

Direct CP Violation in $B \rightarrow \phi K_s$ and New Physics

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(Received 9 August 2002; published 18 November 2002)

In the presence of large new physics contributions to loop-induced $b \rightarrow s$ transitions, sizable direct CP violation in $B \rightarrow \phi K$ decays is expected on general grounds. We compute explicitly CP -violating effects using QCD factorization and find that, even in the restricted case in which new physics has the same penguin structure as the standard model, the rate asymmetry can be of the order of 1. We briefly discuss a more general scenario and comment on the inclusion of power-suppressed corrections to factorization.

DOI: 10.1103/PhysRevLett.89.231802

PACS numbers: 13.25.Hw, 11.30.Er, 12.15.Ji, 12.60.Jv

With the advent of B factories, the measurement of CP asymmetries in nonleptonic B decays has emerged as a very powerful probe of new physics (NP) beyond the standard model (SM). It was pointed out a few years ago that the comparison of time-dependent CP asymmetries in different decay channels measuring the same weak phase in the SM could provide evidence of NP in B decay amplitudes [1]. In particular, $a_{CP}(B \rightarrow J/\Psi K_s)$ and $a_{CP}(B \rightarrow \phi K_s)$ both measure $\sin 2\beta$ with negligible hadronic uncertainties in the SM [2,3]. However, $B \rightarrow \phi K_s$, being a pure penguin process, is expected to be much more sensitive to NP than the tree-level dominated $B \rightarrow J/\Psi K_s$ decay. In many explicit examples of NP, it

has been shown that sizable differences in these two asymmetries can be generated [4–14]. The first measurements of $a_{CP}(B \rightarrow \phi K_s)$ by the BaBar and Belle Collaborations display a 2.7σ deviation from the observed value of $a_{CP}(B \rightarrow J/\Psi K_s)$ [15,16], leaving open the possibility of a NP effect in $B \rightarrow \phi K_s$ [17].

In this Letter, we focus on the possibility of having direct CP violation in $B \rightarrow \phi K_s$ in the presence of generic NP contributions to the $b \rightarrow s\bar{s}s$ transition at the loop level. For simplicity, we first illustrate our argument using QCD factorization in the limit $m_b \rightarrow \infty$ [18], neglecting electroweak corrections. Then, we briefly discuss possible effects of power-suppressed terms.

We write the decay amplitude as

$$\mathcal{A}(B \rightarrow \phi K_s) = -\frac{G_F}{\sqrt{2}} F_0^{B \rightarrow K} f_\phi \sum_{i=3}^5 [\lambda_u \tilde{a}_i^u + \lambda_c \tilde{a}_i^c + \lambda_t (\tilde{a}_i^t + \tilde{a}_i^{\text{NP}})], \quad (1)$$

where $\lambda_q = V_{qb}^* V_{qs}$, $F_0^{B \rightarrow K}$ is the semileptonic $B \rightarrow K$ form factor evaluated at the ϕ mass and f_ϕ is the ϕ decay constant. The coefficients \tilde{a}_i^q are defined in terms of the usual $a_{i,I}^q$ and $a_{i,II}^q$, introduced in QCD factorization [19,20], as follows:

$$\tilde{a}_{(3,5)}^u = 0, \quad \tilde{a}_{(3,5)}^c = 0, \quad \tilde{a}_{(3,5)}^t = a_{(3,5),I} + a_{(3,5),II}, \quad \tilde{a}_4^{(u,c)} = a_{4,I}^{(u,c)} (C_{3,\dots,6} \rightarrow 0), \quad \tilde{a}_4^t = a_{4,I}^t (C_{1,2} \rightarrow 0) + a_{4,II}. \quad (2)$$

The notation $a_{4,I}^u (C_{1,2} \rightarrow 0)$ means that one has to take the expression for $a_{4,I}^u$ given in Ref. [20] neglecting terms proportional to C_1 and C_2 . Furthermore, the coefficients \tilde{a}_i^{NP} in Eq. (1) account for the NP contributions and are defined as $\tilde{a}_i^{\text{NP}} = \tilde{a}_i^t (C_{3,\dots,6} \rightarrow C_{3,\dots,6}^{\text{NP}}/\lambda_t)$. For discussing NP effects, it is useful to distinguish the different λ_q contributions, without using the unitarity of the Cabibbo-Kobayashi-Maskawa matrix. In fact, terms proportional to λ_u and λ_c are not modified by NP loop effects. Since λ_u is doubly Cabibbo suppressed with respect to $\lambda_{c,t}$, we neglect it in the following discussion.

In Table I, we report the values of the coefficients \tilde{a}_i^q . It is remarkable that \tilde{a}_4^c has comparable real and imaginary

parts and, correspondingly, a large strong phase even in the infinite mass limit. However, $a_4^c = \tilde{a}_4^c - \tilde{a}_4^t$, which enters the SM decay amplitude, has a smaller strong phase, due to the constructive (destructive) interference in the real (imaginary) parts. In other words, the strong phase of the SM amplitude is accidentally smaller than its natural value within QCD factorization. Notice, in addition, that $|\tilde{a}_4^c|$ and $|\tilde{a}_4^t|$ are comparable in size.

Assuming that NP effects affect $C_{3,\dots,6}$, we can consider two different scenarios: (i) a universal penguinlike contribution parametrized as $C_{3,\dots,6}^{\text{NP}} = \lambda_t r^{\text{NP}} e^{i\phi^{\text{NP}}} C_{3,\dots,6}$; (ii) a general NP contribution affecting $C_{3,\dots,6}$ in a

TABLE I. Numerical values of the coefficients \tilde{a}_i^q relevant to our discussion obtained for $\mu = m_b = 4.2$ GeV, $\alpha_s(M_Z) = 0.119$, and $m_c(m_b) = 1.3$ GeV.

