Status report of the ANTARES neutrino telescope

E. Carmona[a] (on behalf of the ANTARES Collaboration)

[a]IFIC - Instituto de Física Corpuscular
CSIC-Universitat de València. Apdo. 22085, E-46071, Valencia, Spain

The ANTARES Collaboration has demonstrated the feasibility of a large neutrino telescope located in the Mediterranean Sea. The project, mainly devoted to neutrino astronomy, indirect search of *Dark Matter* and the study of atmospheric neutrino oscillations, has accomplished its R&D phase and has moved into the construction stage. The results obtained after a 3-year R&D program, the expected performances of a 0.1 km^2 detector and the first prototype results are presented.

1. INTRODUCTION

Our knowledge of the Universe is based on the observations made by different instruments. It is a well known fact that the availability of new instruments sensitive to new spectral windows provides further discoveries and knowledge. High energy neutrinos are the last proposed probes to observe the Universe.

Some of the neutrino properties make them interesting for astronomical observations. Neutrinos do not have electric charge, so their direction is not deflected by magnetic fields and their small cross section allows them to escape from the production source and to travel large distances without interacting. Unfortunately, their small cross section makes also difficult their detection which requires a large volume detector.

The ANTARES Collaboration was created in 1996 with the goal of observing atmospheric and extraterrestrial neutrinos. In the project collaborate closely physicists, astronomers and marine technology experts. Since then, a R&D programme has been acomplished and the collaboration has moved into the construction of a 0.1 km^2 detector in the Mediterranean Sea [1].

1.1. Detection principle

The basic idea consists in using the Earth as a filter for the neutrinos. Earth is opaque for all known particles except neutrinos, so an up-going μ^- (μ^+) is a signature of a ν_μ ($\bar{\nu}_\mu$) interaction producing a muon (anti-muon) via a charged current. The other two kind of leptons are not as suitable as $\mu^\pm$ for being detected: $\tau^\pm$ decay too fast and e$^\pm$ are absorbed too quickly.

At high energies, the muon direction is closely correlated with the parent neutrino direction, also an important fraction of the initial neutrino energy is given to the muon. In an adequate optical medium, like water or ice, the muon can be detected by means of a three dimensional array of light sensors that detect the emission of Cherenkov light by the muon. This allows the determination of the muon trajectory and hence the neutrino trajectory.

One source of background are the atmospheric neutrinos produced in the atmospheric cascades initiated by cosmic rays. Another source of background are the down-going atmospheric muons also produced in atmospheric cascades. This flux is about 10 orders of magnitude higher than the up-going flux of muons produced by atmospheric neutrinos and forces the detector to be placed deep in water or ice.

2. ANTARES 0.1 km^2 PROJECT

The ANTARES Collaboration has selected a location in the Mediterranean Sea near the south coast of France (42° 50 N, 6° 10 E) at 2400 m depth, to deploy and operate a 0.1 km^2 effective area detector. This location allows a 3.5π coverage of the sky and the survey of the galactic centre. It also benefits from the nearby infrastructures and an easy acces to the detector.

2.1. Physics programme

Neutrinos are an ideal probe to study the high energy Universe ($E_\nu \geq 1$ TeV). They can be generated in the leptonic decay of mesons produced in cascades after the interaction of high energy protons or nuclei with matter or radiation. Several possible astronomical sources have been proposed [2], the *Active Galactic Nuclei* (AGN) and the *Gamma Ray Bursts* (GRB) being the most promising.

Dark matter could be studied if part of the missing mass is made of the lightest supersymmetric particle, the neutralino. The neutralinos would accumulate in the core of massive bodies like the Earth, the Sun or the Galactic Centre. There they would annihilate producing a constant flux of neutrinos with an angular distribution dependent on the neutralino mass.

Between 10 GeV and 100 GeV, the atmospheric neutrinos can allow the determination of the neutrino oscillation parameters in the range of the SuperKamiokande signal. The energy distribution of the up-going atmospheric neutrinos, in the 10-100 GeV range, should exhibit an oscillation pattern according to the SuperKamiokande value. This is an achievable goal for the neutrino telescopes where the measurement of the muon path length allows the estimation of the muon energy.

