Status of the BAIKAL-GVD Neutrino Project

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Introduction:

The construction of a km^3-scale high-energy neutrino telescope - the Gigaton Volume Detector (GVD) in Lake Baikal - is the central goal of the Baikal collaboration since 2008. The main scientific goal of the GVD is to map the high-energy neutrino sky in the Southern Hemisphere including the region of the Galactic Centre. Other topics include the indirect search for Dark Matter by searching for neutrinos produced in WIMP annihilation, search for exotic particles like magnetic monopoles, super-symmetric Q-balls or nuclearities.

The GVD will be located in the southern basin of Lake Baikal close to NT200+ telescope. The north location of the detector site (51°46'N, 104°24'E) allows to observe the Galactic Center more than 75% of the astronomical time. Since the slope of the shore bottom relief is rather steep, the telescope can be arranged nearly to shore at distances of 4-5 km. The depth of the lake is about 1400 m at this place. Good natural conditions (transparent fresh water, low light scattering, small water currents, low water luminescence, negligible rate of light pulses from K^{40} decays) and the possibility to use ice as a natural platform for detector deployment, maintenance, rearrange if necessary and for shore cable deployment make the Baikal site very favourable for a creation of large scale neutrino telescope.

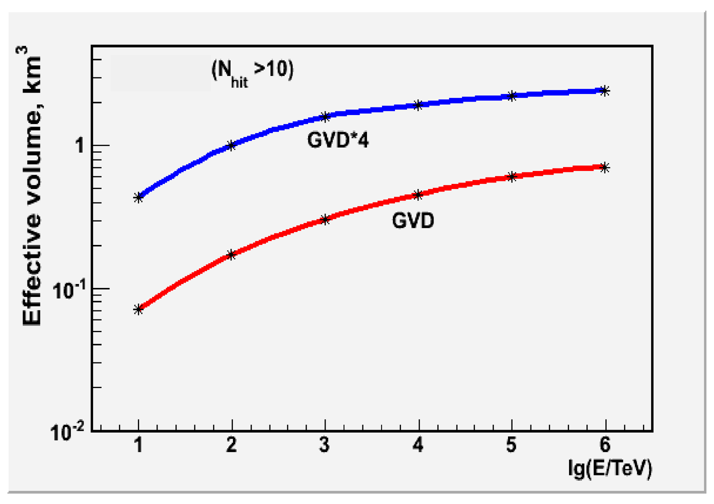
The GVD design:

The basic design approach provides a relatively flexible structure, which allows for a future expansion of the instrumented volume as well as a rearrangement of the main building blocks (clusters) to adapt to requirements of new scientific goals if necessary.

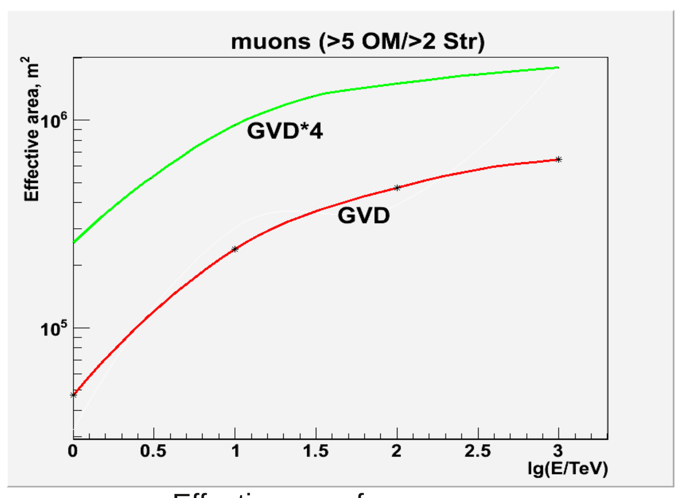
GVD will consist of strings of uniformly spaced optical modules (OM). Strings will be grouped in clusters. Joint operation of strings in a cluster and connection to shore are provided by the central cluster module placed near the water surface. Two detectors are being considered: GVD and GVD4 (see table). MC simulation results are presented in the figures below.

The effective area for muons (6/3 condition) with an arrival direction reconstruction error about of 0.5° (median value) and energy resolution of δlg E ~0.4 rises from 0.1 km^2 at 3 TeV to 0.8 km^2. The effective volume for cascades (15/3 condition) above 100 TeV with reconstruction error about 5–7° (median values) and energy resolution of about 10–15% rises from 0.1 to 0.7 km^3.

