A comprehensive real-time analysis model in Run 2 at the LHCb experiment

Biljana Mitreska
The University of Manchester
on behalf of the LHCb collaboration

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Outline

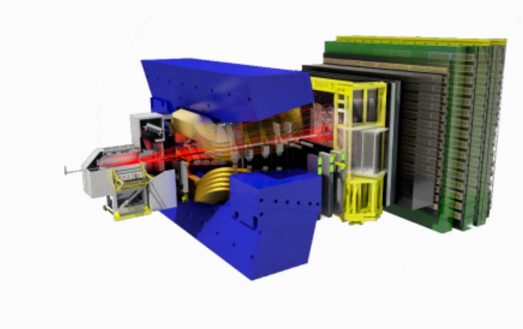
1. The LHCb experiment
2. The Run 2 trigger
3. Real time alignment and calibration
4. The streams
5. Run 2 achievements
6. Run 3 prospects
7. Summary

The LHCb experiment

- **Forward arm spectrometer**
- **Measuring decay properties of beauty and charm hadrons**
- **Tracking system (VELO, TT, IT, OT)**
- **Calorimeter (ECAL, HCAL)**
- **Particle identification (RICH, Muon system)**

▸ Int. J. Mod. Phys. A 30 (2015) 1530022

▸ JINST 3 (2008) S08005



What is needed to observe small effects (New Physics)?

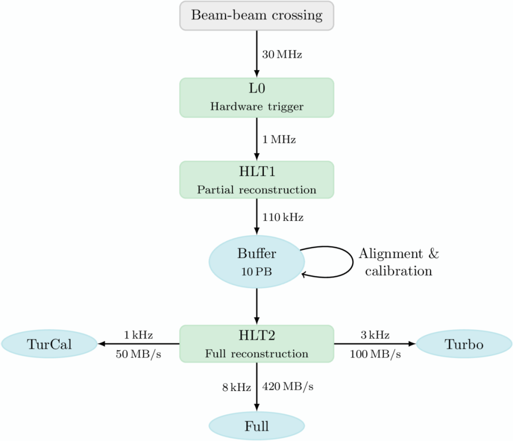
- center of mass energy: Run 1 (7-8 TeV), Run 2 (13 TeV)
- luminosity: Run 1 (3 fb^{-1}), Run 2 (6 fb^{-1})
- **Bandwidth = Trigger output rate $\times$ Average event size**

The Run 2 trigger

- Developed by LHCb for Run 2 (2015 - 2018)
- L0 hardware trigger - uses the muon and calo information
- First stage of the software trigger (HLT1) - partial reconstruction
- 10 PB disk buffer
- Full reconstruction in HLT2

▸ JINST 14 (2019) P04006

▸ Comput. Phys. Commun. 208 35-42

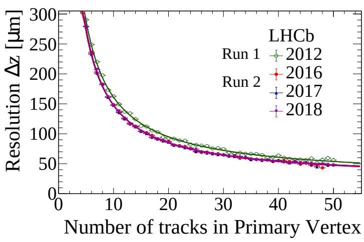


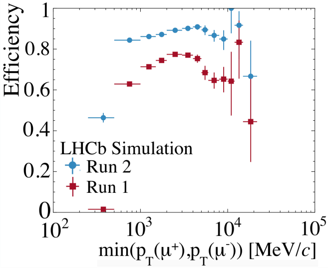
'real time'

is the interval between a collision occurring and the point at which the corresponding event must be either discarded forever or sent offline for permanent storage

HLT1 → disk buffer

HLT1 reconstructs long tracks
$p_T > 500$ MeV/c + precise PV reconstruction + muon identification

