XIV Черенковские чтения
Новые методы в экспериментальной ядерной физике и физике частиц
Москва, ФИАН, 20 апреля 2021 г.

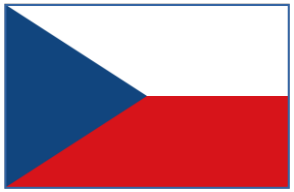
Baikal-GVD neutrino telescope

Vladimir Aynutdinov for the Baikal Collaboration

20 April 2021

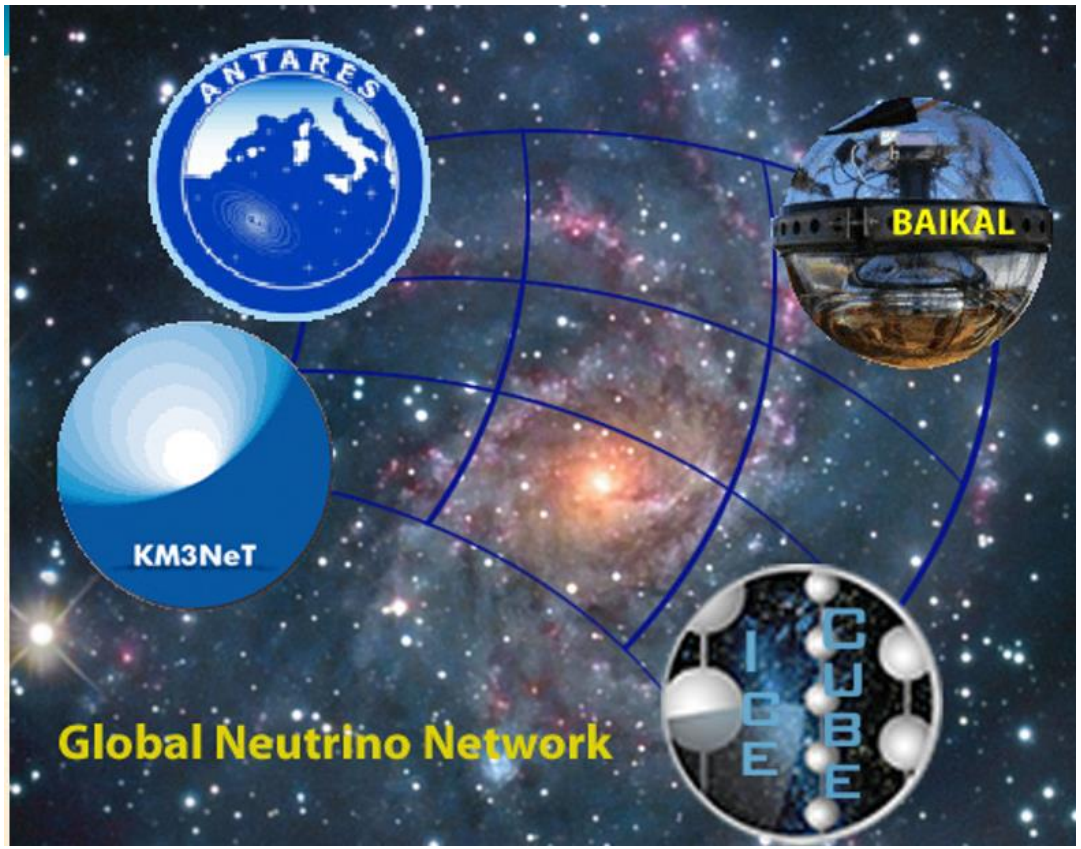
Baikal-GVD collaboration

10 organisations from 5 countries, ~70 collaboration members


- Institute for Nuclear Research RAS (Moscow)
- Joint Institute for Nuclear Research (Dubna)
- Irkutsk State University (Irkutsk)
- Skobeltsyn Institute for Nuclear Physics MSU (Moscow)
- Nizhny Novgorod State Technical University (Nizhny Novgorod)
- Saint-Petersburg State Marine Technical University (Saint-Petersburg)
- Institute of Experimental and Applied Physics, Czech Technical University (Prague, Czech Republic)
- EvoLogics (Berlin, Germany)
- Comenius University (Bratislava, Slovakia)
- Krakow Institue for Nuclear Research (Krakow, Poland)

Neutrino telescopes



Detection modes:

Cascades: $\nu_e : \nu_\mu : \nu_\tau$ - 4π.

Tracks: ν_μ - 2π - bottom hemisphere.

Background:

Atmospheric μ - top hemisphere

Atmospheric ν - bottom hemisphere

Baikal-GVD site

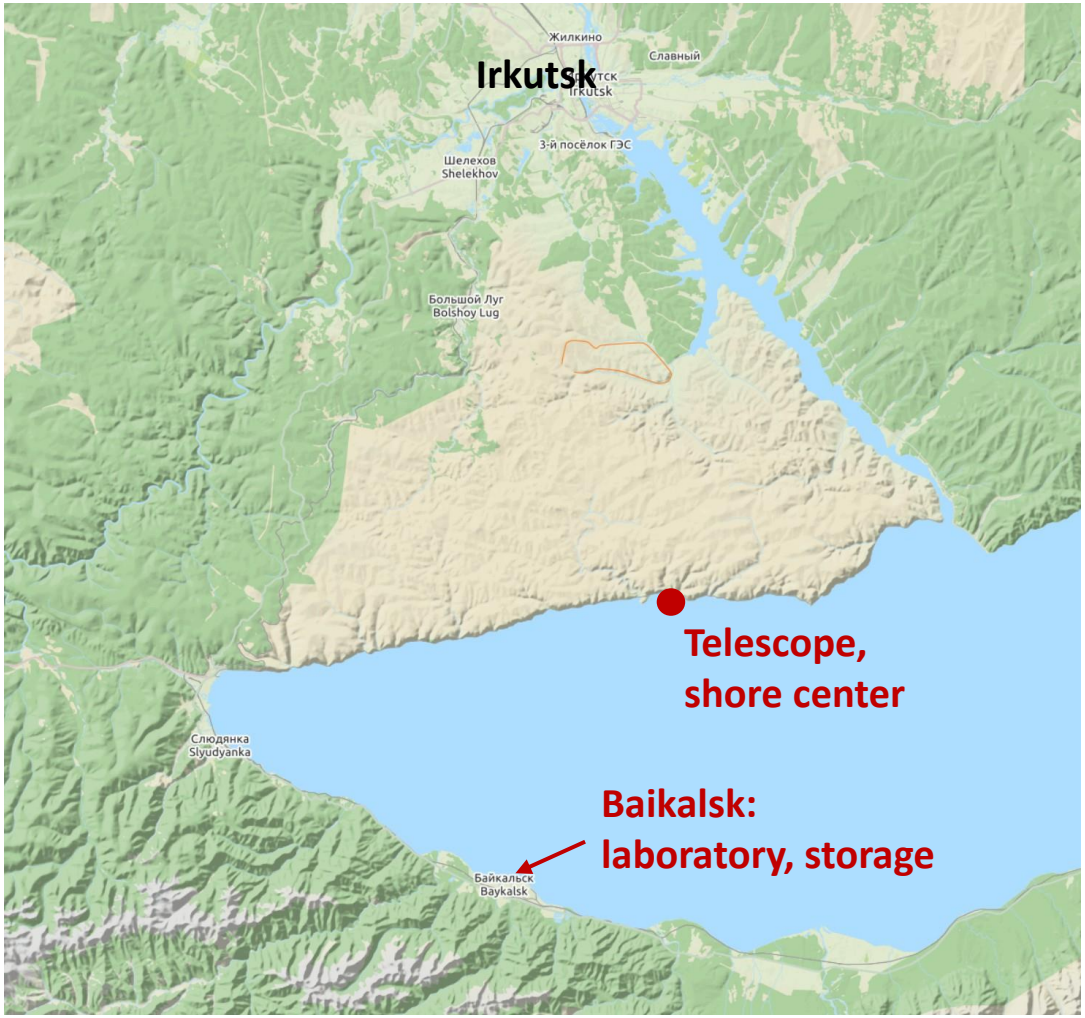
Telescope is located
~4 km away from shore
Constant lake depth:
1366 - 1367 m.

Stable ice cover for 6-8 weeks in February – April: detector deployment and maintenance.

