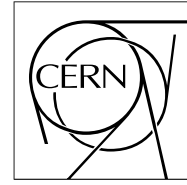**The Compact Muon Solenoid Experiment**

CMS Note

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The CMS Electromagnetic Calorimeter Data Acquisition System at the 2006 Test Beam

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Abstract

The Electromagnetic Calorimeter of the CMS experiment at the CERN LHC is an homogeneous calorimeter made of about 80000 Lead Tungstate crystals.
From June to November 2006, eleven barrel Supermodules (1700 crystals each) were exposed to beam at CERN SPS, both in stand-alone and in association with portions of the Hadron Calorimeter.
We present the description of the system used to configure and readout the calorimeter during this period. The full set of final readout electronics boards was employed, together with the pre-series version of the data acquisition software.
During this testbeam, the hardware and software concepts for the final system were validated and the successfull operation of all the ten supermodules was ensured.

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1   Introduction

The Compact Muon Solenoid [1] (CMS) is one of the experiments that will operate at the Large Hadron Collider [2] (LHC), the new hadron accelerator being finalized at the European Laboratory for Particle Physics CERN, Geneva, Switzerland. The machine will collide protons and heavy ions at the unprecedented center of mass energies and luminosities of 14 TeV and 1.0×10^{34} cm^{-2}s^{-1} (protons). The CMS detector is designed to be operated in the challenging LHC environment. The defining element of the detector is its central superconducting solenoid that will deliver a magnetic field of 4.1 T, determining the compactness of the design. The electromagnetic calorimeter of CMS is an homogeneous calorimeter made of about 80000 Lead Tungstate ($PbWO_4$) crystals, designed to provide excellent energy resolution and granularity.

Lead Tungstate is a fast scintillator that emits light in response to the energy deposited by incident particles. In the barrel region ($|\eta| < 1.479$[1])), light is subsequently converted to current by Avalanche Photo-Diodes. Crystals are mechanically bundled in groups of 5×5, called Trigger Towers, which are then merged together in Supermodules (1700 crystals each, covering $1/36$ of the barrel).

The trigger and readout chain of the calorimeter is physically divided in two sections: the on-detector and the off-detector electronics. The first one is constituted by radiation-tolerant ASICs [3, 4] that have the primary function of shaping, amplifying, sampling and digitizing the signals generated in the photo-detectors. In addition it generates the so-called Trigger Primitives (TP), coarse information on the energy deposition in each trigger tower, which is used for the Level 1 trigger decision (L1A). The on-detector electronics also pipelines the data during the L1A decision latency. The off-detector (OD) electronics is hosted in VME64x crates located in the experiment service cavern and has three main functions: the configuration and control of the on-detector electronics, accomplished by the Clock and Control System board (CCS), the processing and synchronization of the trigger data at the LHC bunch-crossing frequency of 40 MHz, attained by the Trigger Concentrator Card (TCC) and the readout of the full-granularity crystal data at the L1A frequency of 100 kHz, performed by the Data Concentrator Card.

During the summer 2006 a total of 11 barrel supermodules have been operated, in two different test-beams at the Super Proton Synchrotron (SPS) facilities at CERN.

The remaining of this paper is divided in two sections. Firstly, we describe in more detail the trigger and readout system of the CMS Electromagnetic Calorimeter, in both its hardware and software parts and then we discuss the testbeam setups operated during the summer 2006.
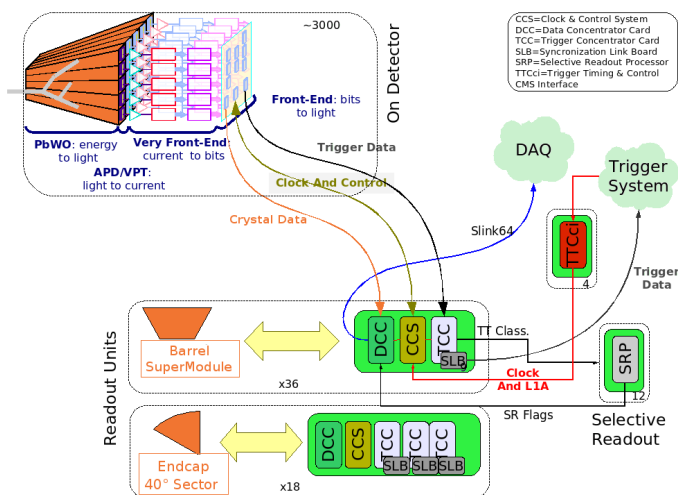

Figure 1: Schema of the trigger and read-out system of the CMS Electromagnetic Calorimeter.

