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1. **General information on the research project of the theme/subproject of the large research infrastructure project (hereinafter LRIP subproject)**

1.1. Theme code *02-1-1088-2009/2025*

1.2. Project/LRIP subproject code 02-1-1088-1-2026/2030

1.3. Laboratory LPHE

1.4. Scientific field Relativistic Nuclear Physics

1.5. Title of the project/LRIP subproject ALICE

1.6. Project/LRIP subproject leader(s) A.S. Vodopyanov

1.7. Project/LRIP subproject deputy leader(s) (scientific supervisor(s)) B.V. Batyunya

2. Scientific case and project organization

2.1. Annotation

The ALICE is a multipurpose experiment to study the interactions of heavy ions, which was created to study the physics of the strongly interacting matter and the quark-gluon plasma in nucleus – nucleus collisions at the LHC. Currently, more than 1,800 specialists from 174 institutes from 42 countries are participating in this experiment.

The main efforts of the JINR group in the data analysis and the physical simulation will be focused on the study of femtoscopic (due to Bose-Einstein and final state interaction) correlations, the production light vector mesons and heavy quarkonia in ultra-peripheral Pb-Pb collisions and the production of **Σ** hyperons in pp collisions. In addition, the JINR group will continue to participate in the maintenance and development of the trigger system ALICE FIT and GRID-ALICE analysis at JINR.

2.2. Femtoscopic correlation study

2.2.1. The investigations carried out during 2021-2025 years

It is believed that a compressed, highly interacting system resulting from a collision is subject to longitudinal and transverse expansion. Experimentally, such an expansion can manifest itself through Bose-Einstein correlations for pairs of identical particles or through correlations of pairs of non-identical particles due to strong interactions in the final state.

During 2021-2025, the JINR group carried out a number of different types of analysis of femtoscopic correlations of 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 (per pair of nucleons), respectively. Experience gained in previous years on methodological studies (the selection of individual particles and pairs, the identification of kaons and consideration of a background) and various Monte-Carlo event generators were used.

The investigations of correlations in pp collisions were carried out with the selection of events using sphericity which was determined by the formula

$$S_{XY} = \frac{1}{\sum_i p_T^i} \sum_i \frac{1}{p_T^i} \begin{pmatrix} (p_x^i)^2 & p_x^i p_y^i \\ p_x^i p_y^i & \left(p_y^i\right)^2 \end{pmatrix},$$

(p_T, p_x, p_y components of particle momenta), which allowed us to select separately spherical events with $S_{XY} > 0.7$ and events with jet formation with $S_{XY} < 0.3$. The main interest lies in comparing the dependences of the source radii on the transverse mass of pairs m_T in these events, to check the possible manifestation of collective effects in pp collisions. The correlation function (CF) was studied by approximation using the formula

$$C(q_{\rm inv}) = N\left[1 - \lambda + \lambda K(r, q_{\rm inv})\left(1 + \exp(-R_{\rm inv}^2 q_{\rm inv}^2)\right)\right] D(q_{\rm inv}),\ q_{\rm inv} = \sqrt{|\mathbf{q}|^2 - q_0^2}\ \text{(1)},$$

where N is the normalization coefficient, R_{inv} is the source radius, K is the Coulomb interaction function with radius r, D is the function reflecting background effects, and λ is the correlation strength factor. The dependences of R_{inv} on the transverse mass (m_T) for pion and kaon pairs in events of different multiplicities and S_T (S_{XY}) are shown in Fig.1, where it is evident that R_{inv} decreases with increasing m_T in both cases of selections by S_T, i.e., in events without jet formation, which may indicate some manifestation of collective hydrodynamic mechanisms in pp collisions.

These results were presented at the conference “5th International Conference on Particle Physics and Astrophysics (ICPPA-2020), October 7, 2020, MEPhI, Moscow”, and published in [1].

In Pb-Pb collisions at an energy of 2.76 GeV (per pair of nucleons), correlations of pairs of K^+K^- mesons were investigated. A typical form of the CF is shown in Fig.2, where the blue points were obtained in the experiment, and the red curve is the result of approximation in the model using the formula

$$C_{\rm FSI}(p_1, p_2) = 1 + C_{\rm sFSI}(p_1, p_2) + N_1 C_{\Phi-\rm direct}(p_1, p_2) + N_2 C_{\Phi}(p_1, p_2). \qquad (2)$$

The above formula is considered in detail in [2]. Here we note that C_{sFSI} determines the contribution of f_0 and a_0 mesons, and $C_{\Phi\text{-direct}}$ and C_{Φ} are the contributions of ϕ mesons formed at the quark-gluon stage and at the final state interaction (FSI), respectively.

The following quantities are taken as free parameters: the radius of the K^+ and K^- emitting source, the f_0 meson mass, the coupling constants for the $f_0 \to K+K-$, $f_0 \to \pi\pi$ channels, and the contribution fractions N_1, N_2. The remaining values are taken from previously studies. During 2020-2021, together with the author of the model R. Lednický, refinements were made to the f_0 mass and width values obtained from the approximation, equaled to 967 ± 3 ± 7 MeV/c^2 and 43.8 ± 8.8 ± 6.9 MeV respectively and correspond to the PDG values. In addition, possible values of N_1 and N_2 were studied in more detail using additional correlation of model parameters. As a result, the parameters N_1 and N_2 were obtained within 0.7–0.8 and 0.3–0.2, respectively, i.e. the fraction of ϕ mesons produced at the FSI stage does not exceed 30%. Figure 3 shows the dependences of the source radii (R_{inv}) on the transverse momentum of the K^+K^- pair (k_T) for events with different centralities. For comparison, the results obtained by the JINR group for pairs of identical kaons (K^+K^+/K^-K^-) [3] are also shown. From Fig.3, it is evident that the radii for non-identical and identical kaon pairs coincide and decrease with increasing values of centrality and k_T, which corresponds to the predictions of hydrodynamic models [4]. The presented results are published in [5].

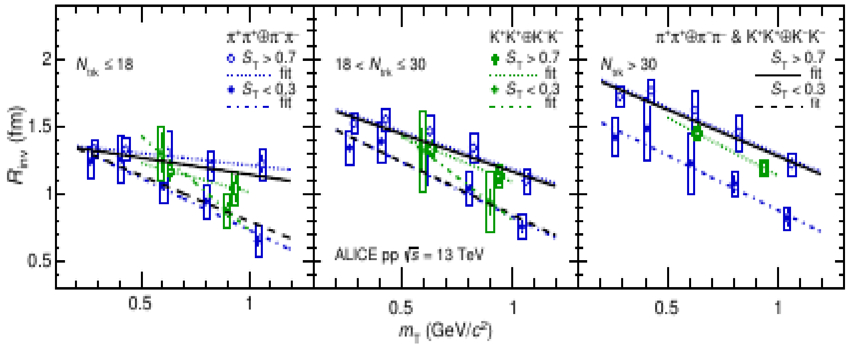

Fig. 1

A 3D analysis of identical charged kaon pairs for Pb-Pb and p-Pb collisions at an energy of 5.02 TeV (per nucleon pair) was performed. Interesting new results were obtained for the kaon emission time (τ) predicted in the hydrodynamic model [6] as a function of the average multiplicity of charged particles $(N_{ch})^{1/3}$ (Fig.4). The value of τ was obtained by a combined fitting of the dependence of the longitudinal component of the emitting source radius (R_{long}) on the transverse mass of the kaon pair (m_T) and the particle spectra. The average value of τ (2.7 ± 0.25 ± 0.15 fm/c) obtained for p-Pb coincides with that in Pb-Pb collisions with the same multiplicity of charged particles, which corresponds to the same source of particle emitting. The dotted line in the figure is the model prediction. Figure 5 shows dependence of

