Measurements of CKM angles β/ϕ_1 and α/ϕ_2 at *BABAR* and Belle experiments

A. Lazzaro on behalf of the *BABAR* and Belle Collaborations
Università degli Studi and INFN, Milano, Italy

We report measurements of the CKM angles β/ϕ_1 and α/ϕ_2 done by the *BABAR* and Belle experiments. Both experiments have collected large data samples, corresponding to a total of more than 1 billion of $B\overline{B}$ pairs, at the e^+e^- asymmetric-energy colliders PEP-II (SLAC) and KEK-B (KEK), respectively.

1. Introduction

CP violation in the Standard Model (SM) [1] is described by an irreducible complex phase in the Cabibbo-Kobayashi-Maskawa (CKM) quark-mixing 3×3 matrix [2]. The equation $V_{ud}V_{ub}^\star + V_{cd}V_{cb}^\star + V_{td}V_{tb}^\star = 0$, which follows from the unitarity of the CKM matrix V, can be depicted as a triangle – called Unitarity Triangle (UT) – in the complex plane [3]. The main goal of the B-factories is to verify the SM picture of the origin of the *CP* violation, measuring the angles (denoted by α, β, and γ [1]) and the sides of the UT in B decays. In this review we report results obtained by the *BABAR* and Belle collaborations concerning the measurements of the angles α and β.

2. Detectors and Datasets

Measurements reported in this paper have been obtained by the *BABAR* and Belle experiments at the asymmetric-energy e^+e^- B factories PEP-II [4] and KEK-B [5], respectively. At the time of writing the two experiments collected more than $430\,\mathrm{fb}^{-1}$ and $750\,\mathrm{fb}^{-1}$, respectively, recorded at the $\Upsilon(4S)$ resonance (center-of-mass energy $\sqrt{s} = 10.58$ GeV), which corresponds to a total of approximately 1.3 billion $B\overline{B}$ events. PEP-II and *BABAR* have stopped data taking at the beginning of April, 2008. The *BABAR* and Belle detectors are described elsewhere [6, 7].

3. Measurements of β

Measurements of time-dependent *CP* asymmetries in B^0 meson decays through a dominant CKM favored $b\to c\bar{c}s$ tree amplitude, such as $B^0\to J/\psi K^0$, have provided a precise measurement of β angle, giving a crucial test of the mechanism of *CP* violation in the SM [8]. For such decays the interference between this amplitude and the amplitude from the $B^0-\overline{B}^0$ mixing is dominated by the single phase $\beta = \arg\left[-(V_{cd}V_{cb}^*)/(V_{td}V_{tb}^*)\right]$ of the CKM mixing matrix. Other quark transitions involving quark c which allow to measure the angle β, using time-dependent measurements of B^0 decays, are $b\to c\bar{c}d$, like $B^0\to J/\psi\pi^0$ and $B^0\to D^{*+}D^{*-}$, and $b\to c\bar{u}d$, like $B^0\to D^{(*)0}h^0$. Either tree and loop (penguin) amplitudes can contribute in these transitions, so they can be sensitive to New Physics (NP) due to the large virtual mass scale occurring in the penguin loops.

To measure time-dependent *CP* asymmetries we reconstruct a B^0 decaying into a *CP* eigenstate (B_{CP}). From the remaining particles in the event we also reconstruct the decay vertex of the other B meson ($B_{\rm tag}$) and identify its flavor. The difference $\Delta t \equiv t_{CP} - t_{\rm tag}$ of the proper decay times t_{CP} and $t_{\rm tag}$ of the *CP* and tag B mesons, respectively, is obtained from the measured distance between the B_{CP} and $B_{\rm tag}$ decay vertices and from the known boost of the e^+e^- system. The distribution of the difference Δt is given by

$$\begin{aligned} P(\Delta t) \;=\; & \frac{e^{-|\Delta t|/\tau}}{4\tau}\{1\pm \\ & [-\eta_f S_f\sin(\Delta m_d\Delta t) - C_f\cos(\Delta m_d\Delta t)]\} \end{aligned} \tag{1}$$

where η_f is the *CP* eigenvalue of final state f, the upper (lower) sign denotes a decay accompanied by a B^0 ($\overline{B}^0$) tag, τ is the mean B^0 lifetime, and Δm_d is the mixing frequency. The parameters C_f and S_f for the final state f are the *CP*-violating parameters

$$S_f = \frac{2\mathrm{Im}(\lambda_f)}{|\lambda_f|^2+1}, \quad C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}, \tag{2}$$

where λ_f is a complex parameter depending on the $B^0-\overline{B}^0$ mixing as well as on the decay amplitudes for both B^0 and $\overline{B}^0$ to the *CP* eigenstate [2].

