BM@N DAQ Data Center

BM@N Experiment at the NICA Facility
14th Collaboration Meeting
JINR, Dubna, May 13 – 15, 2025

ILIA SLEPNEV, JINR

DAQ Data Center

Outline

DAQ Data Center

- Mission & Design Principles
  - Purpose of the DAQ Data Center
  - Guiding Architecture Principles
- Data Flow & Network Fabric
  - End-to-End Data Path
- BM@N DAQ Network Topology
  - DAQ Network Performance & Reliability
  - High Availability & Storage Resilience
  - Readout Link Redundancy Constraints
- Compute, Storage & Virtualization
  - Distributed Storage Cluster (CephFS Layer)
  - Virtual & Bare-Metal Compute Tiers

LHEP Computing Resources

- LHEP data centers in operation

Monitoring

- Incident Resolution
- Node-RED Automation
- Grafana: DDC dashboard

Extra

- Infrastructure Management
- Monitoring Architecture
- Log Message Processing and Analysis

DAQ Data Center

Mission & Design Principles

Purpose of the DAQ Data Center

- Central hub for experiment data reception and archiving
- Decouples micro-second readout from second-scale processing
- Guarantees continuous acquisition during long physics runs
- Operates autonomously, no external IT dependencies
- Hosts online monitoring for quality-of-data checks
- Designed to evolve without disruptive rewiring or downtime

Guiding Architecture Principles

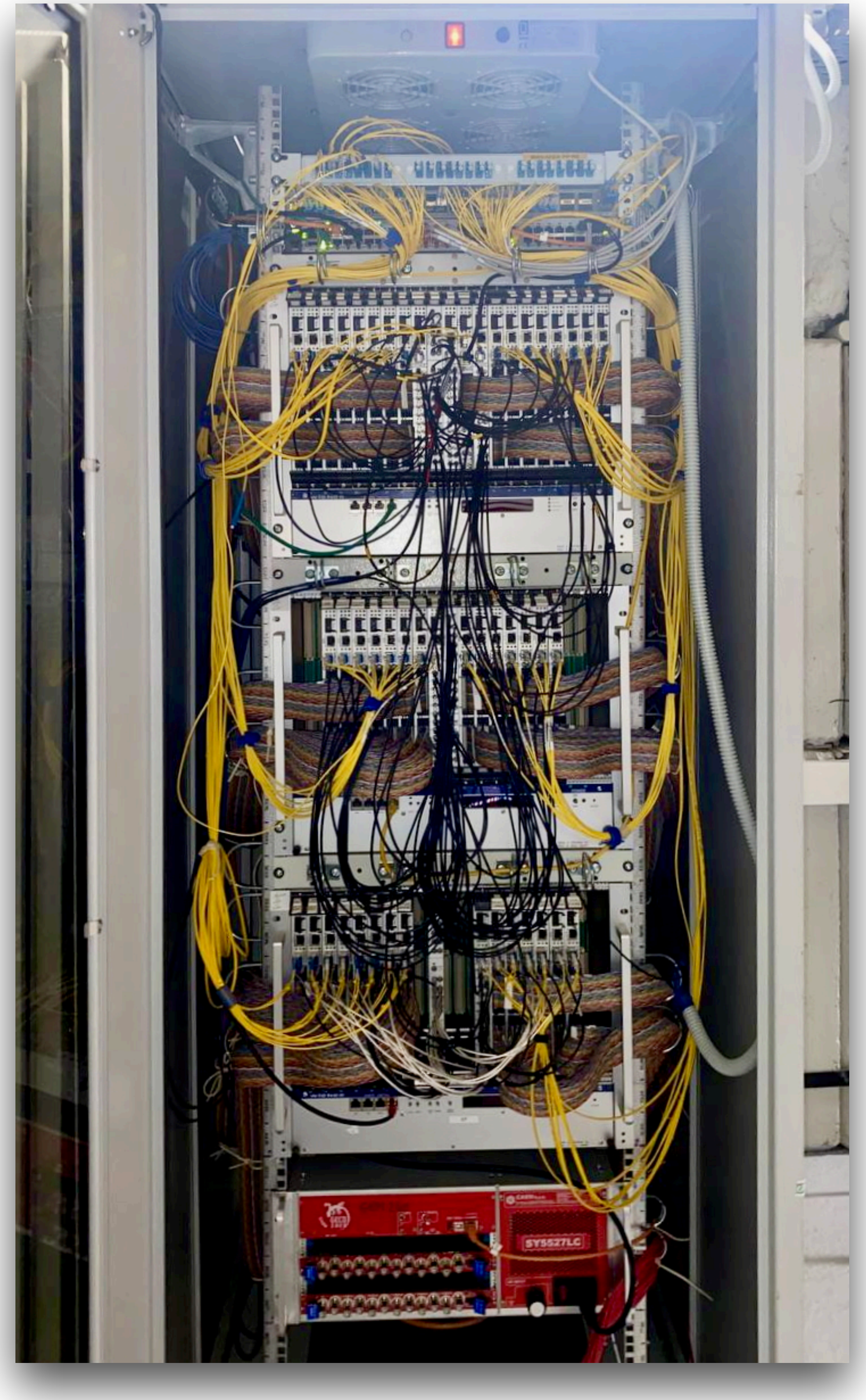
- All critical paths redundant, no single point of failure
- Software-defined everything: storage, network, virtualization
- Hardware chosen for low-latency performance
- Horizontal scalability—add nodes, no redesign required
- Observability first: fine-grained metrics, logs, alerts
- Security via dedicated VLANs, JINR SSO and firewall zoning
- Documentation-driven operations; infra declared in Git
- Emphasizes open-source, vendor-neutral technologies

DAQ Data Center

Data Flow & Network Fabric

End-to-End Data Path

- Detector front-ends push UDP streams via custom MStream protocol
- Hardware IP core in FPGA provides dat transfer and control
- First-Level Processor buffers, validates, formats packets
- Event builders assemble multi-detector fragments asynchronously
- Asynchronous layers prevent back-pressure on readout electronics
- FLP quality checks tag corrupted or partial events
- Event files streamed to high-availability Ceph storage
- Complete files are synchronized to Offline farm immediately



TOF Readout Board

- VXS 6U 160 cm form factor
- Front-Panel: detector I/O
- Backplane: sync, readout 1Gb/s

21-slot, VXS Chassis

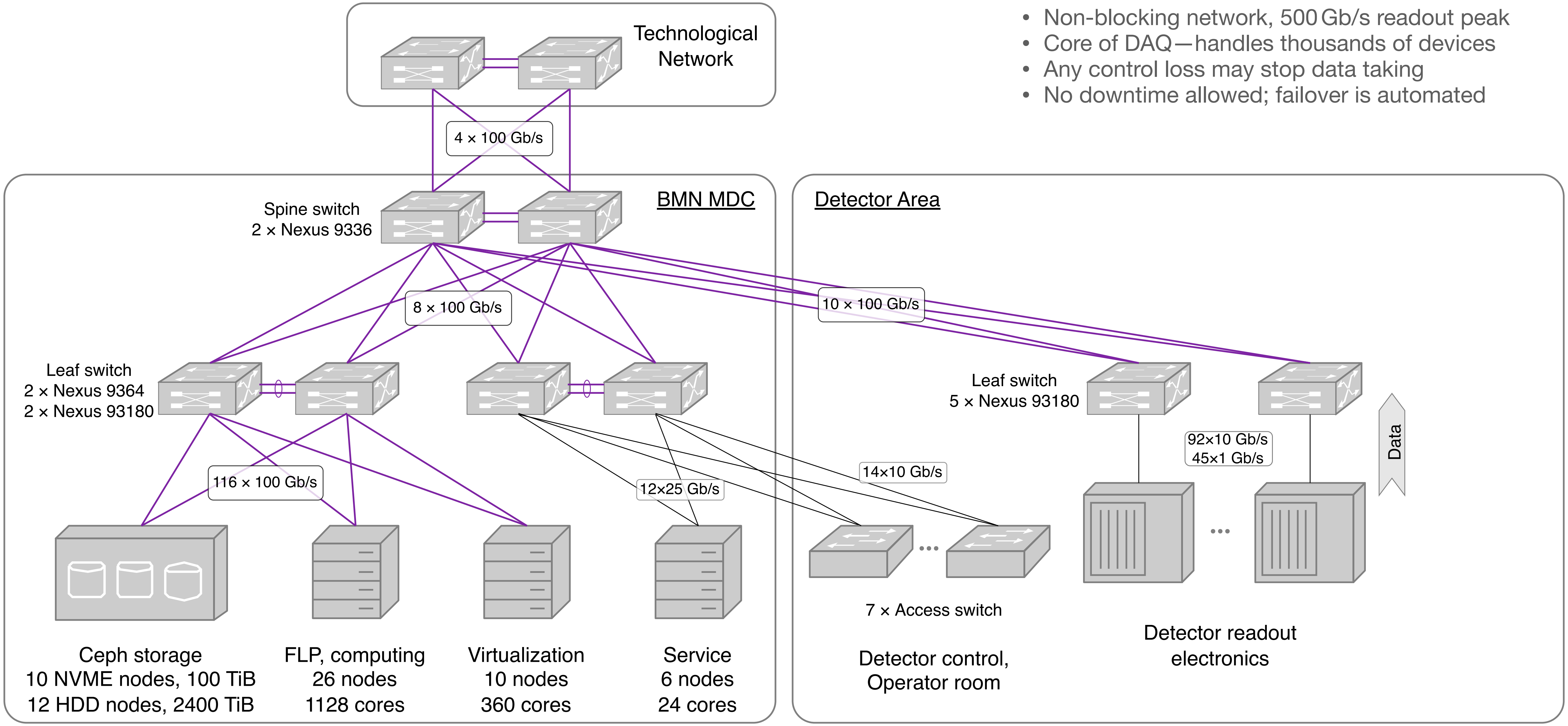
- Power, Cooling, Remote control
- Backplane: Dual-Star, 10 Gb/s per slot

