Recent results from the ANTARES experiment

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ANTARES is currently the largest neutrino telescope operating in the Northern hemisphere. The telescope is designed to search for high-energy neutrinos originating from galactic and extra-galactic sources. The detection principle relies on the observation of Čerenkov light, whose emission is stimulated by the propagation in water of the charged leptons resulting from charged current neutrino interactions in the medium surrounding the detector. The detector is a 3-dimensional array of photomultiplier tubes (PMTs), arranged on twelve vertical lines (each housing 75 PMTs), placed at a depth of about 2500 meters, 40 km off the coast of Toulon, France. The detector was completed in May 2008 and it has been working continuously in its 12-lines configuration for almost one year. The performance and first results will be discussed.

The ANTARES[a] Collaboration[1] has designed and built an underwater neutrino telescope covering an area of about 0.1 km^2 on the sea bed, at 2475 m depth, off-shore Toulon, France. ANTARES is currently the largest neutrino observatory in the Northern hemisphere: its location is such that a wide region of the sky, including most of the Galactic plane and the Galactic center, is observable, complementary to the region that is observable from the Southern hemisphere, where the IceCube[2] neutrino detector is located. The detector, schematically described in figure 1, is an array of PMTs arranged on 12 detection lines, each comprising up to 25 triplets of PMTs (floors), regularly distributed on 350 m, the first floor being located at 100 m above the sea bed. A junction box is connected to the shore station by a 40 km long electro-optical cable, to provide power to each detector element, and to perform data-streaming.
Signals collected by each PMT are digitized by means of two Analogue Ring

[a] Astronomy with a Neutrino Telescope and Abyss environmental RESearch

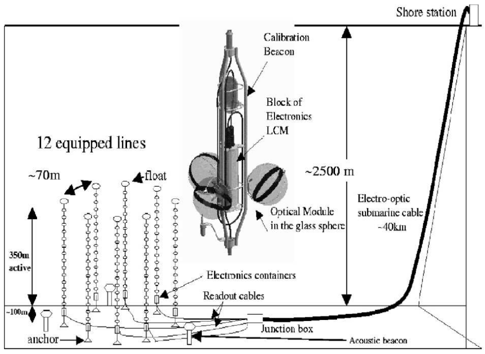

Fig. 1. Schematic description of the ANTARES detector, showing the 12 detection lines, the Junction Box and the electro-optical cable. A storey is also represented in enlarged scale.

Samplers (ARSs),[3] that record time and charge information for signals with amplitude higher than a threshold of 0.3 photoelectrons. Precise timing is provided by a 20 MHz clock system, distributed via the electro-optical cable to each electronics module. Data collected off-shore are then processed by a PC farm, on-shore, running simultaneously several trigger algorithms. An acoustic positioning system, a time calibration system and a set of devices for the monitoring of environmental properties are integrated in the detector for complementary measurements.
The detector realization went through several steps: the first detection line was installed and connected in early 2006; the second line was put in operation in September 2006; three more lines were connected in 2007; 5 additional lines, together with the instrumentation line, were connected by the end of 2007 and the last two lines were connected in May 2008.
The data sample is dominated by the flux of atmospheric muons propagating downward through the detector. Atmospheric neutrinos, with isotropic arrival directions, contribute to the physical background of the experiment, providing a flux that is 4-5 orders of magnitude less abundant than that of atmospheric muons. Light emission due to ^{40}K decay and bioluminescence provides a continuous background, with rates between 60 and 100 kHz: peaks of biological activity can occasionally produce rates up to several MHz. Environmental background hits are mostly uncorrelated and can be easily handled by the trigger/reconstruction algorithms.
The first physics analysis have been performed on data taken in 2007, when the detector was only composed of 5 lines. From January 27th to December

4th, more than 19 million muon triggers have been accumulated during 245 active days. The final sample has been reduced to 168 active days, after a selection that excluded periods with high environmental background. The muon track reconstruction can be performed using the informations on the time and position of the hit PMTs. The arrival direction of neutrinos can

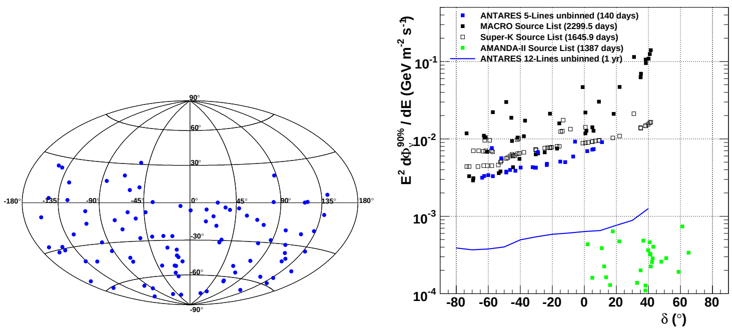

Fig. 2. *Left*: Neutrino candidate events observed by the ANTARES detector during 2007 in the 5-line detector configuration. Optimized cuts for point-source search have been applied to data. *Right*: Neutrino flux upper limit for selected sources (blue points) for a E^{-2} spectrum as a function of declination using the 5 line data. Also shown are the predicted sensitivity for 1 year of the 12 line setup (blue solid line) and upper limits for selected sources by Super-Kamiokande (empty black points), MACRO (full black points) and AMANDA-II (green points).[4]

be measured at sufficiently high energies ($E > 1 \div 10$ TeV), where the flux of atmospheric neutrinos is strongly reduced.

