Search for new physics in CP-violating B decays

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We consider three possible scenarios of new physics in B_d^0-$\overline{B_d^0}$ mixing and propose a simple framework for analyzing their effects. This framework allows us to study the CP asymmetry in semileptonic B_d decays ($\mathcal{A}_{\rm SL}$) and those in nonleptonic transitions such as $B_d \to J/\psi\, K_S$ and $B_d \to \pi^+\pi^-$. Numerically we find that new physics may enhance the magnitude of $\mathcal{A}_{\rm SL}$ up to the percent level within the appropriate parameter space. So measurements of $\mathcal{A}_{\rm SL}$ and its correlation with other CP asymmetries will serve as a sensitive probe for new physics in B_d^0-$\overline{B_d^0}$ mixing. [S0556-2821(97)05823-2]

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I. INTRODUCTION

The B-meson factories under construction at KEK and SLAC will provide a unique opportunity to study CP violation in weak B decays. One type of CP-violating signals, arising from B_d^0-$\overline{B_d^0}$ mixing, is expected to manifest itself in the decay rate asymmetry between two semileptonic channels $B_d^0 \to l^+ \nu_l X^-$ and $\overline{B_d^0} \to l^- \overline{\nu_l} X^+$. This CP asymmetry, denoted as $\mathcal{A}_{\rm SL}$ below, has been estimated to be of the order 10^{-3} within the standard model (SM) [1,2]. Obviously the magnitude of $\mathcal{A}_{\rm SL}^{\rm SM}$ is too small to be measured in the first-round experiments of any B factory. The current experimental constraint on $\mathcal{A}_{\rm SL}$ is very rough: $|\mathcal{A}_{\rm SL}| < 0.18$ at the 90% confidence level [3,4]. Nevertheless, one expects that this limit will be greatly improved once B-meson factories start collecting data.

Importance of the CP asymmetry $\mathcal{A}_{\rm SL}$ has been repeatedly emphasized for the purpose of searching for new physics (NP) in the B-meson system (see, e.g., Refs. [5,6]). The presence of NP in B_d^0-$\overline{B_d^0}$ mixing might enhance the magnitude of $\mathcal{A}_{\rm SL}$ to an observable level. For instance, $|\mathcal{A}_{\rm SL}| \sim 10^{-2}$ can be achieved from a specific superweak model proposed in Ref. [6], where the Kobayashi-Maskawa (KM) matrix is assumed to be real and the CP-violating phase comes solely from the NP. It is therefore worthwhile to search for CP violation in semileptonic B_d decays at B-meson factories, in order to determine or constrain both the magnitude and the phase information of possible NP in B_d^0-$\overline{B_d^0}$ mixing. The CP-violating phase of NP may also be isolated from measuring CP asymmetries in some B_d decays into hadronic CP eigenstates, such as $B_d \to J/\psi\, K_S$ and $B_d \to \pi^+\pi^-$ modes [7,8].

In this paper we investigate the CP asymmetry $\mathcal{A}_{\rm SL}$ and its correlation with the CP asymmetries in $B_d \to J/\psi\, K_S$ and $B_d \to \pi^+\pi^-$, based on three NP scenarios for B_d^0-$\overline{B_d^0}$ mixing. Scenario (A) allows B_d^0-$\overline{B_d^0}$ mixing to contain a real SM-like term and a complex superweak contribution [9], scenario (B) requires B_d^0-$\overline{B_d^0}$ mixing to include the normal SM effect with an additional real superweak contribution [10], and scenario (C) is a general case in which both the SM and NP contributions to B_d^0-$\overline{B_d^0}$ mixing are complex (CP violating).

For each scenario, we first propose a simple parametrization of the NP effect, and then calculate CP-violating asymmetries in the above-mentioned B decays. Some numerical estimates for these CP asymmetries in scenarios (A) and (B) are also made. We find that for all three scenarios the magnitude of $\mathcal{A}_{\rm SL}$ can reach the percent level within the suitable parameter space. Thus an experimental study of the correlation between CP asymmetries in the semileptonic and nonleptonic B_d decays should impose useful constraints on possible NP in B_d^0-$\overline{B_d^0}$ mixing.

The remainder of this paper is organized as follows. In Sec. II, some necessary preliminaries for B_d^0-$\overline{B_d^0}$ mixing, CP violation, and the KM unitarity triangle are briefly reviewed. The SM prediction for CP violation in semileptonic B_d decays, i.e., $\mathcal{A}_{\rm SL}^{\rm SM}$, is updated in Sec. III. Section IV is devoted to parametrizing NP effects in B_d^0-$\overline{B_d^0}$ mixing and calculating $\mathcal{A}_{\rm SL}$ as well as its correlation with the CP asymmetries in $B_d \to J/\psi K_S$ and $B_d \to \pi^+\pi^-$, on the basis of three different NP scenarios. We numerically illustrate the allowed parameter space and CP asymmetries for scenarios (A) and (B) in Sec. V. Finally some concluding remarks are given in Sec. VI.

II. PRELIMINARIES

The mass eigenstates of B_d^0 and $\overline{B_d^0}$ mesons can be written, in the assumption of CPT invariance, as

$$|B_{\rm L}\rangle = p|B_d^0\rangle + q|\overline{B_d^0}\rangle,$$
$$|B_{\rm H}\rangle = p|B_d^0\rangle - q|\overline{B_d^0}\rangle, \tag{2.1}$$

where p and q are complex mixing parameters. In terms of the off-diagonal elements of the 2×2 B_d^0-$\overline{B_d^0}$ mixing Hamiltonian $\mathbf{M} - i\mathbf{\Gamma}/2$, we express the ratio q/p as

$$\frac{q}{p} = \sqrt{\frac{M_{12}^* - i\Gamma_{12}^*/2}{M_{12} - i\Gamma_{12}/2}}. \tag{2.2}$$

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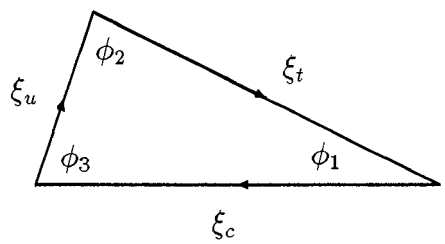

FIG. 1. Unitarity triangle ($\xi_u+\xi_c+\xi_t=0$) in the complex plane.

To a good approximation (i.e., $|M_{12}|\gg|\Gamma_{12}|$), the mass difference of $B_{\rm H}$ and $B_{\rm L}$ (denoted by ΔM) is related to $|M_{12}|$ through $\Delta M=2|M_{12}|$, and $q/p=\sqrt{M_{12}^*/M_{12}}$ holds.

The CP-violating asymmetry $\mathcal{A}_{\rm SL}$, for either incoherent or coherent decays of B_d^0 and $\overline{B_d^0}$ mesons, is given by [11]

$$\mathcal{A}_{\rm SL}=\frac{|p|^4-|q|^4}{|p|^4+|q|^4}={\rm Im}\left(\frac{\Gamma_{12}}{M_{12}}\right), \tag{2.3}$$

At a B-meson factory, this signal can be extracted from the same-sign dilepton asymmetry on the $\Upsilon(4S)$ resonance.

Another observable, which is of particular interest for testing the KM mechanism of CP violation, is the CP asymmetry in B_d^0 vs $\overline{B_d^0}\to J/\psi K_S$ modes [12]:

$$\mathcal{A}_{\psi K}=-{\rm Im}\left(\frac{q}{p}\frac{V_{cb}V_{cs}^*}{V_{cb}^*V_{cs}}\frac{q_K^*}{p_K^*}\right), \tag{2.4}$$

where the minus sign comes from the CP-odd eigenstate $J/\psi K_S$, and q_K/p_K describes the K^0-$\overline{K^0}$ mixing phase in the final state. Neglecting the tiny CP-violating effect measured from K^0-$\overline{K^0}$ mixing, one can find that q_K/p_K is essentially unity in an appropriate phase convention, no matter whether NP exists or not. Thus the above asymmetry turns out approximately to be $\mathcal{A}_{\psi K}=-{\rm Im}(q/p)$, if one adopts the Wolfenstein phase convention [13] for the KM matrix.

