Study of the exclusive $B \to \overline{D}^{(*)} D^{(*)} K$ decays in BaBar

Marco Zito [a]

[a] DSM/DAPNIA, CEA/SACLAY, F-91191 Gif-sur-Yvette, France

The B meson decays to the $\overline{D}^{(*)} D^{(*)} K$ final states are important to understand the $b \to c\bar{c}s$ process, related to the long-standing problem of the semileptonic B decay rate. The 22 possible B decays to $\overline{D}^{(*)} D^{(*)} K$ are reconstructed exclusively. We observe 823±57 B^0 and 970±65 B^+ decays to these doubly charmed final states and the branching fractions or upper limits are determined for all final states.

1. INTRODUCTION

The inconsistency between the measured $b \to c\bar{c}s$ rate and the rate of semileptonic B decays has been a long-standing problem in B physics [1]. As a possible explanation of this problem, it has been conjectured [2] that $\mathcal{B}(b \to c\bar{c}s)$ is larger than expected and that decays of the type $B \to \overline{D}^{(*)} D^{(*)} K\,(X)$ (where $D^{(*)}$ can be either a D^0, D^{*0}, D^+, or D^{*+}) could contribute significantly to the decay rate. Experimental evidence in support of this picture includes the branching fraction measured by CLEO for wrong-sign D production $\mathcal{B}(B \to D X) = (7.9 \pm 2.2)\%$ [3], and the observation of a small number of fully reconstructed decays $B \to \overline{D}^{(*)} D^{(*)} K$, both by CLEO [4] and ALEPH [5]. More recently, *BABAR* [6] and Belle [7] have reported some preliminary results on the evidence for transitions $B^0 \to D^{*-} D^{(*)0} K^+$ with much larger data sets.

$B \to \overline{D}^{(*)} D^{(*)} K$ decays can proceed through two different amplitudes with external or internal (also called color-suppressed) W-emission (Fig. 1). Some decay modes proceed purely through one of these amplitudes while others can proceed through both. In *BABAR*, the large recorded data set now allows comprehensive investigations of these transitions. A detailed description of the results presented here can be found in [8].

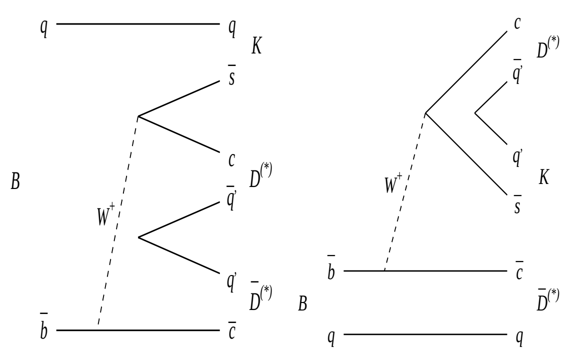

Figure 1. Left: internal (left) and external (right) W-emission diagram for the decays $B \to \overline{D}^{(*)} D^{(*)} K$.

2. MEASUREMENT OF THE BRANCHING FRACTIONS

The BaBar detector is described in detail in [9]. This study is based on $75.9\,\mathrm{fb}^{-1}$ of data collected at the $\Upsilon(4S)$ resonance with the *BABAR* detector at the PEP-II asymmetric-energy B factory, corresponding to $(82.3 \pm 0.9) \times 10^6$ $B\overline{B}$ pairs.

The B^0 and B^+ mesons are reconstructed in a sample of hadronic events for all the possible $\overline{D}DK$ modes. 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 $D^+ \to K^-\pi^+\pi^+$. K^0 are reconstructed only from the decays $K^0_S \to \pi^+\pi^-$. B candidates are reconstructed by combining one $\overline{D}^{(*)}$, one $D^{(*)}$ and one K candidate. A mass-constrained kinematic fit is applied to all intermediate particles. The selection procedure includes a cut on the ratio of the second to the zeroth Fox-Wolfram moments to be less than 0.45 to eliminate continuum $e^+e^- \to q\bar{q}$ events. Charged kaon identification based on the Cherenkov angle measured in the DIRC detector and the the $\mathrm{d}E/\mathrm{d}x$ measurements in the drift chamber and the vertex tracker is used for most D decay modes, as well as for the $K^\pm$ from the B meson decay. To isolate the B meson signal, we use two kinematic variables: the difference between the reconstructed energy of the B candidate and the beam energy in the center of mass frame (ΔE), and the beam energy substituted mass (m_{ES}).

