Radiative and Electroweak Penguin $B$ decays at Belle

Yutaro Sato†
Nagoya University
E-mail: yutaro@hepl.phys.nagoya-u.ac.jp

We report results of radiative and electroweak penguin $B$ decays based on a data sample containing $772 \times 10^6 \bar{B}B$ pairs recorded by the Belle detector at the KEKB $e^+e^-$ collider. The lepton forward-backward asymmetry $A_{FB}$ for the electroweak penguin process $B \rightarrow X_s \ell^+\ell^-$ has been measured for the first time, where $\ell$ is an electron or a muon and $X_s$ is a hadronic recoil system with an $s$ quark. In addition, the $B^0 \rightarrow p\bar{\Lambda}\pi^-\gamma$ decay has been searched.

The European Physical Society Conference on High Energy Physics -EPS-HEP2013
18-24 July 2013
Stockholm, Sweden

†Speaker.
†A footnote may follow.
1. Introduction

In the standard model (SM), flavor-changing neutral current such as $b \to s\gamma$ and $b \to s\ell^+\ell^-$ decays are forbidden at the tree level and allowed at higher order via the electroweak penguin or $W^+W^-$ box diagrams. Non-SM particles may contribute to the loop and change their decay rate and angular distributions. Therefore, $b \to s\gamma$ and $b \to s\ell^+\ell^-$ decays are good probes to search for new physics. Here, we report first measurement of the lepton forward-backward asymmetry in the $B \to X_s\ell^+\ell^-$ decays and the result of search for $B^0 \to p\Lambda\pi^-\gamma$ decays. Both result is based on a data sample containing $772 \times 10^6$ $B\bar{B}$ pairs recorded by the Belle detector at the KEKB $e^+e^-$ collider.

2. Lepton forward-backward asymmetry in inclusive $B \to X_s\ell^+\ell^-$

Inclusive measurements of $b \to s\gamma$ and $b \to s\ell^+\ell^-$ are preferable to exclusive measurements because of lower theoretical uncertainties, although they are experimentally more challenging. The branching fraction of inclusive $B \to X_s\gamma$ and $B \to X_s\ell^+\ell^-$ has been measured by Belle [4], BABAR [3 4], and CLEO [5]. All of them are consistent with the theoretical SM prediction [6 7]. The lepton forward-backward asymmetry $\mathcal{A}_{FB}$ in the $B \to X_s\ell^+\ell^-$ decays defined as

$$\mathcal{A}_{FB} \equiv \frac{\Gamma(b \to s\ell^+\ell^-; \cos\theta > 0) - \Gamma(b \to s\ell^+\ell^-; \cos\theta < 0)}{\Gamma(b \to s\ell^+\ell^-; \cos\theta > 0) + \Gamma(b \to s\ell^+\ell^-; \cos\theta < 0)},$$

is considered to have different and better sensitivity to physics beyond the SM than the branching fraction [8]. Here, $\theta$ is the angle between the $\ell^+\ell^-$ center-of-mass (c.m.) frame in $B^0$ or $B^- (B^0$ or $B^+)$ decays.

The $B \to X_s\ell^+\ell^-$ decays are reconstructed from dilepton pair $\ell^+\ell^-$ ($e^+e^-$ or $\mu^+\mu^-$) and one of ten reconstructed hadronic states: $K^-$, $K^-\pi^+$, $K^-\pi^0$, $K^0_S\pi^-$, $K^\mp\pi^\mp\pi^0$, $K^-\pi^\mp\pi^\mp\pi^0$, $K^\mp\pi^\mp\pi^\mp\pi^0$, and $K^0_S\pi^\mp\pi^\mp\pi^\mp\pi^0$. To examine the dilepton mass squared $q^2$ dependence of $\mathcal{A}_{FB}$, we divide the data into 4 bins of measured $q^2$: $[0.2, 4.3]$, $[4.3, 7.3(8.1)]$, $[10.5(10.2), 11.8(12.5)]$, $[14.3, 25.0]$ GeV$^2$/c$^4$ for the electron (muon) channel, where the gap regions correspond to the veto regions for charm background events. In order to extract $\mathcal{A}_{FB}$, an extended unbinned maximum likelihood fit is performed for each $q^2$ bin simultaneously fitting the four $M_{bc}$ distributions: events with $\cos\theta > 0$ for electron/muon channel and event with $\cos\theta < 0$ for electron/muon channel. The likelihood function consists of four components: signal, self cross-feed, peaking background, and combinatorial background, where we consider three peaking background sources: charmonium background from $B \to J/\psi(\psi(2S))X_s$ decays with $J/\psi(\psi(2S)) \to \ell^+\ell^-$, $B \to D^{(*)n}\pi$ $(n > 0)$ decays with misidentification of two charged pions as two leptons, and $B \to J/\psi(\psi(2S))X_s$ decays with swapped misidentification of a lepton and a pion. Figure[1] shows the $M_{bc}$ distributions for $B \to X_s e^+e^-$ and $B \to X_s \mu^+\mu^-$ candidates with positive and negative $\cos\theta$. The total signal yields for $B \to X_s e^+e^-$ and $B \to X_s \mu^+\mu^-$ are measured to be $139.8 \pm 18.6$(stat) and $160.8 \pm 20.0$(stat), respectively. Figure[2] shows the $\mathcal{A}_{FB}$ distribution as a function of $q^2$. In the high $q^2$ bins, the results are consistent with the SM prediction. In the bins above the $J/\psi$ veto region, $\mathcal{A}_{FB} < 0$ is excluded at the 2.3$\sigma$ level, where $\sigma$ is the standard deviation. In the lowest $q^2$ bin ($q^2 < 4.3$ GeV$^2$/c$^4$), the result is within $1.8\sigma$ of the SM expectation.
Radiative and Electroweak Penguin B decays at Belle

