The LHCb Trigger System: Present and Future

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On behalf of the LHCb-HLT Project

5. December 2014

technische universität dortmund

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft
DFG

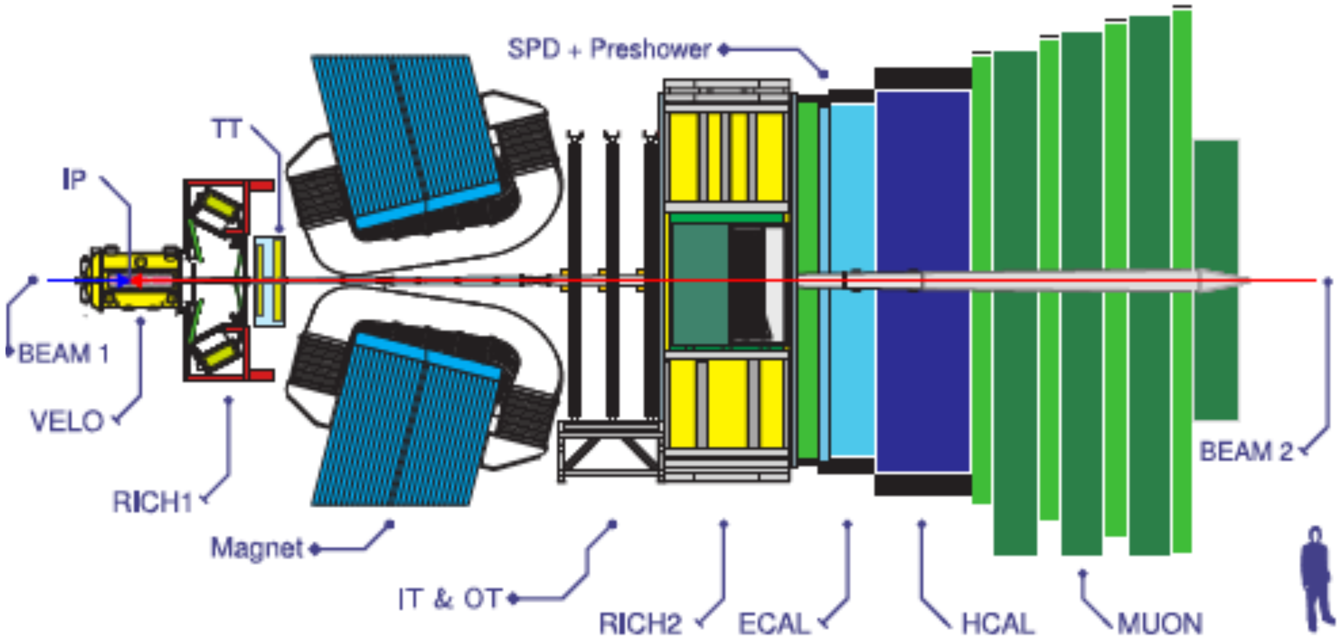
Experimentelle Physik V
Teilchenphysik

Overview

- What is LHCb?
  - Detector design & geometry, physics, performance
- How do we trigger in the LHC environment
  - **In the recent past (Run 1, 2010 – 2012)**
    - Very successful running & triggering, >200 papers produced
  - **In the near future (Run 2, 2015 – 2018)**
    - Identical LHCb detector
    - Increased beam energy 7/8TeV → 13TeV
    - Similar luminosity as in Run 1
  - **In the longer future, called upgrade (Run 3, 2020++)**
    - Largely rebuilt & upgraded detector
    - Increase instantaneous luminosity by factor 5

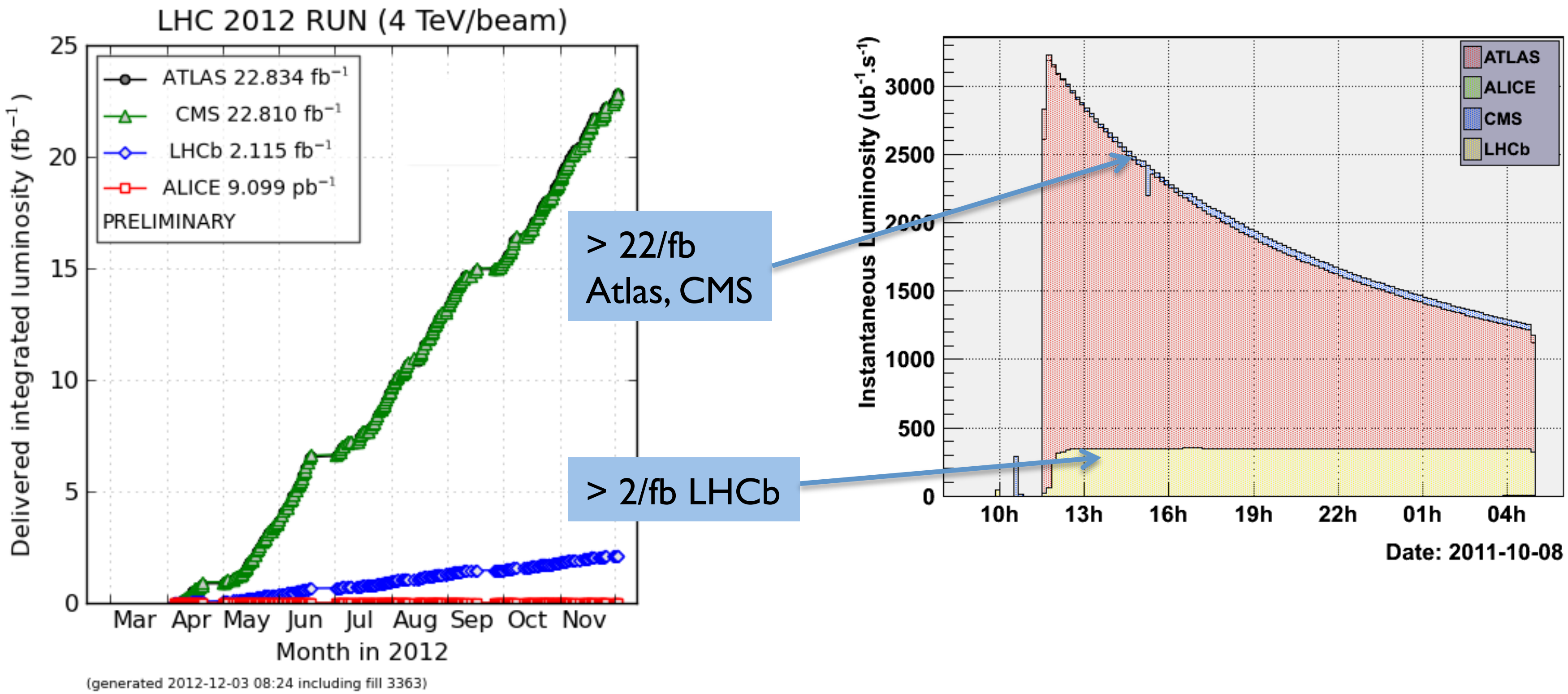
The LHCb Experiment

- LHCb: single arm spectrometer at the LHC
  - Precision beauty and charm physics
  - **L= 4 * $10^{32}cm^{-2}s^{-1}$** (2* design), **μ~1.7** interactions per bunch crossing



- Extremely large σ_{bb} and σ_{cc} in LHC hadron collisions at 8TeV
  - corresponds to **30kHz $b\bar{b}$ and 600kHz $c\bar{c}$** in acceptance
- Trigger system classifies signal to large extend

