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The Electromagnetic Calorimeter of the CMS Experiment

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Abstract

The Electromagnetic Calorimeter of the CMS experiment has been designed to achieve a high precision in photon and electron energy measurements at LHC. The status of the project will be discussed, together with recent results on performance of final components in beam tests.

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The Electromagnetic Calorimeter of the CMS Experiment.

Egidio Longo*, on behalf of the CMS ECAL group*

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INTRODUCTION

The Compact Muon Solenoid (CMS) detector [1] is a general purpose detector to be installed at the LHC at CERN. The main physics goals of the CMS experiment are the discovery of the Higgs boson and the search for new physics phenomena, in particular the appearance of particles predicted by supersymmetric theories. For a mass lower than 150 GeV, the Higgs decay in two photons is the cleanest channel for the discovery. In this mass range the width is very narrow, but the signal will lie above an irreducible background: this led to the choice of a high resolution electromagnetic calorimeter.

The electromagnetic calorimeter (ECAL) [2] of CMS is a hermetic homogeneous calorimeter with 61,200 lead tungstate ($PbWO_4$) crystals in the barrel part, covering the central rapidity region $|\eta| \leq 1.48$, closed by 7,324 crystals in each of two end-caps which extend the coverage up to $|\eta|=3$. It will be mounted inside a 4 Tesla superconducting solenoid. The scale of this detector is an order of magnitude larger than crystal calorimeters of the previous generation experiments. The target value of the energy resolution of the calorimeter at high energies is less than 0.5%.

With this detector a Higgs boson with a mass of 120 GeV could be observed by CMS with 5 σ significance collecting less than 10 fb^{-1} at luminosity $2\cdot10^{33}$ $cm^{-2}s^{-1}$ [3].

CRYSTALS

The choice of $PbWO_4$ has led to a compact high resolution calorimeter: lead tungstate has high density (8.3 g/cm^3) and short radiation length (8.9 mm) allowing a compact design, while its small Moliere radius (2.0 cm) allows high granularity. Light emission peaks at 420-430 nm with 80% emitted within 25 ns. However, the light yield is low and has a temperature dependence of -2.1%/°C. The crystals have a tapered shape, a front face of about 22 mm x 22 mm (28 mm x 28 mm in the end-caps) and a length of 230 mm (220 mm in the end-caps, where a preshower detector is placed in front of the crystals).

The crystals are produced in the Bogoroditsk plant (Russia) and a small fraction in the Shanghai Institute of Ceramic (SICCAS, China) and after delivery their dimensions, light yield and transmission, longitudinal uniformity and radiation resistance are checked. More than 90% of the barrel crystals have been delivered, while end-cap crystal delivery will be completed in 2008.

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 effectively 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] is shown in Fig. 1, where electron signals taken during an irradiation test are effectively corrected using laser monitor runs taken during the same data taking period.

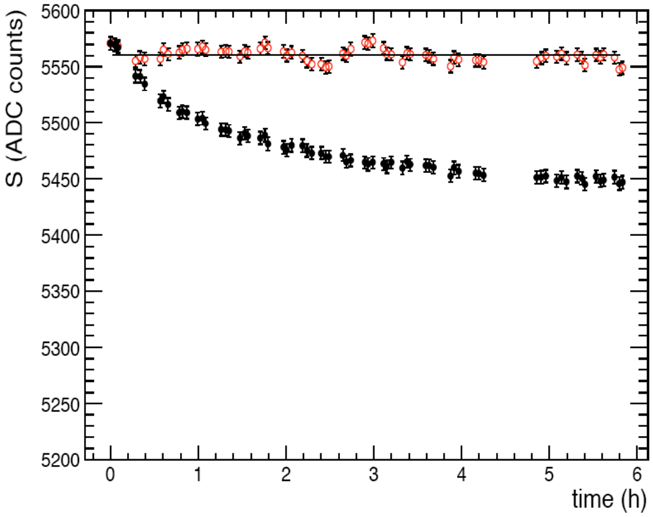

Fig. 1. Effect of the monitor correction procedure on test beam data: black points refer to signals measured during beam irradiation, red points are the same after the monitor correction.

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READ-OUT

The photo-detectors must operate in the 4 T field and have gain because of the low light output of $PbWO_4$. The avalanche photo-diodes (APDs) in the barrel were specially developed by Hamamatsu Photonics for CMS. Radiation-resistant vacuum photo-triodes will be used in the end-caps.

