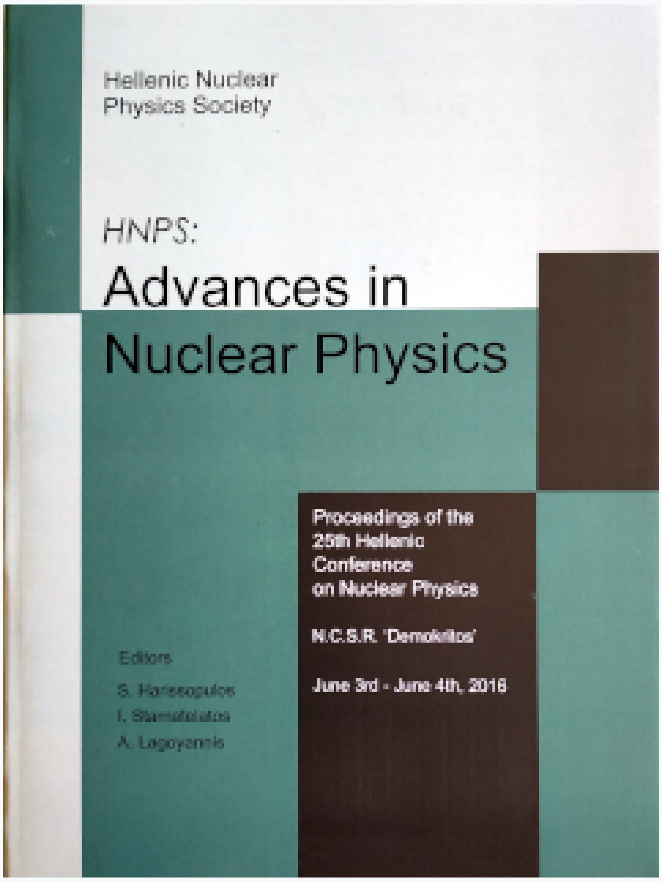
HNPS Advances in Nuclear Physics

Vol 24 (2016)

HNPS2016



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doi: [10.12681/hnps.1865](https://doi.org/10.12681/hnps.1865)

Deployment of an autonomous apparatus for measuring light scattering in deep sea

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Abstract The KM3NeT research infrastructure will be a deep sea multidisciplinary observatory in the Mediterranean Sea housing a neutrino telescope. Accurate knowledge of the optical properties of the sea water is important for the best performance of the telescope. In this work we describe the deployment of the equipment that we had previously examined by Monte Carlo (MC) simulations1, in the context of the “scattering experiment” in order to evaluate the parameters describing the scattering characteristics of the sea water.

Keywords neutrino telescope, scattering, optical properties

INTRODUCTION

The experimental apparatus consisted of four gribs each of 5 m long, made of titanium, attached to each other so that to form a linear and robust structure (Figure 1). At one grid an optical module (OM) of 17” diameter was attached. Inside this OM three pairs of laser diodes were placed, emitting at wavelengths 405 nm, 450 nm and 520 nm. At the other edge of the same grid a field stop was placed in order to avoid the exposure of the detectors to direct light. This grid was connected with two other grids. The last grid which was equipped with the optical module that housed the four Hamamatsu photomultipliers was finally attached. The four grids were placed at the ship side by side, as shown in Figure 1 and the two optical modules (OM's) of the apparatus were covered with a suitable black cloth in order to protect them from light exposure. The one that housed the photomultiplier tubes was more carefully covered with the same cloth as well as a box for extra protection.

