Online software for Baikal-GVD

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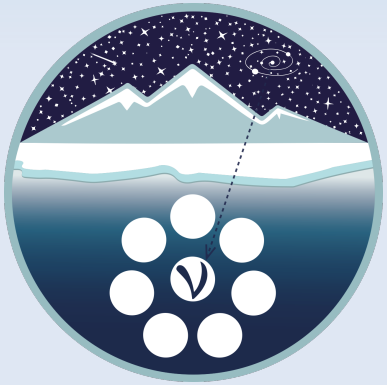
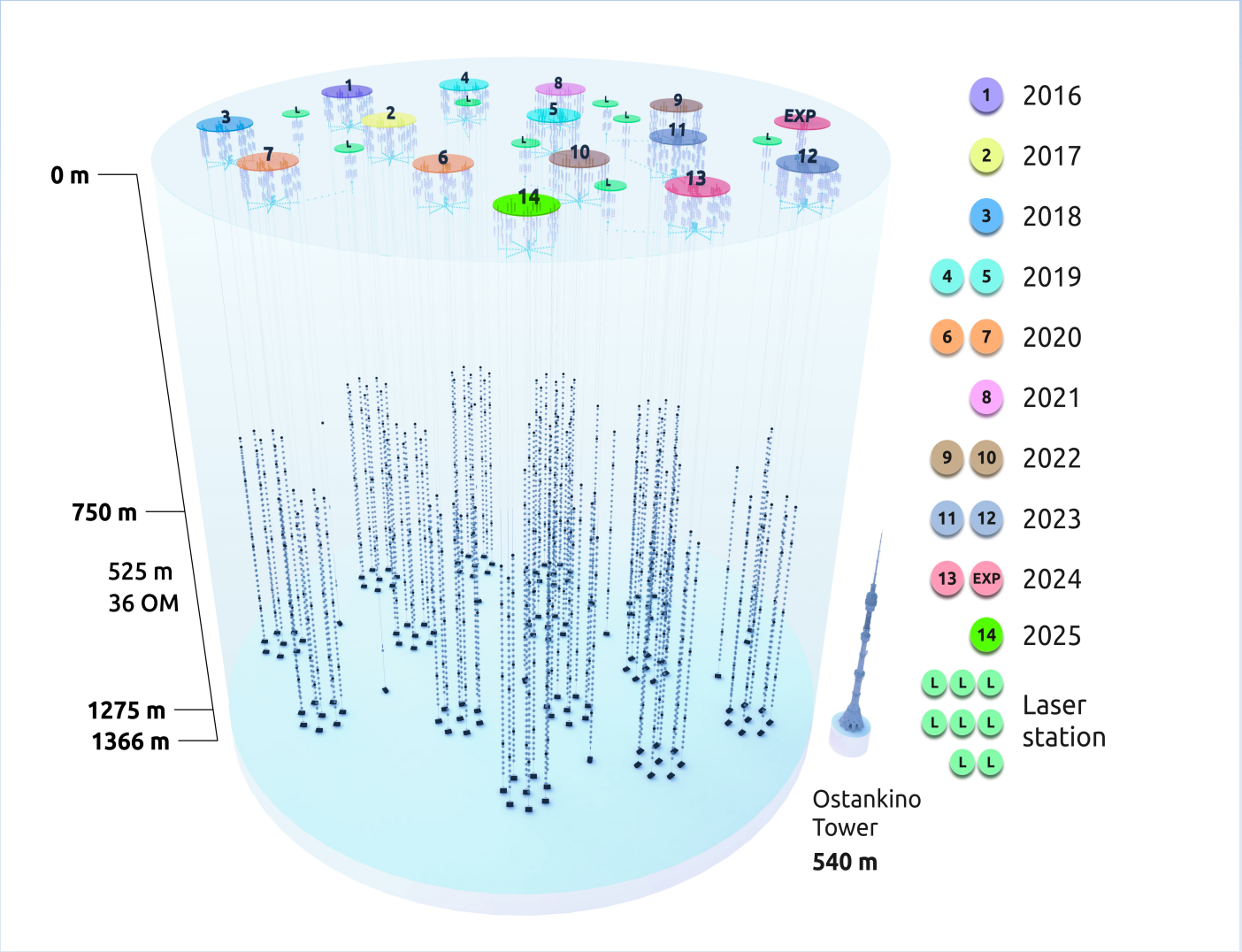


Detector Status

- 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 km^3 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

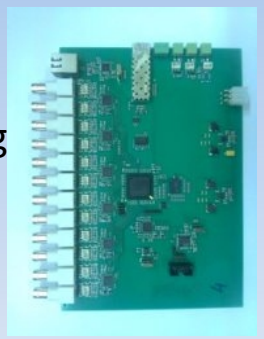
Autonomous operation in the absence of Internet connections

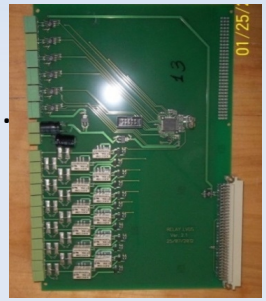
Detector as IT-infrastructure

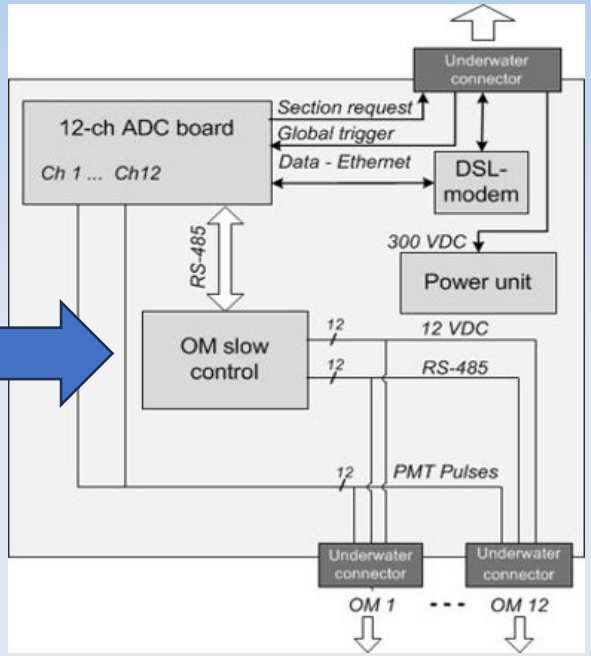
> 4000 microcontrollers in OM's - RS-485
> 350 microcomputers - TCP IP
> 1000 MOXA network hardware components (switches, DSL, Nports) – TCP IP
+ I2C sensors (humidity, pressure, temperature…..)
+ fiber-optic cable to shore, slow DSL connections within a cluster

