Baikal-GVD project: current status and prospects

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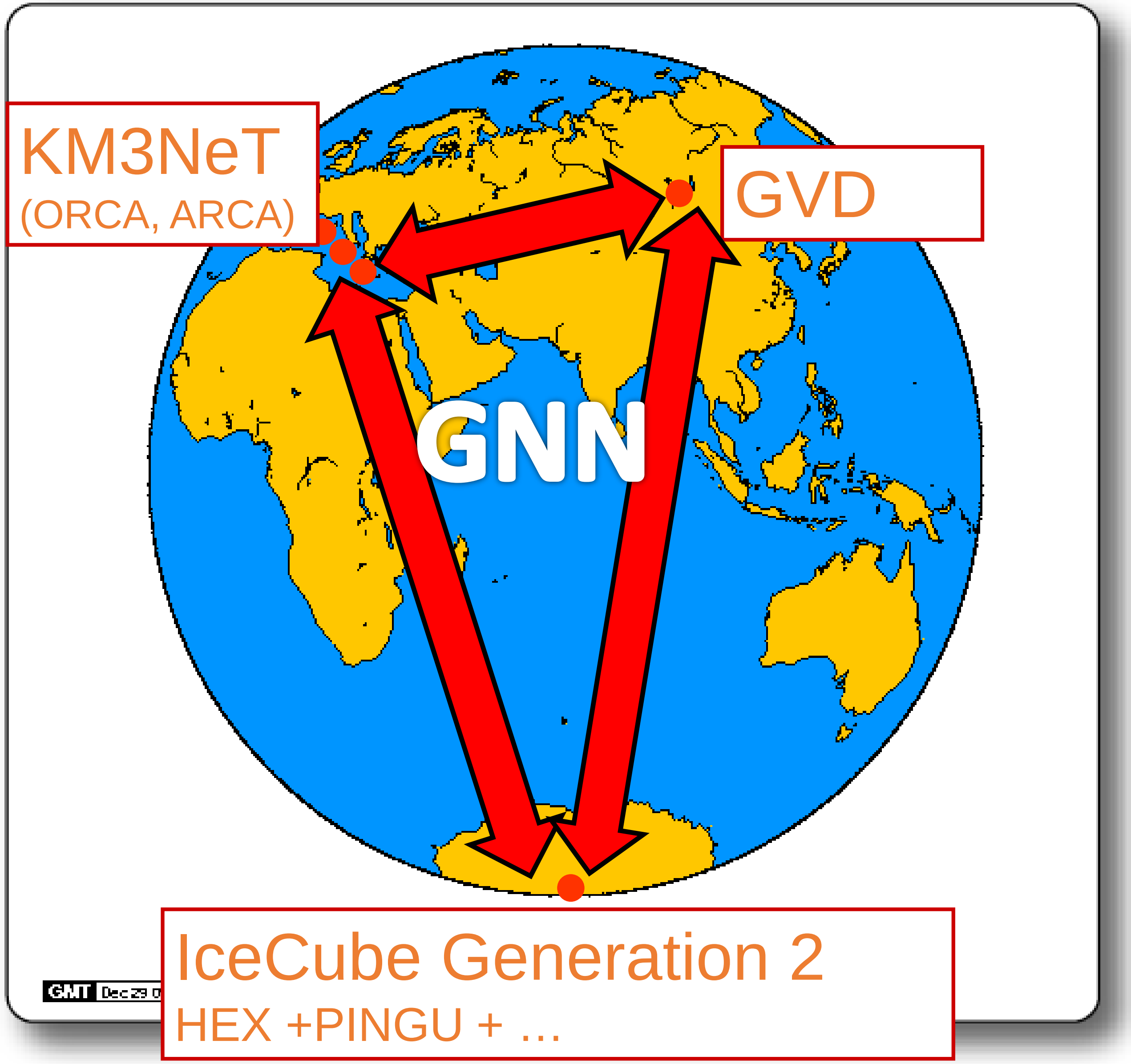
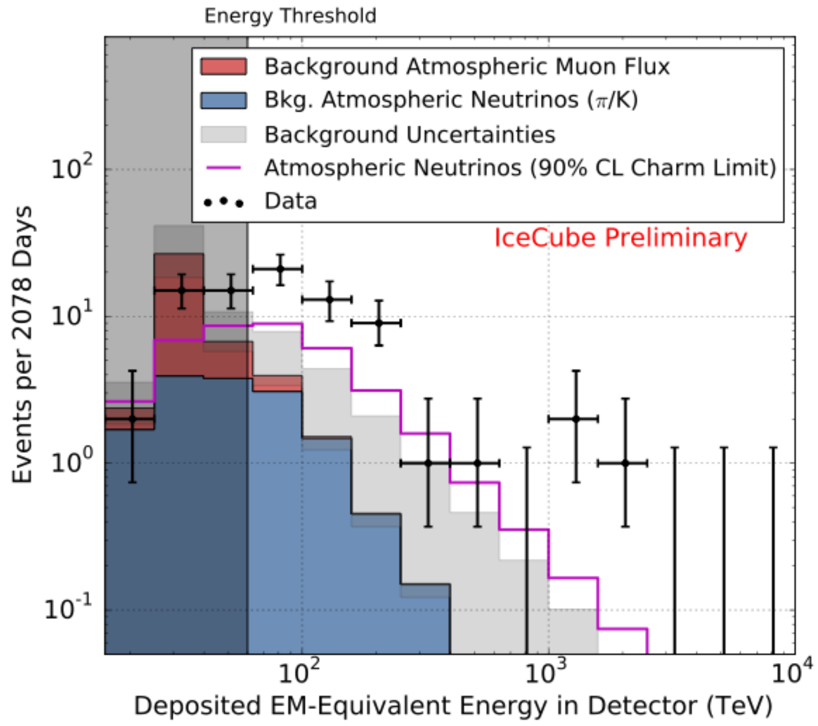
for the Baikal Collaboration
QUARKS-2018, October 07, 2018

Baikal, Mediterranean Sea, South Pole

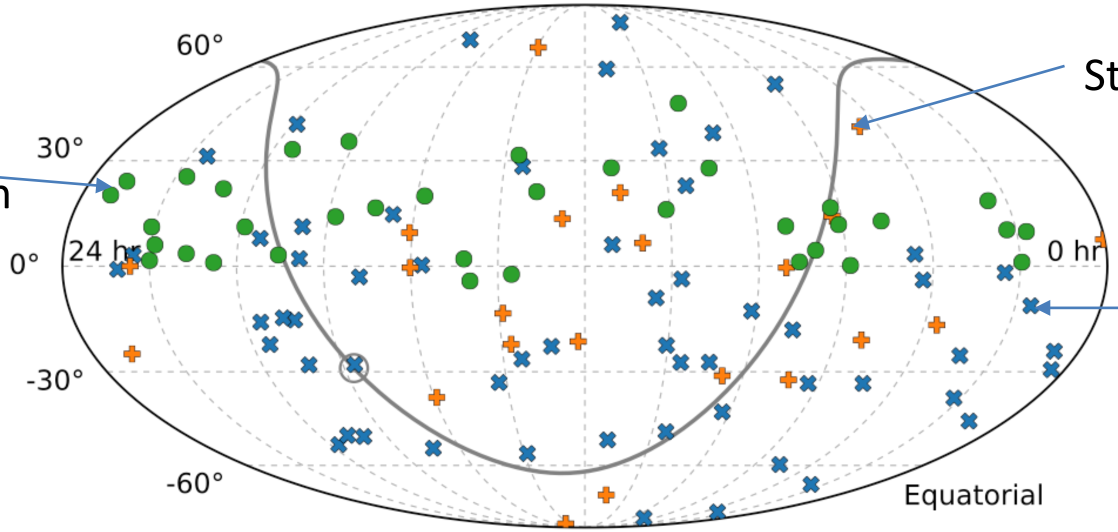


IC astrophysical neutrinos

82 events started
in IC volume in 6 years



Through-going tracks
E>200 TeV, more than
50% of events are
astrophysical



Starting tracks

Cascades

Baikal GVD

baikalweb.jinr.ru

Gigaton Volume Detector (GVD) in Lake Baikal

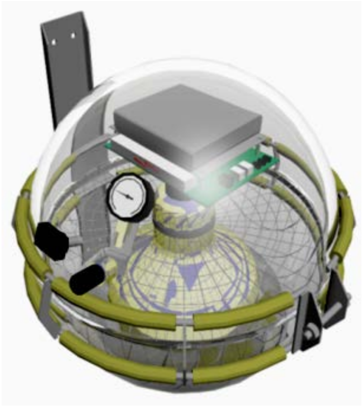
Objectives:

- km3-scale 3D-array of photo sensors
- flexible structure allowing an upgrade and/or a rearrangement of the main building blocks (clusters)
- high sensitivity and resolution of neutrino energy, direction and flavor content

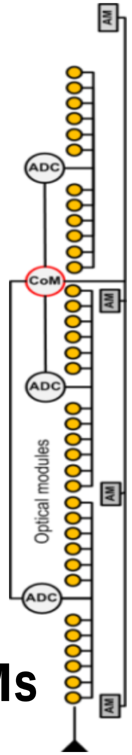
Central Physics Goals:

- Investigate Galactic and extragalactic neutrino "point sources" in energy range > TeV
- Diffuse neutrino flux – energy spectrum, local and global anisotropy, flavor content
- Transient sources (GRB, …)
- Dark matter – indirect search
- Exotic particles – monopoles, Q-balls, nuclearites, …

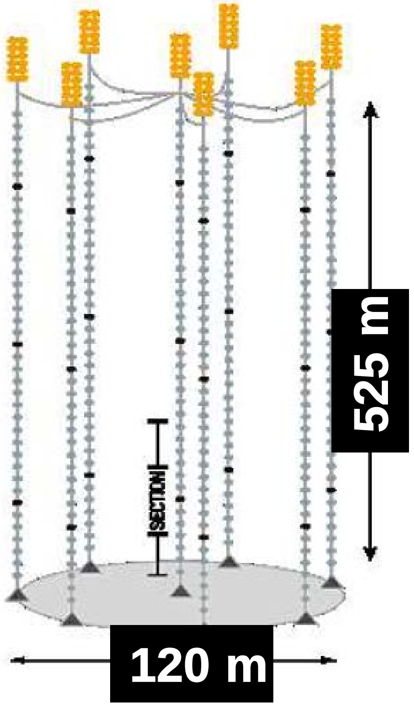
Baikal-GVD : phase 1 (up to 2020)



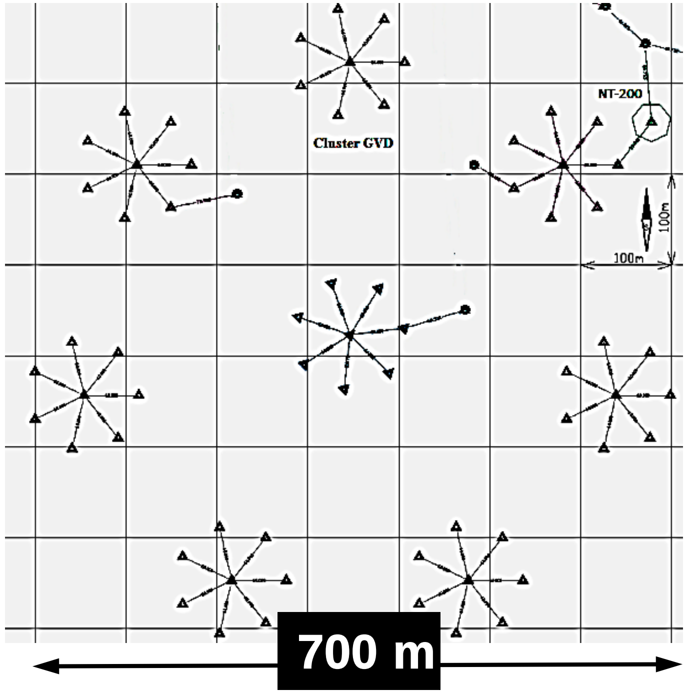
Optical module



String: 36 OMs



Cluster: 8 strings



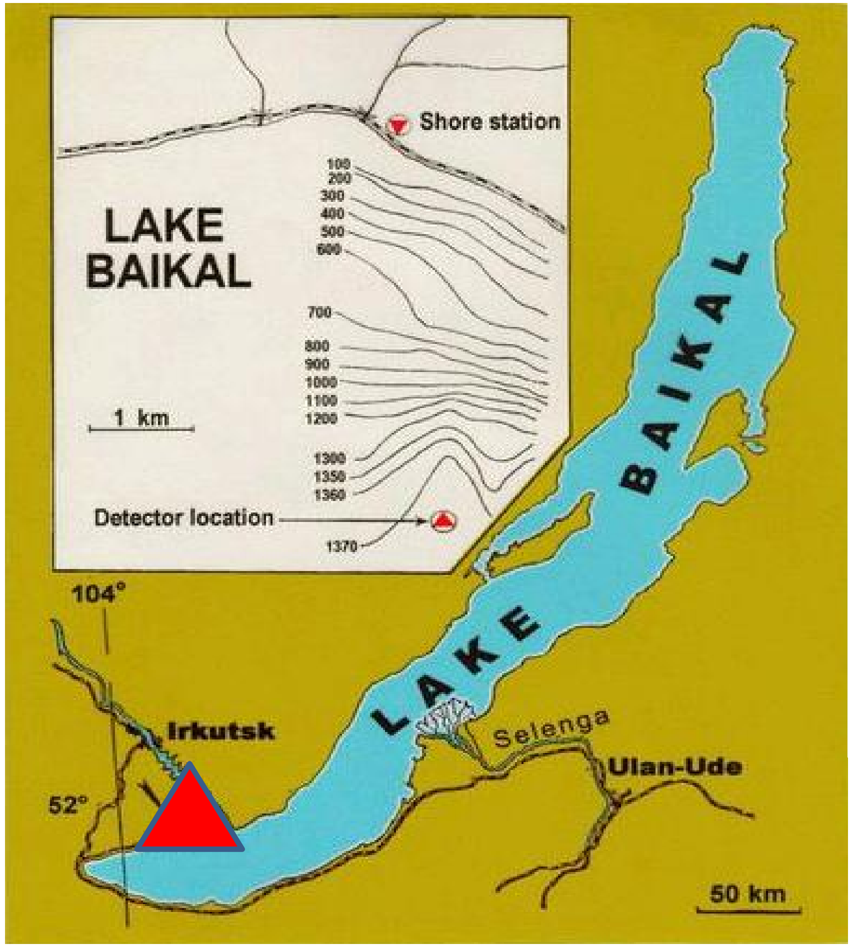
GVD-1: 8 clusters

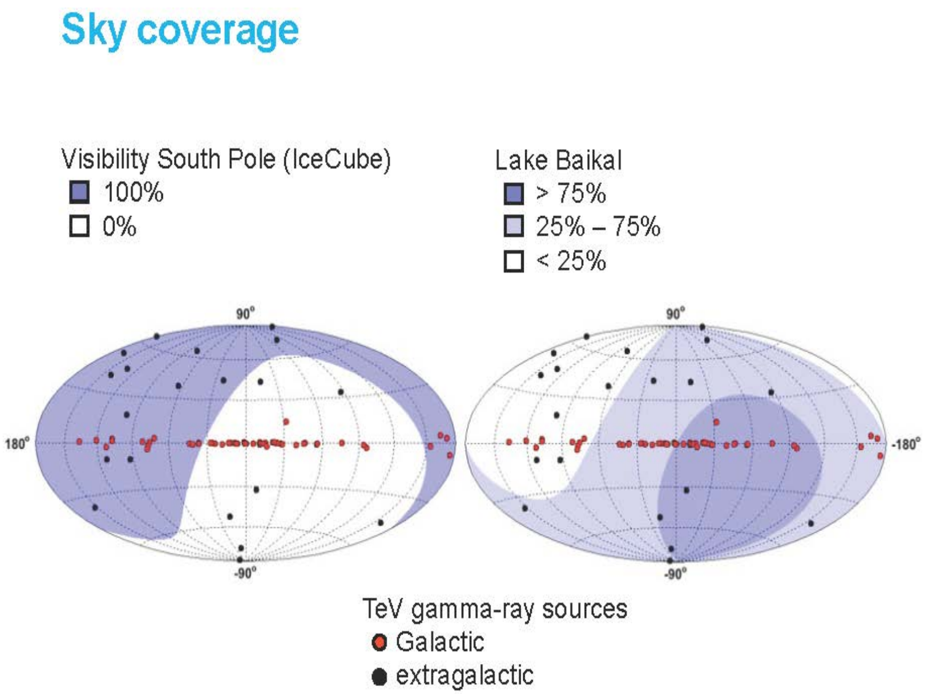
	GVD-1
OMs	2304
Clusters (8 Strings)	8
Depths, m	750 – 1275
Eff. Volume (E_{SH} > 100 TeV)	0.4 km^3

Directional resolution	Energy resolution
Cascades: ~3°	δ(E/Esh) ~ 0.15
Muons: 0.25° - 0.5°	δ(lgE) ~ 0.4

• Location: 104º25’ E; 51º46’ N

Northern hemisphere– GC (~18h/day) and Galactic plane survey

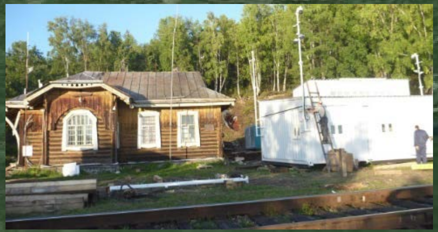




The site

Location: 104°25' E; 51°46' N

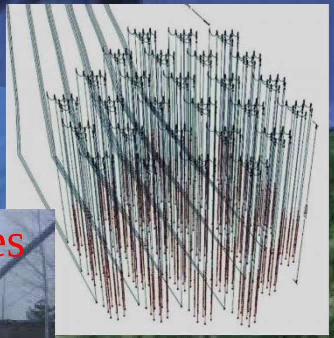
Shore station



36 km

Baika'lsk

Workshop&Storage facilities



Site:

- 1370 m maximum depth
- Distance to shore ~4 km
- No high luminosity bursts from biology.
- No K^{40} background.