2.2. Detector design

The ANTARES 0.1 km^2 detector will be composed of 13 strings anchored at the sea bed and kept in vertical position by means of buoys at their upper end. Strings are 450 m high, but only the top 350 m are instrumented. In each line there are 30 storeys separated every 12 m with three optical modules per storey. The optical modules consist of a 10" diameter photomultiplier housed in a 17" pressure resistant sphere. The optical modules are looking downwards, at 135° from the vertical, in order to optimize the light collection of up-going muons.

As the strings can bend, a system of tiltmeters and acoustic positioning will monitor the string shape, allowing the determination of the optical modules position. All the strings are connected to a *Junction Box* by means of electro-optical cables. The *Junction Box* is connected to the shore station by a ~40 km standard deep sea communication cable. A schematic view of the detector can be seen in Figure 1.

The deployment of the major part of the detector is foreseen for 2002 and 2003.

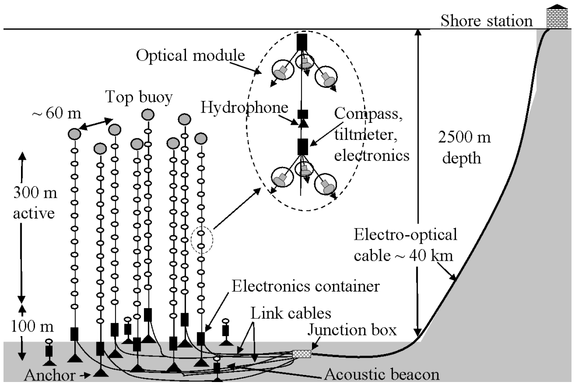

Figure 1. Schematic view of the 0.1 km^2 detector.

2.3. Expected performances

The 0.1 km^2 detector performance has been simulated using specially developed software packages [3]. Simulation shows that above 10 TeV an angular resolution better than 0.4° can be reached. Concerning energy estimation, the light output is correlated with the muon energy. That allows the determination of the particle energy within a factor 3 above 10 TeV.

Different models predict diffuse neutrino fluxes from AGN that could dominate over the atmospheric neutrino background above 10-100 TeV. Table 1 shows, for different models, the number of expected muons with reconstructed energy above a given threshold in a 0.1 km^2 detector.

Concerning oscillations, ANTARES is sensitive to deformations of the atmospheric neutrino spectrum due to oscillations assuming the SuperKamiokande parameters. Values of Δm^2 between 10^{-3} and 8×10^{-3} eV^2 and $\sin 2\theta > 0.6$ could be measured with a precision better than 33% after three years of data taking [4].

Table 1
Diffuse neutrino flux from AGN: the number of events per year with reconstructed muon energy greater than E_μ^{rec}

Model	**Minimum E_μ^{rec}** 10 TeV	100 TeV
Atmospheric		
ATM	68±13	0.8±0.1
Generic AGN models		
SDSS	251±12	134±10
NMB	217±9	64±4
Blazars		
PRO	34±2	21±2
MRLB	7.8±0.4	2.6±0.3

3. RESULTS FROM THE R&D STAGE

Several topics are crucial for the realization of a submarine neutrino telescope and need to be studied. Electronics, data read-out, power supply, connection to the shore, mechanical structure, deployment and recovery procedures, choice of the PMTs and study of the environmental parameters are some of them. An intense R&D programme has been performed by the ANTARES Collaboration on different topics.

During this phase it has been tested *in situ* the marine technologies to be used, with more than 30 deployments of autonomous lines. The connection of the detector to the shore with an electro-optical cable has also been tested. Likewise, the deployment, positioning and recovery of a full length prototype string have been tested and the main environmental parameters measured.

Most of the deployment tests have been devoted to the three kind of tests that measure the more relevant environmental parameters [5]. Each of the tests has its own dedicated autonomous line, the so called *Test 1*, *Test 2* and *Test 3* lines.

Optical backgrounds in deep sea water have been measured with the *Test 1* line. It has been found that the decay of radiactive isotopes, mainly ^{40}K, produces a rate varying from 20 to 47 kHz measured in a 8" photomultiplier tube. It has also been found that the emission of light bursts by different living organisms (bioluminicence) gives peak counting rates in the photomultipliers up to several MHz. However, when integrating the measured distributions of counting rates, the dead time induced on the electronics is less than 5%.

Concerning the biofouling and sedimentation on the optical modules, data from *Test 2* have shown that, at 90° from the vertical, the loss of transparency in an optical module is 1.5% after 8 months of immersion. Actually, this is an upper limit for the final detector, since the optical modules are looking downwards at 135° from the vertical.

