

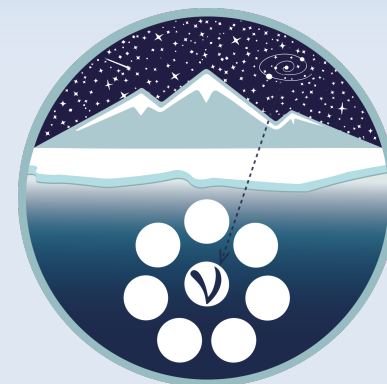
Online software for Baikal-GVD

E.N. Pliskovsky

on behalf of the Baikal-GVD collaboration

Joint Institute for Nuclear Research, Dubna, Russia, 141980

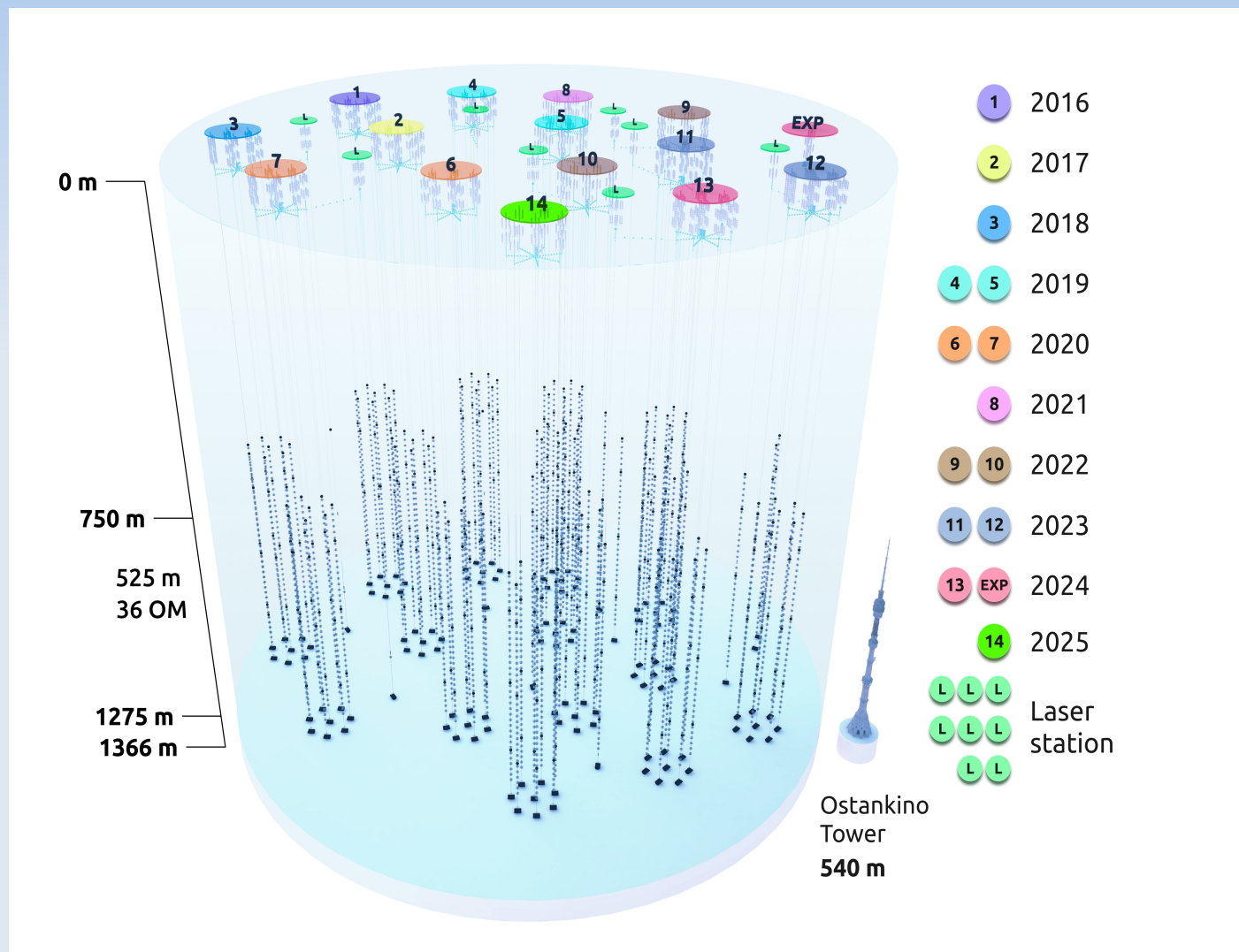
GRID'2025 Computing for MegaScience Projects 10.07.2025





Detector Status

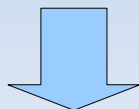
- 4212 Optical modules on 117 strings (14 out of 20 clusters)
- 8 or 9 strings form a cluster - independent array of optical modules
- 36 optical modules per string
- 60 m between strings in a cluster, 250-300 m between clusters
- More than 0.7 km³ of water volume
- More than 400 acoustic modules for positioning
- LED modules and powerful laser sources for calibration
- Each cluster operates in its own subnet





Key features & principles

- Remote location of the detector (~100 km from Irkutsk), no backbone communication lines
- The detector is operated by one person
- Physical inaccessibility of the detector components from mid April to mid February
- Data transmission system : max 50 Mbit/cluster, 5.6 Mbit from string



