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# *CP* Violation in *B* Decays at Belle

# $CP$ Violation in $B$ Decays at Belle

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**Abstract.**
I review the recent Belle measurements on $CP$ violation in $B$ decays. In this review, I cover the experimental constraints on the Cabibbo-Kobayashi-Maskawa (CKM) angles of the Unitarity Triangle by introducing several experimental approaches. Search for new physics beyond the Standard Model in $b \to s\bar{q}q$ transitions is also presented.

## 1. Introduction

The present status on the measurement of $CP$ violation in the quark sector is mainly based on the results achieved by BaBar and Belle. Those $B$-factory experiments, already ended their operations, have been spectacularly successful at discovering and investigating $CP$ violation in $B$-meson decays, thanks to the great success of PEP-II and KEKB asymmetric-energy $e^+e^-$ colliders operating at the center of mass energy corresponding to the mass of $\Upsilon(4S)$. Those experiments have significantly improved our knowledge on $CP$-violation phenomena over a decade.

In the Standard Model (SM), $CP$ violation arises from a complex phase in the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix [1, 2], where $CP$ violation can be quantified in terms of three parameters, $\phi_1$, $\phi_2$ and $\phi_3$[1], representing the three angles of the so-called Unitarity Triangle. Precise measurements of CKM angles are therefore of fundamental importance for the description of the weak interaction of quarks and the investigation for the new sources of $CP$ violation.

In these proceedings, measurements of CKM angles at the Belle experiment are reviewed. This review also includes the measurement of effective $\phi_1$ ($\phi_1^{\rm eff}$) in $b \to s\bar{q}q$ transitions for new-physics search.

## 2. $\phi_1$

$\sin 2\phi_1$ can be obtained using $b \to c\bar{c}s$ transitions, where the most precise measurement for $\phi_1$ comes from $B^0 \to J/\psi K^0$ decays.

With 535 million $B\overline{B}$ pairs, Belle updated the measurement of $\sin 2\phi_1$ using $B^0 \to J/\psi K^0$ decays [3]. Figure 1 shows the results of a fit to the reconstructed candidates in the fit region. Several kinematic variables are used here; for $B^0 \to J/\psi K^0_S$ decay, the energy difference $\Delta E \equiv E^*_B - E^*_{\rm beam}$ and the beam-energy constrained mass $M_{\rm bc} \equiv \sqrt{(E^*_{\rm beam})^2 - (p^*_B)^2}$ are used in the fit, where $E^*_{\rm beam}$ is the beam energy, and $E^*_B$ and $p^*_B$ are the energy and momentum,

[1] The angles $\phi_1$, $\phi_2$ and $\phi_3$ are also sometimes known as $\beta$, $\alpha$ and $\gamma$, respectively.

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respectively, of the reconstructed $B$ candidate, all measured in the center-of-mass system. $p_B^*$ is used in the fit for $B^0 \to J/\psi K_L^0$ candidates.

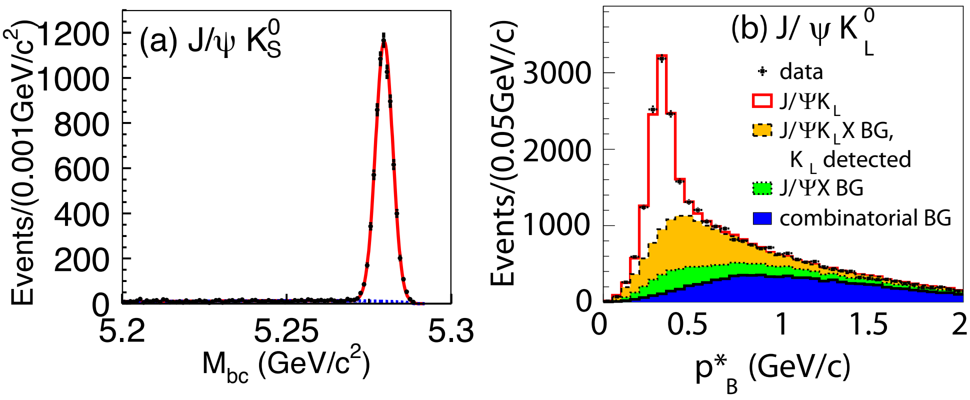


**Figure 1.** (a) $M_{\rm bc}$ distribution in the$\Delta$ $E$ signal region for selected $B^0 \to J/\psi K_S$ candidates and (b) $p_B^*$ distribution for selected $B^0 \to J/\psi K_L$ candidates.

