Baikal-GVD – the Next Generation Neutrino Telescope in Lake Baikal

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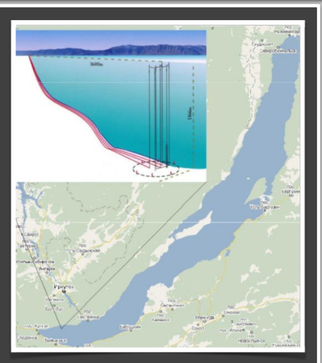
on behalf of the Baikal Collaboration

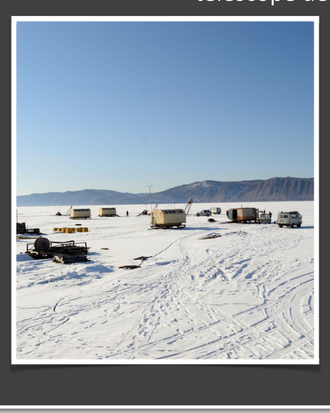
Outline

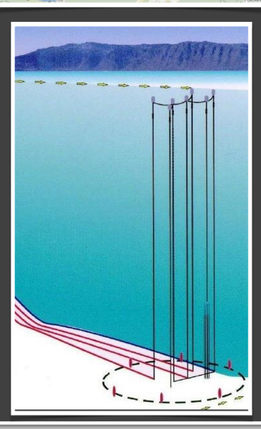
- Baikal-GVD (Gigaton Volume Detector) Phase I allows to investigate
  - Galactic and extragalactic neutrino point sources in TeV – PeV energy range
  - Diffuse neutrino flux – energy spectrum, local and global anisotropy, flavor content
  - Transient sources like GRB etc.
  - Dark matter – indirect search
  - Exotic particles – monopoles, Q-balls, nuclearities, …
- The experiment looks like km^3 - scale 3D-array of photo sensors located deep underwater
- Flexible structure allows to rearrange of the main building blocks to change, for example, energy threshold
- High sensitivity and resolution of neutrino energy, direction and flavor content

Site:

- Location N51.765732° E104.415042°
- Depth of 1366 m at only 3.6 km from shore
- High deep water transparency (22 m) and low light scattering (30-50 m)
- Fresh water (simple mechanical solutions, no background from K40)
- No bioluminescence
- The most northern location allows observing the Galactic Center 18 hours per day
- Reliable ice cover (mid February - mid April) as an excellent platform for:
  - bed cable laying
  - telescope deployment and maintenance

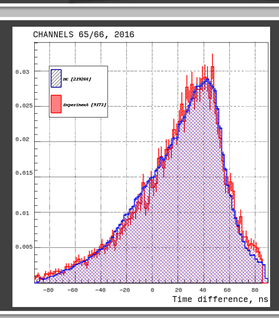






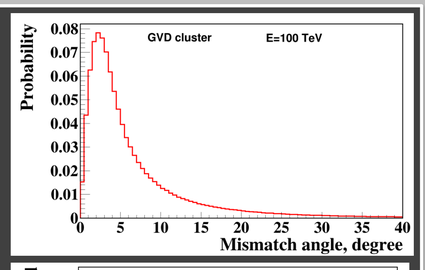
Muon ΔT distribution

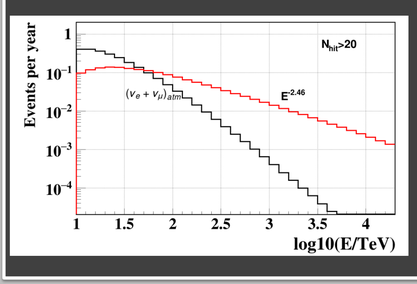
- hit time difference on adjacent OMs
- Muon hit selection:
  - Causality criterion, 20 ns window
  - Three or more OMs in a row must be hitted
  - At least one OM of the three must have Q > 3 p.e.
- Serves as a cross check of time calibration with 5 ns precision, OM sensitivities

