Abstract

We review the present status of the Baikal Deep Underwater Neutrino Experiment. The construction and performance of the large deep underwater Cherenkov detector for muons and neutrinos, NT-200 (Neutrino Telescope with 200 phototubes), which is currently under construction in Lake Baikal are described. Some results obtained with the intermediate detectors NT-36 (1993-95), NT-72 (1995-96) and NT-96 (1996-97) are presented, including the first clear neutrino candidates selected with 1994 and 1996 data.

1 Introduction

The possibility to build a neutrino telescope in Lake Baikal was investigated since 1980, with the basic idea to use – instead of a ship – the winter ice cover as a platform for assembly and deployment of instruments [1]. After first small size tests, in 1984-90 single-string arrays equipped...
with 12 – 36 PMTs (FEU-49 with flat 15 cm photocathode) were deployed and operated via a shore cable \cite{2}. The total life time for these “first generation detectors” made up 270 days. On the methodical side, underwater and ice technologies were developed, optical properties of the Baikal water as well as the long-term variations of the water luminescence were investigated in great details. For the Baikal telescope site the absorption length for wavelength between 470 and 500 nm is about 20 m (fig.1), typical value for scattering length is 15 m \footnote{Sometimes the effective scattering length $L_{\text{eff}} = L_{\text{scatt}}/(1 - \langle \cos \theta \rangle)$ is used to characterize the relative merits of different sites for neutrino telescopes. With $L_{\text{scatt}} = 15 \text{ m}$ and $\langle \cos \theta \rangle = 0.95$ one obtains $L_{\text{eff}} = 300 \text{ m}$ for the Baikal site.} with mean cosine of the scattering angle being close to 0.95 (see \cite{3} and refs. therein). Since 1987, a ”second generation detector” with the capability to identify muons from neutrino interactions was envisaged. Tailored to the needs of the Baikal experiment, a large area hybrid phototube QUASAR \cite{4} with a hemispherical photocathode of 37 cm diameter and a time resolution of better than 3 nsec was developed to replace the FEU-49. According to the approximate number of PMTs this detector was named $NT-200 – \text{Neutrino Telescope with 200 PMTs}$ \cite{5}. With an estimated effective area of about 2300 m$^2$ and 8500 m$^2$ for 1-TeV and 100-TeV muons, respectively, it is a first stage of a future full-scale telescope, which will be built stepwise, via intermediate detectors of rising size and complexity.

2 The Baikal Neutrino Telescope $NT-200$

The Baikal Neutrino Telescope is being deployed in Lake Baikal, 3.6 km from shore at a depth of 1.1 km (fig. 2,3). It will consist of 192 optical modules (OMs). The umbrella-like frame carries the 8 strings with the detector components. Three underwater electrical cables connect the detector with the shore station. Deployment of all detector components is carried out during 5–7 weeks in late winter when the lake is covered by thick ice.

In April 1993, the first part of $NT-200$, the detector $NT-36$ with 36 OMs at 3 short 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 $NT-96$. Summed over 700 days effective life time, $3.2 \cdot 10^8$ muon events have been collected with $NT-36$, -72, -96. Since April 6, 1997, $NT-144$, a six-string array with 144 OMs, is taking data in Lake Baikal.

The OMs are grouped in pairs along the strings. The pulses from two PMTs of a pair after 0.3 p.e. discrimination are fed to a coincidence 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 the value 3 or 4. For such events, amplitude and time of all fired channels are digitized and sent to shore. The event record includes all hits within a time window of -1.0 µsec to +0.8 µsec with respect to the muon trigger signal. A separate monopole trigger system searches for time patterns characteristic for slowly moving objects (see Subsect.4.4).

Stability of digitizing is checked by calibration runs performed typically once per several days. The calibration of the relative time shifts between all channels is performed with the help of a nitrogen laser with 300 ps pulse width positioned 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, for $NT-144$ a special second laser emitting light directly through the water was mounted at one
string 20m below the last layer of OMs. In order to monitor the performance of the OMs, the counting rates of individual PMTs as well as of the channels are measured and transmitted to shore station once per 60 sec. To investigate short time variations of counting rates, in NT-144 a new scaler system has been installed which measures the counting rates of all channels with 0.8 sec step.

