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**CP violation in B decays at Belle**

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**Abstract.** Using the full data sample collected with the Belle detector at the KEKB asymmetric-energy $e^+e^-$ collider, we present three recent measurements of time-dependent $CP$ violation in $B$ decays that are sensitive to potential new physics contributions and a measurement of branching fraction of the $B^0 \to \pi^0\pi^0$ decay. We studied $B \to \omega K$ decays and measured the values of $CP$ violation parameters in $B^0 \to \omega K^0_S$ to be $A_{\omega K^0_S} = 0.36 \pm 0.19 \pm 0.05$ and $S_{\omega K^0_S} = +0.91 \pm 0.32 \pm 0.05$, which gives the first evidence of $CP$ violation in this decay. From the measurement of $CP$ violation parameters in the $B^0 \to J/\psi K^0$ decay we obtain $S_{J/\psi K^0} = 0.68 \pm 0.07 \pm 0.03$ and $A_{J/\psi K^0} = +0.03 \pm 0.05 \pm 0.04$, which are the world's most precise values to date. We present the Belle first measurement of $CP$ violation parameters in $B^0 \to K_S^0 \eta \gamma$ decay, where we measure $S_{K_S^0 \eta \gamma} = -1.32 \pm 0.77 \pm 0.36$ and $A_{K_S^0 \eta \gamma} = -0.48 \pm 0.41 \pm 0.07$ (preliminary). Finally we present our preliminary measurement of the $B^0 \to \pi^0\pi^0$ branching fraction. We measure $B(B^0 \to \pi^0\pi^0) = (0.89 \pm 0.12 \pm 0.10) \times 10^{-6}$, with significantly improved sensitivity compared to previously available results.

1. Introduction

Measuring the parameters of the unitarity triangle (UT) provides a major test of the Standard Model (SM), in particular of the Cabibbo-Kobayashi-Maskawa (CKM) description of flavor changing currents and $CP$ violation. Angles of the UT related to $B_{u,d}$ decays can be determined by measuring $CP$ asymmetries in various $B$ meson decays, and this was the main motivation for construction of two so-called B factory experiments, Belle and BaBar. In the previous decade both experiments have confirmed the complex phase of the CKM matrix as the main source of $CP$ violation.

In these proceedings we present two recent measurements related to the $\phi_1$ angle of the UT, mainly motivated by their sensitivity to possible New Physics contributions ($B^0 \to J/\psi K^0$, and $B \to \omega K$), a measurement sensitive to right-handed currents contributions in $b \to s\gamma$ transition ($B^0 \to K_S^0\eta\gamma$), and a measurement of branching fraction of $B^0 \to \pi^0\pi^0$, which is related to determination of the $\phi_2$ angle of the UT. All measurements are based on the data sample containing 772 millions $B\bar{B}$ pairs collected by the Belle experiment [1], during its full data taking period (1999-2010).

The angles $\phi_1$ and $\phi_2$ can be determined by measuring time-dependent asymmetry in decays of $B^0$ and $\bar{B}^0$ mesons into a common $CP$ eigenstate $f_{CP}$ [2]. At the Belle experiment pairs of $B$ mesons are produced in asymmetric energy collisions of electrons and positrons, through the $e^+e^- \to \Upsilon(4S) \to B\bar{B}$ process. In the measurements of time-dependent asymmetry we demand one of the $B$ mesons ($B_{CP}$) to decay into a $CP$ eigenstate, and the other one ($B_{tag}$) to decay into a flavor specific final state (i.e. state into which only $B^0$ or only $\bar{B}^0$ can decay). Since a $B$
meson pair is in a quantum coherent state, a decay of $B_{\text{tag}}$ into a flavor specific final state $f_{\text{tag}}$ at $t_{\text{tag}}$, determines the flavor of $B_{CP}$ at $t_{\text{tag}}$. In this case the $CP$ asymmetry is given by\(^1\)

$$a_{CP}(\Delta t) = \frac{\Gamma(B^0(\Delta t) \rightarrow f_{\text{CP}}) - \Gamma(\bar{B}^0(\Delta t) \rightarrow f_{\text{CP}})}{\Gamma(B^0(\Delta t) \rightarrow f_{\text{CP}}) + \Gamma(\bar{B}^0(\Delta t) \rightarrow f_{\text{CP}})} = A_f \cos \Delta M \Delta t + S_f \sin \Delta M \Delta t,$$

