Real Time Analysis at the LHCb Experiment

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On behalf of the LHCb Real Time Analysis Project

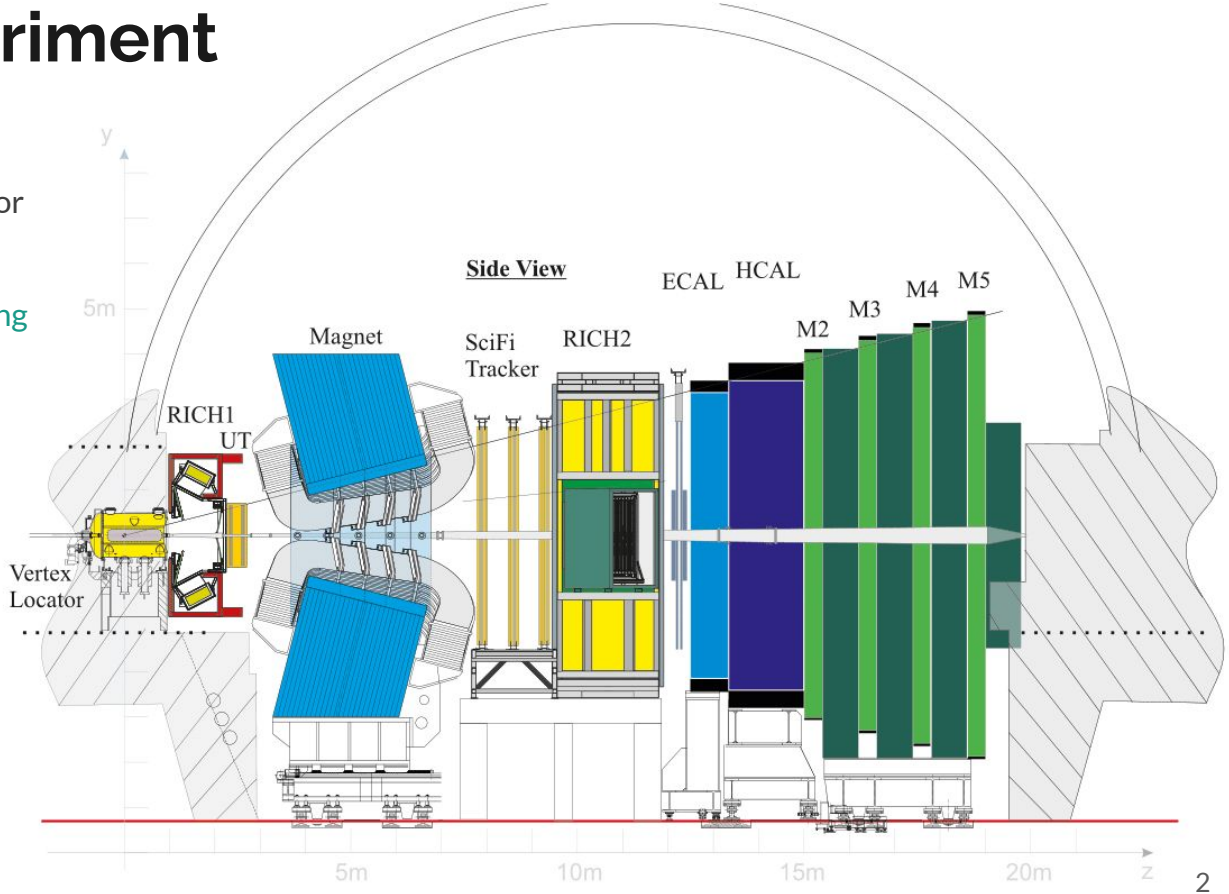
International Meetings on Fundamental Physics and XV CPAN days
2 – 6 October 2023

The LHCb Experiment

- Single-arm forward spectrometer for high-precision flavour physics
- High precision tracking and vertexing and PID
- Since 2022 (Upgrade I), operates at an increased luminosity → major upgrade in all sub-detectors

