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Recent Belle II results on radiative and electroweak penguin decays

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Radiative and electroweak penguin decays are excellent probes for new physics, since they are forbidden at tree level in the Standard Model, and hence any deviation from their predicted branching fractions would be a clear sign of physics processes not accounted for by the theory. In this paper, recent results on radiative and electroweak penguin decays at the Belle II experiment are reported. The results are obtained with a dataset corresponding to an integrated luminosity of 189 fb^{-1}, and include measurements of $B \to X_s\gamma$, $B \to J/\psi(l^+l^-)K$ and $B \to K^*l^+l^-$ decays.

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1. Introduction

Flavor-changing neutral current $b \to s$ processes are forbidden at tree level in the Standard Model, since they only happen through higher order loops in perturbation theory. They are usually described in terms of effective field theory, where they are treated as point-like interactions encoded in Wilson coefficients, while the long-distance contributions are encoded in effective field operators. New Physics particles could appear in the loops, modifying the values of the Wilson coefficients or even adding new ones not present in the Standard Model. The effect of such contributions would be a modification of the branching fraction of these processes with respect to the predictions of the theory.

The Belle II experiment [1] is a multi-purpose detector located at the Super-KEKB accelerator in Tsukuba, Japan, an asymmetric e^+e^- collider. Belle II focuses on B, charm and τ physics and has so far collected a dataset corresponding to an instantaneous luminosity of 362 fb^{-1}, aiming at collecting a total of 50 ab^{-1} at the end of operations. While having excellent tracking performances for charged particles, it is also suited for measurements involving neutrals, missing energy and inclusive decays. Since B mesons are produced in pairs at Belle II, and the inital four-momentum of the collision is known, final states with missing energy can be investigated by reconstructing the partner B produced in the event, via an algorithm called `FEI` [2]. Moreover, Belle II provides good photon detection efficiency and resolution (the π^0 mass resolution being about 5 MeV), while having good and similar identification efficiencies for electrons and muons.

The results presented in this paper are obtained with a dataset corresponding to an integrated luminosity of 189 fb^{-1} collected in the period 2019-2021.

