Frascati Physics Series Vol. XXXVI (2004), pp. 49–54
DAΦNE 2004: Physics at meson factories – Frascati, June 7-11, 2004
Selected Contribution in Plenary Session

STATUS AND PROSPECTS FOR THE MEASUREMENT OF ANGLE γ

Marie Legendre*
CEA Saclay - DAPNIA/SPP

Abstract

We present results on B decays to modes sensitive to the CKM angle γ. These include the time-dependant CP analysis of the mode $B^0 \to D^*\pi$, using both full reconstruction and a powerful method in which the D^{*+} is partially reconstructed using only the soft pion. This process provides a measurement of $\sin(2\beta+\gamma)$. We also present the decay rate asymmetry for $B^+/B^- \to D_{CP^+}K^+/K^-$, where the neutral D meson is reconstructed in the CP even final states $\pi^+\pi^-$ and K^+K^-. Finally we present results from a search for the decay $B^- \to D_{K\pi}K^-$ where the "wrong-sign" $K^+\pi^-$ final sates results either from the usual $b \to c$ transition together with a doubly-Cabibbo-suppressed D decay or a $b \to u$ transition that produces a $\bar{D}^0$, with a favored decay $\bar{D}^0 \to K^+\pi^-$. The interference between these channels means that the mode is sensitive to γ.

---

* On behalf of BaBar Collaboration

1 Introduction

One of the main purpose of BaBar is to study CP violation in the B mesons system, and to test the Standard model, in particular by the measurement of the angles of the unitarity triangle. CP violation is now well established in B mesons by the precise measurement of $\sin(2\beta)$. The next step is now to overconstrain the unitarity triangle by studying other channels and by the measurements of the other angles α and γ. Several ways to measure γ will be presented here. $\sin(2\beta+\gamma)$ has been measured using the decay channels $B^0 \to D^{(*)}\pi$, with full and partial reconstruction methods. γ can also be measured in the decays $B^{\pm} \to D^0 K^{(*)\pm}$ by two methods (GLW and ADS).

2 Measurement of $\sin(2\beta+\gamma)$ with $B^0 \to D^{(*)}\pi$ decays

2.1 CP violation in $B^0 \to D^{(*)}\pi$

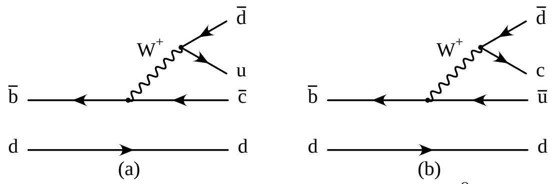

Figure 1: *Feynman diagrams for* $B^0 \to D^{*-}\pi^+$

In that channel, interferences between $b \to c$ and $b \to u$ transitions can occur. The relative weak phase between these diagrams is $2\beta+\gamma$ and we also have to consider a relative strong phase $\delta^{(*)}$.We define $r^{(*)}$ as the ratio between the amplitudes of these two diagrams : $r^{(*)} = \left|A(B^0 \to D^{(*)-}\pi^+)/A(\bar{B}^0 \to D^{(*)-}\pi^+)\right|$. $r^{(*)}$ is estimated using the branching fraction $\mathcal{B}(B^0 \to D_s^{(*)+}\pi^-)$ and assuming $SU(3)$: $r = 0.021^{+0.004}_{-0.005}$ and $r^* = 0.017^{+0.005}_{-0.007}$. We are expecting very small asymmetries, of the order of $2r^{(*)}$. This mode is interesting because only tree decays are involved. The main uncertainty is about the value of $r^{(*)}$.

