Hadronic B decays to open charm at Belle

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ABSTRACT: Studies of hadronic B decays to charm-related modes at Belle are presented. The results include the first observation of color-suppressed $\overline{B}^0 \to D^0 X^0$ decays, a search for $\overline{B}^0 \to D_S^- h^+$, an observation of $B^- \to D^0_{CP} K^-$, and evidence for $\overline{B}^0 \to D^+ D^{*-}$. The results presented here are all preliminary.

1. Introduction

Preliminary results on B decays to charm-related modes at Belle are presented. The data sample was collected with the Belle detector[1] at KEKB[2], and corresponds to an integrated luminosity of 21.3 fb^{-1} at the $\Upsilon(4S)$ resonance, which contains 22.8 million $B\overline{B}$ pairs, and 2.3 fb^{-1} taken 60 MeV below the resonance. In general, the B candidates are identified by two kinematic variables: the beam-constrained mass, $M_{bc} = \sqrt{(E^{\rm CM}_{\rm beam})^2 - (p^{\rm CM}_B)^2}$, and the energy difference, $\Delta E = E^{\rm CM}_B - E^{\rm CM}_{\rm beam}$, where $E^{\rm CM}_B$ and $p^{\rm CM}_B$ are the CM energy and momentum of the $\overline{B}^0$ candidate and $E^{\rm CM}_{\rm beam} = \sqrt{s}/2 = 5.29$ GeV.

2. First observation of color-suppressed $\overline{B}^0 \to D^0 X^0$ decays.

The decay modes $\overline{B}^0 \to D^{(*)0} X^0$, where X^0 is a light neutral meson, proceed via an internal spectator diagram, and are expected to be suppressed relative to the external diagram, since the color of the $\overline{u}$ antiquark produced by the weak current must cancel the color of the c quark, as shown in Fig. 1. Studies of such color-suppressed decay modes can be used to test models of hadronic B meson decays and to provide information on final-state interactions. Results of searches for color-suppressed $\overline{B}^0 \to D^{(*)0} X^0$ decays have been published by the CLEO collaboration [3]; however, only upper limits were obtained.

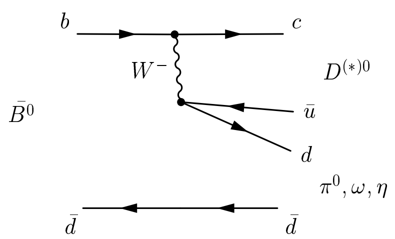

Figure 1: The Feynman diagram for $\overline{B}^0 \to D^{(*)0} X^0$ decays.

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In addition to the $q\overline{q}$ background, we observe large background contributions from color-favored $B \to D^{(*)}(n\pi)^-$ decays and cross-talk from $D^{*0}X^0$ to D^0X^0 modes. The $D^{*+}\rho^-$ mode has the same final state as $D^0\omega$ and $D^0\eta$, but can be suppressed by ω or η mass window cuts. The $D^{(*)0}\rho^-$ final state contaminates the $D^{(*)0}\pi^0$ and $D^{(*)0}\eta$ modes if the ρ^- decays to a fast π^0. About half of these events are removed by explicitly reconstructing the $D^{(*)0}\rho^-$ final state. The contributions of these backgrounds in the η channel, as well as the feed-across from the $D^{(*)0}\pi^0$ mode, is minimized by a π^0 veto. We also check for background contributions from $\overline{B} \to D^{(*)0}\rho'^-$ ($\rho'^- \to \omega\pi^-$) decays, which have recently been observed by CLEO [4]. This two-body decay produces high-momentum $D^{(*)0}$s and ωs that can fake signal events. Monte-Carlo studies indicate that the remaining background events can be distinguished from signal events by fitting the ΔE distribution.

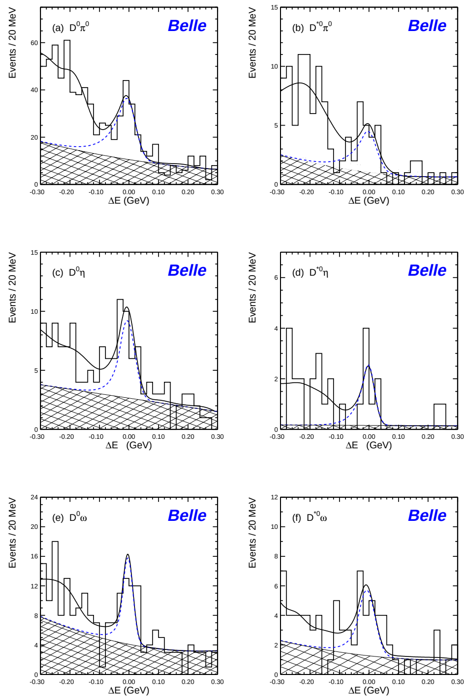

Figure 2: The ΔE distribution for (a) $D^0\pi^0$, (b) $D^{*0}\pi^0$, (c) $D^0\eta$, (d) $D^{*0}\eta$, (e) $D^0\omega$, and (f) $D^{*0}\omega$. The solid line shows the fitting result. The dashed line shows the sum of the signal component and the combinatorial background component. The combinatorial component is shown separately as the cross-hatched area.

