The CKM angle γ/ϕ_3 - B-factories results review

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γ/ϕ_3 is the less precisely known of the Unitarity Triangle angles. The general problematics of measurements of this parameter are discussed and recent experimental results from *Babar* and *Belle* are presented.

1 Measurements of the CKM angle γ/ϕ_3

1.1 Introduction

In the Standard Model, *CP* violation is described by the presence of an irreducible phase in the CKM matrix, the unitary matrix that relates the weak interaction with the mass eigenstates. The CKM can be written as:

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

where $V_{q_1q_2}$ is the coupling related to the transition $q_1 \rightarrow q_2$. Many parametrizations exist in literature, we use here a generalization of the *Wolfenstein parametrization* [1] as presented in [2], where the four independent parameters are λ, A, $\bar{\rho}$ and $\bar{\eta}$ (where the latter is the *CP* violating phase). The matrix is written:

$$V_{CKM} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4) \quad (1)$$

The unitarity of the V_{CKM} matrix implies several relations between its elements that can be represented as triangles in the $(\bar{\rho}, \bar{\eta})$ plane. We choose the relation $V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$, whose elements can be determined by B physics measurements. This triangle, represented in fig. 1, is particularly attracting from the experimental point of view, since it has all the sides of order λ^3. The angles of the triangle are called either α, β and γ or ϕ_2, ϕ_1 and ϕ_3, we adopt

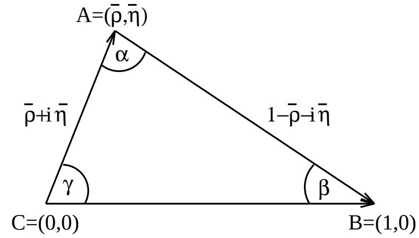

Figure 1: Unitarity Triangle, represented in the $(\bar{\rho}, \bar{\eta})$ plane.

here the first notation.

In the Wolfenstein parametrization the only complex elements, up to terms of order $O(\lambda^5)$, are V_{ub} and V_{td} and the phases γ and β can be directly related to them. In particular, for γ it can be written $V_{ub} = |V_{ub}|e^{-i\gamma}$. Several measurements, using different methods, constrain the weak phase γ from the analyses of $B^+ \to \bar{D}^{(*)0}(D^{(*)0})K^{(*)+}$ and $B^0 \to \bar{D}^{(*)0}(D^{(*)0})K^{(*)0}$ decays, exploiting the interference between $b \to u$ and $b \to c$ transitions whose decay amplitudes will be proportional to the V_{ub} and V_{cb} elements respectively.

1.2 Phenomenology of $B \to DK$ decays

The amplitudes for the $B \to DK$ decays of interest can be expressed:

$$A\,(B^+ \to \overline{D}^0 K^+) = V_{us}\, V_{cb}^* (T + C)\ ,\ \ A\,(B^0 \to \overline{D}^0 K^0) = V_{us}\, V_{cb}^* C\ ,$$

$$A\,(B^+ \to D^0 K^+) = V_{cs}\, V_{ub}^* (\bar{C} + A)\ ,\ \ A\,(B^0 \to D^0 K^0) = V_{cs}\, V_{ub}^* \bar{C}\ . \qquad (2)$$

$$(3)$$

The T parameter will account for a *tree* diagram, C and $\bar{C}$ for*color-suppressed* diagrams and A for an *annihilation* diagram. For the neutral $B \to DK$ decays, both the diagrams for the $b \to c$ and $b \to u$ transitions are *color-suppressed* and their amplitudes are described by the C and $\bar{C}$ parameters respectively (see [3] for a complete treatment).

1.3 Measuring a phase

The idea of measuring a relative phase ϕ through the interference between two amplitudes A_1 and $A_2 e^{i\phi}$ connecting the same initial and final states is based on the fact that the decay rate between these two states is proportional to: $|A_1 + A_2 e^{i\phi}|^2 = A_1^2 + A_2^2 + 2A_1 A_2 \cos\phi$ and hence the interference term gives sensitivity to the relative phase ϕ.

