HLT2 & Alignment and Calibration at LHCb

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1. Overview of the trigger and real-time analysis

- The data volume generated from the LHCb detector currently reaches 5TB/s [1].
- To record the data to permanent storage, this rate is reduced by a factor 400 by the **trigger system** [2], which uses fully reconstructed events to select specific signals of interest.
- This approach is called **real-time analysis** [3]: requires an offline-quality reconstruction enabled by the alignment and calibration of the detector performed in quasi-real-time (Figure 1):
  - **HLT1**: Run in GPUs. Performs a partial reconstruction and reduces data volume by a factor 20 [4].
  - **Alignment and Calibration**: Ensures the physics parameters are computed with the best possible resolution.
  - **HLT2**: Run in CPUs. Performs a full offline-quality reconstruction and selection of physics signatures.

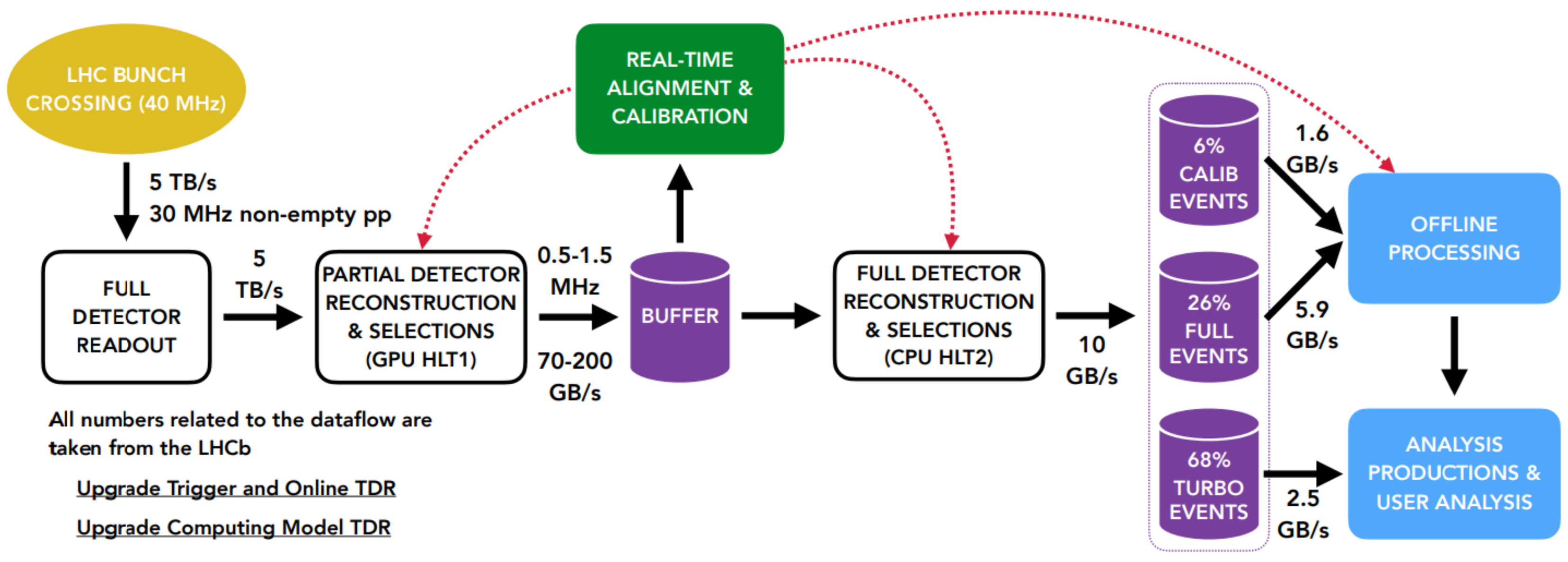

Figure 1: Online dataflow [5]

2. Aspects of HLT2

2.1. Reconstruction

The offline-quality reconstruction is divided into four main components:

- **Charged particle pattern recognition**: Tracking algorithms that use information from VELO, UT and SciFi detectors according to different track types (Figure 2).

