SLAC-PUB-8231
August 1999
hep-ph/9908404

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Submitted to *Physical Review Letters*

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Work supported by Department of Energy contract DE–AC03–76SF00515.

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Large $\Delta I = \frac{3}{2}$ Contribution to ϵ'/ϵ in Supersymmetry

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Abstract

We show that in supersymmetric extensions of the Standard Model gluino box diagrams can yield a large $\Delta I = \frac{3}{2}$ contribution to $s \to d\bar{q}q$ FCNC processes, which may induce a sizable CP-violating contribution to the $I = 2$ isospin amplitude in $K \to \pi\pi$ decays. This contribution only requires moderate mass splitting between the right-handed squarks $\tilde{u}_R$ and $\tilde{d}_R$, and persists for squark masses of order 1 TeV. Taking into account current bounds on $\mathrm{Im}\,\delta^{LL}_{sd}$ from K–$\bar{K}$ mixing, the resulting contribution to ϵ'/ϵ could be an order of magnitude larger than the measured value.

(Submitted to Physical Review Letters)

August 1999

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The recent confirmation of direct CP violation in $K \to \pi\pi$ decays is an important step in testing the Cabibbo–Kobayashi–Maskawa (CKM) mechanism for CP violation in the Standard Model. Combining the recent measurements by the KTeV and NA48 experiments [1] with earlier results from NA31 and E731 [2] gives $\mathrm{Re}\,(\epsilon'/\epsilon) = (2.12 \pm 0.46) \times 10^{-3}$. This value tends to be higher than theoretical predictions in the Standard Model, which center below or around 1×10^{-3} [3]. Unfortunately, it is difficult to gauge the accuracy of these predictions, because they depend on hadronic matrix elements which at present cannot be computed from first principles. A Standard-Model explanation of ϵ'/ϵ can therefore not be excluded. Nevertheless, it is interesting to ask how large ϵ'/ϵ could be in extensions of the Standard Model.

In the context of supersymmetric models, it has been known for some time that it is possible to obtain a large contribution to ϵ'/ϵ via the $\Delta I = \frac{1}{2}$ chromomagnetic dipole operator without violating constraints from K–$\bar{K}$ mixing [4]. It has recently been pointed out that this mechanism can naturally be realized in various supersymmetric scenarios [5]. In this Letter we propose a new mechanism involving a supersymmetric contribution to ϵ'/ϵ induced by $\Delta I = \frac{3}{2}$ penguin operators. These operators are potentially important because their effect is enhanced by the $\Delta I = \frac{1}{2}$ selection rule. Unlike previous proposals, which involve left-right down-squark mass insertions, our effect relies on the left-left insertion δ^{LL}_{sd} and requires (moderate) isospin violation in the right-handed squark sector.

The ratio ϵ'/ϵ parametrizing the strength of direct CP violation in $K \to \pi\pi$ decays can be expressed as

$$\frac{\epsilon'}{\epsilon} = i e^{i(\delta_2 - \delta_0 - \phi_\epsilon)} \, \frac{\omega}{\sqrt{2}\,|\epsilon|} \left(\frac{\mathrm{Im}\, A_2}{\mathrm{Re}\, A_2} - \frac{\mathrm{Im}\, A_0}{\mathrm{Re}\, A_0} \right), \tag{1}$$

where A_I are the isospin amplitudes for the decays $K^0 \to (\pi\pi)_I$, δ_I are the corresponding strong-interaction phases, and the ratio $\omega = \mathrm{Re}\, A_2/\mathrm{Re}\, A_0 \approx 0.045$ signals the strong enhancement of $\Delta I = \frac{1}{2}$ transitions over those with $\Delta I = \frac{3}{2}$. From experiment, we take $|\epsilon| = (2.280 \pm 0.013) \times 10^{-3}$ and $\phi_\epsilon = (43.49 \pm 0.08)^\circ$ for the magnitude and phase of the parameter ϵ measuring CP violation in K–$\bar{K}$ mixing, and $\delta_2 - \delta_0 = -(42 \pm 4)^\circ$ for the difference of the S-wave $\pi\pi$ scattering phases in the two isospin channels. It follows that, to an excellent approximation, ϵ'/ϵ is real.

