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RECENT RESULTS FROM *B* FACTORIES

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We review some of the key 2006 measurements constraining the Unitarity Triangle and probing New Physics at B factory experiments *BELLE* and *BABAR*.

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1. Introduction

The B factories KEK-B (at KEK) and PEP-II (at SLAC) are energy-asymmetric electron-positron colliders operating in the energy region of the $\Upsilon(4S)$ resonance since year 2000. By the end of 2006, over 1 ab^{-1} of data have been accumulated by the B Factory experiments, *BELLE* ($\sim 630\,\mathrm{fb}^{-1}$) and *BABAR* ($\sim 390\,\mathrm{fb}^{-1}$). This corresponds to a combined sample of about one billion $B\overline{B}$ pairs.

The physics of *BELLE* and *BABAR* covers not only a comprehensive study of *CP*-violation in B-meson decays, but also a wide spectrum of subjects in flavor physics, including B-meson and charm physics, hadron spectroscopy and τ physics. In the present report [1], after an introduction to the KM model, *CP* violation in the B-meson system and the physics at the $\Upsilon(4S)$ followed by a short description of the experiments, we review selected *CP*-asymmetry and rate measurements related to the Unitarity Triangle and present searches for suppressed B-meson decays sensitive to New Physics.

1.1. *The Kobayashi-Maskawa model*

In the Standard Model (SM) with three families of quarks and leptons, all effects of *CP* violation in the quark sector can be traced down to a *single* *CP*-violating parameter, a non-trivial phase δ in the Cabbibo-Kobayashi-Maskawa quark flavor mixing matrix (CKM matrix) whose each of the nine complex elements V_{ij} describes the transition of a down-type quark i to an up-type quark j with emission of a (virtual) W^- boson. For complete reviews on the subject, see for instance Ref. [2].

The three diagonal elements of the CKM matrix (V_{ud}, V_{cs} and V_{tb}) are of order one in magnitude; the off-diagonal elements, of order λ for transitions between the second and first family (V_{us} and V_{cd}) and of order λ^2 for transition between the second and third family (V_{cb} and V_{ts}). Here the expansion variable λ is the sine of the Cabbibo angle, $|V_{us}| \simeq -|V_{cd}| \simeq \lambda \equiv \sin\theta_C \sim 0.2$. The smallest two elements of the CKM matrix (V_{ub} and V_{td}), encoding transitions between the third and first family, are of order λ^3 in size. Off-diagonal CKM elements are conveniently expressed as a function of three additional real parameters of order one. In the phase convention, which we adopt throughout this report, where V_{cb} is real, all the CKM elements are real or approximately real except for V_{ub} and V_{td}, and one writes $V_{cb} = A\lambda^2 \simeq -V_{ts}$, $V_{ub} \simeq A\lambda^3(\overline{\rho} - i\overline{\eta})$ and $V_{td} \simeq A\lambda^3(1 - \overline{\rho} - i\overline{\eta})$. Parameter A measures the strength of the $b \to c$ transition in units of λ^2 ($A \approx 0.83$) while $\overline{\rho}$ and $\overline{\eta}$ are the real and imaginary part of $V^*_{ub}/(A\lambda^3)$. *CP* violation occurs in the SM if and only if $\overline{\eta} \neq 0$. This parametrization assumes that the SM is correct by making explicit one of the unitarity relations connecting the elements of the CKM matrix, $V^*_{ub}/(A\lambda^3) - V^*_{cb}/(A\lambda^2) + V_{td}/(A\lambda^3) \simeq 0$. This is the equation of the so-called Unitarity Triangle (UT), a triangle of base unity whose apex is the point of coordinates $\overline{\rho}$ and $\overline{\eta}$ in the complex plane. The three angles of the triangle are[a]: γ, the phase of V^*_{ub}, of order 62°; β, the phase of V^*_{td}, of order 21°; and $\alpha \equiv \pi - \beta - \gamma$, of order 97° (see Fig. 1).

One central feature of the SM is the strong suppression of flavor-changing neutral weak currents (FCNC). Neutral currents are mediated at first order by the Z boson which couples only to combinations of quarks of the same flavor, $u\overline{u}$, $d\overline{d}$, etc. At second order, the contribution of FCNC is further suppressed by the GIM mechanism and the smallness of the off-diagonal elements of the CKM matrix. The suppression of FCNC places strong constraints on the physics beyond the SM. In particular, in B physics, there are two transitions that offer good opportunities of

[a]We follow the α, β, γ notation. Another notation defines $\phi_1 \equiv \beta$, $\phi_2 \equiv \alpha$ and $\phi_3 \equiv \gamma$.

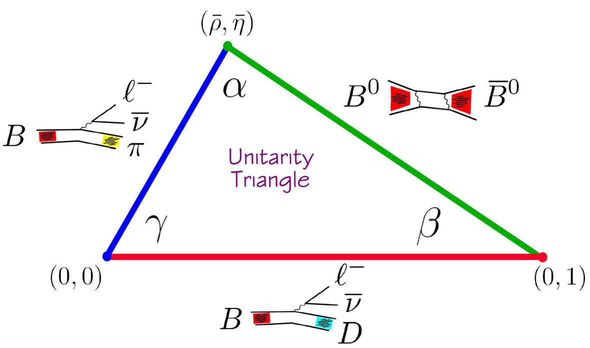


Fig. 1. The Unitarity Triangle.

finding evidence for New Physics (NP), $B^0\overline{B}^0$ mixing and penguin decays. Those transitions can be described by Feynman diagrams where virtual SM particles are exchanged in loops or boxes inside which new massive particles, coupled to quarks and W bosons, could also contribute virtually. The experimental strategy to test the flavor and *CP* violation sectors of the SM is to perform all possible measurements sensitive to combinations of $\overline{\rho}$ and $\overline{\eta}$ with the best achievable precision (*e.g.* determination of the sides and angles of the UT, detection of rare B decay rates), looking for inconsistencies as hints of the presence of NP (see for instance Ref. [3]).

