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Optical follow-up of high energy neutrinos detected by the ANTARES telescope

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The ANTARES Collaboration has completed in 2008 the deployment of what is currently the largest high energy cosmic neutrino detector in the Northern hemisphere, covering a volume of about 0.01 km^3. To enhance the sensitivity of the ANTARES detector to transient sources, such as Gamma Ray Bursts (GRBs), Core Collapse Super Novae (CCSN), flaring active galactic nuclei (AGN) and microquasars, a method based on coincident observations of neutrinos and optical signals has been set up. The observation is triggered whenever a high energy singlet or a burst of neutrino events in space and time coincidence is detected by the ANTARES telescope: the selection of events is such that alerts are sent with a frequency of about twice per month. The system is operational since 2009 and since then, about 40 alerts have been sent to the telescopes network. The optical follow-up system will be described and first results on the optical images analysis searching for GRBs will be presented.

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Transient sources offer a unique opportunity to detect high energy neutrinos, the background of atmospheric muons and neutrinos being strongly reduced in the narrow observation time window. Several authors predict the emission of neutrinos in correlation with multi-wavelength signals, e.g. the Fireball model of GRBs [1].

To search for cosmic neutrinos from transient sources, a peculiar method, earlier proposed in [2], as been developed within the ANTARES Collaboration [3]: it is based on the optical follow-up of selected neutrino events, very shortly after their detection. The system is known as "TAToO" (Telescopes and ANTARES Target of Opportunity) and it is described in [4]. Two online neutrino trigger criteria are currently implemented in this system: the detection of at least two neutrino induced muons coming from similar directions within a predefined time window, and the detection of a single neutrino induced muon.

A basic requirement for the coincident observation of a neutrino and an optical counterpart is that the pointing accuracy of the neutrino telescope should be at least comparable to the field of view of the optical telescopes, namely TAROT and ROTSE [5], having a field of view of about $2^\circ \times 2^\circ$.

To select the events which might trigger an alert, a fast and robust algorithm [6] is used to reconstruct the ANTARES events. The principle is to minimize a χ^2 which compares the times of selected hits with the expectation from a Cherenkov signal of a muon track. The resulting direction of the reconstructed muon track is available within about 10 ms and the obtained minimal χ^2 is used as fit quality parameter to remove mis-reconstructed tracks. This algorithm uses a simplified detector geometry, that does not take into account the actual shape of the detector as well as the storeys orientation and lateral extension. With a larger delay (few minutes after the time of the burst), an additional reconstruction algorithm, originally developed to search for point-like sources, is used to refine the result of the online strategy. Figure 1 shows the angular resolution of the online and offline algorithms, as a function of the neutrino energy.

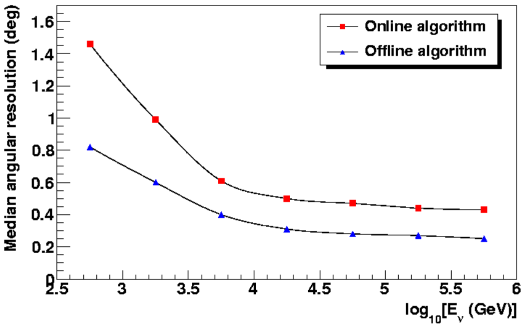

Figure 1: Angular resolution, i.e. the median of the space angle between the direction of the incoming neutrino and the reconstructed neutrino-induced muon, for online and offline reconstructions, as a function of the neutrino energy.

The key point of the TAToO system is the optical follow-up program, that involves the ROTSE and TAROT telescopes. The TAROT network is composed of two 25 cm optical robotic telescopes located at Calern (France) and La Silla (Chile). The ROTSE network is composed of four 45 cm optical robotic telescopes located at Coonabarabran (Australia), Fort Davis (USA), Windhoek (Namibia) and Antalya (Turkey). The main advantages of these instruments are the large field of view, namely about 2 x 2 square degrees, and their very fast positioning time (less than 10s). Thanks to the location of the ANTARES telescope in the Northern hemisphere (42.79 degrees latitude), all the six telescopes are used for the optical follow-up program. With the current settings, the connected telescopes can start taking images with a latency of the order of one minute with respect to the neutrino event.

To be sensitive to a wide range of transient sources, the observational strategy is composed of a real time observation, optimized to search for GRBs, followed by several observations during the following month, optimized to search for longer phenomena, like CCSN. For the prompt observation, 6 images with an exposure of 3 minutes, and 30 images with an exposure of 1 min are taken respectively by the first available TAROT and ROTSE telescopes. The integrated time has been defined in order to reach an average magnitude of about 19. Once the images are collected, they are automatically dark subtracted and flat-fielded at the telescope site. Once the data are copied from the telescopes, an offline analysis is performed combining the images from all sites. This off-line program is composed by three main steps: astrometric and photometric calibration, subtraction between each image and a reference one, and light curve determination for each variable candidates.

The ROTSE pipeline has been applied to five alerts from which optical images have been recorded during the first 24 hours after the neutrino alert sending. The minimum delay between the neutrino detection and the first image is around 70 s. No object has been found for which the light curve is compatible with a fast time decreasing signal.

1. Conclusions

The TAToO system is able to trigger the observation with a network of optical telescopes within one minute from the detection of the neutrino candidate, with an precision on the alert position that is better than one degree. The quasi-online availability of a refined direction further improves the quality and efficiency of the alert system. The alert system is operational since February 2009, and as of October 2011, about 40 alerts have been sent.

The image analysis of five 'prompt' observations has not permitted to discover a GRB afterglow associated to the high energy neutrino. The analysis of the rest of the images to look for the light curve of a core collapse SN is still on-going.

References

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