In the initial project of NT-200, the optical modules are grouped in pairs along the strings directed alternatively upward and 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 uplooking OMs decreased by 50% after 150 days. Hence for NT-96 and NT-144 the orientation of OMs has been changed: only OMs from two layers of the array (the second and eleventh) look upward, and all others look downward. Nevertheless we possibly come back toward symmetrical structure if the problems with sedimentation will be overcame.

3 Track Reconstruction

In contrast with a typical underground detector, it is impossible to determine co-ordinates for some clearly visible points which would belong to a track of a particle crossing an underwater array because it represents a lattice of OMs with large distances between them. The parameters of a muon track crossing an underwater detector have to be determined by minimizing

\[ \chi^2_t = \sum_{i=1}^{N_{hit}} \left( T_i(\theta, \phi, u_0, v_0, t_0) - t_i \right)^2 / \sigma_{ti}^2 \] (1)

Here, \( t_i \) are the measured times and \( T_i \) the times expected for a given set of track parameters. \( N_{hit} \) is the number of hit channels, \( \sigma_{ti} \) are the timing errors. A set of parameters defining a straight track is given by \( \theta \) and \( \phi \) – zenith and azimuth angles of the track, respectively, \( u_0 \) and \( v_0 \) – the two coordinates of the track point closest to the center of the detector, and \( t_0 \) – the time the muon passes this point. For the results given here we do not include an amplitude term \( \chi^2_a \) analogous to \( \chi^2_t \) in the analysis, but use the amplitude information only to calculate the timing errors \( \sigma_{ti} \) in the denominator of the formula above. Only events fulfilling the condition \( \geq 6 \) hits at \( \geq 3 \) strings are selected for the standard track reconstruction procedure which consists of the following steps:

1. A preliminary analysis includes several causality criteria rejecting events which violate the model of a naked muon. After that, a 0-th approximation of \( \theta \) and \( \phi \) is performed.

2. The \( \chi^2 \) minimum search (minimization of the function eq.1), based on the model of a naked muon and using only time data.

"The reconstruction algorithm is based on the assumption that the light radiated by the muons is emitted exactly under the Cherenkov angle (42 degrees) with respect to the muon path. This "naked muon model" is a simplification, since the direction of shower particles accompanying the muons is smeared around the muon direction."
3. Quality criteria to reject most badly reconstructed events.

We have developed a large set of pre-criteria as well as quality criteria to reject misreconstructed events. Most of these criteria are not independent of each other. Furthermore, the optimum set of criteria turned out to depend on the detector configuration. The causality criteria refer to time differences between channels. E.g., one requests that each combination of two channels $i, j$ obeys the condition $c |dt_{ij}| < n |dx_{ij}| + c \delta t$, where $dt_{ij}$ and $dx_{ij}$ are time differences and distances between channels $i$ and $j$, respectively and $n = 1.33$ is refraction coefficient for water. The term $\delta t = 5$ nsec accounts for the time jitter. Some of the most effective quality criteria are, e.g., upper limits on parameters like the minimum $\chi^2$, the probability $P_{\text{nohit}}$ of non-fired channels not to respond to a naked muon and probability $P_{\text{hit}}$ of fired channels to respond to a naked muon.

4 Selected Results

4.1 Atmospheric Muons Vertical Flux

Muon angular distributions are well described by MC expectations. Converting the measured angular dependence obtained with the standard reconstruction procedure (see Sect.3) applied to NT-36 data into a depth dependence of the vertical flux, good agreement with theoretical predictions as well as with others experimental points is observed (see fig.4).