Baikal water

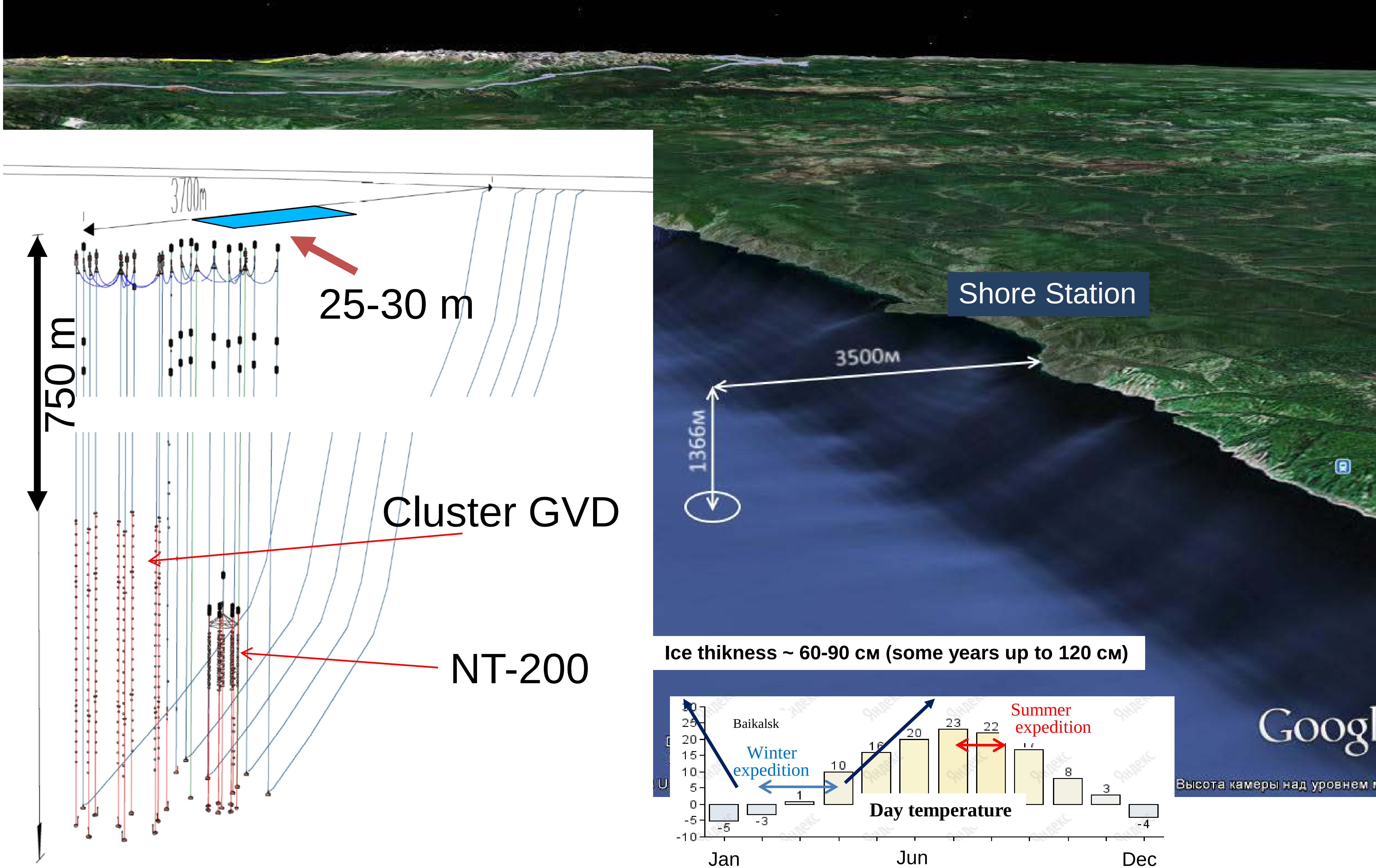
Abs.Length: 22 ± 2 m

Scatt.Length: 30-50 m

Data INTAS Project 99-1669

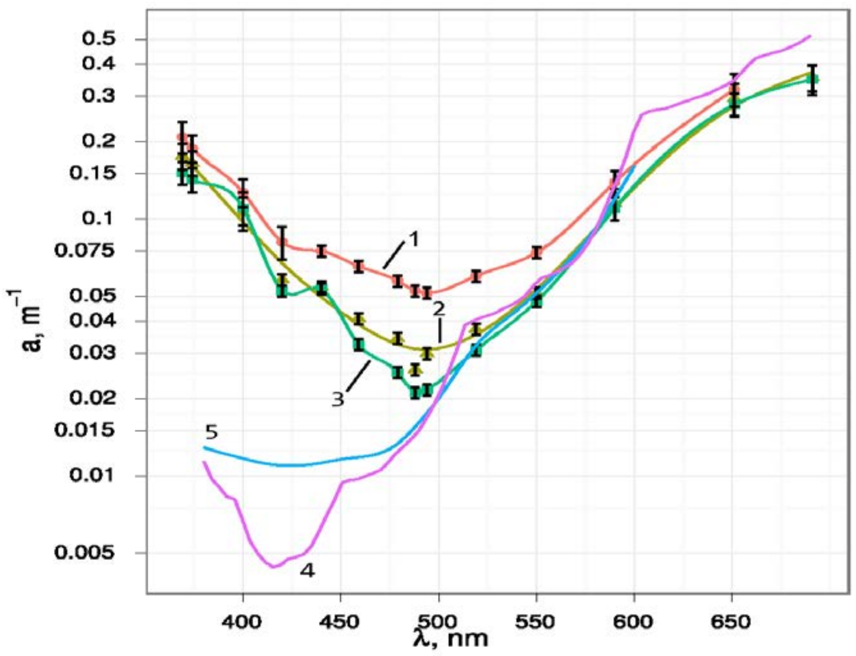
Image Landsat

Google earth

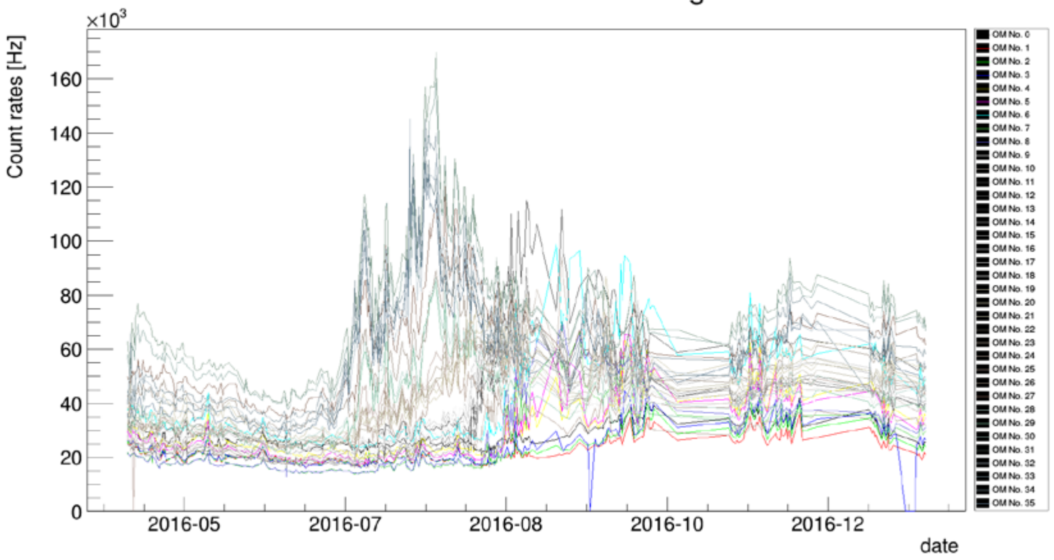


3700m
25-30 m
750 m
Cluster GVD
NT-200
Shore Station
3500м
1366м
Ice thikness ~ 60-90 cм (some years up to 120 cм)
Baikalsk
Winter expedition
Summer expedition
Day temperature
-5
-3
1
10
16
20
23
22
8
3
-4
Jan
Jun
Dec

Water properties



- **Absorption length: ~ 22-24 m**
- **Scattering length: L_s ~ 30-50 m**
  $L_{eff} = L_s /(1- <\cos\theta>)$ ~ 300-500 m
- **Strongly anisotropic phase function: $<\cos\theta>$ ~ 0.9**



- **Moderately low background in fresh water:**

  15 – 40 kHz (R7081HQE)
  absence of high luminosity bursts from biology and K^{40} background.

Infrastructure (site)

Status:

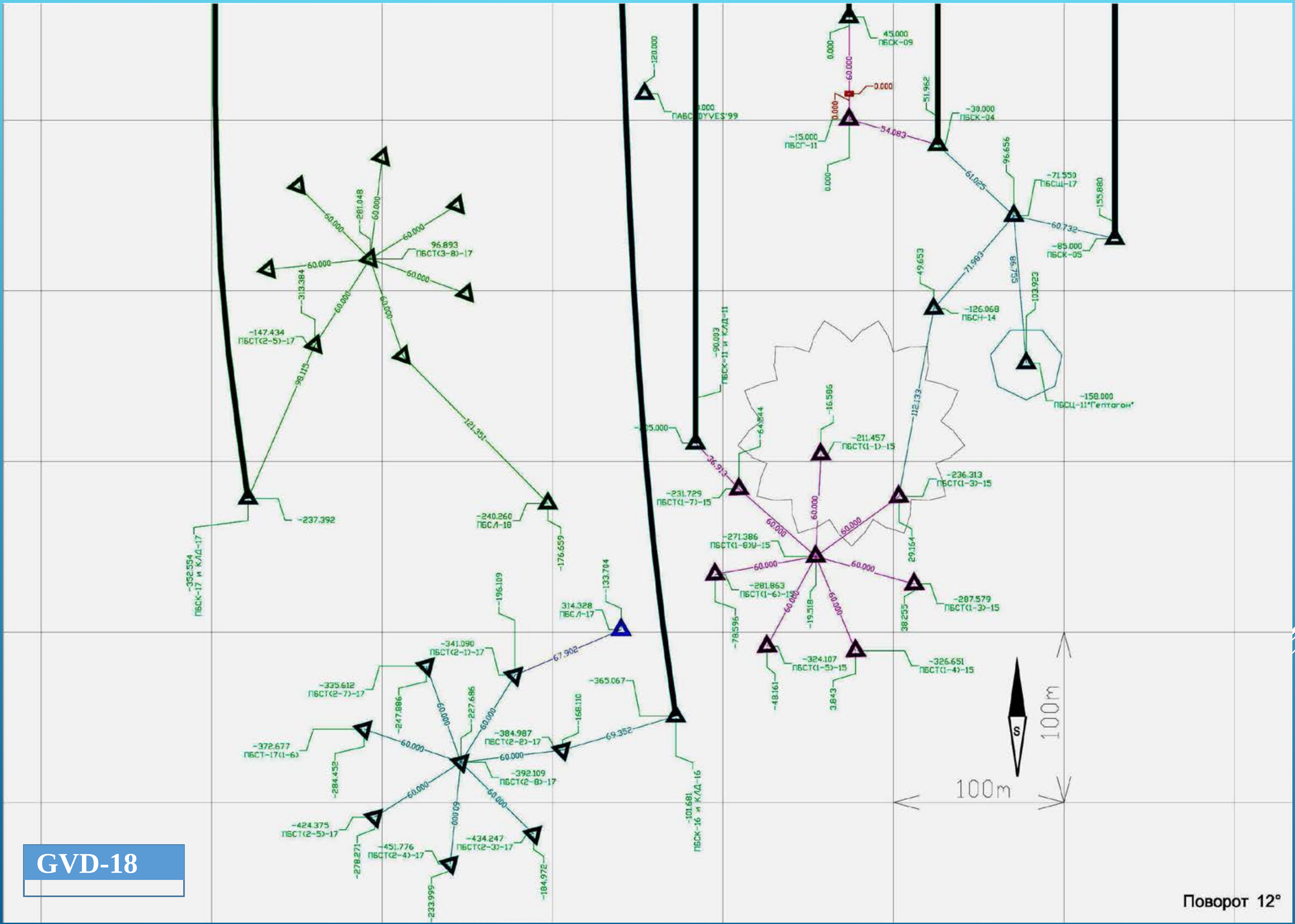
- ✓ The DUBNA cluster installed on April 2015 has been upgraded to a final state one with 288 optical modules in 2016 spring . The second cluster started to operate on April 2017.
- ✓The new data taking center at the array site has been installed.
- ✓The new shore lab was installed on the site during summer 2017.
- ✓The building in Baikalsk is prepared for a local lab and a temporary storage for optical modules of the next stages of the detector.

The optical modules production facility (Rearrangeed 2017)

The facility allows to produce and test up to 12 OM per day
We need to produce and send to the site 600 OM up to end of February

Stages of deployment of the Baikal-GVD

Configuration	2015	2016	2017	2018
The number of OMs	192 (8str×24)	288 (8str×36)	576	864
Geometric sizes	∅80m×345m	∅120m×525m	2×∅120m×525m	3×∅120m×525m
Eff. Vol. (E > 100TeV)	0.03 km^3	0.05 km^3	0.1 km^3	0.15 km^3



GVD-18

Third cluster April 2018
All 3 clusters taking data

Now clearly bypassed ANTARES

Nb PMTs:

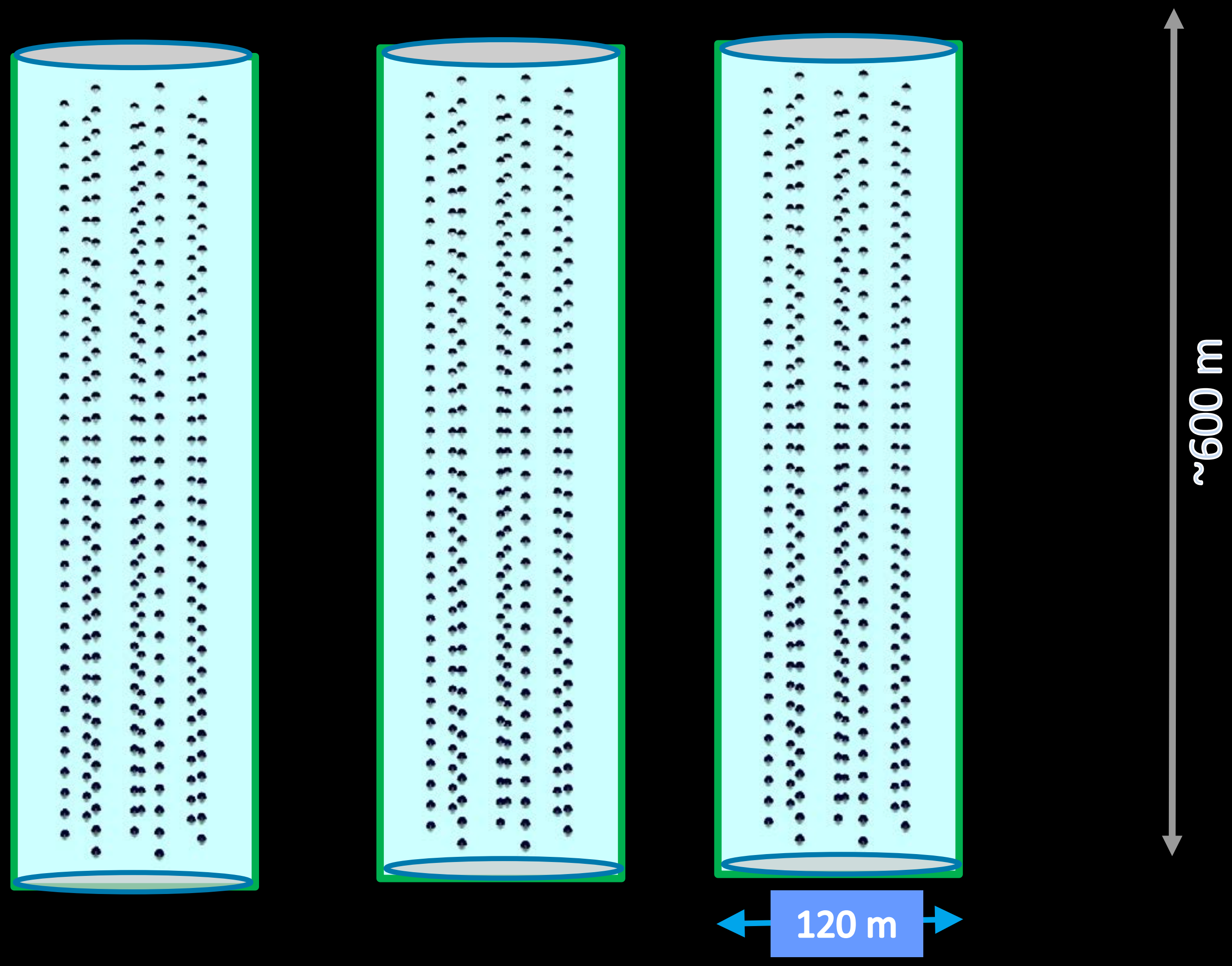
ANTARES: 885

GVD 2018: 864

Nb space points:

