Charmless Hadronic $B$ Decays at BABAR

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Abstract

We present preliminary results of several searches for rare charmless hadronic decays of the $B$ meson using data collected by the BABAR detector at the Stanford Linear Accelerator Center’s PEP-II storage ring. We search for the decays $h^+h^-$, $h^+h^-h^+$, $h^+h^-\pi^0$, $X^0h^+$, and $X^0K^0_S$, where $h = \pi$ or $K$, and $X^0 = \eta'$ or $\omega$. In a sample of 8.8 million $B\bar{B}$ decays we measure the branching fractions: $\mathcal{B}(B^0 \to \pi^+\pi^-) = (9.3^{+2.6+1.2}_{-2.3-1.4}) \times 10^{-6}$, $\mathcal{B}(B^0 \to K^+\pi^-) = (12.5^{+3.0+1.3}_{-2.6-1.7}) \times 10^{-6}$, $\mathcal{B}(B^0 \to \rho^-\pi^+) = (49 \pm 13^{+6}_{-5}) \times 10^{-6}$, and $\mathcal{B}(B^+ \to \eta'K^+) = (62 \pm 18 \pm 8) \times 10^{-6}$. We calculate upper limits for the modes without a significant signal.

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1 Introduction

Charmless hadronic $B$ decays will play an important role in the study of CP violation. Indirect CP violation arises in $B^0 - \bar{B}^0$ mixing due to interference between direct and mixed decays. The CKM angle $\alpha$ can be measured by observing the resulting time-dependent asymmetry in decays to $\pi\pi$ and $\rho\pi$ final states. Direct CP violation results from interference between two or more weak amplitudes and can arise in any decay mode where both tree and penguin contributions are non-negligible. Several modes reported in this paper are “self-tagging”, providing efficient samples for direct CP violation searches. Finally, accurate branching fraction measurements provide important tests of factorization models, which facilitate calculation of $\alpha$ in the presence of significant penguin amplitudes, and can also be used to constrain the CKM angle $\gamma$. [1]

In this paper we summarize preliminary results of searches for the following charmless hadronic $B$ decays: [2]

- $\pi^+\pi^-, K^+\pi^-, K^+K^-$,
- $K^{*0}\pi^+, \rho^0K^+, \rho^0\pi^+, \rho^-\pi^+, K^+\pi^-\pi^+, \pi^+\pi^-\pi^+$,
- $\eta'K^+, \eta'K_{S}^0, \omega h^+, \omega K_{S}^0$,

where charge conjugate modes are assumed throughout. The dataset consists of 8.8 million $B\bar{B}$ decays collected by the BABAR detector [3] at the PEP-II storage ring between January and June 2000.

2 Candidate Selection and Analysis Method

We use only good quality tracks with a minimum transverse momentum of 100 MeV/c in the laboratory (LAB) frame. Charged pions and kaons are identified by their energy loss ($dE/dx$) in the tracking system and the angle $\theta_c$ of Čerenkov photons produced while traversing quartz bars [3]. Neutral kaons are reconstructed in the mode $K_{S}^0 \rightarrow \pi^+\pi^-$, requiring the $K_{S}^0$ flight length to exceed 2 mm and the angle between the flight direction and momentum to be less than 40 mr. Photon candidates are defined as calorimeter energy deposits unassociated with a track and having a shower shape consistent with the photon hypothesis. Candidate $\pi^0$ and $\eta$ mesons are formed from pairs of photons with a minimum LAB energy of 50 MeV. Candidate $\eta'$ mesons are reconstructed in the channel $\eta\pi^+\pi^-$, where the $\eta$ mass is constrained to the world average value. The $\omega$ meson is reconstructed in the dominant decay channel, $\omega \rightarrow \pi^+\pi^-\pi^0$, keeping all candidates within 50 MeV/c² of the known $\omega$ mass. The $\rho$ and $K^*$ resonances are reconstructed in the corresponding $\pi\pi$ and $K\pi$ channels.

We select candidate $B$ mesons based on the energy-substituted mass $m_{ES}$, where $\sqrt{s}/2$ is substituted for the candidate’s energy, and the difference $\Delta E$ between the $B$-candidate energy and $\sqrt{s}/2$. The dominant background for all modes is continuum $q\bar{q}$ production, which exhibits a jet-like structure that distinguishes it from the more spherically symmetric $B\bar{B}$ events. To suppress this background we use the cosine of the angle $\theta_T$ ($\theta_S$) between
the thrust (sphericity) axis of the $B$ candidate and the rest of the event, and the cosine of the angle $\theta_B$ between the candidate’s flight direction and the beam axis. In some cases we include several event-shape variables into a single Fisher discriminant.

