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# B DECAYS TO HADRONIC STATES WITH CHARM/CHARMONIUM IN BABAR

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In this paper the studies of three different B decays to hadronic states are presented. These results are based on 1999-2003 dataset collected by the *BABAR* experiment at the PEP-II $e^+e^-$ storage ring at the Stanford Linear Accelerator Center. The measurements are the hadronic branching fraction of $B^+ \to J/\Psi p\bar{\Lambda}$, $B^0 \to J/\Psi p\bar{p}$, $B^0 \to D^{*\pm}D^{\mp}$, and the direct $CP$-asymmetry in $B^0 \to D^0(CP)K^-$ channels.

## 1 Introduction

The decay of $B$ mesons to open charm and charmonium provides an excellent laboratory for the study of hadronic $B$ decays. With about 88 millions of $B$ pairs, the *BABAR* experiment has collected a sample of data that enable to test models of B decay in more modes and with greater precision than ever before. In this note we present some examples. In section 2 a test on non-relativistic QCD is described. In the next section a measurement of branching fraction and measurements of time-integrated asymmetries in channels suitable for CP violation study are presented. The *BABAR* detector is described in detail elsewhere [1]. Charge conjugation is implied throughout this note.

## 2 B Decays To Charmonium States

The inclusive production of charmonium mesons in $B$ decay at the $\Upsilon(4S)$ shows an excess of $J/\Psi$ mesons at low center-of-mass momentum $p_{CM}$ [2,3,4], when compared to distributions predicted by non-relativistic QCD calculations [5]. Some hypothesis have been proposed to explain the sources of the excess: an intrinsic [6] charm component of the B, the production of an $s\bar{d}g$

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hybrid [7] in conjunction with a $J/\Psi$, or the possibility that the excess comes from decays of the type $B \to J/\Psi$ baryon anti-baryon [8]. The rate of these decays could be enhanced by the intermediate production of an exotic state allowed by QCD but not yet observed. In this section we present the searches for the decays $B^+ \to J/\Psi p\bar{\Lambda}$ and $B^0 \to J/\Psi p\bar{p}$ as a test of this last hypothesis.

The reconstruction of $B^+ \to J/\Psi p\bar{\Lambda}$ candidates is done by combining $J/\Psi$, proton, and $\Lambda$ candidates. $J/\Psi$ are reconstructed in the $e^+e^-$ or $\mu^+\mu^-$ final states. The selection of good proton candidates is one of the key element of the analysis. The separation of low momentum protons from kaons is done by a likelihood method that uses energy deposited and Cherenkov angle measurements. At a typical momentum of 300MeV/c, the selection efficiency is greater than 98% with a kaon misidentification probability less than 1%. The $\Lambda$ is reconstructed from a proton and an oppositely charged track, assumed to be a pion. $B^0 \to J/\Psi p\bar{p}$ candidates are formed from $J/\Psi$ candidates and an oppositely-charged pair of proton candidates. We used the kinematic variables $\Delta E$ and $m_{ES}$ [1] to characterize B candidates. The analysis region considered is defined by $5.2 < m_{ES} < 5.3\text{GeV/c}^2$ and $-0.10 < \Delta E < 0.25\text{GeV}$ ($B^+$ candidates) and $-0.25 < \Delta E < 0.25\text{GeV}$ ($B^0$ candidates). For signal events, $\langle \Delta E \rangle \approx 0$ and $\langle m_{ES} \rangle \approx M_B$. We define a signal region as an ellipse with semi-axes proportional to the resolutions $\sigma_m$ and $\sigma_E$ estimated, from simulated data, to be 3.1 MeV/c$^2$ and 6.5 MeV, respectively, for $B^+ \to J/\Psi p\bar{\Lambda}$, and 2.7MeV/c$^2$ and 5.5MeV for $B^0 \to J/\Psi p\bar{p}$. We use simulated $B^+ \to J/\Psi p\bar{\Lambda}$ and $B^0 \to J/\Psi p\bar{p}$ events to estimate the selection efficiency that is $0.049 \pm 0.009$ for the charged channel and $0.184 \pm 0.024$ for the neutral one. We have studied the accuracy of the simulation of the detector response by comparing data and simulated background events in samples similar to the final selection. The expected background in the signal ellipse is extrapolated from the number of candidates outside the ellipse in the analysis region considered. For $B^+ \to J/\Psi p\bar{\Lambda}$ we have 39 candidates in the analysis region implying an expected background of $0.21 \pm 014$. We observe four candidates in the signal ellipse. The probability of observing $\geq 4$ candidates when expecting $0.21 \pm 0.14$ is $2.5 \times 10^{-4}$. To interpret this result as a $B^+$ branching fraction $\mathcal{B}$, we undertake a Bayesian analysis with a uniform prior above zero. We define the likelihood for $\mathcal{B}$ as the probability of observing exactly four events, including uncertainties on the expected background, signal efficiency, secondary branching fractions, and number of $\Upsilon(4S)$ decays ($(88.9 \pm 1.0) \times 10^6$). The result is $\mathcal{B}(B^+ \to J/\Psi p\Lambda) = 11.6^{+8.5}_{-5.6} \times 10^{-6}$ [9], where the uncertainty includes both statistical and systematic components. We similarly obtain a 90% CL upper limit of $26 \times 10^{-6}$. For the Cabibbo suppressed mode $B^0 \to J/\Psi p\bar{p}$ we followed the same procedure. There are 126 events outside the signal ellipse. The expected background is of $0.64 \pm 0.17$ and one event has been found inside the ellipse. We obtain $\mathcal{B}(B^0 \to J/\Psi p\bar{p}) < 1.9 \times 10^{-6}$ (90% CL). This limit is dominated by statistical uncertainty. Neither final state makes a significant contribution to the observed excess of $J/\Psi$ mesons in inclusive $B$ decay.

