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Hadronic B Decays with BaBar*

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Abstract

We report about the studies of the decay channels $B^- \to D^0 K^-$, $B^0 \to D^{*-} a_1^+$ and $B^0 \to D_s^{(*)-} \pi^+$ with a sample of 62×10^6 $\Upsilon(4S)$ decays into B meson pairs collected with the BaBar detector at the Pep II asymmetric e^+e^- collider.

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The measurement of the CP-violating phase of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1] is an important part of the present scientific program in particle physics. Theoretically clean measurements of the angle β of the unitarity triangle exist [2] but there are no such measurements of the two other angles (α and γ). The determination of these two angles would check the validity of the CKM mechanism in the explanation of the CP-violation. Theoretically clean measurements of γ and $\sin(2\beta+\gamma)$ can be obtained from the study of the decay modes $B \to D^0 K$, $B^0 \to D^{*-} a_1^+$ and $B^0 \to D_s^{(*)+} \pi^-$. In this paper we present the results of the measurements of the branching fractions of the decay modes, as a preliminary step towards the measurements of the γ angle.

1 Detector and data sample

The data were collected in the years 1999-2001 with the BaBar detector at the Pep-II asymmetric e^+ (3.1 GeV) - e^- (9 GeV) storage ring. The BaBar detector is a large-acceptance solenoidal spectrometer (1.5 T) described in detail elsewhere [3]. The analyses described below make use of charged track and π^0 reconstruction and charged particle identification. Charged particle trajectories are measured by a 5-layer double-sided silicon vertex tracker (SVT) and a 40-layer drift chamber (DCH), which also provide ionisation measurements (dE/dx) used for particle identification. Photons and electrons are measured in the electromagnetic calorimeter (EMC), made of 6580 thallium-doped CsI crystals constructed in a non-projective barrel and forward endcap geometry. Charged K/π separation up to 4 GeV/c in momentum is provided by a detector of internally reflected Cherenkov light (DIRC), consisting of 12 sectors of quartz bars that carry the Cherenkov light to an expansion volume filled with water and equipped with 10751 photomultiplier tubes.

2 $B^- \to D^0 K^-$

The study of this decay channel can lead to a clean measurement of the γ angle [4, 5]. $B^- \to D^0 K^-$ decays are obtained with a color-allowed, V_{us} suppressed diagram. $B^- \to \bar{D}^0 K^-$ decay modes also exist and are due to a color- and V_{ub} suppressed diagram. If D^0 decays into a CP eigenstate such as $D^0_{CP} \to K^- K^+$, the decay $B^- \to D^0_{CP} K^-$ can be obtained with both processes. Knowing the decay amplitudes of all three possibilities ($B^- \to D^0 K^-$, $B^- \to \bar{D}^0 K^-$ and $B^- \to D^0_{CP} K^-$), it is possible to measure 2γ and then γ up to discrete ambiguities.

The CP asymmetry $\mathcal{A}_{CP}$:

$$\mathcal{A}_{CP} = \frac{\mathcal{B}(B^+ \to D^0_{CP} K^+) - \mathcal{B}(B^- \to D^0_{CP} K^-)}{\mathcal{B}(B^+ \to D^0_{CP} K^+) + \mathcal{B}(B^- \to D^0_{CP} K^-)} \tag{1}$$

is related to the γ angle. It is expected to be of the order of 10 % in the Standard Model.

$B^- \to D^0 K^-$ decay modes are expected to have a branching fraction 10 times lower than the branching fraction for $B^- \to D^0 \pi^-$ ($\mathcal{B}(B^- \to D^0 \pi^-) = (5.3 \pm 0.5) \times 10^{-3}$ [6])

which constitutes the main background source of this analysis. The capability of the DIRC to distinguish between pions and kaons will then be very important. Moreover the interesting D^0_{CP} decay modes are Cabibbo suppressed and have small branching fractions ($\mathcal{B}\,(D^0_{CP} \to K^+K^-) = (4.12 \pm 0.14) \times 10^{-3}$ [6]). The large data sample available at BaBar will also be useful.

For this analysis, D^0 candidates reconstructed in the decay modes $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^0$, $D^0 \to K^-\pi^+\pi^-\pi^+$ and $D^0_{CP} \to K^-K^+$ are combined with a prompt charged track h^- which creates Cherenkov light in the DIRC. The effective mass of the B^- candidate is calculated using the kaon mass hypothesis so both $B^- \to D^0K^-$ and $B^- \to D^0\pi^-$ are reconstructed.

