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Expected discovery potential and sensitivity of the ANTARES neutrino telescope to neutrino point-like sources.

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Abstract: The ANTARES telescope is being built in the Mediterranean Sea. The detector consists of a 3D array of photomultipliers (PMTs) that detects the Cherenkov light induced by the muons produced in neutrino interactions. Other signatures can also be detected. Since the neutrino fluxes from point-like sources are expected to be small, it is of the utmost importance to take advantage of the ANTARES pointing accuracy (angular resolution better than 0.3 degrees for muon events above 10 TeV) to disentangle a possible signal from the unavoidable atmospheric neutrino background. In order to distinguish an excess of neutrino events from the background, several searching algorithms have been developed within the ANTARES collaboration. In this contribution, the discovery potential and sensitivity to point-like sources of the ANTARES neutrino telescope are presented.

Introduction

The ANTARES collaboration [1] has started the construction of an underwater neutrino telescope in the Mediterranean Sea at a depth of 2475 m. Seven of the twelve lines of the detector have been deployed so far (May 2007) and the whole detector will be commissioned in early 2008. Each line is equipped with 75 10" photomultiplier tubes (PMTs) joined in triplets making 25 floors along the line. The lines are kept vertical by means of a buoy located at their upper end. The mean distance among lines is about 65 m and the instrumented length starts at 100 m over the seabed and covers about 350 m. The angular resolution for the ANTARES telescope at high energies (above 10 TeV) is better than 0.3°. At lower energies, the angular resolution is dominated by the angle between the muon track and the original neutrino direction. The angular resolution together with the effective area determine the performance of a neutrino telescope. The good pointing accuracy and large effective area at high energies (0.06 km^2 at 100 TeV) enables us to search for point-like neutrino sources or, in case no hint of neutrinos source is found, to set restrictive upper limits to neutrino fluxes.

Search for point-like sources

In the search for point-like steady sources, the whole visible sky from the ANTARES location is surveyed making no assumption about time correlation with observations of any other physical phenomenon, like GRBs, flares and other transient sources. In this contribution, we will introduce a new method for the search for point-like sources. This method is based on the Expectation-Maximisation (EM) algorithm which is widely used as a likelihood maximisation algorithm for clustering analysis.

The EM algorithm

The Expectation-Maximisation [2] algorithm is a general approach to maximum-likelihood estimations for finite mixture model problems. For this method a parametrisation of both the signal and neutrino background density distributions is required. The main assumption is that sources signals are supposed to follow Gaussian distributions which is reasonable assumption in our case. The background distribution is inferred from the Monte Carlo data sample, but it could be obtained directly from the real data by scrambling the right ascension coordinate of the measured events. No energy information or further performances of the detector are used in this case. The parameters are determined maximising the likelihood using the EM algorithm. The EM method assumes the existence of *missing* or *hidden* information, in our case the knowledge whether a neutrino event comes from a given source or it is produced by the atmospheric neutrino background. Hence, the real observed data can be understood as an *incomplete* sample, so that, adding a new vector **z** we can build the *complete* data sample, where **z** is a class indicator vector that tells whether an event comes from a source or not. Maximisation of likelihoods analytically intractable can be easily accomplished by means of this methodology. The EM general method follows an iterative procedure where each iteration has two steps:

1. E-step: The expected value of the *complete* data log-likelihood, conditional to the observed data, is computed for a given set of parameters $\{\mathbf{\Psi}^{(m)}\}$
2. M-step: Find $\mathbf{\Psi} = \mathbf{\Psi}^{(m+1)}$ that maximises the expected value. This maximisation will lead to the maximisation of the desirable log-likelihood of the *complete* data sample

The model selection criteria is performed by means of the *Bayesian Information Criterion* or BIC. This BIC value is an approximation of the integrated likelihood when the number of events is high enough. The BIC value can be used as a test statistic and the discovery potential or discovery power of a point-like source to be detected can be inferred using the hypothesis testing theory. This discovery power will be described in section 3.

