CERN-TH.7345/94
TKU-HEP 94/04
CFIF-UTL/IST 2/94

Supersymmetric Contributions to $B^0 - \bar{B}^0$ and $K^0 - \bar{K}^0$ Mixings

G. C. Branco[1*], G. C. Cho[2†], Y. Kizukuri[2], and N. Oshimo[3]

[1] *CERN, Theory Division*
CH-1211 Genève 23, Switzerland
[2] *Department of Physics, Tokai University*
1117 Kita-Kaname, Hiratsuka 259-12, Japan
[3] *GTAE/CFIF, Instituto Superior Técnico*
Av. Rovisco Pais, 1096 Lisboa Codex, Portugal

Abstract

We show that in the supersymmetric standard model (SSM) box diagrams mediated by charginos and up-type squarks may give large contributions to $B^0 - \bar{B}^0$ and $K^0 - \bar{K}^0$ mixings. This is due to the fact that a heavy top quark mass allows large mass differences among the up-type squarks, which leads to a less efficient cancellation among the different squark diagrams. If the ratio of the vacuum expectation values of the Higgs bosons is of order of unity, box diagrams mediated by charged Higgs bosons also contribute appreciably. For sizable regions of the SSM parameter space, the SSM contributions could be sufficiently large to affect significantly the evaluation of the CKM matrix from the experimental values of the mixing parameter x_d and the CP violation parameter ϵ.

* On leave from Departamento de Física and CFIF/UTL, Instituto Superior Técnico, Av. Rovisco Pais, 1096 Lisboa Codex, Portugal.

† Research Fellow of the Japan Society for the Promotion of Science

The supersymmetric standard model (SSM) predicts new contributions to flavor changing neutral current (FCNC) processes, in addition to those already present in the standard model (SM). These new contributions arise from interactions coupling a quark to a squark of a different generation and a chargino, a neutralino, or a gluino [1]. Since the SSM contains two doublets of Higgs bosons, there also exist FCNC processes mediated by charged Higgs bosons [2]. The effects of these new contributions on $K^0 - \bar{K^0}$ and $B^0 - \bar{B^0}$ mixings, as well as on other FCNC processes, have been extensively analyzed. (For a review, see ref. [3]) Initially it was thought that the dominant SSM contribution to the above mixings would arise from gluino-mediated box diagrams and that it would be substantial. However, later analyses [4], taking into account all the new contributions of FCNC, led to the result that box diagrams mediated by charged Higgs bosons gave the largest contribution to $B^0 - \bar{B^0}$ mixing. It was also shown that this charged Higgs boson contribution was at most a few tenth of the SM contribution, making it difficult to observe supersymmetric effects through those mixings.

The recent experimental evidence for a rather large t-quark mass of $174 \pm 10^{+13}_{-12}$ GeV [5] provides motivation to reconsider the SSM contributions to $K^0 - \bar{K^0}$ and $B^0 - \bar{B^0}$ mixings. In the SSM, such a large t-quark mass theoretically implies the possible existence of a light t-squark, provided the squark masses of the first two generations are around 200 GeV or less. Lack of experimental evidence for supersymmetric particles at the Tevatron suggests that the masses of most of the squarks are larger than 150 GeV, but leaves open the possibility of having a lighter t-squark [6], the lower bound on its mass being given only by LEP [7]. There is thus the possibility of having large mass differences among the up-type squarks. In this case the chargino contributions to $K^0 - \bar{K^0}$ and $B^0 - \bar{B^0}$ mixings become potentially important, since the box diagrams with different up-type squarks no longer have the severe cancellation which is present in the case of almost degenerate squark masses. In fact, in the radiative decay $b \to s\gamma$, it was shown [8] that, among the new contributions of FCNC, chargino-mediated diagrams gave the dominant contribution. In particular, if one of the t-squarks is much lighter than the other squarks, the chargino contribution to $b \to s\gamma$ can become as large as the SM contribution. In view of the above, the question naturally arises whether the existence of a light t-squark can also imply large chargino contributions to $K^0 - \bar{K^0}$ and $B^0 - \bar{B^0}$ mixings.

