PROCEEDINGS OF SCIENCE

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

Sanjeeda Bharati Das[a,*] and Kavita Lalwani[b] (for the Belle II collaboration)

[a,b]*Malaviya National Institute of Technology Jaipur,*
Jawahar Lal Nehru Marg, Jhalana Gram, Malviya Nagar, Jaipur, India, 302017

E-mail: 2018rpy9055@mnit.ac.in, kavita.phy@mnit.ac.in

$D^0 \longrightarrow K_s^0 K_s^0$ is a Singly Cabibbo Suppressed decay, which involves the interference of $c\overline{u} \longrightarrow s\overline{s}$ and $c\overline{u} \longrightarrow d\overline{d}$ 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 $D^0 \longrightarrow K_s^0 K_s^0$ is measured using Belle II Monte Carlo (MC) samples at integrated luminosity of 1/ab.

16th International Conference on Heavy Quarks and Leptons (HQL2023)
28 November-2 December 2023
TIFR, Mumbai, Maharashtra, India

*Speaker

1. Introduction

$D^0 \longrightarrow K_s^0 K_s^0$ is a Singly Cabibbo Suppressed (SCS) decay, which involves the interference of $c\overline{u} \longrightarrow s\overline{s}$ and $c\overline{u} \longrightarrow d\overline{d}$ 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].

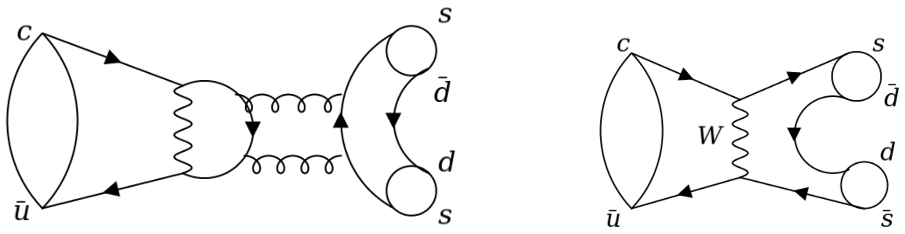

Figure 1: Loop level (left) and tree level (right) Feynman diagrams for $D^0 \longrightarrow K_s^0 K_s^0$ decay.

The world-average determination of $\mathcal{A}_{CP}(D^0 \longrightarrow K_s^0 K_s^0)$, $(-1.9 \pm 1.0)\%$, is limited by the statistical precision [3]. The average is dominated by measurements from Belle [4] and LHCb [2]. Using $e^+ - e^-$ collision data corresponding to an integrated luminosity of 921/fb, Belle measured $\mathcal{A}_{CP}(D^0 \longrightarrow K_s^0 K_s^0) = (-0.02 \pm 1.53 \pm 0.02 \pm 0.17)\%$, where the first uncertainty is statistical, the second systematic, and the third is due to the uncertainty in the CP asymmetry of the reference $D^0 \longrightarrow K_s^0 \pi^0$ mode. 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: $(-3.1 \pm 1.2 \pm 0.4 \pm 0.2)\%$, 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 $D^0 \longrightarrow K^+K^-$.

In this work, the signal yield and corresponding raw CP asymmetry (A_{raw}) for $D^0 \longrightarrow K_s^0 K_s^0$ is measured using Belle II Monte Carlo (MC) samples at integrated luminosity of 1 ab^{-1}. The Belle II [5] is an experimental facility at SuperKEKB [6] located in Tsukuba, Japan. The final goal of this analysis is to measure the $\mathcal{A}_{CP}$ in $D^0 \longrightarrow K_s^0 K_s^0$ with (Belle + Belle II) data-set where, $D^0 \longrightarrow K^+K^-$ is used as a reference mode.

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

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 $D^{*+} \longrightarrow D^0(\longrightarrow K_s^0 K_s^0)\pi_s^+$, where π_s^+ denotes the low-momentum *(soft)* pions. Each K_s^0 decays into a pair of oppositely charged pions. Candidate $K_s^0 \longrightarrow \pi^+\pi^-$ decays are reconstructed by combining the tracks of two oppositely charged pions. Pairs of K_s^0 candidates thus reconstructed are combined to form the decay $D^0 \longrightarrow K_s^0 K_s^0$. Finally, the D^0 candidates are combined with *soft* pions to form the decay $D^{*+} \longrightarrow D^0\pi_s^+$. 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 (p_{cms}) is required to be greater than than 2.5 GeV/c^2. Charge conjugation is implied throughout this document unless explicitly mentioned.

3. Background study

The major background for the decay $D^0 \longrightarrow K_s^0 K_s^0$ is $D^0 \longrightarrow K_s^0 \pi^+ \pi^-$, as they have the same final state particles. Further they also have the same Δm (defined as the difference in the masses of D^{*+} and D^0 candidates) distribution. This makes it difficult to separate the signal from the background using solely the traditionally used Δm distribution.

