The LHCb Trigger Architecture

beyond LS1

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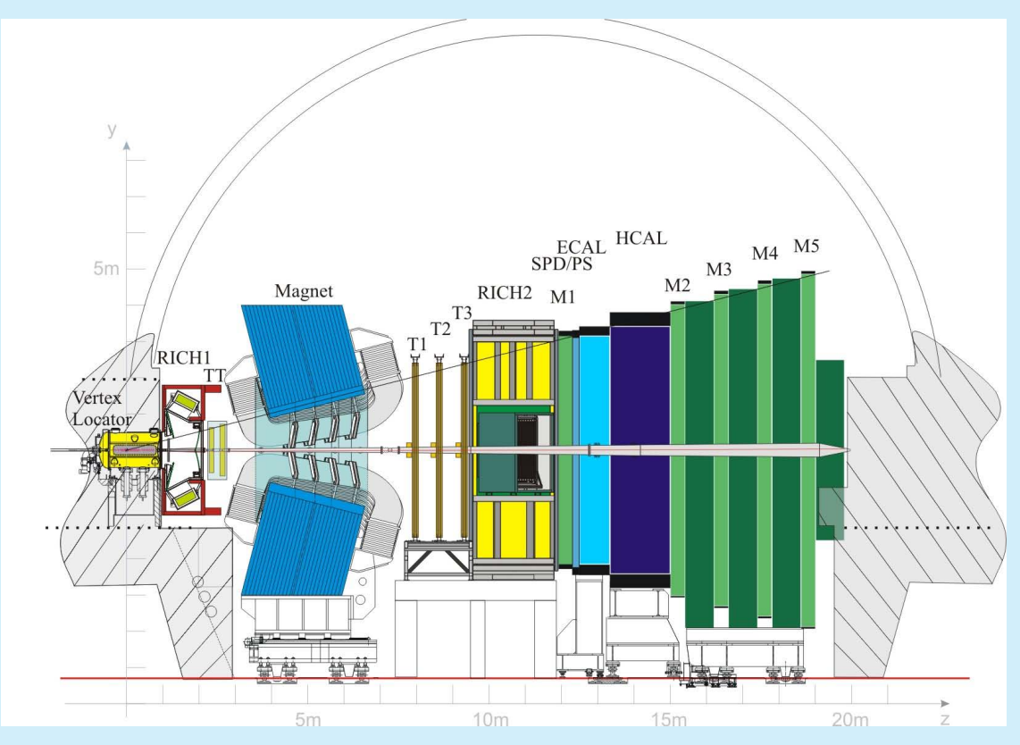
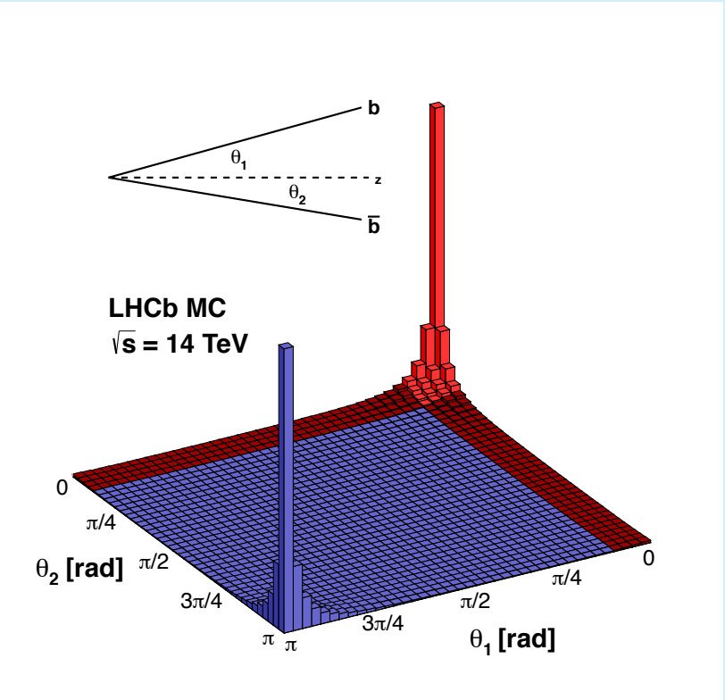
The LHCb Detector





- Single arm forward spectrometer $1.6 < \eta < 4.9$
- 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_S^0 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.

