

Methods, Algorithms and Software for Modeling Physical Systems, Mathematical Processing and Analysis of Experimental Data

Theme leaders: S.V. Shmatov
O. Chuluunbaatar

Deputies: N.N. Voytishin
P.V. Zrellov

Participating countries and international organizations:

Armenia, Belarus, Bulgaria, CERN, China, Egypt, France, Georgia, Italy, Japan, Kazakhstan, Mexico, Mongolia, Russia, Serbia, Slovakia, South Africa, Tajikistan, Vietnam, United Kingdom, USA, Uzbekistan.

The problem under study and the main purpose of the research:

The theme is aimed at organizing and providing computational, algorithmic and software support for the preparation and implementation of experimental and theoretical research conducted with JINR's participation, at elaborating, developing and using computational methods for modelling complex physical systems studied within the projects of the JINR Topical Plan. Within the theme, mathematical methods and software, including those based on machine and deep learning algorithms using recurrent and convolutional neural networks, will be developed for modelling physical processes and experimental facilities, processing and analysing experimental data in the field of elementary particle physics, nuclear physics, neutrino physics, radiobiology, etc. Particular attention will be paid to the creation of systems for the distributed processing and analysis of experimental data, as well as information and computing platforms to support research conducted at JINR and other research centres.

The main directions of work are mathematical and computational physics to support JINR's large research infrastructure projects, primarily, the NICA flagship project in the fixed target mode (BM@N) and in the collider mode for relativistic heavy ion collisions (MPD) and polarized beams (SPD), the Baikal-GVD neutrino telescope. Cooperation with experiments at the world's accelerator centres (CERN, BNL, etc.), experiments in the field of neutrino physics and astrophysics, radiobiological research programmes will also be continued. The possibility of using the developed methods and algorithms within other projects is being considered.

The major direction in modelling complex physical systems, including the states of dense nuclear matter and quantum systems, will be the development of methods, software packages and numerical research based on the solution of the corresponding systems of nonlinear, spatially multidimensional integral, integro-differential or differential equations in partial derivatives with a large number of parameters characterized by the presence of critical modes, bifurcations and phase transitions with the complex application of methods of computational physics, quantum information theory and hybrid quantum-classical programming methods, quantum computing in quantum chemistry and physics.

In addition, the training of specialists in the field of computational physics and information technology within the IT School will be continued.

Projects in the theme:

Name of the project	Project leaders	Project code
1. Mathematical methods, algorithms and software for modeling physical processes and experimental facilities, processing and analyzing experimental data	S.V. Shmatov <i>Deputies:</i> A.S. Ayriyan N.N. Voytishin	06-6-1119-1-2024/2026
2. Methods of computational physics for the study of complex systems	E.V. Zemlyanaya O. Chuluunbaatar <i>Deputies:</i> Yu.L. Kalinovsky A. Khvedelidze	06-6-1119-2-2024/2026

Projects:

Name of the project		Project leaders	Status
Laboratory	Responsible from laboratories		
1. Mathematical methods, algorithms and software for modeling physical processes and experimental facilities, processing and analyzing experimental data		S.V. Shmatov <i>Deputies:</i> A.S. Ayriyan N.N. Voytishin	Realization
MLIT	P.G. Akishin, E.P. Akishina, A.I. Anikina, E.I. Alexandrov, I.N. Alexandrov, T.A. Aushev, D.A. Baranov, T.Zh. Bezhanyan, J. Busa, M.V. Chadeeva, R.N. Chistov, K.A. Chizhov, N.V. Greben, H. Grigorian, S. Hnatic, , O.Yu. Derenovskaya, A.V. Didorenko, N.D. Dikumar, V.V. Ivanov, A.A. Kazakov, A.K. Kiryanov, O.L. Kodolova, A.S. Konak, Yu.V. Korsakov, P.A. Korshunova, B.F. Kostenko, Z.K. Khabaev, M.A. Mineev, N.G. Monakov, Zh.Zh. Musulmanbekov, A.V. Nechaevsky, A.N. Nikitenko, E.G. Nikonov, D.A. Oleynik, S.S. Omelyanchuk, E.S. Osetrov, G.A. Ososkov, V.V. Palichik, V.V. Papoyan, I.S. Pelevanyuk, N.K. Petrov, A.Sh. Petrosyan, D.V. Podgainy, S.M. Polikarpov, D.I. Pryahina, A.G. Reshetnikov, L.R. Romanychev, A.R. Ryabov, I. Satyshev, A.S. Sedelnikov, K.V. Slizhevsky, A.G. Soloviev, T.M. Solovjeva, O.I. Streltsova, S.A. Shadmehri, Z.A. Sharipov, S.K. Slepnev, E.N. Talochka, Z.K. Tuhliev, A.V. Uzhinsky, V.V. Uzhinsky, S.V. Ulyanov, A.V. Yakovlev, V.B. Zlokazov, M.I. Zuev		
VBLHEP	V. Yu. Aleksakhin, A.A. Aparin, Yu.V. Bepalov, O.I. Brovko, D.V. Budkovski, A.V. Bychkov, D.K. Dryablov, I.R. Gabdrakhmanov, A.S. Galoyan, K.V. Gertsenberger, V.M. Golovatyuk, M.N. Kapishin, V.Yu. Karzhavin, A.A. Korobitsyn, A.V. Krylov, A.V. Lanev, V.V. Lenivenko, S.P. Lobastov, S.P. Merts, A.A. Moshkin, Yu.A. Murin, D.N. Nikiforov, M. Patsyuk, O.V. Rogachevsky, V.G. Riabov, V.V. Shalaev, S.G. Shulga, A.V. Taranenko, E.V. Zemlyanichkina, I.A. Zhizhin, A.I. Zinchenko, D.A. Zinchenko		
BLTP	D.I. Kazakov, M.V. Savina, O.V. Teryaev, V.D. Toneev, V.A. Zykunov		
FLNP	M. Balasoïu, M.V. Frontasyeva, A.I. Ivankov, A.H. Islamov, Yu.S. Kovalev, A.I. Kuklin, Yu.N. Pepelishev, Yu.L. Ryzhikov, A.V. Rogachev, V.V. Skoy, K.N. Vergel		
DLNP	V.A. Bednyakov, I.A. Belolaptikov, I.V. Borina, A.N. Borodin, A. Datta, V. Dik, I.I. Denisenko, T.V. Elzhov, A.A. Grinyuk, A.V. Guskov, V.A. Krylov, V.S. Kurbatov, D.V. Naumov, A.E. Pan, F.V. Prokoshin, A.E. Sirenko, L.L. Simbiryatin, M.N. Sorokovikov, B.A. Shaibonov, A.C. Zhemchugov, D.Yu. Zvezdov		
LRB	I.A. Kolesnikova, Yu.S. Severyukhin, D.M. Utina		
Assosiated personnel	A.V. Anisenkov, A.N. Amirkhanov, E.V. Alpatov, A.V. Baskakov, A.R. Buzykaev, S.A. Bulanova, O.V. Bulekov, N.A. Burmasov, M.A. Bykovsky, S.A. Doronin, F.A. Dubinin, A.I. Durov, D.V. Ermak, O.L. Fedin, D.A. Ivanishchev, Yu.D. Karpova, V.T. Kim, V.N. Kovalenko, M.A. Kondratyev, E.V. Kuznetsova, A.S. Kurova, A.V. Lazareva, A.A. Levkov, V.V. Makarenko, M.V. Malaev, V.P. Maleev, T.E. Mokoena, V.A. Mosolov, A.N. Morozikhin, P.V. Nekrasov, G.A. Nigmatkulov, G.E. Petrov, A.S. Povarov, Yu.G. Ryabov, D.R. Sharikova, S.Yu. Smirnov, E.Yu. Soldatov, D.E. Sosnov, K.A. Tertyshnaya, P.E. Teterin, M.V. Zhalov, E.N. Zavidov, A.M. Zakharov, A.V. Zelenov		

Abstract and scientific rationale:

The project is aimed at organizing and providing computational support for physics research programmes implemented with JINR's participation, at developing mathematical methods and software for modelling physical processes and experimental facilities, processing and analysing experimental data in the field of elementary particle physics, nuclear physics, neutrino physics, condensed matter, radiobiology, etc. The particular attention will be paid to the creation of systems for the distributed processing and analysis of experimental data, as well as information and computing platforms to support research at JINR and other world centres.

