MEASUREMENT OF sin(2φ₁) AT BELLE

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With 6.2 fb⁻¹ of data collected on the Υ(4S), Belle reports its first measurement of
sin 2φ₁ = 0.45^{+0.43}_{−0.44}(stat)^{+0.07}_{−0.09}(sys). The result was obtained by fitting the proper time
distribution of flavor tagged and fully reconstructed neutral B mesons decays to five
different charmonia plus a K_s or K_L channels. In this paper the analysis and results
will be described briefly.

1. Introduction

In the Standard Model, the violation of the CP symmetry by the weak interaction
is possible via the complex phase in the CKM mass mixing matrix. This phase
can be extracted by observing processes that involve flavor transitions spanning
the three quark generations. In this analysis we consider decays of the neutral B
meson to final states which are CP eigenstates. The interference between the weak
phase in direct decays and decays that proceed via mixing leads to an asymmetry
in the time-dependent decay rate which is exploited here to measure the value
of sin 2φ₁ . (sin 2β). The particular decay modes considered were selected because
they have relatively large branching fractions, clear experimental signatures and are
essentially free from theoretical uncertainties. Five neutral B decay channels were
used: B → J/ψK_S, ψ(2S)K_S, χ_c1K_S, J/ψK_L and J/ψπ⁰. The first three channels
have odd CP while the last two have even CP.

2. Analysis Procedure

Our analysis includes all of the available data collected by the Belle experiment¹ up
through the end of the Summer 2000. The data sample consists of 6.2 fb⁻¹ taken
at the Υ(4S). At Belle, the center of mass of B̄B pair system is boosted by the
asymmetric configuration of the e⁺e⁻ beams. The boost (γβ = 0.425), the long-
lifetime of the B meson and the excellent resolution of the silicon-vertex detector
makes possible measurements of time-dependent decay rates from the displacement
of the reconstructed B vertices in the boost direction. To deduce the flavor of the
B_{CP} meson, its decays to a CP-eigenstate is flavor non-specific, we tag the flavor of
the $B_{tag}$, the other $B$ meson. The relationship between the time-dependent decay rate, in terms of the proper-time $\Delta t = t_{CP} - t_{tag}$, and the $CP$ violating parameter is given by,

$$\frac{dN}{d\Delta t}(B \to f_{CP}) \propto e^{-|\Delta t|}\{1 - (1 - 2\omega)\eta_{CP} \sin 2\phi_1 \sin(\Delta m \Delta t)\},$$

(1)

here $\Delta m$ determines the frequency of $B^0\bar{B}^0$ mixing, $\eta_{CP}$ is either +1(-1) for even(odd) $CP$ final states and $\sin 2\phi_1$ is the $CP$-violating term. The $(1 - 2\omega)$ term, known as the dilution factor, accounts for the possibility of mis-assigning the flavor to the $B_{tag}$ (wrong-tag).

The analysis procedure used to extract the value of $\sin 2\phi_1$ includes four main components: (1) reconstruct, exclusively, the decay of the $B_{CP}$ meson and identify candidate events, (2) determine the flavor of $B_{CP}$, at the decay time of $B_{tag}$ by tagging its flavor, (3) determine the proper-time of the decay by measuring the difference between the $z$ decay vertices of the two $B$ mesons and compute the proper-time from the $\Delta t = \Delta z/\gamma\beta$ relation and (4) form the proper-time distribution from the sample of tagged and fully reconstructed events and extract the value of $\sin 2\phi_1$ from an unbinned maximum likelihood fit.

### 2.1. Reconstruction of the $B_{CP}$ decay

Event shape variables were used to reject continuum background and particle identification requirements were imposed on tracks used to reconstruct the decay products of the $B_{CP}$. To form $J/\psi$ and $\psi(2S)$ candidates we used dilepton channels ($\mu^+\mu^-$, $e^+e^-$), correcting for final-state radiation in the electron channel. For $\psi(2S)$ candidates we also used the $J/\psi\pi^+\pi^-$ mode. For $\chi_{c1}$ candidates we used only the $J/\psi\gamma$ decay channel. $K_s$ candidates were selected from among $\pi^+\pi^-$ and $\pi^0\pi^0$ combinations. The neutral mode was used exclusively in the reconstruction of $B \to J/\psi K_s$. The signals for $CP$ eigenstates were identified kinematically via the beam-constrained mass and $\Delta E$ (variables in which the beam-energy is substituted for the measured energy) distributions, see Fig. [Fig. 1]. The total number of $B$ candidates found for each mode are listed in Table [Table 1].

