Observation of Atmospheric Neutrino Events with AMANDA

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Abstract

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 302 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 references Woschnagg et al. (1999), Askebjer et al. (1999), and Hill et al. (1999). 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.

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. An analysis of an unfiltered sample of downgoing muons is presented by Hill et al. (1999) and Hundertmark et al. (1999). The remaining 10% of the data are reconstructed by fitting the Cherenkov light cone generated by a relativistic particle to the observed arrival times (Wiebusch et al., 1999). 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 (Wiebusch et al., 1999). 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.

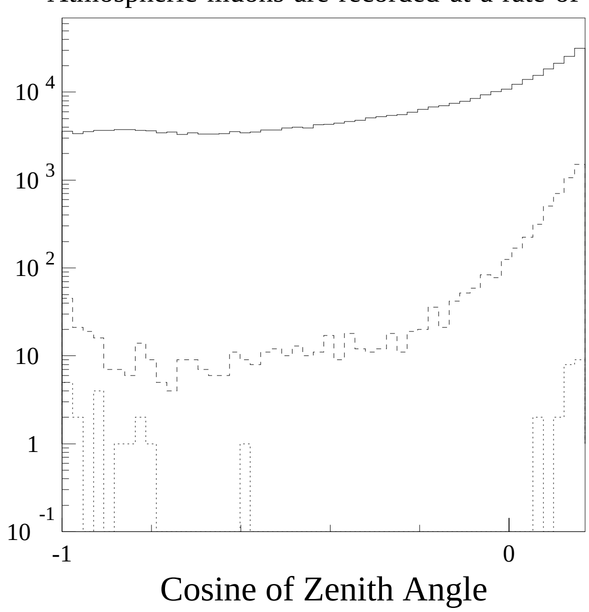

Figure 1: The reconstructed zenith angles of 85 days of AMANDA 10 string data is shown for quality level 2 (solid lines), 3 (dashed) and 4 (dotted).

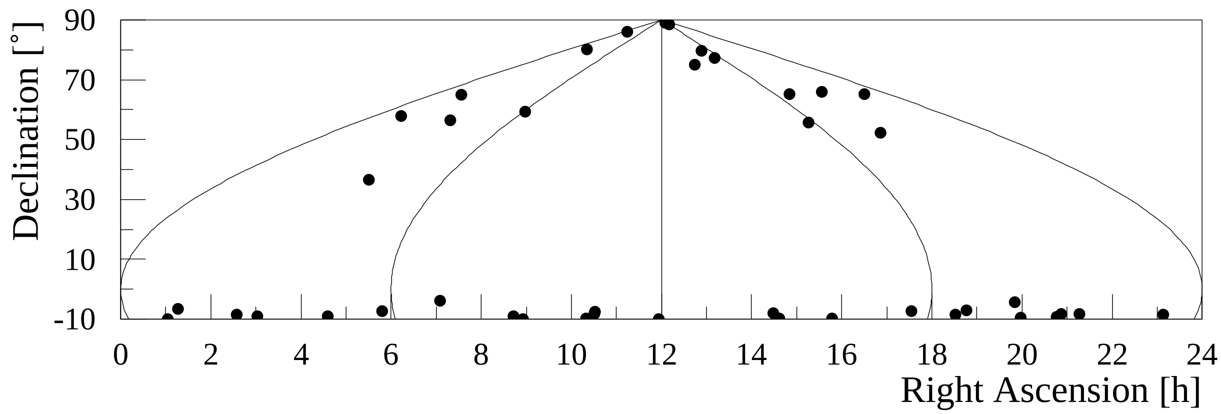

Figure 2: Sky plot of all events that pass level 4 quality cuts.

Table 1: Rejection of background and efficiency for atmospheric neutrinos at background rejection levels 0 to 4. The meaning of the cuts is explained in the text. Two categories of time windows are used for the ”direct hits”: a) N_Dir(-5,25): with a time window of [-5,+25] nsec, and b) N_Dir(-5,75): with [-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).

