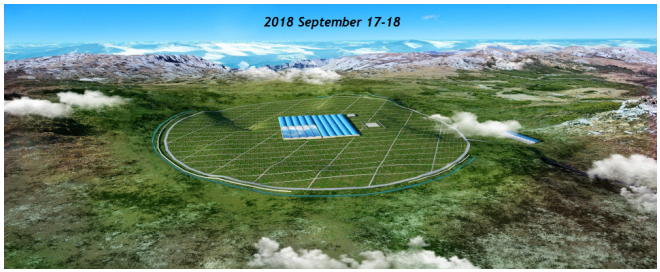


Baikal-GVD neutrino experiment

Olga Suvorova (INR RAS)

on behalf of the Baikal collaboration

The 9th international Workshop in Air Shower Detection at High Altitudes,
17-18 September 2018, INR RAS, Moscow, Russia

Baikal-GVD collaboration:
Gigaton Volume Detector in Lake Baikal

9 institutes, ~60 scientists,
head – G.V.Domogatsky

Irkutsk Univ

St-Petersburg
Marin Tech. U

INR

JINR

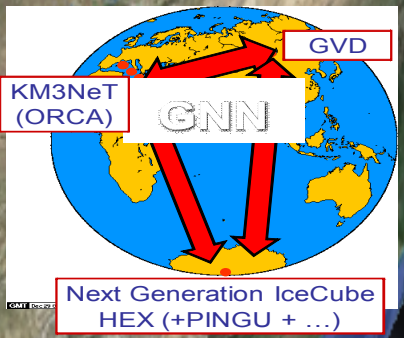
MSU

N-Novgorod
Tech. U

EvoLogics,
Germany

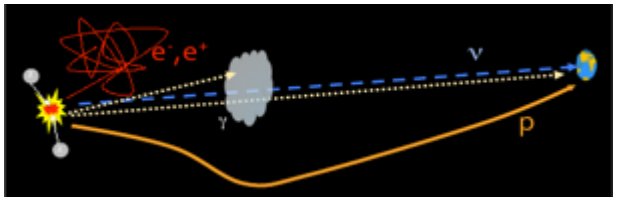
Czech Technical U

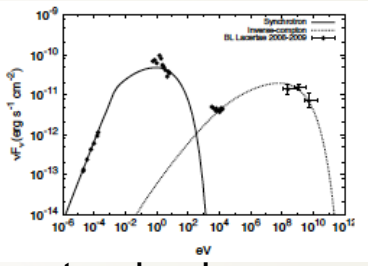
Comenius U, Slovakia.

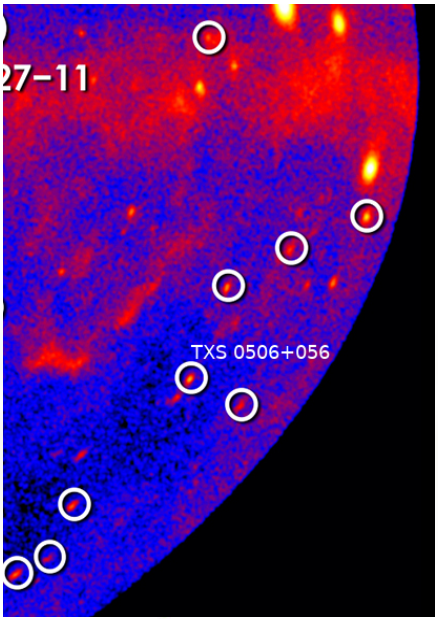


baikalweb.jinr.ru

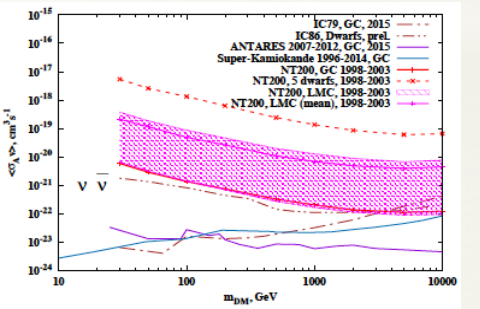
Why would we want to build a Gigaton Volume neutrino detector?







- Multi-messenger high energy astrophysics: EM radiation, GW, neutrinos, CR
- the discovery of PeV events and latest confirmation of cosmic neutrinos with IceCube (S.P.), while it is alone detection
- need a cubic kilometer detector in the North hemisphere (Baikal-GVD, km3NET)
- dark matter



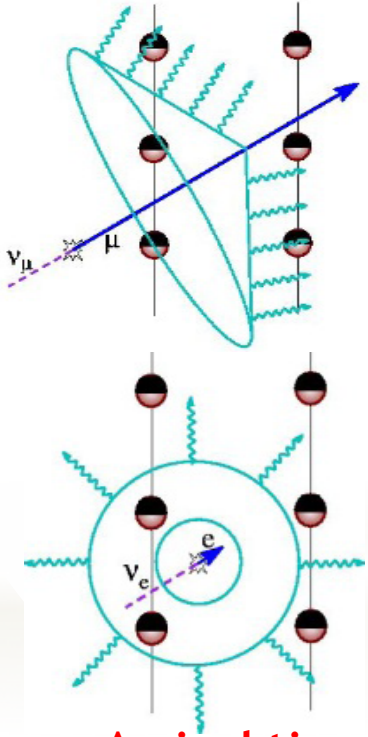
Neutrino detection: direction, energy, flavor

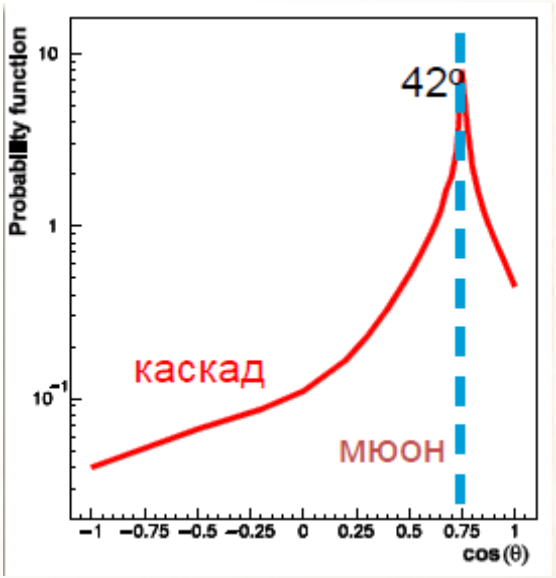
Detection principle

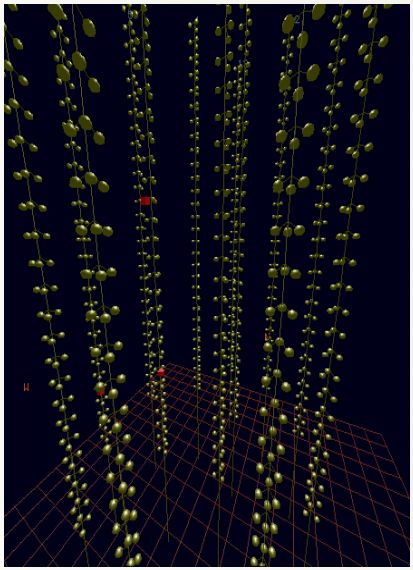
M.Markov, **1960**:

„We propose to install detectors deep in a lake or in the sea and to determine the direction of charged particles with the help of Cherenkov radiation“ Proc. 1960 ICHEP, Rochester, p. 578.

