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A MONTE-CARLO SIMULATION STUDY OF B-MESONS DECAY INTO ωK

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Abstract: The CP violation (violation of matter-antimatter symmetry) was observed only as a small effect in the decay of the neutral K meson in 1964. In order to study the long-standing puzzle about the origin of the CP violation, the KEK B-factory has been constructed at High Energy Accelerator Research Organization (KEK) in Japan. Using the KEK B-factory and the BELLE detector, an experimental study of the production and decay of the B meson will be carried out by the BELLE collaboration to search for the CP violation. We made a Monte-Carlo simulation study of the charmless hadronic decays of the B mesons into ωK using the BELLE Fast Simulator (FSIM). Through this study the sensitivity of the BELLE experiment to the measurement of the direct CP violation and its branching ratio has been estimated.

Key words: B-factory experiment, BELLE detector, Monte Carlo Simulation, CP violation and Branching ratio measurement.

Introduction

Standard Model (SM) (Salam, 1968) is a very powerful tool to explain almost all the phenomena observed in high-energy experiment. However, for example, Higgs particle has not been observed and a mechanism of CP violation has not been understood yet perfectly. It is stated that the CP violation is one of the three necessary ingredients in explaining that the universe is made of matter, not anti-matter (Sakharov, 1967). The first observation of the CP violation in K^0 system was in 1964 (Christenson, 1964). According to Kobayashi-Maskawa model (Kobayashi and Maskawa, 1973), the CP violation should occur not only in the K decay, but also in several different decay modes of B system (Carter and Sanda, 1980).

In order to study the long standing puzzle about the origin of the CP violation, an e^+e^- asymmetric collider, referred to as "KEK B-factory", has been constructed which will produce about 10^8 B mesons/year at KEK in Japan. Using KEK B-factory and the BELLE detector, an experimental study on the decay of B mesons has been carried out from the end of 1999. The CLEO (Cornell Electron Storage Ring in Cornell University, USA) collaboration has recently observed unexpectedly large branching ratios for the two-body charmless hadronic decay channels of $B^{\pm}\prod\omega K^{\pm}$ (Bergfeld, 1998). Although the presence of the hadrionic phases complicates extraction of the CP violation parameters, these charmless hadronic decays of B mesons will provide an opportunity for the direct CP violation to be observed. In addition to this it is one of the interesting topics to study the origin of the large branching ratio of this decay mode. Motivated by the measurement of the large branching ratio of $B^{\pm}\prod \omega K^{\pm}$ many theoretical studies have been made to explain the discrepancy between the standard theory and the experiment (Du and Guo, 1997, Ali and Greub, 1998, Lipkin, 1998). At the moment it is not so clear whether any of these theoretical calculations can explain the experimental data or not because of the large uncertainties in the theoretical calculations and the large statistical errors of the experimental data. In order to understand the origin of the large branching ratio, therefore, it is important to measure the branching ratio of the $B^{\pm}\prod\omega K^{\pm}$ decay with around 10% accuracy.

In this paper, we report results of a Monte-carlo simulation study based on a fast detector simulator (FSIM) on the $B^{\pm}\rightarrow\omega K^{\pm}$, $\omega\rightarrow\pi^0\pi^+\pi^-$, $^{\text{followed}}$ by $\pi^0\rightarrow\gamma\gamma$ decay mode for the BELLE experiment at KEK B-Factory. Through the present simulation study we could estimate an integrated luminosity required to observe signals and CP violation with a given significance in this decay mode.

KEK B-Factory and the BELLE detector

Detailed studies of B physics require a large number of B mesons because of its small branching ratios in the final states. The B-factory at KEK in Japan, referred as "KEKB", is an asymmetric electron-positron collider of energies 8.0×3.5 GeV, which aims to provide electron-positron collision at a center of mass energy 10.58 GeV that corresponds to ϒ(4S) resonance. The ϒ(4S) is the first resonance above the B meson production threshold, decaying to a pair of $B^+ B^-$ or B0B0 in an approximately equal decay rate. The primary goal of the BELLE experiment is to detect the CP violating effects in B meson decays and to provide definitive information regarding the mechanism of the CP violation (BELLE Collaboration, 1994).

