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The LED Beacon prototype system for the on-shore time calibration of the KM3NeT-IT Towers

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Abstract. The first implementation of the KM3NeT-IT neutrino telescope consists in the installation of 24 Strings and 8 Towers. Focusing on the Towers, the idea behind this work is to exploit the LED sources mounted in the OMs to develop a complementary system, on shore and before the deployment, for the determination of time delays, aiming at the characterizations of the time response of the different elements of the detector. During the assembling of the first tower, a set of measurements has been carried out; the test set-up and the measurement procedure are described, together with preliminary results of the calibration system. Lesson learnt is quite encouraging: uncertainties of the order of 400 ps are reached with very few cautions taken during the short calibration session, and with large room for improvement, making this system feasible and effective for the KM3NeT-IT experiment.

1. Introduction

KM3NeT [1] is a deep-sea research infrastructure consisting of a network of neutrino telescopes in the Mediterranean Sea. The KM3NeT Collaboration gathers the decennial experiences of ANTARES [2] NEMO and NESTOR in the design and implementation of sub-marine telescopes. The main detection principle is based on the Cherenkov technique; the Cherenkov light is collected via photomultiplier tubes (PMTs), arranged in three-dimensional structures (detection units) deployed underwater. The design of the detection units, the dimensions of the structures, the distances between the different elements and the geometry of the installation, all these features determine the scientific target of the detector and the energy threshold of the observations. The present project of KM3NeT is "multi-site" and "multi-purpose", and consists of two detectors to be installed in two separate underwater locations in the Mediterranean Sea: KM3NeT-FR, in the proximity of the ANTARES submarine site, with the "ORCA" component of the experiment [3] focused on the low energies (neutrino oscillations and neutrino mass hierarchy), and KM3NeT-IT, in the submarine site selected by the NEMO Collaboration (about 100 km offshore Capo Passero, Sicily, at 3500 m depth), with the "ARCA" [4] component, focused on the high energies and on the astrophysical targets of the experiment. KM3NeT-IT will host two detecting

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structures, the Strings and the Towers; the first phase of the experiment will include 24 Strings and 8 Towers.

The layout of the Towers reflects the design of the NEMO Tower [5] and consists in a three-dimensional flexible structure made up of 14 floors, for a total height of about 400 m; each floor is a 8 m long frame holding 6 Optical Modules (OMs), 2 at each end and 2 at the centre. The OM is a 13-inch pressure-resistant glass sphere, housing a 10-inch PMT and electronics boards for power supply and data acquisition [6]. Concerning the electronics for data acquisition and data transport of the Tower [7], the FEM board is the Front End Module for each OM and the FCM board is for the Floor Control Module; the backbone ensures a point-to-point electro-optical connection between each floor and the tower base. The on-shore station in Capo Passero is where the collected data are received, the power is supplied and the clock distribution is provided; each FCM has an on-shore counterpart which receives data from the floor (OMs, hydrophones, slow-control instruments) and sends the clock signal and the slow control commands by means of a synchronous point-to-point optical link. All the off-shore devices are thus synchronous to a common clock generated on-shore: as a consequence, a synchronization signal generated by the on-shore electronics can be used in a calibration set-up aimed at determining the latency of the different elements of the detector.

2. The LED Beacon Test

Two of the six optical modules in the floor (the ones located at the edge of the floor and downward-looking) host a 470 nm LED source, whose emission is controlled by the FEM, generating trigger pulses in a fixed phase relation with respect to the global timing of the detector. Taking into account the features of the data transport electronics of the tower, the idea behind this work is to exploit the LED sources to develop a complementary system for the determination of time delays, aiming at the characterizations of the time response of the different elements of the detector. The calibration procedure, hereafter called LED Beacon Test, is intended to be carried out during the integration phases of the tower and exploits the facilities of the integration site, in particular the rack system that implements the on-shore electronics in the experimental hall. For each tower, two tests are planned: the Floor Test and the Tower Test. The first is executed for each OM that holds a LED, and thus consists of two separate sets of measurement for each floor. It aims at estimating the floor latency, considering for each LED the system constituted by the FCM, the FEM and the connecting cables. The Floor Test gives indications on the operation, performance and behaviour of each LED and of the floor electronics. Once that the Floor Test has produced an estimate of the floor latency, the information can be combined with the results of the Tower Test, executed on one of the LED of the floor, to compute the latency of the backbone for each floor. Due to the large number of elements to be tested (and the severe time-restrictions imposed during the integration phase), constraints on the time required for a complete set of measurement the possibility to perform the test in parallel with other activities during the integration phase. A fast data analysis is a further item in the wish list, for a fast check of the tested elements and for permitting to take action before the deployment, in case some elements do not to match the specifications. The prototype system here presented fulfils the above listed requirements; it has been employed on October 2014 during the integration of Tower 8 in INFN – Laboratori Nazionali del Sud (LNS, Catania, Sicily) and is a promising procedure to evaluate the time response of the apparatus.

2.1 Description of the time calibration system

The LED sources

The LEDs are placed inside the OM, at the North Pole of the glass sphere. The distance between the LED emitting point and the internal surface of the sphere is less than 0.5 mm; the thickness of the sphere is 12 mm.

