Charmless B decays at $BABAR$

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Abstract. Recent results from the $BABAR$ experiment in charmless B decays are presented, in particular the results of a search for the decays $B^0 \to \omega\omega$ and $B^0 \to \omega\phi$ and preliminary results of a Dalitz-plot analysis of $B^+ \to K_S^0 \pi^+ \pi^0$. The latter includes first evidence for CP violation in the intermediate decay $B^+ \to K^*(892)^+ \pi^0$.

1. Introduction

Charmless hadronic decays of B mesons can typically proceed via two topologies: $b \to u$ tree and $b \to d, s$ loop (or "penguin") diagrams. The amplitudes for these two processes, which have a relative weak phase (equal to the CKM angle γ in the Standard Model (SM)) and may have a similar magnitude, can interfere with one another, potentially giving rise to large CP violation effects. Recent analyses from LHCb of $B^+ \to h^+ h^+ h^-$ decays[1] have observed unexpectedly large CP asymmetries in regions of the Dalitz plots [1, 2, 3]. In addition, the observed CP asymmetries in $B \to K\pi$ decays do not follow the expected behaviour, which is that $\Delta\mathcal{A}_{CP}(K\pi) \equiv \mathcal{A}_{CP}(K^+\pi^0) - \mathcal{A}_{CP}(K^+\pi^-) = 0$. The current world average experimental results are $\mathcal{A}_{CP}(K^+\pi^0) = 0.040 \pm 0.021$ and $\mathcal{A}_{CP}(K^+\pi^-) = -0.082 \pm 0.006$ [4], leading to a value $\Delta\mathcal{A}_{CP}(K\pi) = 0.122 \pm 0.022$, which is significantly different from zero. It has been pointed out (e.g. in Ref. [5]) that additional information can be obtained from $B \to K^*\pi$ and $B \to \rho K$ decays, giving incentive to improve the experimental precision on the asymmetry measurements in these modes. In the $K^*\pi$ system, the least well measured decay is $B^+ \to K^*(892)^+\pi^0$, where the only existing measurement comes from a $BABAR$ analysis of $B^+ \to K^+\pi^0\pi^0$ [6]: $\mathcal{A}_{CP}(K^*(892)^+\pi^0) = -0.06 \pm 0.24$.

Another puzzle from charmless B decays is the lower than expected longitudinal polarisation fraction in $B \to \phi K^*$ decays [7, 8, 9]. It is not clear if the large transverse component arises from SM contributions or beyond-SM effects. The study of other vector-vector decay modes is therefore strongly motivated. In particular, constraints on the SM contributions can be made using information on the branching fractions of $B^0 \to \omega\omega$ and $B^0 \to \omega\phi$ [10].

Both analyses described here use the full $BABAR$ dataset collected at the $\Upsilon(4S)$ resonance. It corresponds to an integrated luminosity of $429\,\text{fb}^{-1}$ and contains 470.9 ± 2.8 million $B\bar{B}$ events.

2. First evidence for $B^0 \to \omega\omega$ and search for $B^0 \to \omega\phi$

The SM expectations for the branching fractions of the decays $B^0 \to \omega\omega$ and $B^0 \to \omega\phi$ are of order 10^{-6} and 10^{-7}, respectively. The existing experimental limits come from a previous

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[1] The inclusion of charge conjugate processes is implied throughout, except in definitions of CP asymmetries.

BABAR analysis [11] that used approximately half the data sample used here. Measurements of the mixing-induced CP asymmetry and the longitudinal polarisation fraction made in these loop-dominated decays will be sensitive to possible new physics contributions. The ω (ϕ) candidates are reconstructed in their decay to $\pi^+\pi^-\pi^0$ (K^+K^-), with their invariant masses required to be in the range $740 < m_{\pi^+\pi^-\pi^0} < 820\,\text{MeV}/c^2$ ($1009 < m_{K^+K^-} < 1029\,\text{MeV}/c^2$). Backgrounds are considered from both continuum light-quark production and from B decays.

