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Triggers and streams for calibration in CMS

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Abstract. Sustained operation of the CMS detector requires feeding the calibration workflows with precisely the information that is needed for optimal determination of the constants. Beyond the regular data streams used for physics analysis, the CMS experiment maintains various data streams that are dedicated for calibration purposes. This includes streams collecting data produced by hardware calibration systems. Some calibrations requiring particularly high events rates are driven by special data streams that select the relevant event fractions already at the HLT level, for example π^0 and η candidates for the intercalibration of the electromagnetic calorimeter. A dedicated express stream drives very low latency workflows that are operated at the CERN Analysis Facility. In many cases, dedicated triggers are essential to select the appropriate event types and build the corresponding streams. Experience from operating this system during the ramp-up of LHC luminosity in spring 2010 is presented.

1. Introduction

The CMS experiment at the Large Hadron Collider at CERN (European Organization for Nuclear Research, Geneva, Switzerland) has the typical structure of a hermetic collider detector, with several layers of detectors of different kinds arranged around the interaction point [1]. Calibration and alignment of such a complex detector is a serious challenge and an important one to reach the physics goals for which the experiment was designed. The silicon tracker has about 76 million channels in 17,000 modules to calibrate and align. The electromagnetic calorimeter (ECAL) comprises about 76,000 crystals for which calibration and alignment is required, and 137,000 channels in the silicon preshower. Calibration is needed for the 10,000 channels of the hadron calorimeter and the more than 1500 gas chambers of the muon detector need to be aligned and calibrated. In this paper we will focus on how calibration data from the CMS detector is made available to apply the necessary calibration and alignment algorithms.

2. Design and implementation of the Alignment and Calibration System

In order to handle calibration and alignment data in an efficient way, a system based on several data streams was designed. A fast turnaround is needed, as precise and up-to-date calibration and alignment payloads are necessary to complete the reconstruction chain. A calibration stream can serve one or more calibration algorithms and is built on an event selection tuned specifically for those algorithms. In order to keep the bandwidth of these streams low and the dataset sizes manageable, events are not saved in their full form, but the content is restricted to the information needed by those particular calibration or alignment tasks. For example, a stream

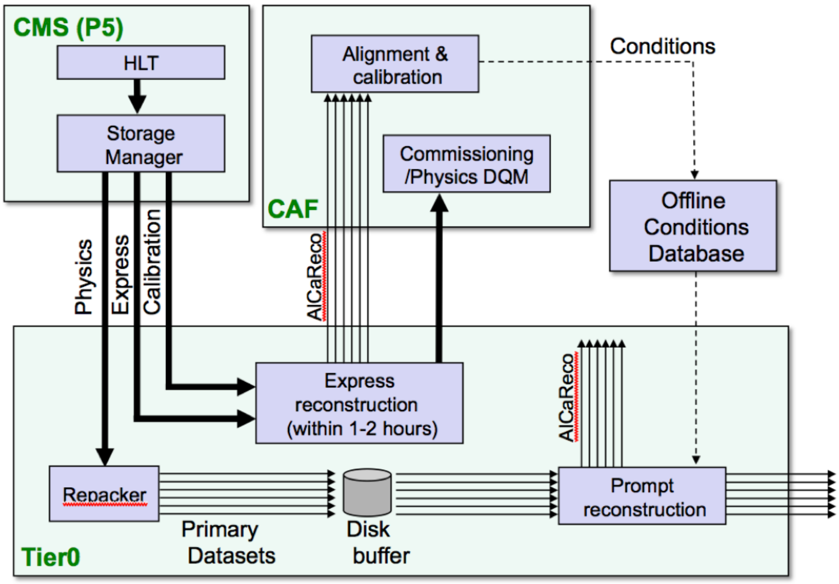

Figure 1. Overall scheme of the CMS calibration and alignment system (see text for details).

devoted to the calibration of the electromagnetic calorimeter may contain only data from that detector.

