CP Violation in Selected B Decays*

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ABSTRACT

We summarize the results of two papers in which we have studied CP violation in inclusive and exclusive decays $b \rightarrow d e^+ e^-$. Two CP-violating effects are calculated: the partial rate asymmetry between $b$ and $\bar{b}$ decay, and the asymmetry between $e^-$ and $e^+$ spectra for an untagged $B/\bar{B}$ mixture. These asymmetries, combined with the branching ratio, can potentially determine the parameters $(\rho, \eta)$ of the unitarity triangle. We also summarize a paper by Browder et al. on a possible CP-violating asymmetry in the inclusive reaction $B \rightarrow K^-(K^{*-})X$.

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Abstract. We summarize the results of two papers in which we have studied CP violation in inclusive and exclusive decays $b \rightarrow d e^+ e^-$. Two CP-violating effects are calculated: the partial rate asymmetry between $b$ and $\bar{b}$ decay, and the asymmetry between $e^-$ and $e^+$ spectra for an untagged $B/\bar{B}$ mixture. These asymmetries, combined with the branching ratio, can potentially determine the parameters $(\rho, \eta)$ of the unitarity triangle. We also summarize a paper by Browder et al. on a possible CP-violating asymmetry in the inclusive reaction $B \rightarrow K^-(K^{*-})X$.

1 Decay $b \rightarrow d e^+ e^-$

The decay $b \rightarrow d e^+ e^-$ invites attention as a testing ground for CP for the following reason [1, 2]. The effective Hamiltonian for $b \rightarrow q e^+ e^-$ ($q = d, s$) calculated on the basis of electroweak box and penguin diagrams (see, for example, Ref. [3]) has the structure

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}} V_{tb} V_{tq}^* \left\{ c_9 (\bar{q} \gamma_\mu P_L b) \bar{l} \gamma^\mu l + c_{10} (\bar{q} \gamma_\mu P_L b) \bar{l} \gamma^\mu \gamma^5 l \right\} - 2 c_9 \frac{q^\nu}{q^2} (m_b P_R + m_q P_L) b \bar{l} \gamma^\nu l,$$

(1)

where the coefficients have numerical values $c_9^{\text{eff}} = -0.315$, $c_9 = 4.227$, and $c_{10} = -4.642$, and $P_{L,R} = (1 \mp \gamma_5)/2$. There is, however, a correction to $c_9$ associated with $\bar{u}u$ and $\bar{c}c$ loop contributions generated by the nonleptonic interaction $b \rightarrow q u \bar{u}$ and $b \rightarrow q c \bar{c}$:

$$c_9^{\text{eff}} \approx c_9 + (3c_1 + c_2) \left\{ g(m_c,s) + \lambda_u \left[ g(m_c,s) - g(m_u,s) \right] \right\},$$

(2)

where the loop functions $g(m_c,s)$ and $g(m_u,s)$ have absorptive parts for $s > 4m_c^2$ and $s > 4m_u^2$, and the coefficient $(3c_1 + c_2) \approx 0.36$. The complex coefficient $\lambda_u = (V_{ub}^* V_{uq}^*)/(V_{tb} V_{tq}^*)$ is of order $\lambda^2$ in the case of $b \rightarrow s e^+ e^-$ ($q = s$), but of order unity in the case of $b \rightarrow d e^+ e^-$ ($q = d$). Notice that $\arg((V_{ub} V_{uq}^*)/(V_{tb} V_{tq}^*)) = \beta + \gamma$, where $\beta, \gamma$ are the base angles of the unitarity triangle. For this latter reaction, therefore, the Hamiltonian possesses both

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the weak (CKM) and dynamical (unitarity) phases that are mandatory for observable CP violation.

