OVERVIEW OF THE CMS ELECTROMAGNETIC CALORIMETER

H. F. HEATH
H.H.Wills Physics Department, Bristol University, Tyndall Ave, Bristol, BS8 1TL, England
E-mail: Helen.Heath@bristol.ac.uk

The Compact Muon Solenoid (CMS) is one of two ominpurpose experiments to be constructed at the Large Hadron Collider (LHC) at CERN. CMS incorporates a precision Electromagnetic Calorimeter which will be the largest crystal calorimeter ever constructed. The harsh environment at the LHC places stringent demands on the detector components. Following an extensive development period production of parts for the CMS ECAL is under way. An overview of the current project status is presented including results from recent prototypes and quality control tests on production components.

1 Introduction

The CMS experiment[1] for the LHC has made high precision electromagnetic calorimetry a priority and is constructing the largest crystal calorimeter ever built. It will contain 80,000 lead tungstate crystals. The calorimeter will be located inside a superconducting solenoid which will produce a field of 4T.

2 Physics Constraints

If the Higgs has a mass of less than 150GeV/c² then the most likely discovery channel is the decay to two photons. The natural width of a Higgs of this mass is very small and so the measured width depends only on the detector resolution. The mass resolution is given by the expression:

$$\sigma_M / M = (\sigma_{E_1} / E_1 \oplus \sigma_{E_2} / E_2 \oplus \sigma_\theta / \tan(\theta/2))/2$$

where E_1 and E_2 are the energies of the two photons and θ is the angle between them. For the range of photon energies associated with the light Higgs decay the energy resolution of the calorimeter can be parameterised as

$$\sigma_E / E = a/\sqrt{E} \oplus b \oplus c/E$$

The "stochastic" term a arises from photoelectron statistics and shower fluctuations. The "constant term" b has contributions from non-uniformities and from shower leakage. The "noise" term c is due to electronics noise and pile-up. The design goals [2] for the CMS ECAL barrel and endcap are a = 2.7% and 5.7%

respectively and $b < 0.55\%$ for both sections of the detector. Expressing the noise as transverse energy the goals are, at low luminosity, $c = 155$MeV and 205 MeV and at high luminosity 210MeV and 245MeV for the barrel and endcap respectively. Results from beam tests with prototype crystals [3][4] have demonstrated that these goals are attainable.

3 Lead Tungstate

To reach its design goals CMS has chosen a homogeneous crystal calorimeter. Lead Tungstate ($PbWO_4$) has been chosen as the detection medium. It the advantages of a short radiation length (0.89cm) and small Molière radius(2.19cm) which means that the ECAL can be relatively compact. A compact ECAL reduces the overall size of the experiment including the solenoidal magnet. Lead Tungstate is intrinsically radiation hard, which is essential for the LHC environment. It is a fast scintillator and the peak emission frequency matches well with the requirements of photodetectors.

An extensive research and development program [5] has produced crystals of the required quality. Recent developments have succeeded in increasing the size of the boules, from which the crystal are cut, enabling two crystals (and possibly four) to be produced from the same boule. This results in a dramatic increase in the potential production rate. The current status is that the order of the barrel crystals has been placed and the order for the endcap crystals is to follow shortly. All the procedures for monitoring the crystal quality are well defined and have been exercised thoroughly with preproduction crystals.

4 Mechanics

Mechanically the CMS ECAL is divided into three sections, a central barrel section and two endcaps. The crystals are arranged such that intercrystal gaps are off-pointing by 3°. To achieve this the barrel has a total of 34 different crystal shapes - 17 pairs of mirror image crystals - approximately $20x20x230mm^3$ in size. The barrel is constructed of 36 supermodules containing 1700 crystals. Each supermodule contains four modules each comprising 400 or 500 crystals. The first fully operational CMS ECAL barrel module has been constructed and a description is given elsewhere in these proceedings[6].

The Endcap design uses a single crystal shape approximately $30x30x220mm^3$. The crystals are slightly tapered and twenty-five of them are inserted into a carbon fibre "alveolar" unit, each with the same orientation. The resulting tapered supercrystal is the basic unit from which the Endcap is constructed. The supercrystals are mounted onto D-shaped back plates with angled mounting blocks. All supercrystals in one quadrant have the same orientation so that the supercrystal angle to the horizontal increases with distance from the beam pipe. This maintains the desired off-pointing.

A full-sized supercrystal has been tested at in electron beams at CERN[3] and in mechanical tests at the Rutherford Appleton Lab a fully loaded supercrystal has been mounted on a mock up of the Dee back plate(Fig 1).

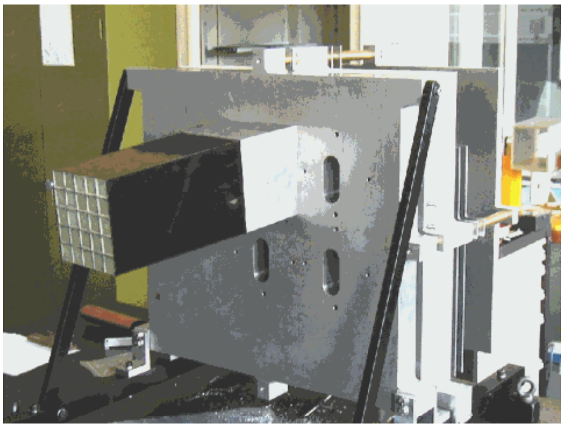

Figure 1. A fully loaded endcap supercrystal suspended from a mock up of the endcap Dee backplate.

