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Recent Results on Electroweak Penguins at Belle

Tetsuo Abe

Graduate School/Faculty of Science, Tohoku University, Sendai, Japan

For the Belle Collaboration

Abstract

Electroweak penguin-mediated decay processes of B mesons have been studied with the Belle detector using a large data sample of $B\bar{B}$ pairs produced by the KEKB collider. We report recent results on exclusive $b \to s\gamma$ and $b \to s\,l^+l^-$ decays and new results on the inclusive measurement of the $b \to s\,l^+l^-$ process.

1 Introduction

Flavor-changing neutral current (FCNC) processes are sensitive to new physics since they are forbidden at tree level in the Standard Model (SM) and occur via loop or box diagrams to which heavy particles in new physics models can contribute. In the Belle experiment [1], electroweak penguin-mediated decays: $b \to s\gamma$ and $b \to s\,l^+l^-$ ($l = e, \mu$) have been studied using a large data sample of $B\bar{B}$ pairs produced by the KEKB asymmetric-energy e^+e^- collider [2] operated at the $\Upsilon(4S)$ resonance.

We report recent results on the exclusive $b \to s\gamma$ decays: $B \to K^*(892)\gamma$ and $B \to K\pi, K\pi\pi\gamma$ above the $K^*(892)$ mass. We also report recent results on the exclusive $b \to s\,l^+l^-$ decays: $B \to K^{(*)}l^+l^-$, and new results on the inclusive mode: $B \to X_s\,l^+l^-$. The $b \to s\,l^+l^-$ process is described not only with the penguin diagram but also with the box one, and leads to rarer decays of B mesons with a smaller branching fraction compared with the $b \to s\gamma$ process. However, $b \to s\,l^+l^-$ provides us the power to distinguish different models by using additional degrees of freedom: the dilepton invariant mass and the forward-backward charge asymmetry of the dilepton [3].

In any analysis shown in this article, signal yields are extracted in the following way. First we reconstruct the energy and momentum of the B-meson candidate in the center-of-mass system (CMS) of the e^+ and e^- beams. Secondly we reconstruct two kinematic variables to identify the B decay: beam constrained mass defined as $M_{bc} = \sqrt{(E_{beam})^2 - (p_B)^2}$ and energy difference defined as $\Delta E = E_B - E_{beam}$, where E_B and p_B are the energy and momentum of the B candidate, respectively, and E_{beam} is the beam energy in the CMS. Finally, we calculate the signal yield by fitting the M_{bc} distribution.

There is a large background from continuum $e^+e^- \to q\bar{q}$ processes. We suppress this background using various variables such as event shape variables, B-flight direction, ΔE, and so on.

2 Exclusive $b \to s\gamma$ Decays

The $B \to K^*(892)\gamma$ decay is reconstructed in the decay chains: $B^0 \to K^*(892)^0\gamma \to K^+\pi^-\gamma$ or $K_S\,\pi^0\gamma$, and $B^+ \to K^*(892)^+\gamma \to K^+\pi^0\gamma$ or $K_S\,\pi^+\gamma$ [4]. There is only a small contribution from the $B\bar{B}$ background: $B \to K^*\pi\gamma$ in this analysis. From the 29.4 fb^{-1} dataset, we obtain branching fractions of $\mathcal{B}(B^0 \to K^{*0}\gamma) = (4.08^{+0.35}_{-0.33}(stat) \pm 0.26(syst)) \times 10^{-5}$ and $\mathcal{B}(B^+ \to K^{*+}\gamma) = (4.92^{+0.59}_{-0.54}(stat)^{+0.38}_{-0.37}(syst)) \times 10^{-5}$.

We also studied CP asymmetry from the self-tagged modes: $K^+\pi^-$, $K_S\pi^+$ and $K^+\pi^0$. The CP asymmetry is defined as

$$A_{CP} = \frac{1}{1-2w}\frac{N(\bar{B}) - N(B)}{N(\bar{B}) + N(B)}, \quad (1)$$

where $N(B)$ ($N(\bar{B})$) indicates number of B ($\bar{B}$) events, and w is the small wrong-tag fraction. The value of w is about 0.9 % for the neutral modes and negligible for the charged modes. This asymmetry is expected to be about 0.5 % in the SM, and in some new physics