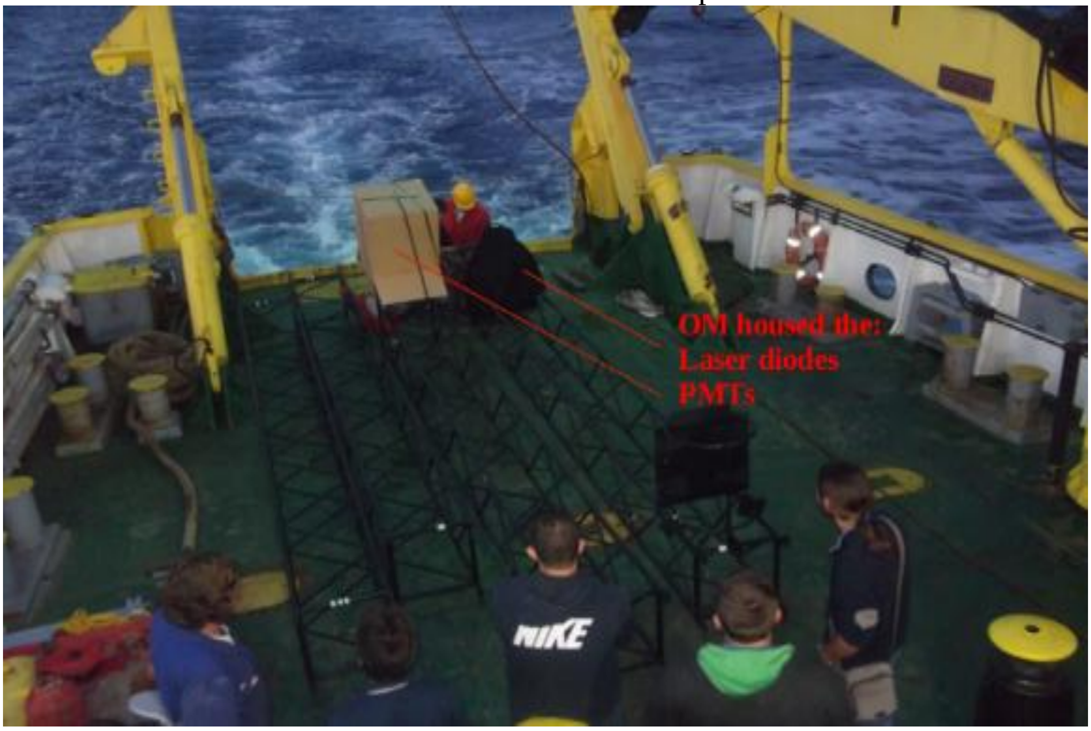

Fig 1 The four grids that were used in the experiment immediately before deployment

The laser diodes were emitting light pulses with pulse width 10 ns, pulse energy 2 pJ and repetition rate around 1 MHz. Their beam divergence was ~ 4 degrees. At the other edge of the same grid a field stop was placed in order to avoid the exposure of the detectors to direct light. This grid was connected with two other grids. The last grid which was equipped with the optical module that housed the four Hamamatsu type H10682 photomultipliers was finally attached. These modules were operating at photon counting mode with their field of view centered at directions -20o, 40o and 120o with respect to the axis formed by the centers of the OMs. The PMTs measured the detected photon arrival times inside 1 μs "time windows" triggered together with the light pulses emitted from the laser diodes. The measured time accuracy was 2.5 ns.

For electrically controlling the experimental apparatus an integration module based on a Xilinx Spartan-6 FPGA was used . This module had a high gate-count FPGA and was placed in the optical module that was equipped with the four photomultipliers. A start-stop connector was also placed at this OM. When the connector was started the FPGA was enabled and after 2 minutes the system activated the Laser Controller, which was placed at the optical module that housed the laser diodes. This counter then started to generate laser pulses.

2).

