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Supersymmetric contributions to the CP asymmetry of the $B \to \phi K_S$ and $B \to \eta' K_S$

Shaaban Khalil[1,2]

[1]IPPP, Physics Department, Durham University, DH1 3LE, Durham, U. K.
[2] Ain Shams University, Faculty of Science, Cairo, 11566, Egypt.

Abstract

We analyse the CP asymmetry of the $B \to \phi K_S$ and $B \to \eta' K_S$ processes in general supersymmetric models. We consider both gluino and chargino exchanges in a model independent way by using the mass insertion approximation method. We adopt the QCD factorization method for evaluating the corresponding hadronic matrix elements. We show that chromomagnetic type of operator may play an important role in accounting for the deviation of the mixing CP asymmetry between $B \to \phi K_S$ and $B \to J/\psi K_S$ processes observed by Belle and BaBar experiments. We also show that due to the different parity in the final states of these processes, their supersymmetric contributions from the R-sector have an opposite sign, which naturally explain the large deviation between their asymmetries.

I. INTRODUCTION

One of the most important tasks for B factory experiments would be to test the Kobayashi-Maskawa (KM) ansatz for the flavor CP violation*. The flavor CP violation has been studied quite a while, however, it is still one of the least tested aspect in the standard model (SM). Although it is unlikely that the SM provides the complete description of CP violation in nature (e.g. Baryon asymmetry in the universe), it is also very difficult to include any additional sources of CP violation beyond the phase in the CKM mixing matrix. Stringent constraints on these phases are usually obtained from the experimental bounds on the electric dipole moment (EDM) of the neutron, electron and mercury atom. Therefore, it remains a challenge for any new physics beyond the SM to give a new source of CP violation that may explain possible deviations from the SM results and also avoid overproduction of the EDMs. In supersymmetric theories, it has been emphasised [1] that there are attractive scenarios where the EDM problem is solved and genuine SUSY CP violating effects are found.

Recently, BABAR and Belle collaborations announced a 2.7σ deviation from $\sin 2\beta$ in the $B \to \phi K_S$ process[2,3]. In the SM, the decay process of $B \to \phi K$ is dominated by the top quark intermediated penguin diagram, which do not include any CP violating phase. Therefore, the CP asymmetry of $B \to J/\psi K_S$ and $B \to \phi K_S$ in SM are caused only by the phase in $B^0 - \overline{B}^0$ mixing diagram and we expect $S_{J/\psi K_S} = S_{\phi K_S}$ where $S_{f_{CP}}$ represents the mixing CP asymmetry. The $B \to \eta' K_S$ process is induced by more diagrams since η' meson contains not only $s\bar{s}$ state but also $u\bar{u}$ and $d\bar{d}$ states with the pseudoscalar mixing angle θ_p. Nevertheless, under an assumption that its tree diagram contribution is very small, which is indeed the case, one can expect $S_{\phi K_S} = S_{\eta' K_S}$ [2,4] as well. Thus, the series of new experimental data surprised us:

$$S^{\text{exp.}}_{J/\psi K_S} = 0.734 \pm 0.054, \tag{1.1}$$

* GNPHE Publication 2004, *e-mail: ajmp@fsr.ac.ma*

$$S^{\rm exp.}_{\phi K_S} = -0.39 \pm 0.41, \quad (1.2)$$
$$S^{\rm exp.}_{\eta' K_S} = 0.33 \pm 0.41 \quad (1.3)$$

It was pointed out[5] that the discrepancy between Eq. (1.1) and Eq. (1.2) might be explained by new physics contribution through the penguin diagram to $B \to \phi K_S$. However, in that case, a simultaneous explanation for the discrepancy between Eq. (1.2) and Eq. (1.3) is also necessary. We show our attempts to understand all the above experimental data within the Supersymmetric models.

II. THE MASS INSERTION APPROXIMATION

As mentioned, the SUSY extension of the SM may provide considerable effects to the CP violation observables since it contains new CP violating phases and also new flavour structures. Thus, SUSY is a natural candidate to resolve the discrepancy among the observed mixing CP asymmetries in B-meson decays.

