Design and expected performance of the ANTARES neutrino telescope.

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The ANTARES Collaboration is aiming at the construction and the operation of a large undersea neutrino telescope for neutrino astronomy, neutrino oscillation and indirect dark matter searches. An intensive R&D program, which started 3 years ago, has shown the feasibility of such a detector in the deep waters of the Mediterranean sea. We have now started the design and the construction of a 0.1 km² detector for which the expected performance will be briefly described here.

1. Aims and principle.

The ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESeach) is an international collaboration which aims at the construction and the operation of a large undersea telescope for the detection and the study of high energy cosmic neutrinos. The collaboration is rapidly growing and is composed of particle physicists and of astronomers, as well experts in sea science and technology.

The physics and astrophysics aims are described in more detail in the contribution from L. Moscoso to this conference. The basic idea of the detection of high energy cosmic neutrino by large undersea or under-ice Cerenkov detectors is almost 40 years old: an array of optical modules (OMs) is used to detect the Cerenkov signal emitted by muons in water. Muons are induced by charged current interaction of neutrinos at some distance of the detector. The target size is thus of the order of the muon range i.e. much larger than the detector itself. The overwhelming background of down going muons produced in the high atmosphere is reduced by shielding the apparatus under some thousands of meters of water and rejecting the remaining atmospheric muons by looking only at upward going muons. The muon trajectory is accurately reconstructed from the Cerenkov photons arrival time information on each photomultiplier (PMT) contained in the optical modules. At high energy (above a few TeV) the neutrino direction is well preserved at the interaction and the resulting pointing accuracy is better than a fraction of a degree allowing accurate source identification. Given that the expected fluxes are very low, the ultimate goal is the realisation of a km³ detector which should record hundreds or thousands of cosmic neutrino events with energies above a few TeV but a 10 times smaller detector would be able to reveal first high energy cosmic neutrinos and maybe identify some point-like sources. At lower energies, contained or semi contained events can be used and the neutrino energy can be inferred from the muon range measurement, giving access to neutrino oscillation physics using atmospheric neutrinos or to indirect neutralino searches in the core of the Earth, the Sun or the Galaxy.

2. The R&D program.

Since 1996, the ANTARES collaboration performed an active R&D program to show the feasibility of a large undersea detector. Indeed, past experience had shown that the realisation of such a detector is not trivial and that specific studies in sea technology were needed. The required studies were carried out by ANTARES and concerned: the mechanical structure of the elementary detector lines, the deployment and recovery techniques, the connection of the detector to the shore with an electro-optical cable for energy supply and data transfer, PMT front-end electron-
ics, data readout and remote control, the monitoring of the OM positions on the whole structure. Furthermore, many questions concerning the deep sea environmental parameters, water optical properties and long term effects needed to be assessed. For that reason, ANTARES performed many in situ measurements to answer these questions.

**Environmental studies:**
Many measurements and long term survey of environmental parameters such as current velocity and variation, optical background, light attenuation and scattering in water, and fouling on OMs were performed. These measurements have been obtained in situ by instrumented autonomous mooring lines deployed on a Mediterranean site located off-shore from Toulon (France) at a depth of 2400 m (hereafter called the ANTARES site).

The optical background is studied by recording the counting rate of OMs as function of the time. For a 8” diameter PMT, it shows a continuous level of less than 50 kHz due to Cerenkov emission from $^{40}$K $\beta$-decays and spikes with typical duration of one second coming from bioluminescence activity.

Several measurements of the sea water optical properties have been performed by looking at the arrival time distribution on a small PMT placed 24 or 44 m away from a pulsed blue LED emitting 466 nm photons. A comparison of the relative proportion of direct and delayed photons leads to an absorption length of 55-65 m accounting for seasonal variations and to a scattering length greater than 200 m for large angle (Rayleigh-like) scattering.

The effect of sedimentation and bio-fouling on the transparency of the optical surface was monitored over long periods using a setup consisting of continuous light source and PIN diodes at different positions on a optical module sphere. The optical attenuation was measured to be less than 1.5% after 8 months.

The ANTARES site is now well studied and the deep water and environmental parameters are found to be acceptable for a neutrino telescope.

**Mastering the detector deployment:**
It was soon understood that owing to the critical deployment of any large mechanical structure and to the necessity to reach long term reliability, the detector structure should be as simple as possible: mere flexible string-like mooring lines anchored on the sea bed and held up by buoyancy, supporting optical modules. The counterpart of this simplicity is a rather sparse horizontal detector density and the necessity to accurately monitor the position of every single element along the strings.