$$\mathcal{L} = 2 \times 10^{33} cm^{-2} s^{-1}$$

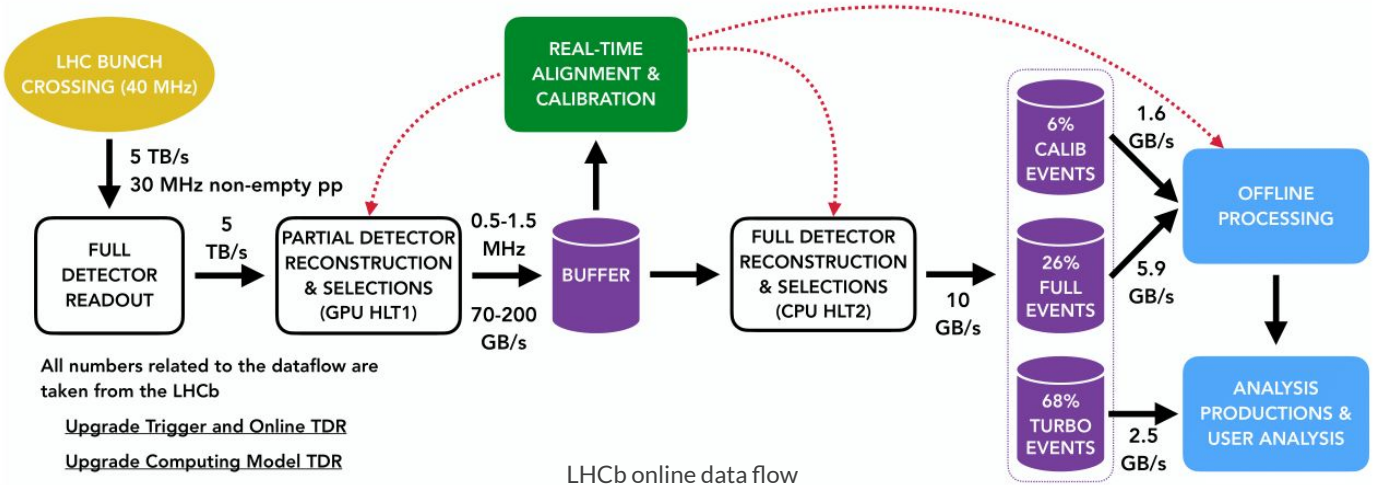
- In order to effectively trigger on physics signatures → full software trigger



The LHCb upgrade I

The LHCb data-flow

- The data flow generated from the LHCb detector currently reaches **5 TB/s**.
- Before storage, this rate is reduced by a factor 400 with the **trigger system**.
- **Real Time Analysis** approach: full event reconstruction and selection of specific signals of interest enabled by a quasi-real-time alignment and calibration.

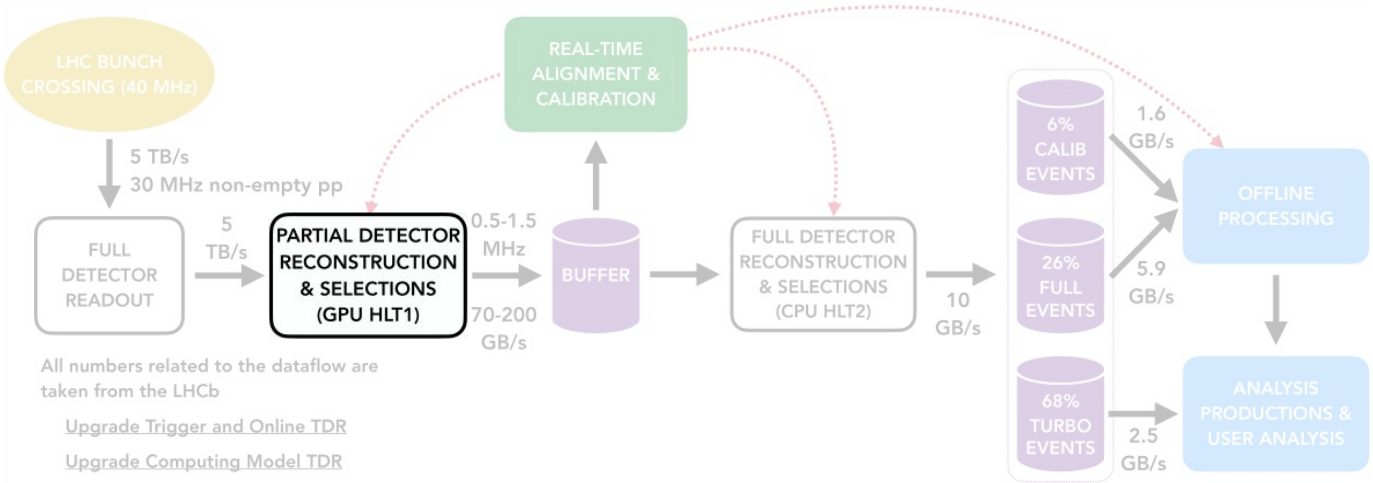


LHCb online data flow
LHCB-FIGURE-2020-016 (2020)

