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CHARMLESS HADRONIC B DECAYS AT BELLE and *BABAR*

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I report on recent measurements from the Belle and *BABAR* collaborations on the decay of the B meson to hadronic final states without a charm quark.

1 Introduction.

The study of the branching fractions and angular distributions of B meson decays to hadronic final states without a charm quark probes the dynamics of both the weak and strong interactions, and plays an important role in understanding *CP* Violation (CPV) in the quark sector. *CP* Violation at the B factories is described graphically by a triangle with sides formed from the CKM matrix elements $V_{qd}V^*_{qb}$ $(q = u, c, t)$ and internal angles α, β, γ (or ϕ_2, ϕ_1, ϕ_3). Discrepancies in the measured values of the sides and angles could be an indication of New Physics beyond the Standard Model (SM) due to enhanced branching fractions or modified *CP* asymmetries. The experimental measurements of branching fractions, *CP* asymmetries, polarization and phases (both weak and strong) can be compared to theoretical models based on, for example, QCD factorization, SU(3) symmetry and Lattice QCD.

The results presented below assume charge-conjugate states and all branching fraction upper limits (UL) are at the 90% confidence level (C.L.). The time-integrated *CP* asymmetry is defined as $A_{CP} = (N_b - N_{\overline{b}})/(N_b + N_{\overline{b}})$ where N_b $(N_{\overline{b}})$ is the number of B mesons containing a $b(\overline{b})$ quark. The latest results are based on a total dataset of 467×10^6 $B\overline{B}$ pairs for *BABAR* and 657×10^6 $B\overline{B}$ pairs for Belle, unless indicated.

2 Decays involving two-body final states.

The last few years have seen considerable advancement in the prediction of the branching fractions and polarizations of B meson decays to Vector-Vector (VV), Vector-Scalar (VS) and Vector-Tensor (VT) final states. In general, there has been good agreement between theory and experiment on branching fractions (with some notable exceptions) but the polarization measurements have presented a challenge. The VV states are expected to be almost fully longitudinally polarized $(f_L \sim 1)$ and this should remain true in the presence of penguin loop decays. However, penguin-dominated decays seem to have a smaller f_L (e.g. $f_L \sim 0.5$ for $B \to \phi K^*$) [1].

Belle has recently measured the decay $B^- \to K^{*0}K^-$ which is dominated by $b \to ds\bar{s}$ gluonic penguin diagrams. They measure a yield of 47.7 ± 11.1 events, corresponding to a branching fraction $\mathcal{B}(B^- \to K^{*0}K^-) = (0.68 \pm 0.16 \pm 0.10) \times 10^{-6}$ with a 4.4σ significance [2]. The event yield for $B^- \to K_2^{*0}(1430)K^-$ is measured to be 23.4 ± 12.1 with an upper limit on the branching fraction of $\mathcal{B}(B^- \to K_2^{*0}(1430)K^-) < 1.1 \times 10^{-6}$. A similar analysis has

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been done for B^0 decays to the VV final states $\rho^0 K^{*0}$ and $f_0 K^{*0}$ [3]. Unlike an earlier *BABAR* analysis [4], Belle sees no evidence for $\rho^0 K^{*0}$ and $f_0 K^{*0}$ (and, consequently, do not measure f_L) but observes $B^0 \to \rho^0 K^+ \pi^-$ and sees first evidence for $B^0 \to f_0 K^+ \pi^-$ and $B^0 \to \pi^+\pi^- K^{*0}$, with branching fractions (significance) of $(2.8 \pm 0.5 \pm 0.5) \times 10^{-6}$ (5.0σ), $(1.4 \pm 0.4^{+0.3}_{-0.4}) \times 10^{-6}$ (3.5σ), and $(4.5^{+1.1+0.9}_{-1.0-1.6}) \times 10^{-6}$ (4.5σ), respectively. *BABAR* has measured B meson decay to an ω accompanied by a K^*, ρ or f_0. Five measurements have a significance above 5σ, with another two above 3σ. This has allowed *BABAR* to measure both f_L and A_{CP}. The VV branching fractions agree with theory predictions and the asymmetries are consistent with zero, as expected, while $f_L \sim 0.5$ except for $\omega\rho^+ \sim 0.9$. The results [5] are summarized in Table 1.

