IPPP/04/42 DCPT/04/84 UCL-IPT-04-12

Supersymmetric Contributions to $B \to K\pi$ Branching Ratio

S. Khalil[1,2], and E. Kou[3]

[1] *IPPP, University of Durham, South Rd., Durham DH1 3LE, U.K.*

[2] *Ain Shams University, Faculty of Science, Cairo, 11566, Egypt.*

[3] *Institut de Physique Théorique, Université Catholique de Louvain, B1348, Belgium.*

We analyze the supersymmetric contributions to the $B \to K\pi$ process. We show that the simultaneous contributions from the penguin diagrams with chargino and gluino in the loop could lead to a possible solution to the $B \to K\pi$ puzzle. Our result indicates that including the stringent constraint from the $b \to s\gamma$ branching ratio, the supersymmeteric models with light right-handed top-squark and large mixing between second and third generation of up and down squarks is the most preferred by the current experimental data.

Recent experimental measurements for the CP-averaged branching ratios of $B \to K\pi$ decays exhibit a possible discrepancy from the Standard Model (SM) prediction [2,3]:

$$\begin{aligned} R_c &\equiv 2\left\{\frac{\overline{Br}[B^+ \to K^+\pi^0] + \overline{Br}[B^- \to K^-\pi^0]}{\overline{Br}[B^+ \to K^0\pi^+] + \overline{Br}[B^- \to \bar{K}^0\pi^-]}\right\} \\ &= (1.12 \pm 0.05)_{exp}, \end{aligned} \tag{1}$$

$$\begin{aligned} R_n &\equiv \frac{1}{2}\left\{\frac{\overline{Br}[B^0 \to K^+\pi^-] + \overline{Br}(\bar{B}^0 \to K^-\pi^+)}{\overline{Br}[B^0 \to K^0\pi^0] + BR[\bar{B}^0 \to \bar{K}^0\pi^0]}\right\} \\ &= (0.79 \pm 0.11)_{exp}. \end{aligned} \tag{2}$$

As discussed in [4], it is very difficult to have the situation $R_c > 1$ and $R_n < 1$ within the SM. While a confirmation with more accurate experimental data is necessary (an overestimate of π^0 can lead to a similar pattern of R_c and R_n, see more in detail [5]), the current experimental values in Eqs. (1) and (2) does not seem to be possible even if we consider large hadronic uncertainties [6,7]. On the other hand, the fact that another combination of the branching ratios,

$$\begin{aligned} R &\equiv \left\{\frac{\overline{Br}[B^0 \to K^+\pi^-] + \overline{Br}[\bar{B}^0 \to K^-\pi^+]}{\overline{Br}[B^+ \to K^0\pi^+] + \overline{Br}[B^- \to \bar{K}^0\pi^-]}\right\}\frac{\tau_B^+}{\tau_{B^0}} \\ &= (0.89 \pm 0.07)_{exp} \end{aligned} \tag{3}$$

with $\frac{\tau_B^+}{\tau_{B^0}} = 1.086 \pm 0.017$ [1], is almost consistent to the SM prediction leads us to the so-called largely enhanced electroweak penguin (EWP) mechanism [8] among various New Physics (NP) scenarios. Possible NP contributions to EWP have been studied (see e.g. in [9–11]) and also an impact on the future experiments of the K decays are investigated [8,12].

In this letter, we analyze the supersymmetric contributions to the $B \to K\pi$ process in a model independent way using the mass insertion approximation. We will show that the Z penguin diagrams with chargino in the loop contribute to the EWP significantly for a light right handed stop mass. Furthermore, the subdominant color suppressed EWP can be also enhanced by the the electromagnetic penguin ($O_{7\gamma}$) with chargino in the loop. The gluino contributions modify mainly the chromomagnetic penguins (O_{8g}), i.e. the QCD penguins. As shown in [13,14], this modified QCD penguin contribution would be the key to understand another hint of NP discovered in the B factories; $S_{\phi K_S} < S_{J/\psi K_S}$. As we will show in this letter, the modified QCD penguin contributions would also help to deviate R_c and R_n in an indirect manner.

