Current status of the BAIKAL-GVD project

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Abstract

We present a status of the Baikal-GVD Project. The objective of this project is a construction of a km3-scale neutrino telescope in the Lake Baikal. As an important milestone, the first GVD engineering array has been deployed and run in April, 2011. Application of a completely new technology gave us an opportunity to study all the basic elements of the future full detector and to finalize the GVD technical design. We discuss the configuration and the design of the engineering array as well as data performance with the preliminary results.

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1. Introduction

The future Gigaton Volume Detector (GVD) will be located in the southern basin of the Lake Baikal close to the NT200+ telescope. The depth of the lake is about 1400 m at this place. The geographical coordinates of the detector site are *51°50′N* and *104°20′E*. The R&D program for the GVD was started in 2006 [1]. The basic achievements were the construction and the deployment of a new technology prototype strings in 2008 – 2010, and then in 2011 the installation of the engineering array with 3 strings [2–5]. The main tasks were numerous in-situ tests of the investigating systems of the future detector. In the article we describe the design of the GVD engineering array. We discuss the preliminary results obtained with the latest installation.

2. GVD configuration

The GVD neutrino telescope will consist of strings of optical modules (OM) to detect the Cherenkov light produced by relativistic charged particles passing through the water. Each string will include a chain of OMs spaced uniformly along the string. A conventional string structure is optimal for a telescope deployment from the natural ice platform of the Lake Baikal. For inter-string communication and connection to shore, strings will be grouped in clusters. Each cluster will be controlled by the cluster DAQ center placed near the water surface.

The optical modules on a string will be grouped into string sections - the lowest-level DAQ units of the detector. A string section is a complete detection unit that forms section trigger and provides data transmission from the OMs to the cluster DAQ center. Technical design of the section electronics [2–5] provides possibility to serve up to 16 optical modules. Each string may include several sections. Optimum number and configuration of the sections depends on the distance between optical modules and the instrumented lengths of the strings. This approach to the GVD design provides a relatively flexible structure, which allows for a rearrangement of the main building blocks (clusters and sections), to adapt to the requirements of new scientific goals, if necessary.

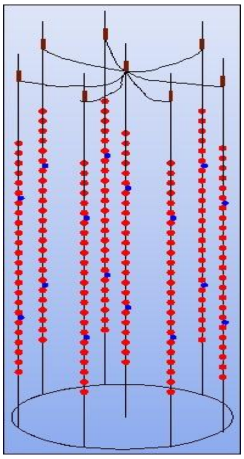

Figure 1. Schematic view of the GVD cluster.

The numbers of string in the GVD cluster, section on the strings, and OMs in the section are subject to optimization. Calculations shows [4, 5] that a neutrino telescope with an effective volume close to one cubic kilometre may be formed by 12 clusters each with 8 strings. Each string includes two sections with 12 OMs, with optical modules spaced uniformly at depths 900 - 1250 m. Fig. 1 shows a schematic view of the 8-string cluster with 2 sections in each string. Distances between OMs are 15 m along the string, distances between the strings and cluster centre are 60 m, distances between different clusters centres are 300 m.

3. GVD engineering array

The operation of the GVD prototype strings in 2008- 2010 [2–4] allows a first assessment of the DAQ performance. On the basis of the experience of the prototype string operation, in April 2011 the engineering array with 3 strings (Cluster-2011) was installed in the Lake Baikal [5]. The sketch of the prototype cluster location is shown in Fig. 2. Each string includes one section with 8 optical modules each housing a large area PMTs with hemispherical photocathode: R7081HQE (see Fig. 3).

The Optical module electronics [2–4] consists of a high voltage power supply unit, a fast two-channel pre-amplifier, and a controller. The PMT gains have been adjusted to about 10^7. Additional signal amplification by a factor ten is provided by the first channel of the pre-amplifier. The second pre-amplifier output is intended for PMT noise monitoring.

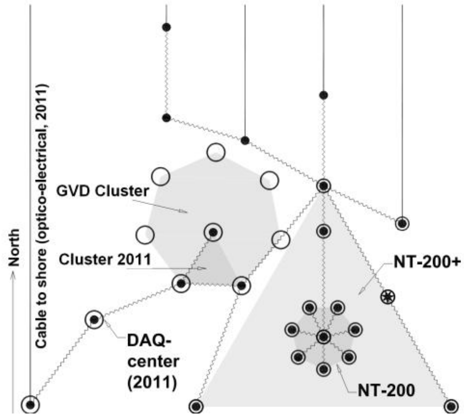

Figure 2. Sketch of the engineering array (GVD cluster-2011), neutrino telescope NT200+, and communication lines locations.

