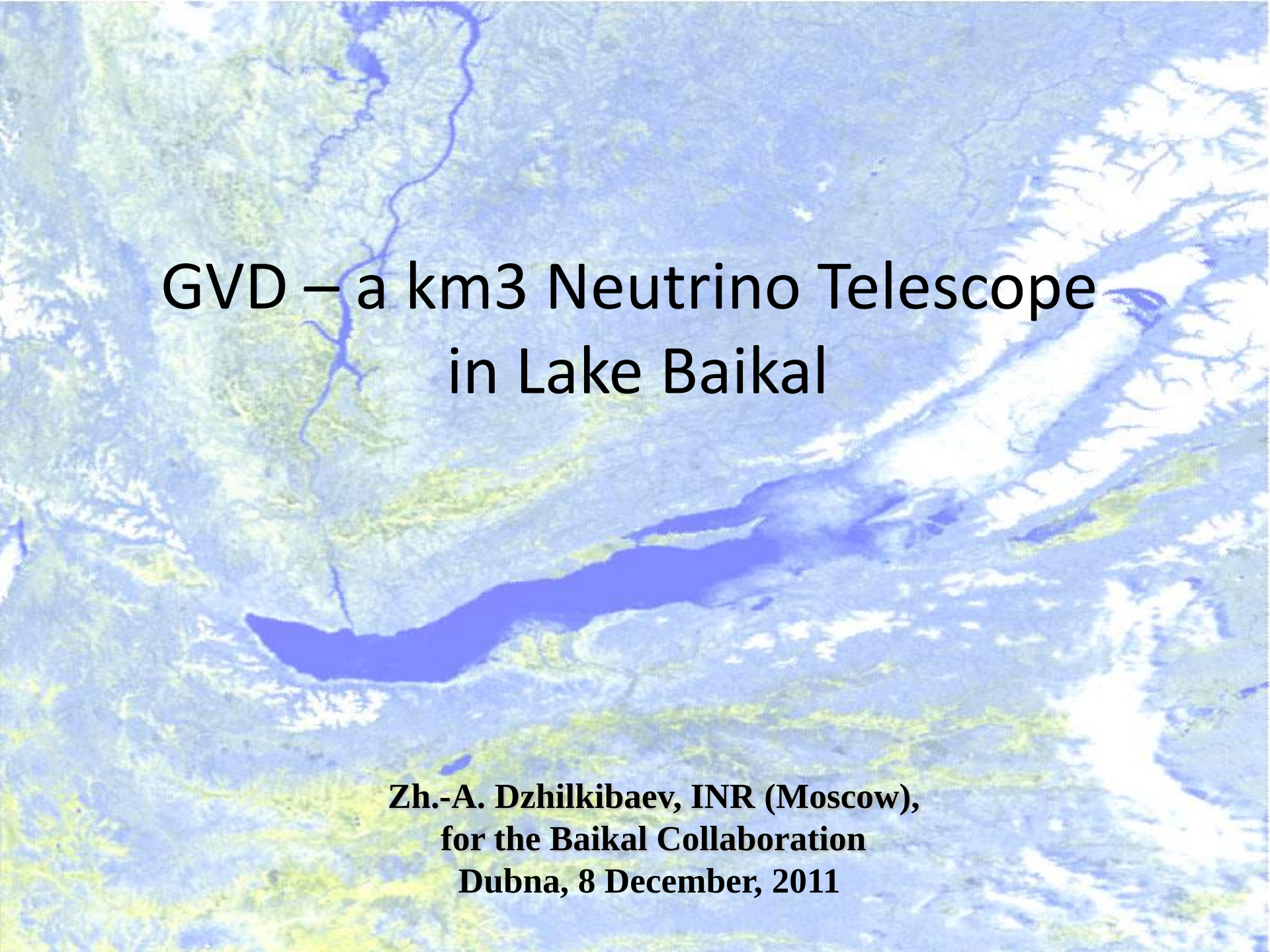
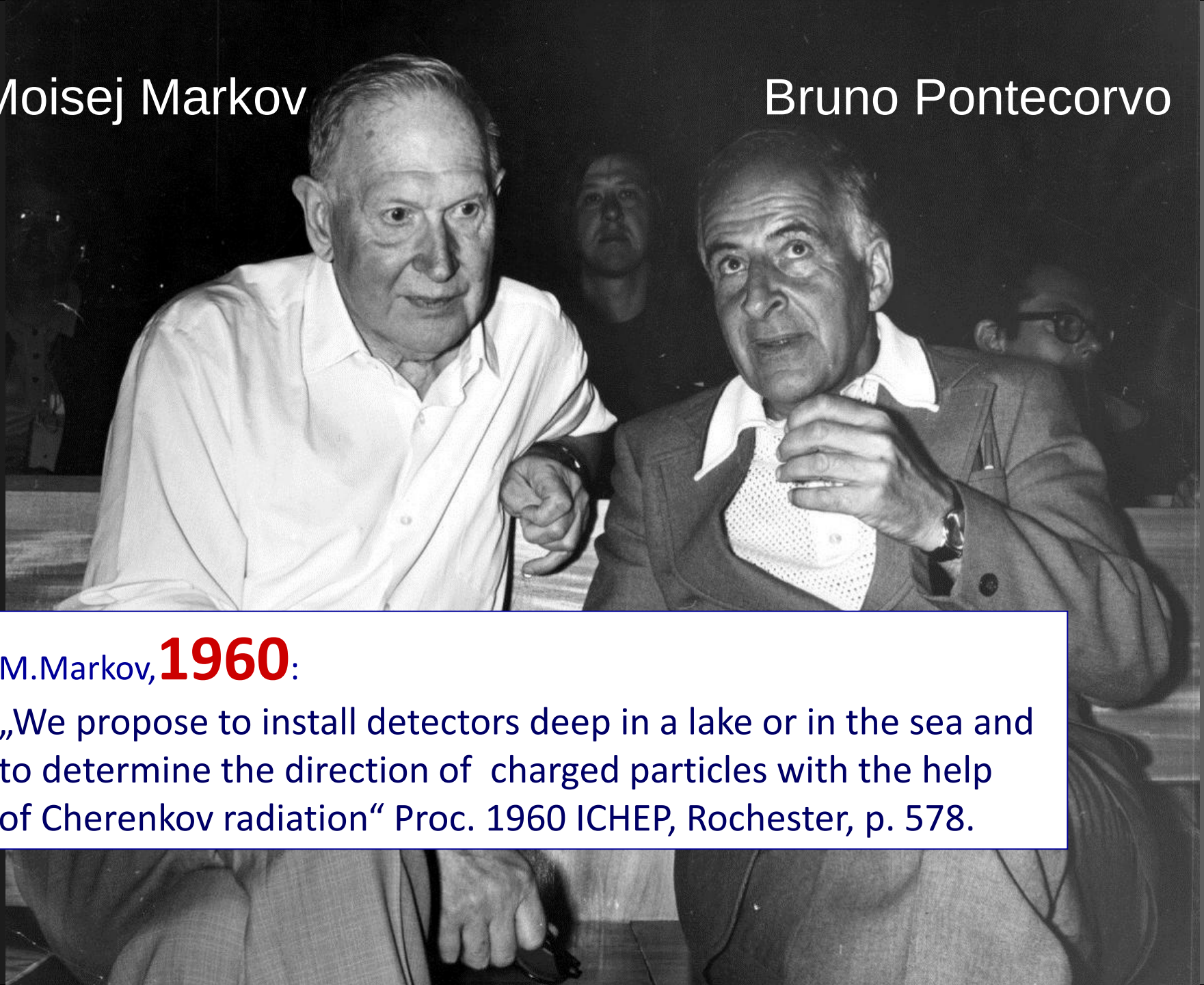


GVD – a km3 Neutrino Telescope in Lake Baikal

Zh.-A. Dzhilkibaev, INR (Moscow),
for the Baikal Collaboration
Dubna, 8 December, 2011

GVD-project

1. **Institute for Nuclear Research, Moscow, Russia.**
2. **Joint Institute for Nuclear Research, Dubna, Russia.**
3. **Irkutsk State University, Russia.**
4. **Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia.**
5. **Nizhny Novgorod State Technical University, Russia.**
6. **St.Petersburg State Marine University, Russia.**
7. **EvoLogics Gmb. Germany.**
8. **Kurchatov Institute, Moscow, Russia.**



M.Markov, **1960**:

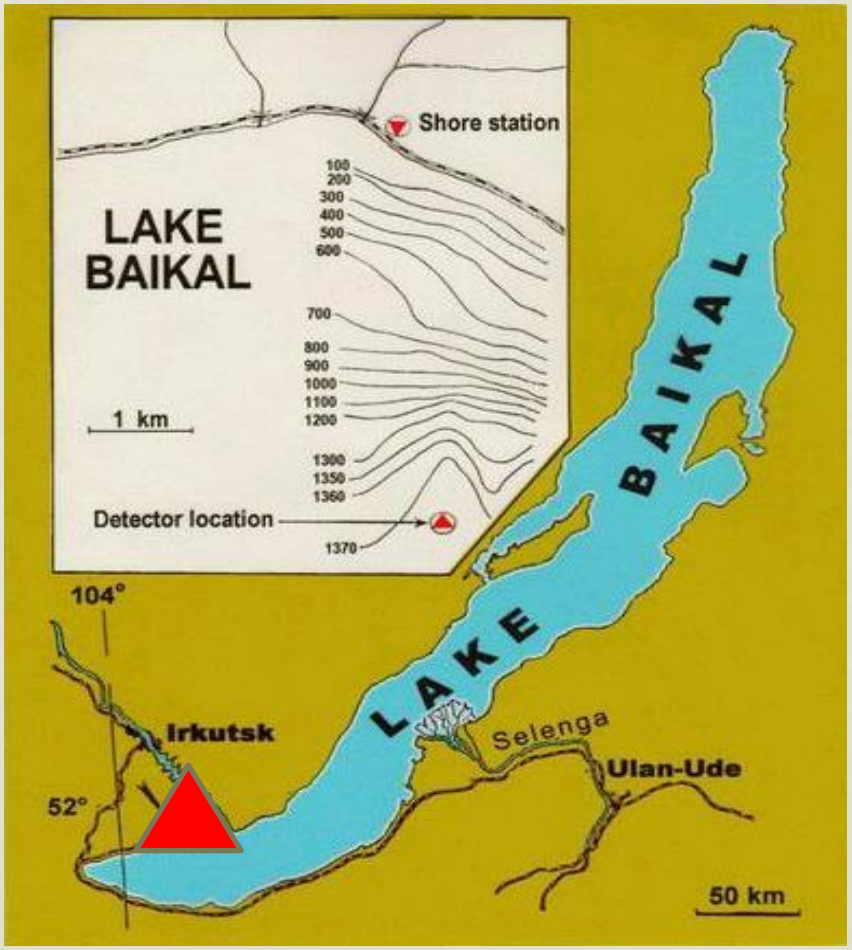
„We propose to install detectors deep in a lake or in the sea and to determine the direction of charged particles with the help of Cherenkov radiation“ Proc. 1960 ICHEP, Rochester, p. 578.

