Current status of the ANTARES neutrino telescope

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Abstract

The Antares collaboration is currently building a neutrino telescope designed for the detection of cosmic neutrinos of TeV energies. It is located 40 km off the French Mediterranean coast at a depth of 2500m and will, once completed, consist of 12 detection lines with a total of 900 photomultiplier tubes, instrumenting a volume of 0.01 km^3. After several years of prototype studies, most recently with the so-called Mini Instrumentation Line, the ANTARES collaboration has now installed and is operating the first complete detector line. In this paper, the design of the experiment is presented together with first results from the two lines currently in operation.

1 Design and Installation

The ANTARES detector is a water Cherenkov neutrino telescope consisting of an array of photomultiplier tubes (PMTs) suspended in the deep sea, which are used to detect the Cherenkov light emitted by muons created in the reaction of high energy neutrinos in the sea water. Its main aims are neutrino astrophysics, namely the detection of neutrino point sources such as active galactic nuclei or gamma ray bursts, and the search for new physics phenomena, such as WIMPs, magnetic monopoles or nuclearites. In addition, interdisciplinary deep-sea studies are also planned. It is being built by an international collaboration of 21 institutes from 6 European countries. Its location 40 km off Toulon at a depth of 2500m makes it complementary to the south pole experiments AMANDA and IceCube and provides a unique view of the galactic centre as a possible source of neutrinos.

1.1 Detector Design

The completed detector will consist of 12 detection lines, each comprising 25 storeys attached to an electromechanical cable between an anchor, the Bottom String Socket (BSS), and a buoy. The lines will be arranged in an octagonal setup covering a total area of 180 by 180 metres, with an average of 70 m between adjacent lines (as shown in figure 1). Together with an additional Instrumentation Line, the detection lines are connected to the shore via a Junction Box and a 40 km undersea cable. The individual storeys are equipped with 3 10-inch PMTs in pressure-tight glass spheres (so-called Optical Modules, OMs) and a read-out module (the local control module, LCM) mounted on a titanium frame. In addition, a fraction of the storeys is equipped with optical beacons for timing calibrations of hydrophones for acoustic positioning. The individual optical modules face downward at an angle of 45° to reduce the optical background from the dominant down-going atmospheric muons.

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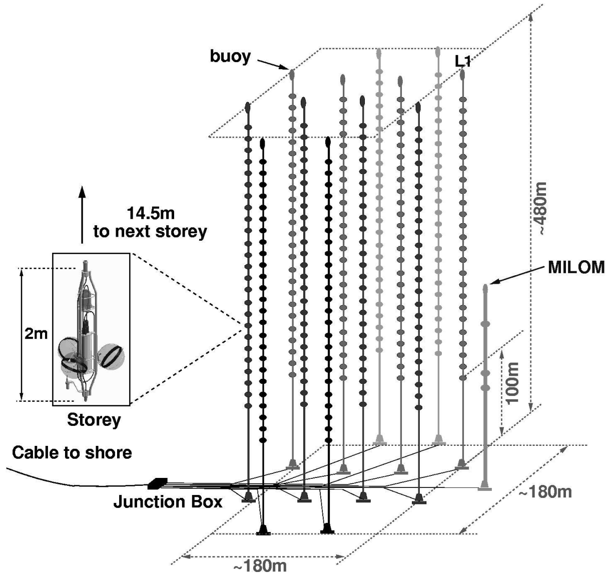

Figure 1: Schematic view of the ANTARES detector. Also shown is one storey with its 3 optical modules (OMs), each containing one PMT (not shown).

1.2 Construction Milestones

After evaluation of the ANTARES site and of the detection principle had been carried out with a number of prototype lines over the course of several years, in 2002 the junction box was installed as the first permanent component of the detector, and has been in operation since then. In April 2005, the so-called MILOM, an instrumentation line equipped with additional optical modules, was installed, followed in March 2006 by the first true detector line, Line 1. Both lines are still in operation and have collected valuable data (see below). After the success of Line 1, the remaining 11 lines will be installed within two years, together with a full instrumentation line replacing the MILOM, so that by the end of 2007 the complete detector will have started collecting physics data.

2 First Results

2.1 Mini Instrumentation Line

The Mini Instrumentation Line (MILOM), deployed on the 18th of March, 2005, is a hybrid prototype line both for optical data-taking and environmental studies. It consists of 3 storeys equipped with optical modules and instruments including acoustic positioning, time calibration, sea-current profiling, light and sound transmission. It also houses an acoustic transducer in the BSS (see figure 2).