The main areas of work are mathematical and computational physics to support JINR's large research infrastructure projects, first of all, the experiments at the NICA accelerator complex and the Baikal-GVD neutrino telescope. Further cooperation with experiments at the largest world accelerator centres (CERN, BNL, etc.), experiments in the field of neutrino physics and astrophysics, radiobiological research programmes will also be continued. The possibility of using the developed methods and algorithms within other megascience projects is being considered.

Expected results upon completion of the project:

Revision of interaction generators and their development for modelling the processes of interactions of light and heavy nuclei, including those at NICA energies (FTF, QGSM, DCM-QGSM-SMM, etc.), and processes beyond the Standard Model, such as the production of candidate particles for the role of dark matter, additional Higgs bosons and processes that violate the lepton number, etc. (QBH, Pythia, MadGraph, etc.) for LHC conditions at a nominal energy and a total integrated luminosity up to 450 fb^{-1} .

Development of algorithms for the reconstruction of charged particle tracks for experimental facilities, including those at NICA and the LHC, creation of appropriate software and its application for data processing and analysis, the study of the physical and technical characteristics of detector systems.

Development of scalable algorithms and software for processing multi-parameter, multi-dimensional, hierarchical data sets of exabyte volume, including those based on recurrent and convolutional neural networks, for machine and deep learning tasks, designed primarily for solving various problems in particle physics experiments, including for the NICA megaproject and neutrino experiments.

Creation and development of data processing and analysis systems and modern research tools for international collaborations (NICA, JINR neutrino programme, experiments at the LHC).

Development of algorithms and software for JINR's research projects in the field of neutron physics.

Development of algorithms, software and computing platforms for radiobiological research, applied research in the field of proton therapy and ecology.

Expected results of the project current year:

Completion of the revision of the Geant4 FTF model, more accurate specification of the functions of fragmentation of quarks and diquarks into strange particles in the Geant4 QGS model. Optimization of the DCM and UrQMD 3.4 models. Attempt to develop a quark-gluon string model for nucleus-nucleus interactions.

Physics analysis of data obtained in the NICA MPD, NICA BM@N and NA61/SHINE experiments within the Geant4 FTF and UrQMD 3.4 models. Mass computing for the given models at the request of the experiments.

Considering various effects of the DCM-QGSM-SMM generator: dependences of the lifetime of resonances on the density of the nuclear medium, suppression of the production cross section of pseudoscalar mesons, enhancement of the production of hyperons in a dense nuclear medium, nucleus deformations. Elaboration of a lattice model of the nucleus and a percolation model of multifragmentation.

Algorithms, software, Monte Carlo modeling and data analysis within the CMS experiment to investigate the 28 GeV resonance in the muon pair spectrum using the LHC Run 3 statistics. Search for a resonance at 28 GeV in the e^+e^- and $\tau^+\tau^-$ decay channel using LHC Run 2 and Run 3 data.

Algorithms, software, Monte Carlo modeling and data analysis within the CMS experiment to search for dark matter particles in Run 3 data in the final state with two muons of different signs and the missing momentum. Interpretation of the results within the Inert Doublet Model and 2HDM+a models.

Debugging of the procedure for testing sensitive elements of the high-granularity calorimeter of the CMS experiment, including track reconstruction and the evaluation of the efficiency of each detector cell. Working out the possibility of monitoring calorimeter cells using physics processes.

Development and adjustment of algorithms and methods for reconstructing muon trajectories in the Cathode-Strip Chambers (CSCs) of the muon system of the CMS experiment to compare the continuous wavelet analysis approach for separating overlapping signals with the neural network approach based on a KAN network, to estimate the CSC spatial resolution and the aging effect on data obtained in 2025 at the GIF++ facility at CERN and in proton-proton beam collisions at the LHC.

