The LHCb Trigger System
Performance and Outlook

A. Puig on behalf of the LHCb collaboration
LHCb: heavy flavor factory

- Production correlated predominantly in the forward/backward direction $\Rightarrow$ single arm forward spectrometer ($2<\eta<5$).
- $\sigma_{b\bar{b}} = (75.3 \pm 14.1) \mu b$ [Phys. Lett. B694 (2010)] $\sim 0.2\%$ of events have a $b$ hadron in acceptance
- $\sigma_{c\bar{c}} = (1419 \pm 134) \mu b$ [Nucl. Phys. B871 (2013)] $\sim 4\%$ of events have a $c$ hadron in acceptance
Heavy flavor signatures

Beauty Hadrons

- \( m(B^+) = 5.28 \text{ GeV} \)
- Daughter \( p_T \) of \( O(1 \text{GeV}) \)
- Lifetime \( (B^+) \sim 1.6 \text{ ps} \)
- Flight distance \( \sim 1 \text{ cm} \)
- Interesting physics signature: detached \( \mu\mu \)

Charm Hadrons

- \( m(D^+) = 1.87 \text{ GeV} \)
- Sizeable daughter \( p_T \)
- Lifetime \( (D^+) \sim 1.0 \text{ ps} \)
- Flight distance \( \sim 4 \text{ mm} \)
LHC environment

- Bunch crossing rate $\sim 40$MHz
  - Visible $pp$ interaction at 15MHz
- Luminosity of $4 \times 10^{32}$ cm$^{-2}$ s$^{-1}$
- Interactions/bunch crossing $\sim 1.6$
- Signal purities stable with number of primary vertices (PV)
2011-2012 trigger architecture

• 3-stage trigger, documented in [JINST 8 (2013) P04022]

• Level 0 (L0)
  - Implemented in hardware
  - Decision in 4 µs

• High Level Trigger (HLT)
  - Two stages (HLT1 and HLT2)
  - Flexible software trigger
  - Farm of 29000 logical cores

- 40 MHz bunch crossing rate (15 MHz visible interactions)

  L0 trigger
  High $p_T/E_T$ signatures
  1 MHz detector readout

  | $450$ kHz | $350$ kHz | $120$ kHz | $80$ kHz |
  | $h^\pm$   | $\mu^\pm$ | $e^\pm/\gamma$ | $\mu^+\mu^-$ |

  HLT1
  Displaced high-$p_T$ tracks
  70 kHz output rate

  HLT2
  Full event reconstruction
  inclusive + exclusive strategy

  5 kHz to offline storage

  | 2 kHz | 2 kHz | 1 kHz |
  | $b$-inclusive | charm | muon |
L0 trigger

- **L0 muon**
  - Single muon $p_T > 1.76$ GeV
  - Dimuon $p_{T1} \times p_{T2} > (1.6$ GeV$)^2$
  - Momentum resolution $\sim 20\%$
  - Efficiency typically $\sim 90\%$

- **L0 calorimeter**
  - Hadrons, $e^{\pm}$, $\gamma$ with $E_T > 2.5–3.5$ GeV
  - Efficiency for hadronic $B$ decays $\sim 50\%$
  - Efficiency for radiative $B$ decays $\sim 80\%$

Disclaimer: all efficiencies shown in this presentation are on offline-selected events.
Deferred trigger

- HLT farm nodes not used between fills + large disks not used by HLT software
- Buffer part of the L0 rate to disk, process in inter-fill time, giving an **effective 20% extra CPU**
  - Lowering of $p_T$ tracking thresholds
  - Addition of downstream tracking to trigger long-lived particles

Peak disk usage ~88%
HLT1: add tracking information

- Tracking and Primary Vertex (PV) info are added
  - Use Vertex locator (VELO) tracking information and perform PV reconstruction
  - High-IP or L0Muon-matched tracks are selected
  - Forward tracking is performed with search window sizes given by a minimum $p_T$ requirement

<table>
<thead>
<tr>
<th>track type</th>
<th>$\mu$</th>
<th>$\mu\mu$</th>
<th>high-IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>min $p_T$ [GeV]</td>
<td>1.0</td>
<td>0.5</td>
<td>1.6</td>
</tr>
</tbody>
</table>

- Output rate is tuned to allow HLT2 processing at max rate
HLT1 triggers

- **HLT1 muon**
  - Single µ: detached or high-\(p_T\)
  - Dimuon: detached or high mass (\(m_{\mu\mu} > 2.7\) GeV)

- **HLT1 inclusive track trigger**
  - Optimized for \(B\) decays
  - Single track with high p\(T\) and separation from the PV

![Graphs showing the efficiency of HLT1 triggers as a function of \(p_T\)](image)

\[B^+ \rightarrow J/\psi K^+\]
HLT2: full event reconstruction

- At this level, events are fully reconstructed
  - Reconstruction performance close to offline

- Powerful and flexible software environment
  - Individual trigger lines cuts and prescales can be adjusted to adapt to running conditions
  - Heavy use of MVA-based selections
  - Smart selections performed in steps

- Combination of inclusive and exclusive approach
HLT2 trigger examples

Inclusive dimuon

Inclusive $\phi$

Topo N-body

B $\to$ hh

Inclusive $D^*$ trigger

$D^+ \to D^0\pi^+$
Trigger performance

<table>
<thead>
<tr>
<th>Hadronic</th>
<th>Muonic</th>
<th>Radiative*</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D^0 \rightarrow K\pi^+)</td>
<td>(B^0 \rightarrow K^+\pi)</td>
<td>(B^+ \rightarrow J/\psi K^+)</td>
</tr>
<tr>
<td>(\varepsilon(L0)) [%]</td>
<td>27</td>
<td>40</td>
</tr>
<tr>
<td>(\varepsilon(Hlt</td>
<td>L0)) [%]</td>
<td>60</td>
</tr>
<tr>
<td>(\varepsilon(\text{total})) [%]</td>
<td>16</td>
<td>27</td>
</tr>
</tbody>
</table>

\*=2011 data

- Extremely pure offline-selected samples
Future developments

• After LS1 (2015): splitting of HLT1 and HLT2
  - Defer HLT1 output to disk, perform online detector alignment and calibration and afterwards run an HLT2 version very close to offline
  - Allow for an optimal use of particle identification

• After LS2 (2019): LHCb upgrade (L=2x10^{33} cm^{-2}s^{-1})
  - 1MHz detector readout is the bottleneck
  - Progressively remove the impact of the L0 (LLT)
  - Apply similar HLT1 and HLT2 inclusive triggers
Summary

• The LHCb trigger has been very successful in 2011-2012 thanks to its flexible implementation, which allows fast adaptation to varying running conditions.

• It covers an impressive physics range.

• Deferred trigger has allowed to optimize resources and improve performance.

• Preparations for the upgrade are ongoing.

Trigger rarest B decay with high efficiency.

Collect the world’s largest charm sample with excellent purity.
Thank you