The m_{ES} and ΔE spectra of the selected events are shown in Fig. 2 for the sum of all the decay modes, separately for B^0 and B^+. An excess of 823±57 B^0 and 970±65 B^+ events over the combinatorial background is observed in the signal region. The number of events due to the combinatorial background is evaluated in the following way. First, the m_{ES} distribution in the background control region $\Delta E > 50\,\mathrm{MeV}$ is fitted with an ARGUS function [10]. Then events are selected in the signal slice $|\Delta E - \Delta E_{\mathrm{shift}}| < 2.5\sigma_{\Delta E}$ where $\Delta E_{\mathrm{shift}} = (-5 \pm 1)\,\mathrm{MeV}$ is fitted from the data and is due to imperfect modeling of the charged K energy loss in the detector material and $\sigma_{\Delta E}$ is the resolution on ΔE. The m_{ES} distribution of the combinatorial background is assumed to be the same as in the control region except for the normalization factor which is refitted in the range $5.22 < m_{\mathrm{ES}} < 5.27\,\mathrm{GeV}/c^2$. This function is used to extrapolate the expected number of combinatorial background events in the region $5.27 < m_{\mathrm{ES}} < 5.29\,\mathrm{GeV}/c^2$ where the signal is expected. Finally the number of background events B determined in this way is subtracted from the total number of events in the signal region to obtain the number of signal events S.

For the determination of the branching fraction this procedure is repeated for all the D secondary decay submodes to take advantage of the different signal to background ratios. The branching fraction is extracted from a maximum likelihood fit to the number of events in the signal region for each submode taking into account the reconstruction efficiency, the submode branching fractions, the combinatorial background estimated as explained above and the cross-feed. The latter is important only for modes containing a D^{*0} and is estimated using a cross-feed matrix determined from the Monte Carlo simulation.

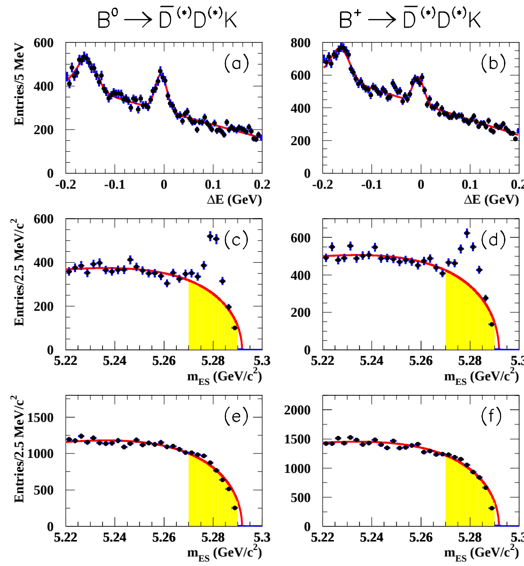

Figure 2. The ΔE and m_{ES} spectra (a,c,e) for the sum of all the $B^0 \to \overline{D}^{(*)}D^{(*)}K$ modes and (b,d,f) for the sum of all the $B^+ \to \overline{D}^{(*)}D^{(*)}K$ modes. (a,b): ΔE for $5.27 < m_{\mathrm{ES}} < 5.29\,\mathrm{GeV}/c^2$. (c,d): m_{ES} for $|\Delta E - \Delta E_{\mathrm{shift}}| < 2.5\sigma_{\Delta E}$. (e,f): m_{ES} for $\Delta E > 50\,\mathrm{MeV}$ (background control region). The curves superimposed on the m_{ES} spectra correspond to the background fits described in the text and the shaded regions represent the background in the signal region $5.27 < m_{\mathrm{ES}} < 5.29\,\mathrm{GeV}/c^2$.

The results of this fit are reported in Table 1. For the decay modes with a significance $S/\sqrt{B}$ smaller than 4, a 90% confidence level (C.L.) upper limit is also derived. The systematical error reported in the table has been computed taking into account the various reconstruction efficiencies (track, photon, kaon identification), the background description, the submode branching fraction uncertainties and decay model dependences.