$$\nu + N \rightarrow l + X$$







Environment properties

absorption, scattering, light background – K^{40}, bioluminescence

Arrival times & amplitudes, PMTs arrangement and orientation

Baikal-GVD project: search for astrophysical neutrinos

- 1370 m maximum depth
- Distance to shore ~4 km

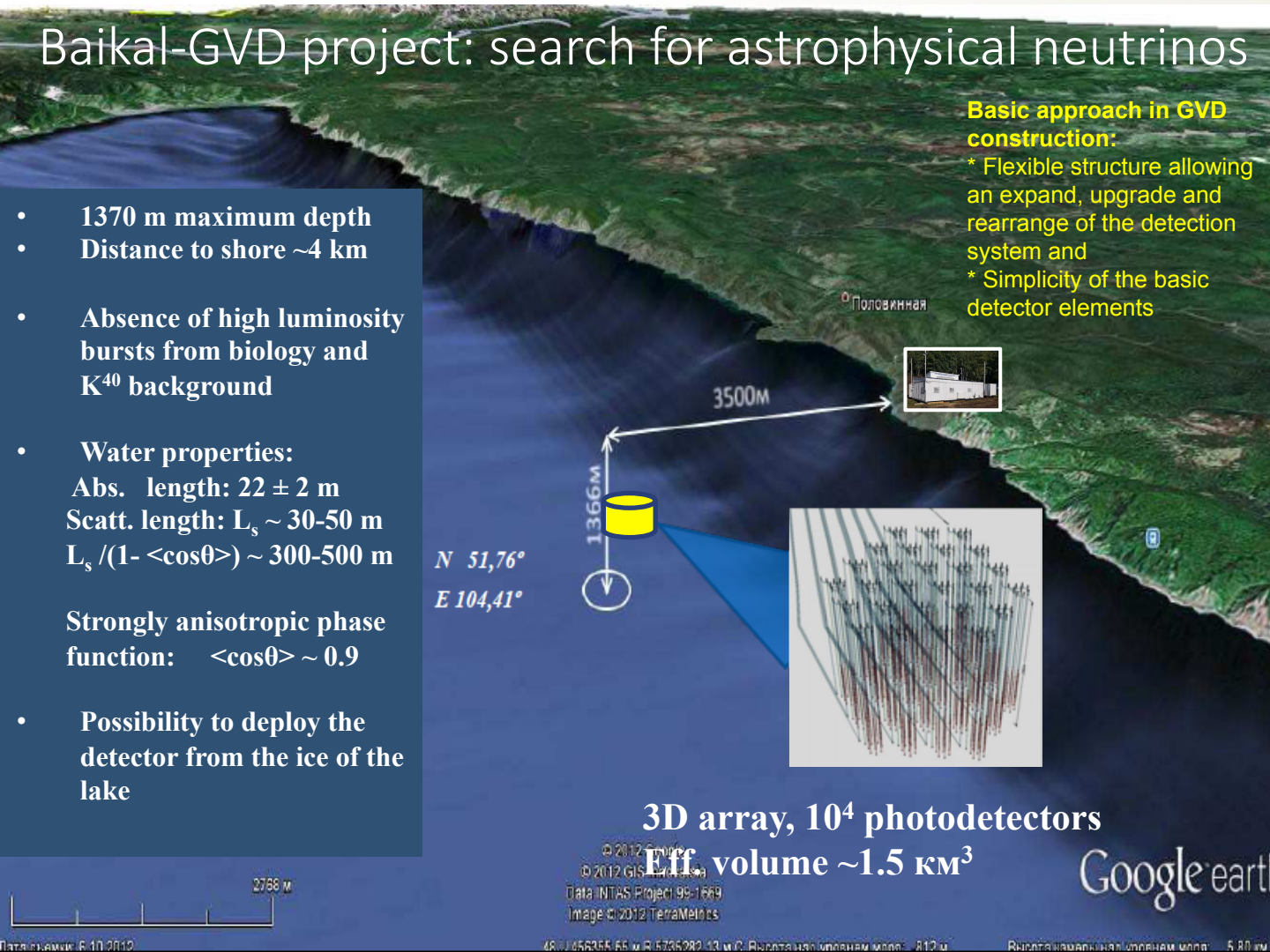
- Absence of high luminosity bursts from biology and K^{40} background

- Water properties:
  Abs. length: 22 ± 2 m
  Scatt. length: L_s ~ 30-50 m
  L_s /(1- <cosθ>) ~ 300-500 m

  Strongly anisotropic phase function: <cosθ> ~ 0.9

- Possibility to deploy the detector from the ice of the lake

Basic approach in GVD construction:
* Flexible structure allowing an expand, upgrade and rearrange of the detection system and
* Simplicity of the basic detector elements



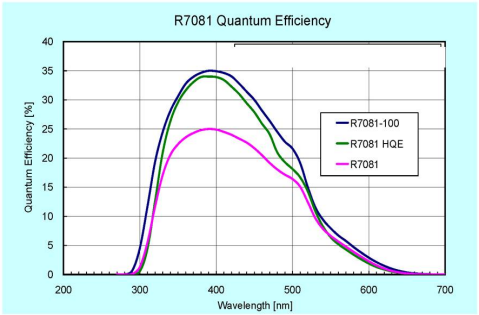
3D array, 10^4 photodetectors
Eff. volume ~1.5 км^3

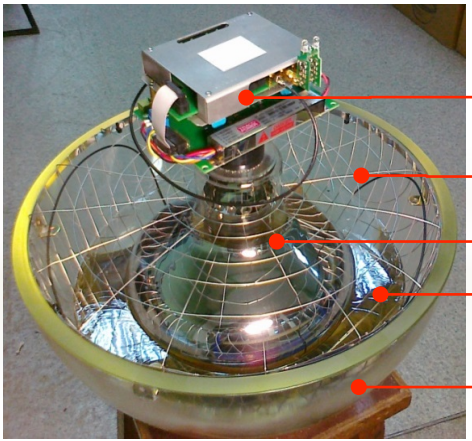
South Baikal in Feb and Apr

Ice thikness ~ 60-90 см (some years up to 120 см)

The Optical Module

PMT
Hamamatsu R7081-100
∅=10 inch
QE ≈ 35% @ 400nm
Gain ~10^7,
Dark current ~8 kHz



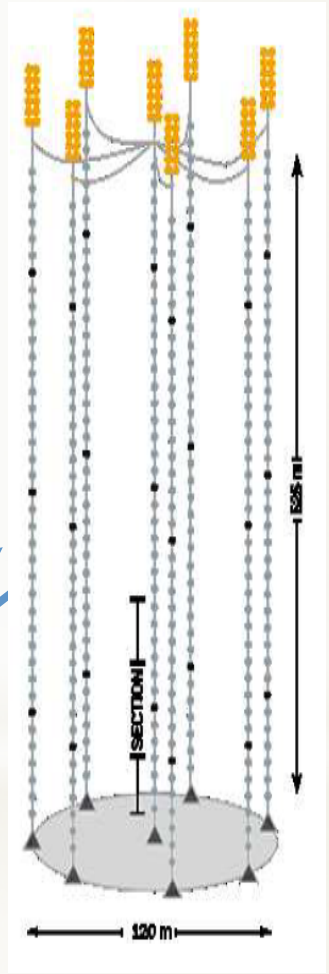


OM electronics
Mu-metal cage
PMT
Optical gel
Pressure-resistant glass sphere VITROVEX (17”)

The Cluster of strings

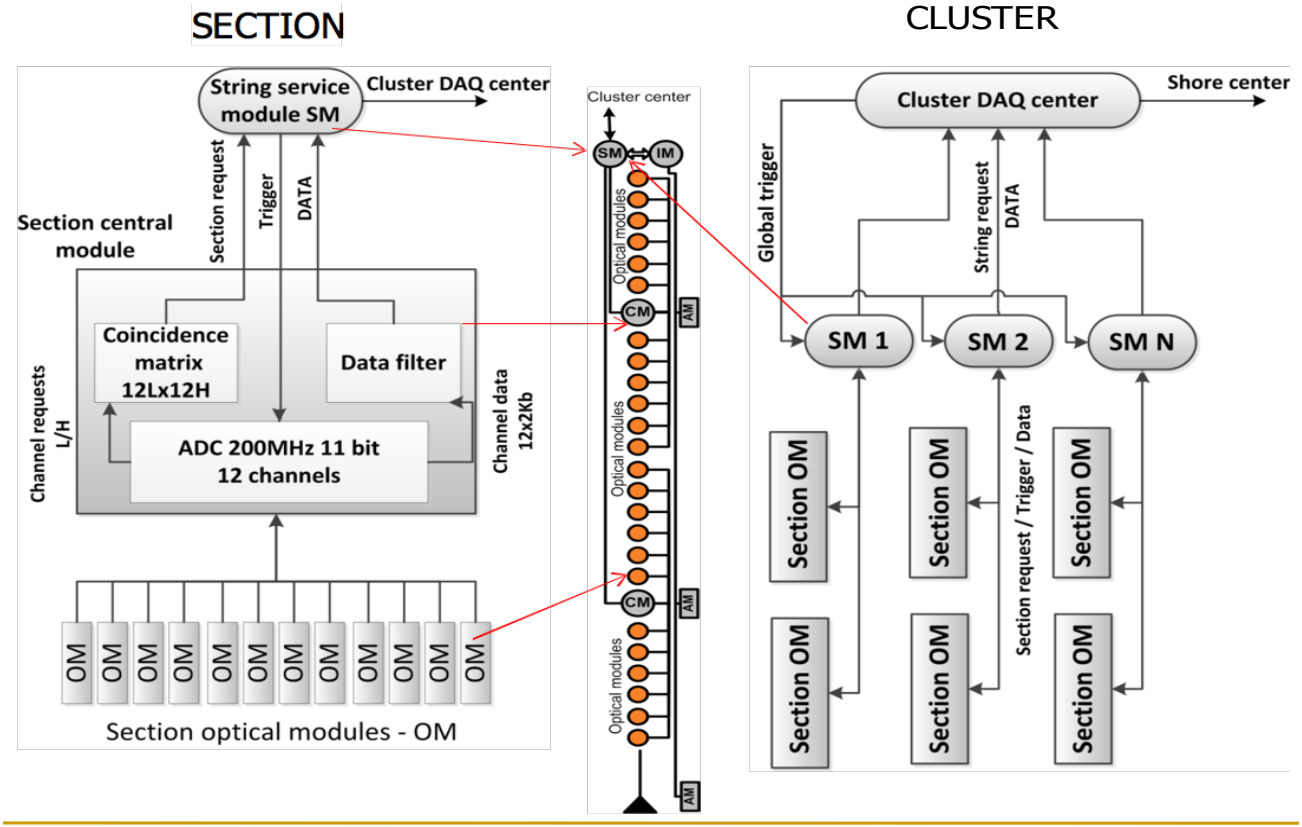
- 288 OMs at 8 strings
  - 36 OMs per string, 15 m spacing
  - depth 750 - 1275 m
  - 60 m between strings
- Cluster DAQ center (30 m below surface)
  - Trigger, power, data transfer systems of the cluster
- Electro-optical cable to shore
- Acoustic positioning system (4 beacons on each string)
- 3 calibration light beacons (matrix of LEDs)
  - Interstring time calibration

