Processing and Storage of HEP Experimental Data @ JINR

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On behalf of
Meshcheryakov Laboratory of Information Technologies,
JINR

CHEP Yerevan 2023

Information Technologies @ JINR

Large research infrastructure project
Multifunctional Information and Computing Complex

Leaders: V.V. Korenkov, S.V. Shmatov
Deputy: A.G. Dolbilov, D.V. Podgainy, T.A. Strizh

- **Activity** Multi-purpose hardware and software platform for Big Data analytics
  Leader: P.V. Zrelov
- **Activity** Digital ecosystem (Digital JINR)
  Leaders: D.S. Belov, V.V. Korenkov

Theme 05-6-1119-2014/...
Mathematical methods, algorithms and software for modeling physical processes and experimental facilities, processing and analyzing experimental data

Leaders: O. Chuluunbatar, S.V. Shmatov
Deputy: N.N. Voytishin, P.V. Zrelov

- **Project** Mathematical methods, algorithms and software for modeling physical processes and experimental facilities, processing and analyzing experimental data
  Leader: S.V. Shmatov
  Deputy: A.S. Ayriyan, N.N. Voytishin
- **Project** Methods of computational physics for the study of complex systems
  Leaders: O. Chuluunbaatar, E.V. Zemlyanaya
  Deputy: Yu.L. Kalinovsky, A. Khvedelidze
- **Activity** Intelligent control of technological processes and physical equipment's in JINR and quantum computing in quantum chemistry and physics
  Leaders: S.V. Ulyanov, P.V. Zrelov
- **Activity** Training of specialists in the field of computational physics and information technologies
  Scientific Leader: V.V. Korenkov
  Leaders: A.V. Nechaevsky, D.I. Pryahina, O.I. Streltsova

Information Technologies @ JINR

Dedicated IT tasks and resources for HEP experiments

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Multifunctional Information and Computing Complex

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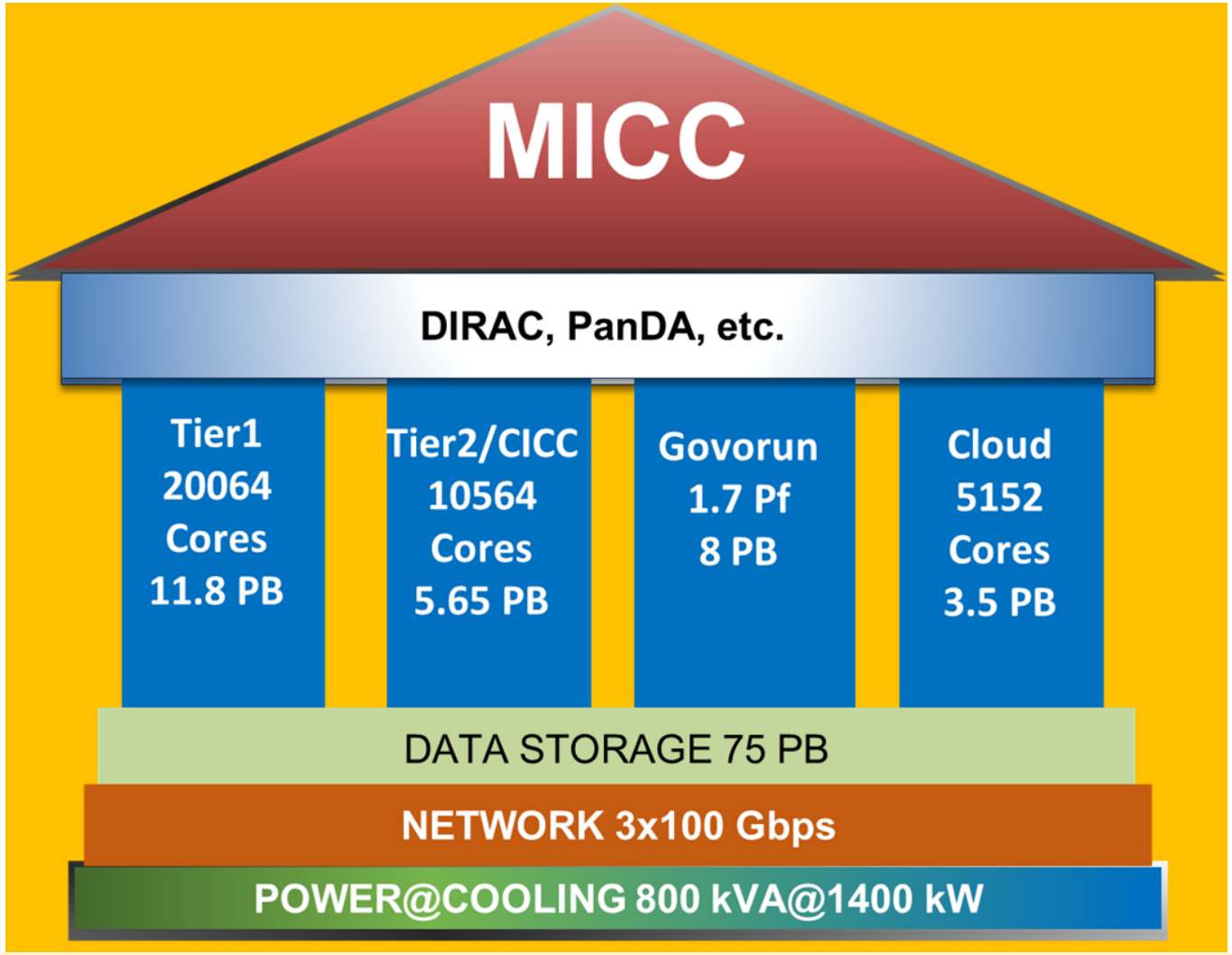
Multifunctional Information and Computing Complex (MICC)



4 advanced software and hardware components

- Tier1 grid site
- Tier2/CICC site
- hyperconverged “Govorun” supercomputer
- cloud infrastructure

Distributed multi-layer data storage system

- Disks
- Robotized tape library

Network

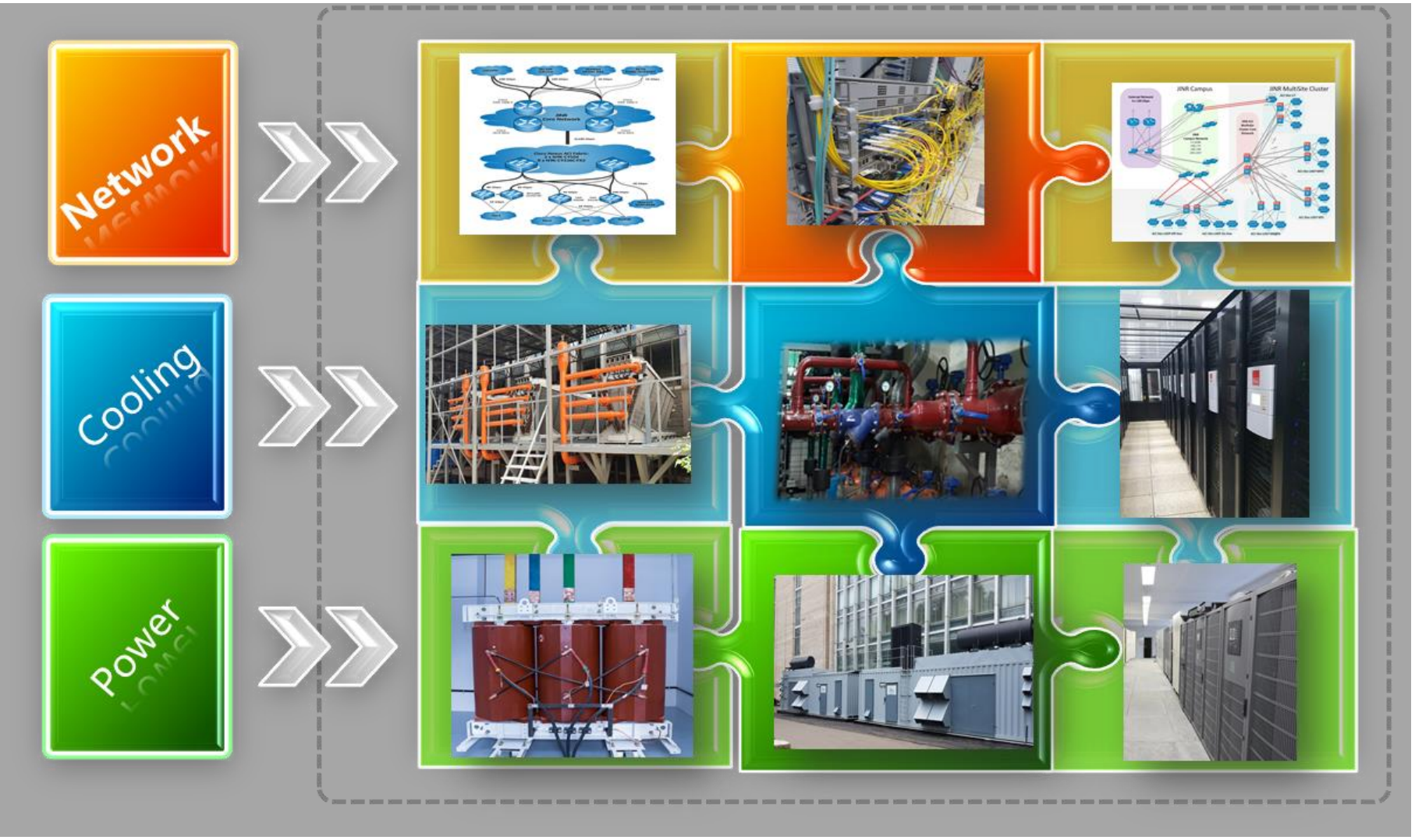
- Wide Area Network
- Local Area Network

Engineering infrastructure

- Power
- Cooling

The main objective of the project is to ensure multifunctionality, scalability, high performance, reliability and availability in 24x7x365 mode for different user groups that carry out scientific studies within the JINR Topical Plan.

MICC Power @ Cooling @ Network



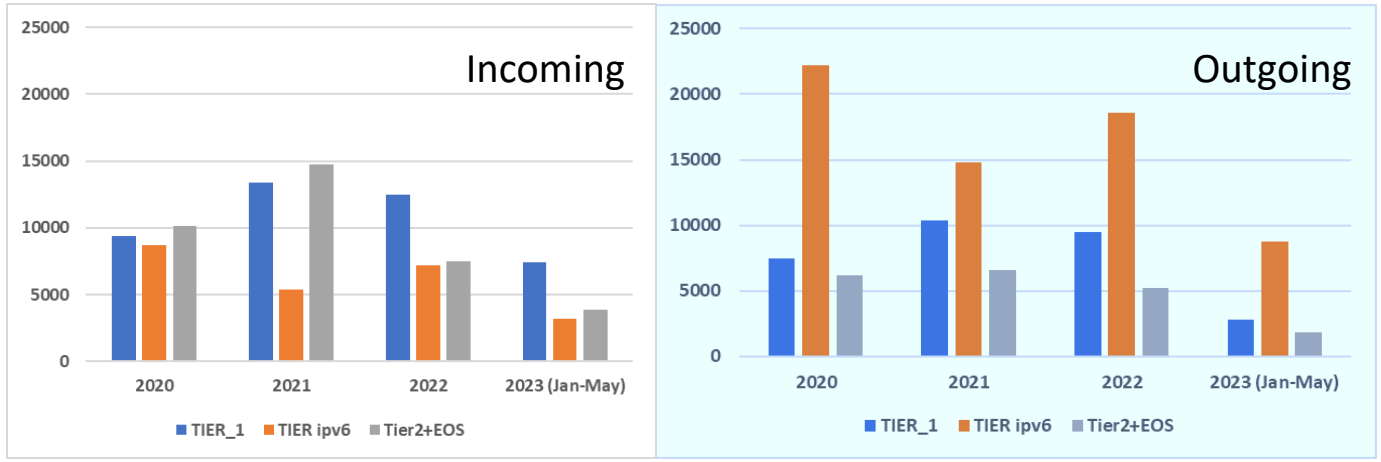
Wide Area Network 3x100 Gbps
Cluster Backbone 4x100 Gbps
Campus Backbone 2x100 Gbps

