LHCb: Real-time reconstruction, alignment and calibration in Run 3

Dorothea vom Bruch
on behalf of the LHCb collaboration

8th LHCP, Paris

May 27th 2020

European Research Council
Established by the European Commission

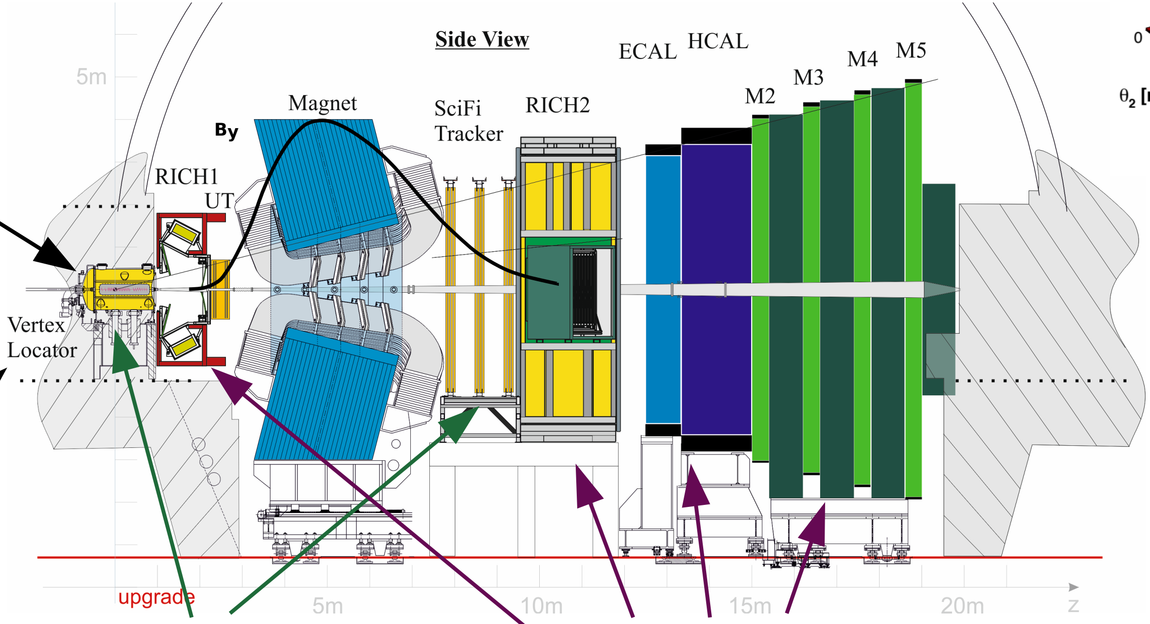
LHCb detector in Run 3

LHCb: General purpose detector specialized in beauty and charm hadrons

Daughters of b- and c-hadron decays:
p_T ~ 1 GeV/c, flight distance ~ 1mm

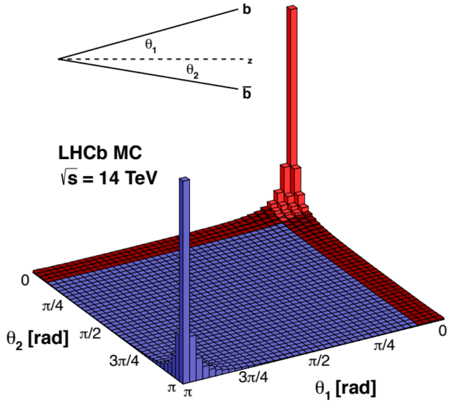
Precise vertex measurements

Excellent decay time resolution



Excellent momentum resolution

Excellent particle identification



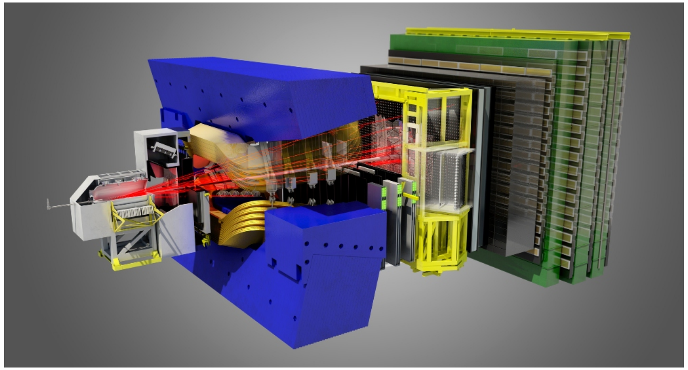
C. Elsässer, bb production angle plots

See also: Mon, 18:00
Mark Tobin: LHCb Upgrades

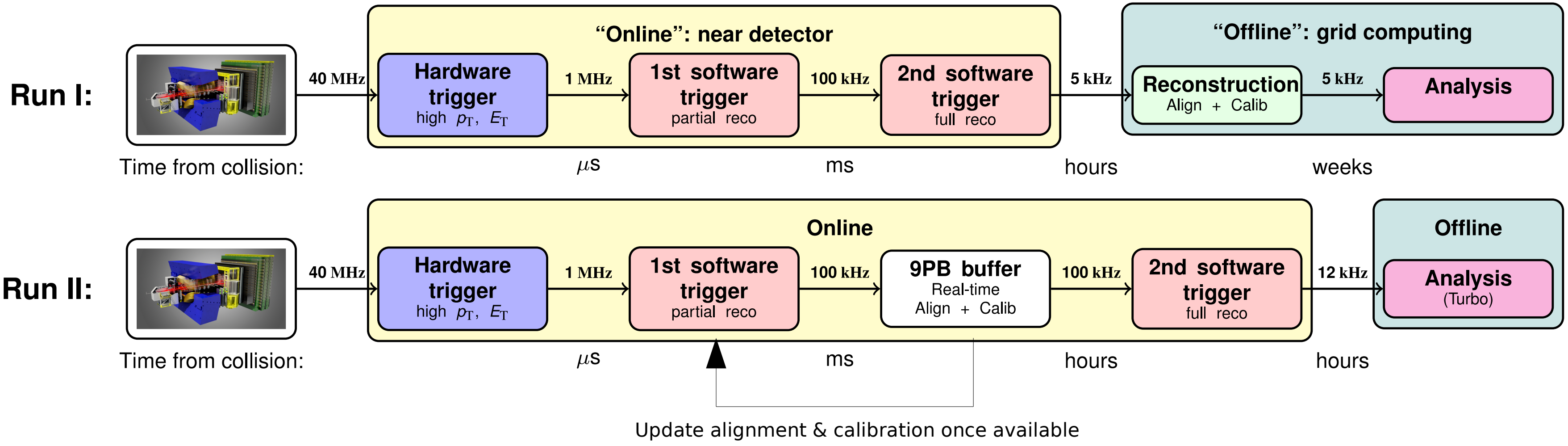
Run 2 detector performance:
Int. J. Mod. Phys. A30 (2015) 1530022

Outline

- LHCb trigger in Runs 1 & 2
- Change in trigger paradigm for Run 3
- High Level Trigger 1
- Alignment & calibration in real-time
- High Level Trigger 2
- Selective persistency



