Charmless Hadronic B Decays at *BABAR*[*]

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Abstract

We report recent measurements of branching fractions and charge asymmetries of charmless hadronic B decays using the data collected with the *BABAR* detector at the PEP-II asymmetric energy e^+e^- collider.

Presented at XII International Conference on Hadron Spectroscopy (HADRON07),
Frascati, Italy, 8-13 October 2007.
Submitted to Frascati Physics Series (Proceedings)

1 Introduction

B meson decays to hadronic final states without a charm quark are an important probe of the Standard Model (SM) of particle physics. The so-called charmless decays play a key role in testing the Cabibbo-Kobayashi-Maskawa (CKM) predictions of charge-parity (CP) violation, with sensitivity to the three angles α, β and γ of the Unitarity Triangle. The dominant contributors to this class of B decays are "penguin" decays mediated by $b \to s$ and $b \to d$ process involving a virtual loop with the emission of a gluon and the CKM-suppressed $b \to u$ tree diagram. Due to the presence of an extra strange quark, the first diagram contributes only to final states containing an odd number of kaons; while the latter two result in final states with no, or an even number of, kaons. Penguin decays provide an ideal environment to look for new physics (NP) with possible contributions from non-SM particles in the loop, while the interference between tree and penguin amplitudes (of comparable magnitudes) allows to search for direct CP violation [1]. Furthermore, studies of these decay processes can be used to constrain varieties of theoretical models of B decays based on factorization, perturbative QCD, and SU(3) flavor symmetry.

In these proceedings, we summarize most recent results on charmless hadronic B decays [2] culminating in three-body, quasi-two-body (Q2B), or other multibody final states; studied using e^+e^- collision data collected with the *BABAR* detector [3] near the $\Upsilon(4S)$ resonance. The results should be considered preliminary, unless a journal reference is given.

2 Analysis Method

The challenge in studying charmless hadronic B decays is to extract a small signal (typical branching fraction is of the order of 10^{-6}) out of a sea of background events. The continuum light-quark production, $e^+e^- \to q\bar{q}\,(q = u, d, s, c)$, forms the most dominant background component. It is suppressed by exploiting the difference in event topology - B mesons are produced almost at rest resulting in a spherical event, while the light-quark pairs tend to have a jetlike shape owing to the large available kinetic energy - and by utilizing flavor and decay-time information of B meson candidates. Particle identification plays a crucial role in separating charged pions from kaon track candidates. This becomes particularly important against the background emanating from B decays with similar hadronic final states. Backgrounds from final states with charm quarks are suppressed by invariant-mass vetoes on charmonia and D mesons. The signal yield is extracted by performing an unbinned maximum-likelihood (ML) fit to event-shape variables (usually combined to a Fisher discriminant $\mathcal{F}$ or an artificial Neural Network NN), and kinematic quantities that make use of precise beam-energy information and energy-momentum conservation. The kinematic variables are the difference ΔE between the energy of the reconstructed B candidate and the beam energy (E_{beam}), and the beam-energy substituted mass $m_{\text{ES}} \equiv \sqrt{E_{\text{beam}}^2 - \mathbf{p}_B^2}$, where $\mathbf{p}_B$ is the momentum of the B candidate [here all quantities are calculated in the $\Upsilon(4S)$ rest frame]. Where available, the invariant-mass and angular variables of Q2B resonances are used to further enhance background suppression. For signal modes with a significant yield, the CP violation or charge asymmetry is measured using $A_{CP} = \frac{N_{\overline{B}} - N_B}{N_{\overline{B}} + N_B}$, where $N_{\overline{B}}$

and N_B correspond to the number of $\overline{B}$ ($\overline{B}^0$ or B^-) and B (B^0 or B^+) decays detected in the inclusive yield, respectively.

3 Experimental Results

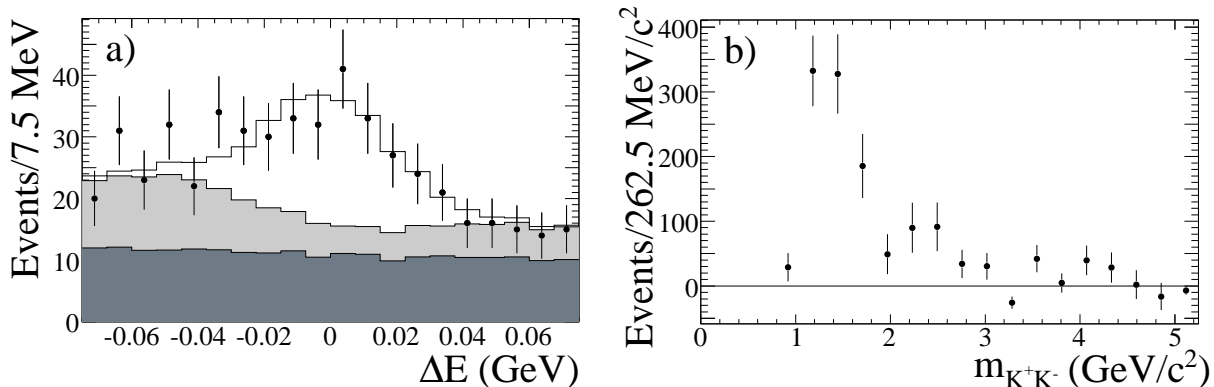## 3.1 Three-body Decay $B^+ \to K^+ K^- \pi^+$

