Observation of $B^{\pm} \to D_{CP}K^{*\pm}$ Decays

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Abstract

We report preliminary results on the decay $B^- \rightarrow D^0 K^{*-}$, $B^- \rightarrow D_{CP} K^{*-}$ and its charge conjugate using a data sample of 95.8 million $B\bar{B}$ pairs recorded at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric $e^+e^-$ storage ring. We find the branching fraction for $B^- \rightarrow D^0 K^{*-}$ to be $B = (5.2\pm0.5(stat)\pm0.6(sys)) \times 10^{-4}$ and the partial-rate charge asymmetries for $B^- \rightarrow D_{CP} K^{*-}$ to be $A_1 = -0.02\pm0.33(stat)\pm0.07(sys)$ and $A_2 = 0.19\pm0.50(stat)\pm0.04(sys)$ where the indices 1 and 2 represent the CP=+1 and CP=−1 eigenstates of the $D^0 - \bar{D}^0$ system, respectively.

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interaction phase difference. The ratio $r \sim$ and is suppressed to the level of silica aerogel threshold Čerenkov counters (ACC), a barrel-like arrangement of time-of-flight layer silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of crystals located inside a super-conducting solenoid coil that provides a 1.5 T magnetic field. The iron flux-return located outside the coil is instrumented to detect scintillation counters (TOF), and an electromagnetic calorimeter (ECL) comprised of CsI(Tl) (denoted by $D$) identify muons (KLM). The detector is described in detail elsewhere [6].

We reconstruct $D^0$ mesons in the following decay channels. For the flavor specific mode (denoted by $D_f$), we use $D^0 \rightarrow K^-\pi^+, K^-\pi^+\pi^0$ and $K^-\pi^+\pi^-\pi^+$ [4]. For CP $=+1$ modes, we use $D_1 \rightarrow \bar{K}^0 K^+$ and $\pi^-\pi^+$ while, for CP $=-1$ modes, we use $D_2 \rightarrow K^0_S\pi^0, K^0_S\phi$, and $K^0_S\omega$. We reconstruct $K^{*-}$ candidates from $K^0_S\pi^-$ combinations where the $K^0_S$ candidate is formed from two oppositely charged pions having a vertex displaced from the interaction point in the direction of the $K^0_S$ momentum. The $K^0_S$ candidates are selected in the mass window of 0.492 GeV/c$^2 < M(\pi^+\pi^-) < 0.505$ GeV/c$^2$. The candidate tracks are then kinematically constrained to its nominal mass value. The $K^{*-}$ is required to have a mass within $\pm$75 MeV/c$^2$ of its nominal mass value. For the $\pi^0$ from the $D^0 \rightarrow K^-\pi^+\pi^0$ decays, we require the $\pi^0$ momentum in the $\Upsilon(4S)$ center-of-mass(c.m.) frame be greater than 0.2 GeV/c and the energy of each photon from the $\pi^0$ be greater than 30 MeV.

Well constrained reconstructed tracks that are not identified as electrons or muons are used as charged hadrons. For each charged track, information from the ACC, TOF and
specific ionization measurements from the CDC are used to determine a $K/\pi$ likelihood ratio $P(K/\pi) = L_K/(L_K + L\pi)$, where $L_K$ and $L\pi$ are kaon and pion likelihoods. For kaons (pions) from the $D^0 \rightarrow K^-\pi^+$ mode we used the particle identification requirement of $P(K/\pi) > 0.4$ ($< 0.7$). For kaons from the $D^0 \rightarrow K^-K^+$ mode we require $P(K/\pi) > 0.7$ while for pions from $D^0 \rightarrow \pi^-\pi^+$ mode we require $P(K/\pi) < 0.7$.