In the Standard Model, the isospin amplitudes A_I receive small, CP-violating contributions via the ratio $(V^*_{ts}V_{td})/(V^*_{us}V_{ud})$ of CKM matrix elements. This ratio enters through the interference of the $s \to u\bar{u}d$ tree diagram with penguin diagrams involving the exchange of a virtual top quark. According to (1), contributions to ϵ'/ϵ due to the $\Delta I = \frac{3}{2}$ amplitude $\mathrm{Im}\, A_2$ are enhanced relative to those due to the $\Delta I = \frac{1}{2}$ amplitude $\mathrm{Im}\, A_0$ by a factor of $\omega^{-1} \approx 22$. However, in the Standard Model the dominant CP-violating contributions to ϵ'/ϵ are due to QCD penguin operators, which only contribute to A_0. Penguin contributions to A_2 arise through electroweak interactions and are suppressed by a power of α. Their effects on ϵ'/ϵ are subleading and of the same order as isospin-violating effects such as π^0–η–η' mixing.

Here we point out that in supersymmetric extensions of the Standard Model potentially large, CP-violating contributions can arise from flavor-changing *strong-interaction*

processes induced by gluino box diagrams. Whereas in the limit of exact isospin symmetry in the squark sector these graphs only induce $\Delta I = \frac{1}{2}$ operators at low energies, in the presence of even moderate up-down squark mass splitting they can lead to operators with large $\Delta I = \frac{3}{2}$ components. In the terminology of the standard effective weak Hamiltonian, this implies that the supersymmetric contributions to the Wilson coefficients of QCD and electroweak penguin operators can be of the same order. Specifically, both sets of coefficients scale like $\alpha_s^2/\widetilde{m}^2$ with $\widetilde{m}$ a generic supersymmetric mass, compared with $\alpha_s\alpha_W/m_W^2$ and $\alpha\alpha_W/m_W^2$, respectively, in the Standard Model. These contributions can be much larger than the electroweak penguins of the Standard Model even for supersymmetric masses of order 1 TeV. On the other hand, supersymmetric contributions to the Wilson coefficients proportional to electroweak gauge couplings are parametrically suppressed and will not be considered here.

We find that the relevant $\Delta S = 1$ gluino box diagrams lead to the effective Hamiltonian

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \sum_{i=1}^{4} \Big[c_i^q(\mu)\, Q_i^q(\mu) + \widetilde{c}_i^q(\mu)\, \widetilde{Q}_i^q(\mu) \Big] + \text{h.c.}\,,$$

where

$$\begin{aligned} Q_1^q &= (\bar{d}_\alpha s_\alpha)_{V-A}\,(\bar{q}_\beta q_\beta)_{V+A}\,, \qquad & Q_2^q &= (\bar{d}_\alpha s_\beta)_{V-A}\,(\bar{q}_\beta q_\alpha)_{V+A}\,, \\ Q_3^q &= (\bar{d}_\alpha s_\alpha)_{V-A}\,(\bar{q}_\beta q_\beta)_{V-A}\,, \qquad & Q_4^q &= (\bar{d}_\alpha s_\beta)_{V-A}\,(\bar{q}_\beta q_\alpha)_{V-A} \end{aligned}$$

are local four-quark operators renormalized at a scale $\mu \ll \widetilde{m}$, $\widetilde{Q}_i^q$ are operators of opposite chirally obtained by interchanging $V-A \leftrightarrow V+A$, and a summation over $q = u, d, \ldots$ and over color indices α, β is implied. In the calculation of the coefficient functions we use the mass insertion approximation, in which case the gluino–quark–squark couplings are flavor diagonal. Flavor mixing is due to small deviations from squark-mass degeneracy and is parametrized by dimensionless quantities δ_{ij}^{AB}, where i, j are squark flavor indices and A, B refer to the chiralities of the corresponding quarks (see, e.g., [4]). In general, these mass insertions can carry new CP-violating phases. Contributions involving left-right squark mixing are neglected, since they are quadratic in small mass insertion parameters, i.e., proportional to $\delta_{sd}^{LR}\,\delta_{qq}^{LR}$. We define the dimensionless ratios