In this letter we study $B^0 - \bar{B^0}$ and $K^0 - \bar{K^0}$ mixings within the SSM, in light of the recent evidence of a heavy t-quark, concentrating our attention on the effects of the chargino and charged Higgs boson contributions. These short distance contributions affect the mass difference ΔM_B of the B^0-mesons and the CP violation parameter ϵ in the K-meson decays. We will show that the SSM contributions to these quantities are indeed large for sizable regions of the SSM parameter space, where a chargino, a t-squark, and/or a charged Higgs boson are predicted to have masses to be explored at the next generation of colliders. Constraints on the SSM will also be discussed by confronting the elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix inferred from $B^0-\bar{B}^0$ and $K^0-\bar{K}^0$ mixings with those measured by other phenomena.

We assume that the masses and mixings of the squarks are given by the model based on N=1 supergravity and grand unification (for reviews, see ref. [9]). At the electroweak scale the interaction eigenstate squarks are mixed in generation space through mass-squared matrices. These generation mixings among the up-type squarks are approximately removed by the same matrices that diagonalize the mass matrix of the up-type quarks. As a result the generation mixings appearing in the interactions between down-type quarks and up-type squarks in the mass eigenstate basis can be described by the CKM matrix of the quarks.

In each flavor the left-handed and right-handed squarks are mixed by the Yukawa interaction. For the first two generations, however, these mixings can be neglected due to the smallness of the corresponding quark masses. The masses of the left-handed squarks $\tilde{u}_L, \tilde{c}_L$ and the right-handed squarks $\tilde{u}_R, \tilde{c}_R$ are given by

$$\begin{aligned} \tilde{M}_{uL}^2 &= \tilde{M}_{cL}^2 = \tilde{m}_Q^2 + \cos 2\beta(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W)M_Z^2, \\ \tilde{M}_{uR}^2 &= \tilde{M}_{cR}^2 = \tilde{m}_U^2 + \frac{2}{3}\cos 2\beta \sin^2\theta_W M_Z^2, \\ \tan\beta &= \frac{v_2}{v_1}, \end{aligned} \tag{1}$$

where v_1 and v_2 stand for the vacuum expectation values of the Higgs bosons. The mass parameters $\tilde{m}_Q$ and $\tilde{m}_U$ are determined by the gravitino and gaugino masses. Assuming a common mass at around the grand unification scale, the difference $(\tilde{m}_Q - \tilde{m}_U)$ arises only from the electroweak interactions, and it is small compared to $\tilde{m}_Q, \tilde{m}_U$. For the third generation, the large t-quark mass m_t leads to an appreciable mixing between $\tilde{t}_L$ and $\tilde{t}_R$. The mass-squared matrix for the t-squarks is given by

$$M_{\tilde{t}}^2 = \begin{pmatrix} \tilde{M}_{uL}^2 + (1-|c|)m_t^2 & (\cot\beta m_H + a_t^* m_{3/2})m_t \\ (\cot\beta m_H^* + a_t m_{3/2})m_t & \tilde{M}_{uR}^2 + (1-2|c|)m_t^2 \end{pmatrix}, \tag{2}$$

where $m_{3/2}$ and m_H denote the gravitino mass and the higgsino mass parameter, respectively. The dimensionless constants a_t and c depend on other SSM parameters:

a_t is related to the breaking of local supersymmetry and its absolute value is constrained to be less than 3 at the grand unification scale; c is related to the radiative corrections to the squark masses. At present, these values cannot be theoretically fixed, although it can be asserted that their magnitudes are of order of unity. The mass eigenstates of the t-squarks are obtained by diagonalizing the matrix M_t^2:

$$S_t M_t^2 S_t^\dagger = \mathrm{diag}(\tilde{M}_{t1}^2, \tilde{M}_{t2}^2), \tag{3}$$

where S_t is a unitary matrix.

The charginos are the mass eigenstates of the $SU(2)$ charged gauginos and the charged higgsinos. Their mass matrix is given by

$$M^- = \begin{pmatrix} \tilde{m}_2 & -\frac{1}{\sqrt{2}} g v_1 \\ -\frac{1}{\sqrt{2}} g v_2 & m_H \end{pmatrix}, \tag{4}$$

where $\tilde{m}_2$ is the $SU(2)$ gaugino mass. The unitary matrices C_L and C_R diagonalize this matrix as

$$C_R^\dagger M^- C_L = \mathrm{diag}(\tilde{m}_{\omega 1}, \tilde{m}_{\omega 2}). \tag{5}$$

The lagrangian for the chargino$-$squark$-$quark interactions can then be written explicitly in terms of particle mass eigenstates [8].