The first level trigger

- CUDA framework, named Allen, run on GPUs that process the entirety of the LHCb raw data at 30 MHz
- Reduce the input rate by a factor 30 to ~1 MHz
- Perform a partial event reconstruction and selection of broad physics signatures

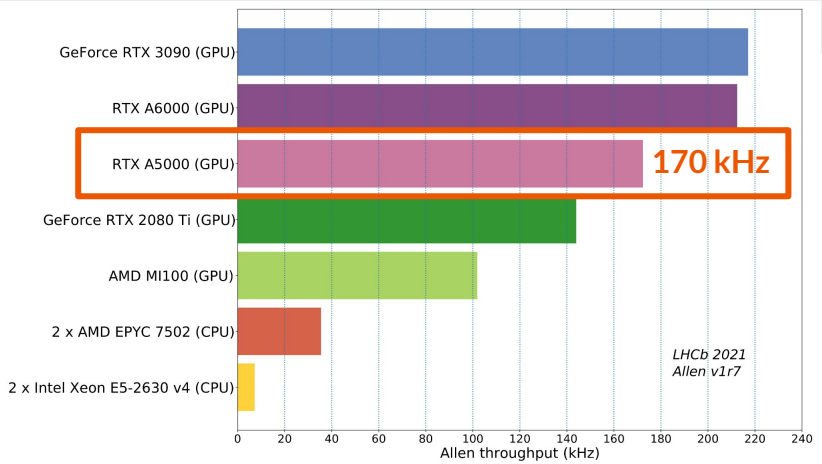
→ First complete high-throughput GPU trigger for a HEP experiment!

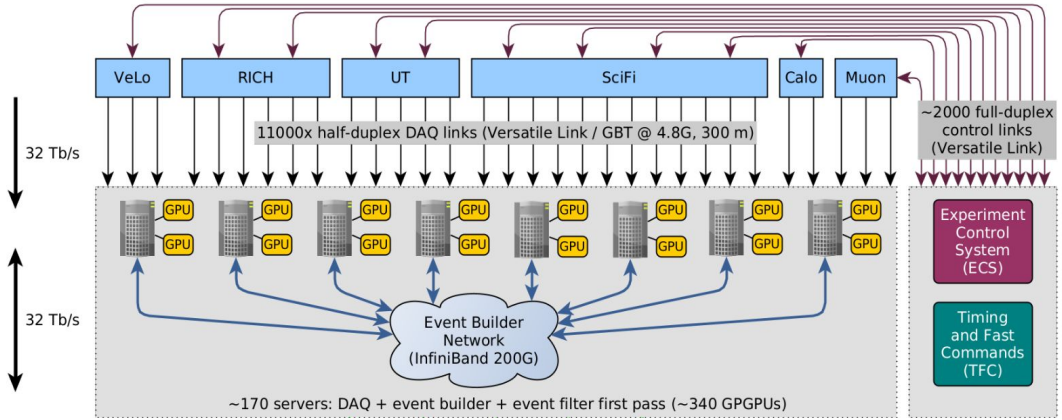


The first level trigger

Why **GPUs**?

- Allow to parallelize the reconstruction per event and per track
- Data acquisition system: receives data from sub-detectors and groups it into events (event building)
- Event building PCs can host three GPUs each
- Allen is currently implemented with O(250) Nvidia RTX A5000 GPUs