$$x_u^{L,R} = \left(\frac{m_{\tilde{u}_{L,R}}}{m_{\tilde{g}}}\right)^2, \qquad x_d^{L,R} = \left(\frac{m_{\tilde{d}_{L,R}}}{m_{\tilde{g}}}\right)^2,$$

where $m_{\tilde{u}_{L,R}}$ and $m_{\tilde{d}_{L,R}}$ denote the average left- or right-handed squark masses in the up and down sector, respectively. $\text{SU}(2)_L$ gauge symmetry implies that the mass splitting between the left-handed up- and down-squarks must be tiny; however, we will not assume such a degeneracy between the right-handed squarks. For the Wilson coefficients c_i^q at the supersymmetric matching scale $\widetilde{m}$ we then obtain

$$c_1^q = \frac{\alpha_s^2 \delta_{sd}^{LL}}{2\sqrt{2} G_F m_{\tilde{g}}^2} \left[\frac{1}{18}\, f(x_d^L, x_q^R) - \frac{5}{18}\, g(x_d^L, x_q^R) \right],$$

$$c_2^q = \frac{\alpha_s^2 \delta_{sd}^{LL}}{2\sqrt{2} G_F m_{\tilde{g}}^2} \left[\frac{7}{6} f(x_d^L, x_q^R) + \frac{1}{6} g(x_d^L, x_q^R) \right],$$

$$c_3^q = \frac{\alpha_s^2 \delta_{sd}^{LL}}{2\sqrt{2} G_F m_{\tilde{g}}^2} \left[-\frac{5}{9} f(x_d^L, x_q^L) + \frac{1}{36} g(x_d^L, x_q^L) \right],$$

$$c_4^q = \frac{\alpha_s^2 \delta_{sd}^{LL}}{2\sqrt{2} G_F m_{\tilde{g}}^2} \left[\frac{1}{3} f(x_d^L, x_q^L) + \frac{7}{12} g(x_d^L, x_q^L) \right],$$

where

$$f(x,y) = \frac{x(x+1-2y)}{(x-1)^2(y-1)(x-y)} - \frac{xy\ln y}{(y-1)^2(x-y)^2} + \frac{x[2x^2-(x+1)y]\ln x}{(x-1)^3(x-y)^2},$$

$$g(x,y) = \frac{x[-2x+(x+1)y]}{(x-1)^2(y-1)(x-y)} + \frac{xy^2\ln y}{(y-1)^2(x-y)^2} - \frac{x^2[x(x+1)-2y]\ln x}{(x-1)^3(x-y)^2}.$$

The results for the coefficients $\widetilde{c}_i^q$ are obtained by interchanging $L \leftrightarrow R$ in the expressions for c_i^q.

It is straightforward to relate the quantities c_i^q to the Wilson coefficients appearing in the effective weak Hamiltonian of the Standard Model as defined, e.g., in [6]. We find ($\lambda_t = V_{ts}^* V_{td}$)

$$(-\lambda_t)\, C_3 = \frac{c_3^u + 2c_3^d}{3}, \qquad (-\lambda_t)\, C_4 = \frac{c_4^u + 2c_4^d}{3},$$

$$(-\lambda_t)\, C_5 = \frac{c_1^u + 2c_1^d}{3}, \qquad (-\lambda_t)\, C_6 = \frac{c_2^u + 2c_2^d}{3}$$

for the QCD penguin coefficients, and

$$\frac{3}{2}(-\lambda_t)\, C_{i+6} = c_i^u - c_i^d \equiv \Delta c_i\,; \quad i = 1\ldots 4 \tag{2}$$

for the coefficients of the electroweak penguin operators. The supersymmetric contributions to the electroweak penguin coefficients vanish in the limit of universal squark masses. However, for moderate up–down squark mass splitting the differences $\Delta c_i = c_i^u - c_i^d$ are of the same order as the coefficients c_i^q themselves. In this case gluino box contributions to QCD and electroweak penguin operators are of similar magnitude. This conclusion is unaltered when additional contributions to $C_{3\ldots6}$ from QCD penguin diagrams with gluino loops are taken into account. Because the electroweak penguin operators contain $\Delta I = \frac{3}{2}$ components their contributions to ϵ'/ϵ are strongly enhanced and thus are expected to be an order of magnitude larger than the contributions from the QCD penguin operators. In this Letter, we focus only on these enhanced contributions.

