The first construction phase of the Baikal-GVD neutrino telescope

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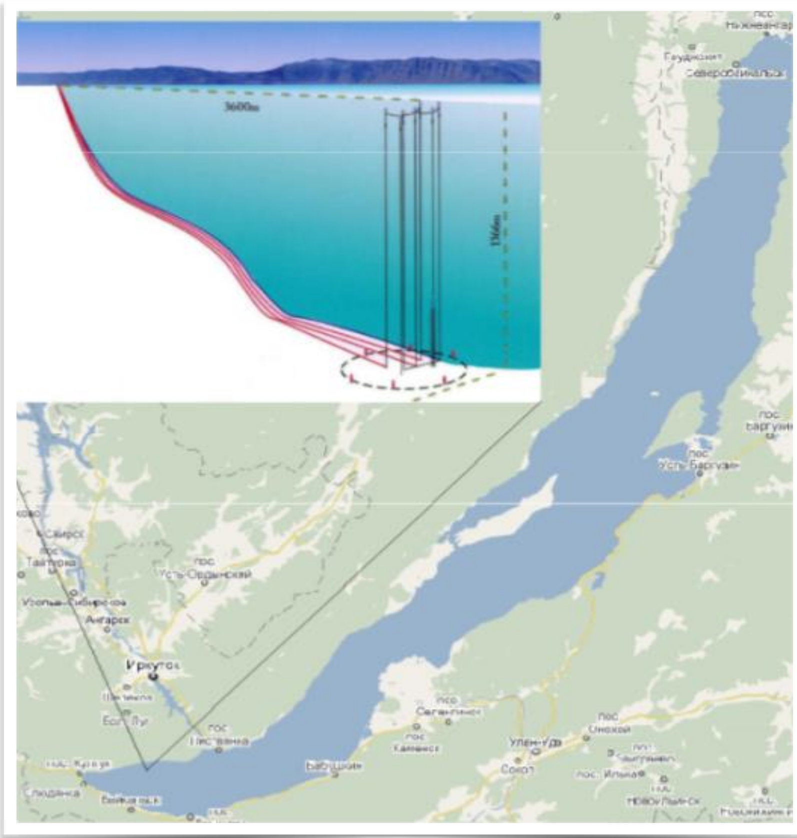
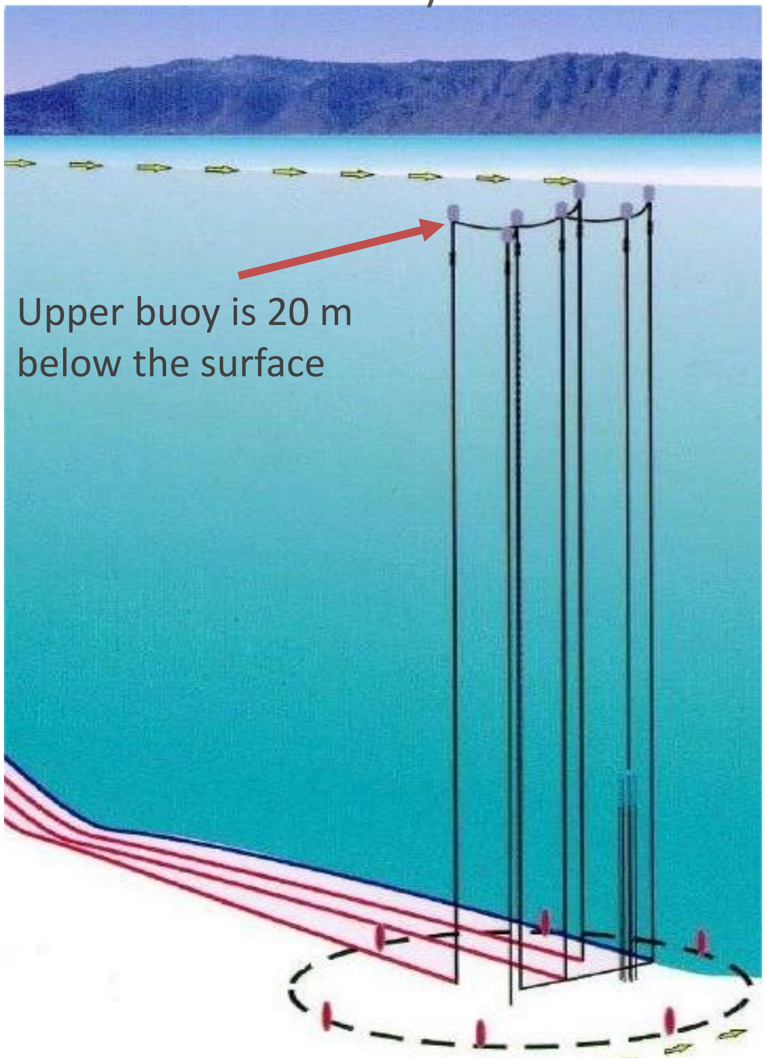
Baikal Site