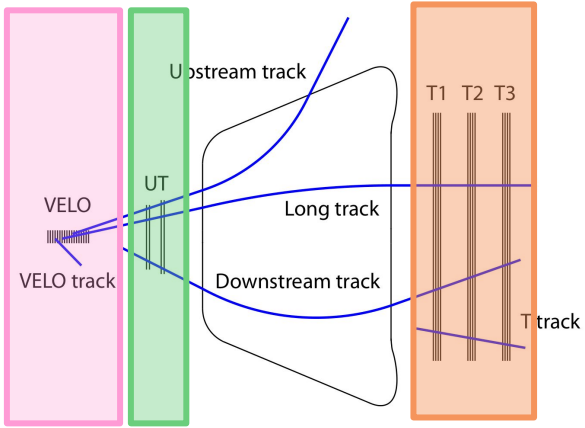
HLT1 sequence

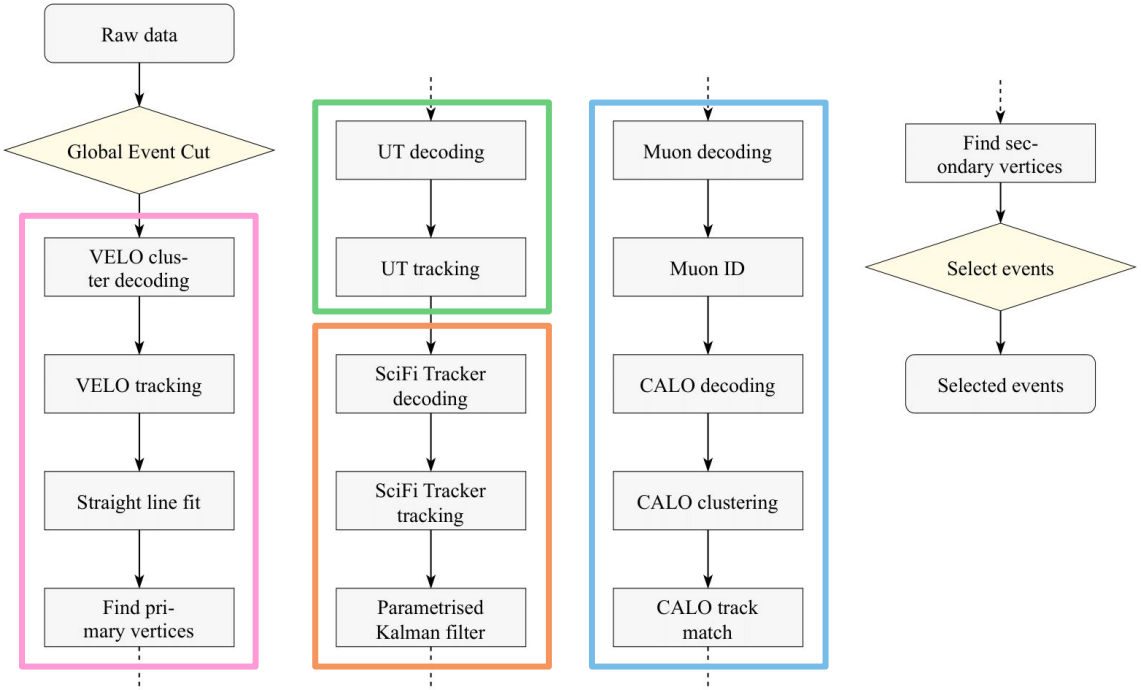
Reconstruction:

- Tracking with VELO, UT and SciFi
- PID with the Muon stations and CALO

Event selection:

- Specific trigger lines

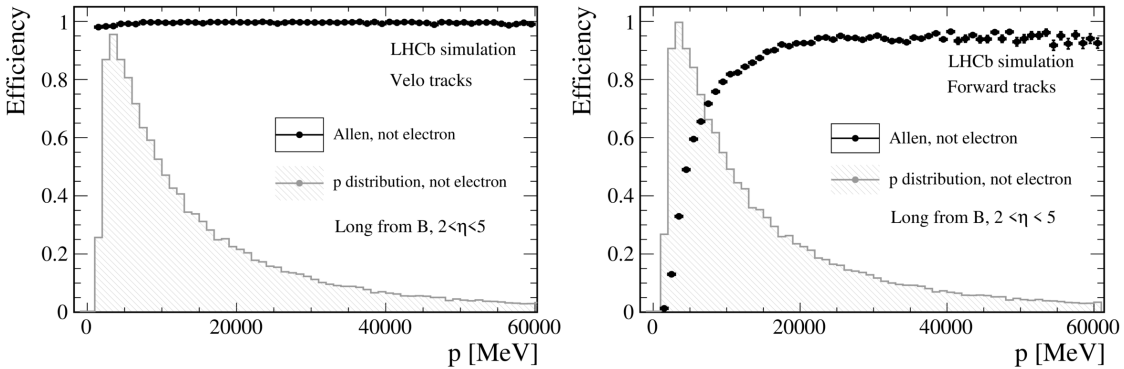




HLT1 performance

Tracking

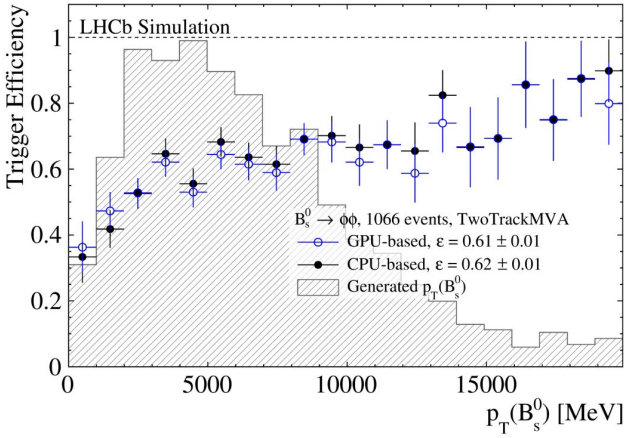
- Maintained performance from Run 2
- Track reconstruction efficiency >99% for VELO, 95% for high-p forward tracks



