CKM-UT Angles: Mixing and CP violation at the B Factories

G. Finocchiaro\(^a\), on behalf of the BaBar and Belle Collaborations.

\(^a\)Laboratori Nazionali di Frascati dell’INFN
Via Enrico Fermi 40,
F.O. Box 00044, Frascati, Rome, Italy

We review the experimental status of the angles of the Unitarity Triangle of the CKM matrix, as measured by the BaBar and Belle experiments.

1. Introduction

The B Factories have demonstrated since the beginning of this decade that CP violation in the B meson system is consistent with the Standard Model (SM) description in terms of the complex phase in the three-by-three Cabibbo-Kobayashi-Maskawa (CKM) matrix \([1]\). With one single phase, the SM predicts clear patterns for quark mixing and CP violations, to be satisfied by all processes. The unitarity relation

\[
V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0
\]

among the first and third columns of the CKM matrix is represented in the complex plane by a Unitarity Triangle (UT) with angles \(\alpha = \arg[-V_{td}V_{tb}^*/V_{ub}V_{ub}^*], \beta = \arg[-V_{cd}V_{cb}^*/V_{ub}V_{ub}^*], \gamma = \arg[-V_{td}V_{td}^*/V_{cd}V_{cd}^*]\). Physics beyond the SM could in general change the picture; for this reason it is very important to make many independent measurements to possibly find inconsistencies of the SM. In the evolution of \(B^0\Bar{B}^0\) pairs, we reconstruct the decay of one meson to final \(f\) at proper time \(t_f\), and identify (tag) its flavor using information from the other B meson in the event, decaying at time \(t_{tag}\). The time-dependent CP asymmetry of \(B^0\Bar{B}^0\) mesons decaying to final state \(f\) can be defined as \(A_{CP}(\Delta t) \equiv (N_f - N_{\bar{f}})/(N_f + N_{\bar{f}}) = S_f \sin(\Delta m_d \Delta t) - C_f \cos(\Delta m_d \Delta t)\). Here \(\Delta t = t_f - t_{tag}\), and \(\Delta m_d\) is the mass difference of the B meson mass eigenstates.\(^1\) The sine term results from the interference between direct decay and decay after a \(B^0\Bar{B}^0\) oscillation. A non-zero cosine term arises from the interference between decay amplitudes with different weak and strong phases (direct CP violation) or from CP violation in \(B^0\Bar{B}^0\) mixing (the latter is predicted to be small in the SM and has not been observed to date).

The results discussed in the present paper were obtained by the BaBar [2] and Belle [3] experiments, respectively located at the PEP-II and KEKB \(e^+e^-\) asymmetric-energy B factories. Here pairs of \(B^0\Bar{B}^0\) mesons are produced almost at rest in the decay of the \(\Upsilon(4S)\) resonance. The separation between their decay vertices is increased in the laboratory frame due to the boost given by the asymmetric-energy beams.

The BaBar experiment has concluded the data taking, collecting a total of 531 fb\(^{-1}\), of which 433 fb\(^{-1}\) on the \(\Upsilon(4S)\) peak, corresponding to about 470 \(\times 10^6\) \(B^0\Bar{B}^0\) pairs. Belle have logged about 850 fb\(^{-1}\) (730 fb\(^{-1}\) on the \(\Upsilon(4S)\) resonance) as of June 2008. The results discussed in the present report refer to about 383 \(\times 10^6\) \(B^0\Bar{B}^0\) pairs (BaBar) and about 535 \(\times 10^6\) \(B^0\Bar{B}^0\) pairs (Belle) unless otherwise noted.

2. Measurements of \(\beta\)

2.1. \(\sin2\beta\) from \(b \rightarrow c\Bar{c}s\)

The B-Factory paradigm of CP violation measurements is \(\sin2\beta\) from \(b \rightarrow c\Bar{c}s\) decays. Being dominated by a single decay amplitude, in the SM with very good accuracy \(C_f = 0\) and