4.2 Separation of Neutrino Events with Standard Track Reconstruction

The most obvious way to select events from the lower hemisphere (which dominantly are due to atmospheric neutrino interactions in the ground or water below the array) is to perform the full spatial track reconstruction (see Sect.3) and select the events with negative $\theta$ values. Taking into account that the flux of downward muons is about 6 orders of magnitude larger than the flux of upward muons, the reconstruction procedure should be performed extremely thoroughly. Even if very small fraction of downward atmospheric muons is misreconstructed as up-going ones, it forms an essential background. Due to small value of $S/N$ ratio (where $S$ is counting rate of upward neutrino induced events and $N$ is counting rate of downward atmospheric muons which are reconstructed as upward events), it is impossible to observe clear neutrino signal with NT-36 and NT-72 data and the current level of standard reconstruction procedure. MC calculations indicate the essentially better characteristics for NT-96 detector which can be considered as a neutrino telescope in the wide region of $\theta$.

The analysis of the NT-96 data with respect to neutrino induced upward muons using the standard reconstruction procedure is presently in progress. We apply final quality cuts after the minimization (see Sect.3). For NT-96 the most effective cuts are the traditional $\chi^2$ cut, cuts on the probability of non-fired channels not to be hit, and fired channels to be hit ($P_{\text{nohit}}$ and $P_{\text{hit}}$, respectively), cuts on the correlation function of measured amplitudes to the amplitudes expected for the reconstructed tracks, and a cut on the amplitude $\chi^2$ defined similar to the time $\chi^2$ defined above. To guarantee a minimum lever arm for track fitting, we reject events with a projection of the most distant channels on the track ($Z_{\text{dist}}$) below 35 meters. Due to the small
transversal dimensions of $NT$-$96$, this cut excludes zenith angles close to the horizon, i.e., the effective area of the detector with respect to atmospheric neutrinos is decreased considerably (fig.5).

The efficiency of all criteria has been tested using MC generated atmospheric muons and upward muons due to atmospheric neutrinos. $1.8 \cdot 10^6$ events from atmospheric muon events (trigger 6/3) have been simulated, with only 2 of them passing all cuts and being reconstructed as upward going muons. This corresponds to $S/N \approx 1$. Rejecting all events with less than 9 hits, no MC fake event is left, with only a small decrease in neutrino sensitivity. This corresponds to $S/N > 1$ and the lowest curve in fig.5.

The table shows the fraction of events after the final quality criteria, normalized to the number of events surviving pre-criteria and reconstruction, for triggers 6/3 and 9/3, respectively:

| Trigger cond. | Experiment | MC atm $\mu$ | MC $\mu$ from $\nu$ |
|---------------|------------|--------------|---------------------|
| 6/3           | 0.19       | 0.21         | 0.20                |
| 9/3           | 0.044      | 0.056        | 0.175               |

With this procedure, we have reconstructed $5.3 \cdot 10^6$ events taken with $NT$-$96$ in April/May 1996. The resulting angular distribution is presented in fig.6. Three events were recognized as upward going muons. Fig.7 displays one of the neutrino candidates. Top right the times of the hit channels are shown as a function of the vertical position of the channel. At each string we observe the time dependence characteristically for upward moving particles.

One of the causality criteria (see item 1 in Sect.3) demands that the zenith angle regions $\theta_{min} - \theta_{max}$ consistent with the observed time differences $\Delta t_{ij}$ between two channels $i, j$ along the same string

$$\cos(\theta_{min} + \eta) < \text{cos} \left( \frac{z_j - z_i}{z_j - z_i} \cdot \frac{\Delta t_{ij}}{z_j - z_i} \right) < \cos(\theta_{max} - \eta)$$

(here $z_i, z_j$ are z coordinates of the channels and $\eta$ is the Cherenkov angle) must overlap for all channels along the string. Applying eq.2 not only to pairs at the same string, but to all pairs of hit channels, one can construct an allowed region in both $\theta$ and $\phi$. For clear neutrino events this region lays totally below horizon. This is demonstrated at the bottom right picture of fig.7. The same holds for the other two events, one of which is shown in fig.8a. Fig.8b, in contrast, shows an ambiguous event giving, apart from the upward solution, also a downward solution. In this case we assign the event to the downward sample.

The analysis presented here is based on the data taken with $NT$-$96$ between April 16 and May 17, 1996 (18 days lifetime). Three neutrino candidates have been separated, in good agreement with the expected number of upward events of approximately 2.3. Our algorithm allows to select neutrino events in a cone with about 50 degrees half-aperture around the opposite zenith, and an effective area of $\sim 350 m^2$.

