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CP violating phase difference between $B \rightarrow J/\psi K_S$ and $J/\psi K_S \pi^0$ from new physics

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Abstract

The P -wave component of $B \rightarrow J/\psi K^*$ turns out to be small, hence one can measure $\sin 2\beta$ using $B^0 \rightarrow J/\psi K^{*0} \rightarrow J/\psi K_S \pi^0$ as well as $B^0 \rightarrow J/\psi K_S$. Since these modes are color suppressed, new physics enhanced color dipole bsg coupling, as hinted from the persistent $\mathcal{B}_{s,1}$ and n_C problems and the newly observed large $B \rightarrow \eta' + X_s$ decay, may have significant impact. We show that it may lead to a difference in $\sin 2\beta$ values between $B^0 \rightarrow J/\psi K_S$ and $J/\psi K_S \pi^0$, measurable at the B Factories in the near future. © 1999 Published by Elsevier Science B.V. All rights reserved.

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The B Factories will soon turn on in 1999, to study CP violation in the B meson system. The benchmark test is to measure the mixing dependent CP violating angle $\sin 2\beta$ in the gold-plated $B \rightarrow J/\psi K_S$ mode, which is predicted to be large in the Standard Model (SM). To enhance statistics, and as a cross check, one should study other modes such as $B \rightarrow J/\psi K^{*0} \rightarrow J/\psi K_S \pi^0$ decay. Such modes suffer, however, from partial cancellation of CP violation effects since both CP even and odd amplitudes are present.

The CLEO Collaboration has recently reported [1] the first full angular analysis of $B \rightarrow J/\psi K^{*0}$ and $J/\psi K^{*+}$ decays. They find that the P -wave component is small, $|P|^2 = 0.16 \pm 0.08 \pm 0.04$, hence $B \rightarrow J/\psi K^{*0} \rightarrow J/\psi K_S \pi^0$ decay is dominated by CP -even final states. Compared to $J/\psi K_S$, one has a dilution factor $\sim 30\%$ but this is now already measured. The mode can therefore be used to measure $\sin 2\beta$ without invoking an angular analysis [2]. An interesting question can now be raised: Can $\sin 2\beta_{J/\psi K_S} \neq \sin 2\beta_{J/\psi K_S \pi^0}$? Naively it is hard to conceive how $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{J/\psi K_S \pi^0}$ could differ, since the decays are dominated by the tree level $b \rightarrow c\bar{c}s$ process, while any change in CP violating phase due to new physics in $B^0-\bar{B}^0$ mixing is just a common factor. One needs new contributions to the decay amplitudes. In this paper we elucidate some new physics mechanisms whereby the $\sin 2\beta$ measurements could differ between $B \rightarrow J/\psi K_S$

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and $B \rightarrow J/\psi K_S \pi^0$ decays, hence illustrating the importance of making and refining these separate measurements.

Let us first show how $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{J/\psi K_S \pi^0}$ could in principle differ. The usual CP violation measure is $\text{Im } \xi = \text{Im} \{ (q/p) (A^* \bar{A} / |A|^2) \}$, where $q/p = e^{-2i\phi_B}$ is from $B^0 - \bar{B}^0$ mixing, while $A, \bar{A}$ are $B, \bar{B}$ decay amplitudes into the same final state. For $B \rightarrow J/\psi K_S$, the final state is P -wave hence CP odd. Setting the weak phase to be ϕ_0 , one has

$$\text{Im } \xi(B \rightarrow J/\psi K_S) = -\sin(2\phi_B + 2\phi_0) \equiv -\sin 2\beta_{J/\psi K_S}.$$

For $B \rightarrow J/\psi K^* \rightarrow J/\psi K_S \pi^0$, the final state has both P -wave (CP odd) and S - and D -wave (CP even) components. If S - and D -wave have a common weak phase ϕ_1 , we have

$$\text{Im } \xi(B \rightarrow J/\psi K_S \pi^0) = \text{Im} \left\{ e^{-2i\phi_B} \left[e^{-2i\phi_1} |P|^2 - e^{-2i\tilde{\phi}_1} (1 - |P|^2) \right] \right\} \equiv (1 - 2|P|^2) \sin 2\beta_{J/\psi K_S \pi^0}, \quad (1)$$

