VLVνT workshop
5th International Workshop on Very Large Volume Neutrino Telescopes

Current status of the BAIKAL-GVD project

Vladimir Aynutdinov for the Baikal Collaboration

Erlangen, 14 October, 2011

Collaboration

55 scientists and engineers, 8 institutions

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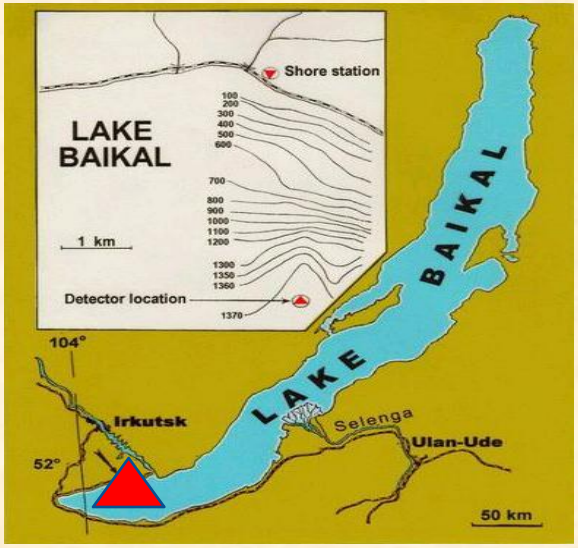
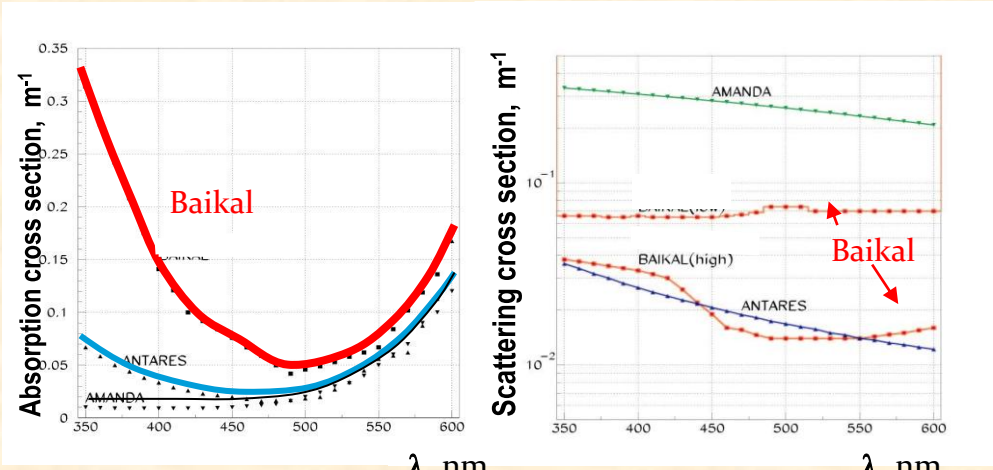
OUTLINE

1. The Baikal neutrino experiment - overview
2. Future Gigaton-Volume Detector in Lake Baikal (BAIKAL-GVD)
   - Optimization of GVD configuration
   - GVD technical design
   - Prototype arrays
     - prototype strings: 2009-2010
     - prototype cluster: 2011
3. Plans
4. Summary

The BAIKAL Site

Lake Baikal, Siberia

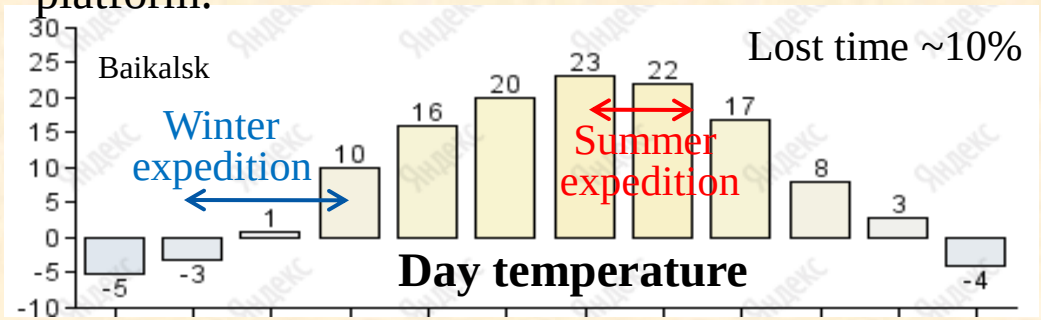


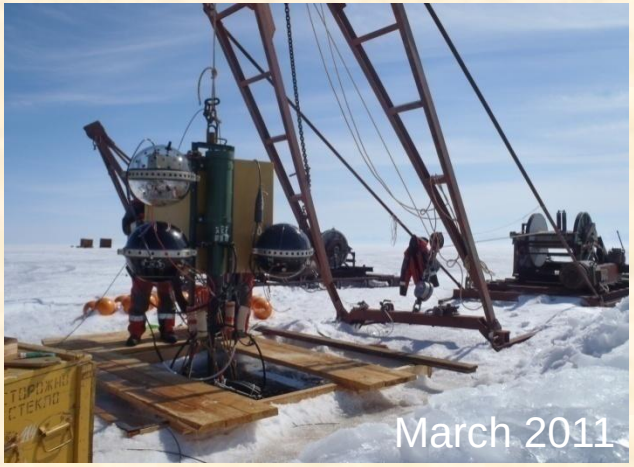


1370 m maximum depth.

- Short distance to shore: ~4 km
- No high luminosity bursts from biology.
- No K^{40} background.
- Deployment simplicity: ice is a natural deployment platform.

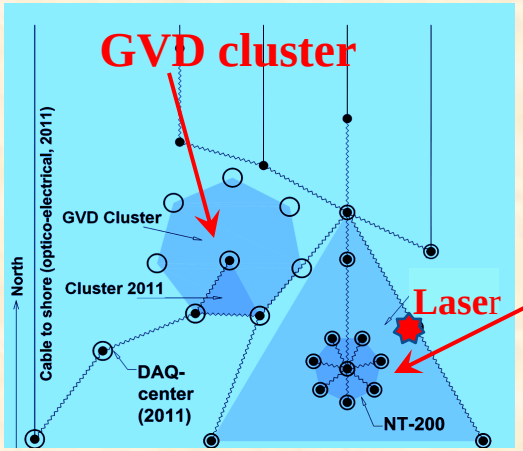
Baikal water properties: Abs.Length: 22 ± 2 m
Scatt.Length: 30-50 m





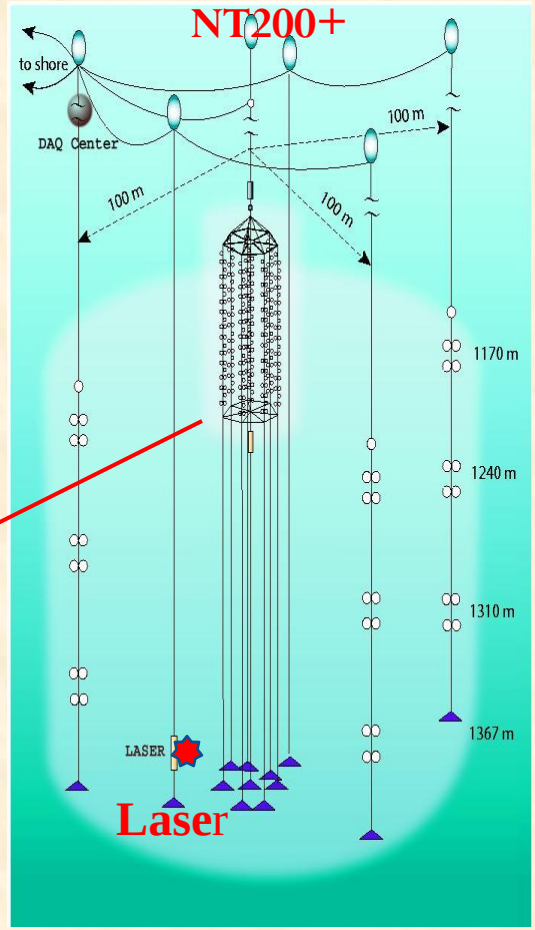
Status of Baikal experiment

GVD prototype cluster was installed in April 2011.