We hope that the further analysis of $NT$-$96$ and $NT$-$144$ data will confirm our capability to select the neutrino induced events over the background of fake events from downward atmospheric
muons. With the experimental confirmation that NT-96 can operate as a neutrino detector, we now are searching for additional possibilities to reject fake events with a smaller loss in effective area. The increased transversal dimensions of the future NT-200 (1998) will significantly increase effective area and angular acceptance for reliably separable up-going events.

4.3 Search for Nearly Upward Moving Neutrinos

To identify nearly vertically upward muons with energies below 1 TeV (as expected, e.g., for muons generated by neutrinos resulting from neutralino annihilation in the core of the Earth), full reconstruction is found to be not necessary [10]. Instead, separation criteria can be applied which make use of two facts: firstly, that the muons searched for have the same vertical direction like the string; secondly, that low-energy muons generate mainly direct Cherenkov light and, consequently, are not visible over large distances and should produce a clear time and amplitude pattern in the detector. We have chosen the following separation criteria:

1. Time differences between any two hit channels $i$ and $j$ must obey the inequality

\[ |(t_i - t_j) - (T_i - T_j)| < dt \]  

where $t_i(t_j)$ are the measured times in channels $i(j)$, $T_i(T_j)$ are the “theoretical” times expected for minimal ionizing, up-going vertical muons and $dt$ is a time cut.

2. The minimum value of amplitude asymmetries for all pairs of alternatively directed hit channels must obey the inequality

\[ dA_{ij}(down - up) > 0.3 \]  

where $dA_{ij}(down - up) = (A_i(down) - A_j(up))/(A_i(down) + A_j(up))$ and $A_i(down)(A_j(up))$ are the amplitudes of channel $i(j)$ facing downward(upward).

3. All amplitudes of downward looking hit channels must exceed 4 photoelectrons:

\[ A_i(down) > 4\text{ph.el.} \]  

4. The amplitude asymmetry $dA(down - down)$ for downward looking hit channels is defined as that of the 3 possible combinations $dA_{ij}(down - down) = (A_i - A_j)/(A_i + A_j) \mid_{i>j}$ with the largest absolute value. For background events due to showers below the array it peaks at values close to 1, for vertical neutrino candidates it should be close to zero. The fourth criterion rejects half of the neutrino sample and nearly all events due to deep showers from downward atmospheric muons:

\[ dA(down - down) < 0. \]  

The dependence of the expected yearly number of muons generated by atmospheric neutrinos and of background events on the time cut $dt$ are presented in fig.9. The curves marked 1, 2, 3
and 4 correspond to the trigger conditions 1, 1-2, 1-3 and 1-4, respectively. The 'crosses' denote background curves and 'asterisks' denote muons from atmospheric neutrinos. One sees that the signal-to-noise ratio $S/N$ is close to 1 for trigger conditions 1-3 and $dt \leq 20\text{ns}$ and improves with decreasing $dt$ or applying criterion 4.

The analysis presented here is based on the data taken with NT-36 between April 8, 1994 and March 5, 1995 (212 days lifetime). There were 6 PMT pairs along each of the 3 strings of NT-36. The orientation of the channels from top (channel #1) to bottom (channel #6) at each string was up-down-up-down-up-down in 1994/95. Upward-going muon candidates were selected from a total of $8.33 \cdot 10^7$ events recorded by the muon-trigger "$\geq 3$ hit channels". The samples fulfilling trigger conditions 1, 1-2, 1-3 and 1–4 with time cut $dt = 20\text{ns}$ contain 131, 17 and 2 events, respectively. Only two events fulfill trigger conditions 1–3 and 1–4. These events were recorded at 6 June and 3 July 1994. The first event is consistent with a nearly vertical upward going muon and the second one with an upward going muon with zenith angle $\theta_\mu = 15^\circ$ (fig.10).

Fig.11 shows the passing rate for two samples of events in dependence on the time cut $dt$. The "experimental neutrino sample" consists of just the two events shown in fig.10, the "experimental background sample" contains all other events with the exception of these two. MC curves have been obtained from modelling upward muons from atmospheric neutrinos ("neutrinos") and from downward going atmospheric muons ("background").

