



ϕ_1 Measurements at Belle

Veronika Chobanova

*Max-Planck-Institut für Physik
D-80805 München, Germany*

Abstract

We present the recent measurements of the $B^0 \rightarrow \eta' K^0$ and the $B \rightarrow \omega K$ decay modes based on the full data set of $772 \times 10^6 B\bar{B}$ pairs collected by the Belle detector at the KEKB e^+e^- collider. In the $B^0 \rightarrow \eta' K^0$ mode, we obtain the CP -violating parameters

$$\begin{aligned}\mathcal{A}_{\eta' K^0} &= +0.03 \pm 0.05 (\text{stat}) \pm 0.04 (\text{syst}), \\ \mathcal{S}_{\eta' K^0} &= +0.68 \pm 0.07 (\text{stat}) \pm 0.03 (\text{syst}).\end{aligned}$$

This is the world's most precise result on the $\eta' K^0$ CP parameters. In $B \rightarrow \omega K$ decays, we measure the branching fractions

$$\begin{aligned}\mathcal{B}_{B^0 \rightarrow \omega K^0} &= (4.5 \pm 0.4 (\text{stat}) \pm 0.3 (\text{syst})) \times 10^{-6}, \\ \mathcal{B}_{B^- \rightarrow \omega K^-} &= (6.8 \pm 0.4 (\text{stat}) \pm 0.4 (\text{syst})) \times 10^{-6},\end{aligned}$$

which are their current most precise results. We measure the first evidence of CP violation in the $B^0 \rightarrow \omega K_S^0$ decay mode, obtaining the CP -violating parameters

$$\begin{aligned}\mathcal{A}_{\omega K_S^0} &= -0.36 \pm 0.19 (\text{stat}) \pm 0.05 (\text{syst}), \\ \mathcal{S}_{\omega K_S^0} &= +0.91 \pm 0.32 (\text{stat}) \pm 0.05 (\text{syst}).\end{aligned}$$

In the $B^- \rightarrow \omega K^-$ mode, we measure the direct CP -violation parameter

$$\mathcal{A}_{\omega K^-} = -0.03 \pm 0.04 (\text{stat}) \pm 0.01 (\text{syst}),$$

which is its most precise measurement to date.

Keywords: CP violation, hep, Belle

1. Introduction

The main purpose of the B factories, Belle and BaBar, was to test the Cabibbo-Kobayashi-Maskawa (CKM) mechanism, which is a part of the Standard Model of particle physics (SM). The CKM mechanism foresees the existence of a CP -violating complex phase in the quark sector that gives rise to CP violation. The B factories measured the angles, ϕ_1 , ϕ_2 and ϕ_3 , and the sides of

the unitarity triangle for B mesons, the area of which is proportional to the SM CP -violating phase. In the past decade, measurements of the $\sin 2\phi_1$ value in $b \rightarrow c\bar{c}s$ transitions confirmed the CKM mechanism predictions. Despite the great success of the CKM theory, it fails to explain the magnitude of the matter-antimatter asymmetry in today's Universe. Thus, attention has turned towards search for new sources of CP violation, intro-

duced by new physics. Decays of the B meson that proceed predominantly through loop-dominated $b \rightarrow sq\bar{q}$ transitions are highly sensitive to heavy particle contributions in the loop, which can be introduced by so far undetected particles. The decays presented in these proceedings, $B^0 \rightarrow \eta' K^0$ and $B \rightarrow \omega K$, fall into this category. They are both sensitive to ϕ_1 , which can be accessed by measuring their time-dependent CP asymmetries.

The B factories operate at the $\Upsilon(4S)$ resonance, which decays almost exclusively into a $B\bar{B}$ pair. For flavour tagging of a B meson of interest, we use flavour-specific decays of the other B meson in the pair, the so-called “tag side”. The time-dependent CP asymmetry for a B decay into a given CP final state f , is given by

$$a_{CP}(\Delta t) = \mathcal{A}_f \cos \Delta m_d \Delta t + \mathcal{S}_f \sin \Delta m_d \Delta t,$$

where Δt is the difference in the decay time of the two B mesons produced in the $\Upsilon(4S)$ decay, Δm_d is the difference between the masses of the heavy and light mass eigenstates of the B^0 meson, and \mathcal{A}_f and \mathcal{S}_f are the CP -violating parameters. Assuming only a loop contribution in $\eta' K^0$ and in ωK_S^0 , we expect $\mathcal{S}_f = -\xi_f \sin 2\phi_1$, where $\xi_f = \pm 1$ is the CP eigenvalue of the final state. Due to pollution by lower-order processes, the measured \mathcal{S}_f value deviates from this expectation by an amount $\Delta \mathcal{S}_f = \mathcal{S}_f - \sin 2\phi_1$ that depends on the decay channel.

