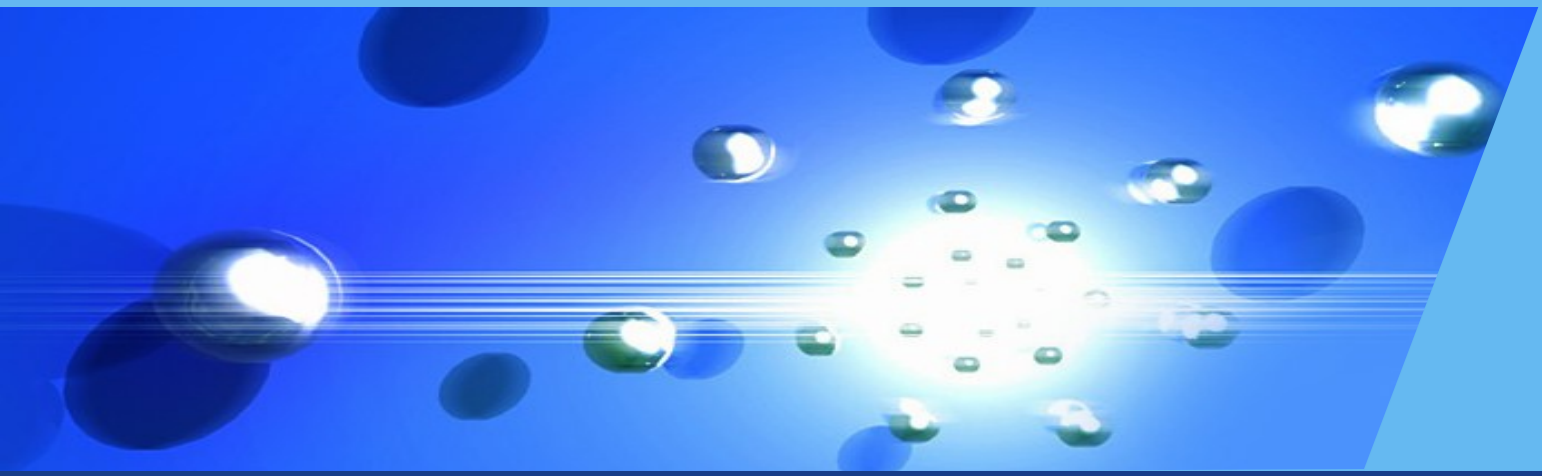
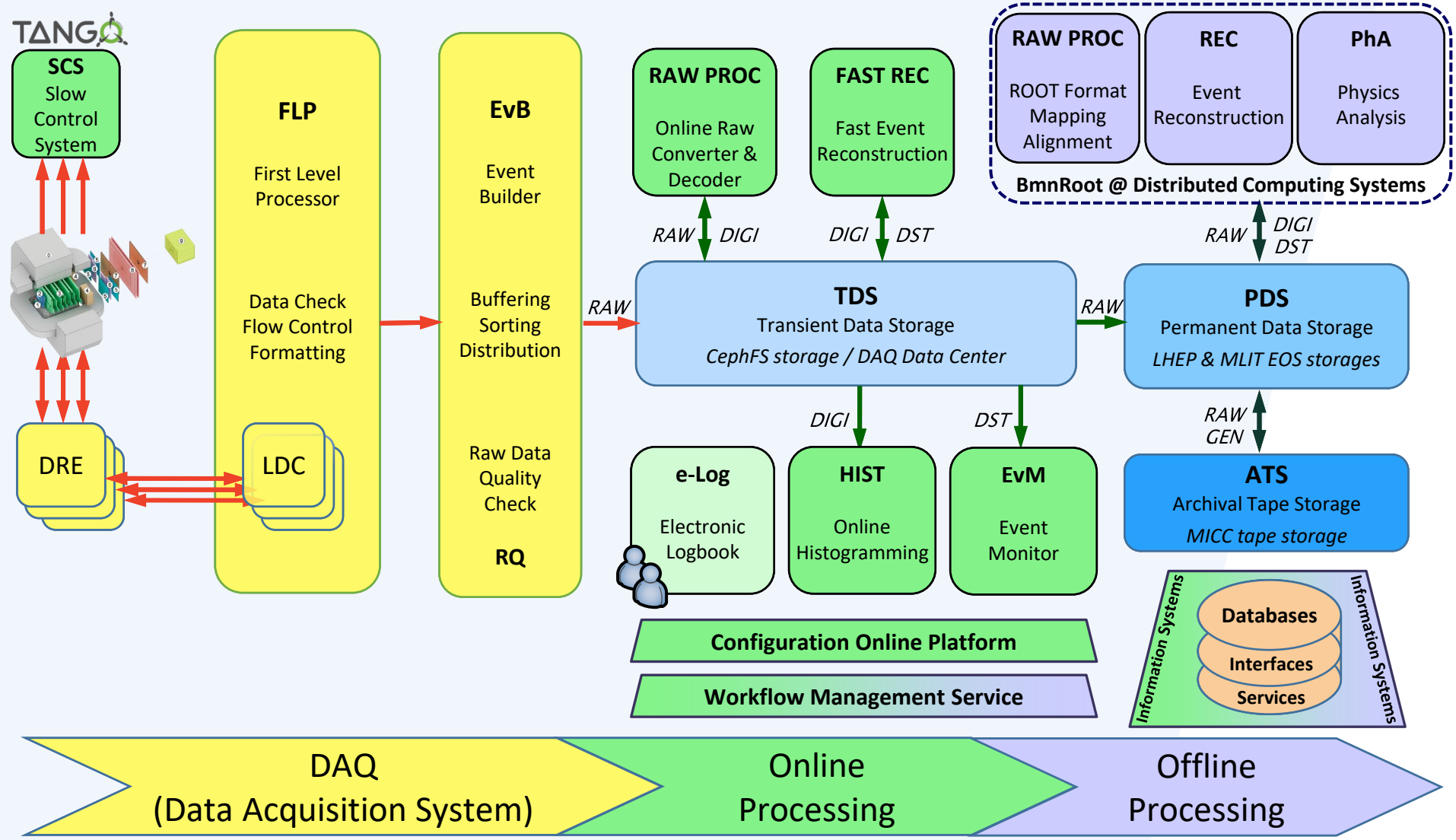


BM@N Software Readiness for Run 9

Konstantin Gertsenberger
BM@N Software Coordinator
V. Veksler and A. Baldin Laboratory of High Energy Physics
Joint Institute for Nuclear Research

13–15 May 2025

BM@N Data Processing Flow



Software Systems

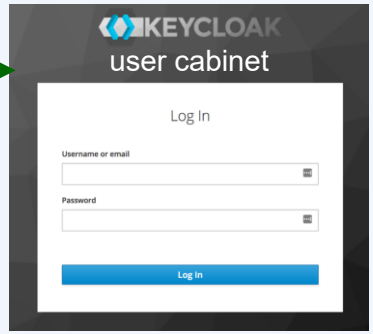
for online data processing

BM@N SSO System

bmn-login.jinr.ru
(BM@N Single Sign-On)

FreeIPA

staff
external users



admin groups
writer groups
reader groups

login.jinr.ru
(JINR Single Sign-On)

JINR SSO

not used because the procedure is impossible for some BM@N collaborators

bmn-user.jinr.ru:8443

Electronic Logbook

Wiki Document Server

Condition Database

Geometry Database

Configuration Online Platform

Event Catalogue

BM@N Forum

Project Management System

DIRAC File Catalog

61 Users

9 Services

19 Groups

Collaboration Members

shift user was disabled because of security

Electronic Logbook Platform

Online Information System

"I'm trying to liven up my entries. What's another word for 'slept?'"

e-Log Platform

create a new run

advanced search

current day records

user cabinet (event subs)

work with dictionaries

records per page

file attachments

username

page

fast search

BM@N Electronic Logbook

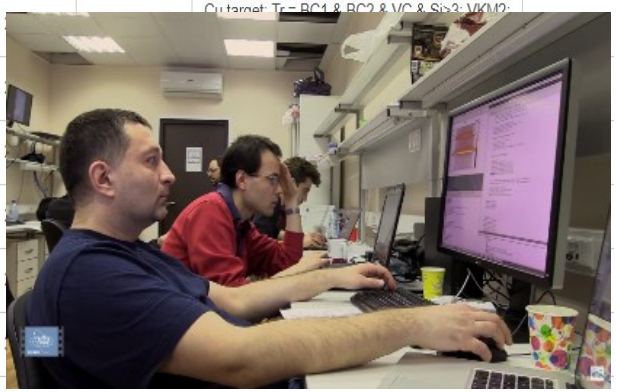
Logged in as shift

Home New Find Last day Account Reference Book

Page: 1 of 282

Number of items per page: 10 Logout

Date	Shift Leader	Type	№ Run	Trigger	DAQ Status	SP-41, A	SP-57, A	VKM2, A	Beam	Energy, GeV	Target	Comment	Attachment
2018-04-05 11:47:06	Rumyantsev	Inform All	5185 per.7	Special Trigger	All	0	0	0	Kr	2.94	Cu (2 mm)	End of the RUN7	
2018-04-05 11:09:20	Rumyantsev	New Run	5184 per.7	Beam Trigger + Si >3	All	1250	50	125	Kr	2.94	Cu (2 mm)	Cu target; Tr.= BC1 & BC2 & VC & Si>3 VKM2: I=125A, SP-57=50A, SP41=1250A; 100 k	
2018-04-05 08:12:35	Rumyantsev	New Run	5183 per.7	Beam Trigger + Si >3	All	1250	50	125	Kr	2.94	Cu (2 mm)	Cu target; Tr.= BC1 & BC2 & VC & Si>2 VKM2: I=125A, SP-57=50A, SP41=1250A; 120 k	
2018-04-05 07:46:35	Babkin	New Run	5182 per.7	Beam Trigger + Si >3	All	1250	50	125	Kr	2.94	Cu (2 mm)	Cu target; Tr.= BC1 & BC2 & VC & Si>3 VKM2: I=125A, SP-57=50A, SP41=1250A; 208 kev	
2018-04-05 07:41:29	Babkin	New Run	5180 per.7	Beam Trigger + Si >3	All	1250	50	125	Kr				
2018-04-05 07:25:08	Babkin	New Run	5179 per.7	Beam Trigger + Si >3	All	1250	50	125	Kr				
2018-04-05 06:01:07	Babkin	New Run	5178 per.7	Beam Trigger + Si >3	All	1250	50	125	Kr				
2018-04-05 05:27:39	Babkin	New Run	5177 per.7	Beam Trigger + Si >3	All	1250	50	125	Kr				
2018-04-05 05:27:06	Babkin	New Run	5176 per.7	Beam Trigger + BD>3	All	1250	50	125	Kr				
2018-04-05 04:47:27	Babkin	New Run	5174 per.7	Beam Trigger + BD>3	All	1250	50	125	Kr				

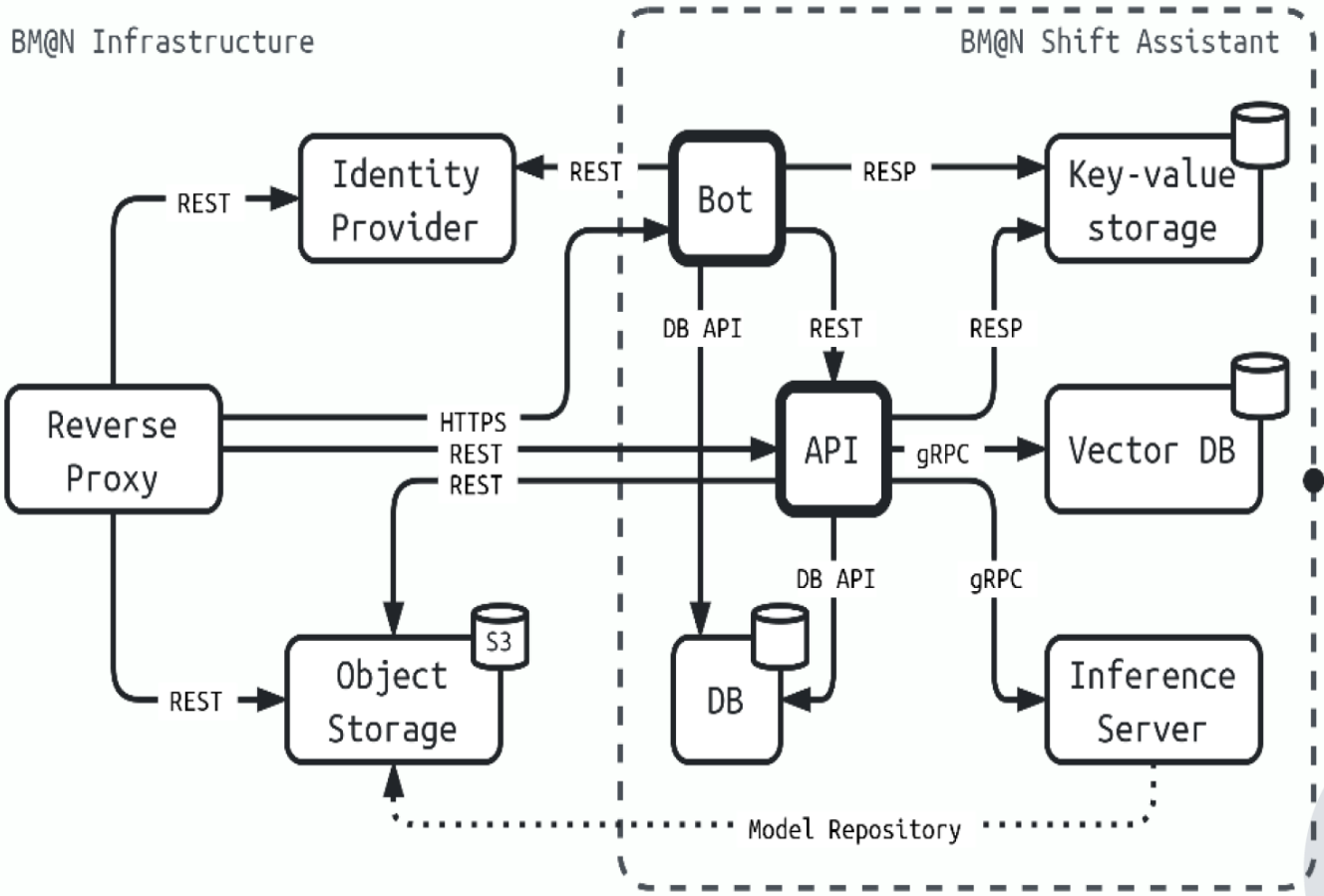


2020 - software team (contact e-mail: gertsen@jinr.ru)

**no connection with DAQ run control information*

Bot Assistant for Shift Operators

Virtual Assistant Architecture



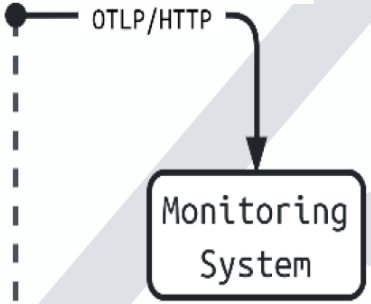
Assistant for BM@N experiment shift operators
Version: 0.1.1

ATTENTION: The bot is in the testing stage! All information provided can be used for informational purposes only!

exclusion zones in building 205

- 2.1. При работе ускорительного комплекса и выводе ускоренного пучка из Нуклотрона в корпус № 205:

- территория канала ВП-1 внутри биологической защиты является зоной запрета (см. Рис.1);
- экспериментальный зал корпуса №205 является контролируемой зоной;
...

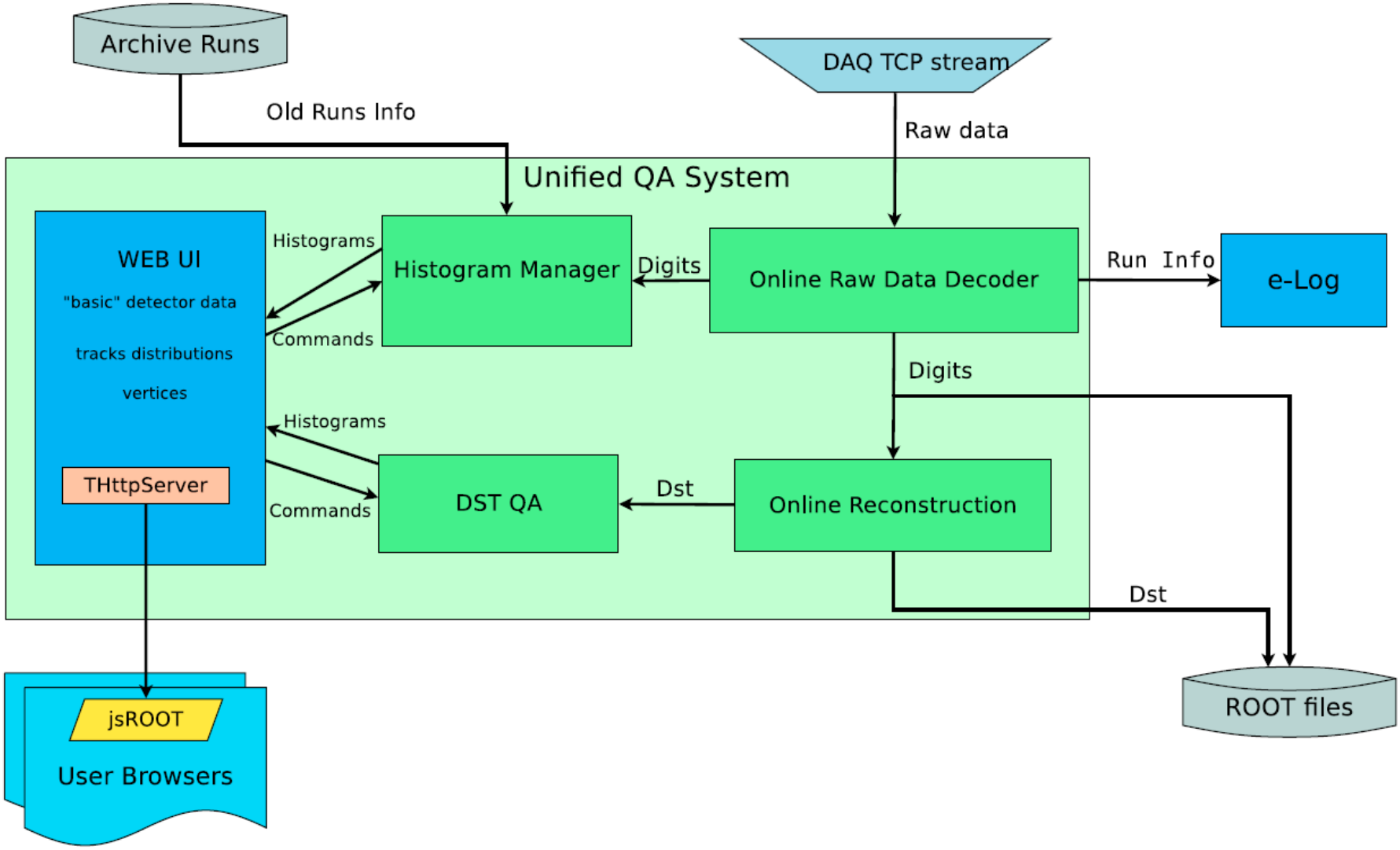


Online Monitoring System

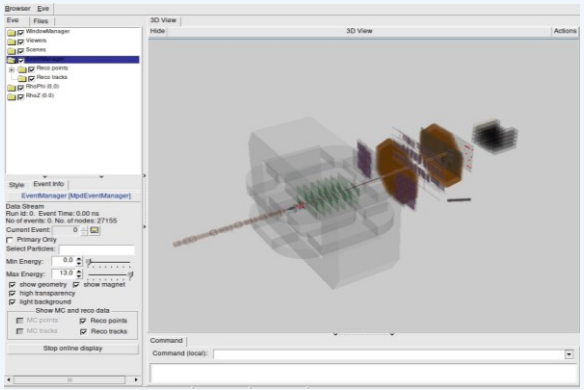
Online Histogramming + Event Display

She says she's from Quality Control. We've failed the furniture inspection.

