IL NUOVO CIMENTO Vol. 34 C, N. 3 Maggio-Giugno 2011
DOI 10.1393/ncc/i2011-10857-2

Colloquia: Scineghe2010

First results of the ANTARES neutrino telescope

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(ricevuto il 25 Febbraio 2011; pubblicato online il 29 Aprile 2011)

Summary. — The ANTARES neutrino telescope was completed in May 2008 and its first results of the searches for point-like and diffuse neutrino fluxes are presented. The sensitivity reached for point-like searches for a live time of 295 days and for declination lower than $-50°$ is of $7.5 \times 10^{-8}\,\mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. For the search of diffuse flux the observed number of events is found to be compatible with the background expectation and a 90% CL upper limit of $5.3 \times 10^{-8}\,\mathrm{GeV}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}$ for a total live time of 334 days was set. The multi-messenger ANTARES program is also briefly described with particular emphasis on the neutrino alert system for the detection of transient source of neutrinos.

PACS 95.85.Ry – Neutrino, muon, pion, and other elementary particles; cosmic rays.
PACS 95.55.Vj – Neutrino, muon, pion, and other elementary particle detectors; cosmic ray detectors.

1. – Introduction

ANTARES is the first operational neutrino detector in the Mediterranean Sea [1]. The main purpose of the detector is the observation of high-energy neutrinos that are expected to be emitted by Galactic and Extragalactic sources where a high-energy acceleration mechanism is present. The properties of neutrino make it complementary to other probes as high-energy gamma and charged particles. In fact, neutrinos can escape from dense matter surrounding the acceleration zone and, due to their neutral charge, they are not deflected by magnetic fields making it possible to point back to the source with high precision. Moreover, the neutrino hadronic origin will allow to distinguish unambiguously between hadronic or leptonic mechanisms.

The neutrino detection principle is based on the observation of Cherenkov light produced in sea water from secondary charged leptons which originate in charged current interaction of neutrino with the water or rock near the instrumented volume. The long muon range makes muon neutrinos privileged with respect to the other neutrino flavours that are detected with lower efficiency and poorer angular resolution. Measuring the photo-sensor positions and the photon arrival time it is possible to reconstruct the neutrino direction (the induced muon and the neutrino are almost collinear at the energy of interest of the telescope).

The ANTARES detector consists of 12 flexible lines, each one hosting 75 photomultipliers contained in glass spheres (Optical Modules OM). The lines are anchored to the sea bed at a distance of around 70 m from each other and are kept vertically by a buoy. The OMs are located along the line and arranged in 25 storeys of three OMs. The distance between storeys is 14.5 m. Each storey contains also the corresponding electronics. The detector is installed about 40 km off the Toulon coast (France) (42°48′ N, 6°10′ E) at a depth of 2475 m. The ANTARES detector was completed in May 2008 but thanks to its modularity has been taking data since the deployment of its first line [1].

The ANTARES detector is the largest operating telescope looking at the Southern sky where the Galactic center and a large part of the Galactic plane are located. In this sky region high-energy gamma detectors, like HESS, have disclosed a large number of TeV gamma sources that are very promising neutrino sources. The ANTARES detector is complementary to the AMANDA/IceCube [2] detectors located at the South Pole.

2. – Searches for point-like sources and diffuse flux

First results of searches for point-like sources are based on data collected in 2007 and 2008 corresponding to an integrated live time of 295 days. In this period the detector was under deployment and it was in a configuration between 5 to 12 operational lines. In the analysis the rejection of atmospheric muons, that are originated by the interaction of cosmic rays with the atmosphere, is based on a likelihood variable Λ deduced from the track reconstruction algorithm. The Λ variable is linked to the goodness of the fit and consequently to the reconstructed track precision. Putting cut on the Λ parameter and on the estimated fit error we can reject most of the atmospheric muons badly reconstructed as up-going. The number of data events selected as up-going was 2040 which is in good agreement with the Monte Carlo expectation. Search of cosmic neutrinos from point-like sources was performed using an unbinned method following two different approaches. In the first approach, the full sky search, no assumption is made regarding the position in the sky of the neutrino sources and a search for event clusters is performed. No significant excess was found. The most significant cluster contains 8 events (only 3 background events are expected) that corresponds to a significance level of 2σ. In the second approach a list of 24 candidate sources was fixed and a search in order to find statistically significant excesses in that directions was carried on. For each source the observed flux limit is reported in fig. 1 (red squares). The sensitivity (90% CL) is reported as a function of the source declination in fig. 1 (red line): the value for the declinations with full visibility is $7.5 \times 10^{-8}\,\mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. The flux limit reached for point-like search is the best one that has been achieved for the Southern sky.