In the neglect of penguin effects, measuring the CP asymmetry in B_d^0 vs $\overline{B_d^0}\to\pi^+\pi^-$ modes is also promising to probe the CP-violating weak phase [12]:

$$\mathcal{A}_{\pi\pi}={\rm Im}\left(\frac{q}{p}\frac{V_{ub}V_{ud}^*}{V_{ub}^*V_{ud}}\right). \tag{2.5}$$

The correlation between $\mathcal{A}_{\pi\pi}$ and $\mathcal{A}_{\psi K}$ is sensitive to a variety of NP scenarios, such as superweak models (see, e.g., Refs. [10,14]).

Within the SM, $\mathcal{A}_{\rm SL}$, $\mathcal{A}_{\psi K}$, and $\mathcal{A}_{\pi\pi}$ are related to the inner angles of the KM unitarity triangle formed by three vectors $\xi_i\equiv V_{ib}^*V_{id}$ $(i=u,c,t)$ in the complex plane (see Fig. 1 for illustration). The sides $|\xi_u|$ and $|\xi_c|$ have been model-independently measured, while the existence of NP may in general affect determination of the side $|\xi_t|$ from the rate of B_d^0-$\overline{B_d^0}$ mixing. In terms of the Wolfenstein parameters, one has

$$\xi_u\approx A\lambda^3(\rho+i\eta),$$

$$\xi_c\approx -A\lambda^3,$$

$$\xi_t\approx A\lambda^3(1-\rho-i\eta). \tag{2.6}$$

For convenience in subsequent discussions, we define

$$\chi\equiv\left|\frac{\xi_u}{\xi_c}\right|\approx\sqrt{\rho^2+\eta^2}, \tag{2.7}$$

which is a NP-independent quantity.

Note that in this work we only assume the kind of NP which does not involve extra quark(s). This requirement implies that quark mixing remains to be described by the 3×3 KM matrix even though NP is present in B_d^0-$\overline{B_d^0}$ mixing. For some interesting extensions of the SM, e.g., the supersymmetric models, the above assumption is of course satisfied. We further assume that the penguin and tree-level contributions to $B_d\to\pi^+\pi^-$ may be separated from each other using some well-known techniques [15,16], and thus $\mathcal{A}_{\pi\pi}$ is useful for probing the CP-violating weak phase(s).

III. *CP* ASYMMETRIES IN THE SM

Within the SM, both M_{12} and Γ_{12} can be reliably calculated in the box-diagram approximation. Because of the dominance of the top-quark contribution, $M_{12}^{\rm SM}$ reads [17,18]

$$M_{12}^{\rm SM}=\frac{G_{\rm F}^2B_Bf_B^2M_Bm_t^2}{12\pi^2}\eta_BF(z)(\xi_t^*)^2, \tag{3.1}$$

where B_B is the ''bag'' parameter describing the uncertainty in evaluation of the hadronic matrix element $\langle B_d^0|\overline{b}\gamma_\mu(1-\gamma_5)d|\overline{B_d^0}\rangle$, M_B and f_B are the B_d-meson mass and decay constants, respectively, m_t is the top-quark mass, η_B denotes the QCD correction factor, and $F(z)$ stands for a slowly decreasing monotonic function of $z\equiv m_t^2/M_W^2$ [19]:

$$F(z)=\frac{1}{4}+\frac{9}{4}\frac{1}{1-z}-\frac{3}{2}\frac{1}{(1-z)^2}-\frac{3}{2}\frac{z^2\ln z}{(1-z)^3}. \tag{3.2}$$

In particular, $F(0)=1$, $F(1)=3/4$, and $F(\infty)=1/4$.

Next, $\Gamma_{12}^{\rm SM}$ is given as follows [11,18]:

$$\Gamma_{12}^{\rm SM}=-\frac{G_{\rm F}^2B_Bf_B^2M_Bm_b^2}{8\pi}[(\xi_u^*)^2T_u(\tilde{z})+(\xi_c^*)^2T_c(\tilde{z})+(\xi_t^*)^2T_t(\tilde{z})], \tag{3.3}$$

where m_b is the bottom-quark mass, and $T_i(\tilde{z})$ is a function of $\tilde{z}\equiv m_c^2/m_b^2$. Explicitly, $T_u(\tilde{z})$, $T_c(\tilde{z})$, and $T_t(\tilde{z})$ read

$$T_u(\tilde{z})=\eta_4\tilde{z}^2(3-2\tilde{z})+\frac{4}{3}\eta_5\tilde{z}(1-\tilde{z})^2,$$

$$T_c(\tilde{z})=\eta_4(1+2\tilde{z})[\sqrt{1-4\tilde{z}}-(1-\tilde{z})^2]-\frac{4}{3}\eta_5\tilde{z}[2\sqrt{1-4\tilde{z}}-(1-\tilde{z})^2],$$

$$T_t(\tilde{z})=\eta_4(1+2\tilde{z})(1-\tilde{z})^2-\frac{4}{3}\eta_5\tilde{z}(1-\tilde{z})^2, \quad (3.4)$$

in which η_4 and η_5 are two QCD correction factors. A numerical calculation shows that $T_t(\tilde{z})$ is dominant over $T_u(\tilde{z})$ and $T_c(\tilde{z})$ in magnitude (see below).

The CP asymmetry in semileptonic B_d decays ($\mathcal{A}_{\rm SL}^{\rm SM}$) turns out to be

$$\mathcal{A}_{\rm SL}^{\rm SM}=C_m\left[{\rm Im}\left(\frac{\xi_u}{\xi_t}\right)^2T_u(\tilde{z})+{\rm Im}\left(\frac{\xi_c}{\xi_t}\right)^2T_c(\tilde{z})\right], \quad (3.5)$$

where $C_m=3\pi m_b^2/[2m_t^2\eta_BF(z)]$, and

$${\rm Im}\left(\frac{\xi_u}{\xi_t}\right)^2\approx\frac{2\eta[\rho(1-\rho)-\eta^2]}{[(1-\rho)^2+\eta^2]^2},$$

$${\rm Im}\left(\frac{\xi_c}{\xi_t}\right)^2\approx\frac{2\eta(1-\rho)}{[(1-\rho)^2+\eta^2]^2}. \quad (3.6)$$

The $T_t(\tilde{z})$ term, which dominates $\Gamma_{12}^{\rm SM}$, has no contribution to the CP asymmetry $\mathcal{A}_{\rm SL}^{\rm SM}$.

Indeed the CP-violating phases ϕ_1 and ϕ_2 can be determined from the CP asymmetries in $B_d\to J/\psi K_S$ and $B_d\to\pi^+\pi^-$, respectively. Within the SM, $q/p=\xi_t/\xi_t^*$ results from the box-diagram calculation. From Eqs. (2.4) and (2.5), it is easy to obtain

$$\mathcal{A}_{\psi K}^{\rm SM}=\sin(2\phi_1)\approx\frac{2\eta(1-\rho)}{(1-\rho)^2+\eta^2},$$

$$\mathcal{A}_{\pi\pi}^{\rm SM}=\sin(2\phi_2)\approx\frac{2\eta[\eta^2-\rho(1-\rho)]}{(\rho^2+\eta^2)[(1-\rho)^2+\eta^2]}. \quad (3.7)$$

A test of the correlation between $\mathcal{A}_{\rm SL}^{\rm SM}$ and $\mathcal{A}_{\psi K}^{\rm SM}$ or that between $\mathcal{A}_{\psi K}^{\rm SM}$ and $\mathcal{A}_{\pi\pi}^{\rm SM}$ at B factories is necessary, in order to find possible NP which may affect these observables in different ways.

