B-Factory Physics from Effective Supersymmetry

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We discuss how to extract non-standard-model effects from B-factory phenomenology. We then analyze the prospects for uncovering evidence for effective supersymmetry, a class of supersymmetric models which naturally suppress flavor changing neutral currents and electric dipole moments without squark universality or small CP violating phases, in experiments at BaBar, BELLE, HERA-B, CDF/D0, and LHC-B. [S0031-9007(97)02730-0]

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The principle of naturalness implies that physics beyond the standard model must be present at or below the "'t Hooft scale" $4\pi m_{\rm W}/g_w \sim 1$ TeV [1]. In the next few years several experiments will probe flavor changing neutral currents (FCNC) and CP violation in the B system, providing both new tests of the standard model (SM) and potential clues to new physics up to energies near 1000 TeV. These experiments may be the first to provide evidence for physics beyond the SM. New physics in rare decays of B mesons and in studies of CP violation in the B_d and B_s systems can originate from: two non-SM phases $\theta_{d,s}$ in the $\Delta B = 2$ operators for $B_{d,s}$ mixing; new phases in the $\Delta B = 1$ $b \rightarrow d$ and $b \rightarrow s$ hadronic transitions ("penguins"); disagreement between CP violation in the B system and ϵ in the kaon system; or departure of Δm_{B_d} and/or Δm_{B_s} from SM predictions.

In this Letter we show that all of the above effects are likely to occur and may be measurable in a class of theories recently proposed by three of us, called "effective supersymmetry" [2]. Effective supersymmetry is a new approach to the problem of naturalness in the weak interactions, providing an experimentally acceptable suppression of FCNC and electric dipole moments (EDMs) for the first two families while avoiding fine tuning in the Higgs sector. In such a theory nature is approximately supersymmetric above a scale $\tilde{M}$, with $1 \ll \tilde{M} \lesssim 20$ TeV. Unlike the minimal supersymmetric standard model (MSSM) [3], however, most of the superpartners have mass of order $\tilde{M}$ and only the Higgsinos, gauginos, top squarks, and left-handed bottom squarks need be lighter than the 't Hooft scale. FCNC and EDMs for light quarks and leptons are small even for large CP violating phases in supersymmetry breaking parameters, due to approximate decoupling of the first two families of squarks and sleptons. Below $\tilde{M}$, the effective theory does not appear supersymmetric, but is nevertheless natural, because of substantial cancellations in quadratically divergent radiative corrections.

The superpartner spectrum of effective supersymmetry can result from new gauge interactions, which are responsible for supersymmetry breaking and which couple more strongly to the first two families than the top quark and up-type Higgs. These new interactions could also explain the fermion mass hierarchy and the absence of observed B and L violation.

We have computed the possible effects on B factory physics from the light gauginos, Higgsinos, and top and bottom squarks. We find different and larger effects are possible than in the MSSM with squark universality [3,4] or alignment [5]. Nonuniversal masses for the third generation of squarks and sleptons have also been considered in [6,7], and the effects of nonuniversal masses and new phases for the third generation of squarks on CP violation in B physics have been considered previously, in the context of grand unified theories [8,9]. However, this earlier work did not take the first two squark generations to be very heavy, and so EDMs and ϵ_K were assumed to constrain new B physics possibilities.

B-factory experiments will be able to distinguish the effects of the standard model Cabbibo-Kobayashi-Maskawa (CKM) phases [10],

$$\alpha \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right), \quad \beta \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right),$$
$$\gamma \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right), \quad \gamma' \equiv \arg\left(-\frac{V_{tb}V_{ub}^*}{V_{ts}V_{us}^*}\right),$$
$$\delta \equiv \arg\left(-\frac{V_{tb}^*V_{ts}}{V_{cb}^*V_{cs}}\right), \quad \omega \equiv \arg\left(-\frac{V_{ud}V_{us}^*}{V_{cd}V_{cs}^*}\right),$$

from the effects of new physics (such as supersymmetric box and penguin diagrams) [11]. With these definitions (and without other assumptions such as CKM unitarity) there are two *identities*,

$$\alpha + \beta + \gamma = \pi; \quad \omega = \gamma - \gamma' - \delta. \tag{1}$$

Note that $\omega > \mathcal{O}(10^{-3})$ requires both CKM nonunitarity *and* new physics in K-$\overline{K}$ mixing. If the 3×3 CKM matrix is nonunitary due to mixing with undiscovered heavy quarks, it must be true that $\omega \lesssim 0.2$. CKM unitarity also constrains $|\delta| < 0.03$.