Raw Data Decoder in BM@N Online Monitoring



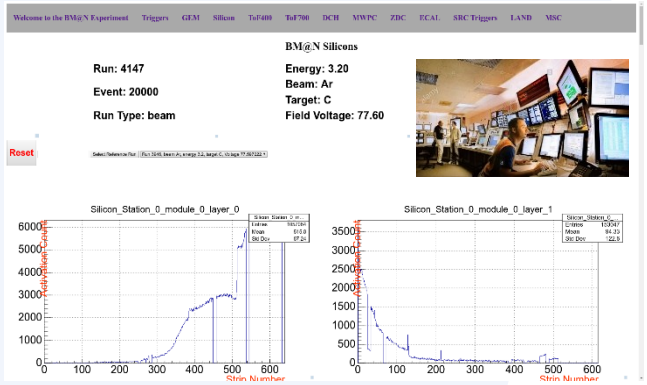
Online Metadata for BM@N Data Processing



DAQ system

EvB

Raw Event Builder



Online Raw

ROOT Format Digit Decoder

EvM

Event Monitor

HIST

Online Histogramming

raw file metadata

period, run

start & end time, event count, file path, file size

e-Log platform

run metadata

period, run

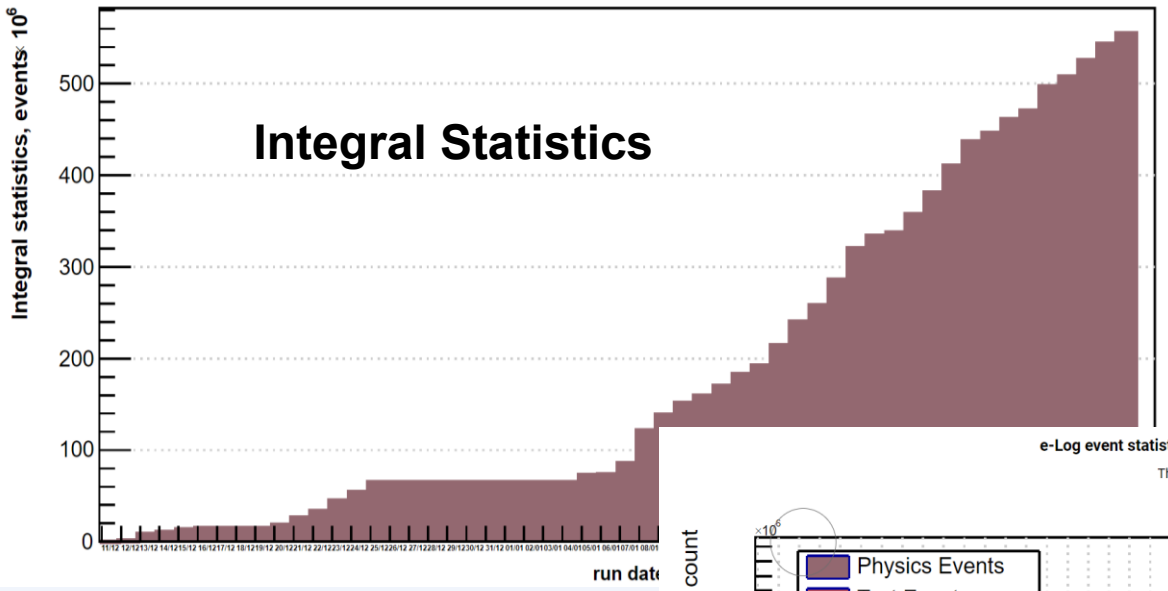
beam, energy, target, magnetic field

Condition Database

online & offline data processing

Event & Run Statistics

Online Run Statistics

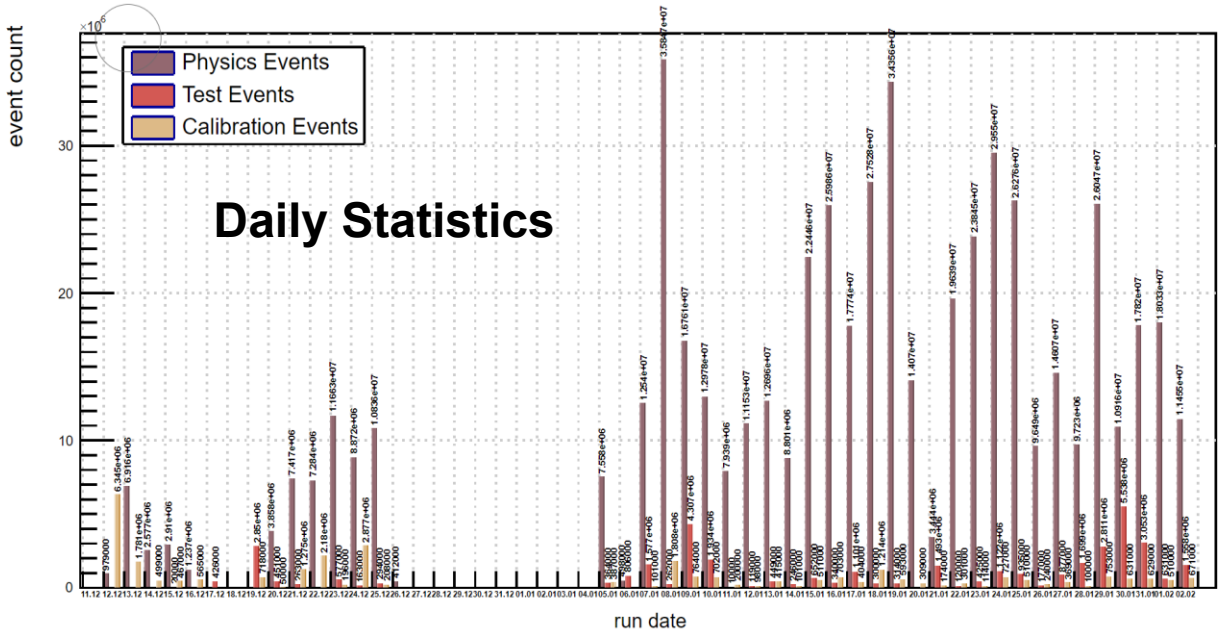


Manual run statistics from the Electronic Logbook is time-consuming, error-prone and inaccurate

e-Log event statistics (Run 8): statistics by event type / integral statistics of physics events

The information is current as of February 20 2023 23:59.

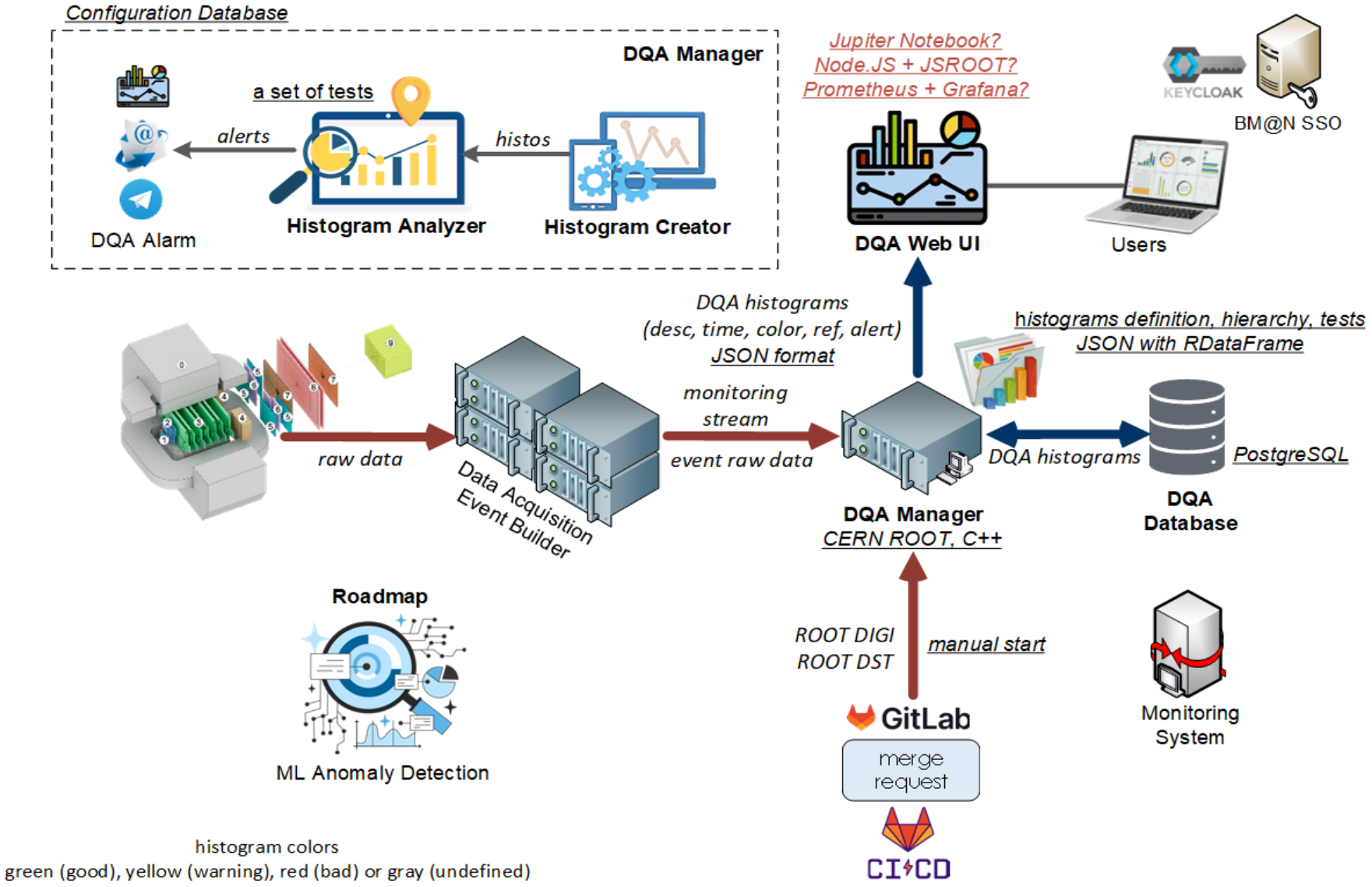
Run statistics from the Condition Database is automatic and accurate but depends on the Raw Data Decoder



Data Quality Assurance (DQA) system for BM@N

- Single DQA system for the BM@N experiment should be developed to provide control histograms in the same way in 3 modes:
  - for online histogramming and reconstruction (online data monitoring)
  - for qualitative assessment of new BmnRoot versions (after MRs)
  - for manual run to check user versions of the software
- The BM@N DQA architecture must ensure predefined checks and graphical representation of control histograms on a central Web service, which receives the displayed data distributions from the BM@N histogram producer (DQA central manager)
- The DQA system must provide the ability to easily add new control histograms with predefined checks and alerts in a user-friendly format (suitable for physicists and detector team, who are not developers), for instance, using *JSON*-description

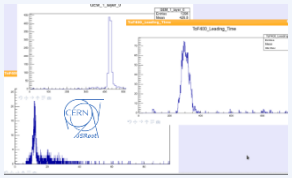
Design of the BM@N DQA system



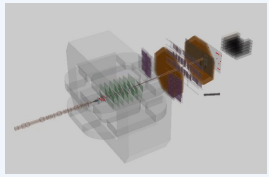
Configuration Online Platform

Online Data Processing

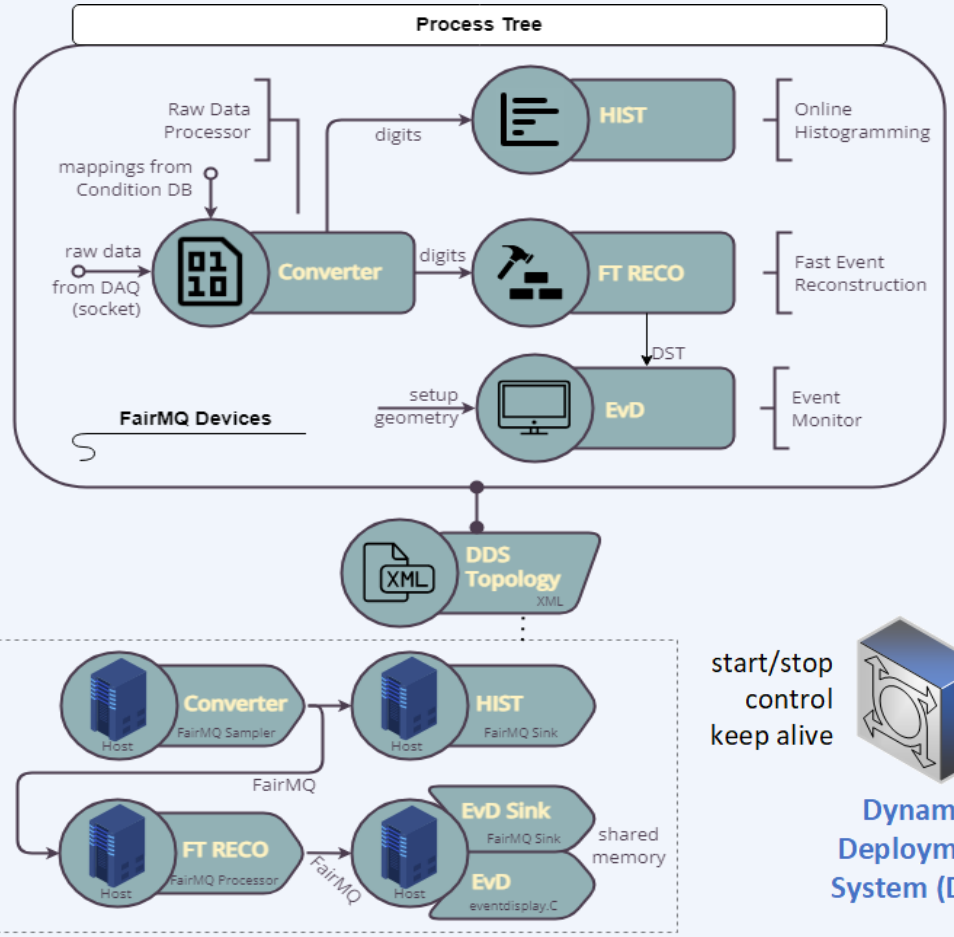
BM@N COnfiguration Online Platform (COOP)

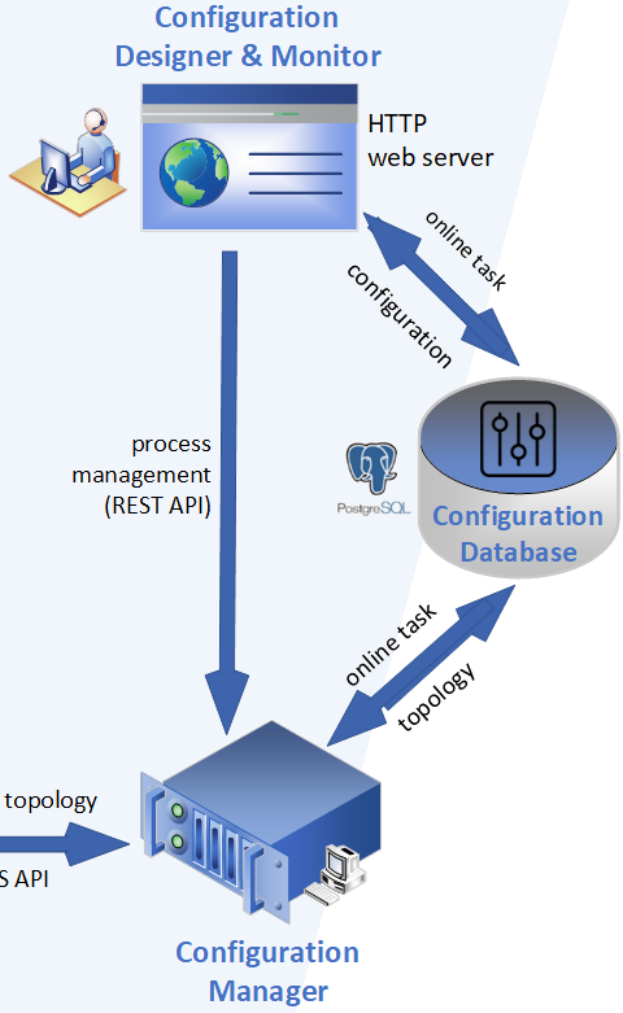


Online Histogramming System

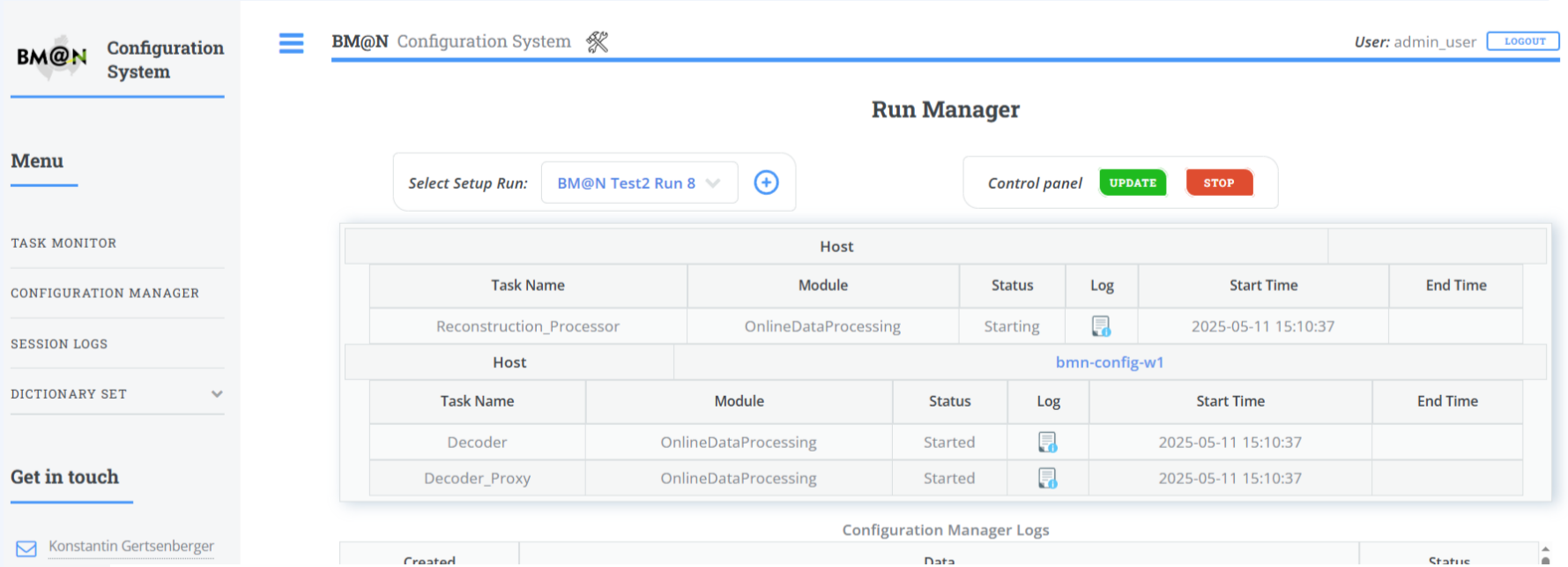


Event Monitor





Configuration Designer & Monitor



Task Monitor

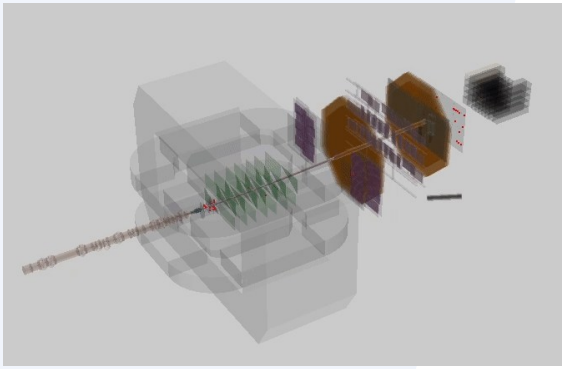
Select task | Select setup | Select module | Started | Select host | FILTER | RESET