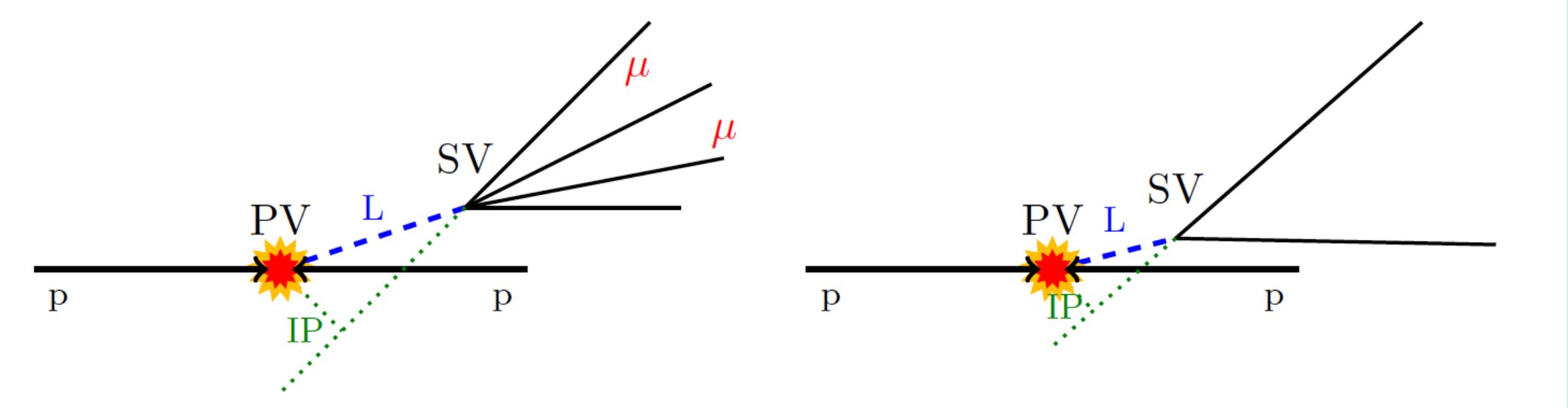
Characteristics of Heavy Flavor Production @ LHC

Beauty 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 $\mathcal{O}(0.3 \cdots 1\,\text{GeV})$
- 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.
  - $\rightarrow$ single arm forward spectrometer,
- $\sigma_{b\bar{b}} = (75.3 \pm 14.1)\,\mu$b at $\sqrt{s} = 7$ TeV [Phys. Lett. **B694** (2010)]
  - $\sim$ 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)]
  - $\sim$ 4% of events contain $c\bar{c}$ in acceptance

Increasing heavy flavor rates after LS1

- $\sigma_{b\bar{b}}$ 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)]
- Fraction of events containing heavy-flavor will increase