The signal yields are determined to be $7484 \pm 87$ for $B^0 \to J/\psi K_S$ and $6512 \pm 123$ for $B^0 \to J/\psi K_L$, where errors are statistical only.

In the decay chain $\Upsilon(4S) \to B^0\overline{B}^0 \to f_{CP} f_{\rm tag}$, where one of the $B$ mesons decays at time $t_{CP}$ to a $CP$ eigenstate $f_{CP}$ and the other decays at time $t_{\rm tag}$ to a final state $f_{\rm tag}$ that distinguishes between $B^0$ and $\overline{B}^0$, the decay rate has a time dependence given by

$$\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left\{1 + q\cdot\left[\mathcal{S}_{CP}\sin(\Delta m_d \Delta t) + \mathcal{A}_{CP}\cos(\Delta m_d \Delta t)\right]\right\}.$$

Here $\mathcal{S}_{CP}$ and $\mathcal{A}_{CP}$ describe mixing-induced and direct $CP$-violation, respectively, and $\tau_{B^0}$ is the $B^0$ lifetime,$\Delta$ $m_d$ is the mass difference between the two $B^0$ mass eigenstates,$\Delta$ $t = t_{CP} - t_{\rm tag}$, and the $b$-flavor charge $q = +1$ $(-1)$ when the tagging $B$ meson is a $B^0$ $(\overline{B}^0)$. Here, the SM predicts $S_f = -\xi_f \sin 2\phi_1$ and $\mathcal{A}_{CP} = 0$ for both $b \to c\bar{c}s$ and $b \to s\bar{q}q$ transitions, where $\xi_f = +1$ $(-1)$ corresponds to the $CP$-even (-odd) final states.$\Delta$ $t$ can be determined from the displacement in the electron beamline $(z)$ between the $f_{CP}$ and $f_{\rm tag}$ decay vertices: $\Delta t \simeq (z_{CP} - z_{\rm tag})/(\beta\gamma c) \equiv \Delta z/(\beta\gamma c)$.

An unbinned maximum-likelihood fit to the observed$\Delta$ $t$ distribution is performed to determine $CP$-violation parameters. Figures 2 shows the$\Delta$ $t$ distributions and asymmetry. $\sin 2\phi_1$ is measured to be $0.642 \pm 0.031 \pm 0.017$ by the results of the fits to$\Delta$ $t$ distributions. Here, the first error is statistical and the second error is systematic.

$\sin 2\phi_1$ will be updated soon at Belle using the full data set (772 million $B\overline{B}$ pairs). The magnitude of the statistical error would be comparable with that of the systematic error, where the statistical error is expected to be around 0.02.

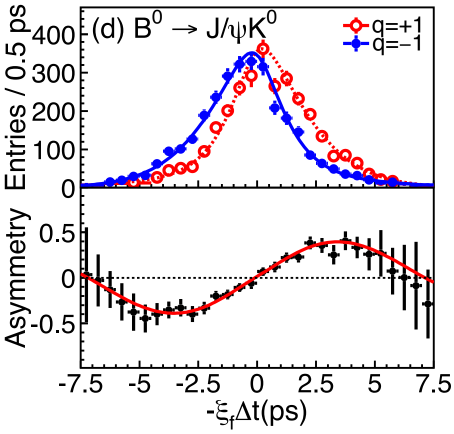


**Figure 2.** Background subtracted$\Delta$ $t$ distributions and asymmetries for events with good tags for $B^0 \to J/\psi K^0$.

## 3. $\phi_2$

$b \to u\overline{u}d$ quark transitions such as $B^0 \to \pi\pi, \rho\pi,\rho\rho$ are sensitive to $\phi_2$.