Figure 1: *a) ΔE projection of $B^+ \to K^+ K^- \pi^+$ candidate events and b) Efficiency-corrected $m_{K^+K^-}$ distribution of the $K^+ K^- \pi^+$ signal candidates with $m_{K^+\pi^-} > 1.5\,\mathrm{GeV}/c^2$.*

Using 383 million $B\overline{B}$ pairs recorded by *BABAR*, we report the first observation of charmless hadronic decays of charged B mesons to the final state $K^+ K^- \pi^+$ [4]. We observe in total 429 ± 43 signal events with a significance of 9.6 standard deviation (σ), and measure the inclusive branching fraction [5] $\mathcal{B}(B^+ \to K^+ K^- \pi^+) = [5.0\pm0.5(\mathrm{stat})\pm0.5(\mathrm{syst})]\times10^{-6}$. Figure 1(a) shows the ΔE distribution of selected candidate events, following a signal-enhancing requirement on the likelihood ratio which is formed out of m_{ES} and NN variables. Points show the data, the dark filled histogram shows the $q\overline{q}$ background and the light filled histogram shows the $B\overline{B}$ background. Approximately half of the signal events appear to originate from a broad structure peaking near 1.5 GeV/c^2 in the $K^+ K^-$ invariant mass distribution (see Figure 1(b)). This structure is reminiscent of similar states observed in Dalitz plot analyses of $B^+ \to K^+ K^- K^+$ [6] and $B^0 \to K_S^0 K^+ K^-$ [7], and is likely to be of great interest for the understanding of low energy hadronic bound states [8]. Results on the $K^- \pi^+$ mass spectrum are in reasonable agreement with a dedicated Q2B analysis [9] that has put the most stringent upper limit (UL) on $B^+ \to \overline{K}^{*0}(892)K^+$ and a first UL on $B^+ \to \overline{K}_0^{*0}(1430)K^+$ at 1.1×10^{-6} and 2.2×10^{-6}, respectively (all quoted ULs are computed at 90 % confidence level). The measured charge asymmetry is found to be consistent with zero.

3.2 Vector-Vector Decay $B^0 \to K^{*0}\overline{K}^{*0}$

We report the observation of the $b \to d$ penguin-dominated vector-vector decay $B^0 \to K^{*0}\overline{K}^{*0}$ at $6\,\sigma$ significance [10] with a sample of 383 million $B\overline{B}$ pairs. Figure 2 shows m_{ES}
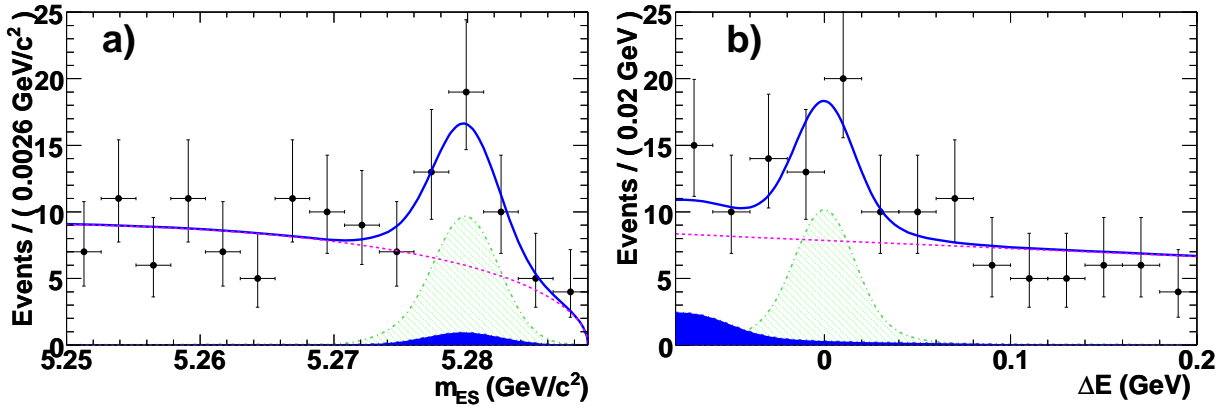
Figure 2: *Projections of a) $m_{\rm ES}$ and b) ΔE of candidate events in the $B^0 \to K^{*0}\overline{K}^{*0}$ decays.*

