



The Baikal Neutrino Telescope: Selected Physics Results

K. ANTIPIN¹, V. AYNUTDINOV¹, V. BALKANOV¹, I. BELOLAPTIKOV⁴, N. BUDNEV², I. DANILCHENKO¹, G. DOMOGATSKY¹, A. DOROSHENKO¹, A. DYACHOK², ZH. DZHILKIBAEV¹, S. FIALKOVSKY⁶, O. GAPONENKO¹, K. GOLUBKOV⁴, O. GRESS², T. GRESS², O. GRISHIN², A. KLABUKOV¹, A. KLIMOV⁸, A. KOCHANOV², K. KONISCHEV⁴, A. KOSHECHKIN¹, V. KULEPOV⁶, L. KUZMICHEV³, E. MIDDPELL⁵, S. MIKHEYEV¹, M. MILENIN⁶, R. MIRGAZOV², E. OSIPOVA³, YU. PAVLOVA¹, G. PAN'KOV², L. PAN'KOV², A. PANFILOV¹, D. PETUKHOV¹, E. PLISKOVSKY⁴, P. POKHIL¹, V. POLESHUK¹, E. POPOVA³, V. PROSIN³, M. ROSANOV⁷, V. RUBTZOV², B. SHAIBONOV⁴, A. SHEIFLER¹, A. SHIROKOV³, CH. SPIERING⁵, B. TARASHANSKY², R. WISCHNEWSKI⁵, I. YASHIN³, V. ZHUKOV¹

¹*Institute for Nuclear Research, Moscow, Russia*

²*Irkutsk State University, Irkutsk, Russia*

³*Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia*

⁴*Joint Institute for Nuclear Research, Dubna, Russia*

⁵*DESY, Zeuthen, Germany*

⁶*Nizhni Novgorod State Technical University, Nizhni Novgorod, Russia*

⁷*St Petersburg State Marine University, St Petersburg, Russia*

⁸*Kurchatov Institute, Moscow, Russia*

wischnew@ifh.de

Abstract: We present results on searches for exotic particles (relativistic magnetic monopoles and WIMPs) and for UHE neutrinos, obtained with the Baikal neutrino telescope NT200.

Introduction

The Baikal Neutrino Telescope is operated in Lake Baikal, Siberia, at a depth of 1.1 km. The first stage telescope configuration NT200 was put into permanent operation on April 6th, 1998. The upgraded telescope NT200+ was put into operation on April 9th, 2005. This configuration consists of the old NT200 telescope, surrounded by three new external strings. Status and description of the detector has been presented elsewhere [1]. In this paper we present selected physics results of a search for fast magnetic monopoles, neutrino signals from WIMP annihilation at the center of the Earth and a search for diffuse neutrinos with energies larger than 10 TeV, obtained with the Baikal neutrino telescope NT200.

Fast Magnetic Monopoles

Fast magnetic monopoles with Dirac charge $g = 68.5e$ are interesting objects to search for with deep underwater neutrino telescopes. The intensity of monopole Cherenkov radiation is ≈ 8300 times higher than that of muons. Optical modules of the Baikal experiment can detect such an object from a distance up to hundred meters. The processing chain for fast monopoles starts with the selection of events with a high multiplicity of hit channels: $N_{hit} > 30$. In order to reduce the background from downward atmospheric muons we restrict ourself to monopoles coming from the lower hemisphere. For an upward going particle the times of hit channels increase with rising z -coordinates from bottom to top of the detector. To suppress events caused by downward moving particles, a cut on the

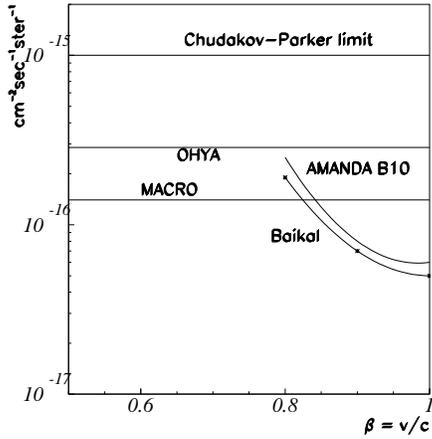


Figure 1: Upper limits on the flux of fast monopoles obtained in this analysis (Baikal) and in other experiments.

value of the time- z -correlation, C_{tz} , is applied:

$$C_{tz} = \frac{\sum_{i=1}^{N_{hit}} (t_i - \bar{t})(z_i - \bar{z})}{N_{hit} \sigma_t \sigma_z} > 0 \quad (1)$$

where t_i and z_i are time and z -coordinate of a fired channel, \bar{t} and \bar{z} are mean values for times and z -coordinates of the event and σ_t and σ_z the rms-errors for time and z -coordinates.

