The ANTARES neutrino telescope: status report

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Abstract

To detect neutrinos from astrophysical sources and explore the Universe, the ANTARES collaboration [1] is building a large neutrino telescope in the Mediterranean Sea. This detector will consist in a 3D array of photomultiplier tubes, designed to detect the Cherenkov light emitted in sea water by neutrino-induced muons. The R&D phase of the project came to a conclusion with the deployment and submarine connections of the junction box, the pre-production sector and instrumented lines. We will briefly describe the detector and its expected performance. Then, results from the period of operation of the lines will be discussed, and plans of the collaboration for the next years will be presented.

A major part of our knowledge of the universe derives from the observation of photons. However, these observations have their limitations. Because of their interaction with the infrared or cosmological diffuse background, photons of energies above 10^{14} eV cannot travel further than 10 Mpc. Cosmic rays opened a new window to observe the sky, but GZK effect limits the observation to a depth of 50 Mpc above 10^{20} eV.

The weakly interacting nature of neutrinos, combined with the fact that they are not deflected by magnetic fields, make them unique messengers to explore high energy sources in particular at large distances (> 50 Mpc). Neutrinos are expected to be produced in cosmic accelerators present for example in active galactic nuclei, microquasars [2] or gamma ray bursts [3]. They may also be produced in the annihilation of neutralinos trapped in the core of massive objects, like Earth, Sun or Galactic Centre, giving an opportunity to detect dark matter [4].

1 The ANTARES neutrino telescope

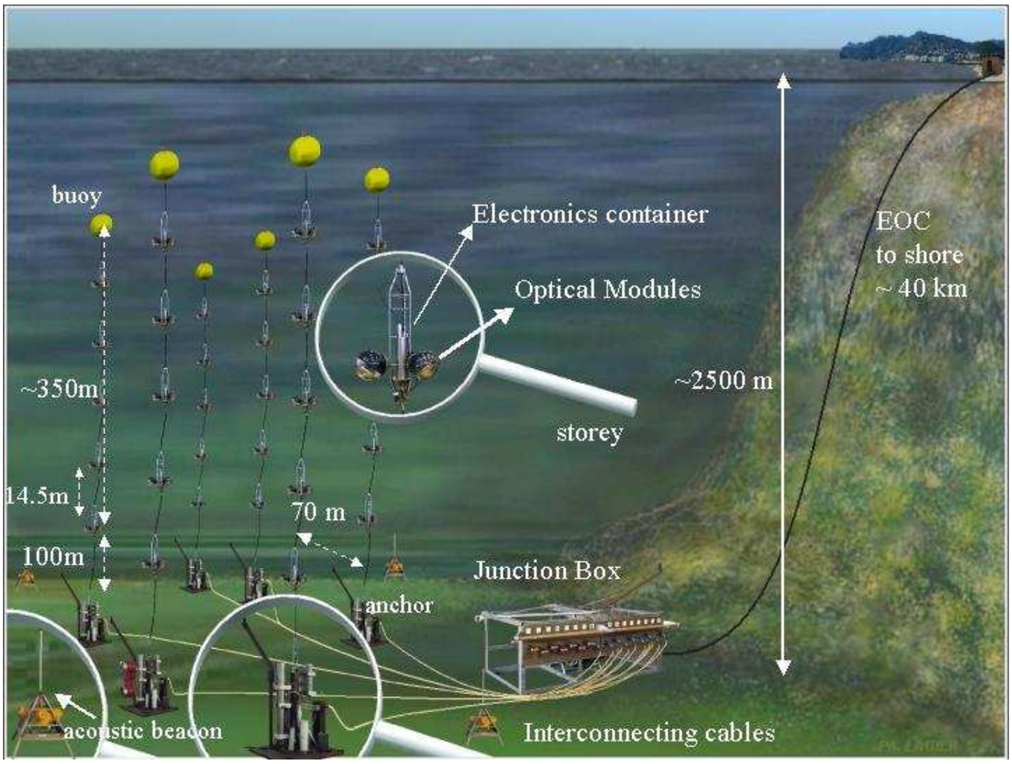

Figure 1: Schematic view of the ANTARES detector

To detect high energy neutrinos, a very large instrumented volume is needed. ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) will use the Mediterranean Sea water as a neutrino detector. The Earth will act as a target in which neutrinos will produce muons. These muons will radiate Cherenkov light when passing through the sea water. Detecting this light with a 3D array of light sensors with accurate timing capabilities, will allow to reconstruct the direction and energy of the neutrinos.

