Fast online reconstruction and online calibration in the ALICE High Level Trigger

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THIS IS AN EXTENDED ABSTRACT,
We want to submit the full paper to IEEE TNS Journal after RealTime conference.

***Abstract*—ALICE (A Large Heavy Ion Experiment) is one of four major experiments at the Large Hadron Collider (LHC) at CERN. The ALICE High Level Trigger (HLT) is a cluster of 200 nodes, which reconstructs collisions as recorded by the ALICE detector in real-time. It employs a custom online data-transport framework to distribute data and workload among the compute nodes.**

ALICE employs subdetectors sensitive to environmental conditions such as pressure and temperature, e.g. the Time Projection Chamber (TPC). A precise reconstruction of particle trajectories requires the calibration of these detectors. Performing the calibration in real time in the HLT improves the online reconstructions and renders certain offline calibration steps obsolete speeding up offline physics analysis. For LHC Run 3, starting in 2020 when data reduction will rely on reconstructed data, online calibration becomes a necessity. Reconstructed particle trajectories build the basis for the calibration making a fast online-tracking mandatory. The main detectors used for this purpose are the TPC and ITS. Reconstructing the trajectories in the TPC is the most compute-intense step.

We present several components of the ALICE High Level Trigger used for fast event reconstruction and then focus on newly developed components for online calibration.

The TPC tracker employs GPUs to speed up the processing and is based on a Cellular Automaton and the Kalman filter. It has been used successfully in proton-proton, lead-lead, and proton-lead runs between 2011 and 2015.

We have implemented a wrapper to run ALICE offline analysis and calibration software inside the HLT. Normally, the HLT works in an event-synchronous mode. We have added asynchronous processing capabilities to support long-running calibration tasks. In order to improve the resiliency, an isolated process performs the asynchronous operations such that even a fatal error does not disturb data taking. We have complemented the original loop-free HLT chain with ZeroMQ data-transfer components. The ZeroMQ components facilitate a feedback loop, that after a short delay inserts the calibration result created at the end of the chain back into tracking components at the beginning of the chain. On top of that, these components are used to ship QA histograms to the Data Quality Monitoring (DQM) and to obtain information of pressure and temperature sensors needed for calibration. All these new features are implemented in a general way, such that they have use-cases aside from online calibration.

In order to gather sufficient statistics for the calibration, the asynchronous calibration component must process enough events per time interval. Since the calibration is only valid for a certain time period, the delay until the feedback loop provides updated calibration data must not be too long. A first full-scale test of the online calibration functionality was performed during the 2015 heavy-ion run under real conditions. We present a timing analysis of this first online-calibration test, which indicates that the HLT is capable of online TPC drift time calibration fast enough to calibrate the tracking via the feedback loop.

***Index Terms*—ALICE, HLT, LHC, Online Calibration**

Manuscript received May 30, 2016. This work was supported in part by the German Federal Ministry of Education and Research (BMBF).

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I. Introduction

ALICE is one of the four large-scale experiments at the Large Hadron Collider (LHC) at CERN [1]. Its main purpose is the study of matter under extreme conditions of high temperature and pressure. This is done through the collisions of lead nuclei accelerated by the LHC to the highest energies possible today. The design interaction rate inside ALICE is 8 kHz.

The ALICE High Level Trigger (HLT)[2] is an online compute farm for real time processing of the events recorded by ALICE. Based on the reconstruction of the data in real time, the HLT can trigger for or tag interesting events. On top of that, the HLT performs a compression of the raw data. During normal operation, the HLT receives and processes an incoming data rate of up to 30 GB/s. The most compute intense part of event reconstruction is the reconstruction of particle trajectories, called tracking. The most important detectors with respect to tracking are the Time Projection Chamber (TPC) and the Inner Tracking System (ITS). For the TPC track reconstruction, the HLT employs a GPU-accelerated algorithm based on the Cellular Automaton and the Kalman Filter [4].

Several detectors employed in the ALICE experiment are sensitive to environmental conditions such as temperature and pressure. The environmental conditions influence several characteristics of the detectors like gain or drift time. In order to perform a precise reconstruction, the detector calibration must take these effects into account. Since these environmental conditions change during data-taking, an initial calibration is insufficient. Instead, the detectors must be calibrated continuously.

Sensors alone, e. g. for pressure and temperature, are not enough for detector calibration. Instead, the calibration needs the reconstruction. For instance, TPC drift time is calculated

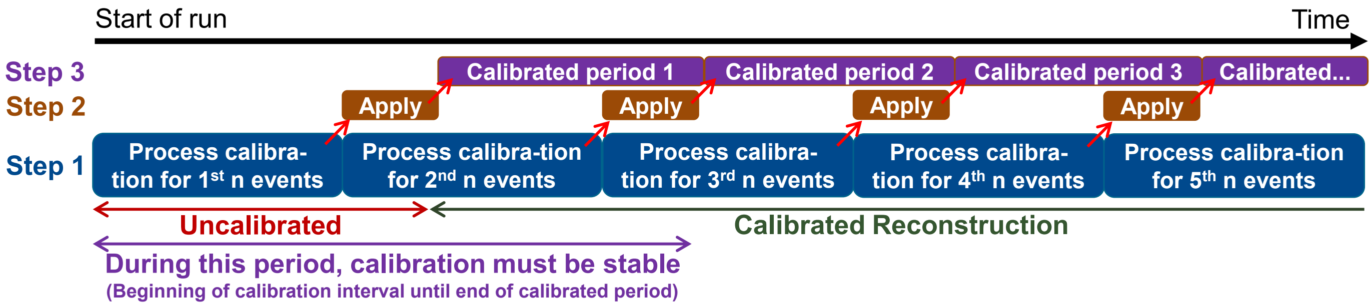

Fig. 1. Illustration of the online calibration approach in the ALICE High Level Trigger.

