The ANTARES neutrino telescope

Ulf Fritsch[1]
on behalf of the Antares Collaboration

http://antares.in2p3.fr

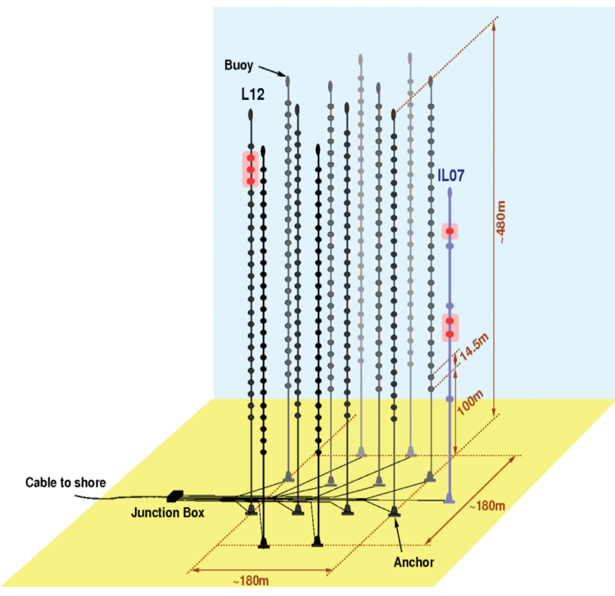
[1]Erlangen Centre for Astroparticle Physics, Erwin-Rommel-Str. 1, 91058 Erlangen, Germany
ulf.fritsch@physik.uni-erlangen.de

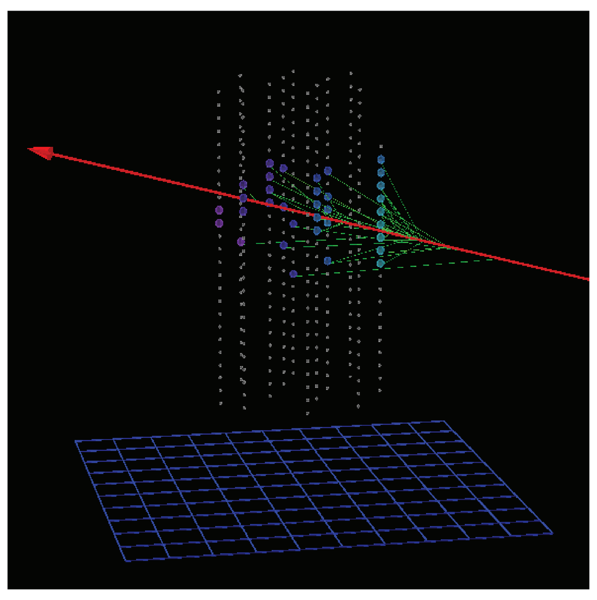
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

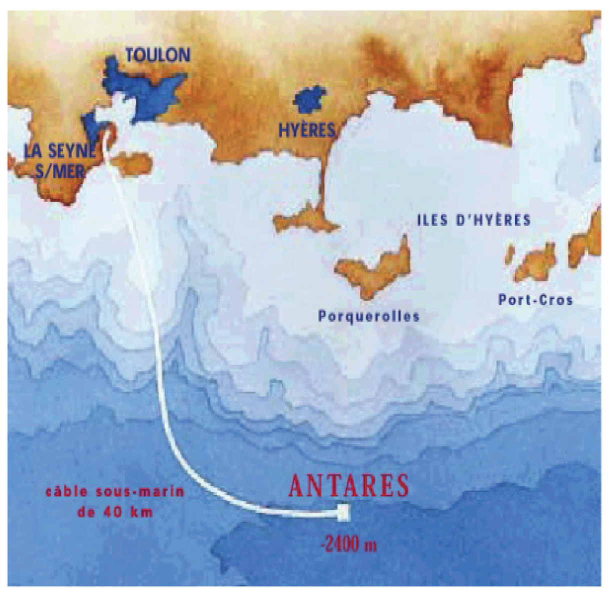
The ANTARES deep-sea neutrino telescope currently is the largest neutrino detector in the Northern Hemisphere. The instrument consists of a three-dimensional array of 885 photomultiplier tubes, arranged in 12 lines anchored at a depth of 2475 m in the Mediterranean Sea, 40 km offshore from Toulon (France). An additional instrumented line is used for environmental monitoring and for R&D towards acoustic neutrino detection. The photomultiplier tubes detect the Cherenkov radiation of charged secondary particles produced by high energy neutrinos interacting in or around the detector. Charged-current interactions of muon neutrinos is the reaction channel of central interest. The trajectories of the resulting muons are reconstructed with high precision, indicating the direction of the incoming neutrinos. ANTARES was completed in May 2008, and has been operated in setups of 5 and then 10 lines for more than a year.

bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

The ANTARES neutrino telescope







The ANTARES neutrino telescope [1] detects the Cherenkov light induced by charged particles produced in neutrino reactions. Its main goal is to reveal cosmic neutrino sources. The detector consists of 885 photomultipliers arranged as triplets on 12 detection strings, which are anchored on the sea-bed and held upright by submersed buoys. A 42 km long cable connects the telescope to the shore station where the incoming data is filtered and archived. The instrument is equipped with several calibration and monitoring devices. In addition to the optical part, a test setup of hydrophones allows to study aspects of envisaged future acoustic neutrino detection. The illustration on the left-hand side is an *schematic view of the detector.* The picture in the middle shows an online reconstructed *neutrino candidate event*. On the right-hand side the ANTARES *site* near Toulon can be seen.

The key element of ANTARES is the *storey*. It is equipped with three 10-inch photo-multipliers (PMTs) from Hamamatsu (R7081-20 type) looking downward at 45 degrees from the vertical and housed in pressure-resistant glass spheres. Each storey is controlled by a Local Control Module enclosed in a titanium cylinder at its center. As can be seen in the lower picture the storey frame also carries LED Optical Beacons, which are light sources for calibration.

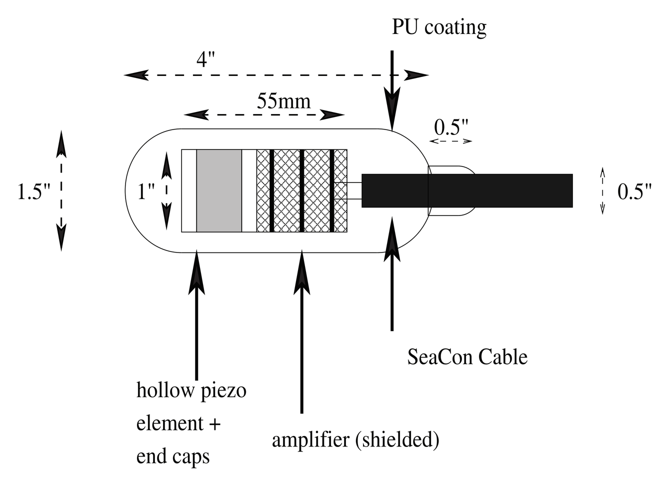
The ANTARES storey carrying three optical modules and the electronics container.

The Analogue Ring Sampler (ARS) - an ASIC - has been developed to perform the complex front-end operations [2]. It records the time when a PMT signal crosses a given threshold, typically 0.3 p.e., and the integrated signal charge. A 20 MHz reference clock is used to timestamp the signals. A Time to Voltage Converter (TVC) is used for high-resolution time measurements between clock pulses. An integrator followed by an Analogue to Voltage Converter (AVC) measures the signal charge. The chip also samples the PMT anode signal continuously at a tunable frequency of up to 1 GHz and holds the analogue information in 128 switched capacitors when a threshold level is crossed. All information is digitized by means of two integrated 8-bit ADCs. Optionally the dynamic range may be increased by sampling the signal from the last dynode. The ARS is capable of discriminating between simple pulses due to single photoelectrons (SPE) from more complex waveforms. The criteria used to discriminate between the two classes are based on the amplitude of the signal, the time above threshold and the occurrence of multiple peaks within a time gate. Only the charge and time information is recorded for SPE events, while a full waveform can be recorded for more complex events. The ARS chips are mounted on a motherboard to serve the optical modules. Two ARS chips, in a "token ring" configuration, perform the charge and time information processing of a single PMT in order to reduce dead time. The settings of each individual chip can be remotely configured from the shore. Special runs reading the electronics at random times allow for measuring the corresponding pedestal value of the AVC channel.