3. SEARCH FOR RESONANT SUBSTRUCTURE

$B \to \overline{D}^{(*)} D^{(*)0} K^+$ decay modes are used to probe the possible presence of intermediate D_{sJ} resonances decaying into $D^{(*)0} K^+$, where D_{sJ} are P-wave excitations of the $c\bar{s}$ system. A search has been performed for $D^+_{s1}(2536)$ in the final state $D^{*0} K^+$ in the four decay modes $B^0 \to D^- D^{*0} K^+$, $B^0 \to D^{*-} D^{*0} K^+$, $B^+ \to \overline{D}^0 D^{*0} K^+$, and $B^+ \to \overline{D}^{*0} D^{*0} K^+$. The distribution of the variable $\Delta m = m\left(D^{*0} K^+\right) - m\left(D^{*0}\right)$ for the events reconstructed in the signal region ($5.27 < m_{\rm ES} < 5.29\,{\rm GeV}/c^2$) for these four decay modes has been fitted with the sum of a threshold function and a Gaussian function describing the signal. This procedure yields an estimated signal of 28^{+8}_{-7} $D^+_{s1}(2536) \to D^{*0} K^+$ events out of 764 ± 50 $B \to \overline{D}^{(*)} D^{*0} K^+$ events.

The same procedure has been used to search for the production of the $D^+_{sJ}(2573)$ resonance decaying in the $D^0 K^+$ mode. The decays modes used for this search are: $B^0 \to D^- D^0 K^+$, $D^{*-} D^0 K^+$, $\overline{D}^0 D^0 K^+$ and $D^{*0} D^0 K^+$. The fitted yield of $D^+_{s1}(2573) \to D^0 K^+$ decays is 13 ± 9 events out of 604 ± 54 $B \to \overline{D}^{(*)} D^0 K^+$ events.

These results show that there is no significant production of these narrow D_{sJ} resonances in these decays. Upper limits are obtained for the individual modes [8] .

Broad D_{sJ} resonance can be searched in these decays by studying the Dalitz plot. This has been done for the mode $B^0 \to D^{*-} D^{*0} K^+$, which has the largest number of reconstructed events and also has the largest purity. The density of events in the lower region of the Dalitz plot (i.e., for small values of $m(D^{*0} K^+)$ and large values of $m(D^{*-} D^{*0})$) is significantly larger in the data than in the simulation with no resonance (phase space density). More data are necessary to confirm this finding and study possible interpretations.

4. CONCLUSIONS

A complete measurement of all possible $B \to \overline{D}^{(*)} D^{(*)} K$ channels has been presented. The measured branching fractions are in good agreement with earlier measurements made with smaller data sets for some of these modes [4–7].

The existence of the decays $B^0 \to D^{*-} D^+ K^0_S$ and $B^0 \to D^{*-} D^{*+} K^0_S$, which are important for the BaBar CP violation program [11–13], has been demonstrated. A significant signal for the color suppressed decay mode $B^+ \to D^{*-} D^+ K^+$ has also been observed.

One of the motivations of this analysis is to understand whether decays $B \to \overline{D}^{(*)} D^{(*)} K$ can explain the wrong-sign D-meson rates in B decays and reconcile the total $b \to c\bar{c}s$ rate with the predictions of Ref. [2]. After summing over all submodes, the branching fractions of the B^0 and of the B^+ to $\overline{D}^{(*)} D^{(*)} K$ are found to be

$$\mathcal{B}(B^0 \to \overline{D}^{(*)} D^{(*)} K) = (4.3 \pm 0.3 \pm 0.6)\,\%, \qquad (1)$$

$$\mathcal{B}(B^+ \to \overline{D}^{(*)} D^{(*)} K) = (3.5 \pm 0.3 \pm 0.5)\,\%. \qquad (2)$$

This study shows that a significant fraction of the transitions $b \to c\bar{c}s$ 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, $\mathcal{B}(B \to D X) = (7.9 \pm 2.2)\%$ [3]; however, because of the large statistical error on the latter measurement, it is not yet clear whether they saturate it.

A search for resonant substructures shows 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 $B \to \overline{D}^{(*)} D^0 K^+$ decays is found. Finally, a simple Dalitz-plot analysis of the decays $B^0 \to D^{*-} D^{*0} K^+$ shows that the three-body phase-space decay model does not give a satisfactory description of these decays.

I wish to thank the organizers for the very pleasant and fruitful conference.

Table 1
Branching fractions for each mode. The first error on each branching fraction is the statistical uncertainty and the second one is the systematic uncertainty. For the decay modes with a significance $S/\sqrt{B}$ smaller than 4, a 90% confidence level (C.L.) upper limit is also derived. The lines separate the B^0 and B^+ decays proceeding through external, external plus internal and internal W-emission amplitudes respectively.