Within 1003 days of live time used in this analysis, about $3 \cdot 10^8$ events with $N_{hit} > 4$ have been recorded, with 21240 of them satisfying conditions $N_{hit} > 30$ and $C_{tz} > 0$. For further background suppression (see [2] for details of the analysis) we use additional cuts, which essentially reject muon events and at the same time only slightly reduce the effective area for relativistic monopoles.

No events from the experimental sample pass all cuts. For the time periods included in the analysis the acceptances A_{eff} varies between $3 \cdot 10^8$ and $6 \cdot 10^8$ $\text{cm}^2 \text{sr}$ (for $\beta = 1$). From the non-observation of candidate events in NT200 and the earlier stage telescopes NT36 and NT96 [3], a combined 90% C.L. upper limit on the flux of fast monopoles is obtained. In Fig. 1 we compare this upper limit to the limits from the experiments Ohya, MACRO and AMANDA [4]. The Baikal limit is currently the most stringent one.

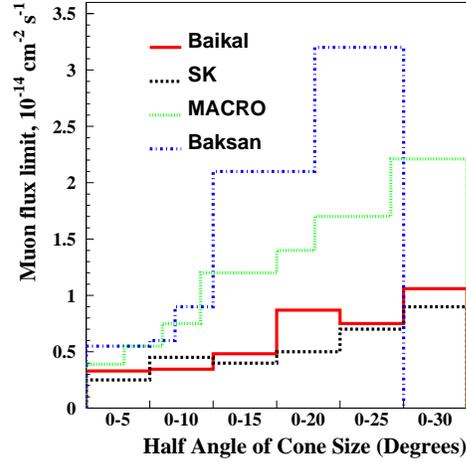


Figure 2: Limits on the excess muon flux from the center of the Earth versus half-cone of the search angle.

WIMPs

The search for WIMPs with the Baikal neutrino telescope is based on a possible signal of nearly vertically upward going muons, exceeding the flux of atmospheric neutrinos. The method of event selection relies on the application of a series of cuts which are tailored to the response of the telescope to nearly vertically upward moving muons.

For the present analysis we included all events with ≥ 5 hit channels, out of which ≥ 4 hits are along at least one of all hit strings. To this sample, a series of 5 cuts is applied (see [5] for details of analysis). The applied cuts select muons with $-1 < \cos(\theta) < -0.65$ and result in a detection area of about 1800 m^2 for vertically upward going muons with energies $> 10 \text{ GeV}$.

From 1038 days of effective data taking between April 1998 and February 2003, 48 events with $-1 < \cos(\theta) < -0.75$ have been selected as neutrino candidates, compared to 56.6 events expected from atmospheric neutrinos in case of oscillations and 73.1 without oscillations. Within statistical uncertainties the experimental angular distribution is consistent with the prediction including neutrino oscillations.

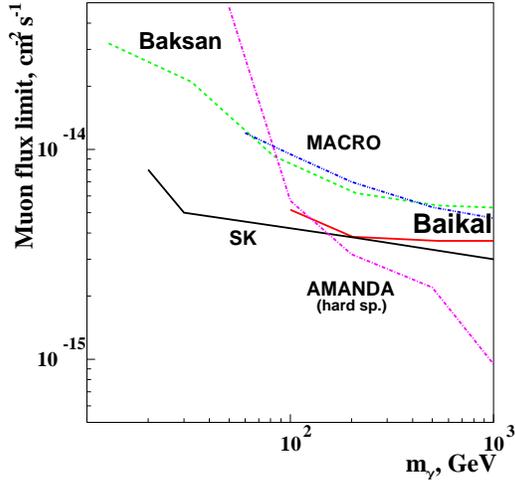


Figure 3: Limits on the excess muon flux from the center of the Earth as a function of WIMP mass.

Regarding the 48 detected events as being induced by atmospheric neutrinos, one can derive an upper limit on the additional flux of muons from the center of the Earth due to annihilation of neutralinos - the favored candidate for cold dark matter. The 90% C.L. muon flux limits for six cones around the opposite zenith obtained with NT200 ($E_{\text{thr}} > 10$ GeV) in 1998-2002 are shown in Fig. 2. It was shown [6] that the size of a cone which contains 90% of signal strongly depends on neutralino mass. The 90% C.L. flux limits are calculated as a function of neutralino mass using cones which collect 90% of the expected signal and are corrected for the 90% collection efficiency due to cone size. Also a correction is applied for each neutralino mass to translate from the threshold of the 10 GeV to the 1 GeV threshold. These limits are shown in Fig. 3. Also shown in Fig. 3 are limits obtained by Baksan, MACRO, Super-Kamiokande and AMANDA [6].

