Monitoring the data quality of the real-time event reconstruction in the ALICE High Level Trigger

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Abstract. ALICE is a dedicated heavy ion experiment at the CERN LHC. The ALICE High Level Trigger was designed to select events with desirable physics properties. Data from several of the major subdetectors in ALICE are processed by the HLT for real-time event reconstruction, for instance the Inner Tracking System, the Time Projection Chamber, the electromagnetic calorimeters, the Transition Radiation Detector and the muon spectrometer.

The HLT reconstructs events in real-time and thus provides input for trigger algorithms. It is necessary to monitor the quality of the reconstruction where one focuses on track and event properties. Also, HLT implemented data compression for the TPC during the heavy ion data taking in 2011 to reduce the data rate from the ALICE detector. The key for the data compression is to store clusters (spacepoints) calculated by HLT rather than storing raw data. It is thus very important to monitor the cluster finder performance as a way to monitor the data compression.

The data monitoring is divided into two stages. The first stage is performed during data taking. A part of the HLT production chain is dedicated to performing online monitoring and facilities are available in the HLT production cluster to have real-time access to the reconstructed events in the ALICE control room. This includes track and event properties, and in addition, this facility gives a way to display a small fraction of the reconstructed events in an online display. The second part of the monitoring is performed after the data has been transferred to permanent storage. After a post-process of the real-time reconstructed data, one can look in more detail at the cluster finder performance, the quality of the reconstruction of tracks, vertices and vertex position. The monitoring solution is presented in detail, with special attention to the heavy ion data taking of 2011.

1. Introduction
ALICE (A Large Ion Collider Experiment) is one of the experiments at the CERN LHC. It is designed to study the properties of strongly interacting matter created in proton-proton and heavy ion collisions at ultrarelativistic energies [1]. The ALICE experiment produces vast amounts of data, the data stream can reach up to 25 GB/s, which imposes great challenges both concerning storage and data analysis. The High Level Trigger (HLT) is an on-line system with the capability of triggering on events based on the physics content, reducing the rate of data recording, data monitoring and event display. The HLT is a part of the ALICE trigger scheme which includes three hardware triggers L0, L1 and L2. Events triggered at L0 level and accepted
at L1 and L2 levels are subsequently fed into the HLT system where they are processed and reconstructed in real time. The reconstructed tracks and vertices are stored in Event Summary Data (ESD) blocks, which are of identical format to those used by the offline analysis. A more detailed description of the tracking and reconstruction scheme in HLT can be found for instance in [2]. The HLT issues trigger decisions based on the physics content of the event, and both the reconstructed event and the trigger decision, as part of the HLTOUT data, are passed on to the Data Acquisition (DAQ). DAQ will subsequently either reject the event or partially or fully store the HLTOUT data together with the raw-data from the detectors to permanent storage.

In addition to selecting events based on the physics content, the HLT reconstruction results are also used to reduce the data volume for the TPC in the Pb-Pb run of 2011. Rather than storing the raw data from the TPC detector, clusters (spacepoints) calculated by HLT are stored in a compressed data format. These clusters are then used in the offline reconstruction.

The HLT consists of a computing cluster of 248 machines with a main production cluster of 205 machines. These 205 machines correspond to a total of 2744 CPU cores, 64 GPUs and 246 FPGAs with an overall distributed memory of approximately 5.3 TB. Each machine is interconnected via a high-throughput InfiniBand network. For more information on the technical aspects of the HLT, see for instance [3].

Several of the major detectors in ALICE are inspected by the HLT, i.e the Inner Tracking System (ITS), the Time Projection Chamber (TPC), the electromagnetic calorimeters (EMCAL), the Photon Spectrometer (PHOS), the Transition Radiation Detector (TRD) and the muon spectrometer. The main focus of this article is the description of the monitoring setup, what can be achieved during data taking and the subsequent quality assessment carried out offline. The monitoring task includes both track and event properties. Starting from the Pb-Pb runs in 2011, it also includes monitoring of the data compression. Section 2 explains the monitoring scheme in detail while section 3 shows some results obtained through 2011.

2. Monitoring of the reconstructed data

The monitoring of HLT TPC and ITS tracking and compression of TPC data is performed in two stages, during data-taking and after data has been transferred to storage. This is referred to as online monitoring and HLT offline Quality Assurance (QA), respectively. An overview of the monitoring scheme is shown in Figure 1. The online monitoring (yellow) involves the creation of monitoring histograms which are stored in the HLT computing cluster and also displayed in the Data Quality Monitoring (DQM). These are further used for creating trend plots showing the mean value of monitored quantities versus run number. HLT offline Quality Assurance (blue) involves inspection of the online reconstruction output and comparison with the offline reconstruction and it also involves rerunning the reconstruction in an HLT emulation.