The CP asymmetries are time-dependant. The B mesons are produced by pairs of correlated B in BaBar : B_{rec}, which decays in $D^{(*)}\pi$ and B_{tag}, which is used to tag the flavor of the B_{rec}, using the time-evolution of the B and the correlation between the 2 B mesons. One need to measure $\Delta t = (z_{rec} - z_{tag})/(\gamma\beta c)$, where z_{rec} (z_{tag}) is the decay position of the B_{rec} (B_{tag}) along the beam axis (z) in the laboratory frame. The decay probabilities for $B^0/\bar{B}^0 \to D^{(*)\mp}\pi^{\pm}$ are : $P(B^0 \to D^{(*)\mp}\pi^{\pm}, \Delta t) \propto [1 \pm \cos(\Delta m_d \Delta t) + (a \mp c \pm b)\sin(\Delta m_d \Delta t)]$ and

$P(\bar{B}^0 \to D^{(*)\mp}\pi^{\pm}, \Delta t) \propto [1 \mp \cos(\Delta m_d \Delta t) - (a \pm c \mp b)\sin(\Delta m_d \Delta t)]$ where a, b, c are the CP parameters. One have to take into account possible $(b \to u)$ interference effects in the tag side. They are parameterized by the effective parameters r' and δ'. The CP parameters are then : $a^{(*)} = 2r^{(*)}\sin(2\beta+\gamma)\cos(\delta^{(*)})$, $b^{(*)} = 2r'\sin(2\beta+\gamma)\cos(\delta')$, $c^{(*)} = 2\cos(2\beta+\gamma)(r^{(*)}\sin(\delta^{(*)}) - r'\sin(\delta'))$.

2.2 Full reconstruction of $B^0 \to D^{(*)}\pi$ [1)]

This method provides a large sample with few background. Signal and background are discriminated by two kinematic variables : the beam-energy substituted mass, $m_{ES} \equiv \sqrt{(\sqrt{s}/2)^2 - {p_B^*}^2}$, and the difference between the B candidate's measured energy and the beam energy, $\Delta E \equiv E_B^* - (\sqrt{s}/2)$, where E_B^* (p_B^*) is the energy (momentum) of the B candidate in the e^+e^- center-of-mass frame, and $\sqrt{s}$ is the total center-of-mass energy. With $82 fb^{-1}$, we

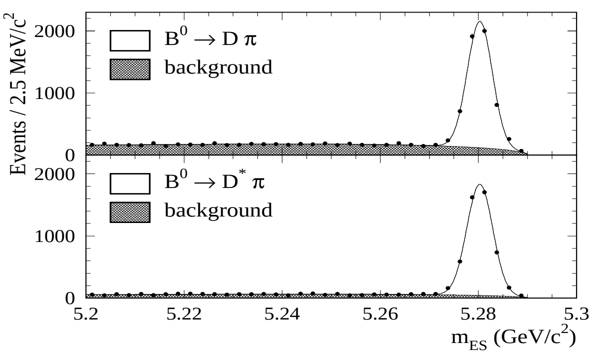

Figure 2: *Distributions of m_{ES} in the ΔE signal region for events in the $B^0 \to D^{\pm}\pi^{\mp}$ (upper plot) and the $B^0 \to D^{*\pm}\pi^{\mp}$ sample (lower plot).*

have 5207 ± 87 and 4746 ± 78 events for the $B^0 \to D^{\pm}\pi^{\mp}$ and $B^0 \to D^{*\pm}\pi^{\mp}$ sample respectively. We measure : $a = -0.022 \pm 0.038 \pm 0.020$ and $a^* = -0.068 \pm 0.038 \pm 0.020$.

2.3 Partial reconstruction of $B^0 \to D^*\pi$ [2)]

In the partial reconstruction method, only the hard pion track π_h from the B decay and the soft pion track π_s from the decay $D^{*-} \to \bar{D}^0\pi_s^-$ are used. Applying kinematic constraints, we calculate the four-momentum of the non-reconstructed D, obtaining its invariant mass M_{miss} [3)]. Signal events peak in the M_{miss} distribution at the nominal D^0 mass (Fig. 3).

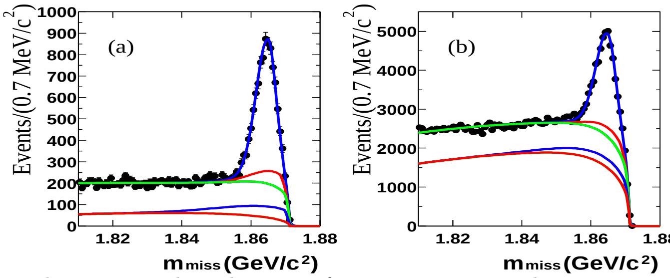

Figure 3: *The M_{miss} distributions for on-resonance lepton-tagged (left) and kaon-tagged (right) data.*

This method allows to select more events but there is also more background. With $76fb^{-1}$, we have 6400 ± 130 (25160 ± 320) signal events for the lepton- (kaon-) tagged sample. The CP asymmetry is then $a^* = -0.063 \pm 0.024 \pm 0.014$. It deviates from zero by 2.3σ.