When only one diagram contributes to the decay process and no other weak or strong phases appear

[1] Also denoted by ϕ_2, ϕ_1, and ϕ_3, respectively. The Greek notation, used by *BABAR* experiment, is used thought this paper.

[2] Note that in the Belle convention $C_f = -A_f$.

in the process, the SM predicts $C_f = 0$ and $S_f = -\eta_f \sin 2\beta$. A nonzero value of the parameter C_f would indicate direct *CP* violation. Any significant deviation from the SM prediction could be a sign of NP.

An alternative way to measure the β angle is to use measurement of time-dependent *CP* asymmetries in decays of B^0 mesons to charmless hadronic final states, such as ϕK^0, $f_0(980)K^0$, $K^+K^-K^0$, $\eta' K^0$, $\pi^0 K^0_S$, $K^0_S K^0_S K^0_S$, $\rho^0 K^0_S$, ωK^0_S. These decays are CKM-suppressed $b \to q\bar{q}s$ ($q = u$, d, s) processes dominated by a single penguin amplitude, with the same week phase as the $b \to c\bar{c}s$ transition [9]. In these modes, assuming the penguin dominance of $b \to s$ transition and neglecting CKM-suppressed amplitudes, the time-dependent *CP*-violating parameter S_f is expected to be $-\eta_f \sin 2\beta$. However, CKM-suppressed amplitudes and the color-suppressed tree-level diagram introduce additional weak phases whose contribution may not be negligible [10–13]. As a consequence, only an effective $S = -\eta_f \sin 2\beta_{\rm eff}$ is determined. The deviation $\Delta S = S - (-\eta_f \sin 2\beta)$ has been estimated in several theoretical approaches [11–16]. The estimates are channel and model dependent. Also for these decays the possible presence of additional diagrams with new heavy particles in the loop and new *CP*-violating phases may contribute to the decay amplitudes. In this case the measurements of significantly larger ΔS are a sensitive probe for NP [10].

3.1. $b \to c\bar{c}s$ Decays

The $b \to c\bar{c}s$ transitions are referred to as the "golden modes" due to their relatively large branching fractions $\mathcal{O}(10^{-4} - 10^{-5})$, low experimental background levels and high reconstruction efficiencies. They are dominated by a color-suppressed tree diagram and the theoretical uncertainties are small [17]. Hence the prediction $S_f = -\eta_f \sin 2\beta$ and $C_f = 0$ is valid to a good accuracy.

BABAR reconstructed the modes B^0 to $J/\psi K^0_S$, $J/\psi K^{*0}$, $\psi(2S)K^0_S$, $J/\psi K^0_L$, $\eta_c K^0_S$, and $\chi_{c1} K^0_S$, extracting the *CP*-violating parameters from a simultaneous fit to all modes. The statistic used corresponds to 383 million of $B\overline{B}$ pairs [18]. Belle reconstructed only the modes $B^0 \to J/\psi K^0_S$ and $B^0 \to J/\psi K^0_L$ using 535 million of $B\overline{B}$ pairs [19]. Recently Belle also reported a measurement of the *CP*-violating parameters in the $B^0 \to \psi(2S)K^0_S$ channel, using a sample of 657 million of $B\overline{B}$ pairs [20]. Comparing *BABAR* and Belle results, they agree within the measurement uncertainties. All results are shown in Table I. A world average, calculated by the Heavy Flavor Averaging Group (HFAG) [21], gives $\sin 2\beta = 0.680 \pm 0.025$, which reduces the total uncertainty on $\sin 2\beta$ to 3.7%. No evidence of direct *CP* violation is seen in these modes.

Table I Results for $b \to c\bar{c}s$ "golden modes" decays. The errors are, in order, statistical and systematic.

