An autonomous underwater telescope for measuring the scattering of light in the 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 performance evaluation of the telescope. In this work we describe the deployment of the equipment that we had previously examined by Monte Carlo (MC) simulations, in the context of the scattering experiment in order to evaluate the parameters describing the scattering characteristics of the sea water. Four photomultipliers (PMTs) were used to measure in situ the scattered light emitted by six laser diodes in three different wavelengths covering the Cherenkov radiation spectrum.

1. 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.

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 -20°, 40° and 120° 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.

The site chosen for the deployment of the detector is the western side of Pylos (36° 03’ B and 21° 26’ A), 40 km from shore at a depth of 3500 m. On 28th of October 2015 we utilized the Aegeon ship of...
the Hellenic Center for Marine Research in order to perform the deployment of the experimental apparatus. The experimental apparatus was tested in detailed both theoretically and in the lab, before deployment. The Monte Carlo (MC) simulations have already been described in detailed 1. The system and electronics had to be tested under pressure. For this the FPGA system and the underwater cable that we were going to use was pressed at 400 bar.

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

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. 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 place (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).

2. Characterization of laser diodes with a new scanning system

In order to obtain the detailed characteristics of the laser diodes used, a CCD camera was utilized. The system was placed inside the dark room. A snapshot of the laser spot for each laser diode was taken. These spots were further collimated with appropriate adjustment of the collimators in use. The spot of each laser was centered at the CCD entrance window and an image was grabbed. By knowing the exposed time the energy of each laser was estimated. The laser diode spots were scanned by a new innovative system that has been designed and constructed by the team, (Dr. Nikolaos Maragos). The system could be moved in the x and y-plane by the help of two motors. A program written in C was used to move the two motors at specific positions. The laser diodes were placed in two groups of three
lasers of blue, green and mauve colour. Two of the lasers in each group were placed at angles 30° and 45° with respect to the axis formed by the center of the two optical modules that are going to be used in the experiment. All group of lasers were placed upon a supporting card that provides the operational voltage. This card was placed at the center of rotation of the scanning system. The scanning system was placed opposite a Hamamatsu PMT of type H10682-210 and circular effective diameter of 8 mm. The laser diode spots were scanned and from the obtained results the position and directions of them were obtained. In Figure 3 the results of the green laser, which was placed in the right top side of the electronic card are shown (left-hand side). In the same Figure the scanning of the same laser source in the y-plane is shown fitted to a Gaussian function (right-hand side).

3. Results

Figure 4 illustrates the photon arrival time distribution after scattering at 3500 m underwater. In the upper left-hand side the scattering rate of the blue laser diode that was recorded on the PMT that was placed at the center of the optical module is shown for a total length of the experimental apparatus of 10 m (shown in black colour) and 15 m (shown in red colour), respectively. At the upper right-hand side the scattering rate of the green laser diode that was recorded on the PMT that was placed at the
Figure 3. Scanning of the green laser diode that was placed in the right top side of the electronic card (left image). Scanning of the green laser diode in the y-plane. Results are fitted to a Gaussian function (right image).

center of the optical module is shown for the same lengths of the experimental apparatus. In the bottom right-hand side image the scattering rate of the blue laser diode that was recorded on the PMT that was placed at the left side of the optical module is shown. In the bottom left-hand side of the Figure the scattering rate (Hz) of the blue laser diode as recorded on the PMT that was placed at the left side of the optical module for all laser diodes is illustrated. As expected, the scattering tail increases with a larger separation between the source and the detector.

4. Summary

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 profile of the arrival time distributions and the number of the detected photons depend on the optical photon absorption and scattering characteristics.
Figure 4. Scattering rate (Hz) of the blue laser diode as recorded on the PMT that was placed at the center of the optical module. Scattering rate (Hz) of the green laser diode as recorded on the PMT that was placed at the center of the optical module. Scattering rate (Hz) of the all laser diodes as recorded on the PMT that was placed at the center of the optical module. Scattering rate (Hz) of the blue laser diode as recorded on the PMT that was placed at the left side of the optical module.

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