Baikal-GVD

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Abstract. We present the status of the Gigaton Volume Detector in Lake Baikal (Baikal-GVD) designed for the detection of high energy neutrinos of astrophysical origin. The telescope consists of functionally independent clusters, sub-arrays of optical modules (OMs), which are connected to shore by individual electro-optical cables. During 2015 the GVD demonstration cluster, comprising 192 OMs, has been successfully operated in Lake Baikal. In 2016 this array was upgraded to baseline configuration of GVD cluster with 288 OMs arranged on eight vertical strings. Thus the instrumented water volume has been increased up to about 5.9 Mtons. The array was commissioned in early April 2016 and takes data since then. We describe the configuration and design of the 2016 array. Preliminary results obtained with data recorded in 2015 are also discussed.

1 Introduction

The deep underwater neutrino telescope, Baikal Gigaton Volume Detector (GVD), is currently under construction in the southern basin of Lake Baikal [1]. The underwater depth is about 1360 m at a distance of more than three kilometres away from the shore. At the detector site the combination of hydrological, hydro-physical, and landscape factors were studied and found to be optimal for the deployment and the operation of the neutrino telescope [1]. The Baikal-GVD neutrino experiment is

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targeting on high energy neutrinos that are expected from astrophysical sources including those visible in gamma-rays and from directions of accumulation sites of dark matter (DM) as the Galactic Centre or the Sun [2]. The Baikal-GVD is composed by a three-dimensional lattice of optical modules. These are photomultiplier tubes housed in transparent pressure resistent spheres, arranged in vertical load-carrying cables to form strings. The telescope has a modular structure and consists of functionally independent clusters, sub-arrays of 8 strings of OMs, which are connected to shore by individual electro-optical cables. The GVD demonstration cluster named "Dubna" has been deployed in 2015 in Lake Baikal. The array operation time spans 213 days from April 2015 till February 2016. In April 2016 the "Dubna" array was upgraded to the baseline configuration of the GVD-cluster which comprises 288 optical modules (OMs) attached to 8 strings at a depth ranging from 750 m to 1275 m. Here we describe the configuration and the basic parameters of the array deployed in 2016 in Lake Baikal and discuss the first preliminary results obtained from the data collected with the "Dubna" array in 2015.

2 Baikal-GVD cluster

The first configuration of the Baikal-GVD cluster was deployed in April 2015. It consisted of eight 345 m long strings of optical modules [4] spaced by 40 m (192 OMs in total). Each string comprises two sections of OMs. Each section consists of 12 optical modules and a central electronics module (CeM). One Hamamatsu R7081-100 photomultiplier tube with a 10-inch hemispherical photocathode and quantum efficiency up to 35% is used as light sensor of OM. The signals arriving from the OMs are digitized in ADC boards located at the CeM (12 channels with a sampling frequency of 200 MHz). When digitized, the signals from the ADC are transferred into a programmable gate array (FPGA). The FPGA memory buffer allows acquisition of the input signal waveform in a time interval of 5 μs. A FPGA logic has been configured to generate a trigger, read data from the ADC channels, and transmit them through Ethernet to the data acquisition center. The highest rate of data transfer from each section has been obtained with SHDSL modems — up to 10 Mbit/s. To reach the required event registration detector rate (100 Hz or higher) to be attained, the data arriving from the sections are processed in real time mode. Details on the data acquisition, the basic controls, the methods of calibrations and on the hardware and software triggers can be found in [3]. The cluster was operated from April 2015 to February 2016. About 1.6×10^9 events have been recorded during the cluster operation. The estimated operation efficiency was of about 72%. The first preliminary results obtained with the "Dubna" cluster are presented in section 3.