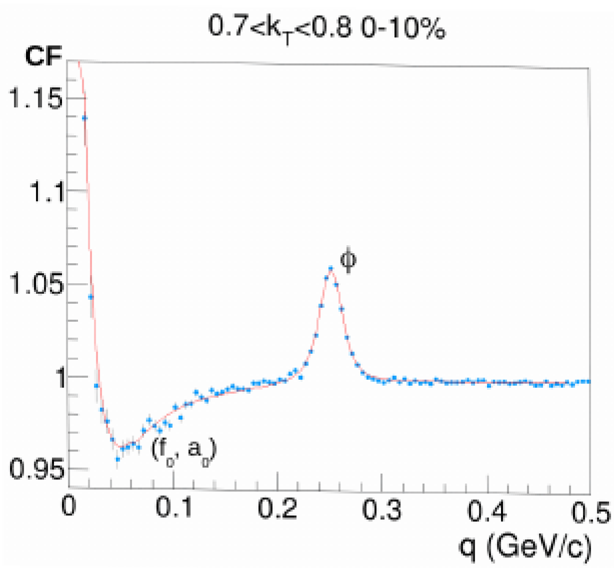

Fig. 2

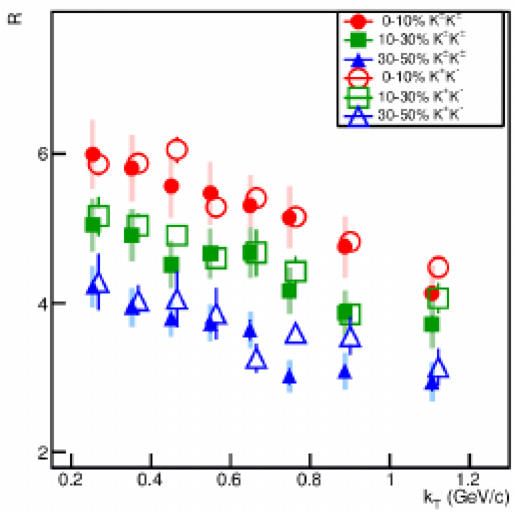

Fig. 3

R_{long} on k_T for p-Pb collisions of different centralities. It is seen that the value of R_{long} decreases for less central events and with growth of transverse momentum kaon pairs.

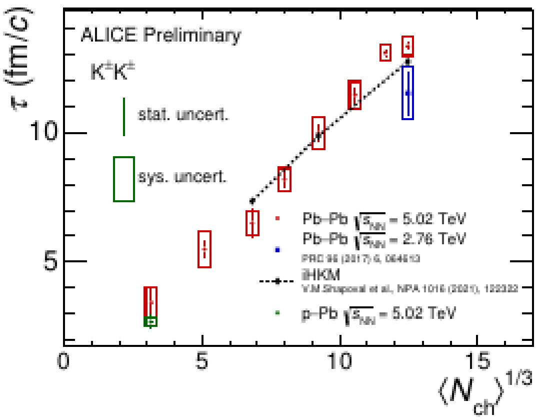

Fig. 4

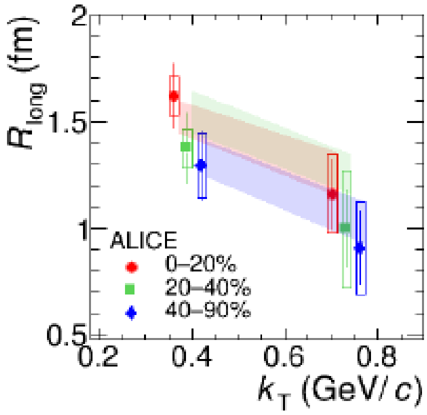

Fig. 5

The filled regions are the prediction of the EPOS hydrodynamic model [7] (the width of the region is the uncertainty of the model). Similar dependences were also obtained for the transverse components of the radiation source radius (not shown in the figures), which indicates the presence of collective effects characteristic of heavy ion interactions. The results were reported at the ICISE-2024 conference, 20th Rencontres du Vietnam, and two publications are in the final stages of preparation at ALICE in 2025.

2.2.2. Plans for 2026-2030

During the planned extension period of the Project, it is proposed the research on femtoscopic correlations of kaon pairs for p-Pb collisions at 5.02 TeV and pp collisions at 13.6 TeV. The study of identical $K^{ch}K^{ch}$ pairs in p-Pb collisions will be carried out by the method described in 2.1 with the selection (by the ST value) of spherical events with a small contribution of jet formations and events with a large contribution of the jets. Here, the greatest interest is in comparing the results with those shown in Fig.1 to verify the conclusions about the influence of collective effects within the framework of hydrodynamic mechanisms.

The next planned task includes the study of the K^+K^- pair correlation in p-Pb interactions using the method described in 2.1. The main goal is to test, within the framework of the FSI model, the dynamics of the formation of kaon emitting sources in systems with small dimensions compared to large dimensions in Pb-Pb collisions. The comparison will be made with the results presented in Figs.2 and 3. It should be noted that these works will be carried out on the available statistics, since the next set of p-Pb interactions is planned for 2029-2032.

Further analysis of the same type is planned for pp interactions (with the smallest emitting source dimensions) at an energy of 13.6 TeV, obtained during Run 3 of the LHC operation, with statistics exceeding the statistics of Run 2 by a factor of 3. In pp collisions, due to the small size of the sources, the sensitivity of the CF to the FSI increases, which may require a more detailed consideration of the FSI mechanisms based on the solution of the Schrödinger equation. Similar studies were made by another ALICE group for the $K^0_sK^0_s$ and $K^0_sK^{ch}$ pairs (in pp at 7 TeV) [8] and good results were obtained within the FSI model for radii of the order of 1 fm. But for K^+K^- pairs, additional consideration of the Coulomb interaction and the influence of the resulting resonance ϕ (1020 MeV) is required, which complicates the analysis.

An analysis of $K^{ch}K^{ch}$ pairs for pp collisions with detailed consideration of the contribution to the CF from known resonances (K^*, ϕ, a_0, f_0) is also planned. A similar type of analysis was proposed and performed by colleagues from different ALICE groups when studying a whole set of pairs of identical and non-identical particles. The main idea is to be able to determine the source size (r_{cor}) due only to femtoscopic correlations without the influence of particles produced by resonance decays. It was assumed that the dependence of r_{cor} on m_T is universal for all types of pairs. This dependence, obtained in the work [9], where the applied method is described in detail with references to the used models, is shown in Fig.6.

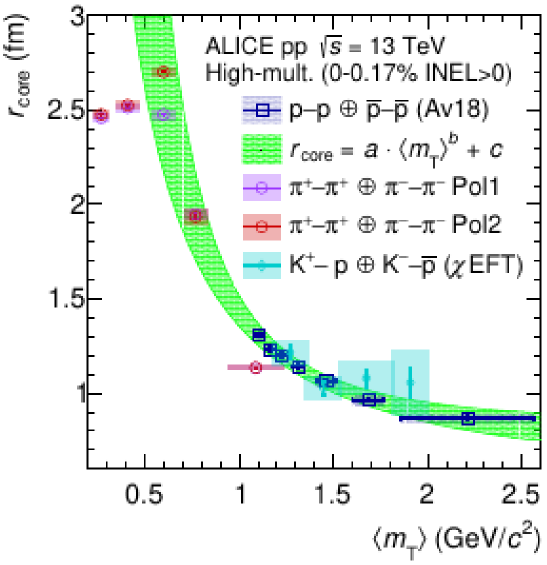

Fig. 6

It can be seen from the figure that the assumed universality holds except for r_{cor} values for pairs of identical pions at the smallest m_T. The reason for this, according to the authors, is related to some properties of the hypersurface of the hadronization source. One can see also from the picture, that there is real interest in adding results for kaon pairs whose transverse masses occupy a position between the pion pairs and the others shown in the figure.