In the following, we will perform a model independent analysis by using the mass insertion approximation[6]. We start with the minimal supersymmetric standard model (MSSM), where a minimal number of super-fields is introduced and R parity is conserved, with the following soft SUSY breaking terms

$$\begin{aligned} V_{SB} &= m^2_{0\alpha}\phi^*_\alpha\phi_\alpha \\ &+ \epsilon_{ab}\Big(A^u_{ij}Y^u_{ij}H^b_2\tilde{q}^a_{L_i}\tilde{u}^*_{R_j} + A^d_{ij}Y^d_{ij}H^a_1\tilde{q}^b_{L_i}\tilde{d}^*_{R_j} \\ &+ A^l_{ij}Y^l_{ij}H^a_1\tilde{l}^b_{L_i}\tilde{e}^*_{R_j} - B\mu H^a_1 H^b_2 + \text{H.c.}\Big) \\ &- \frac{1}{2}\Big(m_3\bar{\tilde{g}}\tilde{g} + m_2\overline{\widetilde{W^a}}\widetilde{W}^a + m_1\bar{\tilde{B}}\tilde{B}\Big)\,, \quad (2.1) \end{aligned}$$

where i,j are family indices, a,b are $SU(2)$ indices, and ϵ_{ab} is the 2×2 fully antisymmetric tensor, with $\epsilon_{12}=1$. Moreover, ϕ_α denotes all the scalar fields of the theory. Although in general the parameters μ, B, A^α and m_i can be complex, two of their phases can be rotated away.

The mass insertion approximation is a technique which is developed to include the soft SUSY breaking term without specifying the models in behind. In this approximation, one adopts a basis where the couplings of the fermion and sfermion are flavour diagonal, leaving all the sources of flavour violation inside the off-diagonal terms of the sfermion mass matrix. These terms are denoted by $(\Delta^q_{AB})^{ij}$, where $A,B=(L,R)$ and $q=u,d$. The sfermion propagator is then expanded as

$$\begin{aligned} \langle\tilde{q}^a_A\tilde{q}^{b*}_B\rangle &= \mathrm{i}\ (k^2\mathbf{1} - \tilde{m}^2\mathbf{1} - \Delta^q_{AB})^{-1}_{ab} \\ &\simeq \frac{\mathrm{i}\ \delta_{ab}}{k^2-\tilde{m}^2} + \frac{\mathrm{i}\ (\Delta^q_{AB})_{ab}}{(k^2-\tilde{m}^2)^2}, \quad (2.2) \end{aligned}$$

where $\mathbf{1}$ is the unit matrix and $\tilde{m}$ is the average squark mass. The SUSY contributions are parameterised in terms of the dimensionless parameters $(\delta^q_{AB})_{ij} = (\Delta^q_{AB})^{ij}/\tilde{m}^2$. This method allows to parametrise, in a model independent way, the main sources of flavor violations in SUSY models.

Including the SUSY contribution, the effective Hamiltonian $H^{\Delta B=1}_{\rm eff}$ for these processes can be expressed via the Operator Product Expansion (OPE) as

$$\begin{aligned} H^{\Delta B=1}_{\rm eff} &= \{\frac{G_F}{\sqrt{2}}\sum_{p=u,c}\lambda_p\ (C_1Q^p_1 + C_2Q^p_2 \\ &+ \sum_{i=3}^{10}C_iQ_i + C_{7\gamma}Q_{7\gamma} + C_{8g}Q_{8g}) + h.c.\} \\ &+ \Big\{Q_i\to\tilde{Q}_i\,,\ C_i\to\tilde{C}_i\Big\}\ , \quad (2.3) \end{aligned}$$

where $\lambda_p = V_{pb}V^\star_{ps}$, with V_{pb} the unitary CKM matrix elements satisfying $\lambda_t+\lambda_u+\lambda_c=0$, and $C_i\equiv C_i(\mu_b)$ are the Wilson coefficients at low energy scale $\mu_b\simeq m_b$.

As emphasised in[7,8], the leading contribution of both gluino and chargino to $\Delta B=1$ processes come from the chromomagnetic penguin operator $O_g(\tilde{O}_g)$. The corresponding Wilson coefficient is given by

$$\begin{aligned} C^{\tilde{g}}_{8g} &= \frac{\alpha_s\pi}{\sqrt{2}G_F m^2_{\tilde{q}}}[(\delta^d_{LL})_{23}(\frac{1}{3}M_3(x)+3M_4(x)) \\ &+ (\delta^d_{LR})_{23}\frac{m_{\tilde{g}}}{m_b}(\frac{1}{3}M_1(x)+3M_3(x))], \quad (2.4) \end{aligned}$$

and

$$\begin{aligned} C^\chi_{8g} &= \big[(\delta^u_{LL})_{32} + \lambda(\delta^u_{LL})_{31}\big]R^{LL}_{8g} \\ &+ \big[(\delta^u_{RL})_{32} + \lambda(\delta^u_{RL})_{31}\big]Y_t R^{RL}_{8g}. \quad (2.5) \end{aligned}$$