\(^1\)Some authors, including the Belle collaboration, use the symbols \(\phi_2, \phi_3, \phi_4\) for the angles \(\alpha, \beta, \gamma\), and \(A_f = -C_f\) for the parameter describing direct CP violation. In the present article we will follow the \(\alpha, \beta, \gamma, C_f\) nomenclature.
$S_f = -\eta_f \sin 2\beta$ for these decays, with $\eta_f$ the CP eigenvalue of the final state. The latest measurement from BaBar [4], $\sin 2\beta = 0.714 \pm 0.032 \pm 0.018$, $C = 0.049 \pm 0.022 \pm 0.017^2$ includes modes with $\eta_f = -1 (B^0 \rightarrow J/\psi K^0_s, \psi(2S)K^0_s, \eta_s K^0_s, \chi_{c1} K^0_s)$, with $\eta_f = +1 (B^0 \rightarrow J/\psi K^0_s)$, and $B^0 \rightarrow J/\psi K^{*0}(\pi^0 K^0_s)$, which has no definite CP parity. Belle’s latest published measurement [5] concentrates on $B^0 \rightarrow J/\psi K^0_s$, $\sin 2\beta = 0.650 \pm 0.029 \pm 0.018$, $C = 0.018 \pm 0.021 \pm 0.014$. Belle have recently published an updated measurement in the $\psi(2S)K^0_s$ channel [6], based on $657 \times 10^6 B\overline{B}$ pairs. The results, $\sin 2\beta = 0.72 \pm 0.09 \pm 0.03$ and $C = 0.019 \pm 0.020 \pm 0.015$, are in good agreement with the $B^0 \rightarrow J/\psi K^0_s$ measurement.

2.2. $b \rightarrow c\bar{c}d$ decays

This class of decays includes both $B^0 \rightarrow J/\psi \pi^0$, whose expected main contribution is a color-suppressed internal spectator tree diagram, and $B^0 \rightarrow D^{(*)-}\bar{D}^{(*)-}$, dominated by a color-allowed tree diagram. In either case the weak phase of the involved CKM matrix elements is the same as in $b \rightarrow \tau\bar{\tau}f$ decays, and the SM would predict $C = 0$ and $S = \sin 2\beta$ in the absence of penguin-mediated contributions. The new BaBar measurement of the CP-even $B^0 \rightarrow J/\psi \pi^0$ channel based on the full dataset of $466 \times 10^6 B\overline{B}$ pairs [7] ($S = -1.23 \pm 0.21 \pm 0.04, C = -0.20 \pm 0.19 \pm 0.03$), constitutes a 4-sigma evidence for CP violation in this channel. The $\Delta t$ distribution for $B^0$ and $\overline{B}^0$ tagged events is shown in Fig. 1. The branching fraction of $B^0 \rightarrow J/\psi \pi^0$ is relevant for constraining possible penguin contributions to the SU(3)-related channel $J/\psi K^0_s$ [8], and is measured to be $B(B^0 \rightarrow J/\psi \pi^0) = (1.69 \pm 0.14 \pm 0.07) \times 10^{-5}$. The recent update from Belle [9] of the time-dependent measurement of $B^0 \rightarrow J/\psi \pi^0$ ($S = -0.65 \pm 0.21 \pm 0.05, C = -0.08 \pm 0.16 \pm 0.05$), is quite consistent with BaBar’s result.

The $B^0 \rightarrow D^{*-}\bar{D}^{*-}$ channel is a Vector-Vector (VV) final state, which can have $L = 0, 1, 2$ angular momentum and therefore both even and odd CP components. It is therefore necessary to measure the CP-odd fraction $R_L$, and to take into account the dilution due to the admixture.

Belle presented a preliminary update [10] of $R_L = 0.116 \pm 0.042 \pm 0.004$, and of the CP-even asymmetry measurement: $S = -0.93 \pm 0.24 \pm 0.15$, $C = -0.16 \pm 0.13 \pm 0.02$. The latest published BaBar measurement [11] found a consistent value of $R_L = 0.143 \pm 0.034 \pm 0.008$, as well as of the CP parameters: $S = -0.66 \pm 0.19 \pm 0.04$, $C = -0.02 \pm 0.11 \pm 0.02$. Belle claim [12] 3.2 sigma evidence of direct CP violation in $B^0 \rightarrow D^+D^-$: $S = -1.13 \pm 0.37 \pm 0.09, C = +0.91 \pm 0.23 \pm 0.06$. This is unexpected in the SM and not supported by BaBar’s measurement [13], which both in the $D^+D^-$ and in $D^{*-}\bar{D}^+$ channels finds CP asymmetries consistent with the SM prediction of tree dominance [14] and therefore with the result in $b \rightarrow \tau\bar{\tau}f$. Since however some new physics models could cause sizable corrections [15], it is important to keep reducing experimental uncertainties.

