Study of electroweak penguin B decays at Belle II experiment

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Abstract. The electroweak $b \to sll$ $(l = e, \mu)$ transition is a flavor-changing neutral current process that mediates through a one-loop penguin diagram. The decay is considered to be a good probe for the New Physics as particles predicted in the beyond Standard Model theories can enter into the loop. The exclusive decay $B \to K^{(*)}l^+l^-$ was first observed by the Belle experiment and it provides many observables such as the branching fraction, CP asymmetry, forward-backward asymmetry, and other angular observables. Recently, the LHCb experiment has reported some clue of a lepton flavor universality violation from the branching fraction ratio of the $B \to K\mu^+\mu^-$ and $B \to Ke^+e^-$ decays. In this presentation, we report the status of the $B \to Kl^+l^-$ decay analysis at the Belle II experiment which started the data taking in 2019. We also, present an activity at the Belle II Chulalongkorn University group where we study the $B \to KJ/\psi$ decay which has the same topology as the $B \to Kl^+l^-$.

1. Introduction

The electroweak penguin (EWP) of B decay is a flavor-changing neutral current (FCNC) process in the Standard Model (SM). In this process, a b quark transits into an s quark and is followed by a pair of leptons, i.e. $b \to sll$, where l can be e or μ. The EWP process is expressed via a one-loop Feynman diagram which the mediators involving in this process can be the virtual SM particles as a t quark, a W^-, and a Z^0 or a γ, see figure 1, or even the virtual non-SM particles which are predicted by some beyond SM (BSM) theories such as charged Higgs bosons predicted by the two-Higgs-doublet model [1, 2], or leptoquark particles predicted by some extended models of the effective field theory [3], etc. The typical exclusive process, $B \to K^{(*)}l^+l^-$ with its branching fraction, CP asymmetry, forward-backward asymmetry, or other angular observables, is considered as some good probes to test the SM or to search for new physics (NP).

2. Previous $B \to K^{(*)}l^+l^-$ analysis

The first observation of the decay $B \to K^{(*)}l^+l^-$ was done by Belle [4] and later by BaBar [5]. The measured branching fraction from both experiments had been refined several times when increasing datasets. At present, the branching fractions of these B decay modes obtain

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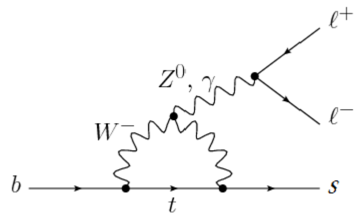

Figure 1. The $b \to sll$ loop diagram.

by combining results from BaBar, Belle, and LHCb measurements are $(4.51 \pm 0.23) \times 10^{-7}$ for $B^+ \to K^+l^+l^-$, $(1.01 \pm 0.11) \times 10^{-6}$ for $B^+ \to K^*(892)^+l^+l^-$, $(3.1^{+0.8}_{-0.7}) \times 10^{-7}$ for $B^0 \to K^0l^+l^-$, and $(9.9^{+1.2}_{-1.1}) \times 10^{-7}$ for $B^0 \to K^*(892)^0l^+l^-$ [6]. Remarkably, these results are consistent with the SM prediction. Later, some observables such as CP asymmetry, forward-backward asymmetry, and other angular observables are also measured. Most of these measurements are compatible with the SM prediction, except some observables such as P_5', measured by Belle [7] and LHCb [8] for which departures from SM predictions have been observed. Recently, LHCb has reported a new result of lepton flavor universality (LFU) violation from this EWP B process by measuring the branching fraction ratio between the decays $B \to K\mu^+\mu^-$ and $B \to Ke^+e^-$ [9].

3. Belle II experiment

The Belle II experiment is a high-energy physics experiment that is mainly designed to study the properties of B meson and is set up at the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan. The experimental facility consists of the SuperKEKB accelerator and the Belle II detector. The SuperKEKB accelerator is a 3-km circumference circular accelerator with two rings for 7 GeV of electron and 4 GeV of positron beams. The collisions take place at a center of mass energy of 10.58 GeV, as a result, $\Upsilon(4S)$ resonances along with $q\bar{q}$ and $\tau^+\tau^-$ are produced. And the $\Upsilon(4S)$ continues decaying to a B meson pair, both charged and neutral. The Belle II detector is a cylindrical shape detector with a 7-m diameter and a 7.5-m length. It is installed covering a crossing beam pipe of the electron and the positron for detecting particles from the electron-positron interaction. The Belle II detector is composed of several subdetectors, i.e. a vertex detector (VXD), the innermost subdetector which consists of a silicon pixel detector (PXD) and a silicon vertex detector (SVD), a central drift chamber (CDC), a time-of-propagation counter (TOP), an aerogel ring imaging Cherenkov counter (ARICH), an electromagnetic calorimeter (ECL), and a kaon (K_L^0) and muon (μ) detector (KLM), the outermost subdetector which is installed outside a 1.5 Tesla solenoid coil. The Belle II experiment started taking data in early 2019. It is designed to operate at a maximum luminosity of 6×10^{35} cm^{-2}s^{-1} with planning to collect data of 50 ab^{-1} during an 8-years operational period [10, 11].

