A Data Acquisition System for the ANTARES Neutrino Telescope

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Abstract

The ANTARES project has started the construction of an underwater neutrino telescope in the Mediterranean sea. The detection principle relies on the detection of Cherenkov light emitted from a muon that emerges from a neutrino interaction. The detector consists of a 3 dimensional array of 900 photo-multiplier tubes (PMTs), supported by 12 vertical strings. A data acquisition (DAQ) system has been designed for the readout and processing of the data. The signals from the PMTs are digitised off-shore and filtered in real-time using an on-shore PC farm. This is done to filter the physics events from the background and to reduce the data rate from 1 GB/s to about 1 MB/s. In the event of alerts provided by other experiments, such as gamma-ray burst alerts, several minutes of unfiltered data will be stored for off-line analysis. The data buffered in memory give access to information before the alert. A specialised data filter algorithm using directional information is under study to increase the detection efficiency for neutrinos from known astrophysical sources. The concept and implementation of this DAQ system will be shown, as well as the present status and scalability to a km^3 detector.

1. Introduction

In the framework of the ANTARES project a neutrino telescope is being built in the Mediterranean sea for detecting high energy neutrinos (typically above 1 TeV). The neutrinos are detected indirectly by the Cherenkov light emitted from the muon produced in a charged current interaction of a muon neutrino. The light is detected by photo-multiplier tubes (PMTs) which are supported by 12 vertical strings, located at a depth of 2.4 km. Each string has 25 triplets of PMTs, called floors, separated by 14.5 m. From the arrival times of the photons on the PMTs the muon trajectory can be reconstructed.
The purpose of the DAQ system is to read out the PMTs and to process the data for off-line analysis. Each floor has a pressure resistant container housing readout electronics. This system digitises the charge and time of the analogue signals, caused by photons that hit the PMTs. All data produced by the off-shore readout system are sent to shore where they are processed in real time. The on-shore pro-

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cessing system consists of a farm of about 100 PCs. The background rate, caused by decay of ^{40}K and bioluminescence, is typically 70 kHz, corresponding to a data rate of about 1 MB/s per PMT. A data filter based on a cluster algorithm that looks for space-time correlations in the data has been developed. This reduces the data rate by a factor of 10^3. Most found clusters consist of accidental correlations due to the high background rate. To limit this background, the minimum cluster size is typically set to 10. As a result, the efficiency is low (10%) for neutrinos with an energy below 50 GeV.
The efficiency of the filtering process can be increased, and the background rate can be reduced, if the direction of the muons is known. One way of getting directional information is by connecting the DAQ system to the gamma ray burst coordinates network (GCN). This network distributes information obtained from satellites that detect gamma ray bursts (GRBs). By using this as an external trigger, the data can be filtered using a different cluster algorithm that looks for time correlated hits from muons from the given direction. Such an algorithm has been developed recently. The same data filter could be used in parallel with the standard data filter to detect neutrinos from known astrophysical sources (e.g. from the annihilation of neutralinos in the Sun and the centre of the Galaxy). Detection of correlated neutrinos will contribute to the understanding of the physics processes taking place in the source.

2. Methods

The integration of the GCN alert system in the DAQ system is shown schematically in Fig. 1. Normally the DataFilter filters the data and saves the

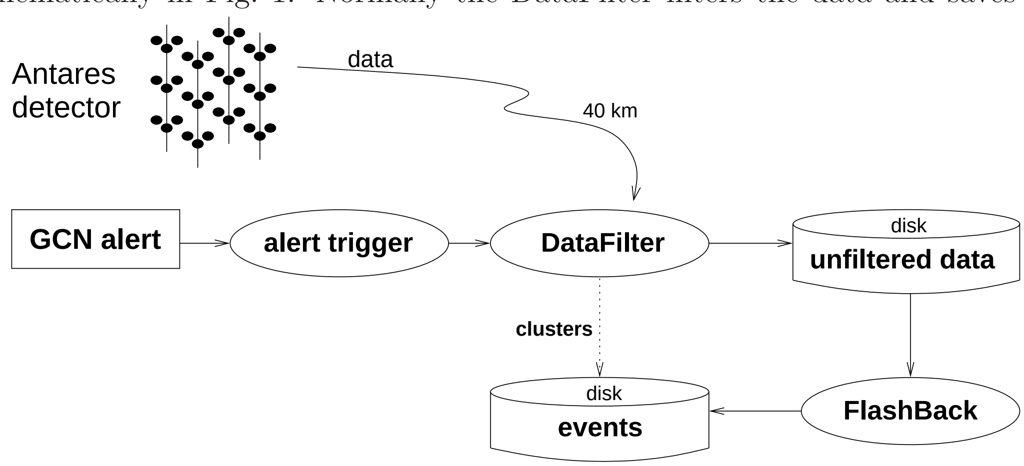

Fig. 1. GCN alert system in the DAQ system

found clusters as (physics) events directly to disk as indicated by the dotted arrow. The GCN distributes alerts that follow the detection of a GRB within 10 s. Possibly messages will follow with the location of the burst. In case of a

