LHCb High Level Trigger design issues for post Long Stop 1 running

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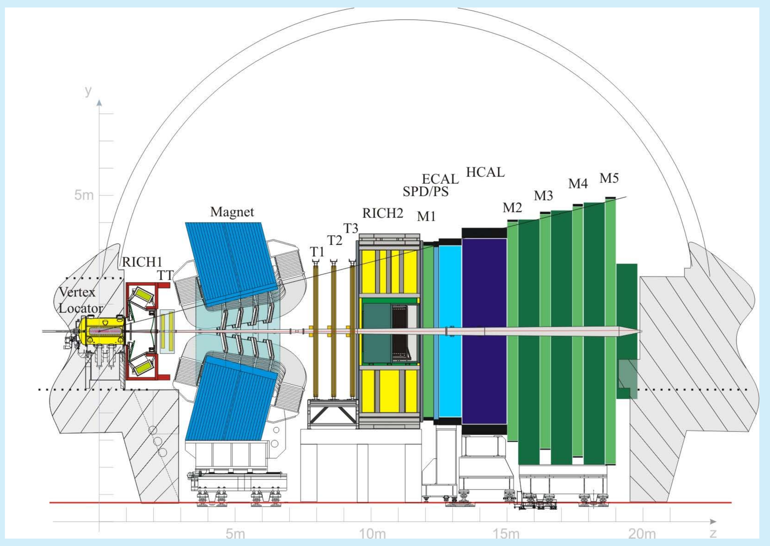
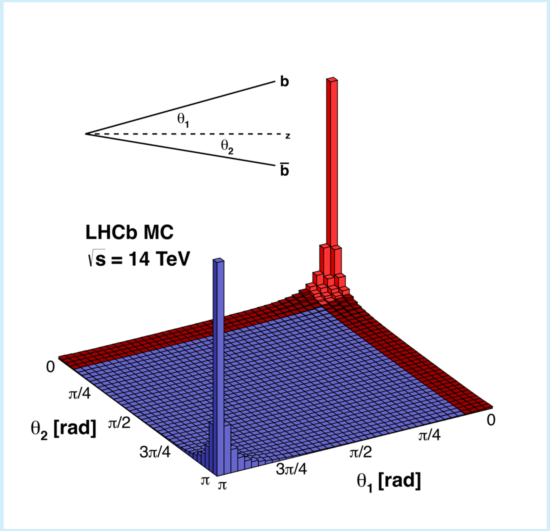
Abstract

- The LHCb High Level Trigger uses two stages of software running on an Event Filter Farm (EFF) to select events for offline reconstruction and analysis.
  - A hardware trigger (L0) reads out ~ 1 MHz of events
  - The first stage of HLT (Hlt1) processes the events accepted by L0.
  - In 2012, the second stage (Hlt2) wrote 5 kHz to permanent storage for later processing.
- For data-taking following the LHC's Long Stop 1 (LS1), we will
  - double the absolute computing power of the EFF,
  - increase the capacity for buffering data for processing between machine fills, and
  - re-optimize our software

  to significantly to increase efficiency for signal while improving signal-to-background ratios.

The LHCb Detector

- Vertex Locator (VELO) provides high precision tracking near the interaction point.
- T-stations provide tracking downstream of the dipole magnet, TT-stations just before (especially important for reconstructing K^0_S and Λ decays).
- Two RICH detectors separate π, K, and p.
- Muon stations identify μ's with high efficiency, already at the trigger level.
- Electromagnetic and hadronic calorimeters used in trigger and to identify $e^{\pm}$ & γ.