Dry chillers
In-Row systems
Total cooling 1400 kW

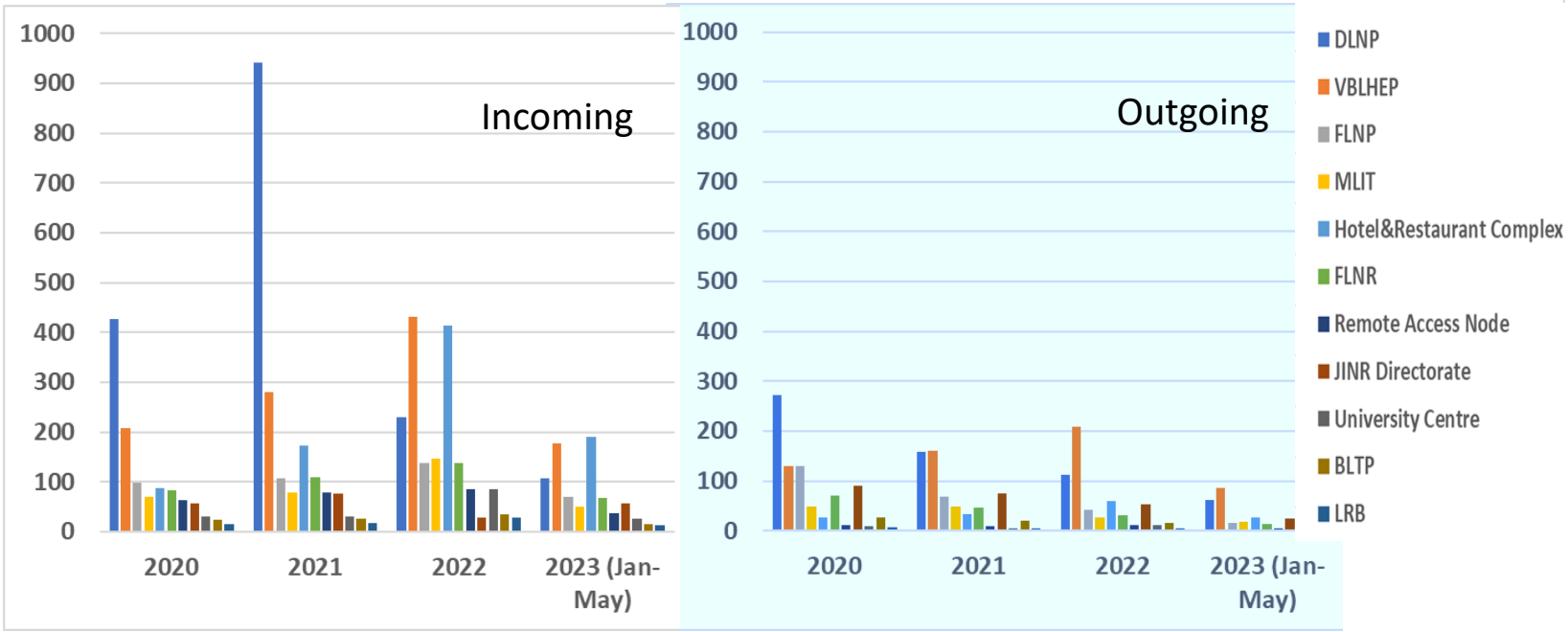
Uninterruptible power supplies (UPS) 8x300 kVA
Diesel-generator units (DGU) 2x1500 kVA
Transformers 2x2500 kVA

Networking @ Traffic

Distribution of the incoming and outgoing traffics by the JINR MICC in 2020-2023 (TB)



Distribution of the incoming and outgoing traffics by the JINR subdivisions in 2020-2023 (TB)



Wide Area Network 3x100 Gbps
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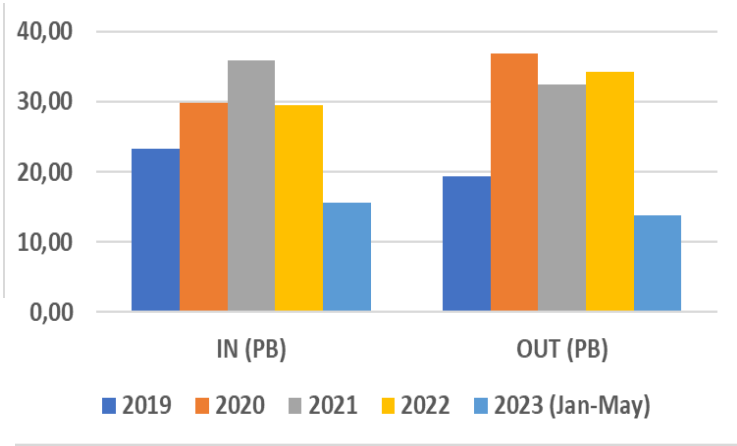
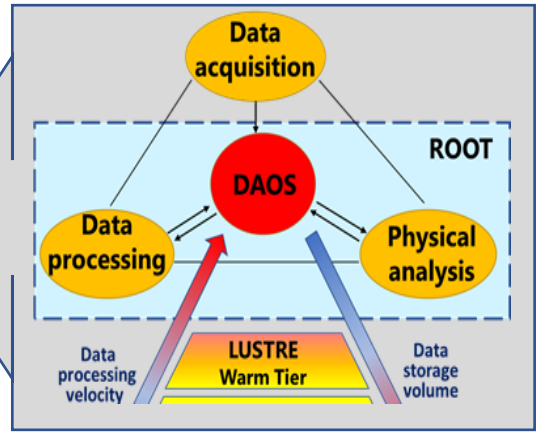
JINR Traffic in PB



Users - 6353
Network elements - 9327
IP addresses - 18163
Remote access - 911
E-library - 1464
VOIP - 121
EDUROAM - 116
Email @jinr.ru - 4579

Distributed Multi-layer Data Storage System

- Limited data and short-term storage – to store the OS itself, temporary user files
- AFS distributed global system – to store user home directories and software
- dCache is traditional for the MICC grid sites – to store large amounts of data (mainly LHC experiments) for the middle-term period
- EOS is extended to all MICC resources – to store large amounts of data for the middle-term period. At present, EOS is used for storage by BM@N, MPD, SPD, BaikalGVD, etc.
- Tape robotic systems – to store large amounts of data for the long-term period. At present, for CMS. BM@N, MPD, SPD, JUNO – in progress.



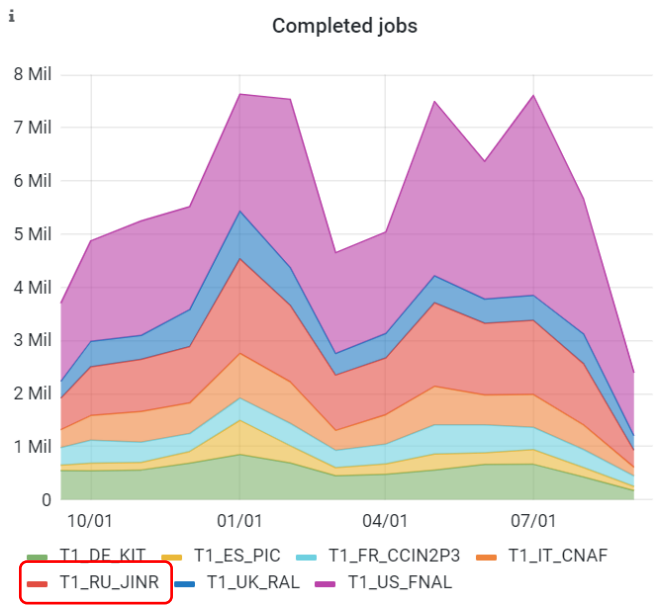
A special hierarchical data processing and storage system with a software-defined architecture was developed and implemented on the “Govorun” supercomputer.

According to the speed of accessing data, there are the following layers:

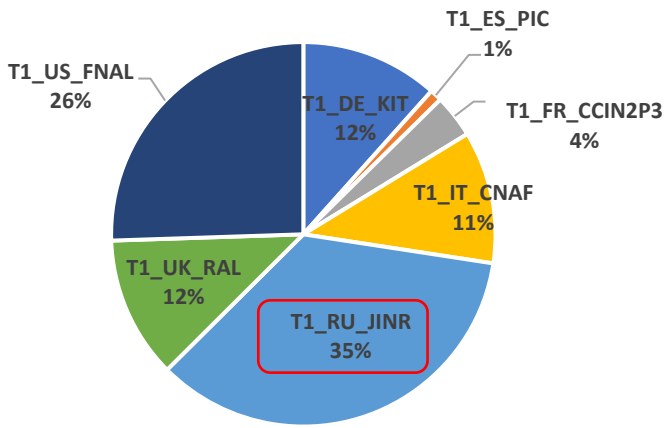
- ✓ very hot data (DAOS (Distributed Asynchronous Object Storage)),
- ✓ the most demanded data (fastest access),
- ✓ hot data,
- ✓ warm data (LUSTRE).

JINR Tier1 for CMS (LHC) and NICA

Last year



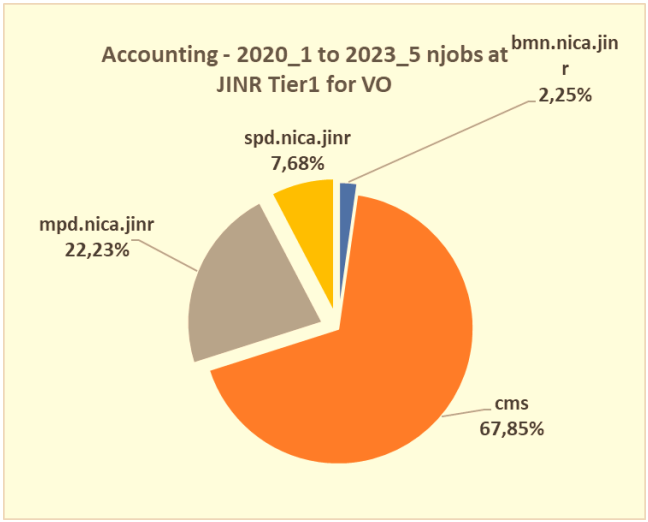
Number of processed events



Since the beginning of 2015, a full-scale WLCG Tier1 site for the CMS experiment has been operating at MLIT JINR.

The importance of developing, modernizing and expanding the computing performance and data storage systems of this center is dictated by the research program of the CMS experiment, in which JINR physicists take an active part within the RDMS CMS collaboration.

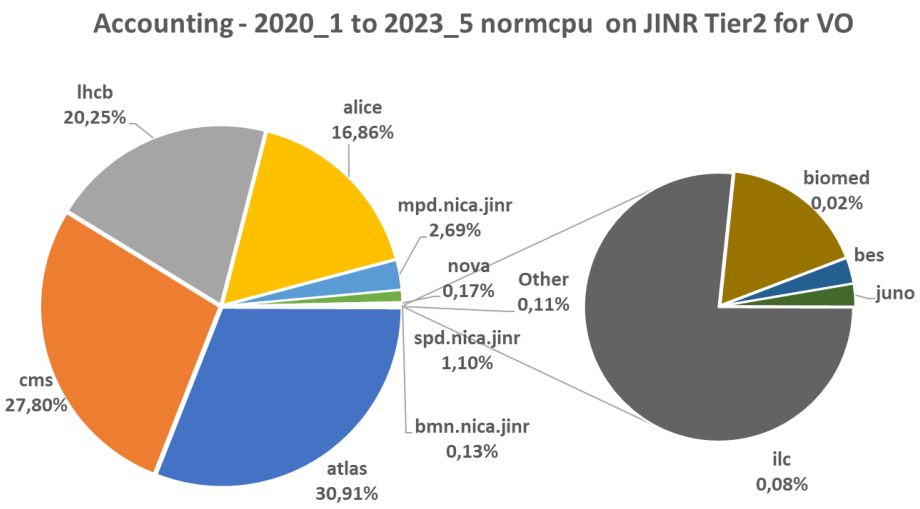
JINR Tier1 is regularly ranked on top among world Tier1 sites that process data from the CMS experiment at the LHC.