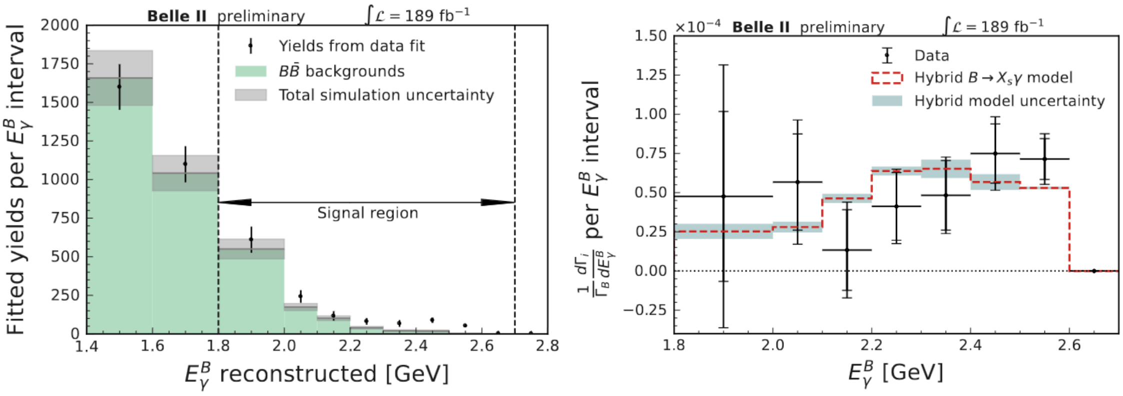
2. Experimental results

2.1 Fully inclusive $B \to X_s\gamma$

The measurement of the branching ratio of inclusive $B \to X_s\gamma$ decays is performed in bins of the photon energy [3]. After reconstructing a hadronic B decay, the most energetic photon in the rest of the event is associated to it. After suppressing the background from $\gamma, \eta \to \gamma\gamma$ and $e^+e^- \to q\bar{q}$ using MVA techniques, a fit to the beam-constrained mass $M_{bc} \equiv \sqrt{(\sqrt{s}/2)^2 - {p^*_B}^2}$ of the hadronic tag-side B is performed in bins of the photon energy, where $\sqrt{s}$ is the center-of-mass energy and p^*_B is the magnitude of the B momentum in the center-of-mass frame. The obtained yield includes $B \to X_{s+d}\gamma$ decays and other non-signal B decays which are estimated using simulations, as shown in Figure 1(a). The contribution from $B \to X_d\gamma$ decays is subtracted from the final yield assuming the same shape and selection efficiency of $B \to X_s\gamma$, and a suppression factor of $|V_{td}/V_{ts}|^2 \approx 4.3\%$. Results in bins of the photon energy are shown in Figure 1(b). The integrated partial branching fraction for photon energies above 1.8 GeV gives

$$\mathcal{B}(B \to X_s\gamma) = (3.54 \pm 0.78\,(\text{stat.}) \pm 0.83\,(\text{syst.})) \cdot 10^{-4}\,, \tag{1}$$

and is in good agreement with both the world average and the theory prediction [4, 5].

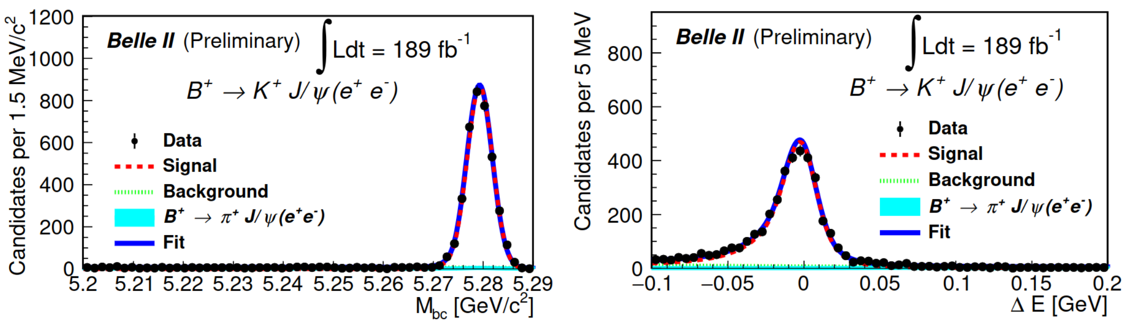


(a) (b)

Figure 1: (a) Yield of $B\bar{B}$ events in data, with background from B decays overlaid, in bins of photon energy. (b) Partial width of $B \to X_s\gamma$ decays in bins of photon energy.

2.2 Measurement of $B \to J/\psi(l^+l^-)K$

The $B \to J/\psi K$ decay is a $b \to c$ transition, favoured with respect to $b \to s$ transitions and used as a control channel for the measurement of the $R(K)$ ratio. The measurement of its branching fraction and of the ratio $R(J/\psi) \equiv \frac{\mathcal{B}(B\to J/\psi(\mu^+\mu^-)K)}{\mathcal{B}(B\to J/\psi(e^+e^-)K)}$ is performed in the charged and neutral channels $B^+ \to J/\psi K^+$ and $B^0 \to J/\psi K_s^0$ [6]. After reconstructing K_s^0 and J/ψ candidates from their decay products, B candidates are required to satisfy $M_{bc} \in [5.20, 5.29]$ GeV and $\Delta E \equiv E_B^* - \sqrt{s}/2 \in [-0.1, 0.2]$, where E_B^* is the energy of the B in the center-of-mass frame. A simultaneous fit to M_{bc} and ΔE is performed in order to extract the signal yield, as shown in Figure 2 for the channel $B^+ \to J/\psi(e^+e^-)K^+$. The results are:



(a) (b)