Outline:

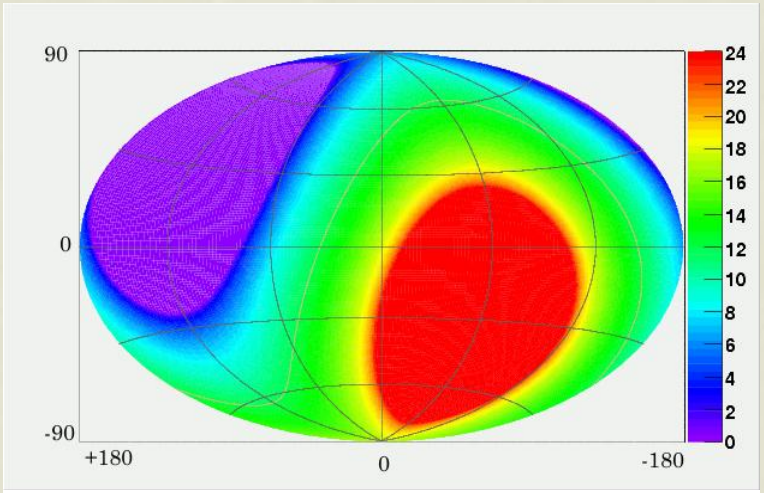
- Site properties
- R&D and design Phase
- Prototyping Phase
- Conclusion

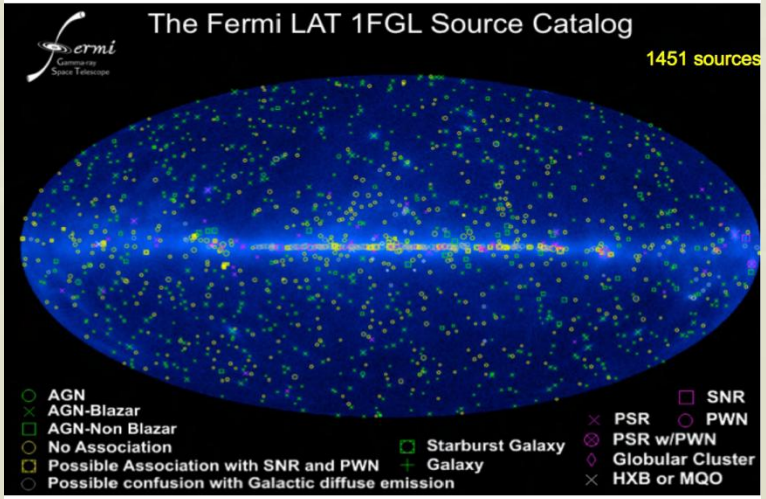
- **Location: 104° N; 52° E**

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

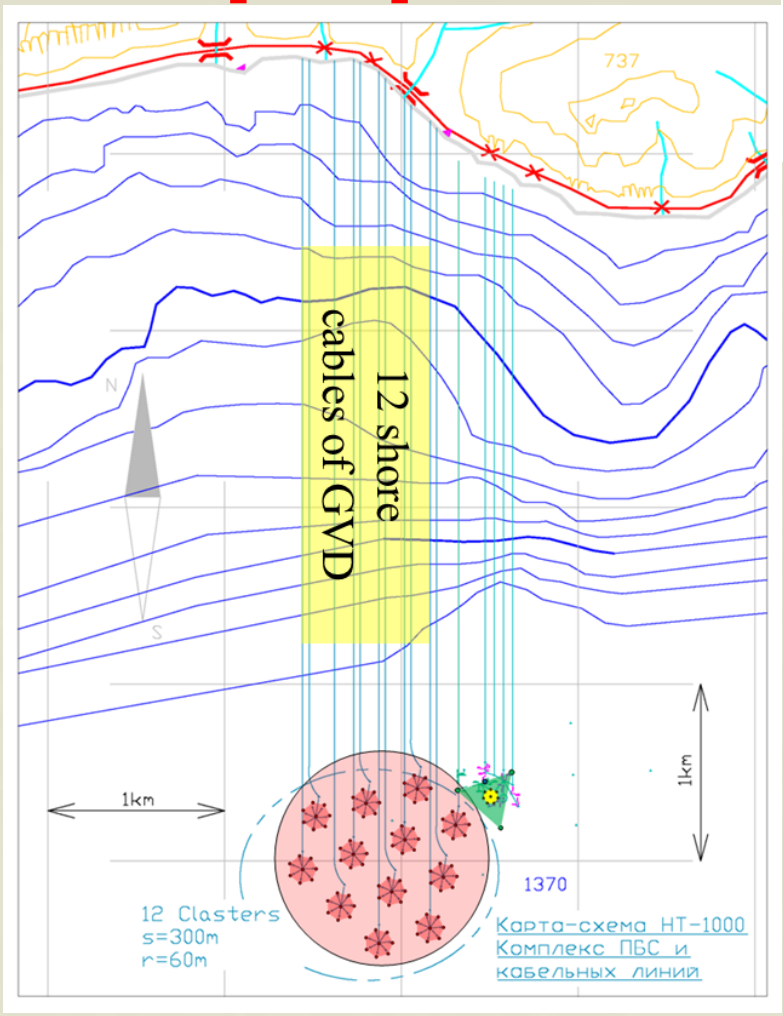


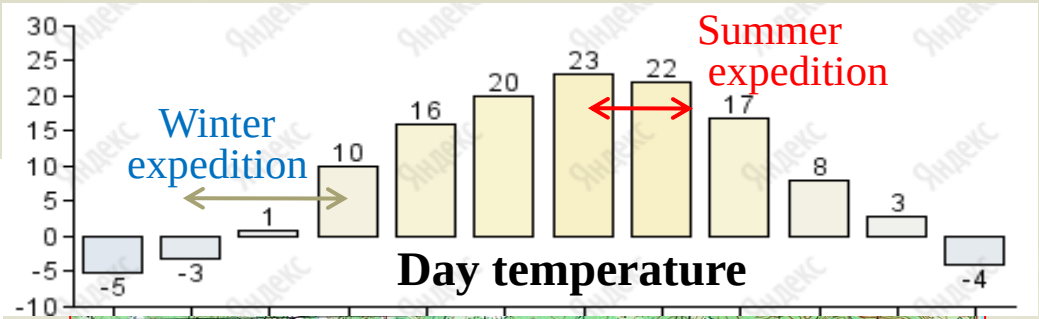
The GVD sky view





- **Cite properties:**



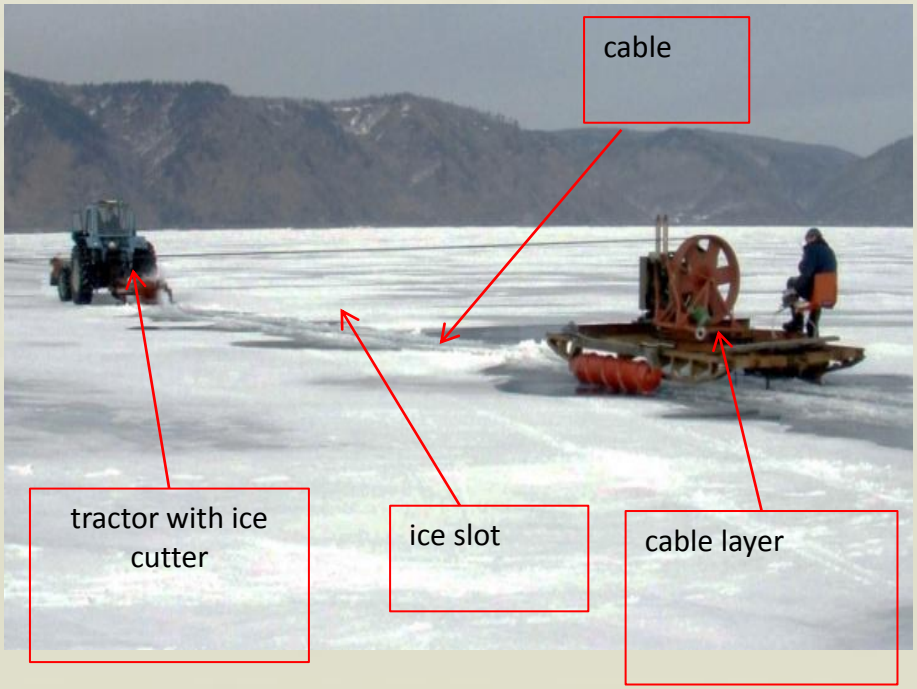


Depth – 1360 m; Flat the lake bed at >3 km from the shore – allows > 250 km^3 Instrumented Volume!