Key Principles for DAQ Software

Ensuring easy maintenance of the detector

Reliability of hardware and software

Autonomous operation in the absence of Internet connections

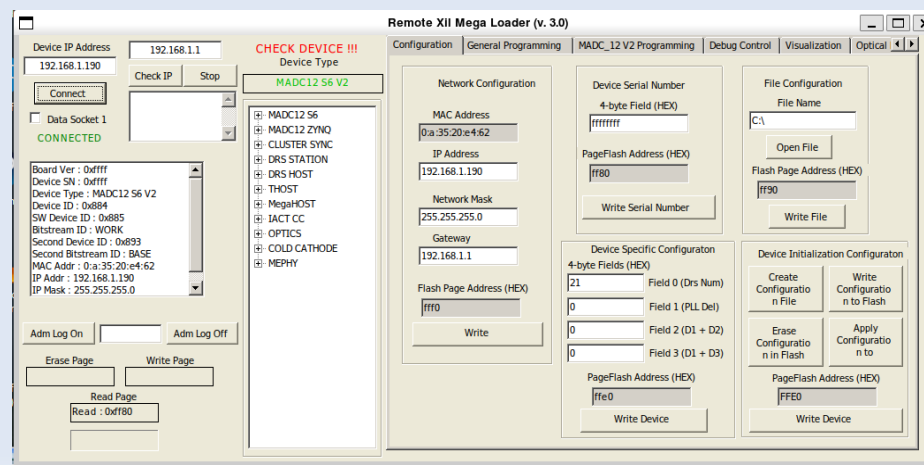
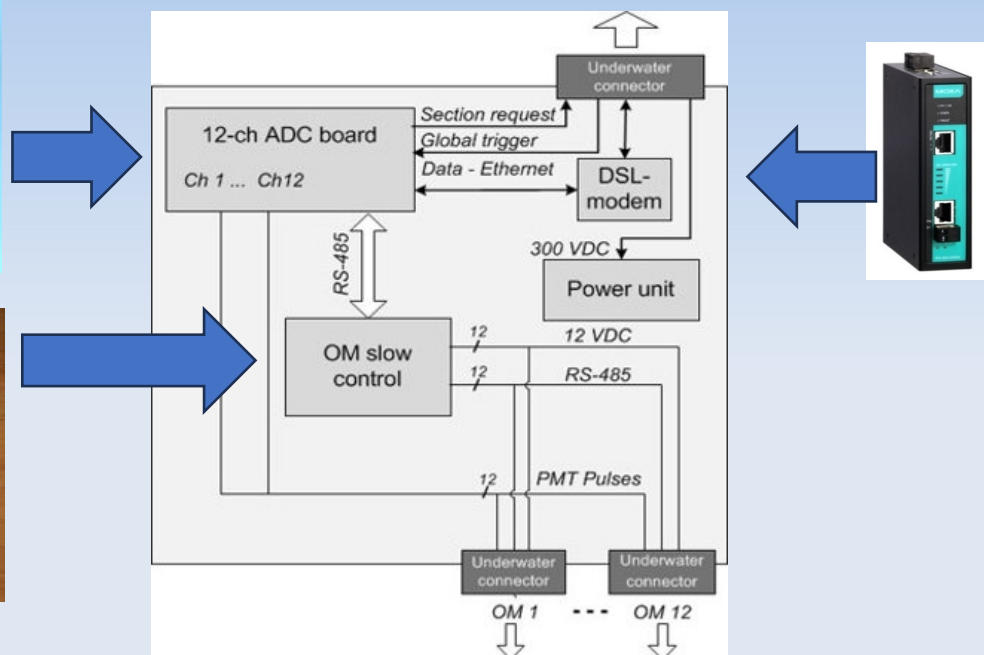
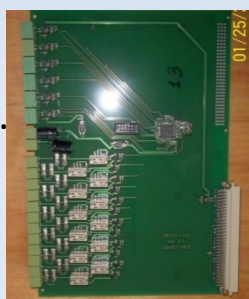
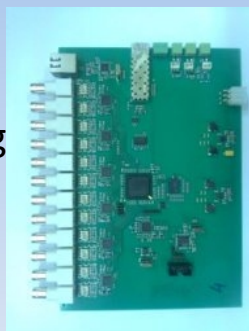
Detector as IT-infrastructure

- > 4000 microcontrollers in OM's - RS-485
- > 350 microcomputers - TCP IP
- > 1000 MOXA network hardware components (switches, DSL, Nports) – TCP IP
- + I2C sensors (humidity, pressure, temperature.....)
- + fiber-optic cable to shore, slow DSL connections within a cluster



Section (as base DAQ cell)

- 12-channel ADC unit (master)** : PMTs analog pulse conversion, time synchronization, data processing, local trigger.
 - Xilinx Spartan 6 & Zync
 - base & work firmware
- Data transmission** : Two outputs of ADC board: optical output (for future detector extension) and 100 BASE-TX (present stage).
- shDSL modem** : Extending the Ethernet line up to 1 km.
- Slow control board (relay)** : OM power on/off and control of OM operation (RS485).





Online Software : Overview

Master (muon) data taking :

Main Program

Service software :

Acoustic data taking software
U/W Lasers control utilites
White-Rabbit (time sync) utilites
Low-level Master & FADC utilite
Power management program

Monitoring software :

Dashboards, web-based monitors
Commutators & shore power boxes monitoring
OM monitoring software
Influx DB, MySQL DB

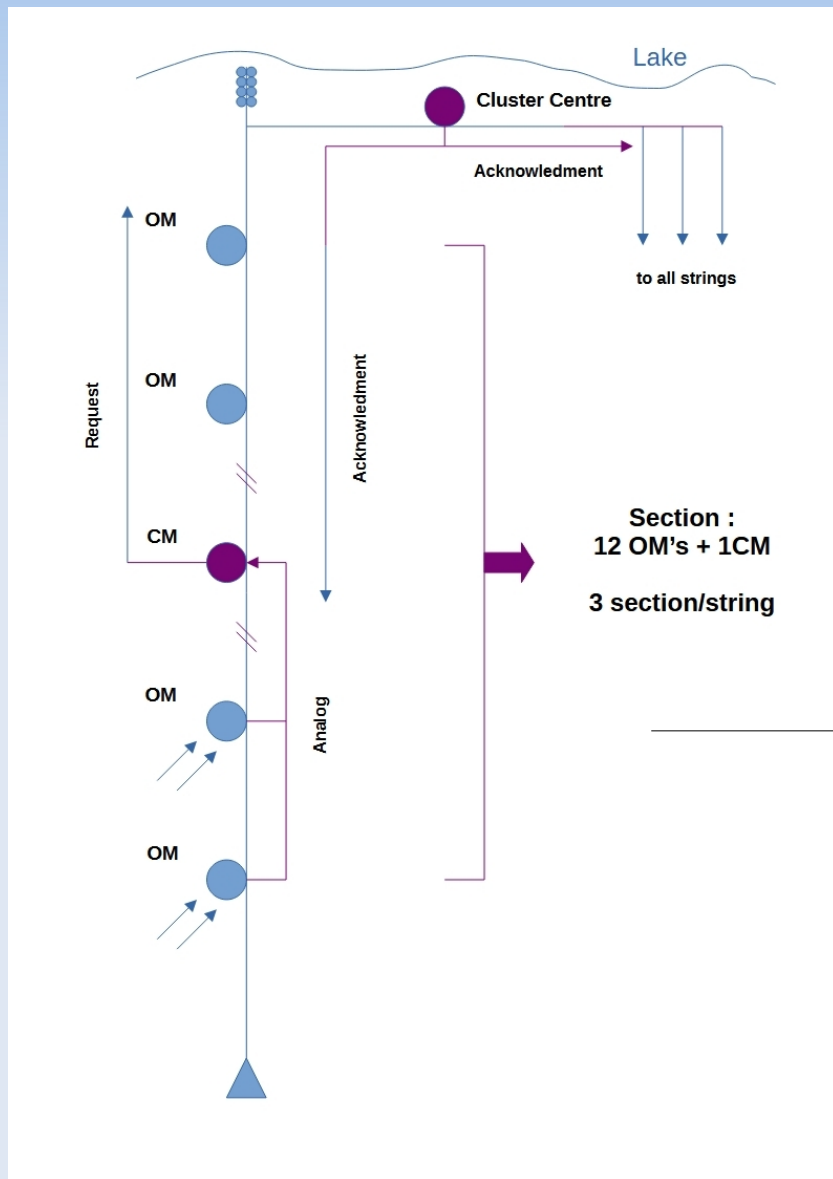
Linux (debian)
C/C++, Qt, Python
Shell scripts, RabbitMQ
Influx, MySQL, grafana

Xeon E5-2643 v4(6 cores) x 3

Maximal use open source solutions !!

