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Status report on the ANTARES high energy neutrino detector

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ANTARES is a neutrino underwater telescope planned to being deployed at a depth of 2500 m in the Mediterranean sea near the Southern French coast. The telescope will use a three-dimensional array of photomultiplier tubes to detect the Cherenkov light emitted in sea water by neutrino-induced muons. The array of 12 lines equipped with 900 photomultipliers is expected to be completed at the beginning of 2007. The main purpose of the experiment is the detection of high-energy neutrinos produced in astrophysical sources such as quasars, microquasars, supernova remnants and gamma-ray burst sources. ANTARES will also be aimed to the indirect search for WIMPs, the preferred candidates for non-baryonic dark matter, by looking for neutrinos from neutralino annihilations in the centres of the Sun, Earth and Galaxy. The expected detector performance is reported. A prototype line and an instrumentation line for monitoring environmental parameters have been successfully deployed. The prototype activities and the present status of the experiment are described.

1. The ANTARES neutrino telescope

The ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) collaboration is building a neutrino underwater telescope planned to being deployed at a depth of 2500 m in the Mediterranean sea near the Southern French coast.
The experiment aims to detect neutrinos with energies above 10 GeV by means of the Cherenkov light emitted in sea water by charged particles which are produced in neutrino interaction.
Such high-energy neutrinos are produced in astrophysical sources such as quasars, microquasars, supernova remnants and gamma-ray burst sources. Given the presence of AMANDA and, in the near future, of IceCube at the South Pole, a detector in the Mediterranean sea will allow the coverage of the whole sky looking for these kind of sources; in particular, from the ANTARES site the Galactic Centre can be observed.
ANTARES will also be aimed to the indirect search for WIMPs, the preferred candidates for non-baryonic dark matter, by looking for neutrinos from neutralino annihilations in the centres of the Sun, Earth and our Galaxy.
In ANTARES the Cherenkov light is detected by a 3D-array of optical modules (OMs): pressure-resistant glass spheres containing phototubes (PMTs). Photon arrival times and PMT charge amplitudes allow the reconstruction of the tracks and the estimate of their energy. The ANTARES detector consists of 12 lines with an effective area of about $0.06\ \mathrm{km}^2$ at 100 TeV. It can be considered as a first step towards the construction of a km^3 detector in the Mediterranean. A junction box distributes the power and clock synchronization signals to the lines and collects the data. It is connected to the shore by a 42 km electro-optical cable. The lines are kept straight by the floating force of a buoy at the top and an anchor at the bottom. They consists of 25 storeys, spaced by 14.5 m starting from 100 m from the sea floor. Each storey contains three 45^0 downward looking $10''$ photomultipliers inside the pressure resistant glass sphere. The electronics boards are inside a titanium cylinder at the center of the storey. Some of them contain supplementary calibration equipment like acoustic or optical beacons. The readout of each PMT signal is shared by two Analog Ring Sampler ASICs which provide the analog signal time and charge digitization. The ARS implements a waveform shape-sensitive discrimination to distinguish single photoelectron-like pulse shapes (more than 98% of events) from larger pulses; for these more complex pulses the pulse shape can be digitized with 1 GHz sampling frequency. Tests have shown that an overall time resolution of ~ 1 ns can be achieved mainly limited by the transit time spread of the PMTs.
All data are sent to the shore station; with a noise light rate of 70 kHz on the single photon level this produces

a data flow of 1 GB/s to the shore. In the shore station a PC farm performs a data filtering to reduce the data rate by at least a factor 100.
The main background for these kind of experiments comes from atmospheric muons. To suppress this background one selects the ν_μ events only out of events that have been reconstructed as up-going ones. The ANTARES angular resolution is about 0.2^0 for $E_\nu > 10$ TeV, where pointing accuracy is limited by the transit time spread of the PMTs and by light scattering in water. At lower energies the pointing accurancy is limited by the angle between the neutrino and the induced muon so that the median angle between the neutrino and the reconstructed muon is for instance 0.7^0 at 1 TeV.

