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First characterization of the Hamamatsu R11265 multi-anode photomultiplier tube

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ABSTRACT

The characterization of the new Hamamatsu *R*11265-103-*M*64 multi-anode photomultiplier tube is presented. The sample available in our laboratory was tested and in particular the response to single photon was extensively studied. The gain, the anode uniformity and the dark current were measured. The tube behaviour in a longitudinal magnetic field up to 100 G was studied and the gain loss due to the ageing was quantified. The characteristics and performance of the photomultiplier tube make the *R*11265-103-*M*64 particularly tailored for an application in high energy physics experiments, such as in the LHCb Ring Imaging Cherenkov (RICH) detector at LHC.

1. Introduction

The Hamamatsu *R*11265-103-*M*64 MaPMT is a 64-channel head-on photomultiplier tube able to detect single photons in the wavelength ranging from 185 to 650 nm. The device provides a fast response and an extremely high sensitivity to single photons. The *R*11265-103-*M*64 is particularly suitable to be used in high energy physics experiments, such as in the LHCb Ring Imaging Cherenkov (RICH) detector at LHC, thanks to its large active area (larger than 77%), the very low dark current, the negligible cross-talk and the pixel size of approximately $2.9 \times 2.9\ \text{mm}^2$.

The LHCb [1] detector at the LHC has shown a very successful operation in the last three years [2]. The data already collected are being used to pursue the experiment's primary physics goal that is the search for New Physics. The LHC is already capable of delivering higher luminosity than the one currently used at LHCb. An important LHCb upgrade [3] is planned for 2018 which will allow the detector to run at higher luminosity. The upgrade aims for a 10-fold increase in luminosity with respect to the current design value and calls for a higher readout speed from all the subdetectors.

The Ring Imaging Cherenkov (RICH) detector at LHCb is now read out by hybrid photon detectors (HPDs). The readout electronics is encapsulated inside the HPD but it is not compatible with the rate of 40 MHz expected after the upgrade. The baseline solution for their replacement consists of multi-anode photomultiplier tubes (MaPMTs) with an external readout electronics. Prior to availability of the *R*11265-103-*M*64, two different tubes made by Hamamatsu have been characterized to verify their compliance with the LHCb RICH requirements: (1) the *H*9500 [4], rejected due to a non-negligible crosstalk between pixels and (2) the *R*7600-03-*M*64 [5] which gives good performance for single photons' detection and is found to correspond to the LHCb requirements.

The characterization of the new Hamamatsu *R*11265-103-*M*64 MaPMT is presented in this paper. The first available sample was tested and in particular the response to single photon, the gain, the anode uniformity and the dark current was studied. Also the tube behaviour in a longitudinal magnetic field up to 100 G and the gain loss due to the ageing were quantified.

2. Setup

The setup used was the same described in Ref. [5]. One pixel was illuminated with a faintly DC biased commercial LED and the others were covered with black tape. The signals from the MaPMT pixels were amplified and shaped by commercial wide-bandwidth current feedback operational amplifiers [6]. The output waveforms were acquired with a Tektronix DPO7254 fast oscilloscope, remotely controlled by a computer. The acquired data could be finally processed off-line.

3. Gain and dark current

The device gain depends on the bias voltage whose maximum allowed value is -1100 V. The graph in Fig. 1 shows the average

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single photon response amplitude versus the MaPMT bias voltage for the pixel with the maximum gain. During these tests the standard bias divider (2.3–1.2–1–⋯–1–0.5 ratio from the first dynode to the last) was used.

Excellent single photon responses were observed in all channels. Fig. 2 shows the comparison between single photon response of different pixels. The spectra are normalized to the number of entries and the measurements are performed at room temperature, with a maximum variation of 1 °C. The gain is not uniform between different pixels and the spread between different pixels is clearly visible.

The photodetector dark current was measured at room temperature by recording the events above a threshold of about 300 ke$^-$ and biasing the MaPMT at −950 V. The dark signal rate was found below 3 Hz per pixel, or about 40 Hz/cm^2. Only a few channels showed a slightly higher rate.

