The CMS Electromagnetic Calorimeter

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Abstract

The CMS experiment at the CERN Large Hadron Collider has placed great emphasis on precise calorimetry. The electromagnetic calorimeter (ECAL) contains 75000 scintillating lead tungstate crystals that are read out using sophisticated electronics; this paper describes these technologies and how they were implemented in the calorimeter. The results of pre-calibration measurements for the detector modules are detailed. Installation of the ECAL into the underground cavern has commenced and the commissioning process and its status are discussed. The experiment is scheduled to start in 2008 and prospects for the first year of operation and running are given.

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1 Introduction

The electromagnetic calorimeter (ECAL)[1, 2] of the CMS experiment is a high precision scintillating crystal calorimeter and will play a key role in the wide LHC physics programme. This paper describes the technical details of the calorimeter, the pre-calibration measurements that have been made and the status of installation and commissioning in preparation for the first LHC run in 2008.

2 The Electromagnetic Calorimeter

2.1 Mechanical Design

The ECAL is divided into sections; a barrel section and two endcap sections. The barrel covers the pseudo-rapidity region $\eta < 1.48$ and is constructed from 61200 lead tungstate crystals. The crystals are grouped into units, called supermodules, of 1700 crystals. There are 36 supermodules in the barrel.

The endcaps cover the pseudo-rapidity region $1.48 < \eta < 3.0$. Each endcap is made from two 'Dees' and 7244 crystals. The crystals are grouped into modules of 25 crystals, known as supercrystals. The inner and outer boundaries of the endcaps are made more circular by the addition of smaller units known as partial supercrystals.

2.2 Lead Tungstate

Lead tungstate ($PbWO_4$) [3] is a dense, fast and radiation-tolerant scintillating crystal. These three properties of the crystal make it an ideal choice for the CMS ECAL. The short radiation length ($0.89\text{cm}/X_0$) and small Molière radius (2.2cm) allow a compact calorimeter to be constructed. The scintillation decay time is very fast with 80% of the scintillation light collected within 25ns (in the LHC bunches of protons collide every 25ns).

The crystal also has very good resistance to radiation. The dose rates that the crystals will receive during LHC operation will be very high. Some loss of transparency does occur during irradiation however due to the formation of colour centres. This damage recovers in the absence of irradiation which means that the transparency of the crystals will fluctuate during a LHC run cycle. The crystal transparency will be monitored by injecting laser light into each crystal during gaps in the bunch structure and the crystal response corrected accordingly [1].

2.3 Read-Out Electronics

Lead tungstate has a comparatively low light yield, so photodetectors with gain are employed to detect the scintillation light. In the barrel, silicon avalanche photodiodes (APDs) [1] are used. In the endcaps, the higher radiation levels preclude the use of APDs and the approximately axial magnetic field allows the use of vacuum photo-triodes (VPTs) [1].

The photodetectors are connected to a multi-gain pre-amplifier (MGPA) and a radiation hard ADC. A Front End board takes the signals from groups of 25 channels and ASIC chips perform basic energy sums, known as trigger primitives, for each bunch crossing. The trigger data are converted to an optical signal and sent off-detector to the Trigger Concentrator Card. Upon receipt of a trigger accept, the full crystal data are read out. These data are also converted to an optical signal and sent to the Data Concentrator Card.

3 Pre-Calibration of the Calorimeter

The energy reconstructed in the calorimeter can be decomposed into the following factors [2]:

$$E = G \times F \times \sum_i A_i \times c_i \tag{1}$$

where G is a global scale factor, F accounts for energy losses from bremsstrhalung, A is the ADC count in a channel and c is the inter-calibration constant for that channel. The key to achieving the

ECAL design performance is obtaining a precise channel to channel inter-calibration of 0.5%. This level of precision may only be achieved with *in-situ* physics events but a series of pre-calibration measurements were carried out to provide good calibration at start-up.

3.1 Laboratory Measurements

Before the crystals are assembled into supermodules various parameters are checked using an automated quality control system [4]. One of the parameters that is checked is the crystal light yield and is measured using a Co^{60} source and a photo-multiplier tube. From the light yield measurements, an initial estimate of the calibration constants can be made:

$$\frac{1}{c_i} \propto LY \cdot M \cdot \epsilon_q \cdot c_e \tag{2}$$

where LY is the crystal light yield, M the electronics gain, ϵ_q the quantum efficiency of the photomultiplier and c_e the electronics calibration constant. The precision of the measured calibration coefficients was determined by comparing crystals that were also measured in the test beam. A precision of 4.5% was achieved.