Here the functions R^{LL}_{8g} and R^{RL}_{8g} are given by

$$\begin{aligned} R^{LL}_{8g} &= \sum_i |V_{i1}|^2\, x_{Wi}\, P^{LL}_{M^{\gamma,g}}(x_i) \\ &- Y_b\sum_i V_{i1}U_{i2}\, x_{Wi}\,\frac{m_{\chi_i}}{m_b}P^{LR}_{M_{\gamma,g}}(x_i), \\ R^{RL}_{8g} &= -\sum_i V_{i1}V^\star_{i2}\, x_{Wi}\, P^{LL}_{M_{\gamma,g}}(x_i), \quad (2.6) \end{aligned}$$

where $x_{Wi} = m^2_W/m^2_{\chi_i}$, $x_i = m^2_{\chi_i}/\tilde{m}^2$, $\bar{x}_i = \tilde{m}^2/m^2_{\chi_i}$, and $x_{ij} = m^2_{\chi_i}/m^2_{\chi_j}$. The loop functions $P^{LL(LR)}_{8g}(x)$ and also the functions $M_i(x)$,

$i = 1, 3, 4$ can be found in Ref.[9]. Finally, U and V are the matrices that diagonalize chargino mass matrix.

It is now clear that the part proportional to LR mass insertions in $C_{8g}^{\tilde{g}}$ which is enhanced by a factor $m_{\tilde{g}}/m_b$ would give a dominant contribution. Also the part proportional to the LL mass insertion in C_{8g}^{χ} is enhanced by m_χ/m_b and could also give significant contribution.

III. CAN WE EXPLAIN THE EXPERIMENTAL DATA OF $S_{\phi K_S}$ IN SUSY?

Following the parametrisation of the SM and SUSY amplitudes in Ref.[7], $S_{\phi K_S}$ can be written as

$$S_{\phi K_S} = \frac{\sin 2\beta + 2R_\phi \cos\delta_{12} \sin(\theta_\phi + 2\beta) + R_\phi^2 \sin(2\theta_\phi + 2\beta)}{1 + 2R_\phi \cos\delta_{12} \cos\theta_\phi + R_\phi^2} \quad (3.1)$$

where $R_\phi = |A^{\rm SUSY}/A^{\rm SM}|$, $\theta_\phi = \arg(A^{\rm SUSY}/A^{\rm SM})$, and δ_{12} is the strong phase.

We will discuss in the following whether the SUSY contributions can make $S_{\phi K_S}$ negative. For $m_{\tilde{q}} = m_{\tilde{g}} = 500$ GeV and adopting the QCD factorization mechanism to evaluate the matrix elements, one obtains

$$R_\phi^{QCDF}|_{\tilde{g}} \simeq \{-0.14 \times e^{-i\,0.1} (\delta_{LR}^d)_{23} - 127 \times e^{-i\,0.08} (\delta_{LR}^d)_{23}\} + \{L \leftrightarrow R\}, \quad (3.2)$$

while in the case of chargino exchange with gaugino mass $M_2 = 200$ GeV, $\mu = 300$ GeV, and $\tilde{m}_{\tilde{t}_R} = 150$ GeV, we obtain, for $\tan\beta = 40$

$$\begin{aligned} R_\Phi^{QCDF}|_{\chi^\pm} \simeq\; & 1.89 \times e^{-i\,0.07} (\delta_{LL}^u)_{32} \\ & - 0.11 \times e^{-i\,0.17} (\delta_{RL}^u)_{32} \\ & + 0.43 \times e^{-i\,0.07} (\delta_{LL}^u)_{31} \\ & - 0.02 \times e^{-i\,0.17} (\delta_{RL}^u)_{31}. \end{aligned} \quad (3.3)$$

From results in Eqs.(3.2)–(3.3), it is clear that the largest SUSY effect is provided by the gluino and chargino contributions to the chromomagnetic operator which are proportional to $(\delta_{LR}^d)_{23}$ and $(\delta_{LL}^u)_{32}$ respectively. However, the $b \to s\gamma$ constraints play a crucial role in this case. For the above SUSY configurations, the $b \to s\gamma$ decay set the following constraints on gluino and chargino contributions, respectively $|(\delta_{LR}^d)_{23}| < 0.016$ and $|(\delta_{LL}^u)_{32}| < 0.1$. Implementing these bounds in Eqs.(3.2)–(3.3), we see that gluino contribution can achieve larger value for R_ϕ than chargino one.