In winter expedition 2016 the cluster was extended with an additional a third top section at each string. Schematic view of cluster is shown in Fig. 1 (left). The upgraded cluster comprises 288 OMs operated at the active depths of 750–1275 m, while 7 side strings are distant at radius of 60 m from the central one, according to the baseline configuration of GVD cluster. Instrumented volume of cluster encloses 5.9 Megatons. The cumulative number of section records generated by the array in the period of April 10 – June 23 of 2016 is shown in Fig. 1 (right).

Basic trigger mode requires coincidences of any neighbouring OMs within a section (thresholds 1.5 p.e. and 4.5 p.e., trigger rate 60 -110 Hz). About 3×10^8 of triggered events have been recorded. The estimated operation efficiency was about 75%.

3 "Dubna" array: operation and preliminary results

The "Dubna" array has the potential to detect astrophysical neutrinos with the flux values measured by IceCube [5]. The search for high-energy neutrinos with the "Dubna" array is based on the selection of cascade events generated by neutrino interactions in the sensitive volume of the array. After

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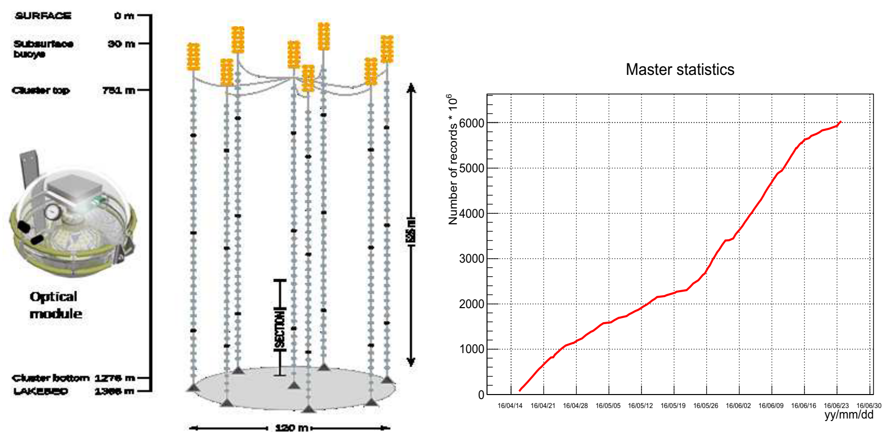

Figure 1. Left: Schematic drawing of the "Dubna" cluster operated in 2016. Right: Integrated number of events recorded by the cluster in period of April 10–June 23 of 2016.

the reconstruction of the cascade vertex, the energy and the direction and after applying quality cuts, events with a final multiplicity of hit OMs N_{hit} >20 are selected as high-energy neutrino events. The accuracy of the cascade energy reconstruction is about 30%. The accuracy of the direction reconstruction is about 4° (median value) and the vertex resolution is of about 2 m [2]. For the IceCube astrophysical fluxes following the power laws of E^{-2} and $E^{-2.46}$ and for the single-flavour normalizations of $1.2 \cdot 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1} and $4.1 \cdot 10^{-6}$ GeV cm^{-2} s^{-1} sr^{-1} respectively [5–7] the expected number of events as function of the neutrino energy is reported in Fig. 2 (left panel). In the same plot the expected number events from the atmopheric neutrino flux is also reported. The expected number of background events from atmospheric neutrinos is strongly suppressed for energies higher than 100 TeV. About 0.5 and 0.4 cascade events per year with energies above 100 TeV and hit multiplicities N_{hit} >20 from astrophysical fluxes with E^{-2} and $E^{-2.46}$ spectra respectively and 0.08 background events from atmospheric neutrinos are expected.

For the search of high energy neutrinos of astrophysical origin the data collected from 24 October till 17 December 2015 has been used. A data sample of 4.4×10^8 triggered events has been recorded by the array, which corresponds to 41.64 days of live time. The causality cuts and requirement of N_{hit} >3, where N_{hit} is the hit OM multiplicity, reduce the number of events for following analysis at about 1.8×10^7 events.