1.2. *CP violation*

CP-violating observables, those sensitive to $\overline{\eta} \neq 0$, stem from quantum interference between contributing amplitudes with different weak phases[b].

Undirect CP violation, or *CP* violation in flavor mixing, involves mixing amplitudes with virtual and on-shell intermediate states. Historically, *CP* violation in $K^0\overline{K}^0$ mixing was the first type of *CP* violation, observed in 1964 at a level given by the ε parameter ($|\varepsilon| \sim 2.3 \times 10^{-3}$), and responsible for the $K^0_L \to \pi\pi$ decay and the K^0_L semileptonic asymmetry. In the $B^0\overline{B}^0$ system, undirect *CP* violation is expected to be small and is still out of experimental reach.

Direct CP violation, or *CP* violation in meson decay, involves competing decay amplitudes. Direct *CP* violation has been established in the $K^0 \to \pi\pi$ decay, with the measurement of a significant value of ε'/ε at the $\sim 17 \times 10^{-4}$ level. In the B meson system, a spectacular *CP* violation effect in $B \to K\pi$ decay has been observed, $B^0 \to K^+\pi^-$ being 11.5% more probable than $\overline{B}^0 \to K^-\pi^+$.

Mixing-induced CP violation, or *CP* violation in the interference between decay without mixing and decay with mixing. The effect of mixing-induced *CP* violation is seen in the time evolution of systems initially prepared in well-defined *CP* or flavor states. The magnitude of the effect is proportional to the difference of the weak phases of the mixing and decay amplitudes. There are many examples of interplay of undirect and mixing-induced *CP* violation in the neutral kaon system. The first *CP* violation observed in the B meson system was pure mixing-induced, in the difference in time evolution between B mesons tagged initially as B^0 or $\overline{B}^0$ and decaying to $J/\psi K^0_S$ or other related *CP* eigenstates. This spectacular effect leads to the precise and unbiased measurement of *CP* parameter $\sin 2\beta$. There are now other evidences of mixing-induced *CP* violation in other rare B^0 decay modes such as $B^0 \to KKK^0$, $B^0 \to D^*D^*$, $B \to \eta' K^0$ and $B \to f_0 K^0$, or of interplay between mixing-induced and direct *CP* violation in $B^0 \to \pi\pi$ and $B^0 \to \rho\pi$ decays.

1.3. *Physics at the $\Upsilon(4S)$*

B factories are e^+e^- colliders operating around $\sqrt{s} \sim 10.58\,\mathrm{GeV}$, on top of the $\Upsilon(4S)$ resonance, a $J^{PC} = 1^{--}$ $(b\overline{b})$ state with mass just above the $B\overline{B}$ production

[b] A weak phase changes sign under *CP*; a strong phase does not.

threshold. There, $B\overline{B}$ pairs (B^+B^- and $B^0\overline{B}^0$ in equal amount) are produced with a cross-section of $\sim 1\,\text{nb}$ over a QED continuum $e^+e^- \to q\bar{q}$ ($q = u,\, d,\, s,\, c$) of $\sim 3\,\text{nb}$. The $B^0\overline{B}^0$ system in $e^+e^- \to \Upsilon(4S) \to B^0\overline{B}^0$ is in a coherent $L = 1$ quantum state: at $\Delta t = 0$ (Δt being the proper time difference between the two B meson decays) the system contains exactly one B^0 and one $\overline{B}^0$. This property, a realization of the EPR paradox, allows for flavor tagging. For a given $B^0 \to f$ decay one can form time-dependent *CP* asymmetries, *i.e.* rate asymmetries as a function of Δt between samples determined by the flavor the accompanying B^0 meson. When the final state f is a *CP* eigenstate, the time-dependent *CP* asymmetry can be written as the sum of two oscillating terms (one odd, one even) at the $B^0\overline{B}^0$ mixing frequency ($\Delta m_d = 0.507\,\text{ps}^{-1}$),

$$A_f^{CP}(\Delta t) = S_f \sin(\Delta m_d \Delta t) - C_f \cos(\Delta m_d \Delta t). \tag{1}$$

The contribution of mixing-induced and direct *CP* violation is expressed by observables S_f and C_f, respectively, which can be written in terms of a phase convention-independent complex parameter λ_f,

$$S_f \equiv \frac{2\,\text{Im}\lambda_f}{1+|\lambda_f|^2}, \quad C_f \equiv \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} \quad \text{with} \quad \lambda_f \equiv e^{-2i\beta}\frac{\overline{A}_f}{A_f}\ ,$$

where 2β is the phase of the $B^0\overline{B}^0$ amplitude (with our phase convention), $A_f \equiv \mathcal{A}(B \to f)$ and $\overline{A}_f \equiv \mathcal{A}(\overline{B} \to f)$.

Experimentally the time-dependent asymmetry (Eq. 1) is diluted by unperfect flavor determination and finite time resolution. The determination of flavor, which relies mainly on the charge of leptons and kaons in the decay products, has an effective efficiency of $\sim 30\%$ at B factories. The measurement of Δt is made possible at B factories thanks to asymmetric-energy beams. The produced $\Upsilon(4S)$ is boosted in the laboratory frame ($\beta\gamma \sim 0.56$ for PEP-II) and Δt is deduced from the distance Δz between the two B decay vertices along the boost axis ($\langle \Delta z \rangle \sim 260\mu\text{m}$ at PEP-II), measured with a typical resolution of $150\mu\text{m}$. Flavor tagging performance and the time resolution function are determined from actual data using large control samples of flavor-specific B^0 decays.

