Implications of $\overline{B} \to D^0 h^0$ Decays on $\overline{B} \to D\overline{K}$, $\overline{D}\overline{K}$ Decays

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The recently observed color suppressed $\overline{B}^0 \to D^0\pi^0$, $D^0\eta^{(\prime)}$, $D_s^+K^-$ and $D^0\overline{K}^0$ decay modes all have rates larger than expected, hinting at the presence of final state interactions. We study rescattering effects in $\overline{B} \to DP$, $D\overline{K}$ and $\overline{D}\overline{K}$ modes in the quasi-elastic approach, which is extended to accommodate $D^0\eta'$ without using U(3) symmetry. The $\overline{D}^0\overline{K}$ modes are of interest in the determination of the unitarity angle ϕ_3/γ. The updated DP data are used to extract the effective Wilson coefficients $a_1^{\rm eff} \simeq 0.92$, $a_2^{\rm eff} \simeq 0.22$, three strong phases $\delta \simeq 62^\circ$, $\theta \simeq 24^\circ$, $\sigma \simeq 127^\circ$, and the mixing angle $\tau \simeq 2^\circ$. The values of δ and θ are close to our previous results. The smallness of τ implies small mixing of $D^0\eta_1$ with other modes. Predictions for D^0K^-, D^+K^- and $D^0\overline{K}^0$ agree with data. Since strong interaction respects charge conjugation symmetry, the framework applies to $\overline{B} \to \overline{D}\overline{K}$, and rates for $\overline{D}^0K^-$, D^-K^0, $D_s^-\pi^0$, $D_s^-\eta$ and $D_s^-\eta'$ modes are predicted. From $B^- \to \overline{D}^0K^-$ and D^0K^- rates, we find $r_B = 0.09 \pm 0.02$, where the error is propagated from the experimental DP rate uncertainties. The error on r_B is doubled when the universality on $a_2^{\rm eff}$ is relaxed.

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The recently observed color-suppressed $\overline{B}^0 \to D^0\pi^0$, $D^0\eta^{(\prime)}$, $D_s^+K^-$ and $D^0\overline{K}^0$ decay modes all have rates larger than expected [1], hinting at the presence of final state interactions. Shortly after the first observation of the color suppressed modes became known, we proposed [2] a quasi-elastic final state rescattering (FSI) picture, where the enhancement of color suppressed D^0h^0 modes can be understood as rescattering from the color allowed $D^+\pi^-$ final state. The framework is applicable to $\overline{B} \to D\overline{K}$, $\overline{D}\overline{K}$ decays.

The color-allowed $B^- \to D^0K^-$ and color-suppressed $\overline{D}^0K^-$ decays are of interest for the determination of the unitary phase angle $\phi_3(\gamma) \equiv \arg V_{ub}^*$, where V is the CKM quark mixing matrix. The amplitude ratio r_B and the strong phase difference δ_B for $\overline{D}^0K^-$ and D^0K^- decay modes, which are governed by different CKM matrices are defined as

$$r_B = \left|\frac{A(B^- \to \overline{D}^0K^-)}{A(B^- \to D^0K^-)}\right|, \qquad \delta_B = \arg\left[\frac{e^{i\phi_3}A(B^- \to \overline{D}^0K^-)}{A(B^- \to D^0K^-)}\right]. \tag{1}$$

The r_B and δ_B parameters are common to the ϕ_3 determination methods of Gronau-London-Wyler (GLW) [3], Atwood-Dunietz-Soni (ADS) [4] and "*DK* Dalitz plot" [5], where one exploits the interference effects of $B^- \to D^0K^- \to f_{\rm CP}K^-$ and $B^- \to \overline{D}^0K^- \to f_{\rm CP}K^-$ amplitudes. The r_B parameter, which governs the strength of interference, is both color and CKM suppressed, hence hard to measure directly. Through the *DK* Dalitz plot method, the BaBar and Belle experiments already find $\gamma = 70^\circ \pm 44^\circ \pm 10^\circ \pm 10^\circ$ and $\phi_3 = 64^\circ \pm 19^\circ \pm 13^\circ \pm 11^\circ$, respectively [6, 7]. Although similar results on ϕ_3 are obtained, the corresponding r_B values are quite different for BaBar and Belle. Belle reports $r_B = 0.21 \pm 0.08 \pm 0.03 \pm 0.04$, while BaBar gives $r_B < 0.19$ at 90% confidence level. As the strength of interference is governed by the size of r_B, the larger error in the γ value of BaBar reflects the smallness of their r_B. Given the experimental situation that Belle and BaBar have quite different r_B values and the critical role it takes in ϕ_3/γ extraction, it is important to give a theoretical or phenomenological prediction of r_B and δ_B. In fact, it was conjectured that the enhancement in color-suppressed rates may also enhance the r_B value [8]. In [9] we study rescattering effects in $\overline{B} \to DP$, $D\overline{K}$ and $\overline{D}\overline{K}$ modes in the quasi-elastic approach, which is extended to accommodate $D^0\eta'$ without using U(3) symmetry. The *DP* data are very useful in predicting the FSI effects in the $\overline{D}P$ system, see Fig. 1, as the strong interaction respects charge conjugation.

