Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 588 (2008) 99–106
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

The Baikal neutrino experiment: Status, selected physics results, and perspectives

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Available online 15 January 2008

Abstract

We review the status of the Baikal neutrino telescope, which is operating in Lake Baikal since 1998 and has been upgraded to the 10 Mton detector NT200+ in 2005. We present selected physics results on searches for upward going neutrinos, relativistic magnetic monopoles and for very high-energy neutrinos. We describe the strategy of creating a detector on the Gigaton (km^3) scale at Lake Baikal. First steps of activities towards a km^3 Baikal neutrino telescope are discussed.

PACS: 95.55.Vj; 95.85.Ry; 96.40.Tv

Keywords: Neutrino telescopes; Neutrino astronomy; UHE neutrinos; Baikal

1. Introduction

The Baikal neutrino telescope NT200 takes data since April 1998. On April 9th, 2005, the 10-Mton scale detector NT200+ was put into operation in Lake Baikal. Description of site properties, detector configuration and performance have been described elsewhere [1–5].

In this paper we review the current status of the Baikal neutrino experiment and the activities toward the km^3-scale detector [6], as well as results obtained from the analysis of data taken with the Baikal neutrino telescope NT200 between April 1998 and February 2003 [7].

2. Selected results obtained with NT200

2.1. Atmospheric neutrinos

The signature of charged current muon neutrino events is a muon crossing the detector from below. Muon track reconstruction algorithms and background rejection have

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0168-9002/$ - see front matter
doi:10.1016/j.nima.2008.01.011

been described elsewhere [8]. Compared to Ref. [8] the analysis of the four-year sample (1038 days live time) was optimized for higher signal passing rate, and accepting a slightly higher contamination of 15–20% fake events [9]. A total of 372 upward going neutrino candidates were selected. From Monte-Carlo simulation a total of 385 atmospheric neutrino and background events are expected. The skyplot of these events is shown in Fig. 1.

2.2. Search for neutrinos from WIMP annihilation

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 [10]. The applied cuts select muons with $-1 < \cos(\theta) < -0.75$ and result in a detection area of about $1800\,\mathrm{m}^2$ for vertically upward going muons. The energy threshold for this analysis is $E_{\mathrm{thr}} \sim 10\,\mathrm{GeV}$ i.e. significantly lower than for the analysis described in Section 2.1 ($E_{\mathrm{thr}} \sim 15$–$20\,\mathrm{GeV}$). Therefore the effect of oscillations is stronger visible. We expect a muon event suppression of (25–30)% due to neutrino oscillations assuming $\delta m^2 = 2.5 \times 10^{-3}\,\mathrm{eV}^2$ with full mixing, $\theta_{\mathrm{m}} \approx \pi/4$.

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 clear neutrino events, compared to 56.6 events expected from atmospheric neutrinos in case of oscillations and 73.1 events without oscillations. The angular distribution of these events as well as the MC-predicted distributions are shown in Fig. 2. For the MC simulations we used the Bartol96 atmospheric neutrino flux [11] without (dashed curve) and with (solid curve) oscillations. Within statistical uncertainties the experimental angular distribution is consistent with the prediction including neutrino oscillations.

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

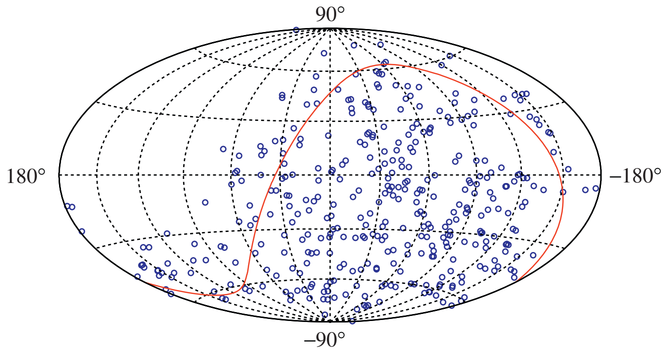

Fig. 1. Skyplot (galactic coordinates) of neutrino events for five years. The solid curve shows the equator.

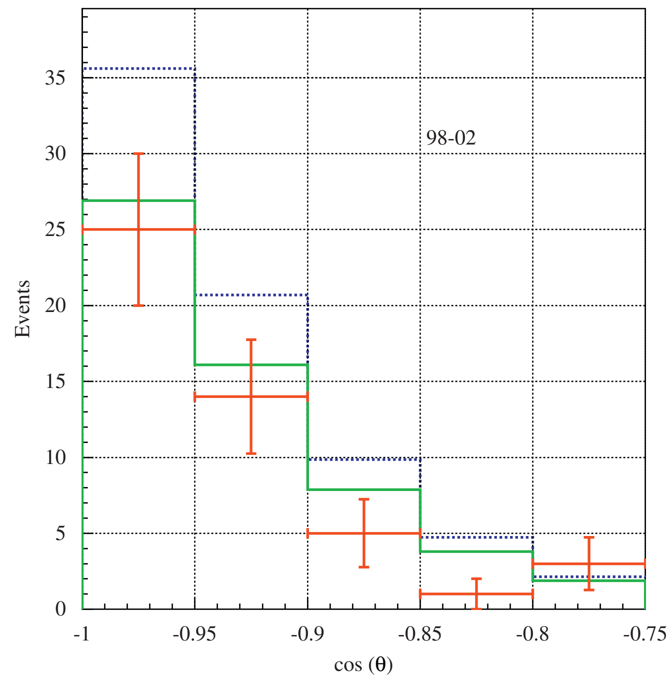

Fig. 2. Angular distributions of selected neutrino candidates as well as expected distributions in a case with and without oscillations (solid and dashed curves, respectively).

for cold dark matter. The 90% CL muon flux limits for six cones around the opposite zenith obtained with NT200 ($E_{\mathrm{thr}} > 10\,\mathrm{GeV}$) in 1998–2002 are shown in Fig. 3. It was shown [12–14] that the size of a cone which contains 90% of signal strongly depends on neutralino mass. The 90% CL 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 10 to 1 GeV threshold (thus modifying the results as presented earlier for 10 GeV threshold [16]). These limits are shown in Fig. 4. Also shown in Figs. 3 and 4 are limits obtained by Baksan [12], MACRO [13], Super-Kamiokande [14] and AMANDA (from the hard neutralino annihilation channels) [15].

2.3. A search for 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 100 m. The processing chain for fast monopoles starts with the selection of events with a high multiplicity of hit channels: $N_{\mathrm{hit}} > 30$. 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 downward