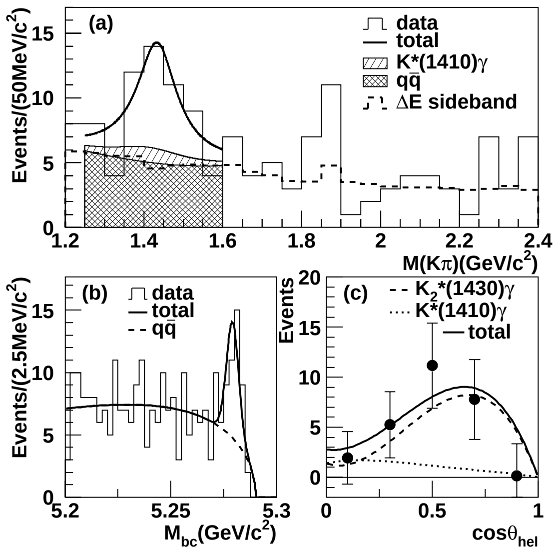

Figure 1: (a) $M_{K\pi}$, (b) M_{bc} and (c) $\cos\theta_{\rm hel}$ distributions for the $K^+\pi^-\gamma$ candidates with fit results superimposed. The cut: $M_{bc} > 5.27\,\mathrm{GeV}$ is applied in (a) and (c), and the cut: $1.25\,\mathrm{GeV} < M_{K\pi} < 1.6\,\mathrm{GeV}$ is applied in (b).

models, it is enhanced up to about 20 %. We obtain $A_{CP}(K^*\gamma) = (+3.2\,^{+6.9}_{-6.8}(stat) \pm 2.0(syst))\,\%$.

Exclusive $b \to s\gamma$ decays with a kaonic system above the $K^*(892)$ mass are studied. Some resonant structure is expected such as $K^*(1410)$, $K_2^*(1430)$ and $K^*(1680)$. We used the same dataset as in the $B \to K^*(892)\gamma$ analysis. Figure 1-(a) shows the $K\pi$ invariant-mass distribution for the $K^+\pi^-\gamma$ candidates. From the M_{bc} distribution shown in Figure 1-(b), we obtain a signal yield of $27^{+8}_{-7}(stat)^{+1}_{-3}(syst)$ events in the region of 1.25 GeV $< M_{K\pi} <$ 1.6 GeV with a statistical significance of $5.0\,\sigma$. Assuming that the signal consists of three components: $K^*(1410)^0\gamma$, $K_2^*(1330)^0\gamma$ and the non-resonant (NR) $K\pi\gamma$, we extract the resonant components by means of a multi-dimensional unbinned maximum likelihood (ML) fit to the distributions of the cosine of the helicity angle (Figure 1-(c)), $K\pi$ invariant mass and M_{bc}. Here the helicity angle is defined as an angle between the kaon flight direction in the K^* rest frame with respect to the K^* direction in the B rest frame. From the fit, we obtain signal yields of $24 \pm 9(stat) \pm 1(syst)$, $5.4^{+8.3}_{-5.4}(stat)$ and $0.0^{+4.3}_{-0.0}(stat)$ for the $K_2^*(1430)\gamma$, $K^*(1410)\gamma$ and NR components, respectively, and a branching fraction for the $K_2^*\gamma$ mode: $\mathcal{B}(B^0 \to K_2^*(1430)^0\gamma) = (1.5^{+0.6}_{-0.5}(stat) \pm 0.1(syst)) \times 10^{-5}$ [5].

We also studied the three-body decay final state: $K^+\pi^-\pi^+\gamma$. It has been suggested that photon-polarization measurements using the $K_1(1400) \to K\pi\pi$ decay could be a tool to search for new physics [6]. From the M_{bc} distribution shown in Figure 2-(a), we obtain a signal yield of $57^{+12}_{-11}(stat)^{+6}_{-2}(syst)$ events in the region of $M_{K\pi\pi} <$ 2.4 GeV with a statistical significance of $5.9\,\sigma$. Assuming the composition of the signal events of $K^{*0}\pi^+\gamma$, $K^+\rho^0\gamma$ and NR $K\pi\pi\gamma$, we extract these three components by means of the multi-

