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Characterization of two prototypes for a new large area four anode photomultiplier

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Abstract

Two prototypes of a new large area 4-anode photomultiplier have been produced by Hamamatsu for the NEMO collaboration. The new multianode photomultiplier allows us to introduce information on the direction of the detected light, by working as four individual photomultipliers. Using a testing facility realized in our laboratory, we have measured the performance of prototypes at room temperature, atmospheric pressure and under different light conditions. The response of the phototube has been measured for each anode separately. The prototype performance meets the design specifications, so these photomultipliers may be proposed for the first time for the construction of a Km^3 scale neutrino underwater telescope, under the KM3NeT framework.

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1. Introduction

The basic principle of an underwater neutrino telescope is to reconstruct the direction of the cosmic neutrino by detecting the Cherenkov light generated by secondary muons. This is done using highly sensitive photo-detectors, called photomultipliers, integrated into a transparent pressure vessel to make an optical module. The NEMO collaboration has proposed the construction of a newly designed direction-sensitive optical module. The results from a simulation by INFN Sezione di Genova[2] have demonstrated an improvement in the effective area of the detector, up to a factor of 2 at low energies (<10TeV), by adding in the reconstruction procedure the information on the direction of the detected Cherenkov light. The main component of this newly developed optical module is a new large area 4-anode photomultiplier, developed by Hamamatsu for the NEMO collaboration. The prototype has a segmented photocathode and four independent amplification chains. Each anode is sensitive to one fourth of the photocathode area, so the new direction-sensitive PMT works as four individual photomultipliers, oriented in different directions, with a total detection

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efficiency and angular acceptance equal to that of a similarly-sized single photomultiplier.

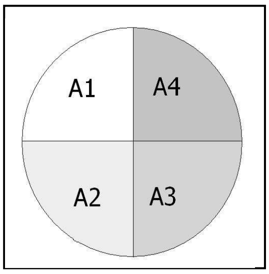

Figure 1 Hamamatsu identification of segmented photocathode. (face-on view of PMT)

In this paper we report measurements of the dark count rate, time and charge characteristics -including transit time spread, peak to valley ratio, charge resolution, linearity and gain - obtained by illuminating the whole photocatode surface. Moreover, the fraction of spurious pulses has been measured. The photomultiplier response has been also studied by scanning the entire photocathode area with a single-photon pulsed laser beam.

2. Testing facility

The apparatus used in the measurements is composed of a dark box, with dimensions of 2 x 1.7 x 1.5 meters, where the PMT under test, the system for the movement of the light source and a PMT used as monitor for the light source are enclosed.

The light source system, a 410 nm pulsed LASER (produced by PICOQuant, with a width of 60 ps and a frequency which can be varied between 0 and 40 MHz), is located outside the box. The light pulses are brought into the dark box by an optical fibre and split onto two fibres to illuminate the PMT under test and the monitor.

To study the photomultiplier response as a function of position, we realized a placement system allowing the optical fibre to scan the photocathode area with a spot of 5 mm diameter. This system (shown in fig. 2) consists of a semi circular guide, capable of rotating to ± 90° with respect to the horizontal position, along which the support of the optical fibre is moved.

The movement of the two elements, operated by two independent motors, allows the scan of the whole photocathode surface with the extremity of the optical fibre always pointing toward the centre of the semicircular guide, perpendicular to the surface of the PMT. Displacing the photomultiplier away from the light source is also possible, to entirely illuminate the photocathode surface. Dedicated software developed in LabView controls all the operations of movement and data acquisition.