Good water properties:
Absorption length: ~ 22-24 m
Scattering length: ~ 30-50 m

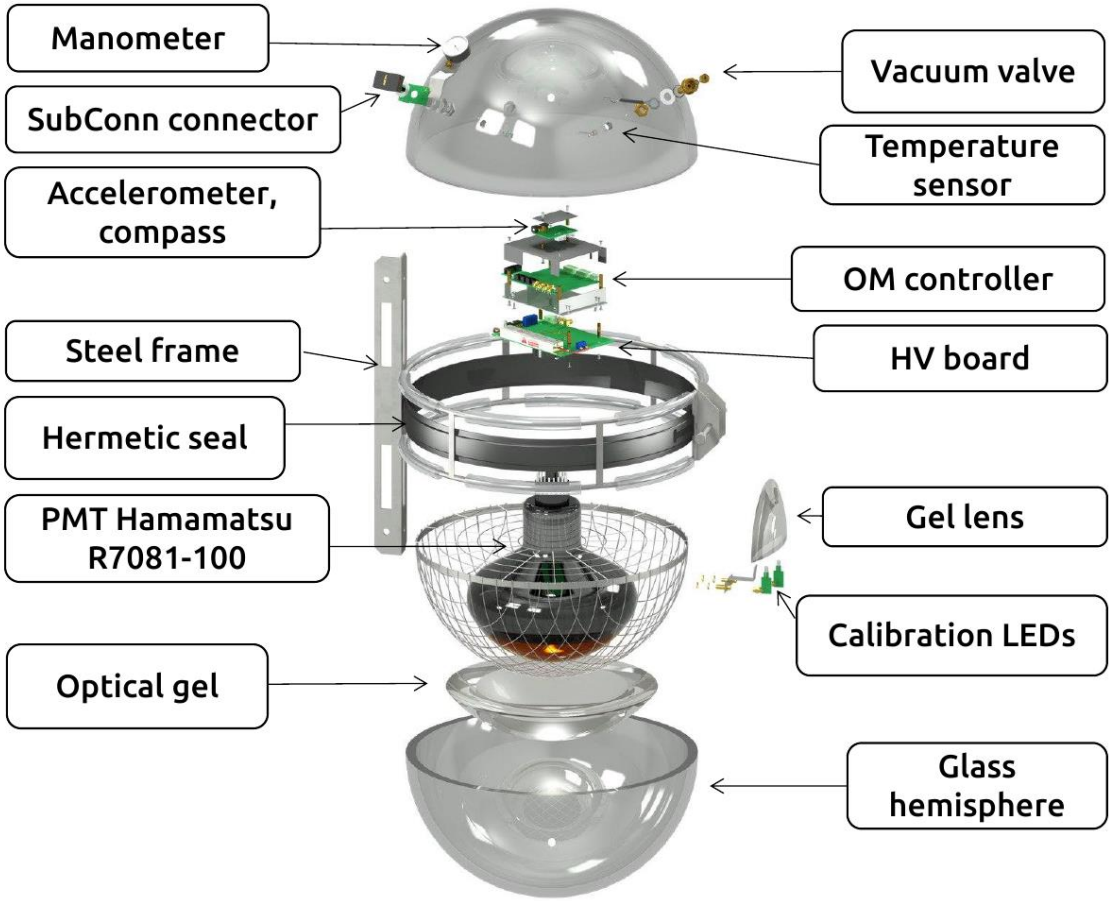
Moderately low background
15–40 kHz: PMT R7081-100 ∅10″

Absence of high luminosity burst from biology and K^{40} background.



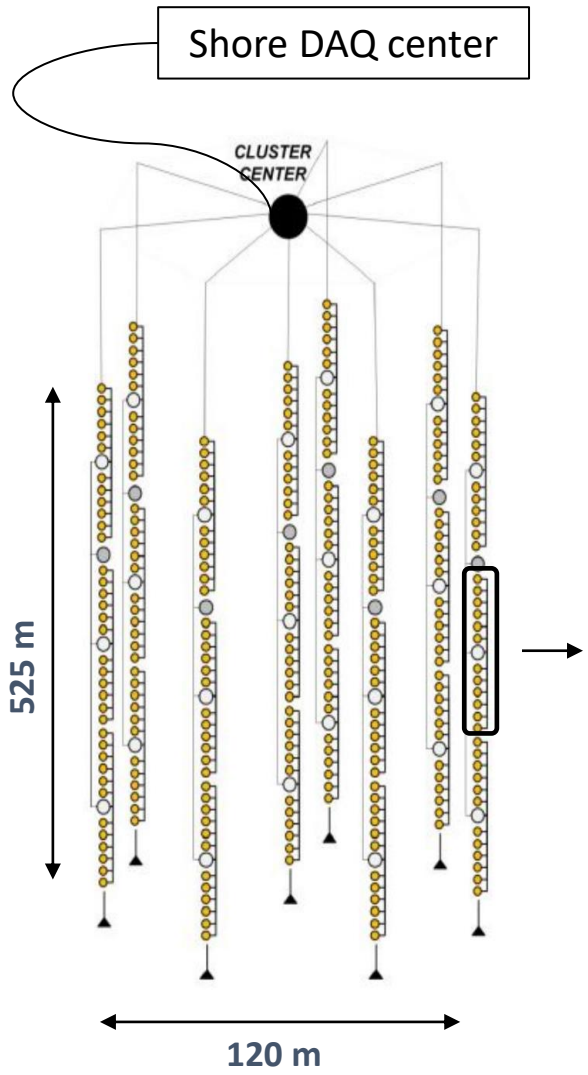
Baikal-GVD optical module

PMT R7081-100 Hamamatsu
∅ 10”, max QE 36%, TTS =3.4 ns

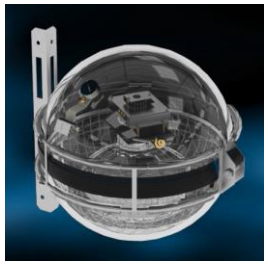


Optical module: OM

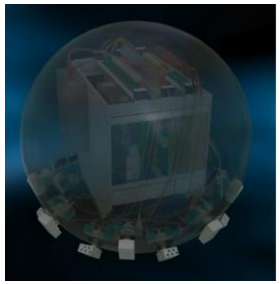
Baikal-GVD detector layout



Section:
12 OMs



Section control module



String

- 3 Sections, 36 Oms
- String control module
- 15 m step between OMs
- All OMs look downward
- Acoustic and LED calibration devices
- Anchored at the lake bottom

Cluster

- 8 strings, 288 OMs
- Cluster DAQ center
- Shore cable
- Depths from 750 to 1275 m
- 60 m step between strings
- Hardware global trigger:
  4.5 p.e. + 1.5 p.e.
  on adjacent OMs in 100 ns.

Calibration devices

Amplitude calibration:

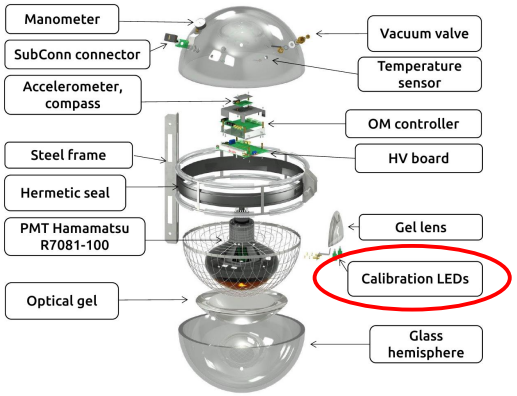
ADC cannel -⟶ photoelectrons

Time calibration:

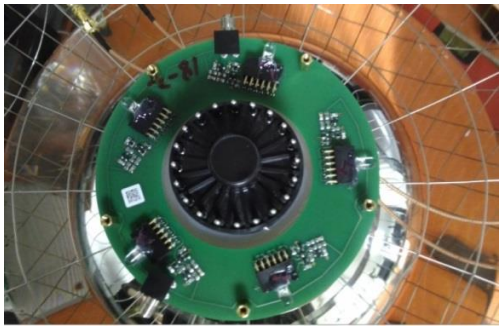
Cable and PMT delays correction

- Section calibration: OM LEDs
- String calibration: LED beacons
- Cluster calibration: Laser

Calibration LEDs in each OM



LED beacons for string time calibration

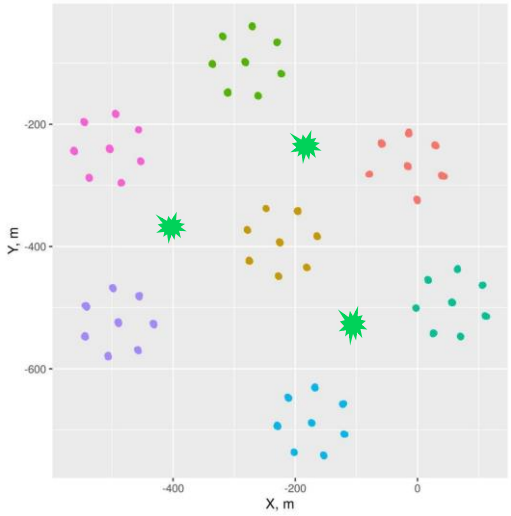


2 vertical and 10 horizontal LEDs (installed in to OM)