In fig. 2 we show an interference scheme for B^+ mesons decays giving sensitivity to γ. The B^+ can decay either to $\overline{D}^0 K^+$ through a $b \to c$ transition or to $D^0 K^+$ through a $b \to u$ transition. If both the D^0 and the $\overline{D}^0$ decay to the same final state f, the study of the decay $B^+ \to [f]K^+$ gives sensitivity to the relative phase between the two decay amplitudes. The amplitude for $b \to c$ and $b \to u$ transitions can be written as $A(b \to u) \equiv |V_{ub}|e^{i\gamma} A_u e^{i\delta_u}$ and $A(b \to c) \equiv |V_{cb}| A_c e^{i\delta_c}$, where $A_{u(c)}$ and $\delta_{u(c)}$ are the absolute value and the phase of the strong interaction contribution to the amplitude. If the neutral D decay is also considered, a term $A_D e^{i\delta_D}$ (or $A_{\bar{D}} e^{i\delta_{\bar{D}}}$) has to be included. In case of B^+, the interference term in the decay rate will be proportional to $\cos(\delta + \gamma)$, where $\delta = \delta_D - \delta_{\bar{D}} + \delta_u - \delta_c$. A similar diagram can be

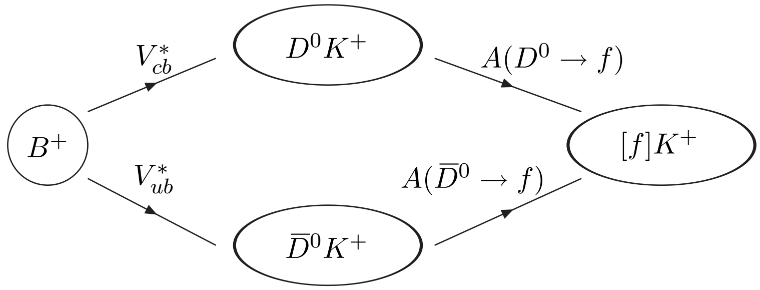

Figure 2: Interference between the $B^+ \to \overline{D}^0K^+$ (a) and the $B^+ \to D^0K^+$ decays.

drawn for the CP conjugate decay ($B^- \to [f]K^-$), in this case the interference term will be proportional to $\cos(\delta - \gamma)$, since the strong interactions conserve CP.

The example shown in fig. 2 refers to the $B^+ \to \overline{D}^0(D^0)K^+$, but equivalent arguments can be done for all the $B^+ \to \overline{D}^{(*)0}(D^{(*)0})K^+$ and $B^- \to D^{(*)0}(\overline{D}^{(*)0})K^-$ as well as for the $B^0 \to \overline{D}^{(*)0}(D^{(*)0})K^{(*)0}$ and $\overline{B}^0 \to D^{(*)0}(\overline{D}^{(*)0})\overline{K}^{(*)0}$ decays.

A fundamental quantity in all the measurements of γ is the parameter $r_B = \frac{|A(b\to u)|}{|A(b\to c)|}$. Being the absolute value of the ratio of the $b \to u$ to the $b \to c$ transition amplitudes, r_B leads the sensitivity to γ in each channel. Following the expressions for the decay amplitudes in 2, the r_B ratio for charged $B \to DK$ channels can be written as:

$$r_B(D^0K^+) = \frac{|A(B^+ \to D^0K^+)|}{|A(B^+ \to \overline{D}^0K^+)|} = \frac{|V_{cs}V_{ub}^*|}{|V_{us}V_{cb}^*|}\frac{|\bar{C} + A|}{|T + C|}; \tag{4}$$

and, for neutral decays, as:

$$r_B(D^0K^0) = \frac{|A(B^0 \to D^0K^0)|}{|A(B^0 \to \overline{D}^0K^0)|} = \frac{|V_{cs}V_{ub}^*|}{|V_{us}V_{cb}^*|}\frac{|\bar{C}|}{|C|}. \tag{5}$$

In the expressions 4 and 5, the term $\frac{|V_{cs}V_{ub}^*|}{|V_{us}V_{cb}^*|}$ only depends on absolute values of CKM parameters and is know to be $\sqrt{\bar{\rho}^2 + \bar{\eta}^2} = 0.372 \pm 0.012$ [4], while the terms depending on the hadronic parameters are not easily predictable. For simple numerical evaluation, the following assumption can be used: $|C|/|T| \approx 0.3$ and $|A|/|T| \approx 0.5$ [5], and one would expect $r_B^{CH} \approx 0.1$ for the charged $B \to DK$ channels and $r_B^{NEUT} \approx 0.4$ for the neutral $B \to DK$ ones.