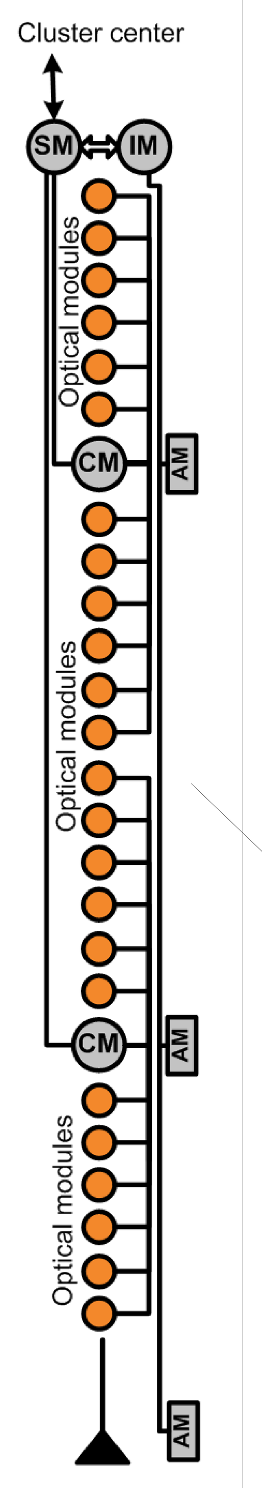
	Number of OMs	Number of strings	Depth, m	String length, m	Number of clusters	Cluster Radius, m	Distance between clusters, m	Distance between OMs, m
GVD	2304	96	900-1250	350	12	60	300	15
GVD4	10368	216	600-1300	700	27	60	300	15