The $CP$-violation parameters are expected to be $\mathcal{S}_{CP} = \sin 2\phi_2$ and $\mathcal{A}_{CP} = 0$ by the SM with the tree diagram only, however, direct $CP$ violation is possible, $\mathcal{A}_{CP} \neq 0$, due to a large contribution from the electroweak penguin-mediated decay processes. $\phi_2$ can be determined by $\mathcal{S}_{CP} = \sqrt{1 - \mathcal{A}^2_{CP}} \sin(2\phi_2 + \kappa)$, where $\kappa$ is the shift due to the penguin contribution and determined by the SU(2) isospin analysis [4]. For the $\phi_2$ measurements through $B^0 \to \pi^+\pi^-$ and $B^0 \to \rho^+\rho^-$ modes, it is possible to determine $\kappa$ by considering the set of three $B \to hh$ decays where $hh$ is either two pions or two longitudinally polarized $\rho$ mesons. The $B \to hh$ amplitudes obey the complex triangle relations,

$$A_{+0} = \frac{1}{\sqrt{2}} A_{+-} + A_{00}, \quad \overline{A}_{-0} = \frac{1}{\sqrt{2}} \overline{A}_{+-} + \overline{A}_{00}.$$

The electroweak penguins can be neglected in the $B^+ \to h^+h^0$, and thus these triangles share the same base, $A_{+0} = \overline{A}_{-0}$. $\kappa$ can be determined from the difference between the two triangles. This method has an 8-fold discrete ambiguity in the determination of $\phi_2$.

### *3.1. $\phi_2$ from $B^0 \to \pi^+\pi^-$*

$\phi_2$ measurement is performed using $B^0 \to \pi^+\pi^-$ mode with 535 million $B\overline{B}$ pairs [5].

The signal yield is estimated by a fit to data, making use of$\Delta$ $E$, $M_{\rm bc}$ and the kaon identification probability. $B^0 \to \pi^+\pi^-$ signal yield is obtained to be $1464 \pm 65$ events. In the time-dependent analysis, direct $CP$ violation is observed, $A_{CP} = +0.55 \pm 0.08(\rm stat) \pm 0.05(\rm syst)$ with a significance of $5.5\sigma$, while mixing-induced $CP$ violation is also observed, $S_{CP} = -0.61 \pm 0.10(\rm stat) \pm 0.04(\rm syst)$ with a significance greater than $5.3\sigma$ for any $A_{CP}$ value.

To constrain $\phi_2$, the isospin relations are used with measured values of $S_{CP}$ and $A_{CP}$, the world average (W.A.) branching ratios of $B^0 \to \pi^+\pi^-$, $\pi^0\pi^0$, and $B^+ \to \pi^+\pi^0$, and the W.A. direct $CP$-asymmetry for $B^0 \to \pi^0\pi^0$ [6]. $\chi^2$ is constructed using the measured values and the six parameters, one of which is $\phi_2$. Four different solutions are found after the minimization of the $\chi^2$. With the expectation from other CKM measurements, $(97 \pm 11)^\circ$ is found. The $\phi_2$ range $11^\circ < \phi_2 < 79^\circ$ is excluded at the 95% confidence level (C.L.). The resulting two-dimensional confidence regions in the $S_{CP}$ and $A_{CP}$ plane and the difference $1 -$ C.L. plotted for a range of $\phi_2$ values are shown in Fig. 3.

