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B decays to charm states at *BABAR*.

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Abstract

In this paper recent results in the field of B meson decays to states containing charm are presented. These analyses are based on the 1999-2003 dataset collected by the *BABAR* experiment at the PEP-II e^+e^- storage ring at the Stanford Linear Accelerator Center. Special attention is devoted to B decays to final states containing D mesons. In addition a few new results from B decays to charmonium states are reported.

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1 Introduction

The decay of B mesons to states containing charm and charmonium provides an excellent laboratory for the study of hadronic B decays. With more than 200 millions of B pairs presently collected, the *BABAR* experiment has integrated an unprecedented luminosity, allowing the test of B decay models in more channels and with greater precision than ever before, and the observation of B decays modes never seen in the past. In this paper we present some examples. In Section 2 new results from analyses of B decays to modes containing D mesons are presented. Section 3 is devoted to B decays to charmonium states. The *BABAR* detector is described in detail elsewhere [1]. Charge conjugation is implied throughout this note.

2 B decays to states containing D mesons

2.1 Study of the decay $B \to D_{sJ} D^{(*)}$

In 2003, the unexpected observation by *BABAR* [2] of a narrow $D_s^+\pi^0$ resonance with a mass of 2317 MeV/c^2 created some excitement. The discovery was soon confirmed by CLEO and Belle. In addition CLEO found a second new state near 2460 MeV/c^2 in $D_s^{*+}\pi^0$ combinations [3], soon confirmed by *BABAR* and Belle, who added the decays into $D_s^+\gamma$ and $D_s^+\pi^+\pi^-$. A recent analysis by *BABAR* was aimed to study the production of D_{sJ} in B decays, in order to use the kinematical constraint to extract additional information on the D_{sJ} spin from the angular distribution of the decay products. The analysis is based on the data collected during *BABAR* Run 1, 2 and 3, which is equivalent to about 125 millions of B pairs. Production of $D_{sJ}(2317)$ and $D_{sJ}(2460)$ has been analyzed in both charged and neutral B decays, through the decays $B^+ \to D_{sJ}^+ D^{(*)0}$ and $B^0 \to D_{sJ}^+ D^{(*)-}$. The $D_{sJ}(2317)$ candidates are reconstructed using $D_s^+\pi^0$ combinations, while $D_{sJ}(2460)$ are reconstructed in the $D_s^{*+}\pi^0$ and $D_s^+\gamma$ modes. The D_{sJ} candidate are then paired with a D or D^* meson. The analysis has shown a signal in all the three D_{sJ} modes (see Fig. 1) and preliminary branching fractions for the twelve decay channels are extracted (see Tab 1).