The ANTARES collaboration started in 1996 and involves physicists, astronomers, sea science experts and engineers from France, Germany, Italy, Russia, Spain, The Netherlands and the United Kingdom. ANTARES will deploy the detector in the Mediterranean Sea (42° 50' N 65° 10' E) at a depth of about 2500m, 40km off the French coast, near Toulon. This location will give an annual sky coverage of about 3.5π sr. The neutrino telescope will consist of 12 lines arranged on the sea bed in an octagonal geometry. Each line is a chain of 25 storeys, ended at the bottom by an anchor, and at the top by a buoy. Fig 1 gives a schematic view of the detector. Each storey is composed of a triplet of optical modules (10 inch PM in a pressure resistant glass sphere), and a titanium cylinder housing the local electronics. The line is equipped also with hydrophones for line positionning, with tiltmeters to reconstruct the line shape, with compasses to indicate the storey orientation, and with pulsed light sources for timing calibration. Lines will be connected from their anchor to the junction box, linked to the coast by a 50 km electro-optical cable.

The geometrical parameters of the lines have been chosen after an intensive measurement program of site properties : water current, optical background, water transparency and sedimentation [5] [6]. Seasonal variations of these parameters could influence the performance of the detector, and a dedicated line to measure these parameters will be part of the detector. This line is a possible facility for long term measurements of sea parameters, extending the scientific goals of ANTARES to oceanography, sea biology or seismology.

2 Expected performance

The capability of Antares to detect point like sources and diffuse fluxes can be characterized by several parameters such as the effective area (the ratio of the number of events to the incoming flux), the angular and energy resolutions. These quantities have been estimated for the 12-lines detector by Monte Carlo simulations.

Fig 2 shows the neutrino effective area for neutrino detection as a func-

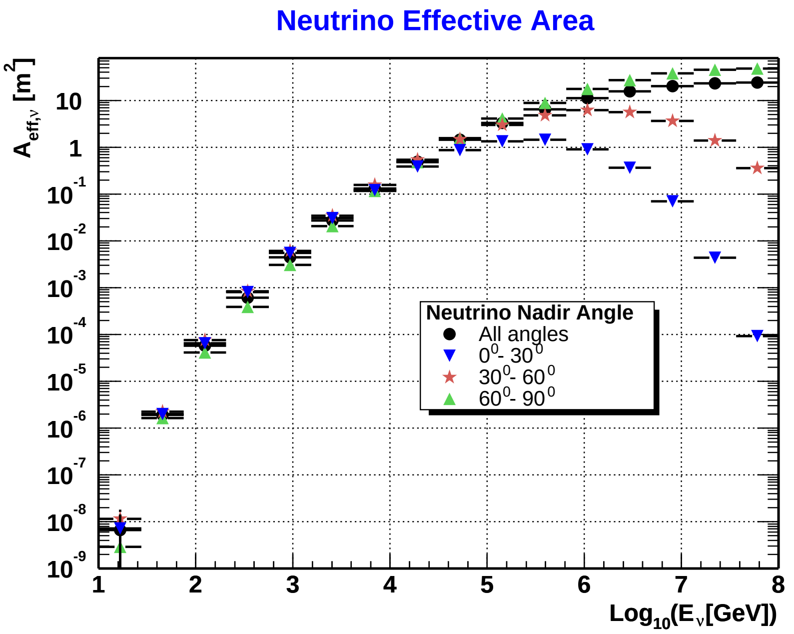

Figure 2: Effective area for neutrinos

tion of the neutrino energy, for uniform angular event distribution (circles), and for different nadir angles of the source position (triangles). The effective area increases rapidly up to 1 PeV, then saturates for uniform angular distribution and horizontal neutrinos. The earth opacity decreases the effective area for vertical neutrinos.

Fig.3 shows the median of the distribution of the angle between the reconstructed muon and the parent neutrino (or the produced muon), as a function of the neutrino energy. For neutrino energy lower than 10 TeV, the angular resolution is dominated by $\nu - \mu$ scattering. At higher energies, the pointing accuracy is about $0.2°$, which is very helpful to reject the background in case of point like sources searches.

Above 1 TeV the muon energy logarithm is estimated with an accuracy of 0.2-0.4, using the amount of light deposited in the PMTs. A more accurate measurement is obtained at low energy (below 200 GeV), using the muon path in the water.

