Vacuum Phototriodes for the CMS Electromagnetic Calorimeter Endcap

K. W. Bell, R. M. Brown, D. J. A. Cockerill, P. S. Flower, P. R. Hobson, B. W. Kennedy,
A. L. Lintern, C. S. Selby, O. Sharif, M. Sproston, J. H. Williams

Abstract—**The measurement of scintillation light from the lead tungstate crystals of the CMS ECAL poses a substantial technical challenge, particularly in the endcap regions, where the radiation levels are highest. The photodetectors must be fast, sensitive, radiation-hard, and operate with significant internal gain in a magnetic field of 4 Tesla. The measured performance characteristics of the first batches of series production vacuum phototriodes (VPT), developed to satisfy the needs of CMS, will be described.**

I. INTRODUCTION

THE CMS experiment is one of two general-purpose detectors currently being constructed for operation at the LHC proton-proton collider at CERN. The CMS electromagnetic calorimeter (ECAL) detector [1] comprises an array of lead tungstate crystals; the crystals are slightly tapered to generate a quasi-pointing geometry, as shown in Fig. 1. The barrel, of length 6m and radius 1.75m, contains approximately 61000 crystals, while the endcaps contain approximately 15000 crystals. The endcap crystals are 30×30mm^2 in cross-section and 220mm long, corresponding to a depth of approximately 25 radiation lengths. The calorimeter lies inside the 4T solenoidal magnetic field of CMS. The benchmark physics channel which drives the ECAL design is the decay of the Higgs boson to two photons; this will be the most significant discovery channel for the Higgs if its mass is less than 130GeV/c^2. The detection of this decay process above background requires that the energy resolution of the ECAL must be less than 1% for photons of 100 GeV energy.

The experimental conditions expected at the LHC impose stringent demands on the detector technology. The radiation environment during collider operation will be very harsh. The ECAL barrel will receive an integrated dose of up to 4 kGy during 10 years of operation, while the dose at the inner edge of the endcap could be as high as 200 kGy, with the dose rate being a strongly increasing function of rapidity [2]. Radiation tolerance is therefore a vital consideration in the detector design.

The LHC will operate at a frequency of 40 MHz, so that the interval between beam crossings will be only 25 ns. The ECAL must therefore be capable of responding on this timescale to provide prompt information to the triggering system.

A further constraint on the ECAL photodetector arises from the fact the scintillation light output of lead tungstate is rather weak; the CMS crystals typically yield 50 photons per MeV of energy deposited, mandating the use of a photodetector with internal gain.

Finally, the photodetectors must function satisfactorily in the 4T solenoidal magnetic field of CMS.

The photodetectors chosen for the ECAL barrel are Avalanche Photodiodes (APDs). The neutron radiation flux in the endcaps is too severe for these solid-state devices, and Vacuum Phototriodes (VPTs) will be used. The properties of these devices will be described in the remainder of this note.

II. DESCRIPTION OF THE CMS VACUUM PHOTOTRIODES

A Vacuum Phototriode, or VPT, is a single-stage photomultiplier. A schematic diagram of a VPT is shown in Fig 2. The anode of the device takes the form of a grid; electrons liberated from the photocathode are able to pass through the holes in the grid to strike the dynode generating secondary electrons, which are collected on the anode.

VPTs for the CMS ECAL endcap typically have a quantum efficiency of 20%, and a gain of 10 at 0T. The specification requires that the loss in output after irradiation to 20 kGy is less than 10%, while the response in a magnetic field of 4T must be at least 75% of that achieved in zero field.

The CMS VPTs are manufactured by Research Institute Electron, St Petersburg, Russia, following a period of development in collaboration with PNPI Gatchina, Russia. A total of 6200 devices have been delivered at the time of writing, comprising a pre-production batch of 500, and 5700 devices manufactured under production conditions. Further

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K.W. Bell, R.M. Brown, D.J.A. Cockerill, P.S. Flower, B.W. Kennedy, A.L. Lintern, M. Sproston and J.H. Williams are with the CCLRC Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire OX11 0QX, UK

P.R. Hobson, C.S. Selby and O. Sharif are with Brunel University, Uxbridge, Middlesex UB8 3PH, UK.

information on the development of VPTs for CMS may be found in [3].