2.3. $b \rightarrow q\bar{q}f$ decays

The interest of $b \rightarrow q\bar{q}f$ decays has been pointed out for a long time. The quark transition $b \rightarrow s$ is forbidden in the SM at the tree level, and proceeds dominantly through a penguin
diagram with CKM coefficients proportional to $V_{tb}V_{ts}^*$ and therefore with the same weak phase as in $B^0 \rightarrow J/\psi K_S^0$ decays. Since the tree amplitude is missing, small effects such as those expected from additional diagrams due to heavy particles circulating in the loop are in principle more easily detectable. For this reason these decays are especially sensitive probes of new physics. We show in Fig. 2 a compilation prepared by the HFAG group [16] of available measurement of $b \rightarrow s$ transitions. No recent measurements are available at the time of the Capri 2008 Workshop, however this is a field of central interest, where improved experimental precision will hopefully help clarifying the nature of the small downward shift of sin2$\beta_{eff}$ observed in most of the $b \rightarrow s$ channels respect to the charmonium reference value.

$$\sin(2\beta_{eff}) = \sin(2\theta^f_1)$$

![Figure 2](image)

Figure 2. Summary of effective sin2$\beta$ measurements in $b \rightarrow s$ decay modes, compared to the world average sin2$\beta$ value in $b \rightarrow c\bar{c}s$.

### 3. Measurements of $\alpha$

The angle $\alpha$ is measured with a time-dependent analysis of charmless decays of neutral $B$ mesons, $B^0 \rightarrow h^+h^-$, with $h = \pi, \rho, a_1$. Due to the interplay of tree and penguin diagrams in these channels, the experiments are actually sensitive to an effective parameter $\alpha_{eff}$. As shown in [17], one can in principle determine the shift $\alpha - \alpha_{eff}$ induced by the penguin amplitudes using the isospin-related decays $B^0 \rightarrow h^+h^-$, $B^0 \rightarrow h^0h^0$ and $B^\pm \rightarrow h^0h^\pm$. The procedure of measuring the so-called "isospin triangles" requires however rather large datasets, and leaves with up to eight-fold ambiguities. A relation less stringent, but more accessible with the current data sample since it does not require to tag the flavor of the decaying $B$ also holds [18]: $\sin^2(\alpha - \alpha_{eff}) \leq B(B^0 \rightarrow h^0h^0)/B(B^\pm \rightarrow h^0h^\pm)$, which is particularly useful for small values of the numerator.

#### 3.1. $\alpha$ from $B \rightarrow \pi\pi$

This is the "classic" channel to measure $\alpha$, with a well-established evidence for indirect CP violation by both $B$-Factory experiments, which still show instead a poor (2.1 sigma) agreement on the $C_{\pi\pi}$ parameter. Both $B_{\Lambda}$ and Belle [20] perform an isospin analysis to extract $\alpha$, using all the available information ($S_{\pm\mp}, C_{\mp\pm}, C_{\pm\mp}, B_{\pm0}, B_{00}$), shown in Fig. 3. One of the allowed solutions ($\alpha = (96^{+11}_{-6})^\circ$ for $B_{\Lambda}$, ($\alpha = 97^{+11}_{-7}$)$^\circ$ for Belle) is consistent with the indirect determination of $\alpha$ in the SM.

![Figure 3](image)

Figure 3. Constraints on the angle $\alpha$ in $B \rightarrow \pi\pi$ from $B_{\Lambda}$ (left) and Belle (right).

