Search for Extraterrestrial Point Sources of Neutrinos with AMANDA-II

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Abstract

We present a search for point sources of high energy neutrinos in the northern hemisphere using AMANDA-II data collected in the year 2000. AMANDA-II demonstrates improved performance, especially near the horizon, over its predecessor AMANDA-B10 [1]. Included are preliminary flux limits on several candidate sources, as well as preliminary results from a full-sky search for excesses above a background of cosmic-ray-induced atmospheric neutrinos and misreconstructed downgoing cosmic-ray muons.

1. Introduction

The search for sources of high-energy extraterrestrial neutrinos is one of the primary scientific missions of AMANDA. The mechanism for accelerating cosmic rays to energies in excess of 10^{19} eV remains a mystery. Cosmic rays are thought to be accelerated in the shock fronts of objects like supernova remnants and microquasars, and in compact regions containing high magnetic fields, which might exist in the cores of active galaxies, magnetars, or gamma ray bursters (GRB).

High energy protons will collide with the ambient gas and radiation surrounding the acceleration region or with Cosmic Microwave Background (CMB) photons to produce charged (and neutral) pions, and finally, highly energetic neutrinos. Acceleration in shock fronts by the Fermi mechanism naturally leads to power-law spectra, $E^{-\alpha}$.

A muon-neutrino interacting with the ice or bedrock in the vicinity of the AMANDA-II Cherenkov detector [2] will produce a muon that propagates hundreds of meters. The angular mismatch between the path of the muon and incident neutrino goes as $1/\sqrt{E_\nu}$ and is about 1.75° at $E_\nu = 1\,\mathrm{TeV}$. After reconstruction, the neutrino pointing resolution is 2 - 2.5°.

Also produced in the atmosphere are cosmic-ray induced neutrinos. Atmospheric neutrinos are an important source for calibration in AMANDA [2], but are also background to a search for extraterrestrial sources. A point source

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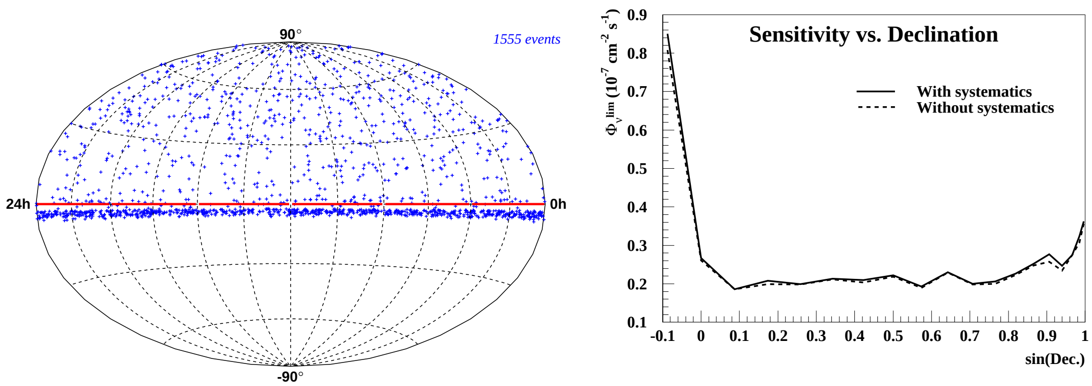

Fig. 1. Left: Skyplot in equatorial coordinates of 1555 AMANDA-II events recorded in year 2000. The thick band of events below the horizon shows the onset of the down-going cosmic ray muon background contamination. Right: Sensitivity (average upper limit above 10 GeV) vs. declination.

search is conducted by looking for an excess of events above this background of atmospheric neutrinos and misreconstructed down-going muons, which can be experimentally measured by looking off-source in the same band of declination.

2. Data Processing and Detector Simulation

The data set collected February through November, 2000, corresponding to 197.0 days livetime, comprises 1.2×10^9 triggered events. 2.1 million events with reconstructed zenith larger than 90° remain in the experimental sample after application of an iterative series of reconstruction algorithms.

To prevent human bias based on the appearance of random upward or downward fluctuations, the data are "blinded" by randomizing the reconstructed azimuth of each event during cut optimization. The original directional information is then restored for the calculation of the actual limits and significances.

A Neural Network (NN) with six input variables (such as the number of direct, i.e. unscattered photon hits, track length, likelihood of the muon track reconstruction, and topological variables [2] was trained using roughly equal numbers of well reconstructed simulated signal events following an E^{-2} energy spectrum and simulated background (atmospheric muon) events which pass low level filters. The single NN output quality parameter is used together with a cut on the ratio of likelihoods between the standard muon track fit and one weighted with an atmospheric muon prior [7]. The final choice of cuts and the optimum size for a circular search bin are determined independently in each 5° band of declination.