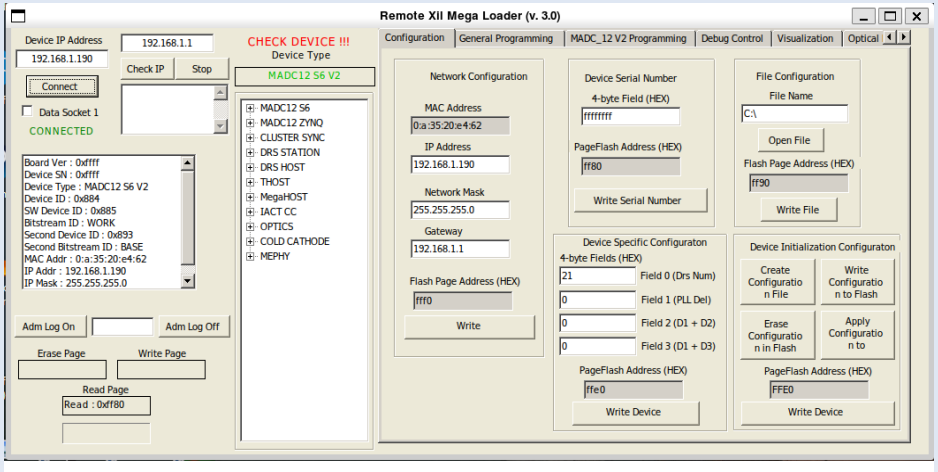
Section (as base DAQ cell)

- 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 :

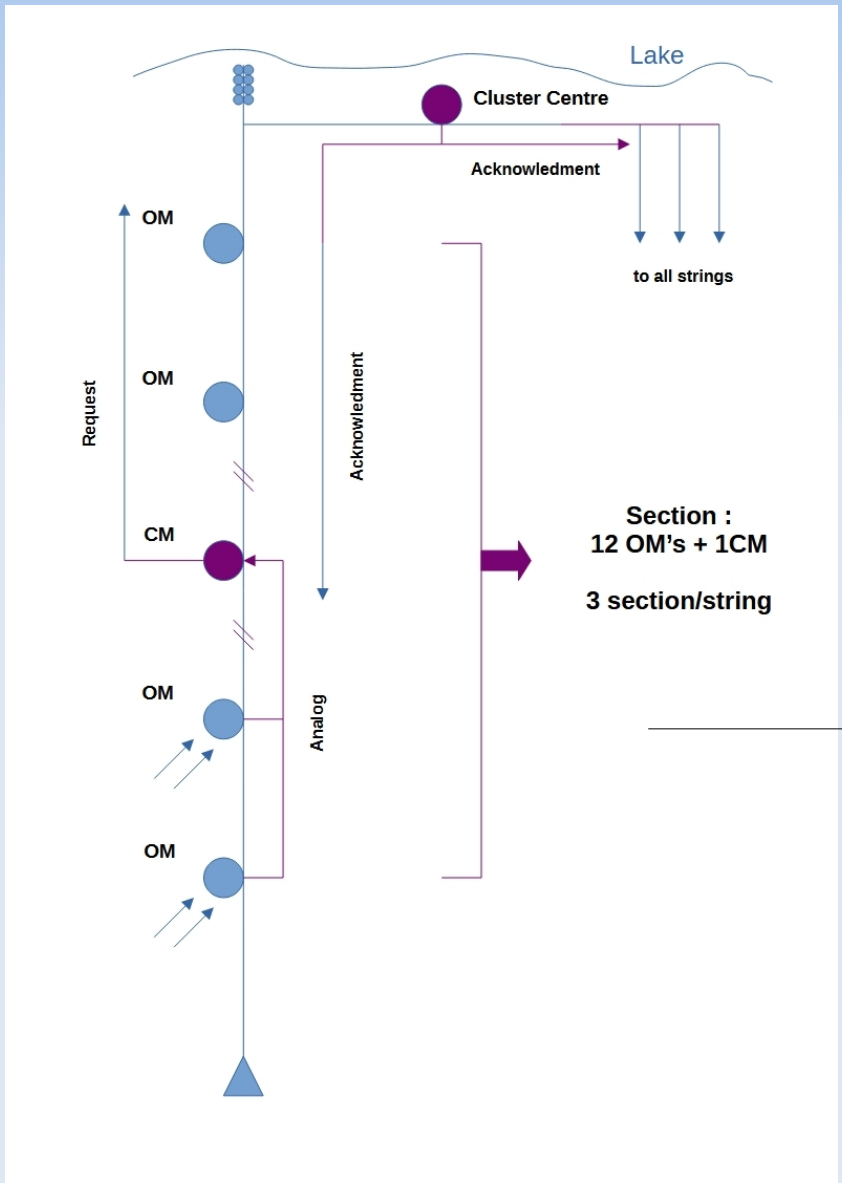
Dashboards, web-based monitors
Commutators & shore power boxes monitoring
OM monitoring software
Influx DB, MySQL DB

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

Xeon E5-2643 v4(6 cores) x 3

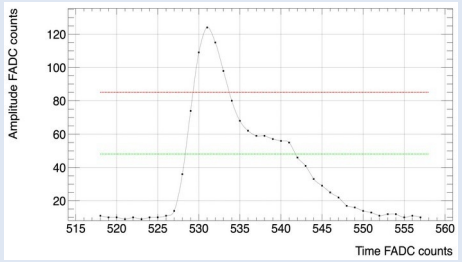
Maximal use open source solutions !!

