Probing anomalous right-handed top quark couplings

in rare B decays

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Abstract

We explore the anomalous right-handed $\bar{t}sW$ and $\bar{t}bW$ couplings using $B \to X_s\gamma$ and $B \to X_sl^+l^-$ decays induced by the flavour-changing penguin diagrams. The anomalous $\bar{t}sW$ coupling can yield 10% enhancement of the $B \to X_sl^+l^-$ decay rate under the constraint from the present $B \to X_s\gamma$ data, while it does not affect the forward-backward asymmetry of the charged lepton. The allowed region for anomalous $\bar{t}bW$ coupling by the $B \to X_s\gamma$ constraint is two-fold, the small value region and the large value region. Though the effect of the small anomalous coupling on the $B \to X_sl^+l^-$ branching ratio is very little, it can yield a substantial change for the forward-backward

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I. INTRODUCTION

After the discovery of the top quark at Tevatron [1,2], several properties of the top quark have been examined such as top quark mass [3], production cross section [4], and the production kinematics [5] etc. The production of $10^7 - 10^8$ top quark pairs per year is expected at Large Hadron Collider (LHC), which will allow us to study the detailed structure of top quark couplings [6]. The top quark dominantly decays through the $t \rightarrow bW$ channel and other channels are highly suppressed by small mixing angles. Thus the $\bar{t}bW$ coupling will be measured at LHC with high precision. Effects of the anomalous $\bar{t}bW$ coupling have been studied in many literatures in direct and indirect ways [7–11]. The subdominant channel in the Standard Model (SM) is the Cabbibo-Kobayashi-Maskawa (CKM) nondiagonal decay $t \rightarrow sW$ of which branching ratio is estimated as

$$Br(t \rightarrow sW) \sim 1.6 \times 10^{-3},$$

when $|V_{ts}| = 0.04$ is assumed. Though the branching ratio of this channel is rather small, the large number of expected top quark production at LHC will give us a chance to measure the $t \rightarrow sW$ process and enable us to probe the $\bar{t}sW$ coupling responsible for this channel directly. Therefore the anomalous $\bar{t}sW$ coupling, which has not been seriously examined yet, is worth examining at present.

Before the LHC, we can study the top quark couplings indirectly in rare $B$ decays. Rare $B$ decays involving loop induced flavour-changing neutral transitions are sensitive to the properties of internal heavy particles, so they can provide a good probe of new physics beyond the SM. The radiative $b \rightarrow s\gamma$ and semileptonic $b \rightarrow sl^+l^-$ decay are the most promising channels to examine the new physics effects. The branching ratio of inclusive $B \rightarrow X_s\gamma$ decay has been measured by CLEO [12], ALEPH [13] groups and recently by Belle collaboration from a 5.8 fb$^{-1}$ data sample [14]. We have the weighted average of the branching ratio of this channel as

$$Br(B \rightarrow X_s\gamma) = (3.23 \pm 0.41) \times 10^{-4},$$

from those measurements. This channel has intensively studied at next-leading order (NLO) in the SM [15,16] and has provided stringent constraints on various new physics models [17–20]. On the other hand, the first observation of $b \rightarrow sl^+l^-$ decay is reported by the Belle group through the exclusive $B \rightarrow Kl^+l^-$ channel [21]

$$Br(B \rightarrow Kl^+l^-) = (0.75^{+0.25}_{-0.21} \pm 0.09) \times 10^{-6},$$

from a 30 fb$^{-1}$ data. BaBar collaboration also present a bound on this mode and the $B \rightarrow K^*\mu^+\mu^+$ mode [22]. The inclusive $B \rightarrow X_s l^+l^-$ decay rate is to be measured soon as more data of $B$ decay will be accumulated. The measurement of this mode provides a complementary study on the flavour-changing penguin decays.