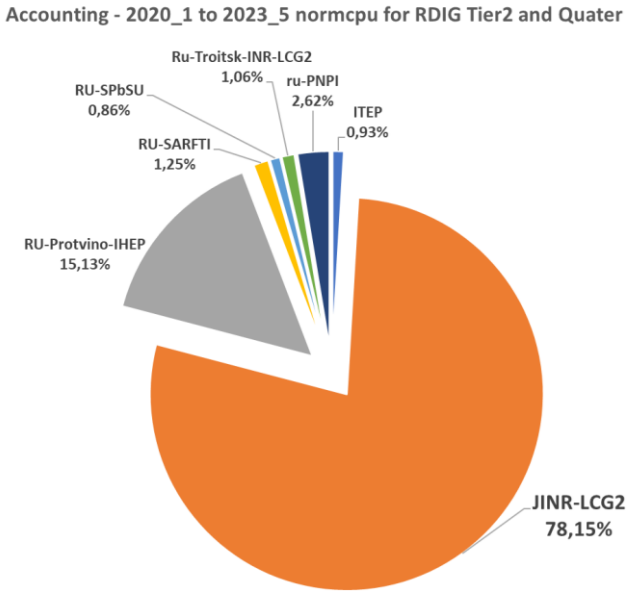
Since 2021, the JINR Tier1 center has demonstrated stable operation not only for CMS (LHC), but also for the NICA experiments.

20060 CPU cores;
11,7 PB dCache based disk storage;
21,3 PB Tape storage
100% reliability and availability

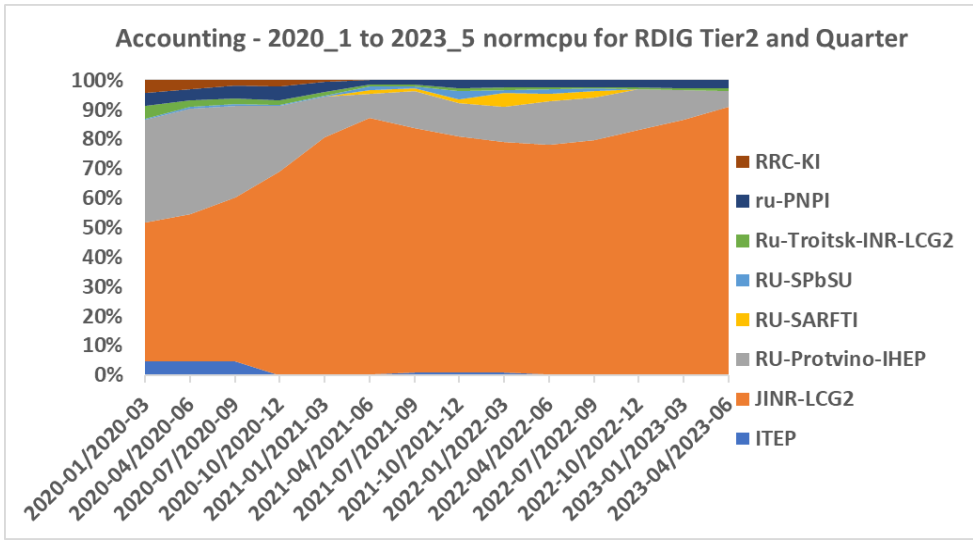
JINR Tier2 in WLCG & RDIG



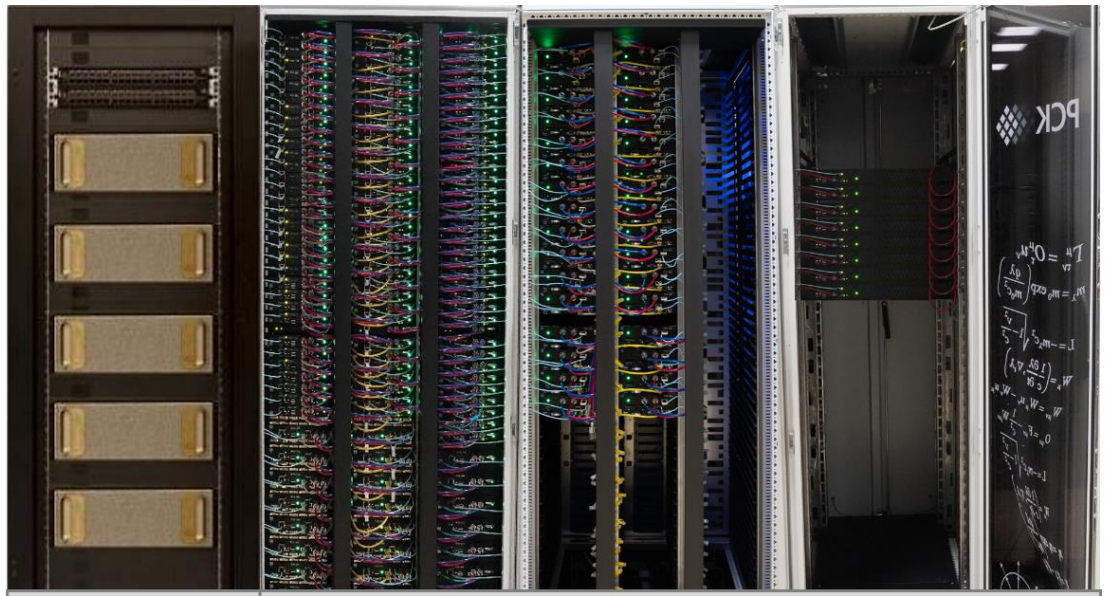
Tier2 at JINR provides computing power and data storage and access systems for the majority of JINR users and user groups, as well as for users of virtual organizations (VOs) of the grid environment (LHC, NICA, etc.).



JINR Tier2 is the most productive in the Russian Data Intensive Grid (RDIG) Federation. Almost 80% of the total CPU time in the RDIG is provided by JINR Tier2 site.



"Govorun" supercomputer modernization in 2022 - 2023



GPU-accelerator | Hyperconverged CPU and Distributed Storage Nodes

\+ 40 NVIDIA A100 GPU accelerators
Performance: + 600 Tflops DP

+32 hyperconverged compute nodes
+2 432 new computational cores
Performance: +239 Tflops DP
"New cores"/"old cores" performance increase by more than 1.5 times

+8 distributed storage nodes
Lustre, EOS increase: +8 PB
DAOS increase: +1.6 PB
+0.4 PB for MPD mass production storages integrated into the DIRAC File Catalog
+1 PB for the MPD EOS storage

\+

5 servers with 8 NVidia A100 GPUs in each

\+

Computation field:
+32 hyperconverged compute nodes

\+

Hierarchical Storage:
+8 distributed storage nodes

"Govorun" SC total peak performance: 1.7 PFlops DP
Total capacity of Hierarchical Storage: 8.6 PB
Data IO rate: 300 Gb/s

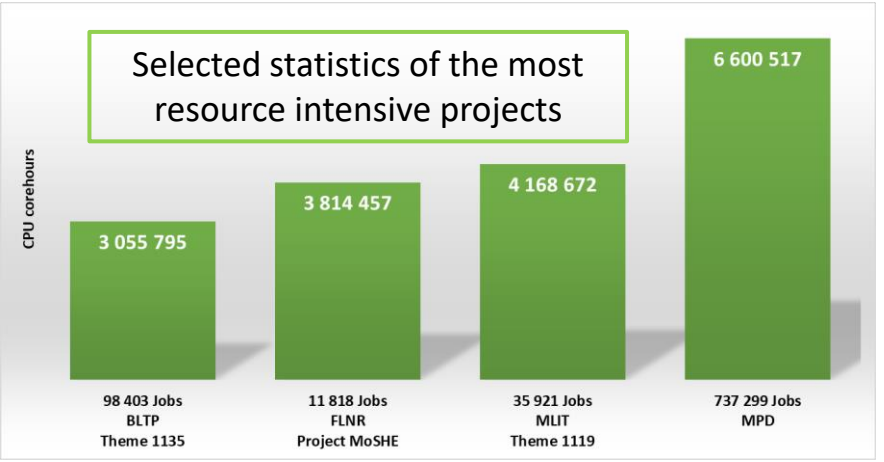
“Govorun” Supercomputer for JINR tasks in 2022

Projects that mostly intensively use the CPU resources of the “Govorun” supercomputer:

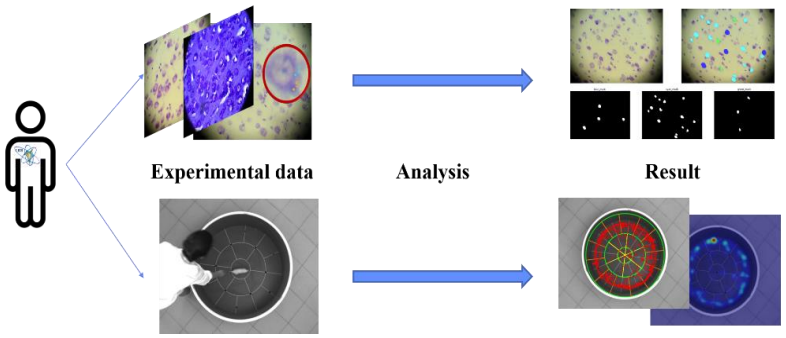
- NICA megaproject,
- simulation of complex physical systems,
- computations of the properties of atoms of superheavy elements,
- calculations of lattice quantum chromodynamics.

The GPU component is actively used for solving applied tasks by the neural network approach:

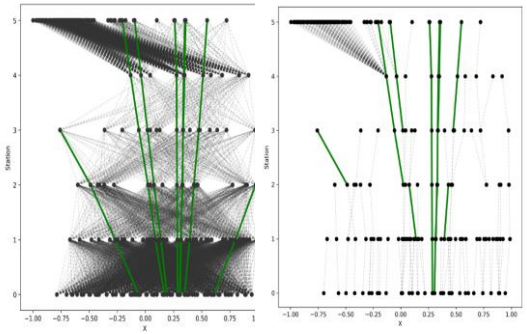
- processing of data from experiments at LRB,
- data processing and analysis at the NICA accelerator complex, etc.



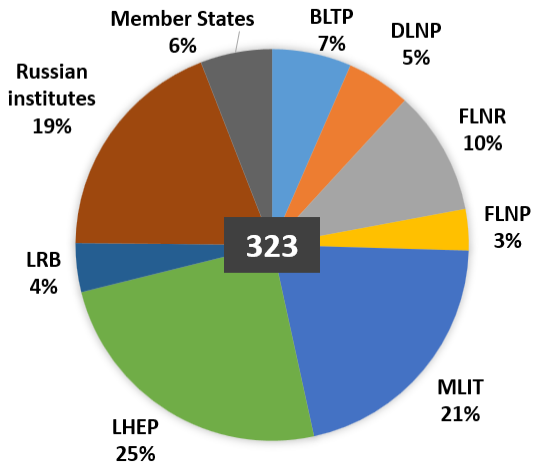
During 2022, **890 911** jobs were performed on the **CPU** component of the “Govorun” supercomputer, which corresponds to **18 543 076** core hours.