In our computation, we apply the QCD factorization (QCDF) [15,16] which offers us an ability of estimating the hadronic matrix element of $O_{7\gamma}$. We extend the parameterization in [15] by including the SUSY contributions. Then, Eq. (18) in [15] can be rewritten as

$$A_{B^-\to\pi^-\overline{K}^0} = P\left[e^{i\theta_P} + \epsilon_a e^{i\phi_a} e^{-i\gamma}\right] \tag{4}$$

$$\begin{aligned} \sqrt{2}A_{B^-\to\pi^0K^-} = P\big[&e^{i\theta_P} + \epsilon_a e^{i\phi_a} e^{-i\gamma} \\ &- \epsilon_{3/2}e^{i\phi}(e^{-i\gamma} - qe^{i\theta_q}e^{i\omega})\big] \end{aligned} \tag{5}$$

$$\begin{aligned} A_{\overline{B}^0\to\pi^+K^-} = P\big[&e^{i\theta_P} + \epsilon_a e^{i\phi_a} e^{-i\gamma} \\ &- \epsilon_T e^{i\phi_T}(e^{-i\gamma} - q_C e^{i\theta_{q_C}}e^{i\omega_C})\big] \end{aligned} \tag{6}$$

$$\begin{aligned} -\sqrt{2}A_{\overline{B}^0\to\pi^0\overline{K}^0} = P\big[&e^{i\theta_P} + \epsilon_a e^{i\phi_a} e^{-i\gamma} \\ &+ \epsilon_{3/2}e^{i\phi}(e^{-i\gamma} - qe^{i\theta_q}e^{i\omega}) \\ &- \epsilon_T e^{i\phi_T}(e^{-i\gamma} - q_C e^{i\theta_{q_C}}e^{i\omega_C})\big] \end{aligned} \tag{7}$$

which satisfies the isospin relation:

$$\sqrt{2}A_{\overline{B}^0\to\pi^0\overline{K}^0} = -A_{B^-\to\pi^-\overline{K}^0} + \sqrt{2}A_{B^-\to\pi^0K^-} - A_{\overline{B}^0\to\pi^+K^-}.$$

The parameters $\phi_a, \phi, \phi_T, \omega, \omega_C$ and $\theta_P, \theta_q, \theta_{qC}$ are the CP conserving (strong) and the CP violating phase, respectively. The parameters are written as:

$$P e^{i\delta_P} e^{i\theta_P} = \lambda_c A_{\pi\overline{K}}[\alpha_4^c - \frac{1}{2}\alpha_{4,EW}^c + \beta_3^c + \beta_{3,EW}^c]$$

$$\epsilon_a e^{i\phi_a} = \frac{\lambda_c \epsilon_{KM}}{P}\left[\beta_2 + \alpha_4^u - \frac{1}{2}\alpha_{4,EW}^u + \beta_3^u + \beta_{3,EW}^u\right]$$

$$\epsilon_{3/2} e^{i\phi} = \frac{-\lambda_c \epsilon_{KM}}{P}\left[\alpha_1 + R_{K\pi}\alpha_2 + \frac{3}{2}(R_{K\pi}\alpha_{3,EW}^u + \alpha_{4,EW}^u)\right]$$

$$\epsilon_T e^{i\phi_T} = \frac{-\lambda_c \epsilon_{KM}}{P}\left[\alpha_1 + \frac{3}{2}\alpha_{4,EW}^u - \frac{3}{2}\beta_{3,EW}^u - \beta_2)\right]$$

$$q e^{i\omega} e^{i\theta_q} \epsilon_{3/2} e^{i\phi} = \frac{\lambda_c}{P}\left[\frac{3}{2}(R_{K\pi}\alpha_{3,EW}^c + \alpha_{4,EW}^c)\right]$$

$$q_C e^{i\omega_C} e^{i\theta_{q_C}} \epsilon_T e^{i\phi_T} = \frac{\lambda_c}{P}\left[\frac{3}{2}(\alpha_{4,EW}^c - \beta_{3,EW}^c)\right]$$