We first consider the effects of new physics through $\Delta B = 2$ operators. Many of the time dependent asymmetries resulting from the interference between B^0-$\overline{B}^0$ mixing and decay into CP eigenstates [12] are cleanly predicted in the standard model as a function of the CKM parameters [13]. While the direct decay amplitudes in Table I will be dominated by SM physics, the CP violating asymmetries which result from interference between mixing and decay are sensitive to gauginos, Higgsinos, and squarks through box diagrams which can produce nonstandard $\Delta B = 2$ effects. This new physics may be parametrized by two phases θ_d, θ_s,

$$\theta_{d,s} \equiv \frac{1}{2} \arg\left(\frac{\langle B_{d,s}|\mathcal{H}_{\rm eff}^{\rm full}|\overline{B}_{d,s}\rangle}{\langle B_{d,s}|\mathcal{H}_{\rm eff}^{\rm SM}|\overline{B}_{d,s}\rangle}\right), \tag{2}$$

where $\mathcal{H}_{\rm eff}^{\rm full}$ is the effective Hamiltonian including both standard and supersymmetry (SUSY) contributions, and $\mathcal{H}_{\rm eff}^{\rm SM}$ only includes the effects of the standard model box diagrams.

With these definitions, CP violating asymmetries in B processes measure the angles as indicated in Table I. These processes have been discussed in the SM in [14]. The measurements of $\alpha - \theta_d$ and $\beta + \theta_d$ are somewhat influenced by penguin contributions, whose effects must be removed [15]. A subtle point is the presence of ω in A_{CP} for $B_d^0 \to \psi K_s$. This arises since we cannot assume the phase in K–$\overline{K}$ mixing is given by the SM analysis [9]. However, we do know, since ϵ_K is small, that the phase is nearly the same as that in *K decay*, given by $\arg V_{ud} V_{us}^*$.

Provided that penguin contributions to the decays of Table I can be removed, $\alpha - \theta_d, \beta + \theta_d, \gamma, \omega$, and $\delta - \theta_s$ may be extracted from experiments [9,16]. As indicated in Figs. 1 and 2, with the additional assumption of CKM unitarity [10], knowledge of V_{ub} can be used to extract α, β, θ_d, δ, and θ_s independently.

We can estimate the sizes of these effects by comparing the superpartner contribution to $\Delta B = 2$ operators with the standard model. Effective supersymmetry requires the squarks $\tilde{Q}_3$ and $\tilde{\overline{T}}$ to have masses $\lesssim$1 TeV. These mass eigenstates are mixtures of flavor eigenstates (where squark flavor, indicated by a lower case letter, is defined by the gluino coupling to the corresponding quark) [2,17]

$$\tilde{Q}_3 \equiv \begin{pmatrix} \tilde{T} \\ \tilde{B} \end{pmatrix} \equiv Z_{tT}^q \begin{pmatrix} \tilde{t} \\ V_{tb}\tilde{b} + V_{ts}\tilde{s} + V_{td}\tilde{d} \end{pmatrix} + Z_{cT}^q \begin{pmatrix} \tilde{c} \\ V_{cb}\tilde{b} + V_{cs}\tilde{s} + V_{cd}\tilde{d} \end{pmatrix} + Z_{uT}^q \begin{pmatrix} \tilde{u} \\ V_{ub}\tilde{b} + V_{us}\tilde{s} + V_{ud}\tilde{d} \end{pmatrix}, \tag{3}$$

TABLE I. CP asymmetries measured in B decays.

