

Multi-year search for a diffuse flux of muon neutrinos with AMANDA-II

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Abstract. A search for TeV to PeV muon neutrinos from unresolved sources was performed on AMANDA-II data collected between 2000 to 2003. The diffuse analysis sought to identify an extraterrestrial neutrino signal on top of the atmospheric muon and neutrino backgrounds. An upper limit of $E^2\Phi_{90\%C.L.} < 8.8 \times 10^{-8} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ was placed on the diffuse flux of muon neutrinos with a $dN/dE \sim E^{-2}$ spectrum for the energy range 15.8 TeV to 2.5 PeV. Limits were also placed on prompt and astrophysical neutrino models with other energy spectra.

1. Introduction

Current theories on cosmic particle acceleration predict that neutrinos and gamma rays are among the by-products of pp and p γ interactions in sources such as AGN (active galactic nuclei) or GRBs (gamma ray bursts). Many extraterrestrial TeV gamma ray sources have already been identified by other experiments, but the missing link is the detection of an extraterrestrial neutrino flux. This search was optimized to look for extraterrestrial neutrinos with a $dN/dE \sim E^{-2}$ spectrum, the most general prediction from first order Fermi acceleration models.

A diffuse search for neutrinos does not use specific time or location information. Instead, it looks for an excess of events over a large sky region over a long period of time. If the neutrino flux from an individual source is too small to be detected by current means, it is possible that many similar sources, isotropically distributed throughout the Universe, would combine to make a detectable signal. An excess of events over the expected atmospheric neutrino background would be indicative of an extraterrestrial neutrino flux.

2. Search Methods

Data for this analysis were collected by AMANDA-II between 2000 to 2003. This period covered 807 days of stable detector livetime. During this period, 5.2×10^9 events triggered AMANDA-II.

2.1. Backgrounds for the diffuse analysis

Several types of events that can trigger the detector were simulated. Atmospheric muons and neutrinos created when cosmic rays interact with the Earth's atmosphere are the main background to extraterrestrial neutrino-induced events. Atmospheric and extraterrestrial neutrinos can travel from the far side of the Earth, interact in the ice or rock near the detector,

¹ A full list of collaboration members appears at the end of the proceedings.

and induce an upward-moving muon that can be detected. Atmospheric muons, on the other hand, do not have enough energy to travel a long distance through the earth, and hence they can only trigger the detector if they travel downward from the polar surface into the ice.

The first step in the analysis was to guess an arrival direction for every event [1], as shown on the left in Figure 1. Using this directional information, all events that were reconstructed in the downgoing direction were removed. The Earth was used as a filter and the actual search for extraterrestrial neutrinos was only performed on upgoing events.

Since the arrival direction of many downgoing atmospheric muons was originally misreconstructed, event quality requirements were introduced. Events were required to have long, smooth tracks of light that had many Cherenkov photons arriving close to their expected arrival times. This helped remove any misreconstructed downgoing events and helped to assure a purely upgoing sample that can be seen on the right in Figure 1.

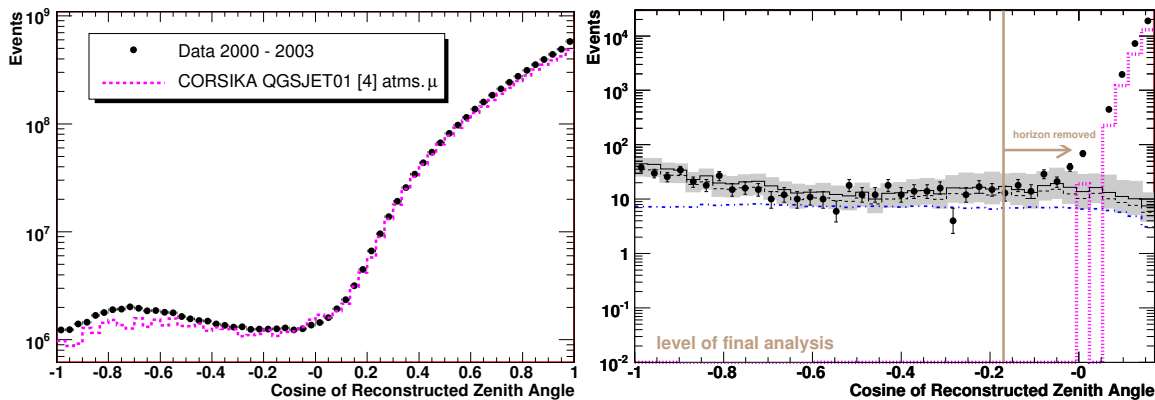
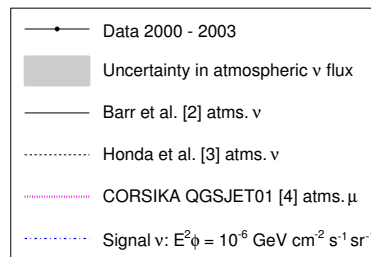


Figure 1. The cosine of the zenith angle is plotted for all events that triggered the detector (left). Events at $\cos(\text{zenith}) = -1$ are traveling straight up through the detector from the Northern Hemisphere. On the right, event quality requirements were used to select the best upgoing tracks. The normalization of the atmospheric neutrino simulation was adjusted so that the number of events hitting between 50 and 100 OMs was the same in the data and simulation.