String: 3 Sections×12 OMs&ADC module

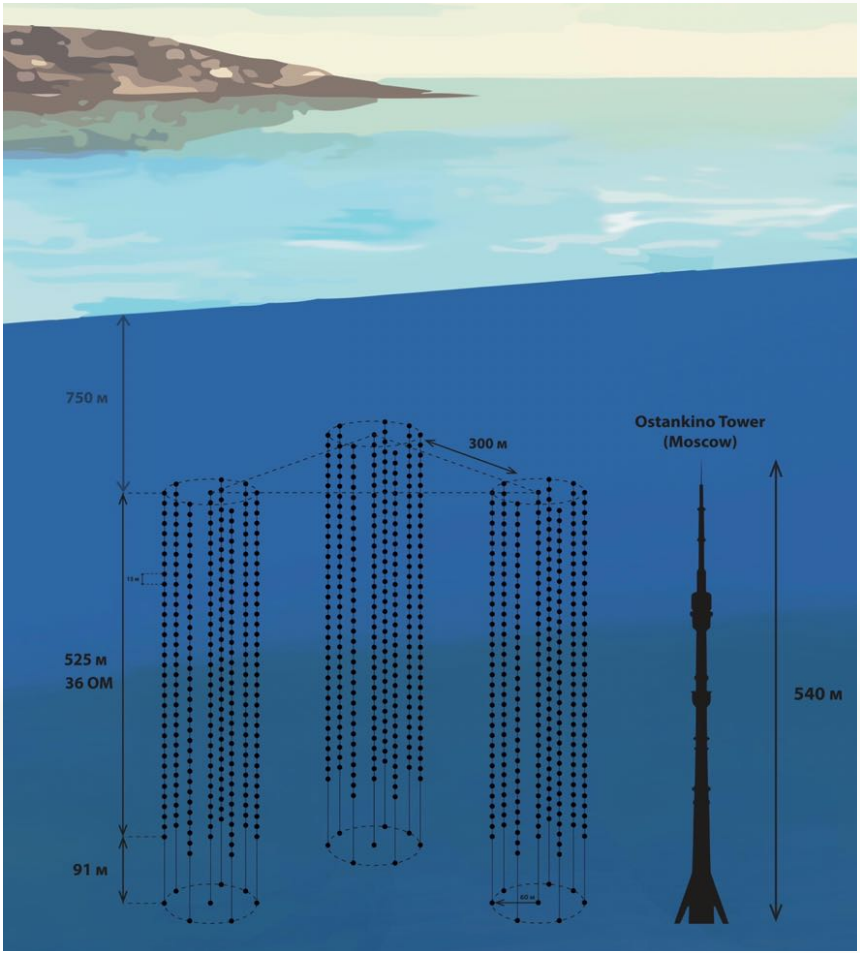


120 m

Triggering and Data Transmission



Status-2018 of the Baikal-GVD project

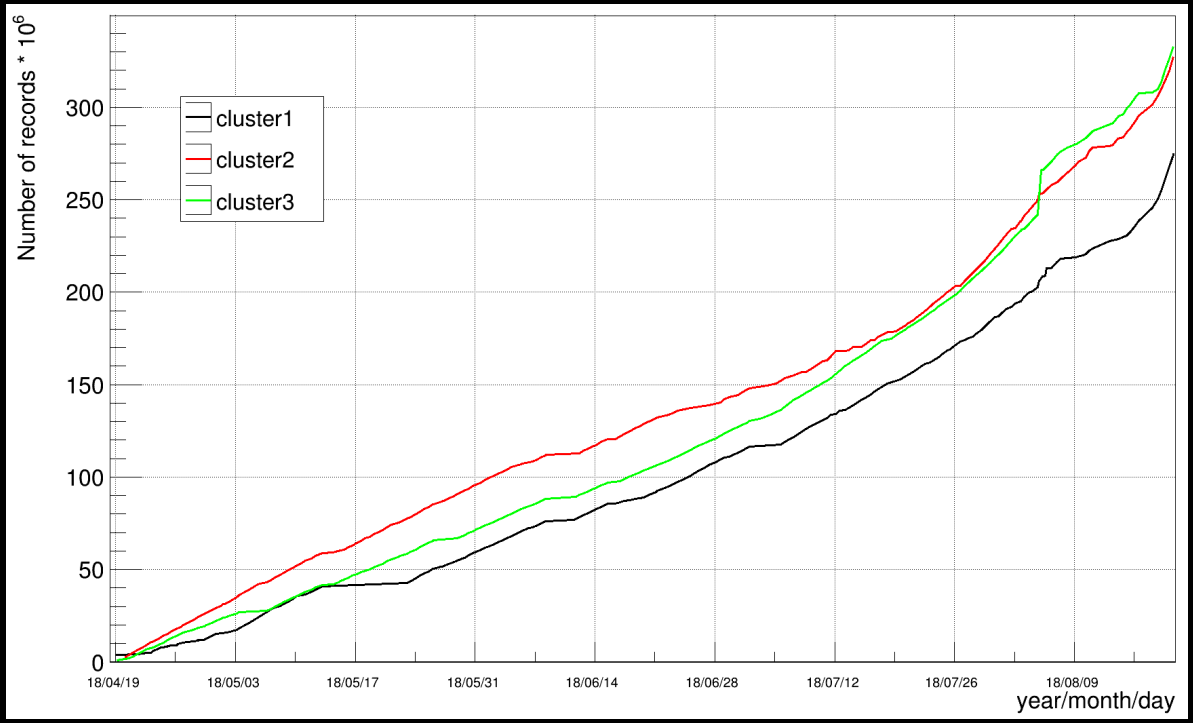


- Cluster 1 since 2016
- Cluster 2 since 2017
- Cluster 3 since 2018
- Powerful isotropic laser source

Data transmition

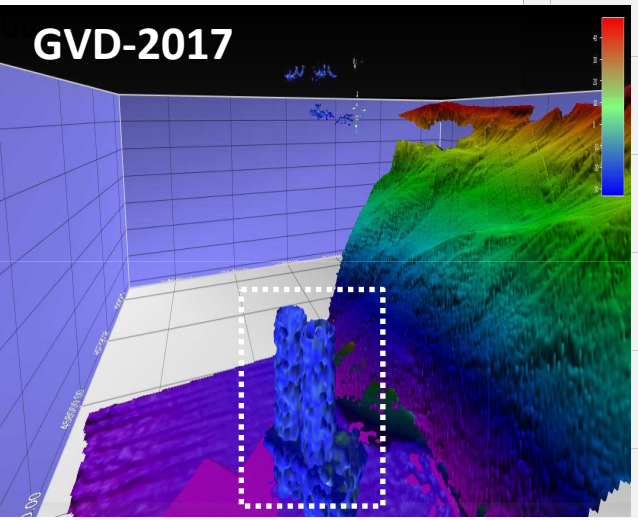
- 40 Gb per cluster per day to shore
- 5 Mb/s 40 km radio channel to Baikalsk
- Raw data transferred to storage Dubna facility through Internet

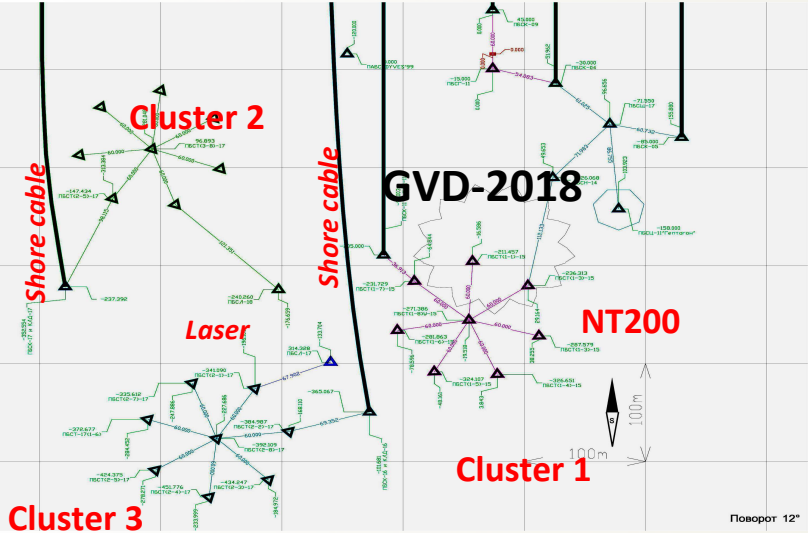
Third cluster April 2018
All 3 clusters taking data



Stages of deployment of the GVD-1

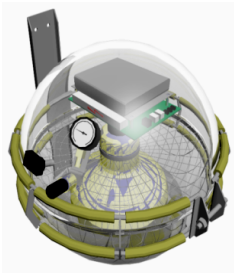
Configuration	2015	2016	2017	2018
The number of OMs	192	288	576	864
Geometric sizes, m	∅80×345	∅120×525	2×∅120×525	3×∅120×525
Eff. Vol	0.03 km^3	0.05 km^3	0.1 km^3	0.15 km^3



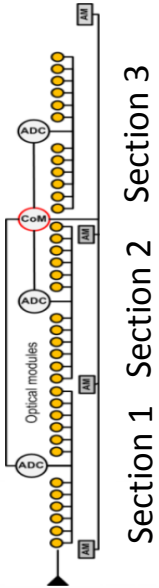


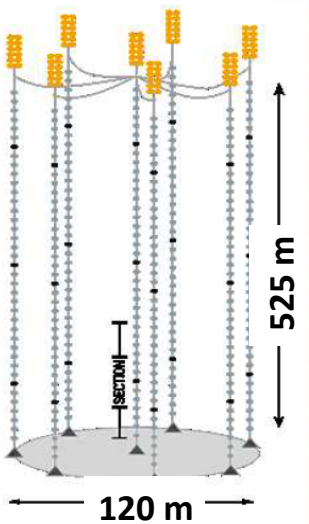
(image: echo location from boat, bathymetry)