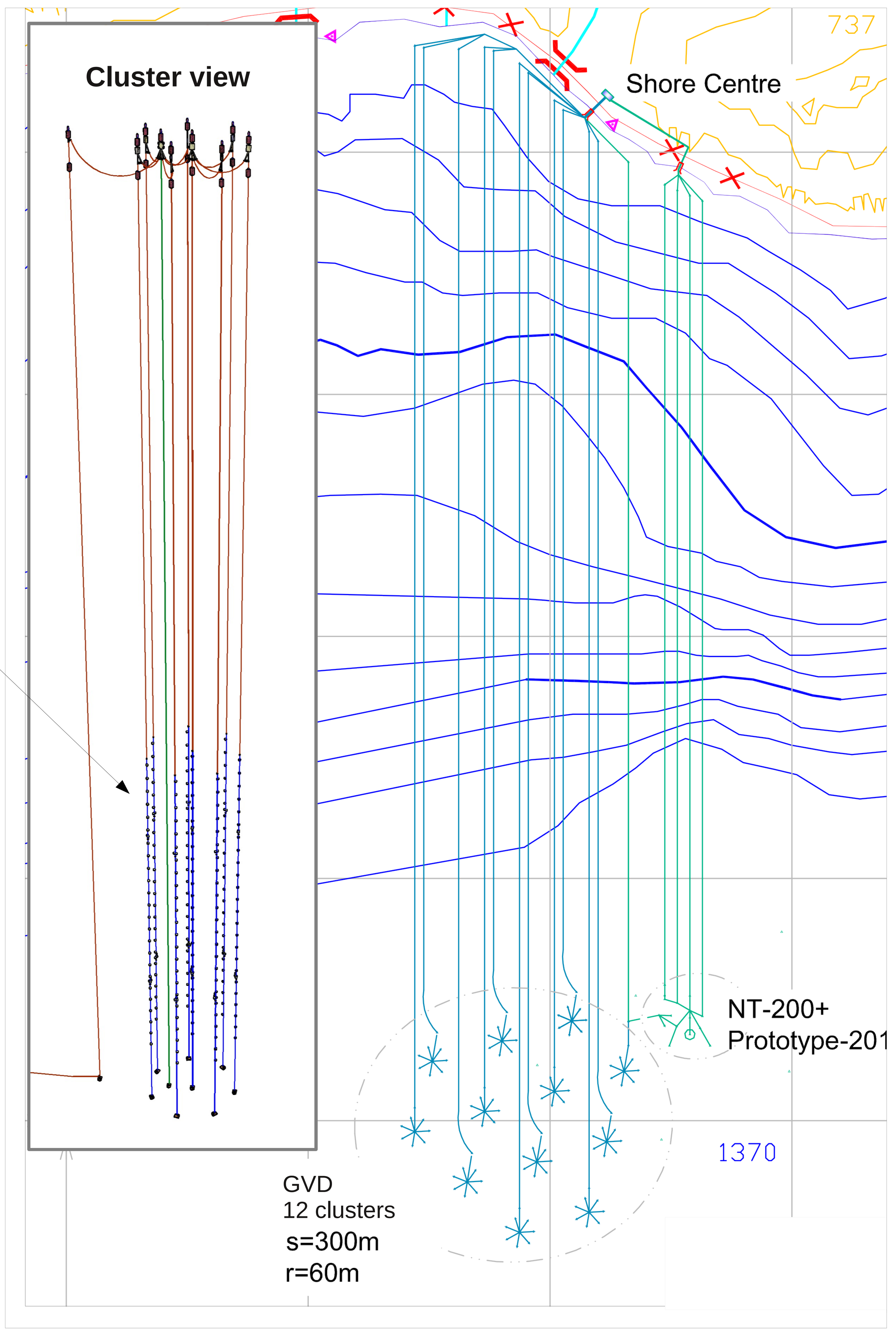


Effective volume for cascades

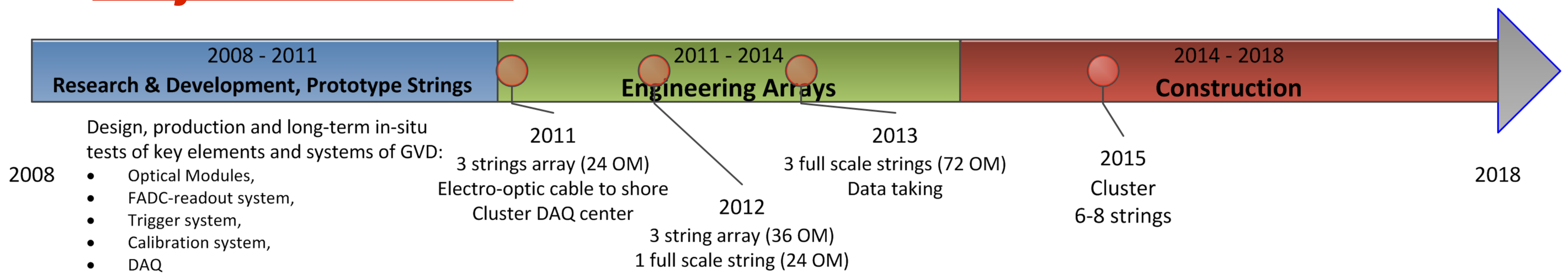


Effective area for muons





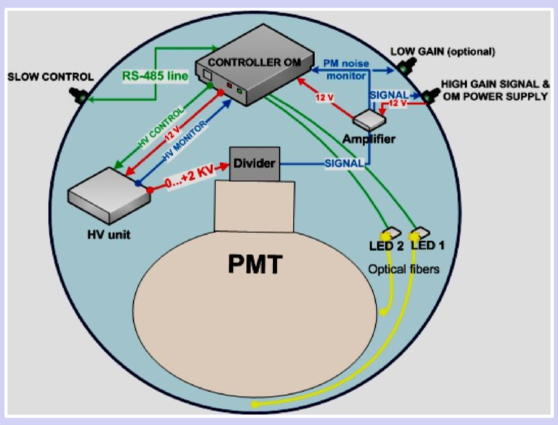
Project Timeline:



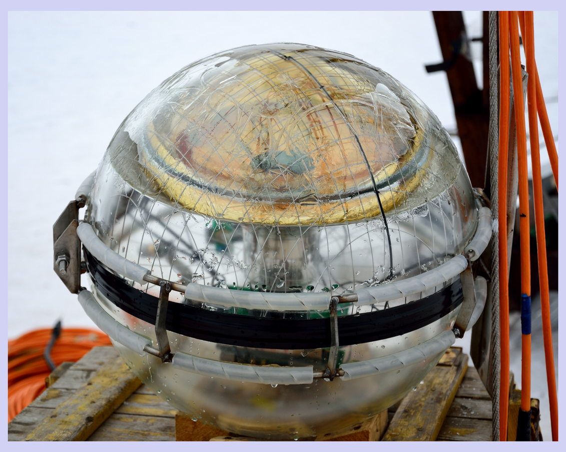
The operation of GVD prototype strings in 2009 and 2010 allowed a first assessment of the DAQ performance. On the basis of the experience of prototype string operation, in April 2011 a prototype GVD cluster with 3 strings and new ground electro-optical cable of 6 km length were installed in lake Baikal and put into operation. In April 2012 the full scale string 350 m long with 24 optical modules has been installed in joint operation with 2 small strings. The basic goals of the prototype cluster installation are investigation and in-situ test of basic elements of the future detector.

