Development of an Acoustic Antenna for Event Triggering in KM3NeT

Miguel Ardid, Salva Ardid, Víctor Espinosa, Alicia Herrero, Carlos D. Llorens, Carlos Quiroz-Rangel
Universitat Politècnica de València, Inst. de Investigación para la Gestión Integrada de Zonas Costeras,
Gandía, Spain.
emails: mardid@fis.upv.es, sardid@upv.es, vespinos@fis.upv.es, aherrero@mat.upv.es, cdavid@upv.es, carquira@upv.es

Manuel Bou-Cabo, Guillermo Lara
Instituto Español de Oceanografía
Murcia, Spain.
emails: manuel.bou@ieo.csic.es, guillermo.lara@ieo.csic.es

***Abstract*— The Cubic Kilometer Neutrino Telescope (KM3NeT), located deep in the Mediterranean Sea, is designed for detecting neutrinos through optical Cherenkov radiation. However, the installation of an acoustic detection system can provide complementary capabilities, extending the detection to ultra-high energies. This paper proposes the development of an acoustic antenna composed of an array of four hydrophones, separated by approximately one meter. This antenna will be used as a trigger for detecting relevant acoustic events, which could include signals from neutrino interactions or other underwater acoustic phenomena. The system is intended to work in conjunction with the existing KM3NeT hydrophone network, enhancing both the detection of neutrinos through acoustic channels and contributing to sea acoustic monitoring.**

Keywords-acoustic detection; deep-sea neutrino telescope; sea acoustic monitoring; hydrophone array.

I. INTRODUCTION

The Cubic Kilometer Neutrino Telescope (KM3NeT) is a neutrino observatory located at depths of up to 3500 meters in the Mediterranean Sea, primarily designed to detect high-energy neutrinos by observing Cherenkov light produced when neutrinos interact with water [1]. In addition to optical detection, there is growing interest in utilizing acoustic techniques to identify neutrino interactions, which may produce characteristic pressure waves in the water and allowing the extension of neutrino detection to ultra-high energies [2]. Such an approach also enables environmental monitoring, offering insight into marine biodiversity (e.g. mammals), seismic activity, and anthropogenic noise pollution.

The integration of an acoustic antenna system that can detect these neutrino-induced acoustic signals or other significant acoustic phenomena is a natural extension of KM3NeT's capabilities. This paper proposes a design for a 4-hydrophone acoustic antenna array that can trigger event detection based on specific acoustic patterns, which complements the current array of hydrophones used in KM3NeT. With this antenna, the feasibility of the acoustic detection of neutrinos will be assessed. In parallel, long-term acoustic studies on marine mammals and on anthropogenic noise are planned.

Notice as well that this kind of infrastructure is very unique, allowing an ideal place for deep-sea science studies and providing the infrastructure the required energy for the equipment to be operated and a broadband connection that allows continuous real-time monitoring with high-frequency sampling.

The paper is structured as follows: in Section II, the conceptual design is discussed. In Section III, the integration of the antenna in KM3NeT is treated. The applications of the antenna beyond acoustic neutrino detection are presented in Section IV. Finally, the main conclusions are highlighted in Section V.

II. CONCEPTUAL DESIGN OF THE ACOUSTIC ANTENNA

The proposed acoustic antenna consists of four hydrophones arranged in a 3D array with a separation of approximately one meter between each hydrophone. It will follow a similar scheme of the acoustic floors in the AMADEUS/ANTARES, or ONDE detection systems [3][4]. The goal is to leverage the spatial configuration and array processing techniques to locate the origin of incoming acoustic signals and assess their characteristics, distinguishing neutrino events from background noise. Fig. 1 shows a schematic view of the conceptual design of the array mounted in a recoverable autonomous structure. There are the four hydrophones of the array fixed with vertical bars at different heights. They are on a structure that contains the electronics of the system and the connector to link it to the KM3NeT infrastructure, thus allowing the control and data capturing communication as well as the needed electrical power. The structure, with sufficient buoyancy, may be automatically recovered using an acoustic release.

