Position Calibration for the KM3NeT Detector

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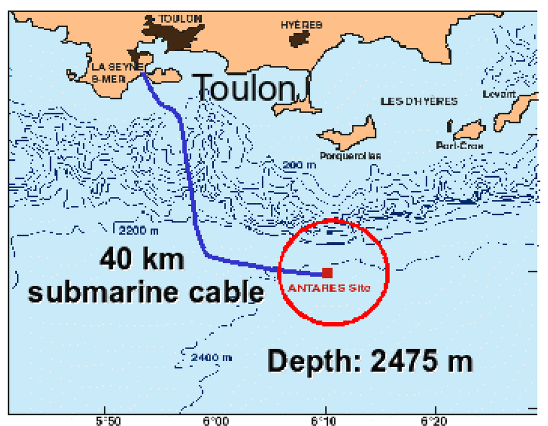
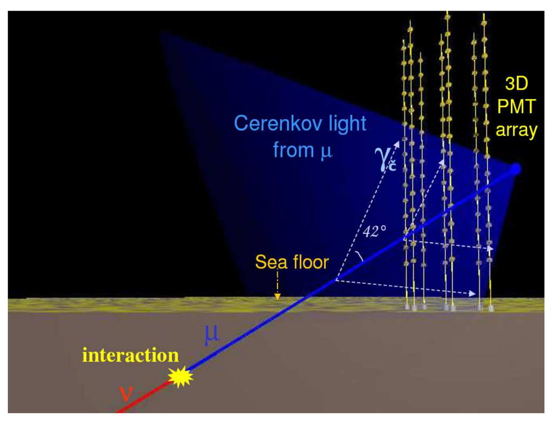
The ANTARES Neutrino Telescope

The ANTARES neutrino telescope, was completed in May 2008 at a depth of 2475 metres in the Mediterranean Sea near Toulon, Southern France. It consists of twelve detector lines on the ocean floor, hosting 885 photomultipliers. The detector lines, also called strings, are made of electro-optical cables, a total of 480 metres in length, fixed at the ocean floor by an anchor and straightened by a buoy. Starting at 100 metres from the bottom, storeys (see bottom right) carrying three 10-inch PMTs in glass spheres (Optical Modules) and an electronics container are attached to the cable every 14.5 metres.

