The Compact Muon Solenoid Experiment
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Commissioning of the CMS Electromagnetic Calorimeter with First Collisions

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Abstract

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Commissioning of the CMS Electromagnetic Calorimeter with First Collisions

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The Compact Muon Solenoid (CMS) detector at the Large Hadron Collider (LHC) has recorded first collision data. The Electromagnetic Calorimeter (ECAL) of CMS is a high resolution detector comprised of nearly 76000 lead tungstate crystals, playing a critical role in physics searches undertaken by CMS. The performance of the CMS ECAL with first LHC collision data will be discussed.

1. INTRODUCTION

The Compact Muon Solenoid (CMS) Experiment is a general purpose particle detector experiment located at the Large Hadron Collider (LHC) at CERN, in Geneva, Switzerland [1]. The CMS electromagnetic calorimeter (ECAL) was designed to optimize the resolution for the discovery of the Higgs in the distinctive, yet challenging, diphoton channel.

The CMS ECAL is a hermetic, high-resolution, high-granularity scintillating crystal calorimeter [1], [2]. The ECAL barrel (EB), covering $0 < |\eta| < 1.48$, comprises 61200 crystals, divided into 36 supermodules (SM) of 1700 crystals each. The ECAL endcaps (EE), covering $1.48 < |\eta| < 3$, comprises 14648 crystals total, with each endcap divided into two “Dees”, further divided into supercrystals of 5x5 crystals. Lead-tungstate (PbWO_4) crystals were selected for their short radiation length, small Molière radius, and fast speed as a scintillator. The crystals are slightly tapered and positioned in EB with an off-pointing angle of $\sim 3^\circ$ with respect to the interaction point for hermiticity. The relatively low light yield of PbWO_4 requires the use of photo-detectors with gain operable in a magnetic field of 3.8T. In EB, avalanche photo-diodes (APD) are used with a gain of 50. In EE, vacuum phototriodes (VPT), which are more radiation hard than silicon diodes, are used at a gain of ~ 8 -10.

In addition, a Pb-Si preshower detector, for π^0/γ discrimination, is placed in front of each endcap.

2. Commissioning of CMS ECAL

The commissioning of the CMS detector prior to first collisions was accomplished with cosmic ray and single beam events. Since 2007, CMS has undergone frequent “global runs” devoted to global commissioning, exercising all of the installed detector subsystems together to prepare for operation with collisions. The cosmic global runs culminated in the Cosmic Run at Four Tesla (CRAFT) in 2008, during which more than 300M cosmic ray events were collected [3].

In Sep 2008, the CMS detector collected first LHC beam data. In the days preceding circulating beams, single beam shots were sent onto closed collimators $\sim 150\text{m}$ from the detector. The interactions of the beam with the collimator and surrounding material created a large number of secondary particles which passed through CMS. These events are called “beam splashes” because of the spectacular signature they left in the detectors, depositing up to 10 GeV per crystal.

First proton collisions at the LHC were delivered with a center-of-mass energy of $\sqrt{s} = 900$ GeV on 23 Nov 2009. Then, first collisions at $\sqrt{s} = 7$ TeV were delivered on 30 Mar 2010.

During this time, the ECAL data acquisition and trigger systems were fully active. More than 99% of channels were active for both trigger and data. Only 0.95% of channels were masked at

*On behalf of the CMS Collaboration.

the readout level. Since ECAL was designed with separate read-out paths for trigger and data, the energy deposition for most of these channels can be recovered using trigger data. As a result, 99.85% of channels can be used for energy measurements. In addition, any remaining problematic regions are handled in the event reconstruction using a dedicated channel status database.

3. Calibration and Energy Scale

To maintain the ECAL design energy resolution, which has a constant term of 0.5%, calibration and monitoring of the crystals must be performed. A crucial issue for ECAL is the channel response uniformity, or intercalibration. A pre-calibration campaign provided intercalibration constants from lab, cosmic ray, test beam, and beam splash measurements [4]. In addition, the energy scale was set at the test beam and further verified with CRAFT cosmic ray events [5].

In situ calibration with collision events is the main method to achieve design resolution. With the earliest data, the rotational symmetry around the beam axis of energy deposited in minimum bias events will be used within fixed η rings. The mass peak of π^0 s in the two photon decay mode will also be used for early calibration.

4. Synchronization

ECAL is synchronized such that $t=0$ ns corresponds to the arrival time of a particle produced at the interaction point and travelling in a straight line at the speed of light. Beam splash events provide us with a synchronous set of events with which to time calibrate ECAL [6]. At the hardware level, the timing of ECAL is adjusted to ~ 1 ns within 5×5 matrices of crystals. The beam splashes were then used to correct for any residual mis-calibration offline; the RMS of the average crystal timing for 5×5 matrices is improved to ~ 0.3 ns. The time resolution function of ECAL from 7 TeV collisions, is shown in Figure 1. The single channel resolution was derived by comparing the time in nearby crystals within the same cluster. The observed noise term $N=(28.5 \pm 0.3)$ ns is consistent with test beam and cosmic ray

Figure 1. The time resolution for EB as a function of the effective amplitude, derived by comparing the time in nearby crystals, in the same cluster.

measurements. The constant term, dominated by systematic effects, is $C=(257 \pm 33)$ ps.

5. Stability: Temperature and Crystal Transparency

In order to maintain the high energy resolution of ECAL, we must monitor and correct for any detector instabilities, including temperature fluctuations and changes in crystal transparency. The scintillation process of lead-tungstate crystals is temperature dependent, on the order of $-2\%/^{\circ}\text{C}$ at the nominal operating temperature of 18°C . Water flow is used to stabilize the temperature below 0.05°C (0.1°C) for EB (EE). To monitor the stability, thermistors with a nominal sensitivity of 0.012°C are placed on the back of each 5×2 (5×5) matrix of crystals in EB (EE). The performance of the temperature monitoring system has been proven during CRAFT [3].

Exposure at the level of the nominal LHC luminosity causes a decrease in crystal transparency due to radiation induced absorption [7]. A laser system is used to monitor and correct for these changes with a precision of 0.2%. The stability

of the monitoring system has been proven to be better than $4 \cdot 10^{-4}$ over a period of ~ 350 hours.

6. Anomalous Signals

Anomalous signals, due to the direct deposition of energy in the silicon of the APDs of EB, have been observed in collision events [8]. Such anomalous signals arise from heavily ionizing hadrons coming either directly from the primary interaction or from secondary interactions, and they can fake a much larger energy deposition in the corresponding channel. These anomalous events are observed with the following characteristics: distinct pulse shape (faster rise time and no scintillation component), early or broad timing distribution, unusual shower topology, observation uniformly in EB but lacking in EE (where VPTs are used). The anomalous events have been observed with a rate of approximately one in every thousand minimum bias events. These events can be easily identified and removed, for instance by selecting on shower shape or using timing and pulse shape discriminants. In addition, it is planned to filter out such events at the trigger level.

7. Data-Simulation Comparisons

Figure 2 shows the energy spectrum of individual EB channels from 7 TeV data, after event quality selection and anomalous signal rejection, normalized to the number of minimum bias triggers in data. The good agreement between the data and simulation validates the accurate description of ECAL in the CMS simulation.

8. Conclusions

The CMS electromagnetic calorimeter has been successfully commissioned and its performance has been proven with first LHC collision events.

9. Acknowledgments

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