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Cluster Search for neutrino flares from pre-defined directions

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Abstract: We present here a method to search for clusters of high energy neutrinos from pre-defined directions, a study of the background rate over short time scales, and report novel results obtained from AMANDA data from years 2004 to 2006. The time structures we search for must indicate an occasional deviation from the background hypothesis while not contradicting observations from time-integrated searches. In the context of the multi-messenger approach, where the information from high energy neutrinos and different electromagnetic wavelengths (e.g., high energy gamma-rays) is combined, we look for correlations between the high energy neutrinos and high states of γ-ray emission of selected sources. This test is performed before the cluster search in order to prevent a posteriori findings of coincidences of neutrino events with γ-ray flares once a significant cluster is found.

Introduction

Different observations of some candidate neutrino sources indicate that their electromagnetic emission is very variable and often shows a flare-like behavior. According to several models one can expect that the neutrino emission from those sources have a similar character. Time integrated analyses [1] [4] [3] are not always sensitive to this behavior: if signal events are emitted in flares, for an equivalent signal efficiency the integrated background is higher over longer exposures. We therefore developed a dedicated time variability analysis with the goal of improving the discovery chance.
Using a time-clustering algorithm, we look for time structures (clusters) in the time distribution of the neutrino events from certain directions. This approach has the advantage of being independent of any a priori assumption on the time structure of the potential signal, but is affected by a high trial factor. An issue for this type of analysis is the reliability of the background estimation over short time scales. So far the background was estimated from the event density as a function of the declination (similar to the ON/OFF-source approach of γ-ray astronomy) [1]. This method however fails when applied to short time scales due to the limited event statistics. To address this problem we developed a parametrization of the background which reduces its statistical uncertainty. In the next section we describe in more detail the principle of this analysis, discuss its performance in comparison to previous analyses and give results obtained on data collected with AMANDA-II in 2004 to 2006.
The analysis presented here is realized in two steps. In order to prevent a posteriori observations of coincidences with γ-rays we first test the event sample for a coincident γ-ray emission for those sources and periods when the γ-ray data is available. The outcome of this test is declared positive if an excess significance equal or higher than 5σ is found. If in the first step none of the observations shows a significance of 5σ or higher (or if there are not enough γ-ray data for a coincidence study) we apply the time-clustering algorithm to the whole analysis period for a set of selected sources. Three types of sources were chosen for this analysis: blazars, XRBs and radio laud AGNs [2]. The selection criteria required: a variable character of the source in one or more wavelengths and indications of non-termal emission.

Time-clustered search for neutrino bursts

For each preselected direction all combinations (clusters) of the arrival time of events within a certain angular bin are constructed. For each cluster its multiplicity (m) is compared to the expected background (μ_{bg}^{loc}) and the significance of the cluster (S_{bg}) is calculated. The cluster with the highest significance (S_{bg}^{best}) is chosen as the "best". The overall probability (P, trial factor corrected) to observe a cluster of significance S_{bg}^{best} or higher is calculated based on 10,000 Monte Carlo (MC) experiments. The main difference between this analysis and what was presented in [2] is that in this work no assumption is made on the duration of signal flares. Moreover, a correct background estimation over short time scales is necessary, in order to properly calculate the cluster's significance and its compatibility with the background hypothesis. The method used previously in the time integrated analysis [1] is simple and fast. However due to the low statistics it is affected by large uncertainties in a case of short time scales (e.g. $\Delta t < 10$ days).

A different approach for a background estimation has been developed for this work. We first tabularise the detector up-time development. This takes into account the inefficiency periods and data gaps after the data quality selection. Once corrected for the detector exposure we calculate the expected neutrino rate from the whole northern sky[1] by fitting the event rate versus time. We obtained 4.13±0.13/3.7±0.13/4.30±0.13 events per day (μ_{bg}^{year}) for 2004/2005/2006 respectively. For each sky angular bin the number of expected events in the whole data period (i.e year 2004, 2005 or 2006) is then calculated as:

$$\mu_{bg}^{loc} = \mu_{bg}^{year} \times \frac{N_{band} \times A_{bin}}{N_{all} \times A_{band}} \qquad (1)$$

where: N_{band} the number of events in the declination band in the sky defined by the bin size, N_{all} the number of all events in the sample for the analysed year, A_{bin} the area of the angular search bin, and A_{band} the area of the declination band defined by the size of the angular search bin. The ratio N_{band}/N_{all} allows to account for the different background density at different declinations.

