Study of a possibility of acoustic detection of super high energy neutrino in Lake Baikal

V.M.Aynutdinov^a, V.A.Balkanov^a, I.A.Belolaptikov^d, L.B.Bezrukov^a, D.A.Borschev^a, N.M.Budnev^b, A.G.Chensky^b, I.A.Danilchenko^a, Ya.I.Davidov^a, Zh.-A.M.Djilkibaev^a, G.V.Domogatsky^a,A.N.Dyachok^b, O.N.Gaponenko^a, O.A.Gress^b, T.I.Gress^b, O.G.Grishin^b, S.V. Fialkovski^f, A.M.Klabukov^a, A.I.Klimov^l, S.I.Klimushin^a, A.A.Kochanov^b, K.V.Konischev^d, A.P.Koshechkin^a, V.F.Kulepov^f, L.A.Kuzmichev^c, B.K.Lubsandorzhiev^a, M.Mehanov^c, S.P.Mikheyev^a,T.Mikolajski^e, M.B. Milenin^f, R.R.Mirgazov^b, E.A.Osipova^c, A.I.Panfilov^a, G.L.Pan'kov^b, L.V.Pan'kov^b, Yu.V.Parfenov^b, A.A.Pavlov^b, D.P.Petuhov^a, E.N.Pliskovsky^d, P.G.Pokhil^a, V.A,Poleschuk^a, E.G.Popova^c, V.V.Prosin^c, M.I.Rozanov^g, V.Yu.Rubtzov^b, B.A.Shaibonov^a, A.Shirokov^c, Ch.Spiering^e, B.A.Tarashansky^b, R.V.Vasiljev^d, R.Wischnewski^e, V.A.Zhukov^a, I.V.Yashin^c

(a) Institute for Nuclear Research, Moscow, Russia
(b) Irkutsk State University, Irkutsk, Russia
(c) Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia
(d) Joint Institute for Nuclear Research, Dubna, Russia
(e) DESY-Zeuthen, Zeuthen, Germany
(f) Nizhni Novgorod State Technical University, Nizhni Novgorod, Russia
(g) St.Petersburg State Marine University, St.Petersburg, Russia
(l) Kurchatov Institute, Moscow, Russia
Presenter: A.A. Kochanov (kochanov@api.isu.ru), rus-kochanov-A-abs1-he15-poster

One of the possible ways to study high energy neutrino is to detect acoustic pulses from showers in water. First results of the study of high frequency acoustic noise in Lake Baikal are presented. Many short pulses with different amplitudes and shapes were observed, they should be considered as a background for acoustic neutrino detection. However, most of the short excesses are explained as a result of noise sound waves interference and can be eliminated by a correlation analysis. An algorithm for separation of acoustic signals with definite shape, which probably were produced by quasi local sources, is presented. The efficiency of the method was tested on real data, obtained with a 2-channels acoustic module. This algorithm is now used for online data filtering in the 4-channels acoustic device, which was designed and will be installed close to the Baikal Neutrino telescope NT-200+.

1. Introduction

The investigation of a very high energy neutrino is one of the most interesting task for astrophysics. For their search the huge arrays with effective volume much more than cubic kilometer are required. One of the possible ways to study high energy neutrino is to detect acoustic pulses from cascade showers [1]. Absorption length for acoustic waves in water is an order of magnitude larger as minimum compared with Cherenkov light, so acoustic pulses can be detected from very large distance. Since several years, feasibility studies towards acoustic detection of particle cascades are performed in Lake Baikal. The mechanism of an acoustic signal is supposed to be thermo-elastic. The energy deposited by the cascade heats the medium and causes a sudden expansion. The width of the resulting bipolar acoustic signal increases with the diameter of the cascade, its amplitude is proportional to the cascade energy and inversely proportional to the squared diameter of the

cascade [1] The signal from neutrino induced cascades is expected to peak at frequencies of 20 kHz, with calculated amplitudes for a 10 PeV cascade at 400 m distance ranging from a few Pa [2] to a few tens of Pa. [1, 3]. Although such a signal is close to the sensitivity of the human ear, its detection is far from being trivial since it has to be separated from various sources of noise. Surface waves, ship traffic and seismic background dominate the frequency range below sub-kHz range, noise from rainfall and wind as well as thermal noise the higher frequencies. Other effects are movements of the ice layer covering northern waters in winter and spring, formation and implosion of bubbles, or biologically generated noise. Most of these sources have transient character. Detection of a single bipolar signal from a high energy particle interaction requests a good understanding and continuous monitoring of the acoustic noise. Apart from that, acoustic detection of underwater signals can been used for environmental studies [4].