Fig.-1 shows the side view of the BELLE detector, which consists of several sub-detectors. A Silicon Vertex Detector (SVD) reconstructs decay vertices of the $B\overline{\ }$ mesons. A Central Drift Chamber (CDC) that is co-axial with the beam provides charged particle tracking. Particle identification is provided by the dE/dx measurement in the CDC, the Aerogel Cherenkov Counter (ACC) and the time of flight (TOF) counter arrays. The TOF and ACC are located radially outside of the CDC. Electromagnetic showers are detected in

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a nine-thousand block array of CsI(Tl) crystals located inside the solenoid coil. Muons and K_L are identified by arrays of detectors interspersed in iron return yoke of magnet. The details of this detector can be obtained from any of the KEK memoranda (BELLE Collaboration, 1994, Khan, 1999 and Suda, 1998).

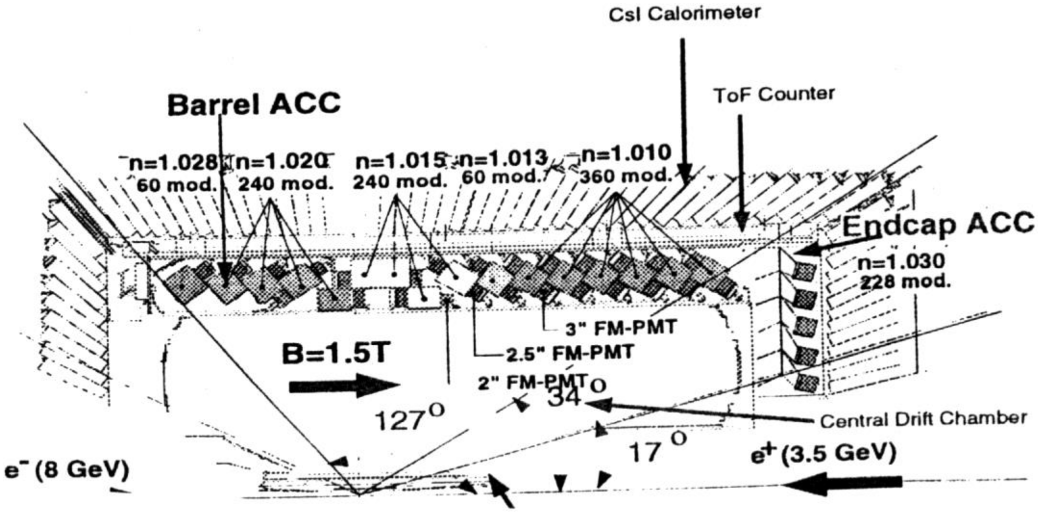

Fig.-1. Side view of the BELLE detector

Event Generation

The two body charmless hadronic decay events were generated using QQ event generator (Itho, 1995) in which the latest experimental results from CLEO-II detector are installed. By using QQ generator the following two data sets corresponding to 100 fb^{-1} were prepared for the present study:

The first data set consists of $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^+B^-$ events, one of which decays as the $B^\pm \rightarrow \omega K^\pm$, $\omega \rightarrow \pi^0\pi^+\pi^-$, followed by $\pi^0 \rightarrow \gamma\gamma$, whereas, the other partner decays in the standard decay mode. This data set contains 1579 generated events.

The second data set contains continuum background events, which do not form the $\Upsilon(4S)$ resonance. These data sets are subsequently passed through the BELLE fast simulator (FSIM) version 5.2 (Ozaki, 1996) using the latest information on the acceptance and performances of the BELLE detector. The information from the CDC, ACC, TOF and ECL subdetectors were used in the present analysis. We transformed all the measured quantities (e.g. track momentum, energy, etc.) into those in the CM frame of the B^+B^- pair for subsequently performing the analysis. The parameters used in the present analysis are shown in Table 1.

