



The ANTARES neutrino telescope: a status report

A. KOUCHNER¹ ON BEHALF OF THE ANTARES COLLABORATION

¹Laboratoire AstroParticle and Cosmology

10, rue A. Domon et L. Duquet, 75205 Paris Cedex 13, France.

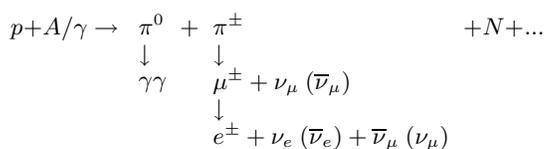
kouchner@apc.univ-paris7.fr

Abstract: ANTARES is a large volume neutrino telescope currently under construction off La Seyne-sur-mer, France, at 2475m depth. Neutrino telescopes aim at detecting neutrinos as a new probe for a sky study at energies greater than 1 TeV. The detection principle relies on the observation, using photomultipliers, of the Cherenkov light emitted by charged leptons induced by neutrino interactions in the surrounding detector medium. Since late January 2007, the ANTARES detector consists of 5 lines, comprising 75 optical detectors each, connected to the shore via a 40 km long undersea cable. The data from these lines not only allow an extensive study of the detector properties but also the reconstruction of downward going cosmic ray muons and the search for the first upward going neutrino induced muons. The operation of these lines follows on from that of the ANTARES instrumentation line, which has provided data for more than a year on the detector stability and the environmental conditions. The full 12 line detector is planned to be fully operational early 2008.

Scientific motivations

One of the major aims of neutrino astronomy is to contribute solving the fundamental question of the origin of high energy cosmic rays (HECR). Neutrinos can indeed escape from the core of the sources and travel with the speed of light through magnetic fields and matter without being deflected or absorbed. Therefore they can deliver direct information about the processes taking place in the core of the production sites and reveal the existence of undetected sources. At high energies, neutrinos are unmatched in their capabilities to probe the Universe.

High energy neutrinos are produced in a beam dump scenario in dense matter via pion decay, when the accelerated protons interact with ambient matter or dense photon fields:



Good candidates for high energy neutrino production are active galactic nuclei (AGN) where the accretion of matter by a supermassive black hole

may lead to relativistic ejecta [1]. Other potential sources of extra-galactic high energy neutrinos are transient sources like gamma ray bursters (GRB). As many models [2] for GRBs involves the collapsing of a star, acceleration of hadrons follows naturally. The diffuse flux of high energy neutrinos from GRBs is lower than the one expected from AGNs, but the background can be dramatically reduced by requiring a spatial and temporal coincidence with the short electromagnetic bursts detected by a satellite.

High Energy activity from our Galaxy has also been reported by ground based gamma-ray telescopes. Many astrophysical sources [3] are candidates to accelerate hadrons and subsequently produce neutrinos. Such sources could only be observed by a northern neutrino telescope like Antares.

Neutrino telescopes are also sensitive to signals due to the annihilation of neutralinos, gravitationally trapped inside the core of massive objects like the Sun, the Earth or the Galactic centre [4].

Finally, deep-sea neutrino telescopes enable researches in the fields of marine biology, oceanography and seismology.

Detection principle

The neutrino's advantage, the weak coupling to matter, is at the same time a big disadvantage. Huge volumes need to be monitored to compensate for the feeble signal expected from the cosmic neutrino sources. In this context, the water Cherenkov technique offers both a cheap and reliable option.

The detection principle relies on the observation, using a 3 dimensional array of photodetectors, of the Cherenkov light emitted, in a transparent medium, by charged leptons induced by charged-current neutrino interactions in the surrounding detector medium.

Thanks to the large muon pathlength, the effective detection volume in the muon channel is substantially higher than for other neutrino flavours. The higher the neutrino energy the smaller the deviation between the muon and the neutrino (typically $\Delta\theta \simeq \frac{0.7^\circ}{(E_\nu(\text{TeV}))^{0.6}}$), thus enabling to point back to the source with a precision close to the one achieved by gamma-ray telescopes. Muon trajectories are reconstructed using the time and amplitude from the photodetector signals.

The energy of the event is estimated thanks to the energy deposited in the detector. Monte Carlo simulations for sea water predict a muon energy estimation by a factor of 2-3.