Laser

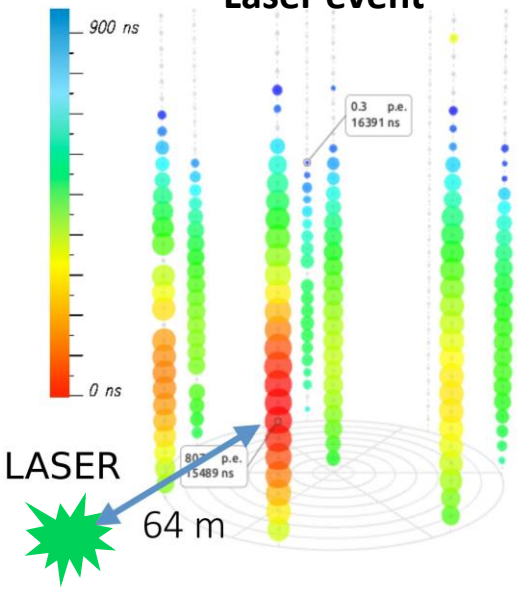
532 nm, 0.37 mJ, 1 ns

Baikal-GVD 2020 top view

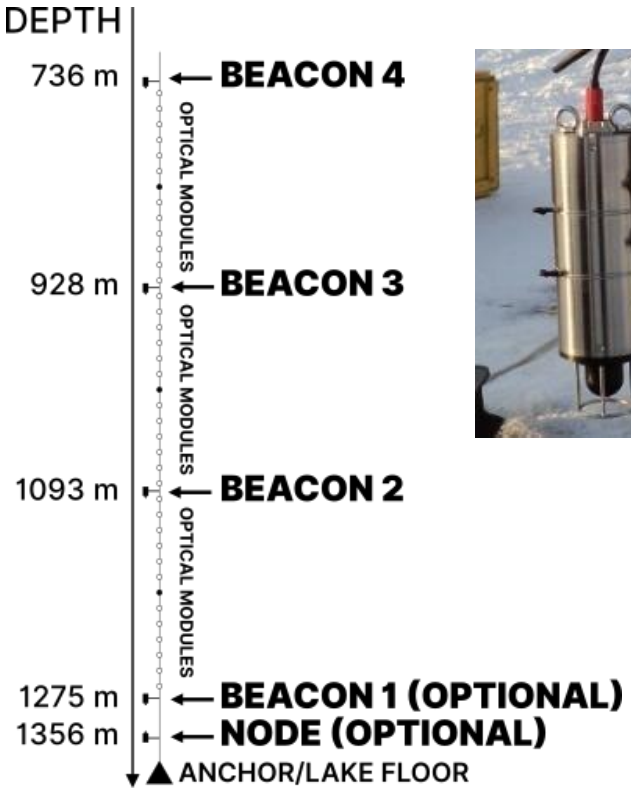


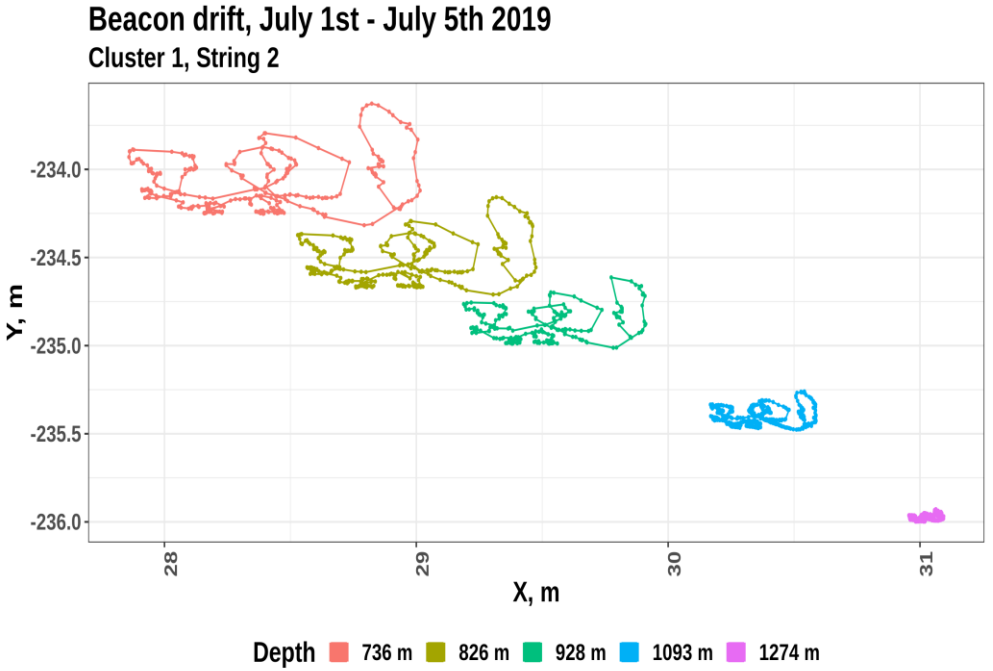
- Cluster 1
- Cluster 2
- Cluster 3
- Cluster 4
- Cluster 5
- Cluster 6
- Cluster 7
- Laser strings: 2 lasers

Laser event



Acoustic positioning system





OM drift can reach tens of meters, depends on season and elevation.

OM coordinates are acquired via an acoustic positioning system.

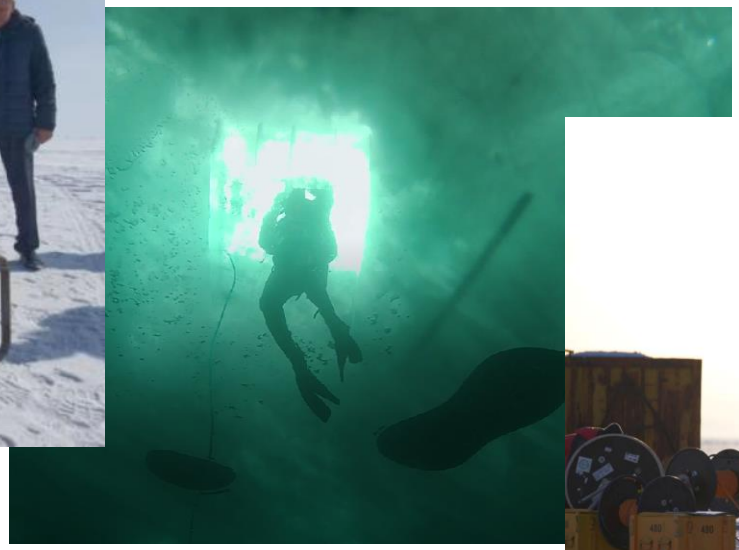
It consists of a network of acoustic modems (AMs) installed along GVD strings

4 AMs per string in a standard configuration.

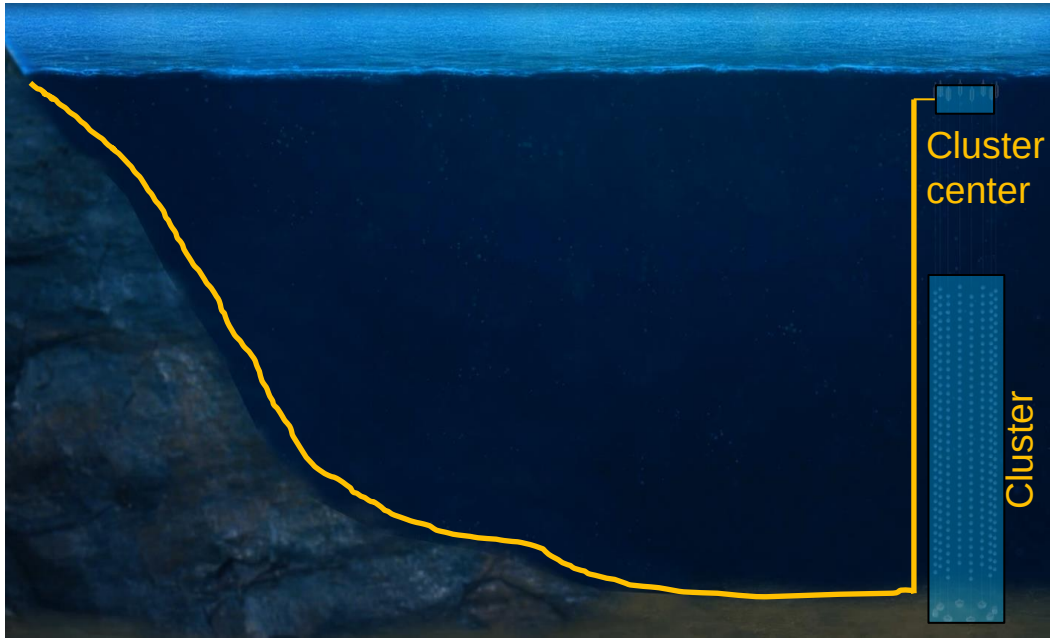
OM coordinates are obtained by interpolating AM coordinates, error < 0.2m,