Run 1 & 2 trigger

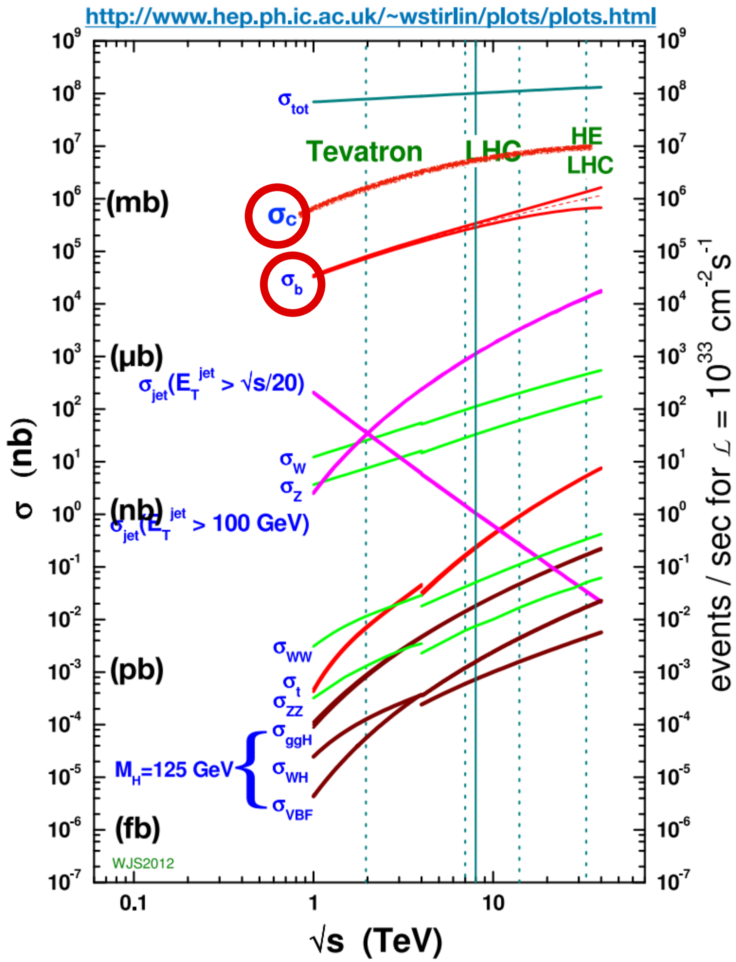


- Hardware trigger: based on muon detectors and calorimeters

Run 2

- Data buffered in between two software trigger stages
- Allows for real-time alignment and calibration
- Offline-quality reconstruction within the trigger

The MHz signal era



Run 3: Luminosity of 2×10^{33} $cm^{-2}s^{-1}$, $\sqrt{s}$ = 14 TeV

General purpose LHC experiments:

- Local characteristic signatures
- Signal rates up to ~100 kHz

} Hardware trigger possible

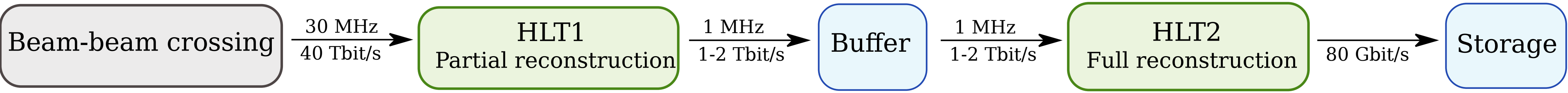
LHCb:

- No “simple” local criteria for selection
- Signal rates up to ~MHz

} Hardware trigger not an option

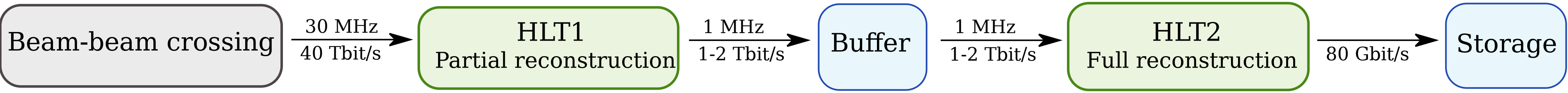
- Access as much information about the collision as early as possible
- Read out the full detector

Trigger only in software



- **High Level Trigger 1 (HLT1):**
  - Full charged particle track reconstruction
  - Few inclusive single and two-track selections
- **High Level Trigger 2 (HLT2):**
  - Aligned and calibrated detector
  - Offline-quality track reconstruction
  - Particle identification
  - Full track fit

Trigger only in software



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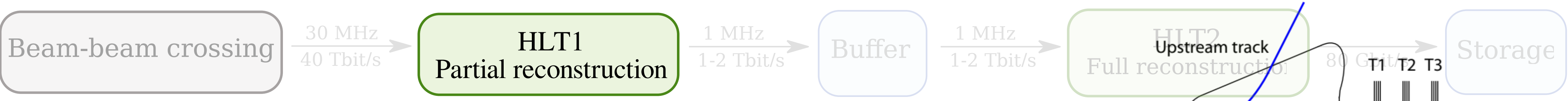
  - Full track fit

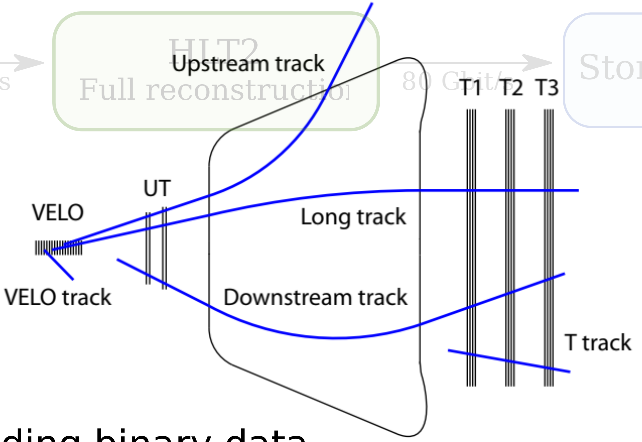
Comparison to Run II trigger

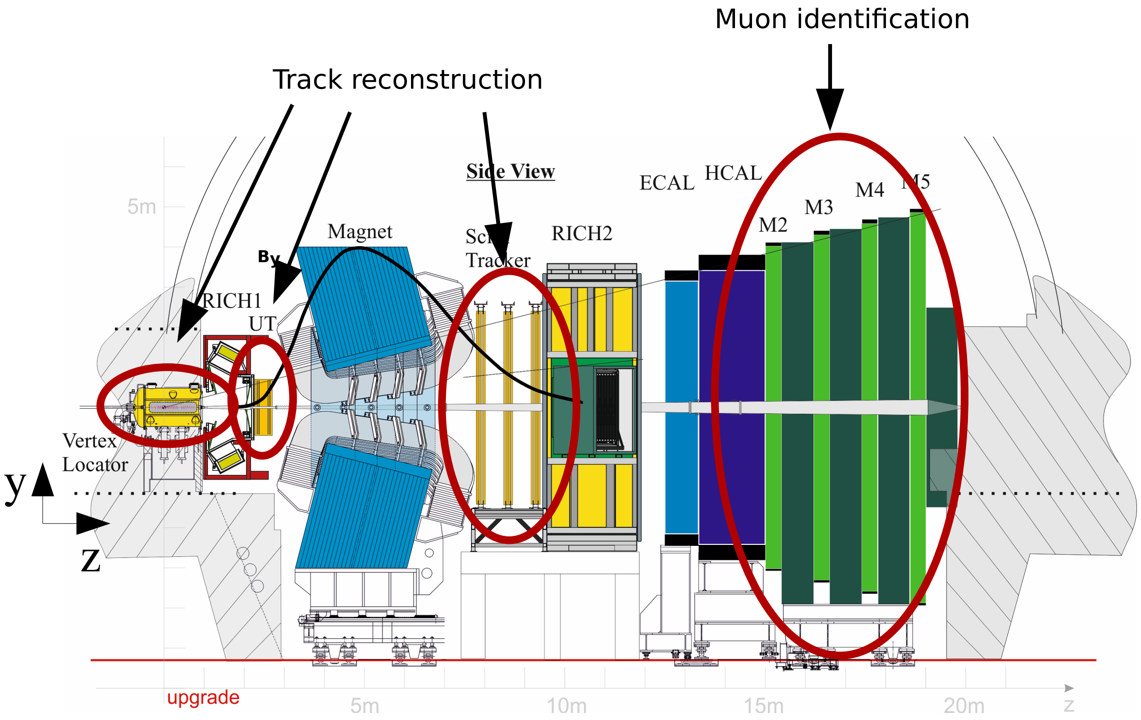
- 5 x higher pileup
- 30 x higher rate into HLT1
- Disk buffer reduces from O(weeks) → O(days)
- Up to 10 x efficiency improvement for some physics channels