The search of flux of high-energy ν produced by astrophysical sources without any particular assumption on the source direction is one of the main aims of a neutrino telescope. The main existing predictions are based on the observed Cosmic Ray (Waxman-Bahcall) and Cosmic Ray and gamma-ray diffuse flux observations (Mannheim-Protheroe-Rachen) [3]. In the analysis the most challenging issue is the separation of atmospheric and astrophysical neutrinos. In ANTARES this goal has been reached with the implementation of an original energy estimator based on the average number of hit repetitions (R) in the OMs due to the different arrival times of direct (Cherenkov not scattered photons) and delayed photons (photons from secondary electromagnetic showers or scattered photons). High-energy muons ($E_\mu > 1\,\mathrm{TeV}$) are expected to produce more electromagnetic showers and the consequence is that the percentage of delayed photons with respect to the direct photons increases with the muon

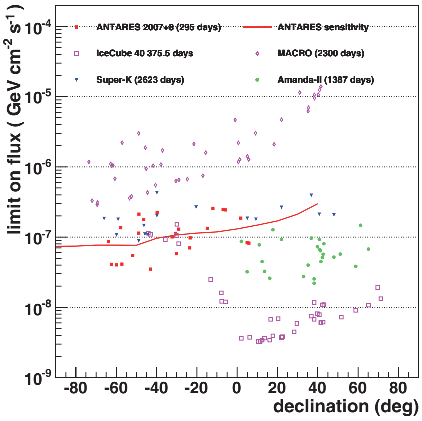

Fig. 1. – (Colour on-line) 90% CL flux limits as a function of the source declination. Published limits from other experiments are also shown.

energy. The separation between the diffuse flux signal from the atmospheric neutrino background is performed by means of a cut on the R variable. The value of the cut on R has been estimated on Monte Carlo following the Feldmann and Cousins method [4] evaluating the best signal-to-noise ratio (Model Rejection Factor minimization). The obtained value is $R = 1.31$. In fig. 2 left are reported Monte Carlo expectations for signal and background neutrino energy spectra as a function of the true neutrino energy before and after the selection of the condition $R \geq 1.31$. The region where the 90% of the astrophysical neutrino signal is present is highlighted. After data unblinding, 9 events have been found in data. From Monte Carlo the number of expected background neutrino events is 10.7 ± 2. The corresponding upper limit is $E^2\Phi_{90\%} = 5.3 \times 10^{-8}\,\mathrm{GeV\,cm^{-2}\,s^{-1}\,sr^{-1}}$ in the energy range between 20 TeV and 2.5 PeV. This limit has been obtained for 334 days of equivalent live time using at least 9 detection lines. In fig. 2 right this limit and, for comparison, limits from other experiments are reported [5].

3. – Multi-messenger astronomy

The multi-messenger astronomy, which can give some help in the understanding of the most violent phenomena in the Universe, is one of the aims of the astrophysical community. In this context the ANTARES Collaboration has developed a program to improve its capability of revealing possible spatial and temporal correlation with other messengers as photons, cosmic rays and gravitational waves. Thanks to the almost background free search, the detection of neutrinos from transient sources is one of the most promising programs for a neutrino telescope. Two strategies are implemented in ANTARES. In the first one alerts are received from the Gamma-ray burst Coordinate Network (GCN). Gamma-ray satellites as Fermi, Swift and AGILE deliver in real time alerts to the GCN when gamma bursts are detected. The direction and detection time are then distributed to the other observatories. ANTARES is connected with the GCN since the end of 2006. In the second strategy ANTARES sends alerts to optical telescopes when multiple neutrinos or high-energy neutrino events are detected. This alert system called TAToO (Telescopes and Antares Target of Opportunity) has been implemented in the ANTARES

