Hadronic $B$ decays at BABAR

Francesco Fabozzi
INFN – Sezione di Napoli
Complesso Universitario di Monte Sant’Angelo
Via Cintia, I-80126 Napoli, Italy
(on behalf of the BABAR Collaboration)

Abstract

We present preliminary results on hadronic decays of $B$ mesons, based on data recorded at the $\Upsilon(4S)$ resonance with the BABAR detector at the PEP-II $B$-factory at SLAC. We measure branching fractions of many $B$ decay modes, including decays to $J/\psi \phi K$, $J/\psi \pi^+\pi^-$ and $\eta_c K$ final states. We report the observation of the decay $B \to D_s^+\pi^-$ and the first measurement of the flavor-tagged $D$ meson production in $B^0$ decays. Since their preliminary nature, the results presented in this paper are based on different data samples.

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1 The BABAR detector

The BABAR detector [1] at the PEP-II asymmetric-energy B-factory [2] at SLAC consists of a silicon vertex tracker (SVT) for precise decay vertex determination, a 40-layer drift chamber (DCH) for momentum and track angles measurement, a detector of internally reflected Cherenkov radiation (DIRC) for charged hadron identification, and a CsI(Tl) electromagnetic calorimeter (EMC) for photon reconstruction and electron identification. A superconducting solenoid provides a magnetic field of $1.5 \, \text{T}$, and the iron of the flux return is instrumented with resistive plate chambers (IFR) to provide muon identification and neutral hadron reconstruction.

2 Hadronic $B$ decays to charmonium

Color suppressed transitions $b \to c\bar{c}s(d)$ are responsible for hadronic $B$ decays to final states containing a charmonium. Theoretical predictions are based on the factorization hypothesis, that can be accurately tested with extensive and precise branching fraction determinations [3].

2.1 Rare $B$ decays to states with a $J/\psi$

The Cabibbo-suppressed decays $B \to J/\psi\eta(\eta')$ are described by a $b \to c\bar{c}d$ transition, as the observed decay $B \to J/\psi\pi$. An upper limit on the decay $B \to J/\psi\eta$ has been set by the L3 Collaboration [4], while there is no published result for the $B \to J/\psi\eta'$ channel.

The decay $B \to J/\psi\phi K$ is described by a $b\bar{q} \to c\bar{c}ssq$ transition, in which the $s\bar{s}$ pair is produced from sea quarks or via gluon emission. This mode has been observed by the CLEO Collaboration [5] with a branching fraction of $B(B \to J/\psi\phi K) = (8.8^{+3.5}_{-3.0} \pm 1.3) \times 10^{-5}$.

The decay $B \to J/\psi\phi$, which has not yet been observed, is explained with the occurrence of $c\bar{c}dd$ rescattering into a $c\bar{c}ss$ state. The above decay modes have been studied at BABAR. The $\eta$ is reconstructed in $\gamma\gamma$ or $\pi^+\pi^-\pi^0$ final states and the $\eta'$ in the $\eta(\to \gamma\gamma)\pi^+\pi^-$ channel. The $\phi$ is reconstructed in the $K^+K^-$ final state. Table 1 shows the preliminary results obtained from the analysis of 50.9 fb$^{-1}$ of data recorded at the $\Upsilon(4S)$ resonance [6].

2.2 Measurement of $B \to J/\psi \pi^+\pi^-$

In the decay $B \to J/\psi \pi^+\pi^-$, the $\pi^+\pi^-$ pair comes from the $B^0 \to J/\psi \rho^0(\to \pi^+\pi^-)$ channel or can be produced in a non-resonant state. The $B^0 \to J/\psi \rho^0$ mode is useful for the measurement of $\sin 2\beta$ and possible interference with higher order diagrams could produce a sizeable deviation of the branching fraction from the tree level expectation. An upper limit on this decay has been set by the CLEO Collaboration [7].

At BABAR, the decay $B^0 \to J/\psi \pi^+\pi^-$ is exclusively reconstructed and the signal yield is extracted from an unbinned maximum likelihood fit to the $\pi^+\pi^-$ invariant mass of the selected candidates [8]. The preliminary result obtained from a sample of 51.7 fb$^{-1}$ of data recorded at the $\Upsilon(4S)$ resonance is $B(B \to J/\psi \pi^+\pi^-) = (5.0 \pm 0.7 \pm 0.6) \times 10^{-5}$.  

\footnote{Unless otherwise stated, charged conjugate modes are implied throughout the paper.}
Table 1: Preliminary branching fraction determinations for rare $B$ decays to final states with a $J/\psi$. When the signal yield is not statistically significant, a 90% C.L. upper limit is reported.

