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Charmless Quasi-Two-Body Modes at BABAR*

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Abstract

We present results for measurements of B^0 meson decays to charmless final states ηK^0, $\eta\omega$, $a_1^+(1260)\pi^-$ with $a_1^+(1260) \to \pi^+\pi^+\pi^-$, $\rho^0 K_S^0$, $K_S^0 K_S^0 K_S^0$, and of B^+ to $\eta\rho^+$ and $\eta'\pi^+$. Analyses are based on data taken with the *BABAR* detector at the PEP-II asymmetric-energy B factory at SLAC. We measure the following branching fractions in units of 10^{-6}: $\mathcal{B}(B^0 \to \eta\omega) = 1.2 \pm 0.6 \pm 0.2$ (< 2.1, 90% C.L.), $\mathcal{B}(B^0 \to \eta K^0) = 2.5 \pm 0.8 \pm 0.1$, $\mathcal{B}(B^+ \to \eta\rho^+) = 8.6 \pm 2.2 \pm 1.1$, $\mathcal{B}(B^+ \to \eta'\pi^+) = 4.2 \pm 1.0 \pm 0.5$, $\mathcal{B}(B^0 \to a_1^+(1260)\pi^-) = 42.6 \pm 4.2 \pm 4.1$, $\mathcal{B}(B^0 \to \rho^0 K^0) = 5.1 \pm 1.0 \pm 1.2$, and $\mathcal{B}(B^0 \to K_S^0 K_S^0 K_S^0) = 6.5 \pm 0.8 \pm 0.8$. The charge asymmetries are $\mathcal{A}_{ch}(\mathcal{B}(B^+ \to \eta\rho^+)) = (7 \pm 19 \pm 2)\%$ and $\mathcal{A}_{ch}(\mathcal{B}(B^+ \to \eta'\pi^+)) = (24 \pm 19 \pm 1)\%$. First error is statistical, the second systematic. All results are preliminary.

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1 Introduction

We report results for measurements of B^0 meson decays to charmless quasi-two-body final states [1] ηK^0, $\eta\omega$, $a_1^+(1260)\pi^-$, $\rho^0 K_S^0$, and of B^+ to $\eta\rho^+$ and $\eta'\pi^+$. We present also measurement of B^0 decay to $K_S^0 K_S^0 K_S^0$. The above-mentioned decay modes with an η on η' in the final state have not been observed definitely [2, 3, 4]. No experimental measurements exist of B^0 decays to $a_1^+(1260)\pi^-$ and $\rho^0 K_S^0$.

All the final states studied here are rare decays which are expected to be dominated by $b \to u$ CKM-suppressed tree amplitudes or by $b \to s$ loop ("penguin") amplitudes. We can test and constrain theoretical models using branching fraction measurements of rare decays. Theoretical approaches include analyses in the framework of flavor SU(3) [5, 6], effective Hamiltonians with factorization and specific B-to-light meson form factors [7], perturbative QCD [8], and QCD factorization [9].

We search for direct *CP* violation by measuring the charge asymmetry $\mathcal{A}_{ch} \equiv (\Gamma^- - \Gamma^+)/(\Gamma^- + \Gamma^+)$ in the rates $\Gamma^\pm = \Gamma(B^\pm \to f^\pm)$, for each observed charged final state $f^\pm$. Such direct *CP* violation measurements are sensitive to "New Physics" beyond the Standard Model (SM) due to possible new particles appearing in additional penguin diagrams.

More details on the analyses presented in this paper can be found elsewhere [10].

2 Data and Analysis Description

The results presented here are based on data collected by *BABAR* detector [11] at the PEP-II asymmetric-energy e^+e^- collider located at the Stanford Linear Accelerator Center.

A B-meson candidate is characterized kinematically by the energy-substituted mass $m_{ES} = \sqrt{(\frac{1}{2}s + \mathbf{p}_0 \cdot \mathbf{p}_B)^2/E_0^2 - \mathbf{p}_B^2}$ and energy difference $\Delta E = E_B^* - \frac{1}{2}\sqrt{s}$, where the subscripts 0 and B refer to the initial $\Upsilon(4S)$ and to the B candidate, respectively, and the asterisk denotes the $\Upsilon(4S)$ frame.

