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CP violation studies in $B \to D^{(*)}K^{(*)}$ in BaBar and Belle

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Abstract. BaBar and Belle results on $B \to D^{(*)}K^{(*)}$ decays are reviewed in the context of constraining the ϕ_3 angle in the Unitarity Triangle.

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1 Introduction

CP violation (CPV) studies in the B-sector are targeted at measurements of the three angles of the Unitarity Triangle. The angle $\phi_3(\gamma) \equiv arg(V_{ud}V^*_{ub}/V_{cd}V^*_{cb})$ can be observed through interference between $b \to c$ and $b \to u$ transitions. Good processes for such studies are strangeness-changing B decays to neutral charmed mesons:

$$B \to DX_s. \tag{1}$$

D stands for D^0 or $\bar{D}^0$ as well as their excited states and X_s denotes a system of light mesons with $S = \pm 1$. Example diagrams for such decays are shown in Fig. 1. The decays $B^- \to D^0K^-$ are driven by $b \to c$ transitions and $B^- \to \bar{D}^0K^-$ by $b \to u$ transitions [1]. When D^0 and $\bar{D}^0$ decay to a common final state, the two amplitudes (denoted $A_{b\to c}$ and $A_{b\to u}$) interfere, leading to direct CPV. Processes of this type, being free from penguin contributions, provide a theoretically clean environment to extract ϕ_3.

The first idea of measuring ϕ_3 in decays of the type (1) came from Gronau, London and Wyler (GLW) [1]. In this method interference between the two amplitudes should be observed in $B \to D_\pm K$ decay modes, where $D_\pm \equiv (D^0 \pm \bar{D}^0)/\sqrt{2}$ denotes D meson CP eigenstates. In such case ϕ_3 can be extracted from CP asymmetries and ratios of decay rates using the following relations [2]:

$$\mathcal{A}_\pm \equiv \frac{\mathcal{B}(B^- \to D_\pm K^-) - \mathcal{B}(B^+ \to D_\pm K^+)}{\mathcal{B}(B^- \to D_\pm K^-) + \mathcal{B}(B^+ \to D_\pm K^+)} = \frac{\pm 2r\sin\delta\sin\phi_3}{1 + r^2 \pm 2r\cos\delta\cos\phi_3} \tag{2}$$

$$\mathcal{R}_\pm \equiv \frac{2(\mathcal{B}(B^- \to D_\pm K^-) + \mathcal{B}(B^+ \to D_\pm K^+))}{\mathcal{B}(B^- \to D^0K^-) + \mathcal{B}(B^+ \to \bar{D}^0K^+)} = 1 + r^2 \pm 2r\cos\delta\cos\phi_3. \tag{3}$$

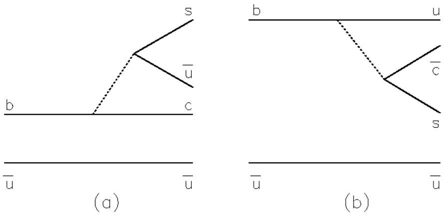

Fig. 1. Diagrams corresponding to $A_{b\to c}$ (**a**) and $A_{b\to u}$ (**b**) amplitudes

In the above equations δ is the relative strong phase of the interfering amplitudes and $r \equiv| A_{b\to u}/A_{b\to c} |$. The observables $\mathcal{A}_\pm$ and $\mathcal{R}_\pm$ contain information sufficient to extract δ and r, and thus ϕ_3 can be measured without hadronic uncertainties. Sensitivity of such measurements, however, depends on the ratio r which for decays with the biggest branching fractions tends to be small. (for $B^- \to DK^-$ the expected value of r is $\sim 0.1\div 0.2$). This is mainly due to the color suppression of the $A_{b\to u}$ amplitude. Many subsequent approaches, which to a large extent can be considered as variants and extensions of the GLW method, try to overcome this difficulty. Altogether they offer a rich experimental program exploiting a variety of final states and observables in decays of the type (1).

2 Experimental results

While a large number of methods have been proposed, all of them present a challenge for experiments. Among the main problems one should mention are: small product branching fractions (e.g. D^0 decays to CP-eigenstates, f_{CP}, constitute $\sim 1\%$ of the total width leading to $\mathcal{B}(B^- \to D^0K^-) \times \mathcal{B}(D^0 \to f_{CP}) \sim 10^{-6}$); observables which weakly depend on interference effects or are difficult to measure and background from much more abundant non-strange modes like $B \to D\pi$. (e.g. one estimates $\frac{\mathcal{B}(B^-\to D^0K^-)}{\mathcal{B}(B^-\to D^0\pi^-)} \approx 0.075$ from the value of the Cabibbo angle).