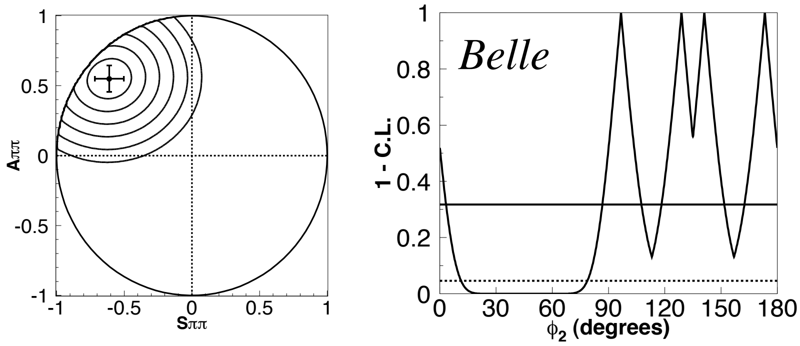


**Figure 3.** The left plot shows confidence regions for $S_{CP}$ and $A_{CP}$. The curves show the contour from $1\sigma$ to $6\sigma$, from inside to outside. The point with error bars is the $S_{CP}$ and $A_{CP}$ measurement. The right plot shows difference $1-$C.L. plotted for a range of $\phi_2$ values obtained with an isospin analysis. The solid and dashed lines indicate C.L. $= 68.3\%$ and $95\%$, respectively.

### *3.2. $\phi_2$ from $B^0 \to \rho^+\rho^-$*

Possible relative angular momentum for the $B^0 \to \rho^+\rho^-$ decay is $L = 0, 1, 2$. The $CP$-violating parameters receive contributions from a longitudinally polarized state ($CP$-even) and two transversely polarized states (an admixture of $CP$-even and $CP$-odd states). However, measurements of the polarization fraction by Belle and BaBar show that the longitudinal polarization fraction is near unity. There is no need to elaborate the angular analysis, and pure $CP$-even state (100% longitudinal polarization) is assumed in this analysis.

Time-dependent analysis is performed for $B^0 \to \rho^+\rho^-$ mode with 535 million $B\overline{B}$ pairs [7]. $\Delta E$, $M_{\rm bc}$ and event shape variables for $e^+e^- \to q\overline{q}$ ($q = u, d, s, c$) continuum and $B\overline{B}$ events are used in a fit to estimate the signal yield. $B^0 \to \rho^+\rho^-$ signal yield is obtained to be $576 \pm 53$ events. Direct $CP$ violation and mixing-induced $CP$ violation are obtained to be $A_{CP} = +0.16 \pm 0.21(\text{stat}) \pm 0.08(\text{syst})$, $S_{CP} = +0.19 \pm 0.30(\text{stat}) \pm 0.08(\text{syst})$, respectively.

In the isospin relations to constrain $\phi_2$, the W.A. branching ratios of $B^0 \to \rho^+\rho^-$ and $B^+ \to \rho^+\pi^0$ are used [6], while the branching ratio of $B^0 \to \rho^0\rho^0$ is obtained from the Belle measurement [8] to constrain $\phi_2$. $\phi_2$ is determined to be $(91.7 \pm 14.9)^\circ$. Figure 4 shows the difference $1 - $C.L. plotted for $\phi_2$.

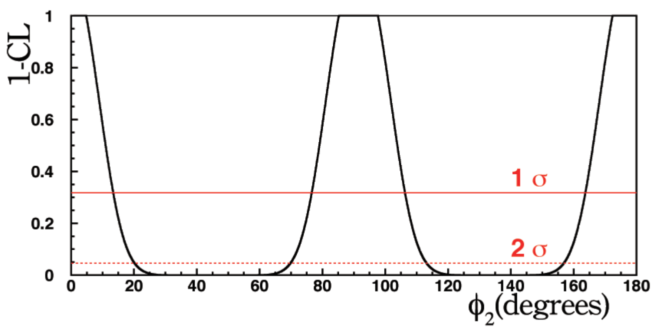


**Figure 4.** $1-$C.L. vs. $\phi_2$ obtained from the isospin analysis of $B \to \rho\rho$ decays.

### *3.3. $\phi_2$ from $B^0 \to \rho\pi$*

$B^0 \to \rho\pi$ mode is also sensitive to $\phi_2$. Since this mode can be treated as an interference of $B^0 \to \rho^+\pi^-$, $\rho^-\pi^+$ and $\rho^0\pi^0$ modes, a time-dependent Dalitz plot analysis (TDPA) is employed, where measurements of interfering parameters must be included. Measurements for relative sizes and complex phases of the amplitudes are required to extract $\phi_2$, however, those amplitudes are related to $\phi_2$ through an isospin relation. In this point, $B^0 \to \rho\pi$ channel has an advantage which can reduce discrete ambiguities, in contrast to the previous quasi-two-body modes for the $\phi_2$ measurements.