from the misalignment of matched reconstructed TPC and ITS tracks. This imposes a cyclic dependency: the reconstruction needs the calibration which needs the reconstruction. Normal ALICE Offline reconstruction copes with this with multiple reconstruction and calibration passes, where the first reconstruction uses a default calibration. This approach is infeasible in the HLT: it is impossible to keep all the data in memory to process the entire data set multiple times.

II. Online Calibration

ONLINE calibration in the High Level Trigger has several advantages:

- The online calibration results improve the online reconstruction in the HLT.
- There are more elaborate possibilities for online QA when the calibration is already available during data-taking.
- When the online calibration results are sufficiently good, it is no longer needed to perform certain calibration tasks offline, which can reduce the offline compute requirements.
- Future experiments like ALICE during LHC Run 3 or the FAIR experiments at GSI will face significantly higher data rates. It will be infeasible to store the entire raw data for later analysis. Instead, more elaborate triggering and data compression algorithms are mandatory, which need precise online reconstruction.

While calibration results are not stable through an entire data taking run, they are stable for a certain time period. In case of the TPC drift time calibration, which we want to discuss exemplarily, the stability interval is defined by the fastest possible weather change, and we assume that a calibration computed at a certain point in time is valid for at least the following 15 minutes. This opens a possibility for real time calibration in the HLT. As the first offline reconstruction pass, the HLT starts with a default calibration. It processes as many events as needed to gather sufficient statistics for the calibration. This statistic is gathered by many instances of the calibration tasks spread among all nodes of the HLT cluster to speed up the process. As a second step when enough statistics is aggregated, the calibration results from all tasks are collected and merged. New transformation objects are precalculated, e. g. to apply the calibration to the TPC hits. These objects are then distributed in the cluster. In the third step, the calibration is applied to the reconstruction for all new events. The final last calibration objects created contains also the entire statistic of the previous calibration intervals of the run. This object is then stored for offline usage. The three steps are arranged in a pipeline. As soon as the tasks have shipped their current calibration objects to the calibration merger, they restart with the computation of the next calibration immediately. The approach is visualized in Figure 1. There is an uncalibrated period at the beginning of a run before the first calibration objects are distributed in the cluster and applied. Afterward, the reconstruction of incoming data uses the calibration. This approach is feasible if the total time from the start of a calibration period (blue box) until the end of the calibrated period (purple box) is shorted than the stability interval of the calibration, in case of the TPC drift time 15 minuts. Afterward, the calibration result from the next calibration interval is used.

We have implemented several new features in the HLT to facilitate running online calibration tasks: New asynchronous processing components enable the execution of long-running tasks in the event synchronous HLT chain and a new Zero-MQ based data transport mechanism facilitates the feedback loop that distributes the calibration result in the cluster [3]. On top of that, a new flat data structure provides fast access to reconstructed events to all HLT components. For the calibration task itself, we have created a wrapper for standard ALICE analysis tasks, which can run any task that supports the new flat data structure. In this way, we can run the same code in the HLT that is used for the calibration offline.

III. First real test of online calibration and analysis

DURING the December 2015 lead-lead data taking, we performed a full-scale test of all the new features under real conditions. At the lead-lead event rates and sizes, around 5000 events are sufficient to gather the statistics needed for the TPC drift time calibration. This first test proved that the HLT is capable of processing these 5000 events fast enough in a maximum load scenario. There are few single large events which take extremely long to process because the matching time of TPC to ITS tracks goes superlinearly with the data size. In that case, the calibration result of the event is skipped for the feedback loop if it is not available in time. It is still used for the final calibration object stored for offline. By excluding the 2 % largest events from calibration, the total time for creation and distribution of calibration objects is around 7 minutes and thus well within the stability period of 15 minutes. Based on the analysis of this first test during heavy ion data taking, we have improved the online calibration procedure for 2016. Instead of processing all or a random selection of events, it is more efficient to select more but smaller events. In this way, the calibration task can match more tracks per second and aggregate sufficient statistics faster. On top of that, there are possibilities to speed up the offline calibration procedure. One important time-consuming part of the drift time calibration is the propagation of tracks through material. This can be sped up through similar techniques as employed in the fast TPC tracking [4]. Shortening the time until the availability of calibration results makes the approach feasible for other calibration tasks with shorter stability interval.

The analysis of the online calibration result and of the influence of the different tracking algorithms used in the HLT and offline on the calibration is ongoing. The online calibration with feedback loop in the HLT has been enabled since the restart of LHC operation in the beginning of 2016. Online calibration is running perfectly stable and there is not effecting normal data taking at all. As a next step we plan to test employing the new framework also for other analysis task and in particular QA tasks.

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