STATUS REPORT ON THE ANTARES PROJECT

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The ANTARES collaboration has started the construction of a submarine neutrino telescope in the Mediterranean Sea. This detector will consist of a three-dimensional array of photomultipliers (PMTs), which will detect the Cherenkov light emitted by muons produced by high energy neutrino interactions. The scientific aims of the project include astrophysics, dark matter and neutrino oscillations. The project, which began in 1996, has carried out an intense R&D effort, including important milestones such as the "Demonstrator Line", which has shown the feasibility of the project, and the deployment of the electro-optical cable which links the detector to shore. These successful steps led, in 2003, to the deployment of a prototype line (1/5 of a full line) and of an instrumentation line (equipped with calibration devices), whose analysis of the first data will be presented.

1. Introduction

High energy neutrinos will allow the study of the Universe in a completely new way. Most of the knowledge we have about cosmic phenomena comes from photons and cosmic rays. However, these messengers have some limitations. High energy photons interact with matter, the infrared radiation and the microwave background, so gamma-rays produced in very far or very dense sources cannot reach us. Protons and nuclei, in addition to interact with radiation and matter, are deflected by magnetic fields, so directional information is lost. On the contrary, neutrinos only interact weakly, so they can be an extraordinary tool in Astrophysics and Particle Physics.

The main goal of the ANTARES detector[1] is the observation of astrophysical objects. The most promising candidates as emitters of detectable flux of high energy neutrinos are the active galactic nuclei (AGNs) and the gamma-ray bursts (GRBs). Other promising sources which could be observed are microquasars and supernova remnants.

Another important issue will be the indirect detection of non-baryonic dark matter. The method consists in detecting neutrinos produced in the decay of secondary particles generated by the annihilation of weakly interacting massive particles (WIMP) captured by celestial bodies (Earth, Sun, Galactic Centre). Finally, oscillation studies could be also performed with atmospheric neutrinos.

2. Detection principle

The detection principle in ANTARES is the following. The charged current interaction of a high energy neutrino produces a muon which emits a cone of Cherenkov light water detected by a matrix of photomultipliers[2]. Other topologies (cascades, tau tracks...) are also detectable.

There are two sources of physical background. The first source is the muons produced by cosmic rays in the atmosphere. In order to avoid this kind of background, the detector is built 2500 m deep and only up-going events are selected. The second and irreducible background is due to the atmospheric neutrinos. The fact that a steeper spectrum in energy is predicted for these neutrinos will be used to discriminate them from the cosmic neutrinos.

3. Expected performances

One of the main parameters to describe the performance of the detector is the angular resolution. Several reconstruction algorithms are used in the ANTARES collaboration based on the amplitude and time information provided by the photomultipliers. For energies below 10 TeV, the resolution is dominated by the angle between the neutrino and the muon. For higher energies, the angular resolution is determined by the precision in the reconstruction of the muon track, that is mainly affected by the scattering of light in the water and the transit time spread of the photomultipliers. This value goes from 0.4° at 10 TeV to 0.15° at very high energies.

The muon energy estimation is based on the fact that the higher the energy, the higher the energy loss along muon tracks. This method is valid above the critical energy (∼600 GeV in water), when radiative processes (bremsstrahlung, pair production and photonuclear interations) dominate over ionization losses. However, the stochastic nature of the processes limits the results: below 100 TeV, the energy resolution is 40% in log E_μ, improving to 30% at higher energies.

The effective area for muons is defined as the ratio of the detected muon rate to the muon flux. It is given by Eq. (1), where N_{sel} and N_{gen} are the number of selected and generated events, respectively. $V_{generation}$ is the generation volume and R_μ is the muon range. For neutrino energies larger than 300 TeV, the effective area for point-like sources is larger than the equipped detector area (0.058 km^2).

$$A_\mu^{eff} = \frac{N_{sel}}{N_{gen}} \frac{V_{generation}}{R_\mu} \tag{1}$$

Finally, as a better way to compare the performances with other experiments and theoretical predictions, the sensitivity, defined as the upper limit on the flux, is used. In Figure 1, the sensitivity for both diffuse fluxes and point-like sources is shown. Concerning neutralino searches, the upper limit on the muon flux (for annihilations in the Sun) is about 400 km^{-2}yr^{-1} for m$_\chi$ >200 GeV[3].