B^0 decays	$B\overline{B}$ pairs ($\times 10^6$)	Results
BABAR		
$J/\psi K^0_S$, $J/\psi K^{*0}$, $\psi(2S)K^0_S$, $J/\psi K^0_L$, $\eta_c K^0_S$, $\chi_{c1} K^0_S$	383	$\sin 2\beta = 0.714 \pm 0.032 \pm 0.018$ $C = 0.049 \pm 0.022 \pm 0.017$
Belle		
$J/\psi K^0_S$, $J/\psi K^0_L$	535	$\sin 2\beta = 0.642 \pm 0.031 \pm 0.017$ $C = -0.018 \pm 0.021 \pm 0.014$
$\psi(2S)K^0_S$	657	$\sin 2\beta = 0.718 \pm 0.090 \pm 0.033$ $C = -0.039 \pm 0.069 \pm 0.049$
Average	–	$\sin 2\beta = 0.650 \pm 0.029 \pm 0.018$ $C = -0.019 \pm 0.020 \pm 0.015$

BABAR and Belle also reported measurements of the β angle using the B^0 decay to $D^{*\pm}D^{*\mp}K^0_S$ [22, 23]. This decay proceeds mainly with the $b \to c\bar{c}s$ transition. A potential interference effect of the decay proceeding through an intermediate resonance can be measured by dividing the B-decay Dalitz plot into regions with $s^+ \leq s^-$ or $s^+ \geq s^-$, where $s^\pm \equiv m^2(D^{*\pm}K^0_S)$. The interesting result from such an analysis is the possibility to extract the sign of the $\cos 2\beta$, which allows to partially resolve the 4-fold ambiguity in the value of β obtained from the measurement of the $\sin 2\beta$. For these modes the time-dependent *CP* asymmetry is described in terms of the coefficients J_c, J_0, J_{s1}, and J_{s2}, which are the integrals over the half-Dalitz space. The results are shown in Table II and there is a general agreement between the two experiments. *BABAR* infers that $\cos 2\beta > 0$ at 94% confidence level (CL), on the assumption that $J_{s2} > 0$ [22].

Table II Results for B^0 decay to $D^{*\pm}D^{*\mp}K^0_S$. The errors are, in order, statistical and systematic.

	$B\overline{B}$ pairs ($\times 10^6$)	Results
BABAR	230	$J_c/J_0 = 0.76 \pm 0.18 \pm 0.07$ $2J_{s1}/J_0 \sin 2\beta = 0.10 \pm 0.24 \pm 0.06$ $2J_{s2}/J_0 \cos 2\beta = 0.38 \pm 0.24 \pm 0.05$
Belle	449	$J_c/J_0 = 0.60^{+0.25}_{-0.28} \pm 0.08$ $2J_{s1}/J_0 \sin 2\beta = -0.17 \pm 0.42 \pm 0.09$ $2J_{s2}/J_0 \cos 2\beta = -0.23^{+0.43}_{-0.41} \pm 0.13$

3.2. $b \to c\bar{c}d$ Decays

The $B^0 \to J/\psi\pi^0$ decay takes place through a $b \to c\bar{c}d$ transition. The dominant tree diagram is Cabibbo suppressed. However there is a penguin diagram of the same order as the tree diagram and with a different weak phase. So, contrary to the golden modes, even within the SM, the deviation of S measured in $b \to c\bar{c}d$ modes from $-\eta_f \sin 2\beta$ could be substantial. Both *BABAR* and Belle have updated measurements for this mode, which are shown in Table III [24, 25]. In particular the *BABAR* result shows an evidence of *CP* violation, with a statistical significance of 4σ (2.4σ for the Belle measurement).

Also the decay $B^0 \to D^{*+}D^{*-}$ goes through the $b \to c\bar{c}d$ transition. This mode requires an angular analysis to disentangle *CP*-odd and *CP*-even events. Results for *CP*-violating parameters are show in Table III [26].

The quark transition $b \to c\bar{c}d$ is also responsible for the B^0 decays to $D^{*+}D^-$, $D^{*-}D^+$, and D^+D^-. Results for *BABAR* and Belle experiments are shown in Table III [27, 28]. Belle reports 3.2σ for direct *CP* violation in the D^+D^- mode, not confirmed by the *BABAR* experiment.