Basic Trigger Strategy

Hardware Level 0 Trigger

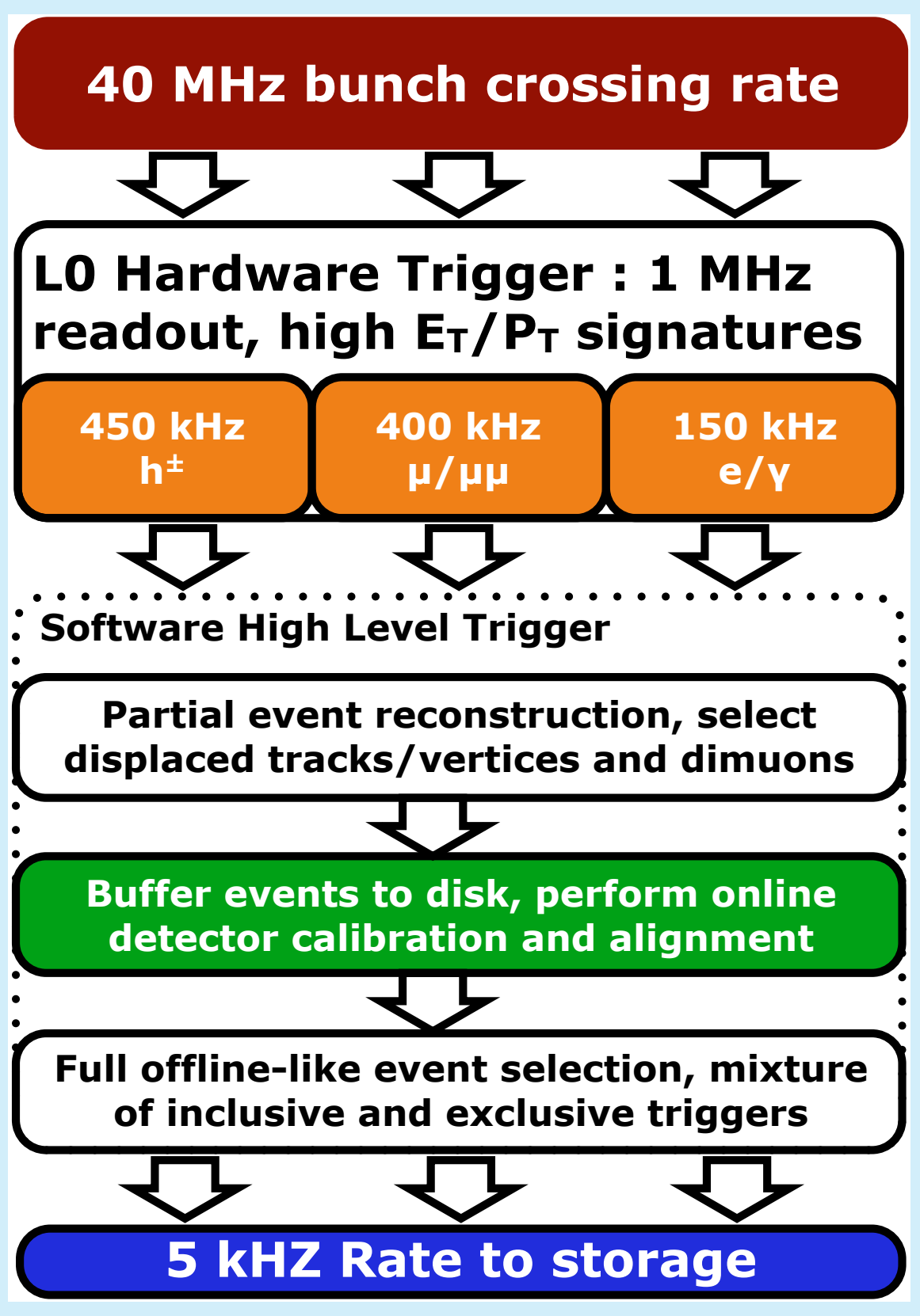
- High $E_T(p_T)$ signatures

2-Stage Software Trigger

- **Hlt1 - Partial Event Reconstruction**
  - Displaced tracks/vertices
  - Dimuons
  - 38 trigger lines (= selection algorithms)
- **Hlt2 - Full Event Reconstruction**
  - Offline-like event selection
  - Reconstruction of intermediate particles Mass cuts, kinematic variables, partial PID
  - Usage of multivariate techniques
  - Inclusive and exclusive selections
  - 131 trigger lines

High Level Trigger Evolution

2015 and beyond: Split HLT Run Configuration



40 MHz bunch crossing rate

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

450 kHz $h^\pm$ | **400 kHz** $\mu/\mu\mu$ | **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

