Quantum-correlated $D^0\overline{D}^0$ systems in LHCb run 3

Ho Sang Lee
Supervisors: Paras Naik, David Hutchcroft, Tara Shears

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Quantum-correlated $D^0\overline{D}^0$ systems - Motivation

- Produced in decays of quarkonia-like states, e.g $\chi_{c1}(3872) \to D^0\overline{D}^0\pi^0/\gamma$ produces C-even/odd $D^0\overline{D}^0$ systems respectively
- Initial aim is to separate C-even/odd $D^0\overline{D}^0$ systems and extract their respective yields without reconstructing neutrals
- Opens up a number of measurements — in-house strong phase input to CKM gamma, T/CPT violation measurements in neutral charm, near-threshold spectroscopy...

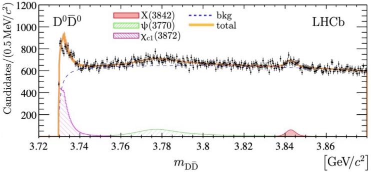
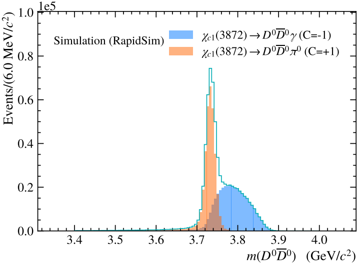
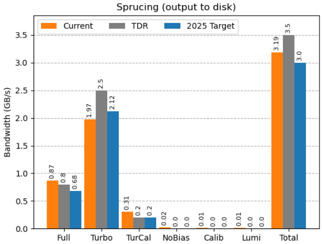


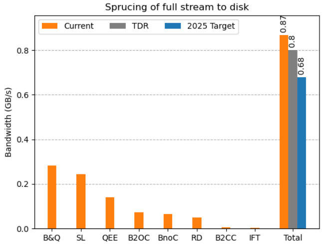
Figure 1: Adapted from JHEP 1907 (2019) 035



DoubleCharm selections - Selective persistence

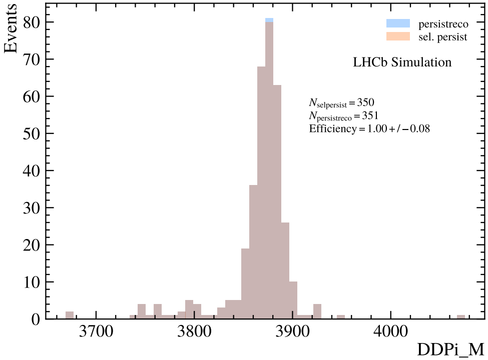
- In 2024, our trigger lines had full-event persistency — i.e. when fired, the entire event would be saved to disk
- BW to disk over budget towards end of 2024 — Quarkonia WG contributed over $0.284\,\mathrm{GB\,s^{-1}}$, with a LHCb-wide target of $0.68\,\mathrm{GB\,s^{-1}}$ — large reduction was needed!
- Held responsibility for re-optimising a number of trigger lines used by the Quarkonia WG





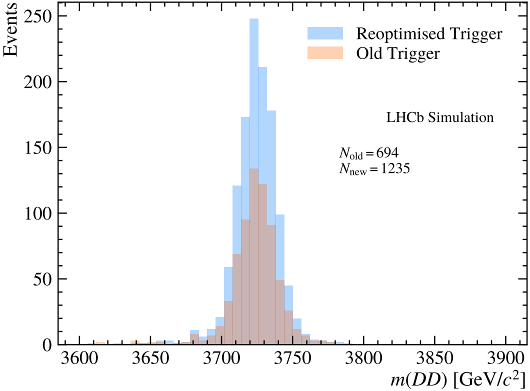
DoubleCharm selections - Selective persistence

- Only save certain parts of the event that we need, e.g. tracks from same PV as $D^0\overline{D}^0$, some detached tracks, neutrals...
- Validated using a $T_{cc}^+ \to D^0 D^0 \pi^+$ MC by combining triggered DD candidates with additional pions to form T_{cc}^+ candidates
- Large reduction in bandwidth for little cost — Event size reduced by $\sim 40\%$ while losing around $\mathcal{O}(1\%)$ signal
- Work is ongoing to validate feature using $D^{*+}(2010) \to D^0\pi^+$ decays in 2025 data



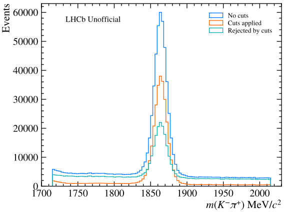
DoubleCharm selections - Charm hadron builders