The measurements of γ are difficult because $b \to u$ transitions are strongly suppressed with respect to $b \to c$ ones, as described by r_B ratios [a] and, as shown from the sketch in fig. 2, the unknowns in any γ analysis are γ itself, the r_B ratio and a strong phase δ. These are usually called polar coordinates. Some analyses make use of the cartesian coordinates, defined in terms of the polar coordinates as $x_\pm = r_B\cos(\delta \pm \delta)$ and $y_\pm = r_B\sin(\delta \pm \gamma)$.

In the following, we denote r_B^* and δ_B^* the amplitude ratio and strong phase relative to $B^+ \to \bar{D}^{*0}(D^{*0})K^+$ decays. In case of a presence of a K^* in the B decay final state, as in the $B^- \to D^0(\bar{D}^0)K^{*-}$ channel, the natural width of the K^* resonance has to be taken into account and effective variables are used, following the formalism shown in [17]. In case of the polar coordinates, these variables are γ (which stays unchanged), k, r_S and δ_S while, in case of the cartesian coordinates, they are called $x_{s\pm}$, $y_{s\pm}$.

1.4 Different experimental methods

There are several methods that aim to measure γ in $B \to DK$ decays (all based on the strategy sketched in fig. 2) that differ because of the neutral D final states f they reconstruct and

[a] It has to be stressed that the parameters r_B are ratios between amplitudes, the ratio between number of events from $b \to u$ and $b \to c$ transitions will be proportional to $r_B{}^2$.

consequently because of different experimental analysis techniques they use.

The Gronau London Wyler method

In the GLW method [6,7], γ is measured from the study of B decays to $D^0_\pm K$ final states, where $D^0_\pm$ is a CP eigenstate (i.e. it is reconstructed in a CP eigenstate final state) with eigenvalues ± 1, defined starting from D^0 and $\bar{D}^0$, as $|D^0_\pm\rangle = \frac{1}{2}(|D^0\rangle \pm |\bar{D}^0\rangle)$.

The following observables are measured:

$$R_{CP\pm} = \frac{\Gamma(B^+ \to D^0_{CP\pm}K^+) + \Gamma(B^- \to D^0_{CP\pm}K^-)}{\Gamma(B^+ \to D^0 K^+) + \Gamma(B^- \to \bar{D}^0 K^-)} = 1 + {r_B}^2 \pm 2r_B \cos\gamma\cos\delta_B$$

$$A_{CP\pm} = \frac{\Gamma(B^+ \to D^0_{CP\pm}K^+) - \Gamma(B^- \to D^0_{CP\pm}K^-)}{\Gamma(B^+ \to D^0_{CP\pm}K^+) + \Gamma(B^- \to D^0_{CP\pm}K^-)} = \frac{\pm 2r_B \sin\gamma\sin\delta_B}{R_{CP\pm}}$$

where δ_B is the relative strong phase between the two B decay amplitudes.

In the GLW method, four observables, $A_{CP\pm}$ and $R_{CP\pm}$, are measured to constraint three unknowns, γ, δ and r_B. This method suffers of an irreducible four-fold ambiguity on the determination of the phases and, with the actual available statistics, is very useful in measuring r_B, but has typically a low sensitivity to γ.