III. MEASUREMENTS OF VPT CHARACTERISTICS

The measured variation in the gain of a typical VPT as a function of the applied voltage is shown in Fig. 3. Two curves are shown, giving the gain as a function of dynode voltage with the anode held at 1000V or 800V, and the photocathode at ground. The operating point in CMS will be V_a=1000V, V_d=800V; at this point, the gain is insensitive to variations in the applied voltage.

Detailed measurements of the photocathode response have been made at the University of Split, Croatia. The quantum efficiency is found to be uniform over the photocathode area.

All VPTs are tested at the Rutherford Appleton laboratory to determine their response as a function of magnetic field up to 1.8T, and as a function of angle to the applied field. The automated testing rig at RAL is able to make measurements on 24 VPTs simultaneously, to determine their response to pulses of light of approximately 420nm wavelength. A typical set of measurements is shown in Fig. 4. The variation of the VPT output shows a characteristic periodic behaviour as a function of angle in a 1.8T field. When the response is measured as a function of magnetic field (with the angle fixed at 15°), the gain is observed to be constant at fields above 1T, but variable at lower fields. The VPTs will be installed in CMS at all angles between 8° and 24° to the magnetic field, and the mean response over this range is taken as a figure of merit characterising the VPT.

The measured yield of the VPTs is found to meet the requirements of the CMS ECAL. No significant variations in the mean yield have been observed during the period of manufacture.

Approximately 10% of the devices, selected at random, are also tested at Brunel University in a 4T superconducting magnet, at a fixed angle of 15°. These measurements are well-correlated with the measurement made at 1.8T, indicating that the response is stable at high magnetic fields, and that the 1.8T measurement is a reliable indicator of the VPT performance in CMS.

IV. RADIATION TOLERANCE

The high radiation dose expected at LHC implies that the radiation tolerance of the VPTs must be carefully monitored. The VPT faceplates are made of radiation-hard glass, which is manufactured in small batches. Before a batch is used for production several samples of each batch of glass are irradiated to 20 kGy using a ^{60}Co source at Brunel University. After irradiation the induced absorbance of the sample is measured as a function of wavelength. A measurement on a typical glass is shown in Fig. 5(a). The total transmission loss after convolution with the lead tungstate scintillation spectrum, shown in Fig 5(b), must be less than 10% for the sample to be accepted for use in VPT production.

V. SUMMARY AND CONCLUSION

Vacuum Phototriodes have been developed that meet the demanding requirements of the CMS ECAL endcap. Approximately 15000 of these devices are required of which 6200 have already been delivered by the manufacturer. The performance of all these VPTs has been measured in a 1.8T magnetic field.. About 10% have also been tested at 4T; these measurements are found to correlate well with the results obtained at 1.8T. The radiation tolerance of the VPTs is assured by the irradiation and testing of all faceplate glass batches prior to manufacture.

VI. ACKNOWLEDGMENT

We are pleased to acknowledge the work of Research Institute Electron, St Petersburg in manufacturing and delivering VPTs according to the CMS technical specifications and the agreed delivery schedule. We also thank our colleagues at PNPI Gatchina for their collaboration in developing the VPT technology and in studying the production devices. We thank colleagues at the University of Split for their careful measurements of the photocathode response of a number of VPTs. We would like to acknowledge the financial support of PPARC.

VII. REFERENCES

[1] The CMS Collaboration, "The Electromagnetic Calorimeter Project Technical Design Report" *CERN/LHCC 97-33,* 15 December 1997.
[2] M. Huhtinen, CMS NOTE 1998/055, 2 September 1998
[3] K. W. Bell, R. M. Brown, D. J. A. Cockerill, P. S. Flower, P. R. Hobson, D.C. Imrie *et al*, “The Development of Vacuum Phototriodes for the CMS Electromagnetic Calorimeter”, NIM A469 (2001) 29-46.

