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Charmless hadronic B decays at BABAR

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Abstract. We report recent measurements for the branching fractions of charmless hadronic B decays obtained from data collected by the *BABAR* detector at the PEP-II asymmetric-energy collider at the Stanford Linear Accelerator Center.

1. Introduction

The hadronic decays of B mesons to charmless states provide an excellent tool to probe the standard model of particle physics (SM). Such processes are generally dominated by $b \to u$ tree amplitudes and $b \to s$ or d gluonic penguin amplitudes. The latter involves a virtual loop with the emission of a gluon. The former is suppressed due to the Cabibbo-Kobayashi-Maskawa mechanism [1] and as such penguin amplitudes often play a prominent role. This allows for numerous important studies: loop processes provide an ideal environment to look for new physics by means of a non-SM particle entering the loop, while the interference between amplitudes of comparable magnitudes accommodate *CP* violation studies and phase analyses of the strong and weak interactions. Further, experimental information can be used phenomenologically to test and develop hadronic models with current theories based, in the main, on factorization, perturbative QCD calculations, and SU(3) flavour symmetry (see, for example, [2, 3]). In these proceedings, *BABAR*'s most recent findings in this class of decays—in terms of measured branching fractions—are presented. All results should be taken to be preliminary if not yet published. Charge-conjugate states are assumed throughout.

2. Common analysis techniques

The *BABAR* detector is described in detail elsewhere [4]. The challenge in studying charmless hadronic B decays is to extract a small signal from, relatively, very large numbers of background events. The dominant background is from continuum light quark production, $e^+e^- \to q\overline{q}$ ($q = u$, d, s, c). Discrimination between signal and background is achieved using variables, which make use of the kinematics and topology of the event. For correctly reconstructed signal events, $\Delta E = E_B^* - \sqrt{s}/2$ peaks at zero, while $m_{\rm ES} = \sqrt{(s/2 + \mathbf{p}_0 \cdot \mathbf{p}_B)^2/E_0^2 - \mathbf{p}_B^2}$ peaks at the B mass. In the detector frame, $(E_0, \mathbf{p}_0)$ is the four momentum of the e^+e^- system, while $\mathbf{p}_B$ is the momentum of the B candidate. In the e^+e^- system's centre-of-mass (CM) frame, $\sqrt{s}$ is the total energy of the e^+e^- and E_B^* is the energy of the reconstructed B candidate. In the CM frame, for true B decays, the event shape is isotropic since the $B\overline{B}$ pair is produced almost at rest. This is in contrast to continuum events, which tend to have a jet-like shape due to the available

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kinetic energy. Where appropriate, variables associated with intermediate resonances can be utilised, including the reconstructed invariant mass and angular information. Backgrounds from B decays, although less abundant, are often more difficult to identify and separate from signal events, and must also be accounted for. Selection criteria are applied to the discriminating variables before an unbinned extended maximum likelihood fit is conducted. Unless otherwise stated the analyses presented here use a data sample corresponding to $(382 \pm 4) \times 10^6$ $B\overline{B}$ pairs produced in e^+e^- annihilation.

3. Experimental results

Branching fraction measurements are presented in table 1 and are discussed in the following subsections.

Table 1. Branching fraction measurements for charmless hadronic B decays at *BABAR*. Where quoted, the first uncertainty is statistical, the second is systematic. Measurements for which a significance is not given in brackets can be taken to have a significance that is greater than 9σ. The significances given take into account systematic uncertainties. Where an upper limit is given, this is at the 90% confidence level (CL). The results on the left are first measurements and first or improved upper limits, those on the right are updated measurements.