1.4. *The BABAR and BELLE detectors*

The *BELLE* and *BABAR* detectors are both composed of a silicon vertex detector and a central drift chamber for charged track reconstruction and momentum measurement inside a 1.5 T solenoidal field, a CsI(Tl) crystal electromagnetic calorimeter for electron and photon identification and energy measurement, and an instrumented iron yoke for muon and neutral hadron identification. The detectors differ mainly by their dedicated system for hadron identification: for *BELLE*, an array of aerogel Cherenkov threshold counters, and time-of-flight scintillation counters; for *BABAR*, a ring-imaging device using Cherenkov light trapped in 5-meter long quartz bar radiators and detected by a large array of photomultipliers immersed in water.

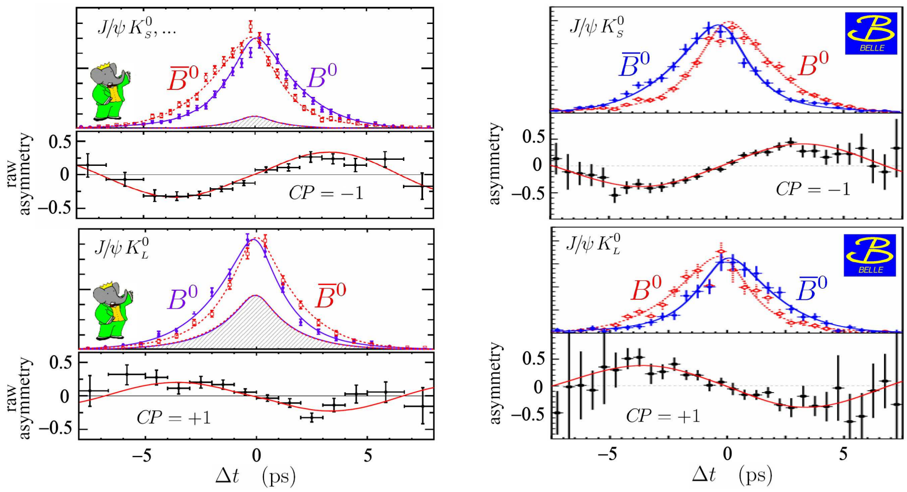


Fig. 2. Measurements of sin2β, *BABAR* (left) and *BELLE* (right), for $CP = -1$ modes as $J/\psi\, K_S^0$ (top) and $CP = +1$ modes as $J/\psi\, K_L^0$ (bottom). The Δt distributions for B^0- and $\overline{B}^0$-tagged samples, as indicated, are clearly separated as a result of mixing-induced *CP* violation. The resulting time-dependent asymmetries follow pure sine distributions with amplitude proportional to sin2β: $A^{CP=\pm}_{b\to c\overline{c}s} \propto \mp \sin 2\beta \times \sin(\Delta m_d \Delta t)$.

2. Unitarity Triangle measurements

2.1. *UT angle β*

The decay modes $B \to (c\overline{c})K$ such as $B \to J/\psi\, K$ are mediated at the quark level by a single weak $b \to c\overline{c}s$ transition[c]. No direct *CP* violation is expected (nor observed) for these modes. Mixing-induced *CP* violation in $B \to J/\psi\, K^0$ is possible thanks to $K^0\overline{K}^0$ mixing. The transition is tree-dominated, therefore insensitive to NP, and the S parameter is related simply to the β angle of the UT. For $B \to J/\psi\, K_S^0$ ($CP = -1$), $\lambda_{J/\psi\, K_S^0} = -e^{-2i\beta}$, from which it follows $S_{J/\psi\, K_S^0} = \sin 2\beta$. Results on sin2$\beta$ by *BABAR* [4] and *BELLE* [5] are illustrated on Fig. 2. Both experiments include K_S^0 and K_L^0 final states. *BABAR* considers several charmonium final states in addition to $J/\psi\, K^0$ ($\psi(2S)K^0$, $\chi_c K^0$ and $\eta_c K^0$) while *BELLE* result is based solely on the $J/\psi\, K^0$ mode. The world average from $B \to (c\overline{c})K$ modes is $\sin 2\beta = 0.674 \pm 0.026$ [6]. The precise measurement of sin2β leads to a two-fold ambiguity (modulo 180°) on the value of β. The two solutions, summing up to 90°, are $\beta = (21.2 \pm 0.1)^\circ$ and $\beta = (68.8 \pm 0.1)^\circ$. The ambiguity can be resolved by exploiting B decay modes sensitive to $\cos 2\beta$ through interference effects. The first class of analyses exploits the time-dependent angular distribution in $B \to J/\psi\, K^*$, where an additional ambiguity due to unknown strong phase difference between transversity amplitudes is resolved using the known $K\pi$ S- and P-wave relative phase motion [7,8].

[c]Throughout this report, *CP* conjugation is implied unless stated otherwise.

Recent constraints of $\cos 2\beta$ are based on a time-dependent Dalitz analysis with $\overline{B}^0 \to D^0(K^0_S\pi^+\pi^-)\pi^0$ [9,10] or $B^0 \to D^{*+}D^{*-}K^0_S$ [11]. At the moment, $\cos 2\beta$ is not precisely measured yet but all the results tend to favor strongly the solution with $\cos 2\beta > 0$ ($\beta = 21.1°$). The solution $\beta > 45°$ is excluded at more than 95% of C.L..

