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Status of the ANTARES project

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Abstract. The ANTARES collaboration is constructing a neutrino telescope in the Mediterranean Sea at a depth of 2400 metres, about 40 kilometres off the French coast near Toulon. The detector will consist of 12 vertical strings anchored at the sea bottom, each supporting 25 triplets of optical modules equipped with photomultipliers, yielding sensitivity to neutrinos with energies above some 10 GeV. The effective detector area is roughly $0.1\,\mathrm{km}^2$ for neutrino energies exceeding 10 TeV. The measurement of the Čerenkov light emitted by muons produced in muon-neutrino charged-current interactions in water and under-sea rock will permit the reconstruction of the neutrino direction with an accuracy of better than $0.3°$ at high energies. ANTARES will complement the field of view of neutrino telescopes at the South Pole in the low-background searches for point-sources of high-energy cosmic neutrinos and will also be sensitive to neutrinos produced by WIMP annihilation in the Sun or the Galactic centre.

PACS. 95.55.Vj Neutrino, muon, pion, and other elementary particle detectors; cosmic ray detectors – 95.35.+d Dark matter (stellar, interstellar, galactic, and cosmological) – 95.30.-k Fundamental aspects of astrophysics

1 Introduction

Due to their weak interactions with matter and radiation, neutrinos are ideal messengers for the observation of distant astrophysical objects and processes in environments that are opaque to photons. However, the tiny neutrino cross sections at the same time require the instrumentation of huge target masses for neutrino detection, suggesting the use of naturally abundant detection materials, such as water or ice. Several such projects are currently operational [1,2] or in preparation [3,4,5,6].

The ANTARES Collaboration, comprising particle physics, astronomy and sea science institutes from 7 European countries, is constructing a neutrino telescope about 40 kilometres off the French Mediterranean coast, at a depth of 2400 metres. First components have been installed, and prototype detector lines have been deployed and operated between Dec. 2002 and July 2003. The full detector will be completed in 2006.

2 Detector design and physics objectives

The ANTARES neutrino telescope [3] will detect the Čerenkov light emitted by secondary particles produced in neutrino reactions in sea water or in the rock below the sea bed. The detector is optimised for charged-current reactions of muon-neutrinos (yielding a high-momentum muon), but will also be sensitive to other neutrino flavours and to neutral-current reactions. It will consist of 12 lines (*"strings"*) that are anchored to the sea bed at distances of about 70 m from each other and kept vertical by buoys. Each string is equipped with 75 optical modules (OMs) [7] arranged in triplets (*storeys*, see Fig. 1) subtended by titanium frames that also support water-tight titanium containers for the electronic components. The OMs are glass spheres housing one 10-inch photo multiplier tube (PMT) each, directed at an angle of 45° towards the sea bed. The storeys are spaced at a vertical distance of 14.5 m and are interconnected with an electro-optical-mechanical cable supplying the electrical power and the control signals and transferring the data to the string bottom. Submersible-deployed electro-optical link cables connect the strings to the *junction box (JB)*, which acts as a fan-out between the main electro-optical cable to shore and the strings. Each string carries optical beacons for timing calibration and acoustic transponders used for position measurements. The detector will be complemented by an *instrumentation line* supporting devices for measurements of environmental parameters and tools used by other scientific communities, such as e.g. a seismometer.

The PMTs detect photons with a quantum efficiency above 20% for the relevant wave lengths between 330 nm and 460 nm. The time resolution is limited by the transit time spread of about 2.7 ns (FWHM). The PMT sig-

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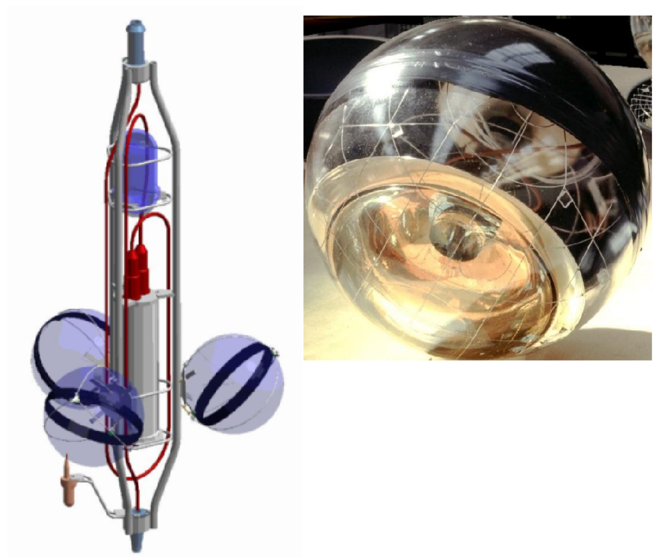