Background arises primarily from random combinations in continuum $e^+e^- \to q\bar{q}$ events ($q = u, d, s, c$). We reject this background with requirements on kinematical variables of resonance daughters and on event-shape variables. In the fit we also use another event-shape variable , a Fisher discriminant $\mathcal{F}$, constructed with the angles with respect to the beam axis of the B momentum and B thrust axis (in the $\Upsilon(4S)$ frame), and the zeroth and second angular moments $L_{0,2}$ of the energy flow about the B thrust axis.

Signal yields are extracted using an unbinned, multivariate maximum-likelihood fit. The likelihood function incorporates m_{ES}, ΔE, $\mathcal{F}$, and other kinematical variables depending on the decay mode.

3 Measurement of the Branching Fraction for the Decay $\mathcal{B}(B^0 \to \eta K^0)$

The branching fraction of the decay mode $B^0 \to \eta K^0$ has been remeasured using a sample of 182 million $B\overline{B}$ pairs [10]. The results of this new measurement are shown in Table 1. The

Table 1: Signal yield Y, detection efficiency ϵ, daughter branching fraction product, significance S (with systematic uncertainties included), measured branching fraction, signal ($\mathcal{A}_{ch}$) charge asymmetry for each mode.

Mode	Y	ϵ (%)	$\prod \mathcal{B}_i$ (%)	S σ	$\mathcal{B}$ (10^{-6})	$\mathcal{A}_{ch}$ (%)
$\eta_{\gamma\gamma}K^0$	19^{+8}_{-7}	29	14	3.7	$2.7^{+1.1}_{-1.0}$	
$\eta_{3\pi}K^0$	6^{+5}_{-4}	22	8	2.1	$1.8^{+1.6}_{-1.1}$	
$\boldsymbol{\eta K^0}$				**4.2**	$\mathbf{2.5 \pm 0.8 \pm 0.1}$	
$\eta_{\gamma\gamma}\omega$	12^{+7}_{-6}	13	35	2.4	$1.4^{+0.7}_{-0.6}$	
$\eta_{3\pi}\omega$	-1^{+7}_{-5}	13	20	0.0	$-0.2^{+1.4}_{-1.0}$	
$\boldsymbol{\eta\omega}$				**2.2**	$\mathbf{1.2 \pm 0.6 \pm 0.2}$	
$\eta_{\gamma\gamma}\rho^+$	110^{+31}_{-29}	16	39	3.2	$8.1^{+2.9}_{-2.7}$	20 ± 23
$\eta_{3\pi}\rho^+$	53^{+19}_{-17}	11	23	2.8	$9.7^{+4.3}_{-3.9}$	-18 ± 32
$\boldsymbol{\eta\rho^+}$				**4.2**	$\mathbf{8.6 \pm 2.2 \pm 1.1}$	$7 \pm 19 \pm 2$
$\eta'_{\eta\pi\pi}\pi^+$	55^{+12}_{-11}	27	18	4.9	$5.4^{+1.4}_{-1.3}$	19 ± 21
$\eta'_{\rho\gamma}\pi^+$	30^{+15}_{-14}	18	30	1.2	$1.9^{+1.6}_{-1.4}$	47 ± 44
$\boldsymbol{\eta'\pi^+}$				**4.8**	$\mathbf{4.2 \pm 1.0 \pm 0.5}$	$24 \pm 19 \pm 1$
$\boldsymbol{a_1^+(1260)\pi^-}$	472 ± 47	18	50	**13.8**	$\mathbf{42.6 \pm 4.2 \pm 4.1}$	
$\boldsymbol{\rho^0 K^0_S}$	99 ± 19	25	34	**3.5**	$\mathbf{5.1 \pm 1.0 \pm 1.2}$	
$\boldsymbol{K^0_S K^0_S K^0_S}$	71 ± 9	16	32	**10.9**	$\mathbf{6.5 \pm 0.8 \pm 0.8}$	

measured branching fraction is comparable with the branching fraction of the decay mode $B^+ \to \eta K^+$ [3] and both these decays are suppressed compared to the B decays to $\eta' K^0$ and $\eta' K^+$ [12] . The reverse happens when in the final states we have K^* mesons instead of K . In fact the decays $B^+ \to \eta K^{*+}$ and $B^0 \to \eta K^{*0}$ are enhanced compared to $B^+ \to \eta' K^{*+}$ and $B^0 \to \eta' K^{*0}$ [13]. This pattern can be explained with the hypothesis, made by Lipkin in 1991 [14], that two penguin diagrams interfere, enhancing B decays to $\eta' K$ and suppressing B decays to ηK . In the final states having K^* instead of K meson the reverse happens because the vector K^* has opposite parity from the kaon.

