SLAC-PUB-13429
BABAR-PROC-08/097
hep-ex/0810.1067
October 2008

# Charmless Two-Body and Quasi-Two-Body $B$-decays at BABAR

Ingrid Ofte
*SLAC, 2575 Sand Hill Road, Menlo Park, CA 94025, USA*
*Representing the BABAR Collaboration*

We present improved measurements of the branching fractions and $CP$ asymmetries in the two-body decays $B^0 \to \pi^0\pi^0$, $B^0 \to K^0\pi^0$ and $B^0 \to K^+\pi^-$ as well as the quasi two-body $B^0 \to K_1(1270)^+\pi^-$ and $B^0 \to K_1(1400)^+\pi^-$ decays. These updated measurements are made using the complete set of BABAR data taken at the Υ(4S) resonance, collected between 1999 and 2007 at the PEP-II collider at SLAC.

## 1. INTRODUCTION

$B$-mesons decaying into charmless hadronic final states are rare events. The leading tree diagrams are CKM suppressed and loop (penguin) diagrams typically contribute at comparable magnitude. Decay rates and $CP$ asymmetries may deviate from Standard Model expectations if yet-unknown heavy particles contribute in the loop. The abundance of related decays allows for multiple independent measurements of CKM matrix parameters and $CP$ violation.

Direct $CP$ asymmetry occurs when the magnitude squared of a decay amplitude differs from that of its $CP$ conjugate process, $|A(\bar{B} \to \bar{f})|^2 \neq |A(B \to f)|^2$. Experimentally, we measure $A_{CP}$ in terms of different yield of one process compared to that of the $CP$ conjugate process. We expect non-zero $A_{CP}$ if two or more amplitudes of comparable size contribute with different weak ($\phi$) and strong ($\delta$) phases, e.g. in the $B \to K\pi$ decay, where we have similar-sized contributions from tree and penguin amplitudes. The direct $CP$ asymmetry is given by $A_{CP} = 2\sin\phi\sin\delta/(|T/P| + |P/T| + 2\cos\phi\cos\delta)$. Theoretically, the amplitudes ratio $|T/P|$ and phase $\delta$ are extremely difficult to compute, as these quantities involve long-distance effects.

The hadronic uncertainties cancel to some extent in appropriately constructed ratios. Sum rules [1] based on isospin and flavor SU(3) symmetries relate decay rates and asymmetries in different final states and can make precision tests possible in spite of the hadronic uncertainties.

In these proceedings we present preliminary results from the analysis of four charmless $B^0$ decay modes to two-body or quasi two-body final states using data from the BABAR [2] detector. The analyses are described in detail in [3, 4].

## 2. ANALYSIS TECHNIQUE

We use 467 million $\Upsilon(4S)$ decays collected between 1999 and 2007, which amounts to about 22% more $B\overline{B}$ pairs than used previously. Improvements in track reconstruction have further increased the efficiency of our analyses and thereby improved the statistical significance. For some of the decay modes, additional sensitivity is obtained from improved analysis techniques.

Charmless two-body and quasi two-body decays of $B$ mesons typically have high reconstruction efficiency and large $q\bar{q}$ backgrounds. To reduce this background we make use of event-shape variables. At the PEP-II collider, the $B$-mesons are produced almost at rest in the center-of-mass (CM) frame, and their decay products are isotropically distributed. Backgrounds from $e^+e^- \to q\bar{q}$ events, on the other hand, are produced with larger momenta and have a more jet-like event structure. To distinguish these from signal $B$ decays, we use one or more of the following

Work supported in part by US Department of Energy contract DE-AC02-76SF00515



Presented at the 34th International Conference on High Energy Physics, 7/29/2008 to 8/5/2008, Philadelphia, PA, USA

observables, all evaluated in the CM frame: the sums $L_0 \equiv \sum_i |\mathbf{p}_i^*|$ and $L_2 \equiv \sum_i |\mathbf{p}_i^*| \cos^2\theta_i^*$, where $\mathbf{p}_i^*$ are the momenta and $\theta_i^*$ are the angles with respect to the thrust axis [5] of the $B$ candidate, of all tracks and clusters not used to reconstruct the signal $B$-meson candidate; $|\cos\theta_S^*|$, where $\theta_S^*$ is the angle between the sphericity axes [6] of the $B$ candidate's decay products and that of the remaining tracks and neutral clusters in the event; $|\cos\theta_B^*|$, where $\theta_B^*$ is the angle between momentum vector of the signal $B$ and the beam axis; and $|\cos\theta_T^*|$, where $\theta_T^*$ is the angle between the thrust axis of the signal $B$-meson's daughters and the beam axis.

