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The Compact Muon Solenoid Experiment

Conference Report

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The Electromagnetic calorimeter of CMS, Status and performance with cosmics data and first LHC data

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Abstract

The CMS detector at the LHC is ready to take physics data. The high resolution Electromagnetic Calorimeter, which consists of 75848 lead tungstate crystals, will play a crucial role in the physics searches undertaken by CMS. The design and the status of the calorimeter will be presented, and its performance in tests with beams, cosmic rays, and data from the first LHC beams

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1 Introduction

The Compact Muon Solenoid (CMS) detector [1] is one of the two general purpose detectors installed at the LHC at CERN.

The main physics goals of the CMS experiment are the observation of the Higgs boson and the search for new physics phenomena, such as particles predicted by theories beyond the Standard Model. For a mass below 150 GeV/c^2, the Higgs decay into two photons is a promising signature for the discovery. In this mass range, the Higgs width is very narrow and the signal lies above an irreducible background: this led to the choice of a high resolution electromagnetic calorimeter.

The electromagnetic calorimeter (ECAL) [1] [2] of CMS is a hermetic homogeneous calorimeter with 61200 lead tungstate ($PbWO_4$) crystals divided in 36 supermodules in the barrel part (EB), covering the central pseudo rapidity region $|\eta|$ <1.48, closed by 7324 crystals in each of two end-caps (EE), which extend the coverage up to $|\eta|$=3. ECAL is located within a 3.8 T superconducting solenoid.

To gain rejection power against fake photons from neutral pion decays, in the pseudo rapidity range $|1.65| < \eta < |2.6|$ a preshower detector is located in front of the crystals: two lead radiators (two and one radiation length thick) initiate electromagnetic showers from incoming photons and electrons, and silicon strip sensors placed after each radiator measure the energy deposited and the transverse shower profiles. The orientation of the strips in the two planes is orthogonal and the two planes are formed from two Dees that join close to the vertical axis. Each silicon sensor measures 63 $\times$ 63 mm ^{2}, with an active region of 61 $\times$ 61 mm ^{2} divided into 32 strips (1.9 mm pitch). The nominal thickness of the silicon is 320 μm, thus a minimum ionizing at normal incidence particle will deposit around 3.6 fC of charge in this thickness.

The target value of the energy resolution of the calorimeter at high energies is less than 0.5%. With these performances a Higgs boson with a mass of 120 GeV could be observed by CMS in the gamma gamma decay with a 5 σ significance collecting less than 10 fb^{-1} [3].

2 Crystals and photodetectors

The usage $PbWO_4$ allows the realization of a compact high resolution calorimeter: lead tungstate has high density (8.3 g/cm^3) and short radiation length (8.9 mm) leading to a compact design, while its small Moliere radius (2.0 cm) permits high granularity. Light emission peaks at 425 nm with 80% emitted within 25 ns. However, the light yield is low and has a temperature dependence of -2.2%/°C.

The crystals have to withstand the high ionizing radiation levels anticipated during LHC running. This causes a wavelength dependent loss of light transmission without changes to the scintillation mechanism. The damage reaches a dose-rate dependent equilibrium level which results from a balance between damage and recovery. This effect can be tracked and corrected for by monitoring the optical transparency with injected light, provided by a fiber-distributed laser system operating at two different wavelengths (440 and 796 nm). The result of the correction procedure [4] during a test beam study is shown in figure 1, where the response to electrons has been corrected through the laser monitoring procedure while irradiating with a dose rate at the level of what is expected in the ECAL barrel at the LHC luminosity of 10^{34}cm^{2}s^{-1}.

The ECAL photo-detectors must operate in the 3.8 T field and have a sizable gain because of the low light output of $PbWO_4$. In the barrel avalanche photo-diodes (APDs), developed by Hamamatsu Photonics for CMS, are operated at a gain of $\times$ 50 and exhibit a temperature coefficient of $-2.4\%/°$C and biasing voltage coefficient of 3%/V. Radiation-resistant vacuum photo-triodes are used in the end-caps.

3 Installation and Commissioning

Prior to installation, each supermodule has been commissioned and precalibrated with cosmic rays (precision of 2%) or with test beam to (0.3%, for one quarter of the barrel) [5] [6]. The whole of the ECAL barrel was installed in the CMS cavern by the end of 2007 and has been regularly operated since, deploying the data acquisition, trigger and monitoring systems. The Endcaps were installed in the Summer of 2008 and readily integrated with the barrel and the rest of the CMS experiment. More than 99.5% of the 75848 channels are in good health and operational for physics measurements.

