Studies of charm mixing and CP violation in four-body decays

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What are you measuring with this study?

A feasibility study in measuring observables encoding charm mixing (x and y) and CP violation ($|q/p|$ and ϕ) with the decay modes $D \to K^+K^-\pi^+\pi^-$ and $D \to \pi^+\pi^-\pi^+\pi^-$ using a binned-phase space approach. This is of interest as, in charm, only direct CP violation has been observed [1,2].

At the same time, the hadronic parameters are required and are calculated with an amplitude model. The c_i (s_i) are the cosine (sine) of the average ϕ in a phase space bin i, but the probability a D^0 ($\bar{D}^0$) decays in bin i is K_i ($\bar{K}_i = K_{-i}$). Then define:

$$T_{\pm i} = \frac{K_{\pm i}}{\sum_i K_{\pm i}}.$$

How are the sensitivities obtained?

200 generator-level datasets (each with 2 million events) are produced using `AmpGen` [3] with the amplitude model of the respective decay. Then split by D^0 flavour, binned in phase space and time, then fit. The PDF's are:

$$P_{D^0}(t_\alpha, i) = \Gamma e^{-\Gamma t_\alpha}\{T_{+i} - \Gamma t_\alpha \sqrt{T_{+i}T_{-i}}[(y_{CP} + \Delta y)c_i + (x_{CP} + \Delta x)s_i]\}$$

$$P_{\bar{D}^0}(t_\alpha, i) = \Gamma e^{-\Gamma t_\alpha}\{T_{-i} - \Gamma t_\alpha \sqrt{T_{+i}T_{-i}}[(y_{CP} - \Delta y)c_i - (x_{CP} - \Delta x)s_i]\}$$

The fit parameters $x_{CP}, \Delta x, y_{CP}, \Delta y$ combine the charm mixing and CP violating observables. The sensitivity is then the average of the uncertainties of each toy.

Decay Mode	$\sigma(x_{CP}) = \sigma(\Delta x)$ $(\times 10^{-3})$	$\sigma(y_{CP}) = \sigma(\Delta y)$ $(\times 10^{-3})$
$D \to K^+K^-\pi^+\pi^-$	1.22	0.83
$D \to \pi^+\pi^-\pi^+\pi^-$	1.19	1.03

What can you learn from this study?

The sensitivities are encouraging - especially as the statistical sensitivity in both modes is expected to decrease with increased LHCb statistics. However the fit exhibits a bias, especially in the mode $D \to \pi^+\pi^-\pi^+\pi^-$.

What is the outlook for the analysis?

Ongoing work on the generator-level study aims to explore fit biases and estimate sensitivities for various binning schemes. Soon, analysis of LHCb Run 2 data and Monte-Carlo will commence. The final measurement will be model-independent, with hadronic parameters determined by BESIII.

So to summarise, a feasibility study in measuring observables that encode charm mixing and CPV using the modes $D \to K^+K^-\pi^+\pi^-$ and $D \to \pi^+\pi^-\pi^+\pi^-$ are presented. The study employed a binned-phase space approach with generator-level simulation and estimated hadronic parameters. The expected precisions are anticipated to improve, but further work is needed to address fit biases.

