Real Time Analysis in LHCb

Arantza Oyanguren
(IFIC – Valencia)

Workshop on EDMs of unstable particles
(Milano, October 2019)
• Introduction
• The trigger
• Real time analysis
• Alignment and calibration
• Prospects for Run3
• Long living particles
• Conclusions
Introduction
Introduction

Proton-proton collision

2028 bunch of protons per beam
Beam energy of 6.5 TeV

$10^{11}$ protons per bunch
Luminosity $10^{34}$ cm$^{-2}$ s$^{-1}$

Averaged crossing rate $\sim 30$ MHz
i.e. 30 M collisions/s

About 1 MB data per collision at ATLAS and CMS
About 0.15 MB data per collision at LHCb

$\rightarrow$ $5$ TB/s $@$ LHCb
Introduction

British Library, London

\(~12\ TB\)
\((25\ M\ books)\)
Impossible to select all the data: need to select the events of interest

Traditional trigger systems:

First level (L0/L1) \( \rightarrow \) Y/N

First High Level (HLT1) \( \rightarrow \) Y/N

Second High Level (HLT2)

Custom electronics (FPGAs), Information from calorimeters and muon stations

Processors farm, fast Information from tracking

Processors farm, detailed information to reconstruct the event
The trigger

How many data can we record?

The need of storage is given by the trigger bandwidth:

\[
\text{Bandwidth [MB/s]} \sim \text{Trigger output rate [kHz]} \times \text{Average event size [kB]}
\]

\(~ 0.8 \text{ GB/s (Run2)}\)

and increasing for Run3

Raw event data size
60 kB (Run2)

12.5 kHz (Run2)

Note: For the Upgrade (Run 3) the raw event size is \(~150 \text{ kB}\)
Real time analysis

**Bandwidth [MB/s] ~ Trigger output rate [kHz] x Average event size [kB]**

- The **trigger rate saturates**: we cannot reduce the trigger output, all our selected events are signals!

- We need then to **reduce the event size**: Instead of taking the raw data, store only the relevant information

→ Need to reconstruct and analyse the event to select them in **real time**, and keep the important data

[LHCb-PUB-2014-027]
Real time analysis

**Turbo**: exploits the event topology and saves only a subset of the objects which are relevant for a posterior analysis. One can use several persistence levels:

<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>

Real time analysis

* Observation of CP Violation in Charm Decays

PR 122 (2019) 211803

* Search for Dark Photons decaying into two muons

PRL 120 (2018) 061801
Real time analysis

* Observation of the Doubly Charmed Baryon $\Xi^{++}_{cc}$

* Search for dimuon resonances (new spin-0 bosons)

PRL 119 (2017) 112001  
JHEP 08 (2018) 147
Alignment & calibration

In Run2 all detectors are aligned & calibrated online using the HLT1 output stored in the Buffer, before the data go to HLT2.

The Buffer has 2 weeks of contingency.
Alignment & calibration

Ex: VELO centers itself around beam at start of each fill, aligned with a Kalman filter using track hit residuals with PV constraints
Alignment & calibration

Search for dimuon resonance (new spin-0 bosons)

JHEP 08 (2018) 147

Fully aligned and calibrated physics objects in real time → allow to perform analysis at the same level that the offline!

Data reprocessing not needed → fast and fresh analyses, results delivered in few days

Reduced systematics in HLT2 selections
Prospects for Run3

Increasing the instantaneous luminosity x 5 + triggerless readout

**Run 2**
- **Bunch crossing rate:** 30 MHz (averaged)
- **L0 Hardware trigger:** high $p_T/E_T$ signatures → 1 MHz
- **High Level Trigger 1:** partial event reconstruction → 110 kHz
- **10 PB buffer** → Alignment & Calibration → High Level Trigger 2: full event reconstruction → 12.5 kHz → Storage

**Run 3**
- **Bunch crossing rate:** 30 MHz (averaged)
- **L0 Hardware trigger** crossed out → 1 MHz
- **High Level Trigger 1:** partial event reconstruction
- **Software trigger:** >10 PB buffer → High Level Trigger 2: full event reconstruction → Storage

For the Upgrade (Run 3) the raw event size is ~150 kB

≤ 10 GB/s
Prospects for Run3

Need to migrate most of trigger lines to RTA

Caveats:
- Risk of not recording relevant information
- One can discard objects from PV not compatible with the signal
- Inclusive triggers: need rejection of tracks/objetcs
- New and unexpected events?
Prospects for Run3

R&D: using computing accelerators (FPGAs, GPUs)?

Several projects are ongoing at LHCb aiming to improve the trigger capabilities

Retina: aiming to implement the most repetitive sequences on FPGAs before the HLT decision
Ex: VELO clustering on PCIe40

Allen: running the entire LHCb HLT1 software on GPUs

![Throughput chart](image)
Prospects for Run3

The case for long living particles

Strong Physics case for $K_s$ and strange baryons at LHCb

Photograph polarization from b-baryon decays

Leptoquark scenarios from Bobeth & Buras, JHEP02(2018)101

Plus a bunch of new exotica long living particles...
Prospects for Run3

The case for long living particles

Track reconstruction

Most long-lived particles decay products

Not triggered by HLT1 (fast tracking reconstruction with Velo hits)

Efficiencies below 30%

Could we trigger these events?
Conclusions

• New **Real Time Analysis** strategies are crucial to reduce the computing needs while keeping the LHCb physics program for Run3

• **Alignment and calibration** in quasi real time allows high quality and fast reconstruction at the trigger level

• Still **room to improve**, new ideas to be more inclusive to come!