Let us illustrate the magnitudes of $\mathcal{A}_{\rm SL}^{\rm SM}$, $\mathcal{A}_{\psi K}^{\rm SM}$, and $\mathcal{A}_{\pi\pi}^{\rm SM}$ explicitly. The current quark masses are typically taken as $m_c=1.4$ GeV, $m_b=4.8$ GeV, and $m_t=167$ GeV, and the QCD correction factors are chosen to be $\eta_B=0.55$, $\eta_4=1.15$, and $\eta_5=0.88$. Then one gets $F(z)\approx0.55$, $T_u(\tilde{z})\approx0.11$, $T_c(\tilde{z})\approx-0.11$, $T_t(\tilde{z})\approx1.04$, and $C_m\approx1.3\times10^{-2}$. An analysis of current data on quark mixing and CP violation yields $\rho\approx0.05$ and $\eta\approx0.36$ as favored values [20]. With these inputs we arrive at

$$\mathcal{A}_{\psi K}^{\rm SM}\approx0.66, \quad \mathcal{A}_{\pi\pi}^{\rm SM}\approx0.43, \quad \mathcal{A}_{\rm SL}^{\rm SM}\approx-9.8\times10^{-4}. \quad (3.8)$$

If the large errors of relevant inputs are taken into account, we find that the magnitude of $\mathcal{A}_{\rm SL}^{\rm SM}$ may change a little bit around 10^{-3}, but its sign remains negative. Clearly it is very difficult to measure such a small CP asymmetry.

IV. EFFECTS OF NP ON *CP* ASYMMETRIES

In most extensions of the SM, NP can significantly contribute to M_{12}. However, NP is not expected to significantly affect the direct B-meson decays via the tree-level W-mediated channels. Thus $\Gamma_{12}=\Gamma_{12}^{\rm SM}$ holds as a good approximation. In the presence of NP, M_{12} can be written as

$$M_{12}=M_{12}^{\rm SM}+M_{12}^{\rm NP}. \quad (4.1)$$

The relative magnitude and the phase difference between $M_{12}^{\rm NP}$ and $M_{12}^{\rm SM}$ are unknown, while $|M_{12}|=\Delta M/2$ holds by definition.

It is convenient to parametrize the magnitude of $M_{12}^{\rm SM}$ as

$$|M_{12}^{\rm SM}|=R_{\rm SM}\frac{\Delta M}{2} \quad (4.2)$$

in subsequent discussions. The allowed range of $R_{\rm SM}$ can be estimated by use of Eq. (3.1) and current data; i.e.,

$$R_{\rm SM}=\frac{G_{\rm F}^2B_Bf_B^2M_Bm_t^2}{6\pi^2\Delta M}\eta_BF(z)|\xi_t|^2. \quad (4.3)$$

Using $f_B\sqrt{B_B}=(200\pm40)$ MeV, $m_t=(167\pm6)$ GeV, $\Delta M=(0.464\pm0.018)$ ps^{-1}, and $\eta_B=0.55\pm0.01$ (see Ref. [21]), we get $R_{\rm SM}\approx(1.34\pm0.71)\times10^4|\xi_t|^2$. The large error comes primarily from the input value of $f_B\sqrt{B_B}$, which will be improved in more delicate lattice-QCD calculations. Since $|\xi_u|$ and $|\xi_c|$ have been measured, the most generous constraint on $|\xi_t|$ (in the presence of NP) should be

$$|\xi_c|-|\xi_u|\leqslant|\xi_t|\leqslant|\xi_c|+|\xi_u|, \quad (4.4)$$

as one can see from Fig. 1. A measurement of the rare decay $K^+\to\pi^+\nu\bar{\nu}$ will provide an independent determination of (or constraint on) $|\xi_t|$. By use of $|\xi_u|=0.003\pm0.001$ and $|\xi_c|=0.0087\pm0.0007$ [4,20], we get $0.1\leqslant R_{\rm SM}\leqslant3.7$ as a conservative result. If only the central values of input parameters are taken into account, then a narrower range can be obtained: $0.43\leqslant R_{\rm SM}\leqslant1.8$.

To illustrate the effect of NP on CP asymmetries $\mathcal{A}_{\rm SL}$, $\mathcal{A}_{\psi K}$, and $\mathcal{A}_{\pi\pi}$, we subsequently consider three possible NP scenarios for M_{12}.

A. Scenario (A): Im($M_{12}^{\rm SM}$)=0 and Im($M_{12}^{\rm NP}$)≠0

In this scenario, the KM matrix is assumed to be real and CP violation arises solely from NP. Then $M_{12}^{\rm SM}$, $M_{12}^{\rm NP}$, and M_{12} in Eq. (4.1) can be instructively parametrized as

$$\{M_{12}^{\rm SM},M_{12}^{\rm NP},M_{12}\}=\{R_{\rm SM},R_{\rm NP}e^{i2\theta},e^{i2\phi}\}\frac{\Delta M}{2}, \quad (4.5)$$

where $R_{\rm NP}$ is a real (positive or vanishing) parameter, θ stands for the phase of NP, and ϕ is an effective phase of

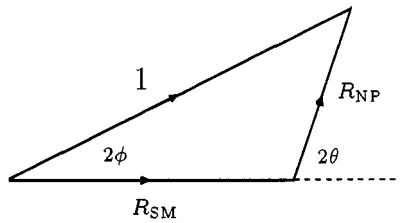

FIG. 2. Triangular relation of $M_{12}^{\rm SM}$, $M_{12}^{\rm NP}$, and M_{12} (rescaled by $\Delta M/2$) in scenario (A).

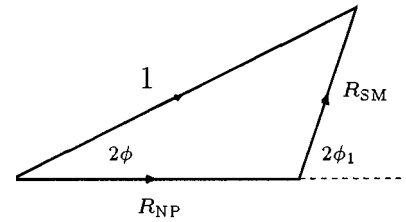

FIG. 3. Triangular relation of $M_{12}^{\rm SM}$, $M_{12}^{\rm NP}$, and M_{12} (rescaled by $\Delta M/2$) in scenario (B).

B_d^0-$\overline{B_d^0}$ mixing. In the complex plane, $M_{12}^{\rm SM}$, $M_{12}^{\rm NP}$, and M_{12} (or, equivalently, $R_{\rm SM}$, $R_{\rm NP}e^{i2\theta}$, and $e^{i2\phi}$) form a triangle [22], as illustrated by Fig. 2. By use of the triangular relation, $R_{\rm NP}$ can be expressed as

$$R_{\rm NP}=-R_{\rm SM}\cos(2\theta)\pm\sqrt{1-R_{\rm SM}^2\sin^2(2\theta)}. \tag{4.6}$$

We find that two solutions exist for $R_{\rm NP}$, corresponding to $(\pm)$ signs on the right-hand side of Eq. (4.6). Since the magnitude of $R_{\rm SM}$ has been constrained to some extent, we are able to obtain the allowed $(\theta,R_{\rm NP})$ parameter space numerically.

The CP-violating phase ϕ can be measured from the CP asymmetry in $B_d\to J/\psi K_S$. With the help of Eq. (2.4), we obtain

$$\mathcal{A}_{\psi K}=\sin(2\phi)=R_{\rm NP}\sin(2\theta). \tag{4.7}$$

Of course, $|\mathcal{A}_{\psi K}|\leqslant 1$ holds for $R_{\rm NP}$ and θ to take values allowed by Eq. (4.6).

The CP asymmetry in $B_d\to\pi^+\pi^-$ is simply related to $\mathcal{A}_{\psi K}$. By use of Eq. (2.5), we find

$$\mathcal{A}_{\pi\pi}=-\sin(2\phi)=-\mathcal{A}_{\psi K}. \tag{4.8}$$

Such a linear correlation between $\mathcal{A}_{\psi K}$ and $\mathcal{A}_{\pi\pi}$ is a straightforward consequence of the superweak scenario of NP considered here.