These uniformity, gain and dark current values are in agreement with the LHCb RICH requirements.

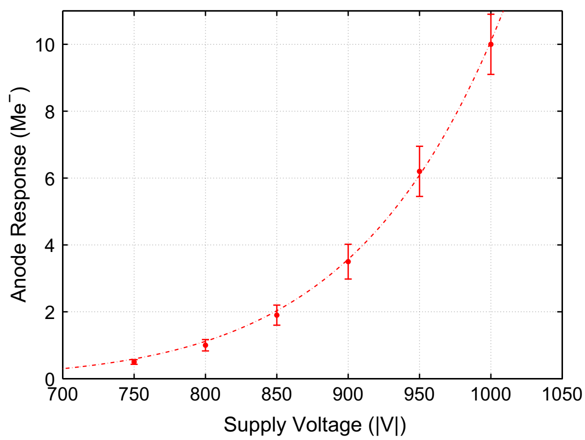

Fig. 1. The single photon peak, in units of 10^6 electrons, versus the MaPMT bias voltage for the pixel with the maximum gain.

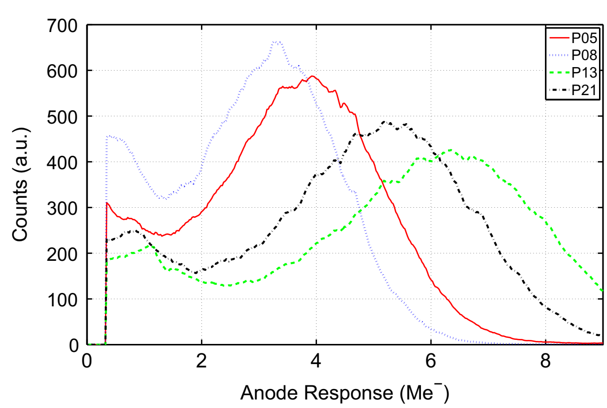

Fig. 2. The single photon spectra for some pixels. The MaPMT was biased at −950 V.

4. Magnetic field behaviour

The response of the tube was also studied in a longitudinal magnetic field. For our tests we used a solenoid capable of generating fields up to 300 G and the field intensity was measured with a Hirst GM04 gaussmeter.

The spectra acquired for four pixels are shown in Figs. 3 and 4. The central pixels seem to be quite insensitive to the magnetic field, while significant single photon spectra deformation is observed for the peripheral ones. The gain decreases but this is not the only effect. If we define the efficiency as the rate of events whose amplitude is larger than a threshold (fixed at 1 Me$^-$), then we can evaluate the photon detection efficiency loss. In particular pixel 5, located on the edge, shows a higher sensitivity to the magnetic field and the efficiency in a 50 G field is only 13% with respect to the no-field measurement. For the pixels located in the central region, for example pixel 21, the efficiency is about 98%, under the same conditions.

The results suggest that this device need to be shielded from the magnetic field to work properly in an environment such as the RICH one, where a field up to 30 G (3 mT) is expected on the photosensitive plane.

5. Ageing measurement

The setup proposed in Ref. [5] was upgraded to quantify the aging of the phototube due to long periods of intense light exposure. The data were acquired for about four months. A commercial blue LED was placed in front of the MaPMT and was biased by an Agilent E3631A DC voltage source, remotely controlled by a PC. The temperature, the humidity and the mean output current from 12 pixels were continuously monitored using a Keithley 2700 Multimeter and acquired by a PC every five minutes. A scheme of this setup is shown in Fig. 5.