Readout Electronics Rack: GEM

- 3 × VME64x chassis with ADC64 boards
- Fiber-optical front panel readout links
- Ribbon cable detector I/O
- Top-of-Rack Cisco Nexus 93180 switch

DAQ Data Center

BM@N DAQ Network Topology



DAQ Network Performance & Reliability

- Non-blocking network, 500 Gb/s readout peak
- Core of DAQ—handles thousands of devices
- Any control loss may stop data taking
- No downtime allowed; failover is automated

High Availability & Storage Resilience

- Ceph ensures 24/7 access with auto-recovery on failure
- HDD pools use erasure coding, NVMe SSD pools triple-replication
- Storage remains online with no data loss or downtime
- External users can access data at all times

Readout Link Redundancy Constraints

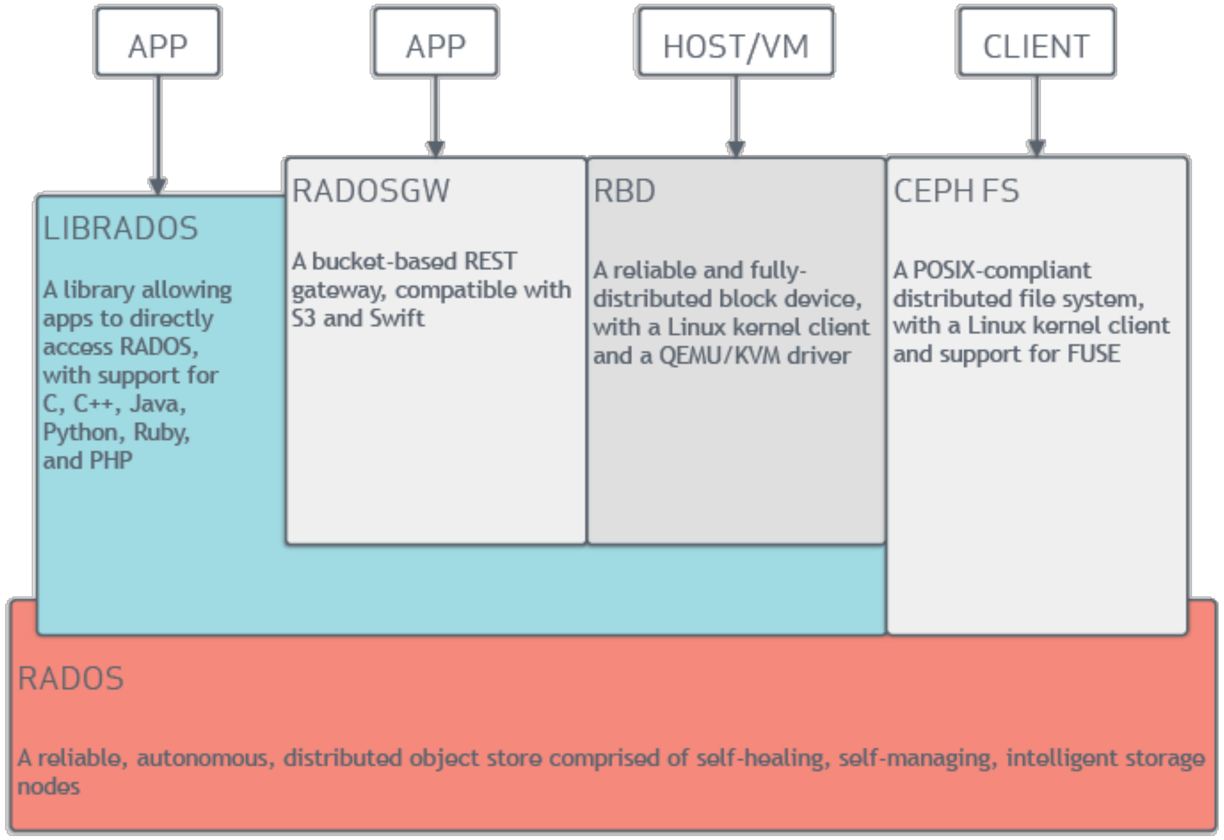
- No redundancy in readout links due to custom hardware
- Failover is complex, costly, and resource-limited
- Manpower and design constraints limit improvements
- Focus is on robustness and failure monitoring

DAQ Data Center

Compute, Storage & Virtualization

Distributed Storage Cluster (CephFS Layer)

- NVMe replicated pools for low-latency RBD workloads
- HDD pools with erasure coding for cost-effective capacity
- CRUSH algorithm enforces fault-domain-aware placement
- Self-healing scrubs verify checksums without operator action
- POSIX CephFS exports RAW data to FLP and event builders
- Grafana dashboards track PG-health, latency, rebuild rate
- Capacity expansion performed online by adding OSD nodes
- Data-at-rest encrypted; keys managed by vault-backed KMS
- Network-isolated background replication to off-site cluster
- Retention policy aligns with collaboration data mandate



APP

APP

HOST/VM

CLIENT

LIBRADOS

A library allowing apps to directly access RADOS, with support for C, C++, Java, Python, Ruby, and PHP

RADOSGW

A bucket-based REST gateway, compatible with S3 and Swift

RBD

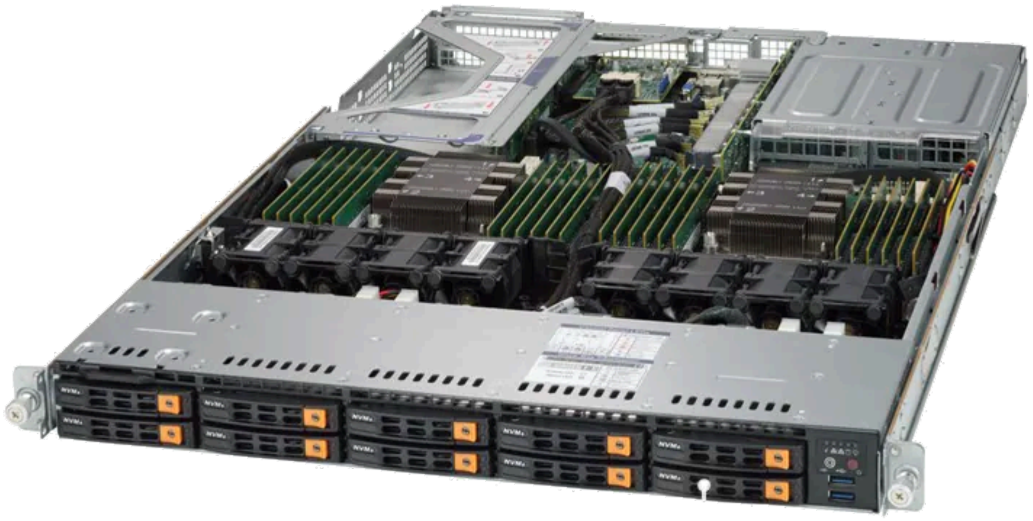
A reliable and fully-distributed block device, with a Linux kernel client and a QEMU/KVM driver

CEPH FS

A POSIX-compliant distributed file system, with a Linux kernel client and support for FUSE

RADOS

A reliable, autonomous, distributed object store comprised of self-healing, self-managing, intelligent storage nodes



