CP violation studies in $B^0 \to D^{(*) \pm} \pi^\mp$ in BaBar and Belle

D. Boutigny

To cite this version:

D. Boutigny. CP violation studies in $B^0 \to D^{(*) \pm} \pi^\mp$ in BaBar and Belle. International Europhysics Conference on High Energy Physics EPS 2003, Jul 2003, Aachen, Germany. pp.s379 - s381, 10.1140/epjcd/s2004-03-1643-1 . in2p3-00014026

HAL Id: in2p3-00014026
http://hal.in2p3.fr/in2p3-00014026
Submitted on 30 Sep 2003

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
CP violation studies in $B^0 \to D^{(*)\pm} \pi^\mp$ in BaBar and Belle

D. Boutigny

LAPP-IN2P3-CNRS
9 chemin de Bellevue - BP. 110
F-74941 Annecy-le-Vieux Cedex

Presented at the International Europhysics Conference on
High Energy Physics EPS, Aachen, Germany, July 17-23, 2003
CP Violation Studies in $B^0 \to D^{(*)\pm}\pi^\mp$ in BABAR and Belle

Dominique Boutigny

Laboratoire d’Annecy-le-Vieux de Physique des Particules CNRS/IN2P3 – BP 110 F-74941 Annecy-le-Vieux CEDEX - FRANCE

the date of receipt and acceptance should be inserted later

Abstract. We present a preliminary measurement of the time-dependent CP asymmetries in decays of $B^0$ mesons to the final states $D^{(*)\pm}\pi^\mp$ using data collected by the BABAR experiment at the PEP-II storage rings. $B$ mesons decaying to $D\pi$ are fully reconstructed, while events containing $B \to D^*\pi$ are selected using a full or a partial reconstruction technique. These results can be interpreted in terms of a constraint on the angles of the unitarity triangle to set a lower bound on $|\sin(2\beta + \gamma)|$. The Belle experiment at the KEK-B collider is performing the same kind of studies and a preliminary estimation of the achievable error is presented.

1 Introduction

The main physics goal of the BABAR and Belle experiments running on B-factories is the measurement of the CP-violating phase of the quark-mixing (CKM) matrix [1] and to over-constrain the unitarity triangle in order to check whether the CKM mechanism is the correct explanation of the CP violation phenomenon. The CP violation in the B sector has been established by measuring the $\beta$ angle of the unitarity triangle [2], [3]. We present here an analysis to constrain $|\sin(2\beta + \gamma)|$ from the study of the time evolution for $B^0 \to D^{(*)\pm}\pi^\mp$ decays [4] [5].

2 Principle of the measurement

2.1 Time-dependent decay rates

The decays $B^0 \to D^{(*)\pm}\pi^\mp$ may proceed via a favored $b \to c\pi d$ or a doubly-CKM-suppressed $b \to u\pi d$ amplitude. Interference between these amplitudes through $B^0 - \bar{B}^0$ mixing provides a time-dependent CP-violation signal.

The time-dependent decay rate for $B^0 \to D^{(*)\pm}\pi^\mp$ decays is:

$$f^\pm(\eta, \Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau} \times$$

$$\left[1 \pm S_{\eta} \sin(\Delta m_d \Delta t) \mp \eta C \cos(\Delta m_d \Delta t)\right],$$

where $\tau$ is the mean $B^0$ lifetime, $\Delta m_d$ is the $B^0$-$\bar{B}^0$ mixing frequency, and $\Delta t = t_{rec} - t_{tag}$ is the time elapsed between the $B^0 \to D^{(*)\pm}\pi^\mp$ decay and the decay of the other $B$ ($B_{tag}$). The superscript $+(-)$ refers to whether the flavor of ($B_{tag}$) was $B^0$ ($\bar{B}^0$), while $\eta = +1(-1)$ for $D^+\pi^- (D^-\pi^+)$ final states. The $S$ and $C$ parameters can be expressed as:

$$S_{\eta} = \frac{2Im\lambda_{\eta}}{1 + |\lambda_{\eta}|^2}, \quad C = \frac{1 - |\lambda_{\eta}|^2}{1 + |\lambda_{\eta}|^2},$$

where we define $|\lambda| = |\lambda_+| = 1/|\lambda_-|$, and $\lambda_{\pm} = \frac{q \pm A}{p}A(B^0 \to D_{\mp\pi})/A(B^0 \to D_{\mp\pi}) = |\lambda|^{\pm1}e^{-(2\beta + \gamma \mp \delta)}, q/p$ is a function of the elements of the mixing matrix and $\delta$ is the relative strong phase between the two contributing amplitudes. The same equations apply for $B^0 \to D^{(*)\pm}\pi^\mp$ decays with $|\lambda|$ and $\delta$ replaced by different values $|\lambda^*|$ and $\delta^*$. The analysis strategy is similar to other BABAR and Belle time-dependent CP asymmetry measurements [2], [3]. The $B^0$ meson decaying to the $D^{(*)\pi}$ final state ($B_{rec}$) is reconstructed using a partial or a full reconstruction method. The flavor of the other $B^0$ meson ($B_{tag}$) is determined using the charge correlation with a lepton or a kaon. Each event is assigned to one of four hierarchical, mutually exclusive tagging categories. The decay time difference $\Delta t$ is computed from the distance separating the $B_{tag}$ and $B_{rec}$ vertices.

2.2 Estimation of $|\lambda^*|$ (3)

In principle the ratio $|\lambda^*|$ of the magnitudes of the suppressed and favored amplitudes can be estimated from a global time-dependent fit of equation 1. In practice, this is not possible with the current BABAR statistics. As suggested in [5] [6], the value of $|\lambda^*|$ is estimated from the ratio of branching fractions $B(B^0 \to D_{\mp}\pi) / B(B^0 \to D_{\mp}\pi)$. Using the BABAR measurement [6]

$$|\lambda|(D\pi) = 0.021^{+0.004}_{-0.006}, \quad |\lambda^*|(D^*\pi) = 0.017^{+0.006}_{-0.007}$$

As this estimation is based on the approximate SU(3) symmetry and is not taking into account annihilation contributions to $B^0 \to D^{(*)\pi}$, there is an unknown, potentially large, theoretical uncertainty on $|\lambda^*|$. 
2.3 CP violation on the tag side

In the same way that the interference between the $b \to u$ and $b \to c$ amplitudes is present in the reco side and is used to measure the CP asymmetry, the same interference exists on the tag side and induces a time-dependent effect which cannot be neglected \cite{7}. This effect depends on the $B_{sK}^0$ decay modes. For each tagging category (i), this interference is parametrized in terms of the effective parameters $|\lambda_i|$ and $\delta_i$. The time-dependent decay rate becomes:

$$f_i^{(+)}(\delta, \Delta t) \propto 1 \mp \left( a^{(+)} \mp \eta b_i - \eta c_i^{(+)} \right) \sin(\Delta m_d \Delta t)$$

$$\mp \eta \cos(\Delta m_d \Delta t)$$

(4)

where

$$a^{(+)} = 2|\lambda(+)| \sin(2\beta + \gamma) \cos \delta^{(+)}$$

$$b_i = 2|\lambda_i| \sin(2\beta + \gamma) \cos \delta_i$$

$$c_i^{(+)} = 2\cos(2\beta + \gamma) \left( |\lambda(+)| \sin \delta^{(+)} - |\lambda_i| \sin \delta_i \right)$$

(5)

The $b$ and $c$ parameters absorb the tag side interference effects while $a$ is independent of them. The lepton tag category does not have doubly-CKM-suppressed amplitude contribution, therefore $|\lambda^{lep}| = 0$.