A maximum likelihood fit is used to separate signal from background and to obtain the signal yields. The likelihood fit is performed to following variables: the beam energy substituted mass of the B candidate (m_{ES}), the difference between the beam energy and that of the reconstructed B candidate (ΔE), a Fisher discriminant of topological variables, the invariant mass and helicity angle of each ω and ϕ resonance, and the "internal" helicity angle of the ω resonance (defined as the polar angle of the π^0 with respect to the ω flight direction in the $\pi^+\pi^-$ rest frame). More details of the analysis can be found in Ref. [12].

The results of the fit can be seen in Figure 1 and the fitted yields of the two decays are found to be 69^{+16}_{-15} for $B^0 \to \omega\omega$ and $-2.9^{+5.7}_{-4.0}$ for $B^0 \to \omega\phi$, where the quoted uncertainties are statistical only. The significance of the $B^0 \to \omega\omega$ signal is determined to be 4.4σ (including systematic uncertainties) and the branching fraction is calculated to be $(1.2 \pm 0.3\,[\text{stat.}]\,{}^{+0.3}_{-0.2}\,[\text{syst.}]) \times 10^{-6}$. The upper limit on the $B^0 \to \omega\phi$ branching fraction is determined to be 0.7×10^{-6} at 90% confidence level. The largest sources of systematic uncertainty arise form the uncertainty on the longitudinal polarisation fraction (which is assumed to be 0.88 in the nominal fit and then varied between 0.58 and 1.0 to determine the systematic uncertainty) and from possible fit bias.
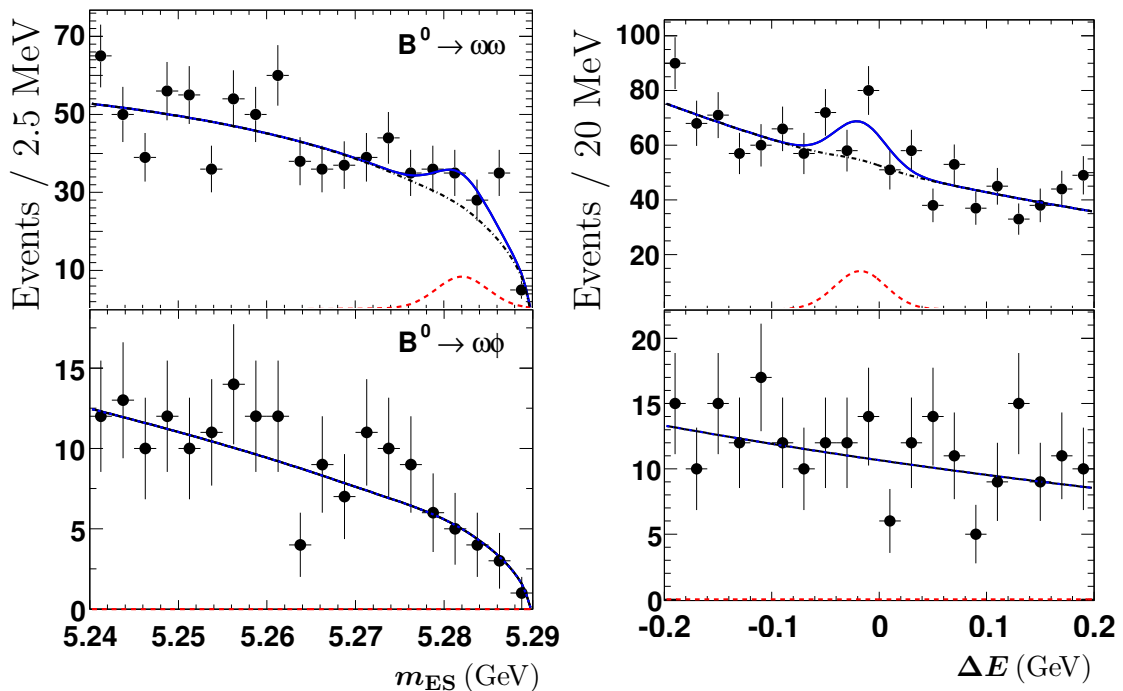
Figure 1. Projections of the fit results on the (left) m_{ES} and (right) ΔE variables, for (top) $B^0 \to \omega\omega$ and (bottom) $B^0 \to \omega\phi$ decays. The points are the data, the solid curve is the total fit, the dashed curve is the signal, and the dot-dashed curve is the background.