In figure 1 the overall CMS processing workflow relevant for alignment and calibration is illustrated [2]. Data originates from the CMS detector where the High Level Trigger (HLT) farm, via the Storage Manager, writes events to three major data paths : the *Physics* path, the *Express* path and the *Calibration* path. Each of these paths can consist of one or several streams directed to the Tier-0 processing facility. The path labeled *Physics* is the main stream used for physics analysis, which is processed within one or two days after acquisition (*prompt reconstruction*). About 10% of the events in the *Physics* path are redirected to the faster *Express* path, which is processed within one to two hours from acquisition in order to provide the calibration and alignment (*AlCaReco*) datasets. These datasets are used to apply the algorithms that eventually produce the calibration and alignment payloads that feed the offline conditions database. The conditions are then ready to be used for offline processing, for example by the *prompt reconstruction* we already mentioned. The *Calibration* path consists of streams of events selected by dedicated calibration triggers. These include events originated by test pulses injected into the electronics, laser and led shots which illuminate the crystals of the ECAL, but also physics triggers: for example one is devoted to the selection of π^0s.

3. Triggers and Calibration Streams

Since the calibration streams and the trigger system are tightly interconnected, we review briefly the basic principle of the latter [3]. The CMS trigger system is organized in two levels. The Level 1 trigger system reduces the event rate from the 40 MHz bunch crossing frequency down to 100 kHz. It is implemented in hardware and has a latency of 4μs. Events accepted at Level 1 are filtered by the High Level Trigger (HLT) to reduce the rate to about 100 Hz. The HLT is implemented in software using a farm of standard linux computers. It performs a full reconstruction of the events in a way very similar to that used in the offline processing, evaluating a series of *trigger paths*. The paths are evaluated in an average time of 40 ms. The available disk bandwidth is about 300 Mb/s, of which about 40 Mb/s are occupied by the calibration paths.

The alignment and calibration streams can be of type *online* or *offline*. The online streams are defined by HLT trigger paths selecting low bias events that would normally be discarded by the physics triggers. They implement at the same time a trigger and a calibration stream. Examples are the π^0 stream for ECAL calibration or the stream containing data for the laser calibration and alignment systems, which allow to read out the response of various subdetectors to the laser light activated during the LHC abort gap [1].

The offline streams are a special selection built from the express stream and the normal physics stream, containing only information relevant for a particular calibration or alignment workflow. Examples are tracker alignment streams using minimum bias events, muons and low mass resonances, ECAL calibration with electrons from W and Z bosons, HCAL calibration with two-jet events.

3.1. Online streams and dedicated triggers

At LHC, the physics case is focused on rare events typically containing objects with high transverse momentum. The trigger table is designed to achieve high efficiency for this kind of events while heavily prescaling low energy objects. On the other hand, calibration and alignment algorithms, in order to achieve the required precision, are in need of large statistics, achievable only with events containing objects of lower energy. In order to cope with these two conflicting requirements, the flexibility of the software HLT is exploited by writing to disk, to separate streams, only the relevant information. In this way, the rate of events written to disk can be kept high (of the order of 100 kHz), while the occupied bandwidth can stay below the allocated 40 Mb/s. Examples of online streams are :

(i) The ECAL π^0 and η streams, which consist of HLT trigger paths devised to select resonance candidates and save a reduced event to a dedicated stream;
(ii) ECAL azimuthal symmetry, which is a low bias selection of hits above a threshold in the calorimeters.

Apart from the abovementioned online streams, the following alignment and calibration datasets are selected with dedicated triggers:

(i) HCAL isolated track, devised to perform a single particle calibration of the hadron calorimeter;
(ii) Tracker cosmic, which, during data taking with collisions, collects triggers generated by cosmic rays;
(iii) Beam halo stream, which selects muons that travel parallel to the beam.

In the remainder of this paragraph, we will describe in more detail one of the online streams, the pi^0 stream.

