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Search for a diffuse flux of high-energy neutrinos with the NT200 neutrino telescope

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We present the results of a search for high energy extraterrestrial neutrinos with the Baikal underwater Cherenkov detector *NT200*, based on data taken in 1998 - 2002 (1038 live days). Upper limits on the diffuse fluxes of $\nu_e + \nu_\mu + \nu_\tau$, predicted by several models of AGN-like neutrino sources, are derived. For an E^{-2} behavior of the neutrino spectrum, our limit is $E^2\Phi_\nu(E) < 8.1 \times 10^{-7}$ cm^{-2} s^{-1} sr^{-1} GeV over an neutrino energy range $2 \times 10^4 \div 5 \times 10^7$ GeV covering 90% of expected events. The upper limit on the resonant $\bar{\nu}_e$ diffuse flux is $\Phi_{\bar{\nu}_e} <3.3\times10^{-20}$ cm^{-2}s^{-1}sr^{-1}GeV^{-1}.

1. Introduction

High energy neutrinos are likely produced in many violent processes in the Universe. Their detection would unambiguously reveal the hadronic nature of the underlying processes. Neutrinos would be generated by proton-proton or proton-photon interactions followed by production and decay of charged mesons.

A description of the Baikal-detector as well as physics results from data collected in the years 1998 - 2000 have been presented elsewhere [1, 2, 3, 4, 5]. In this paper we present new results of a search for diffuse neutrinos with energies larger than 10 TeV. The analysis is based on data taken with the Baikal neutrino telescope *NT200* in the years 1998-2002. Instead of focusing to particles crossing the array, the analysis is tailored to signatures of isolated high-energy cascades in a large volume around the detector. This search strategy dramatically enhances the sensitivity of *NT200* to diffuse high energy processes.

The cascades can stem from leptons and hadrons produced in high energy charged current processes. Obviously, the energy released by the hadronic cascade in NC-reactions is small compared to that of the leptonic cascades in CC-reactions. Since only electrons and taus develop cascades (the one by directly showering up, the

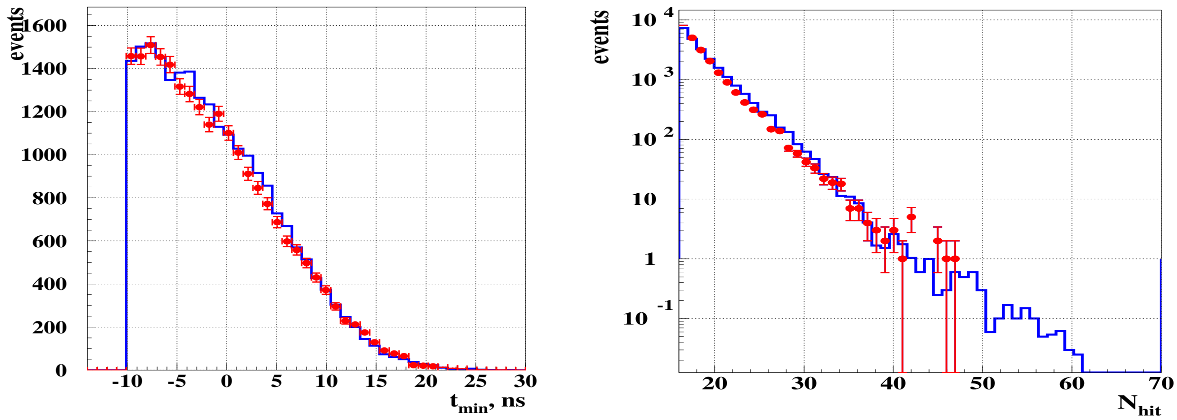

Figure 1. Left panel: the t_{min} distribution of experimental events (dots) which survive condition (1) as well as the expected distribution of simulated background events (histogram). Right panel: the N_{hit} distribution of experimental events (dots) as well as background prediction (histogram).

other via its decay to secondary particles which develop a cascade), the sensitivity of this search is dominated by ν_e and ν_τ detection.

2. Data selection and analysis

Within the 1038 days of the detector live time between April 1998 and February 2003, 3.45×10^8 events with $N_{\mathrm{hit}} \geq 4$ have been recorded. For this analysis we used 22597 events with hit channel multiplicity N_{hit} >15 which obey the condition:

$$t_{\mathrm{min}} = \mathrm{min}(t_i - t_j) > -10 \text{ ns}, \quad i < j. \tag{1}$$

Here, t_i, t_j are the arrival times at channels i, j and the numbering of channels rises from top to bottom along the string.

Figure 1 shows the t_{min} and N_{hit} distributions for experiment (dots) and background simulation (histograms). The distribution of experimental events is consistent with the background simulation. No statistically significant excess above the background from atmospheric muons has been observed.

With no experimental events outside the area populated by background events in the (t_{min}, N_{hit})-parameter space, we derive upper limits on the fluxes of high energy neutrinos as predicted by different models of neutrino sources.

