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THE ANTARES NEUTRINO TELESCOPE
A STATUS REPORT

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1 Introduction

ANTARES is a large volume neutrino telescope installed 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. The ANTARES detector is complete since June 2008 with 12 lines, comprising 75 optical detectors each, connected to the shore via a 40 km long undersea cable. The detector is now complete and working. It has already recorded several hundredth of atmospheric neutrino event candidates and is ready for physics analyses.

2 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:

$$\begin{array}{rccc} p + A/\gamma \rightarrow & \pi^0 + & \pi^{\pm} & +N+... \\ & \downarrow & \downarrow & \\ & \gamma\gamma & \mu^{\pm}+\nu_\mu(\bar{\nu_\mu}) & \\ & & \downarrow & \\ & & e^{\pm}+\nu_e(\bar{\nu_e})+\bar{\nu_\mu}(\nu_\mu) & \end{array}$$

Good candidates for high energy neutrino production are active galactic nuclei (AGN) where the accretion of matter by a supermassive black holemay lead to relativistic ejecta (Halzen & Zas). Other potential sources of extra-galactic high energy neutrinos are transient sources like gamma ray bursters (GRB). As many models (Piras T.) for GRBs involves the collapse 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 (Bednarek *et al.*) 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 (Falchini E.). Finally, deep-sea neutrino telescopes enable researches in the fields of marine biology, oceanography and seismology.

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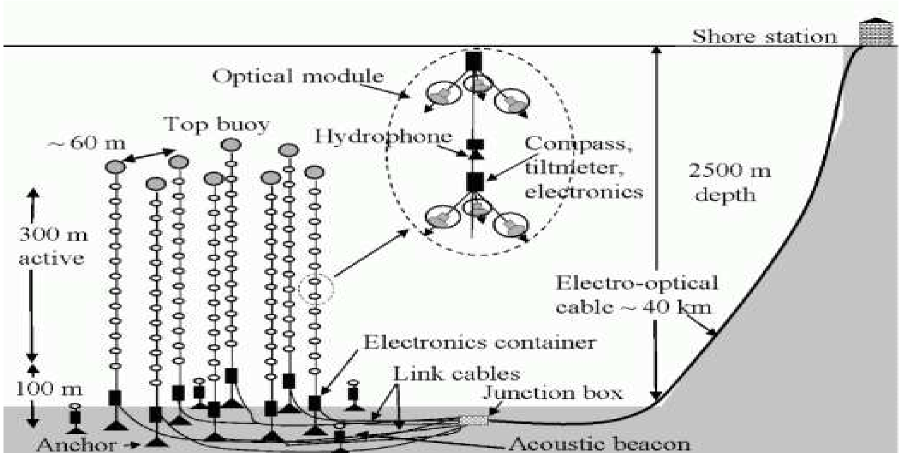

Fig. 1. Schematic layout of the Antares detector. The detector is connected to a junction box (deployed in December 2002) and operated from shore through an electro-optical cable. The actual detector has 12 lines.

3 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 de-tector 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 $\Delta\theta \simeq (E_\nu(TeV))^{-0.6}$), 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.

4 Detector description

Antares is a large European collaboration[1] which has deployed and now operates a 2475 m depth detector 40 km off La-Seyne-sur-Mer (Var, French Riviera) at a location 42o 50 N, 6o 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 (Antares Astrop. Phys. 2005) and an average optical background (induced by bacteria and 40 K decays) of 70 kHz per detection channel. The final detector consists of an array of 12 flexible individual mooring lines separated from each other on the sea bed by 60-80 m.

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[1] for a complete list of antares member see http://antares.in2p3.fr

Figure 1 left 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 nequipped with 75 photomultipliers (Antares NIM A 2005) housed in glass spheres, referred to as optical modules (OM). The OMs are inclined by 45 o 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 (Aguilar J.A.).

The default readout mode (Antares 2006) 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 electrooptical 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 (Fehr F.) 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.

5 First results from deep-sea

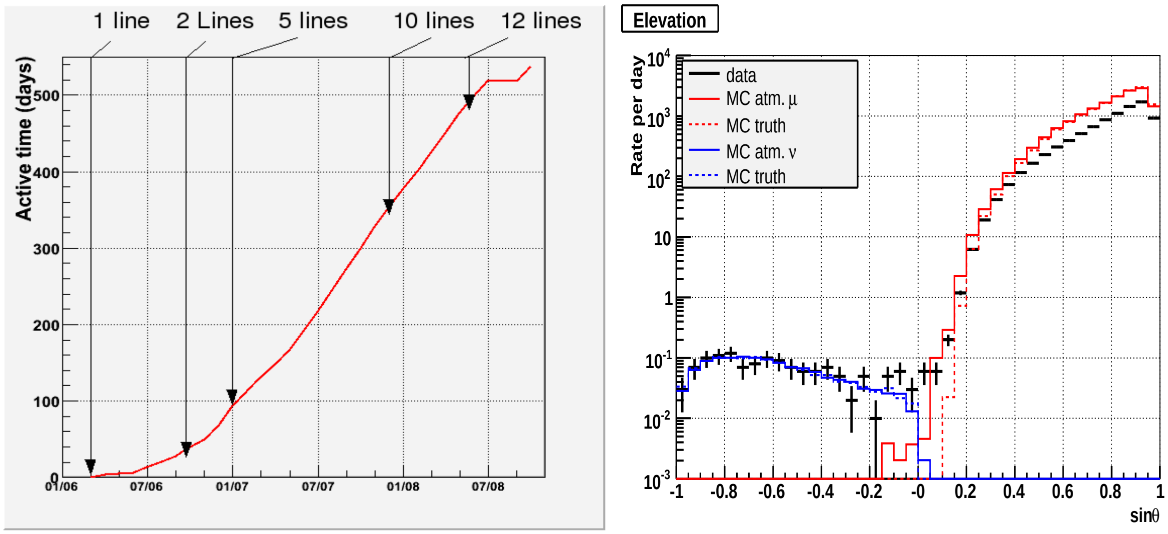

Fig. 2. Left : Integrated number of effective days of data taking since March 2006 taking into account all losses. **Right**: rate versus zenith angle ($\theta = 0$ for downgoing events) distribution after cuts. 5 lines detectector data are presented together with corersponding Monte Carlo simulation.

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. Antares is today the largest neutrino telescope ever built in the northen hemisphere. Data with one line have been taken since March 2006, with 2 lines since October 2006, with 5 lines since january 2007 and 10 lines since december 2007. The telescope is now complete and operational with its 12 lines since june 2008. Figure 2 left gives an indication of the data taking efficiency since the connection of the first line, which has been continuously improving. 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 mesurement of 0.4 ns is achieved which guaranties an angular resolution within expectations ($< 0.5°$). The existing data are dominated by downward going muon bundles, the present trigger rate being roughly 5 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 on figure 2 right. As one can see, upward candidates are also present in the reconstructed sample (so far around 500 have been reconstructed), and both contributions are well understood. One of these neutrino candidates is displayed in figure 3. The detector is now ready for a large variety of physics studies.

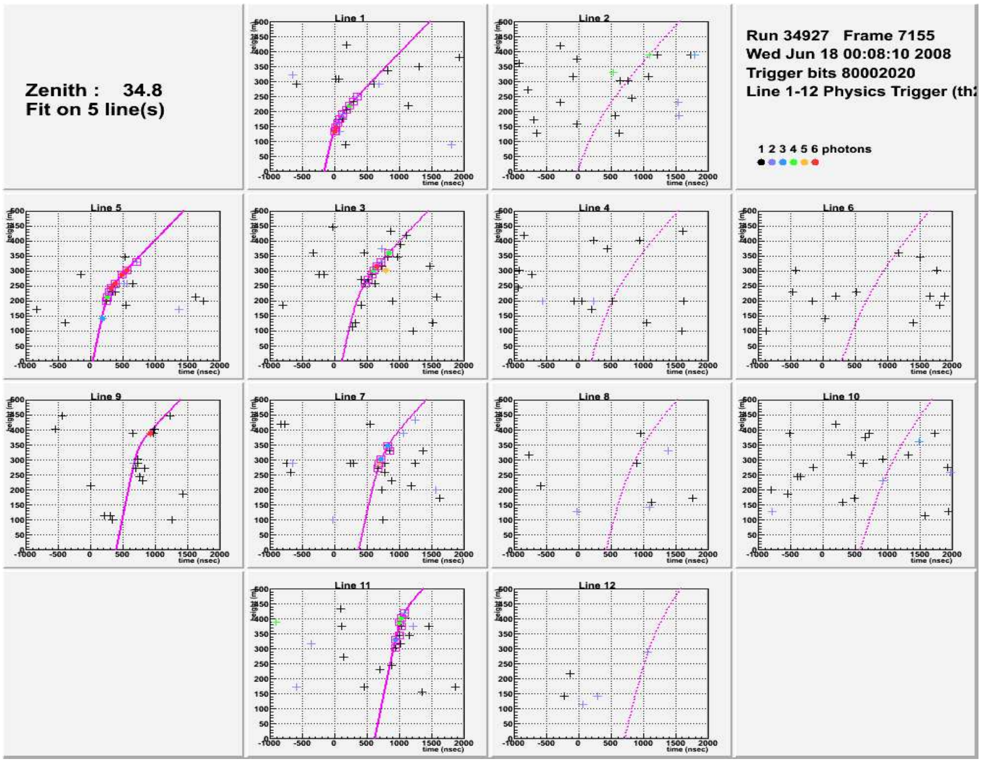

Fig. 3. An example of an atmospheric upward going neutrino induced muon candidate event. Each plot shows a single line hit time versus height distribution with the fitted hyperbola (intersection of the line and Cherenkov cone). The event has a reconstructed zenith angle of 34, 8°.

6 Conclusions

Great achievements have been made by the Antares collaboration in the last year. The detector is now complete working in nominal mode with 12 lines. Downward going muons and upward neutrino candidates are now continously reconstructed that validate the conceptual method and the chosen techniques. It now opens the path to excinting physics analyses. 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

Halzen, F., & Zas, E. 1997, ApJ, 488, 669
Piran, T. 2004, Rev. Mod. Phys., 76
Bednarek, W., Burgio, G.F., & Montaruli, T. 2005, New Astron. Rev., 49, 1
Falchini, E., In ICRC, 2007
Antares. Astropart. Phys., 23:131-155, 2005
Antares. NIM A, 55:132-141, 2005
Aguilar, J.A., In ICRC, 2007
Antares. NIM A, 570:107-116, 2007
Circella, M., In ICRC, 2007
Antares. Astropart. Phys., 26:314-324, 2006
Fehr, F., In ICRC, 2007