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The Lake Baikal Neutrino Telescope NT-200: First year of operation

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Abstract

The Baikal Neutrino Telescope *NT-200* has been put into operation at April 6th, 1998. We describe the parameters and design of the telescope, present preliminary results of the first year of operation of *NT-200* and make a short review of the results obtained from data analysis of the four-string array *NT-96*. Results cover atmospheric muons, selection of upward muons from neutrino interaction, search for magnetic monopoles and combined operation of an underwater telescope and a Cherenkov EAS array, placed on the ice of the lake. We also briefly discuss the potential of NT-200 with respect to oscillation of low-energy neutrinos as well as high energy neutrino identification.

1 Introduction:

The Neutrino Telescope *NT-200* has been put into full operation at April 6th, 1998. The effective area of the array for muons is 2000-10000 m^2 depending on the muon energy (I.A.Sokalski and Ch.Spiering (ed), 1992). The expected rate of muons from atmospheric neutrinos, with a muon energy threshold of 10 GeV and after all cuts rejecting background, is about 0.5 - 1 per day. The array is placed in the southern part of Lake Baikal (51.50N and 104.20E) at a distance of 3.6 km to the shore. The depth of the lake is 1366 m at this location. The absorption length L_{abs} of water for wavelengths between 470 and 500 nm is about 20 m; seasonal variations typically are less than 10%. Light scattering is strongly anisotropic. The mean cosine of the scattering angle is 0.85 - 0.95. Typical values of L_{scatt} are about 15 - 30 m, i.e. close to the absorption length In April 1993, the first part of *NT-200*, the detector *NT-36* with 36 OMs at 3 strings, was put into operation and took data up to March 1995. A 72-OM array, *NT-72*, run in 1995-96. In 1996 it was replaced by the four-string array *NT-96*. In April 1997 this array was replaced by a six-string array with 144 OMs.

2 The Baikal Neutrino Telescope *NT-200*

NT-200 (Fig.1) consists of 192 optical modules (OMs) equipped with a large area hybrid phototube, *QUASAR-370*. This photomultiplier has a hemispherical photocathode of 37 cm diameter and a time resolution of better than 3 nsec (R.I.Bagduev *et al.* 1999). The umbrella-like frame carries 8 strings with the detector components. Three underwater electrical cables and one optical cable (the optical cable is not used up to now) connect the detector with the shore station. Deployment of all detector components is carried out during 7 weeks in late winter when the lake is covered by a thick layer of ice. The OMs are grouped in pairs along the strings. The pulses from two PMTs after 0.3 *p.e.* discrimination are fed to a coincidence unit with 15 ns time window. A pair defines a *channel*. A *muon-trigger* is formed by the requirement of $\geq N$ *hits* (with *hit* referring to a channel) within 500 ns. N is typically set to 3 or 4. A separate *monopole trigger* system searches for time patterns characteristic for slowly moving objects.

The calibration of the relative time shifts between all channels is performed with the help of a nitrogen laser with 300 ps pulse width located above the array. The light from this laser is guided by optical fibers of equal length separately to each OM pair. To cross check this method, a special second laser emitting light directly through the water was mounted at the central string 20 m below the last layer of OMs. In the initial project of *NT-200*, the number of OMs looking upward is equal to the number of OMs looking downward. The distance between pairs looking face to face is 7.5 m, while pairs arranged back to back are 5 m apart. In this case the array has a symmetrical response to upward and downward muons, respectively. We tested this orientation of OMs with *NT-36* and *NT-72*. However, due to sedimentation the sensitivity of up-looking OMs decreased by 50% after 150 days. Hence for *NT-96*, *NT-144*, and *NT-200* (this year's deployment) the orientation of the OMs was changed: only OMs from two layers of the array (second and eleventh) look upward, and all others look downward. In future, when a method of protection from sedimentation will be found, we might come back to the initial orientation of the OMs.