The on-detector electronics is custom designed in IBM CMOS 0.25 μm technology. The photodetector signal passes through a 40 ns shaping preamplifier and then in parallel through amplifiers with gains of 1, 6 and 12 into multichannel 12-bit 40 MHz sampling ADCs to provide a dynamic range of 40,000. The pipelines which store the digitized data during the level 1 trigger latency are in a single ASIC for five channels. The same circuit also provides the energy sums for the trigger generation. Both DAQ and trigger data are transmitted to the counting room by an optical data link operating at 800 Mbit/s through optical fibers over a distance of about 100 m.

PERFORMANCE

The ECAL calibration is a crucial point for the early discovery potential for new physics, as it enters directly in the constant term of the resolution. Several methods are applied to equalize the response before the start-up [5], while in-situ ECAL will be continuosly calibrated with physics events [3].

Performance tests on the final barrel supermodules are done with an electron beam in the CERN North Area [6], [7]. The noise in the single channel has been measured to be around 40 MeV, as expected. No correlated noise is present after processing random trigger events by the signal amplitude reconstruction algorithm [8]. Detailed studies of the energy resolution as a function of the energy and of the impact point on the crystal face are going on.

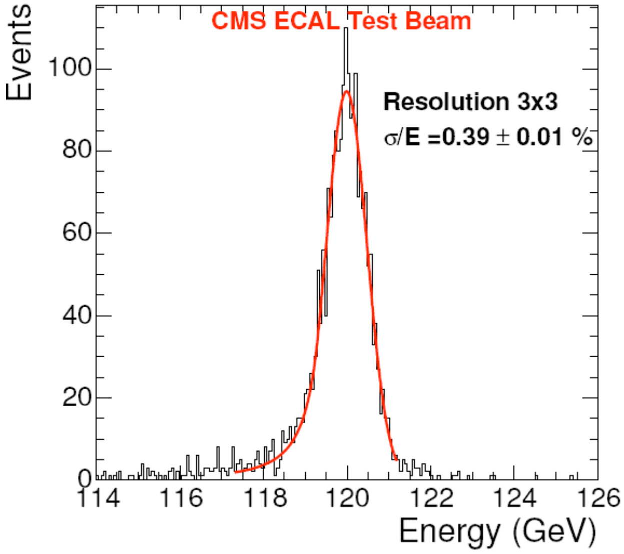

Fig. 2. Energy distribution in a 3x3 matrix of crystals for 120 GeV electrons incident in a 4x4 mm^2 region centred on a crystal.

The measured energy distribution (including a beam spread of 0.09% rms) in a 3x3 matrix of crystals is shown for 120 GeV on Fig. 2, for electrons incident in a 4x4 mm^2 region centred on a crystal, where the response is expected to be uniform. On Fig. 3, the resolution as a function of the energy (after the subtraction of the expected beam spread) is presented for 18 3x3 crystal matrices at two different η positions, illuminated by the same beam spot. This resolution can be parametrised on average as

$$\frac{\sigma}{E} = \frac{2.8\%}{\sqrt{E(\mathrm{GeV})}} \oplus \frac{125}{E(\mathrm{MeV})} \oplus 0.3\%.$$

For particles incident outside this central zone, a correction has been developed [9]. The correction is based on a function of the logarithmic ratios of the energy deposits in 3x3 matrices. This correction does not require external information on the impact point, and thus can be applied to photons. Using a correction function independent from the position and from the energy, and a beam spot of 20x20 mm^2, the resolution as a function of the energy shows a little worsening, still crossing the 0.5% level before 120 GeV, as shown in Fig. 4.

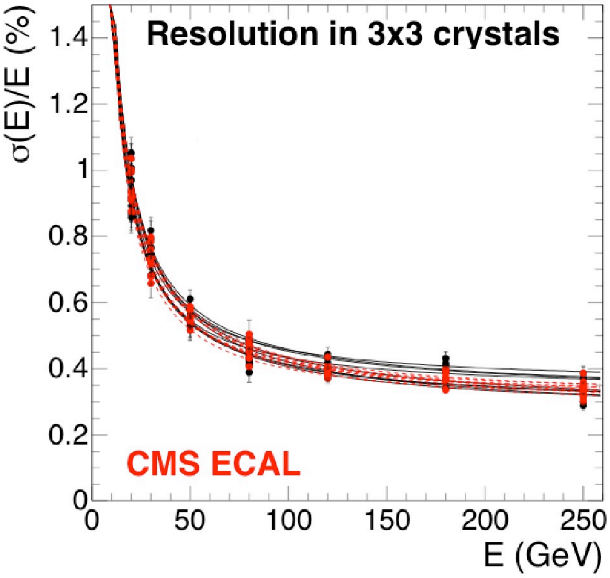

Fig. 3. Resolution as a function of the energy for 18 crystal matrices. Black and red points refer to two different η positions.