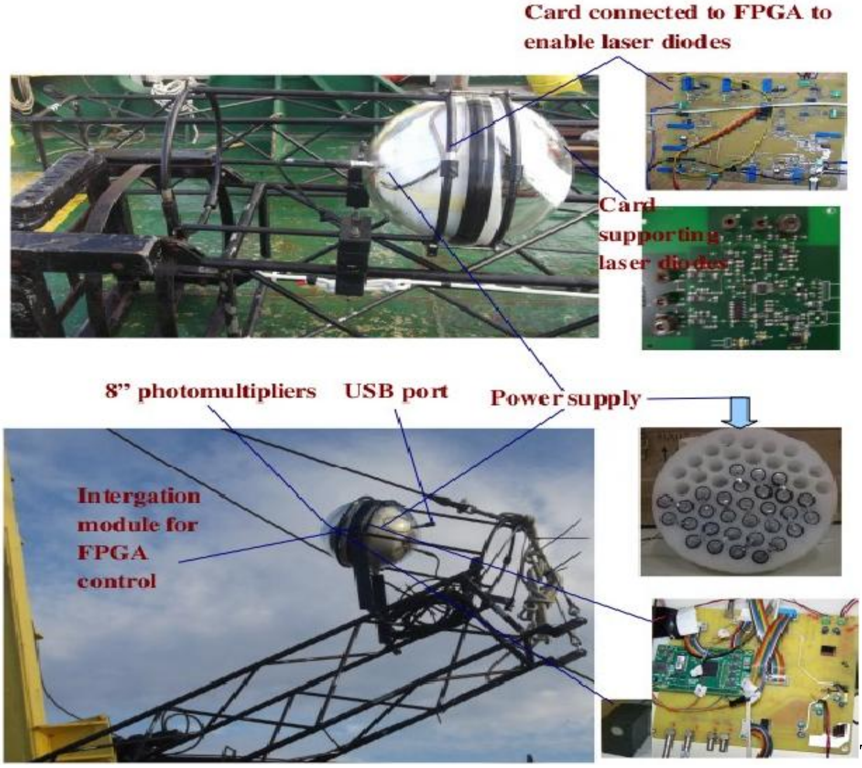

Fig 2 The two optical modules (OMs) that were used in the experiment. One OM housed the six laser diodes (3 pairs) at specific angles to each other. The other OM was equipped with all the electronics (FPGA system) and the four ultrabialkali Hamamatsu 8” photomultipliers. A USB port was placed to allow retrieving the data. In both spheres VARTA batteries type D were placed to electrically supply the system. The spheres were connected by a 37,5 m cable

A microcontroller specified which laser was active. The laser pulses were recorded every 1024 active pulses at a Laser pulse Counter. The scattered light was detected as photons at the four photomultipliers. The Main Counter was stored at a PMT Controller to a temporary space every time a PMT count arrived. The Main Counter was synchronized with the Laser Counter, therefore the storage time of the pulse corresponded to the delay of the light pulse. Just before the Main Counter set to zero every measurement was guided to a storage pace (FIFO). Every active data was guided to FIFO. A USB connector was placed at the optical module that housed the PMTs, in order to retrieve the stored data. The whole system was electrically supplied by VARTA batteries type D, that was placed at the two optical modules that were used. The necessary quantity of the batteries was calculated both theoretically and experimentally. The two spheres were connected by a 37,5 m cable (Figure 2).

DEPLOYMENT PROCEDURE

On October 28, 2015 at 17:00 local time we left from Pylos port with Aegeon ship of the Hellenic Centre for Marine Research, in order to perform the scattering experiment.The four girders were placed at the ship, side by side and the two optical modules (OMs) of the apparatus were covered with a suitable black cloth to protect them from light exposure. The OM housing the PMTs was sealed in a box due to its sensitivity. We arrived at the place of deployment at 19:33 at coordinates: φ =360 31' N and λ = 210 26' E

The scientific team collaborated with the technical team on board in order to prepare the apparatus of the experiment. Initially, the girder that was equipped with the optical module that housed the laser diodes was utilized. A metal mass was placed at the girder behind the optical module, this was used as an anchor. A rope with a connection clip was attached at the other end of the girder, opposite to the optical module, at the backside of the field stop. The clip was connected to the crane, the girder was raised and immersed into the sea, the optical module was the first to be deployed. Then, the other end of the girder was connected to a metal connector that was attached at the ship. The second girder was connected to the end that was attached to the metal connector. The girder was raised and dived in the sea as well. With exactly the same procedure the third girder was connected to the end of the second girder and immersed into the water. Finally, the girder with the optical module that contained the photomultipliers was connected to the end of the girder and guided to the sea water. Therefore, initially 4 girders were connected together, each 5m long, so that the receivers and the detectors were placed at ~20m distance. The electronic system had a timer set and it would start talking measurements when it reached the wanted depth. The system was guided vertically inside the water at 0.7 m/sec and after 1 hour and 30 minutes it reached 3500m depth. The electronic system initialized and started taking measurements for 1 hour. Then, the system was retrieved from the 3500m depth at the same speed as the diving procedure. The girder that held the optical module with the PMTs came out first and disconnected.

