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Charmed-B decays at BABAR

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Abstract. We present recent results on charmed-B decays using data collected by the *BABAR* experiment at the PEP-II storage ring. This report is subdivided in 3 parts. In a first step, we present preliminary results on the measurement of the branching fractions of seven color-suppressed $\overline{B}^0$-meson decays into $D^{(*)0}\pi^0$, $D^{(*)0}\eta$, $D^{(*)0}\omega$, and $D^0\eta'$. Then we discuss the preliminary measurement of the ratio of Cabibbo-suppressed to Cabibbo-favored branching fractions $\mathcal{B}(B^-\to D^0K^-)/\mathcal{B}(B^-\to D^0\pi^-)$, where the D^0 is possibly reconstructed in the CP-even $\pi^-\pi^+$ and K^-K^+ modes. For the D^0 decays into CP-eigenstates, a search for a direct CP asymmetry is performed. For the same category of decay processes, we show a precise preliminary measurement of both the branching fraction of B^- decaying to $D^{*0}K^{*-}$ and of the fraction of longitudinal polarization in this decay. Finally, we present a study where the 22 possible B decays to $\overline{D}^{(*)}D^{(*)}K$ are reconstructed exclusively. The branching fractions of the B^0 and of the B^+ to $\overline{D}^{(*)}D^{(*)}K$ are presented and a search for decays $B\to\overline{D}^{(*)}D^+_{sJ}(\to D^{(*)0}K^+)$, where the D^+_{sJ} represents the orbitally excited D_s states, is also discussed.

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1 Introduction

We report on recent results of studies on charmed-B decays with the *BABAR* detector, which is located at the PEP-II e^+e^- storage ring operating at the Stanford Linear Accelerator Center. This document is organized in three parts.

We start with the presentation of the measurement of seven color-suppressed $\overline{B}^0$-meson decays into $D^{(*)0}\pi^0$, $D^{(*)0}\eta$, $D^{(*)0}\omega$, and $D^0\eta'$. These numerous results provide strong constraints on the predictions of factorization models that describe hadronic-B decays [1]. In a second step, we discuss two preliminary studies on B^- to $D^0{}_{(CP)}K^-$ or $D^{*0}K^{*-}$ decays. A theoretically clean measurement of the CKM-angle γ, which takes place in addition to the β and α angles in the description of CP violation within the framework of B-meson decays, can possibly be obtained in the future with at least five time the existing statistic from the study of the $B^-\to D^{(*)0}K^{(*)-}$ decays by reconstructing the D^0 meson into Cabibbo-allowed, CP-eigenstates and doubly Cabibbo-suppressed decays [2]. Finally, we report on the measurement of the branching fractions for the exclusive decays B^0 and B^+ to $\overline{D}^{(*)}$ $D^{(*)}K$. These decays have been predicted [3] to contribute significantly to the decay rate of $b\to c\overline{c}s$ decays. They therefore give a possible explanation of the problem related to the inconsistency between the measured $b\to c\overline{c}s$ rate and the rate of semi-leptonic B decays that has been a long-standing problem in B physics [4] and that was believed so far to be dominated by decays $B\to D_sX$, with some smaller contributions from decays to charmonium states and to charmed strange baryons.

At PEP-II 9.0–GeV electrons collide with 3.1–GeV positrons to produce a center-of-mass energy of 10.58 GeV, the mass of the $\Upsilon(4S)$. The data used in the various analyses presented here correspond to integrated luminosities equivalent to 61.0×10^6 to 88.8×10^6 $B\overline{B}$ events. The *BABAR* detector is described in details elsewhere [5]. Only detector components relevant for the analyses discussed in this paper are summarized here. Trajectories of charged particles are measured in a five-layer silicon vertex tracker (SVT) and a 40-layer drift chamber (DCH) in a 1.5-T magnetic field. Charged particles are identified as pions or kaons using information from a detector of internally reflected Cherenkov light, as well as measurements of energy loss in the SVT and the DCH. This powerful particle identification device is of prime interest for the reconstruction of B-meson decay modes including $D^{(*)}$ mesons. Photons are detected in a CsI(Tl) calorimeter of high precision that allows the reconstruction of the π^0, or η, or ω, or η' mesons and of the $D^{*0}\to D^0\pi^0$ and $D^0\gamma$ decays with excellent resolutions.