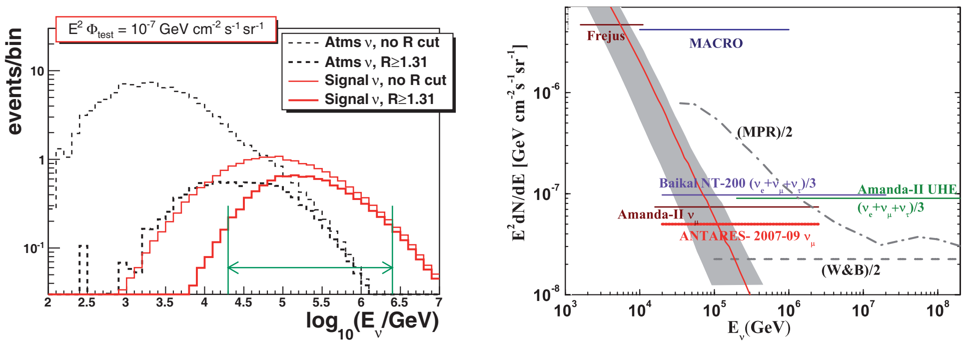

Fig. 2. – Left: Monte Carlo expectation for signal and background neutrino energy spectra as a function of the true neutrino energy before and after the selection on the average number of hit repetitions R. The atmospheric neutrinos are the conventional Bartol+RQPM prompt and the signal is at level of $E^2\Phi = 10^{-7}\,\mathrm{GeV\,cm^{-2}\,s^{-1}\,sr^{-1}}$. Right: ANTARES upper limit (90% CL) for a E^{-2} diffuse high-energy muon-neutrino flux compared with upper limits from other experiments. The predictions for transparent sources are also shown. The grey band represents the variation from vertical to the horizontal direction of the atmospheric ν_μ flux, the central line the average flux.

Collaboration since early 2009. The TAToO system can send alerts to a network of optical telescopes in real time thanks to a fast on-line event reconstruction algorithm with a pointing accuracy of about 1.4°(1 TeV)–0.6°(100 TeV). In order to improve the precision of these alerts an additional reconstruction strategy is used off-line which provide an angular resolution of 0.7°(1 TeV)–0.2°(100 TeV). The good angular accuracy, the ability to filter efficiently events and the time elapsed from the passage of a high-energy particle in the detector to the time in which the alert is sent of few tens of seconds make possible the trigger of optical robotic telescopes such as TAROT and ROTSE for which the typical field of view is $2° \times 2°$. The optical follow-up strategy is composed by real time observations (for rapidly fading sources) and long-term follow-up (for SN search). From early 2009 up to now 22 alerts have been recorded. These numbers are in agreement with the expectations if the unavailability of the two telescopes is taken into account.

Recently a program for coincident searches of high-energy neutrinos and gravitational waves has been undertaken in the ANTARES Collaboration. A coincidence, if observed, will give strong evidence that gravitational waves and high-energy neutrinos are really detected and originate from a common source. A joint search with the VIRGO/LIGO interferometers is going on with a dedicated working group. The common sky view is of around 30%.

REFERENCES

[1] Ageron M. *et al.* (ANTARES Collaboration), *Astropart. Phys.*, **31** (2009) 277.
[2] IceCube web page `http://icecube.wisc.edu`; AMANDA web page `http://amanda.uci.edu/`.
[3] Waxman E. and Bahcall J., *Phys. Rev. D*, **64** (2001) 023002-1; Mannheim K., Protheroe R. J. and Rachen J. P., *Phys. Rev. D*, **63** (2000) 023003.
[4] Feldman G. J. and Cousins R. D., *Phys. Rev. D*, **47** (1998) 3873.
[5] Aguilar *et al.* (ANTARES Collaboration), *Phys. Lett. B.*, **696** (2011) 16.