# The multi-PMT Optical Module for KM3NeT

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**Abstract**

In the future neutrino telescope KM3NeT a novel type of optical module (OM) will be employed to optimize the sensitivity to Cherenkov photons and maximize the environmental background suppression. The multi-PMT OM, a pressure-resistant glass sphere containing 31 photomultiplier tubes (PMTs) of 3-inch diameter, has been developed and prototyped including electronics for high-voltage generation, signal digitization and optical signal transmission. Monte-Carlo simulations show that a multi-PMT OM configuration requires three times less OMs to achieve the same performance as conventional OMs hosting 10-inch PMTs.

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## 1. Introduction

KM3NeT [1], the future deep-sea neutrino telescope of several cubic-km size, is being designed to search for high energy neutrinos originating from galactic and extragalactic sources. The neutrinos can be detected by collecting Cherenkov light emitted from relativistic charged secondary particles caused by the interaction of neutrinos with the medium surrounding the detector. To collect the Cherenkov light, an optical module (OM) containing 31 3-inch diameter photomultiplier tubes (PMTs) has been developed, the multi-PMT OM, to replace the traditional OM containing one 10-inch PMT. The main advantage is to reduce the environmental background by requiring local coincidences between neighbouring photo sensors and to provide a large and homogeneous photon acceptance.

Figure 1: A mechanical reference model of a multi-PMT OM showing various PMTs, surrounded by an expansion cone, in a 17-inch diameter glass sphere.

## 2. The multi-PMT OM

The objective of the multi-PMT OM is to measure photons at the single-photon level. The maximized total photocathode area that can be fitted in a standard 17-inch diameter glass pressure sphere is significantly larger when using several small PMTs instead of a single 10-inch PMT. The segmentation of the detection area in the OM provides directional sensitivity and will aid in distinguishing single-photon from multi-photon hits. Moreover, two-photon hits can be unambiguously recognized if the two photons hit separate tubes, which occurs with 85% probability for photons arriving from a particular direction. New types of 3-inch PMTs have been developed [2, 3] fulfilling the KM3NeT requirements, i.e. a homogeneous photon acceptance with a quantum efficiency > 20% at 470 nm, a transit time spread below 2 ns, and dark noise rates below 1 kHz [2]. This dark rate is to be compared with the environmental background of typically 60-100 kHz measured in the ANTARES 10-inch PMTs, which corresponds to an expected background rate of 5-8 kHz in a 3-inch PMT. The housing of the multi-PMT OM is a transparent glass sphere with PMTs suspended in a foam support structure: 19 in the lower hemisphere and 12 in the upper hemisphere (see fig. 1). The multi-PMT OM is designed as a Digital OM (DOM) providing only digital output and reducing the number of connectors in the detector as much as possible. Each PMT has its own adjustable high-voltage supply and electronic circuitry providing an extra amplification of the photomultiplier signal. A signal-collection board collects signals from the PMTs for transfer to the OM-logic board, see fig. 2, where signals are converted to time, amplitude and PMT-identification information. It also contains electronic and photonic components for an optical serial link to the shore. All necessary DC power is provided by the con-

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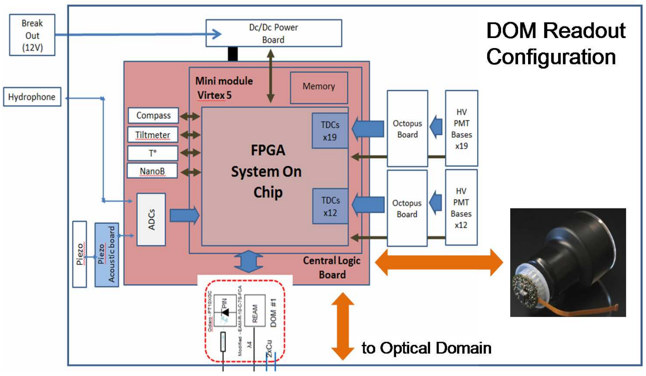


Figure 2: Scheme of the DOM readout configuration transfering data to the optical domain, including calibration devices.