ANTARES: 295

GVD 2018: 864

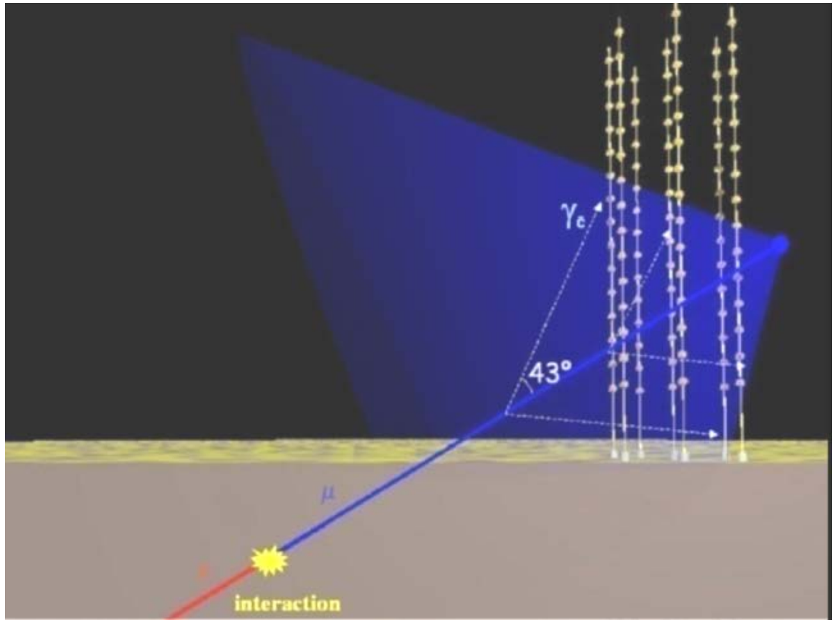


Detection Modes – cascades&muons

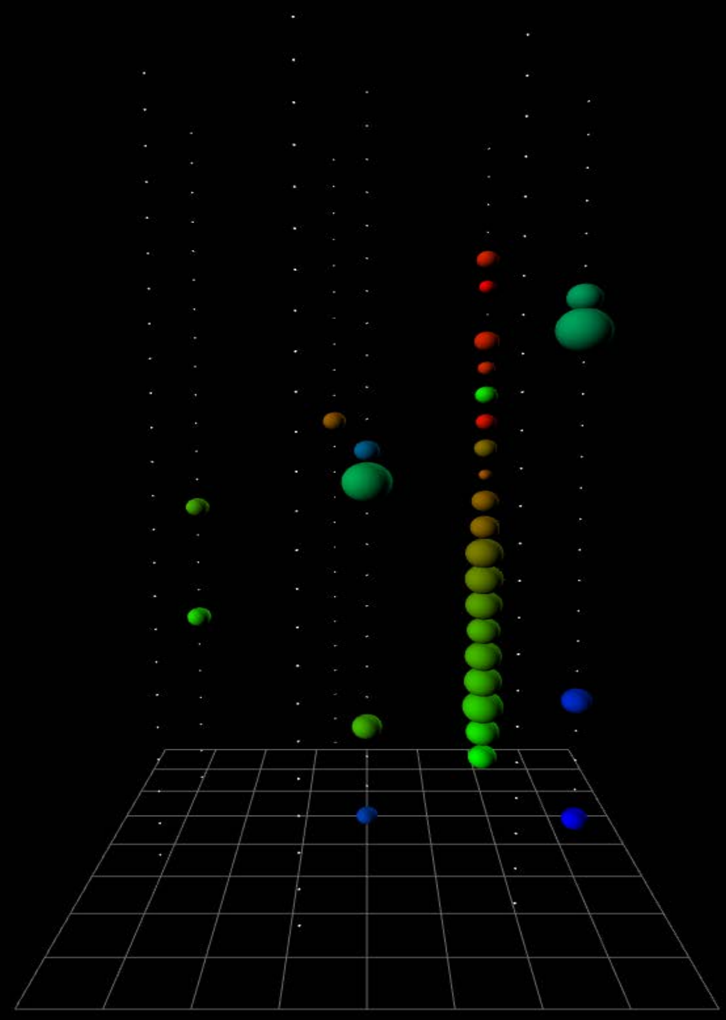
$$\nu_l + N \xrightarrow{CC} \begin{cases} e^- + X \rightarrow cascades \\ \tau^- + X \rightarrow cascades \\ \mu^- + X \rightarrow track + cascade \end{cases}$$

