Behaviour of production VPTs for the CMS Endcap Electromagnetic Calorimeter

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Abstract

This note reports measurements made on the first 700 production Vacuum PhotoTriodes (VPTs) manufactured by RIE (St Petersburg) for the CMS Electromagnetic Endcap Calorimeter. This is an interim report. A more complete report will be produced when all 700 VPTs have been fully tested.

Introduction

This document describes a series of measurements made on the first 700 Vacuum PhotoTriodes (VPTs) manufactured by RIE (St Petersburg) for the CMS Electromagnetic Endcap Calorimeter. The VPTs were delivered in three batches; an initial delivery of 100 received in early January 2002, 400 more delivered two weeks later, and a further batch of 200 received in March 2002. No significant differences have been found between the batches.

The appraisal of the VPTs was carried out at RAL and Brunel University during the period January-April 2002. This document describes the results obtained at RAL.

The VPT specification

Some of the technical specifications of the VPTs which are incorporated into the contractual agreement with the manufacturers are summarised in Table 1. A more detailed and definitive statement of the requirements can be found in [1].

Quantity	**Meaning**	**Range**
P	Photocathode quantum efficiency at 420nm	≥15%
G	Current gain at zero field	≥ 7
PG	$PG = P \times G$	1.4 – 3.8
F	Excess noise factor	< 4.5
i^{a}_{max}	Maximum anode current from 0 - 4T	≤ 2 nA
Length	Overall length of VPT	≤ 46mm
Diameter	External diameter of insulating sleeve	26.5-27.2mm

Table 1. Technical specification of VPTs. Measurements are to be made with anode and dynode voltages of 1000V and 800V respectively relative to the photocathode, using blue LEDs with a peak emission of wavelength 420nm.

The RAL variable-angle test rig

Overview

The test rig at RAL is based on a water-cooled magnet providing fields up to 1.8T over an area of approximately 0.5 m^2. The vertical distance between the pole tips is approximately 10cm. VPTs are held in rows of 8 aluminium cans. Up to 6 such rows can be mounted in the rig, and the rows may be rotated in unison to present the VPTs to the magnetic field at any desired angle up to 90°.

Mechanical design

Figure 1 is a photograph of the RAL test rig area. The 1.8T magnet, slightly to the left of centre in the picture, was formerly used as a bending magnet in a beam line.