(1)

where $\Delta t$ is the time difference between decays of $B_{\text{tag}}$ and $B_{CP}$, $\Delta M$ is the mass difference between the two $B^0$ mass eigenstates ($B_L$ and $B_H$), and $A_f$ and $S_f$ are the so-called $CP$ violation parameters, which can be within the SM related with the UT angles.

2. The Belle detector, flavor tagging and vertexing

In this section we briefly describe the Belle detector and two basic procedures that are common to all measurements of time-dependent asymmetries.

2.1. The Belle detector

The Belle detector operated at the KEKB asymmetric-energy $e^+e^-$ (3.5 GeV on 8.0 GeV) collider [3]. At KEKB, $B\bar{B}$ pairs are produced with a Lorentz boost of $\beta\gamma = 0.425$ nearly along the $+z$ direction, which is opposite the positron beam direction. The Belle detector is a large-solid-angle magnetic spectrometer consisting of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter (ECL) with CsI(Tl) crystals located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return yoke (KLM) located outside of the coil is instrumented to detect $K^0_L$ mesons and to identify muons. The detector is described in detail elsewhere [1, 4].

The data sample used in presented measurements was collected with two different inner detector configurations. The first $152 \times 10^6$ of $B\bar{B}$ pairs were collected with a 2.0-cm-radius beampipe and a three-layer silicon vertex detector (SVD1), while the remaining $620 \times 10^6$ $B\bar{B}$ pairs were collected with a 1.5-cm-radius beampipe, a four-layer silicon vertex detector (SVD2), and an additional small-cell inner drift chamber.

2.2. Flavor tagging

The $b$-flavor of the $B_{\text{tag}}$ meson is determined from inclusive properties of the particles in the event that are not associated with the $B_{CP}$ reconstruction. The algorithm used is described in detail in Ref. [5]. It is based on the correlation between the charge of decay products and the flavor of decaying $B$ meson. The most relevant are high momentum lepton tracks from $B^0 \rightarrow X l^+ \nu$ (or $\bar{B}^0 \rightarrow X l^- \bar{\nu}$) and $K^+ (K^-)$ tracks from $b \rightarrow \bar{c} \rightarrow s$ ($b \rightarrow c \rightarrow s$) cascade decays. The data are separated into seven bins according to the flavor tagging quality information returned by the algorithm. The fraction of wrongly tagged candidates in each bin is determined from self-tagged semileptonic and hadronic $b \rightarrow c$ decays. The presence of wrongly tagged candidates dilutes the expected decay time asymmetry (1) to $a_{CP}^{\text{wt}}(\Delta t) = (1 - 2w)a_{CP}(\Delta t)$, where $w$ is the fraction of wrongly tagged candidates. In all measurements presented here the fit to $\Delta t$ distribution (to extract the $CP$ violation parameters) is done simultaneously to candidates in all flavor tagging quality bins, taking into account different values of $w$, and also signal-to-background fractions used in the fit are determined for each bin separately (as these fractions differ, this increases sensitivity).