Correctly reconstructed $B$ decays are selected based on their kinematic signatures exploiting the fact that each of the $B$ mesons have half of the precisely-known beam energy. Most commonly we use the energy substituted mass, $m_{\rm ES} = \sqrt{(E_{\rm beam}^{\rm CM})^2 - (p_B^{\rm CM})^2}$ and the energy difference, $\Delta E = E_B - \sqrt{s}/2$, where $\sqrt{s}$ is the total CM energy. In the case of $B^0 \to K_S^0\pi^0$, we instead use a kinematic constraint. We define $m_{\rm miss} = |\sqrt{s} - \hat{q}_B|$, where $\hat{q}_B$ is the four-momentum of the reconstructed $B^0$ after a $B^0$ mass constraint has been applied. Also used is $m_B$, the invariant mass of the signal $B$.

In the modes where the $B^0$ decays into a *CP* eigenstate, $B^0_{CP}$, we rely on a multivariate technique [7] to determine the flavor of the other $B$, $B_{\rm tag}$. Finally, we extract the signal yield and *CP* asymmetries via an extended unbinned maximum likelihood (ML) fit to the kinematic and event-shape variables.

## 3. RESULTS

### 3.1. Branching fraction of $B^0 \to K^0\pi^0$

We reconstruct $K_S^0 \to \pi^+\pi^-$ and $\pi^0 \to \gamma\gamma$ and measure the branching fraction via a ML fit to $m_{\rm miss}$, $m_B$, $L_2/L_0$ and $\cos\theta_B^*$, as well as $\Delta t$, the proper time difference between the decay of the signal $B$ and that of the other $B$ in the event, to enable extraction of *CP* asymmetry [8, 9]. The fit extracts a yield of $556 \pm 32$ signal events. With a selection efficiency $\varepsilon = (34.2 \pm 1.2)\%$, this translates into a branching fraction measurement $\mathcal{B}(B^0 \to K^0\pi^0) = (10.1 \pm 0.6 \pm 0.4) \times 10^{-6}$, in agreement with, and superseding, *BABAR*'s previous result [10].

Sum rules assuming flavor SU(3) symmetry [1] can be used to make a prediction based on the other, more precisely measured, $K\pi$ final states: $2\Gamma(B^0 \to K^0\pi^0) + 2\Gamma(B^+ \to K^+\pi^0) = \Gamma(B^+ \to K^0\pi^+) + \Gamma(B^0 \to K^+\pi^-)$. Using this formula, we obtain the prediction $\mathcal{B}(B^0 \to K^0\pi^0)^{\rm Sum\ rule} = (8.4 \pm 0.8) \times 10^{-6}$. Our measurement is in reasonable agreement with this prediction within experimental uncertainties.

### 3.2. Direct *CP* asymmetry in $B^0 \to K^+\pi^-$

This decay is a self-tagging mode and the *CP* asymmetry is apparent from the different decay rates of $B^0 \to K^+\pi^-$ and $\overline{B^0} \to K^-\pi^+$. We reconstruct the $B$-meson from two oppositely charged tracks that are both assumed to be pions for the purpose of calculating $\Delta E$. The signal $\pi\pi$ and $K\pi$ yields are extracted from a ML fit to the kinematic variables $m_{\rm ES}$ and $\Delta E$, a $\mathcal{F}$isher discriminant based on $L_2$ and $L_0$, and $\Delta t$ and $B$ flavor tagging in order to extract the time-dependent *CP* parameters for $\pi^+\pi^-$ (see [11]). In addition, particle-identification observables (the Cherenkov angle $\Theta_C$ in the DIRC [12] and ionization-energy loss $dE/dx$ in the main tracking detector) are used to separate $K$ tracks from $\pi$ tracks. The $\Delta E$ distribution is offset from zero for $K\pi$ events, seen in figure 1, which further aids in distinguishing the $\pi\pi$ and $K\pi$ events. The different rates for $B^0$ and $\overline{B^0}$ is apparent from the figure and we measure $A_{K^+\pi^-} = -0.107 \pm 0.016^{+0.006}_{-0.004}$ with $6.1\sigma$ significance, in agreement with and superseding our previous result [13].

### 3.3. Branching fraction and time-integrated *CP* asymmetry in $B^0 \to \pi^0\pi^0$

The decay $B^0 \to \pi^0\pi^0$ is useful for the extraction of the CKM angle $\alpha$ from an isospin analysis of the $B \to \pi\pi$ system [15]. Combined with the other two $B \to \pi\pi$ modes, the rates and *CP* asymmetries can determine $|\Delta\alpha| = |\alpha - \alpha_{\rm eff}|$ with a four-fold ambiguity. This evaluation has been presented in [11].


