The LHCb High Level trigger in Run 2

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on behalf of the LHCb collaboration,

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The LHCb experiment

VerteX and track finding

Particle identification and first event trigger

\(~45\) kHz \(b\bar{b}\) pairs and \(~1\) MHz \(c\bar{c}\) pairs
at \(13\) TeV and \(L = 4 \times 10^{32}\) cm\(^{-2}\) s\(^{-1}\)
Event selection at LHCb

LHCb 2015 Trigger Diagram

40 MHz bunch crossing rate

L0 Hardware Trigger: 1 MHz readout, high $E_T/P_T$ signatures

450 kHz $h^\pm$

400 kHz $\mu/\mu\mu$

150 kHz $e/\gamma$

Software High Level Trigger

Partial event reconstruction, select displaced tracks/vertices and dimuons

Buffer events to disk, perform online detector calibration and alignment

Full offline-like event selection, mixture of inclusive and exclusive triggers

12.5 kHz Rate to storage

L0 efficiencies:

- HLT, software trigger:
  - Running on large farm
  - Split in HLT1 and HLT2
  - Selects events for offline analysis

- Physics analysis
Online and offline

**Online:**
Compromise between performance and stringent timing requirements.

**Offline:**
Best available performance without stringent timing requirements.

**Differences:**
Pattern recognition, detector alignment and calibration, candidate selection...

**Conclusion for Run 2:**
- Want online same reconstruction as offline.
- Want calibrations and alignments immediately.

Example:
Lifetime measurement

Illustration
Deferred triggering

- Event Filter Farm doubled in Run 2:
  - 800 new nodes and 1000 old nodes, 50880 logical cores, 5 MCHF
- LHC stable beams 30% of time
  → 70% idle time
- Write data to disk, process between fills
  - 5000 TB in farm
- Run 1:
  Defer 20% of L0 accepted events
  → 25% more effective CPU power
- Run 2:
  Defer all HLT1 accepted events
  → Fewer events

- More time for reconstruction
- Calibration between HLT1 and HLT2 possible
HLT1 event reconstruction

- Offline Velo tracking
  - Kalman filter
  - Velo → TT: Initial momentum estimate
  - TT → T-stations: Full track
  - Offline Kalman filter: Optimal track parameters
  - Muon identification

- Offline PV

- Improved sequence (Velo → TT)
- Code optimization
- New offline:
  - PV fit only with Velo tracks
  - Kalman filter with fast geometry description
  - No performance degradation
  → Consistent PV and track parameters

S. Stahl  LHCb High Level Trigger, EPS-HEP 2015
HLT1 trigger

- Inclusive charm and beauty triggers:
  - Single and two track MVA selections
  - \( \rightarrow \sim 100 \text{ kHz} \)
- Inclusive muon triggers:
  - Single and dimuon selections
  - Special low \( p_T \) track reconstruction
  - \( \rightarrow \sim 40 \text{ kHz} \)
- Exclusive triggers:
  - New lifetime unbiased trigger selections for hadronic charm and beauty decays
Real-time alignment and calibration

Alignment and calibration of detectors crucial for optimal physics performance
- E.g. RICH particle identification
  \[ D^0 \to K^- \pi^+ \text{ vs. } D^0 \to K^- K^+ \]

Automatic real-time procedures:
- RICH calibration between HLT1 and HLT2
- Tracker alignment during running, O(min)
- Calorimeter calibration, RICH and Muon alignment monitored
- Apply updates if necessary

Minimizes time with suboptimal alignments and calibrations

Online same alignments and calibrations as offline

More details: P. Seyfert, Friday 27.7.,
“Novel real-time calibration & alignment and tracking performance for LHCb Run II”
**HLT2 event reconstruction**

- **Full event reconstruction:**
  - 1. Start from HLT1 vertices and tracks
  - 2. Reconstruct all tracks (Run 1 $p_T > 300$ MeV, no redundancy)
  - 3. Full particle identification for long tracks (new)
- **Same strategy as offline**

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Time</th>
<th>Run 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total HLT1</td>
<td>~ 35 ms</td>
<td>~ 20 ms</td>
</tr>
<tr>
<td>Track finding</td>
<td>~ 200 ms</td>
<td></td>
</tr>
<tr>
<td>Full track fit</td>
<td>~ 100 ms</td>
<td></td>
</tr>
<tr>
<td>RICH reconstruction</td>
<td>~ 180 ms</td>
<td></td>
</tr>
<tr>
<td>Calo reconstruction</td>
<td>~ 50 ms</td>
<td></td>
</tr>
<tr>
<td>Muon ID</td>
<td>~ 2 ms</td>
<td></td>
</tr>
<tr>
<td>Total Hlt2</td>
<td>~ 650 ms</td>
<td>~ 150 ms</td>
</tr>
</tbody>
</table>
HLT2 trigger selection

- **Inclusive beauty trigger:**
  - MVA based inclusive selection of 2,3,4 body detached vertices
  - Di muon triggers for $B \rightarrow J/\Psi \ X$

- **Exclusive beauty trigger:**
  - E.g. $B \rightarrow \Phi \Phi$, $B \rightarrow \gamma \gamma$ (new) etc.

- **Charm trigger:**
  - Inclusive trigger on $D^*$ resonance
  - Many exclusive lines using particle identification

- **Electroweak trigger**
- ...

- **Almost 400 different trigger selections**
- **Total output to storage 12.5 kHz (twice as in Run 1)**
Turbo stream

• Online has offline quality → use it for physics analyses

• Turbo stream:
  – Write out full information of trigger candidates
  – Throw away raw event data → Saves a lot of space

• Ideal for analyses with very high signal yields (millions)

• Extremely quick turn around

Measurement of differential $J/\Psi$ cross-section:

Measurement of differential charm cross-section:

I. Komarov, QCD 24.7., “First LHCb results from the 13 TeV LHC data”
Conclusion

- Larger farm, lots of hard work and smart ideas
- Online full event reconstruction including particle identification
- Consistent reconstruction online and offline
- Real-time calibration new to detectors of this scale
  → Much better trigger in Run 2 than in Run 1

- We still have more ideas...
Hardware trigger (L0)

- Reduce bunch crossing-rate to ~1 MHz
- Calorimeter trigger:
  - Hadrons: 
    ET > 3.7 GeV, rate 500 kHz
  - Photons and electrons:
    ET > 3 GeV, rate 150 kHz
- Muon trigger
  - Single Muon: pt>1.76 GeV
  - Di Muon: (pt1*pt2) 1.6 GeV2
  - Rate 400 kHz
- Filters out very complex events
- Low multiplicity triggers
Event filter farm

- 900 nodes with 2TB disks, 800 nodes with 4TB disks
  - 900 Intel x5650, 100 AMD 6272, 800 Intel E5-2630v3 (new)
- 27040 physical cores, 50880 logical cores
- Almost doubled the performance from Run1 to Run2
Deferred triggering, Run1 and Run 2

40 MHz bunch crossing rate

L0 Hardware Trigger : 1 MHz readout, high $E_T/\mathcal{P}_T$ signatures
- 450 kHz $\pi^\pm$
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Defer 20% to disk

Software High Level Trigger
- 29000 Logical CPU cores
- Offline reconstruction tuned to trigger time constraints
- Mixture of exclusive and inclusive selection algorithms

5 kHz Rate to storage

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Software High Level Trigger
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50000 logical cores

12.5 kHz Rate to storage