5 kHZ Rate to storage

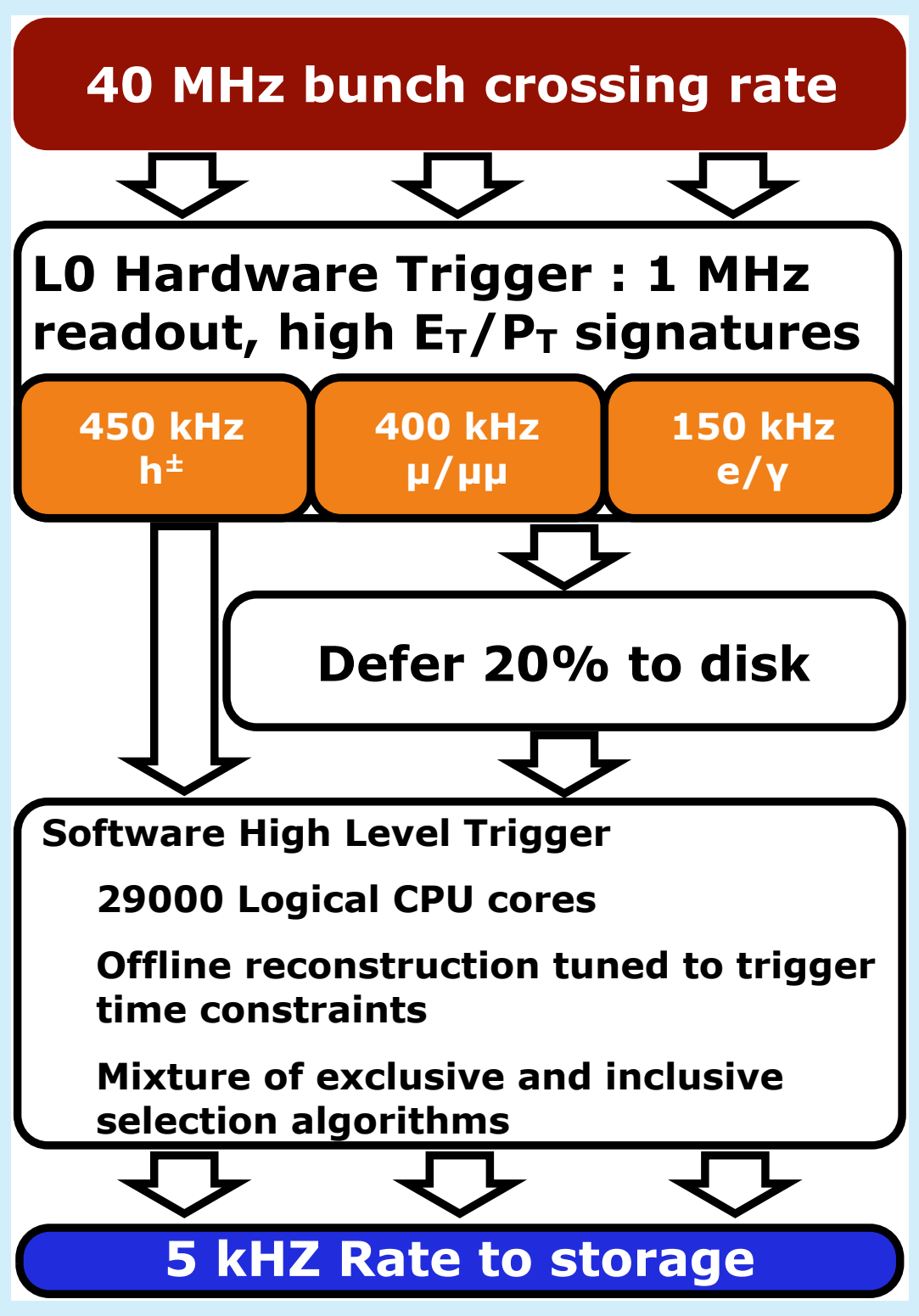
Split High Level Trigger

- Hlt1 runs in real time and writes output to hard disk;
- Hlt2 runs asynchronously, after RICH calibrations are prepared;

- output bandwidth 12 kHz (at least 5 kHz for prompt offline processing).
- Online calibration of RICH required;
- Hlt1 and Hlt2 run on the same nodes to avoid traffic between nodes;
- Reorganize Hlt1 and Hlt2 monitorring;
- New online control of the split HLT is required

