Status of the ANTARES Experiment

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Abstract. The ANTARES Collaboration is building a neutrino telescope in the Mediterranean Sea with the main purpose of searching for high-energy neutrinos from astrophysical sources. A description of the full detector and of its expected physics performances is given. Before the beginning of the construction of the full telescope, the Collaboration has developed, deployed and tested a prototype line with 15 photomultipliers and an instrumentation line equipped with devices for environmental measurements.

1 Introduction

High energy cosmic neutrinos could be produced by powerful cosmic accelerators, as for example in supernova remnants, active galactic nuclei, compact binaries, micro-quasars; neutrinos could also be produced in association with gamma-ray bursts. Neutrino astronomy is complementary to high-energy gamma astronomy: the far Universe cannot be probed with high-energy photons due to photon-matter and photon-photon interactions.

The proposed detectors for neutrino astronomy are the so called "neutrino telescopes": water or ice provides large active natural Cherenkov radiators, which can be instrumented at a reasonable cost. Those experiments are constrained by the small neutrino cross section and the large background due to secondary Cosmic Rays. For this reason, detectors are proposed and constructed at large depths where the atmospheric muon flux is significantly reduced. Neutrinos (having crossed the Earth) are unambiguously recognized when upward-going muons are produced by their charged current interactions in, or close to, the instrumented region.

The ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) collaboration [1] plans to deploy a neutrino telescope in the Mediterranean sea, 37 km off-shore of La Seyne sur Mer, near Toulon, France. An extensive R&D program has been carried out to prove the feasibility of such a detector and to measure the relevant environmental parameters of the selected site [2,3]. The ANTARES apparatus, see Fig. 1, will detect upward-going muons in sea water from charged current interactions of ν_μ inside or around the detector. Relativistic muons crossing seawater produce Cherenkov light with $cos\theta_C = 1/n$. The seawater refraction index n is about 1.35 at 450 nm, and therefore light is emitted at $\theta_C \simeq 42°$ at this wavelength. The emitted light will be detected by a three dimensional array of photomultipliers.

The success of the experiment will be the first step towards the construction of the km^3 detector in the Mediterranean sea.

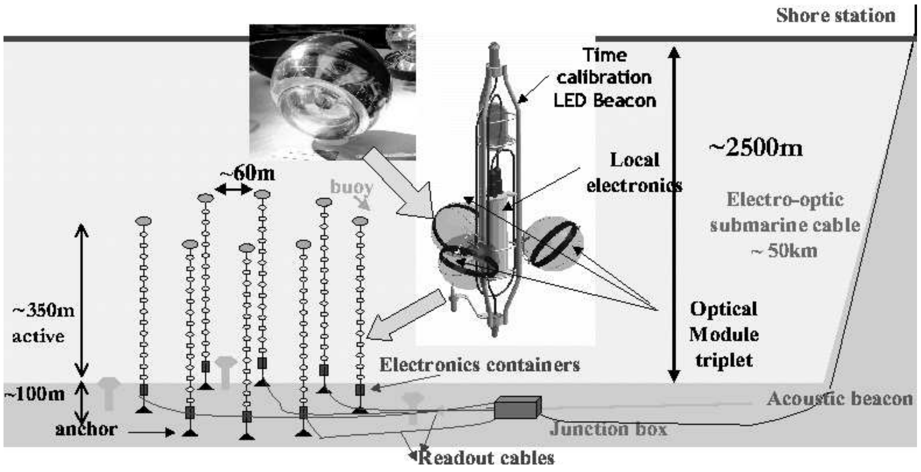


Fig. 1. Schematic view of the ANTARES detector showing some details of an Optical Module and of a storey. The final detector will consist of 12 strings

2 Scientific purposes of the experiment

The main scientific purpose of the experiment is the detection of neutrinos with $E \gtrsim 10$ GeV: astrophysical neutrinos ($E_\nu \gtrsim 1$ TeV), neutrinos from dark matter ($E_\nu \lesssim 1$ TeV) and atmospheric neutrinos [4].