The result of equation (1) is what we expect when we neglect the variation of the efficiency with the azimuth angle caused by the asymmetrical shape of the detector, (shown in 1) and assume a continuous up-time. The variability averages out for long

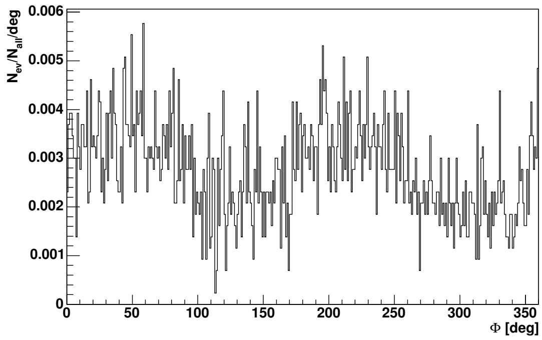

Figure 1: The normalized azimuth distribution of the data sample reported in [1].

periods of data. However, it plays a role for very short periods of integration. We therefore correct the value estimated in equation (1) for the effective azimuth exposure, calculated for each individual time cluster. The correction applied is given by the integral of the azimuth efficiency over the time period of a cluster, taking into account the effective time coverage (up-time) of the azimuth bin. The overall error in the background estimation is a combination of a statistical uncertainty, the error of the fit and the uncertainty introduced by the azimuth corrections.

A comparison of the outcome of this method to previous results shows that for short time scales the new method yields much smaller uncertainties while for longer time periods they are in very good agreement. For example for $\Delta t = 3$ days, we could achieve in this analysis an error of 20% compared to 30% in previous works.

Fig.2 shows a study of the neutrino flare detection chance depending on the strength and duration of the signal. We produced about 10,000 MC experiments simulating a variable neutrino point-

1. We did not observe any dependency of the results for different choices in the binning of the event rates or angular regions of the sky (e.g. estimating the expected rate for different declination regions).

source of different signal strengths and durations, on a background μ_{bg}, characteristic for a chosen region of the sky. Positions in the sky of the on-source events were generated randomly, corresponding to the Point Spread Function, while the number of signal and background events were generated using corresponding Poisson averages. We performed this study for the cases of fixed and variable angular search bin size (chosen among the set of angular distances of the events relative to the sky positions of the pre-selected sources). We found that the best detection chance is obtained with a variable bin size.

The results of the cluster search for neutrino flare for 2004 to 2006 are reported in Table 2.

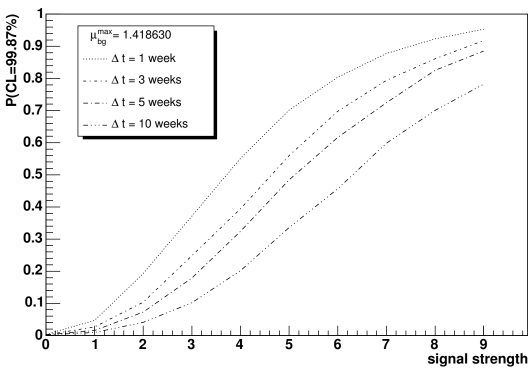

Figure 2: Probability of detecting a neutrino flare with a significance of 99.87% or higher in one year of data (2004 in this example). The X-axis shows the signal strength (mean number of signal events). The curves indicate different time duration of the signal (1, 3, 5 or 10 weeks).

Search for neutrino events in coincidence with γ-ray flares

Observations of strong variability in the high energy (TeV) γ-ray emission exist for various TeV neutrino candidate sources. However, often there is no long coverage of their flux and also a very limited knowledge exists on the frequency of γ-ray flares, as well as on their eventual time correlation with neutrino flares. Nevertheless, a search for coincidences between high energy neutrinos and γ-rays can possibly increase the discovery chance. Here we present the results of a test for correlation of neutrinos with high state of γ-ray emission for a sub-sample of objects for which γ-ray data for the years 2004 to 2006 are published. For each selected source we established a flux threshold for the selection of periods of interest. The number of neutrino events observed - n_{obs} - in the whole period was compared to the expected background - μ_{bg} - and the significance of this observation was calculated.

The threshold to the gamma-ray flux was chosen based on an analysis of combined light-curves [5]. For each source we considered the integral flux above variable thresholds (S) and optimized the latter for the best S/sqrt(B), where B is proportional to the time coverage of the periods above threshold. We exclude periods of measurement gaps longer than one week as well as periods with upper limits on the flux only. In a case of Cygnus X-1 only one day of significant measurement was available so we took the sensitivity of the experiment as the flux threshold.