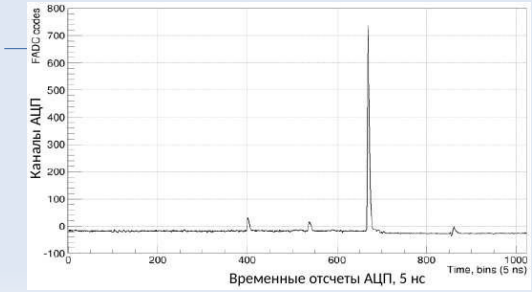
How detector works



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

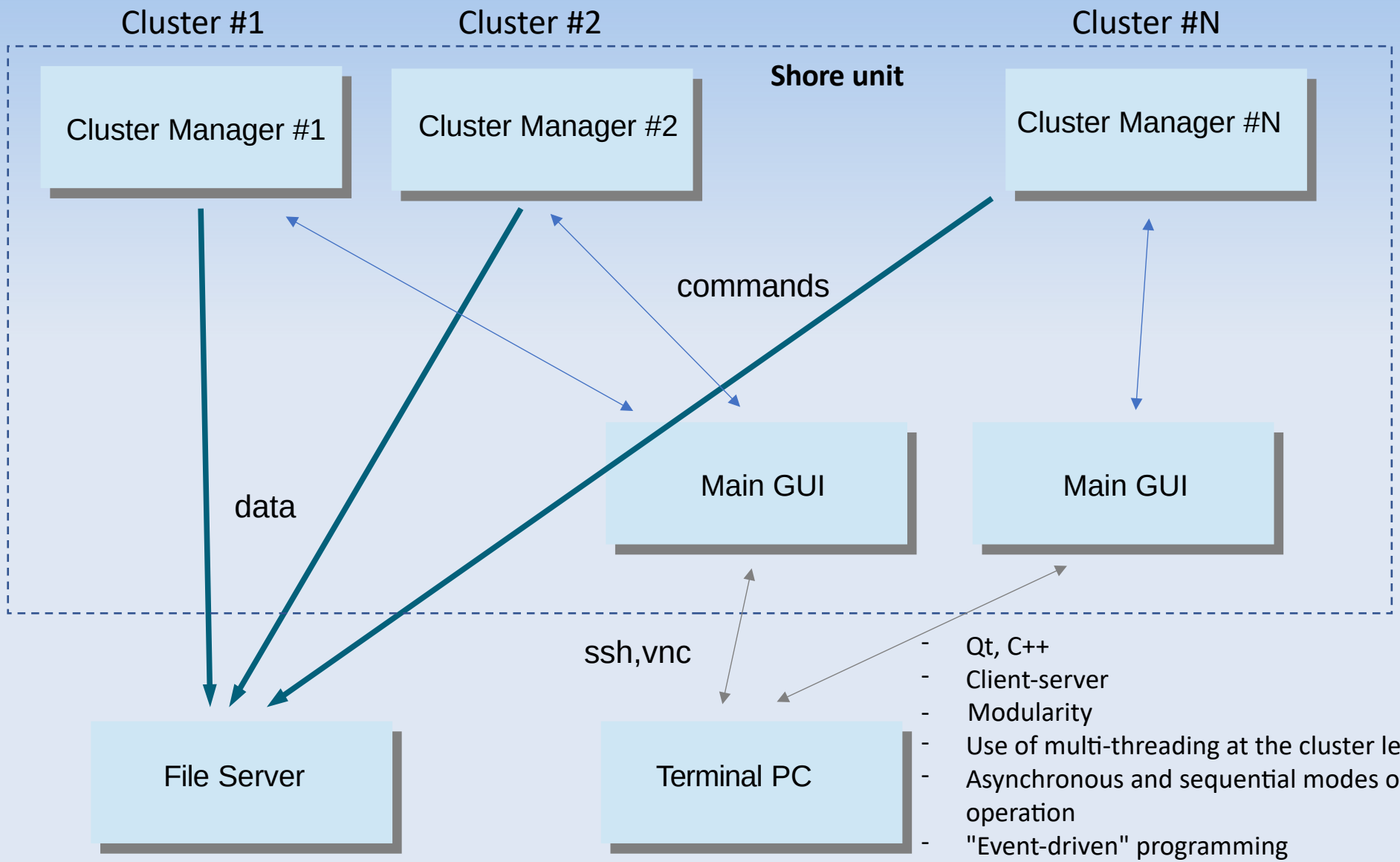




Raw data from each master (CM) :
header (time, master #, counters)
+ wave form

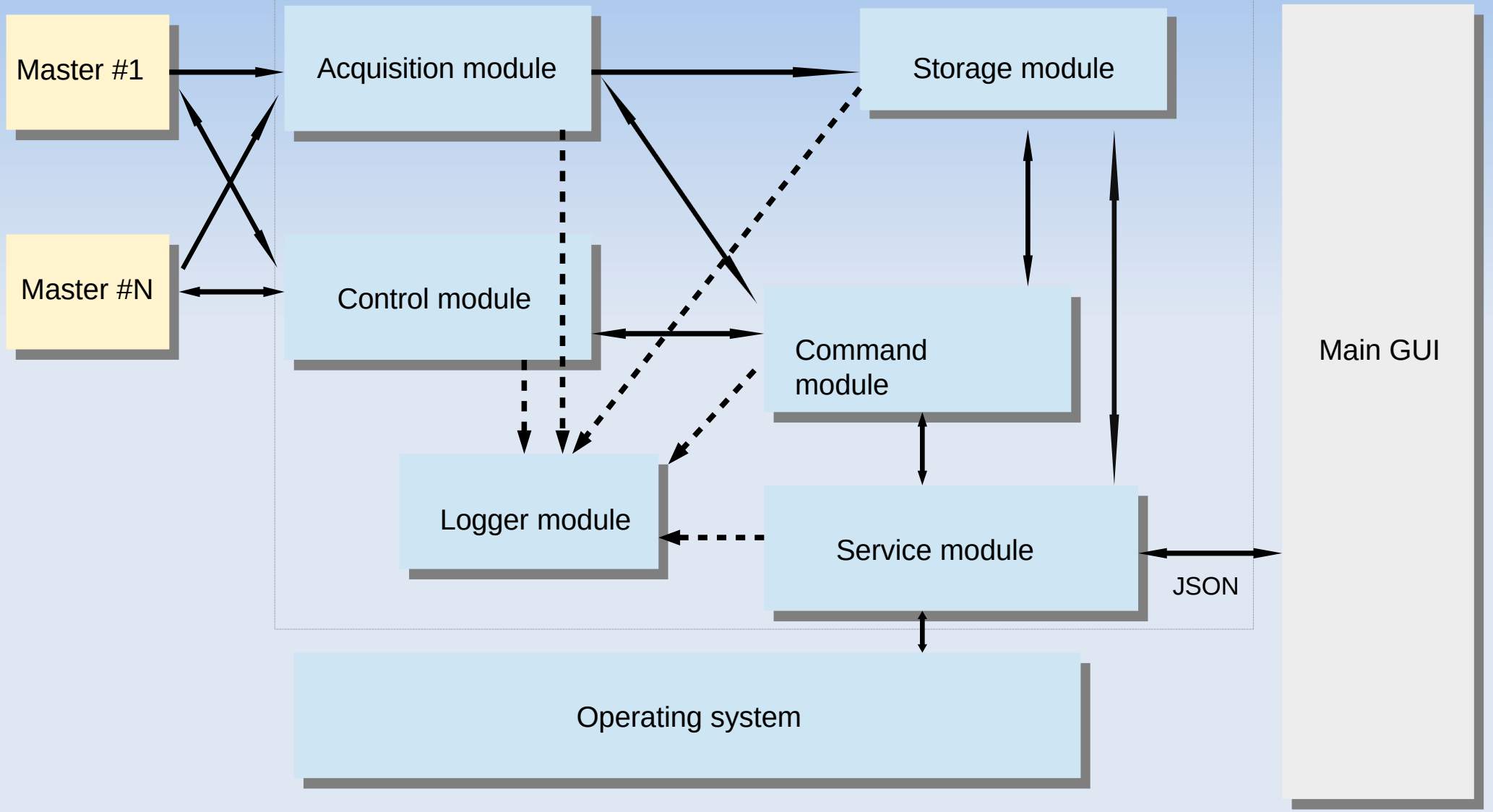
data from all masters can be combined into a single physical event

