SF2A 2008
C. Charbonnel, F. Combes and R. Samadi (eds)

NEUTRINO DETECTION OF TRANSIENT SOURCES WITH OPTICAL FOLLOW-UP OBSERVATIONS

Dornic, D.[1], Basa, S.[2], Brunner, J.[1], Busto, J.[1], Boër, M.[3], Klotz, A.[3,4], Escoffier, S.[1], Gendre, B.[2], Le Van Suu, A.[3], Mazure, A.[2], Atteia, J.L.[5] and Vallage, B.[6]

Abstract. The ANTARES telescope has the opportunity to detect transient neutrino sources, such as gamma-ray bursts (GRBs), core-collapse supernovae (SNe), flares of active galactic nuclei (AGNs)... To enhance the sensitivity to these sources, we are developing a new detection method based on the observation of neutrino bursts followed by an optical detection. The ANTARES Collaboration is implementing a fast on-line event reconstruction with a good angular resolution. These characteristics allow to trigger an optical telescope network in order to identify the nature of the neutrinos (and high energy cosmic-rays) sources. This follow-up can be done with a network of small automatic telescopes and required a small observation time. An optical follow-up of special events, such as neutrino doublets in coincidence in time and space or single neutrino having a very high energy, would not only give access to the nature of the sources but also improve the sensitivity for neutrino detection from SNe or GRBs.

1 Introduction

The ANTARES neutrino telescope [1] is located 40 km off shore Toulon, in the South French coast, at about 2500 m below sea level. The complete detector is composed of 12 lines, each including 75 photomultipliers on 25 storeys, which are the sensitive elements. Data taking started in 2006 with the operation of the first line of the detector. The construction of the 12 line detector was completed in May 2008. The main goal of the experiment is to detect high energy muon induced by neutrino interaction in the vicinity of the detector.

Among all the possible astrophysical sources, transients offer one of the most promising perspectives for the detection of cosmic neutrinos thank to the almost background free search. The detection of these neutrinos would be the only direct probe of hadronic accelerations and so, the discovery of the ultra high energy cosmic ray sources without ambiguity.

In this paper, we discuss the different strategies implemented in ANTARES for the transient sources detection.

2 Transient sources detection strategies

To detect transient sources, two different methods can be used [2]. The first one is based on the search for neutrino candidates in conjunction with an accurate timing and positional information provided by an external source: the triggered search. The second one is based on the search for "special neutrino events" coming from the same position within a given time window: the rolling search.

[1] CPPM, Faculte des Sciences de Luminy, 163 avenue de Luminy, 13288 Marseille Cedex09, France
[2] LAM, BP8, Traverse du Siphon, 133376 Marseille Cedex 12, France
[3] OHP, 04870 Saint Michel L'Observatoire, France
[4] CESR, Observatoire Midi-Pyrénées, CNRS, Université de Toulouse, BP 4346, 31028 Toulouse Cedex 04, France
[5] LATT, Observatoire Midi-Pyrénées, CNRS, Université de Toulouse, 14 avenue E. Berlin, 31400 Toulouse, France
[6] CEA-IRFU, centre de Saclay, 91191 Gif-Sur-Yvette, France

2.1 The triggered search

Classically, GRBs or flare of AGNs are detected by gamma-ray satellites which deliver an alert to the Gamma-ray bursts Coordinates Network (GCN [3]). The characteristics of this alert are then distributed to the other observatories. The small difference in arrival time and position expected between photons and neutrinos allows a very efficient detection even with a low energy threshold due to the very low expected background. This method has been implemented in ANTARES mainly for the GRBs detection since the end of 2006. Today, the alerts are primarily provided by the Swift [4] and the Integral [5] satellites. Data triggered by more than 250 alerts have been stored up to now.

Due to the very low background rate, even the detection of a small number of neutrinos correlated with GRBs could set a discovery. But, due to the relatively small field of view of the gamma-ray satellites (for example, Swift has a 1.4 sr field of view), only a small fraction of the existing bursts are triggered. Moreover, the choked GRBs without photons counterpart can not be detected by this method.

2.2 The rolling search

This second method, originally proposed by Kowalski and Mohr [6], consists on the detection of a burst of neutrinos in temporal and directional coincidence. Applied to ANTARES, the detection of a doublet of neutrinos is almost statistically significant. Indeed, the number of doublet due to atmospheric neutrinos is of the order of 0.05 per year when a temporal window of 900 s and a directional one of 3° x 3° are defined.