In this work, we examine the effects of the anomalous right-handed $\bar{t}bW$ and $\bar{t}sW$ couplings on the inclusive $B \rightarrow X_s\gamma$ and $B \rightarrow X_s l^+l^-$ decays. We concentrate on the anomalous couplings of charged current interactions and ignore effects of new particles and the neutral current interactions. With the anomalous right-handed couplings, we write the effective lagrangian as
\[ \mathcal{L} = -\frac{g}{\sqrt{2}} \sum_{q=s,b} V_{tq} \bar{q} \gamma^\mu (P_L + \xi_q P_R) t W^-_\mu + \text{H.c.}, \]  

(4)

where \( \xi_q \) measures the new physics effects. In section 2, we present the effective Hamiltonian approach with the effective lagrangian Eq. (4). The \( B \to X_s \gamma \) and \( B \to X_s l^+l^- \) decays are described in terms of the effective Hamiltonian and the effects of the anomalous couplings are analyzed in section 3. Our conclusion is given in section 4.

II. THE EFFECTIVE HAMILTONIAN

In order to study the rare decay processes of \( B \) meson, the effective field theoretical approach is required to incorporate the consistent QCD correction, which is substantial in rare \( B \) decays. We can write the \( \Delta B = 1 \) effective Hamiltonian to describe \( b \to s \gamma \) and \( b \to s l^+l^- \) processes as

\[ \mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{ts} V_{tb} \sum_{i=1}^{10} (C_i(\mu)O_i(\mu) + C_i'(\mu)O_i'(\mu)), \]  

(5)

where the dimension 6 operators \( O_i \) constructed in the SM are given in the Ref. [23], and \( O_i' \) are their chiral conjugate operators. Matching the effective theory (5) and the lagrangian (4) at \( \mu = m_W \) scale, we have the Wilson coefficients \( C_i(\mu = m_W) \) and \( C_i'(\mu = m_W) \). When we let \( \xi_q = 0 \), we have the Wilson coefficients in the SM

\[
\begin{align*}
C_2(m_W) &= -1, \\
C_7(m_W) &= F(x_t), \\
C_8(m_W) &= G(x_t), \\
C_9(m_W) &= C_9^\prime + C_9^Z + C_9^{\Box} \\
&= -D_0(x_t) - 4 \left(1 - \frac{1}{4 \sin^2 \theta_W} \right) C_0(x_t) - \frac{1}{\sin^2 \theta_W} B_0(x_t), \\
C_{10}(m_W) &= C_{10}^Z + C_{10}^{\Box} \\
&= -\frac{1}{\sin^2 \theta_W} C_0(x_t) + \frac{1}{\sin^2 \theta_W} B_0(x_t), \\
C_i(m_W) &= C_i'(m_W) = 0, \quad \text{otherwise},
\end{align*}
\]

(6)

where \( F(x), G(x), D_0(x), C_0(x), B_0(x) \) are the well-known Inami-Lim loop functions [23,24]:

\[
\begin{align*}
F(x) &= \frac{x(7 - 5x - 8x^2)}{24(x-1)^3} - \frac{x^2(2 - 3x)}{4(x-1)^4} \ln x, \\
G(x) &= \frac{x(2 + 5x - x^2)}{8(x-1)^3} - \frac{3x^2}{4(x-1)^4} \ln x, \\
D_0(x) &= -\frac{4}{9} \ln x + \frac{x^2(25 - 19x)}{36(x-1)^3} + \frac{x^2(5x^2 - 2x - 6)}{18(x-1)^4} \ln x, \\
C_0(x) &= \frac{x}{8} \left( \frac{x - 6}{x - 1} + \frac{3x + 2}{(x - 1)^2} \ln x \right), \\
B_0(x) &= \frac{1}{4} \left( \frac{x}{1 - x} + \frac{x}{(x - 1)^2} \ln x \right).
\end{align*}
\]

