SEARCH FOR NEUTRINOS FROM THE CORE OF THE EARTH WITH THE BAIKAL UNDERWATER DETECTOR NT-36

THE BAIKAL COLLABORATION:

V.A.BALKANOV\textsuperscript{2}, I.A.BELOLAPTIKOV\textsuperscript{7}, L.B.BEZRUkov\textsuperscript{1}, B.A.BORISOVETS\textsuperscript{1}, N.M.BUDNEV\textsuperscript{2}, A.G.CHERNSKY\textsuperscript{2}, I.A.DANILCHENKO\textsuperscript{1}, ZH.-A.M.DJILKIBAEV\textsuperscript{1}, V.I.DOBRYNIN\textsuperscript{2}, G.V.DOMOGATSKY\textsuperscript{1}, A.A.DOROSHENKO\textsuperscript{1}, S.V.FIALKOVSKY\textsuperscript{4}, O.N.GAPONENKO\textsuperscript{2}, A.A.GARUS\textsuperscript{1}, S.B.IGNAT'EV\textsuperscript{3}, A.KARLE\textsuperscript{8}, A.M.KLABUKOV\textsuperscript{1}, A.I.KLIMOV\textsuperscript{6}, S.I.KLIMUSHIN\textsuperscript{1}, A.P.KOSHECHKIN\textsuperscript{1}, V.F.KULEPOV\textsuperscript{4}, L.A.KUZMICHEV\textsuperscript{3}, B.K.LUBSANDORZHIEV\textsuperscript{1}, T.MIKOLAJSKI\textsuperscript{8}, M.B.MILENIN\textsuperscript{4}, R.R.MIRGAZOV\textsuperscript{2}, A.V.MOROZ\textsuperscript{2}, N.I.MOSEIKO\textsuperscript{3}, S.A.NIKIFOROV\textsuperscript{2}, E.A.OSIPOVA\textsuperscript{3}, A.I.PANFILOV\textsuperscript{1}, YU.V.PARFENOV\textsuperscript{2}, A.A.PAVLOV\textsuperscript{2}, D.P.PETUKHOV\textsuperscript{1}, P.G.POKHLI\textsuperscript{1}, P.A.POKOLEV\textsuperscript{2}, M.I.ROZANO\textsuperscript{5}, V.YU.RUBZOV\textsuperscript{2}, I.A.SOKALSKI\textsuperscript{1}, CH.SPIERING\textsuperscript{8}, O.STREICHER\textsuperscript{8}, B.A.TARASHANSKY\textsuperscript{2}, T.THON\textsuperscript{8}, D.B.VOLKOV\textsuperscript{2}, CH.WIEBUSCH\textsuperscript{8}, R.WISCHNEWSKI\textsuperscript{8}

1 - Institute for Nuclear Research, Russian Academy of Sciences (Moscow); 2 - Irkutsk State University (Irkutsk); 3 - Moscow State University (Moscow); 4 - Nizhni Novgorod State Technical University (Nizhni Novgorod); 5 - St.Petersburg State Marine Technical University (St.Petersburg); 6 - Kurchatov Institute (Moscow); 7 - Joint Institute for Nuclear Research (Dubna); 8 - DESY Institute for High Energy Physics (Zeuthen)

The first stage of the Baikal Neutrino Telescope NT-200, the detector NT-36, was operated from 1993 to 95. The data obtained with this small array were analysed to search for vertically upward muons. Apart from neutrinos generated in the atmosphere at the opposite side of the Earth, such muons might be due to neutrinos produced in neutralino annihilations in the center of the Earth. We have selected two clear neutrino candidates. From this, an 90% upper limit of $1.3 \times 10^{-13}$ muons cm$^{-2}$ sec$^{-1}$ in a cone with 15 degree half-aperture around the opposite zenith is obtained for muons due to neutralino annihilation.