where $\lambda_u/\lambda_c \equiv \epsilon_{KM}e^{-i\gamma}$ and $R_{K\pi} = A_{\pi\overline{K}}/A_{\overline{K}\pi} \simeq 1.01$. Comparing to [15], we have three extra CP violating phases, $\theta_P, \theta_q, \theta_{qC}$ which may be induced by SUSY. $\alpha^{u,c}_{4(3,EW;4,EW)}$ contains the QCD (EW) penguin contribution of both SM and SUSY. The SUSY contributions can be obtained by replacing SM Wilson coefficients in $\alpha^{u,c}_{4,(3,EW;4,EW)}$ to the SUSY Wilson coefficients. α_1 and α_2 are the color allowed and color suppressed tree contributions, which do not contain SUSY contributions. β^p_i represents the so-called weak annihilation contributions. We use the default values of all the input parameters in [15] with $\rho_A=\rho_H=0$ in our numerical analysis. As a result, the SM contributions within QCDF are given by

$$
\begin{aligned}
&(Pe^{i\delta_P})_{\rm SM} = -0.0989e^{-i0.022}, (\epsilon_a e^{i\phi_a})_{\rm SM} = -0.0202e^{i0.25}\\
&(\epsilon_{3/2}e^{i\phi})_{\rm SM} = 0.231e^{-i0.077}, \quad (\epsilon_T e^{i\phi_T})_{\rm SM} = 0.216e^{i0.00077}\\
&(qe^{i\omega})_{\rm SM} = \frac{0.136e^{-i0.075}}{(\epsilon_{3/2}e^{i\phi})_{\rm SM}},\ (q_C e^{i\omega_C})_{\rm SM} = \frac{0.0143e^{-i0.88}}{(\epsilon_T e^{i\phi_T})_{\rm SM}}.
\end{aligned}
$$

Notice that all the CP violating phases apart from γ are zero in SM. These theoretical values lead to

$$
R_c = 1.09(1.60),\ R_n = 1.11(1.73),\ R = 0.96(1.46) \quad (8)
$$

for $\gamma = \pi/3 (2\pi/3)$.

We first introduce a parameterization in which the SUSY contribution manifests itself. By assuming the same strong phases for SM and SUSY, which is not a bad assumption in QCDF where the strong phases enter as higher-order correction, we can write

$$
\begin{aligned}
Pe^{i\theta_P} &= P^{\rm SM}(1+ke^{i\theta'_P}) &(9)\\
qe^{i\omega}e^{i\theta_q} &= q^{\rm SM}e^{i\omega}(1+le^{i\theta'_q}) &(10)\\
q_C e^{i\omega_C}e^{i\theta_{q_C}} &= q_C^{\rm SM}e^{i\omega_C}(1+me^{i\theta'_{q_C}}). &(11)
\end{aligned}
$$

where

$$
ke^{i\theta'_P} \equiv \frac{(\alpha_4^c - \frac{1}{2}\alpha^c_{4,EW} + \beta^c_3 + \beta^c_{3,EW})_{\rm SUSY}}{(\alpha_4^c - \frac{1}{2}\alpha^c_{4,EW} + \beta^c_3 + \beta^c_{3,EW})_{\rm SM}}, \quad (12)
$$

$$
le^{i\theta'_q} \equiv \frac{(R_{K\pi}\alpha^c_{3,EW} + \alpha^c_{4,EW})_{\rm SUSY}}{(R_{K\pi}\alpha^c_{3,EW} + \alpha^c_{4,EW})_{\rm SM}}, \quad (13)
$$

$$
me^{i\theta'_{q_C}} \equiv \frac{(\alpha^c_{4,EW} - \beta^c_{3,EW})_{\rm SUSY}}{(\alpha^c_{4,EW} - \beta^c_{3,EW})_{\rm SM}} \quad (14)
$$