The $B^0 - \bar{B}^0$ mixing receives contributions from the box diagrams in which the charginos and the up-type squarks are exchanged. For the effective lagrangian of the $\Delta B = 2$ process we obtain:

$$L_{\Delta B=2}^C = \frac{1}{8M_W^2}(\frac{g^2}{4\pi})^2 \sum_{a,b} \sum_{i,j} \sum_{k,l} V_{a1}^* V_{a3} V_{b1}^* V_{b3} \tag{6}$$

$$[F_1^C(a,k;b,l;i,j)\bar{d}\gamma^\mu \frac{1-\gamma_5}{2} b \bar{d}\gamma_\mu \frac{1-\gamma_5}{2} b + F_2^C(a,k;b,l;i,j)\bar{d}\frac{1+\gamma_5}{2} b \bar{d}\frac{1+\gamma_5}{2} b],$$

$$F_1^C(a,k;b,l;i,j) = \frac{1}{4} G^{(a,k)i} G^{(a,k)j*} G^{(b,l)i*} G^{(b,l)j} Y_1(r_{(a,k)}, r_{(b,l)}, s_i, s_j),$$
$$F_2^C(a,k;b,l;i,j) = H^{(a,k)i} G^{(a,k)j*} G^{(b,l)i*} H^{(b,l)j} Y_2(r_{(a,k)}, r_{(b,l)}, s_i, s_j),$$

where V denotes the CKM matrix, a,b are generation indices, and i,j and k,l respectively stand for the two charginos and the two squarks in each flavor. The functions Y_1, Y_2 and their arguments coming from loop integrals are given by

$$Y_1(r_\alpha, r_\beta, s_i, s_j)$$
$$= \frac{r_\alpha^2}{(r_\beta - r_\alpha)(s_i - r_\alpha)(s_j - r_\alpha)} \ln r_\alpha + \frac{r_\beta^2}{(r_\alpha - r_\beta)(s_i - r_\beta)(s_j - r_\beta)} \ln r_\beta$$

$$+\frac{s_i^2}{(r_\alpha-s_i)(r_\beta-s_i)(s_j-s_i)}\ln s_i+\frac{s_j^2}{(r_\alpha-s_j)(r_\beta-s_j)(s_i-s_j)}\ln s_j, \tag{7}$$

$$Y_2(r_\alpha,r_\beta,s_i,s_j)$$
$$=\sqrt{s_is_j}[\frac{r_\alpha}{(r_\beta-r_\alpha)(s_i-r_\alpha)(s_j-r_\alpha)}\ln r_\alpha+\frac{r_\beta}{(r_\alpha-r_\beta)(s_i-r_\beta)(s_j-r_\beta)}\ln r_\beta$$
$$+\frac{s_i}{(r_\alpha-s_i)(r_\beta-s_i)(s_j-s_i)}\ln s_i+\frac{s_j}{(r_\alpha-s_j)(r_\beta-s_j)(s_i-s_j)}\ln s_j],$$
$$r_{(1,1)}=r_{(2,1)}=\frac{\tilde{M}_{uL}^2}{M_W^2},\quad r_{(1,2)}=r_{(2,2)}=\frac{\tilde{M}_{uR}^2}{M_W^2},\quad r_{(3,k)}=\frac{\tilde{M}_{tk}^2}{M_W^2},$$
$$s_i=\frac{\tilde{m}_{\omega i}^2}{M_W^2},$$

and the coupling constants $G^{(a,k)i}$, $H^{(a,k)i}$ are:

$$\begin{aligned}
G^{(1,1)i}&=G^{(2,1)i}=\sqrt{2}C_{R1i}^*,\quad G^{(1,2)i}=G^{(2,2)i}=0,\\
G^{(3,k)i}&=\sqrt{2}C_{R1i}^*S_{tk1}-\frac{C_{R2i}^*S_{tk2}}{\sin\beta}\frac{m_t}{M_W},\\
H^{(1,1)i}&=H^{(2,1)i}=\frac{C_{L2i}^*}{\cos\beta}\frac{m_b}{M_W},\quad H^{(1,2)i}=H^{(2,2)i}=0,\\
H^{(3,k)i}&=\frac{C_{L2i}^*S_{tk1}}{\cos\beta}\frac{m_b}{M_W}.
\end{aligned} \tag{8}$$