#### 3.2. $\alpha$ from $B \rightarrow \rho\rho$

The decay channel $B^0 \rightarrow \rho^+\rho^-$ has the same quark content as $\pi^+\pi^-$ and can also be used to measure $\alpha$. There are non-trivial experimental complications due to the presence of two neutral pions in the final state, with just weak mass constraints from the wide intermediate resonances. Moreover, $\rho^+\rho^-$ is a VV state and necessitates in principle a complete angular analysis to disentangle the effect of the three possible helicity
states. On the other hand, the branching fraction is about five times larger than $B(B^0 \to \pi^+ \pi^-)$, and the state is found to be almost purely longitudinally polarized, so that a per-event transversity analysis can be avoided and only the longitudinal CP parameters need to be determined. There is good agreement between CP violation measurement in $\rho^+ \rho^-$ from BABAR [21] and Belle [22]. The HFAG average for the longitudinal components is $C_{\rho^+ \rho^-} = -0.06 \pm 0.13$, $S_{\rho^+ \rho^-} = -0.05 \pm 0.17$. BABAR [23] presented a preliminary first time-dependent measurement in the $B^0 \to \rho^0 \rho^0$ channel. With $85 \pm 28 \pm 17$ signal events in a sample of $427 \times 10^6 B\bar{B}$ events, BABAR measure $B_{\rho^0 \rho^0} = (0.84 \pm 0.29 \pm 0.17) \times 10^{-6}$, $f_L = 0.70 \pm 0.14 \pm 0.05$, $S_L = 0.5 \pm 0.9 \pm 0.2$, $C_L = 0.4 \pm 0.9 \pm 0.2$. Consistently, Belle [24] set the upper limit $B_{\rho^0 \rho^0} < 1.0 \times 10^{-6}$ at 90\% confidence level (C.L.).

### 3.3. $\alpha$ from $B^0 \to \rho \pi$

The third mode used to measure the angle $\alpha$ is $B^0 \to \pi^+ \pi^- \pi^0$. This is not a CP eigenstate, and four flavor-charge configurations ($B^0 (\overline{B}^0) \to \rho^+ \pi^\mp$) must be considered. The corresponding isospin analysis is extremely complicated involving pentagonal relations among the different amplitudes, and cannot be solved for the 12 unknowns with the present statistics. It was however pointed out [25] that the variation of the strong phase of the interfering $\rho$ resonances in the Dalitz plot provides the necessary degrees of freedom to constrain $\alpha$ with only the irreducible $(\alpha \to \alpha + \pi)$ ambiguity. The two B-Factor experiments have both performed this analysis. BABAR [26] constrain $\alpha = (87^{+45}_{-13})^\circ$; Belle [27] obtain the tighter constraint $68^\circ < \alpha < 95^\circ$ at 68\% C.L. for the solution compatible with the SM.

### 3.4. $\alpha$ from $B^0 \to a_1 \pi$

The channel $B^0 \to a_1 \pi$, which has the same quark content as the previous modes, has been recently explored in [28]. With a sample of $608 \pm 52$ signal events, BABAR adopt a quasi-two-body approach to obtain a precise measurement of $\alpha_{eff} = (78.6 \pm 7.3)^\circ$. Following the proposal in [29], BABAR are also measuring branching fractions in the SU(3)-related modes $B \to a_1 K$ [30] and $B \to K_1 \pi$ to constrain $|\alpha - \alpha_{eff}|$.

### 4. Measurements of $\gamma$

Several ways have been proposed to measure the angle $\gamma$ at the B Factories. The most effective methods to date exploit direct CP violation in $B^- \to D^{(*)0}(\overline{D}^{(*)0})K^-$ decays. The tree-level decay amplitudes for the $B^- \to D^{(*)0} K^-$ and $B^- \to \overline{D}^{(*)0} K^-$ transitions differ by a factor $r_B^{(s)} e^{i(\delta_B^{(s)} - \gamma)}$, where $r_B^{(s)}$ is the magnitude of the $(b \to u/b \to c)$ amplitude ratio, and $\delta_B^{(s)}$ the strong phase difference. Estimates of $r_B^{(s)}$ considering CKM and color suppression factors predict small values, $r_B^{(s)} \approx 0.1 \div 0.2$. Different mechanisms have been proposed to obtain interference from identical $D^0$ or $\overline{D}^0$ final states. We shall review recent results in the next subsections.