The master formula for FSI effects in *B* decays is given by

$$A = \mathscr{S}^{1/2}A^0, \tag{2}$$

where A is the $\overline{B}$ decay amplitude, A^0 is real and $\mathscr{S}$ is the rescattering *S*-matrix. Rescattering phases and angles can be obtained by using SU(3) decomposition. Let us consider the *DP* case first. D is an anti-triplet ($D(\overline{\mathbf{3}})$), while P can be reduced to an octet [$\Pi(\mathbf{8})$] and a singlet (η_1). The $D(\overline{\mathbf{3}}) \otimes \Pi(\mathbf{8})$ can be reduced into a $\overline{\mathbf{3}}$, a $\mathbf{6}$ and a $\overline{\mathbf{15}}$, while $D(\overline{\mathbf{3}})\eta_1$ is another anti-triplet. Denoting the latter as $\overline{\mathbf{3}}'$, it can mix with the $\overline{\mathbf{3}}$ from $D\Pi$ via a 2×2 symmetric (from time reversal invariance) unitary matrix $\mathscr{U}$. The invariance of the strong interaction under SU(3) gives

$$\mathscr{S} = |\overline{\mathbf{15}}\rangle\langle\overline{\mathbf{15}}| + e^{2i\delta}|\mathbf{6}\rangle\langle\mathbf{6}| + \left(|\overline{\mathbf{3}}\rangle \;\; |\overline{\mathbf{3}}'\rangle\right)\cdot\mathscr{U}\cdot\begin{pmatrix}\langle\overline{\mathbf{3}}| \\ \langle\overline{\mathbf{3}}'|\end{pmatrix}, \tag{3}$$

with

$$\mathscr{U} = \mathscr{U}^T = \begin{pmatrix}\cos\tau & \sin\tau \\ -\sin\tau & \cos\tau\end{pmatrix}\begin{pmatrix}e^{2i\theta} & 0 \\ 0 & e^{2i\sigma}\end{pmatrix}\begin{pmatrix}\cos\tau & -\sin\tau \\ \sin\tau & \cos\tau\end{pmatrix}. \tag{4}$$

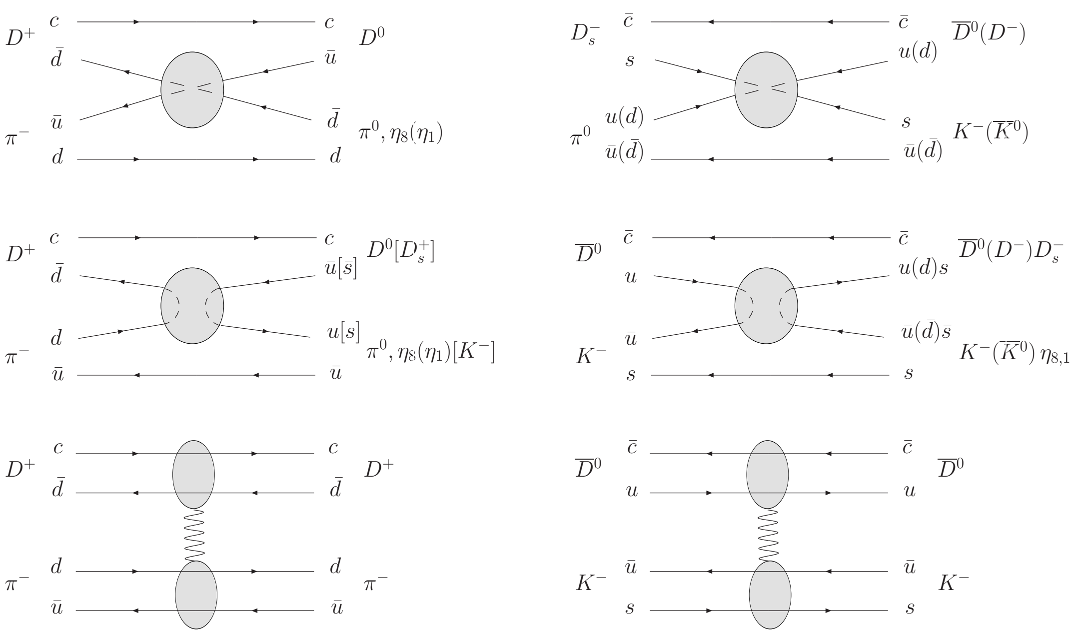

Figure 1: Pictorial representation (from top to bottom) of charge exchange, annihilation and singlet exchange for DP and $\overline{D}P$ (re)scatterings.

Note that in the master formula (2), one should use $\mathscr{S}^{1/2}$. This can be easily obtained by reducing all phases in the right-hand-side of the above equation by half. By charge conjugation invariance of the strong interaction, the above S-matrix can also be applied to the $\overline{D}P$ case with $\overline{\mathbf{15}}$, $\mathbf{6}$ and $\overline{\mathbf{3}}^{(\prime)}$ replaced by $\mathbf{15}$, $\overline{\mathbf{6}}$ and $\mathbf{3}^{(\prime)}$, respectively.