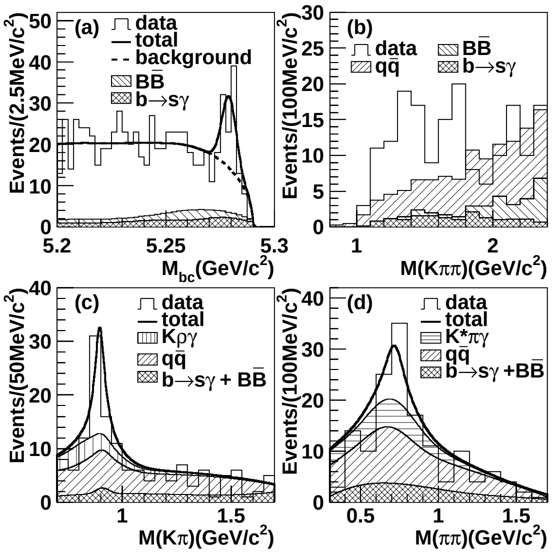

Figure 2: (a) M_{bc}, (b) $M_{K\pi\pi}$, (c) $M_{K\pi}$ and (d) $M_{\pi\pi}$ distributions with fit results for the $K^+\pi^-\pi^+\gamma$ candidates. The cut: $M_{bc} > 5.27$ GeV is applied in (b), (c) and (d).

dimensional unbinned ML fit to the $K\pi$-mass (Figure 2-(c)), $\pi\pi$-mass (Figure 2-(d)) and M_{bc} distributions. From the fit, we obtain signal yields of $33^{+11}_{-10}(stat) \pm 2(syst)$, $24 \pm 12(stat)^{+4}_{-7}(syst)$, $0.0\,^{+11}_{-0}(stat)$ for the $K^{*0}\pi^+\gamma$, $K^+\rho^0\gamma$ and NR components, respectively, and branching fractions: $\mathcal{B}(B^+ \to K^{*0}\pi^+\gamma) = (2.0\,^{+0.7}_{-0.6}(stat) \pm 0.2(syst)) \times 10^{-5}$ and $\mathcal{B}(B^+ \to K^+\rho^0\gamma) = (1.0 \pm 0.5(stat)\,^{+0.2}_{-0.3}(syst)) \times 10^{-5}$ [5].

3 Exclusive and Inclusive $b \to s\, l^+l^-$ Decays

We have performed two kinds of analyses: exclusive and inclusive ones. In the exclusive analyses, the decay modes of $B \to K\, l^+l^-$ and $K^*(892)\, l^+l^-$ are studied. These modes are experimentally easy to analyze, however, we have more theoretical uncertainty due to the meson form factors. On the other hand, the inclusive mode is experimentally difficult, however, we have less theoretical uncertainty in extracting physics parameters.

3.1 The exclusive analysis

The exclusive modes are reconstructed with the decays of $B^0 \to K_S\, l^+l^-$, $B^+ \to K^+\, l^+l^-$, $B^0 \to K^*(892)^0\, l^+l^-$ and $B^+ \to K^*(892)^+\, l^+l^-$, where K^{*0} (K^{*+}) candidates are formed by combining a kaon and a pion: $K^+\pi^-$ or $K_S\pi^0$ ($K^+\pi^0$ or $K_S\pi^+$). We used the 29.1 fb^{-1} dataset for this analysis.

There is a large contribution from long-distance processes with charmonium. This background is strongly suppressed by excluding the charmonium-mass windows in the dilepton invariant-mass distributions. Another significant background is the double semi-

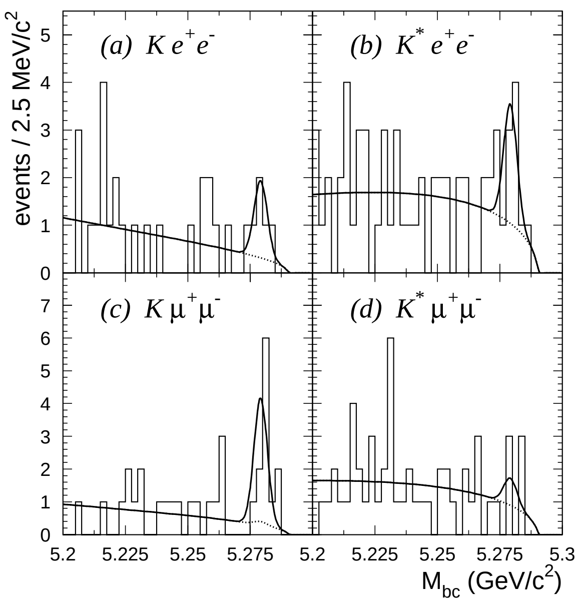

Figure 3: M_{bc} distributions with fit results for the $K^{(*)}l^+l^-$ candidates.

leptonic decay of $B\bar{B}$ pairs, which is suppressed by requiring small missing energy in the event. A peaking background containing a kaon together with a charged hadron pair: $K^{(*)}h^+h^-$, which might be misidentified as $K^{(*)}\mu^+\mu^-$, is estimated using the reconstructed $K^{(*)}h^+h^-$ data sample multiplied by the measured momentum-dependent fake rate.

