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B DECAYS TO CHARM AND CHARMONIUM STATES IN *BABAR*[a]

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Recent measurements in exclusive hadronic B decays to states with charm are presented, including a review of the $B \to D_{sJ} D^{(*)}$ decays, and a study of the $B^- \to J/\psi K^- \pi^+ \pi^-$ decay looking for charmonium resonances. New results are shown on the search of the $B^0 \to D_s^+ \rho^-$ and $B^0 \to J/\psi \gamma$ decays. These analysis 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.

Introduction

B-factories are a versatile tool for hadronic B physic as shown in the set of analysis in this paper: the branching fraction ($\mathcal{B}$) measurement of $B \to D_{sJ} D^{(*)}$ decays and the extraction of angular information for the $D_{sJ}(2460)^+$ [1], the search of the $B^0 \to D_s^+ \rho^-$ [2], the study of $B^- \to J/\psi K^- \pi^+ \pi^-$ [b] with the confirmation of the $X(3782)$ [3], and the search of the $B^0 \to J/\psi \gamma$ decay [4].

1 Study of the $B \to D_{sJ} D^{(*)}$ decays.

In the $c\bar{s}$ mesons system, two states, the $J^P = 0^+$ and the $J^P = 1^+$ are predicted to have mass values above threshold for the decays $D_{s0} \to DK$ and $D_{s1} \to D^* K$, and to have large widths. The observations of *BABAR* [5], CLEO [6], and Belle citeAbe:2003jk gives candidates for both states with masses of 2317 MeV/c^2 and 2460 MeV/c^2, below the expected values and with narrow widths. If these are $c\bar{s}$ states, their decays $D_{sJ}^*(2317) \to D_s \pi^0$ and $D_{sJ}(2460) \to D_s^* \pi^0$ violate isospin. The $D_{sJ}(2460)$ is reconstructed in the observed $D_s \gamma$ mode too.

To interpret their measured properties the theoretical models need to be revised, including other effects, like chiral symmetry. To establish their nature, the production of $D_{sJ}^*(2317)$ and $D_{sJ}(2460)$ is investigated in $B \to D_{sJ} D^{(*)}$ decays, using data corresponding to a luminosity of 113 fb^{-1}. The summary of the branching fractions is in table 1.

The decays $B \to D_{sJ} D^{(*)}$ ($D_{sJ}(2460) \to D_s \gamma$) are used to determine angular properties of the $D_{sJ}(2460)$. Defining the helicity angle as the angle between the D_{sJ} flight direction and the D_s^+ momentum in the D_{sJ} reference frame, the hypothesis J=1 or J=2 (J=0 ruled out

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[b]Charge conjugation is implied throughout this note.

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Table 1: Event yields, efficiencies (including intermediate branching fractions), and measured branching fractions $\mathcal{B}$, for $B \to D_{sJ}^{(*)+} \overline{D}^{(*)}$ decays. The first error on $\mathcal{B}$ is statistical, the second one is systematic, and the third one is from the intermediate branching fractions.