(7)
Let us switch on the right-handed $tbW$ and $tsW$ couplings. Keeping the effects of anomalous couplings in linear order, we obtain the modified Wilson coefficients

$$C_7 \rightarrow C_7^{\text{SM}} + \xi_t \frac{m_t}{m_b} \tilde{F}(x_t),$$
$$C_8 \rightarrow C_8^{\text{SM}} + \xi_t \frac{m_t}{m_b} \tilde{G}(x_t),$$
$$C_9 \rightarrow C_9^{\text{SM}} - \xi_b \frac{m_b}{m_t} \tilde{D}(x_t),$$

and the new Wilson coefficients

$$C_7' = \xi_s \frac{m_t}{m_b} \tilde{F}(x_t),$$
$$C_8' = \xi_s \frac{m_t}{m_b} \tilde{G}(x_t),$$
$$C_9' = -\xi_s \frac{m_b}{m_t} \tilde{D}(x_t),$$

with the new loop functions

$$\tilde{F}(x) = \frac{-20 + 31x - 5x^2}{12(x - 1)^2} + \frac{x(2 - 3x)}{2(x - 1)^3} \ln x,$$
$$\tilde{G}(x) = \frac{-4 + x + x^2}{4(x - 1)^2} + \frac{3x}{2(x - 1)^3} \ln x,$$
$$\tilde{D}(x) = \frac{x(59 - 38x + 25x^2 + 2x^3)}{36(x - 1)^4} - \frac{2(x + 1)}{3(x - 1)^5} \ln x - \frac{x^2}{2(x - 1)^4} \ln x.$$

Our new loop functions $\tilde{F}(x)$ and $\tilde{G}(x)$ agree with those in Ref. [19] and $\tilde{D}(x)$ is the first calculation. Note that the $O(\xi)$ terms of $Z$–penguin diagram are suppressed by the heavy mass of $Z$–boson as $m_b^2/m_Z^2$, or $q^2/m_Z^2$ and we neglect them here. For the box diagram, the $O(\xi)$ terms vanish by the chirality relation and the leading contribution is of $\xi^2$ order. As a consequence, the contribution of order $O(\xi)$ comes only through the $\gamma$-penguin and gluon penguin diagrams. Thus there exists no new effect in $C_{10}$ and $C'_{10} = 0$.

The renormalization group (RG) evolution of the Wilson coefficients $C = (C_i, C'_i)^\dagger$ given by

$$\mu \frac{d}{d\mu} C(M_W) = -\frac{g^2}{16\pi^2} \gamma^T C(M_W),$$

is governed by a $20 \times 20$ anomalous dimension matrix $\gamma$. Since the strong interaction preserves chirality, the operators $Q'_i$ are evolved separately without mixing between those and the SM operators. Thus the $20 \times 20$ anomalous dimension matrix $\gamma$ is decomposed into two identical $10 \times 10$ matrices $\gamma_0$ given in the SM as

$$\gamma = \begin{pmatrix} \gamma_0 & 0 \\ 0 & \gamma_0 \end{pmatrix},$$

The $10 \times 10$ anomalous dimension matrix $\gamma_0$ has been calculated to leading logarithmic level in Ref. [25,26]. Using the initial condition at $\mu = m_W$, the

5
(C_i(M_W), C_i'(M_W)) = (0, -1, 0, 0, 0, C_7, C_8, C_9, C_{10}, 0, 0, 0, 0, C_7', C_8', C_9', 0), \quad (11)

we can solve the RG equation to obtain the Wilson coefficients evolved from \( \mu = m_W \) to \( \mu = m_b \) scales.

### III. RARE B DECAYS

#### A. \( B \to X_s \gamma \)

The branching ratio of \( B \to X_s \gamma \) process with the right-handed interactions are obtained at NLO

\[
\text{Br}(B \to X_s \gamma) = \frac{\text{Br}(B \to X_c e \bar{\nu})}{10.5\%} \\
\times \left[ B_{22}(\delta) + B_{77}(\delta)(|r_7|^2 + |r'_7|^2) + B_{88}(\delta)(|r_8|^2 + |r'_8|^2) \right. \\
\left. + B_{27}(\delta) \Re(r_7) + B_{28}(\delta) \Re(r_8) + B_{78}(\delta)(\Re(r_7 r_8^*) + \Re(r'_7 r'_8^*)) \right], \quad (12)
\]

where the ratios \( r_i \) and \( r'_i \) are defined by

\[
r_i = \frac{C_i(m_W)}{C_i^{SM}(m_W)} = 1 + \frac{C_i^{\text{New}}(m_W)}{C_i^{SM}(m_W)}, \quad \text{and} \quad r'_i = \frac{C'_i(m_W)}{C'_i^{SM}(m_W)}. \quad (13)
\]

The components \( B_{ij}(\delta) \) depends on the kinematic cut \( \delta \), of which numerical values are given in the Ref. [15].

