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B Decays Involving Light Mesons

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Recent *BABAR* results for decays of B-mesons to combinations of non-charm mesons are presented. This includes B decays to two vector mesons, $B \to \eta'(\pi, K, \rho)$ modes, and a comprehensive Dalitz Plot analysis of $B \to KKK$ decays.

1. Introduction

Decays of B mesons to charmless mesons have once again become a very active field of study, due to abundance of new data from the B-factories. This data confronts recent theoretical predictions, including but not limited to approaches using SU(3) flavor symmetry [1] and QCD factorization [2]. The high level of current theoretical activity centered on this topic is reflected at this conference as well [3,4].

Besides being interesting in their own right, measurements of branching fractions and CP asymmetry of charmless B decays provide important constraints for the determination of the unitarity triangle constructed from elements of the Cabibbo-Kobayashi-Maskawa quark-mixing matrix [5]. Systematic study of these branching fractions can offer insights on the relative contributions of tree-level and penguin loop-mediated decay modes. It has been argued that the influence of final-state interactions like charming penguins [6] and similar long-distance rescattering effects [7] on both the branching fraction and CP asymmetry of B decays to pseudoscalar mesons may be significant.

Here we focus on the most recent charmless branching fraction measurements performed by the *BABAR* Experiment. *BABAR* charm and CP violation results are discussed separately at this conference [8,9].

The data used in the analyses presented were collected with the *BABAR* detector [10] at the PEP-II asymmetric-energy e^+e^- storage ring at SLAC. Charged-particle trajectories are measured by a five-layer double-sided silicon vertex tracker and a 40-layer drift chamber located within a 1.5-T solenoidal magnetic field. Charged hadrons are identified by combining energy-loss information from tracking

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with the measurements from a ring-imaging Cherenkov detector. Photons are detected by a CsI(Tl) crystal electromagnetic calorimeter with an energy resolution of $\sigma_E/E = 0.023(E/\,\mathrm{GeV})^{-1/4} \oplus 0.014$. The magnet's flux return is instrumented for muon and K_L^0 identification.

Unless otherwise stated, the data sample includes 232 million $B\overline{B}$ pairs collected at the $\Upsilon(4S)$ resonance, corresponding to an integrated luminosity of 211 fb^{-1}. It is assumed that neutral and charged B meson pairs are produced in equal numbers [11]. In addition, 40 fb^{-1} of data collected at 40 MeV below the $\Upsilon(4S)$ resonance mass were used for background studies.

Common to all analyses presented are two kinematic variables, $\Delta E = E_B^* - \sqrt{s}/2$ and the beam energy substituted mass $m_{\mathrm{ES}} = \sqrt{(s/2 + \mathbf{p}_0 \cdot \mathbf{p}_B)^2/E_0^2 - \mathbf{p}_B^2}$, which are used for the final selection of events. Here E_B^* is the B-meson-candidate energy in the center-of-mass frame, E_0 and $\sqrt{s}$ are the total energies of the e^+e^- system in the laboratory and center-of-mass frames, respectively, and $\mathbf{p}_0$ and $\mathbf{p}_B$ are the three-momenta of the e^+e^- system and the B candidate in the laboratory frame. For correctly reconstructed B meson candidates ΔE peaks at zero.

Continuum quark-antiquark production is the dominant background. It is suppressed by including the event topology in the selection. The decay products of a $B\overline{B}$ event will typically have a more spherical distribution of trajectories than a continuum event. A variety of algorithms is available to describe the event shape, and often a combination of several is used.

Other B decays which appear to have the same final state as the signal event because one or more daughter particles were not identified correctly constitute the most problematic background for charmless B decays. Many combinations can be effectively suppressed using the kinematic variables m_{ES} and ΔE. The remaining background contributions from other B decays are estimated using extensive Monte Carlo simulations, often involving 30 or more different decay modes.

Both signal and background yields are calculated simultaneously using an extended maximum likelihood method. The fit variables always include m_{ES} and ΔE as well as at least one variable characterizing the background. Other variables may be added according to the methodology of the individual analysis. For this level of detail we refer to the publications describing the analysis.

Charge conjugation is implied throughout this paper.

2. Decays to final states containing η'

In B decays to final states comprising $\eta^{(\prime)}K^{(*)}$, $B \to \eta' K^*$ and $B \to \eta K$ are suppressed while $B \to \eta' K$ and $B \to \eta K^*$ are enhanced. While this was predicted as early as 1991 [12], contradictory explanations for the observed pattern exist [13]. From previous experimental data and flavor SU(3) arguments it is expected that the branching fractions for $B \to \eta' K^*$ are less than 10^{-5} [1]. The related decays $B \to \eta' \rho$ occur via CKM suppressed tree diagrams and are expected to be small. Theoretical approaches using QCD factorization [2] and perturbative QCD [14] predict

Table 1. $B \to \eta' K^*/\rho/f_0$ results. All branching fractions are in units of 10^{-6}. For *BABAR* results with less than 5σ significance the 90% confidence limit is given as well.