A full simulation chain including neutrino absorption in the earth, neutral current regeneration, muon propagation and detector response is used to simulate

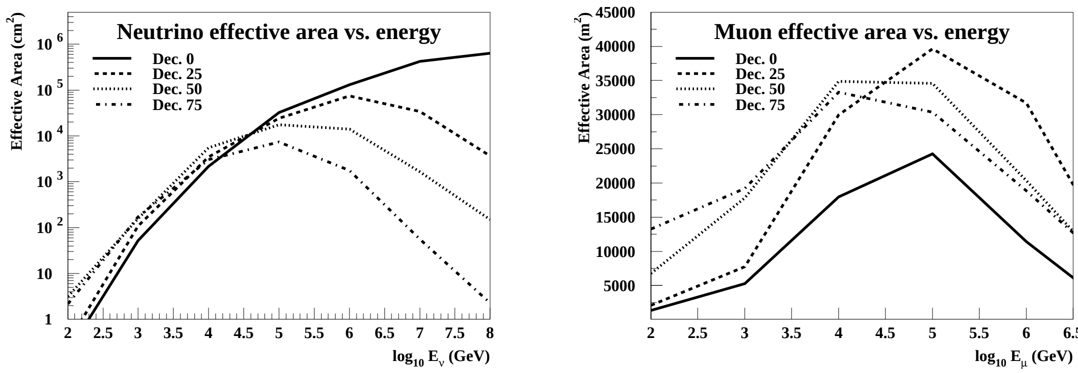

Fig. 2. Neutrino and muon effective areas vs energy for different declinations (Dec.).

neutrino point sources in the center of each declination band. The limits obtained in this analysis are a function of the measured background, n_b, as well as the expected number of events, n_s, from a simulated point source of known flux $\Phi(E)$: $\Phi_{limit}(E) = \Phi(E) \times \mu_{90}(n_{obs}, n_b)/n_s$ where n_{obs} is the number of observed events in the search bin around a candidate source, and μ_{90} is the upper limit on the number of events following the unified ordering prescription of Feldman and Cousins [6].

3. Calibration and Systematic Uncertainty

We compare the number of observed upward going events to the prediction from atmospheric neutrino simulation under much more stringent cuts than for the point source sample to obtain a normalization factor of 86% for simulated events. This is consistent with the theoretical uncertainty of 25% on the atmospheric neutrino flux and systematic uncertainties due to ice properties ($< 13\%$). Having normalized the number of simulated signal events to the data, the 25% flux uncertainty carries over as an effective uncertainty on the signal efficiency.

Systematic uncertainty is incorporated into the limits using the Cousins-Highland [4] prescription with unified Feldman-Cousins ordering [3,6] but with a more appropriate choice of the likelihood ratio test [8].

4. Results

The final sample consists of 697 upward reconstructed events (Fig. 1.). A comparison to the normalized atmospheric neutrino Monte-Carlo reveals that for declinations $\delta > 5°$ about 97% of the sample consists of atmospheric neutrinos. The sensitivity, defined as the average upper limit obtained in an ensemble of identical experiments in the absence of a signal source, is also shown.

A binned search for excesses in the region $0° < \delta < 85°$ has been performed. The search grid contains 301 rectangular bins with zenith-dependent widths ranging from 6° to 10°. The grid is shifted 4 times in declination and right ascension to fully cover boundaries between the bins of the original configuration. No statistically significant excesses are found.

In addition to the binned search, we place limits on a number of extragalactic and galactic candidate sources. In Table 1., we present flux limits for a selection of northern hemisphere blazars and microquasars. For the microquasar SS433 the limit is close to a theoretical prediction [5]. The limits are computed based on an assumed E^{-2} energy spectrum. One can compute limits for other spectral indices using the neutrino or muon effective areas as shown in Figure 2.

Candidate	Dec. [°]	R.A. [h]	n_{obs}	n_b	Φ_μ^{lim}	Φ_ν^{lim}
SS433	5.0	19.20	0	2.38	0.8	0.6
M 87	12.4	12.51	0	0.95	1.1	0.9
Crab Nebula	22.0	5.58	2	1.76	2.1	2.1
Markarian 421	38.2	11.07	3	1.50	2.6	3.1
Markarian 501	39.8	16.90	1	1.57	1.3	1.6
Cygnus X-3	41.0	20.54	3	1.69	2.5	3.1
QSO 0219+428	42.9	2.38	1	1.63	1.1	1.4
Cassiopeia A	58.8	23.39	0	1.01	0.7	1.1
QSO 0716+714	71.3	7.36	2	0.74	2.4	3.8

Table 1. Preliminary 90% CL upper limits on candidate sources. n_{obs} is the number of events observed within the search bin, and n_b is the number of expected background events determined by measuring the background off-source in the same declination band. Muon (and neutrino) limits $\Phi_{\mu(\nu)}^{lim}$ are for an assumed E^{-2} spectral shape, integrated above $E_{\mu(\nu)} = 10\,\text{GeV}$, in units of $10^{-15}\text{cm}^{-2}\,\text{s}^{-1}$ ($10^{-8}\text{cm}^{-2}\,\text{s}^{-1}$).

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