For each B candidate, two variables are calculated using the fact that B mesons are produced in pairs, and are almost at rest in the $\Upsilon(4S)$ frame:

$$m_{ES} = \sqrt{\left(\frac{1}{2}\sqrt{s}\right)^2 - \vec{p}^{*2}} \tag{2}$$

$$\Delta E = E^* - \frac{1}{2}\sqrt{s} \tag{3}$$

Signal $B^- \to D^0K^-$ events will accumulate in a region of the $m_{ES} - \Delta E$ plane which is centered on $\Delta E = 0$ and $m_{ES} = 5.28$ GeV/c^2 (the nominal B mass) whereas background $B^- \to D^0\pi^-$ events will accumulate in a region shifted to positive ΔE values but at the same m_{ES} values since m_{ES} depends only on the laboratory 3-momentum.

The number of signal $B^- \to D^0K^-$ events is computed with an extended maximum likelihood fit which makes use of the position of the B candidate in the $m_{ES} - \Delta E$ plane and of the Cherenkov angle of the prompt track h^- to distinguish between $B^- \to D^0K^-$ events, $B^- \to D^0\pi^-$ events, peaking background and combinatorial background events.

Fig. 1 shows the ΔE projections for all $B^- \to D^0h^-$ candidates reconstructed in a sample of 56.4 fb^{-1} on-resonance data, with $D^0 \to K^-\pi^+$ (left) and $D^0_{CP} \to K^-K^+$ (right) decay modes. On each projection the fitted distribution and the contributions to the total function of $B^- \to D^0K^-$, $B^- \to D^0\pi^-$ and background events are overlaid.

A clear evidence of the signal for $B^- \to D^0K^-$ is obtained requiring tight kaon identification criteria on the prompt track h^-. The corresponding ΔE projections are shown on Fig. 2.

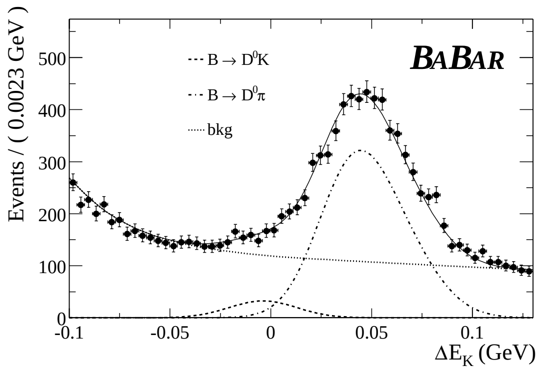
The branching fractions are extracted from these fits on the same data sample. The ratio to the $B^- \to D^0\pi^-$ branching fraction is measured equal to:

$$R = \frac{\mathcal{B}\,(B^- \to D^0K^-)}{\mathcal{B}\,(B^- \to D^0\pi^-)} = (8.31 \pm 0.35(\text{stat}) \pm 0.13(\text{syst}))\,\% \tag{4}$$

for non CP modes and to:

$$R_{CP} = \frac{\mathcal{B}\,(B^- \to D^0_{CP}K^-) + \mathcal{B}\,(B^+ \to D^0_{CP}K^+)}{\mathcal{B}\,(B^- \to D^0_{CP}\pi^-) + \mathcal{B}\,(B^+ \to D^0_{CP}\pi^+)} = (8.4 \pm 2.0(\text{stat}) \pm 0.8(\text{syst}))\,\% \tag{5}$$

for CP-even modes (*ie* $D^0 \to K^-K^+$).



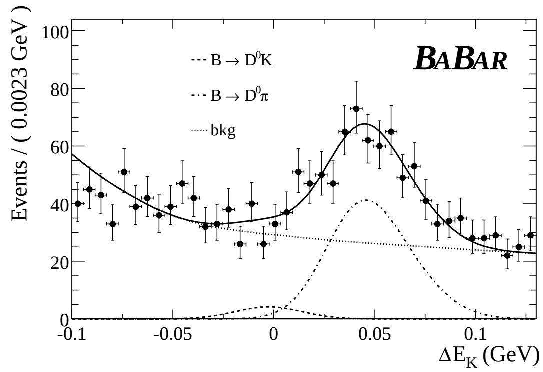


Figure 1: ΔE distribution for $B^- \to D^0 h^-$ candidates, with $D^0 \to K^-\pi^+$ (left) and $D^0_{CP} \to K^- K^+$ (right)

