Proceedings of ICRC 2001: 1 © Copernicus Gesellschaft 2001

ICRC 2001

The ANTARES Neutrino Telescope: Status Report

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Abstract.

We present hereafter progresses made by the ANTARES collaboration and we describe the expected performances of the 0.1 km^2 neutrino detector that will be deployed in the Mediterranean Sea before the end of 2004.

1 Introduction

The observed excess of cosmic rays with energy around 100 EeV (1) is, at present, one of the main open problems in astro-particle physics (2). The fact that no sources of such high energy particles are known in our galaxy and that ultra high energy γ rays or nucleons cannot reach the Earth from distances greater then $\sim$ 50Mpc, due to their interaction with cosmic microwave background, emphasize the importance of cosmic neutrino observation. ANTARES collaboration was formed in 1996 to build a neutrino telescope demonstrator in the Mediterranean Sea, following the idea suggested in 1960 by Markov (3). Deep underwater (or under-ice) Neutrino Telescopes use the Earth as a shield against atmospheric muons and the sea water (also polar ice or lake water) as active media for the detection of the Cherenkov light produced by neutrino-induced leptons (mainly muons).

After a four-year long programme of extensive research and development, the ANTARES collaboration has started, as first phase of its final project, the construction of a large undersea detector, with an effective area of 0.1 km^2 (4). An extensive campaign of measurements of the relevant environmental properties (5) allowed to select the site where the 0.1 km^2 will be deployed, near Toulon, close to the south coast of France (42° 50 N, 6° 10 E), at 2400 m depth. This location allows for the Neutrino Telescope a 3.5π sr. coverage of the sky and the survey of the galactic center.

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2 Scientific Aims

Neutrino detection will provide a novel tool to explore high-energy phenomena in astrophysical objects. Due to their weak interaction with matter (such as matter clouds surrounding high energy sources in the Universe) neutrinos can escape from regions of the Universe too dense for any other particle to escape. Neutrino Telescopes will offer unique information on the nature of known sources, like Supernova remnants, Active Galactic Nuclei (6) and sources of Gamma Ray Bursts (7), and, perhaps, will permit to observe unknown, more distant, objects.

The prominent aims of the collaboration are to measure the energy and angular distribution of cosmic muon neutrinos, to identify point sources and to correlate them to powerful accelerators in the sky.

In addition to exploratory astrophysics a Neutrino Telescope offers an extensive program of particle physics.

Neutrinos could be produced in the annihilation, or decay, of Weakly Interacting Massive Particles (WIMPs) which may have been produced during the Big Bang. A candidate for WIMPs is the neutralino predicted by Supersymmetry, which is its own antiparticle. Neutralinos, by gravitational attraction, may be trapped at the center of massive astronomical objects (like the Earth or the Sun) or around the super massive black hole which may lie in the Galactic center and annihilate there, producing neutrinos. A possible detection of an excess of neutrinos coming from the Earth center (from the Sun or the Galactic center) could allow ANTARES, in few years of operation, to search for dark matter above limits set, at present, by experiments at accelerators.

Very high energy neutrinos (i.e. with energy above 10^{11} GeV), could be due to speculative but highly spectacular sources as ”topological defects”, remnants from the phase transition at the Grand Unification scale. Such ’topological defects” have been proposed as alternative source of Ultra High Energy Cosmic Rays.

ANTARES will also investigate ”neutrino oscillation” for atmospheric muon neutrinos. With about 1500 upgoing events per year below 100 GeV ANTARES will have the possibility to make an independent measurement of oscillation parameters (mass difference and mixing angles) indicated by recent results of the Super-Kamiokande experiment (8), with a precision better than 33%.

3 Detection of neutrinos

Neutrino detection is usually based on the observation of charged particles emerging from its interaction. In a deep underwater neutrino telescope the detection of neutrinos is based on the observation of Cherenkov light from charged particles travelling inside or near the detector. Sea water behaves as an active medium where light can be sampled by an array of photon detectors. The 2000 m thick layer of water above the instrumented volume, provides a reduction, by more than 4 orders of magnitude, of down-going atmospheric muons making easier the identification of up-going tracks originated by neutrino interactions. The detection of up-going high energy muons, which are mostly very well aligned with their parent neutrinos and carry about half of their energy, represent the main motivation for ANTARES project since it will allow to point back neutrinos up to their sources. High energy electron and tau neutrino interactions could be, in principle, observed but the identification of their origin in the sky will not be easy.

4 R&D and site properties study

Since 1996 the effort of ANTARES collaboration was mainly dedicated to master deep-sea technologies like: a) the construction of equipment resistant to high pressure and to sea corrosion, b) the deployment and the recovering of detector strings, c) data and power transmission on electro-optical cables, d) underwater connections. More than 30 deployments of detectors, dedicated to the study of environmental parameters, in the site selected for ANTARES deployment were made over more than four years. All this work allowed to measure site parameters, mainly the water optical properties, also as function of time.

The water transparency was studied using continuous and pulsed light sources. At 470nm the absorption length results to be about 55 m, the scattering length larger than 100 m for large scattering angles.

The optical noise, mainly caused by the decay of ^{40}K, induces on 10” PMTs a signal rate of the order of 60 kHz; superimposed to this noise light bursts, due to bioluminescence, are occasionally present and induce a dead-time less than 5%.

