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Hadronic decays related to γ at BABAR

Neus LOPEZ-MARCH[*][†]
IFIC (Universitat de Valéncia - CSIC)
E-mail: `neus@slac.stanford.edu`

We report a search for the decays $B^- \to D^0K^-$, $B^- \to D^{*0}K^-$, $B^- \to D^0K^{*-}$ and $B^0 \to D^0K^{*0}$ 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 $b \to c$ and $b \to u$ amplitude contributions. The most recent *BABAR* results are discussed.

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[*] Speaker.

[†] On behalf of the *BABAR* Collaboration

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 $B \to DK$ 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 $B^- \to D^0K^-$, 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 $B \to DK$ decays is obtained by exploiting the interference between the favored $B^- \to D^0K^-$ and the suppressed $B^- \to \bar{D}^0K^-$ 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, $r_B = \frac{|A(B\to\bar{D}K)|}{|A(B\to DK)|}$. Its value is $\sim 0.1 (\sim 0.3)$ 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 ($D^0 \to K_S^0\pi^+\pi^-$and $D^0 \to K_S^0K^+K^-$). Finally, they are combined to improve the overall sensitivity to γ.

3. Constraints on γ from charged $B \to DK$ 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, $R_{CP\pm} = \frac{2[\Gamma(B^-\to D^0_{CP\pm}K^-)+\Gamma(B^+\to D^0_{CP\pm}K^+)]}{\Gamma(B^-\to D^0K^-)+\Gamma(B^+\to\bar{D}^0K^+)} = 1 + r_B^2 \pm 2r_B\cos\delta_B\cos\gamma$ and the asymmetries, $A_{CP\pm} = \frac{\Gamma(B^-\to D^0_{CP\pm}K^-)-\Gamma(B^+\to D^0_{CP\pm}K^+)}{\Gamma(B^-\to D^0_{CP\pm}K^-)+\Gamma(B^+\to D^0_{CP\pm}K^+)} = \pm 2r_B\sin\delta_B\sin\gamma/R_{CP\pm}$.

Combining these observables we obtain determinations of $r_B = (R_{CP\pm} + R_{CP\pm} - 2)/2$, 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 $D^0 \to K^-\pi^+$ and doubly-Cabibbo-suppressed $\bar{D}^0 \to K^-\pi^+$ decays. The favoured

Parameter	$B \to D^0 K$	$B \to D^{*0} K$	$B \to DK^*$
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 $R_{ADS} = \frac{\Gamma(B^- \to D[K^+\pi^-]K^-)+\Gamma(B^+ \to D[K^-\pi^+]K^+)}{\Gamma(B^- \to D[K^-\pi^+]K^-)+\Gamma(B^+ \to D[K^+\pi^-]K^+)} = r_B^2 + r_D^2 + 2 r_B r_D \cos\gamma \cos(\delta_B + \delta_D)$, and the direct *CP* asymmetry $A_{ADS} = \frac{\Gamma(B^- \to D[K^+\pi^-]K^-)-\Gamma(B^+ \to D[K^-\pi^+]K^+)}{\Gamma(B^- \to D[K^+\pi^-]K^-)+\Gamma(B^+ \to D[K^-\pi^+]K^+)} = 2 r_B r_D \sin\gamma \sin(\delta_B + \delta_D)/R_{ADS}$. 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 $D^{*+} \to D^0\pi^+$, where the charge of the soft π tags the D^0 flavour. The B decay rate can therefore be written as: $\Gamma_\mp(m_-^2, m_+^2) \propto |A_{D\mp}|^2 + {r_B}^2 |A_{D\pm}|^2 + 2\lambda \left[x_\mp \Re\{A_{D\mp} A_{D_\pm}^*\} + y_\mp \Im\{A_{D\mp} A_{D\pm}^*\} \right]$, where we introduce the *CP* parameters $x_\pm = r_B \cos(\delta_B \mp \gamma)$ and $y_\pm = r_B \sin(\delta \mp \gamma)$, 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 $D^0 K$, $D^{*0} K$ ($D^{*0} \to D^0\gamma$ and $D^0\pi^0$) and $D^0 K^*$, with signal yields 600(112), 133(32), 129 (21), 118, for $D^0 \to K_S^0 \pi^+\pi^-$($D^0 \to K_S^0 K^+ K^-$) 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 $\gamma(mod 180°) = (76 \pm 22 \pm 5 \pm 5)°$, 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: $r_B = (8.6 \pm 3.5)\%$, ${r_B}^* = (13.5 \pm 5.1)\%$, $r_s = (16.3^{+8.8}_{-10.5})\%$, $\delta_B(mod 180°) = \left(109^{+28}_{-31}\right)^\circ$, $\delta_B^*(mod 180°) = \left(-63^{+28}_{-30}\right)^\circ$, and $\delta_s(mod 180°) = \left(104^{+43}_{-41}\right)^\circ$. The 1σ and 2σ confidence intervals for γ are shown in Fig.1. A 3σ evidence of direct *CP* violation in $B \to DK$ 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 $D^{*0} K (D^{*0} \to D^0\gamma$ 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^0K	$1.06\pm0.10\pm0.05$	$0.27\pm0.09\pm0.04$	$1.03\pm0.10\pm0.05$	$-0.09\pm0.09\pm0.02$
$D^{*0}K$	$1.31\pm0.13\pm0.04$	$-0.11\pm0.09\pm0.01$	$1.10\pm0.12\pm0.04$	$0.06\pm0.10\pm0.02$

Table 2: Results of the GLW analysis for D^0K 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: $x_+ = -0.09\pm0.05\pm0.02$ and $x_- = 0.10\pm0.05\pm0.03$ for D^0K and $x^*_+ = 0.09\pm0.07\pm0.02$ and $x^*_- = -0.02\pm0.06\pm0.02$ 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.