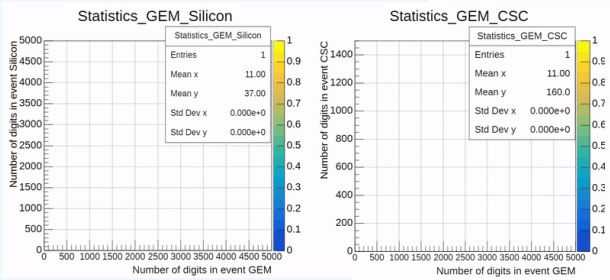
Task Name	Setup:Run	Module	Status	Log	Start Time	End Time	Host
bmn_event_display_imit	BMN:7	OnlineControl	Started		2023-05-05 18:39:16		vps104.jinr.ru
bmn_fast_event_reco_imit	BMN:7	OnlineControl	Started		2023-05-05 18:39:16		vm221-85.jinr.ru
bmn_online_histo_imit	BMN:7	OnlineControl	Started		2023-05-05 18:39:16		vps104.jinr.ru
bmn_root_digi_imit	BMN:7	OnlineControl	Started		2023-05-05 18:39:16		vps104.jinr.ru

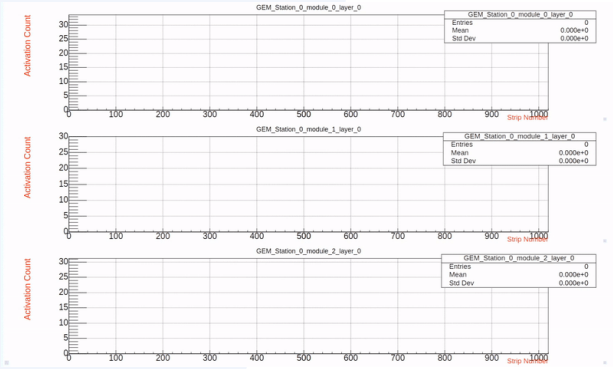
Online Processing System for BM@N

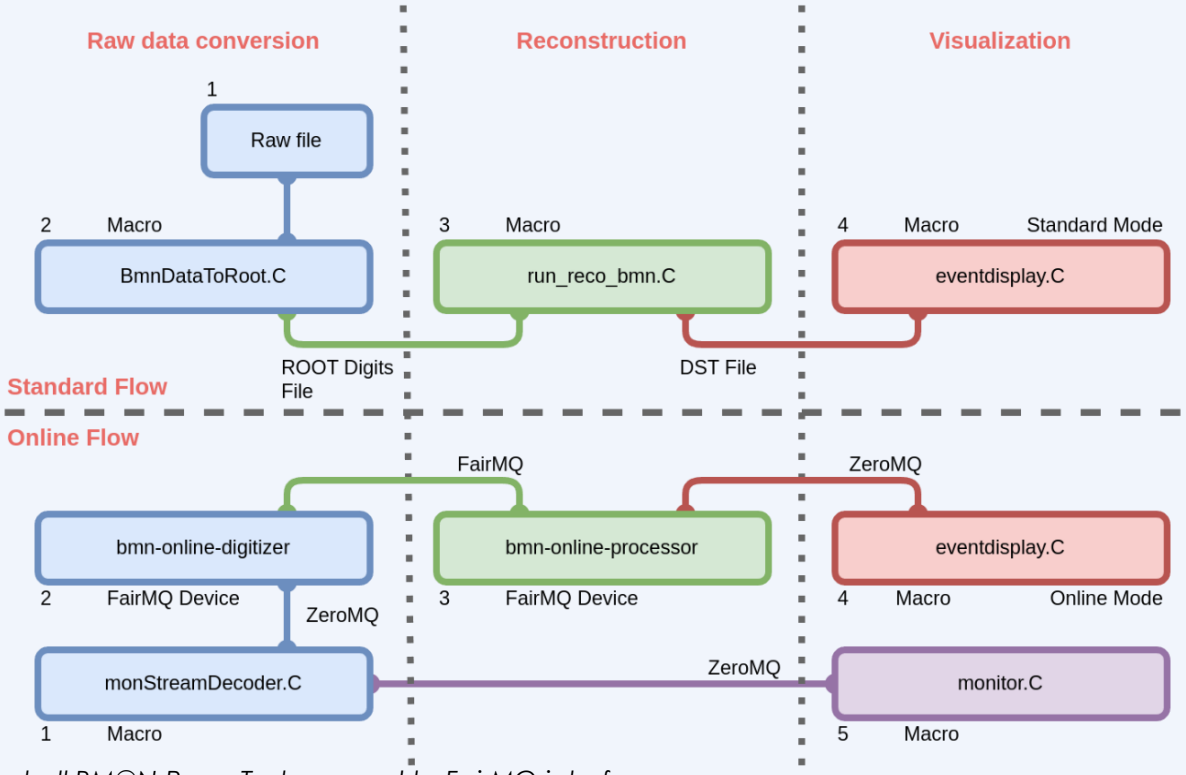
DDS (Dynamic Deployment System) is a set of tools that facilitates the process of system deployment. As a Remote Manipulator System (RMS), it initially provides SSH or SLURM, but also allows you to use other methods.

FairMQ is a messaging library focused on building modular systems for data processing in high energy physics experiments. It represents an abstraction over various messaging technologies such as ZeroMQ, Nanomsg, etc.



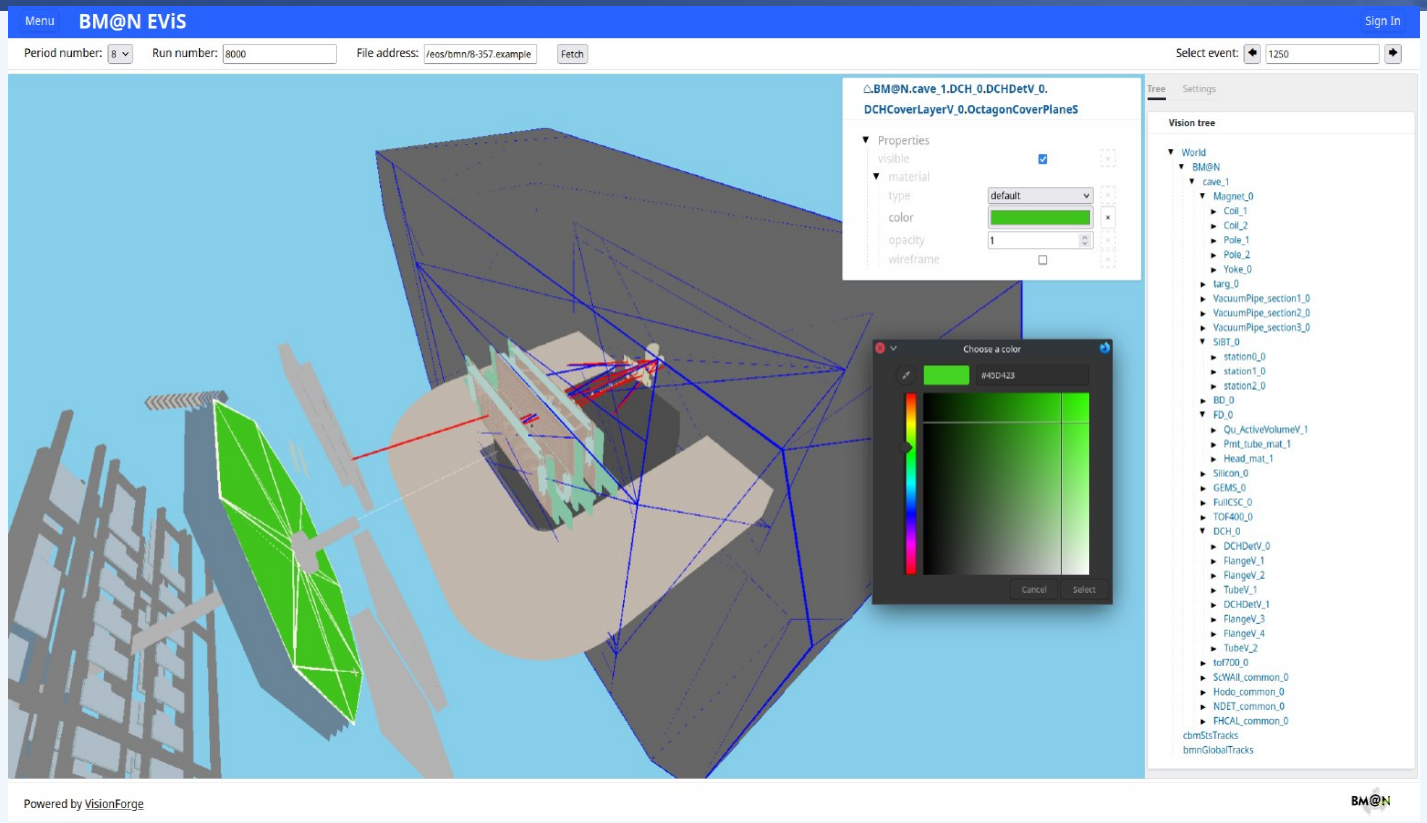




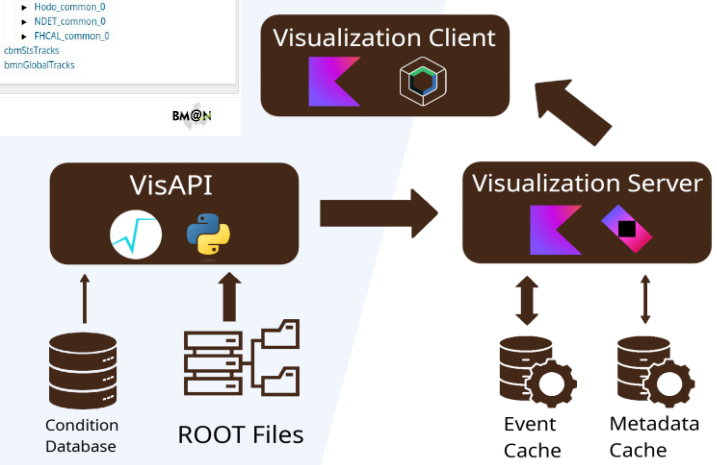


**not all BM@N Reco Tasks moved to FairMQ interface*

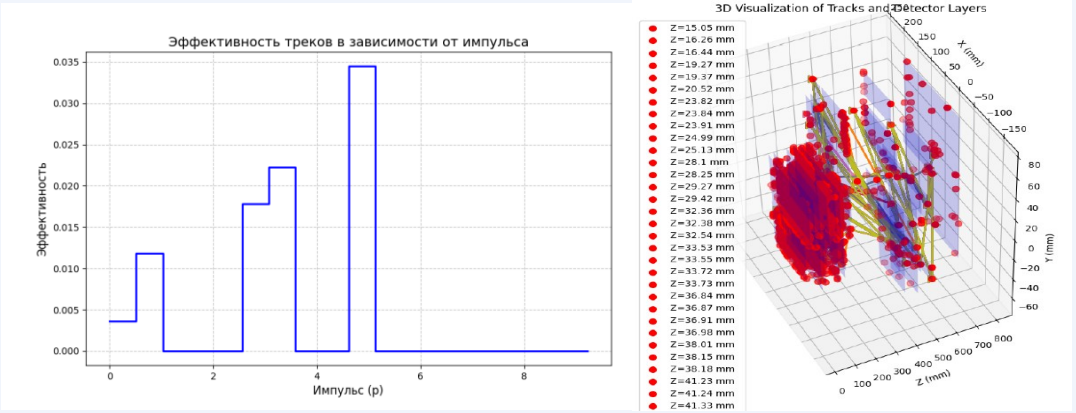
Event Display on the VisionForge platform



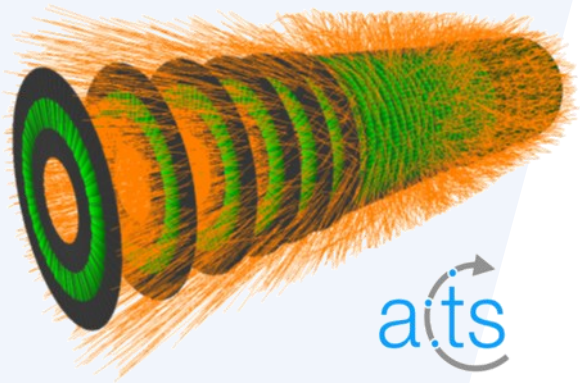
- visualization of detector geometries with a detail level of choice.
- working with the scene
- saving scene configuration (JSON) to a file
- ability to show/hide geometric elements, set color, transparency
- visualization of particle collision events
- event objects and geometry are presented as a hierarchical tree



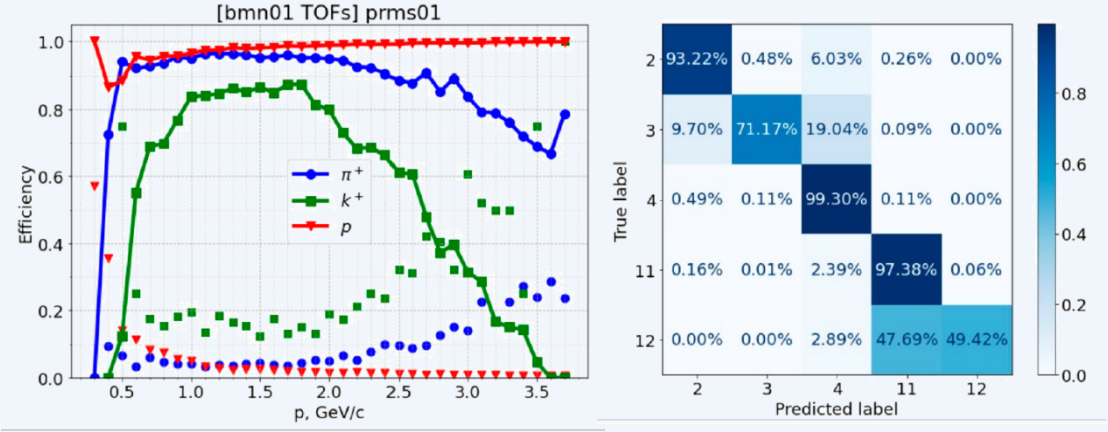
ML for Fast Reconstruction and PID



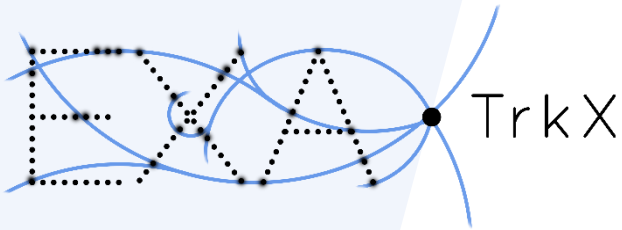
Anatoly ALEXANDROV, Sergey A. NEMNYUGIN
Application of machine learning for particle tracking in BM@N



Tracking machine learning challenge
(currently developers from ATLAS, LHCb, FCC-hh)



Alexander AYRIYAN, Vladimir PAPOYAN
Implementation of Particle IDentification based on Machine Learning



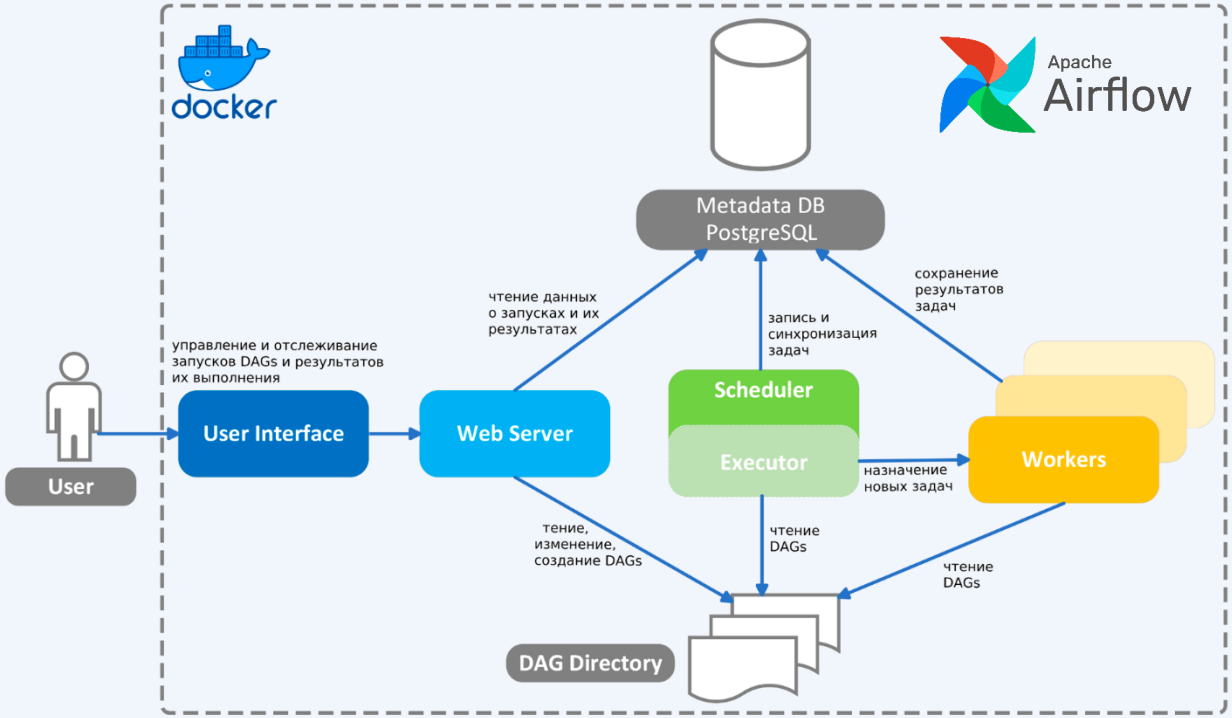
HEP advanced tracking algorithms at the exascale
(Caltech, FNAL, Princeton, SLAC…)