Biofouling on optical modules (on the glass spheres) reduce the sensitivity to photons for less then 2% per year in the PMT window.

The obtained data and experience indicate the good quality of the site and the feasibility of the project.

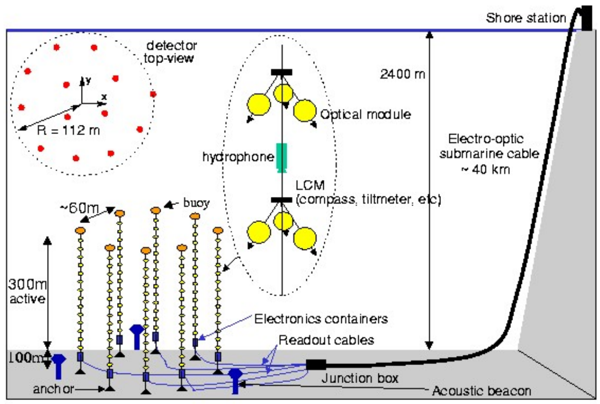

Fig. 1. Figure 1. The ANTARES 0.1 km^2 detector concept.

5 The ANTARES detector design

A schematic drawing of the proposed ANTARES 0.1 km^2 detector is shown in figure 1. It consists of an array of photomultiplier tubes (PMT) installed in deep sea water. The basic element of the detector is the optical module: a pressure-resistant glass sphere housing a large photocatode PMT (a 10” Hamamatsu R 7081-20) and its associated electronics. The PMT is held inside the optical module by means of silicon gel, that ensures a good optical coupling. The PMT is shielded from Earth magnetic field by a mesh of high permeability metal. Optical modules are grouped in storeys of three, with PMTs oriented 45° downward. Storeys are mounted on a vertical string, basically made by a mechanically strong electro-optical cable, anchored at the sea bed and kept taut by a buoy at the top. Located in the frame for the optical modules is also a special container which houses an electronics local control module (LCM), calibration and positioning equipment. There are 30 storeys in each string, one every 12 m, starting 100 m above the sea bed. The detector will consist of 10÷13 strings 450m high, but only the top 350m are instrumented. An extra string, dedicated to the measurement of environmental parameters such as water current, temperature and salinity, sound speed and light attenuation, will complement the Cherenkov detector. The horizontal separation between strings is around 60m and their position, on the sea bed, follows approximately a spiral. As the string can bend, a system of tiltmeters and acoustic positioning will monitor the string shape, allowing the determination of the optical modules position to a precision better than 10cm. Light sources (LED) along the string and in the optical modules act as optical beacons in order to perform the time calibration of the detector. An application specific integrated circuit has been developed for the front-end electronics, the Analogue Ring Sampler (ARS). It captures and stores the PMT signals and digitizes them upon request from a trigger (9). All digital data from each string are gathered in a string control module (SCM) located at the bottom of the string. Electro-optical cables connect all the strings to a junction box, which, in turn, is linked to the shore by a standard deep sea telecommunication cable. The data acquisition system can handle data volumes up to a Gigabit/s/string, sufficient to send all data to shore, with a minimal offshore trigger. On shore the trigger has multi-level architecture and runs on a PC farm of around 100 processors. Each processor will operate on a small (10ms) slice of data from the whole detector. All raw data can be saved for few minutes including the last 10s (in pipeline) before any local or global trigger. From the triggered data tracks are reconstructed while accounting for optical background and light scattering. The final pointing resolution is expected to be better than $0.4°$ for neutrino energy above 5 TeV.

6 Results from a demonstrator string

In order to test the technology developed during our R&D work, the string deployment and recovery techniques, and to get useful indications for the final detector set-up, during November 1999 the collaboration deployed a string not far from the ANTARES site (37 km off the coast of Marseille) at about 1000 m depth. This site was selected due to the availability of a suitable electro-optical cable. The string deployed was not identical to the future 0.1 km^2 detector strings. It consisted of storeys, separated vertically by 14.6 m, holding two optical modules. Only 7 of these optical modules were equipped with PMTs oriented with their axis horizontally, in order to optimize the detection of light from down-going atmospheric muons. A complete positioning system was present allowing the first full scale testing of the positioning system foreseen for the 0.1 km^2 detector. With the help of tiltmeters and compasses distributed along the string, the string shape, and its movement in space, was reconstructed. We recorded more than 50.000 7-fold coincidences due to atmospheric muons (10). The zenith angle was determined from the depth versus timing pattern. The comparison of the reconstructed zenith angle distribution of the collected atmospheric muons with a preliminary result from Monte Carlo simulation is satisfactory (11).

7 Summary

The ANTARES Collaboration has addressed during five years of operations most of the technical aspects related to the construction and operation of a deep sea neutrino telescope. The site evaluation program has lead to the identification of a deep sea site, at 2400m depth, close to the coast, with environmental parameters suitable for the construction, and operation, of a 0.1 km^2 detector. A full scale demonstrator string has been deployed, operated for few months, and recovered. The collected sample of muons (more than 50.000) allowed us to test our reconstruction program and a successful comparison with the Monte Carlo simulation. The detector design at present has been finalized and the detector is under construction. We plan to deploy a reduced version of the final strings during the spring of 2002 and to start the full scale detector deployment during second part of 2002. The detector will be fully operational by the end of 2004.

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