## 3 Results for $h^+h^-$ Modes

We select $B^0 \to h^+h^-$ candidates satisfying $5.22 < m_{ES} < 5.3$ GeV/$c^2$ and $|\Delta E| < 0.420$ GeV. No explicit particle identification is required and the pion mass hypothesis is assumed for both tracks. We require $|\cos \theta_S| < 0.9$ and construct a Fisher discriminant $F$ from nine variables describing the momentum flow of charged and neutral particles around the $B$ candidate thrust axis.

Signal yields in all three modes are determined simultaneously from an unbinned maximum likelihood fit incorporating $m_{ES}$, $\Delta E$, $F$, and the measured $\theta_c$ for each track. A sample of $D^*$-tagged $D^0 \to K^+\pi^-$ decays is used to parameterize the $\theta_c$ distributions for pion and kaon tracks as a function of momentum. The $K/\pi$ separation varies from 2 to 8$\sigma$ across the relevant momentum range. All candidates in the region $-0.200 < \Delta E < 0.140$ GeV are included in the fit. We find signal yields of $N(\pi\pi) = 29^{+8}_{-7}$, $N(K\pi) = 38^{+9}_{-8}$, and $N(KK) = 7^{+5}_{-4}$. As a cross-check we perform a cut-based analysis requiring a tighter cut on $\cos \theta_S$ and addi-
tional cuts on $\cos \theta_B$ and $F$. Signal yields are determined by applying particle identification criteria to isolate independent samples of candidates corresponding to each mode and then fitting the $m_{ES}$ distribution in each sample. The results are consistent with the global likelihood fit. Figure 1 shows the global fit likelihood contour curves for the $\pi\pi$ and $K\pi$ modes, and the $m_{ES}$ and $\Delta E$ distributions for the cut-based analysis. The results are summarized in the upper section of Table 1. For the $KK$ mode we calculate the 90% confidence level upper limit. The dominant systematic errors are due to tracking efficiency and the shapes of the $\Delta E$ and $F$ distributions.

4 Results for Three-body Modes

We search for resonant three-body decays by combining a $\rho$ or $K^{*0}$ resonance with a charged pion or kaon. Kaons are required to be positively identified using $dE/dx$ and $\theta_c$ information, while tracks not identified as kaons are assumed to be pions. We veto any combination consistent with the decay $D^0 \rightarrow K^-\pi^+$. The selection criteria consist of optimized cuts on $\cos \theta_T$, resonance mass, and the angle between the resonance daughters and the $B$ candidate momentum calculated in the rest frame of the vector meson. We also explicitly search for non-resonant $K^+\pi^-\pi^+$ and $\pi^+\pi^-\pi^+$ decays by removing all $K\pi$ and $\pi\pi$ combinations with invariant mass less than 2 GeV/$c^2$, and all three-body combinations consistent with the decay $B^+ \rightarrow J/\psi K^+$.

We define a signal region within 6 MeV/$c^2$ of the $B$ mass in $m_{ES}$ and $\pm 70$ MeV in $\Delta E$. The signal yield is determined by direct background subtraction, where the background in the signal region is estimated from the number of events in the region $5.2 < m_{ES} < 5.27$ GeV/$c^2$. This method is cross-checked using off-resonance data. The results are summarized in the middle section of Table 1. The dominant systematic errors are due to tracking efficiency, $\pi^0$ efficiency, and the background subtraction technique.

5 Results for Modes with $\eta'$ or $\omega$

We search for the modes $\eta'K^+$, $\eta'K^0_S$, $\omega h^+$, and $\omega K^0_S$. For $\eta'K$ the kaon is positively identified, while for $\omega h^+$ the charged hadron is assumed to be a pion and the $\Delta E$ signal window is increased ($-0.113 < \Delta E < 0.070$ GeV) to take into account the resulting shift in energy when the mass is mis-assigned. The angle between the decay plane of the $\omega$ daughters and the $B$ direction in the $\omega$ rest frame is used to reduce combinatoric background. We require $|\cos \theta_T| < 0.9$ and optimize with respect to $F$. Signal yields are determined by background subtraction, where the background is determined from off-resonance data. The results are summarized in the lower third of Table 1. The dominant systematic errors are the same as in the three-body analysis.
Table 1: Branching fraction results. Signal yields ($N_S$) for the $h^+h^−$ modes are determined from a likelihood fit, the rest are obtained by a direct background subtraction. Efficiencies ($\epsilon$) include intermediate branching fractions.