Point-like sources of neutrinos. The most powerful known extra-galactic sources are gamma ray bursts (GRBs) and active galactic nuclei (AGN). They could be candidate sources for the production of UHE cosmic rays ($E > 10^{19}$ eV) and could also be "point sources" of $1 \lesssim E \lesssim 10^3$ TeV neutrinos. Thanks to its angular resolution (see sec. 3), ANTARES sensitivity to upgoing neutrino-induced μ flux from point sources is $(4 \div 50) \times 10^{-15}$ cm^{-2} s^{-1} (90% c.l.) after 1 year. Point-like sources can be searched, looking for an excess of events above the atmospheric ν background. A binning method and a likelihood ratio test were developed. Detailed discussions on search strategies and discovery potential are given in [5]. To illustrate the expected ANTARES sensitivity to point-like sources, the neutrino flux from galactic micro-quasars [7] predicts in a 1° cone 6 and 4 events/year for GX339-4 and SS433, respectively. This event rate can be compared with a background of 0.3 events/year. The ANTARES sky coverage is 3.5 πsr and it is complementary to that of AMANDA [8] at the South Pole. The sky overlap of the two experiments is about 0.5 π sr. ANTARES can look to the Galaxy center for about 70% of the time.

Diffuse flux from astrophysical sources. Diffuse fluxes from astrophysical sources are expected to cross-over the atmospheric neutrinos at energies above $\sim$ 100 TeV. Cosmic ray observations set an upper bound of 4.5×10^{-8} E^{-2} GeV^{-1}cm^{-2}s^{-1}sr^{-1} to the ν flux from sources which are optically thin for high energy gamma-proton and proton-proton (neutron) interactions [6]. The sensitivity (90% c.l.) to a E^{-2} diffuse differential neutrino fluxes, achieved rejecting the atmospheric neutrino background with a cut of $E_\mu \geq 50\ GeV$, is 8×10^{-8} GeV cm^{-2} s^{-1} sr^{-1} [9].

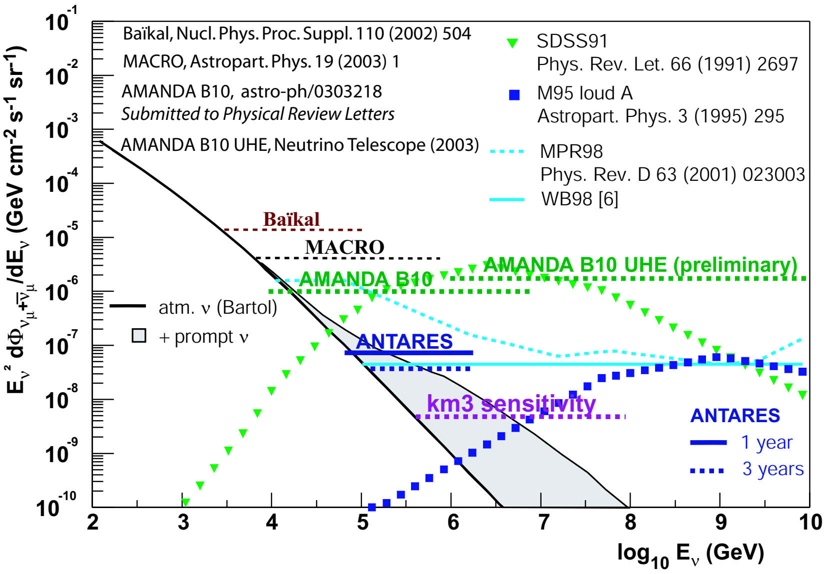


Fig. 2. ANTARES sensitivity compared to diffuse fluxes and experimental limits. A data taking of 1 year allows to set a limit of 8×10^{-8} GeV cm^{-2} s^{-1} sr^{-1} [9].

Dark matter searches. Neutralinos could be part of the dark matter halo in our Galaxy and could appear as Weakly Interacting Massive Particles (WIMPs). WIMPs could slow down by elastic collision in astrophysical objects such as the Sun, the Earth and the Galactic Center, and could be gravitationally trapped in their centers. WIMPs pair annihilation could take place, producing Standard Model particles decaying into neutrinos. In a ν telescope as ANTARES, such processes could be observed as an excess signal of induced muons from the object cores. The resulting ANTARES muon flux limit in the case of neutralinos from the center of the Sun is presented in Fig. 3 [10]. The points superimposed on Fig. 3 correspond to theoretical predictions within the so-called mSUGRA framework, when the number of free SUSY parameters is reduced.