Main Program : Architecture



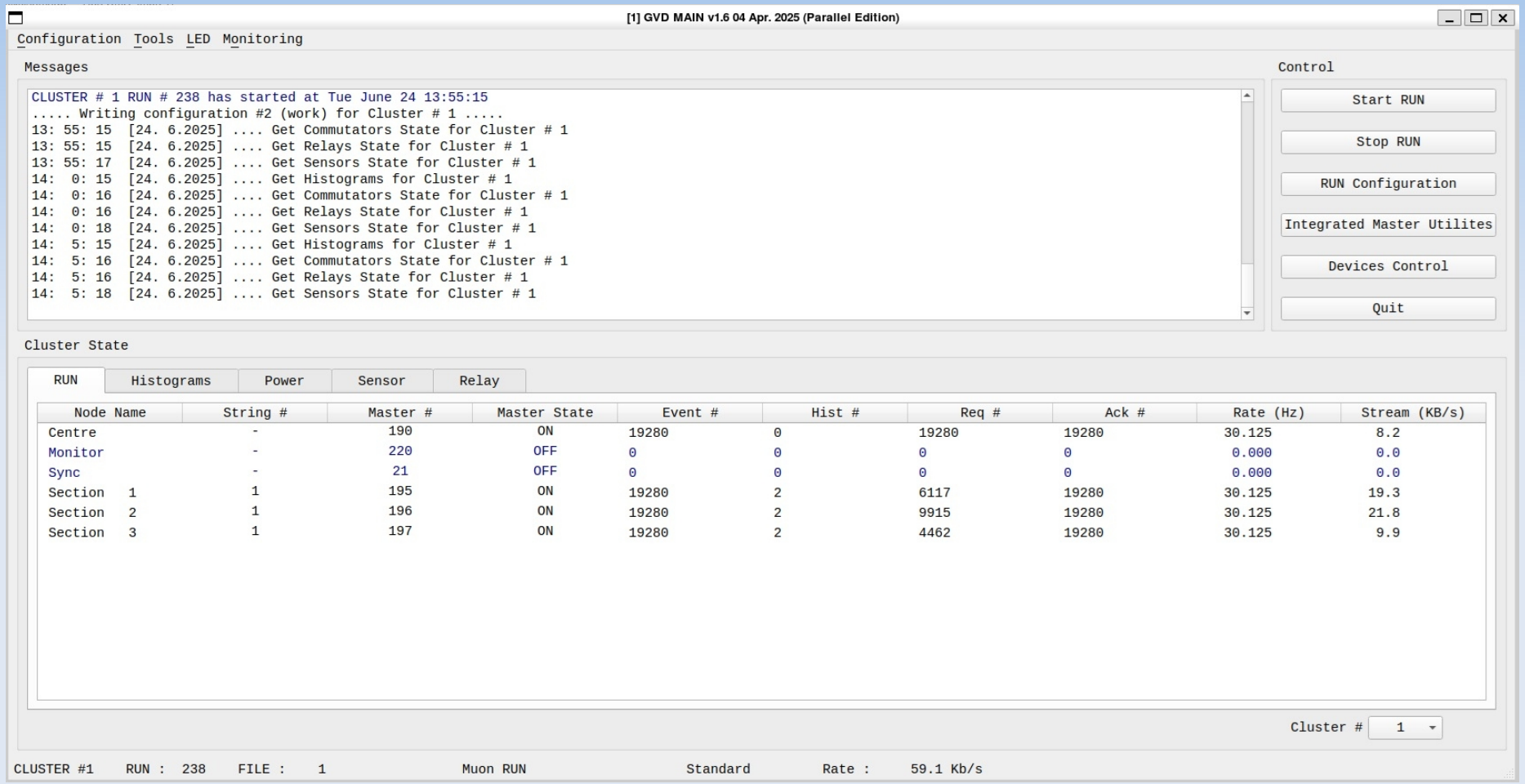
- Qt, C++
- Client-server
- Modularity
- Use of multi-threading at the cluster level
- Asynchronous and sequential modes of operation
- "Event-driven" programming
- Standard mechanisms : network, timers, containers

Main Program : ClusterManager



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

Main Program : GUI



- 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:

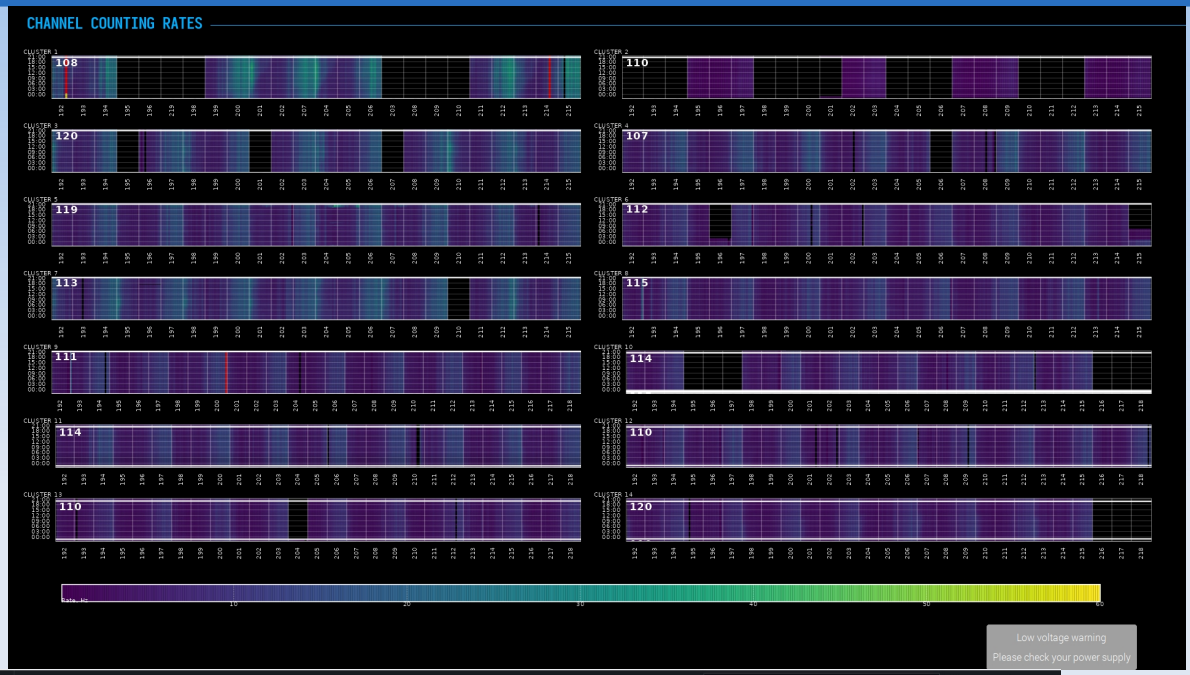
- OM-level sensors: humidity, pressure, HV etc.
- Power commutators.
- Acoustics.
- System module level sensors.