Different systems have been used to measure the water optical properties in different versions of *Test 3*. The effective attenuation length for blue light (466 nm) was measured to be 41±1±1 m. Light scattering is measured with an isotropic light source and a fast 1" photomultiplier located 24 m or 44 m away. The measured time distributions (see Figure 2) exhibit a peak produced by direct photons plus a tail extending to larger delays produced by scattered photons. Data can be reproduced with an absorption length in the range 55-65 m and a scattering length at large angle greater than 200 m with a roughly isotropic scattering angle distribution.

4. PROTOTYPE RESULTS

In order to test the technology and the techniques to be used in the final detector strings, a demonstrator string was deployed in November 1999 [6]. The location of the string was different from the ANTARES site (37 km off the coast of Marseille) and shallower ($\sim$ 1000 m depth). However, it had the advantage of an easy acces to a suitable electro-optical cable. The design of the prototype string was not identical to the 0.1 km^2 detector strings, the string had 16 storeys separated by 14.6 m and two optical modules per storey. Only 7 of these optical modules were equipped with photomultiplier tubes (PMTs). The PMTs were vertically aligned and looking horizontally in order to optimize the detection of light from down-going atmospheric muons.

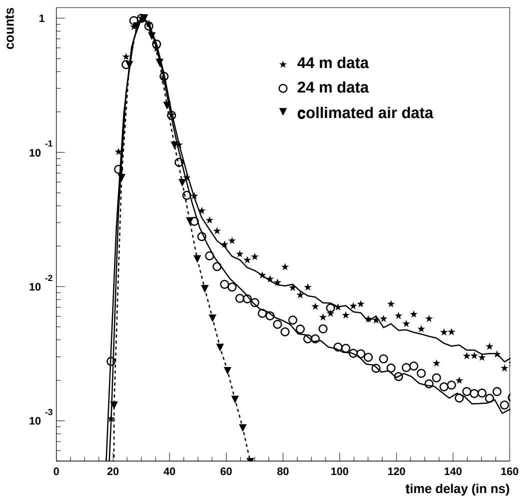

Figure 2. Distribution of photons arrival times for 24 m, 44 m and calibration in air. Monte-Carlo curves are also ploted.

The string shape was reconstructed with the data obtained from the tiltmeters and compasses. Data showed a very stable straight string, inclined 2.5° from the vertical. The twist and the tilt of the line were found to be very stable within 2° and 0.2° respectively, over one week. This allows the positioning of the optical modules on the string with an accuracy better than 10 cm in the horizontal plane and ~1 cm in the vertical plane.

The acoustic system was tested and also used for positioning by means of triangulation between the 3 rangemeters placed in the string and the 4 transponders distributed around the string. The relative distances between these elements were measured with an accuracy of ~1 cm between rangemeters and between transponders and <6 cm between rangemeters and transponders.

The PMTs installed in the demonstrator allowed the detection of down-going atmospheric muons by asking for a coincidence in all PMTs. Muon tracks were fitted using a hyperbolic fit of the time recorded and the position of each PMT. More than 50000 coincidences of 7 PMTs have been recorded leading to more than 1350 reconstructed events per day. The obtained angular distribution agrees with expectation from atmospheric muon distribution.

Finally, the demonstrator string has also provided valuable information on deployment and retrieval techniques, data acquisition, data transmission over the electro-optical cable and data recording.

5. CONCLUSIONS

The ANTARES R&D programme has shown that a submarine neutrino telescope in the Mediterranean Sea is a feasible project. The detector design, environmental studies and specific marine technologies are well stablished as has been proved by the demonstrator string. Now, the ANTARES Collaboration has moved into the construction phase of a 0.1 km^2 detector, to be finished by the end of 2003.

REFERENCES

1. ANTARES Proposal, astro-ph/9907432.
2. F. Halzen, Phys. Rep 333-334, 355 (2000).
3. F. Hubaut, PhD thesis, Université de la Meditérranée, Aix-Marseille II (1999).
4. C. Cârloganu, PhD thesis, Université de la Meditérranée, Aix-Marseille II (1999).
5. ANTARES coll, Astropart. Phys. 13, 127 (2000).
   N. Pallanque-Delabrouille, ICRC 99 proc., Salt Lake City, USA (1999).
6. A. Kouchner, “ANTARES: preliminary demonstrator results”, proc. Rencontres de Moriond (2000).