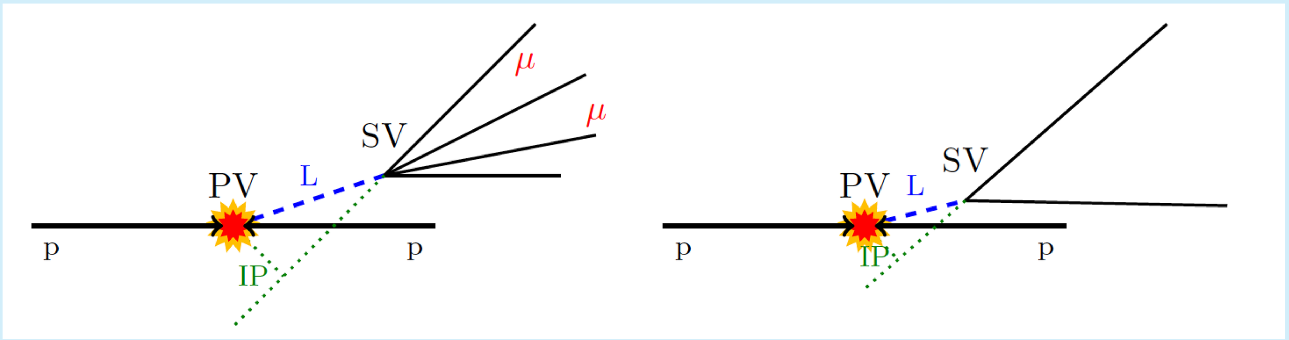
Heavy Flavor Production and Characteristic Properties

b-hadrons

- mass: $m(B^+) = 5.28$ GeV daughter p_T $\mathcal{O}(1\,\text{GeV})$
- lifetime: $\tau(B^+)$ 1.6 ps
- common signature: detached $\mu\mu$ e.g., $B \to J/\psi X$ with $J/\psi \to \mu\mu$