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).

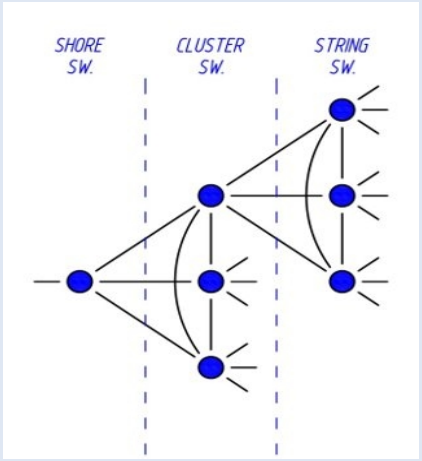
  We look at this data if something goes wrong. The applicable hardware includes:
  - Switches in the Cluster Center.
  - DSL modems in the Cluster Center, String Modules and Section Modules.

NPorts in String Modules and Section Modules.

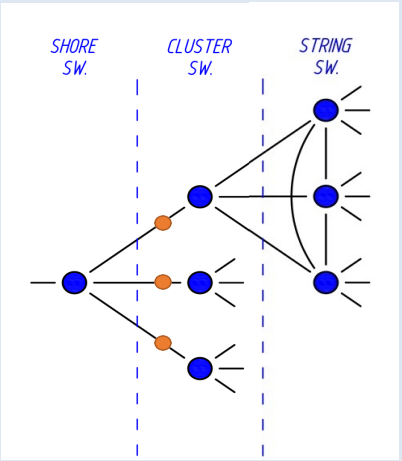
Shore Network Organization (since 2023)

