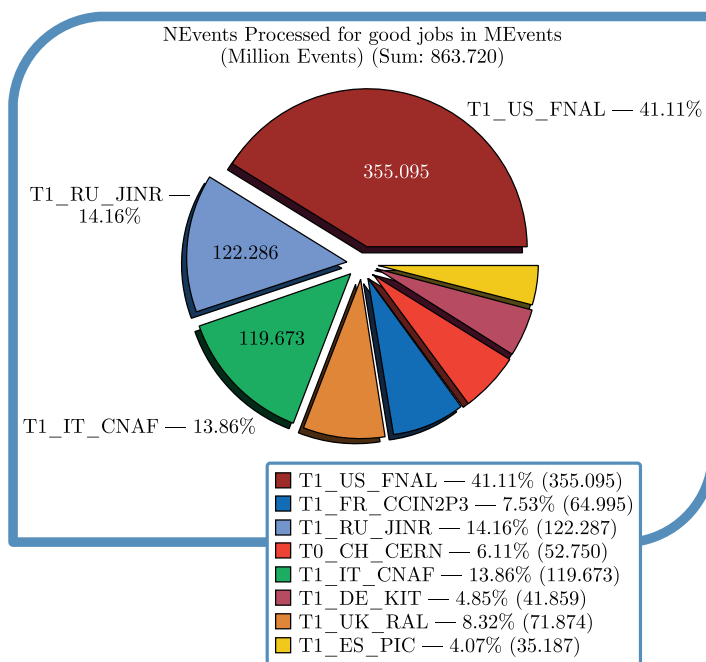# INFORMATION TECHNOLOGIES
AND COMPUTER PHYSICS

The Tier-1 level center for the CMS experiment at the Large Hadron Collider (LHC, CERN) was put into operation in 2015. Since 2017, the JINR Tier-1 site, one of the centers of storing and processing data of the CMS experiment at the LHC, takes the second place in the world — it has processed more than 120 million events that is more than 14% of the total number. Grid component of the JINR Multifunctional Information and Computing Complex is considered as a prototype of centres of the data processing and storing system of the NICA megaproject. The creating of the center of Tier-1 level at JINR opened a new prospect of research in the field of the Big data analytics.

NEvents Processed for good jobs in MEvents
(Million Events) (Sum: 863.720)

T1_US_FNAL — 41.11%

355.095

T1_RU_JINR — 14.16%

122.286

119.673

T1_IT_CNAF — 13.86%

- T1_US_FNAL — 41.11% (355.095)
- T1_FR_CCIN2P3 — 7.53% (64.995)
- T1_RU_JINR — 14.16% (122.287)
- T0_CH_CERN — 6.11% (52.750)
- T1_IT_CNAF — 13.86% (119.673)
- T1_DE_KIT — 4.85% (41.859)
- T1_UK_RAL — 8.32% (71.874)
- T1_ES_PIC — 4.07% (35.187)

The contribution of the world centers of Tier-1 level in the processing of the CMS experimental data (in millions of processed events) for 2017

- *Astakhov N. S. et al.* // Phys. Part. Nucl. Lett. 2016. V. 13. No. 5. P. 714–717.
- *Astakhov N. S. et al.* // JINR GRID TIER-1@TIER-2, CEUR Workshop Proc. (CEUR-WS.org) // Proc. of the XXVI Intern. Symp. on Nuclear Electronics and Computing (NEC'2017), 2017.

In 2018, the "Govorun" supercomputer, which is a heterogeneous high-performance platform, was commissioned. The supercomputer contains

both CPU computing components and GPU computing accelerators NVIDIA V100 (DGX), which enables to carry out resource-intensive massively parallel calculations that require different types of computing architectures. The "Govorun" supercomputer takes the 17th place in the world IOP500 list (July 2020) of the most powerful supercomputers in Russia and is the first in terms of data processing speed among Russian supercomputers. The "Govorun" supercomputer is an innovative hyper-converged software-defined system with unique properties of flexibility in customization to the user task, ensuring the most efficient use of computing resources. This property allows one to create a high-speed storage and data processing system with a speed of about 300 Gb/s per read/write, which is an extremely effective tool for processing large amounts of data. The results obtained using the resources of the "Govorun" supercomputer in the period from July 2018 to September 2020 are presented in more than 80 publications, including the publication in *Nature Physics.*

The "Govorun" supercomputer

- The "Govorun" Supercomputer; http://hlit.jinr.ru/about_govorun/
- *Kircher M., Trinter F., Grundmann S., Vela-Perez I., Brennecke S., Eicke N., Rist J., Eckart S., Houamer S., Chuluunbaatar O., Popov Yu. et al.* // Nature Phys. 2020. V. 16. P. 756–760.

