AMANDA-B10 Limit on UHE Muon-Neutrinos

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Abstract

Data taken in 1997 with the AMANDA-B10 detector is searched for muon-neutrinos with energies above 10^{16} eV. At these energies the earth is opaque to neutrinos and neutrino induced events are concentrated at the horizon. The background are large muon bundles from downgoing atmospheric air shower events. In this search no excess events above background has been observed and a preliminary 90 % C.L. upper limit to an assumed E^{-2} muon-neutrino flux at the detector of $E^2\,\Phi(2.5\cdot 10^{15}\,\mathrm{eV} < E_\nu < 5.6\cdot 10^{18}\,\mathrm{eV}) = 7.2\cdot 10^{-7}\,\mathrm{cm^{-2}\,s^{-1}\,sr^{-1}\,GeV}$ has been set. This is currently the most restrictive experimental bound placed by any neutrino detector at these energies.

1. Introduction

Neutrino telescopes are an unique astronomy tool, designed to look downwards for upward traveling muons caused by muon-neutrinos. At and above 10^{16} eV the earth is essentially opaque to neutrinos [11] and only downward to horizontal neutrinos can be detected. As the overburden above AMANDA (vertically about 1.5 kmwe) and therefore the interaction probability for neutrinos is limited, the muons from high energy neutrinos are concentrated at the horizon. The background for these events are downgoing muon bundles with hundreds to thousands of muons caused by cosmic ray primaries. The rejection of these is helped by the fact that the primary cosmic ray spectrum in the energy region of interest falls steeply ($\approx E^{-3}$) and that the energy of the primary is only partly transfered to muons. Comparing a single muon and a muon bundle of the same total energy, the larger sized bundle spreads its light over a larger volume. Both classes of events can cause a large number of hit channels, but for the same number of hit channels, neutrino induced events have more hits overall, i.e. more multiple hits are found in single channels. This effect is enhanced by the afterpulse behavior of the photomultipliers (PMTs). Each single photoelectron has a certain probability to generate an afterpulse delayed by several microseconds. The afterpulses are used as a “low gain” outlet to identify high energy muons with a large number of undelayed photons incident on the PMT. The analysis

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technique was established in [9] and [10] and a preliminary limit was set. Here the selection criteria are refined, the systematic uncertainties are assessed and the analysis is applied to the full 1997 data set.

2. Method

The AMANDA-B10 Detector

The AMANDA-B10 detector consists of 302 Optical Modules (OMs), housing one PMT each, on 10 strings. The instrumented parts of the strings are located at a depth between 1500 m and 2000 m below the ice surface at the geographical South Pole. For a detailed description see [1].

Signal and Background Simulations

The neutrino induced muon signal was simulated by generating muons following E^{-1} and being uniformly distributed inside an interaction volume large enough to accomodate the pathlength of high energy muons. At high energies, the muon direction is, to a very good approximation, aligned with the neutrino direction. Between 10^{16} eV and 10^{20} eV the average amount of energy transfered from the neutrino to the muon varies between 75 % and 80 %. For simplicity this fraction was taken to be constant at 75 %. The rest of the energy, deposited as hadronic energy at the interaction vertex, is neglected. This leads to a reduced amount of light induced by the neutrino, giving a slightly lower signal efficiency than a full simulation. The muons are reweighted to an assumed neutrino spectrum taking into account the survival and interaction probabilities of the neutrinos to reach the interaction volume (taken from [4]). Inside the volume the uniform distribution of neutrino interactions is reweighted to an exponential distribution.

The background caused by atmospheric air shower events was generated using the CORSIKA generator [6]. As the selection criteria reject events caused by low energy primaries, the generation efficiency was raised by applying a high threshold for the primary energy. Proton and iron primaries are sampled following E^{-2} between $8{\cdot}10^{13}$ eV and 10^{20} eV. The events are reweighted to a two component model taken from [5] describing the averaged measured primary cosmic ray flux.

