Charm mixing in $D^0 \to K^\pm\pi^\mp\pi^\pm\pi^\mp$

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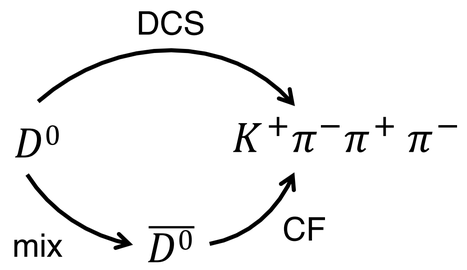
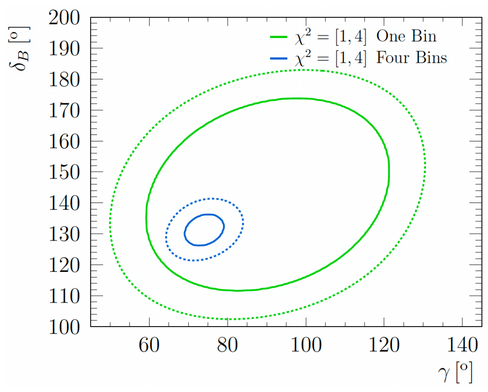
12th LHC Students Poster Session

Motivation





Charm mixing and CPV

⟵ Suppressed WS decays of $D^0 \to K^+\pi^-\pi^+\pi^-$ are sensitive to D^0-$\overline{D}^0$ mixing

$$x = \frac{\Delta M}{\Gamma},\ y = \frac{\Delta\Gamma}{2\Gamma}$$

RS decays of $D^0 \to K^-\pi^+\pi^-\pi^+$ are Cabibbo-favoured and used for normalisation

$$\frac{\Gamma[D^0 \to K^+\pi^-\pi^+\pi^-](t)}{\Gamma[D^0 \to K^-\pi^+\pi^-\pi^+](t)} = r_D^2 - r_D R_D^{K3\pi}(y\cos\delta_D^{K3\pi} - x\sin\delta_D^{K3\pi})t + \frac{x^2+y^2}{4}t^2$$

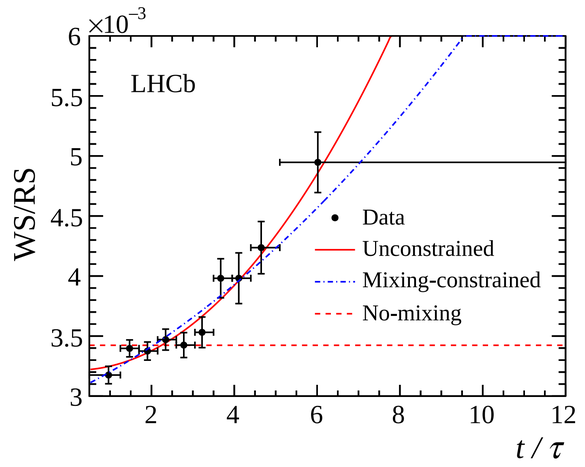
Measurement split by D^0 flavour gives access to CPV parameters $|\frac{q}{p}|, \phi$.

CKM angle γ in $B \to DK$, $D^0 \to K^\pm\pi^\mp\pi^\pm\pi^\mp$ measurement

⟵ Increase sensitivity to γ by splitting into 4 bins of phase-space [1].
LHCb Run 2 measurement [2] limited by external inputs of $R_D^{K3\pi}, \delta_D^{K3\pi}$

$$\gamma = \left(54.8^{+6.0+0.6+6.7}_{-5.8-0.6-4.3}\right)^\circ$$

Model-dependence on LHCb Run 1 amplitude model [3] only leads to decrease in sensitivity to γ, rather than bias.

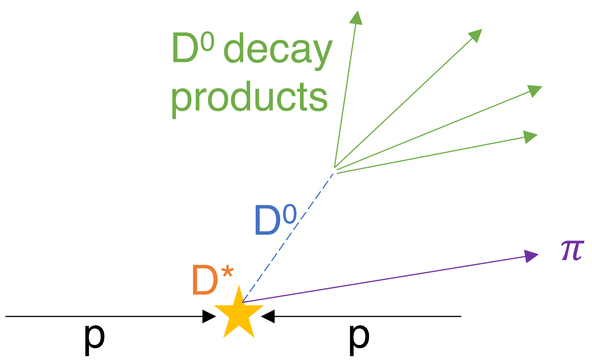


LHCb Run 1 measurement [4]
First observation of mixing in $D^0 \to K^\pm\pi^\mp\pi^\pm\pi^\mp$