#### 4.1. The GLW method

In the GLW method [31] neutral D mesons are reconstructed in CP-even ($D_{CP+}$) and CP-odd ($D_{CP-}$) eigenstates, as well as in flavor eigenstates ($D^0$ or $\overline{D}^0$). The observables $R_{CP} = (B_{CP+} - B_{CP-})/(B_{D^0 K^-} - B_{D_s^+ K^-})/2$ and $A_{CP} = (B_{CP+} - B_{CP-})/(B_{CP+} + B_{CP-})$ are measured\(^3\). These quantities are sensitive to the angle $\gamma$: $R_{CP} = 1 + r_B^2 \pm 2 r_B \cos \delta_B \cos \gamma$, $A_{CP} = \pm 2 r_B \sin \delta_B \sin \gamma / R_{CP}$. BABAR [32] recently published updated measurement in $B^\pm \to D^* K^\pm$, with $D^{*0} \to D^0 \gamma$, $D_s^0$, and $D^0 (\overline{D}^0)$ reconstructed in CP-even ($K^+ K^-$, $\pi^+ \pi^-$), CP-odd ($K^0_s \pi^0$, $K^0_s \omega$, $K^0_s \phi$), and flavor-specific modes ($K^- \pi^+$), obtaining $A_{CP+} = -0.11 \pm 0.09 \pm 0.01$, $A_{CP-} = +0.06 \pm 0.10 \pm 0.02$, $R_{CP+} = 1.31 \pm 0.13 \pm 0.04$, $R_{CP-} = 1.10 \pm 0.12 \pm 0.04$. The accuracy of these measurements does not allow a determination of $\gamma$ with the GLW method alone, but contributes improving the overall precision when combined with the other methods.

#### 4.2. The ADS method

The idea in the ADS approach [33] is to select decays with similar overall amplitudes, in order to maximize the interference and therefore the sensitivity to CP asymmetries. This is achieved\(^3\)

\(^3\)We use the compact notation $B_{CP} = B(B^- \to D_{CP+} K^-)$, $B_{D_0} = B(B^- \to D^0 K^-)$, $B_{\overline{D}^0} = B(B^- \to \overline{D}^0 K^-)$, and analogously for the $B^+$ decays.
selecting favored $B \to D$ decays followed by suppressed $D$ decays, or vice versa. Analogously to the GLW case, it is possible to define ratios of branching fractions of suppressed and favored decays as $R_{ADS} = \frac{B_{B^{-}\to D_{s}\pi^{-}K_{S}}/B_{B^{-}\to D_{s}\pi^{+}K}}{r_{D}^{2} + 2r_{B}r_{D}\cos\gamma\cos\delta_{B}}$, and CP asymmetries as $A_{ADS} = (B_{B^{-}\to D_{s}\pi^{-}K_{S}} - B_{B^{-}\to D_{s}\pi^{+}K})/SUM = 2r_{DTB}\sin\gamma\sin\delta_{B}/R_{ADS}$. Belle [34] recently published an updated analysis of the suppressed decay chain $B^{-} \to DK^{-}$, $D \to K^{+}\pi^{-}$, based on $657 \times 10^{6} B\bar{B}$ pairs. They do not observe a statistically significant signal in the suppressed mode, and obtain $R_{ADS} = (8.0^{+5.3}_{-5.7+2.9}) \times 10^{-3}$, $A_{ADS} = (-0.13^{+0.97}_{-0.88} \pm 0.26)$. These numbers are used to set a 90% C.L. upper limit on $r_{B} < 0.19$.