Decay	Quark process	A_{CP}
$B_d^0 \to \pi^+\pi^-$	$\overline{b} \to \overline{u}u\overline{d}$	$\sin 2(\alpha - \theta_d)$
$B_d^0 \to D^+D^-$	$\overline{b} \to \overline{c}c\overline{d}$	$-\sin 2(\beta + \theta_d)$
$B_d^0 \to \psi K_s$	$\overline{b} \to \overline{c}c\overline{s}$	$-\sin 2(\beta + \theta_d + \omega)$
$B^\pm \to D_{CP}K^\pm$	$\overline{b} \to \overline{c}u\overline{s}, \overline{u}c\overline{s}$	$\gamma - \omega \equiv$
$B_d^0 \to D_{CP}K^*$		$\gamma' + \delta$
$B_s^0 \to \psi\phi$	$\overline{b} \to \overline{c}c\overline{s}$	$\sin 2(\delta - \theta_s)$
$B_s^0 \to D_s^\pm K^*$	$\overline{b} \to \overline{c}u\overline{s}, \overline{u}c\overline{s}$	$\gamma' - \delta + 2\theta_s$

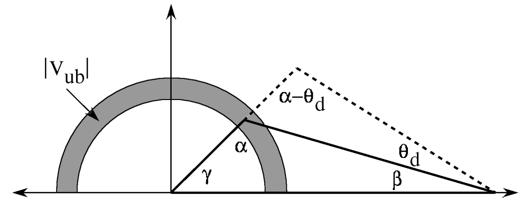

FIG. 1. Solid triangle corresponds to the CKM unitarity condition $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$. The angles $(\alpha - \theta_d)$ and $(\beta + \theta_d)$ are measured; α, β, and θ_d may then be reconstructed from knowledge of $|V_{ub}|$.

$$\tilde{\overline{T}} \equiv Z_{tT}^{\overline{u}}\tilde{\overline{t}} + Z_{cT}^{\overline{u}}\tilde{\overline{c}} + Z_{uT}^{\overline{u}}\tilde{\overline{u}}. \tag{4}$$

Here V is the CKM matrix, while the Z factors arise from diagonalizing the squark mass matrix in the quark mass eigenstate basis (we neglect left-right squark mixing, which is small in realizations of effective supersymmetry which have been studied to date [2,6]). The Z matrices satisfy $\sum_{i=u,c,t} |Z_{iT}^q|^2 = 1, \sum_{i=u,c,t} |Z_{iT}^{\overline{u}}|^2 = 1$. Naturalness imposes order of magnitude constraints on the Z factors: to avoid fine tuning in the Higgs sector, we require

$$|Z_{cT}^q|, |Z_{uT}^q|, |Z_{cT}^{\overline{u}}|, |Z_{uT}^{\overline{u}}| \lesssim \frac{1\ \text{TeV}}{\tilde{M}}, \tag{5}$$

while naturalness of the squark mass matrix requires [17]

$$|Z_{uT}^q| \lesssim \max\left(\frac{m_{\tilde{Q}_3}}{\tilde{M}}, |V_{ub}|\right),$$

$$|Z_{uT}^{\overline{u}}| \lesssim \max\left(\frac{m_{\tilde{\overline{T}}}}{\tilde{M}}, \frac{m_{\tilde{Q}_3}}{\tilde{M}}\right),$$

and similarly with u replaced by c.

The box diagrams with left-handed light squarks and gluinos give [18]

$$\mathcal{H}_{\rm eff}^{\tilde{g}} = \frac{\alpha_s^2}{36 m_{\tilde{B}}^2} (Z_{dB}^q Z_{bB}^{q*})^2 f_1(x_g) Q_1$$
$$\approx \left(\frac{6.4 \times 10^{-12}}{\text{GeV}^2}\right)\left(\frac{1000\ \text{GeV}}{m_{\tilde{B}}}\right)^2 \left(\frac{V_{td} + Z_{uT}^q}{0.05}\right)^2 Q_1, \tag{7}$$