Cosmic particles penetrating the atmosphere undergo a cascade of many secondary particles. Among them, high energy muons can reach the detector and constitute a very intense source of background. To suppress this background the detector concentrates on upward detection. As a result, the field of view is restricted to one half of the celestial sky (2π sr). Severe quality cuts criteria are then applied to the reconstruction to remove remaining mis-reconstructed muons. Atmospheric neutrinos produced in the atmospheric cascades can travel through the Earth and interact in the detector vicinity. To some extent this background is irreducible. Fortunately, the atmospheric neutrino flux shows a dependency upon energy $dN/dE \propto E^{-3.7}$ while cosmic neutrinos are expected to exhibit a flux dependency $dN/dE \propto E^{-2}$. An excess of events above a certain energy can therefore be attributed to extraterrestrial neutrinos.

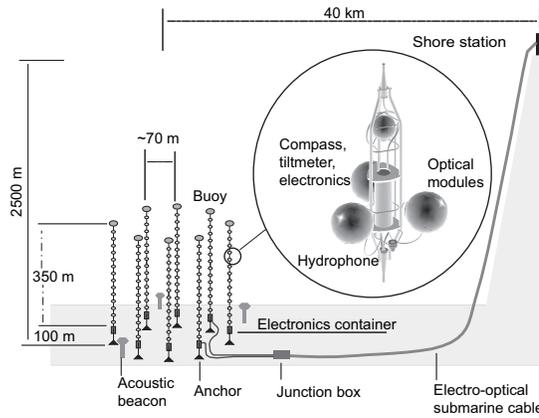


Figure 1: Schematic layout of the future Antares detector. The full detector will consist of 12 lines connected to a junction box (deployed in December 2002) and operated from shore in remote mode through an electro-optical cable.

The Antares Detector

Antares is a large European collaboration¹ currently deploying a 2475 m depth detector 40 km off La-Seyne-sur-Mer (Var, French Riviera) at a location $42^\circ 50' N, 6^\circ 10' E$. The site benefits from the close infrastructures of the French sea science institute IFREMER. The sea water properties have been extensively studied revealing low light scattering, mainly forward [5] and an average optical background (induced by bacteria and ^{40}K decays) of 70 kHz per detection channel.

The final detector will consist of an array of 12 flexible individual mooring lines separated from each other on the sea bed by 60-80 m. Figure 1 shows a sketch of the detector. The lines are weighted to the sea bed and held nearly vertical by syntactic-foam buoys. Each line will be equipped with 75 photomultipliers [6] housed in glass spheres, referred to as optical modules (OM). The OMs are inclined by 45° with respect to the vertical axis to ensure maximum sensitivity to upward moving Cherenkov light fronts. Expected performances, in particular in the frame of point source searches are described in [7].

1. for a complete list of the antares members see <http://antares.in2p3.fr>

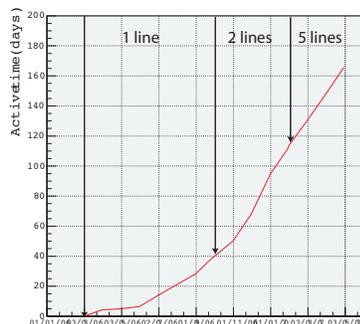


Figure 2: Integrated number of effective days of data taking since March 2006 taking into account all losses.

The default readout mode [8] of the detector is the transmission of the time and amplitude of any light signal above a threshold corresponding to 1/3 of a photo-electron for each OM. Time measurements are relative to a master reference clock signal distributed to each storey from shore via an electro-optical cable. The grouping of three optical modules in a storey allows local coincidences to be made to eventually reduce the readout rate. In addition the front end electronics [9] allows a more detailed readout of the light signal than the standard time and amplitude mode. With this detailed readout it is possible to sample (up to 1 GHz) the full waveform of the signal with 128 channels, enabling special calibration studies of the electronics.

First results from deep-sea

A mini-instrumented line equipped with 3 OMs (MILOM) and mainly dedicated to study environmental parameters (sea current, salinity, pressure, temperature...) has been in operation since spring 2005. The results of this line are presented in details in [10]. Since the end of January 2007, the detector consists of 5 operating detection lines. At this stage, Antares is the largest neutrino telescope ever built in the northern hemisphere. Data with 2 lines have been taken since October 2006 and with one line since March 2006. Figure 2 gives an indication of the data taking efficiency since the connection of the first line, which has been con-

