The AMANDA-B 10 String Array

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Abstract

We discuss the design, calibration and performance of the AMANDA B10 detector. This 10-string array, consisting of 302 PMTs, has been in operation since 1997. Cosmic ray muons are used to monitor detector performance, to understand detector properties, and to experimentally check the analysis methods used. The zenith and azimuth angle distributions of cosmic ray muons are compared with Monte Carlo simulations. The multiplicity of hit optical modules and other parameters are discussed. The angular resolution is determined by reconstructing muons simultaneously observed by the GASP air Cerenkov telescope.

1 Detector Design and Calibration:

The AMANDA-B10 array, located at the Amundsen-Scott South Pole station, was completed in the austral summer of 1996-97. The array consists of 302 optical sensors deployed on 10 strings at depths of 1500-2000m below the surface of the polar ice cap (figure 1.) Strings 1-4 total 86 optical modules; strings 5-10 total 216. About 20 modules failed during re-freeze or have since ceased functioning.

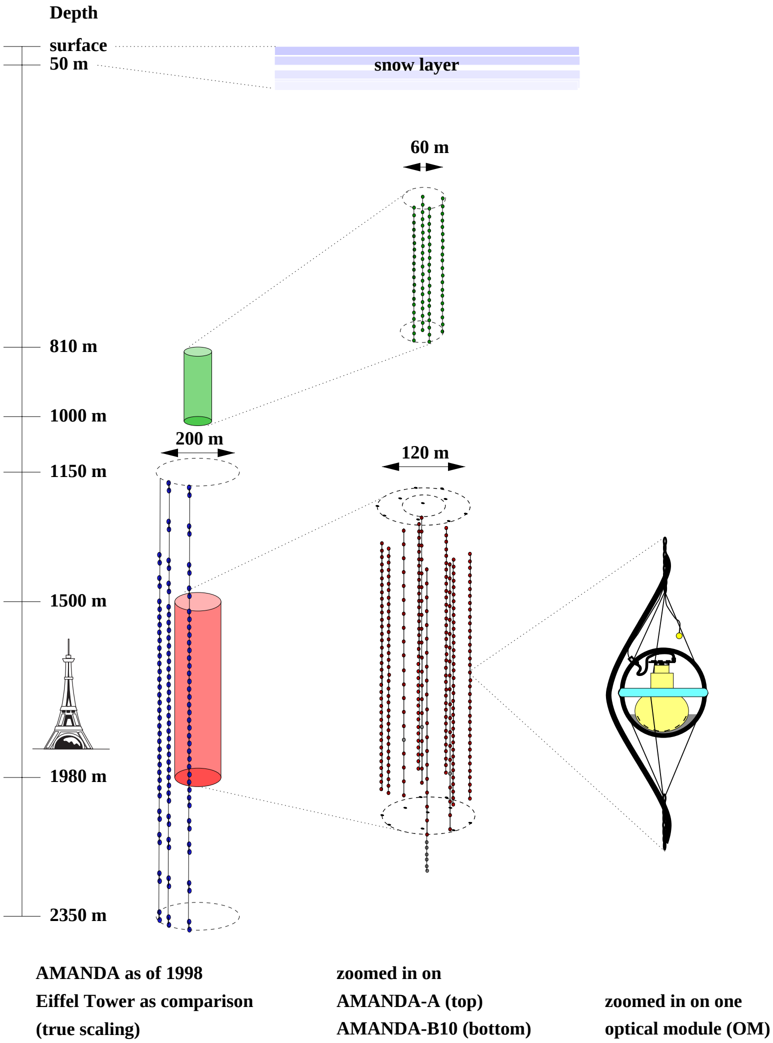

Figure 1: Schematic diagram of the AMANDA detectors.