The index SM (SUSY) means to keep only SM (SUSY) Wilson coefficients in $\alpha^p_{i(,EW)}$ and $\beta^p_{i(,EW)}$. ϵ_a, $\epsilon_{3/2}$ and ϵ_T also include the QCD and EW penguin with the u index. However, these are always suppressed by the factor $\epsilon_{KM}\simeq 0.020$ comparing to the SUSY contributions with the c index. Therefore, neglecting this small contribution, the SUSY effects modify $\epsilon_{\{a,3/2,T\}}$ as

$$
\begin{aligned}
&(\epsilon_a e^{i\phi_a}) = \frac{(\epsilon_a e^{i\phi_a})_{\rm SM}}{|1+ke^{i\theta'_P}|},\quad (\epsilon_{3/2}e^{i\phi}) = \frac{(\epsilon_{3/2}e^{i\phi})_{\rm SM}}{|1+ke^{i\theta'_P}|},\\
&(\epsilon_T e^{i\phi_T}) = \frac{(\epsilon_T e^{i\phi_T})_{\rm SM}}{|1+ke^{i\theta'_P}|} \quad (15)
\end{aligned}
$$

In order to have a general picture of the $B\to K\pi$ puzzle, an expanded formulae in terms of ϵ_T, $\epsilon_{EW}\equiv q\times\epsilon_{3/2}$ and $\epsilon^C_{EW}\equiv q_C\times\epsilon_T$ is often useful. By assuming; i) the strong phases are negligible, i.e., $\phi_a,\phi,\omega,\omega_C$ are all zero, ii)the annihilation tree contribution is negligible, i.e. $\epsilon_a\simeq 0$, iii)the color suppressed tree contribution is negligible, i.e. $\epsilon_{3/2}e^{i\phi} = \epsilon_T e^{i\phi_T}$,we can write R_c and R_n as

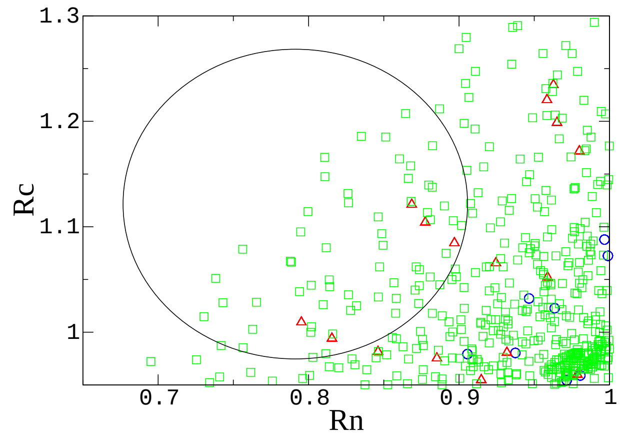

FIG. 1. Scattered plot for R_n versus R_n with $\{k=0,l=1,m=0\}$ (circle (blue)), $\{k=0,l=2,m=0\}$ (triangle (red)) and $\{k=0.3,l=1.5,m=0\}$ (square (green)) by varying $\gamma,\theta'_p,\theta'_q$. The ellipse indicates the experimental value.

$$
\begin{aligned}
R_c \simeq\ & 1+\epsilon_T^2 - 2\epsilon_T\cos(\gamma+\theta_P) + 2\epsilon_{EW}\cos(\theta_P-\theta_q)\\
& - 2\epsilon_T\epsilon_{EW}\cos(\gamma+\theta_q) + \mathcal{O}(\epsilon^2) &(16)\\
R_c - R_n \simeq\ & 2\epsilon_T\epsilon_{EW}\cos(\gamma+2\theta_P-\theta_q)\\
& - 2\epsilon_T\epsilon^C_{EW}\cos(\gamma+2\theta_P-\theta_{q_C}) + \mathcal{O}(\epsilon^2) &(17)
\end{aligned}
$$

Now, let us find the configuration which leads to $R_c - R_n \gtrsim 0.2$. From Eq. (17), we can find that in general, the larger the values of ϵ_T, ϵ_{EW} and ϵ^C_{EW} are, the larger the splitting between R_c and R_n we would acquire. Considering the SM value of $q_C\times\epsilon_T$, the second term in Eq. (17) has only a tiny impact unless m is of order 10. We can see that the phase combinations $\theta_P-\theta_q$ and $\theta_P+\gamma$ also play an important role. The possible solution to the R_c-R_n puzzle by enhancing ϵ_{EW}, which we have parameterized as l, has been intensively studied in the literature [6–8]. As we will see in the following, ϵ_T can also be enhanced when $ke^{i\theta'_P}$ term contributes destructively against the SM and diminish P (see Eq. (9)). However, since P is the dominant contribution to the $B\to K\pi$ process, the branching ratio is very sensitive to $ke^{i\theta'_P}$. Therefore, we are allowed to vary $ke^{i\theta'_P}$ only in the range of the theoretical uncertainty of QCDF, which gives about the right sizes of the $B\to K\pi$ branching ratios. Hence, we would be able to reduce P at most by 30 %, which can be easily compensated by the error e.g. in the transition form factor $F^{B\to\pi,K}$.