Deploying the installation
Expedition 2021: 15 February – 9 April

Ice camp and stages of the strings deployment

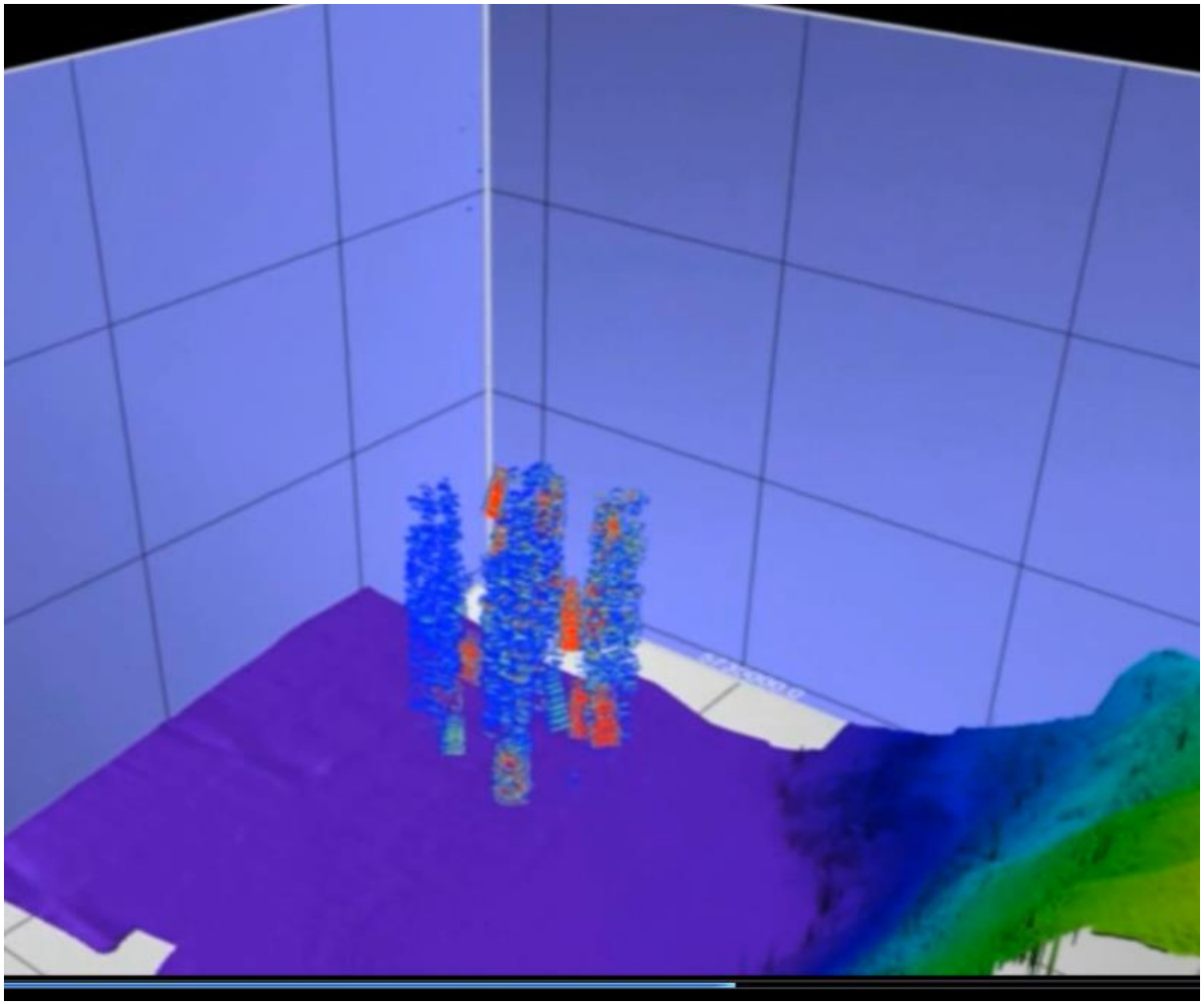


Laying of the shore cable



- Separate cable for each cluster 5 – 7 km length; optical fibers and copper wires
- The cable connects the shore and the cluster center
- Laying two cables during the expedition.

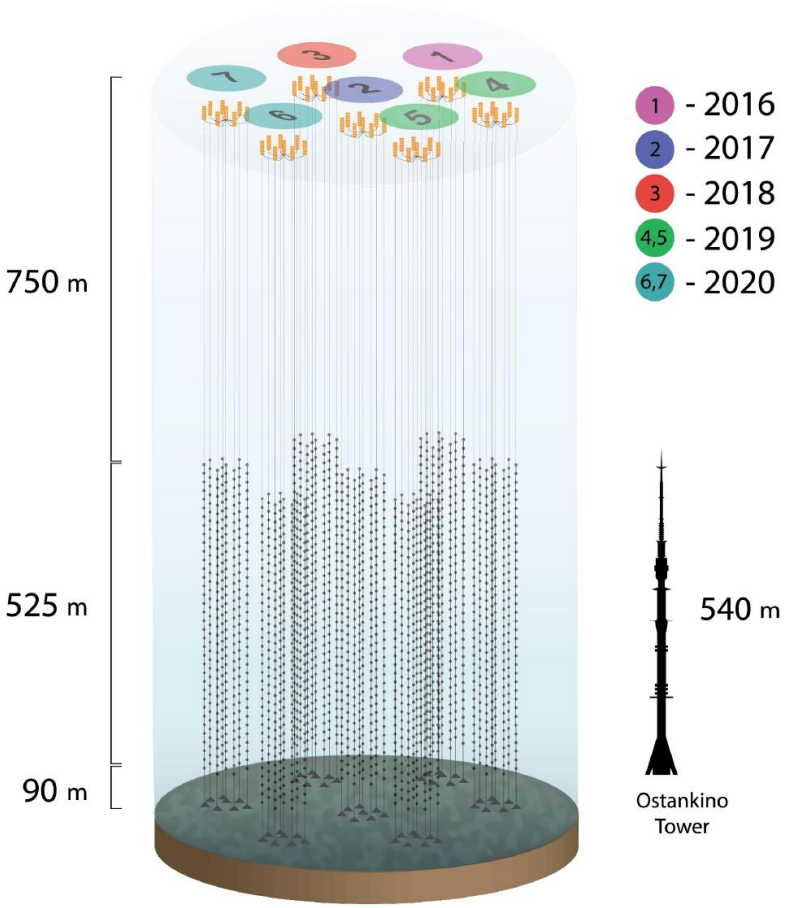
Bathymetry



Ultrasonic scanning, 7 clusters, 2020 yr.

Baikal-GVD construction status and schedule

Status 2020 – 7 clusters



300 m step between clusters

Deployment schedule

Year	Total number of clusters	Total number of strings	Number of OMs
2016	1	8	288
2017	2	16	576
2018	3	24	864
2019	5	40	1440
2020	7	56	2016
2021	8	64	2304
2022	10	80	2880
2023	12	96	3456
2024	14	112	4032

Effective volume 2021: 0.40 km^3

Preliminary resalts

- Muons detection mode: upward going neutrinos
- Cascades detection mode: HE cascades
- MultiMessenger studies

Track analysis

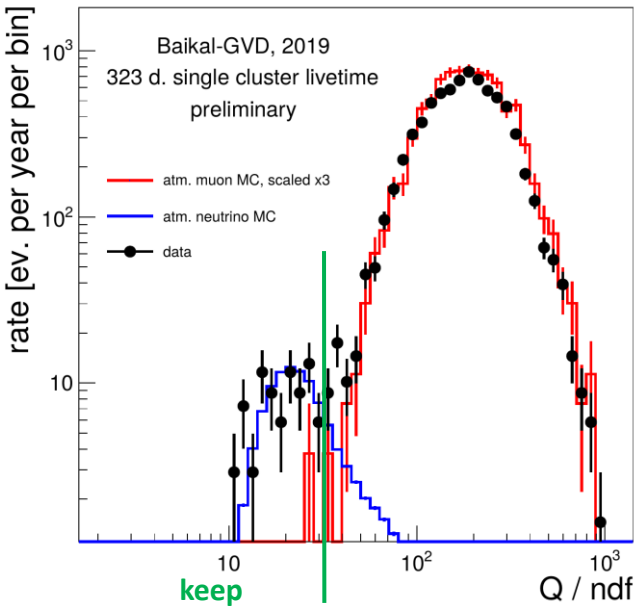
Fit track with quality function

$$Q = \chi^2(t) + f(q, r)$$

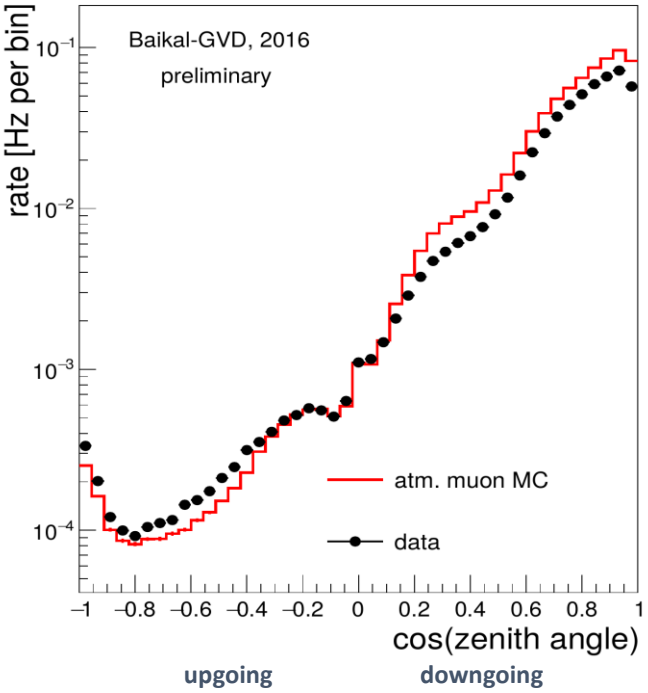
Neutrino selection:

- cut on zenith angle
- cut on fit quality

upgoing: $\theta_{zenith} > 120$ deg.