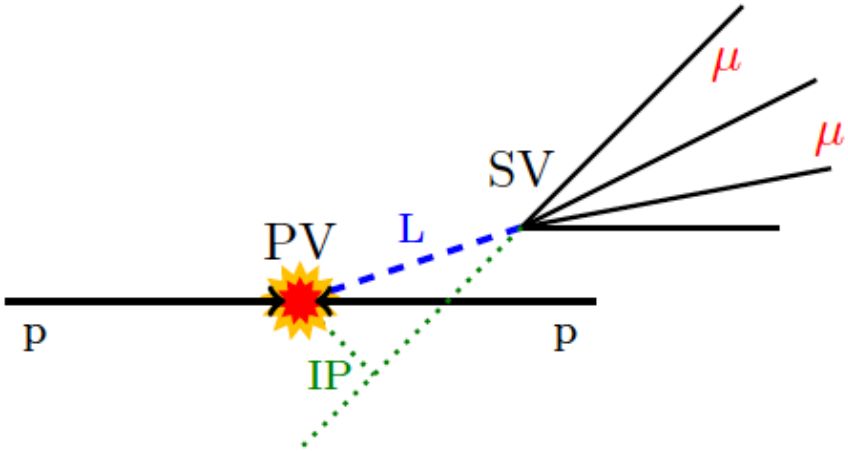
Luminosity



- Luminosity levelling: stable running and trigger conditions for LHCb even with LHC running at high luminosity ($L_{LHCb} = 4 \times 10^{32} cm^{-2} s^{-1}$)
- Plans for 2015
  - $\sqrt{s}$ = 13 TeV (HF cross section x2)
  - Bunch spacing 25ns (smaller pileup)
  - LHCb: ~same luminosity

Heavy Flavour Signatures

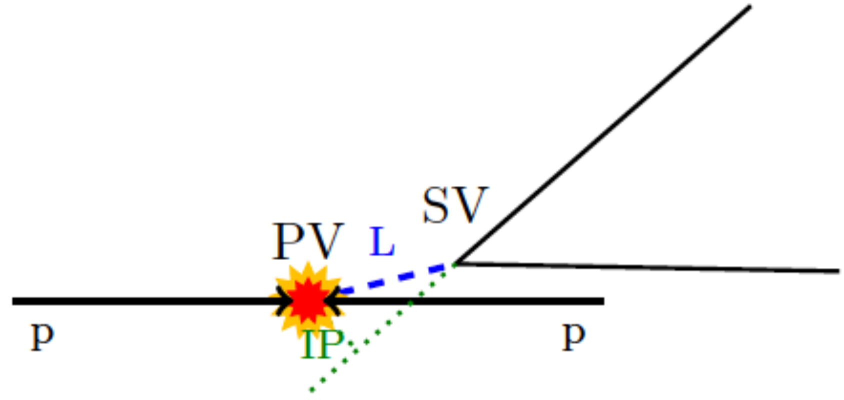
Beauty hadrons



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

30kHz

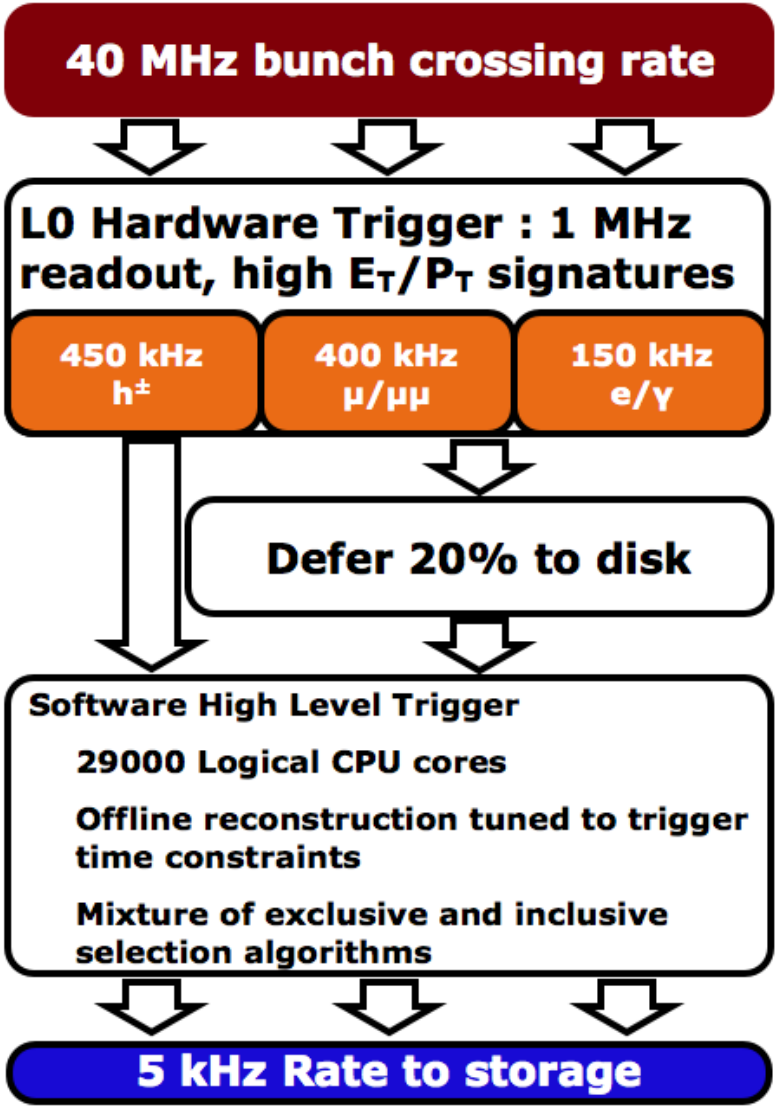
Charmed hadrons



- mass $m(D^0) = 1.86\,\mathrm{GeV}$
  sizeable daughter p_T
- lifetime $\tau(D^0) \sim 0.4\,\mathrm{ps}$
  flight distance $\sim 4\,\mathrm{mm}$
- can be produced in B decays

600kHz

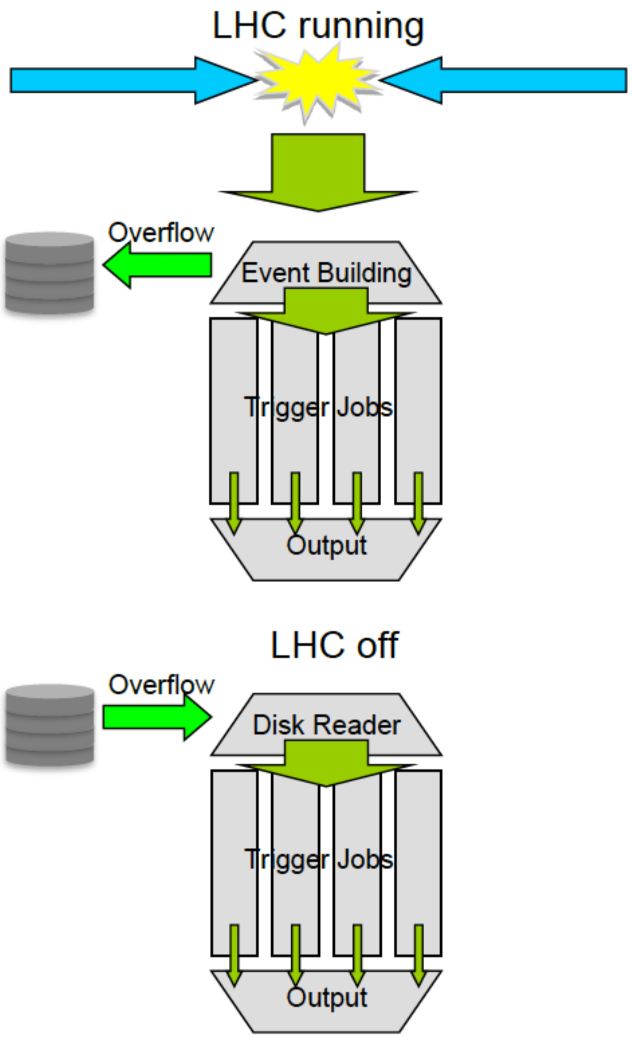
LHCb Trigger Scheme



- L0 hardware:
  - Implemented in custom made hardware
  - Decision to front-end in 4μs
- HLT software
  - 29000 logical cores
  - Split in two levels:
    - Partial reconstruction (HLT1)
    - Full up front reconstruction (HLT2)
  - 5 kHz to storage (2kHz incl. B, 2 kHz charm, 1kHz muons)