where ϕ_1 is the weak phase for the P -wave amplitude. Eq. (1) holds true in SM and, in the Wolfenstein phase convention, one has $\phi_B = \beta$ and $\phi_0 = \phi_1 = \tilde{\phi}_1 = 0$. One easily obtains the usual result of $\sin 2\beta_{J/\psi K_S} = \sin 2\beta_{J/\psi K_S \pi^0} = \sin 2\beta$. Clearly, both measurements provide true information about $\sin 2\beta$ within SM. However, this is no longer true if one goes beyond SM. Even for the case where the weak phases of S - and D -amplitudes are equal, if $\phi_1 \neq \tilde{\phi}_1$ or if $\phi_1, \tilde{\phi}_1 \neq \phi_0$, then $\sin 2\beta_{J/\psi K_S} \neq \sin 2\beta_{J/\psi K_S \pi^0}$ follows. The difference between $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{J/\psi K_S \pi^0}$ is a true measure of CP violation beyond SM.

There are many ways where new physics may change the phases $\phi_{0,1}$ and $\tilde{\phi}_1$. To lowest order they are through dimension 6 four quark operators, or the dimension 5 color dipole operator $\bar{s}i\sigma_{\mu\nu}G^{\mu\nu}(1 \pm \gamma_5)b$, where $G^{\mu\nu}$ is the gluon field strength. Operators of the form $\bar{c}\gamma^\mu(1 \pm \gamma_5)c\bar{s}\gamma_\mu(1 - \gamma_5)b$ may shift $\phi_{0,1}$ and $\tilde{\phi}_1$ by a common amount, whereas for $\bar{c}\gamma^\mu(1 \pm \gamma_5)c\bar{s}\gamma_\mu(1 + \gamma_5)b$ the shift in $\tilde{\phi}_1$ the same as for $\phi_{0,1}$ but with opposite sign. Our primary example, however, is the dimension 5 color dipole operator, since there are experimental hints that it may be large in Nature.

We parametrize the color dipole interaction normalized to SM,

$$\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{g_s}{16\pi^2} F_2 m_b \bar{s}\sigma_{\mu\nu}G^{\mu\nu}(1 + \gamma_5)b.$$

In SM one has $F_2 \simeq 0.286$, and the process $b \rightarrow sg$ (where g is “on-shell”, or jet-like) is only of order 0.2%, and is very hard to measure experimentally. However, the persistent low semileptonic B branching ratio ($\mathcal{B}_{s,l}$) and charm counting (n_c) problems suggest that $b \rightarrow sg$ decay could be enhanced to the 10% level [3,4], which implies $|F_2| \sim 2$. A bound on $b \rightarrow sg$ from the recent $B \rightarrow D\bar{D}K + X$ study [5] does not yet rule this out. while the discovery of a surprisingly large semi-inclusive $B \rightarrow \eta' + X_s$ decay [6] may call for an interplay of [7] the SM bsg charge radius coupling $|F_1^{\text{SM}}| \sim 5$ and the new physics dipole coupling $|F_2| \sim 2$. Furthermore, this new physics enhanced dipole coupling brings in naturally a CKM-independent CP violating phase, and could lead to rate asymmetries at the 10% level [7,8] in the m_{X_s} recoil mass spectrum of the $B \rightarrow \eta' + X_s$ mode.

Still, how can $\phi_{0,1}$ and $\tilde{\phi}_1$ be significantly changed by the color dipole interaction? Note that $B \rightarrow J/\psi K_S(K^*)$ decays are color suppressed. Assuming factorization, the decay rate is proportional to $|c_1 + c_2/N|^2$, which suffer from accidental cancellation for $N=3$. A phenomenological fit suggests $N_{\text{eff}} \simeq 2$ [9,10], or, alternatively, if one takes $N=3$ from QCD, then there must be sizable color-octet and other nonfactorizable contributions. The former amplitude is found to be $\sim 1/N$, similar to the color-singlet term, while other nonfactorizable contributions are $\sim 1/N^2$ [10] in the large N expansion. Thus, the weak phases $\phi_{0,1}$ and $\tilde{\phi}_1$ should be sensitive to color octet operators such as the color dipole. Although the pure dipole contribution to the $B \rightarrow J/\psi K^*$ rate is rather small, the shift in amplitude could be of order 10% if $|F_2| \sim 2$ (hence $b \rightarrow sg \sim 10\%$).