One of the main results obtained from the MILOM are the counting rates of the photomultipliers, both of single photons and of correlated events. The singles rates show both long-term seasonal variations of the so-called single photon baseline from the decay of radioactive ^{40}K and from bioluminescent microorganisms between about 50 kHz and 120 kHz and short-term "bursting" behaviour caused by larger bioluminescent organisms. The coincidence rates between two photomultipliers show a contribution from several photons from a single ^{40}K decay hitting two different PMTs. The total rate of coincidences in an 8 ns time window remains stable over time at around 15-20 Hz, in good agreement with calculations.
As bioluminescent organisms react to sea currents, a correlation between sea currents and bioluminescence activity can be expected, and there is indeed a visible correlation between the

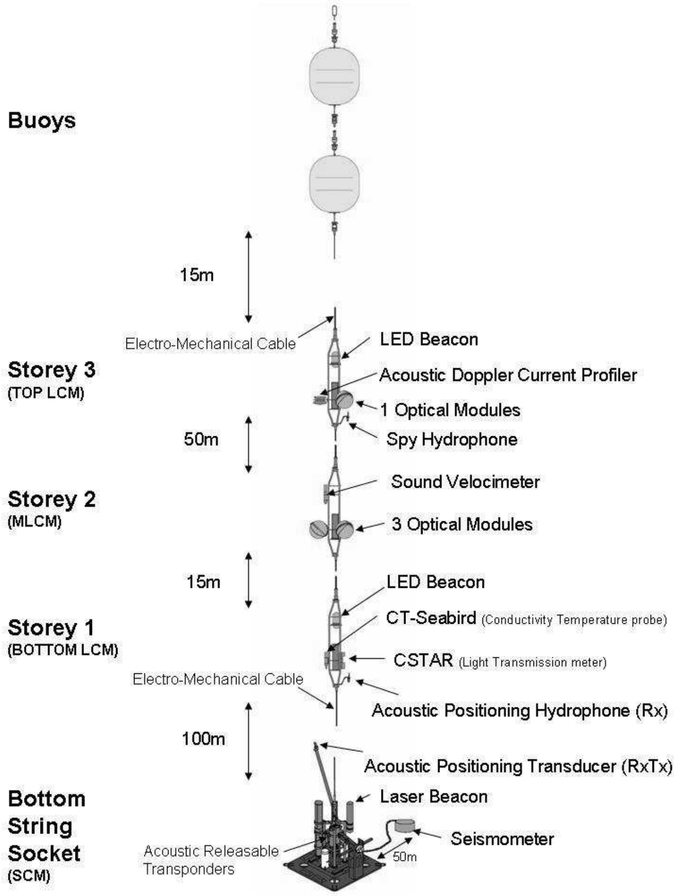

Figure 2: Schematic view of the MILOM showing the different instruments mounted on the line.

counting rates and the current velocity measured by the Acoustic Doppler Current Profiler (ADCP) on the MILOM, showing a significant increase in the bursting frequency with current velocity (see figure 3).

In order to achieve good angular resolution, a precise timing calibration of the optical sensors is important. For this purpose, so-called optical LED beacons are employed, which contain 36 blue LEDs that can be triggered to simultaneously emit a short flash of intense light whose arrival times in the optical modules can be measured and compared with the reference PMT in the beacon. This principle was tested on the MILOM, which contains a LED beacon in storey 1, 15 m below the three optical modules of storey 2. The measured arrival times , shown in figure 4 with offsets removed, follow a Gaussian distribution with a width of around 0.5 ns, as required for direction reconstruction.

As the detector lines are not rigid structures but are held between the BSS and the floating buoy, the position of the optical modules can vary by several metres depending on sea-current direction and velocity. In ANTARES, an acoustic positioning system is therefore used for the determination of the position of each OM. This system was also tested on the MILOM, with the hydrophone receiver on storey one and the RxTx transducers on the BSS of the MILOM and in an autonomous acoustical beacon. A comparison of the measured distances to the known fixed distances between the BSS of the MILOM (175 m horizontal) and the beacon and storey 1 (96 m vertical), respectively, give a resolution of the order of 2-3 mm, much better than the design requirement of $\leq$10 cm.

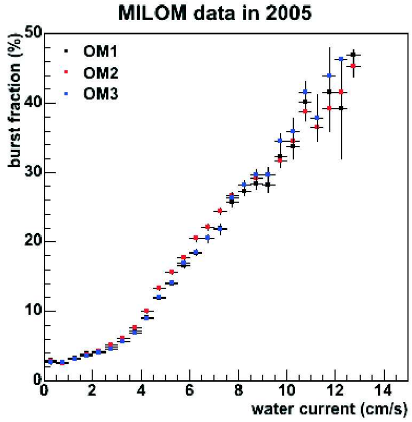

Figure 3: Correlation between current velocity and bioluminescence activity. The burst fraction measures the relative abundance of short bursting events above a steady baseline.