The ΔE distributions for the various $D^{(*)0}X^0$ decays are shown in Fig. 2. Table 1 summarizes the results for each $D^{(*)0}X^0$ mode. In general, the branching fractions are higher than theory predictions [5] based on the factorization hypothesis. This may be accounted for by additional corrections to the factorization models, or by non-factorizable effects, such as final state interactions.

Mode	Signal Yield	Significance	Efficiency(%)	$\mathcal{B}$ ($\times 10^{-4}$)	UL ($\times 10^{-4}$)
$\overline{B}^0 \to D^0\pi^0$	$127.6\ ^{+18.5}_{-17.9}\ ^{+11.6}_{-12.5}$	7.9	1.93	$2.9\ ^{+0.4}_{-0.3} \pm 0.6$	–
$\overline{B}^0 \to D^{*0}\pi^0$	$17.1\ ^{+6.6}_{-5.9}\ ^{+1.6}_{-2.4}$	3.2	0.49	$1.5\ ^{+0.6}_{-0.5}\ ^{+0.3}_{-0.4}$	2.3
$\overline{B}^0 \to D^0\eta$	$25.7\ ^{+8.4}_{-7.7}\ ^{+3.0}_{-2.8}$	3.8	0.79	$1.4\ ^{+0.5}_{-0.4} \pm 0.2$	2.1
$\overline{B}^0 \to D^{*0}\eta$	$7.7\ ^{+3.4}_{-2.7}\ ^{+0.7}_{-0.8}$	3.6	0.22	$1.5\ ^{+0.7}_{-0.6} \pm 0.4$	2.7
$\overline{B}^0 \to D^0\omega$	$30.2\ ^{+8.6}_{-7.8}\ ^{+3.1}_{-3.4}$	4.7	0.80	$1.7\ ^{+0.5}_{-0.4}\ ^{+0.3}_{-0.4}$	–
$\overline{B}^0 \to D^{*0}\omega$	$17.7\ ^{+6.5}_{-5.8}\ ^{+2.3}_{-2.2}$	4.3	0.23	$3.4\ ^{+1.3}_{-1.1} \pm 0.8$	–

Table 1: The obtained signal yield, statistical significance, efficiency including the sub-decay branching fractions, branching fraction ($\mathcal{B}$), and 90% confidence level upper limit (UL) for each $\overline{B}^0 \to D^{(*)0}X^0$ decay mode.

3. Search of $\overline{B}^0 \to D_s^- h^+$ decays.

The $\overline{B}^0 \to D_s^- \pi^+$ decay proceeds via the $b \to u$ transition. Therefore, a measurement of the branching fraction, $\mathcal{B}(\overline{B}^0 \to D_s^- \pi^+)$, gives access to the CKM matrix element, $|V_{ub}|$ [6]. One advantage of measuring V_{ub} from the $B^0 \to D_s^+ \pi^-$ rate is that a tree-level diagram dominates the process, and there is no contribution from the penguin diagram. The $\overline{B}^0 \to D_s^+ K^-$ decay proceeds via W exchange, and is expected to be highly suppressed, by a factor of 10^{-4}, compared to the tree diagram. Therefore, searches for $\overline{B}^0 \to D_s^+ K^-$ decays provide a probe of the final state interactions, which may enhance the branching fraction by several orders of magnitude.

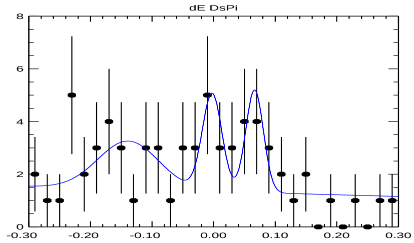

Figure 3: The ΔE distribution for $\overline{B}^0 \to D_s^- \pi^+$ search.

The D_s^- candidates are reconstructed in the $D_s^- \to \phi\pi^-$, $K_S^0 K^-$, and $K^{*0} K^-$ decay modes. We combine D_s^- and h^+ mesons to form $\overline{B}$ candidates, where h^+ is either π^+ or K^+. Fig. 3 shows the ΔE distribution for $\overline{B}^0 \to D_s^- \pi^+$ candidates. The three peaks, from left to right, correspond to the $B^0 \to D^- \rho^+$ background, $D_s^- \pi^+$ signal, and $B^0 \to D^- \pi^+$ background peak. The results of $\overline{B}^0 \to D_s^- h^+$ search are summarized in Table 2 with 90% C.L. upper limits. We obtained an improved upper limit on $\overline{B}^0 \to D_s^+ K^-$ and a limit of $|V_{ub}| < 0.0065$, which is consistent with the PDG [7] value, $|V_{ub}| = 0.005$.