Presented at the 34th International Conference on High Energy Physics, 7/29/2008 to 8/5/2008, Philadelphia, PA, USA

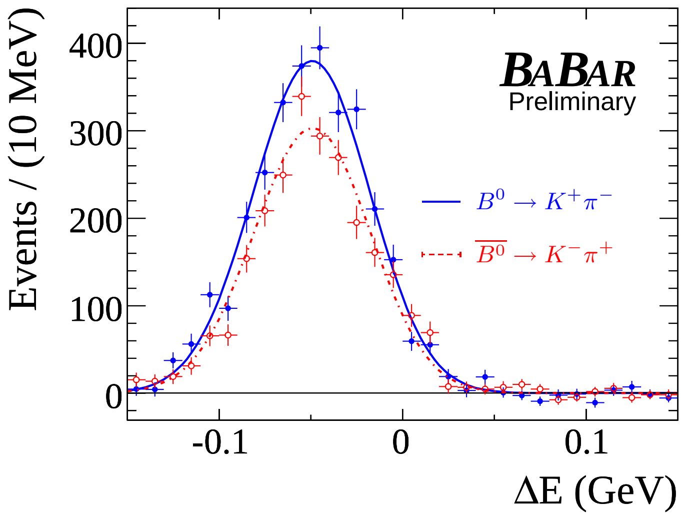


Figure 1: $s\mathcal{P}$lot [14] of $\Delta E$ for $K^{\pm}\pi^{\mp}$ events. The different decay rates for $B^0 \to K^+\pi^-$ and $\overline{B^0} \to K^-\pi^+$ are apparent.

We reconstruct the $B^0$ from a pair of $\pi^0$ candidates. $\pi^0 \to \gamma\gamma$ are formed from pairs of clusters in the EMC that are isolated from any charged tracks. For this mode, we also use $\pi^0$ candidates from a single EMC cluster containing two adjacent photons (a merged $\pi^0$), or one cluster and two tracks from a photon conversion to an $e^+e^-$ pair inside the detectors. The yield and time-integrated *CP* asymmetry is obtained from a ML fit to the kinematic variables $m_{\rm ES}$ and $\Delta E$, as well as the output of a neural network based on event-shape variables. The use of a neural network has improved the statistical sensitivity compared to the previous result. The time-integrated *CP* asymmetry is measured by the $B$-flavor tagging algorithm.

We use an improved background model for the ML fit, where we allow the background shape parameter to be linearly dependent on the neural network output observable. With this, we obtain a better fit to the data than in our previous measurement [16]. We observe $N_{\pi^0\pi^0} = 247 \pm 29$, with an efficiency $\varepsilon = (28.8 \pm 1.8)\%$. This results in the branching fraction measurement $\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.83 \pm 0.21 \pm 0.13) \times 10^{-6}$. We also obtain the time-integrated *CP* asymmetry measurement $A_{CP} = -C_{\pi^0\pi^0} = 0.43 \pm 0.26 \pm 0.05$.

### 3.4. Branching fraction of $B^0 \to K_1(1270)^+\pi^-$ and $K_1(1400)^+\pi^-$

There has been interest recently in $B$-meson decays to an axial vector and a pseudoscalar meson. Experiments have found relatively large branching fractions and more measurements are needed to improve our understanding of these decays. These $B^0$ decays are also of interest to the measurement of the CKM angle $\alpha$. A measurement of $\alpha_{\rm eff}$ can be obtained from $B^0(\overline{B}^0) \to a_1(1260)^{\pm}\pi^{\mp}$ [17]. Using SU(3) flavor-symmetry [18], theoretical bounds can be set on the difference $\Delta\alpha = \alpha - \alpha_{\rm eff}$ by relating $B^0(\overline{B}^0) \to a_1^{\pm}\pi^{\mp}$ with $\Delta S = 1$ decays: $B \to a_1 K$ and $B \to K_{1A}\pi$, where $K_{1A}$ is a mixture of $K_1(1270)$ and $K_1(1400)$.