\(^1\) Here $B^0(t)$ ($\bar{B}^0(t)$) denote states that were at $t = 0$ pure $B^0$ ($\bar{B}^0$) states, but later get mixed due to $B^0 - \bar{B}^0$ mixing.
2.3. Vertexing
Since the $B^0$ and $\bar{B}^0$ mesons are approximately at rest in the $\Upsilon(4S)$ cms, their decay time difference ($\Delta t$) can be inferred from the displacement between $z$ position of the $B_{CP}$ and $B_{tag}$ decay vertices ($z_{CP}$ and $z_{tag}$, respectively):

$$\Delta t \approx \frac{z_{CP} - z_{tag}}{\beta \gamma c}. \quad (2)$$

In order to reconstruct the decay vertex positions, we use the algorithm that is in more detail described in [6]. In the measurements presented here the vertex of the $B_{CP}$ meson is reconstructed by using the associated charged pion tracks. Pion tracks from $K_S^0$ decay are not used, except in the measurement of $B^0 \rightarrow K_S^0 \eta \gamma$. The $z$ coordinate resolution for the $B_{CP}$ meson vertex ranges from 70 to 100 $\mu$m and the reconstruction efficiency is about 95%, both depending on the final state. To reconstruct the decay vertex of the $B_{tag}$ meson, the tracks not associated with $B_{CP}$ are used. The $z$-coordinate resolution for these vertices is about 120 $\mu$m, and the reconstruction efficiency is $\sim 93\%$.

3. Measurement of CP violation parameters in $B^0 \rightarrow \eta' K^0$ decay
The $B^0 \rightarrow \eta' K^0$ decays are sensitive to the $\phi_1 = \arg((-V_{ub} V_{cb}^*)/(V_{td} V_{tb}^*))$ interior angle of the UT. The decay proceeds dominantly by the $b \rightarrow s\bar{q}q$ penguin diagram, and within the SM we expect $A_{\eta'K^0} = 0$ and $S_{\eta'K^0} = -\xi_f \sin 2\phi$ (where $\xi_f = -1$ (+1) for $B \rightarrow \eta' K_S^0$ ($B \rightarrow \eta' K_L^0$)), neglecting other contributing CKM-suppressed amplitudes with a different weak phase. However, the contribution of these CKM-suppressed amplitudes may not be negligible, resulting in a non-zero $A_{\eta'K^0}$ and in a deviation of $S_{\eta'K^0}$ from $\sin 2\phi_1$. Several theoretical methods were used to estimate the possible size of the deviation $\Delta S_{\eta'K^0} = S_{\eta'K^0} - \sin 2\phi_1$ within the SM. For example, the $SU(3)_F$ approach limits $\Delta S_{\eta'K^0}$ to the range [0.05, 0.09] [7], while QCD factorization constrains it to [0.03, 0.03] [8]. Observing values of $\Delta S_{\eta'K^0}$ significantly larger than these predictions would be a sign of new physics contributions in the loops of penguin diagram [9].

The measurement presented here was published and in much grater detail described in [10]. The measurement of CP violation parameters is done in two steps. After event reconstruction we first determine the fraction of signal events in the reconstructed sample. In the second step we use the obtained signal probability in the fit to the measured $\Delta t$ distributions of $B^0$ and $\bar{B}^0$ tagged events to extract the values of CP violation parameters.

To reconstruct the decay we use $K_S^0 \rightarrow \pi^+ \pi^-, \pi^0 \pi^0$ decay modes and also $K_L^0$ candidates reconstructed from KLM clusters, and the following decay modes of $\eta'$: $\eta' \rightarrow \rho^0(\rightarrow \pi^+ \pi^-) \gamma$, $\eta' \rightarrow \pi^+ \pi^- \eta(\rightarrow \gamma \gamma, \pi^+ \pi^- \pi^0)$. Decay vertices of reconstructed $B$ candidates are obtained from the vertex fit of associated charged pion tracks. Several selection criteria on the masses of intermediate states are applied in order to reduce the number of background candidates which mainly originate from the so-called continuum events, where in $e^+ e^-$ collision a pair of lighter quarks ($u,d,s,c$) is produced. After the event selection we obtain the fraction of signal events by studying the distribution of events in beam-energy-constrained mass $M_{bc} = \sqrt{(E_{beam}^*)^2 - (p_B^*)^2}$, energy difference $\Delta E = E_B^* - E_{beam}^*$ and event topology variable $R_{s/b}$ for $K_S^0$ events, and the distribution in $p_B^*$ and $R_{s/b}$ for $K_L^0$ events. Here $E_{beam}^*$ is the beam energy in the center-of-mass system and $E_B^*$ and $p_B^*$ are the measured cms energy and momentum, respectively, of the reconstructed $B$ candidate. The event topology variable $R_{s/b}$ is used in all measurements presented here. It serves to distinguish $BB$ from continuum events and is based on the fact that $BB$ events have spherical topology, while continuum events tend