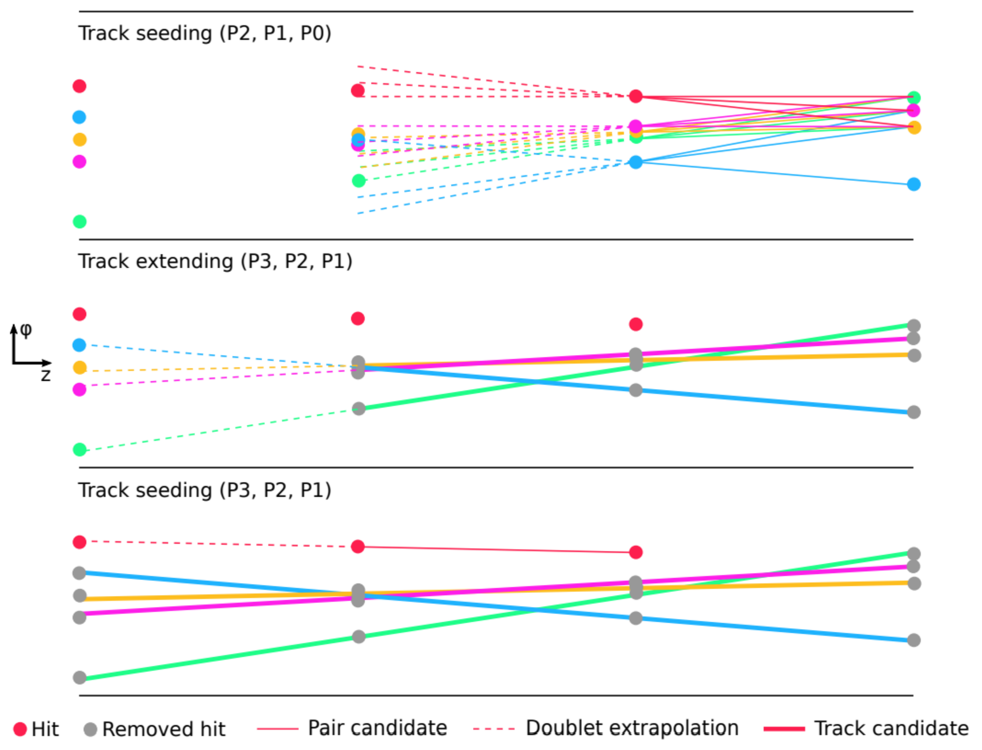

Figure 2: Example of track seeding and extension in the VELO pattern recognition algorithm [11].

- **Calorimeter reconstruction**: Build clusters from ECAL detector (Section 3) and match them with the extrapolation of reconstructed tracks.
- **Kalman fit**: Achieve best accuracy and precision of tracks with a Kalman filter based algorithm (Figure 3).

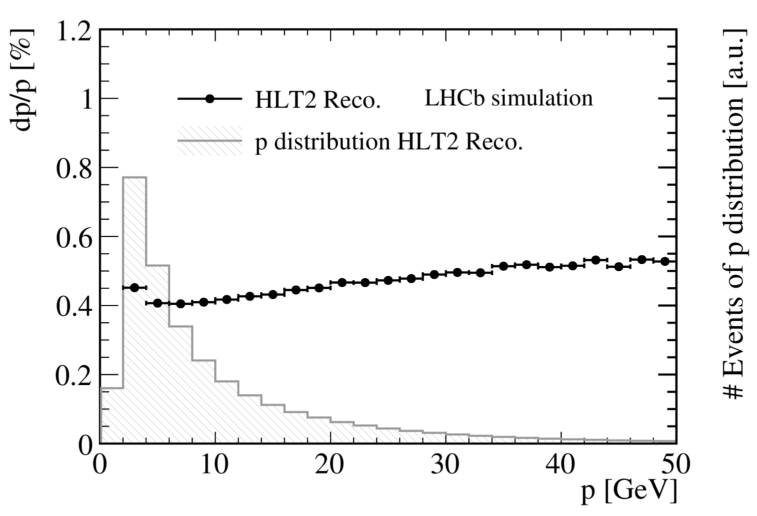

Figure 3: Relative momentum resolution of reconstructed tracks as a function of momentum [10].

