# STATUS REPORT OF THE ANTARES PROJECT

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Antares is a high energy neutrino telescope which is being installed in the Mediterranean off shore of Toulon (France) at 2500 metre depth. The detector design and the expected performances are reported. The results of prototype tests and the development of the construction are described.

## 1. Introduction

The detection of high energy cosmic neutrinos will complete the multi-messenger astronomy performed up to now with γ-rays and with cosmic rays.

Fluxes of high energy neutrinos are expected from sources like supernova remnants [1], micro-quasars [2], active galactic nuclei [3] or gamma ray bursters [4]. Protons are accelerated in these sources up to ultra high energies. Hadrons are produced in the interaction of those protons with low energy photons. Cascades induced by the photo-produced hadrons lead to a flux of very high energy neutrinos.

In a top-down scenario, the decay of topological defects (TD), like monopoles, cosmic strings, cosmic walls, will also produce high energy neutrino fluxes, without any need of particle acceleration, when they annihilate. The resulting energy spectrum of these neutrinos is related to the mass of the TD.

Another source of neutrino flux could be the annihilation of the lightest super-symmetric particles (neutralinos) trapped in celestial bodies like the Sun or the Galactic Centre by the combined effect of elastic scattering and gravitation.

If the very low interaction cross section of the neutrino with matter is an advantage for exploring remote regions of the universe, it constitutes a drawback for the detection. Considering the expected fluxes a huge detector is necessary to detect a few neutrino events per year. It is commonly assumed that the required detector will extend over 1 $km^3$. Moreover, the detector must be protected against the intense flux of cosmic rays.

Both requirements may be achieved by installing a network of light captors in the deep sea or ice capable to detect the Cherenkov light emitted by upward-going muons produced by charge current interaction of high energy muon neutrinos. In this way the high energy cosmic ray flux will be strongly attenuated by the water (ice) depth. Moreover, only neutrinos are capable to cross the Earth to produce a signal of upward-going muons.

## 2. The detector design

The Antares collaboration comprises 180 physicists, astronomers and sea science experts from France, Germany, Italy, Netherlands, Russia, Spain and United Kingdom. The telescope is a network of 900 optical modules to be installed at 2500 m depth in the Mediterranean Sea, off shore of Toulon (France). The location (42°50'N, 6°10'E) allows annual sky coverage of 3.5π sr with an instantaneous common view of 0.5π sr and annual common view of 1.5π sr with Amanda (South Pole). Neutrinos coming from the Galactic Centre are directed upward 2/3 of time at the Antares location.

Intense sea operations have shown that the Antares site is well suited for the detection of

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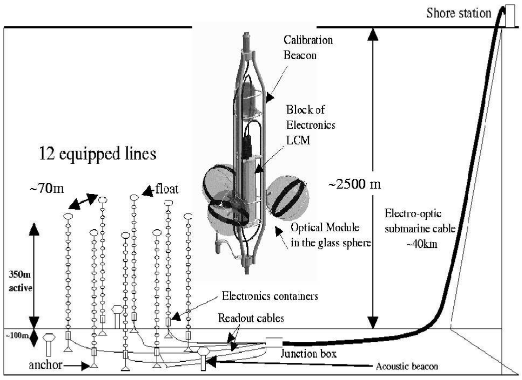


Figure 1. Schematic view of the Antares detector.

Cherenkov light. The sea current ranges between 5 and 15 m/s. The absorption length at 470 nm is 60 m and the effective light scattering (scattering length divided by 1-<cosθ>, where θ is the scattering angle), at the same wavelength, is 300 m. The light background for a 1/3 pe measured by a 10” phototube is composed by a constant 60 kHz counting rate, which is interpreted as a superposition of Cherenkov light emitted by electrons produced in β–decay of $^{40}K$ (13 Bq/litre) present in sea water and by a constant emission of light by bacteria. Short (few seconds) bursts of higher counting rates (reaching few MHz) are observed with variable frequency. It has been estimated that the dead-time introduced by these bursts is of the order of 5%.