2.3. Study of ultra-peripheral collisions of heavy ions

2.3.1. Works performed during the period 2021-2025

Ultra-relativistic heavy ions are the source of a strong ($\sim Z^2$) electromagnetic field – a flux of quasi-real photons in the framework of the Weizsäcker-Williams approach [15]. In the case of large (> sum of radii) the impact parameters of the colliding ions, interactions are called ultra-peripheral collisions (UPC). In such interactions a photoproduction of vector mesons can occur — the photon of the field of one nucleus fluctuates into a bound quark-antiquark pair, which is then elastically scattered on the other nucleus through the exchange of pomeron. During 2021-2021, the JINR-ALICE group participated in studies of the production of the single vector mesons ρ^0 in Pb-Pb ultra-peripheral collisions at energy of 5.02 TeV (per pair of nucleons). A process can proceed on the nucleus as a whole (coherent photoproduction) or on the nucleon of a nucleus (incoherent process). Further, the process of coherent formation of the state of four pions ($\pi^+\pi^-\pi^+\pi^-$) was also studied, which may be the result of the decay of one ρ^0 state or two different ρ^0 states interfering with each other.

The coherent generation of single ρ^0 mesons was studied from the decays of $\rho^0 \rightarrow \pi^+\pi^-$ with the selection of trigger events, which included combined information from detectors located at small angles in the longitudinal direction, including calorimeters. Only events with two tracks of opposite charges in the central track detectors were selected with further identification of π mesons. Figure 7 shows the invariant mass distribution of the $\pi^+\pi^-$ pairs observed in the TPC rapidity region. The large statistics obtained during the Run 2 LHC allowed us to identify the peak of ρ^0 with good accuracy and to observe the heavier state of ρ^0, shown in Fig.8. The blue curve in Fig.7 shows the sum of the contributions of resonance (Breit-Wigner — green curve), ρ^0 - ππ interference (green dotted line), and the contribution of muon decays (red dotted line).

The mass and width values obtained by fitting were 769.5 ± 1.2 ± 2.0 MeV/c^2 and 156 ± 2.0 ± 3.0 MeV/c^2, respectively, which coincided with the values for ρ^0(770) in the PDG.

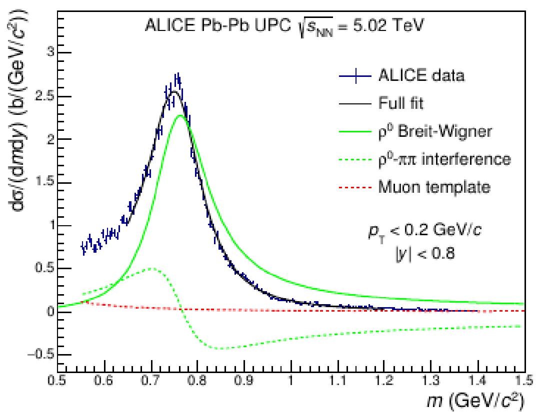

Fig. 7

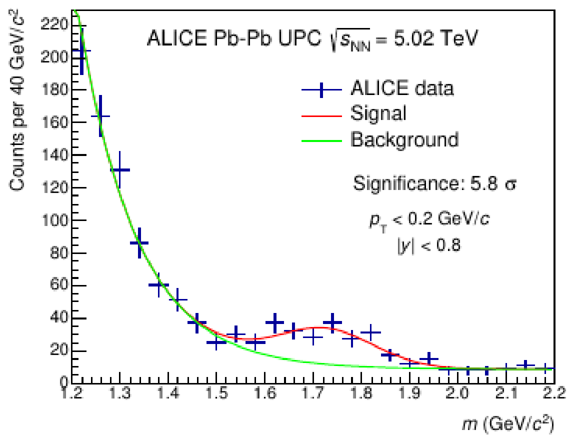

Fig. 8

The mass and width of the heavier resonance obtained from the fitting (Fig.8) were 1725 ± 17 and 143 ± 21 MeV/c^2, which corresponds to the PDG values of ρ^0(1700). The results shown were presented in the ALICE publication [10].

The coherent formation of the state of four pions ($\pi^+\pi^-\pi^+\pi^-$) was studied earlier in the STAR experiment (RHIC) in the Au-Au UPS at an energy of 200 GeV (per pair of nucleons). As a result of fitting the observed wide peak with the Breit-Wigner function, the mass and width of the resonance were determined as parameters with values of 1540 ± 40 MeV/c^2 and 570 ± 60 MeV/c^2, respectively. These values are close, taking into account errors, to the PDG state ρ^0(1700). The supposed possibility of interference between two states of similar mass has not been verified due to insufficient statistics.

Figure 9 shows the double differential cross section in terms of rapidity and invariant mass of four pions obtained in ALICE [11]. The red curve is the result of data fitting by the Breit-Wigner function with the mass and width values of 1463 ± 2 ± 15 MeV/c^2 and 448 ± 6 ± 14 MeV/c^2, respectively, which are close to the PDG values of ρ^0(1450). In Fig.10, the same data are calculated by two Breit-Wigner functions with the mass and width results of 1385 ± 14 ± 36 MeV/c^2 and 431 ± 36 ± 82 MeV/c^2 for the first resonance (close to the values of ρ^0(1450) in PDG) and 1663 ± 13 ± 22 MeV/c^2 and 357 ± 31 ± 49 MeV/c^2 for the second resonance (close to the values of ρ^0(1700) in PDG).

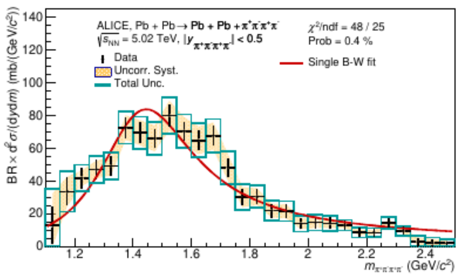

Fig. 9

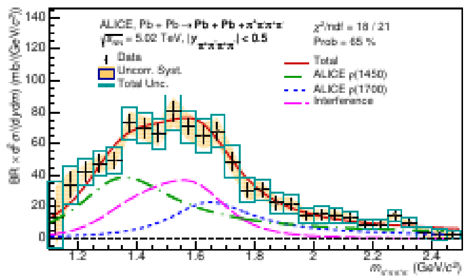

Fig. 10

The mixing angle was 1.52 ± 0.16 ± 0.19 (rad). It can be seen from the labels in Figs.9 and 10 that the quality of the fitting is noticeably better under the assumption of interference between the two resonances.

In 2022, the **Encouraging Prize** was awarded for work on this topic “Study of vector meson photoproduction in the ALICE (CERN)”.

2.3.2. Plans for 2026-2030

During the prolongation period of the Project, it is planned to study the effects of gluon shadowing in UPS Pb-Pb collisions at 5.36 TeV (per pair of nucleons), obtained in the Run3 at the LHC. Previously, such studies were carried out in ALICE for Pb-Pb collisions at 5.02 TeV (Run 2) [12]. This analysis is based on the theoretical prediction of the relationship between the parton distribution function in nuclei and the coherent photoproduction cross section of heavy vector mesons such as J/ψ, ψ(2S) and Υ, and on the assumption that the coherent photoproduction cross section is proportional to the square of the gluon density on the momentum transfer scale $Q = m_V/2$, m_V being the vector meson mass. Figure 11 shows the dependence of the photonuclear cross section of the process γ + Pb → J/ψ + Pb on the interaction energy in the center-of-mass system of the process (on the lower x-axis), which is determined from the expression $W^2_{\gamma Pb} = (s_{NN})^{1/2} M_{J/\psi} e^{-y}$, where s_{NN} is the energy of the Pb-Pb collision, $M_{J/\psi}$ is the mass, and y is the rapidity of J/ψ. The Bjorken variable x is plotted on the upper x-axis. The results obtained in this analysis and earlier at 2.76 GeV/c are shown. The lines represent the predictions of different models. It is evident that the predictions of the Impulse approximation and STARlight models, where there are no gluon shadowing contributions, strongly diverge from the experimental data with increasing energy (decreasing Bjorken x). The remaining models, with the presence of gluon shadowing, are in varying degrees of agreement with the experimental results. During the Run 3 it is expected to increase the statistics by a factor of 6-7, with an increase to about 330k and 6k J/ψ and ψ(2S) decays respectively, and up to 300 decays of Υ, which will allow ALICE to improve the accuracy of the measurement of the coherent J/ψ production cross section, and to study other heavy vector mesons, such as ψ(2S) and Υ.

