International Journal of Modern Physics A

Branching fraction and direct *CP* violating asymmetries in charmless twobody *B* decays at *BABAR*

Wouter D. Hulsbergen
University of Maryland, College Park, MD 20742, USA

Received (Day Month Year)
Revised (Day Month Year)

We present preliminary measurements of branching fractions and direct CP violating asymmetries in charmless twobody B decays, obtained with the *BABAR* detector using a sample of $227\,\mathrm{M}\ \Upsilon(4S) \to B\overline{B}$ decays. We report the first observation of $B^0 \to K^0\overline{K}^0$ and the first observation of direct CP violation in $B^0 \to K^+\pi^-$ decays.

The decays of B mesons into charmless twobody final states ($B \to \pi\pi, K\pi, KK$) provide important information for the study of heavy quark decays and CP violation. Depending on the final state the leading contributions to the decay amplitude can be both from tree and penguin topologies. The observed pattern of branching fractions, spanning over approximately two orders of magnitude, has revealed that penguin contributions are appreciable, leading to the expectation that some of these decays exhibit large direct CP violation effects.

In neutral B decays to final states that are accessible to both B^0 and $\overline{B}^0$, CP violation can occur through mixing and is observed as a decay-time dependent rate asymmetry. Measurements of time-dependent CP violation in the charmless twobody decays $B^0 \to \pi^+\pi^-$[1] and $B^0 \to K^0_S\pi^0$ are reported in talks by N. Danielson and F. Blanc at this conference. Here, we concentrate on CP violation in charged B decays ($B^+ \to \pi^+\pi^0, K^+\pi^0, K^0\pi^+, K^+K^0$) and decays of neutral B mesons to final states which 'tag' the flavor of the b quark ($B^0 \to K^+\pi^-$). Using the unitarity of the CKM matrix, the decay amplitude of $B \to f$ can be written as the sum of exactly two amplitudes A_1^f and A_2^f with different weak phases. The decay rate asymmetry due to direct CP violation takes the form

$$\mathcal{A}_f^{CP} \equiv \frac{N(\overline{B} \to \bar{f}) - N(B \to f)}{N(\overline{B} \to \bar{f}) + N(B \to f)} = \frac{2\,\sin\Delta\phi_w^f\,\sin\Delta\phi_s^f}{|A_1^f/A_2^f| + |A_2^f/A_1^f| + 2\cos\Delta\phi_w^f\cos\Delta\phi_s^f}, \quad (1)$$

where $\Delta\phi_s^f$ is the difference between the CP conserving ('strong') phases in A_1^f and A_2^f and $\Delta\phi_w^f$ is the weak phase difference. The asymmetry is non-zero if both phase differences are non-zero and if the amplitudes are of comparable magnitude. In the Standard Model one expects a sizable asymmetry $|\mathcal{A}^{CP}| \sim 0.1$ in $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$, but a small asymmetry $|\mathcal{A}^{CP}| < 0.01$ in $B^+ \to K^0\pi^+$ and $B^+ \to \pi^+\pi^0$.

The measurements reported here are based on a sample of 227 million $B\overline{B}$ decays, corresponding to an integrated luminosity of $\sim 205\,\mathrm{fb}^{-1}$, collected at the PEP-II asymmetric $e^+e^- \to \Upsilon(4S)$ B-factory at SLAC. The *BABAR* detector is described elsewhere.[2] B candidates are identified through two nearly independent kinematic observables, namely their reconstructed center-of-momentum (CMS) energy and their beam energy-substituted mass, $m_{\mathrm{ES}} = \sqrt{\frac{1}{4}s - p_B^{*2}}$, where p_B^* is the reconstructed CMS momentum. Event topology is used to suppress the large background from $e^+e^- \to q\overline{q}$ ($q \in u, d, s$) events. To separate decays to charged pions from those to charged kaons we use the measured Cherenkov cone angle. Yields and asymmetries are extracted with a maximum likelihood fit to these kinematic, event shape and particle id observables. Analysis details can be found in the references.[3,4,5,6]

Table 1. Measured event yields in $205\,\mathrm{fb}^{-1}$, branching fractions and decay rate asymmetries. For $\mathcal{B}$ and $\mathcal{A}^{CP}$, the first uncertainty is statistical and the second systematic. The $\mathcal{B}$ measurements marked with an asterisk were performed on $81\,\mathrm{fb}^{-1}$.

mode	events/205 fb^{-1}	$\mathcal{B} \times 10^6$	$\mathcal{A}^{CP}$	Ref.
$\pi^+\pi^-$	467 ± 33	$4.7 \pm 0.6 \pm 0.2^*$	–	3, 7
$\pi^0\pi^0$	61 ± 17	$1.2 \pm 0.3 \pm 0.1$	–	4
$\pi^+\pi^0$	379 ± 41	$5.8 \pm 0.6 \pm 0.4$	$0.01 \pm 0.10 \pm 0.02$	4
$K^+\pi^-$	1606 ± 51	$17.9 \pm 0.9 \pm 0.7^*$	$-0.133 \pm 0.030 \pm 0.009$	3, 7
$K^+\pi^0$	672 ± 39	$12.0 \pm 0.7 \pm 0.6$	$0.06 \pm 0.06 \pm 0.01$	4
$K^0\pi^0$	300 ± 23	$11.4 \pm 0.9 \pm 0.6$	–	5
$K^0\pi^+$	743 ± 36	$26.0 \pm 1.3 \pm 1.0$	$-0.087 \pm 0.046 \pm 0.010$	6
K^+K^-	3 ± 12	$< 0.6^*$	–	3, 7
K^0K^+	41 ± 14	$1.45^{+0.53}_{-0.47} \pm 0.12$	$0.15^{+0.33}_{-0.35} \pm 0.03$	6
$K^0\overline{K}^0$	23 ± 7	$1.19^{+0.40}_{-0.35} \pm 0.13$	–	6

