The ANTARES Neutrino Project: Status Report

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Abstract

The ANTARES project aims to build a deep underwater Cherenkov neutrino telescope in the Mediterranean Sea. Currently the experiment is in the construction phase and has recently achieved two important milestones. The electro-optical cable to shore and the junction box that will distribute power to detector strings and allow data transmission have been deployed at the sea floor. A prototype string and a string for environmental parameter measurement have been deployed, connected to the cable using a manned submarine. Data have been sent to shore. The final ANTARES detector consisting in 12 strings each equipped with 75 photomultiplier tubes is planned to be fully deployed and taking data by the end of 2006.

1 Introduction

Neutrino is an attractive tool for astrophysical investigations since interacting weakly they can escape from the source and travel large distances to the Earth without interaction and without deflection by magnetic fields. Nevertheless, due to the same property, large volume neutrino detectors are needed. ANTARES is one of the several on-going projects [1-6] on underwater/ice neutrino telescopes. Given the presence of AMANDA at the South Pole, a detector in the Mediterranean will allow to cover the whole sky. The ANTARES Collaboration (**A**stronomy with a **N**eutrino **T**elescope and **A**byss environmental **RES**earch) was formed in 1996 and currently joins about 200 scientists and engineers from France, Germany, Italy, Russia, Spain, The Netherlands and the United Kingdom. The project aims to detect atmospheric and extraterrestrial neutrinos with energies above $E_\nu \sim 10\,\mathrm{GeV}$ by means of the detection of the Cherenkov light that is generated in water by charged particles which are produced in νN interactions. After extensive R&D program the collaboration moved into construction of a detector in the Mediterranean Sea at 2400 m depth, 50 km off-shore of La Seyne sur Mer, near Toulon ($42^\circ 50'$ N, $6^\circ 10'$ E).

2 R&D stage

In 1996-99 an intense R&D program was performed. The deployment and recovery technologies, electronics and mechanical structures were developed and tested with more than 30 deployments of autonomous strings. The environmental properties at the detector site were investigated [7,8].

Concerning the optical backgrounds it was found that baseline 1 p.e.-counting rate of $\sim$60 kHz is measured by a $10''$ PMT. The counting rate increases during short bursts up to several MHz due to bioluminiscence. These bursts lead to a dead-time of less than 5% per each PMT. However, the long-term measurements that were performed with the so-called 'prototype string' in 2003 (see below) showed that these rates and the burst fraction are sometimes essentially higher (Fig. 1). The experimental work to understand the differences between previous results with autonomous mooring lines and the prototype string is in progress. Perhaps, to suppress the high

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background harder cuts will have to be applied which will slightly increase the energy threshold without altering the detection efficiency of >100 GeV neutrino events. Light transmission loss for glass containers that house PMTs was found strong in long-term tests for up-looking surfaces. It led to the decision to turn all PMTs downward. Signal loss due to bio-fouling and sedimentation was measured to be 1.6% after 8 months at equator of glass sphere saturating with time. The optical properties of water at the experiment site were measured during several years. The effective attenuation length varies in a range $48\,\mathrm{m} < L_{att} < 61\,\mathrm{m}$ while scattering length is $L_{scatt} > 200\,\mathrm{m}$ for blue light ($\lambda = 466$ nm). Only 5% of the photons emitted by an isotropic source located 24 m from PMT are collected out of a 10 ns time window being delayed due to scattering. This allows a good time resolution needed for event reconstruction.

ANTARES R&D program culminated with deployment and 8 month operation of a 350 m length 'demonstrator string' (November 1999 - July 2000) instrumented with 7 PMTs at a depth of 1100 m, 40 km off the coast of Marseille. The string was controlled and read out via 37 km-long electro-optical cable connected to the shore station. It allowed to test the deployment procedure with a full-scale string, positioning system and collect $\sim 5 \cdot 10^4$ seven-fold coincidences from atmospheric muons. Relative distances were measured with an accuracy of ~5 cm and accuracy of absolute positioning was ~1 m. The angular distribution of atmospheric muons was reproduced and the fraction of multi-muon events was found to be ~50% which is in agreement with expectation for such a shallow depth as 1100 m.