Exactly! 😄

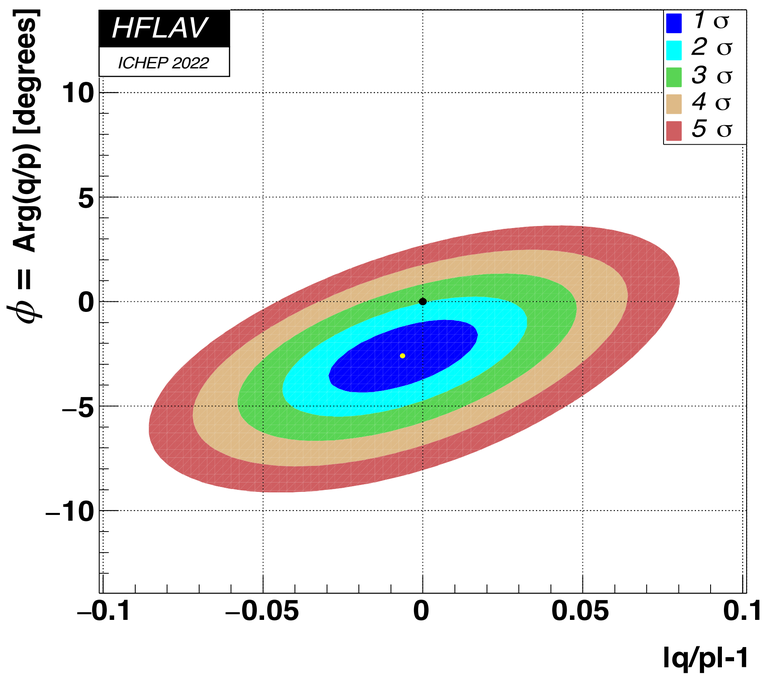
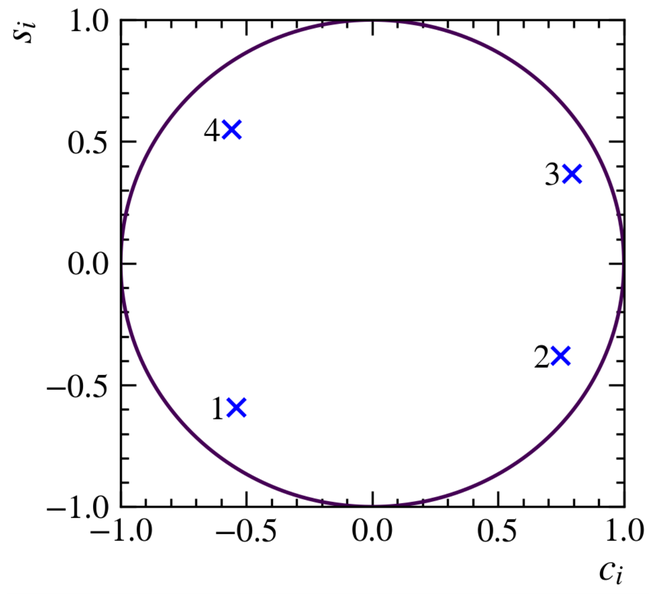


Fig 1: HFLAV group world averages of charm CP violating parameters



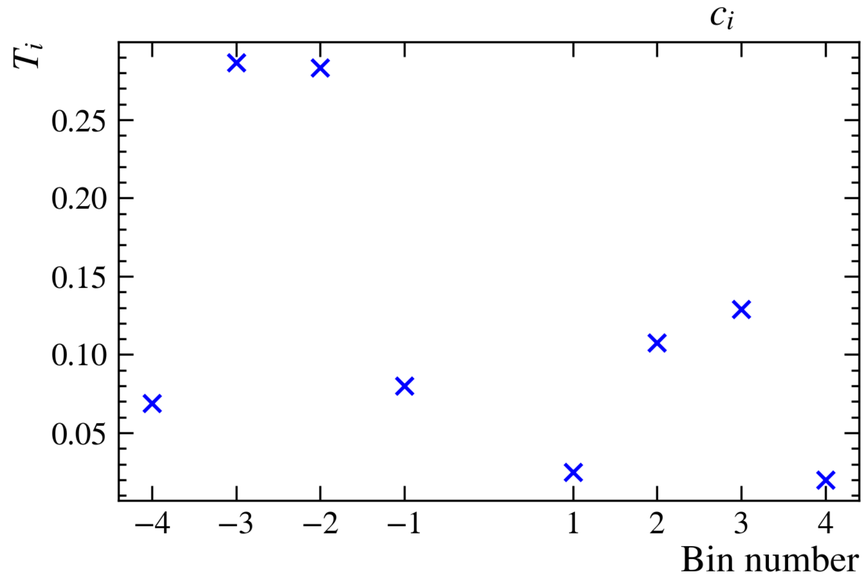


Fig 2: Model predictions of the hadronic parameters used in this analysis for $D \to K^+K^-\pi^+\pi^-$.