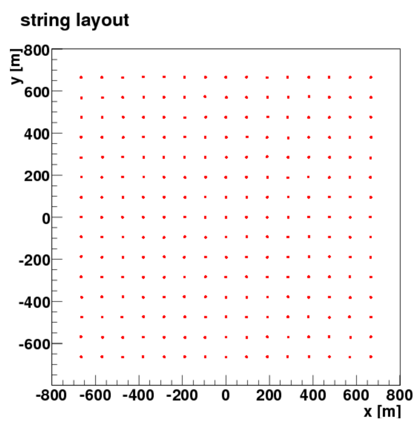


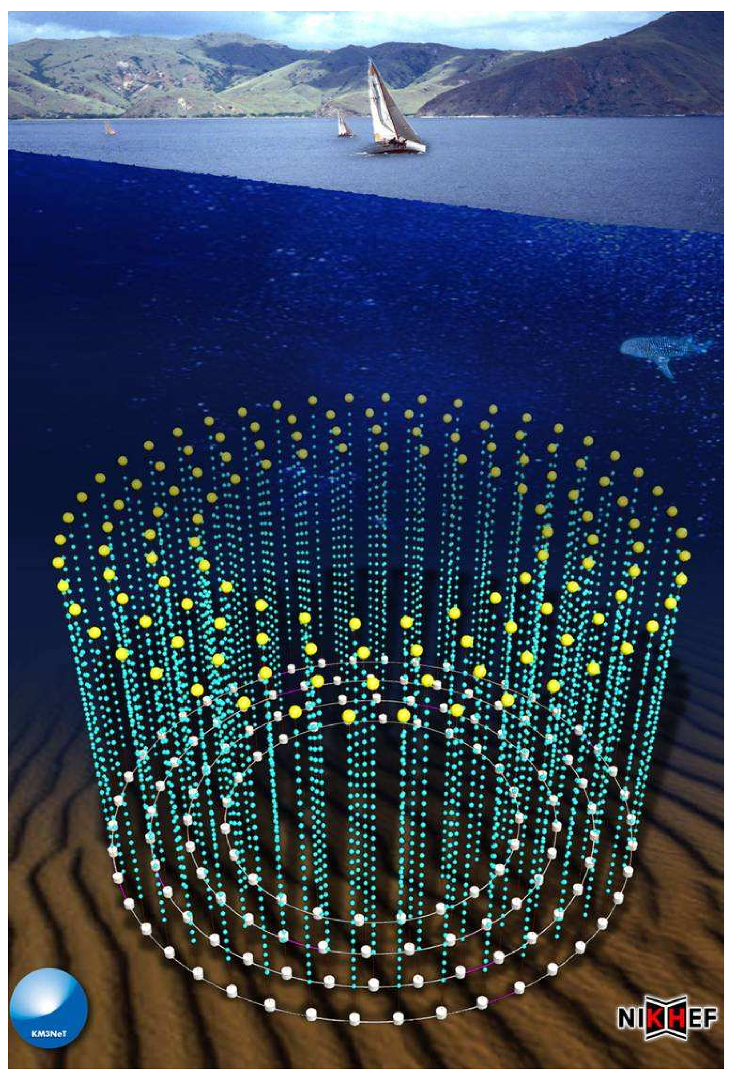
One line holds 25 storeys organised in five sectors, an additional Instumentation Line (IL) is equipped with environment monitoring devices. In addition the IL as well as the topmost sector of line twelve contain the hydrophones of the AMADEUS project (see sections below) instead of optical modules. As flexible structures the lines move with the sea current and the attached storeys are shifted, tilted and rotated with respect to the straight line case without torque. The detection principle, as depicted below on the left, is to reconstruct the direction and postion of muon tracks and hadronic cascades caused by neutrinos from timing and position of their Cherenkov light emissions, which requires a precise knowledge of the position and orientation of each PMT. Therefore ANTARES features a positioning system [2] consisting of a tiltmeter/compass board on each storey to measure its orientation and five hydrophones per line on selected storeys to triangulate their position from the propagation times of signals emitted by fixed transducers and acoustic beacons at the lines anchor stations.



KM3NeT

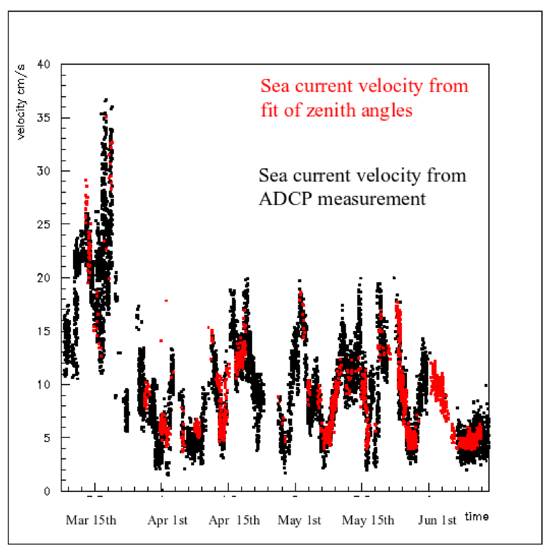
The KM3NeT project [4] aims at the construction and operation of a cubic-kilometre scale neutrino telescope in the Mediterranean Sea. It draws from the experiences gained in the three pilot projects ANTARES, NEMO and NESTOR. During the design study phase, which began in 2006, different possible detector designs are being evaluated, both in the detector layout and in the detector element segment. A possible detector configuration consists of 225 lines, equipped with 30 Optical Modules each, in a cubic grid with a spacing of 100 metres. To provide a cost efficient solution for construction of a detector comprised of such a high number of elements, new technologies are developed. An example for such a solution is an Optical Module with integrated piezo sensors for position calibration. The performance of this concept is currently tested with the setup provided by the AMADEUS project (see sections below).