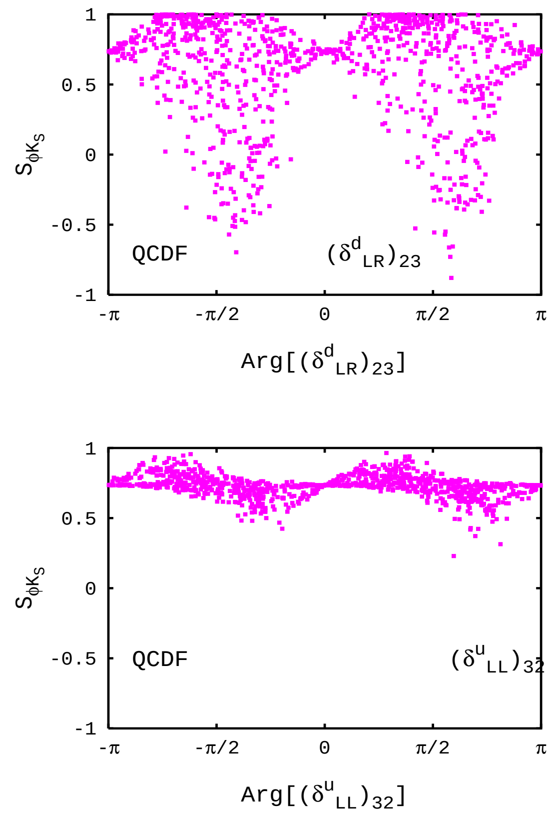


FIG. 1. $S_{\phi K_S}$ as a function of $\arg[(\delta_{LR}^d)_{23}]$ (up) and $\arg[(\delta_{LL}^u)_{32}]$ (down) with gluino and chargino contributions respectively.

We present our numerical results for the gluino and chargino contributions to CP asymmetry $S_{\Phi K_S}$ in Fig. 1. We plot the CP asymmetry as function of the phase of $(\delta_{LR}^d)_{23}$ for gluino dominated scienario and $Arg[(\delta_{LL}^u)_{32}]$ for the chargino dominanted model. We have scanned over the relavant SUSY parameter space, assuming SM central values as in table 1. Namely, the average squark mass $\tilde{m}$, gluino mass $m_{\tilde{g}}$. Moreover we require that the SUSY spectra satisfy the present experimental lower mass bounds. In particular, $m_{\tilde{g}} > 200$ GeV, $\tilde{m} > 300$ GeV. In addition, we scan over the real and imaginary part of the corresponding mass insertions, by requiring that the branching ratio (BR) of $b \to s\gamma$ and the $B^0 - \bar{B}^0$ mixing constraints are satisfied at 95% C.L.. Also we have scanned over the full range of the QCD factorization parameters $\rho_{A,H}$ and $\phi_{A,H}$, We remind here that these parameters are taken into account for the (unknown) infrared contributions in the hard scattering and annihilation diagrams respectively.

As can be seen from this figure, the gluino contributions proportional to $(\delta_{LR}^d)_{23}$ have chances to drive $S_{\Phi K_S}$ toward the region of larger and negative values. While in the chargino dominated scenario negative values of S_ϕ cannot be achieved. The reason why extensive regions of negative values of S_ϕ are excluded here, is only due to the $b \to s\gamma$ constraints. Indeed, the inclusion of $(\delta^u_{LL})_{32}$ mass insertion can generate large and negative values of S_ϕ, by means of chargino contributions to chromomagnetic operator Q_{8g} which are enhanced by terms of order $m_{\chi^\pm}/m_b$. However, contrary to the gluino scenario, chargino contributions to C_{8g} are not enhanced by colour factors. Therefore, large enhancements of the Wilson coefficient C_{8g}, leave unavoidablly to the breaking of $b \to s\gamma$ constraints. As shown in Ref.[8], by scanning over two mass insertion but requiring a common SUSY CP violating phase, a sort of fine tuning to escape $b \to s\gamma$ constraints is always possible, and few points in the negative regions of S_ϕ can be approached.