- 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 K^{40})
  - no bioluminescence,
  - chemiluminescence (1 photon background)
- The most northern location allows observing the Galactic Center 18 hours per day through the Earth
- Good infrastructure (railroad, power line)
- Reliable ice cover as a deployment platform
  - Simple deployment techniques

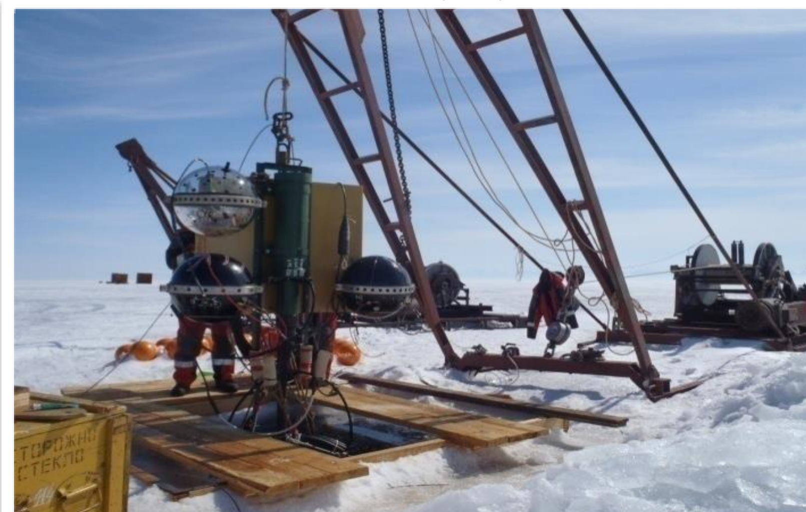


Detector is easily accessible



Bed cable laying

Detector deployment

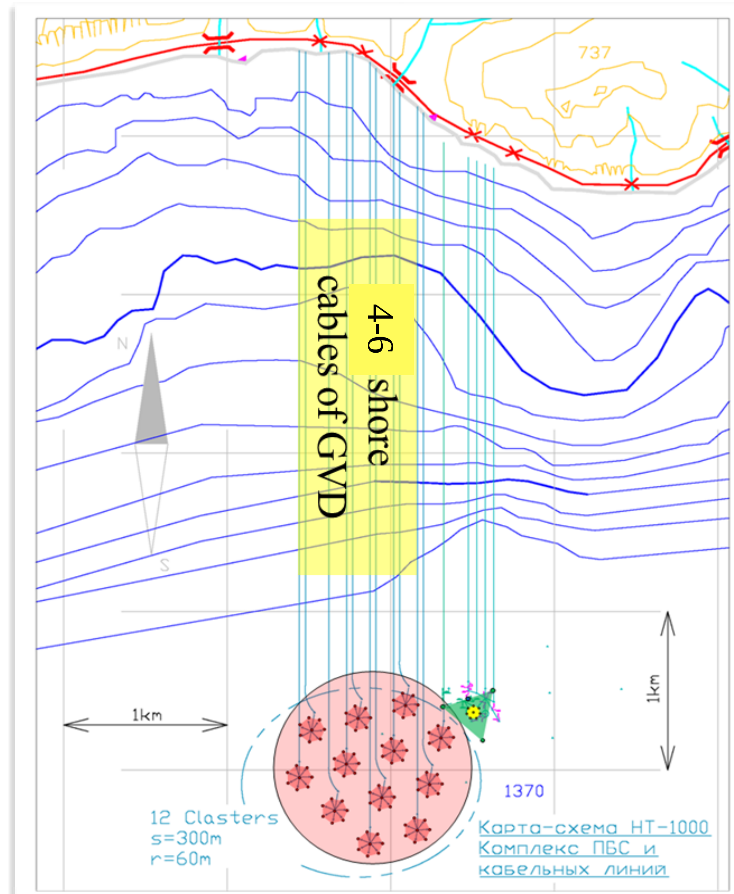


Optical Module

- Optical module (see poster #1163):
  - 10” PMT R7081HQE, $Q_{eff} \approx 0.35$
  - 17” Glass pressure-resistant sphere VITROVEX
