Effects of supersymmetric CP violating phases

on $B \to X_s l^+ l^-$ and $\epsilon_K$

Seungwon Baek* and Pyungwon Ko†

Department of Physics, KAIST

Taejon 305-701, Korea

Abstract

We consider effects of CP violating phases in $\mu$ and $A_t$ parameters in the effective supersymmetric standard model on $B \to X_s l^+ l^-$ and $\epsilon_K$. Scanning over the MSSM parameter space with experimental constraints including edm constraints from Chang-Keung-Pilaftsis (CKP) mechanism, we find that the $\text{Br}(B \to X_s l^+ l^-)$ can be enhanced by up to $\sim 85\%$ compared to the standard model (SM) prediction, and its correlation with $\text{Br}(B \to X_s \gamma)$ is distinctly different from the minimal supergravity scenario. Also we find $1 \lesssim \epsilon_K/\epsilon_K^{SM} \lesssim 1.4$, and fully supersymmetric CP violation in $K_L \to \pi\pi$ is not possible. Namely, $|\epsilon_K^{SUSY}| \lesssim O(10^{-5})$ if the phases of $\mu$ and $A_t$ are the sole origin of CP violation.

*swbaek@muon.kaist.ac.kr

†pko@muon.kaist.ac.kr
In the minimal supersymmetric standard model (MSSM), there can be many new CP violating (CPV) phases beyond the KM phase in the standard model (SM) both in the flavor conserving and flavor violating sectors. The flavor conserving CPV phases in the MSSM are strongly constrained by electron/neutron electric dipole moment (edm) and believed to be very small ($\delta \lesssim 10^{-2}$ for $M_{\text{SUSY}} \sim O(100) \text{ GeV}$) \[1\]. Or, one can imagine that the 1st/2nd generation scalar fermions are very heavy so that edm constraints are evaded via decoupling even for CPV phases of order $O(1) \[2\]$. Also it is possible that various contributions to electron/neutron EDM cancel with each other in substantial parts of the MSSM parameter space even if SUSY CPV phases are $\sim O(1)$ and SUSY particles are relatively light \[3\] \[4\]. In the last two cases where SUSY CPV phases are of $\sim O(1)$, these phases may affect $B$ and $K$ physics in various manners. In the previous letter \[5\], we presented effects of these SUSY CPV phases on $B$ physics: the $B^0 - \bar{B}^0$ mixing and the direct asymmetry in $B \to X_s \gamma$, assuming that EDM constraints and SUSY FCNC problems are evaded by heavy 1st/2nd generation scalar fermions. In this letter, we extend our previous work to $B \to X_s l^+ l^-$ and $\epsilon_K$ (see also Ref. \[6\]) within the same assumptions.

An important ingredient for large $\tan \beta$ in our model is the constraint on the $\mu$ and $A_t$ phases coming from electron/neutron edm’s through Chang-Keung-Pilaftsis (CKP) mechanism \[7\]. Two loop diagrams with CP-odd higgs and photon (gluon) exchanges between the fermion line and the sfermion loop (mainly stops and sbottoms) can contribute significantly to electron/neutron edm’s in the large $\tan \beta$ region. The authors of Ref. \[7\] find that

$$\left(\frac{dL}{e}\right)_{\text{CKP}} = Q_f \frac{3\alpha_{\text{em}} R_f m_f}{64\pi^2 M_A^2} \sum_{q=t,b} \xi_q Q^2 q F \left( \frac{M_q^2}{M_A^2} \right) - F \left( \frac{M_{\tilde{q}}^2}{M_A^2} \right), \tag{1}$$

where $R_f = \cot \beta (\tan \beta)$ for $I_{3f} = 1/2 (-1/2)$, and

$$\xi_t = \frac{\sin 2\beta m_t \text{Im}(\mu e^{i\delta_t})}{\sin^2 \beta v^2}, \quad \xi_b = \frac{\sin 2\beta m_b \text{Im}(A_b e^{-i\delta_b})}{\sin \beta \cos \beta v^2}, \tag{2}$$