Table 1: Branching fraction central value ($\mathcal{B}$) and upper limit (UL) in units of 10^{-6}, significance S in standard deviations, longitudinal polarization (f_L) and CP asymmetry A_{CP} for the Vector-Vector (VV), Vector-Scalar (VS) and Vector-Tensor (VT) decays of $B \to \omega K^*$, ωf_0 and $\omega\rho$.

Mode	Decay	S(σ)	$\mathcal{B}$	UL	f_L	A_{CP}
VV	ωK^{*0}	4.1	$2.2 \pm 0.6 \pm 0.2$	-	$0.72 \pm 0.14 \pm 0.02$	$+0.45 \pm 0.25 \pm 0.02$
VV	ωK^{*+}	2.5	$2.4 \pm 1.0 \pm 0.2$	7.4	$0.41 \pm 0.18 \pm 0.05$	$+0.29 \pm 0.35 \pm 0.02$
VS	$\omega(K\pi)^{*0}_0$	9.8	$18.4 \pm 1.8 \pm 1.7$	-	-	$-0.07 \pm 0.09 \pm 0.02$
VS	$\omega(K\pi)^{*+}_0$	9.2	$27.5 \pm 3.0 \pm 2.6$	-	-	$-0.10 \pm 0.09 \pm 0.02$
VT	$\omega K^*_2(1430)^0$	5.0	$10.1 \pm 2.0 \pm 1.1$	-	$0.45 \pm 0.12 \pm 0.02$	$-0.37 \pm 0.17 \pm 0.02$
VT	$\omega K^*_2(1430)^+$	6.1	$21.5 \pm 3.6 \pm 2.4$	-	$0.56 \pm 0.10 \pm 0.04$	$+0.14 \pm 0.15 \pm 0.02$
VV	$\omega\rho^0$	1.9	$0.8 \pm 0.5 \pm 0.2$	1.6	-	-
VV	ωf_0	4.5	$1.0 \pm 0.3 \pm 0.1$	1.5	-	-
VV	$\omega\rho^+$	9.8	$15.9 \pm 1.6 \pm 1.4$	-	$0.90 \pm 0.05 \pm 0.03$	$-0.20 \pm 0.09 \pm 0.02$

3 Decays involving three-body final states.

An interesting use of the decay to final states with three particles is the search by Belle for the exotic state X(1812) in the decay $B^+ \to K^+ \; X(1812), X(1812) \to \omega\phi$. This is similar to the observation by Belle of the Y(3940) resonance in $B^+ \to K^+\omega\psi$ [6]. Belle observe $N_{K^+\omega\phi} = 22.1^{+8.3}_{-7.2}$ events leading to a branching fraction for the Dalitz plot of $\mathcal{B}(B^+ \to K^+\omega\phi) = (1.15^{+0.43+0.14}_{-0.38-0.13}) \times 10^{-6}$ (2.8σ) and an upper limit $< 1.9 \times 10^{-6}$. Assuming the X(1812) masses and width from BES [7], Belle searches for a near-threshold enhancement in the $M_{\pi^+\pi^-\pi^0 K^+ K^-}$ mass spectrum. No significant yield is seen and an upper limit of 3.2×10^{-7} is placed on the product branching fraction $\mathcal{B}(B^+ \to K^+ X(1812), X(1812) \to \omega\phi)$ [8].

BABAR has also looked at rare processes in Dalitz plots. Previous measurements have shown that almost 50% of the events in $B^0 \to K^+K^-\pi^+$ can be assigned to an ill-defined resonance, called $f_X(1500)$ by *BABAR*. If this is an even-spin resonance, the rate for $f_X(1500) \to K^0_S K^0_S$ would be expected to be half the rate for $f_X(1500) \to K^+K^-$. They see 15 ± 15 events in the whole Dalitz plot placing an upper limit on the total branching fraction of $\mathcal{B}(B^+ \to K^0_S K^0_S \pi^+) < 5.1 \times 10^{-7}$. This makes the even-spin hypothesis unlikely but interpretation is difficult as the exact quantum numbers of the $f_X(1500)$ are unknown [9].

Some MSSM models could enhance the branching fractions of SM-suppressed decays from the SM values of $\sim 10^{-16}$ to $\sim 10^{-6}$. *BABAR* has searched for $B^- \to K^+\pi^-\pi^-$ and $B^- \to K^-K^-\pi^+$ and placed upper limits of 9.5×10^{-7} and 1.6×10^{-7}, respectively, on the branching fractions [10].