We now turn to some details. In the factorization approximation but including color octet contributions, the leading order decay amplitudes for $B \rightarrow J/\psi K_S(K^*)$ can be written as

$$A(B \rightarrow J/\psi K_S(K^*)) = i \frac{G_F}{\sqrt{2}} V_{cb} V_{cs}^* f_\psi m_\psi \varepsilon_\psi^\mu \left\{ (B_1 + 2B_8 r_8) \langle K_S(K^*) | \bar{s} \gamma_\mu (1 - \gamma_5) b | B \rangle \right. \\ \left. + \frac{\alpha_s}{2\pi} \frac{m_b}{q^2} r'_8 \langle K_S(K^*) | \bar{s} i \sigma_{\mu\nu} q^\nu (c_8(1 + \gamma_5) + \tilde{c}_8(1 - \gamma_5)) b | B \rangle \right\}, \quad (2)$$

where we have adopted $c_8 = -F_2$ in the operator language, and

$$B_1 = c_1 + \frac{c_2}{N} - \sum_{i=u,c,t} \frac{V_{ib} V_{is}^*}{V_{cb} V_{cs}^*} \left(c_3^i + \frac{c_4^i}{N} + c_5^i + \frac{c_6^i}{N} \right), \quad B_8 = c_2 - \sum_{i=u,c,t} \frac{V_{ib} V_{is}^*}{V_{cb} V_{cs}^*} (c_4^i + c_6^i),$$

where the Wilson coefficients c_j^i for tree and strong penguin operators evaluated in Ref. [11] will be used. The index i indicates the quark in the penguin loop. The electroweak penguin contributions have been neglected. The decay constant f_ψ is defined by $\langle J/\psi | \bar{c} \gamma^\mu c | 0 \rangle = i f_\psi m_\psi \varepsilon_\psi^\mu$, and is determined from J/ψ leptonic decay to be $f_\psi \approx 410$ MeV. The parameter r_8 is defined as the ratio of color octet to singlet matrix elements

$$r_8 = \frac{\langle J/\psi K_S(K^*) | [\bar{c} \gamma_\mu T^a c] [\bar{s} \gamma^\mu (1 - \gamma_5) T^a b] | B \rangle}{\langle J/\psi | \bar{c} \gamma^\mu c | 0 \rangle \langle K_S(K^*) | \bar{s} \gamma^\mu (1 - \gamma_5) b | B \rangle},$$

and similarly for r'_8 with dipole current replacing the $V - A$ current. These two parameters in general should be different, but at the moment it is not possible to calculate them from first principles. We will determine r_8 by fitting experimental data. Taking $r'_8 = r_8$ to be equal would then give an indication of the size of the effect. We also include a possible color dipole $(1 - \gamma_5)$ term with strength $\tilde{c}_8$ for completeness.

Following the notation of Ref. [12], we parametrize

$$\langle \bar{K}^0 | \bar{s} \gamma_\mu (1 - \gamma_5) b | B \rangle = F_1(q^2) (p_\mu^B + p_\mu^K) + \frac{m_B^2 - m_K^2}{q^2} (F_0(q^2) - F_1(q^2)) q_\mu. \quad (3)$$

The form factors are assumed to be of pole form $F_i(q^2) = F_i(0)/(1 - q^2/m_i^2)^n$, and the values of $F_i(0)$ and m_i are taken from Ref. [12]. Heavy quark effective theory (HQET) suggests that at maximum recoil, $F_1(q_{\max}^2)/F_0(q_{\max}^2)$ scales as m_b [13]. This implies that the pole power for $F_1(q^2)$ and $F_0(q^2)$ differ by -1 . We take $n = 2$ for F_1 and $n = 1$ for F_0 .

