Rare charm decays at Belle II

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Abstract. Belle II detector, situated at the SuperKEKB e^+e^- accelerator, will collect a 50 times larger data sample than the Belle detector. This will allow more precise measurements and tests of the Standard Model (SM). Flavor Changing Neutral Current (FCNC) processes are forbidden at the tree level in the SM. However, there are several new physics (NP) models that can enhance the branching fractions of the FCNC. $D^0 \to \gamma\gamma$ is one such decay mode sensitive to the NP searches. We will discuss the prospects for charm rare decays at Belle II, focusing on the $D^0 \to \gamma\gamma$ decay mode. Further, we will also demonstrate the capability of the Belle II detector by reconstructing the charm mesons from the neutral candidates ($D^0 \to K^0_S\pi^0$). The study uses the most recently collected data by the Belle II detector corresponding to an integrated luminosity of 34.6 fb^{-1}.

1 Introduction

SuperKEKB [1] is an asymmetric e^+e^- collider located at the KEK Laboratory in Tsukuba, Japan. The nominal center-of-mass energy is 10.58 GeV, where the e^+ beam energy is 4 GeV and the e^- beam energy is 7 GeV. The accelerator is designed to deliver a peak instantaneous luminosity 6×10^{35} cm^{-2}s^{-1}, which is 30 times higher than its predecessor, the KEKB accelerator, and the goal of SuperKEKB is to deliver about 50 ab^{-1} of data to Belle II. It is not just a B-factory but also a charm factory with approximately 5×10^{10} $c\bar{c}$ events expected by ~ 2030. Belle II [2] is a general purpose detector designed to perform precision measurements of the Standard Model (SM) parameters to look for hints of new physics (NP).

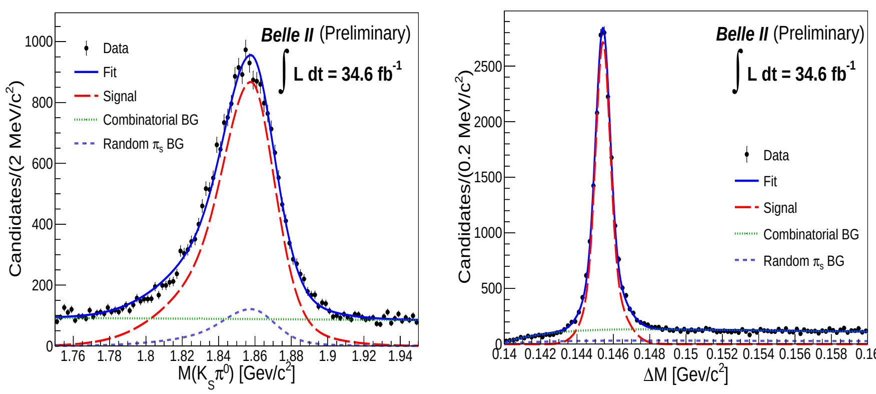
A Flavor Changing Neutral Current (FCNC) is one of the processes that constitute an excellent probe to search for NP. FCNCs are forbidden at tree level but proceed via electroweak loops in the SM. Decays involving $K^0-\bar{K^0}$, $B^0_{d(s)}-B^{\bar{0}}_{d(s)}$ mixing [3] and $b \to s\gamma$ transitions [4] are extensively studied by previous experiments but the processes involving $c \to u$ transitions, such as $D^0 \to \gamma\gamma$, still need further explorations. This is due to the fact that the SM expectations of these processes are very small because of the GIM cancellation [5] of loop-level amplitudes in the SM. The predicted branching ratio of $D^0 \to \gamma\gamma$ is 3×10^{-11}, if we consider only short distance contributions and this branching ratio gets enhanced to $\left(3.5^{+4.0}_{-2.6}\right) \times 10^{-8}$ with the inclusion of long distance contributions [6]. In the minimum supersymmetric SM, decays proceed via exchange of a superpartner of the quark, squark, in the loop and estimated branching ratio of $c \to u\gamma$ process increases to 6×10^{-6} [7]. Previously $D^0 \to \gamma\gamma$ studies had been performed by CLEO [8], BESIII [9], BABAR [10] and Belle [11] experiments. $D^0 \to \gamma\gamma$ decay has not been discovered but the experimental measurements exclude a branching ratio larger than 8.5×10^{-7} at 90% confidence level [11]. New generation detectors such as Belle II and LHCb provide an opportunity to explore these interesting processes. LHCb can perform precise measurements for final states with charged particles but final states with neutrals such as $D^0 \to \gamma\gamma$ that require good energy resolution and low backgrounds can be better explored with the Belle II detector.