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[1]) η is defined as $\eta := -log(tan(\theta/2))$ where θ is the polar angle w.r.t the beam axis and the nominal interaction point.

2 The CMS ECAL data acquisition system

An overview of the CMS ECAL data acquisition system is shown in Fig. 1. The basic readout unit, responsible for the configuration and readout of a barrel supermodule comprises one CCS board, one TCC board and one DCC board. In order to reduce the data rate to a level sustainable by the CMS DAQ system, twelve Selective Readout Processor (SRP) Algorithm Boards [5] are in charge of calculating the regions of interest in the calorimeter, to allow the application of different suppression thresholds to different parts of the detector. Three readout units are grouped together in a crate, so 12 crates are employed for the control and readout of the barrel and 6 crates for the end-caps. Each of the crates is controlled by one rack-mounted PC, located in the service cavern and equipped with Scientific Linux CERN (SLC).
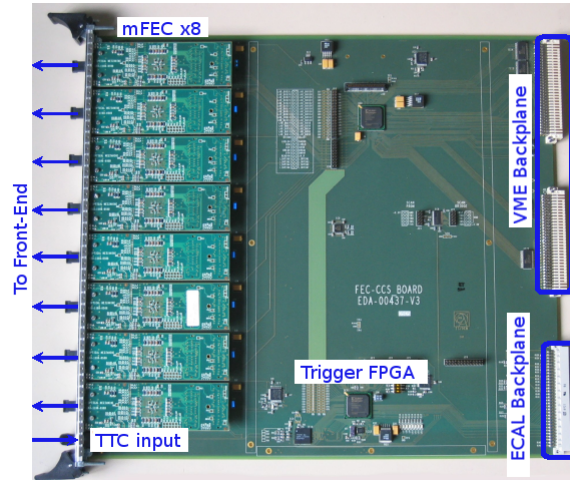

Figure 2: The Clock and Control System Board.

2.1 The Clock and Control System

The CCS board has three main functions:

- configuration and control of the on-detector electronics;
- distribution of Trigger Timing and Control (TTC) commands (the most important of which are the clock and the L1A signals) to the on-detector electronics, as well as to the other components of the readout units through a dedicated backplane;
- merging of the trigger throttling signals coming from the TCC and the DCC and the forwarding of the merged signal to the Trigger Throttling System (TTS).

The board, represented in Fig. 2, hosts eight mezzanine Front End Control (mFEC) cards that are connected to the on-detector electronics by optical links.

2.2 The Trigger Concentrator Card and the Synchronization Link Board

The TCC board (Fig. 3) is responsible for the reception and synchronization of the TP at the LHC bunch-crossing frequency of 40 MHz and their transmission to the Regional Calorimeter Trigger (RCT). It has two other important functions: the finalization of the TP calculations, and the classification of trigger towers by energy deposition categories, required by the Selective Read Processor.

The transmission of the TP to the RCT is delegated to the Synchronization Link Board [6], represented in Fig. 4. These mezzanine boards are connected to the TCC boards and are responsible for the synchronization of the TP with respect to the bunch-crossing time.

2.3 The Data Concentrator Card

The Data Concentrator Card [7], shown in Fig. 5, is the third component of the ECAL readout unit. Its specific task is the readout of the full-granularity crystal data upon a L1A decision which happens, in CMS, at the average
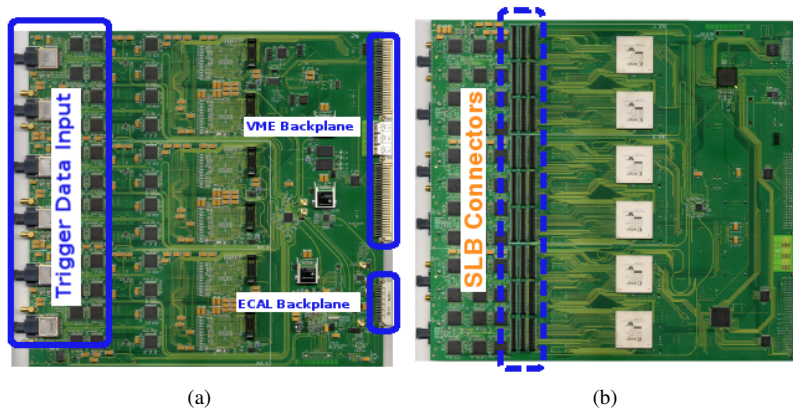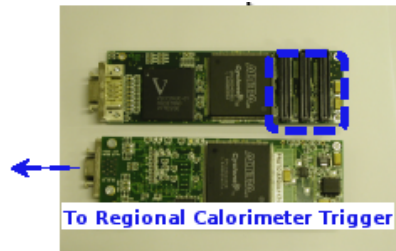
Figure 3: The Trigger Concentrator Card.

