Annex 1.

Form of opening (renewal) for Theme / Large Research Infrastructure Project

APPROVED

JINR Vice-Director

____________/____________

"_____"___________ 2023 г.

THEME PROPOSAL FORM

Opening/renewal of a theme/large research infrastructure project within the Topical plan of JINR

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

1.1. Theme code / LRIP (for extended themes) – *the theme code includes the opening date, the closing date is not given, as it is determined by the completion dates of the projects in the theme.*
02-1-1088-2009/…

1.2. Laboratory: LHEP

1.3. Scientific field: Particle Physics and Relativistic Nuclear Physics

1.4. The title of the Theme / LRIP: ALICE. Study of interactions of heavy ion and proton beams at the LHC.

1.5. Theme / LRIP Leader(s) : A.S.Vodopyanov

1.6. Theme / LRIP Deputy Leader(s) : B.V.Batyunya

2. Scientific case and theme 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, 1,946 specialists from 173 institutes from 42 countries are participating in this experiment.

The main efforts of the JINR group in the data analysis and the physical simulation were focused on the study of femtoscopic (due to Bose-Einstein and final state interaction) correlations, the production light vector mesons in ultra-peripheral Pb-Pb collisions and a development of Thermal model for particle production in pp and A-A collisions. In addition, the JINR group continued to participate in the maintenance and development of the GRID-ALICE analysis at JINR and in modernization of photon spectrometer of the setup.

2.2. Projects in the Theme / LRIP subprojects

2.3. Scientific case (no more than 20 pages) (aim, relevance and scientific novelty, methods and approaches, techniques, expected results, risks).

Section I. Femtoscopic correlation study.

Section I.1. Introduction.

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 2020-2022, 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 dependences of the femtoscopic radii on the event multiplicity (centrality) and the pair transverse momentum (kT) were studied, a comparison was made with particles of other types and predictions of theoretical models. Part of the results was presented at international conferences and published, according to some other results, research is continuing. These results will be discussed in more detail in sections I.2-I.4.

Section I.2. Study of correlations of non-identical kaon (K^+K^-) pairs in Pb-Pb collisions at the energy of 2.76 TeV (per pair of nucleons).

The JINR group wents on a detailed analysis of K^+K^- femtoscopic correlations in the framework of the model describing the final-state interactions proposed by R. Lednitsky and V. Lyuboshits [1]. As before, special attention was paid to the most accurate measurement of the purity of selected kaons using the methods developed by the JINR group in previous studies. The purity of single kaons and kaon pairs is shown in Fig.1.

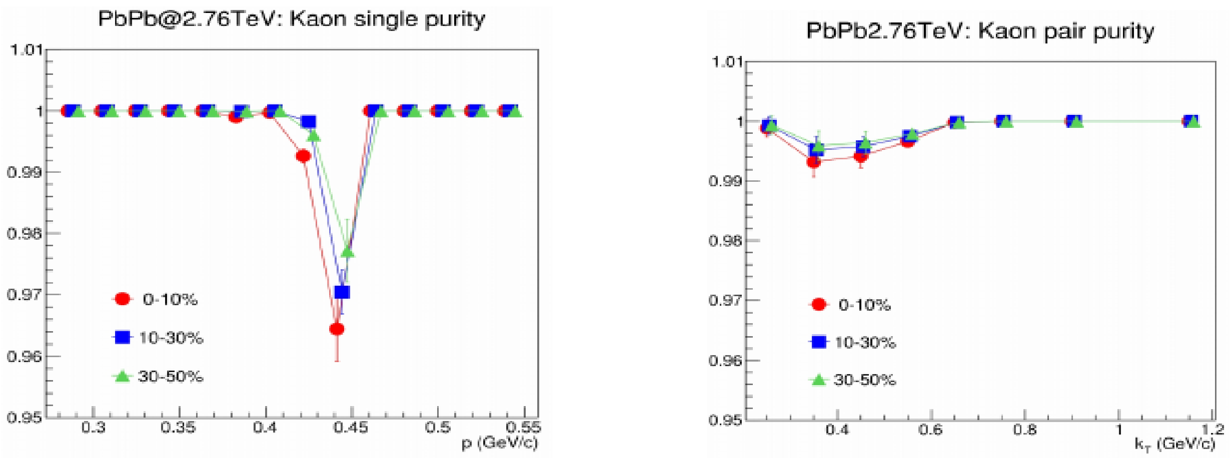


Fig.1. (Left): Purity of an identified kaon as a function of its momentum shown in three centrality bins; (right): purity of an identified pair of kaons as a function of the pair transverse momentum (k_T).

