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Time-integrated WS-to-RS ratio of the $D^0 \longrightarrow K^+\pi^-\pi^0$ decay at Belle II

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In the standard model, mixing and CP violation in the charm sector are expected to be very small, and thus, they constitute a sensitive probe for potential new physics contributions.
The "wrong-sign" $D^0 \longrightarrow K^+\pi^-\pi^0$ decay is one of the most promising channels at Belle II, as this can be produced through two interfering processes: a direct doubly Cabibbo-suppressed decay of the D^0 meson, or through D^0-$\bar{D}^0$ mixing followed by a Cabibbo-favored decay of the $\bar{D}^0$ meson. In this work, we report the time-integrated WS-to-RS ratio of the "wrong-sign" $D^0 \longrightarrow K^+\pi^-\pi^0$ decay in the simulation of the integrated luminosity of $1ab^{-1}$ at Belle II. The Belle II is the upgraded experimental facility at SuperKEKB, KEK, Japan. This study will be used to measure the mixing and CP Violation of the "wrong-sign" $D^0 \longrightarrow K^+\pi^-\pi^0$ decay.

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Introduction

As the standard model predicts extremely minimal mixing and CP violation in the charm sector, thus they represent a sensitive probe for new possible physics contributions [1]. The "Wrong-Sign" (WS) decay $D^0 \to K^+\pi^-\pi^0$ is one of the most promising channels at Belle II [2]. This decay can be produced by two interfering processes: either by D^0-$\bar{D}^0$ mixing followed by a Cabibbo-favored decay of the D^0 meson or through direct doubly Cabibbo-suppressed decay of the $\bar{D}^0$ meson. One of the greatest channels to examine charm mixing and look for the CP violation in D^0-$\bar{D}^0$ oscillations is the WS $D^{*+} \to D^0(\to K^+\pi^-\pi^0)\pi^+$ decay. Separating these two processes and measuring the mixing is made possible by measuring the time-dependent decay rate of wrong-sign decays.

This analysis aims to determine the time-integrated WS-to-RS ratio of the "wrong-sign" $D^0 \to K^+\pi^-\pi^0$ decay in the Belle II simulation at an integrated luminosity of $1ab^{-1}$. The Belle II [2] is an improved experimental facility at SuperKEKB [3], KEK Japan.

Dataset and Selection Criteria

The WS signal decay $D^{*+} \to D^0(\to K^+\pi^-\pi^0)\pi^+$ are reconstructed alongside with the corresponding "Right-Sign" (RS) decay $D^{*+} \to D^0(\to K^-\pi^+\pi^0)\pi^+$, which is used as control channel in the simulation at the integrated luminosity of 1 ab^{-1} at Belle II. The same criteria used to reconstruct the WS decays are also used for the RS decays. The candidates $D^0 \to K^\pm\pi^\mp\pi^0$ are reconstructed from charged kaon, and pion having at least one hit in Silicon Vertex Detector (SVD) [2] and 20 hits in Central Drift Chamber (CDC) [2], combined with $\pi^0 \to \gamma\gamma$. Photon candidates consist of energy clusters from at least 2 ECL crystals (i.e, number of cluster hits > 1.5) that have a polar angle in the range $[17°, 150°]$ (to ensure they are not matched to any CDC track), and energy larger than 80 MeV, 30 MeV, and 60 Mev if reconstructed in the regions 1 (forward), 2 (barrel) and 3 (backward) of the ECL, respectively. The two photons must have a difference in azimuthal angle of $|\Delta\phi| < 1.5$ and a 3D opening angle smaller than 1.4. The diphoton mass is requested to be in the range $[0.12, 0.145] GeV/c^2$. The D^0 is thus reconstructed by combining with low momentum pions, which has at least one hit in CDC to form $D^{*+} \to D^0\pi^+$ decay. The "swapped" D^0 mass, computed by inverting the mass hypothesis on the charged D^0 decay products, is requested to be smaller than $1.81 GeV/c^2$ or larger than $1.9 GeV/c^2$. Such a requirement is estimated to reduce the fraction of doubly misidentified decays in simulation. The criteria on the center of mass momentum of D^{*+} is applied to be greater than 2.5 GeV/c to remove the background contribution coming from D^0 meson from B decays.

Efficiency Variation

Due to the different amplitude models for RS and WS samples, the reconstruction efficiency over the Dalitz plot [6] is required. Using a sample of 60×10^{-3} truth-matched RS signal decays generated with a phase-space model, which comprises both D^{*+} and D^{*-} mesons in the generation, we determine the variation of $\epsilon_{K\pi\pi^0}$ as a function of the three-body phase-space. The phase space of a three-body decay, in which initial and final-state particles all have spin zero, can be parametrized as a function of two independent kinematic variables. We choose the invariant mass, $m(\pi, \pi^0)$, and the cosine of the helicity angle, $\cos\theta(\pi,\pi^0)$ of the π system[1] such that the kinematically allowed domain has a rectangular shape. We evaluate the efficiency for reconstructing and selecting RS decays over this rectangular domain using a grid of equally sized 100×100 bins. The resulting efficiency map, shown in figure 1, is used to correct the simulated WS and RS decays on a per-candidate basis.