For a time and an amplitude calibration of the measuring channel two LEDs in the optical modules are foreseen. The possibility of independent regulation of both LED light intensities allows to measure the channel response function with error less than 10% up to 1000 p.e. Measurements with LED of a single electron spectrum are used for absolute amplitude calibration. The OM controller is intended for HV regulation and monitoring, for PMT noise measurements, and for the control of the OM calibration procedures. Slow control data to and from the OMs are transferred via an underwater RS-485 bus.

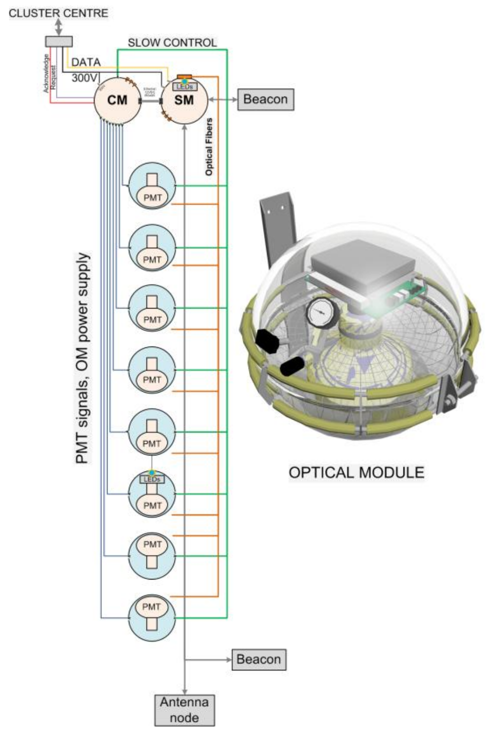

Figure 3. The optical module and schematic view of the string

PMT signals from the OMs are transmitted to the **section central module** (CM) through 90 meters of coaxial cables, where they are digitized by custom-made ADC boards: 12 bit, 200 MHz. ADC memory buffer permits to accumulate waveform data in a programmable time interval (up to 30 ms). The CM consists of three 4-channel ADC boards, an OM slow-control unit, and a Master board. The OM slow-control board provides data communication between OM and a Master board and control of the OM power supply. The Master board forms trigger logic and provides data readout from FADCs and further connection via local Ethernet. To form a local trigger the channel requests L (low threshold ~0.5 p.e.) and H (high threshold ~3 p.e.) are used. There is a programmable coincidence matrix (12H, 12L) with a selectable time window. The basic trigger modes are coincidences of more than N of L-requests or coincidences of L and H requests from any neighbouring OMs.

The cluster DAQ centre is placed near the water surface. It provides the string triggering, power supply control, and communication to shore. The organizations of central and section trigger systems are the same. The string local triggers come to three inputs of the central ADC board. The central Master board works out the global trigger for all strings. The cluster DAQ centre is connected to shore data centre by two optical 1Gbit Ethernet lines. An electro-optical cable of 6 km length with 3 pairs of optical fibers and 3 copper wires was deployed in 2011.

Time calibration is a crucial issue for the neutrino telescope operation. Three methods of time calibration of the string channel are planned:

- Measuring of the time delays of light pulses produced by LED and transmitted to OMs via individual optical fibers with calibrated lengths. A LED flasher is installed in the service module (SM). Calibration error is less than 2 ns [2, 3].
- Measuring of the time delay of the pulses from the additional LED flasher installed in the optical module (see Fig. 3): light pulses pass through the water. Maximum distance for calibration (50 meters along the string) is limited by the flasher light intensity. Preliminary estimation of the error of the time calibration (about 2.5 ns) was obtained using Laser calibration source.
- Direct measurement of the PMT delay. In this mode of operation LED trigger pulse is transmitted to the measuring channel together with the PMT pulse produced by the LED.

The inter-string time calibration was performed by measuring the time intervals between string trigger pulse and the global trigger produced in the DAQ centre. An error of calibration of 5 ns was estimated in a series of special runs as RMS of the time intervals measured using the string triggers from different channels.

To investigate the dynamics of the strings under the influence of water exchange processes in the Lake Baikal, a custom Long-Base-Line (LBL) **Underwater Acoustic Positioning System** (L-UAPS), developed by EvoLogics GmbH (Germany), was deployed at the telescope. The system consisted of a bottom LBL-antenna, comprising three nodes moored at the bottom of the telescope strings, and six acoustic beacons, attached to the optical modules (two beacons per string, see Fig. 3). The L-UAPS's positioning accuracy of 5 mm was experimentally proved for beacons 160 m away from the bottom antenna, thus allowing to track even the smallest movements of the drifting beacons.

