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 on purpose for the NEMO collaboration. The new multianode photomultiplier allows us to introduce the information on the direction of the detected light, working as four individual photomultipliers. Using testing facility realized in our laboratory, we have measured the performances of prototypes at room temperature, atmospheric pressure and different light conditions. The response of the phototube has been measured for each anode separately. The prototype performances agree with design specifications, so they may be proposed for the first time for the construction of a Km^3 scale neutrino underwater telescope, in 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 emitted from muons produced by neutrinos. This is done using highly sensitive photo-detectors, called photomultipliers, integrated into a transparent pressure vessel to make the optical module. The NEMO collaboration has proposed the construction of a newly designed direction-sensitive optical module. The results from a simulation code performed by INFN, sezione 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 optical module is a new large area 4-anode photomultiplier, developed by Hamamatsu on

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purpose 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 efficiency and total angular acceptance equal to that of a single photomultiplier.

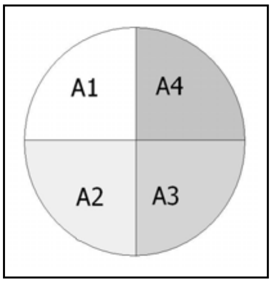

Figure 1 Hamamatsu identification of segmented photocathode. (look at front of PMT)

In this paper we report the measures of the dark count rate, time and charge characteristics such as Transit Time Spread, Peak to Valley ratio, charge resolution, linearity and gain, obtained illuminating the whole photocatode surface. Moreover, the fraction of spurious pulses has been measured. The photomultiplier response has been also studied scanning the photocatode area with a single-photon pulsed laser beam.

2. Testing facility

The apparatus used to operate the measures 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 a 60 ps and a frequency which can vary in a range from 0 to 40 Mhz, is located outside the box. The light pulses are brought into the dark box by an optical fibre, and next split in two fibres to illuminate the PMT under test and the monitor.

In order to study the characteristics of the photomultiplier response as a function of different incident points of light, we realized a moving system for the optical fibre to execute the scanning of the photocatode area with a spot of 5 mm diameter. A drawing of the system is shown in figure 2.

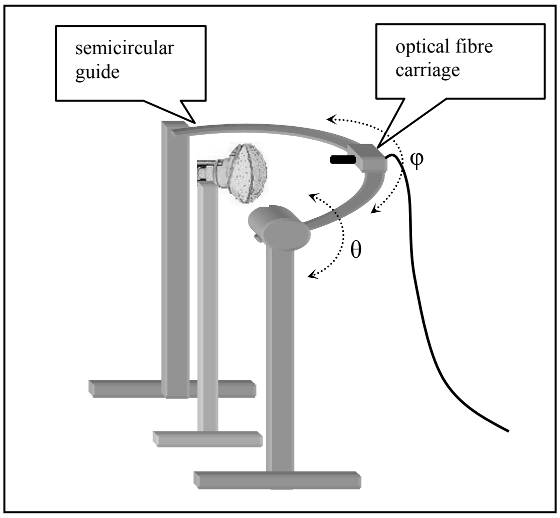

Figure 2 Schematic of the light source moving system. θ is the vertical angle, φ the horizontal.

It consists of a hemi circle guide, able to rotate of ± 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, perpendicularly on the surface of the PMT. Positioning the photomultiplier away from the light source is possible to entirely illuminate the photocathode surface. A dedicated software developed in LabView controls all the operations of movement and data acquisition.

3. Prototype performances

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

To perform the tests, the photomultiplier has been connected to a resistive voltage divider realized according to Hamamatsu specifications.

All measurements have been executed at room temperature and atmospheric pressure, on the PMT equipped by a mu-metal cage to shield it from the Earth's magnetic field.

Using a calibrated charge ADC, the gain has been studied for each anode as a function of the High Voltage supply. Three anodes, identified as anode 1, 2 and 3 according to Hamamatsu enumeration, showed similar behaviour .

Anode 4 exhibits smaller gain, about 25% at 1500 Volt. The dependence from on High Voltage is approximately the same for all the anodes.

A similar behaviour has been also observed for the sample 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 1550 Volt, corresponding to a gain of 5 x 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 photoelectron is the same as observed in standard Hamamatsu PMTs with the same dimensions. Considering the charge and time properties in single photon-electron conditions measured for each anode, the peak to valley ratio varies in the range between 2.7 and 3.1, and the value of the sigma charge resolution is between 30.6% and 37.5%.