IV. WHAT HAPPENED TO THE $B \to \eta' K_S$ PROCESS?

Although $B \to \phi K_S$ and $B \to \eta' K_S$ are very similar processes, the parity of the final states can deviate the result. In $B \to \phi K_S$, the contributions from C_i and $\tilde{C}_i$ to the decay amplitude are identically the same (with the same sign), while in $B \to \eta' K_S$, they have sign difference. This can be simply understood by noticing that

$$\langle \phi K_S | Q_i | B \rangle = \langle \phi K_S | \tilde{Q}_i | B \rangle \,. \quad (4.1)$$

which is due to the invariance of strong interactions under parity transformations, and to the fact that initial and final states have same parity. However, in case of $B \to \eta' K_S$ transition, where the initial and final states have opposite parity, we have

$$\langle \eta' K_S | Q_i | B \rangle_{QCDF} = -\langle \eta' K_S | \tilde{Q}_i | B \rangle_{QCDF} . \quad (4.2)$$

As a result, the sign of the RR and RL in the gluino contributions are different for $B \to \phi K_S$ and $B \to \eta' K_S$[11]. Using the same SUSY inputs adopted in Eqs. (3.3), (3.2). For gluino contributions we have

$$R^{QCDF}_{\eta'}|_{\tilde{g}} \simeq -0.07 \times e^{i\,0.24} (\delta^d_{LL})_{23} - 64 (\delta^d_{LR})_{23} + 0.07 \times e^{i\,0.24} (\delta^d_{RR})_{23} + 64 (\delta^d_{RL})_{23} \quad (4.3)$$

while for chargino exchanges we obtain

$$R^{QCDF}_{\eta'}|_{\chi^\pm} \simeq 0.95\,(\delta^u_{LL})_{32} - 0.025 \times e^{-i\,0.19}\,(\delta^u_{RL})_{32} + 0.21\,(\delta^u_{LL})_{31} - 0.006 \times e^{-i\,0.19}\,(\delta^u_{RL})_{31} . \quad (4.4)$$

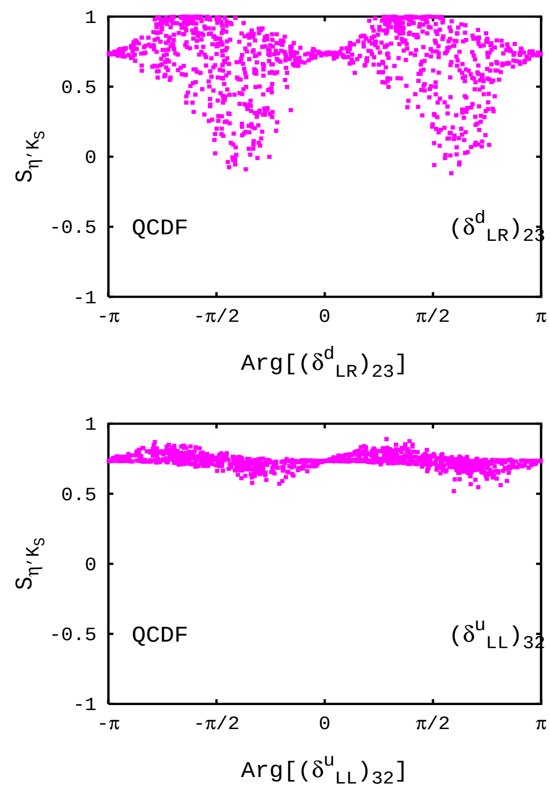


FIG. 2. $S_{\eta' K_S}$ as a function of arg[$(\delta^d_{LR})_{23}$] (up) and arg[$(\delta^u_{LL})_{32}$] (down) with gluino and chargino contributions respectively.

We show our results for gluino and chargino contributions in Fig. 2, where we have just extended the same analysis of $B \to \phi K_S$. Same conventions as in Fig. 1 for $B \to \phi K_S$ have been adopted here. As we can see from these results, there is a depletion of the gluino contribution in $S_{\eta'}$, precisely for the reasons explained above. Negative regions are disfavoured, but a minimum of $S_{\eta'} \simeq 0$ can be achieved. Respect the chargino contributions, it is clear that it can imply at most a deviation from SM predictions of about ±20 %.