3. Amplitude analysis of $B^+ \to K_S^0 \pi^+ \pi^0$

The only previous measurement of the inclusive branching fraction of $B^+ \to K_S^0 \pi^+ \pi^0$ is an upper limit from CLEO: $\mathrm{BF}(B^+ \to K^0 \pi^+ \pi^0) < 66 \times 10^{-6}$ [13]. However, the intermediate decay mode $B^+ \to \rho(770)^+ K_S^0$ has been observed by the *BABAR* collaboration and its branching fraction measured to be $\mathrm{BF}(B^+ \to \rho(770)^+ K^0) = (8.0^{+1.4}_{-1.3} \pm 0.6) \times 10^{-6}$ [14]. The other expected intermediate decays $B^+ \to K^*(892)^+ \pi^0$ and $B^+ \to K^*(892)^0 \pi^+$ have both been observed, although not in their decays to this final state. In addition to providing measurements of the branching fractions and CP asymmetries of the $K^{*+}\pi^0$, $K^{*0}\pi^+$ and $\rho^+ K_S^0$ intermediate states, a Dalitz-plot analysis of $B^+ \to K_S^0 \pi^+ \pi^0$ will measure the relative phases of these various components. Of particular interest are the relative phases of the two $K^*\pi$ components, which can be used to determine the CKM angle γ [15, 16].

The K_S^0 candidates are reconstructed in their decay to $\pi^+ \pi^-$ and are required to have an invariant mass within $15\,\mathrm{MeV}/c^2$ of the known K_S^0 mass. The π^0 candidates are are required to be in the invariant mass range $110 < m_{\gamma\gamma} < 160\,\mathrm{MeV}/c^2$. The largest backgrounds from B decays contain D^0 mesons that subsequently decay to $K_S^0 \pi^0$. These are removed with a veto on the $K_S^0 \pi^0$ invariant mass: $1804 < m_{K_S^0 \pi^0} < 1924\,\mathrm{MeV}/c^2$. Approximately 32,000 candidates remain after all selection criteria are applied.

A maximum likelihood fit is performed to the variables m_{ES}, ΔE, the output of a Boosted Decision Tree (BDT) of topological variables and the Dalitz plot (DP). Since the kinematic variables, m_{ES} and ΔE, are strongly correlated with the Dalitz-plot position for signal events, the signal probability density functions are parametrised as a function of the DP position. The fitted signal yield is 1014 ± 63, where the uncertainty is statistical only.

The signal Dalitz-plot model follows the isobar model formalism, where the total amplitude is formed from the sum of the amplitudes for the various intermediate states

$$\overset{(-)}{A} = \sum_i \overset{(-)}{A_i} = \sum_i \overset{(-)}{c_i} F_i(m^2_{K_S^0 \pi^+}, m^2_{\pi^+ \pi^0})\,, \tag{1}$$

where the F_i describe the dependence of the amplitude on the Dalitz-plot position (e.g., a Breit–Wigner function) and the c_i are the complex coefficients that are determined from the fit. However, since only relative amplitudes can be determined, one component ($K^*(892)^0 \pi^+$ in the nominal fit) is fixed to be real and to have unit magnitude. Quantities such as the branching fractions, CP asymmetries and relative phases are derived from these fitted coefficients. The signal model includes contributions from both the charged and neutral $K^*(892)$ resonances plus the corresponding $K\pi$ S-wave as well as the $\rho(770)^+$ resonance. The $K\pi$ S-wave is modelled using the LASS parametrisation [17], which consists of the sum of the $K_0^*(1430)$ resonance and an effective-range nonresonant term. No other nonresonant contributions were found to be needed to give a satisfactory fit to the data.

