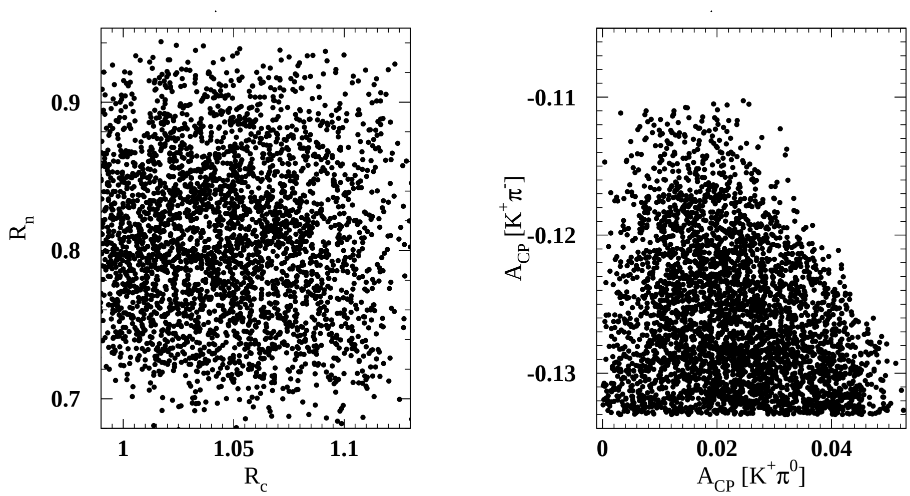

FIG. 1: R_n versus R_c (left one) and A_{CP}^{+-} versus A_{CP}^{+0} (right one) in the R-parity violating SUSY model.

light spectator quark from B meson and P_2 is the other final state meson emitted without absorbing the spectator quark. The parameters b_i' are defined as

$$b_3' = \frac{C_F}{N_c^2} c_C A_3^f \ , \qquad b_4' = \frac{C_F}{N_c^2} c_C A_2^f \ , \tag{18}$$

where

$$\begin{aligned} A_2^i &= \pi\alpha_s \left[18 \left(X_A - 4 + \frac{\pi^2}{3} \right) + 2 r_\chi^2 X_A^2 \right] \ , \\ A_3^f &= 12\pi\alpha_s r_\chi (2X_A^2 - X_A) \ , \end{aligned} \tag{19}$$

with $r_\chi \approx R_\pi$. X_A is the divergent integral as defined in Eq. (3). $c_{A,C}$ are the RGE improved QCD enhanced factors at the scale $\mu = m_b$.

From Eqs. (9) $-$ (11), we note that the R-parity violating couplings d_{ijk}^R and d_{lmn}^L always appear as the combinations $\left(d_{112}^R - d_{121}^L\right)$ and $\left(d_{121}^R - d_{112}^L\right)$. Thus, in this analysis, we actually use three different combinations of R-parity violating couplings: u_{112}^R, $\left(d_{112}^R - d_{121}^L\right)$ and $\left(d_{121}^R - d_{112}^L\right)$. Since each combination can be expressed as a complex number, we have six independent real parameters arising from the new physics effects and we have 9 results to explain. The contributions of the new terms to the amplitudes are mostly different for different decay modes.

By varying the above parameters, we try to fit all the current data *simultaneously* as shown in Table I. In Fig. 1, we show R_n versus R_c (left figure) and A_{CP}^{+-} versus A_{CP}^{+0} (right

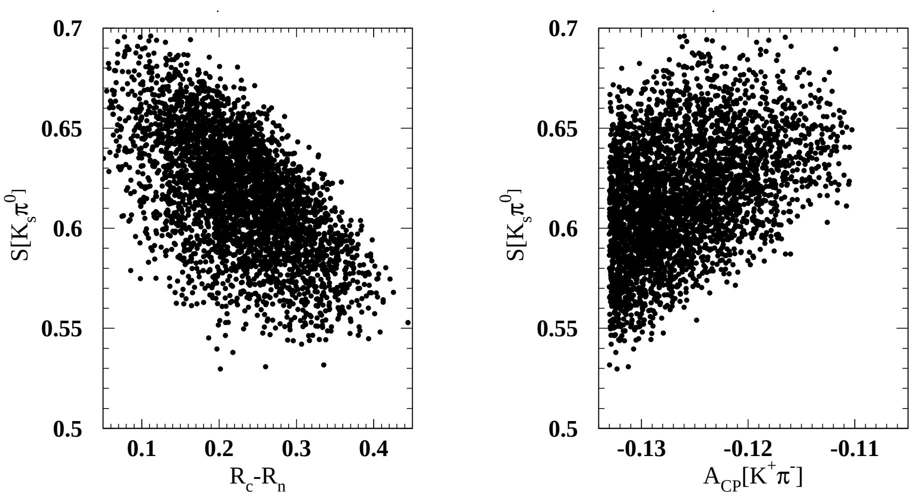

FIG. 2: $S_{K_S\pi^0}$ versus $(R_c - R_n)$ (left one) and $S_{K_S\pi^0}$ versus A_{CP}^{+-} (right one) in the R-parity violating SUSY model.

