THE ANTARES PROJECT

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ABSTRACT

The ANTARES collaboration is building a neutrino telescope in the Mediterranean sea close to the French coast. Recently important construction milestones have been successfully passed. The project and its physics potential will be described and the construction status will be illustrated.

1. History

The ANTARES collaboration has been set up in 1996. Today it involves groups from France, United Kingdom, Spain, Italy, The Netherlands, Russia and Germany. From 1996 to 1999 an extensive R&D program had been successfully performed to prove the feasibility of the detector concept. The environment parameters at various deep sea sites have been studied and a deployment site of the experiment has been chosen1). It is 10 km south of the Hyeres archipelago at 42^o 50' N, 6^o 10' E. It combines the advantage of an important depth of 2475 m with the vicinity to the coast and infrastructure (harbors of Toulon and La Seyne).

2. Detector design

After the successful R&D phase the construction of the ANTARES detector has been decided in 2000 and is progressing. The detector consists of 12 lines and a junction box which distributes the power and clock synchronization signals to the lines and collects the data. The junction box is connected to the shore by a 40 km electro-optical cable. The lines have an equipped vertical length of 350 m starting 100 m above sea floor. Their horizontal distance is about 65 m and they are arranged to form a regular octagon on the sea floor. Each line is connected to the junction box with the help of a submarine using wet-mateable connectors. It is composed of 25 storeys with a vertical distance of 14.5 m. The lines are kept straight by the floating force of a buoy at the top and an anchor at the bottom. They float in the sea current and the positions of the active detector elements are permanently monitored by an acoustic calibration system.

Each storey (see Fig. 1) contains three 45^o downward looking 10" photomultipliers inside pressure resistant glass spheres - the optical modules2) (OM). The electronic cards are inside a titanium cylinder at the center. Some of the storeys contain supplementary calibration equipment like acoustic or optical beacons.

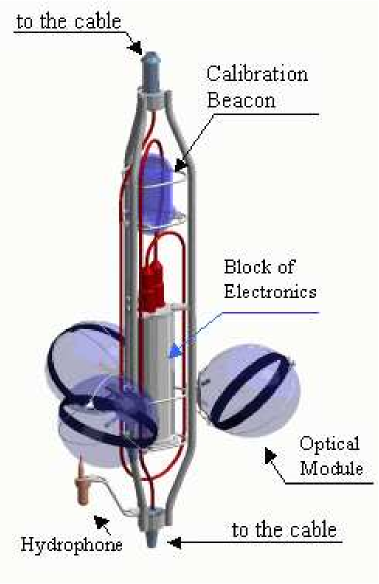

Figure 1: Key element of the detector: The storey

The signals of each photomultiplier are readout by two ASICs. For simple pulses charge and arrival time are digitized and stored for transfer to the shore station. For more complex pulses the pulse shape can be digitized with 1 GHz sampling frequency. The time stamps are synchronized by a clock signal which is sent in regular intervals from the shore to all electronic cards. The overall time calibration is better than 0.5 nsec. Therefore the time resolution of the signal pulses will be limited by the transition time spread of the photomultipliers ($\sigma \sim$1.3 nsec). All data are sent to the shore station. With a noise light rate of 70 kHz on the one photon level this produces a data flow of 1 Gbit/sec to the shore. In the shore station a PC farm performs a data filtering to reduce the data rate by at least a factor 100.

3. Physics performance

Most studies so far concentrated on charged current interactions of ν_μ:

$$\nu_\mu(\bar{\nu}_\mu) + N \rightarrow \mu^-(\mu^+) + X \tag{1}$$

The direction of the muon is reconstructed using the fact that it emits Cherenkov light under a well defined angle and does not suffer from multiple scattering at high energies. In ANTARES several reconstruction algorithms for muons have been developed. They use the direct Cherenkov hits but take also into account secondary effects like diffusion, dispersion and electromagnetic showers which accompany high energetic muons. This leads to an angular resolution for the muons of better than 0.2^o above 1 TeV for the above mentioned 1.3 nsec single pulse resolution (see Fig. 2).

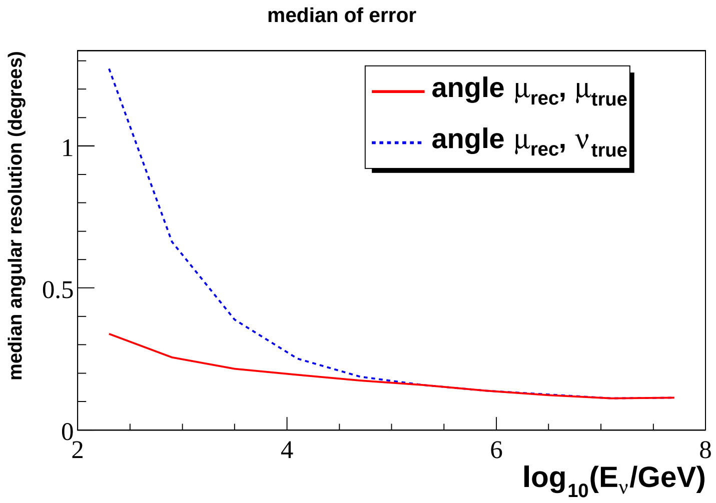

Figure 2: Angular resolution of μ and ν as function of the neutrino energy

To obtain the neutrino angular resolution one has to consider also the interaction kinematics and gets the upper curve of Fig. 2. Above 100 TeV the neutrino angular resolution is dominated by reconstruction.