2.4 Combining the two results to put limits on $\sin(2\beta + \gamma)$

The measured CP-parameters are used to minimize a χ^2, in which we fit $|\sin(2\beta+\gamma)|$, δ, δ^*, r and r^*, applying the method of Ref. [4]. In this method, we assume SU(3) for the value of $r^{(*)}$ and we add a 30% flat theoretical error for $r^{(*)}$. It allows to put constrains in the (ρ, η) plane and the limits $|\sin(2\beta+\gamma)| > 0.74$ (0.58) at 90% (95%) of confidence level. Another method has been used only with the measurements related to $B^0 \to D^*\pi$ decays. In this method, no assumption are made on r^*, which is scanned. It allows to put a 95% confidence level lower limit on $|\sin(2\beta+\gamma)|$ as a function of r^*.

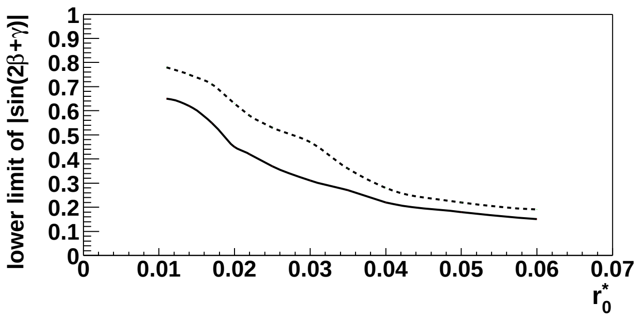

Figure 4: *95% CL lower limit on $|\sin(2\beta+\gamma)|$ as a function of r^*. The solid (dashed) curve corresponds to partial (partial and full) reconstruction*

3 Measuring γ with $B \to DK$ decays

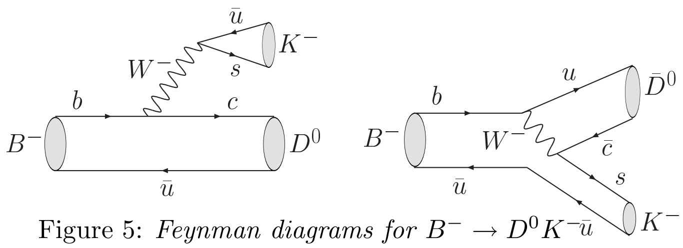

Figure 5: *Feynman diagrams for* $B^- \to D^0 K^- \bar{u}$

The phase γ is due to the interferences between $b \to u$ and $b \to c$ decay amplitudes. These interferences are possible if D^0 and $\bar{D}^0$ decay in the same final state f. Two methods are presented here to extract γ in that decays: GLW, if f is a CP-eigenstate ($\pi^+\pi^-$, K^+K^-) and ADS if f is a non CP eigenstate ($K^+\pi^-$).