Figure 4: The Synchronization Link Board.

frequency of 100 kHz. Before transmitting the data to the DAQ system, the board applies data reduction algorithms based on the regional classification operated by the SRP. The signal amplitude for each crystal is calculated by means of a Finite Impulse Response filter and a zero-suppression threshold is applied on a tower-by-tower basis. Each tower can be flagged in order to be read with high, low or no zero-suppression threshold, according to its proximity to the high interest regions of the calorimeter found by the SRP. In this way, a reduction factor of ~ 20 of the size of the event is obtained (from 40 kB to an average 2 kB per DCC) without degradation of the energy resolution [8].
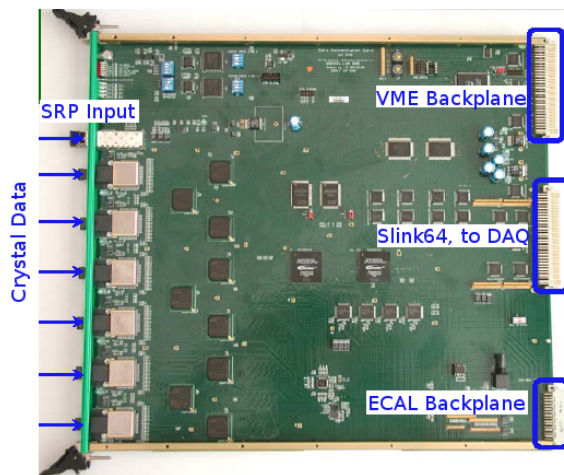

Figure 5: The Data Concentrator Card.

In addition to the full-granularity crystal data, the TPs generated for each tower are transmitted from the TCC to the DCC at L1A-time. At each L1A signal, the DCC merges the crystal-data together with the TP block and the Selective Readout flags to build an event fragment and transmits it to the DAQ system of CMS by means of an Slink64 link.
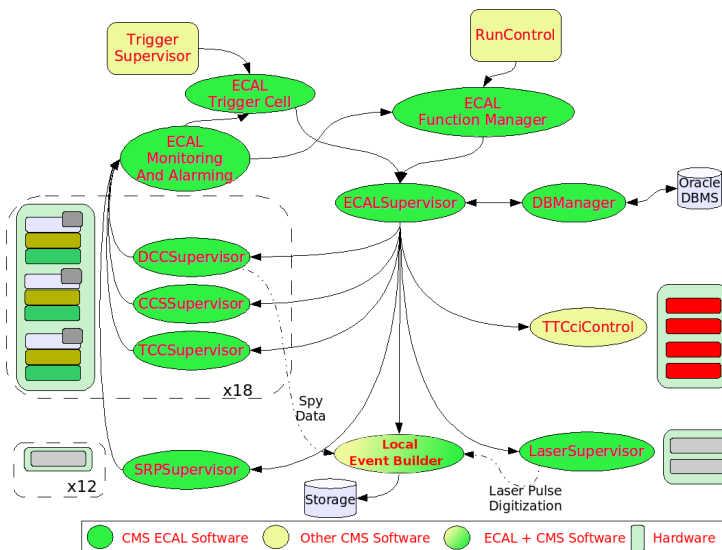
Figure 6: The architecture of the CMS ECAL data acquisition distributed software system.

2.4 The Control Software

The dimension and complexity of the CMS ECAL trigger and data acquisition system requires the use of a distributed software for control and configuration. Such system has been designed following the CMS guidelines for data acquisition and it is based on the CMS data-acquisition frameworks: XDAQ [9, 10], the Trigger Supervisor Framework [11] and RCMS [12]. The XDAQ framework, in particular, is the lower layer upon which the implementation is based. It provides the basic services needed by the ECAL online software, such as:

- inter-process communication, by means of SOAP-based communication channels;

- a data transport service, based on the I2O [13] binary protocol;

- an hardware access library;

- a vendor-independent database access service;

- a distributed logging, monitoring and error-reporting infrastructure.

The architecture of the control software is shown in Fig. 6. The system has two interfaces to the two CMS global control entities, the Run Control and the Trigger Supervisor. The interfaces are represented by the ECAL Trigger Cell and the ECAL Function Manager, implemented using the Trigger Supervisor and the RCMS frameworks respectively. These two applications communicate, through SOAP messages, with the ECALSupervisor application that acts as a proxy for the configuration and operation of the ECAL. A number of applications, generically called DeviceSupervisors, are responsible for the configuration of the different hardware components of the system. All the applications in the system implement a standard Finite State Machine (FSM) for the configuration and the operation of the different boards and instantiate the needed hardware drivers.