where

$$Q_1 = \overline{b}_L^\alpha \gamma_\mu d_{\alpha L} \overline{b}_L^\beta \gamma^\mu d_{\beta L},$$

$$f_1(x) = \frac{11 + 8x - 19x^2 + 26\ \ln(x) + 4x^2\ \ln(x)}{(1 - x)^3},$$

$$Z_{q'B}^q \equiv \sum_{i=u,c,t} Z_{iT} V_{iq'}, \quad q' \equiv d, s, b,$$

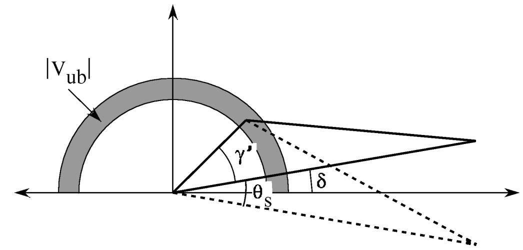

FIG. 2. Solid triangle corresponds to the CKM unitarity condition $V_{tb}V_{ub}^* + V_{ts}V_{us}^* + V_{td}V_{ud}^* = 0$. The angles $(\gamma' + \delta)$ and $(\delta - \theta_s)$ can be measured in B_s decays while δ is constrained by CKM unitarity.

and we have evaluated the function at $x_g \equiv m_{\tilde{g}}^2/m_{\tilde{B}}^2 \simeq 0.1$.

Unless gluinos are significantly heavier than squarks, charginos, and neutralinos (which does not occur in any realization of effective supersymmetry discussed in the literature [2,6]), box diagrams from chargino and neutralino exchange produce a contribution suppressed by $\mathcal{O}(\alpha_w/\alpha_s)^2 \sim 0.1$ when compared with the gluino boxes. Possible exceptions are the charged Higgsino and charged Higgs boxes which are proportional to λ_t^4. However, these have the same phase as the standard model contribution.

From Eq. (7) we see that even TeV mass squarks can produce an order one effect on B_d-$\overline{B}_d$ mixing, detectable via a θ_d as large as $\pm\pi/2$, or via a ratio for x_s/x_d (where $x_{s,d} \equiv \Delta m_{B_{s,d}}/\Gamma_{B_{s,d}}$) which is well outside the SM range. For B_s-$\overline{B}_s$ mixing the effects of the superpartner box diagrams can be comparable to the SM contribution only for rather light ($\sim$200 GeV) b squarks and gluinos. A measurement of θ_s larger than 0.2 would suggest that gluinos and a squark are lighter than $\sim$400 GeV.

In the SM ϵ_K significantly constrains the CKM matrix. However, ϵ_K could be dominated by the contribution from supersymmetric particles, even if all superpartners are as heavy as 500 TeV. With $\sim$20 TeV masses and SUSY mixing angles of order the Cabibbo angle for the first two families of squarks, consistency with the observed value of ϵ_K requires CP violating SUSY phases in the down and strange squark couplings to be less than $\mathcal{O}(1/30)$ [2,5]. Note that suppressing this contribution to ϵ_K does *not* preclude observing new CP violating phases in B physics from effective SUSY. However, it is conceivable that an approximate CP symmetry renders all phases (including CKM phases) small—in this case CP violating asymmetries in B decays would be too small to be measured easily.

In either the MSSM or in effective supersymmetry Δm_{B_d} can receive a significant supersymmetric contribution which has the same phase as the SM contribution. Thus the values of α, β determined by B physics could disagree with the values in the SM given by $V_{ub}, \Delta m_{B_d}$, and ϵ_K, even if $\theta_{d,s}$ are too small to measure.

Effective supersymmetry may also have significant effects through $\Delta B = 1$ operators. Contributions to both the $b \to d$ and $b \to s$ penguins can be comparable to that of the SM but with different phases, provided gluino and third family squark masses are lighter than 200 GeV. The SM predictions for penguin operators and methods for extracting their effects from CP asymmetries has been extensively discussed [9,15,16,19]. In the standard model there is a large uncertainty in the prediction for the phase of the $b \to d$ penguin; however, the uncertainty in the phase of the $b \to s$ penguin is small if the CKM matrix is unitary. Thus one can search for new CP violating phases in penguin contributions to, e.g., the CP asymmetry in $B_d(\overline{B}_d) \to \phi K_S$ or $B_s(\overline{B}_s) \to K^0\overline{K}^0$.