The next planned task is to study the central exclusive production (CEP) of diffraction particle pair states in pp collisions using Run3 statistics. Such processes are usually described in terms of double Pomeron exchange, which is best suited for studying scalar and tensor resonance states of mesons, as well as for searching for bound states of gluons (glueballs) [13].

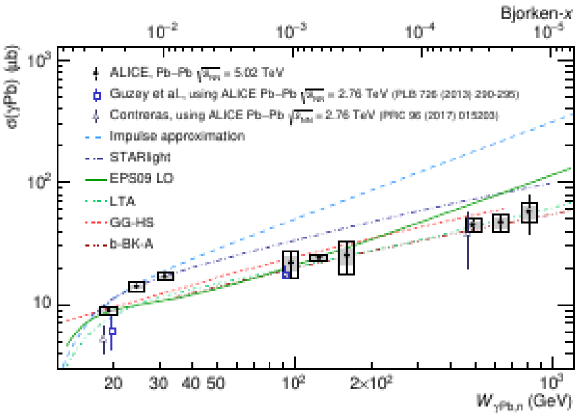

Fig. 11

The results of the studies allow us to test the predictions of perturbative QCD models of hadron pair production in the CEP [14], which are applicable at large invariant masses and transverse momenta of the particle pair. The measurement of the cross-sections of the CEP processes is based on the selection of events with several reconstructed tracks without any additional activity in the experiment's detectors, what is close trigger logic to the selection of UPC events. In addition, interval selections are used in rapidity distributions. The ALICE-

JINR group has already carried out the first preliminary studies of the CEP using Run 2 data. Figure 12 shows the uncorrected invariant mass spectra of ππ, KK pairs for CEP events in proton-proton collisions at $s^{1/2}$ = 13 TeV. Several resonance structures can be easily seen in the spectra: for ππ pairs, peaks corresponding to $f_0(980)$, $f_2(1270)$ are visible, while in the KK spectrum contributions from the $f_0(1500)$, $f_0(1710)$ and $f'_2(1525)$ resonances are seen.

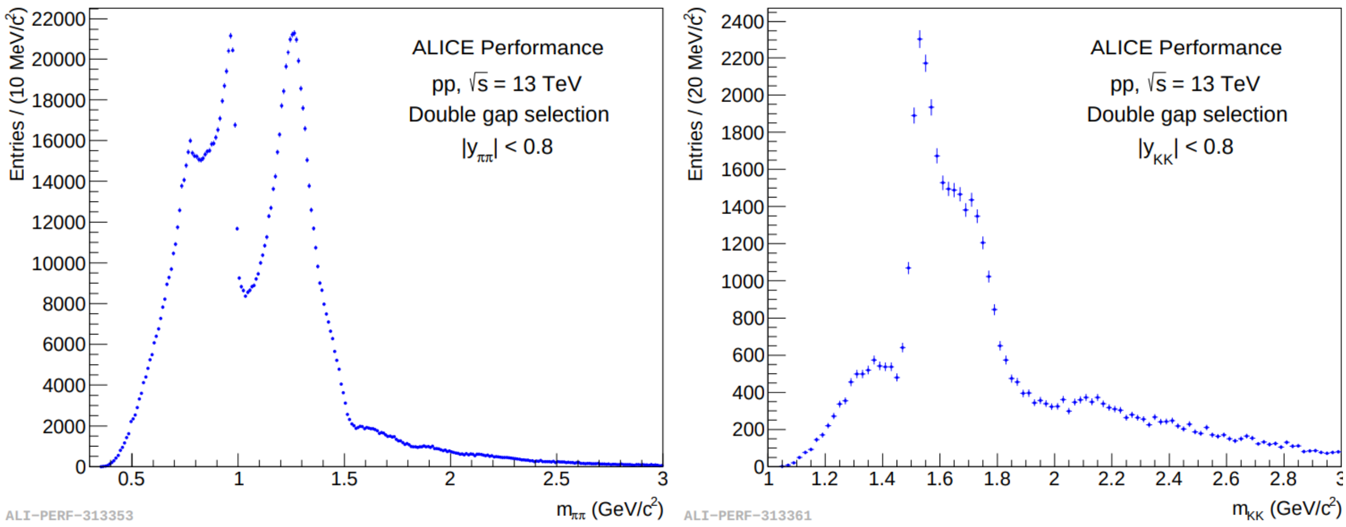

Fig. 12

In Run 3, the ALICE collaboration will obtain a large sample of data on the CEP events in pp collisions at $s^{1/2}$ = 13.6 TeV. In addition, data on pp collisions at $s^{1/2}$ = 5.5 TeV will be collected, which will allow one to research on the energy dependence of the CEP events.

2.4. Studying the processes of Σ hyperon productions

2.4.1. Works completed in the period 2021-2025

The first results of Σ hyperon investigations were obtained in ALICE for pp collisions at energies of 7 and 13 TeV. Neutral hyperons were investigated by decays $\Sigma^0\left(\overline{\Sigma}^0\right) \rightarrow \Lambda\left(\overline{\Lambda}\right) + \gamma$, and charged hyperons (antihyperons) were studied by decays into $p(\overline{p}) + \pi^0$.

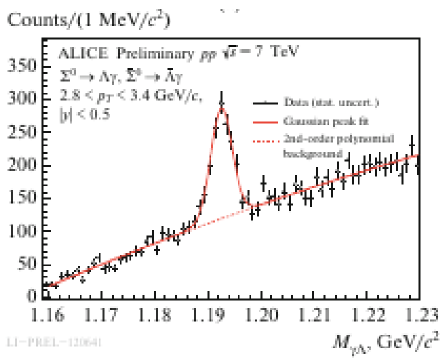

Fig. 13

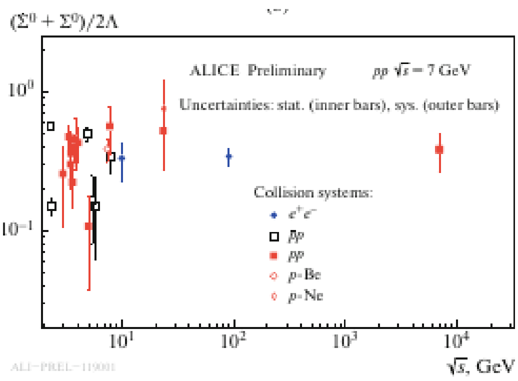

Fig. 14

The presence of photons in these decay modes makes analysis somewhat difficult compared to other strange baryons. Photons were reconstructed either in track detectors by e^+ and e^- conversions, or by signals in electromagnetic calorimeters. Figure 13 shows the invariant mass distribution of $\gamma\Lambda$, from which a strong peak from Σ^0 is visible (summed with antihyperon).

The dotted line in the figure indicates the background distribution, and the solid curve is the result of fitting by the Gaussian function. The peak of the sum of charged hyperons and antihyperons in the spectrum of invariant masses $p\gamma\gamma(\bar{p}\gamma\gamma)$ observed with similar significance (not shown). Figure 14 shows the ratio of the ($\Sigma^0 + \bar{\Sigma}^0$) and doubled Λ hyperons yields depending on the energy of the pp collisions. It can be seen from the figure that this ratio does not change within the errors starting from an energy of ~10 GeV. It should also be noted that ALICE's data has allowed us to advance energy by almost two orders of magnitude.