JINST 8 (2013) P04022
JoP 513 (2014) 012001

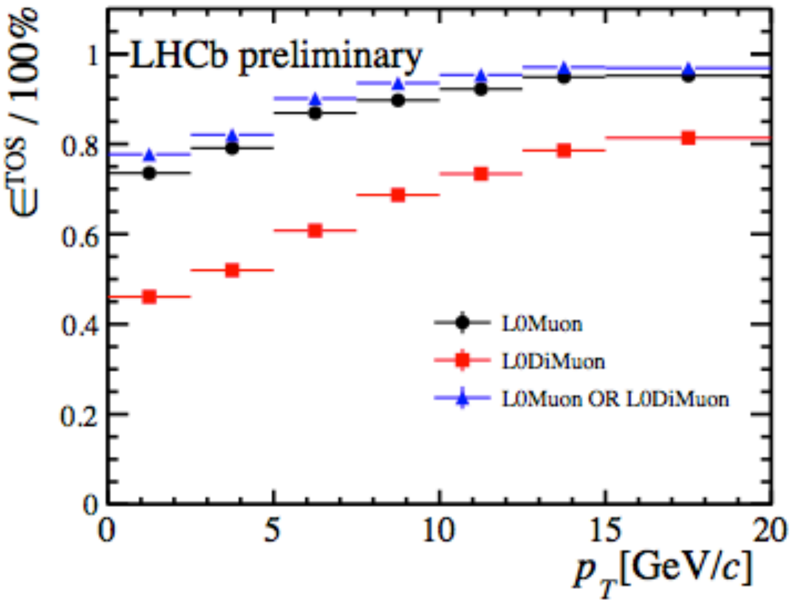
Optimize CPU/€: Deferred Triggering



- LHC delivers ~30% of the time stable beams
  → **70% idle time for EFF**
- Principle:
  - >1000 machines equipped with 1-2TB local discs
  - Overcommit Farm by ~20-30%
  - Data that cannot be processed by the HLT is written to local disc
  - Process data in interfill gaps
- **Effectively > 25% extra CPU**

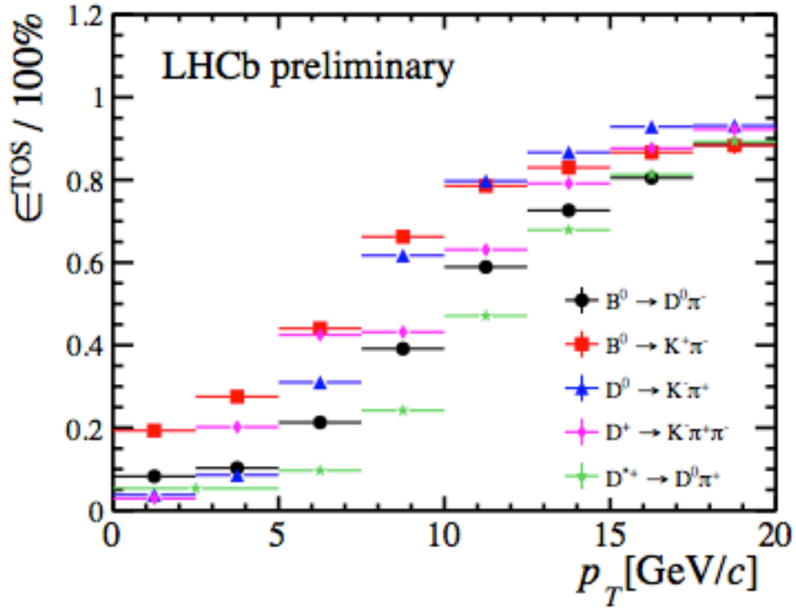
L0 hardware trigger performance

- Muon based



- Very little punch-through and hadronic mis-ID
- Excellent overall performance
  - Efficiency ~ 60 – 95%
  - Output rate ~400kHz

- Calorimeter based



- Large light quark (QCD) background, high rates and relatively low E_T resolution
- Performance
  - Efficiencies ~ 20 – 50%
  - Output rate ~500kHz hadron, 150kHz $e^{\pm}$,γ

HLT first step: Inclusive triggers

Run 1

- Full detector is read out at 1MHz
- At HLT1 level, only partial reconstruction done
- Inclusive selections
  - Dedicated generic b & c selection
  - Special path for muons
  - Few other special triggers
- Output rate ~80kHz

Reconstruction sequence

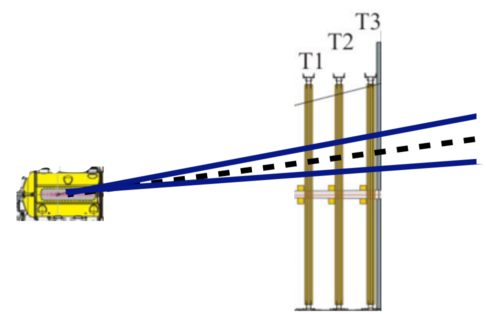
Full reconstruction of tracks in vertex locator

⇓

Select displaced tracks

⇓

Reconstruction of displaced tracks in regions of interest

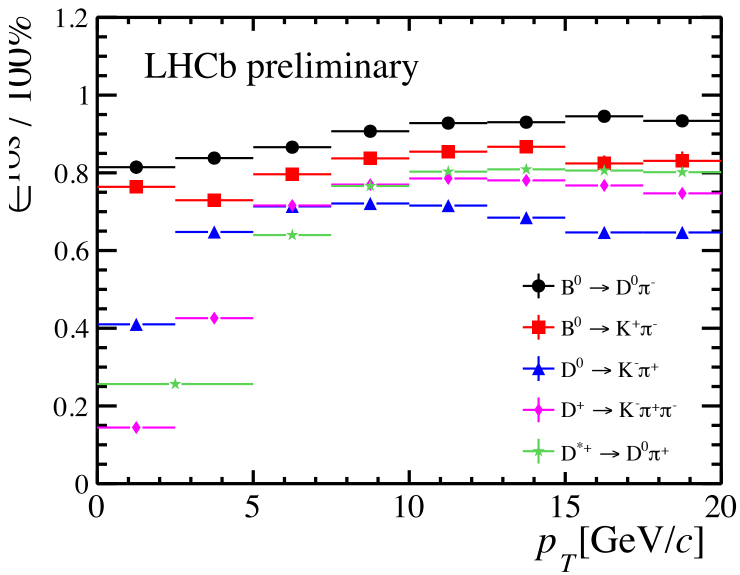


Region of interest defined by assumed track PT (1.6GeV)

