Impact of Subleading Corrections on Hadronic $B$ Decays

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We study the subleading corrections originating from the 3-parton $(q\bar{q}q)$ Fock states of final-state mesons in $B$ decays. The corrections could give significant contributions to decays involving an $\omega$ or $\eta^{(')}$ in the final states. Our results indicate the similarity of $\omega K$ and $\omega\pi^-$ rates, of order $5 \times 10^{-6}$, consistent with the recent measurements. We obtain $a_2(B \to J/\psi K) \approx 0.27 \pm 0.05i$, in good agreement with data. Without resorting to the unknown singlet annihilation effects, 3-parton Fock state contributions can enhance the branching ratios of $K\gamma$ to the level above $50 \times 10^{-6}$.

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The rare $B$ decays allow us to access the Kobayashi-Maskawa (KM) mixing angles and search for new physics. Much progress in the study of $B$ decays [1, 2, 3] has been recently made in QCD-based approaches. In the perturbative QCD (pQCD) framework, the importance of the weak annihilation effects in $B \to K\pi$ decays was first emphasized by [3], where the annihilation contributions are almost pure imaginary and therefore could lead to CP asymmetry predictions different from the QCD factorization (QCDF) results [1]. Nevertheless, the QCDF study showed that the annihilation effects may play only a minor role in the enhancement of $\pi\pi, \pi K$ branching ratios (BRs) [2]. A recent QCDF fit to $K\pi, \pi K$ rates [2] indicated that even if the annihilation contribution is neglected, one can still get quite good fitting results provided that the strange quark mass is of order 80 MeV.

The annihilation effects might be much more important for VP modes, where $P$ and $V$ denote pseudoscalar and vector mesons, respectively. It has been pointed out that in the absence of annihilation effects, the $K\pi$ BRs are $\approx 4 \times 10^{-6}$ [2], which is too small compared to the data $\approx 8 \times 10^{-6}$ [2, 3, 4]. Recently Belle observed a large $\omega K^-$ rate, $(6.7_{-1.2}^{+0.6}) \times 10^{-6}$, and $\omega K^-/\omega\pi^- \approx 1$ [3]. Sizable $\omega K$ results are also reported in new BaBar measurements [5] with $\omega K^{0-} \sim 5 \times 10^{-6}$. It is hard to understand the large strength of $\omega K$ rates from the theoretical point of view. The ratio $\omega K^0/\omega\pi^-$ reads

$$\omega K^0/\omega\pi^- \approx |V_{cb}/V_{ub}|^2 (f_K/f_\pi)^2 \frac{a_4 - a_6 r_\chi^K}{a_1 + r_1 a_2}$$

where $r_1 = f_\omega F_1B_\pi^K/f_\pi A_0^{B\omega}$, $r_2 = (F_1^{BK} f_\omega)/(A_0^{B\omega} f_K)$, $r_\chi^K = 2m_\chi^2/[m_{s, u}(m_s + m_u)]$ is the chirally enhanced factor with $m_{s, u}$ being the current quark masses, and $b_3 \equiv b_3(K, \omega)$ is the annihilation contribution defined in [3]. The $\omega\pi^-$ rate depends weakly on the annihilation effects. Without annihilation, since $a_4$ and $a_6 r_\chi^K$ terms in the $\omega K^0$ amplitude have opposite signs, the ratio $\omega K^0/\omega\pi^-$ should be very small. A possibility to explain the data is that the annihilation effects may give the dominant contribution to $\omega K$ modes as shown in the QCDF fit [3] for $B \to PP$ together with some $B \to VP$ modes. (However, including the contributions from annihilation effects, the pQCD results read $Br(B \to \omega K^0) \lesssim 2 \times 10^{-6}$ [2, 3].) This result hints that, to account for the large $\omega K^-$ rate, the annihilation contributions to the BRs of all $B \to KV$ modes should be over 80%. If it will be true, it should be easy to observe, for instance, the following simple relation $p^+ K^+ - p^0 K^0 - \omega K^+ \sim 1 : (1/\sqrt{2})^2 : (1/\sqrt{2})^2$, the same as their annihilation ratios squared. Nevertheless, if the global fit is extended to all measured $B \to PV$ modes, a small $K\omega$ rate $\sim 2 \times 10^{-6}$ will be obtained [4] and a reliable best fit cannot be reached. The present QCD approach seems hard to offer a coherent picture in dealing with $B \to VP$ modes.

