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CMS ECAL PERFORMANCE - TESTBEAM RESULTS

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The Compact Muon Solenoid (CMS) experiment is a general-purpose detector designed to explore the physics of proton-proton collisions at a centre-of-mass energy of 14 TeV over the full range of luminosities expected at the Large Hadron Collider (LHC). The Electromagnetic Calorimeter (ECAL) will play an essential role in the study of the electroweak symmetry breaking, particularly through the exploration of the Higgs boson sector. To evaluate its characteristics, an ECAL prototype was placed in an electron testbeam at CERN. Highlights of results obtained during the test beam campaign are presented.

Keywords: CMS; Testbeam; Electromagnetic Calorimeter; Lead Tungstate Crystals;

1. Introduction

The CMS detector[1] has been optimized to search for the Higgs boson predicted by the Standard Model, whatever its mass in the theoretical allowed range up to around 1 TeV/c^2. For a light Higgs boson (M_H <150 GeV/c^2), the gold-plated decay mode is H$\rightarrow \gamma\gamma$. The irreducible di-jet background for this channel is quite large while the Higgs boson mass resolution is completely dominated by the detector smearing. Therefore, an excellent energy and position resolution in the electron and photon reconstruction is mandatory.

2. Electromagnetic Calorimeter

The Electromagnetic Calorimeter[2] is designed to provide very precise energy measurement of electrons and photons. It will consist of about 76000 Lead Tungstate ($PbWO_4$) crystals with pointing geometry, arranged in a Barrel part and two Endcaps. In front of each Endcap, a fine-grained Preshower detector will be installed in order to enhance the π^0, γ separation. The main challenges in the calorimeter design were the high radiation environment, the strong magnetic field of 4T that both crystals and electronics should operate, the high bunch crossing rate of 40

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MHz and the large dynamic range that must be covered. The crystals have a short radiation length (X_0 = 8.9 mm) and Molière radius (R_M = 2.19 mm), which allows the construction of a compact and highly granular detector. The scintillation light decay time is approximately 10 ns, the peak emission is at 440 nm while 80% of the light is emitted in 25 ns. The crystals have a light yield (LY) of 9.3±0.8 pe/MeV so photo-detectors with intrinsic gain are required. The scintillation light is collected by Silicon Avalance Photo-Diodes (APDs) in the Barrel and Vacuum Photo-Triodes (VPTs) in the Endcaps. The crystals energy resolution is parameterized traditionally with the formula:

$$\frac{\sigma}{E} = \frac{\alpha}{\sqrt{E}} \oplus \frac{\sigma_n}{E} \oplus c \tag{1}$$

where α is called *stochastic* term and depends on the shower fluctuations, the transverse leakage and the photo-statistics, σ_n is called *noise* term and depends on the electronic noise, the radiation induced dark current and the pileup and finally c is called *constant* term and depends on the calibration accuracy, the LY non-uniformity and the front/rear leakage. The target performance for the energy resolution is a stochastic term of 2.7% (5.7%), a noise term of 155 (770) MeV and a constant term of 0.55% (0.55%) for the ECAL Barrel (Endcap).

3. Testbeam results

During the summer of 2003 an ECAL-Barrel prototype equipped with 50 channels of the final readout electronics was tested in a electron beam at CERN. These channels correspond to two trigger towers of 25 crystals each. Each trigger tower was read by five Very Front End (VFE) electronic cards equipped with radiation-hard Multi-Gain Pre-Amplifiers (MGPAs) and 12-bit ADCs. The five VFEs are connected to one Front-End (FE) electronic card. The VFEs handle the shaping, amplification and digitization of the signal while the FE's task is to provide the necessary information for the trigger decision and on a trigger request to submit the crystals data to off-detector electronics.[3]

The signal from the ECAL crystals is digitized at 40 MHz with 14 samples including two samples before the start of the signal to allow an estimation of the baseline. The baseline variation can be subtracted, event-by-event, by using an appropriate set of weights to compute the signal amplitude. The energy deposited in the crystal is directly proportional to the pulse amplitude and is extracted by fitting 5 samples around the maximum.[4]

An initial inter-calibration of the ECAL can be obtained with an electron beam or from laboratory measurements of the crystal light yield. Detailed studies showed that the calibration in the test beam can reach the 0.3% accuracy. In the laboratory, by using a ^{60}Co source, an accuracy of 4% can be achieved.[5]

After proper crystal inter-calibration, the energy of the electron is estimated from the sum of energies over 9 crystals around the crystal with the maximum response. The noise for the sum of 9 crystals is 129 MeV corresponding to a noise per channel of about 43 MeV. The energy resolution can be estimated using electron beams of various energies. Results indicate an excellent performance of the final readout electronics. The achieved energy resolution was σ/E = 2.93%/$\sqrt{E}$ $\oplus$ 129 MeV/E $\oplus$ 0.40%, quite close to the target values.[4]

The strong temperature dependence (-2%/^{0}C) of the crystal LY implied the need for the thermal stability at 18 ^{0}C to within 0.1 ^{0}C over the inter-calibration time. This temperature variation is also required for a stable APD response which varies significantly with temperature (-2.2%/^{0}C). The typical temperature variations measured by a single thermistor close to APDs and crystals indicate a stability within the required 0.1 ^{0}C.[6]

Radiation affects both crystal LY and the APD response. A Light Monitoring System (LMS) continuously follow these variations by injecting laser light of 440, 495, 700 and 800 nm into the crystal. The variations in the signal response of the crystals to electrons (S/S_0) and to laser light (R/R_0) are correlated in the following way: $(S/S_0) = (R/R_0)^\alpha$ where $\alpha = 1.53 \pm 0.03$ was found to be a crystal independent constant. The stability of the monitoring system was estimated to be within 0.15% over 18 days of operation, which meets the designed specifications.[7]

4. Conclusions

In summer 2003 an ECAL-Barrel prototype, equipped with 50 channels of the final readout electronics based on 0.25 μm technology, was tested in a test beam at CERN. Important detector parameters were measured and it was proved that they satisfy the challenging requirements.

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