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Measurement of time integrated raw asymmetry in $D^0 \to K_s^0 K_s^0$ decay at Belle II

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$D^0 \to K_s^0 K_s^0$ is a Singly Cabibbo Suppressed decay, which involves the interference of $c\overline{u} \to s\overline{s}$ and $c\overline{u} \to d\overline{d}$ transitions. Due to such interference, the Charge Parity asymmetry may be enhanced to an observable level within the Standard Model. In this work, the signal yield and corresponding raw asymmetry (A_{raw}) for $D^0 \to K_s^0 K_s^0$ is estimated using the Belle II Monte Carlo samples corresponding to an integrated luminosity of 1/ab.

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1. Introduction

$D^0 \to K_s^0 K_s^0$ is a Singly Cabibbo Suppressed (SCS) decay, which involves the interference of $c\overline{u} \to s\overline{s}$ and $c\overline{u} \to d\overline{d}$ transitions, mediated by the exchange of a W boson at tree level as shown in Figure 1. Due to such interference, the Charge Parity asymmetry ($\mathcal{A}_{CP}$) may be enhanced to an observable level within the Standard Model (SM) [1].

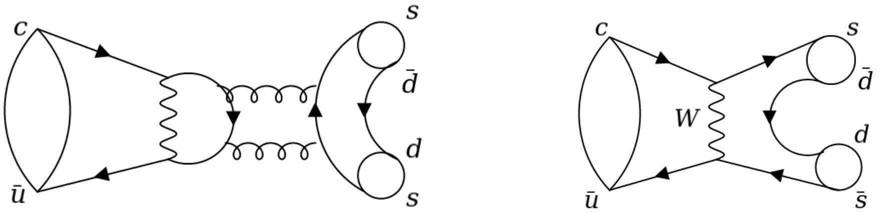

Figure 1: Loop level (left) and tree level (right) Feynman diagrams for $D^0 \to K_s^0 K_s^0$ decay.

The world-average determination of $\mathcal{A}_{CP}(D^0 \to K_s^0 K_s^0) = (-1.9 \pm 1.0)\%$, is limited by the statistical precision [2]. The average is dominated by measurements from Belle [5] and LHCb [3]. Using e^+e^-- collision data corresponding to an integrated luminosity of 921/fb, Belle measured $\mathcal{A}_{CP}(D^0 \to K_s^0 K_s^0) = (-0.02 \pm 1.53 \pm 0.02 \pm 0.17)\%$, where the first uncertainty is statistical, the second systematic, and the third is due to the uncertainty in the CP asymmetry of the reference mode, $D^0 \to K_s^0 \pi^0$. A more precise result is obtained by LHCb measurement using pp-collision data collected during Run 2 and corresponding to an integrated luminosity of 6/fb: $\mathcal{A}_{CP}(D^0 \to K_s^0 K_s^0) = (-3.1 \pm 1.2 \pm 0.4 \pm 0.2)\%$, where the first uncertainty is statistical, the second is systematic, and the third is due to the uncertainty in the CP asymmetry of the reference channel $D^0 \to K^+K^-$.

In this work, the signal yield and corresponding raw CP asymmetry (A_{raw}) for $D^0 \to K_s^0 K_s^0$ is measured using Belle II Monte Carlo (MC) samples at integrated luminosity of 1 ab^{-1}. The Belle II [6] is an experimental facility at SuperKEKB [7] located in Tsukuba, Japan. The final goal of this analysis is to measure the $\mathcal{A}_{CP}$ in $D^0 \to K_s^0 K_s^0$ with the combined Belle and Belle II datasets where, $D^0 \to K^+K^-$ is used as a reference mode.

2. Reconstruction of $D^0 \to K_s^0 K_s^0$

Signal candidates are reconstructed using the centrally produced Belle II MC samples at integrated luminosity of 1 ab^{-1}. The complete decay chain reconstructed for our analysis is $D^{*+} \to D^0(\to K_s^0 K_s^0)\pi_s^+$, where π_s^+ denotes the low-momentum *(soft)* pions. Each K_s^0 is reconstructed by combining two oppositely charged pions. Pairs of K_s^0 candidates thus reconstructed are combined to form the decay $D^0 \to K_s^0 K_s^0$. Finally, the D^0 candidates are combined with *soft* pions originating from the interaction region $|d_r| < 0.5$ cm and $|d_z| < 2$ cm to form the decay $D^{*+} \to D^0\pi_s^+$, where $|d_r|$ and $|d_z|$ are respectively the longitudinal and transverse impact parameters. To suppress events where the D^{*+} candidate comes from B meson decays, the momentum of the D^{*+} in the e^+e^- center-of-mass system is required to be greater than than 2.5 GeV/c^2. The difference between the reconstructed D^{*+} and D^0 masses, Δm, must not exceed 0.16 GeV/c^2. Charge conjugation is implied throughout this document unless explicitly mentioned.

3. Main background

The major background for the decay $D^0 \to K_s^0 K_s^0$ is $D^0 \to K_s^0 \pi^+ \pi^-$. The latter has the same final state particles and also originates from a real D^0, therefore it has the same Δm and D^0 mass distribution as of the signal. This makes it difficult to separate the signal from the background using solely the traditionally used Δm variable.