Ceph OSD node: 10 × 3.8 TB NVMe SSD

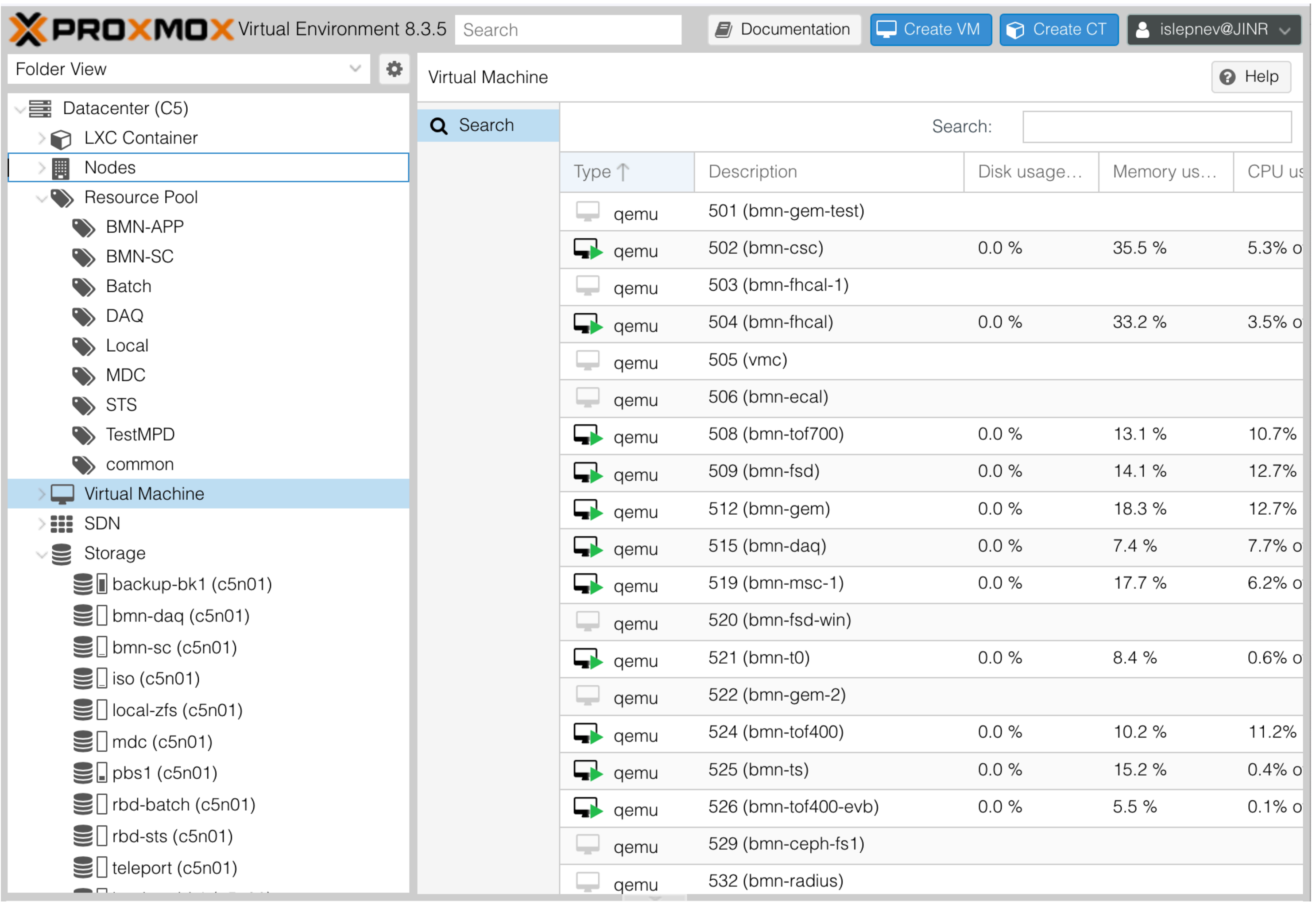
Ceph OSD node: 24 × 18 TB HDD

DAQ Data Center

Compute, Storage & Virtualization

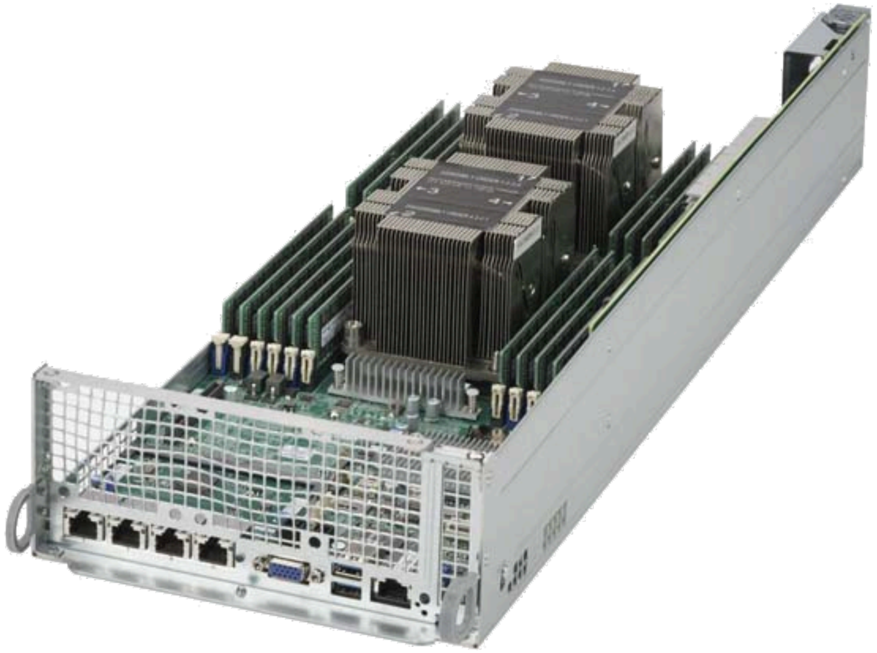
Virtual & Bare-Metal Compute Tiers

- KVM / LXC cluster hosts control, monitoring, DB, web portals
- Bare-metal nodes reserved for FLP and heavy event builders
- Live-migration keeps services online during maintenance
- Snapshot roll-back guards against faulty software updates
- Resources re-balanced when DAQ idle to boost offline jobs
- Continuous incremental backups: hourly, daily, weekly, yearly
- SSO-protected self-service portal for VM lifecycle requests
- Performance tuned: CPU-governor, NUMA pinning, NIC interrupts



Type ↑	Description	Disk usage…	Memory us…	CPU us
qemu	501 (bmn-gem-test)			
qemu	502 (bmn-csc)	0.0 %	35.5 %	5.3% o
qemu	503 (bmn-fhcal-1)			
qemu	504 (bmn-fhcal)	0.0 %	33.2 %	3.5% o
qemu	505 (vmc)			
qemu	506 (bmn-ecal)			
qemu	508 (bmn-tof700)	0.0 %	13.1 %	10.7%
qemu	509 (bmn-fsd)	0.0 %	14.1 %	12.7%
qemu	512 (bmn-gem)	0.0 %	18.3 %	12.7%
qemu	515 (bmn-daq)	0.0 %	7.4 %	7.7% o
qemu	519 (bmn-msc-1)	0.0 %	17.7 %	6.2% o
qemu	520 (bmn-fsd-win)			
qemu	521 (bmn-t0)	0.0 %	8.4 %	0.6% o
qemu	522 (bmn-gem-2)			
qemu	524 (bmn-tof400)	0.0 %	10.2 %	11.2%
qemu	525 (bmn-ts)	0.0 %	15.2 %	0.4% o
qemu	526 (bmn-tof400-evb)	0.0 %	5.5 %	0.1% o
qemu	529 (bmn-ceph-fs1)			
qemu	532 (bmn-radius)			

Dual-node compute server



Compute node

RAM: 384 GB

CPU: Dual Xeon Gold 6154, 6342

LHEP Computing Resources

Data Centers in Operation

DDC — DAQ Data Center

- Data taking, online processing and monitoring
- Primary RAW data storage
- CephFS for immediate data access
- Secondary role: batch jobs outside DAQ periods

NCX — Offline Cluster

- Batch and interactive jobs at large scale
- Experimental and simulation data storage: EOS
- Shared by multiple experiments, 200+ users

	DDC (BMN)	DDC (MPD)	NCX
Location	Building 215, BMN area	MPD Hall	Building 216, room 115
Operating since / Last upgrade	2019 / 2023	2021 / 2024	2019 / 2023
CPU architecture	3.0 GHz Skylake 2.8 GHz Ice Lake	3.1 GHz Cascade Lake 2.8 GHz Ice Lake	2.6 GHz Broadwell-EP 2.0 GHz Skylake 2.5 GHz Cascade Lake
CPU cores — Total	1488	1760	4200
CPU cores — Batch	700 [1]	1000 [1]	3000 [2]
RAM, GB per CPU core	6–7.5	7.5	9.6–16
Node uplink, Gb/s	2×100	2×100	100
Local node storage (/tmp)	32 GB SSD	32 GB SSD	1 TB HDD
Shared storage (workspace, experimental and simulation data)	100 TB NVMe (CephFS) 2.5 PB HDD (CephFS)		124 TB NVMe (NFS+ZFS) 11 PB HDD (EOS)

[1] Additional CPU cores available when DAQ is inactive

[2] May be temporarily unavailable due to maintenance

CephFS

- Distributed POSIX-compliant file system on Ceph
- Supports high-throughput, parallel data access
- Used for RAW data from DAQ in DDC clusters
- Mounted natively on compute and DAQ nodes

EOS

- CERN-developed distributed file system
- Optimized for large-scale data access via XRootD
- Used in NCX cluster for simulation and analysis
- Suited for shared access by many experiments