Table 1. The parameters used in the present analysis

The cross-section for the production of the $\Upsilon(4S)$ resonance	1.2 nb*
The cross-section for the production of a QQ pair	3.5 nb
Integrated luminosity	100 fb^{-1}
$Br(B^\pm \rightarrow \omega K^\pm)$	1.5×10^{-5}
$Br(\omega \rightarrow \pi^0\pi^+\pi)$	0.888
$Br((\pi^0 \rightarrow \gamma\gamma)$	0.987

* We assume that $\Upsilon(4S)$ decays into B^+B^- and $B^0\bar{B}^0$ with equal probability.

General Description of the Selection Procedure

The B candidate was reconstructed both from the $\Upsilon(4S)$ events and from the continuum background events. To select the B candidate for $B^\pm \rightarrow \omega K^\pm$ the following cuts and selections are used.

The beam constrained mass (M_b)

The invariant mass M of the B candidate was derived using the relation

$$M_B = \sqrt{(E_B^2 - P_B^2)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where P_B and E_B are the measured momentum and energy of the B candidate. Using the beam energy E_{beam} that is accurately known instead of measured energy E_B of the B candidate the mass resolution can be improved by the order of magnitude. Therefore Eq.(1) can be replaced as

Energy Constrained (ΔE)

$$M_b = \sqrt{(E_{beam}^2 - P_B^2)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Conservation of energy requires that the B meson and their decay products should carry the full energy of the beam. We define ΔE as

$$\Delta E = E_1 + E_2 - E_{beam} \qquad (3)$$

where E_1 and E_2 are energy of the ω and $K^\pm$, respectively. For true B candidate the ΔE should have a peak at zero whereas for the continuum background it should have uniform distribution. The true B candidates were separated from the continuum background events using the ΔE distribution in this analysis.

Thrust angle cut

The dominant background comes from the continuum hadronic production, i.e. from $e^+e^-\to q\bar{q}$, where q denotes u,d,s and c quarks. Since the produced B meson from ϒ(4S) have kinetic energy of a few MeV they are approximately at rest in the CM system. The decay products of B mesons are thus spherically distributed and are not correlated with each other. On the other hand the hadrons from the continuum qq production tend to appear as a two-jet like structure. To distinguish the continuum events from the signal events we calculated the angle θ_T between the thrust axis of the B candidate particle and that of all the remaining charged and neutral particles in the event.

The thrust axis is defined as a line along the vector n, which gives the maximum of

$$T(n) = \frac{\sum_i \left|\bar{P}_i.\bar{n}_.\right|}{\sum_i \left|\bar{P}_{i.}\right|}$$

where $\bar{P}_i$ is the momentum vector of ith particle among the B candidate ones or the remaining ones in the event. Since the continuum qq events form a two-jet structure and B^+B^- events have no axis correlation the distribution of $\text{Cos}\theta_T$ is strongly peaked near $\text{Cos}\theta_T = \pm 1$ for qq events and nearly flat for B^+B^- events. This is clearly seen in Fig.2 which shows the $\text{Cos}\theta_T$ distribution (a) for the $e^+e^-\to qq$ and (b) for $e^+e^-\to \Upsilon(4S) \to B^+B^-$ events normalized to the same integrated luminosity.