The π^0 stream is a dedicated HLT trigger path which starts from Level 1 candidates such as single photon or electron candidates or single jets. The software unpacks interesting calorimeter regions and performs a simple reconstruction. Hits belonging to candidates of transverse energy above 0.8 GeV are saved to disk. In figure 2 the invariant mass of photon pairs reconstructed from the calibration stream is shown for data and MC. Without a dedicated calibration stream, it would have been impossible to obtain such a high yield. In particular, Figure 3 illustrates the need for a special calibration trigger in order to use the π^0 resonance for the calibration of the calorimeter: as the instantaneous luminosity increases, the regular minimum bias trigger is progressively prescaled, and the rate of accepted events decreases. On the other hand, the rate in the calibration stream keeps increasing. The normal physics stream would be insufficient for this kind of calibration.

[1] The abort gap consists of one or several empty buckets in the filling scheme of the machine. This is necessary to allow the magnetic field in the *kicker* magnets to reach the intensity required to deviate the beam toward the beam dumps

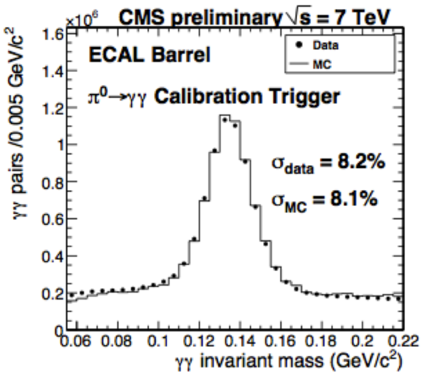

Figure 2. The $\pi^0 \rightarrow \gamma\gamma$ signal as reconstructed from the calibration stream in comparison with the Monte Carlo expectation.

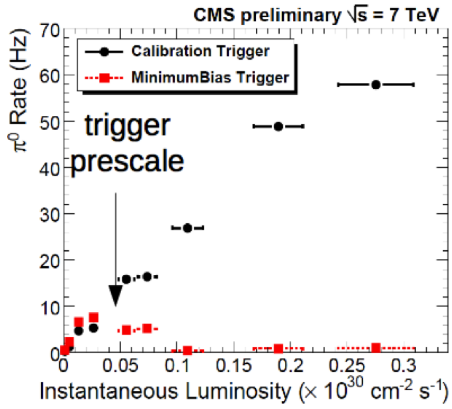

Figure 3. Rate of reconstructed π^0 as a function of instantaneous luminosity for the π^0 calibration stream and for the regular minimum bias physics trigger.

Figure 4 shows the intercalibration precision achieved by the π^0 stream alone in the central part of the calorimeter. The analysis of this stream, in combination with the azimuthal symmetry stream and the initial LHC beam-dump data [6], reached an intercalibration precision of 0.5% in the central region already after only a few months of data taking 5. This is the target precision needed for difficult analyses such as Higgs searches in the $H \rightarrow \gamma\gamma$ channel.

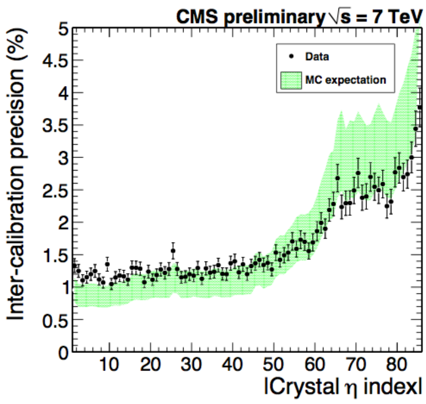

Figure 4. Precision of the ECAL calibration constants derived with the π^0 method as a function of pseudorapidity.

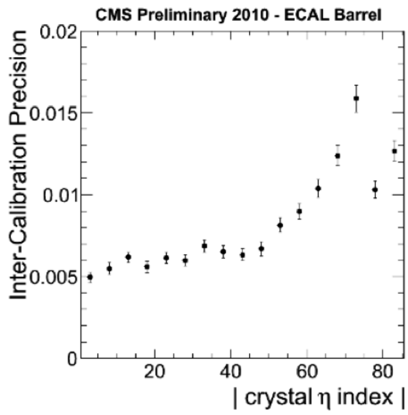

Figure 5. Precision of the ECAL calibration constants from the combination of three methods, as a function of pseudorapidity.