Computing Resources

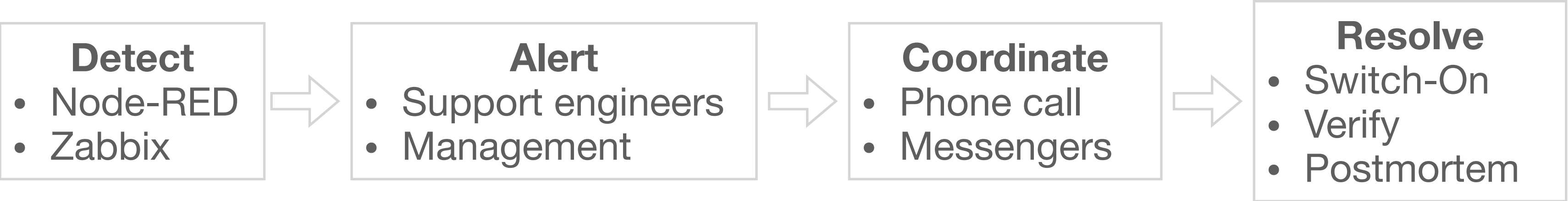
Data Centers in Operation

BM@N DAQ Data Center

NCX Offline Cluster

Monitoring

Incident Resolution

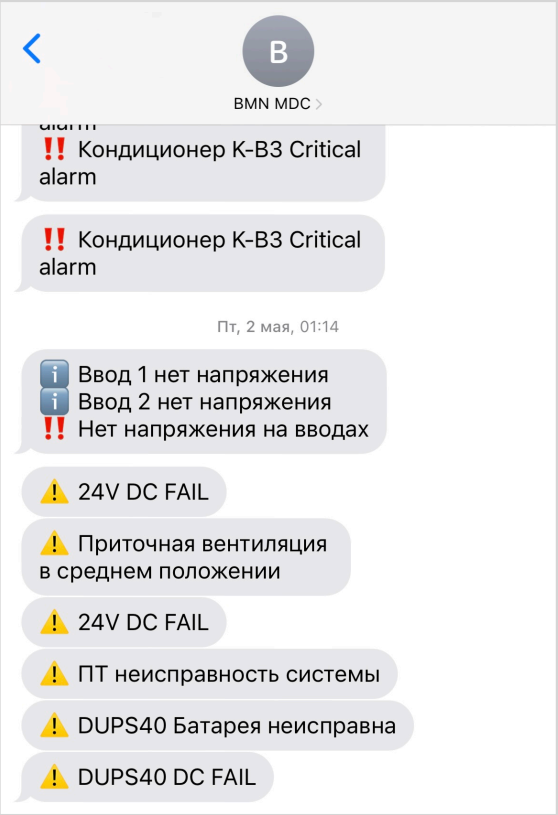


Detect
- Node-RED
- Zabbix

Alert
- Support engineers
- Management

Coordinate
- Phone call
- Messengers

Resolve
- Switch-On
- Verify
- Postmortem



‼️ Кондиционер К-В3 Critical alarm

‼️ Кондиционер К-В3 Critical alarm

Пт, 2 мая, 01:14

ℹ️ Ввод 1 нет напряжения
ℹ️ Ввод 2 нет напряжения
‼️ Нет напряжения на вводах

⚠️ 24V DC FAIL

⚠️ Приточная вентиляция в среднем положении

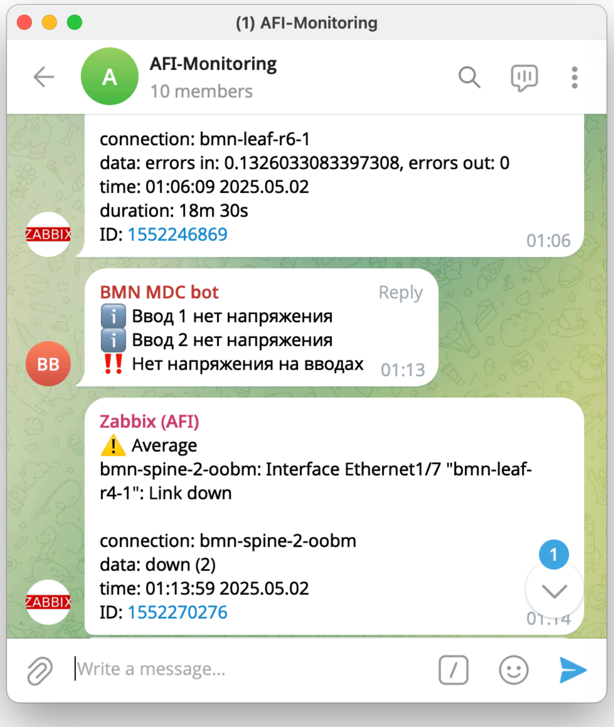
⚠️ 24V DC FAIL

⚠️ ПТ неисправность системы

⚠️ DUPS40 Батарея неисправна

⚠️ DUPS40 DC FAIL

SMS Alert



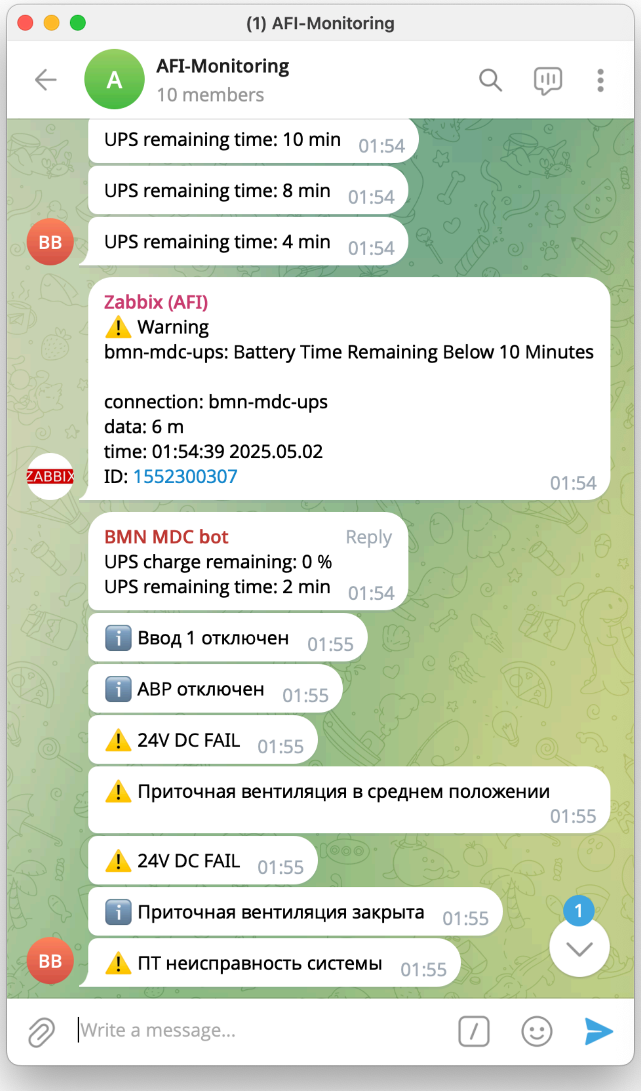
connection: bmn-leaf-r6-1
data: errors in: 0.1326033083397308, errors out: 0
time: 01:06:09 2025.05.02
duration: 18m 30s
ID: 1552246869
01:06

BMN MDC bot
ℹ️ Ввод 1 нет напряжения
ℹ️ Ввод 2 нет напряжения
‼️ Нет напряжения на вводах
01:13

Zabbix (AFI)
⚠️ Average
bmn-spine-2-oobm: Interface Ethernet1/7 "bmn-leaf-r4-1": Link down

connection: bmn-spine-2-oobm
data: down (2)
time: 01:13:59 2025.05.02
ID: 1552270276
01:14

Telegram Alert



UPS remaining time: 10 min 01:54

UPS remaining time: 8 min 01:54

UPS remaining time: 4 min 01:54

Zabbix (AFI)
⚠️ Warning
bmn-mdc-ups: Battery Time Remaining Below 10 Minutes

connection: bmn-mdc-ups
data: 6 m
time: 01:54:39 2025.05.02
ID: 1552300307
01:54

BMN MDC bot
UPS charge remaining: 0 %
UPS remaining time: 2 min
01:54

ℹ️ Ввод 1 отключен 01:55

ℹ️ АВР отключен 01:55

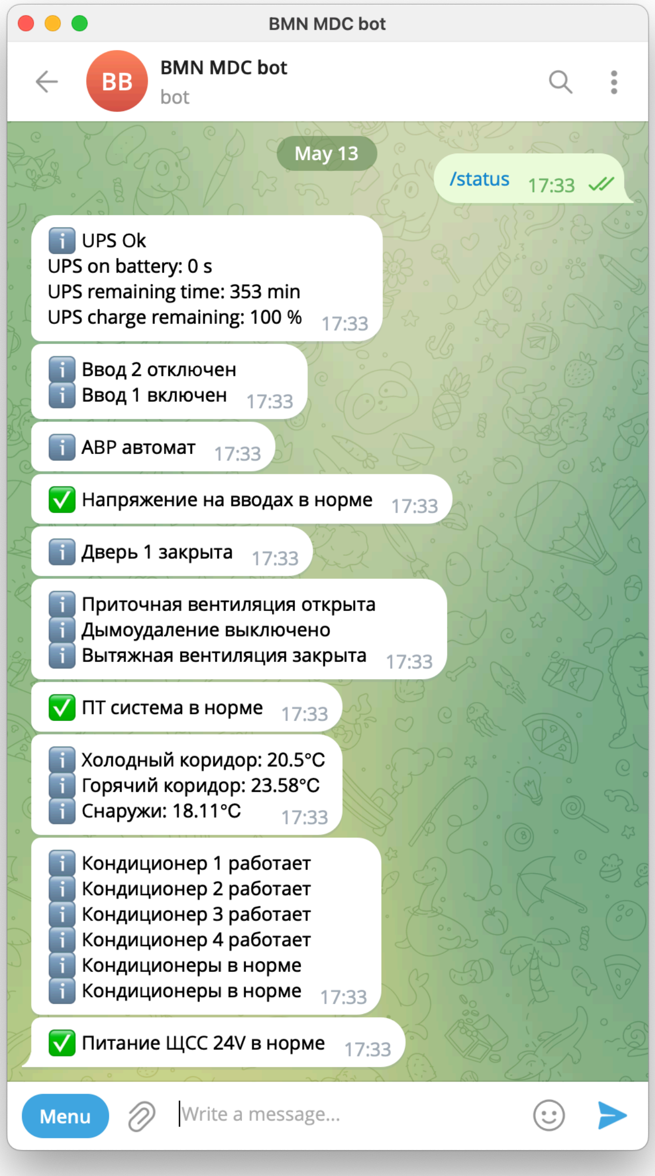
⚠️ 24V DC FAIL 01:55

⚠️ Приточная вентиляция в среднем положении 01:55

⚠️ 24V DC FAIL 01:55

ℹ️ Приточная вентиляция закрыта 01:55

⚠️ ПТ неисправность системы 01:55



/status 17:33

ℹ️ UPS Ok
UPS on battery: 0 s
UPS remaining time: 353 min
UPS charge remaining: 100 %
17:33