Before data can be analysed, the detector must be calibrated. Pulses from a surface YAG laser system, sent down optical fibres to individual modules, are used to make several calibrations. The round trip times of the pulses are used to determine the time of flight of a signal from optical module to the DAQ. Measurements of leading edge time versus pulse amplitude in the ADC are used to determine the corrections required to account for time slewing effects in the TDCs. The time resolution of the PMTs has been determined to be about 3 ns, and the absolute time delays in the signal cables are found to 5 ns. The ice properties (absorption and scattering) are found by studying the timing distributions of laser photons fired from string to string (Woschnagg 1999). Data from the hot-water drill system and pressure sensors are used together with inter-string laser measurements to determine the rela-

[1] see contribution of Halzen et al., HE 6.3.01 for the full author list

tive positions of the modules in the array. The absolute depths of the strings are known to 3 metres, and the relative positions of the optical modules to better than 1 metre.

2 Triggered Data Characteristics:

Figure 2 shows the optical module multiplicity distribution at the trigger level for a sample of downgoing atmospheric muons. During 1997 the detector trigger rate was 100Hz, with a 30% deadtime in the DAQ reducing this to a recorded data rate of 70Hz (Bouchta 1999). The multiplicity trigger was nominally set to require 16 optical modules fire in a 2 μs window. The plot shows a peak at around 30 OMs due to the acceptance of pulses in a 32 μs window by the DAQ. The lack of a sharp cutoff at multiplicity 16 is due to two reasons - firstly a channel in the multipicity unit was suspected to be continuously firing, and secondly there are inefficiencies in the discriminators, such that a channel may sometimes send a pulse to the trigger logic unit, but not to the TDC, thereby resulting in triggered events appearing with less than 16 channels in the recorded event.

Before the data is compared to Monte-Carlo, (unsimulated) hits due to cross talk in the detector are removed by requiring a minimum time-over-threshold in the TDC. Further, about 10 optical modules were considered too unstable (eg noisy) to keep in the analysis presented here. A time cut about the event trigger time was also made to remove hits due to noise. After the cleaning of these hits, a software trigger of 16 modules in 2 μs was applied, leaving an event rate of 32Hz. The comparison between data and Monte Carlo is shown in figure 2. There is a good agreement over five orders of magnitude in occurrence probabilty, with a normalization of the Monte Carlo to the primary cosmic ray spectrum giving a predicted rate of 35Hz. Given the uncertainties in the primary cosmic ray spectrum, this is a reasonable agreement.

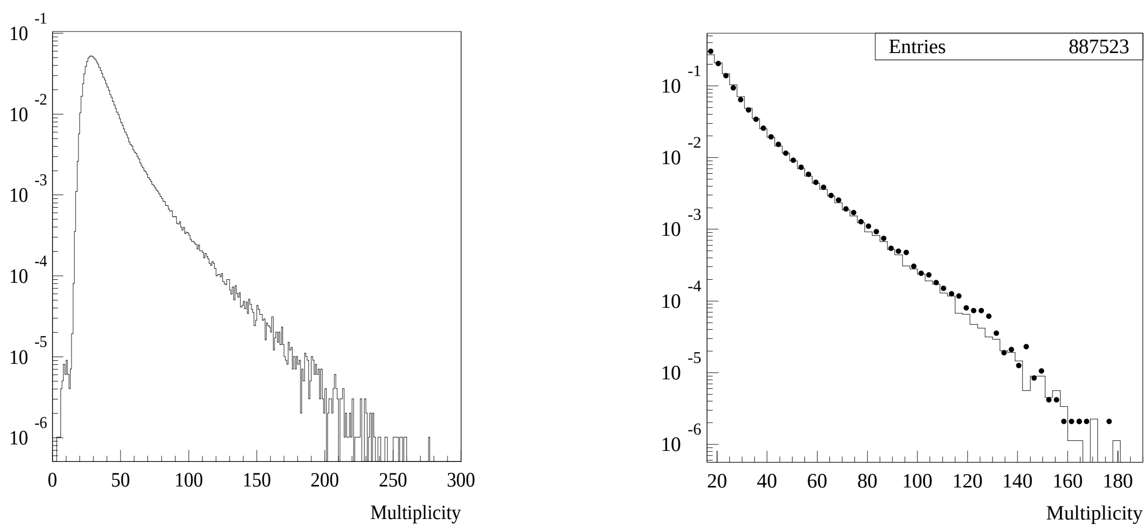

Figure 2: The raw data channel multiplicity distribution is shown in the leftmost plot. The number of events has been normalized to unity. X-axis: number of fired OMs per event, Y-axis: probability. In the rightmost plot, a comparison of the multiplicity distribution between data and Monte Carlo is shown after cleaning of cross talk pulses and noisy optical modules.