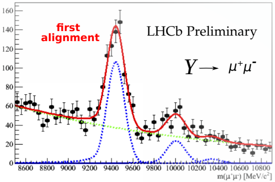


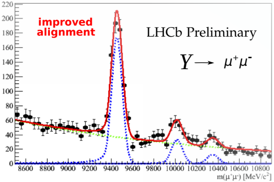


- **HLT1 accepted events written to disk (110 kHz)**
- **The buffer allows for up to two weeks of consecutive HLT1 data taking**
- **Automated alignment and calibration tasks**

▸ JINST 14 (2019) P04013

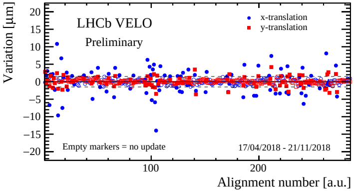
Real time alignment and calibration





Samples selected by HLT1 are used to align and calibrate the detector

- **Alignment procedure with a method based on the Kalman filter**
- **Run automatically at the beginning of each fill (e.g. VELO and tracker alignment take a few min)**
- **Automatic update if the variations are significant**

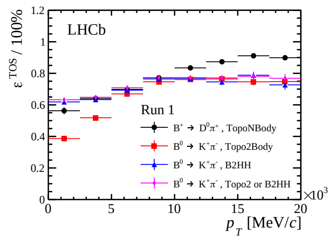


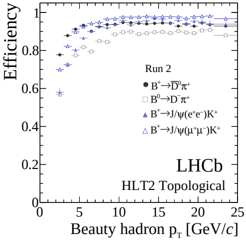
- **Alignment of the full tracker system: VELO, TT, IT, OT, Muon chambers**
- **RICH calibration and alignment of the RICH mirrors**
- **Time calibration of the OT detector**
- **Calibration of the electromagnetic calorimeter using π^0 sample**

S. Borghi | A.Dziurda et al. | W. D. Hulsbergen | more details B. Mitreska poster at EPS

HLT2

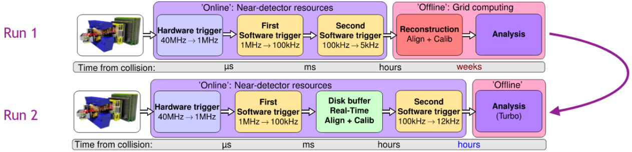
HLT2 reconstructs tracks of charged and neutral particles + particle identification **(500 trigger lines with a rate ∼ 12.5 kHz)**





‣ Int. J. Mod. Phys. A 30 (2015) 1530022 ‣ JINST 14 (2019) P04013

- **In Run 1 offline processing was required**

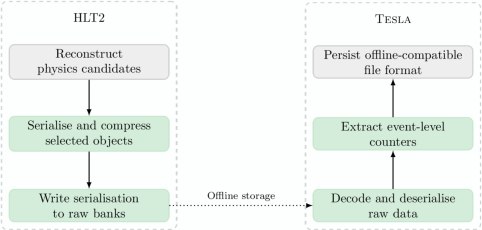


- **same offline-like performance**
- **physics analysis possible just from the trigger output**

‣ more details talk by M. de Cian

The streams

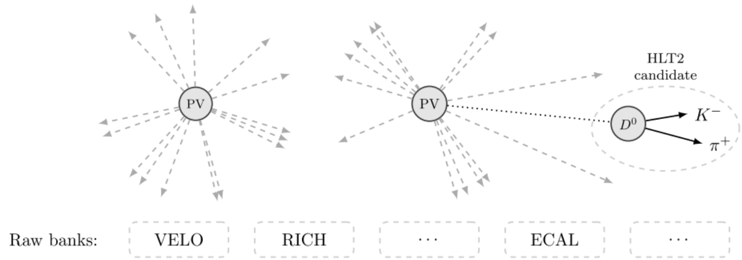
- Events are persisted to a set of **streams** in permanent storage
- **Full stream** contains the full set of sub-detector and trigger raw banks (69 kB)
- **Turbo stream** - a reduced event format is persisted (7-16 kB)
- **TurCal** - calibration stream, both the reduced and full formats are kept ($>$ 70 kB)



