The Compact Muon Solenoid Experiment

Conference Report

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ECAL Front-End Monitoring in the CMS experiment

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Abstract

The CMS detector at LHC is equipped with a high precision lead tungstate crystal electromagnetic calorimeter (ECAL). The front-end boards and the photodetectors are monitored using a network of DCU (Detector Control Unit) chips located on the detector electronics. The DCU data are accessible through token rings controlled by an XDAQ based software component. Relevant parameters are transferred to DCS (Detector Control System) and stored into the Condition DataBase. The operational experience from the ECAL commissioning at the CMS experimental cavern is discussed and summarized.

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ECAL front-end monitoring in the CMS experiment

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Abstract. The CMS detector at LHC is equipped with a high precision lead tungstate crystal electromagnetic calorimeter (ECAL). The front-end boards and the photodetectors are monitored using a network of DCU (Detector Control Unit) chips located on the detector electronics. The DCU data are accessible through token rings controlled by an XDAQ-based software component. Relevant parameters are transferred to DCS (Detector Control System) and stored into the Condition DataBase. The operational experience from the ECAL commissioning at the CMS experimental cavern is discussed and summarized.

1. CMS and ECAL

The Compact Muon Solenoid (CMS[1]) experiment is one of the two multi-purpose detectors at CERN's Large Hadron Collider (LHC). One of the most accurate, distinctive and important detector of the CMS experiment is the high precision Electromagnetic Calorimeter (ECAL). It provides measurements of electrons and photons with an excellent energy resolution and therefore will be essential in the search for new physics, in particular for the postulated Higgs boson.

ECAL[2] is a hermetic homogeneous calorimeter made of 61,200 lead tungstate ($PbWO_4$) crystals mounted in the Barrel part, closed by 7,324 crystals in each of the two end-caps. The calorimeter is designed to perform precision measurements aiming to reach 0.5% energy resolution at high energy. The ECAL Barrel extends up to the pseudorapidity $\eta = \pm 1.479$ and consists of 36 supermodules made of 85×20 crystals, each one divided into 4 modules. The ECAL Endcaps cover the rapidity range $1.479 \leq |\eta| \leq 3.0$: each Endcap is divided into 2 halves (or Dees) and is logically organized in 9 sectors of 40 degrees each.

The front-end electronics dissipate approximately 73 W of thermal power per Trigger Tower (5x5 crystal matrix). At the same time, the strong temperature dependence of the crystal light-yield and Avalanche Photo Diode (APD) gain implies the need for a dedicated water cooling system able to provide a thermal stability to within 0.05 °C. The detector temperatures are monitored by two independent systems: the Precision Temperature Monitoring (PTM) and

Detector Control Unit (DCU) systems.

This paper describes in detail the DCU system and the DCU online software components. The last chapter is devoted to the analysis of the ECAL thermal stability, as measured by the DCU and PTM systems.

2. ECAL Requirements

The energy resolution of the ECAL detector can be described by the formula $\sigma_E/E = a/\sqrt{E} \oplus b/E \oplus c$, where a accounts for the stochastic fluctuations (photostatistics and containment), b is due to the noise in the electronics and c is the constant term comprising uncertainties from the calibration and the temperature stability.

There are two physical reasons why the stabilization and the monitoring of the temperature are crucial for the energy resolution: firstly, the number of photons emitted by scintillation (light yield, LY) is temperature dependent (-2%/°C); secondly, the amplification factor of the APD is also sensitive to the temperature(-2.4%/°C).

The thermal stability affects the constant term c in the parametrization of the energy resolution. The performance target for the cooling system has been to keep the contribution to the energy resolution resulting from thermal fluctuations to a negligible level as compared to the other contributions to the constant term.

3. DCU

In order to monitor ECAL relevant parameters such as crystal and electronic temperatures, APD leakage currents and supply voltages, several DCU chips have been integrated in the on-detector electronics.