To evaluate the resolution for electrons incident on the full surface of the crystal, the beam was in turn centred on the centre of all crystals in a the 3x3 array, on all four corners of the central crystal, and on the edges between the nine crystals, as shown in Fig. 5. The distribution of measured energies is presented in Fig. 6 for 120 GeV, showing that a high energy resolution of 0.5% is reached.

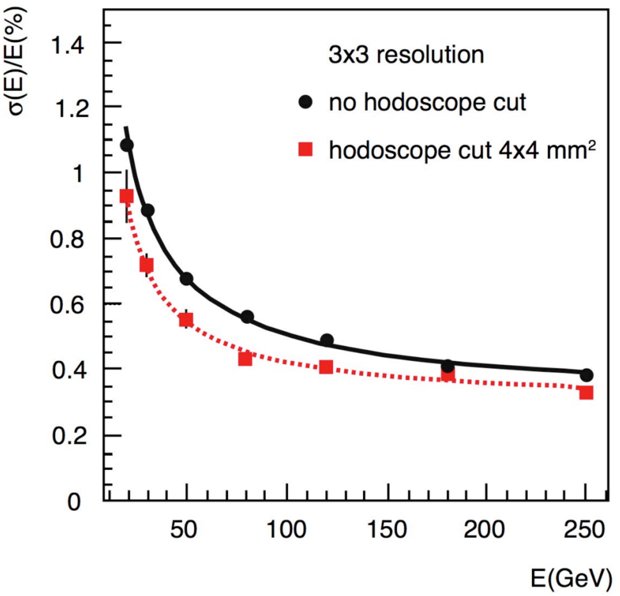

Fig. 4. Energy resolution as a function of the energy for a 3x3 matrix with and without the selection of electrons incident in a 4x4 mm^2 central region, where the response is expected to be uniform.

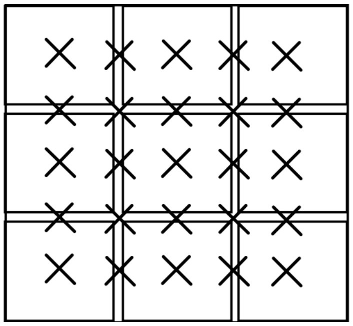

Fig. 5. Beam positions to evaluate the resolution on the full surface of the crystals.

CONSTRUCTION AND COMMISSIONING

The construction and the commissioning of the calorimeter is well under way. Several installation tests are performed in surface. In April 2006, two completely equipped supermodules containing 1700 crystals each were mounted inside the detector, allowing to test the magnet system with full cabling in place. Data taking integration was also checked. The final installation in CMS is foreseen in mid 2007 for the barrel and in 2008 for the end-caps.

CONCLUSIONS

The high resolution electromagnetic calorimeter of the CMS experiment is near to completion. The target resolution of 0.5% at high energy has been reached. A tight schedule will allows its installation in CMS in time for next year LHC pilot run.

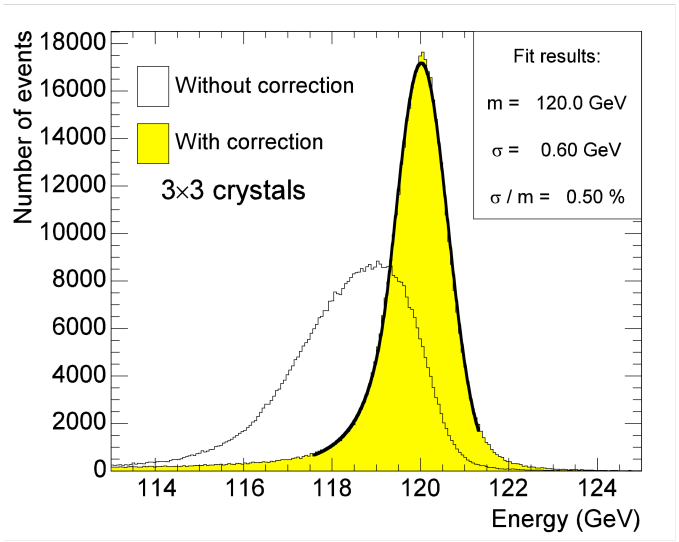

Fig. 6. Distribution of the energy deposited in 3x3 matrices for 120 GeV electrons uniformely distributed on the front faces of the crystals, before and after the correction for the containment.

ACKNOWLEDGMENT

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