Behaviour of production VPTs for the CMS Endcap Electromagnetic Calorimeter: VPTs 501-8600

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Abstract

This note reports measurements made on the first 8100 production Vacuum PhotoTriodes (VPTs) manufactured by RIE (St Petersburg) for the CMS Electromagnetic Endcap Calorimeter.

Introduction

This document describes a series of measurements made on the first 7400 production Vacuum PhotoTriodes (VPTs) manufactured by RIE (St Petersburg) for the CMS Electromagnetic Endcap Calorimeter.

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	ǂ15%
G	Current gain at zero field	ǂ 7
PG	PG = P·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.

Delivery of VPTs

Figure 1 shows the VPT delivery rate as a function of time from 25 September 2000 to the present. It is noticeable that the delivery rate has dropped considerably below the scheduled rate since the start of 2004, and that an increase in the rate of delivery will be required to reach the total of 15500 devices by the third quarter of 2005.

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 feature which is most often seen is a misalignment of the anode grid with respect to the axis of the VPT. Over 20% of the VPTs appear to have some misalignment of the grid. There is no indication that the operation of these VPTs is affected in any way by the grid position: however, this aspect of the VPT appearance will continue to be monitored at RAL.

The other characteristics which were seen most frequently were various imperfections in the photocathode coating. 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. Detailed measurements of the photocathode response confirm [2] that the quantum efficiency of these devices is very low in the "missing" regions. A small number of VPTs showed more random variations in the thickness of the photocathode layer; these are recorded as "Uneven photocathode coverage". Photocathode defects have been observed more frequently in the more recent batches of VPTs. This suggests that the manufacturing conditions may have changed.

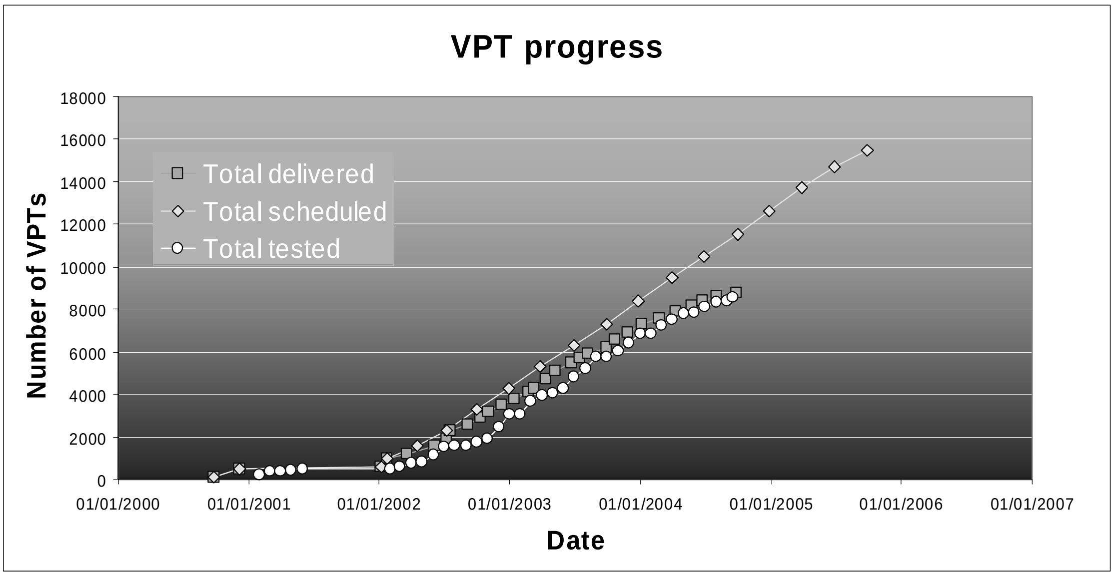

Figure 1. VPT delivery and testing

In recent batches of VPTs (with bar-codes from 5900 to 8600) there has been a significant increase in the number of tubes with poor crimping of the pins onto the leads. While this does not affect the performance of the VPTs, it is time-consuming for staff at RAL to re-crimp the pins on such VPTs before they can be tested. (The most recent batch, 8601-8800, seems to have much better crimping.)

A small number of tubes displayed a reddish-brown discolouration of the photocathode. 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.

