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# Operation of the CMS detector with first collisions at 7 TeV at the LHC

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The CMS detector at the Large Hadron Collider (LHC) is a very complex apparatus with more than 70 million acquisition channels. To exploit its full physics potential, a very careful calibration of the various components, together with an optimal knowledge of their position in space, is essential. The CMS Collaboration has set up a powerful offline infrastructure to allow for the best knowledge of these conditions at any given moment, thus following as quickly as possible any change in running conditions. This paper reviews the design of this framework and reports the experience gained in the first period of data taking.

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## 1. Introduction

The design of the CMS detector [1] is based on a large super-conducting solenoid providing an intense (3.8 T) magnetic field, a high-precision silicon tracking system composed of about 76 millions channels including pixel and strips and hermetic calorimetry including an homogeneous Electromagnetic Calorimeter (ECAL) consisting in about 76000 $PbWO_4$ scintillating crystals. The return yoke of the solenoid houses a muon spectrometer used both for trigger and for tracking purposes.

The high level of complexity and the large number of detector channels reflect in an elaborated structure for the offline workflows managing data and detector conditions. The design of the reconstruction workflows and the alignment and calibration strategies are reviewed in the following sections.

## 2. Tier-0 Processing

The first reconstruction of the data which survived the online High Level Trigger (HLT) selection is performed at CERN on the Tier-0 computer farm. The organization of the data streams and of the Tier-0 processing are tightly coupled to the needs of workflows for data validation and detector monitoring and calibration. The following workflows are currently operated at Tier-0:

- **express processing**: reconstruction of a limited selection of data in order to give prompt feedback about the detector status and physics performance and to provide data for calibration workflows requiring short latency (see Sec. 3.1). The results of the express reconstruction for a given run are usually available one or two hours after the end of the online data taking;
- **bulk processing**: reconstruction of the main data stream meant for physics analysis. This reconstruction step, also called *prompt reconstruction*, can be delayed to profit from updated calibrations performed on the datasets produced during express processing. The output is divided in several Primary Datasets (PD) on the basis of the HLT paths used to select the events;
- **calibration streams**: streams of events selected at HLT level and processed at Tier-0 for calibration purposes.

During normal operation of the CMS experiment about 300 Hz of data are processed in the bulk processing. Only a limited bandwidth, corresponding to about 10% of the bulk, is allocated for express processing in order to guarantee a fast reconstruction.

## 3. Alignment and Calibration Workflows

Most of the alignment and calibration workflows are fed with dedicated data samples, called "AlcaReco", optimized both in terms of event selection and event content. Depending on the needs of the specific workflow, these samples can be selected directly online, at HLT level, or can be selected offline, while performing the reconstruction both during express and bulk processing. The online selection of the events is made possible through the great flexibility of the HLT which runs offline-quality software on a farm of commercial processors. This represents a key asset for

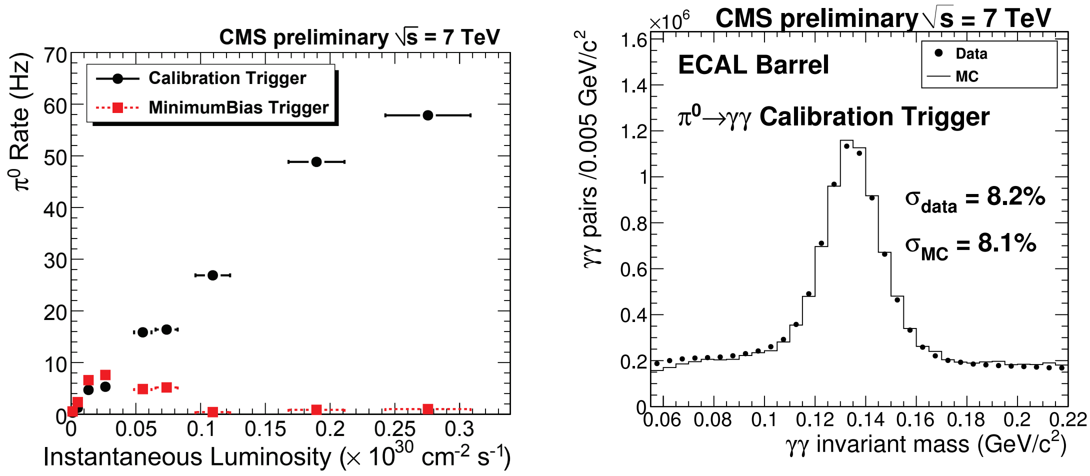


**Figure 1:** Rate of events containing $\pi^0$ candidates in the dedicated calibration skim and in events accepted by the minimum bias trigger (left). The drop in the minimum bias events visible around $\mathscr{L} > 5 \cdot 10^{28} cm^{-2} s^{-1}$ is due to trigger prescaling. Invariant mass distributions for photon pairs accepted by the $\pi^0$ stream for the data and simulations in the central reginof of the detector (right) [2].

the alignment and calibration of the detector since it guarantees an adequate rate of events which would not be selected by the standard trigger paths meant for physics analysis.

