

Hadronic decays related to γ at **B_AB_AR**

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We report a search for the decays $B^- \rightarrow D^0 K^-$, $B^- \rightarrow D^{*0} K^-$, $B^- \rightarrow D^0 K^{*-}$ and $B^0 \rightarrow D^0 K^{*0}$ and their charge conjugates where the flavor of the $D^{(*)0}$ meson is ambiguous. These decays are sensitive to the CKM angle γ due to interference between the $b \rightarrow c$ and $b \rightarrow u$ amplitude contributions. The most recent **B_AB_AR** results are discussed.

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1. Introduction

In the Standard Model CP violation is described by the presence of an irreducible phase in the Cabibbo-Kobayashi-Maskawa (CKM) quark-flavour-mixing matrix. The unitarity of the CKM matrix implies several relations among its elements. In particular, the relation $V_{ub}^*V_{ud} + V_{cb}^*V_{cd} + V_{tb}^*V_{td} = 0$ represents a triangle in the complex plane whose sides and angles can be determined by B meson related measurements. One of the main goal of the B -factories was to over-constrain the triangle improving the precision of all measurements. The angle γ is still one of the crucial measurements to be improved.

2. Why and how to measure γ from $B \rightarrow DK$ decays

The particularity of the angle $\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$ is that it can be measured using only tree-level decays, like $B^- \rightarrow D^0 K^-$, and thus it becomes a reference measurement crucial for constraining physics beyond the Standard Model, when compared with other measurements.

The CKM angle γ in $B \rightarrow DK$ decays is obtained by exploiting the interference between the favored $B^- \rightarrow D^0 K^-$ and the suppressed $B^- \rightarrow \bar{D}^0 K^-$ amplitudes decays once the D^0 and the \bar{D}^0 is reconstructed in the same final state. The interference is proportional to $r_B \cos(\delta_B - \gamma)$ for the B^- meson and $r_B \cos(\delta_B + \gamma)$ for its CP conjugate state. The relevant parameter that gives the sensitivity to γ is r_B , defined as the ratio between the suppressed and favoured decay amplitudes, $r_B = \frac{|A(B \rightarrow \bar{D}K)|}{|A(B \rightarrow DK)|}$. Its value is ~ 0.1 (~ 0.3) for charged (self-tagging neutral) B decays. δ_B is the strong phase (CP -even) and γ the weak phase (CP -odd). Hence, the observables are constructed using the rates of the B decay and its CP -conjugate. The parameters r_B and δ_B are also determined and thus the measurement is free from theoretical inputs.

All the measurements to date are statistically limited since the total branching fraction is of order 10^{-5} - 10^{-7} . Therefore, several final states are considered like, $K^+ K^-$, $\pi^+ \pi^-$ (CP eigenstates), $K\pi$ (Doubly Cabibbo-suppressed decays), multi-body final states ($D^0 \rightarrow K_S^0 \pi^+ \pi^-$ and $D^0 \rightarrow K_S^0 K^+ K^-$). Finally, they are combined to improve the overall sensitivity to γ .

3. Constraints on γ from charged $B \rightarrow DK$ decays

Three methods with different D decay final states are used to measure γ . The first was proposed by Gronau, London and Wyler (GLW) [1], and uses CP -eigenstates, such as $K^+ K^-$, $\pi^+ \pi^-$ (CP -even) or $K_S^0 \pi^0$, $K_S^0 \omega$ (CP -odd). The quantities to measure to extract γ are the double ratios, $R_{CP\pm} = \frac{2[\Gamma(B^- \rightarrow D_{CP\pm}^0 K^-) + \Gamma(B^+ \rightarrow D_{CP\pm}^0 K^+)]}{\Gamma(B^- \rightarrow D^0 K^-) + \Gamma(B^+ \rightarrow \bar{D}^0 K^+)}$ = $1 + r_B^2 \pm 2r_B \cos \delta_B \cos \gamma$ and the asymmetries, $A_{CP\pm} = \frac{\Gamma(B^- \rightarrow D_{CP\pm}^0 K^-) - \Gamma(B^+ \rightarrow D_{CP\pm}^0 K^+)}{\Gamma(B^- \rightarrow D_{CP\pm}^0 K^-) + \Gamma(B^+ \rightarrow D_{CP\pm}^0 K^+)} = \pm 2r_B \sin \delta_B \sin \gamma / R_{CP\pm}$.