Some considerations that have to be taken into account in the design:

- **Hydrophone Spacing:** The separation of one meter is chosen to balance the ability to capture acoustic signals across a range of frequencies, while maintaining a compact structure suitable for deployment in deep-sea conditions. At this separation, it complements the larger distances between acoustic sensors existing in KM3NeT and the array is sensitive to wavelengths in the range of typical acoustic signals generated by high-energy particle interactions or the acoustic phenomena to be studied.

- **Frequency Range:** The hydrophone array will be sensitive to the expected acoustic signature of neutrino interactions, which is in the range of 1–50 kHz. This frequency range also allows for the detection of other underwater acoustic phenomena, including marine mammal vocalizations, oceanographic noise, and seismic signals.

- **Signal Processing and Triggering:** The array will employ beamforming and signal correlation techniques to identify the direction of arrival of acoustic signals and trigger data recording when certain criteria are met [5][6]. This triggering mechanism will be designed to identify sharp, broadband acoustic pulses, such as those expected from neutrino interactions. Advanced algorithms for pattern recognition will be developed to differentiate between neutrino-induced acoustic signals and noise from marine life, ships, or environmental factors.

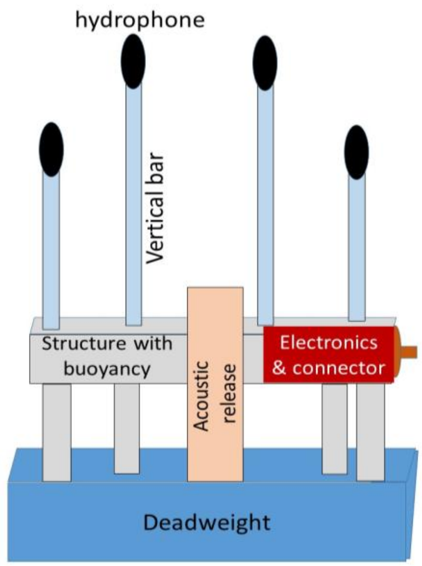

Figure 1. Schematic view of the acoustic antenna.

III. Integration with KM3NeT

The KM3NeT neutrino telescope is already equipped with a large array of hydrophones and acoustic sensors primarily used for positioning and calibration of the optical modules [7]. The proposed 4-hydrophone array will be deployed alongside this system, but with a focus on event detection and triggering relevant events. By complementing the existing infrastructure, this acoustic antenna can enhance KM3NeT's ability to monitor and record transient acoustic events, as well as various other natural and anthropogenic sources of underwater sound.

- **Data Synchronization:** The new hydrophone array will be synchronized with the KM3NeT timing system, ensuring that acoustic data can be correlated with the other acoustic data from the observatory, as well as from the optical detections or other neutrino candidate events.

- **Deployment Strategy:** The compact size of the array allows for flexible deployment within the KM3NeT grid. It can either be mounted on the base of the detector strings, in the calibration base or instrumentation line, or deployed as a standalone unit with dedicated infrastructure.

IV. Applications Beyond Neutrino Detection

In addition to enhancing the detection of neutrino interactions, the proposed hydrophone array will contribute to acoustic studies in the deep sea. The Mediterranean Sea is a rich environment for studying natural and anthropogenic sounds. The proposed system could provide valuable data for:

- **Marine Biology:** Detection of vocalizations from marine mammals and fish populations [8], contributing to biodiversity assessments and behavioral studies.

- **Seismic Monitoring:** Monitoring underwater earthquakes or sub-sea volcanic activity by detecting associated acoustic waves. It could also be part of a warning system for marine hazard, e.g., tsunamis.

- **Anthropogenic Noise Studies**: Long-term monitoring of human-generated noise pollution, such as from shipping or underwater construction, and its impact on marine ecosystems.

V. Conclusions

The proposed 4-hydrophone acoustic antenna represents a novel addition to the KM3NeT neutrino telescope, offering enhanced capabilities for detecting acoustic signals from neutrino interactions and providing valuable data for oceanographic and environmental monitoring. The small array size, signal processing capabilities, and compatibility with the existing KM3NeT infrastructure make it an ideal tool for complementing physics and environmental research objectives in the deep sea. As future work, the design, construction and installation of the acoustic antenna will be finalized. It will be tested initially in the laboratory and at sea at shallow depths. Once verified that it is working properly, it will be integrated into the KM3NeT deep sea neutrino telescope.

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