4. Analysis status of the decay $B \to Kl^+l^-$

With the initial data of 62.8 fb^{-1} collected by the Belle II experiment in 2019, the decay of $B \to Kl^+l^-$ was studied through the $B^+ \to K^+e^+e^-$ and $B^+ \to K^+\mu^+\mu^-$ final states. The particles as K^+, $e^\pm$, and $\mu^\pm$ are selected by applying the criteria of (i) the distance from e^+e^- interaction point (d_0) in xy-plan is less than 2.0 cm, (ii) the distance along the z-axis from the interaction point ($|z_0|$) is less than 4.0 cm, these will confirm that the selected charged particles come from the interaction region, (iii) the momentum ($|\overrightarrow{p}|$) of $e^\pm$ and $\mu^\pm$ is more than 0.5 and 0.8 GeV/c, respectively, and (iv) the particle identification for e, μ, and K. In addition, the $e^{\pm}$ are selected by considering the radiated Bremsstrahlung in the ECL. The B candidate is reconstructed from these charged particles and is selected by examining two variables [12], the energy difference, $\Delta E = E^{*}_{\rm beam} - E^{*}_{B}$, and the beam-energy constrained mass, $M_{\rm bc} = \sqrt{E^{*2}_{\rm beam} - \overrightarrow{p}^{*2}_{B}}$, where $E^{*}_{\rm beam} = \sqrt{s}/2 \cong 5.29$ GeV is the beam energy in the center-of-mass (CM) frame or $\Upsilon(4S)$ rest frame and E^{*}_{B}, $\overrightarrow{p}^{*}_{B}$ are the measured energy and momentum of the B candidate in the CM frame, respectively, and the criteria for selecting B candidate are $|\Delta E| < 0.3$ GeV and $5.20 < M_{\rm bc} < 5.29$ GeV/c^2. The background events from the decays $B \to J/\psi(\to l^+l^-)K$ and $B \to \psi(2S)(\to l^+l^-)K$, the Dalitz decay as $\pi^0 \to e^+e^-\gamma$, and the photon conversion, $\gamma^* \to e^+e^-$ for electron mode, the misidentified particle events as $B^+ \to \overline{D}^0(\to K^+\pi^-)\pi^+$ and $B^+ \to K^+\pi^+\pi^-$, and the K^* mode as $B^+ \to K^*l^+l^-$, including the $q\overline{q}$ continuum backgrounds are all suppressed. Finally, the B signal yield is extracted by performing a 2D un-binned extended maximum likelihood fit on the ΔE and $M_{\rm bc}$ distributions, the results are shown in figure 2 [13], with obtaining $8.6^{+4.3}_{-3.9} \pm 0.4$ events, the first and second errors are statistical and systematic, respectively, and most of the systematic errors are from the $B^+ \to K^+\pi^+\pi^-$ background and the shape of probability density function during fitting.

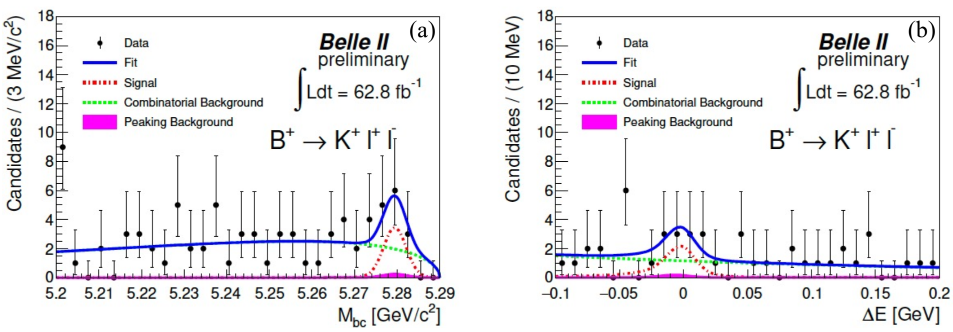

Figure 2. The fitted $M_{\rm bc}$ (a) and ΔE (b) distributions for the decay $B^+ \to K^+l^+l^-$, where combinatorial backgrounds are from $q\overline{q}$ and the other B decay events, while the peaking background is from $B^+ \to K^+\pi^+\pi^-$ event only.