  - Underwater 5-pin industrial SubConn connector
  - OM electronics: amplifier, HV DC-DC, controller
  - 2 on-board LED flashers for calibration: 10^8 p.e., 430 nm, 5 ns
  - Mu-metal cage
  - Elastic gel

Baikal Gigaton Volume Detector

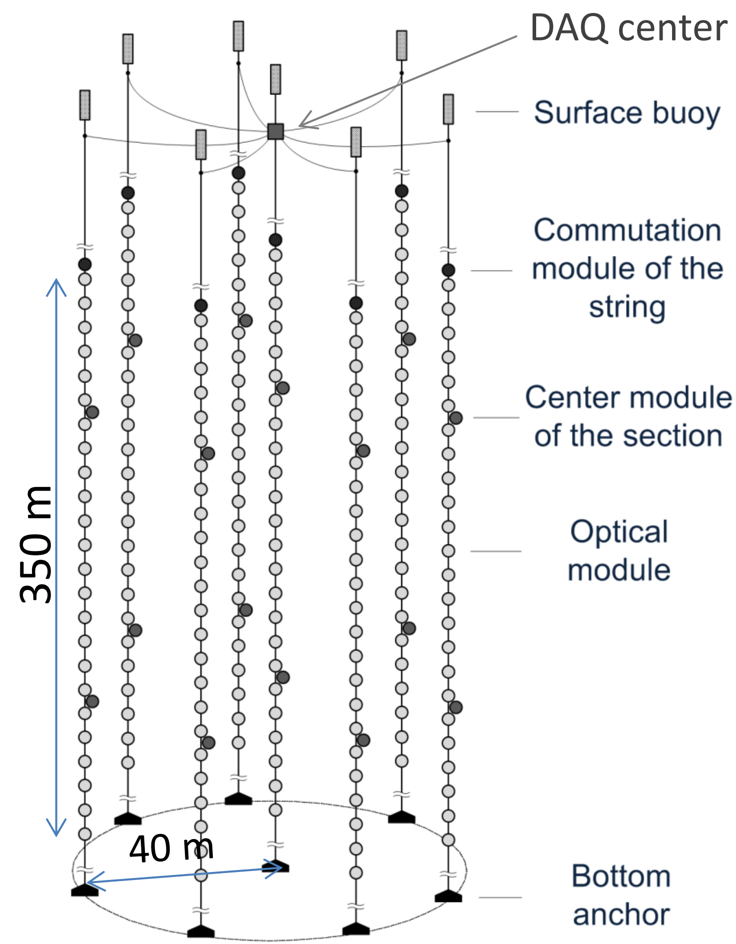
- R&D is almost completed
- Two possible configurations (optimized for both muons and cascades):
  - 12 autonomous telescopes (clusters) at 300 m from each other with 350 m height (depths 950 – 1300 m)
  - 8 autonomous telescopes with a 525 m height (depths 775 – 1300 m)
  - One shore cable for 2 clusters
  - 2304 OMs in total
  - The first cluster is completed in April 2015