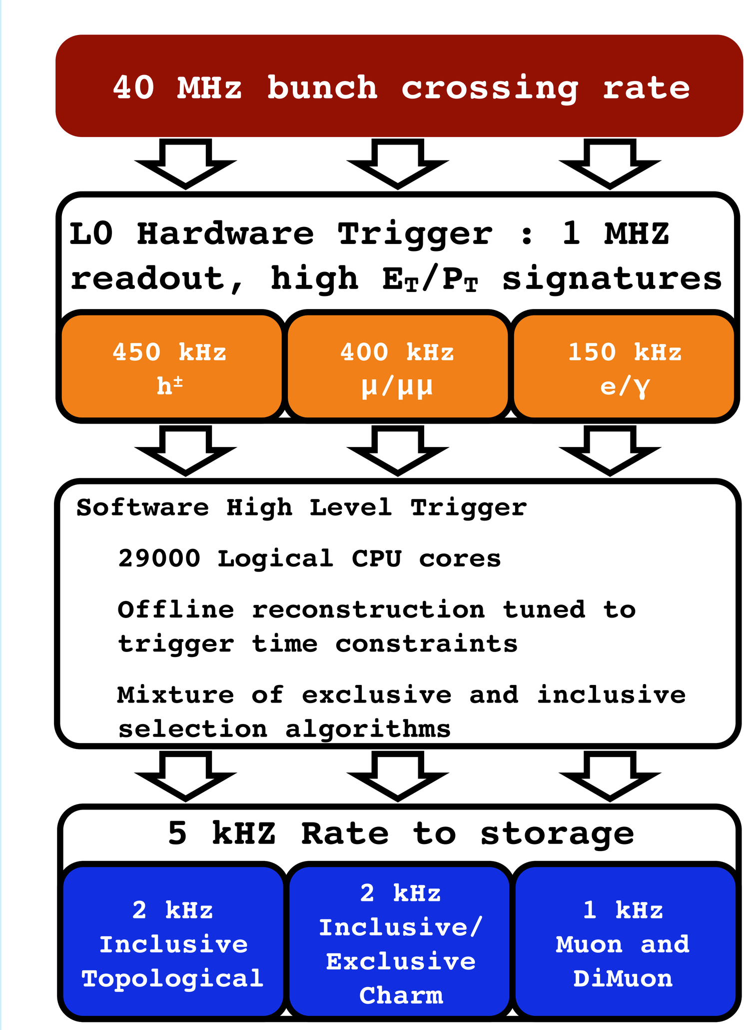
charmed hadrons

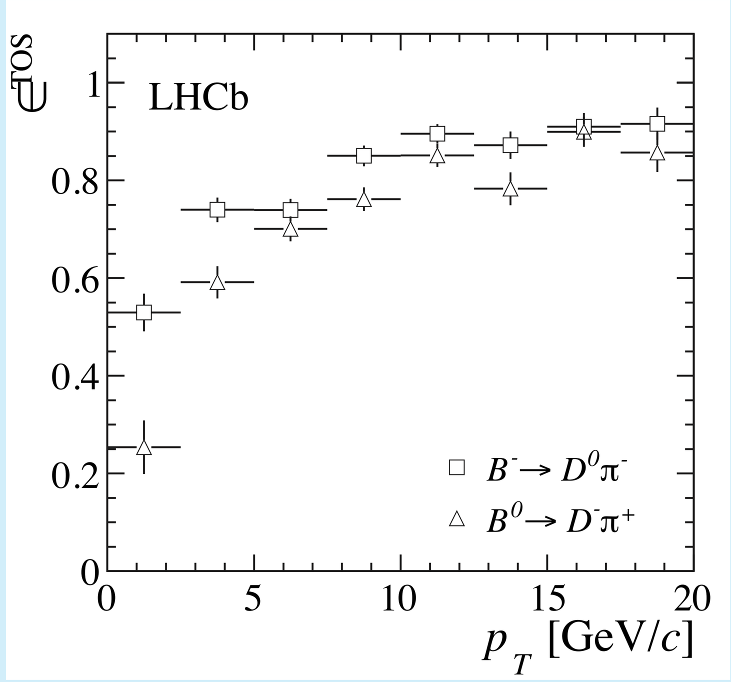
- mass: $m(D^0) = 1.86$ GeV daughter p_T $\mathcal{O}(0.3\,\text{GeV} - 1\,\text{GeV})$
- lifetime: $\tau(D^0)$ 0.4 ps
- secondary charm production from b hadron decay is also common



- Pair production is correlated and predominantly in the forward (backward) direction.
  - $\to$ single arm forward spectrometer, $2 < \eta < 5$
- $\sigma_{b\bar{b}} = (75.3 \pm 14.1)\,\mu$b at $\sqrt{s} = 7$ TeV [Phys. Lett. **B694** (2010)]
  - ~ 0.2% of events contain $b\bar{b}$ in acceptance
- $\sigma_{c\bar{c}} = (1419 \pm 134)\,\mu$b at $\sqrt{s} = 7$ TeV [Nucl. Phys. **B871** (2013)]
  - ~ 4% of events contain $c\bar{c}$ in acceptance
- $\sigma_{b\bar{b}}$ and $\sigma_{c\bar{c}}$ increase linearly as $\sqrt{s}$ increases to 14 TeV. [P. Nason et al, Nucl. Phys. **B327**, 49 (1989)] and [R. Nelson et al., Phys. Rev. **C87**, 014908 (2013)]