At maximum recoil $\langle \bar{K}^0 | \bar{s} i \sigma_{\mu\nu} q^\nu (1 \pm \gamma_5) b | B \rangle$ can be related to $F_i(q^2)$ defined in Eq. (3) by HQET [13]. Taking $m_b \approx m_B$, $p_b \approx p_B$ and extrapolating down to $q^2 \approx m_{J/\psi}^2$, we find

$$\varepsilon_\psi^\mu \langle \bar{K}^0 | \bar{s} i \sigma_{\mu\nu} q^\nu (1 \pm \gamma_5) b | B \rangle \approx 2 \varepsilon_\psi \cdot p_B m_B F_1(q^2) s(q^2), \quad (4)$$

where $s(q^2) = [(F_0(q^2)/F_1(q^2) - 1)(1 - m_K^2/m_B^2) - q^2/m_B^2]/2 \approx -m_\psi^2/m_B^2$ is a suppression factor due to the helicity structure of $\sigma_{\mu\nu}$ at the quark level. Note that in the photon case, $s(q^2)$ vanishes with $q^2 = 0$, as it should. The full decay amplitude is now given by

$$A(B \rightarrow J/\psi K_S) \approx i G_F V_{cb} V_{cs}^* f_\psi m_\psi F_1(m_\psi^2) \varepsilon_\psi \cdot p_B \left\{ [B_1 + 2B_8 r_8] + \frac{\alpha_s}{2\pi} \frac{m_B^2}{m_\psi^2} [c_8 + \tilde{c}_8] r_8 s(m_\psi^2) \right\}, \quad (5)$$

where we have set $r'_8 = r_8$. To fit experimental data, we take $1/N + 2r_8 = 1/N_{\text{eff}} \approx 1/2$ [9,10] from the first term, giving $r_8 \approx 1/12$.

For $B \rightarrow J/\psi K^*$, we continue to use the form factor parametrization of [12],

$$\begin{aligned} \langle K^* | \bar{s} \gamma_\mu (1 - \gamma_5) b | B \rangle = & \frac{2V(q^2)}{m_B + m_{K^*}} \varepsilon_{\mu\nu\alpha\beta} \varepsilon_K^\nu q^\alpha p_{K^*}^\beta + i \frac{A_2(q^2)}{m_B + m_{K^*}} \varepsilon_{K^*} \cdot q (p_B^\mu + p_{K^*}^\mu) \\ & - i(m_B + m_{K^*}) A_1(q^2) \varepsilon_{K^*}^\mu + 2im_{K^*} \frac{A_3(q^2) - A_0(q^2)}{q^2} \varepsilon_{K^*} \cdot q q_\mu, \end{aligned} \quad (6)$$

where $2m_{K^*} A_3(q^2) = (m_B + m_{K^*}) A_1(q^2) - (m_B - m_{K^*}) A_2(q^2)$ and $A_0(0) = A_3(0)$. We assume dipole behavior for $V(q^2)$, $A_2(q^2)$ and monopole for $A_1(q^2)$, $A_0(q^2)$. Pole masses and form factor values at $q^2 = 0$ are again taken from [12].

We parametrize the dipole matrix element as

$$\begin{aligned} \langle K^* | \bar{s} i \sigma_{\mu\nu} b | B \rangle = & \varepsilon_{\mu\nu\alpha\beta} (g_+(q^2) \varepsilon_{K^*}^\alpha (p_B + p_{K^*})^\beta + g_-(q^2) \varepsilon_{K^*}^\alpha (p_B - p_{K^*})^\beta \\ & + h(q^2) (p_B + p_{K^*})^\alpha (p_B - p_{K^*})^\beta \varepsilon_{K^*} \cdot p_B), \end{aligned} \quad (7)$$

while $\langle K^* | \bar{s} i \sigma_{\mu\nu} \gamma_5 b | B \rangle$ can be arrived at via the identity $i\sigma^{\mu\nu} = (1/2)\epsilon^{\mu\nu\alpha\beta}\sigma_{\alpha\beta}\gamma_5$, where $\epsilon^{0123} = 1$. The form factors $g_\pm$ and h are related to $A_{0,1,2}$ and V in HQET at maximal recoil, which are given in Ref. [13]. Extrapolating these down in q^2 , the full decay amplitude is finally given by