$K_1(1270)^+$ and $K_1(1400)^+$ are wide, overlapping axial mesons. Both are reconstructed through their decays to $K^+\pi^+\pi^-$ final state. $B$ mesons are reconstructed from $B^0 \to K_1(1270)^+\pi^-$ and $K_1(1400)^+\pi^-$ in 454 million $B\overline{B}$ pairs. This year's updated analysis uses an improved signal model [19] to describe the production of $K_1(1270)$ and $K_1(1400)$, including interference effects. The decay is described in terms of two real production parameters $(\theta, \phi)$, related to the relative amplitude and phase between $K_1(1270)^+$ and $K_1(1400)^+$. We do a likelihood scan with respect to these two variables. For each likelihood point, we perform a ML fit. At the minimum $-ln\mathcal{L}$, we obtain a combined branching fraction $\mathcal{B}(B^0 \to K_1(1270)^+\pi^- + K_1(1400)^+\pi^-) = (31.0 \pm 2.7 \pm 6.9) \times 10^{-6}$. We evaluate a significance of $5.1\sigma$. We also set limits on the ratio of the production constants for the $K_1(1270)^+$ and $K_1(1400)^+$ mesons in $B^0$ decays: $0.25 < \theta < 1.32$ and $-0.51 < \phi < 4.51$ at 95% probability. This is the first attempt in $B$-decay data to measure the relative phase between $K_1(1270)$ and $K_1(1400)$.

## 4. CONCLUSION

We present preliminary results on several charmless two-body and quasi two-body decays of neutral $B$-mesons based on the complete *BABAR* data sample. We have three improved branching-fraction measurements: $\mathcal{B}(B^0 \to K^0\pi^0) = (10.1 \pm 0.6 \pm 0.4) \times 10^{-6}$, $\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.83 \pm 0.21 \pm 0.13) \times 10^{-6}$ and $\mathcal{B}(B^0 \to K_1(1270)^+\pi^- + K_1(1400)^+\pi^-) = (31.0 \pm 2.7 \pm 6.9) \times 10^{-6}$. We have also two updated measurements of direct $CP$ asymmetry: $A_{\pi^0\pi^0} = -C_{\pi^0\pi^0} = 0.43 \pm 0.26 \pm 0.05$ and $A_{K^+\pi^-} = -0.107 \pm 0.016^{+0.006}_{-0.004}$. We have also made the first attempt to measure the relative production phase between $K_1(1270)$ and $K_1(1400)$ in the decays of $B$-mesons.

## Acknowledgments

I would like to thank the organizers of ICHEP 2008 for an interesting conference, and my *BABAR* and PEP-II collaborators for their contributions. This work was partially supported by U.S. Department of Energy and National Science Foundation.

## References

[1] H. J. Lipkin, Phys. Lett. B **445**, 403 (1999)
M. Gronau and J. L. Rosner, Phys. Rev. D **59**, 113002 (1999)
[2] B. Aubert *et al.* [*BABAR* Collaboration], Nucl. Instrum. Methods Phys. Res. A **479**, 1 (2002).
[3] B. Aubert *et al.* [*BABAR* Collaboration], arXiv:0807.4226 [hep-ex].
[4] B. Aubert *et al.* [*BABAR* Collaboration], arXiv:0807.4760 [hep-ex].
[5] S. Brandt *et al.*, Phys. Lett. **12**, 57 (1964); E. Farhi, Phys. Rev. Lett. **39**, 1587 (1977).
[6] J. D. Bjorken and S. J. Brodsky, Phys. Rev. D **1**, 1416 (1970).
[7] B. Aubert *et al.* [*BABAR* Collaboration], Phys. Rev. Lett. **94**, 161803 (2005).
[8] B. Aubert *et al.* [*BABAR* Collaboration], arXiv:0809.1174 [hep-ex].
[9] J. F. Hirschauer, these proceedings.
[10] B. Aubert *et al.* [*BABAR* Collaboration], Phys. Rev. D **77**, 012003 (2008)
[11] A. Gritsan, these proceedings.
[12] I. Adam *et al.* [*BABAR*-DIRC Collaboration], Nucl. Instrum. Meth. A **538**, 281 (2005).
[13] B. Aubert *et al.* [*BABAR* Collaboration], Phys. Rev. Lett. **99**, 021603 (2007).
[14] M. Pivk and F. R. Le Diberder, Nucl. Instrum. Methods Phys. Res., Sect. A **555**, 356 (2005).
[15] M. Gronau and D. London, Phys. Rev. Lett. **65**, 3381 (1990).
[16] B. Aubert *et al.* [*BABAR* Collaboration], Phys. Rev. D **76**, 091102 (2007).
[17] B. Aubert *et al.* [*BABAR* Collaboration], Phys. Rev. Lett. **98**, 181803 (2007)
[18] M. Gronau and J. Zupan, Phys. Rev. D 73, 057502 (2007)
[19] C. Daum *et al.* [ACCMOR Collaboration], Nucl. Phys. B **187**, 1 (1981).



Presented at the 34th International Conference on High Energy Physics, 7/29/2008 to 8/5/2008, Philadelphia, PA, USA