Performance of the GPU HLT1
LHCB-FIGURE-2020-014

Selection

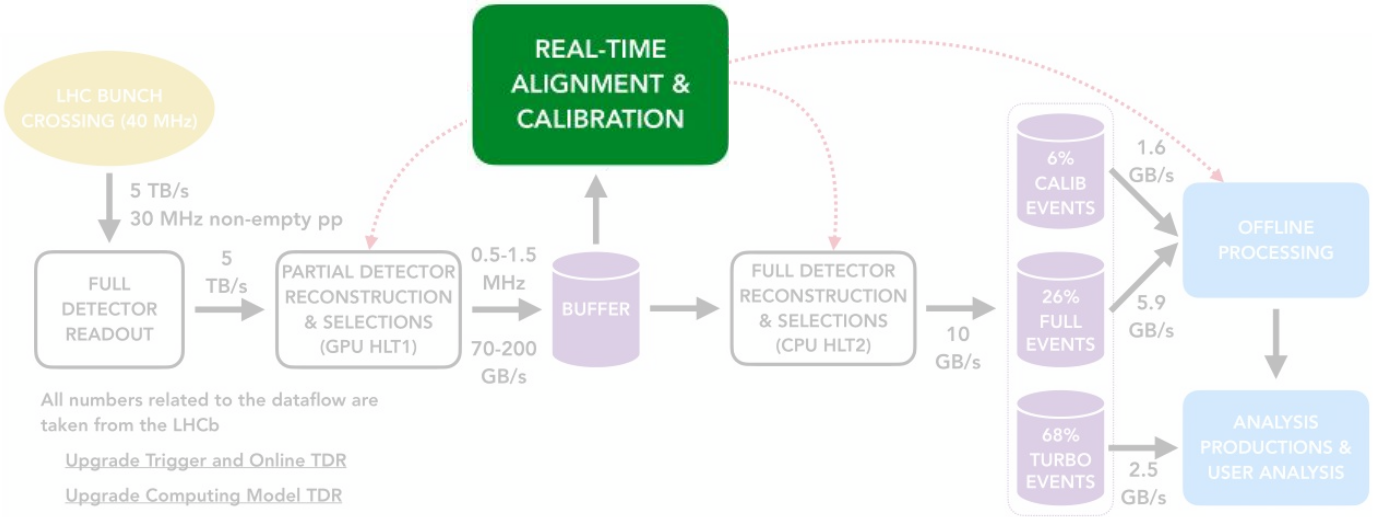
- O(30) lines implemented: LHCb physics program, monitoring, alignment and calibration
- Compatible performance between CPU and GPU



TwoTrackMVA line for
Comput Softw Big Sci 6, 1 (2022)

Alignment and Calibration

- Provides the most accurate alignment and calibration parameters of the sub-detectors
- Allows an offline quality reconstruction in HLT2
- Designed to maximise the physics reach and analysis flexibility → FULL stream allows for offline recalibration