$$\begin{aligned} A(B \rightarrow J/\psi K^*) = & i\sqrt{2} G_F V_{cb} V_{cs}^* f_\psi m_\psi \left\{ [B_1 + 2B_8 r_8] \left(\frac{V(m_\psi^2)}{m_B + m_{K^*}} \varepsilon_{\mu\nu\alpha\beta} \varepsilon_\psi^\mu \varepsilon_{K^*}^\nu p_B^\alpha p_{K^*}^\beta \right. \right. \\ & - \frac{i}{2} (m_B + m_{K^*}) A_1(m_\psi^2) \varepsilon_\psi \cdot \varepsilon_{K^*} + i \frac{A_2(m_\psi^2)}{m_B + m_{K^*}} \varepsilon_\psi \cdot p_B \varepsilon_{K^*} \cdot p_B \Big) \\ & - \frac{\alpha_s}{2\pi} \frac{m_B}{m_\psi^2} [c_8 + \tilde{c}_8] r_8 g_+(m_\psi^2) \varepsilon_{\mu\nu\alpha\beta} \varepsilon_\psi^\mu \varepsilon_{K^*}^\nu p_B^\alpha p_{K^*}^\beta \\ & + i \frac{\alpha_s}{2\pi} \frac{m_B}{m_\psi^2} [c_8 - \tilde{c}_8] r_8 \left(\frac{1}{2} (g_+(m_\psi^2)(m_B^2 - m_{K^*}^2) + g_-(m_\psi^2)m_\psi^2) \varepsilon_\psi \cdot \varepsilon_{K^*} \right. \\ & \left. \left. - (g_+(m_\psi^2) - h(m_\psi^2)m_\psi^2) \varepsilon_\psi \cdot p_B \varepsilon_{K^*} \cdot p_B \right) \right\}. \end{aligned} \quad (8)$$

Unlike the $s(m_\psi^2)$ factor in Eq. (4), the form factor $g_+(m_\psi^2)$ in Eq. (8) is not suppressed by m_ψ^2/m_B^2 . Thus, the dipole contribution to $B \rightarrow J/\psi K_S$ is suppressed by a factor of m_ψ^2/m_B^2 compared to $B \rightarrow J/\psi K^*$. This suppression can be traced to the helicity structure of the $\sigma_{\mu\nu}$ interaction at the quark level. Although we have worked with color singlet operators, we note that QCD is helicity conserving. Soft gluon emissions would not change the helicity structure, hence the color dipole contribution to $B \rightarrow J/\psi K_S$ should still be suppressed compared to $B \rightarrow J/\psi K^*$. If the color dipole coefficients c_8 or $\tilde{c}_8$ contain CP violating phases, the measurements of $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{J/\psi K_S \pi^0}$ could differ.

The source of CP violation must come from physics beyond SM. We consider one possibility here. It has been shown [4,14] that in supersymmetric (SUSY) models, it is possible to have large c_8 in the desired range ($|c_8| \approx 2$) necessary for solving the n_c and $\mathcal{B}_{s,1}$ problems. In these models there are additional CP violating phases [7,8] which cause $c_8(\tilde{c}_8)$ to be complex with a CP violating phase $\phi(\tilde{\phi})$.

As has been discussed earlier, the unique feature of color dipole coupling is that its effect on $B \rightarrow J/\psi K_S$ is small, whereas the impact on $B \rightarrow J/\psi K^*$ is enhanced by $m_B^2/m_\psi^2 \approx 3$. The numerical value depends on $\alpha_s(m_b)$, which we will vary from 0.2 to 0.25. For $|c_8| = 2$ and $\tilde{c}_8 = 0$, we find that the color dipole contribution to the decay amplitude can be as large as 8%. If $\phi \neq 0$, it would generate phases for the CP even and odd amplitudes

$$\phi_0 \approx (0.02 - 0.03) \sin \phi, \quad \tilde{\phi}_1 \approx \phi_1 \approx (0.06 - 0.08) \sin \phi, \quad (9)$$

becoming larger as α_s increases. One would measure $\sin 2\beta_{J/\psi K_S \pi^0} \approx \sin(2\beta + 0.12\sin\phi)$ and $\sin(2\beta + 0.16\sin\phi)$ for $\alpha_s(m_b)$ equal to 0.20 and 0.25 respectively. Taking the present best fit value of 0.68 for $\sin 2\beta$ [15], the enhanced color dipole interaction could shift $\sin 2\beta_{J/\psi K_S \pi^0}$ by as much as 17%. The shift in $\sin 2\beta_{J/\psi K_S}$ is three times smaller. Deviations between $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{J/\psi K_S \pi^0}$ as large as discussed here will be probed soon at asymmetric B factories, and in the future at the LHC, where $\sin 2\beta_{J/\psi K_S(\pi^0)}$ can be measured to 1% accuracy. We note that, if $b \rightarrow sg \sim 10\%$ (hence $|c_8| \approx 2$) sounds extreme, $b \rightarrow sg$ at 3% and 1% level cannot be easily ruled out by experimental methods given in Ref. [5]. Although one would then be decoupled from the n_c and $\mathcal{B}_{s.l.}$ problems, the difference in $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{J/\psi K_S \pi^0}$ would still be at $\sim 60\%$ and 30% of those discussed here, and still measurable.

