CP VIOLATION VIA $\rho\omega$ INTERFERENCE$^{a}$

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We consider $B^{\pm,0} \to \rho^0(\omega)h^{\pm,0}$, where $\rho^0(\omega)$ decays to $\pi^+\pi^-$ and $h$ is any hadronic final state, such as $\pi$ or $K$. We find a large direct $CP$ asymmetry in $B$-meson decays via $\rho\omega$ interference. A possible method to determine weak phases, such as $\phi_{2,3}$, is discussed. The experimental feasibility is also shown.

1 Introduction

The standard model of $CP$ violation predicts large $CP$ asymmetries in the $B$-meson system. Many experimental attempts to detect $CP$ violations of the $B$ meson will be carried out towards the next century.

Unlike $CP$ violations in the neutral $B$ meson, the $CP$ asymmetry of the charged $B$ meson can be caused solely by direct $CP$ violations, which only occur through interference between two amplitudes having different weak and strong phases. In the standard model a weak-phase difference is provided by a different complex phase of the Kobayashi-Maskawa (KM) matrix elements of the tree and penguin diagrams, while the strong phase is given by the absorptive parts of the corresponding diagrams.

Nonperturbative resonance states, in which we know the behavior of the large absorptive part by using the Breit-Wigner shape, are ideal places to obtain large but controllable $CP$ asymmetry. The $CP$ violations via radiative decays of the $B$ meson were predicted by Atwood and Soni. The role of charmonium resonances in the $CP$ violation of $B^{\pm}$ decay has been discussed by Eilam, Gronau and Mendel. Lipkin discussed the use of $\rho-\omega$ interference as a trigger of direct $CP$ violation in neutral $B$-meson decay using a simple quark-model analysis.

In this talk we present a systematic analysis of the $CP$ asymmetries in $B^{\pm,0} \to \rho^0(\omega)h^{\pm,0} \to \pi^+\pi^-h^{\pm,0}$ via $\rho\omega$ interference, where $h$ is any hadronic final state, such as $\pi$, $\rho$, $K$, or $K^*$. We find large $CP$ asymmetries at the interference region.

$^{a}$Talk presented by R. Enomoto at "International Conference on B physics and CP violation", Mar. 1997, Hawaii, USA.
Figure 1: Examples of the Feynman diagrams of the decay $B^{-} \rightarrow \rho^{0}(\omega)\rho^{-}$; (a) tree and (b) penguin diagram.

2 Mechanism

Figures 1 (a) and (b) are examples of quark-level diagrams of the tree (a) and penguin (b) amplitudes for $B^{-} \rightarrow \rho^{0}(\omega)\rho^{-}$. Considering the quark components, diagram (a) gives the final state of $\rho^{0} + \omega$, diagram (b) contributes solely to the $\omega$ meson. The standard model predicts a weak phase difference, $\phi_{2} = \text{arg}((V_{ud}V_{ub}^{\ast})/(V_{td}V_{tb}^{\ast}))$. The absorptive part (strong phase) is provided by both the $\rho-\omega$ interference and the Bander-Silverman-Soni mechanism (the quark loop absorptive part in the penguin diagram).

The size of the interference effect can be evaluated as

$$\frac{\langle \pi^{+}\pi^{-}|J_{\mu}^{\mu}|\langle 0 \rangle \epsilon_{\mu}}{\langle \pi^{+}\pi^{-}|J_{\mu}^{\mu}|\langle 0 \rangle \epsilon_{\mu}} \approx \frac{g_{\omega}}{g_{\rho}} \frac{g_{\rho}^{2}}{m_{\omega}^{2} - i\Gamma_{\omega}m_{\omega} - s} \left[ \frac{g_{\omega}}{3} \frac{e^{2}}{s} g_{\rho} + \tilde{g}_{\omega} \right], \quad (1)$$

where $s$ denotes the invariant mass square of $\pi^{+}\pi^{-}$, and $g_{\omega}$, $g_{\rho}$, and $\tilde{g}_{\omega}$ are the decay constants of the $\omega$ and $\rho$ mesons, and $\rho-\omega$ mixing amplitude, respectively. Considering

$$\Gamma(\omega \rightarrow \pi^{+}\pi^{-}) = \frac{1}{(m_{\rho}^{2} - m_{\omega}^{2})^{2} + \Gamma_{\rho}^{2}m_{\rho}^{2}} \left[ \frac{g_{\omega}}{3} \frac{e^{2}}{s} g_{\rho} + \tilde{g}_{\omega} \right]^{2}, \quad (2)$$

and $\Gamma(\omega \rightarrow \pi^{+}\pi^{-}) = 0.19\text{MeV}$, $\Gamma(\rho \rightarrow \pi^{+}\pi^{-}) = \Gamma_{\rho} = 150\text{MeV}$, and $\Gamma_{\omega} = 8.4\text{MeV}$ into Eq.(2), we find

$$\frac{g_{\omega}}{3} \frac{e^{2}}{s} g_{\rho} + \tilde{g}_{\omega} \simeq 0.63\Gamma_{\omega}m_{\omega}, \quad (3)$$
where the sign is determined from $e^+e^- \to \pi^+\pi^-$ near to the $\rho$-meson mass.