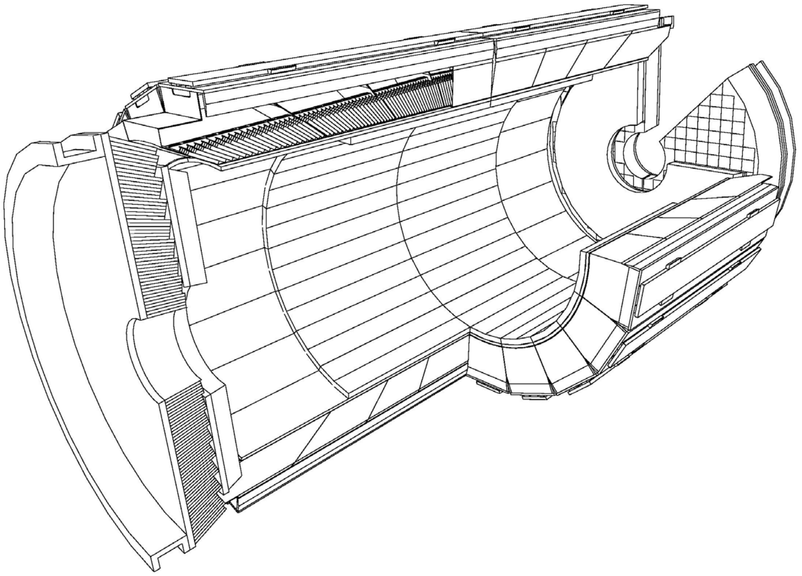

Fig 1. Schematic view of CMS electromagnetic calorimeter.

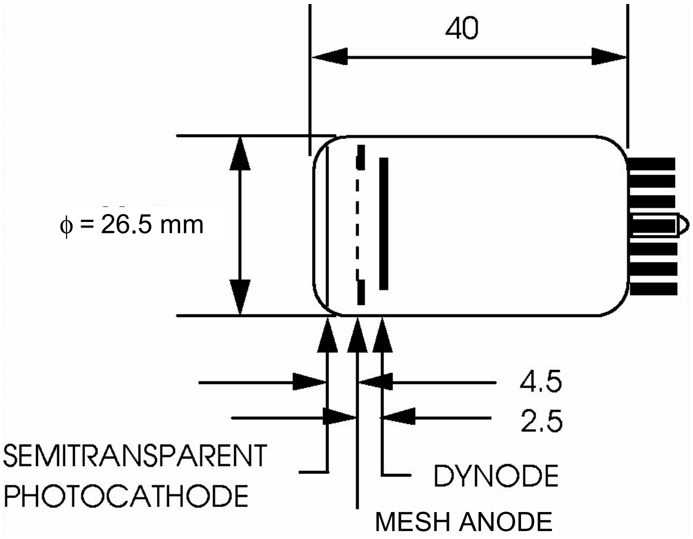

Fig 2. Diagram of a Vacuum PhotoTriode.

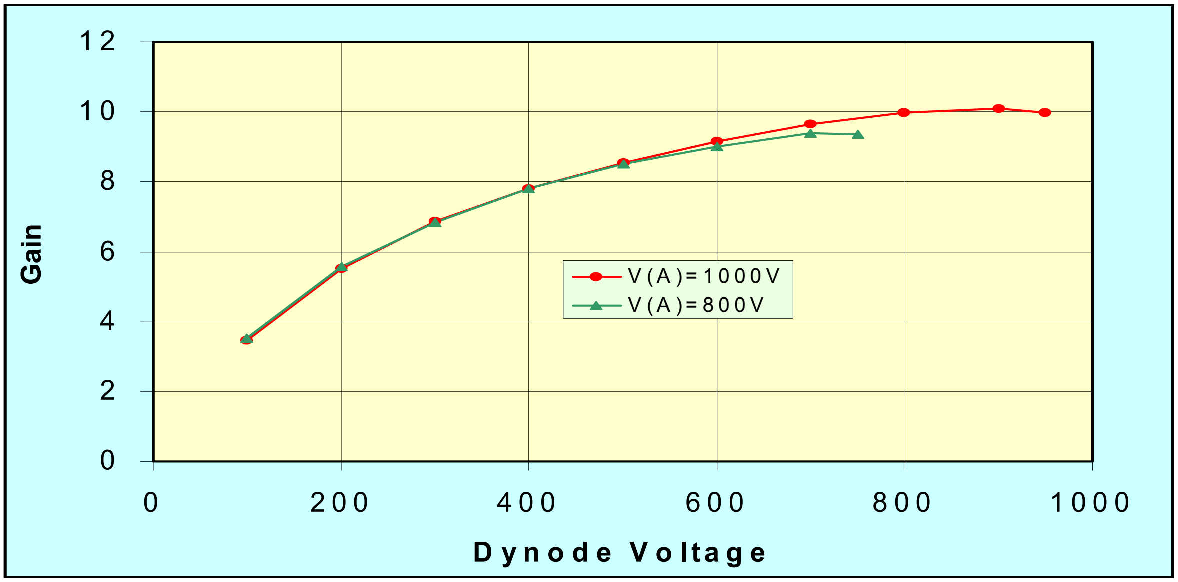

Fig 3. Variation in gain of typical VPT with applied anode and dynode voltage.