In this letter we take into account the subleading corrections arising from the 3-parton Fock states of final state mesons, as depicted in Fig. [2] to QCDF rules amplitudes. We find that it could give significant corrections to decays with $\omega$, or $\eta^{(')}$ in the final states. A simple rule extended to $B \to PP, VP$ modes is obtained for the effective coefficients $a_i^{SL}$ with the subleading corrections,

$$a_{2i}^{SL} = a_{2i} + [1 + (-1)^{3i+1}] c_{2i-1} f_3/2,$$

$$a_{2i-1}^{SL} = a_{2i-1} + (-1)^{3i+1} c_{2i} f_3,$$

where $i = 1, \cdots, 5$, and $c_i$ are the Wilson coefficients defined at the scale $\mu_h = \sqrt{\Lambda\bar{\Lambda}} m_B/2 \approx 1.4$ GeV with $\Lambda$ the momentum of the emitted gluon as shown in Fig. [3] and

$$f_3 = \frac{\sqrt{2}}{m_B^2 f_{\omega} F_1 B \pi^0} \langle \omega\pi^- | O_1 | B^- \rangle_{qgq} = 0.12$$

in the SU(3) limit. Here $O_1 = \bar{\pi}\gamma^\mu(1 - \gamma_5) u \bar{\pi}\gamma_\mu(1 - \gamma_5) b$, and $\pi$ is the averaged fraction of the $\pi^-$ momentum carried by the gluon. For the $\omega K$ amplitudes, the term $a_3 + a_5$, which is originally negligible, is replaced by $a_3 + a_5 + (c_4 + c_6) f_3$ and the latter gives the significantly constructive contribution to the rates. It can thus help understanding the reason for the similarity between $K\omega$ and $\omega\pi^-$. On the other hand, the subleading corrections can contribute significantly to the processes with $\eta^{(')}$ in the final states, for which the term $a_3 - a_5$ always appears in the decay amplitudes and becomes $a_3 - a_5 + (c_4 + c_6) f_3$ after taking into account the corrections. We also get
Due to G-parity, \( \Phi \) and \( \Psi \) are antisymmetric in interchanging \( \alpha_\bar{q} \) and \( \alpha_\omega \), for the \( \omega \), so that Eq. (4) vanishes.

In Fig. 1(b), we consider the emitted gluon which becomes a parton of the pion. We first take \( G_{\mu\nu}(v\bar{x}) \approx G_{\mu
u}(0)e^{ivk^\mu}x\bar{x} \) and then adopt the collinear approximation \( k_\mu = \gamma g_\mu 0 \) in the final stage of the calculation, where \( \gamma g_\mu \) is the average fraction of the pion’s momentum carried by the gluon. The calculation is straightforward and leads to

\[
\langle \omega\pi^- | O_1 | B^- \rangle_{\text{Fig.1(b)}} = \frac{f \omega m_\omega}{4\sqrt{2}N_c} \int \frac{dv}{v} \int_0^1 \phi_\omega(u) \times \langle \pi^- | d\gamma_\mu(1 - \gamma_5)g_\gamma \bar{G}_{\mu\nu}b|B^- \rangle \frac{i\partial}{\partial k_\beta} \left\{ \text{Tr} \left[ \gamma^\nu (v k^\mu + u \bar{p}_\lambda) \gamma^\beta - \gamma^\mu(v k^\beta + u \bar{p}_\lambda) \gamma^\nu \right] \right\} \frac{2\sqrt{2f}}{\alpha_g m_B^2} p_\omega^\mu \langle \pi^- | \bar{d}\gamma^\mu 5\gamma_5 g_\gamma \bar{G}_{\alpha\beta}b|B^- \rangle, \tag{7}
\]

where the \( \omega \) meson’s asymptotic leading-twist distribution amplitude \( \phi_\omega(u) = 6u\bar{u} \) has been taken and \( u = 1 - v \). We have two unknown parameters \( p_\omega^\mu \langle \pi^- | \bar{d}\gamma^\mu 5\gamma_5 g_\gamma \bar{G}_{\alpha\beta}b|B^- \rangle \) and \( \alpha_g \) needed to be determined. First, let us evaluate \( p_\omega^\mu \langle \pi^- | \bar{d}\gamma^\mu 5\gamma_5 g_\gamma \bar{G}_{\alpha\beta}b|B^- \rangle \). The matrix element can be calculated by considering the correlation function:

