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The Antares neutrino detector

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Summary. — The Antares neutrino telescope, operating at 2.5 km depth in the Mediterranean Sea, 40 km off the Toulon shore, represents the worlds largest operational underwater neutrino telescope, optimised for the detection of Cherenkov light produced by neutrino-induced muons. The neutrinos momentum is transferred to the muons allowing for reconstruction of the direction of the neutrino. The main goal of Antares is the search of high-energy neutrinos from astrophysical point or transient sources. Antares has been taking data in its full 12 lines configuration since May 2008: in these Proceedings the description of the detector and its performances will be presented while first preliminary results on neutrino events will be discussed.

PACS 26.30.Jk – Weak interaction and neutrino induced processes, galactic radioactivity.
PACS 95.55.Vj – Neutrino, muon, pion and other elementary particle detectors; cosmic ray detectors.
PACS 98.70.Sa – Cosmic rays (including sources, origin, acceleration, and interactions).

1. – The Detector

In 1996 the ANTARES Collaboration started R&D activities towards the construction of a neutrino telescope in the deep sea. The first operations were made with autonomous mooring lines to measure the properties of the water and environment at the ANTARES site. In 2001 the construction of the actual detector started with the deployment of a new cable between the site and the shore station in La Seyne-sur-Mer while in Nov. 2002 the end of the cable was connected to the junction box (JB) where the fibre optics for the data and the conductor for the power supply are slit to the lines. After the experience made with a prototype line, the first detection line was deployed in February 2006 while the apparatus reached its complete configuration with the last two lines deployed in early 2008 and connected on 29 May 2008 [1]. These lines (also called strings) of 480 metres height are fixed to the seabed by anchors and straightened by buoys as shown in fig. 1. Each string holds 25 triplets (storeys) of 10-inch photomultipliers in pressure resistant

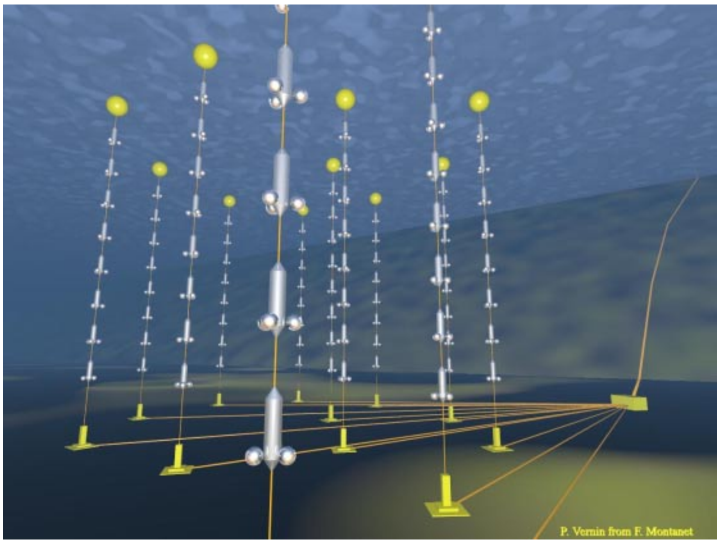

Fig. 1. – Artists impression of the neutrino telescope, showing the detector lines, the seabed interlinks cables, the junction box and the MEOC cable to the shore. For clarity, the number of storeys per line is reduced and items are not drawn to scale.

glass spheres [2] (Optical Modules,OM), vertically spaced by 14.5 m. An additional Instrumentation Line (IL) is equipped with environment monitoring devices including hydrophones for R&D on neutrino acoustic detection. The PMT signal is digitized by an analogue ring sampler (ARS) and sent through optical fibres to the bottom of the line where it is multiplexed by DWDM. The fibres of a line pass through the JB, where the lines are connected to the 40 kilometer electro-optical submarine cable going to the shore. At the shore station, a dedicated computer farm runs various trigger softwares [3] to select physics events. The knowledge of the hit position, arrival time and charge allows the reconstruction of the muon trajectory thus giving information on the parent neutrino.

2. – The performances

The aim of the experiment is to detect high-energy cosmic neutrinos and to identify the source of emission by reconstructing the muon tracks using the position of the PMTs and the arrival time of the Cherenkov photons [4]. To comply with the expected angular resolution both timing and positioning *in situ* calibration are needed. In fact, due to the sea current, horizontal displacements in the lines are possible (see fig. 2) and to take into account this effect, a redundant positioning system is used. The instantaneous shape of each line is determined using tiltmeters and compasses on each storey and 5 hydrophones which communicate with fixed emitters on the sea floor to obtain an acoustic triangulation. This information allows the shape of the lines to be reconstructed with a position accuracy better than 10 cm. The time calibration of the detector is performed on-shore to check the individual time offsets and calibrate the electronics before the deployment in the sea. Then the clock system enables the measurement of the signal time delay from the clock board located on each OM to the shore station. In addition to

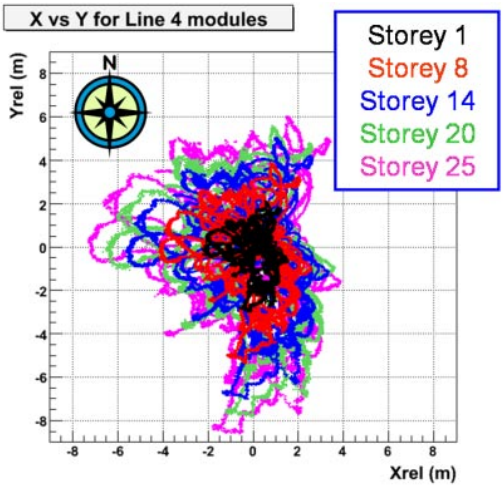

Fig. 2. – Displacement in the horizontal plane on 5 storeys in line1.