V. ON THE BRANCHING RATIO OF $B \to \eta' K_S$

In 1997, CLEO collaboration reported an unexpectedly large branching ratio[12]

$$Br^{\text{exp.}}(B^0 \to K^0 \eta') = (89^{+18}_{-16} \pm 9) \times 10^{-6} \quad (5.1)$$

which is confirmed by Belle[13] and BABAR[4]:

$$\text{BELLE} = (79^{+12}_{-16} \pm 8) \times 10^{-6}, \quad (5.2)$$

$$\text{BABAR} = (76.9 \pm 3.5 \pm 4.4) \times 10^{-6} \quad (5.3)$$

Considering the theoretical prediction by the naive factorisation approximation

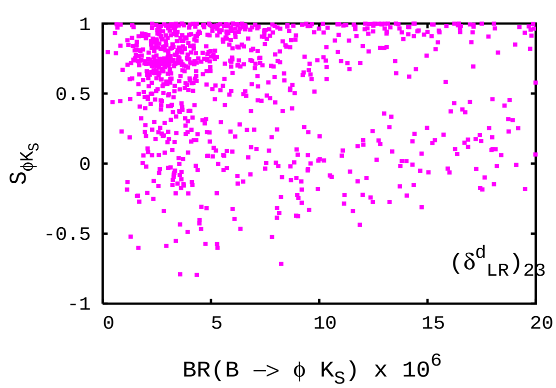
$$Br^{\rm theo.}(B \to K\eta') \simeq 25 \times 10^{-6}, \qquad (5.4)$$

the experimental data is about factor of three large, thus, there have been various efforts to explain this puzzle. On one hand, new physics contributions have been discussed[14]. However, the enhancement by new physics contributions through penguin diagrams ends up with large branching ratios for all other penguin dominated processes. Therefore, one needs a careful treatment to enhance only $B \to \eta' K$ process without changing the predictions for the other processes. On the other hand, since this kind of large branching ratio is observed only in $B \to \eta' K$ process, the gluonium contributors which only exist in this process have been a very interesting candidate to solve the puzzle[15][16] though the amount of gluonium in η' is not precisely known[17]. In this section, we discuss the effect of our including SUSY contributions to the branching ratios for $B \to \phi K$ and $B \to \eta' K$.

Inclusion of the SUSY contributions modify the branching ratio as:

$$Br^{\rm SM\,+\,SUSY} = Br^{\rm SM} \times [1 + 2\cos\theta_{\rm SUSY} R + R^2]$$

where $R = |A^{\rm SUSY}|/|A^{\rm SM}|$. As we have shown, to achieve a negative value of $S_{\phi K_S}$, we need $\theta_{\rm SUSY} \simeq -\pi/2$, which suppresses the leading SUSY contribution. On the other hand, the phase for $B \to \eta' K$ is different from the one for ϕK_S, as is discussed in the previous section. In the following, we will analyze the maximum effect one can obtain from SUSY contribution to $BR(B \to \eta' K_S)$ with taking into account the experimental limits on the $BR(B \to \phi K_S)$, $S_{\phi K_S}$ and $S_{\eta' K_S}$.



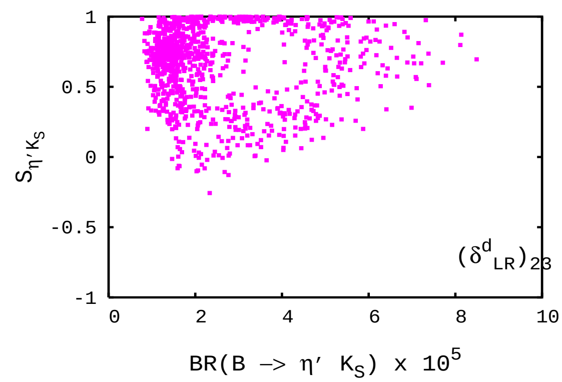
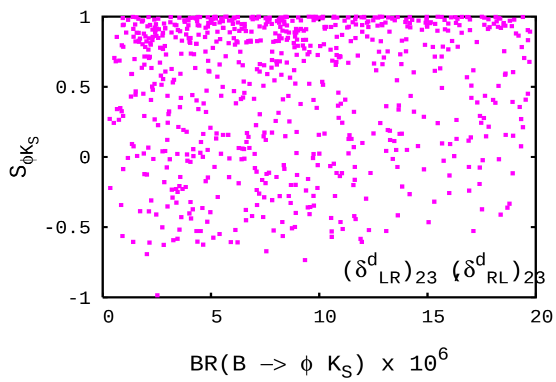


FIG. 3. Correlations of $S_{\phi K_S}$ versus $BR(B \to \phi K_S)$ (left) and $S_{\eta' K_S}$ versus $BR(B \to \eta' K_S)$ (right), for gluino contributions with one single mass insertion $(\delta^d_{LR})_{23}$.

