PROCEEDINGS OF SCIENCE

Status and development of KM3NeT/ARCA

Giorgio Riccobene∗†
Laboratori nazionali del Sud - INFN
E-mail: riccobene@lns.infn.it

The detection of a high energy neutrino flux of cosmic origin claimed by IceCube, and the results from ANTARES, have boosted the quest for building a km^3-sized high energy neutrino telescope in the Mediterranean Sea. A hundred kilometers off the harbour of Portopalo di Capo Passero (Sicily) the deep-sea infrastructure to host the KM3NeT/ARCA detector is under construction. The first two Detection Units of the telescope are collecting and transmitting data, providing valuable information to validate the detector technology and the water column properties. The Phase 1 of ARCA foresees the deployment of 24 Detection Units. In this stage the detector active volume will be a factor 10 larger than ANTARES. The Phase 2 of ARCA foresees the installation of 2 blocks of 115 Detection Units (230 in total) reaching the size of 1 km^3, complementing and competing with IceCube in the search for astrophysical neutrino fluxes. A further expansion to a multi km^3-sized detector is also envisaged.

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∗Speaker.
†on behalf of the KM3NeT Collaboration.

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1. Status and developement of the KM3NeT/ARCA detector

The discovery of a high-energy cosmic neutrino flux originating outside the Solar System by the IceCube Collaboration [1] has paved the way to high-energy neutrino astronomy. The KM3NeT collaboration (http://www.km3net.org) has started the deployment of the ARCA (Astroparticle Research using Cosmics in the Abyss) neutrino telescope in the Mediterranean Sea, 100 km off the cost of Sicily at 3450 m water depth. KM3NeT/ARCA [2] aims larger sky coverage for upgoing events and better angular resolution with respect to IceCube, exploiting the optical characteristics of deep seawater and the use of a sparse array of about four thousand of multi-photomultiplier (PMT) Digital Optical Modules (DOMs). Located in the Northern Hemisphere of the Earth, ARCA will optimally look for neutrinos from point-like Galactic sources. The KM3NeT collaboration has also extended the physics case to the measurement of the neutrino mass hierarchy using atmospheric neutrinos, by means of a denser Megaton-scale detector, called ORCA under construction close to the ANTARES marine site (see talks of A. Heijboer and A. Margiotta at this conference). Both ARCA and ORCA will be built with the same technology and managed centrally by the Collaboration.

A DOM, the basic unit of the detector, is made of 31 PMTs (3" diameter) and it is a fully independent module, equipped with additional sensors for detector calibration, read-out and data transmission systems. Each DOM is a node of an ethernet network, managed from shore. For each PMT, the photon hit time and hit amplitude are sent to shore for analysis. The total photo-cathode area of a single DOM is about three times larger than the one of an ANTARES optical module, and it has an almost uniform angular coverage with respect to the solid angle. Segmentation of the photocathode allows identification of multi-photon hits with high efficiency and purity. Eighteen DOMs are installed on a vertical structure called Detection Unit (DU). The DU is a 700 m high flexible slender string, anchored to the sea floor and kept vertical by buoys. A vertical electro-optical backbone is used to connect the DOMs to the base of the DU. The DU anchor contains an additional vessel, the DU base, hosting a logic board, the DU power and optical fiber distribution systems, and a hydrophone used for the acoustic positioning system. The position and orientation of each DOM is measured in situ using tilt-and-compass boards installed on each DOM and applying a distance triangulation procedure, based on an array of acoustic receivers mounted on each DOM and on the DU base and a geo-referenced long baseline of acoustic emitters anchored on the seafloor. In ARCA, an average horizontal distance of 90 m between the DUs, and a fixed vertical distance of 36 m between DOMs has been defined, to optimise detection of Galactic neutrino sources. In ORCA these figures are reduced, approximately, by a factor of about 4. For the deployment, the detection unit is wrapped on a spherical metallic frame with diameter of about 2 m which is deployed on the seabed. Once on the seabed, the DU is connected to the submarine cable network and it is unfurled. Connection and unfurling is operated via a submarine vehicle (ROV). After the unfurling, the DU reaches its vertical configuration. Batched deployment of four DUs in a single sea operation is planned. Each DU is connected to shore through a seabed network of electro-optical cables. Twelve DUs are connected to a Junction Box (JB) and the JBs are connected to the Cable Termination Frame, the submarine termination of the main electro-optical cable from shore (see Figure 1). The shore-end of the cable is located in the INFN laboratory, n the harbour of Portopalo di Capo Passero. The power feeding equipment, the detector control and data acquisition centre are installed in the shore laboratory, as well. The shore lab is connected to the outside world through a 1 Gbps dedicated optical fiber link provided by GARR-X (http://www.garrxprogress.it/). The seabed infrastructure is operational and the first two DUs, ARCA DU001 and ARCA DU002, deployed respectively in December 2014 and May 2015, are taking data.