With 449 million $B\overline{B}$ pairs, Belle performed a measurement of $\phi_2$ using $B^0 \to \rho\pi$ [9]. The signal yield is determined from a four-dimensional fit to the $\Delta E$-$M_{\rm bc}$ and Dalitz plot distribution. The fit yields $971 \pm 42$ $B^0 \to \pi^+\pi^-\pi^0$ events in the signal region. To constrain $\phi_2$, measurements with results on the branching fractions for $B^0 \to \rho^\pm\pi^\mp$ and $B^+ \to \rho^+\pi^0$, $\rho^0\pi^+$, and flavor asymmetries of the latter two [6] are all combined. $\chi^2$ scans are shown in Fig. 5 where $\phi_2$ can be constrained to be $68° < \phi_2 < 95°$ at 68.3% C.L.

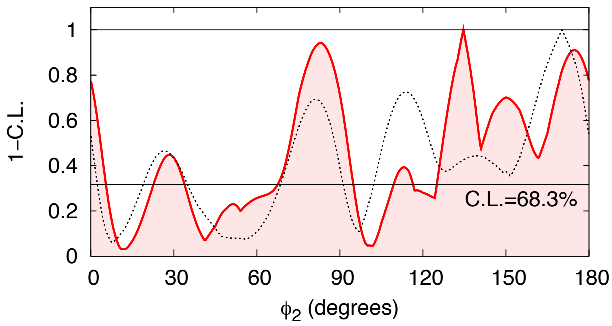


**Figure 5.** $1 - \text{C.L.}$ vs $\phi_2$. Dotted and solid curves correspond to the result from the TDPA only and that from the TDPA and an isospin combined analysis, respectively.

## 4. $\phi_3$

$B \to D^{(*)0}K$ modes provide a good probe for the $\phi_3$ measurement, where the interference between $B \to D^{(*)0}K$ and $B \to \overline{D}^{(*)0}K$ decays is utilized. The magnitude of the amplitude ratio of these decays ($r_B$) can be evaluated to be $\sim 0.1$, using the CKM matrix elements with an additional color suppression factor. The weak phase $\phi_3$ arises from the complex phase of $V_{ub}$ included in the $B^+ \to D^{(*)0}K^+$ decay. There is no contribution from the penguin diagram in these decays.

Among the several approaches proposed for the $\phi_3$ measurement, the current most precise measurement of $\phi_3$ is based on the so-called GGSZ method [10]. In this method, amplitude analysis of the multibody decay of the neutral $D$ meson is required. However, complex phase variations and imperfect assumption of the $D$-decay model potentially includes the irreducible uncertainties for the $\phi_3$ measurement. In other approaches, the so-called ADS method [11] is also considered to be promising. The ADS method can be free from the model uncertainty, while the measurements based on this method have been statistically limited.

### *4.1. $\phi_3$ from the GGSZ method*

In the $B^\pm \to DK^\pm$ interference, $D$ can be either $D^0$ or $\overline{D}^0$, and the amplitude of $D$ can be expressed as

$$|\tilde{D}^0\rangle = r_B e^{\pm i\phi_3 + i\delta_B}|D^0\rangle + |\overline{D}^0\rangle.$$

Here $\delta_B$ is the strong phase difference of the $B$ decays. It is possible to distinguish $D^0$ from $\overline{D}^0$ if the multibody $D$ decays are used.

With 657 million $B\overline{B}$ pairs, Belle updated the $\phi_3$ measurement using the GGSZ method with $B^+ \to D^{(*)}K^+$, $D \to K_S\pi^+\pi^-$ decays [12]. This measurement is based on the model-dependent approach, including the model determination of $D$-meson decay using the $e^+e^- \to q\overline{q}$ continuum processes.