B mode	Yield	Efficiency (10^{-4})	$\mathcal{B}(10^{-3})$
$B^0 \to D_{sJ}^*(2317)^+ D^-$ $[D_s^+ \pi^0]$	34.7 ± 8.0	1.57	$1.8 \pm 0.4 \pm 0.3^{+0.6}_{-0.4}$
$B^0 \to D_{sJ}^*(2317)^+ D^{*-}$ $[D_s^+ \pi^0]$	23.5 ± 6.1	1.29	$1.5 \pm 0.4 \pm 0.2^{+0.5}_{-0.3}$
$B^+ \to D_{sJ}^*(2317)^+ \overline{D}^0$ $[D_s^+ \pi^0]$	32.7 ± 10.8	2.55	$1.0 \pm 0.3 \pm 0.1^{+0.4}_{-0.2}$
$B^+ \to D_{sJ}^*(2317)^+ \overline{D}^{*0}$ $[D_s^+ \pi^0]$	17.6 ± 6.8	0.99	$0.9 \pm 0.6 \pm 0.2^{+0.3}_{-0.2}$
$B^0 \to D_{sJ}(2460)^+ D^-$ $[D_s^{*+} \pi^0]$	17.4 ± 5.1	0.50	$2.8 \pm 0.8 \pm 0.5^{+1.0}_{-0.6}$
$B^0 \to D_{sJ}(2460)^+ D^{*-}$ $[D_s^{*+} \pi^0]$	26.5 ± 5.7	0.39	$5.5 \pm 1.2 \pm 1.0^{+1.9}_{-1.2}$
$B^+ \to D_{sJ}(2460)^+ \overline{D}^0$ $[D_s^{*+} \pi^0]$	29.0 ± 6.8	0.80	$2.7 \pm 0.7 \pm 0.5^{+0.9}_{-0.6}$
$B^+ \to D_{sJ}(2460)^+ \overline{D}^{*0}$ $[D_s^{*+} \pi^0]$	30.5 ± 6.4	0.30	$7.6 \pm 1.7 \pm 1.8^{+2.6}_{-1.6}$
$B^0 \to D_{sJ}(2460)^+ D^-$ $[D_s^+ \gamma]$	24.8 ± 6.5	2.62	$0.8 \pm 0.2 \pm 0.1^{+0.3}_{-0.2}$
$B^0 \to D_{sJ}(2460)^+ D^{*-}$ $[D_s^+ \gamma]$	53.0 ± 7.8	1.92	$2.3 \pm 0.3 \pm 0.3^{+0.8}_{-0.5}$
$B^+ \to D_{sJ}(2460)^+ \overline{D}^0$ $[D_s^+ \gamma]$	31.9 ± 9.0	4.12	$0.6 \pm 0.2 \pm 0.1^{+0.2}_{-0.1}$
$B^+ \to D_{sJ}(2460)^+ \overline{D}^{*0}$ $[D_s^+ \gamma]$	34.6 ± 7.6	1.68	$1.4 \pm 0.4 \pm 0.3^{+0.5}_{-0.3}$

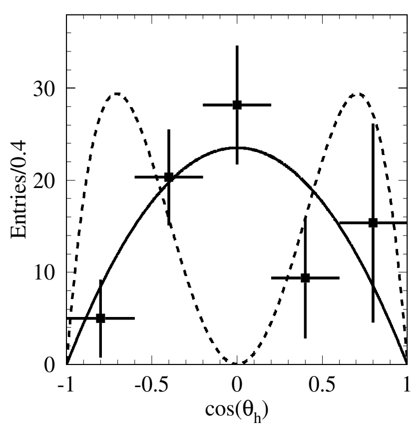

Figure 1: Helicity distribution for $D_{sJ}(2460)$ hypothesis $J = 1$ (solid line), J=2 (dashed line), and for data (points)

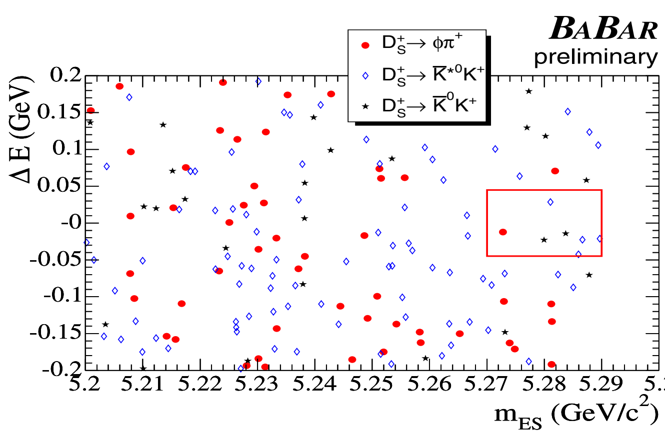

Figure 2: ΔE vs m_{ES} distribution for $B^0 \to D_s^+ \rho^-$ candidates reconstructed in the decays $D_s^+ \to \phi \pi^+$ (circles), $D_s^+ \to \overline{K}^{*0} K^+$ (diamonds) and $D_s^+ \to \overline{K}^0 K^+$ (stars). The box indicates signal region.

by angular momentum conservation) are tested. The observed distribution supports the J=1 hypothesis (Fig. 1).