The CP asymmetry in semileptonic B_d decays, defined in Eq. (2.3), is given by

$$\mathcal{A}_{\rm SL}=C_mR_{\rm SM}R_{\rm NP}\sin(2\theta)\left[\left(\frac{\tilde{\xi}_u}{\tilde{\xi}_t}\right)^2T_u(\tilde{z})+\left(\frac{\tilde{\xi}_c}{\tilde{\xi}_t}\right)^2T_c(\tilde{z})+T_t(\tilde{z})\right], \tag{4.9}$$

where $\tilde{\xi}_u$, $\tilde{\xi}_c$, and $\tilde{\xi}_t$ denote the real KM factors in scenario (A). Different from the SM result in Eq. (3.5), whose magnitude is associated only with $T_u(\tilde{z})\sim 0.1$ and $T_c(\tilde{z})\sim -0.1$, here the magnitude of $\mathcal{A}_{\rm SL}$ is dominated by $T_t(\tilde{z})\sim 1$. Hence $|\mathcal{A}_{\rm SL}/\mathcal{A}_{\rm SL}^{\rm SM}|\geqslant 10$ is possible within an appropriate $(\theta,R_{\rm NP})$ parameter space. We shall present numerical estimates for $\mathcal{A}_{\rm SL}$ and $\mathcal{A}_{\psi K}$ in the next section.

B. Scenario (B): $\mathrm{Im}(M_{12}^{\rm NP})=0$ and $\mathrm{Im}(M_{12}^{\rm SM})\neq 0$

In this scenario the NP contribution is of the so-called ''real superweak'' type [10,24]. The phase of $M_{12}^{\rm SM}$ comes from the KM matrix and amounts to $2\phi_1$, as one can see from Eq. (3.1) and Fig. 1. For simplicity, we parametrize $M_{12}^{\rm SM}$, $M_{12}^{\rm NP}$, and M_{12} as follows:

$$\{M_{12}^{\rm SM},M_{12}^{\rm NP},M_{12}\}=\{R_{\rm SM}e^{i2\phi_1},R_{\rm NP},e^{i2\phi}\}\frac{\Delta M}{2}, \tag{4.10}$$

where $R_{\rm NP}$ is a real parameter, and ϕ denotes the effective phase of B_d^0-$\overline{B_d^0}$ mixing. Clearly $M_{12}^{\rm SM}$, $M_{12}^{\rm NP}$, and M_{12} (or equivalently, $R_{\rm SM}e^{i2\phi_1}$, $R_{\rm NP}$, and $e^{i2\phi}$) form a triangle in the complex plane, as illustrated by Fig. 3. In terms of $R_{\rm SM}$ and ϕ_1, $R_{\rm NP}$ can be written as [10]

$$R_{\rm NP}=-R_{\rm SM}\cos(2\phi_1)\pm\sqrt{1-R_{\rm SM}^2\sin^2(2\phi_1)}. \tag{4.11}$$

We see that there are two solutions for $R_{\rm NP}$, corresponding to $(\pm)$ signs on the right-hand side of Eq. (4.11).

The CP-violating phase ϕ can be determined from the CP asymmetry in $B_d\to J/\psi K_S$:

$$\mathcal{A}_{\psi K}=\sin(2\phi)=R_{\rm SM}\sin(2\phi_1). \tag{4.12}$$

Of course, $|\mathcal{A}_{\psi K}|\leqslant 1$ holds if $R_{\rm SM}$ and ϕ_1 vary in their allowed regions.

The CP asymmetry in $B_d\to\pi^+\pi^-$ reads

$$\mathcal{A}_{\pi\pi}=-\sin 2(\phi+\phi_3)=R_{\rm SM}\sin(2\phi_2)-R_{\rm NP}\sin(2\phi_3), \tag{4.13}$$

where ϕ_2 and ϕ_3 are the second and third angles of the unitarity triangle (see Fig. 1). The correlation between $\mathcal{A}_{\psi K}$ and $\mathcal{A}_{\pi\pi}$ does exist, because of $\phi_1+\phi_2+\phi_3=\pi$. In the absence of NP (i.e., $R_{\rm NP}=0$ and $R_{\rm SM}=1$), Eqs. (4.12) and (4.13) will be simplified to the SM results as given by Eq. (3.7).

The CP asymmetry $\mathcal{A}_{\rm SL}$ in scenario (B) turns out to be

$$\mathcal{A}_{\rm SL}=C_mR_{\rm SM}R_{\rm NP}\left[\mathrm{Im}\left(\frac{\xi_u}{|\xi_t|}\right)^2T_u(\tilde{z})+\mathrm{Im}\left(\frac{\xi_c}{|\xi_t|}\right)^2T_c(\tilde{z})+\mathrm{Im}\left(\frac{\xi_t}{|\xi_t|}\right)^2T_t(\tilde{z})\right]+C_mR_{\rm SM}^2\left[\mathrm{Im}\left(\frac{\xi_u}{\xi_t}\right)^2T_u(\tilde{z})+\mathrm{Im}\left(\frac{\xi_c}{\xi_t}\right)^2T_c(\tilde{z})\right]. \tag{4.14}$$

One can see that $\mathcal{A}_{\rm SL}$ consists of two terms: The first comes from the interference between $M_{12}^{\rm SM}$ and $M_{12}^{\rm NP}$ in M_{12}, while the second is purely a SM-like contribution from $M_{12}^{\rm SM}$ itself [see Eq. (3.5) for comparison]. Within a suitable parameter

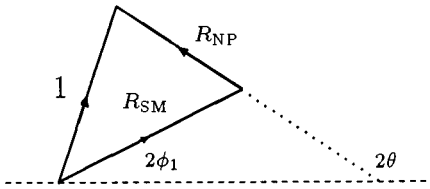

FIG. 4. Triangular relation of $M_{12}^{\rm SM}$, $M_{12}^{\rm NP}$, and M_{12} (rescaled by $\Delta M/2$) in scenario (C).

space, the magnitude of $\mathcal{A}_{\rm SL}$ should be dominated by the term associated with $T_t(\tilde{z})$; thus $|\mathcal{A}_{\rm SL}/\mathcal{A}_{\rm SL}^{\rm SM}|\geqslant 10$ is possible in this NP scenario.

C. Scenario (C): $\mathrm{Im}(M_{12}^{\rm NP})\neq 0$ and $\mathrm{Im}(M_{12}^{\rm SM})\neq 0$

This is a quite general NP scenario which can accommodate both scenarios (A) and (B). As done before, we parametrize $M_{12}^{\rm SM}$, $M_{12}^{\rm NP}$, and M_{12} in the following way:

$$\{M_{12}^{\rm SM},M_{12}^{\rm NP},M_{12}\}=\{R_{\rm SM}e^{i2\phi_1},R_{\rm NP}e^{i2\theta},e^{i2\phi}\}\frac{\Delta M}{2}, \tag{4.15}$$

where $R_{\rm NP}$ is a real (positive or vanishing) parameter, θ represents the NP phase, and ϕ denotes the effective phase of B_d^0-$\overline{B_d^0}$ mixing. In this case, $M_{12}^{\rm SM}$, $M_{12}^{\rm NP}$, and M_{12} (or, equivalently, $R_{\rm SM}e^{i2\phi_1}$, $R_{\rm NP}e^{i2\theta}$, and $e^{i2\phi}$) form a triangle in the complex plane, as illustrated by Fig. 4. In terms of $R_{\rm SM}$, ϕ_1, and θ, $R_{\rm NP}$ can be expressed as

$$R_{\rm NP}=-R_{\rm SM}\cos 2(\theta-\phi_1)\pm\sqrt{1-R_{\rm SM}^2\sin^2 2(\theta-\phi_1)}. \tag{4.16}$$

We observe that $R_{\rm NP}$ depends on the phase difference between θ and ϕ_1. Also there exist two solutions for $R_{\rm NP}$, corresponding to $(\pm)$ signs on the right-hand side of Eq. (4.16). In the special case $\theta=\phi_1$, one arrives at $R_{\rm NP}=-R_{\rm SM}\pm 1$.

