Search for High Energy Neutrinos of All Flavors with AMANDA II

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Abstract

We report on a search for electro-magnetic and/or hadronic showers (cascades) induced by a diffuse flux of high energy neutrinos using the data collected with the AMANDA II detector during the year 2000. The observed event rates are consistent with the expected rate of atmospheric neutrinos and muons. We place preliminary upper limits on a diffuse flux of extraterrestrial electron, tau and muon neutrinos. A flux of neutrinos following a E^{-2} spectrum and consisting of an equal mix of all flavors is limited to $E^2\phi(E) = 9 \times 10^{-7}\text{GeVcm}^{-2}\text{s}^{-1}\text{sr}^{-1}$ (for a neutrino energy range 80 TeV to 7 PeV). The presented bounds are ruling out several existing flux predictions for extraterrestrial neutrinos.

1. Introduction

For neutrino fluxes from generic astrophysical beam dump scenarios one expects a flavor ratio of $\phi_{\nu_e} : \phi_{\nu_\mu} : \phi_{\nu_\tau} \approx 1 : 1 : 1$ due to flavor-mixing during propagation from the source to the earth. The signature of a charged current interaction of ν_e and ν_τ is a hadronic and/or electro-magnetic cascade. Additional cascade events from all neutrino flavors are obtained from neutral current interactions. For cascade events contained within the geometrical volume of the array, AMANDA can be thought of as a calorimeter. Good energy resolution, combined with low intrinsic background from atmospheric neutrinos as well as a uniform sensitivity to all neutrino directions make a search for extraterrestrial high energy neutrinos feasible. Here we report the results of the search for a diffuse flux of high energy ν_e, ν_μ and ν_τ using the data collected with the AMANDA II detector [1] during the austral winter 2000.

2. Experimental and Monte Carlo Data

The data used were collected between February and November 2000. After correcting for dead time (17 %) we are left with a lifetime of 197 days. A total of $1.2 \cdot 10^9$ events were recorded, of which the great majority consists of muons produced in the atmosphere.

pp. 1301–1304

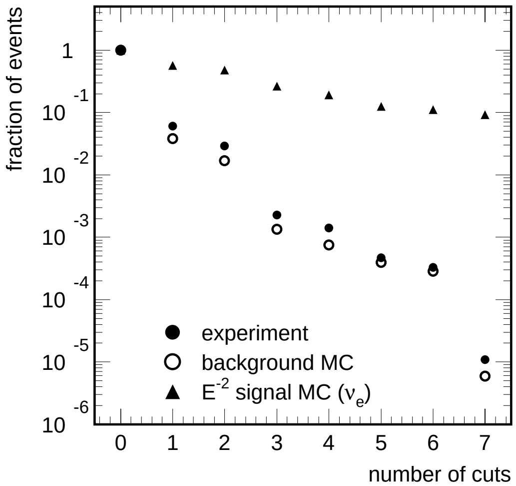

Fig. 1. Fraction of events from trigger level passing the cuts, as a function of the cut number. Shown are experimental data and Monte Carlo (MC) simulations for atmospheric muon background and ν_e signal.

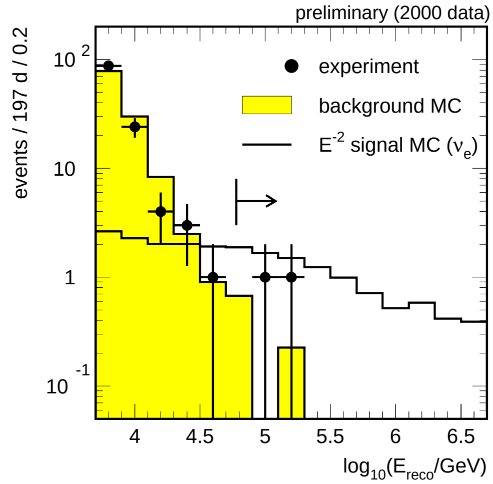

Fig. 2. Energy spectra of events passing the cascade filter. Shown are experimental data, atmospheric muon MC and a hypothetical E^{-2} flux of ν_e. The arrow indicates the final cut value.

The background of atmospheric muons was simulated using CORSIKA and propagated using MMC (see [2,3] for details). With a simulation optimized for this analysis, we generated a sample equivalent to 900 days of atmospheric muon data above TeV energies. The generation of ν_e, ν_μ and ν_τ events was done using ANIS [5]. Simulation of the detector response was described previously [2].

3. Analysis

The reconstruction of cascade-like events was described in [2,4]. The vertex resolution for cascade-like events is about 5 m and the visible energy resolution is 0.1-0.2 in $\log(E)$. The performance of the reconstruction has been verified using in-situ light sources.

A dedicated filter reduces the experimental data sample by a factor $\sim 10^5$. The fraction of events passing the filter steps is summarized in Fig. 1. After application of the filter, one is left with background events due to atmospheric muons, which radiate (mainly through bremsstrahlung) a large fraction of their energy into a single electro-magnetic cascade. The steeply falling energy spectra of remaining experimental and Monte Carlo (MC) events are shown in Fig. 2. The background MC distribution has been normalized to the experiment. In order to separate a potential signal from the background, we introduce a cut on the reconstructed energy. The final energy cut value, $E_{\rm reco} > 60$ TeV, is obtained