UHE neutrinos

The BAIKAL survey for high energy neutrinos searches for bright cascades produced at the neutrino interaction vertex in a large volume around the neutrino telescope [7]. We select events with high multiplicity of hit channels N_{hit} , correspond-

ing to bright cascades. To separate high-energy neutrino events from background events, a cut to select events with upward moving light signals has been developed. We define for each event $t_{\text{min}} = \min(t_i - t_j)$, where t_i, t_j are the arrival times at channels i, j on each string, and the minimum over all strings is calculated. Positive and negative values of t_{min} correspond to upward and downward propagation of light, respectively.

Within the 1038 days of the detector live time between April 1998 and February 2003, 3.45×10^8 events with $N_{\text{hit}} \geq 4$ have been recorded. For this analysis we used 22597 events with hit channel multiplicity $N_{\text{hit}} > 15$ and $t_{\text{min}} > -10$ ns. We conclude that data are consistent with simulated background for both t_{min} and N_{hit} distributions. No statistically significant excess above the background from atmospheric muons has been observed.

	BAIKAL	AMANDA
Model	$n_{90\%}/N_m$	$n_{90\%}/N_m$
$10^{-6} \times E^{-2}$	0.81	0.22
SS Quasar	0.25	0.21
SS05 Quasar	2.5	1.6
SP u	0.062	0.054
SP l	0.37	0.28
P $p\gamma$	1.14	1.99
M $pp + p\gamma$	2.86	1.19
MPR	4.0	2.0
SeSi	2.12	-

Table 1: Model rejection factors for models of astrophysical neutrino sources.

Since no events have been observed which pass the final cuts, upper limits on the diffuse flux of extraterrestrial neutrinos are calculated. For a 90% C.L. an upper limit on the number of signal events of $n_{90\%} = 2.5$ is obtained assuming an uncertainty in signal detection of 24% and a background of zero events. A model of astrophysical neutrino sources, for which the total number of expected events ($\nu_e + \nu_\mu + \nu_\tau$), N_m , is larger than $n_{90\%}$, is ruled out at 90% C.L.. Table 1 represents model rejection factors (MRF) $n_{90\%}/N_m$ for models of astrophysical neutrino sources (see [7] for references) obtained from our search, compared to AMANDA [8].

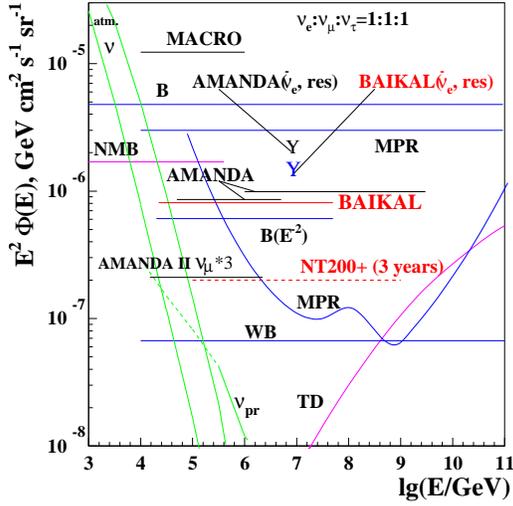


Figure 4: All-flavor neutrino flux predictions in different models of neutrino sources compared to experimental upper limits to E^{-2} fluxes obtained by this analysis and other experiments (see text). Also shown is the sensitivity expected for 3 live years of the new telescope NT200+.

For an E^{-2} behaviour of the neutrino spectrum and a flavor ratio $\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$ at the Earth, the 90% C.L. upper limit on the neutrino flux of all flavors obtained with the Baikal neutrino telescope NT200 (1038 days) is [7]:

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

For the resonant process with the resonant neutrino energy $E_0 = 6.3 \times 10^6 \text{ GeV}$, the model-independent limit on $\bar{\nu}_e$ is [7]:

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

Fig. 4 shows our upper limit on the all-flavor E^{-2} diffuse flux (2) as well as the model independent limit on the resonant $\bar{\nu}_e$ flux (diamond) (3). Also shown are the limits obtained by AMANDA [8] and MACRO [9] and theoretical bounds and predictions for diffuse neutrino fluxes of different origin (see [7]).

Conclusion

The Baikal neutrino telescope NT200 is taking data since April 1998. The upper limit obtained for a diffuse $(\nu_e + \nu_\mu + \nu_\tau)$ flux with E^{-2} shape is $E^2 \Phi = 8.1 \times 10^{-7} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV}$. The limits on fast magnetic monopoles and on a diffuse $\bar{\nu}_e$ flux at the resonant energy $6.3 \times 10^6 \text{ GeV}$ are presently the most stringent ones.

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