- $\sim$ 40 tracks are associated to a PV
- 2–6 tracks are required to reconstruct a heavy flavour decay
- **TESLA** transforms the HLT2 output into a format ready for analysis ▸ Comput. Phys. Commun. 208 35-42

Standard Turbo model

Trigger using the Turbo model that reconstructs and selects $D^0 \to K^-\pi^+$



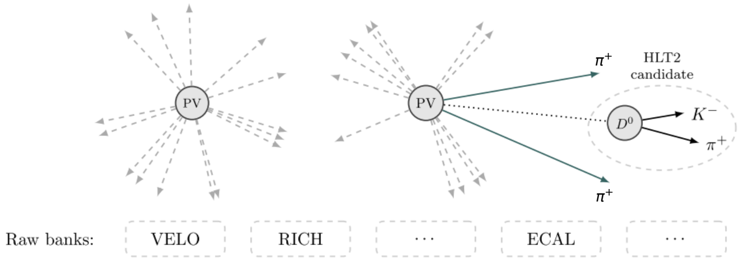
objects saved:

- **The set of all tracks and neutral objects**
- **Calorimeter, PID information and decay vertices that form the candidate**
- **All of the reconstructed primary vertices**

Used in cross section measurements ($J/\psi \to \mu^+\mu^-$, $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$)

Selective persistence

Trigger using the Turbo model that reconstructs and selects $D^0 \to K^-\pi^+$



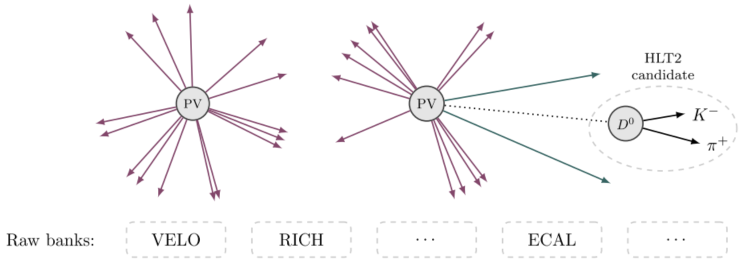
objects saved:

- **Additional objects can be specified**
- **$\pi^\pm$ that are associated to the same PV as the D^0 and form $D^{*\pm}$**
- **Selection applied on both pions and $D^0\pi^\pm$ combination, keeping the pions that pass and D^* candidates discarded**

Used in charm spectroscopy measurements

Complete reconstruction persistence

Trigger using the Turbo model that reconstructs and selects $D^0 \to K^- \pi^+$

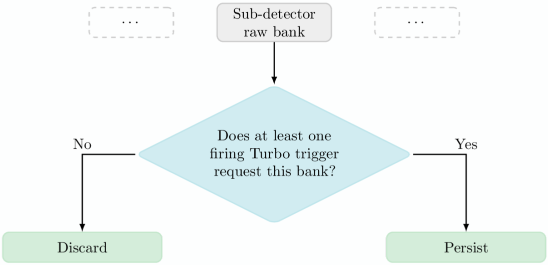


objects saved:

- **Keep all reconstructed objects and drop the raw event**

Used in jet studies

Selective raw persistence



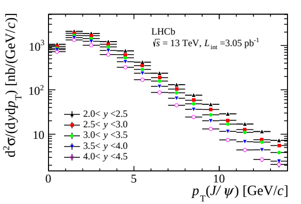
average event sizes measured using 2018 data →

Persistence method	Average event size (kB)
Turbo	7
Selective persistence	16
Complete persistence	48
Raw event	69