ℹ️ Ввод 2 отключен
ℹ️ Ввод 1 включен
17:33

ℹ️ АВР автомат 17:33

✅ Напряжение на вводах в норме 17:33

ℹ️ Дверь 1 закрыта 17:33

ℹ️ Приточная вентиляция открыта
ℹ️ Дымоудаление выключено
ℹ️ Вытяжная вентиляция закрыта
17:33

✅ ПТ система в норме 17:33

ℹ️ Холодный коридор: 20.5°C
ℹ️ Горячий коридор: 23.58°C
ℹ️ Снаружи: 18.11°C
17:33

ℹ️ Кондиционер 1 работает
ℹ️ Кондиционер 2 работает
ℹ️ Кондиционер 3 работает
ℹ️ Кондиционер 4 работает
ℹ️ Кондиционеры в норме
ℹ️ Кондиционеры в норме
17:33

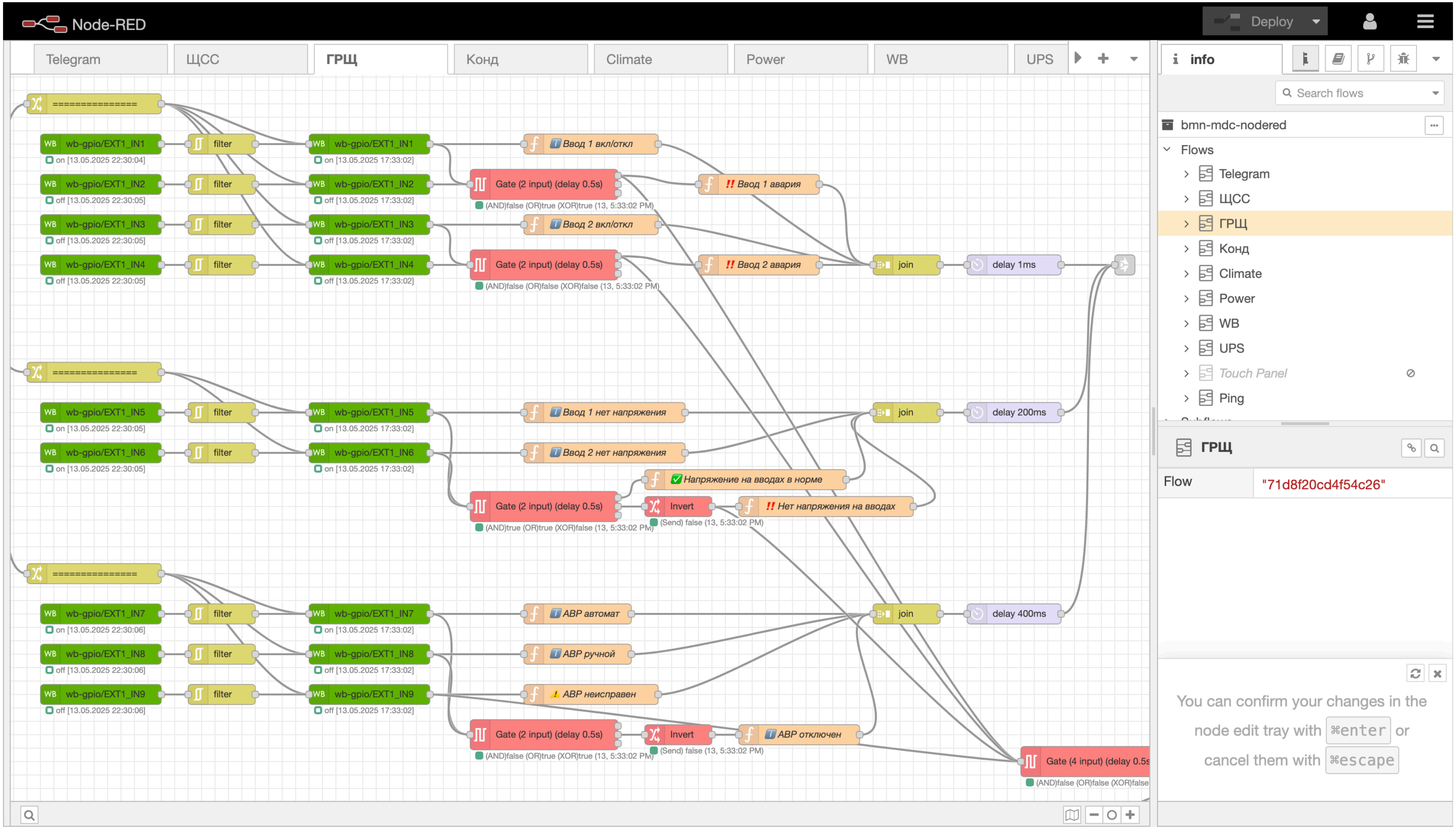
✅ Питание ЩСС 24V в норме 17:33

- Real-time alerts via SMS and Telegram bots
- Automated escalation from monitoring systems
- Critical events resolved via coordinated response
- Status recovery confirmed by bot interaction

Monitoring

Node-RED Automation

- Node-RED automates low-level alert processing
- Monitors power, HVAC, ventilation, security
- Custom logic triggers SMS and Telegram alerts instantly
- Each flow handles real-time decision-making
- Part of end-to-end automated monitoring system

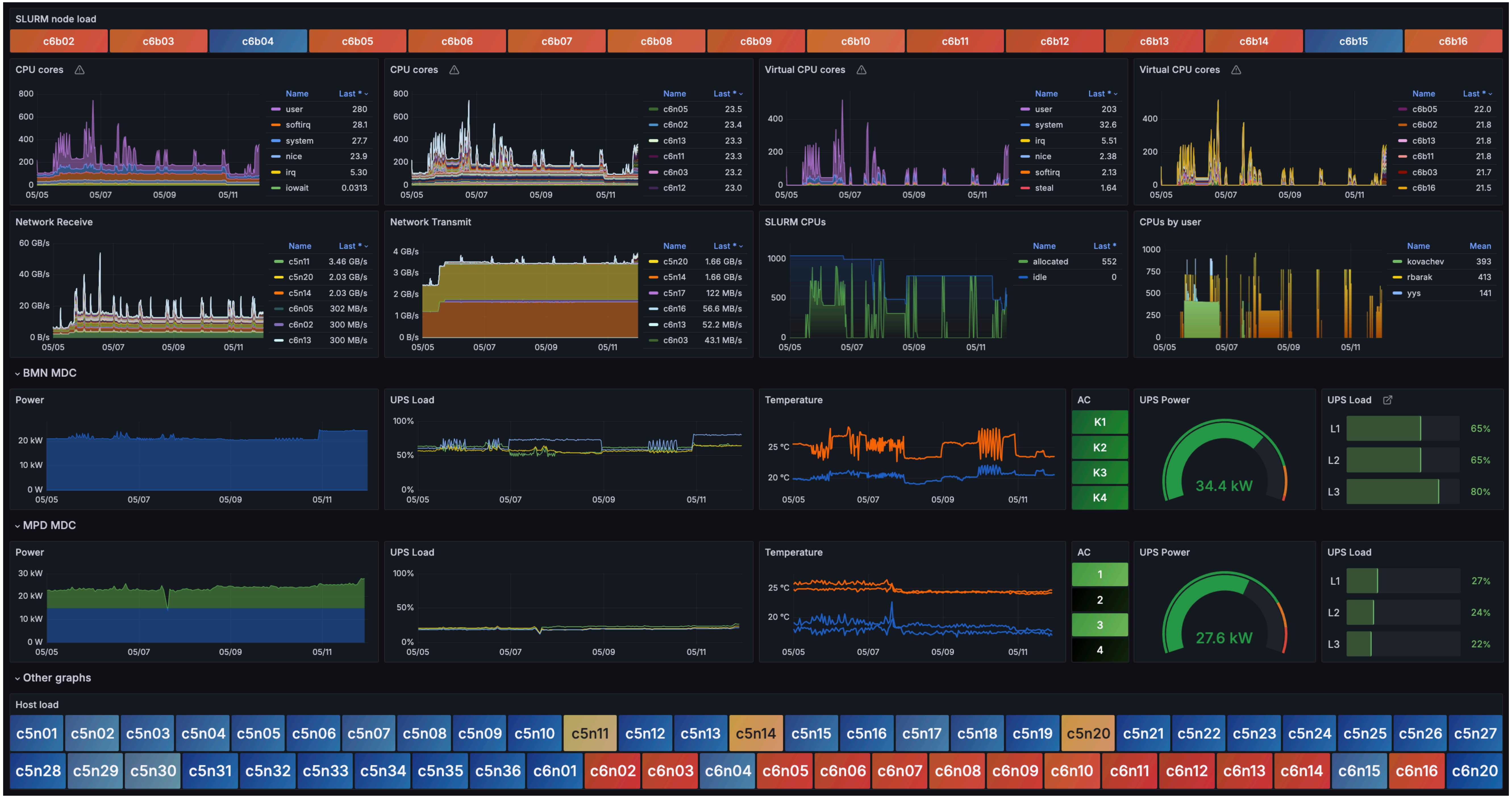


Flow "71d8f20cd4f54c26"

