

The Calibration Units of the KM3NeT neutrino telescope

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Abstract. KM3NeT is a network of deep-sea neutrino telescopes to be deployed in the Mediterranean Sea that will perform neutrino astronomy and oscillation studies. It consists of three-dimensional arrays of thousands of optical modules that detect the Cherenkov light induced by charged particles resulting from the interaction of a neutrino with the surrounding medium. The performance of the neutrino telescope relies on the precise timing and positioning calibration of the detector elements. Other environmental conditions which may affect light and sound transmission, such as water temperature and salinity, must also be continuously monitored. This contribution describes the technical design of the first Calibration Unit, to be deployed on the French site as part of KM3NeT Phase 1.

1. Introduction

The KM3NeT Collaboration is currently constructing the first phase of a next-generation neutrino telescope on two sites in the Mediterranean Sea: KM3NeT-Fr near Toulon, France, and KM3NeT-It near Capo Passero in Sicily [1]. Each site will host a three-dimensional array of thousands of photosensors that will detect the Cherenkov light resulting from neutrino interactions in the vicinity of the detector. The French site will be mainly dedicated to the study of oscillation effects with \sim GeV atmospheric neutrinos (ORCA) while the Italian one will focus on high-energy (TeV-PeV) neutrino astronomy (ARCA). The KM3NeT detector relies on a novel design for its Digital Optical Modules (DOMs) [2] which are distributed along vertical flexible strings anchored to the seabed. The anchor (or base) at the bottom of the string is the interface with the seabed infrastructure: it supports the interlink cable, equipped with a wet-mateable connector, and the base container, which houses a power converter and dedicated optical components. Each string with its anchor constitutes one detection unit (DU) of the KM3NeT detector.

The performance of a neutrino telescope crucially depends on the accurate time and energy calibration of the detector elements, as well as on the precise knowledge of their position, which is affected by sea currents. Measurements of water properties are also important for evaluating the detection efficiency. The water transparency affects the propagation of Cherenkov light in sea water, and

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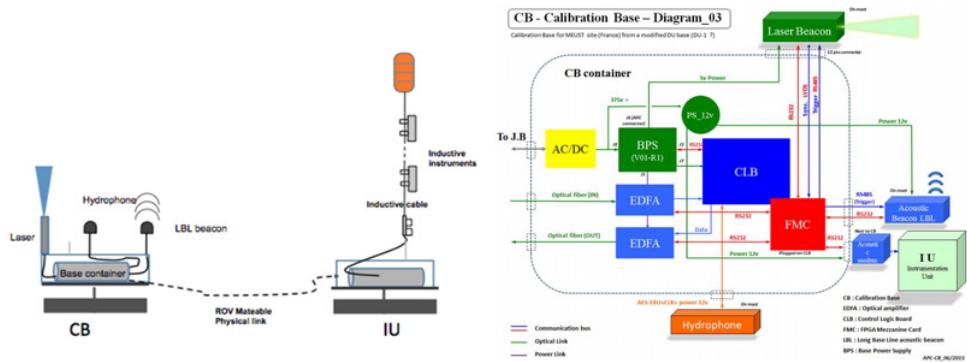


Figure 1. Left: General design of the KM3NeT Calibration Unit. Right: Preliminary electronics scheme for the Calibration Base, with the acoustic option for the communication with the IU.

hence the effective volume and angular resolution. The monitoring of the evolution of these parameters with time and of environmental conditions (temperature, sea currents, bioluminescence...) will be achieved using monitoring tools and probes installed on the detector elements (DOMs and anchors) and on dedicated Calibration Units (CUs) distributed among the detector lines.

The KM3NeT positioning system is based on a network of acoustic transmitters (beacons) and receivers (hydrophones) that will be distributed in the detector installation field, on the CUs (emitter and receiver), DU bases (receiver) and standalone tripods, forming a long-baseline reference system for the determination of the DOM positions by triangulation [3]. The timing calibration will be performed thanks to LED beacons mounted on the DOMs, and to a few laser beacons installed on the CUs [4]. This beacon network will be also used to monitor the water transparency. Other external parameters (sea currents, temperature, salinity...) will be continuously monitored by commercial probes installed on the CUs. Their study is also of great interest for the Earth and Sea Sciences, as already illustrated by joint publications using ANTARES data [5].

2. General description of the Calibration Unit

The general design of a KM3NeT Calibration Unit is shown in Fig. 1. It will comprise two sub-systems: a Calibration Base (CB) and an Instrumentation Unit (IU), powered through the CB. The CB will host the detector calibration devices, namely a laser beacon, a long-baseline acoustic beacon and a hydrophone. The IU consists of an instrumentation base (IB) incorporating an electronics interface board and an inductive modem to be connected to an inductive, semi-autonomous and recoverable instrumentation line (IL) equipped with environmental monitoring instruments distributed in clusters at different depths. The height of the IL will be adapted to the detector configuration (750 m for ARCA and 200–250 m for ORCA are currently being considered). The CB and the IB will be separated by approximately 80 m. The default option for the CB-IU connection is to use a ROV mateable electrical Ethernet connector, but the possibility to use an acoustic modem is also under study, as discussed in Sect. 4.2.