The signal yield is estimated by a two-dimensional fit for the $\Delta E$ and $M_{\rm bc}$ distribution for each decay mode. Signal yields of $B^+ \to DK^+$, $B^+ \to D^*K^+$ followed by $D^* \to D\gamma$ or $D^* \to D\pi^0$ are obtained to be 756, 149 and 141 events in each signal region, respectively.

To obtain $\phi_3$, Dalitz distributions of the $B^+$ and $B^-$ are fitted separately, using Cartesian parameters $x_\pm = r_\pm \cos(\pm\phi_3 + \delta)$ and $y_\pm = r_\pm \sin(\pm\phi_3 + \delta)$, where the indices "+" and "−" correspond to $B^+$ and $B^-$ decays, respectively. Here, $r_+$ and $r_-$ are not constrained to be equal. The advantage of this approach is for the low bias and simple distribution of the fitted parameters. Several kinematic variables are used in a fit; Dalitz plot distribution,$\Delta$ $E$, $M_{\rm bc}$ and event shape variables that separates the $B$ decays from the $e^+e^- \to q\overline{q}$ continuum processes. The results of the separate $B^+$ and $B^-$ data fits are shown in Fig. 6. The separation of the $B^-$ and $B^+$ positions in the $(x, y)$ plane indicates direct $CP$ violation and is measured to be $2r_B|\sin\phi_3|$.

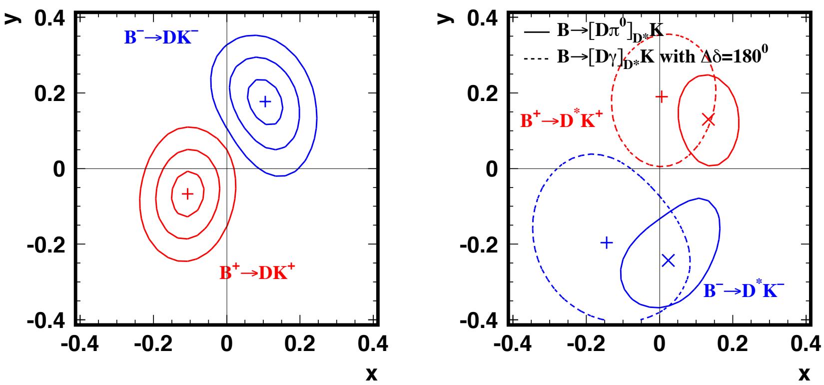


**Figure 6.** Results of signal fits with free parameters $x = r\cos\theta$ and $y = r\sin\theta$ for $B^+ \to DK^+$ (a) and $B^+ \to D^*K^+$ (b) samples, separately for $B^-$ and $B^+$ data. Contours indicate 1, 2, and 3 (for $B^\pm \to DK^\pm$) and 1 standard deviation regions (for $B^\pm \to D^*K^\pm$).

A frequentist technique is used to evaluate the statistical significance of the measurements. In order to improve the sensitivity to $\phi_3$, event samples of $B^+ \to DK^+$ and $B^+ \to D^*K^+$ are combined. $\phi_3$ for the combination of these modes is obtained to be $\phi_3 = 78.4^\circ{}^{+10.8^\circ}_{-11.6^\circ}(\text{stat}) \pm 3.6^\circ(\text{syst}) \pm 8.9^\circ(\text{model})$. $CP$ conservation in this process is ruled out at the confidence level $(1 - \text{C.L.}) = 5 \times 10^{-4}$, or 3.5 standard deviations, which leads to the evidence for direct $CP$ violation for the $B^+ \to D^{(*)0}K^+$ process.

Model uncertainty is dominated by the uncertainty due to the complex phase. To reduce this model uncertainty, model-independent approach is proposed [10, 13, 14]. Based on this method, CLEO recently updated the results of relative phase between $D^0$ and $\overline{D}^0$ by studying the $\psi(3770) \to D^0\overline{D}^0$ decays [15]. The model error in the $\phi_3$ measurement will be replaced by a statistical error of about a few degrees due to the finite $\psi(3770) \to D^0\overline{D}^0$ sample, while the statistical error associated with the $B$ data sample should increase by 10%-20% due to the binned fit procedure.