5 Photodetectors

Two different photodetector technologies are used in the CMS ECAL to meet the constraints of the environment in the barrel and endcaps. The barrel uses solid state Avalanche Photodiodes(APDs). These devices have the advantages that they can operate in a transverse magnetic field, have a high quantum efficiency(~70%) and the thickness of the layer in which charge from shower leakage can be amplified (the nuclear counter effect) is small (6-8μm). Their disadvantages are that they are small in area and the bulk leakage currents increase after radiation. Development work[4] has reduced the excess noise factor (the fluctuations in the amplification process) and improved the stability of the gain with respect to voltage and temperature variations. To address the problem of the small active area a pair of APDs, mounted in a capsule, is used on each crystal. By October 2001 120,000 APDs had been ordered and over 11,000 delivered. The quality control and testing procedures are well defined. Assembly of capsules has been running since Autumn 2000.

The ECAL endcap is instrumented with Vacuum Phototriodes (VPTs) which are essentially single stage photomultiplier tubes. The use of APDs in this region is ruled out because the increase in electronic noise which would be induced by radiation damage is unacceptable. VPTs will operate in magnetic field provided the tube axis is at less than 45° to the magnetic field axis. Development work for CMS[7] has addressed the issues of improving the performance in magnetic fields, increasing the effective photocathode area and producing radiation hard glasses for the face plates. VPTs have a rather low Quantum efficiency(~18%) and gain(~8) and so large area tubes are essential in order to collect as much light as possible. The current status is that "1-inch" VPTs from a preproduction batch of 500 have been tested in the UK in magnetic fields of up to 4.7 T - fully exercising the quality control and acceptance procedures. The first order for 7000 production tubes has just been placed.

6 Monitoring

During the lifetime of CMS there will be an inevitable loss in response from the crystals. The basic scintillation mechanism is unaffected by radiation damage but the formation of colour centres leads to a loss in optical transparency. In order to compensate for this change in response it is necessary to track the changes throughout the lifetime of the experiment. For this purpose CMS is using a laser monitoring system in which light of wavelength 440nm is injected into each crystal. Tests have shown that the response to laser light is linearly related to the response to charged particles[8].

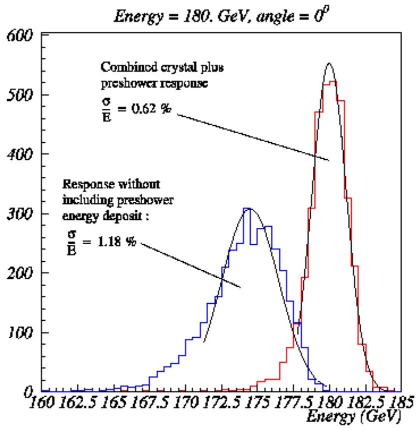

Figure 2 The energy resolution seen in a prototype endcap supercrystal for 180GeV electrons with and without the preshower correction.

7 The Preshower

The reducible contribution to the background to signals with a photon in the final state (including the Higgs decay) is from a jet which fragments into a leading π^0. In the barrel region a π^0 with a E_T of 60GeV will fragment to two photons with a separation of 0.8cm. Here it is possible to reduce the π^0 background using the information from the crystals alone. In the endcap the separation of the photons from the same π^0 would be a few millimetres and the crystals are larger. In order to reduce this background a detector is needed which has a finer granularity than the crystals. CMS has chosen a preshower with lead as the absorber and two orthogonal layers of silicon strip detectors with 1.9mm strip pitch. The π^0 rejection which can be achieved in the endcaps varies from 60-70% at $E_T = 60$GeV, depending on η.

The main purpose of the preshower is to improve π^0/γ separation but it also improves isolation and reduces the longitudinal leakage from the ECAL. The presence of the lead absorber leads to a degradation in the resolution of the ECAL but this can be largely compensated for by applying a correction to the measured energy using the information from the preshower (Fig.2).

8 Summary

The CMS ECAL project is now moving from a successful research and development phase into the construction phase. Orders have been placed for many of the critical components. The quality control procedures for acceptance of these components are in place and have been exercised with preproduction compnents.

References

1. CMS Collaboration (G.L.Bayatian et al.), CERN/LHCC 94-38
2. CMS Collaboration (G.L.Bayatian et al.), CERN/LHCC 97-33
3. M.Apollonio et.al. Test Results from a Prototype Lead Tungstate Crystal Calorimeter with Vacuum Phototriode Readout for the CMS Experiment. Accepted for Publication by Nucl. Instr. and Meth A
4. E. Auffray et.al. Nucl. Instr. and Meth A 412 (1998) 223
5. I. Dafieni Lead Tungstate Crystals for the CMS Electromagnetic Calorimeter at the LHC.
6. P. Sempere Roldan. Construction of first CMS-ECAL fully operational module (400 lead tungstate crystals)
7. K.W.Bell at.al. Nucl. Instr. and Meth A 469 (2001) 29, N.A.Bajanov et. al. Nucl. Instr. and Meth A 442 (2000) 146
8. G. Davies et. al. A Study of the Monitoring of Radiation Damage to CMS ECAL Crystals, Performed at X5-GIF. CMS NOTE-2000/020