Top view

The first cluster is completed in April 2015

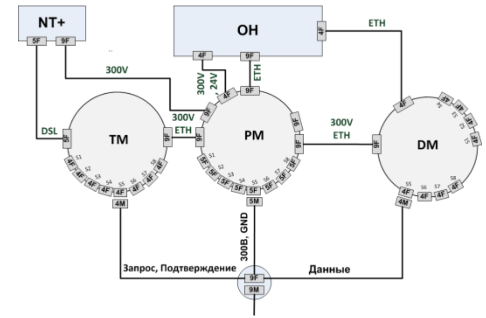
- 192 OMs at 8 strings
  - 24 OMs per string with 15 m spacing
  - depth 950 - 1300 m
  - 40 m between strings (60 m projected)
- Cluster DAQ center (30 m below surface)
  - Trigger, power, data transfer systems of the cluster
- Electro-optical cable to shore
- Acoustic positioning system (4 beacons on each string)
- Calibration light beacon (LEDs)
  - Interstring time calibration



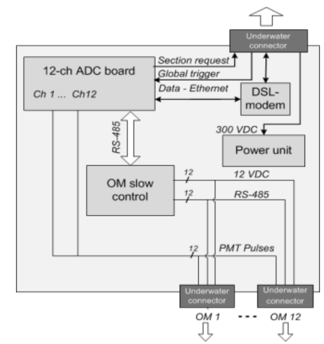
Cluster design

- 12 OMs are connected to a Central Module forming a section
- String can have 2 or 3 such sections, as well as, an additional equipment such as acoustic modules

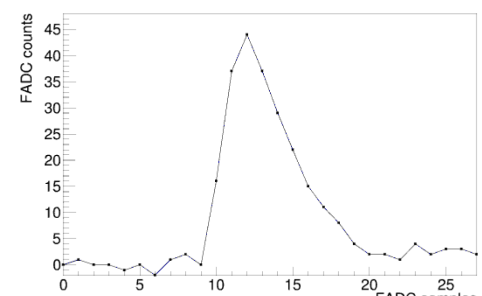
- Central Module provides:
  - PMT data digitization (FADC board, 12 channels, 200 MHz, FPGA Xilinx Spartan 6)
  - Control and power supply of OMs
  - Online data processing (e.g. extraction of PMT pulses)
  - Section trigger logic
    - triggering of neighbor pair of OMs with low (0.5 p.e.) and high (3.0 p.e.) thresholds (main condition)
    - section request to Cluster DAQ Center (1.2 km line)
    - after receiving a global trigger, 5 μs waveform data are extracted from FADC and are sent to the shore



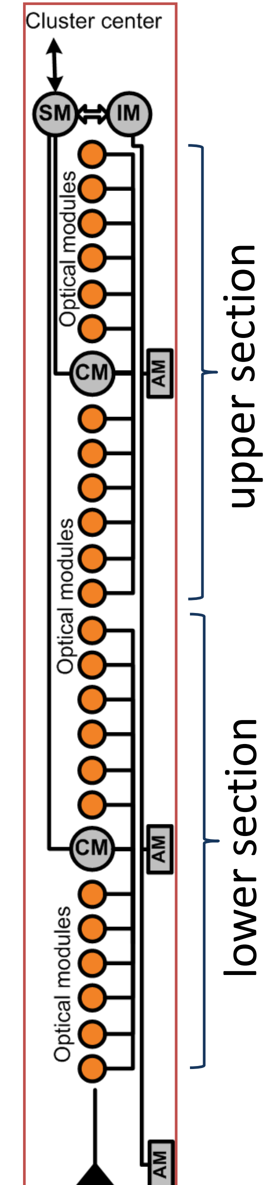
A block diagram of the Cluster DAQ center