The preliminary results for the branching fractions, CP asymmetries and relative phases are given in Table 1. The CP asymmetry of $B^+ \to K^*(892)^+ \pi^0$ has a very large, negative central value (-52%) and is found to have a significance of 3.4σ, corresponding to first evidence of CP violation in this decay. The projection of the fit onto the $K_S^0 \pi^+$ invariant mass can be seen in Figure 2, separated by the charge of the B candidate, where the asymmetry in the $K^*(892)^+$ region can be clearly seen. The uncertainty on this quantity is much improved but is still large with respect to $K^{*+}\pi^-$ and as such still dominates the uncertainty on the updated value of $\Delta \mathcal{A}_{CP}(K^*\pi) = -0.16 \pm 0.14$. An analysis of this decay mode by the Belle experiment would help to further improve this uncertainty. A journal paper describing the *BABAR* analysis and its results in detail is in preparation.
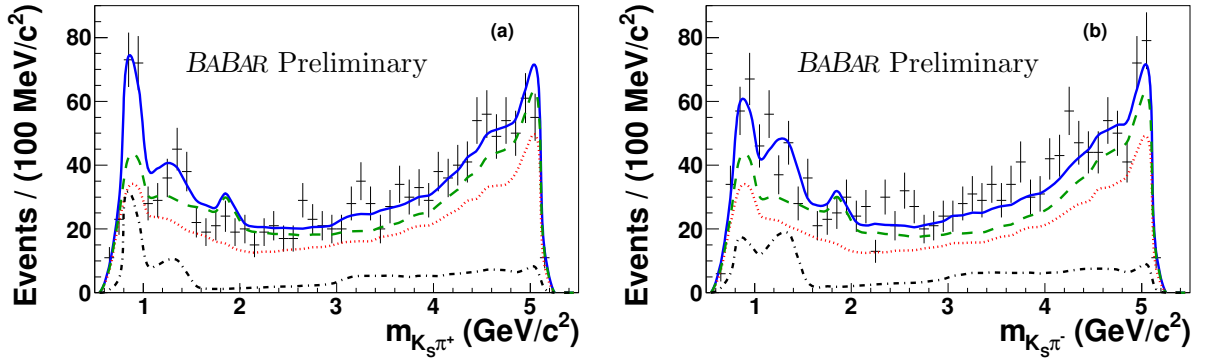
Figure 2. Data distributions of $m_{K_S^0 \pi^+}$ and the corresponding fit projections for (a) B^+, and (b) B^- candidates. Points with error bars are the data, the solid (blue) lines are the total fit result, the dashed (green) lines are the total background contribution, and the dotted (red) lines are the $q\bar{q}$ component. The dash-dotted lines represent the signal contribution. The signal to background ratio has been increased by applying a tighter selection on m_{ES}, ΔE, and BDT.

Table 1. Measured CP-averaged branching fractions (BF), CP asymmetries ($\mathcal{A}_{CP}$), and CP-averaged phases measured relative to the $K^*(892)^0 \pi^+$ reference amplitude. The first uncertainty is statistical, the second is systematic, and the third is due to the signal Dalitz-plot model.

Isobar	BF $(\times 10^{-6})$	$\mathcal{A}_{CP}$	ϕ (°)
$K^0 \pi^+ \pi^0$	$45.9 \pm 2.6 \pm 3.0 \pm 8.6$	$0.07 \pm 0.05 \pm 0.03 \pm 0.04$	–
$K^*(892)^0 \pi^+$	$14.6 \pm 2.4 \pm 1.3 \pm 0.5$	$-0.12 \pm 0.21 \pm 0.08 \pm 0.11$	–
$K^*(892)^+ \pi^0$	$9.2 \pm 1.3 \pm 0.6 \pm 0.5$	$-0.52 \pm 0.14 \pm 0.04 \pm 0.04$	$-95 \pm 43^{+48}_{-36} \pm 70$
$K_0^*(1430)^0 \pi^+$	$50.0 \pm 4.8 \pm 6.0 \pm 4.0$	$0.14 \pm 0.10 \pm 0.04 \pm 0.14$	$174 \pm 11 \pm 11 \pm 6$
$K_0^*(1430)^+ \pi^0$	$17.2 \pm 2.4 \pm 1.5 \pm 1.8$	$0.26 \pm 0.12 \pm 0.08 \pm 0.12$	$-89 \pm 43^{+53}_{-40} \pm 18$
$\rho(770)^+ K^0$	$9.4 \pm 1.6 \pm 1.0 \pm 2.6$	$0.21 \pm 0.19 \pm 0.07 \pm 0.30$	$-122 \pm 43^{+55}_{-47} \pm 68$

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