The light sensor

The instrument used to detect the LED light is the semiconductor device Hamamatsu C11208-350, of the MPPC series (Multi-Pixel Photon Counter). 3600 pixels cover an effective photosensitive area of $3 \times 3\,\text{mm}^2$; each pixel is an APD (Avalanche Photo Diode) operating in Geiger mode. The advantages of the device reside in its excellent photon counting capability, the insensitivity to magnetic fields, the low-voltage operation (provided via USB connection) and its pocket-size. The product used in the prototype system is a starter kit and produces both a digital and an analog output; the peak sensitivity wavelength is at 450 nm.

The optical fibre

An optical fibre is used to collect the light emitted by the LED and to transmit it to the sensor; FC/PC connectors are mounted at each end of the fibre. The coupling of the fibre with the light source and the light sensor is an important mechanical issue to be faced for the accomplishment of the LED Beacon Test. While the task concerning the coupling with the light source is still an open point, the coupling of the fibre with the light sensor has been solved with a PVC "cap" (designed and realized by INFN-Roma), hosting an adaptor for a FC/PC connector and placed on the side of the sensor facing the detection window.

Time difference measurement

Time differences are measured with the TDC Agilent 53230A: the instrument receives two signals, S_A and S_B, at times t_A and t_B, and computes the time difference $\Delta t = t_B - t_A$. The reference signal (S_A) is the synchronization signal produced by the on-shore electronics; signal S_B is the digital output produced by the MPPC sensor when light is detected. The distribution of measured time differences is the observable of the LED Beacon test.

3. The test on Tower 8 (LNS, October 2014)

3.1 Experimental set-up

During the tests performed on Tower 8, a multi-mode 50/125 fibre, 40 m long, was employed; a temporary solution was adopted for positioning the termination of the fibre in front of the LED. 20×10^3 readings were acquired via the TDC for each LED. The analog and the digital output of the MPPC and the reference signal from the on-shore electronics were also visualized on the oscilloscope.

Because of the shortage of time, the Floor Test was performed on Floor 01 only, and no Tower Test was done. The optical modules were not covered nor obscured during the data taking, causing fluctuations in the amount of collected light and of ambient light entering the sensor.

3.2 Results

Because of the severe limitations of the experimental set-up, only preliminary considerations and no conclusive results can be extrapolated from the outcome of the prototype calibration system applied to Tower 8. Nevertheless, what is obtained, shown in Fig. 1, is fully encouraging about the potential of the measurement to investigate on the latency of the system and to help in understanding the different components of time delay. In particular, it is notable that the mean value of the distribution is not the same for the two OMs of the same floor, with a difference of about 1 ns that can reasonably be due to systematic effects, for instance the different emission time of the LEDs or the actual length of the cables for the two modules in symmetric position along the floor.

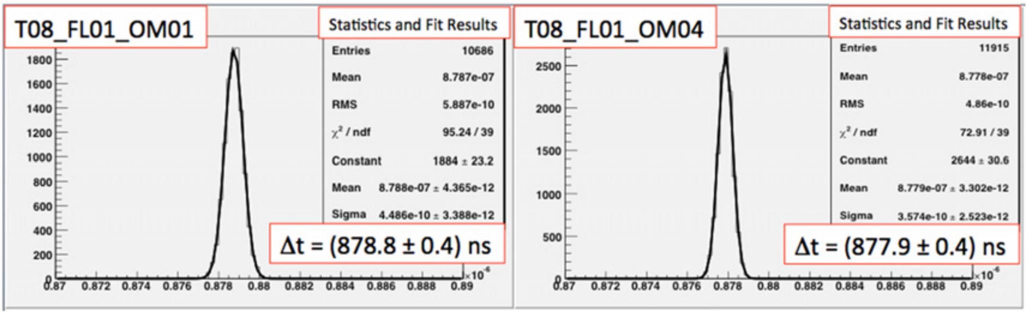

Figure 1. Distribution of the time differences (in seconds) between CH2 of the TDC (the MPPC digital output) and CH1 (the reference signal). Both the measurements have been done setting the same value for the number of readings acquired with the TDC, and the statistics is comparable for the 2 OMs. The result of a Guassian fit is superimposed, showing comparable uncertainties (400 ps) for the two set of measurements.

4. Conclusions

The lesson learnt, valid for the future experiences, is that the LED Beacon Test is already feasible and quite accurate with the instrumentation available. Only few minor improvements may be introduced, for instance the usage of 62.5/125 multi-mode fibres (larger core, for a larger amount of collected light); the use of collimators for optimizing the opto-mechanical interface between the LED and the fibre; the definition of a simple mechanical support to hold the fibre termination in a fixed position in front of the LED source. The test is feasible also with no cover or obscuration of the optical modules: the presence of background light does not affect significantly the measurement. With 20×10^3 readings of the TDC, about half an hour is required for completing the acquisition for a floor having the same statistics collected for T08/FL01; about one working day is taken for completing the Floor Test on the full tower and less than one working day is needed for the Tower Test on the integrated tower. Improved systems for light collection can reduce the number of TDC readings, and thus the time required for the LED Beacon Test.

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