The LED bias voltage was continuously adjusted in order to keep the current of one selected pixel constant and equal to 0.5 μA. This made the system stable with respect to variations in temperature and other environmental conditions which could affect the light yield of the LED. The high voltage was kept constant at −875 V, giving a mean gain of about 2 Me$^-$. This setup was optimized to age different pixels with different currents, from 0.01 μA to 4.33 μA, which correspond to single photon rates from

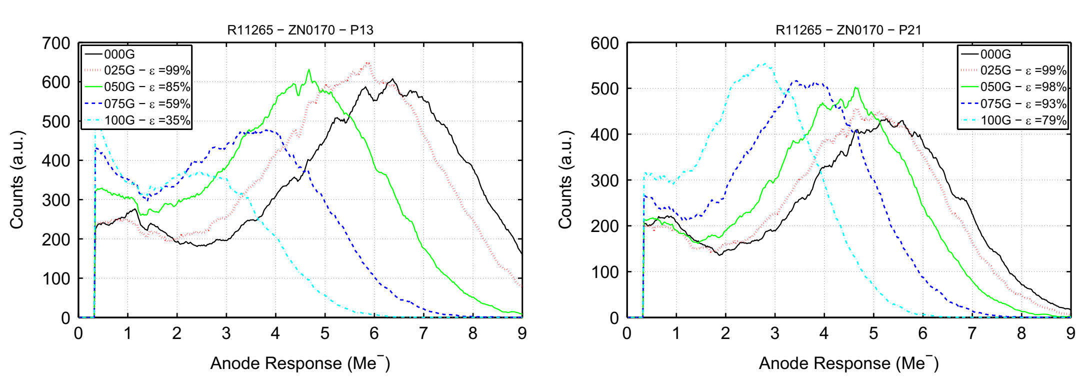

Fig. 3. Superposition of single photon spectra acquired under the action of various longitudinal magnetic fields for pixels located in the central part of the MaPMT.

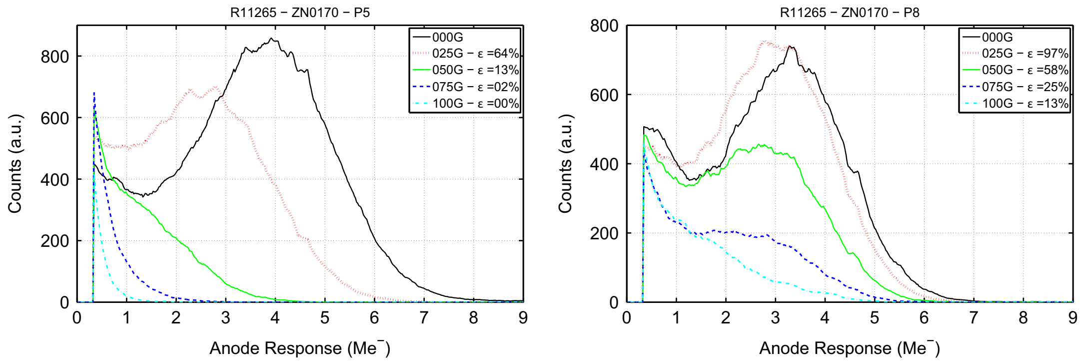

Fig. 4. Superposition of single photon spectra acquired under the action of various longitudinal magnetic fields for pixels located in the peripheral region of the MaPMT.

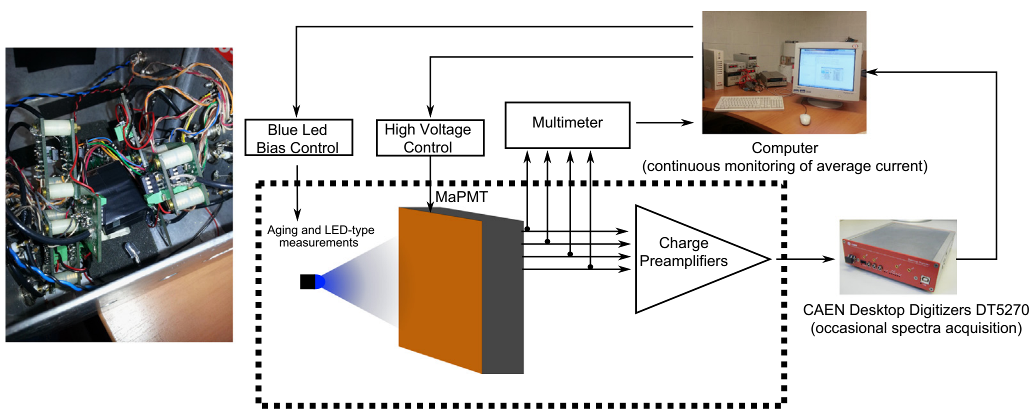

Fig. 5. Schematic picture of the fully automatic system developed for the aging test.

about 0.03 to 13.2 MHz. For instance, if the *R*11265-103-*M*64 is employed for the LHCb RICH detectors, which will operate at a crossing rate of 25 ns, then the most illuminated pixels will correspond to the 33% probability to be hit by a single photon, condition that is not far from the one expected in the highest occupancy region of the RICH.