### *4.2. $\phi_3$ from the ADS method*

In the ADS method, measurements of $CP$ asymmetry ($\mathcal{A}$) and partial rate ($\mathcal{R}$) play an important role for the $\phi_3$ measurement. In the decay chain $B^\pm \to DK^\pm$, $D \to K^\pm\pi^\mp$, where $D$ can be either $D^0$ or $\overline{D}^0$, $\mathcal{A}$ and $\mathcal{R}$ are described by

$$\begin{aligned}
\mathcal{A} &\equiv \frac{\mathcal{B}(B^- \to [K^+\pi^-]_D K^-) - \mathcal{B}(B^+ \to [K^-\pi^+]_D K^+)}{\mathcal{B}(B^- \to [K^+\pi^-]_D K^-) + \mathcal{B}(B^+ \to [K^-\pi^+]_D K^+)} \\
&= 2r_B r_D \sin(\delta_B + \delta_D)\sin(\phi_3)/\mathcal{R}, \\
\mathcal{R} &\equiv \frac{\mathcal{B}(B^- \to [K^+\pi^-]_D K^-) + \mathcal{B}(B^+ \to [K^-\pi^+]_D K^+)}{\mathcal{B}(B^- \to [K^-\pi^+]_D K^-) + \mathcal{B}(B^+ \to [K^+\pi^-]_D K^+)} \\
&= r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D)\cos(\phi_3).
\end{aligned}$$

Here $\delta_D$ is the strong phase difference of the $D$-meson decays, and $r_D$ is the amplitude ratio of $D^0 \to K^+\pi^-$, doubly Cabibbo suppressed mode, to $\overline{D}^0 \to K^+\pi^-$, Cabibbo favored mode. In the $B^- \to [K^+\pi^-]_D K^-$ interference, either $B$ or $D$ decay is suppressed, while the $B^- \to [K^-\pi^+]_D K^-$ decay process is dominated by the favored modes of $B$ and $D$ decays.

With 772 million $B\overline{B}$ pairs, Belle updated the measurement for the ADS method using the above decay chain, where preliminary results are obtained on $\mathcal{A}$ and $\mathcal{R}$. In this measurement, a tool for multi-variate analysis named NeuroBayes is employed. In order to separate the $B \to DK$ signal from backgrounds, ten kinematic variables are used as inputs for NeuroBayes, such as a likelihood ratio of Fisher discriminant of modified Fox-Wolfram moments, the distance of vertices between the reconstructed $B$ and the other $B$, and the decay angle of $D \to K\pi$.

The signal yield is extracted by a two dimensional fit on$\Delta$ $E$ and NeuroBayes output $\mathcal{NB}$, and determined to be $56.0^{+15.1}_{-14.2}$ for $B^- \to [K^+\pi^-]_D K^-$, where the charge-conjugate mode is included. Figure 7 shows the results of the fit to the reconstructed candidates in the fit region. The$\Delta$ $E$ distributions for $[K^+\pi^-]_D K^-$ and $[K^-\pi^+]_D K^+$ in the $\mathcal{NB}$ signal region are shown.

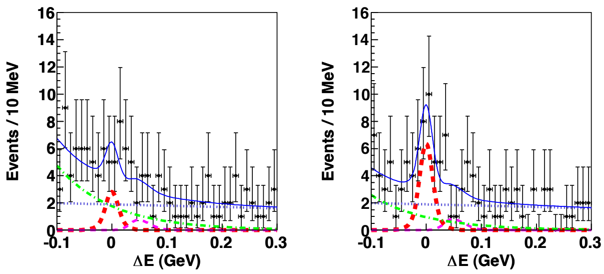


**Figure 7.** $\Delta E$ distributions for $[K^+\pi^-]_D K^-$ (left) and $[K^-\pi^+]_D K^+$ (right). Curves represent the various components from the fit: $DK$ signal (thick dashed line), $D\pi$ backgrounds (dashed line), $B\overline{B}$ backgrounds (dash-dotted line), continuum (dotted line) and sum of all components (solid line).

