The response to high magnetic fields of the Vacuum Phototriodes for the Compact Muon Solenoid endcap electromagnetic calorimeter

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Abstract

The endcap electromagnetic calorimeter of the Compact Muon Solenoid (CMS) detects particles with the dense fast scintillator lead tungstate ($PbWO_4$). Due to the low light yield of this scintillator photodetectors with internal gain are required. Silicon avalanche photodiodes cannot be used in the endcap region due to the intense neutron flux. Following an extensive R&D programme 26 mm diameter single-stage photomultipliers (vacuum phototriodes) have been chosen as the photodetector in the endcap region. The first 1400 production devices are currently being evaluated following recent tests of a pre-production batch of 500 tubes. Tubes passing our acceptance tests have responses, averaged over the angular acceptance of the endcap calorimeter, corresponding to the range 20 to 55 electrons per MeV deposited in $PbWO_4$. These phototriodes operate, with a typical gain of 10, in magnetic fields up to 4T.

Introduction

The Compact Muon Solenoid (CMS) detector which will operate at the Large Hadron Collider is a large general purpose particle detector [1] In order to provide excellent energy resolution the barrel and endcap electromagnetic calorimeters use the dense fast scintillator lead tungstate ($PbWO_4$). Due to the low light yield of this scintillator photodetectors with internal gain are required. In the barrel region silicon avalanche photodiodes will be used, but these cannot be used in the endcap region due to the intense neutron flux. Following an extensive R&D programme 26 mm diameter single-stage photomultipliers (vacuum phototriodes) have been chosen as the photodetector in the endcap region. The first 1400 production devices are currently being evaluated following recent successful tests of a pre-production batch of 500 tubes.

Operating principles

A vacuum phototriode (VPT) is a single stage photomultiplier tube with a fine mesh transmissive anode and a solid high-gain dynode. The gain is dependent upon the transparency of the mesh and the secondary electron gain coefficient of the dynode. For the tubes described here, a transparency of around 50% and a typical secondary emission gain of 20 result in a nominal gain at 0T of about 9. For a constant operating potential the gain of the tube is a function of field strength and angle to the field [2] [3]. At a constant angle to the field tubes show a rapid fall in gain with increasing field, reaching a plateau of 80% of the zero field gain around 1T. In CMS the devices must operate at the full field of the experiment, 4T.

CMS VPT characteristics

Five hundred tubes were delivered by RIE [4] during 2001 and were evaluated at Brunel University and CLRC Rutherford Appleton Laboratory. In particular their characteristics in magnetic fields were studied in detail. At RAL the gain of the tubes is measured as a function of field strength up to a maximum axial field of 1.8T, and the variation of gain with angle within a constant field of 1.8T is also determined. Tubes show a complicated oscillatory response at a fixed field as they are tilted away from axial alignment (figure 1) It has been shown that this is a fundamental feature, which depends only on the construction details in particular the mesh transparency and mesh thickness, and is highly reproducible from tube to tube [5].

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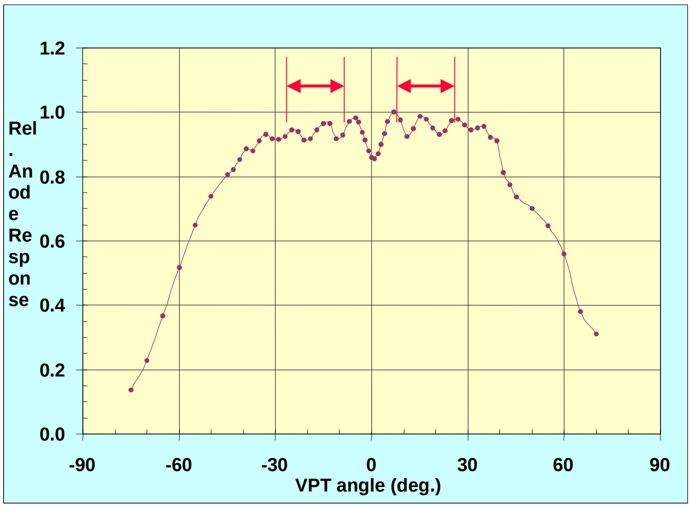


Figure 1 Variation of anode response for constant pulsed LED illumination as a function of angle to an axial field of 1.8T. The vertical bars indicate the range of angles that will be encountered in the endcap calorimeter.

In the CMS endcap, tubes will be placed at angles between 8° and 25° to the field. The gain rises as the tube is tilted away from axial alignment with the field lines, until about 30° when it drops rapidly to zero. This effect partially compensates for the loss in gain at 0° with increasing field and means that the gain ratio 4T/0T at 15° is close to 100% This has been confirmed using the 4T superconducting magnet test facility at Brunel.