If it turns out that c_8 is small but $|\tilde{c}_8| \sim 2$, $\phi_{0,1}$ remains the same, but $\tilde{\phi}_1$ changes sign. We now have $\sin 2\beta_{J/\psi K_S \pi^0} \approx \sin(2\beta - 2\tilde{\phi}_1/(1 - 2|P|^2))$ and the shift is larger by a factor of $1/(1 - 2|P|^2)$ compared with the previous case. The relative sign of ϕ_1 and $\tilde{\phi}_1$ can be probed by performing an angular analysis [2].

The difference between $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{J/\psi K_S \pi^0}$ is sensitive also to other forms of new physics. Let us give an example of possible contributions from dimension 6 operators. In R -parity violating supersymmetric models, exchange of charged sleptons and down type squarks can generate currents involving the right handed quark b_R with a new CP violating phase ϕ_R , and therefore phase shifts of the type $\delta\phi_0 = \delta\phi_1 = -\delta\tilde{\phi}$ as mentioned earlier. The couplings involved are constrained by $b \rightarrow s\gamma$, but contributions at 10% level to the amplitude is still allowed [19]. The difference between $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{J/\psi K_S \pi^0}$ can be of order $-0.3\sin\phi_R \cos 2\phi_B$, where we have used ϕ_B instead of β because new physics may also contribute to ϕ_B , which is in general different from β . The effect is again measurable.

The effects discussed here is really some form of “penguin pollution” due to new physics. As such, the estimates are not fully precise. We have relied on the color octet mechanism to estimate the color dipole contribution. This point needs further clarification. However, we find support from inclusive $B \rightarrow J/\psi X_s$ using the formalism of Ref. [16]. The tree level color octet contribution improves agreement with inclusive rate for $N = 3$. Through interference, the color dipole operator contributes about 20% to the decay rate, which is consistent with the level found in exclusive decays. Hence, we feel that the numerical values obtained here are of the right order of magnitude.

One may worry whether final state interactions (FSI) might ruin our result. Let us briefly discuss how thing may change with FSI phases. In general the P , S and D amplitudes have different CP violating weak and CP conserving FSI phases. The most general decay amplitude for $B \rightarrow J/\psi K^*$ can be parameterized as

$$\bar{A} = \varepsilon_\psi^\mu \left[a e^{-i\phi_a} \varepsilon_{\mu\nu\alpha\beta} \varepsilon_K^\nu \cdot q^\alpha p_{K^*}^\beta + i b e^{-i\phi_b} \varepsilon_{K^*} \cdot q p_{K^*}^\mu + i c e^{-i\phi_c} \varepsilon_{K^*}^\mu \right], \quad (10)$$

where we have explicitly factored out the leading CP violating phase $\phi_{a,b,c}$ for each amplitude. The S and D amplitudes are linear combinations of b and c . In the most general case there are additional CP violating and CP conserving phases in the amplitudes a, b, c which can be studied by looking at angular distributions for each amplitude, which has been discussed in the literature [17,18]. The detailed information can not be extracted by the observable under consideration. In the cases that the CP violating phases in a, b, c are zero, the FSI phases do not play a role even if the weak phases $\phi_{a,b,c}$ are different. We have

$$\begin{aligned} \text{Im} \xi &= -\sin 2(\phi_B + \phi_a) |P|^2 + \sin(2\phi_B + \phi_b + \phi_c) (1 - |P|^2) + [\sin(2\phi_B + 2\phi_b) \\ &\quad - \sin(2\phi_B + \phi_b + \phi_c)] U_b + [\sin(2\phi_B + 2\phi_c) - \sin(2\phi_B + \phi_b + \phi_c)] U_c, \\ U_b &= \frac{|b|^2 \left((m_B^2 - m_{K^*}^2 - m_\psi^2)^2 - 4m_{K^*}^2 m_\psi^2 \right)}{16m_\psi^2 m_{K^*}^2 |A|^2}, \\ U_c &= \frac{|c|^2 \left((m_B^2 - m_{K^*}^2 - m_\psi^2)^2 + 8m_{K^*}^2 m_\psi^2 \right)}{4m_\psi^2 m_{K^*}^2 |A|^2}. \end{aligned} \quad (11)$$