HLT1 inclusive triggers: Performance

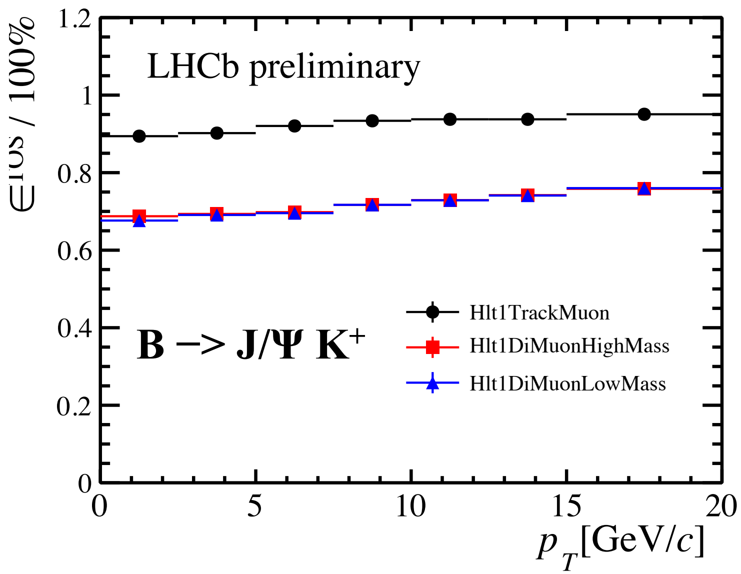
Inclusive beauty and charm trigger

- Single track, selected on PT and IP
- Dominant trigger for non-leptonic modes
- Output rate ~58kHz



Inclusive muon

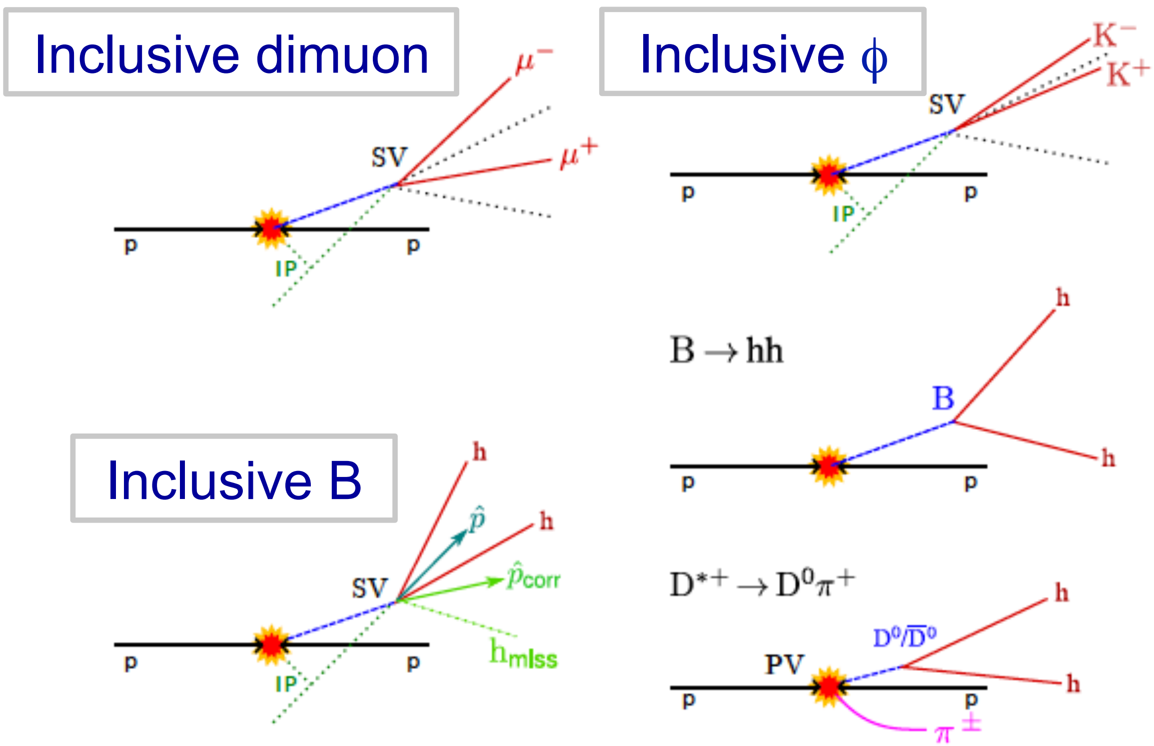
- Single and dimuon selections
- Requirements on PT, IP or dimuon mass
- Total output rate ~14kHz



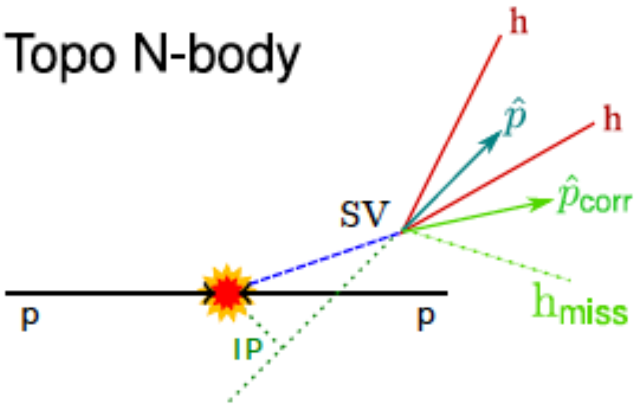
HLT second step: full reconstruction

Run 1

- At HLT2 level, the event is fully reconstructed
  - Reconstruction performance close to offline (p_T>0.3GeV)
  - Extremely powerful, flexible software environment:
    heavy use of MVA-based selections, staged reconstruction (PID)
  - Combination of inclusive and exclusive selections, e.g.:

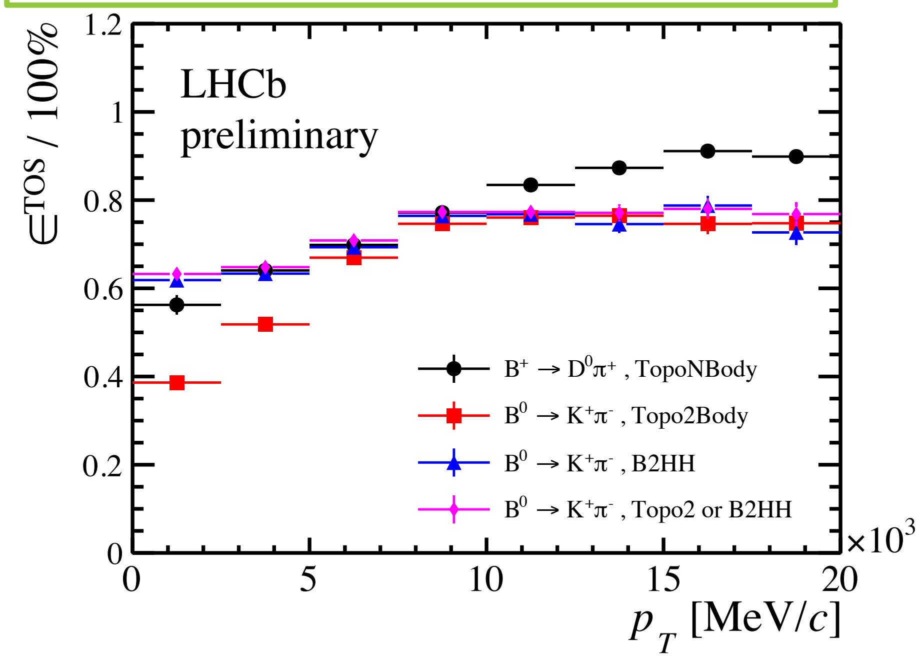


HLT2: Inclusive Beauty trigger



- Inclusive trigger on 2,3,4-body detached vertices
- Primary trigger for B decays to charged tracks
- Uses fast BDT algorithm [JINST 8 (2013) P02013]