Nikolay ERSHOV
Own implementation of Fast Event Reconstruction based on ML/ NN

Workflow Management Service

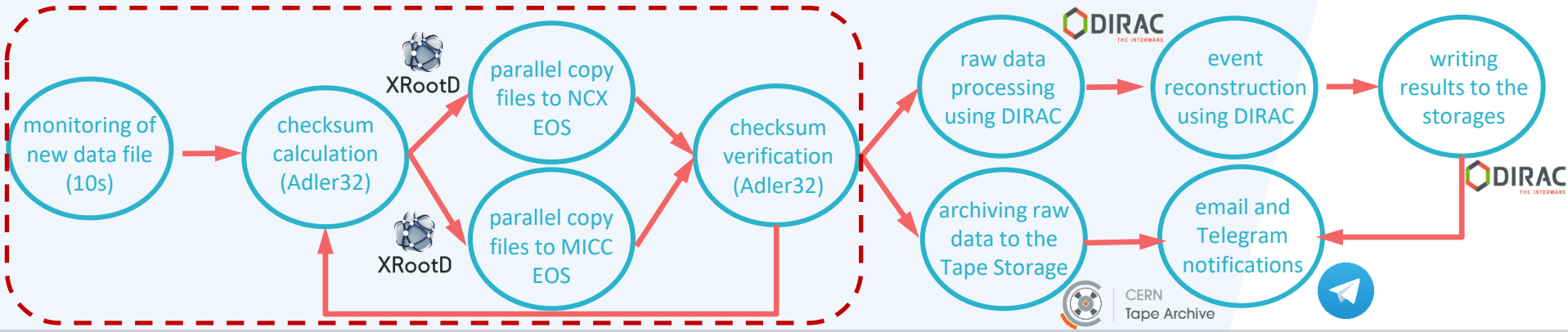
Online & Offline Data Processing

BM@N Orchestration with Workflow Manager

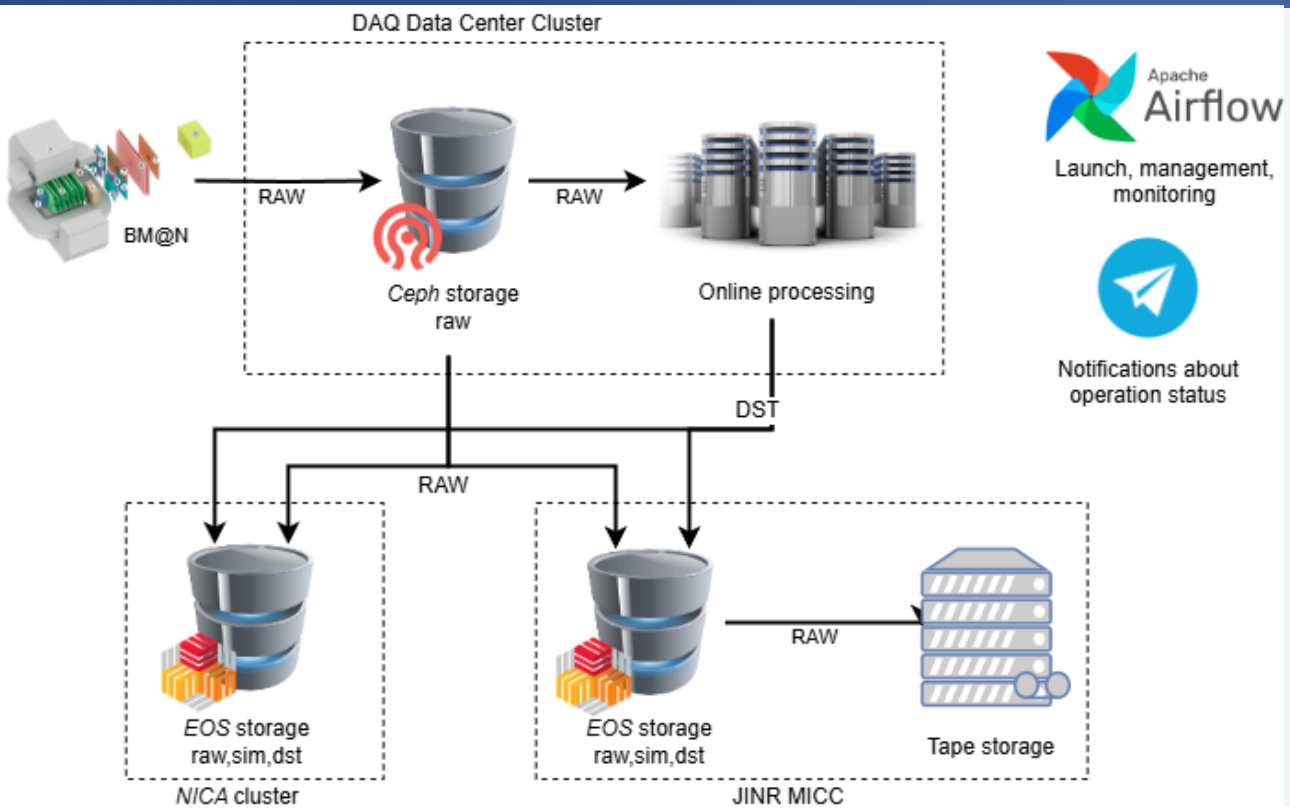


Airflow DAGs can be used for repeating data processing of simulation and experimental events

Airflow DAGs has been developed for online data processing, transferring to the EOS storages, archiving to the Tape Storage



Online Processing Pipeline for Run 9



Apache Airflow

Launch, management, monitoring

Notifications about operation status

Next steps

Final debugging of the current workflow for BM@N Run 9

Implementation of distributed processing of obtaining raw data via the *DIRAC* platform

Integration of user authentication and authorization via BM@N *SSO* system based on *KeyCloak*

Apache Airflow

Online and Offline Processing Pipelines

Airflow deployed on the DAQ C4 cluster

Condition Database (UniConDa)

Offline Information System

UniConDa in BM@N data processing

ROOT-based framework

detector simulation
raw data processing
event reconstruction
physics analysis

viewing and managing parameter data

users

Keycloak ↕ authentication authorization

C++ interface
(connect, I/O, API)

http

SQL

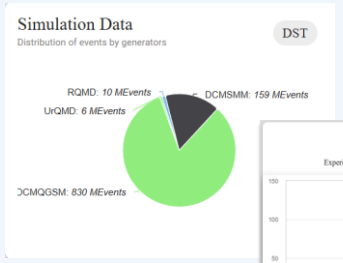
REST API service

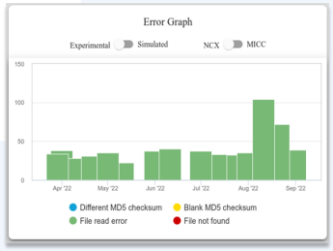
node.JS

Condition Database

Web Service

SimData Crawler



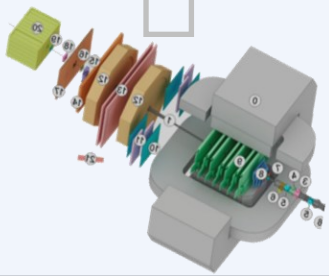


File Inspector

configuration
calibration

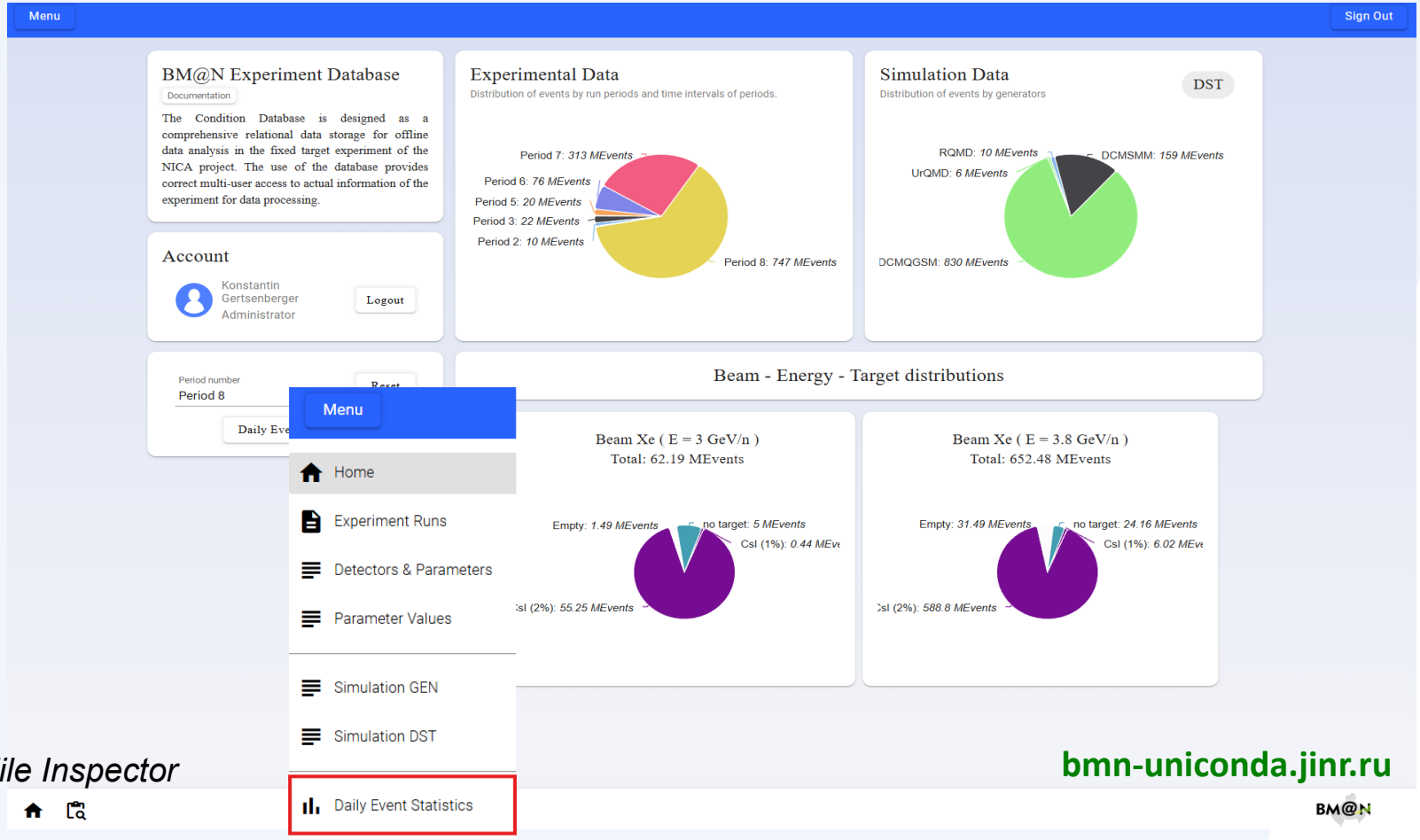
d a t a

parameter
algorithm



ANGULAR node docker HIGHCHARTS CERN JSRoot

UniConDa Web Application

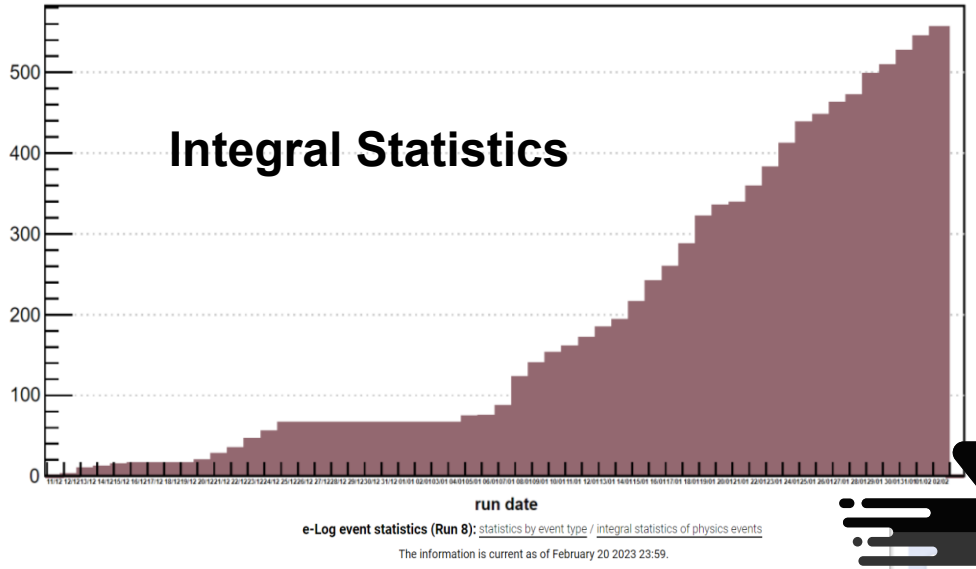


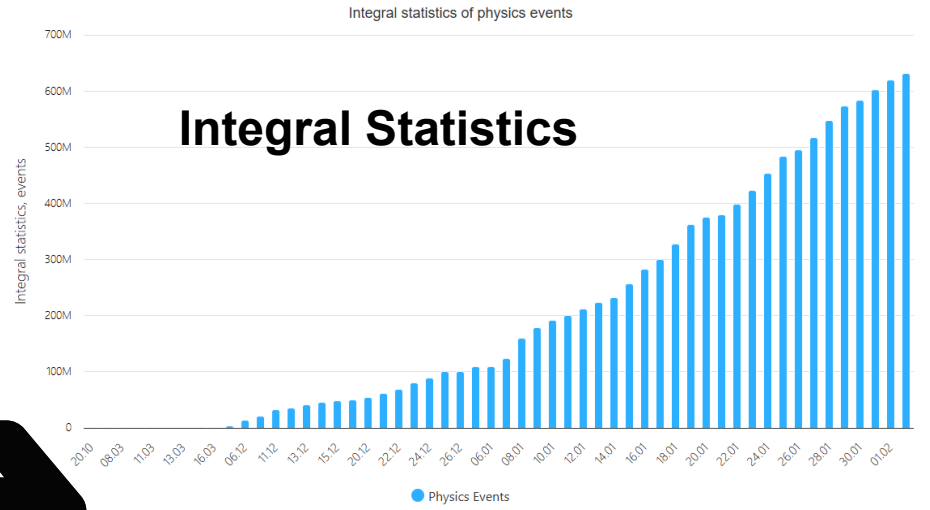
File Inspector

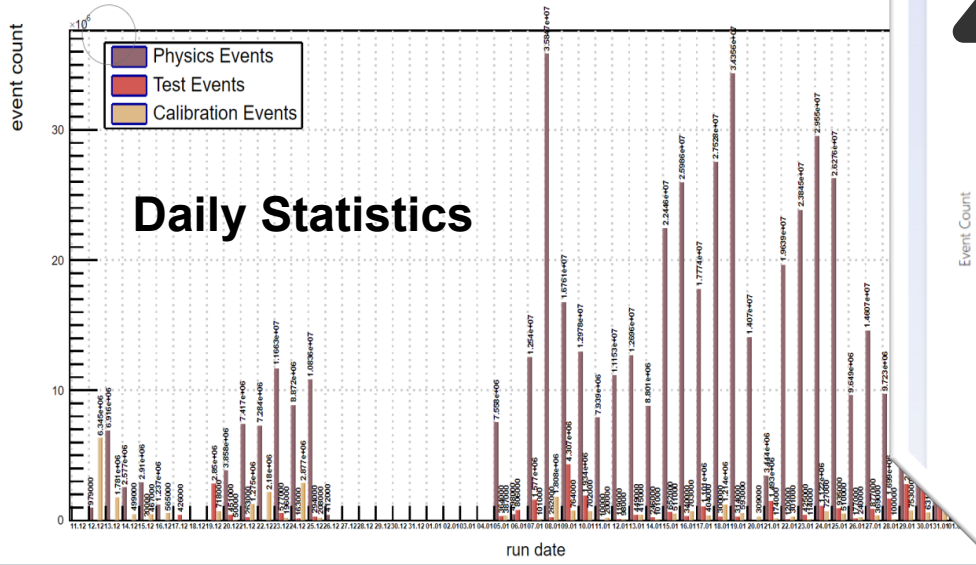
bmn-uniconda.jinr.ru

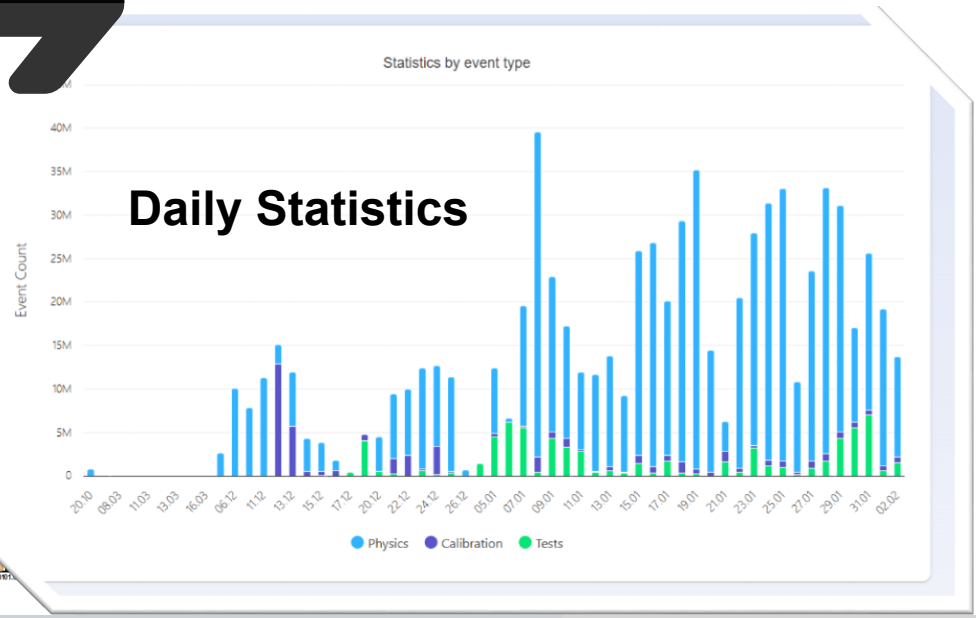
- period #9 with run #1 and run #100000 were created, parameter values should be extended
- run statistics (daily and extended) has been implemented using the data stored in the Condition Database for a selected Run/Period

Run 8 Statistics in the Condition DB









Geometry Database

Offline Information System

Detector Geometry Definition

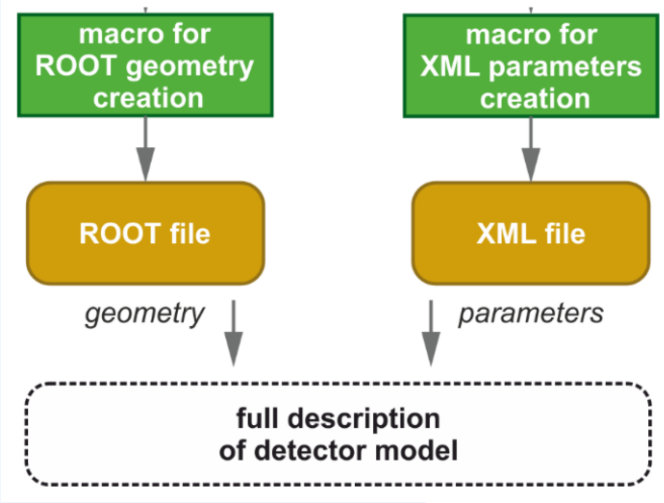
- **Geometry File**

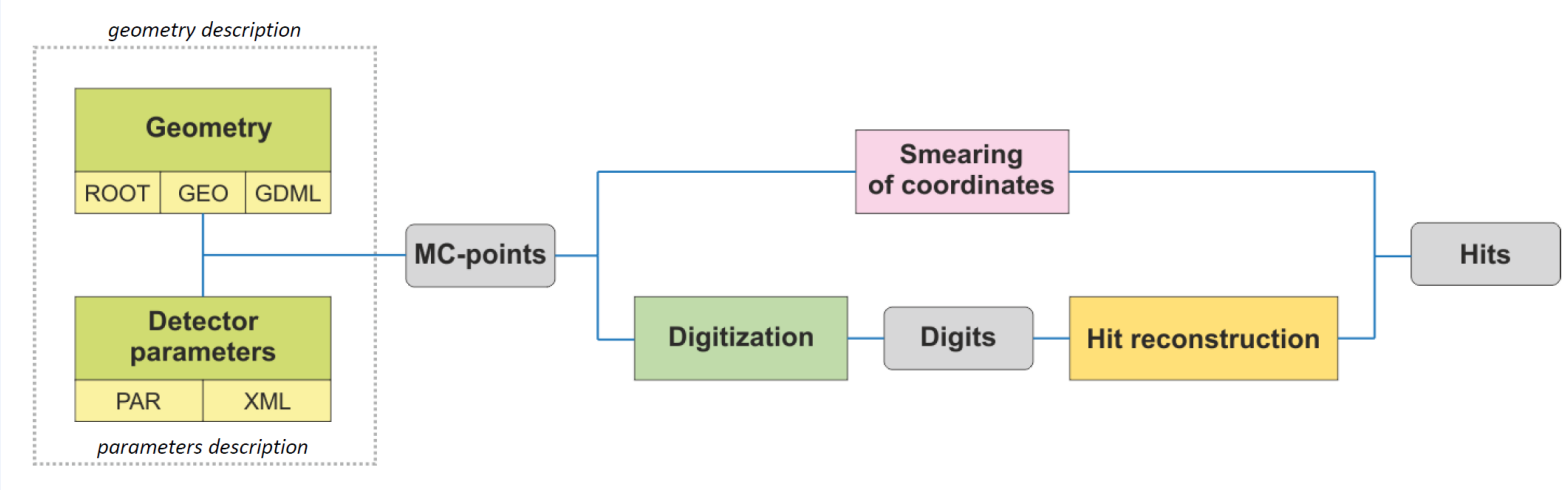
Description of basic detector volumes (sensitive + passive):
dimensions, position, orientation, materials

