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Study of multi-body charmless B decays with the *BABAR* experiment

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Abstract

We report recent measurements of charmless B decays to the final states $K^+K^+K^-$, $\phi\phi K$, $\eta'\eta' K$, $K^0_S K^0_S K^0_L$, $\bar{\Lambda} p \pi^+$, $K^{*+}h^+h^-$ and KX(inclusive). The results were obtained using a data sample of up to $288.5\,\text{fb}^{-1}$ recorded by the *BABAR* detector at the PEP-II asymmetric B factory at SLAC.

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1 Introduction

The properties of the weak interaction, the complex quark couplings described in the Cabibbo-Kobayashi-Maskawa matrix elements[1], as well as models of hadronic decays can all be studied through the decays of B mesons to charmless final states. Theoretical predictions using various hadronic decay models exist for the branching fractions and CP asymmetries of many of these decays. Making precise measurements of these quantities in as many modes as possible can help to discriminate among the models. Measurement of the interference among the decay modes, using a Dalitz-plot analysis technique[2], can provide information on the weak and strong phases. Studies of decays involving "pengiun" loop diagrams are also a window on possible new physics since virtual non Standard Model particles can appear in the loop. In particular the study of time-dependent CP asymmetries in $b \to s$ penguin decays has recently been providing a hint of deviation from the Standard Model expectation[3]. We present here recent results of several multibody charmless B decay studies from the BABAR Collaboration. All results are preliminary if not yet published. Throughout this paper, for any given mode, the corresponding charge-conjugate mode is also implied.

2 Common analysis techniques

The BABAR detector is described in detail elsewhere[4]. The dominant backgrounds in almost all charmless analyses are from continuum light quark pair production. Event shape variables are used to discriminate against such backgrounds. Events from true B decays are isotropic in nature since in the centre of mass frame the B mesons are produced almost at rest, while continuum events have jet-like structure. In most analyses there are also backgrounds from other B decays present.

Further discrimination can be obtained through the use of two kinematic variables. The first is $\Delta E = E^*_B - \sqrt{s}/2$, the difference between the reconstructed center-of-mass (CM) energy of the B-meson candidate and $\sqrt{s}/2$, half the total CM energy. The second is the energy-substituted mass $m_{\rm ES} = \sqrt{(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 - \mathbf{p}_B^2}$, where $\mathbf{p}_B$ is the B momentum and $(E_i, \mathbf{p}_i)$ is the four-momentum of the initial state.

3 Dalitz-plot analysis of $B^+ \to K^+K^+K^-$

This is the first Dalitz-plot analysis of this mode from BABAR and is fully documented in Ref. [5]. It involves a binned maximum likelihood fit to the Dalitz plot and to $m_{\rm ES}$. Figure 1 shows the Dalitz plot of the data events from the $m_{\rm ES}$ signal region. The axes are s_{23} and s_{13}, which are the squares of the invariant masses of the two K^+K^- combinations, ordered such that $s_{23} \leq s_{13}$.

Table 1: Magnitudes, phases, fit fractions, two-body branching fractions, CP asymmetries, symmetric 90% confidence level CP asymmetry intervals, and the phase differences between the two charges for the individual components of the isobar model fit.

Comp.	ρ	ϕ (rad)	F (%)	$F \times \mathcal{B}(B^+ \to K^+K^+K^-)$	A	$(A_{\rm min}, A_{\rm max})_{90\%}$	$\delta\phi$ (rad)
$\phi(1020)$	1.66 ± 0.06	$2.99 \pm 0.20 \pm 0.06$	$11.8 \pm 0.9 \pm 0.8$	$(4.14 \pm 0.32 \pm 0.33)\times10^{-6}$	$0.00 \pm 0.08 \pm 0.02$	$(-0.14, 0.14)$	$-0.67 \pm 0.28 \pm 0.05$
$f_0(980)$	5.2 ± 1.0	$0.48 \pm 0.16 \pm 0.08$	$19 \pm 7 \pm 4$	$(6.5 \pm 2.5 \pm 1.6)\times10^{-6}$	$-0.31 \pm 0.25 \pm 0.08$	$(-0.72, 0.12)$	$-0.20 \pm 0.16 \pm 0.04$
$X_0(1550)$	8.2 ± 1.1	$1.29 \pm 0.10 \pm 0.04$	$121 \pm 19 \pm 6$	$(4.3 \pm 0.6 \pm 0.3)\times10^{-5}$	$-0.04 \pm 0.07 \pm 0.02$	$(-0.17, 0.09)$	$0.02 \pm 0.15 \pm 0.05$
$f_0(1710)$	1.22 ± 0.34	$-0.59 \pm 0.25 \pm 0.11$	$4.8 \pm 2.7 \pm 0.8$	$(1.7 \pm 1.0 \pm 0.3)\times10^{-6}$	$0.0 \pm 0.5 \pm 0.1$	$(-0.66, 0.74)$	$-0.07 \pm 0.38 \pm 0.08$
χ_{c0}	0.437 ± 0.039	$-1.02 \pm 0.23 \pm 0.10$	$3.1 \pm 0.6 \pm 0.2$	$(1.10 \pm 0.20 \pm 0.09)\times10^{-6}$	$0.19 \pm 0.18 \pm 0.05$	$(-0.09, 0.47)$	$0.7 \pm 0.5 \pm 0.2$
NR	13.2 ± 1.4	0	$141 \pm 16 \pm 9$	$(5.0 \pm 0.6 \pm 0.4)\times10^{-5}$	$0.02 \pm 0.08 \pm 0.04$	$(-0.14, 0.18)$	0