3 Detector layout and expected performances

The Cherenkov light emitted by charged particles in deep water is detected using an array of photomultiplier tubes (PMTs), which are housed together with some associated electronic components, in a high pressure-resistant glass sphere

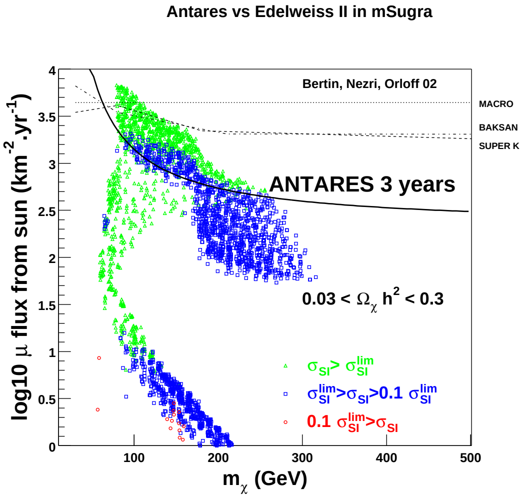


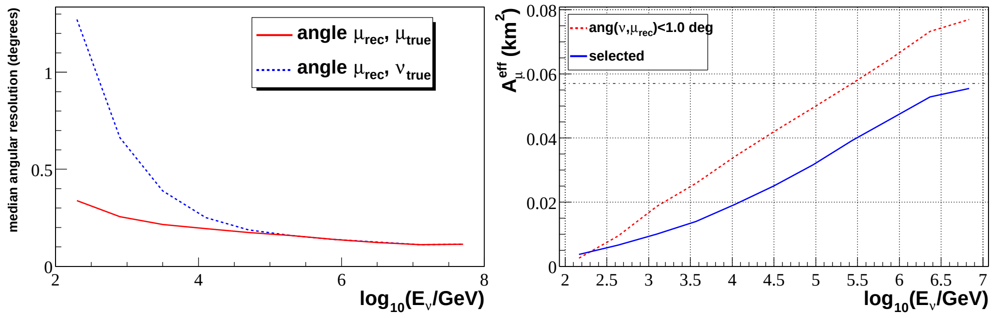
Fig. 3. ANTARES sensitivity to a muon flux from neutralinos in the Sun.

(Optical Module, OM). Photon arrival times will be used for particle tracking and charge distributions for energy reconstruction.

The detector (see Fig. 1) consists of 900 OMs in 12 identical 480 m long mooring lines ("strings") plus an instrumentation line devoted to environmental monitoring. The strings are separated by a distance of ∼ 60 m and are anchored to the seabed. Each string consists of 25 storeys separated by a distance of 14.5 m. Each storey is equipped with 3 OMs oriented at 45° below the horizontal. The storeys are interconnected by an electro-mechanical cable.

An ANTARES OM [3,11] is composed of a 17" (43 cm) diameter pressure resistant glass sphere, containing a 10" Hamamatsu PMT (shielded from the Earth's magnetic field by a mu-metal cage) with its associated electronics. The angular acceptance of the OMs is broad, falling to half maximum at 70° from the axis. The relative positions of all OMs in the detector are given in real time by an acoustic positioning system and by compasses and tilt-meters installed along the line, which allow the reconstruction of the shape of the line and the orientation of each storey. The absorption length in sea water was measured to be about 60 m for blue light and about 26 m for UV light. The average loss of light transmission of an OM due to fouling and sedimentation is less than 2% at its equator one year after deployment [2]. It decreases with increasing zenith angle and tends to saturate with time.

At the base of each line (the "anchor") there is a string control module (SCM), which contains the boards for the Slow Control, for the clock and for the acoustic positioning instruments. The strings are linked to a common junction box (JB) by electro-optical cables and distribute the power to the SCMs. Finally, an electro-optical cable (MEOC) links the JB with the shore station in La Seyne sur Mer. Data will be filtered on shore in real time by a farm of about 100 PCs. The main purpose of this data acquisition system (DAQ) will be to filter the physics events from the ^{40}K and bioluminescence background [12].



(a) (b)

Fig. 4. (a) Median value of the distribution of the angle between the reconstructed muon and the generated muon (solid line), and between the reconstructed muon and the parent neutrino (dashed line) vs neutrino energy. (b) Effective area as a function of neutrino energy after quality cuts: the dotted line is for all selected events, the solid line requires a reconstruction error lower than 1°. The dotted horizontal line is the geometrical area.

The parameters to qualify a neutrino telescope are its effective area, which includes reconstruction and selection efficiency, the angular and the muon energy resolution. Fig. 4b shows the muon effective area computed using a Monte Carlo (MC) simulation of an isotropic neutrino flux as a function of ν energy after two different reconstruction quality cuts. For a typical E^{-2} astrophysical neutrino spectrum $\sim$ 96% of the events are reconstructed with an error smaller than 1°.