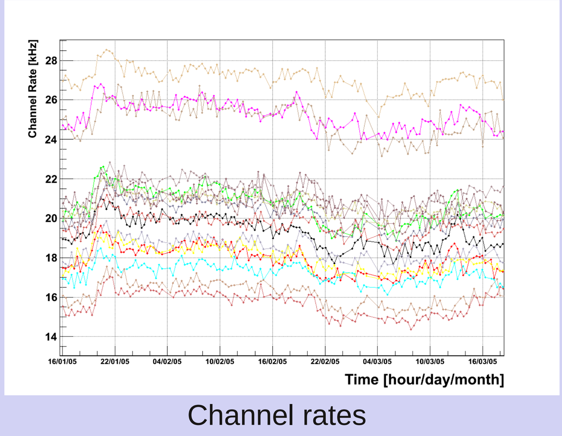
Optical Module

The optical module (OM) is the basic element of the future GVD neutrino telescope. Each OM contains a photomultiplier tube (PMT), which detects the Cherenkov lights produced by relativistic charged particles passing through the water. The information from the ensemble of OMs allows reconstruction of event topology and energy.



- 10" PMT R7081HQE (QE~0.35),
- Mu metal cage,
- Glass pressure-resistant sphere VITROVEX (17"),
- 5-pin Subconn connector LPBH5FSS,
- OM electronics:
  - 2-ch preamplifier (spe ~30-40 mV, linearity up to 1000 pe),
  - HV power supply unit (Traco Power 12-2.0 K 1000 P),
  - Divider (18 MOhm),
  - 2 LEDs (445 nm, 5 ns FWHM),
  - Controller (C8051F124, RS-485 interface, PMT pulse counter with regulated threshold, HV monitor, LED amplitude and pulse delay regulation)


Optical Module photo



Channel rates

String Section

The optical modules on a string are grouped into sections — low-level DAQ units. Each section includes 12 OMs and the central module (CM). PMT signals from all OMs of a section are transmitted to the CM through 90 m long coaxial cables, where they are digitized by custom made 4-channel FADC boards with 200 MHz sampling rate. The corresponding time accuracy of the measuring channel is less than 2 ns.

The CM consists of 3 ADC boards, an OM slow control unit and a Master board (see sketch below). The OM slow control unit provides data communication between OM controllers and Master board via an underwater RS-485 bus. Also, this unit is intended for the OM power control.

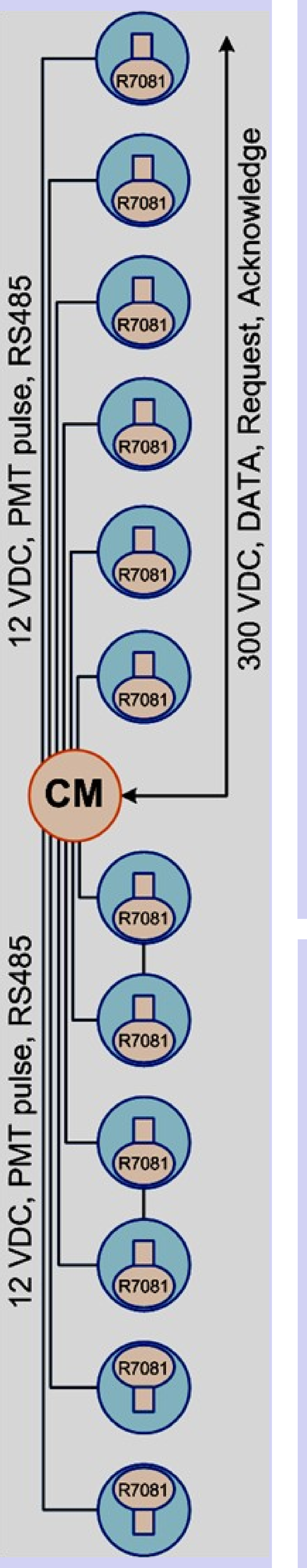
Each channel of an ADC board includes a fast digitizer on the basis of AD9430 microcircuits with 12-bit resolution. The digitized signal from each ADC are transferred to a FPGA Xilinx Spartan 3 (upgrade to Spartan 6 will be in the near future) which handles the data. A memory buffer of 12 Kb allows to accumulate waveform data from the ADC for 30 mks.

The trigger signal from the Master board stops the buffer accumulation and the waveform information is transferred to the Master board (works on the basis of FPGA Xilinx Spartan 6). An ADC trigger request channel includes a smoothing unit for electronics noise reduction, a 2-level adjustable digital comparator (low threshold L and high threshold H) and a request builder, which build the request to the trigger logic. The requests L and H are transferred to the Master board.