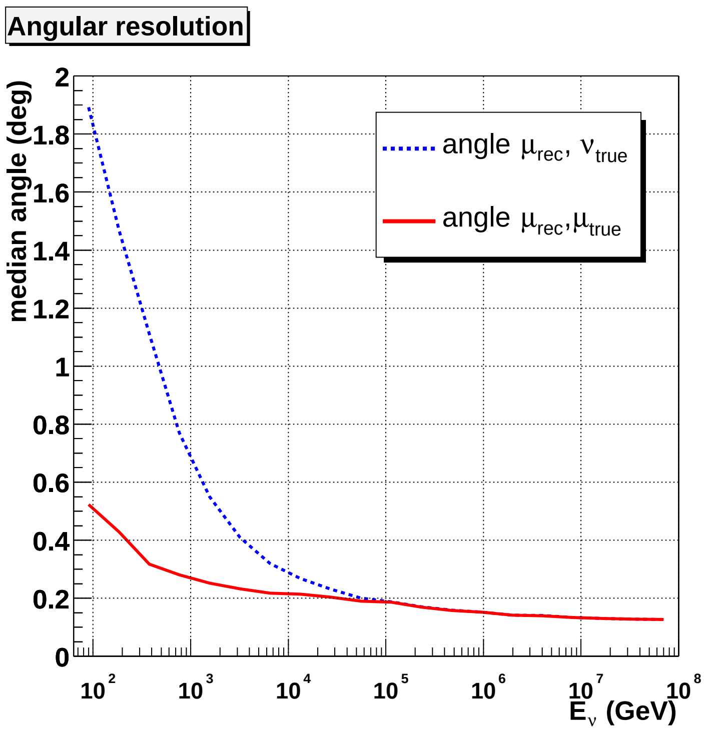

Figure 3: Angular resolution

3 Pre-production Sector Line and Mini Instrumentation Line

Before launching the production of the lines, the ANTARES collaboration decided to build and deploy two prototype lines; the pre-production sector line (PSL) and the mini instrumentation line (MIL). The first one is the basic building block of the detector line: a sector (5 storeys equipped with 15 OMs), that is the minimal functional unit in terms of power supply and data transmission. The second one is instrumented with devices to monitor the environmental parameters: laser calibration system, current meter, positioning systems.

Before the deployment, a series of sea operations has been successfully performed. In October 2001, the electro optical cable for power and data transmission was successfully deployed. On December 9^{th} 2002, after dredging and lifting of 2.5 km of this cable, the junction box has been connected

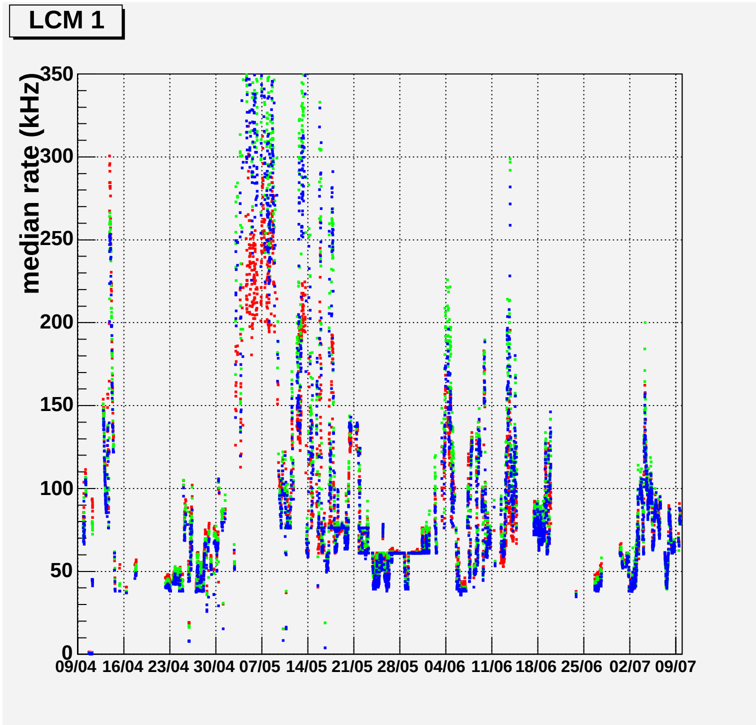

Figure 4: Baseline rate as a function of elapsed time

to it on the deck of a boat, and then immersed at the ANTARES site. The site was at that time ready to host the first lines.

The prototype lines were deployed in December 2002 and February 2003, and connected to the junction box by NAUTILE (manned submarine from IFREMER) on March 16^{th} and 17^{th} 2003.