The configuration of the on and off-detector electronics for the full calorimeter requires order 10^6 parameters, which can be retrieved from a relational database or from XML files. The access to the database services is managed by a dedicated application built on top of the XDAQ database access layer. The configuration of the different readout units is performed in parallel and requires a time of the order of few tens of seconds. In addition, a monitoring and alarm system provides continuous supervision to allow fast reaction to error conditions. The system collects error counters and histograms, filled by the various boards and published by each DeviceSupervisor through a standard interface. This system spots problematic conditions and possibly starts correction procedures.

3 The 2006 CMS ECAL test-beam

A final version of the OD readout unit described earlier and a pre-series implementation of the control software have been employed in the operation and readout of eleven supermodules in a test-beam from June to November 2006.

Two different setups, both located in the CERN SPS Experimental Hall North have been operated. The first one, located on the SPS H4 beam line, used an electron beam for the inter-calibration of ten barrel supermodules and for precision studies of detector properties. The second setup was located on the H2 beam line and used one barrel supermodule together with parts of the hadronic calorimeter (HCAL) barrel and endcaps. A number of beam particle types (p, π, μ) of different momenta was used to study, for the first time, the combined performance of the CMS calorimetry.

3.1 The test-beam trigger and readout system

Figure 7 shows a sketch of the system employed in the H4 area. Each supermodule was mounted on a moving table that allowed to choose the impact position of the beam. In addition to the calorimeter, a few beam-line detectors were needed to generate trigger signals and to measure the timing of the beam particles with respect to the acquisition clock. The hardware was controlled by two dual-core PCs running Scientific Linux. The DCC board was readout using a FEDKit [14], controlled by one of the two computers.

The control software was interfaced with two ancillary systems: one for the configuration of the laser system for the monitoring of the crystals (reversible) transparency losses due to irradiation, and one to control the moving table hosting the supermodules. The control of those systems was performed through some ad-hoc network protocols that had been defined in the course of the years. During the 2006 testbeam such a control was completely integrated in the online system thanks to two dedicated applications acting as bridges to the laser monitoring and the beam positioning systems.

Also, an ad-hoc application responsible for the readout of the beam line detectors was developed. The readout electronics for these detectors was hosted in CAMAC crates driven through a VME-to-CAMAC bridge.
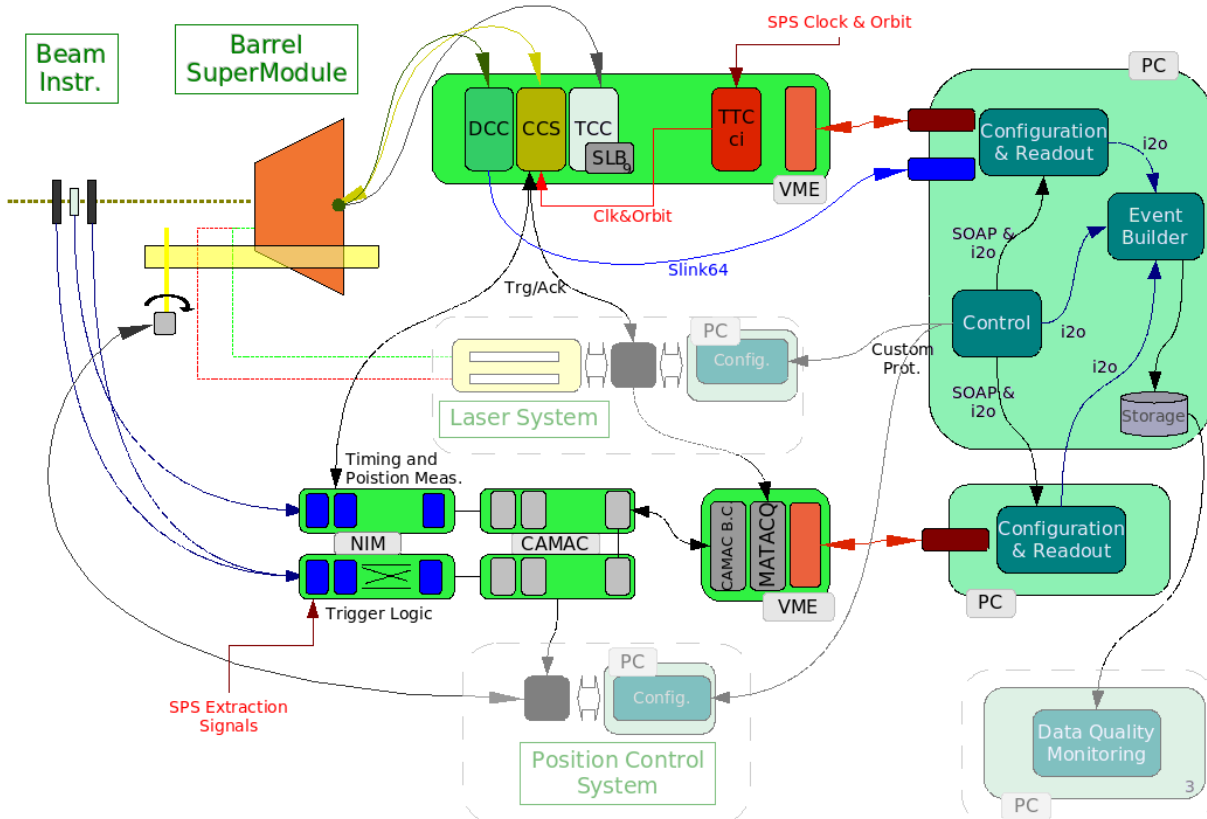