2. Construction status

The ANTARES Collaboration has already tested some lines connected to the shore via undersea cables.
The first such line, the "Demonstrator Line" had been deployed and operated from November 1999 to June 2000 to prove the feasibility of the foreseen project. The shape of the atmospheric muon zenith angular distribution was reproduced, despite the line was instrumented with only 7 PMTs. Moreover it has been verified that the acoustic position system is able to measure relative distances of each OM with a precision of ~ 5 cm and that we are able to deploy at the sea bottom at the metre scale.
In October 2001 the final electro-optical cable for power and data transmission was deployed over a length of 42 km from the detector site to the shore station in La Seyne-sur-Mer, where the control room is located. And since December 2002 the junction box has been in communication with the shore station via the undersea cable.
The next two test lines (called PSL and MIL) were deployed in December 2002 and February 2003 and connected in March 2003 to the junction box by a manned submarine. The PSL was a prototype for a optical detector line and represents 1/5 (a sector) of a full line: 5 storeys with 15 OMs. While the MIL was a prototype instrumentation line equipped with devices to monitor environment parameters (sea currents, sound velocity, salinity, water transparency) and to serve as a calibration tool for the PSL and the subsequent lines since it was equipped with laser and LED beacons. These lines were operated in situ until July and May 2003, respectively. Despite many positive aspects [1] a failure in the line main cable prevent the optical modules to be synchronised and no muon could be reconstructed. A water leak was also encountered in one electronic module. Both problems were investigated and solved.
In Spring 2005 two other test lines were deployed: the LINE 0 and the MILOM.
The prototype line, LINE 0, is the first mechanically complete line deployed; it contains 23 storeys and is very close in all mechanical aspects to a final line, but it doesn't contain any of the electronics for the acquisition from the OMs. It does however contain some autonomous recording devices ("Tinytags") for monitoring fiber optic transmission, leaks and various aspects of electricity connections. The LINE 0 deployment took place in two steps: a first deployment on 15 March 2005 with the line remaining for 1 hour on the seabed followed by an immediate recovery and return to shore for verifications. Then the line was redeployed on 17 March and was connected to the junction box by the remote operated vehicle VICTOR on 13 April. On 12 May, after one month being connected to the shore, the LINE 0 was recovered.
The analysis of the data from LINE 0 was performed both on 16 March and after the final recovery: the results are consistent. There were no water leaks in electronics containers and no electrical conductivity or insulation problems. There were however optical transmission losses at a number of locations in the line during the periods in which the line was on the seabed; the transmission recovered completely when the line returned to the surface. The problem is under intense investigation and the cause as been identified at the entry and exit of the optical fibers from some of the LCM cylinders.
The MILOM line (Figure 1) is a modified version of the instrumentation line (MIL) and represents a key el-

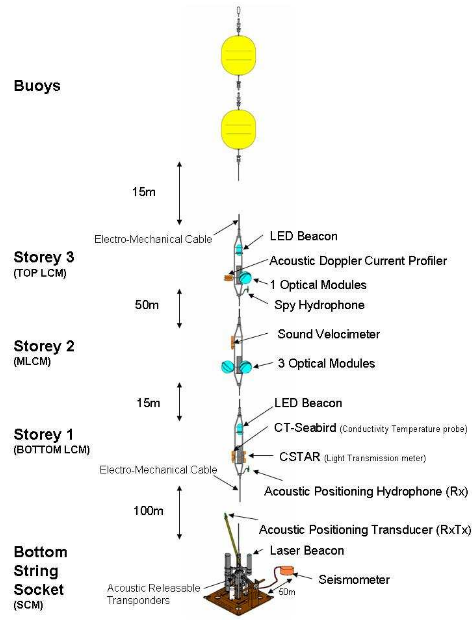

Figure 1. Layout of the MILOM line.