2012 Trigger Overview



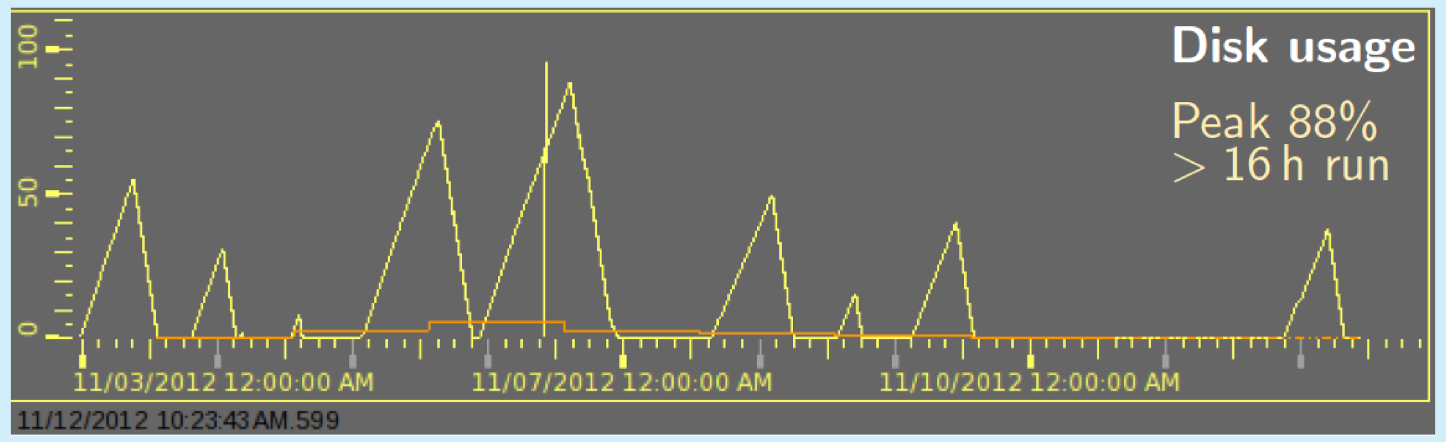


The efficiency of the Hlt2 topological n-body trigger for selected final states when at least one track from the decay satisfies the Hlt1 criteria. [V. V, Gligorov and M. Williams, (20130 JINST 8 P02013]

See R. Aaij et al., (2013) JINST 8 P04022 for a more complete discussion of the LHCb trigger and its performance in 2011. Performance in 2012 was improved:

(i) extended Hlt1 tracking from $p_T > 1.7$ GeV/c to $p_T > 1.6$ GeV/c (for hadrons),
(ii) extended Hlt2 tracking from $p_T > 0.5$ GeV/c to $p_T > 0.3$ GeV/c and added Hlt2 tracking for K^0_S and Λ decays downstream of the VELO,
(iii) deployed "deferred triggering", described below.

2012 Deferred Triggering



$\Rightarrow$ In a nutshell:
- added ~ 1 petabyte of hard disk to the EFF;
- stored 20% of L0 rate on disk;
- processed data stored on disk through Hlt1 and Hlt2 between machine fills.

$\Rightarrow$ overhead ~ 2%; nominal increased capacity 25%; increased throughput ~ 23%.

$\Rightarrow$ allowed more inclusive tracking in both Hlt1 and Hlt2, thus increasing trigger efficiencies, *e.g.*, the exclusive $D^0 \to K^0_S\pi^-\pi^+$ efficiency increased by more than a factor of 3.

Trigger Physics Goals for Post-LS1

$\Rightarrow$ capture as much of the increased heavy quark cross section at $\sqrt{s} = 13$ TeV as allowed by the L0 bandwidth limit;

$\Rightarrow$ increase the absolute efficiency for prompt charm decays by factors of 50% - 200% depending on final state charge multiplicity and lifetime;

$\Rightarrow$ increase efficiencies for B-hadrons and significantly reduce systematics associated with decay time acceptance at the trigger level.

Trigger Implementation Goals for Post-LS1

We plan to significantly increase efficiencies for recording signals while satisfying the limitation that the output bandwidth should be no more than 12 kHz (with 5 kHz designated for prompt offline processing).

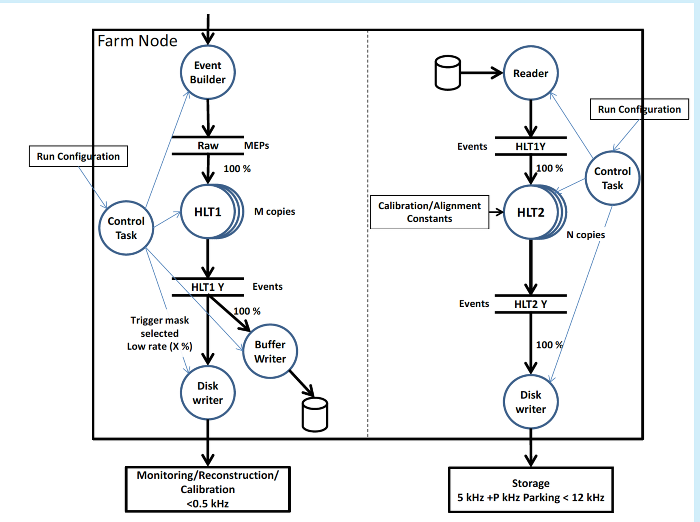
aspirations for improvement

- reduce impact parameter thresholds in Hlt1 from 100μm to 50μm.
- reduce p_T threshold in Hlt1 from 1.6 GeV/c to 0.7 GeV/c.
- use RICH reconstruction in Hlt2 to separate Cabibbo-favored from Cabibbo-suppressed decay modes.