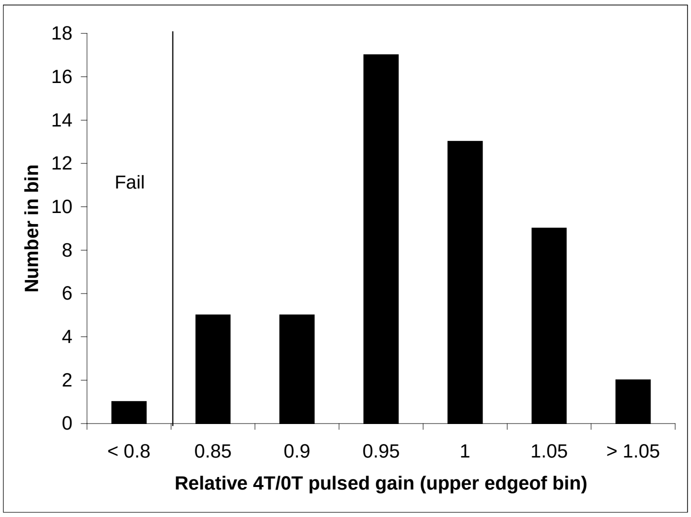
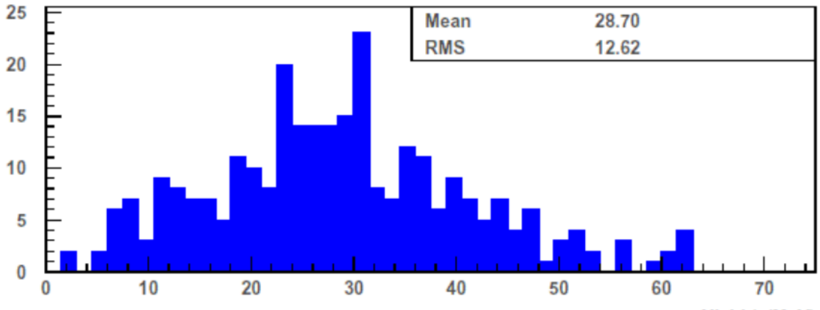
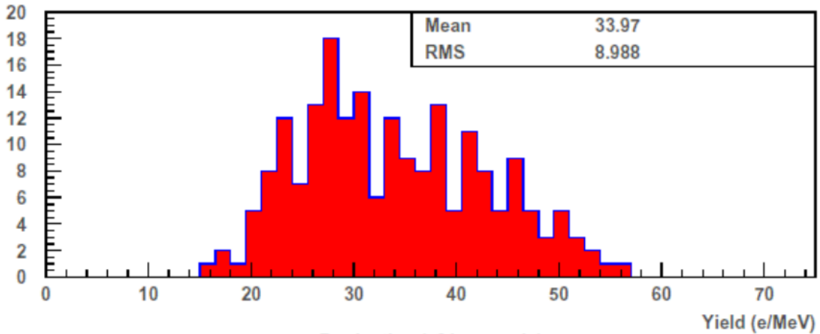


Figure 2 Variation in relative response at 0T and 4T of production tubes. The tubes are aligned at an angle of 15° to the magnetic field.

As part of the acceptance testing all tubes have their response, averaged over the angles 8° to 25° measured at a field of 1.8T. Figure 3 shows the response of both pre-production and production batches tubes averaged over this angular range. The measured anode response has been converted to give the electron yield per MeV deposited in an endcap $PbWO_4$ crystal. Overall the production tubes are better in their response than the pre-production batch since the low yield tail has been eliminated by the producer.



Pre-production (101-500)



Production (501 onwards)

Figure 3 Measured response of the RIE tubes averaged over the angular range 8° to 25° in a 1.8T field. The measured anode response has been converted to give the electron yield per MeV deposited in an endcap $PbWO_4$ crystal.

Summary

Following successful evaluation of 500 pre-production tubes from RIE we are now taking delivery of the first batches of the 15000 tubes destined for the CMS endcap electromagnetic calorimeters. We have demonstrated that vacuum phototriodes, with a gain of about 10 at 15° to a magnetic field of 4T can be commercially produced in quantity. These new devices are superior in many respects to those previously obtainable, notably in having high gain at high magnetic field strength, radiation tolerance, and stability at large photocurrents. Other applications that need these characteristics could benefit from these new photodetectors.

Acknowledgement

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