\[
\Pi_\alpha(p, p + q) = i \int d^4xe^{ip_x} \langle \pi^- | (q)T(j_{3p}(x)j_B(0))|0 \rangle = \frac{m_B^2 f_B}{m_\omega} \frac{1}{m_B - (p^2 + q^2)} \times \langle \pi^- | \bar{d}\gamma^\mu 5\gamma_5 g_\gamma \bar{G}_{\alpha\beta}b|B^- (q + p) \rangle + \cdots, \tag{8}
\]

where \( j_{3p} = d_\bar{q}_\gamma G_{\alpha\beta} g_\gamma 5\gamma_5 5_{1B} = \bar{b}_\gamma 5\bar{u}_\gamma \), the ellipses denote contributions from the higher resonance states, which can couple to the current \( j_{3p} \), and the transition matrix element can be parametrized as

\[
\langle \pi^- | (q)T(\bar{d}\gamma^\mu 5\gamma_5 g_\gamma \bar{G}_{\alpha\beta}b)|B^- (p + q) \rangle = p_\alpha f_{-}(p^2) + (p_{\alpha}^2 + 2q_\alpha) f_{+}(p^2). \tag{9}
\]

In the deep Euclidean region of \( (p + q)^2 \), as depicted in Fig. 2 the correlation function can be perturbatively calculated in QCD and expressed in terms of 3-parton LCDAs of the pion,

\[
\Pi_{\alpha}^{\text{QCD}} = q_\alpha \int_0^1 \frac{du}{m_\omega - (p + uq)^2} \int_0^u \frac{d\alpha_g}{\alpha_g} \times [-2(p \cdot q) f_{3\pi} \phi_{3\pi} + f_{3\pi} m_\omega \phi_{3\pi}(2\bar{u} - 2\bar{u})], \tag{10}
\]

where \( u = \alpha_\bar{q} + \alpha_\omega \), and the 3-parton pion LCDAs are defined by \( \text{Ref.} [12, 13] \)

\[
\langle \pi(q) | d(x) g_\gamma G_{\mu\nu}(v\bar{x}) | \alpha_\gamma \gamma_5 u(0) |0 \rangle = if_{3\pi} (q_\omega g_{\alpha\gamma} - q_\omega g_{\alpha\omega} - q_\omega (q_\alpha g_{\beta\gamma} - q_\omega g_{\beta\omega})) \times \int D\alpha \phi_{3\pi} e^{ix\alpha + \gamma_5 u}, \tag{11}
\]
\[ \langle \pi(q)|\bar{d}(x)\gamma_\mu g_\lambda \tilde{A}_{\alpha\beta}^{\lambda}(vx)u(0)|0\rangle = i f_\pi (q_\alpha g_\beta \mu - q_\beta g_\alpha \mu) \times \int D\alpha \phi_\perp e^{iqx(\alpha + \alpha_q)} - i f_\pi q_\alpha q_\beta(x_\gamma - q_\beta x_\alpha) \times \int D\alpha (\phi_\parallel + \phi_\perp) e^{iqx(\alpha + \alpha_q)}. \tag{12} \]

Here \( \phi_{3\pi} \) is a twist-3 DA, \( \phi_\perp \) and \( \phi_\parallel \) are all of twist-4,

\[
\begin{align*}
\phi_{3\pi}(\alpha_i) &= 360\alpha_0\alpha_0\alpha_2^2 [1 + \omega_1,0,1,2](7\alpha_2 - 3) \\
&+ \omega_2,0(2 - 4\alpha_0\alpha_2 - 3\alpha_0 + 8\alpha_2) \\
&+ \omega_1,1(3\alpha_0\alpha_2 - 2\alpha_0 + 3\alpha_2^2),
\end{align*}
\]
\[
\begin{align*}
\phi_\perp(\alpha_i) &= 30\delta^2\alpha_0^2(1 - \alpha_2)\frac{1}{3} + 2\varepsilon(1 - 2\alpha_2),
\end{align*}
\]
\[
\begin{align*}
\phi_\parallel(\alpha_i) &= -120\delta^2\alpha_0\alpha_2\alpha_3\frac{1}{3} + \varepsilon(1 - 3\alpha_3). \tag{13}
\end{align*}
\]