![Figure 1. Data flow for the HLT monitoring. The yellow box indicates the online monitoring while the blue boxes indicate the offline monitoring.](image-url)
2.1. Online Monitoring

Dedicated monitoring components are running on the HLT computing cluster. These components collect track performance parameters, event properties and compression information from different events. There are two ways of running the monitoring components, they can either be part of the main production chain, which forms part of the readout data path, or the components can be run in a separate monitoring chain decoupled from the main chain. If monitoring components are run inside the production chain the output from the components are published via a separate component called the TCPDumpSubScriber using the HOMER (HLT Online Monitoring Environment including Root) protocol [4].

2.1.1. Running the monitoring components in a dedicated chain

The advantage of running the monitoring components in the main production chain is access to the full statistics. The disadvantage is that all components running inside the main chain need to be very stable, the components cannot be in such a state that they interfere with the running of the chain, thus they require a long commissioning time. To increase the stability of the main chain, it was decided to run a separate monitoring chain in parallel. The monitoring chain was implemented on the HLT production cluster during the autumn of 2011. The separation of monitoring chains reduces the commissioning time of the main production line as well as decouples the monitoring part from it. In addition, the monitoring chain also allows for testing of new components during data taking (live prototyping), if necessary. An overview of the scheme used with the monitoring chain is shown in Figure 2. The data are sampled at random rate, estimated from 5 to 20 Hz, from the main production chain using TCPDumpSubscribers. These data samples are attached to the chain at appropriate points, for instance

1) after the reconstruction to pull out fully reconstructed data
2) after the compression component to extract compression information
3) after the global trigger counters to extract trigger rates
4) after the EMCAL and MUON reconstruction chains to extract data for analysing reconstruction quality that is not necessarily available via ESDs.

With a specialized component using the HOMER protocol, the outputs are extracted from TCPDumpSubscribers and injected into different monitoring components.

2.1.2. Further processing of monitoring objects

Independently of whether the histograms and monitoring objects originate from the production or monitoring chains, an application called MonitorMemoryWriter fetches them over the HOMER protocol from a network connection and

![Diagram of the HLT monitoring system](image-url)
Table 1. The subset of histograms produced in the monitoring chain which are sent to DQM. The HLT also creates histograms with EMCAL information which are sent to DQM, these are not listed here. See [8] for more detailed information on the EMCAL.

| Compression information | Event Properties | TPC cluster | Performance |
|-------------------------|------------------|-------------|-------------|
| Track Information       |                  |             |             |
| TPC clusters per track  | SPD Vertex X,Y,Z | Charge      | Reduction factor vs number of clusters |
| DCAr, Multiplicity      | SPD Vertex X vs Y| Maximum Charge |             |
| Transverse momentum     | Amplitude V0A vs V0C| Maximum Charge vs sector |             |
| ITS clusters per track  | Amplitude V0 vs ZDC| σ_y and σ_z vs sector |             |
| Phi, Polarity           | Centrality       | Pad vs Row per sector |             |

archives them. Web pages displaying the histograms in a dedicated screen in the ALICE Control Room (ACR) are also created, which allows the shift crew a quick inspection of the individual histograms. The histograms are also forwarded to the DQM (Data Quality Monitoring) station in the ACR. DQM is part of the DAQ and provides an online feedback on the quality of the recorded data. It involves online gathering of data, detector specific analysis algorithms and visualization of monitored data [5][6]. Using the HOMER protocol, DQM connects to the monitoring chains in the same way as the MonitorMemoryWriter component. The only difference is that the generated histograms are fed into the DQM framework and subsequently displayed on the DQM screens in the ACR. DQM forms a very important backbone in the online monitoring as there is always a person on shift monitoring these histograms and issues notifications if an error or warning occurs. Table 1 shows an overview of the quantities which are sent to DQM. HLT also creates histograms with EMCAL information which are sent to DQM.

HLT also provides information on the collision region where one uses the SPD vertex distributions calculated by the HLT. The SPD vertexer is a standalone component which calculates the primary vertex based only on the hits in the SPD detector. The histograms are produced in the main production chain and published via TCPDumpSubscribers. A standalone binary called hltdimserver connects to the TCPDumpSubscribers, fetches the SPD vertex distribution histograms and publishes the distribution parameters via DIM (Distributed Information Management) [7]. DIM is a protocol that the DCS (Detector Control System) uses internally for data exchange and communication. The collision region can then be broadcast to the LHC Control Room by the DCS, and published parameters are the X,Y and Z distributions together with their RMS values.

A further part of the online monitoring is the online event display. It provides a visual display of a fraction of the reconstructed events. The event display also connects to the production chain via the TCPDumpSubscriber to fetch the data. The online event display uses the same libraries as the offline event display, but has some additional compiled libraries in order to communicate with the main production chain. Figure 3 shows a Pb-Pb collision from 2011, produced from the HLT reconstructed data.

