ANTARES, Physics potential, progress and status

R. van Dantzig[a]
on behalf of the ANTARES Collaboration

[a]NIKHEF, P.O. Box 41882, 1009 DB Amsterdam, The Netherlands

Observational neutrino astronomy can bring information - also on particle physics - that can not be obtained in other ways. In general this concerns processes at extreme energy and distance scales. Particularly of interest are cosmic accelerators, GUT phase transition remnants and dark matter annihilation. After four years of R&D the ANTARES Collaboration begins the actual construction of a neutrino telescope to be deployed at 2400 m depth near Toulon in the Mediterranean sea. The telescope will be particularly sensitive to high-energy upward-going neutrinos. The physics case, measurements, the structure of the detector and recent progress are discussed.

1. Introduction

The aim of the ANTARES Collaboration is to design, build and operate a deep-sea neutrino detector with a sensitive area of $\sim$ 0.1 km^2. Such a detector gives access to a challenging astroparticle physics research programme and it also provides a realistic feasibility test for a future upscaled km^2 detector. For the latter reason - next to reliability - scalability is of major concern in the choice of technical solutions.

Over the last several years the Collaboration has performed site explorations, computer simulations for different physics topics and different detector configurations, as well as R&D on electronic and electro-mechanical subsystems. This has led to the design [1] summarised below. A site has been selected about 40 km from Toulon (France). An important milestone was the successful deployment, operation and recovery of a 'demonstrator' detector string. Construction of the 0.1 km^2 detector has started.

2. Physics case

In different types of active celestial objects the Fermi mechanism of stochastic acceleration in relativistic shock waves can deliver charged particle 'beams' (particularly protons) with large Lorentz factors. The resulting high-energy (HE) particles can interact with surrounding matter and radiation ('cosmic beam dumps'), and produce $\pi^{\pm}$ and π^0. The π^0s are a source of HE γ-rays, the $\pi^{\pm}$s of neutrinos.

However, γ-rays above 1 TeV can not reach the Earth from distances greater than $\sim$50 Mpc. They degrade in energy (due to electron pair production) in their passage through the cosmic microwave background (CMB). Somewhat similarly, ultra-HE ($>$ 50 EeV) protons (and nuclei) degrade in energy due to pion production on the CMB (GZK [2] cut-off). Also, in galactic magnetic fields charged particle momenta deviate from their original direction. Neutrons, on the other hand, have their reach limited by the lifetime, for example at EeV energies their range is boosted not more than 10 kpc.

Therefore, the observed excess of cosmic ray (CR) events [3] around 100 EeV (UHE) can not be at the same time nucleons or nuclei and reach us from distances larger than $\sim$50 Mpc. However, there are no sources expected within this distance that could explain emission of UHE nuclear particles. The enigmatic nature of the UHECR events emphasizes the importance of cosmic neutrino observations. Neutrinos can escape from the depths of their source and their momentum still points back to it even after travelling over cosmological distances. However, a very large detection volume is needed to detect them.

But a much broader motivation exists for neutrino telescopes of the ANTARES type. As may be expected from the presence at this Workshop, ANTARES can contribute to the study of neutrino oscillations, for atmospheric muon neutrinos [4], and possibly also for cosmic neutrinos [5]. The prominent aims are to measure the energy and angular distribution of cosmic muon neutrinos, to identify point sources and to correlate these with known powerful objects on the Sky. Candidates [6] are active galactic nuclei, X-ray binaries, young supernova remnants and—in particular—gamma-ray bursts (GRB) [7].

Of further interest is the potential to find evidence of super-heavy remnants from an early universe (GUT) phase transition. Such 'topological defects', have been proposed as alternative source of UHECR events. Similarly challenging is the indirect search for annihilations of WIMPS (dark matter, e.g. neutralinos) gravitationally trapped in local massive objects as the Earth, Sun or galactic centre.

Finally, exotic particles like Dirac monopoles or strangelets could leave their traces in the detector. Non-observation of such more speculative signals can provide exclusion limits. With AMANDA [8], already operational in the Antarctic ice, and ANTARES to be built in the Mediterranean Sea, a new window on astro-particle physics with a large discovery potential opens up.

3. Detection of neutrinos

In ANTARES neutrino detection is based on the observation of Čerenkov light from charged particle(s) emerging from a charged-current (CC) interaction of a neutrino inside or near the detector. The light is sampled by an array of photo-multiplier tubes (PMTs). Although HE electron and tau neutrino interactions can be observed inside the detector, the main motivation for ANTARES comes from the detection of up-going HE muons, which are mostly very well aligned with their parent muon neutrino and carry on average about half the neutrino energy. The CC cross-section and sensitive volume both increase with energy, to some extent compensating for the steeply decreasing spectral slope. To locate HE point sources it is important that a large fraction of the Sky (for ANTARES 90 %, part of it part of the time) is covered, with sufficient pointing resolution.

4. Site and R&D studies

Since the start of ANTARES in 1996 deep-sea technologies were mastered, including how to a) construct pressure and corrosion resistant equipment, b) deploy and recover detector strings, and c) establish (by submarine) and operate power lines and electro-optical data connections. More than 30 deployments were made over four years. Site parameters were measured as function of time.