<table>
<thead>
<tr>
<th>Mode</th>
<th>$N_S$</th>
<th>Stat. Sig. ($\sigma$)</th>
<th>$\epsilon$ (%)</th>
<th>$B(10^{-6})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0 \rightarrow \pi^+\pi^−$</td>
<td>$29^{+8}_{-7}^{+3}$</td>
<td>$5.7$</td>
<td>$35$</td>
<td>$9.3_{-2.3}^{+2.0}^{+1.4}$</td>
</tr>
<tr>
<td>$B^0 \rightarrow K^+\pi^−$</td>
<td>$38^{+9}_{-8}^{+5}$</td>
<td>$6.7$</td>
<td>$35$</td>
<td>$12.5_{-2.6}^{+3.0}^{+1.3}$</td>
</tr>
<tr>
<td>$B^0 \rightarrow K^+K^−$</td>
<td>$7_{-4}^{+5}$ ($&lt;15$)</td>
<td>$2.1$</td>
<td>$35$</td>
<td>$&lt;6.6$</td>
</tr>
<tr>
<td>$B^+ \rightarrow K^{*0}\pi^+$</td>
<td>$10.2 \pm 4.8$</td>
<td>$2.4$</td>
<td>$10$</td>
<td>$&lt;28$</td>
</tr>
<tr>
<td>$B^+ \rightarrow \rho^K^+$</td>
<td>$10.7 \pm 5.1$</td>
<td>$2.2$</td>
<td>$10$</td>
<td>$&lt;29$</td>
</tr>
<tr>
<td>$B^+ \rightarrow K^+\pi^-\pi^+$</td>
<td>$16.3 \pm 5.8$</td>
<td>$3.2$</td>
<td>$6$</td>
<td>$&lt;54$</td>
</tr>
<tr>
<td>$B^+ \rightarrow \rho\pi^+$</td>
<td>$24.9 \pm 8.2$</td>
<td>$3.3$</td>
<td>$12$</td>
<td>$&lt;39$</td>
</tr>
<tr>
<td>$B^+ \rightarrow \pi^+\pi^-\pi^+$</td>
<td>$5.4 \pm 5.7$</td>
<td>$0.7$</td>
<td>$8$</td>
<td>$&lt;22$</td>
</tr>
<tr>
<td>$B^0 \rightarrow \rho^-\pi^+$</td>
<td>$35.5 \pm 9.8$</td>
<td>$4.5$</td>
<td>$8$</td>
<td>$49 \pm 13_{-5}^{+6}$</td>
</tr>
<tr>
<td>$B^+ \rightarrow \eta K^+$</td>
<td>$12.1 \pm 3.7$</td>
<td>$5.3$</td>
<td>$3$</td>
<td>$62 \pm 18 \pm 8$</td>
</tr>
<tr>
<td>$B^0 \rightarrow \eta K^0$</td>
<td>$1.4 \pm 1.4$</td>
<td>$1.1$</td>
<td>$0.6$</td>
<td>$&lt;112$</td>
</tr>
<tr>
<td>$B^+ \rightarrow \omega h^+$</td>
<td>$5.9 \pm 3.6$</td>
<td>$1.7$</td>
<td>$7.5$</td>
<td>$&lt;24$</td>
</tr>
<tr>
<td>$B^0 \rightarrow \omega K^0$</td>
<td>$-0.8 \pm 0.0$</td>
<td>$0.0$</td>
<td>$2$</td>
<td>$&lt;14$</td>
</tr>
</tbody>
</table>

6 Summary

We have presented preliminary results of searches for several charmless hadronic $B$ decays. Table 1 summarizes the results. In all cases, our results are consistent with recent measurements reported by the CLEO [4] and Belle [5] collaborations at this conference.

Acknowledgments

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References


[2] For more detailed descriptions of these results see: BABAR Collaboration, B. Aubert et al., BABAR-CONF-00/14 and BABAR-CONF-00/15, submitted to the XXXth International Conference on High Energy Physics, Osaka, Japan, July 2000.


[5] B. Casey, “Rare B Decays without Charm from BELLE”, contributed to this conference.