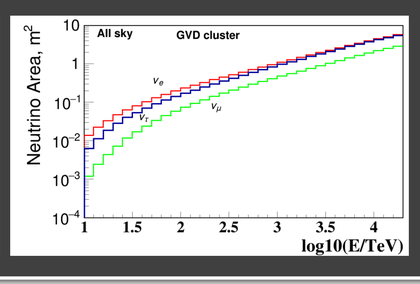


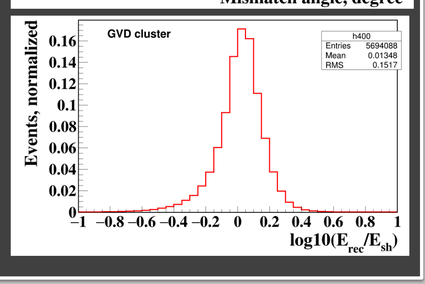
Cascade detection in one cluster

- Directional resolution ≈ 3°- 4° (median)
- Energy resolution δE/E ≈ 30% (averaged by E^{-2} ν_e spectrum
- ≈ 0.6 events/yr (E_{sh} > 100 TeV, N_{hit} >20)
- S_{cl} ≈ (0.05 - 0.1) S_{IC}, S_{IC} – HESE eff. area

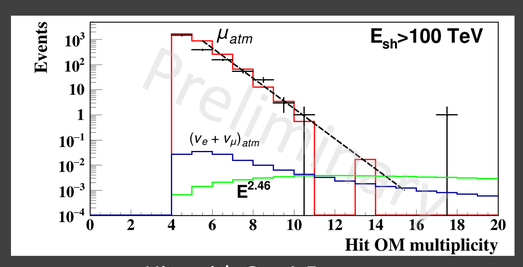








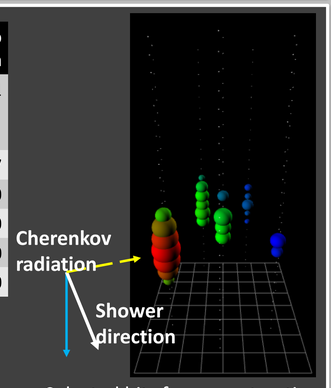
Search for cascades in 2015 (41.6 live days)



Hits with Q > 1.5 p.e

Cuts	Events	Rejection
Reconstruction of coordinates (Q > 1.5 p.e)	1 171 077	1
χ^2 < 2	316229	1/3.7
L_a < 10 & η > 0	12931	1/90
E > 30 TeV	1291	1/900
E > 60 TeV	859	1/1360
E > 100 TeV	539	1/2000

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

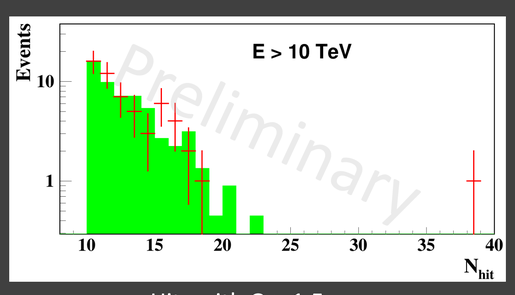


Selected hits for reconstruction (24 hits)

E = 107 TeV, θ = 56.6°, ϕ = 130.5°, ρ = 68 m, z = -59 m

Search for cascades in 2016 (182.0 live days)

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



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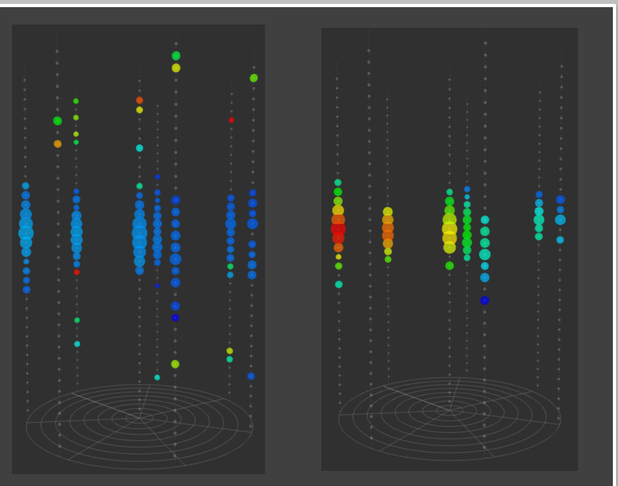


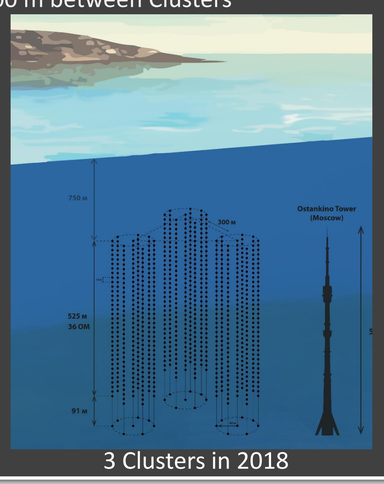
All hit OMs (93 hits)