Other searching algorithms

In ANTARES, other clustering algorithms have been developed in order to exploit the potential of the detector in the search for point-like sources. The first approach was a binning method used to look for a cluster of events in different bins of a grid in which the sky is divided [3]. The significance of clusters is estimated comparing with the distribution of atmospheric neutrino events which is uniform in right ascension. These methods rely on the knowledge of the angular resolution of the detector in order to build the optimum grid. Nevertheless, no hypothesis is made on the neutrino source apart from the neutrino emission according to a power law with spectral index of 2.

The first algorithm that did not rely on a binning approach was a Likelihood Ratio method (LR) [4]. This method operates by testing the data compatibility with two hypotheses: one, often called H_0, is the *null* hypothesis and the other one called H_1. The *null* hypothesis is assumed to be the presence of background only, and H_1 considers the existence of a neutrino point source in addition to the atmospheric background. The parametrisation of the density functions are based on the obtained information from the simulated expected performances of the detector.

Foreseen results for the search for point-like sources in ANTARES

In this section, we will review the results of the point-like source search in ANTARES based on a *blind search* over one year of data taking. A *blind search* is called when no assumption about the source is done beyond the educated assumption of a power law neutrino emission from the sources. This type of search differs from the fixed point searches, where a set of candidate sources are studied. The most direct way of presenting the results in the searching analysis is by means of the discovery power, also called discovery potential. This parameter accounts for the percentage of success of discovering a point-like source over the atmospheric neutrino background. Therefore given a number of events per year observed at the detector from a source, the power of the method is the probability of detecting such source with a given confidence level. This definition enables the construction of plots as the one shown in figure 1. This figure shows the discovery potential for a confidence level of 5σ as a function of the mean number of observed events from a source located at the vicinities of $\delta = -80°$. The three main searching algorithms

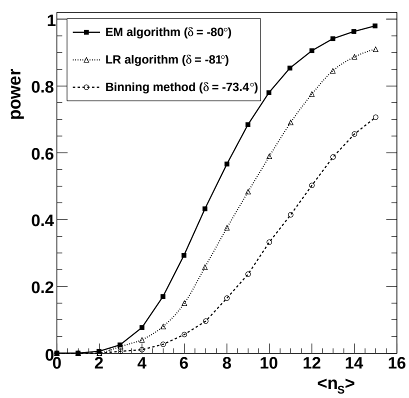

Figure 1: Discovery power (probability of detection) for a source located at low declinations as a function of the averaged detected events for three methods developed in ANTARES for 5σ confidence level.

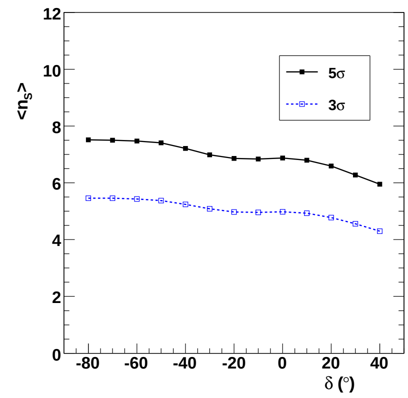

Figure 2: Mean number of observed events required to yield a discovery power of 50% for different confidence levels as a function of declination using the EM algorithm.

are shown. It is important to mention that the results yielded by the different analysis correspond to different Monte Carlo simulations, muon track reconstruction strategies, and therefore different performances of the detector. Hence a direct comparison of the results obtained is not completely fair. Nonetheless, we can observe that unbinned techniques result in a sound improvement with respect to the classical binning approach. This result motivates the use of unbinned techniques in the point-like analysis of real data. Moreover, in this work, the energy estimate information is not used in the EM algorithm which makes it specially appealing for the initial years of operation in a neutrino telescope where the information from the muon energy estimate does not constitute a solid piece of knowledge.

The discovery potential depends on the source location in the sky, specially it depends only on the source declination since the atmospheric neutrino background is right ascension independent. In order to show more clearly this dependence, it is commonly presented as the required number of observed events from a source to claim its existence in 50% of equivalent experiments as a function of the declination. Figure 2 shows this magnitude for two different confidence levels using the EM algorithm. The required number of events is larger at lower declinations since the number of atmospheric neutrinos per solid angle is larger at low declinations. In order to present the results in terms of a neutrino/muon flux, we can divide the required number of events by the exposure of the detector in one year to that declination. Figure 3 shows the required integrated neutrino flux needed to claim the existence of a neutrino source with a probability of 50% as a function of the declination. The required flux increases with declination mainly due to the visibility factor. From the ANTARES location, lowest declinations are visible 100% of the time, whereas high declinations have a small visibility, so that higher fluxes are needed to make a discovery.

