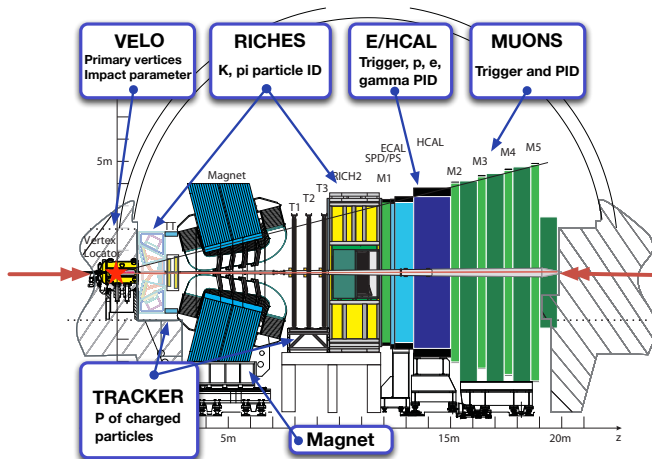# The LHCb Trigger in Run II

Roel Aaij

CERN, Geneva,
on behalf of the LHCb collaboration

September 4th 2015

LHCP 2015, St. Petersburg
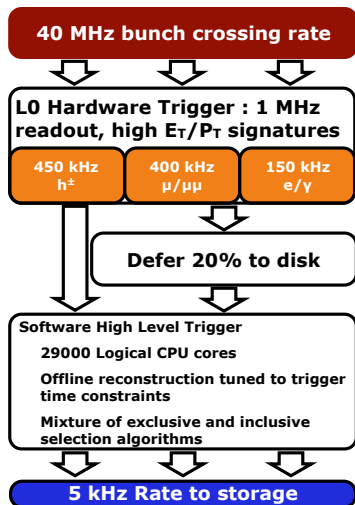
At 13 TeV and $\mathcal{L} = 4 \times 10^{32}$ cm^{-2} s^{-1}:
~ 45 kHz b$\bar{\text{b}}$ pairs and ~ 1 MHz c$\bar{\text{c}}$ pairs

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

40 MHz bunch crossing rate

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

450 kHz $h^{\pm}$	400 kHz μ/μμ	150 kHz e/γ

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**

Run I Reconstruction

- Online:
  Best possible within CPU budget
- Offline:
  Best performance regardless of CPU
- Differences:
  - Pattern recognition
  - Alignment
  - No hadron PID online
 - Selections
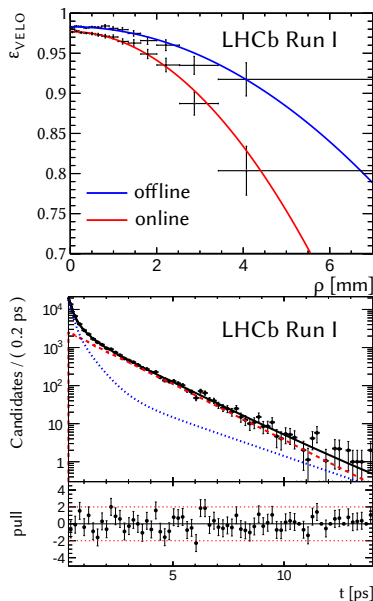
Run I Reconstruction

- Online:
  Best possible within CPU budget
- Offline:
  Best performance regardless of CPU
- Differences:
  - Pattern recognition
  - Alignment
  - No hadron PID online
  - Selections
- Goal for Run II:
  run offline reconstruction online
- Offline quality alignment and
  calibrations needed online
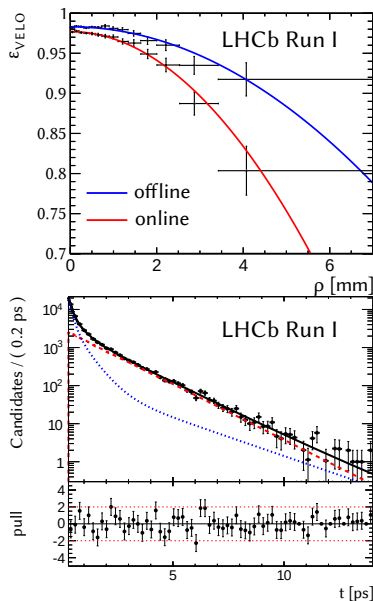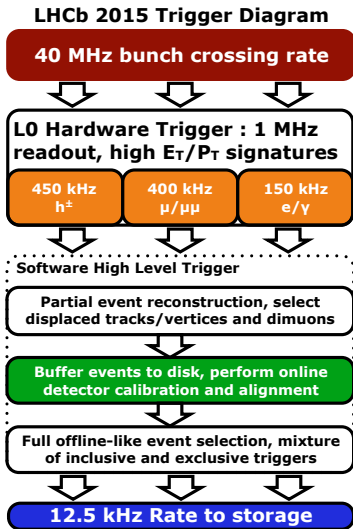
Deferred Triggering

- 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
  $\rightarrow$ buffer after HLT1 $\rightarrow$ 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
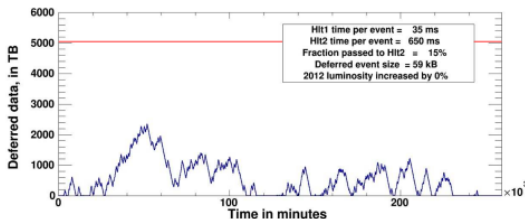

- Allows HLT1 output to be used for calibration and alignment
- Sufficient buffer given LHC's uptime is comparable to 2012