2.2. *UT angle* α

Historically, $B \to \pi^+\pi^-$ was the golden way to measure sin2α. Indeed, if the tree amplitude $b \to u\bar{u}d$ were dominating this decay, one would have $\lambda_{\pi^+\pi^-} = +e^{-2i(\beta+\gamma)} = e^{i\alpha}$ and $S_{\pi^+\pi^-} = \sin 2\alpha$. However another amplitude, the gluonic penguin $b \to d\bar{d}d$ transition, contributes to the decay with a different weak phase. The existence of gluonic penguin transitions is well-established in $B \to K\pi$ decays. The observed large direct *CP* violation in $B^0 \to K^+\pi-$ is a manifestation of tree-penguin interference [12]. In $B \to \pi\pi$, the penguin amplitude could be as large as 30% of the tree amplitude. As a result both direct and mixing-induced *CP* violation effects can be expected, $C_{\pi^+\pi^-} \neq 0$ and $S_{\pi^+\pi^-} = \sqrt{1 - C^2_{\pi^+\pi^-}} \sin 2\alpha^{\rm eff}_{\pi\pi}$. The experimental situation [12,13] on $C_{\pi^+\pi^-}$ and $S_{\pi^+\pi^-}$ is presented on Fig. 3. The difference $\Delta\alpha \equiv \alpha^{\rm eff} - \alpha$ can in principle be determined through an isospin analysis involving other $B \to \pi\pi$ decay rates. Although the $B^0 \to \pi^0\pi^0$ and $\overline{B}^0 \to \pi^0\pi^0$ rates are not yet known individually, the sum is now measured with reasonable precision [6], $\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.31 \pm 0.21) \times 10^{-6}$. Because of the relatively large $\pi^0\pi^0$ rate and

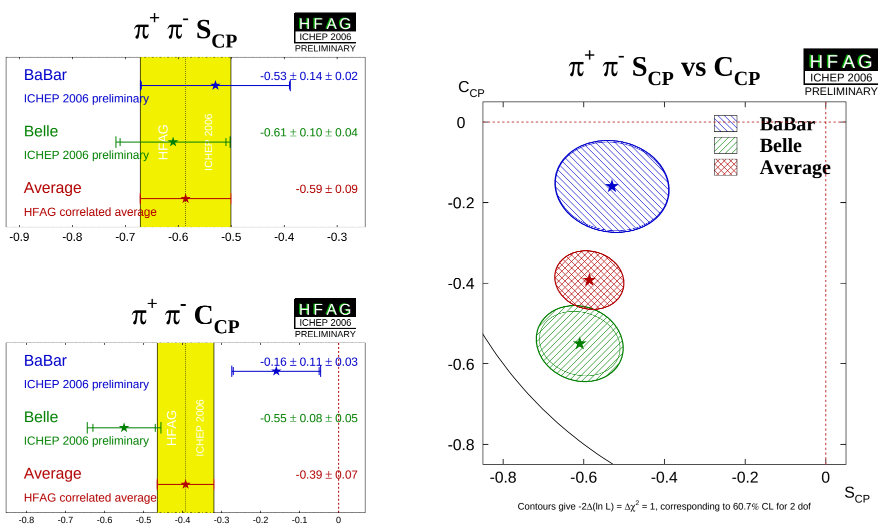


Fig. 3. Results of time-dependent *CP* analysis in $B \to \pi^+\pi^-$. After some confusion with inconsistent early measurements, *BABAR* and *BELLE* are now in good agreement on the value of $S_{\pi^+\pi^-}$. However *BABAR* cannot yet confirm nor exclude the large effect of direct *CP* violation observed by *BELLE*.

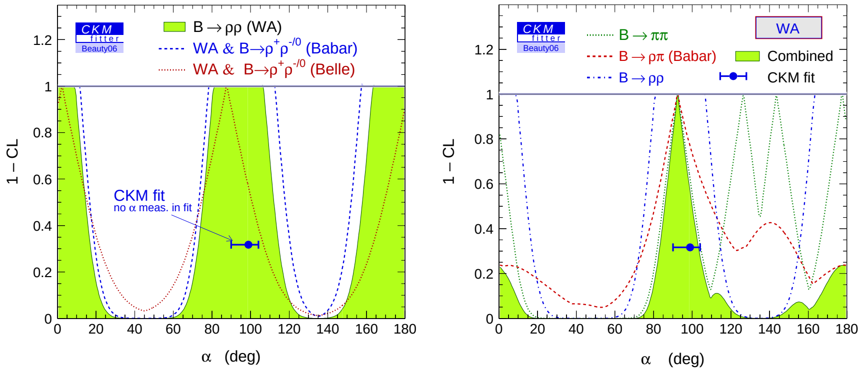


Fig. 4. Confidence level as a function of the value of α (World average), on the left side for the promising $B \to \rho\rho$ mode, and on the right side from the combination of $B \to \pi\pi$, $B \to \rho\rho$ and $B \to 3\pi$ modes. The $B \to 3\pi$ analysis is less sensitive at present but contributes nevertheless at favoring the solution around the SM expectation $\alpha \sim 100°$.

of an additional ambiguity introduced by the isospin analysis, the range of excluded values of α is limited. Unfortunately the problem of multiple solutions will not get solved with increased statistics. Other approaches to extract α are needed.

The time-dependent analysis of $B \to \rho^+\rho^-$ is complicated by a low selection efficiency and large backgrounds due to the presence of neutral pions in the final state, but the signal rate is relatively large [6], $\mathcal{B}(B \to \rho^+\rho^-) = (23.1 \pm 3.3) \times 10^{-6}$. The decay receives the contribution of three partial wave amplitudes with different *CP*. In principle an angular analysis combined with an isospin analysis is necessary to extract α. At the present level of statistics, however, this can be avoided. First, the data shows that the decay is dominated by a single amplitude so that the final state, longitudinally polarized, is mostly *CP* even. Second, the penguin "pollution" is much smaller than in $B \to \pi^+\pi^-$ and the branching fraction $\mathcal{B}(B \to \rho^0\rho^0) = (1.1 \pm 0.3 \pm 0.2) \times 10^{-6}$, only 4% of that of the charged mode, leads to a useful constraint on $\Delta\alpha_{\rho\rho}$. One finds [14] $\alpha^{\text{eff}}_{\rho\rho} = (96 \pm 6)°$ and $|\Delta\alpha_{\rho\rho}| < 18°$(68%C.L.), with a solution around 90% given by $74° < \alpha < 117°$ (68.3%C.L.).