Sensitivity

If no excess of events is observed in the sky and therefore, no evidence of a neutrino point-like source is claimed, we can set an upper limit on the expected flux from a neutrino emitter. This upper limit can be provided in terms of a full sky *blind search*. Nonetheless, most commonly it is presented in terms of a point to point upper limit. Moreover, the concept of upper limit is only applied when the experiment is currently running, an

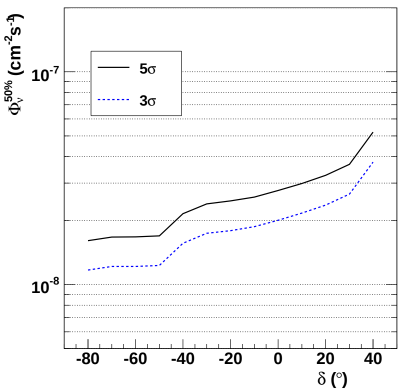

Figure 3: Energy integrated (above 10 GeV) neutrino flux needed to claim the existence of a source with probability of 50% for two confidence levels and the EM algorithm for a E^{-2} spectrum.

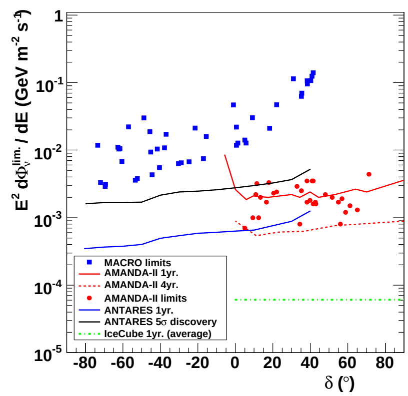

Figure 4: Sensitivity of ANTARES in one year compared to other experiments. See text for further details.

averaged upper limit or sensitivity where the average upper limit is obtained by an ensemble of 10^4 experiments. Figure 4 shows the expected sensitivity for ANTARES for one year of data taking compared to the published results from other experiments. MACRO [5] results are computed after alive-time of 6.3 years. AMANDA upper limits are taken from [6, 7]. The projected sensitivity of IceCube averaged over all Northern declinations is shown [8]. The required flux for a 5σ discovery at 50% for ANTARES in one year is also indicated.

Summary and conclusions

In this contribution we have reviewed the expected performance of the ANTARES neutrino telescope regarding the search for point-like neutrino sources. Several searching algorithms have been devised in ANTARES. Among them, unbinned techniques turn out to be more efficient than the standardised binning approach. In addition, the method based on the EM algorithm presents very good results without the trade-off of higher dependence on the estimated detector performances. Discovery potentials in terms of number of events and required neutrino flux to claim the existence of a source at 50% of probability has been presented. The comparison with other experiments in term of the sensitivity has also been presented.

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References

[1] ANTARES Collaboration. A deep sea telescope of high energy neutrinos. 1999. astro-ph/9907432.

[2] A. P. Dempster et al. Maximum likelihood from incomplete data via the em algorithm. *J. Roy. Stat. Soc. Series B*, 38:1–38, 1977.

[3] E. Carmona. PhD thesis, Universitat de València, Spain, 2003.

[4] A. Heijboer. PhD thesis, Universiteit van Amsterdan, 2004.

[5] M. Ambrosio et al. Neutrino astronomy with the MACRO detector. *Astrophys. J.*, 546:1038–1054, 2001.

[6] J. Ahrens et al. Search for extraterrestrial point sources of neutrinos with AMANDA-II. *Phys. Rev. Lett.*, 92:071102, 2004.

[7] IceCube collaboration. In *ICRC* 2005. astro-ph/0509330.

[8] J. Ahrens et al. Sensitivity of IceCube detector to astrphysical sources of high energy muon neutrinos. *Phys. Rev. Lett.*, 92:071102, 2004.