GVD prototype cluster

- 3 strings × 8 OM
- Cluster DAQ Center
- Optical shore cable



NT200+ is operating now in Lake Baikal

Central part - NT200

8 strings : 192 optical modules

Height x ∅ = 70m x 40m,

Eff. shower volume: 10 TeV~ 0.2 Mton

NT200+ = NT200 + 3 outer strings

228 optical modules

Height x ∅ = 210m x 200m,

Eff. shower volume: 10^4TeV ~ 10 Mton

The Baikal collaboration follows since several years a R&D program for a kilometer-scale Gigaton Volume Detector in Lake Baikal (BAIKAL-GVD). The main scientific goal of GVD is to map the high-energy neutrino sky in the Southern Hemisphere including the region of the galactic center.

Optimization of GVD configuration

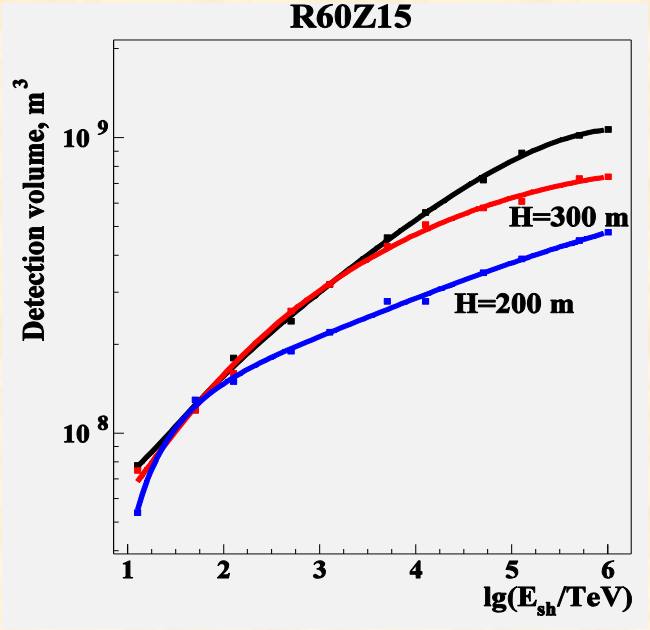
The MC-optimization for GVD was performed for 96 strings grouped in 12 clusters with 192 OMs each.
PMT Hamamatsu R7081HQE ∅ 10 inches.

Parameters for optimization:

Z – vertical distance between OMs

R – distances between strings and cluster center

H – distances between neighbouring clusters centers



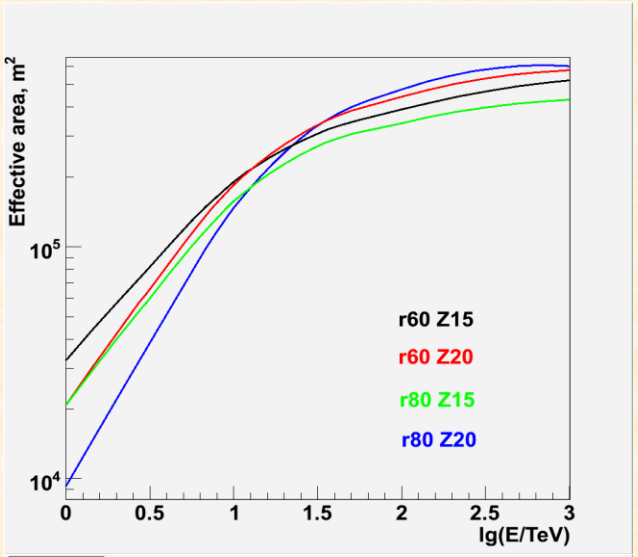
Cascade detection volume

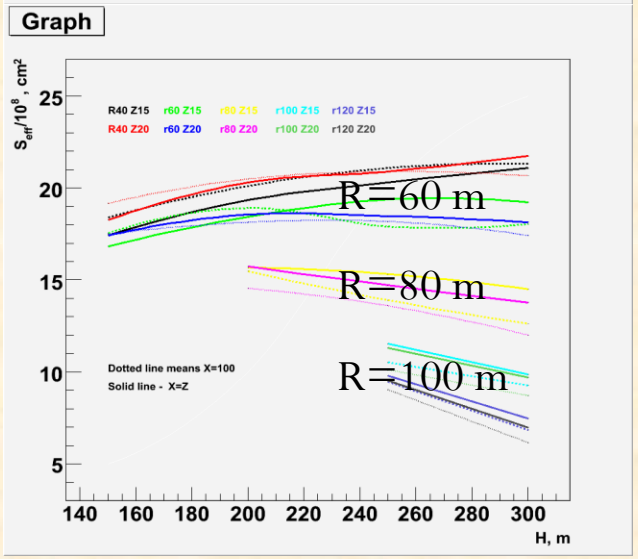
An optimum for cascade detection volume and muon detection area was obtained for :