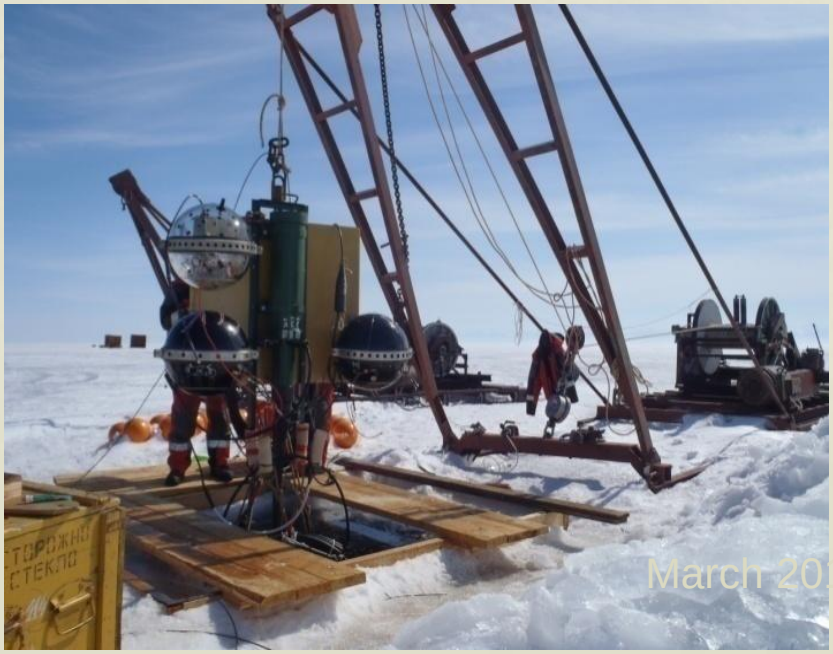
• Strong ice cover during ~2 months:

- Telescope installation, maintenance, upgrade and rearrangement
- Installation & test of a new equipment
- All connections are done on dry
- Fast shore cable installation (3-4 days)

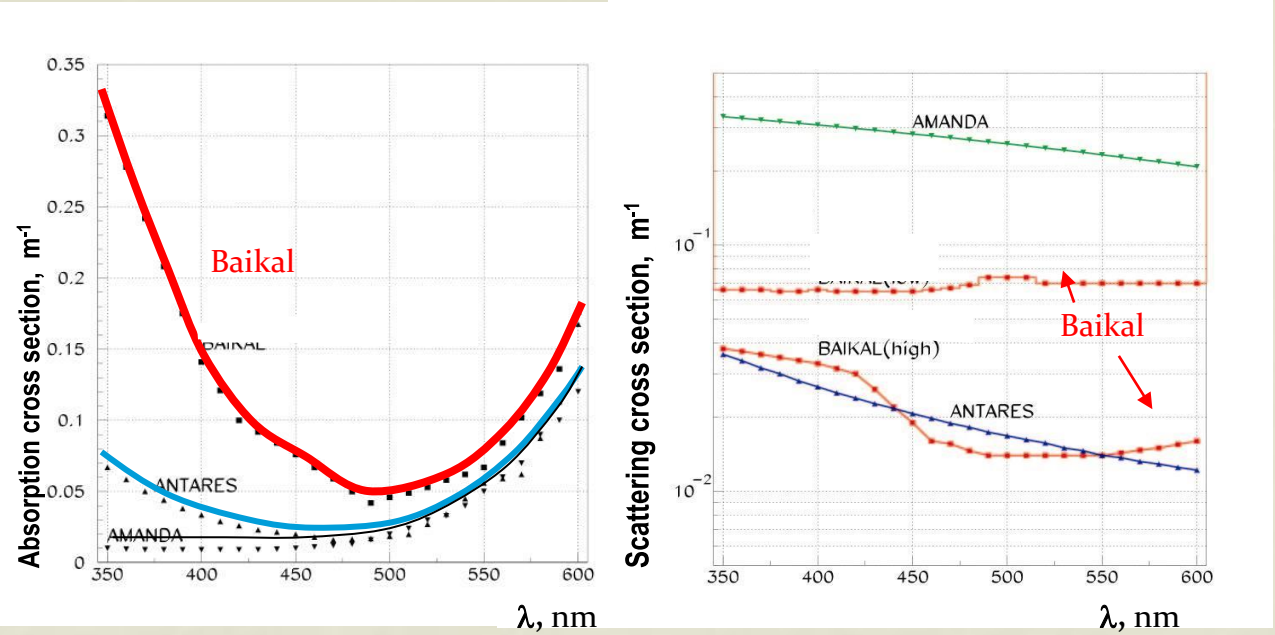
Shore cable deployment



Dry mating



• Water properties



- Absorption length – 22-24 m

- Scattering length: 30-50 m (L_{eff} ~ 300-500 m)

- Moderately low background in fresh water:
not high luminosity bursts from biology and K^{40} background.

Water properties allow detection of all flavor neutrinos with high direction-energy resolution!

Baikal - Milestones

Since 1980 Site tests and early R&D started

1990 Technical Design Report NT200

1993 NT36 started: - the first underwater array
- the first neutrino events.

1998 NT200 commissioned: start full physics program

2005 NT200+ commissioned (NT200 & 3 outer strings)

2006 R&D and design phase of the Gigaton Volume Detector project:

2008-10 In-situ test of the GVD electronics: prototype strings.
Technical Design Report

2011 Prototyping phase:

Prototype cluster (3 strings)

Gigaton Volume Detector (GVD) in Lake Baikal

Objectives:

- km3-scale 3D-array of photodetectors
- 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 > 3 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, …

GVD - design

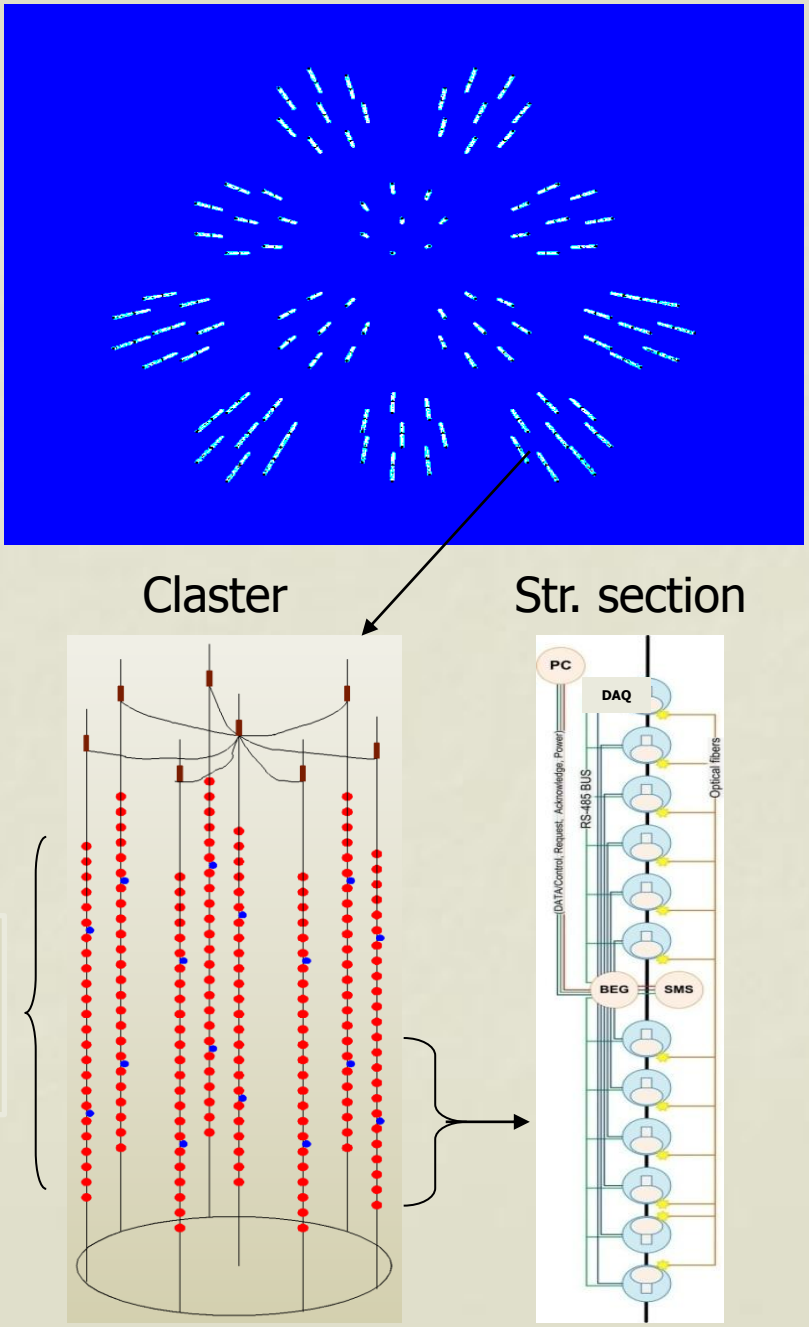
Instrumented volume: 0.3 km^3

Depth: 900 – 1250 m
(345 m long strings)

2304 Optical Modules

96 Strings: 24 OMs/Str.,
2 Sections/Str.

12 Clusters: 8 Str/Cluster



Optimisation of GVD configuration

Parameters for optimization:

Z – vertical distance between OMs

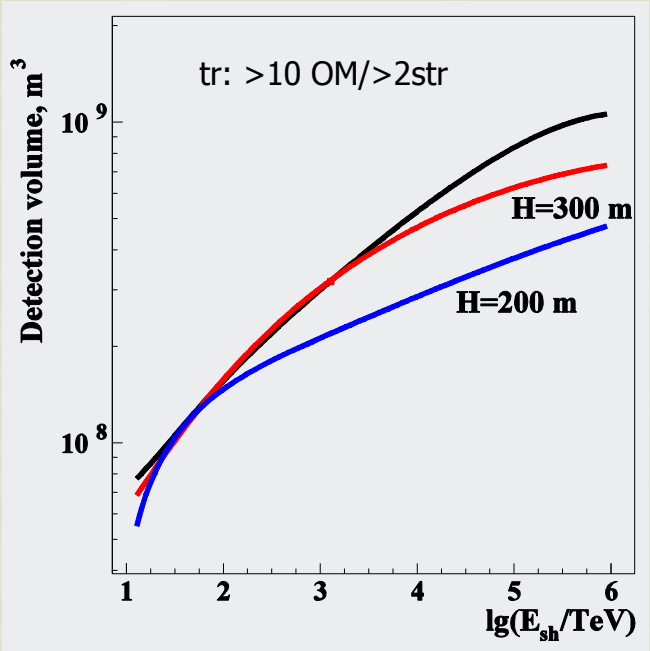
R – distance between string and cluster centre