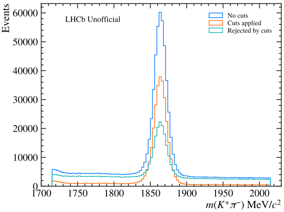
- Reconstruction of charm hadrons in 2024 data used tight kinematic cuts $\implies$ clean $D^0 \to K^-\pi^+$ mass spectrum at expense of efficiency for near-threshold signals (i.e. T_{cc}^+, $\chi_{c1}(3872)$)
- Looked at loosening kinematic cuts; focus more on decay topology
- Tested using $\chi_{c1}(3872) \to D^0\overline{D}^0\pi^0$ MC sample; $\sim$ 80% increase in near-threshold signal efficiency without increasing trigger bandwidth

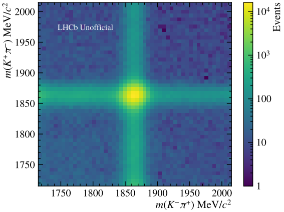


First look at 2024 data

- Started work on analysing 2024 $D^0 \to HH$, $\overline{D}^0 \to HH$ data by looking at selections to reduce background
- As a first step, tighten topological cuts on D^0 and daughter hadrons:
  - Require D^0 to be consistent with originating from associated PV
  - Require daughter hadron tracks to be be detached from closest PV
- Aim to reject random HH combinations as well as D^0 originating from B decays
- Effect of selections on signal readily seen in $D^0 \to K^-\pi^+$, $\overline{D}^0 \to K^+\pi^-$ channels

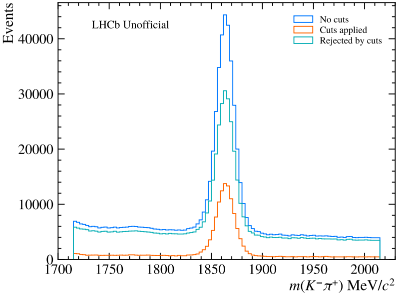


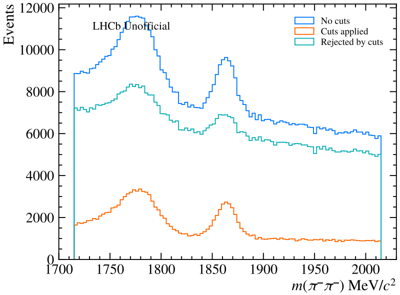




First look at 2024 data

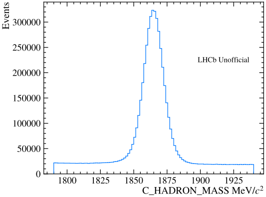
- Large peak at D^0 mass in subsample rejected by cuts — explained by D^0 originating from decay of B mesons
- Need for cut is more readily demonstrated by channel with a $D^0 \to \pi^- \pi^+$ decay, e.g. $D^0 \to K^- \pi^+$, $\overline{D}^0 \to \pi^- \pi^+$



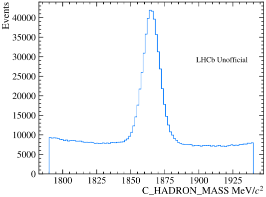


First look at 2025 data

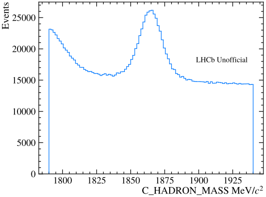
- Implemented monitoring for charm hadron mass distributions in the trigger before combination into DD candidates
  - Useful for checking performance of charm hadron builders due to higher statistics
  - Enables real-time monitoring of trigger performance
- Data taken over a single run corresponding to $1.34\,\mathrm{pb}^{-1}$ of pp collisions during commissioning



(a) $D^0 \to K^-\pi^+$ + c.c.



(b) $D^0 \to K^-K^+$



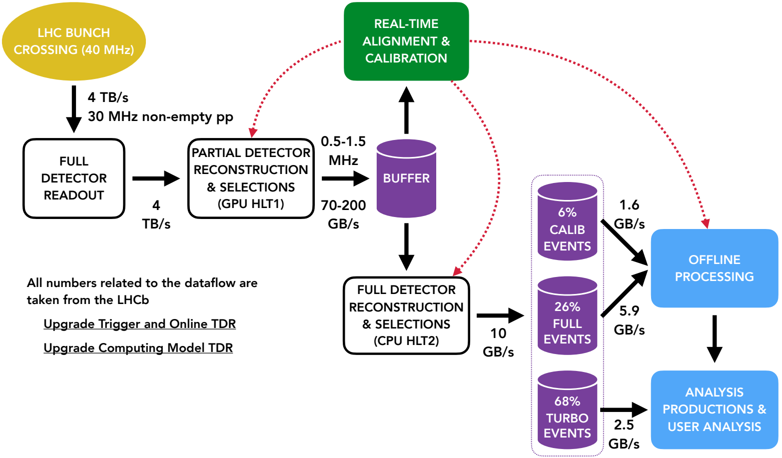
(c) $D^0 \to \pi^-\pi^+$

Summary of work done so far

- Implemented and tested selection persistency for Quarkonia WG spectroscopy lines — Around $100\,\mathrm{MB\,s^{-1}}$ reduction in BW to disk for tiny cost in efficiency
- Reoptimised DoubleCharm trigger lines to improve efficiency for near-threshold exotic hadrons, namely the $X3872$ and T_{cc}^{+}
- Started working on selections for quantum-correlated $D^0\overline{D}^0$ analysis using Run 3 LHCb data
- Ongoing efforts to validate changes to trigger using 2025 data
- Any questions?