Reduce systematic biases

2012 Deferred Triggering



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Defer 20% to disk

Software High Level Trigger

29000 Logical CPU cores

Offline reconstruction tuned to trigger time constraints

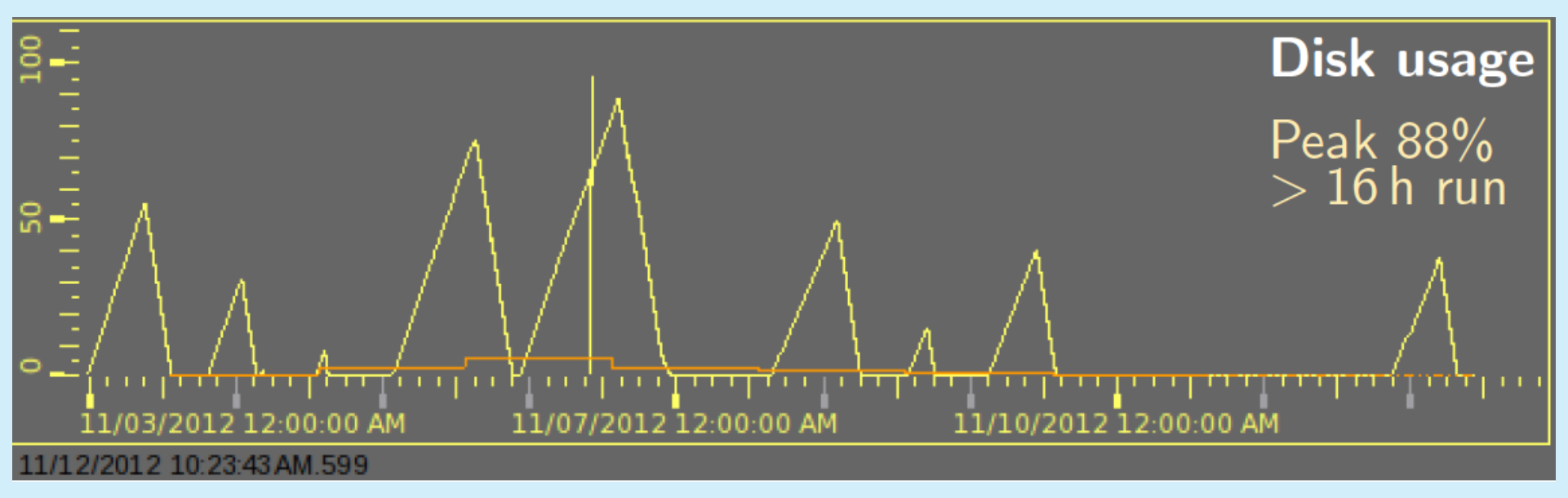
Mixture of exclusive and inclusive selection algorithms

