Measurement of y_{CP} in Charm decays at LHCb

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Problem

Mixing occurs because the mass eigenstates of the neutral D^0 mesons are superpositions of the flavour eigenstates:

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$$

Because of $D^0 - \bar{D}^0$ mixing, the effective decay width, $\Gamma_{CP+} \neq \Gamma$. We define the quantity y_{CP},

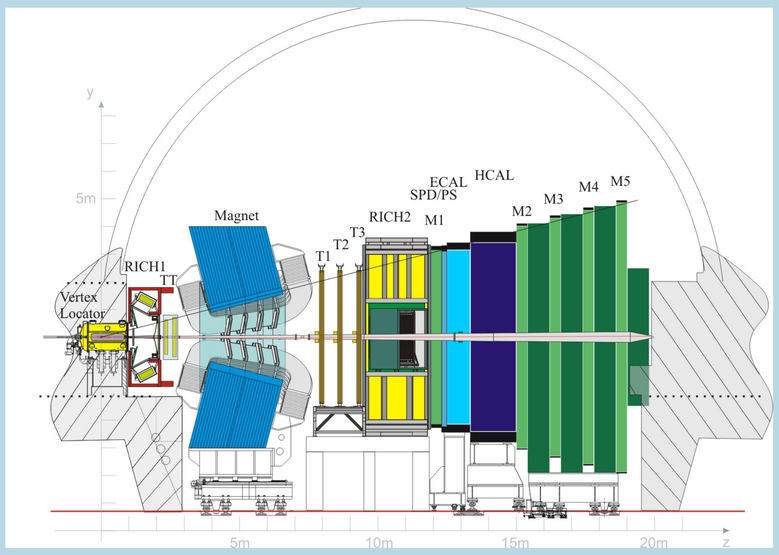
$$y_{CP} \equiv \frac{\Gamma_{CP+}}{\Gamma} - 1.$$

In the limit of *CP*-symmetry, this is equal to the mixing parameter y.

LHCb detector

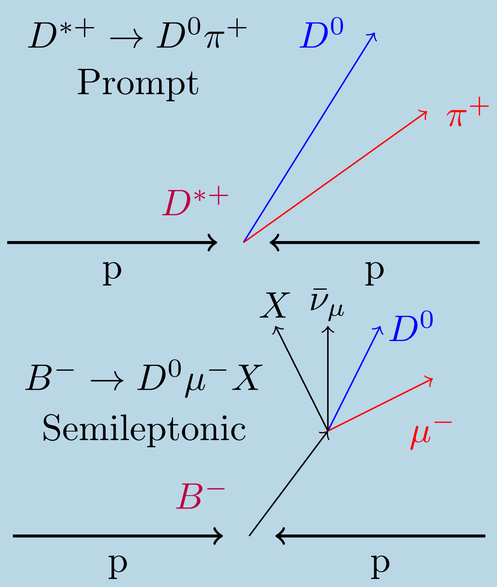
LHCb is a forward spectrometer, optimised for selection of b and c decays.

- Excellent vertex resolution
- Precise and efficient tracking
- PID ($2 < p < 100\text{GeV}/c$)



Data

We use 5.7fb^{-1} of 2016-2018 data collected during the Run II of LHCb. We consider two modes of production for the D^0 meson: prompt production where the D^0 comes from and a D^{*+} meson at the primary vertex, and semileptonic production, where the D^0 comes from the decay of a displaced B meson.



References

[1] Belle, A. Zupanc et al., *Measurement of y_{CP} in D^0 meson decays to the $K_S^0K^+K^-$ final state*, Phys. Rev **D80** (2009) 052006, `arXiv:0905.4185`

[2] BaBar, P. del Amo Sanchez et al., *Measurement of $D^0 - \bar{D}^0$ mixing parameters using $D^0 \to K_S^0\pi^+\pi^-$ and $D^0K_S^0K^+K^-$ decays*, Phys. Rev. Lett. **105** (2010) 081803, `arXiv:1004.5053`

Technique

The phasespace of the $D^0 \to K_S^0K^+K^-$ channel has a unique structure, with a good separation between *CP*-odd and *CP*-even components of the amplitude in phasespace.
We define two regions in phasespace:

$$\text{ON-resonance: } m_{K^+K^-} \in [1015, 1025]\,\text{MeV}/c^2$$
$$\text{OFF-resonance: } m_{K^+K^-} \in [2m_K, 1010] \cup [1033, 1100]\,\text{MeV}/c^2$$