2. A device for detection of acoustic signals from high energy neutrinos

The instrument has 4 hydrophones with bandwidths up to 50 kHz, arranged in a pyramid-like geometry. Signals from the hydrophones are digitized with a sampling rate of about 200 kHz which is equivalent to 5 μs time interval and analyzed online by a computer (NOVA-C400 Series ICP Electronics Inc). The principal scheme of the device is shown in Figure 1. The module is designed for operation together with the Baikal Neutrino
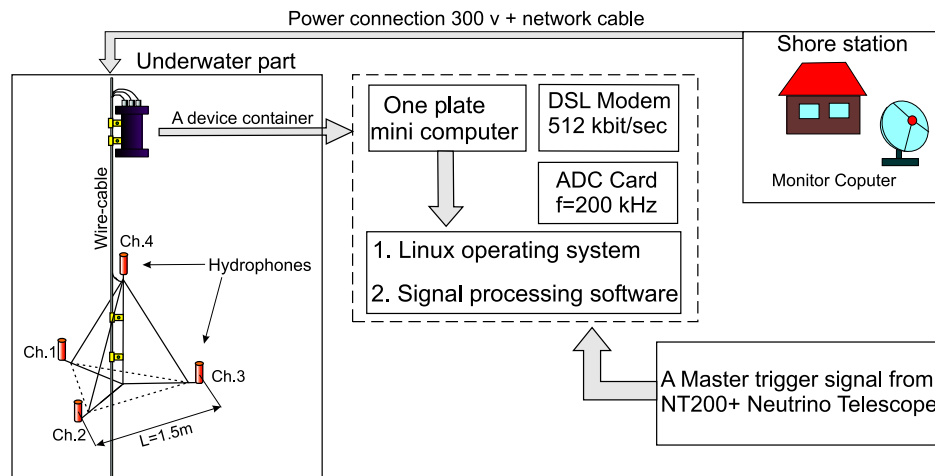

Figure 1. Block scheme of an autonomous hydroacoustic device

Telescope NT-200+. There are 3 regimes of operation of the instrument: **(1)** Transmitting of one second sample of data from all hydrophones to the shore computer centre after trigger signals from NT-200 and outer strings. **(2)** Online search for short acoustic pulses of definite shape, which can be interpreted as signals from quasi local sources. **(3)** An autonomous analysis of acoustic background statistics.

3. A method for separation of acoustic signals from high energy cascades

A number of different acoustic pulses are observed in sea water as well in the Lake Baikal fresh water. An algorithm for separation of acoustic signals with definite shape, which probably were produced by quasi local sources has been developed for this purpose. The algorithm can be devided in to several blocks:

Statistical Analisys Data blocks $A(t_i)$ of N samples in each (where $i = 1 \ldots N$) from the hydrophones enter a statistical routine. At the given stage signal levels $M = \frac{1}{N} \sum_{i=1}^{N} A(t_i)$ and the displaced estimations of a dispersion are calculated:

$$D_{int} = \frac{1}{2m} \sum_{i=1}^{m} (x_i - y_i)^2 \qquad\qquad D_{ext} = \frac{1}{m} \sum_{i=1}^{m} (x_i - M)(y_i - M)$$

Where D_{int} - eigen dispersion, allows to supervise the quality of work of the equipment; $D_{tot} = D_{int} + D_{ext}$ - full dispersion serves for the control of noise of an environment; $x_i = A(t_{2i-1})$, $y_i = A(t_{2i})$ and $N = 2m$. Search of impulses is carried out in quiet intervals of time when D_{tot} is small.

Signal extraction from the time series The program on the basis of the calculated statistical characteristics and the exposed thresholds searches signals which exceed the threshold. The program distinguishes the following properties of signals: coordinates in time series, duration, number of periods, the maximal amplitude and etc. Impulses are classified by these parameters and the information about them is stored in corresponding dynamic arrays.