- **Particle identification**: Information from the two RICH detectors [6], ECAL and the muon system [7] is used to identify charged particles. Optimal performance is achieved with machine learning algorithms.

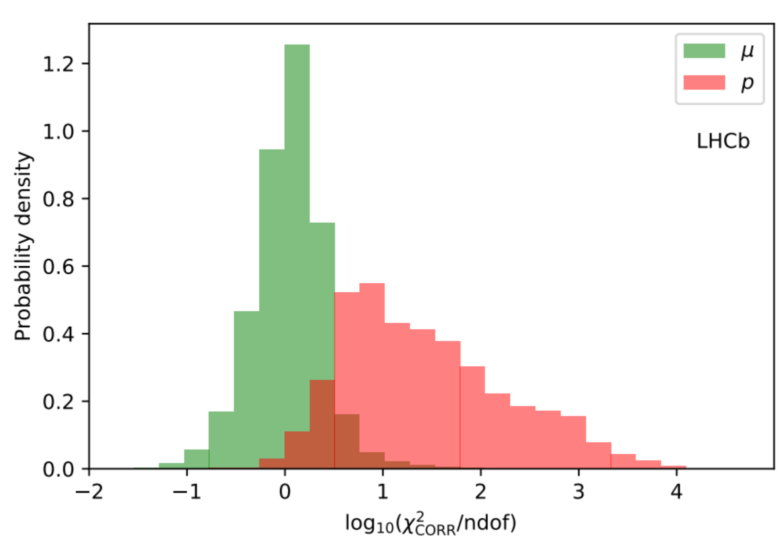

Figure 4: Spectrum of the χ 2 CORR, normalised to the degrees of freedom, for muons and protons samples. Evaluated with Run 2 data [7].

2.2. Selection

- The selection process relies on O(1000) selection algorithms tuned for a particular signal topology or physics analysis that can use multivariate or artificial intelligence models. An example of selected candidates is shown in Figure 5.
- After the selection algorithms, the information is sent to three streams according to its purpose: *full* stream, *Turbo* stream and *TurCal* stream [8].

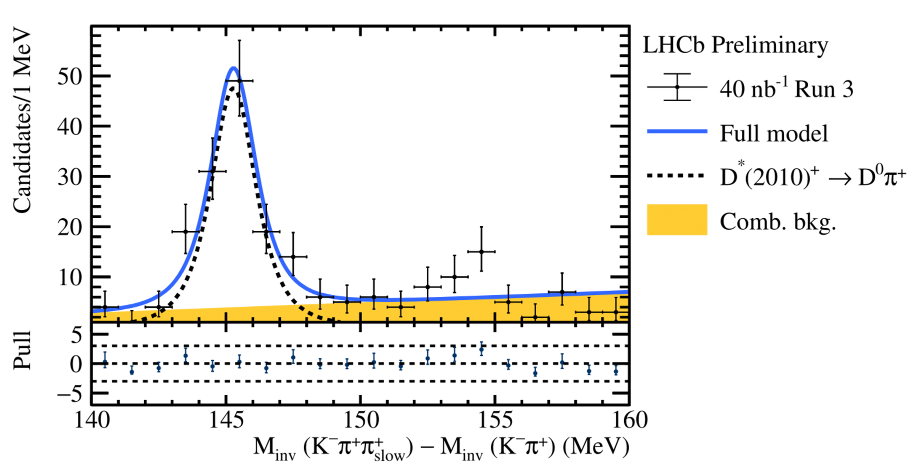

Figure 5: Mass difference of selected $D^*(2010)^+$ candidates.

3. Example of an improved reconstruction algorithm: Calo Graph Clustering

- Graph Clustering is the new default solution for ECAL reconstruction, maintaining the efficiency of the previous algorithm and **improving by 65.4% the execution time** on average (Figure 6).
- It uses graph data structures to store event digits.
- Using a set of rules, it inserts the digits into the graph to create cluster structures (Figure 7).
- It analyses the connected components solving the overlapping cells between clusters in a dedicated algorithm.

