

Measurements of the CKM angle ϕ_3/γ

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We present a review on the measurements of the CKM angle γ (ϕ_3)¹ as performed by the *BABAR* and Belle experiments at the asymmetric-energy e^+e^- B factories colliders PEP-II and KEKB. These measurements are using either charged or neutral B decays. For charged B decays the modes $\tilde{D}^0 K^-$, $\tilde{D}^{*0} K^-$, and $\tilde{D}^0 K^{*-}$ are employed, where \tilde{D}^0 indicates either a D^0 or a \bar{D}^0 meson. Direct CP violation is exploited. It is caused by interferences between V_{ub} and V_{cb} accessible transitions that generate asymmetries in the final states. For these decays various methods exist to enhance the sensitivity to the V_{ub} transition, carrying the weak phase γ . For neutral B decays, the modes $D^{(*)\pm}\pi^\mp$ and $D^\pm\rho^\mp$ are used. In addition to the V_{ub} and V_{cb} interferences, these modes are sensitive to the B^0 - \bar{B}^0 mixing, so that time dependent analyses are performed to extract $\sin(2\beta + \gamma)$. An alternative method would use the lower branching ratios decay modes $\tilde{D}^{(*)0}\bar{K}^{(*)0}$ where much larger asymmetries are expected.

The various available methods are mostly “theoretically clean” and always free of penguins diagrams. In some cases a high sensitivity to γ is expected and large asymmetries may be seen. But these measurements are always experimentally difficult as one has to face with either low branching ratios, or small asymmetries, or additional technical/theoretical difficulties due to Dalitz/SU(3) and re-scattering models needed to treat/estimate nuisance parameters such as unknown strong phases and the relative magnitude of the amplitude of the interfering “ V_{ub} ” transitions. Thus at the present time only a relatively limited precision on γ can be extracted from these measurements. The current world average is $\gamma = (78_{-26}^{+19})^\circ$ [1]. For other methods and long term perspectives, as discussed in details, the reader is invited to consult the proceedings of the recent CKM workshop that was held in Nagoya (Japan) in December 2006 [2].

1. Introduction

We present the results of the measurements performed by the *BABAR* and Belle collaborations, to determine the value of the Cabibbo-Kobayashi-Maskawa (CKM) CP violating phase γ ($\equiv \arg[-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*]$).

These measurements are based on the studies done with the charged B decays $\tilde{D}^0 K^-$, $\tilde{D}^{*0} K^-$, and $\tilde{D}^0 K^{*-}$, where \tilde{D}^0 indicates either a D^0 or a \bar{D}^0 meson. They are based on the interference of the amplitudes proportional to the V_{cb} and V_{ub} CKM-matrix elements that generate asymmetries through direct CP violation effects associated to the electroweak (EW) phase γ carried by the V_{ub} amplitude. These measurements are at the present time the most constraining ones, but neutral B decays such as $D^{(*)\pm}\pi^\mp$ and $D^\pm\rho^\mp$ are also used to extract constraints on $\sin(2\beta + \gamma)$, as B^0 - \bar{B}^0 mixing is present in addition to the above described direct CP violation phenomenon. The sensitivity to the V_{ub} amplitude is relatively small for these decays, so it has been proposed to use the rare decays $\tilde{D}^{(*)0}\bar{K}^{(*)0}$ where larger CP asymmetries are expected.

At the time of this conference the two asymmetric-energy e^+e^- colliders PEP-II at SLAC and KEKB at

KEK have produced a huge quantity of data at the $\Upsilon(4S)$ resonance. *BABAR* [3] and Belle [4] detectors have integrated over 1100 fb⁻¹ of data (respectively about 420 fb⁻¹ and 710 fb⁻¹). This corresponds to a sample of more than one billion $B\bar{B}$ pairs collected. It can be noticed that the measurements presented here are all statistically limited and most of them use only a fraction of the currently available dataset. It is therefore crucial that they will be updated soon.

2. Measuring γ with charged B decays

Methods are exploited [5–7], where the \tilde{D}^0 decays either to a CP eigenstate (GLW method), or to a Doubly Cabibbo-Suppressed flavor Decay (DCSD, “wrong sign” decay, ADS method), or to the $K_S^0\pi^-\pi^+$ final state, for which a Dalitz analysis has to be performed ($GGSZ$ method). To extract γ , those three methods are all based on the fact that a B^- can decay into a color-allowed $D^0 K^-$ (color-suppressed $\bar{D}^0 K^-$) final state via $b \rightarrow c\bar{u}s$ ($b \rightarrow u\bar{c}s$) transitions. The amplitude $\mathcal{A}(\text{“}V_{cb}\text{”})$ of the $b \rightarrow c\bar{u}s$ transition is proportional to λ^3 and the amplitude $\mathcal{A}(\text{“}V_{ub}\text{”})$ of the $b \rightarrow u\bar{c}s$ transition to $\lambda^3\sqrt{\eta^2 + \rho^2}e^{i(\delta_B - \gamma)}$ (where λ is the related to the Cabibbo angle). The second amplitude therefore carries both the EW γ CP phase and the relative strong phase of those two transitions. As the total amplitude for the $\tilde{D}^0 K^-$ decay is the sum of the two amplitudes $\mathcal{A}(\text{“}V_{cb}\text{”})$ and $\mathcal{A}(\text{“}V_{ub}\text{”})$, the two amplitudes interfere when the D^0 and \bar{D}^0 decay into the same final state. This interference leads to dif-

¹The *BABAR* and Belle collaborations use different conventions to label the three CKM angles, where $\beta \equiv \phi_1$, $\alpha \equiv \phi_2$, and $\gamma \equiv \phi_3$. In this report we use the *BABAR* convention: α , β , and γ .

ferent B^+ and B^- decay rates (direct CP violation). These methods apply to the two other charged B decays: $\tilde{D}^{*0}K^-$ and \tilde{D}^0K^{*-} , as well.

The various methods are “theoretically clean” because the main contributions to the amplitudes come from tree-level transitions, in an excellent approximation. In addition to the parameters and to the strong phase, $\mathcal{A}(\text{“}V_{ub}\text{”})$ is significantly reduced with respect to $\mathcal{A}(\text{“}V_{cb}\text{”})$ by the color-suppression phenomenon. One usually defines the parameter $r_B \equiv |\mathcal{A}(\text{“}V_{ub}\text{”})/\mathcal{A}(\text{“}V_{cb}\text{”})|$ that determines the size of the direct CP asymmetry. It is a critical parameter for these analyses. Its value is predicted [8] to lie in the range 0.05 – 0.3 as it has been argued that color-suppression may not be as important as expected from naive factorization in charmed B decays [9]. The smaller r_B is, the smaller is the experimental sensitivity to γ .

As the three decay modes \tilde{D}^0K^- , $\tilde{D}^{*0}K^-$, and \tilde{D}^0K^{*-} are used, one should remark that 7 parameters have to be extracted from the three used methods: the common EW phase γ and the nuisance parameters for the measurements, i.e., a respective strong phase “ δ_B ” and an “ r_B ” parameter for each of the three modes: δ_B , r_B , δ_B^* , r_B^* , δ_{sB} , and r_{sB} .