In Fig.3 we plot the CP asymmetry versus the branching ratio for $B \to \phi K_S$ and $B \to \eta' K_S$. We consider the dominant gluino contribution due to $(\delta^d_{LR})_{23}$ and scan over the other parameters as before. One can see from this figure that, in the region of large negative S_ϕ the $BR(B \to K_S \phi)$ is likely to be close to the SM prediction, namely it is of order $(2-5) \times 10^{-6}$. Larger values for the BR are also possible but correspond to $S_{\phi K_S} \gtrsim -0.5$. In another word, if we consider the central value of $BR(B \to K_S \phi)$ as 8×10^{-6}, it is predicted that $S_{\phi K_S}$ likely to lie in the range $0 \lesssim S_{K_S \phi} \lesssim -0.5$.

Respect to the correlation between $S_{\eta' K_S}$ and $BR(B \to K_S \eta')$, it is remarkable that with just one mass insertion $S_{\eta' K_S}$ is likely positive and around 0.5 which is quite compitable with the experimental results and in this case with large $\mu \simeq m_b$, it is no longer needed to consider LR and RL mass insertions semiltaneously to suppress $R_{\eta'}$ as explained in the previous section. Furthermore, as can be seen from this figure, for $S_{\eta' K_S} \simeq 0.5$ the $BR(B \to \eta' K_S)$ can be large as 80×10^{-6}, *i.e*, it is enhanced by gluino contribution to more than 6 times the SM value and become compitable with the experimental result mentioned above.



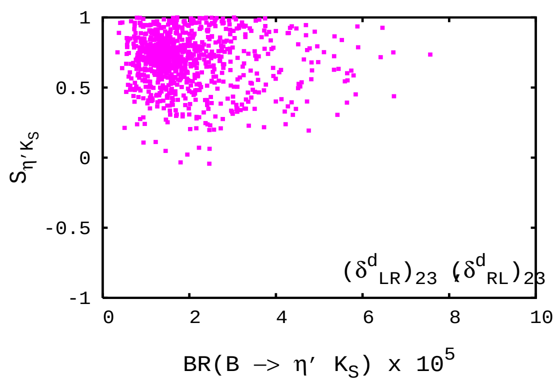
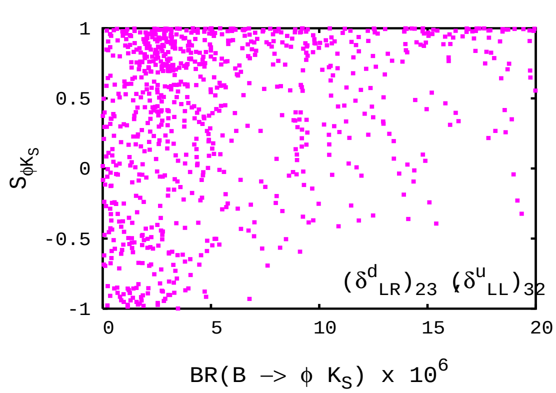


FIG. 4. As in Fig. 3, but for gluino contributions with two mass insertions $(\delta^d_{LR})_{23}$ and $(\delta^d_{RL})_{23}$.

In Fig. 4, we present the correlation between $S_{\phi K_S}$ and $BR(B \to \phi K_S)$ and also the correlation between $S_{\eta' K_S}$ and $BR(B \to \eta' K_S)$. Here we present the gluino contributions with two mass insertions $(\delta^d_{LR})_{23}$ and $(\delta^d_{LR})_{32}$. In this case, we can easily see that the gluino contribution can saturate simultaneously both $S_{\phi K_S}$ and $BR(B \to \phi K_S)$ within their experimental ranges. However, for $B \to \eta' K_S$, as expected the CP asymmetry becomes larger and around the $\sin 2\beta$ while its branching ratio is diminished. Now it is of order $(20-40) \times 10^{-6}$ which is smaller than the experimental measurments.



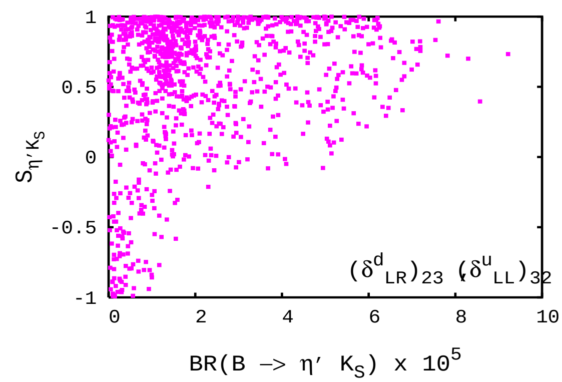


FIG. 5. As in Fig. 3, but for gluino and chargino contributions with mass insertions $(\delta^d_{LR})_{23}$ and $(\delta^u_{LL})_{32}$ respectively.

