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FIRST POINT SOURCE SEARCHES WITH THE ANTARES NEUTRINO TELESCOPE

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Abstract. In the heart of the Mediterranean, at a depth of about 2500 m, the eyes of ANTARES monitor the Universe seeking high energy cosmic neutrinos in order to reveal the secrets of the cosmic rays which their origin remains unknown since the discovery of their existence in the early twentieth century. With its 12 lines, carrying 885 photomultipliers, ANTARES is the largest under water neutrino detector in the world since May 2008. In 2007, ANTARES was taking data with a smaller configuration (5 lines). The analysis of this data for point source will be discussed. The result is a new upper limit on the flux of high energetic cosmic neutrinos in the Southerm Hemisphere.

1 Introduction

To study high energy astrophysical sources such as active galactic nuclei, the gamma-ray bursters, supernovae remnants and microquasars, neutrinos are the ideal messenger. Indeed, they are stable, electrically neutral and they have low cross section of interaction with matter. The importance of neutrino astronomy is to study the origin of cosmic rays and their acceleration mechanism. The detection of high energy neutrinos and the measurement of their flux will constrain the hadronic-leptonic production rate of cosmic rays.

In order to study this sources and to solve these engimas, the ANTARES collaboration has installed a telescope in the Mediterranean sea 40 km off the southern coast of France. The neutrinos are detected, after charged current interactions, through the Cherenkov photons emitted in water by the secondary muons. The muon direction is reconstructed using the positions of touched photomultipliers and the arrival time of Cherenkov light. Above 10 TeV the angular difference between the incoming neutrino and the reconstructed muon is $< 0.3°$, the muon direction will point to the neutrino source.

In this proceeding, the analysis of data with a 5 lines detector (i.e. 375 photomultipliers) for point sources will be presented. These data were taken in 2007 (from February 2nd to December 8th) with effective live-time of 140 days.

2 Data sample used in point source analyses

The main background is the atmospheric muons produced during the interaction of cosmic rays with the atmosphere and the secondary muons produced when the atmospheric neutrinos interact with the matter. In order to reduce this background, several cuts are applied on the data after their optimization with the Monte-Carlo simulation study under the assumption of E^{-2} for the source. Only the up-going muons are considered to reject the very high flux of atmospheric muons. To eliminate the mis-reconstructed atmospheric muons (down-going muons), several quality cuts are used based on the number of hits and the quality of track reconstruction. Thus 94 events are obtained.

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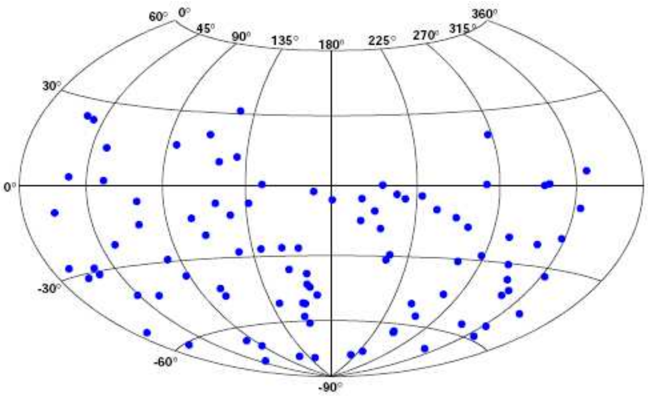

Fig. 1. The selected 94 neutrino candidates presented in equatorial coordinates skymap.

3 Point source search algorithms

For point source search, two statistical methods have been used, unbinned and binned algorithms. The simulations have shown that the sensitivity of the unbinned method, for a given number of signal and background, is 40% better than the binned method because the first one uses the information of the events distribution. This is why the second one is used as a cross-check to the first.

3.1 Unbinned method

The unbinned method, called Expectation-Maximization (EM) algorithm, is an iterative algorithm to maximize the likelihood estimation for finite mixture model problems, in this case mixture of signal and background events. As the name suggests, this method is constituted of two steps (per iteration). The expectation step evaluates the data in order to associate to each event the probability to be signal or background, and the maximization step use the output of E-step to find the set of parameters that maximize the likelihood.

The probability density function (PDF) of the signal is assumed to be a 2-dimensional Gaussian over a non-Gaussian PDF of the background which is a function of declination. This last one can be calculated after the scrambling of the right ascension of the data events.

Once the final set of parameter values is found, a criterion is needed to find the probability of the signal existence. The Bayesian Information Criterion (BIC) was used in this object. Contrary of its name suggestion, it can be used in a purely frequentist manner.

A large number of skymaps are simulated in order to define the BIC distribution for background-only and background+signal models. These distributions are used to calculate the p-value defined as the probability that the background produces a BIC value greater than the data one (BIC_{data}). For a given number of signal events model, if the 90% of the sky map simulations yield a BIC value bigger than BIC_{data}, this model is excluded.

3.2 Binned method

This method is a standard binned method whose goal is to find an excess of events inside a given cone assuming Poissonian statistics. To optimize the radus of the cone, the approach of minimization of the Model Rejection Factor (MRF) is used. This approach produces cone size of 3° to 4.5° (depends on the declination).

4 Results

To evaluate the 94 selected events presented in figure 1, two search strategies have been considered, the candidate source list search and the all-sky search.

For the first one, a list of candidate sources, shown in table 1, are selected in order to decrease the number of degrees of freedom (the right ascension and the declination of the source). No significant event excess was found. The lowest p-value calculated is 0.004 for HESS J1023-575 which corresponds to a 1.6σ post-trial significance.