In September 2008 CMS was active during the LHC operation: beam halo events were collected throughout the running with a single beam. About sixty beam "splash" events were recorded when the LHC beam was deliberately

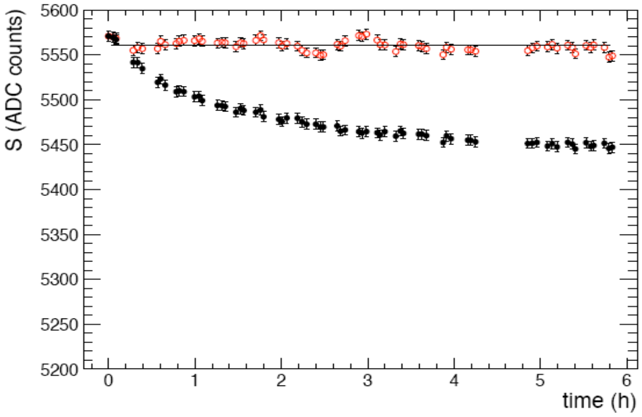

Figure 1: Effect of the transparency correction procedure on test beam electrons: black points refer to signals measured during beam irradiation, red points are the same after the monitor correction. Irradiation was performed with a dose rate at the level of what is expected in the ECAL barrel at the LHC luminosity of $10^{34}\mathrm{cm}^2\mathrm{s}^{-1}$.

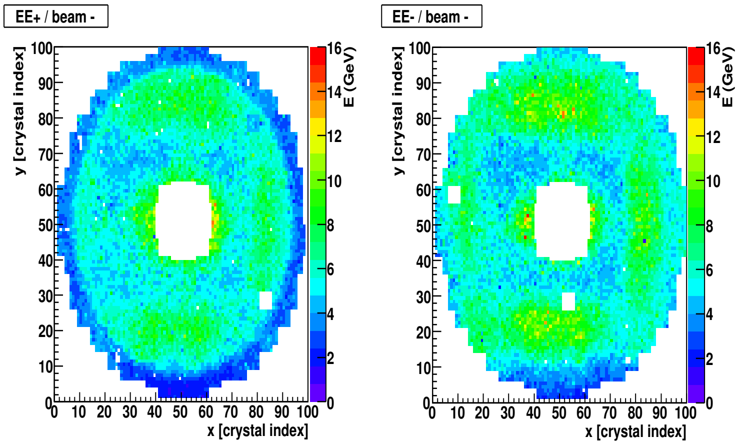

Figure 2: Average energy release in the ECAL endcaps in beam splash events with beam arriving from the negative side.

addressed onto the collimators located 150 m away from the CMS interaction point, resulting in muons reaching the cavern and traversing horizontally the CMS detector. After the LHC accident stopped the commissioning of the accelerator, CMS has run for about one month collecting over 300 million cosmic ray events with the solenoidal magnet active to 3.8 T. The duration of the run allowed the establishment of stable running conditions, and the assessment the robustness of the data acquisition, trigger and stability of the ECAL response. It was the first time that the full ECAL could be tested for temperature and response stability.

The preshower detector has been lowered in the CMS pit in 2009, and its hardware was signed off as completed by March. 99.88% of the 137 thousand channels are functional and the level of noise observed in the CMS cavern is the same as it was on surface: a signal to noise ratio of 3.6 (9) for the minimum ionizing particle signal in low gain (high gain).

The ECAL comprises on-detector and off-detector electronics dedicated to produce level one trigger information (trigger primitives) which are fed into the regional and global calorimetric trigger of CMS. While the commissioning of the ECAL trigger had been already exercised in the 2008 run [7], the installation and commissioning of the endcap part has started in 2009. At the time of this report, the off detector electronics has been installed for one full endcap and the EE trigger has been operated in global CMS running and trigger primitives readout.

4 Splash events

In the splash events nearly all the channels of ECAL recorded amplitudes in the 2-10 GeV range, as shown in figure 2 for the LHC beam coming from the negative side.

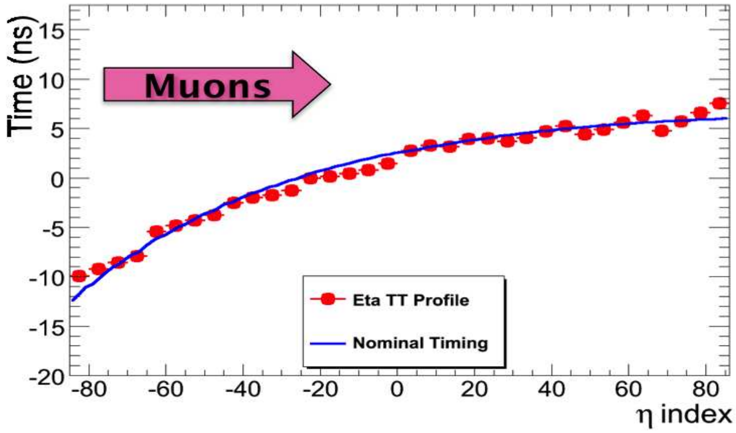

Figure 3: Expected measured time for a plane wave of particles advancing in the ECAL barrel towards positive values of η (blue curve). Red circles are the measured time averaged over all the crystals of 5 η rings.

The presence of shielding structures in the forward region of CMS (square) and of the LHC tunnel floor (bottom) explain the two patterns of reduced average energy in both endcaps. The energy deficit in the outer rings of the positive endcap, which is downstream for the beam splashes coming from the negative side, is ascribed to the presence of the ECAL barrel.