A block diagram of the section

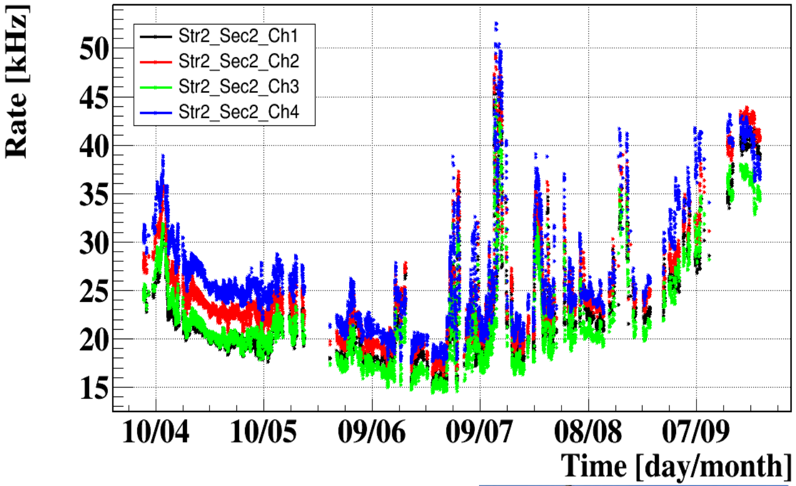


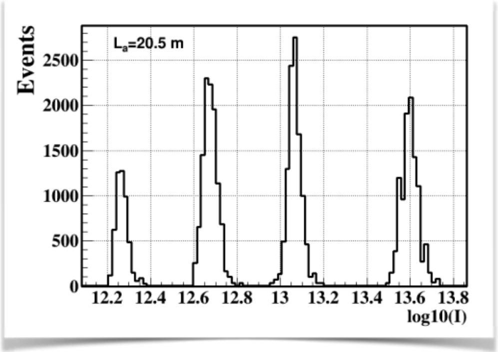
A digitized PMT waveform



Cluster operation

- Typical PMT noise rates are 15-30 kHz
- Typical trigger rate is 500 Hz
- Time and amplitude calibration (see poster #1162)
- Laser beacon which locates ~100 m apart from the cluster:
  - Position reconstruction accuracy ~3 m
  - Intensity reconstruction accuracy ~10%





Laser based light-source

Cluster Performance for cascade detection

A reconstruction of a cascade vertex:

- Iterative procedure: OMs with residual $\delta t > 15$ ns are excluded and final N_{hit} is obtained for the following analysis.
- $\delta r = |r_{rec} - r_{gen}|$ ~2 m (median value)

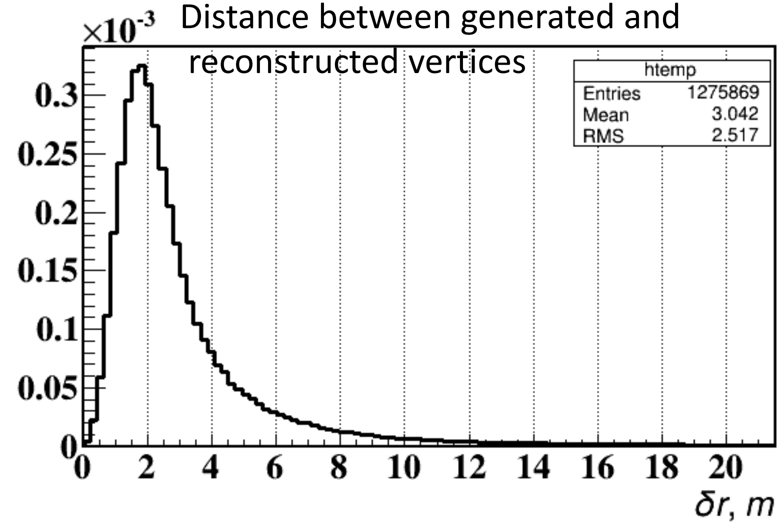
Directional resolution for cascades:

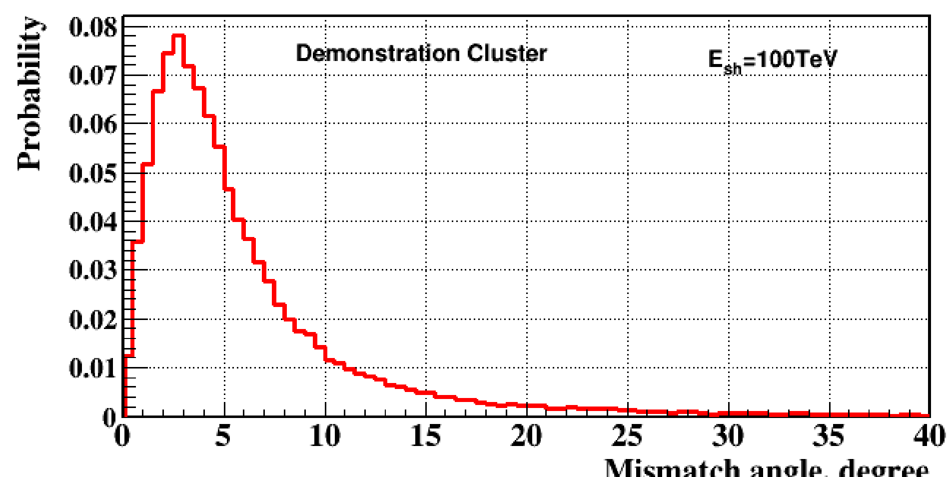
- ~3°- 4° (median)

Energy resolution for cascades:

- $\delta E/E$ ~ 30% , averaged by E^{-2} ν_e spectrum

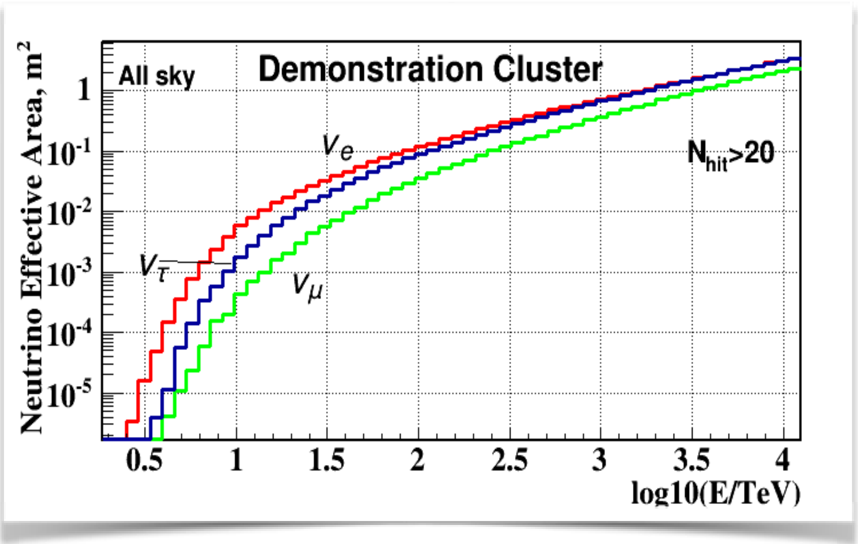
Distance between generated and reconstructed vertices



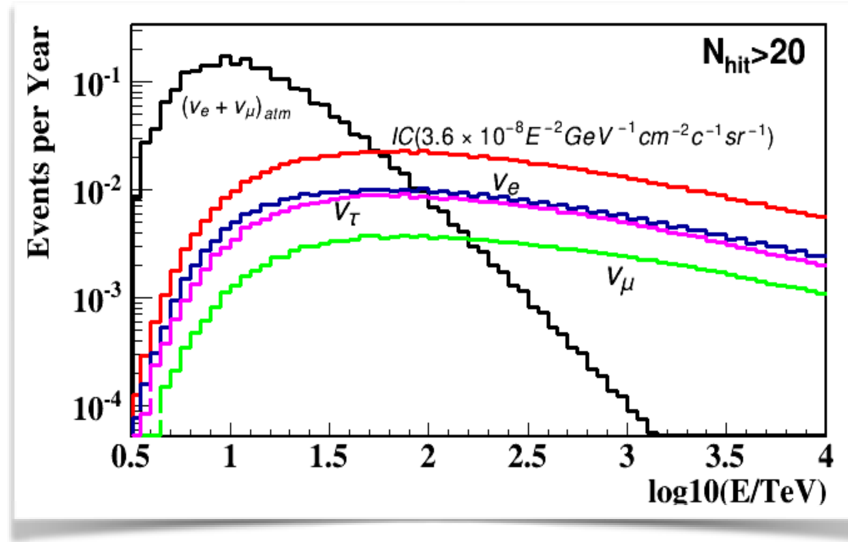


Cluster Performance for cascade detection

Applied cut $N^*_{hit} > 20$



~1 Event per year E>100 TeV for $E^2F_{IC} = 3.6\ 10^{-8}\ GeV^{-1}\ cm^{-2}\ sr^{-1}$

