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Measurement of the time-integrated CP asymmetry in $D^0 \to K^0_S K^0_S$ decays at LHCb

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Summary. — The $D^0 \to K^0_S K^0_S$ decay is a promising discovery channel for CP violation in charm. A prediction based on the Standard Model gives an upper limit for the CP asymmetry of about 1% and further enhancements could result from contributions from physics beyond the Standard Model. A preliminary measurement of the time-integrated CP asymmetry in prompt $D^0 \to K^0_S K^0_S$ decays is presented, performed using data collected with the LHCb experiment in 2015 and 2016 at a 13 TeV pp center-of-mass energy (Run 2). The CP asymmetry is measured to be $A^{CP}(D^0 \to K^0_S K^0_S) = (0.042 \pm 0.034 \pm 0.010)$, where the first uncertainty is statistical and the second is systematic. This result represents a significant improvement with respect to the previous LHCb Run 1 measurement.

1. – Motivations

CP violation has not yet been observed in the charm sector, although measurements of time-integrated CP asymmetry in Cabibbo-suppressed $D^0 \to h^+h^-$ $(h = \pi, K)$ decays have reached the remarkable precision of $\mathcal{O}(10^{-3})$ [1]. The $D^0 \to K^0_S K^0_S$ is a promising discovery channel because only loop-suppressed and exchange diagrams, where the latter vanish in the $SU(3)$ flavour limit, contribute to this decays. These contributions are of similar size and, therefore, A^{CP} could reach the level of ∼1% [2] and be observed. The CP asymmetry is defined as

$$A^{CP}(K^0_S K^0_S) \equiv \frac{\Gamma(D^0 \to K^0_S K^0_S) - \Gamma(\bar{D}^0 \to K^0_S K^0_S)}{\Gamma(D^0 \to K^0_S K^0_S) + \Gamma(\bar{D}^0 \to K^0_S K^0_S)}, \tag{1}$$

where Γ is the decay rate of D^0 ($\bar{D}^0$) in the final state $K^0_S K^0_S$. This quantity has already been measured by the CLEO Collaboration [3], by the Belle Collaboration [4], and by

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the LHCb Collaboration [5] using Run 1 data. All the measurements are compatible with zero and the world's best measurement has been performed by Belle, who measured $A^{CP}(K^0_S K^0_S) = (-0.02 \pm 1.53 \pm 0.17)\%$, where the first uncertainty is statistical and the second is systematic. Here a new LHCb measurement, performed using data collected in the first two years of Run 2 ($\sqrt{s} = 13\,\text{TeV}$, integrated luminosity $\sim 2\,\text{fb}^{-1}$), is presented.

2. – Detector

The LHCb detector [6] is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$, designed for the study of particles containing b or c quarks. The silicon-strip vertex detector surrounding the pp interaction region allows c and b hadrons to be identified from their characteristically long flight distance and the tracking system provides the precise measurement of the momentum of charged particles ($\sigma_p/p \sim 0.5\% - 1\%$).

In LHCb tracks are classified according to the subdetectors crossed. In particular particles traversing the full tracking system are called "long" tracks, while tracks reconstructed in all the tracking stations but not in the vertex-detector are called "downstream" tracks. In this analysis two samples are used: the LL sample, with both K^0_S reconstructed from long tracks, and the LD sample, with one K^0_S reconstructed from long tracks and the other one reconstructed from downstream tracks. The two samples are analysed separately because of the different mass resolution.

3. – Analysis strategy

A sample of flavour-tagged $D^0 \to K^0_S K^0_S$ decays has been obtained by selecting prompt D^{*+} candidates, with subsequent decay $D^{*+} \to D^0\pi^+$ (charge conjugate decays are implied throughout this document, unless explicitly specified). The sign of the pion in this decay gives the flavour of the accompanying D^0, and D^0-$\bar{D}^0$ mixing is negligible at this level of precision. K^0_S candidates are reconstructed in the $\pi^+\pi^-$ decay channel.