The full CUs equipped with a calibration base and an instrumentation unit will be placed in peripheral positions around the detector, in order to allow easy periodical recovery and redeployment of the IU. In a sparse detector configuration (ARCA), CBs alone can also be distributed more homogeneously inside the detector, thereby ensuring a complete coverage of the whole network of strings. The possibility to attach standard detection lines to the bare CBs is also being considered and

taken into account in the CB mechanical design. The first KM3NeT CU to be deployed on the French site will be a full unit with a CB and an IU.

3. The Calibration Base

The CB will consist of a DU base modified so as to host the following instruments on its external frame:

- **a Laser Beacon** for time calibration and measurement of water optical properties. The laser chosen for the calibration of KM3NeT DOMs is the Nd-YAG model STG-03E-040 and its associated control board MLC-03A-BP1 from Teem PhotonicsIt emits at a wavelength of 532 nm (green) and provides high peak power (> 6 kW) pulses of duration < 0.5 ns; it can be triggered at a maximum repetition rate of 4 kHz. The laser beacon equipped with attenuator and diffuser will be mounted in an Aluminium (class 6) cylindrical container with protective coating. One of the sides of the container hosts the connector, while the other one supports the cylindrical quartz rod that serves as optical window.
- **an acoustic receiver (hydrophone)** providing the position of the CB on the seafloor
- **an acoustic long-baseline emitter** for DOM positioning made of a transducer and an Aluminum shielded container hosting the electronics board detailed in [3]
- possibly an **acoustic modem** for connection to the IU, if this solution is retained.

All the electronics, optical and power devices are enclosed in a Titanium cylindrical Base Container attached to the CB frame. This container will in particular incorporate

- **one KM3NeT Central Logic Board (CLB)** [6] and its **FPGA Mezzanine Card (FMC)**, for data acquisition and transmission
- **two optical amplifiers (EDFA)** to read and write from/to the optical fibers
- **a power conversion board** to power all the CB elements and the IU.

A preliminary synoptic view of the electronics components and their connections to the various CB instruments is shown in Fig. 1.

4. The Instrumentation Unit

The Instrumentation Unit is composed of one Instrumentation Base container (IB) laid on the seabed and of an inductive Instrumentation Line (IL), maintained vertical by a buoy, and supporting various autonomous instruments powered on internal batteries. The IU is recoverable in order to allow the change of batteries and the periodical recalibration required by some of the instruments. The design is directly derived from the ALBATROSS project (*Autonomous Line with a Broad Acoustic Transmission for Research in Oceanography and Sea Sciences*) which was recently deployed close to the KM3NeT-Fr site. It is totally autonomous and will communicate its data through an acoustic modem to an Instrumented Interface Module (IIM) to be connected to the KM3NeT-Fr node, as part of the European Multidisciplinary Seafloor and water-column Observatory network.

4.1 The Instrumentation Base

The instrumentation Base consists of a Titanium cylindrical container attached to a dead weight, that will contain

- **an Inductive Modem (IM)** foreseen IM to be the Seabird IIM, with a RS232 data interface
- **the power system** for the IIM (either provided by the CB or by an internal battery)
- **the communication interface with the CB.**

Based on the experience of the ALBATROSS project, the possibility to use an acoustic modem instead of an Ethernet cable is currently under study, with the potential advantage of reducing the number of wet mateable connectors and hence the risk of failure at (de)connection.

4.2 The Instrumentation Line

The inductive mooring line is made of a steel wire rope covered by a plastic jacket except on its ends, which are grounded in seawater, allowing a current loop through the cable. Inductive Modem devices couple to this loop inductively along the insulated part of the cable, without direct electrical connection. The signal induced on the line by the instruments is retrieved by a dedicated Seabird inductive cable coupler (ICC). The configuration of the IL will allow the instrumentation of the full water column of the KM3NeT detector. It will comprise clusters of identical instruments, distributed at different depths depending on the detector configuration (ORCA or ARCA):

- **one CTD (Conductivity, Temperature, Depth) probe.** These measurements are used to calculate the sound velocity. The foreseen instrument is the SeaBird SBE 371IMP-0D0-1b.
- **one sound velocimeter** which performs direct measurements of the celerity by measuring the time of flight of an acoustic signal over a known fixed distance. The foreseen velocimeter is the Valeport Midas Mini SVS which will be powered and interfaced to the mooring line via the RS232-inductive coupler SBE44 from Seabird.
- **one Acoustic Doppler Current Profiler (ADCP)** that measures the current profile over a water column whose length depends on the acoustic signal frequency (from ~ 20 m at 1000 kHz to more than 500 m at 75 kHz). This characteristic strongly influences the cost, weight and dimensions of the instrument and different options are still under study.

The measurement periodicity of all these instruments is typically of 20 minutes.

5. Deployment, calibration and maintenance of the Calibration Units

Specific mechanical tools must be designed for the KM3NeT CUs, in particular to ensure safe deployment and recovery of the IU. Base on the ALBATROSS experience, it is foreseen that the IU will be laid on the seabed from the surface boat using the winch. The deadweight of the IU will support acoustic releases that will be activated in order to recover the IL. The IU instruments are in principle provided already calibrated. The foreseen periodicity for recalibration is every one to three years, to be adjusted taking into account the necessity of battery replacement. The IL recovery will be planned during one of the sea operations for DU deployment in order to minimize the costs. It is foreseen that the first CU will be deployed on the KM3NeT-Fr site by 2017, to allow a validation of the calibration procedure with the first lines of the ORCA demonstrator array.

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