In the limit of $\phi_b = \phi_c$, we obtain Eq. (1). The deviation from Eq. (1) is given by $\cos(2\phi_B)(\phi_b - \phi_c)(U_b - U_c)$ which is small if ϕ_b and ϕ_c are approximately equal, as the specific models predict in this paper. When additional CP violating phases are allowed in a, b, c , the FSI phases will play some role, but will be secondary and suppressed by an additional factor proportional to the CP rate asymmetries for different components.

It is interesting to note that, because $A_{1,2}$ and V are all approximately equal at $q^2 \simeq m_{J/\psi}^2$, and because the new dipole contributions are dominated by the g_+ form factor, the weak phases obtained for S - and D -waves are approximately equal. Thus, Eq. (1) is a good approximation for the color dipole case. Furthermore, in the R -parity violation example, these weak phases are exactly the same, which in fact holds in general for $\bar{c}\gamma^\mu(1 \pm \gamma_5)c\bar{s}\gamma_\mu(1 + \gamma_5)b$ and $\bar{c}\gamma^\mu(1 \pm \gamma_5)c\bar{s}\gamma_\mu(1 - \gamma_5)b$ interactions. We note with interest that the CLEO study shows no evidence for FSI phases [1] in $B \rightarrow J/\psi K^*$. High statistics studies following [1] and [2] can not only uncover FSI phases, but also detect in principle *direct CP* violating phase differences between $B \rightarrow J/\psi K^*$ and $\bar{B} \rightarrow J/\psi \bar{K}^*$ [18].

Before closing, we would like to point out that the color dipole induced *CP* violation can be further studied in $B \rightarrow \phi K_S$ decay, where $\text{Im } \xi(B \rightarrow \phi K_S) = -\sin 2\beta_{\phi K_S}$ is also a measure of $\sin 2\beta$ in SM. The difference between $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{\phi K_S}$ is again a sensitive probe for new physics [19]. At leading order, $B \rightarrow \phi K_S$ is a pure penguin process which is already at loop level, and the amplitude is not color suppressed, hence the enhanced color dipole interaction will have larger effect than in $B \rightarrow J/\psi K^*$. The effect can be comparable to the SM contribution and therefore the shift in $\sin 2\beta_{\phi K_S}$ will be much larger than the case for $B \rightarrow J/\psi K_S \pi^0$. However, $B \rightarrow \phi K_S$ has yet to be measured, while in the parameter space of interest, direct CP violating partial rate asymmetry in $B^- \rightarrow \phi K^-$ can become as large as 50% and can be more readily measured [8,20]. Direct CP violation in $B^- \rightarrow \phi K^-$ and other self-tagging modes such as $B^- \rightarrow \bar{K}^0 \pi^-$ or $\bar{B}^0 \rightarrow K^- \pi^+$ will be discussed elsewhere.

In conclusion, we have argued that physics beyond the Standard Model can change the prediction for $\sin 2\beta_{J/\psi K_S}$ and $\sin 2\beta_{J/\psi K_S \pi^0}$. The shift due to large color dipole interaction is small for $\sin 2\beta_{J/\psi K_S}$, but can be as large as 17% for $\sin 2\beta_{J/\psi K_S \pi^0}$, which can be tested at B factories. The shift can be much larger for $\sin 2\beta_{\phi K_S}$. We would like to emphasize, however, that even though the effect in $B \rightarrow J/\psi K^*$ is smaller than in the yet to be measured $B \rightarrow \phi K_S$ decay, $\sin 2\beta_{J/\psi K_S \pi^0}$ will provide a practical test for new physics beyond SM at B factories. We encourage our experimental colleagues to carry out such an analysis.

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