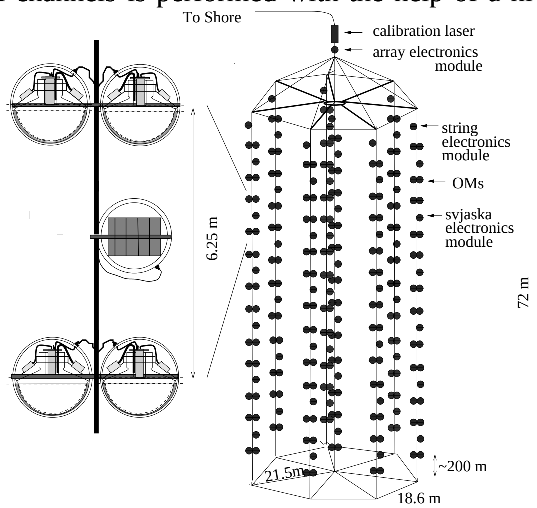

Figure 1: Schematic view of *NT-200*.

3 Joint work of underwater telescope and Cherenkov EAS array

In 1999 a Cherenkov EAS array consisting of four QUASAR tubes was deployed on the ice, just above the underwater telescope, in order to check the angular resolution of the latter. Three Cherenkov detectors were placed at the corners of an equilateral triangle and one in the center. The distance between the central detector and the outside detectors is 100 m. The effective area of each optical detector was increased by 1.5 times using conic reflectors. The trigger rate of the array (4-fold coincidence within 1 μsec) is about 1 Hz. As the angular error in the determination of the EAS direction is less than 1° and since high energy muons maintain the direction of their parent shower, the joint work of the two detectors will yield an estimation of the track reconstruction error close to the vertical direction ($0^\circ - 20^\circ$). At the beginning of April we performed a run of joint work of EAS array and *NT-200*. The rate of coincidence reached $8 \cdot 10^{-3}$ Hz, but due very unstable weather condition we got only 150 coincidence events up to the end of the ice season. The analysis of data is in progress and preliminary results as we hope will be presented at the conference.

4 Selection of neutrino events with full track reconstruction

The most obvious way to select events from the lower hemisphere (which dominantly are due to atmospheric neutrino interactions in the rock or water below the array) is to perform a full spatial track reconstruction and select events with negative $\cos\theta$-values. The reconstruction algorithm (I.A.Belolaptikov *et al.*, 1997) and rejection of bad reconstructed events with special cuts permitted us to select 9 neutrino events from the data of 70.3 days effective operating time of the 4-string array *NT-96* (V.A.Balkanov *et al.*, 1999, HE 4.1.08). Data analysis of *NT-200* is in progress, the rate of the firsts selected neutrino candidates is in approximate agreement with the expected rate of neutrino events. ¿From the first 12 days of *NT-200* operation 14 neutrino candidates were selected.

5 Search for nearly upward moving neutrinos

The effective area for trigger ≥ 5 hit on ≥ 3 strings (being the condition for full track reconstruction) decreases when θ approaches the opposite zenith, since the probability for low energy muons to hit 3 strings decreases. To select upward muons with $\theta > 150^{\circ}$, special cuts on time, amplitude and number of hit channels were used (V.A.Balkanov *et al.*, 1999 HE 4.1.08). In this analysis we also included events with hits on 1 or 2 strings. Four neutrino events from 70 day operating time were selected. MC shows that for *NT-200* the effective area is about 2000 m^2 for $E_\mu > 10 GeV$, two times more than for *NT-96*.
If the energy threshold for upward muons could be decreased to 5 GeV, *NT-200* would permit to select a not negligible amount of muons from neutrinos with the vertex inside the telescope. This will allow to study neutrino oscillations for neutrinos having crossed about 13000 km in the Earth (L.Moscoso, 1998). An estimation shows that the total number of such events will be about 20 per year for $\theta > 165^{\circ}$. In case of $\nu_\mu \leftrightarrow \nu_x$ oscillations the ν_μ flux will be suppressed, and for $\triangle m^2 = 10^{-3} eV^2$ we will find only 7 events.

6 Search for fast magnetic monopoles

Due to the large magnetic charge ($g_0 = 68.5e$), the intensity of Cherenkov radiation from relativistic magnetic monopoles ($\beta \simeq 1$) exceeds the intensity of naked muons by a factor of 8300. Such object would cause hits over distances of ~80 m. The signature of events from monopoles is a high multiplicity of hit channels. More detailed discussions of this problem and an upper limit on the monopole flux from the data of *NT-96* are presented in V.A.Balkanov *et al.*, 1999, HE 5.3.04. The aperture for fast monopoles is about $3.5 \cdot 10^4 m^2 sr$, only 1.5 times more than for *NT-96*.