- **Parameter File** (optional)

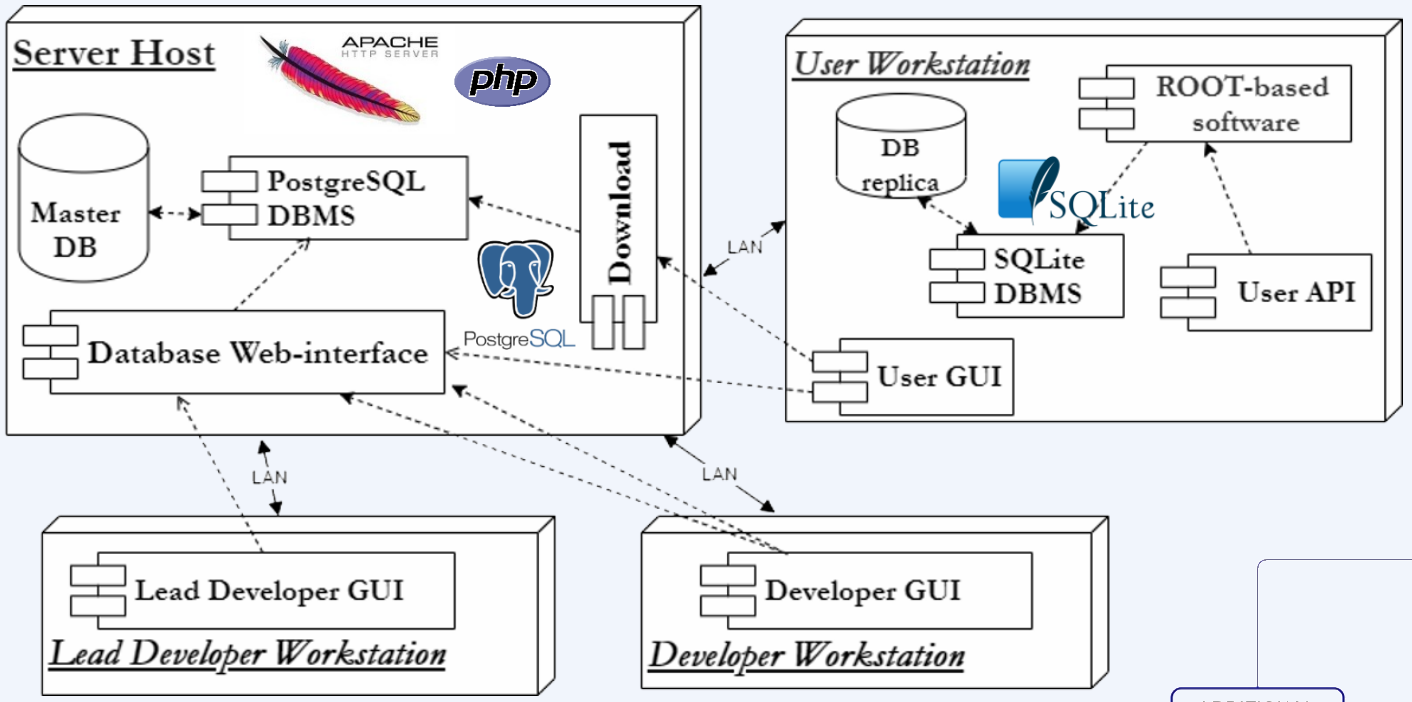
Description of the detailed structure of the detector
required for realistic simulation, digitization, hit reconstruction:

- the internal structure of the detector (stations, modules, layers, dead zones ...), as well as their orientation, position and layout..
- reading elements, e.g. strips (strip angle, strip width, reading order, etc.)
- other parameters required for simulation and reconstruction (width of gaps, direction of electron drift, etc.)

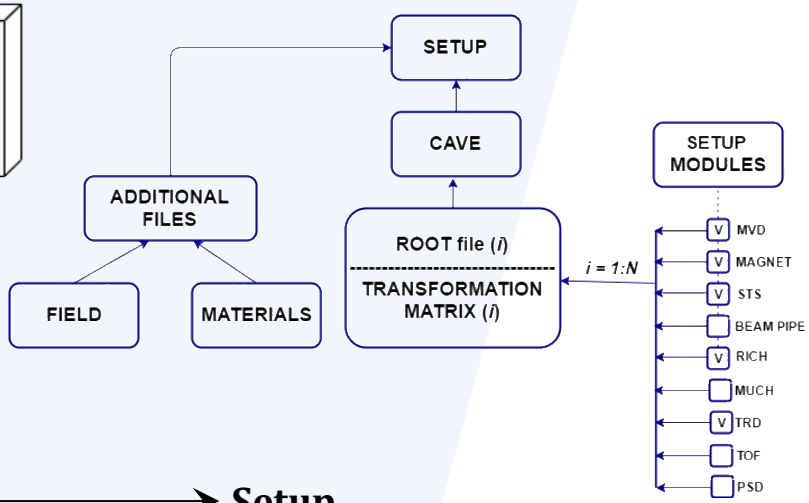




Geometry Information System



3 Roles
- Lead Developer
- Developer
- User (Reader)



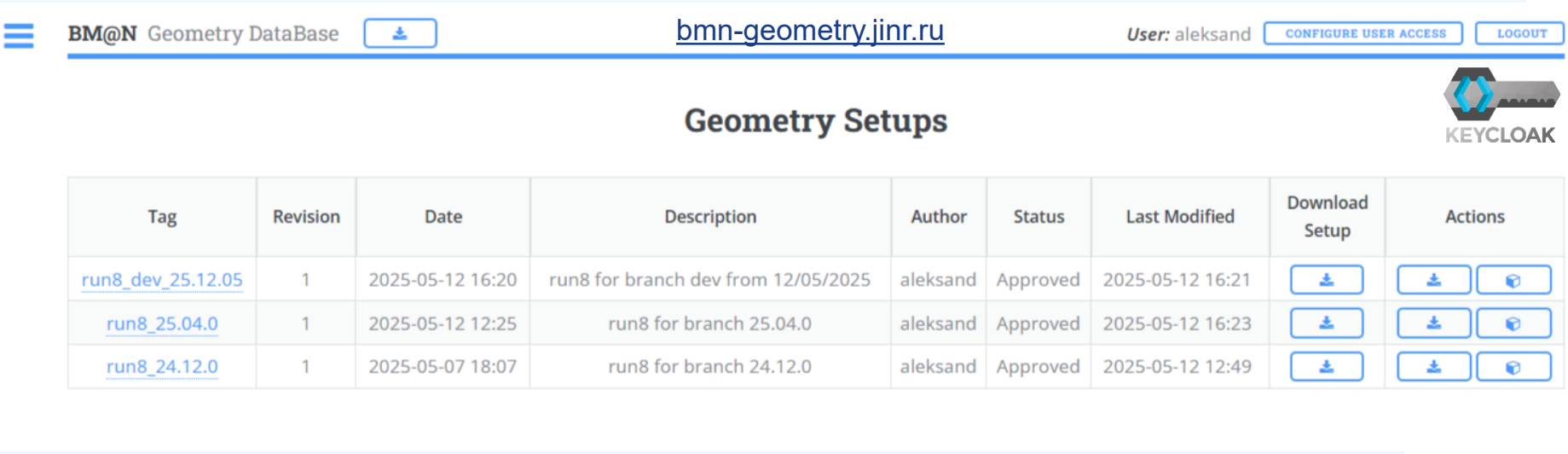
Geometry Module → **Setup Module** → **Setup**

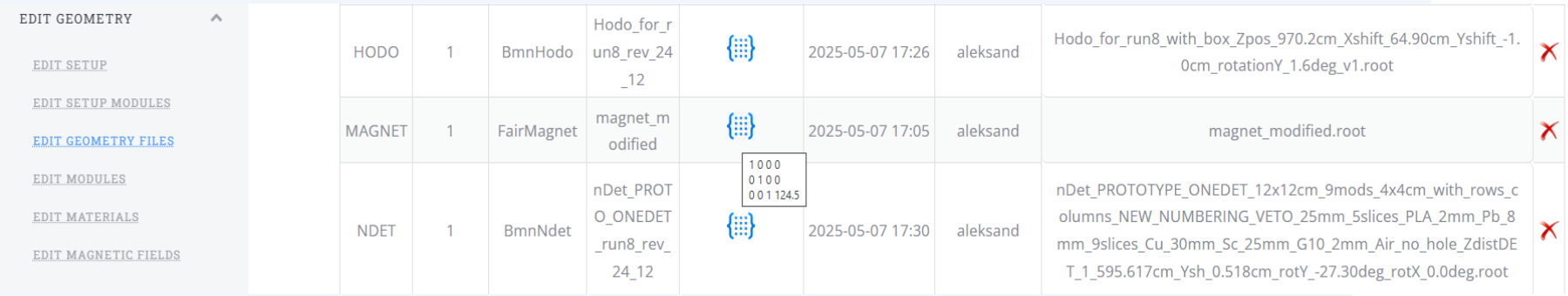
File in the ROOT format containing a detector geometry

Geometry module + link to the parent geometry module + its placement in the parent module

Combination of setup modules, which represents the full setup geometry

Geometry Web Platform





BM@N Geometry Database has filled with the setup geometries for Run 8 (24.12.0, 25.04.0, dev_25.05.11)

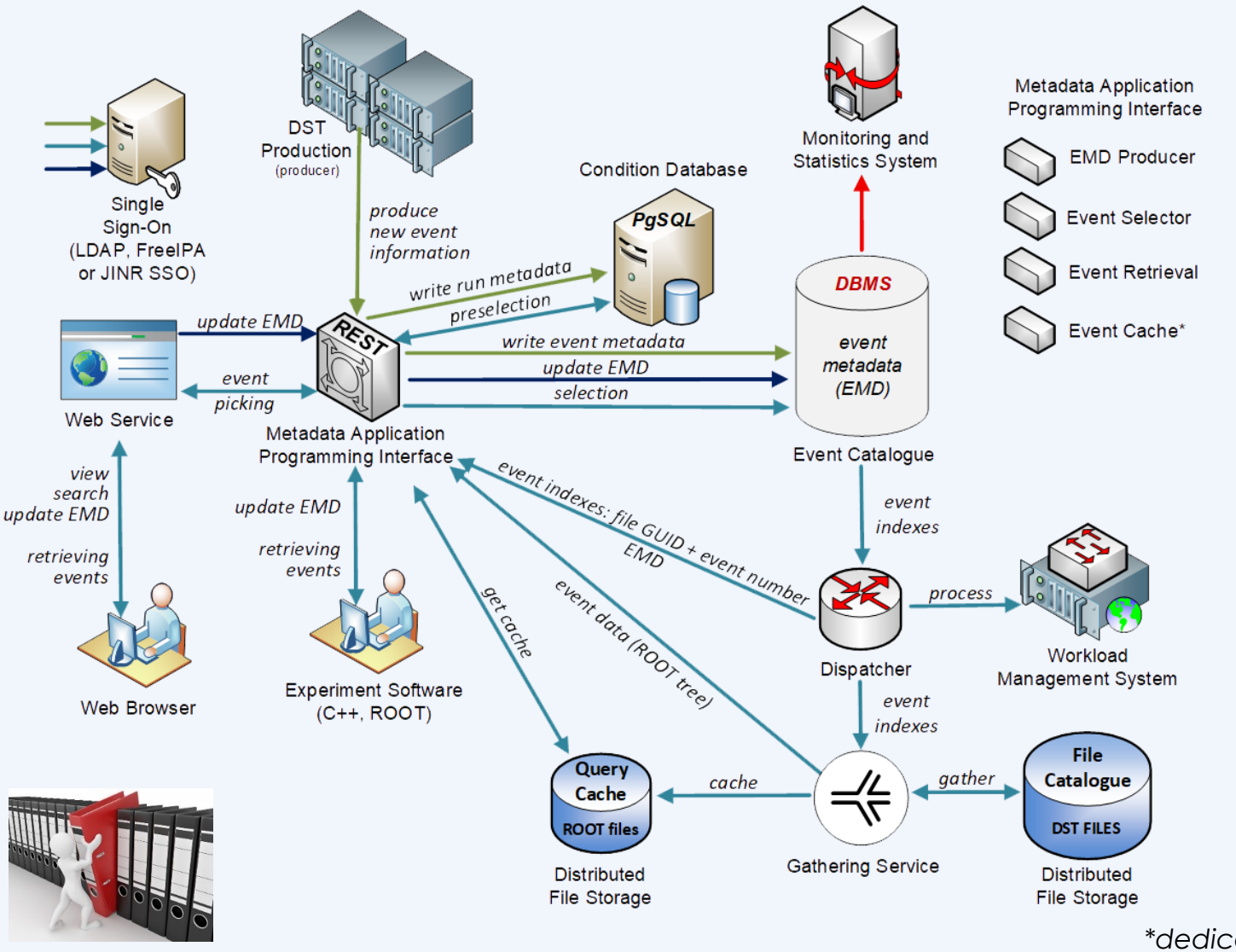
User Interface Functions:

View Add Edit Approve Download

Event Metadata System

Offline Information System

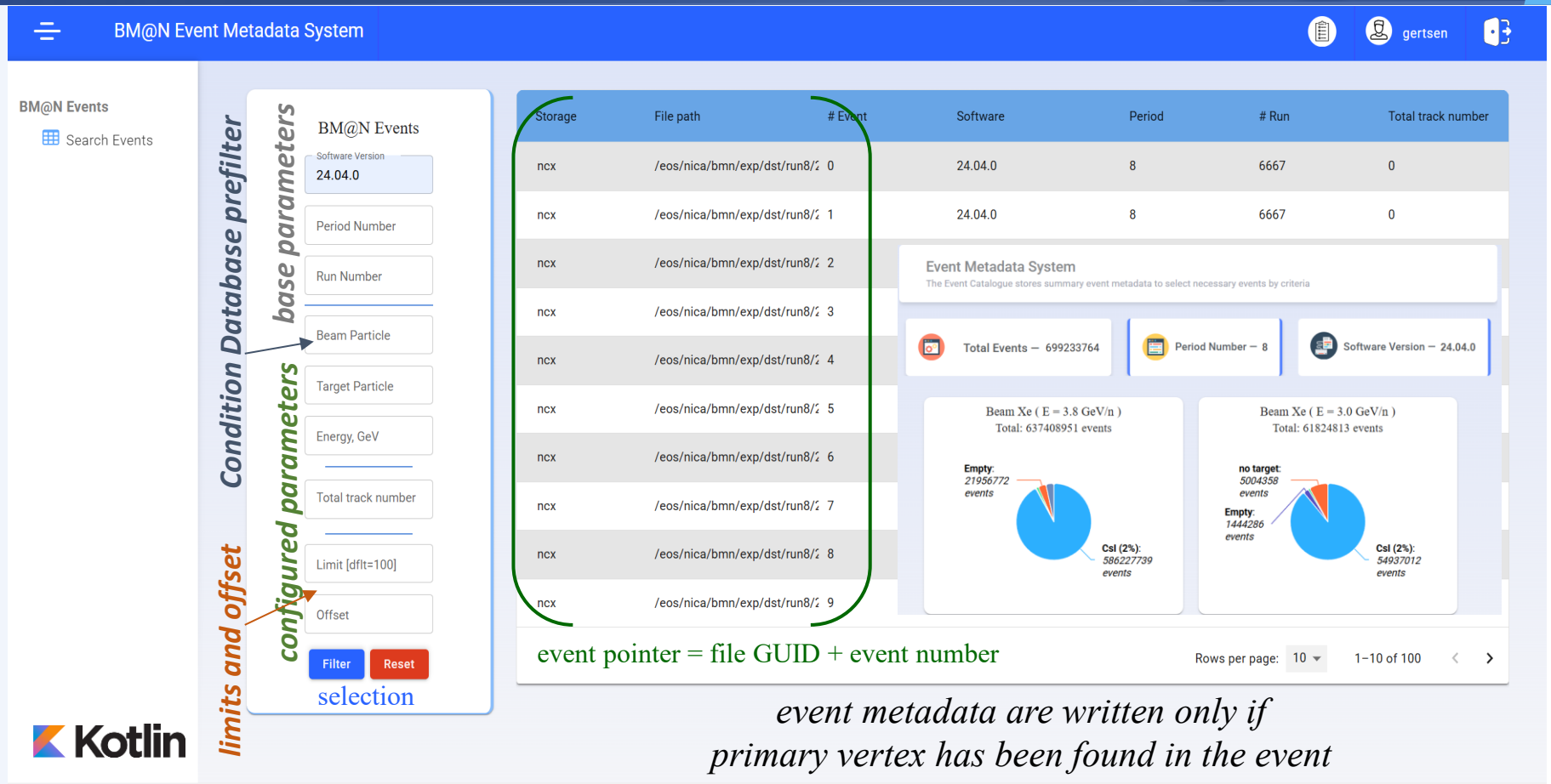
Event Metadata System. *Architecture*



- Event Catalogue based on PostgreSQL
- Integrated with the Condition Database
- REST API and Web UI developed on Kotlin multiplatform
- Configurable to support arbitrary metadata
- Service for automatic writing new event metadata to the Catalogue
- Role-based access control
- Monitoring System