Considering the tiny effect from the second term in Eq. (17), in order to achieve $R_c-R_n\gtrsim 0.2$, we need $\epsilon_T\epsilon_{EW}$ larger than about 0.1 or equivalently, ϵ_{EW} larger than about 0.5 with $\epsilon_T^{\rm SM}$. In figure 1, we show scattered plots by varying $\gamma,\theta'_p,\theta'_q$ in a range of $\pi/3<\gamma<2\pi/3$ and $-\pi<\theta'_{q_{(C)}}<\pi$ (interval of 0.2 for each phase). It should be noted that the figure is obtained by using the full formulae of R_c and R_n with the full QCDF result. The circles (blue), triangles (red) and squares (green) represent the result with $\{k=0,l=1,m=0\}$, $\{k=0,l=2,m=0\}$ and $\{k=0.3,l=1.5,m=0\}$, respectively. We can see that with $k=0$, we need $l\gtrsim 2$ to reproduce the experimental values while an inclusion of a small amount of k lowers this bound significantly.

Now we investigate the SUSY contribution to the $B \to K\pi$ and the possible values of the parameters k and l to be reached. We work in the mass insertion approximation which is a technique to evaluate the SUSY contributions in a model independent manner. In this approximation, the extra FCNC as well as the new sources of CP violation enter in terms of the complex parameters $(\delta^q_{ij})_{AB}$ called mass insertion (MI) where A, B are left (L) or right (R) indices, i, j are generation indices and q refers the up or down sector. While we will here try to constrain the MI from the experiments, it is also computed by given soft SUSY breaking models. As mentioned in the introduction, there are two kinds of new diagrams, one from the gluino loop and the other from the chargino loop. As can be found in [17], the gluino contributions to the Wilson coefficients are proportional to $(\delta^d_{23})_{LL(RR)}$ apart from the magnetic terms, $C_{7\gamma}$ and C_{8g}, which additionally receive contributions proportional to the chirality flipping $(\delta^d_{23})_{LR(RL)}$. For the moderate SUSY mass configurations we will consider in the following, we find that only the $(\delta^d_{23})_{LR(RL)}$ terms, which is enhanced by a factor $m_{\tilde{g}}/m_b$ comparing to the $(\delta^d_{23})_{LL(RR)}$ terms, play a significant role. As the chargino contributions, we consider the general SUSY models with light chargino mass as well as the case with light right handed stop. As given in [14], the Wilson coefficients of the chargino diagrams are proportional to the up sector MI and the leading term come from $(\delta^u_{32})_{RL}$ and $(\delta^u_{32})_{LL}$. The others $(\delta^u_{31})_{LL(RR)}$, $(\delta^u_{32})_{RL}$ and $(\delta^u_{32})_{RR}$ are Cabbibo suppressed by order $\lambda, \lambda^2, \lambda^3$, respectively where $\lambda \simeq 0.22$. The general formulae for the chargino Wilson coefficients are given as

$$F_\chi \simeq (\delta^u_{32})_{LL} R^{LL}_F + (\delta^u_{32})_{RL} Y_t R^{RL}_F, \qquad (18)$$

where the loop functions R^{LL}_F and R^{RL}_F can be found in Ref. [14]. The index F refers to M^γ (electromagnetic-penguin), M^g(chromomagnetic-penguin), and C (Z-penguin). It is important to note that the functions $R^{LL}_{M^{\gamma,g}}$ depend on the bottom Yukawa coupling Y_b so that it can be enhanced for large $\tan\beta$. Also the function R^{RL}_C largely increases when decreasing the mass of the right-stop. In the following, we consider only dominant three mass insertions, $(\delta^d_{23})_{LR}$, $(\delta^u_{32})_{LL}$ and $(\delta^u_{32})_{RL}$ discussed above, which have some enhancement factor and have a potential to lead to a large SUSY contributions to the $B \to K\pi$ process.