The renormalization-group evolution of the coefficients Δc_i (and $\Delta\widetilde{c}_i$) from the supersymmetric matching scale $\widetilde{m}$ down to low energies is well known. In leading logarithmic

Table 1: Values of the coefficients $\Delta c_i(m_c)$ and $\Delta\widetilde{c}_i(m_c)$ in units of $10^{-4}\,\mathrm{Im}\,\delta^{LL}_{sd}$ and $10^{-4}\,\mathrm{Im}\,\delta^{RR}_{sd}$, respectively, for common gluino and down-squark masses of 500 GeV and different values of $m_{\tilde{u}_R}$. The last column shows the corresponding values in the Standard Model in units of 10^{-7}.

$m_{\tilde{u}_R}$ [GeV]	750	1000	1500	SM
$\Delta c_1(m_c)$	−0.05	−0.08	−0.12	0.42
$\Delta c_2(m_c)$	2.12	3.19	4.16	−1.90
$\Delta\widetilde{c}_3(m_c)$	−0.50	−0.76	−1.01	20.64
$\Delta\widetilde{c}_4(m_c)$	0.56	0.87	1.17	−7.63

approximation, one obtains [6]

$$\begin{aligned}
\Delta c_1(\mu) &= \kappa^{-1/\beta_0}\, c_1(\widetilde{m})\,, \\
\Delta c_2(\mu) + \frac{\Delta c_1(\mu)}{3} &= \kappa^{8/\beta_0}\left[\Delta c_2(\widetilde{m}) + \frac{\Delta c_1(\widetilde{m})}{3}\right], \\
\Delta c_3(\mu) + \Delta c_4(\mu) &= \kappa^{-2/\beta_0}\left[\Delta c_3(\widetilde{m}) + \Delta c_4(\widetilde{m})\right], \\
\Delta c_3(\mu) - \Delta c_4(\mu) &= \kappa^{4/\beta_0}\left[\Delta c_3(\widetilde{m}) - \Delta c_4(\widetilde{m})\right],
\end{aligned}$$

where $\kappa = \alpha_s(\mu)/\alpha_s(\widetilde{m})$, and $\beta_0 = 11 - \frac{2}{3}n_f$. It is understood that the value of β_0 is changed at each quark threshold. We use the two-loop running coupling normalized to $\alpha_s(m_Z) = 0.119$ and take the quark thresholds at $m_t = 165\,\mathrm{GeV}$, $m_b = 4.25\,\mathrm{GeV}$ and $m_c = 1.3\,\mathrm{GeV}$. In Table 1 we give the imaginary parts of the coefficients $\Delta c_{1,2}$ and $\Delta\widetilde{c}_{3,4}$ at the scale $\mu = m_c$, obtained for the illustrative choice $\widetilde{m} = m_{\tilde{g}} = m_{\tilde{d}_L} = m_{\tilde{d}_R} = 500\,\mathrm{GeV}$ and three (larger) values of $m_{\tilde{u}_R}$. Since the mass splitting between the left-handed $\tilde{u}_L$ and $\tilde{d}_L$ squarks is tiny, we can safely neglect the coefficients $\Delta c_{3,4}$ and $\Delta\widetilde{c}_{1,2}$ in our analysis. Note that for fixed ratios of the supersymmetric masses the values of the coefficients scale like $\widetilde{m}^{-2}$, i.e., significantly larger values could be obtained for smaller masses. For comparison, the last column contains the imaginary parts of $\Delta c_{1\ldots4}$ in the Standard Model computed from (2) using $\mathrm{Im}\,\lambda_t = 1.2\times10^{-4}$ and the next-to-leading order Wilson coefficients C_i compiled in [6]. We observe that for supersymmetric masses of order 500 GeV, and for a mass insertion parameter $\mathrm{Im}\,\delta^{LL}_{sd}$ of order a few times 10^{-3} (see below), the Wilson coefficient Δc_2 can be significantly larger than the value of the corresponding coefficient in the Standard Model, which is proportional to C_8. This is interesting, since even in the Standard Model the contribution of C_8 to ϵ'/ϵ is significant.