- 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



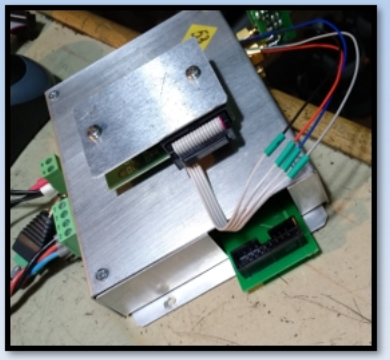
P2P Network
each connect with each



Multi-level Network
separated on shore switch

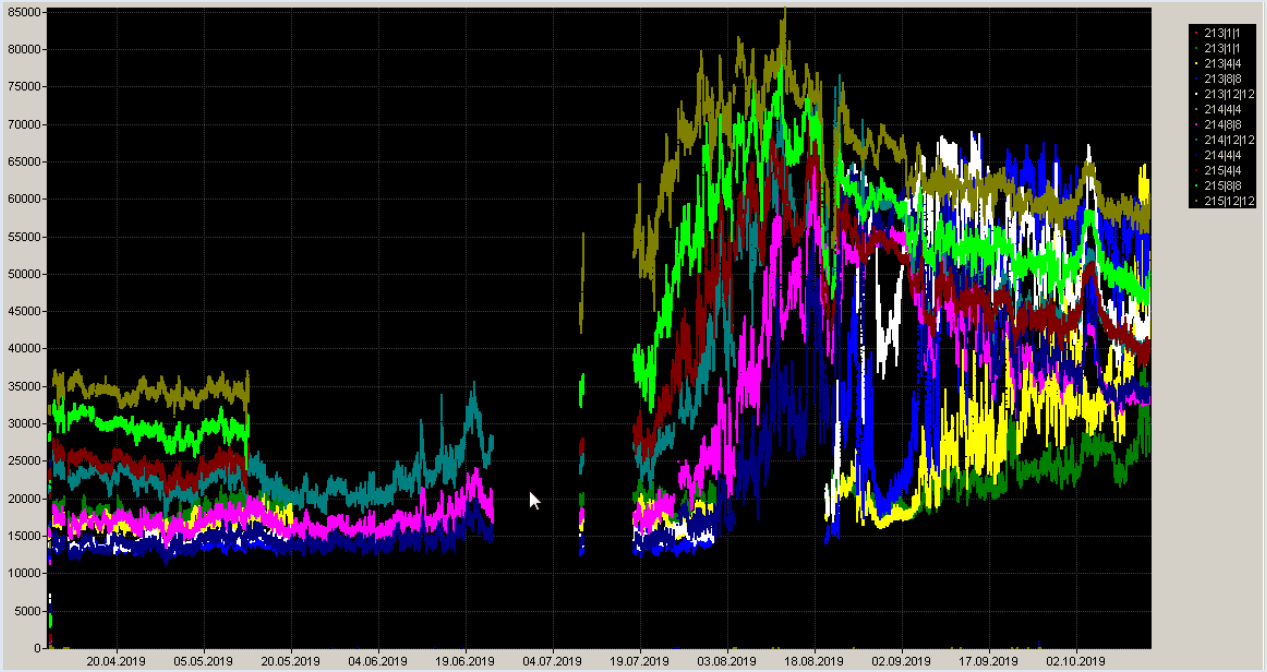
Data Monitoring : OM parameters

OM Controller with sensors block

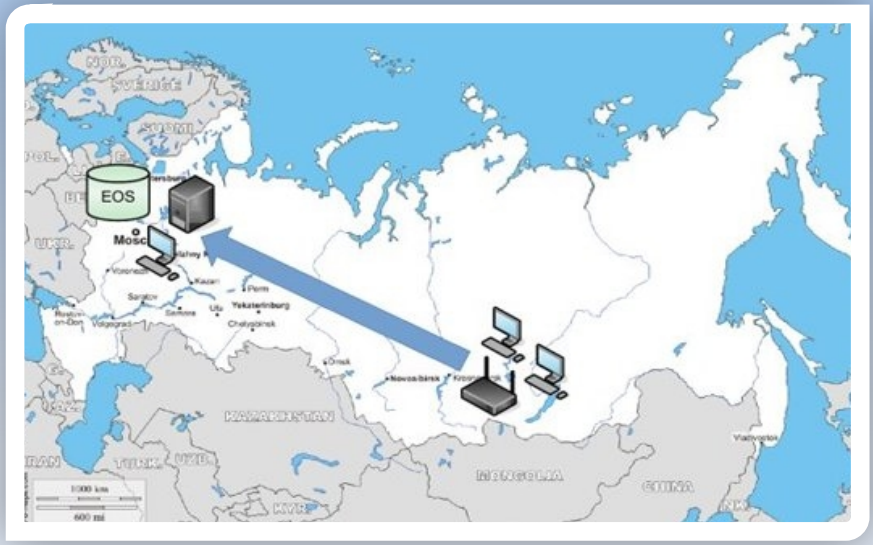


OM parameters monitoring

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

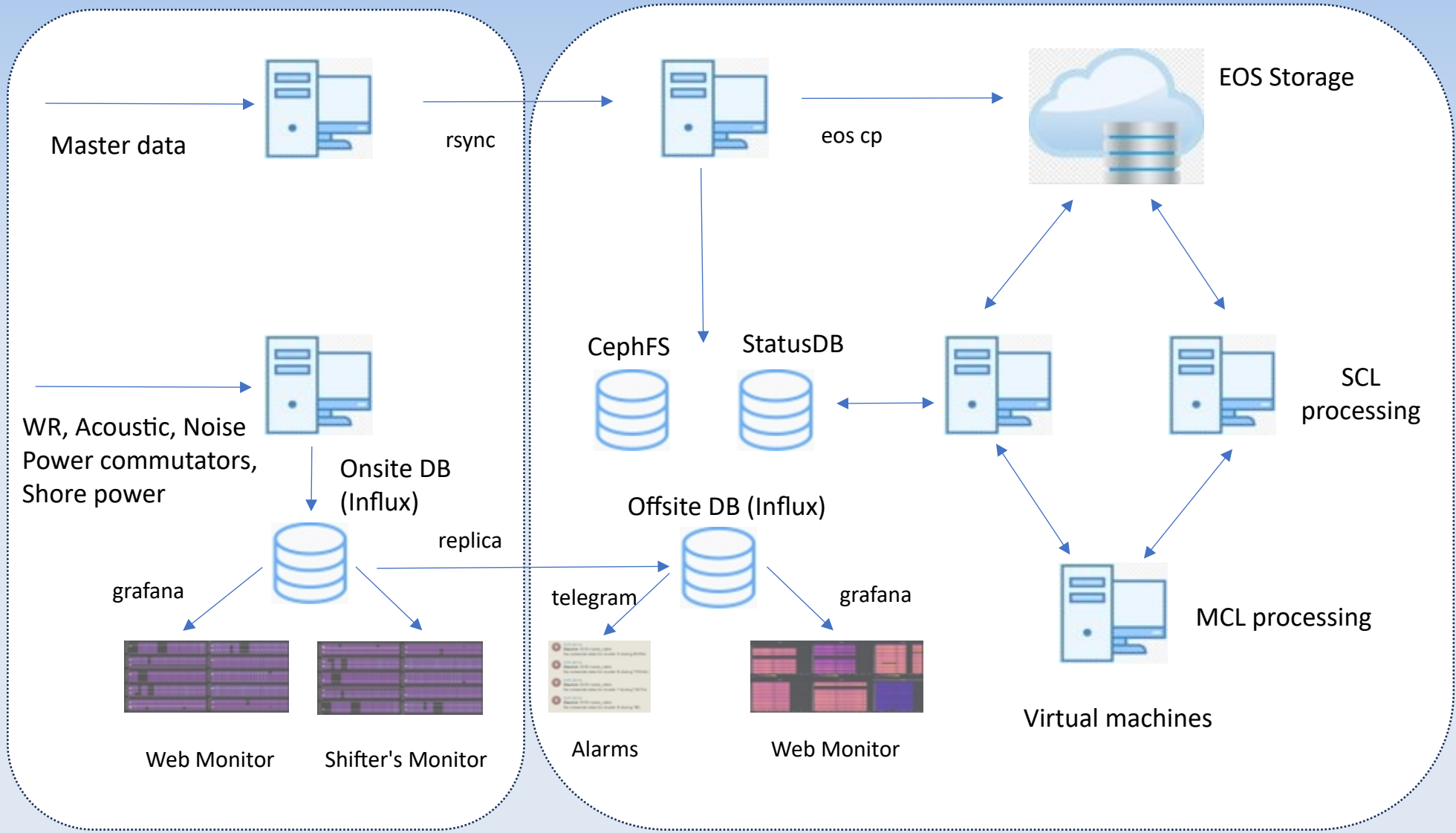
Baikalsk → JINR: standart Internet communication

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 km^3 Baikal-GVD detector with ~6000 OM's is planned in 2027/2028**


Thank you for attention !!

