LATEST BELLE II RESULTS ON BEAUTY AND CHARM DECAYS

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We present the measurements, performed by Belle II experiment, related to the B and D meson decays. These results are based on 63 fb^{-1} (and 9 fb^{-1}) of e^+e^- collision data recorded by Belle II detector at a center of mass energy corresponding to the mass of the $\Upsilon(4S)$ resonance (and 60 MeV below the mass of the $\Upsilon(4S)$ resonance). The results reassure that Belle II is in right direction in pursuit of testing Standard Model predictions with better accuracy.

1 Introduction

The prime objective of the Belle II experiment is to measure the parameters of Standard Model (SM) with better precision and to search for the signs of the new physics (NP) beyond the SM [?]. The SuperKEB asymmetric-energy e^+e^- collider, facilitate large collision rate with its designed instantaneous luminosity 6.5×10^{35} cm^{2}s^{-1} [?]. The Belle II detector consists of several sub-detector components located around the interaction region of SuperKEKB as a cylindrical geometry [5]. The e^+e^- collides at center of mass (CM) energy equal to mass of Υ(4S) resonance ($\sqrt{s} = 10.58$ GeV), which leads to a clean sample of quantum correlated pairs of B mesons. Apart from Υ(4S), c quark and τ lepton pairs are also produced in the e^+e^- collisions with similar cross-sections and this generates equivalently large samples of D mesons and τ leptons. Here, we report on the measurements with the B and D meson decays based on 63 fb^{-1} data recorded at Υ(4S) and an additional 9 fb^{-1} recorded at 60 MeV below the Υ(4S) mass. (Throughout this report charge-conjugation is implied.)

2 Study of $B \to D^{(*)}h$ ($h = \pi, K$) decays

The decays $B^- \to D^{(*)0}K^-$ arise from the $b \to c\bar{u}s$ quark level transition and contributes to the measurement of the CKM angle ϕ_3 (or γ) [6]. And, the decays $\bar{B} \to D^{(*)}\pi^-$ are amongst dominant B decay modes and serve as a good control sample for the reconstruction procedure. The decay modes reconstructed are : (1) $B^- \to D^0h^-$, $D^0 \to K^-\pi^+$ or $D^0 \to K^0_S\pi^+\pi^-$; (2) $B^- \to D^{*0}h^-$, $D^{*0} \to D^0\pi^0$, $D^0 \to K^-\pi^+$; (3) $\bar{B}^0 \to D^+h^-$, $D^+ \to K^-\pi^+\pi^+$; and (4) $\bar{B}^0 \to D^{*+}h^-$, $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$. The final state particles (π^+, K^+, K^0_S and π^0) are selected and combined to form a D meson candidate. A B meson candidate is formed by combining a D candidate and a prompt h candidate selected with a requirement hadron identification either a kaon-like or a pion-like. Further to discriminate the signal events from the background, two kinematic variables are defined: the beam constrained mass $M_{\rm bc}(= \sqrt{E^2_{\rm beam} - (\vec{p}_B)^2})$ and the energy difference $\Delta E(= E_B - E_{\rm beam})$, where $E_{\rm beam}$ is the beam-energy and E_B and $\vec{p}_B$ are the energy and momentum, respectively, of the reconstructed B candidate. All these quantities are

calculated in the e^+e^- CM frame. The signal B candidates are selected by applying criteria on $M_{\rm bc}$ and number of signal events are extracted by performing a fit on ΔE. The ratios between the decays $B^- \to D^{(*)0}K^-/B^- \to D^{(*)0}\pi^-$ have been reported and are found to be compatible with the world-average values [7].

3 Study of hadronic B decays to charmless mesons

3.1 Reconstruction of $B^0 \to \pi^0\pi^0$

Precise measurements of each $B \to \pi\pi$ decay is crucial to invoke the isospin sum-rule to disentangle the shift in the value of CKM angle ϕ_2 due to the presence of gluonic penguin [8]. The decay $B^0 \to \pi^0\pi^0$ is of particular interest in Belle II, as the final states consists of four photons. The signal events are extracted from a simultaneous unbinned maximum likelihood fit on $M_{\rm bc}$, ΔE and output of a boosted decision-tree algorithm (FBDT) with event topological variables. The procedure is validated using the decay $B^0 \to D^0[K^-\pi^+\pi^0]\pi^0$. The signal yield is found to be $[14.0^{+6.8}_{-5.6}]$ which corresponds to the branching fraction ($\mathcal{B}$) $[0.98^{+0.48}_{-0.39} \pm 0.27] \times 10^{-6}$ for the decay $B^0 \to \pi^0\pi^0$. This result agrees with the previous measurements.