It is straightforward to derive the CP asymmetry $\mathcal{A}_{\psi K}$ in B_d^0 vs $\overline{B_d^0}\to J/\psi K_S$ modes:

$$\mathcal{A}_{\psi K}=\sin(2\phi)=R_{\rm SM}\sin(2\phi_1)+R_{\rm NP}\sin(2\theta). \tag{4.17}$$

Since $R_{\rm NP}$, $R_{\rm SM}$, ϕ_1, and θ are dependent on one another through Eq. (4.16), $|\mathcal{A}_{\psi K}|\leqslant 1$ is always guaranteed within the allowed parameter space.

In scenario (C), the CP asymmetry in $B_d\to\pi^+\pi^-$ is given as

$$\mathcal{A}_{\pi\pi}=-\sin 2(\phi+\phi_3)=R_{\rm SM}\sin(2\phi_2)-R_{\rm NP}\sin 2(\theta+\phi_3), \tag{4.18}$$

where ϕ_2 and ϕ_3 are two inner angles of the unitarity triangle in Fig. 1. In comparison with scenarios (A) and (B), here the correlation between $\mathcal{A}_{\psi K}$ and $\mathcal{A}_{\pi\pi}$ becomes more complicated. We see that the results in Eqs. (4.12) and (4.13) can be respectively reproduced from Eqs. (4.17) and (4.18) if $\theta=0$ is taken.

The CP asymmetry $\mathcal{A}_{\rm SL}$ in scenario (C) reads

$$\mathcal{A}_{\rm SL}=C_mR_{\rm SM}R_{\rm NP}\left[\mathrm{Im}\left(\frac{\xi_u}{|\xi_t|}\right)^2T_u(\tilde{z})+\mathrm{Im}\left(\frac{\xi_c}{|\xi_t|}\right)^2T_c(\tilde{z})+\mathrm{Im}\left(\frac{\xi_t}{|\xi_t|}\right)^2T_t(\tilde{z})\right]\cos(2\theta)+C_mR_{\rm SM}^2\left[\mathrm{Im}\left(\frac{\xi_u}{\xi_t}\right)^2T_u(\tilde{z})+\mathrm{Im}\left(\frac{\xi_c}{\xi_t}\right)^2T_c(\tilde{z})\right]+C_mR_{\rm SM}R_{\rm NP}\left[\mathrm{Re}\left(\frac{\xi_u}{|\xi_t|}\right)^2T_u(\tilde{z})+\mathrm{Re}\left(\frac{\xi_c}{|\xi_t|}\right)^2T_c(\tilde{z})+\mathrm{Re}\left(\frac{\xi_t}{|\xi_t|}\right)^2T_t(\tilde{z})\right]\sin(2\theta). \tag{4.19}$$

Clearly the second term of $\mathcal{A}_{\rm SL}$ comes purely from $M_{12}^{\rm SM}$ itself and its magnitude is expected to be of $\sim 10^{-3}$. The first and third terms of $\mathcal{A}_{\rm SL}$ arise from the interference between $M_{12}^{\rm SM}$ and $M_{12}^{\rm NP}$, but they depend on nonvanishing $\mathrm{Im}(M_{12}^{\rm SM})$ and $\mathrm{Im}(M_{12}^{\rm NP})$, respectively. Thus $\mathcal{A}_{\rm SL}(\theta=0)$ is just the result given by Eq. (4.14) for scenario (B). For appropriate values of θ and ϕ_1, magnitudes of both the first and third terms of $\mathcal{A}_{\rm SL}$ may be at the percent level. To obtain $|\mathcal{A}_{\rm SL}|\sim 10^{-2}$, however, there should not be large cancellation between two dominant terms in Eq. (4.19).

V. NUMERICAL ESTIMATES OF CP ASYMMETRIES

For the purpose of illustration, let us estimate the magnitudes of CP asymmetries obtained from the above NP scenarios. Since scenario (C) involves several unknown parameters [though they are related to one another through Eq. (4.16)], a numerical analysis of its allowed parameter space would be complicated and less instructive [25]. Hence we shall only concentrate on scenarios (A) and (B) in the following.

A. Results for scenario (A)

Following the spirit of the Wolfenstein parametrization [13], the real KM matrix $\tilde{V}$ in scenario (A) can be parametrized in terms of three independent parameters $\tilde{\lambda}$, $\tilde{A}$, and $\tilde{\rho}$. Taking $\tilde{V}_{us}=\tilde{\lambda}$, $\tilde{V}_{cb}=\tilde{A}\tilde{\lambda}^2$, and $\tilde{V}_{ub}=\tilde{A}\tilde{\lambda}^3\tilde{\rho}$ and using the orthogonality conditions of $\tilde{V}$, one can derive the other six matrix elements. In particular, we get $\tilde{V}_{td}\approx\tilde{A}\tilde{\lambda}^3(1-\tilde{\rho})$. In view of current data on $|\tilde{V}_{us}|$, $|\tilde{V}_{cb}|$, and $|\tilde{V}_{ub}/\tilde{V}_{cb}|$ (see Ref. [4]), we find $\tilde{\lambda}\approx 0.22$, $\tilde{A}\approx 0.8$, and $\tilde{\rho}\approx\pm 0.36$ typically. The sign ambiguity of $\tilde{\rho}$ may affect the allowed parameter space of NP as well as the CP asymmetries of B-meson decays, as one can see later on.

The size of $R_{\rm SM}$ depends on the real KM factor $\tilde{\xi}_t$. With the help of Eq. (4.3), we get $R_{\rm SM}\approx 1.8$ for $\tilde{\rho}\approx -0.36$ and

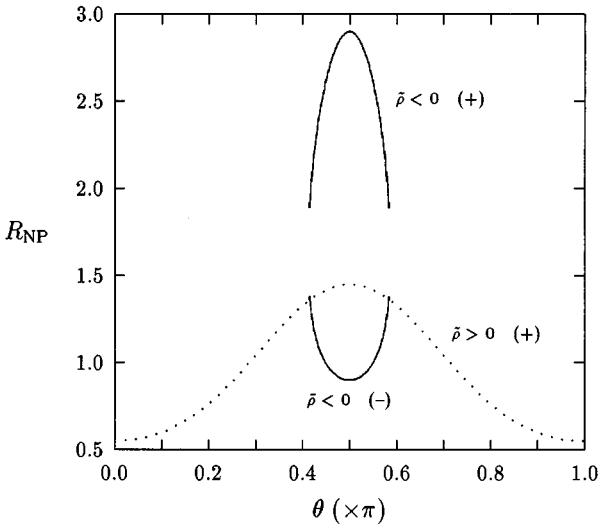

FIG. 5. Illustrative plot for the (θ, R_{NP}) parameter space in scenario (A).

$R_{SM} \approx 0.43$ for $\tilde{\rho} \approx +0.36$. The corresponding results of R_{NP}, changing with θ, can be obtained from Eq. (4.6). We find that for $\tilde{\rho} \approx +0.36$ the $(-)$ solution of R_{NP} is not allowed. The allowed (θ, R_{NP}) parameter space is shown in Fig. 5.