The search for neutrinos from point-like sources is feasible with a reduced detector configuration,[4] since the ANTARES 5-lines detector angular resolution is smaller than 0.5° at 10 TeV. Optimized cuts have been used, obtaining 94 events which are shown in the left plot in figure 2. No statistically significant excess has been found in the data sample and upper limits to the flux of neutrinos have been set for these sources, as shown in the right plot in figure 2.

Indirect search for dark matter can be performed in ANTARES by looking for a neutrino excess from celestial bodies like the Sun or the Galactic Center. Neutrinos with energies below the TeV could be produced in the annihilation of weakly interacting massive particles, e. g. neutralinos, gravitationally trapped in celestial bodies.

For the search for neutralino-induced neutrinos from the Sun, the analysis of the 5 line data[5] is reduced to about 70 active days, because only data taken when the Sun was below the horizon are analysed. The plot in figure 3 shows the upper limit on the total neutrino flux from neutralino annihilation in the Sun with the 5 line data, as function of the neutralino mass.

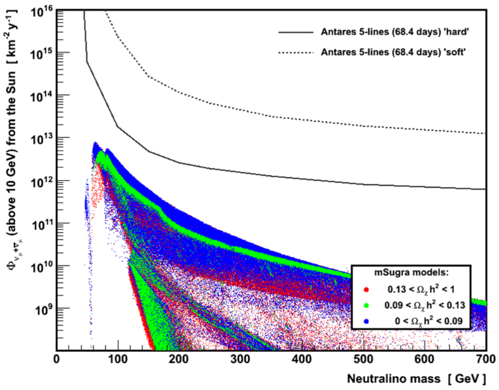

Fig. 3. Upper limit on the total $\nu_\mu + \overline{\nu_\mu}$ flux from neutralino annihilation in the Sun, obtained with 2007 data, with 5 detection lines. Each coloured point corresponds to a supersymmetric model and different observational constraints. Two annihilation models (hard, into W vector bosons and soft, into $b\bar{b}$ quarks) have been studied.[5]

Transient sources, such as gamma-ray bursts (GRBs), core-collapse supernovae or flares, offer a unique opportunity to detect high energy neutrinos, the background of atmospheric muons and neutrinos being strongly reduced over the narrow observation time window.
Two strategies have been implemented in ANTARES to search for neutrino events from transient sources.[6]
The *triggered search* method is based on the GRB alerts received from $\gamma-$rays satellites which are within the GCN[b] network. Whenever a GRB alert is received, a dedicated data-taking, without any filtering, is performed for two minutes, based on the time of the external alert. Analysis is on-going looking for correlation between alerts and candidate neutrino signals. Due to the very low background rates, the detection of a limited number of neutrinos in correlation with an alert could set a discovery.

[b]Gamma Ray Bursts Coordinate Network

The *rolling search* method is based on the optical follow-up of a potential signal observed by ANTARES, made with an optical telescope.[7] The ANTARES detector can trigger the observations made by the optical telescopes that have fast positioning system, suitable for the observation of optical emission in transient sources. Using an online reconstruction algorithm, an alert is sent by ANTARES, whenever a cluster of at least two events is found within a narrow angular bin, or when a high energy neutrino is detected.
Figure 4 shows the elevation of selected muons detected in 2007 and 2008: more than 1000 neutrino candidates have been found.

The ANTARES telescope is running in its final configuration since May 2008: first results allowed to check the reconstruction algorithms as well as simulation codes, demonstrating that the detector performances are well within the expectations. The results obtained by the ANTARES Collaboration show that technology is mature enough to look forward to the realization of a cubic-kilometer scale detector in the Mediterranean sea.

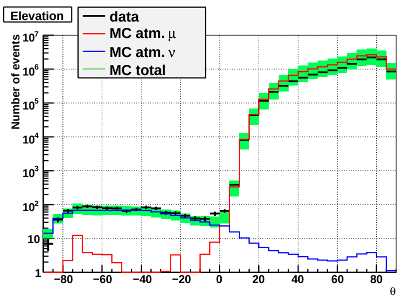

Fig. 4. Elevation angle of the muons detected by the ANTARES detector in 2007 and 2008, for a total lifetime of 341 days. During the whole period 1062 upgoing events have been detected, well within the Monte Carlo predictions.

References

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