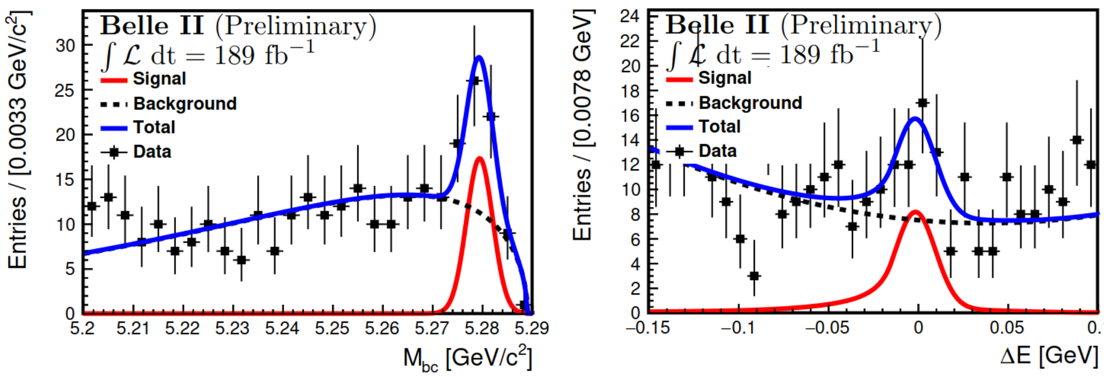
Figure 2: Fit to the (a) M_{bc} and (b) ΔE distributions of $B^+ \to J/\psi(e^+e^-)K^+$ decays.

$$
\begin{aligned}
\mathcal{B}(B^+ \to J/\psi(e^+e^-)K^+) &= (6.00 \pm 0.10 \pm 0.19) \cdot 10^{-5}\,,\\
\mathcal{B}(B^+ \to J/\psi(\mu^+\mu^-)K^+) &= (6.06 \pm 0.09 \pm 0.19) \cdot 10^{-5}\,,\\
\mathcal{B}(B^0 \to J/\psi(e^+e^-)K^0_s) &= (2.67 \pm 0.08 \pm 0.12) \cdot 10^{-5}\,,\\
\mathcal{B}(B^0 \to J/\psi(\mu^+\mu^-)K^0_s) &= (2.78 \pm 0.08 \pm 0.12) \cdot 10^{-5}\,,\\
R(J/\psi)_{K^+} &= 1.009 \pm 0.022 \pm 0.008\,,\\
R(J/\psi)_{K^0_s} &= 1.042 \pm 0.042 \pm 0.008\,,
\end{aligned}
\tag{2}
$$

which are in good agreement with the world average [4], and that show similar performances for the electron and muon modes.

2.3 Measurement of $B \to K^* l^+ l^-$

The measurement of the $B \to K^* l^+ l^-$ branching fraction is performed in the channels $B^+ \to K^{*+} l^+ l^-$, with $K^{*+} \to K^0_s \pi^+$ and $K^+\pi^0$, and $B^0 \to K^{*0} l^+ l^-$, with $K^{*0} \to K^+\pi^-$, where l indicates an electron or a muon [7]. The di-lepton mass ranges corresponding to γ, J/ψ and $\psi(2S)$ are vetoed, while the remaining background is suppressed with the use of a boosted decision tree. A simultaneous fit to M_{bc} and ΔE is performed to extract the number of signal decays, as shown in Figure 3. The $B \to K^* J/\psi(l^+l^-)$ decay is used as a control channel to fix the parameters of the



(a) (b)

Figure 3: Fit to the (a) M_{bc} and (b) ΔE distributions of $B \to K^* l^+ l^-$ events.

signal PDF. The obtained results are:

$$
\begin{aligned}
\mathcal{B}(B \to K^* \mu^+\mu^-) &= 1.19 \pm 0.31^{+0.08}_{-0.07}\,,\\
\mathcal{B}(B \to K^* e^+e^-) &= 1.42 \pm 0.48 \pm 0.09\,,
\end{aligned}
\tag{3}
$$

which are in good agreement with the world average [4]. The results show similar performances for the electron and muon modes.

3. Conclusions

Despite being statistically limited, the results presented in this paper show the potential of Belle II in the study of radiative and electroweak penguin decays. The data-taking is expected to resume at the end of 2023, extending the physics reach and the potential for discoveries of Belle II.

Acknowledgments

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