**dedicated server on the DAQ Farm*

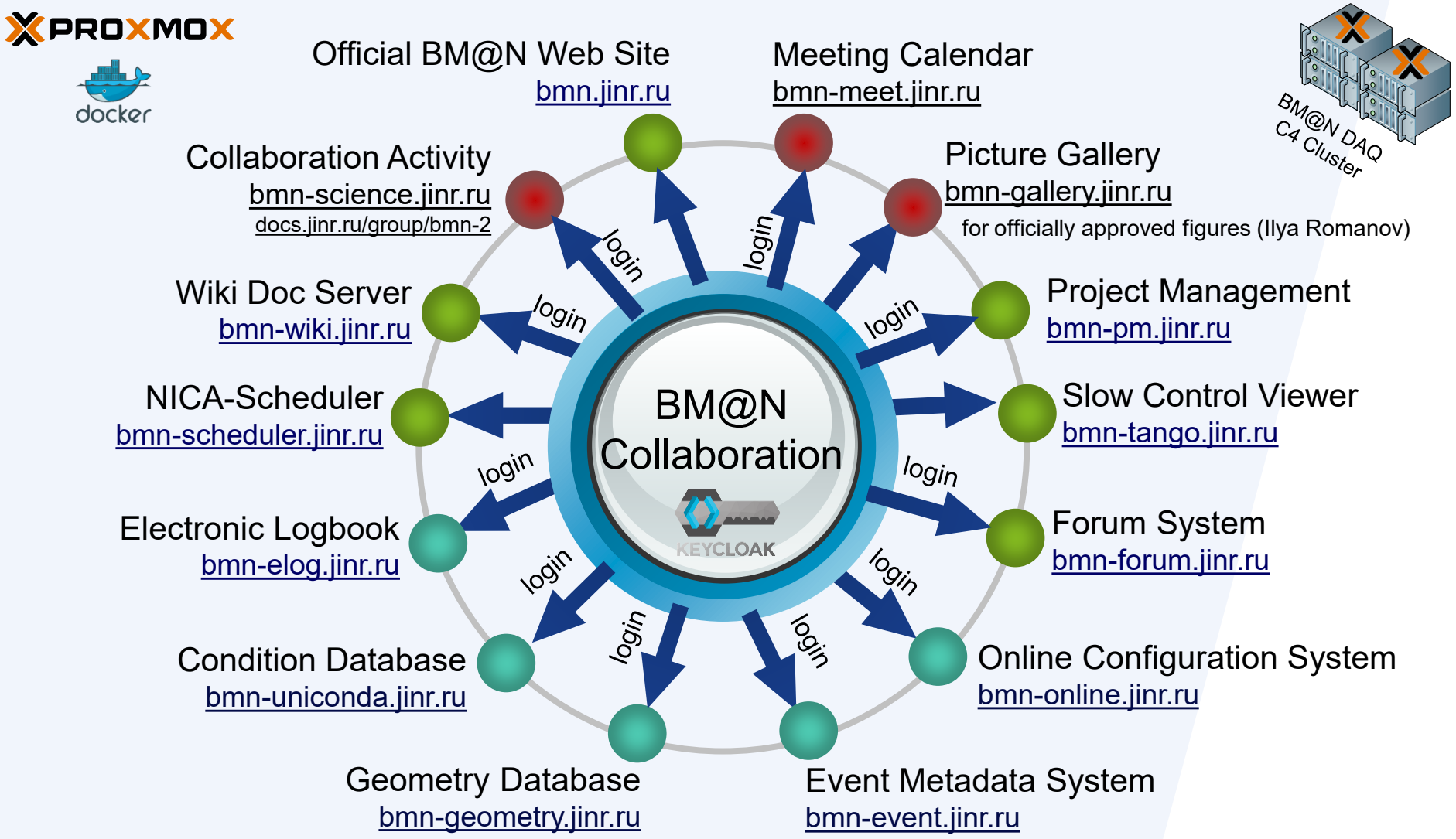
Event Metadata System. *Web Interface*



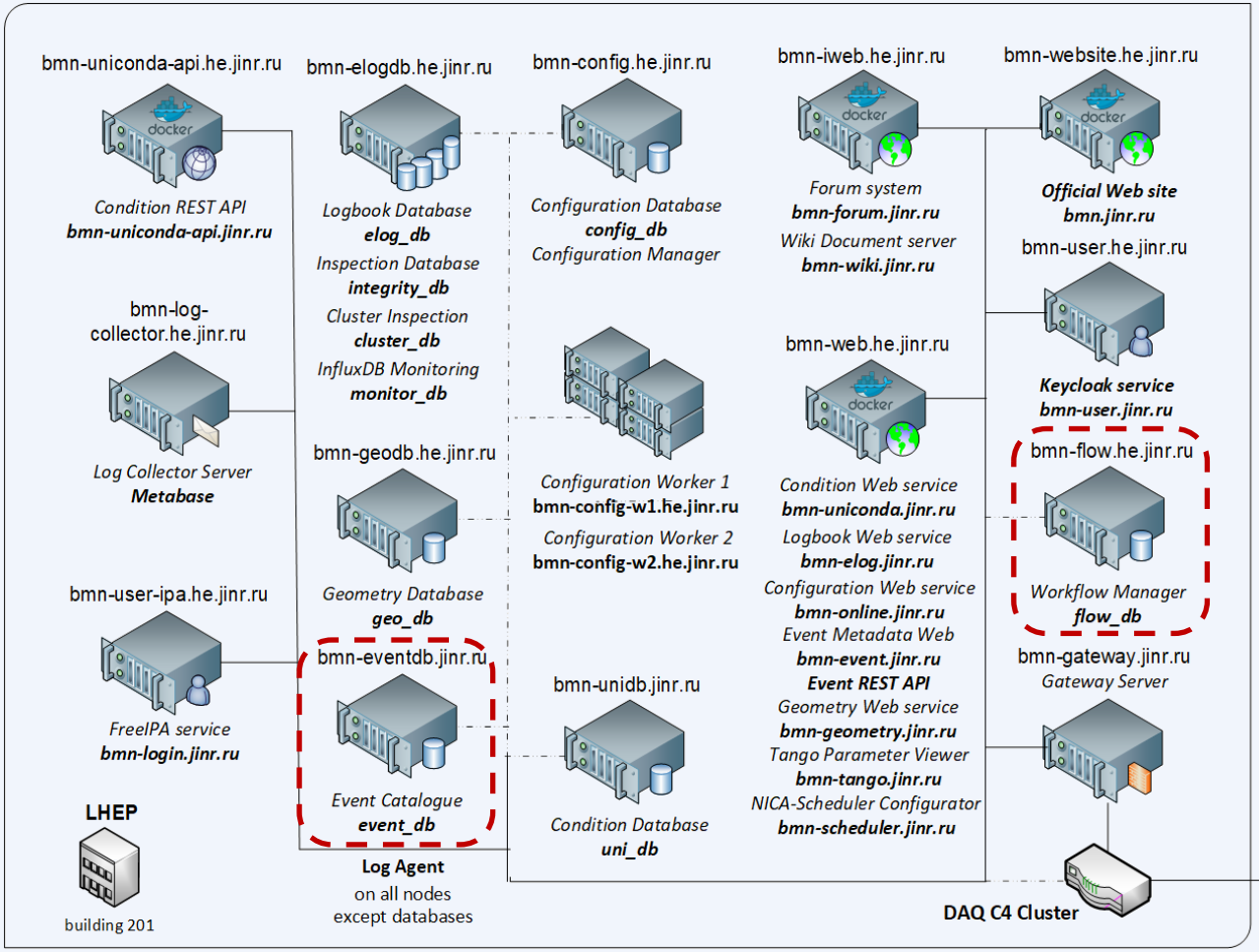
event metadata are written only if primary vertex has been found in the event

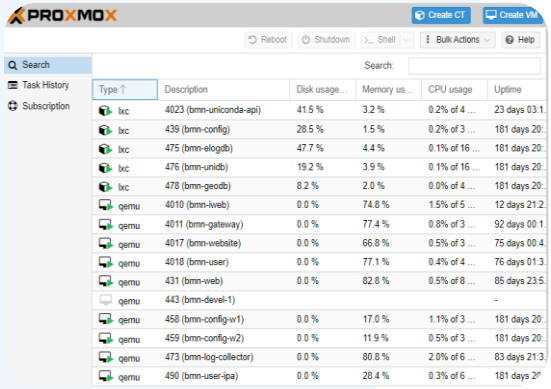
- enables users to browse and quickly search for event metadata stored in the Event Catalogue and retrieve events, which satisfy given parameters
- provides events according to the selected event metadata and run metadata of the Condition Database

BM@N Software Ecosystem



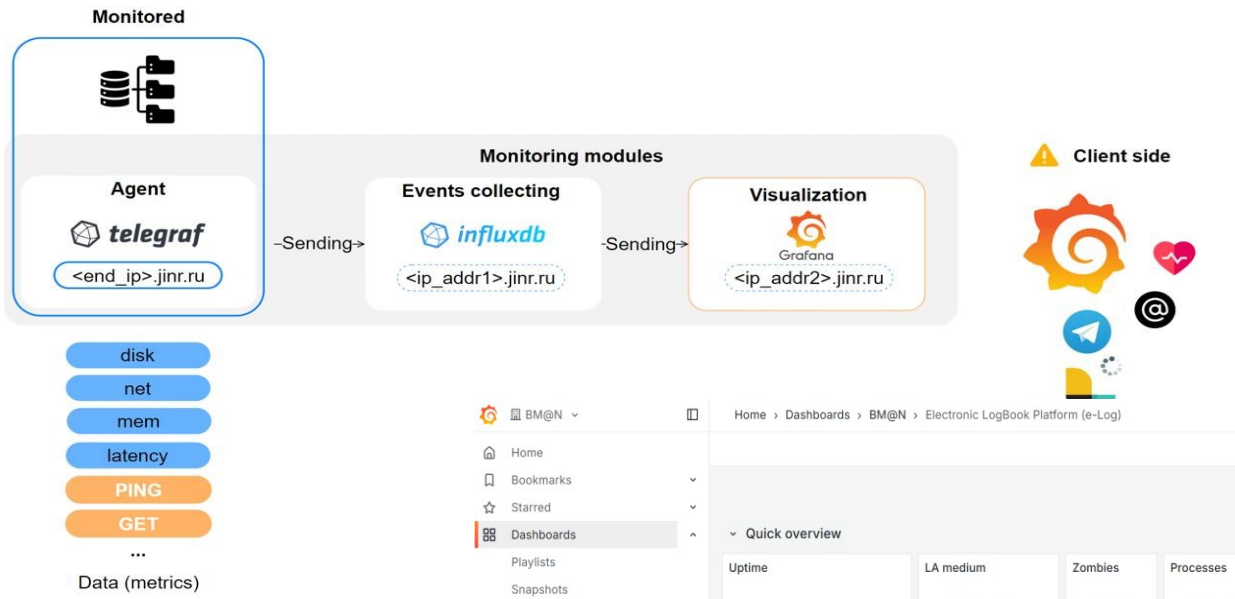
BM@N Software. *Migration to DAQ C4 Cluster*



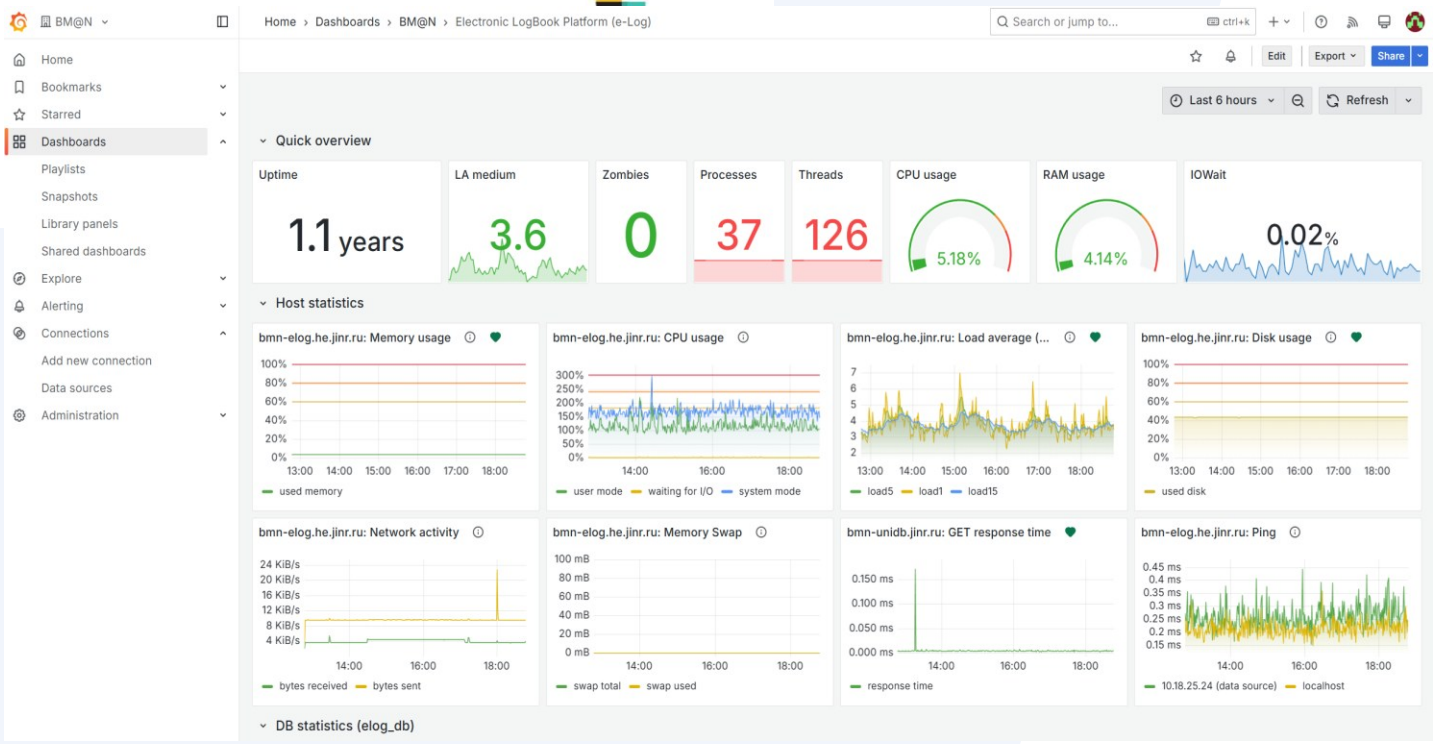


All the systems and services have been moved to the DAQ C4 Cluster (thank to *Ilya Slepnev and DAQ team), which* uses *Proxmox* virtualization and resource management platform

BM@N Monitoring System



- Ping servers, HTTP request and SQL latency to check current status
- Monitor server parameters, such as *Disk*, *CPU*, *Memory*, etc.
- Response time stored in InfluxDB
- Use JINR Grafana service for visualization and failure alerting



- Module architecture
- Configurable via JSON file
- Deploying with **Ansible playbooks**
- Email and **Telegram** notifications

Distributed Processing and Computing Complex

JINR prizes 2024: *Second Prize*

For methodology, research and technology papers

"Development of the software complex for the implementation of a unified architecture for distributed data processing and storage at the BM@N/NICA experiment"

Authors: E. Alexandrov, I. Alexandrov, N. Balashov, A. Chebotov, I. Filozova, K. Gertsenberger, P. Klimai, A. Moshkin, I. Pelevanyuk, G. Shestakova

BM@N Computing Platforms

/bmn-daq-computing-center/

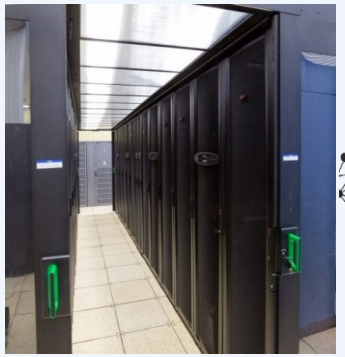
BM@N Online Cluster
ddc.jinr.ru
(LHEP, b.205)

bmn.jinr.ru/nica-cluster/

NICA Cluster
ncx[101-106].jinr.ru
(LHEP, b.216)

bmn.jinr.ru/micc-complex/

GRID Tier1&2 Centres
lxui.jinr.ru (CICC)
(MLIT, b.134)



bmn.jinr.ru/hybrilit-govorun/

HybriLIT platform
(«Govorun» SC)
hydra.jinr.ru
(MLIT, b.134)

OS: AlmaLinux 9.5

OS: CentOS / Scientific Linux 7.9 (EOL on June 30, 2024)

Central Software Repository based on ***CVMFS*** for the experiment

CEPH: 2.8 PB (*replica*)
CEPH (hot): 100 TB_{ssd}
SLURM: ≈**600** cores

EOS: 1.3 PB (*replica*)
NFS: **300 TB** (*for NICA*)
SLURM: ≈**1800** cores
(*for all NICA users*)

EOS: 1.9 PB (*replica*)
EOS CTA: **500** TB_{tapes}
SLURM: 2500 cores
(*for all NICA users*)

ZFS: 200 TB
Lustre: **300** TB_{ssd} (*for NICA*)
SLURM: *bmn* – **192** cores

BM@N software is deployed on JINR CVMFS for Centos 7 and AlmaLinux 9

AlmaLinux 9 does not require cluster configuration script (but different versions of GCC)

BmnRoot & Docker Containers

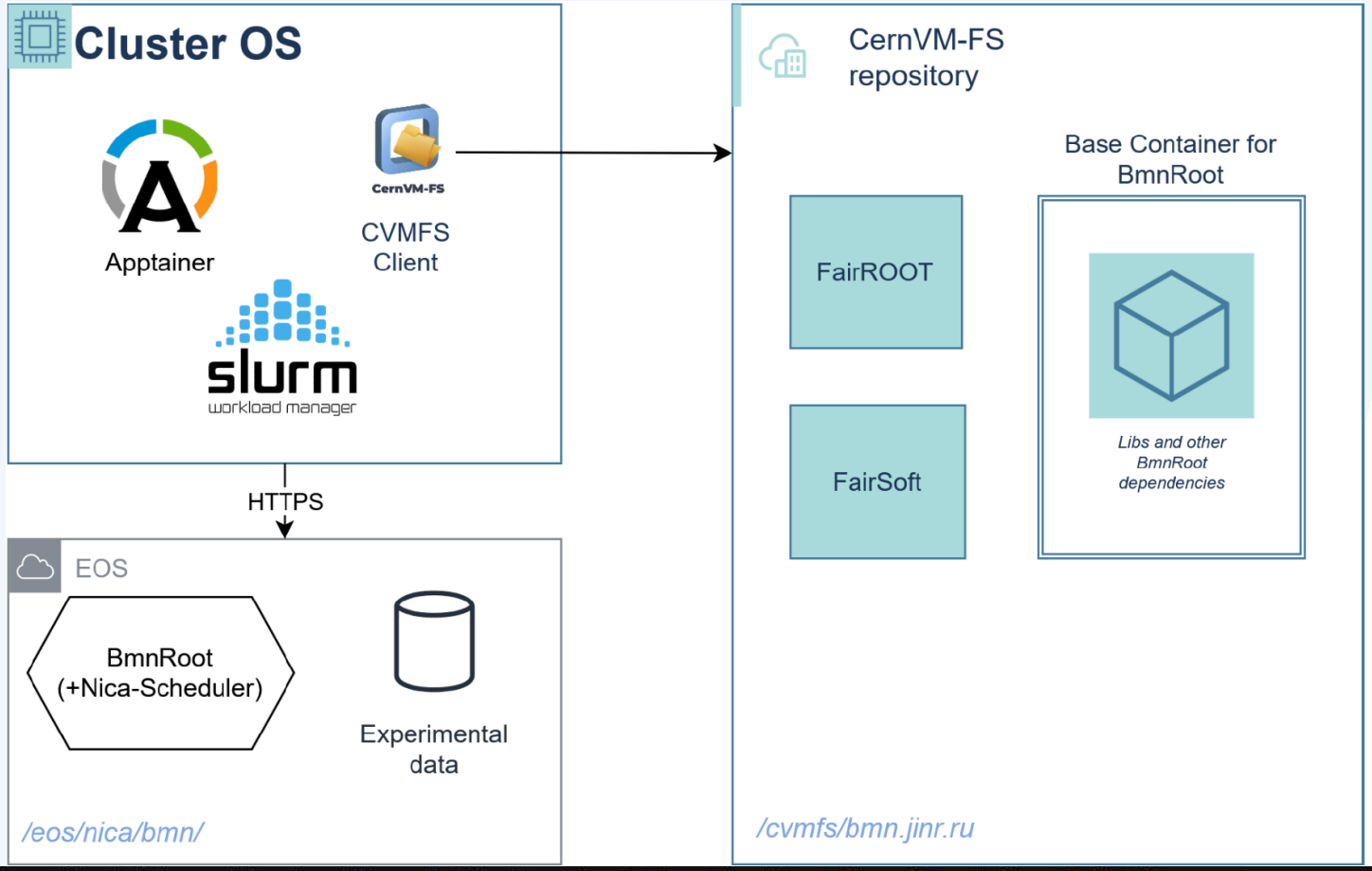
- Bmnroot Pipelines run in Docker containers
  (dynamically provisioned in the JINR Cloud)