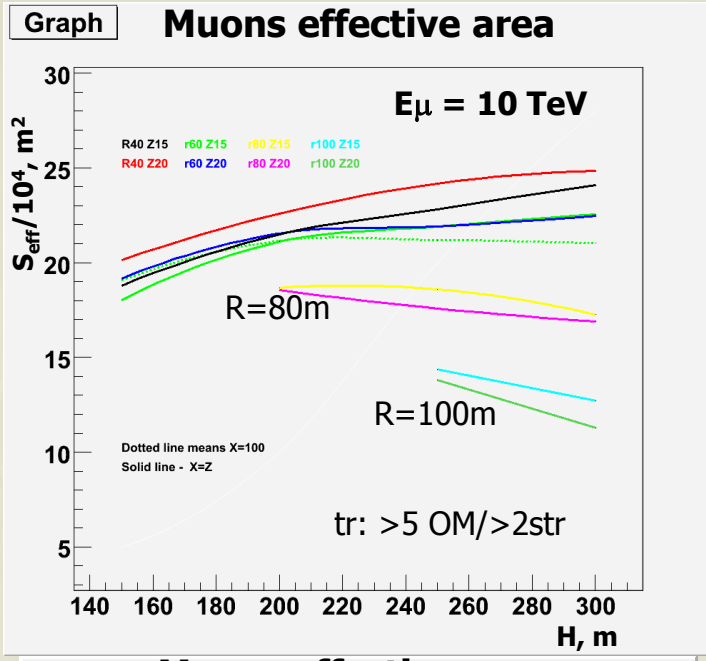
H – distance between centres of neighbouring clusters

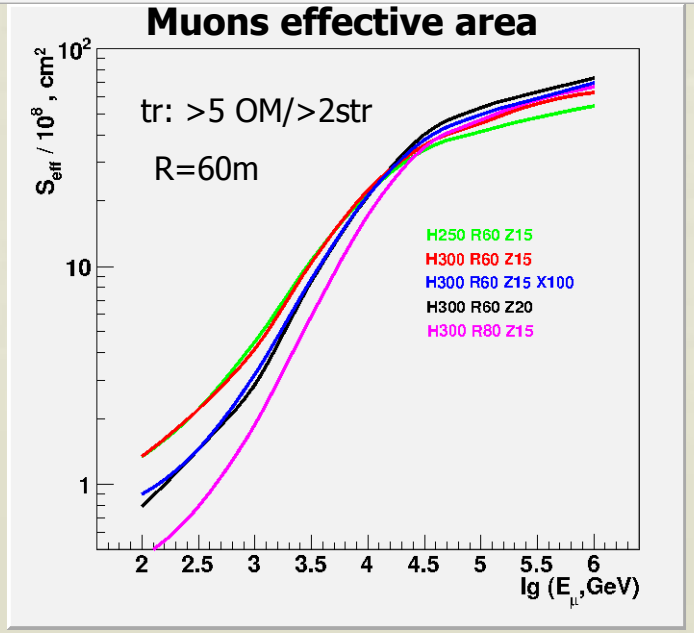
The compromise between cascade detection volume and muon effective area:

H=300 m
R = 60 m
Z = 15 m

Cascades effective volume







Cascades (E>100 TeV):

V_{eff} ~0.2–0.7 km^3; $\delta(E/E_{sh})$ ~25%; $\delta\theta_{med}$~ 5^o

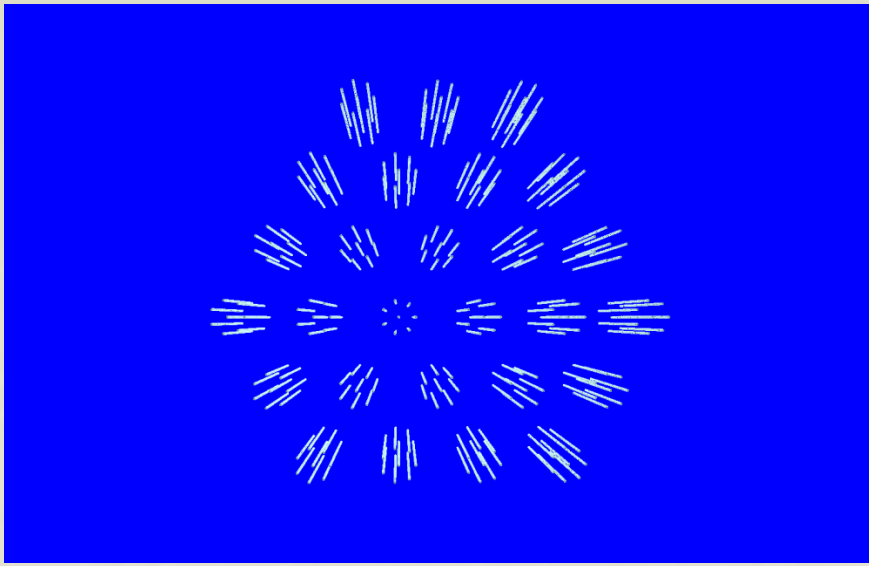
Muons: (E>3 TeV):

S_{eff}~0.2–0.8 km^2; $\delta\theta_{med} < 0.5^o$; $\delta\lg(E/E_\mu)$ ~0.4

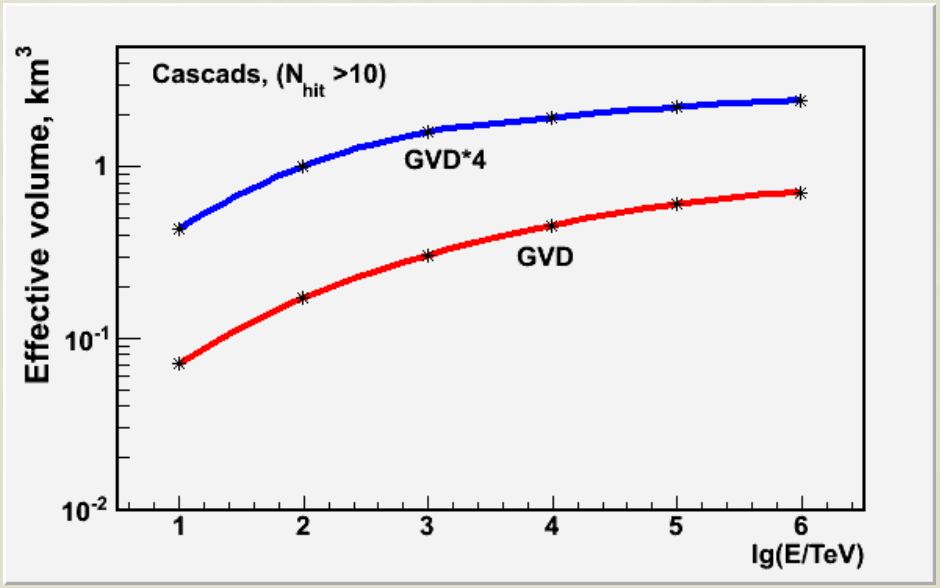
GVD* 4

Instrumented volume: 1.5 km^3
Depth: 600-1300 m (705 m long strings)

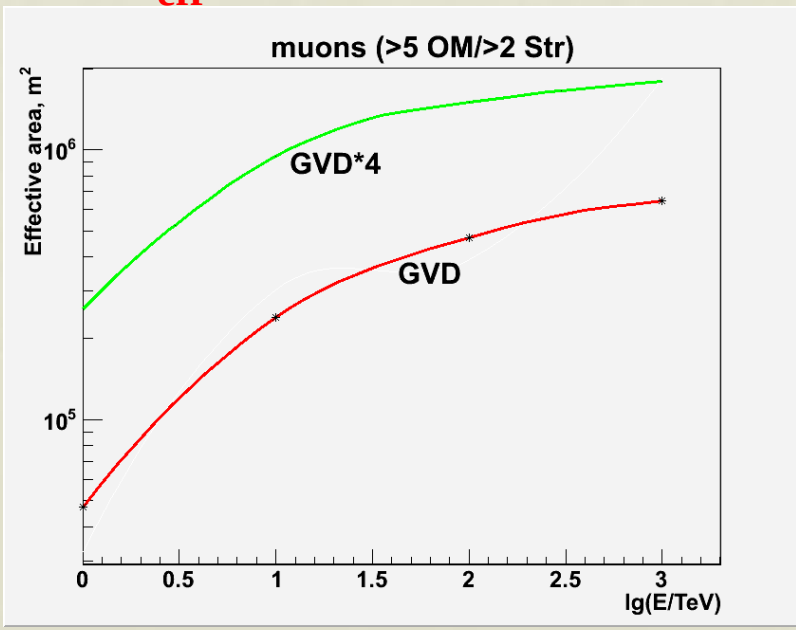
10368 Optical Modules,
216 Strings: 48 OM/Str, 3 Sec./Str
27 Clusters.: 8 Str/Cluster



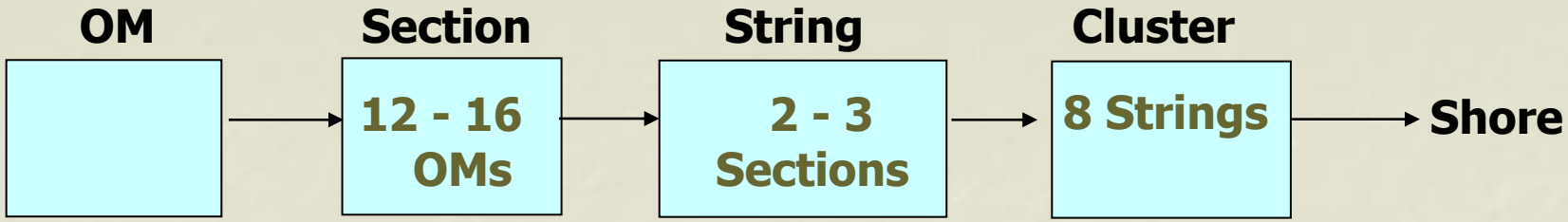
Cascades: (E>10 TeV):
V_{eff} ~0.4–2.4 km^3



Muons: (E>1 TeV):
S_{eff} ~ 0.3–1.8 km^2



GVD – R&D (2006-2010)