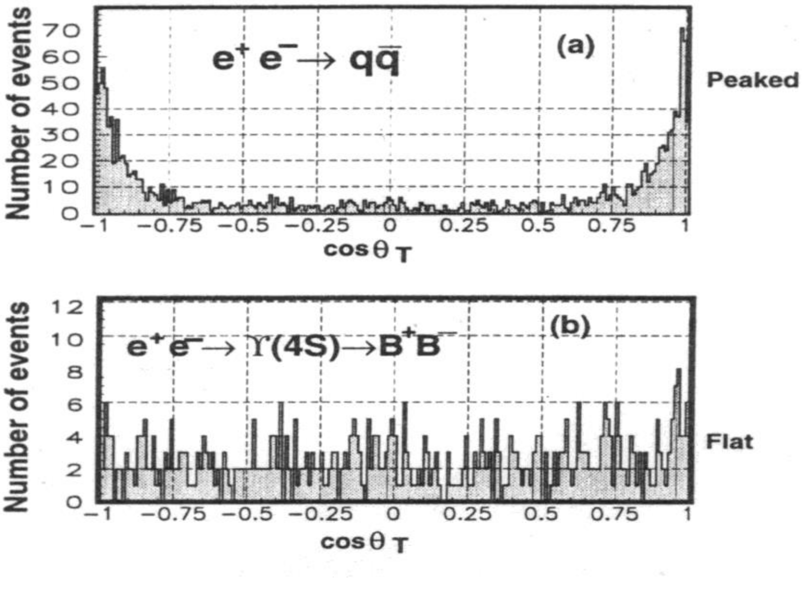

Fig.-2. The $\text{Cos}\theta_T$ distribution (a) for the $e^+e^-\to qq$ continuum background and (b) for $e^+e^-\to \Upsilon(4S) \to B^+B^-$ signal events normalized to the same integrated luminosity.

Particle Identification

In the present analysis the subroutines FCDCPID, FAERPID and TOFPID were used in FSIM for the purpose of charged particle identification using the information from the CDC, ACC and TOF sub-detectors, respectively. In the routines FCDCPID and FTOFPID, the probability of a track being a particular type (=e, μ, π, K, p) is calculated. The combined probability, $prob^i$ is obtained as

$$prob^i = prob(CDC)^i . prob(ACC)^i . prob(TOF)^i \qquad (5)$$

In the present study separation of a kaon from a pion was carried out by using the PID cut requiring

$$prob^K \geq prob^\pi \qquad (6)$$

Reconstruction procedure of the B candidate for $B^\pm \to \omega K^\pm$, $\omega \to \pi^0 \pi^+ \pi^-$ followed by $\pi^0 \to \gamma\gamma$

For the reconstruction of π^0 meson, all the possible 2γ pairs were combined. Fig. 3 shows the invariant mass distribution of the 2γ system which has a π^0 peak (0.135 GeV) as well as η one (0.55 GeV). The η peak at 0.55 GeV is expected to come from the standard decay of B.

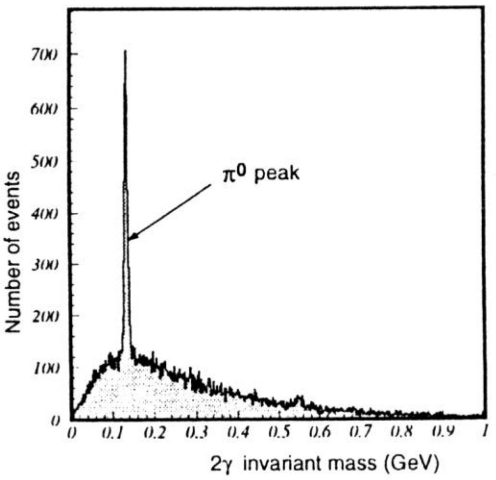

Fig. –3. The invariant mass distribution of the two gamma system

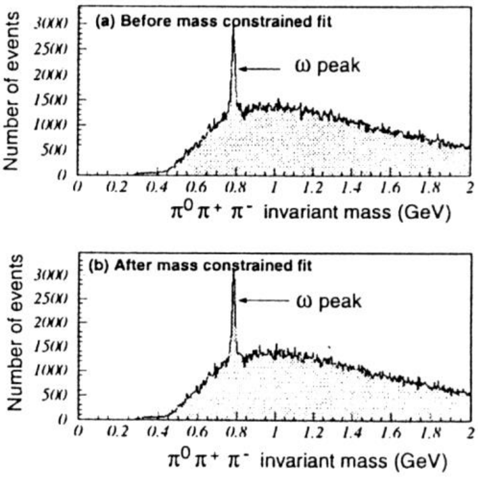

Fig-4. The invariant mass distribution for $\pi^0\pi^+\pi^-$; (a) before and (b) after a mass constrained fit on π^0 mass.

