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

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Outline

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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)

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

‘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 \rightarrow disk buffer**

**HLT1 reconstructs long tracks**

\[ p_T > 500 \text{ MeV/c} + \text{precise PV reconstruction} + \text{muon identification} \]

- 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

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The Run 2 trigger
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 \( \pi^0 \) sample

- S. Borghi
- A. Dziurda et al.
- W. D. Hulsbergen
- more details B. Mitreska poster at EPS
HLT2 reconstructs tracks of charged and neutral particles + particle identification (500 trigger lines with a rate $\sim 12.5$ kHz)

- In Run 1 offline processing was required
- same offline-like performance
- physics analysis possible just from the trigger output

The Run 2 trigger

> 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)

- ~ 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

[Computation. Phys. Commun. 208 35-42]
**Standard Turbo model**

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

**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 ($J/\psi \rightarrow \mu^+ \mu^-, D^0 \rightarrow K^- \pi^+, D^+ \rightarrow K^- \pi^+ \pi^+$)
Selective persistence

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

- Additional objects can be specified
- $\pi^\pm$ that are associated to the same PV as the $D^0$ and form $D^*\pi^\pm$
- 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

_raw_diagram_
Complete reconstruction persistence

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

**Objects saved:**
- Keep all reconstructed objects and drop the raw event

Used in jet studies
Selective raw persistence

<table>
<thead>
<tr>
<th>Persistence method</th>
<th>Average event size (kB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbo</td>
<td>7</td>
</tr>
<tr>
<td>Selective persistence</td>
<td>16</td>
</tr>
<tr>
<td>Complete persistence</td>
<td>48</td>
</tr>
<tr>
<td>Raw event</td>
<td>69</td>
</tr>
</tbody>
</table>

average event sizes measured using 2018 data →
Turbo in Run 2

**Charm and $J/\psi$ cross-sections**

- JHEP 10 (2015) 172

![Graph showing $J/\psi$ cross-sections](image1)

**Searches for dark photons**

- Phys. Rev. Lett. 120 (2018) 061801

![Graph showing dark photon searches](image2)

**CP violation in charm**


![Graph showing CP violation in charm](image3)

**Discovery of excited charm baryons**


![Graph showing excited charm baryons](image4)

**$J/\psi$ production in jets**


![Graph showing $J/\psi$ production in jets](image5)

Run 2 achievements
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

[Diagram of Run 3 process flow with labels and data points, including: Beam-beam crossing, L0, HLT1, HLT2, Buffer, TurCal, Turbo, Full reconstruction, 30 MHz, < 40 Tb/s, 1-2 Tb/s, Alignment & calibration, 80 Gb/s, 26% (rate), 59% (bandwidth), 68%, 25%, 6%, 16%]
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

VELO alignment (~7min)
Tracker alignment (~12min)
OT global calibration
RICH calibration (every 15 min)
RICH 1&2 mirror alignment (~2h)
MUON alignment (~3h)
Calorimeter Calibration

((~7min), (~12min), (~3h), (~2h)) - time needed for both data accumulation and running the task
Real time alignment and calibration

LHCb Tracker

Alignment number [a.u.]

ΔX Variation [mm]

IT1 ASide
IT1 CSide
IT1 Top
IT1 Bottom

LHCb Muon A-side

Alignment number [a.u.]

ΔX Variation [mm]

M1
M2
M3
M4
M5

20/04/2018 - 21/11/2018

22/04/2018 - 21/11/2018
LHCb upgraded detector