Huge computing challenge

LHCb HLT1 tasks







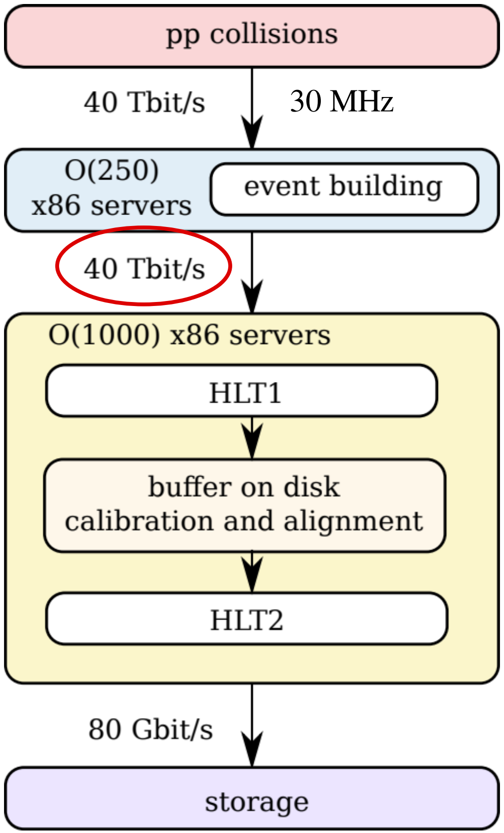
- Decoding binary data
- Pattern recognition
- Match track segments from different sub-detectors
- Track fitting
- Vertex reconstruction

→ Every task is individually parallelizable

HLT1 on GPUs

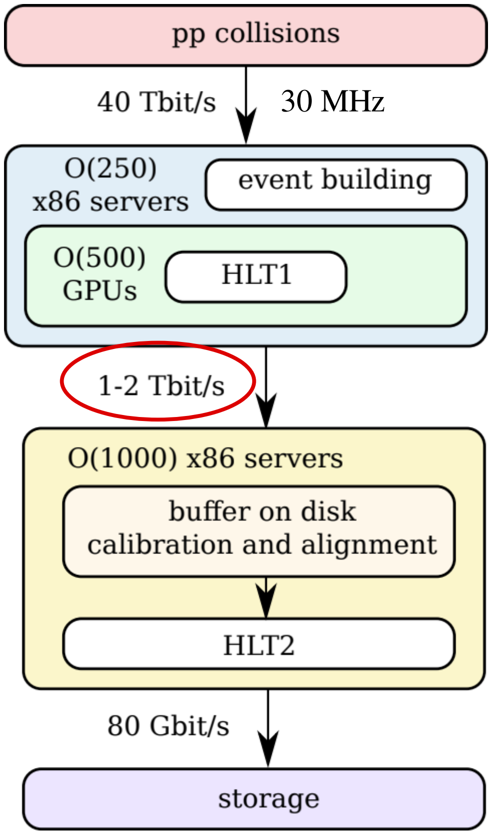
Proposal in TDR (2014)

CERN-LHCC-2014-016



Updated strategy

Comput Softw Big Sci 4, 7 (2020)



HLT1 on GPUs

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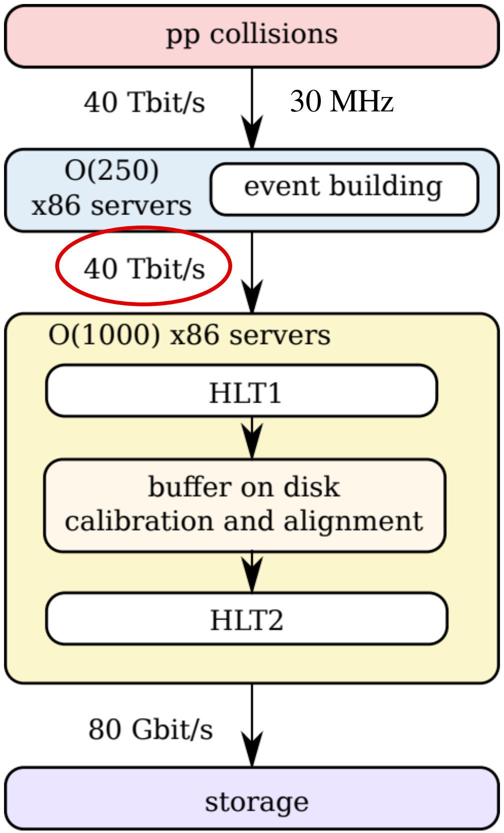

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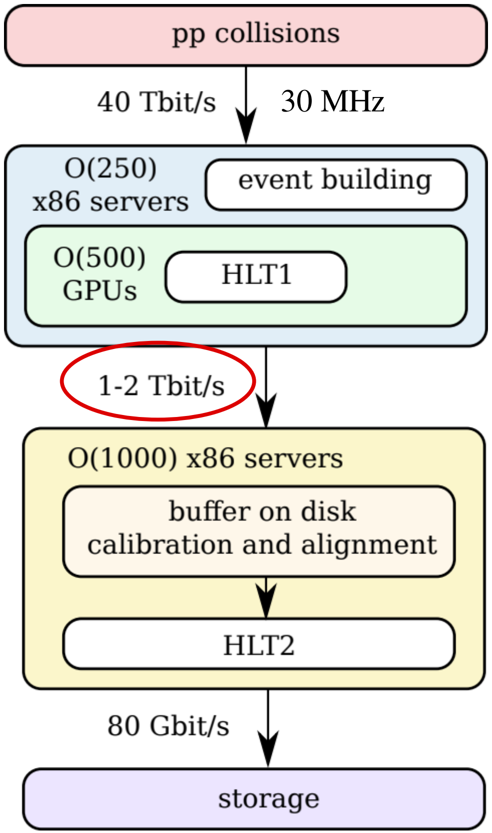
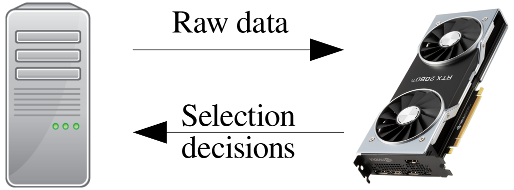


Why GPUs?

- Intrinsically parallel problem
- Sizeable code base for HLT1
- LHCb raw event size: 100 kB

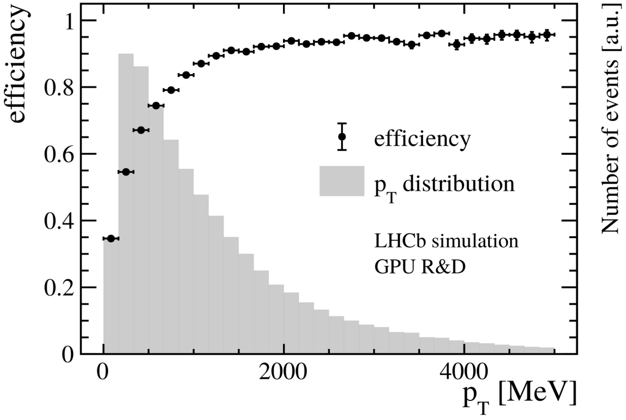


Performance

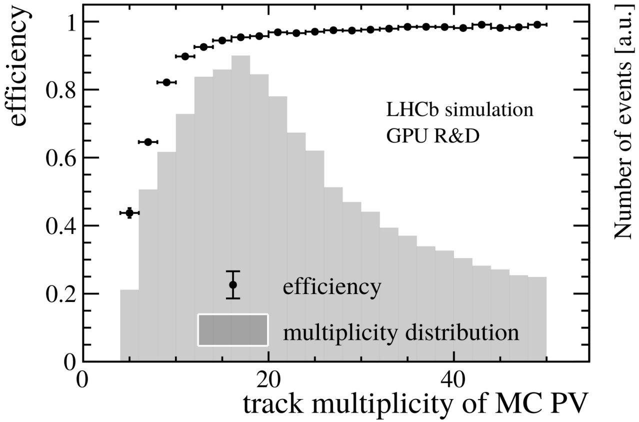
- Process HLT1 @ 30 MHz on less than 500 state of the art GPUs
- Physics performance superior to TDR