Event rate before quality cuts
(dominated by muon bundles)

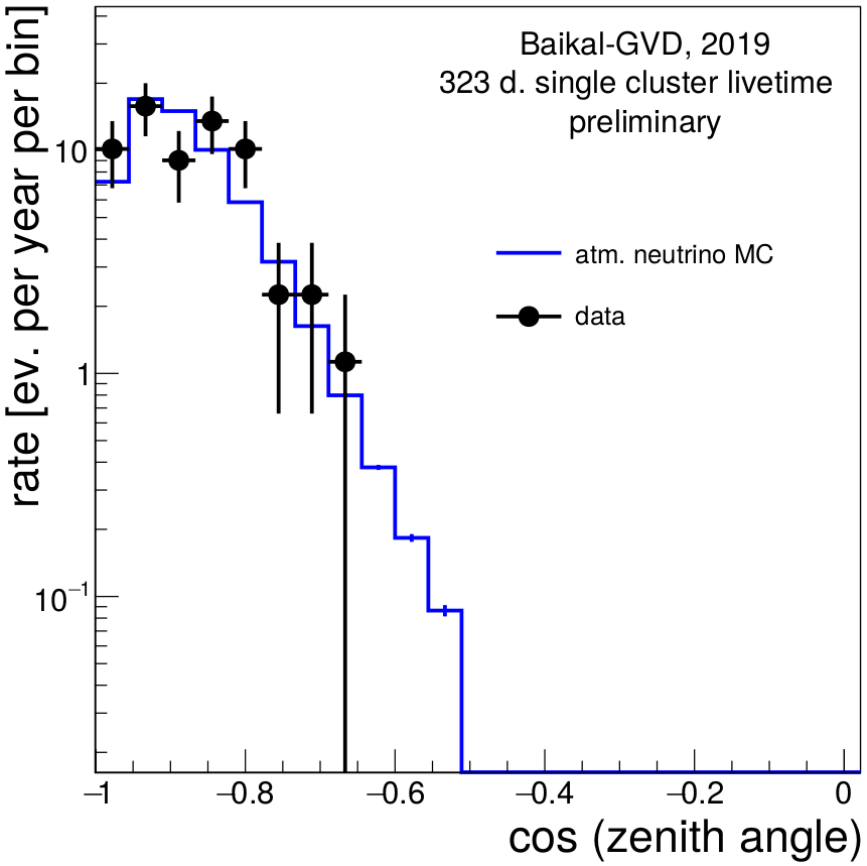


Fair agreement with MC predictions
Neutrino selection works as expected

A likelihood-based reconstruction is in development

Muon neutrino : single-cluster analysis

- Data taken between Apr 1 and Jun 30, 2019
- Live time: 323 days (single-cluster equivalent live time)



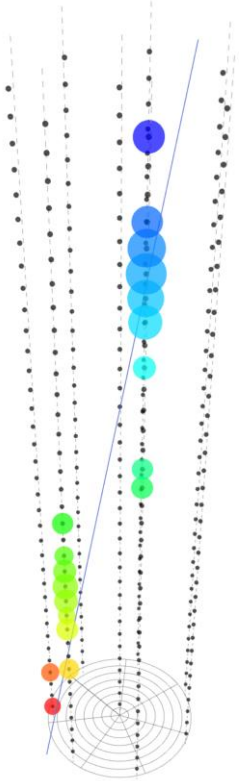
MC expected: 54.3
- atm. neutrino : 54.3
- atm. muon: < 1

Observed: 57

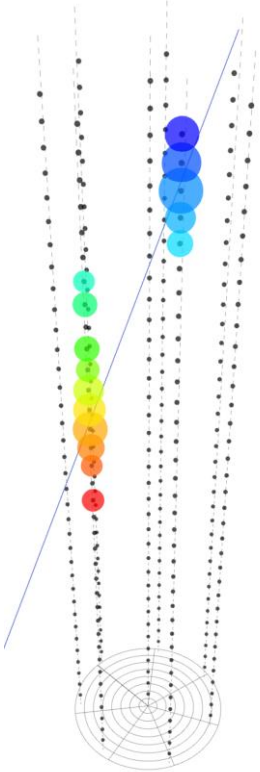
Fair agreement with MC prediction for atmospheric neutrino

Angular resolution: (single cluster)
~ 1° or better

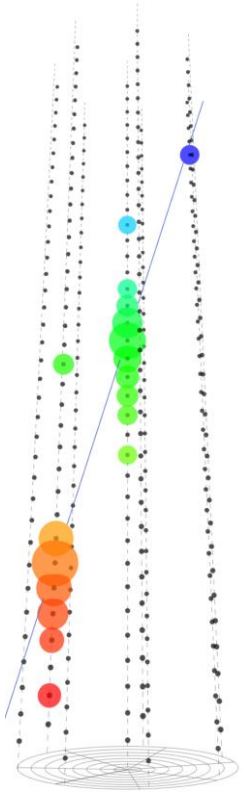
Muon neutrino candidates



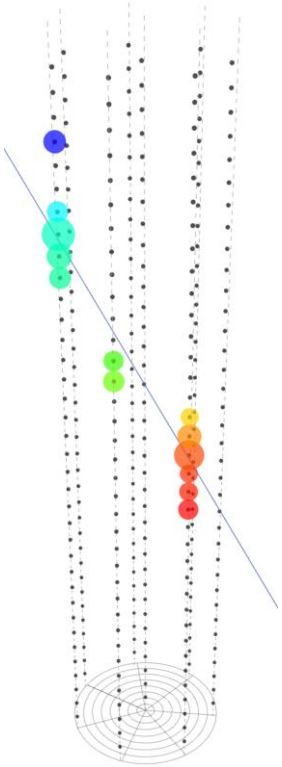
cluster 3, run 122
evt. 1549343
θ_{zenith} = 169.8°
$N_{strings}$ = 3
$N_{strings}$ = 19



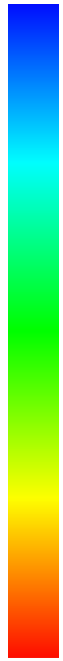
cluster 1, run 157
evt. 1414137
θ_{zenith} = 161.8°
$N_{strings}$ = 2
$N_{strings}$ = 15



cluster 4, run 99
evt. 438088
θ_{zenith} = 162.2°
$N_{strings}$ = 3
N_{hits} = 18



cluster 5, run 162
evt. 1939721
θ_{zenith} = 148.1°
$N_{strings}$ = 3
N_{hits} = 13



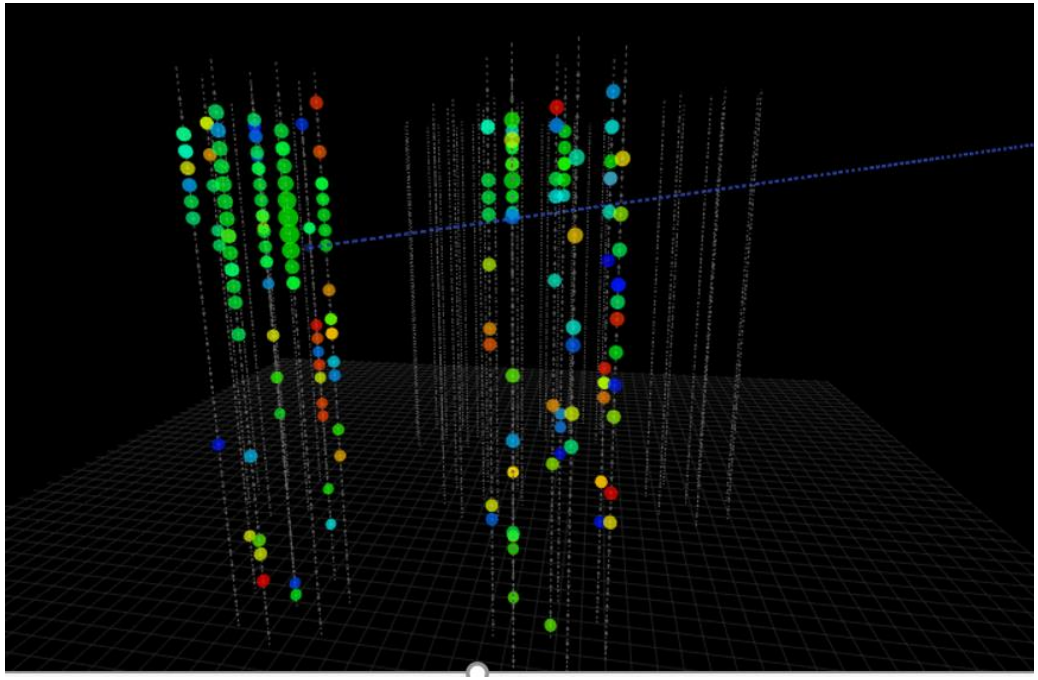
Multi cluster events

Multi-cluster analysis is in preparation

Preliminary

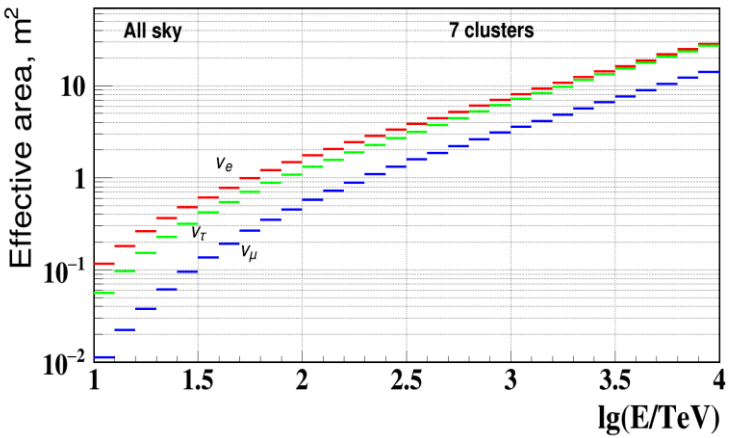
Cluster synchronization accuracy $<$ 5 ns