3.2 Analysis of $B^0 \to \rho^+\rho^0$

The decay $B^0 \to \rho^+\rho^0$, has two vector meson final state, and is dominated by the longitudinal polarization. Large width ρ meson and pions in the final state leads to large background contamination. Signal yields are determined from a 6D unbinned maximum likelihood fit to ΔE, FBDT output with event shape variables, reconstructed invariant masses of ρ^+ and ρ^0, and helicity angles. The signal events observed are 104 ± 16 which corresponds to the $\mathcal{B}[B^0 \to \rho^+\rho^0] = [20.6 \pm 3.2 \pm 4.0] \times 10^{-6}$ and the fraction of the decay with longitudinal polarization is found to be $[0.936^{+0.049}_{-0.041} \pm 0.021]$.

3.3 Analysis of $B^0 \to K^0\pi^0$

The $K\pi$ isospin sum rule offers a stringent null test of the SM, and is written in terms of direct CP asymmetries and $\mathcal{B}$ of the four $B \to K\pi$ decay modes. The experimental uncertainty of the sum rule is currently dominated by the measurements of the decay $B^0 \to K^0\pi^0$. This decay $B^0 \to K^0_s\pi^0$ is reconstructed and 45^{+9}_{-8} signal events are obtained by fitting ΔE and $M_{\rm bc}$ distributions, which corresponds to the $\mathcal{B}[B^0 \to K^0\pi^0] = [8.5^{+1.7}_{-1.6} \pm 1.2] \times 10^{-6}$. [10]. As this decay is a CP eigen-state, we need to rely on the flavor tagger [9], and the decay-time-integrated direct CP asymmetry, $\mathcal{A}_{K^0\pi^0}$, is determined to be $[-0.40^{+0.46}_{-0.44} \pm 0.04]$.

4 Reconstruction of the decay $B^0 \to J/\psi K^0_L$

The decay $B^0 \to J/\psi K^0_L$ provides an independent measurement of Unitarity Triangle angle $\sin(2\phi_1)$. The J/ψ candidates are reconstructed from both di-muon and di-electron final states. And, the K^0_L candidate is identified from hadronic shower cluster in the K^0_L and muon subdetector. The energy and momentum of the K^0_L is inferred with the help of flight direction while reconstructing the decay $B^0 \to J/\psi K^0_L$. The number of signal events is extracted by performing a fit to the ΔE variable. The number of signal events are found to be 267 ± 21(stat.) and 226 ± 20(stat.) in $\mu^+\mu^-$ and e^+e^- final states, respectively. The number of signal events are found to be consistent with the predecessor Belle experiment with similar purity. In future, there is a plan to improve the signal yield by analyzing the hadronic shower clusters in the electromagnetic calorimeter.

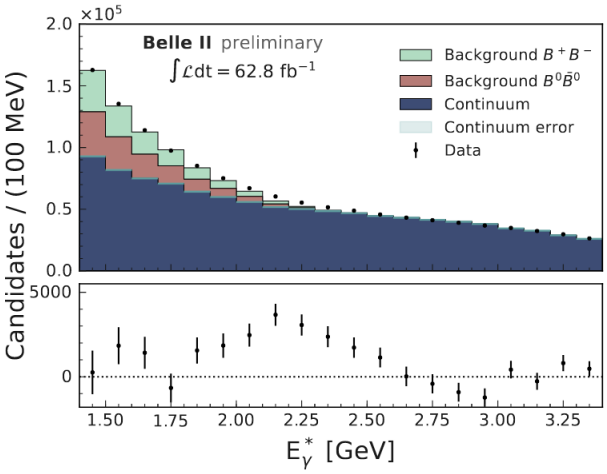

Figure 1 – (Top) The photon energy spectrum of the selected $b \to s\gamma$ candidates in the CM frame. The data events are represented with black dots and the expected background events in data are represented with color-filled histograms. (Bottom) The subtracted distribution of data events with expected background events indicates the presence of $b \to s\gamma$ events.

5 Radiative and electroweak penguin B decays

The B decays with flavour changing neutral current quark-level transitions $b \to s\gamma$, $b \to s\ell^+\ell^-$ and $b \to s\nu\bar{\nu}$, proceed through penguin loop and box diagrams. These decays are considered excellent probes for the NP.