We retrieved the data from the USB connector that was mounted on the light detector OM. We disconnected one girder, so that the distance between the two OMs was ~15m. The 15m system was immersed into the sea water. The 3 girders were deployed at the same speed, in the same depth of 3500m. At this depth the system remained for 1 hour and recorded data. Then, this system was pulled out and another girder was disconnected; now 2 girders were connected to form a ~10m long girder. These girders were again immersed into the water in an identical way as described above and remained for the same time.

RESULTS AND DISCUSSION

Three data sets were taken, one for each of the three deployments of the apparatus. Each data-set contains information about the arrival time distributions of the photons detected at the four PMT modules, for each of the six laser diodes. This means that from each dataset 24 histograms of arrival time distributions are extracted, giving an overall of 72 histograms for the experiment. These distributions contain the desired absorption and scattering information to be extracted at the analysis - reconstruction process.

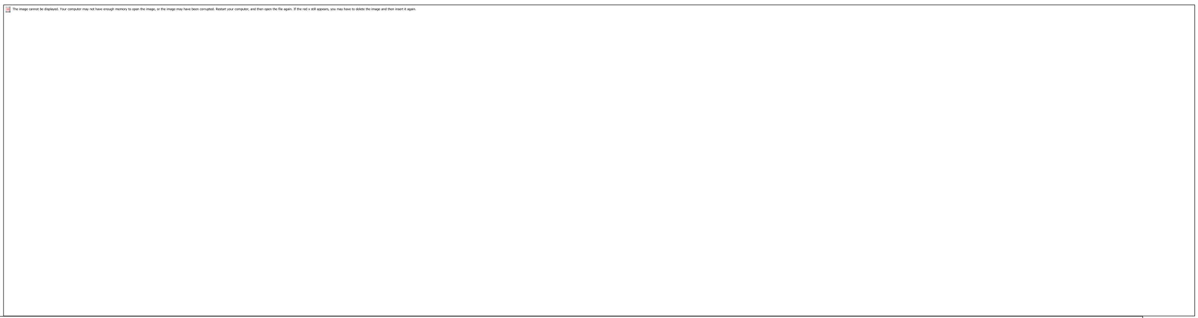

Fig 3 Life activity and bioluminescence in the deep sea

Life activity in the deep sea water has been also observed from a preliminary analysis of the data. (Figure 3) represents part of the "history" of the measurement at the second deployment (~15 m OM distances) as recorded from one of the four PMTs. Bioluminescence is observed by a temporary uniform increase of the detected photon rate inside the 1280 ns "time window", lasting less than a few seconds. Temporary shadowing of the PMTs is also observed.

CONCLUSIONS

In this paper an autonomous underwater telescope for measuring the scattering characteristics of the deep sea water was described. The experiment presented in this paper is motivated by the fact that event simulation and reconstruction techniques for underwater neutrino telescopes rely on the accurate knowledge of sea water optical properties. The multi-PMT optical module, used by KM3NeT, is sensitive to the direction of the incident photons. The desired absorption and scattering information is going to be extracted at the analysis - reconstruction process. Life activity in the deep sea water has been also reported from a preliminary analysis of the data.

ACKNOWLEDGMENTS

This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds. It was fulfilled in the content of KPHPIS-ORASI "Search for the visible and invisible universe with accelerators and new detectors" code no. E.E 11784.

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