The CP asymmetry has been found equal to:

$$\mathcal{A}_{CP} = \frac{\mathcal{B}\left(B^- \to D^0_{CP} K^-\right) - \mathcal{B}\left(B^+ \to D^0_{CP} K^+\right)}{\mathcal{B}\left(B^- \to D^0_{CP} K^-\right) + \mathcal{B}\left(B^+ \to D^0_{CP} K^+\right)} = 0.15 \pm 0.24^{+0.07}_{-0.08} \tag{6}$$

3 $B^0 \to D^{*-} a_1^+$

B^0 mesons can decay either into $D^{*-}\pi^+$ (Cabibbo-Allowed diagram) or into $D^{*+}\pi^-$ (Cabibbo and V_{ub} suppressed diagram). Since B^0 mesons can also oscillate to $\bar{B}^0$, the time dependant evolutions of $B^0 \to D^{*-}\pi^+$ and $B^0 \to D^{*+}\pi^-$ are related to $\sin(2\beta+\gamma)$[7]. This method requires a lot of events to lead to a precise measurement. It may be interesting to use the similar $B^0 \to D^{*-} a_1^+$ decay mode which has a larger branching fraction: from [6], $\mathcal{B}\left(B^0 \to D^{*-}\pi^+\right) = (2.76 \pm 0.21) \times 10^{-3}$ and $\mathcal{B}\left(B^0 \to D^{*-} a_1^+\right) = (1.30 \pm 0.27)\,\%$.

In order to reconstruct even more events, the analysis described here makes use of a partial reconstruction technique [8], using only the soft pion from the D^{*-} decay and the a_1^+. With respect to the full reconstruction technique, it has thus no penalty due to the branching fractions of the reconstructed D^0 decay modes. Since the soft pion in the D^* decay has a low momentum, it is very often only reconstructed in the SVT and the analysis requires a good stand-alone track reconstruction capability of this device.

In the decay chain $B^0 \to D^{*-} a_1^+, D^{*-} \to \bar{D}^0 \pi^-$, only the a_1^+ and the slow π from the D^* decay are reconstructed. a_1^+ is only reconstructed in the decay mode $a_1^+ \to \rho^0 \pi^+$ whose branching fraction is supposed to be equal to 49.2 %. The remaining 12 parameters are determined by applying the constraints of 4-momentum conservation to the B and D^* decay, the invariant masses of the B, D^* and D^0 and the B energy in the Center of Momentum frame, that is to say the half of the Center of Mass energy. By applying the beam energy and B mass constraints, the angle between the B and the a_1 momentum

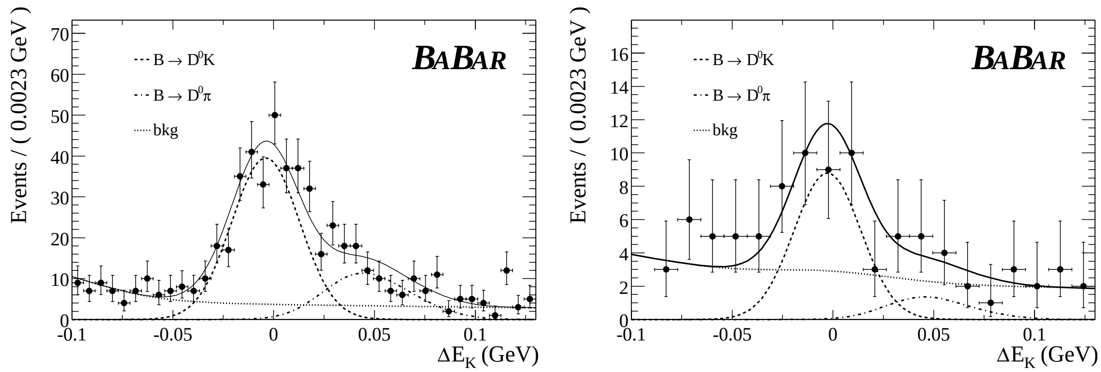


Figure 2: ΔE distribution for $B^- \to D^0 h^-$ candidates, with $D^0 \to K^- \pi^+$ (left) and $D^0_{CP} \to K^- K^+$ (right) with tight kaon identification for the prompt track h^-

can be computed. The B 4-momentum is known up to an azimuthal angle ϕ around the a_1 momentum. ϕ is the only unknown parameter. The missing mass m_{miss} is computed averaging over ϕ.

For signal events, m_{miss} peaks at the nominal D^0 mass but the m_{miss} distribution is broader for background events. A large fraction of background events come from continuum events. This type of background is rejected in this analysis with a Neural Network algorithm [9] using the different topologies between continuum events which have a jet-like structure and $B\bar{B}$ events which are more spherical.