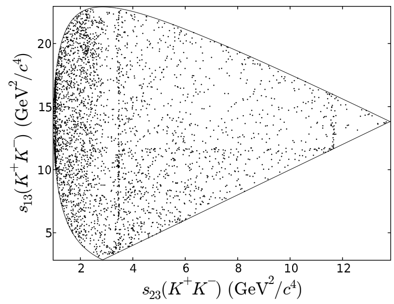

Figure 1: The Dalitz plot of the 1769 $B^+ \to K^+K^+K^-$ and 1730 charge conjugate candidates.

The Dalitz plot signal model is an isobar model[6, 7] consisting of six different contributions: $\phi(1020)$, $f_0(980)$, $f_0(1710)$, χ_{c0} and two broad scalar components. The first is a nonresonant component which has a dependence on the K^+K^- mass of the form $e^{-\alpha s_{23}} + e^{-\alpha s_{13}}$ where α is a shape parameter floated in fit. The second is a resonance dubbed $X_0(1550)$, whose mass and width are floated in the fit. This component is included in an attempt to fit an observed enhancement in the $m_{K^+K^-}$ spectrum and follows the treatment used by the Belle Collaboration in their similar analysis[8].

The total branching fraction is measured to be $\mathcal{B}(B^+ \to K^+K^+K^-) = (35.2 \pm 0.9 \pm 1.6) \times 10^{-6}$. The total charge asymmetry is consistent with zero: $A_{CP} = (-1.7 \pm 2.6 \pm 1.5)\%$. The results of the Dalitz-plot fit are shown in Table 1.

4 Search for $B \to \phi\phi K$

Evidence for $B^+ \to \phi\phi K^+$ has already been reported by the Belle collaboration[9] but there is no measurement of the neutral mode. The analysis is performed in the region $m_{\phi\phi} < 2.85\,\mathrm{GeV}/c^2$ in order to avoid the region dominated by the η_c resonance. Full details are given in Ref. [10].

In the charged mode 64 ± 9 signal events are observed, corresponding to a partial branching fraction of $\mathcal{B}(B^+ \to \phi\phi K^+) = (7.5 \pm 1.0 \pm 0.7) \times 10^{-6}$. The $m_{\phi\phi}$ distribution shows no evidence of glueball production. In the neutral mode $10.0^{+4.1}_{-3.4}$ signal events are observed, with a significance of 4.2σ, corresponding to a partial branching fraction of $\mathcal{B}(B^0 \to \phi\phi K^0) = (4.1^{+1.7}_{-1.4} \pm 0.4) \times 10^{-6}$. This analysis provides the first observation of the charged mode and first evidence of the neutral mode.

5 Search for $B \to \eta'\eta' K$

Neither the charged nor neutral modes have been studied before. The neutral mode could potentially be interesting for CP violation studies since it is both a $b \to s$ penguin and a definite CP eigenstate[11]. It also provides an additional handle to understand the large charmless $B \to \eta' X_s$ branching fraction, see Ref. [12] and references therein. The analysis is fully documented in Ref. [13].

Unfortunately no significant signal is observed in either the neutral or charged decay mode. In the neutral mode the measured branching fraction is $\mathcal{B}(B^0 \to \eta'\eta' K^0) = (5^{+14}_{-9} \pm 1) \times 10^{-6}$, which corresponds to a 90% confidence level upper limit of $< 31 \times 10^{-6}$. In the charged mode the measured branching fraction is $\mathcal{B}(B^+ \to \eta'\eta' K^+) = (11^{+9}_{-7} \pm 1) \times 10^{-6}$, which corresponds to a 90%

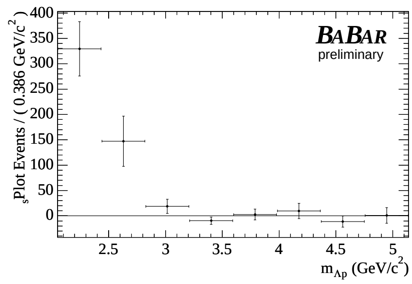

Figure 2: Efficiency corrected ${}_s\mathcal{P}lot$ of $m_{\bar{\Lambda}p}$ distribution for signal events.

confidence level upper limit of $< 25 \times 10^{-6}$. The very small signal in the neutral mode means that it will not be useful for *CP* violation studies without the statistics of a Super B Factory.

