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A new multianodic large area photomultiplier to be used in underwater neutrino detectors

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ABSTRACT

In this article we describe the properties of a new 10-in. hemispherical photomultiplier manufactured by Hamamatsu. The prototype has a segmented photocathode and four independent amplification stages. The photomultiplier is one of the main components of a newly designed direction-sensitive optical module to be employed in large-scale underwater neutrino telescopes. The R&D activity has been co-funded by the INFN and the KM3NeT Consortium. The prototype performance fully meets with the design specifications.

1. Introduction

One important component of an underwater neutrino telescope is the photodetector required to collect the Cherenkov light produced by the ionizing particles that originate from the interaction of the neutrino [1–4]. To efficiently cover 1 km^3 detection volume it would be necessary to deploy $\approx 10^4$ photomultipliers whose main requirements are a relatively large photocathode area, high gain, low noise, low after pulse rate and good timing resolution for single photon detection, the exact values depending on the detector design. The current minimum requirements for such detectors, taken from the KM3NeT Conceptual Design Report [5], are reported in Table 1.

The aim of the European KM3NeT [6] Consortium is to define the Technical Design Report of the km^3 detector to be deployed in the Mediterranean Sea. Several new ideas are being developed to improve the performance of the optical modules, e.g. the prototyping activity in progress at CERN [7], aimed at applying the ideas that originated the Philips "SMART" XP2600 [8] and the later QUASAR-370 [9] to the production of a large area, high single photon resolution detector; or the work being carried on at NIKHEF with the idea of segmenting the photocathode area in order to count the number of photons, by replacing a single 10-in. PMT with at least 12 3-in. PMTs [10].

Monte Carlo simulations show that if it were possible to identify the Cherenkov light direction, reconstruction efficiency would improve in particular for short tracks related to low energy (below 10 TeV) neutrinos or to tracks that partially cross the detector. As an example, in Fig. 1 we report the effect of the information on the direction of the detected Cherenkov light on the response of a km^3 detector à la NEMO [12,13].

In the KM3NeT research framework we have proposed the implementation of this feature by means of a multianodic 10-in. photomultiplier coupled to a light guide system so that all the Cherenkov light arriving from the same direction is focused on a well-defined sector of the photocathode. The basic working principles have been discussed in Ref. [14]. The conceptual design is based on a multi-anodic position sensitive

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Table 1
KM3NeT technologies detector requirements.

Time resolution (for a single photon, photomultiplier + electronics)	<2 ns
Position resolution	<40 cm
Charge dynamic range	$\approx 100/25$ ns
Two-hit time separation	<25 ns
Coincidence acceptance	$>50\%$
False coincidences	Dominated by random coincidences from marine background photons
Dark noise rate	$<20\%$ of the ^{40}K rate
Failure rate of the optical modules	$<10\%$ over 10 years without major maintenance

The table is taken from Ref. [5].

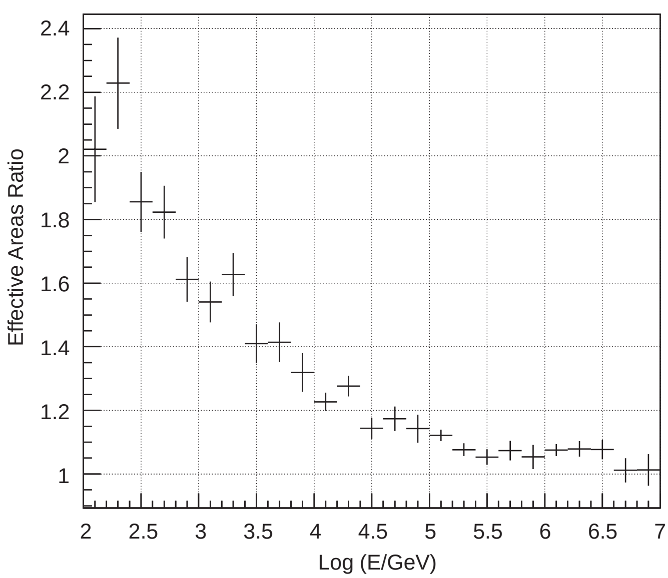

Fig. 1. The ratio of the effective areas of the NEMO detector equipped with direction-sensitive optical modules and the standard NEMO detector.

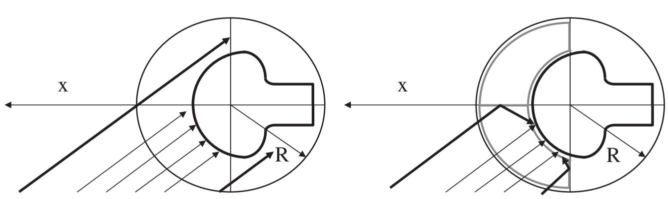

Fig. 2. Left: behaviour of the classical optical module: all the Cherenkov light coming from a specific direction illuminates the whole photocathode surface. Right: the mirrors concentrate the light coming from a specific direction onto a single sector of the photocathode surface.

10-in. photomultiplier coupled to a set of mirrors. The mirrors are realized with 3M Radiant Mirror Films glued onto 2 mm Plexiglas foils. The 3M films are multi-layer polymeric films with a reflectivity larger than 95% in the wavelength interval 400–700 nm [15]. Fig. 2 shows how the side view of the optical module changes with the mirrors: all photons arriving from the same direction are focused by the mirror system onto a single sector of the multi-anodic photomultiplier. In this way the angular acceptance of the optical module is divided into four with only a small overlap along the symmetry axis of the photomultiplier. The result is greater accuracy in the evaluation of the direction of the detected light is increased.

Large area multianodic photomultipliers are not commercially available and, therefore, we contacted the leading companies in the field in order to investigate the feasibility of producing such a device. In this paper we present the performances of the two prototypes of a 10-in. 4-anodic photomultiplier manufactured by Hamamatsu. The two samples (ZF0021 and ZF0025) are of the same shape as the 10-in. Hamamatsu R7081. Like the Hamamatsu R7081, the amplification chain includes 10 dynode stages. The photomultiplier hosts four separate dynode chains with common voltages. To perform the tests the photomultiplier was connected to a resistive voltage divider produced according to the specifications provided by Hamamatsu.

2. Testing facility

The testing facility used to measure the characteristics of the large area photomultipliers is based on a light-tight dark box, with dimensions $2.0 \times 1.7 \times 1.5\,m^3$, equipped with a frame designed to host the photomultiplier, a moving system required to scan the photocathode surface with the light source and a PMT used as a monitor to check the stability of the light source. The light source, located outside, is a 410 nm PICOQUANT pulsed laser [16], with a pulse width of 60 ps, whole frequency can vary in the range of 0–40 MHz using an external generator. For a precise calibration of the source in single photoelectron condition, we used a DEP Hybrid PhotoDiode PP0270K. The laser optical power range was calibrated using tan OPHIR PD-300 bolometer [17], to measure the linearity of the phototube.

The light pulses are brought into the dark box by a 50 μm multimode optical fibre, and then split into two fibres to illuminate the PMT under test and the reference PMT. In order to study the characteristics of the photomultiplier's response locally, the fibre is mounted on a moving system that allows the entire photocathode area to be scanned with a 5 mm diameter single-photon pulsed beam. The moving system is constituted by a semicircular guide capable of rotating vertically in the angular interval 0–180° and a frame holding the optical fibre that can move from one extremity of the guide to the

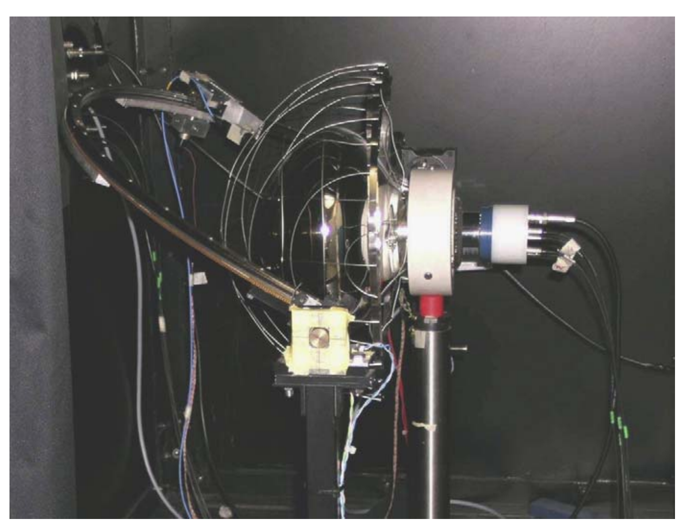

Fig. 3. The picture of the interior of the dark box with the moving system and the photomultiplier with the mu-metal cage.