Fig. 1. *Left:* A storey of a string with the three OMs supported by a titanium frame. The cylindrical container for the electronic components (*bottom*) and an optical beacon (*top*) are located inside the frame. *Right:* An optical module. The metal grid inside the sphere is a mu metal cage shielding the PMT against the Earth magnetic field

nals are processed with custom-designed *Analogue Ring Sampler* ASIC chips that measure the arrival time and charge for signals up to about 10 photo electrons and perform wave form digitisation for larger pulses. All signals above an adjustable threshold (usually corresponding to 0.3 photo electrons) are sent to shore, where an online filter running on a PC farm selects event candidates and reduces the data volume recorded on tape to about 1 MB/s.

Muons from muon-neutrino charged-current reactions are finally identified and reconstructed by offline algorithms. From the arrival times of the photons at the PMTs and the OM positions (known to about 5 cm), the trajectory of muons can be determined with a pointing precision of about $0.2-0.3°$, which is the dominant contribution to the experimental uncertainty on the neutrino direction for neutrino energies $E_\nu \gtrsim 10\,\text{TeV}$. The muon energy, E_μ, is determined from the muon range at small energies and from the Čerenkov intensity due to radiative energy losses at high energies. In the latter case, the RMS resolution on $\log E_\mu$ is $0.2-0.3$.

Detailed simulation studies have been performed to assess the physics sensitivity of ANTARES. After 3 years of operation, the ANTARES data will challenge predicted upper limits for diffuse neutrino fluxes [8] and will be sensitive to point source intensities indicated by different models. In Fig. 2, the expected ANTARES sensitivity to muon flux induced by neutrinos from point sources is compared to upper limits from other experiments. Note in particular the complementary sky coverage of AMANDA and ANTARES. The search for neutrinos from gravitational centres, such as the Sun or the galactic centre, yields sensitivity to WIMP annihilation and thus complements direct-search experiments [9].

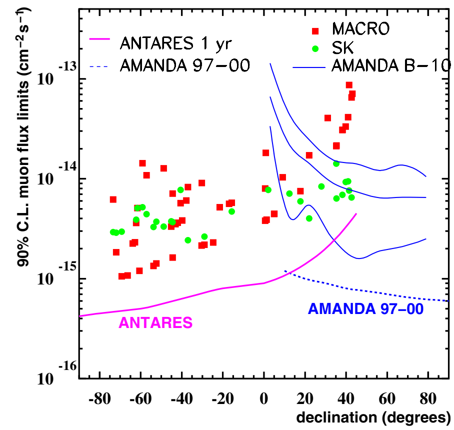

Fig. 2. ANTARES sensitivity to the neutrino-induced muon flux from astrophysical point sources, compared to upper limits from other experiments. The simulation is based on 1 year of ANTARES operation in the final detector configuration

3 The preparatory phase

Since the ANTARES neutrino telescope has to operate in the uncontrollable deep-sea environment of the Mediterranean, the environmental conditions are of prime importance to the site choice and to the detector design. The ANTARES Collaborations has performed a series of more than 40 deployments of explorative devices and prototype modules for site investigations and technical studies. At the ANTARES site, direction and speed of the deep-sea currents, the water transparency, the background rates caused by ^{40}K decays and bioluminescence, the sedimentation, the bio-fouling of the OM surfaces and various other parameters have been repeatedly measured and have been found consistent with the requirements for the detector operation [10].

In 1999, a *demonstrator string* equipped with 7 PMTs, full readout electronics, slow-control devices and an acoustic positioning system was deployed at a depth of 1100 m, connected to an existing telecommunication cable to shore and operated for 8 months. The position and timing calibration have been demonstrated to work as expected, and about 5×10^4 7-fold coincidences from atmospheric muons have been recorded.

4 Detector status

The current status of the ANTARES detector is indicated in Fig. 3. The first component of the final detector configuration, the main electro-optical cable, has been deployed in Oct. 2001 and connected to the shore station. In Dec. 2002, the end of the cable was recovered from the sea-bed, the JB connected to it and subsequently deployed. Communication with the JB slow control is being maintained since then.

