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RECENT RESULTS ON THE CKM ANGLE α

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ABSTRACT

The method to measure the CKM angle α and the modes sensitive to it are discussed. It is shown that the $B \to \rho\rho$ decays provide the most stringent constraint on α, which is found to be $\alpha = 96^o \pm 10^o(stat) \pm 4^o(syst) \pm 13^o(penguin)$

1 Introduction

In the Standard Model, CP-violation arises from an irreducible phase in the Cabibbo-Kobayashi-Maskawa (CKM) matrix that describes weak interaction quark mixing [1]. This matrix is unitary, which leads to several relations among its elements, one being $V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$, where V_{ij} gives the coupling of the W-boson to the ij quark pair. This relationship can be

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presented geometrically as a rescaled triangle in the complex plane. The angles of this triangle (α, β, γ) are related to CP-violation, in the sense that no CP-violation would imply a flat triangle. This report focuses on recent measurements that probe the angle $\alpha = arg[-(V_{td}V_{tb}^*)/(V_{ud}V_{ub}^*)]$. Three $b \to u\bar{u}d$ modes, $B \to \pi\pi$, $B \to \rho\pi$ and $B \to \rho\rho$ are directly sensitive to α. The time dependent asymmetry rates (for the $\pi\pi$ and $\rho\rho$ systems) when either the B^0 or the $\bar{B^0}$ from the $\Upsilon(4S)$ decay into a CP eigenstate, f_{CP} and the other into a state, f_{tag} that allows one to distinguish between B^0 and $\bar{B^0}$, is written as

$$f_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}[1 \pm S_f sin(\Delta m_d \Delta t) \mp C_f cos(\Delta m_d \Delta t)] \tag{1}$$

where $f_+(f_-)$ is the decay rate distribution when B_{tag} is a $B^0(\bar{B}^0)$, τ is the B-meson lifetime, Δm_d is the mass difference between the two B^0 mass eigenstates and $\Delta t = \Delta t_{CP} - \Delta t_{tag}$. The CP-parameters of interest are

$$S_f = \frac{2Im\lambda}{1+|\lambda|^2}, C_f = \frac{1-|\lambda|^2}{1+|\lambda|^2}, \tag{2}$$

The parameter λ describes all the interference effects that give rise to CP-violation, $\lambda = (q/p)(\bar{A}_{\bar{f}}/A_f)$. The first part q/p is the mixing phase $\pm e^{-2i\beta}$, where the sign depends on the CP final state. The experimentally favored assumption that there is no CP violation in mixing, $|q/p| = 1$ is implicit. The information about the decay is contained in the decay amplitudes $\bar{A}_{\bar{f}}$ and A_f. The decays can proceed through both so called tree and penguin amplitudes and what makes the extraction of α complicated is that the trees and the penguins carry different weak phases. This scenario is different from $b \to c\bar{c}s$ transitions, where both amplitudes carry the same weak phase. In the presence of penguins one obtains for $\pi\pi$ (and also for $\rho\rho$),

$$\lambda = e^{2i\alpha}\frac{1-re^{i(\delta-\alpha)}}{1-re^{i(\delta+\alpha)}} = |\lambda|e^{2i\alpha_{eff}} \tag{3}$$

where r is the ratio of the penguin and tree amplitudes. In the absence of penguin contributions one would obtain $S = sin2\alpha$. However as long as there is a penguin contribution to the process, the shift on α, $\theta = \alpha_{eff} - \alpha$, can be significant and can also lead to direct CP-violation, $C \neq 0$. Performing a time-dependent analysis and measuring S is the first step. To extract alpha one needs to perform an SU(2) isospin analysis [2]. In an isospin analysis one constructs two triangular relations from the decay amplitudes, and their complex conjugates, to the charged and neutral final states. The closure of the triangles is required by SU(2) symmetry and if electroweak penguins are neglected the two triangles can be given a common base. All observables, CP-asymmetries and branching ratios, can be related to the sides of the triangles.

Alternatively one could use a general bound on the penguin induced shift, θ [3]. One such bound is the Grossman-Quinn bound and is obtained from the ratio of branching fractions for $B^0 \to \pi^0\pi^0$ and $B^+ \to \pi^+\pi^0$ (or the corresponding ones for $B \to \rho\rho$). This bound provides a good initial estimate of the maximum shift on α from penguins.

2 $B \to \pi\pi$

The $B \to \pi\pi$ system has been studied extensively at both BaBar and Belle experiments [4]. The current HFAG [5] average values of the CP-asymmetries are, $C_{\pi\pi} = -0.46 \pm 0.13$, $S_{\pi\pi} = -0.73 \pm 0.16$ and $A_{CP}(\pi^+\pi^0) = -0.07 \pm 0.14$ and corresponding average branching ratios are, $BR(B \to \pi^+\pi^-) = (4.55 \pm 0.44) \times 10^{-6}$ and $BR(B^+ \to \pi^+\pi^0) = (5.18^{+0.77}_{-0.76}) \times 10^{-6}$.

The last side of the isospin triangle, the $B^0 \to \pi^0\pi^0$ branching ratio, is considerably more difficult to measure. Measurements were only recently provided by Babar and Belle and the average value is $BR(B^0 \to \pi^0\pi^0) = (1.90 \pm 0.47) \times 10^{-6}$ [5]. Penguin processes are expected to contribute significantly to this decay, although a large branching ratio does not necessarily imply large penguin contributions. However a small $B^0 \to \pi^0\pi^0$ branching ratio would imply small penguin contributions and consequently a small shift on alpha, $\theta = \alpha_{eff} - \alpha$. With the current measurements, the general Grossman-Quinn bound on θ is not very constraining as it implies $\theta < 48^o$ at $90\%CL$. If the $\pi^0\pi^0$ decay rate were larger one could in addition measure $C_{\pi^0\pi^0}$ and do the full isospin analysis. Thus there are currently no meaningful constraints on α from the $B \to \pi\pi$ system.