The CP asymmetries $\mathcal{A}_{SL}$ and $\mathcal{A}_{\psi K}$ (or $\mathcal{A}_{\pi\pi}$) in this scenario can then be calculated by use of the above-obtained parameter space. For simplicity, we express the KM factors $\tilde{\xi}_u$, $\tilde{\xi}_c$, and $\tilde{\xi}_t$ in Eq. (4.9) in terms of $\tilde{\lambda}$, $\tilde{A}$, and $\tilde{\rho}$. Then the correlation between $\mathcal{A}_{SL}$ and $\mathcal{A}_{\psi K}$ reads

$$\mathcal{A}_{SL} \approx C_m R_{SM} \left[\frac{\tilde{\rho}^2}{(1-\tilde{\rho})^2} T_u(\tilde{z}) + \frac{1}{(1-\tilde{\rho})^2} T_c(\tilde{z}) + T_t(\tilde{z}) \right] \mathcal{A}_{\psi K}, \tag{5.1}$$

with $\tilde{\rho} \approx \pm 0.36$. The results of $\mathcal{A}_{SL}$ and $\mathcal{A}_{\psi K}$, changing with the CP-violating phase θ, are depicted in Fig. 6. Two remarks are in order.

(a) With the typical inputs mentioned above, we have found $\mathcal{A}_{SL}/\mathcal{A}_{\psi K} \approx 0.023$ for $\tilde{\rho} \approx -0.36$ and $\mathcal{A}_{SL}/\mathcal{A}_{\psi K} \approx 0.0042$ for $\tilde{\rho} \approx +0.36$. Because of $|\mathcal{A}_{\psi K}| \leqslant 1$, only the former case is likely to lead the magnitude of $\mathcal{A}_{SL}$ to the percent level.

(b) In both cases, however, the CP asymmetry $\mathcal{A}_{\psi K}$ may take promising values (e.g., $|\mathcal{A}_{\psi K}| \geqslant 0.5$). The correlation between $\mathcal{A}_{\psi K}$ and $\mathcal{A}_{\pi\pi}$, i.e., $\mathcal{A}_{\pi\pi} = -\mathcal{A}_{\psi K}$, is particularly interesting in this superweak scenario of NP. If this correlation and the one between $\mathcal{A}_{SL}$ and $\mathcal{A}_{\psi K}$ can be measured at a B-meson factory, they will provide a strong constraint on the underlying NP in B_d^0-$\overline{B_d^0}$ mixing.

B. Results for scenario (B)

To calculate R_{NP} with the help of Eq. (4.11), we should first estimate R_{SM} by use of Eq. (4.3). The magnitude of R_{SM} depends on $|\xi_t|$:

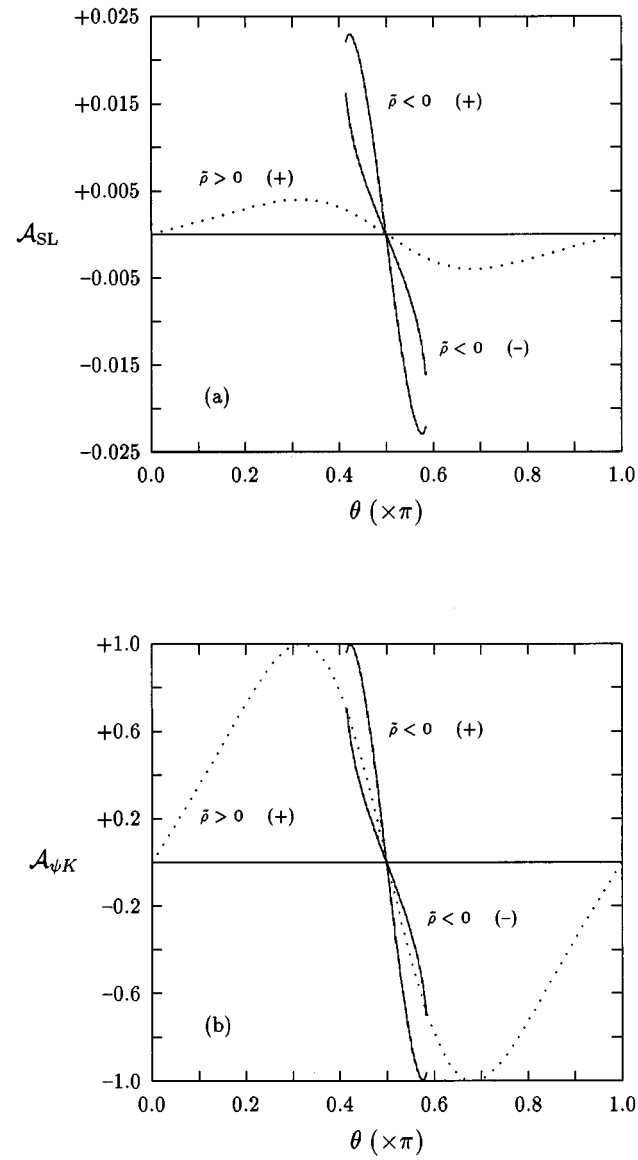

FIG. 6. Illustrative plot for the CP asymmetries $\mathcal{A}_{SL}$ and $\mathcal{A}_{\psi K}$ in scenario (A).

$$|\xi_t| \approx A\lambda^3 \sqrt{(1-\rho)^2 + \eta^2} \approx A\lambda^3 \sqrt{1 - 2\rho + \chi^2}, \tag{5.2}$$

where χ has been defined in Eq. (2.7). From current data on $|V_{us}|$, $|V_{cb}|$, and $|V_{ub}/V_{cb}|$, we get $\lambda \approx 0.22$, $A \approx 0.8$, and $\chi \approx 0.36$. The most generous range of ρ, due to the presence of NP, should be $-\chi \leqslant \rho \leqslant +\chi$. We find that the resultant region of $|\xi_t|$ is just the one given in Eq. (4.4). Note that ϕ_1 is also a function of ρ and χ, i.e.,

$$\tan\phi_1 \approx \pm \frac{\sqrt{\chi^2 - \rho^2}}{1-\rho}, \tag{5.3}$$

and thus it cannot take arbitrary values from 0 to π. For this reason, it is more convenient to calculate the (ρ, R_{NP}) parameter space of scenario (B) by taking $\rho \in [-0.36, +0.36]$. We get $0° \leqslant \phi_1 \leqslant 20.1°$ or $158.9° \leqslant \phi_1 \leqslant 180°$, corresponding to the $(+)$ or $(-)$ sign of $\tan\phi_1$. The allowed region of R_{NP} changing with ρ is shown in Fig. 7.

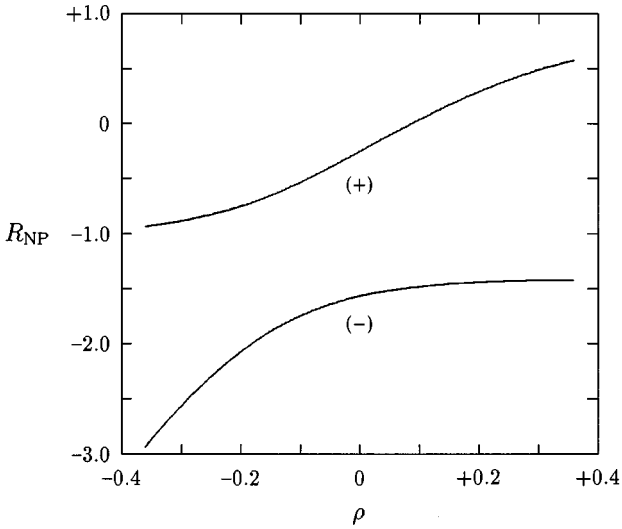

FIG. 7. Illustrative plot for the $(\rho, R_{\rm NP})$ parameter space in scenario (B).