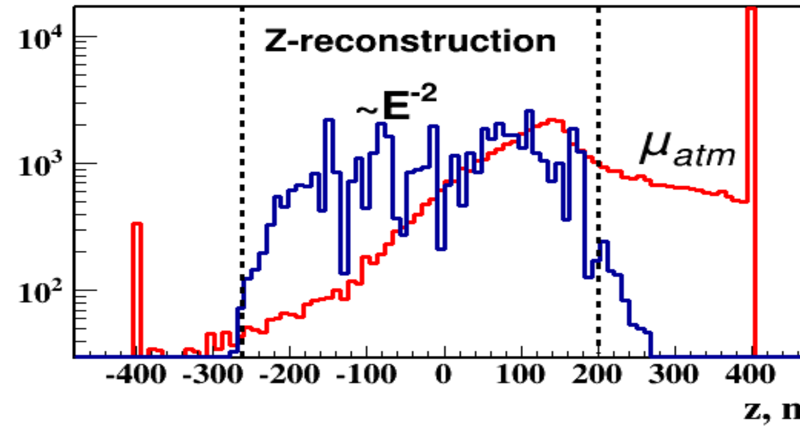


External water volume is used

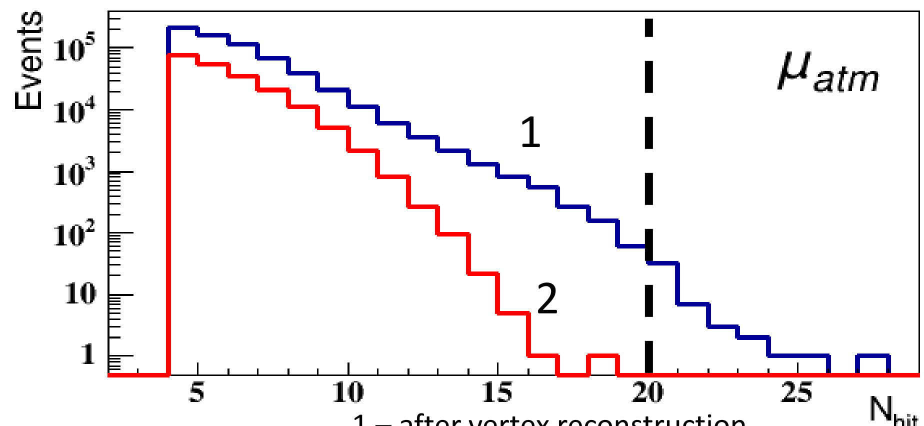
Neutrino effective area for 100 TeV: ≈0.1 m^2

Atmospheric muons MC-sample (341 days)

Vertex reconstruction filter:
$-270 < z_{rec} < 200$ m,
(OMs location: -172.5 ÷ +172.5 m)



Hit channel multiplicity distributions

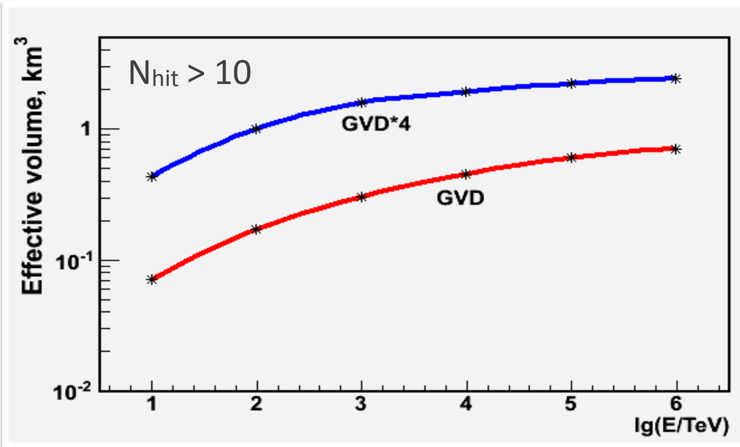


1 – after vertex reconstruction
2 – after vertex reconstruction and quality cut $-270 < z_{rec} < 200$ m,