Baikal-GVD: phase 1 (2020-2021)

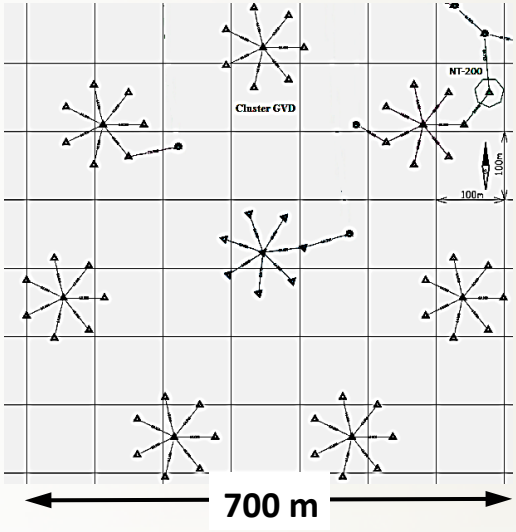


Optical module
PMT: R7081-100





Cluster: 8 strings



GVD-1: 8 clusters

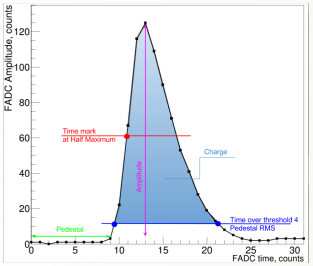
GVD-1	
OMs	2304
Clusters (8 Strings)	8
Depths, m	750 – 1275
Eff. Volume	0.4 km^3

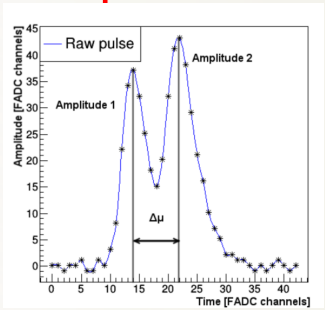
Directional resolution	Energy resolution
Cascades: 3.5° – 5.5°	δ(E/Esh) ~ 0.15
Muons: 0.25° - 0.5°	δ(lgE) ~ 0.4

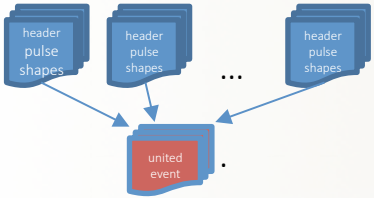
Data processing and analysis steps

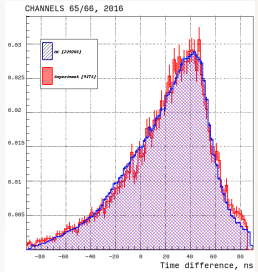
- Extraction of hit parameters from waveforms
- Joint events production
- Time and Amplitude calibration with light sources (laser source, LED matrixes, built-in OM LEDs) and atmospheric muons
- Geometry calibration with acoustic positioning system
- Data and Trigger quality monitoring

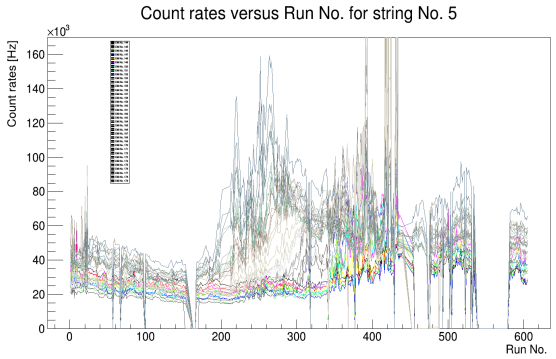
→ Telescope response: $Q\downarrow i, T\downarrow i, R\perp\rightarrow$