Selected hits for reconstruction (53 hits)

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

Baikal-GVD Phase I Array:

- 2304 Optical Modules (OM) in GVD Phase I
- OMs arranged in 8 Clusters with 8 Strings each
- Depth is 750 – 1275 m (91 m above the bed)
- 15 m between OMs in a String
- 300 m between Clusters

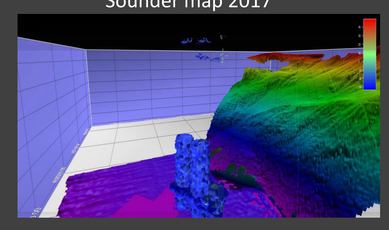


3 Clusters in 2018

Optical Module:

- 10" PMT R7081HQE, Q_{eff}≈0.35
- 17" Glass pressure-resistant sphere
- Underwater 5-pin SubConn connector
- Amplifier, HV DC-DC, controller
- 2 on-board LED flashers for calibration
- Mu-metal cage
- Elastic gel

Sounder map 2017



Year	2016	2017	2018	2019	2020	2021
# of Clusters planned	1	2	4	6	8	10
# of Clusters actual	1	2	3	5	7	9
# of Oms	288	576	864	1440	2016	2592

Timeline

Baikal Site Infrastructure:

- Railroad, Power line on the shore
- The new data taking center at the array site has been installed in 2016.
- The new shore lab was created on the site during summer 2017.
- The building in Baikalsk town is ready for the local lab and temporary OMs storage for detector maintenance and upgrade.

The optical modules production facility in Dubna:

- The facility allows to produce and test up to 12 OM per day
- We need to produce and send to the site 600 OM per season

Search for muon neutrino in 2016 (33 live days)

Muon Neutrino Selection

Polar angle distribution of muons selected with the requirement of at least 6 hits OM's at 3 strings. Comparison of reconstructed events in obtained Data and simulated atmospheric muon flux generated with CORSIKA QGSJET

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.

BDT reponse cut:

- > 0.20, 80% signal efficiency
- > 0.25, 65%
- > 0.30, 40%

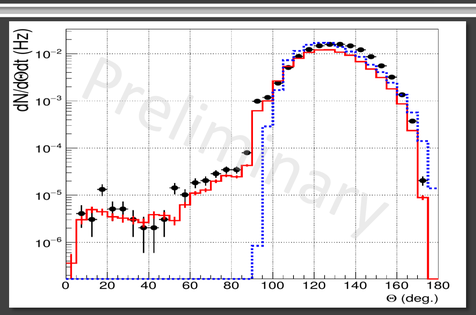
Result

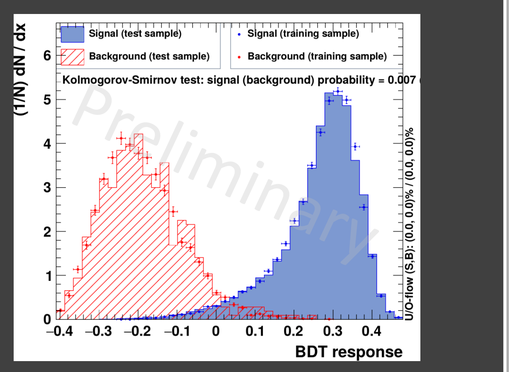
Angular distribution for BDT > 0.2 cut

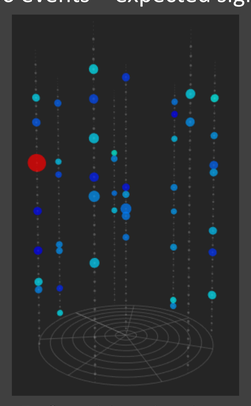
23 events were selected in the signal region

≈ 3 events – expected bkg. from atm. muons

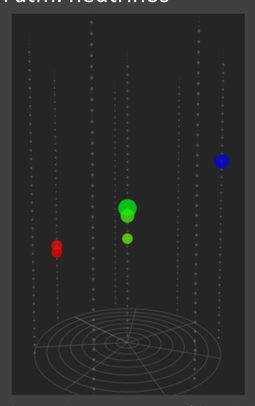
≈ 36 events – expected signal from atm. neutrinos