with $\delta_q = \text{Arg}(A_q + R_q \mu^*)$, and $F(z)$ is a two-loop function given in Ref. \[7\]. This new contribution is independent of the 1st/2nd generation scalar fermion masses, so that it does not decouple for heavy 1st/2nd generation scalar fermions. Therefore it can be important.
for the electron or down quark edm for the large tan \( \beta \) case. This is in sharp contrast with the usual one-loop contributions to edm’s, for which \[ (d_{ef}/e) \sim 10^{-25} \text{cm} \times \frac{|\text{Im}\mu, \text{Im}A_f|}{\text{max}(M_{\tilde{f}},M_{\lambda})} \left( \frac{1 \text{ TeV}}{M_{\tilde{f}} \text{ max}(M_{\tilde{f}},M_{\lambda})} \right)^2 \left( \frac{m_f}{10 \text{ MeV}} \right), \] and one can evade the edm constraints by having small phases for \( \mu, A_{e,u,d} \), or heavy 1st/2nd generation scalar fermions. However, this would involve enlargement of our model parameter space, since one has to consider the sbottom sector as well as the stop sector. Therefore, more parameters have to be introduced in principle: \( m_{\tilde{b}}^2 \) and \( A_b \) where \( A_b \) may be complex like \( A_t \). In order to avoid such enlargement, we will assume that there is no accidental cancellation between the stop and sbottom loop contributions.

This CKP edm constraint has not been included in the recent paper by Demir et al. \[6\], who made claims that there could be a large new phase shift in the \( B^0 - \overline{B^0} \) mixing and it is possible to have a fully supersymmetric \( \epsilon_K \) from the phases of \( \mu \) and \( A_t \) only. However, if \( \tan \beta \) is large (\( \tan \beta \approx 60 \)) as in Ref. \[6\], the CKP edm constraints via the CKP mechanism have to be properly included. This constraint reduces the possible new phase shift in the \( B^0 - \overline{B^0} \) mixing to a very small number, \( 2|\theta_d| \lesssim 1^\circ \), as demonstrated in Fig. 1 (a) of Ref. \[6\]. On the other hand, the CKP edm constraint does not affect too much the direct CP asymmetry in \( B \rightarrow X_s\gamma \) \[5\].

In this work, we continue studying the effects of the phases of \( \mu \) and \( A_t \) on \( B \rightarrow X_s l^+ l^- \) and \( \epsilon_K \). We also reconsider a possibility of fully supersymmetric CP violation, namely generating \( \epsilon_K \) entirely from the phases of \( \mu \) and \( A_t \) with vanishing KM phase (\( \delta_{KM} = 0 \)). Our conclusion is at variance with the claim made in Ref. \[6\].

2. As in Refs. \[5\] \[6\], we assume that the 1st and the 2nd family squarks are degenerate and very heavy in order to solve the SUSY FCNC/CP problems. Only the third family squarks can be light enough to affect \( B \) and \( K \) physics. We also ignore possible flavor changing squark mass matrix elements that could generate gluino-mediated flavor changing neutral current (FCNC) processes in addition to those effects we consider below, relegating the details to the existing literature \[8\]- \[10\]. Therefore the only source of the FCNC in our
case is the CKM matrix, whereas there are new CPV phases coming from the phases of $\mu$ and $A_t$ parameters (see below), in addition to the KM phase $\delta_{KM}$. Definitions for the chargino and stop mass matrices are the same as Ref. [5]. There are two new flavor conserving CPV phases in our model, $\text{Arg} (\mu)$ and $\text{Arg} (A_t)$ in the basis where $M_2$ is real.