The CKM-angle γ , and the parameters “ r_B ”, and “ δ_B ” can be measured experimentally by two quantities (Asymmetry and Ratio of branching ratios):

$$\mathbf{A} \equiv \frac{\Gamma(B^- \rightarrow \tilde{D}^{(*)0}K^{(*)-}) - \Gamma(B^+ \rightarrow \tilde{D}^{(*)0}K^{(*)+})}{\Gamma(B^- \rightarrow \tilde{D}^{(*)0}K^{(*)-}) + \Gamma(B^+ \rightarrow \tilde{D}^{(*)0}K^{(*)+})} \quad (1)$$

$$\mathbf{R} \equiv \frac{\Gamma(B^- \rightarrow \tilde{D}^{(*)0}K^{(*)-}) + \Gamma(B^+ \rightarrow \tilde{D}^{(*)0}K^{(*)+})}{\Gamma(B^- \rightarrow D^{(*)0}K^{(*)-}) + \Gamma(B^+ \rightarrow \tilde{D}^{(*)0}K^{(*)+})} \quad (2)$$

For \mathbf{R} , the denominator is built with branching ratios of specific flavor D^0 decays.

2.1. The GLW method: \tilde{D}^0 CP eigenstates

For the GLW method [5] the \tilde{D}^0 is reconstructed in various CP eigenstate decay channels [10, 11]: K^+K^- , $\pi^+\pi^-$ (CP_+ eigenstates); and $K_S^0\pi^0$, $K_S^0\phi$, $K_S^0\omega$ (CP_- eigenstates). The \tilde{D}^{*0} is reconstructed in the decay mode $\tilde{D}^{*0}\pi^0$ only and the $K^*(892)^-$ mesons into the decay $K^{*-} \rightarrow K_S^0\pi^-$. The total branching ratio of each considered decay mode, including secondary decays is relatively small (10^{-6} or less). As many modes are taken into account to reconstruct the \tilde{D}^0 it is anyway possible to have enough signal events to study asymmetries, but this technique is obviously strongly statistically limited. So the small CP asymmetry ($r_B \simeq 0.05 - 0.3$) and the rareness of these D^0 CP eigenstate modes, make this method difficult with the present B factories dataset.

In the GLW method, there exist 4 observable quantities, for three unknowns (γ , r_B , and δ_B): $\mathbf{R}_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos \delta \cos \gamma$ and $\mathbf{A}_{CP\pm} = \pm 2r_B \sin \delta \sin \gamma / \mathbf{R}_{CP\pm}$. Only three are independent, as: $\mathbf{R}_{CP-} \mathbf{A}_{CP-} = -\mathbf{R}_{CP+} \mathbf{A}_{CP+}$. The observable \mathbf{R}_{CP} is normalized to the branching ratios as obtained from three flavor state decays: $D^0 \rightarrow K^-\pi^+$, $K^-\pi^+\pi^0$, and $K^-\pi^+\pi^+\pi^-$. In principle with infinite statistics this method is very clean to determine γ , but up to an 8 fold-ambiguity, as the above equations show. It can be noticed from the definition of \mathbf{R}_{CP} that the sensitivity to the nuisance parameter r_B is quite weak, as it is expected to be much smaller than unity.

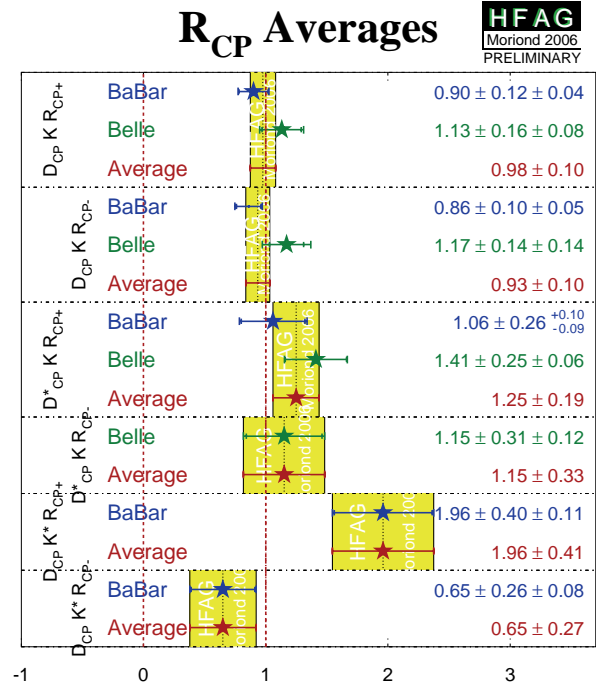


Figure 1: World HFAG [12] compilation on the \mathbf{R}_{CP} observable.

The $BABAR$ [10] and $Belle$ [11] collaborations have published results based on a limited fraction only of their full available dataset. They respectively use 232×10^6 and 275×10^6 $B\bar{B}$ pairs to measure the observables \mathbf{R}_{CP} and \mathbf{A}_{CP} . Significant signals allow to compute \mathbf{R}_{CP} and \mathbf{A}_{CP} observables with however limited precision. The (peaking)-background is estimated from the m_{ES} (m_{bc}) and D^0 mass sidebands. The CP_+ pollution for CP_- eigenstate from decays $K_S^0[K^+K^-]_{\text{non } \phi}$ and $K_S^0[\pi^+\pi^-\pi^0]_{\text{non } \omega}$ is estimated using data. Finally, in the systematic uncertainty accounting, the possible strong phases as generated by probable $K\pi S$ waves in the $K^{*-} \rightarrow K_S^0\pi^-$ decays are taken into account.

Figures 1 and 2 summarize the averages computed by the HFAG collaboration [12] for the measurements

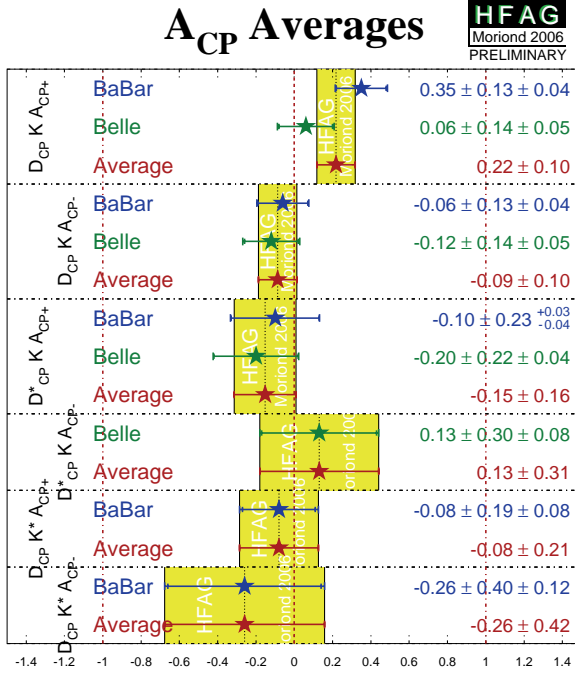


Figure 2: World HFAG [12] compilation on the \mathbf{A}_{CP} observable.

of the two B factories. At the present time, the measured values of \mathbf{A}_{CP} (\mathbf{R}_{CP}) are not precise enough to differ significantly from zero (unity) so that a precise constraint on γ can not be obtained from the GLW method alone.

From $\mathbf{R}_{CP\pm}$ and $\mathbf{A}_{CP\pm}$ one can derive the so called *Cartesian coordinates*: $x_{\pm} \equiv r_B \cos(\delta_B \pm \gamma)$, as $x_{\pm} = (\mathbf{R}_{CP+}(1 \mp \mathbf{A}_{CP+}) - \mathbf{R}_{CP-}(1 \mp \mathbf{R}_{CP+}))/4$ and $r_B^2 = (\mathbf{R}_{CP+} + \mathbf{R}_{CP-} - 2)/2$. For the $\tilde{D}^0 K^-$ BABAR [10] extracts $r_B^2 = -0.12 \pm 0.08(\text{stat}) \pm 0.03(\text{syst})$, and $x_+ = -0.082 \pm 0.052(\text{stat}) \pm 0.018(\text{syst})$, $x_- = 0.102 \pm 0.062(\text{stat}) \pm 0.022(\text{syst})$ and for $\tilde{D}^0 K^{*-}$ BABAR obtains $r_{sB}^2 = 0.30 \pm 0.25$, $x_{s+} = 0.32 \pm 0.18(\text{stat}) \pm 0.07(\text{syst})$, and $x_{s-} = 0.33 \pm 0.16(\text{stat}) \pm 0.06(\text{syst})$. These measurements have a precision already competitive with those of the $GGSZ$ method (see Sect. 2.3), that is the reason why the GLW method is useful into the global fit to γ in a combined statistical treatment of the various methods.