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

LHCb 2015 Trigger Diagram

40 MHz bunch crossing rate

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

| 450 kHz h± | 400 kHz μ/μμ | 150 kHz e/γ |

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

HLT1

- 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
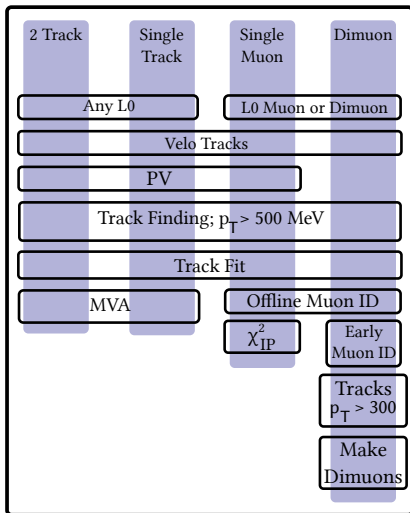
Real-Time Calibration and Alignment

- Same online and offline reconstructions requires prompt alignment and calibration
- Alignment per fill:
    - Collect suitable data with dedicated HLT1 selections, e.g. $D^0 \to K^+\pi^-$ and $J/\psi \to \mu^+\mu^-$
    - Run alignment workers on the HLT farm (1 per node)
    - Contoller 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
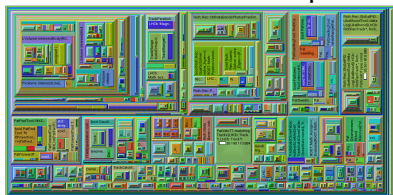- For more details see Manuel's talk and Varvara's poster.
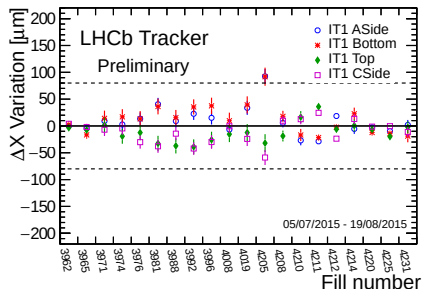
HLT2 Reconstruction

2012 CPU Heat Map
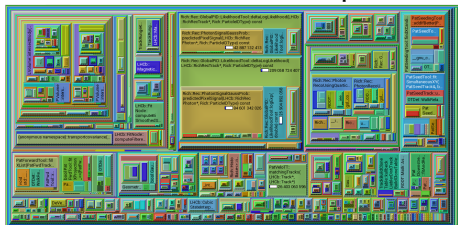
2015 CPU Heat Map

- 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

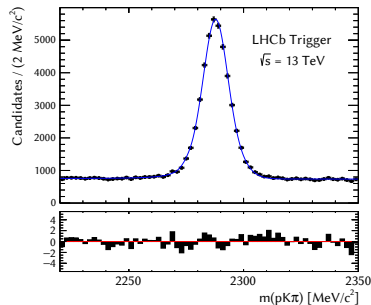| Reconstruction	Run II		Run I
HLT1 rate	$\sim$150	kHz	$\sim$ 80 kHz
HLT1 time	$\sim$ 35	ms	$\sim$ 20 ms
Track finding	$\sim$200	ms	
Track fit	$\sim$100	ms	
Calorimeter reco	$\sim$ 50	ms	
RICH PID	$\sim$180	ms	
Muon ID	$\sim$200	ms	
Total HLT2	$\sim$650	ms	$\sim$150 ms
HLT2 rate	$\sim$ 12.5	kHz	$\sim$ 5 kHz

HLT2 Selections

- Inclusive beauty selections:
  - MVA based 2, 3, and 4 body detached vertices
  - Dimuon selections
- Exclusive beauty selections:
  - E.g. B $\to \varphi\varphi$, B $\to \gamma\gamma$
- Charm selections
  - Inclusive selection of $D^* \to (D^0 \to X)\, \pi^+$
  - 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
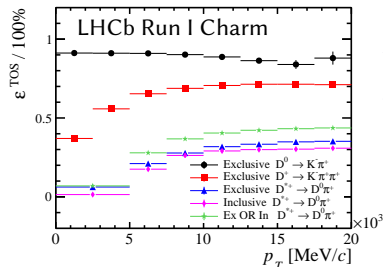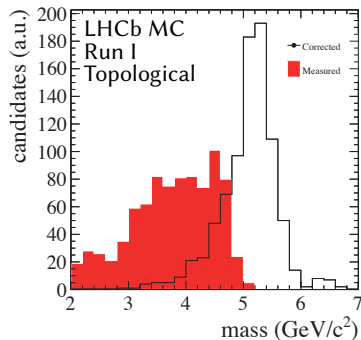
Turbo Stream

- Offline reconstruction available online
  $\rightarrow$ 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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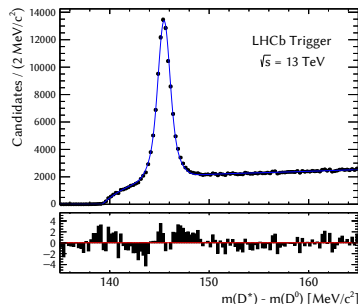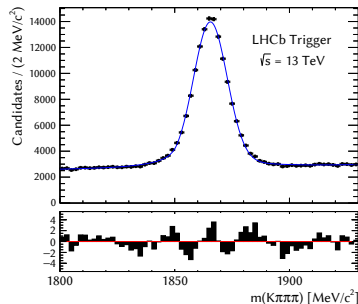
Summary

- 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 $\sqrt{13}$ TeV
  - $c\bar{c}$ cross-sections in pp collisions at $\sqrt{13}$ TeV