The LHCb Trigger in Run II

Roel Aaij

CERN, Geneva,
on behalf of the LHCb collaboration

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At 13 TeV and $\mathcal{L} = 4 \times 10^{32}$ cm$^{-2}$ s$^{-1}$:

$\sim 45$ kHz $\overline{b}b$ pairs and $\sim 1$ MHz $c\overline{c}$ pairs
Run I Trigger Overview

- LHCb detector read out at 1 MHz
- Hardware trigger (L0)
  - Based on multiplicity, calorimeters and muon detectors
  - Fixed latency of 4 µs
  - Reduces rate to 1 MHz
- Software trigger (HLT)
  - Runs on HLT farm
  - Split in two stages: HLT1 and HLT2
  - Events buffered to allow processing out of fill
  - Output rate 5 kHz
  - Total time budget $O(35)$ ms/event
Run I Reconstruction

- **Online:**
  
  Best possible within CPU budget

- **Offline:**
  
  Best performance regardless of CPU

- **Differences:**
  
  - Pattern recognition
  - Alignment
  - No hadron PID online
  - Selections
Run I Reconstruction

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- **Goal for Run II:**
  run offline reconstruction online

- Offline quality alignment and calibrations needed online
Deferred Triggering

- Stable beams 30% of the time
- Buffer events to allow for out of fill processing
- Larger real-time reduction allows more efficient use of buffers
  → buffer after HLT1 → HLT split in 2 applications
- 5000 TiB buffer on local disks
- Space for 160 hours of data with 150 kHz of 60 kiB events out of HLT1

- Allows HLT1 output to be used for calibration and alignment
- Sufficient buffer given LHC’s uptime is comparable to 2012
Run II Trigger Overview

- LHCb detector read out at 1 MHz
- Hardware trigger (L0)
  - Based on multiplicity, calorimeters and muon detectors
  - Fixed latency of 4 µs
  - Reduces rate to 1 MHz
  - Higher thresholds in Run II
- Software trigger (HLT)
  - HLT farm nearly doubled.
  - HLT Split in two applications: HLT1 and HLT2
  - Events buffered after HLT1
  - Output rate 12.5 kHz
  - HLT software 40% faster
Inclusive selections:
- Single and two track MVA selections
- ~ 100 kHz

Inclusive muon selections
- Single and dimuon selections
- Additional low $p_T$ track reconstruction
- ~ 40 kHz

Exclusive selections
- Lifetime unbiased beauty and charm selections
- Selections for alignment

Low multiplicity trigger for central exclusive production analyses
Real-Time Calibration and Alignment

- Same online and offline reconstructions requires prompt alignment and calibration
- Alignment per fill:
  - Collect suitable data with dedicated HLT1 selections, e.g. $D^0 \rightarrow K^+\pi^-$ and $J/\psi \rightarrow \mu^+\mu^-$
  - Run alignment workers on the HLT farm (1 per node)
  - Controller iterates until converged, $O(5)$ min
  - Apply updates of Velo and/or tracker alignment if needed
  - RICH mirror alignment and muon alignment for monitoring
  - ECAL gain calibration
- Calibration per 1 h run:
  - RICH and Outer Tracker $t_0$
  - Available $O(1)$ minute after collection of data
- For more details see Manuel’s talk and Varvara’s poster.
Full event reconstruction  
Starts from HLT1 objects  
All charged tracks  
Neutral particles  
RICH, Muon and Calo PID  
Same reconstruction online and offline  
30% speedup achieved

<table>
<thead>
<tr>
<th>Reconstruction</th>
<th>Run II</th>
<th>Run I</th>
</tr>
</thead>
<tbody>
<tr>
<td>HLT1 rate</td>
<td>~150 kHz</td>
<td>~ 80 kHz</td>
</tr>
<tr>
<td>HLT1 time</td>
<td>~ 35 ms</td>
<td>~ 20 ms</td>
</tr>
<tr>
<td>Track finding</td>
<td>~200 ms</td>
<td></td>
</tr>
<tr>
<td>Track fit</td>
<td>~100 ms</td>
<td></td>
</tr>
<tr>
<td>Calorimeter reco</td>
<td>~ 50 ms</td>
<td></td>
</tr>
<tr>
<td>RICH PID</td>
<td>~180 ms</td>
<td></td>
</tr>
<tr>
<td>Muon ID</td>
<td>~200 ms</td>
<td></td>
</tr>
<tr>
<td>Total HLT2</td>
<td>~650 ms</td>
<td>~150 ms</td>
</tr>
<tr>
<td>HLT2 rate</td>
<td>~ 12.5 kHz</td>
<td>~ 5 kHz</td>
</tr>
</tbody>
</table>
HLT2 Selections

- Inclusive beauty selections:
  - MVA based 2, 3, and 4 body detached vertices
  - Dimuon selections
- Exclusive beauty selections:
  - E.g. $B \rightarrow \phi \phi$, $B \rightarrow \gamma \gamma$
- Charm selections
  - Inclusive selection of $D^* \rightarrow (D^0 \rightarrow X) \pi^+$
  - Charmed baryons
  - Final states with $K_S^0$
  - 2,3,4,5–body final states
- Electroweak bosons
- ...

- Nearly 400 selections in total
- 12.5 kHz to tape

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LHCb MC Run I Topological

LHCb Run I Charm

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Roel Aaij (CERN)
Turbo Stream

- Offline reconstruction available online → do physics analysis with HLT candidates
- Turbo stream:
  - Store HLT candidate information.
  - Remove most of detector raw data.
  - Space required reduced by > 90 %.
- Ideal for high-yield analyses.
- O(24) h turn-around.
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Full offline-quality reconstruction available online
Calibration and alignment running online
HLT reorganised to allow buffering after HLT1
Additional HLT farm purchased, now effectively 2 times larger
  - 1800 servers
  - 27000 physical cores
  - 5 PiB disk space
Software optimised to fit reconstruction in time budget
Turbo stream implemented; first results public, e.g.
  - Measurement of forward J/ψ production cross-sections in pp collisions at √13 TeV
  - c\bar{c} cross-sections in pp collisions at √13 TeV