2.2. The ADS method: \tilde{D}^0 Doubly Cabibbo Suppressed Decays (DCSD)

For the ADS method [6], the D^0 meson as generated from the $b \rightarrow c\bar{u}s$ transition is required to decay to the Doubly Cabibbo-Suppressed $K^+\pi^-$ mode (DCSD or "wrong sign"), while the \bar{D}^0 meson, from

the $b \rightarrow u\bar{c}s$ transition, decays to Cabibbo-favored final state $K^+\pi^-$. The overall branching ratio for a final state $B^- \rightarrow [K^+\pi^-]_{\tilde{D}^0} K^{(*)-}$ is expected to be very small ($\sim 10^{-6}$), but the two interfering diagrams are of the same order of magnitude. The challenge in this method is therefore to detect B candidate in this final state with two opposite charge kaons. The total amplitude is complicated by an additional unknown relative strong phase δ_D in the $D^0\text{-}\bar{D}^0 \rightarrow [K^+\pi^-]$ system, while the ratio of their respective amplitude r_D^2 is now very precisely measured and is equal to $(0.376 \pm 0.009)\%$ [13]. It can be written as $A([K^+\pi^-]_{\tilde{D}^0} K^{(*)-}) \propto r_B e^{i(\delta_B - \gamma)} + r_D e^{-i\delta_D}$. Using the $B^- \rightarrow [K^-\pi^+] K^{(*)-}$ modes as normalisation for \mathbf{R}_{ADS} , one can write the equations for the two experimental observable quantities: $\mathbf{R}_{ADS} = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D) \cos(\gamma)$ and $\mathbf{A}_{ADS} = 2r_B r_D \sin(\delta_B + \delta_D) \sin(\gamma) / \mathbf{R}_{ADS}$, where \mathbf{R}_{ADS} is clearly highly sensitive to r_B^2 . The observable \mathbf{A}_{ADS} can obviously only be measured if a significant number of DCSD candidates is seen.

For the $\tilde{D}^0 K^-$ and $\tilde{D}^{*0} K^-$ channels [14] and [16], no significant signal has been measured yet. For the $\tilde{D}^{*0} K^-$ modes BABAR uses both the $D^{*0} \rightarrow D^0 \pi^0$ and $D^0 \gamma$ modes. It has been demonstrated [17] that the strong phase δ_B^* differs by an effective phase π , so that they can be combined to extract δ_B^* and to set a more constraining limit on r_B^* . These measurements have been obtained with dataset corresponding respectively to 232×10^6 and $386 \times 10^6 B\bar{B}$ pairs. At 90 % of confidence level (C.L.), BABAR sets the upper limits $r_B < 0.23$ and $r_B^{*2} < (0.16)^2$. With about 1.7 times the BABAR statistics Belle obtains a slightly better limit: $r_B < 0.18$ at 90 % of C.L.. For the $\tilde{D}^0 K^{*-}$ decay [14], no significant signal is seen yet, BABAR measures $\mathbf{R}_{ADS} = 0.046 \pm 0.031(\text{stat}) \pm 0.008(\text{syst})$, $\mathbf{A}_{ADS} = -0.22 \pm 0.61(\text{stat}) \pm 0.17(\text{syst})$. As part of the systematic uncertainty accounting, BABAR considers effect of the possible strong phases as generated by probable $K\pi S$ waves in the $K^{*-} \rightarrow K_s^0 \pi^-$ decays. It is the dominant contribution.

Using a frequentist approach [1], and combining both the GLW and ADS methods for the $\tilde{D}^0 K^{*-}$ channel [14], BABAR extracts $r_{sB} = 0.28_{-0.10}^{+0.06}$, and excludes at the two-standard deviation level the interval $75^\circ < \gamma < 105^\circ$.

More recently, BABAR [15] has performed a measurement on another DCSD using $226 \times 10^6 B\bar{B}$ pairs: the D^0 "wrong sign" decays to $K^+\pi^-\pi^0$. In this case the extraction of γ is complicated by the variation of the D^0 decay amplitude and of the strong phase δ_D over the Dalitz decay plane $K^+\pi^-\pi^0$. The relative value of r_D^2 is smaller than for the $K^+\pi^-$ decay and equals to $(0.241 \pm 0.011)\%$ [18], a larger sensitivity on \mathbf{R}_{ADS} and r_B is therefore expected. The price to pay is however a larger background level. From a fit to ΔE , m_{ES} , and a neural-network multi-

variable discriminant to suppress the light $q\bar{q}$ pairs background, *BABAR* extracts 18_{-15}^{+18} candidates, compatible with no DCSD signal, and sets the Bayesian limits: $\mathbf{R}_{ADS} < 0.039$ and $r_B < 0.185$ at 95 % of credibility interval. One can remark that this constraint on r_B is at the same level of sensitivity as the one obtained from the $K^+\pi^-$ DCSD decay.

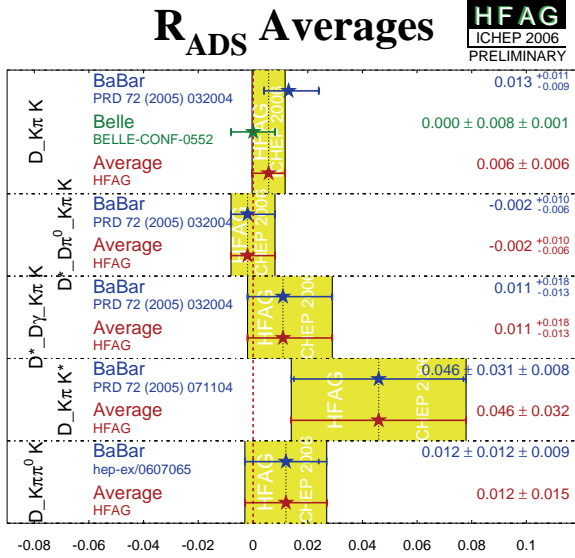


Figure 3: World HFAG [12] compilation on the \mathbf{R}_{ADS} observable.

Figure 3 summarizes the averages computed by the HFAG collaboration [12] for the measurements of the two B factories. At the present time, the measured values of \mathbf{R}_{ADS} are not precise enough. So only limits on “ r_B ” parameters are set. By extension the ADS method can not provide us yet with any strong constraint on γ alone.