The loss of transparency due to bio-fouling for the optical module has been measured to be less than 1.5% in one year.

Figure 1 gives a schematic view of the detector. Twelve lines arranged at distances ranging from 60 to 75 m will support 25 storeys separated vertically by 14.50 m. Each storey is equipped with 3 optical modules (OM), consisting of a 17” pressure resistant glass sphere housing a 10” Hamamatsu R7081-20 14 stage photomultiplier, an electronics titanium container and calibration devices. The axis of the photocathode looks downward at 45° from the vertical. The azimuth angles of the three OMs of the same storey are 120° apart from their neighbour. The lowest storey of each line is 100 m above the seabed. Each line is anchored to the seabed and tightened by buoys. The total length of each line is 450 m.

All lines move due to the water current. Therefore, the position of each OM is continuously monitored by using a long baseline acoustic beacon network, compasses and tilt-metres. The positioning accuracy is estimated to 10 cm.

## 3. Expected performances

The figure of merit to express the sensitivity of a detector is the effective area which can be defined as the ratio of the detected event rate to the flux.

In the case of Antares the estimate effective area for muon neutrinos is an increasing function of the neutrino energy. Typical values are [5] $2\times10^{-3}$ $m^2$ for neutrinos of 1 TeV requiring an estimated pointing accuracy of 0.3°, 3 $m^2$ at 100 TeV. Above 10 PeV it saturates at about 50 $m^2$ because the Earth has become opaque for neutrinos.

Figure 2 shows the median angle between the simulated neutrino direction and the

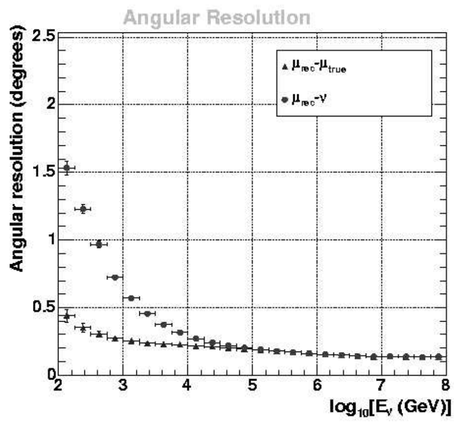


Figure 2. Variations with the neutrino energy of the median of the angle between the direction of the reconstructed muon and the generated parent neutrino (upper distribution) and between the reconstructed muon and the generated muon at the production point (lower distribution).

reconstructed muon direction. This distribution has been obtained by adding a realistic light background to the simulated event and by simulating the light scattering too. The distribution of the median angle between the reconstructed muon direction and the muon direction at the production point is also plotted in this figure for comparison. Above 100 TeV, the angular resolution becomes less than 0.2°. For lower energies the angular error is dominated by the angle between the parent neutrino and the produced muon.

However, even for energies around 1 TeV the angular resolution is better than 1°. This very good pointing power will allow the selection of only a small fraction of atmospheric neutrino background event, in one year running time, in the direction of any potential source. This means that few events will be enough to claim the evidence of a signal, even if not previously identified as a gamma-ray source.

Very far regions of the Universe could contribute to a high energy diffuse neutrino flux with an energy spectrum harder (differential spectral index ≈ 2) than the energy spectrum of atmospheric neutrinos (≈ 3.7). The unique signature of this flux will be the presence of an excess of high energy neutrinos. In the high energy regime the muon energy loss per length unit is proportional to the energy. The energy losses are due to radiative effects leading to electron and positron productions, which emit additional Cherenkov light. Therefore, the higher the muon energy, the higher the emitted light quantity is. This makes the recorded light quantity an estimator of the detected muon energy and, thus, of the parent neutrino. Analyses of simulated events show that between 50 GeV and 10 TeV the ratio of the reconstructed muon energy to the simulated energy is between 0.3 and 3. For energies above 100 TeV this ratio is between 0.5 and 2. This allows the definition of selection criteria suppressing low energy muons, mainly due to atmospheric neutrinos interactions. Selected events are composed of a clean sample of cosmic neutrinos. The Antares detector will be capable to constrain models predicting muon neutrino fluxes $d\Phi/dE \geq 5\times10^{-8}E^{-2}\ \mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$ in 3 years of data acquisition [6].