Characteristic	Number of VPTs (by bar-code)						% of VPTs inspected
	501-1600	1601-3200	3201-4500	4501-5900	5901-8600	All	
Misaligned anode grid	78	384	234	201	744	1641	20.3%
Wrinkled anode grid	2	4	0	1	5	12	0.1%
Missing photocathode (5-9% of faceplate)	29	6	2	5	29	71	0.9%
Missing photocathode (10-19% of faceplate)	25	6	1	0	4	36	0.4%
Missing photocathode (20-29% of faceplate)	15	1	1	0	1	18	0.2%
Missing photocathode (30-39% of faceplate)	6	0	0	0	0	6	0.1%
Missing photocathode (‡40% of faceplate)	4	0	0	0	0	4	0.1%
Uneven photocathode coverage	11	11	3	5	8	38	0.5%
Dark spot on photocathode or faceplate	7	5	8	0	21	41	0.5%
Red-brown discolouration of photocathode	4	0	0	0	0	4	0.1%
Poor or untidy crimping of pins to wires	8	0	0	2	181	191	2.4%
Pin came off during inspection	1	1	1	0	0	3	0.1%
Wire came off during inspection	3	0	1	0	1	5	0.1%
Bloom on photocathode	0	45	12	13	163	233	2.9%
Bloom on grid	0	3	0	0	0	3	0.1%

Table 2. Summary of visual inspection of 8100 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. 5000 LED pulses are measured at each field point, at a rate of approximately 150Hz. Figure 2 shows the variation in output with field for a typical VPT.

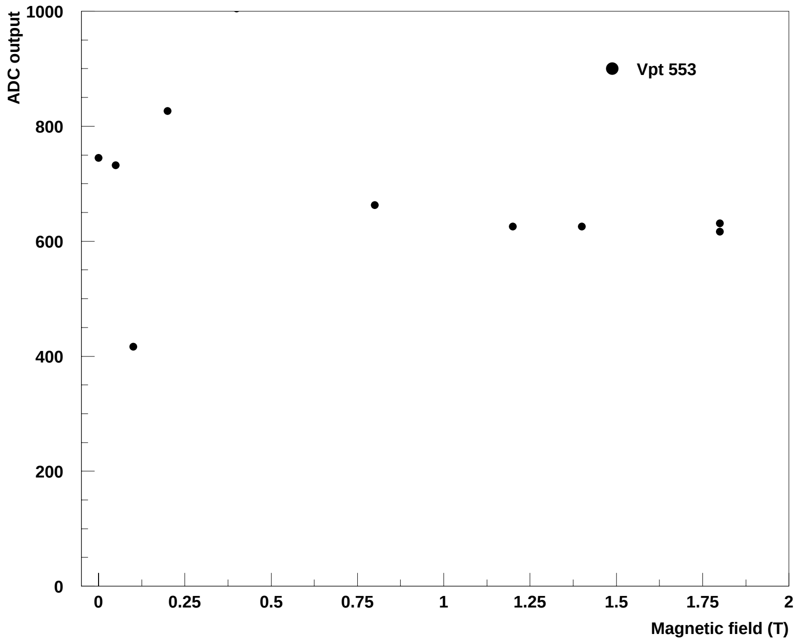

Figure 2. Examples of magnetic field scan on a typical VPT

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. Many VPTs display similar behaviour at fields below 1T; a minority are unstable at 1.8T, and have been analysed in a separate report [3].

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 angles from 30 to -35 ; after every movement, a short settling period is allowed so that any induced instabilities in the VPTs can decay before taking data. Again, each measurement consists of 5000 LED pulses. Figure 3 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 respect to the axis of rotation. The orientation of all the grids has been determined at RAL, and in the standard measurement procedure the grid lines are aligned with the axis of rotation.