In the ideal case, we obtain the maximum strong-phase difference at $s = m_\omega$.

### 3 Determination of Weak Phases

We next discuss how we can extract the weak phase from the observed $CP$ asymmetries.

The relevant hadronic form factors are parametrized by six parameters. Including one weak phase difference, the amplitudes are written in terms of seven unknown parameters. On the other hand, we will measure branching ratios of $B^- \to \rho^0 h^-$, $B^+ \to \rho^0 h^+$, $B^- \to \omega h^-$, and $B^+ \to \omega h^+$. Also, $CP$ conserving $\rho\omega$ interference, e.g., the pole position and the interference amplitude will be measured to fix two parameters. Finally, the $CP$ asymmetry in the $\rho\omega$ interference region gives two types of information. Setting aside one normalization factor, we should experimentally have seven measurements. We can therefore determine such weak phases as $\phi_2$ and $\phi_3$. We emphasize here that this method does not rely on the factorization assumption. We also note that the existence of the electroweak penguin operators does not affect this determination.

### 4 Estimation

The hadronic form factors are evaluated in Ref\[11\] so as to demonstrate the feasibility to detect $CP$ asymmetries in this mode. We have taken into account the finite radiative correction to the penguin-type on-shell quark amplitude coming from the tree hamiltonian\[14,16,17\]. The factorization was assumed with $N_c$ being treated as a parameter to parametrize uncertainty of this assumption. Measurements of the branching fractions of $B \to D$ decays indicate $N_c \simeq 2 \sim 3$ in this parametrization. In the reference, we used $N_c = 2$ and $N_c = \infty$, and the gluon momentum in the Penguin diagram ($k^2$) to be $0.5m_b^2$ and $0.3m_b^2$. For the meson form factors, we used the BSW model\[19\].

A summary is listed in Table 1 for the $N_c = 2$ and $k^2 = 0.5m_b^2$ case. $A(\rho^0)$ and $A(\omega)$ are the asymmetries of the $\rho^0 h$ and $\omega h$ modes. $A(\rho\omega)$ is the mean asymmetry of the $M(\pi^+\pi^-)$ invariant mass spectra around $M(\omega) \pm \Gamma(\omega)$, and $A^{max}(\rho\omega)$ is the maximum asymmetry in this region. $A^0(\rho\omega)$ is obtained by assuming the “zero hadronic phase”. The branching ratios were also estimated using this formalism. The $CP$ asymmetries via $\rho-\omega$ interference are large (>10%) in most cases.
5 Experimental Feasibility

We demonstrate the asymmetry patterns ($\pi^+\pi^-$ invariant mass spectra) in Figures 2 (a1)-(d3), where (a), (b), (c), and (d) denote the $B^- \to \rho^0 \rho^+$, $\rho^0 K^*$, $\rho^0 K^-$, and $B^0 \to \rho^0 K^0$ decay modes, respectively. The results using $(N_c, k^2) = (2, 0.5m^2_b)$ are given in Figures 2 (a1), (b1), (c1), and (d1), and those with $(N_c, k^2) = (2, 0.5m^2_b)$ are shown in Figures 2 (a3), (b3), (c3), and (d3). In Figures 2 (a2), (b2), (c2), and (d2), we assumed “zero short distance hadronic phases” with $(N_c, k^2) = (2, 0.5m^2_b)$. The solid lines are for $B^+$ or $B$ and the dashed ones are for $B^-$ or $\bar{B}$. Here, we have assumed the KM matrix of the Wolfenstein parametrization ($\lambda = 0.221, \rho = -0.12, \eta = 0.34$ and $A = 0.84$), which corresponds to the $(\phi_1, \phi_2, \phi_3) = (15, 55, 110)$ degrees. The branching ratios in these parameters are given in Table 1. The vertical scales are normalized to give the number of entries at $10^8$ $B\bar{B}$ events with an 100-% acceptance. Drastic asymmetries appear around the $\omega$ mass region.

In order to check the feasibility for detecting this $CP$ asymmetry, we performed a simulation assuming the BELLE detector of the KEK B-factory, an asymmetric $e^+ e^-$ collider (8 x 3.5GeV). The invariant mass resolution of $\pi^+\pi^-$ around $\omega$ mass is expected to be 3.2 MeV for the $B \rightarrow \omega h$, $\omega \rightarrow \pi^+\pi^-$ decay; this is enough to resolve the interference pattern. Here, the momentum resolution is derived from $(dP_T/P_T)^2 = (0.001P_T/1\text{GeV})^2 + 0.002^2$. In the case of a symmetric collider, the mass resolution will be better. In the case of a hadron machine, the average $B$ mesons’ $P_T$ would be several GeV or more. Although the mass resolution slightly deteriorates, the statistics are sufficient in hadron machines.

