29th International Cosmic Ray Conference Pune (2005) **5**, 5–8

Search for high energy neutrino point sources in the northern hemisphere with the AMANDA-II neutrino telescope

M. Ackermann[a], E. Bernardini[a] and T. Hauschildt[b] for the IceCube Collaboration
(a) DESY Zeuthen, Platanenallee 6 D-15738 Zeuthen, Germany
(b) Bartol Research Institute University of Delaware, 217 Sharp Lab Newark, DE 19716, USA
Presenter: M. Ackermann (Markus.Ackermann@desy.de), ger-ackermann-M-abs2-og25-poster

In this paper we report the most recent survey of the northern sky to search for neutrino point sources using the AMANDA-II telescope. A search for astrophysical neutrinos of energies above a few tens of GeV was performed on the data collected between the years 2000 and 2003 for a total live-time of 807 days. Thanks to a higher reconstruction accuracy and background rejection power compared to past analyses, together with a longer exposure time, a noticeable improvement has been achieved in the sensitivity of the telescope. The sensitivity to individual point sources, assuming a signal energy spectrum proportional to dΦ/dE $\sim E^{-\gamma}$ with a spectral index of 2, is $\mathrm{E}^2 \cdot \mathrm{d}\Phi/\mathrm{dE} \leqslant 6 \cdot 10^{-8}\mathrm{GeVcm}^{-2}\mathrm{s}^{-1}$, weakly dependent on declination. We have obtained a large sample of neutrino candidates with high reconstructed track quality, consisting of 3329 selected up-going events. We searched this sample for a signal from point sources. Individual potential neutrino sources belonging to a catalogue of 33 preselected objects were scanned together with the complete northern sky. We report the outcomes of the individual observations and the significance map of the northern sky.

1. Introduction

The search for high energy extraterrestrial neutrinos is the major focus of research of the Antarctic Muon And Neutrino Detector Array AMANDA [1]. The goal is the understanding of the origin, propagation and nature of cosmic rays. The elusive nature of neutrinos makes them rather unique astronomical messengers: neutrinos can escape from dense matter regions and propagate freely over cosmological distances. Their observation would also provide an incontrovertible signature of a hadronic component in the flux of accelerated particles. Any source that accelerates charged hadrons to high energy is a likely source of neutrinos: high energy particles will interact with other nuclei or the ambient photon fields producing hadronic showers. In these scenarios, high energy photons and neutrinos are expected to be produced simultaneously. The search for high energy cosmic neutrinos reported in this paper strongly focuses on identified sources of high energy gamma-rays.

Searches for astrophysical sources of neutrinos have to cope with the backgrounds from the interaction of cosmic rays with the Earth's atmosphere. This results in a background of downward-going muons and a more uniform background of neutrinos from mesons decay. Downward-going muons are rejected by selecting only events that are reconstructed as upward-going, yet an indistinguishable background remains, composed of atmospheric neutrino induced muons and mis-reconstructed downward-going muons. Both sources of background are equivalent within the scope of this work and are treated identically. The final event sample was selected in a blind approach to avoid the enhancement of apparent excesses in the data or the introduction of biases that cannot be statistically described. This was accomplished by randomizing the events in right ascension.

2. Event reconstruction and selection

The major goal of this analysis was the selection of a high statistics sample of high energy events which would be searched for evidence of steady and transient point sources in the northern sky. Event reconstruction and selection were therefore optimized to provide tracks with good angular resolution in a wide energy range. The analyzed data were collected with the AMANDA-II detector between the years 2000 and 2003. Periods corresponding to the detector maintenance activities (roughly from November to February) have not been used. The total live-time, after data quality selection, is 807 days. Details of the pre-processing techniques (hits and Optical Modules selection) and of the reconstruction algorithms can be found in [2].

Neutrino induced up-going tracks were selected by imposing track quality requirements. Event selection criteria were chosen to achieve the best average flux upper limit ("sensitivity" [6]) and were optimized for each declination band independently. Selection criteria included: a parameter describing the hit distribution along the track, the fit likelihood (from two independent track reconstruction procedures) and the event-based angular resolution [5]. The search bin radius in the sky was an additional free parameter. The event selection depends also on energy, due to the energy dependence in the light deposit in the array and a varying detection efficiency. We therefore considered two extreme spectral indexes as reference: γ=2 and γ=3. The effects of the different signal spectra on the event cut optimization were investigated separately and the results were combined in the final event selection, to achieve the best performance for both spectra simultaneously. Figure 1 shows the resulting sensitivity and effective area as a function of declination. An overall improvement of about a factor three was obtained compared to the baseline sensitivity of the fully deployed AMANDA-II detector after 197 days of exposure [3].