ement of the detector: it is intended to monitor the deep sea environment and will be used for absolute time calibration. It is equipped with LED beacons that are able to illuminate the full detector during a very short time. It also contains a full storey equipped with three optical modules and the final electronic cards. This allows the study of the detector response in real conditions before the first detection lines are immersed. The MILOM was deployed in the sea on 18 March 2005 and connected to the junction box on 12 April 2005.
Results from the MILOM are summarized in the next section.
Meanwhile the mass production for the full scale detector has started. For LINE 1, all optical modules are already available and all electronics containers should be available by July 2005. The line assembly must wait for the solution to the optical transmission problem observed in LINE 0. Then the assembly of the 12 ANTARES lines will rapidly start and in the peak of the production process it is planned to deploy approximately one line per month during 2006. With this schedule it is planned that the detector will be complete and fully operational early in 2007.

3. Results from the MILOM

Clock Calibration: The excellent angular resolution of the ANTARES neutrino telescope relies on good timing resolution of the light signals recorded in the OMs. A very precise time reference clock distribution system has been implemented in order to obtain the necessary time resolution in the electronics (< 0.5 ns). With the operation of the MILOM the clock system has been verified in the sea environment for the first time. The time delay measured with the clock calibration over the distance of 42 km between the shore station and the SCM at the bottom of the MILOM shows a spread of the data over the 48 days of operation of about 1.5 ns. The measured delay in the clock system within the MILOM between the SCM and the top storey indicates a time resolution of ~ 0.01 ns very much within the specifications.

Optical Module Timing Resolution: The LED beacon is the optical beacon system used to measure the complete timing resolution of the OMs with the MILOM. The LED beacon contains 60 individual LEDs synchronised in time and arranged to give reasonable isotropic light emission, and a small PMT to monitor the output light pulse time spread (~ 4 ns) and amplitude. In the MILOM the LED beacon is located in the first storey and the three OMs in the second storey at a distance of about 15 m. The test on the timing resolution in the OMs is performed by pulsing the LED beacon with a frequency of 1 kHz and studying the differences between the signals recorded by two OMs within a certain time window. The distribution of differences shows a peak with $\sigma \sim 0.7$ ns, which yields a timing resolution of one Optical Module of ~ 0.5 ns.

Acoustic Positioning Resolution: The second essential element to realise the best angular resolution of the neutrino telescope is the knowledge of the position in 3D space of the OMs with a precision of $10 \div 20$ cm in real time. These position measurements are provided by the acoustic positioning system. Again the MILOM provides the final proof that ANTARES can achieve the necessary spatial position and so completing confidence that the good angular resolution will be obtained.
The full acoustic positioning system will consist of a 3D array of transponders and receivers exchanging precisely timed acoustic signals between each other. At the present time only a limited number of devices are installed in the site: one transponder and one receiver are installed on the MILOM. Later on 10 May an autonomous trasponder line was deployed at 84 m from the MILOM, and on 17 June further transponders ("pyramids") were deployed on the seabed.
At the present only 1D measurements between fixed points are preformed and for raw data the precision is < 3 cm. It is expected that, when appropriate corrections for variations in sound velocity and orientations of the storey can be included in the analysis, that the spread on the data will be greatly reduced.

MILOM instruments: The Acoustic Doppler Current Profiler (ADCP) on the MILOM measures the sea current as a function of the depth from the top storey on the MILOM to 160 m down towards the seabed.
Another important instrument on the MILOM is the CSTAR device which measures the water transparency. The CT-Seabird device measures the sea temperature and conductivity from which the salinity and density can be calculated. A separated instrument measures the sound velocity.
Each storey of the MILOM also contains a compass/tiltmeter to measure the line orientation. These devices are standard throughout the ANTARES detector and supplement the position information from the acoustic positioning devices, both adding precision and providing checks.

4. Conclusions

The recent operation of the MILOM and LINE 0 has been an immense advance in the ANTARES project. The elements necessary for obtaining the excellent angular resolution of the detector have been proven.
The construction of the ANTARES detector has started and data from the complete detector can be expected in 2007.

References

[1] M. Circella et al. (The ANTARES Collaboration), "Toward the ANTARES Neutrino Telescope: Results from a Prototype Line", ICRC 2003.