Regular measurements were taken in April 2011, the overall number of measurement cycles exceeding 60000. The measurement cycles were launched by an operator at the coastal centre (the minimum duration of a measurement cycle was limited to 30 s). The whole measurement period took the second half of April 2011. Coordinates of the beacons were evaluated under the assumption that the sound velocity is constant, its actual value being measured in April 2011 (observations indicate that seasonal variations of the sound velocity at the location do not exceed 0.1 m/s). Fig. 4 shows the measured beacon coordinates (the spots at altitudes 81 m and 162 m), as well as positions of the bottom LBL-antenna nodes (the points near the triangles that represent string anchors).

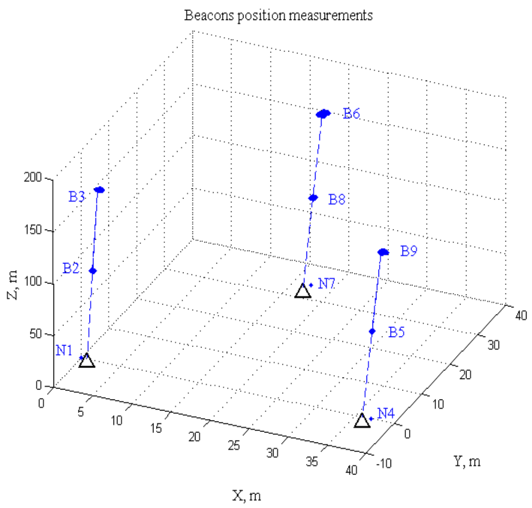

Figure 4. Overlap of the measured beacon positions in local coordinates. The beacons are: B2, B3, B5, B6, B8, B9. The bottom antenna nodes are: N1, N4, N7. Axes X and Y: distances from the local reference point (the node N1) in meters, axis Z: elevation above the bottom antenna plane.

Underwater currents made the beacons deviate from their stable positions, so that the overlaps of measured points demonstrate the areas (the spots), where the beacons movements occurred during the whole measurement period. In Fig. 4, these areas are true to scale. As expected, the areas of beacon deviations at higher elevations above the bottom are wider than the lower ones. The dashed lines drawn from the anchors across the centres of the areas represent the strings slopes, caused by the dominant water current at location.

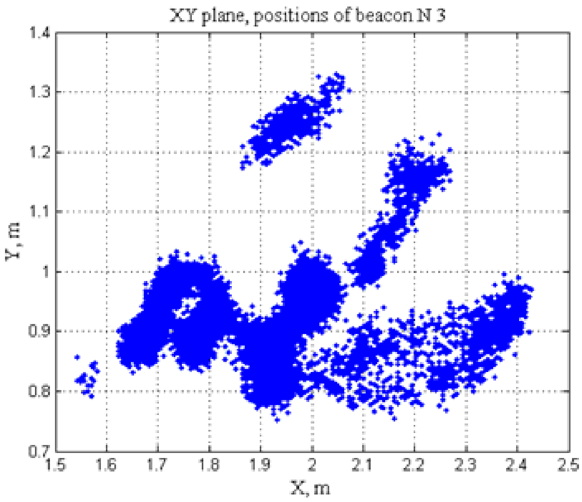

Figure 5. Dynamics of the B3 beacon.

Fig. 5 shows the results of coordinate measurements for beacon B3, located 162 m above the bottom antenna: even in the absence of intensive water flow (in April the lake surface is still covered with ice) the deviations of the beacon from its stable position can reach up to 1 m, whereas the beacon moves at 0.2 m per hour. In general, the range of beacon deviations was 40-70 cm at 81 m, and 80-150 cm at 162 m above the bottom antenna. The beacon deviations were thus proportional to the corresponding elevations above the bottom.

4. Conclusion

An engineering array which comprises all the key elements of the measuring and communication systems of GVD cluster is successfully operating in Lake Baikal since April 2011. The objective of this installation was the check up the trigger approaches, time calibration procedures, new acoustic positioning system, and comparison expected and observed performance of the measuring system. Data analysis is in progress now. Preliminary estimation of inter-string time calibration error is about 5 ns. The precision of the time calibration may be significantly increased using Laser calibration source together with string acoustic positioning system. First full scale GVD string completed in final versions of key elements and electronics is planned to be deployed in the Lake Baikal in 2012.

Acknowledgments

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References

[1] V.M.Aynutdinov, et al., Nucl. Iinstr. and Meth. A 567 (2006) 433.
[2] V.M.Aynutdinov, et al., Nucl. Iinstr. and Meth. A 588 (2008) 99.
[3] A.V.Avrorin, et al., Nucl. Iinstr. and Meth. A 639 (2011) 30.
[4] A.V.Avrorin, et al., Nucl. Iinstr. and Meth. A 626 (2011) 13.
[5] A.V.Avrorin, et al., Nucl. Iinstr. and Meth. A, in press