Radiative/EW penguin decays at Belle

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Abstract. We present recent results for radiative and electroweak penguin decays of \( B \)-meson at Belle. Measurements of differential branching fraction, isospin asymmetry, \( K^* \) polarization, and forward-backward asymmetry as functions of \( q^2 \) for \( B \to K^{(*)}l\bar{l} \) decays are reported. For the results of the radiative process, we report measurements of branching fractions for inclusive \( B \to X_s\gamma \) and the exclusive \( B \to K\eta'\gamma \) modes.

1. Introduction
\( b \to s \) transition is the Flavor changing neutral currents (FCNC) which are forbidden at the tree level in the Standard Model. However, loop-induced FCNC (called penguin decays) are possible. New particles in the loops can give effects at the same order as Standard Model contributions. The process is a sensitive probe to new physics.

2. Analysis techniques
\( B \)-factory provide large clear sample of \( \Upsilon(4S) \) decays \( B\bar{B} \) pairs. The main background source comes from continuum events \( (e^+e^- \to q\bar{q}(\gamma), q = u,d,s,c) \). To suppress the continuum background, we use a selection criteria making use of the difference of the event topology between \( B \) decays and continuum events. In the inclusive analysis, these continuum backgrounds are subtracted using the off-resonance data sample taken slightly below the \( \Upsilon(4S) \) resonance. In the exclusive measurements, one can require the kinematic constraints on the beam-energy constrained mass \( M_{bc} = \sqrt{E_{\text{beam}}^* - p_B^*} \) and \( \Delta E = E_B^* - E_{\text{beam}}^* \), using the beam energy \( E_{\text{beam}}^* \) and momentum \( p_B^* \) of \( B \) candidate in the center-of-mass system (c.m.s).

3. \( B \to K^{(*)}l\bar{l} \)
The decay \( b \to sl\) is induced through penguin or box diagrams at lower order\[1\]. There are many observable such as branching fraction, isospin asymmetry and forward-backward asymmetry where new physics can contribute. These observable can be interpreted in term of Wilson coefficients. Three Wilson coefficients, \( C_7,9,10 \) contribute. The \( B(B \to X_s\gamma) \) can constraint to \( |C_7| \). The \( b \to sl\) is sensitive to sign of \( C_7 \).

We have measured \( b \to sl\) exclusively \( (B \to K^{(*)}l\bar{l}) \) on 657M \( B\bar{B} \) pairs \[2\]. 10 final state \( (K^+\pi^-, K_s\pi^+, K^+\pi^0, K^+ \) and \( K_S \) are reconstructed for \( K^{(*)} \) and combined with electron and muon pairs. \( B \) meson is exclusively reconstructed with \( M_{bc} \) and \( \Delta E \). Main backgrounds are continuum event and semi-leptonic \( B \) decays. The continuum background is suppressed using information of event topology and the semi-leptonic \( B \) decays are suppressed using information of missing mass and lepton vertex separation. Dominant peaking background from \( B \to J/\psi(\to ll)X \) and \( \psi(2S)(\to ll)X \) decays are rejected in the \( q^2 \)(invariant mass of dilepton).
We obtain \( \mathcal{B}(B \to K^*\ell\ell) = (10.8 \pm 1.0 \pm 0.9) \times 10^{-7} \) and \( \mathcal{B}(B \to K\ell\ell) = (4.8^{+0.5}_{-0.4} \pm 0.9) \times 10^{-7} \) by fitting to \( M_{bc} \) (and \( M_{K\pi} \) for \( K^*\ell\ell \)). Fig. 1 shows the distributions of \( M_{K\pi} (M_{bc}) \) with fit results superimposed for the event in the \( M_{bc} (M_{K\pi}) \) signal region.

**Figure 1.** Distributions of \( M_{K\pi} (M_{bc}) \) with fit results superimposed for the events in the \( M_{bc} (M_{K\pi}) \) signal region. The solid curves, solid peak, dashed curves, and dotted curves represent the combined fit result, fitted signal, combinatorial background, and \( J/\psi(\psi')X \) background, respectively.

We divide \( q^2 \) into 6 bins and extract the signal and combinatorial background yield in each bin. The \( K^* \) longitudinal polarization fractions \( (F_L) \) and the forward-backward asymmetry \( (A_{FB}) \) are extracted from fits in the signal region to \( \cos\theta_{K^*} \) and \( \cos\theta_{B\ell} \), respectively, where \( \theta_{K^*} \) is the angle between the kaon direction and the direction opposite the \( B \) meson in the \( K^* \) rest frame, and \( \theta_{B\ell} \) is the angle between the \( \ell^+ (\ell^-) \) and the opposite of the \( B (\bar{B}) \) direction in the dilepton rest frame. The differential branching fraction, \( F_L \), and \( A_{FB} \) as functions of \( q^2 \) for \( K^*\ell^+\ell^- \) and \( K\ell^+\ell^- \) modes are shown in Fig. 2, Fig. 3, and Fig. 4, respectively. The differential branching fraction and \( F_L \) are consistent with the Standard Model predictions. The \( A_{FB}(q^2) \) spectrum, although consistent with previous measurements \([5]\), tends to be shifted toward the positive side from the SM expectation. A much larger data is needed for more precise measurement.