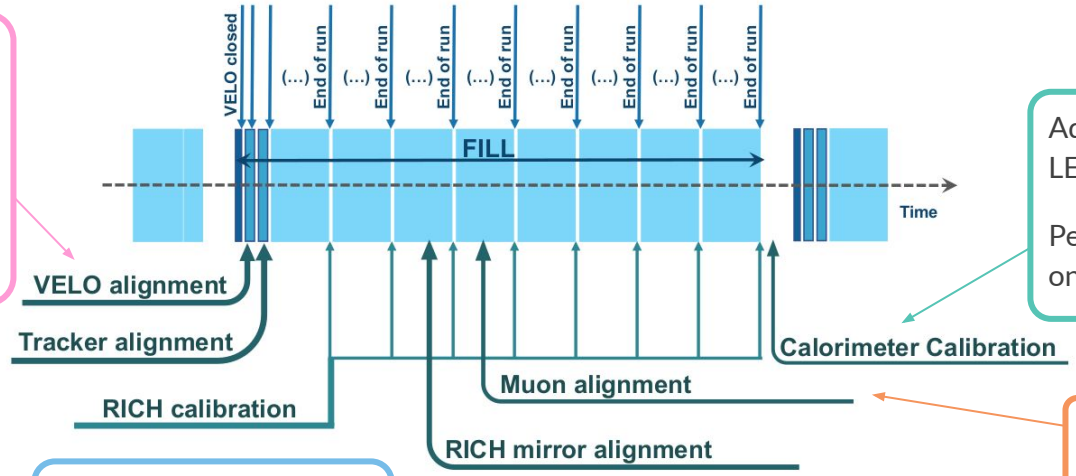


Alignment and Calibration

Needs a track sample crossing all its modules

Accounts for the opening and closing of the VELO

Done within few minutes



Adjust the PMT gain using LED monitoring

Per cell π^0 mass calibration once per month

Needs signal tracks from well known resonances collected by dedicated HLT1 selections

Done within seconds

Calibration of the gas radiator refractive index

Needs dedicated samples selected in HLT1

Mirror alignment performed each fill

Needs Cherenkov photons equally distributed among its mirrors

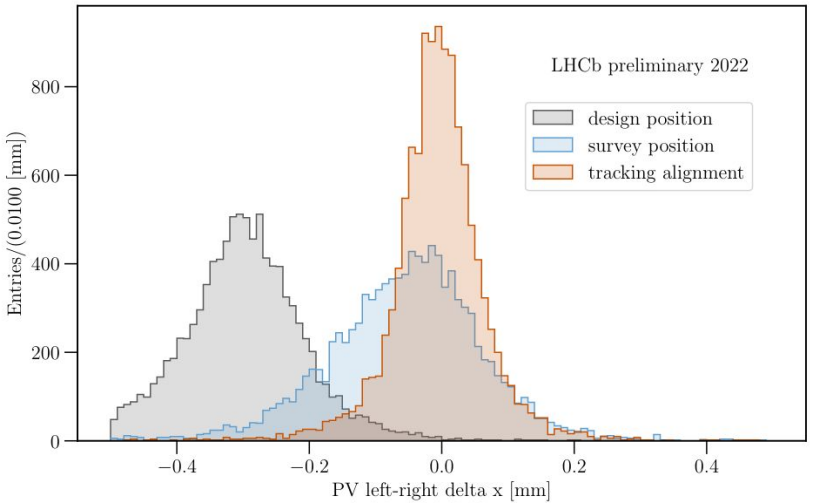
Takes a few hours

Needs J/psi decays

Run as monitoring

Alignment and Calibration

First results for Run 3:

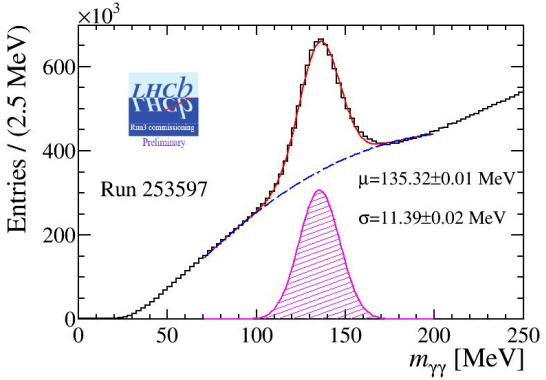


Misalignment of the VELO halves evaluated as the difference in x-position of the PVs on each VELO half, for different alignment conditions

LHCb-FIGURE-2022-016

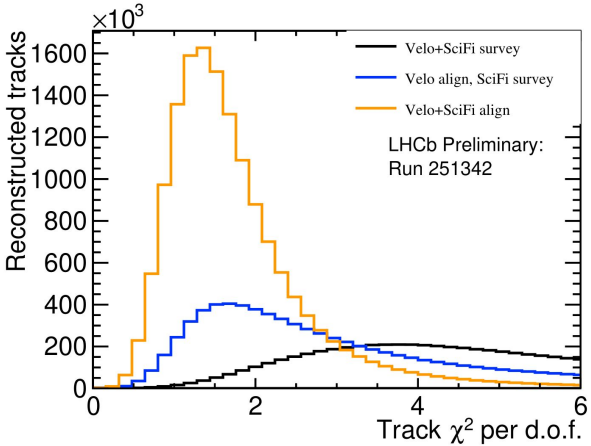
Di-photon invariant mass after per-cell calibration