The combination effects from gluino and chargino on $BR(B \to \phi K_S)$ and $BR(B \to \eta' K_S)$ are shown in Fig.5. We present the CP asymmetry versus the branching ratio for each process. We scan on the allowed range of the most relevant mass insertions for these two contributions: $(\delta^d_{LR})_{23}$ and $(\delta^u_{LL})_{32}$. We also vary the other parameters as in the previous figures. The message of this figure is that with both gluino and chargino we can easily accommodate the experimental results for the CP asymmetries and the branching ratios of $BR(B \to \phi K_S)$ and $BR(B \to \eta' K_S)$. It is important to stress that the striengent bound on $(\delta^u_{LL})_{32}$ from the experimental limits on $BR(B \to X_s \gamma)$ are relaxed when one consider both gluino and chargino contributions, which comes with different sign. Now some configuration with large $\tan\beta$ are allowed and therefore chragino can contribute significantly to the CP asymmetries $S_{\phi K_S}$ and $S_{\eta' K_S}$. It is also remarkable that in this scienario, the value of the branching ratio $BR(B \to \eta' K_S)$ can be of order 60×10^{-6} which is compitable with the central value of the experimental results.

VI. CONCLUSIONS

We studied the supersymmetric contributions to the CP asymmetry of $B \to \phi K_S$ and $B \to \eta' K_S$ in a model independent way. We found that the observed large discrepancy between $S_{J/\psi K_S}$ and $S_{\phi K_S}$ can be explained within some SUSY models with large $(\delta_{LR})_{23}$ or $(\delta_{RL})_{23}$ mass insertions. We showed that the SUSY contributions of $(\delta_{RR})_{23}$ and $(\delta_{RL})_{23}$ to $B \to \phi K_S$ and $B \to \eta' K_S$ have different signs. Therefore, the current observation, $S_{\phi K_S} < S_{\eta' K_S}$, favours the $(\delta_{RR,RL})_{23}$ dominated models. We also discussed the SUSY contributions to the branching ratios. We showed that negative

$S_{\phi K_S}$ and small SUSY effect to $Br(B \to \phi K)$ can be simultaneously achieved. On the other hand, we showed that SUSY contribution itself may *not* solve the puzzle of the large branching ratio of $B \to \eta' K_S$.

[1] S. Abel, S. Khalil and O. Lebedev, Nucl. Phys. B **606**, 151 (2001).
[2] K. Abe *et al.* [Belle Collaboration], arXiv:hep-ex/0207098.
[3] B. Aubert *et al.* [BABAR Collaboration], arXiv:hep-ex/0207070.
[4] B. Aubert *et al.* [BABAR Collaboration], arXiv:hep-ex/0303046.
[5] Y. Nir, Nucl. Phys. Proc. Suppl. **117** (2003) 111 [arXiv:hep-ph/0208080].
[6] L. J. Hall, V. A. Kostelecky and S. Raby, Nucl. Phys. B **267** (1986) 415.
[7] S. Khalil and E. Kou, Phys. Rev. D **67** (2003) 055009 [arXiv:hep-ph/0212023].
[8] D. Chakraverty, E. Gabrielli, K. Huitu and S. Khalil, Phys. Rev. D **68**, 095004 (2003) [arXiv:hep-ph/0306076].
[9] E. Gabrielli, K. Huitu and S. Khalil, in preparation.
[10] M. Ciuchini, E. Franco, A. Masiero and L. Silvestrini, Phys. Rev. D **67** (2003) 075016 [arXiv:hep-ph/0212397].
[11] S. Khalil and E. Kou, arXiv:hep-ph/0303214.
[12] S. J. Richichi *et al.* [CLEO Collaboration], arXiv:hep-ex/9908019.
[13] K. Abe *et al.* [Belle Collaboration], Phys. Lett. B **517**, 309 (2001) [arXiv:hep-ex/0108010].
[14] A. Kundu, Pramana **60** (2003) 345 [arXiv:hep-ph/0205100].
[15] D. Atwood and A. Soni, Phys. Lett. B **405** (1997) 150 [arXiv:hep-ph/9704357].
[16] M. R. Ahmady, E. Kou and A. Sugamoto, Phys. Rev. D **58** (1998) 014015 [arXiv:hep-ph/9710509].
[17] E. Kou, Phys. Rev. D **63** (2001) 054027 [arXiv:hep-ph/9908214].