HLT2 inclusive B trigger efficiency



- Output rate: 2kHz (pure beauty signal)
- Efficiencies

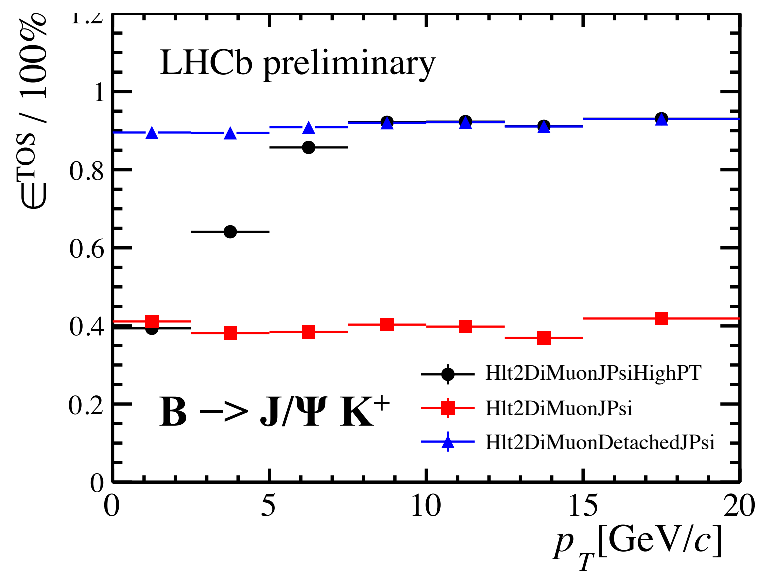
	Average ε
$B^0 \to K^+\pi^-$	78%
$B^0 \to D^+\pi^-$	76%

HLT2: dimuon and charm triggers

Run 1

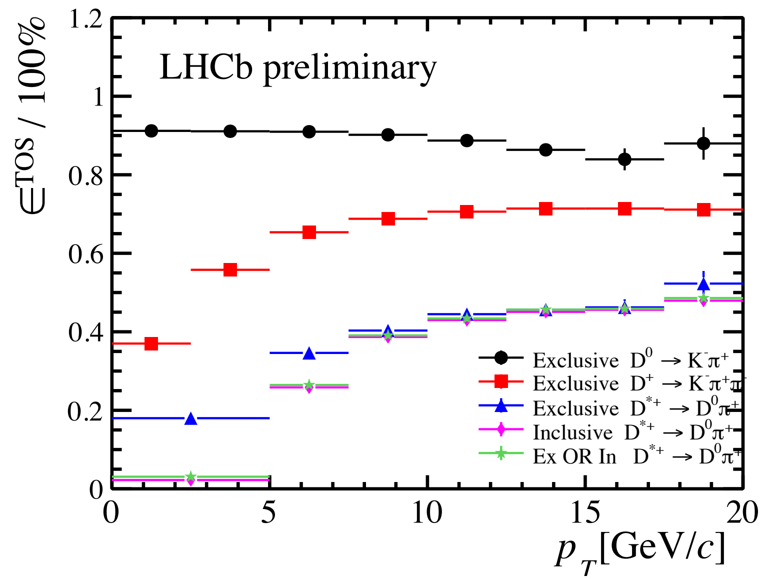
Inclusive dimuon

- Prompt and detached dimuon lines
- Muon ID identical to offline
- Total output rate ~1kHz



Exclusive charm

- Based on tight mass cuts
- Only $D^* \rightarrow D^0\pi$ selected inclusively
- Total charm output rate ~2kHz



Run 2 (2015)

Running conditions in Run 2

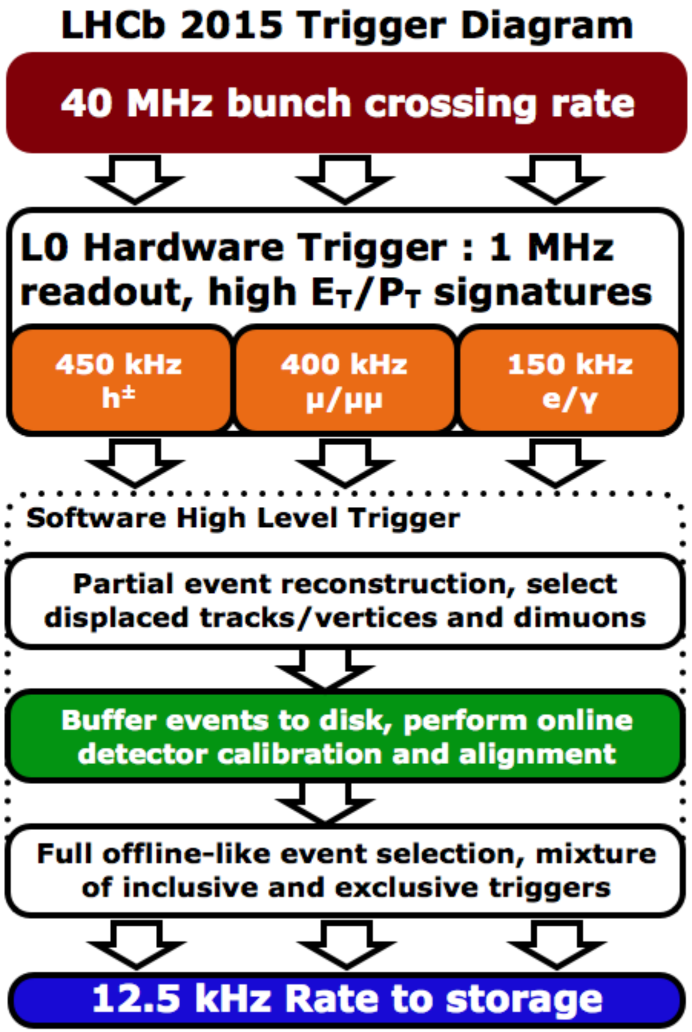
- Running at 13TeV
  - 15% increase of inelastic collision rate
  - 20% increase of multiplicity per collision
  - 60% increase of σ_{bb}

- LHCb baseline: keep luminosity in 2015 at 4 * 10^{32} $cm^{-2}s^{-1}$

- Bunch spacing will be reduced to 25ns
  - Number of visible collision reduced: 1.7 → 1.1

- **Slightly simpler events than in 2012, but with more physics content**

Run 2 trigger strategy

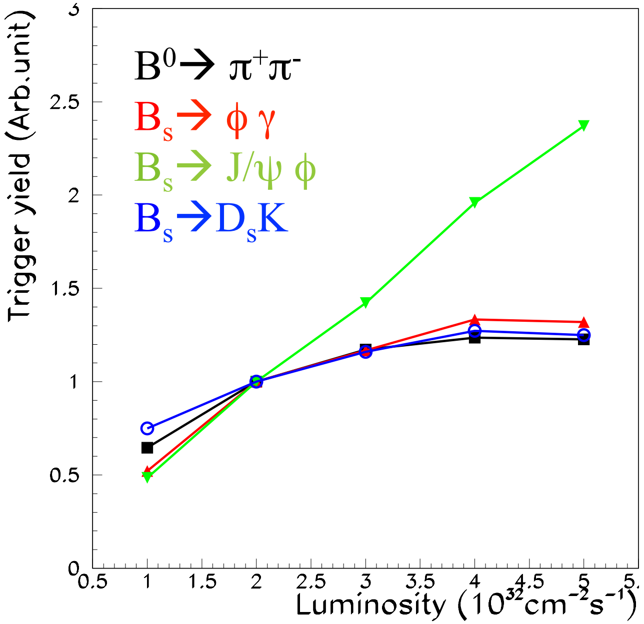


- More signal
  → more selective trigger
  → make trigger more compatible with offline
- Requirements
  – Alignment and detector calibration in real time
  – Offline like RICH PID
- Strategy
  – Event buffering after HLT1 and used to run calibration
  – Full offline-like selection in HLT2
- Additional ressources
  – CPU in Event Filter Farm doubled
  – Buffer storage: 1PB -> 4PB

Run 3 (2020)

Why upgrade LHCb?