Information system for radiation biology tasks



Neural network for HEP data reconstruction and analysis

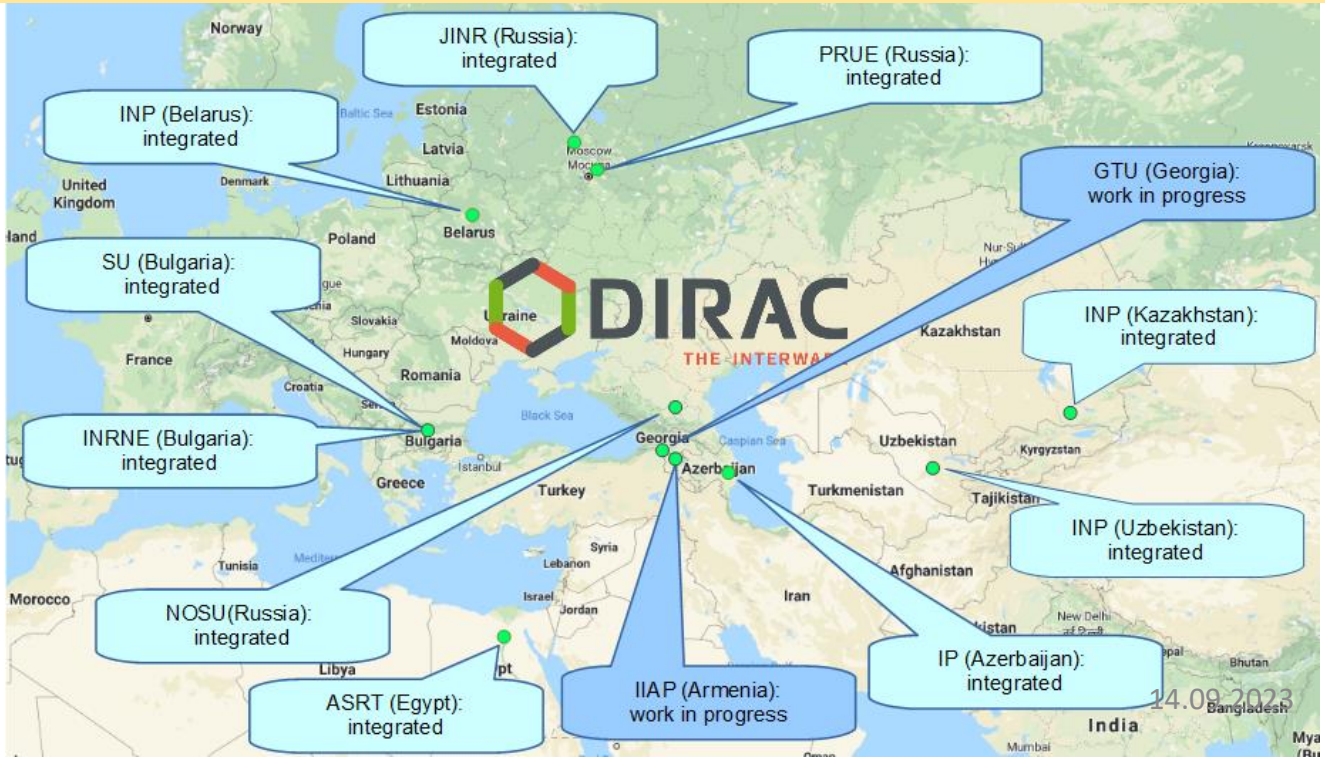


The resources of the “Govorun” spercomputer are used by scientific groups from all the Laboratories of the Institute within **25 themes** of the JINR Topical Plan.

Cloud Infrastructure

- Computational resources for neutrino experiments
- VMs for JINR users
- Testbeds for research and development in IT
- COMPASS production system services
- Data management system of the UNECE ICP Vegetation
- Service for data visualization, Gitlab and some others

DIRAC-based distributed information and computing environment (DICE) that integrates the JINR Member State organizations' clouds



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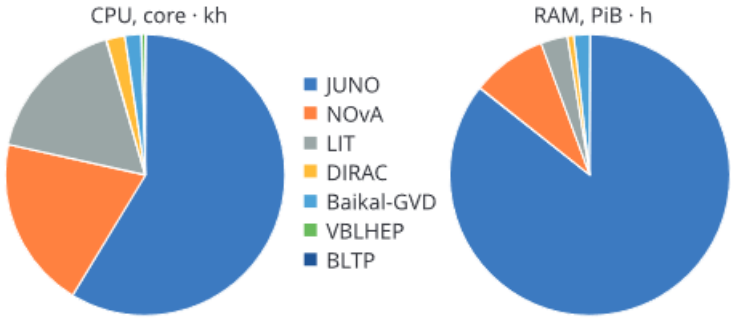
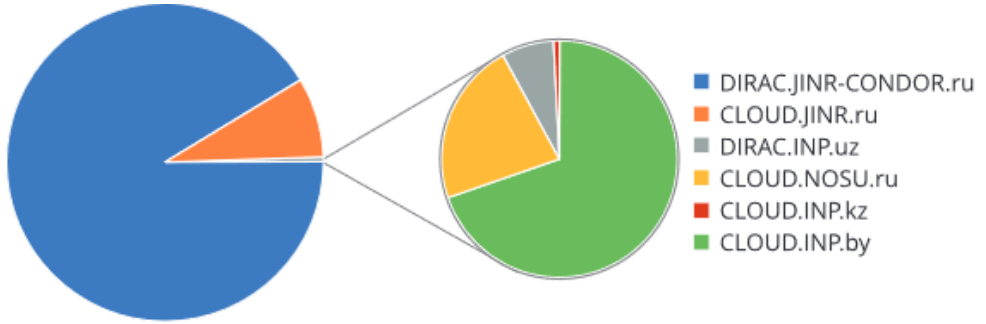
The Baikal-GVD, NOvA and JUNO experiments are the major users of the cloud infrastructure.



Usage of cloud computing by experiments and JINR subdivisions in 2022

Most of the jobs in the JINR DICE in 2022 were performed on the neutrino computing platform (DIRAC.JINR-CONDOR.ru).

Distribution of the number of jobs completed in the JINR DICE by participants



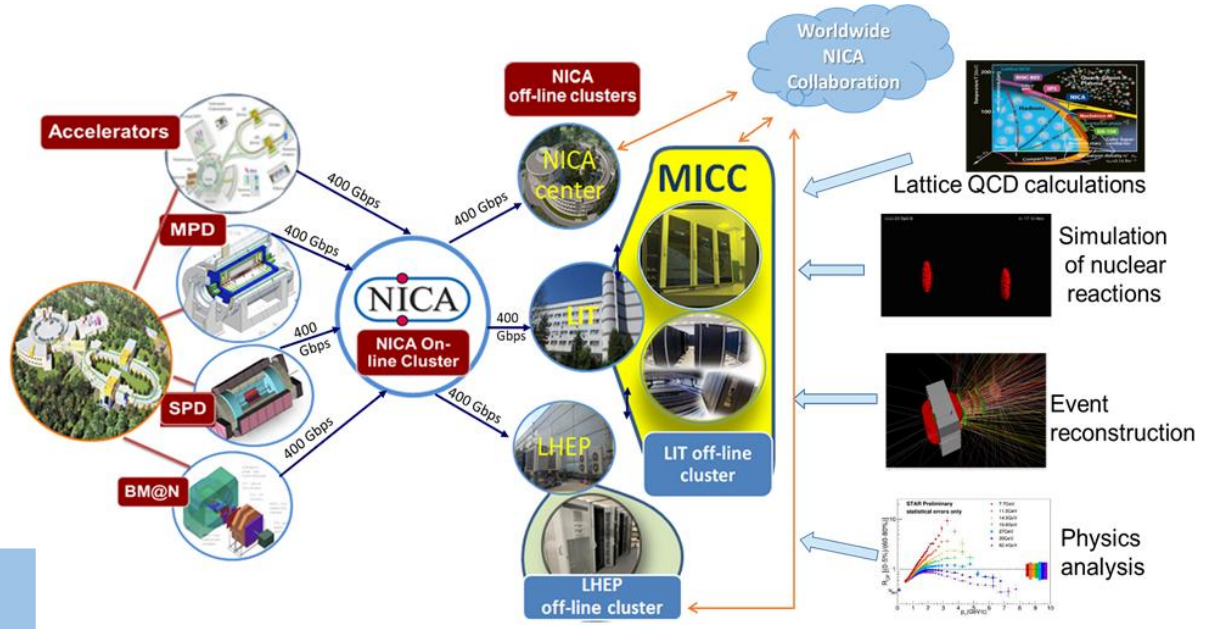
The main consumer of the JINR DICE resources in 2022 was the Baikal-GVD experiment (96%).

Development of the NICA Information and Computer Complex

The creation of a long-term data storage center on the MICC resources at MLIT (Tier0) is planed. The process of modeling, processing and analyzing experimental data obtained from the BM@N, MPD and SPD detectors will be implemented in a distributed computing environment based on the MICC and the computing centers of VBLHEP and collaboration member countries.

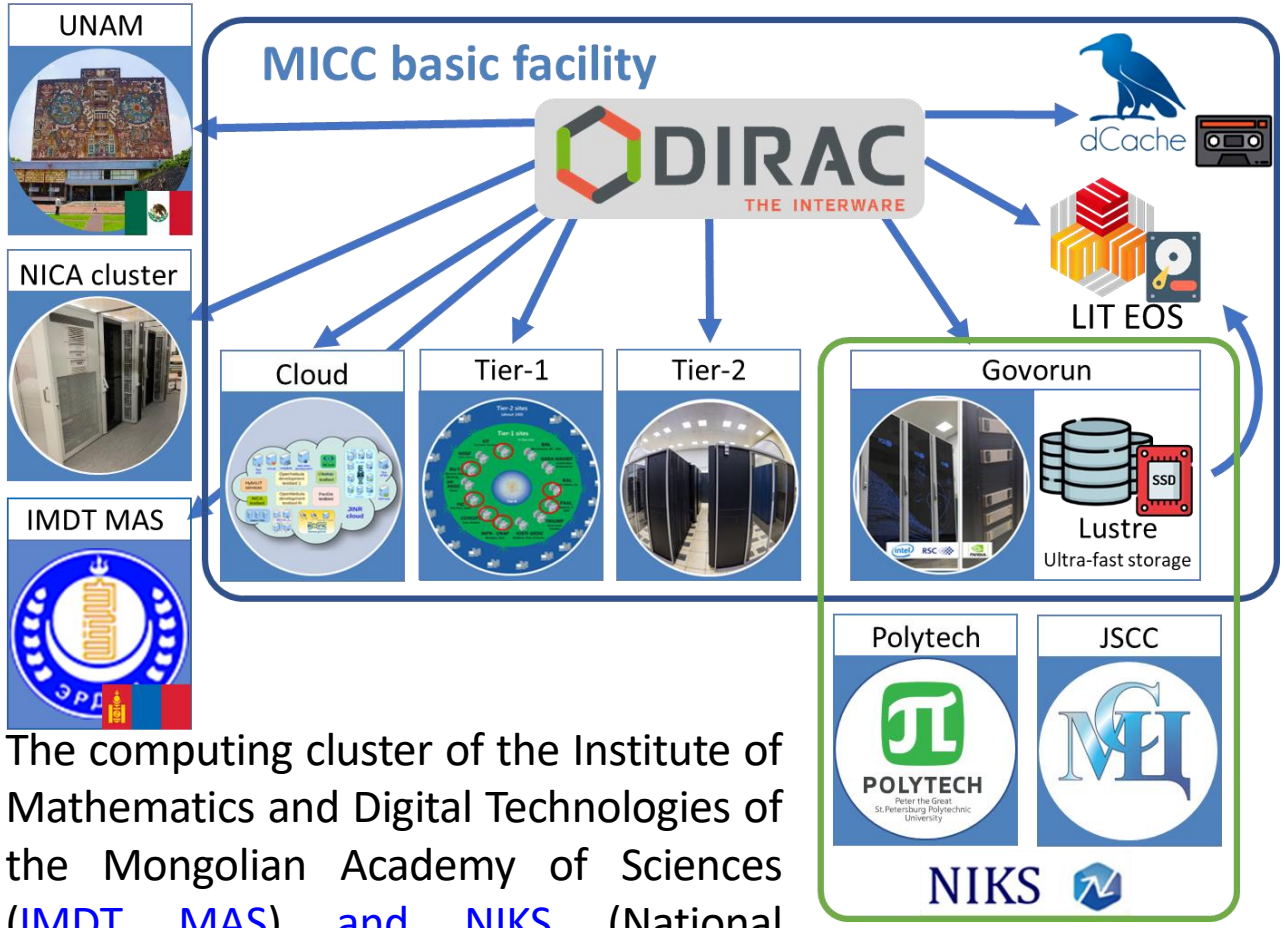
The information and computing unit of the NICA complex embraces:

1. **online NICA cluster**,
2. **offline NICA cluster at VBLHEP**,
3. **all MICC components** (Tier0, Tier1, Tier2, “Govorun” supercomputer, cloud computing),
4. multi-layer **data storage system**,
5. **distributed computing network**.