Acoustic neutrino detection

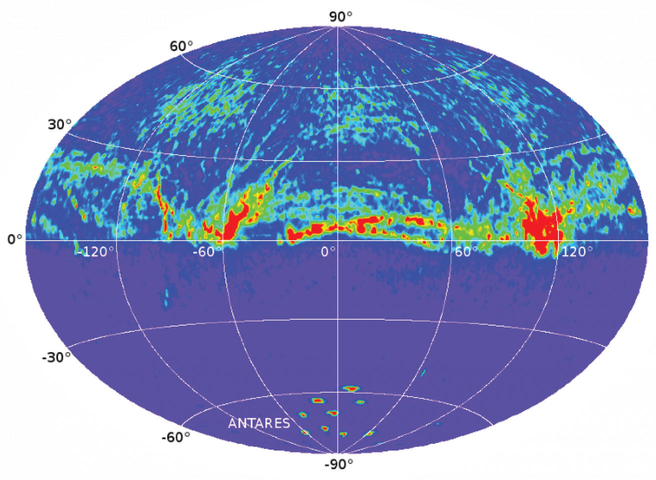
The main goal of the AMADEUS (Antares Modules for Acoustic DEtection Under the Sea) project is to conclude on the feasibility of acoustic UHE (>10^{18} eV) neutrino detection in large, sea-based acoustic detector arrays. Besides the optical part ANTARES is also equipped with six *Acoustic Storeys* where the three PMTs of each storey have been replaced by six acoustic sensors each, based on *piezo-ceramics.* The sensors are mounted directly on the storey frame or have been glued inside three glass spheres (so called acoustic modules). The distances between sensors in the AMADEUS setup vary between 1 m and 350 m. After amplification by the preamplifier and the main amplifier at the storey, the acoustic signals have a sensitivity of approx. 0.5V/Pa for default operation. They are filtered with an 1-100 kHz bandpass filter and digitised at 250 kSamples per second, 16bits, over the input voltage range from -2 to +2 V. All data is sent to an onshore server cluster for filtering and storing.

Acoustic storeys: six hydrophones (left). Three acoustic modules with 6 sensors (right).

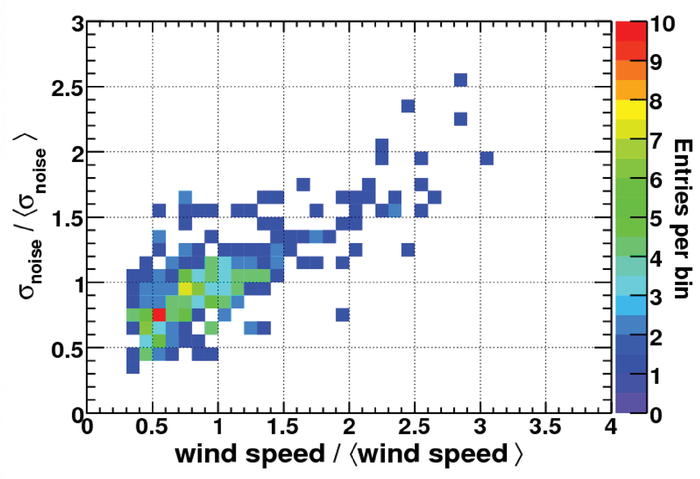


Technical drawing of the hydrophone.

Position reconstruction of acoustic point-like sources is implemented by reconstructing their arrival directions from individual storeys, taking advantage of these local sensor groups. A *skymap* plot of transient signals in the vicinity of ANTARES can be seen below. The upper hemisphere is dominated of anthropogenic origin (e.g. shipping noise) and by those generated from fauna (e.g. dolphin clicks). In the lower hemisphere the pattern of ANTARES originating from the acoustic positioning system is clearly visible. Not only transient sources but also the *ambient noise* has been studied: On the right the correlation between the ambient noise and the surface wind speed is shown.