The Adwood Dunietz Soni method

In the ADS method [8,9], γ is measured from the study of $B \to DK$ decays, where D mesons decay into non CP eigenstate final states. In this method the B meson is reconstructed in final states which can be reached in two ways: either through a favored $b \to c$ B decay followed by a suppressed D decay ($D^0 \to f$, or $\bar{D}^0 \to \bar{f}$), or through a suppressed $b \to u$ B decay followed by a favored D decay ($D^0 \to \bar{f}$ or $\bar{D}^0 \to f$). In this way the two amplitudes are comparable and one can expect larger interference terms.
In the ADS method, one measures the observables:

$$R_{ADS} = \frac{\Gamma(B^+ \to \bar{f}K^+) + \Gamma(B^- \to fK^-)}{\Gamma(B^+ \to fK^+) + \Gamma(B^- \to \bar{f}K^-)} = r_D^2 + {r_B}^2 + 2r_B r_D \cos\gamma\cos(\delta_B + \delta_D) \tag{6}$$

$$A_{ADS} = \frac{\Gamma(B^- \to fK^-) - \Gamma(B^+ \to \bar{f}K^+)}{\Gamma(B^- \to fK^-) + \Gamma(B^+ \to \bar{f}K^+)} = r_B r_D[\cos(\delta+\gamma) + \cos(\delta-\gamma)]/R_{ADS}. \tag{7}$$

Here δ_D is the relative strong phase between the favored and suppressed D decay amplitudes, and r_D is the ratio between the absolute values of their amplitudes $r_D = |A(D^0 \to f)|/|A(D^0 \to \bar{f})|$. This method is very useful in measuring r_B, but normally it has very low sensitivity to γ.

The Giri Grossman Soffer Zupan method

In this method [10], usually called Dalitz method, γ is measured from the $B \to DK$ decays with the D decaying to multi-body CP eigenstate final states. Multi-body decays are usually described by the isobar model, in which the decay amplitude is written as a sum of amplitudes with quasi two-body intermediate states and determined on independent neutral D samples. This information is used in input to the Dalitz analyses (that directly extracts form data γ, r_B and δ or the polar coordinates) where the complete and rich structure of the multi-body D decay is exploited and detectable interference terms are expected because of the presence of different strong phases. This method is indeed very powerful and it is the one that gives the best error on the weak phase γ.

2 Common experimental techniques

We present here the results obtained by the two B-factories experiments: *Babar* at the PEP-II asymmetric-energy e^+e^- collider, located at the Stanford Linear Accelerator Center (USA) and *Belle* at the KEK asymmetric-energy e^+e^- collider, located in Tsukuba (Japan). All the analyses presented reconstruct excusively B decays and make use of some common techinques.

The B mesons are caracterized by two almost independent kinematic variables: the beam-energy substituted mass $m_{ES}(M_{bc}) \equiv \sqrt{(E_0^{*2}/2 + \vec{p_0} \cdot \vec{p_B})^2/E_0^2 - p_B{}^2}$ and the energy difference $\Delta E \equiv E_B^* - E_0^*/2$, where E and p are the energy and the momentum respectively, the subscripts B and 0 refer to the candidate B and to the e^+e^- system respectively and the asterisk denotes the e^+e^- CM frame.

Since both PEP-II and KEK e^+e^- collide at $\sqrt{s} = M(\Upsilon(4S))$, the $\Upsilon(4S)$ resonance is produced almost at rest in the e^+e^- center of mass frame. Given the values of the masses of the $\Upsilon(4S)$ and of the B mesons, the latter have a very low residual momentum in the e^+e^- center of mass frame. On the other hand, in case of $e^+e^- \to q\bar{q}$ events, with $q = u, d, s, c$ (called continuum events), the two quarks are produced with large momentum and for this reason, these events have a jet-like spatial shape, different from the spherically distributed one for $B\bar{B}$ events.

Several variables account for these differences and are used in the analyses to fight continuum background, which is typycally the main source of background to these analyses.

3 Experimental results on the charged B decays

We present here the recent results on γ from *Babar* and *Belle* , using the different methods.