5. Monte Carlo study for the decay $B \to KJ/\psi$

The decay $B \to KJ/\psi$ is considered as a control sample or a physics background of the $B \to Kl^+l^-$ process since it has the same final states as $B \to Kl^+l^-$ when J/ψ decays to a lepton pair. The Belle II Chulalongkorn University group study this B decay mode by using the Belle II analysis software framework (`basf2`) [14] and analyze the decays $B^{\pm} \to K^{\pm}J/\psi(\to e^+e^-)$ and $B^{\pm} \to K^{\pm}J/\psi(\to \mu^+\mu^-)$ by using Monte Carlo (MC) samples. The signal MC sample used to estimate the reconstruction efficiency consists of a pure of $B^{\pm} \to K^{\pm}J/\psi(\to e^+e^-)$ and $B^{\pm} \to K^{\pm}J/\psi(\to \mu^+\mu^-)$ datasets with 1,000,000 events each. The MC sample simulated for the whole $e^+e^- \to \Upsilon(4S) \to B\overline{B}$ and continuum process as $e^+e^- \to q\overline{q}$ $(q = u, d, s, c)$ corresponds to 10 fb^{-1} for each dataset used in this analysis as experimental data. We begin the analysis by selecting the charged final state particles, $K^{\pm}$, $e^{\pm}$, and $\mu^{\pm}$ and apply the criteria from the $B \to Kl^+l^-$ analysis, detailed in section 4. The J/ψ is reconstructed from a lepton pair with selecting its invariant mass in the range between 2.91 and 3.19 GeV/c^2 for electron mode and 2.96 and 3.19 GeV/c^2 for muon mode, these ranges cover all J/ψ mass region. The B candidate is reconstructed from the $K^{\pm}$ and J/ψ by considering two essential variables described in section 4, the ΔE and $M_{\rm bc}$. The selection criteria for ΔE and $M_{\rm bc}$ are $|\Delta E| < 0.1$ GeV/c and $5.20 < M_{\rm bc} < 5.29$ GeV/c^2, respectively. This ΔE range can suppress some peaking backgrounds from $B^0\overline{B}^0$ events. Finally, we extract the B signal yield by fitting the $M_{\rm bc}$ distribution with the Crystal Ball function for a signal peak and the ARGUS function for continuum backgrounds. Using this MC sample, we measure 255 ± 16(stat) signal events for $B^\pm \to K^\pm J/\psi(\to e^+e^-)$ decay mode and 283 ± 17(stat) signal events for $B^\pm \to K^\pm J/\psi(\to \mu^+\mu^-)$ decay mode.

To calculate the branching fraction ($\mathcal{B}$) of B^+, we use the formula as,

$$\mathcal{B}(B^+ \to K^+ J/\psi) = \frac{\text{no. of observed } B^\pm \text{ signal events}}{(2)(\text{no. of produced } \Upsilon(4S) \to B^+B^- \text{ events})(\mathcal{B}(J/\psi \to l^+l^-))(\varepsilon)}, \quad (1)$$

where the number of produced B^+B^- events from the $B\overline{B}$ MC dataset equals 5,205,442 events, the branching fraction of the decays $J/\psi \to e^+e^-$ and $J/\psi \to \mu^+\mu^-$ equal $(5.971 \pm 0.032)\%$ and $(5.961 \pm 0.033)\%$, respectively [6], and the reconstruction efficiency (ε) extracted from the signal MC equals $(38.473 \pm 0.062(\text{stat}))\%$ and $(44.315 \pm 0.067(\text{stat}))\%$ for the decays $B^\pm \to K^\pm J/\psi(\to e^+e^-)$ and $B^\pm \to K^\pm J/\psi(\to \mu^+\mu^-)$, respectively. We obtain the branching fraction as,

$$\begin{aligned} \mathcal{B}(B^+ \to K^+ J/\psi) &= (1.066 \pm 0.067(\text{stat})) \times 10^{-3} \text{ (for } e \text{ mode)}, \\ \mathcal{B}(B^+ \to K^+ J/\psi) &= (1.029 \pm 0.062(\text{stat})) \times 10^{-3} \text{ (for } \mu \text{ mode)}. \end{aligned} \quad (2)$$

These measured values are consistent with the branching fraction specified for generating the $B\overline{B}$ MC event which is equal to 1.014×10^{-3} for $B^+ \to K^+ J/\psi$ decay mode [15].

6. Conclusion

The decay $B \to K^{(*)}l^+l^-$ is one of the other B decay modes that is the main target for investigating at the Belle II experiment. The observable, such as the branching fraction, will be measured at the first stage of the experiment, followed by other observables with improved precision respecting previous measurements. The Belle II group at Chulalongkorn University contributes to this study by analyzing the $B \to KJ/\psi$ decay mode which is considered as one of the critical control samples for $B \to Kl^+l^-$ studies.

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