H=300 m

R = 60 m

Z = 15 m



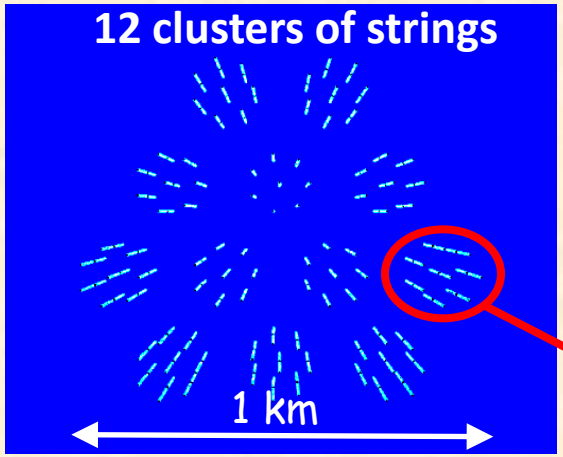


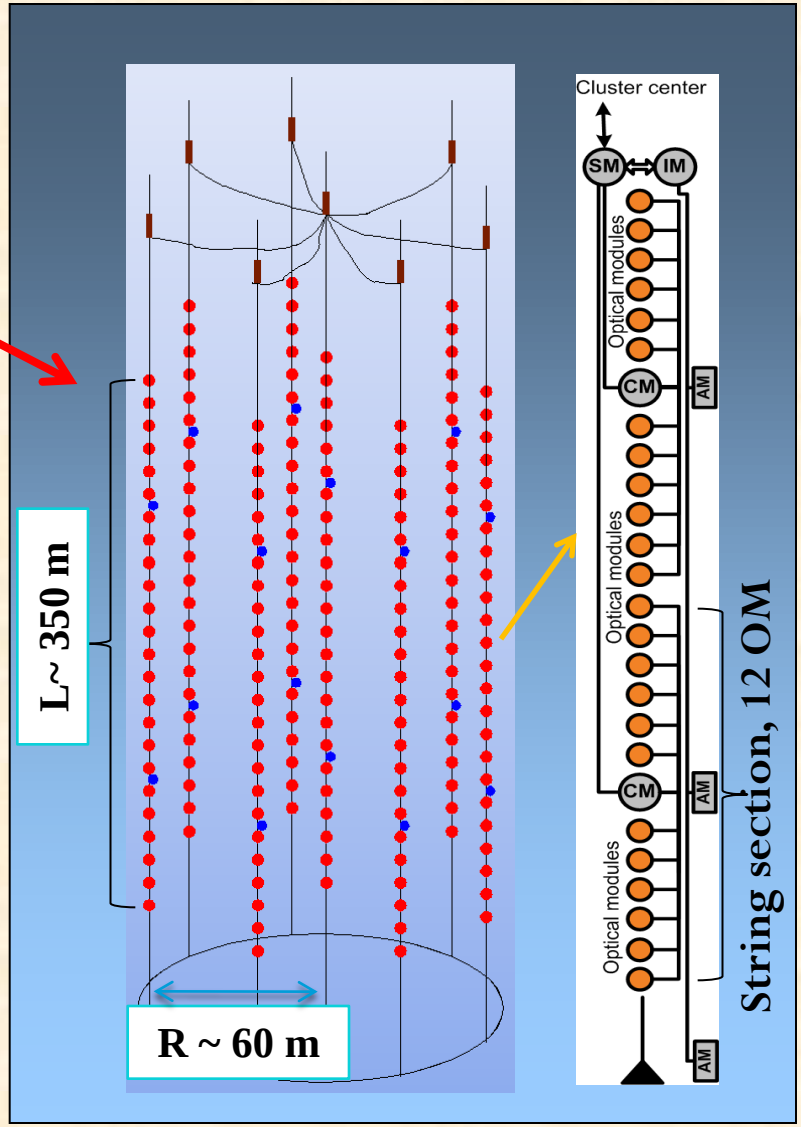
Muon effective area

GVD design

Configuration

12 clusters ×8 strings
String: 2 section ×12OM
H=300 m
R=60 m,
Z=15 m





Effective cascade volume

Conditions 15/3: at least 15 hit OMs on 3 strings.
Cascade energy >100TeV

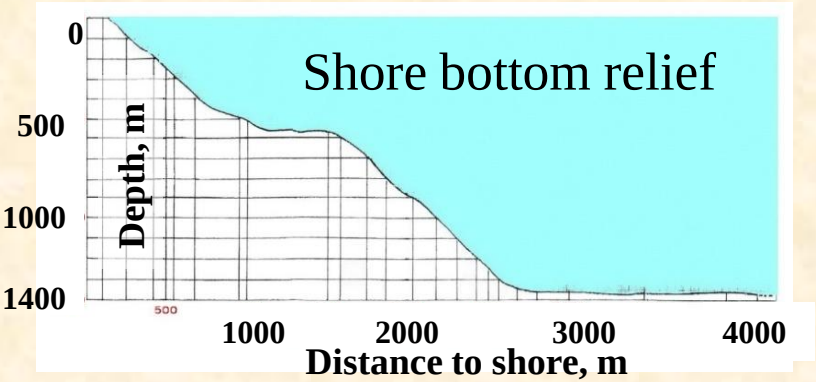
V_{eff} = 0.1– 0.7km^3, δ(lgE) ~ 0.1, $\Delta\theta_{med}$ ~ 5^o-7^o

Effective muon area

Conditions 6/3: at least 6 hit OMs on 3 strings.
Muon energy *>3 TeV*

S_{eff} ~ 0.1– 0.8 km^2, δ(lgE) ~ 0.4, $\Delta\theta_{med}$ ~ 0.5^o

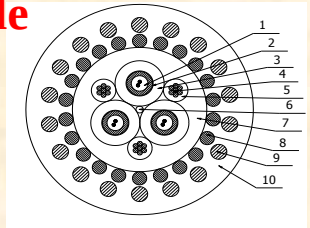
GVD cable system



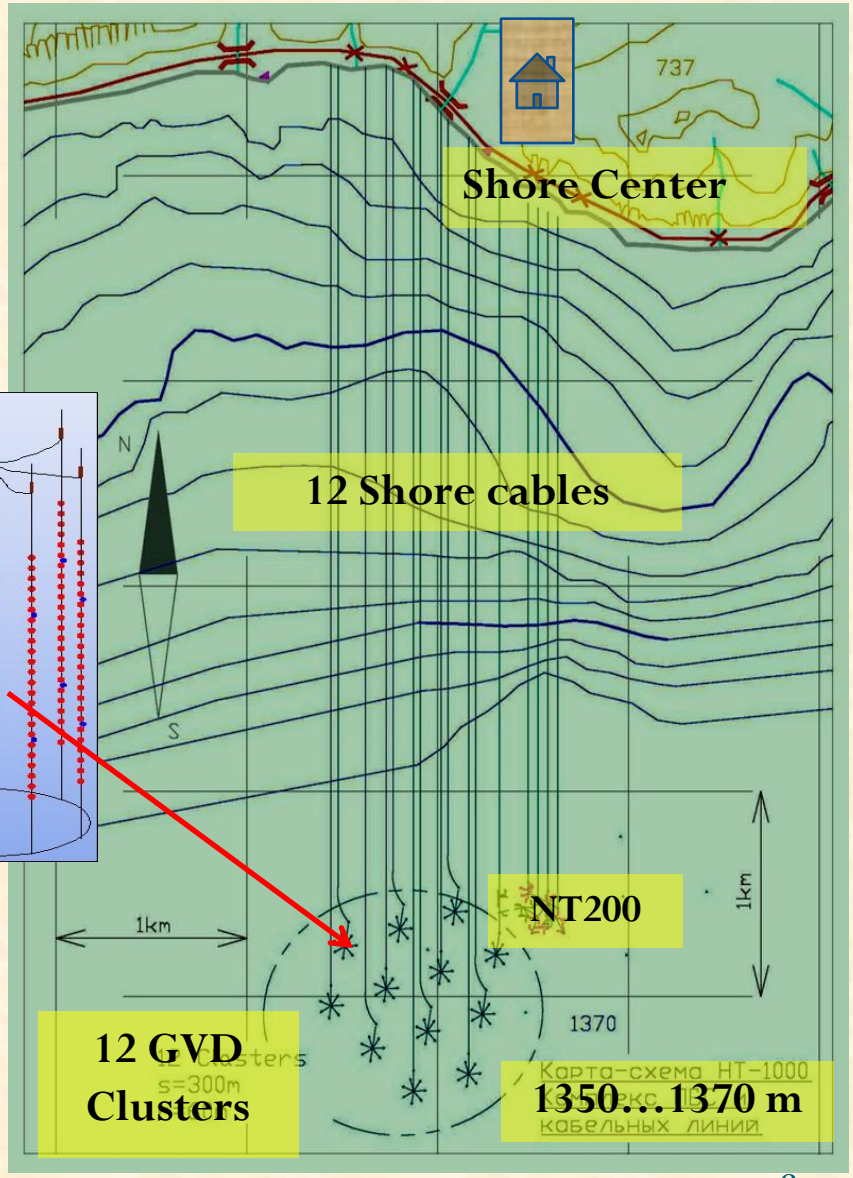
Distance to shore: *4 – 5 km*

Individual cable for each cluster,
5 – 6 km length

Specialized optical cable
3 pairs of optical fibers
3 copper lines (1.5 kV)
~6000 euro/km .