The $\omega$ mesons are reconstructed from $\pi^+\pi^-\pi^0$ combinations in the mass window $0.732 \text{ GeV}/c^2 < M(\pi^+\pi^-\pi^0) < 0.82 \text{ GeV}/c^2$ with the charged pion particle identification requirement $P(K/\pi) < 0.8$. To reduce the contribution from the non-resonant background, a helicity angle requirement $|\cos \theta_{hel}| > 0.4$ is applied, where $\theta_{hel}$ is the angle between the normal to the $\omega$ decay plane in the $\omega$ rest frame and the $\omega$ momentum in the $D^0$ frame. To remove the contribution from $D^0 \rightarrow K^+\rho^+$, we require the $K^0\pi^-$ invariant mass to be greater than 75 $\text{MeV}/c^2$ from the $K^+$ nominal mass.

The $\phi$ mesons are reconstructed from two oppositely charged kaons in the mass window of $1.008 \text{ GeV}/c^2 < M(K^+K^-) < 1.032 \text{ GeV}/c^2$ with $P(K/\pi) > 0.2$. We also apply the $\phi$ helicity angle cut $|\cos \theta_{hel}| > 0.4$, where $\theta_{hel}$ is the angle between one of the $\phi$ daughters in the $\phi$ rest frame and the $\phi$ momentum in the $D^0$ frame. The $D^0$ candidates are required to have masses within $\pm 2.5\sigma$ of their nominal masses, where $\sigma$ is the measured mass resolution that ranges from 5 $\text{MeV}/c^2$ to 18 $\text{MeV}/c^2$ depending on the decay channel. A $D^0$ mass and (wherever possible) vertex constrained fit is then performed on the remaining candidates.

We combine the $D^0$ and $K^{*-}$ candidates to form $B$ candidates. The signal is identified by two kinematic variables: the energy difference $\Delta E = E_D + E_{K^{*-}} - E_{beam}$ and the beam energy constrained mass $M_{bc} = \sqrt{E_{beam}^2 - |\vec{p}_D + \vec{p}_{K^{*-}}|^2}$. Here $E_D$ is the energy of the $D^0$ candidate, $E_{K^{*-}}$ is the energy of the $K^{*-}$ and $E_{beam}$ is the beam energy, and $\vec{p}_D$ and $\vec{p}_{K^{*-}}$ are the momenta of the $D^0$ and $K^{*-}$ candidates, respectively, all calculated in the c.m. frame. Event candidates are accepted if they have $5.2 \text{ GeV}/c^2 < M_{bc} < 5.3 \text{ GeV}/c^2$ and $|\Delta E| < 0.2 \text{ GeV}$. In case of multiple candidates from a single event, we choose the best candidate on the basis of a $\chi^2$ determined from the differences between the measured and nominal values of $M_D$ and $M_{K^{*-}}$. Since $B^- \rightarrow D^0 K^{*-}$ is a pseudoscalar to pseudoscalar-vector decay, the $K^{*-}$ is polarized. We define the $K^{*-}$ helicity angle $\cos \theta_{hel}$ as the angle between one of the $K^{*-}$ decay products in the $K^{*-}$ rest frame and the $K^{*-}$ momentum in the $B$ rest frame. The $K^{*-}$ helicity angle follows a $\cos^2 \theta_{hel}$ distribution. We require $|\cos \theta_{hel}| > 0.4$.

To suppress the large combinatorial background from the two-jet-like $e^+e^- \rightarrow q\bar{q}$ ($q = u, d, s$ or $c$) continuum processes, variables that characterize the event topology are used. We use a Fisher discriminant $F$, constructed from six modified Fox Wolfram moments and $\cos \theta_B$, the cosine of the angle of the $B$ flight direction with respect to the beam axis, in a single likelihood ratio variable ($LR$) that distinguishes signal from continuum background. We apply a different requirement for each sub-mode based on the expected signal yield and the backgrounds in the $M_{bc}$ sideband data. To give an example of the performance of this selection, the $LR > 0.4$ requirement keeps 89.4% of the $B^- \rightarrow D^0[K^-K^+]K^{*-}$ signal while removing 69.2% of the continuum background.