2 Measurement of branching fractions of color-suppressed $\overline{B}^0$-meson decays

Weak decays like $\overline{B}^0\to D^{(*)+}h^-$ (where the h^- is either a π^- or a ρ^- meson) can proceed through the emission of a virtual W^-, which then can materialize as a charged

Table 1. Measured branching fractions for $\overline{B}^0 \to D^{(*)0}h^0$ (the first uncertainty is statistical and the second systematic).

$\overline{B}^0$ mode (decay channel)	$\mathcal{B}$ ($\times 10^{-4}$)	statistical significance
$D^0\pi^0$	$2.9 \pm 0.2 \pm 0.3$	> 6.5
$D^{*0}\pi^0$	$2.9 \pm 0.4 \pm 0.5$	> 6.5
$D^0\eta(\to\gamma\gamma)$	$2.4 \pm 0.3 \pm 0.3$	> 6.5
$D^0\eta(\to\pi^+\pi^-\pi^0)$	$2.8 \pm 0.4 \pm 0.4$	6.2
$D^0\eta$ (combined)	$2.5 \pm 0.2 \pm 0.3$	> 6.5
$D^{*0}\eta(\to\gamma\gamma)$	$2.6 \pm 0.4 \pm 0.4$	5.5
$D^0\omega$	$3.0 \pm 0.3 \pm 0.4$	> 6.5
$D^{*0}\omega$	$4.2 \pm 0.7 \pm 0.9$	6.1
$D^0\eta'$	$1.7 \pm 0.4 \pm 0.2$	6.3
$D^{*0}\eta'$	< 2.6 (90% CL)	3.0

hadron. Because the W^- carries no color, no exchange of gluons with the rest of the final state is required. Such decays are called color-allowed. By contrast, decays like $\overline{B}^0 \to D^{(*)0}h^0$ (where the h^0 is either a π^0, or an η, or an ω, or an η', or a ρ^0 meson) cannot occur in this fashion. The quark from the decay of the virtual W^- must be combined with some anti-quark other than its partner from the W^-. However, other anti-quarks will have the right color to make a color singlet only one-third of the time. As a result, these decays are "color-suppressed".

Since non-perturbative calculations of decay rates are at present not possible, we must rely on models to describe the above processes. In a model [1], the "naive" (or "generalized") factorization model, which is very successful in describing charmed meson decays, the decay amplitudes of exclusive two-body non-leptonic weak decays of heavy flavor mesons are estimated by replacing hadronic matrix elements of four-quark operators in the effective weak Hamiltonian by products of current matrix elements. The branching fractions for the color-suppressed modes are predicted to be in the range (0.3–1.7) $\times 10^{-4}$. It has nevertheless been argued that the inclusion of final state interaction in a model-dependent way can increase the branching fractions to (1.0–3.0) $\times 10^{-4}$.

Based on a data sample corresponding to 88.8×10^6 $B\overline{B}$ events, we report on the branching fraction measurements of the seven color-suppressed $\overline{B}^0$-meson decays to $D^{(*)0}\pi^0$, $D^{(*)0}\eta$, $D^{(*)0}\omega$, and $D^0\eta'$. We also report on a search for the $\overline{B}^0 \to D^{*0}\eta'$ decay. We present the first measurement of the $\overline{B}^0 \to D^{*0}\eta$, $D^{*0}\omega$, and $D^0\eta'$ modes with more than five-sigma statistical significance [6].

The D^0 mesons are reconstructed in the decay modes: $K^-\pi^+$, $K^-\pi^+\pi^0$, and $K^-\pi^+\pi^+\pi^-$, while the D^{*0} mesons are reconstructed in the $D^0\pi^0$ mode. The light neutral-hadron h^0 is reconstructed as a $\pi^0(\to\gamma\gamma)$, or an $\eta(\to\gamma\gamma$ or $\pi^+\pi^-\pi^0)$, or an $\omega(\to\pi^+\pi^-\pi^0)$, or an $\eta'(\to\pi^+\pi^-\eta)$. The branching fractions of these color-suppressed modes are listed Tab. 1. Except for the $D^{*0}\eta'$ decay channel all measurements have statistical significance in excess of five-standard deviations. For the $D^{*0}\eta'$ decay channel we quote a 90% confidence level upper limit using Poisson statistics. These results can be compared to previous measurements performed by the Belle and CLEO collaborations and to a preliminary measurement by *BABAR* [7]. All these results are in good agreement and our results have a better precision mainly due to the use of a data sample with a larger statistic.