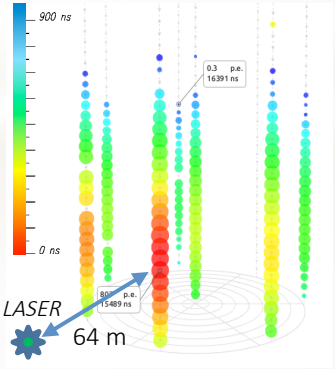


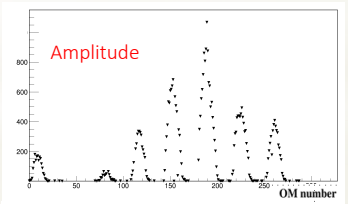


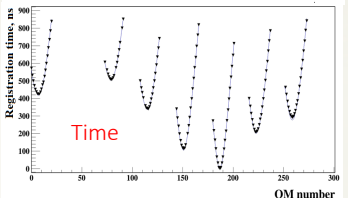




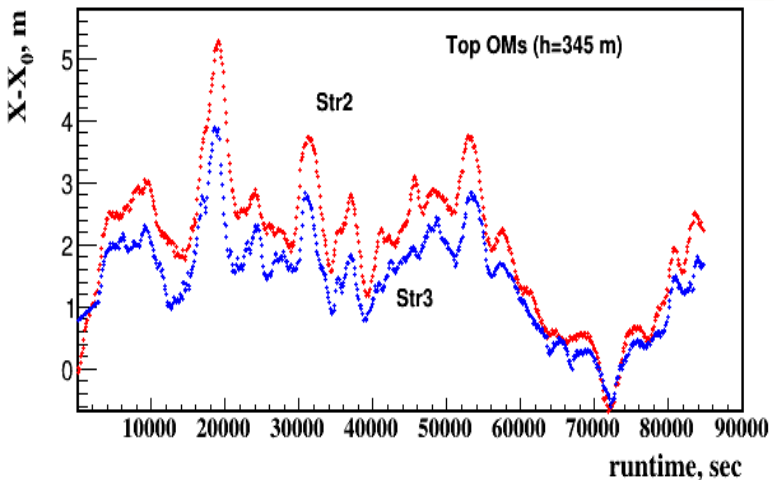




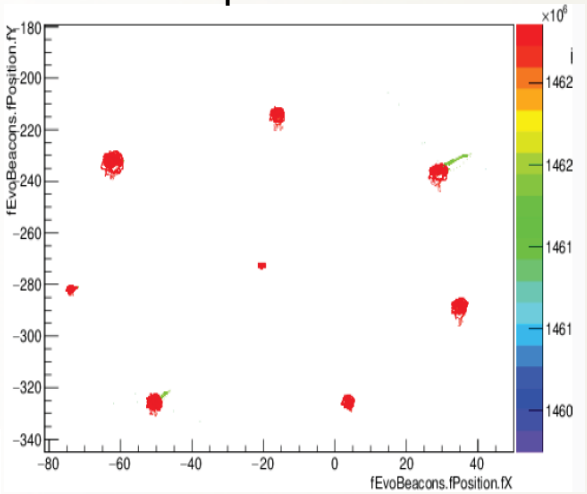


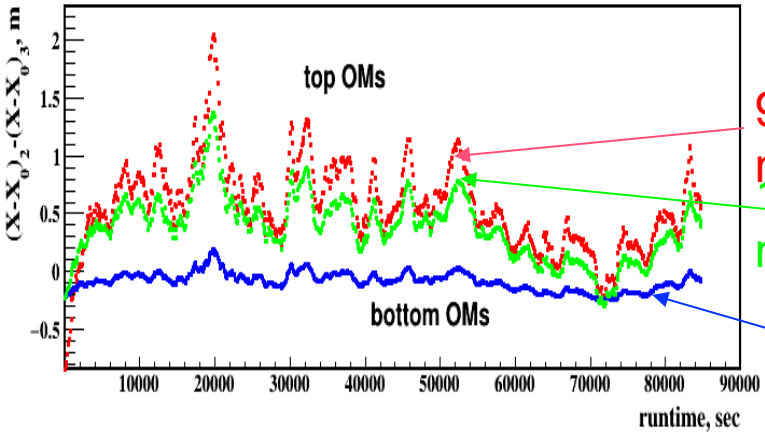


Performance of acoustic positioning system



Y-X node positions





925 m

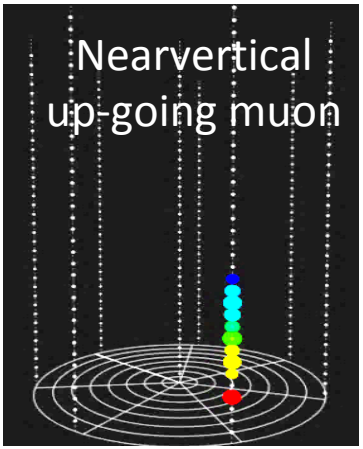
1105 m

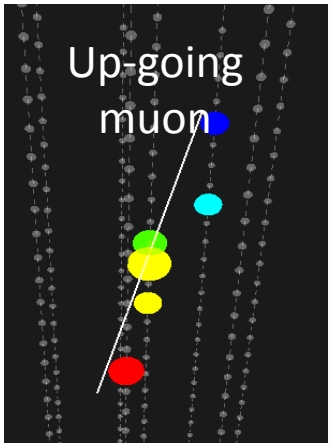
1270 m

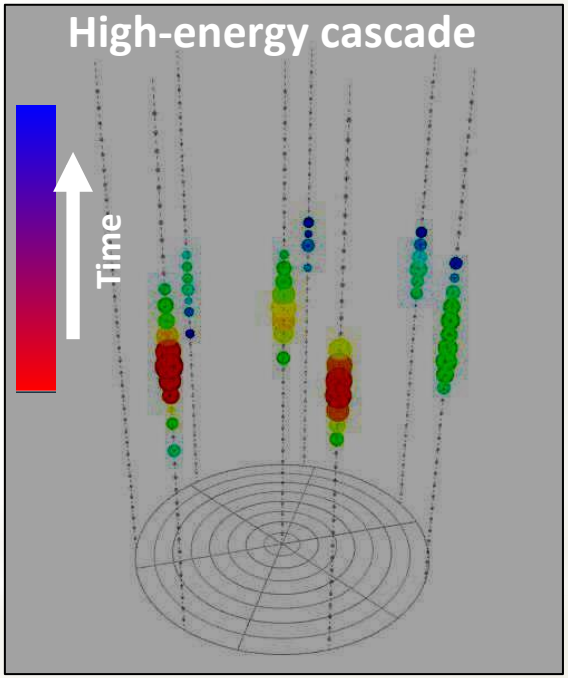
Detector response

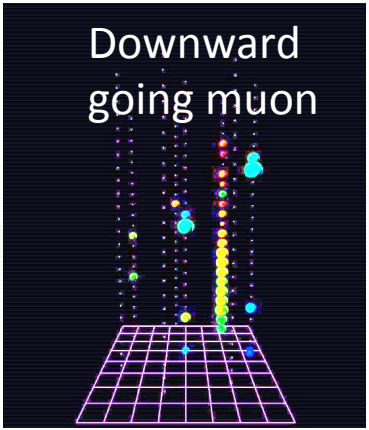
Neutrino signals

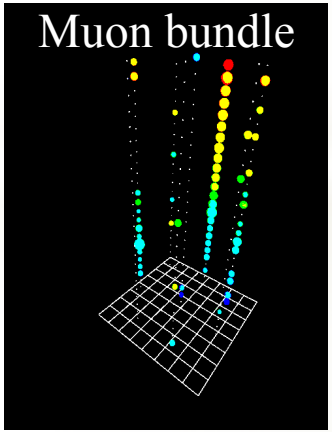
Background











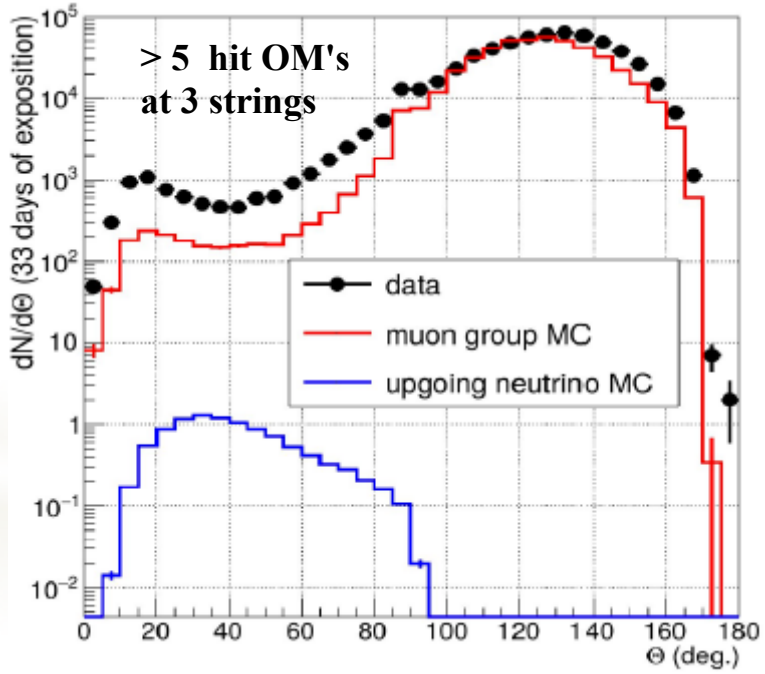
Search for muon neutrinos

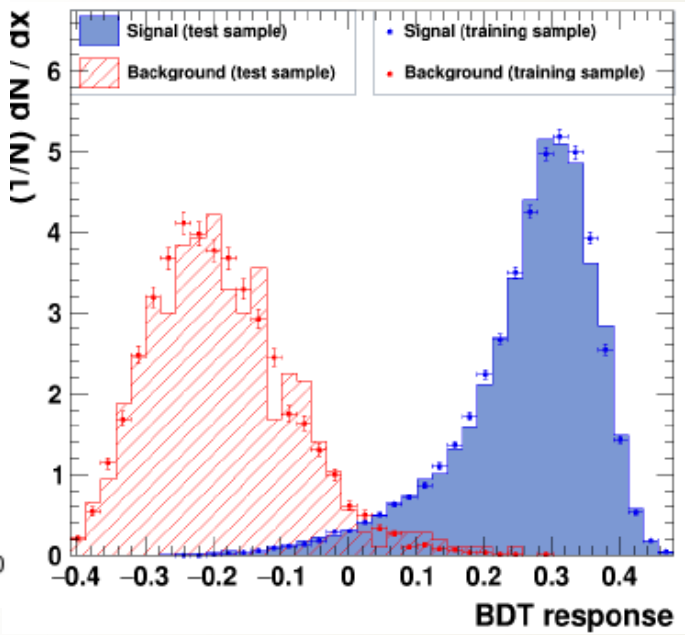
(analysis of 2016 data sample – ***PRELIMINARY!***)

Muon neutrino are detected as a muon tracks from bottom hemisphere

After reconstruction: 1 cluster, 33 live days

After track reconstruction and cuts on quality variables have been done, Boosted decision tree (BDT) was used



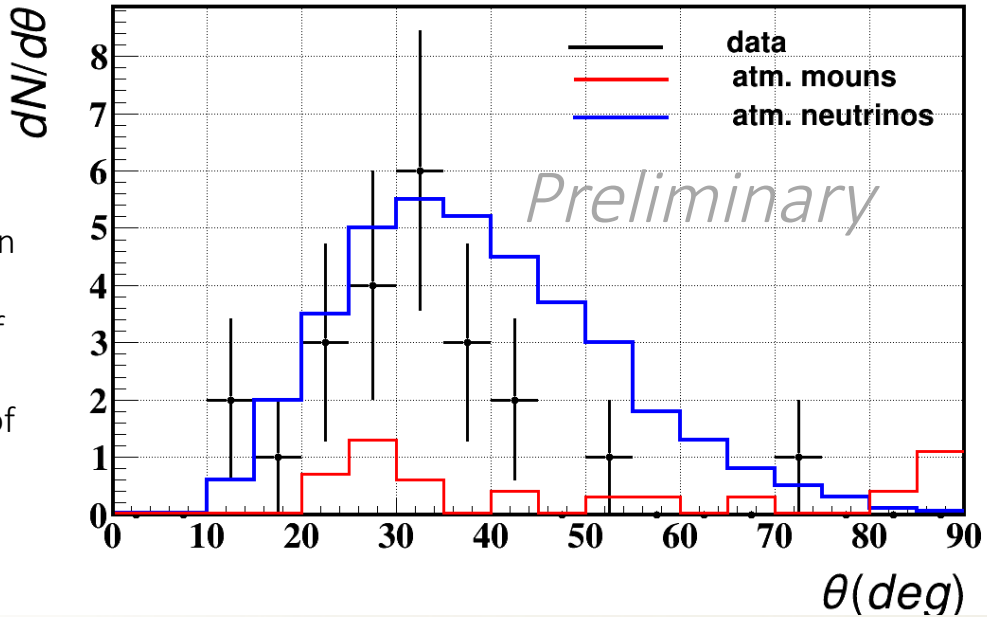


Zenith angle distributions of muons

First neutrinos selected

33 live days were used

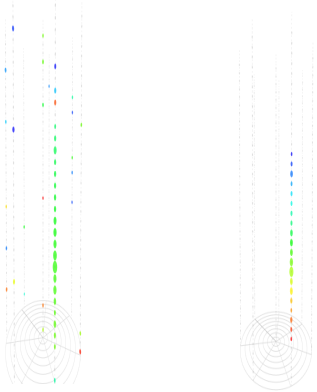
Angular distribution
BDT > 0.2 cut



- 23 events were selected in the signal region in data
- ~ 3 events – estimation of atm. muons background
- ~36 events – estimation of signal atm. neutrinos

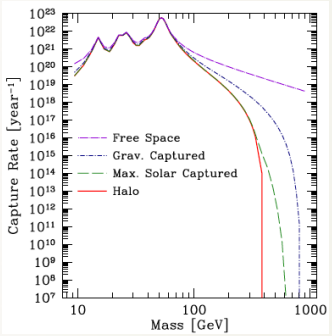
Near vertical events: start searches for DM from the Earth core

MC original Reconstructed (20 hits)

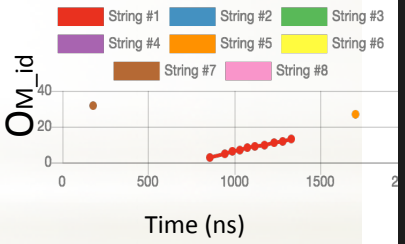


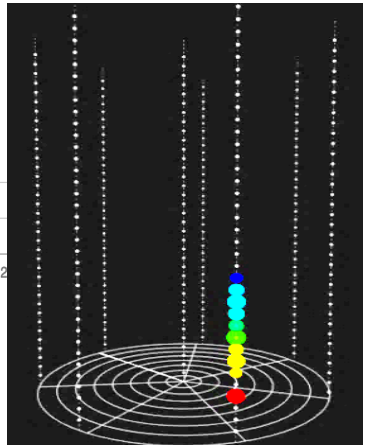
Example: nuEnergy =1.6TeV;
Theta_MC= 4.60°; Theta_rec=3.99°

Selection criteria:
presence at one string the chain of 5 hits or more with velocities of speed of light between OM pairs within physical window 0.2—0.4 m/ns, while their amplitudes per OM should be higher 3p.e.
Also preferable is a single pulse per hit.