Isospin asymmetry \( (A_I) \) is shown in Fig. 5. In the Standard Model, \( A_I \) is expected to be small. Babar found a large negative asymmetry in the low \( q^2 \) region \([4]\), however no significant asymmetry is found in Belle data.
$A_{FB}$ as a function of $q^2$. The solid (dashed) curve shows the SM ($C_7 = -C_7^{SM}$) prediction.

Figure 4. Fit results for $A_{FB}$ as a function of $q^2$. The solid (dashed) curve shows the SM ($C_7 = -C_7^{SM}$) prediction.

$A_{I}$ as a function of $q^2$ for $K^+\ell^+\ell^-$ (red) and $K\ell^+\ell^-$ (blue) modes.

Figure 5. $A_{I}$ as a function of $q^2$ for $K^+\ell^+\ell^-$ (red) and $K\ell^+\ell^-$ (blue) modes.

$b \to s\gamma$

The decay $b \to s\gamma$ is induced through penguin diagrams. The high energy real photon is an excellent experimental signature of the fully inclusive measurement.

4.1. Inclusive $B \to X_s\gamma$

The $B(B \to X_s\gamma)$ have been measured in fully inclusive method [6]. We collect all high-energy photons, vetoing those originating from $\pi^0$ and $\eta$ decays two photons, in calorimeter. The continuum background is suppressed using event topology information and reminder is subtracted. We estimate the contribution from continuum event using off-resonance data. The events from $B$ decays are estimated using MC sample which calibrated with control data sample. Fig. 6 show the extracted photon energy spectrum. We obtain $B(B \to X_s\gamma) = (3.31 \pm 0.19 \pm 0.37 \pm 0.01) \times 10^{-4}$, $\langle E_{\gamma} \rangle = 2.281 \pm 0.032 \pm 0.053 \pm 0.002$ GeV, $\langle E_{\gamma}^2 \rangle - \langle E_{\gamma} \rangle^2 = 0.0396 \pm 0.0156 \pm 0.0214 \pm 0.0012$ GeV$^2$ for $E_{\gamma}^{c.m.s} > 1.7$ GeV. These results are the most precise measurements to date.

Figure 6. The extracted photon energy spectrum of $B \to X_{s,d}\gamma$. The two error bars show the statistical and total errors.

Figure 7. The comparison of experimental results and theoretical predictions. $B(B \to X_{s}\gamma)$ is scaled for $E_{\gamma}^{c.m.s} > 1.6$ GeV.

Fig. 7 is the comparison of experimental results and theoretical predictions for the branching fraction. The experimental results are in agreement with the theoretical predictions [7].
4.2. **Exclusive \( B \to K\eta'\gamma \)**

We find evidence for \( B^+ \to K^+\eta'\gamma \) decays at the 3.3\( \sigma \) level with a partial branching fraction of \((3.2^{+1.2}_{-1.1} \pm 0.3) \times 10^{-6}\). This measurement is restricted to the region of combined \( K\eta' \) invariant mass less than 3.4 GeV/\( c^2 \). A 90\% C.L upper limit of \(6.3 \times 10^{-6} \) is obtained for the decay \( B^0 \to K_S^0\eta'\gamma \) in the same \( K\eta' \) invariant mass region. Fig. 8 shows the distributions of \( M_{bc} \) and \( \Delta E \) with projections from 2D fit results.

![Figure 8](image)

**Figure 8.** Projections from the 2D fit to data. The \( K\eta'\gamma \) function is shown in dashed red, continuum in dotted black, \( b \to c \) in dash-dotted green, \( b \to u.d.s \) in solid magenta, and the combined function in solid blue.

5. **Summary**

We have improved measurements of differential branching fraction, isospin asymmetry, \( K^* \) polarization, and forward-backward asymmetry as functions of \( q^2 \) for \( B \to K^{(*)}ll \) decays and branching fractions for inclusive \( B \to Xsl\gamma \) and the exclusive \( B \to K\eta'\gamma \) modes. There is no evidence so far for new physics. We need much more data sample to improve the sensitivity. Super \( B \)-factory will provide one order of magnitude mode luminosity.

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