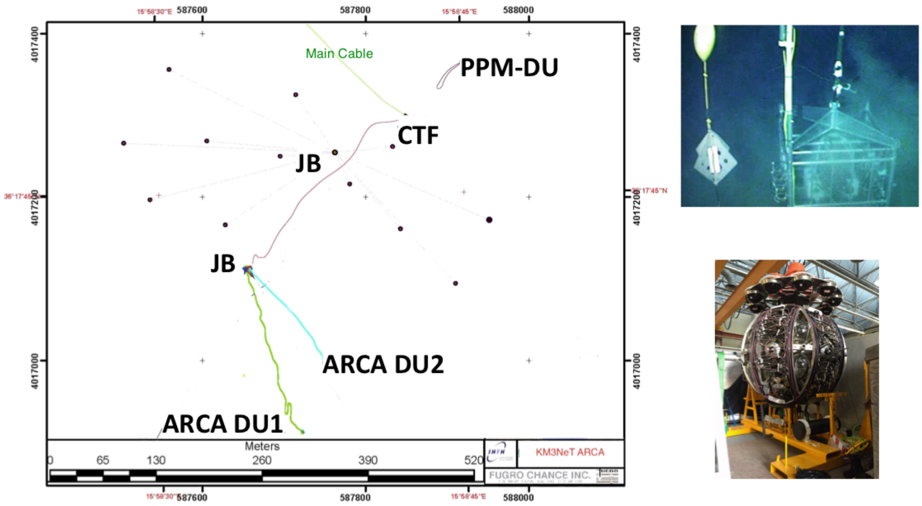

Figure 1: Left: the seabed network for ARCA Phase 1. Right top: a Junction Box on the seabed. Right bottom: ARCA DU2 ready for the deployment.

The first DOM prototype was deployed in 2013, attached to an ANTARES line. It provided a technological proof of concept for the multi-PMT optical module. Cherenkov light hits produced by atmospheric muons were clearly identified over the optical noise, using multi-fold time coincidences among PMTs: thanks to the DOM segmentation, and to the different PMT orientation, a clear "top-down" space-time sequence of hits is observed for high multiplicity events, associated, in agreement with simulations, to atmospheric muon tracks [3]. A DU prototype was deployed in 2014 in Capo Passero. It consisted of 3 DOMs assembled on a 160 m long string. On each DOM, atmospheric muon signals were clearly separated from the optical noise. The analysis of coincidences among DOMs allowed measurement of the muon flux as a function of the zenith angle [4]. The success of the protoypes paved the way to the construction of DOMs and DUs. Before the deployment, each DU is tested and calibrated. To perform time calibration of the detector, the time delays between each DOM and the base of the detection unit (synchronised with the detector master clock, dispatched from shore) are measured in a dark room, equipped with a laser source, also synchronised with the master clock. Time delays between all PMTs in each DOM are also determined measuring the average time of 2/3-fold coincidences produced by Cherenkov photons originated by decay electrons of ^{40}K present in the DOM glass housing. Time offsets measured on-shore are checked, monitored and, if necessary, re-tuned in situ, using the seawater ambient ^{40}K signals and measuring the time of flight of light pulses emitted by small LED beacons, installed on each DOM, received by PMTs of neighbour DOMs. Data from deployed DUs show that the differences between time calibration offsets measured on shore and in situ are smaller than 1 ns for each DOM. The PMT signal amplitude is equalised tuning the High Voltage (HV) of each tube in order to have a gain of 3×10^6. HV is tuned at several stages: in a dedicated setup before installation in the DOMs [5], then in the dark room during DU calibration, and eventually in situ, meausring the amplitude of single photon hits produced by ^{40}K. The study of 2/3-fold coincidences rate in PMTs of each DOM (dominated by ^{40}K density and seawater optical properties) indicates that the optical properties along the water column do not change with depth, as shown in Figure 2. Morevover the analysis of $\geq$10-fold coincidences rate (10 PMTs in a DOM, hit within 25 ns) shows an exponential decrease versus depth, correlated to the expected decrease of the atmospheric muon flux and, consequently, of the Cherenkov light signals.