The decay $B^+ \to \pi^+\pi^+\pi^-$ can in principle be used to extract the CKM angle γ by measuring the interference between $\pi^+\pi^-$ resonances and the χ_{c0} resonance which has no CP violating phase. It can also be helpful in understanding broad resonances and nonresonant backgrounds that are present in $B^0 \to \pi^+\pi^-\pi^0$ and so improve our measurement of the CKM angle α. *BABAR*'s results [11] for $B^+ \to \pi^+\pi^+\pi^-$ are summarized in Table 2. No significant direct *CP* asymmetry is measured and, although some resonances are significant, no evidence is found for χ_{c0} and χ_{c2}, leading to branching fraction upper limits for $B^+ \to \chi_{c0}\pi^+ < 1.5 \times 10^{-5}$ and $B^+ \to \chi_{c2}\pi^+ < 2.0 \times 10^{-5}$, making the measurement of γ in this mode unlikely at Belle or *BABAR*.

Table 2: Branching fraction ($\mathcal{B}$), *CP* asymmetry A_{CP}, and Fit Fraction for the decay $B^+ \to \pi^+\pi^+\pi^-$ with the resonance decaying to $\pi^+\pi^-$. The errors are statistical, systematic and model-dependent, respectively.

Decay	Fit Fraction (%)	$\mathcal{B}$ ($\times 10^{-6}$)	A_{CP} (%)
$\pi^+\ \pi^+\ \pi^-$ Total	-	$15.2 \pm 0.6 \pm 1.2^{+0.4}_{-0.3}$	$3.2 \pm 4.4 \pm 3.1^{+2.5}_{-2.0}$
$\pi^+\ \pi^+\ \pi^-$ nonresonant	$34.9 \pm 4.2 \pm 2.9^{+7.5}_{-3.4}$	$5.3 \pm 0.7 \pm 0.6^{+1.1}_{-0.5}$	$-14 \pm 14 \pm 7^{+17}_{-3}$
$\rho^0(770)\pi^\pm; \rho^0 \to \pi^+\pi^-$	$53.2 \pm 3.7 \pm 2.5^{+1.5}_{-7.4}$	$8.1 \pm 0.7 \pm 1.2^{+0.4}_{-1.1}$	$18 \pm 7 \pm 5^{+2}_{-14}$
$\rho^0(1450)\pi^\pm; \rho^0 \to \pi^+\pi^-$	$9.1 \pm 2.3 \pm 2.4^{+1.9}_{-4.5}$	$1.4 \pm 0.4 \pm 0.4^{+0.3}_{-0.7}$	$-6 \pm 28 \pm 20^{+12}_{-35}$
$f_2(1270)\pi^\pm; f_2 \to \pi^+\pi^-$	$5.9 \pm 1.6 \pm 0.4^{+2.0}_{-0.7}$	$0.9 \pm 0.2 \pm 0.1^{+0.3}_{-0.1}$	$41 \pm 25 \pm 13^{+12}_{-8}$
$f_0(1370)\pi^\pm; f_0 \to \pi^+\pi^-$	$18.0 \pm 3.3 \pm 2.6^{+4.3}_{-3.5}$	$2.9 \pm 0.5 \pm 0.5^{+0.7}_{-0.5} (< 4.0)$	$72 \pm 15 \pm 14^{+7}_{-8}$
$f_0(980)\pi^\pm; f_0 \to \pi^+\pi^-$	-	< 1.5	-
$\chi_{c0}\pi^\pm; \chi_{c0} \to \pi^+\pi^-$	-	< 0.1	-
$\chi_{c2}\pi^\pm; \chi_{c2} \to \pi^+\pi^-$	-	< 0.1	-

4 *CP* Violation and the CKM angle $\alpha(\phi_2)$.