Yutaro Sato

3. Search for $B^0 \rightarrow p\bar{\Lambda}\pi^-\gamma$

In the Monte Carlo (MC) simulation of the $s \rightarrow X_{s}$ fragmentation/hadronization process by JETSET [9], the $X_{s}$ with a $\Lambda$ in the final state contribute only at 1% level. This is consistent with the known baryonic $B$ decay rate, $\mathcal{B}(B^+ \rightarrow p\bar{\Lambda}\gamma) = (2.45^{+0.44}_{-0.38} \pm 0.22) \times 10^{-6}$ [10]. There is an intriguing feature of this three-body decay that the mass of the $p\Lambda$ system is peaked near threshold. A similar feature is also seen in many other baryonic $B$ decay processes and quite likely offers the explanation to the observed hierarchy, e.g. $\mathcal{B}(B^0 \rightarrow p\bar{\Lambda}\pi^-\pi^+) > \mathcal{B}(B^0 \rightarrow p\bar{\Lambda}\pi^-) > \mathcal{B}(B^+ \rightarrow p\bar{\Lambda})$ and $\mathcal{B}(B^0 \rightarrow p\bar{\Lambda}_c\pi^+\pi^-) > \mathcal{B}(B^+ \rightarrow p\bar{\Lambda}_c\pi^+) > \mathcal{B}(B^0 \rightarrow p\bar{\Lambda}_c^{-})$ [11].

The signal yield of the $B^0 \rightarrow p\bar{\Lambda}\pi^-\gamma$ mode is extracted from a two-dimensional extended unbinned maximum likelihood fit. The fit result is shown in Fig.3 The fitted signal yield is $9.5^{+11.5}_{-10.7}$ with a statistical significance of 0.9. The statistical significance is defined as $\sqrt{-2\ln(L_0/L_{\text{max}})}$, where $L_0$ and $L_{\text{max}}$ are the likelihood values obtained by the fit with and without the signal yield fixed to zero, respectively. The branching fraction $\mathcal{B}$ is calculated using the following formula:

$$\mathcal{B} = \frac{N_{\text{sig}}}{e \cdot N_{BB}},$$

(3.1)
Radiative and Electroweak Penguin B decays at Belle

Yutaro Sato

4

\[ \frac{N_{\text{sig}}}{N_{\bar{B}B}}, N_{\bar{B}B}, \text{and } \epsilon \text{ are the fitted signal yield, the number of } B\bar{B} \text{ pairs, and the reconstruction efficiency of signal, respectively. The reconstruction efficiency for the signal is estimated to be 5.27\% from the MC samples and control data sample. Since the observed yield for } B^0 \rightarrow p\bar{\Lambda}\pi^- \gamma \text{ is not significant enough, we evaluate the 90\% confidence level Bayesian upper limit (} \mathcal{B}_{UL} \text{) to be } 6.5 \times 10^{-7}. \text{ We conclude that the decay under study does not follow the expected hierarchy, namely } \mathcal{B}(B^0 \rightarrow p\bar{\Lambda}\pi^- \gamma) > \mathcal{B}(B^+ \rightarrow p\bar{\Lambda}\gamma). \]

4. Summary

We present new results on radiative and electroweak penguin B decays obtained from a data sample containing \(772 \times 10^6 \) \( B\bar{B} \) pairs recorded by the Belle detector at the KEKB \( e^+e^- \) collider. The lepton forward-backward asymmetry \( \mathcal{A}_{FB} \) for the electroweak penguin process \( B \rightarrow X_s \ell^+\ell^- \) has been measured for the first time. For \( q^2 > 10.2 \text{ GeV}^2/c^4 \), \( \mathcal{A}_{FB} < 0 \) is excluded at the 2.3\( \sigma \) level. For \( q^2 < 4.3 \text{ GeV}^2/c^4 \), the result is within 1.8\( \sigma \) of the SM expectation. The results can be used to constrain extensions of the SM. The \( B^0 \rightarrow p\bar{\Lambda}\pi^- \gamma \) decay has been searched and set the 90\% confidence level Bayesian upper limit (\( \mathcal{B}_{UL} \)) to be \( 6.5 \times 10^{-7} \). We conclude that the decay under study does not follow the expected hierarchy, namely \( \mathcal{B}(B^0 \rightarrow p\bar{\Lambda}\pi^- \gamma) > \mathcal{B}(B^+ \rightarrow p\bar{\Lambda}\gamma). \)

References

Figure 3: $M_{bc}$ and $\Delta E$ distribution. The solid (red) curve shows the signal component. The dashed (green) curve shows the self-cross feed component. The (blue) curve shows the continuum background component. The dashed (magenta and cyan) lines show $B \rightarrow p\Lambda \gamma$ and $p\Lambda \pi^0$ background events. The solid (black) line shows the sum of all components.