Combining these observables we obtain determinations of $r_B = (R_{CP+} + R_{CP-} - 2)/2$, and $x_{\pm} = (R_{CP+}(1 \mp A_{CP+}) - R_{CP-}(1 \mp A_{CP-}))/4 = r_B \cos(\delta_B \pm \gamma)$. With the actual statistics this method does not constraint γ but when r_B and x_{\pm} are combined with the Dalitz method (described later) it improves the overall precision by a few degrees.

An alternative method was proposed by Atwood, Dunietz and Soni (ADS) [2], which uses Cabibbo-favoured $D^0 \rightarrow K^- \pi^+$ and doubly-Cabibbo-suppressed $\bar{D}^0 \rightarrow K^- \pi^+$ decays. The favoured

Parameter	$B \rightarrow D^0 K$	$B \rightarrow D^{*0} K$	$B \rightarrow DK^*$
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} and y_{\pm} . The first error is statistical, the second is experimental systematic uncertainty and the third is the systematic uncertainty associated with the Dalitz model.

amplitude corresponds to the Cabbibo-suppressed B decay, and vice versa. Therefore, the interfering amplitudes are of the same order of magnitude and sizable CP asymmetries are expected. The observables to measure in this method are the fraction of the suppressed to the allowed branching ratios $R_{ADS} = \frac{\Gamma(B^- \rightarrow D[K^+\pi^-]K^-) + \Gamma(B^+ \rightarrow D[K^-\pi^+]K^+)}{\Gamma(B^- \rightarrow D[K^-\pi^+]K^-) + \Gamma(B^+ \rightarrow D[K^+\pi^-]K^+)} = r_B^2 + r_D^2 + 2r_B r_D \cos \gamma \cos(\delta_B + \delta_D)$, and the direct CP asymmetry $A_{ADS} = \frac{\Gamma(B^- \rightarrow D[K^+\pi^-]K^-) - \Gamma(B^+ \rightarrow D[K^-\pi^+]K^+)}{\Gamma(B^- \rightarrow D[K^+\pi^-]K^-) + \Gamma(B^+ \rightarrow D[K^-\pi^+]K^+)} = 2r_B r_D \sin \gamma \sin(\delta_B + \delta_D) / R_{ADS}$. This method is mainly sensitive to r_B .

The third method uses the Dalitz plot analysis of the D^0 decay into 3-body final states [3]. To date, it is the only method that provides a measurement of γ using a single D decay final state. The input for this method is the amplitude of the D^0 decay, $A_{D\mp}$, which is determined from a sample of $D^{*+} \rightarrow D^0 \pi^+$, where the charge of the soft π tags the D^0 flavour. The B decay rate can therefore be written as: $\Gamma_{\mp}(m_-^2, m_+^2) \propto |A_{D\mp}|^2 + r_B^2 |A_{D\pm}|^2 + 2\lambda [x_{\mp} \Re\{A_{D\mp} A_{D\pm}^*\} + y_{\mp} \Im\{A_{D\mp} A_{D\pm}^*\}]$, where we introduce the CP parameters $x_{\pm} = r_B \cos(\delta_B \mp \gamma)$ and $y_{\pm} = r_B \sin(\delta_B \mp \gamma)$, with $x_{\mp}^2 + y_{\mp}^2 = r_B^2$. The B^+ and B^- Dalitz plots are fitted separately and the Cartesian coordinates, x_{\mp} and y_{\pm} , are obtained. The observables introduced for the three methods apply also to D^{*0} and $D^0 K^*$.

3.1 Dalitz plot method results

The most recent measurement of γ using the Dalitz method by BABAR uses 383M $B\bar{B}$ pairs [4]. The 7 reconstructed B channels are $D^0 K$, $D^{*0} K$ ($D^{*0} \rightarrow D^0 \gamma$ and $D^0 \pi^0$) and $D^0 K^*$, with signal yields 600(112), 133(32), 129 (21), 118, for $D^0 \rightarrow K_S^0 \pi^+ \pi^-$ ($D^0 \rightarrow K_S^0 K^+ K^-$) respectively. The D^0 amplitude was determined as explained above. The results for x_{\pm} and y_{\pm} ($D^0 K^-$), x_{\pm}^* and y_{\pm}^* ($D^{*0} K$), x_s and y_s ($D^0 K^*$) are shown in Table 1. These results are consistent and have similar precision to those obtained by Belle [5].

