Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008

Vol. 3 (OG part 2), pages 1261–1264

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07 Mérida, México

The Baikal Neutrino Telescope: Status and Plans

K. Antipin[1], V. Aynutdinov[1], V. Balkanov[1], I. Belolaptikov[4], N. Budnev[2], I. Danilchenko[1], G. Domogatsky[1], A. Doroshenko[1], A. Dyachok[2], Zh. Dzhilkibaev[1], S. Fialkovsky[6], O. Gaponenko[1], K. Golubkov[4], O. Gress[2], T. Gress[2], O. Grishin[2], A. Klabukov[1], A. Klimov[8], A. Kochanov[2], K. Konischev[4], A. Koshechkin[1], V. Kulepov[6], L. Kuzmichev[3], E. Middell[5], S. Mikheyev[1], M. Milenin[6], R. Mirgazov[2], E. Osipova[3], Yu. Pavlova[1], G. Pan'kov[2], L. Pan'kov[2], A. Panfilov[1], D. Petukhov[1], E. Pliskovsky[4], P. Pokhil[1], V. Poleshuk[1], E. Popova[3], V. Prosin[3], M. Rosanov[7], V. Rubtzov[2], B. Shaibonov[4], A. Sheifler[1], A. Shirokov[3], Ch. Spiering[5], B. Tarashansky[2], R. Wischnewski[5], I. Yashin[3], V. Zhukov[1]

[1]*Institute for Nuclear Research, Moscow, Russia*
[2]*Irkutsk State University, Irkutsk, Russia*
[3]*Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia*
[4]*Joint Institute for Nuclear Research, Dubna, Russia*
[5]*DESY, Zeuthen, Germany*
[6]*Nizhni Novgorod State Technical University, Nizhni Novgorod, Russia*
[7]*St Petersburg State Marine University, St Petersburg, Russia*
[8]*Kurchatov Institute, Moscow, Russia*

ralf.wischnewski@desy.de

Abstract: The high energy neutrino telescope NT200+ is currently in operation in Lake Baikal. We review the status of the Baikal Neutrino Telescope, and describe recent progress on key components of the next generation kilometer-cube (km3) Lake Baikal detector, like investigation of new large area phototubes, integrated into the telescope.

Introduction

The Baikal Neutrino Telescope is operated in Lake Baikal, Siberia, at a depth of 1.1 km. Deep Baikal water is characterized by an absorption length of $L_{abs}(480\text{nm}) = 20 \div 24$ m, a (geometric) scattering length of $L_s = 30 \div 70$ m and a strongly anisotropic scattering function with a mean cosine of scattering angle $0.85 \div 0.9$ [1], and by a level of bioluminescence and other natural backgrounds that are well below seawater sites.

The first stage telescope, NT200, started full operation in spring 1998 and contained 192 Optical Modules (OMs). The favorable water properties, and a relatively simple and reliable design led to the physics success of this comparably small telescope. Low light scattering allows for a sensitive volume of a few Mtons at PeV shower energy scale, well beyond the geometric detector limits. For a review of the high sensitivity limits on UHE astrophysical neutrino's as well as best so far obtained limits on relativistic magnetic monopoles and other results, see [2]. The upgrade to NT200+ was a logical consequence of the large external sensitive volume, now to be fenced by sparsely instrumented external strings of OMs.

In this paper, we review the current status of the Baikal Neutrino Telescope as of 2007, and the activities towards the km3-scale detector. Results on a prototype device for acoustic neutrino detection, obtained with a stationary setup in 2006/2007, are reported elsewhere in these proceedings [3].

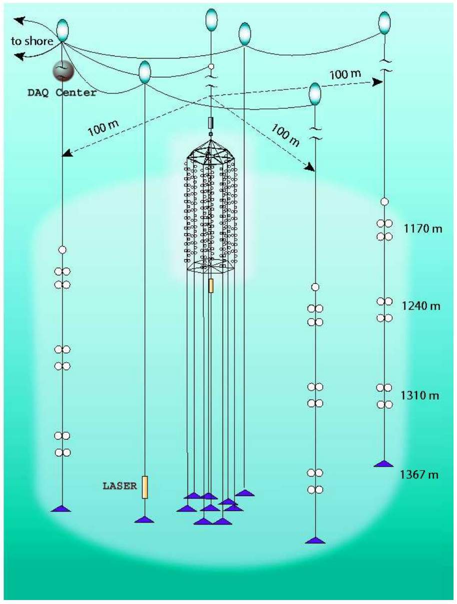

Figure 1: Baikal Telescope NT200+ : old NT200 surrounded by three external long strings; indicated: external laser and underwater DAQ center.

The NT200+ Telescope

The telescope NT200+ [4] was commissioned in April, 2005, and is made of a central part (the old telescope NT200) and three additional external strings, see Fig.1. Underwater electrical cables connect the detector with the shore station.

The first stage telescope configuration NT200 [1] is made of an umbrella-like frame, carrying 8 strings, each with 24 pairwise arranged OMs (see central part of Fig. 1). Each optical module contains a 37-cm diameter photomultiplier (PM) QUASAR-370, developed specially for this project [5]. The two PMs of a pair are switched in local coincidence (a *channel*) in order to suppress background from bioluminescence and PM noise.