Decay mode	Theoretical predictions		Experimental results		
	SU(3) [1]	QCDF [2]	HFAG 2005 [16]	New *BABAR* results	
$B^0 \to \eta' K^{*0}$	$3.0^{+1.2}_{-0.3}$	$3.9^{+9.2}_{-5.1}$	< 7.6	$3.8 \pm 1.1 \pm 0.5$	
$B^+ \to \eta' K^{*+}$	$2.8^{+1.2}_{-0.3}$	$5.1^{+10.3}_{-5.9}$	< 14	$4.9^{+1.9}_{-1.7} \pm 0.8$	< 7.9
$B^0 \to \eta' \rho^0$	$0.07^{+0.10}_{-0.05}$	$0.01^{+0.12}_{-0.06}$	< 4.3	$(0.4^{+1.2+1.6}_{-0.9-0.6})$	< 3.7
$B^+ \to \eta' \rho^+$	$4.9^{+0.7}_{-0.7}$	$6.3^{+4.0}_{-3.3}$	< 22	$(6.8^{+3.2+3.9}_{-2.9-1.2})$	< 14
$B^0 \to \eta' f_0$	–		–	$(0.1^{+0.6+0.9}_{-0.4-0.4})$	< 1.5

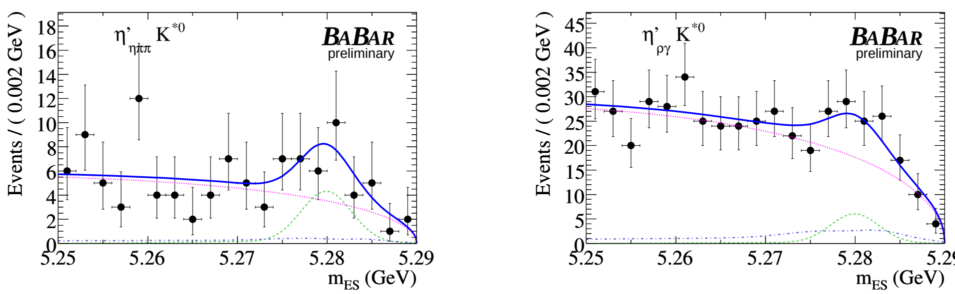

Fig. 1. $m_{\rm ES}$ distribution for $B^0 \to \eta' K^{*0}$, for $\eta' \to \eta\pi\pi$ (left) and $\eta' \to \rho\gamma$ final states (right). Shown are the fit result (blue solid line), signal component (green dashed line), continuum contribution (dotted red line), and background from B decays (dashed-dotted blue line). The data points shown represent a subset with a minimum signal/background likelihood ratio.

Table 2. $B \to \eta(\eta')K(K^*)$ branching fractions, including the new *BABAR* results. Modes predicted to be suppressed (s) or enhanced (e) are indicated.

	$K^\pm$	$K^{*\pm}$	K^0	K^{*0}
η	2.5 ± 0.3 (s)	24.3 ± 3.0 (e)	< 1.9 (s)	18.7 ± 1.7 (e)
η'	69.4 ± 2.7 (e)	< 7.9 (s)	63.2 ± 3.3 (e)	3.8 ± 1.2 (s)

branching fractions for $B^+ \to \eta' \rho^+$ of $6-9\times10^{-6}$ and for $B^0 \to \eta' \rho^0$ of $0.5-2\times10^{-7}$. We present measurements for the decays $B \to \eta' K^*$ and $B^+ \to \eta' \rho^+$ (Tab. 1) [15]. They allow the level of suppression of these decays, with respect to the enhanced partner modes, to be determined (Tab. 2). A simultaneous fit of all charged and neutral $\eta' K^*$ modes results in the observation of $B \to \eta' K^*$ (Fig. 1) with a total significance of 5.6σ including systematics. In addition, the upper limit for $B^0 \to \eta' \rho^0$ has been improved significantly. We have also studied $B^0 \to \eta' f_0(980)$ for the first time. The results are consistent with previous upper limits, where they existed. In all cases, predictions based on SU(3) flavor symmetry and QCD factorization are in good agreement with the measured central values. No charge asymmetry is observed in any of the channels.

Table 3. New 90% confidence upper limits for $B \rightarrow \eta^{(\prime)}\pi$ modes, and for three-body decays with two η'.

