Measurement of time-integrated CP Asymmetry of $D^0 \to K_s^0 K_s^0$ decay (Belle + Belle II)

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Abstract. We measure the time-integrated CP asymmetry, A_{CP}, in $D^0 \to K_s^0 K_s^0$ decays reconstructed in $e^+e^- \to c\bar{c}$ events collected by Belle and Belle II experiments. The full Belle data sample is used, corresponding to an integrated luminosity of $980 fb^{-1}$. For Belle II, the data collected before long shutdown 1 are used, and correspond to an integrated luminosity of 427 fb^{-1}. The D^0 decays are required to come from the flavor-conserving $D^{*+} \to D^0\pi^+$ decay (D^{*+} tag) to determine the charm flavor at production time. A control sample of D^{*+}-tagged $D^0 \to K^+K^-$ is used to correct for production and detection asymmetries. The result, $A_{cp}(D^0 \to K_S^0 K_S^0)$ = (-1.4 $\pm$ 1.3($stat$) $\pm$ 0.1($syst$))% , is consistent with previous determinations and with CP symmetry.

Keywords: Belle, Belle II, CP Asymmetry, Charm decay

1 Introduction

The decay $D^0 \to K_S^0 K_S^0$ is a Singly Cabibbo Suppressed (SCS) decay, which involves the interference of $c\bar{u} \to s\bar{s}$ and $c\bar{u} \to d\bar{d}$ transitions. Such interference can generate CP asymmetries at the 1% level, even if the Cabibbo-Kobayashi-Maskawa phase is the only source of CP violation. These features make the $D^0 \to K_s^0 K_s^0$ mode an important ingredient in understanding of the origin of CP violation in charm decays. The world-average determination of the CP asymmetry in $D^0 \to K_s^0 K_s^0$ decays, $A_{cp}(D^0 \to K_S^0 K_S^0)$ = (-1.9 $\pm$ 1.0)% [1], is dominated by measurements from Belle [2] and LHCb [3]. Using e^+e^-− collision data corresponding to an integrated luminosity of 921 fb^{-1} , Belle measured $A_{cp}(D^0 \to K_S^0 K_S^0)$ = (-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 $D^0 \to K_S^0 \pi^0$ mode. A more precise result is obtained by LHCb using pp−collision data collected during Run 2 and corresponding to an integrated luminosity of 6 fb^{-1} : (-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 $D^0 \to K^+K^-$ channel. The measurement of $A_{CP}(D^0 \to K^+K^-)$ has been recently improved by LHCb [4], bringing the corresponding uncertainty below the 0.1% level. Therefore by getting the motivation from LHCb, our goal in this work is to measure the

$A_{CP}(D^0 \to K_S^0 K_S^0)$ using a combination of Belle and Belle II data, corresponding to an integrated luminosity of 980 fb^{-1} and $427 fb^{-1}$, respectively. The Belle experiment [5] operated at KEKB asymmetric-energy e^+e^- collider [6] between 1999 and 2010. The Belle II detector [7] is an upgrade with several new subdetectors designed to handle the significantly larger beam-related backgrounds of the new collider, SuperKEKB [8].

2 Reconstruction and Event Selection

The Candidate $K_S^0 \to \pi^+\pi^-$ decays are reconstructed from combinations of oppositely charged pions that are constrained to originate from a common vertex and resulting dipion mass is required to be in the [0.45, 0.55] GeV/c^2 range. Pairs of K_S^0 candidates are combined to form candidate $D^0 \to K_S^0 K_S^0$ decays. The mass of the D^0 candidate, $m(K_S^0 K_S^0)$, is required to be in the [1.85, 1.89] GeV/c^2 range for Belle and in the [1.85, 1.88] GeV/c^2 range for Belle II. The different ranges are due to an observed small offset in the D^0 mass-peak positions in the two datasets and to the different mass resolutions. For the control mode decays, candidate D^0 mesons are formed by combining pairs of oppositely charged kaons with mass, $m(K^+K^-)$, in the $[1.75, 2.05]$ GeV/c^2 range. Tracks originating from charged kaons must have at least 20 hits in the central drift chamber and at least one hit in the silicon vertex detector. They must have a distance of closest approach to the e^+e^- interaction point (IP) smaller than 2 cm in the longitudinal direction and smaller than 0.5 cm in the transverse plane. The D^0 candidates for both signal and control modes are then combined with low momentum pions to form a $D^{*+} \to D^0\pi$ decay.