In estimating the supersymmetric contribution to ϵ'/ϵ we focus only on the $(V-A)\otimes(V+A)$ operators associated with the coefficients Δc_1 and Δc_2, because their matrix elements are chirally enhanced with respect to those of the $(V-A)\otimes(V-A)$ operators. The penguin operators contribute to the imaginary part of the isospin amplitude A_2.

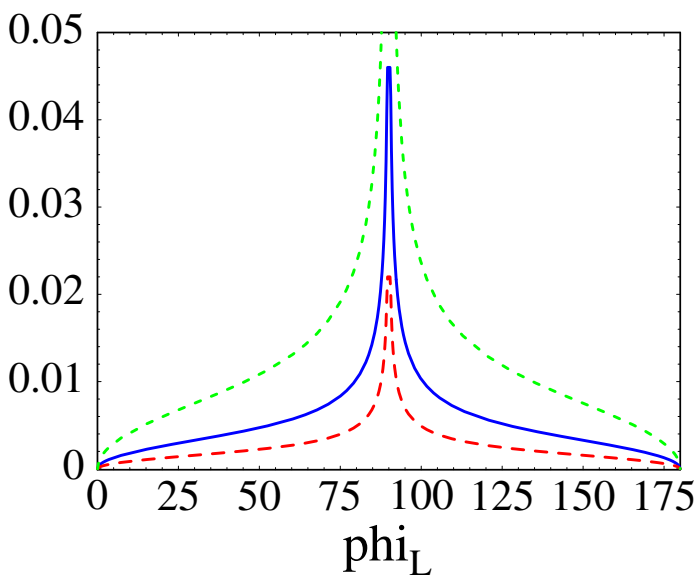

Figure 1: Upper bound on $|\mathrm{Im}\,\delta^{LL}_{sd}|$ versus the weak phase $|\phi_L|$ (in degrees) for $m_{\tilde{d}_L} = 500\,\mathrm{GeV}$ and $(m_{\tilde{g}}/m_{\tilde{d}_L})^2 = 1$ (solid), 0.3 (dashed) and 4 (short-dashed).

The real part is, to an excellent approximation, given by the matrix elements of the standard current–current operators in the effective weak Hamiltonian. Evaluating the matrix elements of the four-quark operators in the factorization approximation, and parametrizing nonfactorizable corrections by hadronic parameters $B_i^{(2)}$ as defined in [6], we obtain

$$\frac{\mathrm{Im}\,A_2^{\mathrm{susy}}}{\mathrm{Re}\,A_2} \approx \frac{3}{2}\,\frac{m_K^2}{m_s^2(m_c) - m_d^2(m_c)}\,\frac{\mathrm{Im}\,[\Delta c_2(m_c) + \frac{1}{3}\Delta c_1(m_c)]\,B_8^{(2)}(m_c)}{|V_{us}^* V_{ud}|\,z_+(m_c)\,B_1^{(2)}(m_c)}\,.$$

Following common practice we have neglected a tiny contribution proportional to the difference $B_7^{(2)} - B_8^{(2)}$. In the above formula z_+ is a combination of Wilson coefficients. The product $z_+\,B_1^{(2)} = 0.363$ is scheme independent and can be extracted from experiment. Note that at leading logarithmic order the scale dependence of the combination $\Delta c_2 + \frac{1}{3}\Delta c_1$ cancels the scale dependence of the running quark masses, and hence the hadronic parameter $B_8^{(2)}$ is scale independent.

Putting everything together, we find for the supersymmetric $\Delta I = \frac{3}{2}$ contribution to ϵ'/ϵ

$$\frac{\epsilon'}{\epsilon} \approx 19.2 \left[\frac{500\,\mathrm{GeV}}{m_{\tilde{g}}}\right]^2 \left[\frac{\alpha_s(\widetilde{m})}{0.096}\right]^{\frac{34}{21}} \left[\frac{130\,\mathrm{MeV}}{m_s(m_c)}\right]^2 B_8^{(2)}(m_c)\,X(x_d^L, x_u^R, x_d^R)\,\mathrm{Im}\,\delta^{LL}_{sd}\,, \qquad (3)$$

where

$$X(x,y,z) = \frac{32}{27}\,[f(x,y) - f(x,z)] + \frac{2}{27}\,[g(x,y) - g(x,z)]\,.$$