Figure 15 shows the double differential distribution of $(\Sigma^0 + \bar{\Sigma}^0)/2$ transverse momentum (in the range of rapidity $|y|<0.5$). The points are ALICE data, the curved line is the prediction of the PYTHIA model, which, as can be seen, underestimates the experimental values. Figure 16 shows similar results for charged hyperons (in the range of $|y|<0.8$). The black points represent ALICE data, and the colored poits represent predictions from different models, of which only the EPOS LHC model describes the experimental values well enough.

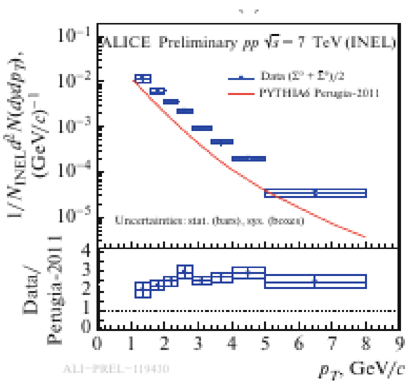

Fig. 15

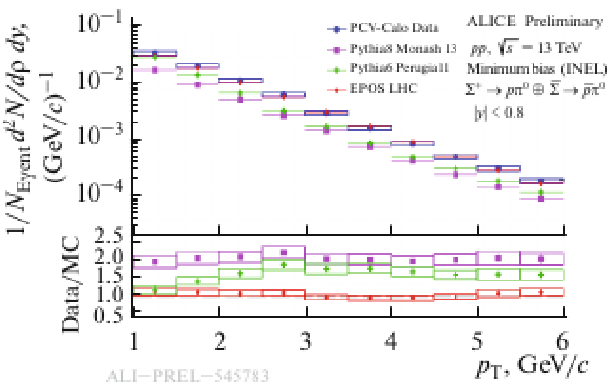

Fig. 16

These preliminary results were presented at international conferences and published in [15,16].

2.4.2. Plans for 2026-2030

The analysis of $\Sigma^0 + \bar{\Sigma}^0$ гиперонов production in pp collisions at 7 TeV is expected to be completed during the planned Project extension period with the publication of ALICE's final article in the process of completing the analysis, additional methods of subtracting the combinatorial background are included, the peak is fitted with various functions, and new, more complete estimates of systematic errors are considered. Additional research on Monte Carlo simulation of the formation of Σ^0 hyperons as a result of heavy resonance decays in pp collisions will be carried out.

The next step is to consider possible studies of $\Sigma^0 + \bar{\Sigma}^0$ hyperon production in pp collisions at energies of 13 TeV and 13.6 TeV and in collisions of Pb-Pb, O-O and p-Pb nuclei.

Next, it is planned to search for a new Σ^0-hypertriton nuclei consisting of (p, n, Σ^0) by its decay into a Λ-hypertriton nuclei (p, n, Λ) and a photon. The possibility of this study was published in [17] and presented at the conference. Data on the observation of the nucleus (p, n, Σ^0) or its absence make a significant contribution to the development of models on binding energy in hypernuclei [18].

The next problem under consideration is related to the study of spin flow of rotating hadron matter formed during off-center collisions of particles and nuclei with the transfer of large angular momentum to final states, i.e., the search for a special multiparticle observable, handedness [19,20]. The handedness is defined as the ratio of the difference between the left-hand and right-hand rotation flow of the observed particles to their sum. ALICE data on the asymmetry of particle flows in Pb-Pb collisions and the hyperon polarization allow us to study a new macroscopic variable handedness for various types of elementary particles in a wide momentum range. The analysis of experimental data carried out for the first time is necessary both to test the theoretical hypothesis about the presence of the handedness effect and to further develop it, as well as to find the most optimal kinematic area for observing this effect.

2.5. Phenomenological BWTP model for hadron production in pp, p-A and A-A collisions

2.5.1. Works completed during the period 2021-2025

Since 2020, the ALICE group at JINR has been developing (based on the previously publication [21]), a phenomenological BWTP model for describing the transverse momentum (p_T) spectra of various hadrons in the central rapidity region measured in pp, p-A and A-A collisions. The model assumes that hot and dense matter (quark-gluon plasma) is formed in high-energy collisions, which expands, cools, thermalizes and hadronizes, passing through the chemical and kinetic freeze-out phases. The model includes three components (the first letters of their names give BWTP): 1) the standard blast-wave model (BW) [2] to describe the hydrodynamical processes of radial expansion and kinetic freeze-out of the produced hadronic matter; 2) the Tsallis distribution (T) [3,1] to take into account the contribution from resonance decays; 3) a term with a power-law (P) dependence on p_T to describe hard QCD processes. Spectral data for thirteen particles (from pions to charmonia) produced in pp and Pb-Pb were analyzed for different collision energies and centralities at the LHC. The model describes all these data well, as well as the data on the nuclear modification of the spectra. A detailed description of the model and the results of the work were published in [25].

The BWTP model was then developed and generalized for several purposes:

- The number of model parameters has been reduced taking into account the corresponding dependencies of experimental data and theoretical approaches.
- It was shown that the new version of the model describes the Pb-Pb collision data as well as the version in [25].
- It was added the description of p_T spectra of different hadrons measured in Xe-Xe collisions at energy 5.44 TeV and for different centralities at LHC.
- It was added the description of the effect of growth of strange particle yields relative to pion yields with increasing collision centrality, observed in A-A collisions.
- It was added the description of the effect of suppression of short-lived resonances ρ^0 and K^{*0} with increasing centrality, observed in A-A collisions.
- It was done the description of the p_T-dependence of the elliptic flow coefficient v_2 for different hadrons at the midrapidity measured in A-A at different energies and collision centralities. To achieve this goal, the azimuthal asymmetry of physical

processes characteristic of peripheral nuclear collisions is added to our model using the generalized blast-wave model [26].

The new version of the model also allows for data description on p_T spectra and v_2 for various hadrons measured at low energies at RHIC. The current version of the BWTP model achieves these goals and successfully describes the mentioned experimental data obtained mainly by the ALICE collaboration, but also by other collaborations at LHC and RHIC. Figure 17 shows a good description of the yield ratios for different hadrons as a function of the charged-particle multiplicity in Pb-Pb collisions obtained in ALICE. The effect of the growth of the strange particle yields and the effect of the suppression of the ρ^0 and K^{*0} yields with increasing centrality are demonstrated. The model predictions, presented as lines, agree well with the experimental data. Figure 18 shows a good description of the ALICE and CMS data on the elliptic flow v_2 for pions, kaons, protons and all charged particles in Pb-Pb at different centralities.

2.5.2. Plans for 2026-2030

The following work is planned for 2026-2030 on new applications and further development of the BWTP model:

– Description of data obtained in Pb-Pb collisions at 5.02 TeV on the production of hadrons not yet considered by us, such as ω and D_s mesons, as well as on the production of deuterons and other light nuclei.

– Application of the model to describe new data obtained in Pb-Pb collisions at 5.36 TeV, as well as in other A-A collisions.

– Development of the BWTP model to describe, in addition to v_2, other features of the azimuthal asymmetry in A-A collisions, such as v_3 and v_4.

– Development of the BWTP model for describing pp and p-A data at LHC for p_T spectra and for v_2, v_3 and v_4 for different hadrons.

– Generalization of the model with the addition of the rapidity dependence of particle characteristics.

– Further development of the BWTP model with the aim of creating on its basis a particle generator in p-p, p-A and A-A collisions.