A DCU is a radiation hard ASIC (0.25 μm IBM CMOS) that can be represented in 6 main blocks (see figure 1):

- a serial slave interface based on the standard I2C protocol
- an analogue multiplexer
- a 20 μA constant current source
- a 12-bit ADC
- one on-chip temperature sensor
- a band-gap reference

The DCU chip only accepts voltages as input: it provides a good temperature estimation driving the 20 μA current source through an external thermistor and comparing its voltage drop with the band-gap voltage reference (reaching a sensitivity of 0.012 °C). Good voltage measurements are achievable connecting directly the voltage source to the DCU chip input (sensitivity $\sim$mV), while currents are evaluated by measuring the voltage drop over a fixed well known resistance (sensitivity 340 nA).

4. Calorimeter Read-Out Chain

The readout chain[3] of the scintillating crystals, consists of almost 16,000 Very-Front-End (VFE) boards that process signals from APDs in the central Barrel region and Vacuum Phototriodes (VPTs) in the forward end-caps regions.

Two types of VFE boards were designed, one covering a dynamic energy range up to 1.7 TeV (Barrel) and one up to 3.5 TeV (Endcaps). Both types comprise five identical read-out channels, each processing the signal from one crystal.

A Multi Gain Proportional Amplifier (MGPA) chip shapes and amplify the photodetector signal, using three parallel gain stages with nominal gain 1, 6, and 12. The three analogue output signals of the MGPA are then digitized in parallel by a multi-channel 40 MHz 12-bit ADC. An internal
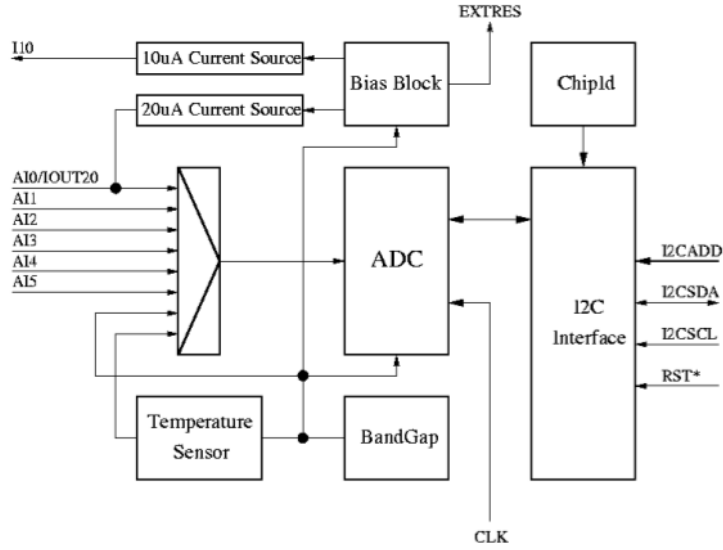
Figure 1. Detector Control Unit Schema

logic determines whether a gain is saturated and then outputs the highest non-saturated value. The basic readout geometry is a 5x5 crystal matrix determined by the front end card (FE) which gathers five VFE cards and one low voltage regulator board (LVRB).

Every VFE board houses a DCU chip which reads the temperature of the crystals, the leakage currents of the APDs and measures its own internal temperature. Three DCU chips are also located on the LVRB, measuring temperatures and supply voltages of the FE and VFE cards. The DCU chips are read-out via the control token rings driven by the off-detector electronics.

5. CMS Online Framework and DCU Software architecture

The online software uses a common framework written in C++ (XDAQ) and runs on Scientific Linux. The online processes are embedded in the hierarchical control structure of Run Control and Monitor System (RCMS [4]) which is the collection of software components responsible for controlling and monitoring the CMS experiment during data taking. A tree of finite state machines called Function Manager (FM) controls the data taking operation.

The online software which controls the DCU system is a XDAQ application (DCUSupervisor), which can be either controlled by the ECAL FM or in standalone mode.

The DCUSupervisor takes care of: initializing the configuration parameters, locking the hardware resources and retrieving calibration constants from the Conditions Database (CondDB).

When the start command is issued, the DCUSupervisor calls the "DCU Reader", which takes care of configuring the front end boards and the DCU internal registers in order to read the data through the token rings.