Now let us show our numerical result. As a default value of the SUSY parameters, we chose

$$\begin{aligned} m_{\tilde{g}} &= 500\text{GeV}, \tilde{m}_{\tilde{q}} = 500\text{GeV}, \\ m_{\tilde{t}_R} &= 125\text{GeV}, m_2 = 150\text{GeV}, \mu = 250\text{GeV} \end{aligned} \qquad (19)$$

First we present SUSY contributions to each $\alpha^c_{i,(EW)}$ from each MI. The $(\delta^d_{23})_{LR}$ and $(\delta^u_{32})_{LL}$ terms which contribute to $C_{7\gamma}$ and C_{8g} lead to

$$\frac{\alpha_4^{c,\tilde{g}}}{\alpha_4^{c,\mathrm{SM}}} \simeq -36.7(\delta^d_{23})_{LR}, \ \frac{\alpha_{4,EW}^{c,\tilde{g}}}{\alpha_{4,EW}^{c,\mathrm{SM}}} \simeq 27.7(\delta^d_{23})_{LR},$$

$$\frac{\alpha_4^{c,\chi^+}}{\alpha_4^{c,\mathrm{SM}}} \simeq -0.00110\tan\beta(\delta^u_{32})_{LL}, \ \frac{\alpha_{4,EW}^{c,\chi^+}}{\alpha_{4,EW}^{c,\mathrm{SM}}} \simeq 0.148\tan\beta(\delta^u_{32})_{LL},$$

respectively and the $(\delta^u_{32})_{RL}$ term which contributes to Z penguin are obtained as

$$\frac{\alpha_{4,EW}^{c,Z}}{\alpha_{4,EW}^{c,\mathrm{SM}}} \simeq 1.68(\delta^u_{32})_{RL}, \ \frac{\alpha_{3,EW}^{c,Z}}{\alpha_{3,EW}^{c,\mathrm{SM}}} \simeq 1.18(\delta^u_{32})_{RL}.$$

Collecting all the SUSY contributions, our parameters k, l, and m are obtained as

$$\begin{aligned} ke^{i\theta_P} &= -0.0019\tan\beta(\delta^u_{32})_{LL} - 35.0(\delta^d_{23})_{LR} + 0.061(\delta^u_{32})_{RL} \\ le^{i\theta_q} &= 0.0528\tan\beta(\delta^u_{32})_{LL} - 2.78(\delta^d_{23})_{LR} + 1.11(\delta^u_{32})_{RL} \\ me^{i\theta_{qC}} &= 0.134\tan\beta(\delta^u_{32})_{LL} + 26.4(\delta^d_{23})_{LR} + 1.62(\delta^u_{32})_{RL} \end{aligned}$$

Note that we do not consider $(\delta^d_{23})_{RL}$ here but it is the same as $(\delta^d_{23})_{LR}$ with an opposite sign (see also [18]).