Mode	$\mathcal{B}$, 10^{-6}	Mode	$\mathcal{B}$, 10^{-6}
$B^+ \to K^+K^-\pi^+$ inclusive	$5.0 \pm 0.5 \pm 0.5$ (9.6σ)	$B^0 \to K^0\pi^0$	$10.3 \pm 0.7 \pm 0.6$
$B^+ \to \overline{K}^{*0}(892)K^+$	< 1.1 (90% CL)	$B^0 \to \pi^0\pi^0$	$1.5 \pm 0.3 \pm 0.1$ (8.3σ)
$B^+ \to \overline{K}^{*0}_0(1430)K^+$	< 2.2 (90% CL)	$B^+ \to \pi^+\pi^0$	$5.0 \pm 0.5 \pm 0.3$
$B^+ \to a_1^+(1260)\pi^0$	$26.4 \pm 5.4 \pm 4.1$ (4.2σ)	$B^+ \to K^+\pi^0$	$13.6 \pm 0.6 \pm 0.7$
$B^+ \to a_1^0(1260)\pi^+$	$20.4 \pm 4.7 \pm 3.4$ (3.8σ)	$B^+ \to \eta\pi^+$	$5.0 \pm 0.5 \pm 0.3$
$B^+ \to b_1^0(1235)\pi^+$	$6.7 \pm 1.7 \pm 1.0$ (4.0σ)	$B^+ \to \eta K^+$	$3.7 \pm 0.4 \pm 0.1$
$B^+ \to b_1^0(1235)K^+$	$9.1 \pm 1.7 \pm 1.0$ (5.3σ)	$B^+ \to \eta'\pi^+$	$3.9 \pm 0.7 \pm 0.3$ (6.6σ)
$B^0 \to b_1^{\mp}(1235)\pi^{\pm}$	$10.9 \pm 1.2 \pm 0.9$ (8.9σ)	$B^+ \to \eta' K^+$	$70.0 \pm 1.5 \pm 2.8$
$B^0 \to b_1^-(1235)K^+$	$7.4 \pm 1.0 \pm 1.0$ (6.1σ)	$B^0 \to \eta' K^0$	$66.6 \pm 2.6 \pm 2.8$
$B^+ \to \eta(1475)K^+$, $\eta(1475) \to \overline{K}^*K$	$13.8 \pm 1.8 \pm 1.0$ (7.5σ)†	$B^+ \to \omega\pi^+$	$6.7 \pm 0.5 \pm 0.4$
$B^+ \to \eta(1405)K^+$, $\eta(1405) \to \overline{K}^*K$	< 1.2 (90% CL)	$B^+ \to \omega K^+$	$6.3 \pm 0.5 \pm 0.3$
$B^+ \to f_1(1420)K^+$, $f_1(1420) \to \overline{K}^*K$	< 4.1 (90% CL)	$B^0 \to \omega K^0$	$5.4 \pm 0.8 \pm 0.3$
$B^+ \to \phi(1680)K^+$, $\phi(1680) \to \overline{K}^*K$	< 3.4 (90% CL)		
$B^+ \to \eta(1295)K^+$, $\eta(1295) \to \eta\pi\pi$	$2.9 \pm 0.8 \pm 0.2$ (3.5σ)		
$B^+ \to \eta(1405)K^+$, $\eta(1405) \to \eta\pi\pi$	< 1.3 (90% CL)		
$B^+ \to f_1(1285)K^+$, $f_1(1285) \to \eta\pi\pi$	< 0.8 (90% CL)		
$B^+ \to f_1(1420)K^+$, $f_1(1420) \to \eta\pi\pi$	< 2.9 (90% CL)		

†: This measurement assumes that the S-wave contributions to the final state are $\eta(1475)K^+$ and phase space $\overline{K}^*KK$ only. See main text.

3.1. $B^+ \to K^+K^-\pi^+$

BABAR reports the first observation of the decay of a charged B meson to a three-body, charmless final state with an even number of kaons [5]. Such decays may proceed by the $b \to d$ penguin transition, or by other processes followed by $s\overline{s}$ production. Inspection of the Dalitz plot of signal candidates shows a broad structure peaking near $1.5\,\mathrm{GeV}/c^2$ in the K^+K^- invariant mass distribution. Similar structures have been observed in the K^+K^- spectrum in [6, 7, 8]. A small excess of signal candidates is also seen at low $K^-\pi^+$ invariant mass. This is reasonably consistent with the results of dedicated quasi-two-body analyses in which improved upper limits have been placed on the branching fractions of $B^+ \to \overline{K}^{*0}(892)K^+$ and $B^+ \to \overline{K}^{*0}_0(1430)K^+$ from a data sample corresponding to $(232 \pm 3) \times 10^6$ $B\overline{B}$ events. The limits are consistent with theoretical predictions and the $\overline{K}^{*0}(892)$ result is useful phenomenologically in studying differences between the measurements of the Unitarity Triangle angle β made using different decay channels [9].