The updated DP data are used to extract the effective Wilson coefficients $a_1^{\rm eff} \simeq 0.92$, $a_2^{\rm eff} \simeq 0.22$, three strong phases $\delta \simeq \pm 62^\circ$, $\theta \simeq \pm 24^\circ$, $\sigma \simeq \pm 127^\circ$, and the mixing angle $\tau \simeq 2^\circ$. The values of δ and θ are close to our previous results [2]. The smallness of τ implies small mixing of

Table 1: The branching ratios of various $\overline{B} \to DP$ and $D\overline{K}$ and $\overline{D}P$ modes. The factorization results are obtained by using the same set of parameters but with FSI phases set to zero. The errors for the FSI results are from DP data only.

Mode	$\mathscr{B}^{\rm exp}$ (10^{-4})	$\mathscr{B}^{\rm FSI}$ $[\mathscr{B}^{\rm fac}]$ (10^{-4})	Mode	$\mathscr{B}^{\rm exp}$ (10^{-5})	$\mathscr{B}^{\rm FSI}$ $[\mathscr{B}^{\rm fac}]$ (10^{-5})
$D^+\pi^-$	27.6 ± 2.5	input $[33.0^{+3.0}_{-4.3}]$	$\overline{D}^0K^-$	–	$0.28^{+0.23}_{-0.15}$ $[0.17^{+0.23}_{-0.11}]$
$D^0\pi^0$	2.53 ± 0.20	input $[0.51^{+0.72}_{-0.34}]$	$D^-\overline{K}^0$	< 0.5	$0.05^{+0.06}_{-0.03}$ $[0]$
$D_s^+K^-$	0.38 ± 0.13	input $[0]$	$D_s^-\pi^0$	< 20	$0.59^{+0.06}_{-0.05}$ $[0.77^{+0.07}_{-0.10}]$
$D^0\eta$	2.11 ± 0.33	input $[0.29^{+0.41}_{-0.20}]$	$D_s^-\eta$	< 50	$0.17^{+0.30}_{-0.09}$ $[0.46^{+0.04}_{-0.06}]$
$D^0\eta'$	1.26 ± 0.26	input $[0.18^{+0.26}_{-0.12}]$	$D_s^-\eta'$	–	$0.58^{+0.12}_{-0.26}$ $[0.30 \pm 0.03]$
$D^0\pi^-$	49.8 ± 2.9	input $[49.8 \pm 2.9]$			
D^0K^-	3.7 ± 0.6	$3.91^{+0.37}_{-0.32}$ $[3.91^{+0.37}_{-0.32}]$			
D^+K^-	2.0 ± 0.6	$1.78^{+0.20}_{-0.17}$ $[2.38^{+0.21}_{-0.31}]$			
$D^0\overline{K}^0$	0.50 ± 0.14	$0.73^{+0.08}_{-0.10}$ $[0.12^{+0.17}_{-0.08}]$			

Table 2: Naive factorization and FSI results on r_B, δ_B with $|V_{ub}| = 3.67\times10^{-3}$, and compared to the experimental results [6, 7, 10]. The errors for the FSI results are from *DP* data only.

	Expt	fac	FSI
r_B	$0.21\pm0.08\pm0.03\pm0.04$ (Belle)	0.07 ± 0.03	0.09 ± 0.02
	<0.19 (90% CL) (BaBar)		
	0.10 ± 0.04 (UT$_{fit}$)		
$\delta_B-\pi$	$-23^\circ\pm19^\circ\pm11^\circ\pm21^\circ$ (Belle)	0	$(\mp19.9^{+25.1}_{-13.9})^\circ$
	$-66^\circ\pm41^\circ\pm8^\circ\pm10^\circ$ (BaBar)		

$D^0\eta_1$ with other modes. The predicted $B^-\to D^0K^-$ and $\overline{B}^0\to D^+K^-$, $D^0\overline{K}^0$ rates are in agreement with data (see Table 1). The predicted rates for $\overline{B}\to\overline{D}\,\overline{K}$ modes, and the rates for $\overline{D}^0K^-$, $D^-\overline{K}^0$, $D_s^-\pi^0$, $D_s^-\eta$ and $D_s^-\eta'$ modes are also given. In Table 2, we show the prediction on r_B and δ_B. With a universal $a_2^{\rm eff}$ we predict $r_B = 0.09\pm0.02$, where the error is propagated from experimental uncertainties in the *DP* rates. With the relaxation on the universality of $a_2^{\rm eff}$ the above error is doubled. The predicted r_B agrees with the UT$_{fit}$ extraction [10]. Furthermore, our r_B value prefers the lower value of the BaBar experiment and disfavors the Belle result, extracted from the ϕ_3/γ fit to $B^-\to\{D^0,\overline{D}^0\}K^-$ data using the *DK* Dalitz method. The smallness of the ratio r_B would demand larger statistics of data for this particular ϕ_3/γ program. In turn, with larger statistics the r_B extracted from our approach can be cross checked from the value extracted from the ϕ_3/γ program.

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