LHCb-FIGURE-2022-019



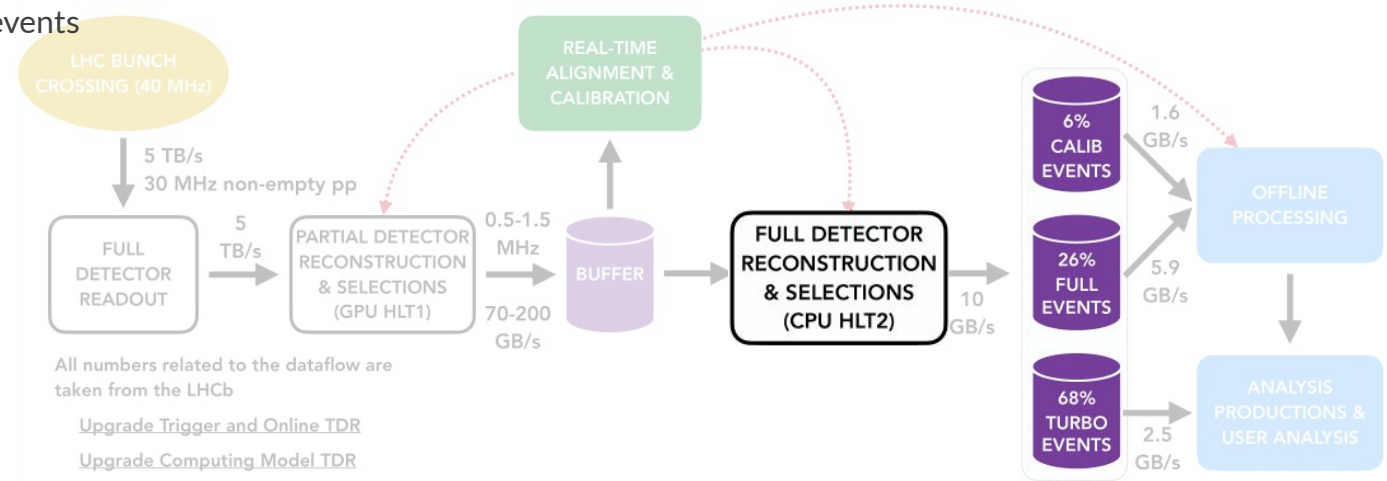
Tracking performance for different alignment conditions using VELO and SciFi

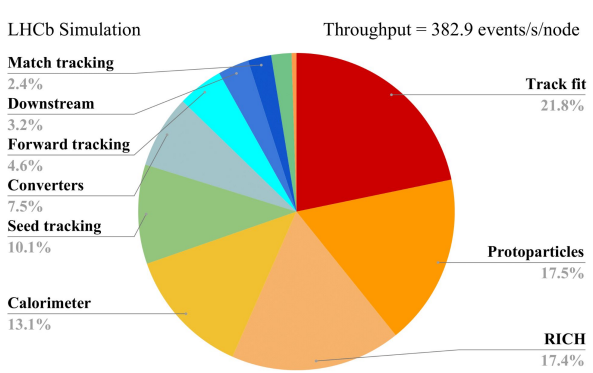
LHCb-FIGURE-2022-018



The second level trigger

- Processes data from a 30 PB disk buffer that allows for real-time alignment and calibration
- Performs a full offline-quality reconstruction and selection of physics signatures
- Run in O(4000) CPU servers
- Selected events are optimally stored using streams, save only relevant information from reconstructed events





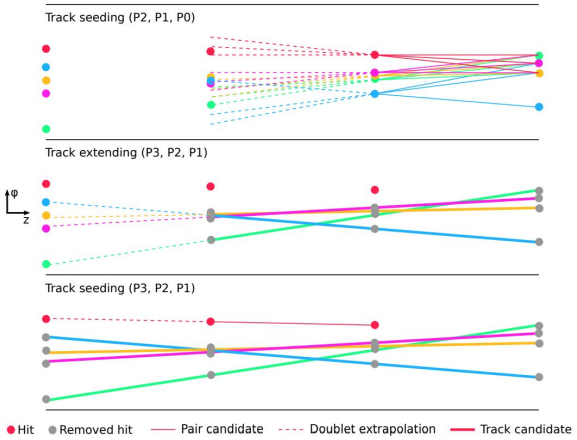
The second level trigger

Reconstruction

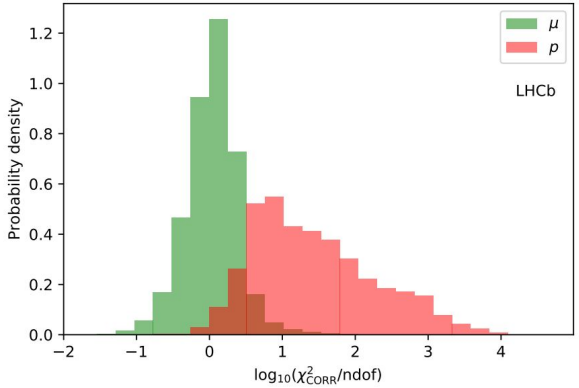
- **Charged particle pattern recognition**: Tracking with VELO, UT and SciFi
- **Kalman fit**: Achieve best accuracy and precision of tracks with a Kalman filter based algorithm