Backup Slides

LHCb dataflow - A brief overview

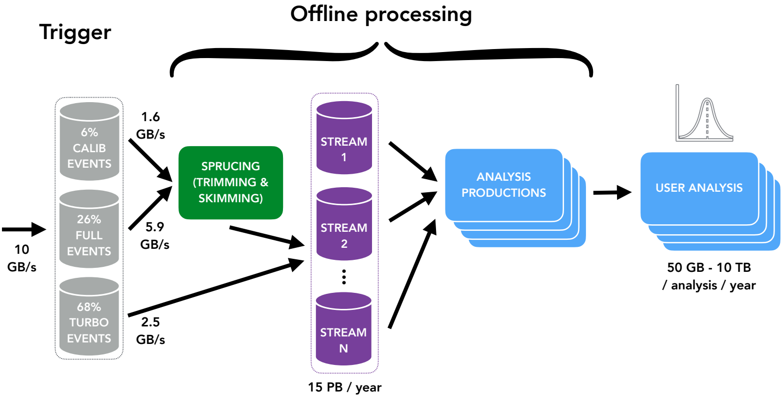


All numbers related to the dataflow are taken from the LHCb

Upgrade Trigger and Online TDR

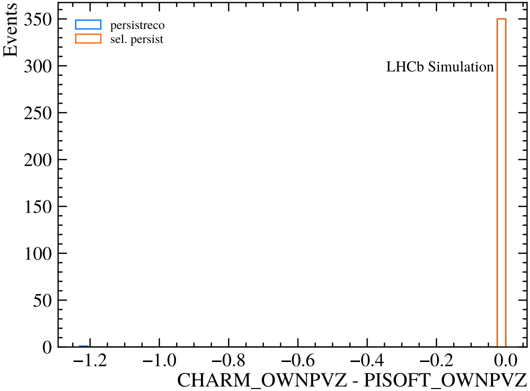
Upgrade Computing Model TDR

LHCb dataflow - A brief overview



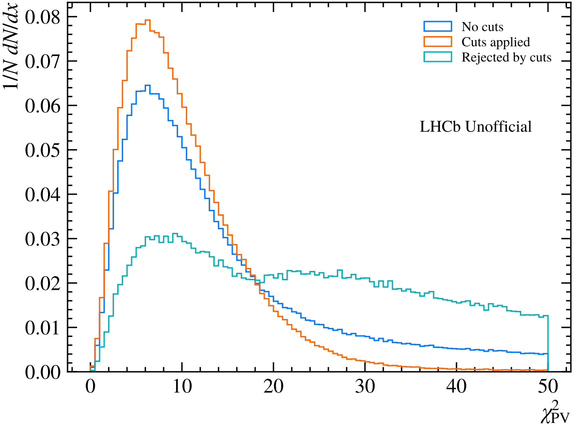
Selective persistence - Signal loss

- MC sample was truth-matched by imposing requirements on the true origin vertex of the D mesons and extra π^+, PID and parent/daughter IDs and keys
- Single event lost when moving to selective persistence corresponds to an event where the DD candidate and additional π^+ have been reconstructed to originate from different PVs (i.e. PV mis-association)
- Seen in distribution of difference in PV z-position between DD candidate and π^+



First look at 2024 data - Background studies

- Studied events rejected by tightening topological cuts by looking at χ^2_{PV}
- χ^2_{PV} refers to the χ^2 obtained when refitting the decay tree of a DD candidate under the constraint that both D mesons originate from the same PV
- Serves as a measure of how consistent a DD candidate is with the hypothesis that both D mesons originate from the same PV
- Wide tail in distribution of χ^2_{PV} indicates that a large number of rejected events originate from B decays



First look at 2024 data - Background studies

- Applying $\chi^2_{PV} < 16$ cut beforehand shows that the D^0 and daughter selection cuts have a drastically different effect on the mass distribution of rejected events — lose around $\mathcal{O}(10\%)$ events in the D^0 mass peak
- Signal loss consistent with a $\mathcal{O}(1\%)$ signal loss seen from a 2024 $D^{*+}(2010) \to D^0\pi^+$ sample using the same D^0 selections but without the requirement to form a DD candidate.