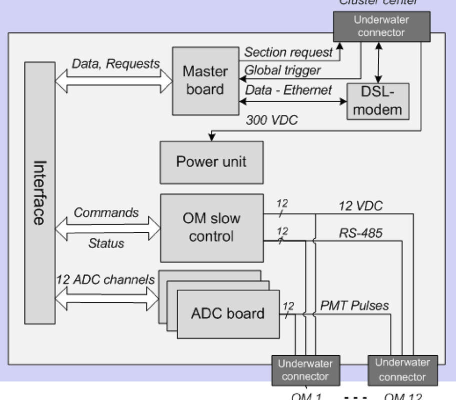
The Master board provides trigger logic, data readout from ADC board, connection via local Ethernet to the cluster DAQ center and control of the section operation. The request analyzer forms the section trigger request on the basis of requests L and H from 12 ADC channels. This unit contains a programmable coincidence matrix (12Hx12L), which provides a simple way to generate the section trigger request. The basic trigger modes are:

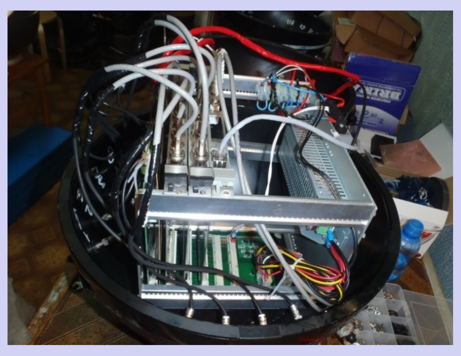
- coincidences of >N L-requests within selectable time window,
- coincidences of L and H requests from any neighbouring OMs within a section.

The section trigger request is transferred to the cluster DAQ center, where a global trigger for all sections is formed. The global trigger produces the stop signal for all ADC channels and initiates waveform information readout. The time delay of the global trigger is about 15 mks (2x1.2 km of the string cable and electronics delay). Each event contains waveform data for all ADCs of the section, the global trigger number and the local time. The event trigger number provides the possibility of event synchronization for the different sections. Data from the event buffer are transmitted via an Ethernet connection to the cluster DAQ center.



Central Module





Cluster Center

The cluster is controlled by the cluster DAQ center placed near the water surface (30 m depth). It provides the string triggering, power supply and communication to shore.

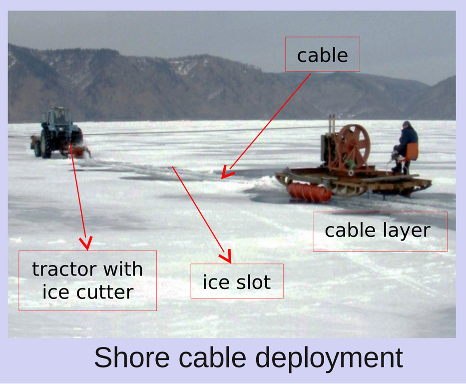
Data from the strings are transferred through DSL-modem Ethernet channel to the cluster center. The DSL-modem bandwidth was set to the level 4 Mb/s (about half of maximum data rate supported for 1.2 km cable line). This value restricts the maximum event rate per string section 25 events/s.

The cluster DAQ center is connected to shore by optical Ethernet lines. The electro-optical cable of 6 km length with 3 pairs of optical fibers and 3 copper lines was deployed in 2011 and have a data rate of 1 Gb/s.

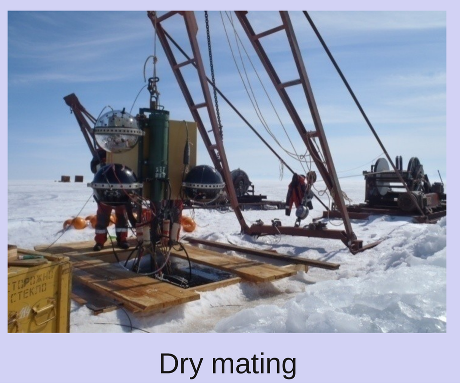
- Commutation Module (CM): cluster trigger (4 FADC-200 MHz), strings power supply.
- Underwater PC: strings data transmission by DSL-modems.
- AM: communication module of acoustic positioning system
- Module of optical communication channel

Ice Technology

The Baikal collaboration has a broad practical experience on the detector deployment, maintenance, upgrade and the shore cable laying from the ice cover which is stable during 2 months in a year. All connections are done on dry from the ice surface. Custom-made winches and cable layer equipment are developed by the collaboration.



Shore cable deployment


Dry mating

Reference: *A.V. Avrorin, et al., Nuclear Instruments & Methods In Physics Research A (2012), doi:10.1016/j.nima.2011.12.106*