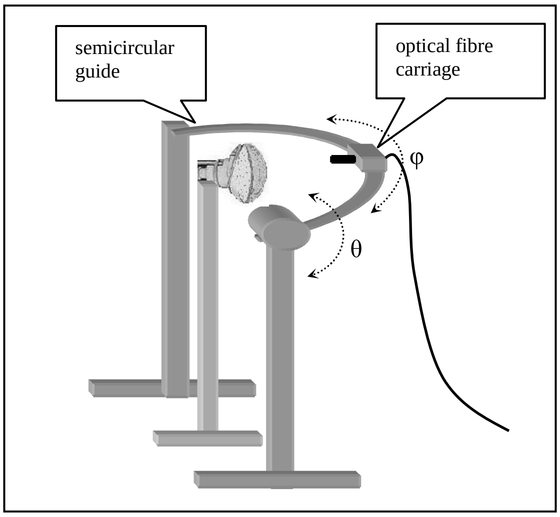

Figure 2 Schematic of the light source moving system. θ is the vertical angle, φ the horizontal.

3. Prototype performance

The two samples measured, named ZF0021 and ZF0025, have the same envelope as a 10” Hamamatsu PMT. They host four independent amplification chains, with common voltage, which include 10 dynode stages each.

To perform the tests, the photomultipliers were connected to a resistive voltage divider realized according to Hamamatsu specifications.

All measurements were made at room temperature and atmospheric pressure, with the PMT equipped with a mu-metal cage to shield it from the Earth’s magnetic field.

Using a calibrated charge ADC, the gain was studied for each anode as a function of the high voltage. Three anodes, identified as anodes 1, 2 and 3 according to Hamamatsu enumeration, showed similar behaviour . Anode 4 exhibited lower gain, by about 25%, at 1500V. The gain dependence on high voltage is approximately the same for all four anodes.

Similar behaviour was also observed for prototype ZF0025, where the same anode 4 presents a gain about 20% smaller. This suggests that the different behaviour of anode 4 could be related to the geometry of the dynodes.

3.1 The overall response

This section reports the characteristics of the photomultiplier response when the whole photocathode surface is illuminated by the pulsed laser. The applied voltage was 1550V, corresponding to a gain of 5.10^7.

The linearity has been separately measured for each anode: all anodes exhibit a good linearity up to about 100 photoelectrons.

Moreover, the loss of linearity above 100 photoelectrons is the same as observed in standard Hamamatsu PMTs with the same dimensions. Considering the charge and time properties in single photoelectron conditions measured for each anode, the peak to valley ratio varies in the range between 2.7 and 3.1, and the (sigma) value of the charge resolution is between 30.6% and 37.5%.

For measurement of the transit time distribution, the discriminator threshold was regulated to 20 mV, corresponding to about 1/3 of the mean amplitude of the single photoelectron signals.

The FWHM transit time spread varies between 3.5 and 4.6 ns for all anodes.

Table 1 indicates that the performances of the four anodes are comparable, except for the smaller gain of anode 4.

The dark count rate for each anode, measured at a threshold of 1/3 that of a single photoelectron signal, was of the order of 1 kHz.

Table 1 Time and charge characteristics of sample ZF0025

Anode	**A1**	**A2**	**A3**	**A4**
P/V ratio	3.03	3.09	2.95	2.75
Gain (x 10^7) at 1550 V	5.0	5.4	5.0	3.9
σE / E [%]	33.62	30.62	37.34	35.15
TTS [ns] (FWHM)	4.62	3.95	3.54	4.16

Other measurements were made of the fraction of the four different types of spurious pulses. According to Hamamatsu these are defined as:

- Pre-pulses: arriving in the 10-80 ns interval before the main pulse, not correlated with the main pulse.
- delayed pulses: arriving in the 10-80 ns interval after the main pulse, not correlated with the main pulse
- type 1 after pulses: arriving in the 10-80 ns interval before the main pulse, correlated with the main pulse
- type 2 after pulses: arriving in the 80 ns - 16 μs interval after the main pulse, correlated with the main pulse.

The results are summarized in table 2, which shows the percentage of spurious pulses with respect to main pulses for each anode of prototype ZF0025, measured in single photoelectron conditions, with a threshold of about 1/3 of the signal, at about 1kHz of rate.