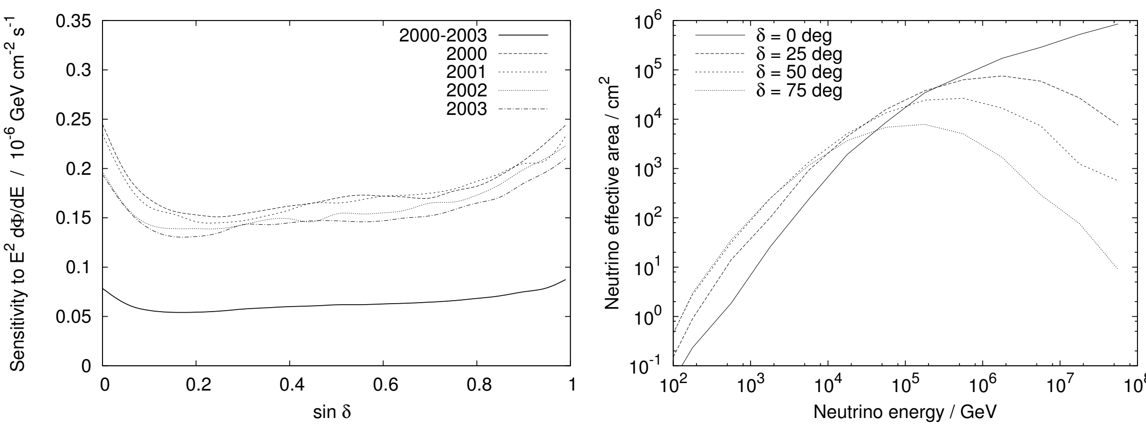

Figure 1. Left: Sensitivity as a function of declination (δ), for a signal spectral index of 2. The results for individual years and for the combined data sample are shown. Right: Neutrino effective area as a function of the neutrino energy.

A final sample of 3369 events was selected, of which 3329 are up-going. The corresponding directions are shown in Fig. 2 (left). A relatively uniform coverage of the northern sky is obtained. Due to the event selection optimization allowing wider spectral scenarios compared to [3, 4], this data sample contains a certain contribution from lower energy events.

3. Search for point sources in the northern sky

A search for point sources of neutrinos in the sample of 3329 up-going neutrino candidates was performed by looking for excesses of events from the directions of individual known high-energy gamma emitting objects and by a survey of the full northern sky. In both surveys we used circular search bins, with a size defined by the bin radius optimized together with the event selection for optimal sensitivity. The radius depends on declination

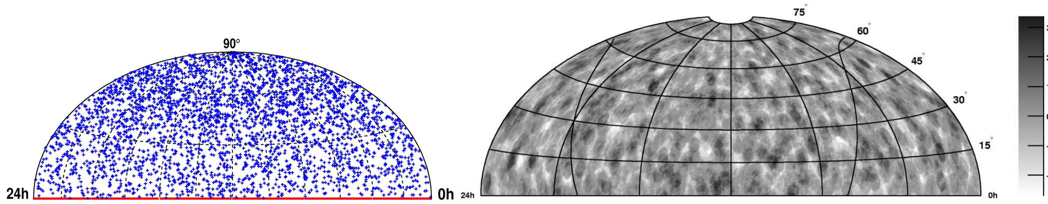

Figure 2. Left: Sky-plot (in celestial coordinates) of the selected 3329 up-going neutrino candidate events. Right: Significance map from a scan of the northern sky to search for event clusters. The significance is positive for excesses and negative for deficits of events (compared to the expected background).

Candidate	$\delta(°)$	α(h)	n_{obs}	n_b	Φ_ν^{lim}	Candidate	$\delta(°)$	α(h)	n_{obs}	n_b	Φ_ν^{lim}
TeV Blazars											
Markarian 421	38.2	11.07	6	5.6	0.68	1ES 2344+514	51.7	23.78	3	4.9	0.38
Markarian 501	39.8	16.90	5	5.0	0.61	1ES 1959+650	65.1	20.00	5	3.7	1.0
1ES 1426+428	42.7	14.48	4	4.3	0.54						
GeV Blazars											
QSO 0528+134	13.4	5.52	4	5.0	0.39	QSO 0219+428	42.9	2.38	4	4.3	0.54
QSO 0235+164	16.6	2.62	6	5.0	0.70	QSO 0954+556	55.0	9.87	2	5.2	0.22
QSO 1611+343	34.4	16.24	5	5.2	0.56	QSO 0716+714	71.3	7.36	1	3.3	0.30
QSO 1633+382	38.2	16.59	4	5.6	0.37						
Microquasars											
SS433	5.0	19.20	2	4.5	0.21	Cygnus X3	41.0	20.54	6	5.0	0.77
GRS 1915+105	10.9	19.25	6	4.8	0.71	XTE J1118+480	48.0	11.30	2	5.4	0.20
GRO J0422+32	32.9	4.36	5	5.1	0.59	CI Cam	56.0	4.33	5	5.1	0.66
Cygnus X1	35.2	19.97	4	5.2	0.40	LS I +61 303	61.2	2.68	3	3.7	0.60
SNR & Pulsars											
SGR 1900+14	9.3	19.12	3	4.3	0.35	Crab Nebula	22.0	5.58	10	5.4	1.3
Geminga	17.9	6.57	3	5.2	0.29	Cassiopeia A	58.8	23.39	4	4.6	0.57
Miscellaneous											
3EG J0450+1105	11.4	4.82	6	4.7	0.72	J2032+4131	41.5	20.54	6	5.3	0.74
M 87	12.4	12.51	4	4.9	0.39	NGC 1275	41.5	3.33	4	5.3	0.41
UHE CR Doublet	20.4	1.28	3	5.1	0.30	UHE CR Triplet	56.9	11.32	6	4.7	0.95
AO 0535+26	26.3	5.65	5	5.0	0.57	PSR J0205+6449	64.8	2.09	1	3.7	0.24
PSR 1951+32	32.9	19.88	2	5.1	0.21						

