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Novel real-time alignment and calibration of the LHCb detector in Run II

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ABSTRACT

An automatic real-time alignment and calibration strategy of the LHCb detector was developed for the Run II. Thanks to the online calibration, tighter event selection criteria can be used in the trigger. Furthermore, the online calibration facilitates the use of hadronic particle identification using the Ring Imaging Cherenkov (RICH) detectors at the trigger level. The motivation for a real-time alignment and calibration of the LHCb detector is discussed from both the operational and physics performance points of view. Specific challenges of this novel configuration are discussed, as well as the working procedures of the framework and its performance.

1. Introduction

The LHCb detector [1] achieved excellent performance in Run I [2] but faces more challenging conditions in Run II. The LHC will collide protons at an increased centre-of-mass energy of 13 TeV and with 25 ns bunch spacing. The spatial alignment of the detector and the accurate calibration of its subcomponents are essential elements to achieve the best physics performance [2,3]. An exclusive selection using hadron particle identification criteria relies on the complete calibration of the RICH detectors [2,4].

The LHCb trigger strategies for Run I and Run II data taking are shown in Fig. 1. The online event reconstruction in Run I was simpler and faster than that used offline and did not have the latest alignment and calibration constants applied. In Run II, the selected events after the first stage of the software trigger are buffered on local disks and an automatic calibration and alignment is performed. The alignment is evaluated using a dedicated event sample that can be enriched also with well known particle decays (e.g. $D^0 \to K\pi$, $J/\psi \to \mu\mu$) and the calibration is run on several nodes of the farm used for the trigger within few minutes. This online procedure enables the best possible calibration and alignment information to be used at the trigger level and, therefore, provide better reconstruction performance in the trigger. It also minimises the differences between online and offline reconstruction performance, and allows some physics analyses to be run directly on the trigger output [5].

2. Alignment and calibration framework

In the new framework, to coordinate the different alignment and calibration activities, two kind of tasks are present: the analyser and the iterator. The analyser performs the track reconstruction based on the alignment constants provided by the iterator and is parallelised on ~1700 nodes. A dedicated framework has been put in place to parallelise the alignment tasks on the multi-core farm infrastructure used for the trigger in order to meet the computing time constraints. The iterator collects the output of the analysers and minimises the χ^2 computing the alignment constants that can be used for the next iteration. The automatic evaluation is performed at the beginning of each fill. A change of run is triggered when the new alignment and calibration constants are available if significant variations are observed. These new constants are updated for the next run, are used online by the two stages of the software trigger, and offline for further reconstruction and selection.

3. Alignment of the LHCb detector

The alignment of the LHCb detector consists of four steps, corresponding to the detectors that are aligned: Vertex Locator (VELO), tracker, RICH mirrors and the muon system.

3.1. VELO, tracker and muon system alignment

The alignment of the VELO, tracker and muon system uses a Kalman filter fit to minimise the χ^2 calculated on residuals of reconstructed tracks [6,7]. Multiple scattering and energy loss in the material together with magnetic field information are taken into account. The Kalman filter also allows mass and vertex

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0168-9002/

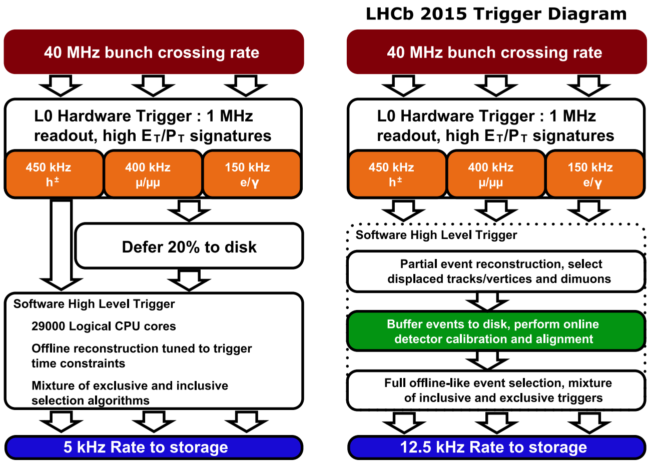

Fig. 1. Schematic diagram of the LHCb trigger data-flow in Run I data taking (left) compared to the proposed data-flow in Run II (right).

constraints to be incorporated, and to align multiple sub-detectors at once. Detector elements can be constrained to their nominal, surveyed or previously aligned position.