Within the experimental uncertainties, all results for $b \to c\bar{c}d$ decays are compatible with the SM prediction.

Table III Results for B^0 decays to $J/\psi\pi^0$, $D^{*+}D^{*-}$, $D^{*+}D^-$, $D^{*-}D^+$, and D^+D^- ($b \to c\bar{c}d$ decays). The errors are, in order, statistical and systematic.

	$B\overline{B}$ pairs ($\times 10^6$)	Results
	$J/\psi\pi^0$	
BABAR	466	$S = -1.23 \pm 0.21 \pm 0.04$
		$C = -0.20 \pm 0.19 \pm 0.03$
Belle	535	$S = -0.65 \pm 0.21 \pm 0.05$
		$C = -0.08 \pm 0.16 \pm 0.05$
	$D^{*+}D^{*-}$	
BABAR	383	$S = -0.66 \pm 0.19 \pm 0.04$
		$C = -0.02 \pm 0.11 \pm 0.02$
Belle	657	$S = -0.93 \pm 0.24 \pm 0.15$
		$C = -0.16 \pm 0.13 \pm 0.02$
	$D^{*+}D^-$	
BABAR	383	$S = -0.79 \pm 0.21 \pm 0.06$
		$C = \quad 0.18 \pm 0.15 \pm 0.04$
Belle	152	$S = -0.55 \pm 0.39 \pm 0.12$
		$C = -0.37 \pm 0.22 \pm 0.06$
	$D^{*-}D^+$	
BABAR	383	$S = -0.44 \pm 0.22 \pm 0.06$
		$C = \quad 0.23 \pm 0.15 \pm 0.04$
Belle	152	$S = -0.96 \pm 0.43 \pm 0.12$
		$C = \quad 0.23 \pm 0.25 \pm 0.06$
	D^+D^-	
BABAR	383	$S = -0.54 \pm 0.34 \pm 0.06$
		$C = \quad 0.11 \pm 0.22 \pm 0.07$
Belle	535	$S = -1.13 \pm 0.37 \pm 0.09$
		$C = -0.91 \pm 0.23 \pm 0.06$

3.3. $b \to c\bar{u}d$ Decays

The decay $B^0 \to D^{(*)0}_{CP} h^0 (h^0 = \pi^0, \eta, \omega)$ is governed by a color-suppressed $b \to c\bar{u}d$ tree diagram. When the neutral D meson decays to a *CP* eigenstate Eq. 1 is still valid. In these modes the possible effects of NP are expected small, so we expect $S = \sin 2\beta$ [9]. Only *BABAR* reported a measurement of such decays [29], by reconstructing the following decay modes $D^{*0} \to D^0\pi^0$ and $D^0 \to K^+K^-$, $D^0 \to K^0_S\pi^0$ and $D^0 \to K^0_S\omega$. The analysis is performed on 383×10^6 $B\overline{B}$ pairs of which 340 ± 32 signal events are reconstructed. The measured *CP*-violating parameters,

$$
\begin{aligned}
\sin 2\beta &= \quad 0.56 \pm 0.23(\mathrm{stat}) \pm 0.05(\mathrm{syst}) \\
C &= -0.23 \pm 0.16(\mathrm{stat}) \pm 0.04(\mathrm{syst}),
\end{aligned}
$$

are consistent with the SM expectations.

Also the decay $B^0 \to D^{(*)0}h^0$, where $h^0 = \pi^0, \eta, \omega, \eta'$, is governed by the $b \to c\bar{u}d$ tree diagram. This decay can occur with and without $B^0-\overline{B}^0$ mixing and interference effects are visible across the $D^0 \to K^0_S\pi^+\pi^-$ Dalitz plot. The interesting result from this measurement is the possibility to extract the sign of $\cos 2\beta$ in order to resolve the 4-fold ambiguity in the value of β obtained from the measurement of the $\sin 2\beta$. The results from *BABAR* are obtained using 383 million of $B\overline{B}$ pairs:

$$
\begin{aligned}
\sin 2\beta &= 0.29 \pm 0.34(\mathrm{stat}) \pm 0.03(\mathrm{syst}) \pm 0.05(\mathrm{Dalitz}) \\
\cos 2\beta &= 0.42 \pm 0.49(\mathrm{stat}) \pm 0.09(\mathrm{syst}) \pm 0.13(\mathrm{Dalitz}),
\end{aligned}
$$