	decay mode	BR/(10^{-3})	
		this analysis	Belle
I	$B^0 \to D_{s0}^+ D^-$ $(D_{s0}^+ \to D_s^+\pi^0)$	$2.09 \pm 0.40 \pm 0.34^{+0.70}_{-0.42}$	$0.86 \pm 0.26^{+0.33}_{-0.26}$
II	$B^0 \to D_{s0}^+ D^{*-}$ $(D_{s0}^+ \to D_s^+\pi^0)$	$1.12 \pm 0.38 \pm 0.20^{+0.37}_{-0.22}$	—
III	$B^+ \to D_{s0}^+ \overline{D}^0$ $(D_{s0}^+ \to D_s^+\pi^0)$	$1.28 \pm 0.37 \pm 0.22^{+0.42}_{-0.26}$	$0.81 \pm 0.24^{+0.30}_{-0.27}$
IV	$B^+ \to D_{s0}^+ \overline{D}^{*0}$ $(D_{s0}^+ \to D_s^+\pi^0)$	$1.91 \pm 0.84 \pm 0.50^{+0.63}_{-0.38}$	—
V	$B^0 \to D_{s1}^+ D^-$ $(D_{s1}^+ \to D_s^{*+}\pi^0)$	$1.71 \pm 0.72 \pm 0.27^{+0.57}_{-0.35}$	$2.27 \pm 0.68^{+0.73}_{-0.62}$
VI	$B^0 \to D_{s1}^+ D^{*-}$ $(D_{s1}^+ \to D_s^{*+}\pi^0)$	$5.89 \pm 1.24 \pm 1.16^{+1.96}_{-1.17}$	—
VII	$B^+ \to D_{s1}^+ \overline{D}^0$ $(D_{s1}^+ \to D_s^{*+}\pi^0)$	$2.07 \pm 0.71 \pm 0.45^{+0.69}_{-0.41}$	$1.19 \pm 0.36^{+0.61}_{-0.49}$
VIII	$B^+ \to D_{s1}^+ \overline{D}^{*0}$ $(D_{s1}^+ \to D_s^{*+}\pi^0)$	$7.30 \pm 1.68 \pm 1.68^{+2.40}_{-1.43}$	—
IX	$B^0 \to D_{s1}^+ D^-$ $(D_{s1}^+ \to D_s^+\gamma)$	$0.92 \pm 0.24 \pm 0.11^{+0.30}_{-0.19}$	$0.82 \pm 0.25^{+0.22}_{-0.19}$
X	$B^0 \to D_{s1}^+ D^{*-}$ $(D_{s1}^+ \to D_s^+\gamma)$	$2.60 \pm 0.39 \pm 0.34^{+0.86}_{-0.52}$	—
XI	$B^+ \to D_{s1}^+ \overline{D}^0$ $(D_{s1}^+ \to D_s^+\gamma)$	$0.80 \pm 0.21 \pm 0.12^{+0.26}_{-0.16}$	$0.56 \pm 0.17^{+0.16}_{-0.15}$
XII	$B^+ \to D_{s1}^+ \overline{D}^{*0}$ $(D_{s1}^+ \to D_s^+\gamma)$	$2.26 \pm 0.47 \pm 0.43^{+0.74}_{-0.44}$	—

Table 1: Branching fractions measured in the *BABAR* analysis and corresponding Belle results

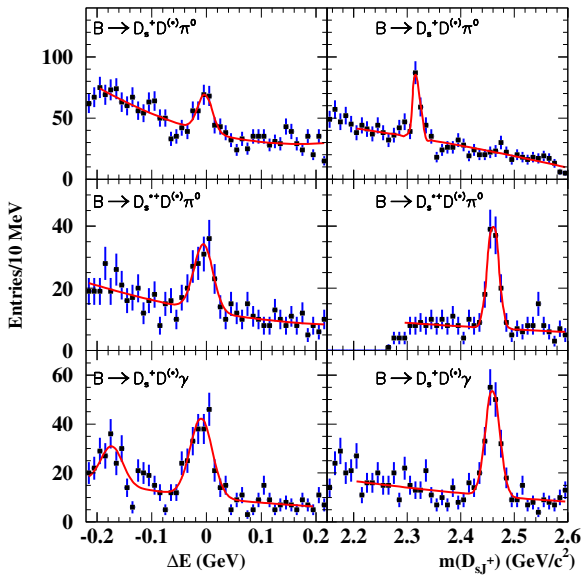

Figure 1: ΔE and $m(D_{sJ})$ spectra for (a,b) the sum of $B \to D^+_{s0}\overline{D}^{(*)}, D^+_{s0} \to D_s\pi^0$; (c,d) the sum of $B \to D^+_{s1}\overline{D}^{(*)}, D^+_{s1} \to D_s\pi^0$; (e,f) the sum of $B \to D^+_{s1}\overline{D}^{(*)}, D^+_{s1} \to D_s\gamma$

The decay modes involving combinations of the D_{sJ} and a neutral or charged D^* are first observations. The modes with D_{sJ} and a neutral or charged D were also observed by Belle [4] and the results of the two experiments are in rather good agreement.

The spin of the $D_{sJ}(2460)$ has been investigated using the $D_s\gamma$ decay. The distribution of the angle Θ_h between the D_{sJ} flight direction and the D_s momentum in the D_{sJ} reference frame has been studied. The distribution favours the $J = 1$ spin hypothesis over the $J = 2$ (Fig. 2). Spin J=0 is ruled out by parity and angular momentum conservation. A similar conclusion has been reached by Belle [4].

2.2 Study of the decay $B \to DK$

The B^+ decay to $\overset{(-)}{D}{}^0K^+$ state is a crucial mode for the extraction of the γ angle of the Unitarity Triangle. The original method, suggested by Gronau and Wyler [5], was based on the interference between the $B \to D^0K$ $(b \to c)$ and the $B \to \overline{D}^0K$ $(b \to u)$ diagrams once the D^0 and the $\overline{D}^0$ mesons decay to CP states (K^+K^-,$\pi^+\pi^-$,$K_s\pi^0$ etc). The two diagrams for the two B decays are shown in Fig. 3. The limitation of this method is that the branching fractions for D decays to CP modes are rather small and the interference is even smaller, since the contribution of the $(b \to u)$ diagram is suppressed with respect to the $(b \to c)$ one. More recently a variation of the method has been proposed by Atwood, Dunietz and Soni (ADS)[6]. It is based on the separate measurement of B^+ and B^- to a final state which can be reached by primarily two amplitudes, each of the same order of magnitude. One amplitude is from a doubly suppressed decay $B^+ \to \overline{D}^0K^+$ combined with a favored $\overline{D}$ decay $\overline{D}^0 \to K^+\pi^-$; the other amplitude is from a favored decay $B^+ \to D^0K^+$, followed by a doubly suppressed D decay $D^0 \to K^+\pi^-$. In this way the interference is enhanced.

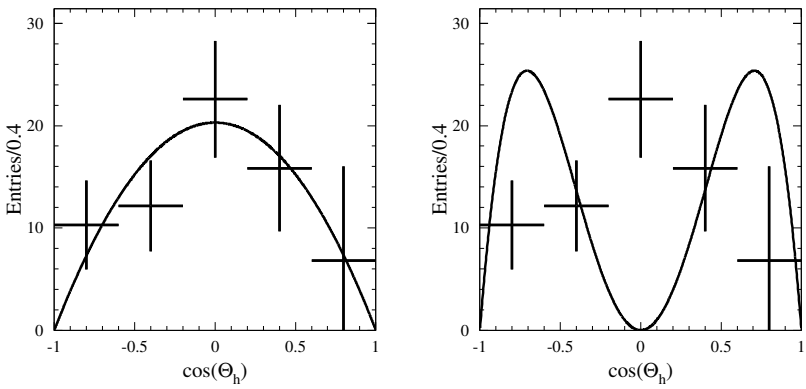

Figure 2: Helicity distributions obtained from $m(D_s\gamma)$ fits in the corres ponding $\cos(\Theta_h)$ region for selected BaBar data. The solid curves are the analytical expectations for two different $D^*_{sJ}(2460)^+$ spin hypotheses, which have been normalized to the data: (left) $J = 1$ and (right) $J = 2$.

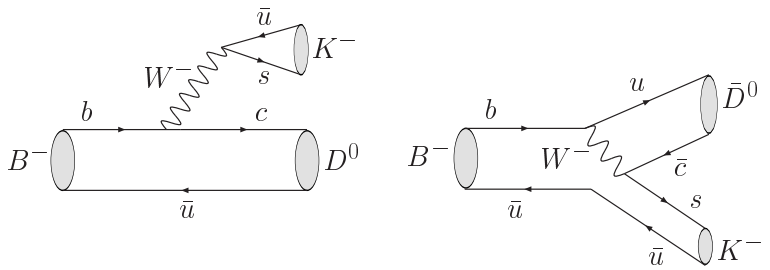

Figure 3: The two contributing B-decay Feynman diagrams for $B^- \to DK^-$. The diagram on the right, which has a $b \to u$ transition, is color suppressed, while the $b \to c$ diagram on the left is not.

Following the ADS method [6] it is possible to write:

$$R_{DCS} \equiv \frac{\Gamma(B^- \to D_{K^+\pi^-}) + \Gamma(B^+ \to D_{K^-\pi^+})}{\Gamma(B^- \to D_{K^-\pi^+}) + \Gamma(B^+ \to D_{K^+\pi^-})} = r_D^2 + r_B^2 + 2r_D r_B \cos\gamma \cos\delta \qquad (1)$$

where $r_D = |A(D^0 \to K^+\pi^-)|/|A(\overline{D}^0 \to K^+\pi^-)| \approx 0.060 \pm 0.003$, $r_B = |A(b \to u)|/|A(b \to c)|$, and δ is an overall strong phase difference.

Based on this motivation, an analysis has been performed at *BABAR* to study the decay of B^+ to $\overline{D}^0 K^+$. The D candidates are reconstructed in $K^\pm\pi^\mp$ modes. The study is based on data collected in Run 1,2,3. In spite of the fact that the method is both theoretically and experimentally very clean, the strong overall suppression of the two amplitudes and the required level of background rejection still represents a challenge with the present statistics. In fig. 4 the fit to m_{ES} distribution is shown for candidates respectively in the double-Cabibbo suppressed mode (plot a), in the D sidebands (plot b) in the Cabibbo favored decay (plot c). The excess of events in the suppressed mode $N_{suppr} = 1.1 \pm 3.0$ is compatible with zero while the number of candidates in the favored mode is $N_{fav} = 261 \pm 22$. This result only allows to set a limit for $R_{DCS} : R_{DCS} < 0.026$ at 90%

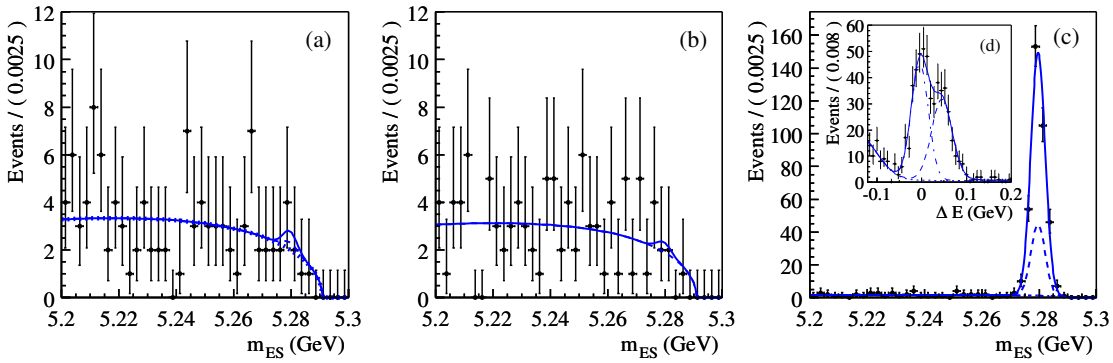

Figure 4: m_{es} distributions for (a) signal ($[K^{\mp}\pi^{\pm}]_D K^{\pm}$) candidates, (b) candidates from the $\overline{D}^0$ sideband, and (c) $B \to DK$ candidates. (d) ΔE distribution for $B \to DK$ candidates; the peak centered at ≈ 0.05 GeV is from $B \to D\pi$. The superimposed curves are described in the text. In (c), the dashed Gaussian centered at m_B represents the $B \to D\pi$ contribution estimated from (d).

CL. This limit, making no assumptions about γ or the overall strong phase difference δ translates into a limit for the ratio of the B decay amplitudes $r_B < 0.22$ at 90% CL. This result is by itself relevant, because if r_B is small, as this analysis suggests, the suppression of the $b \to u$ amplitude will reduce the sensitivity of the ADS method in the measurement of γ (see eq. 1).

3 B decays to states containing charmonium

3.1 Study of the process $B \to J/\psi K\pi\pi$ and search for $X(3872)$

One of the most recent results from *BABAR* in the field of B decays to states containing charmonium, is the study of the branching fraction of the process $B \to J/\psi K\pi\pi$. The analysis is even more important due to the observation of a state $X(3872) \to J/\psi\pi\pi$ by Belle [7] and CDF [8]. In addition, this analysis addresses the search for the unconfirmed $h_c(3526)$ charmonium state [9], and for an intrinsic charm component in the B meson, leading to an anomalously large ($B^- \to J/\psi D^0\pi^-$) decay rate [10]. The study is based on the data collected by *BABAR* during Run 1,2, and 3. As a first step, the energy substituted mass and ΔE distributions are reconstructed for $J/\psi K\pi\pi$ combinations (see fig. 5).
There is a very clean signal in the expected region, with a yield of $N_{ev} = 2540 \pm 72$ (upper plot), which allows to quote the branching fraction:

$$BR(B \to J/\psi K\pi\pi) = (11.6 \pm 0.7 \pm 0.9) \times 10^{-4}$$

If the same distribution is plotted for $J/\psi\pi\pi$ candidates inside a mass window of $20 MeV/c^2$ around the expected mass of the $X(3870)$ there is still an excess of events in the m_{ES} distribution (fig. 5, lower plot), The indication that part of the process proceeds through the X(3870) state is clear from the study of the invariant mass distribution of the $J/\psi\pi\pi$ combinations (see fig. 6) while no hint of a h_c signal is found.
The product branching fractions is found to be:

$$BR(B^- \to X(3872)K^-) \times BR(X \to J/\psi\pi\pi) = (1.28 \pm 0.41) \times 10^{-5}$$

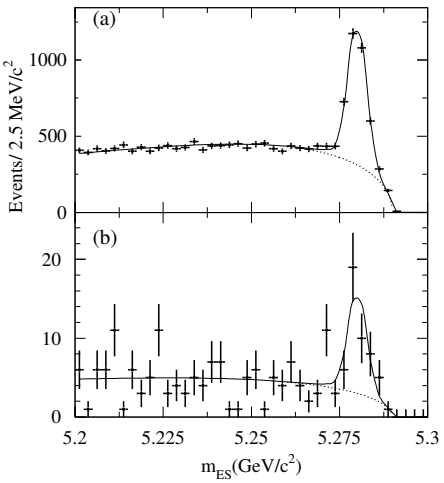

Figure 5: Distribution of m_{ES} for: (a)$B \to J/\psi K\pi\pi$ candidates, (b) events with $3862 < m_{J/\psi\pi\pi} < 3882 MeV/c^2$

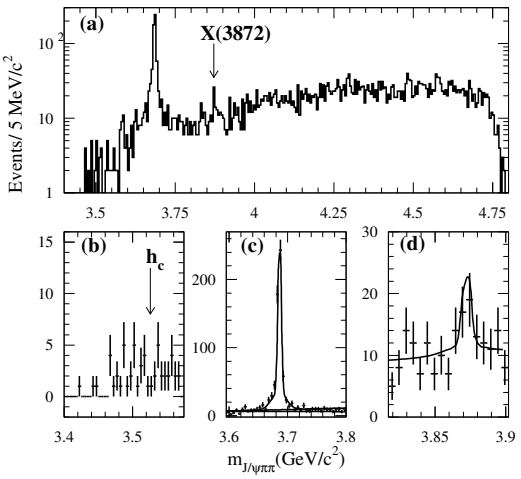

Figure 6: Distribution of $m_{J/\psi\pi\pi}$ (top) and detailed analysis in the expected regions for h_c (bottom left), $\psi(2s)$ (bottom center), and $X(3872)$ (bottom right). No excess is observed for the h_c while a clear excee is visible in the region where the $X(3872)$ is expected.

while limits are set for the h_c production and the $B^- \to J/\psi D^0 \pi^-$ decay rate:

$$BR(B^- \to h_c K^-) \times BR(h_c \to J/\psi\pi\pi) < 4.3 \times 10^{-6};\ BR(B^- \to J/\psi D^0 \pi) < 5.2 \times 10^{-5}\ (90\% C.L.)$$

3.2 Study of the process $B \to J/\psi\eta K$

An analysis has recently addressed this decay mode, not only because the branching fraction has never been measured by *BABAR* before, but in particular to understand better the properties of the $X(3872)$ state. Indeed, if the state $X(3872)$ behaves like conventional charmonium, then we could expect a product branching fraction:

$$BR(B^- \to X(3872) K^-) \times BR(X \to J/\psi\eta) \approx \mathcal{O}(3 \times 10^{-6})$$

For this reason both the decays $B^0 \to J/\psi\eta K_s$ and $B^+ \to J/\psi\eta K^+$ have been investigated. A clean signal has been measured in both processes and the following branching fractions have been quoted:

$$BR(B^+ \to J/\psi\eta K^+) = (10.8 \pm 2.3 \pm 2.4) \times 10^{-5};\ B^0 \to J/\psi\eta K_s = (8.4 \pm 2.6 \pm 2.7) \times 10^{-5}$$

The specific search for the decay to proceed through the $X(3872) \to J/\psi\eta$ transition has been carried out. The $J/\psi\eta$ mass distribution has been studied for combinations inside the m_{ES}, ΔE window for the B decay. No excess of events is observed in the region where a contribution coming

from $X(3872)$ should be expected to appear. This allows to set a limit for the product branching fraction:

$$BR(B^- \to X(3872)K^-) \times BR(X \to J/\psi\eta) < 7.7 \times 10^{-6} \ (90\% C.L.)$$

which is anyway still compatible with the phenomenological expectations.

4 Conclusions

Thanks to the unprecedented number of B pairs collected at the last-generation B-factories, in the last few years many new results have become available. In this paper we have presented only a few examples of the most recent analyses from the *BABAR* Collaboration in the sector of B transitions to final states containing charm. Of particular interest is the new observation and branching fractions measurement for B decays to several $D_{sJ}D^{(*)}$ states and the studies of the spin of $D_{sJ}(2460)$. The first results on the $B \to DK$ transition where the D is searched in its double-Cabibbo suppressed decay modes, and the extraction of a new limit on r_B. The observation of the $X(3872)$ decay to $J/\psi\pi\pi$ and the study of $X(3872)$ properties.

References

[1] B.Aubert *et al.* [*BABAR* Collaboration], Nucl.Inst.Methods A**479**, 117 (2002).

[2] B.Aubert *et al.* [*BABAR* Collaboration], Phys.Rev.Lett. **90**, 242001(2003);

[3] D.Besson *et al.* [CLEO Collaboration], Phys.Rev. **D68**, 032002 (2003);

[4] P. Krokovny *et al.* [Belle Collaboration], Phys. Rev. Lett. **91**, 262002 (2003) [arXiv:hep-ex/0308019].

[5] M.Gronau and D.Wyler, Phys.Lett. **B265**, 172(1991); M.Gronau and D.London, Phys.Lett. **B253**, 483(1991);

[6] D.Atwood and I.Dunietz, and A.Soni, Phys.Rev.Lett. **78**, 3257(1997); Phys.Rev. **D63**, 036005(2001).

[7] S.K.Choi *et al.* [Belle Collaboration], Phys.Rev.Lett. **91**, 262001(2003);

[8] D.Acosta *et al.* [CDF Collaboration], hep-ex/0312021, submitted to Phys.Rev.Lett.

[9] T.A.Armstrong *et al.*, Phys.Rev.Lett.**69**, 2337(1992).

[10] C.H.Chang and W.S.Hou, Phys.Rev.D **64**, 071501(2001).