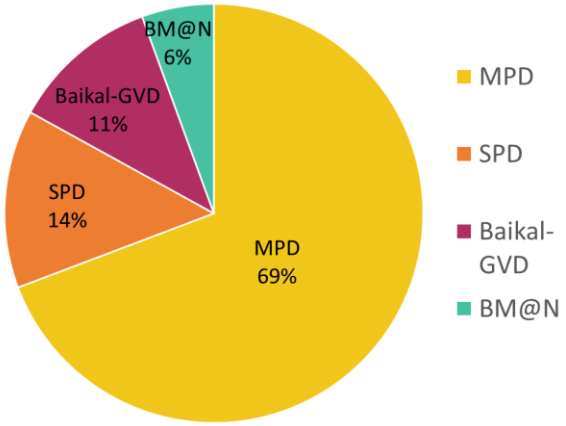
NICA Tier 0,1,2	2024	2025	2026	2027	2028	2029	2030
CPU (PFlops)	2.2	2.6	8.6	8.6	15.6	15.6	15.6
DISK (PB)	17	24	47	75	96	119	142
TAPE (PB)	45	88	170	226	352	444	536
NETWORK (Gbps)	400	400	800	800	800	1000	1000

DIRAC-based distributed heterogeneous environment

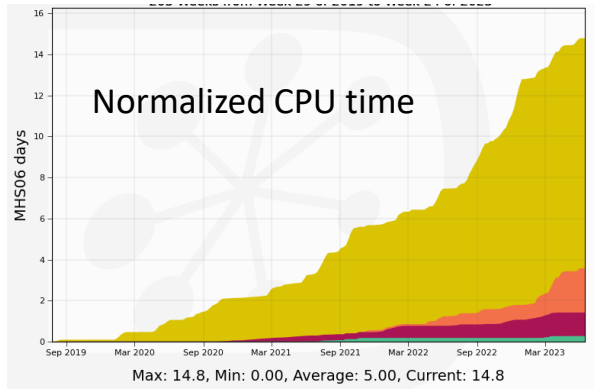


The computing cluster of the Institute of Mathematics and Digital Technologies of the Mongolian Academy of Sciences (IMDT MAS) and NIKS (National Research Computer Network, Russia's largest research and education network) were integrated into the heterogeneous distributed environment based on the DIRAC platform.

Usage of the DIRAC platform by experiments in 2019-2022

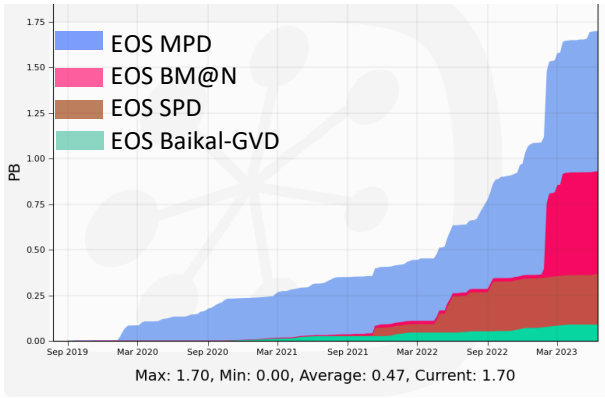


Total number of executed jobs



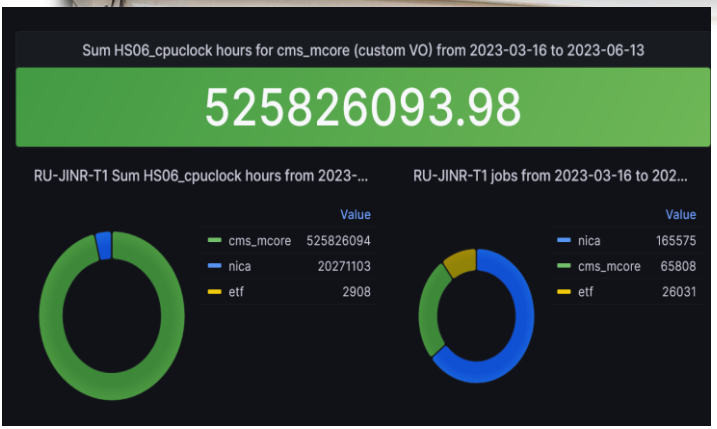
The major user of the distributed platform is the MPD experiment.

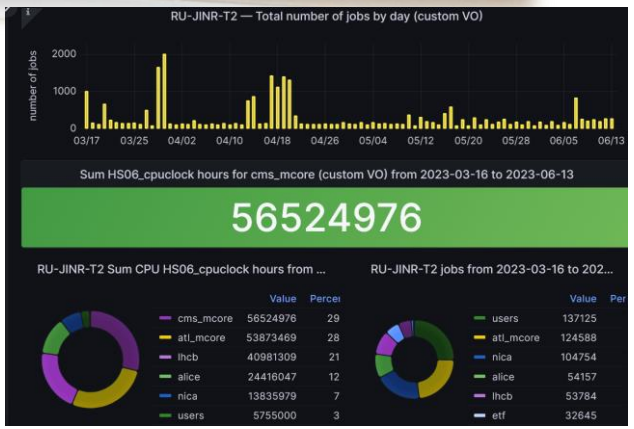
Data processed by experiments



Summary statistics of using the DIRAC platform for MPD tasks in 2019-2022

MICC Monitoring @Accounting





- ❖ **3 monitoring servers**
- ❖ **About 1800 nodes**
- ❖ **About 16000 service checks**

The successful functioning of the computing complex is ensured by the system that monitors all MICC components. We must

- expand the monitoring system by integrating local monitoring systems for power supply systems into it (diesel generators, power distribution units, transformers and uninterruptible power supplies);
- organize the monitoring of the cooling system (cooling towers, pumps, hot and cold water circuits, heat exchangers, chillers);
- create an engineering infrastructure control center (special information panels for visualizing all statuses of the MICC engineering infrastructure in a single access point);
- account each user job on each MICC component.

It is required to develop intelligent systems that will enable to detect anomalies in time series on the basis of training samples, which will result in the need to create a special analytical system within the monitoring system to automate the process.

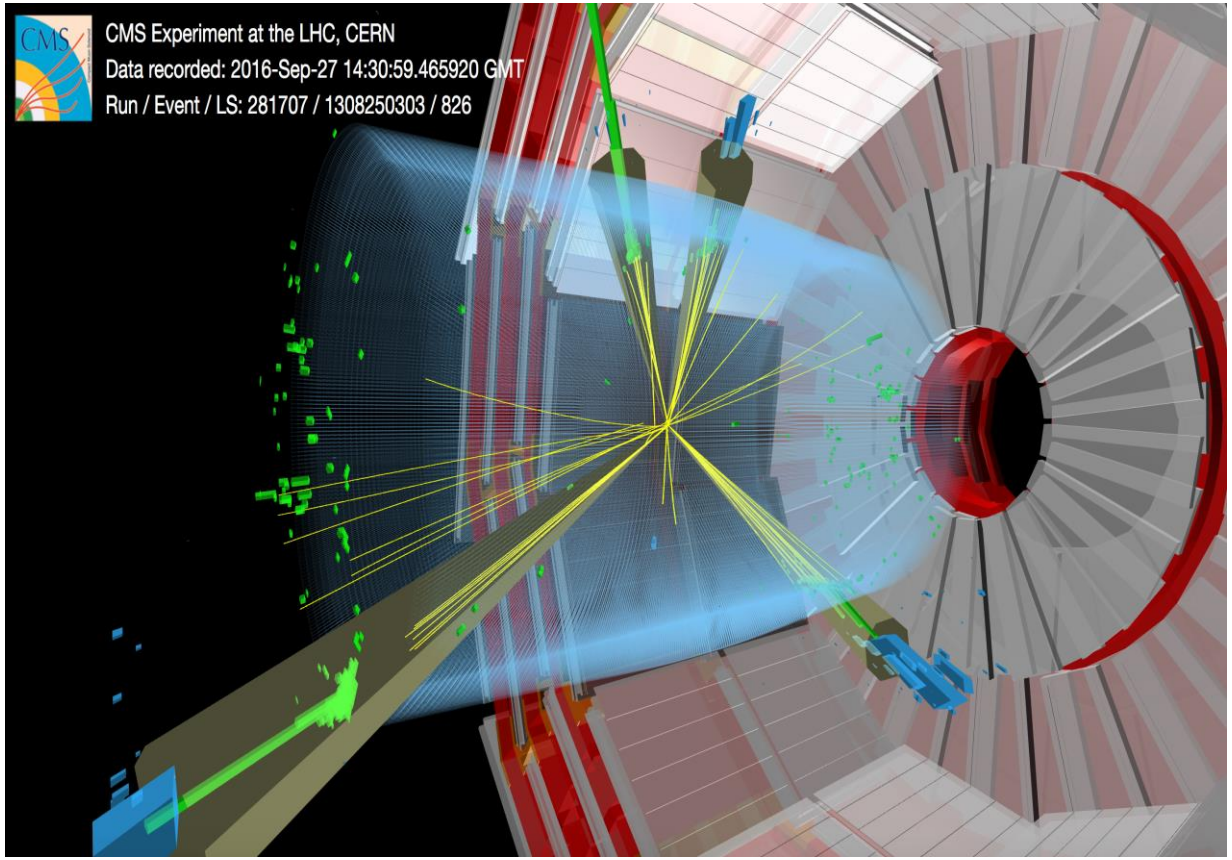
The Project Structure

Simulation of Physics Processes and Facilities	Reconstruction and Data Analysis	Software Environment for Experiments
Physics event simulation	Particle trajectory reconstruction	Data processing and analysis models
GEANT-simulation of experimental setups	Particle identification	Data models
	Reconstruction of physics processes	Software platforms and systems
	Experimental data analysis	Development and maintenance of DBs
		Event visualization

The main strategy is to use common solutions and methods for different experiments

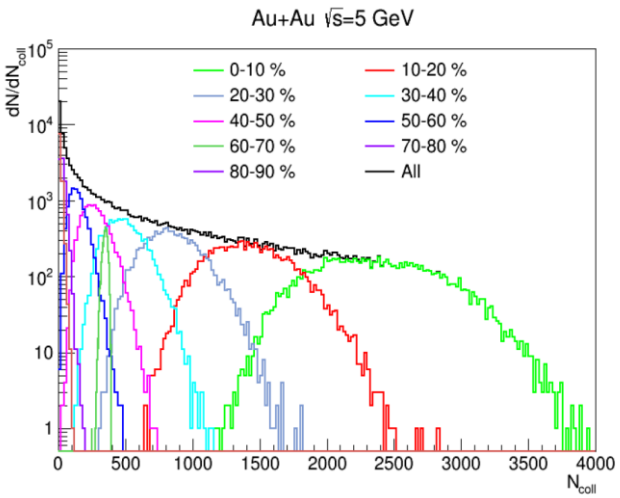
Simulation of physical processes and experimental facilities

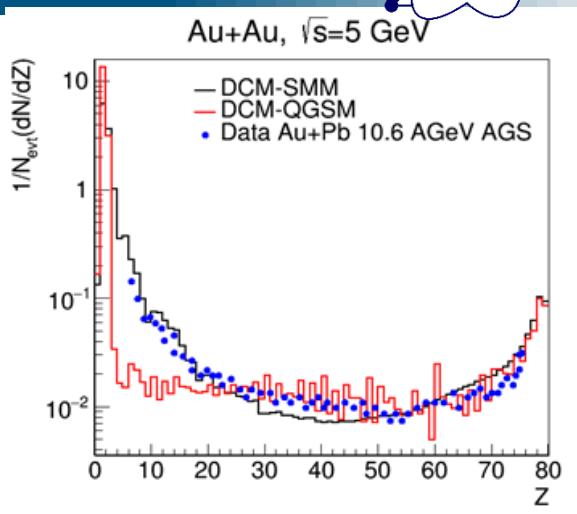
- analytical and numerical calculations of physical processes, software optimization, including tuning and adaptation of physics event generators;
- MC event production, development and support of information systems for event catalogues;
- participation in the creation of computer models of experimental facilities and simulation of elementary particles passing through them based on GEANT4 (and others) and fast simulation of the response of the detectors.