Since the quark’s momentum after emitting the gluon is roughly of order \( m_B/2 \) and the emitted gluon’s momentum is \( \Lambda \sim \mu g_{\pi}\). \((\mu g_{\pi} \text{ will be discussed below})\), we set the scale for the separation of the perturbative and non-perturbative parts at \( \mu_b = \sqrt{\Lambda m_B/2} \approx 1.4 \text{ GeV}. \) The corresponding parameters at the scale \( \mu_b \) read: \( f_{3\pi} = 0.0032 \text{ GeV}^2, \omega_1,0 = -2.63, \omega_2,0 = 9.62, \omega_1,1 = -1.05, \delta^2 = 0.19 \text{ GeV}^2, \varepsilon = 0.45. \) To calculate \( f_\mp \), the contributions of higher resonances in Eq. (3) are approximated by

\[
\frac{1}{\pi} \int_{s_0}^{\infty} \frac{\text{Im} \Pi^{ \text{QCD}}}{s - (p + q)^2} ds, \tag{14}
\]

where \( s_0 \) is the threshold of higher resonances. Equating Eqs. (3) and (14) and making the Borel transformation: \( \mathcal{B}[m_B^2 - (p + q)^2]^{-1} = \exp(-m_B^2/M^2) \), we obtain the light-cone sum rule

\[
f_-(p^2) = \frac{m_B}{2m_B^2 F_B} \int_0^1 du \int_u^1 d\alpha_2 e^{m_B^2 u - m_B^2 s u^2} \times \left[ f_{3\pi} \frac{m_B^2 - p^2}{u^2} \phi_{3\pi} - f_\perp \frac{m_B}{u} (\phi_\parallel - 2\phi_\perp) \right], \tag{15}
\]

and \( f_+(p^2) = -f_-(p^2) \), where \( \Delta = u - (m_B^2 - p^2)/(s_0 - p^2) \).

Using the above parameters for LCDA, \( m_b = (4.7 \pm 0.1) \text{ GeV} \), and \( F_B = 180 \text{ MeV} \), we obtain the stable

\[ f_\pm \text{ prediction by adopting } s_0 \approx 37 \text{ GeV}^2 \text{ and } M^2 \approx (9 - 20) \text{ GeV}^2. \text{ The result is depicted in Fig. 3(a).} \]

The resulting value is \( f_\pm(m_\pi^2) = (\pm 0.057 \pm 0.005) \text{ GeV}^2 \), where the uncertainty comes from the sum rule analysis. We then get

\[
p_{\pi}^0(\pi^0|\bar{d}t_\gamma \gamma_5 g_\Lambda \tilde{A}_{\alpha\beta} b B^-) = -f_-(m_\pi^2) \times (m_\pi^2 - m_\pi^2) \approx -1.6 \text{ GeV}^2. \tag{16}
\]

Next, we determine the value of \( \bar{\sigma}_{\pi} \). For illustration, we plot in Fig. 3(b) the amplitude \( A_\pi \) of the \( f_-(m_\pi^2) \) sum rule versus \( \alpha_0 = \alpha_d + \alpha_g \) by adopting \( M^2 = 10 \text{ GeV}^2 \), where \( A_\pi \) satisfies \( f_\pm = \int_0^1 du \int_u^1 d\alpha_2 A_{\pi}, \) i.e. the volume in the plot is equal to \( f_\pm(m_\pi^2) \). The resultant form factor is dominated by the region where \( u \gtrsim 60\%, \alpha_0 \lesssim 30\% \). The averaged fraction of the pion momentum carried by the gluon is then estimated to be \( \bar{\sigma}_{\pi} = (\int_0^1 du \int_u^1 d\alpha_2 A_{\pi})/f_\pm \approx 0.23. \)

We therefore obtain \( \langle \omega\pi^- | O_{15} B^- \rangle _{\text{Fig. 1(b)}} \approx 0.13 \) and \( f_3 = 0.12 \) which gives the correction to \( \alpha_i \) as defined in Eq. (2). We list \( \alpha_i \) without and with the subleading corrections in Table II where the approximation \(-\sqrt{2}p_{\pi}^0(\omega | \bar{d}t_\gamma \gamma_5 g_\Lambda \tilde{A}_{\alpha\beta} b B^-)/A_0 \approx p_{\pi}^0(\pi^0 | \bar{d}t_\gamma \gamma_5 g_\Lambda \tilde{A}_{\alpha\beta} b B^-)/F_B^\pi \) has been made. Note that \( a_0 \) and \( a_\perp \) do not receive subleading corrections.