With the measured branching ratio, Eq. (2), we can set the conservative bounds on the parameter \( \xi_b \) and \( \xi_s \) as

\[
-0.0021 < \xi_b < 0.0031 \quad \text{(A)}, \quad -0.0485 < \xi_b < -0.0433 \quad \text{(B)}, \quad |\xi_s| < 0.012, \quad (14)
\]

at 2-\( \sigma \) level. We assume that \( \xi_b \) and \( \xi_s \) are real for simplicity. The anomalous coupling \( \xi_b \) contributes in the linear and quadratic order while \( \xi_s \) dominantly contributes in the quadratic order since the contribution of the linear order is strongly suppressed by the ratio \( m_s^2/m_b^2 \).

Thus the parameter \( \xi_s \) is less constrained by the \( B \to X_s \gamma \) measurement than \( \xi_b \) in general. Due to the cancellation by the interference term \( B_{27} \Re(r_7) \), however, the large \( |\xi_b| \) solution in the region B is also allowed, which gives the positive Wilson coefficient \( C_7(m_W) > 0 \).

#### B. \( B \to X_s l^+ l^- \)

The dilepton invariant mass distribution of \( B \to X_s l^+ l^- \) decays consists of following contributions:

\[
\frac{d\text{Br}(B \to X_s l^+ l^-)}{d\hat{s}} = \frac{dB_0}{d\hat{s}} + \frac{dB_{1/m_b^2}}{d\hat{s}} + \frac{dB_{1/q^2}}{d\hat{s}}, \quad (15)
\]

where the first term denotes the decay at the parton level, the second term the power correction in the heavy quark effective theory (HQET), and the last term is due to the
nonperturbative virtual quark loop effects with soft gluon. We have the explicit expression including the HQET corrections of order $O(1/m_b^2)$ given in Ref. [27, 29],
\[
\frac{d\text{Br}(B \to X_c\ell^+\ell^-)}{d\hat{s}} = 2B_0 \left[ \frac{\left( \frac{1}{3}(1 - \hat{s})^2(1 + 2\hat{s})(2 + \hat{\lambda}_1) + (1 - 15\hat{s}^2 + 10\hat{s}^3)\hat{\lambda}_2 \right)}{\left( |C_9|^2 + |C'_9|^2 + |C_{10}|^2 \right)} \times \left( \frac{4}{3}(1 - \hat{s})^2(2 + \hat{s})(2 + \hat{\lambda}_1) + 4(-6 - 3\hat{s} + 5\hat{s}^3)\hat{\lambda}_2 \right) \right]
\]
\[
= \frac{\left( |C'_7|^2 + |C''_7|^2 \right)}{\hat{s}} \frac{\left( 4(1 - \hat{s})^2(2 + \hat{\lambda}_1) + 4(-5 - 6\hat{s} + 7\hat{s}^2)\hat{\lambda}_2 \right)}{\Re(C_7C''_8 + C'_7C''_8)},
\]
where $\hat{s} = (p_+ + p_-)^2/m_b^2$ is the normalized dilepton invariant mass, $\hat{\lambda}_{1,2} = \lambda_{1,2}/m_b^2$ the normalized HQET parameters, and the normalization constant is given by
\[
B_0 \equiv \text{Br}(B \to X_c\ell\ell^+) \frac{3\alpha^2}{16\pi^2} \frac{|V_{tb}^\ast V_{cb}|^2}{|V_{cb}|^2} \frac{1}{f(m_c)\kappa(m_c)},
\]
with the phase space function $f(m_c)$ and the perturbative QCD correction $\kappa(m_c)$ of $B \to X_c\ell\ell$ decay. The long-distance correction due to the virtual $c\bar{c}$ loop is considered in Ref. [30]. Numerically this correction is at 1 - 2% level in the region of $\hat{s}$ considered here away from the resonances and we ignore them. We plot the differential branching ratio with respect to $\hat{s}$ in the Fig. 1. The values of $\xi_{b,s}$ given in Eq. (14) are used. We consider the region for $\hat{s}$ as $1\text{ GeV}^2 < \hat{s}m_b^2 < 7.5\text{ GeV}^2$ in order to avoid the large resonant contribution of $J/\psi$ and $\psi'$. We show that the total decay rate over this region is enhanced by the anomalous couplings. The $\xi_s = 0.012$ leads to 10% enhancement of the branching ratio. The enhancement by $\xi_b$ in the region A is less than 1% and the branching ratio with $\xi_b$ in the region B is more than twice the SM prediction since there is no interference term between $C_2$ and $C_7$ in the $B \to X_c\ell^-\ell^+$ decay rate, which cancels the enhanced $|C'_7|^2$ contribution. Hence such a enhancement should be observed in the near future, if $\xi_b$ coupling in the region B exists.