4.3. Dalitz plot method

Selecting three-body decays of $D^{0}$ and $\bar{D}^{0}$ such as $K_{S}^{0}h\bar{h}^{+}$ ($h = \pi, K$), the Dalitz plot distribution depends on the interference of Cabibbo allowed, doubly-Cabibbo suppressed and CP eigenstate decay amplitudes. Neglecting mixing and CP violation in the $D^{0}\bar{D}^{0}$ meson system, the amplitude for $B^{+} \to D[K_{S}^{0}h\bar{h}^{+}]K^{\pm}$ can be written as $A_{\pi}^{(s)}(m_{2}^{2}, m_{3}^{2}) \propto A_{D}^{(s)} + \lambda r_{B}^{(s)} e^{i(\delta_{B}^{(s)}+\gamma)} A_{D\pm}$, where $m_{2}^{2}$ and $m_{3}^{2}$ are the squared invariant masses of the $K_{S}^{0}h^{-}$ and $K_{S}^{0}h^{+}$ combinations respectively, $\lambda = -1$ for $D^{0*} \to \gamma D^{0}$ and $\lambda = 1$ otherwise, and $A_{D^{+}}$ ($A_{D^{-}}$) are the amplitudes of the $D^{0}(\bar{D}^{0}) \to K_{S}^{0}h^{+}\bar{h}^{-}$ decay, described with a detailed model involving several intermediate resonances and extracted from large control samples of flavor-tagged $D^{+} \to D^{0}\pi^{+}$ decays produced in $\pi^{-}\pi^{+}$ events. The ‘cartesian’ variables $x_{\pi}^{(s)} = r_{B}^{(s)} \cos(\delta_{B}^{(s)} + \gamma)$, $y_{\pi}^{(s)} = r_{B}^{(s)} \sin(\delta_{B}^{(s)} + \gamma)$ are used by the experiments to avoid the bias due to $r_{B}^{(s)}$ being positive definite. In their preliminary work [35] based on $657 \times 10^{6} B\bar{B}$ pairs, the Belle collaboration reconstruct the decays $B^{+} \to D^{(s)0}K^{\mp}$, with $D^{*0} \to D^{0}\pi^{0}$ and $D^{0} \to K_{S}^{0}\pi^{+}\pi^{-}$, producing new and more precise results for the $(x, y)_{\pi}^{(s)}$ parameters. With a statistical procedure they find $r_{D} = 0.16 \pm 0.04$, $r_{B} = 0.21 \pm 0.08$ and $\gamma = (76^{+12}_{-13})^{o}$. BBar is also publishing an updated result [36], based on $383 \times 10^{6} B\bar{B}$ pairs. In addition to the modes used by Belle, BBar also reconstruct the decays $D^{*0} \to D^{0}\gamma$, $B^{+} \to D^{0}K^{+}[K_{S}^{0}\pi^{+}]$, and $D^{0} \to K_{S}^{0}K^{+}K^{-}$. As an illustration, results for $(x, y)_{\pi}^{(s)}$ in the $B^{+} \to D^{0}\bar{K}^{+}$ mode from BBar and Belle are shown in Fig.4. Thanks to the larger number of reconstructed channels and to a better analysis efficiency, BBar determines the $(x, y)_{\pi}^{(s)}$ parameters with the same accuracy as Belle despite the smaller data sample, finding 3 sigma evidence of CP violation. However, the BBar data favor smaller $r_{B}$ values ($r_{B} = 0.086 \pm 0.035$, $r_{B} = 0.135 \pm 0.051$, $\kappa_{s} = 0.163^{+0.088}_{-0.105}$), and thus a larger error for $\gamma$ ($\gamma = (76^{+23}_{-24})^{o}$).

5. Summary and outlook

The $B$ Factories have established CP violation in several $B$ decays, and measured $\sin 2\beta$ in charmonium decays with precision better than 4%. All $\beta$ measurements in many different channels are consistent. Some channels, such as the penguin-dominated $b \to s$ modes are particularly promising because they are especially sensitive to heavy virtual states.

The angle $\alpha$ is being studied in charmless $B^{0} \to \pi\pi$, $\rho\rho$ and $\rho\tau$ transitions. The first measurements of the $B^{0} \to \rho^{0}\rho^{0}$ decay confirm the indication that the effect of penguin amplitudes is relatively small in $\rho\rho$ decays, which in fact yield the most stringent constraints on $\alpha$. New channels such as $B^{0} \to a_{1}\pi$ and SU(3)-related decays are being studied, and will hopefully contribute to

\footnote{The amplitude ratio in $B^{\mp} \to D^{0}\bar{K}^{\mp}$ events is described by $\kappa_{s}$, with $\kappa$ taking into account non-resonant $K_{S}^{0}\pi^{+}$ contributions.}
improve the determination of $\alpha$, which will eventually be limited by penguin pollution.

A precise measurement of the angle $\gamma$, simply unthinkable at the beginning of the $B$-Factory era, is now a reality thanks to the large accumulated statistics and the number of $B$ decays sensitive to this angle. Several new measurements of $B^+ \to D^0 K^+$ transitions have appeared recently, and strong evidence for direct $CP$ violation in these decays is building up. The Dalitz method in particular provides the most stringent constraints to date.

