Measurements of α at the B-Factories

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Measurements from BaBar and Belle collaborations are presented that lead to the constraint of the angle α in the CKM unitarity triangle.

1. Introduction

The Cabibbo-Kobayashi-Maskawa matrix (V_{CKM}) describes the unitary rotation between the mass eigenstates and weak Eigen states of the quark system. This matrix can be described in terms of three angles and one non-trivial phase [1]. CP violation is possible if the remaining phase is non-zero, leading to complex terms in V_{CKM}. The unitary relation $V_{ub}^{*}V_{ud} + V_{cb}^{*}V_{cd} + V_{tb}^{*}V_{td} = 0$ describes a unitary triangle, which has three angles (α, β, γ) or sometimes (ϕ_2, ϕ_1, ϕ_3).

α (or ϕ_2) is defined as $\arg[-V_{td}V_{tb}^{*}/V_{ud}V_{ub}^{*}]$. To be sensitive to α two processes are required that interfere, one that depends on V_{td} and the other V_{ub}. In B^0 decays[1] the B^0 oscillates with the $\overline{B}^0$ with a frequency that depends on V_{tb}, in the tree decay of B^0 to two charmless mesons (π or ρ) the decay amplitude depends on V_{ub} which means there is a time dependant difference between $B^0 \to \pi^+\pi^-$ and $\overline{B}^0 \to \pi^+\pi^-$. However the gluonic penguin decays give the same final state but have an amplitude that depends on V_{td} which dilutes the time dependent interference and adds an additional phase difference between the strong phases of the final states. Using analyses of $B^0 \to \rho^0\rho^0$ and $B^+ \to \rho^+\rho^0$ provide constraints on the correction required for the gluonic penguins [2].

The time dependant partial width of B^0 and $\overline{B}^0$ decays are described by equation 1.

$$f(B^0 \to f, \Delta t) = \frac{\Gamma}{4}e^{-\Gamma|\Delta t|}[1 + \eta S \sin(\Delta m_d \Delta t) - \eta C \cos(\Delta m_d \Delta t)] \quad (1)$$

[1]Charge conjugation is assumed throughout

Where $\eta = +1(-1)$ for B^0 ($\overline{B}^0$) and S and C are the indirect and direct *CP* components of the time dependence. In the absence of penguin decays the prediction is that $C = 0$ and $S = \sin(2\alpha)$, when gluonic penguin diagrams are also considered this becomes $C \propto \sin(\delta), S = \sqrt{1 - C^2}\sin(2\alpha_{\rm eff})$ and δ is the difference between the tree and penguin strong phases. The difference between the effective and true values of α is $\Delta\alpha = |\alpha - \alpha_{\rm eff}|$.

The branching ratios for charmless B decays are small, $\mathcal{O}(10^{-5})$, so very large samples of $B\overline{B}$ events are required to measure properties of theses decays. There are two $B-$factories one in the United States called PEP-II and one in Japan called KEKII, these each have one detector called BaBar[3] and Belle[4] respectively. Both of the accelerators predominately operate on the $\Upsilon(4S)$ resonance producing $B\overline{B}$ events and non-resonant continuum events. The two detectors have collected around $1\,\mathrm{ab}^{-1}$ between them, totalling more than 1×10^9 $B\overline{B}$ pairs. Additional data has been taken below the $\Upsilon(4S)$ resonance which is used to characterise the backgrounds.

2. $B^0 \to \pi\pi$

Both Belle and BaBar have measured the properties of the decays of $B^0 \to \pi^+\pi^-$ [5,6]. The measured values of S and C, given in Table 1, are taken from fits to the time dependent decay of $B^0 \to \pi^+\pi^-$ shown in Figure 1. The combination of these results provides a measurement of $\alpha_{\rm eff}$.