A simulation model of data storage and processing for the NICA accelerator complex (JINR) has been developed along the lines previously implemented in GridSim. The created simulation system allows one to perform various experiments with an object under study without its physical implementation.

- *Korenkov V. V., Nechaevskiy A. V., Trofimov V. V.* // Inf. Technol. Comp. Syst. 2013. No. 4. P. 37–44.

An approach to creating cloud autonomous Grid-infrastructures intended for solving various problems in the field of cloud and grid-technologies has been

proposed. Implementation of such a complex and its operation experience were described. On the basis of the developed approach, a specialized cloud soft- and hardware complex in the JINR CICC structure has been created.

- *Kutovsky N. A.* // Informat. Educ. Sci. 2013. No. 4(20). P. 15–29.

The efficiency and the speed of a track recognition algorithm of charged particle trajectories were assessed on a LIT-JINR multicore server based on simulated events generated with the help of the GEANT3 package in the CBM-ROOT environment. The algorithm has shown an efficiency of track reconstruction of 96–97% and a low level of incorrectly found tracks of 2–4%. A high rate of event processing on one core has been reached, amounting on average to 220 ms per one central event and to 25 ms per one mixed event. It was found that the increase in the number of the cores included in the processing resulted practically in a linear growth of the number of processed events.

- *Kulakov I. S. et al.* // Part. Nucl., Lett. 2013. V. 10, No. 2(179). P. 253–267.

The possibility to record $J/\psi \to e^+e^-$ fissions appearing in Au–Au collisions with beam energy equal to 25 GeV/nucleon at CMB (GSI, Germany) has been analyzed. For marking signaling events under the conditions of predominant background, particular criteria have been developed, and the optimized target thickness has been chosen. An effective approach to the detection of a critical boundary to the indicated selection criteria has been suggested. It is shown that employed criteria allow realization of a number of acceptable $J/\psi \to e^+e^-$ fissions statistics with high reliability and at a high rate.

- *Derenovskaya O. Yu., Vasilyev Yu. O.* // Part. Nucl., Lett. 2013. V. 10, No. 5(182). P. 694–705.

A new grid and cloud services simulation for the NICA accelerator complex data storage and processing system has been developed. This system is focused on improving the efficiency of the grid–cloud systems development by using work quality indicators of some real system to design and predict its evolution. For these purposes, the simulation program is combined with real monitoring system of the grid–cloud service through a special database. An example of the program usage to simulate a sufficiently general cloud structure, which can be used for more common purposes, was given.

- *Korenkov V. V. et al.* // Comp. Res. Model. 2014. V. 6, No. 5.

A comparative analysis of packages for modeling of cloud infrastructures such as CloudSim, iCanCloud, CReST has been done. These program packages allow developing the models of cloud systems with particular functionality and configuration. The model is launched for simulation, and as a result, the modeling systems provide statistical information on the most important features: execution time, virtual machine lifecycle, the use of recourses. Analyzing this information, the developer can detect bottle neck in the model and provide for solution, the realization of which allows control by means of the following simulation iteration.

- *Korenkov V. V., Muravyev A. N., Nechaevsky A. V.* // System Analysis in Science and Education. 2014. No. 2.

Approaches for content integration and interoperability of information systems, accompanying research at JINR, namely, server of scientific documents JINR Document Server (JDS), information-analytical system "Personal Information of JINR employees" (PIN) and tools for the scientific activities management Indico, have been developed. The main goal of this investigation is complete automation of research activities of JINR based on Internet technology.

- *Zaikina T. N. et al.* // Proc. of XVI All-Russian Sci. Conf. RCDL-2014, Dubna, 2014. P. 349.