MC Generators for the NICA and LHC Experiments

- Development of the heavy ion collision generators
  - Dubna Cascade Model, Quark-Gluon-String Model, Statistical Multifragmentation Model for the NICA Experiments
  - tuning the HIJING generator with data of NA49 and NA61/SHINE @ CERN, STAR@RHIC (can be used in MPD and SPD experiments)
- Analytical and numerical methods for calculating neutron-proton systems under strong compression at the NICA



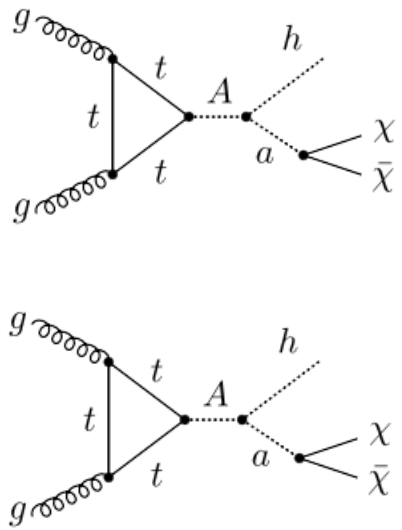


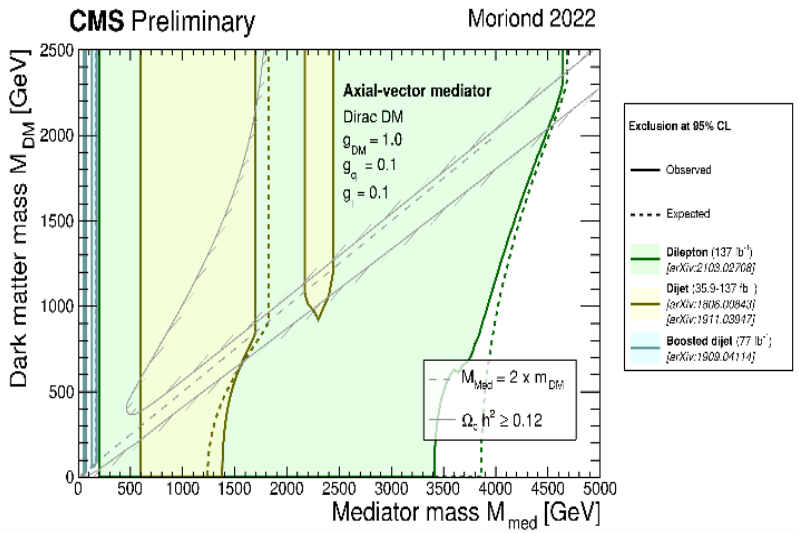
The priority tasks of the JINR Groups in LHC physics program (ATLAS and CMS) include searches for candidates for dark matter particles, tests of predictions of TeV-energy scenarios

- Fine tuning the generators for searches for new physics
  - revision of model parameters for 2HDM+a, 2HDM+s, etc.
  - simulation with Pythia8, QBH, MadGraph5_aMC@NLO + FeynRules (simplified DMM, HDM+a, 2HDM+s, etc.)
  - mass production + Geant4 response

Ex., Dark Matter can be probed with two fermions/two fermions + MET/higgs + MET/Z + MET in the final states

h (→ bbar) + a (→ χχ) = bbar + MET



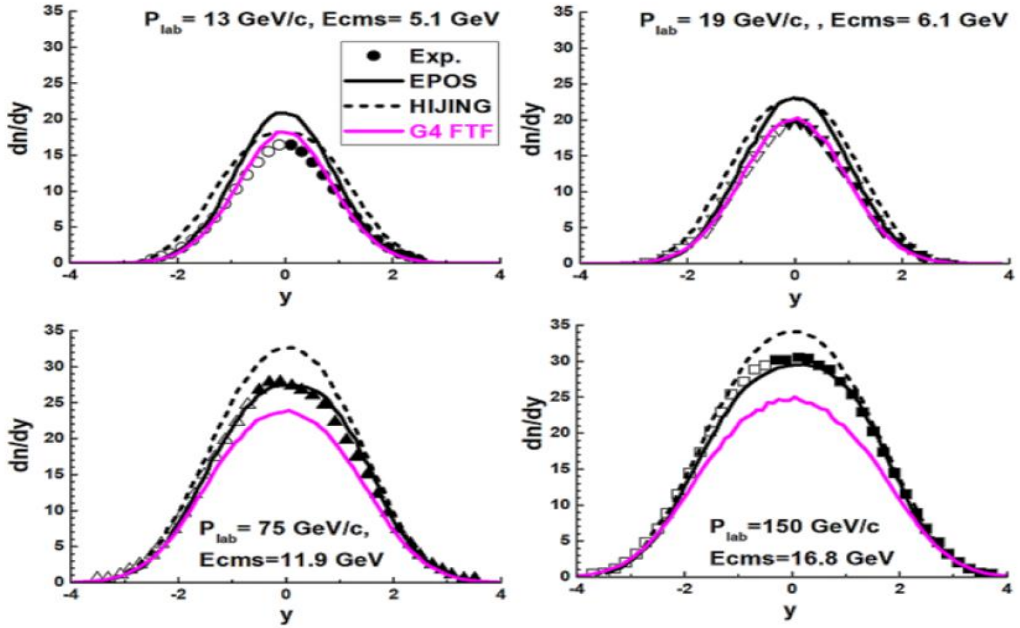


MLIT + BLTP + VBLHEP

Modeling Experimental Facilities for the NICA, LHC, etc.

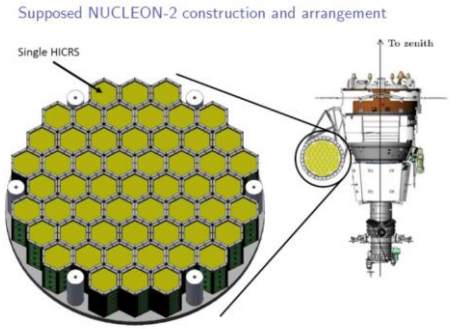
- Development, verification, validation and application of FTF (Fritiof) and QGSM (Quark-Gluon-String-Model) hadronic models

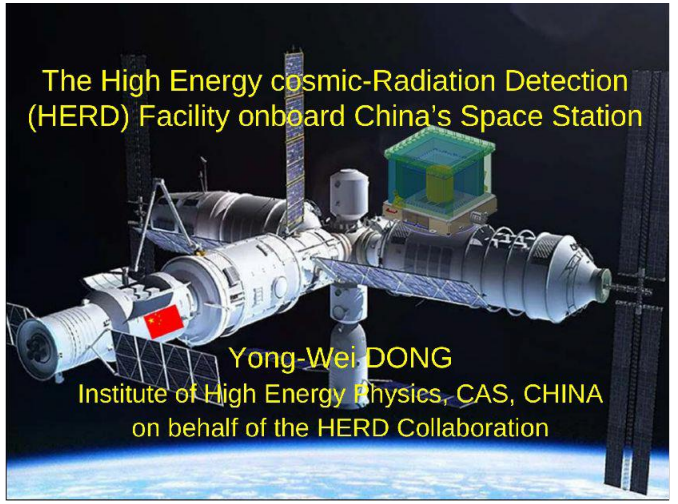
Rapidity distributions of π^- mesons in $^{40}Ar + ^{45}Sc$ interactions (EPJ , C82 (2022)

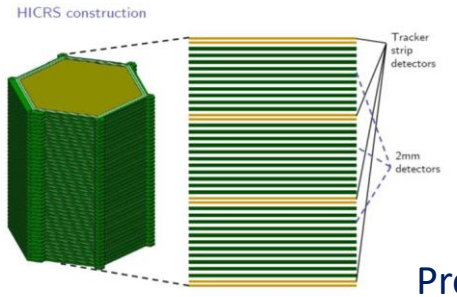


Exp. conclusion: “There is no model (EPOS, UrQMD, HIJING …) able to describe the data!” from NA61/SHINE Collab. on PP, $^{40}Ar + ^{45}Sc$ and $^{7}Be + ^{9}Be$

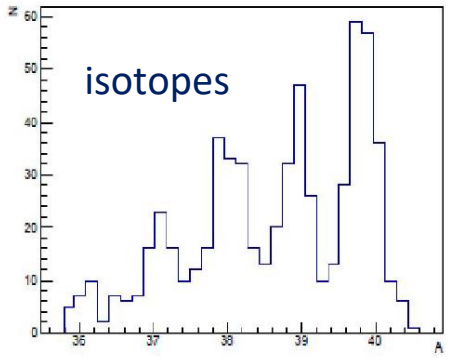
- Simulation and prototype testing for present and future orbital detectors: NUCLEON, NUCLEON-2, HERD