In order to learn about the complex deployment procedure as well as the mechanical behaviour of the detector during the deployment phase and when it rests at the bottom of the sea, a demonstrator line consisting of a 350 m high detector string was designed and built. This line is made of two vertical cables, separated by 2 m, supporting 16 frames each holding a pair of optical modules. The frames are placed every 15 m, starting 100 m above the sea bed. It is fully equipped as far as cabling and electronics containers. The line also contains all the sensors needed for the precise positioning of the detector elements and for the recording of the environmental parameters. Successful deployment tests of this line at a depth of 2400 m have been performed in summer 1998 using a dynamical positioning ship, showing that the deployment and recovery procedures were well mastered. It was also proved that the bottom of a string could be set at its aimed position on the sea bed with an accuracy of the order of a meter. The string was then equipped with 8 large dimension PMTs (8 and 10”) as well as the electronics needed to transmit the signal to the shore via a 37 km long electro-optical cable. It has been successfully connected to the shore station and deployed November 26th 1999 at a depth of 1100 m for long-term running.

Raw background events and atmospheric muon data are currently being recorded and analysis is in progress.

In December 1998, we also performed successful tests of undersea electrical connections of a detector anchor at 2400 m depth using the IFREMER submarine vehicle (*Le Nautile*).

All this insures the feasibility of the installation of an array of instrumented strings at the bottom of the sea.
3. A 0.1 km\(^2\) detector.

Since spring 1999, the ANTARES Collaboration is starting the second phase of the project which is the design of a 0.1 km\(^2\) undersea neutrino detector[1].

This detector will be equipped with a total of about 1000 OMs placed on 13 mooring lines of 400 m high and spaced by 60 to 80 m. Each line will be connected to a junction box using a submarine vehicle, the junction box being connected to the shore station through a 50 km electro-optical cable. This 13 string detector is aimed to be deployed on the ANTARES site by 2003.

This second phase of the ANTARES project is already approved by the French and Spanish scientific councils, it will be decided soon in the UK and the Netherlands.

This 0.1 km\(^2\) detector is foreseen to be devoted to three main topics. The first one is the neutrino astronomy i.e. the study of cosmic neutrinos with an energy above 1 TeV which may come from diffuse signal, point sources such as individual AGN. The second subject is the search for neutrinos coming from dark matter particle annihilations in the centre of the Earth, in the Sun or in the Galactic centre. The third topic is the study of atmospheric neutrino oscillations in the 5-100 GeV range.

Extensive simulation studies have been carried out to understand the performances of such a detector for these different topics (see for example ICRC proc. references in [2]). For high energy neutrino astronomy, the angular resolution is a crucial point. Simulations show that because of the good optical quality of the sea water (low scattering) and taking into account the good timing capability of the detector, a point source will be reconstructed with half of the events contained within 0.2° of the source direction. This result will permit the division of the sky map into 200 000 pixels. From the amount of light measured by the optical modules, the energy of the muon is estimated within a factor 3 for muons in the 1-10 TeV range and within a factor 2 above 10 TeV. These performances will allow the detection of a signal of cosmic neutrinos coming from cosmic sources such as AGNs above the atmospheric neutrino background: this analysis would be performed by imposing a threshold on the reconstructed neutrino energy to reduce the atmospheric neutrino contribution to the diffuse flux or enriching a signal coming from point sources by overlaying the pixels of the 43 known AGNs detected by EGRET.

Studying upward going atmospheric neutrino events with an interaction point inside the detector and using the low energy (5-100 GeV) muon range as an estimator of the parent neutrino energy, on can explore the physics of atmospheric neutrino oscillations with mass difference in the range \(\Delta m^2\) between \(10^{-3}\) and \(10^{-4}\) eV\(^2\). Our analysis is based on the shape of \(E/L\) distribution and is basically independent of the poorly known absolute \(\nu_{\text{atm}}\) flux. In case of a positive oscillation signal in \(\Delta m^2\)-sin\(^2\theta\) region allowed by the Super-Kamiokande experiment, the fit would lead to a precise determination of the oscillation parameters. On the contrary, in absence of oscillation, the excluded region would well cover the region allowed by Super-Kamiokande.

4. Conclusions

The R&D program performed by the ANTARES Collaboration has demonstrated that the water and environmental properties of the chosen ANTARES site are well suited for the installation of the first stage of a large size neutrino telescope. It was also demonstrated that the necessary marine technologies concerning aspects such as detector deployment, undersea connections, positioning, long term reliability, etc, are well under control. ANTARES is starting the next step towards the km-scale neutrino telescope by the design, the installation and the running of a 0.1 km\(^2\) detector off the Mediterranean coast of France by 2003. This detector will play a pioneering role in neutrino astronomy.

REFERENCES

1. ANTARES proposal, 1999, astro-ph/9907432
   see also http://antares.in2p3.fr/antares
2. “High Energy Neutrino Astronomy” by Luciano Moscoso, this conference.