All measurements of CKM angles are at present statistically limited, and will therefore become more precise in the near future, when the BaBar collaboration analyze their full dataset, and Belle continue to accumulate new data.

REFERENCES

1. N. Cabibbo, Phys. Rev. Lett. 10, 531 (1963); M. Kobayashi and T. Maskawa, Prog. Th. Phys. 49, 652 (1973).
2. B. Aubert et al., the BaBar Collaboration, Nucl. Instr. and Methods A479, 1 (2002).
3. A. Abashian et al., the Belle Collaboration, Nucl. Instr. and Methods A479, 117 (2002).
4. B. Aubert et al., the BaBar Collaboration, Phys. Rev. Lett. 99, 171803 (2007).
5. K.-F. Chen et al., the Belle Collaboration, Phys. Rev. Lett. 98, 031802 (2007).
6. K.-F. Chen et al., the Belle Collaboration, Phys. Rev. D77, 091103 (2008).
7. B. Aubert et al., the BaBar Collaboration, Phys. Rev. Lett. 101, 021801 (2008).
8. M. Ciuchini, M. Pierini and L. Silvestrini, Phys. Rev. Lett. 95, 221804 (2005).
9. S. E. Lee et al., the Belle Collaboration, Phys. Rev. D77, 0711011 (2008).
10. The Belle Collaboration, Moriond 2008 preliminary, unpublished.
11. B. Aubert et al., the BaBar Collaboration, Phys. Rev. D76, 111102 (2007).
12. S. Fratina et al., the Belle Collaboration, Phys. Rev. Lett. 98, 221802 (2007).
13. B. Aubert et al., the BaBar Collaboration, Phys. Rev. Lett. 98, 071801 (2007).
14. X. Y. Pham and Z.-Z. Xing, Phys. Lett. B 458, 375 (1999); Z.-Z. Xing, Phys. Rev. D61, 014010 (2000).
15. Y. Grossman and M. P. Worah, Phys. Lett. B395, 241 (1997).
16. The Heavy Flavor Averaging Group, http://www.slac.stanford.edu/xorg/hfag
17. M. Gronau and D. London, Phys. Rev. Lett. 65, 3381 (1990).
18. Y. Grossman et al., Phys. Rev. D58, 017504 (1998).
19. B. Aubert et al., the BaBar Collaboration, Phys. Rev. D76, 091102 (2007).
20. H. Ishino et al., the Belle Collaboration, Phys. Rev. Lett. 98, 211801 (2007).
21. B. Aubert et al., the BaBar Collaboration, Phys. Rev. D76, 052007 (2007).
22. K. Abe et al., the Belle Collaboration, Phys. Rev. D76, 011104 (2007).
23. B. Aubert et al., the BaBar Collaboration, arXiv:0708.1630 [hep-ex].
24. The Belle Collaboration, La Thuile 2008 preliminary, unpublished.
25. H.R. Quinn and A.E. Snyder, Phys. Rev. D48, 2139 (1993).
26. B. Aubert et al., the BaBar Collaboration, Phys. Rev. D76, 012004 (2007).
27. A. Kusaka et al., the Belle Collaboration, Phys. Rev. Lett. 98, 211802 (2007).
28. B. Aubert et al., the BaBar Collaboration, Phys. Rev. Lett. 98, 181803 (2007).
29. M. Gronau and J. Zupan, Phys. Rev. D73, 057502 (2006).
30. B. Aubert et al., the BaBar Collaboration, Phys. Rev. Lett. 100, 051803 (2008).
31. M. Gronau and D. London, Phys. Lett. B253, 483 (1991); M. Gronau and D. Wyler, Phys. Lett. B265, 172 (1991).
32. B. Aubert et al., the BaBar Collaboration, arXiv:0807.2408v1 [hep-ex].
33. D. Atwood, I. Dunietz, and A. Soni, Phys. Rev. Lett. 78, 3257 (1997); Phys. Rev. D 63, 036005 (2001).
34. Y. Horii et al., the Belle Collaboration, arXiv:0804.2063v1 [hep-ex].
35. K. Abe et al., the Belle Collaboration, arXiv:0803.3375 [hep-ex].
36. B. Aubert et al., the BaBar Collaboration, Phys. Rev. D 78, 034023 (2008).