2016, 1st cluster, Run 404, event with no gap in 10 hits





Experimental data sample:
1st GVD-cluster 2016, 182 l.days, total number of events 4.5x10^8, 5674 selected candidates to look for neutrinos: 144 events with 6 hits, 15 events with 7 hits, 6 events - 8 hits and only one of them has 10 hits, .

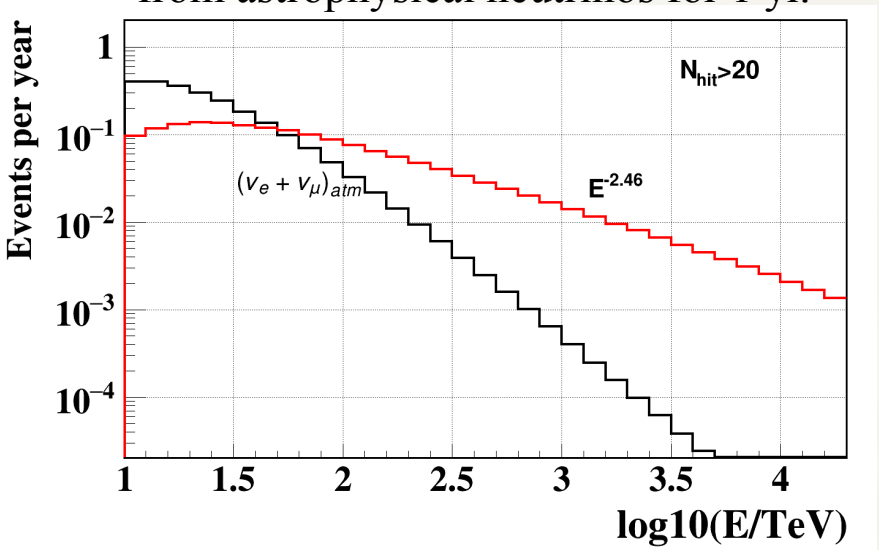
Search for cascades induced by astrophysical neutrinos

Directional resolution of cascades in water: 3°- 5°

Cascade selection:

- Causality cuts (noise rejection);
- Reconstruction of cascade position direction and energy and cuts on quality parameters;
- $N_{hit} > 20$

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



About 0.6 events/year are expected for 1 GVD cluster

A search for cascades induced by astrophysical neutrinos

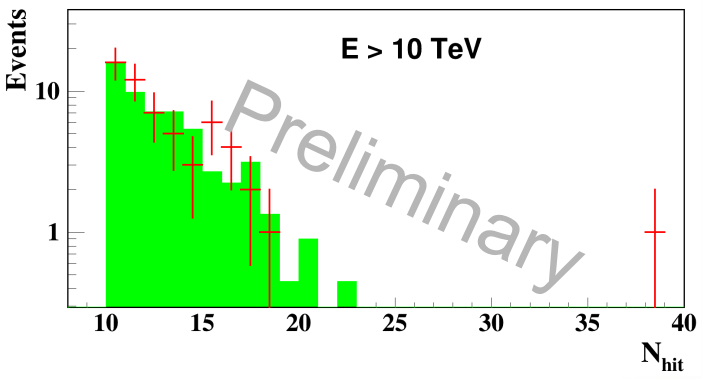
(analysis of 2016 data– ***PRELIMINARY!***)

- Life time – 15 693 192 s = 182.0 days
- Total number of accumulated events – 6.86×10^8 events

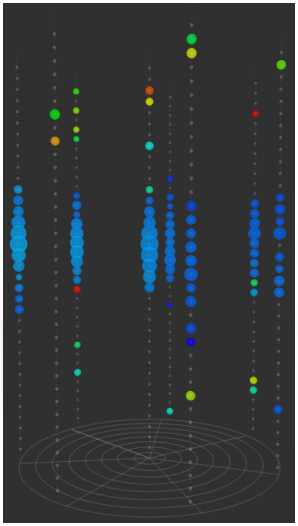
  (thresholds: low/high = 1.5/4 ph.el. & Q >1.5 ph.el.)
- After causality cuts – 3.27×10^8 events

  ($N_{hit} > 4$; $|t_i - t_j| < \Delta r_{ij}/v + \delta t$)

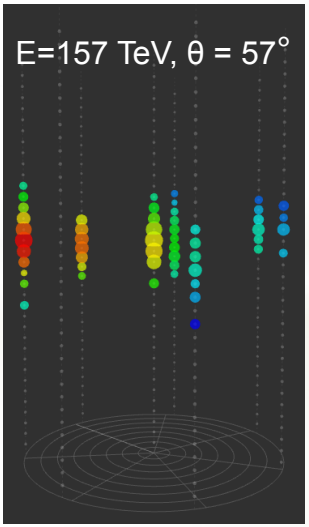
Cascade analysis with the first GVD cluster 2016



Cuts	Events	Rejection
Coordinates reconstruction & N_{hit} >9	577495	1
$\chi^2 < 4$	2405	1/240
Energy reconstruction		
$L_a < 20$	374	1/6.4
$\eta > 0$	159	1/2.4
E > 10 TeV	57	1/2.8
E > 100 TeV	5	1/11.4
Total rejection factor:		1/115499

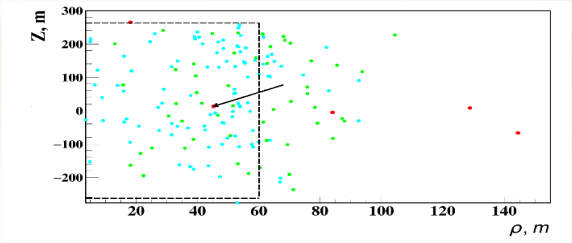


All hit OMs (93 hits)

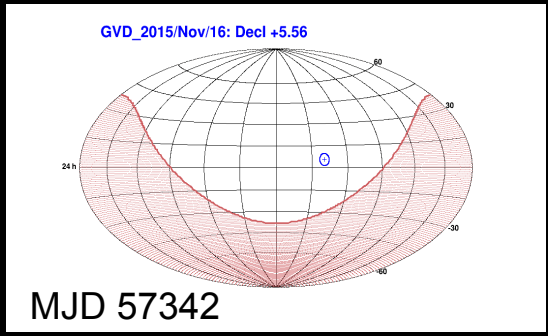


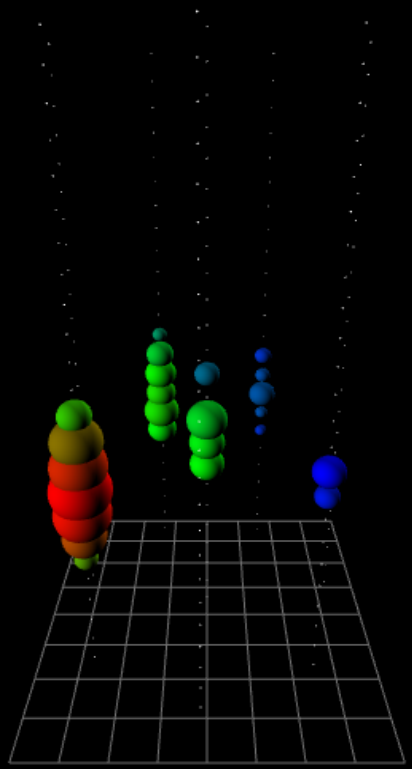
Selected hits for reconstruction (53 hits)