Filtration procedure Those signals which satisfy to the following condition: $t_{ij} < \delta t_{max}$ will be accepted. Here $t_{max} = L_{ij}/V_s$ is propagation time of a signal from one hydrophone to another, L_{ij} - is the distance between two hydrophones, V_s - sound velocity at the depth where antenna is placed. $\delta = 1.2$ - is an error in estimation of t_{ij}

Direction estimation At the final step we obtain direction angles θ, φ by minimization of a functional

$$S = \sum_{i=1}^{4} [t_i - \tilde{t}_i]^2 / \sigma_{ti}$$

here $t_i = t_0 + \frac{(\vec{r}_i - \vec{r}_0)\vec{n}}{V_s}$ is an expected start point of a signal in a time series. $\tilde{t}_i$ - is the measured start point; $\vec{r}_0$ - position of the center of the pyramid in the chosen system of coordinates; t_0 - is the moment of propagation of a sound wave through a point $\vec{r}_0$; σ_{ti} - a mistake of the measurement of time coordinate t_i; $\vec{n}$ - is a vector which is normal to the acoustic front.

The efficiency of the method was tested on real data, obtained with a 2-channel acoustic module. This algorithm is now used for online data filtering in the 4-channels acoustic device.

4. Results

The combined data taken by the acoustic antenna allow us to estimate vertical and horizontal angles of incidence of acoustic signals. The arrangement of antenna's hydrophones in water is fixed by acoustic transponders shown in Fig 2b. The results of preliminary analysis show, as it was expected, that the most part of impulses come from the upper hemisphere. It means that their sources are on a surface of lake. Insignificant number of impulses come from the bottom hemisphere but with the angles not more than $20°$ to the horizon. These signals also could arise on a surface of lake, but changed their direction due to refraction and reflection. The bipolar signals entering Fig2a have been requested to have a length smaller than $50\mu s$ and an amplitude larger than four standard deviations. These criteria have been chosen in order to select only signals which may simulate signals due to high energy particle cascades.
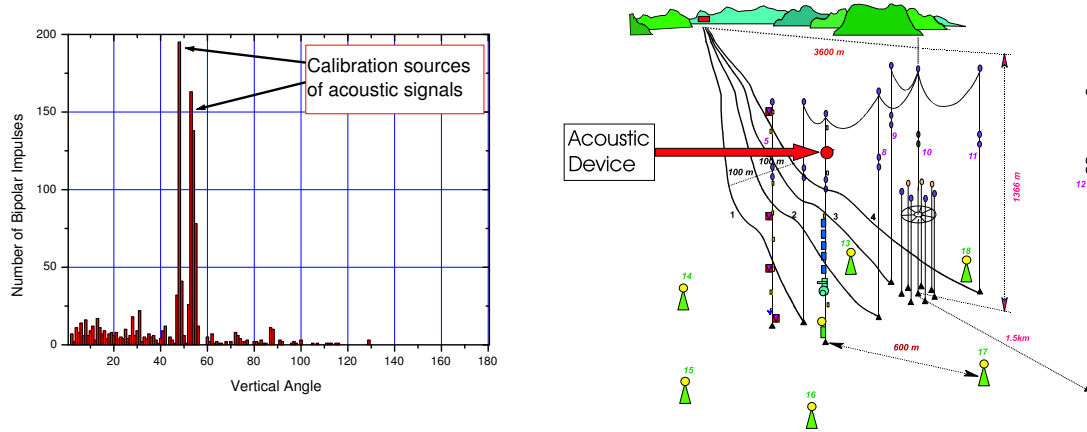
Figure 2. Left (a): The angular distribution of bipolar impulses. Right (b): The location point of the acoustic device. The transponders are marked by numbers 13,14,15,16,17,18

5.   Summary and Outlook

A device for registration and preliminary analysis of acoustic signals has been constructed and tested in-situ in April, 2005. Apparently, for the search of acoustic signals from high energy cascades it is expedient to listen to water volume from top to down, that is to place acoustic antennas on depths of the order of 100 - 200 m. And also one should reduce the sensitivity reception of signals from above, for example, by means of caps from a sound-proof material. The results of the measurement of acoustic noise in Lake Baikal show its complicated structure and strong dependence on different factors. To study it more systematically in 2006, we intend to deploy the device for one year operation together with the Baikal Neutrino Telescope.

6.   Acknowledgements

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