A FORTRAN 77 program POTHEA is developed for calculating with a predetermined accuracy of eigenvalues, surface eigenfunctions and their first derivatives with respect to a parameter of the parametric self-adjoined 2D elliptic partial differential equation with the Dirichlet and/or Neumann-type boundary conditions in a finite two-dimensional region. The program also calculates potential matrix elements that are integrals of the products of the surface eigenfunctions and/or the first derivatives of the surface eigenfunctions with respect to a parameter. Eigenvalues and matrix elements computed by the POTHEA program can be used for solving the bound state and multichannel scattering problems for a system of the coupled second-order ordinary differential equations with the help of the KANTBP Benchmark.

- *Gusev A. A. et al.* // Comp. Phys. Commun. 2014. V. 185. P. 2636–2654.

A numerical investigation of complexes of localized states has been performed in two dynamical systems: a directly driven nonlinear Schrödinger equation (NLS) and a double sine-Gordon equation (2SG). Both systems have a wide range of physical applications. In both cases the numerical approach is based on a numerical continuation with respect to the control parameters of the quiescent (stationary) solutions and stability and bifurcation analysis of the linearized eigenvalue problem. Multisoliton complexes of the NLS equation are studied in the undamped and weak damping regimes. It has been shown that in the weak damping case the directly driven NLS equation holds stable and unstable multisoliton complexes. The obtained numerical results are confirmed by means of direct numerical simulations of the time-dependent NLS equation. The properties of the multifluxon solutions of 2SG equation are studied depending on the parameter of the second harmonic. It is shown that the second harmonic changes properties and increases the complexity of coexisting static fluxons of 2SG equation.

- *Zemlyanaya E. V., Alexeeva N. V., Atanasova P. Kh.* // Bull. of Peoples' Friendship Univ. of Russia. Ser.: Mathematics, Informatics, Physics. 2014. No. 2. P. 363.

The unitary $U(d)$-equivalence relation between elements of the space $\mathbb{R}_+$ of mixed states of d-dimensional quantum system defines the orbit space $\mathbb{R}_+/U(d)$ and provides its description in terms the ring $\mathbb{R}[\mathbb{R}_+]^{U(d)}$ of $U(d)$-invariant

polynomials. It is proved that the semi-algebraic structure of $\mathbb{R}_+/U(d)$ is determined completely by two basic properties of density matrices, their semi-positivity and hermicity. Particularly, it is shown that the Processi–Schwarz inequalities in elements of integrity basis for $\mathbb{R}[\mathbb{R}_+]^{U(d)}$ defining the orbit space are identically satisfied for all elements of $\mathbb{R}_+$.

- *Gerdt V., Khvedelidzhe A., Palii Yu.* // J. "Notes of PDMI". 2014. V. 421. P. 68–80.

Matrix-valued functional integrals generated by solutions of the Dirac equation are considered. These integrals are defined on one-dimensional continuous paths x: $|s, t| \rightarrow \mathbb{R}$ and take values in the space of complex $d \times d$ matrices. Matrix-valued integrals are widely used in relativistic quantum mechanics for research on particles in an electromagnetic field. Namely, the integrals are applied to represent the fundamental solution of the Cauchy problem for the Dirac equation. A method of approximate evaluation of matrix-valued integrals has been proposed. This method is based on the expansion of functional into a series. The terms of the series have a form of a product of linear functionals with increasing total power. The proposed method can be used in case of small and large parameters included in the integral.

- *Ayryan E. A., Malyutin V. B.* // Bull. of Peoples' Friendship Univ. of Russia, Ser.: Mathematics, Informatics, Physics. 2014. No. 1. P. 43.

A program code widely applied at RHIC and LHC for calculations of geometrical properties of nucleus–nucleus interactions has been adapted for experiments NICA/MPD and CBM. A parameterization of pp elastic scattering amplitude earlier proposed by the authors and valid at $E_{cms} \geqslant 3$ GeV is used for setting the nucleon–nucleon collision profile. An approach well known in physics of low and intermediate energies is used for determination of nuclear parameters. The code is enlarged by a possibility to account Gribov inelastic screening.

- *Galoyan A. S., Uzhinsky V. V.* // Part. Nucl., Lett. 2015. V. 12, No. 1. P. 231–236.