The estimation of the neutrino energy is based on the measurement of the light output of the muon track in the vicinity of the detector. In the TeV range the light output increases with energy due to radiative processes. However the measurement is compromised by the facts that these radiative processes are stochastic, the neutrino interaction point is invisible in most cases and only a short fraction of the muon track is seen in the detector. Nevertheless procedures have been found which estimate the neutrino energy within a factor 3 for energies below 100 TeV and within a factor 2 for higher energies.

The effective area is another important parameter which characterizes the performance of the detector. Conventionally it is given for a flux of muons induced by neutrinos at the detector. This means the total neutrino cross section and the opacity of the Earth are not taken into account. The left plot of Fig. 3 illustrates the energy dependence of the effective area under these conditions. The angular distribution is averaged over the upward going hemisphere. The lower curve refers to an isotropic flux which requires the full power of reconstruction quality cuts to ensure purity against misreconstructed fake track. The upper curve refers to a search for fluxes from known point sources where stringent quality cuts are relaxed and an angular cut around the known source position is added. The raise of the effective area with energy is explained by the increasing muon range and the increasing light output of the muon due to radiative processes. At neutrino energies of 300 TeV the effective area of the ANTARES detector reaches its equipped area (horizontal line) for the

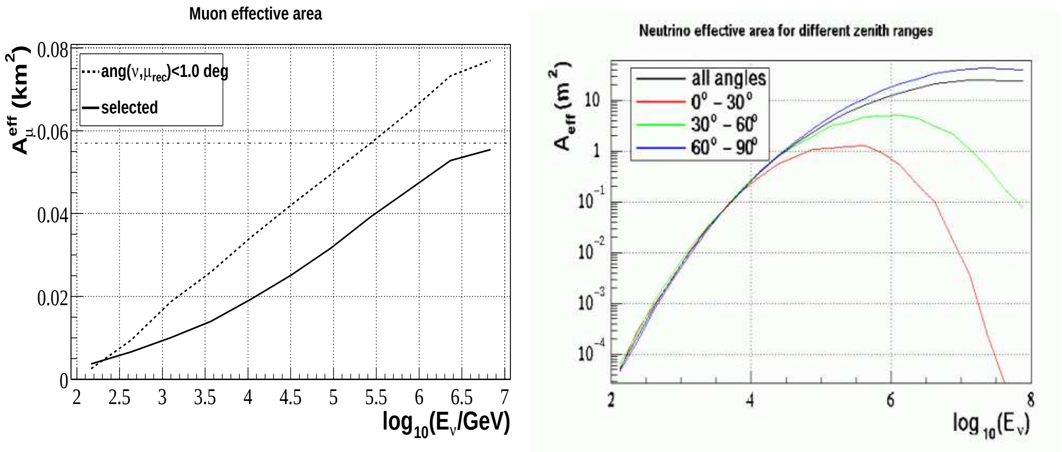

Figure 3: Effective area as function of the neutrino energy; left: Muons induced by neutrinos at the detector; right: Neutrinos entering the Earth

point source search. The right plot of Fig. 3 gives the effective areas for various zenith angle bins for a neutrino flux before interaction and before penetration of the Earth. This leads to three effects: the overall scale of the effective area changes from km^2 to m^2 due to the smallness of the neutrino cross section; the energy dependence becomes much stronger due to the almost linear raise of the neutrino cross section; the opacity of the Earth limits the effective area to values below 20 m^2.

Using the above performance parameters one can estimate that ANTARES will detect about 2500 upward going muon tracks from atmospheric neutrinos per year. They are the major background for the search for diffuse astronomical neutrino fluxes. The only distinction is their supposedly harder spectrum. With an energy cut of 50 TeV a flux $E^2\Phi(E)$ of 10^{-7} GeV cm^{-2}s^{-1}sr^{-1} can be excluded after one year of data taking assuming $\Phi(E) \sim E^{-2}$. For the search for point like sources an energy cut is a priori not needed. Cluster algorithms and likelihood methods have been developed to identify unknown point sources on an isotropic background of tracks from atmospheric neutrinos. After one year an E^{-2} flux of 4-22$\cdot 10^{-16}$cm^{-2}s^{-1} (depending on declination) can be tested for declination angles of the source smaller than 40^o. This remains the biggest discovery potential of ANTARES complementary to South pole experiments.