2.3. The $GGSZ$ method: \tilde{D}^0 to $K_S^0\pi^-\pi^+$ Dalitz decay analysis

Among the \tilde{D}^0 decay modes studied so far the $K_S^0\pi^-\pi^+$ channel is the one with the highest sensitivity to γ [7] because of the best overall combination of branching ratio magnitude, D^0 - \bar{D}^0 interference and background level. This mode offers a reasonably high branching ratio ($\sim 10^{-5}$, including secondary decays) and a clean experimental signature (only charged tracks in the final state). The decay mode $K_S^0\pi^-\pi^+$ can be accessed through many intermediate states: “wrong sign” or “right” K^* resonances (such as $K^*(892)$, $K^*(1410)$, $K_0^*(1430)$, $K_2^*(1430)$, or $K^*(1680)$), CP eigenstates $K_S^0\rho^0$, $K_S^0\omega$, or $K_S^0f^0$, ... Therefore, an analysis of the amplitude

of the \tilde{D}^0 decay over the $m^2(K_S^0\pi^-)$ vs $m^2(K_S^0\pi^+)$ (i.e.: m_-^2 vs m_+^2) Dalitz plane structure is sensitive to the same kind of observable as for both the GLW and ADS methods, and obviously carries more information. The sensitivity to γ varies strongly over the Dalitz plane. The contribution from the $b \rightarrow u\bar{c}s$ transition in the $B^- \rightarrow D^{(*)0}K^{(*)-}$ ($B^+ \rightarrow \bar{D}^{(*)0}K^{(*)+}$) decay can significantly be amplified by the amplitude \mathcal{A}_{D+} (\mathcal{A}_{D-}) of the $\bar{D}^0 \rightarrow K_S^0\pi^-\pi^+$ ($D^0 \rightarrow K_S^0\pi^+\pi^-$) decay ($\mathcal{A}_{D\mp} \equiv \mathcal{A}_D(m_{\mp}^2, m_{\pm}^2)$). Assuming no CP asymmetry in D decays, and neglecting D^0 - \bar{D}^0 mixing, the decay rate of the chain $B^- \rightarrow D^{(*)0}K^{(*)-}$ ($B^+ \rightarrow \bar{D}^{(*)0}K^{(*)+}$), and $\tilde{D}^0 \rightarrow K_S^0\pi^-\pi^+$, can be written as:

$$\Gamma_{\mp}(m_-^2, m_+^2) \propto |\mathcal{A}_{D\mp}|^2 + r_B^2 |\mathcal{A}_{D\pm}|^2 + 2\{x_{\mp} \text{Re}[\mathcal{A}_{D\mp}\mathcal{A}_{D\pm}^*] + y_{\mp} \text{Im}[\mathcal{A}_{D\mp}\mathcal{A}_{D\pm}^*]\}. \quad (3)$$

In the above equation, the *Cartesian coordinates* have been introduced: $\{x_{\pm}, y_{\pm}\} = \{\text{Re}, \text{Im}\}[r_B e^{i(\delta_B \pm \gamma)}]$, for which the constraint $r_B^2 = x_{\pm}^2 + y_{\pm}^2$ holds. They replace the physical constants: “ δ_B ”, “ r_B ”, and γ in the measurements as when dealing with low statistical samples and low sensitivities to direct CP violation effects due to small “ r_B ” values close to zero, non Gaussian effects and biases arise when fitting for the amplitude $\Gamma_{\mp}(m_-^2, m_+^2)$. These are also natural parameters to describe the amplitude of the decay. A simultaneous fit both to the B^{\pm} decays and $\tilde{D}^0 \rightarrow K_S^0\pi^-\pi^+$ decays is then performed to extract 12 parameters: $\{x_{\pm}, y_{\pm}\}$ from $\tilde{D}^0 K^{\pm}$, $\{x_{\pm}^*, y_{\pm}^*\}$ from $\tilde{D}^{*0} K^{\pm}$, and $\{x_{s\pm}, y_{s\pm}\}$ from $\tilde{D}^0 K^{*\pm}$. In the last case, *BABAR* [19] deals with $(K_S^0\pi^{\mp})_{\text{non-}K^*}$ contributions, by defining an effective dilution parameter κ following the concept of “generalized” *Cartesian coordinates* [20]: $x_{s\pm}^2 + y_{s\pm}^2 = \kappa^2 r_{sB}^2$, with $0 \leq \kappa \leq 1$. Belle [21] fits directly for r_{sB} and addresses these effects in the systematic uncertainty budgets.

Since the measurement of γ arises from the interference term in $\Gamma_{\mp}(m_-^2, m_+^2)$, the uncertainty in the knowledge of the complex form of \mathcal{A}_D can lead to a systematic uncertainty. The additional phase of the previous amplitude varies over the Dalitz plane. One can remark that it is an additional technical difficulty with respect to the GLW and ADS methods where there is only the unknown constant strong phases δ_B and possibly an other strong phase δ_D for \tilde{D}^0 pure two-body decays. The extraction of γ relies then on a Dalitz model for the complex amplitude \mathcal{A}_D as a function of (m_-^2, m_+^2) . Both *BABAR* [19] and Belle [21] use “home made” isobar models [22] with coherent sums of Breit-Wigner amplitudes, where the three-body $K_S^0\pi^-\pi^+$ decay is supposed to proceed via quasi two-body decay amplitudes only. These models includes also an additional non-resonant term (NR):

$$\mathcal{A}_D(m_-^2, m_+^2) = \Sigma_r a_r e^{i\phi_r} \mathcal{A}_r(m_-^2, m_+^2) + a_{NR} e^{i\phi_{NR}}. \quad (4)$$

To build their isobar models, the *BABAR* and Belle collaborations use very high statistics flavor-tagged D^0 sample ($D^{*+} \rightarrow D^0 \pi_s^+$, where π_s is a low momentum pion) selected from data $e^+e^- \rightarrow c\bar{c}$ events (respectively about 390×10^3 and 260×10^3 events). These samples have an excellent purity, larger than 97 %.

The *BABAR* model is based on 16 resonances (including three DCSD) and on one NR term. Most of the resonance parameters are extracted from the PDG [13], except the $K_0^*(1430)$ that is taken from the E791 experiment that uses an isobar model, while the PDG quotes LASS parametrization. It includes also two “ad hoc” $\sigma(500)$ and $\sigma'(1000)$ resonances to describe the broad $\pi\pi$ S waves. Their parameters are determined in an effective way directly from the continuum D^0 data sample. In a second model (hereafter referred as the $\pi\pi$ S wave K-matrix model) the treatment of the $\pi\pi$ S wave states in $D^0 \rightarrow K_S^0 \pi^- \pi^+$ uses a K-matrix formalism to account for the non-trivial dynamics due to the presence of broad and overlapping resonances. This model is used in the Dalitz-model systematic uncertainty determination. The total amplitude fit fraction for the reference isobar model is about 1.2 and the value of $\chi^2/n.d.o.f.$ of the fitted model is equal to 1.2.

The Belle model is built with 18 resonances (including 5 DCSD) and one NR term, most of the resonance parameters are extracted from the PDG [13], except also the two “ad hoc” $\sigma(500)$ and $\sigma'(1000)$ resonances, fitted directly on the data. The total amplitude fit fraction is about 1.2 and the value of $\chi^2/n.d.o.f.$ of the fitted model is equal to about 2.7.

A simultaneous fit to the m_{ES} (or m_{bc}), ΔE , Fisher (for B signal to $q\bar{q}$ light quarks separation) variables and Dalitz model is then performed to extract the values of the *Cartesian coordinates*, after selection of the B^\pm candidates. The measurements have been performed by *BABAR* [19] and Belle [21] with dataset corresponding to 347×10^6 and 386×10^6 $B\bar{B}$ pairs respectively. For the $\tilde{D}^0 K^{*\pm}$ mode *BABAR* uses a sample of 227×10^6 $B\bar{B}$ pairs. Belle fits 331 ± 17 $\tilde{D}^0 K^\pm$, 81 ± 11 $\tilde{D}^{*0} K^\pm$, and 54 ± 8 $\tilde{D}^0 K^{*\pm}$, with purities respectively equal to 67 %, 77 %, and 65 %. The *BABAR* B^\pm sample corresponds to 398 ± 23 $\tilde{D}^0 K^\pm$, 97 ± 13 (93 ± 12) $\tilde{D}^{*0} K^\pm$, where $D^{*0} \rightarrow D^0 \pi^0$ ($D^0 \gamma$ (different from Belle)), and 42 ± 8 $\tilde{D}^0 K^{*\pm}$, and with similar purities as those from Belle. The *BABAR* dataset is therefore slightly larger than that of Belle, due to better selection efficiencies.