7 Search for very high energy electron neutrinos

High energy electron neutrinos can be detected due to the large flux of Cherenkov photons emitted from electromagnetic and (or) hadronic cascades produced at these interactions. The trigger condition for the event selection was chosen to be the same as for fast monopole detection (V.A.Balkanov *et al.*, 1999, HE 5.3.04). In this case the effective volume of NT-96 is about $3.0 \cdot 10^5 m^3$ for $E_\nu = 100 TeV$ and about $2.0 \cdot 10^6 m^3$ for $E_\nu = 10 PeV$. After analysis of 70 days of *NT-96* no evidence for any neutrino-induced cascades was found. The future improvement of this search will be due not only to the increasing time of observation but also to the choice of a more adequate trigger condition for high energy cascades selection.

7.1 The limit to the $\tilde{\nu}_e$ flux at the W resonance energy The cross section of $\tilde{\nu}_e$e interactions at 6.3 PeV ($5.0 \cdot 10^{-31} cm^2$) is larger than the ν_eN cross section at any energy up to $10^{21} eV$. Using the calculated effective volume and not taking into consideration the behavior of the neutrino spectrum at energies smaller than 6.3 PeV, from *NT-96* we can get the following 90% CL upper limit on the flux of $\tilde{\nu}_e$ at resonance energy:

$$\frac{dF_{\tilde{\nu}}}{dE} \leq 3.7 \cdot 10^{-18} cm^{-2} s^{-1} sr^{-1} GeV^{-1}$$

This limit lies between upper limits on the flux obtained by DUMAND (J.W. Bolesta *et al.*, 1997), $1.1 \cdot 10^{-18} cm^{-2} s^{-1} sr^{-1} GeV^{-1}$, and EAS-TOP (M. Aglietta *et al.*, 1994), $7.6 \cdot 10^{-18} cm^{-2} s^{-1} sr^{-1} GeV^{-1}$.

7.2 The limit on the $\tilde{\nu}_e + \nu_e$ flux For setting a limit to the $\tilde{\nu}_e + \nu_e$ flux we have used the cross section for $\nu_e(\tilde{\nu}_e)$ CC-interactions with nucleons (R.Gandhi *et al.*, 1996), when all neutrino energy is transferred to the cascade. The energy dependence of neutrino absorption in the Earth has been taken into account. The energy spectrum of extraterrestrial neutrinos from 10^5 to 10^6 GeV was approximated by a power law with $\gamma = 2$ as expected from first order Fermi acceleration on shock waves. The upper limit on neutrino flux in this case can be written in the form:

$$\frac{dF_{\tilde{\nu}+\nu}}{dE} \leq 5.0 \cdot 10^{-15} \cdot (\frac{E_\nu}{10^5 GeV})^{-2} cm^{-2} s^{-1} sr^{-1} GeV^{-1}$$

Our limit is 4–10 times lower than the limits from AMANDA-A (R.Porrata *et al*, 1997), EAS-TOP (M.Aglietta *al.*, 1994) and DUMAND (J.W.Bolesta *et al.*), but still 3–4 orders higher than theoreticians expectation (R.J.Protheroe, 1998).

8 Future plans

Our main effort in the near future (5 years) will be the collection and analysis of data with *NT-200*. The main physics problem seems to be the investigation of atmospheric neutrinos. Presumably still too small to detect neutrinos from AGN and other extraterrestrial sources, *NT-200* can be used to push harder upper limits on the flux of neutrinos from such sources as well as better limits for neutrinos from WIMP annihilation and for magnetic monopoles. The data from *NT-200* will be also used to study water processes in Lake Baikal. Apart from its own value, *NT-200* is regarded to be a prototype for a telescope with an effective area of 50,000 to 100,000 m^2. This telescope would have a realistic potential for extraterrestrial sources of high energy neutrinos. The basic design of such a detector is under discussion at present.

9 Acknowledgments

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