E=157 TeV, θ = 57°, φ_{loc} = 249°,
x=-25m, y=-37m, z=11m, ρ=44m



2015: E = 107 TeV, θ = 56.6°, φ_{loc} = 130°, ρ = 68 m, z = -59 m





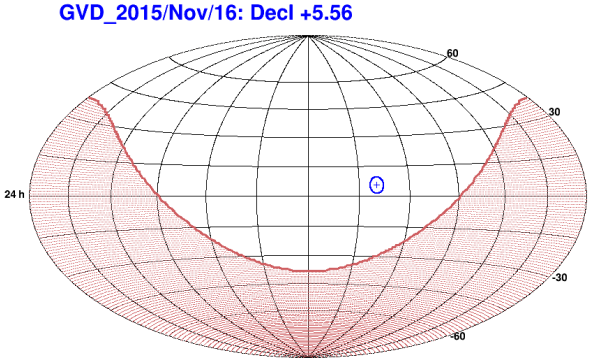
Cherenkov radiation

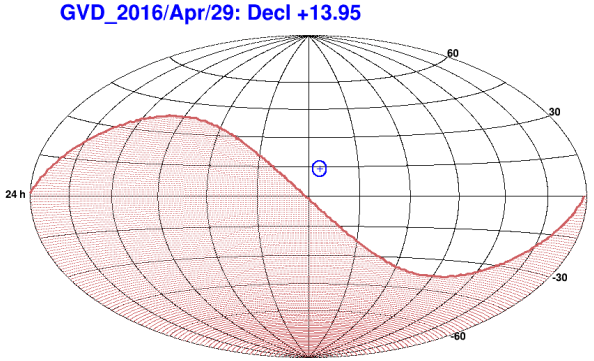
Shower direction

Skymap on two GVD cascade events with E>100 TeV

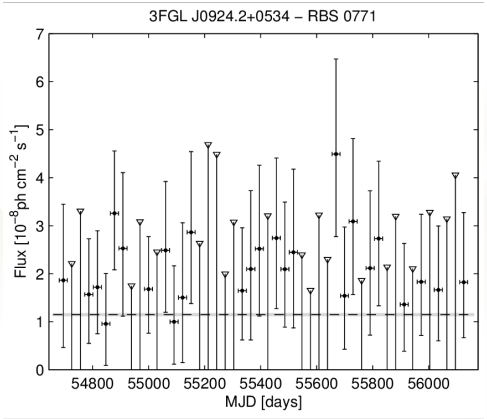
MJD 57342, E_{sh} 107 TeV

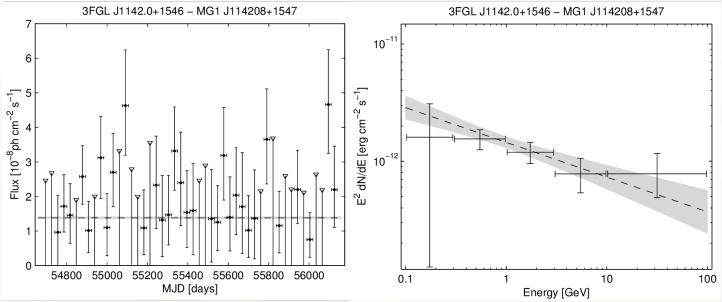
MJD 57507, E_{sh} 157 TeV





analysis in term of p-val is in progress



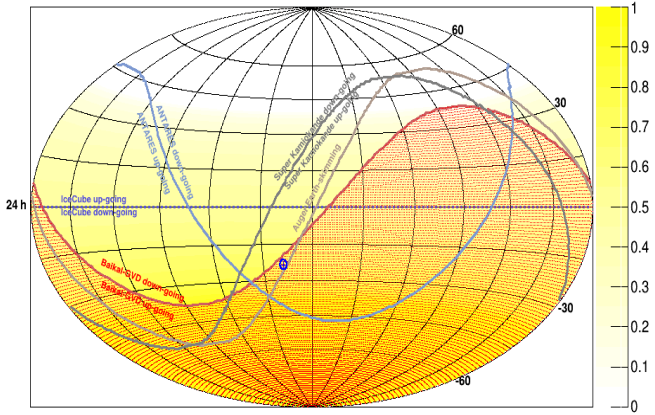


No TeV cat, MJD 54800-56008

2017: GVD horizon in time of 2 cosmic events

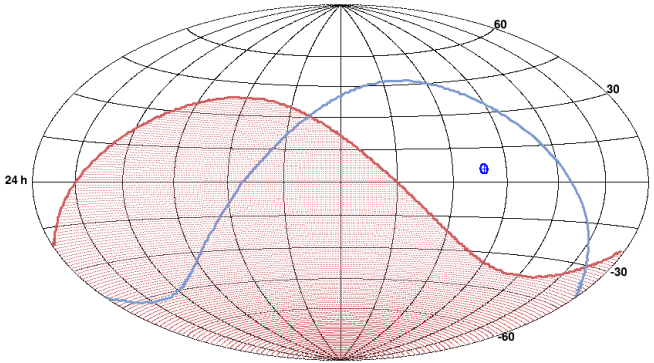
GW170817: NGC4993 Decl -23.38

GW: 17.08.2017, (Advanced LIGO & Advanced VIRGO)
GRB170817A - 1.7 s delay (Fermi-GBM and INTEGRAL)



Cascade mode: search for events in two time-windows:
GW ± 500 sec (prompt emission): zenith angle θ = 93°.
GW +14 days (delayed emission); 74° < θ < 150°

IC170922A: TXS0506+056



IceCube on 22 September 2017: the first evidence for the existence of an astrophysical source of high-energy neutrinos

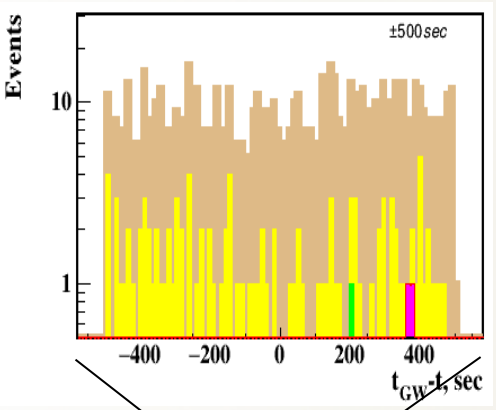
Baikal-GVD ANTARES

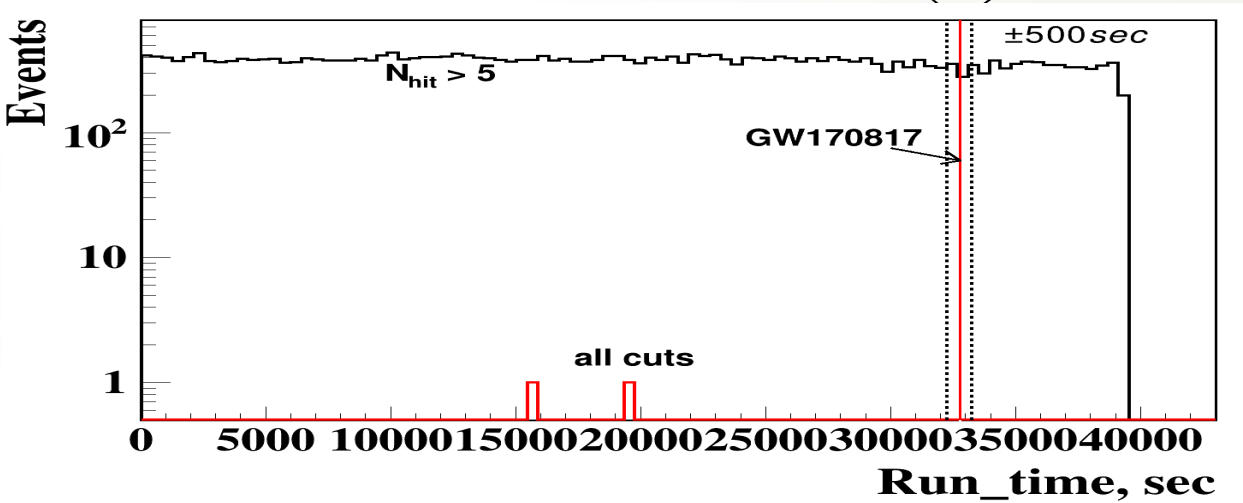
Cascade mode: analysis is in progress

Search for neutrinos toward GW170817 within ± 500 sec

Cl.#1, run g0269; duration 39347 sec; 2463792 ev.

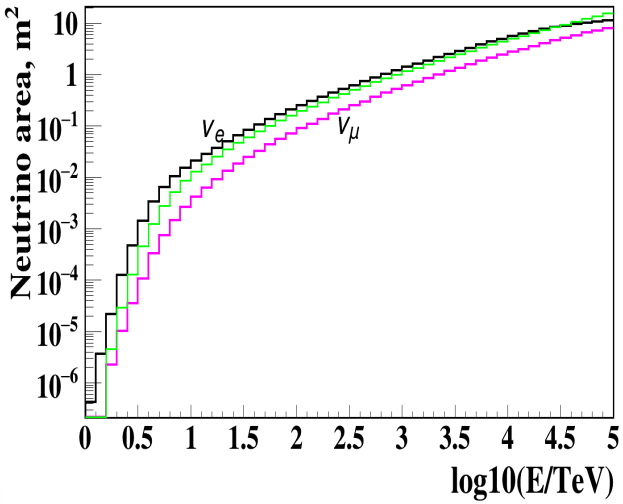
Cut	Events in ± 500 sec window
N_{hit} > 5 OM/3 Str.	731
χ^2_t < 10	108
η > 0	3
L_a < 30	2
ψ < 20°	0 (0.05 events is expected)





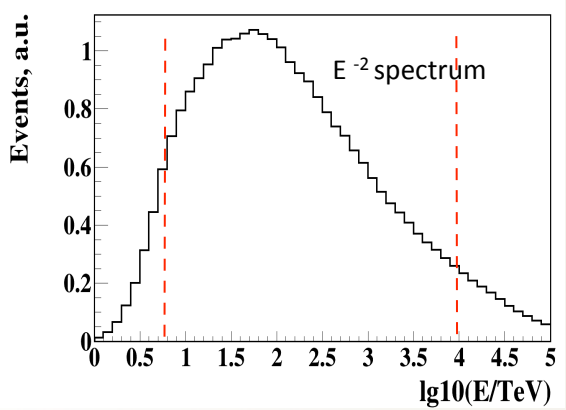
Search for neutrinos within GW ± 500 s time-window

Neutrino effective area after all cuts

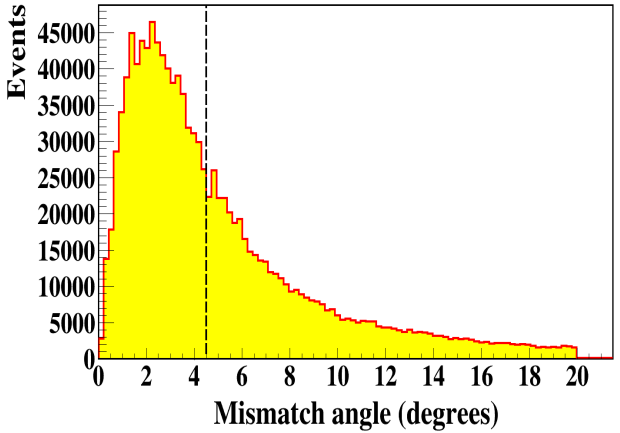


Cone$^{1/2}$ ~ 4.2°

Expected energy distribution of events.
90 % of E^{-2} events within 5 TeV < E < 10 PeV