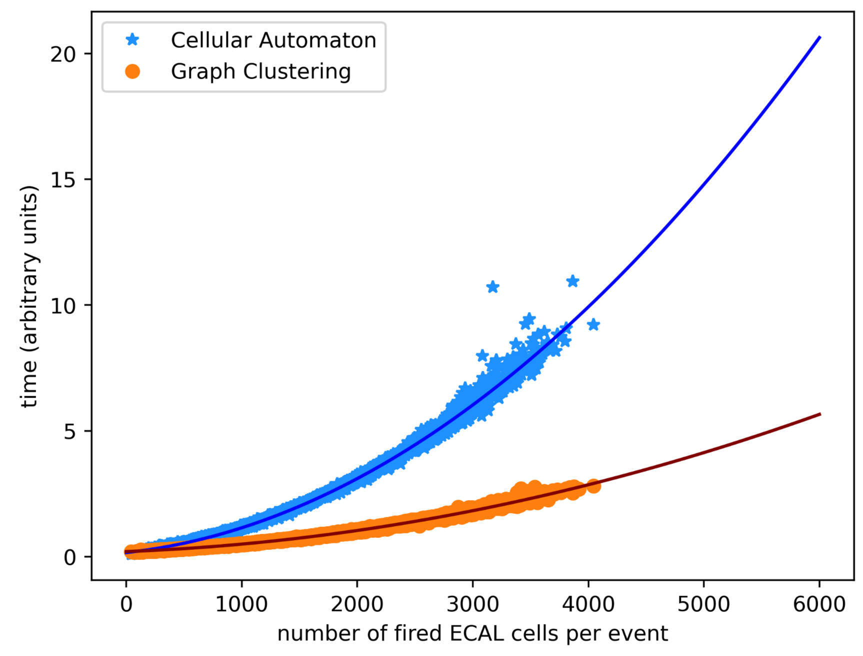

Figure 6: Complexity comparison between Cellular Automaton and Graph Clustering

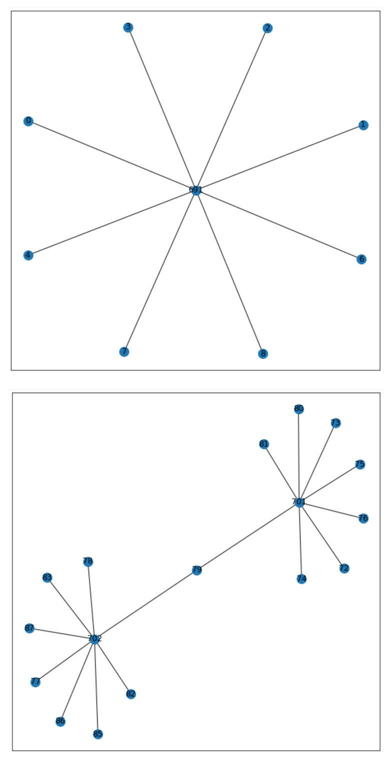

Figure 7: Examples of graph structures

4. Alignment and Calibration

- Provides the most accurate alignment and calibration parameters for reconstruction and selections.
- Each step is performed with a different frequency [13, 14].
  - Full tracking system: aligned at the beginning of each fill within few minutes.
  - Calorimeter calibration: evaluated every 2 weeks.
  - RICH calibration: evaluated on run basis. Mirror alignment performed for each fill within some tens of minutes.
  - Muon alignment: run as monitoring.