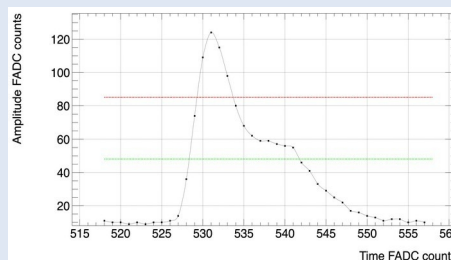


How detector works

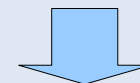


Base detector operation mode

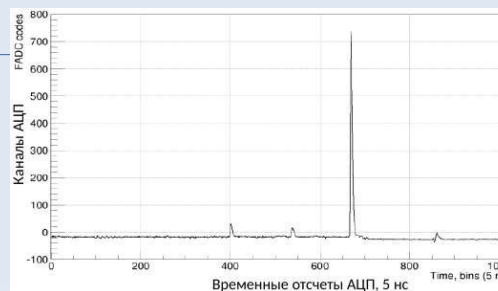
- coincidence pair OM's
- coincidence window 100 ns. (CM) / 500 ns. (Cluster Centre)
- acknowledgment from Cluster Centre
- FADC data filtration
- RUN duration : ~24 hours
- FADC thresholds : ~1.5-2.0/~ 4.0 ph.e
- Rate : 10 – 150 Hz from cluster



Raw data from each master (CM) :
header (time, master #, counters)
+ wave form

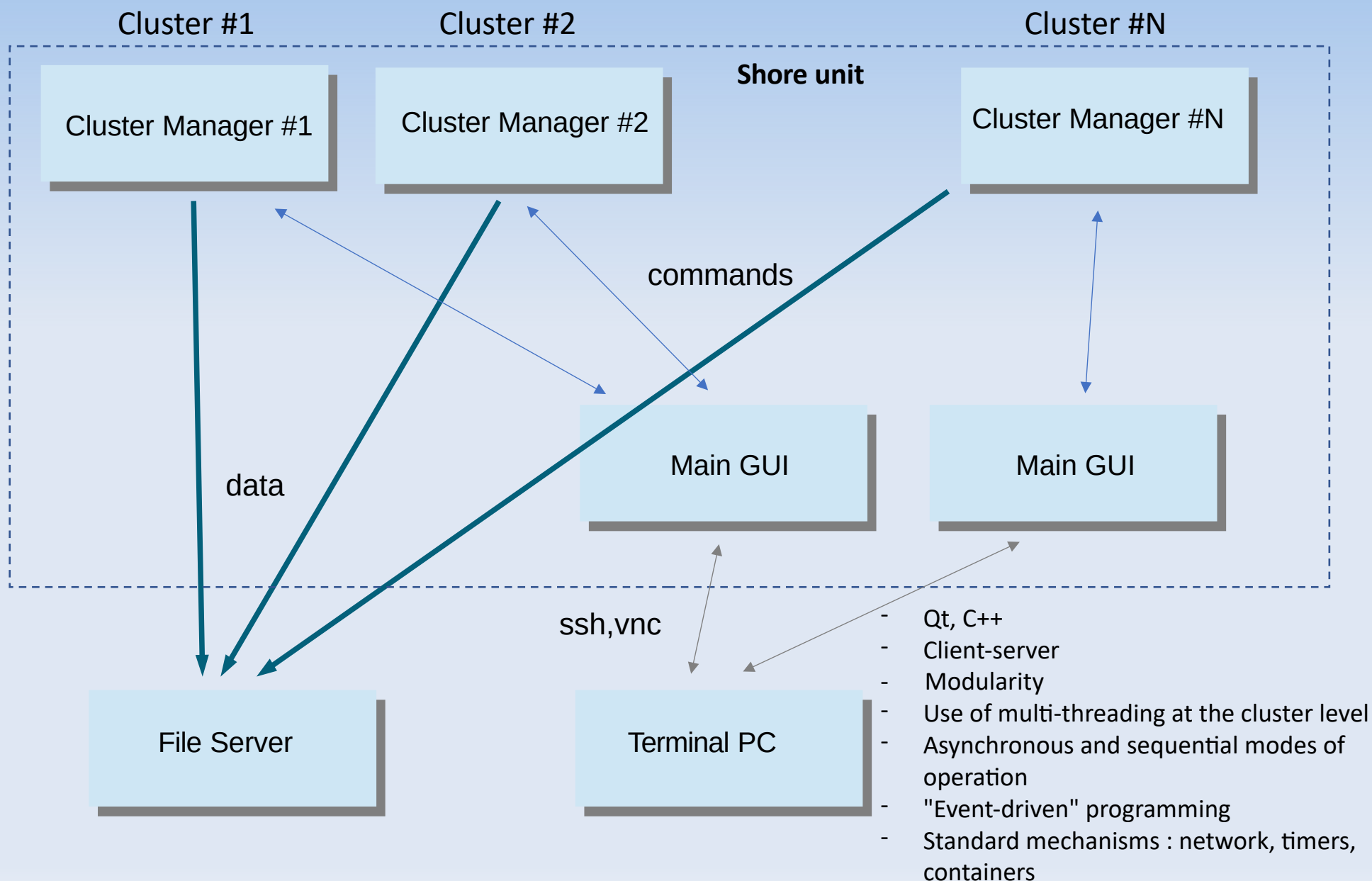


**data from all masters can
be combined into a single
physical event**



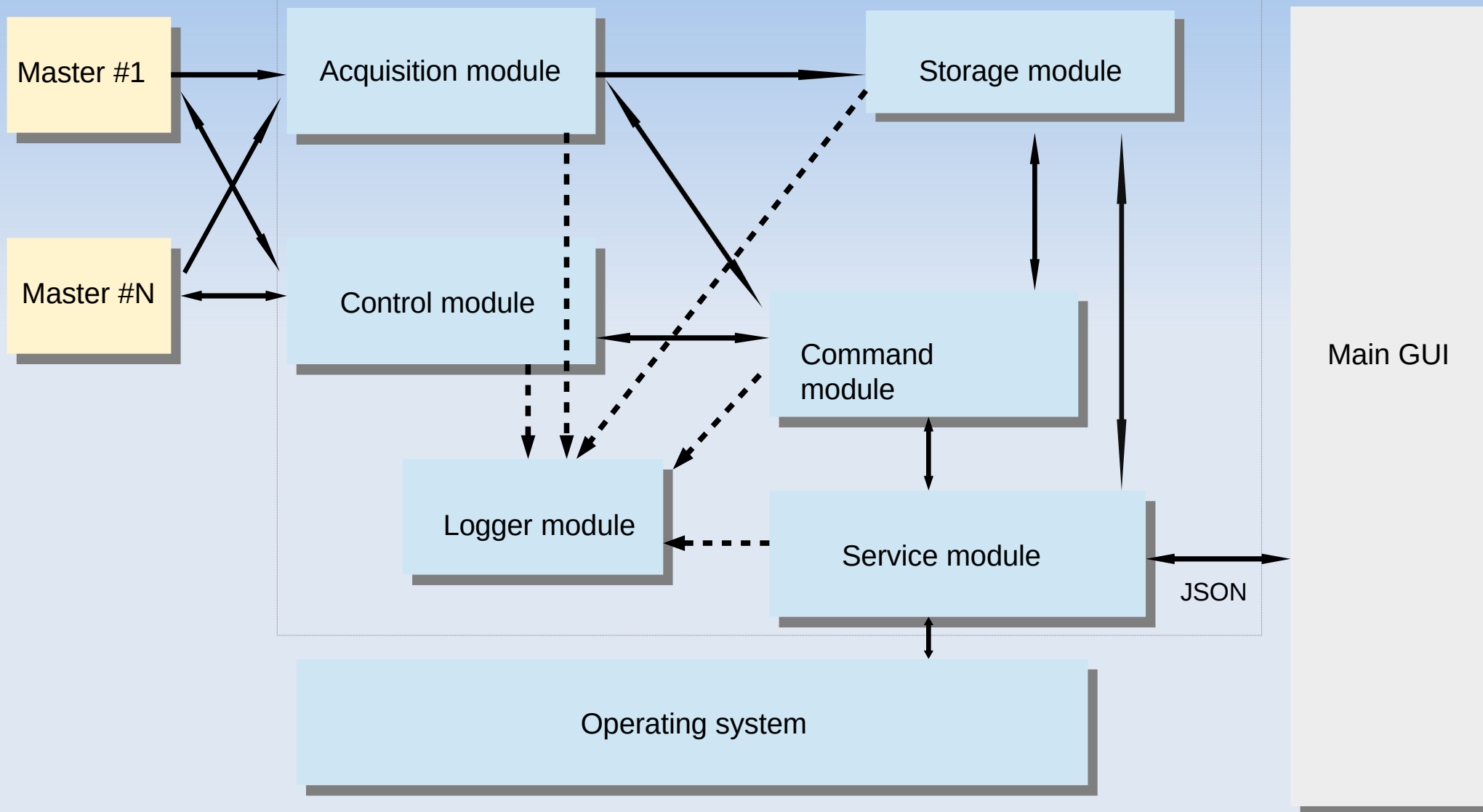


Main Program : Architecture





Main Program : ClusterManager



run as **systemd** service for each GVD cluster



Main Program : GUI

[1] GVD MAIN v1.6 04 Apr. 2025 (Parallel Edition)