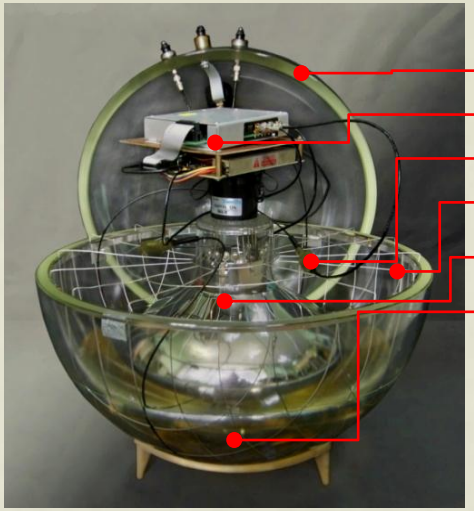


GVD - Key Elements and Systems:

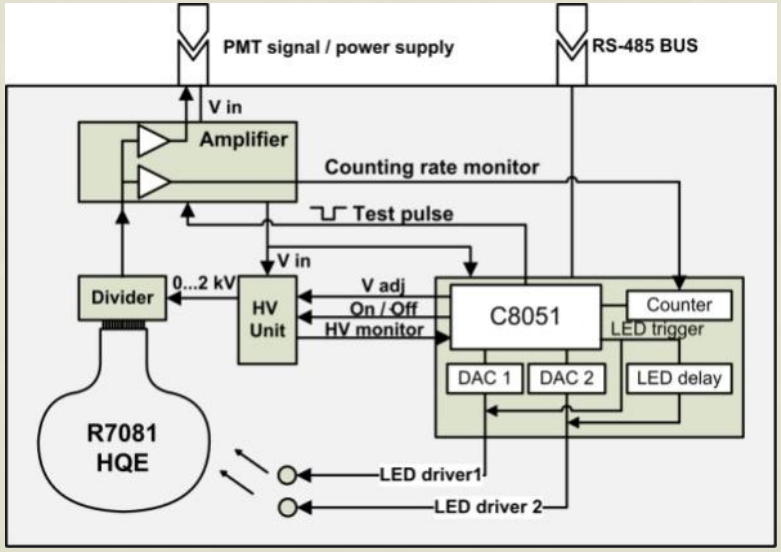
Development, production, long-term in-situ test

- Optical Module
- FADC-readout system
- Section Trigger Logics
- Calibration
- Data Transport
- Cluster Trigger System, DAQ
- Data Transport to Shore

Optical module (OM)

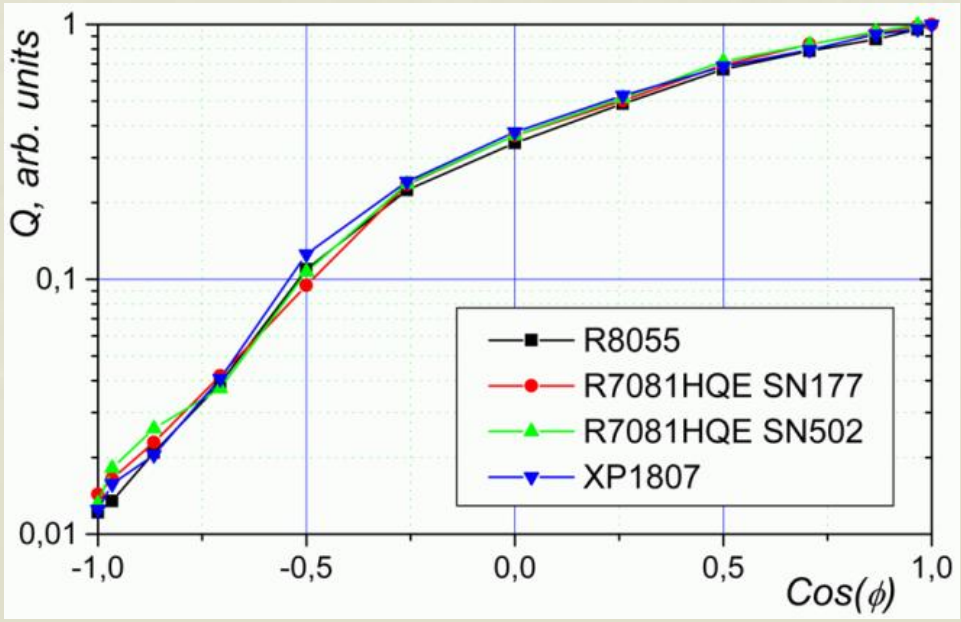


- Glass pressure-resistant sphere VITROVEX (17”)
- OM electronics: amplifier, HV DC-DC, RS485 controller
- 2 on-board LED flashers: 1…10^8 pe., 430 nm, 5 ns
- Mu-metal cage
- PMT R7081HQE : *D*=10”, ~0.35QE
- Elastic gel

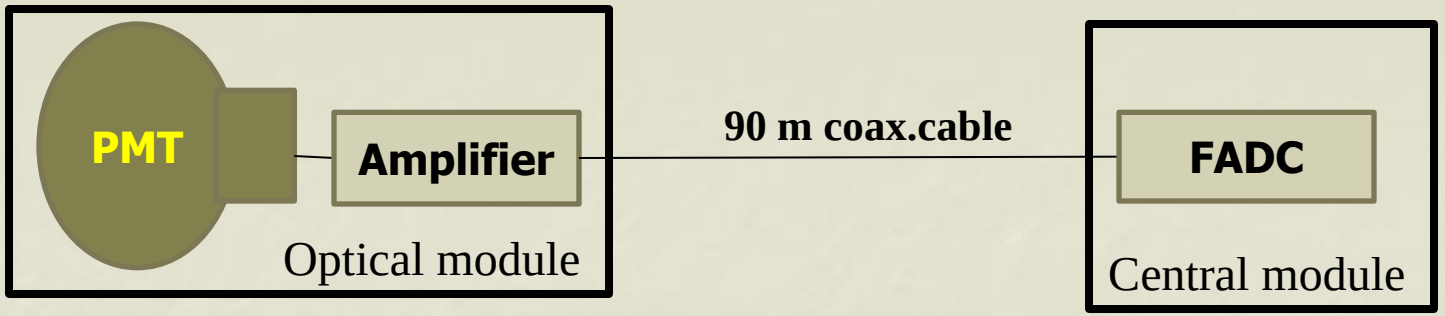


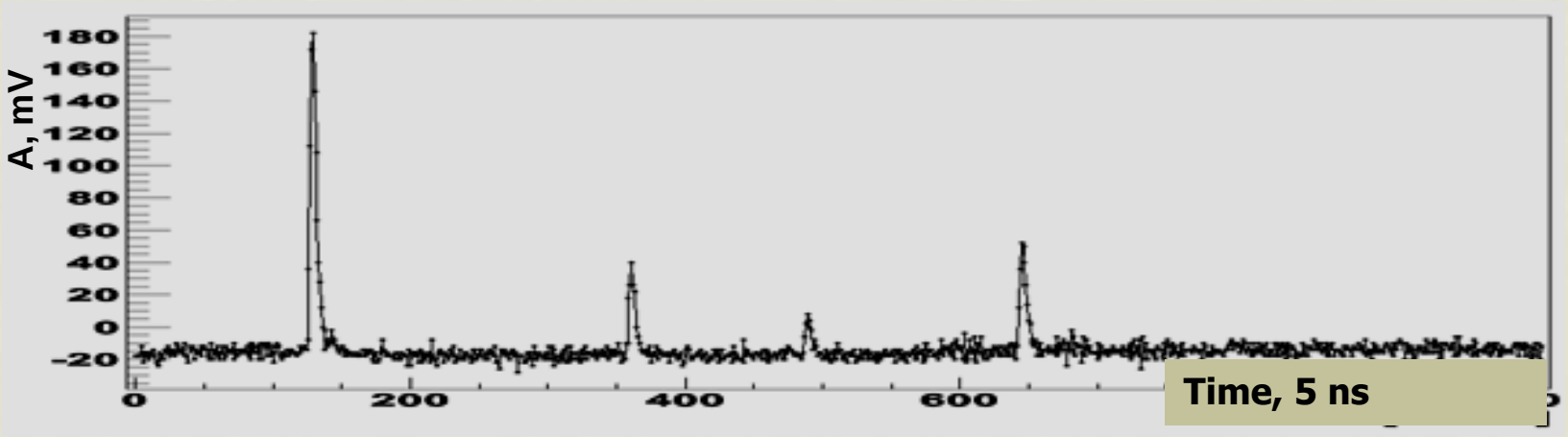
Functional scheme of the optical module electronics

Angular sensitivity



Measuring channel





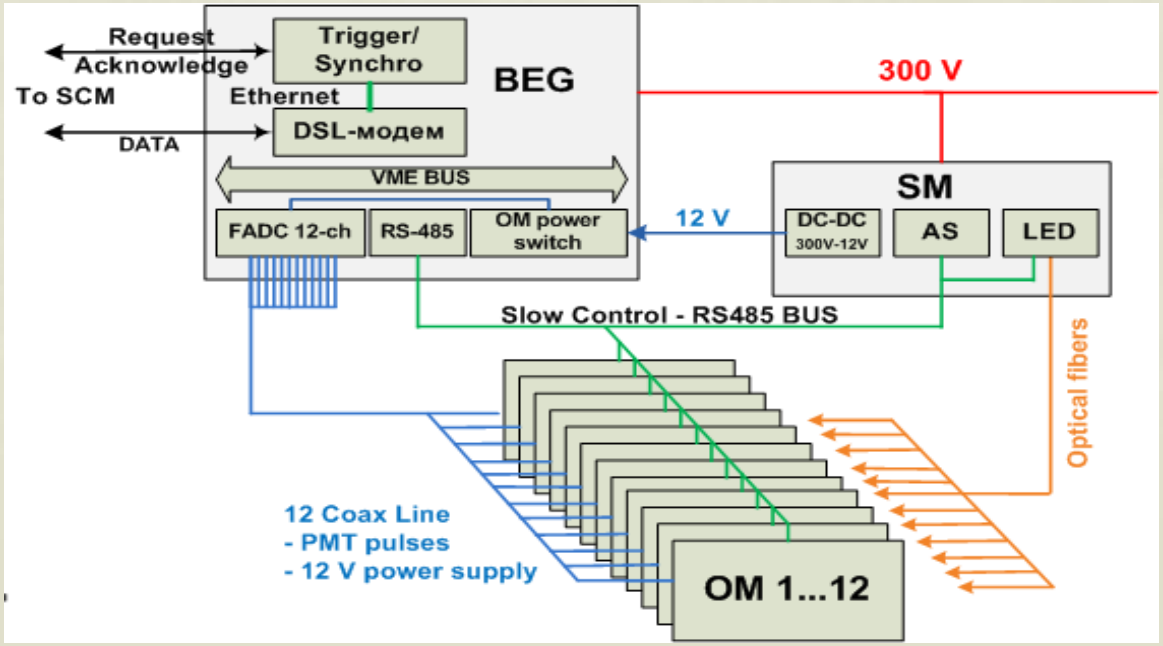
- Nominal PMT gain 1×10^7 (PMT voltage 1250 – 1650 V)
- Amplifier, k_{amp}=10;
- Pulse width ~20 ns
- ADC: 12 bit 200 MHz FADC (5 ns time bin);
- Waveform information is collected for a programmable interval (up to 30 mks)
- Linearity range: 1 ─ 100 p.e.;