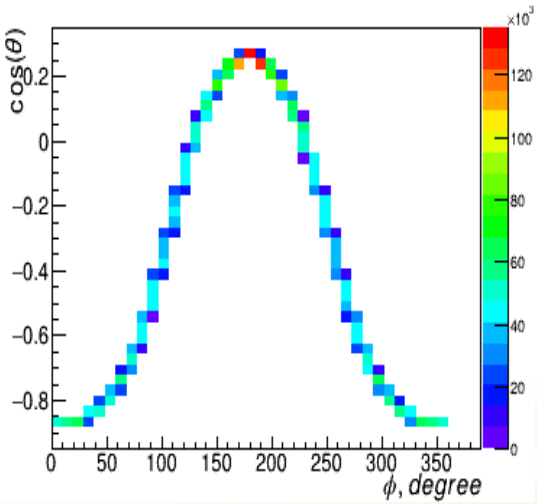


Shower direction reconstruction error



Search for neutrinos in GW170817 following 14 days time-window

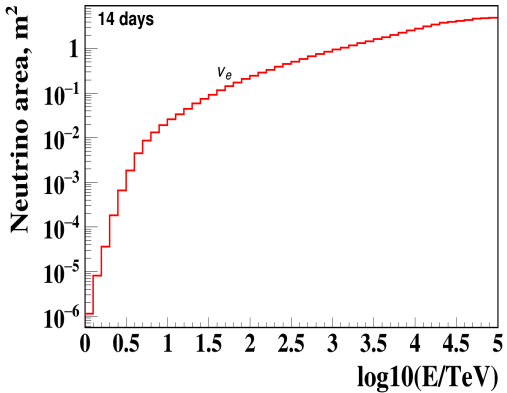
Coordinates of NGC4993
zenith angle range 74° < θ <150°



Selection cuts

Cut	Events in 14 day window
N_{hit} > 7 OM/ 3 Str.	384116
χ^2_t < 6	12186
η > 0	445
L_a < 30	372
ψ < 20°	0

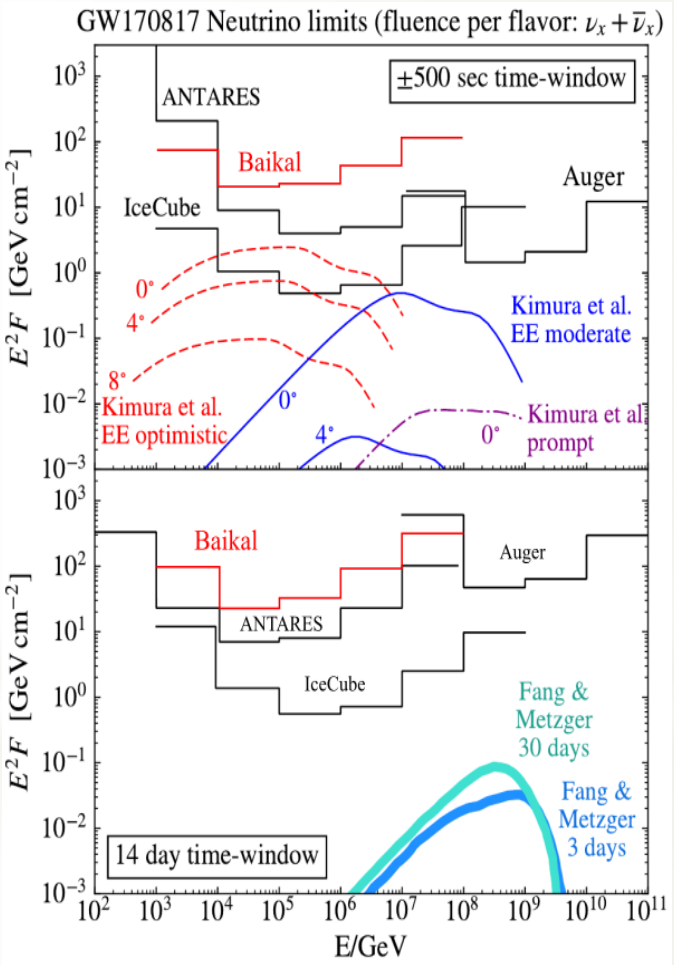
Neutrino detection area

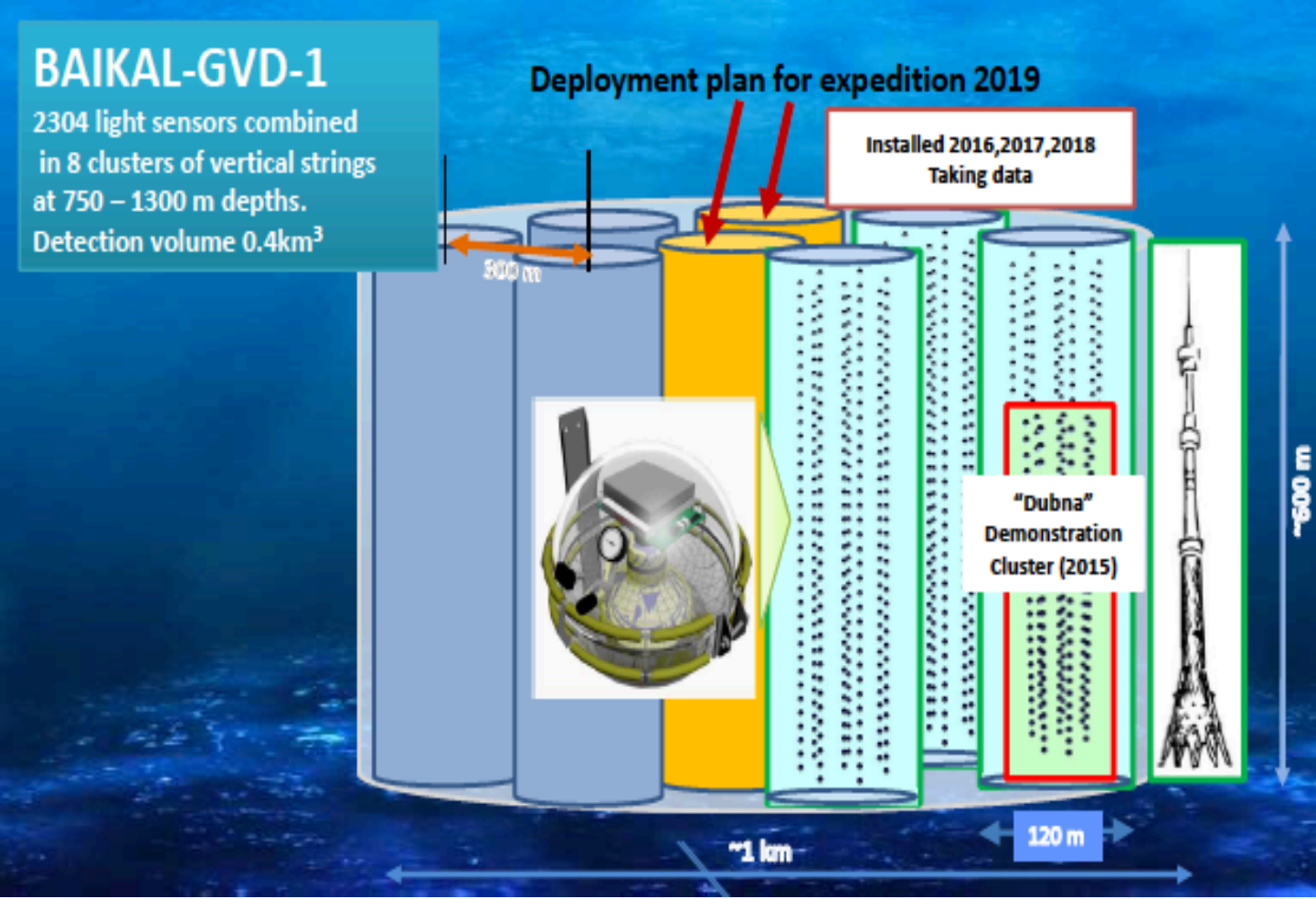


Upper limits on fluence of neutrinos associated with GW170817

No neutrino events associated with event GW170817A have been found in cascade search mode within the time window ± 500 seconds and 14 days after neutron stars merging.

Assuming E^{-2} spectral behavior and equal fluence in all flavors, upper limits at 90% c.l. have been derived on the neutrino fluence from GW170817 for each energy decade.




BAIKAL-GVD-1
2304 light sensors combined
in 8 clusters of vertical strings
at 750 – 1300 m depths.
Detection volume 0.4km³
Deployment plan for expedition 2019
Installed 2016,2017,2018
Taking data
300 m
"Dubna"
Demonstration
Cluster (2015)
~1 km
120 m
~600 m

Timeline GVD 1

Year	2016	2017	2018	2019	2020	2021
Nb. of clusters	*1*	*2*	*3*	*5*	*7*	*9*
Nb. of OMs	*288*	*576*	*864*	*1440*	*2016*	*2592*

Summary

- Prototyping & Early Construction Phase of Baikal-GVD project is concluded with construction of the first GVD Cluster in 2015, that was upgraded to baseline configuration in 2016
- The second and the third full-scale GVD clusters were installed and commissioned in April 2017 and April 2018
- Experimental data obtained in period 2015 - 2017 were used to search for neutrino events of astrophysical nature
- Completion of the GVD-1 is expected in 2020-2021

Thank you for your attention