Configuration Tools LED Monitoring

Messages

```
CLUSTER # 1 RUN # 238 has started at Tue June 24 13:55:15
..... Writing configuration #2 (work) for Cluster # 1 .....
13: 55: 15 [24. 6.2025] .... Get Commutators State for Cluster # 1
13: 55: 15 [24. 6.2025] .... Get Relays State for Cluster # 1
13: 55: 17 [24. 6.2025] .... Get Sensors State for Cluster # 1
14: 0: 15 [24. 6.2025] .... Get Histograms for Cluster # 1
14: 0: 16 [24. 6.2025] .... Get Commutators State for Cluster # 1
14: 0: 16 [24. 6.2025] .... Get Relays State for Cluster # 1
14: 0: 18 [24. 6.2025] .... Get Sensors State for Cluster # 1
14: 5: 15 [24. 6.2025] .... Get Histograms for Cluster # 1
14: 5: 16 [24. 6.2025] .... Get Commutators State for Cluster # 1
14: 5: 16 [24. 6.2025] .... Get Relays State for Cluster # 1
14: 5: 18 [24. 6.2025] .... Get Sensors State for Cluster # 1
```

Control

Start RUN

Stop RUN

RUN Configuration

Integrated Master Utilites

Devices Control

Quit

Cluster State

RUN	Histograms	Power	Sensor	Relay					
Node Name	String #	Master #	Master State	Event #	Hist #	Req #	Ack #	Rate (Hz)	Stream (KB/s)
Centre	-	190	ON	19280	0	19280	19280	30.125	8.2
Monitor	-	220	OFF	0	0	0	0	0.000	0.0
Sync	-	21	OFF	0	0	0	0	0.000	0.0
Section 1	1	195	ON	19280	2	6117	19280	30.125	19.3
Section 2	1	196	ON	19280	2	9915	19280	30.125	21.8
Section 3	1	197	ON	19280	2	4462	19280	30.125	9.9

Cluster # 1

CLUSTER #1 RUN : 238 FILE : 1 Muon RUN Standard Rate : 59.1 Kb/s

- Simple for use
- Single & multi – cluster
- Semi-automatic
- CPU usage for base RUNs < 5 % !
- RUN restart time (if NO hardware failure) < 3 min.



Data monitoring : Base

The telescope produces a considerable amount of monitoring data produced by multiple independent sources:

Underwater components:

- OM-level sensors: humidity, pressure, HV etc.
- Power commutators.
- Acoustics.
- System module level sensors.

Communications equipment monitoring.

Shore power supplies.

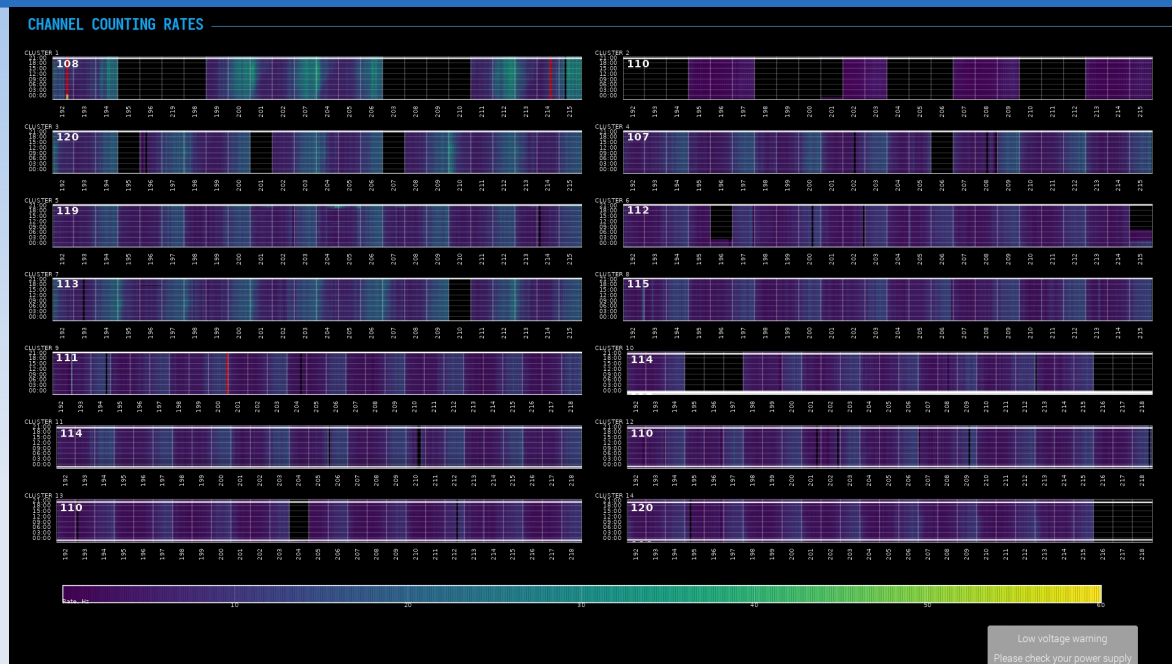
OM counting rates.

The goal is to aggregate the monitoring data, making it available for comprehensive analysis and shifter-level alerts.