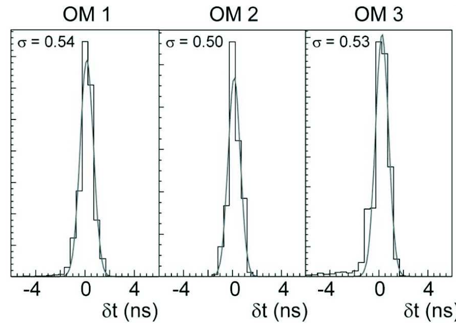

Figure 4: Time distribution of LED signals from the optical beacon in storey 2 of the MILOM recorded by the 3 OMs of storey 3.

2.2 Line 1

After the successful connection of the first complete detector line on March 2, 2006, it was for the first time possible to collect proper physics data and attempt the reconstruction of cosmic muons. Figure 5 shows an example of a reconstructed track of a down-going muon and the hits used for reconstruction (solid dots). First results indicate that, even with a single line, track reconstruction is working well and the addition of more strings will allow the accurate reconstruction of up-going muon (neutrino) tracks and the discrimination from down-going atmospheric muons. In the reconstructed data samples, the statistical distribution of likelihoods agrees well with Monte-Carlo predictions.

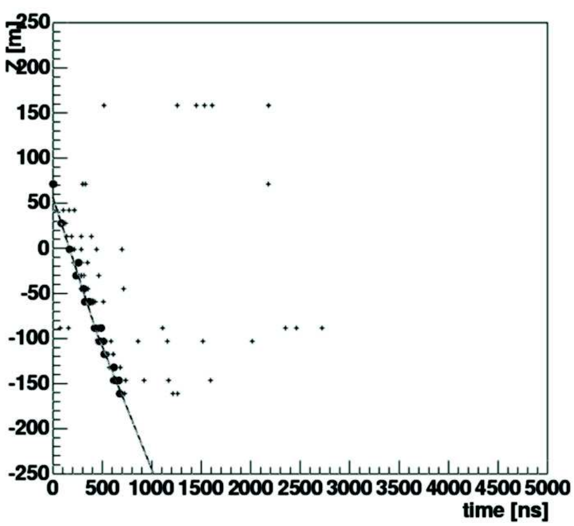

Figure 5: Example of a reconstructed down-going muon track. The solid circles indicate the hits used for triggering the event, the crosses are all hits in the selected snapshot around the triggering hits. The solid line represents the best-fit track, corresponding to a down-going, probably atmospheric, muon event.

Together with the MILOM, combined time calibration studies were performed using the LED beacon on the MILOM and the optical modules on Line 1. Thus, it was possible to analyse different distances ranging from 70 m (the horizontal distance between the lines) to about 350 m (to the top storey of Line 1). Figure 6 shows the arrival time distributions at a distance of 70 m (lower plot) and 150 m (upper plot) from the LED beacon. In the lower storey, the time distribution is close to the timing resolution of the PMT and electronics, whereas in the storey higher up the distribution is widened due to chromatic dispersion and scattering resulting from the greater distance.

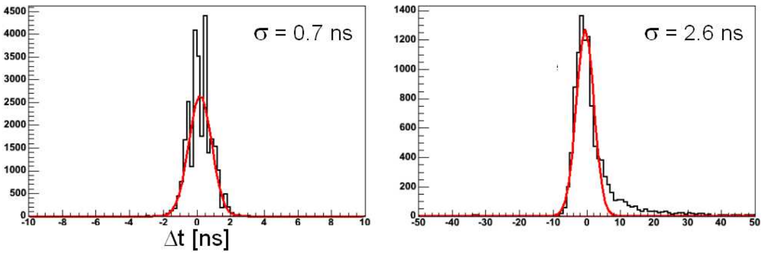

Figure 6: Arrival time distribution in optical modules 150 m (upper) and 70 m (lower) away from the MILOM LED beacon.

3 Conclusions

As of May 2006, both an instrumented prototype string as well as the first detector string of the final setup have been installed at the ANTARES detector site and have been in continuous operation since their connection. First results confirm a stable operation within design specifications, with the timing resolution and positional reconstruction matching or exceeding the required accuracy. First atmospheric muons have also been successfully reconstructed, confirming the correct functioning of both the hardware and software involved.
The full detector, comprising 12 detection lines and an upgraded instrumentation line, is expected to be installed and operational by the end of 2007.

References

References

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