

Baikal neutrino telescope NT200+ : Upgrade of data acquisition and time calibration systems

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The Baikal neutrino telescope NT200, operating since 1998, has been upgraded in spring 2005 to NT200+. This telescope with 3 additional outer strings at 100 m radius from the center encloses a geometric volume of 5 Mtons. We describe the modernized data acquisition and control system, which allows for higher bandwidth, full multiplexing of data and control streams over a single cable to shore, redundant system components and underwater data pre-processing. To calibrate all time offsets between new distant strings and the central telescope on the nsec-scale, a new external laser unit with a powerful N2-Dye laser and a light diffusor, has been developed. This laser is also used to tune reconstruction techniques for pointlike showers with energies from 20 TeV to 10 PeV.

1. Introduction

The deep underwater neutrino telescope NT200+, the successor of the telescope NT200, started operation in April, 2005 [1]. It consists of the old telescope NT200 and three external strings at radial distance of 100 m from the center, see Fig.1. NT200 was operating since 1998, with a number of relevant physics results [1, 2, 3, 4, 5].

The main challenge with the upgrade towards NT200+ was the need for a second, parallel running data acquisition (DAQ) and control system. Since a simple doubling of the system was compatible neither with the number of available cable connections to shore, nor with future upgrades, we decided to significantly modernize the system by introducing for the first time embedded PCs with reliable industrial ethernet infrastructure underwater.

The report describes (1) this DAQ upgrade and (2) the new laser unit, developed to calibrate the time offsets for photosensors at large distances to nsec precision, and to simulate pointlike bright showers up to 10 PeV.

2. Upgrade of Data Acquisition and Control System

The NT200 data acquisition and slow control system has been described in detail in [2, 6]. It is entirely based on custom-made interfaces, including the modems for control and for data lines to shore. Control information is sent via the 300 V power lines to all modules (detector, string and optical module-controllers), while data are collected via a central modem, that reads out the string buffers. For the old NT200 design, both control and data modems are located at shore, and require two separate underwater cables, to avoid interferences due to cross talk. No redundancy on this critical connection was available. At the shore, experiment control was done by DOS-PCs, interfacing to a transputer-farm which performed online event-building and monitoring.

For NT200+, all data and control cable connections of NT200 and the outer strings go through a new central control and readout unit 30 m below surface (upper left unit in Fig.1) [1]. At this place, the synchronization between clocks of NT200 and the external strings (“NT+”) takes place; it allows also for a centralized handling of all communications to shore. Figure 2 sketches the DAQ and control system of NT200+, composed of the two subsystems for NT200 and NT+. Abbreviations have the following meaning: *BED* - detector electronics module, *BEG* - string electronics module, *BSD* - module to measure NT200/NT+ relative trigger times. Trigger formation is by *BED* for NT200 and by *BEGs* for NT+ [1]. The slow control connection to all 8 and 3 strings, respectively, is done via electronic fanout units (“*Relay*”).

For the new system, we kept all front-end units and the internal telescope buses unchanged, and introduced two central “underwater PC spheres” (see Figs.2 and 3). They are housing the experiment data and control modems for NT200 and for the external strings, formerly located at shore. The modems are handled by two embedded Linux PCs in PC/104 standard, which are connecting via tcp/ip sockets to the shore data center PCs for NT200 and NT+. The connection to shore is by a single DSL-Modem at a speed of up to 2Mbit/s. This full multiplexing of all data and control streams (NT200 and NT+) reduces the number of shore wires to two, and allows for a spare connection, which is in “cold standby” mode (activated only in case of failure, or if larger bandwidth would be needed).

Both “underwater PC spheres” are nearly identical, their content is detailed in Fig.3: a single board PC/104 (*PC104*: Advantech-PCM9340), a DSL-modem (*DSL-M*: FlexDSL-PAM-SAN, with hub and router), a managed ethernet switch (*SwRSTP*: RS2-4R, running RSTP protocols for the two-fold redundant ethernet network between the PC spheres), an Ethernet-ComServer (*CSrv*: WUT-58211, for PC-terminal emulation), two media-converters (*Mc*: for coaxial connection to external control units) and the experiment data and control modems (*D-Mod* and *C-Mod*). Both PC spheres are connected via two twisted pair cables (100Base-TX). This underwater system works stable since its first installation in 2004. The old shore transputer farm was replaced by a powerful Linux PC. Using Linux throughout the system allows for easy remote control from home institutions.

Modern off-the-shelf data communication and automatization components were used for all new components and functionalities. This way a modern, reliable system with much improved performance could be built and commissioned with minimal effort. The system is scaleable to modifications of the detector design, and is ready for physics performance improvement by e.g. introduction of more complex trigger strategies (low-level trigger decisions with underwater PCs). We are also considering the possibility to upgrade components like string and detector controllers, to improve physics potential of NT200+.