4 Measurement of the Branching Fraction and Charge Asymmetry for the Decays $B^+ \to \eta\rho^+$ and $B^+ \to \eta'\pi^+$

The decays $B^+ \to \eta\rho^+$ and $B^+ \to \eta'\pi^+$ have been reanalysed using 182 million $B\overline{B}$ pairs [10]. The results of this new measurement are shown in Table 1. These decay modes are expected to be dominated by CKM-suppressed $b \to u$ tree amplitudes. These amplitudes may interfere significantly with penguin amplitudes, possibly leading to large direct CP violation in $\eta\rho^+$ and $\eta'\pi^+$ [15]. Both decay modes are observed with a significance $S > 4\sigma$ and no evidence is seen of direct CP violation.

5 Search for the $B^0 \to \eta\omega$ Decay

Recently *BABAR* has measured the branching fractions of B^0 meson decays to combinations of two charmless isoscalar mesons [2], using a sample of 89 million of $B\overline{B}$ pairs. As expected there was a substantial improvement of upper limits. In addition to the interest in searching for signals and in improving upper limits, these decay modes are particularly interesting because by using their branching fractions (or upper limits) one can constrain the difference $\Delta S = S - \sin 2\beta$ between the parameter S appearing in the sinusoidal term of the time evolution of penguin-dominated decays (like $B^0 \to \eta' K^0_S$) and $\sin 2\beta$ as measured in the charmonium-K^0_S decays. Using the new measured upper limits in B^0 decays to charmless isoscalar pairs, a more stringent bound has been determined on ΔS [2, 16]. This is important taking into account the new *BABAR* measurement [17] of CP time dependent asymmetries in $B^0 \to \eta' K^0_S$ with a measured value of S at 3.0 standard deviations from the *BABAR* measurement of $\sin 2\beta$ in $B \to$ charmonium K^0_S decays [18] .

The measured branching fraction of $B^0 \to \eta\omega$, unexpectedly was found with a significance of 4.3σ. For this reason we have remeasured it , using 182 million of $B\overline{B}$ pairs [10]. The new measurement is shown in Table 1. The new signal significance is 2.2σ. Because the two analyses have been done in the same way , we conclude that the large significance in the first measurement was due to a statistical fluctuation.

6 Observation of B^0 Meson Decay to $a_1^+(1260)\pi^-$

We measure the branching fraction of the B^0 meson decay to $a_1^+(1260)\pi^-$with $a_1^+(1260) \to \pi^+\pi^+\pi^-$, using 124 million $B\overline{B}$ pairs [10]. The decay $a_1^+(1260) \to \pi^+\pi^+\pi^-$ proceeds mainly through the intermediate states $(\pi\pi)_\rho\pi$ and $(\pi\pi)_\sigma\pi$. In this preliminary measurement we do not distinguish between the final states $(\pi\pi)_\rho\pi$ and $(\pi\pi)_\sigma\pi$. Such an analysis would require a study of the angular distributions of the decay products. Background contributions from B^0 decays to $a_2(1320)\pi$ and $\pi(1300)\pi$ are assumed to be negligible. The results of this analysis are shown in Table 1. A substantial signal is seen in the mass region of $a_1^+(1260)$ meson. The fitted values of the $a_1^+(1260)$ parameters are $m_{a_1} = 1.19 \pm 0.02$ GeV$/c^2$ and $\Gamma_{a_1} = 312 \pm 55$ MeV$/c^2$. These values are close to those found in hadronic production of the $a_1^+(1260)$ meson.

7 Evidence for $B^0 \to \rho^0 K^0_S$

We measure the branching fraction of the B^0 meson decay $B^0 \to \rho^0 K^0_S$ using a sample of 227 million $B\overline{B}$ pairs [10]. This process is expected to be dominated by a penguin amplitude . The analysis is done in a quasi-two-body approach in the region of the $\pi^+\pi^- K^0_S$ Dalitz plot dominated by the ρ^0 resonance. Interference effects between the ρ^0 and other resonances on the Dalitz plot are taken as a systematic uncertainty. With higher statistics this channel can be used to measure time-dependent CP asymmetries. Results of this analysis are shown in Table 1. Assuming as signal the combination of $B^0 \to \rho^0 K^0_S$ and $B^0 \to f_0(600) K^0_S$, the hypothesis of zero signal is excluded at 6.1σ level. Allowing in the fit also the yield of $B^0 \to f_0(600)K^0_S$, we can exclude the hypothesis of zero $B^0 \to \rho^0 K^0_S$ signal at 3.5σ level.