Detailed discussion of the upgrade by R. Jacobsson (Tuesday)

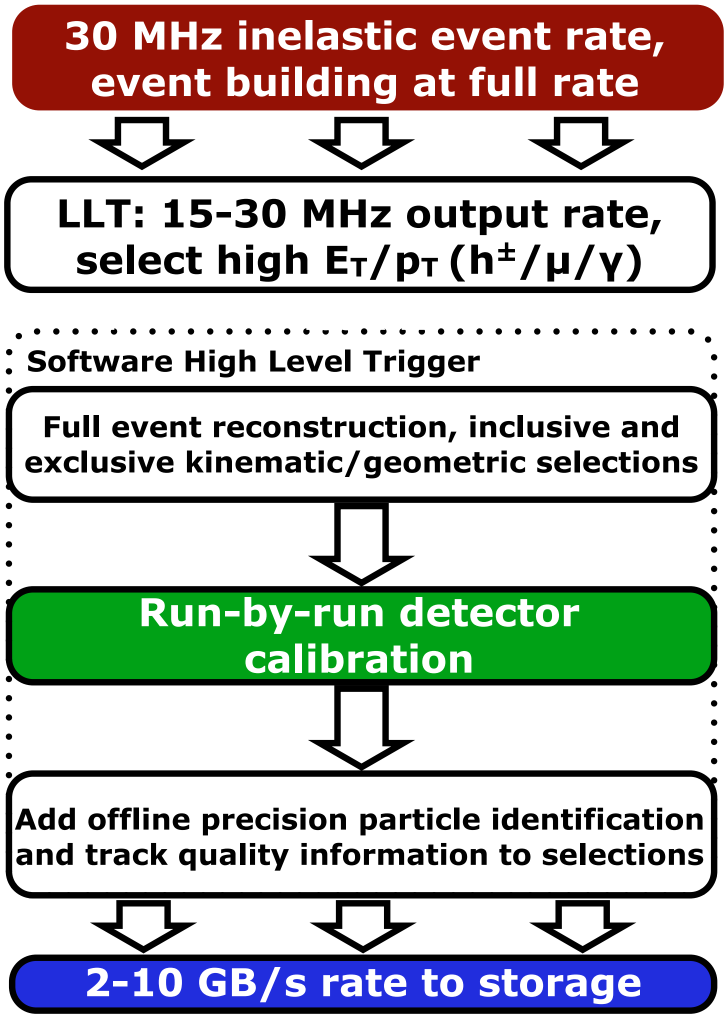


- Key point: remove 1MHz detector readout bottleneck
  - Upgrade detector and DAQ to readout at 40MHz
  - Full software trigger building on architecture for LHC run II
- **Large gains for hadronic triggers**
  (and keep excellent muonic triggers)

Run 3 trigger strategy

CERN-LHCC-2014-016
LHCB-TDR-016

Full detector readout at 30MHz + fully software based trigger



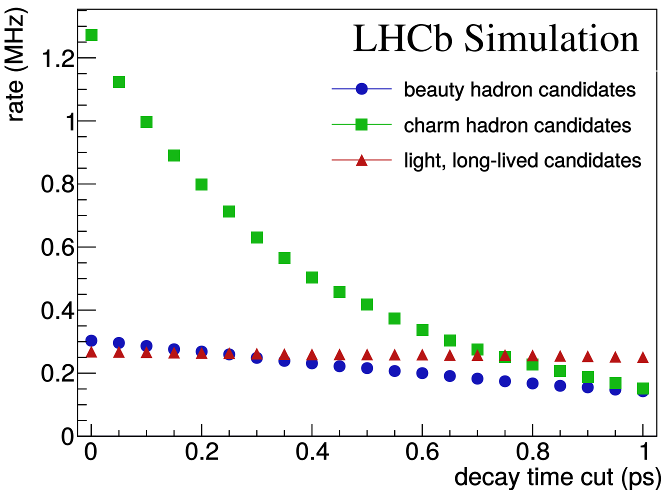
- Software based Low Level Trigger (LLT) kept as backup
  - Uses limited information from muon / CALO
  - Can reduce HLT input rate by a factor 2
  - Not planned to be used in default scenario
- Event Filter Farm
  - O(1000) nodes
    → 13ms on todays CPU
  - Total output rate 20 – 100kHz

Upgrade signal rates

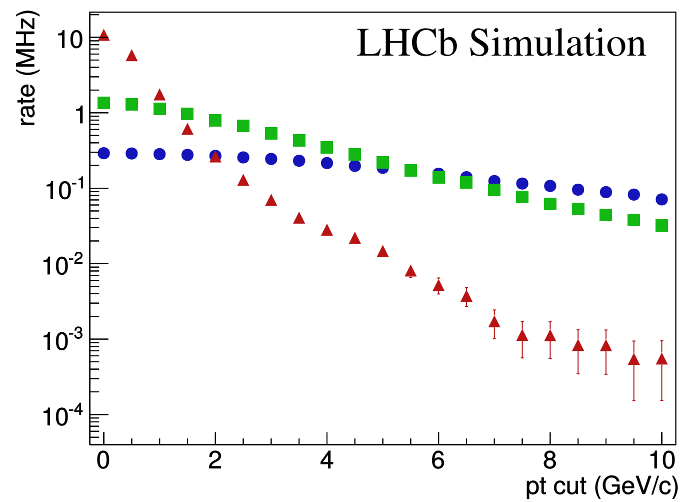
LHCb-PUB-2014-027

- Upgrade conditions inside LHCb acceptance

Rates as a function of decay time cut for part. reco. candidates



Rates as a function of pT cut for part. reco. candidates



- Output rate (PT>2GeV, τ > 0.2ps)

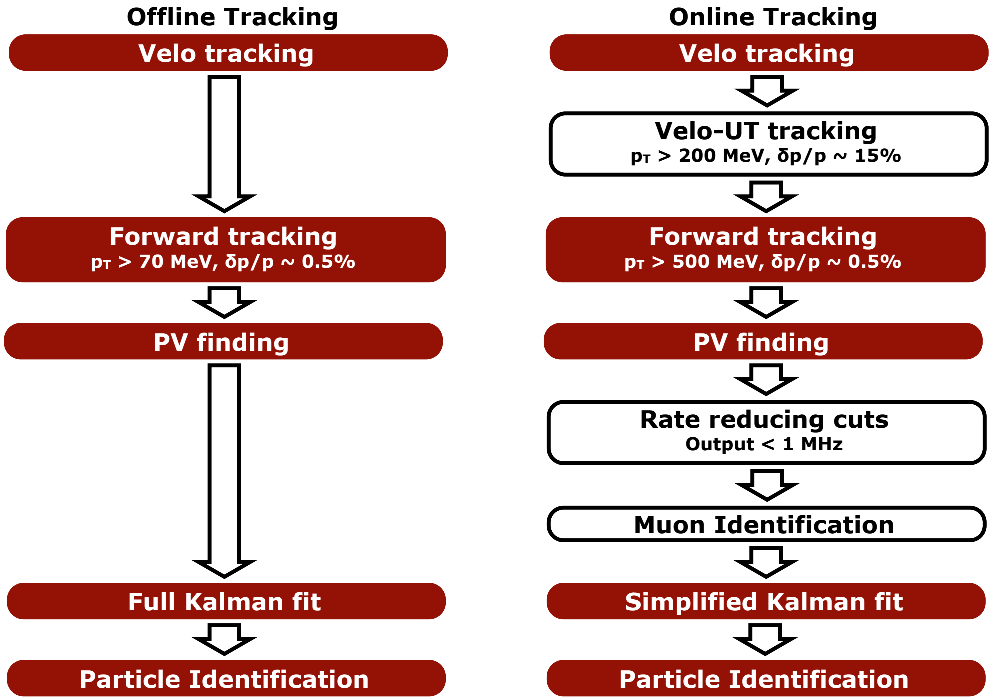
[kHz]	b-hadrons	c-hadrons	long lived hadrons
Run 1	9	33	11
Run 3	270	800	260

