Charm mixing in $D^0 \rightarrow K^{\pm} \pi^{\mp} \pi^{\pm} \pi^{\mp}$

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Motivation

Charm mixing and CPV

$D^0 \rightarrow K^{+} \pi^{-} \pi^{+} \pi^{-}$ are sensitive to $D^0 \bar{D}^0$ mixing

$x = \frac{\Delta M}{k} \quad y = \frac{\Delta t}{k}$

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

$\Gamma'(D^0 \rightarrow K^+ \pi^- \pi^+ \pi^-) = r D H_{\text{RS}}(y \cos \delta_{\text{CPV}} - x \sin \delta_{\text{CPV}}) t + x^2 + y^2 t^2$

Measurement split by $D^0$ flavour gives access to CPV parameters $(x, y)$.

CKM angle $\gamma$ in $B \rightarrow D^0 K^\pm \pi^\mp \pi^\pm$ measurement

Increase sensitivity to $\gamma$ by splitting into 4 bins of phase-space \cite{1}.

LHCb Run 2 measurement \cite{2} limited by external inputs of $D^0_{\text{eff}}$, $D^0_{\text{fit}}$

$\gamma = (54.8^{+0.6+0.9}_{-0.6-0.5})^\circ$

Model-dependence on LHCb Run 1 amplitude model \cite{3} only leads to decrease in sensitivity to $\gamma$, rather than bias.

Methodology

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

$D^{\pm} \rightarrow D^{\pi \pm}, D^{0} \rightarrow \pi^{0} \pi^{+} \pi^{-}$.

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

3. Train BDT \cite{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
  GBReweighting \cite{6} and
  Cabibbo-Maksymowicz parametrisation of phase-space \cite{7}.
- $D^0 \rightarrow \pi^{0} \pi^{+} \pi^{-}$ 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.

Backgrounds

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

Sensitivity to charm mixing and CPV

Split sample by $D^0$ flavour to measure CPV parameters:

- Traditional parameters: $\Delta t$, $\Delta M$
- $x, y, \phi$ parameters for fitting $(x, y, \Delta t, \Delta M)$

CPV parameters by $D^0$ flavour:

\begin{align*}
x_{D^0} &= x + \Delta x \\
x_{\bar{D}^0} &= x - \Delta x \\
y_{D^0} &= y + \Delta y \\
y_{\bar{D}^0} &= y - \Delta y
\end{align*}

Statistical sensitivity:

\begin{align*}
\sigma(x) &= 1.7 \times 10^{-5} \\
\sigma(y) &= 1.1 \times 10^{-5} \\
\sigma(\Delta x) &= 0.2 \times 10^{-2} \\
\sigma(\Delta y) &= 0.2 \times 10^{-2}
\end{align*}

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

References

\cite{1} T. Evans et al., “Improved sensitivity to the CKM phase $\gamma$ through binning phase space in $B \rightarrow D^+ K^+ \pi^- \pi^- \pi^0$ decays”, Physics Letters B 802 (2019).
\cite{2} LHCb Collaboration, “Measurement of the CKM angle $\gamma$ with $B \rightarrow D^+ K^+ \pi^- \pi^- \pi^0$ decays using a binned phase-space approach”, (2022).
\cite{3} LHCb Collaboration, “Studies of the resonance structure in $D^0 \rightarrow K^{+} \pi^{-} \pi^{+} \pi^{-}$ decays”, European Physical Journal C 78 (2018).
\cite{4} LHCb Collaboration, “First observation of $D^0 \rightarrow D^+ \pi^-$ oscillations in $D^0 \rightarrow K^{+} \pi^{-} \pi^{+} \pi^{-}$ decays and measurement of the associated coherence parameters”, PRL 116 (2016).
\cite{7} Cabibbo and A. Maksymowicz, “Angular correlations in $K_{L3}$ decays and determination of low-energy $\pi$--$\pi$ phase shifts”, Phys. Rev. 137 (1965).