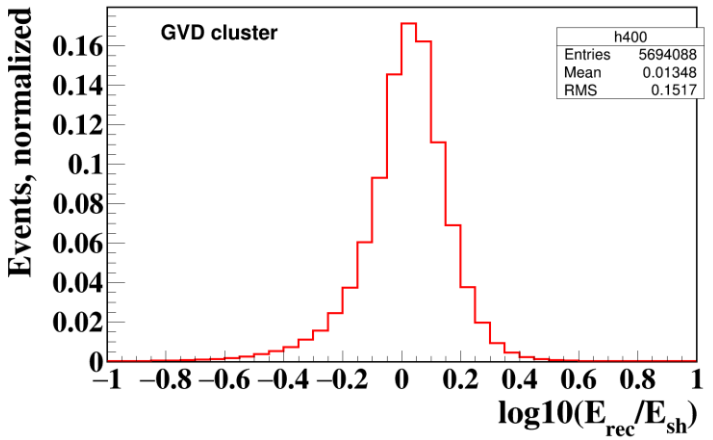
Expected angular resolution (track mode): $0.1 \ldots 0.2°$



Cascades detection with GVD Cluster

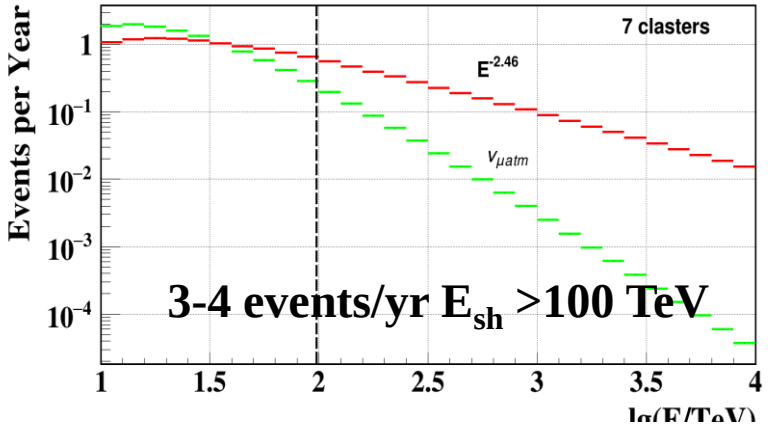
Neutrino Effective Area for 7 GVD Clusters

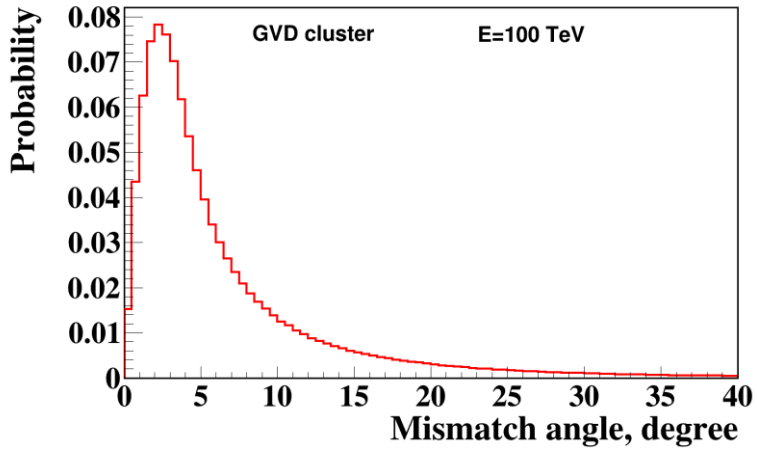




Energy resolution : δE/E ~ 10%-30%

Expected number of events in 7 GVD Clusters from astrophysical neutrinos for 1 yr.





Directional resolution for cascades:

2°- 4° - median value of mismatch angles

19

Data sample

T = 3714 days (10.1 years) of one Cluster operation (2018, 2019, 2020)

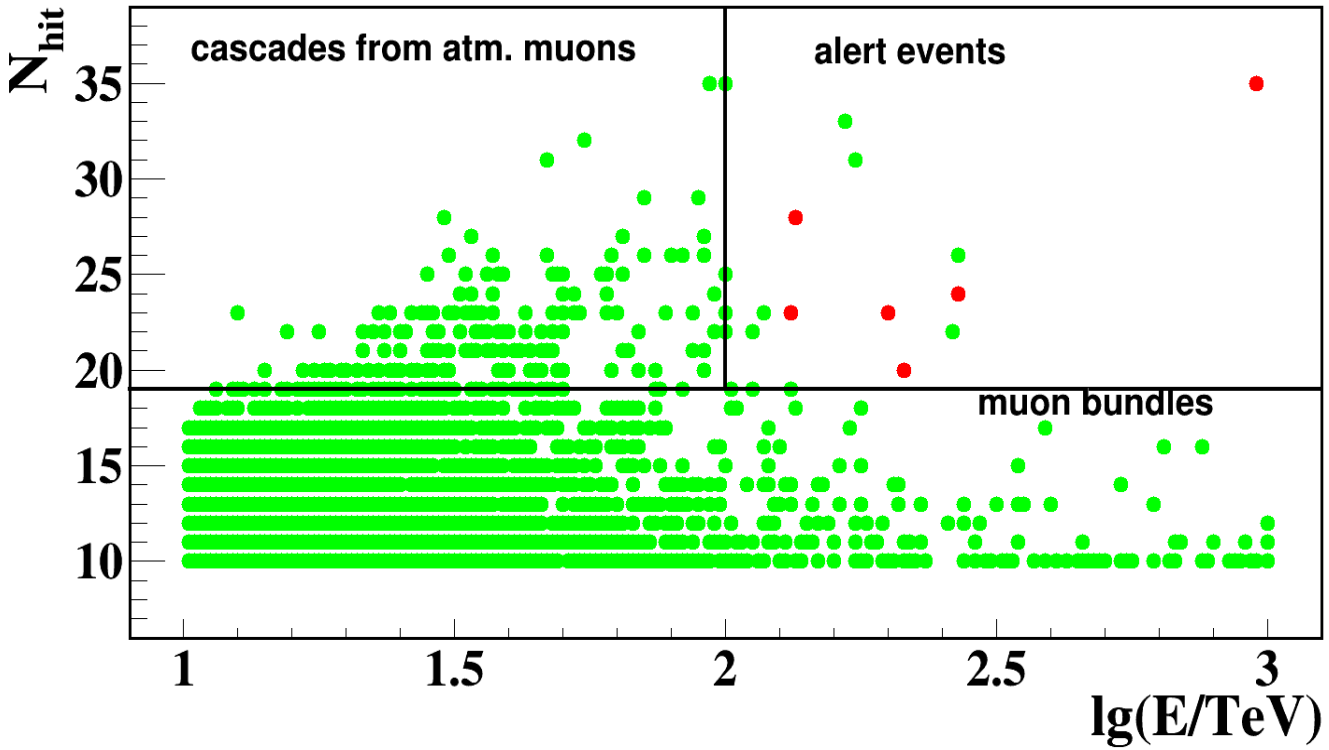
After reconstruction and all cuts applying, 9357 events have been selected with $N_{hit} > 9$ & E > 10 TeV

Trigger conditions for different studies

Multi-Messenger studies: $N_{hit} > 9$

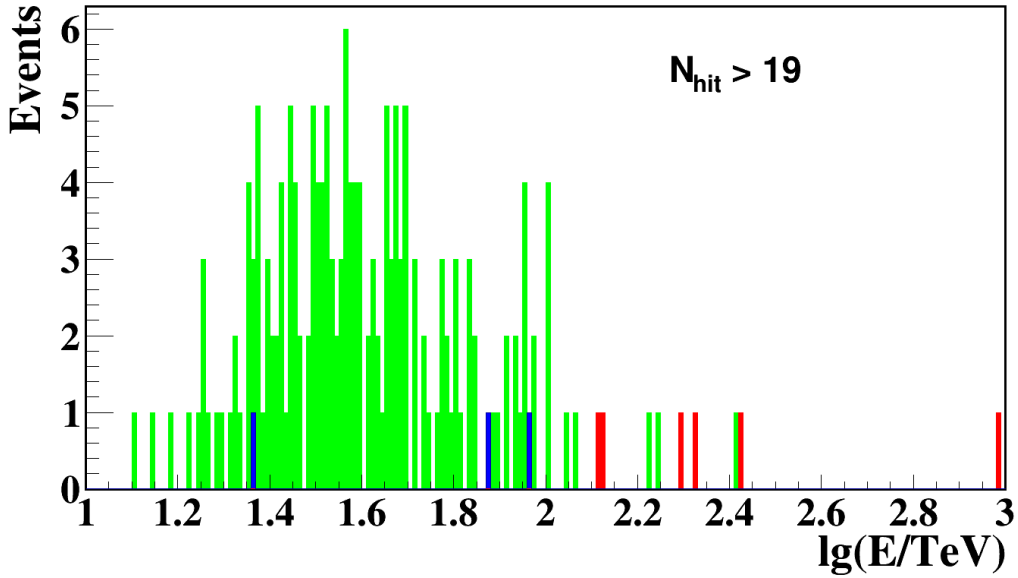
Upward going neutrinos: $N_{hit} > 10$ & $\theta > 90°$