Track seeding and extension in VELO

A. Hennequin et al 2020 JINST 15 P06018



- **Calorimeter reconstruction**: ECAL cluster reconstruction and track matching
- **Particle identification**: using RICH1, RICH2, ECAL and Muon sub-detectors



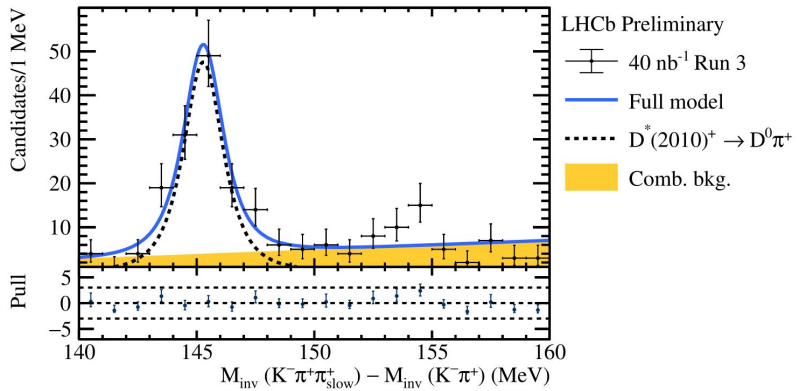
Spectrum of the χ 2 CORR, normalised to the degrees of freedom, for muons and protons samples using Run 2 data

L. Anderlini et al 2020 JINST 15 T12005

The second level trigger

Selections

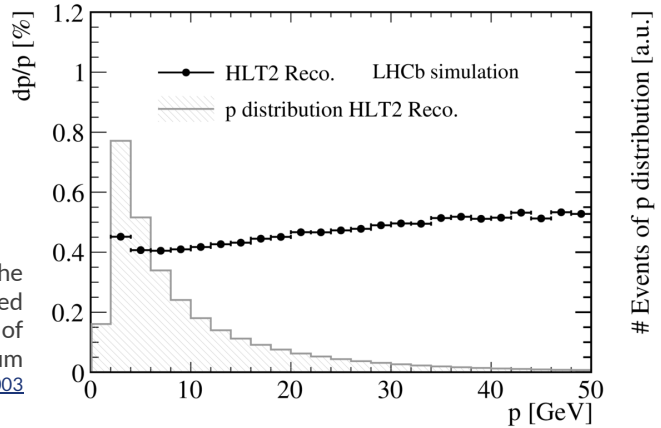
- O(1000) selection algorithms tuned for particular signal topologies of physics analysis
- Using multivariate or AI models



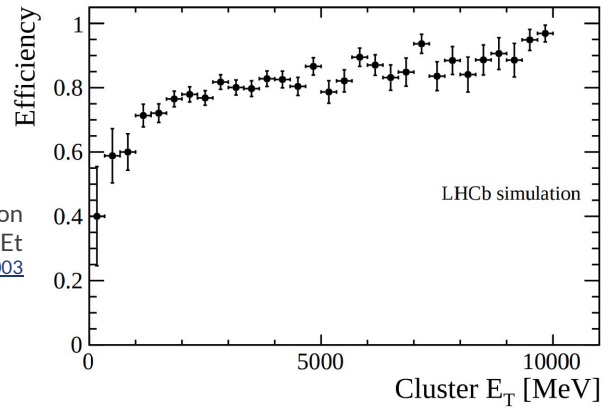
Mass difference of selected $D^*(2010)^+$ candidates

Performance

Relative resolution of the momentum of reconstructed tracks as a function of momentum
LHCB-FIGURE-2021-003



ECAL cluster reconstruction efficiency vs Et
LHCB-FIGURE-2021-003



Summary

- Current technology does not allow all LHCb proton-proton collision data to be stored and analyzed
- LHCb has a unique approach to real-time data processing
- RTA processes 5 TB/s and reduces it to 10 GB/s to permanent storage
- Succeed to run the first complete high-throughput GPU trigger in HLT1
- Long journey ahead for Run 3 and beyond!

Thank you!

Any questions?

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Backup

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