International Journal of Modern Physics A

MEASUREMENTS OF $B \to D^{(*)0}K^{(*)0-}$ DECAYS RELATED TO γ

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Received (7 November 2004)

We present measurements of branching fractions and *CP* asymmetries of several $B^- \to D^{(*)0}K^{(*)-}$ decays, with the $D^{(*)0}$ decaying to *CP*-even, *CP*-odd, and flavor eigenstates, that can constrain the *CP* angle γ as well as the amplitude ratio $r_b = A(B \to u)/A(B \to c)$, using methods proposed by Gronau, London and Wyler or Atwood, Dunietz and Sony[1]. We use data collected with the *BABAR* detector at the PEP-II asymmetric energy e^+e^- collider at SLAC.

1. Introduction

The unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix yields several relationships for its components, such as $V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$. This describes the extent of *CP* violation in the Standard Model (SM) in the B meson system and can be represented in the imaginary plane as a triangle, where the angles (α, β and γ) can be written in terms of the couplings between quarks:

$$\alpha \equiv \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right] \quad , \quad \beta \equiv \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right] \quad , \quad \gamma \equiv \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right] . \tag{1}$$

These angles can be extracted via *CP* asymmetries measured in several decay modes of the B meson. In particular γ measurements can be made in modes which have both $b \to c$ and $b \to u$ tree diagrams, which interfere. The magnitude of the interference is determined by the ratio of the two methods of decay. We report on recent analyses which aim to measure the angle γ with data collected with the *BABAR* detector[2]. All results are preliminary.

$B^- \to D^{(*)0}K^{(*)-}$ decays[a] can be used to constrain the angle γ of the Cabibbo-Kobayashi-Maskawa (CKM) matrix in a theoretically clean way. The small branching fractions of these modes demand high efficiency and the exploitation of as many decay modes as possible. Two quantities are used to discriminate between signal and background: the beam-energy-substituted mass $m_{\rm ES} \equiv \sqrt{(E_i^{*2}/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 - p_B^2}$ and the energy difference $\Delta E \equiv E_B^* - E_i^*/2$, where

[a] Reference to the charge-conjugate decays is implied throughout the text, unless otherwise stated.

the subscripts i and B refer to the initial e^+e^- system and the B candidate respectively, the asterisk denotes the CM frame, and the kaon mass hypothesis of the prompt track is used to calculate ΔE. The continuum background is also suppressed using topological variables which exploit the fact that $B\overline{B}$ events are isotropic while continuum events are jet-like. Whenever we need to separate $B \to D^{(*)0}K$ and $B \to D^{(*)0}\pi$ events, we use measurements of the Cherenkov angle of the prompt track[2]. At BABAR 3 standard deviation separations between the kaon and pion hypotheses are achieved for tracks up to 3.5 GeV/c. ΔE is also useful for this purpose, as it depends on the mass assigned to the tracks forming the B candidate. Backgrounds are characterized using simulation and off-resonance data. The best candidate in each event is selected using observables which are not used as inputs to the fits. Finally, unbinned maximum likelihood fits are preformed to extract the signal yields. The main systematic uncertainties are due to the characterization of the probability density functions for signal and backgrounds and to the particle identification, but many of these (e.g the absolute efficiencies) cancel when measuring ratios of branching fractions. For measurements of CP asymmetries, possible detector charge asymmetries (all consistent with zero) are also taken into account.

2. GLW related measurements

In the SM, for $B^-\to D^0K^-$ decays, we have: $R_{CP\pm}/R_{\mathrm{non}-CP} \simeq 1 + r_b^2 \pm 2r_b\cos\delta_b\cos\gamma$ (in the absence of $D^0\overline{D^0}$ mixing) , where

$$R_{\mathrm{non}-CP/CP\pm} \equiv \frac{\Gamma(B^- \to D^0_{\mathrm{non}-CP/CP\pm}K^-)}{\Gamma(B^- \to D^0_{\mathrm{non}-CP/CP\pm}\pi^-)}, \tag{2}$$

r_b is the ratio of the color suppressed $B^+ \to D^0K^+$ and color allowed $B^- \to D^0K^-$ amplitudes ($r_b \sim 0.1 - 0.3$), and δ_b is the CP-conserving strong phase difference between these amplitudes. Furthermore, defining the direct CP asymmetry

$$A_{CP\pm} \equiv \frac{\Gamma(B^-\to D^0_{CP\pm}K^-) - \Gamma(B^+\to D^0_{CP\pm}K^+)}{\Gamma(B^-\to D^0_{CP\pm}K^-) + \Gamma(B^+\to D^0_{CP\pm}K^+)}, \tag{3}$$