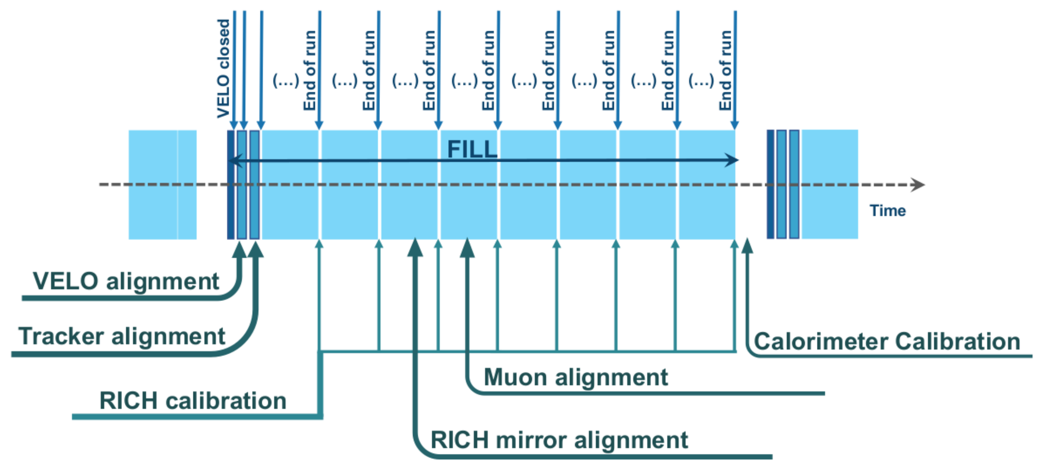

Figure 8: Schematic view of the real-time alignment and calibration procedure.

- **First alignment of the tracking system on Run 3 data has been evaluated** (Figure 9, 10).

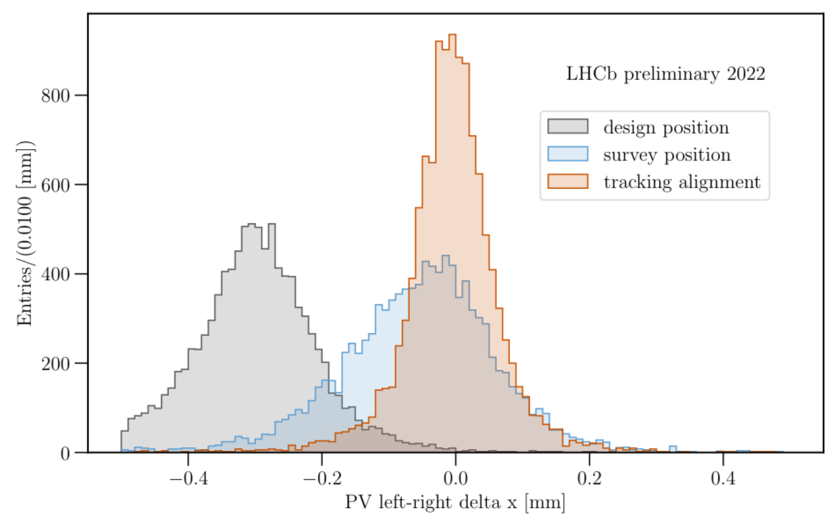

Figure 9: Misalignment of the VELO halves evaluated as the difference in x-position of the PVs on each VELO half, for different alignment conditions [12]

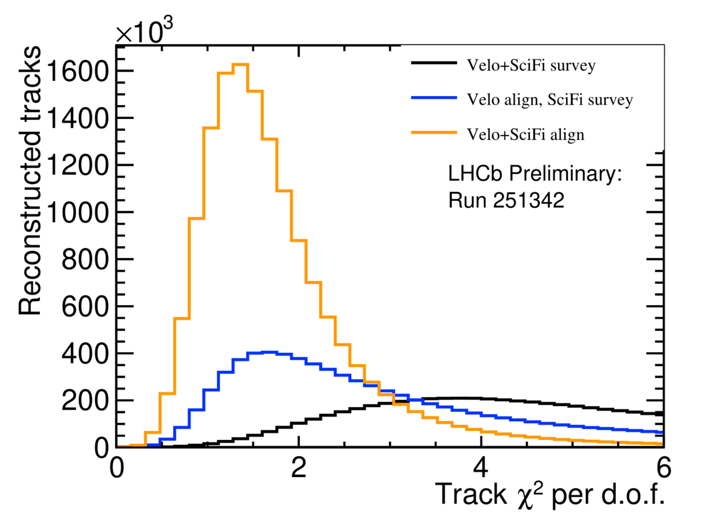

Figure 10: Tracking performance for different alignment conditions using VELO and SciFi [16].