It is also possible to search for single cosmic neutrino events by requiring that the reconstructed muon energy is higher than a given energy threshold (typically above a few tens of TeV if a Waxman−Bahcall flux is considered). This high threshold reduces significantly the atmospheric neutrino background [7].

In contrary to the current gamma-ray observatories, a neutrino telescope covers at least a half hemisphere if only up-going events are analyzed and even 4π sr if down-going events are considered. When the neutrino telescope is running, this method is around 100% efficient. Moreover, this method requires no hypothesis on the period during which the neutrinos are emitted with respect to the gamma flash, a parameter not really constrained by the different models. More importantly no assumption is made on the nature of the source and the mechanisms occurring inside.

The main drawback of the rolling search is that a detection is not automatically associated to an astronomical source. To overcome this problem, it is fundamental to organize a complementary follow-up program. This program can be done with a small optical telescope network. The observation of any transient sources will require a quasi real-time analysis and a very good angular precision. It will be described in detail in section 4.

3 The ANTARES neutrino triggers

ANTARES is implementing a new on-line event reconstruction (named BBfit). This analysis strategy contains a very efficient trigger based on local clusters of photomultiplier hits and a simple event reconstruction. The two main advantages are a very fast analysis (between 5 and 10 ms per event) and a good angular resolution. The minimal condition for an event to be reconstructed is to contain a minimum of six storeys triggered on at least two lines. To select a high purity sample of up-going neutrino candidates, one quality cut is applied to the result of the χ^2 minimisation of the muon track reconstruction based on the measured time and amplitude of the hits. In order to obtain a fast answer, the on-line reconstruction does not use the dynamic reconstructed geometry of the detector lines. This has the consequence that the angular resolution is degraded with respect to the one obtained with the standard off-line ANTARES reconstruction (of about 0.2 - 0.3°) which includes the detector positioning.

In order to set the cuts used for the special event selection, we have analysed the data taken from December 2007 to May 2008 (around 109 active days) with a 10 line detector. During this period, around 350 up-going neutrino candidates were recorded. The figure 1 shows the elevation distribution of the well reconstructed muon events which pass the quality cuts during this period. This plot shows as the same time the down-going atmospheric muons and the up-going neutrino candidates. It also illustrates the very low contamination of the bad reconstructed atmospheric muons in the up-going sample.

In order to obtain an angular resolution lower than the field of view of the telescope (around 1.9°), we select reconstructed events which trigger several hits on at least 3 lines. The dependence of this resolution with the

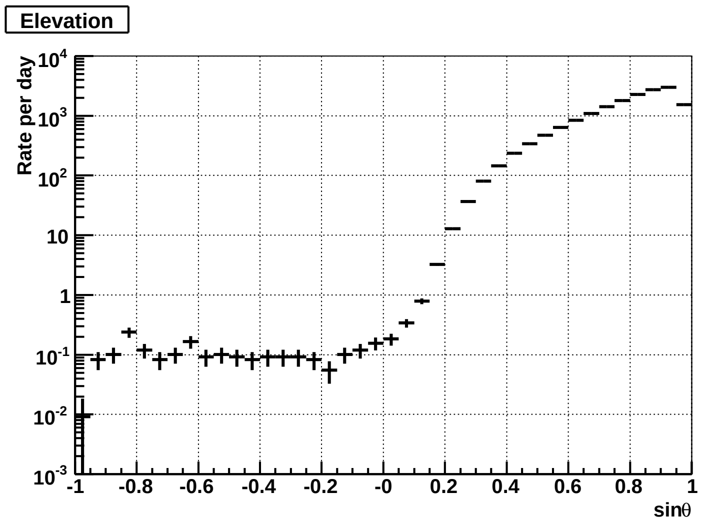

Fig. 1. Elevation distribution of the well reconstructed muon tracks recorded with the 10 line detector (Dec 2007 to May 2008). The region where the elevation is negative represents the up-going part of the distribution.

number of lines used in the fit is shown in the figure 2. For the high energy events, this resolution can be as good as 0.5 degree.