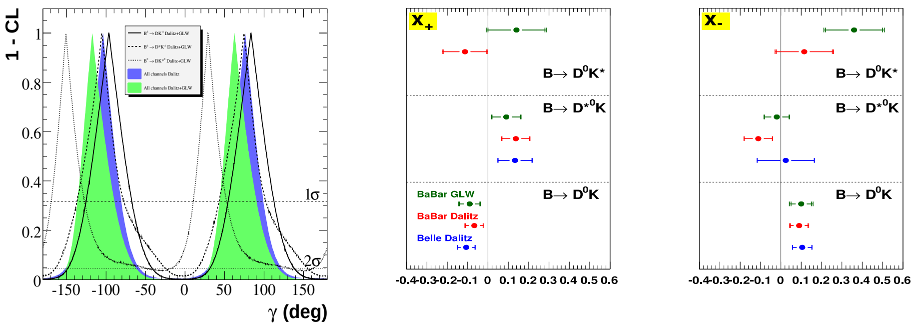

Figure 1: The left-most plot shows the 1-CL as a function of γ for the combination of the Dalitz and GLW methods, for all the channels separately and for its combination. The two right-most plots show the results for $x_\pm$ for the *BABAR* GLW and Dalitz analyses and for the Belle Dalitz analysis.

3.3 ADS result

BABAR has performed a new analysis of the $B \to D^{(*)0}K^-$ decays using the ADS method,using the full dataset consisting of 467M $B\bar{B}$ pairs. The final state particles for the D^0K^- 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 $B^- \to D^{(*)0}\pi^-$ $(D^0 \to K^+\pi^-)$ 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 $B \to D^0K$ and $B \to D^{*0}(D^0\pi^0)K$ are observed with a statistical significance of 2.9σ and 2.4σ. For the $B \to D^{*0}(D^0\gamma)K$ channel no statistical significance is yet found. From these results and using as input $r_D = (5.78\pm0.08)\%$ [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 $B^0 \to D^0K^{*0}$ decays

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

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Parameter	D^0K	$D^{*0}K(D^0\pi^0)$	$D^{*0}K(D^0\gamma)$
$R_{ADS}(\%)$	$1.36 \pm 0.55 \pm 0.27$	$1.76 \pm 0.93 \pm 0.42$	$1.3 \pm 1.4 \pm 0.7$
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^0K 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 $B^0 \to DK^*(892)^0$ 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 $D \to K\pi$, $D \to K\pi\pi^0$ and $D \to K\pi\pi\pi$ 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 $D^0 \to K^0_S\pi^+\pi^-$decay in $B^0 \to DK^*(892)^0$ [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 $B \to D^{(*)}K^{(*)}$ decays perfomed by the BaBar collaboration. In particular, we presented a new result using the ADS method in $B^- \to D^{(*)0}K^-$ 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.

References

[1] M. Gronau and D. London, *Phys. Lett.* B **253**, 483 (1991). M. Gronau and D. Wyler, *Phys. Lett.* B **265**, 172 (1991).

[2] D. Atwood, I. Dunietz and A. Soni, *Phys. Rev. Lett.* **78**, 3257 (1997); *Phys. Rev.* D **63**, 036005 (2001).

[3] A. Giri, Y. Grossman, A. Soffer and J. Zupan, *Phys. Rev.* D **68**, 054018 (2003).

[4] *BABAR* Collaboration, B. Aubert et al., *Phys. Rev.* D**78**, 034023 (2008).

[5] Belle Collaboration, K. Abe et al., arXiv:0803.3375 [hep-ex](2008).

[6] *BABAR* Collaboration, B. Aubert et al., *Phys. Rev.* D**77**, 111102 (2008).

[7] *BABAR* Collaboration, B. Aubert et al., *Phys. Rev.* D**78**, 092002 (2008).

[8] E. Barberio et al., *Averages of b-hadron and c-hadron properties at the end of 2007*,[arXiv:0808.1297v3][hep-exp].

[9] CLEO Collaboration, J.L. Rosner et al., *Phys. Rev. Lett.***100**, 221801 (2008).

[10] *BABAR* Collaboration, B. Aubert et al., *Phys. Rev.* D**79**, 072003 (2008).

[11] *BABAR* Collaboration, B. Aubert et al., arXiv: 0904.2112 [hep-ex] (2008).