we have: $A_{CP\pm} = \pm 2r_b\sin\delta_b\sin\gamma/(1 + r_b^2 \pm 2r_b\cos\delta_b\cos\gamma)$. Similar quantities and relationships exist for the the modes $B^-\to D^{*0}K^-$ and $B^-\to D^0K^{*-}$, where the corresponding r_b and δ_b might have different values from the ones for the $B^-\to D^0K^-$ mode. The unknowns δ_b, r_b, and γ can be constrained from the measurements of $R_{\mathrm{non}-CP}$, $R_{CP\pm}$, and $A_{CP\pm}$. The smaller r_b is, the more difficult is the measurement of γ with this method.

At BABAR we have studied the $B^\pm \to D^0K^\pm$ modes[3] in the flavor ($D^0 \to K^-\pi+$), $CP = +1$ ($D^0 \to K^+K^-$ and $\pi^+\pi^-$), and $CP = -1$ ($D^0 \to K^0_S\pi^0$) eigenstates. Figure1 shows the $B^-\to D^0K^-$ signal after requiring that the prompt track be consistent with the kaon hypothesis for the flavor and CP eigenstates. In a dataset of ∼216 million $B\overline{B}$ pairs, we find 897 events in the flavor, 93 in the $CP = +1$, and 76 in the $CP = -1$ eigenstates.

The $B^\pm \to D^{*0}K^\pm$ modes[4] have been studied, where the D^{*0} decays into $D^0\pi^0$, with the D^0 reconstructed in the *CP* even eigenstates K^-K^+ and $\pi^-\pi^+$, and in the flavor eigenstates $K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$, and $K^-\pi^+\pi^0$. Figure 2 shows the distributions of ΔE for the combined non-*CP* and *CP* modes before and after enhancing the $B \to D^{*0}K$ component. This is accomplished by requiring that the prompt track be consistent with the kaon hypothesis and that $m_{\rm ES} > 5.27$ GeV/c^2. From a dataset of ~123 million $B\overline{B}$ pairs, we select 360 $B^\pm \to D^{*0}K^\pm$ events in the non-*CP* modes and 29 events in the *CP* modes. The ΔE projections of the fit results are also shown.

Finally we have studied the $B^\pm \to D^0K^{*\pm}$ modes[5] in the flavor ($D^0 \to K^-\pi+$, $K^-\pi^+\pi^+\pi^-$, and $K^-\pi^+\pi^0$), $CP = +1$ ($D^0 \to K^+K^-$ and $\pi^+\pi^-$), and $CP = -1$ ($D^0 \to K^0_S\pi^0$, $K^0_S\omega$, $K^0_S\phi$) eigenstates, with $K^{*-} \to K^0_S\pi^-$. After requiring that the prompt track be consistent with the kaon hypothesis, from a dataset of ~227 million $B\overline{B}$ pairs, we find 498 events in flavor, 34 events in $CP = +1$, and 15 events in $CP = -1$ eigenstates. *BaBar*'s results for the modes used in the GLW method are reported in Table 1.

Table 1. *BaBar* summary of results (GLW method). The first error is due to statistical and the second to systematic uncertainties. The third, when present, reflects possible interference effects in the final states with ϕ and ω resonances.

Observables	$B^-\to D^0K^-$	$B^-\to D^{*0}K^-$	$B^-\to D^0K^{*-}$
R_{CP+}	$0.87 \pm 0.14 \pm 0.06$	$1.09 \pm 0.26^{+0.010}_{-0.08}$	$1.77 \pm 0.37 \pm 0.12$
A_{CP+}	$0.40 \pm 0.15 \pm 0.08$	$-0.02 \pm 0.24 \pm 0.05$	$-0.09 \pm 0.20 \pm 0.06$
R_{CP-}	$0.80 \pm 0.14 \pm 0.08$		$0.76 \pm 0.29 \pm 0.06^{-0.04}_{-\ 0.14}$
A_{CP-}	$0.21 \pm 0.17 \pm 0.07$		$-0.33 \pm 0.34 \pm 0.10$
			$(+0.15 \pm 0.10) \cdot (A_{CP-} - A_{CP+})$