You can confirm your changes in the node edit tray with ⌘enter or cancel them with ⌘escape

Monitoring

Grafana: DDC dashboard



SLURM node load

CPU cores ⚠

Name	Last *
user	280
softirq	28.1
system	27.7
nice	23.9
irq	5.30
iowait	0.0313

CPU cores ⚠

Name	Last *
c6n05	23.5
c6n02	23.4
c6n13	23.3
c6n11	23.3
c6n03	23.2
c6n12	23.0

Virtual CPU cores ⚠

Name	Last *
user	203
system	32.6
irq	5.51
nice	2.38
softirq	2.13
steal	1.64

Virtual CPU cores ⚠

Name	Last *
c6b05	22.0
c6b02	21.8
c6b13	21.8
c6b11	21.8
c6b03	21.7
c6b16	21.5

Network Receive

Name	Last *
c5n11	3.46 GB/s
c5n20	2.03 GB/s
c5n14	2.03 GB/s
c6n05	302 MB/s
c6n02	300 MB/s
c6n13	300 MB/s

Network Transmit

Name	Last *
c5n20	1.66 GB/s
c5n14	1.66 GB/s
c5n17	122 MB/s
c6n16	56.6 MB/s
c6n13	52.2 MB/s
c6n03	43.1 MB/s

SLURM CPUs

Name	Last *
allocated	552
idle	0

CPUs by user

Name	Mean
kovachev	393
rbarak	413
yys	141

BMN MDC

Power

UPS Load

Temperature

AC

UPS Power

UPS Load

L1	65%
L2	65%
L3	80%

MPD MDC

Power

UPS Load

Temperature

AC

UPS Power

UPS Load

L1	27%
L2	24%
L3	22%

Other graphs

Host load

Acknowledgements

DAQ Data Center

Sergey Bazylev

Andrey Egorov

Alexander Fediunin

Ivan Filippov

Sergey Kuklin

Andrey Shchipunov

NCX Offline Cluster

Ivan Slepov

Your contributions made this work possible.

Thank you!

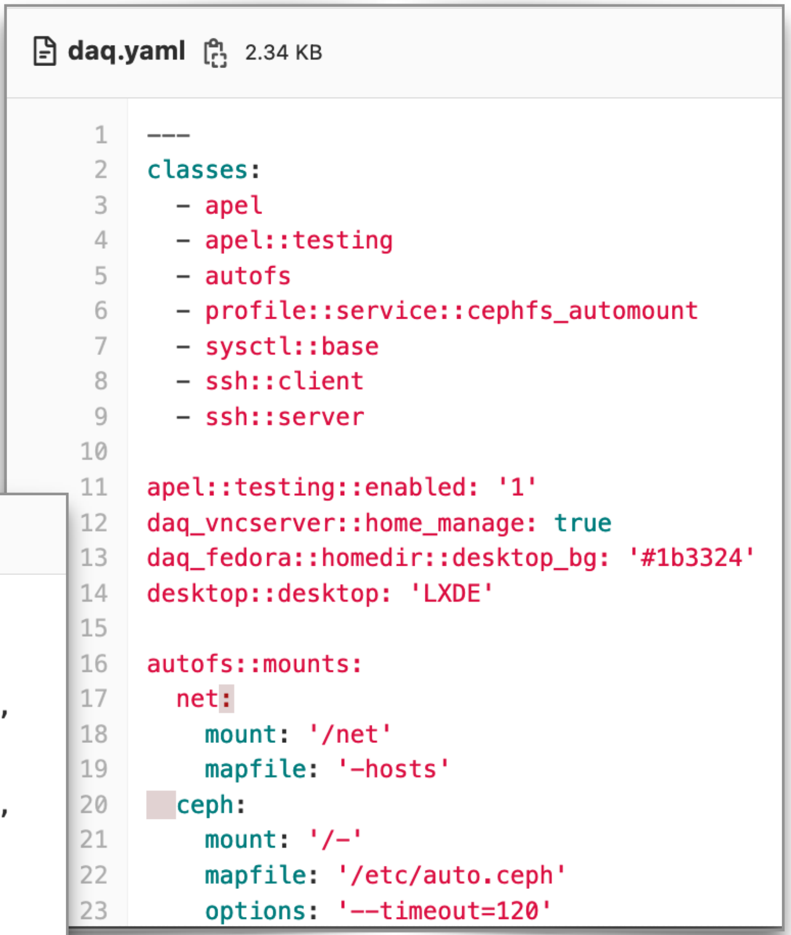
Extra slides

Infrastructure Management

Infrastructure-as-Code

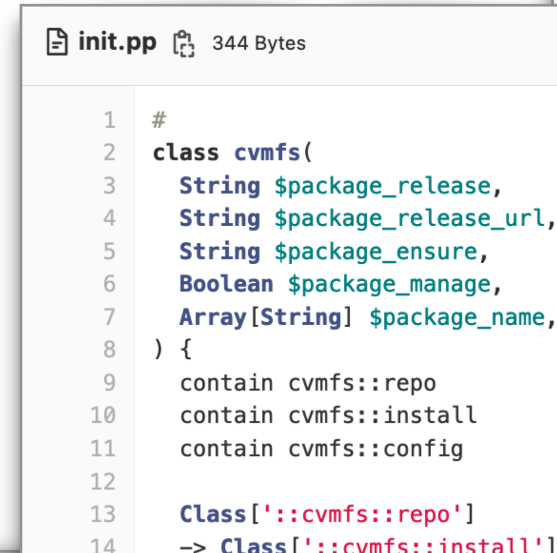
Tool	Method	Approach, our usage	Tasks
Puppet	Pull	functional (declarative)	configure services, settings
Ansible	Push	procedural (imperative)	updates, one-time tasks
—	—	manual admnistration	other complex tasks

- Machine-readable, version-controlled configuration files (YAML, Ruby)
- Puppet modules:
  - provision, configure, manage OS and application components
  - supported by community or our custom solution
- Hierarchical design: roles, profiles, classes are assigned to groups of computers. Dev and Prod environments.
- Documentation of IT Infrastructure configuration



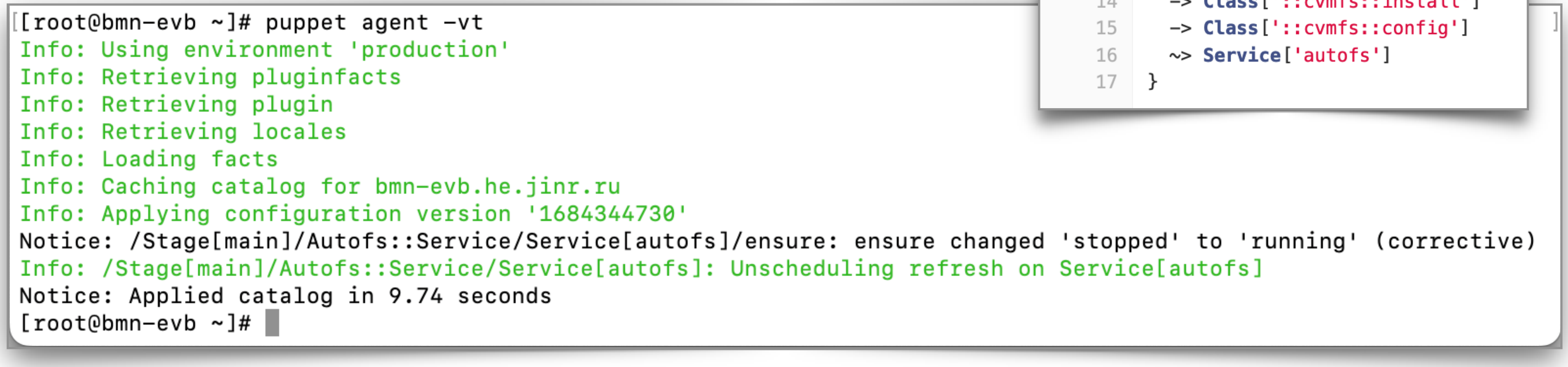
daq.yaml 2.34 KB

```yaml
---
classes:
  - apel
  - apel::testing
  - autofs
  - profile::service::cephfs_automount
  - sysctl::base
  - ssh::client
  - ssh::server

apel::testing::enabled: '1'
daq_vncserver::home_manage: true
daq_fedora::homedir::desktop_bg: '#1b3324'
desktop::desktop: 'LXDE'

autofs::mounts:
  net:
    mount: '/net'
    mapfile: '-hosts'
  ceph:
    mount: '/-'
    mapfile: '/etc/auto.ceph'
    options: '--timeout=120'
```