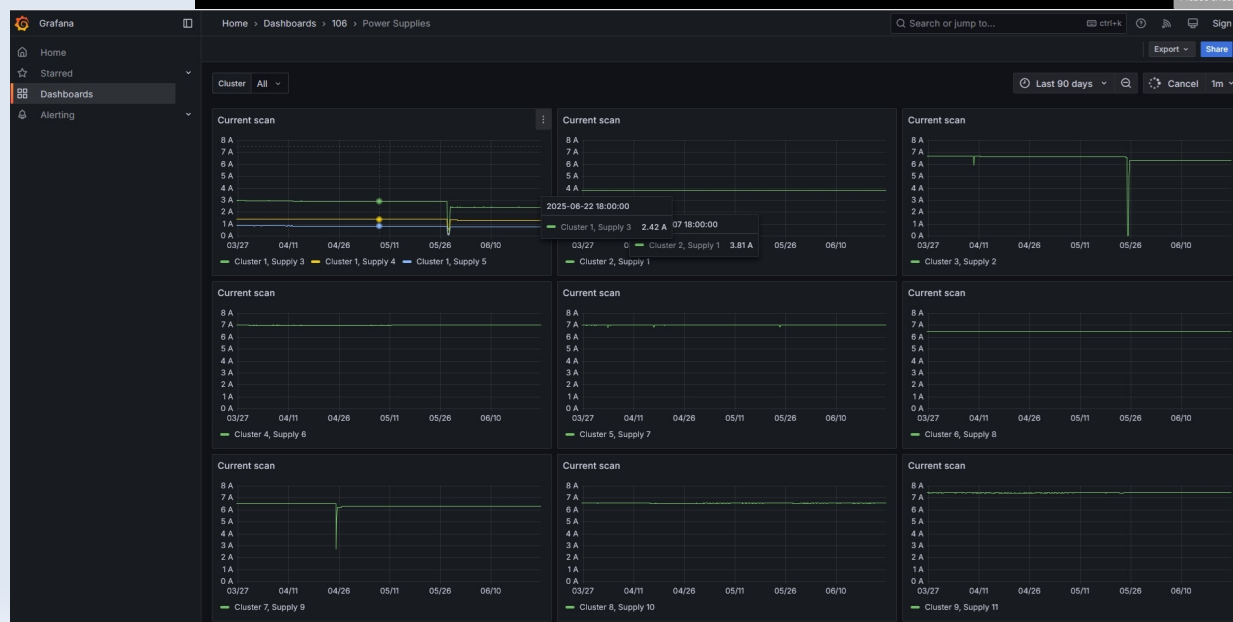


Data Monitoring : Shore

Shore Station: Voltage monitoring, event rates, detector occupancies, OM sensor data at web-based dashboard, detector geometry monitoring, thunderstorm alarm



Shore power supplies support online monitoring. Each power supply box is polled Every 5 seconds, V and I are stored locally, sent to JINR and displayed to the shifter.





Data Monitoring : underwater network

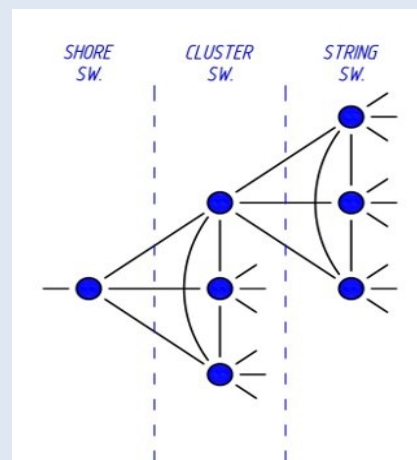
Underwater networking

- Reachability of the addressable detector components:
 - Regularly tested via ICMP (ping && fping) from the shore.
 - Output is stored locally at the moment, integration in progress.
 - Current status available to the shifter.
 - MOXA hardware provides some statistics on network operations (number of packets in/out).
We look at this data if something goes wrong. The applicable hardware includes:
 - Switches in the Cluster Center.
 - DSL modems in the Cluster Center, String Modules and Section Modules.
- NPorts in String Modules and Section Modules.

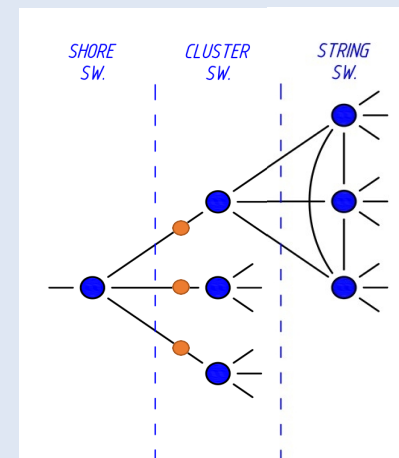
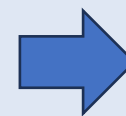
Shore Network Organization (since 2023)

- VLAN technology are supported by Baikal-GVD network devices
- VLAN based network is introduced on shore switch and servers
- Virtually separated networks
- Peer-to-peer network -> multi-level network