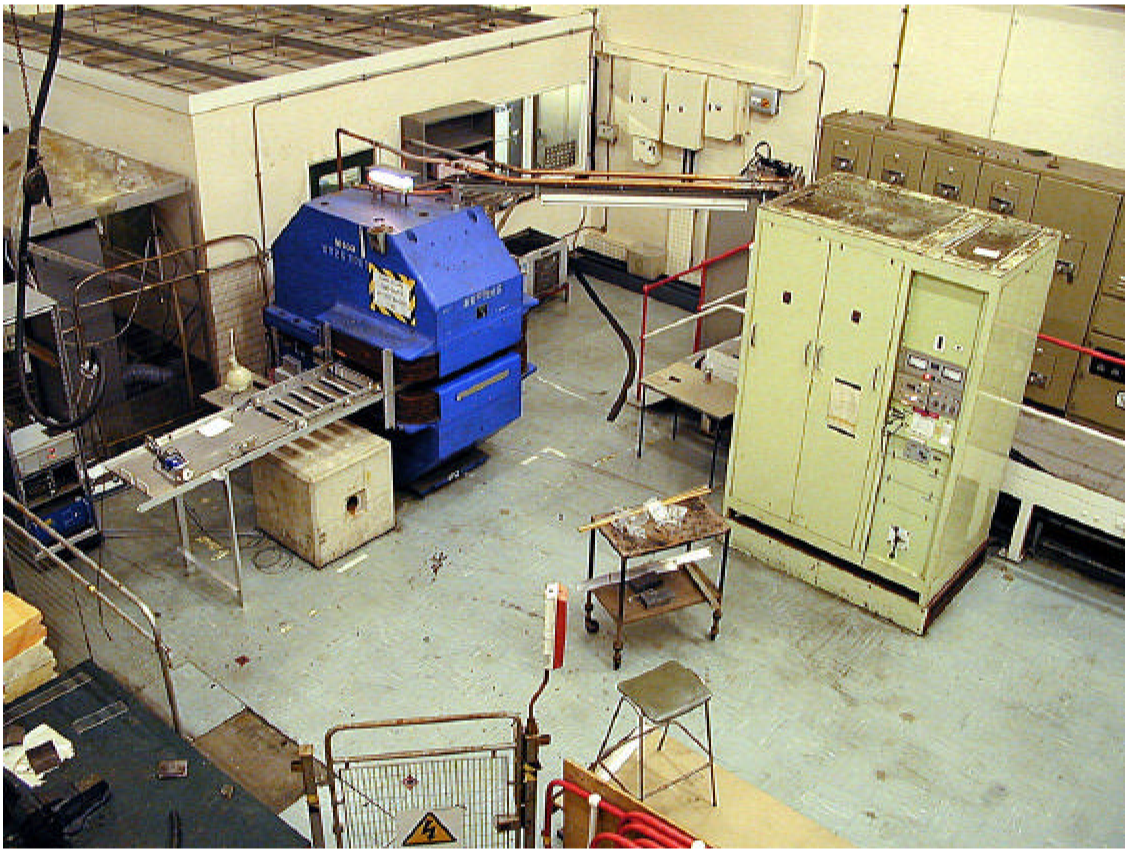

Figure 1. General view of the RAL test rig

The VPTs are held in aluminium cans; Figure 2 shows an example. Cans are glued together in rows of eight, with each row attached to the rig by a shaft, so that it may be rotated to present the VPTs at any desired angle to the magnetic field. A stepper motor is used to rotate all of the VPTs simultaneously by means of a system of drive belts.

When the rig is in use, the magnet pole tips are covered with a black cloth to eliminate stray light.

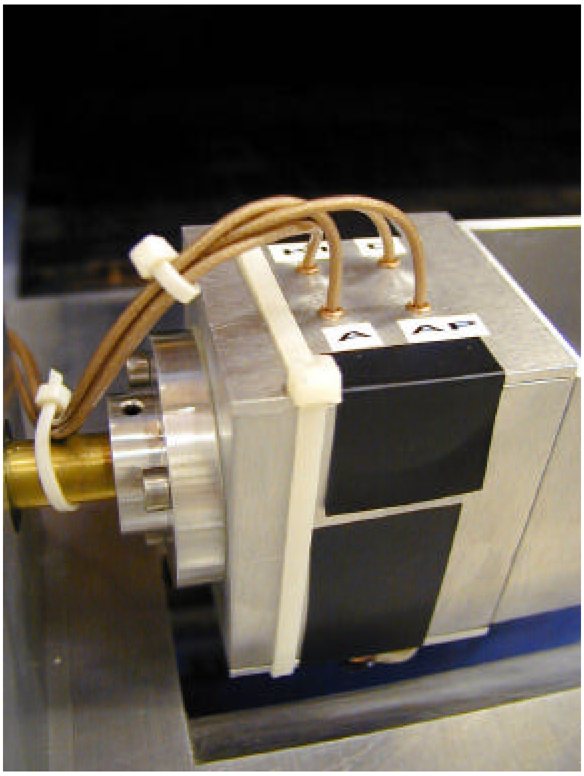

Figure 2. Close-up view of a VPT holder.

Illumination of photocathodes

Considerable care has been taken to illuminate the photocathodes as uniformly as possible. Each VPT is illuminated by a diffuser plate equipped with four 430nm LEDs, as illustrated in Figure 3. A metal mask is used to block the direct light from the LEDs, and to reduce electronic pick-up from the LED drive pulse.

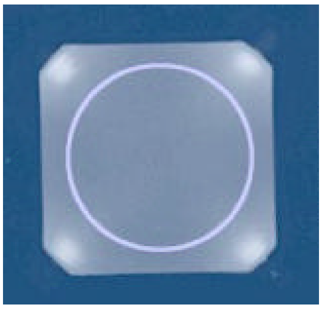

Figure 3. Frosted perspex diffuser plate equipped with four 430nm blue LEDs. In operation, the direct light from the LEDs is masked. The circle indicates the unmasked area.

Electronics

Figure 4 shows a schematic diagram of the control and readout logic of the RAL test system. The system is constructed from standard CAMAC and NIM modules, with the exception of the anode signal amplifiers, which are low-noise devices designed at RAL. The HT power supply for the VPTs is an ISEG NHQ 222M high-precision unit allowing the output current to be monitored with a precision of 100pA.