	Cut Level	0	1	2	3	4
Filter	filter		yes	yes	yes	yes
Quality cuts	N_Dir(-5,25)			≥ 5	≥ 5	≥ 6
	N_Dir(-5,75)				≥ 10	≥ 15
	D. Length [m]				≥ 100	≥ 100
	Edge cut					yes
Zenith angle	θ_1 (line fit)				$\geq 80°$	$\geq 100°$
	θ_2 (full fit)		$\geq 80°$	$\geq 80°$	$\geq 100°$	$\geq 100°$
Results	MC: atmos. μ	$3.4 \cdot 10^6$	$2.1 \cdot 10^5$	853	0	0
	MC: atmos. ν	2000	1016	272	89	21.1
	Exp. Data	$4.9 \cdot 10^8$	$4.5 \cdot 10^7$	$3.5 \cdot 10^5$	452	17

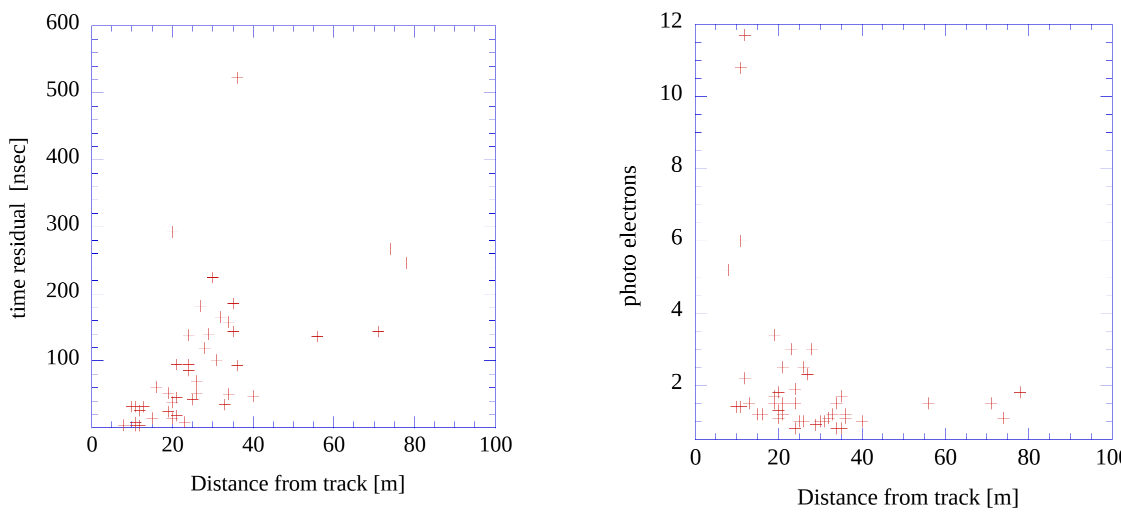

Figure 3: Event 1197960: The arrival time delay of photons with respect to the reconstructed Cherenkov cone is plotted versus the distance of the reconstructed track (left). The observed pulse amplitudes are plotted versus distance of the track (right).

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. The method has been applied to Monte-Carlo simulations of downgoing muon background (live time 14 hours), to simulation of atmospheric neutrinos and finally to data of about 85 days live time (table 1). Figure 1 shows the distribution of the reconstructed zenith angles up to 10° above the horizon for the applied quality cuts from level 2 to 4. In figure 2 the sky coordinates of the remaining 17 events are shown for quality level 4. Above the horizon the tail of downgoing muons is visible. At cut level two and three a background of fakes is present at all angles below the horizon. However, the 17 of $4.9 \cdot 10^8$ events which pass the highest quality cuts are concentrated at larger zenith angles, most of them at zenith angles greater than 140°. The distribution in right ascension is statistically consistent with a random distribution. The events are distributed randomly in azimuth, and in the time of their occurence during the total observation period of 113 days. A close inspection of the spatial topology and the amplitudes of the 17 events shows that one of these events is very different from all others. It shows the characteristics of a shower and it could well originate from a cosmic ray muon with a catastrophic energy loss. The event characteristics of the remaining 16 events are in good 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 in figure 4. The upward moving signature of this event is illustrated in the same figure (right) 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°, which agrees with the result of the full Cherenkov cone fit. Figure 3 shows the amplitudes and the time residuals as a function of distance of the reconstructed muon track. The observed photon density is highest while the time residuals are smallest for sensors close to the track.