Each measured pixel was connected to a standard charge sensitive preamplifier circuit and the shaped signals were acquired by three 4-channel ADCs CAEN Desktop Digitizers DT5720 and analyzed off-line. During the aging process, every three hours, the LED was biased for about five minutes at a very low voltage so that it is operated in a single photon regime compatible with the acquisition rate and the signal-to-noise ratio. This data allowed one to obtain for every pixel the single photon spectrum and to estimate the gain loss from the variation in peak position.

More than 600 acquisitions were performed over more than 3000 h. For each of them, the gain of each pixel was obtained from the acquired spectra by measuring the energy of the single photon peak. A whole day of illumination turned out to be necessary to stabilize the MaPMT response, so the percentage gain variation was evaluated considering the gain value at 24 h as the starting point condition.

The results are plotted in Fig. 6. Unexpectedly, the gain loss seems not to be correlated with the integrated charge of the pixels but only with the LED illumination time, so the gain variation does not depend on the illumination level. After the first 500 h, the gain loss is about 10%. After that, a quite linear trend with a gain variation rate of about 120 ppm/h can be observed until about 1500 h of illumination are reached. Then the plateau can be seen: the response stabilizes and the total gain loss amounts to about 25%. An almost linear gain loss as a function of time was also observed for the two covered pixels until 1500 h of illumination, when the plateau is reached; the whole gain loss variation amounts to about 15%.

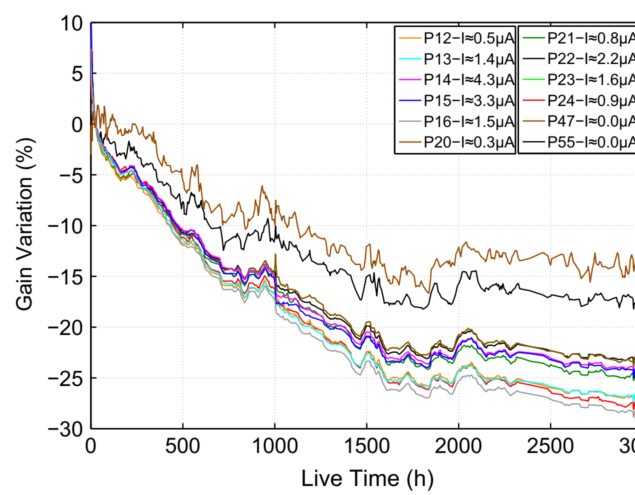

Fig. 6. Gain variation versus live-time for the tested pixels with the relative DC aging current.

6. Conclusions

We have tested a *R*11265-103-*M*64 multi-anode photomultiplier tube produced by Hamamatsu which represents the baseline device for the upgrade of the RICH subdetectors of the LHCb experiment. Its capability to detect single photon signals, the gain and the dark current values indicate that this photomultiplier tube is adequate for an application in high energy physics, such as in RICH detectors. A pixel-to-pixel gain spread has been observed, which suggests the need to couple the phototube with a read-out electronics able to compensate this effect [7].

The MaPMT has been tested in a magnetic field up to 100 G and an adequate shield is needed in view of its use in the upgraded LHCb RICH at LHC. The MaPMT aging is evaluated and seems not to depend on DC current but only on aging time. The gain loss amounted to about 25% after about 3000 h and a gain plateau is reached after about 1500 h. Further investigations are planned to characterize other *R*11265-103-*M*64 samples and to verify the possibility to use this tube in the upgraded LHCb RICH.

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