figure). Here the same parameter sets are used to fit both the BRs and the direct CP asymmetries. We see that the values of R_n, R_c, A_{CP}^{+-}, and A_{CP}^{+0} are consistent with the current data at 1σ level. In fact, it turns out that all the current data for the BRs and the direct CP asymmetries, including A_{CP}^{0+} and A_{CP}^{00}, can be explained at 1σ level in the R-parity violating SUSY model. In other words, the possible discrepancy between the SM predictions and the current data for the BRs and the direct CP asymmetries can be explained by the new physics contributions which, in particular, come from the new operators having the new chirality structure as mentioned below Eq. (7).

Using the same values of the parameters used in Fig. 1, we predict the mixing induced CP violating observable $S_{K_S\pi^0}$. In Fig. 2, our result is presented as $S_{K_S\pi^0}$ versus $(R_c - R_n)$ (left figure) and $S_{K_S\pi^0}$ versus A_{CP}^{+-} (right figure). We see that our prediction is in good agreement with the current data at 1σ level. We shall see in next section that in R-parity conserving SUSY case, it is very difficult to explain the small value of the current data for $S_{K_S\pi^0}$ together with the other data, especially R_c and R_n.

In Table II, we show the representative values of our prediction to the BRs, the direct CP asymmetries and the mixing induced CP asymmetry in the R-parity violating SUSY model. We consider two cases: (i) $\rho_{_{H,A}} = 0$ and (ii) $\rho_{_A} = 0.3,\ \rho_{_H} = \phi_{_{H,A}} = 0$. The corresponding

TABLE II: Predictions of the R-parity violating SUSY model for two cases: (i) $\rho_{_{H,A}} = 0$ and (ii) $\rho_{_A} = 0.3,\ \rho_{_H} = \phi_{H,A} = 0$. The case (ii) are shown in the bracket. ($\bar{\mathcal{B}}$ in units of 10^{-6})

BR	Prediction	CP asymmetry	Prediction
$\bar{\mathcal{B}}(B^\pm \to K^0\pi^\pm)$	23.6 [24.8]	$\mathcal{A}_{CP}^{0+}$	−0.010 [−0.007]
$\bar{\mathcal{B}}(B^\pm \to K^\pm\pi^0)$	13.3 [13.0]	$\mathcal{A}_{CP}^{+0}$	+0.026 [+0.018]
$\bar{\mathcal{B}}(B^0 \to K^\pm\pi^\mp)$	19.0 [18.9]	$\mathcal{A}_{CP}^{+-}$	−0.134 [−0.115]
$\bar{\mathcal{B}}(B^0 \to K^0\pi^0)$	11.9 [12.6]	$\mathcal{A}_{CP}^{00}$	−0.142 [−0.141]
		$S_{K_s\pi^0}$	+0.51 [+0.55]

values of the couplings are (in 10^{-8})

$$|d^R_{112} - d^L_{121}| \sim 3.2\ (3.1), \quad |d^R_{121} - d^L_{112}| \sim 0.87\ (0.60), \quad |u^R_{112}| \sim 2.1\ (2.2) \tag{20}$$

The values in the parenthesis are for the $\rho_{_A} = 0.3$ case. The constraints on the RPV couplings need to be checked. However, apart from u^R_{112}, the rest of the couplings appears in the amplitude as combinations (e.g., $d^R_{112} - d^L_{121}$) of 3 or 4 different RPV couplings λ'_{ijk} so that they easily satisfy the constraints. u^R_{112} involves $\lambda'_{i12}\lambda'^*_{i13}$. In our example above (for $\rho_{_{H,A}}$=0 case), $\lambda'_{31k} \sim 8 \times 10^{-2}$ was used. It is also important to note that u^R_{112} involves $m^2_{\tilde{e}}$ which we assume to be $\sim$ 200 GeV. The experimental bound on λ'_{31k} is given by $\lambda'_{31k} < 1.2 \times 10^{-1}$ for 1 TeV of squark mass by using the ratio of BRs of $K^+ \to \pi^+\nu\bar{\nu}$ and $K^+ \to \pi^0\nu e^+$ decay [32]. However, the bound on λ' determined from the experimental value of the BR of $K \to \pi\nu\bar{\nu}$ decay depends on the squark mass and in GUT models, it is quite natural to expect a large hierarchy (~ 5) between the squark and the slepton masses.