An example of online calibration stream is the one selecting events containing $\pi^0$ and $\eta$ candidates detected in ECAL and used for the inter-calibration of the $PbWO_4$ scintillating crystals [2]. The calibration performance depends on the number of selected $\pi^0$ candidates per crystal and on the signal to background ratio. The candidate di-photon decays are selected at HLT level from events passing single-e/$\gamma$ and single-jet L1 triggers. After selection, only information about a limited region of ECAL (energy deposits in 20 to 40 individual crystals) near the $\pi^0$ candidates is stored for the actual calibration. This allows to save bandwidth and CPU time.

The effectiveness of this calibration stream is demonstrated by the plots in Fig. 1, which show the measured signal rate from the online stream and from generic minimum bias event stream as a function of the instantaneous luminosity and the invariant mass of the candidates in the central region of the detector. While the need of prescale on the minimum bias triggers suppresses the yield of $\pi^0$ events, the rate keeps increasing for the dedicated ECAL stream.

Dedicated resources are allocated for the Alignment and Calibration workflows; the CMS Analysis Facility (CAF) at CERN is a dedicated cluster of CPUs and storage where the calibration jobs are run.

### 3.1 Prompt Calibration Concept

For the case of conditions changing on a short time scale, a special calibration workflow has been designed to allow updates with very short latency. This is based on the delay between express and the bulk processing at Tier-0: a selection of the data of the express stream is used to compute the updated conditions for a given run while the bulk of the data is buffered on disk. When the conditions are ready, the prompt reconstruction can run profiting of the updated constants. The

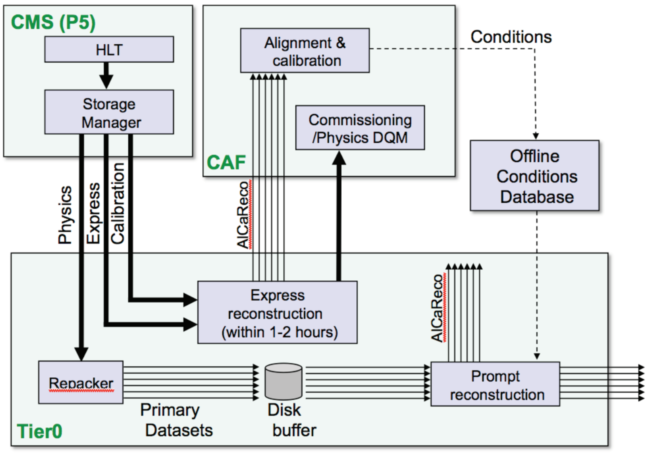


**Figure 2:** Data and calibration workflows during Tier-0 processing.

delay of the prompt reconstruction jobs is a configurable parameter in the Tier-0 processing. This is what is called *prompt calibration loop* and it is illustrated in the cartoon in Fig. 2.

This type of workflow is used, for example, for the determination of the beam line parameters [3]. In the first step of this workflow, the beam line fit is performed once per luminosity section (corresponding to 23 seconds of data taking) using the express stream. In a second step, ranges with stable constants are "collapsed" increasing the statistical precision and reducing the database storage size. Finally, the calibration object is validated and uploaded to the database. This allows the best possible knowledge of the position of the luminous region already a few hours after the data acquisition.

Other workflows running in the prompt calibration loop are those for the determination of the problematic channels in the tracker silicon strips and in the ECAL calorimeter.

## 4. Conclusions

The CMS collaboration set up a powerful framework for the the reconstruction, the alignment and calibration and for the validation of the detector data. This infrastructure demonstrated its reliability and flexibility since the beginning of the data taking, delivering well calibrated and validated data with very fast turnaround. The present commitment of the CMS collaboration is to optimize and consolidate all steps of the offline workflows.

## References

[1] R. Adolphi *et al.* [CMS Collaboration], *The CMS experiment at the CERN LHC*, **JINST 3 (2008) S08004**.

[2] The CMS Collaboration, *Electromagnetic calorimeter calibration with 7 TeV data*, **CMS-PAS-EGM-10-003**.

[3] The CMS Collaboration, *Tracking and Primary Vertex Results in First 7 TeV Collisions*, **CMS-PAS-TRK-10-005**.