Let us first discuss the contributions from a single mass insertion $(\delta^u_{32})_{LL}, (\delta^d_{23})_{LR}$ or $(\delta^u_{32})_{RL}$ to $\{k, l, m\}$; keeping only one mass insertion and switching off the other two. Note that, as is well known, the absolute values of mass insertions $(\delta^u_{32})_{LL}$ and $(\delta^d_{23})_{LR}$ receive constraints from the $b \to s\gamma$ branching ratio which are $|\tan\beta \times (\delta^u_{32})_{LL}| \leq 1$ and $|(\delta^d_{23})_{LR}| \leq 0.005$. The mass insertion $(\delta^u_{32})_{RL}$ has only a constraint from its definition $|(\delta^u_{32})_{RL}| \leq 1$. Firstly we discuss the $(\delta^u_{32})_{RL}$ term. Using $|(\delta^u_{32})_{RL}| = 1$, the maximum value is found to be $\{k, l, m\} = \{0.061, 1.11, 1.62\}$. Thus, in this case where k is almost negligible, we would need $l \simeq 2$ to explain the experimental data. We have a chance to enlarge the coefficients for $(\delta^u_{32})_{RL}$ by, for instance, increasing the averaged squark mass $\tilde{m}_{\tilde{q}}$. However, even if we choose $\tilde{m}_{\tilde{q}} = 5$ TeV, we find that l is increased only by 20 to 30 %. Secondly, let us evaluate the $(\delta^d_{23})_{LR}$ and $(\delta^u_{32})_{LL}$ terms. Including the constraints from the $b \to s\gamma$ branching ratio, the maximum contributions from $(\delta^d_{23})_{LR}$ and $(\delta^u_{32})_{LL}$ are found to be $\{k, l, m\} = \{0.18, 0.014, 0.13\}$ and $\{0.0019, 0.053, 0.13\}$, which are far too small to explain the experimental data. The coefficients for $(\delta^d_{23})_{LR}$ depend on the overall factor $1/\tilde{m}_{\tilde{q}}$ and on also the variable of the loop function $x = m_{\tilde{g}}/\tilde{m}_{\tilde{q}}$ and we found that $m_{\tilde{g}} = \tilde{m}_{\tilde{q}} = 250$ GeV can lead to 100 % increase. However, the value of l is still too small to deviate $R_c - R_n$ significantly. As a whole, we found that it is extremely difficult to have $R_c - R_n \gtrsim 0.2$ from a single mass insertion contribution.

Let us try to combine two main contributions, $(\delta^d_{23})_{LR}$ and $(\delta^u_{32})_{RL}$ terms. Using the default SUSY masses in Eq. (19) and including the $b \to s\gamma$ constraint to $|(\delta^d_{23})_{LR}|$, the maximum value is found to be $\{k, l, m\} = \{0.24, 1.12, 1.48\}$. The resulting $R_c - R_n$ are given as circles (blue) of Fig. 2 by varying $\arg(\delta^d_{23})_{LR}, \arg(\delta^u_{32})_{RL}, \gamma$. We can see that the experimental data are not reproduced very well. As discussed above, for a large value of the averaged squark masses, l increases while k decreases. On the contrary, k also depends on the ratio of gluino and squark masses. Hence we need to optimize these masses so as to increase k and l simultaneously. For instance, with $m_{\tilde{g}}$=250 GeV and $\tilde{m}_{\tilde{q}}$=1 TeV, we obtain $\{k, l, m\}$=$\{0.30, 1.36, 1.90\}$ with which we find that quite a few points become well within the experimental bounds of R_c and R_n as shown in triangles (red) of Fig. 2.

Before concluding, let us mention about the relaxation of the $b \to s\gamma$ constraint as a possible solution when the experimental values of R_c and R_n remain around their

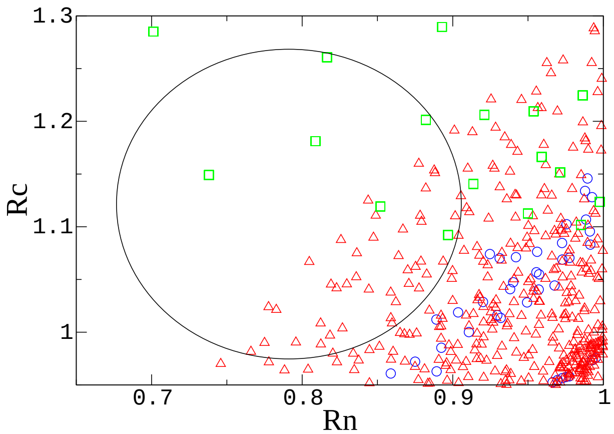

FIG. 2. Results of SUSY models with $|(\delta^u_{32})_{RL}| = 1$ and $|(\delta^d_{23})_{LR}| = 0.005$ (circle (blue) and triangles (red); see the text for the other parameters) and $|(\delta^u_{32})_{RL}| = 1$, $|(\delta^d_{23})_{LR}| = 0.018$ and $|\tan\beta \times (\delta^u_{32})_{LL}| = 6$ (square (green)).