HLT1 physics performance

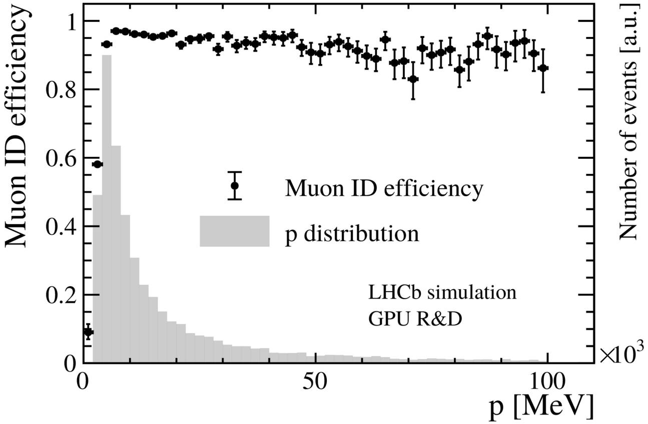
Track reconstruction efficiency for tracks originating from B decays



Primary vertex reconstruction efficiency



Muon identification efficiency

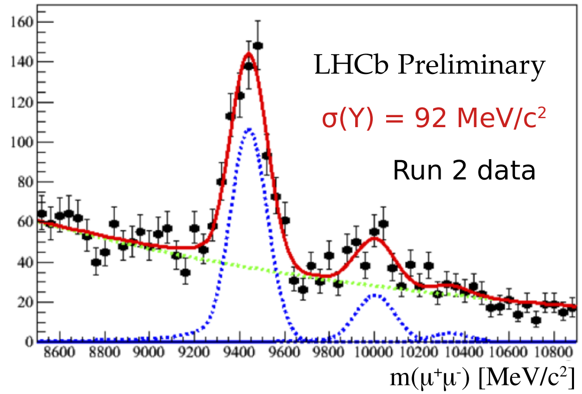


Trigger	Rate [kHz]
1-Track	215 ± 18
2-Track	659 ± 31
High-p_T muon	5 ± 3
Displaced dimuon	74 ± 10
High-mass dimuon	134 ± 14
Total	999 ± 38

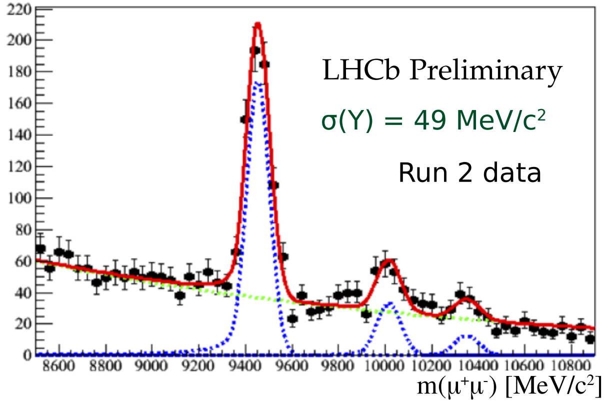
Comput Softw Big Sci 4, 7 (2020)

Online alignment & calibration

Before alignment

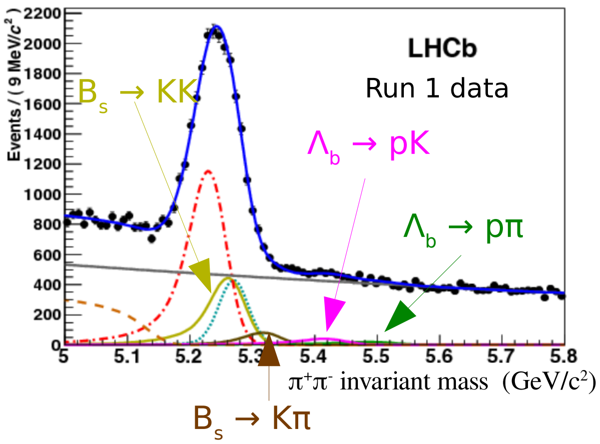


After alignment

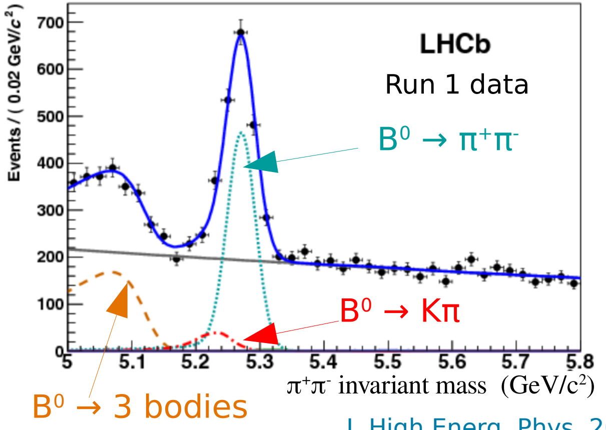


Journal of Physics: Conference Series, 664 (2015)

Without PID



With PID

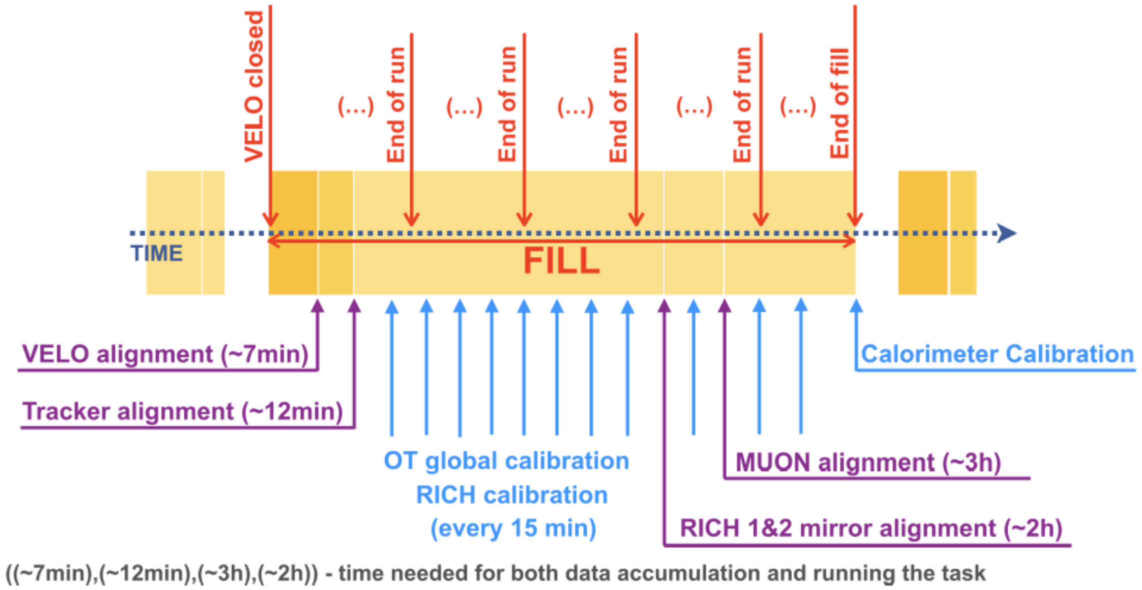


J. High Energ. Phys. 2012, 37 (2012)

- Efficient and pure selections require offline-quality reconstruction at the HLT2 level
  - Better mass resolution
  - Better particle identification
  - Less background