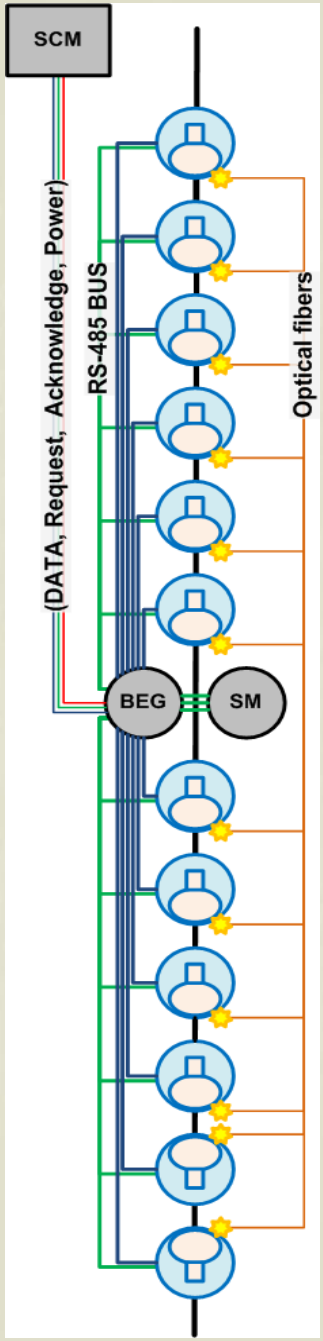
Section – basic detection unit

Section:
- 12 (16) Optical Modules
- BEG with 12 (16) FADC channels and trigger unit
- Service Module (SM): LEDs for OM calibration, OM power supply, acoustic positioning system.

Basic trigger: coincidences of nearby OM (threch. ~0.5&3 p.e.)
expected count rate < 100 Hz

Communications:
BEG ↔ cluster centre: DSL-modem, expected dataflow < 1Mbit/s
BEG ↔ OMs: RS-485 Bus (slow control)





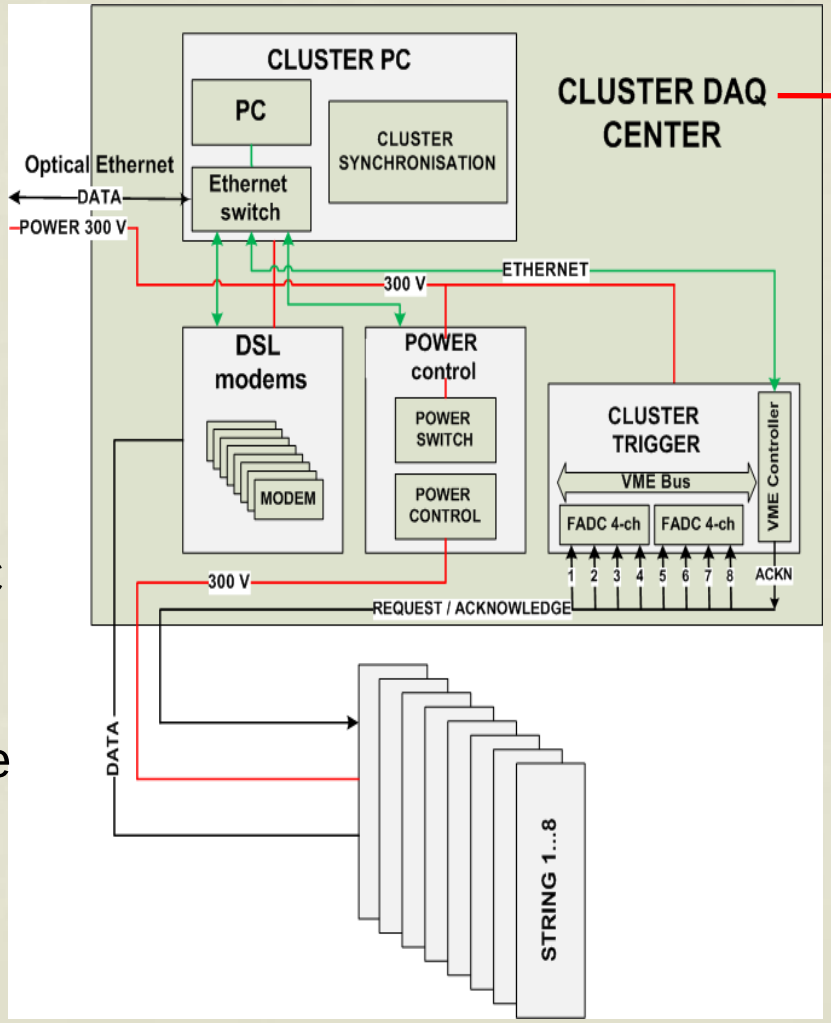
Cluster of strings

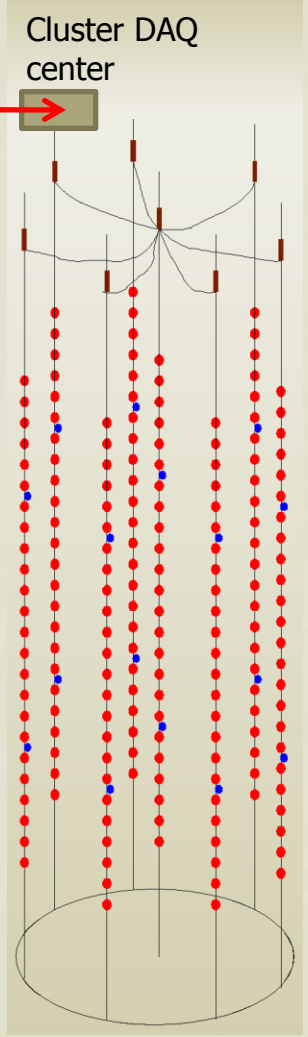
8 Strings

String consists of 2 – 3 sections (2×12 or 3×16 OMs)

Cluster DAQ Centre (4 modules)

1. PC-module with optical Ethernet communication to shore (data transmission and synchronization)
2. Trigger module with 8 FADC channels (time mark of string trigger)
3. Data communication module (8 DSL-modems for communication to strings, ~10 Mbit/s for 1 km)
4. Power control system

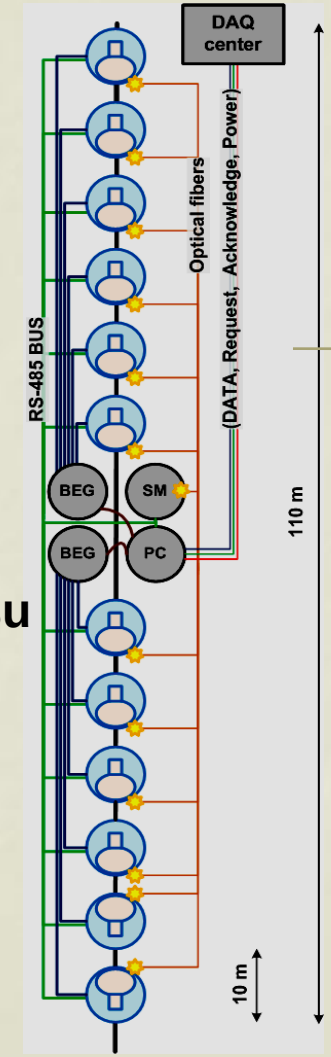


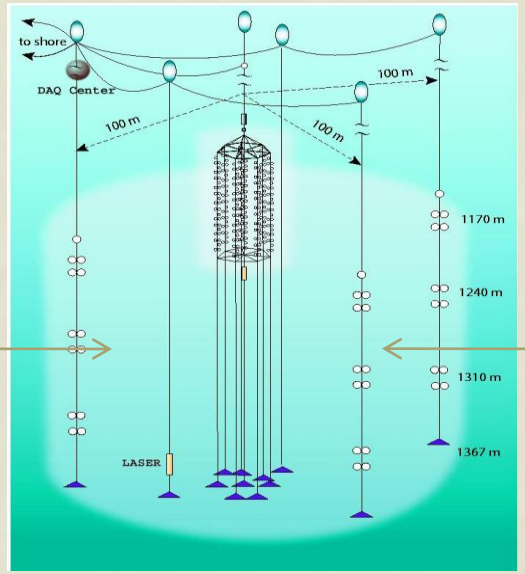


GVD prototype strings 2009 - 2010

Prototype string 2009

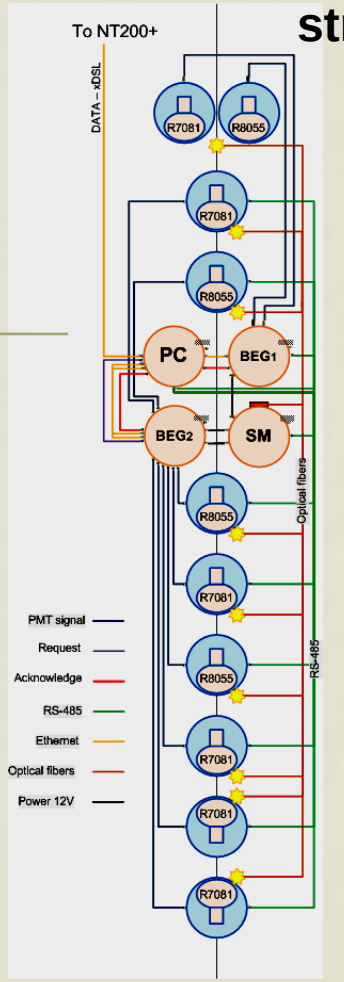
PMT: Photonis XP1807
6 OM
Hamamatsu R8055
6 OM





NT200+

Prototype string 2010



PMT: Hamamatsu R7081HQE
7 OM
Hamamatsu R8055
3 OM

In-situ tests of basic elements of GVD with prototypes strings (2009...2010)

Investigation and tests of new optical modules, DAQ system, cabling system, triggering approaches
(LED Laser Muons)

Prototype string 2010: muon reconstruction

- Performance of time measuring systems.
- Reliability of calibration methods.
- Efficiency of background suppression.