[2] R-parity conserving SUSY case

In this case the SUSY contributions appear in loop. The one loop SUSY contributions are available in the literature, e.g., Refs. [33, 34]. In our calculation, we do not use the mass insertion approximation, but rather do a complete calculation. The SUGRA model starts at the GUT scale. We assume the breakdown of the universality to accommodate the $B \to \pi K$ data. While we satisfy this data, we also have to be careful to also satisfy other data, e.g., $b \to s\gamma$, ΔM_K, ΔB_d, ϵ_K, etc.

We use the following boundary conditions at the GUT scale:

$$(m^2)^{ij}_{(Q_{LL},U_{RR},D_{RR})} = m_0^2 \left(\delta^{ij} + \Delta^{ij}_{(Q_{LL},U_{RR},D_{RR})}\right) \ ; \quad A^{ij}_{(u,d)} = A_0 \left(Y^{ij}_{(u,d)} + \Delta A^{ij}_{(u,d)}\right) \ . \tag{21}$$

TABLE III: Predictions of the R-parity conserving SUSY model. The SUSY parameters are mentioned in the text. ($\bar{\mathcal{B}}$ in units of 10^{-6})

BR	Prediction	CP asymmetry	Prediction
$\bar{\mathcal{B}}(B^\pm \to K^0\pi^\pm)$	23	$\mathcal{A}_{CP}^{0+}$	-0.030
$\bar{\mathcal{B}}(B^\pm \to K^\pm\pi^0)$	10.3	$\mathcal{A}_{CP}^{+0}$	-0.0073
$\bar{\mathcal{B}}(B^0 \to K^\pm\pi^\mp)$	19.1	$\mathcal{A}_{CP}^{+-}$	-0.105
$\bar{\mathcal{B}}(B^0 \to K^0\pi^0)$	11.3	$\mathcal{A}_{CP}^{00}$	-0.08
		$S_{K_s\pi^0}$	$+0.73$

The SUSY parameters can have phases at the GUT scale: $m_i = |m_{1/2}|e^{i\theta_i}$ $(i = 1, 2, 3)$ (the gaugino masses for the $U(1)$, $SU(2)$ and $SU(3)$ groups), $A_0 = |A_0|e^{i\alpha_A}$ and $\mu = |\mu|e^{i\theta_\mu}$. However, we can set one of the gaugino phases to zero and we choose $\theta_2 = 0$. The electric dipole moments (EDMs) of the electron and neutron can now allow the existence of large phases in the theory [35, 36, 37]. In our calculation, we use $O(1)$ phases but calculate the EDMs to make sure that current bounds ($|d_e| < 1.2 \times 10^{-27}$ecm [38] and $|d_n| < 6.3 \times 10^{-26}$ecm [39]) are satisfied.

We evaluate the squark masses and mixings at the weak scale by using the above boundary conditions at the GUT scale. The RGE evolution mixes the non-universality of type LR (A terms) via $dm_{Q^2_{LL,RR}}/dt \propto A^\dagger_{u(d)}A_{u(d)}$ terms and creates new LL and RR contributions at the weak scale. We then evaluate the Wilson coefficients from all these new contributions. We have both chargino and gluino contributions arising due to the LL, LR, RL, RR up type and down type squark mixing. These contributions affect the following Wilson coffecients $C_3 - C_{10}$, $C_{7\gamma}$ and C_{8g}. The chargino contributions affect mostly the electroweak penguins (C_7 and C_9) and the dipole penguins, while the gluino penguin has a large contribution to the dipole terms due to the presence of an enhancement factor $m_{\tilde{g}}/m_b$ (the gluino contribution also affects the QCD penguins, but the effect is small). We include all contributions in our calculation. The SUSY contributions also bring new operator contributions over the SM by having a chirality exchange in the SM operators.

