Observation of high energy atmospheric neutrinos with AMANDA


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Abstract. In 1997 the Antarctic Muon and Neutrino Detector Array (AMANDA) started operating with 10 strings. In an analysis of data taken during the first year of operation 188 atmospheric neutrino candidates were found. Their zenith angle distribution agrees with expectations based on Monte Carlo simulations. A preliminary
upper limit is given on a diffuse flux of high energy neutrinos of astrophysical origin.

I STATUS OF AMANDA

In the Austral summer of 1996-97 the construction of the first generation Antarctic Muon and Neutrino Detector Array (AMANDA) was completed. This detector, referred to as AMANDA-B10, consists of 302 optical sensors on 10 strings located at depths of 1500 to 2000 m in the deep Antarctic ice. The array forms a cylinder of 400 m height and 120 m diameter. Figure 1 shows an optical module, together with a schematic view of the array and a neutrino event observed in 1997.

![Schematic diagram of AMANDA-B10 array](image)

**FIGURE 1.** A schematic view of the AMANDA-B10 array with an event display of an upgoing muon track. Each dot represents an optical module, a schematic of which is shown. The circles show pulses from the photomultipliers; the size of the circles indicates the amplitude of the pulse and the shading shows the timing.

An optical module consists of an 8-inch photomultiplier tube (Hamamatsu R5912-02) and its voltage divider, housed in a glass pressure vessel. A cable
provides the high voltage and transmits the anode current signals of the photomultiplier to the data acquisition electronics at the surface.

In January 2000 the detector was upgraded to an array of 19 strings consisting of 677 optical sensors. The additional strings, located on an outer ring of 200 m diameter, use fiber-optic cables for calibration and for analog signal transmission of the photomultiplier pulses. A proposal exists to construct the IceCube detector which would consist of 4800 photomultipliers to be deployed on 80 strings. It will allow us to reach a 1 km² effective telescope area. It’s energy threshold is 100 GeV.

II ATMOSPHERIC NEUTRINOS

The results presented in this report were obtained from data collected by AMANDA-B10 during 1997. The effective livetime has been determined to $1.20 \cdot 10^7$ seconds for the selected data. The method of calibration and the characteristics of the optical sensors are very similar to the 4 string prototype array described in ref. [2]. Figure 1 shows a neutrino-generated muon with a recorded track length of about 400 m inside the array. Simulations predict a rate of 24 events per day from atmospheric neutrinos above a threshold of 30-50 GeV, compared to $6 \cdot 10^6$ events from cosmic ray muons. We use a maximum likelihood method, incorporating a detailed description of the scattering and absorption of photons in the ice, to reconstruct muon tracks from the measured photon arrival times.

A small fraction of the downgoing muons ($5 \cdot 10^{-5}$) are reconstructed as upward and form a background to the neutrino-induced events. This background is removed by applying a total of six quality criteria to the time profiles of the observed photons as well as to their spatial distribution in the array. The application of the quality criteria reduces the background by a factor of approximately $10^8$, while retaining about 5% of the neutrino signal. When the quality cuts are applied 188 events remain, a rate of approximately 1.4 events per day of livetime. The following table gives the total number of events at trigger level and after the background has been rejected, both, for the experimental data and the prediction of atmospheric neutrino induced events.

<table>
<thead>
<tr>
<th></th>
<th>Experimental Data</th>
<th>MC: Atmospheric Neutrinos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triggered</td>
<td>$1.2 \cdot 10^9$</td>
<td>4574</td>
</tr>
<tr>
<td>Upward going</td>
<td>188</td>
<td>235</td>
</tr>
</tbody>
</table>

Based on this analysis and on background studies under way, the backgrounds are estimated to contribute less than 15% of the signal. A complete simulation of the background generated by cosmic ray muons is under way.

The zenith angle distribution for the 188 events is shown in Figure 2, and compared to that for the signal simulation. In the figure the MonteCarlo events (235) was normalized to the observed events. The achieved agreement in the absolute flux of atmospheric neutrinos is consistent with the systematic uncertainties of the absolute sensitivity and the flux of high energy atmospheric neutrinos. The shape
of the distribution, which agrees well with the prediction reflects the angular acceptance of the narrow but tall detector. The observation of atmospheric neutrinos at a rate consistent with Monte-Carlo prediction establishes AMANDA-B10 as a neutrino telescope.

III SEARCH FOR DIFFUSE FLUX OF NEUTRINOS OF ASTROPHYSICAL ORIGIN

![Graph](image)

**FIGURE 2.** Reconstructed zenith angle distribution. The points mark the data and the shaded boxes a simulation of atmospheric neutrino events, the widths of the boxes indicating the error bars.

![Graph](image)

**FIGURE 3.** Number of observed photomultiplier pulses for events that pass the neutrino search criteria for a) experimental data b) MC simulation for atmospheric neutrinos, and c) MC of an E-2 type diffuse neutrino flux.

Searches for neutrinos from point sources and gamma ray bursts, for magnetic monopoles, and for a cold dark matter signal from the center of the Earth are in progress [4] and yield limits comparable or better than those obtained from smaller underground neutrino detectors run for many years.

The search for a diffuse neutrino flux of astronomical origin follows naturally from the observation of diffuse flux of neutrinos generated in the atmosphere. Neutrinos from generic astrophysical sources are expected to extend to higher energies while the energy spectrum of atmospheric neutrinos falls off steeply with increasing energy. A very simple and robust measure of the energy of the observed muons is the number of optical sensors that observed at least one photoelectron in a given event. Figure 3 shows the distribution of the number of photomultiplier signals as predicted for a) atmospheric neutrinos, b) an assumed energy spectrum for astrophysical neutrinos following a power law of $dN/dE_\nu = 10^{-5} E_\nu^{-2} \text{ cm}^{-2} \text{s}^{-1} \text{sr}^{-1} \text{GeV}^{-1}$.
and c) experimental data. The experimental data agree well with the atmospheric neutrino spectrum. The assumed astronomical neutrino flux would generate a significant excess at high multiplicities of fired photomultipliers. No such excess is observed. From the non-observation of an excess of high energy events, we derive an upper limit on an assumed diffuse $E^{-2}$ spectrum of astrophysical neutrinos. Our preliminary 90% confidence limit is

$$\frac{dN}{dE_{\nu}} \leq 1.6 \times 10^{-6} E_{\nu}^{-2} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV}^{-1}.$$

This limit on the diffuse neutrino flux is below previously stated upper limits by experiments such as BAIKAL [7], SPS-DUMAND [5], AMANDA-A [6], and FREJUS [8]. It is comparable to the AGN prediction by Salamon and Stecker [9] and approaches the prediction of Protheroe [10]. The analysis of the data taken in 1998 and 1999 is under way and will improve the present results significantly.

**ACKNOWLEDGMENTS**


**REFERENCES**