PROCEEDINGS OF SCIENCE

Baikal-GVD neutrino telescope: recent status

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The current status after the winter 2023 deployment of the Baikal-GVD neutrino telescope is reviewed. The detector consists of 3 456 optical modules installed on 96 vertical strings. Data collected in 2018-2022 by Baikal-GVD manifest the presence of cosmic neutrino flux in high-energy cascade events consistent with observations by the IceCube neutrino telescope.

XVIII International Conference on Topics in Astroparticle and Underground Physics (TAUP2023)
28.08-01.09.2023
University of Vienna

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PoS(TAUP2023)343

PoS(TAUP2023)343

1. Introduction

The construction of large-volume neutrino telescopes, installed in ice or under water in both the Southern Hemisphere (IceCube) and the Northern Hemisphere (Baikal-GVD, ANTARES, and KM3NeT), has enabled the registration of high-energy neutrinos of astrophysical origin. A report on a diffuse neutrino flux has been given by the IceCube neutrino observatory [1]. Recently, first hints of sources established with radio, optical, x-ray and gamma-astronomy observations to high-energy neutrino have been reported [2, 3]. In this contribution, current progress on the construction of the Baikal-GVD neutrino telescope is presented. Developments in cascade-like event analyses are reviewed. Results of the diffuse neutrino flux obtained in cascade channel are shown.

2. Recent progress in Baikal-GVD construction

The Baikal-GVD neutrino observatory is a water Cherenkov neutrino telescope under construction in the southern part of Lake Baikal where lakebed is nearly flat at a constant depth of 1 366 m. The neutrino events registered in the detector are divided into two classes: tracks and cascades. Events resulting from charged current (CC) interactions of muon (anti-)neutrinos posses a track-like topology, while the CC interactions of the other neutrino flavors and neutral current (NC) interactions of all flavors typically mimic nearly point-like events. The layout of the Baikal-GVD has been aimed for optimal measurement of astrophysical neutrinos in the TeV-PeV energy range. The Baikal-GVD neutrino observatory is a 3-dimensional array of photo-sensitive units - optical modules (OMs). A 10-inch high quantum efficiency Hamamatsu R7081-100 photomultiplier tube (PMT) oriented downwards, as well as control electronics, is housed in each OM. 36 OMs are vertically arranged with 15 m spacing in 3 sections on a load-carrying cable forming a string. A section consisting of 12 OMs and a control module (CM) is a basic element of the detector readout. The CM controls the OM status, converts the analog signals of the PMT into the digital form by

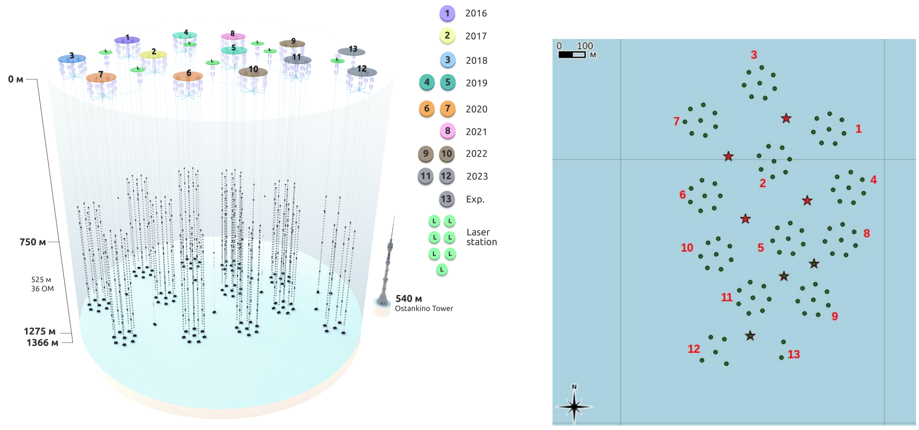

Figure 1: Left panel: Schematic view of the Baikal-GVD detector after the winter 2023 deployment. The legend shows annual progress in the deployment. Right panel: Schematic top view of the Baikal-GVD detector after the winter 2023 deployment.

a 12-channel ADC, and forms local triggers of the section [4]. 7 peripheral strings surrounding a central one at a 60 m distance form a cluster - a fully functionally independent unit of the detector. The clusters are placed in a hexagonal pattern, with a distance of ~300 m between the cluster centers (see Fig.(1) left panel). Recently, 3 456 OMs are deployed in total and attached to 96 strings. There are 3 the so-called inter-cluster strings (ICS) among these 96 strings deployed in the detector. The first inter-cluster string (ICS) was installed in 2022 and two more were commissioned in 2023. Except 36 OMs arranged to 3 sections, these ICS are equipped with high-power pulsed lasers (red and green stars in Fig.(1) right panel) and placed in the middle of three surrounding clusters. MC simulation shows that the installation of the ICSs is the most effective way to increase the telescope sensitivity of cascade-like neutrino events, i.e. for cascades energy higher than 100 TeV the number of events increased by 24% (distance between clusters being 250 m) [5].