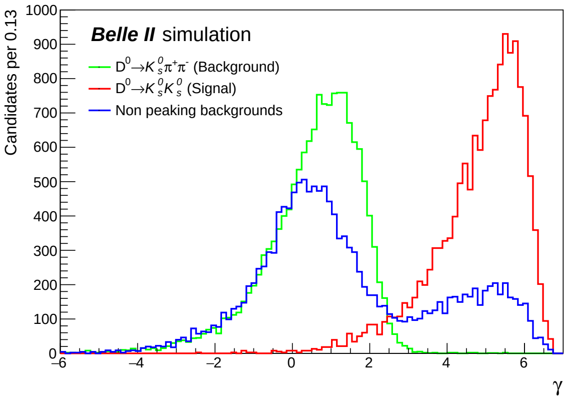

Figure 2: Distributions of γ for signal and background components. *Non-peaking backgrounds* denotes the backgrounds that do not peak in Δm.

The flight distance of the K_s^0 with respect to the D^0 vertex is exploited to provide a better separation of the signal and peaking background components. We introduce a new variable γ, defined as the minimum of the flight-distance significance of the K_s^0 candidates. Its distribution for signal and background candidates is shown in Figure 2. No dedicated selection criteria is applied to suppress the $D^0 \to K_s^0 \pi^+ \pi^-$ background, instead, γ is used as fitting variable, together with Δm.

4. Results

Two variables, Δm and γ are used to discriminate between the signal and the background components for the $D^0 \to K_s^0 K_s^0$ decay, and to measure its yield and A_{raw} which is defined by

$$A_{raw} = \frac{N(D^0 \to K_s^0 K_s^0) - N(\bar{D}^0 \to K_s^0 K_s^0)}{N(D^0 \to K_s^0 K_s^0) + N(\bar{D}^0 \to K_s^0 K_s^0)}, \tag{1}$$

where N denotes the number of signal candidates. A simultaneous unbinned maximum likelihood fit to $(\Delta m, \gamma)$ of D^0 and $\bar{D}^0$ candidates is performed for candidates populating the $m(K_s^0 K_s^0)$ signal window: [1.85, 1.88] GeV/c^2. The Δm and γ projections of the fit to 1/ab equivalent Belle II Monte Carlo is shown in Figure 3. The signal shape in both dimensions is modelled using a Johnson's S_U [8] probability distribution function (PDF). The $D^0 \to K_s^0 \pi^+ \pi^-$ *(Background)* component is modelled in the Δm dimension using the sum of a Gaussian and a Johnson's S_U [8] PDFs, both with the same mean. In the γ dimension, it is modelled using a Johnson's S_U [8] function. *Other background* components in the γ dimension is extracted from the Δm side-bands and are modelled using the sum of two Johnson's S_U PDFs. In the Δm dimension, it is modelled using the function:

$((\Delta m\text{-}\Delta m_0) + \alpha(\Delta m\text{-}\Delta m_0)^{3/2})$, where Δm_0 is 0.13957039 GeV/c^2. All shape parameters of the fit are fixed to their values obtained from the separate fits to the components in simulation. The yields corresponding to the three components, the corresponding raw asymmetries and α is left free to float. Same shapes are assumed to correctly describe both the D^0 and the $\bar{D}^0$ samples.

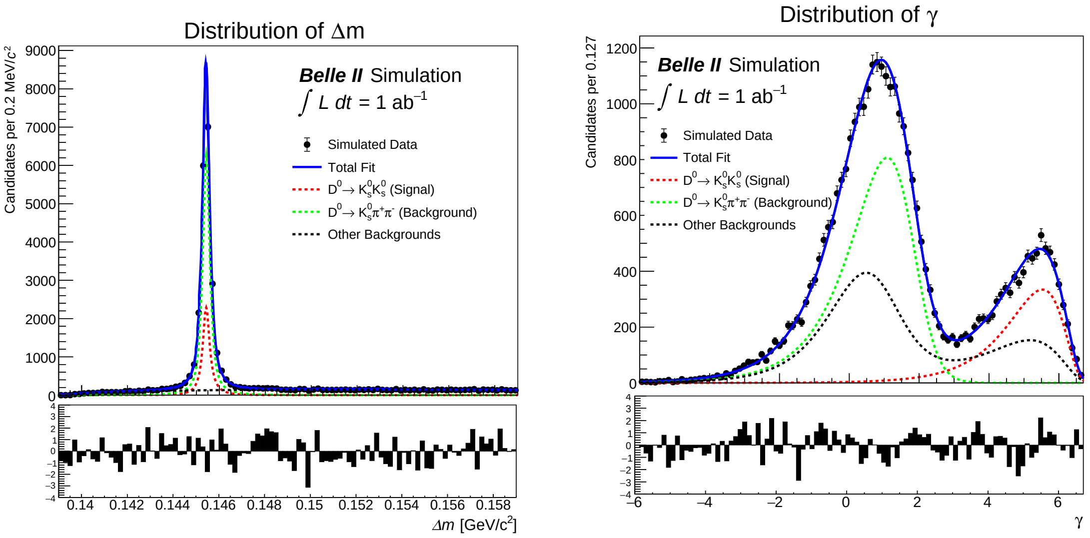

Figure 3: Distributions of Δm (left) and γ (right), with fit projections overlaid. The normalized residuals (pulls) are also shown in the lower panel of each plot.

The measured signal yield is 5853 ± 83 and the corresponding A_{raw} is (0.7 ± 1.4)%. Our simulation result is ~10% better as compared to that expected from the same analysis performed on Belle simulated data.

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