- ECAL calibration requires to adjust the gain of PMTs using a LED reference value after each fill [15].
- A more fine-grained calibration is based upon the observed π^0 mass on each cell (Figure 11).

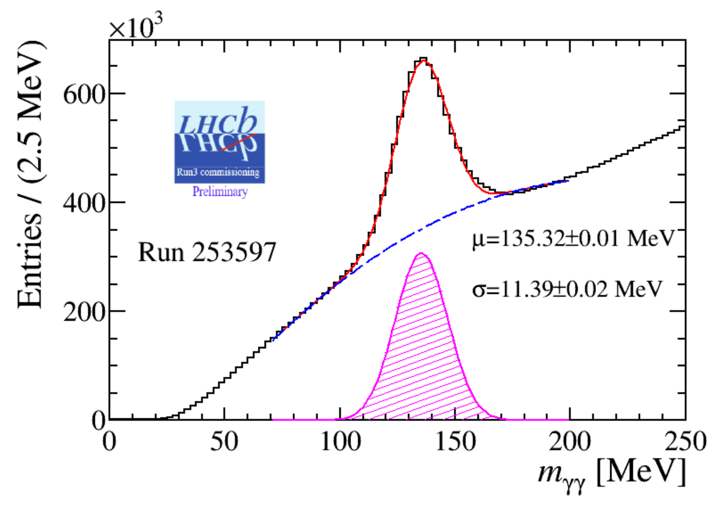

Figure 11: mDi-photon invariant mass after per-cell calibration.

References

[1] LHCb collaboration, *Framework TDR for the LHCb Upgrade: Technical Design Report*, CERN-LHCC-2012-007, 2012.
[2] R. Aaij *et al.*, *A comprehensive real-time analysis model at the LHCb experiment*, JINST 14 (2019) P04006, arXiv:1903.01360.
[3] R. Aaij *et al.*, *Tesla: an application for real-time data analysis in High Energy Physics*, Comput. Phys. Commun. 208 (2016) 35, arXiv:1604.05596.
[4] LHCb collaboration, *LHCb Upgrade GPU High Level Trigger Technical Design Report*, CERN-LHCC-2020-006, 2020.
[5] LHCb collaboration, *RTA and DPA dataflow diagrams for Run 1, Run 2, and the upgraded LHCb detector*, LHCb-FIGURE-2020-016, 2020.
[6] M. Adinolfi *et al.*, *Performance of the LHCb RICH detector at the LHC*, Eur. Phys. J. **C73** (2013) 2431, arXiv:1211.6759.
[7] L. Anderlini *et al.*, *Muon identification for LHCb Run 3*, JINST **15** (2020) T12005, arXiv:2008.01579.
[8] LHCb collaboration, *Computing Model of the Upgrade LHCb experiment*, CERN-LHCC-2018-014, 2018.
[9] V. Breton *et al.*, *A clustering algorithm for the LHCb electromagnetic calorimeter using a cellular automaton*, CERN-LHCb-2001-123, 2001.
[10] LHCb collaboration, *Selected HLT2 reconstruction performance for the LHCb upgrade*, LHCb-FIGURE-2021-003, 2021.
[11] A. Hennequin *et al.*, *A fast and efficient SIMD track reconstruction algorithm for the LHCb Upgrade 1 VELO-PIX detector*, JINST **15** (2020) P06018, arXiv:1912.09901.
[12] LHCb Collaboration, *VELO alignment with LHCb Run 3 early data*, LHCb-FIGURE-2022-016, 2022.
[13] S. Borghi, *Novel real-time alignment and calibration of the lhcb detector and its performance*, NIMA **845** (2017) 560.
[14] F. Reiss, *Real-time alignment procedure at the LHCb experiment for Run 3*, Proceedings of the CTD 2022 PROC-CTD2022-31.
[15] C. Abellán Beteta *et al.*, *Calibration and performance of the LHCb calorimeters in Run 1 and 2 at the LHC*, arXiv:2008.11556.
[16] LHCb Collaboration, *SciFi tracking alignment with LHCb Run 3 commissioning data*, LHCb-FIGURE-2022-032, 2022