2.2. Offline Quality Assurance

During offline reconstruction, the online HLT ESD data blocks in the HLTOOUT data are extracted from the raw data and stored in parallel to the offline ESD data. As the formats of the two are identical, subsequent analysis can be applied to either the ESD or HLT ESD, or both.

Because no further event reconstruction is required, data from HLTOOUT can be very quickly extracted from raw data files immediately after a run is registered on permanent storage. This allows for a fast feedback on the quality of the online reconstruction and calibration,
independently of the central reconstruction cycle.

In addition, there is a HLT simulation in place which makes it possible to run the HLT reconstruction offline. At this stage one has access to the Offline Conditions DataBase (OCDB) stored on Grid, which makes it possible to run the reconstruction with improved calibration. The HLT simulation is thus a good tool to assess the quality of the calibration used in the online reconstruction and also very valuable when assessing an update in the reconstruction algorithm.

3. Performance of the HLT tracking extracted from the monitoring routine

Results on HLT QA for 2010 proton-proton collisions are presented in [9]. While the HLT TPC QA in 2010 mainly focused on comparing the offline and online reconstruction results, for 2011 data the focus shifted towards the stability of the HLT TPC tracking over time. This comes as a natural consequence of the fact that the HLT tracking had been fully commissioned and transferred to stable production mode.

As mentioned in section 2.1.2, the plots produced in the monitoring chain are archived in the HLT cluster farm. These histograms are produced for every run including the HLT, thus they are a natural choice when creating trend plots, i.e. plots which show the performance over time. The mean value is calculated for each quantity and plotted versus run number. Figure 4 shows the trend of the number of assigned TPC clusters per track and the distance of closest approach in the transverse plane of tracks to the calculated primary vertex (DCAr). The plots show all the physics pp runs with a duration of more than 10 minutes in which the HLT participated in 2011. Run periods for proton-proton 2011 are labelled LHC11a, LHC11b, LHC11c, LHC11d, LHC11e and LHC11f. The runs from LHC11a and LHC11b were taken during a commissioning period for the HLT, thus the performance in these periods are of variable quality. This is improved in LHC11c although one can still see some instability especially in the trend for TPC clusters per track due to changing TPC settings. For instance, between run 153876 and run 153905 on June 9th there was a change in the voltage settings for the TPC detector. This caused a shift in the TPC cluster distribution and thus a lower mean value which is clearly visible on the plot. The monitoring scheme was changed during the LHC11e period and during this period no monitoring components were running for the TPC, thus there are no points for this period. LHC11f was the commissioning period for the upcoming Pb-Pb period, hence the performance in the period
Figure 4. 2011 pp data trend - average DCAr and the number of TPC clusters per track. Different periods are marked with different colors and symbols.

Figure 5. 2011 pp data trends - the average value of SPD vertex X, Y and Z coordinates per run.

is of variable quality.

Figure 5 shows the mean SPD X, Y and Z vertex coordinates versus the run number for pp in 2011. The trend for the SPD vertex in pp shows that the vertex distributions is generally quite stable with some outliers. After a careful examination it was noticed that the outliers have a higher background than other runs and this could explain the lower mean value. Some of the runs are also marked by the offline group as “bad” runs and will not be part of the runs used for physics analysis. Thus, this is not a performance issue related to the online reconstruction but rather illustrates changes in the run conditions.

As mentioned previously, HLT reconstructed clusters replaced the TPC raw data during the Pb-Pb 2011 run. The HLT TPC data reduction was activated during the whole period and achieved an overall reduction factor of at least 4.4. The trend of the HLT TPC data reduction (Figure 6) shows a very stable performance of the data compression over the entire Pb-Pb run. The missing points are runs where the monitoring histograms were not available due to technical problems with the monitoring chain in the beginning of the Pb-Pb run period. Because of the
good performance of the HLT cluster finder, it was decided to also use it in the 2012 running period.

4. Conclusions
With the continuous operation of the ALICE HLT in 2011, the online monitoring of the event reconstruction performance has become an integral part of the ALICE online system. The environment for online monitoring and offline quality assurance was expanded and improved during 2011 resulting in a very stable tool to monitor and assess the quality of the online reconstruction. There was a paradigm shift in the online monitoring during 2011 where the monitoring components were moved from the main production chain to a separate monitoring chain which communicates asynchronously to the main chain. This paradigm shift shows great promise and has improved the stability of the main chain.

The performance of the HLT tracking proved to be quite stable for most of the data taking in 2011. The implementation of the TPC cluster finder for Pb-Pb run of 2011 was very successful, achieving a data reduction factor of at least 4.4. The HLT TPC clusters will also be used in the data taking of 2012.

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Figure 6. Trend of the total reduction factor when using HLT TPC clusters compared to TPC raw data in Pb-Pb 2011. The missing points are runs where the monitoring histograms were not available.