

A software trigger for the AMANDA neutrino detector

T. Messarius for the IceCube Collaboration

University of Dortmund, Otto-Hahn-Str. 4, 44221 Dortmund, Germany

Presenter: T. Messarius (messarius@physik.uni-dortmund.de), ger-messarius-T-abs1-og27-oral

In the last few years a new Data Acquisition System (DAQ) for the AMANDA-II detector was built and commissioned. The new system uses Flash ADCs and works nearly dead time free (0.015%), compared to 15% dead time for the old DAQ. Up to now, this new DAQ was triggered solely by the existing trigger system. Recently a software trigger was developed to take advantage of the new hardware. The first advantage is the ability to define more complex trigger-settings. A local coincidence trigger will improve the acceptance for low energy neutrinos. The second advantage is that the new system can more readily integrate the existing 19 AMANDA strings into the new IceCube observatory.

1. Introduction

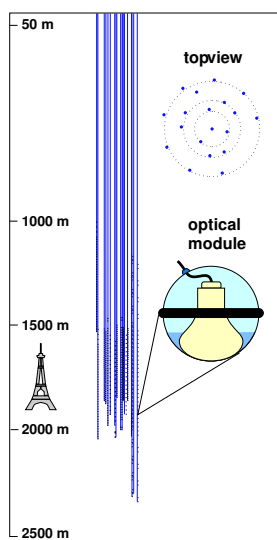


Figure 1. Amanda II.

AMANDA has produced scientific results for many years and is a working neutrino detector [1, 2].

2. The new TWR-DAQ system and science goals

The μ -DAQ system uses TDCs and peak sensing ADCs to extract information from an analog PMT pulse. It uses the DMADD trigger logic with a multiplicity $M=24$ which results in a trigger rate of ~ 100 Hz. The vast majority of these triggered events are due to atmospheric muons. The settings are a compromise between the energy threshold and deadtime of the detector. This and other limitations [3, 6] of the μ -DAQ led to the development of a new DAQ system based on Transient Waveform Recorders [4] (TWR), which are flash ADCs (FADC) capable of recording the complete waveform of a PMT in a time window of $10.24 \mu\text{sec}$ with a resolution of 12 bit and a sampling frequency of 100 MHz. The new system - TWR-DAQ - has a

¹Discriminator and Multiplicity ADDer

Since construction first began in 1996, the Antarctic Muon And Neutrino Detector Array (AMANDA) has detected high energy muons and neutrinos. Neutrinos are observed indirectly by measuring the Cherenkov light from secondary leptons generated in neutrino-nucleon interactions. AMANDA uses the ice sheet at the geographical South Pole as its active volume and consists of 19 strings of Optical Modules (OM) each containing a photomultiplier tube (PMT) and electronics in a glass sphere. Most of the 677 OMs of the detector are located at a depth of 1.5 to 2 km below the ice surface. The detector is displayed schematically in Fig. 1.

The analog PMT signals are transmitted via electrical cables or optical fibers to the surface electronics. For the reconstruction of the energy and direction of the particles, the arrival times of the pulses and the number of photons contained in each PMT pulse are used.

The original Data Acquisition system (μ -DAQ) is triggered by a hardware based trigger logic, the DMADD¹, which identifies events through a pre-set global multiplicity condition: i.e., more than M OMs with a signal in a $2.5 \mu\text{sec}$ time window. At low multiplicities, random coincidence of PMT noise pulses ("noise events") dominate the muon signal. Lower multiplicity signals are triggered by local coincidence on a single string ("string trigger").

significantly lower dead time (approx 0.015%) compared to the μ -DAQ system (15% deadtime), and a better readout performance leading to a higher data bandwidth. Since Feb 2003, the TWR-DAQ used the DMADD as a trigger source. In 2003, a M=24 level was used while in 2004 the trigger multiplicity was lowered to M=18 with a corresponding trigger rate of ~ 140 Hz. The μ -DAQ still uses a M=24 multiplicity level. For each PMT pulse, the whole waveform is written out resulting in a larger amount of data compared to the μ -DAQ system. A first reduction is performed by a Digital Signal Processor (DSP) collecting the data from the TWRs in each crate and performing a so called Feature Extraction (FE) to extract the rather short PMT pulses from the waveform. The new TWR-DAQ system is running and taking data continuously for two years [3]. In 2003 and 2004, the system produced a data rate of ~ 65 GB per day, nearly exceeding the capability of network communication at the South Pole. For a further extension of the capabilities of the detector with respect to the intended integration of AMANDA into the IceCube detector [7, 8], the TWR-DAQ will be further upgraded. The goals for the next upgrade are:

1. to reduce the energy threshold of the detector in order to increase the sensitivity for low energy particles,
2. to introduce fast algorithms to search for patterns, i.e. local coincidences, in low multiplicity events to distinguish reconstructable events from noise events, and,
3. to send trigger signals to the IceCube trigger system in order to integrate AMANDA into the IceCube detector.