$$\nu_l + N \xrightarrow{NC} \nu_l + cascade$$

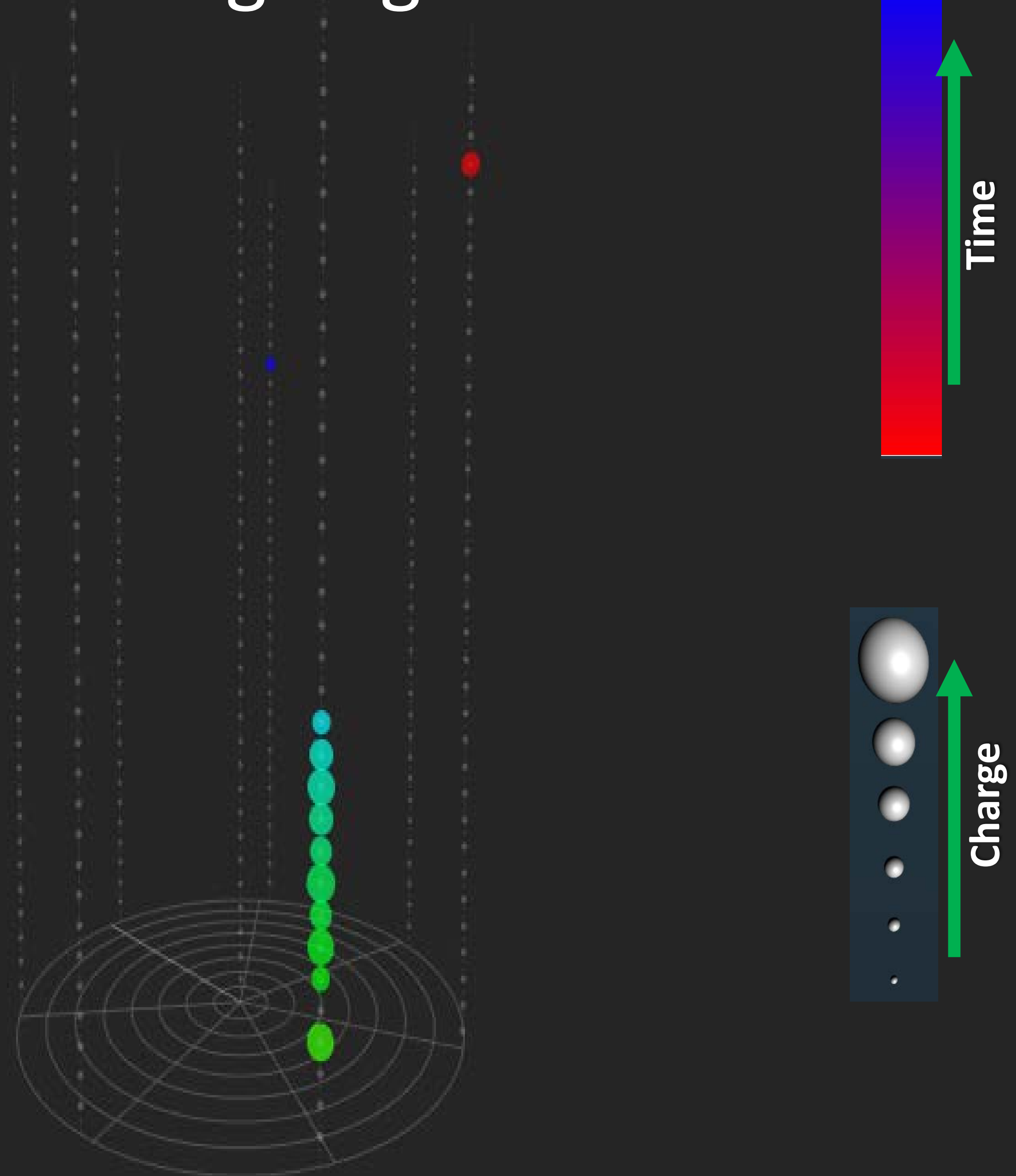
μ/casc. ~ 1/3 for 1:1:1



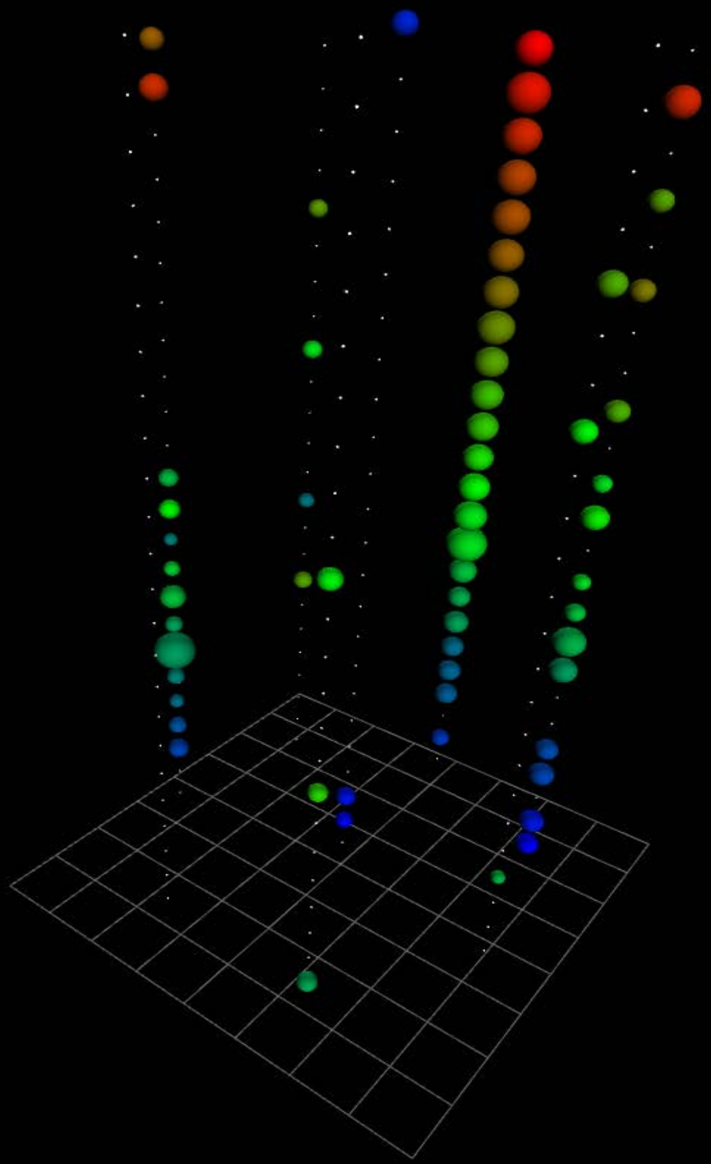
Downward going muon



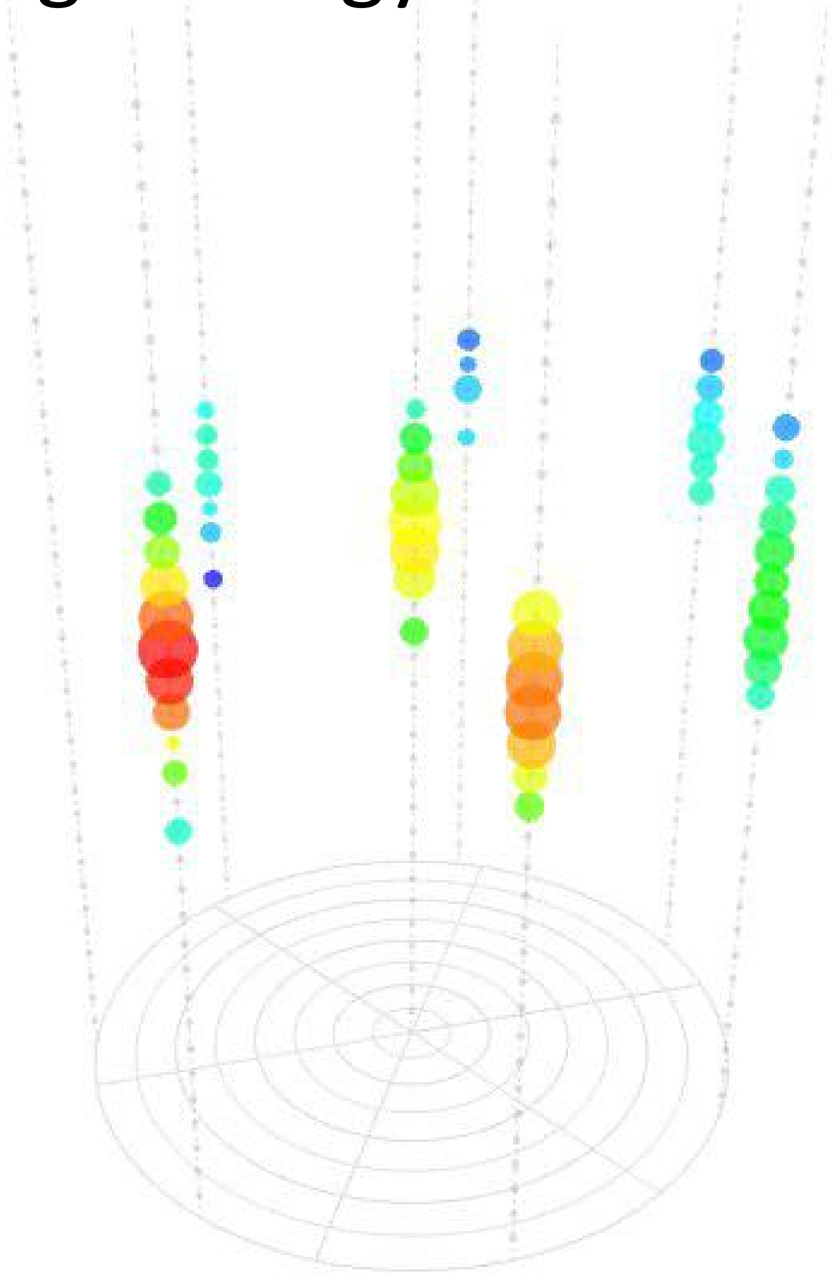
upward going neutrino



Background muon bundle

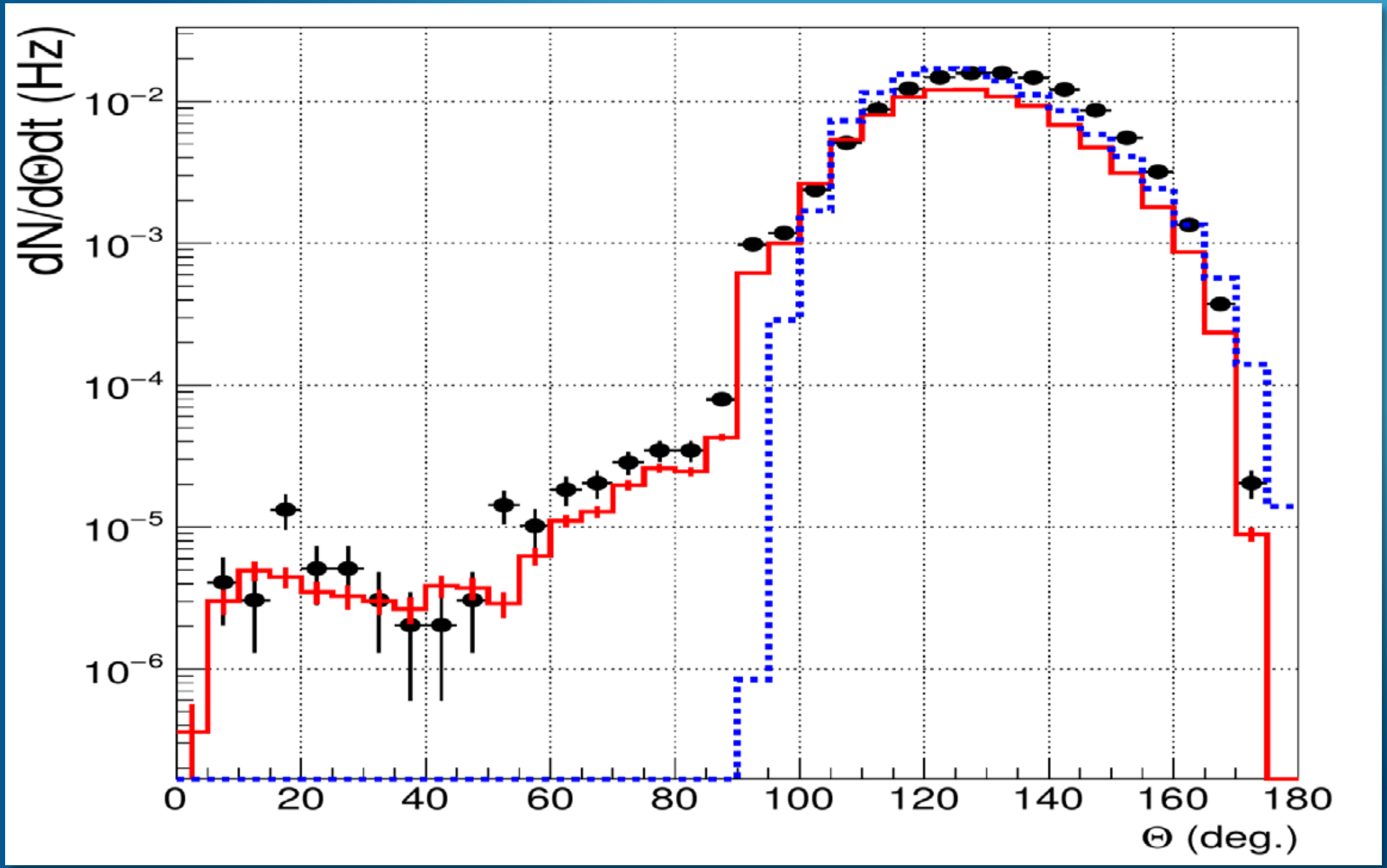


High-energy cascade



Search for muon neutrinos (2016 yr.)

Reconstructed zenith angle distribution with cuts



Polar angle distribution of muons selected with the requirement of at least 6 hit OM's at 3 strings. Data (black dots) is compared to the atmospheric muon flux generated with CORSIKA (dashed histogram) and passed through the detector simulation (histogram)

Atmospheric background suppression

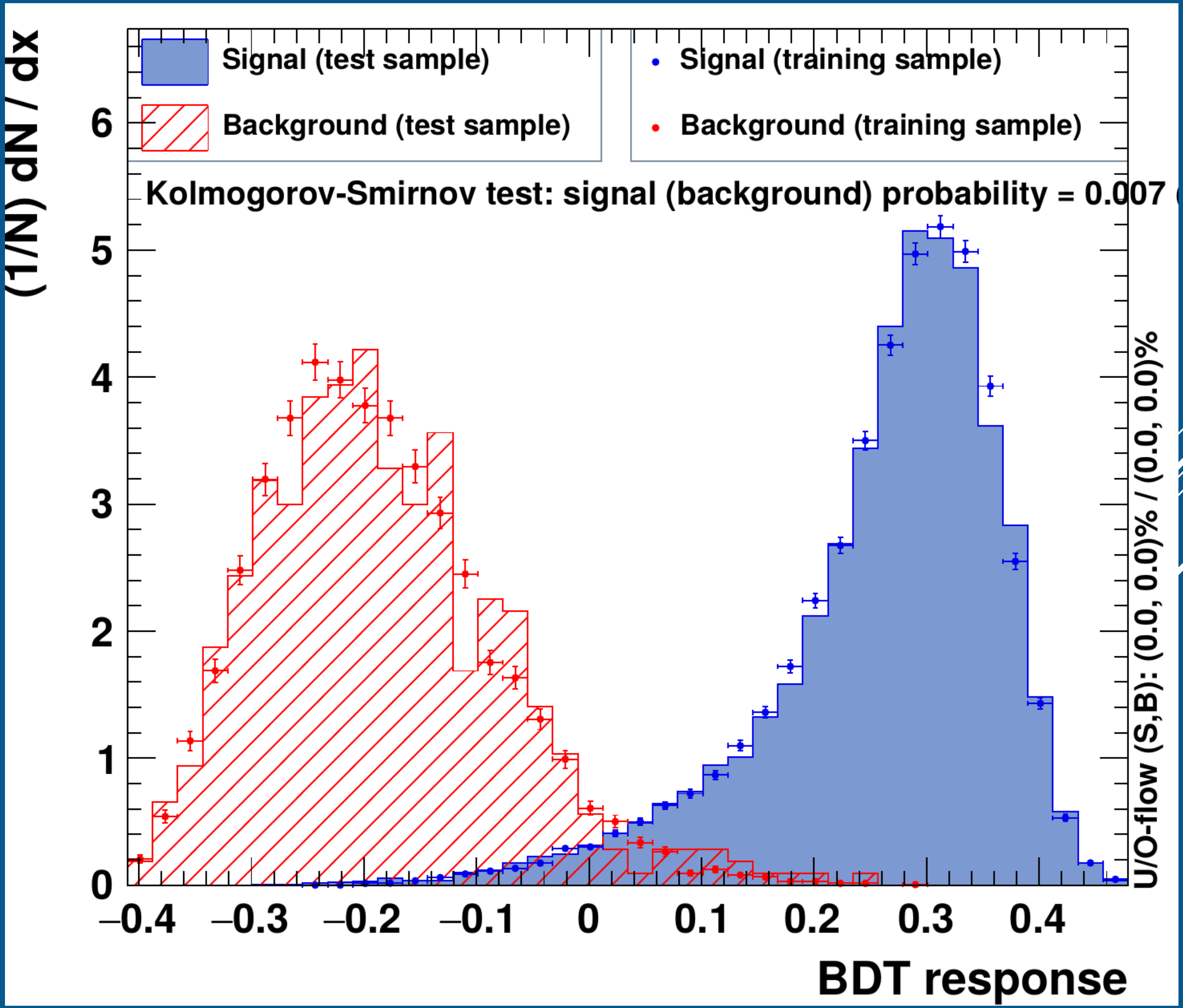
After track reconstruction and cuts on quality variables have been done, Boosted decision tree (BDT) was used.

BDT is trained on events reconstructed as upgoing with 0 < θ < 80 deg.

30k signal events
9k background evts.

signal is separated from the background by the BDT classifier value

cut BDT > 0.2 is 80% efficient for signal
> 0.25 -> 65% efficient
> 0.3 -> 40% eff.

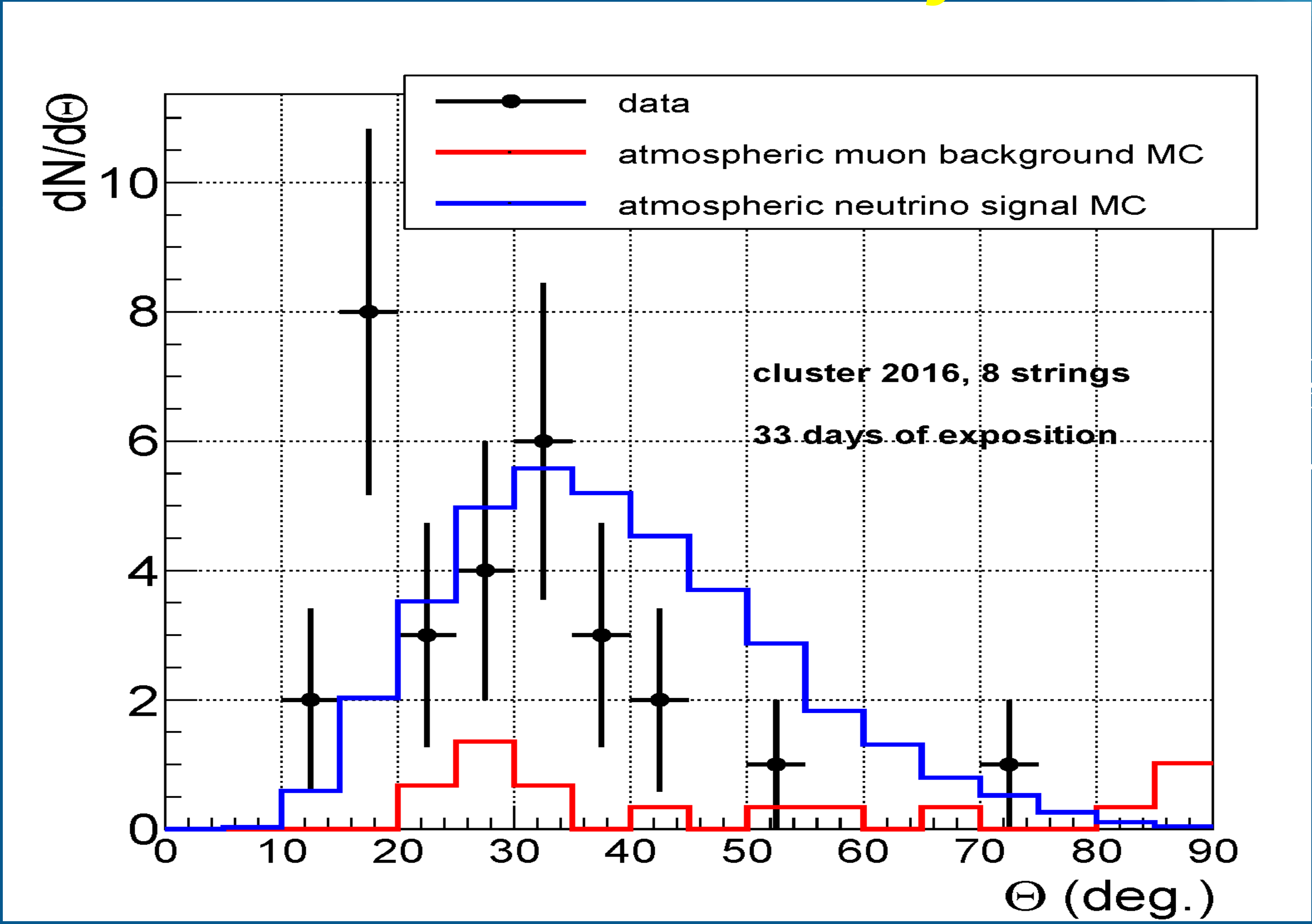


2016: 33 live days

Preliminary

Angular distribution for BDT > 0.2 cut

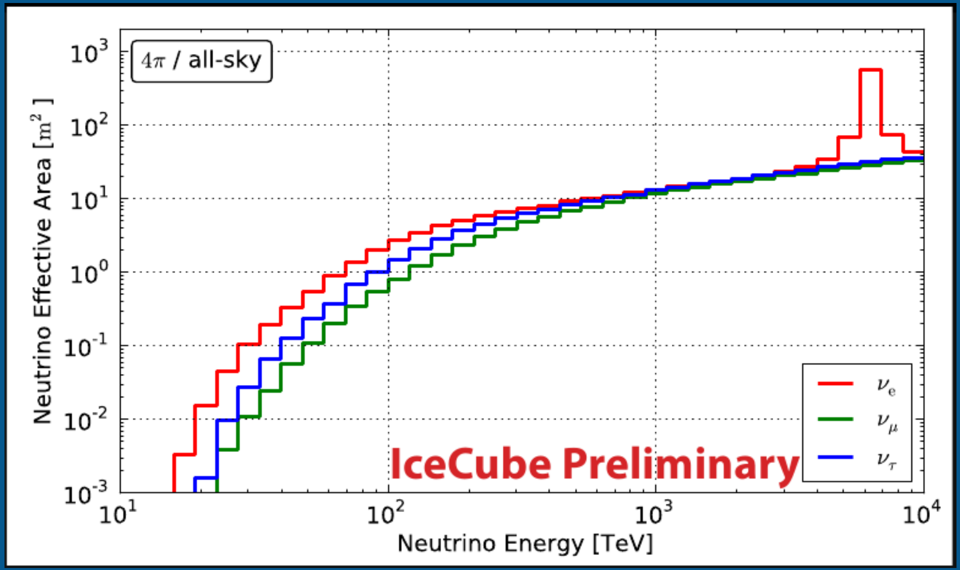
- 30 events were selected in signal region in data
- < 3 background events are expected
- about of 36 signal events are expected