Another method to extract α, proposed initially by Snyder and Quinn, is through a time-dependent Dalitz analysis of $B \to \pi^+\pi^-\pi^0$. Exploiting the interfering contributions of $\rho^+\pi^-$, $\rho^-\pi^+$ and $\rho^0\rho^0$, the method allows in principle an extraction of α free from ambiguities. This method does not give by itself meaningful measurements of α with present available statistics [15,16] but favors a solution around 100°.

The combination of the $\pi\pi$, $\rho\rho$ and $\pi\pi\pi$ results [17], presented on Fig. 4, leads to the constraint $83.3° < \alpha < 113.3°$ (68.3%C.L.), consistent with an indirect constraint from a CKM fit excluding these measurements, $\alpha_{\text{CKM}} = (100^{+5}_{-7})°$.

2.3. *UT angle* γ

The basic idea to measure angle γ is to exploit the interference between $b \to c$ and $b \to u$ amplitudes, which have relative weak phase γ and no contribution from New Physics since no loop diagram is involved. Consider for instance the Cabbibo-suppressed $B^- \to D^0 K^-$ decay and the CKM- and color-suppressed $B^- \to \overline{D}^0 K^-$ decay. These two can interfere through the decay of the $\overline{D}^0$ and the D^0 to a common final state f. Direct *CP* violation effects, related to γ, are governed by an interference parameter

$$R \equiv \frac{\mathcal{A}(B^- \to \overline{D}^0 K^-)}{\mathcal{A}(B^- \to D^0 K^-)} \frac{\mathcal{A}(\overline{D}^0 \to f)}{\mathcal{A}(D^0 \to f)} = r_B e^{i\delta_B} \frac{\mathcal{A}(D^0 \to f)}{\mathcal{A}(\overline{D}^0 \to f)} .$$

The parameter r_B, to be determined experimentally, is expected in the range $0.1 - 0.3$. The *CP*-invariant strong phase δ_B is not known either. There are three strategies depending on the considered D final state f.

In the Gronau-Wyler-London method (GWL) one considers decays of the D^0 and the $\overline{D}^0$ to *CP* eigenstates ($D_+^{CP} \to \pi^+\pi^-$, K^+K^- or $D_-^{CP} \to K_S^0\pi^0$, $K_S^0\phi$, $K_S^0\omega$). This method is sensitive to γ but the interference is small ($|R| \sim r_B$) and an external measurement of r_B is needed. In addition statistics suffers from extremely small branching fractions of D mesons to *CP* final states [18].

In the Atwood-Dunietz-Soni method (ADS) one considers the $K^+\pi^-$ final state, which is dominant for the $\overline{D}^0$ and doubly-Cabbibo suppressed for the D^0. The interference is larger ($|R| \gg r_B$) but due to unknown relative D^0-decay strong phases the method is mostly sensitive to r_B. To date, the decay $B^- \to D^0[K^+\pi^-]K^-$ has not been observed and an upper limit $r_B < 0.23$ (90%C.L.) is placed [19].

In the Giri-Grossman-Soffer-Zupan method (GGSZ) one consider the decay of the D^0 and the $\overline{D}^0$ to the $K_S^0\pi^+\pi^-$ final state, exploiting the interference patterns

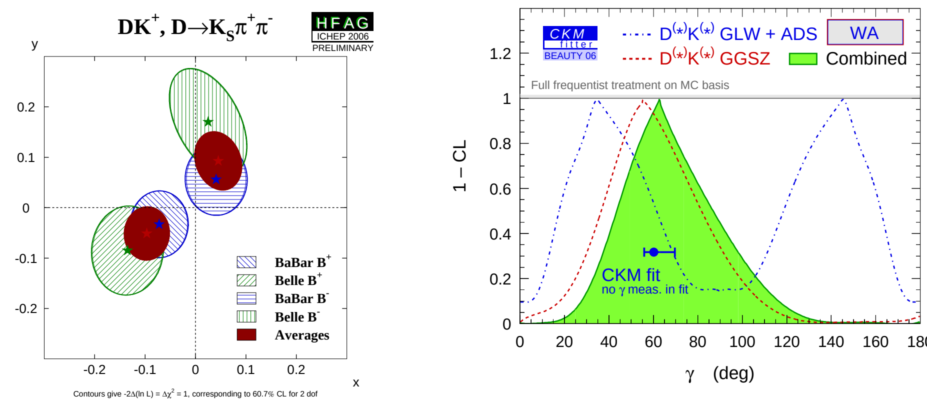


Fig. 5. On the left side: summary of results for the GGSZ method in the DK mode. The two solutions have modulus $r_B = 0.16 \pm 0.07$ and phase $\delta_B \pm \gamma$. On the right side: confidence level as a function of the value of γ (World average) combining GLW, ADS and GGSZ methods.