We scan over the MSSM parameter space as in Ref. [5] indicated below (including that relevant to the EWBGEN scenario in the MSSM):

$$
80 \text{ GeV} < |\mu| < 1 \text{ TeV}, \quad 80 \text{ GeV} < M_2 < 1 \text{ TeV},
$$

$$
60 \text{ GeV} < M_A < 1 \text{ TeV}, \quad 2 < \tan \beta < 70,
$$

$$
(130 \text{ GeV})^2 < M_Q^2 < (1 \text{ TeV})^2,
$$

$$
-(80 \text{ GeV})^2 < M_U^2 < (500 \text{ GeV})^2,
$$

$$
0 < \phi_\mu, \phi_{A_t} < 2\pi, \quad 0 < |A_t| < 1.5 \text{ TeV},
$$

with the following experimental constraints: $M_{\tilde{t}_1} > 80 \text{ GeV}$ independent of the mixing angle $\theta_{\tilde{t}}$, $M_{\tilde{c}_\pm} > 83 \text{ GeV}$, and $0.77 \leq R_\gamma \leq 1.15$ [14], where $R_\gamma$ is defined as $R_\gamma = BR(B \to X_s\gamma)^{\text{exp}} / BR(B \to X_s\gamma)^{\text{SM}}$ and $BR(B \to X_s\gamma)^{\text{SM}} = (3.29 \pm 0.44) \times 10^{-4}$. We also impose $\text{Br}(B \to X_{sg}) < 6.8\%$ [12], and vary $\tan \beta$ from 2 to 70 [1]. This parameter space is larger than that in the constrained MSSM (CMSSM) where the universality of soft terms at the GUT scale is assumed. Especially, our parameter space includes the electroweak baryogenesis scenario in the MSSM [13]. In the numerical analysis, we used the following numbers for the input parameters (running masses in the \overline{MS} scheme are used for the quark masses):

$$
\overline{m}_c(m_c(\text{pole})) = 1.25 \text{ GeV}, \quad \overline{m}_b(m_b(\text{pole})) = 4.3 \text{ GeV}, \quad \overline{m}_t(m_t(\text{pole})) = 165 \text{ GeV}, \quad \text{and}\ |V_{cb}| = 0.0410, |V_{tb}| = 1, |V_{ts}| = 0.0400 \text{ and } \gamma(\phi_3) = 90^\circ \text{ in the CKM matrix elements.}
$$

3. Let us first consider the branching ratio for $B \to X_s\ell^+\ell^-$. The SM and the MSSM contributions to this decay were considered by several groups [14] and [15], respectively.

---

1 This may be too large for perturbation theory to be valid, but we did extend to $\tan \beta \sim 70$ in order to check the claims made in Ref. [3].
We use the standard notation for the effective Hamiltonian for this decay as described in Refs. \cite{14} and \cite{15}. The new CPV phases in $C_{7,9,10}$ can affect the branching ratio and other observables in $B \rightarrow X_s l^+ l^-$ as discussed in the first half of Ref. \cite{10} in a model independent way. In the second half of Ref. \cite{10}, specific supersymmetric models were presented where new CPV phases reside in flavor changing squark mass matrices. In the present work, new CPV phases lie in flavor conserving sector, namely in $A_t$ and $\mu$ parameters. Although these new phases are flavor conserving, they affect the branching ratio of $B \rightarrow X_s l^+ l^-$ and its correlation with $Br(B \rightarrow X_s \gamma)$, as discussed in the first half of Ref. \cite{10}. Note that $C_{9,10}$ depend on the sneutrino mass, and we have scanned over $60 \text{ GeV} < m_{\tilde{\nu}} < 200 \text{ GeV}$. In the numerical evaluation for $R_{ll} \equiv Br(B \rightarrow X_s l^+ l^-)/Br(B \rightarrow X_s l^+ l^-)_{\text{SM}}$, we considered the nonresonant contributions only for simplicity, neglecting the contributions from $J/\psi, \psi'$, etc. It would be straightforward to incorporate these resonance effects. In Figs. 1 (a) and (b), we plot the correlations of $R_{\mu \mu}$ with $Br(B \rightarrow X_s \gamma)$ and $\tan \beta$, respectively. Those points that (do not) satisfy the CKP edm constraints are denoted by the squares (crosses). Some points are denoted by both the square and the cross. This means that there are two classes of points in the MSSM parameter space, and for one class the CKP edm constraints are satisfied but for another class the CKP edm constraints are not satisfied, and these two classes happen to lead to the same branching ratios for $B \rightarrow X_s \gamma$ and $R_{ll}$. In the presence of the new phases $\phi_\mu$ and $\phi_{A_t}$, $R_{\mu \mu}$ can be as large as 1.85, and the deviations from the SM prediction can be large, if $\tan \beta > 8$. As noticed in Ref. \cite{10}, the correlation between the $Br(B \rightarrow X_s \gamma)$ and $R_{ll}$ is distinctly different from that in the minimal supergravity case \cite{13}. In the latter case, only the envelop of Fig. 1 (a) is allowed, whereas everywhere in between is allowed in the presence of new CPV phases in the MSSM. Even if one introduces the phases of $\mu$ and $A_0$ at GUT scale in the minimal supergravity scenario, this correlation does not change very much from the case of the minimal supergravity scenario with real $\mu$ and $A_0$, since the $A_0$ phase becomes very small at the electroweak scale because of the renormalization effects \cite{17}. Only $\mu$ phase can affect the electroweak scale physics, but this phase is strongly constrained by the usual edm constraints so that $\mu$ should be essentially real parameter.
Therefore the correlation between $B \to X_s \gamma$ and $R_d$ can be a clean distinction between the minimal supergravity scenario and our model (or some other models with new CPV phases in the flavor changing \cite{13}).