1 Introduction

The Baikal Neutrino Telescope NT-200 is being deployed in the Siberian Lake Baikal. In April 1993, its first stage, the detector NT-36 with 36 PMTs at 3 strings, was put into operation. Being slightly modified in March-April, 1994, it took data up to March 1995. There were 6 PMT pairs along each of the 3 strings of NT-36. The two PMTs of a pair are switched in coincidence and represent a recording channel. The orientation of the channels from top (channel #1) to bottom (channel #6) at each string was down-up-down-up-down-up for the period from April, 1993 till March, 1994 and up-down-up-down-up-down for the period from April, 1994 till March, 1995. The array NT-36 was the first underwater detector with the capability to perform full spatial track reconstruction. Atmospheric muon angular distributions experimentally obtained with the standard reconstruction and NT-36 data are well described by MC expectations. However, due to small value of the $S/N$ ratio ($S/N \approx 1/50$, where $S$ is rate of upward neutrino induced events and $N$ is rate of downward atmospheric muons which are misreconstructed as upward events), it is impossible to observe a clear neutrino signal with NT-36 data and the standard reconstruction procedure.
However, for neutrinos coming nearly straight upward, $S/N$ has to be much better - once due to the noise steeply falling with increasing zenith angle, secondly since an up-down rejection may be achieved even in the case of no full track reconstruction, i.e. for events hitting only channels from one or two strings, but applying criteria tailored to this case. Here we discuss this method of neutrino event selection and present results obtained with NT-36 data.

2 Method

In contrast with our standard reconstruction strategy, which suppose $\geq 6$ hits at $\geq 3$ strings (necessary for full spatial reconstruction), we did not perform a reconstruction at all, but applied cuts, which effectively reject all events with the exception of nearly vertically moving upward muons. We selected events triggering $\geq 4$ channels (3 looking down and at least one looking up) exclusively along a single string, since the tracks of the objects searched for have nearly the same vertical orientation as the strings.

We tested the following off-line selection criteria for selected events:

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

$$dA_{i,j}(\text{down} - \text{up}) > 0.3,$$

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

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

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

4. The amplitude asymmetry $dA(\text{down} - \text{down})$ for downward looking hit channels is defined as that of the 3 possible combinations $dA_{i,j}(\text{down} - \text{down}) = (A_i - A_j)/(A_i + A_j) |_{i>j}$ 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:

$$dA(\text{down} - \text{down}) < 0.$$
Figure 1: 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 2: 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 3: 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.
3 Results

The analysis presented here is based on the data taken with NT-36 between April 8, 1994 and March 5, 1995 (212 days lifetime). Upward-going muon candidates were selected from a total of $8.33 \cdot 10^7$ events recorded by the muon-trigger "≥ 3 hit channels". The samples fulfilling trigger conditions 1, 1-2, 1-3 and 1-4 with time cut $dt = 20$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.2).

Fig. 3 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.2, 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. 3a demonstrates that MC describes the data within a factor of 3-4. From fig. 3b one sees that the probability to observe a background event with $dt < 20$ns sec is about 2 percent only. Whereas the shapes of experimental and MC distributions in Fig.3b 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 rough 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, Baksan and MACRO. The effective area of NT-36 for nearly vertical upward going muons fulfilling our separation criteria 1-3 with $dt = 20$ns is $S_{eff} = 50$ 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 $S_{eff} \approx 400 - 800$ m$^2$.

References

1. I.A.Belolaptikov et al., Proc. Third Int. Workshop on Neutrino Telescopes (Venice, 1991) 365; I.A.Belolaptikov et al., Nucl. Phys. B19 (1991) 375; I.A.Belolaptikov et al., Proc. 23rd ICRC vol.4 (Calgary 1993) 573; I.A.Sokalsky and Ch.Spiering (eds.), The Baikal Neutrino Telescope NT-200, BAikal 92-03 (1992); I.A.Belolaptikov et al., Proc. 24rd ICRC vol.1 (Rome 1995) 742; I.A.Belolaptikov et al., Proc. 7th Int. Workshop on Neutrino Telescopes, 373 (Venice, 1996); V.A.Balkanov et al, Proc. XXXIInd Rencontres de Moriond (Les Arcs, 1997), to be published (E-preprint astro-ph/9705017); I.A.Belolaptikov et al., Astroparticle Physics (1997), in press; V.A.Balkanov et al.,Proc. 25rd ICRC HE 4.1.9 (Durban, 1997), to be published.
2. I.A.Belolaptikov et al., Nucl. Phys. B35 (1994) 301.
3. I.A. Belolaptikov et al., *Nucl. Phys.* **B43** (1995) 241.
4. M. Mori et al., *Phys. Rev.* **D48** (1993) 5505.
5. M. Boliev et al., *Nucl. Phys. B (Proc. Suppl.)* **48**, 83 (1996) and talk given at *Int. Workshop on Aspects of Dark Matter in Astro- and Particle Physics* (Heidelberg, 1996), in press.
6. T. Montaruli et al., *Nucl. Phys. B (Proc. Suppl.)* **48**, 87 (1996)