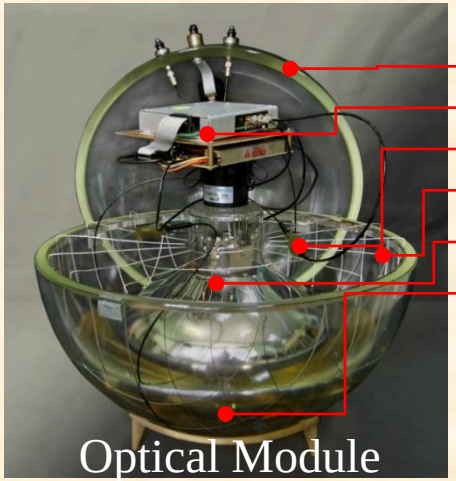


The first shore optical cable for GVD cluster was deployed in March 2011.



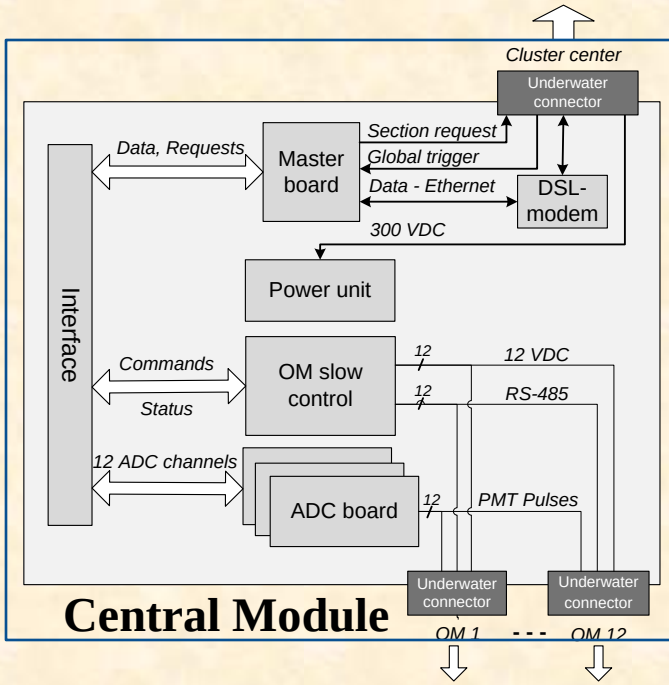
String section – low level DAQ unit

Section: 12 Optical Modules (OM) & Central Module (CM)



- Glass pressure 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”, QE~0.32…0.35
- Elastic gel

PMT signals are transmitted to the CM



Central Module

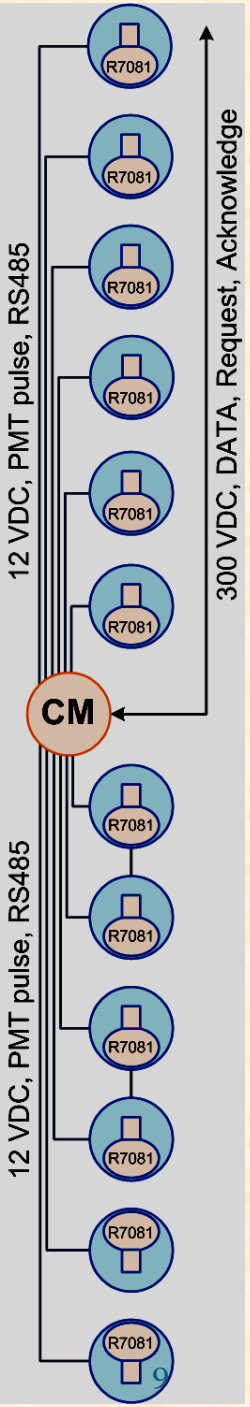
3 ADC boards: 12 FADC channels, 200 MHz

Slow control and power unit

- Data communication with OM via an underwater RS-485 bus
- OM power supply.

Master board

- Trigger logic
- Data readout from ADC boards
- Connection via local Ethernet to the cluster DAQ center (1.2 km cable, DSL-modem, 8 Mb).



ADC board

4 ADC channels, FPGA logic

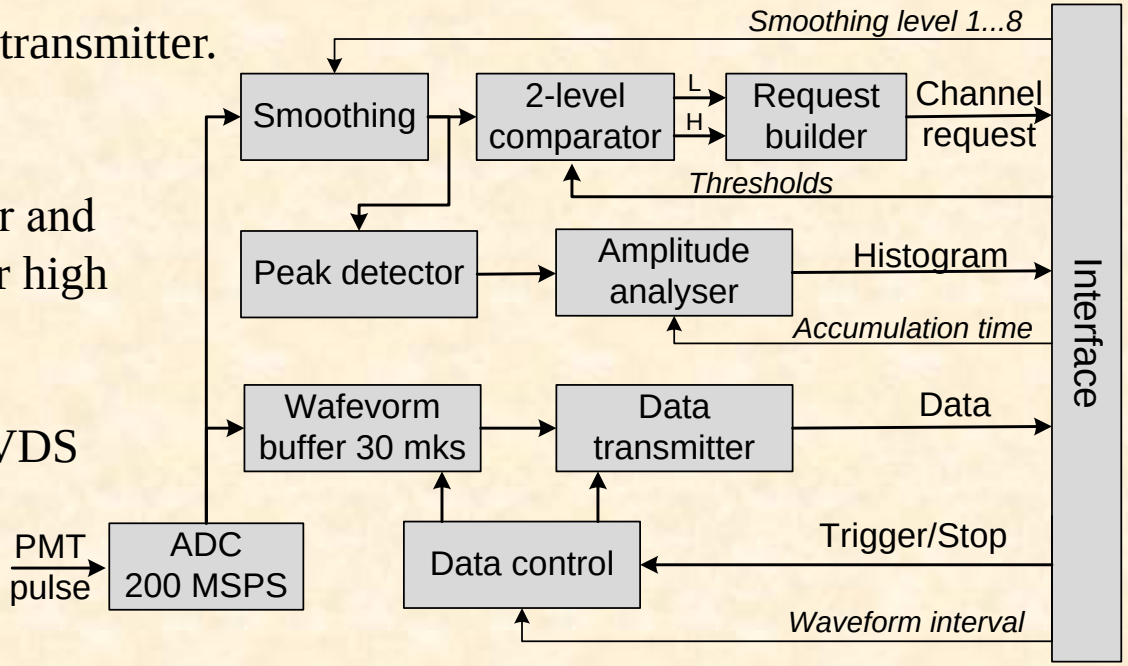
FADC (AD9430) 12bit, 200MHz

FPGA Xilinx Spartan 3 (Spartan 6 - 2012)

- **Data channel**:
  memory buffer (30 mks) and data transmitter.