## 3 B Decays To Open Charm States

In this section we describe the analysis of two channels interesting for CP violation studies.

The measurements of the parameter $\sin(2\beta)$ using the quark process $b \to c\bar{c}s$ have shown that $CP$ is violated in the neutral $B$-meson system [10,11], consistently with the Standard Model (SM) expectation [12]. In order to search for additional sources of $CP$ violation from new physics processes, different quark decays such as a $b \to c\bar{c}d$ must be examined. We describe here the measurements of branching fraction and of time-integrated $CP$-asymmetry in $B \to D^{*\pm}D^{\mp}$. $B$ decays to $D^{*+}D^-$ and $D^{*-}D^+$ are selected via full reconstruction of the decay products. The $D^{*+}$ is reconstructed in its decay to $D^0\pi^+$, where the $D^0$ subsequently decays to one of the four modes $K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^-\pi^+$, or $K^0_S\pi^+\pi^-$. The $D^-$ is reconstructed in its decays to $K^+\pi^-\pi^-$ and to $K^0_S\pi^-$. B candidate selection is based on a likelihood which

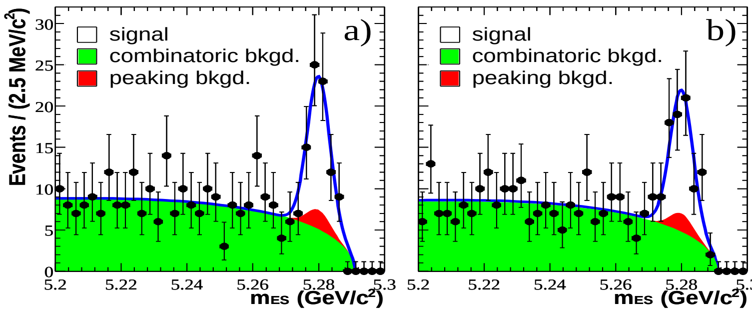


Figure 1: The $m_{ES}$ distributions of a) $B \to D^{*-}D^+$ and b) $B \to D^{*+}D^-$ candidates with $|\Delta E| < 18$MeV. The fit includes Gaussian distributions to model the signal and a small peaking background component, and an ARGUS function to model the combinatoric background shape.

includes all measured $D^\pm$, $D^0$ mass values and the $D^* - D$ mass difference. Candidates are then characterized by the kinematic variables $\Delta E$ and $m_{ES}$. The signal region in $\Delta E$ is defined to be $|\Delta E| < 18$MeV. According to Monte Carlo simulations, the width of this region corresponds to approximately twice the signal resolution. $B \to D^{*\pm}D^\mp$ candidates in the region $5.27 < m_{ES} < 5.30$Gev/c$^2$ and $|\Delta E| < 18$ MeV are used to extract signal events. A sideband, defined as $5.20 < m_{ES} < 5.27$GeV/c$^2$ and $|\Delta E| < 18$ MeV, and a "large sideband", defined as $5.20 < m_{ES} < 5.27$Gev/c$^2$ and $|\Delta E| < 200$MeV, are used to extract various background parameters. The total numbers of selected events in the signal region, the sideband, and the large sideband are 197, 461, and 5187, respectively. We use an unbinned extended maximum likelihood fit to the $m_{ES}$ distribution to extract the number of signal events above background as well as the time-integrated $CP$ asymmetry, defined as:

$$\mathcal{A} = \frac{N_{D^{*+}D^-} - N_{D^{*-}D^+}}{N_{D^{*+}D^-} + N_{D^{*-}D^+}}. \quad (1)$$