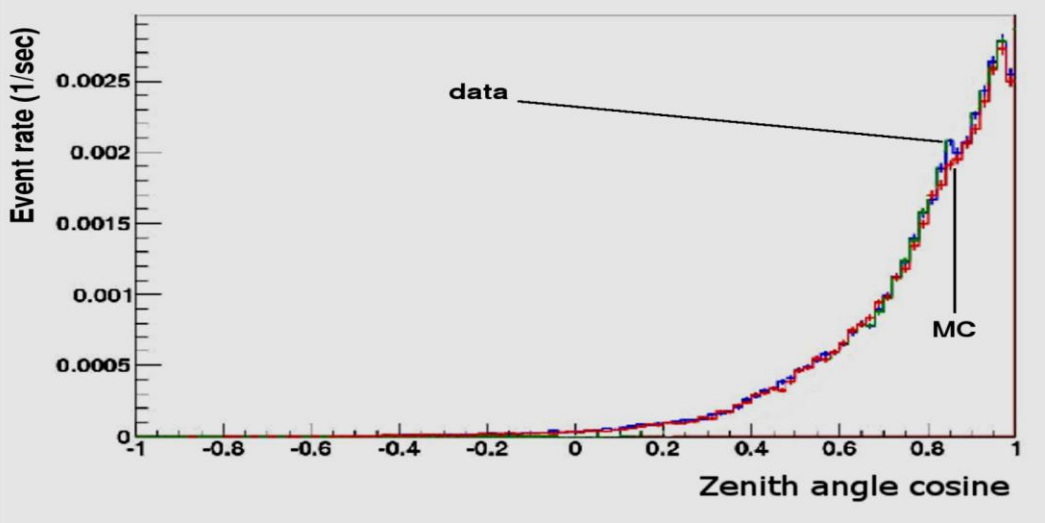
Selected sample of 2010 string data:

- Trigger condition: >3 hit OMs
- PMT noise: ~15kHz

Muon track reconstruction: $\chi^2 = \sum_{i=0}^{Nhit} (T_i(\theta, x, y) - t_i)^2 / \sigma_{t_i}^2$

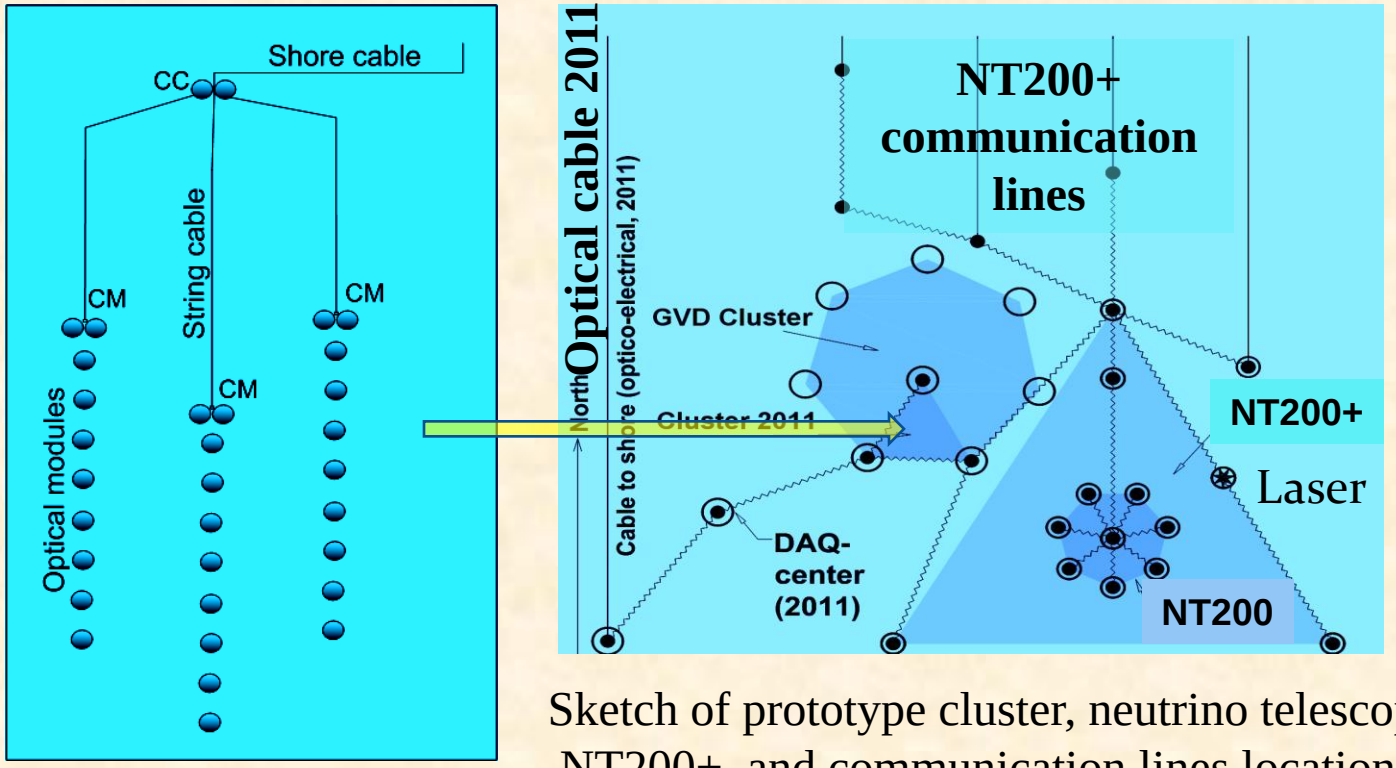
Noise suppression procedure:
The time difference between the pulses of any pair of OMs should be smaller than the light propagation time.

$$| \Delta t_{ij} | < (r_{ij}\, n_g)/c + \delta,$$



Zenith angular distributions of experimental and MC-simulated events after cut on χ^2 value

Prototyping phase: cluster 2011

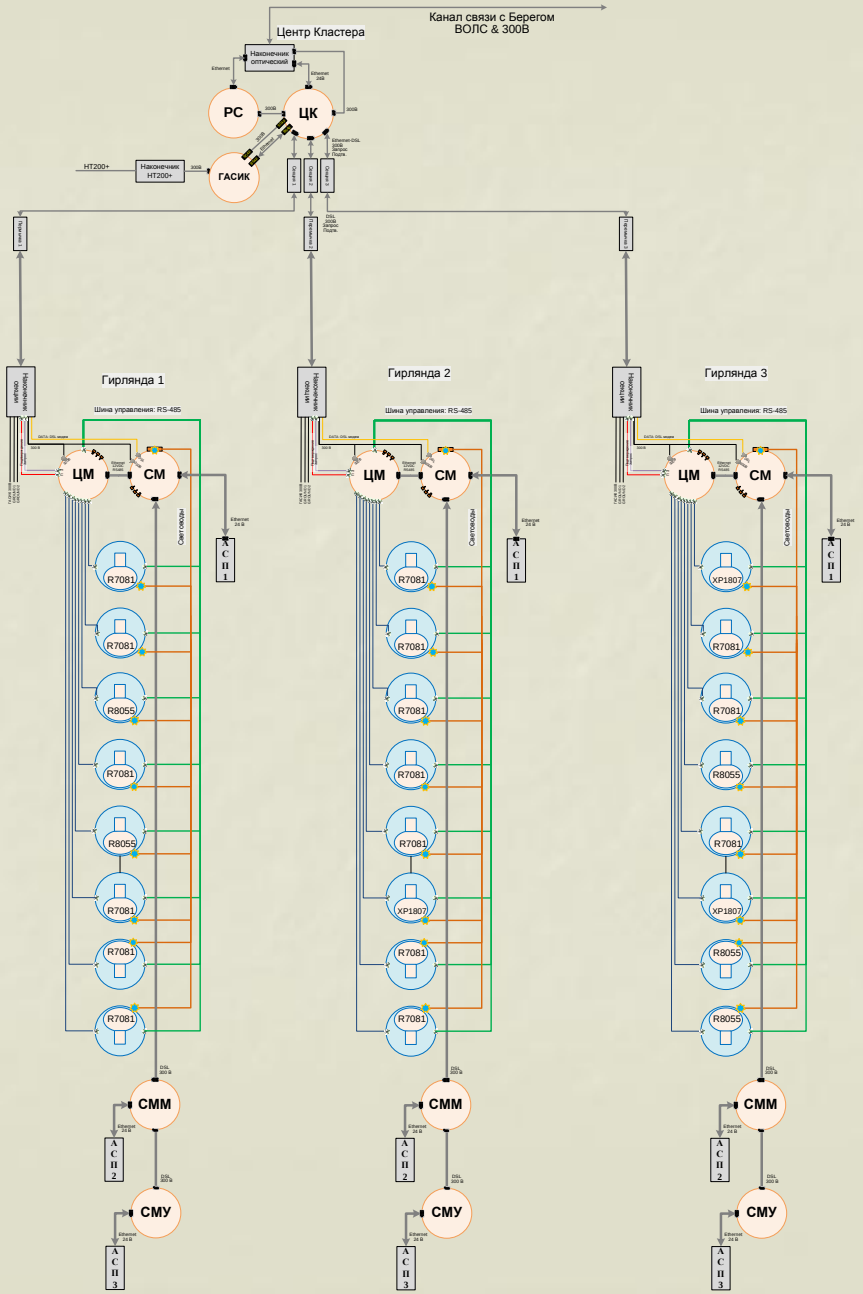


Sketch of prototype cluster, neutrino telescope NT200+, and communication lines locations.