3 ANTARES detector

After this R&D experience, the collaboration moved to the next stage: construction of a 12-string detector [2] which can be considered as a step toward a $1\,\mathrm{km}^3$ detector (Fig. 2). Strings are anchored at the sea floor and held taut by buoys. Each string is instrumented with 75 optical modules (OMs) [9] containing 10" Hamamatsu R7081-20 PMTs housed in glass spheres. OMs are grouped in triplets at 25 levels separated by 14.5 m. 3 PMTs in each triplet are oriented at 45° to the nadir. Strings are separated from each other by ~70 m. All the strings are connected to a Junction Box (JB) by means of electro-optical link cables. The JB is connected to the shore station by a 50 km length 48-fiber electro-optical cable. Undersea connections are performed with a manned submarine. PMT signals are processed by Analogue Ring Samplers ASIC which measure the arrival time and charge for 1 p.e.-pulses (99% of the pulses) and perform wave form digitization for larger amplitudes. Digitized data from each OM are sent to shore (~1 GB/s/detector). The data flow is reduced down to ~1 MB/s by means of an on-shore data filter [10]. 100 PC farm is foreseen on shore to process and collect the data. The telescope will be complemented with an instrumentation string for hydrological parameter measurements and for calibration purposes. The deployment of the detector is planned for 2004-2006.

The important milestones that have been achieved by the collaboration are:

1) the electro-optical cable connecting detector and shore station was deployed in October 2001;

2) the industrial production of 900 OMs started in April 2002;

3) since December 2002 the JB is in communication with the shore station;

4) in December 2002 and February 2003 the 'prototype instrumentation string' and the 'prototype detection string' (equipped with 15 OMs) were successfully deployed [11] (recovered in May and July, 2003, respectively);

5) in March 2003 both strings were connected to JB with the Nautile manned submarine and data taking started.

The aim of the deployment and operation of two prototype strings were to test all the components of the future detectors in their final design. Mechanical problems occurred: 1 fiber for clock signal transmission was found broken and 1 connector leaked. After strings recovery it was found that these problems occurred due to manufacturers who changed design without notification. Solutions have been found for the final detector design and severe quality control will be applied.

The detailed description of ANTARES physics performance can be found in [12]. The angular resolution of the 12-string detector (Fig. 3) is about 0.2° for $E_\nu \geq 100\,\mathrm{TeV}$ where it is limited only by PMT TTS and light scattering and ~0.5°–1° at $E_\nu \sim 0.1$–$10\,\mathrm{TeV}$ where accuracy is dominated by $\nu - \mu$ kinematics. Energy resolution (Fig. 4) improves at high energies: dispersion of the $\log_{10}(E_{rec}/E_t)$ distribution (where E_t is the true energy and E_{rec} is the reconstructed energy, respectively) is around $\sigma \approx 0.5$ at $E_\nu \sim 5\,\mathrm{TeV}$ and $\sigma \approx 0.3$ for $E_\nu \geq 100\,\mathrm{TeV}$. Effective area for muons grows from $A_{eff} = 0.01\,\mathrm{km}^2$ at $E_\nu = 1\,\mathrm{TeV}$ to $A_{eff} = 0.06\,\mathrm{km}^2$ at $E_\nu = 10\,\mathrm{PeV}$. The sensitivity of the detector to diffuse neutrino fluxes achieved by rejecting the background with an energy cut of $E_{cut} = 50\,\mathrm{GeV}$ allows to reach Waxmann & Bahcall limit [13] in 3 years. The ANTARES sensitivity for point-like source searches (90% C.L.) assuming E^{-2} differential ν flux is in the range $4 \div 50 \cdot 10^{-16}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ after 1 yr which gives a real hope to detect a signal from the most promising sources (e.g., galactic microquasars [14]). The ANTARES potential for WIMP searches is high enough to improve existing experimental upper limits on ν-induced muon fluxes from neutralino annihilation in the Sun and on relativistic magnetic monopole flux obtained by other detectors by an order of magnitude.

4 Conclusions

The construction of the ANTARES detector is underway. It is planned to be fully deployed and start to take data by the end of 2006. Calculations based on the data on environmental conditions at the experiment site and on studied properties of electronic components shows that predicted sensitivity of the detector to diffuse neutrino fluxes, point-like neutrino searches and WIMP searches is better by several orders of magnitude compared to data published by other experimental groups. The deployment of the ANTARES neutrino telescope can be considered as a step toward the deployment of a 1 km^3 detector in the Mediterranean Sea.

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FIGURE CAPTIONS

Fig.1: Summary of counting rate in 3 PMTs during 65 days of 'prototype string' operation in April–May, 2003. Top figure: the average baseline rate. Bottom figure: the fraction of time the rate is significantly higher than this average baseline rate (burst fraction).