The forward-backward (FB) asymmetry $A_{FB}$ is defined as
\[
\frac{dA_{FB}}{d\hat{s}} = \int_0^1 d^2\text{Br}d\cos\theta d\cos\theta - \int_{-1}^0 d^2\text{Br}d\cos\theta d\cos\theta,
\]
where the angle $\theta$ is measured between $b$-quark and the positively charged lepton $l^+$ in the dilepton center-of-mass (CM) frame. The $A_{FB}$ distribution with respect to $\hat{s}$ is depicted in the Fig. 2. We find that $\xi_b$ in the region A can bring a substantial shift of the differential FB asymmetry although the branching ratio is not much affected. It is because the branching ratio is dominated by the SM contribution $|C_9|^2 + |C_{10}|^2$ but $A_{FB}$ is proportional to the substantial Wilson coefficient $C_{10}$ and shifted by the term $\sim \xi_b C_{10}$. As a consequence, $A_{FB}$ summed over the region considered here is enhanced by 4 times with $\xi_b = -0.0021$ and even its sign is changed if $\xi_b = 0.0031$. With $\xi_b$ in the region B, the shift of $dA_{FB}/d\hat{s}$ is huge as is the case of decay rate, because of the large shift of $C_7$. Besides, the anomalous $\bar{t}sW$ coupling does not affect $A_{FB}$, since $C''_7 = 0$. 7
IV. CONCLUDING REMARKS

We studied rare $B$ decays with the anomalous right-handed $\bar{t}bW$ and $\bar{t}sW$ couplings in the model-independent way. This kind of anomalous couplings can be obtained in the general left-right (LR) model based on $SU(2)_L \times SU(2)_R \times U(1)$ gauge group \[31\] or the dynamical electroweak symmetry breaking model \[32\]. In the LR model, the right-handed quark mixing is also an observable. If we do not demand the symmetry between left- and right-handed sectors manifest, the right-handed quark mixing is not necessarily identical to the left-handed quark mixing described by the CKM matrix. Thus we have right-handed charged current interactions, which is suppressed by the heavy mass of extra $W$ boson, but still enhanced relatively by the right-handed quark mixing matrix. On the other hand, when the electroweak symmetry breakdown is dynamical, one may expect that some nonuniversal interactions exist which lead to anomalous couplings on charged current interactions.

