PROCEEDINGS OF SCIENCE

Reconstruction of double cascades in the Baikal-GVD neutrino telescope

E. Eckerová[a,b,*] **on behalf of the Baikal-GVD Collaboration**

[a] *Comenius University, 81499 Bratislava, Slovakia*

[b] *Czech Technical University in Prague, Institute of Experimental and Applied Physics, 11000 Prague, Czech Republic*

E-mail: eliska.eckerova@fmph.uniba.sk

Baikal Gigaton Volume Detector is a cubic kilometer scale water Cherenkov neutrino telescope aimed at registration of astrophysical neutrinos. Detection of the double cascade signature events is of particular interest. A description of the double cascade reconstruction technique is presented. The evaluation of precision of this algorithm is shown in this contribution.

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

*Speaker

PoS(TAUP2023)258

1. Introduction

The Baikal Gigaton Volume Detector (Baikal-GVD) is an underwater neutrino telescope currently under construction in the southern part of Lake Baikal [1]. The detector is a three-dimensional array of photomultiplier tubes and its purpose is to detect Cherenkov radiation emitted by the charged particles that originate in interactions of high-energy astrophysical neutrinos. The basic detection unit of Baikal-GVD – optical module (OM) – is a 10" photomultiplier tube enclosed in a pressure resistant glass sphere with a diameter of 42 cm (see Fig. 1 (left panel)). 36 OMs with equal spacing of 15 meters are installed on a vertical string. After winter expedition in year 2023, the Baikal-GVD detector array consists of 3456 OMs installed on 96 strings (see Fig. 1 (right panel)).

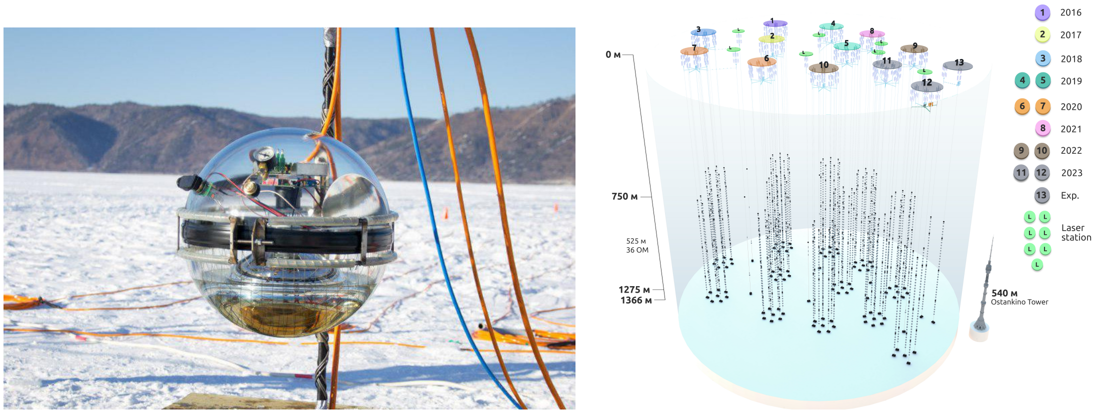

Figure 1: Left panel: Optical module of the Baikal-GVD neutrino telescope. Right panel: Structure of Baikal-GVD in 2023. The yearly progression of detector installation is shown in the legend.

In charged current interaction of tau neutrino, τ-lepton is produced. In case of τ-lepton decay into electron or hadrons a double cascade signature of Cherenkov light topology is created. The importance of tau neutrino detection arises from the fact that production rate of tau neutrinos in the atmosphere is negligible [2]. Therefore, if tau neutrino interaction is observed, the probability of astrophysical origin of this neutrino is very high. In this contribution, a description of reconstruction technique for double cascade events is given. An evaluation of the performance of the algorithm is presented.

2. Double cascade reconstruction algorithm

The purpose of the double cascade reconstruction algorithm is to estimate parameters of double cascade events – positions and times of the vertices of both cascades, direction of the event and cascade energies. The reconstruction algorithm consists of four principal steps:

1. Hit selection
2. Hit sorting
3. Position and time reconstruction
4. Energy reconstruction

The main goal of the first step of the algorithm is to suppress noise hits and thus select signal hits from cascades. The following step – Hit sorting is responsible for categorizing hits to two subsets – one corresponding to ν_τ cascade and the second one that belongs to τ decay cascade. Subset of hits that is chosen first is labeled as cascade A, the other one is tagged as cascade B. In the third step of the algorithm final estimation of the positions and times of the cascade vertices and direction of the double cascade event (vector connecting two cascade vertices) is obtained, by minimization of the χ^2 function using the OM hit arrival times. The fourth step is to estimate energies of both cascades. The energy reconstruction includes a prefit and a maximum likelihood fit, both relaying on the measured OM hit charges. Simplified flowchart of the reconstruction algorithm is shown in Fig. 2.

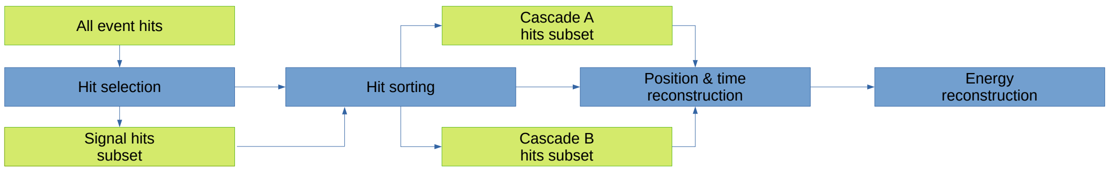

Figure 2: Flowchart of the double cascade reconstruction algorithm.