$\mathcal{B}(B^0 \rightarrow \eta'\eta)$	$< 1.7 \times 10^{-6}$
$\mathcal{B}(B^0 \rightarrow \eta\pi^0)$	$< 1.3 \times 10^{-6}$
$\mathcal{B}(B^0 \rightarrow \eta'\pi^0)$	$< 2.1 \times 10^{-6}$
$\mathcal{B}(B^0 \rightarrow \eta'\eta' K^0)$	$< 31 \times 10^{-6}$
$\mathcal{B}(B^+ \rightarrow \eta'\eta' K^+)$	$< 25 \times 10^{-6}$

Progress has been made in constraining the branching ratios of other decays to final states containing η or η' as well (Tab. 3). New upper limits have been established for $B^0 \rightarrow \eta^{(\prime)}\pi^0$ modes [17] and three-body $B \rightarrow \eta'\eta' K$ decays [18].

3. Decays to two vector mesons

Hadronic decays of B mesons to pairs of light vector mesons provide a wider set of observables than decays involving pseudoscalar mesons. In particular, CP asymmetries constructed from polarization components [19] complement direct CP violation measurements. Many of these decays are expected to be completely dominated by penguin diagrams and may therefore be sensitive to physics beyond the Standard Model.

Until the fraction of longitudinal polarization was measured to be $f_L \sim 0.5$ by *BABAR* in 2003 [20], this parameter had been assumed to be close to unity for both tree- and penguin-dominated decays [21]. Naturally, this discovery boosted interest in this class of decays.

The longitudinal polarization fraction f_L can be defined as

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_1 d\cos\theta_2} \sim \frac{1}{4}(1-f_L)\sin^2\theta_1\sin^2\theta_2 + f_L\cos^2\theta_1\cos^2\theta_2,$$

where the helicity angles θ_1 and θ_2 describe the direction between the two vector mesons and their decay products in the vector meson's rest frame.

The decay $B^+ \rightarrow \rho^+ K^{*0}$ is a pure penguin mode while $B^+ \rightarrow \rho^0 K^{*+}$ also has a tree contribution. Besides the interest in the polarization, the four $B \rightarrow \rho K^*$ modes can also be used to help constrain the angles α and γ of the Unitarity Triangle [22]. The latest *BABAR* results [23] are summarized in Table 4. The $B^+ \rightarrow \rho^+ K^{*0}$ (Fig. 2) branching fraction and longitudinal polarization fraction are in good agreement with the recent measurement by the BELLE Collaboration [24].

The vector-vector decays discussed above are penguin-dominated. For decay modes with the K^* replaced by a ρ, ω, or ϕ meson, tree diagrams are expected to play a bigger role. A recent search by *BABAR* for seven charmless hadronic B decays to ω plus another light vector meson has yielded the observation of $B^+ \rightarrow \omega\rho^+$ with

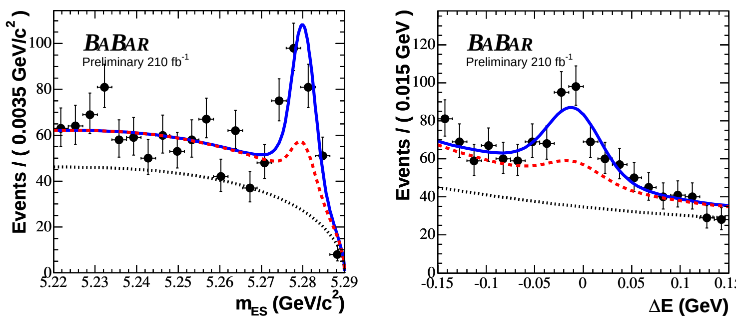

Fig. 2. m_{ES} and ΔE projections of the fit results for $B^+ \to \rho^+ K^{*0}$. See Fig. 1 for legend.

Table 4. New results for $B \to \rho K^*$ modes.

Decay mode	$\mathcal{B} \times 10^{-6}$	Upper limit	f_L	$\mathcal{A}_{CP}$
$B^+ \to K^{*0}\rho^+$	$9.6 \pm 1.7 \pm 1.5$		$0.52 \pm 0.10 \pm 0.04$	$-0.01 \pm 0.16 \pm 0.02$
$B^+ \to \rho^0 K^{*+}$	$3.6 \pm 1.7 \pm 0.8$	< 6.1 (90% CL)	0.9 ± 0.2	–
$B^+ \to f_0(980)K^{*+}$	$5.2 \pm 1.2 \pm 0.5$	–	–	$-0.34 \pm 0.21 \pm 0.03$

a significance of 5.7σ [25]. The longitudinal polarization fraction for this mode was measured to be $f_L = 0.82 \pm 0.11 \pm 0.02$. No charge asymmetry was observed. For the other six branching fractions improved upper limits could be established (Tab. 5).