and ΔE projections of candidate events with a requirement on the signal-to-background likelihood ratio, calculated excluding the plotted variable. Points with error bars show the data, the solid line shows the projection for signal-plus-background, the dashed line is the continuum background, the hatched region is the signal, and the shaded region is the $B\overline{B}$ background. Performing a simultaneous likelihood fit we determine the branching fraction $\mathcal{B}(B^0 \to K^{*0}\overline{K}^{*0}) = [1.28^{+0.35}_{-0.30}(\text{stat}) \pm 0.11(\text{syst})] \times 10^{-6}$, and the fraction of longitudinal polarization $f_L = 0.80^{+0.10}_{-0.12}(\text{stat}) \pm 0.06(\text{syst})$. The branching fraction measurement is consistent with theoretical predictions [11]. The measured f_L value agrees with the model expectation of QCD factorization [12], which predicts it to be ~ 0.9 in the vector-vector decay of a pseudoscalar (B^0 here). We have also improved the existing UL on the SM-suppressed decay $B^0 \to K^{*0}K^{*0}$ by two orders of magnitude to 4.1×10^{-7}.

3.3 Decays involving a Vector and two Pseudoscalars

Using a data sample of 383 million $\Upsilon(4S) \to B\overline{B}$ events, we measure the branching fractions and CP violation asymmetries [13] of hadronic decays $B^0 \to K^{*0}h^+h'^-$, where h and h' refers to either a kaon or a pion. The K^{*0} is detected via its self-tagging decay mode $K^{*0} \to K^+\pi^-$. Table 1 summarizes results of these measurements. We have made three new observations in the final states $K^{*0}K^+K^-$, $K^{*0}\pi^+\pi^-$ and $K^{*0}\pi^+K^-$. In the SM-suppressed decay $B^0 \to K^{*0}K^+\pi^-$, where a branching fraction comparable to or larger than that of the $K^{*0}\pi^+K^-$ mode would be a signature of NP, no signal is observed and a first UL is set at 2.2×10^{-6}. We find no evidence for CP violation in these $B^0 \to K^{*0}h^+h'^-$ decays.

3.4 Axial-vector and Pseudoscalar Modes

We report results of a first search for B meson decays to final states with an axial-vector meson, $b_1(1235)$, and a pseudoscalar meson (pion or kaon), carried out with a data sample containing 382 million $B\overline{B}$ pairs. In the quark model the b_1 is the $I^G = 1^+$ member of the $J^{PC} = 1^{+-}$, $^1P_1$ nonet. Its mass and width are (1229.5 ± 3.2) MeV/c^2 and (142 ± 9) MeV,

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Table 1: *Measured signal yields, branching fractions (B), significance (S) and CP violation asymmetries (for the significant modes) of $B^0 \to K^{*0}(892)h^+h'^-$. The first uncertainty is statistical and the second is systematic.*

$B^0 \to$ Mode	Signal yield	$\mathcal{B}(\times 10^{-6})$	$S(\sigma)$	A_{CP}
$K^{*0}K^+K^-$	984 ± 46	$27.5 \pm 1.3 \pm 2.2$	> 10	$0.01 \pm 0.05 \pm 0.02$
$K^{*0}\pi^+K^-$	183 ± 42.4	$4.6 \pm 1.1 \pm 0.8$	5.3	$0.22 \pm 0.33 \pm 0.20$
$K^{*0}K^+\pi^-$	18.8 ± 29.4	< 2.2	0.9	$-$
$K^{*0}\pi^+\pi^-$	2019 ± 108	$54.5 \pm 2.9 \pm 4.3$	> 10	$0.07 \pm 0.04 \pm 0.03$

respectively, and the dominant decay is to $\omega(782)\pi$ [14]. By performing an extended ML fit to ΔE, m_{ES}, $\mathcal{F}$, and reconstructed invariant masses of the b_1 and ω resonances [15], we find clear signals for $B^+ \to b_1^0\pi^+$, $B^+ \to b_1^0K^+$, $B^0 \to b_1^\mp\pi^\pm$ and $B^0 \to b_1^-K^+$. Table 2 summarizes the signal yield, branching fraction, significance and charge asymmetry of these four decay modes. Measured branching fractions and charge asymmetries agree with QCD factorization predictions [16]. Observations in the $B \to b_1K$ modes, if confirmed with higher precision, would indicate a sizable weak annihilation contribution to these modes [16]. Furthermore, the measurement of an asymmetry parameter, $\Gamma(B^0 \to b_1^+\pi^-)/\Gamma(B^0 \to b_1^-\pi^+) = -0.01\pm0.12$ in the decays $B^0 \to b_1^\mp\pi^\pm$ agrees well with G-parity suppression [17].