The constraint on $\xi_s$ by the $B \to X_s \gamma$ data is weaker than that of $\xi_b$ in the region A by the chirality relation. As a result, the considerable enhancement of the branching ratios for $B \to X_s l^+ l^-$ decay is possible with the anomalous $\bar{t}sW$ coupling while the influence of the anomalous $\bar{t}bW$ coupling in the region A is rather small. Besides anomalous $\bar{t}bW$ coupling can change the forward-backward asymmetry considerably under the $B \to X_s \gamma$ constraints, and even the sign of $A_{FB}$ may be reversed while the anomalous $\bar{t}sW$ coupling does not affect $A_{FB}$. Therefore it is possible to discriminate the effects of the anomalous $\bar{t}bW$ and $\bar{t}sW$ couplings if we combine the analysis of the branching ratio and $A_{FB}$ for $B \to X_s l^+ l^-$ process. On the other hand, relatively large value of $|\xi_b|$ in the region B is also allowed due to the cancellation between the $C_2 C_7$ and $|C_7|^2$ terms for $B \to X_s \gamma$ decay, which leads to much larger branching ratio and altered $A_{FB}$ for $B \to X_s l^+ l^-$ decay. The measured branching ratio of the exclusive $B \to K l^+ l^-$ decay given in Eq. (3), is rather higher than the SM prediction, though it is still consistent with the SM \[33\] due to large errors and theoretical uncertainties. Thus it may be the clue of the new physics signal and the anomalous coupling $\xi_b$ in the region B can be a candidate of the new physics. If we measure $A_{FB}$ in the future, it will be a clear probe of the nature of the top quark anomalous couplings.