Participation in the modernization of the ATLAS Athena IOVDbSvc package for CREST, adaptation of the EventIndexPicking service to the requirements of the Production System Group, modification of the TDAQ Resource manager in accordance with the tasks of the ATLAS JIRA system.

Study of the efficiency and speed of various machine learning methods for particle identification in the BM@N experiment.

Finding a full set of correction parameters for the STS and GEM detectors of the BM@N experiment (with and without magnetic fields) and their software implementation for current detector configurations in 2025-2026.

Preparation of the detailed geometry of track detectors for the current configuration of the facility within BM@N Run 9. Preparation of algorithms for simulating realistic responses for the gas and semiconductor detectors of the hybrid tracking system, as well as algorithms for reconstructing coordinates from the microstrip planes of the detectors to process experimental data collected in 2025 within BM@N Run 9.

Algorithms for modeling responses of the track detectors of the BM@N experiment on top of generative adversarial networks (GANs). Algorithms for spatial coordinate reconstruction in the track detectors using a hybrid approach based on classical and quantum neural networks.

Monte Carlo modeling investigation of multi-particle correlations in pp interactions at the NICA beam energy of 13 GeV, comparison with theoretical models.

Implementation of the gradient boosting-based charged particle identification program in MPDroot.

Modernization of clustering algorithms and completion of the ACTS tracker integration into global reconstruction within the MPDroot software shell. ACTS testing by users in mass production conditions.

Update of the external dependencies of MPDRoot and its adaptation to changes in the packages used (GCC 15.x, GEANT4 11.4+, ROOT 6.38+, C++23). End of support for CentOS 7 and start of support for Alma Linux 10.x. Assessment of the possibility of distributing the MPDRoot package using CVMFS on the macOS platform.

Elaboration and implementation of neural network algorithms for event reconstruction tasks in the SPD experiment at the NICA accelerator complex.

Elaboration and implementation of neural network methods based on Kolmogorov-Arnold networks (KANs) for the deconvolution of multicomponent signals obtained in a physics experiment.

Development of algorithms on top of tensor networks for the charged particle track reconstruction task in TPC MPD at the NICA accelerator complex.

Application of classical tracking methods for constructing and extrapolating tracks from TPC to the ToF system of the MPD experiment.

Development and support of the functioning of information systems of the BM@N and MPD experiments to describe the facility geometry, detector configuration, and management process. Creation of a prototype of the BM@N Data Quality Assurance system. Creation and implementation of an MPD e-log system. Participation in the development of an MPD DAQ online system.

Investigation of the properties of hadron jet/cluster reconstruction algorithms under SPD conditions. Study of the possibility of observing particle clusters in the inclusive case. Determination of the kinematics of partons of a hard process using machine learning algorithms.

Implementation of a model for processing and storing simulated data from the SPD experiment, relevant for 2025-2026. Integration of the SPD middleware and application software being created on the Sampo software platform.

Functional testing and debugging of the components and interfaces of the middleware complex for the data preprocessing system of the SPD experiment on the hardware-software prototype of a primary data processing cluster, SPD Online Filter.

Provision of the required level of functioning that meets the needs for the mass modeling of physics processes of the SPD experiment in a distributed computing environment based on the PanDA load management system and a data management system on top of the RUCIO DDM package.

Development of processing management systems, addition of new processes and a system for accounting data processing requests. Elaboration of security issues, in particular, user authentication and authorization, experimental data access policies. Enhancement of monitoring tools for the infrastructure, services, and data processing processes. Development of systems for the semi- and automatic testing of services of the created distributed computing environment.

Optimization of Baikal-GVD automated data processing graphs for the efficient use of multithreading in processing programs.

Development of software for data processing on the YuMO small-angle neutron scattering spectrometer.

Construction of a machine learning model for the hadron and gamma quantum classification task in the TAIGA experiment.

Modeling of an upgraded version of the OLVE-HERO prototype for accelerator beam tests.

Development of mathematical methods and algorithms for trajectory reconstruction in the proton digital calorimeter simulation task.

Further optimization of the web application for experimental data fitting: selection of the best LLM model, elaboration of an additional user interface, increasing the number of accepted data formats.

Application of high-order BEM polynomials to enhance the methodology of processing reactor data and neutron noise from the IBR-2M reactor.

Development of an algorithmic module on top of deep learning models and explainable artificial intelligence models for the tasks of analyzing data obtained using the Morris Water Maze test system in experiments aimed at studying the behavioral reactions of laboratory animals exposed to various factors.

Elaboration of algorithms based on deep learning and computer vision methods and creation of a web application for analyzing data obtained using the Open Field test system in experiments aimed at studying the effects of ionizing radiation and other factors on biological objects.

Research in the field of enhancing the accuracy of plant disease classification and detection models. Assessment of the efficiency and applicability of various methods for generating synthetic images of plant diseases.

Investigations in the field of soil pollution prediction using remote sensing data and various machine learning methods. Development of neural network methods for calibrating mobile platforms to evaluate air purity.

Development of new computational methods on the basis of the universal inverse Radon transform and creation of software for the enhanced analysis of computed tomography data.

Elaboration of algorithms for neutron spectrum reconstruction based on Bonner spectrometer readings using deep neural networks with input feature transformation. Creation of a web application prototype.

Testing and refinement of the prototype of a quantum fuzzy PID controller and the demonstration model of a robot with the built-in prototype of a self-organizing controller. Testing in operational mode of the prototype of an intelligent system for controlling cryogenic systems for superconducting magnets of the NICA accelerator complex in normal and abnormal situations on the basis of a quantum coordination self-organizing PID controller. Enhancement of the methodology of the developed structure of the intelligent RF station control system.

2. Methods of computational physics for the study of complex systems

E.V. Zemlyanaya
O. Chuluunbaatar
Deputies:
Yu.L. Kalinovsky
A. Khvedelidze

Realization

MLIT	V. Abgaryan, G. Adam, S. Adam, P.G. Akishin, A.S. Ayriyan, E.A. Ayrjan, D.R. Badreeva, I.V. Barashenkov, M.V. Bashashin, A.A. Bogolubskaya, L. Bordag, M. Bures, J. Buša, Jr.J. Buša, A.M. Chervyakov, G. Chuluunbaatar, Kh. Chuluunbaatar, D. Goderidze, H. Grigorian, A.A. Gusev, T.V. Karamysheva, A.V. Khmelev, V.V. Korniyak, O.O. Kovalev, D.S. Kulyabov, K.V. Lukyanov, N.V. Makhaldiani, S.D. Mavlonberdieva, T.I. Mikhailova, A.V. Nechaevsky, E.G. Nikonov, Yu. Palii, V.V. Papoyan, D.V. Podgainy, R.V. Polyakova, A.R. Rakhmonova, V.S. Rikhvitsky, I.A. Rogojin, B. Saha, I. Sarkhadov, Z.A. Sharipov, O.I. Streltsova, L.A. Syurakshina, Yu.N. Talochka, O.V. Tarasov, A.G. Torosyan, Z.K. Tukhliev, K.D. Verkhovtseva, A.V. Volokhova, O.O. Voskresenskaya, R.M. Yamaleev, E.P. Yukalova, O.I. Yuldashev, M.B. Yuldasheva, M.I. Zuev
BLTP	M.A. Abdelghani, A.A. Donkov, A.V. Friesen, M. Hnatic, K.V. Kulikov, V.K. Lukyanov, E.V. Mardyban, R.G. Nazmitdinov, Yu.V. Popov, I.R. Rahmonov, Yu.M. Shukrinov, S.I. Vinitsky, D.N. Voskresensky, V.I. Yukalov, V.Yu. Yushankhai
FLNR	E. Batchuluun, A.V. Karpov, M.N. Mirzayev, V.V. Samarin, Yu.M. Sereda
FLNP	M.A. Kiselev, N. Kucerka, E.E. Perepelkin
DLNP	O.V. Karamyshev, G.A. Karamysheva, I.D. Lyapin, E.P. Popov
VBLHEP	A.V. Bychkov, D.N. Nikiforov
LRB	A.N. Bugay, A.V. Chizhov

Abstract and scientific rationale:

The project is aimed at the development and application of mathematical and computational methods for modelling complex physical systems studied within the JINR Topical Plan and described by systems of dynamic nonlinear, spatially multidimensional integral, integro-differential or differential equations that depend on the parameters of models. The evolution of solutions to such systems can be characterized by the occurrence of critical modes, bifurcations and phase transitions. Mathematical modelling is an inseparable part of modern scientific research.

It entails an adequate mathematical formulation of problems within the models under study, the adaptation of known numerical approaches or elaboration of new ones to effectively take into account the features of the studied physical processes, the development of algorithms and software packages for high-performance simulation on modern computer systems, including the resources of the JINR Multifunctional Information and Computing Complex.

Expected results upon completion of the project:

Development of methods, algorithms and software packages for conducting the numerical research of interactions of various types in complex systems of nuclear physics and quantum mechanics.

Methods for modelling multifactorial processes in materials and condensed matter under external actions.

Methods for solving simulation tasks in the design of experimental facilities and the optimization of their operating modes.

Methods for modelling complex processes in dense nuclear matter based on the equation of state.

Methods for modelling quantum systems using quantum information theory methods and hybrid quantum-classical programming methods.

Expected results of the project current year:

Development of methods for solving multidimensional initial-boundary value problems for quantum tunneling in subbarrier heavy-ion fusion reactions and methods for calculating the characteristics of the inelastic scattering of fast electrons on atoms at large transferred momenta, taking into account the Migdal effect.

Elaboration of finite element methods for solving multidimensional boundary value problems, including a computational scheme for solving six-dimensional boundary value problems to study quadrupole-octupole collective models of the atomic nucleus.

Simulation of nucleon transfer and nuclear fragmentation processes in heavy ion interactions in the medium energy range within the transport-statistical approach. Microscopic models-based analysis of the optical potential of experimental data on proton-nucleus scattering and nucleus-nucleus interactions to obtain information on the structure of interacting nuclei and to investigate the influence of the nuclear environment on the mechanisms of these reactions.

Development of high-precision algorithms and methods of their parallel implementation for the numerical study of equations of motion that describe models of few-particle systems.

Numerical solution of many-particle quantum mechanics problems in applications of condensed matter physics by tensor network methods, including hybrid ones, with the introduction of neural network technologies. Study on this basis of quantum magnetism in low-dimensional spin systems, nonequilibrium quantum dynamics of isolated and open electron and magnetic quantum systems. Quantum-chemical computation of the electronic structure and spin states of organometallic molecular magnets based on transition and rare-earth metals.

Investigation of coherent dynamic phenomena in the Rabi-Josephson boson transition. Simulation of probabilistic dynamic networks with various memory types.

Modeling of complex processes in materials under the influence of high-energy heavy ion irradiation, nanoclusters and laser irradiation within a combined approach that integrates molecular dynamics methods and a thermal peak model.

Development of methods for the high-performance numerical study of dynamic processes in Josephson structures of various types. Simulation of the dynamics of a chain of parallel superconductor–ferromagnet–superconductor j_0 transitions, including the study of resonance properties and the emergence of magnons in such systems. Investigation of intertype superconductors and superconductors with impurities.

Numerical analysis of small-angle scattering data on small-radius vesicular systems within various approaches to obtain new information on the structure and properties of such systems depending on external factors.

Study of localized structures in systems described by nonlinear dynamic equations in one- and multidimensional field theory models, including moving oscillons, as well as the periodic solutions of the Ablowitz-Ladik equation with a nonlinear phase.

Optimization of the method and the software package for calculating the motion trajectories of a particle beam in the isochronous cyclotron to speed up the computation of the beam transmission coefficient.

Comparative analysis of various scenarios of the finite-element modeling of the magnetization phenomenon of a massive MgB_2 superconductor using the COMSOL package in order to select the optimal numerical approach.

Development, parallel implementation, and theoretical justification of a matrix-free h-p semi-adaptive three-level iterative loop method to solve large-scale finite-element systems on multi-core computers. Computations for optimizing the characteristics of superconducting magnets on the basis of 3D computer modeling and the volume integral equation method.

Optimization of computational methods and modernization of a software package for the parallel computer modeling of neutron star cooling, as well as for the validation of equation-of-state models of superconducting strongly interacting nuclear matter on the basis of observational data for compact objects. Study of the role of the spinor field in the accelerated expansion of the Universe based on the solution of a self-consistent system of Einstein–Dirac equations and comparison of the obtained numerical results with observational data and known theoretical models.

Investigation of nonlocal interaction models to describe meson spectra and development of numerical solution methods for the corresponding systems of equations, calculation on this basis of the physical characteristics of the systems under study. Description of the processes of production and dissociation of heavy quarkonia.

Implementation of a quantum circuit of the QAOA algorithm for 2- and 3-dimensional variants of the Ising model with a transverse electric field in the Quda-Q environment. Implementation of a quantum circuit of a nonlocal gate to create a two-qubit state with specified entanglement characteristics in the Cirq environment on the basis of the factorization of SU(4) transformations, which enables the construction of a double coset $SU(2) \times SU(2) \backslash SU(4) / U(1)^4$.

Study of the manifestations of deviation of a quantum system from the classical version based on a joint analysis of the negativity of the Wigner function for the qutrit and the characteristics of entanglement in a system of two qubits.

Construction of a model of a finite-dimensional quantum system on top of the Weyl-Heisenberg and Clifford groups with a description of quantum states by means of discrete Wigner functions defined over Galois fields.

Construction of chains of functional relation reduction for multi-loop Feynman integrals using a software package in the Maple system.

Elaboration of an algorithm for minimizing the influence of environmental interference and systematic experimental errors on single-qubit logic gates by implementing a specific sequence of unitary operations.

Implementation of quantum particle tracking algorithms using the qbsolv, neal libraries, and Google OR-Tools for efficient parallel processing in QUBO tasks. Solution of the tracking task in the QUBO formulation using the quantum-inspired QIOPT optimizer, designed for solving combinatorial, integer, and mixed optimization problems.

Model building speed-up and introduction of enhanced false segment filtering in tracking algorithms to reduce the impact of noise interference when using SPD datasets.

Analysis of the band structure and modeling of nonequilibrium carrier relaxation in mixed scintillation crystals promising for use in ionizing radiation detectors using the Quantum Espresso DFT package and the computing resources of the “Govorun” supercomputer.

Activity of the theme:

Name of the activity		Leaders	Implementation period
Laboratory	Responsible from laboratories		Status
1. Training of specialists in the field of computational physics and information technology		V.V. Korenkov	2024-2026
		A.V. Nechaevsky	
		D.I. Pryahina	
		O.I. Streltsov	
		Realization	
MLIT	T.Zh. Bezhanyan, O.Yu. Derenovskaya, E. Mazhitova, I.S. Pelevanyuk, A.S. Vorontsov, E.N. Voytishina, M.I. Zuev		
UC	D.V. Kamanin, A.Yu. Verkheev		
Assosiated personnel	A.V. Bogdanov, V.V. Korkhov, Zh.U. Kiyamov, A.N. Nikolskaya		

Abstract and scientific rationale:

The training and retraining of specialists in computational physics and information technology on the basis of the Multifunctional Information and Computing Complex (MICC) of the Joint Institute for Nuclear Research (JINR) and its educational components are performed for:

- upskilling JINR staff members in order to develop scientific projects, including megascience ones, which are implemented at JINR or with its participation, as well as to create and support the JINR Digital EcoSystem (DES);
- disseminating competencies in computational physics and information technology to the regions of Russia and the JINR Member States to enhance the personnel potential of JINR and organizations cooperating with the Institute;

- the main prerequisite for the creation of the activity is the necessity to form a research environment in order to ensure the professional growth of IT specialists, the creation and development of scientific groups, and the engagement of new specialists in JINR projects. The additional training of the personnel, mainly on request of the JINR Laboratories, should be aimed at developing special competencies, in-depth knowledge and practical skills in computational physics and information technology.

Expected results upon completion of the activity:

Holding events for JINR staff members to study state-of-the-art information technologies and opportunities to work on the MICC components and in the DES.

Forming a set of JINR projects in which students can participate.

Forming a list of competencies and required courses for the implementation of projects.

Elaboration of training courses and educational programmes that will provide personnel training for solving a variety of tasks within projects.

Creation of an ecosystem for the implementation of educational programmes on the basis of the JINR MICC, including the cloud infrastructure, the HybriLIT heterogeneous computing platform, which comprises the education and testing polygon and the “Govorun” supercomputer.

Creation of a software and information environment and a platform for organizing and holding events, lectures, workshops, hackathons, etc.

Involvement of specialists from JINR and JINR Information Centres, researchers from the JINR Member States’ organizations, lecturers from leading educational organizations that cooperate with JINR in order to hold educational and scientific events.

Forming event programmes and organizing interaction with universities and JINR Information Centres.

Expected results of the activity in the current year:

Elaboration of training courses and implementation of the educational master’s program entitled “Data Processing Methods and Technologies in Heterogeneous Computing Environments” in direction 01.04.02 Applied Mathematics and Computer Science at the branch of Lomonosov Moscow State University.

Holding the Lomonosov Universiade for students from universities of the Russian Federation and the JINR Member States in order to discover and support talented youth, as well as to attract students to enroll for the master’s course at the MSU branch in Dubna.

Holding JINR Schools of Information Technologies.

Training of highly qualified specialists for scientific projects implemented at JINR in collaboration with scientific and educational organizations of the Russian Federation and the JINR Member States.

Conducting educational practices and scientific seminars on information technologies for students from the Russian Federation and the JINR Member States.

Development of the components of the ecosystem on top of the JINR MICC, including the cloud infrastructure and the HybriLIT heterogeneous computing platform, for the implementation of educational programs and the information support of the activity.

Collaboration 1119

Country or International Organization	City, region	Institute or laboratory	
Armenia	Yerevan, ER	AANL	
		YSU	
Belarus	Gomel, HO	GSU	
	Minsk, MI	IM NASB	
		INP BSU	
		IP NASB	
Bulgaria	Sofia	SU	
CERN	Geneva, CH	CERN	

Country or International Organization	City, region	Institute or laboratory	
China	Beijing, BJ	CIAE	
Egypt	Giza, GZ	CU	
France	Gif-sur-Yvette, IDF	Irfu	
Georgia	Tbilisi, TB	GTU	
		TSU	
		UG	
Italy	Genoa, GE	INFN	
Japan	Sendai	IMRAM	
Kazakhstan	Almaty, ALA	IETP KazNU	
		INP	
	Astana, AST	ENU	
Mexico	Mexico City, CDMX	UNAM	
Mongolia	Ulaanbaatar	IMDT MAS	
		MUST	
Russia	Chelyabinsk, CHE	SUSU	
	Dubna, MOS	MSU Branch	
		Uni Dubna	
	Gatchina, LEN	NRC KI PNPI	
	Moscow, MOW	HSE	
		ITEP	
		LPI RAS	
		MEPhI	
		MISIS	
		MPEI	
		MSU	
		PFUR	
		RCC MSU	
		SINP MSU	
	Petropavlovsk-Kamchatsky, KAM	KamGU	
	Pushchino, MOS	IMPB RAS	
	Saint Petersburg, SPE	SPbSU	
	Samara, SAM	SNRU	
	Saratov, SAR	SGU	
	Sarov, NIZ	MSU Branch	
	Tomsk, TOM	TPU	
		TSU	
	Troitsk, MOW	INR RAS	
	Tula, TUL	TuISU	
	Tver, TVE	TverSU	
	Vladikavkaz, SE	NOSU	
	Vladivostok, PRI	FEFU	
	Voronezh, VOR	VSU	

Country or International Organization	City, region	Institute or laboratory	
Serbia	Belgrade, BG	UB	
Slovakia	Kosice, KI	UPJS	
South Africa	Cape Town, WC	UCT	
	Somerset West, WC	iThemba LABS	
Tajikistan	Khujand, SU	KSU	
United Kingdom	Oxford, OXF	Univ.	
USA	Arlington, TX	UTA	
Uzbekistan	Tashkent, TK	AS RUz	
		INP AS RUz	
		Physics-Sun	
Vietnam	Ho Chi Minh City, SG	HCMUE	