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CMS CR -2009/156

The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

27 May 2009

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Presented at *Frontier Detectors for Frontier Physics - 11th Pisa Meeting on Advanced Detectors,24-30 May 2009,La Biodola, Elba,Italy,30/05/2009*

The CMS Electromagnetic Calorimeter detector control and monitoring system

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Abstract

The Electromagnetic Calorimeter of the CMS experiment at the LHC is made of 75848 lead tungstate scintillating crystals and photo-detectors. In order to ensure the design stability and precision, the detector's properties must be continuously monitored. The tests to determine the performance of the detector's crystals, photo detectors and readout electronics are presented in detail. In particular, the identification of different hardware problems that were found is discussed as well as on their development in time.

Key words: Electromagnetic calorimeter, lead tungstate crystals, readout electronics, detector control system

1. Introduction

The CMS experiment [1] is a general purpose detector, designed to study 14 TeV proton-proton collisions at the Large Hadron Collider with a bunch crossing rate of 40 MHz and a design luminosity of $10^{34}\,\text{cm}^{-2}\ \text{s}^{-1}$. The detector consists of a barrel part that is sealed with two end-caps installed perpendicular to the beam axis. For the studies of many new physics phenoma, the measurement of the energy of electrons and photons with very high accuracy is of primary importance.

The CMS Electromagnetic Calorimeter (ECAL) [2] is a high-resolution, high-granularity and fast-responding crystal calorimeter. The calorimeter is made of 61200 and 14648 fast scintillating lead tungstate ($PbWO_4$) crystals with a lenght of ~26 and ~25 radiation lengths in the ECAL barrel and end-caps, respectively. The crystals are read out by two different types of photo detectors: silicon based Avalance Photo-Diodes (APD) in the barrel and Vacuum Photo-Triodes in the end-caps. Both are running at a high voltage of several hundred Volts.

A total of 25000 Printed circuit boards of 5 different types are used to process the signals and 8800 Gigabit Optical Links send the resulting data to the off-detector electronics for further treatment.

The strong temperature dependance of crystals' light yield and the APDs' gain of each $\sim 2\%/^{\circ}$C require a constant ECAL environment temperature. A water cooling system is used to keep the nominal temperature of $(18.00 \pm 0.05)^{\circ}$C.

The light loss of the crystals occurring during the CMS operation trough irradiation will be determined by a laser light-injection system. Their response is accordingly re-calibrated.

2. Trigger Tower Electronics

The so-called Trigger Tower electronics (see figure 1) reads and processes the data of 5×5 crystals and provides all necessary services; it uses 13 different types of application specic integrated circuits. A Tigger Tower consists of five Very Front End boards (VFE), one Front End board and one Low Voltage Regulator board (LVR).

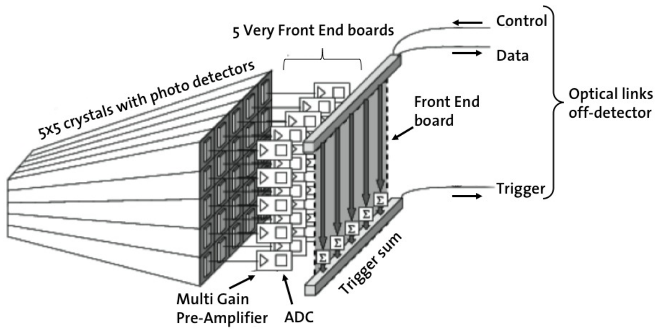

Figure 1: Schematic view of the trigger tower readout electronics

Each VFE treats signals from five crystals in parallel. First, it shapes and amplifies each signal simultaneously with gains 1, 6 and 12 using the so-called Multi Gain Pre-Amplifier (MGPA). Secondly, the three signals are digitized at a rate of 40 MHz using a 12 bit ADC. A logic chooses the highest non-saturated signal as output.

The Front End Board collects the information of five VFEs and calculates the trigger sum (energy sum of five or 25 channels for end-caps and barrel, respectively). The trigger primitives are send via an optical link to the regional off-detector trigger every 25 ns while the specific data of each channel are buffered. On reception of a level 1 trigger, the data from the buffers are send via the second optical link to the off-detector data acquisition system. The LVR distributes the incoming supply low voltage and stabilizes it for each part the trigger tower electronics.