3 Studies of B^- to $D^0{}_{(CP)}K^-$ or $D^{*0}K^{*-}$ decays

3.1 Measurement of B^- to $D^0{}_{(CP)}K^-$ decays

In this paper we present the measurement of the ratio of Cabibbo-suppressed to Cabibbo-favored branching fractions

$$R_{(CP)} = \frac{\mathcal{B}(B^- \to D^0_{(CP)}K^-) + \mathcal{B}(B^+ \to \bar{D^0}_{(CP)}K^+)}{\mathcal{B}(B^- \to D^0_{(CP)}\pi^-) + \mathcal{B}(B^+ \to \bar{D^0}_{(CP)}\pi^+)} \quad (1)$$

with D^0 reconstructed into Cabibbo-allowed or CP-even (D^0_{CP}) channels. The measurement of this ratio allows to reduce the uncertainties originating from the estimate of the reconstruction efficiency. The direct CP asymmetry

$$A_{CP} = \frac{\mathcal{B}(B^-\to D^0_{CP}K^-) - \mathcal{B}(B^+\to D^0_{CP}K^+)}{\mathcal{B}(B^-\to D^0_{CP}K^-) + \mathcal{B}(B^+\to D^0_{CP}K^+)} \quad (2)$$

is also measured. The measurement of R is based on a sample of 61.0×10^6 $B\overline{B}$ pairs. The analysis of $B^\pm\to D^0_{CP}K^\pm$ decays uses a sample of 88.8×10^6 $B\overline{B}$ [8].

The $B^- \to D^0h^-$ decays are reconstructed, where the prompt track h^- is a kaon or a pion. D^0 candidates are reconstructed in the flavor-eigenstates $K^-\pi^+$, $K^-\pi^+\pi^0$, and $K^-\pi^+\pi^+\pi^-$ (non-CP modes) and in the CP-even eigenstates $\pi^-\pi^+$ and K^-K^+ (CP modes, collectively referred to as h^-h^+). In the case of the $D^0 \to \pi^-\pi^+$ decay, the analysis is more complicated as the background receive non-negligible contributions from the charmless $\pi^-\pi^+\pi^-$ and $D^0(\to K^-\pi^+)\,\pi^-$ decays.

The event yields for the $B^-\to D^0K^-$ and $B^-\to D^0\pi^-$ candidates are extracted from a simultaneous unbinned maximum likelihood fit to the value of $m_{\rm ES}$, ΔE (respectively the B-meson candidates beam-energy-substituted mass and energy difference), and of a particle identification probability for the prompt track h based on the Cherenkov angle θ_C, the momentum p at the DIRC and the polar angle θ of the track. In the case of $D^0 \to \pi^-\pi^+$, $m_{\rm ES}$ is replaced by m_{D^0}.

We measure the ratio of branching fractions for the non-CP D^0 decays: $(8.31 \pm 0.35(stat.) \pm 0.20(syst.)) \times 10^{-2}$. For the CP-even decays, we measure the ratio $(8.8\pm 1.6(stat.)\pm0.5(syst.))\times10^{-2}$ and the CP-asymmetry $0.07\pm 0.17(stat.)\pm0.06(syst.)$. The ratio of branching fraction is in good agreement with the suppression by a factor equal to $sin^2(\theta_C)\times(f_K/f_\pi)^2 \simeq 7.5\%$ (the Cabibbo angle and the semi-leptonic decay form factors of the B mesons) of the value of the branching fraction of the $B^-\to D^0\pi^-$ decay and so far no direct CP-asymmetry is seen in these decay modes. These results can be compared to the measurements performed by the CLEO and Belle collaborations [9].

3.2 Measurement of branching fraction and polarization for the decay B^- to $D^{*0}K^{*-}$

The analysis for the B^- to $D^{*0}K^{*-}$ decay mode is based on a sample of 85.9×10^6 $B\overline{B}$ decays [10]. We reconstruct $B^- \to D^{*0}K^{*-}$ in the following modes: $D^{*0} \to D^0\pi^0$ and $D^0\gamma$; $D^0 \to K^-\pi^+, K^-\pi^+\pi^0$, and $K^-\pi^+\pi^+\pi^-$; $K^{*-} \to K_S\pi^-$; $K_S \to \pi^+\pi^-$; $\pi^0 \to \gamma\gamma$. Combining the six D^{*0}/D^0 modes, we measure a branching fraction equal to $(8.3 \pm 1.1(stat.) \pm 1.0(syst.)) \times 10^{-4}$, which is about twice as precise as the previous measurement by the CLEO collaboration [11] and is coherent with a reduction by a factor equal to $sin^2(\theta_C) \times (f_K/f_{\rho^-})^2 \simeq 2.9\%$ of the value of the branching fraction of the $B^- \to D^{*0}\rho^-$ decay.