5 kHZ Rate to storage

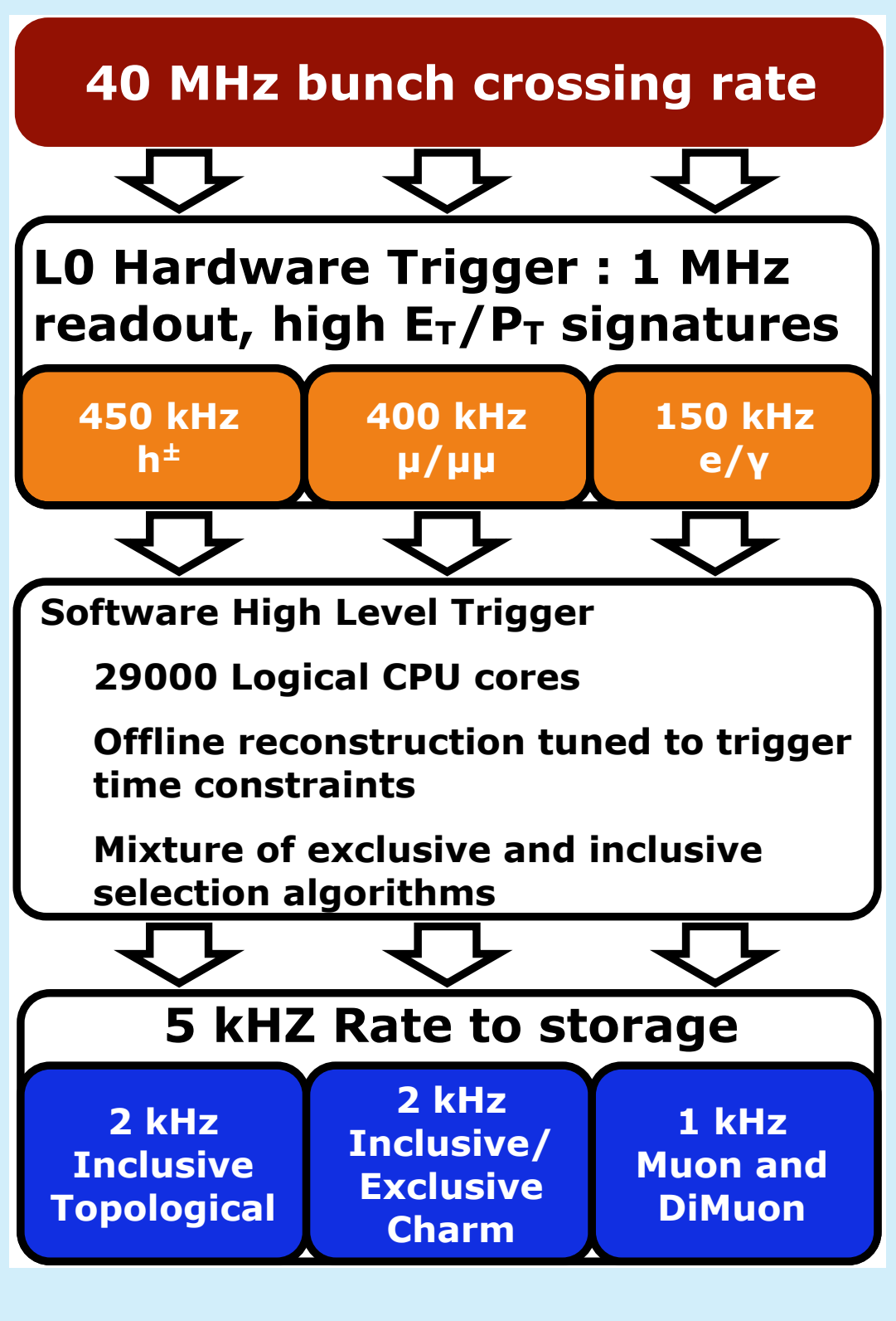
⇒ **In a nutshell:**
  - added $\sim$ 1 petabyte of hard disk to the EFF;
  - stored 20% of L0 rate on disk;
  - processed data stored on disk through Hlt1 and Hlt2 between machine fills.

⇒ overhead $\sim$ 2%; nominal increased capacity 25%; increased throughput $\sim$ 23%.

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



2011/12 Trigger Architecture



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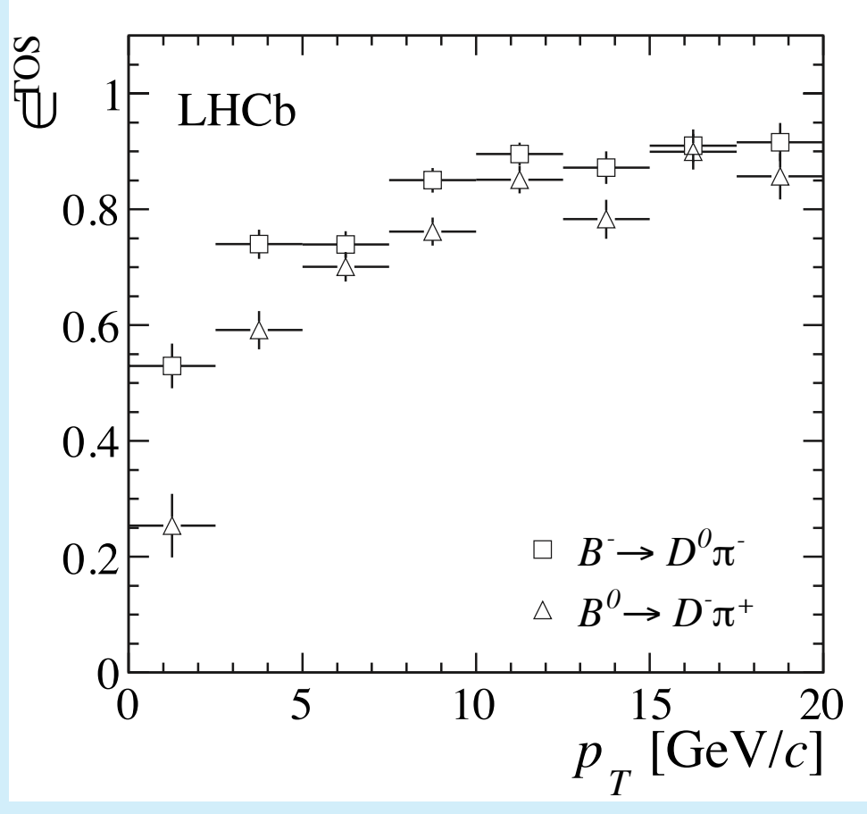
5 kHZ Rate to storage