On Figures 4, 5, and 6 one can see the contours plots for the *Cartesian coordinates* and for the three decay channels computed by the HFAG collaboration [12] from the measurements of the two B fac-

tories. These contours at 1 standard deviation do not include the Dalitz model uncertainty. An overall good agreement between *BABAR* and Belle measurements is visible. The precision on the x_\pm variables is equivalent with what what discussed in Sec. 2.1 with the *GLW* method. On these Figures, one can see that the B^+ and B^- contours are flipped going from the $\tilde{D}^0 K^\pm$ decays to $\tilde{D}^{*0} K^\pm$, because they differ by a relative phase π . The deviations from the $(0, 0)$ coordinates size the importance of the direct *CP* violations effect and are proportional to the “ r_B ” nuisance parameters, possibly different in the measurement from B^+ and B^- candidates. Finally, the angle in between the directions of the segments $[(0, 0); (x_+, y_+)]$ and $[(0, 0); (x_-, y_-)]$ is by definition equal to 2γ .

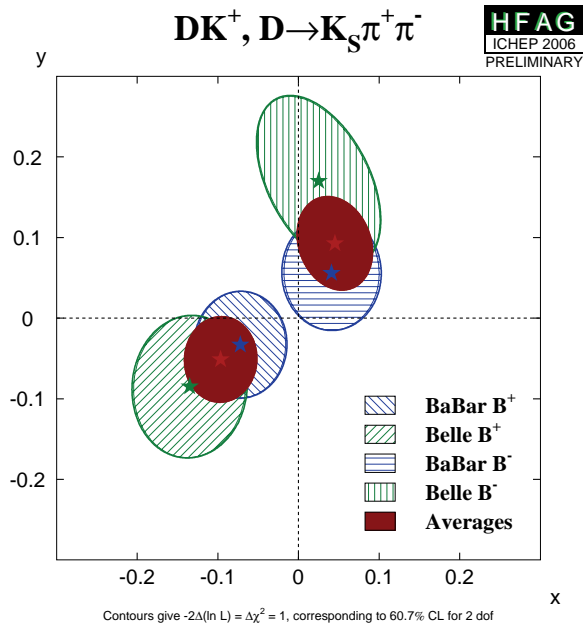


Figure 4: World HFAG [12] compilation on the $\{x_\pm, y_\pm\}$ observables.

At the end of the analysis, the 7 parameters: γ , δ_B , δ_B^* , δ_{sB} , r_B , r_B^* , and $(\kappa.)r_{sB}$, are extracted from the 12 *Cartesian coordinates* using a frequentist approach that defines a 5-dimension (D) (3- D) classical Neyman Confidence Region (C.R.), in the case of *BABAR*. The statistical extraction method used by Belle is slightly different. A 7- D C.R. is computed using the refined frequentist Feldman-Cousins ordering technique in order to address the issue raised by possible un-physical different values of “ r_B ” as obtained for the B^+ and B^- populations.

The overall value for the *EW CP* phase measured by *BABAR* [19] is: $\gamma = [92 \pm 41 \pm 11 \pm 12]^\circ$ (the first uncertainty is statistical, the second accounts for experimental systematic effects, and the third for the *Dalitz model*), where it can be noticed that the uncer-

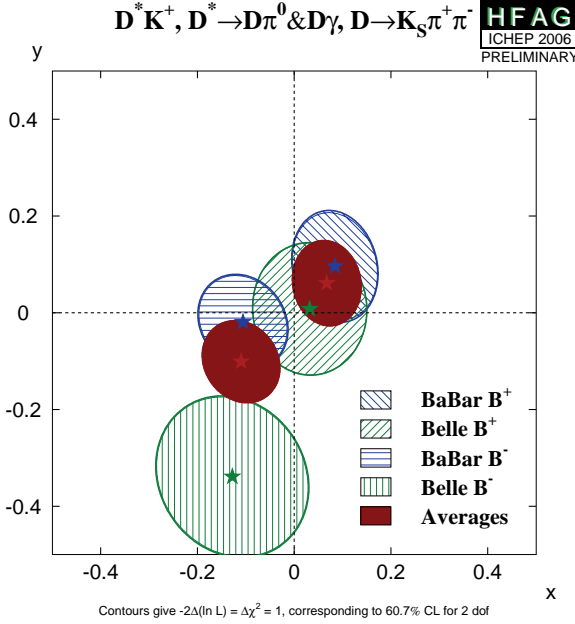


Figure 5: World HFAG [12] compilation on the $\{x_{\pm}^*, y_{\pm}^*\}$ observables.

tainty coming from the employed Dalitz model would limit the measurement at infinite statistics. This value is obtained with the $\tilde{D}^0 K^{\pm}$ and $\tilde{D}^{*0} K^{\pm}$ decays alone, and is somewhat less precise than the 2005 published measurement. It is due to lower estimated values for the “ r_B ”: $r_B < 0.142$ (0.198) and $0.016 < r_B^* < 0.206$ (0.282), at 1 (2) standard deviation(s), when the previous values were respectively $0.12 \pm 0.08 \pm 0.03 \pm 0.04$ and $0.17 \pm 0.10 \pm 0.03 \pm 0.03$. As the sensitivity to γ and as well the precision of the measurement, varies as $1/r_B$, so that these smaller values explain a larger statistical error on γ . No constraint at 1 standard deviation is derived from the $\tilde{D}^0 K^{\pm}$ mode alone, and a relatively loose upper limit on $\kappa \cdot r_{sB}$ is set at 0.5.

The measurement performed by Belle has a better precision as the estimated “ r_B ” values are found to be larger: $r_B = 0.159_{-0.050}^{+0.054} \pm 0.012 \pm 0.049$, $r_B^* = 0.175_{-0.099}^{+0.108} \pm 0.013 \pm 0.049$, and $r_{sB} = 0.564_{-0.155}^{+0.216} \pm 0.041 \pm 0.084$. They correspond to a global value: $\gamma = [53_{-18}^{+15} \pm 3 \pm 9]^\circ$ ($8^\circ < \gamma < 111^\circ$ at 2 standard deviations). This value is somewhat more precise from what one would expect by scaling the statistics from the previously published measurement in 2004. The value of r_B^* has been shifted up, as it was previously equal to $0.12_{-0.11}^{+0.16} \pm 0.02 \pm 0.04$ and r_B did not change significantly as it was previously $0.21 \pm 0.08 \pm 0.03 \pm 0.04$. The experimental systematic uncertainty has been significantly reduced due to the use of a control high statistic control samples of $D^{(*)0} \pi^-$ and $D^{*-} \pi^+$ B decays.