Methodology

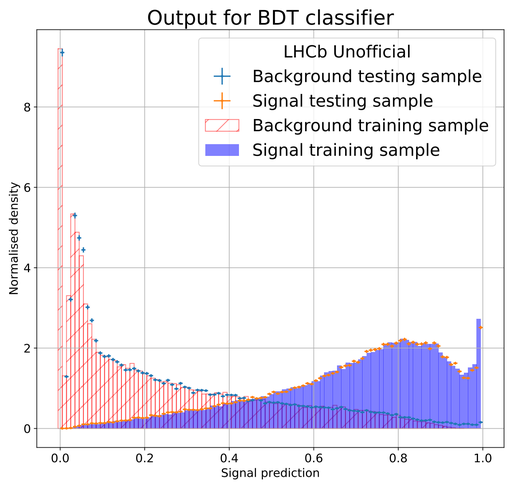
1. Using LHCb Run 2 data, prompt decays tag D^0 flavour at production

$$D^{*+} \to D^0\pi^+, D^{*-} \to \overline{D}^0\pi^-.$$



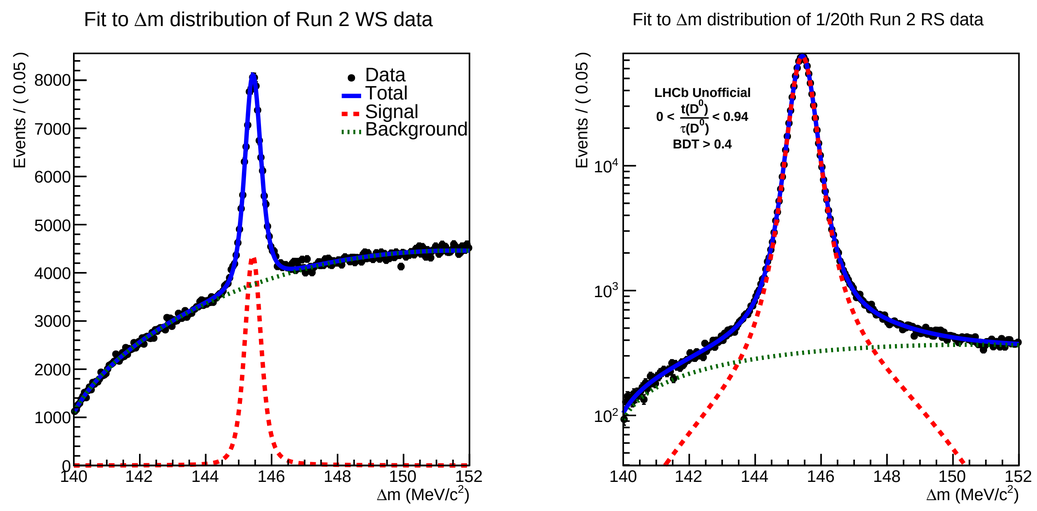
2. Trigger on high E_T deposits in calorimeter, or independent of final-state.

3. Train BDT [5] on MC to increase purity of WS sample.



4. Apply **efficiency correction** for small differences in WS and RS detection.

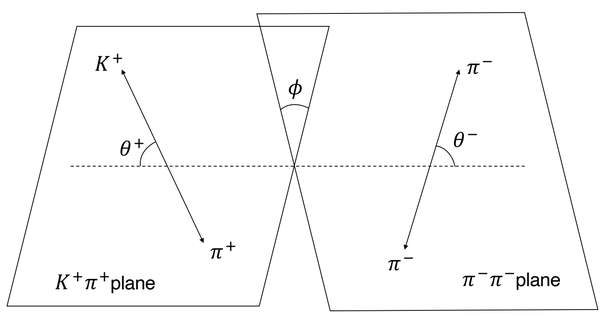
5. Signal yields from fit to $\Delta m = m(D^*) - m(D^0)$ distributions to remove combinatorial background.



6. Correct for specific **backgrounds** that remain in sample.
7. Fit WS/RS against time, in bins of phase-space and split by D^0 flavour.

Efficiency correction

- 5D+time efficiency correction of WS vs RS final state differences using GBReweighter [6] and Cabibbo-Maksymowicz parametrisation of phase-space [7].
- $D^{*\pm}$ production asymmetry cancels in ratio, as does tagging pion detection asymmetry.
- When split by flavour, detection asymmetry of $K^+\pi^-\pi^+\pi^-$ vs $K^-\pi^+\pi^-\pi^+$ must be accounted for.