Box and electroweak penguin diagrams involving superpartners can affect the rates, polarizations, and lepton momentum distributions in $b \to (s,d)\ell^+\ell^-$, which can also be tested in B factories. In the MSSM with universality, the only potential discrepancies larger than 5% arise through changes in the coefficient C_7 [20] in the effective Lagrangian (we follow the notation of [21]). In effective supersymmetry with small left-right squark mixing and heavy charged Higgs the corrections to C_7 are small. With a bottom squark lighter than $\sim$100 GeV and gluino lighter than $\sim$200 GeV it is possible to change the size and/or phase of the coefficient C_9 by as much as 30%. If the bottom and/or top squarks, the weak gauginos, and the τ charged slepton and/or τ sneutrino have masses $\sim$100 GeV, it is possible for box diagrams to change the size and phase of $C_{9,10}$ (for the τ lepton only) by a maximum of $\mathcal{O}(10\%)$.

The B factories will also search for mixing and CP violation in the D^0 system, which are both predicted to be very small in the SM ($x_D \equiv \Delta m_{D^0}/\Gamma_{D^0} \sim 10^{-4}$–$10^{-5}$, $y_D \equiv \Delta\Gamma_{D^0}/(2\Gamma_{D^0}) \sim 10^{-2}$–$10^{-4}$, $\epsilon_D \sim 10^{-4}$–10^{-6}) [22]. In effective supersymmetry there can be significant contributions to x_D from both heavy squarks with masses $\sim\tilde{M}$ and from the lighter third family squarks, with comparable maximum possible size. For example, the box diagrams with a right-handed top squark and gluinos give a contribution

$$x_D = \frac{\alpha_s^2 M_D B_D f_D^2}{54 m_{\tilde{\overline{T}}}^2 \Gamma_D} |(Z_{uT}^{\overline{u}} Z_{cT}^{\overline{u}})|^2 f_1(x_g) \approx 5 \times 10^{-4}\left(\frac{1000\text{ GeV}}{m_{\tilde{\overline{T}}}^2}\right)^2 \left(\frac{f_D\sqrt{B_D}}{200\text{ MeV}}\right)^2 \left(\frac{Z_{uT}^{\overline{u}} Z_{cT}^{\overline{u}}}{0.0025}\right)^2, \tag{8}$$

where again we have taken $x_g \simeq 0.1$. The current experimental bound is ($x_D < 0.09$) [23]. Charm decays will be dominated by the SM contribution and so there are no significant new contributions to y_D. We conclude that unless suppressed by flavor symmetries, D^0-$\overline{D}^0$ mixing could be much larger than in the SM, although substantially smaller than the current experimental bounds. The superpartner contribution may also have a different phase than the SM contribution. If Δm_{D^0} and $\Delta\Gamma/2$ turn out to be comparable, ϵ_D could be $\mathcal{O}(1)$, although ϵ_D is difficult to measure if D^0-$\overline{D}^0$ mixing is very slow. In principle D^0-$\overline{D}^0$ mixing affects the extraction of the CKM parameter $\gamma - \omega$ from $B \to D_{CP}K$ decays; however, such effects are suppressed by x_D, y_D, and are negligible. However, even if ϵ_D is small, x_D may be as large as $\mathcal{O}(10^{-2})$, and then CP violation in interference between D^0 mixing and decays might be detectable [24].

