ICRC'07 Mérida, México

Cluster Search for neutrino flares from pre-defined directions

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Abstract: 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 present a method to search for clusters of neutrinos from pre-defined directions. The time structures we search for must indicate an occasional deviation from the background hypothesis while not contradicting observations from time-integrated searches. We report recent developments of this method, a study of the background rate over short time scales, and novel results obtained from recent AMANDA data (year 2004 and later). To prevent a posteriori findings of coincidences with γ-ray flare a propaedeutic test is performed, to look for correlations between the high energy neutrinos and high states of γ-ray emission of selected sources.

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] [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 a certain direction. This approach is independent of any a priori assumption on the time structure of the potential signal.

An issue for this type of analysis is however 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 statistics event statistics. To address this problem we developed a parametrization of the background which reduces its statistical uncertainty.

For this work, we decided a priori to apply a statistical test in two steps. In what follows we describe in more details the principle of this search for neutrino flares, discuss its performance in comparison to previous analyses and give results obtained on data collected with AMANDA-II in 2004 and 2006.

In order to prevent a posteriori observations of coincidences with γ-rays we first tested the event sample for a coincident γ-ray emission for those sources and periods when the γ-ray data was available. The outcome of this test is declared positive if a significance equal or higher than 5σ is found. If in the first step none of the observations will show a significance of 5 σ or higher (or if we do not have enough data to estimate the flux threshold for the source) we apply the time-clustering algorithm to the whole analysis period for a set of selected sources. Two types of sources were chosen for this analysis: blazars and XRB [2]. Important criteria for the source selection in

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this analysis are: 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 (trial factor corrected) to observe a cluster of significance S_{bg}^{best} or higher is calculated based on 9,980 Monte Carlo (MC) experiments (P). 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.

One of the most important requirements is, however a correct background estimation over short time scales, 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 is simple and fast. However due to the low statistics it is affected by large uncertainties in a case of short time scales (flare duration $\Delta t < 10$ days).

A different approach has been developed for this work. We first describe the detector up-time development. This takes into account the inefficiency periods and gaps after the data quality selection. We then describe the development of the neutrino rate. For this purpose we integrated the observation over the whole northern sky[1]. We then apply a linear fit to the expected neutrino rate we obtained 4.13±0.13 events per day (μ_{bg}^{year}) for 2004 and 4.30±0.13 for 2006. For each sky angular bin the number of expected events in the whole data period (i.e year 2004 or 2006) is then given by:

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

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 error in the background determination is a combination of the statistical uncertainty and the error of the fit. The result of the equation is what we expect when we neglect the variation of the efficiency with the azimuth angle caused by the asymmetrical shape of the detector, as shown in Fig.1. This variability averages out for long

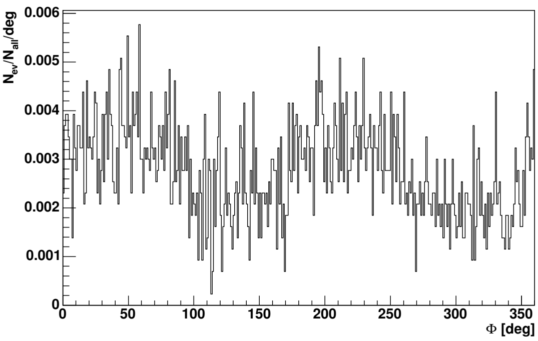

Figure 1: The azimuth distribution of the data sample reported in [1]. X-axis: azimuth angle in degrees. Y-axis: number of events per degree normalized to the number of all events in the data sample.

periods of data. However, it plays a role for very short periods of integration. We therefore correct the 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 data gaps. The overall error in the background estimation also accounts for 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 it is in very good agreement with the old

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

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method. 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 9,880 MC experiments simulating a variable neutrino point-source of different signal strength and duration, 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; number of signal and background events were generated using corresponding Poisson distributions. This study is still in progress - results will be presented on the Conference.

The results of the cluster search for neutrino flare for 2004 and 2006 will be reported on the Conference.

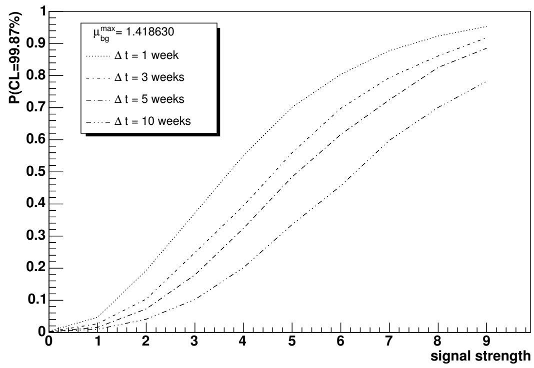

Figure 2: Probability of detecting a neutrino flare with a significance of 99.87% or higher in 2004. The X-axis shows the signal strength (number of signal events). The curves indicate different time duration of the signal (1, 3, 5 or 10 weeks).

Search for neutrino events with 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 continuous measurement of their flux and no prediction for the frequency of γ-ray flares, as well as on their eventual time correlation with neutrino flares.
Nevertheless, we decided to select from our source sample a sub-sample of objects for which γ-ray data for the years 2004 and 2006 are published and for each of them establish a flux threshold above which we would consider the source as being in a high state. Then we calculate the number of neutrino events we observe - n_{obs} - and the integrated background - μ_{bg} - in each of the high state periods, as well as the significance of this observation.
The threshold to the gamma-ray flux was chosen based on an analysis of combined light-curves [4]. 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 measurements gaps longer than one week as well as periods with upper limits on the flux only.
The only source for which the collected light-curves allowed us to establish a high state flux threshold (1 Crab) and select interesting periods for our analysis was Mkn 421 (MJD 2004: 53108-53115; MJD 2006: 53790-53793, 53845-53846, 53850, 53856, 53873, 53880-53884).
In 2004 (2006) 0 (0) events were observed on a background of 0.057±0.007 (0.078±0.009).

Results

The input data sample for this analysis for 2004 was taken from [1]. For 2006 we used the results of the AMANDA on-line event reconstruction and filtering chain, which was implemented following the scheme reported in [1]. After excluding periods of IceCube calibration with flasher and selecting high quality data we used 239.5 effective days of data taking for the year 2006. Analysis of 2005 data is in progress and a time variable search will be also performed following the scheme of this paper.
The results of the clustered search for neutrino flare for 2004 and 2006 will be reported on the

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Conference.

Discussion and Outlook

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 flare a pre-test was performed, to look for correlations between the high energy neutrinos and high states of γ-ray emission of selected sources: no excess was found. To accomplish the time-clustered search we have developed a new background estimation method which allows to reduce the statistical uncertainties 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-homogenus detector. This approach become relevant when analysing data for IceCube, a detector under construction with a non-homogenus distribution of the strings before completion.

Acknowledgments We thank the Office of Polar Programs of the National Science Foundation, as well as DESY and the Helmholtz Association.

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