OBSERVATION OF ATMOSPHERIC NEUTRINO EVENTS
WITH THE AMANDA EXPERIMENT

Abrecht Karle for the AMANDA collaboration

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Talk presented at the 17th International Workshop on Weak Interactions and Neutrinos (WIN99), Cape Town, South Africa, January 1999
A first analysis of the AMANDA-B 10-string array data is presented. A total of 113 days of data from its first year of operation in 1997 have been analyzed. High energy neutrinos generate upward moving muons. Cosmic ray muons penetrating the ice sheet to a depth of 2000 m are the major source of background. We discuss the method used to reject the background of approximately $0.5 \cdot 10^9$ downgoing muons and leave 17 upward going events. The neutrino candidates are discussed and compared with expectations.

1 Rejection of atmospheric muon background

In the Austral summer 96-97 the construction of the first generation AMANDA detector was completed. The detector consists of 300 optical sensors on 10 strings located at depths of 1500 to 2000 m in the deep Antarctic ice. The calibration and the performance characteristics of the AMANDA array are described in reference [1]. In this report we present a first analysis of data taken during a period of 113 days during the first year of operation in 1997. The detector live time corresponds to about 85 days of data.

Table 1: Rejection of background and efficiency for atmospheric neutrinos at background rejection levels 1 to 4. The meaning of the cuts is explained in the text. Two categories of ”direct hits” are used: B) [-5,+25] nsec, and C) [-5,+75] nsec. The results are given for a Monte-Carlo simulation of cosmic ray muons (14 h), for a simulation of atmospheric neutrinos (85 d), and for experimental data (85 d).

| Filter       | Cut Level | 0     | 1     | 2     | 3     | 4     |
|--------------|-----------|-------|-------|-------|-------|-------|
| Quality cuts | Direct B Hits | yes   | yes   | ≥ 5   | ≥ 5   | ≥ 6   |
|              | Direct C Hits |       |       | ≥ 10  | ≥ 15  |       |
|              | D. Length [m] |       |       | ≥ 100 | ≥ 100 |       |
|              | Edge cut    |       |       | yes   |       |       |
| Zenith angle | $\theta_1$ (line fit) | ≥ 80° | ≥ 80° | ≥ 80° | ≥ 100° | ≥ 100° |
|              | $\theta_2$ (full fit) |       |       |       |       |       |
| Results      | MC: atmos. $\mu$ | 3.4 \cdot 10^6 | 2.1 \cdot 10^6 | 853 | 0 | 0 |
|              | MC: atmos. $\nu$ | 2000 | 1016 | 272 | 89 | 21.1 |
|              | Exp. Data   | 4.9 \cdot 10^9 | 4.5 \cdot 10^7 | 3.5 \cdot 10^5 | 452 | 17 |

Atmospheric muons are recorded at a rate of 70 Hz. Upward going atmospheric muon neutrinos are expected to trigger the AMANDA 10-string detector at a rate of about $3 \cdot 10^{-4}$ Hz or 25 events per day. The only parameter for background rejection is the direction of the reconstructed track, which decides whether a muon was moving upward or downward. Upward muon tracks are generated by neutrinos, where downward moving tracks are totally dominated.
by penetrating cosmic ray muons generated in the atmosphere. About 90% of the cosmic ray muons are rejected with a simple filter method based on the correlation of arrival times and depth of the observed Cherenkov photons. The remaining events are reconstructed by fitting the Cherenkov light cone generated by a relativistic particle to the observed arrival times. After the initial reconstruction a set of quality cuts are applied to suppress a remaining background of muons which were reconstructed as upward moving. The most important cut is the number of "direct hits" in an event. A direct hit is a photon that is detected within a time interval of [-5,+25] nsec of the fitted Cherenkov cone. Another important criterion is the "direct length" cut which requires that the direct hits are distributed over a muon track of at least 100 m length. A combination of two other cuts is the "edge cut" which requires that the event was not exclusively concentrated at the top or bottom edge of the detector.

2 Observation of atmospheric neutrino candidates

We reduce the cosmic ray muon background in four steps, to which we refer as rejection level 1 to 4. The definitions of the four cut levels are summarized in table 1. Figure 1 shows the distribution of the reconstructed zenith angles up to $10^5$ above the horizon for the applied quality cuts from level 2 to 4. In the same figure the sky coordinates of the remaining 17 events are shown for quality level 4. Above the horizon the tail of downgoing muons is visible. However, where at cut level 2 and 3 a background of fakes is present below the horizon, a cluster of upgoing tracks appears which is separated from the downgoing
background. The 17 of $4.9 \cdot 10^8$ events which pass the highest quality cuts are concentrated at larger zenith angles. The distribution in right ascension is statistically consistent with a random distribution. A close inspection of the spatial topology and the amplitudes of the 17 events shows that one of the 17 events is likely to be a $\nu_e$ initiated cascade or a bremsstrahlung event. The event characteristics of the remaining 16 events are in agreement with the expectation for upgoing neutrino induced muons. A display of a neutrino candidate which extends over a length of 400 m through the entire detector is shown by Halzen. The upward moving signature of this event is illustrated in figure 2 where the photon arrival times of this event are plotted versus the depth of the sensors. The slope matches the vertical velocity of a track reconstructed at a zenith angle of $155^\circ$, which agrees with the result of the full Cherenkov cone fit. Figure 2 also shows the amplitudes as a function of distance of the reconstructed muon track. The observed photon density is high for sensors close to the track.

3 Comparison with Monte-Carlo prediction and conclusion

A full simulation of atmospheric neutrinos has been performed which predicts that 21 $\nu_\mu$ and $\nu_\mu$ events pass the level 4 cuts. Figure 3 shows the zenith angle distribution of all events at level 4 along with the prediction of the atmospheric neutrino simulation. The energy distribution of simulated atmospheric neutrinos is shown for cut levels 0, 3, and 4. The energy and angular characteristics of the atmospheric neutrino spectrum are taken from Lipari.
Figure 3: Left: Zenith angle distribution of neutrino candidates and of MonteCarlo simulated atmospheric neutrinos. Right: The simulated energy spectrum (true neutrino energy) is shown at trigger level of the 10 string array (solid lines), at level 3 cuts (dashed lines) and at level 4 (dotted).

We estimate that the combined error of theoretical prediction and absolute sensitivity of the detector is 50% or greater. The angular distribution of the observed upward moving tracks agrees well with the expectation from atmospheric neutrinos. It illustrates the higher sensitivity of the 10 string array to small nadir angles, reflecting that the detector is 400 m tall, but only 120 m in diameter. Deployments in the 99-00 Antarctic summer will result in a more symmetric detector.

Acknowledgments

This research was supported by the following agencies:
1. U.S. National Science Foundation, Office of Polar Programs; 2. U.S. National Science Foundation, Physics Division; 3. University of Wisconsin Alumni Research Foundation; 4. U.S. Department of Energy; 5. U.S. National Energy Research Scientific Computing Center (supported by the Office of Energy Research of the U.S. Department of Energy); 6. Swedish Natural Science Research Council; 7. Swedish Polar Research Secretariat; 8. Knut and Alice Wallenberg Foundation, Sweden; 9. Deutsches Elektronen-Synchrotron (DESY).

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