The DCU reader also takes care of converting the DCU raw data into physics quantities. Moreover, crystal temperature values and APD leakage currents are corrected using the calibration constants retrieved from the CondDB. Finally, the converted data are sent to the Detector Control System (DCS), to the CondDB and stored locally as text files.

In the following subsections the interfaces to DCS and CondDB are summarized.

5.1. DCS and PVSS

The ECAL DCS [5] system has been designed to provide several functionalities: monitoring of the detector environmental parameters and of the operational conditions of the on-detector electronics, as well as the monitoring and control of the configuration and running parameters of all ECAL subsystems (HV, LV, Cooling and Laser monitoring systems). The ECAL DCS also provides early detection of abnormal conditions, executes predefined control actions and triggers hard-wired interlocks to protect the detector and its electronics from severe damage.

All ECAL DCS applications have been developed using the commercial SCADA (Supervisory Control And Data Acquisition) software PVSS 3.6 [6], running on Windows.

The data in PVSS are structured in DataPoints (DP), which contain the information related to a particular instance of a device. In our case, all the safety-related measurements coming from the DCU chips are converted into DPs and sent to the DCS: crystals and electronics temperatures, supply voltages. The maximum amount of data is quite huge: ∼65000 measurements have to be handled and transferred at every read-out process. The PVSS project receives the DPs both for the Barrel and for the Endcaps.

The DCU online software is a XDAQ application, which cannot communicate directly with PVSS projects. In order to bypass this incompatibility, the DCU Supervisor sends the DPs to DCS using a dedicated interface, which takes care of forwarding the SOAP messages received from the XDAQ applications to the PVSS SOAP Service.

In the final working schema, it is foreseen to send updates (only data changing more than 2%) every 5 minutes and the whole ECAL every 20 minutes. As an example, the summary view of the Endcap in the DCU project interface is presented in figure 2.
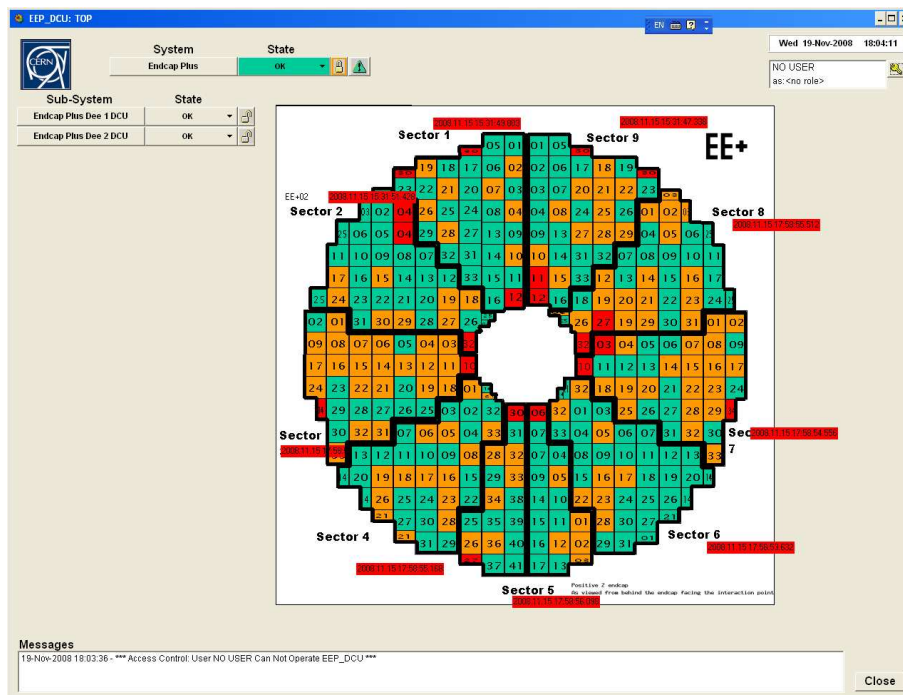

Figure 2. Summary view of the Endcap in the DCU project interface

5.2. Conditions Database

The ECAL Conditions Database[7] is the repository where, among the other information, the detector status during runtime is going to be stored.