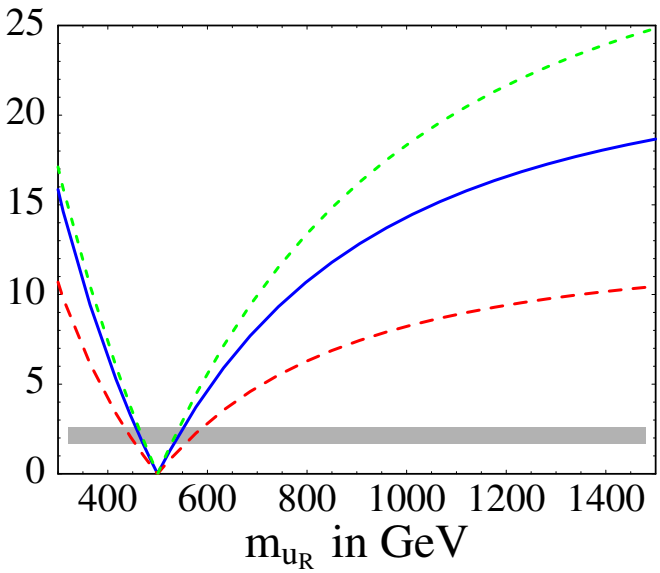

Figure 2: Supersymmetric contribution to $|\epsilon'/\epsilon|$ (in units of 10^{-3}) versus $m_{\tilde{u}_R}$, for $m_s(m_c) = 130\,\text{MeV}$, $B_8^{(2)}(m_c) = 1$, $m_{\tilde{d}_L} = m_{\tilde{d}_R} = 500\,\text{GeV}$, and $(m_{\tilde{g}}/m_{\tilde{d}_L})^2 = 1$ (solid), 0.3 (dashed) and 4 (short-dashed). The values of $|\text{Im}\,\delta_{sd}^{LL}|$ corresponding to the three curves are 0.011, 0.005 and 0.027, respectively (see text). The band shows the average experimental value.

The existence of this contribution requires a new CP-violating phase ϕ_L defined by $\text{Im}\,\delta_{sd}^{LL} \equiv |\delta_{sd}^{LL}|\sin\phi_L$. The measured values of Δm_K and ϵ in K–$\bar{K}$ mixing give bounds on $\text{Re}\,(\delta_{sd}^{LL})^2$ and $\text{Im}\,(\delta_{sd}^{LL})^2$, respectively, which can be combined to obtain a bound on $\text{Im}\,\delta_{sd}^{LL}$ as a function of ϕ_L. Using the most recent analysis of supersymmetric contributions to K–$\bar{K}$ mixing in [7], we show in Figure 1 the results obtained for $m_{\tilde{d}_L} = 500\,\text{GeV}$ and three choices of $m_{\tilde{g}}$. It is evident that the bound on $\text{Im}\,\delta_{sd}^{LL}$ depends strongly on the precise value of ϕ_L. To address the issue of how large a supersymmetric contribution to ϵ'/ϵ one can reasonably expect via the mechanism proposed in this Letter, it appears unnatural to take the absolute maximum of the bound given the peaked nature of the curves. To be conservative we evaluate our result (3) taking for $\text{Im}\,\delta_{sd}^{LL}$ one quarter of the maximal allowed values shown in Figure 1, noting however that a larger effect could be obtained for the special case of $|\phi_L|$ very close to 90°.