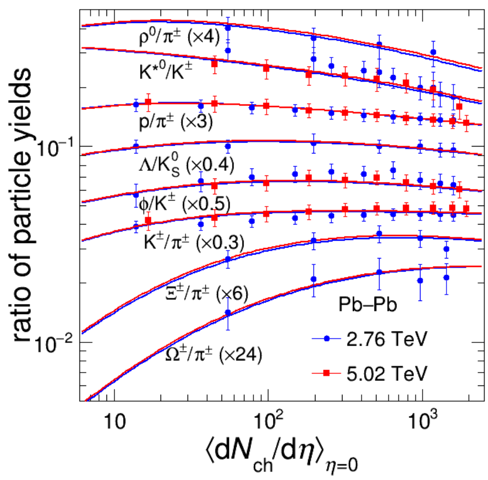

Fig. 17

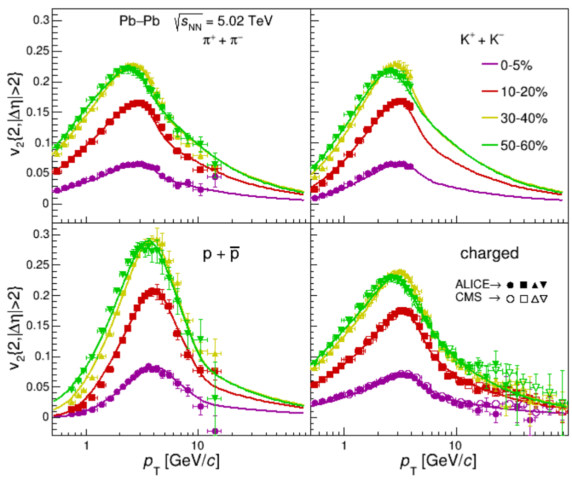

Fig. 18

2.6. New ALICE FIT trigger system

As part of the program of modernization of detector systems of the ALICE facility at the

Large Hadron Collider, a new hybrid FIT (Fast Interaction Trigger) detector consisting of three subsystems FT0 (FIT Time-zero detector), FV0 (FIT Vertex-zero detector), FDD (FIT Forward Diffractive Detector) with different particle detection technology was developed and put into operation. Subsystems FT0, FDD consist of two assemblies located on both sides (side A and C) of the interaction point (IP - Interaction Point). Figure 19 shows the assemblies of detectors FV0, FT0-A, FT0-A, FT0-A, FT0-C, FDD-A, FDD-C with respect to IP.

The FT0 subsystem of the FIT detector is based on two arrays of 24 and 28 Cherenkov modules on either side of the interaction point. Each Cherenkov module is based on four 2 cm thick quartz radiators. Electronic boards for photomultipliers were specially developed at INR. The FV0 subsystem is based on 4 cm thick EJ-204 plastic scintillator plates with light signal acquisition on Hamamatsu H6614-70-Y001 grid dynode photomultipliers. The FDD subsystem is an assembly of four BC-420 scintillator planes arranged in quadrants. Light is collected using WLS plates and optical fibers leading to an H8409-70 PMT.

2.6.1. Main functions of FIT system

The scientific program of the ALICE experiment in the RUN3 and RUN4 sessions of the LHC implies a set of extremely high values of the integrated collision luminosity in different operating modes. FIT is a new subsystem of the upgraded ALICE for LHC RUN 3 and RUN 4 that provides the following ALICE requirements:

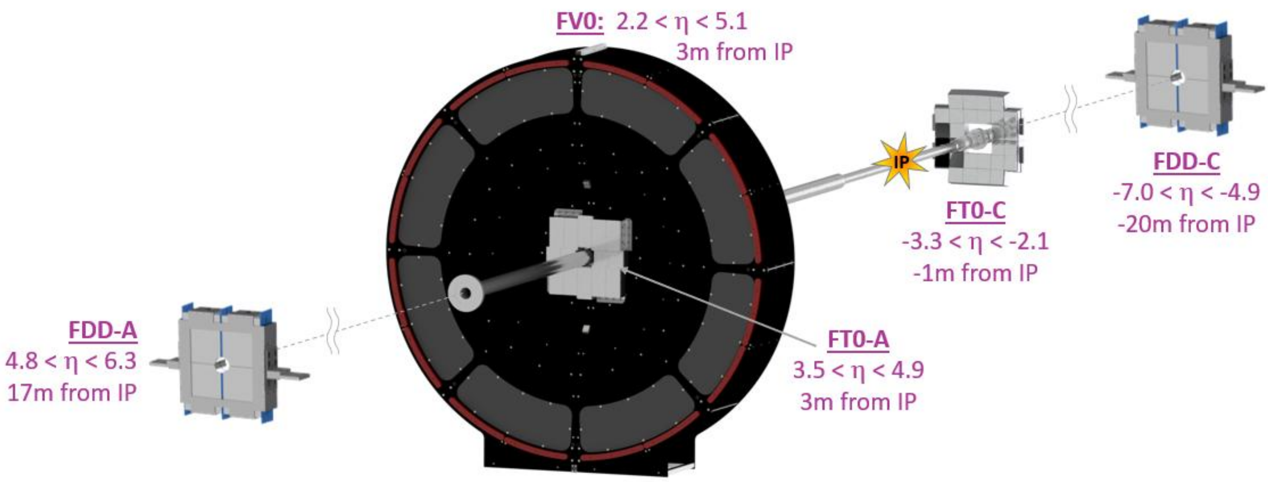

Рис. 19

- BC-per-BC readout capability (BC-Bunch Crossing interval (25 ns, dead time ~15 ns);
- Minimal latency – trigger decisions in less than 425 ns from the collision (150 ns cabling delay included);
- Efficient running at full LHC Pb-Pb collision rate (50 kHz);
- Tolerance to the solenoid field B = 0.5 T and harsh radiation conditions
- Operability outside the LHC’s “stable beams” mode.

FIT system detectors are trigger detectors and are used for:

- luminosity measurements - online and offline, FT0 is the main luminometer of the ALICE experiment;
- Bunch Cross synchronization of the other ALICE detectors (FT0);

- monitoring collision rates and providing real-time luminosity feedback to the LHC;
- measuring the exact collision time required for particle identification based on time-of-flight (TOF) with a record time resolution of 17 ps and 4 ps for proton and ion collisions, respectively;
- determinations of global collision parameters based on the multiplicity of secondary particles:
- centrality of collisions;
- determination of the reaction plane of events;
- diffraction physics, mainly with FT0, FDD as veto;
- monitoring background events (beam halo, gas interactions).

2.6.2. Required Service Activities for FIT System

The FT0-A and FT0-C subsystems of the FIT detector system, the entire electronics of the FIT detector system FT0, FV0, FDD, as well as the control and monitoring systems are developed by INR RAS, so the participation of specialists is extremely important to provide expert support for the FIT detector system and to participate in on-duty activities.

The FT0 detector is a trigger detector, so for stable and effective operation of the detector trigger system, it is necessary to perform a correction of the signal amplitude. For this purpose, it is necessary to monitor the ageing of the MCP-PMT and to correct the gain of the photomultiplier tubes on a regular basis.

FIT service task:

1. data and Trigger Quality;
2. simulation and Reconstruction;
3. readout Experts;
4. calibration;
5. development and Maintenance of DQ algorithms;
6. DCS/DSS Expert;
7. software developments and automated testing;
8. disconnection - reconnection of FIT-A.

2.6.3. Development and support of the ALICE event selection framework

Event selection is one of the critical steps in any physics analysis performed in the ALICE experiment. For Run 3 analyses, a dedicated framework has been developed and supported by the ALICE-JINR group. The framework provides common tools to select clean minimum bias pp and heavy-ion collisions, reject beam-gas, pileup and poor-quality events, perform selections based on trigger classes and other tools. In addition, the framework includes a possibility to monitor the analyzed event counts and corresponding integrated luminosity.

The standard event selection strategy in Run 3 is based on the requirement of signals on both sides of the FT0 detector compatible with beam-beam collision timing. Most of the beam-gas events are suppressed with this selection, however a small fraction (about 10^{-5}) of proton-proton collisions is still contaminated by coincidences with the beam-gas background, resulting in unphysical high-multiplicity tails in forward multiplicity distributions. This background imposes a challenge for the physics program of the ALICE experiment in Run 3, limiting a high-multiplicity reach in pp collisions. One of the tasks of the ALICE-JINR group for the next few years is the development of an event selection strategy aimed for suppression of the remaining high-multiplicity background. Various options are considered: FDD and FV0 signal checks, correlation of FT0 signals with information from the central barrel detectors, channel-by-channel checks of FT0 timing and multiplicity signals etc.