4. The new complex phases in $\mu$ and $A_t$ will also affect the $K^0 - \bar{K}^0$ mixing. The relevant $\Delta S = 2$ effective Hamiltonian is given by

$$H_{\text{eff}}^{\Delta S=2} = -\frac{G_2^2 M_W^2}{(2\pi)^2} \sum_{i=1}^{3} C_i Q_i,$$

where

$$C_1(\mu_0) = (V_{td}^* V_{ts})^2 \left[ F_V^W (3; 3) + F_V^H (3; 3) + A_V^C \right]$$

$$+ (V_{cd}^* V_{cs})^2 \left[ F_V^W (2; 2) + F_V^H (2; 2) \right]$$

$$+ 2 (V_{td}^* V_{ts} V_{cd}^* V_{cs}) \left[ F_V^W (3; 2) + F_V^H (3; 2) \right],$$

$$C_2(\mu_0) = (V_{td}^* V_{ts})^2 F_S^H (3; 3) + (V_{cd}^* V_{cs})^2 F_S^H (2; 2)$$

$$+ 2 (V_{td}^* V_{ts} V_{cd}^* V_{cs}) F_S^H (3; 2),$$

$$C_3(\mu_0) = (V_{td}^* V_{ts})^2 A_S^C,$$

where the charm quark contributions have been kept. The superscripts $W, H, C$ denote the $W^\pm$, $H^\pm$ and chargino contributions respectively, and

$$A_V^C = \sum_{i,j=1}^{2} \sum_{k,l=1}^{2} \frac{1}{4} G^{(3,k)i} G^{(3,k)j} G^{(3,j)\ast} G^{(3,i)\ast} G^{(3,i)\ast} Y_1(r_k, r_l, s_i, s_j),$$

$$A_S^C = \sum_{i,j=1}^{2} \sum_{k,l=1}^{2} H^{(3,k)i} G^{(3,k)j} G^{(3,j)\ast} H^{(3,i)\ast} Y_2(r_k, r_l, s_i, s_j).$$

Here $G^{(3,k)i}$ and $H^{(3,k)i}$ are the couplings of $k$–th stop and $i$–th chargino with left-handed and right-handed quarks, respectively:

$$G^{(3,k)i} = \sqrt{2} C_{Ri}^* S_{ttk1} - \frac{C_{Rj}^* S_{ttk2}}{\sin \beta} \frac{m_t}{M_W},$$

$$H^{(3,k)i} = \frac{C_{Li}^* S_{ttk1}}{\cos \beta} \frac{m_s}{M_W},$$

and $C_{L,R}$ and $S_i$ are unitary matrices that diagonalize the chargino and stop mass matrices \cite{14}.