The external strings of NT200+ are 200 m long (140 m instrumented) and are placed at 100 m distance from the center of NT200. Each string contains 12 OMs, also pairwise grouped like in NT200. The upper channels are at approximately the same depth as the bottom OMs of NT200, adjacent channel distances are 20, 50, 20, 30 and 20 m from top to bottom (for absolute depths of upper,

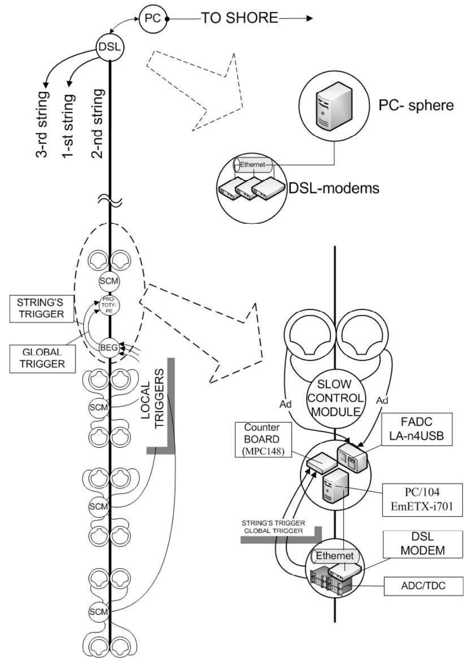

Figure 2: The external string readout/control system, with the FADC prototype for two 13” PMs.

3rd and lower channels see Fig.1). All channels are downlooking, except the lower two on each string (uplooking).

Changes made to NT200+ during the 2007 expedition are described below; in addition a half-string of NT200 was lowered by 85 m, to improve background rejection and lower the shower threshold.

Towards a km3 detector in Lake Baikal

The construction of NT200+ is a first step towards a km3-scale Baikal neutrino telescope. Such a detector could be made of building blocks similar to NT200+, but with NT200 replaced by a single string, still allowing separation of high energy neutrino cascades from background. It will contain a total of 1300-1700 OMs, arranged at 90-100 strings with 12-16 OMs each, and a length of 300-350 m. Interstring distance will be ≈100 m. The effective volume for cascades with energy above 100 TeV is 0.5-0.8 km^3.

The existing NT200+ allows to verify all key elements and design principles of the km3 (Gigaton-

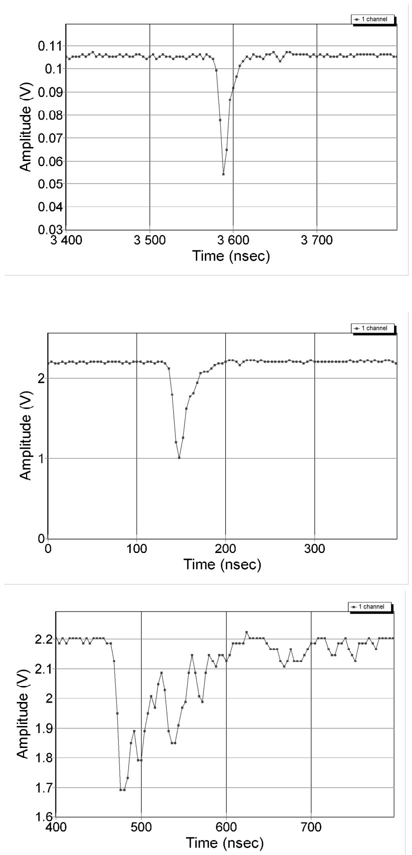

Figure 3: Examples of 13" PM pulses from FADC-prototype, see fig.2. Upper: noise pulse, middle: muon event, lower: laser backward illumination.

Volume) Baikal telescope. Next milestone of the ongoing km3-telescope research and development work (R&D) will be spring 2008: Installation of a "new technology" prototype string, as part of NT200+. This string will consist of 16 optical modules and an FADC based measuring system. Three issues, discussed in the remainder of this paper, are investigated in 2007, and will permit installation of this prototype string: (1) increase of underwater (uw) data transmission bandwidth, (2) in-situ study of FADC PM-pulses, (3) preliminary selection of optimal PM.

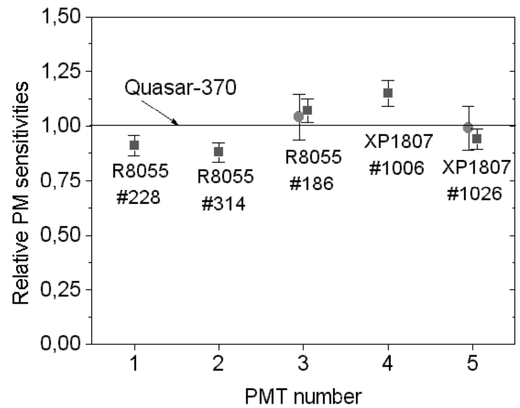

Figure 4: Ratio of effective sensitivity of large area PMs R8055/13" and XP1807/12" to QUASAR-370/14.6". Laboratory (squares), in-situ (dots).

