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

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ABSTRACT

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 $\gamma$ 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 $\bar{B}$A$\bar{B}$AR 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 ($\alpha$, $\beta$ and $\gamma$) can be written in terms of the couplings between quarks:

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

(1)

These angles can be extracted via $CP$ asymmetries measured in several decay modes of the $B$ meson. In particular $\gamma$ 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 $\gamma$ with data collected with the $\bar{B}$A$\bar{B}$AR detector[2]. All results are preliminary.

$B^- \to D^{(*)0}K^{(*)-}$ decays$^a$ can be used to constrain the angle $\gamma$ 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 $m_{ES} \equiv \sqrt{(E_i^* t^2/2 + p_i \cdot p_B)^2/E_i^* t^2 - p_B^2}$ and the energy difference $\Delta E \equiv E_i^* t - E_B^* t/2$, where 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 $\Delta E$. The continuum background

$^a$Reference to the charge-conjugate decays is implied throughout the text, unless otherwise stated.
is also suppressed using topological variables which exploit the fact that $B\bar{B}$ events are isotropic while continuum events are jet-like. Whenever we need to separate $B \to D^{(*)0}\pi$ and $B \to D^{(*)0}\pi$ events, we use measurements of the Cherenkov angle of the prompt track at $\Delta E$. At $\Delta E$ 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 performed 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.

Figure 1: $B^-\to D^0 K^-$ 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 $B^\pm \to D^0 K^\pm$ 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.

Table 1: $\text{BaBar}$ 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 $\phi$ and $\omega$ resonances.

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

2. GLW related measurements

In the SM, for $B^-\to D^0 K^-$ decays, we have: $R_{CP^\pm}/R_{\text{non-CP}} \simeq 1 + r_b^2 \pm 2r_b \cos \delta_b \cos \gamma$
Figure 2: Distributions of $\Delta E$ 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 $m_{ES} > 5.27 \text{GeV}/c^2$. 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.

At $\text{BaBar}$ we have studied the $B^\pm \to D^0 K^\pm$ modes 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. Figure 2 shows the $B^- \to D^0 K^-$ signal after requiring that the prompt track be consistent with the kaon
hypothesis for the flavor and CP eigenstates. In a dataset of \( \sim 216 \) million \( B \bar{B} \) 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 \( \Delta E \) 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 \( m_{ES} > 5.27 \text{ GeV}/c^2 \). From a dataset of \( \sim 123 \) million \( B \bar{B} \) 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 \( \Delta E \) projections of the fit results are also shown.

Finally we have studied the \( B^\pm \to D^0 K^{\pm*} \) 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 \( CP = -1 \) (\( D^0 \to K_S^0\pi^0 \), \( K_S^0\omega \), \( K_S^0\phi \)) eigenstates, with \( K^{*+} \to K_S^0\pi^- \). After requiring that the prompt track be consistent with the kaon hypothesis, from a dataset of \( \sim 227 \) million \( B \bar{B} \) pairs, we find 498 events in flavor, 34 events in \( CP = +1 \), and 15 events in \( CP = -1 \) eigenstates.

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**Figure 3:** Signal for the three suppressed decay modes used for the ADS method: \( B^\pm \to [K^\pm\pi^\mp]D^0 K^\mp \) (a) \((4.7_{-3.2}^{+4.0}) \) events, \( B^\pm \to [K^\pm\pi^\mp]D^*(D\pi) \) (b) \((-0.2_{-0.8}^{+1.3}) \) events, and \( B^\pm \to [K^\pm\pi^\mp]D^*(D\gamma) \) (c) \((1.2_{-1.4}^{+2.1}) \) events.

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

\[ B\bar{B} \text{'s results for the modes used in the GLW method are reported in Table 1.} \]

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 \( B^+ \to D^0 K^+ \) 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 \( D^0 \to K^- \pi^+ \) decay. Using this method we can measure:

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

where \( r_d = |A(D^0 \to K^+\pi^-)|/|A(D^0 \to K^-\pi^+)| = 0.060 \pm 0.003 \), \( \delta \) is the sum of the strong phase difference of the \( B_s \) and \( D_s \) 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 \( B^+ \to [K^\pm \pi^\mp]_D K^\mp \) and \( B^+ \to [K^\pm \pi^\mp]_D^{(*)} K^\mp \) decays. Figure 3 shows the signal for the three suppressed decay modes. \( B\bar{B} \text{'s results from a dataset of } \sim 227 \text{ million } B\bar{B} \text{ pairs are consistent with no signal. Using a Bayesian model, we measure: } r_b < 0.23 \text{ at } 90\% \text{ C.L. for the } D^0 K \text{ mode, and } r_b < 0.21 \text{ at } 90\% \text{ C.L. for the } D^{*0} K \text{ mode} \), as shown in Figure 4 results which make a measurement of \( \gamma \) quite difficult.

4. Constraints on \( r_b \) and \( \gamma \)

The latest conference results by \( B\bar{B} \text{ and Belle on the modes previously described have been combined by the UTfit } \) 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 \( \gamma \), and tighter constraints on its value will be found, once larger data sets become available.
from both BaBar and Belle, though these measurements appear quite difficult given the latest BaBar measurements of a small $r_3$ for the $D^0K$ and the $D^{*0}K$ modes.

6. References

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