In eq. (6) each term is proportional to $V_{11}^*V_{13}$, $V_{21}^*V_{23}$, or $V_{31}^*V_{33}$. However, from unitarity of the CKM matrix, the following relation holds:

$$\sum_{a,b}V_{a1}^*V_{a3}V_{b1}^*V_{b3}F_n^C(a,k;b,l;i,j)=(V_{31}^*V_{33})^2[F_n^C(3,k;3,l;i,j) \tag{9}$$
$$+F_n^C(1,k;1,l;i,j)-F_n^C(1,k;3,l;i,j)-F_n^C(3,k;1,l;i,j)].$$

Therefore, the effective lagrangian $L_{\Delta B=2}^C$ is proportional to $(V_{31}^*V_{33})^2$.

The large t-quark mass has two effects. First, one of the t-squarks becomes light due to large off-diagonal elements of the mass-squared matrix (2). Second, the Yukawa interaction of $\tilde{t}_R$ with the charged higgsino and the b-quark becomes strong, so that the chargino coupling strengths with the t-squarks are induced to be different from those with the other up-type squarks, as seen in eq. (8). These effects soften the cancellation among different squark contributions in eq. (9), which otherwise is rather severe.

The effective lagrangian (6) contains two $\Delta B=2$ operators

$$O_V^{LL}=\bar{d}\gamma^\mu\frac{1-\gamma_5}{2}b\bar{d}\gamma_\mu\frac{1-\gamma_5}{2}b,\quad O_S^{RR}=\bar{d}\frac{1+\gamma_5}{2}b\bar{d}\frac{1+\gamma_5}{2}b. \tag{10}$$

The standard W-boson contribution yields O_V^{LL} alone, whereas the chargino contribution yields both. Therefore one might expect that the SSM effects could be observed in processes where O_S^{RR} gives a sizable contribution. For $\tan\beta \sim 1$ the ratio F_2^C/F_1^C is roughly estimated as $(m_b/M_W)^2$, so that O_S^{RR} can be neglected. However, for a considerably large value of $\tan\beta$ the effects of the operator O_S^{RR} would become sizable.

For the charged Higgs boson contribution the exchanged bosons in the box diagrams are either only charged Higgs bosons or charged Higgs bosons and W-bosons. The effective lagrangian of the $\Delta B = 2$ process is given by

$$\begin{aligned} L^H_{\Delta B=2} &= \frac{1}{8M_W^2}(\frac{g^2}{4\pi})^2 \sum_{a,b} V^*_{a1}V_{a3}V^*_{b1}V_{b3} \\ &[F_1^H(a;b)\bar{d}\gamma^\mu\frac{1-\gamma_5}{2}b\bar{d}\gamma_\mu\frac{1-\gamma_5}{2}b + F_2^H(a;b)\bar{d}\frac{1+\gamma_5}{2}b\bar{d}\frac{1+\gamma_5}{2}b], \end{aligned} \tag{11}$$

$$\begin{aligned} F_1^H(a;b) &= \frac{1}{4\tan^4\beta}s_a s_b Y_1(r_H, r_H, s_a, s_b) \\ &+ \frac{1}{2\tan^2\beta}s_a s_b Y_1(1, r_H, s_a, s_b) - \frac{2}{\tan^2\beta}\sqrt{s_a s_b}Y_2(1, r_H, s_a, s_b), \\ F_2^H(a;b) &= \frac{m_b^2}{M_W^2}\sqrt{s_a s_b}Y_2(r_H, r_H, s_a, s_b), \\ r_H &= \frac{M^2_{H\pm}}{M_W^2}, \quad s_a = \frac{m^2_{ua}}{M_W^2}, \end{aligned}$$

where $M_{H\pm}$ and m_{ua} are respectively the charged Higgs boson mass and the up-type quark mass of the a-th generation. Since the t-quark box diagrams predominate over other diagrams, $L^H_{\Delta B=2}$ becomes approximately proportional to $(V^*_{31}V_{33})^2$. The standard W-boson contribution is also proportional to $(V^*_{31}V_{33})^2$, due to a predominant t-quark box diagram.

The effective lagrangians of the ΔS=2 process due to the chargino and the charged Higgs boson contributions are obtained in a similar way. The chargino-induced lagrangian $L^C_{\Delta S=2}$ is shown to be proportional to $(V^*_{31}V_{32})^2$. The effects of the operator O_S^{RR} are suppressed by $(m_s/M_W)^2$ and thus negligible.