The $m_{ES}$ distribution for the simultaneous fit to all the selected events is described by Gaussian distributions for the $D^{*+}D^-$ and $D^{*-}D^+$ signals, an ARGUS threshold function [13], and a Gaussian distribution to describe a small "peaking" background estimated to be of $12 \pm 8$ events, from studies performed with both data and Monte Carlo simulations. There are a total of four free parameters in the nominal fit: the shape and normalization of the background ARGUS function (2), the total $B \to D^{*\pm}D^\mp$ signal yield (1), and the $CP$ asymmetry $\mathcal{A}$ (1). We use a Monte Carlo simulation of the BaBar detector to determine the reconstruction efficiencies, that range from 6% to 18% depending on the $D$ decay modes. From these efficiencies and the total number of recorded $B\bar{B}$ pairs, and assuming the $\Upsilon(4S)$ decaying equally in $B^+B^-$ and $B^0\bar{B}^0$ we determine the branching fraction to be:

$$\mathcal{B}(B \to D^{*\pm}D^\mp) = (8.8 \pm 1.0(\text{stat.}) \pm 1.3(\text{syst.})) \times 10^{-4}.$$

The total systematic uncertainty from all considered sources is 14.5%. The fitted value for $\mathcal{A}$ is

$$\mathcal{A} = -0.03 \pm 0.11(\text{stat.}) \pm 0.05(\text{syst.}).$$

Systematic uncertainties on $\mathcal{A}$ are dominated by potential differences in the reconstruction efficiencies of positively and negatively charged tracks (0.04), and by uncertainty in the $m_{ES}$ resolution for $B \to D^{*\pm}D^\mp$ signal events (0.03).

A theoretically clean measurement of the angle $\gamma$ can be obtained from the study of $B^- \to D^{(*)0}K^{*-}$ decay by reconstructing the $D^0$ meson into Cabibbo allowed CP eigenstates and double Cabibbo suppressed decays [15,16]. We will describe here a first step through this analysis describing the measurement of the direct CP asymmetry defined as:

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

where $D^0_{CP}$ is a $D^0$ meson reconstructed in either the Cabibbo allowed $K^+K^-$ $CP$ final state or in the Cabibbo soppressed $\pi^+\pi^-$ $CP$ mode. The analysis procedure for the two channels is similar but not identical. For the $K^+K^-$ mode the signal is extracted using a unbinned maximum likelihood fit to the variables $\Delta E$, $m_{ES}$ and the kaon ID probability of the prompt track in the final state. For the $\pi^+\pi^-$ mode the $m_{ES}$ variable is replaced by the $D^0$ invariant mass because of a possible dangerous contribution to this channel from the non resonant $B^- \to K^-\pi^-\pi^+$ decay. The variable $m_{ES}$ has in fact the same property for the signal and this background while $D^0$ mass has respectively peaking or flat distribution in the two cases. The shapes of signal and background distribution are determined by off-resonance data, Monte Carlo simulation and data control samples. The measured direct $CP$-asymmetry is $0.17 \pm 0.23^{+0.09}_{-0.07}$ for $B^\pm \to D^0(K^+K^-)K^\pm$ and $-0.44 \pm 0.34 \pm 0.06$ for $B^\pm \to D^0(K^+K^-)K^\pm$. The dominant sources of uncertainties are signal and background parametrization, particle ID and detector asymmetry.

## 4 Conclusion

We have measured the branching fraction of $B^+ \to J/\Psi p\bar{\Lambda}$ and $B^0 \to J/\Psi p\bar{p}$ and we can conclude that these channels could not be responsible of the observed excess of $J/\Psi$ mesons in inclusive $B$ decay. We have shown the results of the measurement of the branching fraction and time integrated $CP$-asymmetry in the channel $B \to D^{*\pm}D^{\mp}$ which is examined to analyse different modes measuring $\sin(2\beta)$, with the goal of understand CP violation as well as penguin contributions thoroughly. We have then shown the measurement of direct $CP$ asymmetries in the channels $B^\pm \to D^0(K^+K^-, \pi^+\pi^-)K^\pm$ which will allow in the future, with a data sample few times the current one, the measurement of the angle $\gamma$ of the Unitarity Triangle of the CKM mixing matrix.

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