Belle II detector is expected to collect approximately 1 ab^{-1} of data by summer 2022 which will be enough to improve on the existing $D^0 \to \gamma\gamma$ limit. While Belle II accumulates sufficient statistics to look for the rare decays, it is important that the performance of each sub-detector and particle reconstruction is well established using well understood processes such as $D^0 \to K^0_S\pi^0$, $D^0 \to \pi^+\pi^-$, $D^0 \to K^-\pi^+$, etc. Here, we present a first look at the $D^0 \to K^0_S\pi^0$, which is an important control process in the context of the $D^0 \to \gamma\gamma$ analysis.

2 Rediscovery of $D^0 \to K^0_S\pi^0$ decay with Belle II data

Belle II data recorded at the $\Upsilon(4S)$ resonance, corresponding to an integrated luminosity of 34.6 fb^{-1}, is analyzed to look for the $D^0 \to K^0_S\pi^0$ process. The decay mode of interest $D^0 \to K^0_S\pi^0$ is reconstructed in the decay chain $D^{*+} \to D^0(\to K^0_S\pi^0)\pi^+$. Requiring that the D^0 candidate is consistent with being a decay product of a D^{*+} meson will suppress the background that comes from a random combination of final state particles. An electromagnetic calorimeter (ECL) cluster is treated as a photon (γ) candidate if it is isolated from the extrapolated charged tracks. The photon energy in the laboratory frame, is required to have a minimum value of 30 MeV, 120 MeV or 80 MeV depending upon whether it was reconstructed in the barrel, forward endcap or backward endcap of the ECL, respectively. The π^0 candidate is reconstructed from a pair of photons with invariant mass that lies in the range, 121 Mev/c^2 $< M(\gamma\gamma) <$ 142 MeV/c^2. Further, the mass of the selected π^0 candidate, $M(\gamma\gamma)$ is constraint to the nominal π^0 mass, in order to improve the resolution. K^0_S candidates are reconstructed by using a pair of oppositely charged pion tracks with invariant mass that lies within $\pm$ 30 MeV/c^2 of the nominal K^0_S mass (497 MeV/c^2) [12]. Selected K^0_S and π^0 candidates are combined to reconstruct the D^0 candidate by requiring the invariant mass $M(K^0_S\pi^0)$ lies between 1.75 GeV/c^2 and 1.95 GeV/c^2. Further, this D^0 candidate is combined with low momentum pions known as “slow” pions, π^+_s, to reconstruct D^{*+} candidates and the mass difference between D^0 and D^{*+} candidates, ΔM, is required to have a value between 0.14 GeV/c^2 and 0.16 GeV/c^2. The center of mass momentum of the D^{*+} candidate, $p^*(D^{*+})$ is required to be $>$ 2.5 GeV/c, which removes the background of charmed particles coming from the B decays.

Figure 1 (a) and (b) show the $M(K_S^0\pi^0)$ and $\varDelta M$ distributions for the selected data candidates. These distributions show a clear peak corresponding to the presence of the $D^{*+} \to D^0(\to K_S^0\pi^0)\pi^+$ mode. To extract the $D^0 \to K_S^0\pi^0$ signal yield, distributions are fitted with signal and background probability distribution functions. A two dimensional unbinned maximum likelihood fit is performed on $M(K_S^0\pi^0)$ and $\varDelta M$ observables. For $M(K_S^0\pi^0)$, the signal shape is described by the sum of double Gaussian and bifurcated Gaussian functions. An exponential and a sum of double Gaussian and bifurcated Gaussian functions, with the same parameters as the signal, is used to fit combinatorial and random π_s(peaking) background, respectively. Peaking background is due to the combination of real D^0 candidates and fake π_s candidates. For $\varDelta M$, the sum of bifurcated Gaussian and Gaussian functions is used to model the signal and the threshold function is used to fit both combinatorial and random π_s background. The signal yield is measured to be 16800 $\pm$ 150, where the uncertainty is statistical only.



(a) (b)

Fig. 1. (a) $M(K_S^0\pi^0)$ and (b) $\varDelta M$ distributions for the Belle II data set, represented with black points with error bars. Solid blue line, red dashed line, green dotted line and purple dashed line represents total fit, signal, combinatorial background and random π_s background, respectively [13].

3 Summary and Conclusion

FCNCs provide interesting decays to search for NP as SM expectations are very small for these rare processes. With higher statistics, the Belle II experiment will be able to probe these decays for physics beyond the SM. Detector and particle reconstruction performance is validated with a $D^0 \to K_S^0\pi^0$ control channel.

These studies give confidence in the readiness of the Belle II experiment to explore the rare radiative decay $D^0 \to \gamma\gamma$ and improve the existing limit.

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