Table 2 Spurious pulses in prototype ZF0025

Anode	**A1**	**A2**	**A3**	**A4**
Pre pulse [%]	0.05	0.18	0.24	0.05
Delayed pulse [%]	7.74	7.96	7.14	6.50
After Pulse 1 [%]	1.57	1.91	1.68	1.22
After Pulse 2 [%]	10.87	12.53	13.49	10.41

3.2 The local response

To characterize the multianode PMT as a direction sensitive photo-detector, we have studied its capability to recognize the position of the photocathode emission point with good precision. The response of the photomultiplier has been studied for each anode, scanning the photocathode surface with a single-photon pulsed beam with a diameter of 5 mm, according to a grid of 324 local measurements with an equal angular step.

The results confirm a good identification of the four quadrants of the photocathode surface: each anode measured correctly corresponds to only one fourth of the photocathode.

As example, the measurement of the area of the single photon peak for only one anode is shown in figure 3.

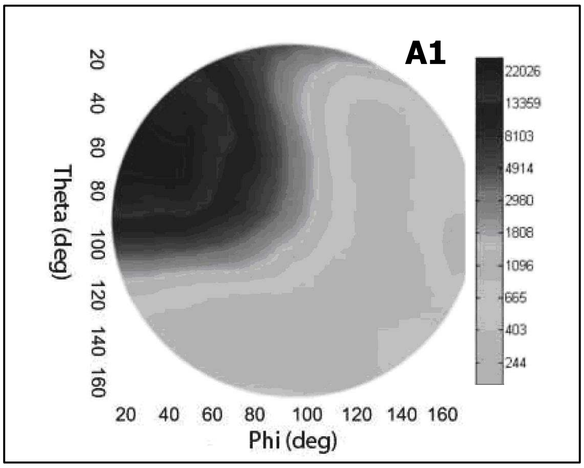

Figure 3 Photocathode local response for anode 1 of prototype ZF0025. The highest signal strength measurements are dark coloured, and the smallest ones, equal to less than 2% of largest, are light.

In order to understand the behaviour of the prototype response, we studied all four anode outputs when the center of only one sector of the photocathode was illuminated with a small beam.

The measurements show three parasitic signals with a bipolar shape in the other three anodes (fig. 4), in coincidence with the main unipolar signal from the illuminated anode.

These signals are generated by the capacitive coupling between the dynode chains.

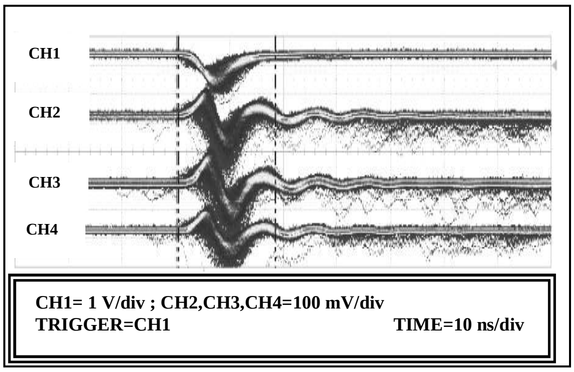

Figure 4 Anodic outputs when sector 1 was illuminated by a laser with a mean intensity of 15 pe. The numbers of the channels correspond to the anodes. The CH1 shows the main signal. In the other channels there are the parasitic signals.

The amplitude of the parasitic signal is approximately 16 % of the main signal, with a charge less than 3%. The effect is the same for all anodes at up to 100 photoelectrons, i.e. the dynamic range studied.

An analysis of the different shape of the signals and the different total charge using dedicated electronics might be used in the future to discriminate the main signal from the parasitic signals.

4. Conclusions

Two prototypes of a new large area four-anode photomultiplier produced by Hamamatsu were tested for each anode separately.

The measurements exhibit good linearity up to 100 photoelectrons, and a gain of 5.10^7 for a voltage of about 1550 V.

Time and charge characteristics measured for each anode are rather similar, except for the smaller gain of anode 4.

By scanning the photocathode surface we verified good identification of the emission point from the photocathode as well as the presence of a crosstalk between the anodes, with bipolar parasitic signals with amplitude around 16 % of the main signal and a negligible charge, less than 3% of the main.

The measured performance meets the requirements for the use of a multianode photomultiplier in an underwater neutrino telescope.

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