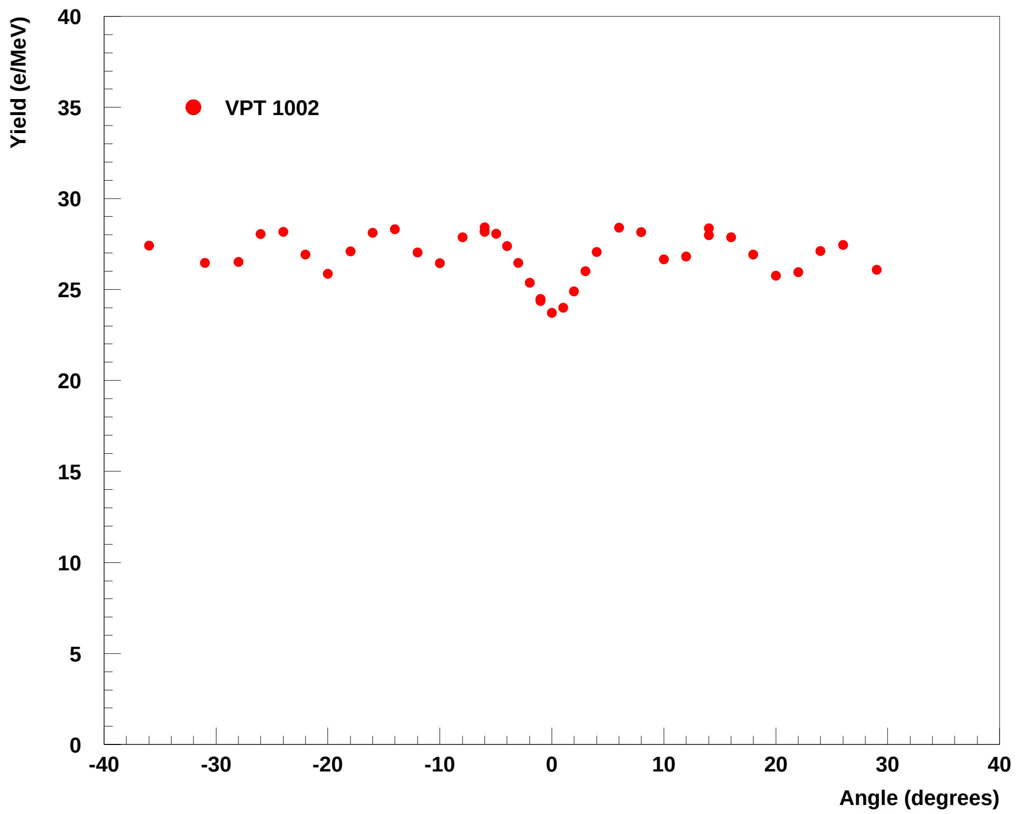

Figure 3. Angular scan at 1.8T on a typical VPT

Summary of RAL 1.8T measurements

8100 of the production tubes have so far been tested in the RAL test rig. Figure 4 shows the distribution of anode pulse heights measured in a 1.8T magnetic field; 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.

Figure 5 shows the correlation between the mean pulse height in the 1.8T magnetic field and the quality factor *PG* supplied by the manufacturer. The correlation between the manufacturer's measurements at 0T and the RAL measurements at 1.8T is striking.