The π^0 meson was selected applying a 3σ cut around the π^0 mass peak ($0.122 \text{ GeV} \leq m_{2\gamma} \leq 0.148$ GeV). Then the selected π^0 meson was combined with two charged tracks with opposite charges to reconstruct ω meson. All the possible charged particles were combined with the π^0 meson assuming that they are pions. Fig. 4(a) shows the invariant mass distribution of $\pi^0\pi^+\pi^-$. The peak around the mass of ω (0.781 GeV) is seen but it is wider compared to the natural width of ω. To make ω mass resolution much more precise, the mass constrained fit on π^0 invariant mass was used. The invariant mass distribution for the $\pi^0\pi^+\pi^-$ system after the mass constrained fit on π^0 is shown in Fig. 4(b). Due to the large natural width of ω (8.41 MeV) the mass constrained fit is not effective to reduce the peak width of ω. The ω meson was selected by imposing a 3σ cut around the ω peak ($0.757 \text{ GeV} \leq m_{\pi 0 \pi + \pi -} \leq 0.809$ GeV) .

Finally to reconstruct B, the reconstructed ω was combined with another charged track assuming that it was a kaon. Using the measured energies and momenta of ω and K the energy imbalance ΔE and the beam constrained mass M_b were obtained. Since the mass resolution of the B invariant mass is worse than that of the beam constrained mass M_b, we used the beam-constrained mass M_b instead of B invariant mass M_B in the present analysis.

Applying a ΔE cut of $|\Delta E| \leq 0.04$ GeV on this ΔE distribution the S/N (signal/noise) ratio was calculated to be 0.13 with a reconstruction efficiency ε of 49.8 %. The reconstruction efficiency ε is defined as the ratio of the measured number of signal events to the number of signal events generated.

In order to eliminate the continuum background the M_b+ΔE cut, M_b+PID+ΔE cut, Mb+thrust angle+ ΔE cut and M_b+PID+thrust angle+ΔE cut were used in the present analysis successively to select the best cut. Figs.

5(a), 5(b) and 5(c) show the ΔE distributions after the M_b+ΔE cut, the M_b+PID+ΔE cut and the M_b+PID +thrust angle+ΔE cut, respectively. It is shown that the highest sensitivity can be achieved with the M_b+PID+ thrust angle+ΔE cut with a cut value of $|\cos\theta_T| \leq 0.6$ when a ΔE cut of $|\Delta E| \leq 0.03$ GeV is used in Fig.5(c). The statistical significance of the signal after this cut is 5.4σ at an integrated luminosity of 10 fb^{-1}. With this condition the S/N ratio is 1.79 and the reconstruction efficiency is 29.1%.

In this study it has been found that the PID cut reduces the continuum background events down to ~40% level. The S/N ratio, reconstruction efficiency and statistical significance of the signal after several different combinations of cuts are summarized in Table 2. It is clear that the M_b+PID+ thrust angle+ΔE cut is the optimized cut for the present analysis.

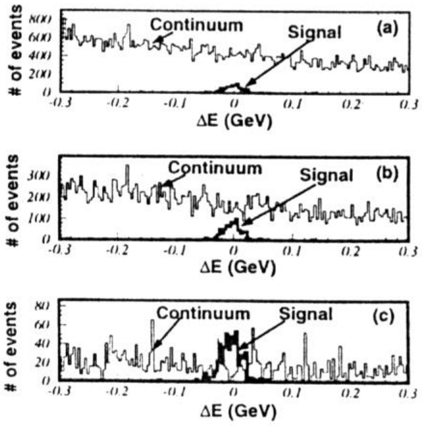

Fig.-5. ΔE distributions for the signal and continuum background events after (a) the M_b+ΔE, (b) the M_b+PID+ΔE and (c) the M_b+PID +thrust angle+ΔE cut, respectively.