The lines took data continuously till their recovery: May 2003 for the MIL and July 2003 for the PSL.

Two problems occured during the prototype tests. A water leak, due to a bad specification in the tolerance of the hole's dimension of a specific type of connector, in one of the electronic containers of the MIL made its operation not fully secure. To avoid a possible propagation of the water leak, the line was recovered in May 2003. A broken fiber in the electro-mecanical cable of the PSL prevented the propagation of the clock signal from the bottom of the PSL to the first storey. This failure did not allow the data taking at nanosecond precision level, which is needed for muon track reconstruction.

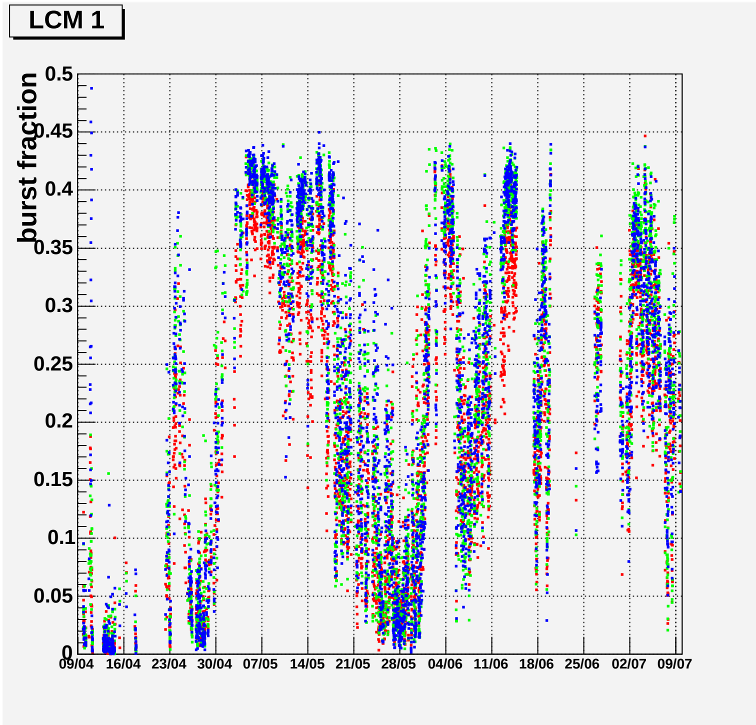

Figure 5: Burst fraction as a function of elapsed time

Nevertheless, counting rates of the optical modules were recorded during the whole data taking period (about 100 days). These measurements give relevant information on the optical background. The general behaviour of the counting rate of an optical module, as a function of time, is the superposition of bursts due to light flashes produced by bioluminescent organisms on a baseline coming from β decay of K^{40} and from bacteria. Figures 4 and 5 present the results obtained with the PSL. The first one shows the median value of the distribution of the baseline for 15mn, over the whole data taking period, for the 3 OMs of one storey. The second one shows the burst fraction in the same conditions. The burst fraction is the fraction of time that the rate is 20 percent higher than the median rate. These new data confirm previous measurements with stand alone lines [6], but show larger variability. Correlations with the sea currents have also been observed.

The heading and tilt of the storeys of the PSL have also been recorded during this operation. The main conclusions are that the line is in average close to vertical, the maximum tilt observed is 1°. The storeys rotate coherently: the line behaves as a pseudo-rigid body in the water current.

4 Conclusions

The construction of the ANTARES neutrino telescope in the Mediterranean Sea has started. The main electro-optical cable and the junction box have been deployed on the ANTARES site. Two prototype lines have been operated in 2003. These tests have been useful to validate technical choices and marine operations. Data from these tests have been analysed. Some problems occured, which have been corrected and do not modify the general design of the detector. A last verification will be the deployement of a mixed line (a combination of MIL and PSL) in early 2005, just before the first line. The full 12 strings detector of $0.1km^2$ scale will be in place by 2007.

ANTARES is a first step toward a km^3 detector. Discussions are under way in a larger scientific collaboration to design such a detector in the Mediterranean sea.

References

[1] more information on the detector and publications of the collaboration can be found on the ANTARES web page: http://antares.in2p3.f

[2] Distefano et al.: ApJ 575 (2002) 378.

[3] Waxmann and Bahcall : PRL 78 (1997) 2292.

[4] Edsjö and Gondolo : PR D56 (1997) 1879.

[5] P.Amram et al. Astroparticle Physics 19 (2003) 253.

[6] P.Amram et al. Astroparticle Physics 13 (2000) 127.