In Run 3, data acquisition in the ITS detector is performed in portions of ~5 μs for proton-proton sessions and ~15 μs for nuclear-nuclear sessions ("ITS readout frame"). A portion of data in TPC corresponds to ~1 ms. Events that are on the readout boundary are not fully reconstructed, and some tracks are lost. The ALICE-JINR group has developed special filtering procedures for such events taking into account the characteristics of the data set. In the future, it is planned to optimize the selection and monitor the quality under conditions of changing beam collision schemes. Finally, the ALICE-JINR group is responsible for quality control of event selection. A number of checks on various indicators are carried out using a specially developed software tool event-selection-QA. The results of such checks for each data collection session are published on a special website — https://evsel-qa.web.cern.ch. Over the coming years, the ALICE-JINR group will continue monitoring the quality of event selection and working on improving the set of developed tools.

2.7. Maintenance and development of the ALICE-GRID system at JINR

In the period 2021-2025, the maintenance and development of the JINR tier 2 ALICE-GRID system continued. The capacity of the JINR-ALICE computer center is 1200 CPU cores and 1530 Tb of disk storage (Disk-SE), which made it possible to carry out 40% of the calculations among all Russian Tier 2 centers. The total contribution of all Russian institutes to ALICE-GRID, including the level 1 center at the Kurchatov Institute, was 4%. Following the imposition of sanctions by CERN on Russian institutes, JINR remains the only Russian participant in ALICE-GRID. Fig.20 shows a diagram of the contributions of different countries to the total number of CPU hours spent in 2024 on computing all jobs. It can be seen from the diagram that the contribution of JINR (designated RDIG) is 0.5% and is equal in level to the contributions of some individual countries (Slovakia, Poland, Czech Republic, Austria, China).

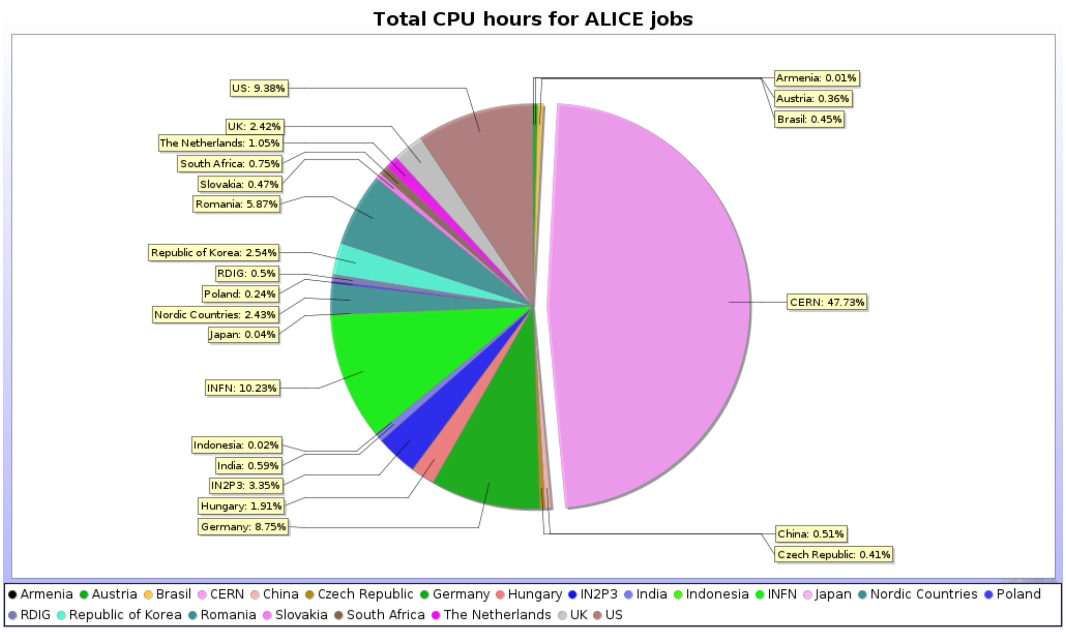

Fig. 20

During the planned extension period of the Project, the JINR-ALICE group plans to:

- maintenance of the JINR ALICE-GRID system;
- transition to new software, regular replacement of outdated computing 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 in ALICE.

List of publications (publications of the JINR group are highlighted in bold)

1. ALICE Collaboration (S.Acharya et al.), "Femtoscopic correlations of identical charged pions and kaons in pp collisions at $\sqrt{s} = 13$ TeV with event-shape selection", Phys. Rev. C 109 (2024) 024915.
2. R.Lednicky, V.L. Lyuboshitz, Sov. J. Nucl. Phys. 35 (1982) 770; R.Lednicky, Phys. of Part. and Nucl. Lett. 8 (2011) 965.
3. ALICE Collaboration (S.Acharya et al.), "Kaon femtoscopy in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV", Phys. Rev. C 96 (2017) 064613.
4. V.M.Shapoval et al., Nucl. Phys. A 929 (2914) 1-8.
5. ALICE Collaboration (S.Acharya et al.), "Investigation of K^+K^- interactions via femtoscopy in Pb-Pb collisionsat at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV at the LHC.", Phys. Rev. C 107 (2023) 054904.
6. Yu.M.Sinyukov et al., Nucl. Phys. A 946 (2016) 227-239.
7. K.Werner et al., Phys. Rev. C 83 (2011) 044915.
8. ALICE Collaboration (B.Abelev et al.) Phys. Lett. B 717 (2012) 151-161; ALICE Collaboration (S.Acharya et al.), Phys. Lett. B 790 (2019) 22-34.
9. ALICE Collaboration (S.Acharya et al.), Eur. Phys. J. C 85 (2025) 198.
10. ALICE Collaboration (S.Acharya et al.), «Coherent photoproduction of ρ^0 vector meson in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV», JHEP 06 (2020) 35.
11. ALICE Collaboration (S.Acharya et al.), "Exclusive four pion photoproduction in ultraperipheral Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV", arXiv:2404.07542 (2024).
12. ALICE Collaboration (S.Acharya et al.), "Energy dependence of coherent photonuclear production of J/Ψ in ultraperipheral Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV", JHEP 10 (2023) 119.
13. P.Azzi et al., CERN Yellow Rep. Monogr. 7 (2019) 1.
14. L.A.Harland-Lang et al., Eur. Phys. J. C71 (2011) 1714.
15. A.Borissov, "Production of Σ Hyperons in pp and p-PB Collisions at LHC with ALICE", Physics of Particles and Nuclei 55, No. 4 (2024) 1070-1074.
16. A.Borissov, "Production of Σ Hyperons and Search of Σ Hypernuclei at LHC with ALICE", Physics of Atomic Nuclei 86, No. 6 (2023) 1336-1340.
17. Z.Citron et al., CERN Yellow Rep. Monogr. 7 (2019) 1159.
18. Nagae et al., Phys. Rev. Lett. 80 (1998) 1605.
19. A.V.Efremov et al., Phys. Lett. D 284 (1992) 394-400.
20. O.Teryaev, R.Usubov, arXiv:1406.4451.
21. S.Grigoryan, "Using the Tsallis distribution for hadron spectra in pp collisions: Pions and quarkonia at $\sqrt{s} = 5 - 13000$ GeV", Phys.Rev. D 95 (2017) 056021.
22. E.Schnedermann, J.Sollfrank, U.Heinz, Phys. Rev. C 48 (1993) 2462.
23. C.Tsallis, J. Stat. Phys. 52 (1988) 479.
24. S.Grigoryan, "A three component model for hadron p_T-spectra in pp and Pb-Pb collisions at the LHC", Eur. Phys. J. A 57 (2021) 328.
25. F.Retiere, M.A.Lisa, Phys. Rev. C 70 (2004) 044907.