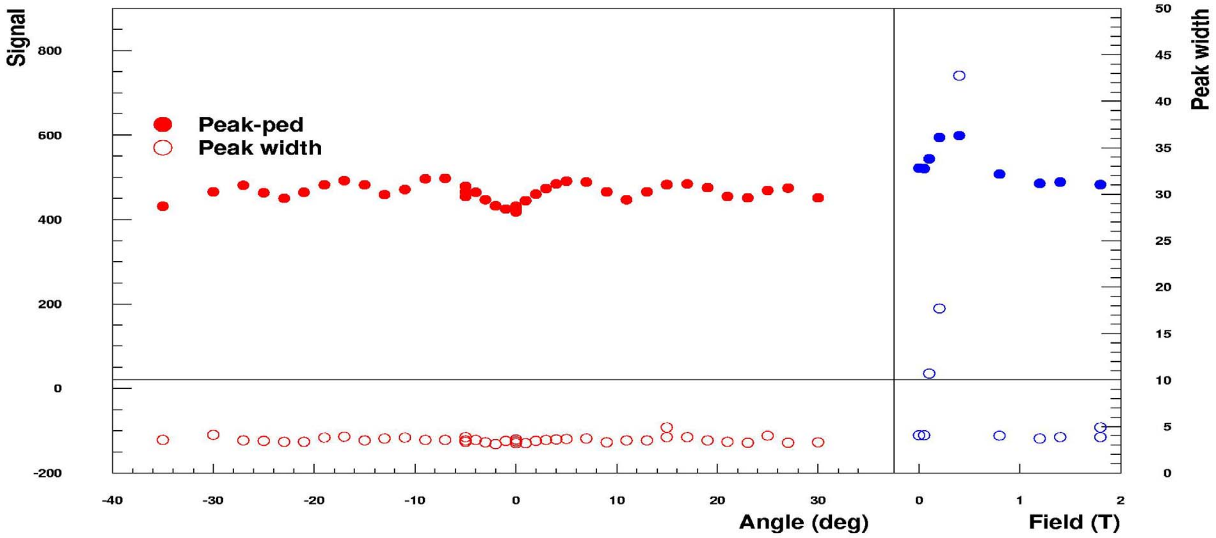

Fig 4. Response of VPT (arbitrary units) as a function of angle (left-hand side) and magnetic field (right-hand side). The closed circles show the measured response, while the open circles indicate the Gaussian width of the response peak at each point.

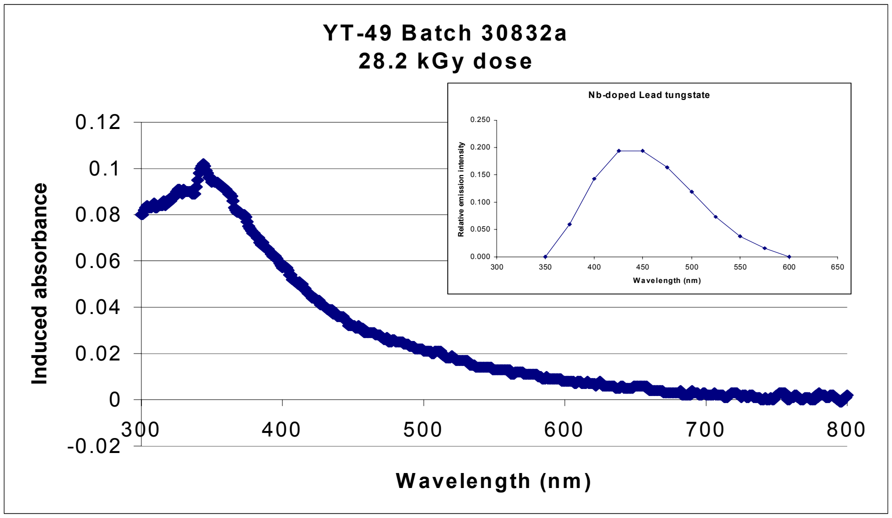

Fig 5. The induced absorbance of a typical faceplate glass sample, measured after exposure to a gamma dose 20 kGy from a ^{60}Co source. The inset shows the $PbWO_4$ scintillation spectrum.