The complete set of DCU values has been included in this database since the data taking is, at the moment, discontinuous. In the final configuration, the DCU data will be stored with the following schema: APD currents will be recorded twice per day, since the growth of the leakage current is slow; crystal temperatures will be sent every hour to allow good monitoring of the detector thermal stability (necessary to correct offline, if needed, the crystal light yield and the APD gain). For what concerns the supply voltages and electronics temperatures, they will be stored once per day.

DCU measurements stored in condDB can be visualized using the Web Based Monitor (WBM) of CMS. From the WBM the user can display 2D maps and histograms or dump the data in a text file. An example of 2D map taken from WBM is shown in figure 3.
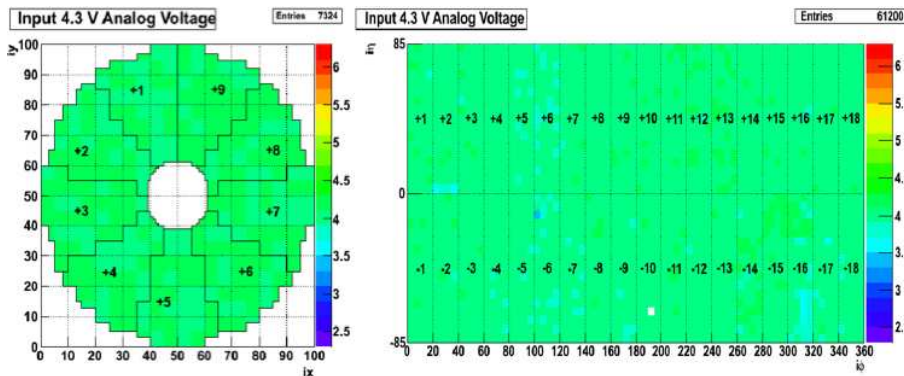

Figure 3. 2D map of the distribution of the low voltage values (4.3V analogic) both in the barrel and in the endcap, as seen from the Web Based Monitor

6. Operational Experiences

During 2008, more than 500 DCU runs (150 runs in regular data taking) have been taken. The DCU measurements have been used for:

- studying the detector stability during operational periods
- investigating sources of problems and dead channels

In the following section, among the various DCU data studies, the validation of the Barrel thermal stability is presented. This analysis has been done considering the crystal temperature measurements obtained from thermistors installed in each submodule (two crystals in phi and five crystals in eta) of ECAL. The thermistors are physically located on the avalanche photodiode capsules at the rear of the crystals: the total amount of thermistors is 170 per supermodule.

Moreover, a set of accurate temperature sensors belonging to the Precision Temperature Monitor (PTM) system has been installed inside the detector.

In each supermodule there are one sensor on both the incoming and outgoing coolant lines, and a redundant pair on each module, one on the supporting structure and one on the thermal screen.

DCU thermistors have been calibrated in the lab to detect very precisely changes in temperature. Since the internal resistance of the ECAL read-out differs from circuit to circuit, absolute temperatures read by DCU thermistors are inaccurate. Therefore a set of data taken during

the cosmic ray test campaign (2006) was used to calibrate the thermistors by comparing DCU measurements to PTM sensors values[8].