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REFERENCES

[1] F. Abe et al., CDF Collaboration, Phys. Rev. Lett. 73, 225 (1994).
[2] F. Abe et al., CDF Collaboration, Phys. Rev. Lett. 74, 2626 (1995); S. Abachi et al., D0 Collaboration, Phys. Rev. Lett. 74, 2632 (1995).
[3] S. Abachi et al., D0 Collaboration, Phys. Rev. Lett. 79, 1197 (1997); D. Abbott et al., D0 Collaboration, Phys. Rev. Lett. 80, 2063 (1998); Phys. Rev. D 58, 052001 (1998); Phys. Rev. D 60, 052001 (1999); F. Abe et al., CDF Collaboration, Phys. Rev. Lett. 80, 2767 (1998); ibid. 2779; Phys. Rev. Lett. 82, 271 (1999).
[4] S. Abachi et al., D0 Collaboration, Phys. Rev. Lett. 79, 1203 (1997); F. Abe et al., CDF Collaboration, Phys. Rev. Lett. 80, 2773 (1998).
[5] F. Abe et al., CDF Collaboration, Phys. Rev. D 59, 092001 (1999).
[6] M. Beneke et al., hep-ph/0003033.
[7] F. Larios, M.A. Perez, and C.P. Yuan, Phys. Lett. B 457, 334 (1999).
[8] E. Boos, A. Pukhov, M. Sachwitz, and H.J. Schreiber, Phys. Lett. B 404, 119 (1997); E. Boos, M. Dubinin, M. Sachwitz, and H.J. Schreiber, Eur. Phys. J. C 16, 269 (2000).
[9] S.D. Rindani, Pramana 54, 791 (2000).
[10] A. Abd El-Hady and G. Valencia, Phys. Lett. B 414, 173 (1997).
[11] C.-X. Yue, G.-R. Lu, and W.-B. Li, Chinese Phys. Lett. 18, 349 (2001).
[12] S. Chen et al., CLEO Collaboration, Phys. Rev. Lett. 87, 251807 (2001).
[13] R. Barate et al., ALEPH Collaboration, Phys. Lett. B 429, 169 (1998).
[14] Belle Collaboration, hep-ex/0111037, to appear in the proceedings of 20th International Symposium on Lepton and Photon Interactions at High Energies (Lepton Photon 01), Rome, Italy, 23-28 July 2001.
[15] A.L. Kagan and M. Neubert, Eur. Phys. J. C 7, 5 (1999).
[16] A.J. Buras, A. Czarnecki, M. Misiak, and J. Urban, hep-ph/0203133; A.J. Buras, A. Czarnecki, M. Misiak, and J. Urban, Nucl. Phys. B611, 488 (2001); P. Gambino and M. Misiak, Nucl. Phys. B611, 338 (2001); K. Chetyrkin, M. Misiak, and M. Münn, Phys. Lett. B 400, 206 (1997); Erratum ibid B 425, 414 (1998); C. Greub, T. Hurth, and D. Wyler, Phys. Rev. D 54, 3350 (1996).
[17] H. Baer and M. Brhlik, Phys. Rev. D 55, 3201 (1997); H. Baer, M. Brhlik, D. Castano, and X. Tata, Phys. Rev. D 58, 015007 (1998); Y.G. Kim, P. Ko, and J.S. Lee, Nucl. Phys. B544, 64 (1999); M. Carena, D. Garcia, U. Nierste, and C.E.M. Wagner, Phys. Lett. B 499, 141 (2001); G. Degrassi, P. Gambino, and G.F. Giudice, JHEP 0012, 009 (2000).
[18] C.S. Kim and Y.G. Kim, Phys. Rev. D 61, 054008 (2000).
[19] P. Cho and M. Misiak, Phys. Rev. D 49, 5894 (1994).
[20] K. Agashe, N.G. Deshpande, and G.H. Wu, Phys. Lett. B 514, 309 (2001); C.S. Kim, J.D. Kim, and J. Song, hep-ph/0204002.
[21] K. Abe et al., Belle Collaboration, Phys. Rev. Lett. 88, 021801 (2002).
[22] B. Aubert et al., BaBar Collaboration, hep-ex/0201008.
[23] A.J. Buras, hep-ph/9806471; G. Buchalla, A.J. Buras, and M.E. Lautenbacher, Rev. Mod. Phys. 68, 1125 (1996).
[24] T. Inami and C.S. Lim, Prog. Theo. Phys. 65, 297 (1981).
[25] M. Ciuchini, E. Franco, L. Reina, and L. Silvestrini, Nucl. Phys. B421, 41 (1994); M. Ciuchini et al., Phys. Lett. B 316, 127 (1993).
[26] A. Buras, M.E. Lautenbacher, M. Misiak, and M. Münz, Nucl. Phys. B423, 349 (1994).
[27] A. Ali, G.F. Giudice, and T. Mannel, Z. Phys. C 67, 417 (1995).
[28] A. Ali, G. Hiller, L.T. Handoko, and T. Morozumi, Phys. Rev. D 55, 4105 (1997).
[29] A.J. Buras and M. Münz, Phys. Rev. D 52, 186 (1995).
[30] G. Buchalla and G. Isidori, Nucl. Phys. B525, 333 (1998); G. Buchalla, G. Isidori, and S.J. Rey, Nucl. Phys. B511, 594 (1998).
[31] For review, see R.N. Mohapatra, Unification and Supersymmetry (Springer, New York, 1986); D. London and D. Wyler, Phys. Lett. B 232, 503 (1989); T. Kurimoto, A. Tomita, and S. Wakaizumi, Phys. Lett. B 381, 470 (1996); J. Chay, K.Y. Lee, and S.-h. Nam, Phys. Rev. D 61, 035002 (2000); J.-h. Jang, K.Y. Lee, S.C. Park, and H.S. Song, [hep-ph/0010107].
[32] R.D. Peccei and X. Zhang, Nucl. Phys. B337, 269 (1990); R.D. Peccei, S. Peris, and X. Zhang, Nucl. Phys. B349, 305 (1991).
[33] A. Ali et al., Phys. Rev. D 61, 074024 (2000); C. Greub, A. Ioannissian, and D. Wyler, Phys. Lett. B 346, 149 (1995); D. Melikhov, N. Nikitin, and S. Simula, Phys. Lett. B 410, 290 (1997).
FIG. 1. The differential branching ratio of $B \to X_s l^+ l^-$ decays. The solid line denotes the SM prediction, the dotted line the prediction with $\xi_b$ in the region A, the dashed line the prediction with $\xi_b$ in the region B, and the dash-dotted line the prediction with $\xi_s = 0.012$. 
FIG. 2. The forward-backward asymmetry of $B \to X_s l^+ l^-$ decays. The solid line denotes the SM prediction, the dotted line the prediction with $\xi_b$ in the region A, the dashed line the prediction with $\xi_b$ in the region B.