$C_R^t M_L^- C_L = \text{diag}(M_{\tilde{\chi}_1}, M_{\tilde{\chi}_2})$ and $S_i M_i^2 S_{ti}^\dagger = \text{diag}(M_{t_1}^2, M_{t_2}^2)$. Explicit forms for
functions $Y_{1,2}$ and $F$’s can be found in Ref. [18], and $r_k = M_{k}^2/M_W^2$ and $s_i = M_{\tilde{\chi}^\pm_i}/M_W^2$. It should be noted that $C_2(\mu_0)$ was misidentified as $C_3^H(\mu_0)$ in Ref. [6]. The gluino and neutralino contributions are negligible in our model. The Wilson coefficients at lower scales are obtained by renomalization group running. The relevant formulae with the NLO QCD corrections at $\mu = 2$ GeV are given in Ref. [19]. It is important to note that $C_1(\mu_0)$ and $C_2(\mu_0)$ are real relative to the SM contribution in our model. On the other hand, the chargino exchange contributions to $C_3(\mu_0)$ (namely $A_0^C$) are generically complex relative to the SM contributions, and can generate a new phase shift in the $K^0 - \bar{K^0}$ mixing relative to the SM value. This effect is in fact significant for large $\tan \beta (\simeq 1/\cos \beta)$ [6], since $C_3(\mu_0)$ is proportional to $(m_s/M_W \cos \beta)^2$.

The CP violating parameter $\epsilon_K$ can be calculated from

$$\epsilon_K \simeq \frac{e^{i\pi/4} \text{Im} M_{12}}{\sqrt{2} \Delta M_K},$$

where $M_{12}$ can be obtained from the $\Delta S = 2$ effective Hamiltonian through $2M_K M_{12} = \langle K^0 | H_{\Delta S=2}^{\text{eff}} | \bar{K^0} \rangle$. For $\Delta M_K$, we use the experimental value $\Delta M_K = (3.489 \pm 0.009) \times 10^{-12}$ MeV, instead of theoretical relation $\Delta M_K = 2 \text{Re} M_{12}$, since the long distance contributions to $M_{12}$ is hard to calculate reliably unlike the $\Delta S = 2$ box diagrams. For the strange quark mass, we use the $\overline{\text{MS}}$ mass at $\mu = 2$ GeV scale: $m_s(\mu = 2\text{GeV}) = 125$ MeV. In Figs. 2 (a) and (b), we plot the results of scanning the MSSM parameter space: the correlations between $\epsilon_K/\epsilon_K^{\text{SM}}$ and (a) $\tan \beta$ and (b) the lighter stop mass. We note that $\epsilon_K/\epsilon_K^{\text{SM}}$ can be as large as 1.4 for $\delta_{KM} = 90^\circ$ if $\tan \beta$ is small. This is a factor 2 larger deviation from the SM compared to the minimal supergravity case [20]. The dependence on the lighter stop is close to the case of the minimal supergravity case, but we can have a larger deviations. Such deviation is reasonably close to the experimental value, and will affect the CKM phenomenology at a certain level.

In the MSSM with new CPV phases, there is an intriguing possibility that the observed CP violation in $K_L \to \pi\pi$ is fully due to the complex parameters $\mu$ and $A_t$ in the soft SUSY breaking terms which also break CP softly. This possibility was recently considered
by Demir et al. [3]. Their claim was that it was possible to generate $\epsilon_K$ entirely from SUSY CPV phases for large $\tan \beta \approx 60$ with certain choice of soft parameters [4]. In such a scenario, only $\text{Im}\,(A^C_S)$ in Eq. (6) can contribute to $\epsilon_K$, if we ignore a possible mixing between $C_2$ and $C_3$ under QCD renormalization. In actual numerical analysis we have included this effect using the results in Ref. [19]. We repeated their calculations using the same set of parameters, but could not confirm their claim. For $\delta_{KM} = 0^\circ$, we found that the supersymmetric $\epsilon_K$ is less than $\sim 2 \times 10^{-5}$, which is too small compared to the observed value: $|\epsilon_K| = (2.280 \pm 0.019) \times 10^{-3}$ determined from $K_{L,S} \to \pi^+\pi^-$ [21].