Figure 7: Schema of the read-out system used during the 2006 CMS ECAL test-beam at the SPS H4 experimental area.

The standard CMS event builder was used to merge the calorimeter data with other pieces of information. Data were stored locally on the acquisition machine, equipped with a RAID system, and subsequently copied to the CERN archival infrastructure. Data quality was performed by the ECAL Data Quality Monitoring system (based on the CMS offline framework), which was interfaced to the online software.

All available online informations were stored in the events: calorimeter data, beam detector data, laser pulse digitalization informations as well as the informations coming from the positioning system. Data coming from all sources were formatted in the CMS standard format through a dedicated library and funneled through the standard CMS event building system.

The system was able to take several types of runs: manual and automatic beam-scan of the supermodule crystals as well as monitoring, laser, electronic test-pulse and pedestal runs. In order to maximize the efficiency of the data acquisition, events were buffered during the spill period (~ 3 s) and subsequently sent to the event builder during the gap between beam spills. A dedicate fast messaging system, based on the I2O protocol, was developed in order to allow the realtime operation of the readout chain. A spill-by-spill check was ensuring the synchronization of the calorimeter and the beam detector readouts. In case of desynchronization, a resynchronizations procedure was issued and the data were either discarded or flagged as not synchronized.

All these tactics allowed to increase the efficiency of the data taking with respect to previous testbeams, ensuring the synchronization of all the informations and providing a coherent output containing all informations on the events.

The efficiency of the DAQ was limited by the CAMAC-based readout of the beam detectors that introduced a deadtime of $150 \div 200 \, \mu$s per event. Thus, the efficiency at the average rate of 5000 events/3s was roughly 80%. The data were stored in POOL format[15] and the bandwith of the storage process was saturated at around 4000 events/spill (i.e. $12 \, \text{MB/s}$). At such rates, the use of two streaming processes was necessary to overcome such limitation and exploit the bandwith of the disk drives.

In the H2 area, the ECAL system was driven by a custom run control system during the combined beam runs. The calibration runs were taken with a standalone system with the same features as the H4 beam area one.

3.2   Main test-beam results

In the H4 area the system operated for more than 1600 hours acquiring $\sim 2 \times 10^9$ events. Several important studies of the calorimeter performances were possible thanks to the data acquired during the 2006 test-beams: almost $1/4$ of the calorimeter crystals was inter-calibrated, several analyses on different subjects, like radiation recovery performances, response linearity in a wide range of energies and energy resolution have been carried out. The reconstruction performance of the combined calorimeter system evaluation was made possible.

The test-beams offered the possibility of evaluating the performance of the off-detector electronics, in conditions similar to the LHC mode of operation. For the first time, a full readout unit of the ECAL, in its production version, was exercised in a comprehensive way. Specific studies of the boards' performances have also been completed: the DCC zero-suppression algorithm was tested [8] and, thanks to a period of bunched operation of the SPS beam, the SLB boards could be exercised in realistic conditions [16].

4   Conclusion

The trigger and data acquisition system of the CMS Electromagnetic Calorimeter and its operation during the 2006 test-beams was described. The system architecture was presented and the performances of the system were discussed. The 2006 test-beams offered, from the data acquisition point of view, an unique occasion for testing the system performances in realistic conditions. A final version of the OD readout unit has been used, together with a pre-series version of the control software. The system as a whole proved to be efficient and reliable. Exhaustive studies of the detector performance have been made possible and the hardware and software architectures were validated.

Acknowledgments

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