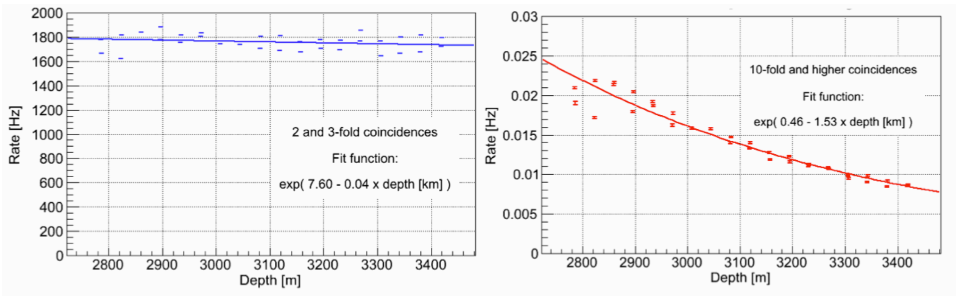

Figure 2: Left: Average coincidence rate vs. depth of DOM for 2/3-fold coincidence is dominated by ^{40}K signals and determined by seawater optical properties. Right: Multi-fold coincidence rate is dominated by Cherenkov light produced by downgoing muons.

KM3NeT/ARCA Phase 1 will be the most sensitive neutrino telescope in the Northern Hemisphere and it will be equivalent to about 10% of the IceCube detector. A detailed study of the response of ARCA Phase 2 to neutrino detection has been carried out using full Monte Carlo simulations [2] . Two different topologies of events can be identified in a neutrino telescope, depending on the neutrino interactions: track-like events and cascade-like events. The track-like events correspond to muons produced in the proximity of the detector. They are produced via Charge Current (CC) interactions of (anti)ν_μ and (anti)ν_τ, after decay of τ into μ. The cascade-like events have their vertex inside the active volume of the detector, through CC interactions of electron and tau (anti)ν and in Neutral Current interactions of neutrinos of all flavours. For track-like events at $E_\nu > 10$ TeV, the expected angular resolution is better than 0.2° and the energy resolution is 0.27 in $log E_\nu$. For cascade events ($E_\nu > 50$ TeV), after a geometrical cut of the outer layers of the detector, that decreases the fiducial volume to about 80% of the instrumented one, the expected angular resolution is about 2° and the energy resolution is 0.1 of E_ν. Due to its good angular resolution, KM3NeT/ARCA is a very promising instrument for the detection of point-like sources, and thnks to its location, expecially for the Galactic ones. The 5σ discovery potential as a function of the source declination for KM3NeT/ARCA Phase 2 is shown in Figure 3. It is also worth mentioning that real-time data from optical and acoustic sensors are of great interest for the Sea and Earth Science community, such as the EMSO ERIC (http://www.emso-eu.org), that also profits from the KM3NeT facilities to install a distributed network of sensors in the Mediterranean Sea.

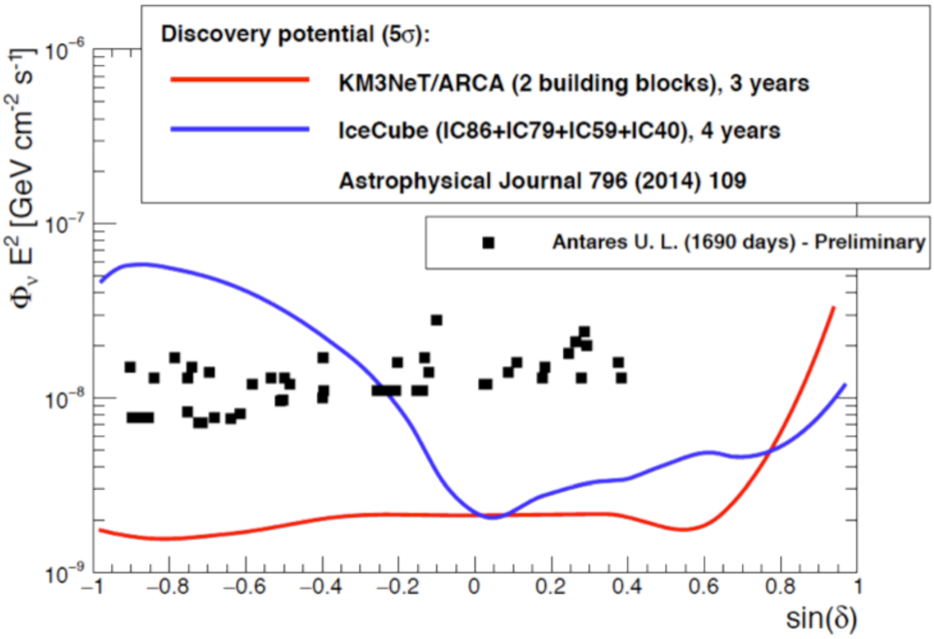

Figure 3: Five σ discovery potential as a function of the source declination for ARCA Phase 2 for one neutrino flavour, point-like sources with a spectrum $\propto E^{-2}$ and 3 years of data-taking (red line). The discovery potential for the IceCube detector (blue line), and upper limits on selected sources for ANTARES (blue squares) are shown for comparison. See [2] and reference therein.

References

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