→ use output bandwidth more efficiently

Run 2: Real-time alignment & calibration



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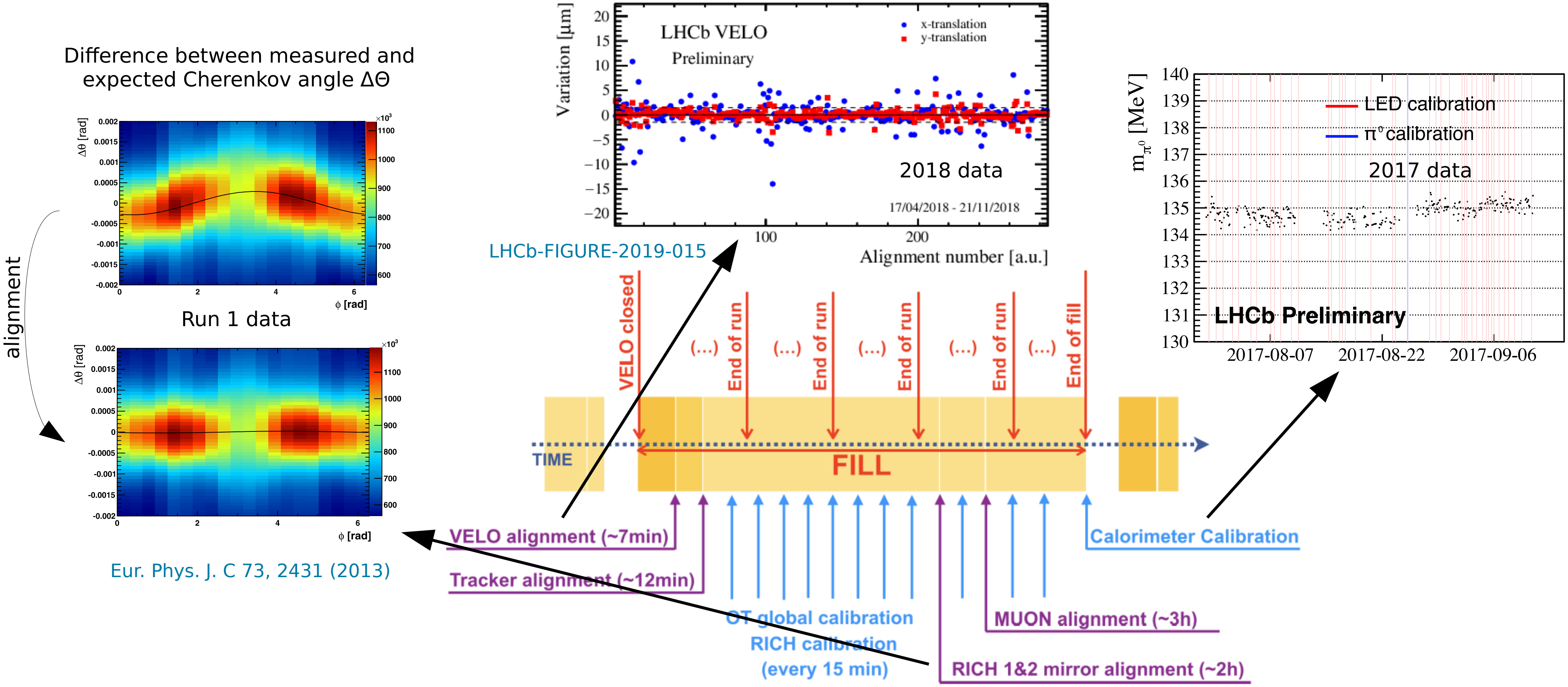
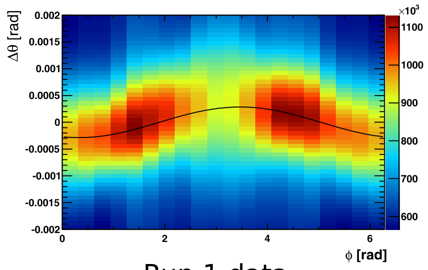


((~7min),(~12min),(~3h),(~2h)) - time needed for both data accumulation and running the task

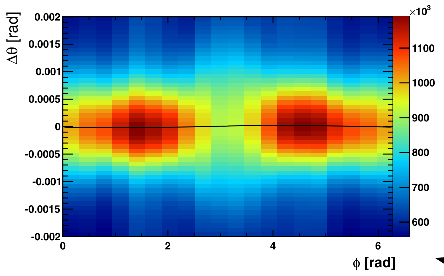
Run 2: Real-time alignment & calibration

Difference between measured and expected Cherenkov angle ΔΘ

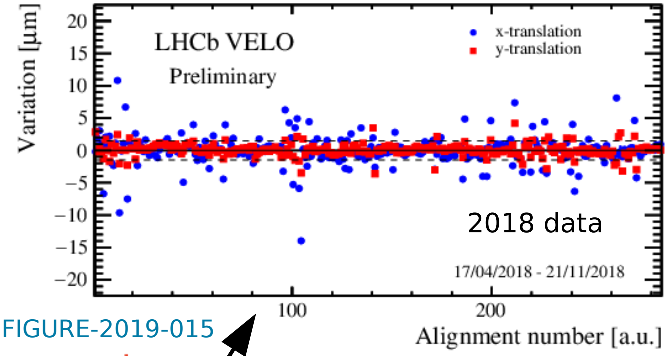
alignment



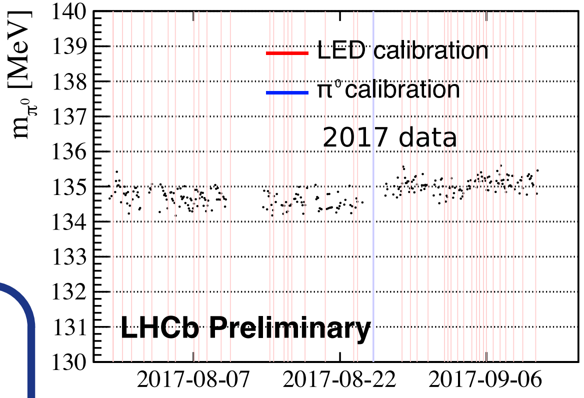
Run 1 data



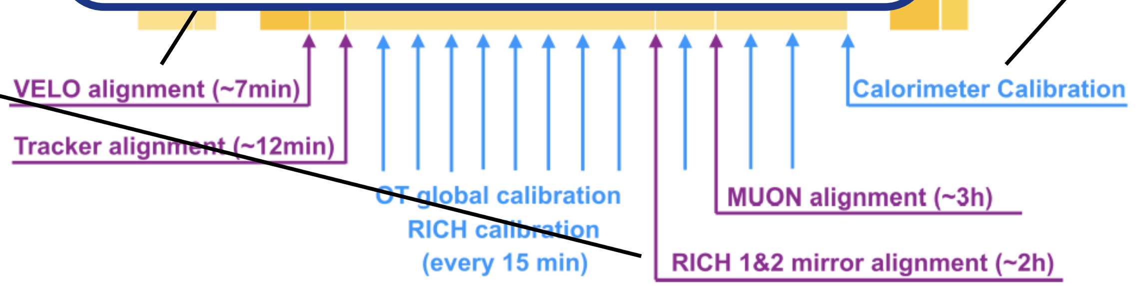
Eur. Phys. J. C 73, 2431 (2013)