6.1. Results

During the "Cosmic Run at Four Tesla (CRaFT)" period (October and November 2008), ECAL cooling system was nominally kept under stable conditions. The analysis of temperature measurements was performed using data collected in about 50 DCU runs. Every run has been studied in detail extracting maps of ECAL Barrel instantaneous temperatures as in figure 4. In
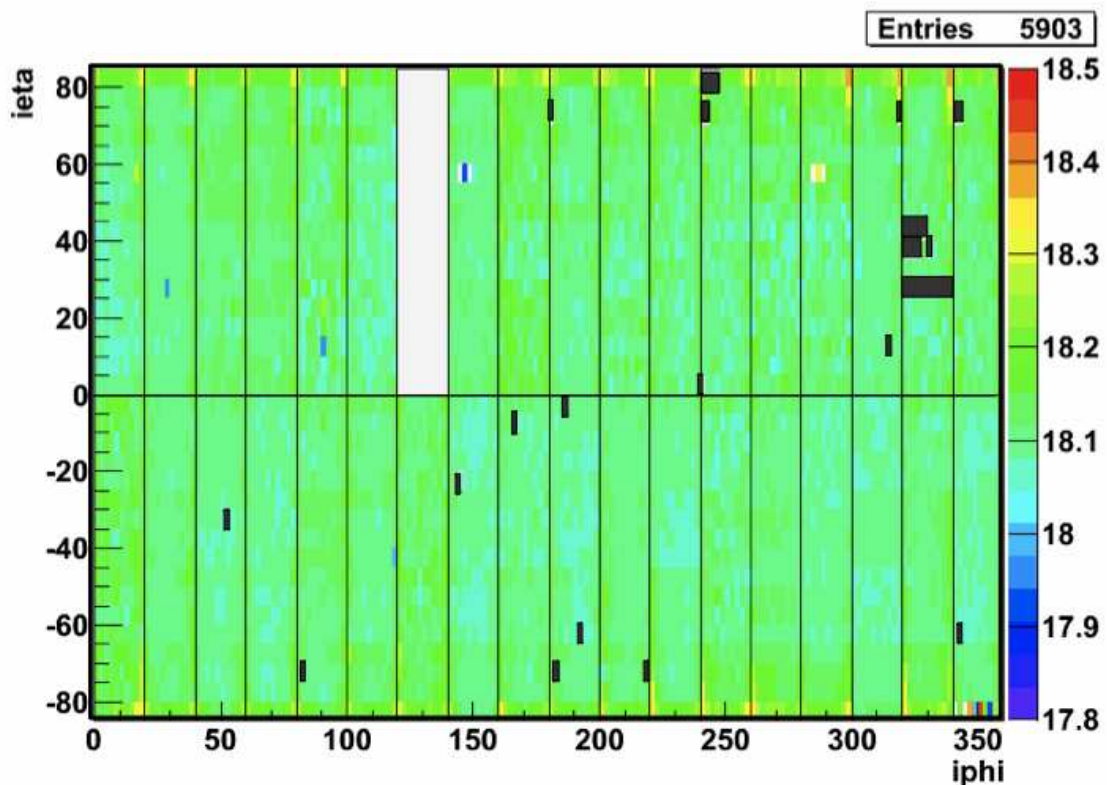

Figure 4. Maps of ECAL Barrel instantaneous temperatures taken on Oct 14th,2008

this plot an unrolled view of the Barrel is presented in azimuthal and polar coordinates where each box of the grid represents one of the 36 supermodules. One supermodule was excluded from the data taking because of a low voltage problem.

Every thermistor measurement has been represented as a coloured square: only channels within 17.8-18.5 degrees have been shown. White spots indicate thermistor measurements out of range (percentage 0.6%, under investigation) while black spots represent missing measurements (0.6%, mostly recoverable). Figure 4 clearly shows that hotter thermistors are on the outer sides of the Barrel, in the vicinity of the power supply cables' patch panel.

The whole temperatures distribution (during CRaFT) is presented in figure 5. The average temperature is 18.12 ± 0.04 °C, which shows a very good homogeneity and stability. The distribution presents a tail at high temperature. Superimposed (in blue) is the temperature distribution of the thermistors located in the outer parts of the Barrel: its average temperature is 0.09 °C higher than the rest of the Barrel.
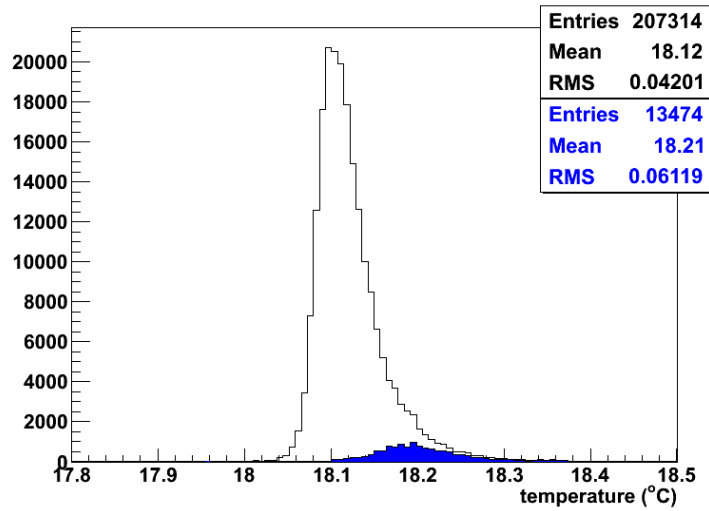
Figure 5. ECAL Barrel Temperatures distribution, measured at the APD capsules level (DCU system) during CRaFT. Superimposed in blue the temperature distribution of the thermistors located in the outer parts of the Barrel