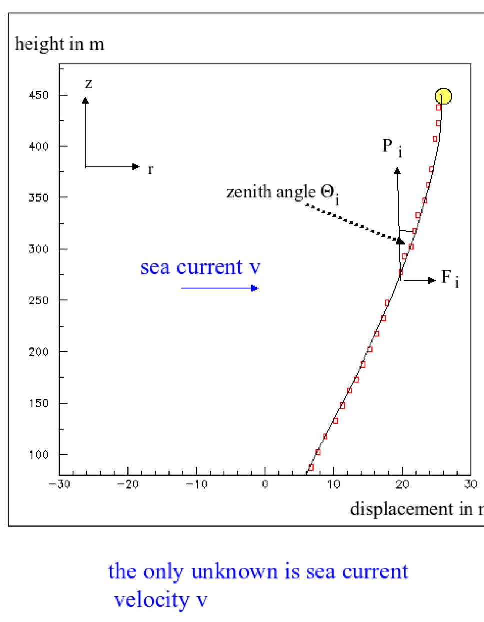




Line Shape Reconstruction

The acoustic positioning system provides data on the position of five of the 25 storeys of a line. In order to reconstruct the full line geometry and to determine the position of storeys not equipped with hydrophones, a line-shape model derived from the drag and buoyancy forces on the line components is fitted to the acoustic position and tiltmeter data, with only sea current velocity and direction remaining as free parameters. The displacement $r(z)$ of the line is calculated as the integral over inclination which is determined by known properties of the line components i.e. buoyancy P, area A and drag coefficient c_w outlined in the schematic below on the right. To include the current direction, the formulae are employed on two orthogonal planes with current components v_x and v_y. From these formulae the shape of the line can be calculated even without acoustic triangulation, resorting only to tiltmeter and compass data, albeit at significantly lower precision. To test the reliability of this model, the fitted sea current velocity was compared to measurements by an ADCP (Acoustic Doppler Current Profiler) device installed in the ANTARES detector, which gave good agreement as shown in the figure below on the left side.





Inclination of line results from buoyancy P and horizontal force F due to sea current:

$$\tan(\Theta_i) = \sum_{j>i}^{N} F_j \Big/ \sum_{j>i}^{N} P_j$$

$$P_j = \text{buoyancy} - \text{weight}$$

$$F_j = 1/2\, \rho\, c_{w_j} A_j v^2$$

of element j of the line

$$\tan(\Theta_i) = dr/dz$$

integration → Line shape:

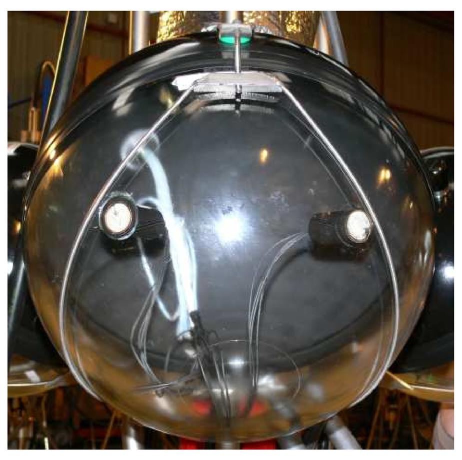
$$r(z) = a\, v^2 z - b\, v^2 \ln[1 - cz]$$