3.1 Analyses using the GLW method

We report on the update of the GLW analysis [12] of $B^- \to D^0K^-$, with $D^0 \to K^+K^-$, $\pi^+\pi^-$, $K_S\pi^0$ and $K_S\omega$ [b] using 383 10^6 $B\bar{B}$ pairs collected with the *Babar* detector. In this analysis, after a cut on m_{ES} and on a combination of event shape variables, the observables are extracted using a maximum likelihood fit to the variables ΔE and the Cerenkov angle of the charged K produced in the charged B decay.
The results obtained for the direct *CP* asymmetries and the ratios are the following:

$$R_{CP^+} = 1.06 \pm 0.10 \pm 0.05\ ,\ A_{CP^+} = 0.27 \pm 0.09 \pm 0.04\,,$$
$$R_{CP^-} = 1.03 \pm 0.10 \pm 0.05\ ,\ A_{CP^-} = -0.09 \pm 0.09 \pm 0.02\,,$$

where the first error is statistical and the second one is systematic. For the first time for a GLW analysis, the results are extracted from data also in terms of the cartesian coordinates:

$$\begin{aligned} x_+ &= -0.09 \pm 0.05 \pm 0.02\,, \\ x_- &= +0.10 \pm 0.05 \pm 0.03\,, \\ r^2 &= +0.05 \pm 0.07 \pm 0.03, \end{aligned}$$

where the first error is statistical and the second one is systematic.

The uncertainties on $A_{CP^\pm}$ ($R_{CP^\pm}$) are smaller by a factor of 0.7 (0.9) and 0.6 (0.6) than the previous *Babar* [13] and *Belle* [14] measurements, respectively.

[b] the $K^-\pi^+$ mode is also reconstructed for normalization

3.2 *Analyses using the ADS method*

We report on the update of the ADS analysis [15] of $B^- \to D^0 K^-$, with $D^0 \to K^-\pi^+$ using 657 10^6 $B\bar{B}$ pairs collected with the *Belle* detector. In this analysis, after a cut on m_{ES} and on a combination of event shape variables, the observables are extracted using a maximum likelihood fit to the variable ΔE, giving the following results:

$$R_{ADS} = (8.0^{+6.3+2.0}_{-5.7-2.8})10^{-3}\ ,\ A_{ADS} = -0.13^{+0.97}_{-0.88} \pm 0.26,$$

where the first error is statistical and the second one is systematic.

The results obtained for R_{ADS} show that no evidence of $b \to u$ transition is found, even with the very high statistics used. This result implies an upper limit on the ratio r_B, $r_B < 0.19$ 90% C.L. . This result on r_B is consistent with the previous *Belle* and *Babar* analyses and confirms the expectation for a small value of r_B ($r_B \sim 0.1$) in charged $B \to DK$ decays.

3.3 *Analyses using the GGSZ method*

Both the *Babar* and *Belle* collaboration have presented at this conference new results using Dalitz techinque, that strongly improve the precision on the determination of γ.

We first report on a new Dalitz analysis [16] of $B^- \to D^0 K^-$ and $B^- \to D^{*0} K^-$, that for the first time uses neutral D reconstructed into the final state $D^0 \to K_s K^+ K^-$ and on the update of the Dalitz analysis of $B^- \to D^0 K^-$, $B^- \to D^{*0} K^-$ and $B^- \to D^0 K^{*-}$, with $D^0 \to K_S \pi^+\pi^-$ using 383 10^6 $B\bar{B}$ pairs collected with the *Babar* detector. In this analysis, m_{ES}, ΔE and a combination of event shape variables are used in the maximum likelihood fit to extract the number of signal and background events and then a *CP* fit is perfomed to extract the cartesian coordinates for the three channels, $B^- \to D^0 K^-$, $B^- \to D^{*0} K^-$ and $B^- \to D^0 K^{*-}$. In the *CP* fit, the D Dalitz distribution, for $D^0 \to K_S \pi^+\pi^-$ and $D^0 \to K_s K^+ K^-$, as they are determined on independent data samples, are used as an input. The results for the cartesian coordinates are shown in tab. 1, for the three analyzed channels (in the tables, the symbol $\tilde{D}^0$ indicates either a D^0 or a $\bar{D}^0$). The first error is statistical, the second is experimental systematic uncertainty and the third is the systematic uncertainty associated with the Dalitz models.