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Branching Fraction</th>
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<tbody>
<tr>
<td>$B^0 \rightarrow J/\psi \eta(\to \gamma \gamma)$</td>
<td>$&lt; 3.0 \times 10^{-5}$</td>
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<tr>
<td>$B^0 \rightarrow J/\psi \eta(\to \pi^+ \pi^- \pi^0)$</td>
<td>$&lt; 3.0 \times 10^{-5}$</td>
</tr>
<tr>
<td>$B^0 \rightarrow J/\psi \eta$(combined)</td>
<td>$&lt; 2.7 \times 10^{-5}$</td>
</tr>
<tr>
<td>$B^0 \rightarrow J/\psi \eta'(\to \eta(\gamma \gamma) \pi^+ \pi^-)$</td>
<td>$&lt; 6.4 \times 10^{-5}$</td>
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<tr>
<td>$B^+ \rightarrow J/\psi \phi K^+$</td>
<td>$(4.4 \pm 1.4 \pm 0.7) \times 10^{-5}$</td>
</tr>
<tr>
<td>$B^0 \rightarrow J/\psi \phi K^0$</td>
<td>$(10.2 \pm 3.8 \pm 1.8) \times 10^{-5}$</td>
</tr>
<tr>
<td>$B \rightarrow J/\psi \phi K$ (combined)</td>
<td>$(5.0 \pm 1.3 \pm 0.7) \times 10^{-5}$</td>
</tr>
<tr>
<td>$B^0 \rightarrow J/\psi \phi$</td>
<td>$&lt; 0.95 \times 10^{-5}$</td>
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2.3 Measurement of $B \rightarrow \eta_c K$

The decay $B^0 \rightarrow \eta_c K_S$ can be used for a theoretically clean determination of $\sin 2\beta$, in the same way as the "golden" mode $B^0 \rightarrow J/\psi K_S$. Previous studies of the neutral and charged decay modes were performed by the CLEO Collaboration [9].

At BABAR, the decay $B \rightarrow \eta_c K$ is exclusively reconstructed, with the $\eta_c$ decaying in $K_S K^{+\pm} \pi^\pm$, $K^{+} K^- \pi^0$ or $K^{+} K^- K^{+} K^-$ final states [10]. The preliminary results obtained from a data sample of 20.7 fb$^{-1}$ recorded at the $\Upsilon(4S)$ resonance are $\mathcal{B}(B^+ \rightarrow \eta_c K^+) = (1.50 \pm 0.19 \pm 0.15 \pm 0.46) \times 10^{-3}$ and $\mathcal{B}(B^0 \rightarrow \eta_c K^0) = (1.06 \pm 0.28 \pm 0.11 \pm 0.33) \times 10^{-3}$, where the third error contribution is due to the uncertainty on the value of $\mathcal{B}(\eta_c \rightarrow K K \pi)$, as reported in the PDG [11].

3 Observation of $B^0 \rightarrow D_s^{+} \pi^-$

One of the methods to determine the angle $\gamma$ of the unitarity triangle [12] is the measurement of $\sin(2\beta + \gamma)$ from the time dependent $CP$-asymmetry of the decay $B^0 \rightarrow D^+ \pi^-$. The asymmetry evolution depends on the parameter $\lambda_{D\pi} \equiv A(B^0 \rightarrow D^+ \pi^-)/A(B^0 \rightarrow D^- \pi^+)$ which can be determined from the branching fraction measurement of $B^0 \rightarrow D_s^{+} \pi^-$ through the relation:

$$\mathcal{B}(B^0 \rightarrow D_s^{+} \pi^-) \approx \frac{\mathcal{B}(B^0 \rightarrow D^+ \pi^-)}{\cos^2 \theta_C} \left( \frac{f_{D_s}^2}{f_D^2} \right) |\lambda_{D\pi}|^2.$$  \hspace{1cm} (1)

The above equation is valid in the limit of the tree diagram dominance for $D_s^{+} \pi^-$ and $D^+ \pi^-$ modes.

At BABAR, the decay $B^0 \rightarrow D_s^{+} \pi^-$ is exclusively reconstructed, with the $D_s^+$ decaying in $\phi \pi^+$, $K^{*0} K^+$ or $K_S K^+$ final states. From the analysis of a data sample of 56.4 fb$^{-1}$ recorded at the
Table 2: Preliminary branching fraction measurements of flavor-tagged $D$ meson production in $B^0$ decays. World data values for $D$ meson production in $B$ decays are reported for comparison. Here “$B$” is an admixture of charged and neutral $B$ mesons at the $\Upsilon(4S)$.