The detection volume V_{eff} averaged over all neutrino arrival directions, rises from $\sim 10^5$ m^3 for 10 TeV up to (4-6)$\times 10^6$ m^3 for 10^4 TeV and significantly exceeds the geometrical volume $V_g \approx 10^5$ m^3 of *NT200*. This is due to the low light scattering and the nearly not dispersed light fronts from Cherenkov waves originating far outside the geometrical volume.

Since no event has been observed which fulfills the selection conditions, upper limits on the diffuse flux of extraterrestrial neutrinos are calculated. For a 90% confidence level an upper limit, $n_{90\%}$ =2.5, on the number of signal events is obtained according to Conrad et al. [6] with the unified Feldman-Cousins ordering [7]. We assume an uncertainty in signal detection of 24% and a background of zero events (which leads to a conservative estimation of $n_{90\%}$ according to the Feldman-Cousins approach). If the expected numbers of signal events N_{model} is larger than $n_{90\%}$, the model is ruled out at 90% CL. Table 1 represents event rates and model rejection factors (MRF) $n_{90\%}/N_{\text{model}}$ for models of astrophysical neutrino sources obtained from our search. Recently, similar results have been presented by the AMANDA collaboration [8, 9]. Model rejection factors obtained by AMANDA are also shown in Table 1. The models by Stecker and Salamon [10] labeled

Table 1. Event rates and model rejection factors for models of astrophysical neutrino sources. The assumed upper limit on the number of signal events with all uncertainties incorporated is $n_{90\%} = 2.5$

	BAIKAL					AMANDA [8, 9]
Model	ν_e	ν_μ	ν_τ	$\nu_e + \nu_\mu + \nu_\tau$	$n_{90\%}/N_{\text{model}}$	$n_{90\%}/N_{\text{model}}$
$10^{-6} \times E^{-2}$	1.33	0.63	1.12	3.08	0.81	0.86
SS Quasar [10]	4.16	2.13	3.71	10.00	0.25	0.21
SP u [11]	17.93	7.82	14.43	40.18	0.062	0.054
SP l [11]	3.14	1.24	2.37	6.75	0.37	0.28
P $p\gamma$ [12]	0.81	0.53	0.85	2.19	1.14	1.99
M $pp + p\gamma$ [13]	0.29	0.22	0.35	0.86	2.86	1.19
MPR [14]	0.25	0.14	0.24	0.63	4.0	4.41
SeSi [15]	0.47	0.26	0.44	1.18	2.12	-

"SS Q", as well as the models by Szabo and Protheroe [11] "SP u" and "SP l" represent models for neutrino production in the central region of Active Galactic Nuclei and are ruled out with $n_{90\%}/N_{\text{model}} \approx$ 0.06 - 0.4. Further shown are models for neutrino production in AGN jets: calculations by Protheroe [12], by Mannheim [13], by Mannheim, Protheroe and Rachen [14] (model "MPR") and by Semikoz and Sigl [15] "SeSi". The latter models for blazars are currently not excluded. For an E^{-2} behaviour of the neutrino spectrum and a flavor ratio $\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$, the 90% C.L. upper limit on the neutrino flux of all flavors obtained with the Baikal neutrino telescope *NT200* (1038 days) is:

$$E^2\Phi < 8.1 \times 10^{-7}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{GeV}. \quad (2)$$

Assuming an upper limit on the number of signal events $n_{90\%}$ =2.5, the model-independent limit on $\bar{\nu_e}$ at the W - resonance energy is:

$$\Phi_{\bar{\nu_e}} < 3.3 \times 10^{-20}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{GeV}^{-1}. \quad (3)$$

Figure 2 (left panel) shows our upper limit on the $(\nu_e+\nu_\mu+\nu_\tau)\,E^{-2}$ diffuse flux as well as the model independent limit on the resonant $\bar{\nu}_e$ flux (diamond). Also shown are the limits obtained by AMANDA and MACRO [8, 9, 16], theoretical bounds obtained by Berezinsky (model independent (B) and for an E^{-2} shape of the neutrino spectrum (B(E^{-2})) [17], by Waxman and Bahcall (WB) [18], by Mannheim et al.(MPR) [14], predictions for neutrino fluxes from topological defects (TD) [15], prediction on diffuse flux from AGNs according to Nellen et al. (NMB) [19], as well as the atmospheric conventional neutrino fluxes [20] from horizontal and vertical directions (upper and lower curves, respectively) and atmospheric prompt neutrino fluxes obtained by Volkova et al. [21]. Our upper limits (solid curves) on diffuse fluxes from AGNs shaped according to the model of Stecker and Salamon (SS) [10] and of Semikoz and Sigl (SeSi) [15] are shown in the right panel of fig. 2.