- **Trigger channel:**
  smoothing unit (1…8), comparator and request builder (low threshold L or high threshold H), amplitude analyzer

- **Interface board** on the basis of LVDS



Master board

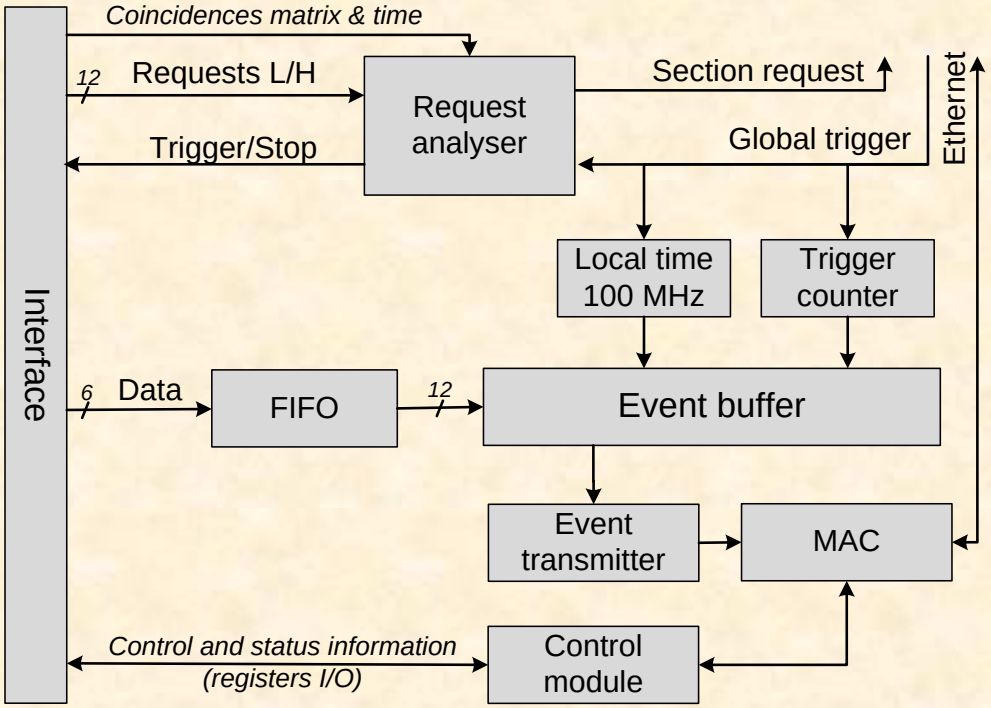
FPGA Xilinx Spartan 3 (Spartan 6 - 2012)

Trigger logic, data readout from ADC boards, control of the section operation, connection to the cluster DAQ center.

Request analyzer → section trigger logic.
Coincidence matrix (12L×12H inputs).
Two basic trigger modes:
L>n - any OMs of the section
L&H – only neighbouring OMs

Event buffer (512 K) → data for a12 ADC
- waveform stamp
- global trigger number
- local time

Control module
- access to the I/O registers
- OM slow control: RS-485 bus.

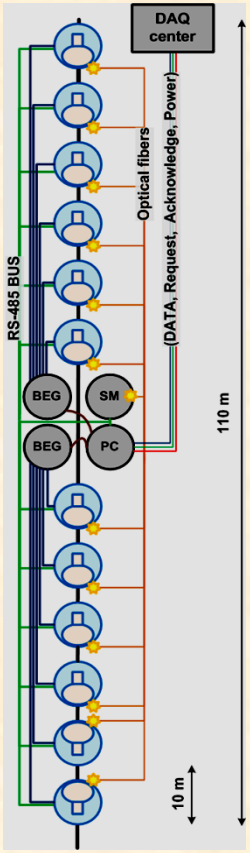


Ethernet module (MAC) – connection via local Ethernet to the cluster DAQ center.

Prototype strings

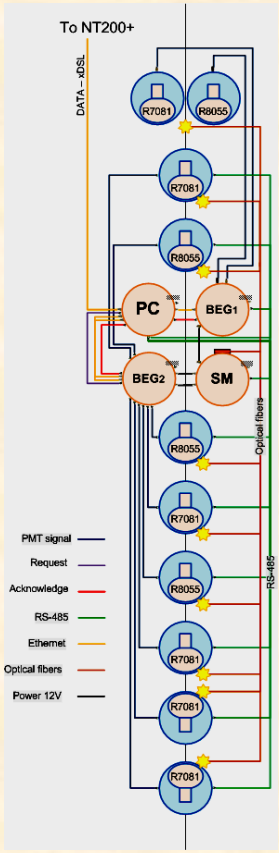
In-situ tests of basic elements of the future detector: optical modules, data acquisition system, communication lines.

2009



XP1807
R8055

2010



R7081HQE
R8055

Tests with LED

LED flasher produces pairs of delayed pulses, which are transmitted to each OM via individual optical fibre. Times between pulses **dT** are calculated from the waveform data.

Time resolution: σ(dT) = 1.6 ns

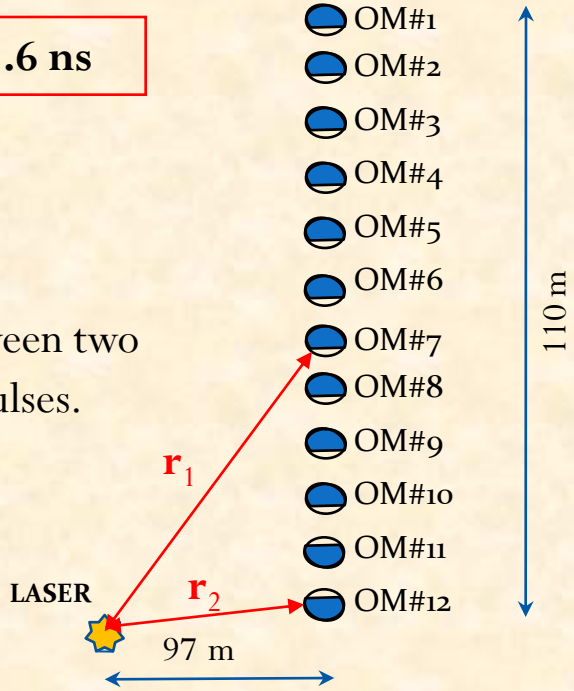
Tests with LASER

$$\Delta T = \langle dT_{EXPECTED} - dT_{LASER} \rangle$$

$$dT_{EXPECTED} = (\mathbf{r}_2 - \mathbf{r}_1) \times c_{water}$$

dT_{LASER} - time difference between two channels measured for Laser pulses.

Time error: ΔT ~ 2 ns



Prototype string: muon reconstruction

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

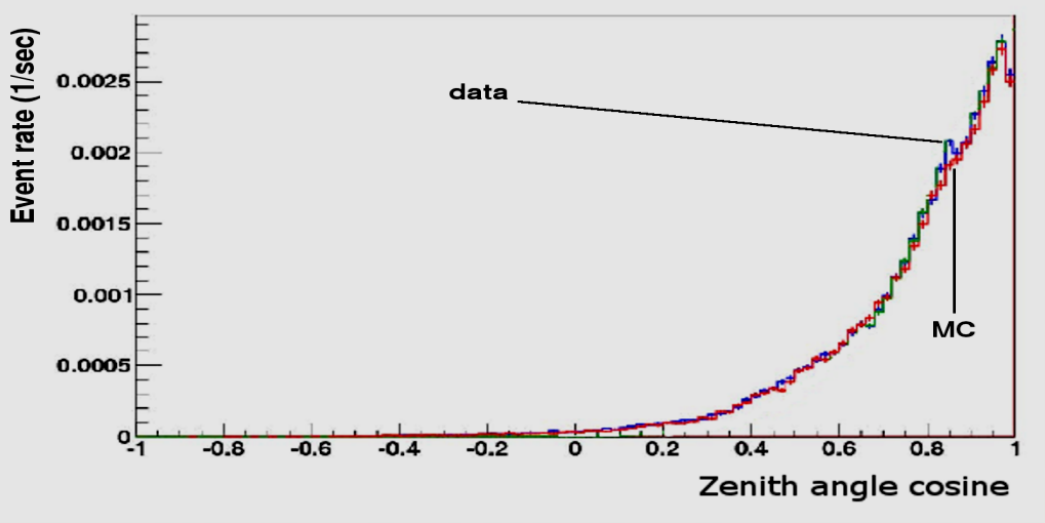
Selected data sample of the string-2010:

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

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

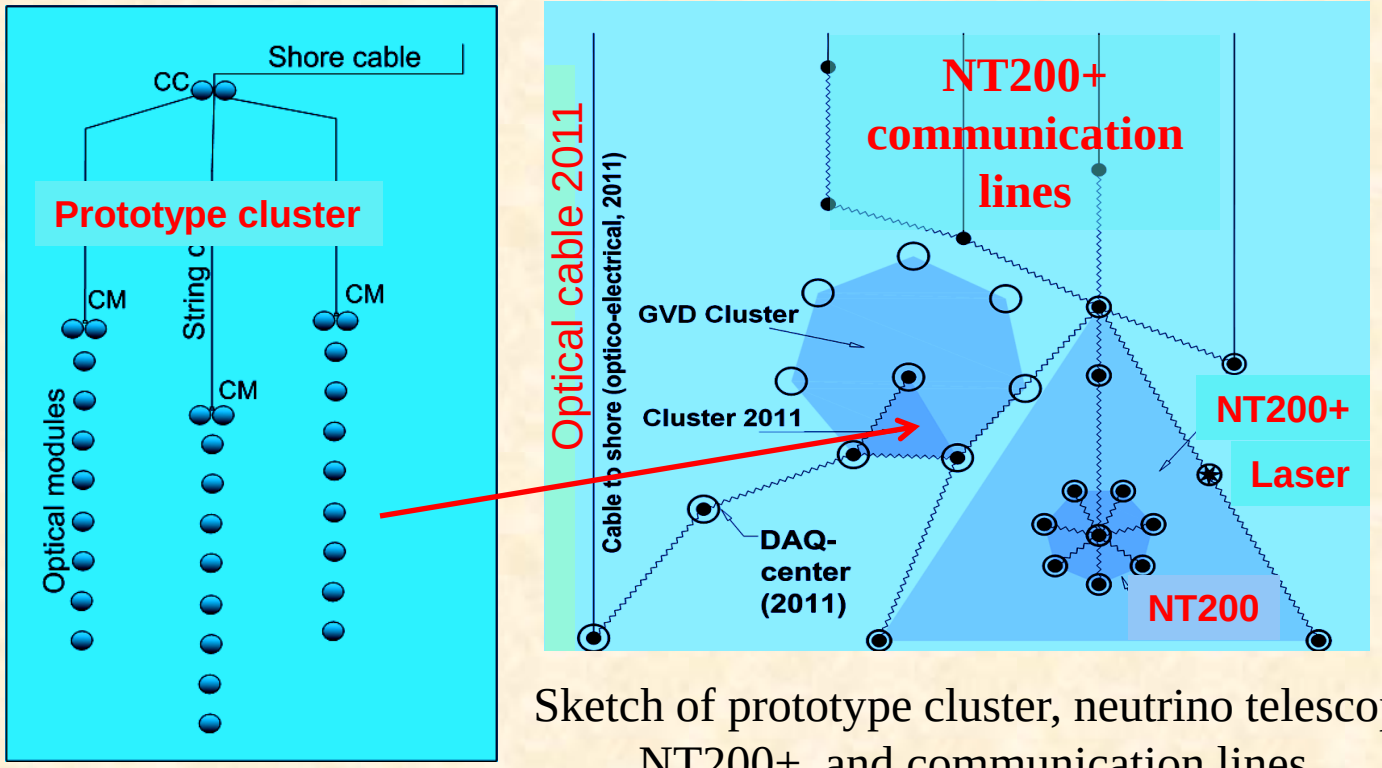
Noise suppression:
The time difference between the pulses of any pair of OMs should be smaller than the light propagation time.

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



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

BAIKAL-GVD prototype cluster: 2011

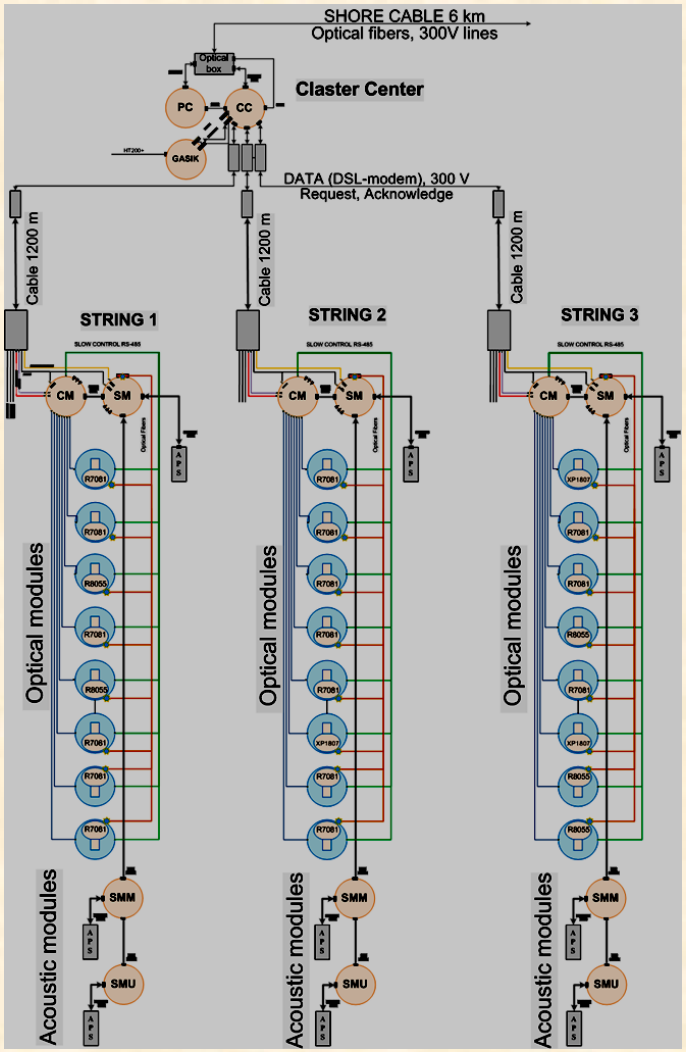


Sketch of prototype cluster, neutrino telescope NT200+, and communication lines.

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.

Technical design



Optical modules

16 PMT R7081HQE Hamamatsu, ∅10 inch
5 PMT R8055 Hamamatsu, ∅13 inch
3 PMT XP1807 Photonis, ∅12 inch

String section

- Size reduced section:8 optical modules, CM and SM.
- CM (Central module): 2ADC (8 chan.) & Master .
- SM (Service module): Power control and connection to the cluster DAQ center via DSL-modem line.
- Acoustic positioning system, 3 modules on each string.