leading to a preferred positive sign for $\cos 2\beta$ at 86% CL [30]. The Dalitz error refers to the Dalitz model parameterization used in the analysis. Belle performed a similar analysis on 386 million of $B\overline{B}$ pairs:

$$
\begin{aligned}
\sin 2\beta &= 0.78 \pm 0.44(\mathrm{stat}) \pm 0.22(\mathrm{syst} + \mathrm{Dalitz}) \\
\cos 2\beta &= 1.87^{+0.40}_{-0.53}(\mathrm{stat})^{+0.22}_{-0.32}(\mathrm{syst} + \mathrm{Dalitz}),
\end{aligned}
$$

which gives a preferred positive sign of $\cos 2\beta$ at 98.3% CL [31].

3.4. $b \to s$ Decays

No major updates on the $b \to s$ decays have been reported by the *BABAR* and Belle recently. Summary of the results for the time-dependent S parameter is shown in the Fig. 1 [21]. In general the results are consistent between *BABAR* and Belle, and consistent with SM expectations inside statistical uncertainties. Some tensions are observed for the $B^0 \to \pi^0\pi^0 K^0_S$ decay results with respect to the SM expectation. Also tensions are observed in $B^0 \to f_0(980) K^0_S$ decay between *BABAR* and Belle results. However, in this case the *BABAR* result reported in the figure is a combination of results from the two Dalitz plot analyses, considering $f_0(980) \to K^+K^-$ and $f_0(980) \to \pi^+\pi^-$, while Belle uses only the $f_0(980) \to \pi^+\pi^-$ mode. The results are found in agreement using only the $f_0(980) \to \pi^+\pi^-$ decay. No evidence of direct *CP* violation is observed.

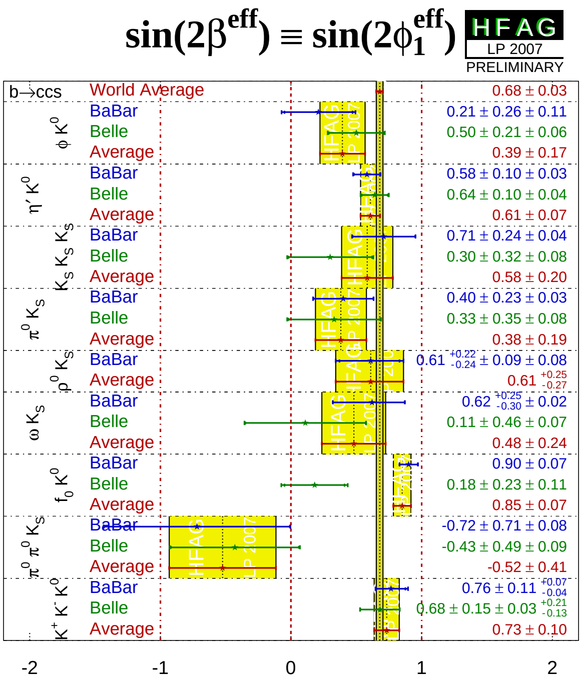

Figure 1: Summary of time-dependent S parameter results for $b \to s$ penguin modes [21].

4. Measurements of α

The UT angle α, defined as $\arg\left[-(V_{td}V^*_{tb})/(V_{ud}V^*_{ub})\right]$, can be determined by measuring a time-dependent *CP* asymmetry in charmless $b \to u\bar{u}d$ decays such as $B^0 \to \pi^+\pi^-$, $\pi^+\pi^-\pi^0$, $\rho^+\rho^-$, and $a_1^\pm(1260)\pi^\mp$, in a way similar to what described in section 3. The B decays proceed mainly through a tree and gluonic penguin amplitude. The penguin amplitude is irrelevant to the α and contaminates the measurement. The penguin contribution can be constrained by using isospin relations or approximate flavour SU(3) relations [32–34].