So-called Detector Control Units (DCU) are mounted to the VFEs and LVRs. Each one on the VFEs measures the crystal's and the photo detector's temperatures as well as the photo detector's leakage current. Three DCUs on the LVR monitor all incoming and outgoing voltages as well as their temperatures.

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3. Detector Control system

The Detector Control System [3] consists of the Precision Temperature Monitoring (PTM), the Humidity Monitoring (HM) and ECAL Safety System (ESS).

The PTM monitors the crystals' and photo detectors' temperatures with a precision of < 0.01°C.

The HM reads 440 humidity sensors with a precision of 5%.

The ESS controls the electronics' temperatures with a precision of < 0.1°C, is connected to a dedicated the Water Leak Detector and measures the water flow and temperature of the ECAL cooling system.

It also controls the parameterization and operation of the electronics low voltage supplies, the photo detectors high voltage supplies, the cooling system and the ECAL laser light-injection system. In case of problematic situations it is able to automatically interlock the corresponding system, to trigger predefined control actions and to alert.

4. Data Quality Monitoring (DQM) tests

For the Data Quality Monitoring the following tests are run frequently on all ECAL channels yo ensure their performance:

A The **Pedestal run (HV on)** measures the mean output (pedestal) and its fluctuation (RMS) without signal injection for all three gains. The RMS is considered as electronic noise which contributes to the ECAL resolution. The measurements have to agree with the expectations.

B The **Pedestal run (HV off)** is used to find bad connections between photo detector and readout chain in the ECAL barrel. Without high voltage applied to the APD its intrinsic electronic noise naturally increases. For a disconnected APD the channel's electronics noise will stay at the same level as in the Pedestal run (HV on).

C The **Test pulse run** verifies the functionality of the readout chain by measuring amplitudes of test pulses of all three gains injected by the MGPA. The resulting mean amplitudes and RMSs are compared with the expectations.

D The **Laser run** tests the whole detector chain including crystals and photo detectors by using a dedicated laser system that injects 532 nm laser pulses in each crystal.

E The **DCU run** checks all DCU outputs of VFE and LVR cards. Here, we emphasize the measurement of the leakage currents of the photo detectors.

5. Classification of problematic channels

With the help of the DQM tests we were able to identify five classes of single channel errors that occur repeatedly during ECAL testing. In order to find the patterns for the classication, a binary evaluation criteria was chosen, where each channel was classied with an 1 or a 0 for each of the test runs A to E from above. The results are summarized in table 1.

The channels that fall into the categories 'Bad photo detector connection', 'Photo detector shorted' or 'MGPA broken' are not usable for physics measurements. Channels that have a 'Noisy MGPA' can be used, however with a reduced resolution. All channels with 'Low laser amplitude' during the commissioning were proven to work for physics measurements during the cosmic muon runs in 2008. Consequently, these channels are considered as working.

Hardware problem	A	B	C	D	E
1) Bad photo detector connection	1	0	1	0	1
2) Photo detector shorted	0	1	1	1	0
3) MGPA broken	0	1	0	0	1
4) Noisy MGPA	0	1	1	1	1
5) Low laser amplitude	1	1	1	0	1

Table 1: Classification of hardware problems. 1 and 0 represent the passing or failing of one channel in each test A to E. Test E includes here only the leakage current measurement.

Testing campaign	1)	2)	3)	4)
Electronics integration in spring 2007	21	6	0	14
Installation in CMS summer 2007	23	5	4	15
'Good health test' winter 2009	23	6	20	24

Table 2: Development of the hardware problems 1 to 4 in time

The development of the number of the different problematic channels in time is summarized in table 2 for three ECAL testing campaigns. The total of channels from the first two categories was stable, whereas the broken and noisy MGPAs increased significantly. We believe that this is due to the very frequent switching on and off the detector in the last years.

6. Conclusions

The Electromagnetic Calorimeter of CMS has an excellent noise performance of ∼1.1 and 2 ADC counts in the highest amplification gain in barrel and end-cap, respectively. Accordingly, contributing resolution terms are ∼40 and ∼50 MeV. In spring 2009 we find 49 single channels, that are unusable for physics measurements. 20 additional channels are dead due to failures of the LVR boards. About 8 Trigger Towers have problems with optical links and/or the data integrity. In total, we have reached a very low plateau of less than 0.4 % unusable channels since fall 2008.

Acknowledgments

The author thanks the CMS ECAL group for the possibility of participating the Pisa meeting on advanced detectors 2009. Financial support by the Swiss National Science Foundation is gratefully acknowledged.

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