this a dedicated Optical Beacons system, which consist of LED and laser sources of pulsed light with a well-known emission time, is used for *in situ* timing calibration. Finally the Cherenkov light from the ^{40}K decays in water allows an independent check of the time differences among PMTs in the same floor. These calibrations allow a position and timing resolution well within the designed performances and according to simulation studies, the expected angular resolution of the ANTARES detector is better than 0.3 degree for neutrino events with an energy above a few TeV. At lower energy the kinematic angle between the neutrino and the induced muon dominates. The detector energy threshold for reconstructed muons is approximately few GeV, the effective area increasing sharply with energy. Calculation of the effective area takes into account the background produced by bioluminescent organisms and Cherenkov photons from ^{40}K decay. These two light sources give a continuous background, which varies between 60 and 100 kHz. Peaks of biological activity can occasionally increase the counting rate up to the order of several MHz. Fortunately the hits produced by ^{40}K decays and bioluminescence are mostly uncorrelated and can be easily discarded by the trigger algorithm.

3. – The results

The main goal of the experiment is to identify distant astronomic objects which would then appear as a concentration of events from a particular location in the sky. The downwards orientation of the PMT in the detector allows to concentrate on upward-going events where the neutrino has traversed the Earth. However the most abundant registered events correspond to the high-energy downward-going atmospheric muons with a flux of about six orders of magnitude larger with respect to the atmospheric upward neutrino flux. These atmospheric muons represent a dangerous background for track reconstruction as their Cherenkov light can mimic fake upward-going tracks. On the other hand, they are a useful tool to test offline analysis software, to check the understanding of the detector and to estimate systematic uncertainties. Figure 3 gives an example of one recorded neutrino event. Figure 4 shows the angular distribution of reconstructed events

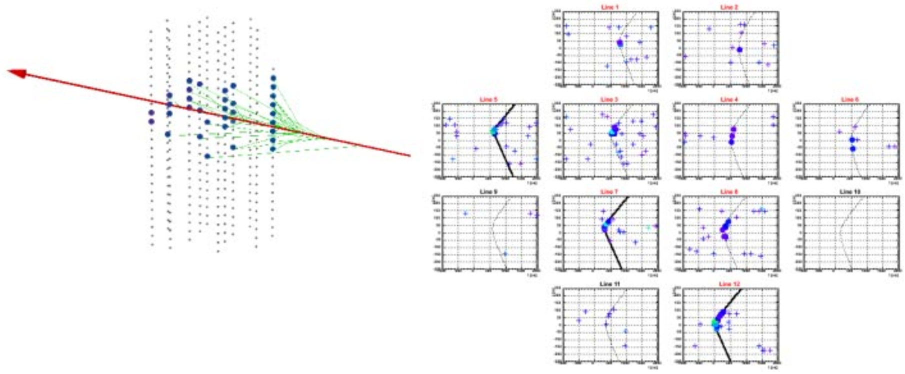

Fig. 3. – Example of a neutrino event. On the left a series of 2D plots, one for each detector line, showing on the y-axis the vertical position of the hit OM and on the x-axis the time of arrival of the light at the OM.

recorded in data taken in 2008 for the multi-line events in comparison to simulation. The data were taken using a 9,10 and 12 line detector for an effective time of 173 days. A combined theoretical and systematic uncertainty of 30 (50)% on the expected number of neutrinos (muons) accounts for uncertainties in the primary flux and interaction model, and in the detector acceptance. The arrival directions of the upward-going events are consistent with being produced by cosmic ray interactions in the atmosphere of the Earth. In addition to the search of pointlike sources, various analyses are underway: dark matter search by looking for an excess of neutrinos from celestial bodies like the Sun, diffuse flux looking at possible excess of neutrino events from the galactic plane, detection of exotics particles like monopoles or nuclearites, neutrino oscillations.

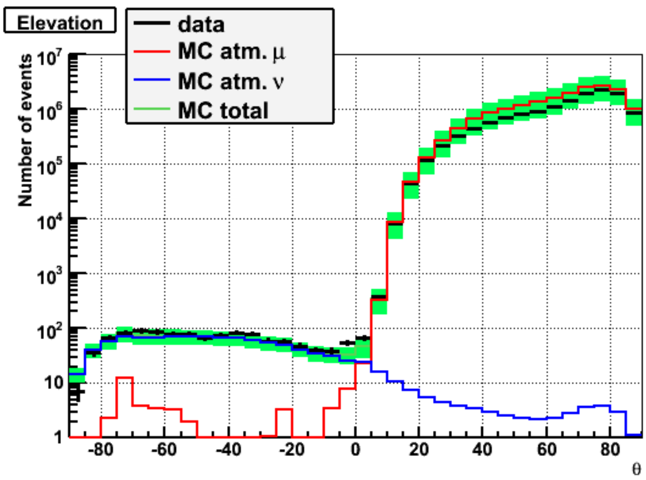

Fig. 4. – Distribution of reconstructed tracks as a function of θ, where θ is the angle of the track to the horizontal. Values of negative θ correspond to upward-going tracks and are dominated by neutrino events. The black points are the data and the coloured histograms the results of Monte Carlo simulations.

4. – Conclusions

Antares is the largest neutrino telescope in the Northern hemisphere taking data. Since the deployment of the first five lines of the detector, the Antares Collaboration has been routinely detecting muons and atmospheric neutrinos. Elements of the detector have worked reliably for more than four years already and much data both for neutrino astronomy and environmental research has been collected, the number of detected neutrinos and their zenith and azimuth angle distributions being in good agreement with simulations. This achievement demonstrates the feasibility of long-term permanent scientific observatories in the deep sea and encourages the development of underwater neutrino detectors of larger volumes [5].

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