- Gitlab-shared-runners – used to run tests before merging a new code:
  AlmaLinux9.4/Ubuntu22.04/CentOS7.9 images = OS + FairSoft + FairRoot
- Gitlab-shared-runners-no-cvmfs – used to run deploy jobs for publishing
- quickly add any OS environments to CI pipelines

- User Apptainer Containers with BmnRoot software

- base image = OS + FairSoft + FairRoot
  2 containers (on AlmaLinux 9 & Ubuntu 22.04) with full local installation
  2 containers with CernVM-FS client to the central JINR CVMFS repository
- users do not need to install software – just run the BmnRoot container
  the user instructions: https://bmn.jinr.ru/software-installation (2nd tab)
- hosting computer can potentially run any operating system
- great for short-period students and fast analysis
- BmnRoot (& its dockers) is automatically built and published with GitLab CI

BmnRoot Containers for Distributed Computing




```
lxui01:/eos/nica/bmn/users/itsrin8/bmnroot/services/nica_scheduler/examples > nica-scheduler -d bmn_sim_container_lxui.xml
Warning in <UnknownClass::SetDisplay>: DISPLAY not set, setting it to softco-v32.cust.smartspb.net:0.0
DEBUG nica-scheduler$ File count in the regular expression: 99
DEBUG nica-scheduler$ Batch command (length 194): sbatch -J bmn_sim_container  -a 1-99%30 -D /afs/jinr.ru/user/i/itsrin8/scheduler_cont /eos/nica/bmn/users/its
rin8/bmnroot/build/bin/job_3a2d40c4245169e1.sh
DEBUG nica-scheduler$ Batch command output = Submitted batch job 11943230

nica-scheduler$ The job 'bmn_sim_container' has been submitted with ID: 11943230. Enter 'squeue' command to check status.
lxui01:/eos/nica/bmn/users/itsrin8/bmnroot/services/nica_scheduler/examples > squeue -u itsrin8
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
11943230_[31-99%30      cicc bmn_sim_  itsrin8 PD       0:00      1 (JobArrayTaskLimit)
```

Data Storages for BM@N

ceph

for BM@N online (2.8 PB)

build on HDD with SSD buffer, 1.4 PB free

NICA cluster

EOS

for BM@N offline (1.3 PB)

build on HDD, 330 TB free

sync | duplicate

MLIT MICC

EOS

for BM@N offline (1.9 PB)

build on HDD , 700 TB free

NICA cluster

NFS

fast on NVMe SSD

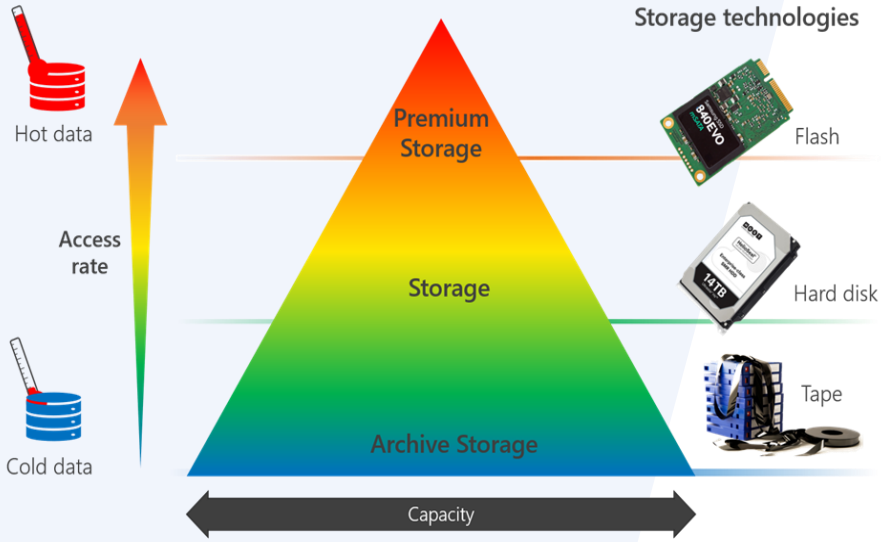
MLIT CICC

nope

HybriLIT

lustre

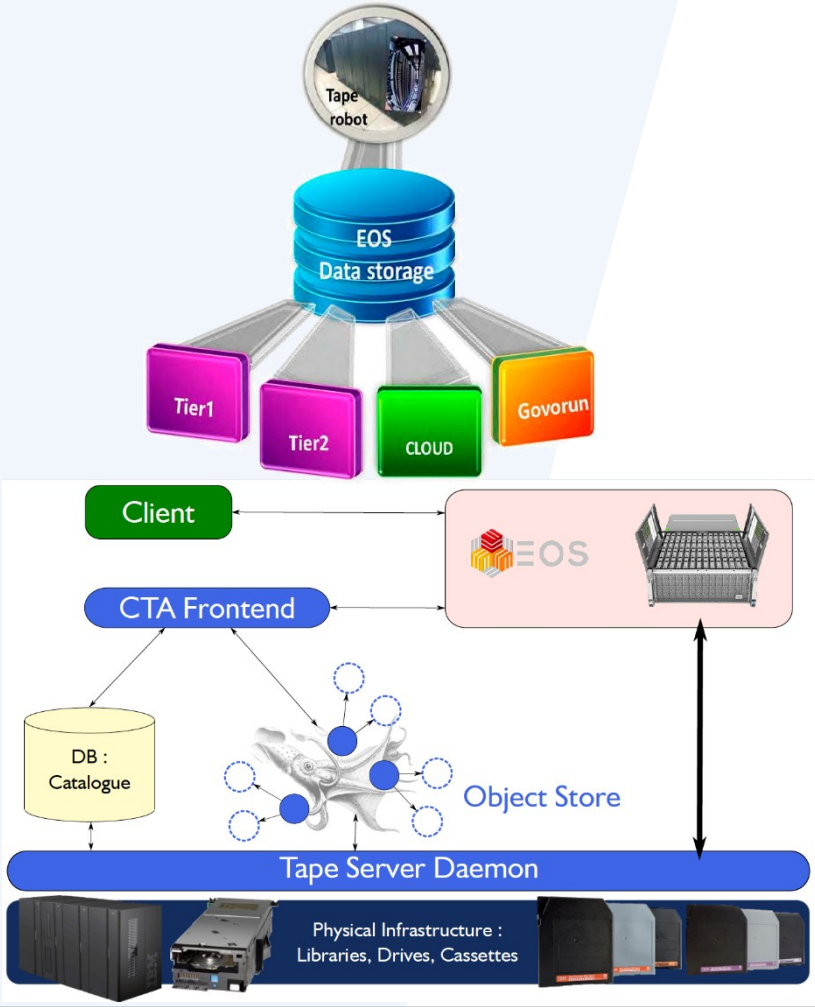
fast on NVMe SSD



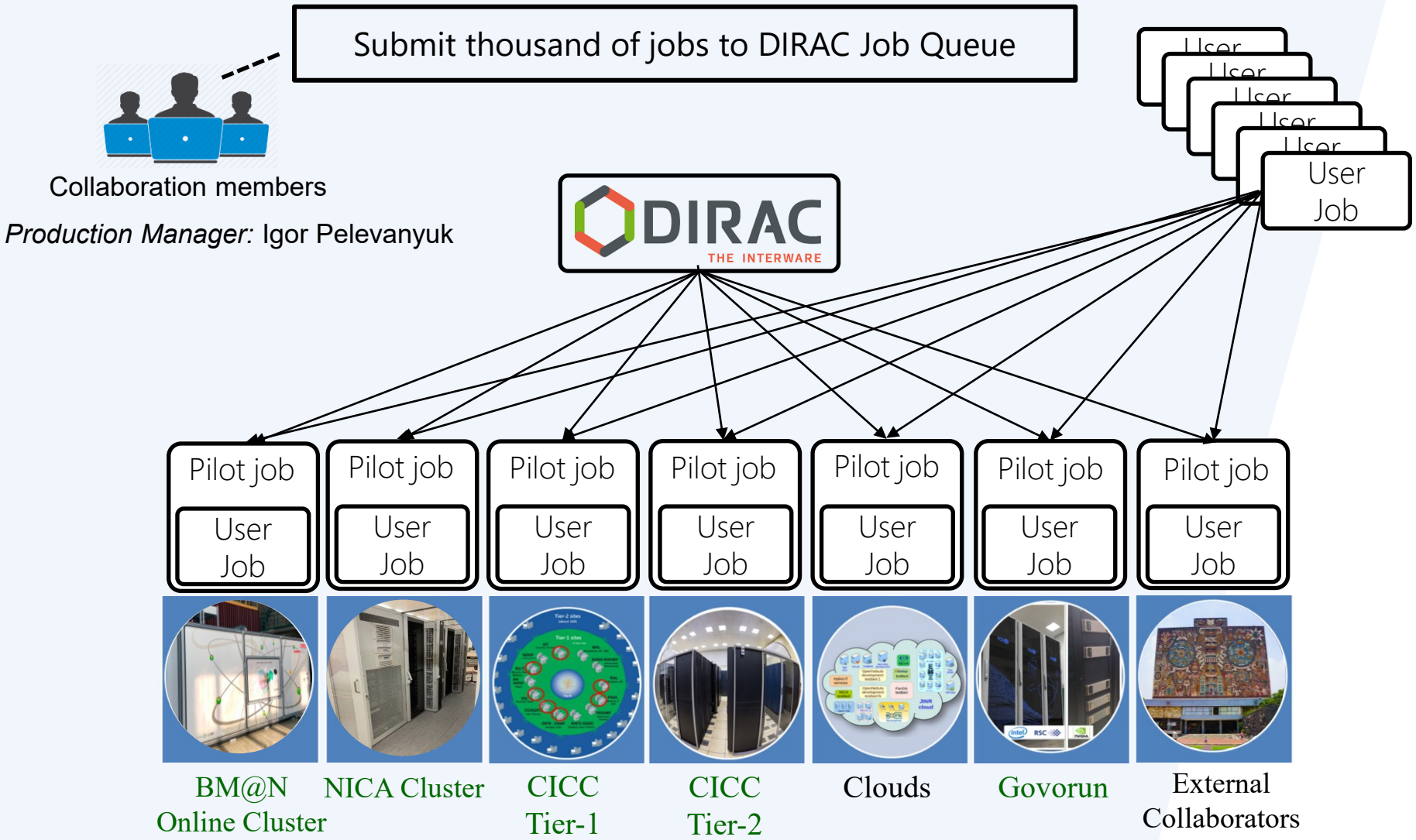
Archival Tape Storage for BM@N

EOS CTA Integration in MLIT

- CTA tape is a new archive solution developed at CERN to replace Castor
- Extends MLIT EOS with tape backend functionality
- Tape “bringonline” exposed via EOS, and XRootD protocols, Gfal2 support
- Can be handled transparently by FTS
- Advantages: long lifespan, cost of use, energy efficiency, security
- Tape robotic systems – a long-term storage for BM@N, stores *raw* and *gen* data, *online raw data backup to tapes*
- Stores Run8 raw data already



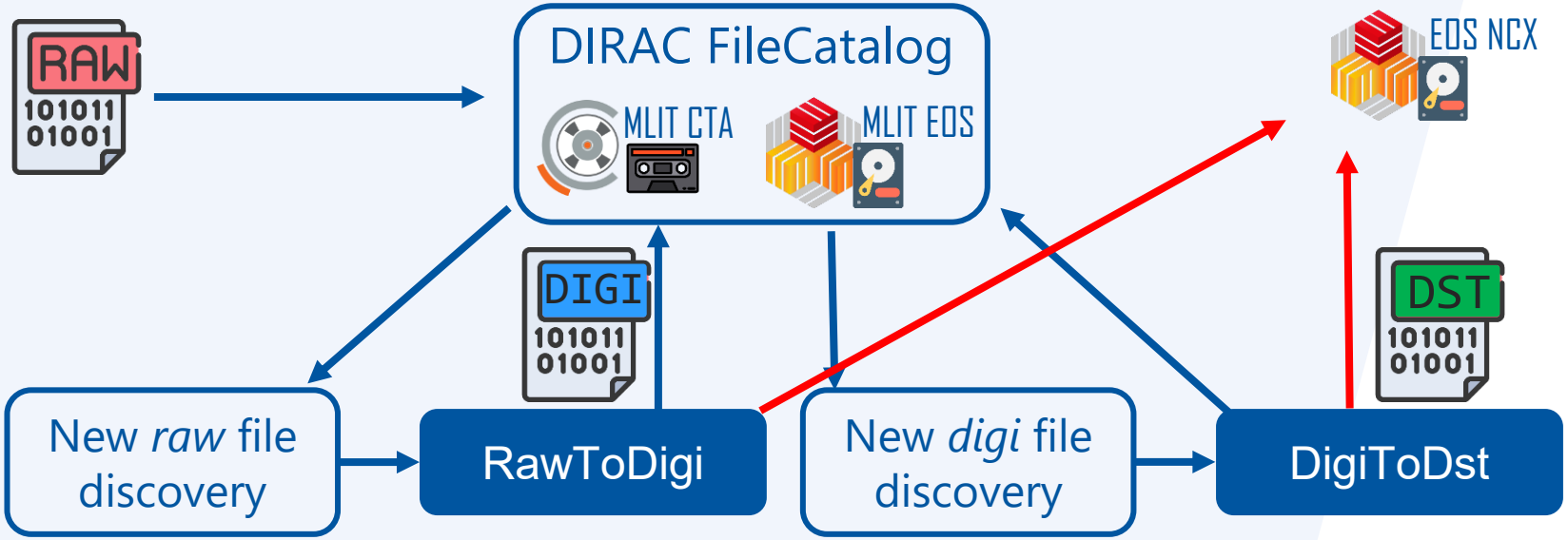
DIRAC Workload Manager for BM@N



Automation Scheme with DIRAC

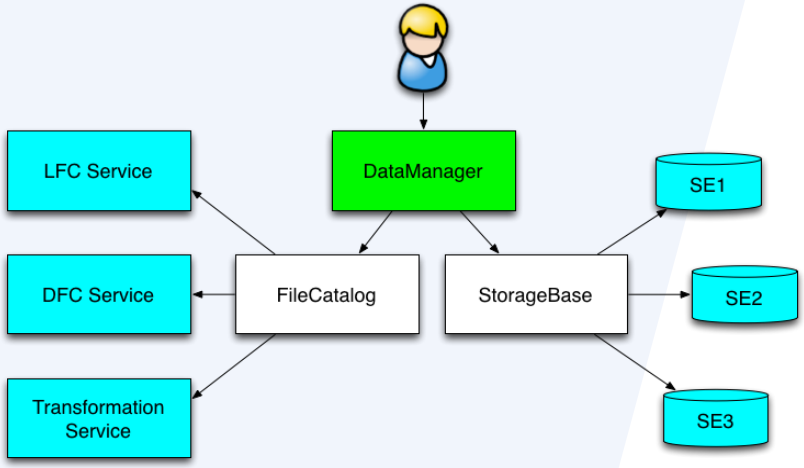
To automate job processing the following tasks should be completed:

1. **Upload** new *raw* file to DIRAC file catalog.
2. **Detect** new *raw* file in DIRAC file catalog and **submit** RawToDigi job for each new *raw* file.
3. **Detect** new *digi* file in DIRAC file catalog and **submit** DigiToDst job for each new *digi* file.
4. **Upload** *digi* and *dst* files to NCX cluster.



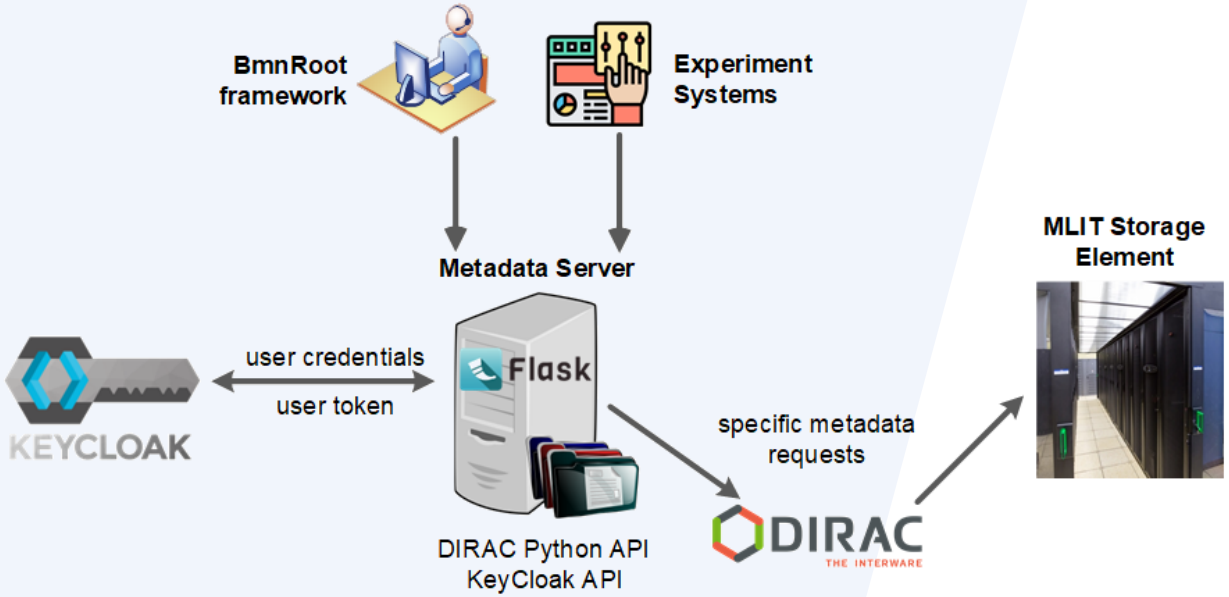
Data Management System for BM@N

- DIRAC File Catalog (DFC) is maintaining a single global logical name space
- A user sees it as a single catalogue with additional features
- DataManager is a single client interface for logical data operations
- DFC also may host Metadata



BM@N DFC Metadata (Run 8):

- **period and run number**
- **start and end datetime**
- **beam and target particles**
- **run type**
- **energy**
- **magnetic field**
- **start and end event number**
- **event count**
- **file size**