\footnote{Since the energy of the $K_L^0$ cannot be measured, $M_{bc}$ and $\Delta E$ cannot be calculated as for the $B^0 \rightarrow \eta' K_S^0$ decays.}
to be jet-like\textsuperscript{3}. In Figure 1 the comparison of the data distribution and the fitted PDF in $M_{bc}$ and $\Delta E$ are shown, for the $B^0 \rightarrow \eta' K^0_S$ sample. Altogether we reconstruct $2503 \pm 63$ $B^0 \rightarrow \eta' K^0_S$ signal events, and $1041 \pm 41$ $B^0 \rightarrow \eta' K^0_L$ signal events, where the uncertainties are statistical only. Following this, we perform an unbinned maximum likelihood fit to extract the values of CP violation parameters from the measured $\Delta t, q$ distribution of all reconstructed events ($K_S^0 + K_L^0$). Fit results are

\[ S_{\eta'K^0} = +0.68 \pm 0.07 (\text{stat}) \pm 0.03 (\text{syst}), \]
\[ A_{\eta'K^0} = +0.03 \pm 0.05 (\text{stat}) \pm 0.04 (\text{syst}), \]

where the first uncertainty is statistical and the second is systematic. The main contribution to the latter comes from the uncertainties in the $\Delta t$ resolution function parameters for $S_{\eta'K^0}$ and from the tag-side interference effect for $A_{\eta'K^0}$. The comparison of data distribution and the fitted PDF is shown in Figure 1. The measured values of $S_{\eta'K^0}$ and $A_{\eta'K^0}$ are the world’s most precise values of CP violation parameters in this particular decay, as well as among all $b \rightarrow s\bar{q}q$ transition dominated decays. In Figure 2 a comparison of our result with the BaBar measurement and the SM predicted value is shown, and consistency with both can be seen.

\textbf{Figure 1. Left two:} Distribution of reconstructed $B^0 \rightarrow \eta' K^0_S$ events in $M_{bc}$ and $\Delta E$ (black points) along with the fitted PDF (the red). The yellow area shows contribution of the continuum background, and the blue area of the background from $BB$ events. \textbf{Right:} Distribution of the reconstructed events in $\Delta t$ (events with $B^0$ (red points) and $\bar{B}^0$ (blue points)) along with the corresponding parts of the fitted PDF; bottom plot shows the asymmetry in data distributions and in the fitted PDF.

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

The $B^0 \rightarrow \omega K_S^0$ decay also proceeds dominantly by the $b \rightarrow s\bar{q}q$ penguin diagram, and within the SM we expect $A_{\omega K_S^0} \simeq 0$ and $S_{\omega K_S^0} \simeq \sin 2\phi_1$, neglecting other contributing CKM-suppressed amplitudes. Possible deviations from these values within the SM were studied using several theoretical methods, indicating the expected value of $S_{\omega K_S^0}$ slightly higher than $\sin 2\phi_1$ [12]. However, current experimental measurements indicate the opposite [13, 14], which might be a consequence of a contribution of new heavy particles in the loop of the penguin diagram [9].

\textsuperscript{3} We combine a set of variables that characterize the event topology into a signal (background) likelihood variable $L_{sig} (L_{bkg})$, and form the likelihood ratio $R_{bkg/sig} = L_{bkg} / (L_{sig} + L_{bkg})$. The likelihood $L_{sig} (L_{bkg})$ includes a Fisher discriminant $F$ constructed from the transverse sphericity $S_t$ [6], the angle between the thrust axis of the $B$ candidate and the other particles in the cms, and a set of modified Fox-Wolfram moments [11].
Figure 2. Comparison of our result (blue area) with the Babar result (green area) and the SM model prediction (yellow area) in the $S_{CP} - (C_{CP} \equiv -A_{CP})$ plane.