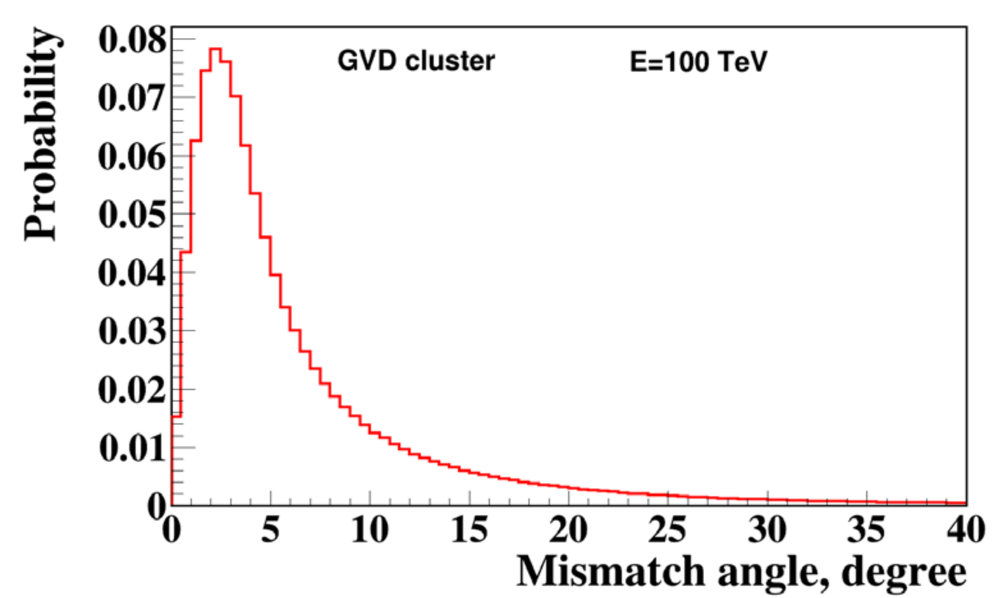
Neutrino Effective Area

Cascades detection with GVD Cluster

IceCube HESE

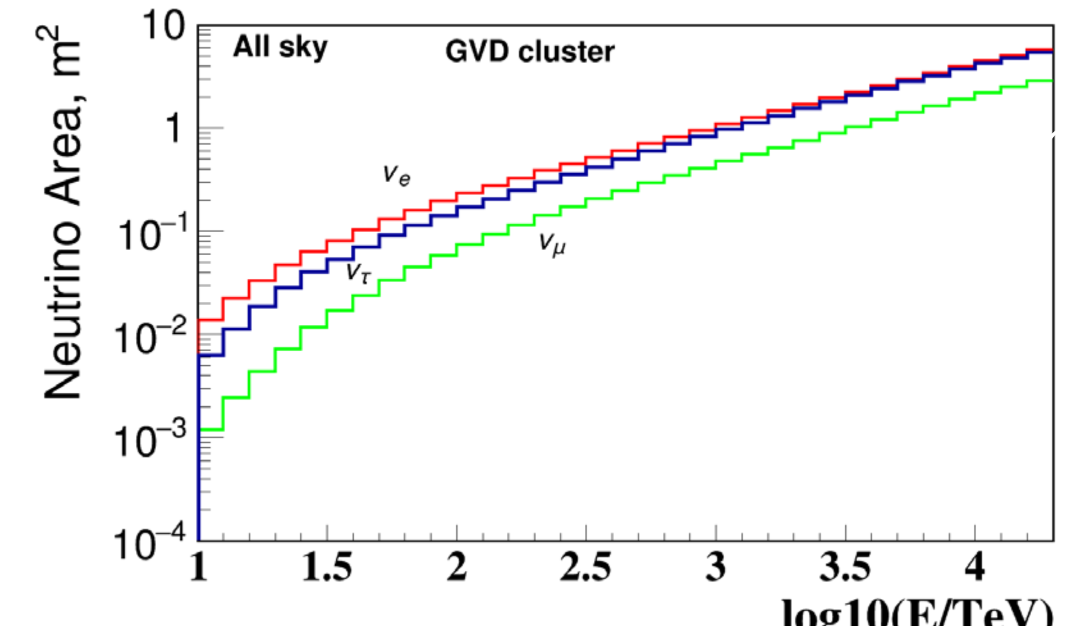


Distribution of mismatch angles



Directional resolution for cascades:
~ 3°- 4° - median value of mismatch angles

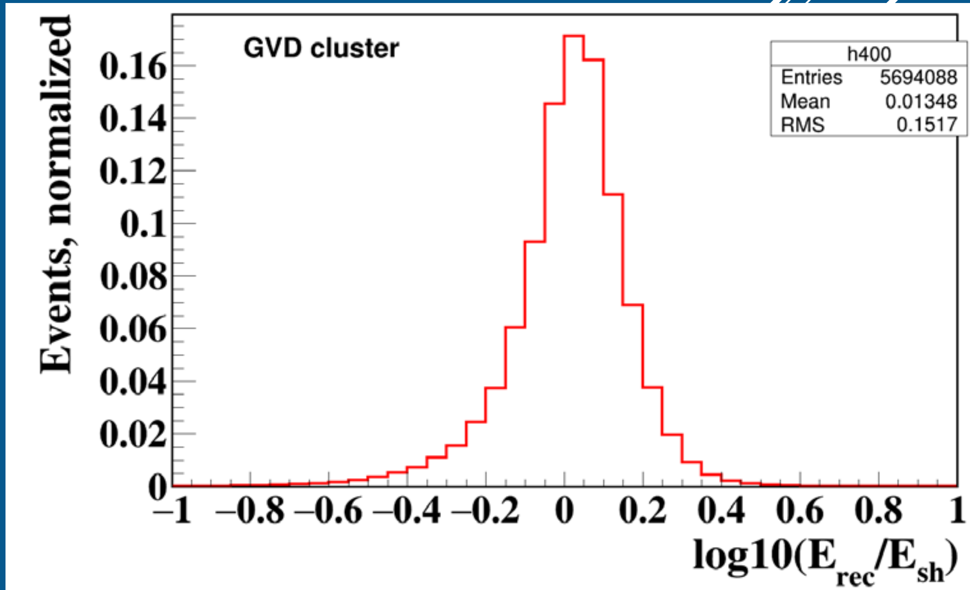
Baseline GVD Cluster S_{cl} ~ (0.05 - 0.1) S_{IC}



Energy resolution :

δE/E ~ 30%

averaged by E^{-2} ν_e spectrum



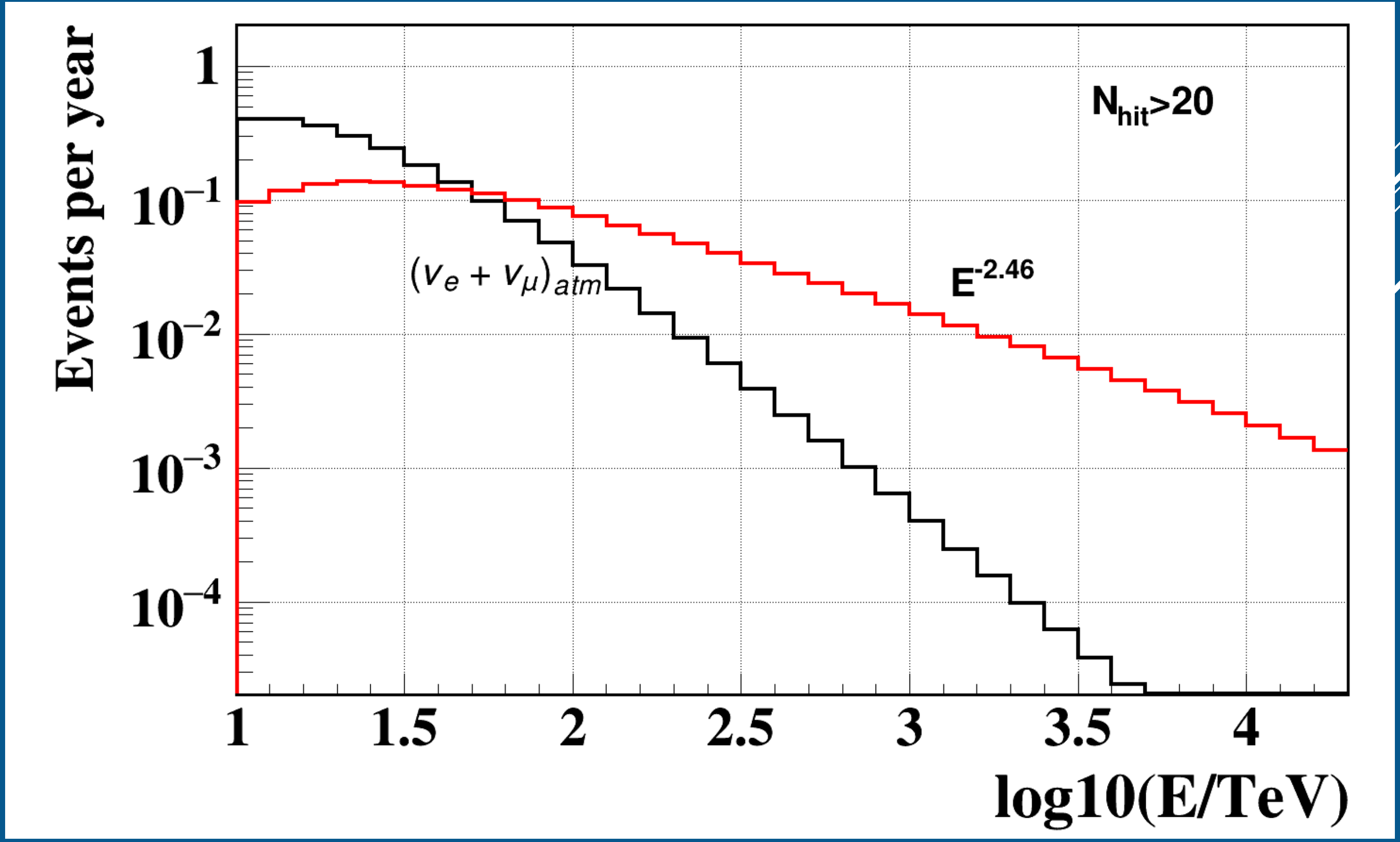
Energy spectrum of astrophysical neutrinos measured by IceCube:

$4.1 \cdot 10^{-6}$ $E^{-2.46}$ GeV^{-1} cm^{-2} s^{-1} sr^{-1}

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

Event selection criteria (E_{sh} >100 TeV, N_{hit} >20):

~0.6 events/yr are expected



A search for cascades induced by astrophysical neutrinos

(analysis of 2015 data – ***PRELIMINARY!***)

- Total number of accumulated events – 437 970 024 events

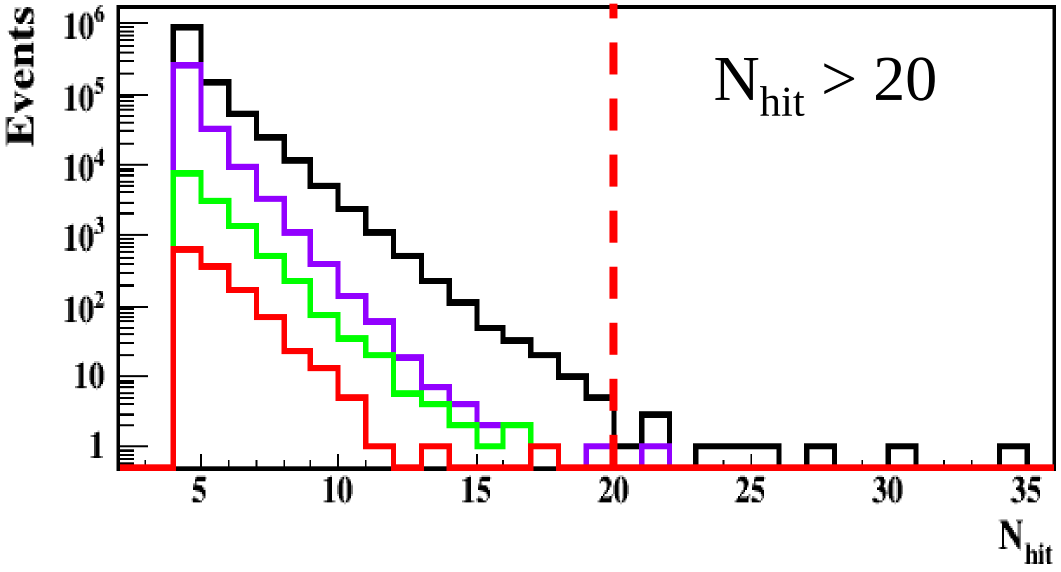
  (thresholds: low/high = 1.5/4 ph.el.)

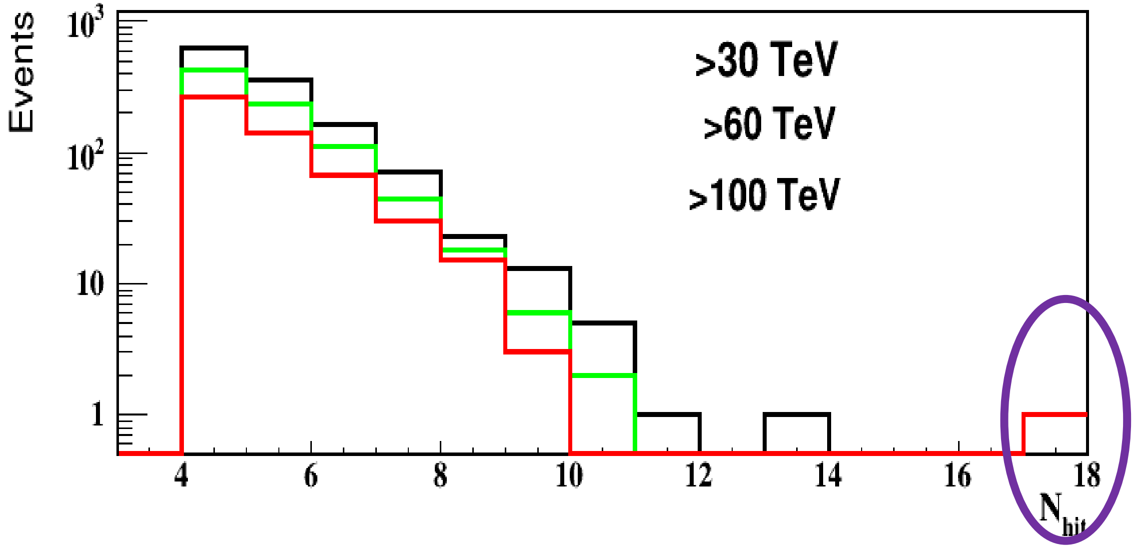
- Life time – 3 597 921 s = 41.6 days

- After causality cuts – 18 840 822 events

  ($N_{hit} > 3$; $|t_i - t_j| < \Delta r_{ij}/v + \delta t$)

Hit OM multiplicity dependence on cuts



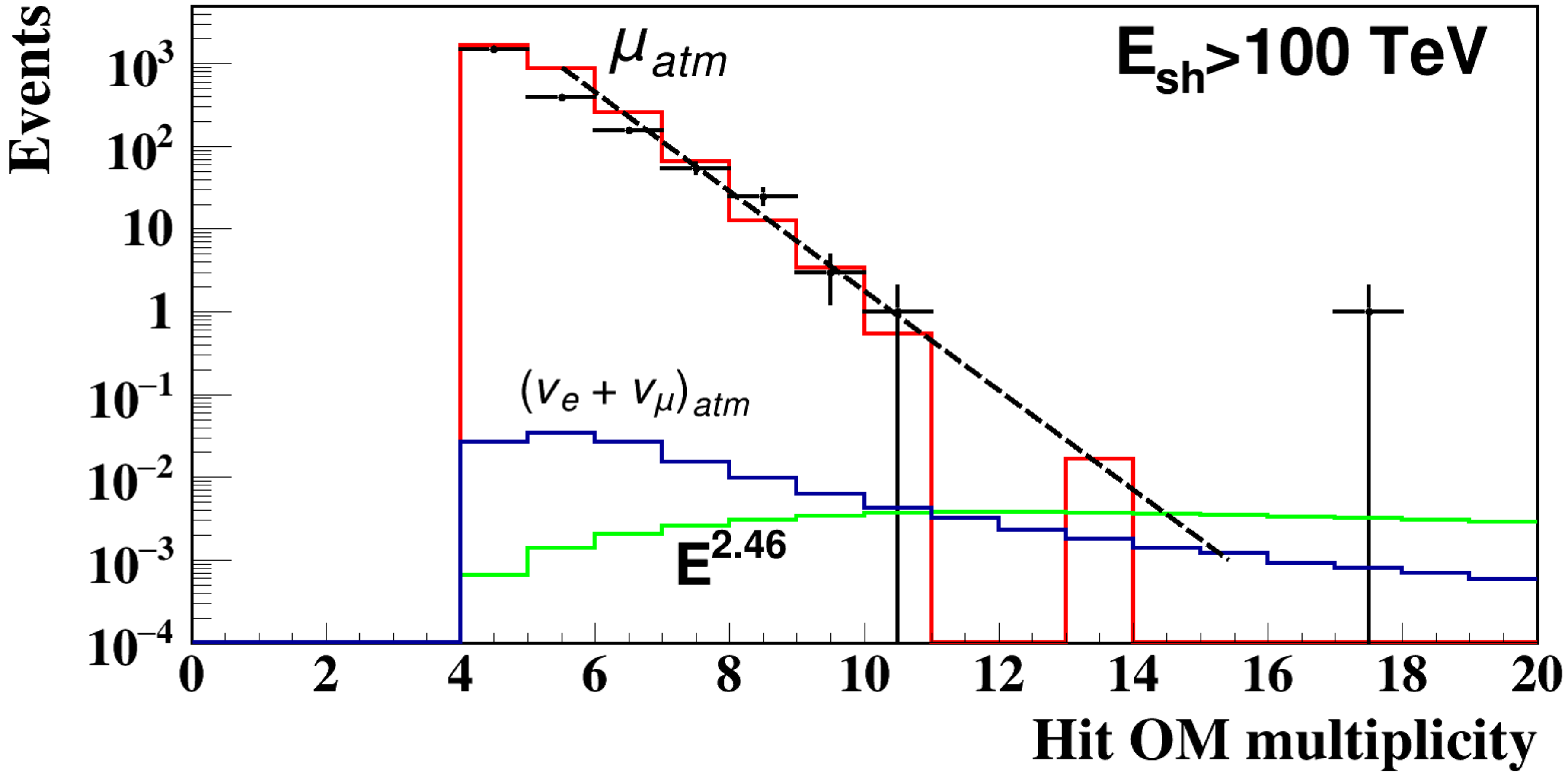


One event with N_{hit} = 17 OMs and E > 100 TeV is delected!