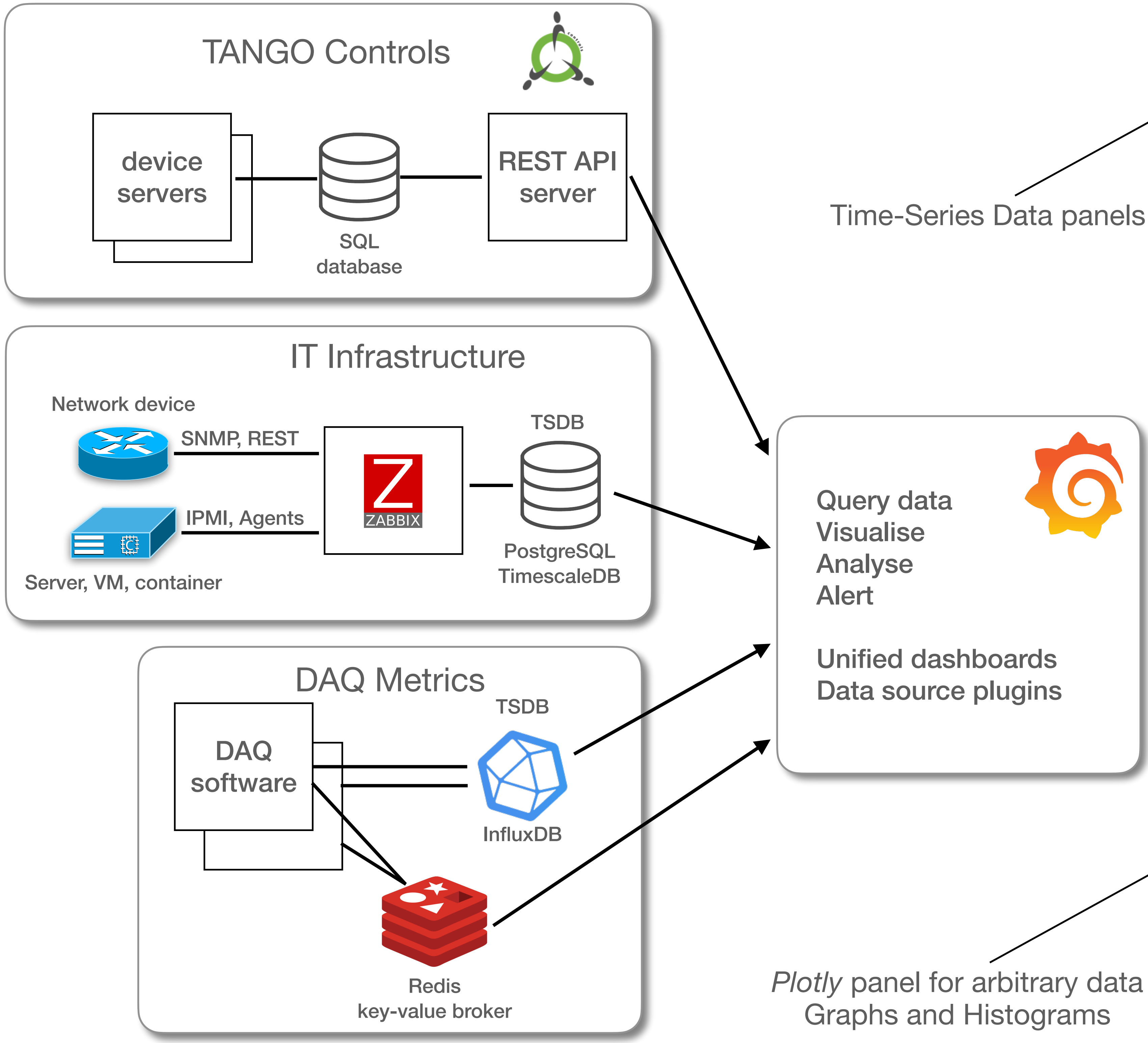
init.pp 344 Bytes

```puppet
#
class cvmfs(
  String $package_release,
  String $package_release_url,
  String $package_ensure,
  Boolean $package_manage,
  Array[String] $package_name,
) {
  contain cvmfs::repo
  contain cvmfs::install
  contain cvmfs::config

  Class['::cvmfs::repo']
  -> Class['::cvmfs::install']
  -> Class['::cvmfs::config']
  ~> Service['autofs']
}
```



```
[root@bmn-evb ~]# puppet agent -vt
Info: Using environment 'production'
Info: Retrieving pluginfacts
Info: Retrieving plugin
Info: Retrieving locales
Info: Loading facts
Info: Caching catalog for bmn-evb.he.jinr.ru
Info: Applying configuration version '1684344730'
Notice: /Stage[main]/Autofs::Service/Service[autofs]/ensure: ensure changed 'stopped' to 'running' (corrective)
Info: /Stage[main]/Autofs::Service/Service[autofs]: Unscheduling refresh on Service[autofs]
Notice: Applied catalog in 9.74 seconds
[root@bmn-evb ~]#
```