Conference reports

1. E.Rogochaya (JINR, on behalf of the ALICE Collaboration), “Determination of the strong interaction for hyperon-nucleon pairs with ALIVE” The 55th Rencontres de Moriond “QCD & High Energy Interactions” 27.03-3.04, 2021.
2. V.Pozdnyakov (JINR, on behalf of the ALICE Collaboration), “Recent results on ultra-peripheral collision studies with ALICE at the LHC”, 20th Lomonosov Conference on Elementary Particle Physics, MSU, 19-25.08, 2021.
3. V.Pozdnyakov (JINR, on behalf of the ALICE Collaboration), “Coherent photoproduction of ρ^0 vector mesons in ultra-peripheral Pb-Pb and Xe-Xe collisions with ALICE”. XXVIII International Workshop on Deep- Inelastic Scattering and Related Subjects. Stony Brook University, 12-14.04.2021.
4. G.Romanenko (JINR, on behalf of the ALICE Collaboration) “Identical charged kaons femtoscopic analisys in PbPb collisions at 5.02 TeV in ALICE”, Nucleus-2022, Fundamental problems and applications, Moscow State University, 2022.
5. V.Pozdnyakov (JINR, on behalf of the ALICE Collaboration) “Photoproduction of vector mesons in Ultra-peripheral heavy-ion collisions with ALICE”, 56th Rencontres de Moriond 2022, Italy.6. E.Rogochaya (JINR, on behalf of the ALICE Collaboration), “Studying the size of the emitting source of particles and their strong interaction using femtoscopy”, HEP2023 Conference, Hamburg.
6. E.Rogochaya (JINR, on behalf of the ALICE Collaboration), “Studying the size of the emitting source of particles and their strong interaction using femtoscopy”, HEP2023 Conference, Hamburg.
7. V.Pozdnyakov (JINR, on behalf of the ALICE Collaboration), “Exclusive and dissociative J/ψ photoproduction off protons with ALICE”, DIS-23 Conference, Michigan SU, USA.
8. V.Pozdnyakov (JINR, on behalf of the ALICE Collaboration), “Vector meson photoproduction in UPC with ALICE”, Conference SPIN Physics 2023, Durham, USA.
9. E.Rogochaya (JINR, on behalf of the ALICE Collaboration), “Particle emitting source dynamics via femtoscopy at the LHC energies with ALICE”, PASCOS 2024, QUY NHON, Vietnam, July 7-13, 2024.
10. K.Mikhaylov (NRC, JINR, on behalf of the ALICE Collaboration), “Charged kaon femtoscopy with ALICE at the LHC”, Session of Russian Academy of Sciences, Dubna, April 1-5, 2024.

3. Manpower

3.1. Manpower needs in the first year of implementation

№№ n/a	Category of personnel	JINR staff, amount of FTE	JINR Associated Personnel, amount of FTE
1.	research scientists	6.6	8
2.	engineers	1.8	
3.	specialists		
4.	office workers		
5.	technicians		
	Total:	**8.4**	**8**

3.2. Available manpower

3.2.1. JINR staff

No.	Category of personnel	Full name	Division	Position	Amount of FTE
1.	research scientists	Vodopyanov A.S. Batyunya B.V. Gorbunov N.V. Grigoryan S. Kryshen E.L. Mikhailov K.R. Nomokonov P.V. Rogochaya E.P. Rufanov I.A.	NEOFTI-LHC NEOFTI-LHC NEOF-CMS NEOFTI-LHC NEOFTI-LHC NEOFTI-LHC NEOFTI-LHC NEOFTI-LHC NEOFSTI	Head of Dept. Head of Sect. Head of Sect. Lead. Scient. Lead. Scient. Senior Scient. Lead. Scient. Lead. Scient. Senior Scient.	1 1 0.3 1 0.5 0.5 1 1 0.3
2.	engineers	Vertogradova Yu.L. Kuznetsov A.V. Stiforov G.G.	NEOFTI-LHC NEOFTI-LHC SASUTP	Engineer Senior Eng. Dep. Head	0.5 1 0.3
3.	specialists				
4.	technicians				
	Total:	**12**			**8.4**

3.2.2. JINR associated personnel

No.	Category of personnel	Partner organization	Amount of FTE
1.	research scientists	INR RAS (Moscow) MEPHI MFTI	6 1 1
2.	engineers		
3.	specialists		
4.	technicians		
	Total:		**8**

4. Financing

4.1 Total estimated cost of the project/LRIP subproject

The total cost estimate of the project (for the whole period, excluding salary).
The details are given in a separate table below.

4.2 Extra funding sources

Expected funding from partners/customers – a total estimate.

Project (LRIP subproject) Leader ____ /_Vodopyanov A.S./

Date of submission of the project (LRIP subproject) to the Chief Scientific Secretary: _________

Date of decision of the laboratory's STC: _08.04.2025__ document number: _________

Year of the project (LRIP subproject) start: ____2026____________

(for extended projects) – Project start year: ___2009____

Proposed schedule and resource request for the Project / LRIP subproject

<table>
<tr><th colspan="3" rowspan="2">Expenditures, resources, funding sources</th><th rowspan="2">Cost (thousands of US dollars)/ Resource requirements</th><th colspan="5">Cost/Resources, distribution by years</th></tr>
<tr><th>1st year</th><th>2nd year</th><th>3rd year</th><th>4th year</th><th>5th year</th></tr>
<tr><td colspan="2" rowspan="8"></td><td>International cooperation</td><td>520</td><td>110</td><td>100</td><td>100</td><td>100</td><td>110</td></tr>
<tr><td>Materials</td><td>600</td><td>120</td><td>120</td><td>120</td><td>120</td><td>120</td></tr>
<tr><td>Equipment, Third-party company services</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Commissioning</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>R&D contracts with other research organizations</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Software purchasing</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Design/construction</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Service costs (planned in case of direct project affiliation)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">Resources required</td><td rowspan="4">Standard hours</td><td>Resources</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>– the amount of FTE,</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>– accelerator/ installation,</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>– reactor,…</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sources of funding</td><td>JINR Budget</td><td>JINR budget (budget items)</td><td>1120</td><td>230</td><td>220</td><td>220</td><td>220</td><td>230</td></tr>
</table>

	Extra fudning (supplementary estimates)	Contributions by partners Funds under contracts with customers Other sources of funding						

Project (LRIP subproject) Leader ___/_A.S.Vodopyanov__/

Laboratory Economist ___/_V.V. MOROZOV_/

APPROVAL SHEET FOR PROJECT / LRIP SUBPROJECT

ALICE

SHORT DESIGNATION OF THE PROJECT / SUBPROJECT OF THE LRIP

02-1-1088-1-2026/2030

02-1-1088-2009/2025

A.S. Vodopyanov

AGREED

JINR VICE-DIRECTOR	SIGNATURE	Kekelidze V.D. NAME	DATE
CHIEF SCIENTIFIC SECRETARY	SIGNATURE	Nedelko S.N. NAME	DATE
CHIEF ENGINEER	SIGNATURE	Gikal B.N. NAME	DATE
LABORATORY DIRECTOR	SIGNATURE	Butenko A.V. NAME	DATE
CHIEF LABORATORY ENGINEER	SIGNATURE	Agapov N.N. NAME	DATE
LABORATORY SCIENTIFIC SECRETARY	SIGNATURE	Cheplakov A.P. NAME	DATE
THEME / LRIP LEADER	SIGNATURE	Vodopyanov A.S.. NAME	DATE
PROJECT / LRIP SUBPROJECT LEADER	SIGNATURE	Vodopyanov A.S. NAME	DATE

APPROVED BY THE PAC

SIGNATURE	NAME	DATE