The signal yields are extracted by a fit to the $\Delta E$ distribution in the region $5.27 \text{ GeV}/c^2 < M_{bc} < 5.29 \text{ GeV}/c^2$. The signal is parameterized as a Gaussian with parameters determined from MC simulation. The continuum background function is modeled as a first order polynomial function with parameters determined from the $\Delta E$ distribution for the events in the sideband region $5.2 \text{ GeV}/c^2 < M_{bc} < 5.26 \text{ GeV}/c^2$. Backgrounds from other $B$ decays such as $B^- \rightarrow D^{*0}K^{*-}$, where $D^{*0} \rightarrow D^0\pi^0$ and $D^{*0} \rightarrow D^0\gamma$, are modeled as a smoothed...
FIG. 1: The distributions in the $B^{-} \rightarrow D^{0}K^{*-}$ signal region for (a) $\Delta E$ with $5.27 \text{ GeV}/c^2 < M_{bc} < 5.29 \text{ GeV}/c^2$. The solid-line shows the fit, the dashed-line is the signal, the dot-dashed line is continuum background and the hatched histogram shows the contribution from other $B$ decays. In (b) we show $M_{bc}$ distribution with a $\pm 3\sigma \Delta E$ cut where the solid-line shows the fit, the dotted line shows the continuum background and the dashed line is signal. In (c) we show the results of fits to the $\Delta E$ distribution in bins of $K_{S}^{0}\pi^{-}$ invariant mass (points with error bars). In (d) we show the results of fits to the $\Delta E$ distribution in bins of $\cos \theta_{\text{hel}}$ (points with error bars). In both (c) and (d) the hatched histogram is a Monte Carlo (MC) simulation of $B^{-} \rightarrow D^{0}K^{*-}$.

The following sources of systematic error are found to be sizeable: the tracking efficiency (1% per track), $\pi^{0}$ efficiency (4.8%), $K_{S}^{0}$ efficiency (4.5%), fitting of the $B\bar{B}$ background (5–7%) and particle identification (6–12 %). Other backgrounds including rare decays that could contribute to the $\Delta E$ signal region, are estimated from the $D^{0}$ sideband data (1 %). The uncertainty in the $\Delta E$ signal shape parametrization is determined by varying the mean and width of the signal Gaussian parameters within their errors. The uncertainty from the slope of the background is determined by changing its value by its error. Both of the resulting changes are included in the systematic error from fitting. The
combined systematic errors from these sources are 9.5% for $B^- \to D^0[K^-\pi^+][K^*]$, 11.8% for $B^- \to D^0[K^-\pi^+\pi^0][K^*]$ and 15.5% for $B^- \to D^0[K^-\pi^+\pi^-][K^*]$. The systematic error in the final branching fraction is calculated by weighting according to the efficiency times branching fraction of the three $D^0$ decay channels [8].

![Figure 2](image)

**FIG. 2:** The distributions in the $B^- \to D_1K^*$ signal region for (a) $\Delta E$ with $5.27 \text{ GeV}/c^2 < M_{bc} < 5.29 \text{ GeV}/c^2$ (b) $M_{bc}$ with a $\pm 3 \sigma \Delta E$ cut. The distributions in the $B^- \to D_2K^*$ signal region for (c) $\Delta E$ with $5.27 \text{ GeV}/c^2 < M_{bc} < 5.29 \text{ GeV}/c^2$ (d) $M_{bc}$ with a $\pm 3 \sigma \Delta E$ cut. The solid-line shows the fit and the dashed-line shows the signal.