For high energy clusters, the accuracy of the internal synchronization determines the ECAL resolution on the time measurement, which will be used both to reject asynchronous backgrounds (e.g. cosmic rays, beam halo) and in searches physics signals with delayed particles. By travelling parallel to the beam pipe and releasing energy nearly simultaneously in all crystals at a given η, the splash events could be use to assess the level of internal synchronization of the ECAL. In figure 3 the measured time of the signal in ECAL is shown as a function of pseudo rapidity.

The few ns of deviation from the nominal timing are ascribed to systematics introduced when by synchronizing the channels of each supermodule using laser events as a reference: the modularity in steps of 20 or 25 channels along η reflects the regions with constant travel time for the laser light. The deviations from the nominal timing have been utilized to adjust the latencies of each readout region (5×5 crystals) in steps of 1 ns, as the hardware allows. Further sub-ns residuals are taken into account in the offline reconstruction by means of a single channel time calibration.

5 Stability

Because of the thermal coefficient of the crystal light yield ($-2.2\%/°$C) and of the APD gain ($-2.4\%/°$C), thermal instabilities would harm the resolution of the calorimeter at high energies. To comply with the target of less than 0.5$\%$ resolution, the thermal stability has to be at the level of a few 0.01 °C. The ECAL cooling system was shown in compliance with these specifications in the 2006 test beam with one supermodule [9]. During the 2008 cosmic rays run, temperatures were regularly measured with the 6120 precision thermistors located throughout the barrel. Such thermistors are in good thermal contact both with the photodetector and the crystals, and are meant to monitor the thermal stability of the system. Figure 4 shows for each thermistor the RMS of the temperatures measured during one month of data taking. The observed stability is 0.009 °C on average, and less than 0.05 °C in all cases, which demonstrates that the thermal stability specifications are met also on the entire barrel.

By operating in the absence of radiation-induced transparency loss, the stability of the ECAL laser monitoring system and of the ECAL readout (APD and electronics) could be tested during the 2008 cosmic rays run. Each crystal is flashed by laser light six hundred times for each laser cycle, which repeats about every twenty minutes. In order compensate for variations of the laser intensity, the amplitude recorded by each channel (APD) is normalized, event by event, to the amplitude of a reference channel (APD$_{ref}$). The six hundred normalized amplitudes are averaged to extract the channel response at any given laser cycle ($< APD/APD_{ref} >$). For operations at the LHC, dedicated external diodes will be used as normalization reference; they have not been utilized for this analysis because unavailable in the data for the 2008 run. Stability has been evaluated with the RMS of the normalized channel response over 200 hours of stable running. Values of the RMS are shown for all channels in figure 5. In the ECAL barrel, the RMS is better than 2 per mille in 99.9$\%$ of the channels, which proves the level of stability

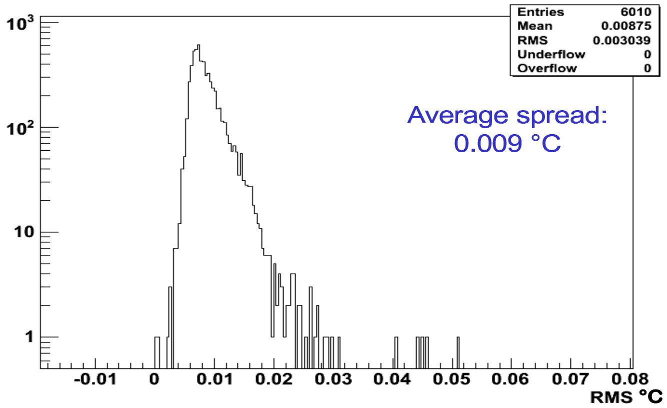

Figure 4: For thermistor of the ECAL barrel, the RMS over 700 hours of the measured temperature is used to assess the thermal stability.

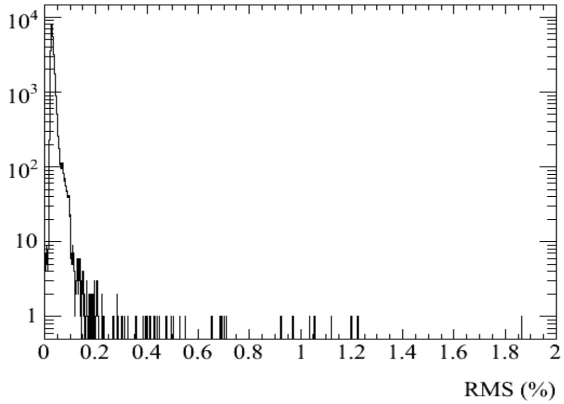

Figure 5: For each channel of the ECAL barrel, the RMS over 200 hours of the normalized $<$APD/APD$_{ref}>$ is used to assess the stability of the laser monitoring system.

of the ECAL monitoring and readout to be within the specifications.

6 Conclusions

The electromagnetic calorimeter of the CMS experiment is installed in the experimental cavern and ready for physics at the LHC. The health of both the crystal part and the preshower is excellent. The 2008 run, during the LHC beam operations and the extended cosmic rays runs, has allowed several performance tests have been carried out. In particular, thermal stability and monitoring stability (in EB) have been proven within the specifications.

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