Modernization of data acquisition system

The basic goal of the NT200+ DAQ modernization is a substantial increase of the uw-data rate - to allow for transmission of significant FADC data rates, and also for more complex trigger concepts (e.g. lower thresholds). In a first step, in 2005 a high speed data/control tcp/ip connection between the shore station and the central uw-PCs (data center) had been established (full multiplexing over a single pair of wires, with a hot spare) [6], based on DSL-modems (FlexDSL). In 2007, the communication on the remaining segment uw-PC - string controller was upgraded using the same approach, see fig.2. The basic elements are new string-controllers (handling TDC/ADC-readout) with an ethernet-interface, connected by a DSL-modem to the central uw-DSL unit (3 DSL modems, max. 2 Mbps each), connected by ethernet to the uw-PCs. The significant increase in uw-data rate (string to uw-PC) provided the possibility to operate the new prototype FADC system.

Prototype of a FADC based system

A prototype FADC readout system was installed during the Baikal expedition 2007. It should yield input for the design of the 2008 km3-prototype string (FADC), such as: optimal sampling time window, dynamic range, achievable pulse parameter precisions, algorithms for online data handling, estimation of true bandwidth needs. These data will also be useful to decide about the basic DAQ / Triggering approach for the km3-detector: at this stage, both a complex FADC based, as well as a classical TDC/ADC approach seem feasible.

The FADC prototype is located at the upper part of the 2nd outer string, see Fig.2. It includes two optical modules with up-looking PM R8055, a slow control module and a FADC sphere. The FADC sphere consists of two 250 MSPS FADCs, with USB connection to an embedded PC104 computer emETX-i701, and a counter board MPC148. The standard string trigger (2-fold channel coincidence) is used as FADC trigger. Data are transfered via local ethernet and the DSL-link of the 2nd string. Data analysis from FADC the prototype is in progress. Fig.3 shows examples of FADC pulses for different classes of events. The upper panel gives a 1 photoelectron (p.e.) noise hit, for scale. A muon trigger (multi-p.e.) is given in the middle panel; the lower panel shows an interesting event, due to backward illumination by an intense calibration laser, located $\sim$140 m away. The PM orientation opposite to the calibration laser explains the significant signal duration ($>$ 100 ns), illustrating the light scattering influence on particle detection for large distances.

PM selection for the km3 prototype string

Selection of the optimal PM type for the km3 telescope is a key question of detector design. Assuming similar values for time resolution and linearity range, the basic criteria of PM selection is its effective sensitivity to Cherenkov light, determined as the fraction of registered photons per photon flux unit. It is determined by photocathode area, quantum efficiency, and photoelectron collection efficiency. We compared effective sensitivities of Hamamatsu R8055 (13" photocathode diameter) and XP1807 (12") with Quasar-370 (14.6") [5], which was successfully operated in NT200 over more than 15 years. In laboratory we used blue LEDs (470 nm), located at 150 cm distance from the PM. Underwater measurements are done for 2 R8055 and 2 XP1807, installed permanently as two NT200-channels, which are illuminated by the external laser calibration source [6], located $160 - 180$ m away (see Fig.1). Preliminary results of these effective PM sensitivity measurements are given in Fig.4, and show relatively small deviations. Smaller size (R8055, XP1807) tends to be compensated by larger photocathode sensitivties. In addition, we emphasize the advantage of a spherical shape (as QUASAR-370); we are investigating the angular integrated sensitivity losses due to various deviations from that optimum.

Summary

The Baikal Neutrino Telescope is taking data currently in it's NT200+ configuration - an upgrade of the original NT200 telescope for improved high energy shower sensitivity.

For a km3-detector in Lake Baikal, R&D-activities have been started. The NT200+ detector is, beyond its better physics sensitivity, used as an ideal testbed for critical new components. Modernization of the NT200+ DAQ allowed to install a prototype FADC PM readout. Six large area hemispherical PMs have been integrated into NT200+ (2 Photonis XP1807/12" and 4 Hamamatsu R8055/13"), to facilitate an optimal PM choice. A prototype new technology string will be installed in spring 2008; and a km3-detector Technical Design Report is planned for fall 2008.

This work was supported by the Russian Ministry of Education and Science, the German Ministry of Education and Research and the Russian Fund of Basic Research (grants 05-02-17476, 05-02-16593, 07-02-10013, 07-02-00791), by the Grant of the President of Russia NSh-4580.2006.2 and by NATO-Grant NIG-9811707 (2005).

References

[1] I. Belolaptikov et al., Astropart. Phys. **7** 263 (1997)

[2] K. Antipin et al., The Baikal Neutrino Telescope - Selected Physics Results, *these Proc.*; V. Aynutdinov et al., Astropart. Phys. **25** 140 (2006)

[3] K. Antipin et al., A prototype device for acoustic neutrino detection, *these Proc.*

[4] V. Aynutdinov et al., Nucl.Instr.Methods A **567** 433 (2006)

[5] R. Bagduev et al., Nucl.Instr.Methods A **420** 138 (1999)

[6] V. Aynutdinov et al., Proc. 29th ICRC, V5, p231 astro-ph/0507715