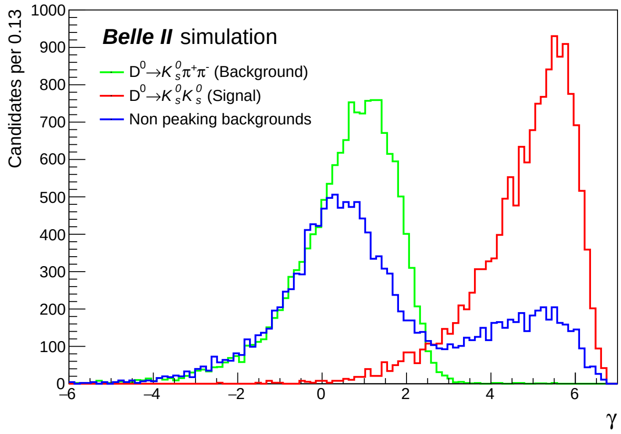

Figure 2: Distributions of γ for signal and background components. It is to be noted that *Non-peaking backgrounds* denote the backgrounds that do not peak in Δm

The flight distance of the K_s^0 with respect to the D^0 vertex is exploited to provide a clear separation of the signal and peaking background components. A new variable γ, defined as the minimum of the flight-distance significance of the K_s^0 candidates is introduced as shown in Figure 2. No selection criteria is applied to suppress the $D^0 \longrightarrow K_s^0 \pi^+ \pi^-$ *(Background)*.

4. Results

Two variables Δm and γ are used to discriminate between the signal and the background components for the $D^0 \longrightarrow K_s^0 K_s^0$ decay and to measure its yield and A_{raw}. The definition of A_{raw} is given 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 candidates. A simultaneous, unbinned maximum likelihood fit to $(\Delta m, \gamma)$ is performed for candidates populating the $m(K_s^0 K_s^0)$ signal window [1.85, 1.88] GeV/c^2. As shown in Figure 3, the signal shape in both dimensions is modelled using a Johnson's S_U [7] distribution. The $D^0 \longrightarrow K_s^0 \pi^+ \pi^-$ *(Background)* component is modelled in the Δm dimension using the sum of a Gaussian and a Johnson's S_U [7] distributions, both with the same mean. In the γ dimension, it is modelled using a Johnson's S_U [7] distribution. *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 distributions. In the Δm dimension, it is modelled using $((\Delta m\text{-}\Delta m_0) + \alpha(\Delta m\text{-}\Delta m_0)^{3/2})$, 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 MC. The yields corresponding to the three components, the corresponding raw asymmetries and α is left free to float. Same shapes are assumed to hold for the D^0 and $\bar{D}^0$ samples.

The measured signal yield is 5853 ± 83 and the corresponding A_{raw} is (0.7 ± 1.4)%.

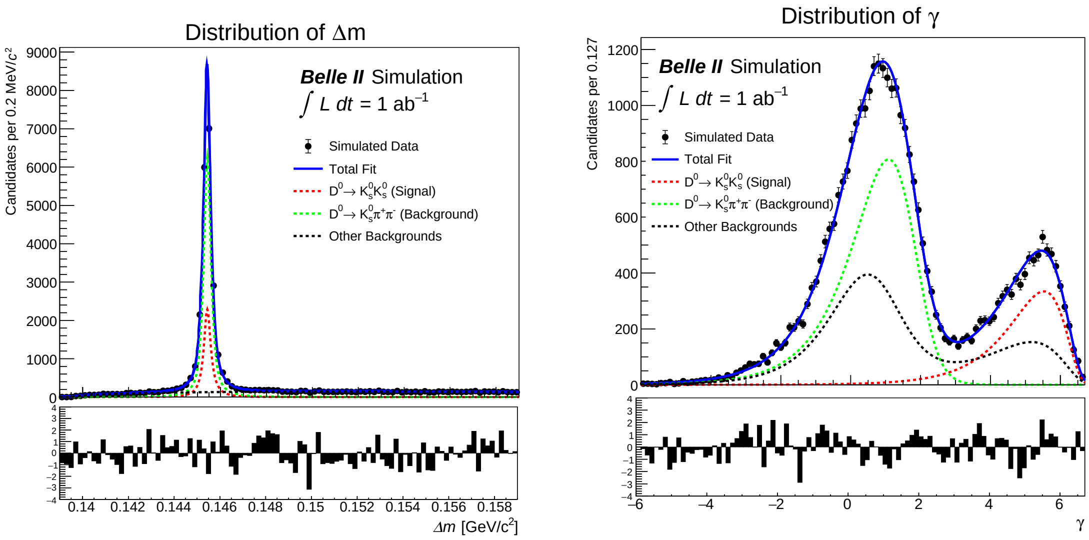

Figure 3: Distributions of Δm (left) and γ (right), with fit projections overlaid. The normalized residuals (pulls) are also shown in the lower panel of each plot.

References

[1] Ulrich Nierste and Stefan Schacht , CP violation in $D^0 \longrightarrow K_s^0 K_s^0$, Phys. Rev. D **92** 054036 (2015).

[2] R. Aaij et al., Measurement of CP Asymmetry in $D^0 \longrightarrow K_s^0 K_s^0$ decays, Phys. Rev. D **104** L031102 (2021).

[3] Heavy Flavor Averaging Group, Y. Amhis et al., Averages of b-hadron, c-hadron, and τ -lepton properties as of 2021.

[4] N.Dash et al., Search for CP violation and measurement of the branching fraction in the decay $D^0 \longrightarrow K_s^0 K_s^0$, Phys. Rev. Lett **119** 171801 (2017).

[5] E Kou. et al., The Belle II Physics Book, **2019** 123C01 (2019).

[6] Akai et al., SuperKEKB collider, Nucl. Instrum. Meth., **907**, 188-199 (2018).

[7] N. L. Johnson, Systems of frequency curves generated by methods of translation, Biometrika **36**, 149-176 (1949).