### 2.2. Flavor Tagging

To determine the flavor of the $B_{CP}$ candidates, we examined the remaining tracks in the event to identify the flavor of $B_{tag}$. The flavor tagging algorithm employs four methods: (1) high momentum ($p_T^l > 1.1$ GeV/c) lepton charge; this tags the $b$ quark flavor via its primary decay to a lepton, (2) sum of the charge for all well identified kaons; this tag relies on the flavor of the $s$ quark from cascade decays, (3) medium momentum lepton ($0.6 < p_T^l < 1.1$ GeV/c); here if the sum of $p_T^l$ and $p_T^{miss}$ is greater than 2.0 GeV/c then the charge of the lepton tags the $b$ quark

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$^a$Since, the decay of the $T(4s)$ creates a pair of $B\bar{B}$ mesons in a coherent quantum state, tagging the flavor of one of the $B$ automatically determines the flavor of the other $B$ at the time when the tagged $B$ decayed.
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Fig. 1. The plot on the left, shows the beam-constrained mass distribution used to identify the number of reconstructed \(B_{CP}\) in all but the \(J/\psi K_L\) mode. The plot on the right, shows the \(p_T^B\) distribution used to identify the \(J/\psi K_L\). The signal region in \(p_T^B\) is defined from 0.2 to 0.45 GeV/c. The background distribution in the fit is divided into components describing the contribution from resonant and (non-resonant) \(B \rightarrow J/\psi K^*(0)(K_L,\pi^0)\) and all other \(B\) decays.

The value of sin 2\(\phi_1\) is extracted from an unbinned maximum-likelihood fit to the proper-time distribution of tagged and fully reconstructed \(B_{CP}\) decays. The proper-

| \(CP\) | \(B\) Decay Mode | Signal | Background | Tagged |
|-------|------------------|--------|------------|--------|
| -1    | \(J/\psi K_s, K_s \rightarrow \pi^+\pi^-\) | 70     | 3.4        | 40     |
| -1    | \(J/\psi K_s, K_s \rightarrow \pi^0\pi^0\) | 4      | 0.3        | 4      |
| -1    | \(\psi(2s)K_s, \psi(2s) \rightarrow l^+l^-\) | 5      | 0.2        | 2      |
| -1    | \(\psi(2s)K_s, \psi(2s) \rightarrow J/\psi\pi^-\pi^+\) | 8      | 0.6        | 3      |
| -1    | \(\chi_{c1}K_s\) | 5      | 0.8        | 3      |
| +1    | \(J/\psi K_L\) | 102    | 48.0       | 42     |
| +1    | \(J/\psi \pi^0\) | 10     | 0.6        | 4      |
| Total |                  | 204    | 53.9       | 98     |
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Fig. 2. The fitted proper-time distribution including data from both $B^0$ and $\bar{B}^0$ candidates $(dN/d\Delta t|_{B^0} + dN/d(-\Delta t)|_{\bar{B}^0})$. The plot on the left includes all modes with odd $CP$. The plot on the right includes all modes.

To improve the statistical accuracy of our measurement the data from all decay modes including those with odd and even $CP$ were combined in the final likelihood fit. The likelihood function for each event takes into account the finite resolution of the detector, the charm-lifetime and includes terms for background contributions from decays with or without their own $CP$ asymmetry. The $CP$-asymmetry, $B^0\bar{B}^0$ mixing and dilution due to wrong-tagged events were included in the functional form as illustrated by Equation 1. The maximum-likelihood fits to the data are shown in Fig. 2. Our preliminary result is:

$$\sin 2\phi_1 = 0.45^{+0.43}_{-0.44}(\text{stat})^{+0.07}_{-0.09}(\text{sys}). \tag{2}$$

The systematic error includes effects from uncertainty in the fraction of wrong tags, the $\Delta t$ resolution function for both background and signal and input values used for $B$ lifetime and mixing parameter. The dominant effect comes from the uncertainty in the wrong tagged fraction. We also checked for biases in the analysis by examining modes where no $CP$-asymmetry is expected. In particular we ran the entire analysis including the vertexing, tagging and $CP$-fitting algorithm on reconstructed samples of $B \to J/\psi K^{*0}(K^-\pi^+), B^- \to J/\psi K^-, B^- \to D^0\pi^-$ and $B^0 \to D^{*-}l^+\nu$. We observed no $CP$-asymmetry in these modes as expected.
3. Conclusion

We have obtained a preliminary value for the $\sin 2\phi_1$ by analyzing 6.2 $fb^{-1}$ of data collected at the $\Upsilon(4S)$. Due to the large statistical errors our result does not, at this time, show conclusive evidence for $CP$ violation in the $B$ system. As more data become available we expect to significantly improve the accuracy of our measurement and establish whether or not the Standard Model can account for $CP$ violation in the $B$ system.

4. References

1. The Belle Collaboration, “The Belle Detector,” to be submitted to Nucl. Inst. Meth.
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3. H. Aihara, “A Measurement of $CP$ Violation in $B^0$ Meson Decays With Belle,” to appear in the Proceeding of the XXXth International Conference on High Energy Physics, Osaka Japan, July 2000. e-Print [hep-ex/0010008]