3. Cascade events analysis in Baikal-GVD

A reliable reconstruction of high-energy neutrino induced cascades is crucial in the search for high-energy astrophysical neutrinos. This was achieved by setting cuts on quality variables obtained through Monte Carlo simulations, based on the data sample accumulated in 2016 – 2017. For example, pulses with a charge (Q) higher than 1.5 p.e. are selected, and events with a large multiplicity of hits on at least three strings $N_{hit} > 7$ are considered. High-energy cascade reconstruction (energy, direction, and vertex) is a two step process [6]. Firstly, cascade vertex coordinates are found by minimization of χ_t^2 function with use of time information of pulses on OMs. The obtained vertex poistion is an input for the second step in which cascade energy and direction is achieved by use of the maximum-likelihood method. The precision of estimated energy and direction of the cascade varies typically between 10% – 30% and 2° – 4°, respectively. A search for astrophysical neutrinos in data colected by Baikal-GVD in 2018-2021 was

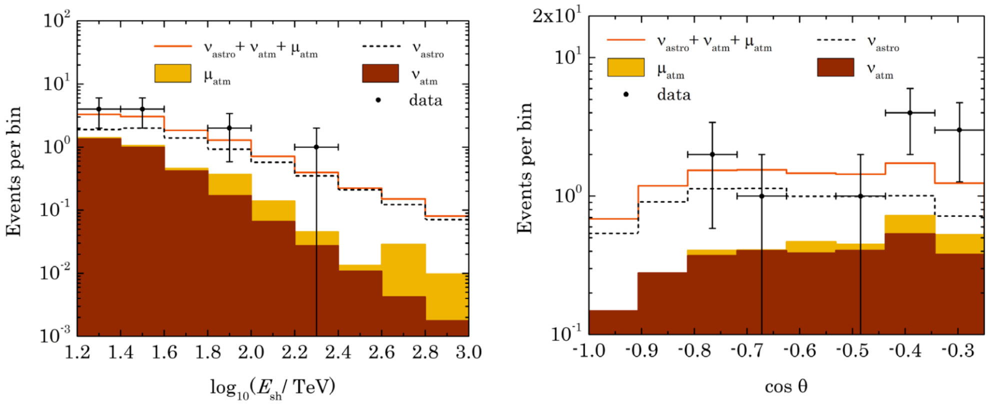

Figure 2: Left panel: Reconstructed cascade energy distributions of the dataset consisting of 11 selected events. The best-fit distribution of astrophysical neutrinos (dashed line), expected distributions from atmospheric muons (yellow) and atmospheric neutrinos (brown) and the sum of the expected signal and background distributions (orange line) are also shown. The atmospheric background histograms are stacked (filled colors). Right panel: The same for the reconstructed zenith angle distribution.

PoS(TAUP2023)343

performed by use of analysis described in more detail in the paper [6]. Cuts on OM hit multiplicity $N_{hit} > 11$, reconstructed energy $E_{sh} > 15$ TeV, and reconstructed zenith angle $\cos\theta <$ -0.25 has been applied additionally. The result is a set of 11 high-energy cascade events which are considered as astrophysical neutrino candidates. The energy and zenith angle distributions of these 11 events with MC simulation distributions are shown in Fig.(2). Assuming the single power law model

$$\Phi^{\nu+\bar{\nu}}_{astro} = 3 \times 10^{-18} \Phi_0 \left(\frac{E_\nu}{E_0} \right)^{-\gamma_{astro}} \; [\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}] \tag{1}$$

for the diffuse neutrino flux, main characterization is obtained from this dataset. Here, $E_0 = 100$ TeV, Φ_0 is one neutrino flavor flux normalization constant, and γ_{astro} represents a spectral index. By use of a binned likelihood approach the best fit parameters are found to be $\Phi_0 = 3.04$ and $\gamma_{astro} = 2.58$ [7]. The background-only hypothesis is excluded at the level of 3.05σ. The results on cosmic neutrino diffuse flux measurements obtained by the Baikal-GVD neutrino telescope are consistent with measurements of IceCube and ANTARES (all-neutrino flavor) experiments.

4. Conclusion

A progress in the construction of the Baikal-GVD neutrino observatory that recently comprises 3 456 optical modules on 96 vertical strings has been reported. In addition to the first special inter-cluster string installed in 2022, there were two more such strings installed in 2023. Based on their positive operation experience, there is a plan to equip all Baikal-GVD clusters with the inter-cluster strings in the future. A set of 11 events has been selected as astrophysical neutrino candidates. These data were used to fit the astrophysical power law model. The measured values of spectral index of $\gamma_{astro} = 2.58$ and the flux normalization $\Phi_0 = 3.04$ for each neutrino flavor at $E_0 = 100$ TeV are in good agreement with the previous fits derived in various analyses of the IceCube data and ANTARES data. A selected sample of high-energy cascades is consistent with the astrophysical neutrino flux at the level of 3.05 σ.

5. Acknowledgements

The author (R. Dvornický) is supported by Slovak Research and Development Agency (Contract No. APVV-22-0413).

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PoS(TAUP2023)343