8 Measurement of the Branching Fraction for the Decay $B^0 \to K^0_S K^0_S K^0_S$

The branching fraction of this process has already been measured by the Belle Collaboration [19], $\mathcal{B}(B^0 \to K^0_S K^0_S K^0_S)=(4.2^{+1.6}_{-1.3} \pm 0.8)\times 10^{-6}$, using an integrated luminosity of 78 fb^{-1}. In this analysis [10] we use 211 million $B\overline{B}$ pairs (corresponding to 191 fb^{-1}). We do an inclusive measurement of $B^0 \to K^0_S K^0_S K^0_S$. Several processes in fact can produce this final state : non resonant three-body $b \to s\bar{s}s$ and $b \to s\bar{d}d$, charmless resonant intermediate states (like $B^0 \to f_0 K^0_S$), and also $b \to s\bar{c}c$ decays (the dominant one in this case is the decay $B^0 \to \chi_{c0}$). The results of this measurement are shown in Table 1. The measured branching fraction is in agreement with, but more precise than, the previous Belle measurement.

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References

[1] Except as noted otherwise, we use a particle name to denote either member of a charge-conjugate pair.

[2] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett.**93**, 181806 (2004)

[3] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett.**92**, 061801 (2004).

[4] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **70**, 032006 (2004).

[5] C.-W. Chiang *et al.*, Phys. Rev. D **70**, 034020 (2004) and references therein.

[6] H. K. Fu *et al.*, Phys. Rev. D **69**, 074002 (2004); Nucl. Phys. Proc. Suppl. **115**, 279 (2003).

[7] M. Bauer *et al.*, Z. Phys. C **34**, 103 (1987); A. Ali, G. Kramer and C. D. Lu Phys. Rev. D **58**, 094009 (1998); Y. H. Chen *et al.*, Phys. Rev. D **60**, 094014 (1999); J. H. Jang *et al.*, Phys. Rev. D **59**, 034025 (1999).

[8] G. P. Lepage and S. Brodsky, Phys. Rev. D **22**, 2157 (1980); J. Botts and G. Sterman, Nucl. Phys. B **225**, 62 (1989); Y. Y. Keum *et al.*, Phys. Lett.B **504**, 6 (2001), Phys. Rev. D **63**, 074006 (2001);

[9] M. Beneke *et al.*, Phys. Rev. Lett.**83**, 1914 (1999), Nucl. Phys. B **606**, 245 (2001), Nucl. Phys. B **651**, 225 (2003); Nucl. Phys. B **675**, 333 (2003).

[10] *BABAR* Collaboration, B. Aubert *et al.*, hep-ex/0408058, hep-ex/0408021, hep-ex/0408079, hep-ex/0408065.

[11] *BABAR* Collaboration, B. Aubert *et al.*, Nucl. Instr. Meth. A **479**, 1 (2002).

[12] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. Lett.**91**, 161801 (2003).

[13] *BABAR* Collaboration, B. Aubert *et al.*, Phys. Rev. D **70**, 032006 (2004).

[14] H. J. Lipkin, Phys. Lett.B **254**, 247 (1991).

[15] M. Bander, D. Silverman, and A. Soni, Phys. Rev. Lett.**43**, 242 (1979); S. Barshay, D. Rein, and L.M. Sehgal, Phys. Lett.B **259**, 475 (1991); G. Kramer, W.F. Palmer, and H. Simma, Nucl. Phys. B **428**, 77 (1994); A.S. Dighe, M. Gronau, and J.L. Rosner, Phys. Rev. Lett.**79**, 4333 (1997). A. Ali, G. Kramer, and C.-D. Lü, Phys. Rev. D **59**, 014005 (1999). M.-Z. Yang and Y.-D. Yang, Nucl. Phys. B **609**, 469 (2001); M. Beneke and M. Neubert, Nucl. Phys. B **651**, 225 (2003).

[16] C.-W. Chiang *et al.*, Phys. Lett. B **596**, 107 (2004); M. Gronau, hep-ph/0407316.

[17] *BABAR* Collaboration, B. Aubert *et al.*, hep-ex/0408090; see also A. Höcker, in these proceedings .

[18] *BABAR* Collaboration, B. Aubert *et al.*, hep-ex/0408127; see also M. Bruinsma , in these proceedings .

[19] Belle Collaboration, A. Garmash *et al.*, Phys. Rev. D **69**, 012001 (2004)