In order to suppress the large background from continuum events under $\Upsilon(4S)$, we used two cuts in analyzing the $\rho^0 h_{\pm,0}$ decay, one was that the

| Mode       | BR $\times 10^{-8}$ | $A(\rho^0)$ % | $A(\omega)$ % | $A(\rho\omega)$ % | $A_{\text{max}}(\rho\omega)$ % | $A^0(\rho\omega)$ % | $N(B\bar{B}) \times 10^8$ |
|------------|---------------------|----------------|----------------|------------------|-------------------------------|-------------------|-----------------|
| $\rho^0\rho^-$ | 2100               | 0              | 10             | 13               | 26                            | 11                | 70              |
| $\rho^0 K^*$  | 720                | -36            | -19            | -45              | -79                           | -19               | 12              |
| $\rho^0 \pi^-$ | 660                | -6             | 11             | 16               | 37                            | 18                | 29              |
| $\rho^0 K^-$  | 62                 | -41            | -26            | -82              | -91                           | -67               | 7.6             |

Table 1: Asymmetries for the various decay modes. BR is the branching ratios in unit of $10^{-8}$; $A(\rho^0)$ and $A(\omega)$ are asymmetries for $B^- \to \rho^0 h$ and $\omega h$ modes, respectively. $A(\rho\omega)$ is that in the region of $M(\omega) \pm \Gamma(\omega)$. $A_{\text{max}}(\rho\omega)$ is the maximum asymmetry in this region. $A^0(\rho\omega)$ is that under the assumption of “zero hadronic phase”. $N(B\bar{B})$ is the necessary number of $B\bar{B}$ events in order to obtain a 3σ asymmetry in $\rho - \omega$ interference region.
Figure 2: Expected invariant mass spectra of unlike-sign pion pairs. The solid lines are for $B^+$ or $B^0$ decays, and the dashed ones are for $B^-$ or $B^0$ decays. The vertical scale is the differential yield for $\pi^+\pi^-h^{\pm,0}$ combinations, and is normalized to give the number of entries at $10^8 BB$ events, assuming a 100\%- acceptance. The details concerning the notations (a1)-(d3) are described in the text.
absolute value of the cosine of the angle between the thrust axes of B decay products and the other particles at center-of-mass-system of \( \Upsilon(4S) \) be less than 0.6; the other was that the energy of the B candidate be between 5.25 and 5.325 GeV. The beam-energy constraint mass spectra were used.

The results of a simulation for the \( B^\pm \rightarrow \rho^0 h^\pm \) \( (h^\pm = \pi^\pm, \rho^\pm, K^\pm, K^*\pm) \) decay modes are summarized in \( N(B\bar{B}) \) of Table 1, the necessary number of \( BB \) events for detecting the \( 3\sigma \ CP \) asymmetry at the \( \rho-\omega \) interference region. The branching ratios quoted in Table 1 are assumed. In some of these decay modes, \( 3\sigma-CP \) violations are detectable with \( 10^9 \ BB \) events by the \( \rho-\omega \) interference modes. If a good method can be found to suppress the background from the continuum, the necessary luminosity can be significantly reduced. Also, at this conference, CLEO indicated that the branching ratio of \( B \rightarrow \omega K \) is on the order of \( 10^{-5} \). If this is correct, the necessary luminosity will be greatly reduced to \( \sim 30 \ fb^{-1} \), i.e., definitely within an experiment involving a few years.

6 Conclusion

We have studied the effect of \( \rho-\omega \) interference in the decay modes \( B \rightarrow \rho^0(\omega)h, \rho^0(\omega) \rightarrow \pi^+\pi^- \), where \( h \) is any hadronic final state, such as \( \pi, \rho \), or \( K \). Although the isospin-violating decay of \( \omega \rightarrow \pi^+\pi^- \) is a small effect with \( BR=2.2 \% \), the interference at the kinematical region \( M(\pi^+\pi^-) \sim M(\omega) \pm \Gamma_\omega \) is enhanced by the \( \omega \) pole. We have shown the \( CP \) asymmetry to be sufficiently large to be detected. The \( CP \) asymmetry appears in the deformation of the Breit-Wigner shape of the \( \rho^0 \rightarrow \pi^+\pi^- \) invariant mass spectrum. The prediction of the \( CP \) asymmetry is not very sensitive to the hadronic phase calculation, i.e., a “sure” prediction. Any B-factory, even if it is a symmetric \( e^+e^- \) collider or hadron machine, can carry out this measurement. We only need to accumulate enough statistics and to have a mass resolution \( [\Delta M(\pi^+\pi^-)] \) better than the width of the \( \omega \) meson (8.4MeV) at around the \( \omega \) mass region.

Acknowledgments

We thank Drs. M. Kobayashi, A. I. Sanda, A. Soni, M. Tanaka and I. Dunietz for useful discussions. We also thank the Belle collaboration for providing the detector simulation programs. This work was partially supported by the Inoue Foundation for Science and the Grant-in-Aid of Monbusho (the Japanese Ministry of Education, Science, Sports and Culture) #09740185 and #09246203.
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