Cuts	Events	Rejection
Reconstruction of coordinates (Q>1.5ph.el.)	1 171 077	1
($\chi^2 < 2$)	316229	1/3.7
($L_a < 10$)&($\eta > 0$)	12931	1/90
E > 30 TeV	1291	1/900

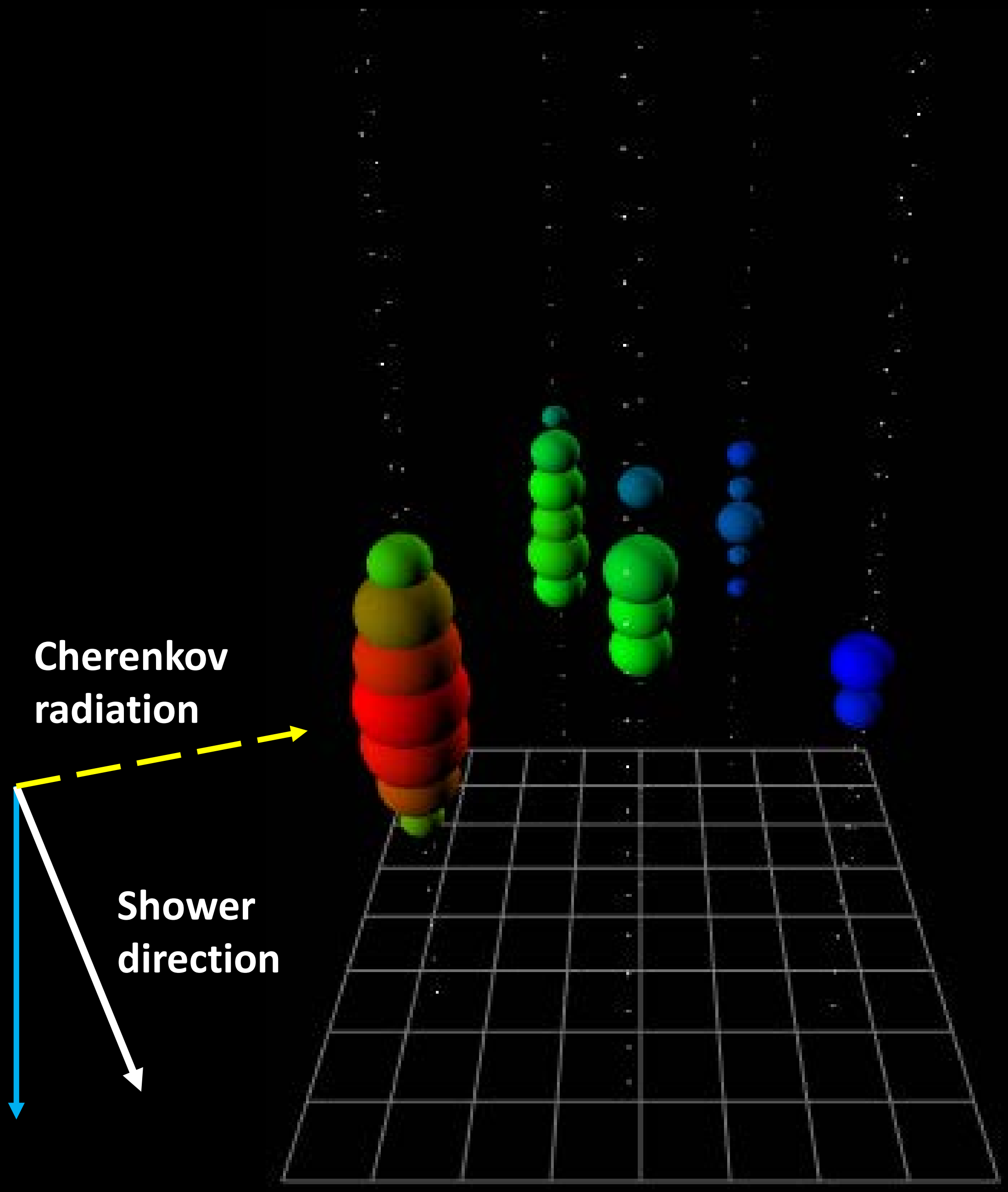
Cuts	Events	Rejection
E > 30 TeV	1291	1/900
E > 60 TeV	859	1/1360
E > 100 TeV	539	1/2000

Hit OMs multiplicity after all cuts



	$E^{-2.46}$	atm. ν_e	atm. ν_μ	atm. ν (total)
Probability of N_{hit} >16 OM:	0.047	0.0015	0.0026	0.0041

E = 107 TeV, θ = 56.6°, ρ = 68 m, z = -59 m

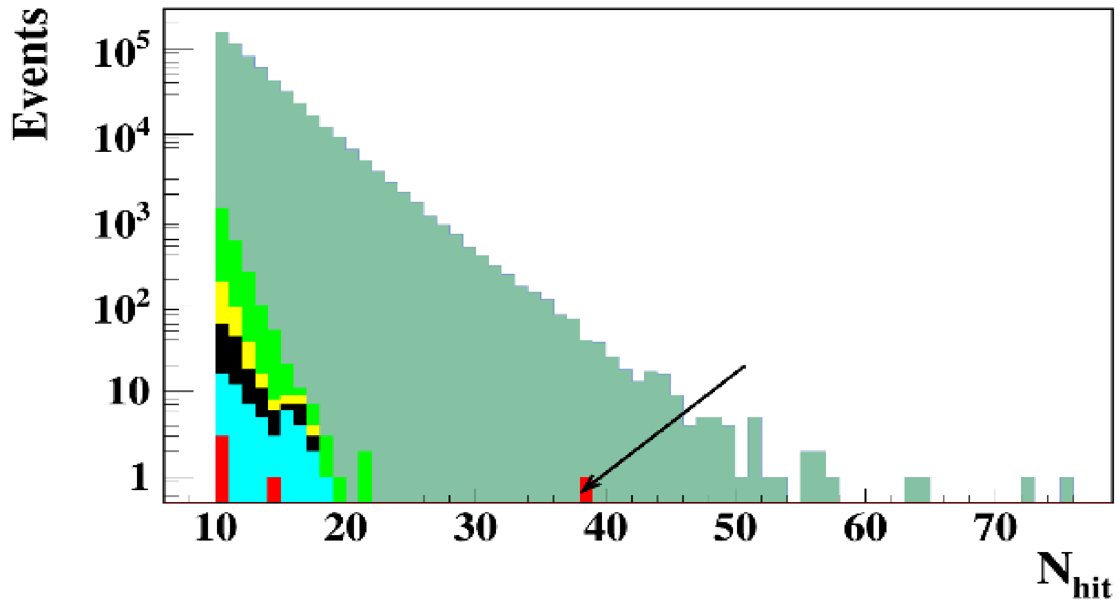


A search for cascades induced in GVD-2016 (*Preliminary*)

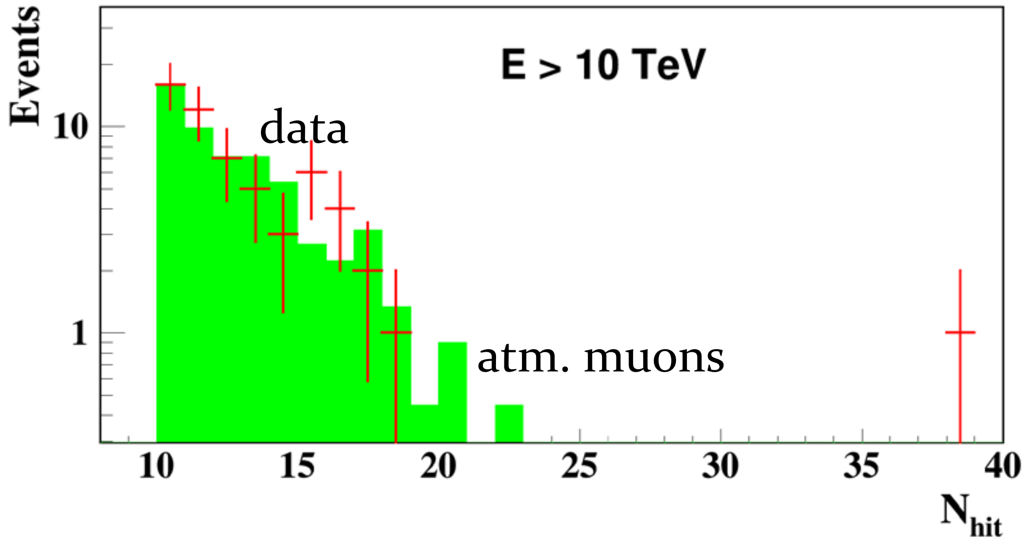
- Life time – 15 693 192 s = 182.0 days
- Total number of accumulated events – 685523932 events
  (thresholds: low/high = 1.5/4 ph.el. & Q >1.5 ph.el.)
- After causality cuts – 327053415 events

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

Hit OM multiplicity of events surviving different cuts

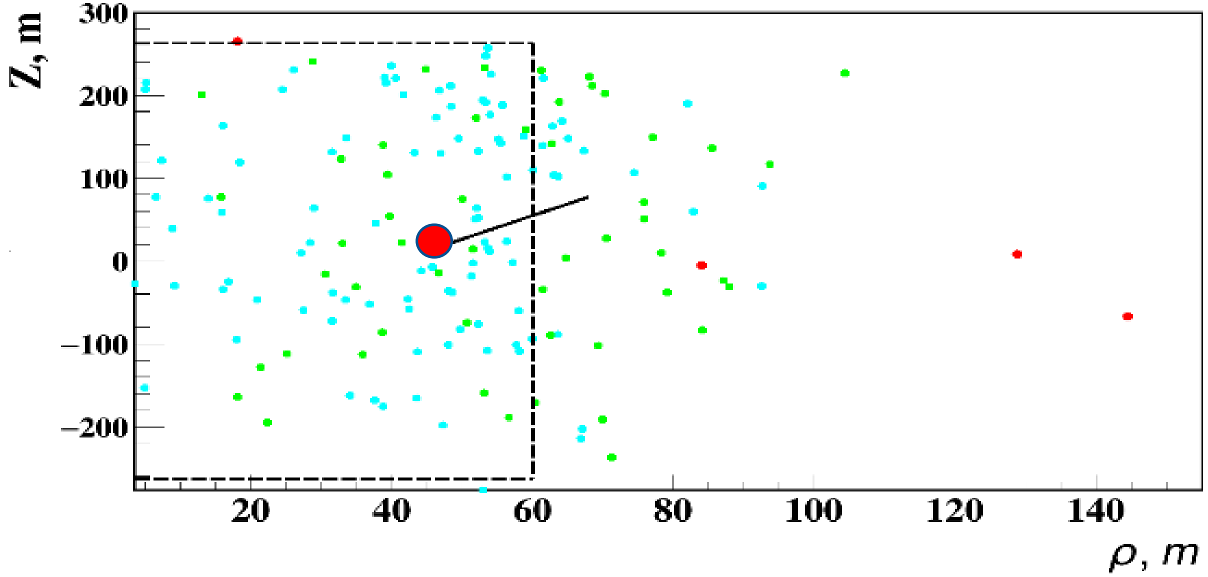


Hit OM multiplicity of events with E > 10 TeV



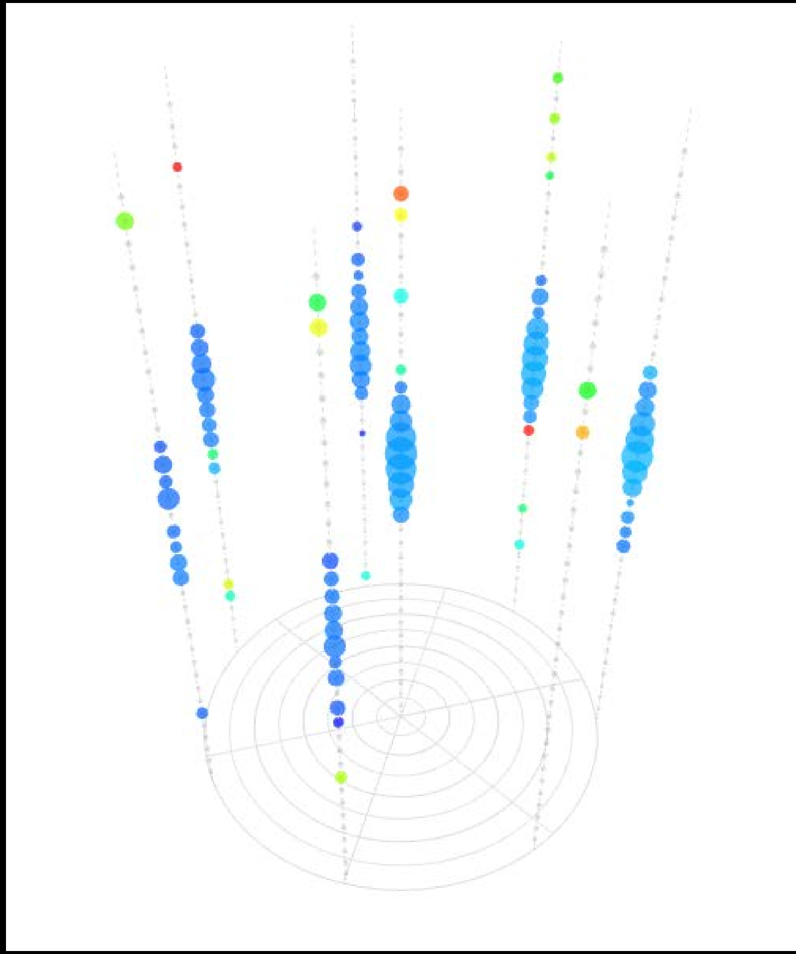
Cuts	Events	Rejection
Coordinates reconstruction & $N_{hit} > 9$	577495	1
$\chi^2 < 4$	2405	1/240
Energy reconstruction		
$L_a < 20$	374	1/6.4
$\eta > 0$	159	1/2.4
E > 10 TeV	57	1/2.8
E > 100 TeV	5	1/11.4
Total rejection factor:		1/115499

Reconstructed cascades positions

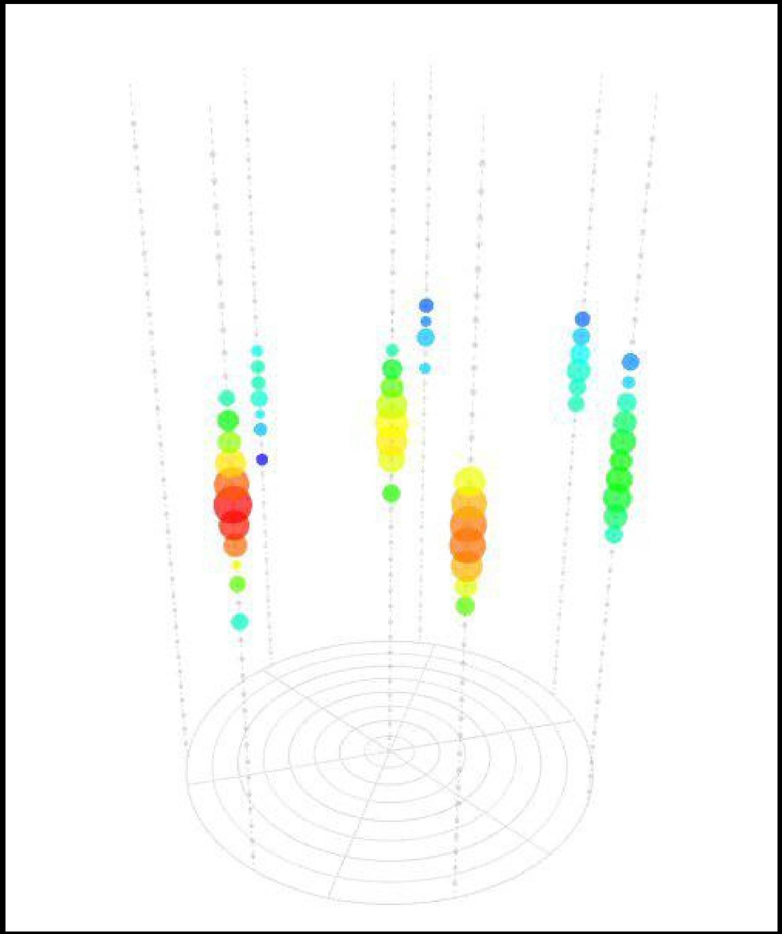


Cascade: E=157 TeV, θ = 57°, φ = 249°
x=-25m, y=-37m, z=11m, ρ=44m

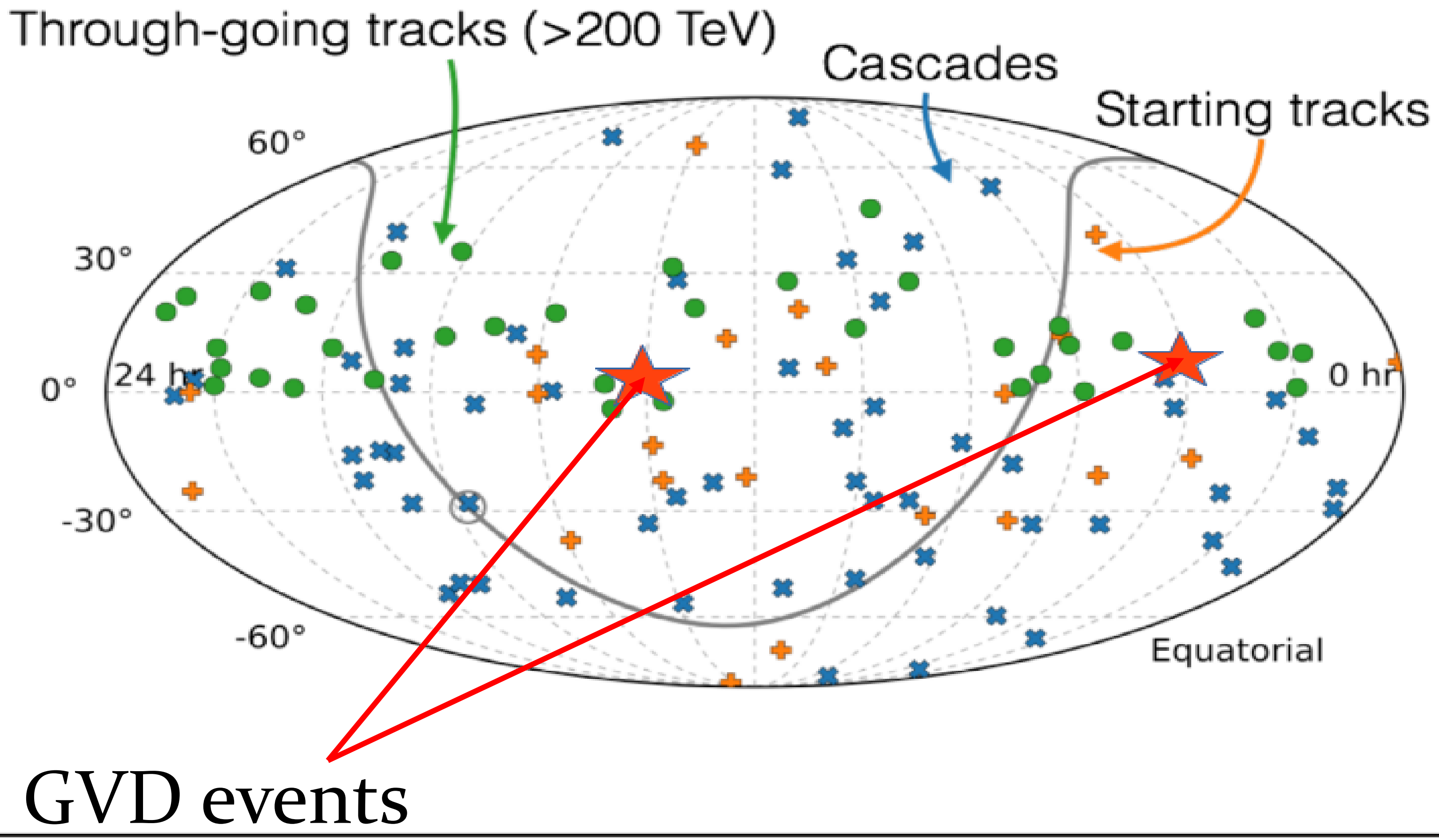
All hit OMs (93 hits)



Selected hits (53 hits)



Events from above event selections with energy cut.