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[1] Charge conjugation is implied throughout the paper unless explicitly stated otherwise.

Consequently, all the methods require a huge data sample (typically of the order of 500 M B$\bar{\text{B}}$'s or more) and high performance of a multipurpose detector. Experiments at B-factories are potentially a good place to perform such measurements. In particular they provide good kinematical resolution and K/π separation, which are essential for these studies. With the present luminosities the data sample of 500 fb^{-1} can be collected after a few years of running. The results reported here are based on data samples typically of ≈ 80 fb^{-1} and represent preliminary studies towards the ϕ_3 measurement.

2.1 $B^- \to DK^{(*)-}$

$B^- \to D^0K^-$ decays have been observed by experiments running at $\Upsilon(4S)$. Recent measurements of the ratios of branching fractions of Cabibbo-suppressed to Cabibbo-favored modes $R = \frac{\mathcal{B}(B^- \to D^0K^-)}{\mathcal{B}(B^- \to D^0\pi^-)}$ are summarized in Table 1. The results are consistent with the Cabibbo suppression mentioned above. Belle and BaBar have also studied $B^- \to D_\pm K^-$ modes with data samples of 78 fb^{-1} and 82 fb^{-1} respectively [4], [5]. Both experiments found signals in the channels with D decaying to CP-even eigenstates: $D_+ \to K^+K^-$, $\pi^+\pi^-$. Belle also observed CP-odd modes: $D_- \to K_s^0\pi^0$, $K_s^0\phi$, $K_s^0\omega$, $K_s^0\eta$, $K_s^0\eta'$. Figures 2 and 3 present ΔE distributions for these channels (ΔE is a difference between reconstructed B-meson energy and its nominal value in the $\Upsilon(4S)$ rest frame).

Results on $\mathcal{A}_\pm$ and $\mathcal{R}_\pm$ are summarized in Table 2. Measurement errors preclude direct determination of ϕ_3 from these data but meaningful constraints should be feasible in the near future by means of inequalities resulting from (2, 3): $\sin^2\phi_3 \le \mathcal{R}_\pm$, $r \ge 1/4 \mid \mathcal{R}_+ - \mathcal{R}_- \mid$ [2].

Decay modes with excited kaons,such as $B^- \to DK^{*-}$ can be used in a similar way to constrain ϕ_3. Belle studied these channels with 88 fb^{-1} of data [7]. K^{*-} was reconstructed from $K^{*-} \to K_s^0\pi^-, K_s^0 \to \pi^+\pi^-$ decays. The measured branching fraction $\mathcal{B} = (5.2 \pm 0.5(stat) \pm 0.6(sys)) \times 10^{-4}$ is consistent with earlier CLEO result based on much lower statistics [6]. The performed analysis showed no indication of a non-resonant $D^0K_s^0\pi^-$ contribution. Event yields obtained in bins of $K_s^0\pi^-$ invariant mass and K^{*-} helicity angle are shown in Fig. 4 a and 4 b respectively. Results are consistent with Monte Carlo simulations of pure $B^- \to D^0K^{*-}$ decay.

With this data sample Belle observed for the first time $B^- \to D_\pm K^{*-}$ decays (see Fig. 5). The significance is 4.3σ for CP-even (K^+K^-, $\pi^+\pi^-$) and 2.4 σ for CP-odd ($K_s^0\pi^0$, $K_s^0\phi$, $K_s^0\omega$) states. Event yields are substantially lower than for $B^- \to D_\pm K^-$, which is due to the limited reconstruction efficiency of K^{*-}. Preliminary measurements of CP asymmetries are presented in Table 2.