We now discuss how large the SSM contributions could be. One observable for $B^0 - \bar{B}^0$ mixing is the mixing parameter $x_d \equiv \Delta M_B/\Gamma_B$, ΔM_B and Γ_B being the mass difference and the average width for the B^0-meson mass eigenstates. The mass difference is induced dominantly by the short distance contributions of box diagrams. Abbreviating the effective lagrangians as $L_{\Delta B=2} =$

$(1/8M_W^2)(g^2/4\pi)^2(V_{31}^* V_{33})^2 A O_V^{LL}$, we can express the mixing parameter x_d as

$$x_d = \frac{G_F^2}{6\pi^2} M_W^2 \frac{M_B}{\Gamma_B} f_B^2 B_B |V_{31}^* V_{33}|^2 |A_{tt}^W + A^C + A_{tt}^H|, \qquad (12)$$

where G_F, f_B, and B_B are the Fermi constant, the B-meson decay constant, and the bag factor. The indices W, C, and H stand for the W-boson, the chargino, and the charged Higgs boson contributions, respectively, and tt for the t-quark box diagrams. The O_S^{RR} operator has been neglected. The expression for x_d in the SM is given by eq. (12) with $A^C = A_{tt}^H = 0$.

The effects of the chargino and the charged Higgs boson contributions are seen respectively by the ratios $R_C = (A_{tt}^W + A^C)/A_{tt}^W$ and $R_H = (A_{tt}^W + A_{tt}^H)/A_{tt}^W$. In Fig. 1 we show R_C as a function of the higgsino mass parameter m_H taking four sets of values for $\tilde{m}_Q$ and $\tan\beta$ listed in table 1. The values of the other parameters are set, as typical values, for $\tilde{m}_2 = 200$ GeV, $\tilde{m}_Q = \tilde{m}_U = a_t m_{3/2}$, and $|c| = 0.3$. For the t-quark mass we use m_t=170 GeV. Since QCD corrections in A_{tt}^W and A^C do not differ much from each other, they almost cancel in R_C and can be neglected. The mass of the lighter t-squark corresponding to these parameter values are exhibited in Fig. 2. The mass of the lighter chargino is smaller than 100 GeV for -80 GeV $\lesssim m_H \lesssim$ 160 GeV, but the range -20 GeV $\lesssim m_H \lesssim$ 80 GeV is experimentally ruled out since it leads to a chargino lighter than 45 GeV. We can see that the sign of the chargino contribution is the same as that of the W-boson contribution, and these contributions interfere constructively. In case (i.a) R_C is larger than 1.5 for -90 GeV $\lesssim m_H \lesssim$ 150 GeV and $R_C \simeq 2.3$ in the region with the lighter t-squark mass 45 GeV $\lesssim \tilde{M}_{t1} \lesssim$ 100 GeV. The ratio R_C can also have a value around 1.5 in case (i.b). The manifest dependence of R_C on $\tan\beta$ arises from the chargino Yukawa interactions: R_C increases as $\tan\beta$ decreases, since a smaller value for v_2 enhances the Yukawa couplings of the charginos to the t-squarks.

In Fig. 3 we show R_H as a function of the charged Higgs Boson mass for (a)$\tan\beta$=1.2 and (b)$\tan\beta$=2. The charged Higgs bosons also contribute constructively. The ratio R_H is larger than 1.5 for $M_{H\pm} \lesssim$ 180 GeV in case (a). Similarly to R_C, the value of R_H increases as $\tan\beta$ decreases. Note that all of A_{tt}^W, A^C, and A_{tt}^H have the same sign. The physical effects of the SSM are given by their sum, and the net contribution of the SSM is measured by the ratio

$$R = \frac{A_{tt}^W + A^C + A_{tt}^H}{A_{tt}^W}. \qquad (13)$$

This ratio becomes larger than R_C and R_H shown in Fig. 1 and Fig. 3. For example, in case (i.a) with $M_{H\pm} = 200$ GeV, the ratio R becomes $R \simeq 1.9$ for

$m_H = -100$ GeV ($\tilde{M}_{t1} \simeq 188$ GeV, $\tilde{m}_{\omega 1} \simeq 119$ GeV) and $R \simeq 2.7$ for $m_H = 100$ GeV ($\tilde{M}_{t1} \simeq 85$ GeV, $\tilde{m}_{\omega 1} \simeq 56$ GeV).