- Major challenge: discriminate between different signals
→ trigger must be maximally flexible and close to offline

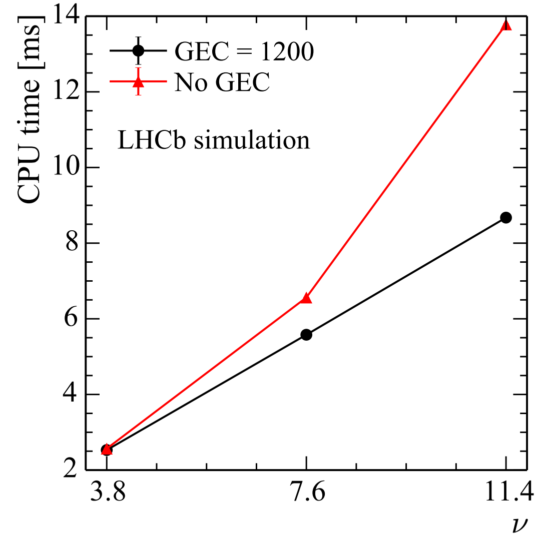
Run 3 tracking

Run 3

- Main challenge: tracking similar to offline in online time budget
  - Reconstruct all tracks without prior cuts at 30MHz



Timing for
1,2 and 4 x 10^{33} $cm^{-2}s^{-1}$



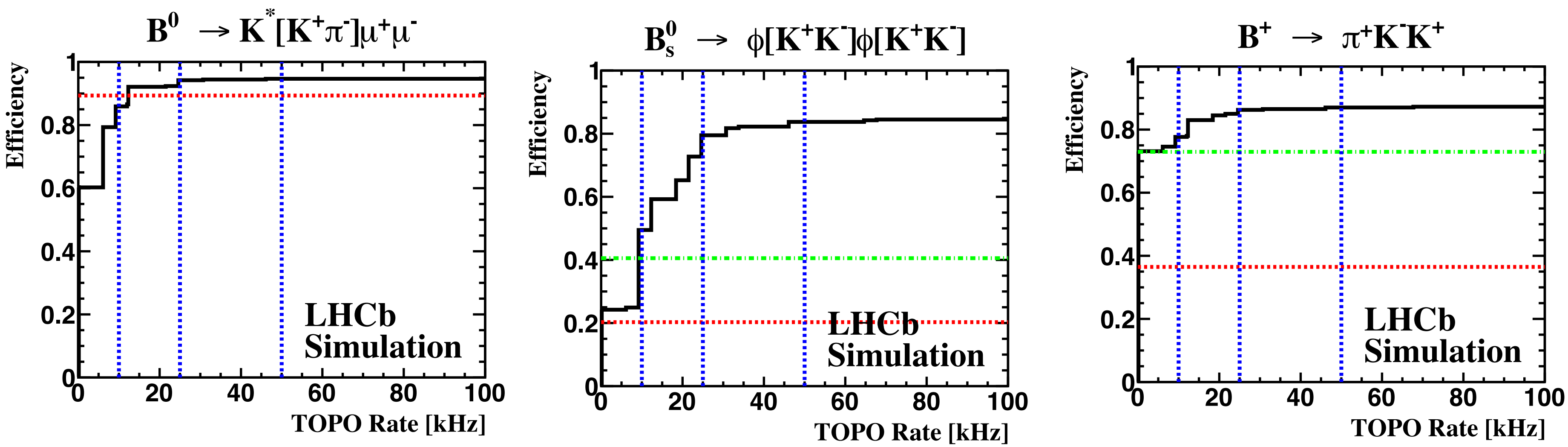
(global event cuts (GEC) reject high multiplicity events)

- Track finding performance
  - Track finding efficiency relative to offline: 98.7% (PT>0.5GeV)
  - Total tracking time ~ 50% of budget given by EFF size

- **First time: Possible to reconstruct events at 30MHz at hadron collider**

Inclusive beauty trigger

- Use same strategy as Run 1 inclusive trigger (topological)
  - Based on BDT with corrected mass
- Performance depends on output rate
  - Three scenarios indicated (20, 50 and 100kHz)



Run 1 performance
2 x Run 1 performance

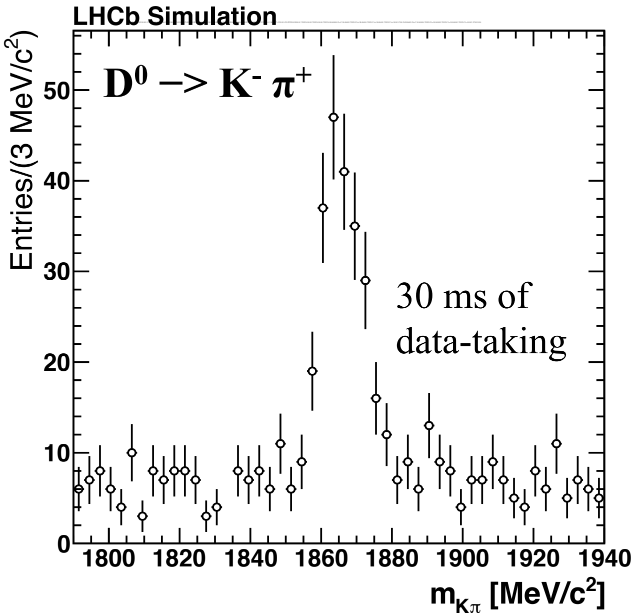
- **Trigger performance in hadronic modes greatly improved**

Exclusive selections

- Availability of up-front tracking allows efficient exclusive selections

- Special case: “lifetime unbiased” triggers
  - Trigger which introduces no bias on lifetime
  - Removes the need to control acceptance effects → reduced systematic uncertainties
  - Challenge: control the CPU time needed to make all track combinations

- Typical performances
  - B→hh signal efficiency: 60% (D→hh: 10%)
  - CPU time: ~0.16ms



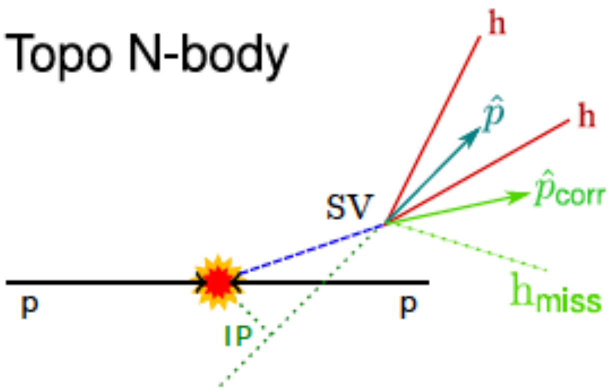
Summary

- LHCb trigger has been very successful in 2011 and 2012
  - Flexible implementation in software
    - Allows to quickly adapt to running conditions
    - Deferred triggering: optimize resources for mean usage of farm
- For Run 2: many improvements planned
  - implement online calibration → high performance RICH particle ID
- Major upgrade of LHCb and its trigger planned for 2018
  - Concept: Full Software Trigger
  - Reconstruction of all events at inelastic collision rate
  - Allows very diverse, efficient triggers that minimally bias the physics observables (eg. lifetime unbiased hadronic triggers)