Table 1. Results from the search for neutrinos from selected objects. δ is the declination in degrees, α the right ascension in hours, n_{obs} is the number of observed events and n_b the expected background. Φ_ν^{lim} is the 90% CL upper limits in units of $10^{-8}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for a spectral index of 2 and integrated above 10 GeV. These results are preliminary (the systematic errors are under assessment).

and varies between 2.25° and 3.75°. The number of events in each declination band is a few hundred and the statistical uncertainty in the background in any given search bin is below 10%.

A sample of 33 candidate neutrino sources have been tested for an excess (or deficit) of events. The investigated sources include galactic and extragalactic objects and their corresponding locations are listed in Tab. 1. The directions of two cosmic rays multiplets (a triplet and the highest energy doublet [7]) were also tested. The background is estimated by averaging in right ascension the event density as a function of declination. A toy Monte Carlo, simulating equivalent tests using sets of events with randomized right ascension values, was used to evaluate the significance of the observations (which expresses the probability of a background fluctuation in units of standard deviations). All the observations are compatible with the expected background. The highest excess corresponds to the direction of the Crab Nebula, with 10 observed events compared to an average of

5.4 expected background (about 1.7 σ). The probability that a background fluctuation produces this or a larger deviation in any of the 33 search bins is 64%, taking into account the trial factor (due to the multiplicity of the directions examined and the correlation between overlapping search bins).

A full scan of the northern sky was also performed to look for any localized event cluster. We used overlapping search bins with optimal radius and centered on a grid with a spacing of $0.5°$. The search was extended up to 85° in declination[1]. Figure 2 shows a sky map of the 3329 neutrino events and a map of significances from the northern sky cluster search. All the observations are compatible with the background hypothesis. The highest excess corresponds to a significance of about 3.4 σ. The probability to observe this or a higher excess, taking into account the trial factor, is 92%.

4. Summary and outlook

We performed a search for a signal from point sources of neutrinos in the northern sky with data from the AMANDA-II neutrino telescope. Improved event reconstruction and selection techniques have been applied to the data collected between the years 2000 and 2003. Special emphasis has been put on the energy spectrum of the Monte Carlo events passing the selection cuts, to be sensitive to the largest variety of possible signal energy distributions. The achieved sensitivity to point sources is the most relevant numerical outcome of this analysis, and is equal to $E^2 \cdot d\Phi/dE \leqslant 6 \cdot 10^{-8}$GeVcm^{-2}s^{-1}, after 807 days of exposure and assuming a signal spectral index of 2. The sensitivity is weakly dependent on declination. We have obtained a large sample of neutrinos with high energies, consisting of 3329 selected up-going events. No statistically significant excess has been observed in the search for a signal from either candidate sources from a catalogue of pre-selected objects or in the full northern sky. We are currently extending this analysis to the data collected in the year 2004. An investigation of the possible sources of systematic uncertainties is also in progress and the upper limits reported here will be updated to account for the systematic error.

Three other contributions to this conference present preliminary results on searches with the four years sample of 3329 events for a variable signal from candidate neutrino sources [8], for a cumulative excess for classes of objects from predefined source catalogues (source stacking analysis) [9] and for a neutrino signal from the galactic plane [10].

References

[1] E. Andrés, *et al.*, Astropart. Phys. 13, 1 (2000).
[2] J. Ahrens *et al.*, Nucl. Inst. Meth. A524, 169 (2004).
[3] J. Ahrens *et al.*, Phys. Rev. Lett. 92, 071102 (2004).
[4] M. Ackermann *et al.*, submitted to Phys. Rev. D, astro-ph/0412347.
[5] T. Neunhoeffer, submitted to Astropart. Phys., astro-ph/0403367.
[6] G. C. Hill and K. Rawlins, Astropart. Phys. 19, 393 (2003).
[7] M. Takeda *et al*, Astrophys. J. 522, 225 (1999) and also N. Hayashida *et al*, astro-ph/0008102.
[8] "Multi-wavelength comparison of selected neutrino point source candidates", this conference.
[9] "A source stacking analysis of AGN as neutrino point source candidates with AMANDA", this conference.
[10] "A Search for high-energy neutrinos from the galactic plane with AMANDA-II", this conference.

[1] For a telescope located at the South Pole the zenith angle of a sources is fixed. This causes a sky coverage which is constant in time and equal for all directions. A simple integration in right ascension of the event density at different declinations allows a measurement of the background without time-dependent corrections. However, the limited statistics in the polar bin prevents an accurate estimation of the background.