Here we only give a short summary of the measurement method and results, while a more detailed description is given in [15]. In this measurement we measured two branching fractions (of $B_0 \to \omega K_0$ and $B^+ \to \omega K^+$), time-dependent $CP$ violation parameters in $B_0 \to \omega K_0$, and the direct $CP$ violation parameter $A_{CP}$ in the charged $B^+ \to \omega K^+$ decay, defined as

$$A_{CP} = \frac{\Gamma(B^- \to \omega K^-) - \Gamma(B^+ \to \omega K^+)}{\Gamma(B^- \to \omega K^-) + \Gamma(B^+ \to \omega K^+)}.$$  

where again a deviation from the expected asymmetry could be an indication of New Physics. Furthermore, the measurement of the branching fractions provides an important test of the QCD factorization (QCDF) and perturbative QCD (pQCD) approaches.

To obtain the two branching fractions and $CP$ violation parameters we perform a seven-dimensional unbinned extended maximum likelihood fit to $M_{bc}$, $\Delta E$, $R_s/b$, $m_3\pi$ (invariant mass of the reconstructed $\omega$), $H_{3\pi}$ (helicity angle), $\Delta t$ and $q$ (where $q = +1$ ($q = -1$) for $B_{tag} = B_0$ ($B^0$)). The fit is performed simultaneously to $B_0 \to \omega K_0$ and $B^+ \to \omega K^+$ data samples, sharing common calibration factors. Following this, the model shape is fixed and the $A_{CP}(B^+ \to \omega K^+)$ parameter is obtained from two further fits to extract the number of $B^+$ and $B^-$ events. The fit results are

$$B(B_0 \to \omega K^0) = (4.5 \pm 0.4(stat) \pm 0.3(syst)) \times 10^{-6},$$  

$$B(B^+ \to \omega K^+) = (6.8 \pm 0.4(stat) \pm 0.4(syst)) \times 10^{-6},$$  

$$A_{\omega K_0} = -0.36 \pm 0.19(stat) \pm 0.05(syst),$$  

$$S_{\omega K_0} = +0.91 \pm 0.32(stat) \pm 0.05(syst),$$  

$$A_{CP}(B^+ \to \omega K^+) = -0.03 \pm 0.04(stat) \pm 0.01(syst),$$

where the first uncertainty is statistical and the second is systematic. The latter is dominated by uncertainties of the $\Delta t$ resolution function parameters for $A_{\omega K_0}$ and $S_{K_0}$, and by parameters
of the background PDF shape for the branching fractions. The comparison of data distributions and the fitted PDF is shown in Figure 3. The results given in (5) are the world’s most precise measurements of the branching fractions and CP violation parameters in $B \to \omega K$ decays. The observed values of $A_{\omega K^{0}}$ and $S_{\omega K^{0}}$ differ from zero with a significance of 3.1 standard deviations, which gives the first evidence of CP violation in the $B^{0} \to \omega K^{0}$ decay.

![Figure 3. Left two: Distribution of reconstructed events in $M_{bc}$ and $m_{3\pi}$ (black points) along with the fitted PDF (the full line). The dashed line shows contribution of the $q\bar{q}$ background (from $e^{+}e^{-} \to q\bar{q}$ ($q = u, d, s, c$) events), the dotted line of the $B\bar{B}$ background. Right: Distributions of reconstructed events in $\Delta t$ (events with $B^{0}$ (blue points) and $B^{0}$ (red points)) along with the corresponding parts of the fitted PDF; bottom plot shows the asymmetry in data distributions and in the fitted PDF.](image)