For the acquisition of the Transit Time distribution, the discriminator threshold has been regulated to 20 mV, corresponding to about 1/3 of the mean amplitude of the single photoelectron signals.

The Transit Time Spread, calculated as the FWHM varies between 3.5 and 4.6 ns for all anodes.

Look at the summary table 1, is evident that the performances of the four anodes are comparable, except for the smaller gain of anode 4.

The dark count rate for each anode has been measured at the same threshold of 1/3 of single photoelectrons : it resulted of 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

Another measured quantity is the fraction of the four different types of spurious pulses. According to Hamamatsu they are defined as:

- pre pulse: arriving pulses in the 10-80 ns interval before the main pulse, not correlated with the main pulse.
- delay pulse: arriving pulses in the 10-80 ns interval after the main pulse, not correlated with the main pulse
- after pulse 1: arriving pulses in the 10-80 ns interval before the main pulse, correlated with the main pulse
- after pulse 2: arriving pulses in the 80 ns - 16 μs interval after the main Pulse, correlated with the main pulse.

The results are summarized in table 2, which reports the percentage of spurious events with respect to main events for each anodes of sample ZF0025, measured in single photoelectron condition, with a threshold of about 1/3 of the signal, at about 1Khz of rate.

Table 2 Spurious pulses of sample 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

In order to use the multianodic PMT as a direction sensitive photo-detector, it has been verified the 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

5mm, 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 measure of the area of the single photon peak for only one anode is shown in the figure 3.

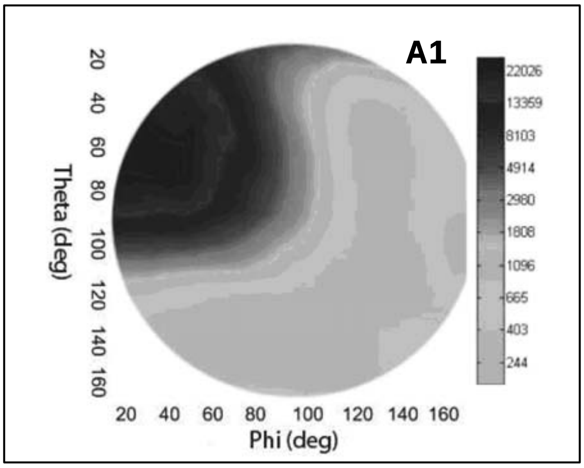

Figure 3 Photocathode local response for anode 1 of sample ZF0025. The largest measures are dark coloured, and the smallest ones, equal to less than 2% of largest, are light.

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

The measures show that there are three parasitic signals with a bipolar shape in the other three anodes, in coincidence with the main unipolar signal from the illuminated anode.

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

The amplitude of the parasitic signal is approximately 16 % the main signal, with a charge less than 3%. The effect is the same for all anodes and 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 a dedicated electronic could be the way to discriminate the main signal against the parasitic signals.

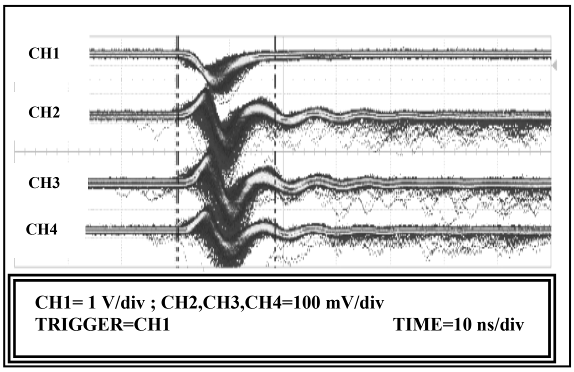

Figure 4 Anodic outputs when sector 1 was illuminated by a laser with a mean intensity of 15 pe. The numbers of the channels correspond to the anodes. The CH1 shows the main signal. In the other channels there are the parasitic signals.

4. Conclusions

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

The measures exhibit good linearity up to 100 photoelectrons, and a gain of 5E7 for a voltage of about 1550 volt.

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 a 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 % the main signal and a negligible charge, less than 3% the main.

The measured performances meet the requirements to use the multianode photomultiplier in an underwater neutrino telescope.

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