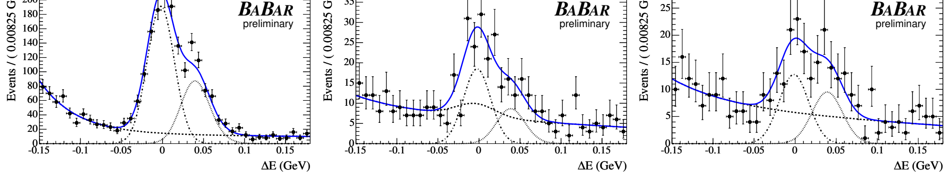

Fig. 1. $B^-\to D^0K^-$ signal after requiring that the prompt track be consistent with the kaon hypothesis for the flavor (left), $CP = +1$ (center), and $CP = -1$ (right) eigenstates. The $B^\pm \to D^0\pi^\pm$ signal contribution on the right of each plot is shown as a dotted line, the $B^\pm \to D^0K^\pm$ signal on the left as a dashed-dotted line, and the background as a dashed line. The total fit with all the contributions is shown with a solid line.

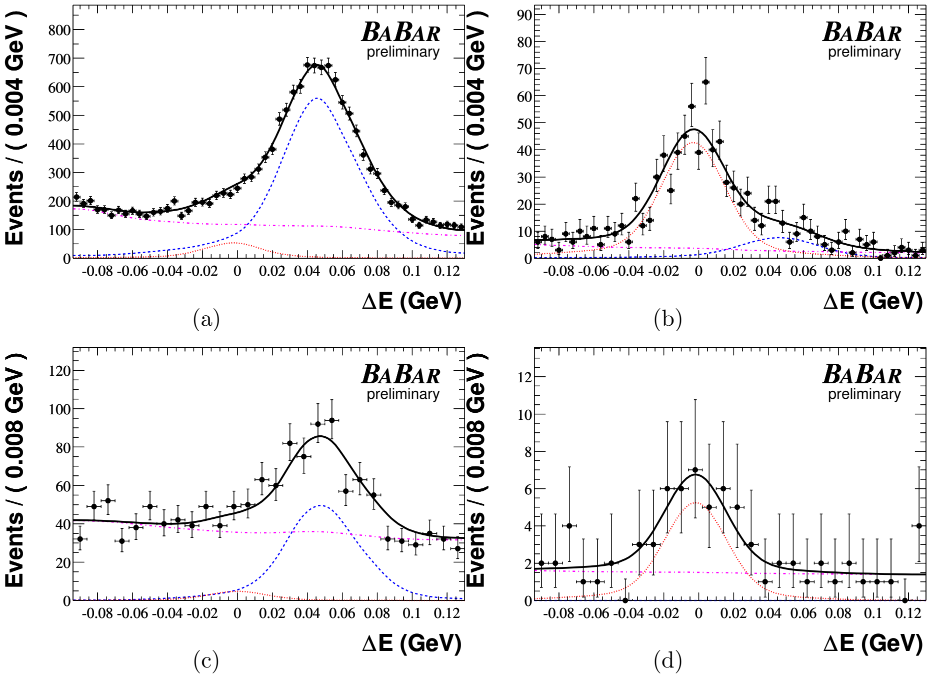

Fig. 2. Distributions of ΔE in the $B \to D^{*0}h$ sample, for $D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$ ((a), (b)) and $D^0 \to K^-K^+, \pi^-\pi^+$ ((c), (d)), before ((a), (c)) and after ((b), (d)) enhancing the $B \to D^{*0}K$ component by requiring that the prompt track be consistent with the kaon hypothesis and $m_{\rm ES} > 5.27{\rm GeV}/c^2$. The $B^\pm \to D^{*0}\pi^\pm$ signal contribution on the right of each plot is shown as a dashed line, the $B^\pm \to D^{*0}K^\pm$ signal on the left as a dotted line, and the background as a dashed-dotted line. The total fit with all the contributions is shown with a thick solid line.

3. ADS related measurements

We can also use the Atwood, Dunietz and Soni method, which exploits the interference between the decay chain combining the CKM and color suppressed $B^+ \to D^0K^+$ decay and the CKM allowed $D^0 \to K^-\pi^+$ decay and the one with a color allowed $B^+ \to \overline{D^0}K^+$ decay and the doubly CKM suppressed $\overline{D^0} \to K^-\pi^+$ decay. Using this method we can measure:

$$R_{K\pi} = \frac{\Gamma(B^- \to [K^+\pi^-]_D K^-) + \Gamma(B^+ \to [K^-\pi^+]_D K^+)}{\Gamma(B^- \to [K^-\pi^+]_D K^-) + \Gamma(B^+ \to [K^+\pi^-]_D K^+)} \\ = r_b^2 + r_d^2 + 2r_d r_b \cos\gamma \cos\delta \qquad (4)$$

where $r_d = |A(D^0 \to K^+\pi^-)|/|A(D^0 \to K^-\pi^+)| = 0.060 \pm 0.003$, δ is the sum of the strong phase difference of the Bs and Ds decay amplitudes and r_d is the ratio of the suppressed D decay to the dominant D decay.