2 kHz Inclusive Topological | **2 kHz Inclusive/ Exclusive Charm** | **1 kHz Muon and DiMuon**



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, (2013) JINST 8 P02013 and R. Aaij et al., (2013) JINST 8 P04022

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_S^0 and Λ decays downstream of the VELO,

(iii) deployed "deferred triggering"

Improve selectivity

Goals for the LHCb Trigger @ $\sqrt{s} = 14$TeV

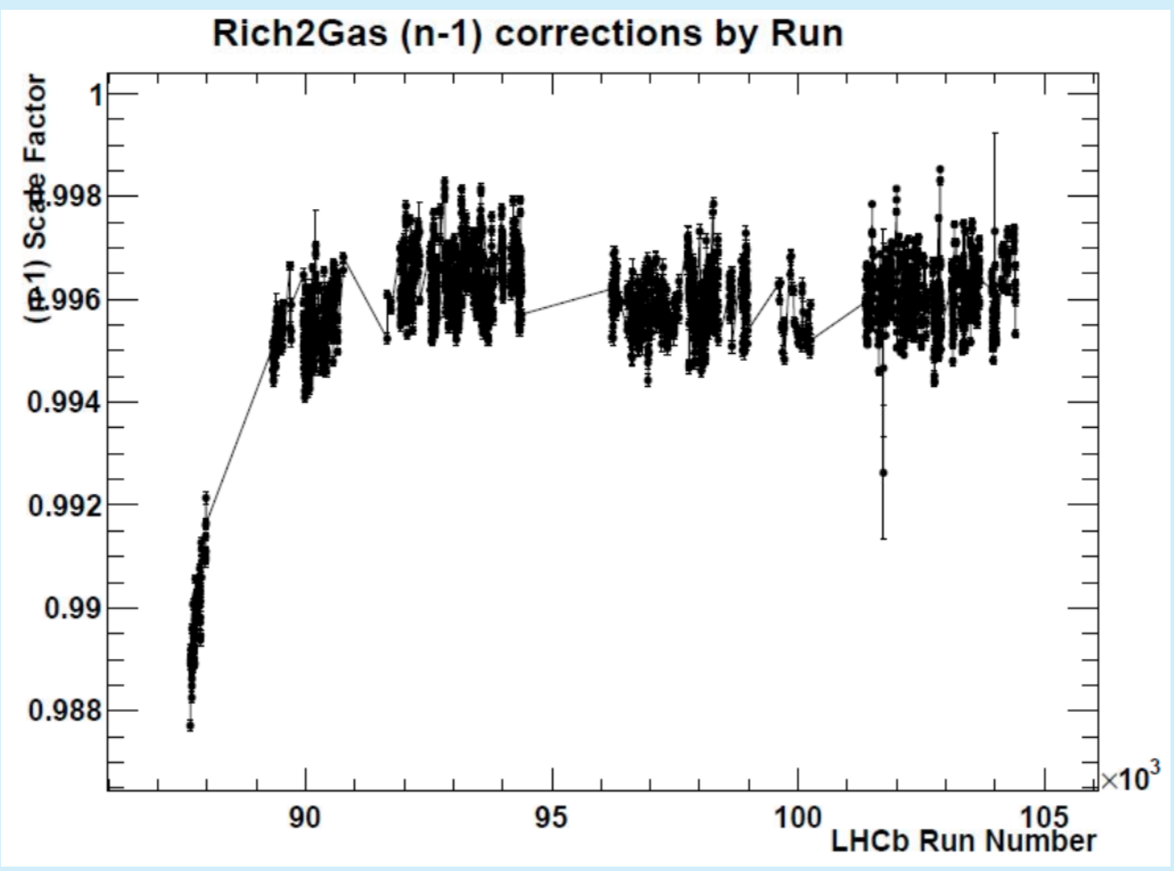
⇒ **Increase efficiency for prompt charm decays** by factors of 50% - 200% depending on final state charge multiplicity and lifetime;