The VELO halves are moved every fill in order to be at a safe distance from the beam during LHC injection, thus the alignment may change for each fill. A maximum variation of $\mathcal{O}(10\ \mu\text{m})$ is more than the $\mathcal{O}(2\ \mu\text{m})$ precision of the alignment procedure. The detector conditions for tracker may change mainly due to the magnet polarity switch or technical stops. Small fluctuations of about 100 μm and 1 mrad are observed in Run I over time for the translational and rotational degrees of freedom, respectively.

Independent jobs for the VELO, tracker and muon system alignment are performed for each fill. The VELO alignment runs at the beginning of each fill and the alignment constants are updated immediately if required. Alignment of the trackers is run after the VELO and an update is expected every few weeks. Finally, the muon system alignment is run after the tracker. Variations are not expected [8] and the alignment is used for monitoring purposes.

3.2. RICH mirror alignment

Misalignments in the RICH mirrors cause the observed Cherenkov ring on the Hybrid Photon Detector (HPD) plane to be shifted by $\Delta\theta$ with respect to the position expected from the momentum of the incoming track. The misalignments are extracted in an iterative procedure by fitting the variation of the Cherenkov angle, θ, given by:

$$\Delta\theta = \theta_x \cos\phi + \theta_y \sin\phi$$

where θ_x and θ_y are the misalignment on the HPD plane and ϕ is the polar angle measured from the vector that defines the distance of the point where the track hit the detector and the reconstructed centre of the Cherenkov ring. The alignment constants are determined at the beginning of each fill.

4. Online calibration for RICH, OT and CALO

Calibration for RICH, Outer Tracker (OT) and Calorimeter System (CALO) is done online using either the output of the online reconstruction or monitoring data coming from the first stage of the software trigger. These online analysis tasks run on single CPU. Calibration constants are typically available within a few minutes after a change of run.

4.1. OT global time alignment

The largest contribution to variations in the time-offset t_0 of detection channels in the OT is due to a small drift in the LHCb clock relative to the time of collisions [9]. This variation is typically of the order of 0.4 ns per month. A global shift in the t_0 is estimated from the average drift time residual of OT hits. The algorithm is applied every run and constants are updated if the shift is above a certain threshold.

4.2. RICH calibration

The refractive index of the gas radiators depends on the composition of the gas mixture, temperature and pressure. Therefore, it changes with time and this affects the performance of the particle identification. Corrections are calculated by fitting the difference between the reconstructed and expected Cherenkov angle and will be updated for every run.

The position of the photon hit is reconstructed on the HPD plane. Movements of the projected images were observed and these movements were linked to the electrostatic effect probably due to switching off the High Voltage during every beam injection. The issue was resolved by the implementation of an automatic online correction for every run where the corrections are calculated by fitting a circle to the HPD image.

4.3. CALO calibration

The occupancy for each cell is defined as the fraction of events in which the cell is above a certain ADC threshold and the ratio of occupancies is proportional to changes in hardware characteristics. A relative calibration online will be performed on a per fill basis using an occupancy method to adjust the High Voltage based on the gain changes calculated from occupancy profiles.

An online calibration with π^0 will be performed to apply a calibration coefficient λ for each cell to move the reconstructed π^0 mass closer to the nominal mass. The reconstructed π^0 mass can be determined for each cell by fitting diphoton mass histograms where one of the photons has the cell as the seed. The full process takes more than an hour and will be run probably during the technical stops or even more frequently.

5. Summary

An automatic real-time alignment and calibration strategy will be used by LHCb in Run II. It provides a higher degree of coherence between the trigger and offline processing. Identical constants can be used in the online and offline reconstruction and thus stronger constraints can be applied in the trigger.

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