Let us give a simple estimate for fully supersymmetric $\epsilon_K$, in which case only $C_3(\mu_0)$ develops imaginary part and can contribute to $\epsilon_K$. For $m_{\tilde{t}_1} \sim m_{\chi^\pm} \sim M_W$, we would get $Y_2 \sim Y_2(1,1,1,1) = 1/6$, and

$$|G^{(3,k)i}| \lesssim O(1), \text{ and } |H^{(3,k)i}| \sim \frac{m_s \tan \beta}{M_W},$$

because any components of unitary matrices $C_R$ and $S_t$ are $\lesssim O(1)$. Therefore $\text{Im}(A^C_S) \lesssim O(10^{-3})$. Now using

$$\text{Im}(M_{12}) = -\frac{G_F^2 M_W^2}{(2\pi)^2} f_K^2 M_K \left(\frac{M_K}{m_s}\right)^2 \frac{1}{24} B_3(\mu) \text{Im}(C_3(\mu)), \quad (10)$$

and Eq. (9), we get $|\epsilon_K| \lesssim 2 \times 10^{-5}$. 

7. In conclusion, we extended our previous studies of SUSY CPV phases to $B \to X_s l^+ l^-$ and $\epsilon_K$. Our results can be summarized as follows:

- The branching ratio for $B \to X_s l^+ l^-$ can be enhanced up to $\sim 85\%$ compared to the SM prediction, and the correlation between $\text{Br}(B \to X_s \gamma)$ and $\text{Br}(B \to X_s l^+ l^-)$ is distinctly different from the minimal supergravity scenario (CMSSM) (even with new CP violating phases) [16] in the presence of new CP violating phases in $C_{7,8,9}$ as demonstrated in model-independent analysis by Kim, Ko and Lee [10].

---

2 Their choice of parameters leads to $M_{\chi^\pm} = 80$ GeV and $M_{\tilde{t}} = 85$ GeV, which are very close to the recent lower limits set by LEP2 experiments.
• $\epsilon_K/\epsilon_{KM}^S$ can be as large as 1.4 for $\delta_{KM} = 90^\circ$. This is the extent to which the new phases in $\mu$ and $A_t$ can affect the construction of the unitarity triangle through $\epsilon_K$.

• Fully supersymmetric CP violation is not possible even for large $\tan \beta \sim 60$ and light enough chargino and stop, contrary to the claim made in Ref. [6]. With real CKM matrix elements, we get very small $|\epsilon_K| \lesssim O(10^{-5})$, which is two orders of magnitude smaller than the experimental value.

Before closing this paper, we’d like to emphasize that all of our results are based on the assumption that there are no new CPV phases in the flavor changing sector. Once this assumption is relaxed, then gluino-mediated FCNC with additional new CPV phases may play important roles, and many of our results may change [11]. Within our assumption, the results presented here and in Ref. [5] are conservative since we did not impose any conditions on the soft SUSY breaking terms except that the resulting mass spectra for chargino, stop and other sparticles satisfy the current lower bounds from LEP and Tevatron. More detailed analysis of phenomenological implications of our works on $B_{d(s)}^0 - \overline{B_{d(s)}^0}$ mixing, $B \to X_{s(d)}\gamma, X_{s(d)}l^+l^-$, $B_{s(d)}^0 \to l^+l^-$ and their direct CP asymmetries will be presented elsewhere.

ACKNOWLEDGMENTS

The authors wish to thank G.C. Cho for clarifying $O_2$ and $O_3$ in Ref. [3], and A. Ali, A. Grant, A. Pilaftsis and O. Vives for useful communications. A part of this work was done while one of the authors (PK) was visiting Harvard University under the Distinguished Scholar Exchange Program of Korea Research Foundation. This work is supported in part by KOSEF Contract No. 971-0201-002-2, KOSEF through Center for Theoretical Physics at Seoul National University, Korea Research Foundation Program 1998-015-D00054 (PK), and by KOSEF Postdoctoral Fellowship Program (SB).
REFERENCES

[1] See, for example, S.M. Barr and W.J. Marciano, in CP Violation, edited by C. Jarlskog (World Scientific, Singapore, 1989), p. 455; W. Bernreuther and M. Suzuki, Rev. Mod. Phys. 63, 313 (1991).