Parameters	$B^- \to \tilde{D}^0 K^-$	$B^- \to \tilde{D}^{*0} K^-$	$B^- \to \tilde{D}^0 K^{*-}$
$x_-\ ,\ x_-^*\ ,\ x_{s-}$	$0.090 \pm 0.043 \pm 0.015 \pm 0.011$	$-0.111 \pm 0.069 \pm 0.014 \pm 0.004$	$0.115 \pm 0.138 \pm 0.039 \pm 0.014$
$y_-\ ,\ y_-^*\ ,\ y_{s-}$	$0.053 \pm 0.056 \pm 0.007 \pm 0.015$	$-0.051 \pm 0.080 \pm 0.009 \pm 0.010$	$0.226 \pm 0.142 \pm 0.058 \pm 0.011$
$x_+\ ,\ x_+^*\ ,\ x_{s+}$	$-0.067 \pm 0.043 \pm 0.014 \pm 0.011$	$0.137 \pm 0.068 \pm 0.014 \pm 0.005$	$-0.113 \pm 0.107 \pm 0.028 \pm 0.018$
$y_+\ ,\ y_+^*\ ,\ y_{s+}$	$-0.015 \pm 0.055 \pm 0.006 \pm 0.008$	$0.080 \pm 0.102 \pm 0.010 \pm 0.012$	$0.125 \pm 0.139 \pm 0.051 \pm 0.010$

Table 1: *CP*-violating parameters $x_\pm^{(*)}$, $y_\pm^{(*)}$, $x_{s\pm}$, and $y_{s\pm}$, as obtained from the *CP* fit.

Using a frequentist analysis, the experimental results for $x_\pm^{(*)}$, $y_\pm^{(*)}$, $x_{s\pm}$, and $y_{s\pm}$ are interpreted in terms of the weak phase γ, the amplitude ratios r_B, r_B^*, and r_S, and the strong phases δ_B, δ_B^*, and δ_S, giving $\gamma = (76 \pm 22 \pm 5 \pm 5)^\circ$ (mod 180°), $r_B = 0.086 \pm 0.035 \pm 0.010 \pm 0.011$, $r_B^* = 0.135 \pm 0.051 \pm 0.011 \pm 0.005$, $kr_S = 0.163^{+0.088}_{-0.105} \pm 0.037 \pm 0.021$ $\delta_B = \left(109^{+28}_{-31} \pm 4 \pm 7\right)^\circ$ (mod 180°), $\delta_B^* = \left(-63^{+28}_{-30} \pm 5 \pm 4\right)^\circ$ (mod 180°), and $\delta_S = \left(104^{+43}_{-41} \pm 17 \pm 5\right)^\circ$. The first error is statistical, the second is the experimental systematic uncertainty and the third reflects the uncertainty on the D decay Dalitz models. The results for γ and the ratios r_B, r_B^* and r_S are shown in fig. 3.

We also report on the update of the Dalitz analysis [19] of $B^- \to D^0 K^-$ and $B^- \to D^{*0} K^-$ ($D^{*0} \to D^0 \pi^0$), with $D^0 \to K_S \pi^+\pi^-$ using 635 10^6 $B\bar{B}$ pairs collected with the *Belle* detector. In this analysis, M_{bc}, ΔE and a combination of event shape variables are used in the maximum