After applying an iterative procedure of cascade vertex reconstruction followed by the rejection of hits contradicting the cascade hypothesis on each iteration stage, 12931 events survived as cascade-like events. Finally, after applying the cascade energy reconstruction and the event quality cuts, 1192 cascade-like events with energy above 100 TeV are selected. The hit OMs multiplicity distribution of these events is shown (top, black) in Fig. 2 (centre), as well as the expected event distribution (bottom, red) from the astrophysical flux with $E^{-2.46}$ spectrum and IceCube normalization. All events, but one, have hit OMs multiplicities less than 10 OMs and are consistent with the expected background events from atmospheric muons. The event with 17 hit OMs was reconstructed as downward moving cascade event with a zenith angle of 59° and an energy of 158 TeV energy. The neutrino telescope sensitivity to DM annihilation inside distant sources is estimated by the expected number of signal events in the search angular window ψ_0 for the life time T and astrophysical factor J of modeled DM profile, as follow

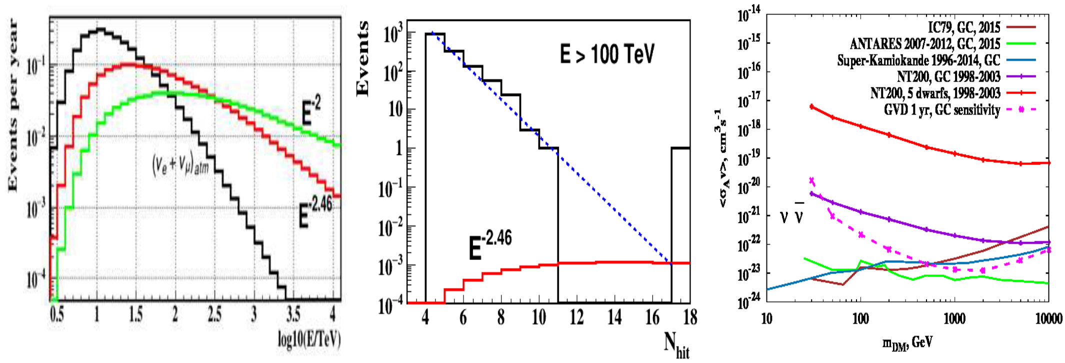

Figure 2. Left: Energy distributions of events expected for one year observation from astrophysical fluxes with E^{-2} and $E^{-2.46}$ spectra and IceCube normalization, and from atmospheric neutrinos (see text). Centre: Hit OMs multiplicity distribution of cascade-like events with energies above 100 TeV (histogram, see text). Right: Sensitivity of the GVD to neutrino-channel of the DM annihilations in the GC in comparison with the NT200 limits towards the GC direction and limits of joint dSphs analysis.

$$N(\psi_0) = T\frac{\langle\sigma_A v\rangle R_0 \rho^2_{local}}{8\pi m^2_{DM}} J_{\Delta\Omega} \int dE \cdot S(E)\frac{dN_\nu}{dE}, \quad (1)$$

where $S(E)$ is neutrino the effective area of the telescope averaged over the neutrino energy spectrum $\frac{dN_\nu}{dE}$ in the given annihilation channel. Here we present the GVD sensitivity based on the simulated muon-like events in the high energy neutrino interactions. Comparison of the Baikal results in most energetic $\nu\bar{\nu}$ channel of the DM annihilation is presented in Fig. 2 (right). The 90% c.l. sensitivity to DM annihilation in the Galactic Center (GC) as a function of DM mass for the GVD of 12 clusters [8] (red line) and the upper limits for the Baikal NT200 telescope [9] (blue line) are shown. In Fig. 2 (right) is also shown the new combined upper limit, performed with a likelihood analysis, for 5 dwarf spheroidal galaxies (dSphs),which have been chosen among 22 dwarfs with the NT200 data sample [10]. By 2020, GVD will consist of 2304 cumulative number of OMs on 8 clusters with a total volume of about 0.4 km^3, that aims at the discovery of non-atmospheric neutrinos.

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