In summary, effective supersymmetry, with naturalness and with $\tilde{M} \sim 20$ TeV, allows for interesting new physics for B factories. Effective supersymmetry shares with other supersymmetric models the possibility of nonstandard contributions to ϵ_K and B_d-$\overline{B}_d$ mixing. Observable possibilities which are precluded in other supersymmetric models (assuming R-parity conservation) include $\mathcal{O}(\pi/2)$ values for the new physics parameters θ_d and θ_s, a 30% effect on the coefficient C_9 which affects $b \to s\ell^+\ell^-$ decays, and large new phases in $b \to s$ penguins. D^0-$\overline{D}^0$ mixing is likely to be much larger than in the standard model but very difficult to observe. Observation of large θ_s, nonstandard phases in $b \to s$ penguins, or significant deviation from the SM in $b \to (d,s)\ell^+\ell^-$, would imply that gluinos and third family squarks are lighter than ~200 GeV, i.e., within near term experimental reach.

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[1] G. 't Hooft, in *Recent Developments In Gauge Theories,* NATO Advanced Study Institute (Plenum, New York, 1980).

[2] A. G. Cohen, D. B. Kaplan, and A. E. Nelson, Phys. Lett. B **388**, 588 (1996).

[3] S. Dimopoulos and H. Georgi, Nucl. Phys. **B193**, 150 (1981); N. Sakai, Z. Phys. C **11**, 153 (1981).

[4] G. C. Branco, G. C. Cho, Y. Kizukuri, and N. Oshimo, Nucl. Phys. **B449**, 483 (1995); T. Goto, T. Nihei, and Y. Okada, KEK-TH-445, KEK preprint 95-125, ICRR-Report-341-95-7, TU-485; Phys. Rev. D **53**, 5233 (1996); **54**, 5904(E) (1996); M. Worah, Phys. Rev. D **54**, 2198 (1996); G. Couture and H. König, Z. Phys. C **69**, 499 (1996), Report No. hep-ph/9511234 [Z. Phys. C (to be published)].

[5] Y. Nir and N. Seiberg, Phys. Lett. B **309**, 337 (1993); M. Leurer, Y. Nir, and N. Seiberg, Nucl. Phys. **B420**, 468 (1994).

[6] G. Dvali and A. Pomarol, Report No. CERN-TH/96-192, hep-ph/9607383; R. N. Mohapatra and A. Riotto, Report No. hep-ph/9608441.

[7] M. Dine, A. Kagan, and S. Samuel, Phys. Lett. B **243**, 250 (1990); M. Dine, A. Kagan, and R. G. Leigh, Phys. Rev. D **48**, 4269 (1993); S. Dimopoulos and G. F. Giudice, Phys. Lett. B **357**, 573 (1995); P. Pouliot and N. Seiberg, Phys. Lett. B **318**, 169 (1993); A. Pomarol and D. Thommasini, Report. No. hep-ph/9507462 [Nucl. Phys. B (to be published)]; R. Barbieri, G. Dvali, and L. Hall, Phys. Lett. B **377**, 76 (1996); P. Binetruy and E. Dudas, Report No. LPTHE-ORSAY-96-60, hep-th/9607172.

[8] R. Barbieri, L. Hall, and A. Strumia, Nucl. Phys. **B449**, 437 (1995).

[9] N. G. Deshpande, B. Dutta, and S. Oh, Phys. Rev. Lett. **77**, 4499 (1996).

[10] We prefer to call the latter two parameters δ and ω rather than ϵ and ϵ' as defined in R. Aleksan, B. Kayser, and D. London, Phys. Rev. Lett. **73**, 18 (1994), in order to avoid confusion with the *CP* violating parameters in the kaon system.

[11] For reviews see, e.g., Y. Nir and H. R. Quinn, Annu. Rev. Nucl. Part. Sci. **42**, 211 (1992); J. Rosner, Report No. EFI-95-36, hep-ph/9506364; A. Ali and D. London, Report No. DESY 95-148, UdeM-GPP-TH-95-32, hep-ph/9508272; A. J. Buras, Nucl. Instrum. Methods Phys. Res., Sect. A **368**, 1 (1995); Report No. hep-ph/9509329; Y. Nir, Report No. WIS-95-28-PH, hep-ph/9507290; M. Gronau and D. London, Report No. TECHNION-PH-96-37, UdeM-GPP-TH-96-39, hep-ph/9608430; T. Nakada, Report No. PSI-PR-96-22, hep-ex/9609015; M. Gronau, Report No. TECHNION-PH-96-39, hep-ph/9609430.

