New Capabilities of the AMANDA-II High Energy Neutrino Detector

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Abstract

During the past Austral summer, the AMANDA collaboration completed a major upgrade of the detector, especially aiming at the highest energy phenomena. Nearly deadtimeless operation has been achieved while the information content of the recorded event has improved dramatically by adding full waveform capture to the electronic readout. This report will describe the hardware improvements, characterize the performance with data acquired in 2003, and discuss several areas of current scientific interest that benefit from the upgrade.

1. Introduction

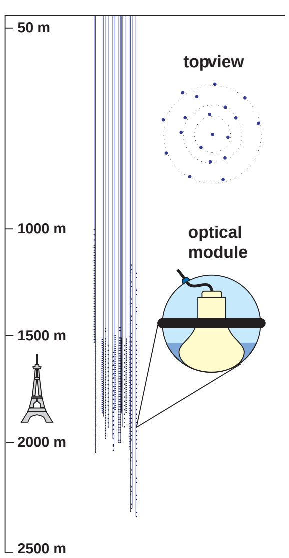

Fig. 1. Amanda II.

The Antarctic Muon And Neutrino Detector Array AMANDA detects high energy neutrinos indirectly by measuring the Cherenkov light emitted by secondaries. Using the ice sheet at the geographical South Pole as active volume, it consists of 19 strings of Optical Modules (OM) each containing a photomultiplier tube (PMT) and dedicated electronics in a glass sphere. Most of the 677 OMs are located at depths between 1.5 and 2 km below the ice surface. Fig. 1. shows the detector in its present configuration. The analogue PMT signals are transmitted up the strings to the surface electronics. For the reconstruction of the particle trajectories and energies the exact arrival times of the PMT pulses and the number of photons in each PMT pulse are used. AMANDA has been producing physics result since 1996 and is a working neutrino telescope [1,2,3]. Limitations of the original system have led to the development and installation of a new Data AcQuisition system (DAQ).

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2. Science goals

The present DAQ uses multihit Time to Digital Converters (TDC) to measure the exact arrival times of each PMT pulse and a peak sensing Analog to Digital Converters (pADC) to deliver one value representing the maximum pulse height per channel for one event [7]. The TDC is only capable of storing 16 edges limiting the number of detected PMT pulses.

Muon tracks with low light intensity can be reconstructed using only the first pulses in each PMT. UHE particles and cascades produce large numbers of photons in the detector and these scattered and dispersed photons can be used for track and energy reconstruction as the dispersion of photons depends on the distance to the light source. Thus for high energy particles a wide dynamic range for detecting photons as well as the recording of the full waveform is desirable.

The goals for the development of a new DAQ are

- to utilize all of the information available from the sensors, record the whole waveform and build a reliable DAQ.
- to extend the integrated dynamic range by a factor of ~ 100. This provides more information to help reconstruct the direction and energy of high energy muons and cascade events, since ν_τ and ν_e are detected as cascades with a large amount of light in a small time interval.
- to reduce electronic-induced deadtime to negligible levels. The deadtime of the original system is approximately 15% and is mainly determined by the readout process of the DAQ.

These goals can be achieved using Transient Waveform Recorders (TWR) [4], Flash ADCs, which are capable of recording the complete waveform of the PMT in a window of 10.24 μsec with a time resolution of 10 nsec and an accuracy of 12 bits. With this technique the above mentioned goals can be fulfilled. The TWRs are equipped with a Field Programmable Gate Array (FPGA) making the TWR a very flexible device.

During the Austral summer 2001/2002 an initial test setup with 48 channels was installed. The results were promising, leading to the decision to upgrade the system in the following summer season 2002/2003 and to enhance it to read out 576 OMs. At present the TWR DAQ is running in parallel with the original system. The remaining OMs will be connected in the next season. A detailed description of the system can be found in [5].

3. TWR system performance and first results

The TWR DAQ has been running since the middle of February 2003 with a data rate of 50 GB/day, a trigger rate of about 90 Hz and a negligible deadtime, proving the stability of the system.