LHCb-FIGURE-2019-015

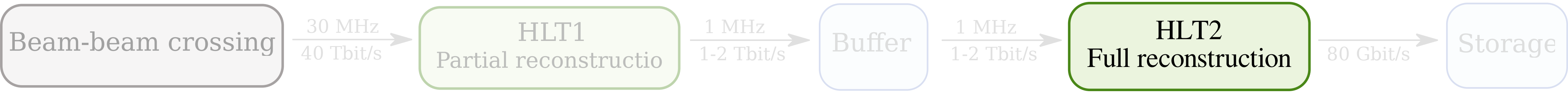


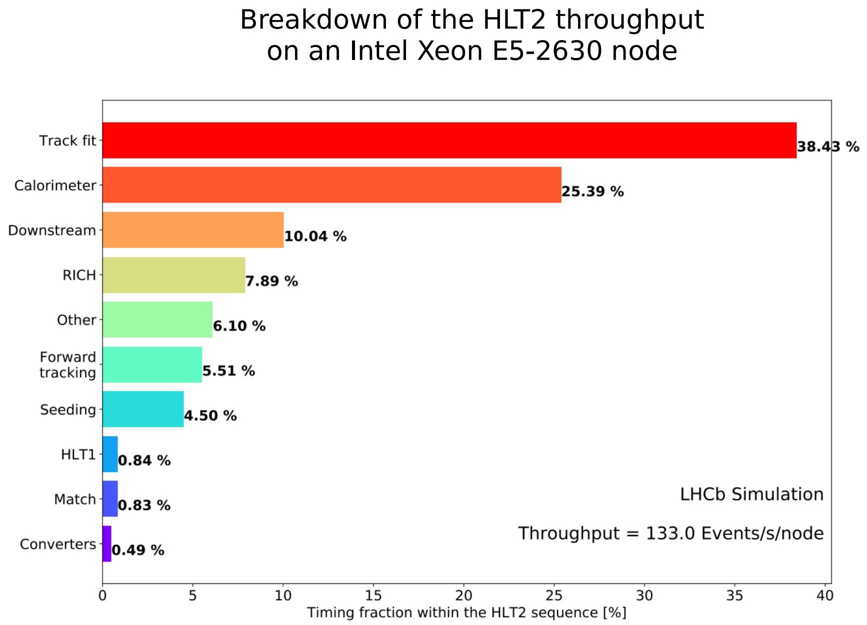
Same strategy planned for Run 3



((~7min),(~12min),(~3h),(~2h)) - time needed for both data accumulation and running the task

HLT2 on CPUs



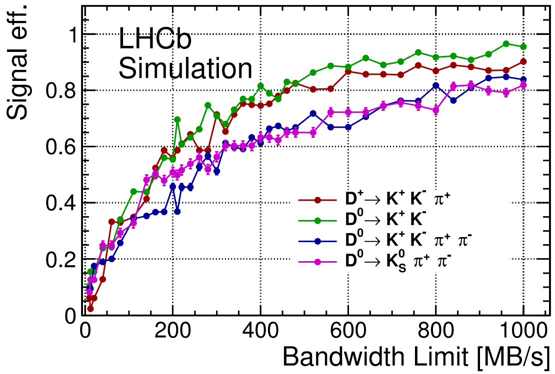


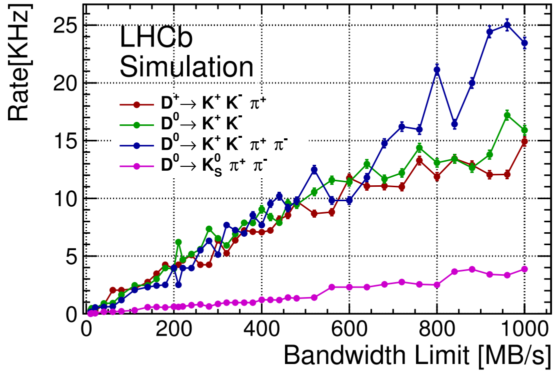
LHCb-FIGURE-2020-007

- Fully aligned & calibrated detector
- Offline quality track fit & particle identification @ 1MHz
- Work ongoing to improve the throughput of HLT2
- Concentrated effort first on HLT1, now shifting towards HLT2
- Reduced bandwidth during the first year of data taking

Selection efficiencies

- Extensive usage of MVA based selections
- Ongoing studies on multivariate selections to select tracks generically coming from B and D decays (JINST 14 (2019) P04006)
- O(500) selections will be implemented
- Studies on bandwidth and efficiency for various decay channels ongoing





LHCb-PUB-2017-006

Selective persistency

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

- Trigger *bandwidth* is crucial, not trigger rate
- Real-time selection occurs with offline quality
- Only store high-level objects reconstructed in real-time
- Reduced event format → reduction of event size
  → higher efficiency for same bandwidth
- “Turbo stream”

Selective persistency

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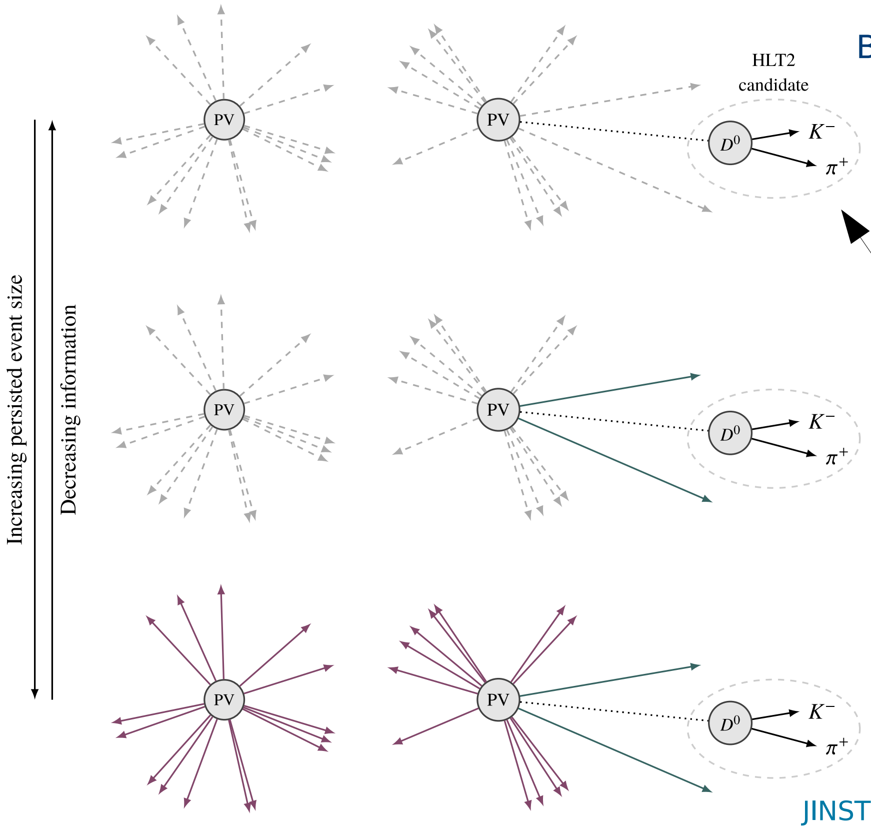


- Trigger *bandwidth* is crucial, not trigger rate
- Real-time selection occurs with offline quality
- Only store high-level objects reconstructed in real-time
- Reduced event format → reduction of event size
  → higher efficiency for same bandwidth
- "Turbo stream"
- High degree of flexibility:
  - Only objects used in trigger selection
  - Objects used in trigger selection & user-defined selection
  - All reconstructed objects
- Raw data only stored in calibration stream

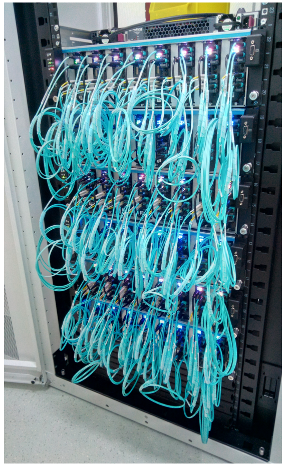
JINST 14 (2019) P04006

Summary & Outlook

- MHz signal era leads to a change in trigger paradigm:
    - Reject background → select signal
    - Reduce rate → reduce bandwidth
- Read out full detector, do offline quality reconstruction in real time
- Partial reconstruction @ 30 MHz on GPUs
- Full reconstruction @ 1 MHz on CPUs
- Build on successful alignment & calibration in real-time during Run 2
- Store reduced event format, rather than full raw event

Current developments:

- Improve HLT2 computing performance
- Implementation of selections
- Get ready to commission the system

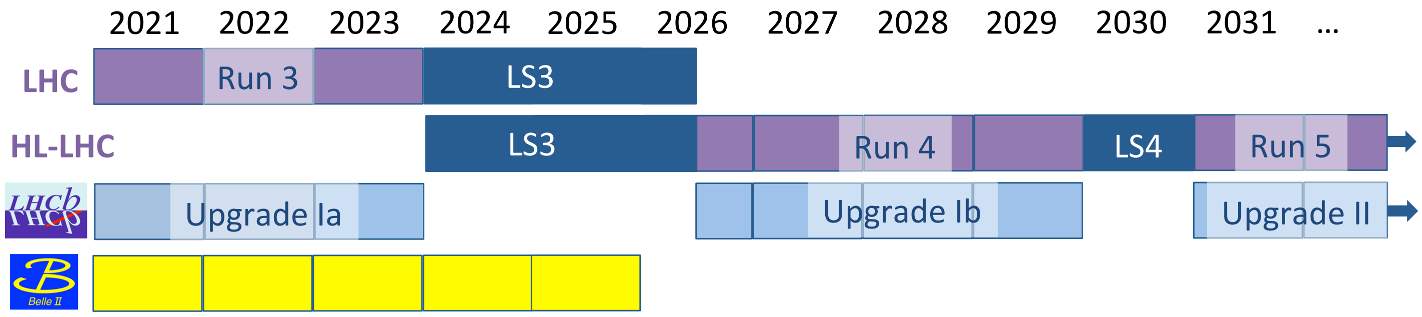


Zoom meeting room for discussion after the session at 16:00 (same password as for this session):
https://cern.zoom.us/j/5602841283?pwd=a1B6UjhRbmR6c3J0bnNYaSt3djdLUT09
If zoom does not work, we use this vidyo room: https://vidyoportal.cern.ch/join/ngyPSyM9Sw

Backup

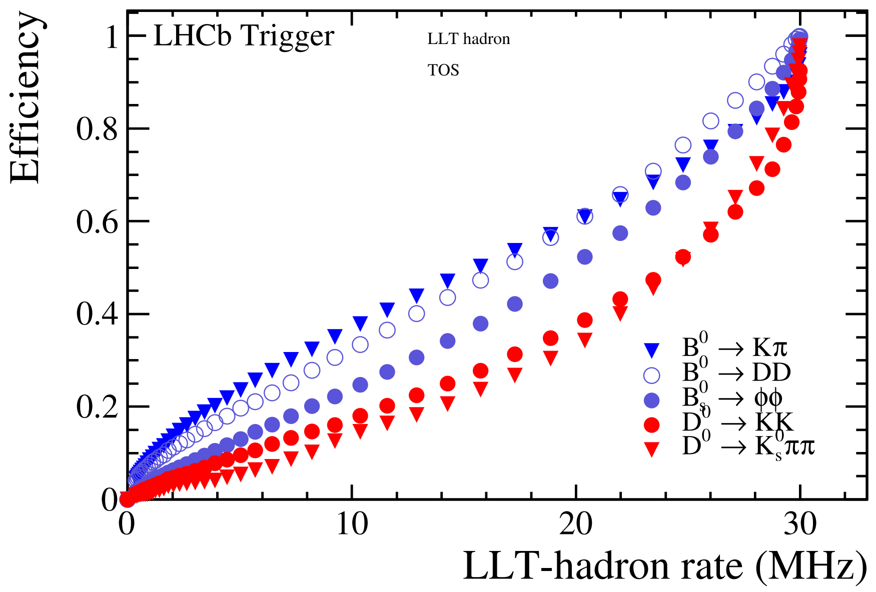
LHC schedule

CERN-LHCC-2018-027

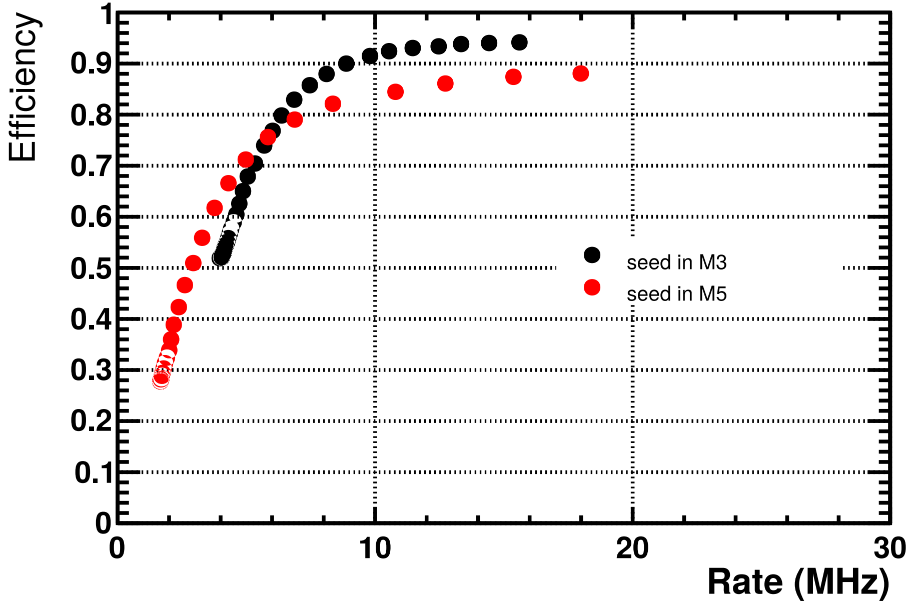


Why no low level trigger?