Table 2: *Measured signal yields, branching fractions (B), significance (S) and direct CP asymmetries of $B \to b_1(1235)h$ where $h = K/\pi$. The first uncertainty is statistical and the second is systematic.*

Decay mode	Signal yield	$\mathcal{B}(\times 10^{-6})$	$S(\sigma)$	A_{CP}
$B^+ \to b_1^0\pi^+$	178^{+39}_{-37}	$6.7 \pm 1.7 \pm 1.0$	4.0	$0.05 \pm 0.16 \pm 0.02$
$B^+ \to b_1^0K^+$	219^{+38}_{-36}	$9.1 \pm 1.7 \pm 1.0$	5.3	$-0.46 \pm 0.20 \pm 0.02$
$B^0 \to b_1^\mp\pi^\pm$	387^{+41}_{-39}	$10.9 \pm 1.2 \pm 0.9$	8.9	$-0.05 \pm 0.10 \pm 0.02$
$B^0 \to b_1^-K^+$	267^{+33}_{-32}	$7.4 \pm 1.0 \pm 1.0$	6.1	$-0.07 \pm 0.12 \pm 0.02$

Moving on to another axial-vector state $a_1(1260)$, which is the $I^G = 1^-$ state of the $J^{PC} = 1^{++}$, $^3P_1$ nonet, we report evidence of two decay modes containing pions in the final state [18] and two observations in kaon modes [19]. For pion modes the analysis comprises a smaller dataset containing 232 million $B\overline{B}$ pairs, while in kaon modes we have utilized 383 million $\Upsilon(4S) \to B\overline{B}$ events. Here the a_1 meson is reconstructed via its most dominant decay to three pions. Neglecting contributions from isoscalars, such as the σ meson, to the two-pion state; we assume $\mathcal{B}(a_1^\pm(1260) \to \pi^\pm\pi^+\pi^-)$ is equal to $\mathcal{B}(a_1^\pm(1260) \to \pi^\pm\pi^0\pi^0)$ and $\mathcal{B}(a_1^\pm(1260) \to (3\pi)^\pm) = 100\%$. The three-pion decay is also considered as the only possible decay mode for neutral a_1 mesons. These assumptions help in translating the product of $\mathcal{B}(B \to a_1(1260)h)$ and $\mathcal{B}(a_1(1260) \to 3\pi)$ into the former. Table 3 summarizes this branching fraction measurement in the decays $B^+ \to a_1^+\pi^0$, $B^+ \to a_1^0\pi^+$, $B^+ \to a_1^+K^0$ and $B^0 \to a_1^-K^+$ along with the assorted signal yield and significance. Measured branching

fractions are in reasonable agreement with factorization model predictions [20]. In the case of kaon modes, we find no evidence for direct CP violation.

Table 3: *Measured signal yields, branching fractions ($\mathcal{B}$) and significance (S) of $B \to a_1(1260)h$ where $h = K/\pi$. The first uncertainty is statistical and the second is systematic.*

Decay mode	Signal yield	$\mathcal{B}(\times 10^{-6})$	$S(\sigma)$
$B^+ \to a_1^+ \pi^0$	459 ± 78	$26.4 \pm 5.4 \pm 4.1$	4.2
$B^+ \to a_1^0 \pi^+$	382 ± 79	$20.4 \pm 4.7 \pm 3.4$	3.8
$B^+ \to a_1^+ K^0$	241 ± 32	$34.9 \pm 5.0 \pm 4.4$	6.2
$B^0 \to a_1^- K^+$	272 ± 44	$16.3 \pm 2.9 \pm 2.3$	5.1

4   Conclusions

BABAR is pioneering several new measurements in charmless hadronic B decays that probe the SM in two orthogonal directions - the weak interaction by measuring the CKM angles [21], and the strong interaction by exploring low-lying hadronic bound states and by providing precision tests of QCD models. We eagerly look forward to the last run, which together with data taken during the year 2006-2007 and not used in the presented results, would double the dataset. This will be crucial for realizing other rare hadronic decay modes such as $B^+ \to K_S^0 K_S^0 \pi^+$ within our reach.

5   Acknowledgments

References

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