2.2. Separating atmospheric neutrinos from extraterrestrial neutrinos

Atmospheric neutrinos from pions and kaons ($dN/dE \sim E^{-3.7}$) have a softer energy spectrum than the proposed extraterrestrial neutrino signal ($dN/dE \sim E^{-2}$). As a result, these two event classes can be separated best by their energy. At high energy, the extraterrestrial neutrino flux would dominate over the atmospheric neutrinos.

Since the energy of an event is not directly observable, the number of optical modules (OMs) hit during an event was used as an energy-correlated parameter. Optimization studies performed on the simulation indicated that the best signal-to-background region would be obtained by using events with at least 100 OMs triggered. The number of data events seen in this high energy window was compared to the predicted atmospheric neutrino background, shown in Figure 2.

3. Systematic uncertainties

An extensive systematic uncertainty analysis was performed to include uncertainties in the neutrino flux models and detector performance. Two different atmospheric neutrino models

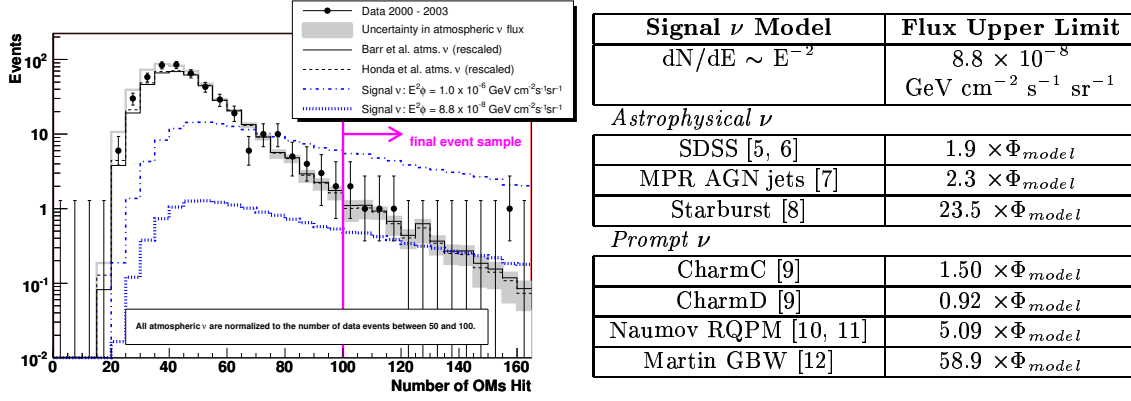


Figure 2. (Left) The number of OMs triggered during each event is an energy-correlated observable. Events triggering at least 100 OMs appeared in the final data set, and the number of observed data events was compared to the simulated atmospheric neutrino background. (Right) Upper limits were also determined for flux models (Φ_{model}) with different energy spectra.

were used, Barr *et al.* [2] and Honda *et al.* [3]. Uncertainties in the cosmic ray flux and the hadronic interaction model were also considered. All of the atmospheric neutrino simulation was scaled so that the number of simulation events matched the number of data events in the region $50 < \text{number of OMs hit} < 100$.

To assess detector and simulation performance, an inverted analysis was performed in which the highest quality downgoing events were studied. Downgoing events that were previously eliminated ($0^\circ < \text{zenith angle} < 80^\circ$) were reintroduced. With very high statistics available from these downgoing events, the characteristics of high energy events were studied without having to reveal the high energy upgoing data events.

4. Results

Six data events were observed on an average predicted atmospheric neutrino background of 6.1 events. Since no excess of events was seen indicating an extraterrestrial signal, an upper limit was set for a $dN/dE \sim E^{-2}$ flux between 15.8 TeV to 2.5 PeV (the energy region covered by 90% of the simulated signal). The upper limit on the diffuse flux of muon neutrinos from AMANDA-II data from 2000 to 2003 is $E^2 \Phi_{90\%C.L.} < 8.8 \times 10^{-8} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$.

Signal models with other energy spectra were also tested with this data. Due to the different nature of their energy spectra, the requirement of how many OMs were triggered during an event was reoptimized. The upper limit on each of the models appears in the table above.

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