From the M_{bc} distributions shown in Figure 3, we obtain signal yields of $4.1^{+2.7}_{-2.1}(stat)$ $^{+0.6}_{-0.8}(syst)$, $6.3^{+3.7}_{-3.0}(stat)^{+1.0}_{-1.1}(syst)$, $9.5^{+3.8}_{-3.1}(stat)^{+0.8}_{-1.0}(syst)$ and $2.1^{+2.9}_{-2.1}(stat)^{+0.9}_{-1.0}(syst)$ for the decay modes of $K\,e^+e^-$, $K^*\,e^+e^-$, $K\,\mu^+\mu^-$ and $K^*\,\mu^+\mu^-$, respectively. Combining the $K\,e^+e^-$ and $K\,\mu^+\mu^-$ modes, we have made the first observation of the electroweak penguin decay: $B \to K\,l^+l^-$ with a branching fraction of $\mathcal{B}(B \to K\,l^+l^-) = (0.75^{+0.25}_{-0.21}(stat) \pm 0.09(syst)) \times 10^{-6}$ and a $5.3\,\sigma$ statistical significance [7].

The dimuon invariant-mass distribution from the $K\,\mu^+\mu^-$ mode is shown in Figure 4. The data distribution is consistent with the SM prediction within the data statistics.

3.2 The inclusive analysis

In this analysis, a kaonic system (X_s) is reconstructed using the pseudo-reconstruction technique, where the kaonic system is required to contain one kaon, either K^+ or K_S, together with zero or up to four pions. Here we allow at most one neutral pion. Backgrounds are suppressed as in the exclusive analysis.

Figure 5 shows the M_{bc} distributions from the $43\,\mathrm{fb}^{-1}$ dataset. Signal yields are $16.6^{+8.0}_{-7.3}(stat)^{+3.9}_{-3.8}(syst)$ and $30.7^{+7.9}_{-7.4}(stat)^{+5.4}_{-3.8}(syst)$ for the $X_s\,e^+e^-$ and $X_s\,\mu^+\mu^-$ modes, respectively. Combining these two modes, we have obtained the first evidence for the inclusive $b \to s\,l^+l^-$ decay process with a branching fraction of $\mathcal{B}(B \to X_s\,l^+l^-) =$

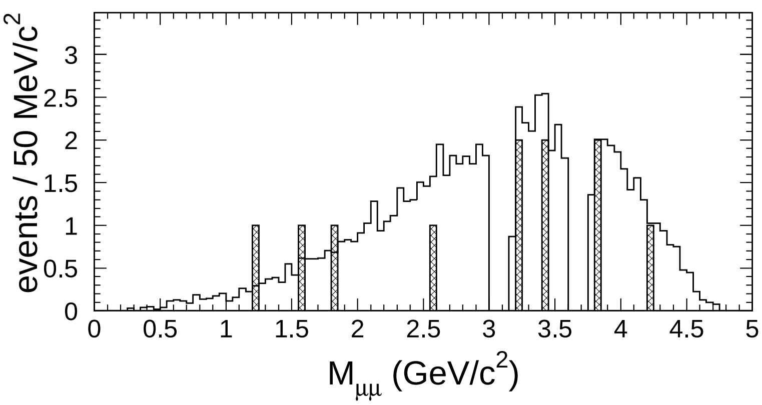

Figure 4: Dimuon invariant-mass distribution for the $B \to K\,\mu^+\mu^-$ candidates. The hatched histogram indicates the data and the open one is the SM prediction. There are two regions with no entries due to the J/ψ and ψ' vetos.