2.2 $B^- \to D^*K^{*-}$

Decay modes into two vector mesons can be also used to measure ϕ_3 [9]. An interesting feature of these channels

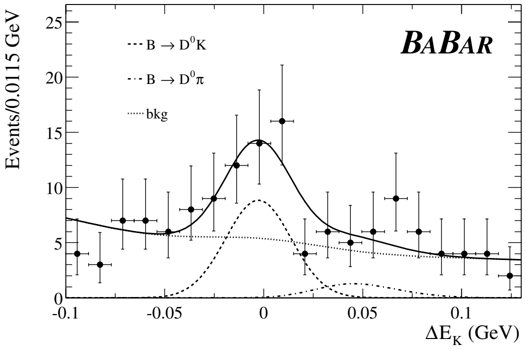

Fig. 2. ΔE distributions of $B^\pm \to D_+K^\pm$ from BaBar. The kaon mass is assumed for the prompt hadron. Contributions from $B^\pm \to D_+\pi^\pm$ are seen at $\Delta E \approx 0.05$ GeV

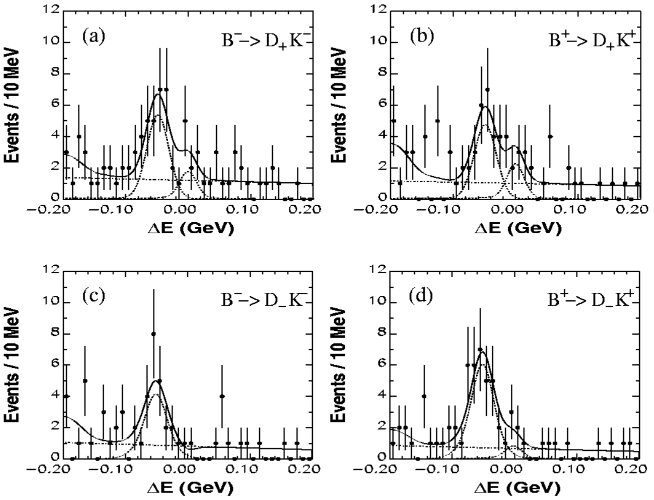

Fig. 3. ΔE distributions of $B^\pm \to D_\pm K^\pm$ from Belle. The pion mass is assumed for the prompt hadron. Contributions from $B^\pm \to D_\pm\pi^\pm$ are seen at $\Delta E = 0$

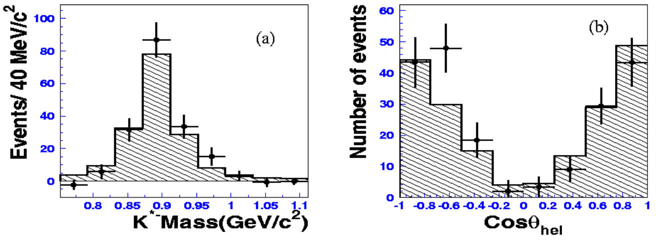

Fig. 4. Yields for $B^\pm \to D^0K^{*\pm}$ from Belle in bins of $K_s^0\pi^-$ invariant mass (**a**) and in the bins of $\cos\theta_{hel}$ (**b**). The *hatched histograms* are Monte Carlo simulations of $B^- \to D^0K^{*-}$

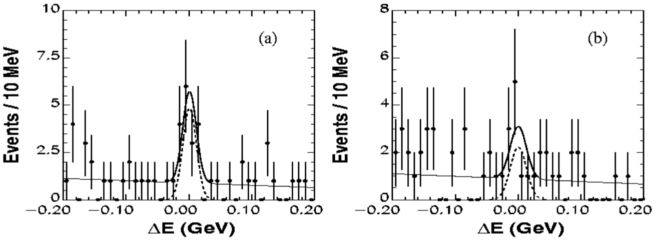

Fig. 5. ΔE distributions of $B^\pm \to D_+K^{*\pm}$ (**a**) and $B^\pm \to D_-K^{*\pm}$ (**b**) from Belle

Table 1. Measurements of $R = \frac{\mathcal{B}(B^- \to D^0 K^-)}{\mathcal{B}(B^- \to D^0 \pi^-)}$ The first error is statistical and the is second systematic

experiment	R	data sample
CLEO [3]	$(9.9 \pm 1.3 \pm 0.7)\%$	15.3 fb^{-1}
BaBar [4]	$(8.31 \pm 0.25 \pm 0.2)\%$	56 fb^{-1}
Belle [5]	$(7.7 \pm 0.5 \pm 0.6)\%$	79 fb^{-1}

Table 2. Results on $\mathcal{A}_\pm$ and $\mathcal{R}_\pm$. The first error is statistical and the is second systematic

mode	$\mathcal{A}_\pm$	$\mathcal{R}_\pm$	exp.
D_+K^-	$0.17 \pm 0.23 \pm 0.08$	$1.06 \pm 0.26 \pm 0.17$	BaBar
D_+K^-	$0.06 \pm 0.19 \pm 0.04$	$1.21 \pm 0.25 \pm 0.14$	Belle
D_-K^-	$-0.19 \pm 0.17 \pm 0.05$	$1.41 \pm 0.27 \pm 0.15$	Belle
D_+K^{*-}	$-0.02 \pm 0.33 \pm 0.07$	-	Belle
D_-K^{*-}	$0.19 \pm 0.50 \pm 0.04$	-	Belle

is the presence of additional observables resulting from interference between helicity amplitudes.