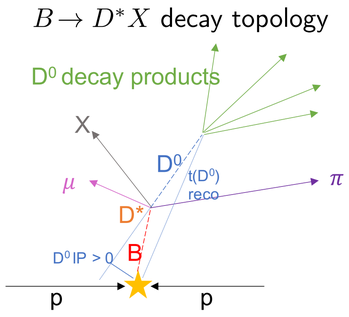


$\mathbf{p} = \{m(K^+\pi^+), m(\pi^-\pi^-), \cos(\theta^+), \cos(\theta^-), \phi\}$

Backgrounds

- $B \to D^*X$: reduced by good vertexing and cut on $\chi^2_{IP}(D^0)$, correction for yield & time bias
- $D^0 \to \pi\pi\pi\pi$, $D^0 \to KK\pi\pi$: reduced by excellent PID performance
- $D^0 \to K^0_S K\pi$: removed by vertex requirements and veto on $m(K^0_S)$
- RS → WS double mis-ID: reduced by PID cuts
- Ghost tagging π: reduced by cut to ghost probability
- Clone tracks: removed by cut on angle between tracks

$B \to D^*X$ decay topology



Sensitivity to charm mixing and CPV

Split sample by D^0 flavour to measure CPV parameters:
Traditional parameters ⟶ Parameters for fitting
$(x, y, |\frac{q}{p}|, \phi) \longrightarrow (x, y, \Delta x, \Delta y)$

CPV parameters by D^0 flavour:

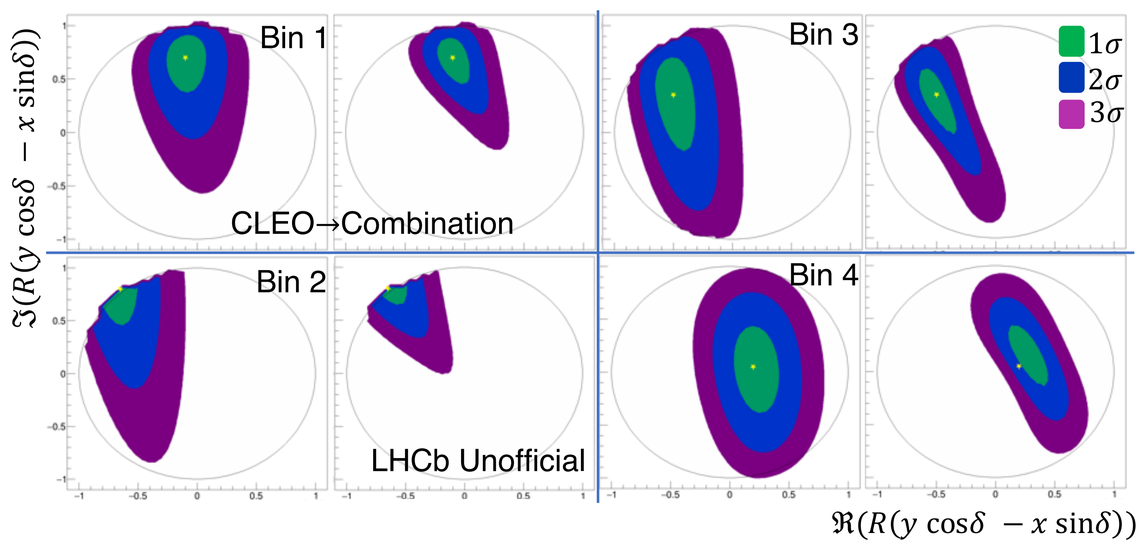
$$x_{D^0} = x + \Delta x$$
$$x_{\overline{D}^0} = x - \Delta x$$
$$y_{D^0} = y + \Delta y$$
$$y_{\overline{D}^0} = y - \Delta y$$

Statistical sensitivity:

$$\sigma(x) = 1.7 \times 10^{-3}$$
$$\sigma(y) = 1.1 \times 10^{-3}$$
$$\sigma(\Delta x) = 0.2 \times 10^{-3}$$
$$\sigma(\Delta y) = 0.2 \times 10^{-3}$$

Sensitivity is dependent on current knowledge of hadronic parameters which are constrained inputs in the fit.

Sensitivity to hadronic parameters



References

[1] T. Evans et al., "Improved sensitivity to the CKM phase γ through binning phase space in $B^- \to DK^-, D \to K^+\pi^-\pi^-\pi^+$ decays", Physics Letters B **802** (2019).
[2] LHCb Collaboration, "Measurement of the CKM angle γ with $B^\pm \to D[K^\mp\pi^\pm\pi^\pm\pi^\mp]h^\pm$ decays using a binned phase-space approach", (2022).
[3] LHCb Collaboration, "Studies of the resonance structure in $D^0 \to K^\mp\pi^\pm\pi^\pm\pi^\mp$ decays", European Physical Journal C **78** (2018).
[4] LHCb Collaboration, "First observation of $D^0 - \bar{D}^0$ oscillations in $D^0 \to K^+\pi^-\pi^+\pi^-$ decays and measurement of the associated coherence parameters", PRL **116** (2016).
[5] A. Rogozhnikov et al., "New approaches for boosting to uniformity", Journal of Instrumentation **10** (2015).
[6] A. Rogozhnikov, "Reweighting with boosted decision trees", Journal of Physics: Conference Series **762** (2016).
[7] N. Cabibbo and A. Maksymowicz, "Angular correlations in K_{e4} decays and determination of low-energy π-π phase shifts", Phys. Rev. **137** (1965).