Acoustic positioning system for KM3NeT

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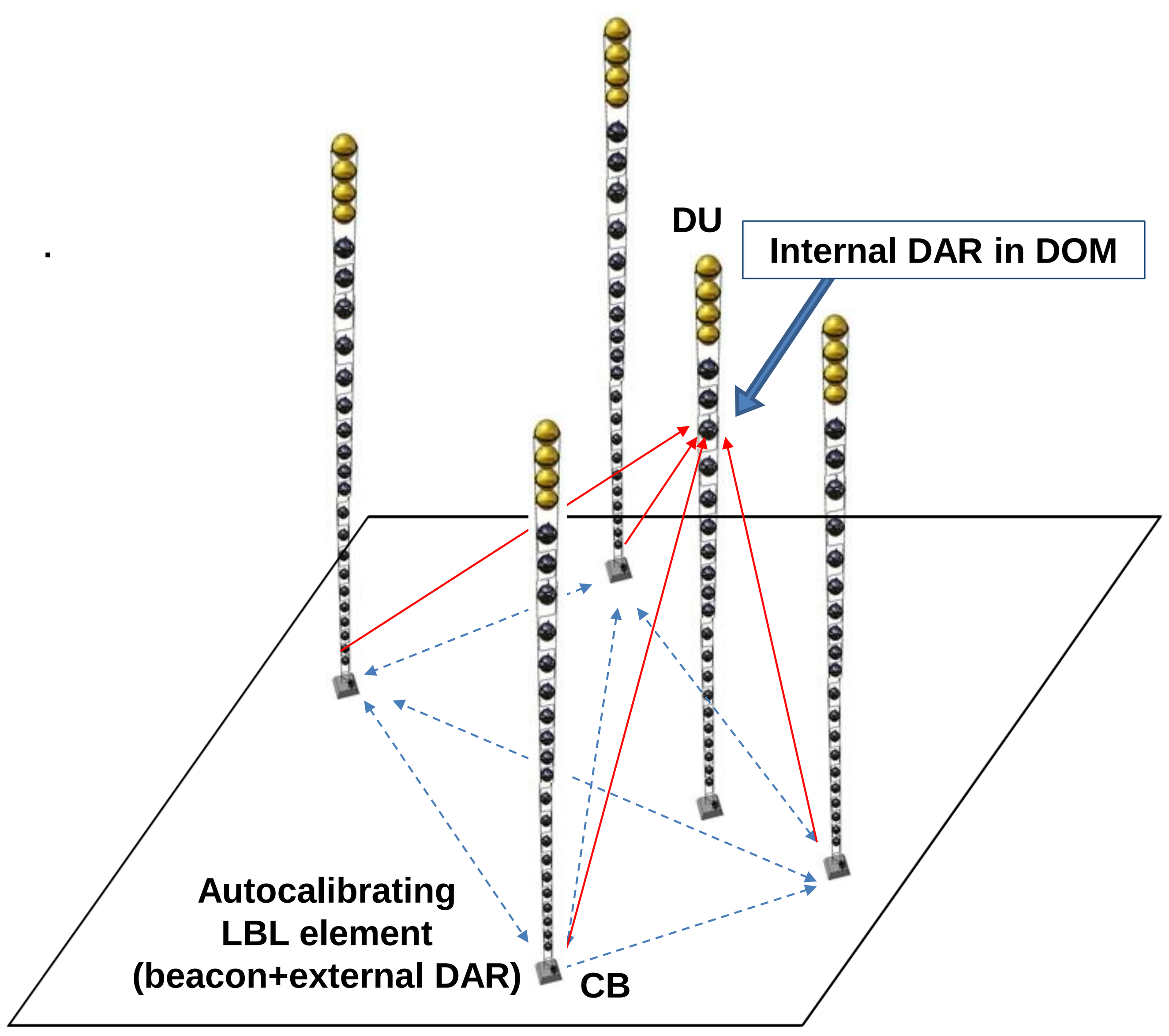
KM3NeT is a multi-km^3 sized neutrino telescope that will be installed in the Mediterranean Sea [1]. The detection principle is based on the measurement of the Cherenkov light induced by relativistic charged particles emerging from an interaction of a neutrino in the vicinity of the detector. During the telescope operation, in order to effectively reconstruct charged particles tracks, generated by the interaction of cosmic neutrinos with water nuclei, via the optical Cherenkov technique, the coordinates of the optical sensors must be known (relative to a well-defined reference system) with an accuracy of about 10 cm. The KM3NeT acoustic positioning system is composed of three main sub-systems: 1) a Long Base-Line (LBL) of acoustic transmitters (beacons) and receivers, located at known positions; 2) an array of digital acoustic receivers (DARs) installed along the detection units (DUs) of the telescope; 3) a farm of PCs for the acoustic data analysis, on-shore.