Backup slides

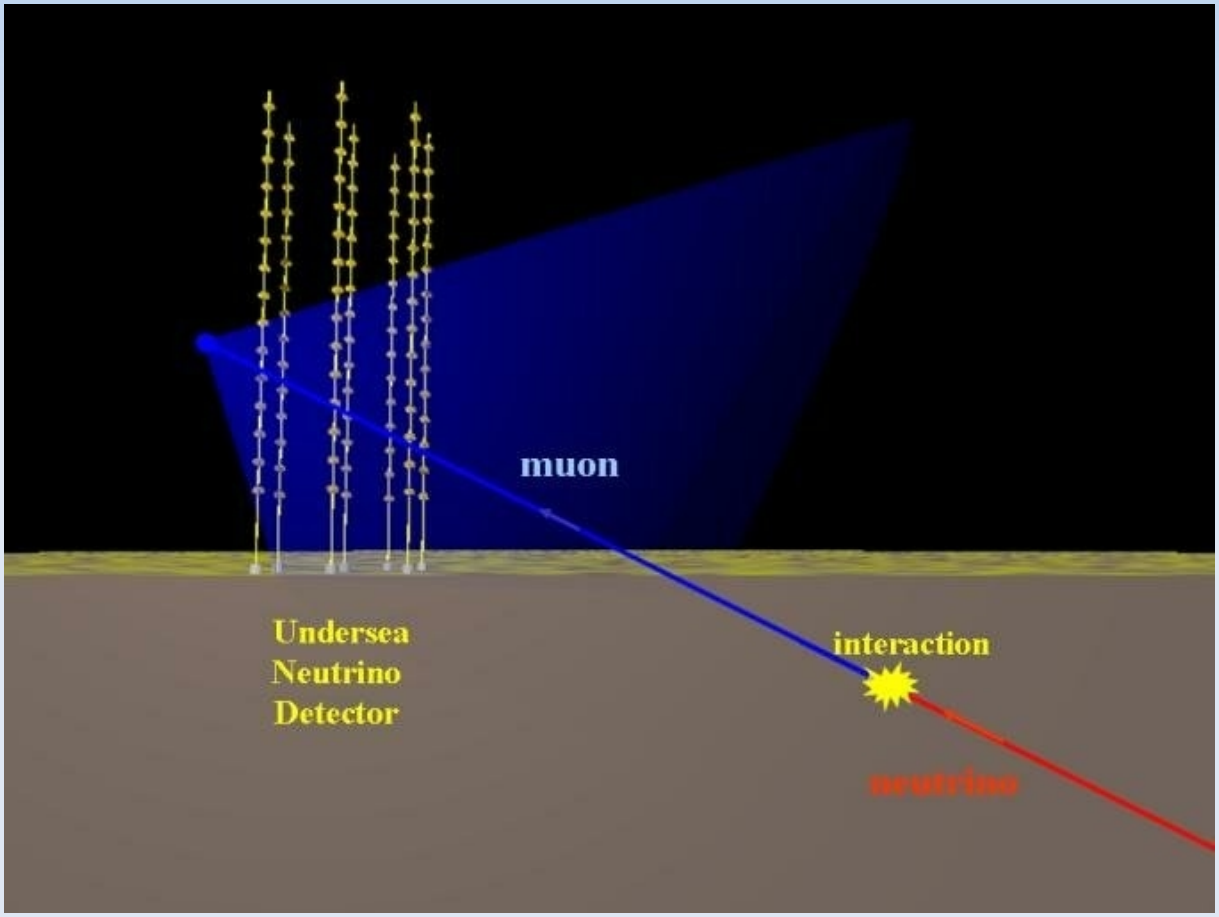
Neutrino detection

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

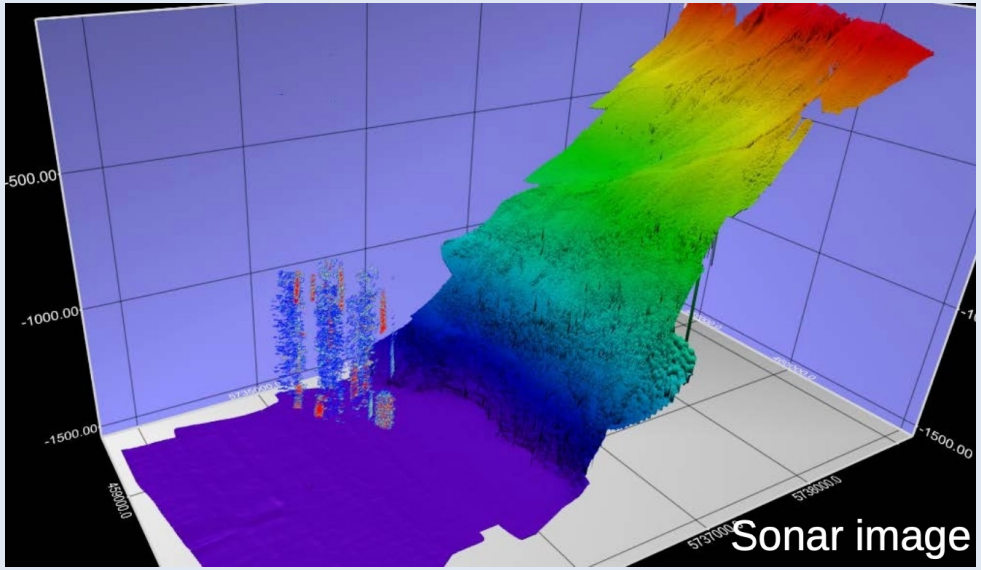
$$\nu_\mu + p \rightarrow n + \mu^+$$

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



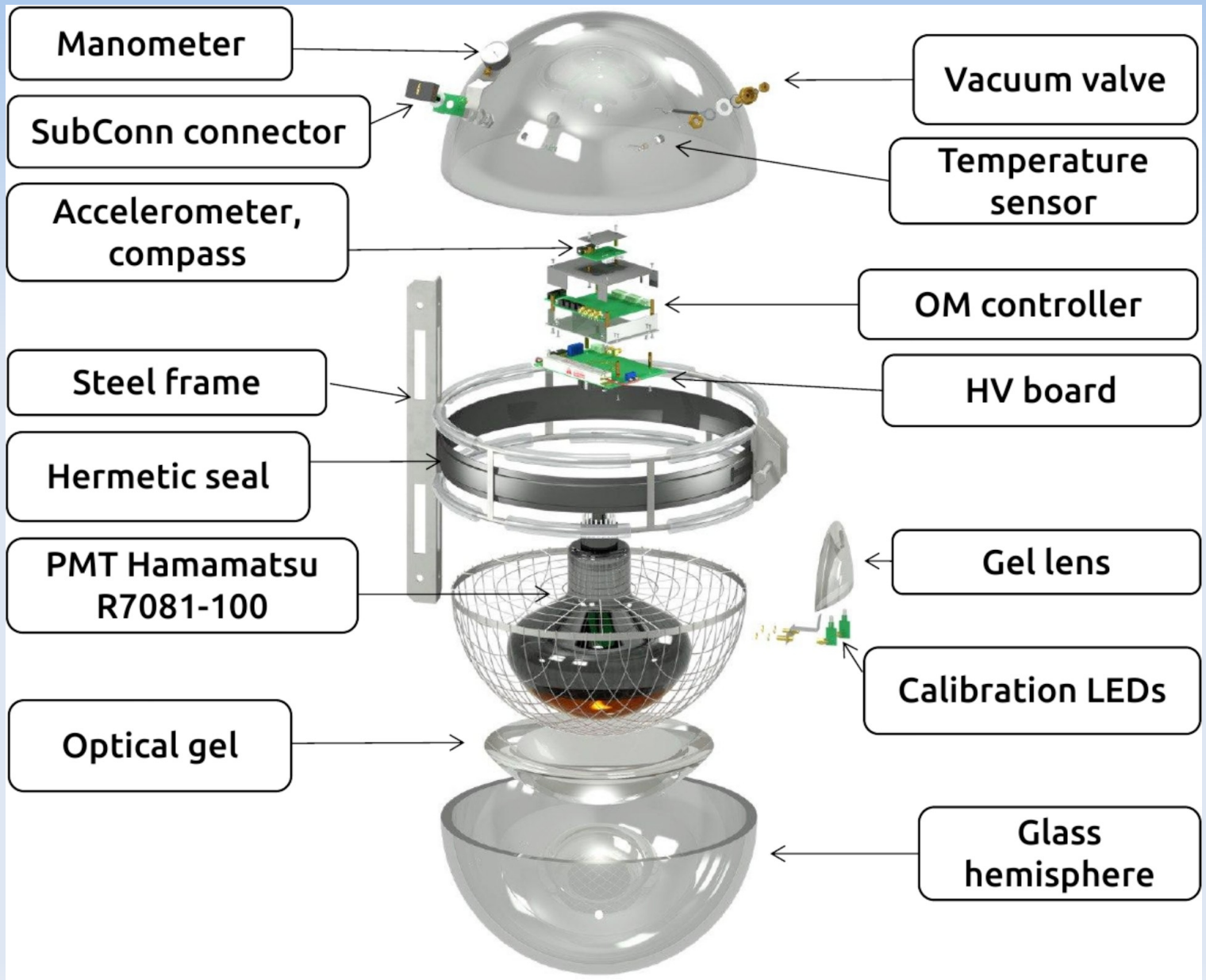
Baikal-GVD Site