HE astrophys. neutrinos: $N_{hit} > 19$ & E >100 TeV



High energy cascades (data)

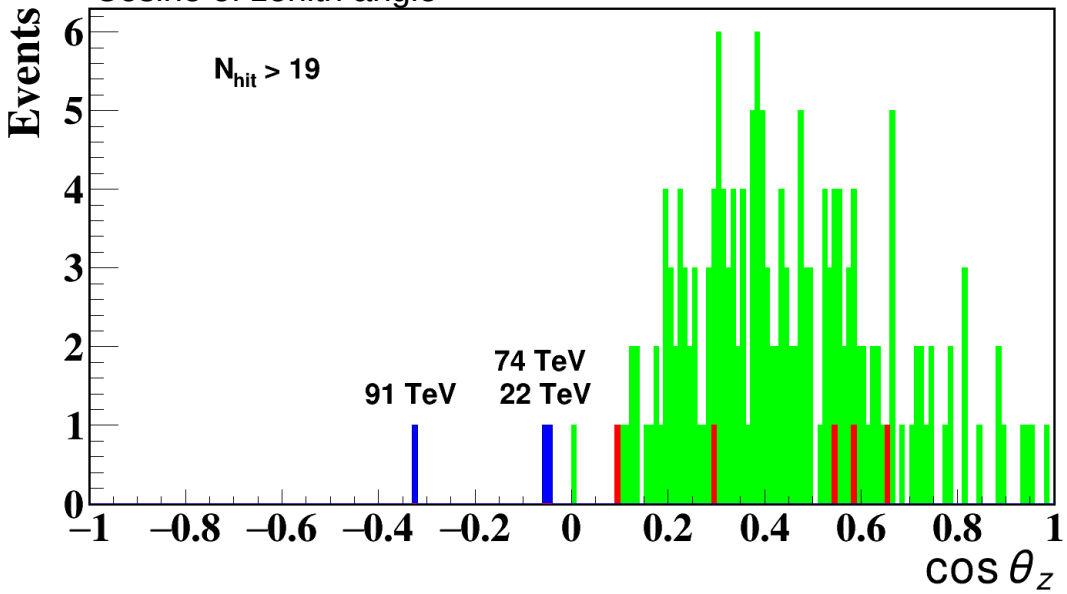
Energy distribution



Data from 2018 - 2020 ,
exposition: 3714 days

12 events with E > 100 TeV and N_{hit} >19:
6 events - cascades with muon
5 events - cascades
1 event - under investigation

Cosine of zenith angle

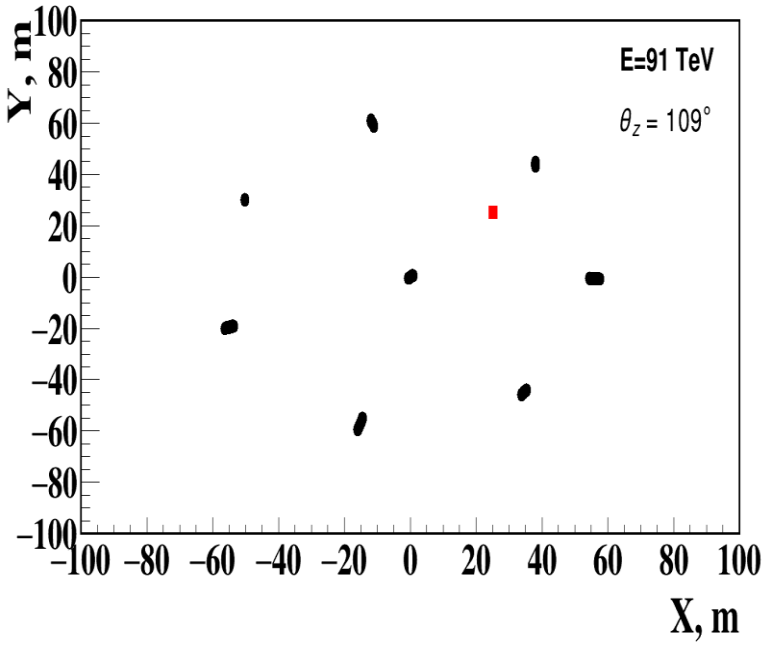


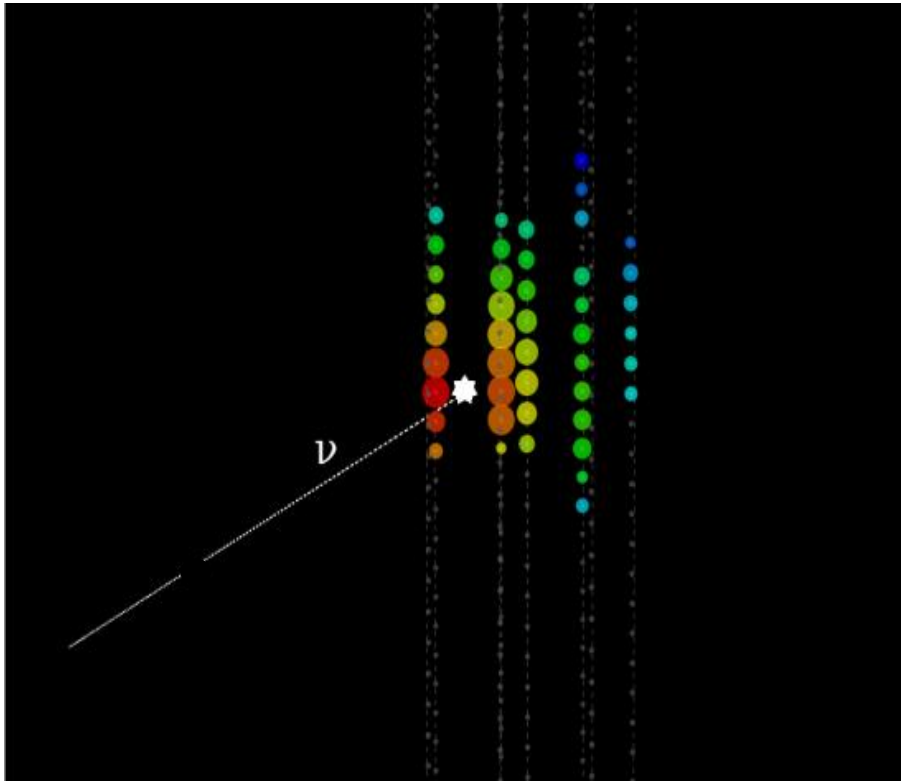
3 upgoing cascades: E ≈ 91 TeV
and E ≈ 74 TeV and 22 TeV

The first clear cascade event from the interaction of an upward moving electron- or tau-neutrino at the 100 TeV

Preliminary

Contained event
Reconstructed energy E = (91 ± 11) TeV
Zenith angle $\theta_z = 109°$