Turbo in Run 2

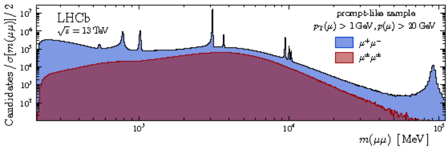
Charm and J/ψ cross-sections

‣ JHEP 10 (2015) 172



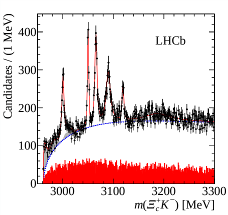
Searches for dark photons

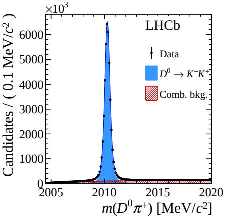
‣ Phys. Rev. Lett. 120 (2018) 061801

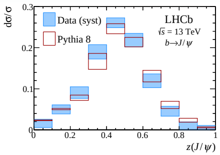


CP violation in charm

‣ Phys. Rev. Lett. 122 (2019) 211803







‣ Phys. Rev. Lett. 118 (2017) 182001

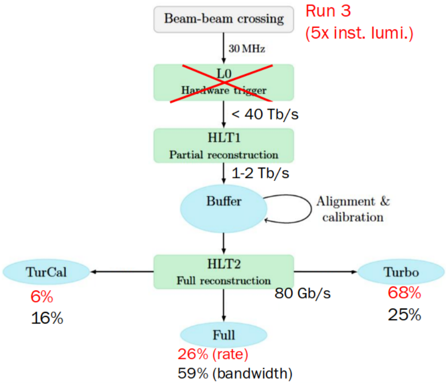
‣ Phys. Rev. Lett. 118 (2017) 192001

Discovery of excited charm baryons

J/ψ production in jets

Run 3 prospects

- LHCb detector is undergoing a major upgrade for Run 3 (x 5 luminosity)
- Full detector readout at 40 MHz
- Full software trigger
- Speed-up of the Run 2 algorithms, use of different architectures for HLT1 and HLT2 reconstruction
- 70 % of the rate will be Turbo



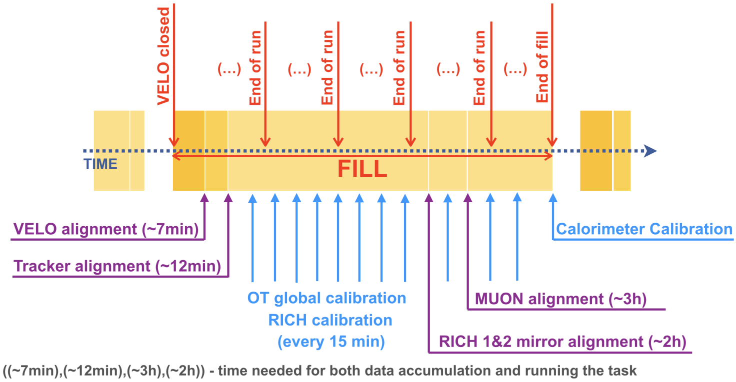
Summary

- Since 2015, a novel real-time procedure has been developed for LHCb
- The real time alignment and calibration procedure between trigger is a key element for exploiting the Turbo model
- Signal candidates are persisted directly from the trigger for later analysis
- The model is now capable of supporting the entirety of the experiment's broad research programme
- Turbo model has already provided a 50 % reduction in bandwidth in comparison with saving the full reconstruction
- Acquired experience developed up to now can be used in Run 3

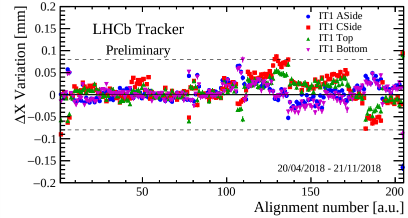
Thank you!

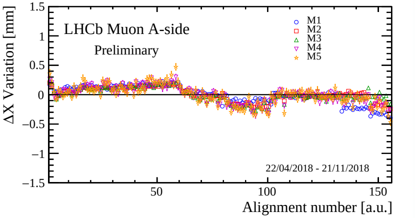
BACK UP

Real time alignment and calibration



Real time alignment and calibration





LHCb upgraded detector