Our results for $|\epsilon'/\epsilon|$ are shown in Figure 2 as a function of $m_{\tilde{u}_R}$ for the case $m_{\tilde{d}_L} = m_{\tilde{d}_R} = 500\,\text{GeV}$ and the same three values of $m_{\tilde{g}}$ considered in the previous figure. The choice $m_{\tilde{d}_L} = m_{\tilde{d}_R}$ is made for simplicity only and does not affect our conclusions in a qualitative way. Except for the special case of highly degenerate right-handed up- and down-squark masses, the $\Delta I = \frac{3}{2}$ gluino box-diagram contribution to ϵ'/ϵ can by far exceed the experimental result, even taking into account the bounds from Δm_K and ϵ. Indeed, even for moderate splitting Figure 2 implies substantially stronger bounds on $|\text{Im}\,\delta_{sd}^{LL}|$ than those obtained from K–$\bar{K}$ mixing. This finding is in contrast to

the commonly held view that supersymmetric contributions to the electroweak penguin operators have a negligible impact on ϵ'/ϵ. In this context, it is worth noting that a large mass splitting between $\tilde{u}_R$ and $\tilde{d}_R$ can be obtained, e.g., in GUT theories without $\mathrm{SU}(2)_R$ symmetry and with hypercharge embedded in the unified gauge group, without encountering difficulties with naturalness [8].

The allowed contribution to ϵ'/ϵ in Figure 2 increases with the gluino mass (for fixed squark masses) because the K–$\bar{K}$ bounds become weaker in this case. If all supersymmetric masses are rescaled by a common factor ξ, and the bounds from K–$\bar{K}$ mixing are rescaled accordingly, the values for ϵ'/ϵ scale like $1/\xi$ modulo logarithmic effects from the running coupling $\alpha_s(\xi\widetilde{m})$. Therefore, even for larger squark masses of order 1 TeV the new contribution to ϵ'/ϵ can exceed the experimental value by a large amount, implying nontrivial constraints on $\mathrm{Im}\,\delta_{sd}^{LL}$.

Before concluding, we note that in the above discussion we have made no assumption regarding the mass insertion parameter $\mathrm{Im}\,\delta_{sd}^{RR} \equiv |\delta_{sd}^{RR}| \sin\phi_R$ for right-handed squarks. In models where $|\delta_{sd}^{RR}|$ is not highly suppressed relative to $|\delta_{sd}^{LL}|$, much tighter constraints on $\mathrm{Im}\,\delta_{sd}^{LL}$ can be derived by applying the severe bounds on the product $\delta_{sd}^{LL}\,\delta_{sd}^{RR}$ obtained from the chirally-enhanced contributions to K–$\bar{K}$ mixing. In analogy with Figure 1, we obtain an upper bound on $|\mathrm{Im}\,\delta_{sd}^{LL}|$ as a function of ϕ_L and ϕ_R, which is sharply peaked along the line $\phi_L + \phi_R = 0 \mod \pi$ and scales like $|\delta_{sd}^{LL}/\delta_{sd}^{RR}|^{1/2}$. As above, we take one quarter of the peak value obtained using the results compiled in [7]. Considering the case $m_{\tilde{d}_L} = m_{\tilde{g}} = 500\,\mathrm{GeV}$ for example, we find that the upper bounds on $|\mathrm{Im}\,\delta_{sd}^{LL}|$ a reduced by a factor ranging from 3% in the limit where $|\delta_{sd}^{RR}| = |\delta_{sd}^{LL}|$ to 8% for $|\delta_{sd}^{RR}| = 0.1|\delta_{sd}^{LL}|$. In the latter case, the supersymmetric contribution to ϵ'/ϵ can still be of order 10^{-3}, i.e., comparable to the measured value. Moreover, significantly larger values can be obtained for special points in moduli space, where the weak phases obey $\phi_L + \phi_R \approx 0 \mod \pi$.

In summary, we have shown that in supersymmetric extensions of the Standard Model gluino box diagrams can yield a large $\Delta I = \frac{3}{2}$ contribution to ϵ'/ϵ, which only requires moderate mass splitting between the right-handed squarks, i.e., $(m_{\tilde{u}_R} - m_{\tilde{d}_R})/m_{\tilde{d}_R} > 0.1$. In a large region of parameter space, the measured value of ϵ'/ϵ implies a significantly stronger bound on $\mathrm{Im}\,\delta_{sd}^{LL}$ than is obtained from K–$\bar{K}$ mixing.

Acknowledgments: We are grateful to Yuval Grossman and JoAnne Hewett for useful discussions. A.K. is supported by the United States Department of Energy under Grant No. DE-FG02-84ER40153, and M.N. under contract DE–AC03–76SF00515.

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