Analysis

The analysis uses eight variables: number of hit channels, number of hits, fraction of hit channels with exactly one hit (F1H), mean amplitude for hit channels, zenith angles for first guess and likelihood reconstruction, the likelihood parameter and the smallest moment of the tensor of inertia. To efficiently separate signal from background two neural nets (NN1 and NN2) use subsamples of the eight variables. NN1 uses F1H, the zenith angles from the first guess and the likelihood reconstruction and the likelihood parameter. The NN2 combines

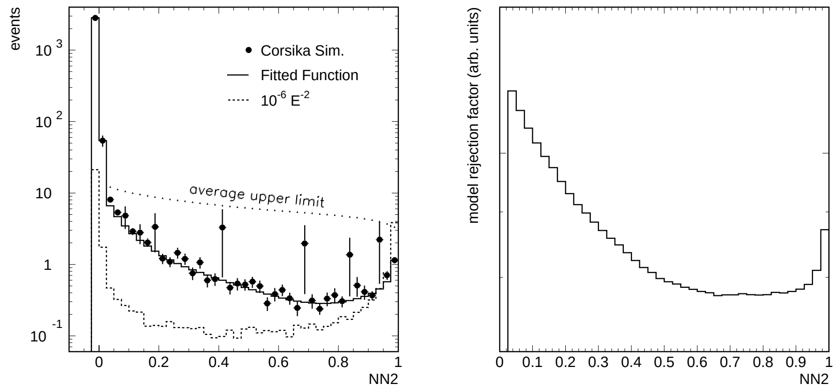

Fig. 1. The simulated background expectation (points with error bars, the outlayers are caused by high weight events) and a fitted function (line) is shown (left). The average upper limit derived from the fitted background expectation and the signal (E^{-2}) is also shown. The model rejection factor shows a broad minimum between 0.6 and 0.9 (right).

F1H with the rest of the variables. The most powerfull variable is F1H. More information about the selection procedure is found in [9] and [10].

A selection on high multiplicity events, the variable F1H and the neural net NN1 is applied to reduce the $1 \cdot 10^9$ experimental events seen in 131 days of livetime to 3326 events. The expectation from background simulation is 2938 events. The distribution of the experimental data, the simulated background and a neutrino flux following E^{-2} is shown in figure 2. The experimental data is in agreement (shape and absolute number) with the expectation from the background simulation.

To find the selection that provides the strongest constraint to a theoretical model, we use the “model rejection method” [7]. This method minimises the ratio of the average upper limit, derived from background simulations, to the signal expectation. During the procedure we found that the weighted, binned background estimation as a function of the neural net parameter NN2 was not smooth enough to reliably find the minimum and therefore a function was fitted. This function is shown in fig. 1 (left) in comparison to the binned expectation together with the signal expectation. The model rejection factor has a broad minimum between 0.6 and 0.9 (fig. 1 (right)). A value of NN2>0.7 is choosen as the final selection criterion.

During the analysis we evaluated the systematic uncertainties for neutrino induced events with respect to muon propagation, photon propagation in ice, absolute detector sensitivity and neutrino cross section at high energies. For the atmospheric air shower simulation the uncertainties in the absolute flux and the sensitivity to the composition was investigated. The systematic uncertainties were

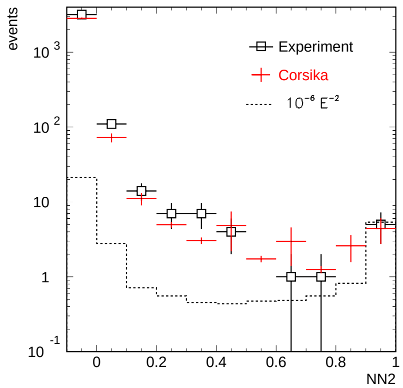

Fig. 2. The neural net output used for the final selection criterion is shown for experimental data and simulated air shower events. The expectation for a neutrino flux of $E^2\Phi_{90} = 10^{-6}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}\,\mathrm{GeV}$ is also shown.

determined to be approximately 40 % for the signal and 25 % for the background.

3. Results and Conclusions

Using fig. 2 and applying NN2>0.7 the expectation from the atmospheric air shower simulation is 8.3 events. For an assumed E^{-2} muon neutrino spectrum the sensitivity, as defined in [3], is $E^2\Phi_{90} = 9.3 \cdot 10^{-7}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}\,\mathrm{GeV}$. The experiment recorded 6 events. Neglecting systematic uncertainties and using [3], an event upper limit of 3.6 (90 % C.L.) is calculated. Including systematic uncertainties as stated above and using [2] the event upper limit worsens to 4.9. The preliminary flux upper limit (90 % C.L.) for an E^{-2} neutrino flux at the detector including systematic uncertainties is $E^2\Phi_{90} = 7.2 \cdot 10^{-7}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}\,\mathrm{GeV}$. The neutrino peak energy is at $4{\cdot}10^{16}$ eV and 90 % of the events are within $2.5{\cdot}10^{15}$ eV and $5.6{\cdot}10^{18}$ eV. This limit is the best placed to date by a neutrino detector in the energy range above PeV and complements the limits set by the same detector in the TeV to PeV range [8]. It demonstrates the potential of neutrino telescopes in the extreme high energy region.

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