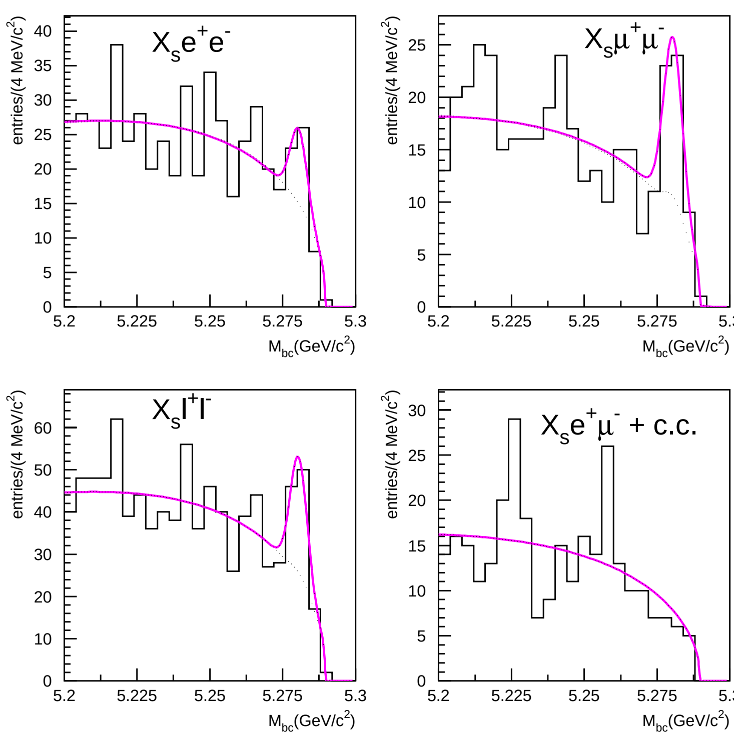

Figure 5: M_{bc} distributions with fit results for the $X_s l^+ l^-$ candidates. The $X_s e\mu$ sample is used to check the background parameterization.

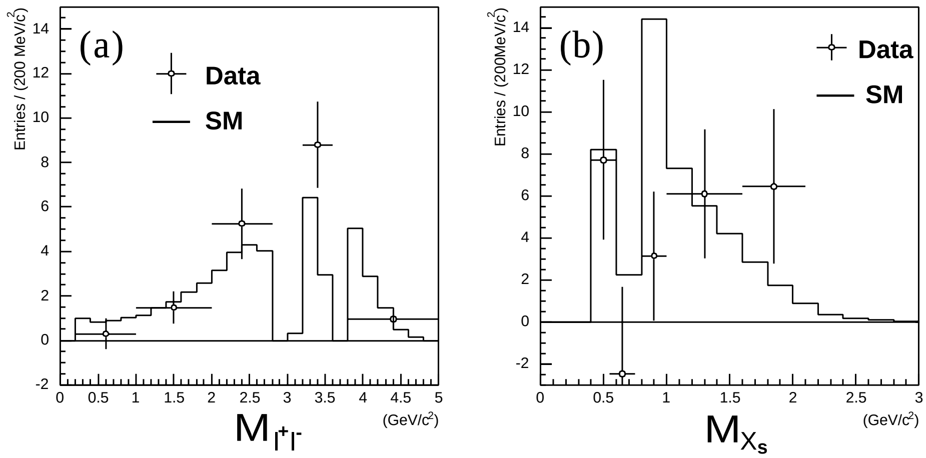

Figure 6: Invariant-mass distributions of (a) the dilepton system and (b) the kaonic system for the $B \to X_s l^+ l^-$ candidates, where the cut: $M_{X_s} < 2.1\,\mathrm{GeV}$ is applied to reject combinatorial background. There are two regions with no entries in (a) due to the J/ψ and ψ' vetos.

$(7.1 \pm 1.6(stat)^{+1.4}_{-1.2}(syst)) \times 10^{-6}$, where the statistical significance is $4.8\,\sigma$. This result is consistent with the recent theoretical prediction based on NNLO perturbative QCD [8].

Figure 6 shows the invariant-mass distributions of the dilepton and the kaonic system. The data distributions are consistent with the SM predictions within the data statistics.

On the systematic uncertainty in the inclusive branching-fraction measurement, the largest contribution comes from the decay modeling uncertainty of about $^{+15}_{-10}\%$, followed by the tracking-efficiency uncertainty of about 8%.

4 Summary and Conclusions

We have studied the FCNC processes: $b \to s\gamma$ and $b \to s\,l^+l^-$.

On the $b \to s\gamma$ process, we have measured branching fractions of the $K\pi$ and $K\pi\pi\gamma$ decay final states, and can account for 35 % of the measured inclusive branching fraction with the $K^*\gamma$, $K_2^*\gamma$ and $K\pi\pi\gamma$ modes. We furthermore perform extensive studies of exclusive decay modes with a multi-body and with a higher-mass kaonic system for a better understanding of $b \to s\gamma$ measurements

On the $b \to s\,l^+l^-$ process, we have made the first observation of the exclusive penguin decay: $B \to K\,l^+l^-$. In addition, we have obtained the first evidence for the inclusive decay: $B \to X_s l^+l^-$. Both results are consistent with recent SM predictions.

More data is coming; the KEKB collider is getting close to its design luminosity. Furthermore, a higher-luminosity B factory (Super KEKB) is being proposed. We can conclude that the FCNC processes: $b \to s\gamma$ and $b \to s\,l^+l^-$ are very promising probes for beyond-SM physics in the next few years.

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