3. Algorithm performance

By means of MC simulations of ν_τ double cascade events, precision of the double cascade reconstruction algorithm was evaluated. The expected astrophysical neutrino flux used in these simulations is given as $\phi(E) = 2.41 \cdot 10^{-5}(E/\mathrm{GeV})^{-2.58}$ $[\mathrm{GeV}^{-1}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{cm}^{-2}]$ [3]. Evaluations of the algorithm precision were performed with a subset of all MC generated ν_τ double cascade events – double cascade-like events. The main selection criteria used are distance between cascade vertices larger than 10 m and energy of ν_τ higher than 100 TeV.

The obtained precision of reconstruction of cascade vertex positions is summarized in Tab. 1. The mean and median values of distributions showing difference between reconstructed and simulated values of some particular parameters of double cascade events are given.

Table 1: The precision of reconstruction of the double cascade event parameters. The mean and median values of distributions of differences between simulated x_{sim} and reconstructed x_{reco} values of particular parameters of double cascade events are presented.

Double cascade parameter	$\lvert x_{sim} - x_{reco}\rvert$ mean	median
cascade A position [m]	2.76	2.21
cascade B position [m]	4.11	2.44
distance between vertices [m]	1.96	0.71

Angular resolution in the reconstruction of double cascade events with respect to the simulated distance between cascade vertices is shown in Fig. 3 (left panel). The green line represents the median of the mismatch angle distribution. The green belt indicates the 68% containment region.

In Fig. 3 (right panel), the precision of energy reconstruction is illustrated. The two-dimensional distribution of fractional errors in energy reconstruction – ratios of reconstructed to simulated energy of cascade A and B is shown. The fit of this distribution with two-dimensional Gaussian function $f(x, y) \approx e^{-(x-\mu_A)^2/(2\sigma_A^2)-(y-\mu_B)^2/(2\sigma_B^2)}$ was performed and the values of the parameters obtained from the fit are $\mu_A = 1.02$, $\mu_B = 1.04$, $\sigma_A = 0.18$, and $\sigma_B = 0.24$.

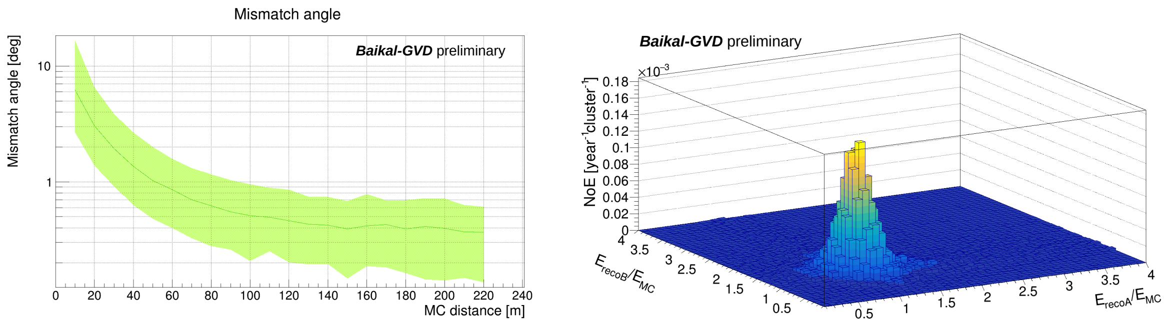

Figure 3: Left panel: Angular resolution in the reconstruction of ν_τ double cascade events as a function of true distance between cascade vertices. The median value is displayed as a green line and a 68% containment region is represented by the green belt. Right panel: Fractional errors in energy reconstruction of double cascade events.

4. Conclusion

Development of the double cascade reconstruction technique in the Baikal-GVD was presented in this contribution. Particular steps of the recent version of the algorithm were described. An estimation of the precision of the reconstruction of the double cascade event parameters such as cascade vertex positions, distance between the cascade vertices, energies of the cascades, and direction of the double cascade event was given. An extension of the double cascade reconstruction technique for events with shorter distance between cascade vertices, less than 10 m, is in development.

5. Acknowledgements

The author (E. Eckerová) is supported by Slovak Research and Development Agency (Contract No. APVV-22-0413). We acknowledge support by the MEYS of the Czech Republic (Contract Number LM2023063).

References

[1] Baikal-GVD Collaboration: I.A. Belolaptikov et al., *Neutrino Telescope in Lake Baikal: Present and Nearest Future,* PoS ICRC2021 (2021), 002, doi: 10.22323/1.395.0002, arXiv:2109.14344 [astro-ph.HE].

[2] A. Palladino et al., *The importance of observing astrophysical tau neutrinos,* J. Cosmol. Astropart. P. 8 (2018).

[3] Baikal-GVD Collaboration: V.A. Allakhverdyan et al., *Diffuse neutrino flux measurements with the Baikal-GVD neutrino telescope,* Phys. Rev. D 107.042005 (2023), doi:10.1103/PhysRevD.107.042005.