current central values. The branching ratio of $b \to s\gamma$ depends not only on the absolute value of the mass insertion but also on the argument of it due to the overlap term of the SM and SUSY contributions. The constraints to the absolute value considered above are obtained independently from the phase. On the contrary, for a certain value of the argument, much larger absolute value could be allowed. For example, $|(\delta^d_{23})_{LR}| = 0.02$ with $\arg(\delta^d_{23})_{LR} \simeq \pm\pi$ and $|\tan\beta \times (\delta^u_{32})_{LL}| = 6$ with $\arg(\delta^u_{32})_{LL} \simeq 0$ can also accommodate the experimental value of the $b \to s\gamma$ branching ratio. However, this does not help unfortunately since the constraint to $|(\delta^u_{32})_{LL}|$ is still too strict to deviate R_c and R_n significantly and also the phase condition for the $(\delta^d_{23})_{LR}$ term, $\arg(\delta^d_{23})_{LR} \simeq \pm\pi$, works in a direction of diminishing $R_c - R_n$. The situation is different once we consider the $(\delta^d_{23})_{LR}$ and $(\delta^u_{32})_{LL}$ terms simultaneously. When a condition $|(\delta^d_{23})_{LR}| = \mathcal{O}(10^2) \times |\tan\beta \times (\delta^u_{32})_{LL}|$ is satisfied, the cancellation between the $(\delta^d_{23})_{LR}$ and $(\delta^u_{32})_{LL}$ terms occurs. Under this circumstance, we find that the same kind of relaxation for the absolute values can be expected but for much larger range of the phases comparing to the previous case. The squares (green) in Fig. 2 show a scattered plot with $|(\delta^u_{32})_{RL}| = 1$, $|(\delta^d_{23})_{LR}| = 0.018$ and $|\tan\beta \times (\delta^u_{32})_{LL}| = 6$ by varying the phases in a rage of $\pi/3 < \gamma < 2\pi/3$ and $-\pi < \arg(\delta^u_{32})_{RL}, \arg(\delta^d_{23})_{LR}, \arg(\delta^u_{32})_{LL} < \pi$ *and excluding the points which do not satisfy the* $b \to s\gamma$ *branching ratio*. We observe much larger R_c–R_n in this scenario.

In conclusion, we have examined the supersymmetric models as a solutions to the $B \to K\pi$ puzzle. We have shown that the Z penguin diagram with chargino in the loop could be enhanced for the small value of right handed stop mass and order one $(\delta^u_{32})_{RL}$. We, however, found that this contribution itself is not large enough to solve the puzzle when choosing moderate values of the SUSY particle masses. We also found that $B \to K\pi$ receives a large gluino chromomagnetic penguin contributions ($(\delta^d_{23})_{LR}$ term), which could explain another hint of new physics discovered in the B factories, $S_{\phi K_S} < S_{J/\psi K_S}$. While the $(\delta^d_{23})_{LR}$ term modifies only the QCD penguins and does not solve the $R_c - R_n$ puzzle directly, we found that it plays a complementary role to the $(\delta^u_{32})_{RL}$ term and we can well explain the experimental values of R_c and R_n within the $b \to s\gamma$ constraint. The chargino electromagnetic penguin diagram could also enhance EWP especially for large value of $\tan\beta$, however, we found that the stringent constraint to $|\tan\beta \times (\delta^u_{32})_{LL}|$ from the branching ratio of $b \to s\gamma$ prevents the $(\delta^u_{32})_{LL}$ term influencing the values of R_c and R_n. We examined a possible relaxation of the $b \to s\gamma$ constraint considering the phase configuration of the mass insertions. We found that the relaxation is quite possible especially, when a cancellation between the $(\delta^d_{23})_{LR}$ and $(\delta^u_{32})_{LL}$ term occur.

As represented in the relaxation scenario, we found that the R_c and R_n data and furthermore the full spectrum of the $B \to K\pi$ branching ratios constrain the SUSY parameters for FCNC and CP violation very severely, which would provide a great opportunity of improving our knowledge of the SUSY breaking nature [19].

Acknowledgments

The authors acknowledge discussions with Emidio Gabrielli. The work by E.K. was supported by the Belgian Federal Office for Scientific, Technical and Cultural Affairs through IAP P5/27. The work by S.K. was supported by PPARC.

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