3.1 Gronau-London-Wyler method : $B^\pm \to D^0_{CP} K^\pm$ [5]

The angle γ is related to the ratios of Cabibbo-suppressed to Cabibbo-favored decays $R_{(CP)} = [\mathcal{B}(B^- \to D^0(D^0_{CP})K^-) + \mathcal{B}(B^+ \to \bar{D}^0(D^0_{CP})K^+)]/[\mathcal{B}(B^- \to D^0(D^0_{CP})\pi^-) + \mathcal{B}(B^+ \to \bar{D}^0(D^0_{CP})\pi^+)]$ with D^0 reconstructed in Cabibbo-allowed or CP-even (D^0_{CP}) channels. The direct CP asymmetry is : $A_{CP} = [\mathcal{B}(B^- \to D^0_{CP}K^-) - \mathcal{B}(B^+ \to D^0_{CP}K^+)]/[\mathcal{B}(B^- \to D^0_{CP}K^-) + \mathcal{B}(B^+ \to D^0_{CP}K^+)]$. We measure $R = (8.31 \pm 0.35$ (stat) ± 0.20 (syst) $) \times 10^{-2}$, $R_{CP} = (8.8 \pm 1.6$ (stat) ± 0.5 (syst) $) \times 10^{-2}$ and the CP asymmetry $A_{CP} = 0.07 \pm 0.17$ (stat) ± 0.06 (syst). The measured ratio R is consistent with Standard Model expectation ($\approx 7.5\%$) assuming factorization [8]. In the Standard Model $R_{CP}/R = 1 + r^2 + 2r\cos\delta\cos\gamma$ and $A_{CP} = 2r\sin\delta\sin\gamma/(1 + r^2 + 2r\cos\delta\cos\gamma)$, where $r \approx 0.1 - 0.2$ is the magnitude of the ratio of the amplitudes for the processes $B^- \to D^0K^-$ and $B^- \to D^0K^-$, and δ is the (unknown) relative strong phase between these two amplitudes [9]. The measured values of R and R_{CP} are equal within errors, and A_{CP} is consistent with zero.

3.2 Atwood-Dunietz-Soni method : $B^\pm \to D^0 K^\pm$, $D^0 \to K^+\pi^-/K^-\pi^+$ [6]

We measure the branching ratios of the decay chains $B^- \to D^0K^-$ ($b \to c$ transition) followed by the doubly Cabibbo-suppressed $D^0 \to K^+\pi^-$ and $B^- \to \bar{D}^0K^-$ ($b \to u$ transition) followed by the Cabibbo-favored $\bar{D}^0 \to K^+\pi^-$.

The interferences between these two decay chains is sensitive to γ. We measure $R = [\mathcal{B}(B^- \to D_{K^+\pi^-} K^-) + \mathcal{B}(B^+ \to D_{K^-\pi^+} K^+)]/[\mathcal{B}(B^- \to D_{K^-\pi^+} K^-) + \mathcal{B}(B^+ \to D_{K^+\pi^-} K^+)]$, which corresponds to the ratio of branching fractions for suppressed and favored decays. We measure no events for the suppressed decays ($N_{suppressed} = 1.1 \pm 3.0$ and $N_{favored} = 261 \pm 32$). This leads to $R = 0.004 \pm 0.012$. We can put the limit $R < 0.026$ at 90 % C.L. We don't have enough statistics to conclude for that mode but it seems difficult to measure γ in that way.

4 Conclusion and prospects

The first steps to extract γ are promising. $D^{(*)}\pi$ analysis are well established ($|\sin(2\beta+\gamma)| > 0.74$ (0.58) at 90% (95%)) and will be updated with more data. GLW and ADS methods are actually limited by the statistics, but the analysis will also be updated and interesting results are expected. There are several other channels to explore in order to extract γ : $D^{(*)}\rho$, by the measurement of $\sin(2\beta+\gamma)$, GLW and ADS method with other final states and using D^*K^* and D^*K decays.

References

1. BABAR Collaboration, B. Aubert *et al*, Phys. Rev. Lett. **92** 251801 (2004).
2. BABAR Collaboration, B. Aubert *et al*, Phys. Rev. Lett. **92** 251802 (2004).
3. BABAR Collaboration, B. Aubert *et al*, Phys. Rev. D **67** 091101 (2003).
4. G. Feldman and R. Cousins, Phys. Rev. D **57**, 3873 (1998).
5. BABAR Collaboration, B. Aubert *et al*, hep-ex/0311032.
6. BABAR Collaboration, B. Aubert *et al*, hep-ex/0408028.
7. J.H. Christenson *et al*, Phys. Rev. Lett. **13**, 138 (1964).
8. M Gronau *et al.*, Phys. Rev. **D52** 6356-6373 (1995).
9. M. Gronau and D. Wyler, Phys. Lett. **B265**, 172 (1991); M. Gronau and D. London, Phys. Lett. **B253** 483 (1991); D. Atwood, I. Dunietz and A. Soni, Phys. Rev. Lett. **78**, 3257 (1997); M. Gronau, Phys. Lett. **B557** 198-206 (2003).