ANTARES : a Deep-Sea 0.1 km^2 Neutrino Telescope

V. BERTIN (on behalf of the ANTARES Collaboration)
C.P.P.M., CNRS/IN2P3-Université de la Méditerranée,
123 avenue de Luminy - Case 907 - 13288 Marseille Cedex 9, France

After a 4-year R&D programme to demonstrate the feasibility of a large undersea neutrino telescope, the ANTARES Collaboration is now engaged in the building of a 0.1 km^2 detector to be deployed in the Mediterranean Sea by 2002-2004.

1 Introduction

Four years ago at this same Moriond Conference, the author gave the first presentation of the newborn ANTARES project at a conference[1]. At that time, ANTARES was presented as a R&D project to study the feasibility of a large undersea high energy neutrino detector, performed by a French collaboration regrouping particle physicists, astrophysicists and sea science people. The conclusion of that first presentation was that numerous R&D studies were needed, and that new collaborators were welcome to participate in these developments.

Today, the R&D phase has been successfully completed, and the project has evolved to the design and the construction of a 0.1 km^2 neutrino telescope to be deployed in the Mediterranean Sea. In conjunction, the ANTARES Collaboration has grown to an international community grouping 18 institutes from France, Holland, Italy, Russia, Spain and the United Kingdom.

The basic idea of such an undersea neutrino detector is to use the Earth as a shield against atmospheric muons and to take advantage of sea water as the active medium for the detection of the Cherenkov light produced by the neutrino induced muons. This detection is performed by a lattice of Optical Modules (OMs), consisting of large hemispherical photomultiplier tubes (PMTs) housed in pressure resistant glass spheres, installed on a set of mooring lines. The reconstruction of the muon track direction, pointing to less than a degree towards the direction of the parent neutrino source for high energy muons, is achieved from the measurements of the arrival times of the Cherenkov photons on the PMTs. In addition, an estimation of the muon energy is obtained from the measured amount of light for high energy muons, or from its propagation range in water for low energy muons.

A large detection volume is required to be sensitive to the low flux of high energy cosmic neutrinos. A km^3 detector is expected to record 200 to 2000 cosmic neutrinos with an energy higher than 10 TeV.

2 The R&D phase

As we have learned from past and current attempts, the realization of such a detector is not trivial and needs specific studies of the marine environment as well as sea technologies.

2.1 Water properties measurements

Since 1996, we have performed precise measurements and a long term survey of crucial environmental parameters such as current velocity, optical background, light attenuation and scattering in water, and fouling of the Optical Modules. All these measurements have been obtained in-situ by immersing autonomous instrumented mooring lines on a Mediterranean site located off-shore Toulon (France) at a depth of 2400 m (ANTARES site).

The optical background is studied by recording the counting rate of OMs as function of the time. For a 10" diameter PMT, a continuous level of about 60 kHz is observed, partly due to Cherenkov emission from ^{40}K β-decays, with in addition spikes with typical duration of one second coming from bioluminescence activity [3].

Several measurements of the sea water optical properties have been performed by looking at the arrival time distribution of light on a 1" PMT placed 24 m and 44 m away from a pulsed blue LED emitting 466 nm photons. A comparison of the relative proportion of direct and delayed photons observed at both distances leads to an absorption length of 55-65 m, depending on seasonal variations, and to a scattering length greater than 100 m for large angle (Rayleigh-like) scattering.

2.2 Demonstrator string

During this R&D phase of the ANTARES project, we have also designed and build a demonstrator consisting of a 350 m high detector string. This line was made of two vertical cables, separated by 2 m, supporting 16 frames holding a pair of optical modules. The frames were placed every 15 m, starting 100 m above the sea bed. The main goal of this line was 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. Successful deployment tests at a depth of 2300 m have been performed in Summer 1998. From December 1999 to June 2000, the demonstrator was immersed at 1200 m depth off the coast of Marseille (France) and linked to shore by a 40 km electro-optical cable. During this period, the line was remotely operated from a shore station by Ethernet communication through the electro-optical cable.

The demonstrator string was equipped with 7 OMs as well as the necessary electronics for their control and for the acquisition and transmission of their signals. The OMs were installed with the PMT photocathodes looking horizontally in order to be sensitive to the Cherenkov light produced by down-going atmospheric muons. More than 50 000 events with a coincidence in all of the 7 PMTs were recorded. Although the information obtained with just one string does not allow the reconstruction of the muon tracks, their zenith angle can be determined by an hyperbolic fit to the depth versus time pattern of the recorded hits. Such a reconstruction algorithm was applied to the data taking into account the rejection of off-time hits most likely due to ^{40}K decay background photons. It led to more than 1350 reconstructed events per day. The comparison of the zenith angle distribution of the reconstructed muons with expectation from a simulated sample of atmospheric muons is satisfactory, indicating a large contribution from multiple muon events.

The demonstrator line was also equipped with an acoustic positioning system remotely controlled from the shore station. It consisted of three rangemeters, being an emitter-receiver hydrophone and its electronics, placed along the string, and four autonomous transponders anchored on the sea bed 200 m around the demonstrator line. Travel time measurements of high frequency acoustic signals between the rangemeters and each transponder allowed the determination of all hydrophone relative spatial positions by triangulation. This acoustic positioning system, developed for ANTARES, has shown an excellent performance. The accuracies of the distance measurements between two transponders and between one rangemeter and one transponder are found to be 1 cm and 3 cm respectively, allowing a determination of the hydrophone positions with a precision better than 5 cm.