A last class of online calibration streams is populated by the data from the laser calibration systems. During the abort gap the ECAL crystals are illuminated by laser light of several wavelengths and read out by an independent photodetector to measure the change in transparency due to radiation damage. Transparency corrections are calculated on a dedicated

PC farm. Data acquired using the laser system flow on a separate ECAL laser calibration stream.

3.2. Offline streams

The offline datasets are either created from the *Express* path, which consists of a fast turnaround path for 10% of the physics events, or from the primary datasets arising from the physics streams. They consist of skimmed-down datasets containing only the information relevant for calibration and alignment purposes. As an example of offline workflow, we will describe in some more detail the case of the calibration and alignment of the silicon tracker. Information on the procedures adopted for the muon detector, ECAL and HCAL can be found in [5], [6] and [7] respectively. Four sets of conditions need to be calibrated in the case of the silicon tracker:

(i) Channel gain;
(ii) Channel status;
(iii) Hit efficiency;
(iv) Lorentz angle.

The calibration of these parameters is performed using a dedicated offline stream that selects low bias events and saves tracker related information for each selected event. The channel status workflow must identify bad channels and exclude them from calibration. In order to do so, the Data Quality Monitor (DQM) system is exploited to produce the several thousand histograms needed to complete this task. The alignment of the tracker is another serious challenge, with alignment parameters to be measured for about 17,000 modules. A module-level alignment was performed using 1.7 million collision tracks (corresponding to the first nb^{-1} of 7 TeV data) in combination with 1.5 million cosmic ray tracks. As already mentioned, cosmic ray triggers are acquired even during collision data taking in order to provide more constraints. Collision tracks are selected using three offline streams: minimum bias, $\mu^+\mu^-$ resonances and isolated muons. In figure 6 we report the distribution of the median of the residuals for the tracker inner barrel (TIB) for data and Monte Carlo. From this distribution it can be inferred that an alignment precision of about 5 μm was achieved [8].

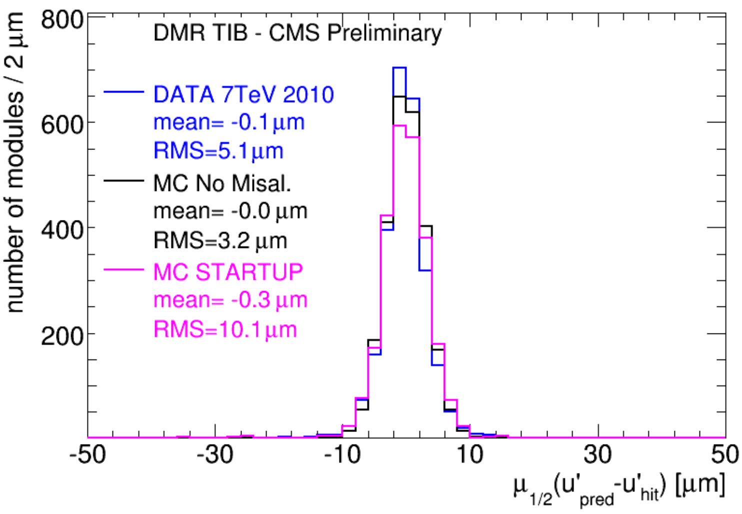

Figure 6. Distribution of the median of residuals for the Tracker Inner Barrel for data and two misalignment scenarios.

4. Conclusions

The CMS calibration and alignment system relies on the concept of calibration streams. We have described the two types of calibration streams: online (in which case they are implemented as a dedicated trigger path) or offline. All the calibration streams have ramped up as expected during the initial data taking period. The system has performed well and the calibration and alignment precision has exceeded expectations in some cases, reaching the systematic limit of the methods. The next challenge to be faced by the CMS collaboration is the automation of all calibration and alignment workflows in order to withstand routine operation for the coming years.

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