Fig. 3 shows the missing mass distributions obtained with a sample of 20.6 fb^{-1} on-resonance data and 2.5 fb^{-1} off-resonance data, for opposite sign combinations (top, $a_1^+ - \pi^-$) and same sign combinations (bottom, $a_1^+ - \pi^+$) where no signal is present. In the distributions presented, the distributions obtained from the off-resonance data are subtracted from that obtained from data recorded at the $\Upsilon(4S)$ peak. To compute the total number of signal events, the resulting distribution for opposite sign combinations is fitted with a linear combination of a distribution from background B Monte-Carlo events and a distribution from signal Monte-Carlo events. This procedure yields an estimated signal of 18427 ± 1200 events.

The branching ratio resulting from this analysis is found equal to:

$$\mathcal{B}\left(B^0 \to D^{*-} a_1^+\right) = 1.20 \pm 0.07(\text{stat}) \pm 0.14(\text{syst})\ \% \tag{7}$$

An additional systematic bias due to the unknown presence of background $B \to D^{**} a_1$ decays has to be added to the systematic error. If $B^{**} = \mathcal{B}\left(B \to D^{**} a_1\right) \times \mathcal{B}\left(D^{**} \to D^* \pi\right)$ this bias is:

$$\sigma = \left({}^{+0}_{-0.05 \times B^{**}/0.35\%} \right)\ \% \tag{8}$$

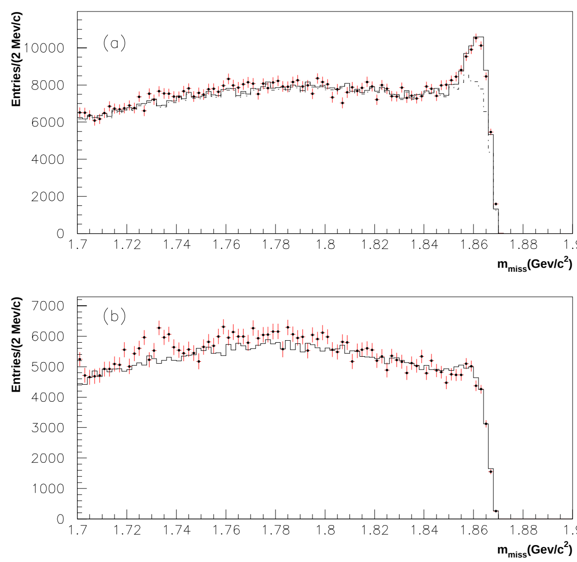


Figure 3: (a) m_{miss} distribution of continuum-substracted on-resonance data events (data points), $B\bar{B}$ background MC events (dashed histogram) and $B\bar{B}$ background plus signal events (solid histogram) for "right-sign" $a_1\pi$ combinations. The histograms are the result of the fit procedure described in the text. (b) Same distributions for "wrong-sign" $a_1\pi$ combinations

4 $B^0 \to D_s^{(*)+}\pi^-$

The determination of $\sin(2\beta+\gamma)$ with $B^0 \to D^*\pi$ or $B^0 \to D^*a_1$ mentioned in the previous section requires the knowledge of the ratio λ between the two decay amplitudes of the allowed and suppressed processes:

$$\lambda = \frac{\mathcal{A}\left(B^0 \to D^{*+}\pi^-\right)}{\mathcal{A}\left(B^0 \to D^{*-}\pi^+\right)} \tag{9}$$

λ cannot be measured directly because the two processes cannot be distinguished experimentally. A way to measure λ is to study the decay $B^0 \to D_s^{(*)+}\pi^-$ whose branching fraction is related to λ [10]:

$$\mathcal{B}\left(B^0 \to D_s^{(*)+}\pi^-\right) = \frac{\mathcal{B}\left(B^0 \to D^{(*)-}\pi^+\right)}{\cos\theta^2_{\text{cabibbo}}}\left(\frac{f_{D_s^{(*)}}}{f_{D^{(*)}}}\right)^2\lambda^2 \tag{10}$$

where $f_{D_s^{(*)}}$ and $f_{D^{(*)}}$ are the decay constants of $D_s^{(*)}$ and $D^{(*)}$. The decay $B^0 \to D_s^{(*)+}\pi^-$ can also be used for a measurement of $|V_{ub}/V_{cb}|$ [11].