In the following analysis, the LC sum rule form factors and \( m_s = 80 \text{ MeV} \) are used. We will instead use a smaller \( A_0^B = 0.28 \) which is preferred by the \( \omega\pi^- \) data. The \( \omega\pi^- \) mode is ideal for extracting \( A_0^B \) since its rate is insensitive to annihilation effects. We find that the spectator parameter \( X_H = \ln \frac{m_B^2}{m_B^2 - 1 + \rho_H e^{i\phi_H}} \) is consistent with zero in the analysis. The reason is that since the spectator interaction with a gluon exchange between the emitted meson and the recoiled pseudoscalar meson of twist-3 LCDA \( \Phi_3 \) is an end-point divergent in the collinear expansion, the vertex of the gluon and spectator quark should be considered inside the pion wave function, i.e., for this situation the pion itself is at a 3-parton Fock state. Annihilation effects have been emphasized in \( \phi K \) studies [3].

We adopt the annihilation parameters \( \rho_A \approx 0.9, \phi_A \approx 0 \) which give \( Br(B^- \to \phi K^-) \approx 8.5 \times 10^{-6} \), consistent with the current data. Here the annihilation parameter of VP modes is defined as \( \lambda_{VP} \).
TABLE I: Values for $a_i$, for charmless $B$ decay processes without (first row) and with (second row) 3-parton Fock state contributions of final state mesons, where $a_{3-10}$ are in units of $10^{-4}$ and the annihilation effects are not included.

<table>
<thead>
<tr>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>$a_4$</th>
<th>$a_5$</th>
<th>$a_6$</th>
<th>$a_7$</th>
<th>$a_8$</th>
<th>$a_9$</th>
<th>$a_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.926 + 0.001i</td>
<td>0.10 + 0.008i</td>
<td>25 + 26i</td>
<td>-28 + 9i</td>
<td>0.2 + 0.3i</td>
<td>4.5 + 0.6i</td>
<td>-60 + 0.4i</td>
<td>-5.9 + 7i</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.974 + 0.014i</td>
<td>0.25 + 0.08i</td>
<td>-55 + 26i</td>
<td>-91 + 11i</td>
<td>-30 + 4i</td>
<td>4.5 + 0.6i</td>
<td>-80 + 0.1i</td>
<td>-5.9 + 7i</td>
<td></td>
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</tr>
</tbody>
</table>

FIG. 4: (a) Dash, solid, and dot-dash for $\overline{B} \rightarrow \omega \pi^-, \omega K^-$ and $\omega K^{-}$; (b) solid, dots, dot-dash, and dash for $K^-\eta', \overline{K}^0 \eta', K^+ \eta$, and $\overline{K}^0 \eta$. Brs are in units of $10^{-6}$.

FIG. 5: (a) Solid, dash, dot-dash, and dots for $\overline{B} \rightarrow \overline{K}^0 \rho^0, K^- \rho^+, K^0 \rho^-$, and $K^- \rho^0$; (b) solid, dot-dash, dash, and dots for $\overline{B} \rightarrow K^+ \pi^-, \overline{K}^0 \pi^0, \rho^- \eta$ and $\rho^- \eta'$. Brs are in units of $10^{-6}$.

and its the imaginary part is neglected since the BRs are insensitive to it. In Fig. 4 (a) we plot the BRs of $\omega \pi^-$ and $\omega K$ modes versus $\gamma (\equiv \arg V_{ub}^\ast)$. The results for $\gamma \approx (60-120)^\circ$ are in good agreement with data. At $\gamma = 90^\circ$, it gives $\omega \pi^-, \omega K^-, \omega K^0$ to be 5.5, 4.5, 4.3, respectively, in units of $10^{-6}$. Without the contributions from 3-parton Fock states of mesons, $\phi K^-, \omega \pi^-, \omega K^-, \omega K^0$ will become 11, 3, 9.3, 3.1, 2.9 (in units of $10^{-6}$). The 3-parton Fock state effects give constructive contributions to $\omega K$, $\omega K$ modes, while destructive to the $\phi K$ mode.