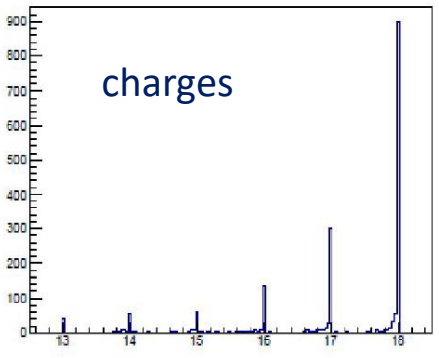






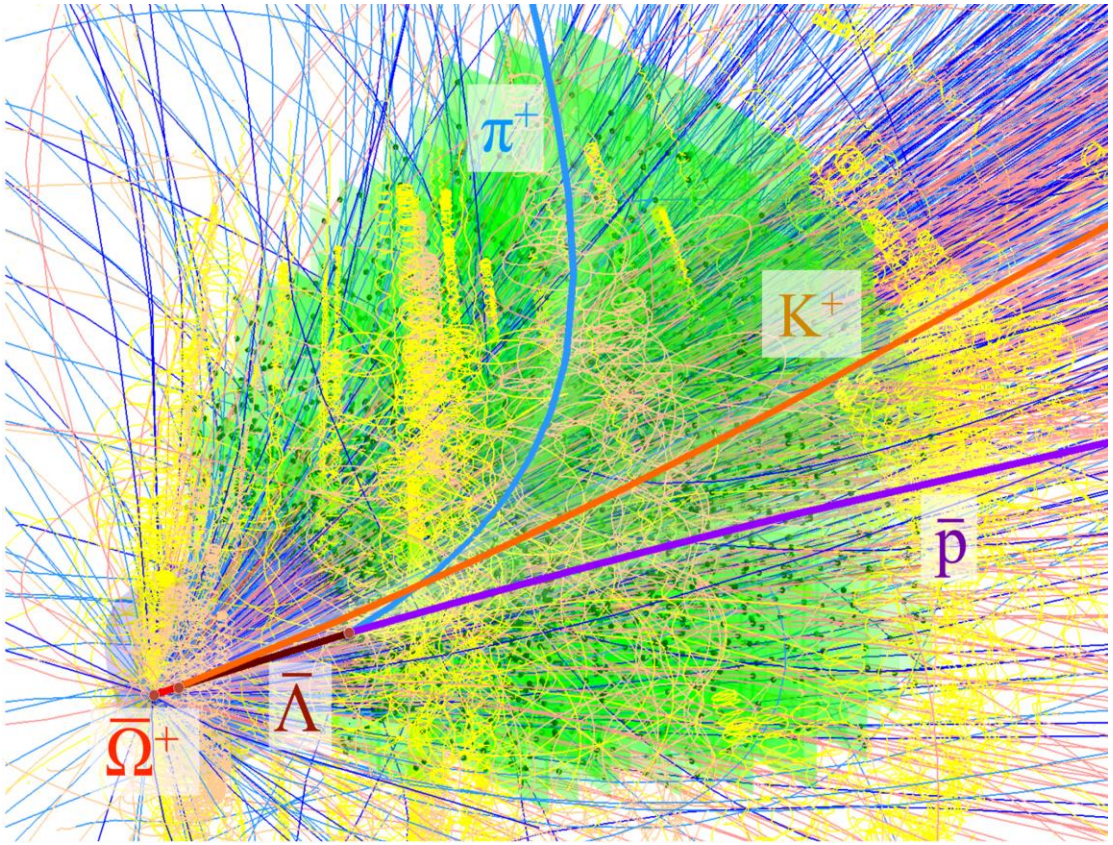
Prototypes tested @ Nuclotron JINR





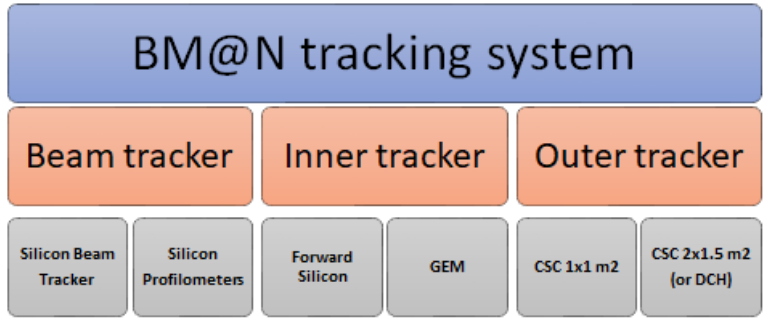
Reconstruction of physical objects and analysis of experimental data

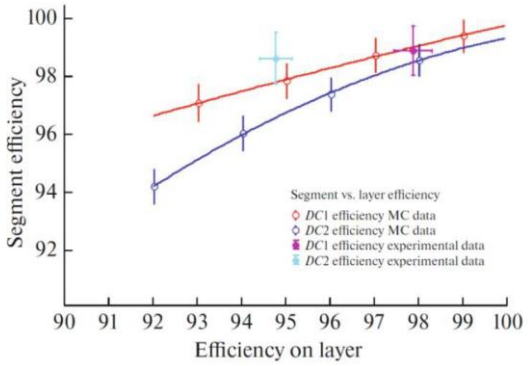
- development of algorithms, including those based on recurrent and convolutional neural networks for machine and deep learning tasks, and creation of corresponding software for the reconstruction of physical objects (tracks, particles, clusters, etc.) and physical processes;
- development of methods and algorithms for data analysis, including statistical analysis;
- adaptation of existing software for specific experiments, reconstruction and analysis of experimental data;
- analysis of Open Data of experiments, in particular, experiments at the LHC;
- conducting a global analysis of data from various experiments (in particular, a combined analysis of data from accelerator and astrophysical experiments in search for candidates for the role of dark matter).



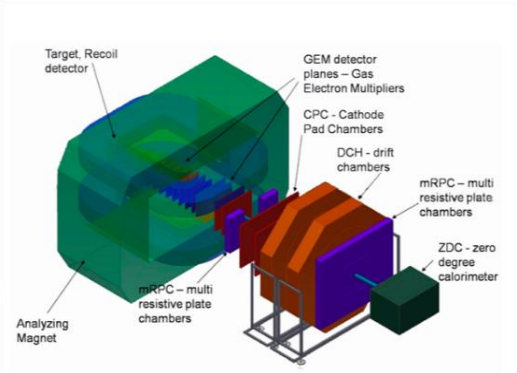
Tracking Algorithms for HEP Experiments

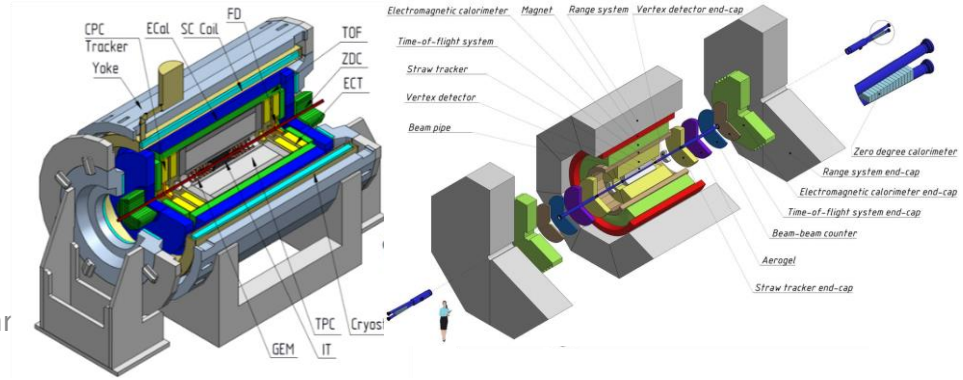
- Mathematical methods and software for processing and analyzing data from the experiments @ NICA
  - software for alignment and calibration of the BM@N STS (silicon chambers) and GEM (gas electron multipliers) track detectors



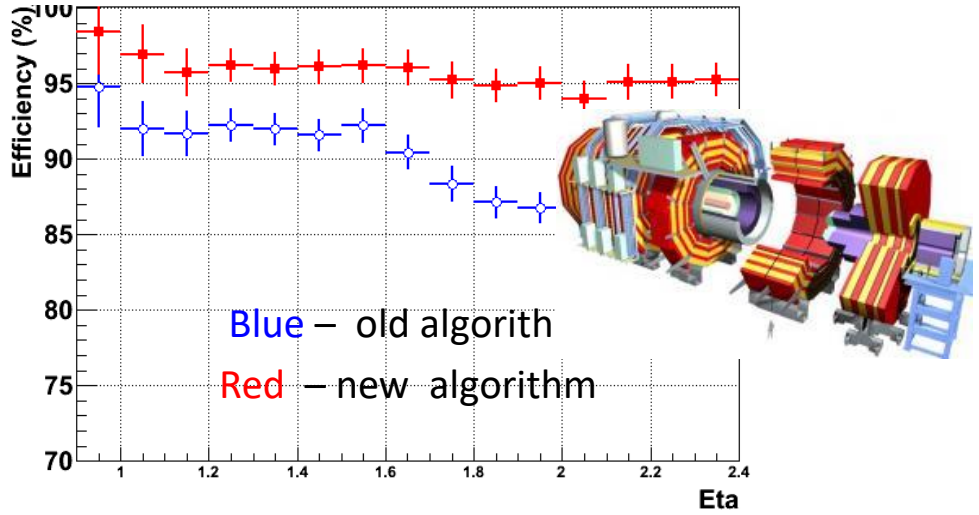


  - development and application of methods and algorithms for processing and analyzing experimental data for the coordinate detectors





- Mathematical methods and software for muon reconstruction and the estimation of operation parameters of CMS detectors @ LHC
  - reconstruction of the cosmic muon trajectory in the setup for testing active elements of the CMS HGCal, as well as evaluation of the efficiency of HGCal modules;
  - usage of discrete wavelet analysis to recognize the coordinates of close-flying particles from over-lapping signals in the Cathode Strip Chambers (CSC). Evaluation of the operation parameters of CSC detectors and of the rate of background particles for different types of experimental data.

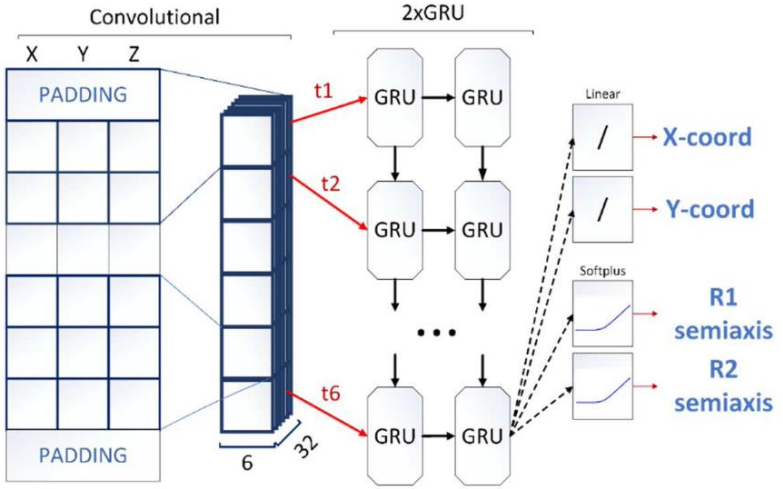


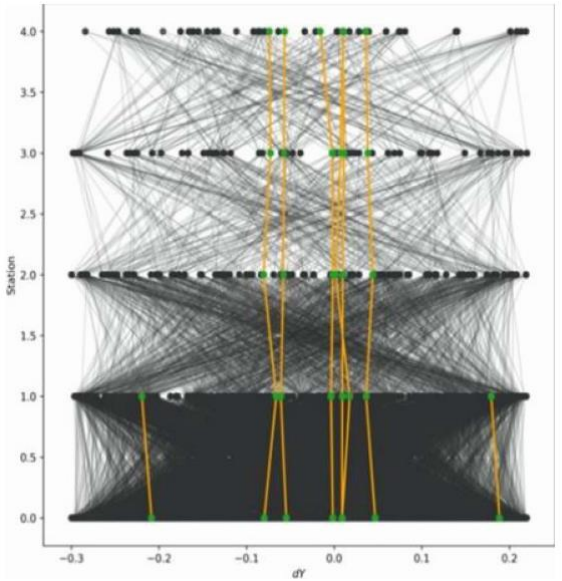
Machine Learning Methods for the Track Reconstruction and PID

- particle identification based on the gradient boosting of decision trees with MPD Time-Projection Chamber (TPC) and Time-of-Flight (TOF)

- new approaches to track recognition in SPD strip and pixel detectors based on a recurrent neural network and a graph network (already used for track recognition in the BM@N experiment at JINR and in the BESIII experiment in China)

