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The CMS Electromagnetic Calorimeter: Construction, Commissioning and Calibration

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The Compact Muon Solenoid (CMS) detector at the Large Hadron Colider (LHC) is ready for first collisions. The Electromagnetic Calorimeter (ECAL) of CMS, a high resolution detector comprised of nearly 76000 lead tungstate crystals, will play a crucial role in the coming physics searches undertaken by CMS. The design and performance of the CMS ECAL with test beams, cosmic rays, and first single beam data will be presented. In addition, the status of the calorimeter and plans for calibration with first collisions will be discussed.

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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. In the low mass range where the diphoton channel will be the most promising, the decay width of the Higgs is expected to be very narrow, and the discovery potential is directly related to the energy resolution of ECAL.

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; all ideal qualities for use at the LHC. The crystals are slightly tapered and positioned 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 are used with a gain of 50. In EE, vacuum photo-triodes, which are more radiation hard than silicon diodes, are used at a gain of $\sim$8-10.

A Pb-Si preshower detector, for π^0/γ discrimination, is placed in front of each endcap, covering $1.65 < |\eta| < 2.6$. The preshower detector is composed of two orthogonal planes of silicon strip detectors placed behind 2 X_0 and 1 X_0 of lead absorber. The 4300 silicon detectors have 32 strips, each 63mm long, with a pitch of 1.9 mm, covering an area of 1.65 m^2.

2. Commissioning of CMS ECAL with First Beam and Cosmic Muons

In September 2008, the CMS detector collected first beam data from the LHC. The first proton beams were circulated successfully on 10 September 2008. In the days preceding, single beam shots were sent onto closed collimators $\sim$150 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. As seen in Figure 1, these events are called “beam splashes” because of the spectacular signature they left in the detectors. Figure 2 shows ECAL energy maps for one beam splash event. In a single beam splash event, up to 10 GeV was deposited per crystal and $\sim$ 200 GeV of total energy was deposited in ECAL.

In addition to illuminating the entire detector, these beam splash events provide a source of "synchronous" hits with which to adjust the internal readout timing of ECAL. Figure 3 shows the average timing per η ring (dots) overlaid with the predicted time (curve). The difference between the observed and predicted timing from splash events will provide the start-up synchronization constants.

Following first beam events, CMS participated in a four-week Cosmic Run at Full Tesla (CRAFT) in October-November 2008. The aim of CRAFT was to collect data continuously with all subsystems participating, to further gain operational experience before data-taking with p-p collisions, and to operate the field at 3.8T for as much of the four weeks as possible. During CRAFT,

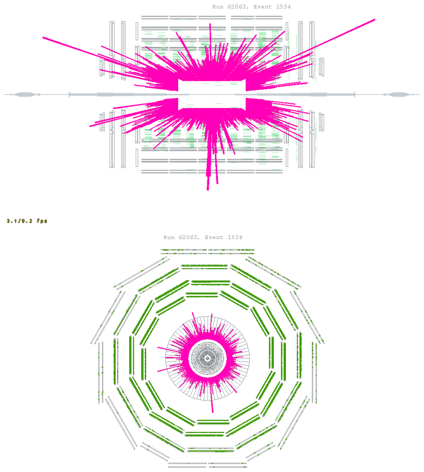

Figure 1: Event displays from a single "beam splash" event, depicting the energy deposited in the electromagnetic calorimeter in longitudinal (top) and transverse (bottom) views of the CMS Detector.

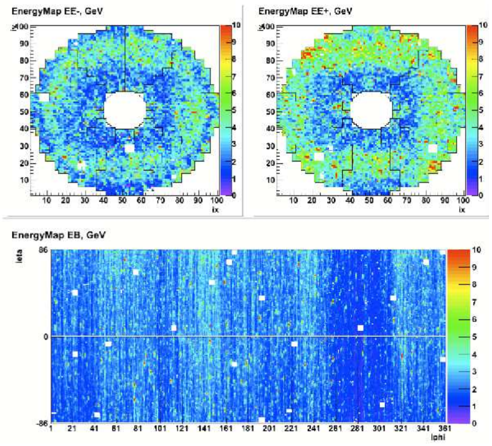

Figure 2: Energy maps for the ECAL endcaps and barrel for one beam splash event. Colors indicate energy (in GeV) deposited per crystal. (The white areas correspond to read out channels which were masked during first beam. The annular structure in the endcaps is due to the fact that the energies were uncalibrated, and the lowest gain photodetectors are nearest the beam pipe.)