The first evidence of the $DK$ signal is obtained with a significance of $4.1\sigma$ including systematic uncertainties. The obtained results for the $CP$ asymmetry and the ratio of the suppressed to favored decay rate are, $\mathcal{A} = -0.39^{+0.26}_{-0.28}(\text{stat})^{+0.04}_{-0.03}(\text{syst})$, and $\mathcal{R} = [1.63^{+0.44}_{-0.41}(\text{stat})^{+0.07}_{-0.13}(\text{syst})] \times 10^{-2}$. To constrain $\phi_3$, $r_D$, $\delta_D$ and other relevant observables will be used.

## 5. $\phi_1^{\text{eff}}$

Precise measurement of $\phi_1$ also provides a useful comparison between decays mediated by $b \to s\overline{q}q$ and $b \to c\overline{c}s$ transitions. A new physics may enter into the loop diagram, and to search for the new physics effects, various approaches have been tested by investigating deviations of $CP$ violating parameter $\phi_1^{\rm eff}$ from $\phi_1$ determined by $b \to c\bar{c}s$ decays.

With 657 million $B\overline{B}$ pairs, Belle performed a measurement of $\phi_1^{\rm eff}$ using $B^0 \to K^+K^-K_S$ decay with a time-dependent Dalitz approach [16]. Several decay modes are included in the signal model: $\phi(1020)K_S$, $f_0(980)K_S$, $f_X K_S$, $\chi_{c0}K_S$ and nonresonant $K^+K^-K_S$.

The signal yield is estimated by a fit to data, making use of$\Delta$ $E$, $M_{\rm bc}$ and the flavor-tag quality interval. $B^0 \to K^+K^-K_S$ signal yield is obtained to be $1176 \pm 51$ events. In the time-dependent analysis, four solutions are found from a fit. A single solution is preferred from all the solutions using the branching fractions of $f_0(980) \to \pi\pi$ and $f_0(1500) \to \pi\pi$ as external information. Figure 8 shows the$\Delta$ $t$ distributions and asymmetry of the preferred solution.

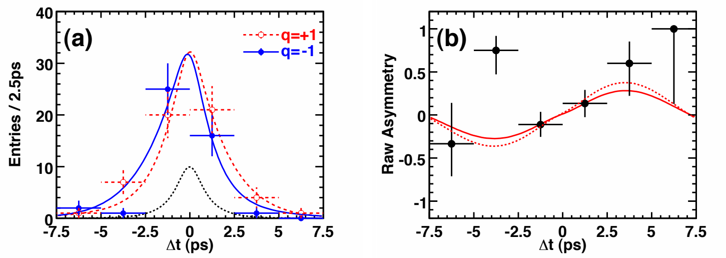


**Figure 8.** (a)$\Delta$ $t$ distribution and (b) raw asymmetry for the $B^0 \to K^+K^-K_S$ candidates in the $\phi(1020)K_S^0$ region, with good tags. In (a), the dotted black curve shows the background component. In (b), the solid curve shows the fit projection, while the dashed curve shows the SM expectation from the time-dependent $CP$ asymmetry measurement in $b \to c\bar{c}s$ decays.

In the preferred solution, $\phi_1^{\rm eff}$ is measured to be $(32.2 \pm 9.0 \pm 2.6 \pm 1.4)^\circ$ for $\phi(1020)K_S$ mode, and $(31.3 \pm 9.0 \pm 3.4 \pm 4.0)^\circ$ for $f_0(980)K_S$ mode. The results are still consistent with the SM expectation like other results from Belle, where measurements of $\phi_1^{\rm eff}$ are all consistent with the value of $\phi_1$ obtained from the decay $B^0 \to J/\psi K^0$ within the two standard deviations.

## 6. Summary

Various studies have been performed to investigate $CP$ violation in the $B$ decays at Belle. The upgraded Belle II experiment will allow us to constrain the CKM angles with much higher statistics, and also help us to explore and clarify the nature of $CP$ violation.

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