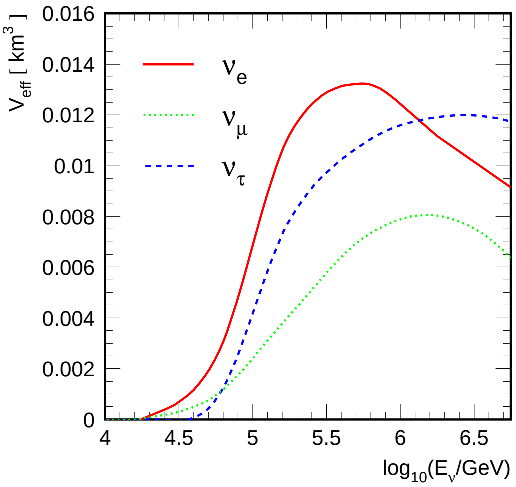

Fig. 3. Effective volume for ν_e, ν_μ and ν_τ as a function of the neutrino energy. An initially isotropic flux of neutrinos has been assumed which is then partially degraded by neutrino absorption in the earth.

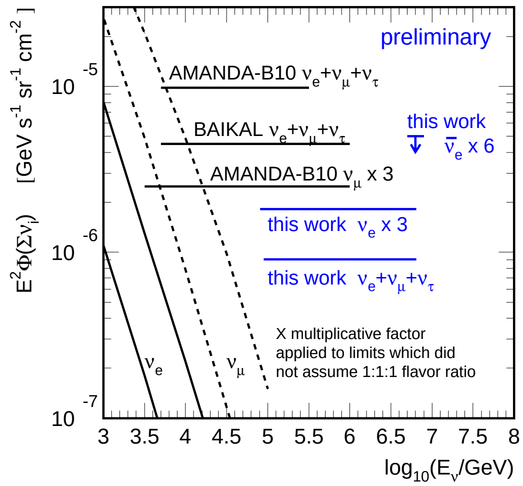

Fig. 4. Limits on the flux of astrophysical neutrinos following an E^{-2} spectrum and flavor ratio $\phi_{\nu_e} : \phi_{\nu_\mu} : \phi_{\nu_\tau} = 1 : 1 : 1$ (see text for details). The falling lines represent the atmospheric neutrino fluxes.

by using MC data to optimize the sensitivity towards a hypothetical flux of ν_e with an energy spectrum falling as E^{-2} (according a method from [6]). Two experimental data events passed all selection criteria. The expected number of atmospheric muon events is $0.45^{+0.5}_{-0.3}$, where the largest contribution to the error is due to limited MC statistics. The expected number of events from atmospheric neutrinos is about 0.1 ± 0.05 where the largest contribution to the error is due to uncertainties in the optical properties in the ice. The effective volume, after all selection criteria applied, is shown in Fig. 3 as a function of the neutrino energy, for all three neutrino flavors. The effective volume peaks for energies above the threshold energies and is then slowly falling for higher energies due to detector saturation and neutrino absorption effects.

Compared to the AMANDA-B10 cascade search [2], the improvements of this analysis are the significant larger effective volume and an angular acceptance which is now nearly uniform over 4π.

4. Results

The observed events are statistically consistent with the expected background, and hence we place upper limits on the flux of astrophysical high energy neutrinos. The expected event numbers from a diffuse flux with an assumed spectrum of $10^{-6}E^{-2}\text{GeV}^{-1}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$ are about 9.3 ν_e, 6.2 ν_τ and 3.8 ν_μ events within the data set of the year 2000. The error is smaller than in the case of atmospheric neutrinos, due to the reduced threshold effects. 90 % of the contributing neutrinos have an energy between 80 TeV and 7 PeV. We estimate an error of 25 % on the signal expectation. The preliminary limit on a flux of $\nu_e(\nu_\tau/\nu_\mu)$, taking into account the uncertainties on signal and background (according to a previously described method [3]), is $6(9/15) \times 10^{-7} E^{-2}\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$ (at 90 % C.L.). Assuming a flavor ratio of $\phi_{\nu_e} : \phi_{\nu_\mu} : \phi_{\nu_\tau} = 1 : 1 : 1$ one can limit the total flux of neutrinos of all flavors to $9 \times 10^{-7} E^{-2}\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$. No events have been observed with $E_{\mathrm{reco}} > 1$ PeV, the energy region of the *Glashow* resonance [5] resulting in a limit on the differential flux of $\overline{\nu}_e$ at 6.3 PeV of 2.3×10^{-20} $\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$.

5. Conclusion and Outlook

Present experimental bounds on astrophysical neutrinos are shown in Fig. 4. The limits on a diffuse flux of high energy ν_e, as well as the sum of neutrinos of all flavors, in the energy region 80 TeV to 7 PeV are currently the most stringent available, being about 4-5 times better than limits reported by BAIKAL [7] and about a magnitude better than the previous AMANDA-B10 limit [2]. The limits for ν_e and ν_τ are also competitive with the limits for ν_μ resulting from AMANDA-B10 [3]. One should note however, that this analysis is probing higher energies. Assuming a flavor ratio $\phi_{\nu_e} : \phi_{\nu_\mu} : \phi_{\nu_\tau} \approx 1 : 1 : 1$ one obtains a more than two times better sensitivity by setting limits on the sum of all flavors. Certain models for a diffuse flux from AGNs are excluded at 90 % C.L. by the limit on the flux of ν_e alone (the quasar core models of references [8] and [9]). The blazar jet model of [9] is excluded by the limit on the sum of all flavors.

Summarizing, it can be said that the cascade detection channel is an important complementation of the ability of AMANDA to observe astrophysical muon neutrinos. AMANDA has now the potential to effectively observe astrophysical neutrinos of all flavors over a large range of neutrino energies.

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