Mode	Signal Yield	Upper limit	CLEO UL	Theory pred.
$\overline{B}^0 \to D_s^- \pi^+$	7.3 ± 3.7	$< 16 \times 10^{-5}$	$7.5 \times 10^{-5\dagger}$	$4.5 \times 10^{-5*}$
$\overline{B}^0 \to D_s^- K^+$	2.2 ± 2.5	$< 14 \times 10^{-5}$	$24 \times 10^{-5\ddagger}$	$0.66 \times 10^{-5\S}$

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Table 2: Summary of the $\overline{B}^0 \to D_s^- h^+$ search results.

4. Observation of $B^- \to D_{CP}^0 K^-$ decays.

The extraction of the ϕ_3 angle in the CKM triangle [6] is challenging even with modern high-luminosity B factories. Recent theoretical work has demonstrated that ϕ_3 can be determined from $B^- \to DK^-$ decays by using the interference between the $b \to c$ and $b \to u$ processes, which are shown in Fig. 4. The angle ϕ_3 can be extracted from $B^- \to D_{1,2}K^-$ decays, where D_1 and D_2 are CP $= +$ and $-$ eigenstates, respectively. Assuming the absence of D^0 - $\overline{D}^0$ mixing, the observables sensitive to CP violation that are used to extract the angle ϕ_3 are :

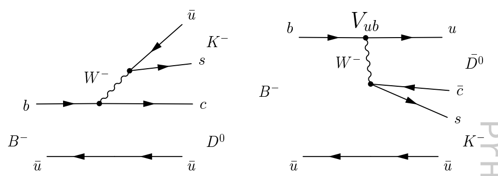

Figure 4: $B^- \to DK^-$ decay amplitudes.

$$\mathcal{A}_{1,2} \equiv \frac{\mathcal{B}(B^- \to D_{1,2}K^-) - \mathcal{B}(B^+ \to D_{1,2}K^+)}{\mathcal{B}(B^- \to D_{1,2}K^-) + \mathcal{B}(B^+ \to D_{1,2}K^+)} = \frac{2r \sin\delta' \sin\phi_3}{1 + r^2 + 2r\cos\delta' \cos\phi_3}$$

$$R_{1,2} \equiv \frac{\frac{\mathcal{B}(B^-\to D_{1,2}K^-)+\mathcal{B}(B^+\to D_{1,2}K^+)}{\mathcal{B}(B^-\to D_{1,2}\pi^-)+\mathcal{B}(B^+\to D_{1,2}\pi^+)}}{\frac{\mathcal{B}(B^-\to D^0K^-)+\mathcal{B}(B^+\to \bar{D}^0K^+)}{\mathcal{B}(B^-\to D^0\pi^-)+\mathcal{B}(B^+\to \bar{D}^0\pi^+)}} = 1 + r^2 + 2r\cos\delta'\cos\phi_3$$

$$\delta' = \delta \quad \text{for} \quad D_1; \qquad \delta + \pi \quad \text{for} \quad D_2.$$

Here r denotes the ratio of the amplitudes, $r \equiv A(B^- \to \bar{D}^0K^-)/A(B^- \to D^0K^-)$, and δ is the strong phase difference. Here, we report on a study of $B^- \to DK^-$ decays, where the D^0 meson decays into a flavor-specific state, $K^-\pi^+$, or into a CP $= +1$ eigenstate, K^-K^+ or $\pi^-\pi^+$.

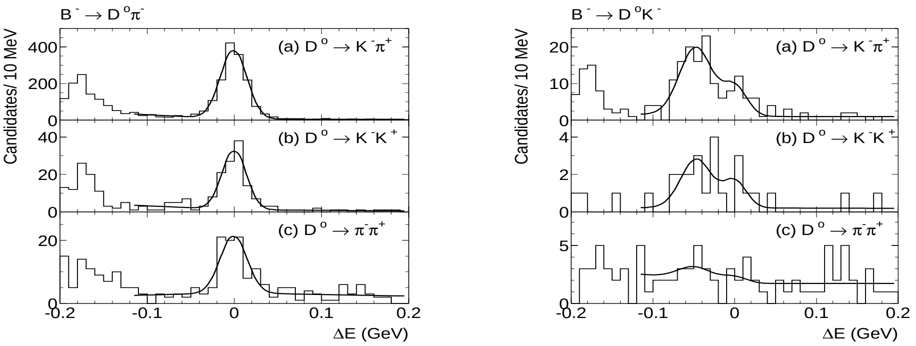

Figure 5: The ΔE distribution for $B^- \to D^0\pi^-$ and $B^- \to D^0K^-$ candidates.

