Present status of the BAIKAL-GVD project development

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Abstract. We present a current status of the Baikal-GVD Project. The objective of this project is a construction of a km$^3$-scale neutrino telescope in the Baikal lake. Set of prototype arrays which were installed and operated during 2009-2011 in Lake Baikal allowed to study all basic elements of the future full detector and to finalize the GVD technical design. We discuss the configuration and the design of the engineering arrays as well as DAQ performance and the preliminary results.

1. Introduction

The Baikal collaboration follows since several years a R&D program for a Gigaton Volume Detector (GVD) in Lake Baikal. GVD will be a kilometer-scale high-energy neutrino observatory [1, 2]. The main scientific goal of GVD is to map the high-energy neutrino sky in the Southern Hemisphere including the region of the galactic centre. Other topics include the indirect search for dark matter by searching for neutrinos produced by WIMP annihilation in the Sun or in the center of the Earth. GVD will also search for exotic particles like magnetic monopoles, super-symmetric Q-balls or nuclearites.

The GVD detector will be located in the southern basin of Lake Baikal close to the NT200+ telescope [3–6]. The geographical coordinates of the detector site are 51°50’N and
104°20'E. Since the slope of the coastal bed relief is rather steep, the telescope can be arranged comparatively nearly to the shore at the distances about of 4-5 km. The depth of the lake is about 1400 m at this place.

The important km³-milestones were the construction and the installation of a prototype strings in 2009 - 2010 [1, 2] and the engineering GVD cluster, comprising 3 strings, in 2011 - 2012. The primary goals of the prototype array installation are investigation and in-situ test of basic elements of the future detector. Below we discuss the preliminary results obtained with the latest installation.

2. GVD design
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 along the string. A conventional string structure is optimal for a telescope deployment from the natural ice platform of 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 [1, 2] 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.

The numbers of strings in the GVD cluster, sections on the strings and OMs in the section are subject to optimization. Calculations show that a neutrino telescope with an effective volume about two cubic kilometres may be formed by 27 clusters (figure 1) each with 8 strings. Each string includes four sections with 12 OMs, with optical modules spaced uniformly at depths 600 - 1300 m. Figure 2 shows a schematic view of the section and optical module. 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.

For the above configuration of GVD the effective area for muons above 1 TeV with an arrival direction reconstruction error of about 0.25 degree (median value) and energy resolution of $\delta \lg E \sim 0.4$ is about 0.3-1.8 km$^2$. The effective volume for cascades above 10 TeV with reconstruction error about 5 degrees (median values) and energy resolution of about (20-35)% is of about 0.4-2.4 km$^3$.

3. GVD engineering array

The operation of the GVD prototype strings in 2008−2010 [1–3] allows a first assessment of the DAQ performance. On the basis of the experience of the prototype detectors operation, in April 2012 the engineering array with 3 strings (Cluster-2012), one of them with 2 sections was installed in the Baikal lake. Two strings contain 6 OMs for each (“short” strings) and 3rd one has 24 optical modules (“long” string) each housing a large area PMTs with hemispherical photocathode: R7081HQE (see figure 2).

The optical module electronics [1, 2] 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.

For a time and an amplitude calibration of the measuring channel two LEDs in the optical modules are foreseen. The OM controller is intended for HV regulation and monitoring, for PMT noise measurements, and for the control of the OM calibration procedures. An example of noise long-term measurements is presented in figure 3 for 3 OMs of the “long” string. Slow control data to and from the OMs are transferred via an underwater RS-485 bus.

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 allows 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.

The cluster DAQ centre is placed near the water surface. It provides the section triggering, power supply control, and communication to the shore. The organizations of central and section trigger systems are the same. The section local triggers (requests) come to three inputs of the central ADC board. The central Master board works out the global trigger for all sections. The cluster DAQ centre is connected to the 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 point for the neutrino telescope operation. Three methods of time calibration of the measuring channel are provided:

- 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 [1, 3].

- Measuring of the time delay of the pulses from the additional LED flasher installed in the optical module (see figure 2): light pulses pass through the water. Maximum distance for calibration (about 60 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 signal delay. LED trigger signal is transmitted to the measuring channel together with the PMT signal induced by the LED flash in this method.

The inter-string time calibration was performed by measuring the time interval between section trigger request 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 obtain coordinates of each OM during data taken

Figure 3. Counting rates of the optical modules in 2012 (Empty gaps mean that monitoring was stopped).

Figure 4. Measured distance between top and bottom beacons of “long” string vs time.

period a custom Long-Base-Line (LBL) Underwater Acoustic Positioning System (L-UAPS)[7], developed by EvoLogics GmbH (Germany), was deployed at the detector. The system consists of a bottom LBL-antenna, comprising four nodes moored at the bottom of the telescope strings, and six acoustic beacons, attached to the strings (one beacon for each of “short” strings and three ones for “long” string). Measurements performed since the Cluster-2012 starts to operate. Figure 4 shows a distance monitoring between the bottom and top beacons of the “long” string in April 2012.

4. Conclusion
The primary goal of the Baikal Project is the construction of a kilometer-scale high-energy neutrino observatory: the Gigaton Volume Detector (GVD) in Lake Baikal. All basic elements of the GVD were investigated and tested in-situ with GVD engineering array in 2011-2012. The objective of these installations was the check up the trigger approaches, time calibration procedures, acoustic positioning system and comparison of expected and observed performance of the measuring system. Data analysis is in progress now.

Three full scale GVD strings with two sections each in final version of key elements and electronics are planned to be installed in Lake Baikal in 2013.

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