The results of the search for neutrino events in coincidence with γ-ray flares are reported in Table 1. No significant excess was found.

Table 1: Results of the search for neutrino events in coincidence with γ-ray flares. Column "Selected periods" give the year and integrated up-time of the detector in days.

Source	Sel. periods	n_{obs} / μ_{bg}
Mkn421	2004 (7.6)	0 / 0.057±0.007
	2005 (1.0)	0 /0.0067±0.0008
	2006 (10.8)	0 / 0.078±0.009
Mkn501	2005 (21.1)	1 / 0.13±0.02
1ES1959+650	2005 (0.95)	0 / 0.0040±0.0007
BL Lac	2005 (2.0)	0 / 0.008±0.001
H1426+428	2006 (3.0)	0 / 0.018±0.002
Cyg X-1	2006 (1.0)	0 / 0.0070±0.0008
M87	2005 (4.7)	0 / 0.033±0.004

Results

The input data sample for this analysis for 2004 and 2005 was taken from [1] and [3] respectively. For 2006 we used the results of the AMANDA online event reconstruction and filtering chain, which was implemented following the scheme reported in [1]. After excluding periods of IceCube calibration with an artificial light source and selecting high quality data we used 247.5/199.9/239.5 effective days of data taking for the year 2004/2005/2006.

Table 2 reports the results of the cluster search for neutrino flares for combined data sets of 2004, 2005 and 2006. The highest excess observed (for Cygnus X-3) corresponds to 3.56σ. The overall probability to observe a cluster of this significance or higher at any time in the whole periods analyzed equals 5.9% (not including the trial factors due to looking on several sources) and is well compatible with the background hypothesis.

Table 2: Results of the search for neutrino clusters: duration Δt [days], angular bin size $\Delta\psi$ [deg], significance of the best cluster found S_{bg}^{best} [σ] and the overall probability to observe a cluster of this significance or higher at any time in the whole periods analyzed P [%] .

Source	Δt	$\Delta\psi$	S_{bg}^{best}	P
Mkn 421	3.9	5.2	1.6	95.0
Mkn 501	26.5	4.8	3.2	14.5
Mkn 180	0.35	2.2	2.92	30.0
1ES 1959+650	11.2	2.8	2.82	29.0
1ES 2234+514	42.2	3.4	2.7	35.0
1ES 1218+30.4	5.0	6.0	1.4	95.0
BL Lac	51.6	4.6	2.45	46.0
H1426+428	4.4	5.2	1.5	92.0
3C 66A	7.7	5.0	2.45	44.0
3C 454.3	8.1	4.8	2.7	33.0
GRO J0422+32	19.5	5.8	1.75	90.0
GRS 1915+150	94.4	2.0	3.2	8.4
LSI+61 303	0.2	4.5	2.9	31.0
Cyg X-1	27.5	6.37	3.2	15.0
Cyg X-3	**8.8**	**4.3**	**3.56**	**5.9**
XTE J1118+480	31.1	4.5	2.25	64.0
3C 273	194.5	6.1	2.88	9.1
M87	11.1	6.6	2.0	69.0

Summary

We have presented the first search for neutrino flares from pre-selected sources in AMANDA-II with no a priori assumption on the time structure of the signal. In order to prevent a posteriori findings of coincidences with γ-ray flares a pre-test was performed, to look for correlations between the high energy neutrinos and high states of γ-ray emission of selected sources. In both cases no significant excess was found above the expected background. To accomplish the time-clustered search we have developed a new background estimation method which allows to reduce the statistical uncertainties as compared to the classical ON/OFF-source approach. The method here presented also properly takes into account the effects due to the detector asymmetries arising from a non-homogeneous detector. This approach becomes relevant when analysing data for IceCube, a detector under construction with a non-homogeneous distribution of the strings before completion.

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References

[1] A. Achterberg for the IceCube Collaboration. *Phys. Rev. D accepted for publication*, 2007. arXiv:astro-ph/0611063.

[2] M. Ackerman et al. for the IceCube Collaboration: Contributions to the ICRC, Pune, India, Aug. 3-10. pages 24–27, 2005.

[3] J. Braun et al. for the IceCube Collaboration: Contributions to the ICRC, Merida, Mexico, Jul. 3-11. 2007.

[4] C. Finley et al. for the IceCube Collaboration: Contributions to the ICRC, Merida, Mexico, Jul. 3-11. 2007.

[5] M. Tluczykont et al. *J. Phys.: Conf. Ser.*, 60:318–320, 2007.