SELECTED RESULTS FROM THE ANTARES NEUTRINO TELESCOPE

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The ANTARES telescope is the largest underwater neutrino telescope existing at present. It is based on the detection of Cherenkov light produced in sea water by neutrino-induced muons. The detector, consisting of a tri-dimensional array of 885 photomultipliers arranged on twelve vertical lines, is located at a depth of 2475 m in the Mediterranean Sea, 40 km off the French coast. The main goal of the experiment is to probe the Universe by means of neutrino events in an attempt to investigate the nature of high energy astrophysical sources, to contribute to the identification of cosmic ray sources, and to explore the nature of dark matter. In this contribution we will review the status of the detector, illustrate its operation and performance, and present the first results from the analysis carried out on atmospheric muons and neutrinos, as well as from the search for astrophysical neutrino sources.

1 Introduction

The main goal of the ANTARES neutrino telescope experiment is the observation of cosmic neutrinos. The advantage of using neutrinos with respect to other cosmic particles are that they are not deflected by magnetic fields and are weakly interacting. The neutrinos point directly back to the source of emission and can provide an unbiased information about the source.

ANTARES is located in the Mediterranean Sea, 40 km off the French coast at 42°50′N, 6°10′E. The detector was completed in May 2008 and consists of twelve vertical lines equipped with 885 photomultipliers in total, installed at a depth of 2475 m. Before completion ANTARES has been taking data in different line configurations. The distance between adjacent lines is of the order of 70 m. Each line is equipped with up to 25 triplets of photomultipliers spaced vertically by 14.5 m. The photomultipliers are oriented with their axis pointing at 45° from the vertical. The instrumented detector volume is about 0.02 km$^3$.

The detection principle relies on the observation of Cherenkov light emitted by relativistic charged particles in water and is optimized for the detection of muons. The muon trajectory is reconstructed from the arrival times of the Cherenkov light detected by the photomultipliers, whose positions are monitored by means of a positioning system.

2 Selected results: search for cosmic neutrinos

A variety of analyses have been performed since the data taking started with the installation of the first line in 2006. In this paper we will focus on three different data analyses which are related to the search for cosmic neutrinos. There is not enough room to discuss here also of the other topics which were illustrated at the workshop, such as the atmospheric muons and the spatial and temporal correlation of neutrinos with cosmic messengers like photons, cosmic rays and gravitational waves, for which the reader is referred to elsewhere.

The main physical background to identify cosmic neutrinos are atmospheric muons and upward going atmospheric neutrinos. A significant fraction of the atmospheric muons which are produced in the upper atmosphere by the interaction of cosmic rays can reach the apparatus
Figure 1: Left: The distribution of the energy estimator parameter for reconstructed events (points), simulated events from a flux of atmospheric neutrinos normalized to the data (dashed line) and from a signal neutrino distribution normalized to the upper limit given in top of the Figure (solid line). Right: The upper limit (90% C.L.) for a $E^{-2}$ diffuse muon neutrino flux compared to the limits from other experiments (Frejus, Macro, Amanda-II, Amanda-II UHE, and Baikal) and to predictions (W&B and MPR).

despite the shielding provided by 2 km of water. At the depth of ANTARES, the flux of atmospheric muons is around $10^6$ times higher than that of atmospheric neutrinos. The muons produced by the interaction of neutrinos can be isolated from the atmospheric muons by selecting upward going particles. Upward going atmospheric neutrinos will be also detected in this way. The way to search for a signal of cosmic neutrinos is to look at their direction or to try to discriminate the atmospheric neutrinos based on an estimator of the particle energy.

2.1 Diffuse cosmic neutrino flux

The diffuse cosmic neutrino flux analysis does neither use the time nor the location of the reconstructed neutrinos candidates in contrast to the point source search and dark matter search presented in the following sections. The data used for this analysis were collected from Dec. 2007 to Dec. 2009 with 334 days of livetime.

The diffuse flux analysis is based on the observation of an excess of high energy neutrinos above the irreducible background of the upgoing atmospheric neutrinos. The challenge of this analysis is the correct evaluation of the background, especially the one represented by atmospheric muons in large bundles. Downward going particles, wrongly reconstructed as upward going can have the same signature as high energy neutrinos. To study this effect one year of livetime of atmospheric muons has been simulated with the MUPAGE package, where parametrized muon bundles are generated directly at the detector level.