3 Reconstructed Data Characteristics:

The arrival directions of muons in the AMANDA detector are determined by fitting the optical module hit times to those expected for a through going muon. In the case where the detector medium is non-scattering, a simple χ^2 fit to the muon Cerenkov cone is sufficent. However, because the absorption length of Cerenkov light in ice is long compared to the scattering length, the distribution of photon arrival times has a long tail of scattered photons arriving well after the times expected from the Cerenkov wavefront. Event reconstruction is therefore based on a Maximum Likelihood method (Wiebusch 1997), comparing the observed arrival times with an analytic parametrization of the expected photon arrival time distribution (Pandel 1996) as obtained from a full simulation of photon propagation through ice.

The distributions of reconstructed zenith and azimuthal angles of atmospheric muons are shown in figure 3. The top curve in the left-most plot shows the reconstructed arrival directions without any quality cut criteria applied to the fits. There are a large number of down-going events which have been misreconstructed as upward going. The structure in the azimuthal distribution reflects the topology of the six outermost strings, which are arranged in three pairs on the perimeter of the array.

The application of quality cuts to the reconstructed events reduces the number of misreconstructions. The most powerful cut found is to require that a reconstructed event contains a high number of direct (unscattered) photons. Typically we require 5 or more photons to arrive within -5 to +25 ns of the expected Cerenkov time and 10 or more to arrive within -5 to 75 ns. Other quality cuts include a minimum track length and various topological event cuts. Further details are given in Karle (1999). As progressively more stringent criteria are applied, the tail of misreconstructed events is eliminated, as shown in figure 3. The same reduction in misreconstructed events is also seen in the simulated events, with reasonable agreement between data and simulation as the harder cuts are applied.