3 $B^0 \to D^{(*)}\pm \pi \mp$ full reconstruction method

In the full reconstruction method \cite{8}, the final state $B^0 \to D^{(*)}\pm \pi \mp$ is completely reconstructed. The $D^{(*)}$ is reconstructed in its decay to $D^{0}\pi^{\mp}$, where the $D^0$ subsequently decays to $K^{-}\pi^+, K^{-}\pi^+\pi^0, K^{-}\pi^+\pi^-\pi^0$ or $K^0_s\pi^+\pi^-$. The $D^+$ is reconstructed in $K^-\pi^+\pi^0$ or $K^0_s\pi^+\pi^-$. After selection, signal and background are discriminated by two kinematic variables: the beam energy substituted mass, $m_{ES} \equiv \sqrt{\left(\sqrt{s}/2\right)^2 - p_B^2}$ and the difference between the $B$ candidate's measured energy and the beam energy, $\Delta E \equiv E_B - \left(\sqrt{s}/2\right)$. $E_B$ ($p_B$) 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. This method provides a very clean signal selection, with a small background coming mainly from combinatorics. The remaining peaking is of the order of 1%. Based on an integrated luminosity of 81.9 fb$^{-1}$ on the $T(4S)$ resonance, the signal yield is $520 \pm 87$ events with a 85% purity for $B^0 \to D^{+}\pi^-$ and $4746 \pm 78$ events with a 94% purity for $B^0 \to D^{+}\pi^-$. An unbinned maximum likelihood fit is performed on the selected candidates using the $\Delta t$ distribution in Eq. 4 convoluted with a three-Gaussian resolution function and taking into account the probabilities of incorrect tagging. The results from the fit to the data including the systematic uncertainties summarized in Table 1 are:

$$a = -0.022 \pm 0.038(stat) \pm 0.021(syst)$$

$$a^* = -0.068 \pm 0.038(stat) \pm 0.021(syst)$$

$$c_{lep} = 0.025 \pm 0.068(stat) \pm 0.035(syst)$$

$$c_{lep}^* = 0.031 \pm 0.070(stat) \pm 0.035(syst)$$

(6)

These results can be interpreted in terms of $\sin(2\beta + \gamma)$, $\delta$ and $\delta^*$ by minimizing the $\chi^2$:

$$\chi^2 = \sum_i \left( \frac{\hat{x}_i - x_i}{\sigma_i} \right)^2 + \chi^2(|\lambda|) + \chi^2(|\lambda^*|),$$

(7)

where $\hat{x}_i$ refers to the measured values for $a^{(*)}$ and $c^{(*)}$.

<table>
<thead>
<tr>
<th>Source</th>
<th>$\sigma_a = \sigma_a^{(*)}$</th>
<th>$\sigma_c = \sigma_c^{(*)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertexing</td>
<td>0.015</td>
<td>0.026</td>
</tr>
<tr>
<td>Tagging</td>
<td>0.004</td>
<td>0.003</td>
</tr>
<tr>
<td>Background</td>
<td>0.001</td>
<td>0.003</td>
</tr>
<tr>
<td>Fit</td>
<td>0.014</td>
<td>0.023</td>
</tr>
</tbody>
</table>

Total ($\sigma_{tot}$) 0.021 0.035

4 $B^0 \to D^* \pm \pi \mp$ partial reconstruction method

In the partial reconstruction method \cite{9}, only the $B^0 \to D^{(*)}\pi \mp$ decay channel is considered. Only the hard pion track from the $B^0$ decay and the soft pion track from the decay $D^* \to D^0\pi$ are reconstructed. Using the two pions and kinematic constraints, a missing mass variable is computed. In this variable, signal events peak at the nominal $D^0$ mass with a spread of about 3 MeV/$c^2$, while the distribution of the combinatoric background is significantly broader. The background is coming mainly from combinatorics and from $B^0 \to D^*\mu$. The statistics is larger than for the full reconstruction method: 6409 $\pm 129$ events with a lepton tag and 25157 $\pm 323$ events with a kaon tag for 76.4 fb$^{-1}$ on the $T(4S)$ resonance.