5.1 Inclusive photon energy spectrum of the decay $B \to X_s\gamma$

The inclusive γ energy spectrum moments in the $b \to s\gamma$ transition is important for the determination of $b-$quark mass and its motion inside the B meson. In this analysis [11], firstly a high energy photon ($E^*_\gamma > 1.4$ GeV in the CM frame) is searched in the collision events, which should not be arising from a π^0 or an η meson decays. The continuum events are suppressed with event shape variables. The expected spectra of background events in data is obtained by scaling the Monte Carlo distribution from off-resonance sample and side-bands of data. Clearly visible excess in data is observed around the expected region of E^*_γ as shown in figure 1.

5.2 $B^+ \to K^+\ell^+\ell^-$ in the early data-set of Belle II

The decays $B^+ \to K^+\ell^+\ell^-$ have raised a lot of interest in study of lepton-flavor-universality ratios. These rare decays (BF $\sim 10^{-7}$) are challenging to be observed in the early data-set of Belle II. However, in a recent analysis at Belle II, $8.6^{+4.3}_{-3.9} \pm 0.4$ signal events are observed for decay $B^+ \to K^+\ell^+\ell^-$ [12].

5.3 Search for the decay $B^+ \to K^+\nu\bar{\nu}$

The decay $B^+ \to K^+\nu\bar{\nu}$ is theoretically cleaner as there is no contribution from the virtual photon in the diagrams unlike the case of decays with $b \to s\ell^+\ell^-$ transition. The decay $B^+ \to K^+\nu\bar{\nu}$ is experimentally challenging as the final states consist of two neutrinos. In this search at Belle II, a new analysis method has been developed that exploits the topological features of the decay which leads to larger signal reconstruction efficiency. The method has been validated with the decay $B^+ \to K^+J/\psi[\to \mu^+\mu^-]$, by ignoring the dimuons from the J/ψ decay to mimic the missing energy from two neutrino and K^+ momentum is also modified to correspond to a three body decay. The signal strength obtained from the fit to be $[4.2^{+2.9}_{-2.8}\ (\text{stat.})^{+1.8}_{-1.6}\ (\text{syst.})]$, which corresponds to a BF $= [1.9^{+1.3}_{-1.3}\ (\text{stat.})^{+0.8}_{-0.7}\ (\text{syst.})] \times 10^{-5}$. This measurement is competitive with the previous results, taking into account of the amount of data-sample used. As no significant signal is observed the expected 90% confidence level (CL) upper limit (UL) on the BF of 2.3×10^{-5} is derived and the observed UL is 4.1×10^{-5} at 90% CL is set.

6 Study of charm meson decays

6.1 Measurement of the D^0 lifetime

The lifetime measurement of D^0 meson is performed on 9.6 fb^{-1} Belle II data recorded in 2019 [14]. The D^0 meson is reconstructed in three decay modes: $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^0$ and $D^0 \to K^-\pi^+\pi^+\pi^-$ and coming from the decay $D^{*+} \to D^0\pi^+$. The lifetime of D^0 is obtained by performing a two-dimensional unbinned maximum likelihood fit to the proper time and its uncertainty distribution. The average lifetime of D^0 meson is measured to be $[412.3 \pm 2.0]$ fs. With 72 fb^{-1} of Belle II data, the lifetime measurement of D^0 is expected to be competitive with the world-averages.

6.2 Preliminary analysis of $D^{*+} \to D^0[\to \pi^+\pi^-\pi^0]\pi^+$

The CP violation in the charm mesons is an important topic to study in the Belle II experiment. The ultimate aim is to perform a time-averaged Dalitz analysis for the decay $D^{*+} \to D^0[\to \pi^+\pi^-\pi^0]\pi^+$. Currently, the decay has been reconstructed and signal events are extracted using a binned log-likelihood fit to the ΔM, difference between the reconstructed invariant masses of D^{*+} and D^0. The number of signal events per fb^{-1} is estimated to be 305 ± 15 [15].

Summary

Belle II detector is recording data steadily amid CoViD-19 pandemic towards its ultimate goal of accumulating atleast 50 ab^{-1} of e^+e^- collision data. This upcoming large and clean samples of B's, D's (and tau's) will allow Belle II to search for NP and improve the measurements of the SM parameters. Measurements in this report are based on the early data recorded with improved Belle II detector and analysed with novel methods. These results demonstrates that all the sub-detectors of Belle II are performing as per expectation and some results are already competitive.

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