## 4. Prototype results

A test line equipped with 7 OMs has been deployed in November 1999. Muon hits have been recorded and tracks have been reconstructed. Figure 3 shows the nadir angle of the direction of the reconstructed muon. The comparison of the distributions of the reconstructed muons in real data and in simulated data shows a good agreement.

In 2003 the collaboration has deployed a prototype line with 5 storeys and a simplified version of the instrumented line. The aim of this operation was to test the capability of performing a precise positioning, of connecting the devices to the junction box, of checking the correct data transmission of a complex system and of controlling and handling the detector

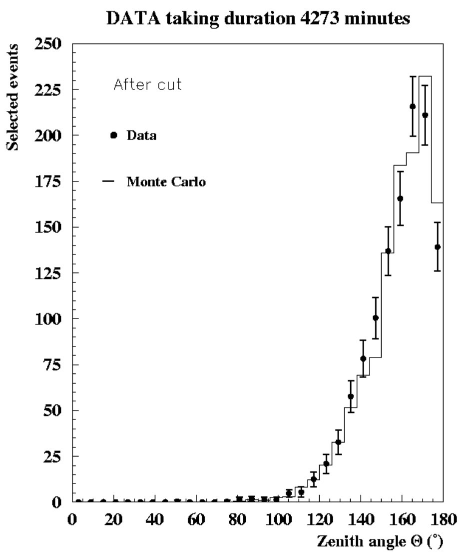


Figure 3. Nadir angle of the direction of reconstructed muons for events recorded with the prototype deployed in 1999. The distribution of simulated muons (histogram) has been normalised to the data.

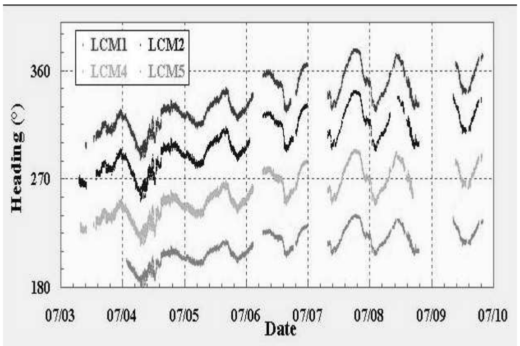


Figure 4. Variations of the headings of storeys 1, 2, 4 and 5 (from top to bottom) with time. The curves have been vertically shifted.

parameters from the shore. Most of these tests were successful. As an example Figure 4 shows the behaviour of the storey heading as a function of time over one week. This figure shows that all storeys slowly oscillate with amplitude of the order of 20° in phase with each other.

Nevertheless, some small failures occurred. Due to a not notified change of the cable specification by the manufacturer, the clock signal aimed to allow the 5 storey synchronisation was not transferred from the bottom of the line to the storeys. This failure prevented the time information at the level of the nanosecond and, therefore, no muons could be reconstructed.

Other tests have been successfully done. The counting rate of the OMs was continuously recorded by varying, from the shore, several parameters like the high voltage of the photomultipliers and the integration time window.

The project is now finishing its prototyping stage. The assembly of the lines has started. Their deployment will start in 2005 and the detector completion will be achieved in 2007.

## 5. Conclusions

The Antares detector will be devoted to the detection of high energy cosmic neutrinos, which is an essential stage to complete the multi-wavelength and multi-messenger astronomy. The location of the detector makes it complimentary with Amanda. Measurements performed have shown that the quality of water is good enough to make the project competitive.

Studies performed with prototypes have shown our capability in handling the detector from the shore. Some problems occurred during this prototyping stage are understood and corrected. The construction stage has started.

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