For the all-sky search strategy, a pre-clustering algorithm selects at least two events separated by less than 5°. Then the p-value of the most significant cluster is given by the EM algorithm. The largest significant excess is found at ($\delta = -63.7°$, $RA = 243.9°$), with $\sigma = 1$. With the binned method, two events are found at this location.

Source name	δ (°)	RA (°)	$n_{bin.}$	p-value	Φ_{90}
PSR B1259-63	-63.83	195.70	0	-	3.1
RCW 86	-62.48	220.68	0	-	3.3
HESS J1023-575	-57.76	155.83	1	0.004	7.6
CIR X-1	-57.17	230.17	0	-	3.3
HESS J1614-518	-51.82	243.58	1	0.088	5.6
GX 339	-48.79	255.70	0	-	3.8
RX J0852.0-4622	-46.37	133.00	0	-	4.0
RX J1713.7-3946	-39.75	258.25	0	-	4.3
Galactic Centre	-29.01	266.42	1	0.055	6.8
W28	-23.34	270.43	0	-	4.8
LS 5039	-14.83	276.56	0	-	5.0
HESS J1837-069	-6.95	279.41	0	-	5.9
SS 433	4.98	287.96	0	-	7.3
HESS J0632+057	5.81	98.24	0	-	7.4
ESO 139-G12	-59.94	264.41	0	-	3.4
PKS 2005-489	-48.82	302.37	0	-	3.7
Centaurus A	-43.02	201.36	0	-	3.9
PKS 0548-322	-32.27	87.67	0	-	4.3
H 2356-309	-30.63	359.78	0	-	4.2
PKS 2155-304	-30.22	329.72	0	-	4.2
1ES 1101-232	-23.49	165.91	0	-	4.6
1ES 0347-121	-11.99	57.35	0	-	5.0
3C 279	-5.79	194.05	1	0.030	9.2
RGB J0152+017	1.79	28.17	0	-	7.0
IC22 hotspot	11.4	153.40	0	-	9.1

Table 1. Results of the search for cosmic neutrinos correlated with potential neutrino sources. The sources are divided into three groups: galactic (top), extra-galactic (middle) and the hotspot from IceCube with 22 lines (bottom). The source name and location in equatorial coordinates are shown together with the number of events within the optimum cone for the binned search, the p-value of the unbinned method (when different from 1) and the corresponding upper limit at 90% C.L. Φ_{90} is the value of the normalization constant of the differential muon-neutrino flux assuming an E^{-2} spectrum (i.e. $E^2 d\Phi_{\nu_\mu}/dE \leq \Phi_{90} \times 10^{-10}$TeV cm^{-2}s^{-1}). The integration energy range is 10 GeV - 1 PeV.

4.1 Systemtic uncertainties

The p-value is not affected by systematic uncertainties since the PDF of the background is calculated using the data. For the cosmic neutrino flux limits, the main systematic errors are the effective area and the angular resolution. The first one is estimated to be 15% in the energy range of 3 to 400 TeV. The main contribution is coming from the uncertainty of the optical modules efficiency and the absorption length of the light in the water. Above 10 TeV, the intrinsic angular resolution is better than 0.5° resulting from the reconstruction algorithm (0.3° for 12 lines detector). The absolute pointing precision is estimated to be about 0.2°. This one is calculated using the boat GPS position and analyzing the ANTARES acoustic positioning data.

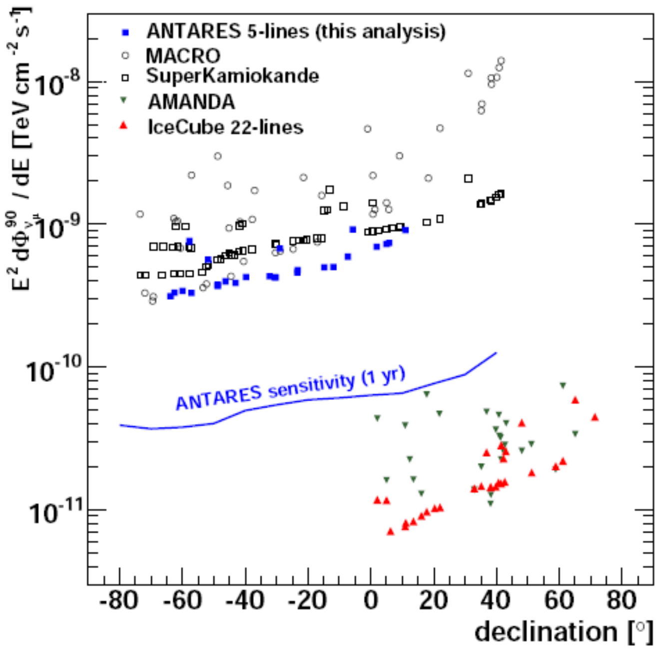

Fig. 2. Neutrino flux upper limits at 90% C.L. obtained by this analysis (solid squares), compared with the results from other experiments (IceCube , AMANDA , SuperKamiokande and MACRO). The sensitivity of ANTARES for one year with twelve lines is also shown (solid line). The source spectrum assumed in these results is E^{-2}, except for MACRO, for which an $E^{-2.1}$ spectrum was used.

5 Conclusion

The ANTARES telescope is complete since May 2008 and takes data. No evidence of neutrino sources has been found in the 5-line data taken in 2007. The analysis for point source (with binned and unbinned methods) provide a maximum excess of 1.6σ post-trial significance. The most restrictive upper limits on the flux of high energetic cosmic neutrinos in the Southerm Hemisphere have been set at the range $E^2 d\Phi_{\nu_\mu}/dE \sim 3-10 \times 10^{-10} TeV cm^{-2} s^{-1}$.

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