Table 5. New results for $B \to \omega X$ modes. Upper limits at 90% confidence.

Decay mode	$\mathcal{B} \times 10^{-6}$ central value	Upper limit
$B^0 \to \omega K^{*0}$	$2.4 \pm 1.1 \pm 0.4$	< 4.2
$B^+ \to \omega K^{*+}$	$0.6\ ^{+1.4}_{-1.2}\ ^{+1.1}_{-0.9}$	< 3.4
$B^0 \to \omega \rho^0$	$-0.6\ ^{+0.7}_{-0.6}\ ^{+0.8}_{-0.3}$	< 1.5
$B^+ \to \omega \rho^+$	$10.6 \pm 2.1^{+1.6}_{-1.0}$	–
$B^0 \to \omega\omega$	–	< 4.0
$B^0 \to \omega\phi$	–	< 1.2
$B^0 \to \omega f_0$	$0.9 \pm 0.4 \pm 0.2$	< 1.5

4. $B \to KKK$ Dalitz analysis and other results

The abundance of statistics accumulated at the B-Factories now allows for comprehensive Dalitz plot analyses to be carried out for decay modes where previously only inclusive branching fractions and CP asymmetries could be measured. This is the case for the decay $B^+ \to K^+K^-K^+$, for which BELLE published a first Dalitz plot analysis in 2005, based on $152 \times 10^6 B\overline{B}$ events. More recently, *BABAR* completed a similar study based on $226 \times 10^6 B\overline{B}$ events [27]. The total $B^+ \to K^+K^-K^+$

branching fraction obtained from this analysis is $(35.2 \pm 0.9 \pm 1.6) \times 10^{-6}$, slightly bigger than BELLE's result. This discrepancy may be entirely due to a difference in background treatment. *BABAR* observes a broad scalar resonance centered at $\sim 1.55\,\mathrm{GeV}/c^2$, and a significant non-resonant component which is not uniformly distributed across the Dalitz plot. The $f_0(980)$ resonance is observed as well.

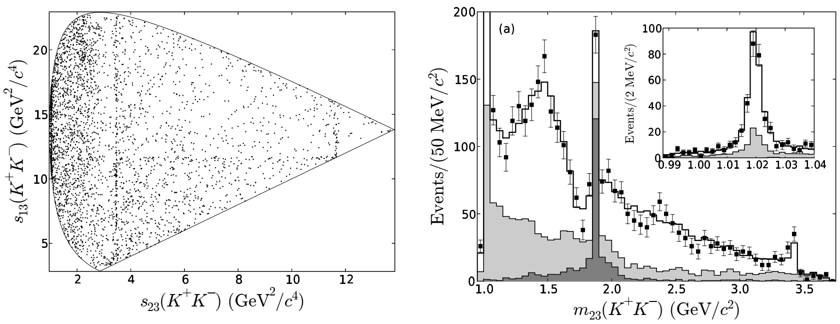

Fig. 3. $B^+ \to K^+K^-K^+$ Dalitz analysis: Dalitz plot of the 1769 B^+ and 1730 B^- candidates (left); Projected $m(K^+K^-)$ invariant-mass distribution (right). The inset shows the fit projection near the $\phi(1020)$ resonance. The histogram shows the result of the fit, B-background and continuum contributions are shown shaded in dark and light gray, respectively.

A search for the decay $B^0 \to a_1^+\rho-$, with $a_1^+ \to \pi^+\pi^-\pi^+$, has been completed using 110 million $B\overline{B}$ events. A new 90% confidence limit of 30×10^{-6} was established [28], improving the previous limit [29] by almost a factor 100.

The decay $B \to \phi\pi$ is strongly suppressed in the Standard Model, and a measurement of its branching ratio of more than 10^{-7} would be evidence for new physics, for example supersymmetric contributions [30]. *BABAR* has recently completed a search for this decay, both in its charged and neutral modes, resulting in updated upper limits at 90% confidence of $\mathcal{B}(B^+ \to \phi\pi^+) < 0.24 \times 10^{-6}$ and $\mathcal{B}(B^0 \to \phi\pi^0) < 0.28 \times 10^{-6}$ [31].

5. Conclusions

The physics of charmless hadronic B decays is an active field today and will continue to be exciting for years to come, as more data is pouring in from the B-Factories and theoretical predictions become more and more precise. Numerous charmless decays have been instrumental in constraining the description of Standard Model parameters such as the angle α of the unitarity triangle. With the statistics now available, branching fractions as small as 10^{-7} can be measured, opening the door for the kind of sensitivity one needs to detect signs of physics beyond the Standard Model in B decays.

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