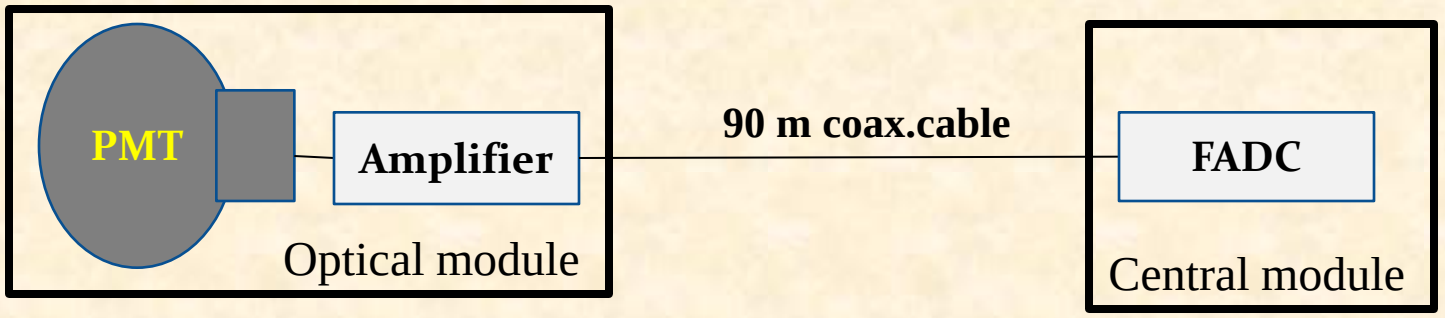
DAQ center

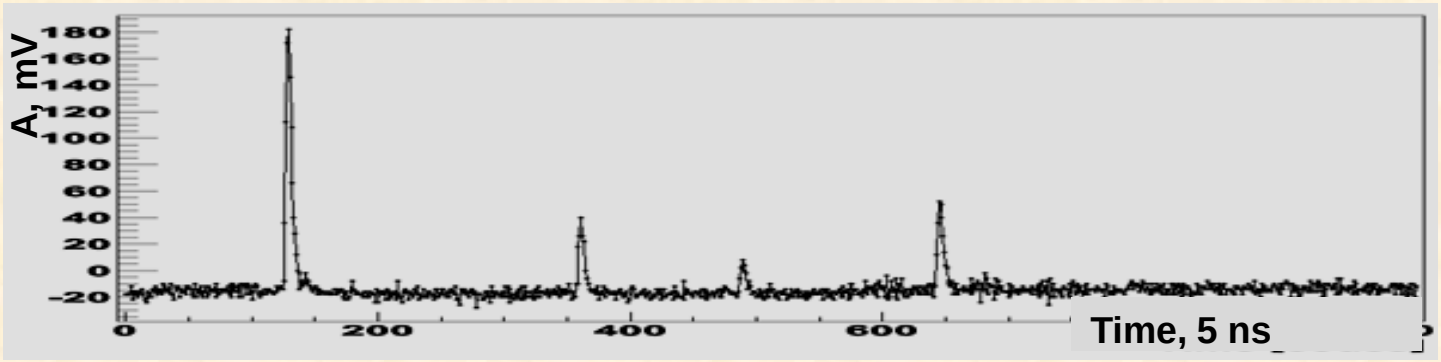
String triggering, power supply, and communication to shore.

Communication lines

Strings ↔ Cluster center: 1.2 km copper cable.
Cluster center ↔ Shore center: 6 km optical cable.

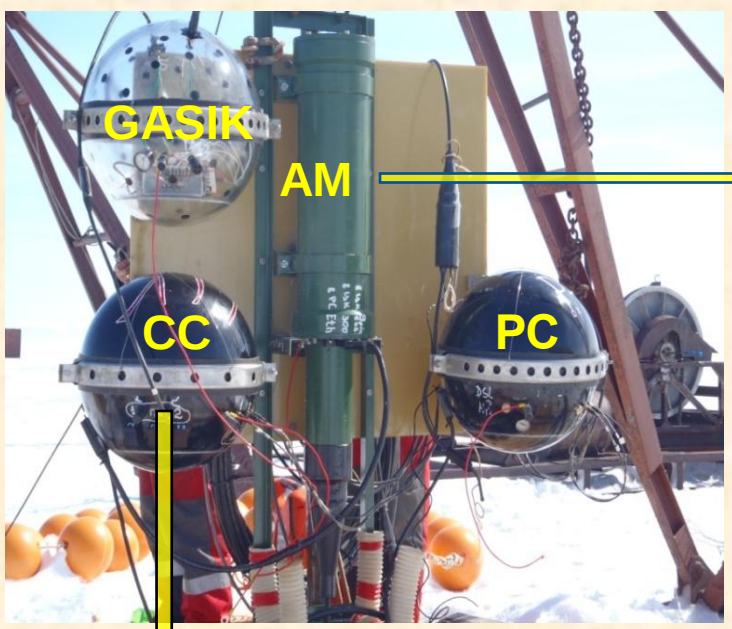
Measuring channel

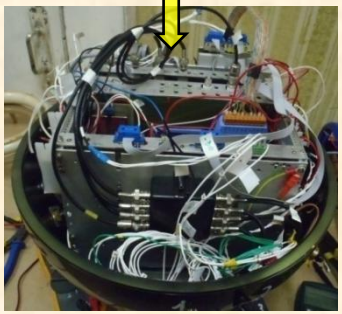




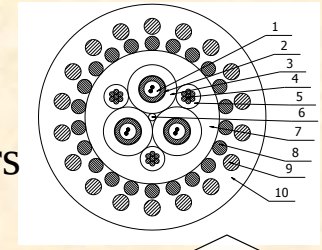
- Nominal PMT gain 1×10^7 (PMT voltage 1250 – 1650 V)
- Amplifier, k_{amp}=10;
- Pulse width ~20 ns
- ADC: 12 bit 200 MHz FADC (5 ns time bin);
- Waveform information is collected for a programmable interval (up to 30 mks)
- Linearity range: 1 ─ 100 p.e.;

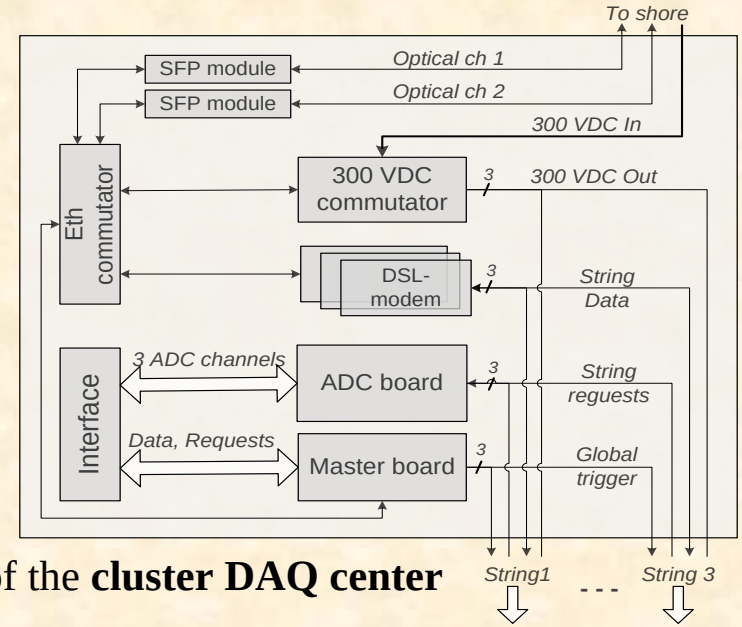
DAQ center





Shore optical cable
6 km length
3 pairs of optical fibers
3 copper lines





Block diagram of the **cluster DAQ center**

Data from 3 strings are transmitted through 8 Mbit DSL-modem to the cluster DAQ center. DSL-modems are installed in **PC-module**.

DAQ center is connected to shore by two optical 1Gbit Ethernet lines.

Optical converters and power units are installed in **Adjunction module (AM)**

Communication Center (CC) provides global trigger and string power supply.