3. NT200+ Laser

Large volume underwater Cherenkov detectors need calibration of the relative time-offsets between all light-sensors to a precision of a few nsecs, since event reconstruction and classification are based on the precise light arrival times. For NT200+, interstring calibration (and for outer strings also intrastring calibration) is done with

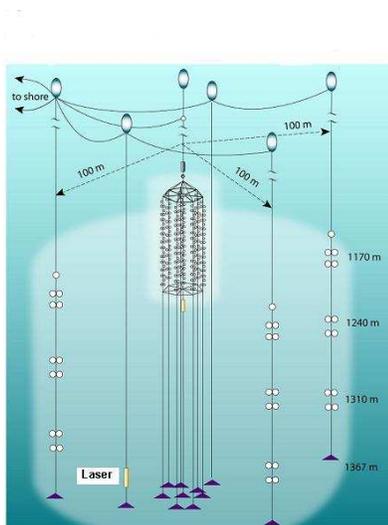


Figure 1. NT200+: the old NT200 telescope surrounded by 3 new strings at 100 m radius. The new NT200+ laser is indicated; central DAQ is located in left upper unit.

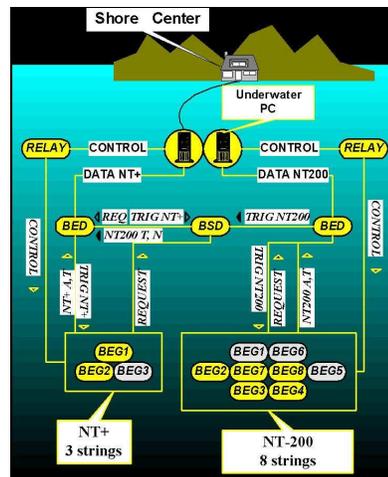


Figure 2. Sketch of data collection and slow control in NT200+: 8-string telescope NT200 and 3 new outer strings (“NT+”), controlled from two underwater PCs (see Fig.3).

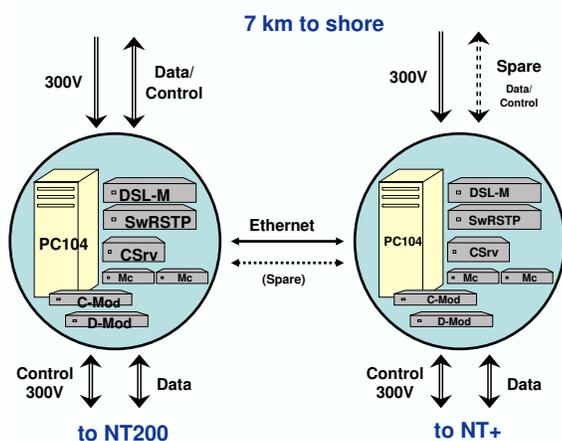


Figure 3. Sketch of the new NT200+ central DAQ/Control spheres with embedded PC104, redundant network components, and the experiment bus interfaces. See also Fig.2.



Figure 4. NT200+ central DAQ electronics in its pressure housings, before deployment. Upper spheres are underwater PC-NT200 and PC-NT+, detailed in Fig.3.

a short and powerful external laser light source with $> 10^{12}$ photons per pulse and nsec-pulse duration, located between two outer strings and close to lake bottom, see Fig.1. This ensures amplitudes of ~ 100 photoelectrons on a few PMTs on each external string and on NT200. High amplitudes minimize uncertainties due to light scattering. If the emission characteristics is also isotropic, the light source can be used to imitate light and amplitude patterns from high energy particle cascades and to verify energy and vertex reconstruction [3].

The NT200+ laser calibration unit is made of a powerful short-pulse Nitrogen laser ($\lambda = 337$ nm) with about $100 \mu\text{J}$ for < 1 nsec pulse duration. It is pumping a Coumarin dye laser at 480 nm, which yields about 10% of the original intensity. After passing through a computer-controlled attenuator disc the light is isotropized by a light diffuser ball, made of a round-bottom flask filled with Silicone Gel (RTV-6156) admixed with hollow micro-glass spheres at about 5%-volume ratio (S32 from 3M, with $\approx 40 \mu\text{m}$ diameter; following an idea developed for SNO [7]). The total loss of this isotropizing sphere is $\approx 25\%$. This guarantees that light output at maximum intensity is well above the design value of $> 10^{12}$ photons/pulse.

All components are mounted into a 1 m-long cylindrical glass pressure housing, which gives isotropic emission for more than the upper hemisphere. The unit is installed at a depth of 1290 m below surface and operated in autonomous mode: after power-on from shore, a series of pulses at various intensities is conducted.

This laser allowed an independent performance check of the key elements of the NT200+ timing system. We performed the relative time synchronization of all news strings and NT200, and find the jitter of this to be less than 3 nsec (see also [1]). The laser unit will be used, varying the total intensity, to calibrate pointlike shower vertex and energy reconstruction algorithms for energies from 20 TeV to 10 PeV.

4. Conclusions

The Baikal neutrino telescope NT200 was upgraded to the much larger detector NT200+ in spring 2005, by adding three distant outer strings. The modernized data acquisition and control system uses for the first time PCs underwater, interconnected by a redundant ethernet network. This allowed to unify the connections from shore station to the underwater site: all data and control lines are multiplexed via a single DSL-line from shore. For all new components and functionalities modern off-the-shelf data communication and automatization components were used, facilitating to build a reliable and scalable system with minimal effort. The new system can be viewed as a test-bed for a larger (km^3) detector project.

A new external laser unit was constructed for calibration of time offsets between optical modules over the large distances in NT200+. This nsec-pulse N2/Dye laser with a light-isotropizer and intensity of $> 10^{12}$ photons/pulse is also used to simulate point-like showers up to 10 PeV. We verified that for the NT200+ detector design, based on electrical (coaxial) cables of up to km's, an overall time synchronizaton of < 3 nsec can be reached.

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