REVIEW
for the ALICE Project report for the period 2021-2025.
and its extension for 2026-2030.
(PTP Topic 1088)

Experiments with ultra-relativistic heavy ion collisions allow for a very short time and in very small volumes to create and study in laboratory conditions new forms of QCD matter - the so-called quark-gluon matter (QGM). Lattice calculations of QCD indicate that at zero baryonic chemical potential μB = 0 and temperature T~ 156 MeV there is a crossover-type phase transition from the hadronic gas state to the QGM state. Nuclear collisions at LHC collider energies are aimed at studying the properties of the QGM in the region of the phase diagram of the QCD, characterized by temperatures in the range 150 < T < 300 MeV and practically zero values of the chemical potential. For this reason, the properties of the QGM formed in the collisions of nuclei at the LHC are similar to the properties of the matter that made up the Universe at the initial stage of its existence in the first microseconds after the Big Bang. Studies at LHC energies focus on determining the fundamental properties of matter at high temperatures and are ideally suited for testing the thermodynamic properties and hydrodynamic behavior of the QGM.

The ALICE (A Large Ion Collider Experiment) facility is a multipurpose detector specifically designed to study heavy ion collisions at the energies of the LHC collider. The ALICE International Collaboration includes more than 1800 specialists from 174 institutes from 42 countries. The JINR group is a full member of the ALICE International Collaboration. It has made a significant contribution to the development of the dipole magnet of the facility, to the design and construction of the 800-ton magnet yoke, to the production of drift chambers for the transient radiation detector, to the supply and testing of crystals for the electromagnetic calorimeter, continues to participate actively in the collection and analysis of experimental data, in the support of the ALICE FIT trigger system, in the preparation of publications of results in scientific journals and in the presentation of these results at conferences.

During the reporting period, the main efforts of the JINR group were concentrated on the study of: femtoscopic (Bose-Einstein) correlations in the production of light vector mesons in ultra-peripheral Pb-Pb collisions, and the formation of Σ hyperons in pp collisions. The JINR group continued to participate in the maintenance and development of the ALICE FIT trigger system, in the development of a strategy for trigger event analysis, and in the maintenance and development of GRID-ALICE technologies for data analysis at JINR.

Over the period 2021-2025, the JINR group in the ALICA experiment made a significant contribution to obtaining new world-class physical results:

1. A detailed analysis of femtoscopic correlations for charged kaons ($K^{ch}K^{ch)}$ in pp, p-Pb, and Pb-Pb collisions at energies of 13 TeV, 2.76 TeV, and 5.02 TeV, respectively, has been performed. Studies of correlations in pp collisions were carried out with selection of events by sphericity, which allowed us to select spherical events and jet-forming events separately. A comparison of the obtained dependences of the source radii R_{inv} on the transverse mass of pairs m_T in such events showed their similarity, which may indicate the manifestation of collective hydrodynamic mechanisms in pp collisions.
2. It is shown for the first time that the source radii for nonidentical and identical kaon pairs in Pb-Pb collisions at energies of 2.76 TeV, coincide and decrease with increasing

values of the centrality and transverse momentum of the pair k_T, which is consistent with the predictions of hydrodynamic models.
3. A 3D analysis for pairs of identical charged kaons in Pb-Pb and p-Pb collisions at energies of 5.02 TeV is made. The dependence of the kaon emission time (τ) on the average charged particle multiplicity $(N_{ch})^{1/3}$ is obtained for the first time, which shows the similarity of τ times for p-Pb and Pb-Pb collisions at the same charged particle multiplicity.
4. For ultra-peripheral Pb-Pb collisions (UPCs) at 5.02 TeV, a detailed analysis of the coherent birth of single ρ^0 mesons and the formation of a four-pion state ($\pi^{+\ \pi(-)}\pi^{+\ \pi(-))}$, which can result from the decay of a single ρ^0 state or two different ρ^0 states interfering with each other, has been performed. For the first time at LHC energies, a double differential cross section on the rapidity and invariant mass of four pions was obtained.
5. The first results on the measurement of Σ hyperon yields in pp collisions at energies of 7 and 13 TeV have been obtained. It is shown that only the EPOS LHC model describes well enough the measured double differential distribution over the transverse momentum p_T for charged hyperons, while various versions of the PYTHIA model underestimate the yield by a factor of 1.5-2.
6. The phenomenological model BWTP has been further developed to describe the transverse momentum (p_T) spectra of various hadrons in the central rapidity region measured in pp, p-A, and A-A collisions. The new version of the model can also describe data on p_T-spectra and values of the elliptic flow coefficient v_2 for various hadrons obtained at the energies of the RHIC and LHC colliders.