3.2. Axialvector-pseudoscalar modes

Three modes involving the decay of a B meson to a $b_1(1235)$ axialvector meson and a pion or a kaon have been observed for the first time. *BABAR* also reports first evidence for a further such mode, and for two modes where the $b_1(1235)$ is replaced with the $a_1(1260)$ [10, 11]. The results for the a_1 modes are based on a data sample of $(232 \pm 3) \times 10^6$ $B\overline{B}$ events. In the quark model the b_1 is the $I^G = 1^+$ member of the $J^{PC} = 1^{+-}$, ${}^1P_1$ nonet, whereas the a_1 is the $I^G = 1^-$ state in the $J^{PC} = 1^{++}$, ${}^3P_1$ nonet. Theoretical predictions for the branching fractions include those based on naive factorization. For the a_1 modes, the measurements are consistent with these predictions [11]. For the b_1 modes, the predictions depend on the mixing angle between the aforementioned nonets, which is known to within a few degrees but with a two-fold ambiguity about 45°. The $b_1\pi$ measurements favour the lower of these two angles, while the b_1K results are inconclusive in determining a preferred angle indicating a need for theoretical refinement beyond naive factorization [10]. (Very recently calculations based on QCD factorization have been put forward [12] and are in reasonable agreement with the measurements). The measurement of an asymmetry parameter for the decay $B^0 \to b_1^{\mp}(1235)\pi^{\pm}$ implies $\Gamma(B^0 \to b_1^+\pi^-)/\Gamma(B^0 \to b_1^-\pi^+) = -0.01 \pm 0.12$. This is expected in the SM since G-parity suppression predicts a b_1 decay constant of approximately zero. The decays discussed in section 3.2 occur as $b \to u\overline{u}q_d$ tree level and penguin transitions ($q_d = d$ or s). It is thought the $B \to b_1K$ modes also receive a sizable annihilation contribution [12].

3.3. $B^+ \to \eta_X K^+$

The first study of charged B meson decays to a charged kaon and a charmless resonance η_X—with an invariant mass in the range $1.2 - 1.8\,\mathrm{GeV}/c^2$ and which decays to $\overline{K}^*K$ or $\eta\pi\pi$—is presented [13]. The main focus is a search for excited states of η and η' with candidates for such states including $\eta(1295)$, $\eta(1405)$ and $\eta(1475)$. Further resonances to be found in the selected invariant mass spectrum are $f_1(1285)$, $f_1(1420)$ and $\phi(1680)$, which are also considered. An excess of signal-like events is observed in the $\overline{K}^*KK^+$ final state. Taking all of these events to be either $B^+ \to \eta(1475)K^+$ or phase space events translates as a first observation of the $\eta(1475)$ mode, with the substantial rate hinting at new dynamics [14, 15] or an exotic structure of the resonance [16]. Similarly, for the $\eta\pi\pi K^+$ final state, the findings can be interpreted as first evidence for the decay $B^+ \to \eta(1295)K^+$.

3.4. Updated measurements

An important test of hadronic models in the charmless B sector is how they fare when applied to the relatively simple $B \to K\pi$ and $B \to \pi\pi$ systems. However, to interpret any discrepancy between theoretical prediction and experimental observation as physics beyond the SM would be difficult to authenticate. The Lipkin ratio (see Eq. 2 in [17]) is a theoretically robust quantity, which, in the absence of non-SM physics, is expected to be equal to unity at the $1 - 2\%$ level. *BABAR*'s most recent measurements [18, 19] (table 1) yield a value of 1.11 ± 0.07 for this ratio. Also presented are updated measurements for the decays $B \to h_1h_2$ where $h_1 = \eta$, η' or ω, and $h_2 = K^+$, π^+ or K^0 [20].

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