The electroweak penguin contribution is required to solve the $B \to \pi K$ puzzle for the BRs and can solve the CP asymmetries [14]. If we do not consider the BRs, then the direct CP asymmetries of the $B \to \pi K$ modes can be solved by the dipole penguin contributions

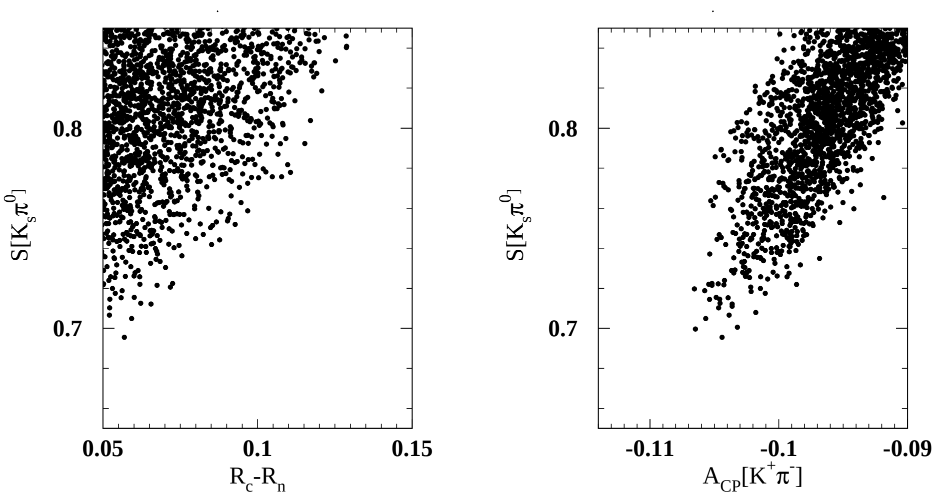

FIG. 3: $S_{K_S\pi^0}$ versus $(R_c - R_n)$ (left one) and $S_{K_S\pi^0}$ versus A_{CP}^{+-} (right one) in the SUGRA model.

only. The dipole penguin contributions can not be arbitrarily large, since it is also present in the $b \to s\gamma$. In order to obtain a fit, we find that $A_{u,d}^{23}$ are necessary. The nonzero values of these parameters generate the dipole penguin and the (Z-mediated) electroweak penguin diagrams. In Table III, we show an example of a fit. From the fit one finds the prediction for $S_{K_s\pi^0}$ to be large. The SUSY parameters used for this fit are: $m_{1/2} = 450$ GeV, $A_0 = -800$ GeV, $m_0 = 300$ GeV, $\Delta_{Q_{LL}}^{23} = 0.2\ e^{-0.3i}$, $\Delta A_u^{23} = 0.55\ e^{0.8i}$, $\Delta A_d^{23} = 0.05\ e^{-1.5i}$, $\tan\beta = 40$, $\mu > 0$. Since the SUSY parameters have phases, the EDMs of the electron and the neutron need to be checked, and we do indeed satisfy the experimental bounds for these EDMs. For this example, we find $|d_e| = 2.23 \times 10^{-29}$ e cm and $|d_n| = 8.2 \times 10^{-27}$ e cm. The QCD parameters for this fit are: $\rho_A = 2$ and $\phi_A = 2.77$. In this fit we have used nonzero $\Delta_{Q_{LL}}$, but it is possible to obtain fits without $\Delta_{Q_{LL}}$. We can obtain fits for other $\tan\beta$ values as well.

In Fig.3, we show $S_{K_s\pi^0}$ as a function of $(R_c - R_n)$ and $S_{K_s\pi^0}$ as a function of A_{CP}^{+-}. In order to generate these figures, we have varied $m_{1/2}$, m_0, $\tan\beta$ and Δ's. We see from the figures that the lowest value of $S_{K_s\pi^0}$ is about 0.69 and the maximum direct CP asymmetry A_{CP}^{+-} predicted by the SUGRA model is about -0.107. If we compare Figure 3 with Figure 2, we find that the prediction for $S_{K_s\pi^0}$ in the R-parity conserving SUSY model is much higher than in the R-parity violating SUSY model and therefore the future data on $S_{K_s\pi^0}$ will be crucial. The future data (with reduced error) of A_{CP}^{+-} is also crucial to distinguish two scenarios since the maximum direct CP asymmetry A_{CP}^{+-} predicted by the SUGRA model is about -0.107, whereas the asymmetry can be larger negative in the R-parity violating model.

In conclusion, we have explained the recent experimental results on the BRs and CP asymmetries of different $B \to \pi K$ modes in R-parity violating and R-parity conserving SUSY models. We have found that the R-parity conserving SUSY model tends to generate large $S_{K_S\pi^0}$ when we use all the constraints on the BRs and CP asymmetries, and the lowest value of $S_{K_S\pi^0}$ is about 0.69. However, lower values of $S_{K_S\pi^0}$ can be accommodated in the R-parity violating SUSY model. We also find that the future data of A_{CP}^{+-} is important to distinguish the two models.

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