An energy estimator has been used to discriminate between the high energy neutrino signal and the atmospheric neutrino background. The Model Rejection Potential technique has been used to optimize the cuts on the energy estimator in order to find the strongest constraint on theoretical signal models. After a cut in the energy estimator variable ($R > 1.31$) nine events are found in the data sample (see Figure 1 left), while around ten atmospheric neutrino events (Bartol flux plus prompt contribution) were expected. The upper limit for a $E^{-2}$ diffuse flux of muon neutrinos at Earth with 90% confidence level is given in Figure 1 right, extended over an energy range from 20 TeV to 2.5 PeV. This is currently the most stringent upper limit set worldwide.

2.2 Point sources

Antares is in a very good location for the search of cosmic point sources, because large part of the Galactic plain, where several sources of possible neutrino emitters exist, is visible.
A set of cuts have been optimized to search for an $E^{-2}$ neutrino flux in the data sample taken in 2007 extended over a livetime of 140 days. Taking the direction and time of detection of the 276 upward going events which survive the cuts a sky view is obtained as shown in Figure 2 left. A fast and robust reconstruction algorithm with an angular resolution of around 3° for energies above 10 TeV was used for this analysis. An all sky point source search based on an expectation-maximization method as well as a likelihood method did not reveal any significant excess for any direction. As a further attempt, the information of the presence of galactic and extragalactic luminous source such as supernova remnants, pulsar wind nebulae and other gamma sources is used to constrain the search to specific regions of the sky. By specifying the directions of the candidate sources the chance of the background to imitate a signal is reduced. 24 sources have been selected among the most promising neutrino source candidates. No significant excess has been found. The Hess J1023-575 source with equatorial coordinates $\delta = -57.76^\circ$, $RA = 155.8^\circ$ has the highest excess at the level of 1.8 $\sigma$. This is expected in 7.5% of the experiments when looking at 24 sources. The upper limits on the neutrino flux from these 24 candidate sources are shown in Figure 2 right. A more sophisticated reconstruction algorithm which can reach an angular resolution as low as 0.5° above 10 TeV of particle energy is now being used in the analysis of the data collected in 2007 and 2008.

2.3 Dark matter

The indirect search for dark matter in the universe is one further goal of ANTARES. The relic neutralinos could gravitationally be trapped in the Sun and thereby increase the local neutralino density. In the subsequent neutralino annihilation process neutrinos can be created.

A prediction of the neutrino flux coming from dark matter annihilation in the Sun has been calculated in the framework of the mSUGRA model with a neutralino WIMP. The data taken during 2007 were used to search for possible excess in the neutrino flux from the Sun. The livetime of this analysis corresponds to 68.4 days, reduced from the 140 days due to the condition that the Sun has to be below the horizon. The number of events in a search cone around the Sun is shown in Figure 3 left as a function of the search cone radius. The number of observed events is in good agreement with the expected number of background events from Monte Carlo simulation. There is no evidence for a flux of neutrinos from the Sun and the upper limits on the corresponding muon flux are shown in Figure 3 right and compared with other experiments. The mSUGRA parameter space is not reached with this data set, but with a few years of more data ANTARES will become sensitive to the focus point region of the mSUGRA

Figure 2: Left: Propagation directions of the 276 neutrino events selected from the 2007 data. The plot is in equatorial coordinates. Declinations above 47° are always above the horizon and are invisible to the detector. Right: The upper point source limits for 2007 data (filled points) compared with the results published by other neutrino experiments (Macro14, Super-K15, Amanda16 and IceCube17). The predicted sensitivity of ANTARES for 365 days (line) is also shown.
Figure 3: Left: The number of observed neutrinos and expected background events as a function of the search cone radius around the Sun. Right: The upper limit on the muon flux from the Sun above $E_\mu = 1$ GeV as a function of the neutralino mass, in comparison to the expected flux from different mSUGRA models and other indirect detection experiments (IceCube\cite{18}, Amanda\cite{19}, Super-K\cite{20} and Macro\cite{21}).

3 Conclusion

Antares has been taking data since 2006 with a broad physics program and starts to produce competing results. Three cosmic neutrino searches (diffuse flux, point sources and dark matter) have been presented. No signal has been found in these three analyses; upper limits were set.

Acknowledgments

I gratefully acknowledge the support of the JAE-Doc postdoctoral programme of CSIC. This work has also been supported by the following Spanish projects: FPA2009-13983-C02-01, MultiDark Consolider CSD2009-00064, ACI2009-1020 of MICINN and Prometeo/2009/026 of Generalitat Valenciana.

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