- 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

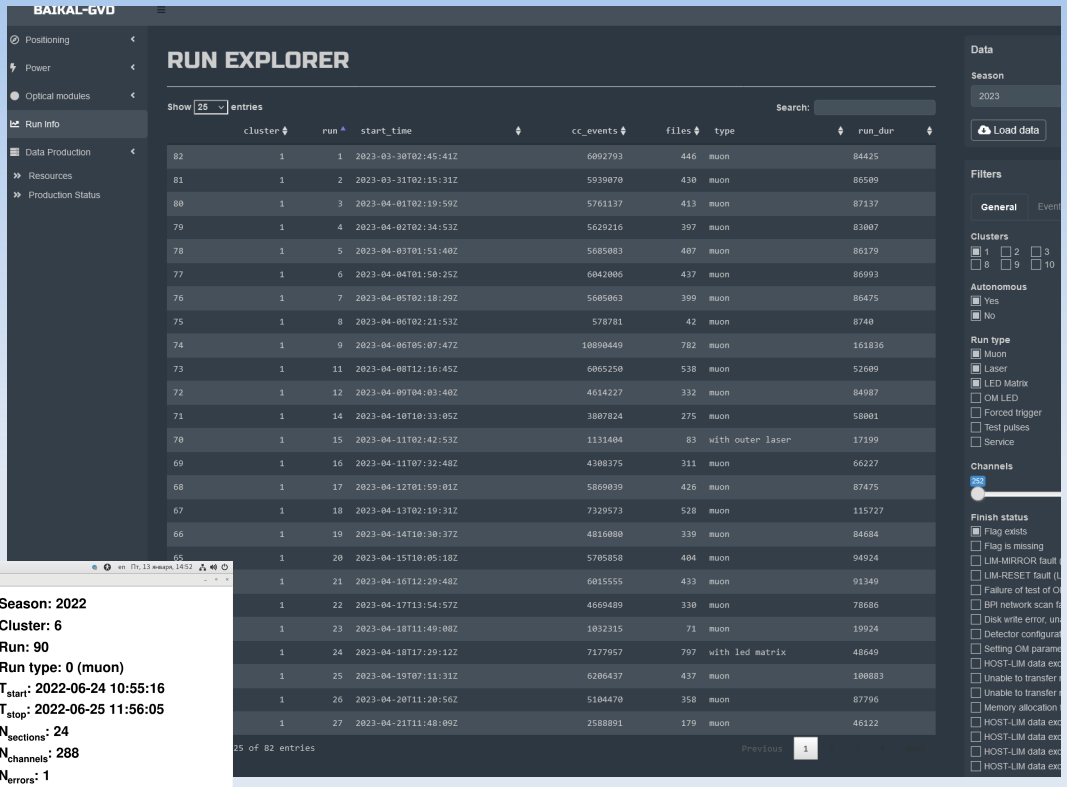
- 17 inches sphere (42 cm)
- 10 inch Hamamatsu PMT R7081-100

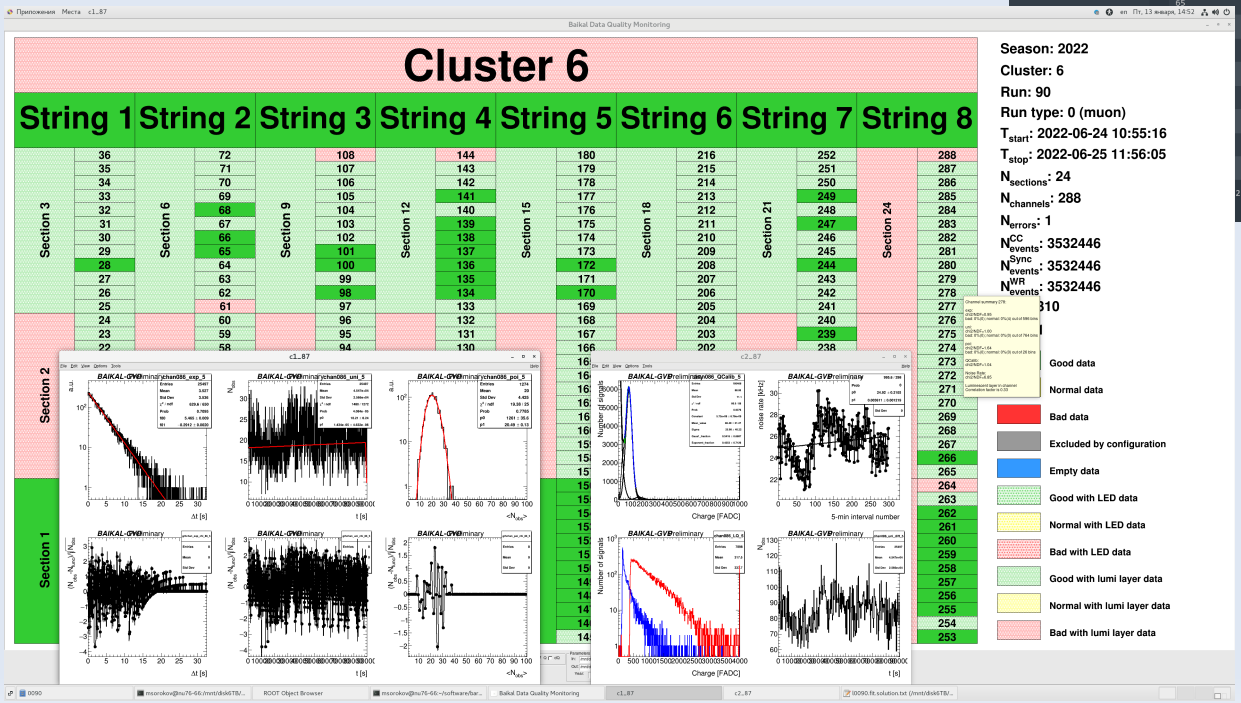


Data Monitoring : JINR

JINR: A posteriori data quality monitoring (DQM) within BARS framework, databases

- **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