planned upgrades

- re-organize & re-optimize Hlt tracking code;
- double nominal CPU power of EFF;
- increase deferral storage capacity from 1000 TB to 8000 TB;
- split Hlt1 and Hlt2 (described below).

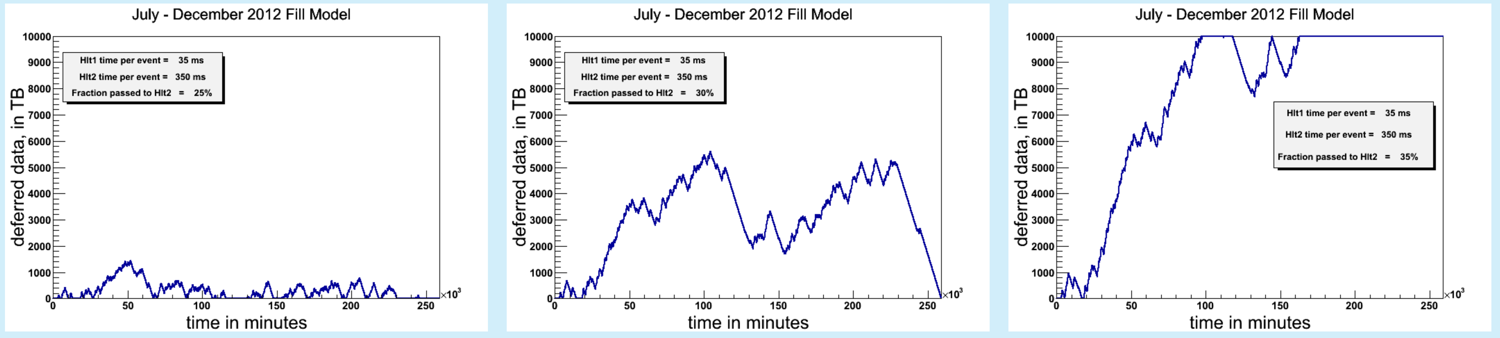
Split HLT Run Configuration



- Hlt1 runs in real time and writes output to hard disk;
- Hlt2 runs asynchronously, after RICH calibrations are prepared;
- Online calibration of RICH required;
- Hlt1 and Hlt2 run on the same nodes to avoid traffic between nodes;
- Reorganize Hlt1 and Hlt2 monitoring;
- New online control of the split HLT is required, see figure.

Some Deferral Model Studies for Post-LS1 Running

$\Rightarrow$ Simulate how much data is deferred to disk as a function of time using the 2012 July - December fill structure as a model. For fixed resources, we can tune three knobs and compare performances:
- time per event in Hlt1; was ~ 15 ms in 2012;
- time per events in Hlt2; was ~ 200 ms in 2012;
- fraction of L0 output passed to Hlt2 by Hlt1; was ~ 8.3% in 2012.



$\Rightarrow$ As illustrated in the plots above, for fixed time per event in Hlt1 and Hlt2 (35 ms and 350 ms, respectively), 8 PB of hard disk provides sufficient storage to process 30% in Hlt2, but not 35%.

$\Rightarrow$ The three knobs are correlated. For example, as the IP and p_T thresholds are relaxed in Hlt1, more processing time is required in Hlt1 and more data is passed to Hlt2. As the timing will depend on event multiplicities, etc., appropriate operating points will be determined once 13 TeV data is available.

Conclusions

We plan to fully exploit the higher heavy flavor cross sections at 13 TeV, increase the absolute efficiency for charm, and reduce systematic uncertainties associated with decay time biases introduced by the HLT.