4.1. $B^0 \to \pi^+\pi^-$ and $B^0 \to \rho^+\rho^-$ Decays

Similar to Eq. 1, the time-dependent rate for $B^0 \to \pi^+\pi^-$ is given by

$$P(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}\{1 \pm [S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)]\} \quad (3)$$

where C and S are *CP* asymmetry coefficients. If the decay amplitude is dominated by a tree diagram then $S = \sin 2\alpha$ and $C = 0$. The presence of an amplitude with a different weak phase (such as from a gluonic penguin diagram) gives rise to direct *CP* violation and shifts S from $\sin 2\alpha$:

$$S = \sqrt{1 - C^2}\sin 2\alpha_{\rm eff}, \quad (4)$$

where $\alpha_{\rm eff} = \alpha + \delta\alpha$, and $\delta\alpha$ is the phase shift.

BABAR and Belle results for $B^0 \to \pi^+\pi^-$ time-dependent *CP*-violating parameters are shown in Table IV [35, 36]. Both measurements indicate a large mixing-induces *CP*-violation with a significance greater than 5σ for any values of C. Belle also observed large direct *CP* violation (5.5σ). The difference between *BABAR* and Belle on (S, C) plane is about 2.1σ [21]. The angle α can be extracted using isospin relations, which require the measurement of branching fractions and *CP*-violating parameters for the SU(2) partners of the $B^0 \to \pi^+\pi^-$ decay: $B^0 \to \pi^0\pi^0$ and $B^\pm \to \pi^0\pi^\pm$ [32]. The *BABAR* and Belle constraint on α consistent with the SM are $(96^{+10}_{-6})^\circ$ and $(97 \pm 11)^\circ$, respectively, at 68% CL.

Another decay used to measure the angle α is $B^0 \to \rho^+\rho^-$. For this mode the same considerations described above for the $B^0 \to \pi^+\pi^-$ mode are still valid. $B^0 \to \rho^+\rho^-$ channel has several advantages comparing with $B^0 \to \pi^+\pi^-$:

- higher branching fraction (about 4.4 times larger) [3];
- smaller contribution by the penguin amplitude with respect to the leading tree diagram, constrained by the small branching fraction of $B^0 \to \rho^0\rho^0$ [37];
- possibility to measure the time-dependent *CP*-violating parameters in $B^0 \to \rho^0\rho^0$ for the SU(2) constraint.

However there are also certain disadvantages:

- higher combinatorial background due to the relatively large width of ρ meson (~ 150 MeV);

- $\rho^+\rho^-$ is a vector-vector final state. For the time-dependent analysis it requires to disentangle longitudinally and transversely polarized events. However, recent measurements of the polarization fraction by *BABAR* and Belle show that the mode has almost a pure longitudinal polarization [38, 39].

BABAR and Belle results are shown in Table IV [38, 39]. Both experiments are consistent each other and consistent with no *CP* violation. To extract α using SU(2) relations, *BABAR* has recently performed the measurement of the time-dependent *CP*-violating parameters in $B^0 \to \rho^0\rho^0$ with 427 million of $B\overline{B}$ pairs, measuring a branching fraction of $(0.84 \pm 0.29 \pm 0.17) \times 10^{-6}$, a longitudinal polarization of $0.70 \pm 0.14 \pm 0.05$ and for the longitudinally polarized events $S_L = 0.5 \pm 0.9 \pm 0.2$ and $C_L = 0.4 \pm 0.9 \pm 0.2$ (errors are statistical and systematic, respectively) [40]. Together with all other measurements from SU(2) partners, it results $74^\circ < \alpha < 117^\circ$ at 68% CL, with a constraint of $|\delta\alpha| < 14.5^\circ$ at 68% CL and a preferred solution of $\delta\alpha = +11.3^\circ$. There are not time-dependent *CP*-violating measurements by Belle for $B^0 \to \rho^0\rho^0$ mode, setting an upper limit with 657 million of $B\overline{B}$ pairs for the branching fraction of this mode of 1.0×10^{-6} at 90% CL. The Belle constraint on α is $(91.7 \pm 14.9)^\circ$ [41].

Table IV Results for B^0 decays to $\pi^+\pi^-$ and $\rho^+\rho^-$. Note that the *CP*-violating parameters for $B^0 \to \rho^+\rho^-$ refer to longitudinally polarized events. The errors are, in order, statistical and systematic.

