Nuclear Instruments and Methods in Physics Research A 692 (2012) 41–45

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Status and recent results of the ANTARES deep-sea neutrino telescope

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ARTICLE INFO

Available online 20 January 2012

Keywords:
ANTARES
Neutrino astronomy

ABSTRACT

ANTARES is currently the largest operating neutrino telescope located in the Northern Hemisphere. The main goal of ANTARES is to detect high energy neutrinos that are expected from cosmic ray acceleration sites. The construction of ANTARES was completed in 2008. It consists of 12 lines deployed at 2475 m depth offshore from Toulon. Data are continuously taken by 885 photo-multipliers that detect the Cherenkov light induced by relativistic charge particles reaching the detector. The status of the experiment will be discussed, together with the latest results including searches for a diffuse high-energy cosmic neutrino flux and for neutrinos from point-like sources.

1. Introduction

The main goal of high energy neutrino astronomy is to detect neutrinos coming from the most extreme regions of the Universe. The advantage of neutrinos, with respect to other probes such as protons or gammas, is that neutrinos interact only weakly with matter and therefore are not either deviated as protons by galactic magnetic fields, or absorbed by cosmic microwave background as gammas. Neutrinos point back directly to their sources and can therefore tell us information about the most remote objects of the Universe. ANTARES [1] is a deep-sea neutrino telescope, designed for the detection of all flavours of high-energy neutrinos emitted by both Galactic (supernova remnants, micro-quasars, etc.) and extragalactic (gamma-ray bursters, active galactic nuclei, etc.) astrophysical sources. Such sources have been observed to emit high energy gammas and the eventual detection of neutrinos would place important constraints on the nature of these astrophysical accelerators, allowing to test their hadronic nature and contributing to the understanding of the origin of cosmic rays. Due to the extremely low cross-section of neutrino interactions, neutrino detectors need to have very large volumes and to be built in a low background environment. The current neutrino telescopes exploit the idea, proposed by Markov [2], of instrumenting a large volume of water or ice, in order to detect the charged leptons (in particular muons) emerging from CC neutrino interactions.

2. The ANTARES detector

The ANTARES detector is located at a depth of 2475 m in the Mediterranean Sea, 42 km from La Seyne sur-Mer in the South of France (42°48N, 6°10E). The location of the ANTARES detector is well suited for the observation of the galactic plane and galactic centre. The visibility is shown in Fig. 1 together with the location of some galactic neutrino candidate sources. A further advantage of the ANTARES detector location is the complementarity to the IceCube detector [3] that is located at the geographical South Pole.

ANTARES is equipped with 885 optical sensors arranged on 12 flexible lines. Each line comprises up to 25 detection storeys each equipped with three downward-looking 10-in. photo-multipliers (PMTs), oriented at 45° from the vertical. Each PMT is installed in a Optical Module (OM) that consists in a 17-in. glass sphere in which the optical connection between the PMT and the glass is assured by an optical gel. The lines are maintained taught by a buoy at the top of the 450 m long line. The spacing between storeys is 14.5 m. The distance between adjacent lines is of the order of 60 m (Fig. 2).

The first detection line was installed in 2006. Five lines have been operating since March 2007. Five more lines were put into operation in December 2007. With the installation of the last two lines in May 2008, the detector construction was completed. An additional line (IL07) contains a set of oceanographic sensors dedicated to the measurement of environmental parameters.

An average background pulse rate of 60 kHz is measured on each PMT. This background comes mainly from the bioluminescent micro-organisms present at the ANTARES site and from the Cherenkov light produced by the electron that comes from the ^{40}K decay present in the salty sea water. On top of this constant rate, one can observe bursts with a time scale of few seconds that increase the rate up to several hundreds of kHz. Those bursts are produced by macro-bioluminescent organisms passing close to the PMTs. The rate of these bursts is directly correlated with the sea current velocity that is constantly measured with the instrumentation line. Other phenomena that have been observed much more rarely are long-term high-noise intervals that increase the

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doi:10.1016/j.nima.2012.01.023

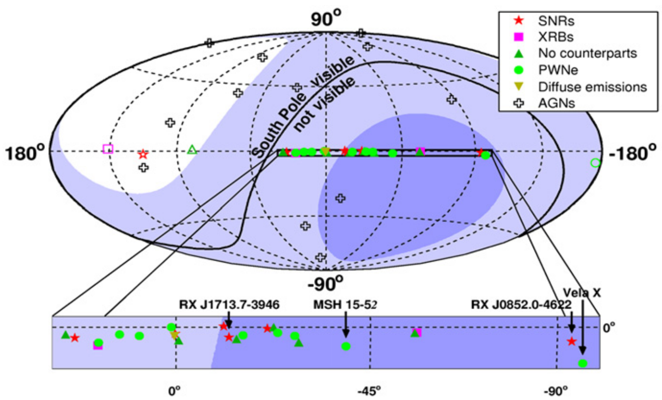

Fig. 1. The visibility of the ANTARES detector is presented in galactic coordinated together with the location of potential neutrino sources detected by gamma telescopes. The light blue zone corresponds to a visibility of 25% while the dark blue zone corresponds to a visibility of 75%. The zoom region shows the galactic plane portion visible to the ANTARES detector where most of the potential sources are located. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

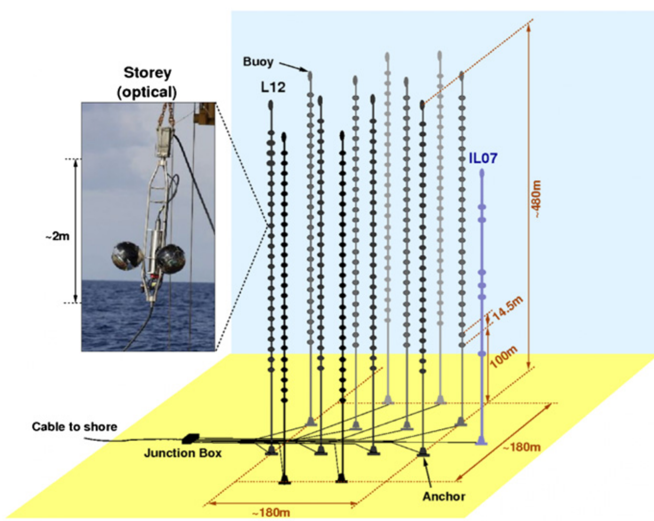

Fig. 2. The layout of the completed ANTARES detector. The insert shows an image of a storey.

baseline rate and are not correlated to current velocity. The origin of this background increase has not been understood yet.

The three-dimensional grid of photomultiplier tubes is used to measure the arrival time and position of Cherenkov photons induced by the passage of relativistic charged particles through the sea water. The muon-reconstruction algorithm relies on the characteristic emission angle of the Cherenkov light (about 43°) to determine the direction of the muon and hence infer that of the incident neutrino.

One of the main features of the ANTARES detector is the extremely good angular resolution of 0.3° for neutrino reconstruction expected at energies greater than 10 TeV. This relies on good timing resolution and accuracy of the location of the PMTs. The positions of the PMTs are measured every 2 min with a high-frequency long-baseline acoustic positioning system comprising fixed acoustic emitters-receivers at the bottom of each line and acoustic receivers distributed along each line. The displacement of the PMTs depends on the intensity of the sea current. For typical currents of few cm/s the displacement of the top storeys is of the order of few meters. The uncertainty on the positions of the PMTs is of the order of 10 cm. Even more crucial is the time calibration of the single PMTs. This is performed with several different systems. A common clock signal is delivered from shore to the whole apparatus. The clock system is also capable of determining the time offsets between the different storeys of the detector. The determination of the remaining residual time offsets within a storey, due to the transit time of the PMT and to the front-end electronics, is obtained before the deployment of the line, in a dark room where groups of OMs are illuminated by a common laser source. Then, the time calibration is in situ controlled by means of a system of optical beacons distributed throughout the detector. During special calibration runs, each beacon illuminates the neighbouring storeys on its line. By measuring the time difference between the optical beacon and the PMT it is possible to determine the relative time offsets. The time resolution, i.e. the precision on the determination of the time offset, is dominated by the transit time spread of 1.3 ns of the PMT while the resolution due to the electronics is of the order of 0.5 ns [4].

3. Atmospheric muons and neutrinos

The main goal of a neutrino telescope is to detect extraterrestrial neutrinos. The events observed by ANTARES are dominated by downgoing muons generated by cosmic rays, interacting in the atmosphere. The muons measured by ANTARES constitute an important test beam to test reconstruction algorithms and understand the systematics of the detector. Two different studies of the vertical depth-intensity relation have been performed. In the first, the attenuation of the muon flux as a function of depth is observed as a reduction in the rate of coincidences between adjacent storeys along the length of the detection lines [5]. This method has the advantage that it does not rely on track reconstruction and allows to test directly the response of the detector. The second method is based on full reconstruction algorithm and the reconstructed zenith angle is converted to an equivalent slant depth through the sea water. Taking into account the known angular distribution of the incident muons, a depth-intensity relation can be extracted [6]. The results are in reasonable agreement with previous measurements as it can be seen in Fig. 3. The large error band is coming mainly from the systematic uncertainty on the angular acceptance at large angles that affects in particular down-going events and on the uncertainty on the determination of the absorption length of light in water.

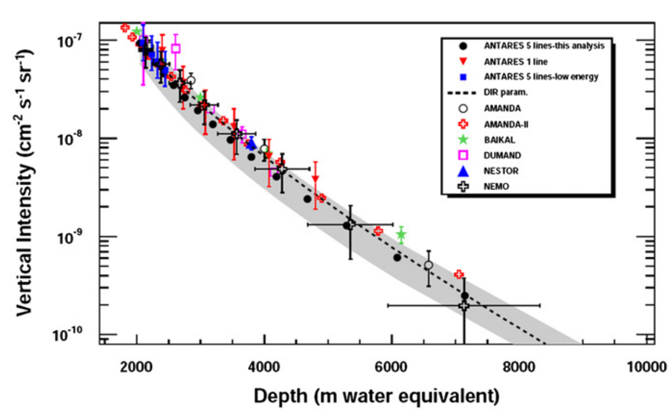

Fig. 3. Vertical muon flux of atmospheric muons for the 5 line ANTARES data (black points) as a function of the slant depth. Full squares show the results obtained using the method that does not depend on muon reconstruction. The shaded area represents the systematic uncertainty. The comparison with previous measurements is also reported. References to these measurements can be found in Ref. [6].