2 Search for $B^0 \to D_s^+ \rho^-$

A measurement of $\sin(2\beta+\gamma)$ is possible with a time dependent analysis of the decay $B^0 \to D^- \rho^+$ and the doubly cabibbo suppress $B^0 \to D^+ \rho^-$. Since this decay is not distinguishable from the $\overline{B}^0 \to D^+ \rho^-$, an independent estimation is needed. Under the SU(3) flavor symmetry assumption, the amplitudes for $D^{(*)+}\rho^-$ can be related to $D_s^{(*)+}\rho^-$ by:

$$r(D^{(*)}\rho) = \frac{|A(B^0 \to D^{(*)+}\rho^-)|}{|A(B^0 \to D^{(*)-}\rho^+)|} \cong (tan\theta_c)\frac{f_D}{f_{D_s}}\sqrt{\frac{\mathcal{B}(B^0 \to D_s^{(*)+}\rho^-)}{\mathcal{B}(B^0 \to D^{(*)-}\rho^+)}} \quad (1)$$

Thus a measurement of $\mathcal{B}(B^0 \to D_s^+ \rho^-)$ and $\mathcal{B}(B^0 \to D^- \rho^+)$ allows to know $r(D\rho)$ and to measure $\sin(2\beta+\gamma)$.

Analyzing 90 million $B\overline{B}$ pairs, 7 events are observed in the signal box (Fig. 2), compatible with the expected background of 6.4, mainly due to $D_s^{*+}\rho^-$, $D_s^{*+}\pi^-$ and $D_s^+\rho^0$ decays. An upper limit to this branching fraction and to the value of $r(D\rho)$ (eq. 1) is set to:

$$\mathcal{B}(B^0 \to D_s^+\rho^-) < 2.5 \times 10^{-5}; \quad r(D\rho) < 0.01 \; (90\% C.L.)$$

The low value of $r(D\rho)$ indicates a small sensitivity of *CP* asymmetries in $B^0 \to D_s^{\mp}\rho^{\pm}$ and a measurement of $\sin(2\beta + \gamma)$ more challenging than expected.

3 Study of the $B^- \to J/\psi K^-\pi^+\pi^-$ decay

The observation of $X(3782) \to J/\psi\pi^+\pi^-$ by the Belle[8] and CDF[9] experiments arose interest on the decay $B^- \to J/\psi K^-\pi^+\pi^-$ as a good environment to search for possible charmonium states decaying into $J/\psi\pi^+\pi^-$. In addition to the $X(3782)$ this analysis looks for the unconfirmed $h_c(3526)$ [10], the $^1P_1$ missing charmonium state, and for an intrinsic charm component in the B meson that can cause the excess at low p^* of J/ψ production trough an anomalously large $\mathcal{B}(B^- \to J/\psi D^0\pi^-)$, with $D^0 \to K^-\pi^+$ [11].

Using 117 million $B\overline{B}$ pairs, the reconstruction of $J/\psi K\pi\pi$ combinations shows a clean signal in the distribution of the $m_{\rm ES}$ (Fig. 3(a)) allowing the measurement:

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

Looking at the invariant mass $J/\psi\pi^+\pi^-$ (Fig. 4), the huge peak corresponds to the $\psi(2s)$,

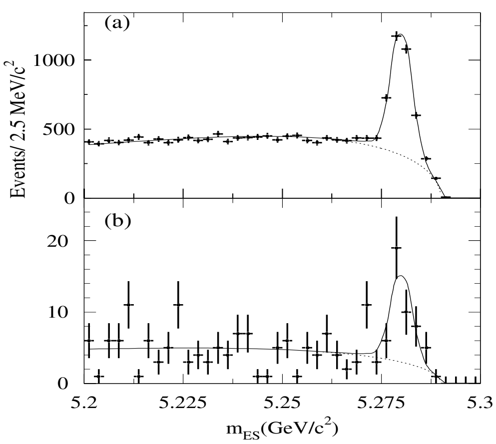

Figure 3: $m_{\rm ES}$ for non-resonant $B \to J/\psi K\pi\pi$ candidates (a) and for events with $3862 < m_{J/\psi\pi\pi} < 3882\,{\rm MeV}/c^2$ (b)

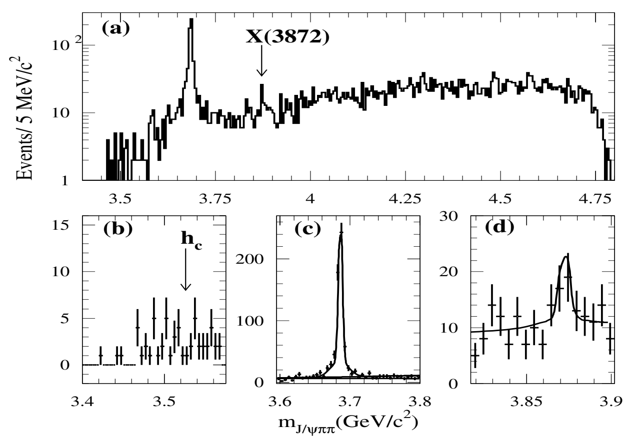

Figure 4: Invariant mass $m_{J/\psi\pi\pi}$ (a) and the zoom in three different regions: $h_c(3526)$ (b), $\psi(2s)$ (c), and $X(3782)$ (d).