Significantly (10 times) reduced the number of “freezes” of DSL modems



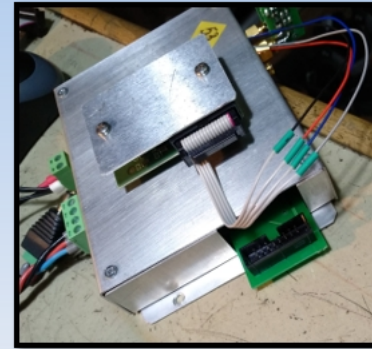
P2P Network
each connect with each



Multi-level Network
separated on shore switch

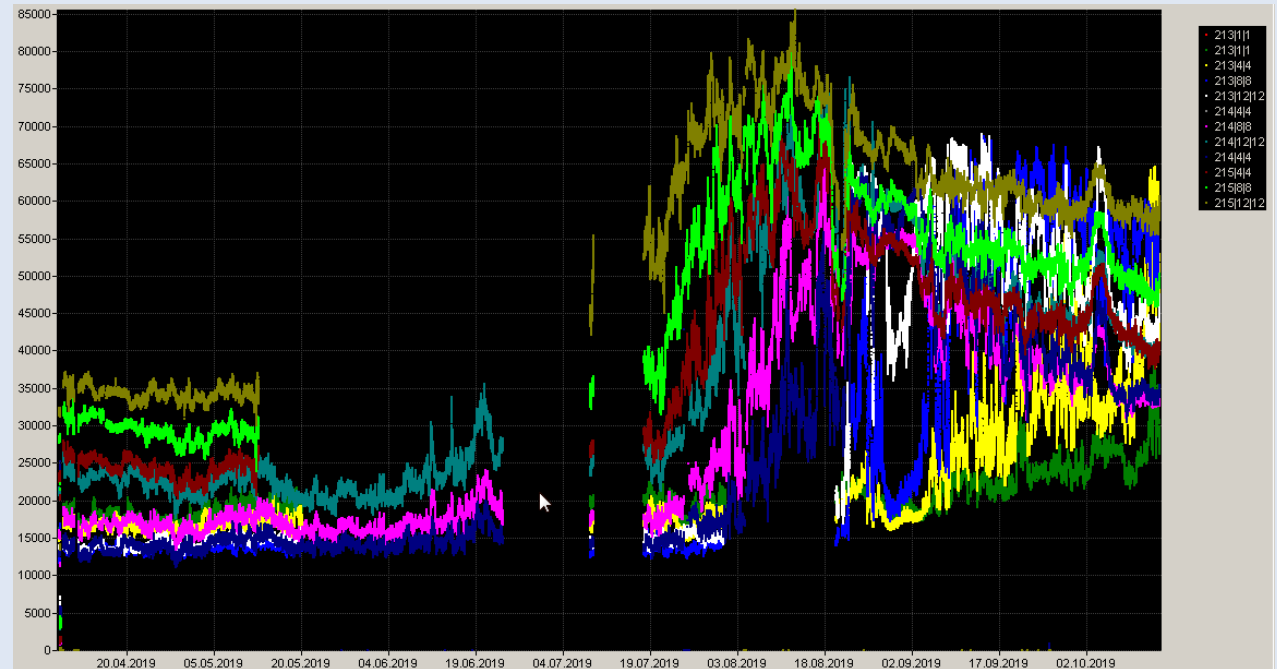
Data Monitoring : OM parameters

OM Controller with sensors block



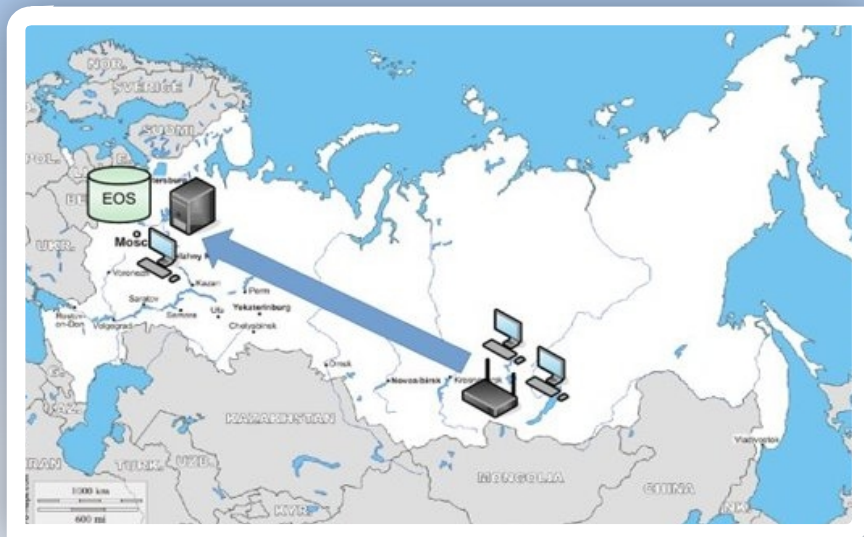
OM parameters monitoring

Controller Uptime
PMT Hight Voltage
3 x Onboard Voltage
Controller Temperature
PMT Pulse Detector Rate
Inside Air Temperature
Relative Humidity
3 Axis Acceleration (Gravity)
3 Axis Magnetic Field Strength
Inside Air Pressure





Shore Station & Data Stream



Raw data are transferred from the Shore Center to JINR:

Shore center → Baikalsk: 300 Mbit/s radio-channel

Baikalsk → JINR: standart Internet communication

Compressed data volume ~40-150 GB per day

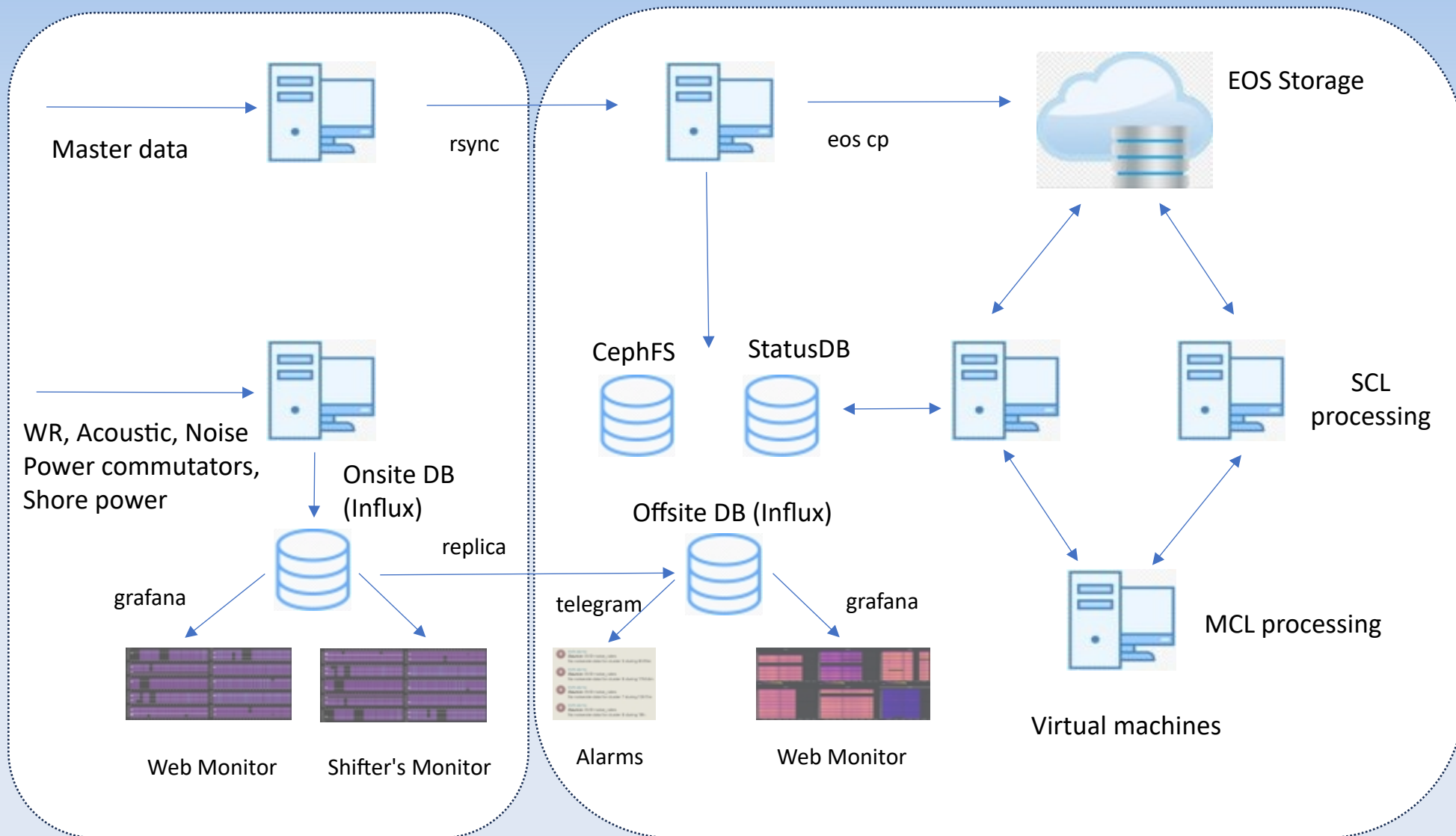
Full-scale reconstruction at JINR

Delay due to shore - JINR data transfer < 1 min





Data flow : Overview





Conclusions

- **An almost complete set of software for collecting, monitoring and storing detector data has been developed**
- **Data acquisition software proven to be reliable and efficient (detector efficiency for 2024 : ~96 %)**
- **Over the last years most of the monitoring tools has been streamlined: data formats are documented and available via a central repository (JINR GitLab). New monitoring data is regularly pushed to JINR.**
- **The completion of work on the creation of 1 km³ Baikal-GVD detector with ~6000 OM's is planned in 2027/2028**



Thank you for attention !!