More recently *BABAR* [23] has studied the Dalitz de-

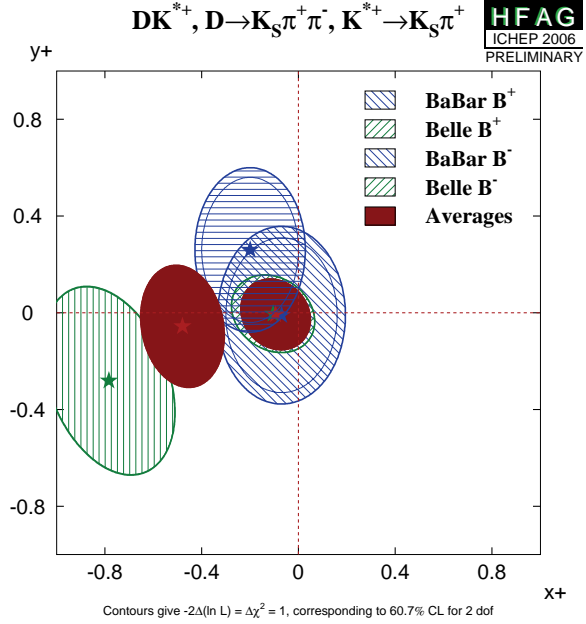


Figure 6: World HFAG [12] compilation on the $\{x_{s\pm}, y_{s\pm}\}$ observables.

cay $\tilde{D}^0 K^{\pm}$, where the \tilde{D}^0 decays to $\pi^0 \pi^- \pi^+$. With respect to the $K_s^0 \pi^- \pi^+$ mode the signal rate is divided by about a factor 2. The background is also larger due to the presence of a π^0 meson. *BABAR* has measured for the first time the isobar model of this Dalitz decay. Due to significant non-linear correlations it has been found that with the present statistic the *Cartesian coordinates* can not be used in the global fit extraction, neither the γ , r_B , and δ_B constants. If one defines $z_{\pm} \equiv r_B e^{i(\delta_B \pm \gamma)}$, it has been demonstrated that the fit biases are strongly reduced when fitting for the so-called *polar coordinates*: $\rho_{\pm} \equiv |z_{\pm} - x_0|$ and $\theta_{\pm} \equiv \tan^{-1} \left(\frac{y_{\pm}}{x_{\pm} - x_0} \right)$, where x_0 is a coordinate transformation parameter equal to 0.85. For no *CP* violation the B^+ and B^- contours are centered in the $(\rho_{\pm}, \theta_{\pm})$ plane on the coordinate $(0.85, 180^\circ)$. *BABAR* obtains: $\rho_- = 0.72 \pm 0.11 \pm 0.04$, $\rho_+ = 0.75 \pm 0.11 \pm 0.04$, $\theta_- = (173 \pm 42 \pm 2)^\circ$, and $\theta_+ = (147 \pm 23 \pm 1)^\circ$ (where the uncertainties are respectively for statistical and for the systematic effects). So far no strong deviation from that position as been established and no attempt has been made to extract the physics constants γ , r_B , and δ_B by *BABAR*. A quite loose constraint on γ is foreseen.

3. Measuring γ with neutral B decays

The decays of neutral B mesons that allow to constrain $\sin(2\beta + \gamma)$ have either small sensitivity to the V_{ub} phase or small branching fractions. At the present

time these measurements can only help in improving the overall picture on the determination of the CKM-angle γ . The presence of hadronic parameters in the observables (r and δ , the amplitude ratio and the strong phase difference between the V_{cb} and V_{ub} interfering amplitudes), as for previously discussed for charged B decay, complicates the extraction of the weak phase informations. The problem here is even more crucial as in case of $D^{(*)\pm}\pi^\mp$ and $D^\pm\rho^\mp$ mode the V_{ub} amplitude counts only as about 2 % [24] of the total amplitude and in the case of $\tilde{D}^{(*)0}\bar{K}^{(*)0}$ these modes are so rare that the value of r can not yet be directly measured. There exist however approaches based on SU(3) symmetry to estimate the magnitude of the nuisance parameter r and as a consequence to set constraints on $\sin(2\beta + \gamma)$.

3.1. CP asymmetry in neutral $D^{(*)\pm}\pi^\mp$ and $D^\pm\rho^\mp$ B decays

This technique has been proposed [24] as the $D^{(*)-}\pi^+$ and $D^-\rho^+$ decays can be produced either in the decay of a B^0 or a \bar{B}^0 , respectively through the $\bar{b} \rightarrow \bar{c}u\bar{d}$ (the “ V_{cb} amplitude”, Cabibbo favored (\mathcal{A}_{CF})) or $b \rightarrow u\bar{c}d$ transition (the “ V_{ub} amplitude”, doubly Cabibbo suppressed (\mathcal{A}_{DCS})). These are pure tree decays with relatively large branching ratios of the order of 0.3 – 0.8%. Their relative weak phase is γ . An additional weak phase 2β may come from initial B^0 - \bar{B}^0 mixing. Another unknown relative strong phase δ arises from strong interaction in the final state in between these two amplitudes. Due to mixing, the $D^{(*)\pm}\pi^\mp$ decay rate evolves with time as:

$$\begin{aligned} P(B^0 \rightarrow D^{(*)\pm}\pi^\mp, \Delta t) &\propto 1 \pm C^{(*)} \cos(\Delta m_d \Delta t) \\ &\quad + S^{(*)\mp} \sin(\Delta m_d \Delta t), \\ P(\bar{B}^0 \rightarrow D^{(*)\mp}\pi^\pm, \Delta t) &\propto 1 \mp C^{(*)} \cos(\Delta m_d \Delta t) \\ &\quad - S^{(*)\pm} \sin(\Delta m_d \Delta t), \end{aligned} \quad (5)$$

where Δm_d is the mixing frequency, and Δt is the time difference in between the time of the $B \rightarrow D^{(*)\pm}\pi^\mp$ decay (hereafter referred as the reconstructed B meson, B_{rec}) and the decay of the other B meson (hereafter referred as the tagging B meson, B_{tag}). In the above equation the flavor B^0 (\bar{B}^0) can be experimentally determined from the flavor of the B_{tag} (using a flavor specific final state). Therefore the technique employed to extract the relevant constants is similar to the time dependent analyses performed with $(c\bar{c})K_s^0$ decays for the determination of $\sin(2\beta)$ [25]. The parameter $C^{(*)}$ and $S^{(*)\pm}$ are given by:

$$C^{(*)} \equiv \frac{1 - r^{(*)2}}{1 + r^{(*)2}} (\simeq 1), \quad (6)$$

$$S^{(*)\pm} \equiv \frac{2r^{(*)}}{1 + r^{(*)2}} \sin(2\beta + \gamma \pm \delta^{(*)}). \quad (7)$$

We can also define the strong phase differences in between \mathcal{A}_{CF} and \mathcal{A}_{DCS} as $\delta^{(*)}$ and $r^{(*)}$ as the ratio $|\mathcal{A}_{CF}/\mathcal{A}_{DCS}|$. There exist as well two constants “ r ” and “ δ ” for the $D^\pm\rho^\mp$ mode. As expected from the DCSD phenomenon [24], the “ r ” constants are expected to be of the order of 2 %. Due to the small value of $r^{(*)2}$ ($\sim 10^{-4}$) it obviously impossible to extract “ r ” from the measurements with the present statistic of the available samples (i.e., from $C^{(*)}$). It is also mandatory to have large data sample for extracting statistically significant measurements of $S^{(*)\pm}$.

The BABAR [26] and Belle [27] collaborations are using two different techniques to select high-statistics samples of $D^{(*)\pm}\pi^\mp$ and $D^\pm\rho^\mp$ B decays. These measurements have been obtained with dataset corresponding respectively to 232×10^6 and 386×10^6 $B\bar{B}$ pairs. A full reconstruction technique is accessible for the three above decays, while a partial reconstruction technique allows to use the $D^*\pi$ decay mode only.

For the exclusive method, the full decay chain is reconstructed. Therefore an excellent purity of the order of 90 % for $D^*\pi$ decay is achieved. The price to pay, in addition to the limited tagging efficiency and when determining the B_{tag} flavor, is the relatively limited event yields. Belle gets about 30×10^3 events for the $D^*\pi$ decay.