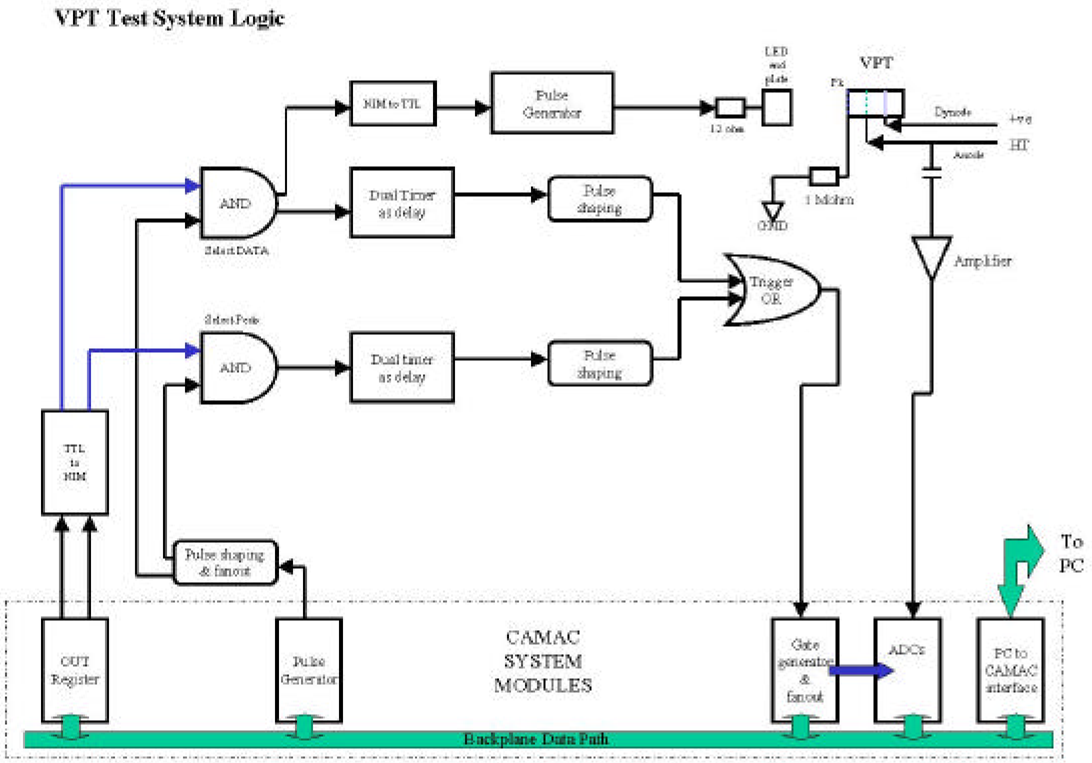

Figure 4. Schematic diagram of the VPT test system electronics

The DAQ and control software

The HT control and data acquisition systems are controlled by a PC running LabView software written at RAL. The 1.8T magnet is controlled by a Visual Basic program running on the same PC.

A second PC runs a simple database system to allow the bar codes to be automatically registered when VPTs are loaded into the test rig. For safety reasons, this PC also controls a small ‘web-cam’ which views the test rig area; images from this camera may be viewed remotely by means of a web-browser.

Visual inspection of VPTs

All of the VPTs received have been inspected visually, to detect obvious defects or anomalies in their photocathodes, anode grids, or other aspects of their appearance. Table 2 summarises the results.

The characteristics which were seen most frequently were imperfections in the photocathode coating and misalignment of the anode grid with respect to the axis of the VPT. The entries given as "Missing photocathode" refer to crescent-shaped areas of the faceplate which appeared to have no photocathode coating – in these cases, the approximate size of the missing area has been estimated by eye. A small number of VPTs showed more random variations in the thickness of the photocathode layer; these are recorded as "Uneven photocathode coverage".

A small number of tubes displayed a reddish-brown discolouration of the photocathode. It is notable that three of these had production numbers very close together (bar-code / production-numbers 938 / 2048, 939 / 2052, and 953 / 2049), so that the discolouration may indicate a quickly-corrected anomaly in the manufacturing process.

In general, this batch of production VPTs are very similar in appearance to the second batch of 400 pre-production devices received in December 2000.

Characteristic	**Number of VPTs**	**% of VPTs inspected**
Misaligned anode grid	30	4.3%
Missing photocathode (5-9% of faceplate)	28	4.0%
Missing photocathode (10-19% of faceplate)	25	3.6%
Missing photocathode (20-29% of faceplate)	13	1.9%
Missing photocathode (30-39% of faceplate)	5	0.7%
Missing photocathode (≥40% of faceplate)	4	0.6%
Uneven photocathode coverage	12	1.7%
Dark spot on photocathode or faceplate	7	1.0%
Red-brown discolouration of photocathode	4	0.6%
Poor or untidy crimping of pins to wires	9	1.3%
Pin came off during inspection	1	0.1%
Wire came off during inspection	1	0.1%

Table 2. Summary of visual inspection of 700 production VPTs

Measurements in the RAL 1.8T test rig

Magnetic field scans up to 1.8T

The RAL test rig allows VPTs to be operated at any magnetic field up to 1.8T. A standard part of the testing procedure is to scan the field from 1.8T to 0T with the VPT held at an angle of 15° to the field. After each change of field, a short settling period of about 2 minutes is allowed to ensure that the magnet and the VPTs are stable before starting to pulse the LEDs. 1000 LED pulses are measured at each field point. Figure 5 shows the variation in output with field for a typical sample of VPTs.