**TABLE I:** The fit results for $B^- \to D_f K^*$ decay. The signal yields, statistical significance, and branching fraction for each mode are given. The errors shown in the BF are statistical and systematic, respectively.

| decay mode       | Yield($\Delta E$ fit) | Yield($M_{bc}$ fit) | sig | BR(10$^{-4}$) |
|------------------|------------------------|---------------------|-----|--------------|
| $D_f \to K^-\pi^+$ | 67.6$\pm$9.5           | 75.1$\pm$9.5        | 10.8| 5.0 $\pm$ 0.7 $\pm$ 0.5 |
| $D_f \to K^-\pi^+\pi^0$ | 66.3$\pm$9.6           | 65.3$\pm$9.4        | 9.5 | 6.3 $\pm$ 0.9 $\pm$ 0.7 |
| $D_f \to K^-\pi^+\pi^-$ | 40.3$\pm$7.9           | 43.0$\pm$8.1        | 6.9 | 4.3$\pm$ 0.8 $\pm$ 0.7 |
| weighted mean    | 5.2 $\pm$0.5(stat)     | 5.0 $\pm$0.6(sys)   |     |              |

For $B^- \to D_{CP}K^*$ decay the signal yields are extracted by a fit to the $\Delta E$ distribution in the region $5.27 \text{ GeV}/c^2 < M_{bc} < 5.29 \text{ GeV}/c^2$ where $-0.2 \text{ GeV} < \Delta E < -0.1 \text{ GeV}$ is excluded. The signal is parameterized as a Gaussian with parameters determined from MC simulation. The continuum background function is modeled as a first order polynomial function with parameters determined from the $\Delta E$ distribution for the events in the sideband region $5.2 \text{ GeV}/c^2 < M_{bc} < 5.26 \text{ GeV}/c^2$. The $\Delta E$ and $M_{bc}$ distributions are shown in Fig.2. We observe a signal of 13.1$\pm$4.3 events for $B^- \to D_1K^*$ and 7.2$\pm$3.6 events for $B^- \to D_2K^*$ with 4.3$\sigma$ and 2.4$\sigma$ statistical significances, respectively. The partial-rate
TABLE II: Yields, partial-rate charge asymmetries and 90 % C.L intervals for asymmetries.

| Mode               | $N(B^+)$     | $N(B^-)$     | $A_{CP}$       | 90 % C.L       |
|--------------------|--------------|--------------|----------------|----------------|
| $B^\pm \rightarrow D_f K^{\ast \pm}$ | 68.9±10.1    | 95.3±11.3    | 0.16 ± 0.09±0.08 | −0.04 < $A_f$ < 0.36 |
| $B^\pm \rightarrow D_1 K^{\ast \pm}$  | 6.7±3.0      | 6.5±3.1      | −0.02 ± 0.33 ±0.07 | −0.57 < $A_1$ < 0.53 |
| $B^\pm \rightarrow D_2 K^{\ast \pm}$  | 2.9±2.4      | 4.3±2.7      | 0.19 ± 0.50±0.04  | −0.63 < $A_2$ < 1.00 |

asymmetries $A_{1,2}$ are evaluated using signal yields obtained from separate fits to the $B^+$ and $B^-$ samples. The results are given in Table II. The systematic uncertainty is from the intrinsic detector charge asymmetry (1 %), the $B^-$ and $B^+$ yield extractions (4–7 %), and the asymmetry in particle identification efficiency of pions (1 %). The systematic error from yield extraction is calculated by changing the fitting parameters by ±1σ. At 90 % C.L intervals, we find

$$-0.57 < A_1 < 0.53,$$
$$-0.63 < A_2 < 1.00$$

In summary, using 88 fb$^{-1}$ of data collected with the Belle detector, we report a measurement of the exclusive decay mode $B^- \rightarrow D_f K^{\ast -}$. This mode has been observed previously. In this paper, we report a new measurement of the branching fraction $B(B^- \rightarrow D_f K^{\ast -})$. We also report the partial-rate charge asymmetries for the decay $B^- \rightarrow D_{CP} K^{\ast -}$, where $D_{CP}$ are the neutral $D$ meson CP eigenstates. The measured partial-rate charge asymmetries $A_{1,2}$ are consistent with zero.

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