Backup slides

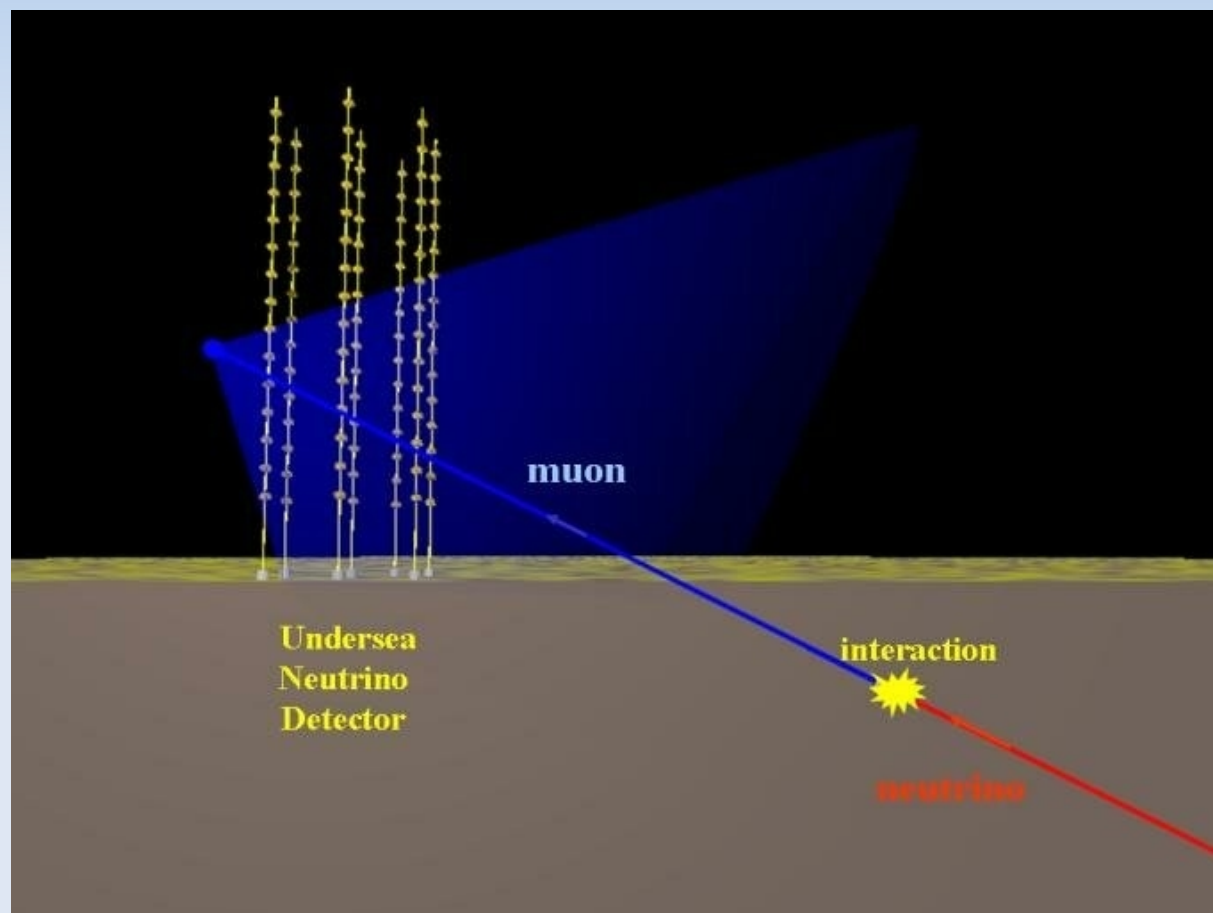


Neutrino detection

$$\nu_{\mu} + n \rightarrow p + \mu^{-}$$

$$\nu_{\mu} + p \rightarrow n + \mu^{+}$$

Based on idea from M. A. Markov, 1960
recording Cherenkov radiation from secondary
muons and/or high-energy showers produced
by neutrinos during their interactions with
matter in transparent natural media

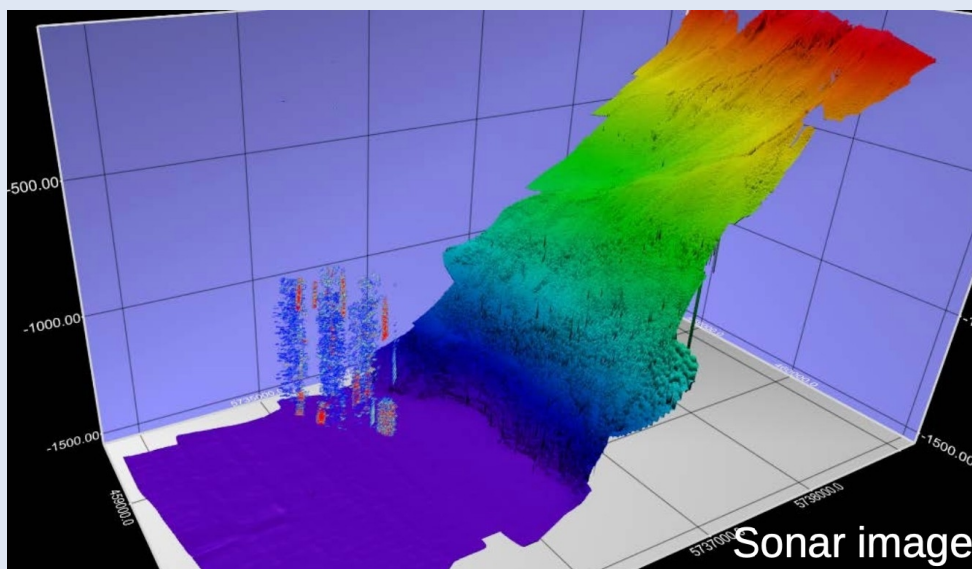




Baikal-GVD Site



- Southern basin of the lake
- ~3.6 km offshore
- Flat area at depths 1366–1367 m
- High water transparency
- Railway infrastructure
- Moderately low optical background: 15–50 kHz
- Deployment from the ice cover of the lake