3 $B \to \rho\pi$

The $B \to \rho\pi$ decay is also sensitive to α but its extraction is complicated by the fact that $\rho^+\pi^-$ is not a CP-eigenstate and therefore two more decay amplitudes are introduced. This yields a new relative unknown strong phase that needs to be considered in addition to the shift from penguins.

A quasi-two body time dependent analysis of $B^0 \to \rho^+\pi^-$ has been carried out at BaBar [7] but unfortunately the results do not provide a constraint on α. With the current measurements, even in the absence of penguins, one would have an eightfold ambiguity on the solution.

A full SU(2) isospin analysis for the $\rho\pi$ system has been proposed [8], and instead of triangular relations, pentagon relations need to be constructed. The branching ratio of $B^0 \to \rho^0\pi^0$ is important for the full isospin analysis, since a small value would indicate a small penguin contribution. BaBar has set an upper limit, $BR(B^0 \to \rho^0\pi^0) < 2.5 \times 10^{-6}$, while Belle finds a large but not statistically significant value [9]: $BR(B^0 \to \rho^0\pi^0) = (5.1 \pm 1.6 \pm 0.9) \times 10^{-6}$. Studies indicate that only a small branching ratio for this mode would allow a determination of α from a full isospin analysis of the $B \to \rho\pi$ system [10]. However even such a favorable scenario is beyond the reach of first generation B-factories, as data on the order of $1ab^{-1}$ are required.

4 $B \to \rho\rho$

This process is a vector-vector decay and three partial waves (S, P, D) contribute to it. The P wave corresponds to a CP-odd eigenstate while S and D are CP-even. Three helicity states, $h = \pm 1$ and $h = 0$, need to be considered. The zero helicity state, $h = 0$, is longitudinally polarized while the other two are transversely polarized. Only the S and D partial waves contribute to the longitudinal polarization, which makes this a CP-even final state. Recently BaBar measured the $B^0 \to \rho^+\rho^-$ branching ratio and polarization [11]. The decay was found to have a relatively large branching ratio,$(30 \pm 4 \pm 5) \times 10^{-6}$, and to be 99% longitudinally polarized, implying that nearly all events are decays into a state with a definite CP value. The state with transverse polarization is a mixture of CP-even and odd eigenstates.

Applying the Grossmann-Quinn bound, one finds the upper limit on the penguin pollution to be less than $13^o(16^o)$ at $67(90)\%C.L.$ Such a good constraint is achievable due to the small branching ratio of $B^0 \to \rho^0\rho^0$ relative to that of $B^+ \to \rho^+\rho^0$.

The $B^0 \to \rho^+\rho^-$ time dependent analysis has been performed at Babar with a simultaneous measurement of the polarization and branching fraction [11]. The CP-parameters from the initial measurement have been updated with more

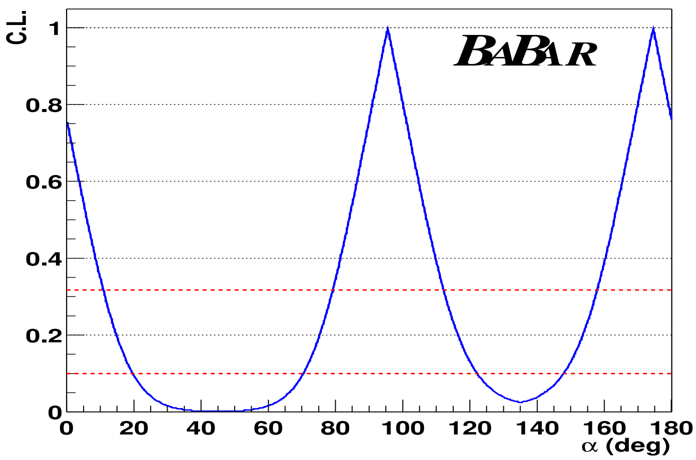

Figure 1: *Confidence level scan in α from $B \to \rho\rho$.*

statistics and the new results are [12], $C_{\rho^+\rho^-} = -0.23 \pm 0.24 \pm 0.14$ and $S_{\rho^+\rho^-} = -0.19 \pm 0.33 \pm 0.11$.

An SU(2) isospin analysis, to determine the angle α was also performed. This analysis neglects $I = 1$ transition amplitudes, electroweak penguins and interference with other modes that decay to the same final state. This isospin analysis uses the $\rho^+\rho^-$ CP-parameters, the averaged branching fractions and polarizations for the neutral and charged $\rho\rho$ decay modes [5]. In the case of $B^0 \to \rho^0\rho^0$ no polarization measurement is available, thus the longitudinal polarization fraction was conservatively assumed to be 1.0. The isospin analysis confidence level scan in α is plotted in Figure 1. Selecting the solution closest to the global CKM best fit [10], we find $\alpha = 96^o \pm 10^o(stat) \pm 4^o(syst) \pm 13^o(penguin)$.

The limiting factor in the measurement is the theoretical uncertainty of the amount of penguin pollution. Of great importance is the $B^0 \to \rho^0\rho^0$ branching ratio, which if truly small ($< 1 \times 10^{-6}$) can be used to set a stringent limit on the shift on α. If the branching ratio is however large ($> 2 \times 10^{-6}$), a time dependent analysis on this mode can be done. The new additional observables $S_{\rho^0\rho^0}, C_{\rho^0\rho^0}$, would make a full isospin analysis possible, giving a better measurement of α.

In summary, the best constraint on the CKM angle α is currently provided by the $B \to \rho\rho$ system. The measurement still remains limited by the uncertainty about the precise amount of penguin pollution.

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