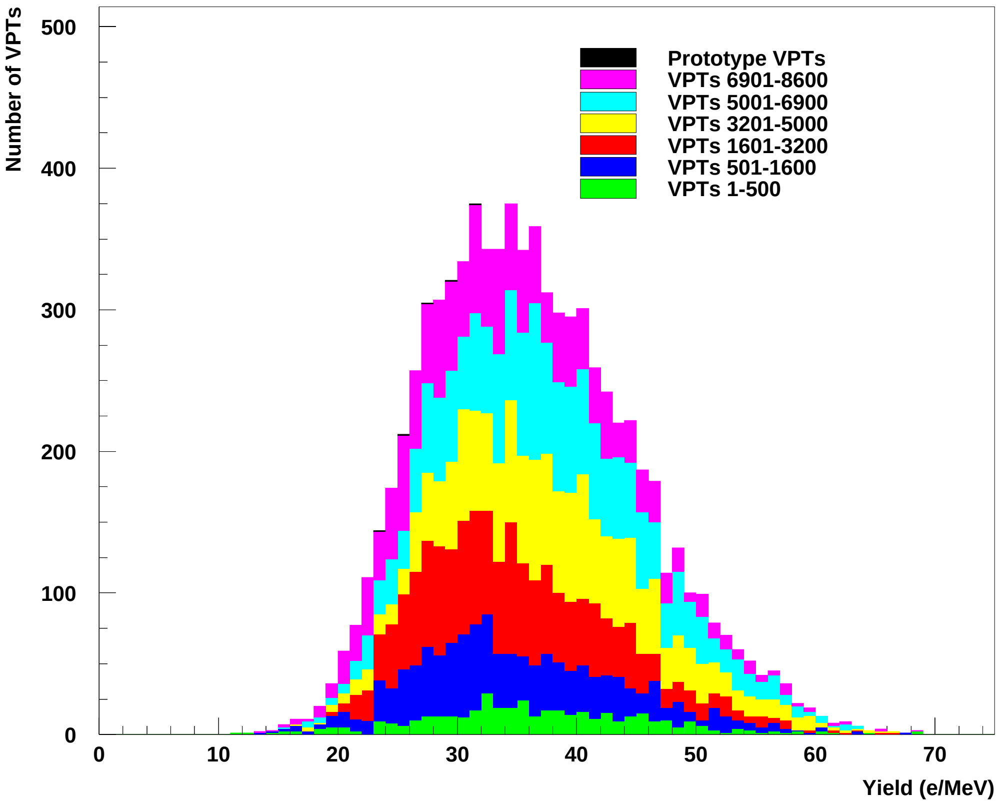

Figure 4. Mean anode pulse height over the angular range 8 -25 in a 1.8T magnetic field

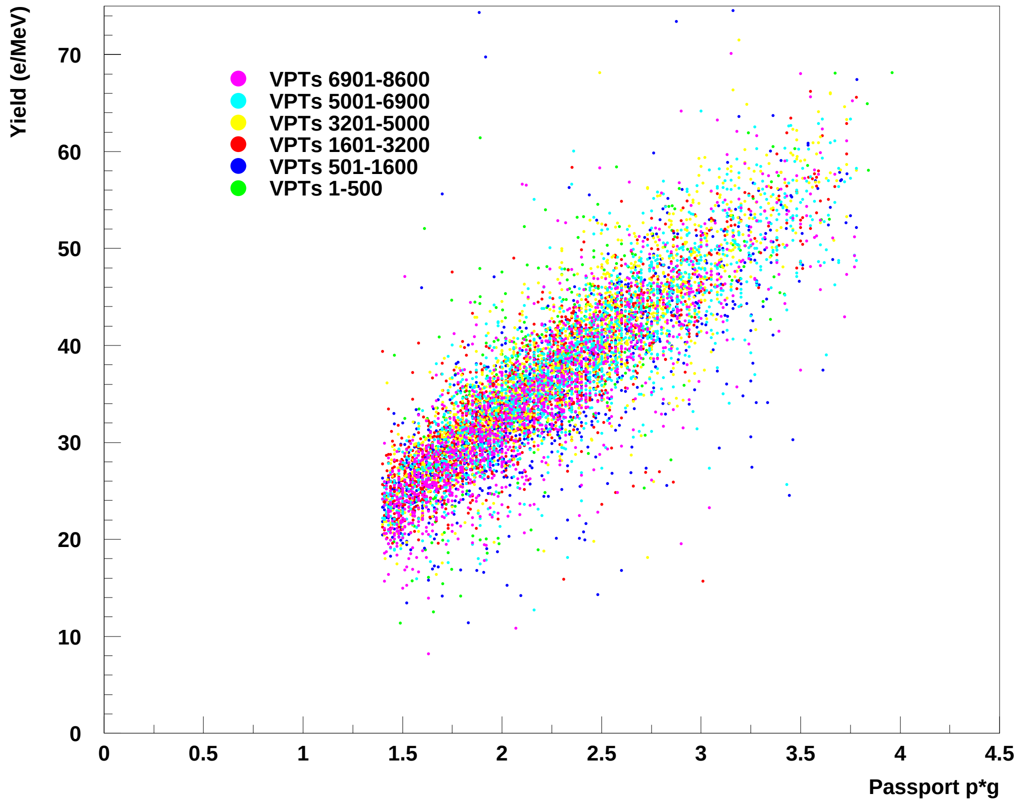

Figure 5. VPT response at 8 -25 and 1.8T v quality factor *PG*

Summary and Conclusions

The first 8100 production VPTs supplied by RIE have been subjected to a variety of measurements at RAL and Brunel University. The parameters supplied in the VPT passport are found to correlate well with these measurements.

VPTs with bar codes from 5901 to 8600 show an increased frequency of photocathode defects, and of unsatisfactory crimping of pins to the leads.

While the VPT performance meets the needs of the CMS experiment, the delivery schedule is a cause for some concern. The delivery rate has fallen significantly during 2004, and an increase in the rate will be required to complete the delivery of 15500 devices by the third quarter of 2005.

References

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

[2] ‘Uniformity measurements across the photosensitive area of CMS ECAL photodetectors’, N. Godinovic et al, CMS NOTE in preparation.

[3] ‘Observation of noise in production VPTs at 1.8T: VPTs with bar-codes 1501-8600’, B W Kennedy, 14 October 2004.