The other method is based on a partial reconstruction where only the soft (low momentum) π track of the D^* -meson decay and the prompt (high momentum) π track of the B decay are detected. As the D^* s are not explicitly reconstructed one gains on the secondary decay branching ratios. The price to pay is a relatively lower purity that depends on the tagging category. It goes from 30 % in case of kaons tags to about 55 % for prompt leptons tags. The statistics for this method can be enhanced up to 5 or 6 times with respect to the one obtained for the fully exclusive technique. With 232×10^6 $B\bar{B}$ pairs, BABAR analyse a data sample of about 71×10^3 K -tagged $D^*\pi$ (19×10^3 lepton-tagged). The K -tagged sample has about 4 times the statistics of the leptons-tagged one.

An important experimental difficulty has to be mentioned. As the expected CP asymmetries for these measurements are small, the interferences of $b \rightarrow u$ and $b \rightarrow c$ amplitudes in the decay of the B_{tag} have to be taken into account. They dilute the effective B_{rec} CP asymmetry. The BABAR collaboration uses an alternative parametrization to the $S^{(*)\pm}$:

$$\begin{aligned} a &\equiv 2r \sin(2\beta + \gamma) \cos(\delta), \\ b &\equiv 2r' \sin(2\beta + \gamma) \cos(\delta'), \\ c &\equiv 2 \cos(2\beta + \gamma) (r \sin(\delta) - r' \sin(\delta')). \end{aligned} \quad (8)$$

For each $D^{(*)\pm}\pi^\mp$ and $D^\pm\rho^\mp$ decay mode, each measurement technique (partial or full reconstruction) and for each tagging category one gets a different interference on the tagging side, as the background differ from one case to the other. Effective “ r ” and “ δ' ” parameters are therefore derived. One notes that r' automatically vanishes in a and c when using the lepton tagging category.

BABAR [26] uses both kind of tags for the partial reconstruction technique and only lepton tags for the full reconstruction technique. *Belle* [27] uses only lepton tags for the partial reconstruction method (thus limiting the yield of useful $D^*\pi$ candidates for the CP violation measurement), and all tags categories for the fully exclusive method. The DCSD interferences in the B_{tag} side are measured using control samples of $D^{(*)}l\nu B$ decays.

These measured values for a and c , in the two methods and for the three types of decay mode, are in good agreement in between the two experiments, the detailed values can be found in the HFAG collaboration winter 2007 document [12]. The combined values of $(a;c)$ are: $(-0.030 \pm 0.017; -0.022 \pm 0.021)$ for $D^\pm\pi^\mp$, $(-0.037 \pm 0.011; -0.006 \pm 0.014)$ for $D^{*\pm}\pi^\mp$, and $(-0.024 \pm 0.033; -0.098 \pm 0.058)$ for $D^\pm\rho^\mp$. Figures 7 and 8 show in a graphical way the combined $(a;c)$ values for $D^\pm\pi^\mp$ and $D^{*\pm}\pi^\mp$.

A 3.4σ deviation from 0 is visible for a in the D^* mode indicating that observation of CP violation is within reach for the B factories with some additional statistics. The currently published results by *BABAR* and *Belle* are anyway not using the full available dataset.

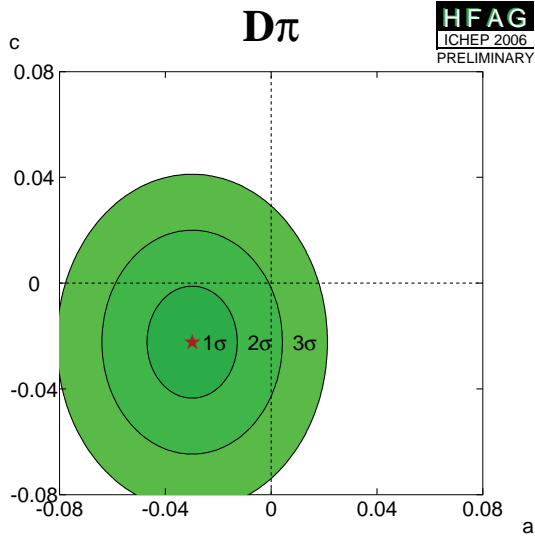


Figure 7: Graphical view of the world HFAG [12] compilation for the a and c parameters for the $D^\pm\pi^\mp$ decay mode.

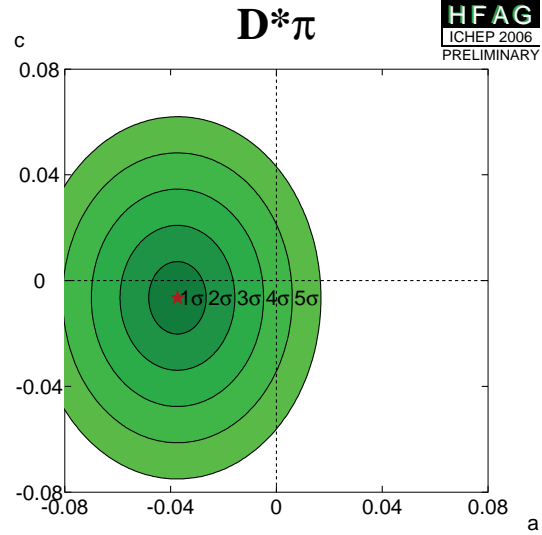


Figure 8: Graphical view of the world HFAG [12] compilation for the a^* and c^* parameters for the $D^{*\pm}\pi^\mp$ decay mode.

Both *BABAR* [26] and *Belle* [27] have extracted limits on $|\sin(2\beta + \gamma)|$. For this it is mandatory to estimate the value of “ r ”. This is done using SU(3) flavor symmetry, with available branching fractions (including recent *BABAR* [28] measurement for the $D_s^{(*)+}\pi^-$ modes), and lattice calculations for decay constants. These extractions of r have a relative 30 % uncertainty due to estimation of SU(3) breaking and limited knowledge on W -exchange and annihilation diagrams. With all the three *BABAR* sets lower limits on $|\sin(2\beta + \gamma)|$ respectively equal to 0.64 (0.40) at 68 % of C.L. (90 %). With the $D^{*\pm}\pi^\mp$ mode *Belle* sets the lower limit 0.44 (0.13) at 68 % of C.L. (95 %). With the $D^\pm\pi^\mp$ *Belle* sets lower limit 0.52 (0.07) at 68 % of C.L. (95 %).

Based on an updated and more sophisticated version of the *BABAR* model, a re-scattering SU(3) symmetry model [29], the following values of “ r ” are computed: $r^{D\pi} = (1.53 \pm 0.33 \pm 0.08)\%$, $r^{D^*\pi} = (2.10 \pm 0.47 \pm 0.11)\%$, and $r^{D\rho} = (0.31 \pm 0.59 \pm 0.02)\%$, where the first uncertainty is a Gaussian error for SU(3) breaking from non-factorizable contributions and the second is a 5 % flat error for SU(3) breaking from W -exchange and annihilation diagrams. A global combined frequentist [1] constraint of all the available results is shown for $|\sin(2\beta + \gamma)|$ on Figure 9, where the C.L. distributions are displayed. A lower limit on this quantity is set at 0.59 (0.37) at 68 % of C.L. (95.5 %).

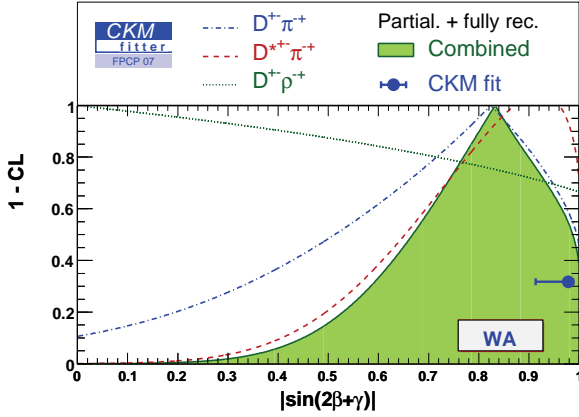


Figure 9: 1-C.L. constraint profile as obtained for $|\sin(2\beta + \gamma)|$ [1].