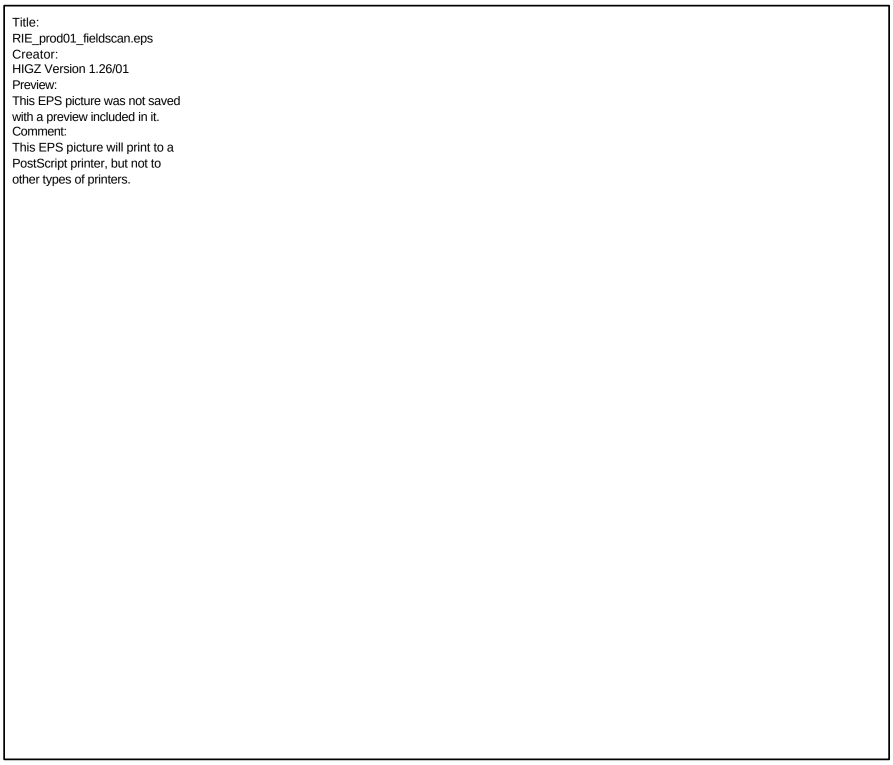

Figure 5. Examples of magnetic field scan on a typical VPT.

The VPT in this figure (bar code 553) exhibits a significant instability in the anode pulse size at low field. The pulse width also increases substantially in this field range. Approximately 20% of the VPTs display similar noisy behaviour at fields between 0.1T and 0.8T, though in all cases the tubes are stable at fields above 1T.

Angular scans on the VPTs at 1.8T

In the CMS endcap detector, the VPTs will be operated at a range of angles from 7° to 24° to the magnetic field. In the RAL test rig, the devices can be placed at any desired angle with respect to the 1.8T field. In the standard angle scan, measurements are taken at 35 positions from 40° to -40°; after every movement, a short settling period so that any induced instabilities in the VPTs can decay before taking data. Again, each measurement consists of 1000 LED pulses. Figure 6 shows the variation in output with angle for a typical VPT.

The periodicity shown in this figure is seen in all of the VPTs supplied by RIE, and is dependent on the alignment of the anode grid with the axis of rotation. All of the grids have been inspected at RAL using a microscope, and in the standard measurement procedure the grid lines are aligned with the axis of rotation.