The inclusive aspects of the decay $B \to X_d e^+ e^-$ can be calculated in the parton model approximation. The differential cross section $d\Gamma/ds$ is a quadratic function of the couplings $c_9^{\text{eff}}$, $c_9^{\text{eff}}$ and $c_{10}$. The spectrum of the antiparticle reaction $\bar{b} \to \bar{d} e^+ e^-$ is obtained by replacing $\lambda_u$ by $\lambda_u^*$, giving rise to a partial rate asymmetry

$$A_{\text{CP}}(s) = \frac{d\Gamma/ds - d\bar{\Gamma}/ds}{d\Gamma/ds + d\bar{\Gamma}/ds} = \frac{\eta}{(1 - \rho)^2 + \eta^2} \times (\text{kinematical factor}) . \quad (3)$$

A second spectral feature is the angular distribution of the $e^-$ in the $e^- e^+$ centre-of-mass system, $d\Gamma/d\cos\theta$, which contains a term linear in $\cos\theta$, producing a forward-backward asymmetry

$$A_{\text{FB}}(s) = c_{10} \left[ \hat{s} \text{Re} c_9^{\text{eff}} + 2c_7^{\text{eff}} \left( 1 + \hat{m}_d^2 \right) \right] \times (\text{kinematical factor}) \quad (4)$$

with the notation $\hat{s} = s/m_b^2$ and $\hat{m}_d = m_d/m_b$. The corresponding asymmetry of the $e^+$ in $\bar{b} \to \bar{d} e^+ e^-$ is obtained by replacing $\lambda_u$ by $\lambda_u^*$ in $c_9^{\text{eff}}$ [cf. Eq. (2)]. The difference of $A_{\text{FB}}$ and $\bar{A}_{\text{FB}}$ is a CP-violating effect

$$\delta_{\text{FB}} = A_{\text{FB}} - \bar{A}_{\text{FB}} = c_{10} \frac{\eta}{(1 - \rho)^2 + \eta^2} \times (\text{kinematical factor}) . \quad (5)$$

Notice that $\delta_{\text{FB}}$ is twice the forward-backward asymmetry of the electron produced by an equal mixture of $B$ and $\bar{B}$ mesons. Equivalently, $\delta_{\text{FB}}$ is twice the energy asymmetry of $e^+$ and $e^-$ produced by a $B/\bar{B}$ mixture:

$$A_{\text{E}} = \frac{\Gamma(E_+ > E_-) - \Gamma(E_+ < E_-)}{\Gamma(E_+ > E_-) + \Gamma(E_+ < E_-)} = \frac{1}{2} \delta_{\text{FB}} , \quad (6)$$

where $E_\pm$ denote the lepton energies in the $B$ rest frame. The branching ratio of $b \to d e^+ e^-$ is clearly proportional to $|V_{td}|^2 \sim (1 - \rho)^2 + \eta^2$. A measurement of the branching ratio, together with the asymmetry $A_{\text{CP}}$ or $\delta_{\text{FB}}$ can potentially provide a self-contained determination of the parameters $(\rho, \eta)$ of the unitarity triangle, as illustrated in Fig. 1 (for related discussions, see [5]). In [2], we have investigated the exclusive channels $B \to \pi e^+ e^-$ and $B \to \rho e^+ e^-$, employing different models for the form factors [6, 7]. Some representative results are given in Table 1.

### 2 CP Violation in Inclusive $B \to K^{(*)} X$

In a paper by Browder et al. [8], attention is focussed on the decays $B^- \to K^{(*)-} X$ and $B^0 \to K^{(*)-} X$ with a highly energetic $K$ ($K^*$), the system $X$ containing $u$ and $d$ quarks only. By requiring $E_{K^{(*)}} > 2$ GeV, the background from $b \to c \to s$ is effectively suppressed. An attempt is made to relate such “quasi-inclusive” decays to the elementary process $b \to s g^* \to s\bar{u}u$
Fig. 1. Constraints on $(\rho, \eta)$ imposed by measurement of branching ratio $B_r$ for $B \to X_d e^+ e^-$, combined with the $CP$-violating asymmetries $A_{CP}$ (a) or $\delta_{FB}$ (b).