3.2. CP asymmetry in neutral $\tilde{D}^{(*)0}\bar{K}^{(*)0} B$ decays

It has been proposed [5, 6, 30] that the rare neutral $\tilde{D}^{(*)0}\bar{K}^{(*)0} B$ decays can be used for the time dependent CP asymmetry measurement of $\sin(2\beta + \gamma)$. These final states can be produced through $b \rightarrow c$ or $\bar{b} \rightarrow \bar{u}$ transitions. Both are color-suppressed and Cabibbo-suppressed transitions and are of the same order of magnitude ($\propto \lambda^3$). Despite the rareness of these modes, it has been stressed that the ratio of the ratio \tilde{r}_B should be relatively large and of the order of 0.4, thus making these modes appealing with large B meson dataset. As \tilde{r}_B is large enough, in the time dependent analysis and as opposed to the previously described neutral B decays, it is feasible to extract both $S^{(*)\pm}$ and $C^{(*)}$ coefficients, so that no theoretical assumption nor any model is needed to measure $\sin(2\beta + \gamma)$, $\tilde{\delta}_B$, and \tilde{r}_B at the same time.

So far, Belle with $88 \times 10^6 B\bar{B}$ pairs and BABAR [31] with $226 \times 10^6 B\bar{B}$ pairs, have measured the branching ratios of these decays. They lie in the range $4 - 5 \times 10^{-5}$, while the mode $\bar{B}^0 \rightarrow \bar{D}^0\bar{K}^{*0}$ has not yet been observed. The most precise upper limit for its branching fraction is 1.1×10^{-5} at 90 % C.L.. It is then obvious that no direct measurement of \tilde{r}_B is yet accessible.

Using the self tagging decay $\bar{K}^{*0} \rightarrow K^-\pi^+$, it is possible to estimate the ratio $|\mathcal{A}(\bar{B}^0 \rightarrow \bar{D}^0\bar{K}^{*0})/\mathcal{A}(\bar{B}^0 \rightarrow D^0\bar{K}^{*0})|$. These decays can be therefore distinguished by the kaons charges correlations in the D and K^* meson decays (the V_{ub} transition would have opposite charges kaons, as for the ADS method described in Sec. 2.2). Again the sensitivity to \tilde{r}_B is diluted by the presence of DCS decays: $D^0 \rightarrow K^+\pi^-$, $K^+\pi^-\pi^0$, and $K^+\pi^-\pi^+\pi^-$ modes for which r_D constants have measured relatively precisely [13]. From the ratio of branching ratios $\mathbf{R} =$

$\Gamma(\bar{B}^0 \rightarrow (K^+X_i^-)_D\bar{K}^{*0})/\Gamma(\bar{B}^0 \rightarrow (K^-X_i^+)_D\bar{K}^{*0})$, where $X_i^\pm = \pi^\pm, \pi^\pm\pi^0$, or $\pi^\pm\pi^-\pi^+$, one can extract constraints on \tilde{r}_B^2 , when knowing r_D^2 and doing assumptions on $\tilde{\delta}_B$, γ , and δ_D (see Sec. 2.2). Doing this, BABAR [31] has set the upper limit $\tilde{r}_B^2 < 0.40$ at 90 % of C.L.. This suggests that, as the branching fraction of the decay $\bar{B}^0 \rightarrow \bar{D}^0\bar{K}^{*0}$ is still unknown, that this technique is still not yet powerful enough with the existing B factories dataset and will not even be in near future.

4. Conclusions, perspectives, and global constraints on γ

We have presented a review on the measurements of the CKM-angle γ (ϕ_3) as performed at the B factories PEP-II and KEKB by BABAR and Belle collaborations. These measurements were considered as more or less impossible for these $\Upsilon(4S)$ experiments a few years ago. Though we have not yet entered the era of precision, many methods using charged or neutral B -decays have been employed, pioneering the measurements at the future LHCb experiment, or possibly at future super B factories.

Before to get there, the present existing B factories will have to update these results with already existing additional dataset and non negligible forthcoming statistics. In addition, many refinements and new methods continue to be developed [2]. One can therefore anticipate substantial improvements. All the machinery is in place, but all these measurements are by far dominated by statistics uncertainty. Puzzles remain such as the exact value of the r_B that sizes the sensitivity to γ and that is always exploited in each of the previously described methods. The bigger it is, the shorter will be the way to precision era.

So far the GGSZ method exploiting the Dalitz Decay $\bar{D}^0 \rightarrow K_S^0\pi^-\pi^+$ in charged B decays $\tilde{D}^{(*)0}K^{(*)-}$ continues to provide us with the most powerful constraint on γ . The Dalitz model systematic uncertainty is not yet a concern at the present time. Nevertheless, it is possible to reduce the model dependence systematic uncertainty by using the original idea of the GGSZ method [6, 7]. Using CLEO-c and future τ -charm factories it is possible [32] to produce at the $\psi(3770)$ resonance coherent states of D^0 and \bar{D}^0 pairs. The amplitude $\Gamma_{\mp}(m_-^2, m_+^2)$ is no more fitted but replaced by event yields of CP and flavor tagged \tilde{D}^0 within bins of the Dalitz plan. With the existing CLEO-c statistics (280 pb^{-1} corresponding to about 570 CP tagged events) this method should help reducing this uncertainty down to $6^\circ - 7^\circ$. For a projection to about 750 pb^{-1} , corresponding to about 1500 CP tagged events, one should reduce it down to about 4° . At a Super B factory with 50 ab^{-1} , in addition to 10 fb^{-1} of data collected at future τ -charm facto-

ries, on should ultimately be able to measure γ , in a model-independent way, with an accuracy of the order of 2° .

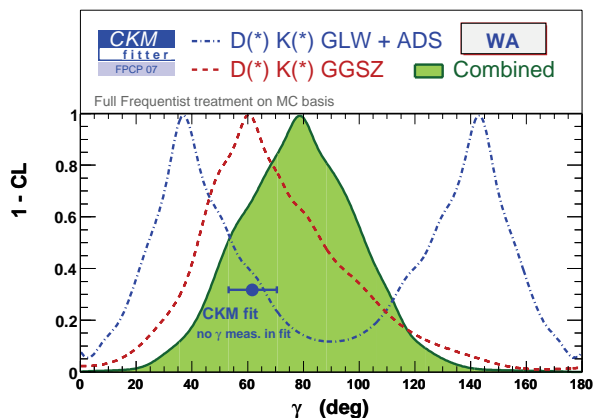


Figure 10: 1-C.L. constraint profile as obtained for γ [1].

To conclude, we present on Figure 10 the combination on the constraints on γ obtained with the charged B decays. The present fit [1] is performed with the HFAG [12] combinations of 32 observables (the $\mathbf{R}_{CP\pm}$, $\mathbf{A}_{CP\pm}$, \mathbf{R}_{ADS} , and *Cartesian coordinates*) to extract 11 physics constants (we have evaluated the strong phases and relative amplitudes ratios for \tilde{D}^0 decays to $K\pi$ and $K\pi\pi^0$ modes). The value $\gamma = (77 \pm 31)^\circ$ is extracted. This is coherent with the 1σ interval from a global CKM coherence fit where these measurement are absent: $52.8^\circ < \gamma < 70.1^\circ$. At 90 % of C.L. one gets from that fit: $r_B^{DK} < 0.13$, $r_B^{D^*K} < 0.13$, and $r_B^{DK^*} < 0.27$. Adding the information coming from the constraint on $|\sin(2\beta + \gamma)|$ a slightly more precise value is obtained: $\gamma = (78_{-26}^{+19})^\circ$.

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