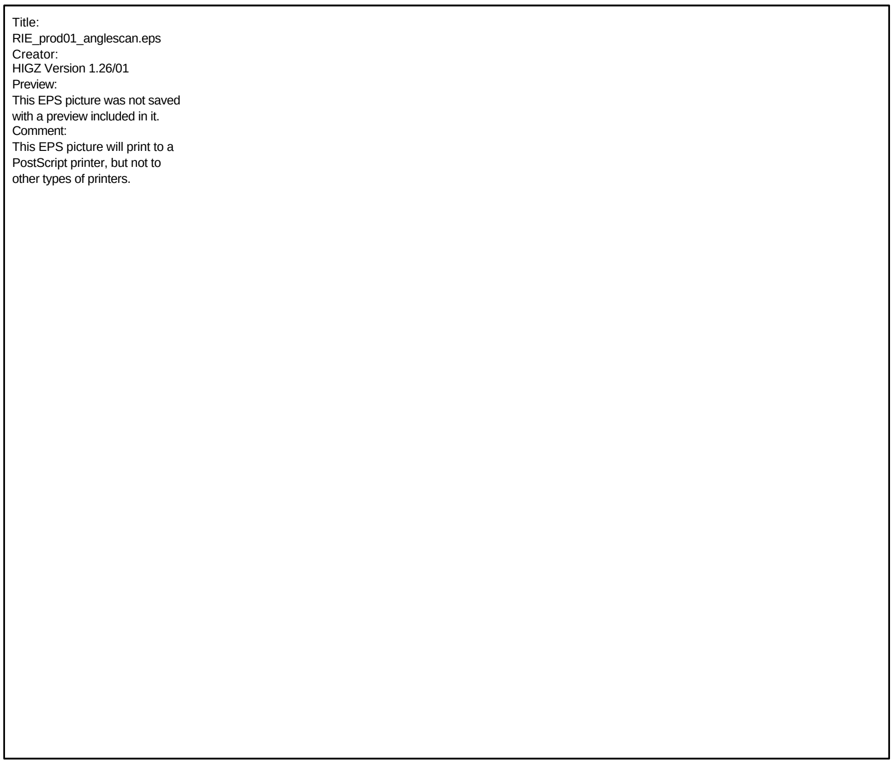

Figure 6. Angular scan at 1.8T on a typical VPT.

Summary of RAL 1.8T measurements

Approximately 300 of the production tubes have so far been tested in the 1.8T test rig. Six VPTs could not pass the whole testing procedure because they were found to draw excessive anode current – typically hundreds of μA, compared to one or two nA in normal operation. This behaviour was triggered during the magnetic field scan, at fields below 1T.   One other tube drew a large dynode current, and could not be tested. Tow of these tubes (556 and 771) have been returned to RIE, while the rest will be tested further at RAL. Table 3 gives details of these tubes.

Bar code	RIE serial number	Nature of failure
514	1006	Excess anode current at low field
556	1361	Excess anode current at low field
699	1604	Excess anode current at low field
700	1684	Excess anode current at low field
733	1727	Excess dynode current at 1.8T
771	1910	Excess anode current at low field
798	1751	Excess anode current at low field

Table 3. VPTs drawing excessive current during test procedure.

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Figure 7. Mean anode pulse height over the angular range 8°-25° in a 1.8T magnetic field.

Figure 7 shows the distribution of anode pulse heights measured in the RAL test rig at 1.8T; the quantity plotted is the mean pulse height over the angular range 8°-25° to the magnetic field. For comparison, results obtained from the pre-production batch are also shown. The measured pulse heights have been converted into the expected experimental yield of electrons per MeV of energy deposited in the CMS calorimeter. The production batch has a rather smaller spread than the preproduction tubes. Part of this effect arises from improvements in the resolution of the RAL measuring rig, but it is notable that the production batch has no tubes with yields below 10 e / MeV, as in the preproduction devices.

Figure 8 shows the correlation between the mean pulse height in the 1.8T magnetic field and the quality factor *PG* supplied by the manufacturer. Very similar results are seen with the magnet current set to zero.

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Figure 8. VPT response at 8°-25° and 1.8T v quality factor *PG*

Summary and Conclusions

The first 700 production VPTs supplied by RIE have been subjected to a variety of measurements at RAL and Brunel. All have been visually inspected, and approximately 300 have so far been tested in the RAL 1.8T test rig. The data supplied in the VPT passport is found to correlate well with these measurements. The overall quality factor *PG* is well-correlated with the measurements in the test rig.

The performance of the production devices appears superior to that of the pre-production batch, in that there is a smaller variation between the best and worst-performing tubes.

While the majority of the VPTs perform well, a few areas of concern have been identified:

- Misaligned anode grids: there is a concern that the reduced mechanical clearances will increase the risk of electrical breakdown after a long period under high voltage.
- Uneven and discoloured photocathodes: the occurrence of visible photocathode defects indicates that the photocathode deposition process needs tighter control.
- The large variation in anode current – a factor greater than three between the highest and lowest yield – will limit the dynamic range which can be achieved by the calorimeter.
- A small number of VPTs could not be tested because they drew excessive current.

References

[1] 'Technical specification of vacuum phototriodes for the endcap electromagnetic calorimeters of the Compact Muon Solenoid (CMS) experiment', May 11 2001