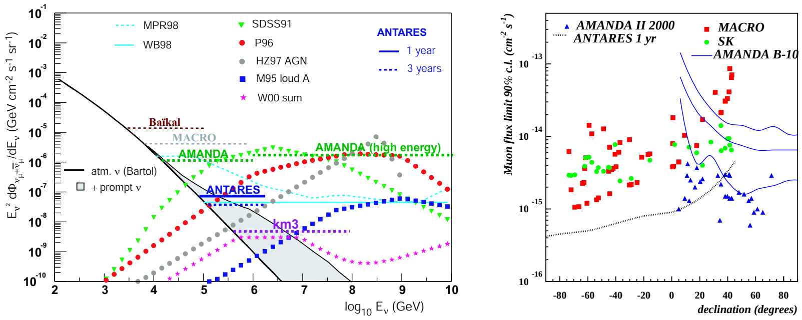

Figure 1. ANTARES sensitivity for diffuse fluxes (left) and for point-like sources (right), compared with other experiments and theoretical predictions (see [4,5] for references).

4. Detector layout and status

The ANTARES site is located at 42°50N 6°10E, 40 km off the coast of Toulon, France. It is a matrix of 900 photomultipliers distributed in 12 lines. The PMTs are grouped in triplets, with a distance of 14.5 m between floors. The separation between two close lines is 60-75 m. Other important elements are the 40 km electro-optical cable, which provides power and data link to shore, and the junction box, which distributes power to the lines.

Several milestones have been already reached. The first task of the collaboration was to characterize the site where the detector will be deployed

(1996-1999). Some of the results of this stage worth mentioning are the measurement of the absorption and scattering lengths in water[6], the rate of background due to ^{40}K and bioluminescence[7] and the effect of biofouling on the optical surfaces[8].

The next relevant step was the inmersion (November 1999 to June 2000) of a "Demonstrator Line", which allowed to check the acoustic positioning system and the detection of atmospheric muons. After these site research studies were done, the deployment of the detector began. Firstly, the electro-optical cable and the junction box were installed (in 2001 and 2002, respectively). Then, the so-called "Pre-production Sector Line" (PSL) and the "Mini-Instrumentation Line" (MIL) where deployed and connected to the junction box in 2003, which allowed to start taking data.

The Pre-production Sector Line is a shorter version (one fifth) of a complete line. All the electronic elements are basically the same as those which will be used in the final design. This includes 15 PMTs, a LED beacon, a sound velocimeter, a pressure sensor, hydrophones and an acoustic transceiver.

In the Mini-Instrumentation Line there were several devices for triangulation (hydrophones and an acoustic transceiver), monitoring of the environmental parameters (a seismometer, a sound velocimeter, a pressure sensor and an instrument to measure conductivity, temperature and density) and for time calibration (a LED and a laser beacons).

This pre-production stage has been extremely useful, since it has allowed the test of the detector design and most of its components in realistic conditions. Procedures for construction, integration, remote control and onshore calibration have been checked too. Sea operations (deployment, connection and recovery), which are crucial in the experiment, were completely successful.

This operation allowed also revealing some malfunctioning. As it was seen after recovering the PSL and the MIL, one of the optical fibers was broken. In addition to this, there was a water leak in one component of the Mini-Intrumentation Line. The main consequence of these problems was that timing accuracy was $\sim$1 ms (instead of $\sim$1 ns).

5. First data

Despite the limitation in time accuracy, the count rates in the photomultipliers could be measured. These data, together with the information of the remaining devices, allowed a better monitoring *in situ* of the environmental parameters.

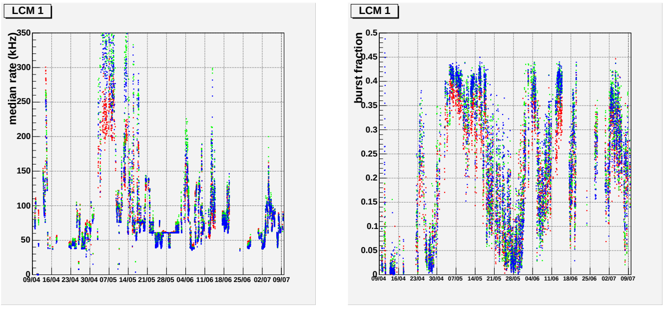

Figure 2. Left: Base rate (defined as the median value of the rate distribution in a time slice of 15 minutes) as a function of time. Right: Burst fraction (defined as the fraction of time, in a time slice of 15 minutes, during which the rate is 20% larger than the base rate) as a function of time. Both plots correspond to three months of data taking).

6. Conclusions

The ANTARES collaboration has successfully completed intense R&D studies and has performed tests of the main components of the experiment. After this stage, the collaboration is ready to start the deployment of the first full line. Between 2005 and 2006, the twelve lines of the detector will be installed.

References

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