Table 2. The number of the signal events S, the background events N, the S/N ratio, reconstruction efficiency ε and significance of the signal $\sum_{signal}$ for different combinations of cuts

Cut	S	N	S/N	ε(%)	$\sum_{signal}$
M_b+ΔE	78.6±2.8	614.0±7.8	0.13±0.01	49.8±1.8	3.0±0.11
M_b+PID+ΔE	76.8±2.8	234.7±4.8	0.33±0.01	48.6±1.8	4.4±0.16
M_b+ thrust angle+ΔE	46.4±2.2	63.4±2.5	0.73±0.05	29.4±1.4	4.4±0.22
M_b+PID+ thrust angle+ΔE	45.9±2.1	25.6 ±1.6	1.79±0.14	29.1±1.4	5.4±0.27

Results and Discussions

The data shown in Table-2 were used to estimate the required integrated luminosity to measure the branching ratio with a given statistical error and to observe a given CP asymmetry with a given significance. At present, the branching ratios for the $B^{\pm} \to \omega K^{\pm}$ decay mode measured by CLEO collaboration has a large relative statistical error of about 47%. Through the present simulation study a relative statistical error and a signal sensitivity at a given integrated luminosity were estimated for the decay mode $B^{\pm} \to \omega K^{\pm}$.
The relative statistical error of the branching ratio in terms of the integrated luminosity is given as (Khan, 1999)

$$\frac{\Delta < Br >}{< Br >} = \sqrt{\frac{(1+\frac{N}{S})}{\sigma \times \int Ldt \times < Br > \times Br^{sub} \times \varepsilon}}. \quad (7)$$

where S is the total number of the $B^{\pm} \to \omega K^{\pm}$ events, N is the number of the continuum background events, σ is the cross-section for ϒ(4S) production, ∫Ldt the integrated luminosity, <Br> is the average branching ratio of the $B^{\pm}$ decay, Br^{sub} is the branching ratio for the sub-decay modes and ε is the reconstruction efficiency. From Eq.(7) and the present simulation data, the relative statistical error of the branching ratio measurement at a given integrated luminosity was estimated. It has been shown that one can measure the <Br> with relative statistical errors of 18.4 % for the present decay mode at an integrated luminosity of 10 fb^{-1}. Data with this level of relative statistical error will give important information for the comparison of the experimental data with the theoretically predicted values.

The required integrated luminosity to observe a given CP asymmetry can be expressed as (Khan, 1999):

$$\int Ldt = \frac{\varepsilon \times Br(1+\frac{N}{S})}{\sigma(\varepsilon \times Br)^2} \times \frac{\Sigma_{asym}^2}{A_{asym}^2}. \qquad (8)$$

Using the present simulation data given in Table 2 and the measured branching ratio by CLEO, the required integrated luminosity to observe a given CP asymmetry with a given statistical significance Σ_{asym} was calculated. In Table-3 the required integrated luminosity to observe 10%, 20% and 40% CP asymmetry for 2σ and 3σ significance is shown.

Table-3: Required integrated luminosity to observe a given CP asymmetry with 2σ and 3σ significance of the asymmetry for $B^{\pm}\to\omega K^{\pm}$, $\omega\to\pi^0\pi^+\pi^-$ followed by $\pi^0\to\gamma\gamma$ decay mode.

Asymmetry(%)	Required $\int Ldt$ (fb^{-1})	
	2σ	3σ
40	8.5	19.1
20	33.9	76.3
10	135.6	305.0

Conclusion

In order to study a feasibility of the measurement of direct CP violation and of the branching ratio with much better accuracy than the presently available data, a Monte Carlo simulation study using a fast simulator has been carried out for two body charmless decays of B mesons ($B^{\pm}\to\omega K^{\pm}$). It has been found from the present simple cut analysis method that the BELLE detector can detect the process $B^{\pm}\to\omega K^{\pm}$ with an efficiency of 29.1 %. If the CP asymmetry is as large as 20%, 3σ asymmetry can be observed at an integrated luminosity of 76.3 fb^{-1}. The relative statistical error at an integrated luminosity of 10 fb^{-1} are estimated to be 18.4 %. The measurement of the branching ratio with the relative statistical error of this level will give an useful information to understand the origin of the large branching ratio.

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