Review of the ALICE Project Report for the Period 2021–2025 and Proposed Extension for 2026–2030 (PTP Topic 1088)

The ALICE project at JINR, carried out within the framework of the Large Hadron Collider (LHC) at CERN, focuses on the study of relativistic heavy-ion collisions with the aim of understanding the properties of strongly interacting matter and the quark-gluon plasma. During the period 2021–2025, the JINR group contributed extensively across multiple areas of the ALICE experiment. In the area of femtoscopy, systematic studies were performed on the correlations of charged kaon pairs in pp, p-Pb, and Pb-Pb collisions at various energies. These analyses revealed dependencies of source radii on transverse mass that are consistent with the presence of collective effects, even in small systems such as pp collisions. Using detailed modeling—including Coulomb and strong final state interactions (FSI)—the team extracted information on kaon emission source dimensions and resonance contributions, including a refined determination of f_0 meson parameters. A particularly important result was the observation that the kaon emission time in p-Pb collisions matches that in Pb-Pb for the same charged particle multiplicity, supporting the existence of collective behavior.

Parallel efforts were directed toward the study of ultra-peripheral Pb-Pb collisions (UPC), where the group investigated the coherent and incoherent photoproduction of vector mesons, especially ρ^0 and four-pion final states. They successfully identified both $\rho^0(770)$ and heavier resonances such as $\rho^0(1700)$, observing interference patterns that required multi-resonance fits. These results were supported by high-statistics data collected during Run 2 and contributed significantly to the ALICE publication record, receiving recognition including an Encouraging Prize in 2022.

In another line of work, the group analyzed the production of Σ hyperons in pp collisions at 7 and 13 TeV. Despite the challenges introduced by electromagnetic decays, they reconstructed Σ^0 and $\Sigma^\pm$ states and reported that the Σ/Λ ratio remains constant over a wide energy range. Their measurements revealed that common Monte Carlo models underestimate transverse momentum distributions of hyperons, with only EPOS LHC reproducing the observed spectra satisfactorily.

The JINR team also made substantial contributions to phenomenological modeling by developing and extending the BWTP model—a unified framework combining blast-wave hydrodynamics, Tsallis statistics, and a power-law component to describe hadron spectra and flow. The model successfully reproduced transverse momentum spectra and elliptic flow (v_2) for a broad set of hadrons in pp, p-A, and A-A collisions at both LHC and RHIC energies. It also captured important phenomena such as strangeness enhancement and resonance suppression as functions of collision centrality.

On the hardware and infrastructure side, the JINR group was responsible for the design, development, and maintenance of the new FIT (Fast Interaction Trigger) system, which plays a critical role in ALICE's trigger and timing capabilities in Run 3 and 4. The group developed a dedicated event selection framework used to filter background and pile-up events, optimized for new data acquisition modes in ITS and TPC subsystems. They also ensured the stability and calibration of the FIT detectors and supported quality assurance procedures through custom software tools.

JINR continued to support the ALICE-GRID distributed computing infrastructure, maintaining Tier-2 center operations with 1200 CPU cores and over 1.5 PB of disk space. Despite CERN sanctions on other Russian institutes, JINR remained a significant contributor to ALICE-GRID, comparable in scale to some European countries.

Looking ahead to the period 2026–2030, the project will continue with focused research in all major directions. In femtoscopy, further analysis will be conducted on kaon pair correlations in p-Pb and pp collisions using Run 3 data, emphasizing the separation of spherical and jetty events to refine the understanding of collectivity in small systems. A detailed study of K^+K^- correlations in p-Pb collisions is also planned to test FSI-based modeling of source formation in systems with reduced spatial scales. The analysis will extend to pp collisions at 13.6 TeV, where increased sensitivity to FSI and resonant contributions (ϕ, K^*, a_0, f_0) is expected, requiring sophisticated treatment of quantum interference and Coulomb effects.

In UPC studies, the focus will shift to exploring gluon shadowing effects in coherent photoproduction of J/ψ, $\psi(2S)$, and Υ mesons in Pb-Pb collisions at 5.36 TeV. These measurements will leverage improved Run 3 statistics to test predictions of nuclear parton distribution functions. Moreover, the group plans to investigate central exclusive production (CEP) processes in pp collisions, aiming to explore glueball candidates and QCD dynamics in double-Pomeron exchange.

Σ hyperon studies will be extended to include analyses in Pb-Pb, O-O, and p-Pb systems. The group also plans to explore the feasibility of observing a new Σ^0-hypertriton nucleus via its decay into a Λ-hypertriton and a photon, with potential implications for models of hypernuclear binding energy. A novel direction involves the study of rotational flow and handedness in non-central collisions as a macroscopic observable sensitive to angular momentum transfer in QCD matter.

The BWTP model will be further developed to include additional particle species such as ω and D_s mesons, deuterons, and light nuclei. The model will be generalized to describe higher-order azimuthal harmonics (v_3, v_4), as well as applied to pp and p-A collisions. Future development aims to incorporate rapidity dependence and to create a practical event generator based on the model.

On the technical side, continued support and calibration of the FIT system will be ensured, including MCP-PMT gain correction, trigger stability, and expansion of the event selection framework. Efforts to further automate event filtering and quality control will continue. The ALICE-GRID center at JINR will be modernized with new hardware and software tools, and the group will participate in ongoing projects to integrate supercomputing resources into the ALICE distributed computing infrastructure.

In summary, the JINR ALICE team has demonstrated substantial scientific, technical, and infrastructural contributions to the ALICE experiment and plans an ambitious and coherent research program for the upcoming five-year period, building on its recognized expertise in femtoscopy, resonance production, hyperons, modeling, and detector operations.

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