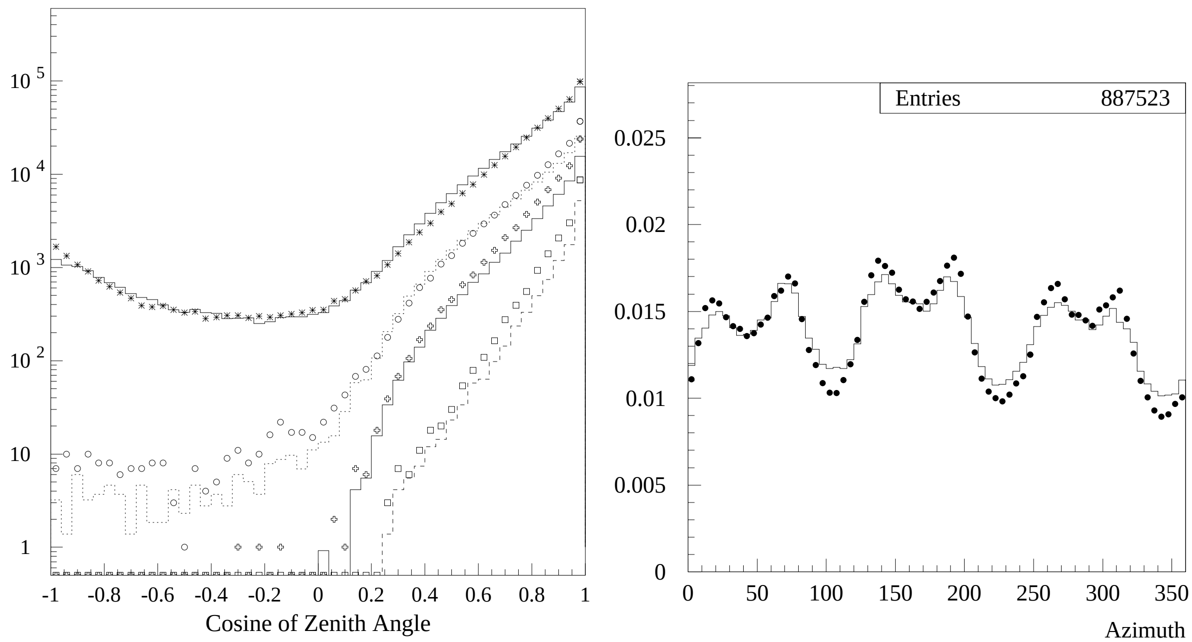

Figure 3: The reconstructed zenith and azimuthal angles of atmospheric muons for data (dots) and MC (line). The tail of zenith angles below the horizon consists of misreconstructed events, which are eliminated as progressively stricter quality criteria are imposed. The observed structure in the azimuth distribution reflects the topology of the array.

4 Pointing and Angular Resolution from GASP coincident events:

The angular resolution and absolute pointing accuracy of the array are crucial in the search for point source of neutrinos (Bay 1999, Kim 1999). The angular resolution of the array depends on the event-quality criteria imposed, as discussed in the previous section.

In 1997, AMANDA was run in coincidence with the GASP air Cerenkov telescope at the surface (Romenesko 1999). GASP was triggered by cosmic ray showers in the atmosphere, which sometimes produced muons with sufficient energy to reach AMANDA, 1500 m below. Since GASP is an optical telescope whose pointing has been established by tracking stars, GASP coincidences offer a unique opportunity to check AMANDA's absolute pointing accuracy, as well as verifying its angular resolution.

The angular distribution of GASP events as reconstructed with AMANDA is shown in the figure 4. The mean reconstructed zenith angle is $26.33°$ in the data, and $26.78°$ in a Monte Carlo simulation, with an angular resolution in both cases of less than $3°$. These numbers are consistent with the expected zenith angle for GASP events of $27.15°$.

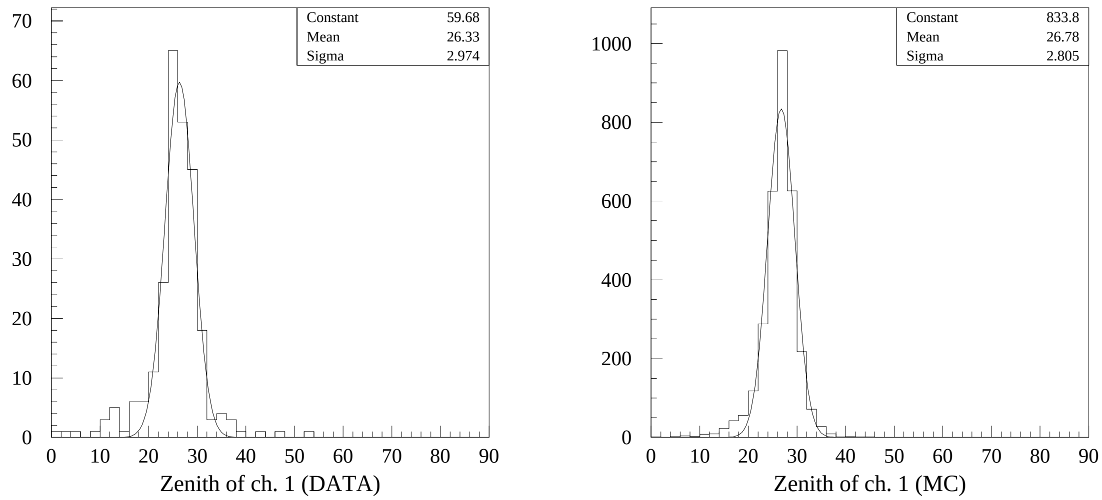

Figure 4: The zenith angle resolution for GASP-coincident events in data (left) and Monte Carlo (right).

5 Conclusions:

The AMANDA-B 10 string array was completed during the austral summer 1996-97. Analysis of the data and comparison with Monte Carlo simulation of the downgoing muon flux and of GASP-coincident events shows that the response of the detector is sufficiently well understood for Physics analyses to proceed.

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