Table 1. Branching ratios, forward-backward asymmetries, and the $CP$-violating asymmetries $A_{CP}$ and $\delta_{FB}$ in inclusive and exclusive $b \to d e^+ e^-$ reactions $(\rho = -0.07, \eta = 0.34)$.

|                  | $B \to X_d e^+ e^-$ | $B \to \pi e^+ e^-$ | $B \to \rho e^+ e^-$ |
|------------------|----------------------|---------------------|---------------------|
| $B_r$            | $5.5 \times 10^{-7}$ | $3.1 \times 10^{-8}$ | $5.0 \times 10^{-8}$ |
| $\langle A_{FB} \rangle$ | $-9\%$                | $\equiv 0$          | $-17\%$            |
| $\langle A_{CP} \rangle$ | $-2.7\%$               | $-3.1\%$           | $-2.8\%$           |
| $\langle \delta_{FB} \rangle$ | $+1\%$                | $\equiv 0$          | $+2\%$             |

$^a$ for $1 \text{GeV} < \sqrt{s} < 3 \text{GeV}$.

$^b$ using form factors of Melikhov and Nikitin [7].
Interference of this process with the tree-level transition $b \to s\bar{u}u$ generates a CP-violating asymmetry between $B \to K^{(*)} X$ and $\bar{B} \to K^{(*)} \bar{X}$. The implementation of this idea involves an effective Hamiltonian containing a tree-level term proportional to $V_{ub} V_{us}^*$ and a QCD penguin interaction $\sim (V_{ub} V_{us}^* G_u + V_{cb} V_{cs}^* G_c)$, where $G_u(q^2)$ and $G_c(q^2)$ are functions denoting the $u\bar{u}$ and $c\bar{c}$ loop contributions to $b \to sg^*$. For the transition $b \to su\bar{u}$, the essential unitarity phase comes from $G_c(q^2)$ for $q^2 > 4m_c^2$.

The hadronic amplitude for $B \to K^{(*)} X$ is simulated by two types of matrix elements, one of which has the kinematical features of $B^+\to K^- u\bar{u}$ ("three-body" decay) while the other resembles $b \to K^- u$ ("two-body" decay). The latter is the principal source of energetic $K$'s. While the calculation involves several uncertainties, e.g. the choice of $q^2$ in $G_c(q^2)$, asymmetries of order 10%, with branching ratios $\text{Br}(B \to KX, E_K > 2\text{ GeV}) \sim 10^{-4}$ are shown to be possible. Since evidence for QCD penguins is emerging from the two-body decays of the $B$ meson [9], a search for $b \to sg^*$ in inclusive $B \to KX$, and the associated CP asymmetry, would be of interest.

References

[1] F. Krüger and L. M. Sehgal, Phys. Rev. D55 (1997) 2799.
[2] F. Krüger and L. M. Sehgal, Phys. Rev. D56 (1997) 5452.
[3] G. Buchalla, A.J. Buras and M.E. Lautenbacher, Rev. Mod. Phys. 68 (1996) 1125.
[4] A. Ali, T. Mannel and T. Morozumi, Phys. Lett. B273 (1991) 505.
[5] L.T. Handoko, preprint hep-ph/9707222; C.S. Kim, T. Morozumi and A.I. Sanda, preprint hep-ph/9708299 (to appear in Phys. Rev. D);
S. Rai Choudhury Phys. Rev. D56 (1997) 6028.
[6] P. Colangelo, F. De Fazio, P. Santorelli and E. Scrimieri, Phys. Rev. D53 (1996) 3672.
[7] D. Melikhov and N. Nikitin, preprint hep-ph/9609503.
[8] T.E. Browder, A. Datta, X.G. He and S. Pakvasa, preprint hep-ph/9705320.
[9] M. Neubert, these proceedings.