We present the measurements of the $B^0 \rightarrow \eta' K^0$ and $B \rightarrow \omega K$ CP -asymmetry parameters, along with a measurement of the $B \rightarrow \omega K$ branching fractions, based on the full Belle [1] data set containing 772 millions $B\bar{B}$ pairs.

2. Measurement of CP violation parameters in the $B^0 \rightarrow \eta' K^0$ decay

In the $B^0 \rightarrow \eta' K^0$ decay channel, the Standard Model predicts $-0.05 \leq \Delta \mathcal{S}_{\eta' K^0} \leq 0.09$ [2]. The CP parameters of the two CP final states $\eta' K_S^0$ and $\eta' K_L^0$ are measured separately and in the end combined to a common value, since they are equal according to the theory.

After the event reconstruction, we estimate the signal yield. For this, in the $\eta' K_S^0$ decay mode, we fit the event distributions of the beam-constrained mass of the B meson M_{bc} , the difference between the reconstructed B meson energy and the beam energy ΔE and a $q\bar{q}$ -background suppression likelihood ratio $R_{s/b}$, based on event-shape variables. In the $\eta' K_L^0$ decay mode, we extract the signal yield by fitting $R_{s/b}$ and the B meson momentum, reconstructed with the knowledge of the beam

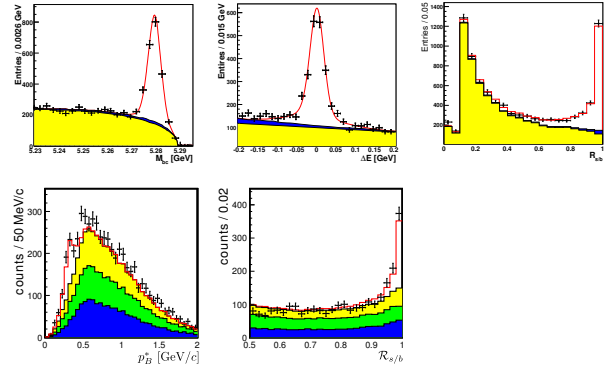


Figure 1: Projections of the fit to the data for the fit observables of $\eta' K_S^0$ (first three plots from the right) and $\eta' K_L^0$ (fourth and fifth plot). For $\eta' K_S^0$, the total PDF is given in red, the $q\bar{q}$ background contribution - in yellow and the $B\bar{B}$ background contribution - in blue. For $\eta' K_L^0$, the total PDF is in red, the combinatorial backgrounds with fake η' , with fake K_L^0 and with both real η' and K_L^0 are given in blue, green and yellow, respectively.

energy and the nominal K_L^0 mass. In total, we reconstruct 2503 ± 63 $\eta' K_S^0$ events and 1041 ± 41 $\eta' K_L^0$ signal events, where the uncertainties are statistical only. Following this, we fit the Δt distribution for the two B meson flavours q to extract the CP parameters, where $q = +1$ or $q = -1$ if the B on the tag side is B or \bar{B} . Projections of the fit to the data are shown in Fig. 2. Our preliminary results are

$$\begin{aligned} \mathcal{A}_{\eta' K^0} &= +0.03 \pm 0.05 \text{ (stat)} \pm 0.04 \text{ (syst)}, \\ \mathcal{S}_{\eta' K^0} &= +0.68 \pm 0.07 \text{ (stat)} \pm 0.03 \text{ (syst)}. \end{aligned}$$

The main contribution to the $A_{\eta' K^0}$ systematic uncertainty comes from the tag-side interference effect and for $S_{\eta' K^0}$ - from the uncertainties in the Δt resolution function parameters. Signal enhanced projections from the fit to the data are shown in Fig. 1. The measured values of $A_{\eta' K^0}$ and $S_{\eta' K^0}$ are the world's most precise values of CP violation parameters in this particular decay and also out of all $b \rightarrow sq\bar{q}$ transition dominated decays. They are consistent with previous measurements by Belle [3] and BaBar [4] and with the SM predictions.

3. Measurement of branching fractions and CP violation parameters in $B \rightarrow \omega K$ decays

We present the results from the measurements of the neutral decay mode $B^0 \rightarrow \omega K_S^0$ and the charged decay mode $B^- \rightarrow \omega K^-$. The SM predicts $0.1 \leq \Delta \mathcal{S}_{\omega K_S^0} \leq 0.2$ [5, 6, 7, 8].