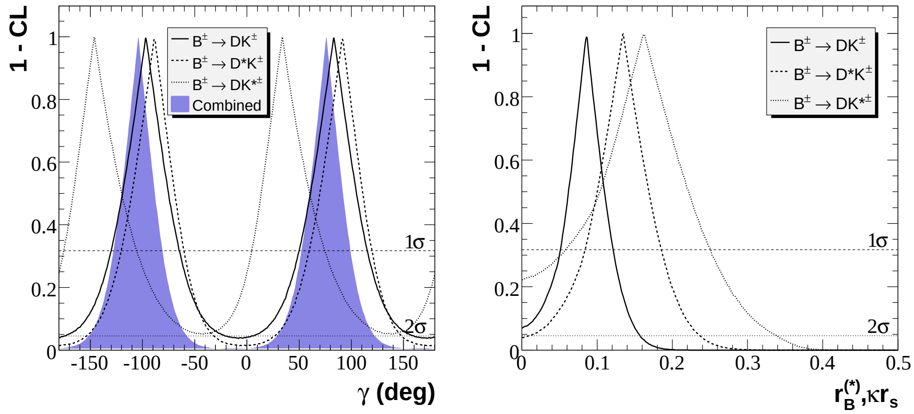

Figure 3: [*Babar* **Dalitz analysis**] $\alpha = 1 - \text{CL}$ as a function of γ (left plot) and of r_B, r_B^* and r_S (right plot) for $B^- \to \tilde{D}^0 K^-$, $B^- \to \tilde{D}^{*0} K^-$, and $B^- \to \tilde{D}^0 K^{*-}$ decays separately, and their combination, including statistical and systematic uncertainties and their correlations. The dashed (upper) and dotted (lower) horizontal lines correspond to the one- and two-standard deviation intervals, respectively.

likelihood fit to extract the number of signal and background events and then a *CP* fit is perfomed to extract the cartesian coordinates for the two channels, $B^- \to D^0 K^-$, $B^- \to D^{*0} K^-$ (with $D^{*0} \to D^0 \pi^0$). In the *CP* fit, the D Dalitz distribution for $D^0 \to K_S \pi^+ \pi^-$, as it is determined on independent data samples, is used as an input. The results are shown in tab. 2, where the first error is statistical and the second is experimental systematic uncertainty. The uncertainty associated with the Dalitz model is not shown and it is assumed to be equal to the one evaluated in the previous analysis by *Belle* collaboration [18].

Parameter	$B^- \to \tilde{D}^0 K^-$	$B^- \to \tilde{D}^{*0} K^-$
x_-	$+0.105 \pm 0.047 \pm 0.011$	$+0.024 \pm 0.140 \pm 0.018$
y_-	$+0.177 \pm 0.060 \pm 0.018$	$-0.243 \pm 0.137 \pm 0.022$
x_+	$-0.107 \pm 0.043 \pm 0.011$	$+0.133 \pm 0.083 \pm 0.018$
y_+	$-0.067 \pm 0.059 \pm 0.018$	$+0.130 \pm 0.120 \pm 0.022$

Table 2: *CP*-violating parameters $x_\pm^{(*)}$ and $y_\pm^{(*)}$, as obtained from the *CP* fit.

Using a frequentist analysis, the experimental results for $x_\pm^{(*)}$ and $y_\pm^{(*)}$ are interpreted in terms of the weak phase γ, the amplitude ratios r_B, r_B^* and the strong phases δ_B, δ_B^*, giving $\gamma = \left(76^{+12}_{-13} \pm 4 \pm 9\right)^\circ$ (mod 180°), $\delta_B = \left(136^{+14}_{-16} \pm 4 \pm 23\right)^\circ$ (mod 180°), $\delta_B^* = \left(343^{+20}_{-22} \pm 4 \pm 23\right)^\circ$ (mod 180°), $r_B = 0.16 \pm 0.04 \pm 0.01 \pm 0.05$ and $r_B^* = 0.21 \pm 0.08 \pm 0.02 \pm 0.05$. The first error is statistical, the second is the experimental systematic uncertainty and the third reflects the uncertainty on the D decay Dalitz model. It can be noticed that this analysis finds slightly higher values for the r_B and r_B^* ratios with respect to the *Babar* analysis, which explains the smaller statistical errors on γ, also if the precision on the cartesian coordinates is similar. The results for γ and the ratios r_B and r_B^* are shown in fig. 4

4 Experimental results on the neutral B decays

Lately, within the *Babar* collaboration, there have been efforts to constrain γ and related quantities from the study of neutral $B \to DK$ decays. As already discussed, the r_B ratios in these channels are expected to be higher than in the charged ones, hence giving higher sensitivity to γ.