The corrections from 3-parton Fock states of the kaon also give a definite answer to the long-standing problem for $a_2(J/\psi K)$. In the earlier study, to account for the experimental value $|a_2|$, the parameter $\rho_H$ has to be $\gtrsim 1.5$ [14]. As emphasized in passing, without fine-tuning $\rho_H$, we calculate the amplitudes from the 3-parton Fock states of the kaon. With the same procedure as shown above, we obtain $f_3(m^2_{J/\psi}) \approx 0.08$, $f_3 \approx 0.14$ and thus $a_2^{SL} = a_2^\ast + c_1(\mu_b) f_3 \simeq 0.10 + 0.05i + c_1(\mu_b) 0.14 = 0.27 + 0.05i$, where $a_2^\ast$ is determined up to the twist-2 order and the SU(3) approximation for $f_3$ has been made. The result for $a_2^{SL}$ is well consistent with that extracted from data. This solves the long-standing sign ambiguity of $a_2(J/\psi K)$ which turns out to be positive for its real part. Note that if Re($a_2$) was negative, $f_3$ would have to be $\sim -0.3$ which in turns would lead to $\phi K \sim 20 \times 10^{-6}$ and $\omega \pi^-, \omega K \sim 1 \times 10^{-6}$!

The subleading corrections could give significant contributions to the decays with $\eta^0$ in the final states because these decay amplitudes always contain the singlet factor $a_3 - a_5$. We plot the BRs of $K\eta', K\eta$ modes versus $\gamma$ in Fig. 4 (b), where $X_A^{PP} \approx 0$, the annihilation parameter for $PP$ modes, has been used as it could give good fit results for $K\pi, \pi\pi$ rates [2]. We do not consider the singlet annihilation correction [15] in $K\eta$ modes because it is still hard to determine at present. With (without) the subleading corrections, we see that $K^-\eta' \gtrsim \overline{K}^0 \eta' \approx 55 (35)$, and $K^+\eta \gtrsim \overline{K}^0 \eta \approx 24 (20)$, in units of $10^{-6}$. The corrections give 70% and 25% enhancements to $K\eta$ and $K\eta$ rates, respectively. Note that with (without) the corrections, $K^+\eta \lesssim 1 \times 10^{-6}$ ($\lesssim 4 \times 10^{-6}$) and $K\eta \lesssim 1 \times 10^{-6}$ ($\lesssim 1 \times 10^{-6}$). In pQCD calculation [16], it seems that $K^+\eta(= 41 \times 10^{-6})$ was underestimated while $K\eta(= 7 \times 10^{-6})$ overestimated compared to the data [3, 4]. Within the QCDF framework, by only considering the two-parton LCDs of mesons, Beneke and Neubert [15] obtained $K^+\eta \sim 13 \times 10^{-6}$, just half of the experimental value, but with a huge error.

For further comparison with other calculations, we plot $K\rho, K^+\pi, \rho^- \eta^0$ modes in Fig. 5. The subleading contributions to these BRs are $\lesssim 15\%$. At $\gamma = 90^\circ$, we have $\overline{K}^0 \rho^0, K^-\rho^+, K^0 \rho^-, K^- \rho^0 = 0.6, 7.2, 1, 2 \times 10^{-6}$, and $K^+\pi^+, \overline{K}^0 \pi^0, \rho^- \eta, \rho^- \eta' = 9.2, 6.4 \times 10^{-6}$. In [7], to fit $\phi K, \omega K$ rates, the annihilation effects dominate the decay amplitudes and the form factors $F_{BR}^{A_0}, A_0^{\pi \pi}$ are rather small, such that it will lead to $\rho^+ K^{-0}: \rho^0 K^{-0} : \omega K^{-0} \approx 1 : (1/\sqrt{2})^2 : (1/\sqrt{2})^2$, while the pQCD results for rates are $\overline{K}^0 \rho^0, K^- \rho^+, K^0 \rho^-, K^- \rho^0 = 2.5, 4, 3.0, 2.2 \times 10^{-6}$ [3].

In conclusion, we have calculated the contributions arising from 3-parton Fock states of mesons in $B$ decays. We find that the contributions could give significant corrections to decays with an $\omega$ or $\eta^0$ in the final states. Our main results for $\gamma \approx (60-110)^\circ$ are $\omega \pi^-, \omega K^-, \omega K \approx 6.0, (6, \sim 5), 5.1$, respectively, in units of $10^{-6}$, while the previous QCDF global fit to $VP$ modes and the pQCD results gave smaller $\omega K$ BRs of order $\lesssim 3 \times 10^{-6}$ [3, 14]. We predict that $\overline{K}^0 \rho^0 \sim \omega K$ and
Including the corrections we obtain $a_2(J/\psi K) \approx 0.27 + 0.05i$ which is well consistent with the data. The sign of Re($a_2$) turns out to be positive. Without resorting to the unknown singlet annihilation effects, 3-parton Fock state contributions can enhance $K\eta'$ to the level above $5 \times 10^{-5}$.

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