Using a frequentist analysis, x_{\pm} and y_{\pm} are interpreted in terms of the weak phase γ , the ratios r_B , r_B^* , r_s (equivalent to the parameter r_B but modified due to the finite width of the K^{*-} resonance) and the strong phases, δ_B , δ_B^* , δ_s , giving $\gamma(mod 180^\circ) = (76 \pm 22 \pm 5 \pm 5)^\circ$, where the first error is statistical, the second is the experimental uncertainty and the third reflects the uncertainty on the D decay Dalitz models. For the amplitude ratios, we obtain: $r_B = (8.6 \pm 3.5)\%$, $r_B^* = (13.5 \pm 5.1)\%$, $r_s = (16.3_{-10.5}^{+8.8})\%$, $\delta_B(mod 180^\circ) = (109_{-31}^{+28})^\circ$, $\delta_B^*(mod 180^\circ) = (-63_{-30}^{+28})^\circ$, and $\delta_s(mod 180^\circ) = (104_{-41}^{+43})^\circ$. The 1σ and 2σ confidence intervals for γ are shown in Fig.1. A 3σ evidence of direct CP violation in $B \rightarrow DK$ decays is found combining all the channels.

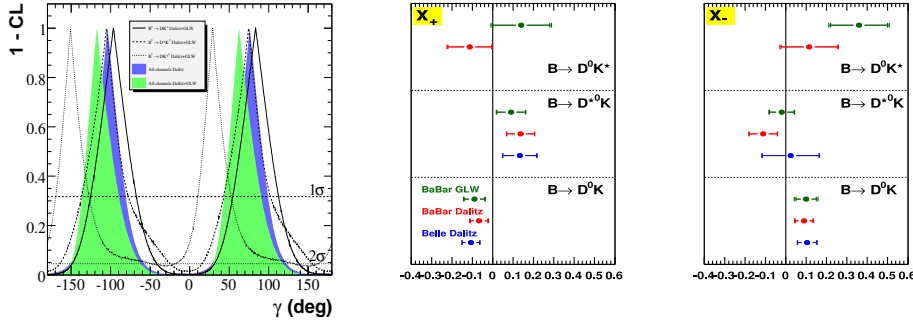
3.2 GLW results

The most recent update of GLW method analyzes the $K^+ K^-$, $\pi^+ \pi^-$, $K_S^0 \pi^0$ and $K_S^0 \omega$ D^0 decay modes, using 382M $B\bar{B}$ pairs. The B meson is reconstructed in $D^0 K$ [6] and also in $D^{*0} K$ ($D^{*0} \rightarrow D^0 \gamma$ and $D^0 \pi^0$) [7] final states, with signal yields 474, 168 and 261, respectively, from which

B decay	R_{CP+}	A_{CP+}	R_{CP-}	A_{CP-}
$D^0 K$	$1.06 \pm 0.10 \pm 0.05$	$0.27 \pm 0.09 \pm 0.04$	$1.03 \pm 0.10 \pm 0.05$	$-0.09 \pm 0.09 \pm 0.02$
$D^{*0} K$	$1.31 \pm 0.13 \pm 0.04$	$-0.11 \pm 0.09 \pm 0.01$	$1.10 \pm 0.12 \pm 0.04$	$0.06 \pm 0.10 \pm 0.02$

Table 2: Results of the GLW analysis for $D^0 K$ and $D^{*0} K$ channels.

we determine the $R_{CP\pm}$ and $A_{CP\pm}$ observables. The results are summarized in Table 2. As mentioned before, these results can be expressed in terms of the parameters used in the Dalitz analysis: $x_+ = -0.09 \pm 0.05 \pm 0.02$ and $x_- = 0.10 \pm 0.05 \pm 0.03$ for $D^0 K$ and $x_+^* = 0.09 \pm 0.07 \pm 0.02$ and $x_-^* = -0.02 \pm 0.06 \pm 0.02$ for $D^{*0} K$. These results are consistent with the Dalitz measurements by BABAR [4] and Belle [5] and have similar precision, see Fig.1. The 1-CL as a function of γ for the combination of the Dalitz method and the GLW method for each decay chain and for all the modes combined can be seen in Fig.1.