in the Dalitz plot. Here the interference parameter depends on the location in the Dalitz plot,

$$R(m_+^2, m_-^2) = r_B e^{i\delta_B} \frac{\mathcal{A}(m_-^2, m_+^2)}{\mathcal{A}(m_+^2, m_-^2)}\,,$$

where $m_\pm^2 = (p_{K_S^0} + p_{\pi^\pm})^2$. The Dalitz decay amplitude, $\mathcal{A}(m_-^2, m_+^2) \equiv \mathcal{A}(D^0 \to K_S^0\pi^+\pi^-; p_{K_S^0}, p_{\pi^+}, p_{\pi^-})$, studied using huge samples of flavor-tagged D^0 mesons from $D^{*+} \to \pi^+ D^0$ decays in $c\bar{c}$ continuum, is modeled as a combination of many interfering resonances. The sensitivity to γ is largest along the band of the doubly Cabbibo-suppressed decay $D^0 \to K^*(892)^+\pi^-$, with a situation similar to the ADS method in the interference region with the Cabbibo-allowed $K^*(892)^-\pi^+$ decay. The GGSZ is potentially a powerful method sensitive to γ, r_B and δ_B, but it introduces extra uncertainties due to the Dalitz modeling and necessitates large statistics of events [20,21]. The combined GGSZ for $B \to DK$ results are illustrated on Fig. 5 (left).

Similar but in general less sensitive GWL, ADS and GGSZ analyses exist for modes $B \to D^*K$, DK^* and D^*K^*. The combination of all the results on γ, presented on Fig. 5 (right), leads to yet a poor constraint $36° < \gamma < 98°$ (68.3%C.L.), consistent with the indirect constraint from a CKM fit excluding these measurements, $\gamma_{\rm CKM} = (59^{+9}_{-4})°$.

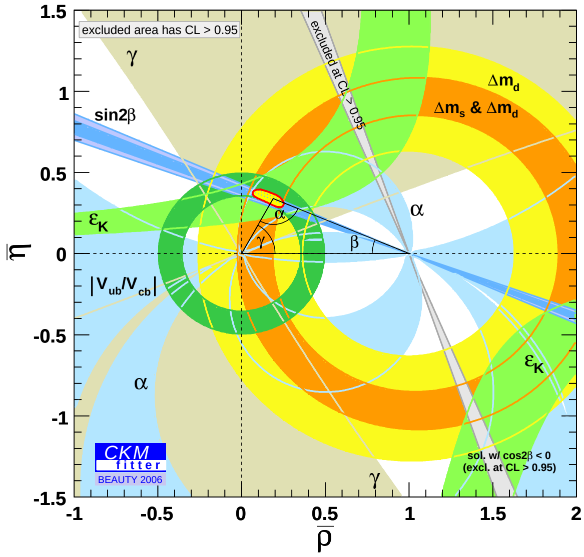
2.4. *CP-conserving measurements*

B factories produce many *CP*-conserving measurements related to the magnitudes of CKM matrix elements involved in B-meson decays, in particular $|V_{cb}|$ and $|V_{ub}|$. In general the interpretation of these measurement is made difficult by the effects of the strong interactions (QCD).

There are two main approaches for the measurement of $|V_{cb}|$, using exclusive decays like $B \to D^*\ell\nu$ or studying inclusive processes like $B \to X_c\ell\nu$ where X_c is an hadronic system carrying charm. The exclusive method has in general more theoretical uncertainty due to the lack of knowledge of involved form factors in the decay. The inclusive measurement dominated average is $|V_{cb}| = (41.6 \pm 0.6) \times 10^{-3}$.

The magnitude of V_{ub} is difficult to measure because it is ten times smaller than $|V_{cb}|$. There are several approaches: study of the lepton spectrum beyond the end-point of $B \to X_c\ell\nu$, study exclusive charmless semileptonic decays like $B \to \rho\ell\nu$, study of inclusive $B \to X_u\ell\nu$ in events where the other B is fully-reconstructed with both leptonic and hadronic system measured, etc. Here again, the exclusive methods suffers from theoretical uncertainties on the form factors. The inclusive measurement dominated average, $|V_{ub}| = (4.31 \pm 0.30)^{-3}$, is in slight disagreement with the indirect value of $|V_{ub}|$ from the CKM fit, $(3.6 \pm 0.2) \times 10^{-3}$.

The magnitude of V_{td} is related to the frequency of the $B^0\overline{B}^0$ flavor oscillations, precisely measured at B factory, $\Delta m_d = (0.507 \pm 0.004)\,\mathrm{ps}^{-1}$. However the accuracy on $|V_{td}|$ is limited by theoretical uncertainties in hadronic effects, $|V_{td}| = (7.4 \pm 0.8) \times 10^{-3}$. These uncertainties are considerably reduced by considering instead



observable	meas.
α (deg)	$92.6^{+10.7}_{-9.3}$
β (deg)	21.2 ± 0.1
γ (deg)	60^{+38}_{-24}
V_{cb} (10^{-3})	41.6 ± 0.6
V_{ub} (10^{-3})	4.3 ± 0.3
Δm_d (ps^{-1})	0.507 ± 0.004
Δm_s (ps^{-1})	17.8 ± 0.1
ε_K (10^{-3})	2.221 ± 0.008

Fig. 6. Summary of CKM constraints by the end of 2006.

the ratio $|V_{td}/V_{ts}|$, which can now be evaluated thanks to the recent observation of $B_s\overline{B}_s$ mixing and the precise measurement of its frequency, $\Delta m_s = (17.77 \pm 0.10 \pm 0.07)\,\mathrm{ps}^{-1}$, by CDF at the Tevatron [22]: $|V_{td}/V_{ts}| = 0.200^{+0.015}_{-0.006}$.