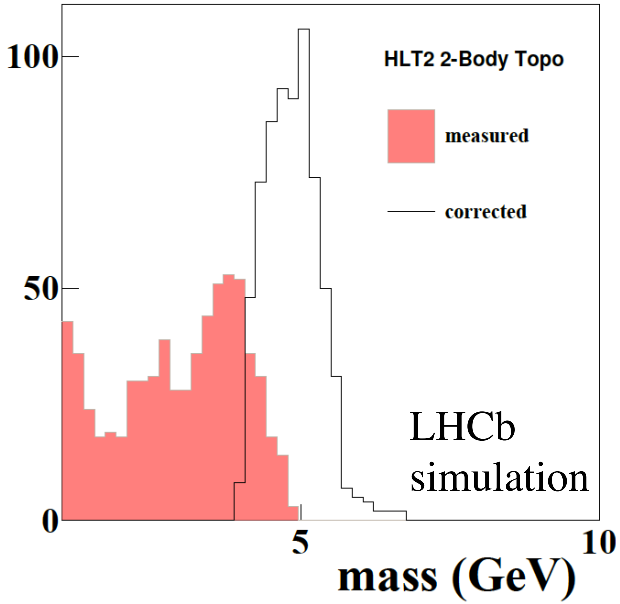
The end


CERN/LHCC 2014-016
LHCb TDR 16
21 May 2014
UPGRADE
TDR
LHCb
Trigger and Online
Technical Design Report

HLT2: Inclusive Beauty trigger I



(corrected) mass



- Inclusive trigger on 2,3,4-body detached vertices
- Primary trigger for B decays to charged tracks
- Uses fast BDT algorithm [JINST 8 (2013) P02013]
- BDT inputs: p_T, IPχ^2, flight distance χ^2, mass and corrected mass

$$m_{corr} = \sqrt{m^2 + |p_{T\,miss}|^2} + |p_{T\,miss}|$$

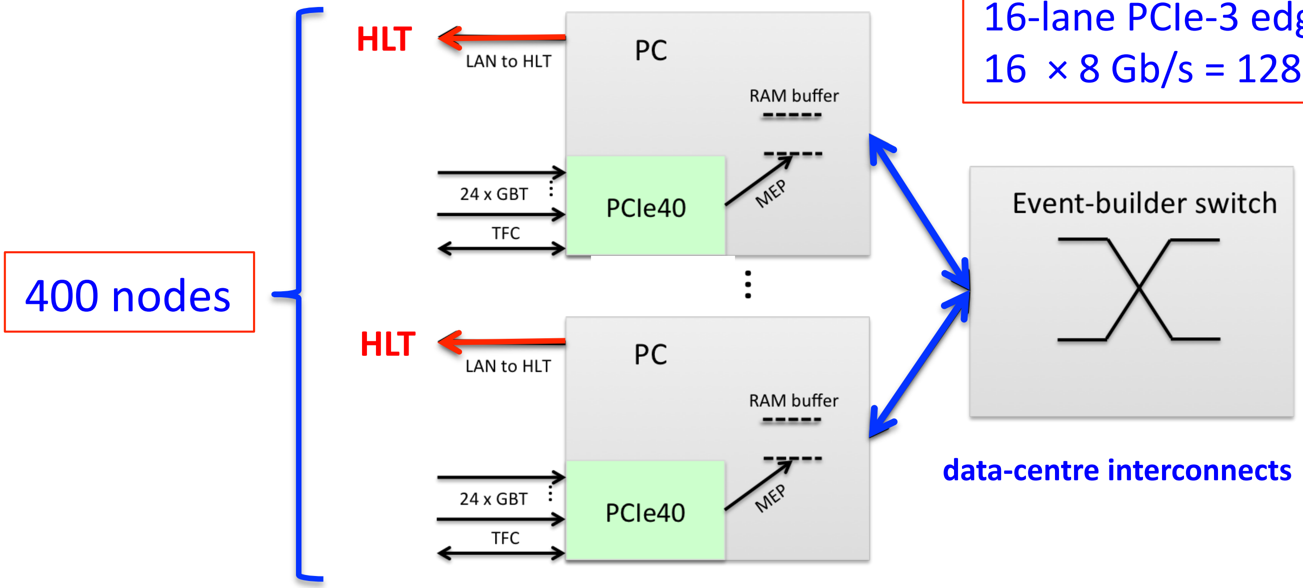
$p_{T\,miss}$: missing momentum transverse to flight direction

- Very efficient even on partially reconstructed beauty decays

Trigger-less readout & Bidirectional event builder

- Use PCIe Generation 3 as communication protocol to inject data from the FEE directly into the event-builder PC …

16-lane PCIe-3 edge-connector bandwidth:
16 × 8 Gb/s = 128 Gb/s = **16 GB/s**

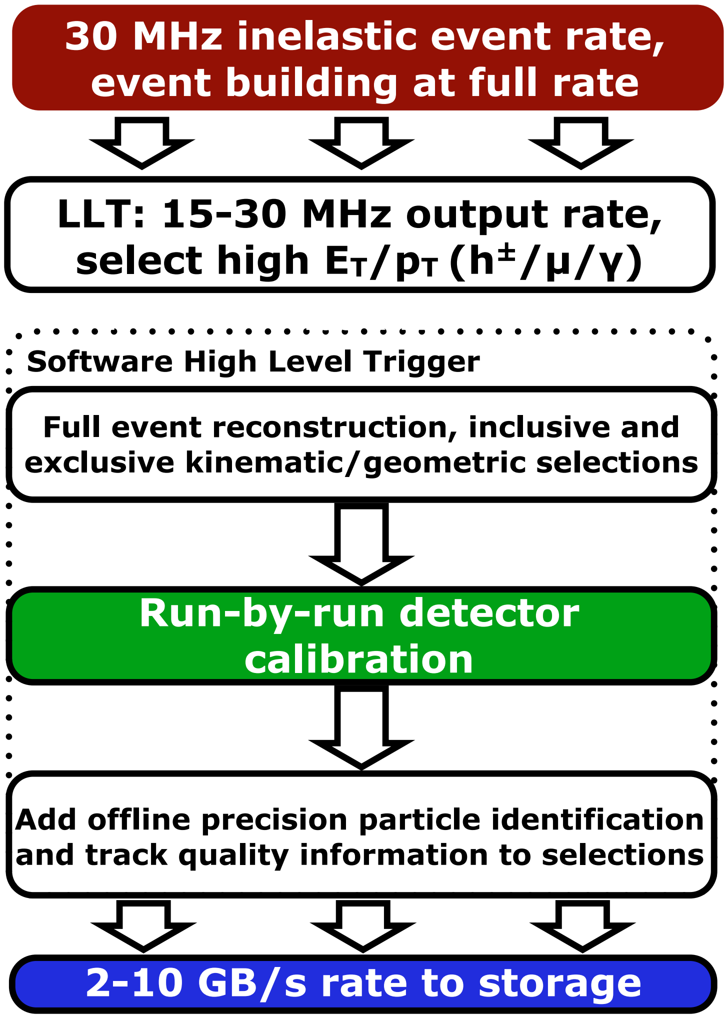


- A **much cheaper event-builder network** because **data-centre interconnects** can be used on the PC, which are not realistically implementable on an FPGA (large software stack, lack of soft IP cores,…)
- Moreover PC provides: huge memory for buffering, OS and libraries.

  Up to date network adapter cards and drivers available as pluggable modules.

Run 3 trigger strategy

Full detector readout at 30MHz + fully software based trigger



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