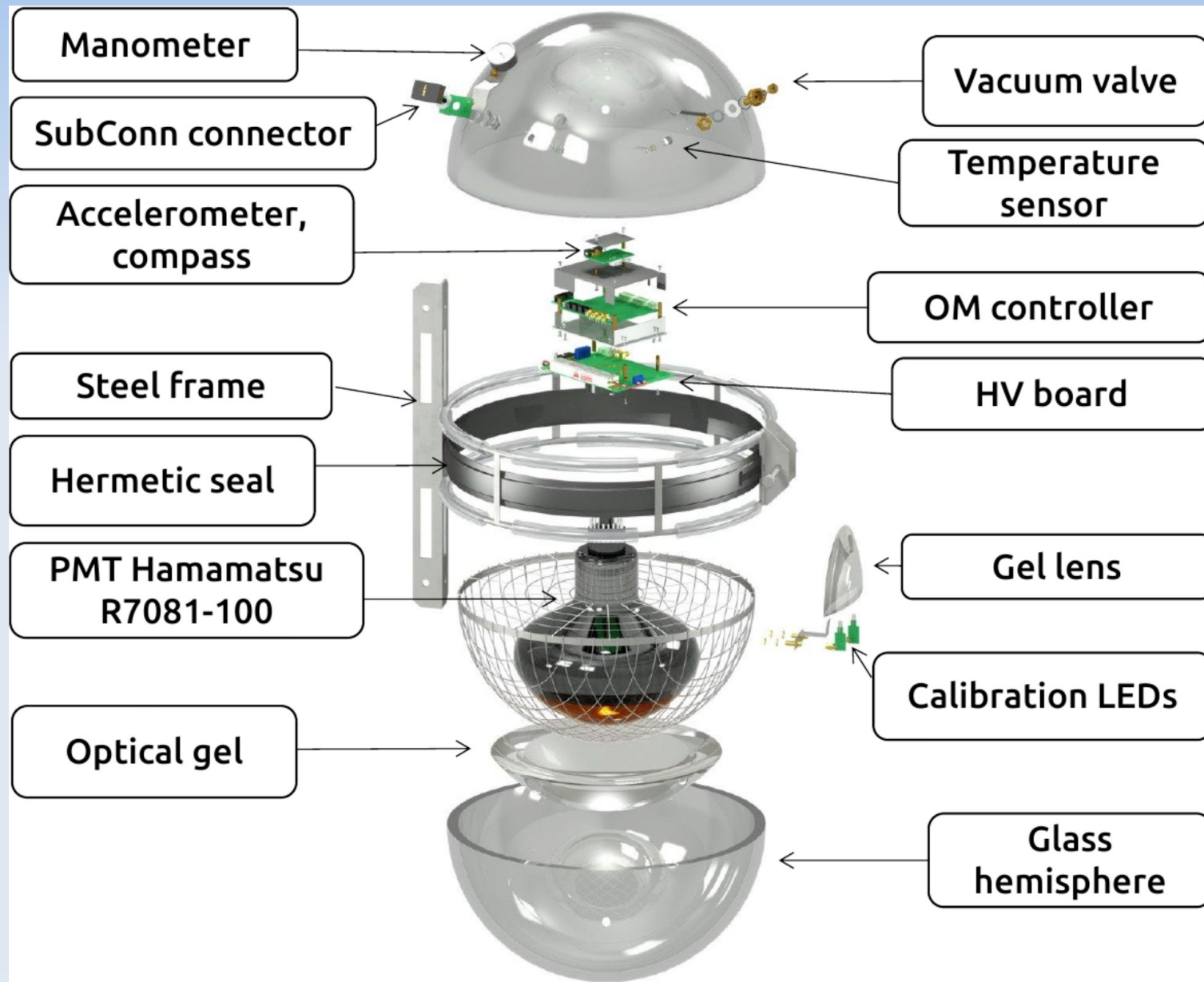




Optical Module

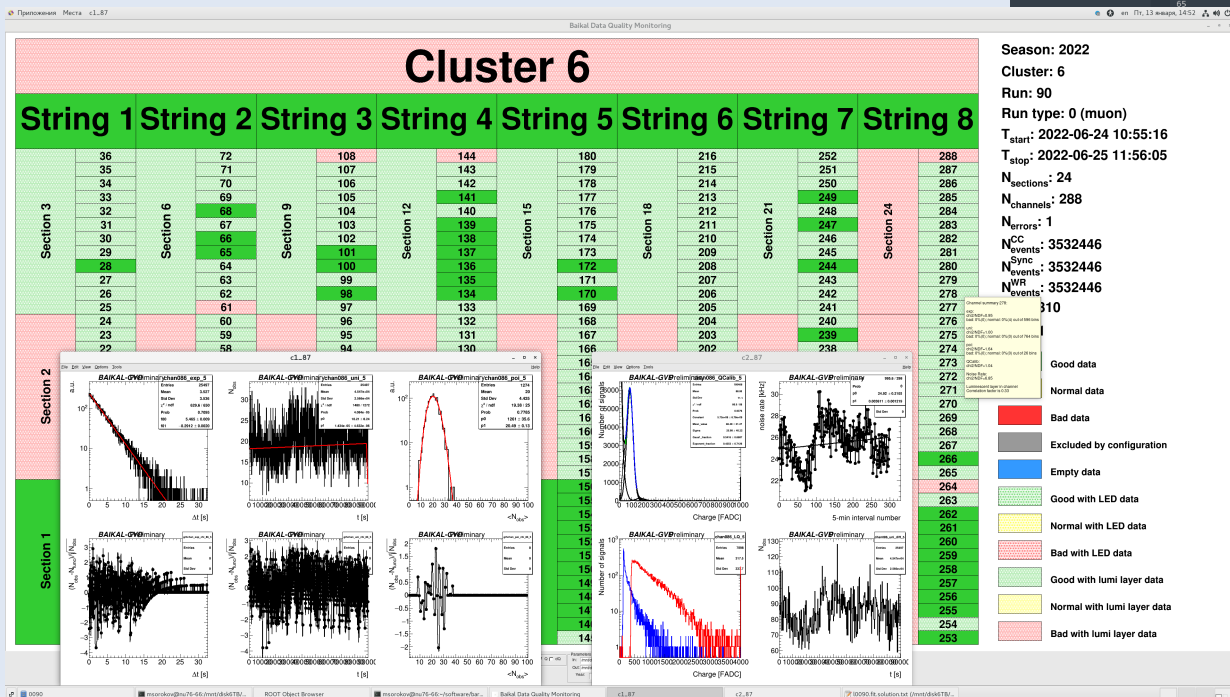


- 17 inches sphere (42 cm)
- 10 inch Hamamatsu PMT R7081-100





- **DQM:** Uniformity of event rate, hot channels, charge distributions, charge calibration
- **Dashboard:** web-based interface to JINR databases containing OM sensor data, detector geometry data, HV and LV data, run info, data processing status





Power management program

GVD Commutators Manager v4.03

Cluster: All String: All Load config: Load IP: Ping: Period: NONE Switch ON Switch OFF Get V Stop Time to automatic ping: --- ABOCT

	MG_1	MG_2	MG_3	MG_4	MG_5	MG_6	MG_7	MG_8	TM	DM	Laser	Sync	MG_1	MG_2	MG_3	MG_4	MG_5	MG_6	MG_7	MG_8	TM	DM	Laser	Sync	MG_1	MG_2	MG_3	MG_4	MG_5	MG_6	MG_7	MG_8	TM	DM	Laser	Sync	
C	41	39	70	80	76	33	37	32	31				72	40	80	92		100	60	50	190	31			21	90	80	100	60	50	70	110	40	31	32	120	21
R																																					
1	206	192	202	204	203	208	216						195	192	213	203		207	197	202					207	204		198	195	201	213	192			125		
2	166	152	162	164	163	168	176						155	152	173	163		167	157	162					167	164		158	153	161	173	152					
3	200	198	222	195	217	207	209						196	193	205	200		210	199	204					208	205	211	199	196	202	214	193					
4	160	158	182	155	177	167	169						156	153	165	160		170	159	164					168	165	171	159	156	162	174	153			124		
5	219	197	215	212	218	221	213						201	194	214	209		212	198	208					209	206	212	200	197	203	215	194					
6	179	157	175	172	178	181	173						161	154	174	169		172	158	168					169	166	172	160	157	163	175	154					
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8																																					
9	42	40	72	86	78	240	242						71	41	81	91		101	61	51					91	81	101	61	51	71	111	41					
10	42	40		243	78	240							71	41	81	91		101	61	51					96	86	106	66	56	76	116	46					
11	42	40	72	243	78	240	242						71	41	81	91		101	61	51													47				
12																																					
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2	152	155	158	161	164	167	170	173					152	155	158	161		167	170	173					152	155	158	161	164	167	170	173					
3	193	196	199	202	205	208	211	214					193	196	199	202	205	208	211	214					193	196	199	202	205	208	211	214					
4	153	156	159	162	165	168	171	174					153	156	159	162	165	168	171	174					153	156	159	162	165	168	171	174					
5	194	197	200	203	206	209	212	215					194	197	200	203	206	209	212	215					194	197	200	203	206	209	212	215					
6	154	157	160	163	166	169	172	175					154	157	160	163	166	169	172	175					154	157	160	163	166	169	172	175					
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9	41	51	61	71	81	91	101	111																													
10	46	56	66	76	86	96	106	116																													
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2	152	155	158	161	164	167	170	173					152	155	158	161	164	167	170	173				176	152		158		164		170	173			176		
3	193	196	199	202	205	208	211	214					193	196	199	202	205	208	211	214				217	193		199		205		211	214			217		
4	153	156	159	162	165	168	171	174					153	156	159	162	165	168	171	174				177	153		159		165		171	174			177		
5	194	197	200	203	206	209	212	215					194	197	200	203	206	209	212	215				218	194		200		206		212	215			218		
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GVD_PowManager

Кластер 4 гирлянда 8 канал 4

Restore GetV Switch OFF Switch ON Ping Cancel