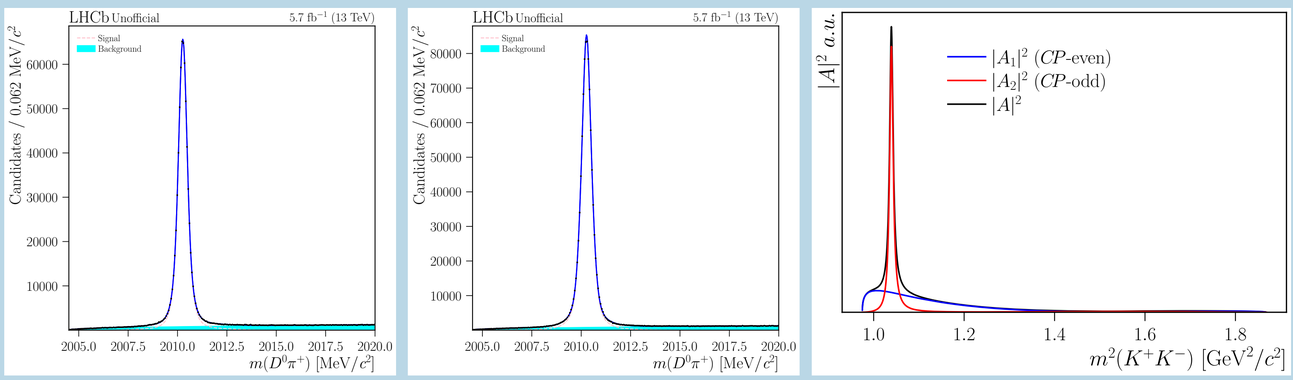
We can study the ratio of the number of events decaying in the two regions over time to obtain,

$$\frac{dN_{\text{ON}}}{dN_{\text{OFF}}} = 1 - 2\left(f_{\text{ON}} - f_{\text{OFF}}\right)\frac{t}{\tau_{D^0}}y_{CP} + \mathcal{O}\left(y_{CP}^2\right),$$

where,

$$f_{\mathcal{R}} = \frac{\int_{\mathcal{R}} a_2\left(s_0\right) ds_0}{\int_{\mathcal{R}} \left(a_1\left(s_0\right) + a_2\left(s_0\right)\right) ds_0}$$

is the fraction of the *CP*-odd amplitude over the total amplitude.



We split each sample into 15 evenly populated bins of decay time and in each fit the D^{*+} and D^0 mass for the prompt and semileptonic samples respectively, in both the ON- and OFF-resonance regions.

Systematic uncertainties

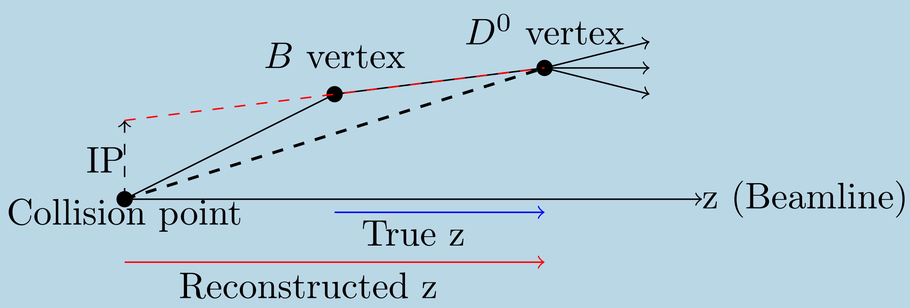
One of the main advantages of this analysis technique is many systematics due to asymmetries cancel out in the ratio of events between the ON- and OFF-resonance region. This leaves us with 3 dominant sources of systematics:

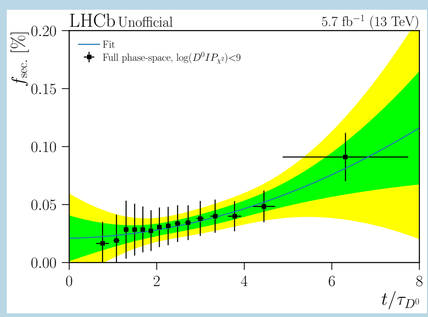
1. Time-dependent efficiency correction
2. Secondaries contamination of the prompt sample
3. Uncertainty on the amplitude model

D^0 mesons originating from secondary decays of a B meson can be mis-reconstructed as prompt decays
The decay time of the D^0 is calculated as

$$t = \text{FD}\frac{m}{p},$$

where FD is the flight distance of the D^0 from the primary vertex. Therefore if the flight distance of the D^0 is overestimated so is the decay time. This has the effect of putting events with lower true decay time (i.e. with less time to oscillate) into higher decay time bins.





The paramaters $f_{\text{ON,OFF}}$ are calculated from an amplitude model published by the BaBar collaboration in 2010 (arxiv.1004.5053v3). We vary the parameters within their prescribed uncertainties, each time calculating the value of $f_{\text{ON}} - f_{\text{OFF}}$.