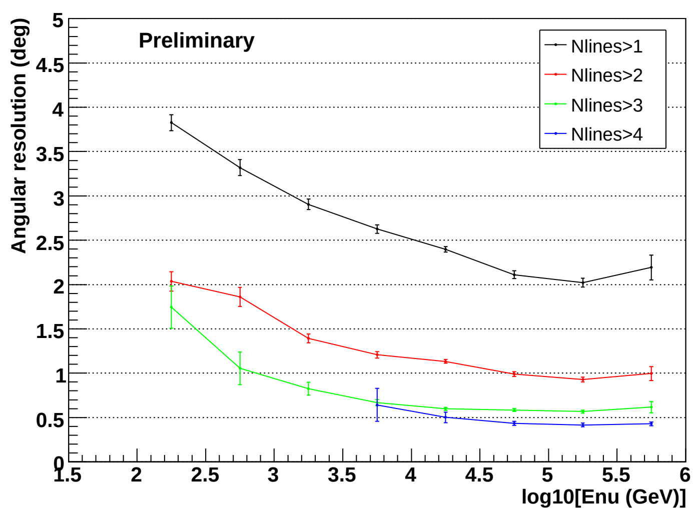

Fig. 2. Angular resolution evolution with energy for the event with at least 2, 3, 4 and 5 lines used in the fit.

An estimation of the energy in the on-line reconstruction is indirectly determined using the number of hits of the event and the total amplitude of these hits. In order to select events with an energy above a few tens of TeV, a minimum of about 20 hits and about 200 photoelectrons per track are required. These two different trigger logics applied on the 10 line data period select six events in about 109 active days.

4 Optical follow-up network

ANTARES is organizing a follow-up program in collaboration with TAROT (*Télescope à Action Rapide pour les Objets Transitoires*, Rapid Action Telescope for Transient Objects; [8]). This network is composed of two 25 cm optical telescopes located at Calern (South of France) and La Silla (Chile). The main advantages of the TAROT instruments are the large field of view of 1.86 ° x 1.86 ° and their very fast positioning time (less than 10 s). These telescopes are perfectly tailored for such a program. Since 2004, they observe automatically the alerts provided by different GRB satellites [9].

As it was said in the section 2, the rolling search method is sensitive to all transient sources which produced high energy neutrinos. Different observation strategies will be defined according to the different source types. For example a GRB afterglow requires a very fast observation strategy in contrary to a core collapse supernovae for which the signal will appear several days after the neutrino signal.

Such a program would not require a large observation time. Depending on the neutrino trigger settings, an alert sent to TAROT by this rolling search program would be issued at a rate of about one or two times per month.

5 Summary

The detection of neutrinos from transient sources is favorized by the fact that external triggers are provided by spacecraft currently in operation. The follow-up of interesting events would improve significantly the perspective for neutrino detection from transient sources. These special events are selected with two complementary triggers: search of a neutrino doublet (the most sensitive) or a single high energy event. The most important point of the rolling search method is that it is sensitive to any transient source. The confirmation by the optical telescope of a neutrino alert will give not only the nature of the source but also allow to increase the precision of the source direction determination in order to target other observatories (for example very large telescopes for the redshift measurement).

The key of the success of the search method is to analyze all the events on a very fast way while keeping a good angular precision. This good angular resolution will be an advantage not only to reduce the background and also to increase the probability to find an optical counterpart. The ANTARES Collaboration has an agreement with TAROT to develop this Target-of-Opportunity program. The implementation of this new technique has already started and we expect to send the first alert by the end of 2008.

References

Antares Collaboration, Proposal, arXiv:astro-ph/9907342v1

Basa, S., Dornic, D. et al. 2008, arXiv:astro-ph/0810.1394

GCN network, http://gcn.gsfc.nasa.gov

Barthelemy, S.D., Barbier, L.M., Cummings, J.R., et al. 2005, Space Science Reviews, 120, 143

Mereghetti, S., et al. 2003, Astron. Astrophys., 411, 291

Kowalski, M., & Mohr, A. 2007, Astroparticle Physics, 27, 533

D. Dornic et al, arXiv:astro-ph/0810.1452

Bringer M., Boer M., et al. 1999, A&AS, 138, 581

Klotz, A., Boer, M., Atteia, J.L., & Gendre, B. 2008, AJ, submited