Now we calculate the CP asymmetries $\mathcal{A}_{\psi K}$, $\mathcal{A}_{\pi\pi}$, and $\mathcal{A}_{\rm SL}$ by use of Eqs. (4.12), (4.13), and (4.14), respectively. In terms of the parameters ρ and χ, the correlation between $\mathcal{A}_{\pi\pi}$ and $\mathcal{A}_{\psi K}$ can be given as

$$\mathcal{A}_{\pi\pi} \approx -\left[\frac{\rho-\chi^2}{\chi^2(1-\rho)} + \frac{\rho(1-2\rho+\chi^2)}{\chi^2(1-\rho)}\frac{R_{\rm NP}}{R_{\rm SM}}\right]\mathcal{A}_{\psi K}. \tag{5.4}$$

Similarly we obtain the correlation between $\mathcal{A}_{\rm SL}$ and $\mathcal{A}_{\psi K}$ as follows:

$$\mathcal{A}_{\rm SL} \approx C_m f(\rho,\chi)\mathcal{A}_{\psi K}, \tag{5.5}$$

where

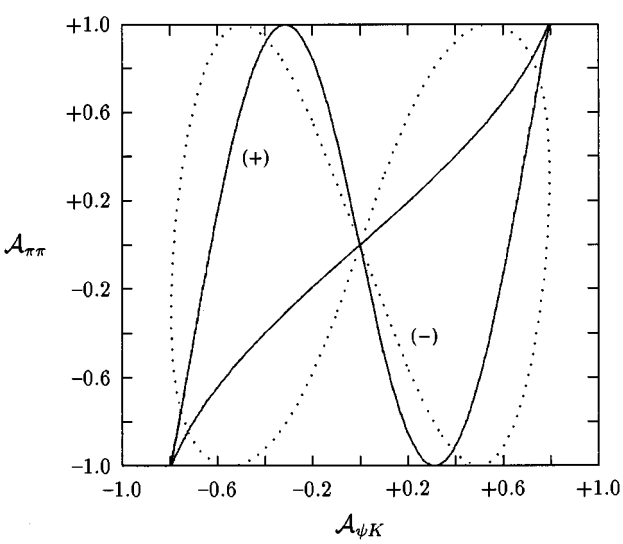

FIG. 8. Illustrative plot for the correlation between $\mathcal{A}_{\psi K}$ and $\mathcal{A}_{\pi\pi}$ in scenario (B).

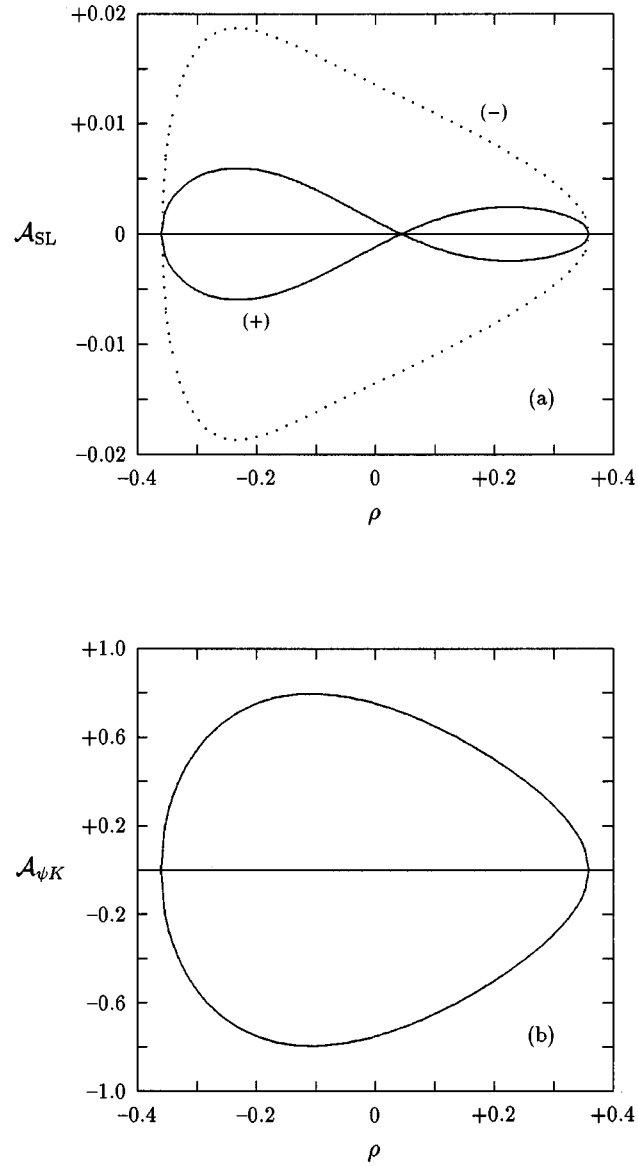

FIG. 9. Illustrative plot for the CP asymmetries $\mathcal{A}_{\rm SL}$ and $\mathcal{A}_{\psi K}$ in scenario (B).

$$f(\rho,\chi) \equiv R_{\rm SM}\left[\frac{\rho-\chi^2}{(1-\rho)(1-2\rho+\chi^2)}T_u(\tilde{z}) + \frac{1}{1-2\rho+\chi^2}T_c(\tilde{z})\right] + R_{\rm NP}\left[\frac{\rho}{1-\rho}T_u(\tilde{z}) - T_t(\tilde{z})\right]. \tag{5.6}$$

Note that the term associated with the KM factor $\mathrm{Im}(\xi_c/|\xi_t|)^2$ in Eq. (4.14) does not appear in $f(\rho,\chi)$, because this factor approximately vanishes in the Wolfenstein parametrization. The numerical results for three CP asymmetries are shown in Figs. 8 and 9, where relevant inputs have been used to get the $(\rho, R_{\rm NP})$ parameter space in Fig. 7. Three remarks are in order.

(a) The two solutions of $R_{\rm NP}$ lead to identical results for the CP asymmetry $\mathcal{A}_{\psi K}$. The reason is simply that $\mathcal{A}_{\psi K}$ depends only on $R_{\rm SM}$ and ϕ_1, as given in Eq. (4.12).

(b) The correlation between $\mathcal{A}_{\pi\pi}$ and $\mathcal{A}_{\psi K}$ is complicated here, compared with that in scenario (A) where the superweak relation $\mathcal{A}_{\pi\pi}=-\mathcal{A}_{\psi K}$ holds. We observe that both CP asymmetries can take the same sign and promising magnitudes in scenario (B) [23].

(c) Because of their correlation, behaviors of $\mathcal{A}_{\rm SL}$ and $\mathcal{A}_{\psi K}$ changing with ρ are similar. The magnitude of $\mathcal{A}_{\rm SL}$ can reach the percent level for appropriate values of ρ, if $R_{\rm NP}$ takes its $(-)$ solution.

VI. CONCLUDING REMARKS

The importance of measuring the CP asymmetry ($\mathcal{A}_{\rm SL}$) in semileptonic B_d decays, which can serve as a sensitive probe of NP in B_d^0-$\overline{B_d^0}$ mixing, has been highly stressed. We have taken three NP scenarios into account, and proposed a simple framework for analyzing their effects on $\mathcal{A}_{\rm SL}$ and other CP asymmetries. Some numerical estimates have also been made to illustrate possible enhancement of CP asymmetries in the presence of NP. We find that the magnitude of $\mathcal{A}_{\rm SL}$ at the percent level cannot be excluded within the appropriate parameter space. The correlation of $\mathcal{A}_{\rm SL}$ with the CP asymmetries in $B_d\to J/\psi K_S$ and $B_d\to\pi^+\pi^-$ (i.e., $\mathcal{A}_{\psi K}$ and $\mathcal{A}_{\pi\pi}$) have been discussed. Measuring the correlation between $\mathcal{A}_{\psi K}$ and $\mathcal{A}_{\pi\pi}$ may partly testify or abandon the superweak model of CP violation which was proposed a long time ago [26], at least within the B_d^0-$\overline{B_d^0}$ system [27].