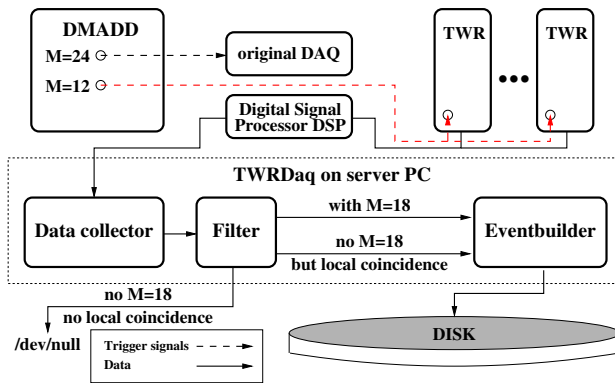


Figure 2. Structure of the AMANDA DAQ system in 2005.

DAQ in January 2005 an online monitoring was implemented to the TWR-DAQ. Changes in the trigger rates and noise rates of each PMT can be monitored for each file.

3. Performance of the new TWR-DAQ system including the software trigger

The TWR-DAQ including the software trigger is running stably since mid - February 2005. Particles with high energy (100 GeV to TeV range) produce a sufficient amount of light in the detector to be triggered reliably by the DMADD multiplicity trigger while the detection efficiency for smaller energies is low. One challenge for the software trigger is an improvement of the sensitivity of the array for low energy particles by distinguishing between noise induced and particle induced events. The PMT pulses of particle induced events are correlated in time and space. A dedicated trigger algorithm searching for local coincidences identifies these events in the detector. The so-called next neighborhood algorithm (NEXT) measures the level of local coincidence in the event. For each OM with a pulse, a sphere of 90 m radius around the OM is searched for further OMs

These goals can be achieved by implementing software trigger algorithms into the TWR-DAQ system. The layout of the trigger system is displayed in Fig. 2. The DMADD system is still used as a pre-trigger with a low multiplicity threshold. The global multiplicity level can be lowered from M=18 to M=12. Events with a multiplicity of $M > 18$ are directly written to disk, while the remaining events are tested for local coincidences in software. The algorithm is described in the next section. A total trigger rate of ~ 195 Hz is reached and noise events are mostly rejected. During the last update of the TWR-

with a pulse. If there is at least one additional OM with a pulse, the number of modules with at least one local coincidence pair N_{1hit} is increased by 1. Alternatively, the number of local coincidence pairs is counted in N_{pair} . Double counts are excluded in these numbers. In 2005, the software trigger uses $N_{pair} > 8$ or $N_{1hit} > 5$ to trigger event readout.

While muons produce long tracks in the detector, electrons and taus will lose their energy contained in a small volume inside the detector producing a cascade like event. Figure 3 shows that the NEXT trigger is sensitive to both of the event types.

The pre-trigger rate from the DMADD is ~ 250 Hz. First, multiplicity ($M=18$) events are written to disk and excluded from further processing. The software trigger keeps about 50% of the remaining events. The distribution of the number of PMT pulses in the triggered event, N_{hit} ², are shown in Fig. 4. For this analysis a set of random data was taken using a frequency generator as trigger. Since the frequency generator is not correlated to any physical events the data can be used to investigate the trigger settings without any pre-trigger thresholds. At small N_{hit} ($N_{hit} < 25$) the distribution of the random data is dominated by Poissonian noise events. At $N_{hit} > 25$ the distribution is dominated by the slowly decreasing contribution of μ -events. The NEXT trigger filters at small N_{hit} down to $N_{hit} = 12$ the reconstructable³ events out of the event stream leading to an increase of low-energy events.

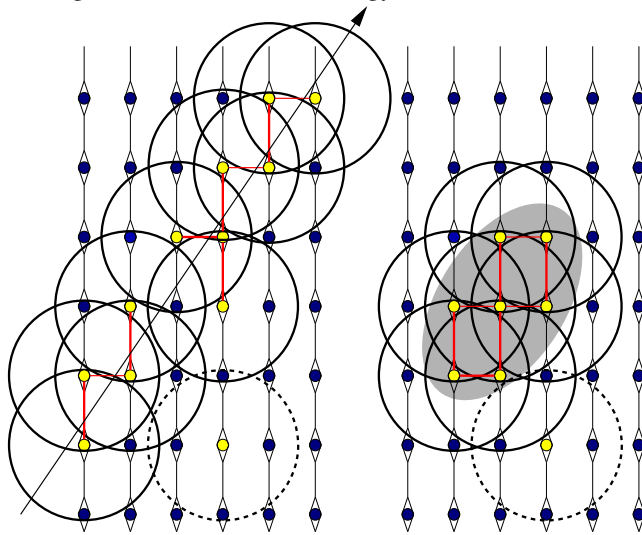


Figure 3. 2D schematic of the functionality of the next neighborhood trigger. The red/gray lines between the OMs show counted pairs of hit OMs. The left picture shows a track like event, the right picture a cascade like event. The black circles show the search volume.