we collected more than 370M cosmic events, with the field operated at B=3.8T for 19 days. We have used the large CRAFT dataset to study the energy deposition of cosmic ray muons in ECAL. Figure 4 shows the $dE/\rho dx$ stopping power of cosmic muons traversing ECAL as a function of the muon momentum measured by the tracker. We see good agreement between the measured $dE/\rho dx$ and the expected stopping power for lead-tungstate crystals. These results indicate the correctness of the tracker momentum scale and the pre-calibrated energy scale of ECAL.

3. Calibration and Monitoring of ECAL

To maintain the ECAL design energy resolution, which has a constant term of 0.5%, in situ calibration and monitoring of the crystals must be performed. A crucial issue for ECAL is the channel response uniformity, or intercalibration. Prior to installation, each barrel SM underwent cosmic muon calibration to achieve intercalibration precision better than $\sim 1.5\%$, on average. Nine of the SMs were also calibrated with electrons in a test beam to obtain calibration on the order of 0.3% [3]. Due to construction and schedule constraints, the endcaps were not precalibrated with the same accuracy; lab measurements provide a calibration of about $10-15\%$ for EE.

In situ calibration with collision events is the main method to achieve the design energy resolution. With the earliest data, the rotational symmetry around the beam axis of energy deposited in minimum bias events (or ϕ symmetry) will be used within fixed pseudo-rapidity regions. The mass peak of π^0 decays in the two photon decay mode provides another promising channel for calibration with early data. According to simulation studies, an intercalibration accuracy of $< 1\%$ can be achieved for EB within a few weeks at low luminosity (2×10^{30} cm^{-2}s^{-1}). With more data, a

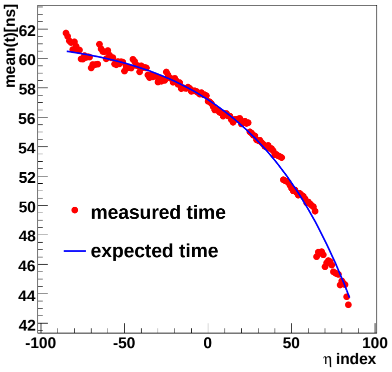

Figure 3: ECAL barrel timing (ns) as a function of η index. Red dots show measured time from beam splash events; blue line shows expected time through the detector. Secondary particles from these beam splash events traversed the detector from positive to negative η index.

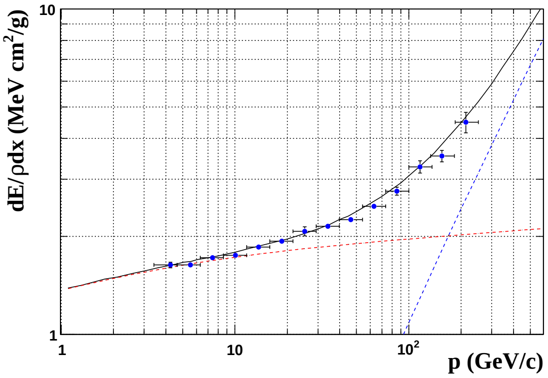

Figure 4: $dE/\rho dx$ stopping power of ECAL PbWO$_4$ crystals, measured with cosmic ray muons. CRAFT data (dots) are compared to the expected stopping power of PbWO$_4$ (black continuous line). Dashed lines are contributions from collision loss (red) and bremsstrahlung radiation (blue).

precision intercalibration can be obtained with $W \rightarrow e\nu$ decays, by comparing the energy measured for electrons and the momentum measured by the tracker.

Exposure at the level of the nominal LHC luminosity causes a decrease in crystal transparency due to radiation induced absorption. A high precision laser monitoring system which will be used to monitor and correct these changes has been tested extensively during CRAFT.

4. Conclusions

CMS ECAL has been integrated and commissioned in situ. The design performance of ECAL has been proven with first LHC circulating beam, as well as cosmic ray muons during the CRAFT run. CMS ECAL is prepared to collect data during first LHC collisions.

5. Acknowledgments

I am grateful to my colleagues in the CMS ECAL group for their effort and support.

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