A number of NP models, which can contribute to both B_d^0-$\overline{B_d^0}$ mixing and CP violation, has been proposed in the literature [28]. Our framework is applicable to most of those models to analyze their effects on the CP asymmetries $\mathcal{A}_{\rm SL}$, $\mathcal{A}_{\psi K}$, and $\mathcal{A}_{\pi\pi}$, only if they do not involve extra quark(s). For the model of four-quark families or that of Z-mediated flavor changing neutral currents, a new charge $+2/3$ quark or a vector-singlet charge $-1/3$ quark may significantly contribute to B_d^0-$\overline{B_d^0}$ mixing and therefore affect the magnitude of $\mathcal{A}_{\rm SL}$ and other CP asymmetries. Since unitarity of the 3×3 KM matrix is violated in either of these two models, the analysis of $\mathcal{A}_{\rm SL}$ will involve much more uncertainties. Note also that the NP contributing to B_d^0-$\overline{B_d^0}$ mixing will simultaneously affect the rare penguin-induced decay modes such as $b\to dl^+l^-$ and $B_d\to X_d\gamma$. Thus measurements of rare flavor-changing transitions may yield complementary information about any NP in the B-meson system [28].

If the CP asymmetry $\mathcal{A}_{\rm SL}$ is really of the order 10^{-2}, it should be detected at the forthcoming B-meson factories, where as many as 10^8 $B_d^0\overline{B_d^0}$ events will be produced at the $\Upsilon(4S)$ resonance in about one year. Indeed the experimental sensitivities to $\mathcal{A}_{\rm SL}$ are expected to be well within few percent for either single lepton or dilepton asymmetry measurements [29], if the number of $B_d^0\overline{B_d^0}$ events is larger than 10^7 or so.

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[1] T. Altomari, L. Wolfenstein, and J. D. Bjorken, Phys. Rev. D **37**, 1860 (1988).

[2] M. Lusignoli, Z. Phys. C **41**, 645 (1989); A. Acuto and D. Cocolicchio, Phys. Rev. D **47**, 3945 (1993).

[3] CLEO Collaboration, J. Bartelt *et al.*, Phys. Rev. Lett. **71**, 1680 (1993); CDF Collaboration, F. Abe *et al.*, Phys. Rev. D **55**, 2546 (1997). A new measurement of CERN yields $\mathcal{A}_{\rm SL}=0.008\pm0.028\pm0.012$ under CPT symmetry. See OPAL Collaboration, K. Ackerstaff *et al.*, Z. Phys. C (to be published).

[4] Particle Data Group, R. M. Barnett *et al.*, Phys. Rev. D **54**, 1 (1996).

[5] A. I. Sanda, in Proceedings of the Linear Collider $B\overline{B}$ Factory Conceptual Design Workshop, Los Angeles, CA, 1987 (unpublished), p. 163.

[6] D. Cocolicchio and L. Maiani, Phys. Lett. B **291**, 155 (1992).

[7] See, e.g., J. P. Silva and L. Wolfenstein, Phys. Rev. D **55**, 5331 (1997); A. G. Cohen, D. B. Kaplan, F. Lepeintre, and A. E. Nelson, Phys. Rev. Lett. **78**, 2300 (1997); Y. Grossman and H. R. Quinn, this issue, Phys. Rev. D **56**, 7259 (1997); Y. Grossman, Y. Nir, and M. P. Worah, Phys. Lett. B **407**, 307 (1997); T. Kurimoto and A. Tomita, Prog. Theor. Phys. (to be published).

[8] Z. Z. Xing, in *Production and Decay of Hyperons, Charm and Beauty Hadrons*, Proceedings of the Conference, Strasbourg, France, 1995, edited by J. Engel *et al.* [Nucl. Phys. B. (Proc. Suppl.) **50**, 24 (1996)]; Phys. Lett. B **371**, 310 (1996).

[9] This scenario is essentially different from the one proposed by Cocolicchio and Maiani [6]. In the latter, the rate of B_d^0-$\overline{B_d^0}$ mixing remains to be governed completely by the SM with a real KM matrix. Hence it seems difficult to simultaneously accommodate current data on $|V_{ub}/V_{cb}|$ and B_d^0-$\overline{B_d^0}$ mixing.

[10] J. M. Soares and L. Wolfenstein, Phys. Rev. D **47**, 1021 (1993).

[11] J. S. Hagelin, Nucl. Phys. **B193**, 123 (1981), and references therein.

[12] A. B. Carter and A. I. Sanda, Phys. Rev. Lett. **45**, 952 (1980); Phys. Rev. D **23**, 1567 (1981); I. I. Bigi and A. I. Sanda, Nucl. Phys. **B193**, 85 (1981); **B281**, 41 (1987).

[13] L. Wolfenstein, Phys. Rev. Lett. **51**, 1945 (1983).

[14] J. M. Gerard and T. Nakada, Phys. Lett. B **261**, 474 (1991); B. Winstein, Phys. Rev. Lett. **68**, 1271 (1992).

[15] For a review, see A. I. Sanda and Z. Z. Xing, presented at the 7th International Symposium on Heavy Flavor Physics, Santa Barbara, CA, 1997.

[16] For a review, see M. Gronau, presented at the 3rd Workshop on Heavy Qaurks at Fixed Target, St. Goar, Germany, 1996; N. G. Deshpande, presented at the 2nd International Conference on B Physics and CP Violation, Honolulu, Hawaii, 1997.

[17] H. Y. Cheng, Phys. Rev. D **26**, 143 (1982).
[18] A. J. Buras, W. Slominski, and H. Steger, Nucl. Phys. **B245**, 369 (1984).
[19] T. Inami and C. S. Lim, Prog. Theor. Phys. **65**, 297 (1981); **65**, 1772(E) (1981).
[20] A. Ali and D. London, in *QCD '96*, Proceedings of the Conference, Montpellier, France, 1996, edited by S. Narison [Nucl. Phys. B (Proc. Suppl.) **54A** (1997)].
[21] A. J. Buras, presented at the 28th International Conference on High Energy Physics, Warsaw, Poland, 1996 (unpublished).
[22] Here we follow the procedure of Soares and Wolfenstein [10] to express Eq. (4.1) geometrically, i.e., in the form of a triangle in the complex plane.
[23] Based on the same NP scenario as our scenario (B), Soares and Wolfenstein have studied the correlation between the CP asymmetries in $B_d \to J/\psi K_S$ and $B_d \to \pi^+\pi^-$ [10]. The difference between their and our numerical results can be traced back to different values of input parameters.
[24] J. Liu and L. Wolfenstein, Phys. Lett. B **197**, 536 (1987); L. Wolfenstein, Comments Nucl. Part. Phys. **21**, 275 (1994).
[25] Constraints on $M_{12}^{\rm NP}$ from current data have been model-independently analyzed by T. Goto, N. Kitazawa, Y. Okada, and M. Tanaka, Phys. Rev. D **53**, 6662 (1996).
[26] L. Wolfenstein, Phys. Rev. Lett. **13**, 536 (1964).
[27] Similarly one can study NP effects on CP violation in semileptonic and nonleptonic decays of B_s mesons. For B_s^0-$\overline{B_s^0}$ mixing, however, the SM contribution to M_{12} is primarily real [12]. Hence only the NP scenario (A) or (C) considered in this work is of particular interest. See Z. Z. Xing, Z. Phys. C (to be published).
[28] For a detailed review, see M. Gronau and D. London, Phys. Rev. D **55**, 2845 (1997). For an explicit discussion about $\mathcal{A}_{\rm SL}$ in supersymmetric models or in the model with Z-mediated flavor changing neutral currents, see I. I. Bigi and F. Gabbiani, Nucl. Phys. **B352**, 309 (1991); G. C. Branco, P. A. Parada, T. Morozumi, and M. N. Rebelo, Phys. Lett. B **306**, 398 (1993).
[29] H. Yamamoto, Phys. Lett. B **401**, 91 (1997); Y. Sakai, presented at the KEK *B* Physics Mini-workshop, Izu, Shizuoka, Japan, 1997.