6 Search for $B^0 \to K^0_S K^0_S K^0_L$

Another potential mode for expanding the study of time-dependent *CP* violation in $b \to s$ penguin decays is $B^0 \to K^0_S K^0_S K^0_L$. This mode is also a purely $b \to s\bar{s}s$ transition and consequently has smaller theoretical uncertainty than many other modes[14]. Branching fraction predictions for this mode include $(5.23^{+2.52}_{-1.96}{}^{+6.86}_{-2.53}{}^{+0.05}_{-0.06}) \times 10^{-6}$ and 2×10^{-6} in Ref. [15]. This analysis is fully documented in Ref. [16]. The reconstruction of the K^0_L and vertexing three neutral particles make this a very challenging analysis. The ϕ region of the Dalitz plot is excluded in this anaysis.

The observed signal yield is $23^{+23}_{-22} \pm 6$. Assuming a uniform distribution of signal events in the Dalitz plot this corresponds to a branching fraction of $\mathcal{B}(B^0 \to K^0_S K^0_S K^0_L) = (2.4^{+2.7}_{-2.5} \pm 0.6) \times 10^{-6}$. Since there is not a significant signal observed a 90% confidence level upper limit is calculated of $< 7.4 \times 10^{-6}$ and hence this mode is of limited use for *CP* violation studies at the current level of statistics.

7 Study of $B^0 \to \bar{\Lambda} p \pi^+$

Two common features of three-body baryonic B decays that have been reported recently by both the *BABAR* and Belle collaborations [17, 18] are that the baryon-antibaryon invariant mass spectrum exhibits a strong peaking towards threshold and that these decays have branching fractions larger than predictions. Theorists have seized upon the former as a possible explanation for the latter[19, 20]. The analysis is fully documented in Ref. [21] and makes extensive use of the ${}_s\mathcal{P}lots$ technique[22] in order to correctly account for the efficiency variation over the Dalitz plot. The branching fraction result is $\mathcal{B}(B^0 \to \bar{\Lambda} p \pi^+) = (3.30 \pm 0.53 \pm 0.31) \times 10^{-6}$, which is compatible with the previous measurement by Belle[17]. The efficiency corrected ${}_s\mathcal{P}lot$ of the baryon-antibaryon mass spectrum is shown in Fig. 2 and clearly exhibits strong threshold enhancement.

8 Study of $B^+ \to K^{*+} h^+ h^-$

This analysis, documented in Ref. [23], is the first study of these four inclusive decay modes since the ARGUS collaboration[24] in 1991. Branching fraction and asymmetry measurements of these inclusive modes are also useful for estimating possible interferences in the exclusive decays such as

$B^+ \to K^{*+}\phi$ and $B^+ \to K^{*+}\rho^0$. In this analysis the K^{*+} is reconstructed in its decay to $K^0_S\pi^+$. The ${}_s\mathcal{P}lots$ technique is again used to correctly account for the variation in signal efficiency over the Dalitz plot in the measurement of the branching fractions and asymmetries.

The branching fraction results are as follows: $\mathcal{B}(B^+ \to K^{*+}\pi^+\pi^-) = (75.3 \pm 6.0 \pm 8.1) \times 10^{-6}$, $\mathcal{B}(B^+ \to K^{*+}K^+\pi^-) < 6.2 \times 10^{-6}$, $\mathcal{B}(B^+ \to K^{*+}\pi^+K^-) < 11.8 \times 10^{-6}$ and $\mathcal{B}(B^+ \to K^{*+}K^+K^-) = (36.2 \pm 3.3 \pm 3.6) \times 10^{-6}$. The asymmetry measurements are both consistent with zero: $A_{CP}(B^+ \to K^{*+}\pi^+\pi^-) = (7 \pm 7 \pm 4)\%$, $A_{CP}(B^+ \to K^{*+}K^+K^-) = (11 \pm 8 \pm 3)\%$.

9 Search for inclusive $B \to KX$ decays

This inclusive analysis of $B \to KX$ decays, fully documented in Ref. [25], is the first use of the recoil analysis technique in a charmless hadronic B decay. In a recoil analysis one B is fully reconstructed in a decay to a D or D^* meson plus a number of pions and/or kaons. The tracks and neutrals not associated with this fully reconstructed B are then analysed in an attempt to find the signature of a signal decay. This method leads to a very high signal purity since continuum background is dramatically reduced, however there is a cost in terms of the signal efficiency.

In this analysis the signal signature is a K^+ or K^0_S candidate with a momentum in the B rest frame of $p^*(K) > 2.34\,\mathrm{GeV}/c$. This momentum requirement is used to eliminate $b \to c$ events. A maximum likelihood fit is then performed using m_{ES}, ΔE and $p^*(K)$. The partial branching fraction results are: $\mathcal{B}(B \to K^+X) = (196^{+37}_{-34}\,^{+31}_{-30})\times 10^{-6}$ $\mathcal{B}(B \to K^0X) = (154^{+55}_{-48}\,^{+55}_{-41})\times 10^{-6} (< 266\times 10^{-6})$

10 Summary

Several recent measurements from *BABAR* of charmless multi-body B decays have been presented in a wide variety of modes. With the greatly increasing statistics and more sophisticated analysis techniques (e.g. Dalitz plot and recoil) being applied the area of charmless B decays looks to have a very rich future.

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