Search for high-energy neutrinos associated with the GW170817 in GVD-2017

GW170817 from binary neutron star merger

GW: 17.08.2017, 12:41:04 UTC = 1502973664 sec UNIX
(Advanced LIGO & Advanced VIRGO)

GRB170817A - (1.7 s delay – Fermi-GBM and INTEGRAL)

Location – galaxy NGS4993 at ~ 40 Mpc,
at equatorial coordinates
$\alpha(J2000.0) = 13^h\,09^m\,48^s.085$,
$\delta(J2000.0) = -23°22'53''.343$

Search for neutrinos in coincidence with GW170817

Search for neutrinos by muon and cascade detection
in two time-windows: GW ± 500 sec (prompt emission)
GW +14 days (delayed emission)

Zenith angle of the source at detection time:

IceCube: 66.6°

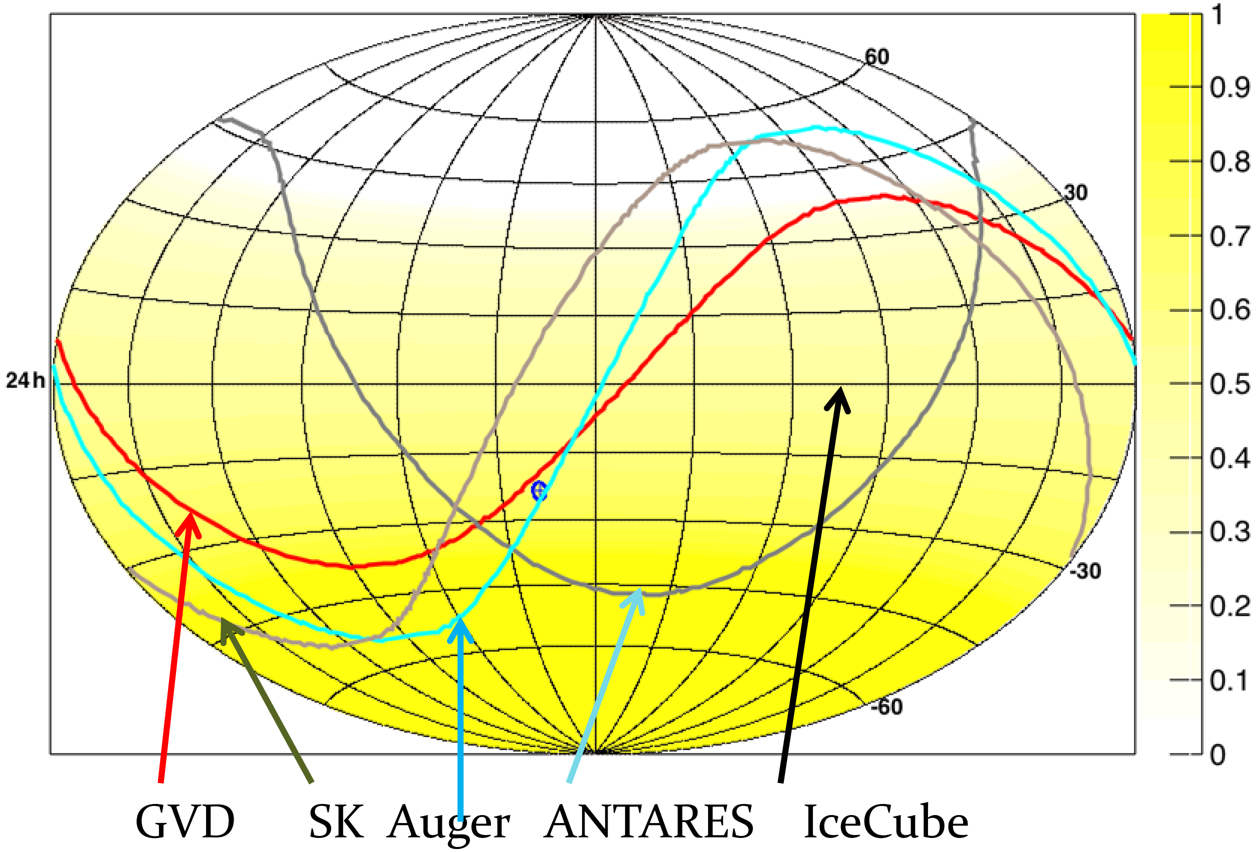
ANTARES: 73.8°

Auger: 91.9°

SK: 108°

GVD: 93.3°

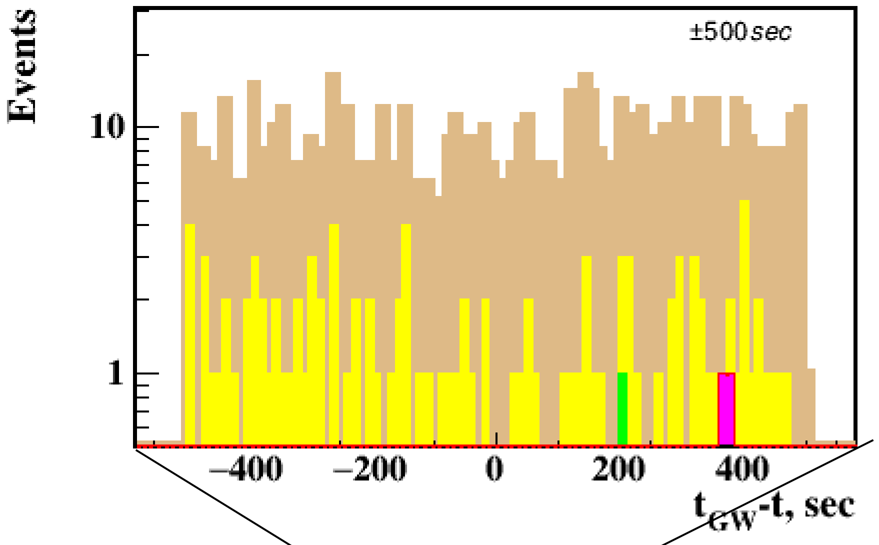
Horizons of arrays at equatorial coordinates

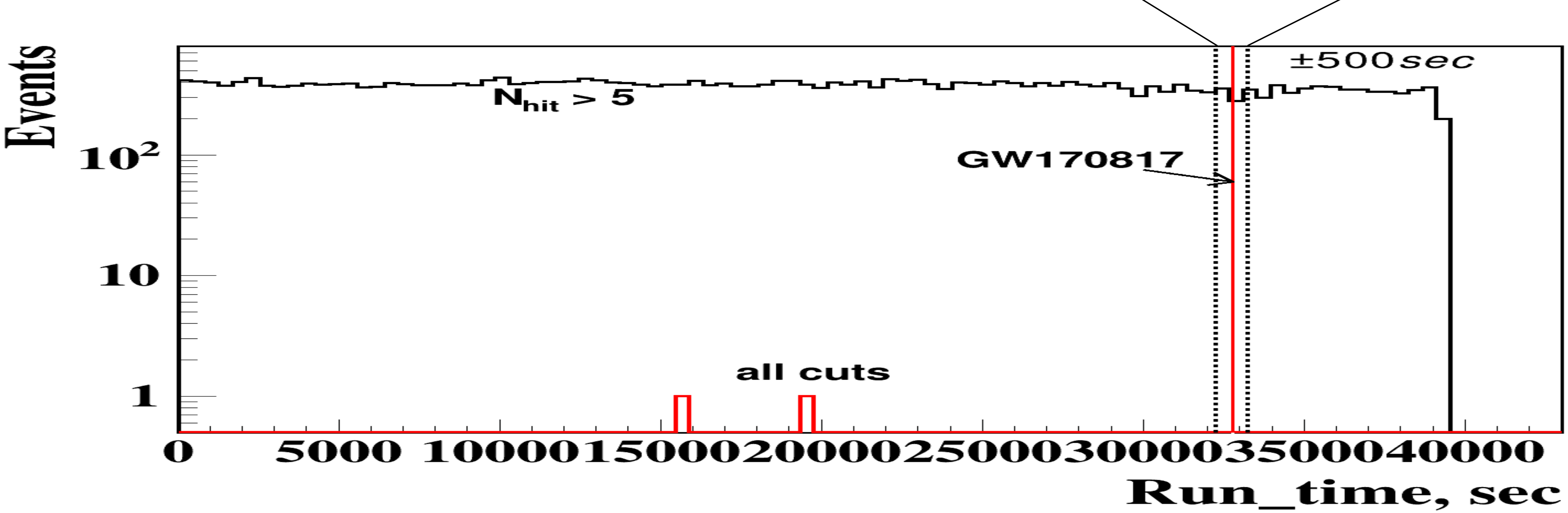


Search for neutrinos within GW ± 500 s time-window

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

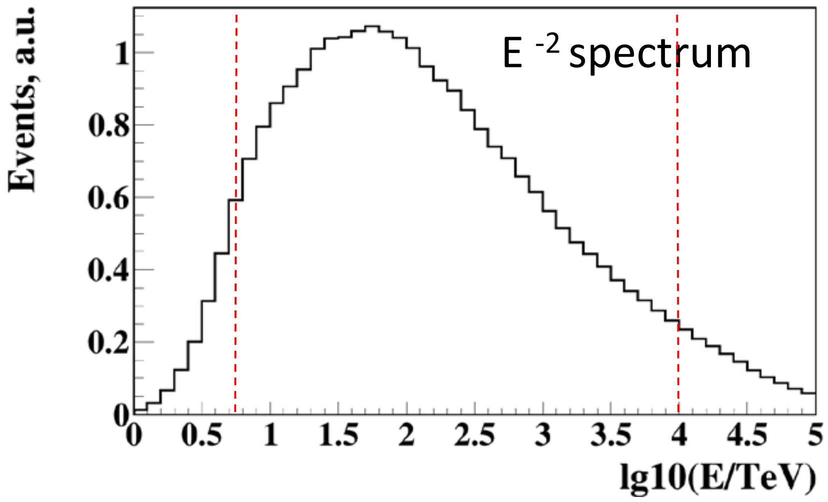
Cut	Events in ± 500 sec window
N_{hit} > 5 OM/3 Str.	731
$\chi^2_t < 10$	108
$\eta > 0$	3
$L_a < 30$	2
$\psi < 20°$	0 (0.05 events is expected)



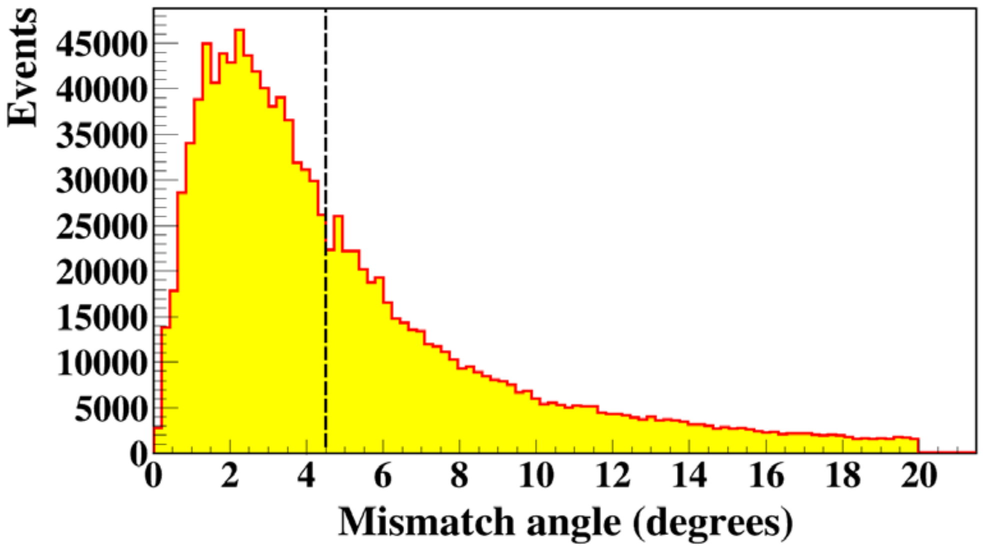


Search for neutrinos within GW ± 500 s time-window

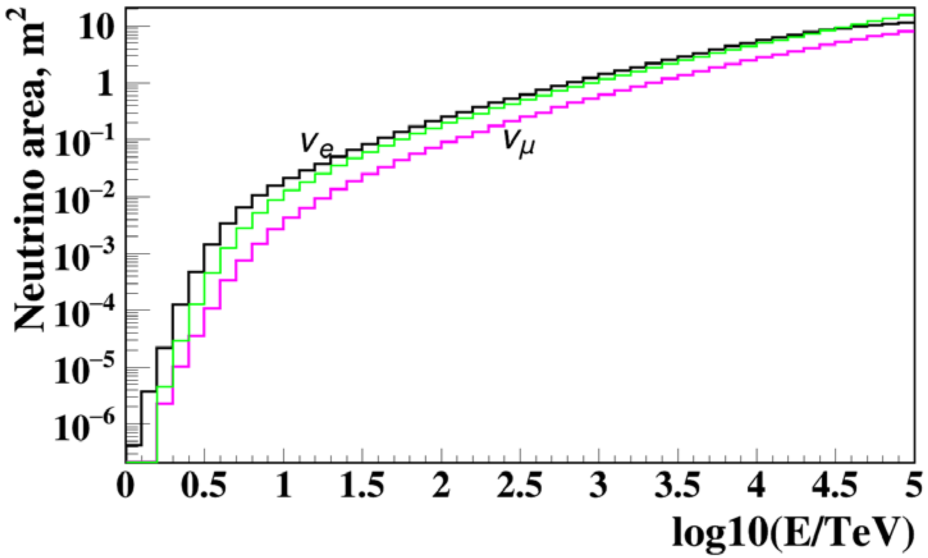
Expected energy distribution of events.
90 % of events within 5 TeV < E < 10 PeV