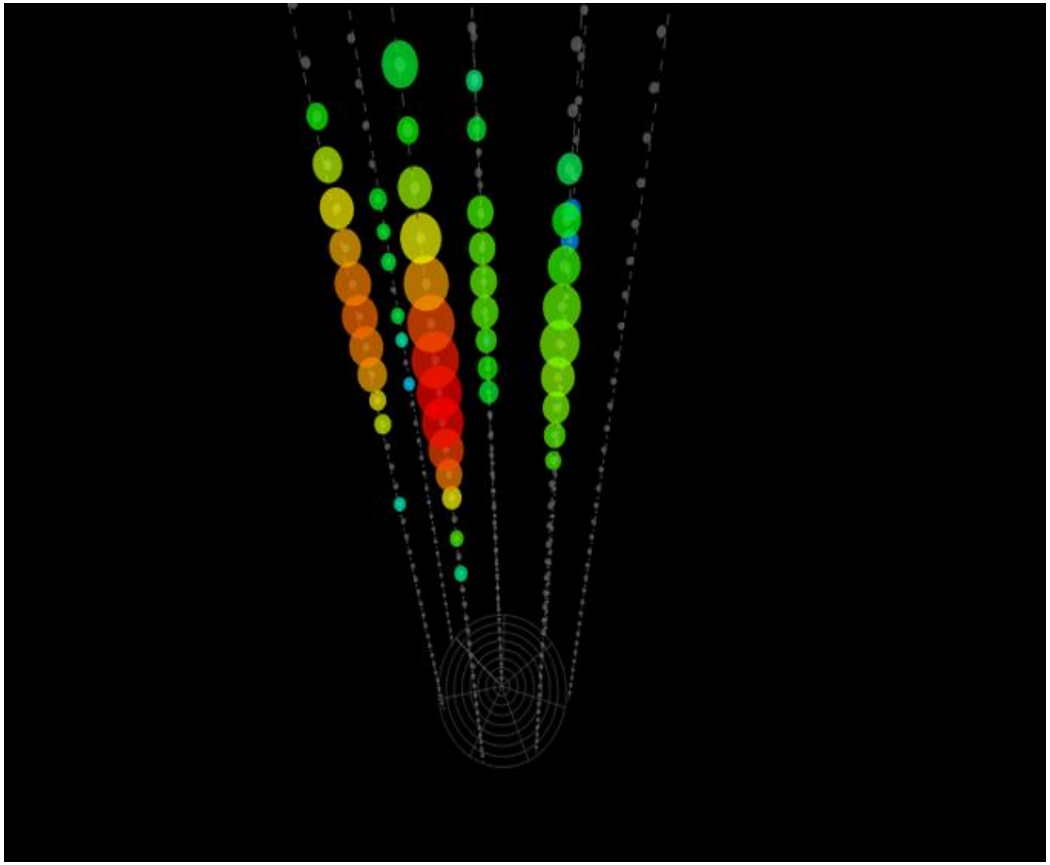




First PeV_scale cascade

Preliminary

Reconstructed energy E = 955 TeV (±20%);
distance from central string r = 91 m;
zenith angle = 61°



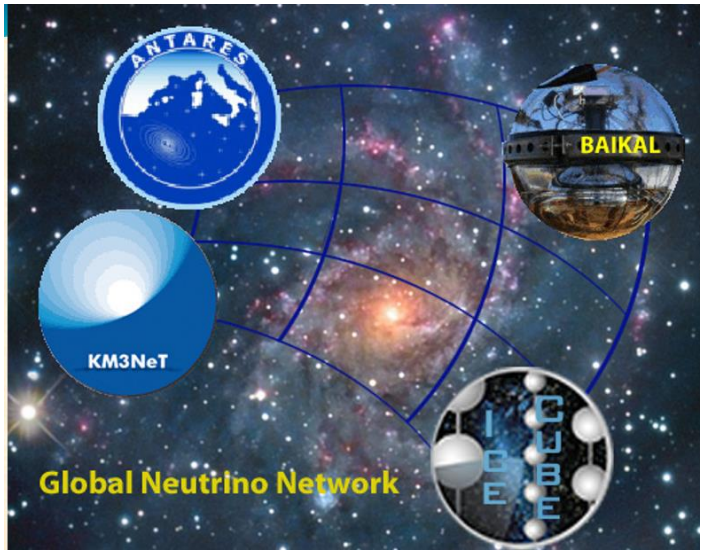
Baikal GVD: Multi-Messenger Studies

ANTARES (TAToO) $\mu_{\uparrow}$ since Dec 2018 <E> 7 TeV

ICECUBE (GCN) $\mu_{\uparrow}$ since Sept 2020 E > 100 TeV

- in cascade mode within 4.5° half-open cone towards sources over 4π-sky
- in track mode: within 1.5° half-open cone towards sources in down hemisphere

No prompt coincidence in time and direction was found



LIGO/Virgo : GW170817

No neutrino events associated with GW170817 have been observed using cascade mode within ± 500 sec window and 14 days after the neutron star merger.

Fiber optic data acquisition system for GVD

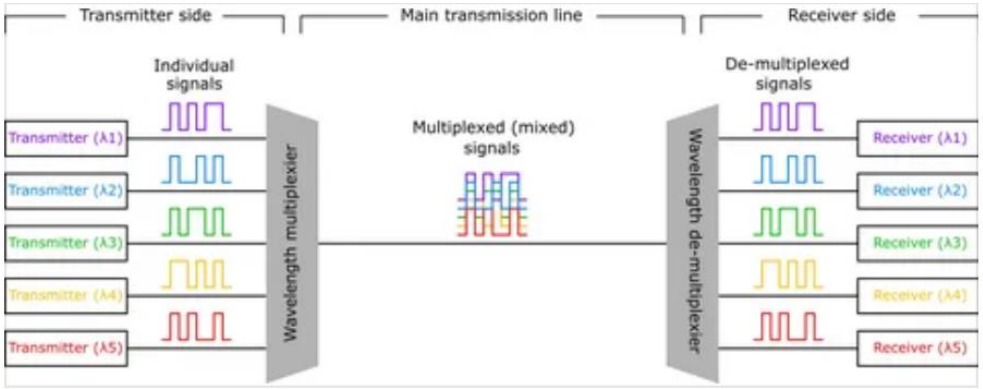
Development of fiber-optic DAQ is focused on GVD step 2.

The goal of upgrading the DAQ is to reduce the event registration threshold by increasing the data transfer speed and implementing a smart trigger system.

Basic requirements :

- "One fiber per one string".
- "Common clock" for all sections and clusters
- "Multi-trigger" operation mode

To meet these requirements CWDM optical multiplexers are applied (up to 9 channels per one fiber)



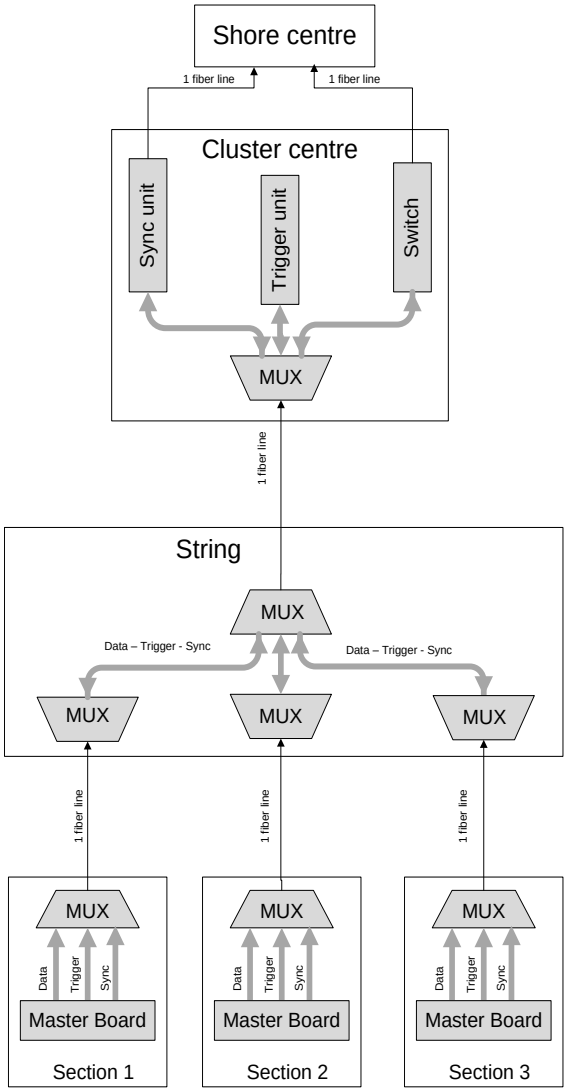
Experimental string with optical DAQ

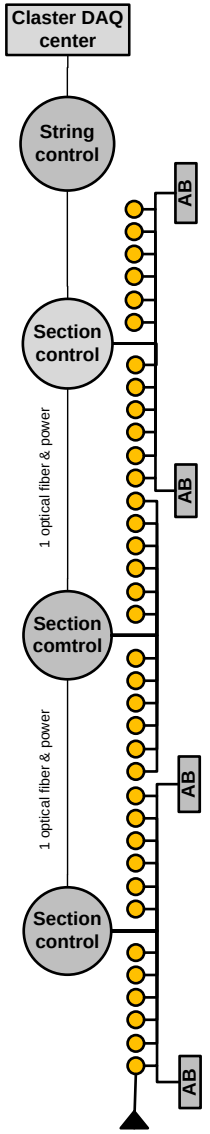
Experimental string – 2021

- 3 sections: 36 OMs
- String module
- Optical DAQ center

Basic elements of the optical communication is CWDM multiplexors (MUX) that provided up to 9 physical line for 1 fiber using different wavelengths.

Present DAQ	Optical DAQ
Bandwidth of the string channel 6 Mbit. Threshold 1.5/4 pe	Bandwidth of the string channel 1 Gbit. Threshold < 0.3/1.5 pe
Synchronization only using common trigger	Synchronization using as common trigger and section clocks.
One universal trigger for all sorts of events.	Multitrigger mode and local triggers of the sections.





Conclusion

- Baikal-GVD is now the largest neutrino telescope in the Northern Hemisphere: 0.40 km^3 and growing

- Modular structure of GVD design allows a search for HE neutrinos and multimessenger studies at the early phases of array construction.

- Observations of atmospheric neutrinos by Baikal-GVD agree with expectations; first astrophysics neutrino candidate events have been selected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