BaBar has recently released results on the $B^- \to D^{*0}K^{*-}$ decays based on data sample of 79 fb^{-1} [8]. The measured branching fraction of $(8.3 \pm 1.1(stat) \pm 1.0(sys)) \times 10^{-4}$ agrees well with the earlier CLEO result [6]. BaBar also presented the first measurement of the fraction of longitudinal polarization $\Gamma_L/\Gamma = 0.86 \pm 0.06(stat) \pm 0.03(sys)$ in these decays.

2.3 $\bar{B}^0 \to D\bar{K}^{(*)0}$

Neutral B decays of the type (1) are of special interest. In this case the amplitude $A_{b\to c}$ is also color suppressed. This leads to decay rates as low as $\approx 10^{-5}$, but at the same time the larger amplitude ratio $r \sim 0.4$ augments interference effects ([10]). The flavor of B^0 can be tagged in the modes with excited kaons from $\bar{K}^{*0} \to K^-\pi^+$ decay products. The ϕ_3 can be constrained from decays of this type in a similar way as from charged B decays [11]. When the final states contain K_s^0, $B^0 - \bar{B}^0$ mixing leads to time-dependent asymmetries, which are sensitive to a combination of mixing and decay "phases ([10], [12])." Belle, using a data sample of 78 fb^{-1}, observed for the first time the decays $\bar{B}^0 \to D^0\bar{K}^0$ and $\bar{B}^0 \to D^0\bar{K}^{*0}$ (Fig. 6) with the branching fractions $\mathcal{B}(\bar{B}^0 \to D^0\bar{K}^0) = (5.0^{+1.3}_{-1.2}(stat) \pm 0.6(sys)) \times 10^{-5}$ and $\mathcal{B}(\bar{B}^0 \to D^0\bar{K}^{*0}) = (4.8^{+1.1}_{-1.0}(stat) \pm 0.5(sys)) \times 10^{-5}$ [13]. Also in this case no indication of non-resonant contribution to $\bar{B}^0 \to D^0\bar{K}^{*0}$ was found.

3 Summary

Belle and BaBar continue a steady progress in the studies of the decays of the type (1). Among the most important results one should mention measurements of charged B decays to D CP-eigenstates which provide the complete set of observables needed in the GLW method and observation of the color suppressed $\bar{B}^0 \to D^0\bar{K}^{(*)0}$ decays. With new theoretical approaches and the excellent performance of KEKB and PEPII, one can hope for meaningful constraints on ϕ_3 in the near future. [2] This also gives good prospects for ϕ_3 measurements at B-factories with upgraded luminosities.

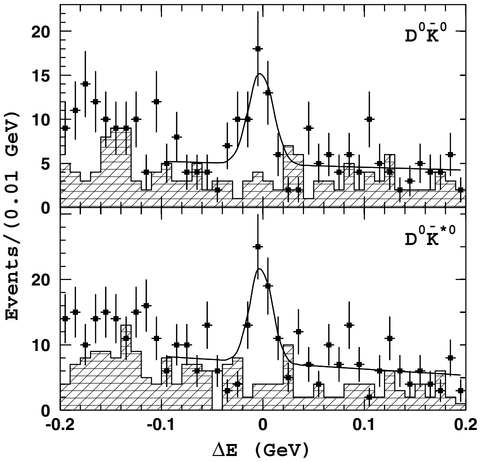

Fig. 6. ΔE distributions for $\bar{B}^0 \to D^0\bar{K}^{(*)0}$ from Belle. The *hatched histograms* show the distributions of events in D^0 sideband regions

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[2] After this conference Belle presented 90% confidence interval for the ϕ_3: $61^o \le \phi_3 \le 142^o$ [14]. The result was obtained with 140 fb^{-1} of data using a novel method which employs interference between three-body D^0 and $\bar{D}^0$ decays [15].