The decays of $B^0 \to \pi^0\pi^0$ can be used to con-

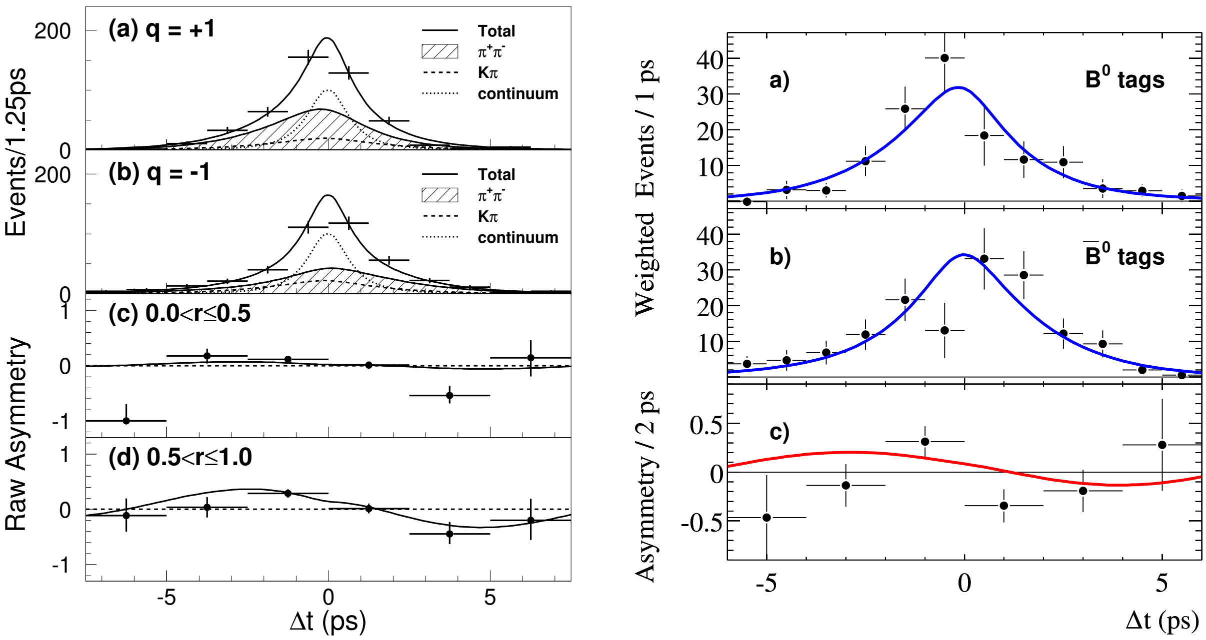

Figure 1. The time dependant decays of $B^0 \to \pi^+\pi^-$ and the asymmetry as measured by Belle (left) and BaBar (right). Belle and BaBar have separated the B^0 and $\overline{B}^0$ into (a) and (b), and shown the asymmetry between them in the lower parts of the figures, (c) for BaBar. Belle further divide the sample into poor tagged (c) and good tagged (d) samples.

Table 1
CP violating properties of the $B^0 \to \pi^+\pi^-$ decays

	Belle	BaBar
$S =$	$-0.67 \pm 0.16 \pm 0.06$	$-0.30 \pm 0.17 \pm 0.03$
$C =$	$-0.56 \pm 0.12 \pm 0.06$	$-0.09 \pm 0.15 \pm 0.04$

strain $\Delta\alpha$, a small branching ratio implying a small penguin contribution to the $\pi\pi$ system and that $\Delta\alpha$ is small. The averaged measurements of BaBar and Belle [7–9] are $\mathcal{B}(B^0 \to \pi^0\pi^0) = 1.45 \pm 0.29$, which means in the isospin interpretation $\Delta\alpha \leq 35°$ at 90% confidence level (CL).

3. $B \to \rho\rho$

The same isospin analysis holds for the $\rho\rho$ system. Starting with the neutral decays, BaBar has measured $\mathcal{B}(B^0 \to \rho^0\rho^0) = (1.16^{+0.37}_{-0.36} \pm 0.27) \times 10^{-6}$ with a 3σ significance of having observed a signal [10]. This implies that the tree decays dominate in the $\rho\rho$ modes. The $B^+ \to \rho^+\rho^0$ decay have also been measured with higher statistics by BaBar [11] with the results given in Table 2. The branching ratio is consistent with the isospin expectation, the polarisation (f_L) means the final state is almost entirely *CP* even and the charge asymmetry (A_{CP}) is compatible with zero and the assumption that electro-weak penguin effects are very small. Using these results the constraint on $\alpha_{\mathrm{eff}} < 11°$ at 68% CL can be derived.

Table 2
Properties of the $B^+ \to \rho^+\rho^0$ decays.

	BaBar
$\mathcal{B}=$	$(16.8 \pm 2.2 \pm 2.3) \times 10^{-6}$
$f_L =$	$0.905 \pm 0.042^{+0.023}_{-0.027}$
$A_{CP} =$	$-0.12 \pm 0.13 \pm 0.10$

Both Belle and BaBar have measured the time dependant asymmetry in $B^0 \to \rho^+\rho^+$ decays [13, 12], with the results listed in Table 3.