Monitoring Architecture



TANGO Controls

device servers

SQL database

REST API server

IT Infrastructure

Network device

SNMP, REST

IPMI, Agents

Server, VM, container

ZABBIX

TSDB

PostgreSQL TimescaleDB

DAQ Metrics

DAQ software

TSDB

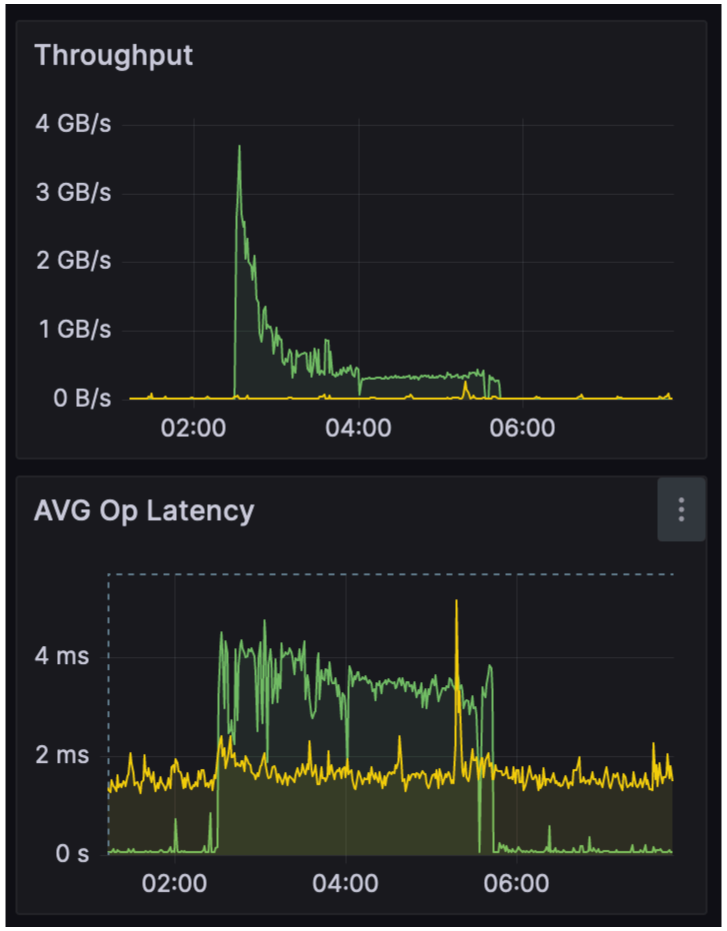
InfluxDB

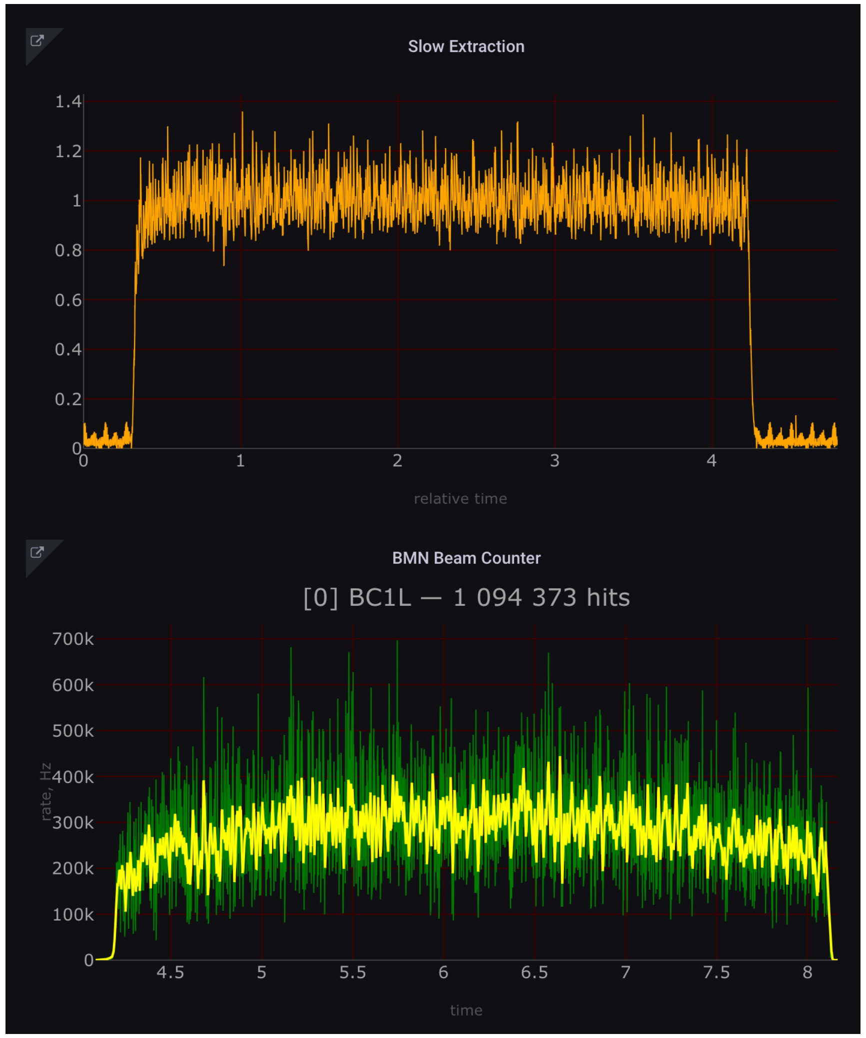
Redis key-value broker

Query data
Visualise
Analyse
Alert

Unified dashboards
Data source plugins

Time-Series Data panels

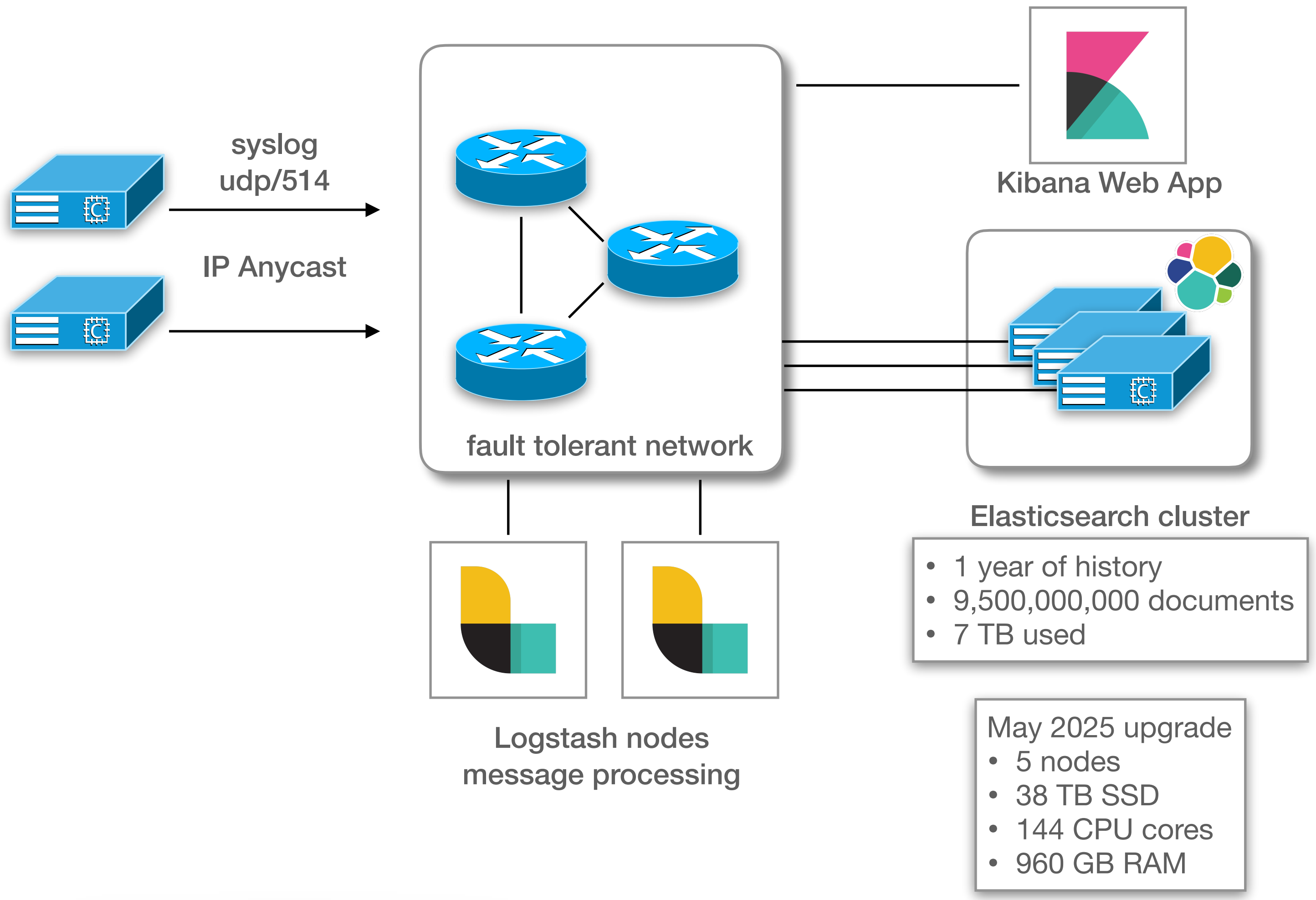




Plotly panel for arbitrary data
Graphs and Histograms

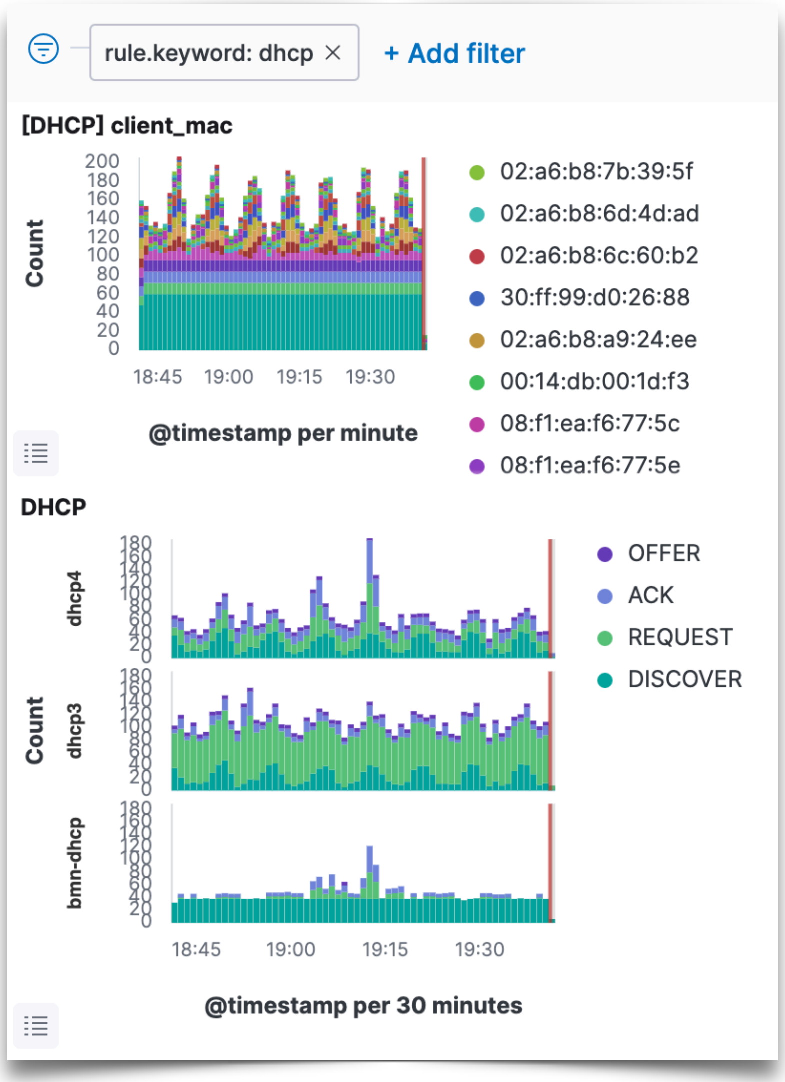
Log Message Processing and Analysis

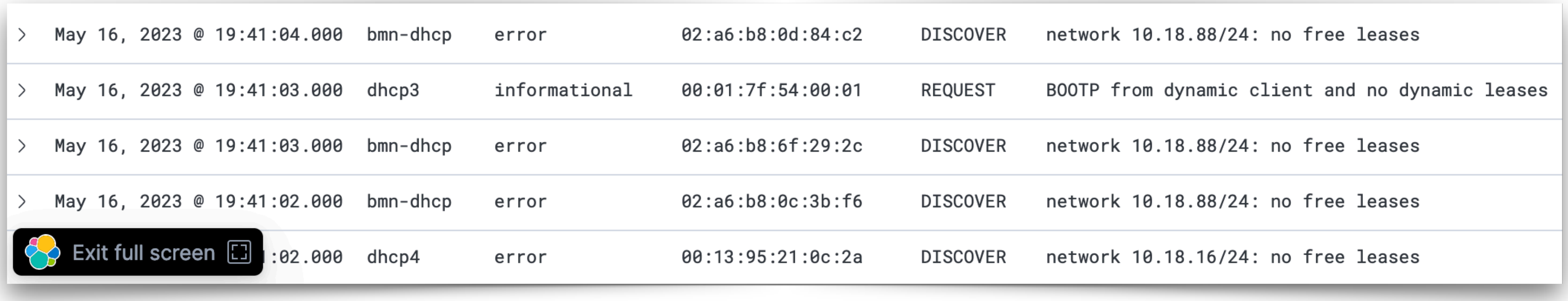
Elasticsearch, Logstash, Kibana



- 1 year of history
- 9,500,000,000 documents
- 7 TB used

May 2025 upgrade
- 5 nodes
- 38 TB SSD
- 144 CPU cores
- 960 GB RAM





```
>  May 16, 2023 @ 19:41:04.000  bmn-dhcp  error          02:a6:b8:0d:84:c2  DISCOVER  network 10.18.88/24: no free leases
>  May 16, 2023 @ 19:41:03.000  dhcp3     informational  00:01:7f:54:00:01  REQUEST   BOOTP from dynamic client and no dynamic leases
>  May 16, 2023 @ 19:41:03.000  bmn-dhcp  error          02:a6:b8:6f:29:2c  DISCOVER  network 10.18.88/24: no free leases
>  May 16, 2023 @ 19:41:02.000  bmn-dhcp  error          02:a6:b8:0c:3b:f6  DISCOVER  network 10.18.88/24: no free leases
   Exit full screen        :02.000  dhcp4     error          00:13:95:21:0c:2a  DISCOVER  network 10.18.16/24: no free leases
```