3. Search for New Physics

Fig. 6 presents the summary of constraints in the $(\overline{\rho}, \overline{\eta})$ plane by the time of this conference (from Ref. [17]). There is consistency of all measurements and an overall agreement with SM expectations (despite perhaps the so-called "tension", a 2-sigma level disagreement between $|V_{ub}/V_{cb}|$ and $\sin 2\beta$ that can be seen on the figure). The apex of the UT lies in the small bean-like area indicated around $(\overline{\rho}, \overline{\eta}) = (0.195^{+0.022}_{-0.055}, 0.326^{+0.027}_{-0.015})$, at the intersection of the allowed regions by all available *CP*-conserving and *CP*-violating measurements. That such a region exists is a highly non-trivial test of the flavor and *CP* violation sectors of the SM. The implication is that any model of physics beyond the SM must satisfy SM-like flavor structure at low energy. In particular to a good approximation a single parameter (a non-trivial phase in the CKM matrix) is sufficient as the source of all *CP* violation effects in the quarks sector.

The strategy for probing NP at B factories follows several avenues: looking for discrepancies in measuring *CP*-violating parameters (*e.g.* $\sin 2\beta$) with tree-dominated (unsensitive to NP) or penguin-dominated processes; looking for deviations from the SM in flavor mixing; looking for very suppressed B decays (FCFN or leptonic); looking for lepton flavor violation; etc.

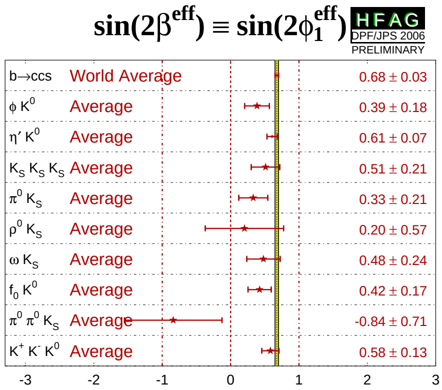


Fig. 7. Summary of averaged measurements of $\sin 2\beta_{\rm eff}$ for modes involving the $b \to s\bar{s}s$ transition (s-penguin modes) compared to $\sin2\beta$ as measured with $b \to c\bar{c}s$ modes.

3.1. sin2*β* *with s-penguin modes*

The S parameter in tree-dominated $b \to c\bar{c}s$ transitions like $B \to J/\psi K^0$ yields a measure of $\sin2\beta$ free from theoretical uncertainty. Other decays mediated dominantly by FCNC transitions $b \to q\bar{q}s$, q being a down-type quark, carry the same weak phase as $b \to c\bar{c}s$ and therefore can be used to measure $\sin2\beta$ as well. Sometimes these decays also receive sub-dominant contribution of amplitudes with a difference weak phase $b \to u\bar{u}s$, leading to calculable small deviations of the corresponding S parameters with respect to $\sin2\beta$. Decays mediated by $b \to s\bar{s}s$ such as $B \to \phi K^0$, $B \to K^0K^0K^0$, $B \to \eta' K^0$, are called s-penguin modes. Fig. 7 presents the value of $\sin 2\beta_{\rm eff} \equiv -\eta^{CP} S$ for various CP-eigenstates with a neutral kaon (detected either as a K^0_S or a K^0_L) and CP-parity η^{CP}. The values of $\sin2\beta_{\rm eff}$ from s-penguin modes are consistently smaller than the reference value measured in $c\bar{c}s$ modes ($\sin2\beta = 0.68 \pm 0.03$). Taken to face value, the naive average $\langle \sin2\beta_{\rm eff} \rangle = 0.53 \pm 0.05$ is statistically inconsistent with $\sin2\beta$ at the $\sim 2.6\sigma$ level, even more so if one includes theoretical predictions mode by mode. Should this discrepancy be confirmed with increased statistics, this would be an indication of NP entering the FCNC $b \to s$ transitions. Since NP may affect different modes in different ways, the idea would be then to use the pattern of deviations for the various modes to go beyond the naive average and start constraining the parameter space of NP models [3].

3.2. *b* → *s transitions*

Rare B decays originating from the $b \to s$ transition serve as sensitive probes of NP. Deviations of measurements with respect to SM expectations can be exploited to determine how the Wilson coefficients that appear in the Operator Product

Expansion (OPE) of the effective Hamiltonian describing $\Delta B = \pm 1$ decays are affected by NP. In the OPE a decay amplitude such as $b \to s\gamma$ can be written as the product of a CKM term (here $V_{tb}^* V_{ts}$), a Wilson coefficient which encodes short distance physics, calculated perturbatively at the electroweak scale m_W and evolved to the low energy scale around the b-quark mass using the Renormalization Group Equations (RGE), and a non-perturbative term which can be calculated using an effective Lagrangian in powers of Λ/m_B. Fig. 8 pictures three Wilson coefficients, C_7, C_9 and C_{10}, involved in $b \to s\gamma$ and $b \to s\ell^+\ell^-$ transitions.

The electroweak process $b \to s\gamma$ is being studied in a variety of ways: exclusive (*e.g.* in $B \to K^*\gamma$); semi-inclusive [23] (sum of many exclusive final states with kaons, amounting to large fraction of the total $b \to s$); or fully inclusive [24,25]. The inclusive-dominated combination of analyses from CLEO, *BABAR* and *BELLE* gives $\mathcal{B}(b \to s\gamma)_{E_\gamma^* > 1.6\,\mathrm{GeV}} = (3.55 \pm 0.26) \times 10^{-4}$, in excellent agreement with the SM predictions, averaged to $(3.6 \pm 0.4) \times 10^{-4}$. The fact that theory and data agree so well with typical errors better than 10% imposes strong constraints on the effect of SUSY "LL" mass insertions on the modulus of the Wilson coefficient C_7. The sign of C_7 is determined to that predicted by the SM from studies of the inclusive $b \to s\ell^+\ell^-$ transition in a region of low q^2 of the lepton pair below the J/ψ, $1 < q^2(\ell^+\ell^-) < 6\,\mathrm{GeV}^2$, where predictions for C_7 and $-C_7$ differ significantly [26,27].