In order to compute the time difference $\Delta t$ the $B^0 \to D^{(*)}\pi \mp$ decay position along the beam axis is estimated by fitting the hard pion track with a beam spot constraint in the plane perpendicular to the beams. The typical $\Delta t$ resolution is $\approx 1$ ps.
The analysis is carried out with a series of unbinned maximum likelihood fits performed simultaneously on the on- and off-resonance data samples and independently for the lepton-tagged and kaon-tagged events. The parameters $S_+$ and $S_-$ from Eq. 1 are extracted from the lepton tags while $a$, $b$ and $c$ of Eq. 4 are determined from kaon tags. Combining both tagging categories:

$$a = -0.063 \pm 0.024 \text{(stat)} \pm 0.017 \text{(syst)}$$
$$c_{r \phi} = -0.004 \pm 0.037 \text{(stat)} \pm 0.020 \text{(syst)}.$$  

(8)

The systematic uncertainties are summarized in Table 2.

<table>
<thead>
<tr>
<th>Source</th>
<th>Error ($\times 10^{-3}$) in</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$S_-$</td>
</tr>
<tr>
<td>Background</td>
<td>3.0</td>
</tr>
<tr>
<td>Bkg CP content</td>
<td>10.0</td>
</tr>
<tr>
<td>Fit</td>
<td>5.0</td>
</tr>
<tr>
<td>Detector</td>
<td>10.0</td>
</tr>
<tr>
<td>MC stat</td>
<td>13.0</td>
</tr>
<tr>
<td>Total</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Table 2. Systematic uncertainties on $S_-$, $S_+$, $a$, $b$ and $c^{(*)}$ and the total uncertainty

interpretation of the result identical to the one exposed in section 3 allows to give the following limits on $|\sin(2\beta + \gamma)|$, assuming a 30% non-gaussian error on $|\lambda|$: $|\sin(2\beta + \gamma)| > 0.88$ at 68% C.L. $|\sin(2\beta + \gamma)| > 0.75$ at 90% C.L. $|\sin(2\beta + \gamma)| > 0.62$ at 95% C.L. and the value $|\sin(2\beta + \gamma)| = 0$ is excluded at 98.3% C.L.

5 Combined results

The results from the full reconstruction and the partial reconstruction method are combined and give the following limits: $|\sin(2\beta + \gamma)| > 0.89$ at 68% C.L. $|\sin(2\beta + \gamma)| > 0.76$ at 90% C.L. and $|\sin(2\beta + \gamma)| = 0$ is excluded at 99.5% C.L.

As there is a large theoretical uncertainty on the value of $|\lambda^{(*)}|$, the lower limit on $|\sin(2\beta + \gamma)|$ is plotted in Fig. 1 as a function of $r = |\lambda|$ for various values of the confidence level. In this case $r = |\lambda|$ and $|\lambda^{(*)}|$ are assumed to be equal.

6 Status of $B^0 \rightarrow D^{(*)}\pi^\pm$ in Belle

The Belle experiment is performing similar studies on $B^0 \rightarrow D^{(*)}\pi^\pm$. For the partial reconstruction technique, with 78 fb$^{-1}$ of data and including background effect, the expected statistical uncertainty on $2|\lambda|\sin(2\beta + \gamma)$ is equal to $\pm 0.029$. For the full reconstruction method, with the complete data sample available this summer, estimated from a Monte-Carlo simulation study and not taking into account background effect, the statistical uncertainty on $2|\lambda|\sin(2\beta + \gamma)$ is equal to $\pm 0.028$.  

References

8. The BaBaR Collaboration, B. Aubert et al., SLAC-PUB-10103, hep-ex/0308018.