For this method we have studied both $B^\mp \to [K^\pm\pi^\mp]_D K^\mp$ and $B^\mp \to [K^\pm\pi^\mp]_{D^*(D\pi/\gamma)} K^\mp$ decays. Figure 3 shows the signal for the three suppressed decay modes. BABAR's results from a dataset of ∼227 million $B\overline{B}$ pairs are consis-

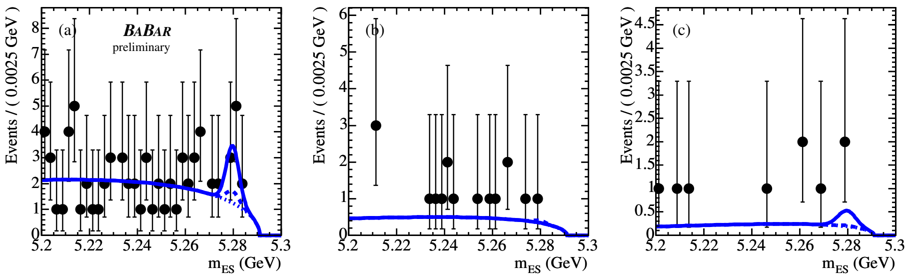

Fig. 3. Signal for the three suppressed decay modes used for the ADS method: $B^\mp \to [K^\pm\pi^\mp]_D K^\mp$ (a) ($4.7^{+4.0}_{-3.2}$ events), $B^\mp \to [K^\pm\pi^\mp]_{D^*(D\pi)}$ (b) ($-0.2^{+1.3}_{-0.8}$ events), and $B^\mp \to [K^\pm\pi^\mp]_{D^*(D\gamma)}$ (c) ($1.2^{+2.1}_{-1.4}$ events).

tent with no signal. Using a Bayesian model, we measure: $r_b < 0.23$ at 90% C.L. for the D^0K mode, and $r_b < 0.21$ at 90% C.L. for the $D^{*0}K$ mode[6], as shown in Figure 4, results which make a measurement of γ quite difficult.

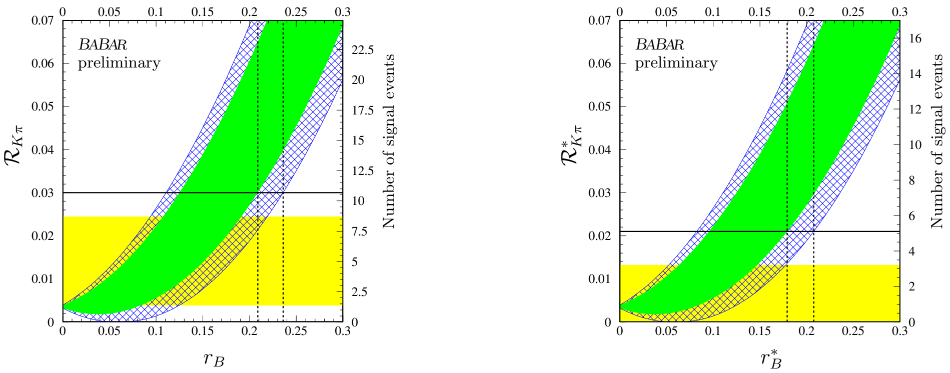

Fig. 4. Dependence of $R_{K\pi}$ on r_b for the D^0K mode (left) and for the $D^{*0}K$ mode (right) using $0^o < \gamma,\ \delta < 180^o$ (hashed area) and the range of γ from CKM fits ($48^o < \gamma < 73^o$).

4. Constraints on r_b and γ

The latest conference results by BABAR and Belle on the modes previoulsy described have been combined by the UTfit[7] group, and some of the results, derived using a Bayesian approach, are reported in Figure 5.

5. Conclusions

Many decays and methods have been or are being investigated to extract the angle γ, and tighter constraints on its value will be found, once larger data sets become

Fig. 5. 68% and 95% C.L. as calculated by the UTfit group for r_b for the D^0K mode (left) and for the $D^{*0}K$ mode (right) vs. γ.

available from both *BABAR* and Belle, though these measurements appear quite difficult given the latest *BABAR* measurements of a small r_b for the D^0K and the $D^{*0}K$ modes.

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