With the 121 ± 15 signal $B^\pm$ candidates selected in this analysis, the longitudinal polarization fraction in that decay mode is measured for the first time. We obtain the value $0.86 \pm 0.06(stat.) \pm 0.03(syst.)$. This last result is consistent with expectations [12] based on factorization, Heavy Quark Effective Theory, and the measurement of semi-leptonic B-decay form factors, assuming that the external spectator amplitude ($b \to cW^{*-}$; $W^{*-} \to K^{*-}$) dominates in $B^- \to D^{*0}K^{*-}$.

4 Measurement of the branching fractions for the exclusive decays B^0 and B^+ to $\overline{D}^{(*)}D^{(*)}K$

The B^0 and B^+ to $\overline{D}^{(*)}D^{(*)}K$ analysis is described in detail in Ref. [13]. The B^0 and B^+ mesons are reconstructed in a sample of 82.3×10^6 $B\overline{B}$ for all the 22 possible $\overline{D}DK$ modes, namely $B^0 \to D^{(*)-}D^{(*)0}K^+$, or $D^{(*)-}D^{(*)+}K^0$, or $\overline{D}^{(*)0}D^{(*)0}K^0$ and $B^+ \to \overline{D}^{(*)0}D^{(*)+}K^0$, or $\overline{D}^{(*)0}D^{(*)0}K^+$, or $D^{(*)-}D^{(*)+}$ K^+. Where the various final states are produced by external (color-allowed decays) or internal (color-suppressed decays) W-emission or through the interference of these two topologies.

The K^0 mesons are reconstructed only from the decays $K^0_S \to \pi^+\pi^-$. The D^* candidates are reconstructed in the decay modes $D^{*+} \to D^0\pi^+$, $D^{*+} \to D^+\pi^0$, $D^{*0} \to D^0\pi^0$, and $D^{*0} \to D^0\gamma$. The D^0 and D^+ mesons are reconstructed in the decay modes $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$, and $D^+ \to K^-\pi^+\pi^+$.

Based on a global maximum likelihood fit that takes feed-across in between the various modes into account, we obtain measurements with more than four-sigma statistical significance for 12 modes out of the 22 possible decay modes. After summing over all the submodes, the branching fractions of the B^0 and of the B^+ to $\overline{D}^{(*)}D^{(*)}K$ are found to be respectively equal to $(4.3 \pm 0.3(stat.) \pm 0.6(syst.))\%$ and $(3.5 \pm 0.3(stat.) \pm 0.5(syst.))\%$. This study shows that a significant fraction of the transitions $b \to c\overline{c}s$ proceed through the decays $B \to \overline{D}^{(*)}D^{(*)}K$. These decay modes account for about one half of the wrong-sign D production rate in B decays, $\mathcal{B}(B \to D\,X) = (7.9 \pm 2.2)\%$ [14]; however, because of the large statistical error on the latter measurement, it is not yet clear whether they saturate it.

A search for resonant sub-structures, such as the orbitally excited D_s states, has also been performed. It is shown that the $D^+_{s1}(2536)$ contribution to $B \to \overline{D}^{(*)}D^{*0}K^+$ decays is small. No evidence for a $D^+_{sJ}(2573)$ contribution to $B \to \overline{D}^{(*)}D^0K^+$ decays is found. Finally, a simple Dalitz-plot analysis of the decays $B^0 \to D^{*-}D^{*0}K^+$ based on a clean sample of 205 ± 18 events for that decay shows that the three-body phase-space decay model does not give a satisfactory description of these decays. The lack of convincing signal for intermediate broad orbitally excited D_s states is also coherent with the recent observation of the two narrow states at 2.32 GeV/$c^2$and 2.46 GeV/c^2, and below the $D^{(*)}K$ mass threshold, by the *BABAR*, CLEO, and Belle collaborations[15].

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