Fig.11a demonstrates that MC describes the data within a factor of 3-4. From fig.11b one sees that the probability to observe a background event with $dt < 20\text{ns}$ is about 2 percent only. Whereas the shapes of experimental and MC distributions in fig.11b are quite similar, the absolute values disagree by a factor of 1.5-4, depending on the criterion. The MC calculated numbers of upward going muons are systematically below the two experimentally observed events. Apart from statistics, the reason may be the following: MC simulations of the NT-36 response to upward going muons from atmospheric neutrinos has been performed without taking into account light scattering in water. A raw estimate shows that the expected number of detected upward going muons may rise by 40-80% when scattering process will be taken into account.

Considering the two neutrino candidates as atmospheric neutrino events, a 90 \% CL upper limit of $1.3 \cdot 10^{-13}$ (muons cm$^{-2}$ sec$^{-1}$) in a cone with 15 degree half-aperture around the opposite zenith is obtained for upward going muons generated by neutrinos due to neutralino annihilation in the center of the Earth. The limit corresponds to muons with energies greater than the threshold energy $E_{th} \approx 6$ GeV, defined by 30m string length. This is still an order of magnitude higher than the limits obtained by Kamiokande [11], Baksan [12] and MACRO [13].

The effective area of NT-36 for nearly vertical upward going muons fulfilling our separation criteria 1-3 with $dt = 20\text{ns}$ is $S_{eff} = 50 \text{ m}^2/$string. A rough estimate of the effective area of the full-scale Baikal Neutrino Telescope NT-200 (with eight strings twice as long as those of NT-36) with respect to nearly vertically upward going muons gives $S_{e,ff} \approx 400 - 800 \text{ m}^2$. 

7
4.4 Search for Magnetic Monopoles

4.4.1 Monopoles Catalyzing Baryon Decay

It was shown by Rubakov [14] and Callan [15] that baryon number violation is possible in the presence of a GUT magnetic monopole. For reasonable velocities ($\beta \leq 10^{-3}$), a catalysis cross section

$$\sigma_c = 0.17 \cdot \sigma_0 / \beta^2$$

is predicted for monopole-proton interactions [11] with $\sigma_0$ being of the order of magnitude typical for strong interactions. Following these predictions, the average distances between two sequential proton decays along the monopole track in water can be as short as $10^{-2} - 10^1$ cm.

In order to search for GUT monopoles, a dedicated trigger system was implemented in the electronics scheme. It is based on the method which has been developed for the first-stage Baikal setups GIRLYANDA [2] which operated in 1984-89. The method selects events which are defined as a short-time (0.1 - 1 msec) 1 p.e. increase of the counting rate of individual channels. This pattern is expected from sequential Cherenkov flashes produced by a monopole along it’s track via the proton decay products. Due to the large $\sigma_c$ values, for a short time interval the rate of detected flashes can appreciably exceed the counting rate from PMT dark current noise and water luminescence, even for monopoles passing a channel at a distance of several tens of meters.

Our monopole system consists of several nearly independent modules. They are synchronized by a common 10 kHz clock. One module reads the signals of 6 neighbouring channels placed on the same string. During standard data taking runs, the monopole trigger condition was defined as \( \geq 3 \) hits within a time window of 500 \( \mu \)sec in any of the channels (values for number of hits and time windows duration can be set from shore). Once the trigger condition is fulfilled, the information about the number of hits in each of the 6 channels which occur within the given time window is sent to shore. Time and amplitude information is not recorded by the monopole system.

Since the method is based on the search for counting rate excesses, it was important to perform a long-term in situ check and to verify that the time behaviour of local triggers is described by a Poisson distribution. If not, the search for monopoles via counting rate splashes would become essentially complicated. It was elucidated that non-Poisson effects are suppressed effectively by the coincidence between the two PMTs of a pair. This can be seen from fig.12. We compare the number of hits detected within 8 msec-time windows to the calculated distribution. Calculating it, we assumed pure Poisson fluctuations around the independently measured average hit rate. Such good agreement with the Poisson assumption is observed for all channels with only very few exceptions.