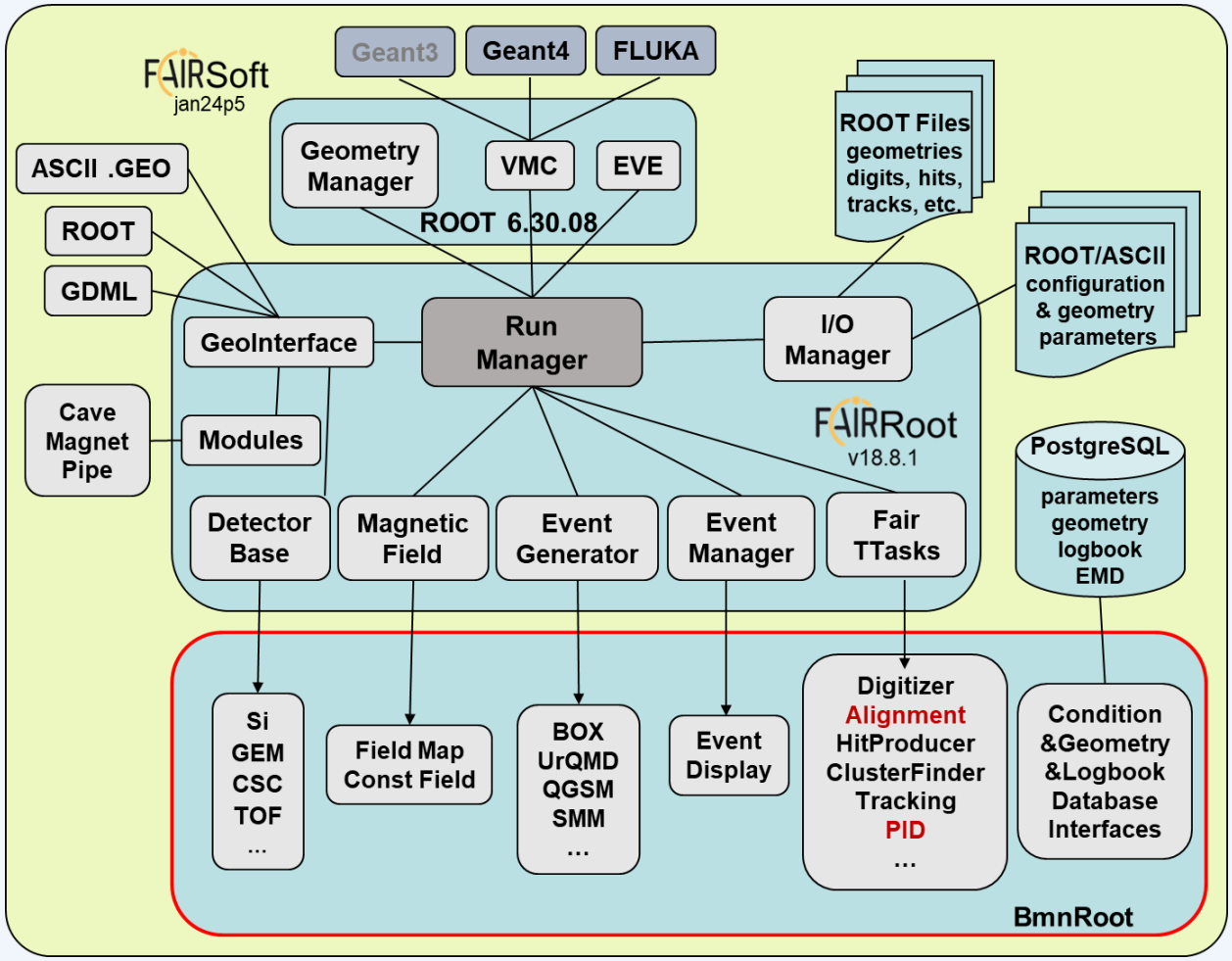
BmnRoot Framework

as a central BM@N software system

BmnRoot. *Production Tag 25.04.0*

FAIRSoft jan24p5 FAIRRoot v18.8.1

- FairSoft jan24p5 is used now (with ROOT 6.30.08)
- FairRoot v19.0.0 is available but requires new compilation approach in BmnRoot



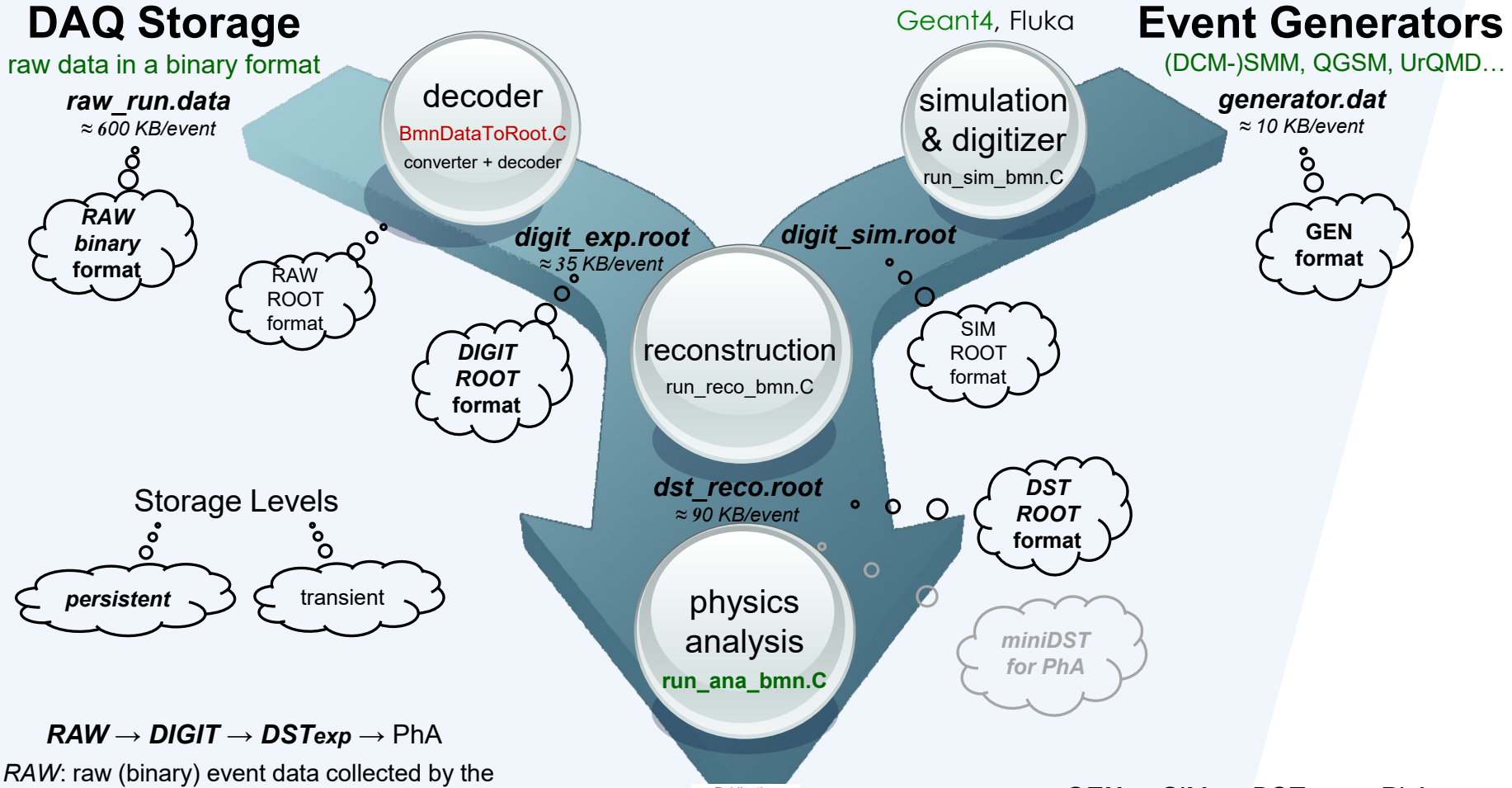
- BmnRoot tag 25.04.0 has been issued and DST production has been done using DIRAC
- The new BmnRoot tag has a bug (*25.04.2025*) restricting us from reading previous DST data
- Detector geometries have been added for BM@N Run 9
- Raw Data Decoder has been updated for Run 9
- Single source for simulated and experimental data has been implemented (BmnFileSource)
- The C++ interface of the Geometry Database has been included to the compilation
- A new test for the raw decoder has been added to the pipeline
- Clang-format checker has been updated to version 19.1.3

Current BmnRoot Issues

- ✓ Raw Data Decoder should be checked to write correct run and raw file metadata including correct datetime
- ✓ The current BM@N geometry is not passing standard ROOT tests because of several overlaps
- ✓ BmnRoot macros must contain common logic and parameters without local input parameters, user paths, hardcoded global parameters:
  - No default input parameters for a concrete user (but for production)
  - No inner logic for own local machine
  - No own local paths and local parameters

  Simple check of all the macros was integrated to the BM@N pipeline (night checks)
- ✓ Strict separation of short summary output (by default) from debug output for individuals (macro output should be adapted for mass production), new debug messages *FairLoggger::Severity* (debug level) or *fVerbose* flag (*SetVerbose* function) must be used
- ✓ Pure BmnRoot (from GitLab) takes up 1050 MB of disk space, where “bmnroot/input/” ≈ 700 MB (mostly, magnetic field files) and “bmnroot/parameter/” ≈ 100 MB.
- ✓ SRC information will be removed from the BM@N databases → not done yet
- ✓ The task of generating Doxygen documentation for BmnRoot is still open

BmnRoot. *Event Data Model*



RAW → ***DIGIT*** → ***DSTexp*** → PhA

RAW: raw (binary) event data collected by the DAQ system after the Event Builder

DIGIT: detector readings (event digits) after the raw data decoder (ROOT macro)

DSTexp: reconstructed data of experimental events

hists
plots
results

GEN → SIM → ***DSTsim*** → PhA

GEN: particle collisions description received by event generators

DSTsim: reconstructed data of simulated events

BM@N Software Contribution

BM@N Software Contribution

Tagir AUSHEV, *Peter KLIMAI, Alexander NOZIK, PhD student, 3 x students (6y)*
Event Metadata System, Event Display, Monitoring Service, Services for BM@N Databases…

Sergei NEMNYUGIN, *Anatoly ALEXANDROV, Rinat NIZAMOV, Anastasiya IUSUPOVA*
RUCIO File Catalogue, Docker Containers for BmnRoot, BM@N Event Visualization

***Director*: S. V. SHMATOV. *Scientific Leader*: V. V. KORENKOV**

Igor ALEXANDROV, Evgeniy ALEXANDROV, Irina FILOZOVA, et alia
Geometry Database, Configuration Online Platform, DQA System

Zarif SHARIPOV, Zafar TUKHLIEV. ***Automation of BM@N Alignment***

Alexander AYRIYAN, Vladimir PAPOYAN
Implementation of BM@N Particle IDentification based on ML

Spokesperson: Mikhail KAPISHIN

BM@N Software "Group" (4 FTE)

Konstantin GERTSENBERGER
Alexander CHEBOTOV, Ilya ROMANOV, Igor POLEV

BM@N Computing and Technical Contribution

BM@N Computing & Technical Contribution

***NICA Computing Leader*: Andrey DOLBILOV**

Ilia SLEPNEV (LHEP Deputy Director for Computing)
BM@N DAQ & DDC support

Ivan SLEPOV
NICA Cluster support

Igor ZIRONKIN
BM@N data management system based on DIRAC File Catalogue

***Director*: S. V. SHMATOV. *Scientific Leader*: V. V. KORENKOV**

Nikita BALASHOV: ***CVMFS Deployment, GitLab Services, Docker Containers***

Igor PELEVANYUK: ***DIRAC workload management system and BM@N mass production***

Dmitriy PODGAYNY, Oksana STRELTSOVA
HybriLIT and SC Govorun support

Daria PRIAKHINA, Vladimir TROFIMOV
Modelling System for BM@N computing infrastructure

Software Strategy Risks

- Software Fund
  - *no financial fund*
  - *no support of the external software participants*
- Staff
  - *no full-fledged software group*
- Computing Resources
  - *not enough guaranteed resources for BM@N (only 192 cores on Govorun, online cluster)*
    2025→2027: 6 000 cores required
  - *not stable work of the NICA cluster*
  - *unrealizable procedure of obtaining VPN (SSO) account for some external collaborators*

Thank you for your attention

BACKUP

Automating Run Statistics

*root bmnroot/database/examples/uni_db/**postrun_update.C***

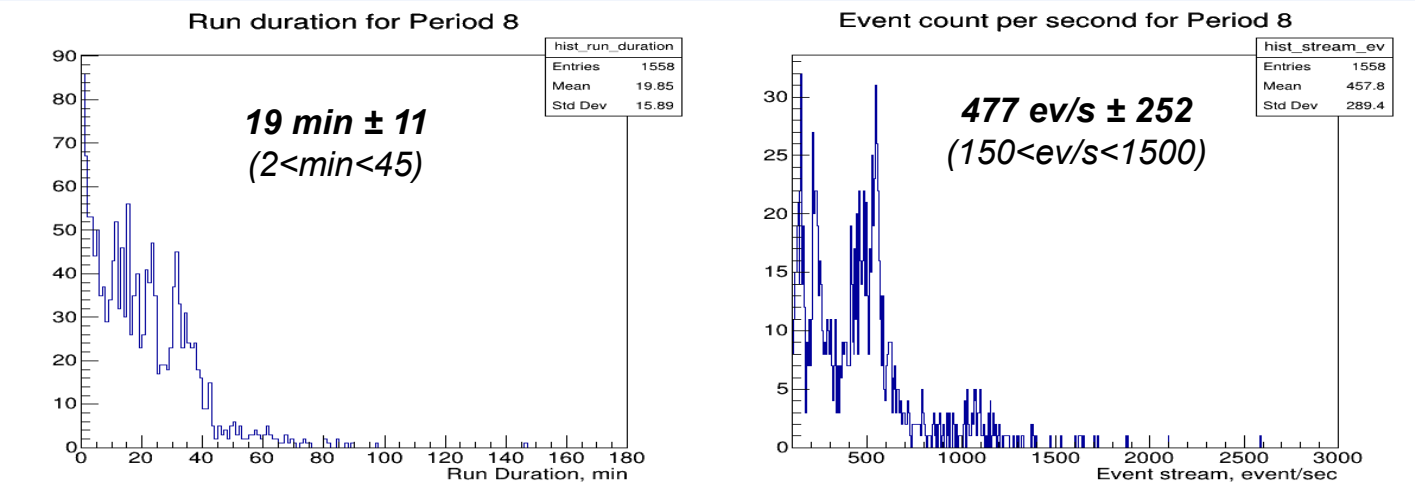
*root bmnroot/database/examples/uni_db/**postrun_check.C***

*root bmnroot/database/tango/examples/**show_avg_field.C***

*root bmnroot/database/uni_db/examples/run/**show_run_stats.C***

*root bmnroot/database/uni_db/examples/raw/**show_raw_stats.C***

*root bmnroot/database/uni_db/examples/root/**show_root_stats.C***

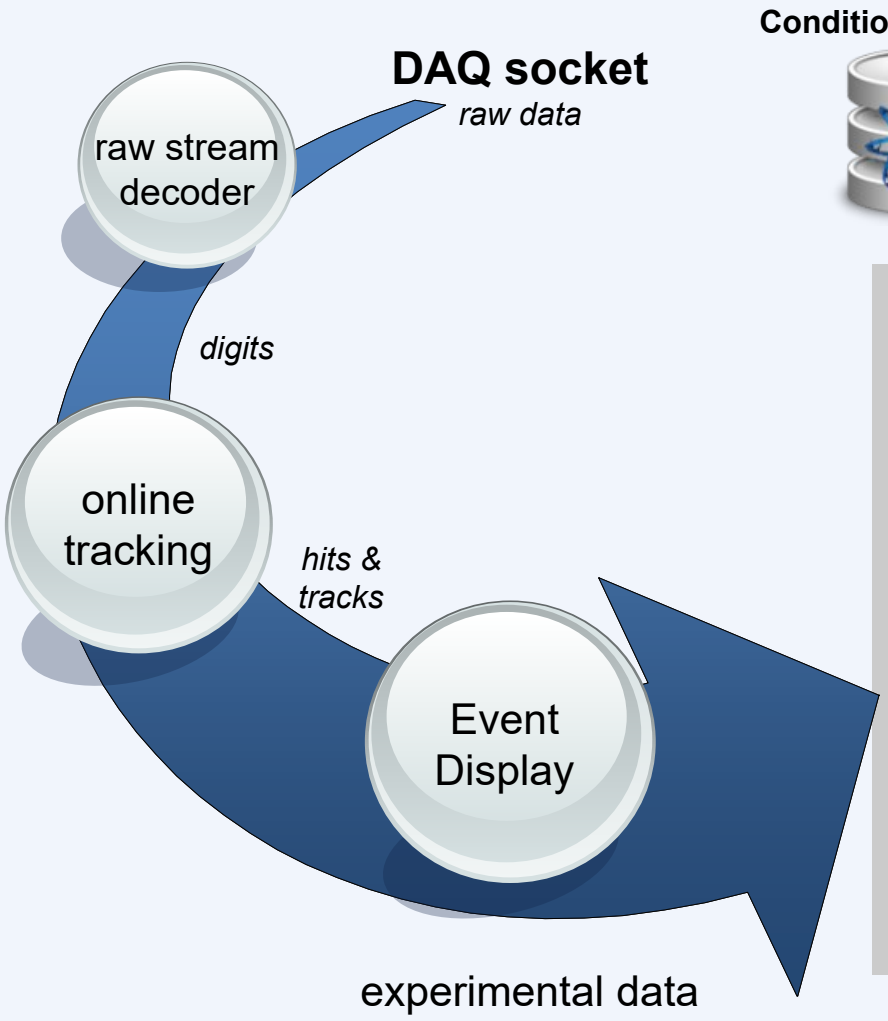


python bmnroot/services/inspection/raw_inspection/filter_raw_data.py python bmnroot/services/inspection/raw_inspection/catalog_raw_data.py

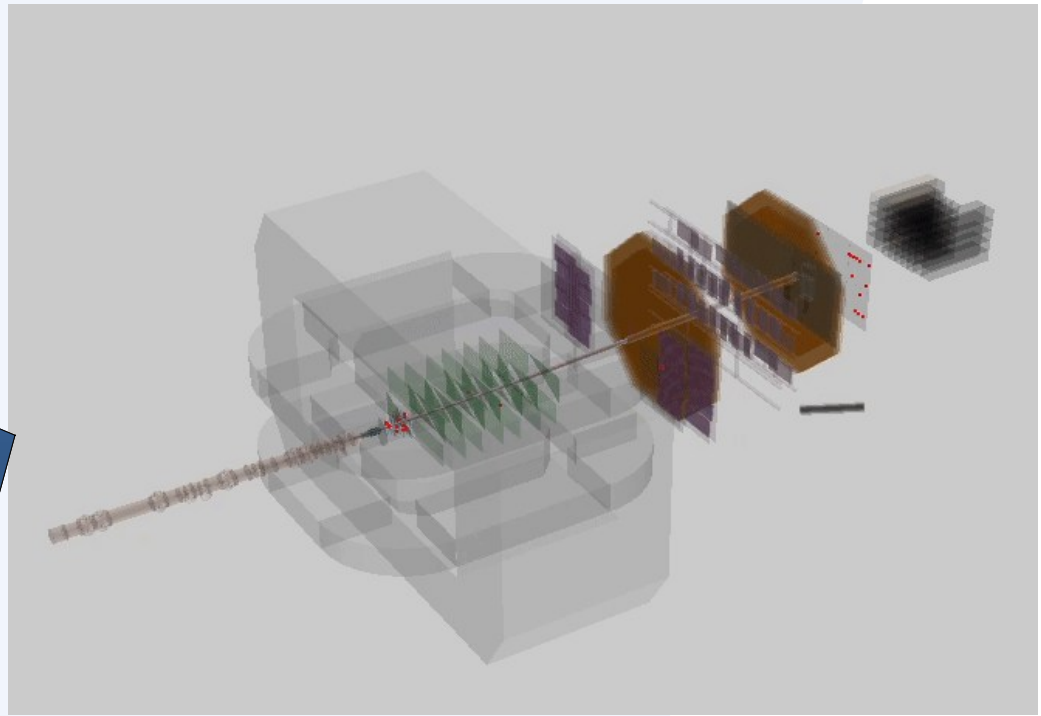
python bmnroot/services/inspection/raw_inspection/transfer_raw_data.py

python bmnroot/services/statistics/stats .py

Online Event Display (BM@N Event Monitor)



Event Display was updated with new branch names and new grouping of reconstructed tracks



Online Event Display
BM@N hits and tracks

BM@N Computing Software Architecture