The exclusive modes $B \to K^{(*)}\ell^+\ell^-$ have all been measured consistent with SM predictions, with errors comparable to theory uncertainties. An observable very sensitive to NP is the forward-backward asymmetry of the lepton pair in $B \to K^*\ell^+\ell^-$, which is driven by the interference between vector (C_7 and C_9) and axial-vector (C_{10}) amplitudes. The SM predicts an asymmetry close to zero at small q^2 and positive at large q^2. At the moment both experiments favor positive integrated asymmetry as expected by the SM [28,29], but the statistics is not yet sufficient at B factories to perform a precise study as a function of q^2. This observable is promising in the future (at LHCb for instance) to probe SUSY "RR" and "LL" mass insertions.

3.3. *Leptonic decays*

The SM decay rate for the purely leptonic decay $B^- \to \tau^-\overline{\nu}_\tau$ is proportional to $f_B^2|V_{ub}|^2$, where f_B is the B decay constant, calculable on the QCD lattice with an uncertainty of $\sim 15\%$. Combined with the precise measurement of Δm_d, this

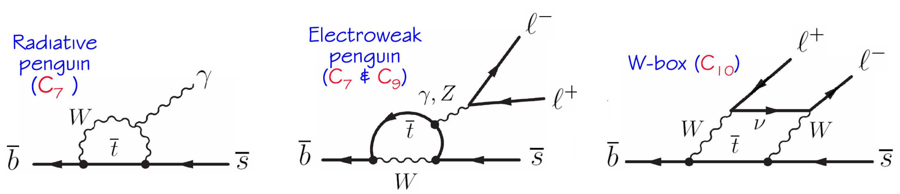


Fig. 8. Wilson coefficients C_7, C_9 and C_{10} involved in $b \to s\gamma$ and $b \to s\ell^+\ell^-$ transitions. New Physics may affect Wilson coefficients, for which reliable calculations in the Standard Model exist.

rate can be used to measure $|V_{ub}|/(|V_{td}|\sqrt{B_B})$, where B_B is a QCD bag parameter, currently calculated on the lattice with $\sim$ 8% uncertainty. Experimentally a recoil technique is used. The candidate events are tagged with a fully reconstructed hadronic (*BELLE* analysis) or semileptonic (*BABAR* analysis) B final state and the τ lepton is reconstructed in its leptonic or hadronic one and three prong decays. The final variable to discriminate against backgrounds is the sum of all extra energy in the electromagnetic calorimeter, expected to be zero for the signal. *BELLE* claims a signal at the 3.5 standard deviation level [30] and measures $\mathcal{B}(B^- \to \tau^-\overline{\nu}_\tau) = (1.79^{+0.56}_{-0.49}{}^{+0.46}_{-0.51}) \times 10^{-4}$, to be compared to the expected SM value of $(1.05 \pm 0.31) \times 10^{-4}$. This evidence is not confirmed by *BABAR*, which places a limit $\mathcal{B}(B^- \to \tau^-\overline{\nu}_\tau) < 1.8 \times 10^{-4}$ at the 90%C.L. with an analysis of comparable sensitivity [31]. Combined with the measured value of V_{ub} and the calculated value of f_B, these results can be used to constrain the possibility of a charged Higgs boson, which would contribute to the decay without helicity suppression. In two-Higgs doublet models coupled separately to up- and down-type quarks (such as the MSSM) the interference with the helicity-suppressed W-exchange amplitude is always destructive, $R_{B\tau\nu} \equiv \mathrm{SUSY/SM} \approx \left(1 - \tan^2\beta \times (m_H^2/m_B^2)\right)^2$. From the slight excess observed by *BELLE*, an indication that the actual branching fraction is not much smaller than the SM expectation, it is already possible to exclude a large fraction of the m_H-$\tan\beta$ plane [30]. More complete analyses combining $B \to \tau\nu$ and $b \to s\gamma$ have been carried out [3]. At present, $b \to s\gamma$ is the more sensitive observable. However, with increased statistics, $\mathcal{B}(b \to s\gamma)$ will become limited by systematic errors on theory predictions while the improved sensitivity from $\mathcal{B}(B \to \tau\nu)$ will allow to further constrain the parameter space of SUSY models.

4. Conclusion

This review covers only a small part all the physics performed at B factories, and especially does not touch fascinating topics such as the recent evidence for $D^0\overline{D}^0$ mixing [32,33] [d]. However the results reviewed here demonstrate we hope the tremendous quality of the measurements of the sides and angles of the Unitarity Triangle produced since 2001 by B factories. The situation of flavor physics and *CP* violation in the Standard Model is now clarified. At present there is an overall excellent consistency of the CKM fit, except perhaps for a "tension" between the measurements of $|V_{ub}/V_{cb}|$ and $\sin 2\beta$, and a value of $\sin 2\beta$ measured with s-penguin modes sightly lower than expected. Whether these are hints for New Physics or mere statistical fluctuations might be answered by B factories experiments themselves, as they plan to double their statistics in the next two years. Strong constraints are already imposed on the flavor structure of New Physics, leading to models where new sources of flavor or *CP* violation simply do not exist (Minimal Flavor Violation) or

[d] The reader is invited to consult the full lists of *BELLE* [34] and *BABAR* [35] publications, which evolve at the incredible pace of roughly one submitted paper per week.

are confined in $b \to s$ transitions. By the study of very suppressed flavor-changing neutral weak currents, precision measurements in flavor physics will continue to bring crucial information on the nature of the physics beyond the Standard Model, complementary to the great direct discoveries of Higgs bosons and new particles anticipated at the LHC.

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