Table 3
Properties of $B^0 \to \rho^+\rho^+$ decays

	Belle	BaBar
$\mathcal{B} =$	$(22.8 \pm 3.8^{+2.8}_{-2.6})$ $\times 10^{-6}$	$(23.5 \pm 2.2 \pm 4.1)$ $\times 10^{-6}$
$f_L =$	$0.941^{+0.034}_{-0.040} \pm 0.030$	$0.977 \pm 0.024^{+0.015}_{-0.013}$
$S =$	$0.08 \pm 0.41 \pm 0.09$	$-0.19 \pm 0.21^{+0.05}_{-0.07}$
$C =$	$0.00 \pm 0.30 \pm 0.09$	$-0.07 \pm 0.15 \pm 0.06$

4. $B^0 \to (\rho\pi)^0$

The final useful channel is the $B^0 \to (\rho\pi)^0$, which is not CP Eigenstate, so requires a full Dalitz analysis of the 6 decays $(B^0(\overline{B}^0) \to \rho^\pm\pi^\mp, \rho^0\pi^0$ to disentangle the results [14]. BaBar and Belle have measured the $\rho^\pm$ parts of the phase space only but were not able to set limits on S and C using those analyses. BaBar have also measured the full Dalitz plane [15], using a square variant of the Dalitz plot, see Figure 2. The results are shown in table 4.

Table 4
CP violating properties of the $B^0 \to (\rho\pi)^0$ decays

	BaBar
C=	$-0.154 \pm 0.090 \pm 0.037$
S=	$0.01 \pm 0.12 \pm 0.03$

5. Conclusion

Each of the above decay modes contributes to the constraints on α, the $\rho\rho$ system gives the best measurement and the $\rho\pi$ unfolds the ambiguity in the sign of α_{eff}. The CKM fitter group combination [16] of the measurements of α is shown in Fig. 3. The HFAG average [9] of the measurements of α is $\alpha = 99^{+12}_{-9}$, which is consistent with the fit to all of the CKM data except that of α which predicts $\alpha = 97^{+5}_{-16}$ [16].

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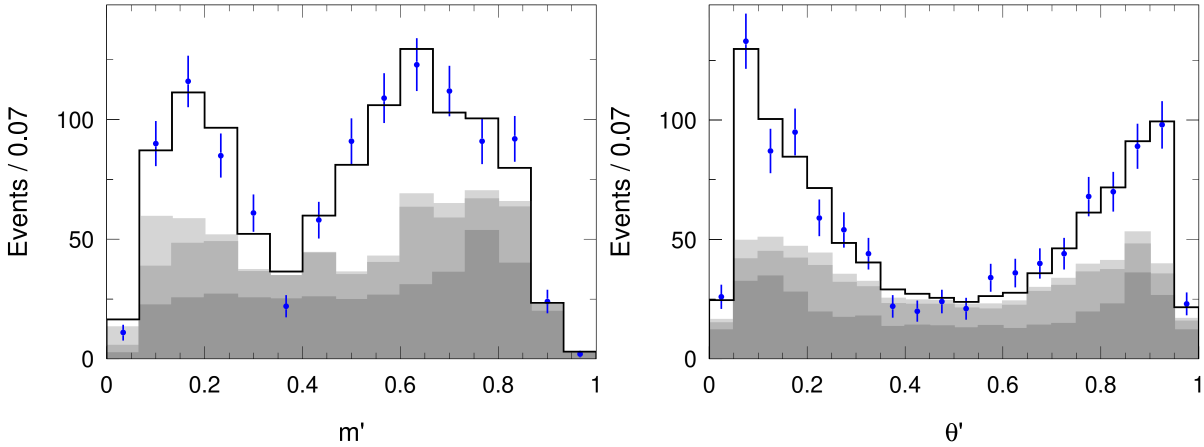

Figure 2. The projection on the two square Dalitz variables of the BaBar $(\rho\pi)^0$ analysis. The grey bands represent the continuum, B and miss reconstructed backgrounds in that order on the plot. The points are the data and the solid line is the projection of the PDF of the fit to the sample.

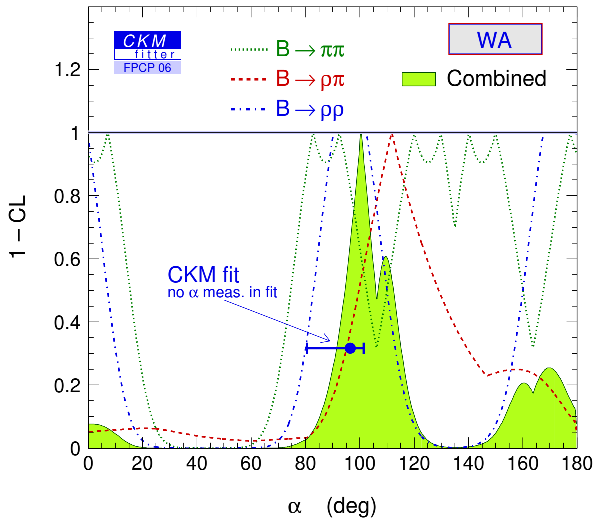

Figure 3. CKM fitter combination of the light charmless meson decays contributions to the measurement of α. Also indicated is the average of the indirect measurement of α from CKM fits.

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