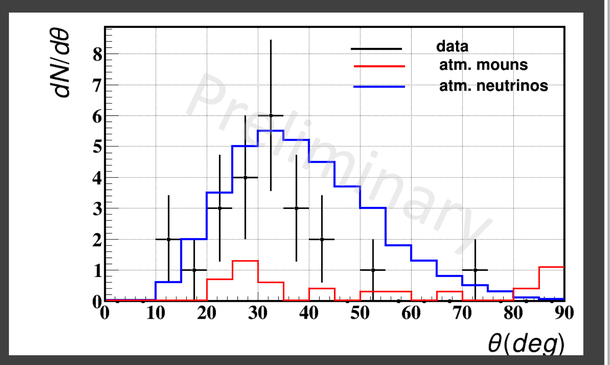




Before hit selection

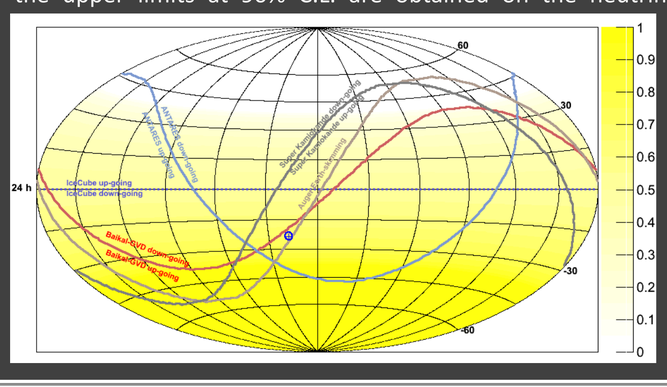


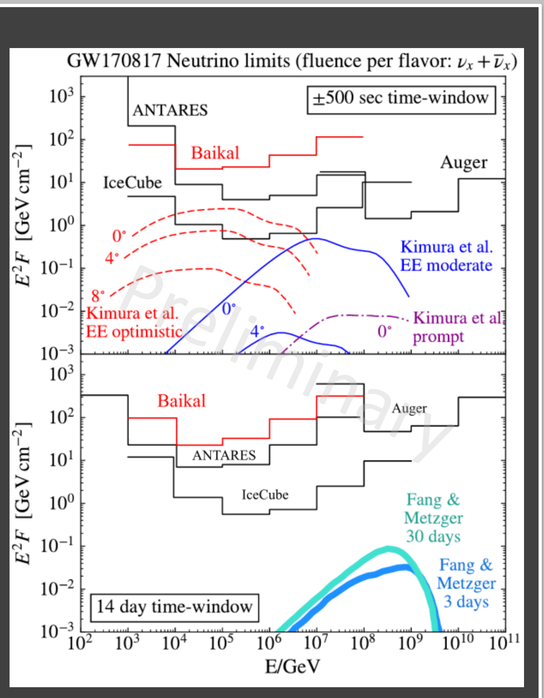
After hit selection (θ = 142.0°)



Search for high-energy neutrinos associated with the GW170817

- GW: 17.08.2017, 12:41:04 UTC = 1502973664 sec UNIX
- NGS4993 at ~ 40 Mpc, equatorial coordinates α (J2000.0) = 13h 09m 48s.085, β(J2000.0) = -23°22'53''.343
- Zenith angle of the source at registration time: 93.3°
- No neutrino events associated with GW170817 using cascade mode within both ± 500 sec and 14 days are observed
- Assuming E-2 spectral behavior and equal fluence in all flavors the upper limits at 90% C.L. are obtained on the neutrino





1. A.D. Avrorin et al., "Gigaton Volume Detector (GVD) in Lake Baikal: status of the project", XVII International Workshop on Neutrino Telescope, 13-17 March 2017, Venezia, Italy, https://pos.sissa.it/307/063/
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3. A.D. Avrorin et al., "The optical module of Baikal-GVD" , 2016. 10 pp., Published in Phys.Part.Nucl.Lett. 13 (2016) no.6, 737-746, DOI: 10.1134/S1547477116060029.
4. A.D. Avrorin et al., "Data acquisition system for the Baikal-GVD neutrino telescope" , Published in Phys.Part.Nucl. 47 (2016) no.6, 933-937, DOI: 10.1134/S1063779616060058.
5. A.D. Avrorin et al., "Cascades in GVD", 35th ICRC-2017 12-20 июля 2017, Bexco, Busan, S.Korea, https://pos.sissa.it/301/962/pdf