In order to identify $B^- \to DK^-(\pi^-)$ samples, we looked at the ΔE distributions shown in Fig. 5 for various modes. With the pion mass assumption, $B^- \to D\pi^-$ events peak at $\Delta E = 0$, while the DK^- peak is shifted to $\Delta E = -49$ MeV. The signal yields are 12.3 ± 3.9 events with a significance of 4.3 for $B^- \to D^0(K^+K^-)K^-$ and 4.9 ± 5.4 events with a significance of 0.94 for the $B^- \to D^0(\pi^+\pi^-)K^-$ mode.

Using the signal yields in the $D_{CP}K$ modes, the 90% C.L. range for the asymmetry is determined to be $-0.78 < \mathcal{A}_1 < 0.94$. The double ratio ($R_1$) is obtained to be $R_1 = 1.39 \pm 0.53(stat.) \pm 0.26(syst.)$. The results for R_1 and $\mathcal{A}_1$ are in good agreement with the Standard Model prediction.

5. Evidence of $\overline{B}^0 \to D^+D^{*-}$ decays.

The decays $B^0 \to D^\pm D^{*\mp}$ are of special interest for the measurement of the CP violation parameter $\sin 2\phi_1$. A full reconstruction of both charm mesons results a small overall efficiency for B reconstruction. In this analysis the D^+ is fully reconstructed, while only the slow pion from the D^{*-} decay is used. The slow pion, π^-_{slow}, from the D^{*-} decay approximately retains the D^{*-} momentum direction because of the small energy release in the decay and the polarization of the D^{*-} meson. Thus, the angle α between the slow pion and the D^+ meson can be employed as a signature of the studied decay.

The continuum contribution is subtracted using data taken at energies below the threshold of $B\overline{B}$ production. Data are further divided into two data sets, with and without a high-momentum lepton tag. The high-momentum lepton tag suppresses the continuum background to a negligible level, and can be used as a tagging particle for future CP studies.

Fig. 6 shows the $\cos\alpha$ distribution for the data with and without a lepton tag; the signal yields are 244 ± 87 and 35.8 ± 11.3 events, respectively. The systematic error is found to be dominated by the treatment of background. The peaking backgrounds from $B^0 \to D^{*+}D^{*-}$ and $D_s^{(*)+}D^{*-}$ decays are estimated by Monte-Carlo simulation and subtracted from the data. Other possible backgrounds from B decays to double-charm mesons, like $D_{s1}^+D^{(*)-}$, $D_1(2420)D+$, and $D_2^*(2460)D^{(*)+}$, are estimated to be negiligible assuming 10^{-3} branching ratios for each mode. The possible contributions of these modes are also included in the systematic error. The combined results from two data samples give the branching fraction,

$$\mathcal{B}(\overline{B}^0 \to D^+D^{*-}) = (0.92 \pm 0.23^{+0.34}_{-0.30}) \times 10^{-3}.$$

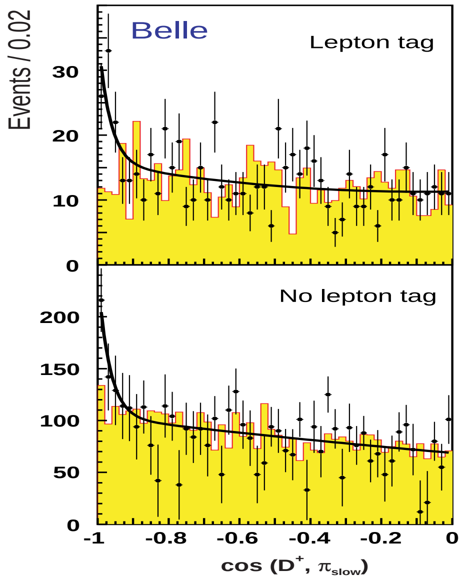

Figure 6: The $\cos\alpha$ distribution for the data set (a) with a lepton and (b) without a high-momentum lepton.

6. Conclusion

We have presented new Belle results for B decays with charm mesons. The color-suppressed $\overline{B}^0 \to D^0\pi^0$, $D^0\omega$, and $D^{*0}\omega$ modes were observed for the first time. We also obtained an improved upper limit on the $\overline{B}^0 \to D_s^+K^-$ mode. A study of the extraction of the CKM angle ϕ_3 has been presented using the $B^- \to D^0_{CP}K^-$ decay; we observed for the first time $\overline{B}^0 \to D^0_{CP}K^-$ where $D^0 \to K^+K^-$. Evidence for $\overline{B}^0 \to D^+D^{*-}$ has been seen with a partial reconstruction method; this mode can be used in future CP violation studies.

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