The quantity measured in LHCb is $A^{\text{raw}} = (N_{D^0} - N_{\bar{D}^0})/(N_{D^0} + N_{\bar{D}^0})$, where N_{D^0} is the measured yield of $D^{*+} \to D^0\pi^+$ and $N_{\bar{D}^0}$ is the measured yield of $D^{*-} \to \bar{D}^0\pi^-$ decays. This observable is related to the CP asymmetry by the expression, valid to first order, $A^{\text{raw}} \approx A^{CP} + A^{\text{prod}} + A^{\text{det}}$, where A^{prod} is the production asymmetry of the $D^{*\pm}$ and A^{det} is the detection asymmetry of the tag pion. To remove these two asymmetries $D^0 \to K^+K^-$ is used as a calibration channel. The raw asymmetry is extracted by fitting the $\Delta m = m(D^{*+}) - m(D^0)$ distribution. Rectangular cuts are applied to reduce the background which peaks in the Δm distribution, while a selection on the output of a k-Nearest-Neighbors classifier is applied to reduce the combinatorial background. The signal yields in the selected sample are 759 ± 32 LL candidates and 308 ± 26 LD candidates.

4. – Results and outlook

The result, obtained by performing a simultaneous maximum likelihood fit to the separate D^{*+} and D^{*-} unbinned Δm distributions is [7]

$$A^{CP}(K^0_S K^0_S) = (0.042 \pm 0.034 \pm 0.010),$$

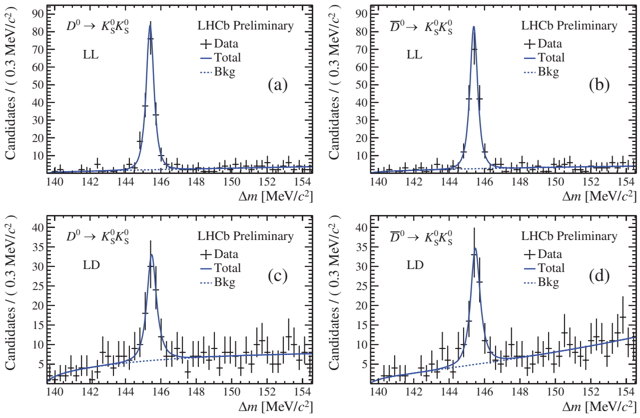

Fig. 1. – Preliminary fits to Δm distributions of $D^0 \to K^0_S K^0_S$ candidates for the "magnet up" polarity. The fit to (a) $D^{*+} \to D^0\pi^+$ and (b) $D^{*-} \to \bar{D}^0\pi^-$ candidates for the LL sample and the fit to (c) $D^{*+} \to D^0\pi^+$ and (d) $D^{*-} \to \bar{D}^0\pi^-$ candidates for the LD sample are shown. The black crosses represent the data points, the solid blue curve is the total fit function, and the dashed blue curve is the background component of the fit.

where the first uncertainty is statistical and the second is systematic. The raw asymmetry A^{raw} is a free and shared parameter in the fit. The fitted Δm distributions, obtained for the "magnet up" polarity, are shown in fig. 1. Results obtained on LL and LD samples and on the two separate magnet polarities are compatible within 2σ. Combining these results with the previous LHCb measurement on the Run 1 dataset, the asymmetry value obtained is

$$A^{CP}(K^0_S K^0_S) = (0.020 \pm 0.029 \pm 0.010),$$

therefore no evidence of CP violation is found. Using the full Run 2 dataset collected by LHCb, the statistical uncertainty on this measurement will approach the precision reached by Belle, and further improvements are expected from the LHCb Upgrade. For the recently proposed Phase-II LHCb Upgrade, the LHCb Collaboration is actively considering the deployment of dedicated accelerators in the trigger and data-processing chain to find tracks downstream of the magnet and present these tracks to the earliest stage of the software trigger [8]. This would allow to significantly increase the efficiency for these decay modes and thus offer the opportunity to probe the Standard Model predictions on these channels with significantly better precision, at the 10^{-3} level.

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