5. Time-dependent CP violation in $B^{0} \to K^{0}_{S}\eta\gamma$ decay

The $B^{0} \to K^{0}_{S}\eta\gamma$ decay proceeds through the $b \to s\gamma$ transition at the quark level. In the SM the photon emitted in this process is predominantly left-handed. Due to the V-A structure of charged current in the loop of $b \to s\gamma$ penguin diagram, the emission of right-handed photon is suppressed by a factor of $m_{s}/m_{b}$ compared to the left-handed photon. However, in many beyond SM theories, for instance Left-Right symmetric models, the emission of right-handed photon can be strongly enhanced [16, 17]. Measuring time-dependent CP violation in $b \to s\gamma$ dominated decays provides a method to detect presence of RH photon component in the final state and therefore examine these beyond the SM theories.

As mentioned in the introduction the time dependent CP violation is induced by the interference of $B^{0}$ and $\bar{B}^{0}$ decays into a common final state (CP eigenstate). In the case of $B^{0} \to K^{0}_{S}\eta\gamma$ however, $B^{0}$ decays predominantly to $K^{0}_{S}\eta\gamma_{L}$ and $\bar{B}^{0}$ decays to $K^{0}_{S}\eta\gamma_{R}$, which are different final states due to different photon polarizations. As $B^{0} \to K^{0}_{S}\eta\gamma_{R}$ is suppressed within the SM, so is the mixing induced CP violation [18]:

$$S_{K^{0}_{S}\eta\gamma} \simeq 2 \frac{m_{s}}{m_{b}} \sin 2\phi_{1}.$$  

(6)

In the case of enhanced right-handed photon emission in $b \to s\gamma$, as predicted by some NP theories, the enhanced $B^{0} \to K^{0}_{S}\eta\gamma_{R}$ rate potentially induces large $S_{K^{0}_{S}\eta\gamma}$.

In the measurement we reconstruct signal events using the following decay modes: $K^{0}_{S} \to \pi^{+}\pi^{-}, \eta \to \gamma\gamma$ and $\eta \to \pi^{+}\pi^{-}\pi^{0}$. Here also the main background contribution arises from continuum events. We first determine the fraction of signal events in the reconstructed sample, by performing a fit to the data distribution in $M_{bc}, \Delta E$ and $NB$. The latter is the output.
variable of neural network which mainly utilizes event shape variables. The comparison of the data distribution and the fit model is shown in Figure 4.

**Figure 4.** Distribution of reconstructed $B^0 \rightarrow K^0\eta\gamma$ events in $M_{bc}$, $\Delta E$ and $NB$ (black points) along with the fitted PDF (the red line). The blue line shows contribution from background events (continuum + $BB$), and the green line shows contribution of $BB$ background events. The amount and shape of the latter contribution is fixed to the values obtained from study of simulated events.

**Figure 5.** Left: Distribution of the reconstructed events in $\Delta t$ (events with $B^0$ (red points) and $\bar{B}^0$ (blue points)) along with the corresponding parts of the fitted PDF; bottom plot shows the asymmetry in data distributions and in the fitted PDF. Left: Likelihood scan in the $S - A$ plane including systematic uncertainties. The black circle represents the physical boundary of CP violation. The red marker shows the fit result and the concentric curves represent the contours from 1 to 3 standard deviations from the fit result.

Following the signal-to-background fraction fit we perform an unbinned maximum likelihood fit to the $\Delta$ distributions of reconstructed candidates, tagged as $B^0$ and $\bar{B}^0$, to extract the values of $CP$ violation parameters. Our preliminary results are

$$A_{CP} = -0.48 \pm 0.41(stat) \pm 0.07(syst)$$
$$S_{CP} = -1.32 \pm 0.77(stat) \pm 0.36(syst),$$

(7)
where the first error given is statistical and the second systematic. The main contribution to the systematic error comes from the uncertainties in the $\Delta t$ resolution function and the reconstructed vertex quality selection criteria. In Figure 5 (left) the distribution of reconstructed candidates in $\Delta t$ is shown along with the measured asymmetry. We use the Feldman-Cousins approach to determine the significance of the result. In Figure 5 (right) the result along with obtained confidence intervals is shown. The measured values are consistent with no $CP$ violation.