Table 1 shows the measured event yields, branching fractions and decay rate asymmetries. All results are preliminary, except for those from Ref. 3, 7. The result for $B^0 \to K^0\overline{K}^0$ has a significance of 4.5 σ, including systematic uncertainty, and establishes the first observation of this rare decay. Figure 1a shows the corresponding background subtracted m_{ES} distribution. Background subtraction was performed using the s-Plot technique.[8]

The asymmetry in $B^0 \to K^+\pi^-$ constitutes the first observation of direct CP violation in the B system, with a significance of 3.9 σ including the systematic uncertainty. Figure 1b shows the observed m_{ES} distribution for a signal enhanced sample of $B^0 \to K^+\pi^-$ and $\overline{B}^0 \to K^-\pi^+$ decays. There is a clear asymmetry in the signal region ($m_{\mathrm{ES}} \gtrsim 5.27\,\mathrm{GeV}/c^2$, figure 1c), while the asymmetry in the background, $\mathcal{A}_{\mathrm{bkg}} = 0.001 \pm 0.008$, is fully consistent with zero.

To extract information on the weak phases from the observed asymmetries one exploits isospin and $SU(3)$ symmetries to relate the decay amplitudes of different modes and eliminate the strong phases and the relative magnitudes of the amplitudes.[9] The reliability of these techniques depends on the accurateness of the applied symmetries. As an example, consider the Lipkin sum rule which is a

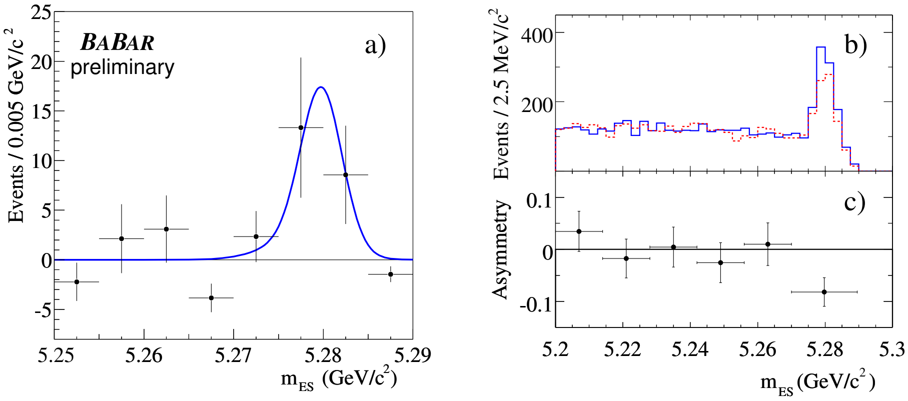

Fig. 1. (a) Background subtracted $m_{\rm ES}$ distribution for $B^0 \to K^0_S K^0_S$. (b) $m_{\rm ES}$ distribution for a signal enhanced sample of $B^0 \to K^+\pi^-$ (solid histogram) and $\overline{B}^0 \to K^-\pi^+$ (dashed histogram) decays and (c) corresponding asymmetry.

consequence of isospin symmetry,

$$R_L \equiv \frac{2\Gamma(B^+ \to K^+\pi^0) + 2\Gamma(B^0 \to K^0\pi^0)}{\Gamma(B^+ \to K^0\pi^+) + \Gamma(B^0 \to K^+\pi^-)} = 1 + O\left(\frac{P_{\rm EW} + T}{P}\right)^2, \qquad (2)$$

where the magnitudes of the tree $T \sim \lambda^4$ and electroweak penguin $P_{\rm EW} \sim \lambda^2$ amplitudes are expected to be small in comparison with the penguin amplitude $P \sim \lambda^2$. The *BABAR* measurements yield $R_L = 1.07 \pm 0.08$, in perfect agreement with the expectation.

In summary, we have presented branching fractions and direct *CP* violating asymmetries for charmless twobody B decays, including the observation of $B^0 \to K^0\overline{K}^0$ and the observation of direct CP violation in $B^0 \to K^+\pi^-$. These results are important input for collaborations working on the extraction of parameters of the CKM matrix.[9]

References

1. Unless explicitly stated, conjugate decay modes are assumed throughout this paper.
2. B. Aubert *et al.* [*BABAR* Collaboration] , Nucl. Instr. Methods Phys. Res., Sect. A **479**, 1 (2002).
3. B. Aubert *et al.* [BaBar Collaboration], Phys. Rev. Lett. **93**, 131801 (2004).
4. B. Aubert *et.al.* [BABAR Collaboration], hep-ex/0408081.
5. B. Aubert *et al.* [BABAR Collaboration], hep-ex/0408062.
6. B. Aubert *et.al.* [BABAR Collaboration], hep-ex/0408080.
7. B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **89**, 281802 (2002).
8. M. Pivk and F. R. Le Diberder, physics/0402083.
9. See for example A. J. Buras, R. Fleischer, S. Recksiegel and F. Schwab, Nucl. Phys. B **697**, 133 (2004); J. Charles *et al.* [CKMfitter Collaboration],hep-ph/0406184; M. Bona *et al.* [UTfit Collaboration], hep-ph/0408079.
10. H. J. Lipkin, hep-ph/9809347; M. Gronau and J. L. Rosner, Phys. Rev. D **59**, 113002 (1999).