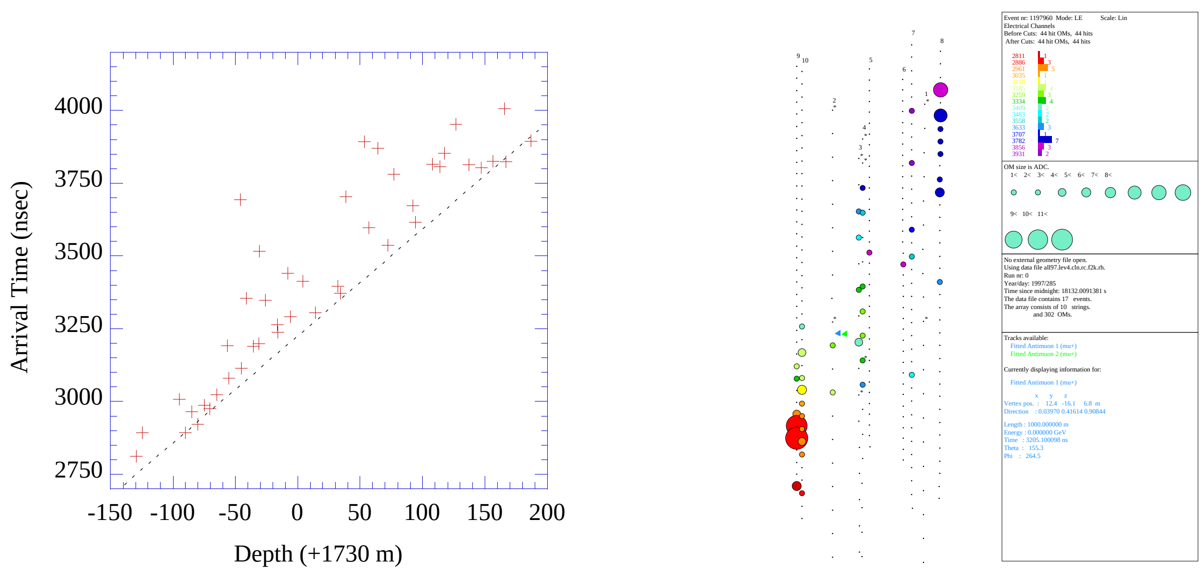

Figure 4: Event 1197960. Left: The recorded arrival times of photons are plotted versus the depth of the observing sensors. The slope of the dashed line is the result of the reconstructed zenith angle of 155°. Right: Neutrino candidate event in the 10 string array. The shading (size) of the data represents time (amplitude) of triggered photomultipliers. The reconstructed muon track moves upward over more than 300 m.

3 Comparison with Monte-Carlo prediction and conclusion

A full simulation of atmospheric neutrinos has been performed which predicts that 21 ν_μ and $\overline{\nu_\mu}$ events pass the level 4 cuts. Figure 5 shows the zenith angle distribution of all events at level 4 along with the prediction of

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

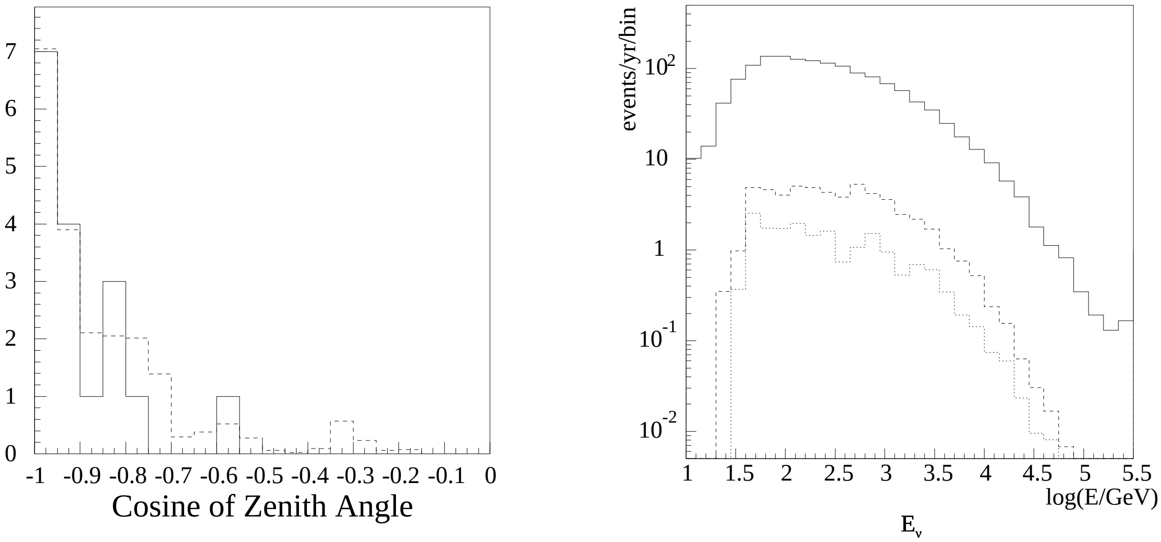

Figure 5: Left: Zenith angle distribution of neutrino candidates and of MonteCarlo simulated atmospheric neutrinos. Right: The simulated energy spectrum (true neutrino energy) is shown at trigger level of the 10 string array (solid lines), at level 3 cuts (dashed lines) and at level 4 (dotted).

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 (1993). 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 (Halzen et al., 1999). It should be noted that this analysis did not use all event information such as the spacial hit topology and the amplitudes. A systematic use of all available parameters as well as improved fitting algorithms are expected to further increase the rejection power and thus the sensitivity.

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