Two prototype strings, an optical line with 5 storeys (*prototype sector line, PSL*) and the *mini instrumentation*

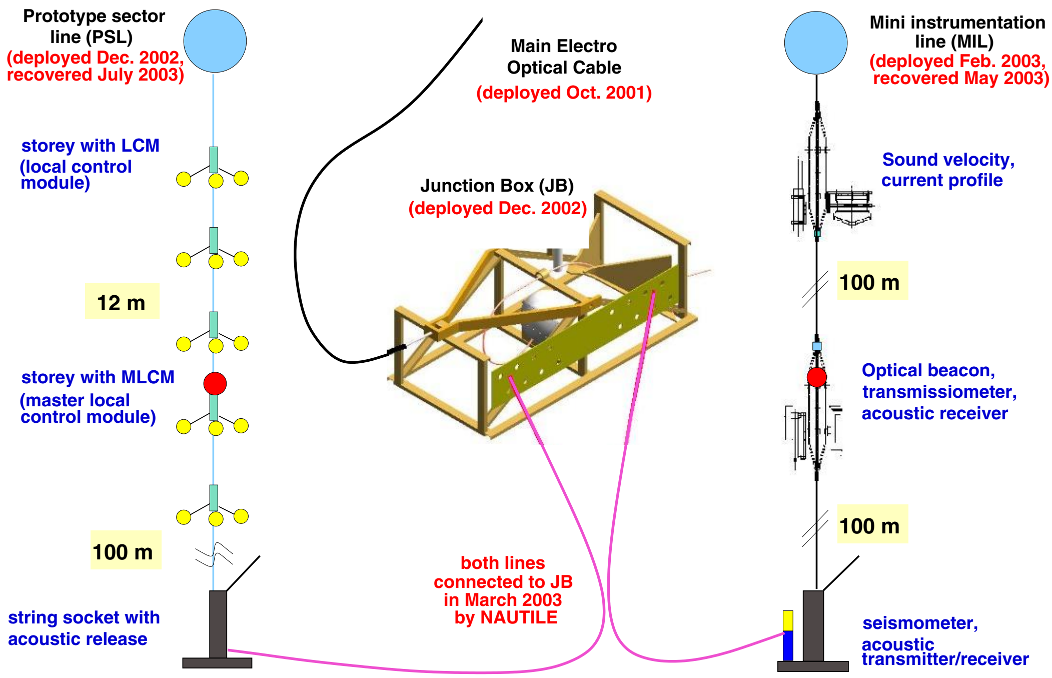

Fig. 3. Components of the ANTARES neutrino telescope and prototype strings deployed by summer 2003

line (MIL), were deployed in Dec. 2002 and Feb. 2003, respectively, and connected to the JB in an undersea operation by the manned submersible *Nautile* in March 2003. Communication with both lines was established immediately after connection. The systems were found to be functional with the exceptions detailed below. A large bulk of data has been acquired and is currently analysed. The lines have been recovered in May (MIL) and July 2003 (PSL).

Two problems occured in the prototype tests: In the MIL, a water leak developed in one of the electronic containers, leading to a short circuit in the power supply that made further operation impossible. After recovery of the MIL in May 2003 a faulty supplier specification for the installation of a connector was identified as reason for the leak; the design has been modified to exclude this problem in the future. The second problem was that in both lines the clock signal, sent from shore to the off-shore electronic modules to synchronise the readout, reached the bottom string socket (BSS) but not the detector. In the MIL, the clock failure was due to a damaged glass fibre in the cable between BSS and first storey, caused by the supplier's use of an unsuited material for the fibre coating. In the PSL, the corresponding investigation is still on-going.

Due to the absence of the clock signal, no data with timing information at nanosecond precision could be taken. Nevertheless, the long-term operation of the PSL over more than 3 months yielded a wealth of information, both on the functionality of the detector and the environmental conditions. In particular, the rate of signals above threshold was monitored continuously for each OM. It was found that the rates exhibit strong temporal variations that are attributed to bioluminescent organisms. A continuous rate, varying between about 50 kHz and 250 kHz per OM, is accompanied by short light bursts that cover between less than 1% and more than 30% of the overall time. Also monitored were the heading and tilt of the PSL storeys. It was found that they move almost synchronously, i.e. the PSL behaves as a pseudo-rigid body in the water current. Correlations of the background rates with the movement of the PSL and hence with the sea currents have been observed. Detailed investigations of the on-line filter requirements imposed by high rates and of relations between water currents, string movements and bioluminescence are under way.

5 Conclusion and outlook

With the installation of the main electro-optical cable and the junction box, the ANTARES project has entered the construction phase. Prototype detector strings have been successfully deployed and operated, verifying the detector design and functionality and yielding a vast amount of environmental data. Failures that occured in a connector to one of the electronics containers and in the transmission of the clock signal will be avoided in the future by implementing modest design modifications. For an ultimate verification of all elements of the detector design, it is forseen to deploy a new instrumentation line combining instrumentation and optical modules in mid-2004. The first final detector string will be installed by the end of 2004. First physics data are expected by 2005, the completion of the detector is scheduled for 2006.

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