⇒ **Separate Cabibbo-favored from Cabibbo-suppressed** decay modes using RICH reconstruction in Hlt2 ↔ needs online calibration;

⇒ **Reduce systematics on decay time acceptance** increase efficiencies for B-hadrons

Towards Analysis-Quality Online Reconstruction

Split HLT architecture will enable the application of **offline-quality calibrations / alignment** in the software trigger



Example: RICH calibration constants vary with time ⇒ need online calibrations.

Reducing biases

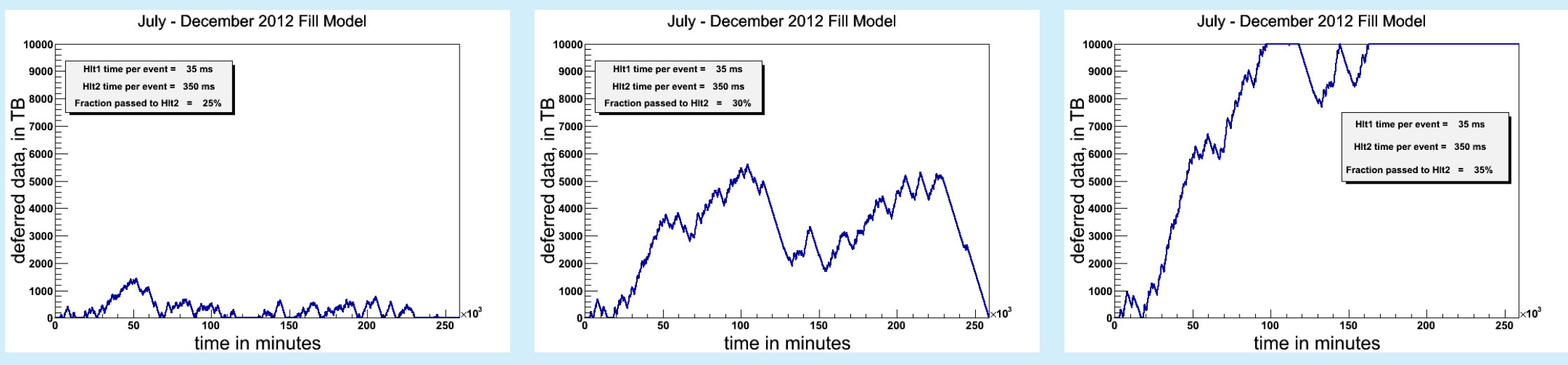
- reduce impact parameter thresholds in Hlt1 from 100μm to 50μm.
- reduce p_T threshold in Hlt1 from 1.6 GeV/c to 0.7 GeV/c.

Planned upgrades

- re-organize & re-optimize Hlt tracking code;
- double nominal CPU power of the Event Filter Farm;
- increase deferral storage capacity from 1000 TB to 8000 TB;
- split Hlt1 and Hlt2

How much disk-space will be needed?

⇒ Simulate how much data is deferred to disk as a function of time 2012 July - December fill structure model Assuming doubled CPU power



⇒ 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%.

⇒ Final tuning will be determined once 13 TeV data is available.

The HLT Software Architecture

Framework

- Based on the **GAUDI** event processing framework
- Running the same code (tools, algorithms and services) as the offline software
- Core written in C++, configuration in Python

How to manage trigger conditions?

- HLT is organized into selection sequences, called *trigger lines*
- 38 HLT1 lines, 131 HLT2 lines
- **Trigger Configuration Key (TCK)**
  - Defines **structure and parameters** of the filter algorithms
  - 32 bit label for configuration
  - 128bit configuration ID by hashing configuration code
  - Is stored with each event
- **Checkpointing** (reduce configuration time)
  - Store snapshot of configured application using MTCP
  - Distribute compressed snapshot over the farm
  - Fast run configuration change possible if only parameters have changed in TCK and structure remains invariant

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