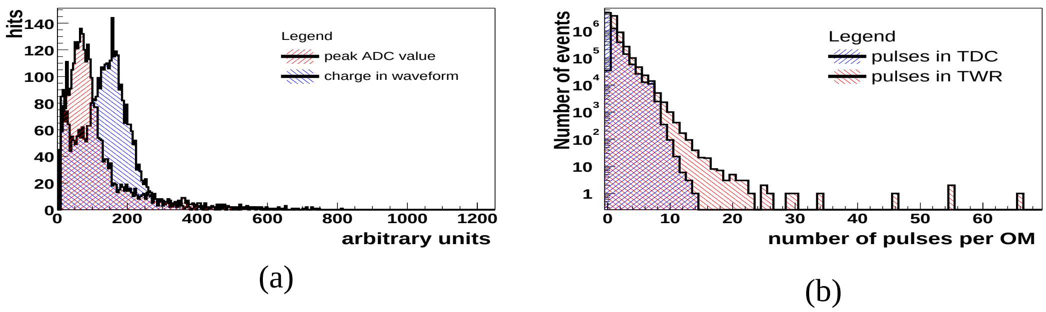

Fig. 2. Fig. (a) shows the integrated charge of the pulses in the waveform compared to the pADC value distribution. The number of pulses found in the TWR and the number of pulses detected by the TDC is shown in Fig. (b).

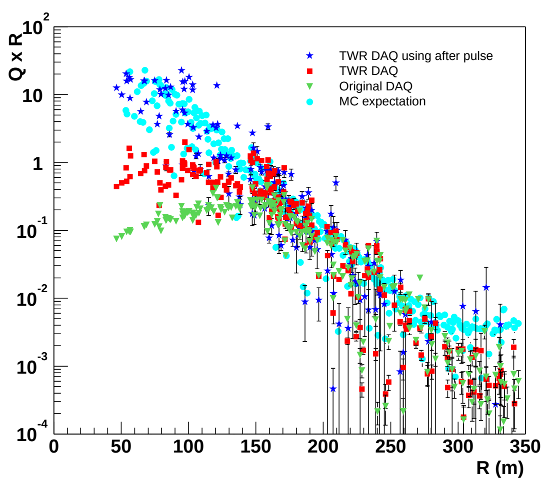

Fig. 3. The correlation of R versus Q · R.

An important point to prove is that the new DAQ using TWRs gives a resolution comparable to the original system. A first analysis shows that the single photoelectron charge resolution for the TWR system achieves a better performance than the original system. In Fig. 2.(a), the ADC values from the original system and the integrated charge of the pulses in the waveform are shown. The increase in the number of detected pulses is displayed in Fig. 2.(b).

An initial laser calibration was done in February 2003 using a Nitrogen laser emebedded near the bottom of the detector. The theoretical relation between expected photon flux and distance from the laser can be expressed as

$$I = I_0 \frac{1}{R} e^{-\frac{R}{\lambda_{att}}} \qquad \Longrightarrow \qquad \log(Q \cdot R) \sim -\frac{R}{\lambda_{att}} \tag{1}$$

with the expected number of photons I, which is proportional to the observed charge Q, the distance R between optical module and laser and the effective attenuation length λ_{att}. λ_{att} can be determined by plotting $\log(Q \cdot R)$ versus R. The linear relation can be seen in Fig.3., where Monte Carlo simulated data, TWR data and data from the original system (pADC) are shown. For the measured data the linear relation degrades at a certain point when approaching smaller distances R. This point determines the end of the dynamic range for the number of reconstructed photoelectrons. It can be seen that for the TWR data the dynamic range is three times higher than for the original system. With a more advanced method using afterpulses the linear dynamic range can be extended up to 5000 photons [6].

4. Future opportunities

The increased information content per event and further plans to extend the maximum trigger rate up to 200 Hz will result in a significant increase in the data rate. This can be accomodated only by further improvements of the Feature Extraction, a self-developed compression algorithm, and by increasing the readout speed of the system.

One final advantage of using programmable logic devices is the potential to build a fast software trigger. The original system is triggered by a hardware trigger using global or local multiplicity conditions. With the programmable logic used in the TWRs and other parts of the readout chain a more flexible software trigger can be developed.

References

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