The intrinsic angular resolution of the neutrino telescope is evaluated with MC events, as the median angular separation between the real and the reconstructed muon track. It depends on timing accuracy, reconstruction algorithms, and selection programs. In Fig. 4a the median value of the distribution of the angle between the reconstructed and the simulated muon, and between the reconstructed muon and the parent neutrino vs. the neutrino energy are shown. Below 10 TeV the median angle between the muon and the neutrino is dominated by interaction kinematics, while above 10 TeV it is limited by the PMT transit time spread ($\sigma \simeq 2.8$ ns) and by light scattering in water ($\sigma \simeq 1.5$ ns), giving an angular resolution of about 0.2°.

The energy resolution is a qualifying parameter for what concern the capability to select high energy events from the diffuse flux of astrophysical neutrinos. Above $\sim$ 1 TeV the energy will be estimated by the features of the muon energy losses. Three different energy estimators have been developed [9]. The achieved energy resolution is a factor between 2 and 3 on E_μ above 1 TeV.

4 The prototype lines

Before the construction of the full telescope the ANTARES Collaboration has built a prototype optical line equipped with 15 optical modules and a prototype instrumented line for environmental studies.

Sea operations and line calibrations. Sea operations for the deployment of the two prototype lines began on October 2001, when the main 50 km electro-optical cable (MEOC) has been successfully laid down the seabed. In December 2002 the junction box and the prototype optical line have been deployed at the ANTARES site. With the success of the deployment of the instrumented line in February 2003 and the connection operation of the two lines to the junction box via the Nautile submarine in March 2003, the data acquisition started.

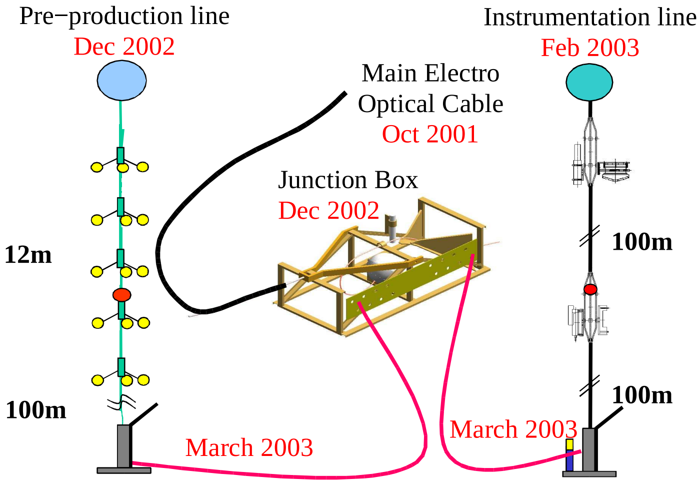


Fig. 5. Situation on ANTARES site on March 2003. The MEOC and the JB (center) have been permanently installed. The prototype instrumented line (right) and the prototype optical line (left) were respectively recovered in May and in July 2003.

The prototype optical line is 1/5 of a full future line, with 5 storeys and 15 PMTs, interspaced by 12 m of cable, see Fig. 5 on the left. The top and bottom storeys are equipped with acoustic receivers; the second storey from the bottom has a LED beacon for time calibrations [13], and at the anchor a String Control Module, an acoustic receiver/transceiver and a pressure sensor are located.

The prototype instrumented line (see Fig. 5 on the right) is formed of an anchor and two storeys. At the anchor a seismograph, an acoustic receiver/transceiver, a pressure sensor, and a laser beacon for optical modules calibrations are located. In the lower storey there are a conductivity-temperature-density meter, an optical beacon, an acoustic receiver and a deep-sea light transmissometer. In the upper storey a sound velocimeter and an acoustic Doppler current profiler are located.

Underwater measurements. Two environmental background sources are expected to contribute in sea water to the rate acquired by the PMTs: continuous ^{40}K radioactive decays and bioluminescence (light produced by chemical reactions taking place in marine organisms). The DAQ was successfully tested, together with the transmission of digital data through the main cable. Counting rate measurements with the prototype optical line were performed for about three months, together with environmental measurements from the prototype instrumented line. The compasses and tiltmeters monitored the movements of the lines. More details on the status and results of the two prototype lines are in [14].

5 Conclusions

The ANTARES project has completed the design and test phases and is starting the construction phase. The Collaboration has successfully deployed and connected the pre-production optical line and the instrumented line. Both lines have proved to be operational in real data taking conditions, and valuable data have been collected. By the end of 2004 the first full string is foreseen to be deployed and connected and in 2006 the full 12 string detector will be completed.

Acknowledgments. I would like to acknowledge the members of the ANTARES collaboration, the Bologna group in particular. ANTARES is a collaboration of several European Institutions, see [1] for the list of Authors and Institutions.

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