Fig.2: Schematic view of the ANTARES 12-string detector.

Fig.3: Angular resolution of the ANTARES detector versus E_ν: median of the distribution of the angle in space between the reconstructed muon track and true muon track (solid) or the parent neutrino track (dashed).

Fig.4: Energy resolution of the ANTARES detector: sigma of the distributions of $\log_{10}(E_{rec}/E_{gen})$ (where E_{rec} is reconstructed muon energy and E_{gen} is generated muon energy) versus generated energy.

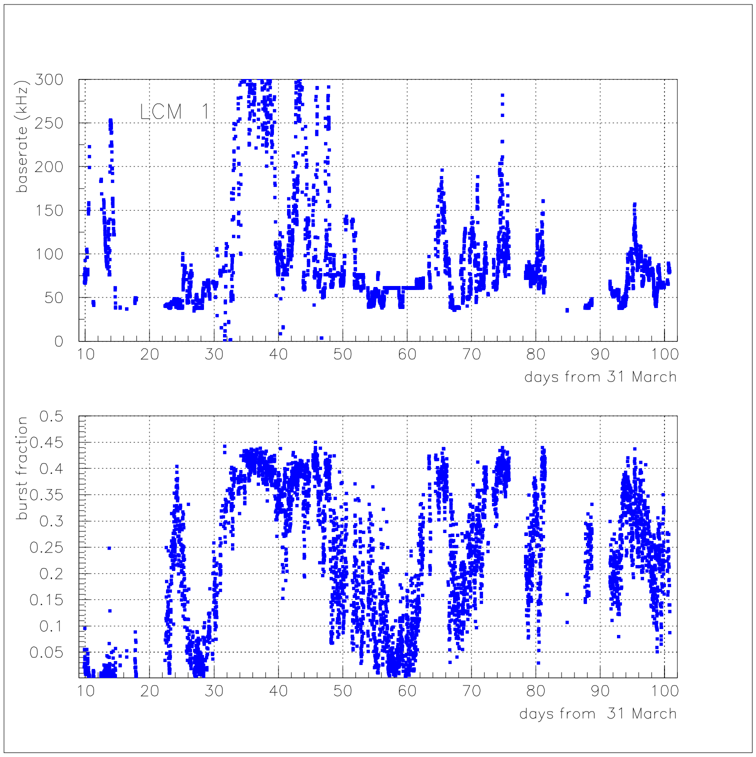
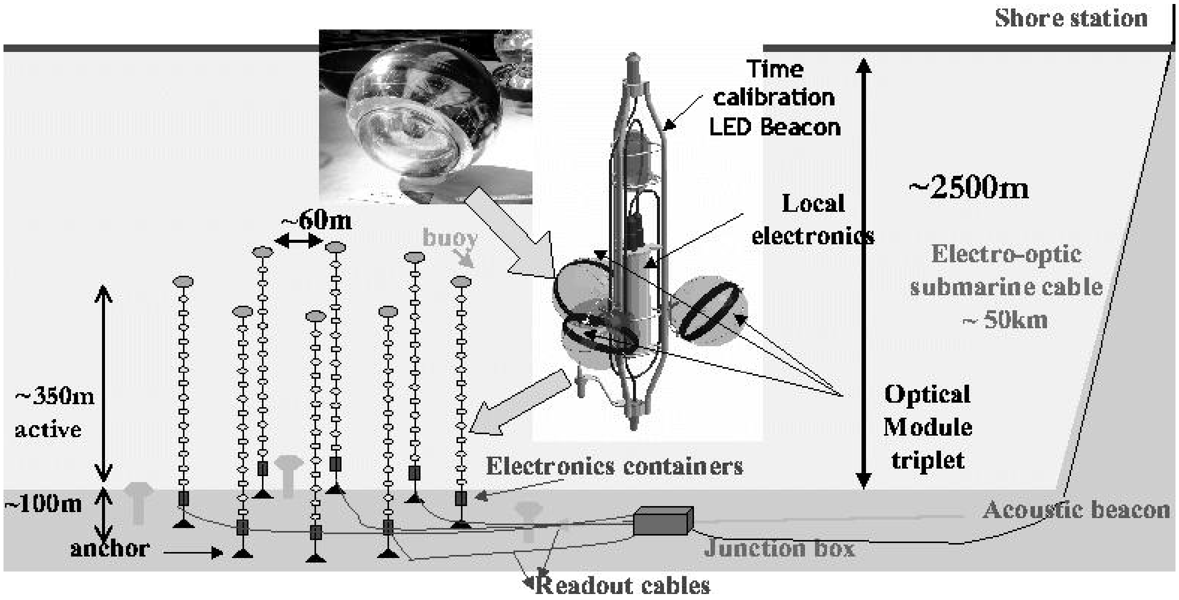