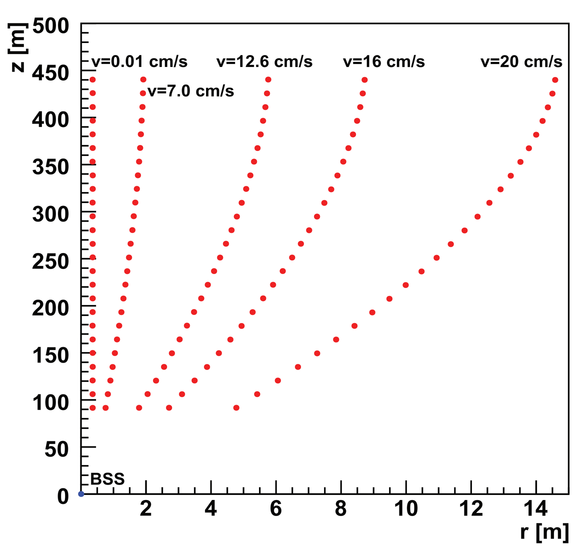


Mapping of the arrival directions of transient acoustic signals, sampled over the period of about one month.



Correlation between the ambient noise at the ANTARES site and the wind speed measured 30 km away at Cap Cepet.

Calibration and first physics results



Storey positions in the r-z-plane after position reconstruction at different sea current velocities.

Position calibration

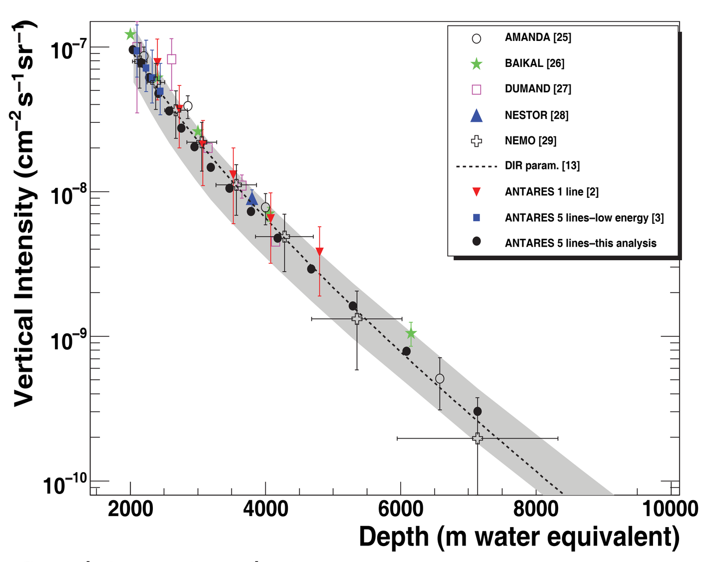
As the ANTARES detector has no rigid structure and is exposed to sea currents of several cm/s (typically 3-5 cm/s) the OMs are displaced meters away from the straight vertical configuration. The interlink electro-optical cable connecting adjacent storeys allows them to rotate around the string axis. Therefore a system of real-time position and orientation calibration is needed. For the relative detector positioning two main systems are used. Five receiver hydrophones [3] with piezo-ceramics inside are installed on five storeys of each line. Further an emitter/receiver module is located at the anchor of each string. By measuring travel times of acoustic waves and by a subsequent triangulation the positions are obtained within 5 cm accuracy. As the sound velocity is a function of pressure, salinity and temperature, ANTARES is equipped with a set of sound velocimeters to provide the necessary information for the acoustic positioning system. Together with this acoustic information the tilt and heading of each ANTARES storey are monitored every two minutes. A tiltmeter and a compass measuring two B-field components are installed in each LCM. The sensors to obtain the storey heading have been calibrated prior to deployment and are regularly calibrated in-situ. Using a mechanical model derived from drag and buoyancy forces, the shape of the line is fitted to the data of hydrophones, tiltmeters and compasses.

Time calibration

Concerning the time calibration we distinguish between absolute and relative time resolution. The requirement on absolute temporal resolution has the main purpose of correlating detected signals with astrophysical transient events (GRBs, AGN flares, SGR bursts). In this case the precision needed to measure the time of each event with respect to the universal time (to establish correlations) is of the order of milliseconds. The absolute timestamping is made by interfacing the shore station master clock and a card receiving the GPS time (100 ns accuracy with respect to UTC). The relative time resolution refers to the individual time offsets in the photon detection due to differences on the transit times and the front-end electronics among PMTs. The main uncertainties come from the transit time spread of the signal in the PMTs (1.3 ns RMS) and the optical properties of the sea water (light scattering and chromatic dispersion), amounting to 1.5 ns at 40 m distance. Therefore, all electronics and calibration system are required to contribute less than 0.5 ns to the relative time resolution in order to guarantee the required angular resolution of 0.3 degrees.

The in-situ calibration of the time offsets is performed with a system of light emitters called Optical Beacons [4]. This system comprises two kinds of devices: 13 LED Optical Beacons and one Laser Beacon. LED Beacons are conceived to calibrate the relative time offsets among OMs within each line. Moreover they can also be used for other purposes such as measuring and monitoring optical water properties, or studying possible PMT efficiency loss. The Laser Beacon is being used for interline calibration and cross-checking of the time offsets of the lower floors.

One of 36 LED Optical Beacons distributed across the dector volume.



Depth intensity relation.

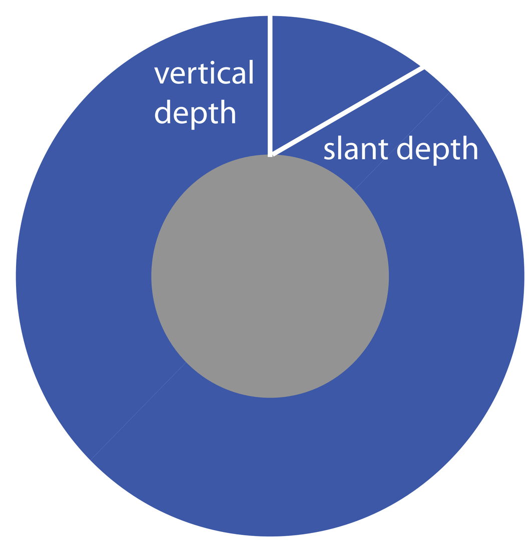


Illustration of slant depth.

The plot above shows the *depth-intensity relation* (DIR) for atmospheric muons obtained by the analysis of data of the first five installed lines [6]. DIR means the vertical muon flux versus depth. The number of moun tracks in an angular bin around a given direction w is measured. The intensity I(H) of the flux at depth H is obtained by multiplying by the corresponding mean multiplicity for muon bundles and dividing by the effectiv area, the live time and the solid angle. From this intersity the vertical intensity as function of the effectiv slant depth h = H/cos(w) is obtained by

$$I(w=0,h) = I(w,H)\ |\cos(w)|\ c(w).$$

The factor c(w) takes into account the curvature of the Earth. Also shown are the previous results published by ANTARES and other experiments. All measurements agree within the systematic uncertainties with the model predictions.

Conclusions and outlook

Since the deployment of the first line in 2006, data taking has proceeded continuously. All systems for in-situ calibration have been proven to work within specifications and the achievable accuracy for the detector calibration reaches the design goals. Several physics analyses such as the above presented DIR demonstrate the potential of the ANTARES neutrino telescope.

[1] J. Carr for the ANTARES collaboration, J. Phys. Conf. Ser. 136 (2008) 022047.
[2] F. Feinstein, "The analog ring sampler: A front-end chip for ANTARES, Nuc. Instrum. Meth., vol A504, pp. 258, 2003.
[3] V. Niess, "Underwater acoustic positioning in ANTARES", Proceedings of 29th ICRC, vol.5, 2005.
[4] ANTARES Coll., "The ANTARES Optical Beacon System", M. Ageron et al., astro-ph/0703355.
[5] R. Lahmann et al., NIMA 604 1-2 (Sup 1), 158, 2009
[6] ANTARES Coll., Zenith distirbution and flux of atmospheric muons measured with the 5-line ANTARES detector", paper in preparation.