**Figure 1:** The left-most plot shows the 1-CL as a function of γ for the combination of the Dalitz and GLW methods, for all the channels separately and for its combination. The two right-most plots show the results for x_{\pm} for the BABAR GLW and Dalitz analyses and for the Belle Dalitz analysis.

3.3 ADS result

BABAR has performed a new analysis of the $B \rightarrow D^{(*)0} K^-$ decays using the ADS method, using the full dataset consisting of 467M $B\bar{B}$ pairs. The final state particles for the $D^0 K^-$ and the $D^{*0} K^-$ modes are $[K^+ \pi^-] K^-$ and $([K^+ \pi^-] \pi^0) K^-$ or $([K^+ \pi^-] \gamma) K^-$ respectively, but also the doubly Cabibbo suppressed decays $B^- \rightarrow D^{(*)0} \pi^-$ ($D^0 \rightarrow K^+ \pi^-$) and their charge conjugates, used as a control sample. The results for the double ratios and the CP asymmetries are summarized in Table 3. First indications of signals for $B \rightarrow D^0 K$ and $B \rightarrow D^{*0} (D^0 \pi^0) K$ are observed with a statistical significance of 2.9σ and 2.4σ . For the $B \rightarrow D^{*0} (D^0 \gamma) K$ channel no statistical significance is yet found. From these results and using as input $r_D = (5.78 \pm 0.08)\%$ [8] and $\delta_D = (202^{+11+9}_{-12-11})^\circ$ [9], we determine the ratios r_B and r_B^* with a frequentist approach to be $r_B = (10.9^{+4.9}_{-5.6})\%$ and $r_B^* = (11.6^{+3.3}_{-5.1})\%$, in good agreement with the BABAR and Belle Dalitz and GLW results.

4. Constraining γ using neutral $B^0 \rightarrow D^0 K^{*0}$ decays

The motivation to use neutral decays of the B meson is that larger CP asymmetries are ex-

Parameter	$D^0 K$	$D^{*0} K(D^0 \pi^0)$	$D^{*0} K(D^0 \gamma)$
$R_{ADS}(\%)$	$1.36 \pm 0.55 \pm 0.27$	$1.76 \pm 0.93 \pm 0.42$	$1.3 \pm 1.4 \pm 0.7$
A_{ADS}	$-0.70 \pm 0.35^{+0.09}_{-0.15}$	$0.77 \pm 0.35 \pm 0.12$	$0.36 \pm 0.94^{+0.25}_{-0.41}$

Table 3: Results of the ADS analysis for $D^0 K$ and $D^{*0} K$ channels

pected. The two interfering amplitudes are color-suppressed and consequently r_s is expected to be larger, of order 0.3. BABAR has performed two analyses using different B and D decay chains.

In the $B^0 \rightarrow DK^*(892)^0$ decay the charge of the kaon produced in the $K^*(892)^0$ decaying to $K^+ \pi^-$ or $K^- \pi^+$ tags the flavour of the B so that no time-dependent analysis is needed to disentangle decay and mixing. The D^0 modes considered are $D \rightarrow K\pi$, $D \rightarrow K\pi\pi^0$ and $D \rightarrow K\pi\pi\pi$ using a sample of 465M $B\bar{B}$ pairs [10]. Using as input the values obtained from CLEO-c for r_D and δ_D , r_s is constrained $r_s \in [0.07, 0.41]$ at 95% CL.

BABAR has also performed a Dalitz plot analysis of $D^0 \rightarrow K_S^0 \pi^+ \pi^-$ decay in $B^0 \rightarrow DK^*(892)^0$ [11]. The model used to described the D^0 amplitude is similar to the Dalitz analysis in charged B decays. Using a sample of 371 M $B\bar{B}$ pairs the result for γ is $(162 \pm 56)^\circ$ with $r_s < 0.55$ at 90% CL.

5. Conclusions

We reviewed the currently available determinations of the CKM phase gamma from $B \rightarrow D^{(*)}K^{(*)}$ decays performed by the BaBar collaboration. In particular, we presented a new result using the ADS method in $B^- \rightarrow D^{(*)0}K^-$ decays, which provides for the first time evidence of these decays. Combining several measurements the precision of the angle γ is still about 20° , statistically limited.

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