	Re	Im
\tilde{a}_3^c	0	0
\tilde{a}_4^c	-1.4×10^{-2}	-1.1×10^{-2}
\tilde{a}_5^c	0	0
\tilde{a}_3^t	-4.3×10^{-3}	-2.7×10^{-3}
\tilde{a}_4^t	1.9×10^{-2}	-3.4×10^{-3}
\tilde{a}_5^t	4.1×10^{-3}	3.1×10^{-3}

nonuniversal way. This is the case, for example, of general R_p -conserving supersymmetric (SUSY) models where, in addition to penguins, there is also a box contribution [21].

It is easy to see that, in both scenarios, there is more than one contribution to the amplitude carrying different strong and weak phases. Since the strong phases are not

$$\mathcal{A}(B \rightarrow \phi K_s) \simeq -\frac{G_F}{\sqrt{2}} F_0^{B \rightarrow K} f_\phi \sum_{i=3}^5 [\lambda_c \tilde{a}_i^c + \lambda_t (1 + r^{\text{NP}} e^{i\phi^{\text{NP}}}) \tilde{a}_i^t]. \quad (3)$$

Using the values in Table I, we get

$$\mathcal{A}(B \rightarrow \phi K_s) \propto \lambda_c (1.4 + 1.1i) + \lambda_t (1 + r^{\text{NP}} e^{i\phi^{\text{NP}}}) (-1.9 + 0.3i). \quad (4)$$

It is apparent that, for r^{NP} of $\mathcal{O}(1)$, a large rate asymmetry is generated, namely $|\bar{\mathcal{A}}/\mathcal{A}| \equiv |\mathcal{A}(\bar{B}^0 \rightarrow \phi K_s)|/|\mathcal{A}(B^0 \rightarrow \phi K_s)| \neq 1$ (see Fig. 1). Correspondingly, the full expression for the time-dependent asymmetry, including the $\cos\Delta M_B t$ term, should be used and hadronic uncertainties are expected in the extraction of the weak phases from the data.

In the more general scenario (ii), there are even more terms in the amplitude with different strong and weak phases. In this case, a_i^{NP} contain an admixture of strong and weak phases. Therefore, it is no longer useful to use the notation of Eq. (1). As an example, we give the coefficients $C_{\phi K}$ and $S_{\phi K}$ of the time-dependent CP asymmetry computed in a SUSY model with $\mathcal{O}(1)$ $\tilde{s} - \tilde{b}$ mixing, for an average squark and gluino mass of 250 GeV (see Refs. [22,23] for a detailed analysis). For central values of the parameters in QCD factorization and the extreme value $(\delta_{23}^d)_{LL} = e^{3\pi i/2}$ (for the definition, see Ref. [21]), we get

$$C_{\phi K} = -0.24, \quad S_{\phi K} = -0.13. \quad (5)$$

To conclude our discussion, we notice that, as suggested by $B \rightarrow K\pi$ decays, large corrections to QCD factorization in the infinite b -mass limit are expected in penguin-dominated $b \rightarrow s$ decays [24]. However, the inclusion of power corrections following any of the available approaches [20,24–27] can only strengthen our conclusion,

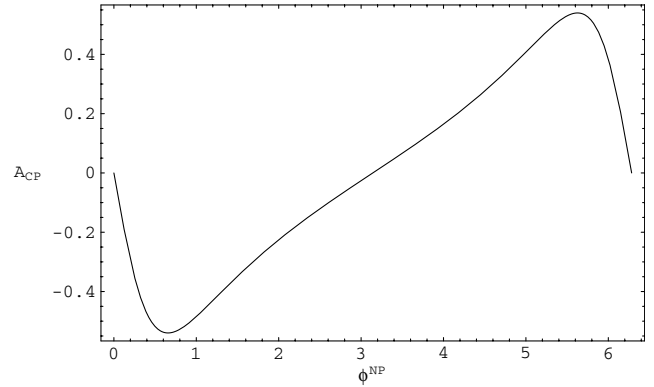


FIG. 1. The direct CP asymmetry in $B^0 \rightarrow \phi K_s$ from Eq. (4), for $r^{\text{NP}} = 1$, as a function of ϕ^{NP} .

negligible, one expects sizable direct CP violation if the NP contribution is large enough. Indeed, in the first scenario, we have

since in general subleading terms produce additional strong phases (barring accidental cancellations). Furthermore, given the dependence of hadronic matrix elements on the final state, no simple relation among the time-dependent CP asymmetries in $B \rightarrow \phi K_s$, $B \rightarrow \eta' K_s$, and other penguin-dominated $b \rightarrow s$ transitions can be established. Therefore, it is quite possible that, in the presence of NP, $a_{CP}(B \rightarrow \phi K_s) \neq a_{CP}(B \rightarrow \eta' K_s)$, contrary to what was very recently suggested in Ref. [17]. If the present 2.7σ discrepancy between $S_{J/\psi K}$ and $S_{\phi K}$ will be confirmed, pointing to a large NP contribution in the $B \rightarrow \phi K_s$ decay amplitude, a nonvanishing $C_{\phi K}$ is expected on general grounds, as well as CP violation in the decay $B^+ \rightarrow \phi K^+$.

We thank F. Zwirner for carefully reading the manuscript.

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