The search for dark matter is another important physics subject apart from astronomy. Weakly interacting massive particles (WIMPS) are candidates for dark matter. They could be gravitationally captured in the center of astronomical bodies until an equilibrium between capture rate and annihilation rate is reached. The annihilation produces conventional particles which subsequently produce also neutrinos in their decay chain. Fig. 4 shows the sensitivity of ANTARES after three years of data taking for a signal from the Sun. The lightest supersymmetric particle χ is

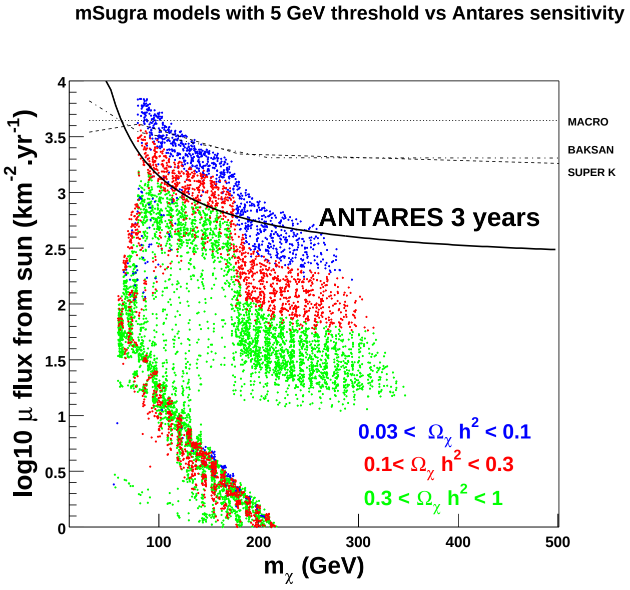

Figure 4: Limits for muon flux from the direction of the Sun due to annihilation of WIMPS, existing limits and expectation from mSUGRA models are also indicated

stable in R-parity conserving models and therefore a possible candidate for such a WIMP. For $m_W < m_\chi < m_t$, where the annihilation produces mainly W-, and Z-pairs which in turn give a very hard neutrino spectrum (up to $E_\nu = m_\chi$) ANTARES can test a significant section of the shown mSUGRA points and also for $m_\chi > m_t$ a certain sensitivity remains. For the shown models in the above mentioned mass range ANTARES offers a complementarity with respect to direct dark matter search experiments.

4. Construction status

From November 1999 to June 2000 a "demonstrator line" had been operated to prove the feasibility of the foreseen project. Its most important result was the verification that the acoustic position system is able to locate each OM with a precision of 5 cm with respect to a grid of fix points on the sea floor.

In October 2001 the final electro-optical cable was deployed over a length of 40 km from the foreseen ANTARES site to La Seyne where the power station and the control room are located.

During summer 2002 a first prototype line has been assembled using in all parts the technologies which will be used for the final detector. The prototype line represents 1/5 of a full line, 5 storeys with 15 OMs. Extensive tests of this line have been performed. The most important result is the verification of the timing accuracy which can be reached by the system. The corresponding measurements have been made with an external laser calibration system in a dark room at CPPM which can accommodate the complete line. As a first step the internal clock calibration corrects for the various cable delays. Applying this correction offsets of only few nanoseconds between pulses from different OMs have been observed. This is compatible with expected variations of the transition times between different photomultipliers. The time resolution of the pulses has been confirmed to be 1.3 nsec at the single photoelectron level (better for higher pulses).

On December 9th 2002, the junction box was connected to the remote cable end and was deployed. This required dredging and lifting of 2.5 km of the main cable. The connection was done on the deployment ship and after various tests the connected junction box was placed on the sea floor. It is supposed to serve for the full lifetime of ANTARES. Since its deployment it is permanently monitored and has flawlessly functioned.

On December 21st 2002 the prototype line has been deployed within a few meters of its foreseen position and about 300 m away from the junction box. Two months later a second line is deployed 100 m away from the prototype line. It contains two storeys which are not equipped with OMs but with supplementary devices to monitor environment parameters (sea currents, sound velocity, salinity, water transparency) or to serve as calibration elements for the prototype line (laser and LED beacons).

5. Epilogue

The two deployed lines needed to be connected to the junction box by a submarine. On 17th March, only three days after the Venice workshop the team of the Nautile submarine from IFREMER succeeded in connecting both lines. From the first day on both lines were operational and a continuous data flow arrives at the shore station. Analyses of these data are in progress and will be presented in forthcoming conferences. It is planned to operate the prototype lines for several months before recovery. Meanwhile the mass production for the full scale detector has started. The ANTARES detector should be fully operational in two years from now.

6. References

1) P. Amram et al. (ANTARES collab.) , *Astropart. Phys.* **13** (2000) 127.
2) P. Amram et al. (ANTARES collab.) , *Nucl. Instr. Meth.* **A484** (2002) 369.