another peak is present at $(3873.4{\pm}1.4)\,{\rm MeV}/c^2$, but there is no evidence of the $h_c(3526)$. The signal peak in $m_{\rm ES}$ (Fig. 3(b)), due to selected candidates in a window of $\pm 20\,{\rm MeV}/c^2$ around the expected mass of the $X(3782)$, allows to measure:

$$\mathcal{B}(B^- \to X(3782)K^-) \times \mathcal{B}(X(3782) \to J/\psi\pi^+\pi^-) = (1.28 \pm 0.41) \times 10^{-5}$$

An upper limit is set on the $h_c(3526)$ production and, looking to the $K\pi$ invariant mass, on the $B^- \to J/\psi D^0\pi^-$ decay rate:

$$\mathcal{B}(B^- \to h_c(3526)K^-) \times \mathcal{B}(h_c \to J/\psi\pi\pi) < 4.3 \times 10^{-6} \; (90\% C.L.)$$
$$\mathcal{B}(B^- \to J/\psi D^0\pi^-) < 5.2 \times 10^{-5} \; (90\% C.L.)$$

4 Search for $B^0 \to J/\psi\gamma$

The rate for this decay, searched for the first time, is expected to be very low ($\sim 10^{-9}$), so presence of signal would indicate new physics effects. J/ψ is reconstructed into e^+e^- or $\mu^+\mu^-$ lepton pairs while the photon is rejected if combined with any other photon candidate forms a pair with an invariant mass within 20 MeV/c^2 of the neutral pion mass.

Using 113 fb^{-1} of data, no candidates are seen in the signal region while 0.71 candidates are expected from background, mainly $J/\psi\pi^0$ and $J/\psi K_L^0$ (Fig. 5). An upper limit is set to:

$$\mathcal{B}(B^0 \to J/\psi\gamma) < 1.6 \times 10^{-6}\ (90\% C.L.)$$

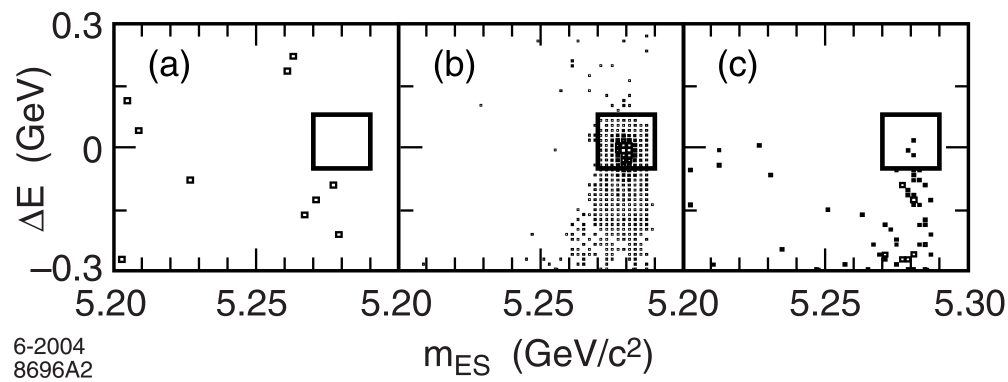

Figure 5: ΔE-$m_{\rm ES}$ distributions for (a) on-peak data, (b) simulated signal, and (c) simulated background. The box indicates signal region. The sample in (c) is about nine times the data sample in (a).

Conclusions

Thanks to the large amount of data collected and to the clean environment conditions, different results from *BABAR* have been presented: the study of the decays $B \to D_{sJ}D^{(*)}$ allowed to measure the branching fraction and support the hypothesis J=1 for the $D_{sJ}(2460)^+$; the upper limit on the $\mathcal{B}(B^0 \to D_s^+\rho^-)$ and on the value of $r(D\rho)$ indicate small sensitivity on *CP* violation; the study of the decay $B^- \to J/\psi K^-\pi^+\pi^-$ allows to identify the $X(3782)$ and poses upper limits on the production of the resonance $h_c(3526)$ and on the intrinsic charm in the B meson; an upper limit is set on $\mathcal{B}(B^0 \to J/\psi\gamma)$.

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