3 The 0.1 km^2 detector

3.1 Design

The ANTARES Collaboration has now moved on to the second phase of the project, the design and building of a 0.1 km^2 undersea neutrino detector [2]. This detector will consist of 10 strings of 30 storeys, each storey being equipped with a triplet of Optical Modules, giving thus a grand-total of 900 OMs. The OMs are instrumented with 10" Hamamatsu PMTs oriented downwards at 45° to the vertical in order to have an uniform collection efficiency to the upward-going muons from nadir angle to horizontal.

The storey also supports a local electronics container which includes the front-end readout electronics of the PMTs, an Ethernet board for the data acquisition, electronic boards for triggering and for clock distribution, and a tiltmeter-compass board measuring the local tilt and orientation of the storey. Some storeys also support an hydrophone for acoustic positioning or a LED Optical Beacon used for inter-string time calibration.

The distance between storeys is 12 m, the first one being placed at 100 m above the sea bed, leading to a total height of the detector strings of more than 450 m. Each string is anchored on the sea floor at a distance of 60 m from its neighbours.

Each detector string is connected to a Junction Box by a few hundred metre interconnection cable. The Junction Box is itself linked to the shore station by a 40 km electro-optical cable equipped with 48 optical fibres. This standard telecommunication cable will be deployed between the beach of La-Seyne-sur-Mer and the ANTARES site (42°48'N-6°10'E) in September 2001. The installation of the 0.1 km^2 detector will then start in 2002 to be achieved in 2004. The location of the ANTARES site allows a 3.5π sr coverage of the sky and the survey of the Galactic centre.

3.2 Performances

Extensive simulation studies have been performed to control the performances of the foreseen detector. For high energy neutrinos above 10 TeV, the angular resolution is found to be better than 0.4° including all effects coming from reconstruction and selection of muon tracks, of PMT time transit spreads, of detector positioning and timing calibration, and of light scattering in water. At lower energy, the angular error on the neutrino direction is dominated by the $\nu - \mu$ physical angle.

Concerning the energy resolution, the amount of light measured by the phototubes leads to an estimation of the muon energy within a factor 3 when its energy is greater than 1 TeV. At low energy ($E_\mu < 100$ GeV), the energy of the muon is estimated from a measurement of its travel range in water.

3.3 Scientific programme

The 0.1 km^2 detector is foreseen to be devoted to three main topics, according to the neutrino energy domain.

At low energy, for neutrinos below 100 GeV, ANTARES has the capability to study muon-neutrino oscillations by looking at the energy spectrum of atmospheric muon-neutrinos that have passed through the Earth. A signal from ν_μ oscillation should result in the modification of the E/L spectrum.

At medium energy, for neutrinos up to few TeV, we will concentrate on the search of neutrinos produced by annihilations of neutralinos. If this supersymmetric particle is the cold dark matter, a relic of the Big Bang, it should concentrate in the centre of celestial bodies via gravitational capture. In some regions of the supersymmetry parameter space, the annihilation of the neutralinos should result in a sizable flux of neutrinos coming from the centre of the Earth, of the Sun or of the Galaxy.

At high energy, above 10 TeV, the irreducible background coming from atmospheric neutrinos becomes small and ANTARES aims at the detection and study of cosmic neutrinos coming from galactic or extra-galactic sources. As it has been presented throughout this conference, promising sources of high energy cosmic neutrinos are objects such as Gamma Ray Bursts, Active Galactic Nuclei, Supernovae remnants, Micro-Quasars,...

4 Conclusions

The ANTARES project has made excellent progress over the past four years. The R&D program performed by the ANTARES Collaboration has demonstrated that the water properties of the chosen ANTARES Mediterranean site are well suited for the installation of the first stage of a large size neutrino telescope, and that the necessary specific marine technologies concerning aspects such as detector deployment and undersea connections are well under control. This phase was concluded by the successful deployment and operation of a demonstrator string which permitted the first reconstruction of down-going atmospheric muons by the experiment.

ANTARES is now well advanced in the second phase of its programme; the design, the installation and the running of a 10 strings 0.1 km^2 detector off the Mediterranean coast of France in 2002-2004. This detector will constitute a major step towards the construction of a km-scale neutrino telescope in the Mediterranean Sea.

Acknowledgments

I would like to thank Tran Thanh Van and the Moriond organizing committee for both the quality of the scientific program and the unique atmosphere of the conference. The author would also like to thank the European Union for funding his participation to this Euroconference.

References

1. V. Bertin et al., ANTARES Collaboration, "Status of the Antares project", XXXIInd Rencontres de Moriond on *Very High Energy Phenomena in the Universe*, Jan. 97, Les Arcs, France.
2. "A deep sea telescope for high energy neutrinos", ANTARES Proposal, astro-ph/9907432, see also http://antares.in2p3.fr/antares
3. P. Amram et al., ANTARES Collaboration, *Astropart. Phys.* **13** (2000) 127.