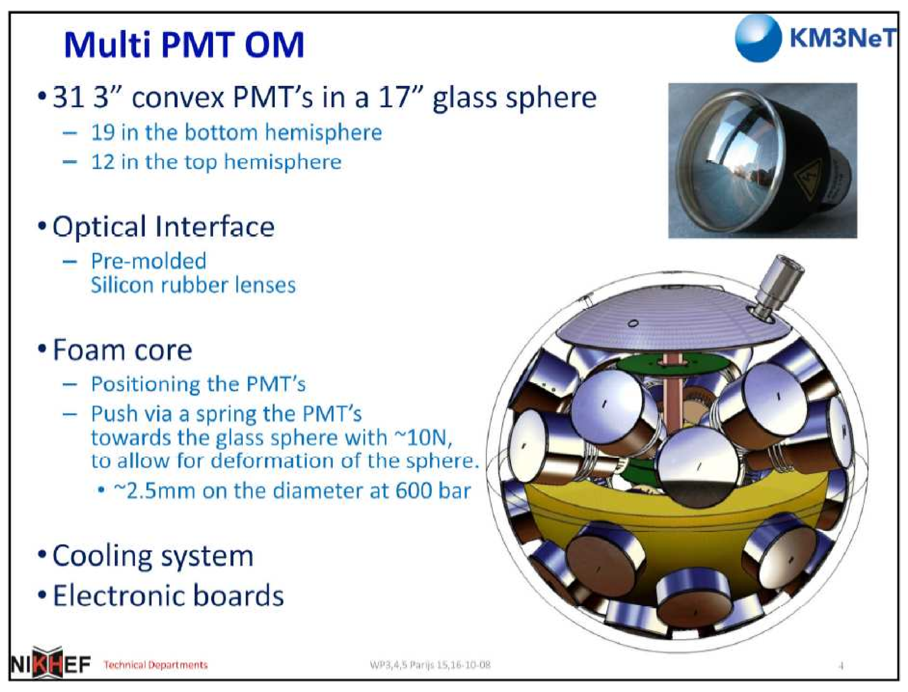
a, b, c known constants

Acoustic Modules and Multi-PMT Optical Modules

A proposed design for the Optical Module is layed out in the sketch below to the right. It holds 31 three-inch PMTs and would allow for the installation of additional piezo sensors for position calibration, similar to the Acoustic Modules (AMs) of AMADEUS (see sections below) [3]. The AMADEUS Acoustic Modules use the same 17-inch glass sphere as the ANTARES Optical Module with the PMT replaced by two piezo sensors glued to the inner side of the sphere. The same piezo elements, preamplifiers and readout scheme are used as for the hydrophones produced in Erlangen. The piezo element is glued directly to the inside of the glass sphere. Unlike with molded hydrophones the received sound is conducted inhomogenously by the components of the Acoustic Module, i.e. the glass sphere. This effect distorts the signal but it can be compensated for, allowing for precise reconstruction of the signal arrival time (see section on results below).

The photo below shows one of the AMs installed on Storey 21 of Line 12 with two piezo elements glued to the inside of the glass sphere.

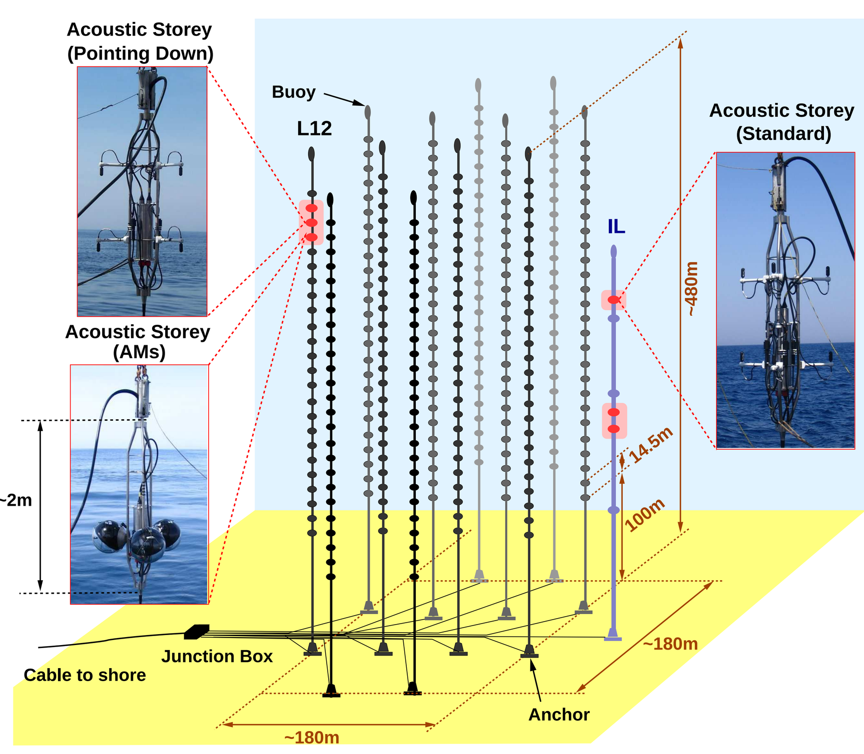




AMADEUS

AMADEUS (Antares Modules for Acoustic Detection under the Sea) [1] is a project that is part of the ANTARES neutrino telescope in the Mediterranean Sea and aims for the investigation of techniques for acoustic detection of ultra-high energy neutrinos (above approximately 10^{18}eV). The cascade from such highly energetic particles interacting in water causes instant heating, resulting in a bipolar pressure pulse, which can be detected at several hundred metres of distance. The far longer range of acoustic compared to optical (Cherenkov) signals allows intrumentation of larger volumes with less detector material, a prerequisite for detection of the extremly low expected fluxes associated with the ultra-high energy range of the cosmic ray and neutrino spectrum.