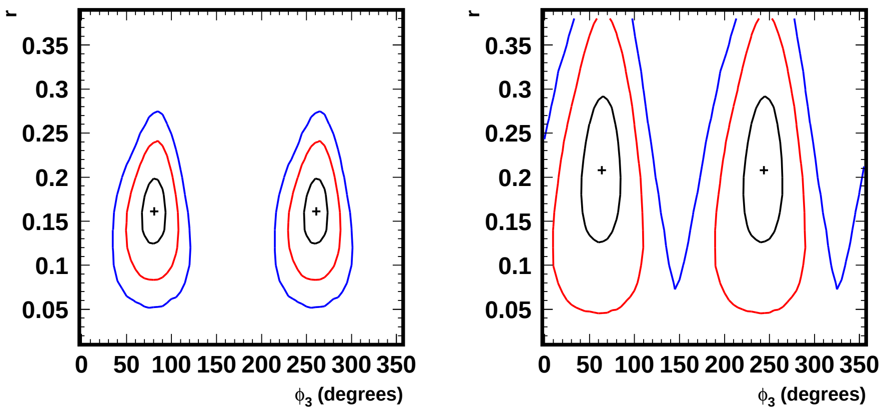

Figure 4: [*Belle* **Dalitz analysis**] Projections of confidence regions for the $B^- \to D^0K^-$ (left plot) and $B^- \to D^{*0}K^-$ (right plot) mode onto the (r_B, γ) and (r^*_B, γ) planes respectively. Contours indicate projections of one, two and three standard deviation regions.

We first report on a new Dalitz analysis [21] of $B^0 \to D^0K^{*0}$, with $K^{*0} \to K^+\pi^-$ and $D^0 \to K_S\pi^+\pi^-$ using 371 10^6 $B\bar{B}$ pairs collected with the *Babar* detector. In this analysis, m_{ES} and a combination of event shape variables are used in the maximum likelihood fit to extract the number of signal and background events and then a *CP* fit is perfomed. A likelihood scan in polar coordinates (γ, δ^0_S, r^0_S) is extracted from data and combined with an external information on r^0_S [20]. The results obtained are shown in tab. 3, where the first error is statistical, the second is the experimental systematic uncertainty and the third reflects the uncertainty on the D decay Dalitz model.

Parameters	
γ [°]	$162 \pm 55 \pm 1.6 \pm 6.5$ (mod 180°)
δ^0_S [°]	$62 \pm 55 \pm 3.1 \pm 15.8$ (mod 180°)
r^0_S	< 0.55 95 % probability

Table 3: Results for γ, δ^0_S and r^0_S, as obtained from the *CP* fit.

We also report on a new time-dependent Dalitz plot analysis [22] of $B^0 \to D^-K^0\pi^+$ using 347 10^6 $B\bar{B}$ pairs collected with the *Babar* detector. This analysis studies the interference between $b \to u$ and $b \to c$ transitions through the B mesons mixing and hence gives sensitivity to the combination of CKM weak phases $2\beta + \gamma$. In this analysis, m_{ES}, ΔE and a combination of event shape variables are used in the maximum likelihood fit to extract the number of signal and background events and then a time-dependent fit to the neutral B Dalitz distribution is performed to extract $2\beta + \gamma$. In this fit, the ratio r^0_B is assumed to be $r^0_B = 0.3$ and the effect of this assumption is taken into account in the systematics evaluation by varying this ratio of ± 0.1. The result obtained for $2\beta + \gamma$ is the following:

$$2\beta + \gamma = (83 \pm 53 \pm 20)^\circ \text{ (mod } 180^\circ),$$

where the first error is statistical and the second one is systematic.

5 Combined results and conclusions

From all the available measurements, including the new ones presented here, the knowledge of γ, according to the combination performed by the UTfit collaboration, is $\gamma = (80 \pm 13)^\circ$.

The combined results obtained for the other quantities are $r_B = 0.10 \pm 0.02$, $r_B^* = 0.09 \pm 0.04$, $r_S = 0.13 \pm 0.09$, $r_S^0 < 0.55$ 95 % probability and $2\beta + \gamma = (88 \pm 29)^\circ$.

In conclusion both the *Babar* and *Belle* collaboration have made enormous efforts to constraint the CKM angle γ and related quantities using many methods in different channels, leading to a precision in the determination that was not expected to be accessible at the B-factories experiments.

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