Laser intensity reconstruction with prototype cluster

Preliminary

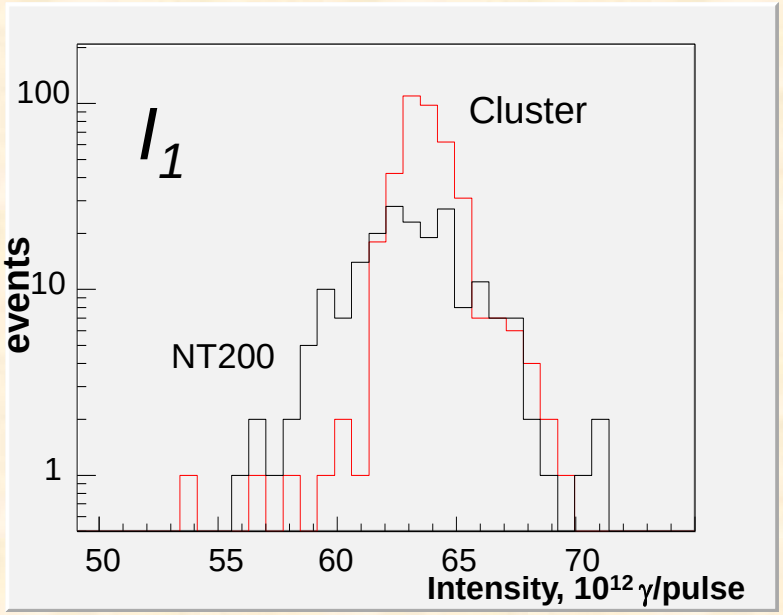
External calibration laser:

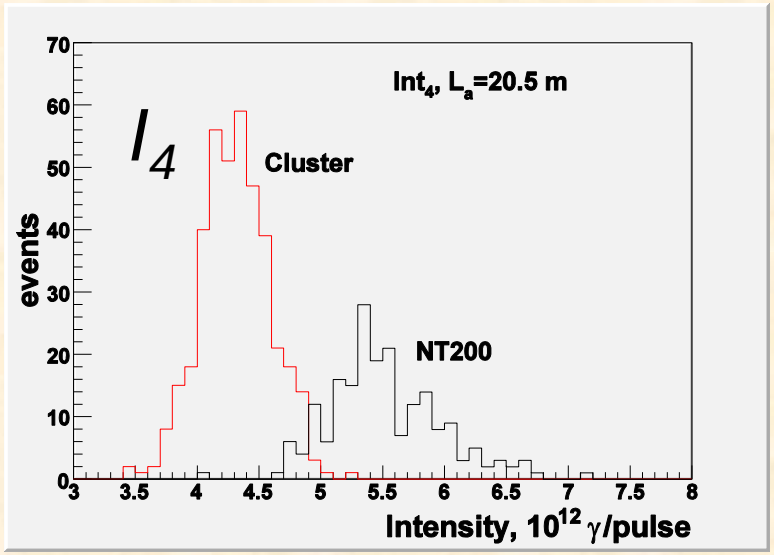
- 480 nm light pulses;
- Five fixed intensities: ~10^{12} – 6×10^{13} γ /*pulse*
  (~10 PeV – 600 PeV shower energy)
- Distances: 110 – 180 m.

Reconstructed laser intensities for five output series

$I, 10^{12}\gamma$/*pulse*	I_1	I_2	I_3	I_4	I_5
Cluster	**64**	**27**	**9.7**	**4.3**	**2.4**
NT200	**63**	**28**	**10.4**	**5.5**	**3.8**

Results obtained with two arrays are consistent within systematic error near NT200 threshold





Distributions of reconstructed laser intensities: NT200 and Cluster

The next steps

GVD final technical design – 2012. Full scale GVD string with 24 OM.

String modernization

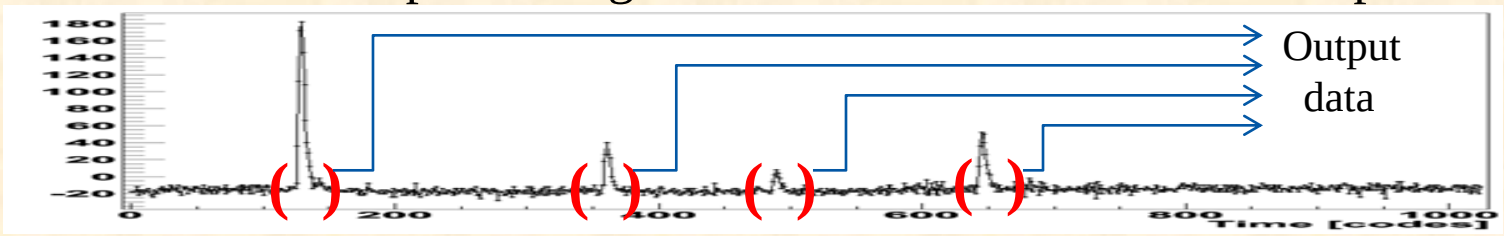
1. Optical modules:

One OM connector (SubConn LF, 5 pin) instead of two coax. conn:

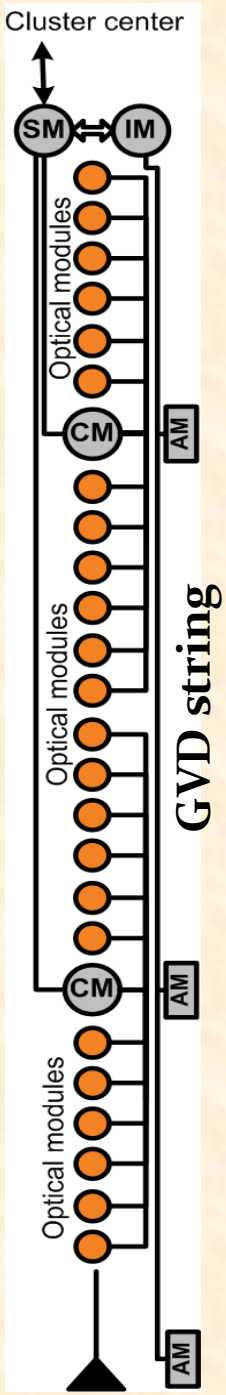
- reliability increasing;
- separation power supply and analog pulse lines → decreasing the channel thresholds (0.5 p.e. to 0.25 p.e.)

2. String central module electronics:

Master boards : new FPGA Xilinx “Spartan 6” instead of “Spartan 3” for on-line data processing – cut out waveform data without pulses.



On-line data processing provides increasing the event transmission rate with 10 Mbit DSL-modem to factor ~100 (10Hz → 1 kHz)



Plans

Preproduction:

2013–2014. Full scale GVD cluster, 8 strings (192 Oms)

Production (preliminary) Cost estimation 25 MEuro

- 2014–2015: Effective volume 0.1 – 0.3 km^3
- 2016–2017: Effective volume 0.3 – 0.6 km^3
- 2017–2018: Effective volume 0.6 – 0.9 km^3

Summary

1. Preparation towards a km^3-scale Gigaton Volume Detector in Lake Baikal is currently a central activity:

   - In-situ tests of the prototype string show good performance of basic string elements (2009-2010).
   - A prototype GVD cluster with 3 strings was installed (2011)
   - Optical cable between shore center and cluster was deployed (2011).

2. GVD Technical Design Report was prepared (2011)

3. Full scale GVD string(24 OMs) will be installed in April 2012.

4. Full scale GVD cluster (192 OMs) is expected at 2013(14).

THANK YOU