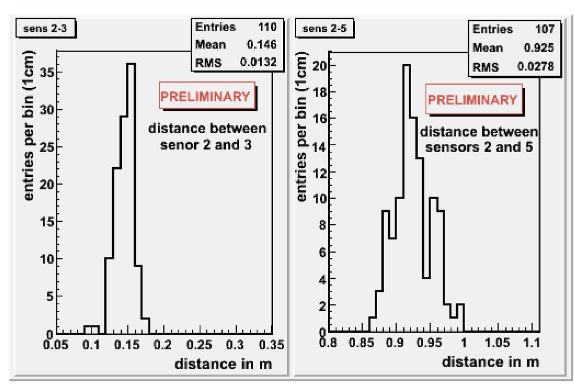
The sensors of AMADEUS are mounted on three storeys at the top of Line 12 and on three storeys on the Instrumentation Line (IL) as shown in the scheme of the ANTARES detector to the right. The IL-storeys feature 18 hydrophones, 6 per storey, developed by the AMADEUS group as well as a company. On Line 12 two storeys are equipped with hydrophones, the third features three Acoustic Modules (see section on the left). While designed for investigation into a new method of high energy particle detection, the sensors are also able to identify and track marine mammals by their acoustic communication, opening a window for interdisciplinary science. As an example the section on results on the right shows the triangulation of a dolphin click.

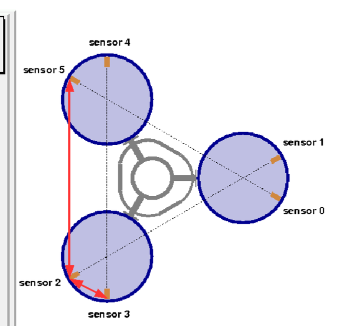


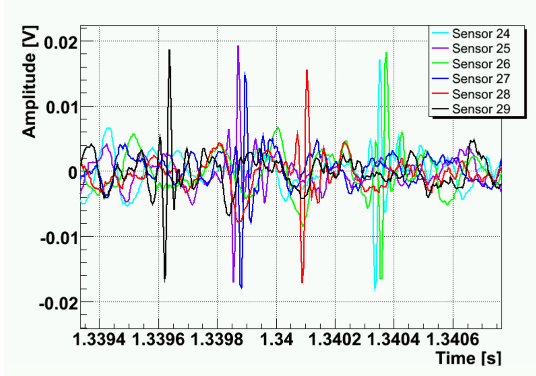
Results from AMADEUS

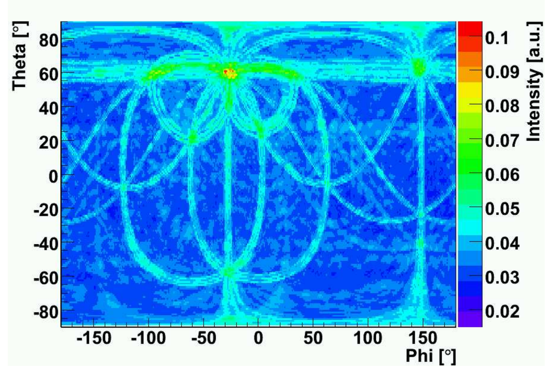
The signals from the pingers of the ANTARES positioning system are also recorded by the AMADEUS system and are used to reconstruct the positions of the acoustic sensors within the ANTARES detector to investigate the precision achievable with the positioning system described above. The topmost histogram on the right shows the statistical fluctuations for distance measurements by the reconstructed distances between the fixed sensors in the Acoustic Modules as shown in the sketch right of it. The spread is in the order of a few centimetres, indicating the achievable precision.

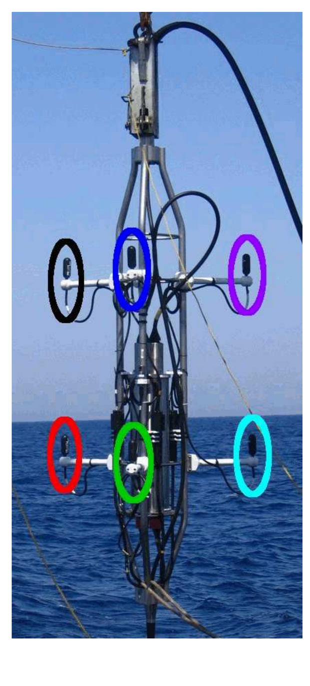
With six hydrophones a single AMADEUS storey can be used to determine the direction of sound sources. The histogram to the right shows the signal versus time from a dolphin click recieved by the six hydrophones - indicated on the rightmost picture of Storey two of the IL by the line color. The graphic to the right below shows the result of a beam-forming algorithm applied to the data. The maximum, at theta=59 degrees and phi=-29 degrees indicates the signal arrival direction.











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