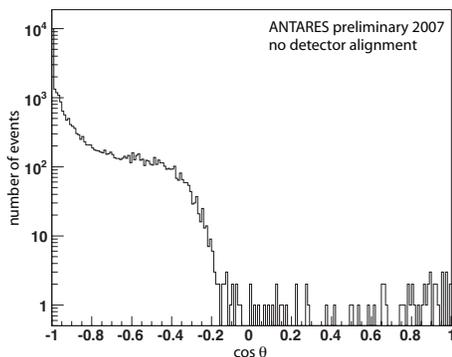


Figure 3: The zenith angle distribution of data taken during Feb-May 2007 with a quality cut based on the fit likelihood. This preliminary reconstruction is based on the nominal positions of the OMs. Alignment data, now available, will considerably improve the reconstruction efficiency. While most of the tracks are reconstructed in the downward-going direction there is a steep fall around $\cos\theta = -0.2$ as expected from the flux of cosmic ray muons. Some upward going events are seen which are candidates for neutrino events.

tinuously improving. In spring of 2007 two further lines were immersed and two more lines will be deployed in July. These latter four lines are planned to be connected in September 2007. The detector is expected to be complete early 2008.

The line motions are monitored by acoustic devices (high frequency long base line LBL) and by inclinometers regularly spread along the line, allowing redundancy. The system allows a location of each OM with a precision close to 10 cm. Timing calibration is ensured by a network of laser and LED beacons [11]. According to the design specifications, a precision measurement of 0.4 ns is achieved which guaranties an angular resolution within expectations ($< 0.5^\circ$).

The existing 5 line data are dominated by downward going muon bundles, the present trigger rate being roughly 1 Hz. The reconstruction program fits a single track to these events under the assumption that light is emitted under the Cherenkov angle w.r.t the muon path. The angular distribution obtained, after quality cuts, is shown in figure 3. As one can see, upward candidates are also present

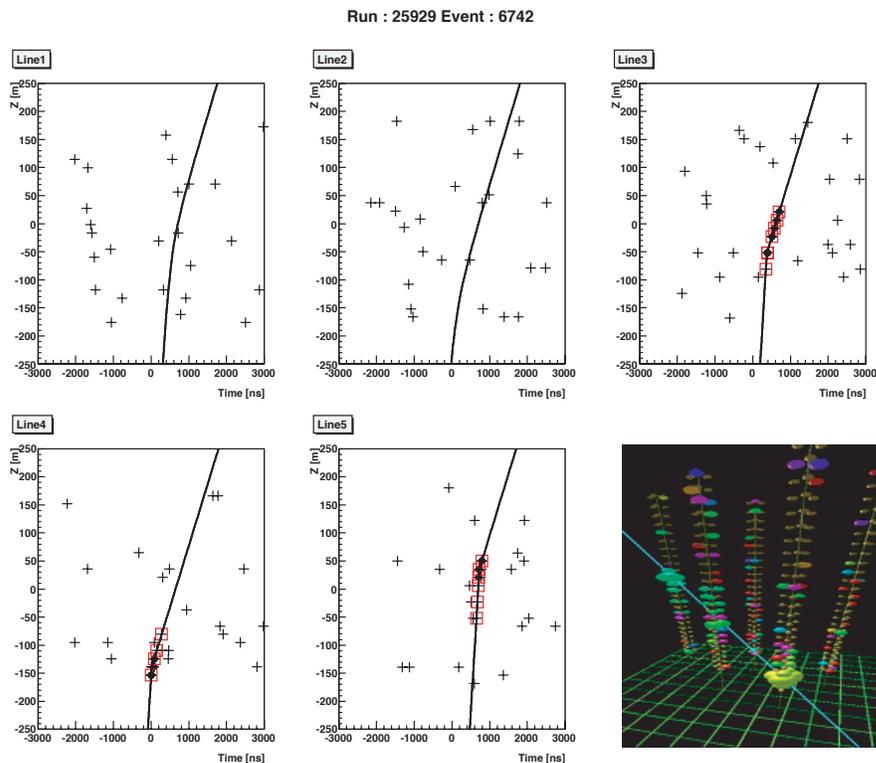


Figure 4: Example of atmospheric neutrino induced muon candidate obtained with the 5 line detector. Each plot shows a single line hit distribution as a function of time. The bottom-right drawing is a 3D display of the same event. The muon trajectory is reconstructed upgoing with a zenith angle 35.4° away from vertical.

in the reconstructed sample. One of these neutrino candidates is displayed in figure 4.

Conclusions

Great achievements have been made by the Antares collaboration in the last year. The detector is working in nominal mode with 5 lines and should be complete early 2008. Upward neutrino candidates have been found that validate the conceptual method and the chosen techniques. Very exciting times have started with a detector looking for neutrinos in a region of the celestial sky which has never been studied with such a level of sensitivity.

References

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