<table>
<thead>
<tr>
<th>BABAR Measurements</th>
<th>World Data</th>
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<tbody>
<tr>
<td>Decay Mode</td>
<td>Branching Fraction</td>
</tr>
<tr>
<td>$\bar{B}^0 \to D^0$</td>
<td>$(50.3 \pm 3.0 \pm 3.7)%$</td>
</tr>
<tr>
<td>$\bar{B}^0 \to D^+$</td>
<td>$(32.8 \pm 2.5 \pm 3.5)%$</td>
</tr>
<tr>
<td>$\bar{B}^0 \to D^0 + D^+$</td>
<td>$(83.1 \pm 6.4)%$</td>
</tr>
<tr>
<td>$\bar{B}^0 \to \bar{D}^0$</td>
<td>$(7.6 \pm 1.7 \pm 1.1)%$</td>
</tr>
<tr>
<td>$\bar{B}^0 \to D^-$</td>
<td>$(2.7 \pm 1.2 \pm 0.6)%$</td>
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$\Upsilon(4S)$ resonance, the number of observed signal events is $N_{D_s\pi} = 14.9 \pm 4.1$ with a statistical significance of $3.5\sigma$. The preliminary branching fraction is $B(B^0 \to D_s^+\pi^-) \times B(D_s^+ \to \phi\pi^+) = (1.11 \pm 0.37 \pm 0.24) \times 10^{-6}$. Using the value of $B(D_s^+ \to \phi\pi^+)$ in the PDG, which has a 25% uncertainty, a branching fraction $B(B^0 \to D_s^+\pi^-) = (3.1 \pm 1.0 \pm 1.0) \times 10^{-5}$ is obtained.

4 $D$ meson production in $B^0$ decays

Inclusive branching fractions of charged and neutral $B$ mesons to charmed hadrons will help to solve the longstanding $n_c$ puzzle [14]: the mean number of charm quarks per $B$ decay obtained from direct counting does not agree with theoretical estimates based on branching fraction measurements of semileptonic decays.

The analysis of $D$ meson production in $B^0$ decays at BABAR is based on the exclusive reconstruction of one $B$ meson coming from the decay of the $\Upsilon(4S)$ ($\equiv B_{reco}^0$) in a semileptonic ($D^*l\nu$, with $l = e, \mu$) or hadronic mode ($D^{(*)}\pi^-, D^{(*)}\rho^-, D^{(*)}a_1^-\pi$). The recoil system is then analyzed to search for a neutral (charged) $D$ in the $B^0 \to K\pi\pi$ ($D^\pm \to K\pi\pi\pi$) channel. The inclusive branching fractions $B(B^0 \to D)$ and $B(B^0 \to D^\pm)$ are determined from a fit to the invariant mass distribution of the selected $D$ candidates.

In the inclusive decays $\bar{B}^0 \to D^0$ and $\bar{B}^0 \to D^+$ the charm quark comes directly from the decaying $b$ quark, and the $D$ meson is said to be of “right-sign”. On the contrary, the $D$ meson in the inclusive decays $\bar{B}^0 \to \bar{D}^0$ and $\bar{B}^0 \to D^-$ is said to be of “wrong-sign”. The fraction $w$ of decays with a “wrong-sign” $D$ is determined by comparing the flavor of the $B_{reco}^0$ with that of the $D$, after correcting for the $B$ mixing probability $\chi_d$:

$$\chi_{obs} = \chi_d + w \times (1 - 2\chi_d) .$$

If $\Delta t$ is the time difference between the decays of the two $B$ mesons, events with $|\Delta t| > 2.5\text{ps}$ are discarded. Indeed, they do not contribute significantly to $w$ measurement because $\chi_d(|\Delta t| > 2.5\text{ps}) = 1/2$. The requirement on $|\Delta t|$ increases the sensitivity to $w$, thereby improving the statistical error. It improves also the systematic error since the reduced contribution from the $B$ mixing.
Preliminary measurements of $\mathcal{B}(B^0 \to D)$ and $\mathcal{B}(B^0 \to D^\pm)$ are based on a sample of 30.4 fb$^{-1}$, while the fractions $w$ are determined from a sample of 51.1 fb$^{-1}$, all recorded at the $\Upsilon(4S)$ resonance. These determinations are combined to obtain the first measurements of flavor tagged $D^0$ and $D^\pm$ production in $B^0$ decays. Preliminary results are shown in Table 2. They agree with existing measurements of flavor tagged $D$ meson production in a $\Upsilon(4S)$ environment. The flavor of the spectator quark in the parent $B$ appears to have a negligible effect in the production of “wrong-sign” $D$ mesons. The increase in the central value of the measured branching fractions goes in the direction of a better agreement with theoretical predictions. However, in order to solve the $n_c$ puzzle other inclusive branching fraction measurements are needed.

References