The scientific program of the ALICE experiment in the third (RUN3) and fourth (RUN4) sessions of the LHC assumes a set of extremely large integrated collision luminosities in different operating modes. To address this challenge, a new hybrid FIT (Fast Interaction Trigger) system has been developed and commissioned. In 2021-2025, the JINR group continued to participate in maintaining the operation and development of the ALICE FIT trigger system, in the development of software for trigger event analysis and quality assessment.

The JINR Group is responsible for the maintenance and development of the ALICE-GRID tier-2 system at JINR. The resources and efficiency of the JINR Computer Center ensured the leading position of JINR among Russian computer centers of the 2nd level. After 2024, JINR remains the only participant from Russia in ALICE-GRID.

The results obtained by the JINR group in the period 2021-2025 have been published in 8 papers in refereed journals and reported 10 times at various international conferences. For the period of work in the ALICE experiment in 2026-2030, the JINR group plans to participate in the following items of the scientific program:

Femtoscopic correlation studies:
1. Investigate femtoscopic correlations for kaon pairs in p-Pb collisions at 5.02 TeV with selection of spherical events with a small contribution of jets and events with a large contribution of jets.
2. To verify the correctness of the model description of the final state interactions (FSE) and the dynamics of the formation of kaon emission sources in systems of small size in p+Pb collisions compared to large systems in Pb-Pb collisions. We repeat this analysis for pp collisions at 13.6 TeV.

3. Analysis of $K^{ch}K^{ch}$ pairs in pp collisions with a detailed account of the contribution to the correlation function from known resonances (K^*, ϕ, a_0, f_0). We study the possibility of determining the source size (r_{cor}) due only to femtoscopic correlations without the influence of particles produced by the decays of resonances.

Ultra-peripheral collision studies:

1. Investigation of the gluon shielding effects in UPS Pb-Pb collisions at 5.36 TeV obtained in the Run 3. The expected statistics will allow ALICE to improve the accuracy of the measurement of the J/ψ coherent birth cross section, and to investigate other heavy vector mesons such as ψ(2S) and Y.
2. Study of the central exclusive birth (CER) of diffraction states with small mass in pp collisions at energies of 13.6 TeV. The proposed method of analysis is best suited for the study of scalar and tensor resonance states of mesons.

Study of the birth processes of Σ-hyperons:

1. Complete the analysis of the production of $\Sigma^0 + \overline{\Sigma}^0$ hyperons in pp collisions at 7 TeV with the publication of the final results in the ALICE Collaboration paper.
2. Study of the production of $\Sigma^0 + \overline{\Sigma}^0$ hyperons in pp collisions at energies of 13 TeV and 13.6 TeV and in collisions of Pb-Pb, O-O, and p-Pb nuclei.
3. Search for a new nucleus Σ^0 - hypertriton consisting of (p, n, Σ^0) by its decay into a nucleus Λ - hypertriton (p, n, Λ) and a photon.
4. Study of the possibility of measuring spin flow of rotating hadronic matter generated in non-central collisions of particles and nuclei with large angular momentum transfer to final states in the ALICE experiment.

Further development of the BWTP model to describe the production of hadrons in pp, p-A, and A-A collisions:

1- Generalization of the model with the addition of rapidity dependence.
2. Addition of the possibility to describe the high harmonics (n>2) of azimuthal anisotropy of hadrons.
3. Addition of the possibility to describe the data obtained in Pb-Pb collisions at 5.02 TeV on the production of ω and D_s mesons, as well as deuterons and other light nuclei;
4. Model-based creation of a particle generator in p-p collisions.

Service work for FIT detectors includes expert support for: data reading and calibration systems, control and monitoring systems, data quality assessment and triggers. Further software development and automated testing is needed. The ALICE-JINR group develops and maintains a specialized set of programs that are common to all analyses and allow sampling of pp collisions and heavy nuclei collisions using a system of triggers and specially designed sampling conditions, while suppressing beam interaction events with the residual gas and beam tube, possible superposition of several events simultaneously (pile-up), and events with insufficient data quality.

Support of the GRID structure of the ALICE experiment at JINR: transition to new software, regular replacement of aging computational nodes and data storage systems with new ones; participation in the implementation of the project on the use of supercomputer capacities and in the development of other GRID technologies at ALICE.

The JINR group plans to present the results at international conferences and participate in the preparation of publications at all stages of research in these directions.

In general, the physical research program proposed in the project is well justified and its successful implementation is beyond doubt.

The funding requested by the project authors is in line with the tasks to be accomplished. I propose to approve the report on the ALICE Project for the period 2021-2025. I recommend to accept the Project on JINR participation in the ALICE experiment in 2026-2030 with the first priority and to provide the resources requested by the authors in full.

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