For $K^0 - \bar{K^0}$ mixing the mass difference ΔM_K receives large long distance contributions, which have not yet been calculated reliably. As a result, it is not feasible to detect SSM effects through ΔM_K. However, the CP violation parameter ϵ receives its dominant contribution from the short distance effects, which can be written as

$$\begin{aligned}\epsilon = -e^{i\pi/4}\frac{G_F^2}{12\sqrt{2}\pi^2}M_W^2\frac{M_K}{\Delta M_K}f_K^2 B_K \mathrm{Im}[(V_{31}^* V_{32})^2(A_{tt}^W + A^C + A_{tt}^H)\\ + (V_{21}^* V_{22})^2(A_{cc}^W + A_{cc}^H) + 2V_{31}^* V_{32} V_{21}^* V_{22}(A_{tc}^W + A_{tc}^H)].\end{aligned} \tag{14}$$

The term proportional to $(V_{31}^* V_{32})^2$ is enhanced by the same amount as for $B^0 - \bar{B^0}$ mixing given by eq. (13), whereas the enhancements of the other terms due to the charged Higgs boson contribution are small.

We next discuss the implication of the above enhancements in x_d and ϵ for the evaluation of the CKM matrix, and consider possible constraints on the SSM parameters. In Fig. 4 we show the allowed range for the ratio R derived from the experimental values of x_d, ϵ, and CKM matrix elements, as a function of $\cos\delta$, δ being the CP-violating phase appearing in the standard parametrization [7] of the CKM matrix. As a typical example, we have taken $|V_{12}| = 0.22$, $|V_{23}| = 0.4$, $|V_{13}/V_{23}| = 0.08$ [10], $x_d = 0.71$[11], $|\epsilon| = 2.26 \times 10^{-3}$ [7] and incorporated the uncertainties of B_K, B_B, and f_B as $0.6 < B_K < 0.9$ [12] and 180 MeV $< \sqrt{f_B^2 B_B} <$ 260 MeV [13]. For the QCD correction factors we have used 0.55 for A_{tt}^W in $B^0 - \bar{B^0}$ mixing and 0.57, 1.1, and 0.36 for A_{tt}^W, A_{cc}^W, and A_{tc}^W in $K^0 - \bar{K^0}$ mixing [14]. The regions between the solid curves and between the dashed curves are respectively allowed by x_d and ϵ. In the region consistent with both x_d and ϵ, the ratio R is smaller than or around 2. The SSM with $R > 1$ favors for $\cos\delta$ a value larger than the one predicted by the SM ($R = 1$). Although present uncertainties in the input parameters make it difficult to state a definite prediction, the SSM parameter regions which give $R > 2$ are likely to be in conflict with the experimental values of the CKM matrix.

In conclusion, we have studied $B^0 - \bar{B^0}$ and $K^0 - \bar{K^0}$ mixings within the framework of the SSM, emphasizing the importance of the box diagrams mediated by charginos and charged Higgs bosons. If a chargino, a t-squark, and/or a charged Higgs boson have masses around 100 GeV or less and $\tan\beta$ is not much larger than unity, the SSM contribution to the mixing parameter x_d could be enhanced by a factor around 2, compared to the SM contribution. The SSM contribution to the CP violation parameter ϵ could also be enhanced by a comparable amount. Note that although the enhancements of ϵ and x_d are correlated, they are not equal due to the presence of the last two terms in eq. (14) whose contribution to ϵ cannot be neglected.

Experimentally, fairly precise measurements have been achieved for x_d [11] and ϵ [7]. The experimental values of these quantities can be used to determine the CKM matrix elements. If the ratio R defined in eq. (13) is larger than unity, the values of $|V_{31}^* V_{33}|^2$ and $\mathrm{Im}[(V_{31}^* V_{32})^2]$ are predicted to be smaller than those obtained in the SM. On the other hand, some of the CKM matrix elements have been measured by particle decays for which new contributions by the SSM are negligible. Owing to the unitarity of the CKM matrix, all of these measured values are not independent of each other. We have shown that the present knowledge for the CKM matrix could already give nontrivial constraints on the SSM. Future measurements will give further information on the CKM matrix. For example, the measurement of CP asymmetries (for reviews, see ref. [15]) in B^0 decays will determine the angles of the unitarity triangle formed by $V_{31}V_{33}^*$, $V_{21}V_{23}^*$, and $V_{11}V_{13}^*$. The study of the compatibility of all these measurements, taking into account the stringent constraints of CKM unitarity, has the potential of either providing indirect evidence for the SSM or putting stringent bonds on some of its parameters.

