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Increasing the detection efficiency for neutrinos from GRBs(*)

M. Bouwhuis on behalf of the ANTARES Collaboration
NIKHEF - Kruislaan 409, 1098 SJ, Amsterdam, The Netherlands

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Summary. — When the data acquisition (DAQ) system of an underwater neutrino telescope is interfaced with IBAS and GCN, all raw data can be saved to disk for a few minutes when a GRB alert message is received. If the DAQ system is designed such that it constantly buffers a few minutes of raw data, the data that were taken before the alert could then also be saved to disk. Consequently all raw data covering a few burst durations before and after the burst will be available. Any time-correlated neutrino signal will thus be included in these data. The data can be analysed offline using the known position of the GRB. Using the time and direction information of GRBs, the detection threshold for the neutrinos they emit could be lowered. The increase in detection efficiency achieved in this way will be quantified for the ANTARES experiment.

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1. – Introduction

Neutrinos from GRBs can be detected with neutrino telescopes, situated under water or in ice. The detection principle of these detectors is based on the detection of the Cherenkov light emitted by the lepton that is produced after a charged current neutrino interaction near the detector, and that moves relativistically through the water or ice. This light can be detected by photo multiplier tubes (PMTs) that are arranged in a three-dimensional array in the detection medium. Muon neutrinos are mainly considered, as the muon resulting from the interaction can travel large distances. From the positions of the PMTs and the arrival times of the detected photons the path of the muon can be reconstructed and its direction can be derived. From its direction can be concluded if it concerns a neutrino from a GRB, as the direction of the muon is approximately the same as that of the neutrino.

The neutrino telescope considered here is the ANTARES detector [1]. The construction of the detector has started, and the full detector will be completed in 2007.

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2. – Standard data taking in ANTARES

The data acquisition (DAQ) system of the ANTARES detector, that takes care of the readout of the detector, the transportation of the data from the detector to shore, and the processing of the data, has some unique features. In this system all raw data are sent to shore. On shore the data arrive in a computer farm consisting of a few tens of computers. Each of these PCs runs a filter program that looks for correlations in the data. Only the data that resemble the data produced by physics signals are stored on disk. All other data are considered as background. The physics signal stored on disk is used for the physics analyses. Not all data can be used for the physics analysis as the data output of the detector consists mainly of background. The background is partly caused by atmospheric muons and neutrinos produced after the interaction of cosmic rays entering the atmosphere. Most of the background is due to bioluminescence and radio active decay of nuclei in the sea water, and produces, in contrast to the atmospheric background, uncorrelated data. As a result of this, the total data rate is about 1 GB/ s. The data-processing programs have to filter the data in real time as the detector will continuously take data, 24 hours per day. The resulting data rate after filtering is less than 1 MB/ s, which is manageable for the data analysis. Because of the required speed of the algorithms used for the processing of the data, cuts are applied that imply partial loss of physics signal.

3. – Data taking in case of a GRB

The DAQ system has a socket connection with the GCN [2] and IBAS [3] warning systems for GRBs. When a GRB alert message is received from either of these systems, a possible neutrino signal from this GRB could be detected at the same time. When this happens, all raw data are saved to disk as shown in fig. 1, instead of processing the data online. This will continue for a few minutes, as GRBs can last up to a few tens of seconds, and the neutrino signal from a GRB is expected to arrive within a few burst durations around the burst. This way of data taking will only last for a few minutes because of the high data rate. After this time, the system will return to normal data taking. Later, when the location of the GRB is distributed by the same GRB warning systems, a specialised analysis can be applied to these data. The fact that a GRB lasts for only a short time makes it possible to handle all these data. The standard data processing and analysis tools, that are normally used, look for a neutrino signal in all directions. In this case the location of the GRB and thus the direction of the neutrinos is known. This information is used to analyse the data.

Not only the data taken during these few minutes will be available for the data analysis, but also the data that were in the memories of the data processing PCs at the time the alert message was received. The data processing programs hold continuously as much data as possible in memory before processing them. With tens of data processing PCs, all raw data corresponding to about one minute of data taking are buffered. These data will also be saved to disk when an alert message is received. The buffered data will cover the delays involved in the GRB warning systems, and a possible early neutrino signal [4]. In this way, all data that were taken during a few burst durations around the burst are available and will contain any time-correlated neutrino signal, assuming that the alert message arrives within about 20 seconds after the detection of the gamma rays.