### 6. Measurement of the branching fraction of $B \to \pi^0\pi^0$ decay

Measuring the branching fraction of $B \to \pi^0\pi^0$ decay is interesting for two main reasons. First, previous measurements indicate somewhat larger value than theoretically predicted by the perturbative QCD and the QCD factorization approaches. Values measured by the BaBar collaboration [20] and the latest published result by Belle collaboration (2005, [21]) are

$$B(B \to \pi^0\pi^0) = (1.83 \pm 0.21 \pm 0.13) \times 10^{-6} \text{ (BaBar)}$$

$$B(B \to \pi^0\pi^0) = (2.32 \pm 0.5 \pm 0.3) \times 10^{-6} \text{ (Belle)},$$

while the theory predictions range up to $< 1 \times 10^{-6}$ [22, 23]. Second motivation for this measurement is related to the measurement of the $\phi_2$ angle of the UT. The time-dependent asymmetry in $B^0 \to \pi^+\pi^-$ is proportional to $\sin 2\phi_2$, assuming that only $b \to u$ tree level diagram contributes to the decay. However, the non-negligible $b \to d$ penguin amplitude potentially modifies this asymmetry by introducing a phase difference $\Delta \phi_{\pi\pi}$ in $\sin(2\phi_2 - 2\Delta \phi_{\pi\pi})$ and inducing a non-zero $A_{\pi\pi}$. Therefore, to extract the value of $\phi_2$ penguin amplitude contribution and its relative phase have to be determined. This can be done using isospin relations between several $B \to \pi\pi$ amplitudes, among which is also $B^0 \to \pi^0\pi^0$ [19].

In our measurement we reconstruct $\pi^0$ by combining two photon candidate clusters from the ECL. We impose selection criteria on invariant mass of $\gamma\gamma$ pair ($115 \text{ MeV}/c^2 < M_{\gamma\gamma} < 152 \text{ MeV}/c^2$) and on the mass constrained vertex fit quality ($\chi^2 < 50$). The main background contribution arises from continuum events and an event shape variable ($T_C$) is used to suppress this contribution. In our previous analysis there was also a substantial contribution of background from $BB$ events. It was later realized that this background arises from the pile-up of $e^+e^-$ scattering events and $BB$ events in the ECL, and we were able to remove 99% of it by applying a cut on the ECL trigger time. The remaining $BB$ background comes from other rare charmless $B$ decays (mainly $B^+ \to \rho^+\pi^0$).

We extract the signal yield by performing a fit to the reconstructed candidates distribution in the $M_{bc} - \Delta E - T_C$ space. The signal and $BB$ backgrounds are modeled by fitting their distributions from large MC samples, and for continuum background we fit the distribution of candidates in the $M_{bc}, \Delta E$ sidebands of the measured data. The comparison of the fitted PDF projections and the data distributions in the $M_{bc}, \Delta E$, and $T_C$ are shown in Figure 6. Our preliminary result for the branching fraction is

$$B(B^0 \to \pi^0\pi^0) = (0.89 \pm 0.12 \pm 0.10) \times 10^{-6},$$

where the first uncertainty given is statistic and the second is systematic. The main contribution to the latter comes from the signal region definition, continuum background parametrization, $\pi^0$ detection efficiency, and uncertainties in the assumed branching fractions of the contributing rare $B$ decays. The measured branching fraction is the most accurate to date, and significantly more consistent with theoretical predictions than previous measurements.
**Figure 6.** $\Delta E, M_{bc}$ and $T_c$ distributions of $B^0 \rightarrow \pi^0\pi^0$ candidates (dots with errors) with the projections of fitted PDF superimposed (black line). Contributions from the signal, continuum background, $B \rightarrow \rho\pi$ and other $BB$ backgrounds are shown in the blue, green, red and cyan, respectively.

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