Figure 1:



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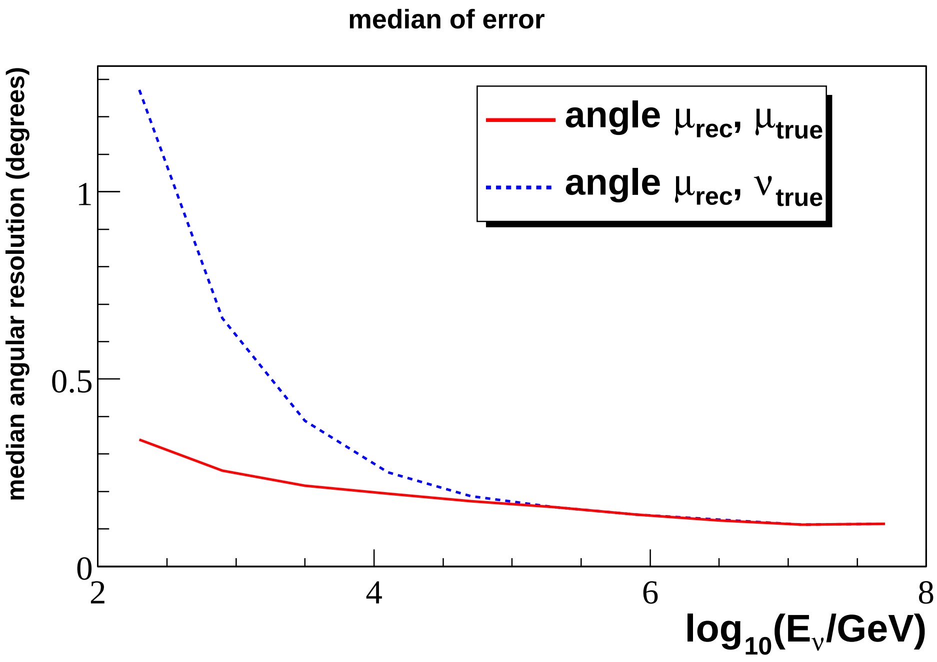

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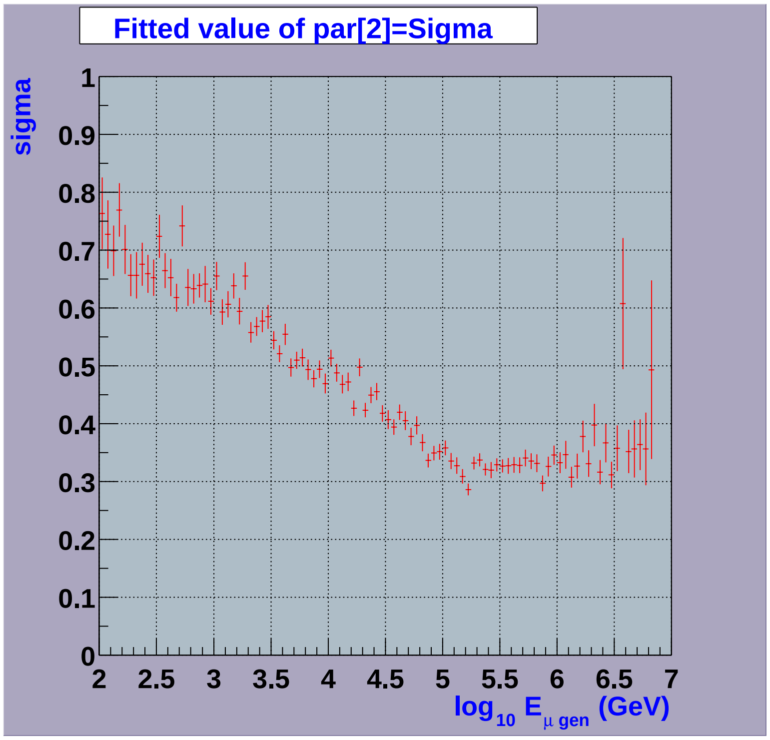

Figure 4: