



The ML/DL/HPC ecosystem of the HybriLIT heterogeneous platform for machine and deep learning tasks and quantum computing

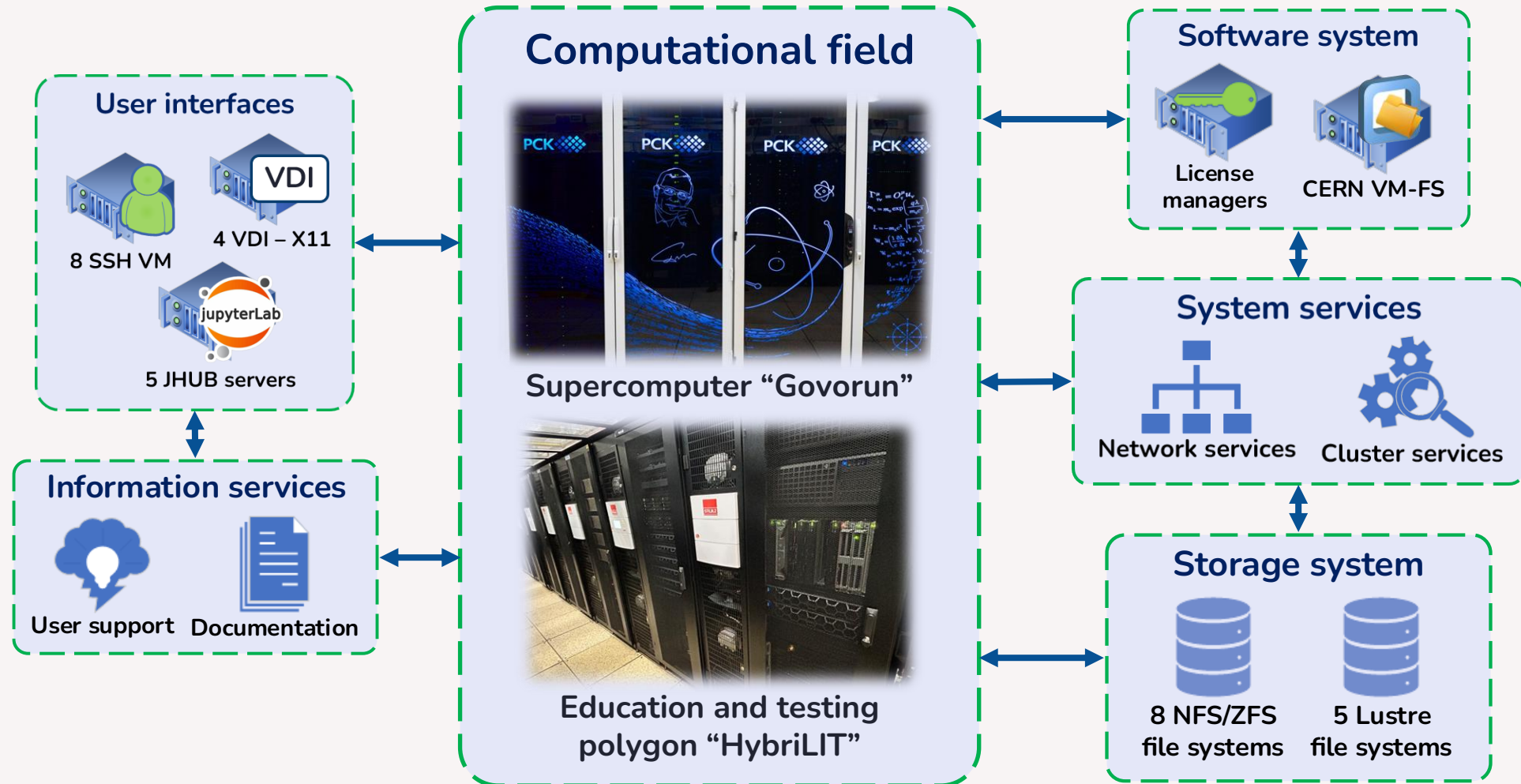
Belyakov D., Matveev M., Podgainy D., Streltsova O., Zuev M.

Meshcheryakov Laboratory of Information Technologies, Joint Institute for Nuclear Research, Dubna

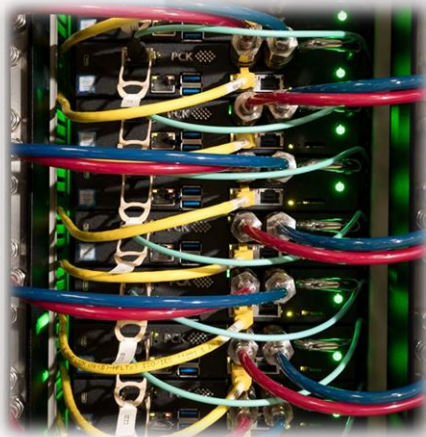
Суперкомпьютерные дни в России 2026
Инструменты и технологии обеспечения эффективной работы
суперкомпьютерных центров
28 сентября 2026

Software and hardware structure and services of the HybriLIT heterogeneous computing platform

Unified software-hardware structure



The HybriLIT heterogeneous computing platform



CPU component

- **21x servers with Intel Xeon Phi**
Intel Xeon Phi 7290 (72 cores @1.50 GHz), 96 GB RAM
- **76x servers with Intel Xeon Scalable Gen2 (RSC Tornado TDN511)**
2x Intel Xeon Platinum 8268 (24 Cores @2.90 GHz), 192 GB RAM
- **32x servers with Intel Xeon Scalable Gen2 (RSC Tornado TDN511S)**
2x Intel Xeon Platinum 8368Q (38 Cores @2.60 GHz), 2 TB RAM



Peak performance: 0.8 PFLOPS double precision

GPU component

- **5x servers with NVIDIA V100**
2x Intel Xeon E5-2698 v4 (20 cores @2.20 GHz),
8x NVIDIA V100 16 GB, 512 GB RAM
- **5x servers with NVIDIA A100**
2x AMD EPYC 7763 (64 Cores @2.45 GHz),
8x NVIDIA A100 80 GB, 2 TB RAM
- **2x servers with NVIDIA H100 (RSC Exastream AI)**
2x Intel Xeon Platinum 8468 (48 Cores @2.1 GHz),
8x NVIDIA H100 80 GB, 1 TB RAM



Peak performance: 58 PFLOPS half-precision

Total peak performance

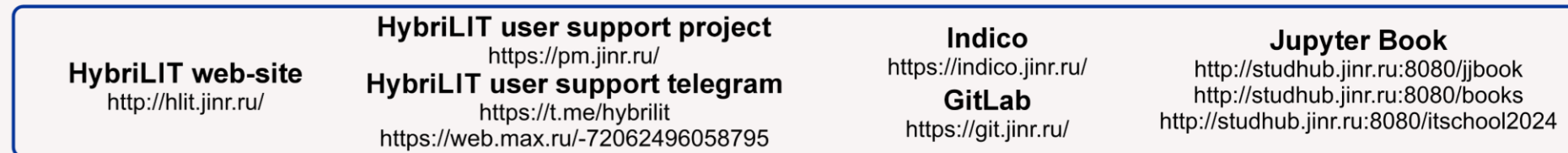
**2.2 PFLOPS double precision
58 PFLOPS half precision**

Storage system: 12.3 PB

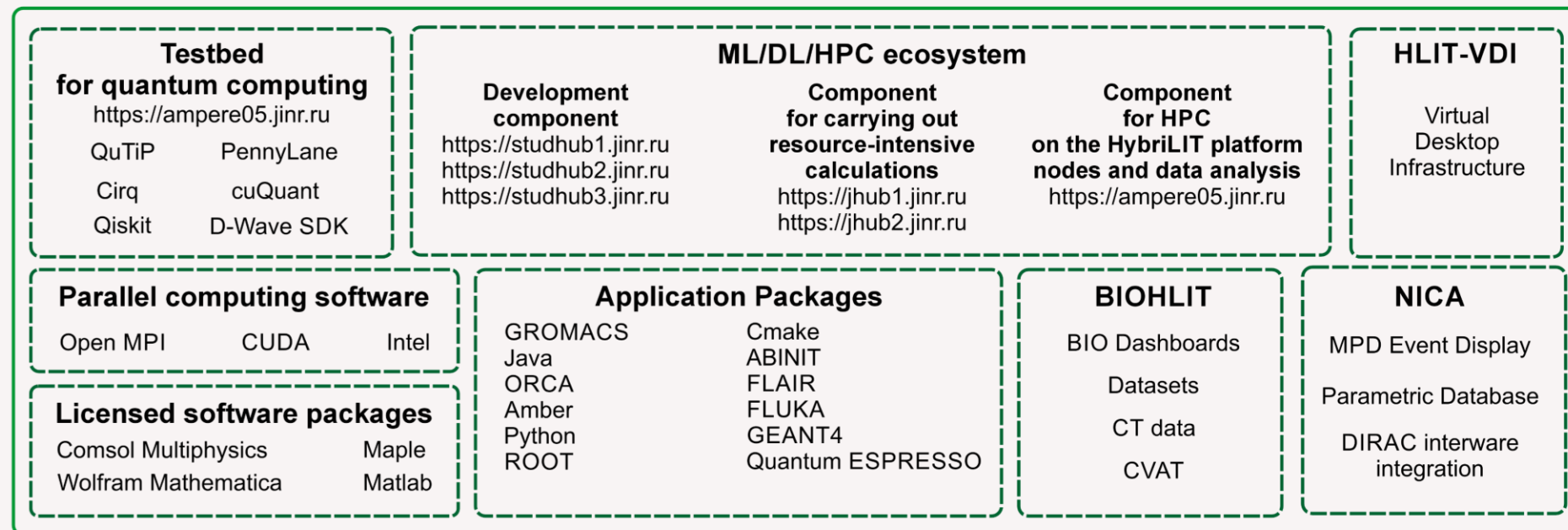


Software and information environment of the Platform

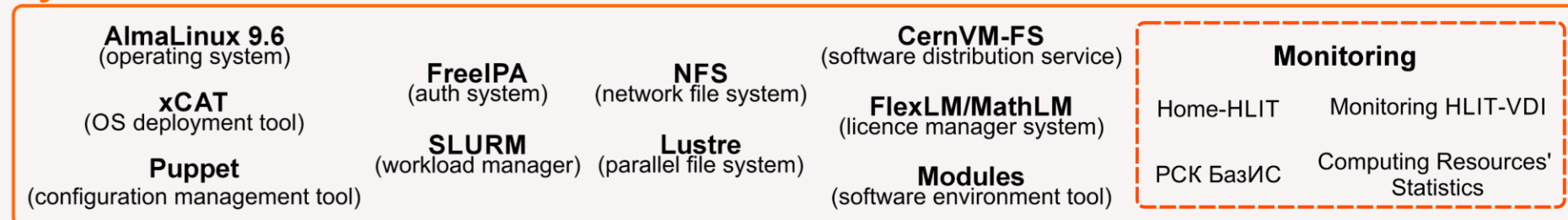
Information Level



Software Level



System Level



Capabilities of the HybriLIT heterogeneous computing platform

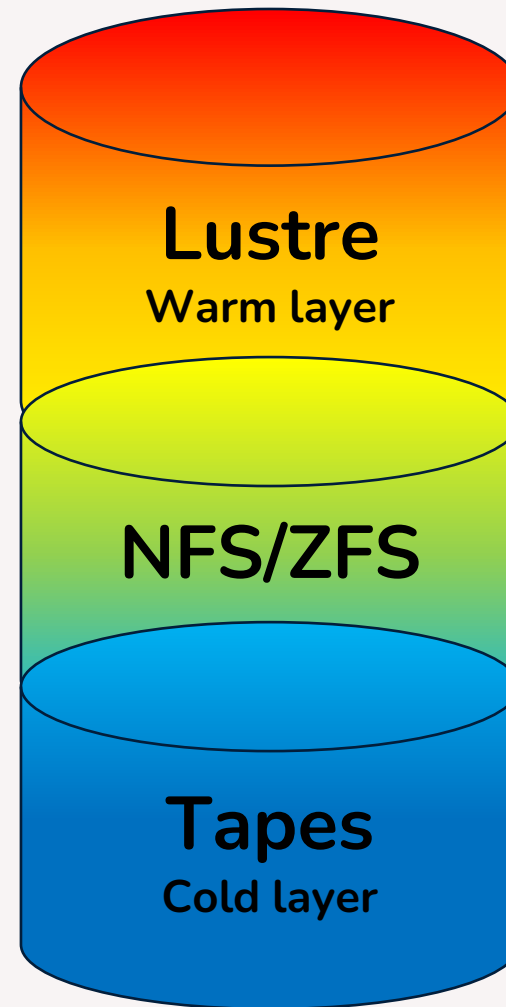
Hierarchical data
processing and
storage system

HPC. Solving complex computational problems that require massive parallel processing power

- ✓ Calculations of Quantum Chromodynamics Problems on Lattice
- ✓ Modelling of systems based on Josephson junctions

HTC. Processing and analysis of big data in high energy physics, nuclear physics and others

- ✓ Computing for NICA megascience project
- ✓ Calculations of radiobiology problems



ML/DL. Development of algorithms

- ✓ Applying of methods of machine learning and deep learning for analysis of video and images
- ✓ Applying Computer Vision for analysis of video and images
- ✓ Applying quantum computing for nuclear physics

Set of specialized services

- ✓ Radiobiology studies
- ✓ Toolkit for modeling superconductor/magnetic hybrid nanostructures
- ✓ Polygon for visualization of brain computer tomography data
- ✓ Quantum computing polygon

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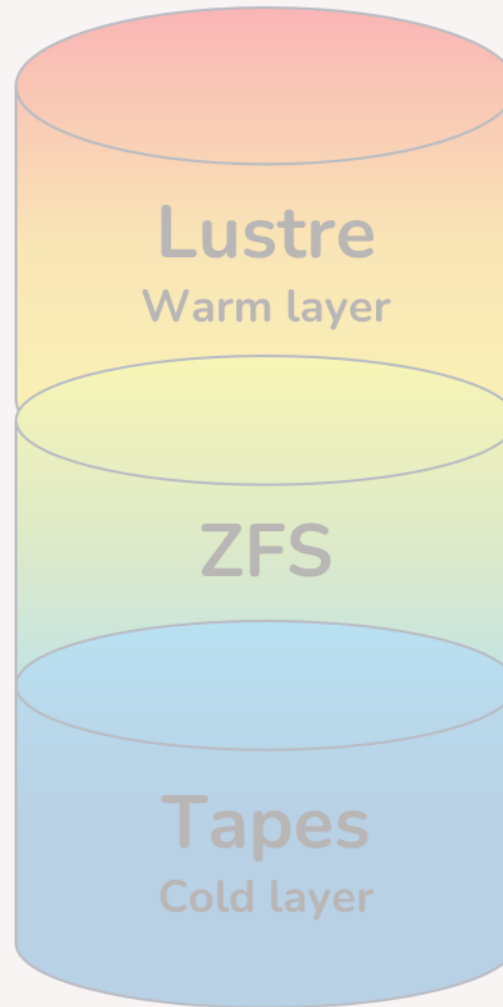
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ML/DL/HPC ecosystem

Component for educational purposes (without GPUs)

For teaching students
<https://studhub1.jinr.ru>

For conducting workshops within the framework of JINR scientific events
<https://studhub2.jinr.ru>
<https://studhub3.jinr.ru>

Component for carrying out resource-intensive computations (with GPUs)

<https://jhub1.jinr.ru>
<https://jhub2.jinr.ru>



HPC component for scientific projects (with installed specialized libraries)

BioProject services

<https://cell.jinr.ru>
<http://mostlit.jinr.ru>
<http://bio-dashboards.jinr.ru/morris>

Jupyter Books infrastructure

<http://studhub.jinr.ru:8080/jjbook>
<http://studhub.jinr.ru:8080/books>
<http://studhub.jinr.ru:8080/itschool2024>

CVAT services

<http://159.93.36.88:8080>
<http://159.93.36.67:8080>

A polygon for visualization of brain CT data

hlit-th-ct.jinr.ru

A polygon for quantum computing

<https://ampere05.jinr.ru>

Study the dynamics of magnetization in a Phi-0 Josephson Junction

MLIT, BLTP

The dynamics of the magnetic moment M of the system under consideration is described by the Landau-Lifshitz-Gilbert equation:

$$\begin{aligned}\frac{dm_x}{dt} &= -\frac{1}{1 + M^2 \alpha^2} \{m_y H_z - m_z H_y + \alpha [m_x (M, H) - H_x]\}, \\ \frac{dm_y}{dt} &= -\frac{1}{1 + M^2 \alpha^2} \{m_z H_x - m_x H_z + \alpha [m_y (M, H) - H_y]\}, \\ \frac{dm_z}{dt} &= -\frac{1}{1 + M^2 \alpha^2} \{m_x H_y - m_y H_x + \alpha [m_z (M, H) - H_z]\},\end{aligned}$$

$M = [m_x, m_y, m_z]$ are the magnetic moment components; the effective field components $H = [H_x, H_y, H_z]$ depend on the Josephson phase difference ϕ and are defined as follows:

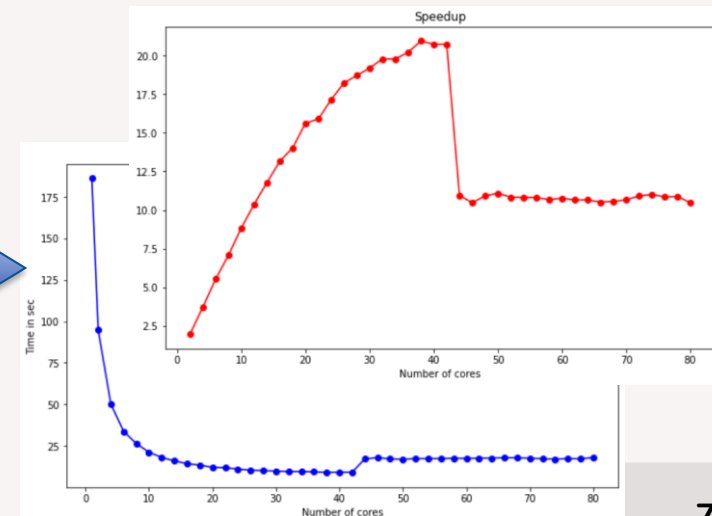
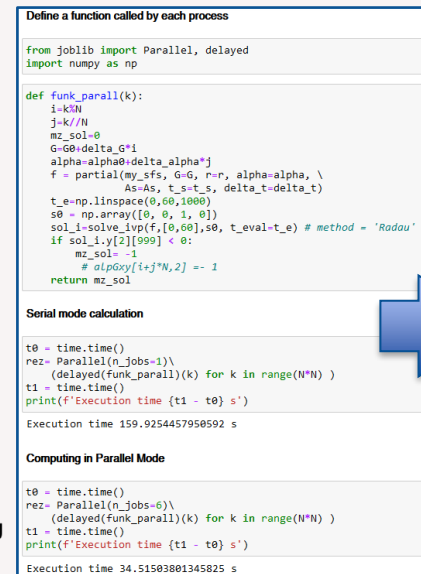
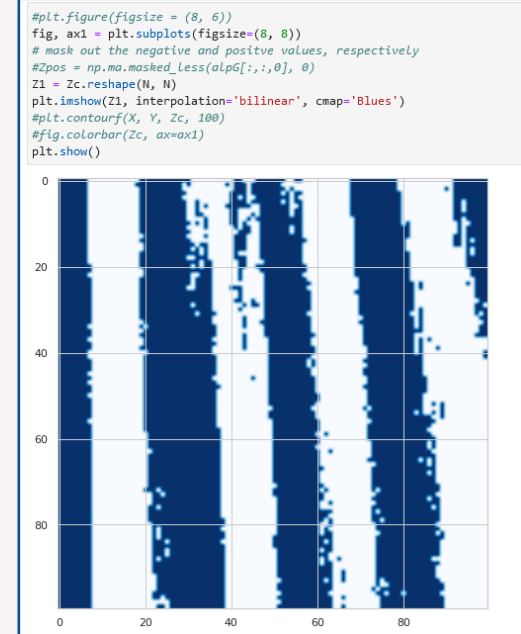
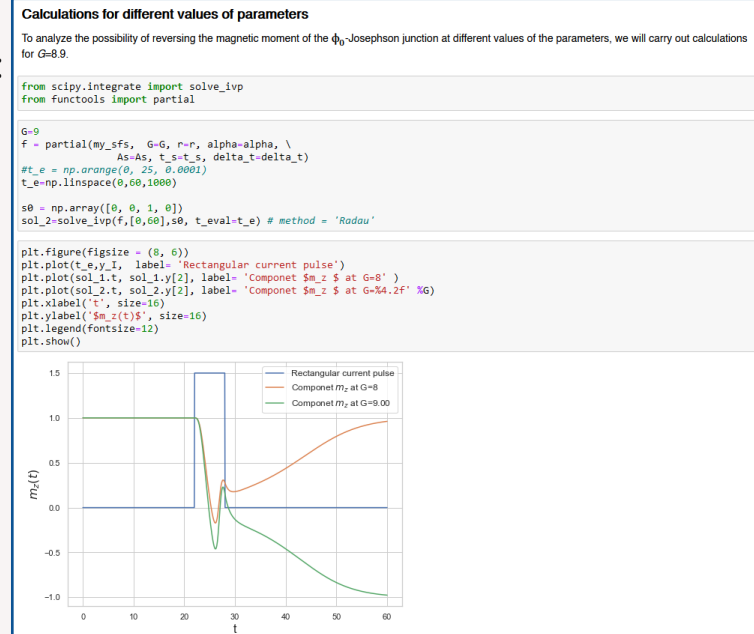
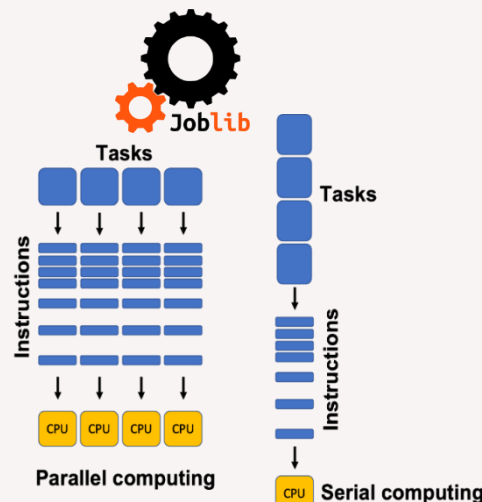
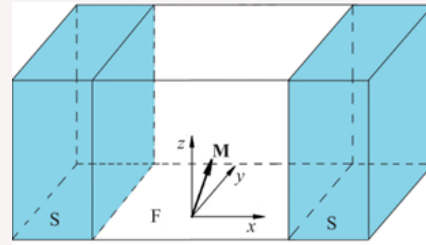
$$H_x(t) = 0,$$

$$H_y = Gr \sin(\phi(t) - tm_y(t)),$$

$$H_z(t) = m_z(t).$$

The equation for the Josephson phase difference $\phi(t)$ is determined from the equation for the electric current I flowing through the Josephson junction, measured in units of the critical current I_c :

$$\frac{d\phi}{dt} = -\frac{1}{w} \left(\sin(\phi - rm_y) + r \frac{dm_y}{dt} \right) + \frac{1}{w} I,$$



Jupyter Books for modelling superconductor/magnetic hybrid nanostructures

MLIT, BLTP

<http://studhub.jinr.ru:8080/jjbook>, <http://studhub.jinr.ru:8080/books>, <http://studhub.jinr.ru:8080/itschool2024>

As part of a joint project between **MLIT** and the **Laboratory of Theoretical Physics (BLTP)** on modelling hybrid superconductor/magnetic nanostructures, a package of tools in the form of Jupyter Notebook, which are posted in the format of electronic publications **Jupyter Book** on the Platform resources has been developed.

Define a function called by each process

```
from joblib import Parallel, delayed
import numpy as np
```

```
def funk_parallel(k):
    i=k*N
    j=k//N
    mz_sol=0
    G=G0+delta_G*i
    alpha=alpha0+delta_t*j
    f = partial(my_sol,
                As=As,
                t_e=np.linspace(0, 60, 1000))
    sol_i=solve_ivp(f, 0, s0, t_eval=t_e)
    return mz_sol
```

Calculations for different values of parameters

To analyze the possibility of reversing the magnetic moment of the Φ_0 -Josephson junction at different values of the parameters, we will carry out calculations for $G=8.9$.

```
from scipy.integrate import solve_ivp
from funtools import partial

G=9
f = partial(my_sfs, G=G, n=r, alpha=alpha, \
            As=As, t_s=t_s, delta_t=delta_t)
# t_e = np.arange(0, 25, 0.0001)
t_e=np.linspace(0,60,1000)
s0 = np.array([0, 0, 1, 0])
sol_2=solve_ivp(f,[0,60],s0, t_eval=t_e) # method = 'Radau'
```

Serial mode calculation

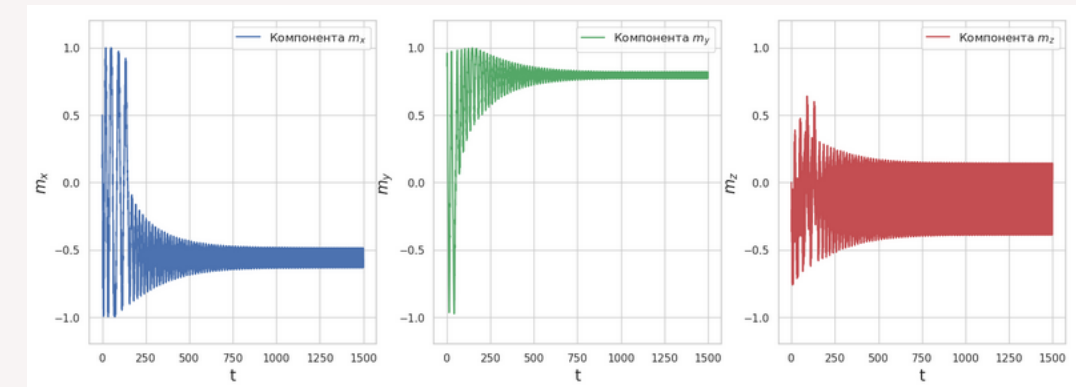
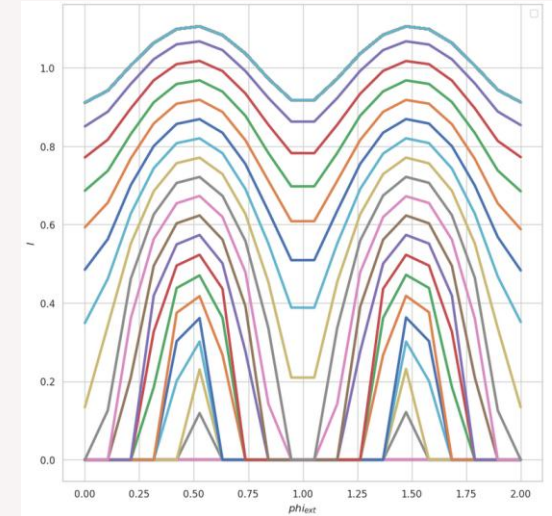
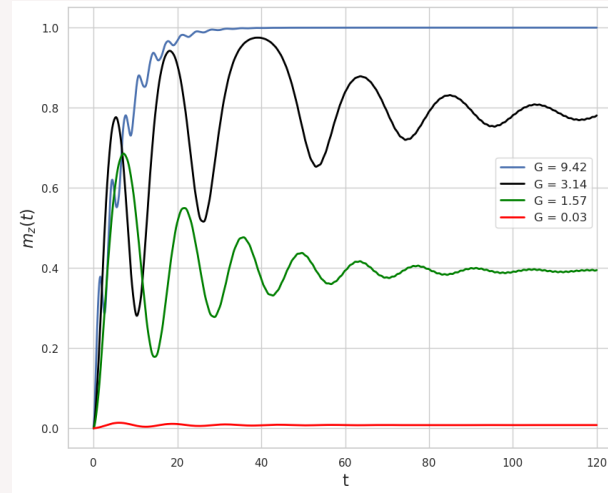
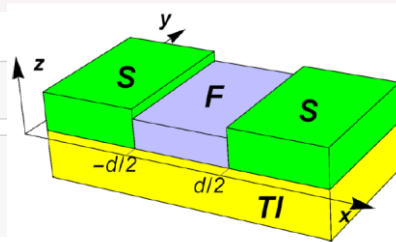
```
t0 = time.time()
rez= Parallel(n_jobs=
              )(delayed(funk_parallel)
               )
t1 = time.time()
print(f'Execution time {t1-t0}')

Execution time 159.9;
```

Computing in Parallel Mode

```
t0 = time.time()
rez= Parallel(n_jobs=
              )(delayed(funk_parallel)
               )
t1 = time.time()
print(f'Execution time {t1-t0}')

Execution time 34.51;
```



This work was supported by Russian Science Foundation grant № 22-71-10022.

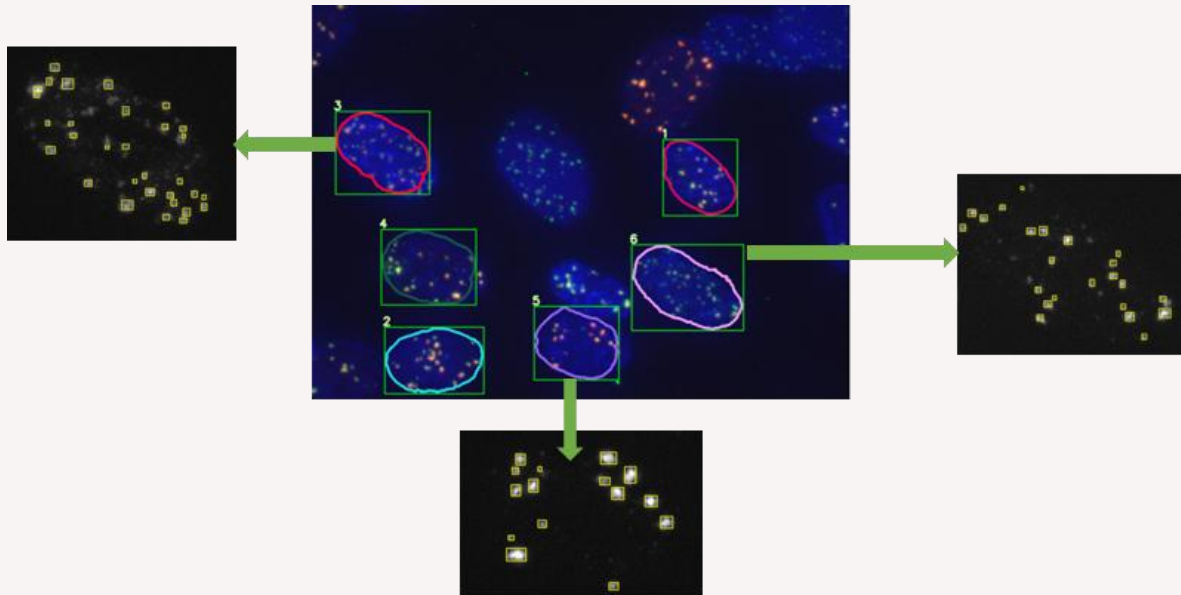
BIOHLIT information system for radiobiological studies

MLIT, LRB

Within the framework of the joint project between **Meshcheryakov Laboratory of Information Technologies (MLIT)** and the **Laboratory of Radiation Biology (LRB)**, the web services are developed and deployed based on the ML/DL/HPC ecosystem of the HybriLIT Heterogeneous Computing Platform.

Detecting DNA repair foci in cell nuclei

<http://mostlit.jinr.ru>



Our web service allows to process the group of fluorescent images with minimal operator's involvement and automate the analysis of radiation induced DNA double-strand breaks.

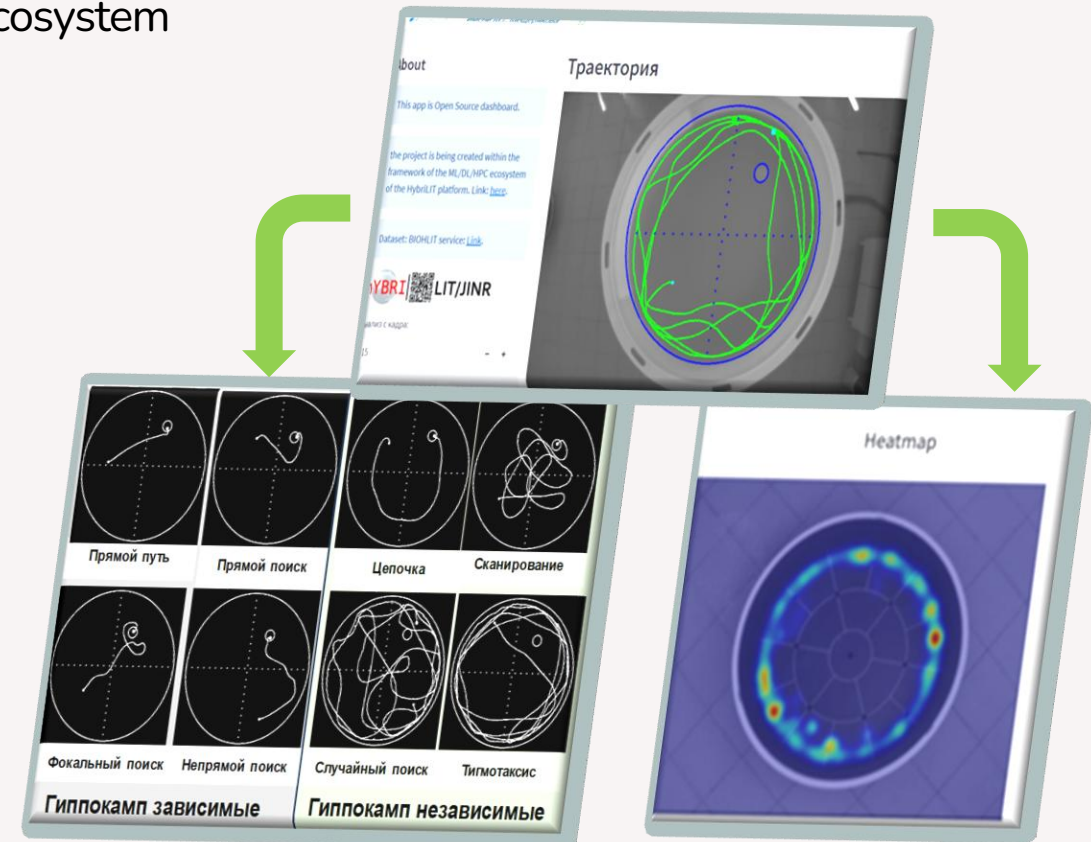
S. Shadmehri, T. Bezhanyan, M. Yu. Bondarev, O. I. Streltsova, M. I. Zuev, A. V. Boreyko, T. S. Khramko, M. E. Krupnova. Web Service for Automated Detection and Analysis of Radiation-Induced Foci in Cell Nuclei // Phys. Part. Nuclei, Vol. 57, No. 4, pp. 779-781, 2026. DOI: 10.1134/S1063779626700826.

Bezhanyan, T.Z., Streltsova, O.I., Shadmehri, S. et al. A Deep Learning Algorithm for Tracking Laboratory Animals in the "Morris Water Maze". Phys. Part. Nuclei **57**, 786-788 (2026).

<https://doi.org/10.1134/S106377962670084X>

Trajectory analysis

<http://bio-dashboards.jinr.ru/morris>



The developed web service allows one to study spatial learning, behavioral reactions and memory of small laboratory animals exposed to irradiations.

CVAT BIOHLIT. CVAT. Image & Video Data Annotation Platform

MLIT, LRB

<http://159.93.36.88:8080>
CVAT version 2.2.0

The screenshot displays the CVAT 2.2.0 interface. On the left, a sidebar lists projects with thumbnails and metadata. The main area shows a grid of project thumbnails. A box at the bottom right of the interface provides summary statistics:

Projects: 20
Tasks: 134
Jobs: 134

<http://159.93.36.67:8080>
CVAT version 2.40.0

The screenshot displays the CVAT 2.40.0 interface. It shows a list of projects with detailed task information, including creation and update dates, and action buttons. A box at the bottom right of the interface provides summary statistics:

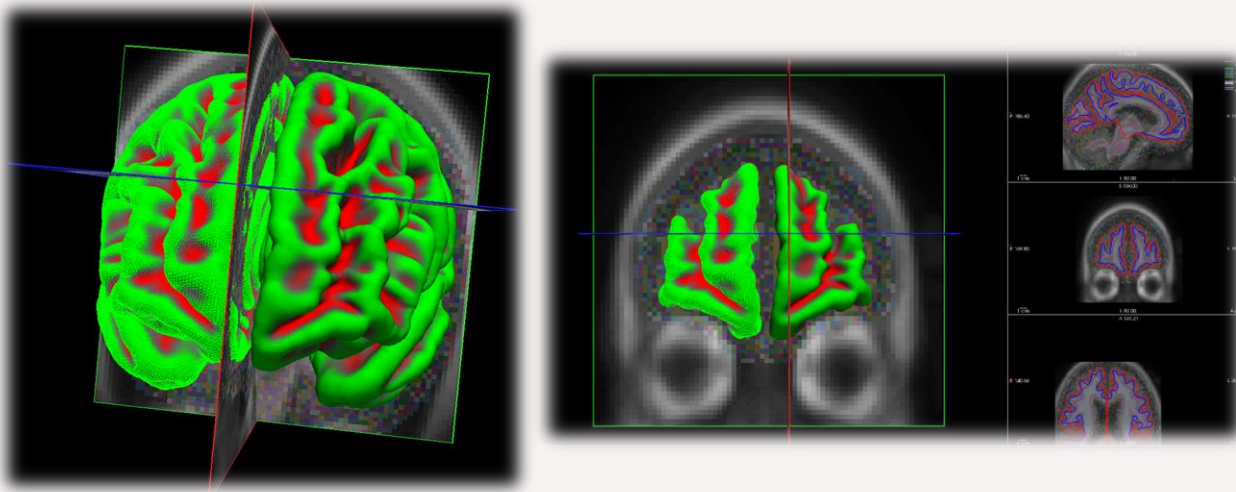
Projects: 2
Tasks: 8
Jobs: 8

A polygon for visualization of brain CT and MRI/fMRI data

JINR (MLIT, BLTP), FMBA

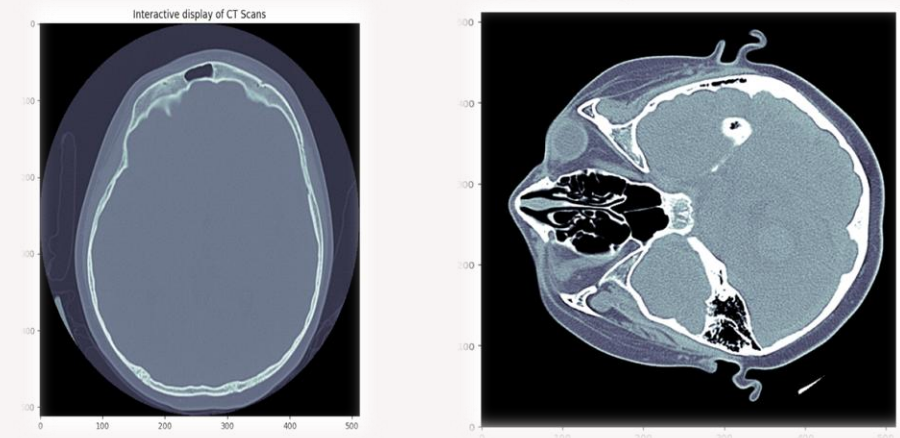
Work tools for processing

- ❑ **MRI Convert** for converting the NIFTI file from the original set of DICOM files;
- ❑ **FreeSurfer** for NIFTI file processing;
- ❑ **FreeView** (viewer from the FreeSurfer package) for building images after NIFTI file processing.
- ❑ **FSL**, alternative package for NIFTI file processing;
- ❑ **FSLeves** (viewer from the FSL package) for building images after NIFTI file processing



Work tools for visualization

- ❑ **PyDicom** – for read, modify, and write DICOM (Digital Imaging and Communications in Medicine) files, which are commonly used in medical imaging and related information.
- ❑ **Nipype** offer users an incredible opportunity to analyze data using a variety of different algorithms and provides a uniform interface to neuroimaging software.
- ❑ **Pysurfer** for visualizing cortical surface representations of neuroimaging data.



Quantum Computing Polygon

While quantum computers are not available for widespread use, various simulators of quantum computing on classical computers are being developed.

These are libraries on various programming languages or frameworks that allow to create, transform, optimize and effectively simulate quantum circuits. Thus, they allow user to completely control the behavior of a quantum system.

The work is organized in two modes:

- **using task scheduler (in SLURM queue mode)**

The main advantages:

- the ability to perform multi-node computations using MPI technology;
- the use of resources of the entire Platform.

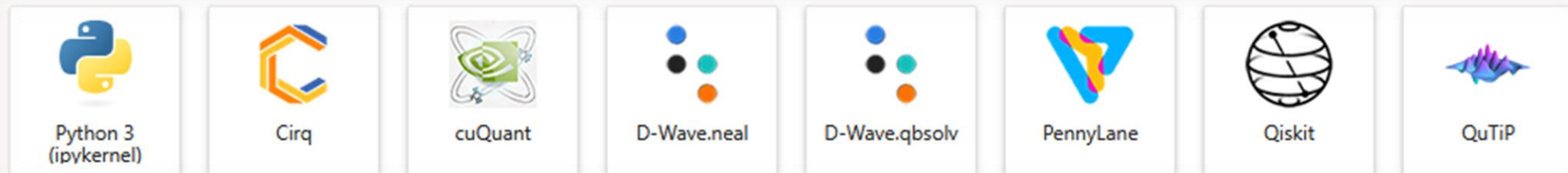
- **in interactive mode via web-browser**

The main advantages:

- the ability to visually develop algorithms, visualize quantum circuits;
- available Python language materials can significantly speed up research.

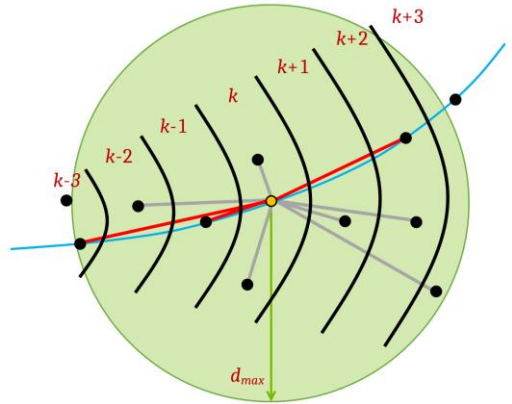
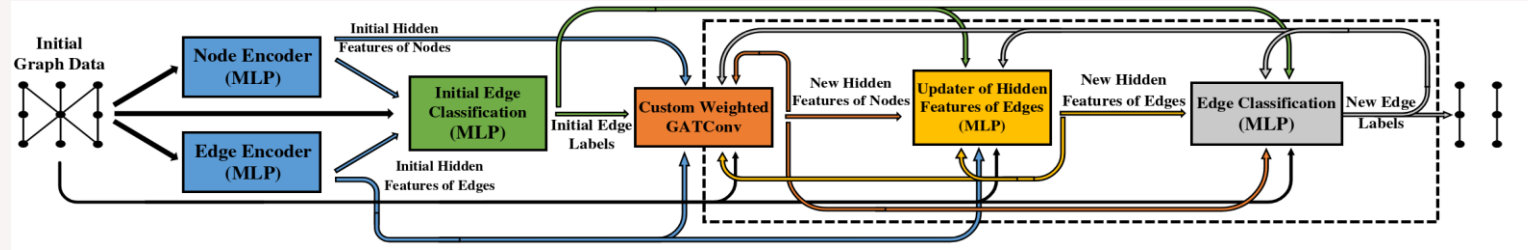
Server specifications:

2x AMD EPYC 7763 (64 Cores @2.45 GHz),
8x NVIDIA A100 80 GB, 2 TB RAM



Using the GNN for particle track reconstruction in the MPD of the NICA

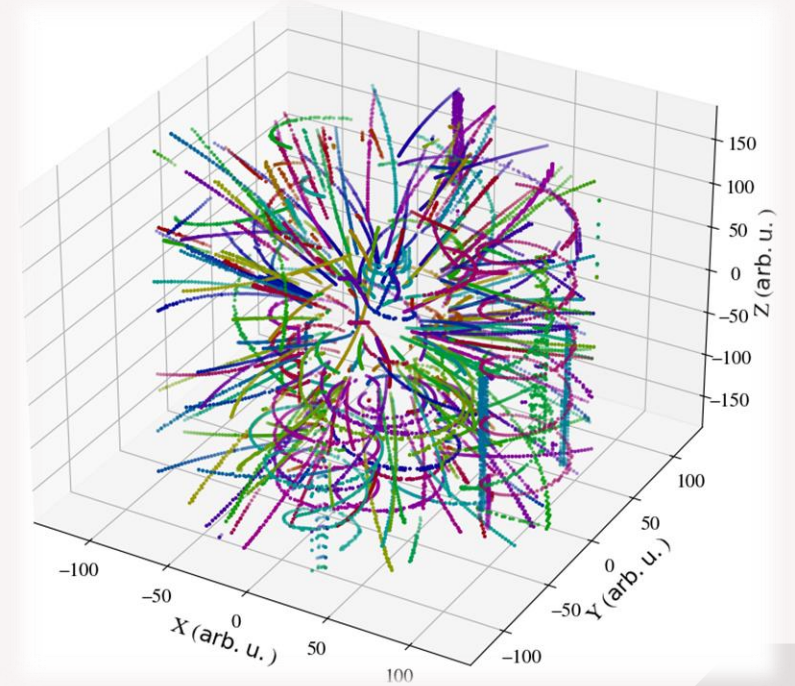
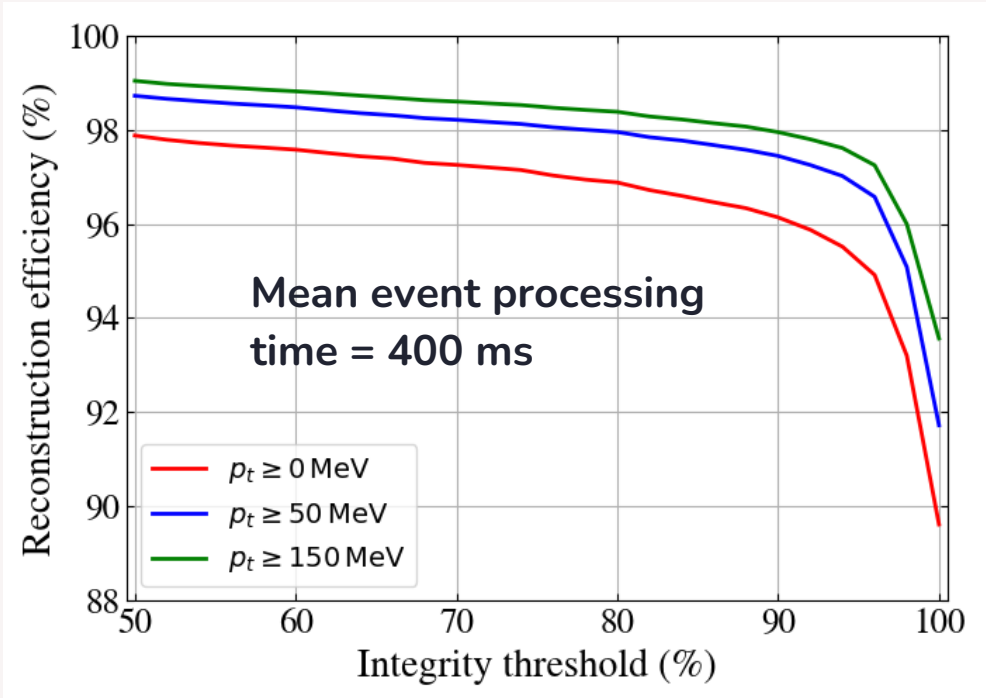
Dr. Yauheni Talochka, Prof. Gennady Ososkov, Dr. Nikolay Voytishin



Context-Aware Graph Building: The model connects hits from the three nearest layers (both forward and backward) within a maximum distance d_{max} .

Multi-Component Loss: The total loss consists of a Binary Cross-Entropy (BCE) loss with a contrastive embedding penalty for track hits and a Mean Squared Error (MSE) term to match predicted edge weights with true hit degrees.

	GATNN
Accuracy (%)	97.7
Purity & Efficiency (%)	98.5



TensorNet: toolkit for many-body problem simulations using tensor networks

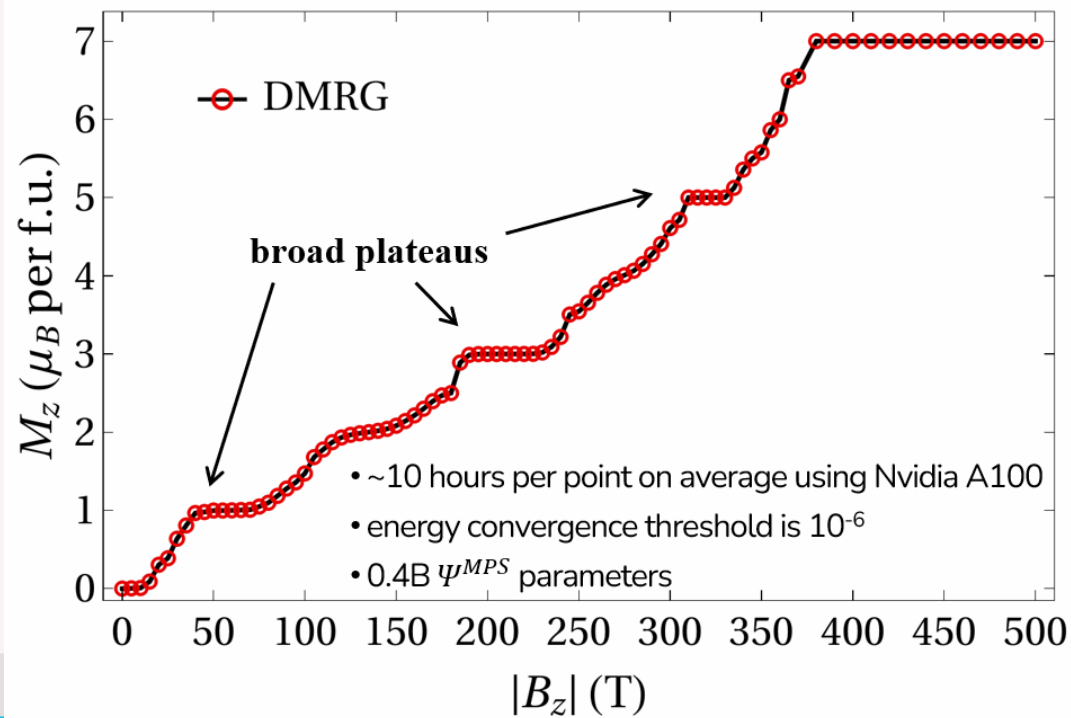
Dr. Yauheni Talochka [<https://github.com/YauheniTalochka/QTensorNet>]



- Currently, the toolkit supports any **single-level**, **loop-free** tensor network.
- The toolkit utilizes **a single Nvidia GPU** (or **multiple GPUs via MPI**) for contraction of a tensor network.
- The toolkit uses **cuSOLVER**, **cuTENSOR**, and **cuBLAS** to solve linear algebra problems.
- The **TEBD**, **DMRG** & **TDVP** methods are implemented.
- Basic operations for operator algebra and Hilbert space vectors represented as TNs are implemented.

Decorated Square-Kagome Heisenberg Antiferromagnet

$$\hat{H} = -g\mu_B \frac{\hbar}{2} \sum_{i=1}^N B_z \hat{\sigma}_{z,i} + \frac{\hbar^2}{4} \sum_{i<j} J_{i,j} \hat{\sigma}_i \cdot \hat{\sigma}_j, \chi_{max}^{MPS} = 1500, \chi_{max}^{MPO} = 300, |\Psi\rangle \rightarrow \Psi^{MPS}, \hat{H} \rightarrow H^{MPO}, M_z = \frac{1}{16} \langle \Psi_{gs}^{MPS} | \sum_{i=1}^N \hat{\sigma}_{z,i} | \Psi_{gs}^{MPS} \rangle$$

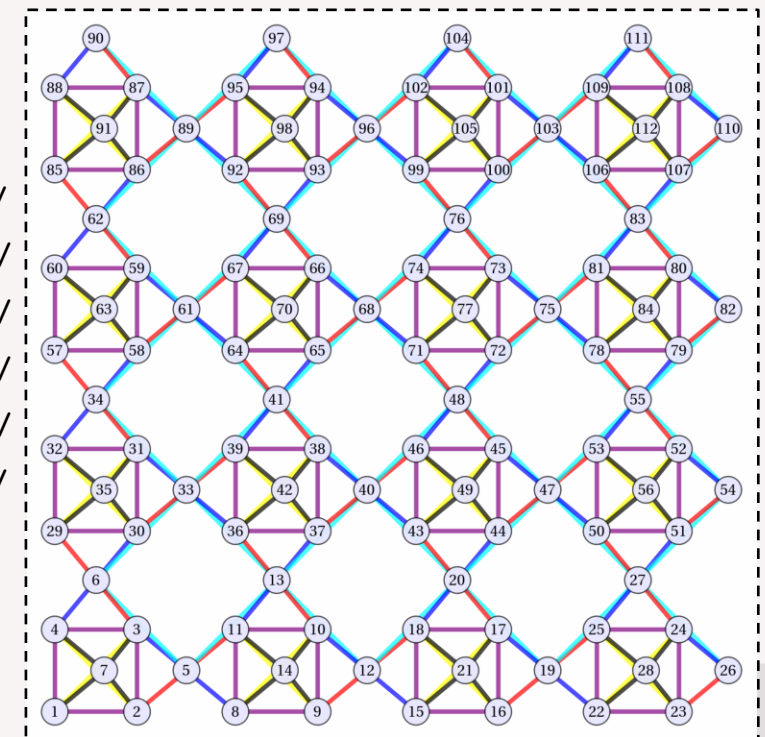


$4 \times 4 \times 7$ cluster = 112 spins

RAM capacity = $2^{112} \times 32$ bits

- $J_1 = 0.1723$ meV
- $J_2 = 10.1685$ meV
- $J_3 = 14.2186$ meV
- $J_4 = 14.6495$ meV
- $J_5 = 13.0983$ meV
- $J_6 = 2.6714$ meV

Periodic Boundary Conditions



Simulation of the Variational Quantum Algorithms for the Ising Model. Cirq

(<https://quantumai.google/cirq>)

qsim simulator integrated into Cirq library (C++ with SIMD, OpenMP, CUDA) was used for calculations

Task1: Ising model on 3x3x3 lattice (27 qubits)

Memory usage: ~1 TB CPU RAM, ~1.5 GB GPU RAM

Computation time:

Ising Model 3x3x3 lattice 27 qubits	AMD EPYC 7763, 128 threads	Intel Xeon Platinum 8368Q, 128 threads	NVIDIA A100, cuStateV ec
Total VQE cycle time	3 h 20 min	3 h 10 min	14 min 35 sec

NVIDIA A100: 14x speedup vs CPU

Task2: TFIM, 6-param universal entangling two-qubit gate for ansatz generation

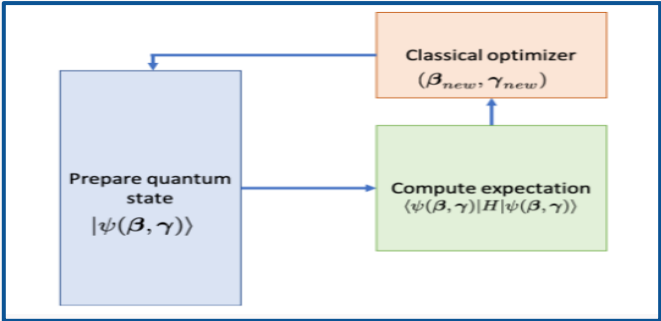
18-qubit VQE cycle:

~40 min on A100 (HybriLIT) vs >2 h on PC

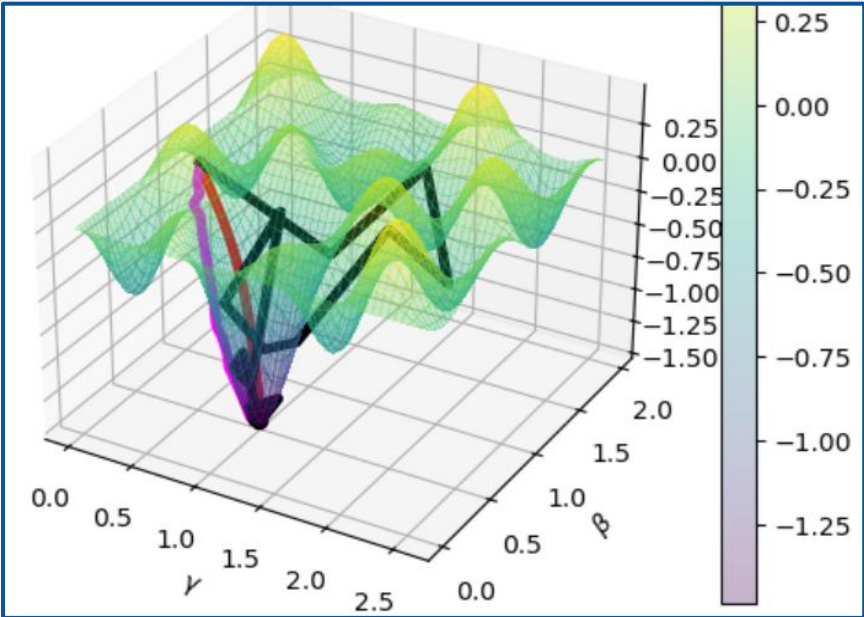
Scaling:

- 25-30 qubits: ≥1 day on PC, state vector exceeds PC memory
- HybriLIT quantum polygon: routine even at this scale

Finding the lowest-energy state of the Ising model via Variational Quantum Algorithms. VQE cycle:

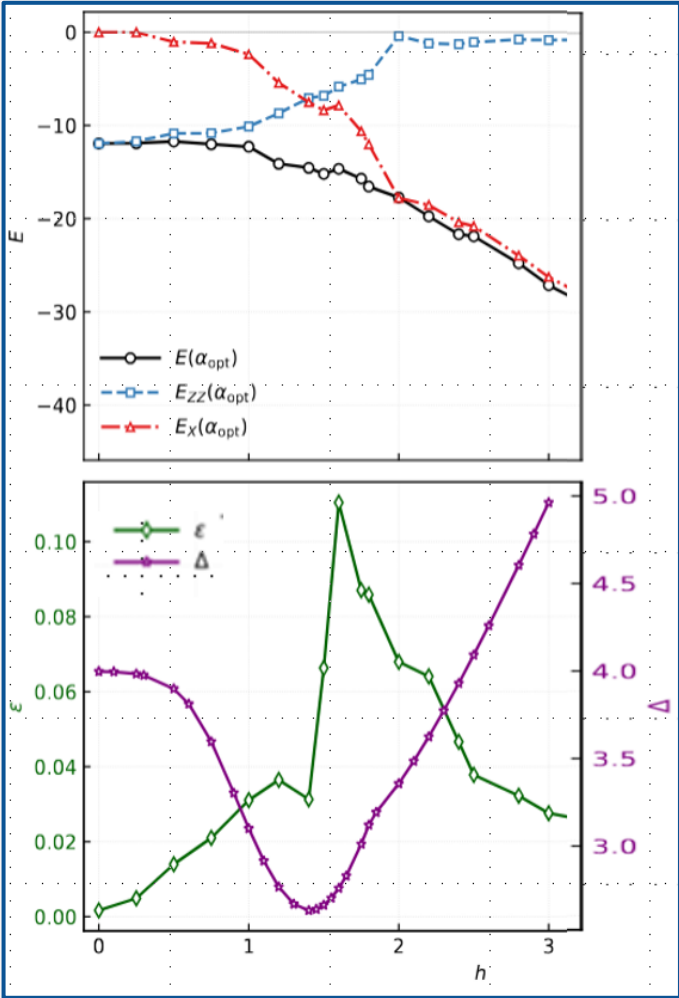


Task1: Ising model with a longitudinal magnetic field via QAOA. Find γ and β minimizing $E(\gamma, \beta)$. Energy minimization trajectories for different optimizers: GD, Nelder-Mead, COBYLA.



Yu. Palii, D. Belyakov, A. Bogolubskaya, M. Zuev, D. Yanovich. PEPAN. Vol. 56 No.4 (2025), pp.1661-1669.

Task2: Transverse-field Ising model (TFIM) with a 6-parameter universal entangling two-qubit gate for ansatz generation. Energy components (top) and error/gap analysis (bottom):

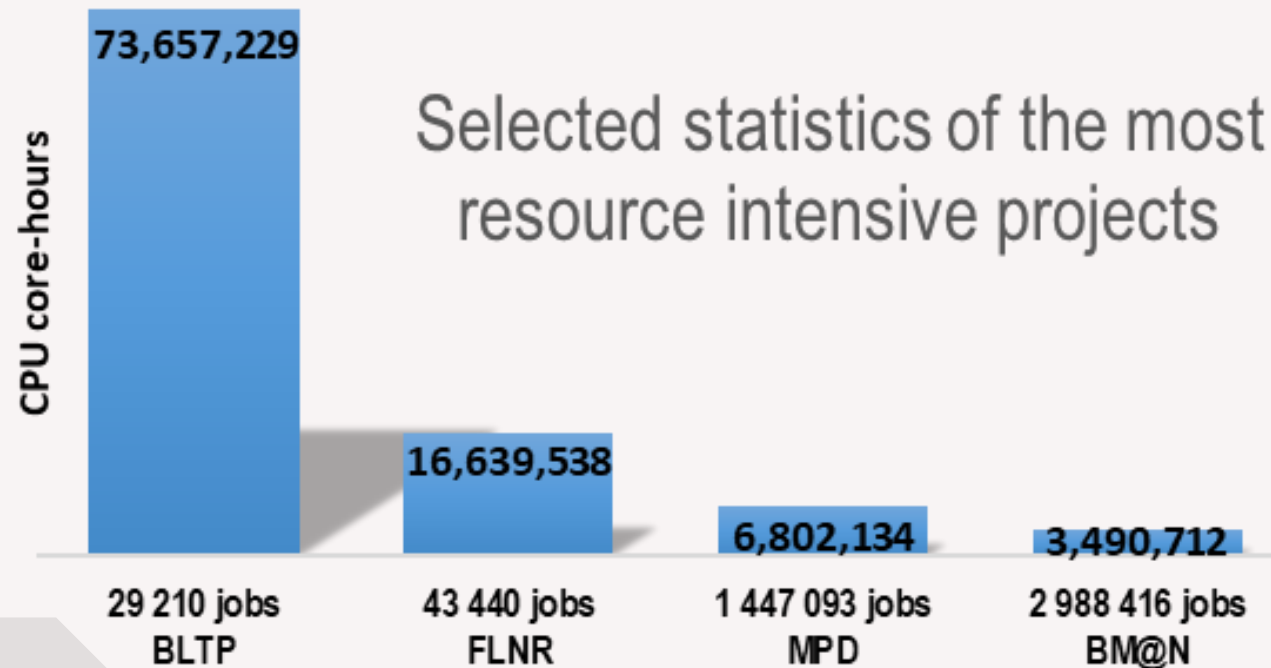


A. Bogolubskaya, A. Khvedelidze, Yu. Palii, I. Rogojin, Verkhovceva K. On implementation of variational quantum algorithm on the HybriLIT quantum testbed. Proceedings of MMCP-2026.

Using of the Govorun supercomputer

The resources of the Govorun SC are used by scientific groups from all the Laboratories of the Institute. **The projects that mostly intensive use the CPU resources of the Govorun SC:**

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



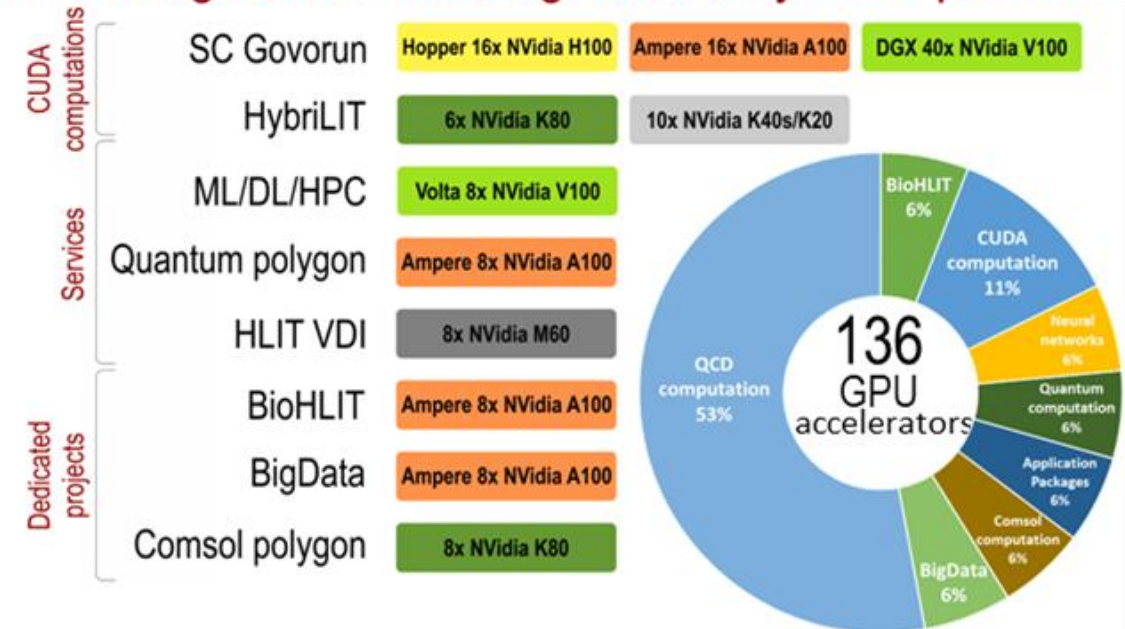
The Govorun SC users completed **13.94 M jobs** what corresponds to the **111.87 M core-hours**.

The average load of the **CPU component** was **97.2%**

The average load of the **GPU component:**

DGX load was **99.2%**, **Ampere** load was **87.7%**.

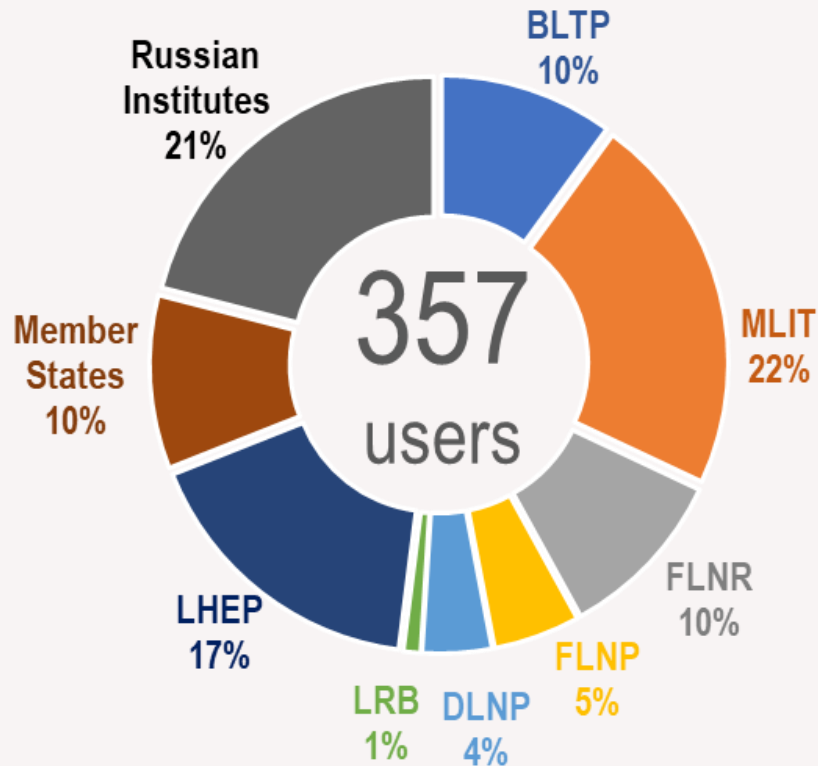
GPU usage at the Heterogeneous HybriLIT platform



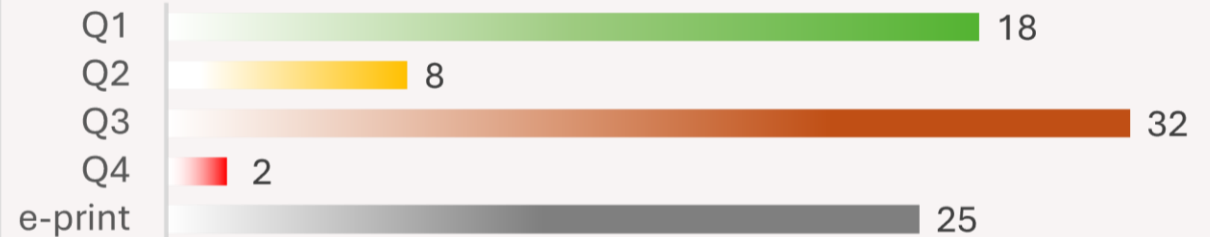
Publications

For all the time, users of the heterogeneous HybriLIT platform published articles in various fields:

- physics of elementary particles and the atomic nucleus,
- high energy physics,
- biophysics and chemistry,
- neural network approach, methods and algorithms of machine learning and deep learning (ML/DL), etc.



In 2025, an additional **94** articles were published.



Research results obtained using the supercomputer resources since 2014 are presented in **599** publications. Two of them were prepared in Nature Physics:

- M. Kircher ... O. Chuluunbaatar et al. Kinetically complete experimental study of Compton scattering at helium atoms near the threshold. Vol. 16. № 4. Pp. 756-760
- BM@N Collaboration. Unperturbed inverse kinematics nucleon knockout measurements with a 48 GeV/c carbon beam. Vol. 17. Pp. 693-699



Educational activities on the Platform

Platform resources are used as a base platform for studying new IT technologies and for training IT specialists. The International School on Information Technologies of JINR is held annually at LIT; it is aimed at attracting young specialists to solving JINR tasks using modern information technologies.

The **Dubna State University**, **Tver State University** and **MSU branch in Dubna** regularly conducts training courses in such disciplines as:

- “Architecture and technologies of high-performance systems”,
- “Parallel distributed computing”,
- “Languages and technologies of data analysis”,
- “High-performance computing technologies”,
- “Software tools for mathematical calculations”.

Over the 2022-2025 academic year, **more than 400 students** participated in these courses.



ОСЕННЯЯ ШКОЛА
по информационным технологиям ОИЯИ
6 - 10 Октября 2025
57 студентов

Санкт-Петербург

18 университетов РФ

- Национальный исследовательский ядерный университет «МИФИ»
- Российский университет дружбы народов им. Патриса Лумумбы
- Национальный исследовательский университет «МЭИ»
- Государственный университет управления
- Российский экономический университет им. Г.В. Плеханова
- Национальный исследовательский технологический университет «МИСИС»
- Санкт-Петербургский государственный университет
- Университет ИТМО
- Государственный университет «Дубна»
- Тульский государственный университет
- Воронежский государственный университет
- Южно-Российский государственный политехнический университет
- Северо-Осетинский государственный университет им. К.Л. Хетагурова
- Казанский федеральный университет
- Самарский университет
- Южно-Уральский государственный университет
- Национальный исследовательский томский государственный университет
- Томский политехнический университет

+ 4 университета из стран СНГ

- Беларусь: Полесский государственный университет, Гомельский государственный технический университет им. П.О. Сухого
- Казахстан: Казахский национальный университет им. Аль-Фараби
- Узбекистан: Ташкентский филиал Санкт-Петербургского государственного университета
- Таджикистан: Ташкентский филиал Санкт-Петербургского государственного университета

<https://itschool.jinr.ru>



Training courses, lectures, tutorials





Thank you for your attention!

Heterogeneous platform “HybriLIT”

<http://hlit.jinr.ru/>



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