The KM3NeT Long Base-Line

The LBL of KM3NeT is composed of an array of acoustic transmitters and receivers hosted on the Detection Units (DUs) bases and on Calibration bases (CBs) of the telescope. Each DU base hosts a digital hydrophone, each CB hosts an acoustic beacon and a digital hydrophone placed at known distance from the beacon. The positions of the LBL elements in the KM3NeT-Fr site are geo-referenced thanks to a custom version of the RAMSES positioning system [2]; in the KM3NeT-It site the absolute positions of acoustic beacons and receivers of the LBL are recovered using a USBL (Ultra-Short BaseLine) system available on board the ship that performs the deployment.

The LBL Acoustic Beacon

The commercially available piezo-ceramic Free Flooded Rings (FFR) transducers SX30 from Sensor Tech Ltd [3] have been chosen for LBL beacons. Each beacon can be reconfigured via a dedicated RS232 connection with a Central Logic Board (CLB) installed on the CB electronics, in order to allow reconfiguration of acoustic emission signal parameters (amplitude, waveform, timing) for "in situ" optimization of the signal detection. The signal emission trigger is synchronized with the detector master clock with calibrated time delay of 7±1 μs.

Fig. 1 - Acoustic beacon assembly used for the KM3NeT LBL, produced by the Mediterráneo Señales Marìtimas [4].

Acoustic specifications of the Acoustic Beacon for the LBL

Sound Pressure Level (SPL)	180 dB @ 34kHz re1 μPa at1 m
Frequency range	20 kHz to 50 kHz
Maximum variation of the TVR per frequency	±6 dB in the frequency range interval
Beam pattern (Radial; Horizontal plane)	Omnidireccional (±2dB) for each work frequency
Beam pattern (Axial; Vertical Plane)	Toroidal:60° (±10 dB) (±5 dB) for each work frequency in 180°
Intrinsic noise	<-120 dB re V^2/Hz
Test Pressure	400 bars

The 'external' Digital Acoustic Receiver

Digital hydrophones are hosted on the base of the DUs and on CBs. These 'external' hydrophones are used to calibrate the LBL measuring the relative distances among LBL elements. The selected hydrophone is the DG0330 manufactured by Colmar s.r.l. [5]. It consists of a spherical piezo-ceramic element read-out by an analogue board, splitting the signal in two lines with different gains (+46 dB and +26 dB respectively). The time latency of the hydrophone electronics (including 4.5 m cable) has been measured using a dedicated setup and its value is 50.65 ± 0.02 μs for the low gain channel and 50.71 ± 0.02 μs for the high gain channel.

Fig. 2 – The "external" digital hydrophone used for the LBL calibration, compared with a KM3NeT 3'' PMT.

The 'internal' Digital Acoustic Receiver

The movement of the DUs under sea currents are monitored thanks to "internal" piezo-electric Digital Acoustic Receivers (DAR) [6] glued from the inside to the glass sphere of each KM3NeT Digital Optical Module (DOM) [7]. The design sensitivity of the sensors is - 160 ± 6 dB re 1V/Pa at 50 kHz with a ± 3 dB variation (long time average) in the range 10 ÷ 70 kHz. Acoustic data are acquired continuously at 195 kHz, with a resolution of 24 bits.

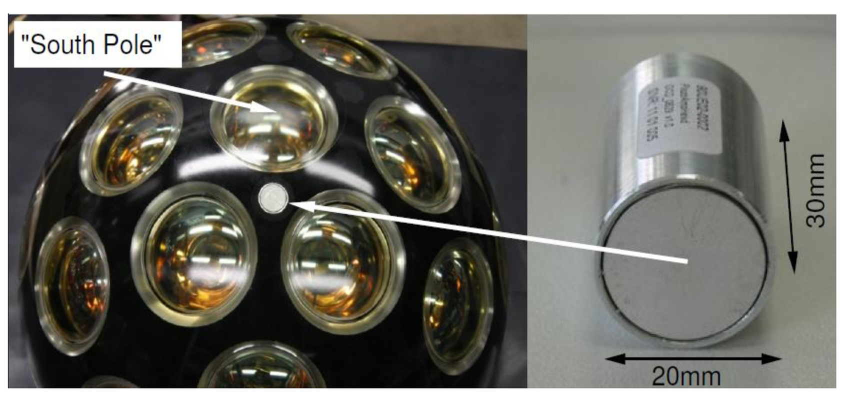


Fig. 3 - Piezo-electric digital acoustic receiver integrated in a KM3NeT DOM.

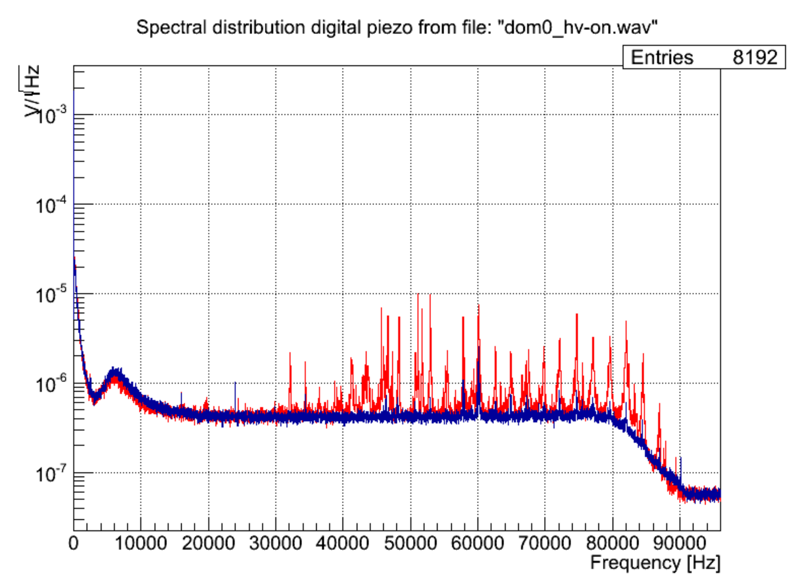
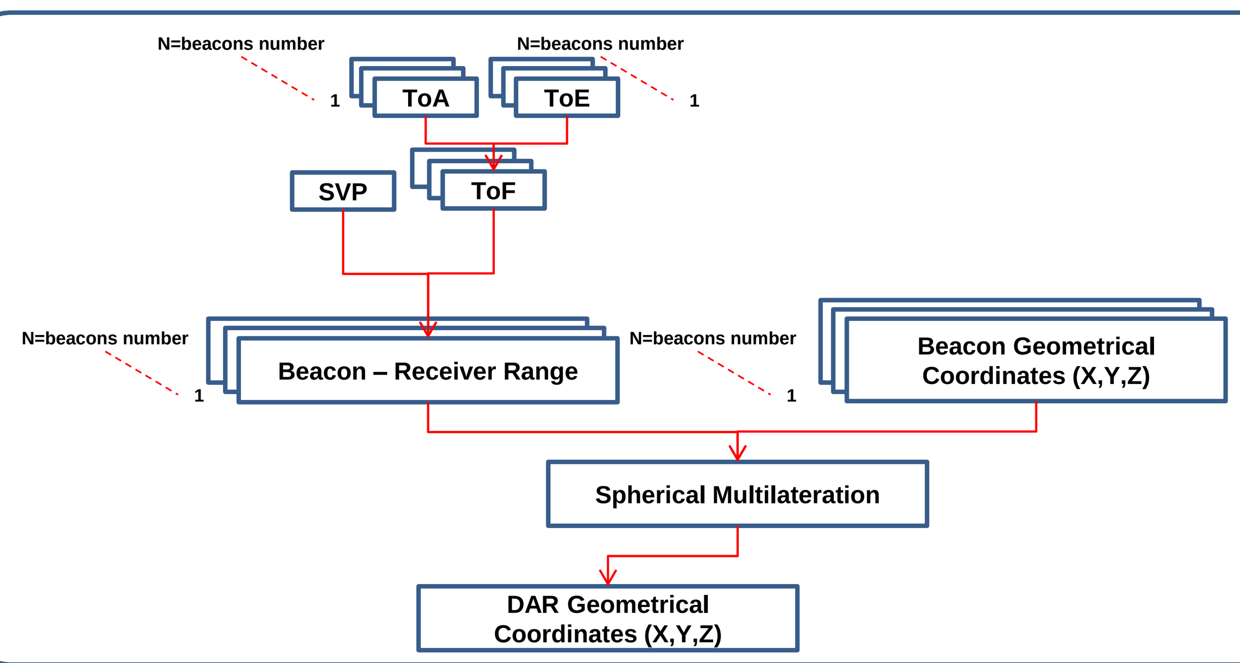


Fig. 4 - Power spectral density of the electronic noise for an internal digital acoustic receiver as measured within a DOM in the laboratory. The blue curve shows the distribution for PMTs power off, the red curve for PMTs power on.



The on-shore data analysis

The acoustic positioning data analysis is performed on-shore by a farm of PCs. These PCs receive, on a intranet, data from the DARs, parsed from the main data stream. The Time of Arrival (ToA) of the acoustic signals detected by DARs are measured, analyzing the DAR raw data flow using software algorithms based on matched filters. Once a LBL-beacon pulse is identified, the code associates to it the detection absolute GPS time (ToA). The distance between each beacon and each DAR will be then calculated taking into account the time of emission (ToE) of the acoustic signal and the sound velocity (SVP) along the water column. Knowing the location of the LBL beacons, each DAR position is recovered using algorithms based on spherical multi-lateration.

Conclusions

The expected accuracy of the KM3NeT acoustic positioning system for DOM positioning is estimated to be of about 10 cm, allowing a precise reconstruction of Cherenkov neutrino-induced events. Thanks to the synchronization of each DAR with the Master Clock of the telescope [8], the KM3NeT acoustic positioning system represents a good tool to study the feasibility of an acoustic neutrino detector and the possible correlation between acoustic and optical signals induced by neutrino events [9]. Multidisciplinary studies on bioacoustics and geophysics will be also possible.

References

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