3.2 Cosmic Rays

The cosmic ray method of pre-calibration was proposed to ensure that all supermodules could be pre-calibrated before insertion into CMS. A MIP traversing the full length of a crystal will deposit 250 MeV. For this test, the gain of the APDs is set 4 times higher than normal to ensure a good signal to noise ratio. This allows the use of a veto to reject events where a MIP crosses several crystals without the need for a dedicated trigger system. The inter-calibration coefficients are obtained by normalising the response of each crystal to the MIPs. All supermodules have been calibrated in this way and a precision on the calibration coefficients of around 1.5% was achieved [5]

3.3 Test Beam

During the summer of 2006, 9 supermodules (a quarter of the barrel detector) were calibrated to high precision in 120 GeV electron beams at CERN. The supermodules were equipped with the final CMS versions of the DAQ, data monitoring and detector monitoring systems. The short term reproducibility of the coefficients was approximately 0.2% [5] (see Fig. 1).

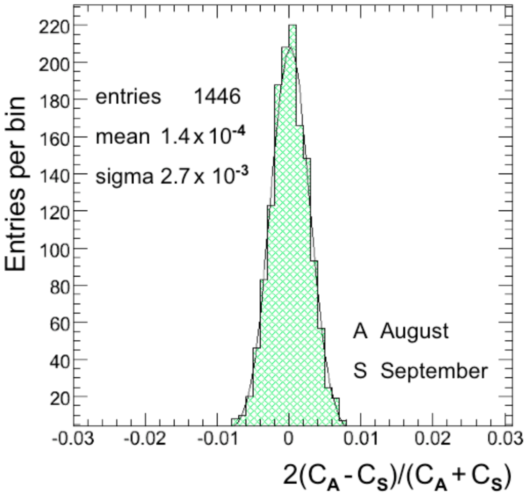

Figure 1: The short term reproducibility of intercalibration coefficients as measured for a supermodule using electron beams.

4 Commissioning and Outlook

Installation of the barrel detector has been completed and the ECAL has participated in combined data-taking tests in unison with the hadron calorimeter and muon sub-detector systems (see Fig. 2). These test are invaluable for gaining experience in many aspects of detector operation and readout, such as trigger and timing generation and distribution.

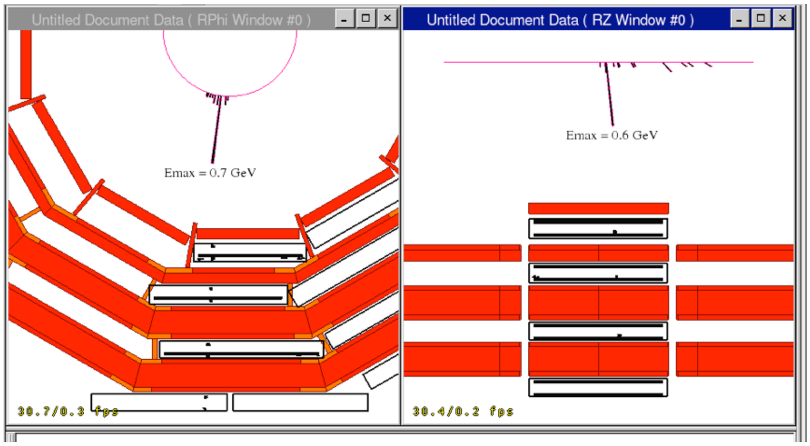

Figure 2: One of the first cosmic ray muons seen in the ECAL detector during a commissioning run. The muon's track can also be seen in the muon detectors.

When the LHC begins operation in 2008 one of the first and most urgent tasks for the ECAL group will be in-situ calibration of the detector. Three strategies have been identified to achieve this [2]. The first is a rapid method that uses the fact that mean energy deposition in the ECAL averaged over a large number of minimum bias events, is uniform in ϕ. Pairs of rings of crystals will be calibrated in this way, with an ECAL-wide calibration of 2-3% achieved within 10 hours, assuming a jet rate of 1kHz.

Achieving the target precision on intercalibration will require around two months of data taking at an average luminosity of $2\times10^{33}\mathrm{cm}^2\mathrm{s}^1$ and will rely on measurements of isolated electrons from $W \rightarrow e\nu$ decays. The third method, currently being investigated, uses the reconstructed mass of $\pi^0 \rightarrow \gamma\gamma$. Current simulation results suggest this will provide a much speedier approach to the desired precision.

5 Summary

The CMS electromagnetic calorimeter is a key detector of the CMS experiment and it's installation into the experiment has been completed. All barrel supermodules have been calibrated using cosmic rays and a precision on the intercalibration coefficients of 1.5% was achieved. Nine supermodules (a quarter of the detector) have been calibrated using electron beams and an intercalibration precision of 0.2% was achieved.

The detector is now being commissioned in unison with larger fractions of the CMS experiment and the CMS collaboration look forward to taking the first data when the LHC becomes operational in 2008.

References

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