In March/April 2005 we fenced a large part of the search volume with three sparsely instrumented strings (see [4] for details). The three-year sensitivity of this enlarged detector *NT200+*, with about 5 Mton enclosed volume, is approximately $E^2\Phi_{\nu_e} \sim 10^{-7}\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$GeV for $E >10^2$ TeV, i.e. three-four times better than *NT200*. *NT200+* will search for neutrinos from AGNs, GRBs and other extraterrestrial sources, neutrinos from cosmic ray interactions in the Galaxy as well as high energy atmospheric muons with $E_\mu > 10$ TeV.

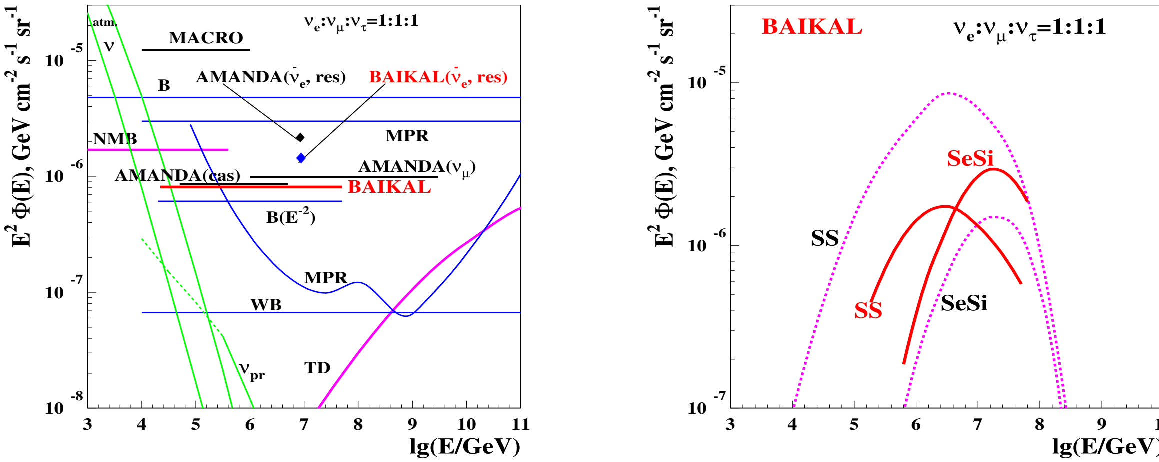

Figure 2. Left panel: neutrino flux predictions in different models of neutrino sources compared to experimental upper limits to E^{-2} fluxes obtained by various experiments. (see text). Right panel: experimental limits compared to two model predictions. Dotted curves: predictions from model SS [10] and SeSi [15]. Full curves: upper limits to spectra of the same shape. Model SS is excluded (MRF=0.21), model SeSi is not (MRF=2.12).

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References

[1] I. Belolaptikov et al. [BAIKAL Collaboration], Astropart. Phys. 7 (1997) 263.
[2] I. Belolaptikov et al. [BAIKAL Collaboration], Astropart. Phys. 12 (1999) 75.
[3] V. Aynutdinov et al. [BAIKAL Collaboration], Nucl. Phys. (Proc. Suppl.) B143 (2005) 335-342.
[4] V. Aynutdinov et al. [BAIKAL Collaboration], these proceedings: rus-kuzmichev-lA-abs3-og25-oral.
[5] V. Aynutdinov et al. [BAIKAL Collaboration], these proceedings: ger-wischnewski-R-abs2-he23-poster.
[6] J. Conrad et al., Phys. Rev. D67 (2003) 012002.
[7] G.J. Feldman and R.D. Cousins, Phys. ReV. D57 (1998) 3873.
[8] M. Ackermann et al., Astropart Phys. 22 (2004) 127.
[9] M. Ackermann et al., Astropart. Phys. 22 (2005) 339.
[10] F. Stecker and M. Salamon, Space Sci. Rev. 75 (1996) 341.
[11] A. Szabo and R. Protheroe, Proc. High Energy Neutrino Astrophysics, ed. V.J. Stenger et al., Honolulu, Hawaii (1992).
[12] R.J. Protheroe, arXiv:astro-ph /9612213.
[13] K. Mannheim, Astropart. Phys. 3 (1995) 295.
[14] K. Mannheim, R.J. Protheroe and J.P. Rachen, Phys. Rev. D63 (2001) 023003.
[15] D. Semikoz and G. Sigl, arXiv:hep-ph/0309328.
[16] M. Ambrosio et al., Nucl. Phys. (Proc. Suppl.) B110 (2002) 519.
[17] V. Berezinsky et al., Astrophysics of Cosmic Rays, North Holland (1990).
[18] E. Waxman and J. Bahcall, Phys. Rev. D59 (1999) 023002.
[19] L. Nellen, K. Mannheim and P. Biermann, Phys. Rev. D47 (1993) 5270.
[20] L.V. Volkova, Yad. Fiz. 31 (1980) 1510; Sov. J. Nucl. Phys. 31 (1980) 784.
[21] L.V. Volkova and G.T. Zatsepin, Phys. Lett. B462 (1999) 211.