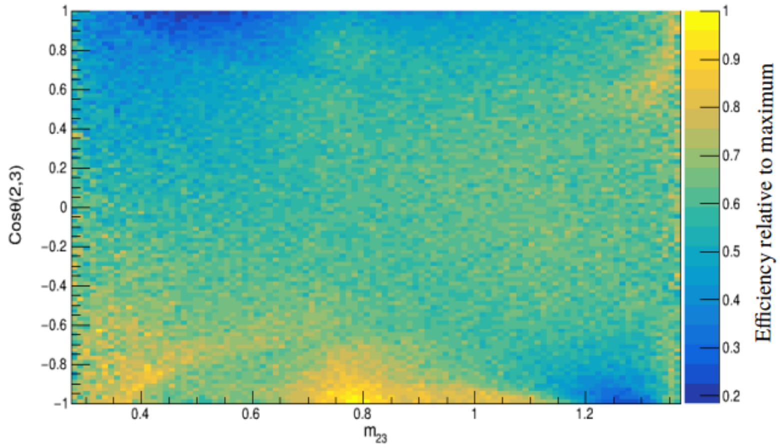

Figure 1: Efficiency across the Dalitz plot evaluated as a function of m(π,π^0) invariant mass and helicity angle $\cos\theta$ (π,π^0).

Results

The background components are identified for $D^0 \to K^\pm\pi^\mp\pi^0$ candidates, and a two-dimensional binned fit ($m(D^0)$, $m(D^0\pi^+)$) is performed to determine the signal yield, where $m(D^0\pi^+)$ is the mass of the D^* but with no mass hypothesis on the D^0 daughters [4]. The Probability Density Function (PDF) for signal component corresponding to $m(D^0)$ and $m(D^0\pi^+)$ are Double Gaussian and Johnson [5], fixed to that of the RS signal. The random-pion (background) shape due to correctly reconstructed D^0 candidates combined with unrelated π_s, $m(D^0\pi^+)$ parametrization by $[m - m_0]^{1/2} + \alpha[m - m_0]^{3/2}$ and $m(D^0)$ is the same as that of the signal. A background component due to $D^{*+} \to D^0(\to \pi^-\pi^+\pi^0)\pi^+$ decays in which the positively charged pion is misidentified as a kaon, $m(D^0)$ PDF parametrized as a double Gaussian function and $m(D^0\pi^+)$ is the same as that of the signal. For partially reconstructed $D^{*+} \to D^0(\to h^+h'^-\pi^0X)\pi^+$ and combinatorial background components, $m(D^0)$ shape is parametrized using a first-order Chebyshev polynomial. The $m(D^0\pi^+)$ shape modelled using a Johnson's S_U function, for the peaking component due to partially reconstructed decays, and as random pion background, for the combinatorial component. The parameters of the Johnson's S_U function are determined from fits to the data candidates populating the $m(D^0)$ sideband region $[1.8, 1.82] \cup [1.9, 1.93] GeV/c^2$.

All fit parameters are fixed to the values obtained from separate fits to all signal and background components. The efficiency corrected fit results of $m(D^0)$ and $m(D^0\pi^+)$ distribution for WS sample are reported in figure 2.

[1]The π helicity angle is defined as the angle between the neutral-pion and the kaon momenta in the rest frame of the π system.

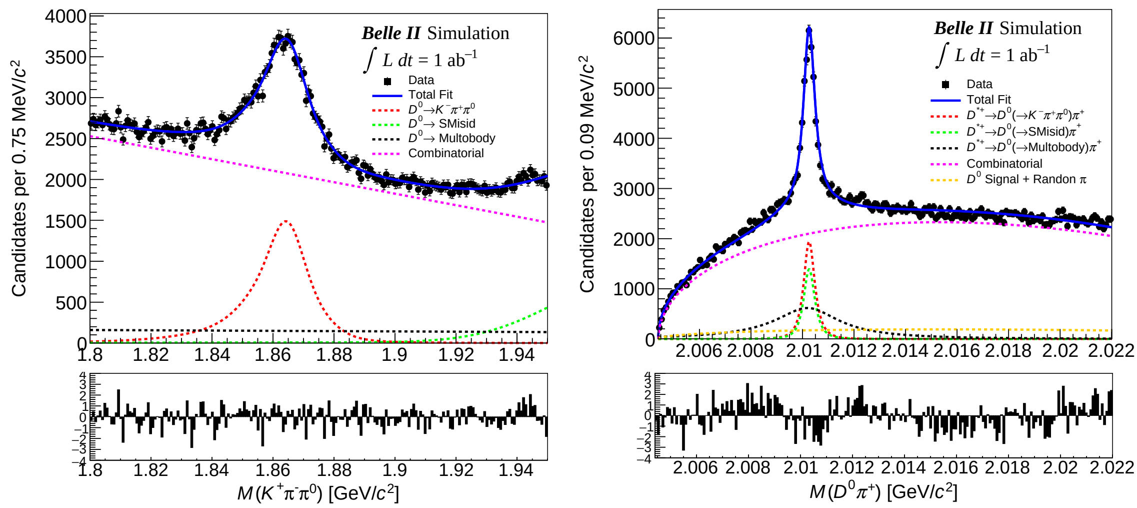

Figure 2: Distribution of $m(D^0)$ (left) and $m(D^0\pi^+)$ (right) for WS $D^0 \to K^+\pi^-\pi^0$ candidates reconstructed in simulation, with fit projections overlaid.

We have rediscovered the wrong-sign $D^0 \to K^+\pi^-\pi^0$ decay in simulation. The observed yield of WS and RS Sample are N($D^0 \to K^+\pi^-\pi^0$) = 14322 ± 262 and N($D^0 \to K^-\pi^+\pi^0$) = 6713521 ± 4030, where the uncertainties are only statistical. The ratios of WS to RS yields are measured to be,

$$\frac{N(D^0 \to K^+\pi^-\pi^0)}{N(D^0 \to K^-\pi^+\pi^0)} = (2.13 \pm 0.04) \times 10^{-3}, \tag{1}$$

The results are in agreement with the value of ratio used in generation, 2.12×10^{-3}.

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