B decay mode	Branching Fraction (%)	Upper Limit (%)
$B^0 \to D^- D^0 K^+$	$0.17 \pm 0.03 \pm 0.03$	
$B^0 \to D^- D^{*0} K^+$	$0.46 \pm 0.07 \pm 0.07$	
$B^0 \to D^{*-} D^0 K^+$	$0.31^{+0.04}_{-0.03} \pm 0.04$	
$B^0 \to D^{*-} D^{*0} K^+$	$1.18 \pm 0.10 \pm 0.17$	
$B^0 \to D^- D^+ K^0$	$0.08^{+0.06}_{-0.05} \pm 0.03$	0.17
$B^0 \to D^{*-} D^+ K^0 + D^- D^{*+} K^0$	$0.65 \pm 0.12 \pm 0.10$	
$B^0 \to D^{*-} D^{*+} K^0$	$0.88^{+0.15}_{-0.14} \pm 0.13$	
$B^0 \to \overline{D}^0 D^0 K^0$	$0.08 \pm 0.04 \pm 0.02$	0.14
$B^0 \to \overline{D}^0 D^{*0} K^0 + \overline{D}^{*0} D^0 K^0$	$0.17^{+0.14}_{-0.13} \pm 0.07$	0.37
$B^0 \to \overline{D}^{*0} D^{*0} K^0$	$0.33^{+0.21}_{-0.20} \pm 0.14$	0.66
$B^+ \to \overline{D}^0 D^+ K^0$	$0.18 \pm 0.07 \pm 0.04$	0.28
$B^+ \to \overline{D}^{*0} D^+ K^0$	$0.41^{+0.15}_{-0.14} \pm 0.08$	0.61
$B^+ \to \overline{D}^0 D^{*+} K^0$	$0.52^{+0.10}_{-0.09} \pm 0.07$	
$B^+ \to \overline{D}^{*0} D^{*+} K^0$	$0.78^{+0.23}_{-0.21} \pm 0.14$	
$B^+ \to \overline{D}^0 D^0 K^+$	$0.19 \pm 0.03 \pm 0.03$	
$B^+ \to \overline{D}^{*0} D^0 K^+$	$0.18^{+0.07}_{-0.06} \pm 0.04$	0.38
$B^+ \to \overline{D}^0 D^{*0} K^+$	$0.47 \pm 0.07 \pm 0.07$	
$B^+ \to \overline{D}^{*0} D^{*0} K^+$	$0.53^{+0.11}_{-0.10} \pm 0.12$	
$B^+ \to D^- D^+ K^+$	$0.00 \pm 0.03 \pm 0.01$	0.04
$B^+ \to D^- D^{*+} K^+$	$0.02 \pm 0.02 \pm 0.01$	0.07
$B^+ \to D^{*-} D^+ K^+$	$0.15 \pm 0.03 \pm 0.02$	
$B^+ \to D^{*-} D^{*+} K^+$	$0.09 \pm 0.04 \pm 0.02$	0.18

REFERENCES

1. I. I. Bigi, B. Blok, M. Shifman, and A. Vainshtein, Phys. Lett. B **323**, 408 (1994).
2. G. Buchalla, I. Dunietz, and H. Yamamoto, Phys. Lett. B **364**, 188 (1995).
3. CLEO Collaboration, T. E. Coan *et al.*, Phys. Rev. Lett. **80**, 1150 (1998).
4. CLEO Collaboration, CLEO CONF 97-26, EPS97 337 (1997).
5. ALEPH Collaboration, R. Barate *et al.*, Eur. Phys. Jour. C **4**, 387 (1998).
6. *BABAR* Collaboration, B. Aubert *et al.*, SLAC-PUB-8924, hep-ex/0107056.
7. Belle Collaboration, K. Abe *et al.*, BELLE-CONF-0104.
8. *BABAR* Collaboration, B. Aubert *et al.*, SLAC-PUB-9736, hep-ex/0305003, submitted to Phys. Rev. D.
9. *BABAR* Collaboration, B. Aubert *et al.*, Nucl. Instr. Meth. A **479**, 1 (2002).
10. ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. B **241**, 278 (1990).
11. J. Charles, A. Le Yaouanc, L. Oliver, O. Pene, and J. C. Raynal, Phys. Lett. B **425**, 375 (1998) [Erratum-ibid. B **433**, 441 (1998)].
12. P. Colangelo, F. De Fazio, G. Nardulli, N. Paver and Riazuddin, Phys. Rev. D **60**, 033002 (1999).
13. T. E. Browder, A. Datta, P. J. O'Donnell and S. Pakvasa, Phys. Rev. D **61**, 054009 (2000).