The data taken from April 16th to November 15th 1993 with NT-36 have been analyzed with respect to monopoles catalyzing baryon decay. Using the off-line threshold \( \geq 7 \) hits within 500 \( \mu \)sec we rejected most events, registering only the uppermost tail of the Poisson distribution. To suppress the remaining accidental noise, we defined an even tighter trigger, requesting that
one channel had counted $\geq 7$ hits and the second channel looking to it’s face and situated 7.5 m away along the same string had counted $\geq 3$ hits in the same 500 $\mu$sec (two channels looking face to face define a svjaska which is one of the main levels in the hierarchy of the Baikal array [3]. This reduces the number of the experimentally observed monopole candidates to zero. Fig.13 shows the number of hits from the channel 1 of a svjaska plotted versus the number of hits from the face-to-face channel 2. The product of effective data taking time and number of svjaskas with both channels operating is 4573 hours for the investigated period. $3.5 \cdot 10^7$ monopole triggers with $\geq 3$ hits have been taken.

After calculating the effective area, from the non-observation of monopole candidates we obtain the upper flux limits (90 % CL) shown in fig.14 together with our earlier results [2], results from IMB [17] and KAMIOKANDE [18] and with the theoretical Chudakov-Parker limit [19]. A limit of $2.7 \cdot 10^{-16}$ cm$^{-2}$ s$^{-1}$ has been obtained by the Baksan Telescope [20] for $\beta > 2 \cdot 10^{-4}$.

The present analysis is rather straight-forward using the same tight trigger condition for all time periods. This trigger suppresses fake monopole candidates even during periods with a high level of water luminescence. It is planned to tune the trigger depending on the local trigger counting rate. Using this more sophisticated trigger and the whole statistics taken for 4.5 years with $NT-36$, -72, -96 and -144 (more than 800 day’s data sample by September 1997) one can decrease the minimal detectable fluxes by a factor 10 – 100 compared to the results presented here. A further considerable progress is expected with the whole $NT-200$.

4.4.2 Search for Fast Magnetic Monopoles

The basic mechanism for light generation by a relativistic magnetic monopole is Cherenkov radiation. The large magnetic charge results in a giant light intensity, equal to that of a 14-PeV muon for a relativistic monopole with magnetic charge $g_o = 68.5e$. One can search for such monopoles analysing the data obtained with the muon trigger. Due to the non-stochastical nature of the Cherenkov light emission of relativistic monopoles (contrary to a 14 PeV muon!), there is a close correspondence between reconstructed monopole track parameters and the number of hit channels. This can be effectively used to select monopole candidates. For $NT-200$, we estimate an effective area roughly as a of $\approx 2 \cdot 10^4$ m$^2$ with respect to monopoles with $\beta \approx 1$. More detailed calculations which take into account the background from fake events produced by atmospheric muons are needed, but preliminary study shows that these events can be rejected rather effectively.

The data provided by the muon trigger can be used to search for monopoles with velocities down to $\beta \approx 0.1$. As was mentioned in Sect.2, the time and amplitude information is collected for all channels hit within a time window of 1.8 $\mu$sec around the muon trigger. This time is comparable with the time needed by particles with velocities $\beta \approx 0.1$ to cross the array volume. For velocities $0.6 \leq \beta \leq 0.75$, most light is due to Cherenkov radiation generated by $\delta$-electrons knocked out by the monopole. For $\beta \leq 0.6$ the basic mode of light emission is water luminescence [21]. The luminescence of the Baikal water is extremely small (about one photon per 5 MeV energy loss, as we have studied experimentally with $\alpha$-particles). Nevertheless, due to the giant energy released, the luminescence stimulated by a monopole with charge $g_o$ exceeds the Cherenkov light emitted by a relativistic muon down to monopole velocities of $\beta \approx 0.1$. The effective area of $NT-200$ for monopoles with $\beta = 0.5$ and $\beta = 0.2$ is estimated as 1000 m$^2$ and 500 m$^2$, respectively.
We plan to analyse data which taken with the various Baikal arrays with respect to the search for fast magnetic monopoles.