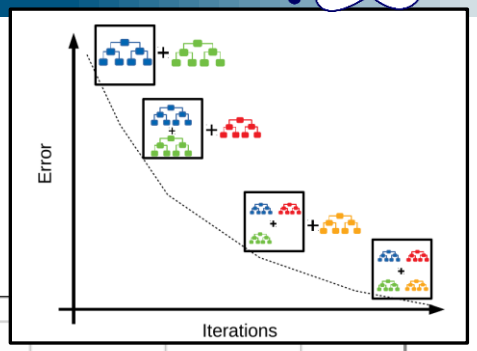
BM@N

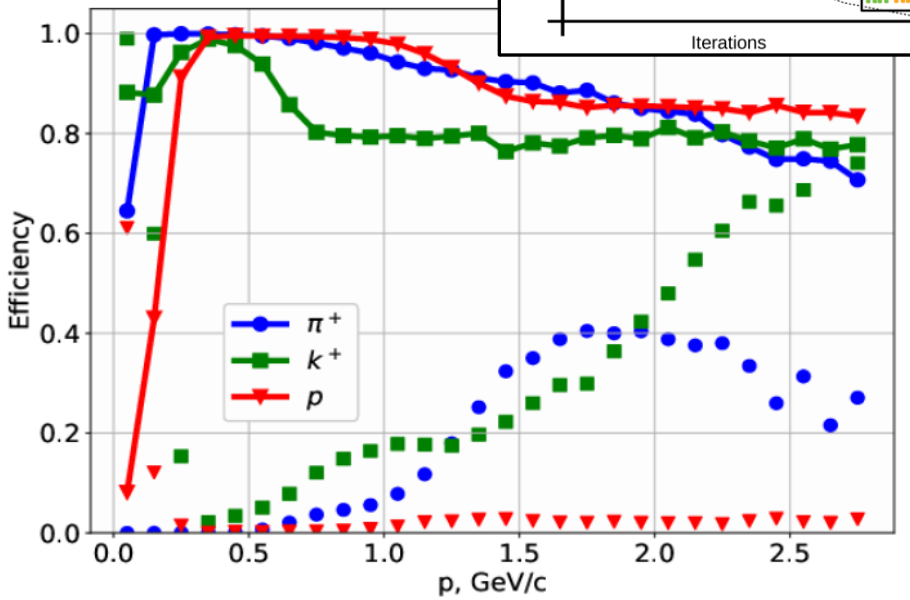




Preliminary results: accuracy of about 99% for testing data (18% of true segments are lost)

MPD

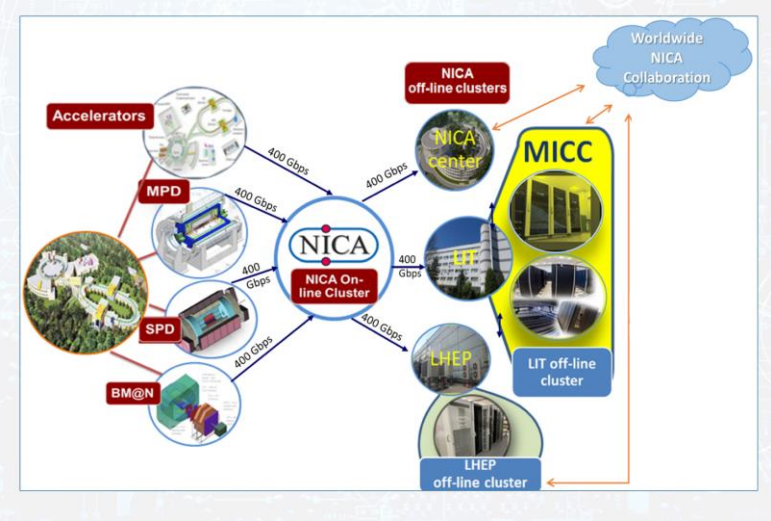


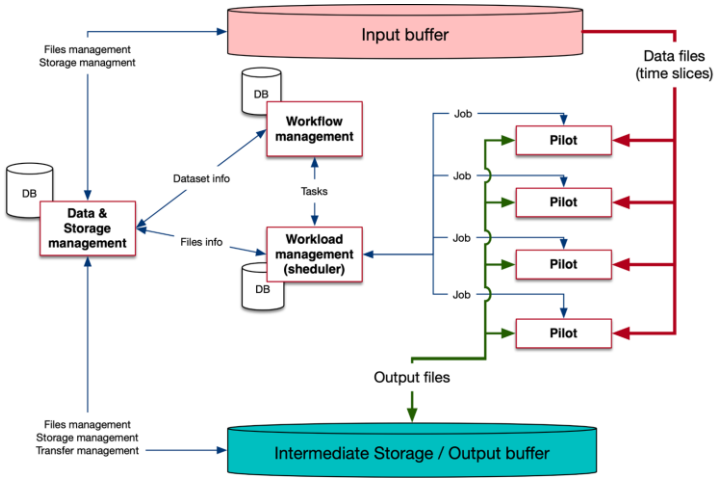


Efficiency and contamination of the identification of positively charged particles in the MPD model data, obtained by the method of decision trees with gradient boosting

Support and development of the software environment for JINR research

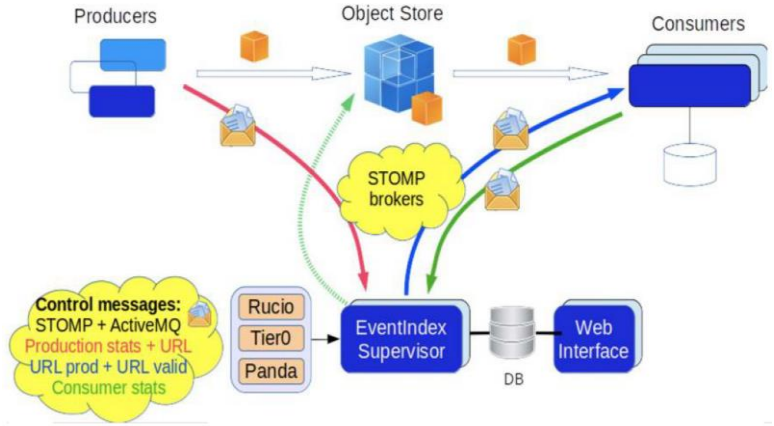
- Development of the software environment for processing and analyzing data from the NICA experiments
- Creation, implementation and development of an information and computing complex for processing, analyzing and storing data for the SPD experiment
- Creation of specialized databases and information systems for the Collaborations @ NICA and LHC (ATLAS, BM@N, MPD)
- Development and creation of an information and computing system for
  - automating the processing of data from radiobiological studies
  - intelligent determining the state of agricultural and decorative plants
  - monitoring and predicting the state of the environment



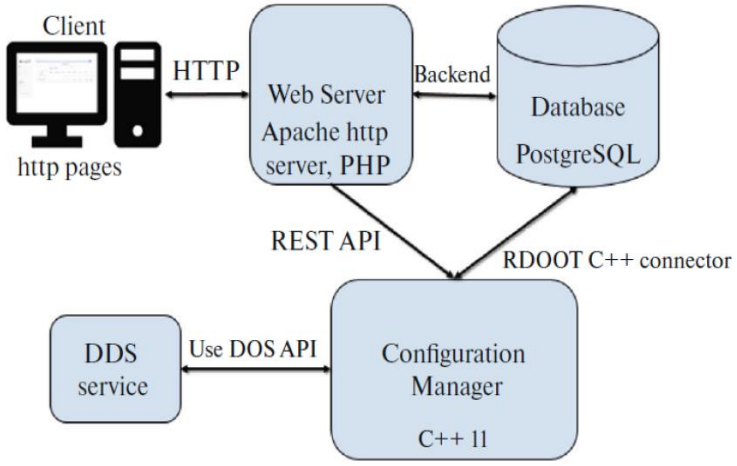


Data Bases for HEP Computing

- ATLAS EventPickingService
  - the first version for automated event collection has been created.
  - the service was used for the second stage oa the «γγ→WW» analysis (136 K events)
  - further modernization of the service is ongoing according to the received results



- ATLAS CREST (Condition DB)
  - C++ API for CREST (implemented into Athena software package)
  - COOL2CREST converter (developed, but not yet implemented)
  - both parts require constant improvement for compatibility with the updated CREST server
- Event metadata system for the experiments at NICA (BM@N, MPD and SPD)
  - has been designed to index events of the NICA experiments and store their metadata
  - quick search by required conditions and parameters used in various physics analyses for a set of physics events to use in further event data processing



- Geometry DB
  - The geometry database is the main element of the information system designed to store, process and manage information about the geometric models of detectors. It is implemented into BMNROOT software
- Configuration DB (Configuration Information System, CIS)
  - Configuration database for managing online applications for collecting and processing high energy physics events. It was created for process launching in BM@N environment.

Collaboration

Collaborations with 19 research centers and universities from 9 countries (4 members, 1 associate, 4 non-members), Collaborations @ NICA, CERN, etc					
	AANL, Yerevan		GSU, Gomel INP BSU, Minsk		Oxford Un., GB
	CEA, Saclay		INFN, Genova		UTA, Arlington
	INP AS RUz., Tashkent		CERN, Geneva		
	NOSU, Vladikavkaz; NRC KI PNPI; ITEP; SINP MSU; NNRU “MEPhI”; LPI RAS; INR RAS, IHEP; SSU, Samara; SPbSU				
Member States of the Collaborations @ NICA (BM@N, MPD, SPD)		Member States of the Collaborations @ CERN (ALICE, ATLAS, CMS, AMBER, GEANT4, etc)		Member States of the BAIKAL-GVD anf TAIGA projects	

Development of the system for training and retraining IT specialists

Training courses, master classes and lectures

MLIT staff and leading scientists from JINR and its Member States

Leading manufacturers of modern computing architectures and software

Parallel programming technologies

OpenMP

MPI

OpenCL

NVIDIA CUDA

Tools for debugging and profiling parallel applications

Intel Cluster Studio

Work with applied software packages

COMSOL MULTIPHYSICS

Wolfram Mathematica

ROOT

MATLAB

GEANT4

Maple

Frameworks and tools for ML/DL tasks

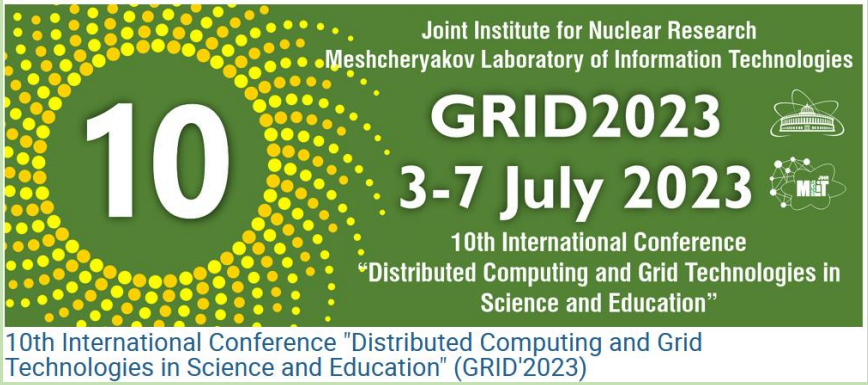
jupyterhub

TensorFlow

NumPy

scikit learn

Quantum algorithms, quantum programming and quantum control



10th International Conference "Distributed Computing and Grid Technologies in Science and Education" (GRID'2023)

- Distributed Computing Systems
- HPC
- Cloud Technologies
- Distributed Storage Systems
- Distributed Computing and HPC Applications in science, education, industry and business, open data.
- Computing for MegaScience Projects
- Quantum informatics and computing
- Big Data, Machine Learning and Artificial Intelligence

MATHEMATICAL MODELING AND COMPUTATIONAL PHYSICS

- methods, software and program packages for data processing and analysis;
- mathematical methods and tools for modeling complex physical and technical systems, computational biochemistry and bioinformatics;
- methods of computer algebra, quantum computing and quantum information processing;
- machine learning and big data analytics;
- algorithms for parallel and hybrid calculations.

JINR School of Information Technology

10th International Conference "Distributed Computing and Grid Technologies in Science and Education" (GRID'2023)

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- Distributed Computing
  education, industry and
- Computing for MegaSci
- Quantum informatics a
- Big Data, Machine Learn

MMCP

MATHEMATICAL MODELING AND COMPUTATIONAL PHYSICS

- methods, software and program packages for data processing and analysis;
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- methods of computer algebra, quantum computing and quantum information processing;
- ne learning and big data analytics;
- hms for parallel and hybrid
  ons.

MMCP2024 will be most likely held @ Yerevan in October 2024
follow https://lit.jinr.ru/ site for updates and news

Thank you for your attention!



BackUp

Support for the JINR Neutrino Program

MLIT contribution: engineering infrastructure (electricity, UPS, cooling, network, racks, manpower)

DLNP contribution: computing and storage resources (CPUs/GPUs&disks)

Computational resources for the **JINR neutrino program** using the cloud infrastructure of the MICC. The **NOvA, Baikal-GVD and JUNO** experiments are the **major consumers** of the cloud infrastructure.