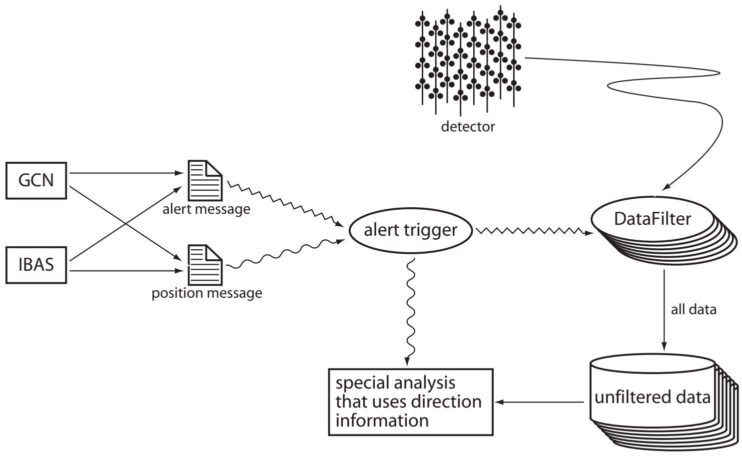

Fig. 1. – Special data taking when a GRB is detected by using the GCN and IBAS systems as external triggers. Normally all data are sent from the detector to shore, and processed there by the DataFilter processes. When a GRB alert message is received, indicated by the zig-zag arrows, the DataFilter programs are instructed to stop filtering the data. Instead, all data are written to disk for a few minutes. Later, when the position of the GRB is received, indicated by the wavy arrows, the data will be analysed using the direction information.

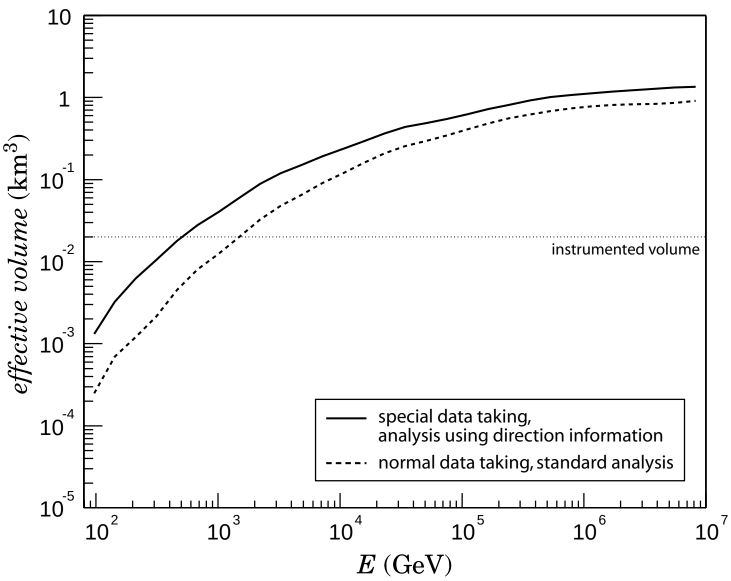

Fig. 2. – The effective volume as a function of the neutrino energy for neutrinos from GRB030329 when the special data taking is applied, and the special analysis was used for the data that were taken during this burst. Also shown is the effective volume for normal data taking and standard analysis (dashed line). The dotted line indicates the instrumented volume of the detector.

4. – Results

As soon as the message with the location of the GRB has arrived, the stored raw data are analysed using specialised algorithms that use this direction information. Because of this extra information, and because the data processing is not done in real time, less strict cuts are applied to the data.

This results in a higher efficiency for the physics signal. Considering the expected frequency of detection of GRBs by satellites, and the time needed to analyse the data in this way, the message with the location of the GRB should arrive within 12 hours after the initial alert message. The described way of data taking and data analysis has been applied to simulated data. For this, GRB030329 was used as an example. The effective volume that can be obtained with the ANTARES detector for neutrinos from the direction of this GRB is shown in fig. 2 as a function of the neutrino energy. The effective volume is 2-3 times bigger than when no special data taking and data analysis was applied.

5. – Conclusions

Neutrino telescopes can profit from the GRB warning systems as the moment a GRB occurs and the direction of the neutrinos they emit is known. The alert messages should arrive within about 20 seconds after the gamma rays are detected, and the final message with the position of the GRB within 12 hours. These GRB warning systems are especially of great importance for neutrino telescopes like ANTARES, that have the all-data-to-shore concept implemented, where all raw data covering a few minutes can be saved, including data that were taken prior to the arrival of the alert message. Using the time and direction information obtained from the GRB warning systems in this way increases the discovery potential of neutrinos from GRBs. Considering the expected number of at least 100 GRB triggers from GRB satellites per year [5], the 50% field of view of the ANTARES detector, and the predicted neutrino fluxes from GRBs, this could result in the detection of a few events per year [6].

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