4. Integration of AMANDA into IceCube

The existing AMANDA-II detector will be incorporated into the IceCube detector, which is currently under construction. The first IceCube string was installed in the ice in Jan 2005 and additional strings are planned for the next deployment season (Nov. 2005 -Feb. 2006). With the AMANDA TWR-DAQ system it is more straightforward to integrate information from the AMANDA strings into the IceCube trigger and data formats. After the successful completion of the integration of the TWR-DAQ with the IceCube DAQ, the original AMANDA DAQ will be decommissioned. The AMANDA and IceCube strings will be synchronized via a common GPS clock. The TWR-DAQ will send its trigger information to IceCube Global Trigger (GT), which

The dotted line in Fig. 4 shows the distribution of reconstructable events. At $N_{hit} > 24$ the percentage of reconstructable events is about 90% to 100%. It decreases to $\sim 50\%$ for $N_{hit} = 16$ and is down to $\sim 15\%$ for $N_{hit} \leq 14$.

The update of the TWR-DAQ would result in an increase of the data volume to ~ 95 GB/day. To decrease the data volume an on-line compression, based on the Huffman algorithm, is used. The performance of this algorithm depends strongly on the distribution of values in the uncompressed data. In order to improve the performance of the compression, a linear prediction of the waveform values is used. Only the difference between the true value and the prediction is stored. These steps reduce the data volume to 35 GB/day. Compared to 2004, the average number of bytes per event decreased by 50% while the trigger rate increased by 40%.

²Total number of PMT pulses in a time window of $10.24 \mu\text{sec}$.

³These events pass the standard track reconstruction of the AMANDA analysis chain.

identifies physical events in the data stream with a software trigger algorithm. The TWR-DAQ sends its trigger information via TCP/IP to GT which handles the triggers from the IceCube sub-detectors. The IceCube DAQ is based on a custom IP-like communication with the DOMs (Digital Optical Modules). There can be a latency of several 100 milliseconds before the signals from the DOMs reach the surface. Once all sub-detectors have produced and send their own triggers to the GT, the GT orders them in time and then starts producing higher triggers which are sent to the IceCube event builder (EB). Upon receipt of the triggers from the GT, the EB requests and reads raw data including waveform information from the string processors (SP) which can hold raw data for about 30 seconds. Due to the different DAQ and Trigger architecture, only the trigger information from the TWR-DAQ will be sent to IceCube GT but not vice versa. Both data streams will be combined offline at the South Pole or in the northern hemisphere.

5. Outlook

The new software trigger and a future implementation of the hardware string trigger as a pre-trigger gives a great opportunity to lower the energy threshold for several analyses as well as increasing the sensitivity due to the 40% gain in trigger rate. It is intended to implement further filter algorithms to flag events containing down-going μ tracks to accelerate an offline analysis. A further idea is to implement a compensation for the cable delays of the detector to be able to reduce the time window and multiplicity level for a trigger decision. The TWR-DAQ system will be equipped with a special Gamma Ray Burst (GRB) trigger. A GRB trigger will be sent from the GCN network and will be received via satellite at the Pole. As soon as a GRB alert arrived, the TWR-DAQ will store all data in the buffer and all the subsequent data for several hours.

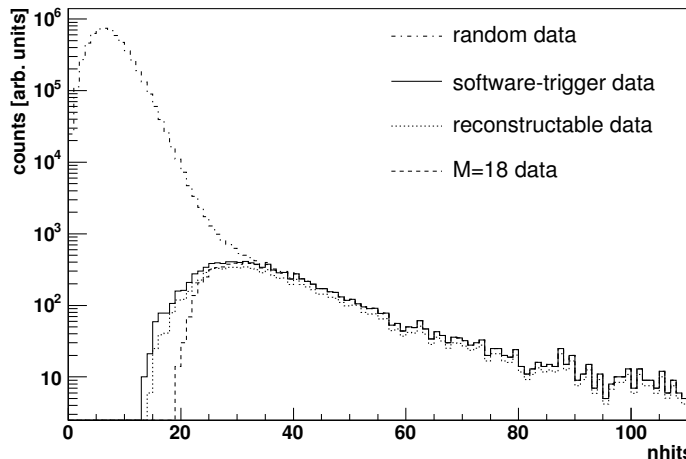


Figure 4. The distribution of N_{hit} . The solid line shows the triggered data with the NEXT trigger and the global multiplicity. The dotted line shows the reconstructable events and the dashed line shows the triggered events of the year 2004 as comparison. The dash-dotted line represents N_{hit} distribution obtained from random data.

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