5 The Next Steps

On April 6, 1997, a six-string array with 144 optical modules, NT-144, was put into operation. By September 1, 1997 it has collected \( \approx 1.5 \cdot 10^8 \) muons. We plan to complete the NT-200 array in April, 1998.

6 Acknowledgements

This work was supported by the Russian Ministry of Research, the German Ministry of Education and Research and the Russian Fund of Fundamental Research (grants 96-02-17308 and 97-02-31010).

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Figure 1: Coefficients for light absorption ($\kappa$) (dots) and scattering ($\sigma$) (triangles) at the site of the Baikal Neutrino Telescope as a function of wavelength. Date of measurement: Oct./Nov.1993. Depth: 1100 m.
Figure 2: The Baikal detector complex (status since 1994).

1. Wire cables to shore,
2. Opto-electrical cable to shore,
3. String stations for shore cables 1, 2, respectively,
4. String with the telescope,
5. Hydrometric string,
6. Ultrasonic emitters.

9 - 14: Wire cables to shore.
Figure 3: Schematic view of the Baikal Telescope NT-200. The modules of NT-144, operating since April 6, 1997 are in black. The expansion left-hand shows 2 pairs of optical modules ("svjaska") with the svjaska electronics module, which houses parts of the read-out and control electronics.
Figure 4: Vertical muon flux, $I_{\mu}(\cos \theta = 1)$, vs. water depth $L$. The nine NT-36 values (full squares) are calculated for $\cos \theta = 0.2$ to 1.0 in steps of 0.1. The other data points are taken from refs. [8]. The curve is taken from [7].
Figure 5: Effective area for upward muons satisfying trigger \( \theta/3 \); solid line – no quality cuts; dashed line – final quality cuts; dotted line – final quality cuts and restriction on \( Z_{\text{dist}} \) (see text).
Figure 6: Experimental angular distribution of events satisfying trigger 9/3, all final quality cuts and the limit on Z_{dist} (see text).
Figure 7: A "gold plated" 19-hit neutrino event. Left: Event display. Hit channels are in black. The thick line gives the reconstructed muon path, thin lines pointing to the channels mark the path of the Cherenkov photons as given by the fit to the measured times. The areas of the circles are proportional to the measured amplitudes. Top right: Hit times versus vertical channel positions. Bottom right: The allowed $\theta/\phi$ regions (see text).
Figure 8: a) - an unambiguous 14-hit neutrino candidate; b) - an ambiguous event reconstructed as a neutrino event (dashed line) but with a second solution above the horizon (solid line). This event was assigned to the sample of downward going muons.
Figure 9: Expected numbers of muons from atmospheric neutrinos (asterisks) and background events (crosses) per year vs. time cut $dt$. Curves marked 1; 2; 3 and 4 correspond to trigger conditions 1, 1-2, 1-3 and 1-4.
Figure 10: The two neutrino candidates. The hit PMT pairs (channels) are marked in black. Numbers give the measured amplitudes (in photoelectrons) and times with respect to the first hit channel. Times in brackets are those expected for a vertical going upward muon (left) and an upward muon passing the string under 15° (right).
Figure 11: Distribution of experimental sample vs. time cut $dt$. Numbers 1; 2; 3 and 4 correspond to trigger conditions 1, 1-2, 1-3 and 1-4, respectively. a) - background events: lines present MC expectations for different trigger conditions; b) - neutrino candidates: solid and dashed lines present MC expectations for upward going muons generated by atmospheric neutrinos (not taking into account light scattering in water) and for background events.
Figure 12: Hit distributions for a time window of 8 msec, as recorded in a 2 hours test run for channels 14 and 18 of NT-36. Experimental data are indicated by points, the curve gives the Poisson prediction.
Figure 13: Hit numbers in channel 2 versus channel 1 for the channels of all operating *svjaskas*. The shaded region corresponds to the off-line trigger condition (see text).
Figure 14: Upper limits (90 % CL) on the natural flux of magnetic monopoles versus their velocity $\beta$, for different parameters $\sigma_0$ (see text).