The Barrel temperature stability during CRAFT period has been investigated using both DCU and PTM data. The RMS distribution of all the DCU temperature measurements is shown in figure 6. The average fluctuation is 0.009 ± 0.003 °C, which demonstrates both DCU thermistor
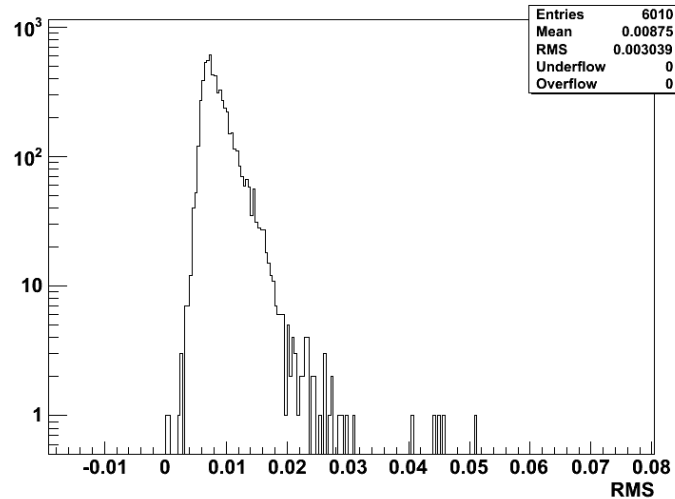

Figure 6. Distribution of ECAL Barrel thermistor fluctuations during CRaFT

measurements precision and a temperature stability within specifications.

7. Conclusion

The ECAL DCU online software has been commissioned both for Barrel and Endcap, integrating the read-out software in the XDAQ online framework. DCU data are now shared with the DCS

and sent to the Conditions Database to ensure storage and prompt reaction in case of front end problems. The DCU data analysis allowed a detailed study of Barrel thermal conditions showing a stability better than the design specifications of 0.05 °C.

Acknowledgements

References

[1] S. Chatrchyan et al., "The CMS experiment at the CERN LHC", (2008) JINST 3 S08004
[2] G.L. Bayatian et al, "CMS ECAL Technical Design Report", (1997) CERN/LHCC 97-33
[3] J. Blaha et al., "Calibration and performance tests of the Very-Front-End electronics for the CMS electromagnetic calorimeter", presented at the Topical Workshop on Electronics for Particle Physics, Prague, Czech Republic, 03 07 Sep 2007
[4] G. Bauer et al.,"The Run Control and Monitoring System of the CMS Experiment", (2007) CERN CMS CR-2007/062
[5] P. Adzic et al.,"Implementation and performance of the Detector Control System for the electromagnetic calorimeter of the CMS experiment", (2007), presented at Topical workshop on electronics for particle physics, 3-7 September 2007, Prague, Czech Republic
[6] http://itcobe.web.cern.ch/itcobe/Services/Pvss/
[7] R. Arcidiacono et al., "The CMS ECAL Database services for detector control and monitoring", presented at the CHEP09, Prague, Czech Republic, 22 - 27 Sep 2009
[8] N. Eggert, G. Franzoni, R. Rusack, F. Cavallari, P. Rumerio, "Calibration of the ECAL Thermal Sensors Using Cosmics Stand Data", CERN CMS IN-2008/043