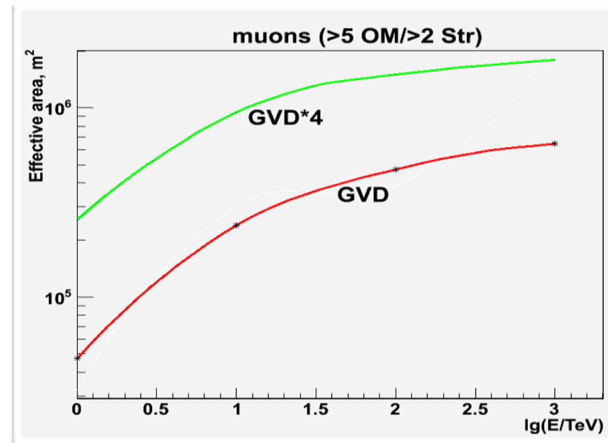
Expected number of events for 1 year exposition:
~1 event from astrophysical IC flux
0.05 events – atm. ν;
0.05 events – atm. μ

Baikal-GVD Performance

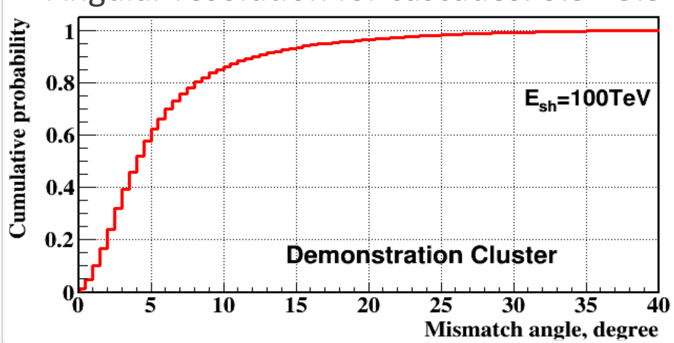
Effective volume for cascades E>100 TeV: ~0.2 - 0.6 km^3



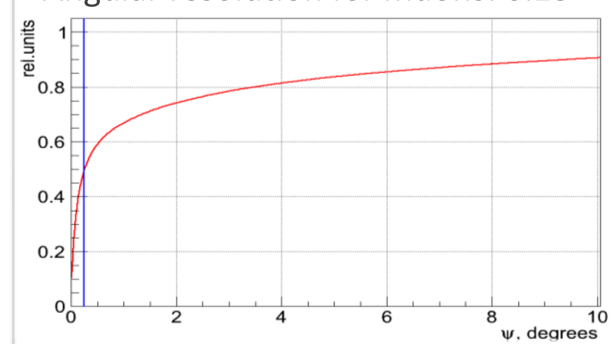
Effective area for muons E>10 TeV: 0.2 - 0.6 km^2



Angular resolution for cascades: 3.5 - 5.5°



Angular resolution for muons: 0.25°



Baikal-GVD timeline

Cumulative number of clusters vs. year

Year	2015	2016	2017	2018	2019	2020
Cluster 192 OM	***1*** ***192***	***1*** ***192***	***3*** ***576***	***5*** ***960***	***7*** ***1344***	***10*** ***1920***
Cluster 288 OM	***2/3*** ***192***	***1*** ***288***	***2*** ***576***	***4*** ***1152***	***6*** ***1728***	***8*** ***2304***

Conclusion

- Baikal Collaboration has more than 30 year long an extensive positive experience on development, construction and operation of underwater facilities in lake Baikal
- The key elements and systems of the Baikal-GVD have been developed, produced and tested in Lake Baikal. Prototyping & Early Construction Phase of the project concluded with a construction of the first Cluster in April 2015. A cluster is sensitive to about 1 cascade event with E > 100 TeV of IC flux.
- Completion of the Baikal-GVD with 2304 OMs with about of 0.4 km^3 effective volume for cascade detection is expected in 2020