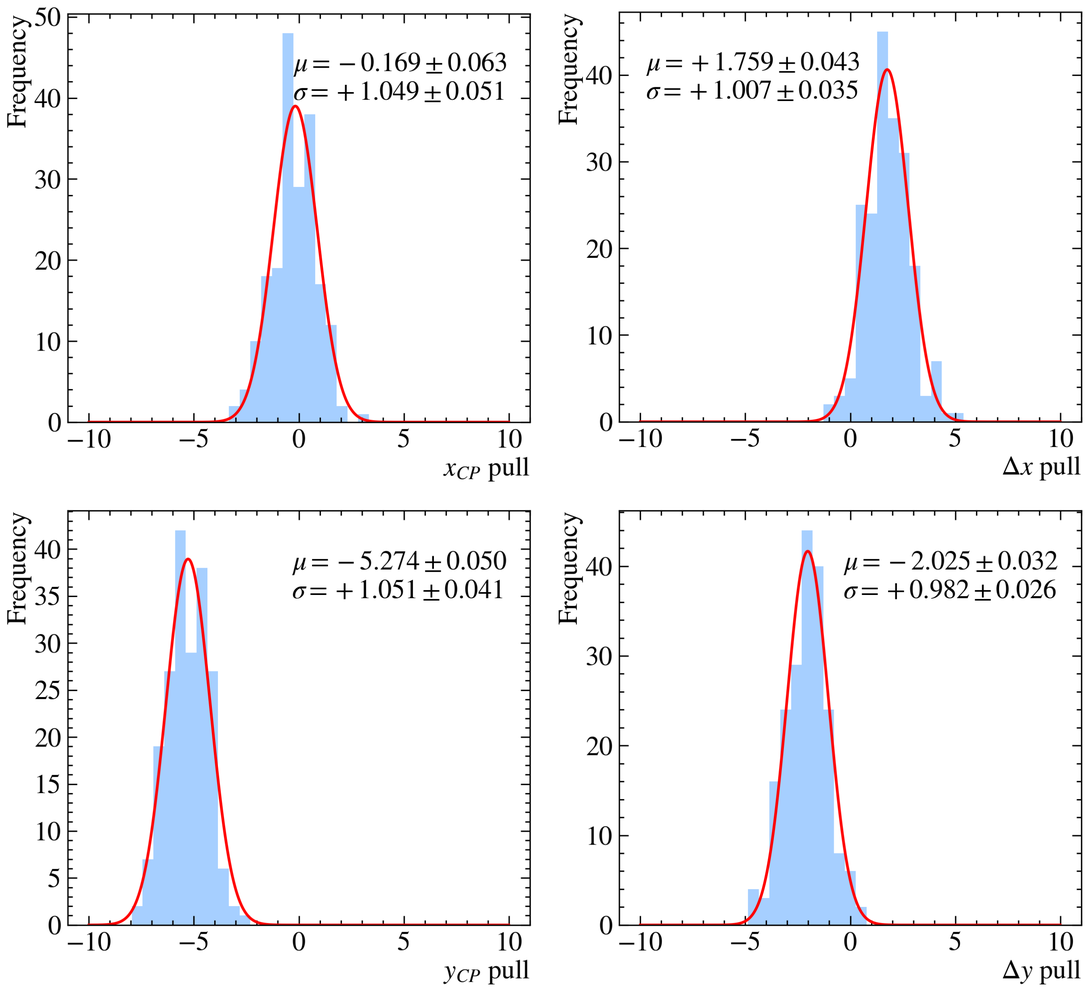


Fig 3: Pull distributions in $D \to \pi^+\pi^-\pi^+\pi^-$ from 200 `AmpGen` toys.

References

1. R. Aaij et al., Phys. Rev. Lett. 116 (2016) 241801.
2. R. Aaij et al., Phys. Rev. Lett. 122 (2019) 211803
3. T. Evans et al., "*AmpGen*" (2018), https://gitlab.com/tevans1260/AmpGen