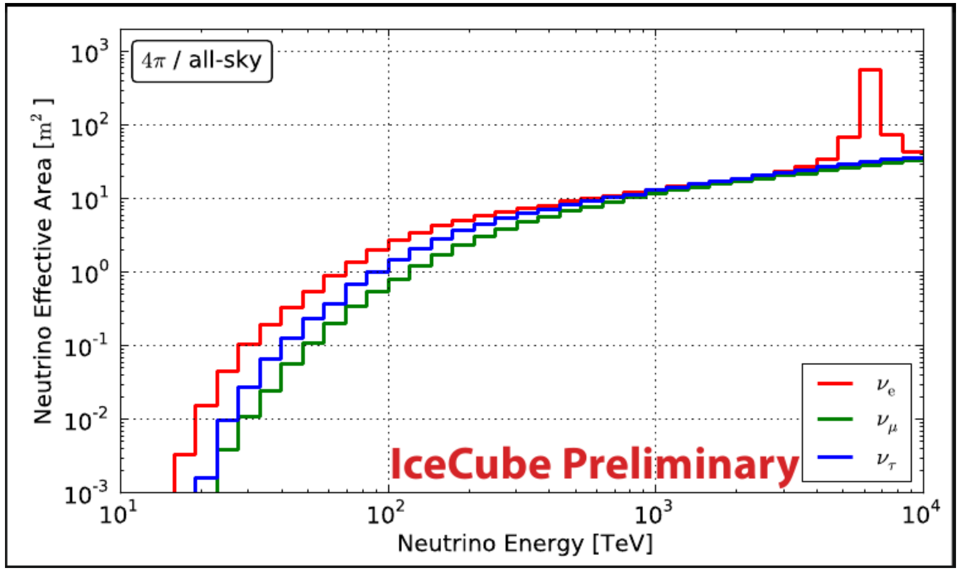


Shower direction reconstruction error



Neutrino effective area after all cuts

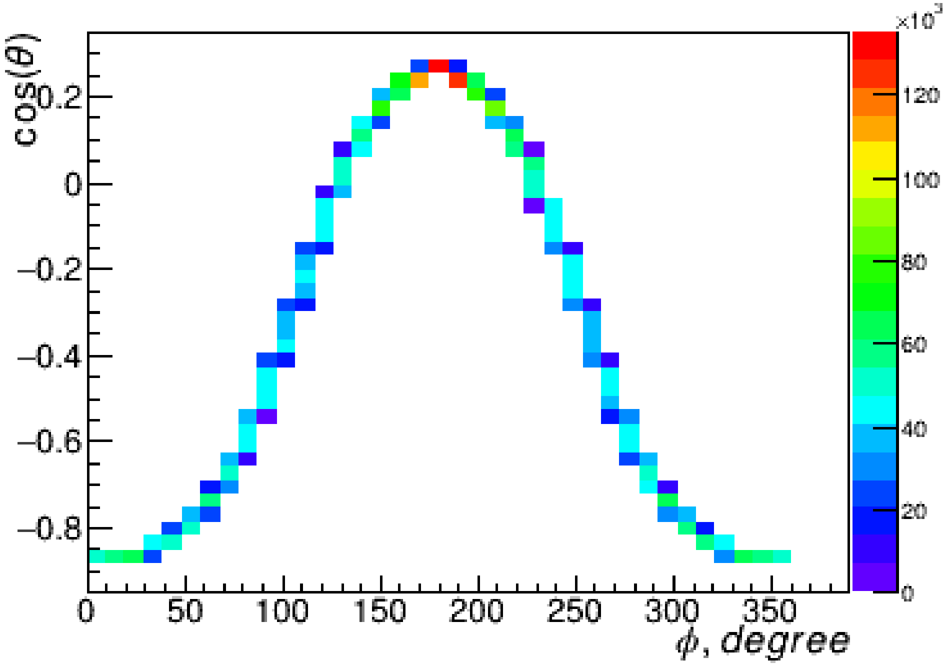




Search for neutrinos in GW170817 following 14 days time-window

Coordinates of NGC4993

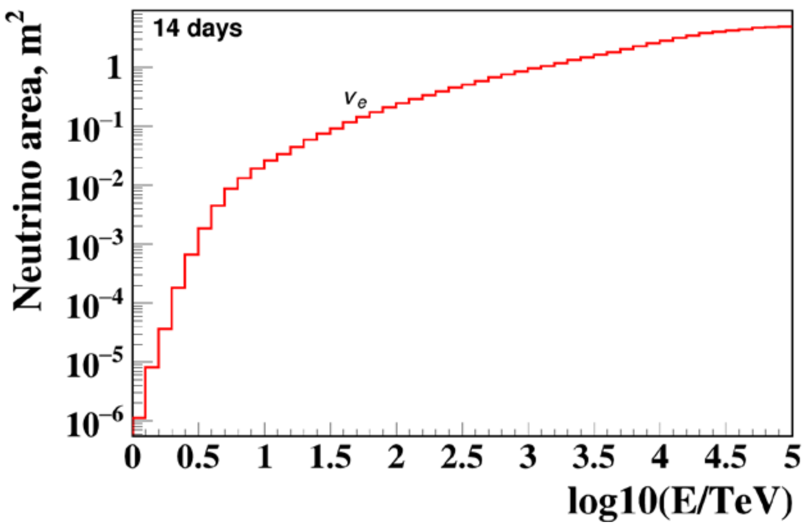
zenith angle range 74° < θ <150°



Selection cuts

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

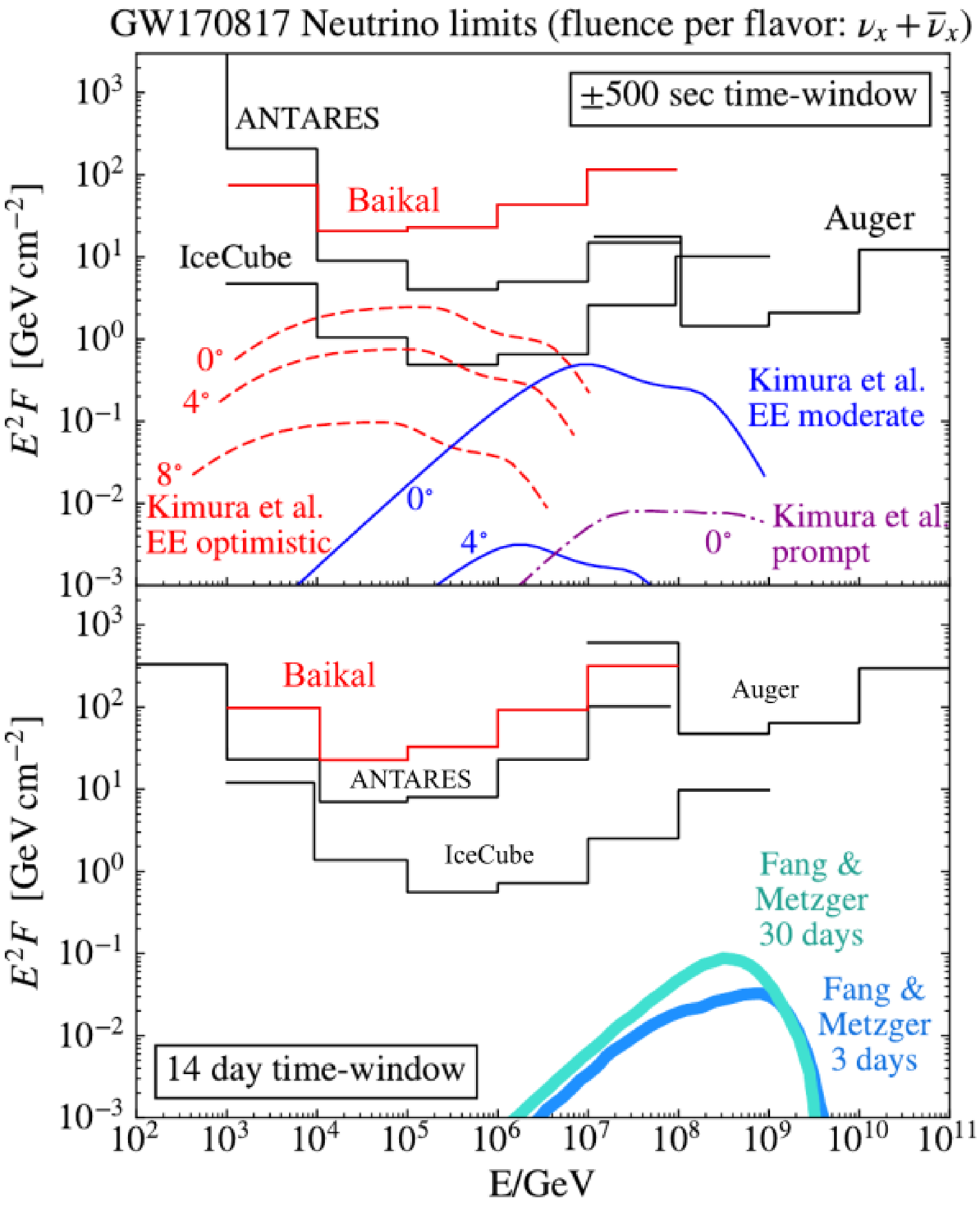
Neutrino detection area



Upper limits on fluence of neutrinos associated with GW170817

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

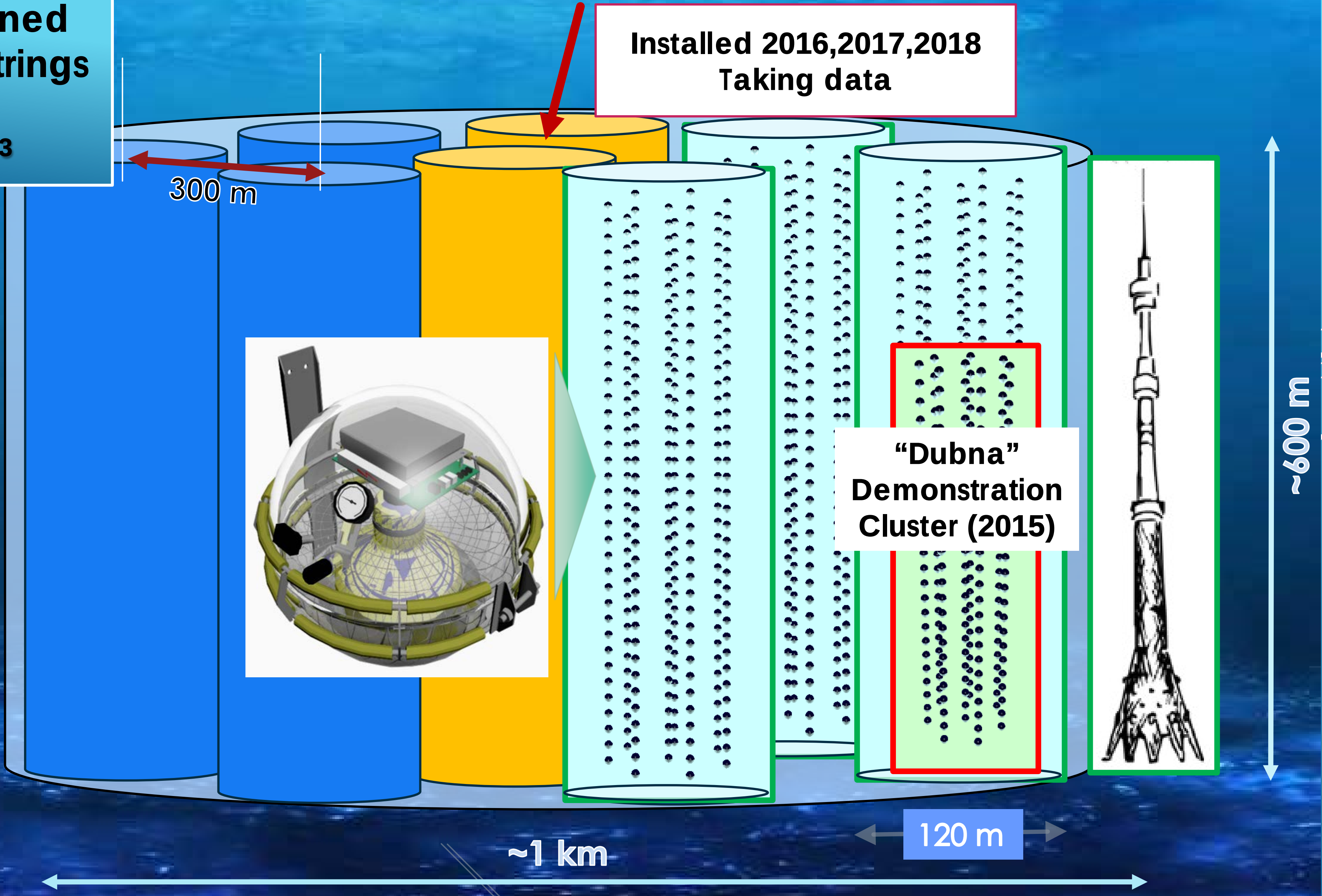
Assuming E^{-2} spectral behavior and equal fluence in all flavors upper limits at 90% c.l. have been derived on the neutrino fluence from GW170817 for each energy decade.



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



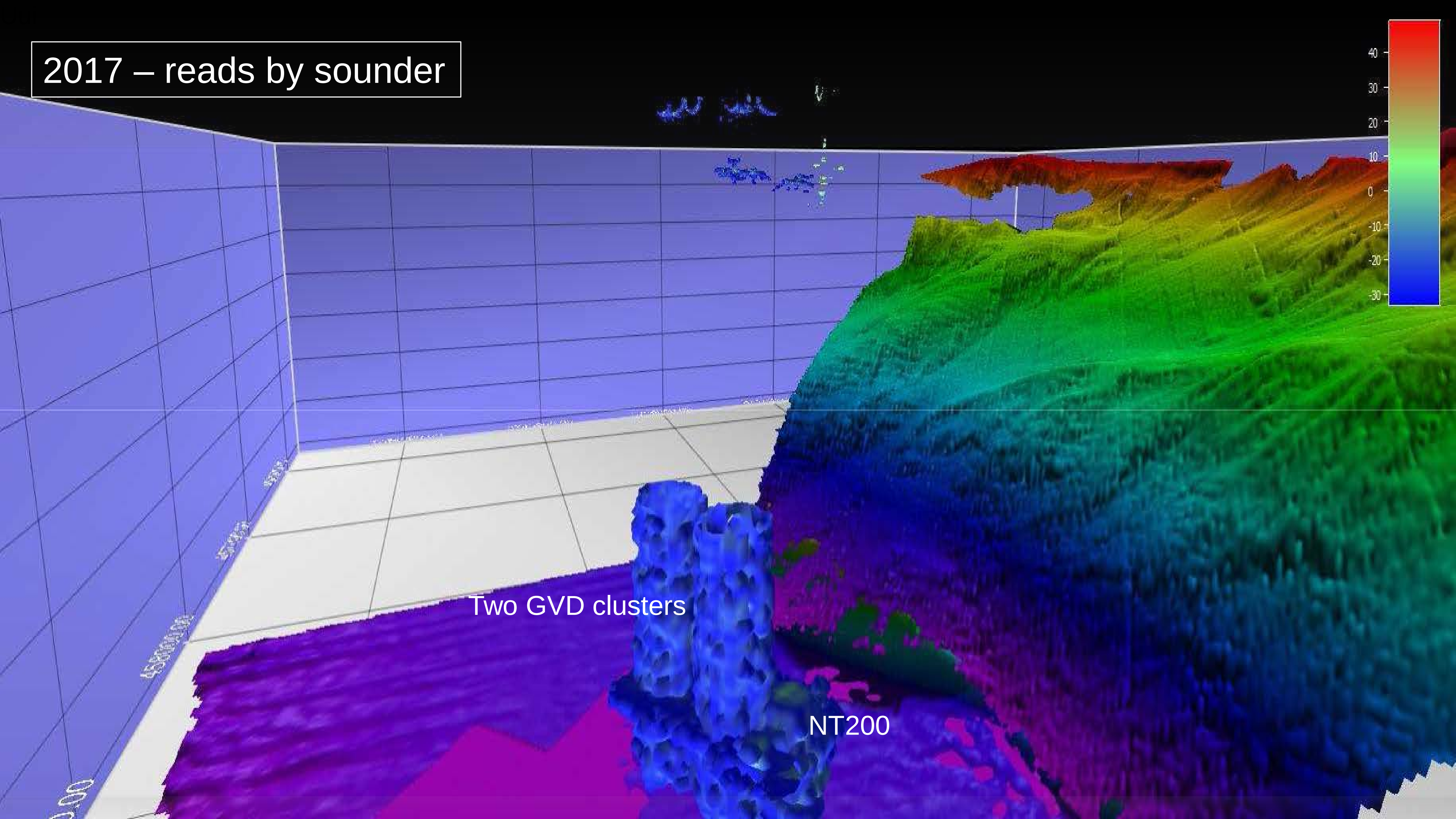
Timeline GVD 1

Cumulative number of clusters vs. year

Year	2016	2017	2018	2019	2020	2021
Nb. of clusters	***1***	***2***	***4***	***6***	***8***	***10***
Nb. of OMs	***288***	***576***	***1152***	***1728***	***2304***	***2592***

Actual numbers → **3** **5** **7** **9**

2017 – reads by sounder



Summary

- Prototyping & Early Construction Phase of Baikal-GVD project is concluded with construction and commission of the first GVD Cluster “Dubna” in 2015
- Array “Dubna” was upgraded to baseline configuration of GVD cluster with 288 OMs in 2016.
- The second and the third full-scale GVD clusters were installed and commissioned in April 2017 and April 2018.
- Completion of the GVD-1 is expected in 2020-2021.

Thank you!