[12] A. B. Carter and A. I. Sanda, Phys. Rev. D **23**, 1567 (1981); I. I. Bigi and A. I. Sanda, Nucl. Phys. **B193**, 85 (1981).

[13] I. Dunietz and J. Rosner, Phys. Rev. D **34**, 1404 (1986).

[14] M. Gronau and D. London, Phys. Lett. B **253**, 483 (1991); I. Dunietz, Phys. Lett. B **270**, 75 (1991); M. Gronau and D. Wyler, Phys. Lett. B **265**, 172 (1991); R. Aleksan, I. Dunietz, and B. Kayser, Z. Phys. C **54**, 653 (1992).

[15] See, e.g., M. Gronau and D. London, Phys. Rev. Lett. **65**, 3381 (1990); J. M. Gérard and W. S. Hou, Phys. Rev. D **43**, 2909 (1991), Phys. Lett. B **253**, 478 (1991); H. Simma, G. Eilam, and D. Wyler, Nucl. Phys. **B352**, 367 (1991); H. Quinn and R. Snyder, Phys. Rev. D **48**, 2139 (1993); R. Fleischer, Phys. Lett. **41B**, 205 (1994); Report No. hep-ph/9610357; J. P. Silva and L. Wolfenstein, Phys. Rev. D **49**, R1151 (1994); A. J. Buras and R. Fleischer, Phys. Lett. B **341**, 379 (1995); **360**, 138 (1996).

[16] After this work was completed the following Letter appeared, which gives a similar analysis of non-SM contributions to *CP* asymmetries in *B* physics. J. P. Silva and L. Wolfenstein, Report No. hep-ph/9610208.

[17] A. G. Cohen, D. B. Kaplan, and A. E. Nelson (to be published).

[18] Note that the gluino mass dependence of Eqs. (7) and (8) differs from that given in the following references because we have not made the approximation of near degeneracy in the squarks. J. S. Hagelin, S. Kelley, and T. Tanaka, Nucl. Phys. **B415**, 293 (1994); F. Gabbiani, E. Gabrielli, A. Masiero, and L. Silvestrini, Nucl. Phys. **B477**, 321 (1996).

[19] Y. Grossman and M. P. Worah, Report No. hep-ph/9612269.

[20] T. Goto, Y. Okada, Y. Shimizu, and M. Tanaka, Report No. KEK-TH-483, hep-ph/9609512; P. Cho, M. Misiak, and D. Wyler, Phys. Rev. D **54**, 3329 (1996); S. Bertolini, F. Borzumati, A. Masiero, and G. Ridolfi, Nucl. Phys. **B353**, 591 (1991).

[21] B. Grinstein, M. J. Savage, and M. B. Wise, Nucl. Phys. **B319**, 271 (1989).

[22] L. Wolfenstein, Phys. Lett. **164B**, 170 (1985); J. F. Donoghue *et al.*, Phys. Rev. D **33**, 179 (1986); S. Pakvasa, Chin. J. Phys. **32**, 1163 (1994); H. Georgi, Phys. Lett. B **297**, 353 (1992); T. Ohl, G. Ricciardi, and E. H. Simmons, Nucl. Phys. **B403**, 605 (1993).

[23] Particle Data Group, Review of Particle Physics, Phys. Rev. D **54**, 455 (1996).

[24] L. Wolfenstein, Phys. Rev. Lett. **75**, 2460 (1995); G. Blaylock, A. Seiden, and Y. Nir, Phys. Lett. B **355**, 555 (1995); T. E. Browder and S. Pakvasa, Phys. Lett. B **383**, 475 (1996); Z-z. Xing, Phys. Rev. D **55**, 196 (1997); G. C. Branco, W. Grimus, and L. Lavoura, Phys. Lett. B **372**, 311 (1996).