N.O. would like to thank S. Komamiya for discussions on experimental status of $B^0 - \bar{B}^0$ mixing at LEP. G.C.B. thanks the CERN Theory Division for their hospitality. The work of G.C.B. was supported in part by Science Project No. SCI-CT91-0729 and EC contract No. CHRX-CT93-0132. This work is also supported in part by Grant-in-Aid for Scientific Research (G. C. Cho) and (No. 06640409, Y. K.) from the Japanese Ministry of Education, Science and Culture.

References

[1] J. Ellis and D.V. Nanopoulos, Phys. Lett. 110B (1982) 44;
R. Barbieri and R. Gatto, Phys. Lett. 110B (1982) 211;
T. Inami and C.S. Lim, Nucl. Phys. B207 (1982) 533;
M.J. Duncan, Nucl. Phys. B221 (1983) 285;
J.F. Donoghue, H.P. Nilles, and D. Wyler, Phys. Lett. 128B (1983) 55;
A. Bouquet, J. Kaplan, and C.A. Savoy, Phys. Lett. 148B (1984) 69.

[2] L.F. Abbott, P. Sikivie, and M.B. Wise, Phys. Rev. D21 (1980) 1393.

[3] W. Grimus, Fortschr. Phys. 36 (1988) 201.

[4] T. Kurimoto, Phys. Rev. D39 (1989) 3447;
S. Bertolini, F. Borzumati, A. Masiero, and G. Ridolfi, Nucl. Phys. B353 (1991) 591;
F.M. Borzumati, DESY-93-090.

[5] CDF Collaboration, FERMILAB-PUB-94/097-E; FERMILAB-PUB-94/116-E.

[6] H. Baer, M. Drees, R. Godbole, J.F. Gunion, and X. Tata, Phys. Rev. D44 (1991) 725.

[7] Review of Particle Properties, Phys. Rev. D45 (1992) S1.

[8] N. Oshimo, Nucl. Phys. B404 (1993) 20.

[9] H.P. Nilles, Phys. Rep. 110 (1984) 1;
P. Nath, R. Arnowitt, and A.H. Chamseddine, *Applied N=1 Supergravity* (World Scientific, Singapore, 1984);
H.E. Haber and G.L. Kane, Phys. Rep. 117 (1985) 75.

[10] D.Z. Besson, in Proc. of the XVI International Symposium on Lepton and Photon Interactions, Ithaca, 1993.

[11] CLEO Collaboration, Phys. Rev. Lett. 71 (1993) 1680;
ARGUS Collaboration, Phys. Lett. B324 (1994) 249;
S. Tarem, talk given at the Rencontre de Moriond, Les Arcs, 1994.

[12] P.B. Mackenzie, in Proc. of the XVI International Symposium on Lepton and Photon Interactions, Ithaca, 1993.

[13] A. Abada, LPTHE Orsay-94/57.

[14] A.J. Buras, M.E. Lautenbacher, and G. Ostermaier, MPI-Ph/94-14.

[15] I.I. Bigi, V.A. Khoze, N.G. Uraltsev, and A.I. Sanda, in *CP violation*, ed. C. Jarlskog (World Scientific, Singapore, 1989);
Y. Nir and H.R. Quinn, SLAC-PUB-5737, 1992.

Table Caption

Table 1: The values for $\tilde{m}_Q$ and $\tan\beta$.

Figure Captions

Fig. 1: The ratio R_C for the parameter values in table 1. Other parameters are fixed as $\tilde{m}_2$=200 GeV, $\tilde{m}_Q = \tilde{m}_U = a_t m_{3/2}$, and $|c|$=0.3.

Fig. 2: The lighter t-squark mass for the same parameter values as in Fig. 1.

Fig. 3: The ratio R_H for (a)$\tan\beta$=1.2 and (b)$\tan\beta$=2.

Fig. 4: The ratio R allowed by the experimental values of x_d and ϵ.

	(i.a)	(i.b)	(ii.a)	(ii.b)
$\tilde{m}_Q$ (GeV)	200	200	300	300
$\tan\beta$	1.2	2.0	1.2	2.0

Table 1