3 Results: Measured Asymmetries of $D^0 \to K_s^0 K_s^0$ and $D^0 \to K^+K^-$

The asymmetries between observed numbers of D^{*+} and D^{*-} signal candidates are determined using unbinned maximum-likelihood fits to distributions that help to distinguish signal and control mode decays from backgrounds processes. The fit models are assumed to be the same for charm and anti-charm mesons. The major background in $D^0 \to K_S^0 K_S^0$ is coming from peaking background $D^0 \to K_S^0 \pi^+\pi^-$. The flight distance of the K_s^0 (with respect to the D^0 vertex) is exploited to provide separation of the peaking background ($D^0 \to K_S^0 \pi^+\pi^-$) from the signal ($D^0 \to K_S^0 K_S^0$), and it is defined as $S_{min}(K_S^0) = log[min(L_1/\sigma_{L_1}, L_2/\sigma_{L_2})]$, where $L_{1(2)}$ and $\sigma_{L_{1(2)}}$ are the distance and its uncertainty for the first (second) K_S^0 candidate, respectively. Both the signal and peaking-background $S_{min}(K_S^0)$ distributions exhibit a peaking structure, but they peak at very different values. We determine the signal yield and raw asymmetry by performing a fit to the m$(D^0\pi^+)$ and $S_{min}(K_S^0)$ distributions, simultaneously for D^{*+} and D^{*-} candidates (figure 1). The measured signal yields are 4864 ± 78 in Belle and 2214 ± 51 in Belle II. The raw asymmetry is measured to be $(-1.0 \pm 1.6)\%$ in Belle and $(-0.6 \pm 2.3)\%$ in Belle II. Further, the

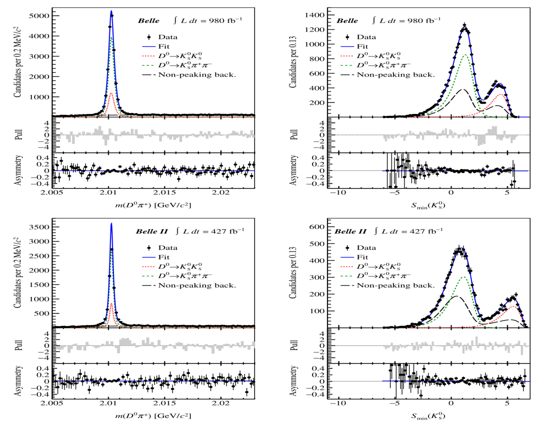

Fig. 1. Distributions of (left) $m(D^0\pi^+)$ and (right) $S_{min}(K_S^0)$ for combined $D^0 \to K_S^0K_S^0$ and $\bar{D}^0 \to K_S^0K_S^0$ candidates, in (top) Belle and (bottom) Belle II data, with fit projections overlaid. The middle panel of each plot shows the distribution of the pull between fit and data, the bottom panel shows the asymmetry between D^0 and $\bar{D}^0$ candidates with fit projection overlaid.

raw asymmetry of the control decay $D^0 \to K^+K^-$ is determined using a fit to the two-dimensional distribution of $m(K^+K^-)$ and $m(D^0\pi^+)$. The fit consists of the following components: $D^0 \to K^+K^-$ control mode decays; $D^0 \to K^-\pi^+$ decays in which the pion is mis-identified as a kaon, peaking at $m(K^+K^-)$ values around 1.94 GeV/c^2; partially reconstructed $D^0 \to$ multi body decays (eg. $D^0 \to K^-\pi^+\pi^0$), where the charged pion is mis-identified as a kaon and the neutral pion is not reconstructed, or semileptonic D^0 decays, where the neutrino is not reconstructed, populating mostly the low $m(K^+K^-)$ region; $D_s^+ \to K^+K^-\pi^+$ decays in which π^+ is reconstructed as a soft pion candidate. The fit results are shown in figure 2. The measured K^+K^- yields are 308760 ± 570 in Belle and 145520 ± 400 in Belle II. The K^+K^- raw asymmetry is measured to be $(0.17 \pm 0.19)\%$ in Belle and $(1.61 \pm 0.27)\%$ in Belle II. The details of the analysis work is summarized in the Belle II note [9].

4 Summary

We have measured the A_{CP} in $D^0 \to K_s^0K_s^0$ with (Belle + Belle II) dataset to be $A_{CP}(D^0 \to K_s^0K_s^0)$ (Belle): $(-1.1 \pm 1.6 \pm 0.1)\%$, $A_{CP}(D^0 \to K_s^0K_s^0)$ (Belle II): $(-2.2 \pm 2.3 \pm 0.1)\%$, and $A_{CP}(D^0 \to K_s^0K_s^0)$ (Belle + Belle II): $(-1.4 \pm 1.3 \pm 0.1)\%$. Our results A_{CP} in $D^0 \to K_s^0K_s^0$ has a factor-two better systematic uncertainty compared to the previous Belle published results, thanks to the usage of the K^+K^- control mode, which provides a more precise A_{CP} external input compared to the $D^0 \to K_S^0\pi^0$ control mode used in previous study [2].