$B^0 \to D_s^{(*)+}\pi^-$ candidates are fully reconstructed, with D_s candidates reconstructed in the decay modes: $D_s^+ \to \phi\pi^+$, $D_s^+ \to K^{*0}K^+$ and $D_s^+ \to K_s K^+$ with $\phi \to K^+K^-$, $K^{*0} \to K^+\pi^-$ and $K_s \to \pi^+\pi^-$. D_s^* candidates are reconstructed in the decay mode $D_s^{*+} \to D_s^+\gamma$. Background from continuum events is rejected using a Fisher discriminant [12] and the cosine of the angle between the thrust axis of the reconstructed B and the thrust axis of the remaining tracks of the event. For jet-like continuum events, the two thrusts are back to back whereas for $B\bar{B}$ events, the cosine distribution is flat. The selection algorithm [13] makes use of kaon identification, $D_s^+\pi^-$ vertex probability and the helicity angle in the decays $D_s^+ \to \phi\pi^+$ and $D_s \to K^{*0}K^+$ in order to reduce the combinatorial background from continuum and $B\bar{B}$ events.

Fig. 4 show the $m_{\rm ES}$ distributions obtained with 56.4 fb^{-1} on-resonance data. The mass distributions are fitted with a Gaussian function for the signal and a so-called "ARGUS" shape function for the background [14].

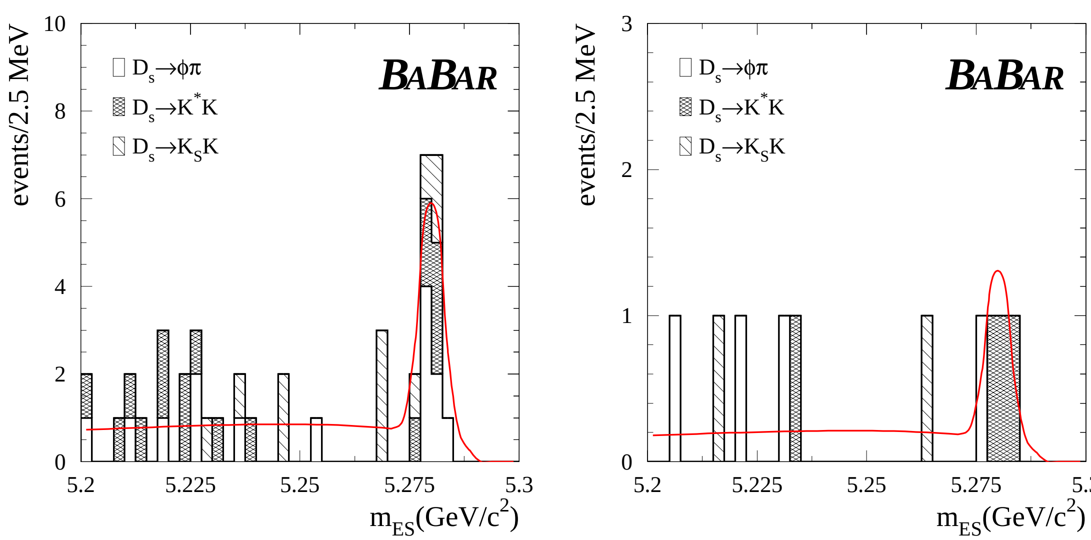


Figure 4: $m_{\rm ES}$ distribution for $B^0 \to D_s^+\pi^-$ (left) and $B^0 \to D_s^{*+}\pi^-$ (right)

A signal of 14.9 ± 4.1 events is found for the $B^0 \to D_s^+\pi^-$ decay mode with a statistical significance of 3.5 σ. This corresponds to a branching fraction of:

$$\mathcal{B}\left(B^0 \to D_s^+\pi^-\right) = (3.1 \pm 1.0(\text{stat}) \pm 1.0(\text{syst})) \times 10^{-5} \tag{11}$$

No significant signal is found for the $B^0 \to D_s^{*+}\pi^-$ decay mode. An upper limit at 90 % of confidence level is derived:

$$\mathcal{B}\left(B^0 \to D_s^{*+}\pi^-\right) < 4.3 \times 10^{-5} \tag{12}$$

5 Conclusions

Preliminary results from the BaBar experiment have been presented concerning the branching fractions for the decay modes $B^- \to D^0_{CP} K^-$, $B^0 \to D^{*-} a_1^+$ and $B^0 \to D_s^{(*)+} \pi^-$. These studies show the feasibility of the analyses but more statistics are needed to have access to the γ angle of the unitarity triangle.

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