	$B\overline{B}$ pairs ($\times 10^6$)	Results
	$\pi^+\pi^-$	
BABAR	383	$S = -0.60 \pm 0.11 \pm 0.03$ $C = -0.21 \pm 0.09 \pm 0.02$
Belle	535	$S = -0.61 \pm 0.10 \pm 0.04$ $C = -0.55 \pm 0.08 \pm 0.05$
	$\rho^+\rho^-$	
BABAR	383	$S_L = -0.17 \pm 0.20^{+0.05}_{-0.06}$ $C_L = 0.01 \pm 0.15 \pm 0.06$
Belle	535	$S_L = 0.19 \pm 0.30 \pm 0.08$ $C_L = -0.16 \pm 0.21 \pm 0.08$

4.2. $B^0 \to \pi^+\pi^-\pi^0$ $(\rho\pi)^0$ and $B^0 \to a_1^\pm(1260)\pi^\mp$ Decays

An alternative way to measure the angle α is to perform a time-dependent Dalitz plot analysis in $B^0 \to \pi^+\pi^-\pi^0$ decays. We model the interference between the intersecting ρ resonance bands and so determines the strong phase differences from the Dalitz plot structure [42]. The Dalitz amplitudes and time-dependence are contained in complex parameters that are determined by fit on data. This technique allows to extract directly α. *BABAR* and Belle have performed measurements using 383 million and 449 million of $B\overline{B}$ pairs, respectively. The intervals at 68% CL are $74^\circ < \alpha < 132^\circ$ for *BABAR* [43] and $68^\circ < \alpha < 95^\circ$ for Belle [44].

Another channel which allows to measure α is $B^0 \to a_1^\pm(1260)\pi^\mp$. For this mode a Dalitz plot analysis is not feasible with the current statistics, so it is used a quasi-two-body approach. As the final state $a_1^\pm(1260)\pi^\mp$ is not a *CP* eigenstate, one has to consider four decay modes, divided in two groups, with different charge and flavor combinations: $B^0 \to a_1^+(1260)\pi^-$ and $\overline{B}^0 \to a_1^+(1260)\pi^-$; $B^0 \to a_1^-(1260)\pi^+$ and $\overline{B}^0 \to a_1^-(1260)\pi^+$. For each group is valid the Eq. 3, where we denote the *CP*-violating parameters as S^+, C^+ and S^-, C^-, respectively [45]. It is possible to redefine these parameters as $S = (S^+ + S^-)/2$, $C = (C^+ + C^-)/2$, $\Delta S = (S^+ - S^-)/2$, $\Delta C = (C^+ - C^-)/2$. *BABAR* performed this analysis using 383 million of $B\overline{B}$ pairs [46], extracting 608 ± 52 signal events and the following time-dependent *CP*-violating parameters:

$$\begin{aligned} S &= 0.37 \pm 0.21 \pm 0.07 \\ C &= -0.10 \pm 0.15 \pm 0.09 \\ \Delta S &= -0.14 \pm 0.21 \pm 0.06 \\ \Delta C &= 0.26 \pm 0.15 \pm 0.07 \end{aligned}$$

where the errors are, in order, statistical and systematic. Also a time- and flavour-integrated charge asymmetry for direct *CP* violation has been measured, $\mathcal{A}_{CP} = -0.07 \pm 0.07 \pm 0.02$. These measurements indicate no direct and time-dependent *CP* violation in $B^0 \to a_1^\pm(1260)\pi^\mp$ decay. The effective angle $\alpha_{\rm eff}$ is $(78.6 \pm 7.3)^\circ$. The extraction of α can be performed using an SU(3) flavor symmetry [45]. Once the measurements of branching fractions for the SU(3)-related decays become available, it will be possible to determine an upper bound on $\delta\alpha$ for $B^0 \to a_1^\pm(1260)\pi^\mp$ to constraint the angle α.

5. Conclusions

In this review we have presented measurements, done by the *BABAR* and Belle experiments, used to measure the angles β and α of the UT. The world averages give a favored value of $\beta = (21.5 \pm 1.0)^\circ$ [21] and $\alpha = (87.5^{+6.2}_{-5.3})^\circ$ [47]. The *CP*-violating parameters are consistent with the Standard Model expectations within the uncertainties of the measurements.

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