We measure the branching fractions and the CP parameters of the two decay modes in a seven-dimensional

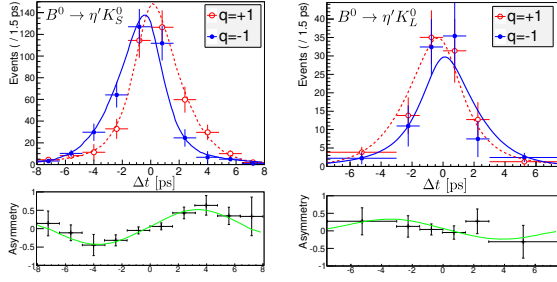


Figure 2: Projections of the data fit to the Δt distribution for $\eta' K_S^0$ (left) and $\eta' K_L^0$ (right).

unbinned maximum likelihood fit to M_{bc} , ΔE , the mass $m_{3\pi}$ and helicity angle $\mathcal{H}_{3\pi}$ of the ω candidates, a Fisher discriminant $\mathcal{F}_{B\bar{B}/q\bar{q}}$, Δt and the B flavour q . The fit is performed simultaneously to the neutral and charged modes, sharing common calibration factors. Following that, the shapes of the fit observables are fixed and the \mathcal{A}_{CP} parameter is obtained from two further fits to extract the number of B^+ and B^- events. Projections of the fit to the data are shown in Fig. 3. We obtain

$$\begin{aligned} \mathcal{B}_{B^0 \rightarrow \omega K^0} &= (4.5 \pm 0.4 \text{ (stat)} \pm 0.3 \text{ (syst)}) \times 10^{-6}, \\ \mathcal{B}_{B^- \rightarrow \omega K^-} &= (6.8 \pm 0.4 \text{ (stat)} \pm 0.4 \text{ (syst)}) \times 10^{-6}, \\ \mathcal{A}_{\omega K_S^0} &= -0.36 \pm 0.19 \text{ (stat)} \pm 0.05 \text{ (syst)}, \\ \mathcal{S}_{\omega K_S^0} &= +0.91 \pm 0.32 \text{ (stat)} \pm 0.05 \text{ (syst)}, \\ \mathcal{A}_{\omega K^-} &= -0.03 \pm 0.04 \text{ (stat)} \pm 0.01 \text{ (syst)}. \end{aligned}$$

For the branching fractions, the main contribution to the systematic uncertainties is the π^0 reconstruction efficiency. For $\mathcal{A}_{\omega K_S^0}$, the dominant systematic effect is the tag-side interference and for $\mathcal{S}_{\omega K_S^0}$ and $\mathcal{A}_{\omega K^-}$ - the Δt resolution function. By performing a likelihood scan in the $\mathcal{A}_{CP} - \mathcal{S}_{CP}$ plane, we find a deviation of 3.1σ from the CP conservation hypothesis, which makes this result the first evidence for CP violation in the $B^0 \rightarrow \omega K_S^0$ decay mode. Apart from the $\mathcal{S}_{\omega K_S^0}$ result, this is the most precise measurement of the $B \rightarrow \omega K$ decay modes. The results are mostly in agreement with the previous measurements of Belle [9, 10] and BaBar [11, 12]. The analysis has been published in the July 2014 issue of Physical Review D [13].

4. Conclusion

The results from the measurements on $b \rightarrow sq\bar{q}$ decays presented in these proceedings are consistent with the SM predictions and with the current world average

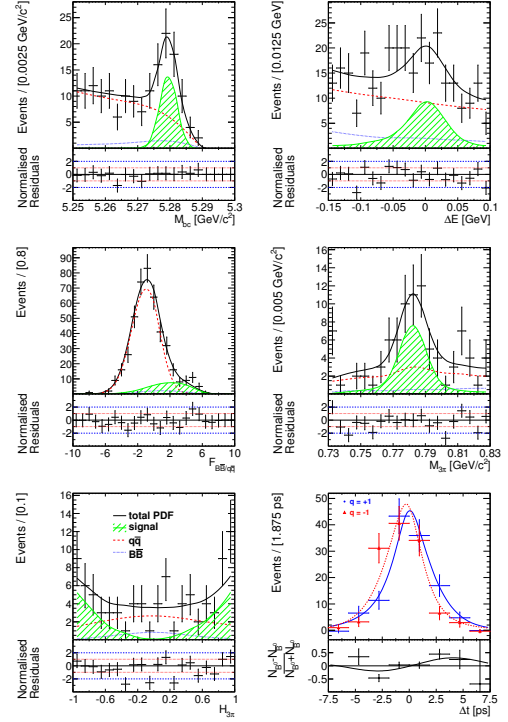


Figure 3: Projections of the data fit to the $B^0 \rightarrow \omega K_S^0$ observables.

on $\sin 2\phi_1$ measured in $b \rightarrow c\bar{c}s$ transitions [14]. The uncertainties on the parameter are still very large and so for new physics to be observed in these decay modes, more data is needed. This will be provided in the future by the Belle II and the LHCb experiments.

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