Low level trigger on E_T from the calorimeter

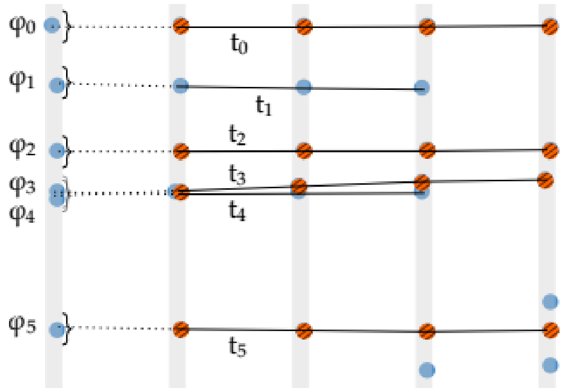


Low level trigger on muon p_T, $B \to K^*\mu\mu$

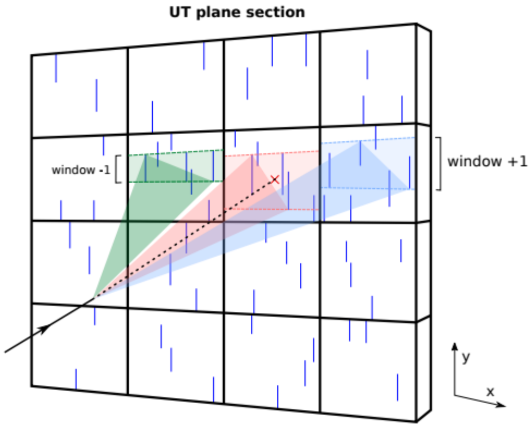


Parallelization of reconstruction tasks

Search for combinations
of hits in parallel

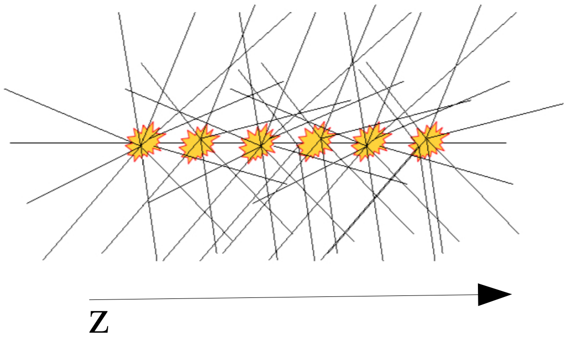


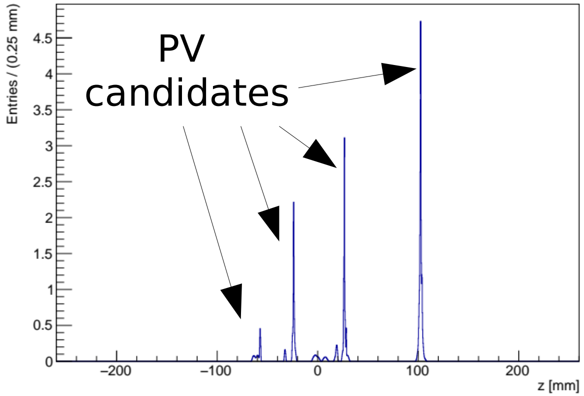
Store objects (for example hits)
In best suited memory layout



Split problem into
independent tasks

Example: primary vertex
(PV) reconstruction





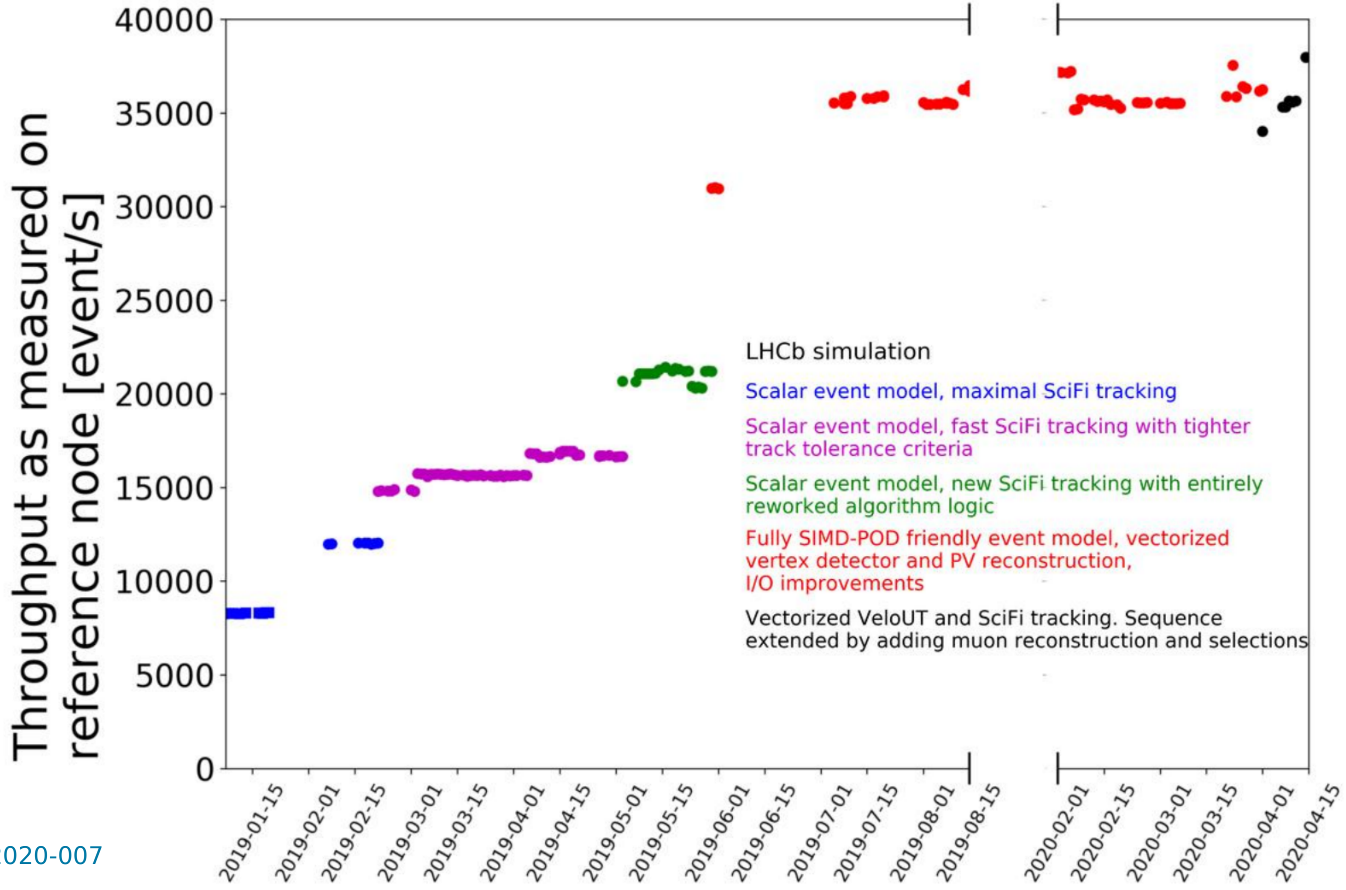
HLT1 rates & efficiencies

Trigger	Rate [kHz]
1-Track	215 ± 18
2-Track	659 ± 31
High-p_T muon	5 ± 3
Displaced dimuon	74 ± 10
High-mass dimuon	134 ± 14
Total	999 ± 38

Selection efficiencies, values given in %

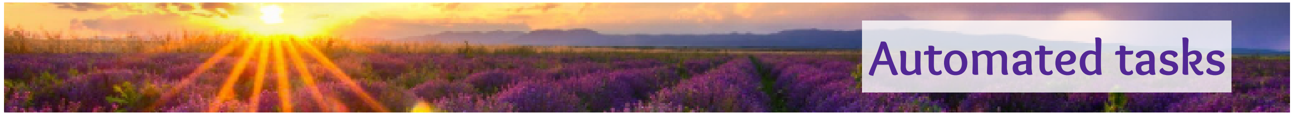
Signal	GEC	TIS -OR- TOS	TOS	GEC × TOS
$B^0 \to K^{*0}\mu^+\mu^-$	89 ± 2	91 ± 2	89 ± 2	79 ± 3
$B^0 \to K^{*0}e^+e^-$	84 ± 3	69 ± 4	62 ± 4	52 ± 4
$B_s^0 \to \phi\phi$	83 ± 3	76 ± 3	69 ± 3	57 ± 3
$D_s^+ \to K^+K^-\pi^+$	82 ± 4	59 ± 5	43 ± 5	35 ± 4
$Z \to \mu^+\mu^-$	78 ± 1	99 ± 0	99 ± 0	77 ± 1

Evolution of HLT1 on CPUs throughput



LHCb-FIGURE-2020-007

Run 2 alignment & calibration



Task	Update	Sample	Data collection	Duration	When?
Velo alignment	Automatic	50k minbias + beamgas	< 1 min	2 min	Every fill
Tracker alignment	Automatic	100k $D^0 \to K\,\pi$	< 1 min	7 min	Every fill
RICH mirror alignment	Automatic	3M good tracks	2 h	20 min	Every fill
Muon alignment	Expert	250k $J/\psi \to \mu^+\,\mu^-$	3 h	7 min	Every fill
OT t_0 calibration	Automatic	Some minbias	15 min	O(min)	Every run
RICH Calibration	Automatic	Good tracks	15 min	O(min)	Every run
Relative CALO calibration	Automatic	LED monitoring system	N/A	2 min	Between fills
Absolute HCAL calibration	Expert	Caesium scan	N/A	2 hours	Technical stops
Absolute ECAL calibration	Automatic	300M minbias	O(4 weeks)	2 hours	When sample ready