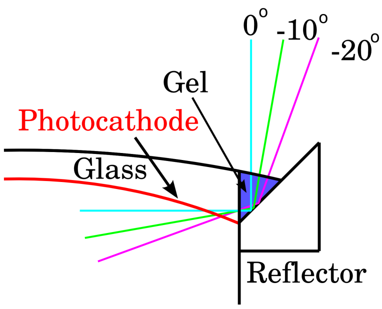


Figure 3: The idea of light collection by an expansion cone.

verter board. A mushroom-shaped aluminium structure serves to transfer the heat (7 W) generated by the OM electronics via the glass sphere to the seawater. The outer connector is a dry mateable bulkhead connector that penetrates the glass sphere and allows for two power conductors and one fibre to be connected to the high-pressure oil-filled storey cable.

## 3. Expansion cone to increase photo sensitivity

The space available around the photocathode area is exploited for extra light collection. An expansion cone is employed to reflect additional light to the photocathode, see fig. 3. The expansion cone is made of silicon gel which is shaped and kept in place by an aluminium structure with silver evaporation serving as reflector. Measurements were performed in air with a single PMT equipped with an expansion cone. The relative collection efficiency $C$ was derived from the number of events with a charge above 0.3 SPE (single photoelectrons) out of a total number of laser shots for various points on the photocathode and angles of incidence. The gained collection efficiency $C_{gained}$ was calculated as a ratio $C_{gained} = 100\% \cdot (C_{PMT+Cone} - C_{PMT})/C_{PMT}$, where $C_{PMT+Cone}$ and $C_{PMT}$ are the collection efficiencies of the system PMT+Cone and bare PMT, respectively. Experimental results are presented in fig. 4 (upper panel) compared to corresponding SLitrani [4] simulations. An increase in collection efficiency by 30 % on average is observed with a maximum of 35% for perpendicular incidence. Simulations of the relative collection efficiency

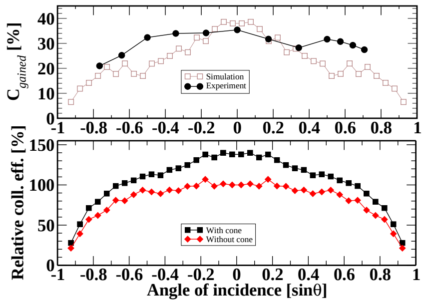


Figure 4: Results of the measured gain in collection efficiency under various angles of incidence (upper panel) compared to photon-propagation simulations. Black and red curves in the lower panel show the simulated collection efficiency as a function of the angle of incidence for a single PMT with and without expansion cone, respectively.

(fig. 4 lower panel) allow for estimating an increase in the overall sensitivity, integrated over all angles of incidence, of 27%.

## 4. Performance simulations

The Monte Carlo simulated effective area for neutrino detection has been investigated for the multi-PMT option compared to the design option with triplets of 10-inch PMTs. Results are obtained after a full reconstruction applying cuts for the maximum neutrino point-source sensitivity for a neutrino flux with an energy spectrum decreasing as $E_\nu^{-2}$ with the neutrino energy $E_\nu$. To enable a fair comparison, a so called *reference detector* was simulated with the same structure in both cases: 154 detection units (towers), 20 floors with 40 m spacing, and the same detector footprint. Each floor consists of a 6 m bar with two multi-PMT OMs or six 10-inch PMTs. The distance between towers was set to 180 m. The detector configuration with multi-PMT OMs requires three times less OMs to achieve the same performance as conventional OMs hosting 10-inch PMTs. Moreover, simulations of coincident photon hits from muon tracks or from neutrino-induced showers, with realistic environmental background on basis of ANTARES measurements, indicate that the multi-PMT DOM yields an about 9 times higher signal-background ratio than a comparable detector employing triplets of 10-inch OMs.

In summary, the above mentioned advantages make the multi-PMT DOM an optimal solution for the KM3NeT neutrino telescope. Moreover, this solution also provides benefits for other experiments based on single-photon detection in large sensor arrays. Currently, prototype DOMs are under construction for deep-sea deployment and tests.

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