[2] A.G. Cohen, D.B. Kaplan, A.E. Nelson, Phys. Lett. B388, 588 (1996); A. G. Cohen, David B. Kaplan, F. Lepeintre, Ann E. Nelson, Phys. Rev. Lett. 78, 2300 (1997).

[3] T. Ibrahim and P. Nath, Phys. Lett. B 418, 98 (1998); Phys. Rev. D 57, 478 (1998); (E) ibid., D 58, 019901 (1998); Phys. Rev. D 58, 111301 (1998).

[4] M. Brhlik, G.J. Good and G.L. Kane, hep-ph/9810457.

[5] Seungwon Baek and P. Ko, KAIST-20/98, SNUTP 98-139, hep-ph/9812229 (1998).

[6] D.A. Demir, A. Masiero and O. Vives, Phys. Rev. Lett. 82, 2447 (1999).

[7] D. Chang, Wai-Yee Keung, Apostolos Pilaftsis, Phys. Rev. Lett. 82, 900 (1999).

[8] L. Randall and S. Su, Nucl. Phys. B 540, 37 (1999).

[9] C.-K. Chua, X.-G. He and W.-S. Hou, hep-ph/9808431.

[10] Y.G. Kim, P. Ko and J.S. Lee, Nucl. Phys. B 544, 64 (1999).

[11] J. Alexander, plenary talk at ICHEP98, Vancouver, Canada.

[12] T.E. Coan et al. (CLEO Collaboration), Preprint CLNS 97/1516, Phys. Rev. Lett. 80, 1150 (1998).

[13] M. Carena and C.E.M. Wagner, hep-ph/9704347; J. M. Cline, M. Joyce and K. Kainulainen, Phys. Lett. B 417, 79 (1998); M. Carena, M. Quiros and C.E.M. Wagner, Nucl. Phys. B 524, 3 (1998); J.M. Cline and G.D. Moore, Phys. Rev. Lett. 81, 3315 (1998).

[14] B. Grinstein, M.J. Savage and M.B. Wise, Nucl. Phys. B 319, 271 (1994); M. Misiak,
[15] S. Bertolini, F. Borzumati, A. Masiero and G. Ridolfi, Nucl. Phys. 353, 591 (1991); P. Cho, M. Misiak and D. Wyler, Phys. Rev. D 54, 3329 (1996).

[16] T. Goto, Y. Okada and Y. Shimizu, Phys. Rev. D 58, 094006 (1998).

[17] T. Falk and K. Olive, Phys. Lett. B 439, 71 (1998); T. Goto, Y.Y. Keum, T. Nihei, Y. Okada, Y. Shimizu, hep-ph/9812369.

[18] G.C. Branco, G.C. Cho, Y. Kizukuri and N. Oshimo, Phys. Lett. B 337, 316 (1994); Nucl. Phys. B 449, 483 (1995).

[19] R. Contino and I. Scimemi, hep-ph/9809437.

[20] T. Goto, T. Nihei and Y. Okada, Phys. Rev. D 53, 5233 (1996).

[21] Particle Data Group, Eur. Phys. J. C 3, 1 (1998).
FIG. 1. The correlations of $R_{\mu\mu}$ with (a) $\text{Br}(B \rightarrow X_s\gamma)$ and (b) $\tan\beta$. The squares (the crosses) denote those which (do not) satisfy the CKP edm constraints.
FIG. 2. The correlations between $\epsilon_{K}/\epsilon_{K}^{SM}$ and the lighter chargino mass $M_{\tilde{\chi}_1^\pm}$ for (a) $2 < \tan\beta < 35$ and (b) $35 < \tan\beta < 70$, respectively. The squares (the crosses) denote those which (do not) satisfy the CKP edm constraints.