The precision of the measurement of the CKM angle $\alpha(\phi_2)$ continues to improve. In the absence of penguin loops in the decays, the angle α can be measured in the time-dependent decay of $B^0 \to \rho\rho$ and $B^0 \to \pi\pi$. However the penguin contribution, particularly in $\pi^0\pi^0$, is not small and so the measured α_{eff} differs from the true α by $\Delta\alpha = \alpha - \alpha_{eff}$. $\Delta\alpha$ can be constrained by performing an Isospin analysis on the decays $B^0 \to \rho^0\rho^0$, $B^\pm \to \rho^\pm\rho^0$ and $B^0 \to \rho^+\rho^-$. Table 3 summarizes the measurements from *BABAR* [12], where the *CP* parameters are quoted for the longitudinally polarized (*CP*-even) component of the VV decays. When combined, $\Delta\alpha$ is constrained to be between -1.8^o and 6.7^o (68% C.L.). The angle α is measured to be $(92.4^{+6.0}_{-6.5})^o$ and can be compared to the recent result from Belle [13] of $\alpha = (91.7 \pm 14.9)^o$. A similar analysis using $B \to \pi\pi$ decays produces a looser constraint $\mid \Delta\alpha \mid < 43^o$, which results in an exclusion range for α between 23^o and 43^o at the 90% C.L. The result of combining these measurements using the CKMfitter programme [14] with earlier measurements of $B \to \pi\rho$ are shown in Fig. 1.

Table 3: Branching fraction ($\mathcal{B}$), longitudinal polarization (f_L), direct *CP* asymmetry (C_L), *CP* asymmetry in the interference between mixing and decay (S_L) and *CP* asymmetry A_{CP} for the decays $B^0 \to \rho^+\rho^-$, $B^0 \to \rho^0\rho^0$ and $B^+ \to \rho^+\rho^0$ measured by *BABAR*.

	$B^0 \to \rho^+\rho^-$	$B^0 \to \rho^0\rho^0$	$B^+ \to \rho^+\rho^0$
$\mathcal{B}(\times 10^{-6})$	$25.5 \pm 2.1^{+3.6}_{-3.9}$	$0.92 \pm 0.32 \pm 0.14$	$23.7 \pm 1.4 \pm 1.4$
f_L	$0.992 \pm 0.024^{+0.026}_{-0.013}$	$0.75 \pm 0.14 \pm 0.04$	$0.950 \pm 0.015 \pm 0.006$
C_L	$0.01 \pm 0.15 \pm 0.06$	$0.2 \pm 0.8 \pm 0.3$	-
S_L	$-0.17 \pm 0.20^{+0.05}_{-0.06}$	$0.3 \pm 0.7 \pm 0.2$	-
A_{CP}	-	-	$-0.054 \pm 0.055 \pm 0.01$

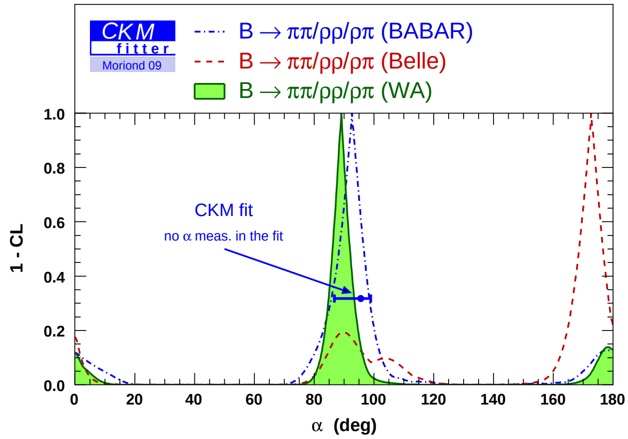

Figure 1: Constraints on α (ϕ_2) from $B \to \pi\pi$, $B \to \rho\pi$ and $B \to \rho\rho$ *BABAR* and Belle measurements compared to the prediction from the global CKM fit from CKMfitter. Similar results are available from the UTfit group[14].

Belle has seen direct *CP* in $B^0 \to \pi^+\pi^-$ but *BABAR* does not, reporting only that $C_{\pi^+\pi^-} = -0.25 \pm 0.08 \pm 0.02$ with a significance of just 2.2σ. However, both experiments see significant direct *CP* in $B^0 \to K^+\pi^-$ with *BABAR* reporting $A_{CP} = -0.107 \pm 0.016^{+0.006}_{-0.004}$ with 6.1σ significance, to be compared to $-0.094 \pm 0.018 \pm 0.008$ from Belle. Both experiments also measure A_{CP} for $B^\pm \to K^\pm\pi^0$ to be slightly positive but consistent with zero. A_{CP} should be similar for both $K\pi$ modes but Belle reports a 4.4σ difference and *BABAR* sees a similar discrepancy[15].

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