The results [1] can be summarised as: absorption length 55 m at 470 nm, scattering length larger than 100 m for large scattering angles, ^{40}K optical background (for the 10" PMTs) 60 kHz, bio-luminescence imposing a dead-time less than 5 %, bio-fouling photo-sensitivity loss less than 2 % per year in the PMT window (which is below the horizon). The obtained data and experience indicate quality of the site and feasibility of the project.

5. Conceptual design

The telescope, schematically shown in Fig. 1, is designed to consist of 10 to 13 detector strings, basically made from a mechanically strong electro-optical (EO) cable of 400 m height and equipped with 30 PMT triplets (storeys) and DAQ electronics. The PMTs look down at 45 with the horizon. The strings are anchored at the sea bed and kept taut by a buoy at the top. A 'junction box' located at the detector site is connected to shore with an electro-optical cable. There power and optical telecommunication channels from shore are distributed to the strings, and data channels from the strings are bundled

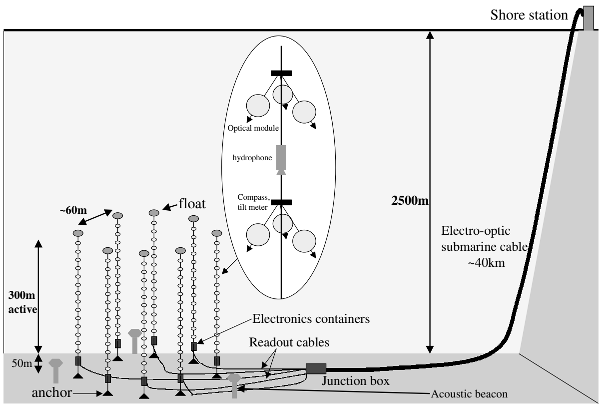

Figure 1. Schematic view of the first phase of the ANTARES detector.

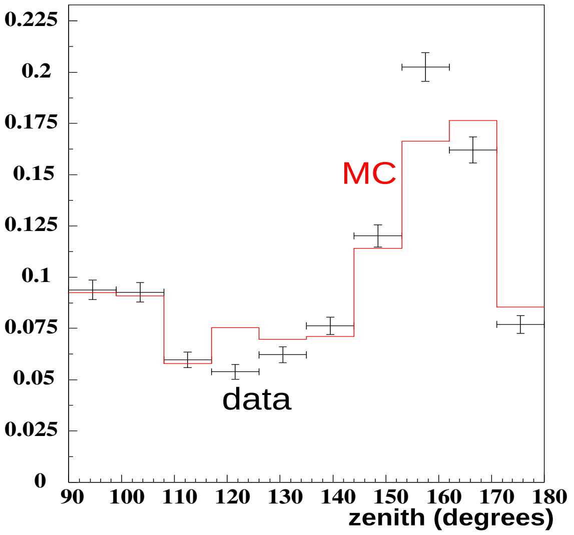

Figure 2. Zenith angle distribution of atmospheric muons measured with the demonstrator string and in a preliminary analysis compared with a Monte Carlo simulation.

towards the shore.

The relative positions of all PMTs are measured continuously to a precision better than 10 cm by an acoustic positioning system, compasses and tiltmeters. Digital timing has a precision better than 1 ns. Water properties, are monitored continuously. All digital data collected from PMTs per string can be sent through a Gigabit Ethernet link to shore.

On a Linux farm of 100 processors, a flexible and smart software trigger that can be tuned precisely, is implemented. Each processor operates on a 10 ms slice of data from the whole detector. All raw data can be saved for few minutes including the last 10 s (in pipeline) before any local or global (e.g. GRB) trigger. This is important for grasping also the pre-stage and on-set of particularly interesting events. From the triggered data, tracks are reconstructed while accounting for optical backgrounds and light scattering. After filtering and reconstruction, the pointing resolution is expected to be better than $0.4°$ for $E > 5$ TeV. The energy resolution on a logarithmic scale is a third of a decade or better.

6. Demonstrator string

A major recent accomplishment is the deployment (at 1000 m depth), operation, and recovery of a partially instrumented 340 m high 'demonstrator' string containing 7 PMTs, an acoustic positioning system, compasses, tiltmeters, as well as controls, read-out and data transmission to shore through an electro-optical cable. The positions of PMTs were measured by acoustic triangulation with 5 cm accuracy. The string was stable, oriented at $2.3°$ from vertical with a tilt stability of $0.2°$ and heading stability of $2°$ over a week. The demonstrator was operational for several months starting December 1999.

More than 5×10^4 7-fold coincidence events from atmospheric muons were collected. The zenith angle was determined from the depth versus timing pattern. The angular distribution is shown in Fig. 2 with a preliminary MC simulation.

7. Summary

ANTARES has completed the R&D programme and the design of a 0.1 km^2 detector. According to current planning, the detector can be deployed between 2002 and 2004. It has a viable research potential and will be a test-bench for a future km^2 under-sea telescope.

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