In April 2011, a prototype cluster of GVD was installed in Lake Baikal.

- 3 vertical strings with 8 optical modules each.
- Vertical spacing between OMs is 10 m.
- Horizontal distance between strings is 40 m.
- Depths is 1205 – 1275 m.

Prototype Cluster – 2011 (24 OMs)



Optical modules

24 OM, R7081HQE (10”) R8055 (13”) XP1807 (12”)

DAQ, control and calibration systems of the section

- 3 service modules
- 3 BEGs - 24 FADC

Cluster DAQ-center

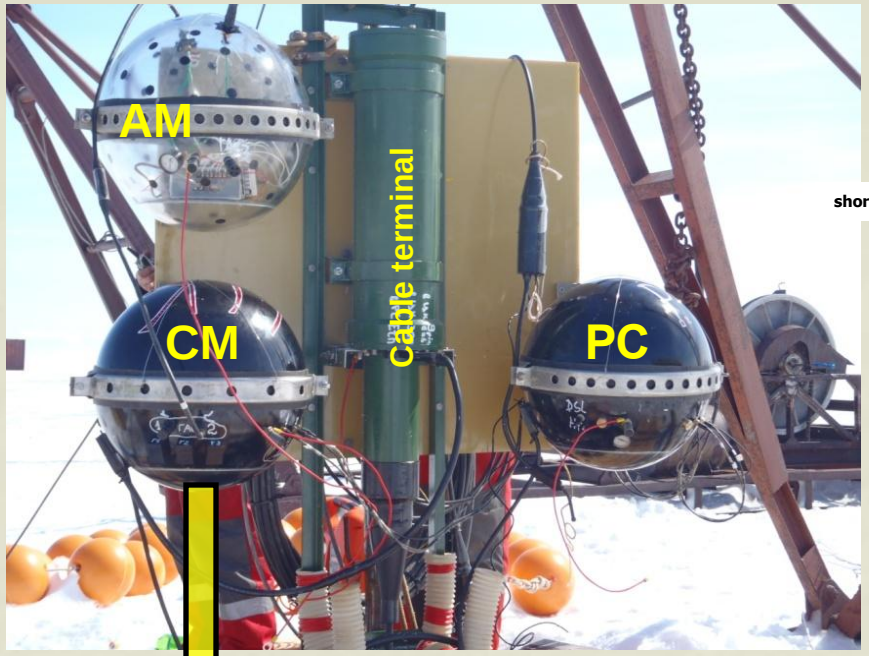
- Module of optical communication channel
- Underwater PC
- Commutation module
- Communication module of acoustic positioning system

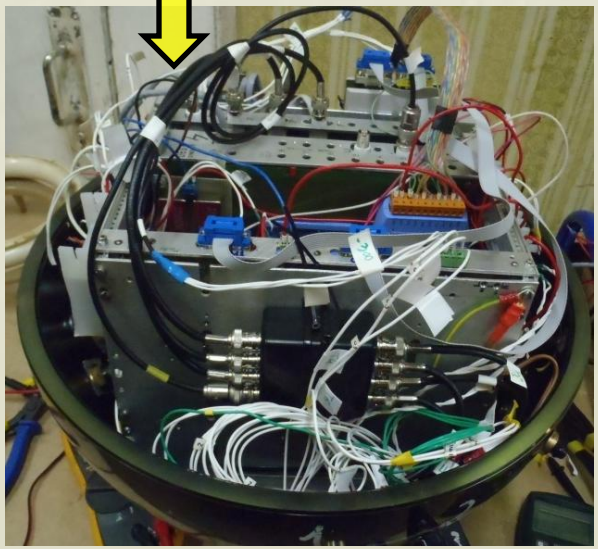
Modules of alternative acoustic positioning system - 9 modules

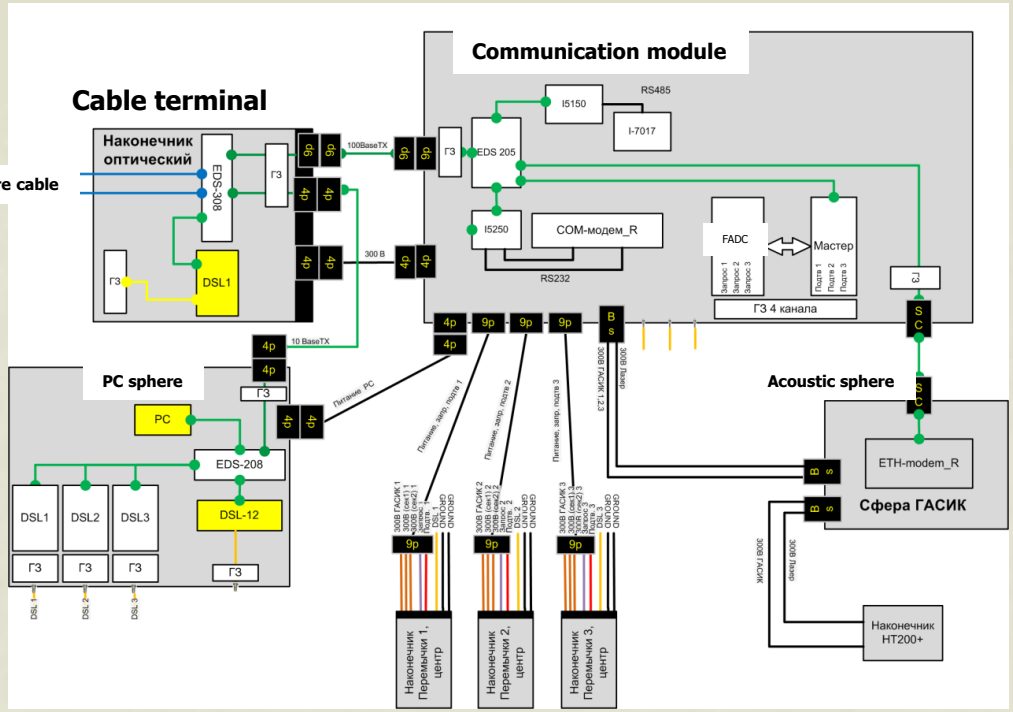
Cables

- To-shore electro-optical cable

Cluster DAQ-center

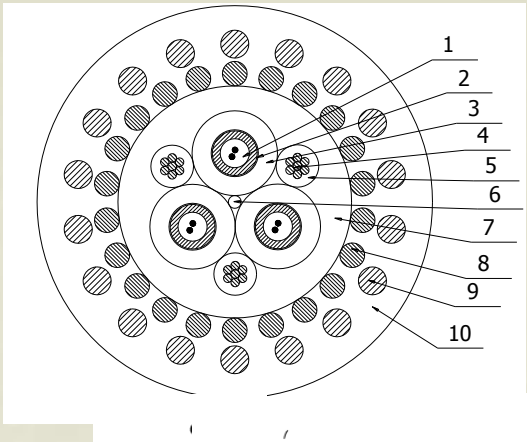




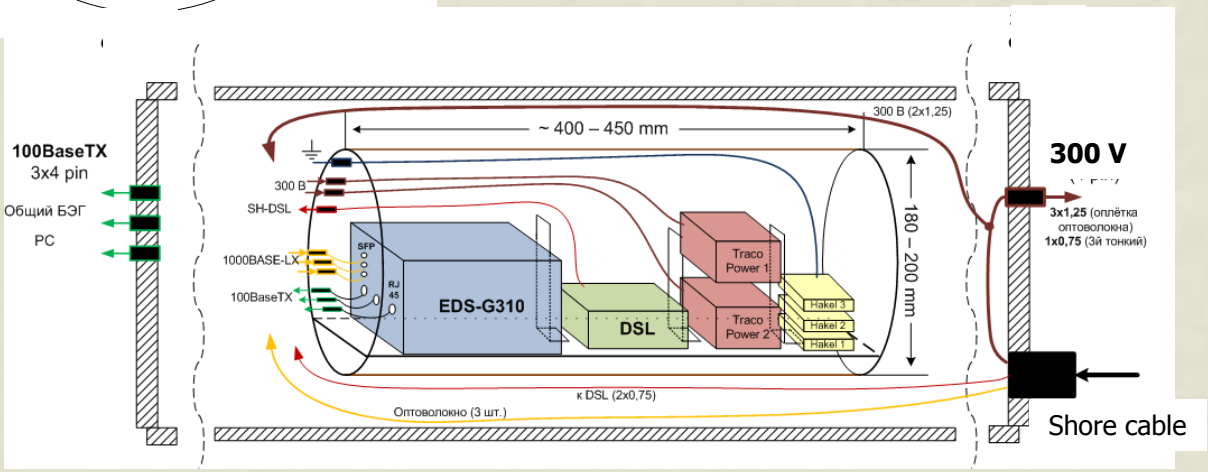


– **Commutation Module (CM)**: cluster trigger (4 FADC-200 MHz), strings power supply.
– **Underwater PC**: strings data transmission by DSL-modems.
– **AM:** communication module of acoustic positioning system
– **Module of optical communication channel**

GVD – shore connection



Deep underwater electro-optical cable
6 optical fibers, 6 copper leads.



Module of optical communication channel: 2 data transmission channels 1 Gbit/c (3 optical fibers), 3 reserve optical lines, voltage supply (DC-DC TracoPower, MTBF 3×10^6 hours).

Schedule:

2012-14 **Prototyping & Construction Phase**

2012 - **First full-scale string, upgrade of prototype Cluster. Technical Proposal**

2013 - **Upgrade of prototype cluster**

2014 - **First GVD Cluster/Data taking**

2014-18 **Construction/Data taking**

Overall investment (without personnel, contingency, overhead):

GVD (2304 OMs) - 25-30 **M€;**

GVD*4 (10368 OMs) - 80-100 **M€**

Conclusion:

- During 2006-2010 key elements and systems of the GVD have been developed, produced and tested in Lake Baikal

- Prototyping & Construction Phase of project is started in 2011 with operation of the 3-string array – prototype of the GVD Cluster in Lake Baikal, which comprises all elements and systems of the future telescope

- We expect that Prototyping Phase of project will be concluded in 2014 with construction of the first Cluster of GVD