A model of microscopic optical potential (OP) has been applied to construct the pion-nucleus differential cross sections of elastic and inelastic scattering on the nuclei ^{28}Si, ^{58}Ni, ^{208}Pb at $T_{lab} = 291$ MeV. The density distributions of ^{10}Be and ^{11}Be nuclei obtained within the quantum Monte Carlo model and the generator coordinate method are used to calculate the OPs and cross sections of elastic scattering of these nuclei on protons and ^{12}C at energies $E < 100$ MeV/nucleon. The real part of the OP is calculated using the folding model with the exchange terms included, while the imaginary part of the OP that reproduces the phase of scattering is obtained in the high-energy approximation. In this hybrid model of OP, the free parameters are the depths of the real and imaginary parts obtained by fitting the experimental data. The well-known energy dependence of the volume integrals is used as a physical constraint to resolve the ambiguities of the parameter values. The potentials can be used in further calculations of cross section of the reactions with these nuclei.

- *Zemlyanaya E. V., Spasova K., Lukyanov K. V., Antonov A. N., Gaidarov M. K.* // Phys. Rev. C. 2015. V. 91. P. 034606.
- *Lukyanov V. K., Zemlyanaya E. V., Lukyanov K. V., Ellithi A. Y., Abdul-Magead I. A. M.* // Intern. J. Mod. Phys. E. 2015. V. 24, No. 4. P. 1550035.
- *Lukyanov V. K., Zemlyanaya E. V., Lukyanov K. V.* // Yad. Fiz. 2015. V. 78, No. 1. P. 147–155.

An algorithm of the charged particle track reconstruction based on the Kalman filter has been proposed. This algorithm is used for solving one of the key tasks of the CBM experiment (GSI, Germany), i.e., recognition of the trajectories of charged particles and their parameters. Since within the CBM experiment a full reconstruction of signal events in a real-time experiment is planned, the developed algorithms should be fast and they have to use maximally the possibilities of present-day multicore processors and GPU-architectures. Computations were performed with a high-performance server with two processors Intel Xeon X5660 and card Nvidia GTX GPU 480.

- *Ablyazimov T. O. et al.* // Phys. Part. Nucl. Lett. 2014. V. 11, No. 4. P. 828.
- *Ablyazimov T. O., Zyzak M. V., Ivanov V. V., Kisel P. I.* // Part. Nucl., Lett. 2015. V. 12, No. 3. P. 423–427.

Using the DIRAC (Distributed Infrastructure with Remote Agent Control) Interware, the computing resources of Tier-1/Tier-2, the "Govorun" supercomputer, the computing cloud of JINR and its Member States, the NICA cluster, the cluster of the National Autonomous University of Mexico (UNAM) and storage resources, namely, dCache, EOS and the Lustre ultrafast data storage system, were combined. Using this distributed infrastructure, the program of Monte Carlo data simulation for experiments of the NICA megascience project is performed.

- *Kutovskiy N. et al.* Integration of Distributed Heterogeneous Computing Resources for the MPD Experiment with DIRAC Interware // Phys. Part. Nucl. (in press).

Tier-1   CICC/Tier-2   Cloud   "Govorun"   NICA cluster   UNAM
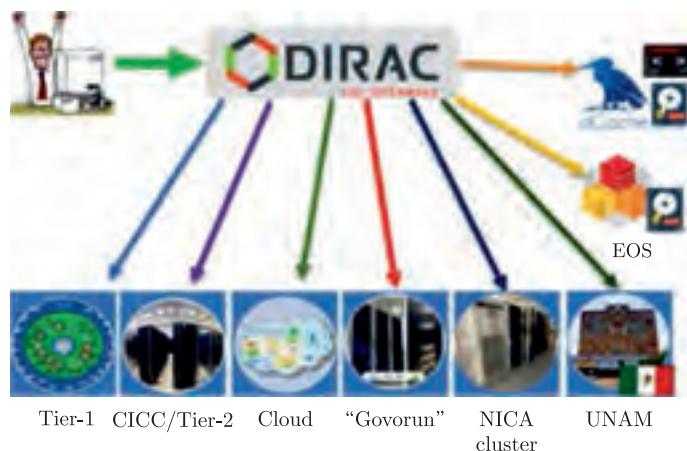
Scheme of the integration of geographically distributed heterogeneous resources based on the DIRAC Interware