GCN alert, the alert trigger in the DAQ system notifies the DataFilter programs to stop normal filtering and instead write all data to disk for a few minutes, including all data in memory. Each DataFilter node has approximately 1 s of data prior to the alert in memory. As soon as the message with the location of this GRB is received, the program FlashBack can be initialised, and the saved data will be filtered using the corresponding direction.
The cluster algorithm in the DataFilter uses the following relation to find space-time correlations of the hits:

$$|\text{ time difference between two hits }| \times c/n \leq \text{distance between the PMTs} \quad (1)$$

where n is the refractive index of the water, and c the speed of light. The directional information is used in the FlashBack program to constrain (1) further. By choosing the z axis along the direction of the muon, the arrival time t_j of a

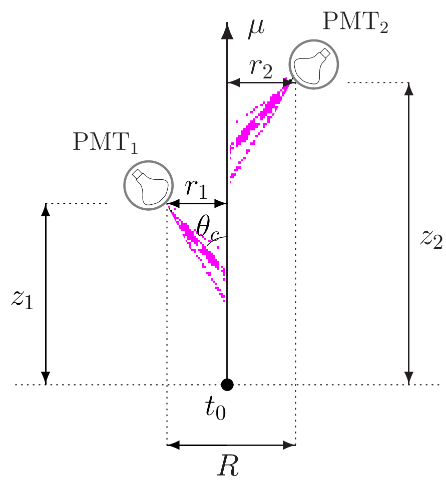

Fig. 2. Schematic view of a muon traversing part of the detector. The Cherenkov photons are emitted under an angle θ_c with respect to the muon trajectory.

Cherenkov photon on $\mathrm{PMT_j}$ is given by (see Fig. 2):

$$t_j = t_0 + \frac{1}{c}(z_j + \kappa r_j) \quad (2)$$

where t_0 is some reference time, $\kappa \equiv \frac{c}{v_g}\frac{1}{\sin\theta_c} - \frac{1}{\tan\theta_c}$, v_g the group velocity of light in water, and θ_c the Cherenkov angle. For the couple of PMTs 1 and 2 in Fig. 2, the parameters r_1 and r_2 are the distances of closest approach from the PMTs to the muon trajectory. As the position of the muon trajectory is not known, only its direction, the values of r_1 and r_2 are not known. The difference in hit times of the two hits can then be constrained as follows:

$$\frac{1}{c}(z_2 - z_1) - \frac{\kappa}{c}R \leq t_2 - t_1 \leq \frac{1}{c}(z_2 - z_1) + \frac{\kappa}{c}R \quad (3)$$

where R is defined as the 2D distance between the positions of the two PMTs projected on a plane perpendicular to the muon trajectory. Since (3) is more stringent than (1) (note the same sign of the terms $(z_2 - z_1)$), looser filter conditions can be applied (e.g. minimum cluster size of 5).

3. Results

A Monte Carlo simulation has been made to study the detector response and filter efficiencies for different incident neutrino directions. Fig. 3 shows the efficiency of FlashBack and DataFilter programs for neutrino events as a function of neutrino energy. In this, events have been selected with at least five detected photons. As can be seen from Fig. 3, the efficiency of the cluster algorithm is

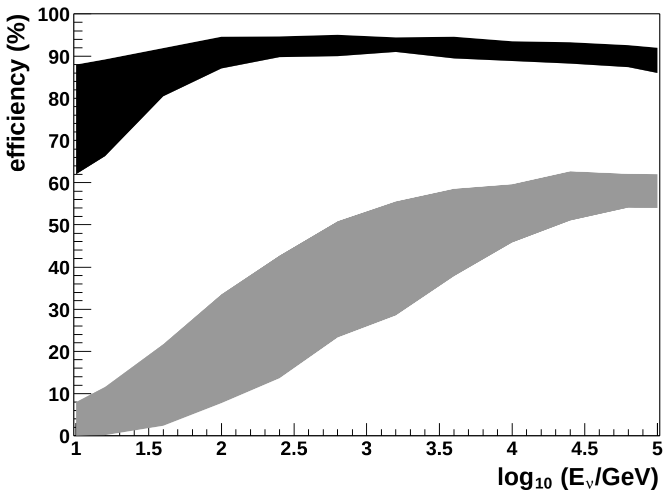

Fig. 3. Efficiency of the two cluster algorithms as a function of neutrino energy. The black area is the result of FlashBack, the grey area is the result of DataFilter. The areas cover the results for neutrinos that come from directions with zenith angles in the range 0°-90°.

greatly improved when using the directional information. Preliminary studies of the background show that due to the tighter constraints (using (3) instead of (1)) the probability of accidental correlations is significantly reduced.

4. Outlook

Since mid March 2003 the first detector string containing five floors is operational [1]. With this first detector, background rates are measured extensively. In spring 2004 the construction of the full detector will start, and it is expected to be ready in 2006.
In view of the continuous increase in processing speed of standard PCs, it is expected that for a future km^3 neutrino detector the present DAQ concept can be applied.

5. References

1. Circella M., *Toward the ANTARES Neutrino Telescope: Results from a Prototype Line*, these proceedings.