The correlation function of K^+K^- pairs was determined experimentally by the well-known ratio C(p1, p2) = A(p1, p2)/B(p1, p2), where two-particle distributions A and B were obtained for pairs of kaons from the same and from different events (mixing), respectively. In 1-D analysis, C (p1, p2) is presented depending on

$$q_{inv} = \sqrt{|\mathbf{q}|^2 - q_0^2}, \quad \mathbf{q} = \mathbf{p}1 - \mathbf{p}2,\ q0 = E1 - E2 .$$

A typical correlation function is shown in Fig. 2 where the blue points show the experimental data and the red curve is the result of the approximation in the model using the formula

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

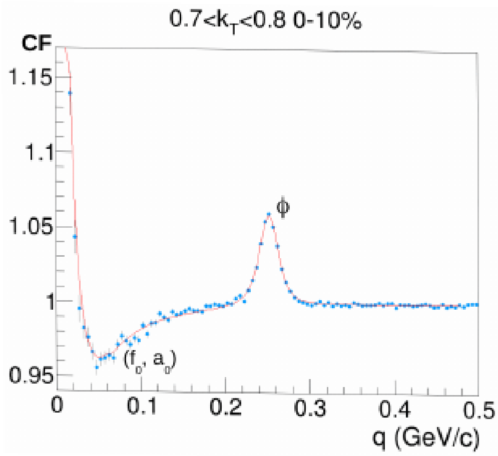


Fig.2. Correlation function of K^+K^- pairs as a function of q_{inv} for Pb-Pb collisions. The blue points are present the experimental data, the red curve is the result of the model fit.

The fit function presented above was discussed in the detail in [1]. Here it should be noted that C_{sFSI} determines contributions of f_0 and a_0 mesons, and $C_{\varphi\text{-direct}}$ and C_φ – contributions of φ mesons, which are produced at the quark-gluon stage and at the hadron interaction stage, respectively. The following parameters are supposed to be free: the radius of the K^+K^- emitting source, the mass of the f0 meson, the coupling constants for the f0 ⟶ K^+K^-, f0 ⟶ $\pi\pi$ channels and the fraction of the contributions N1, N2. The remaining values were taken from previous studies. The values of the f0 mass and width were obtained from the approximation and are 967 ± 3 ± 7 and 43.8 ± 8.8 ± 6.9 MeV/c2, respectively, which corresponds to the PDG values. The values of N_1 and N_2 were 0.7-0.8 and 0.3-0.2, respectively, i.e. the fraction of ϕ production in the FSI stage is no more of 30%.

Figure 3 shows the radii of the emitting source (R_{inv}) depending on the transverse momentum of the K^+K^- pair (k_T) in three different multiplicity classes. The results are compared with those obtained for pairs of identical kaons ($K^\pm K^\pm$) [2].

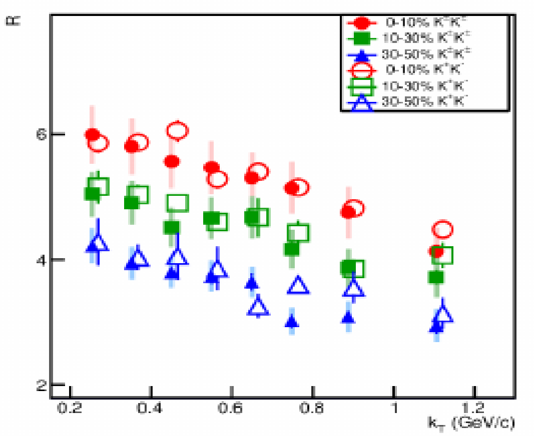


Fig.3. Invariant radius of the source as a function of the pair transverse momentum in Pb-Pb collisions in three event multiplicity classes. The results for K^+K^- ($K^\pm K^\pm$) are shown by empty (full) points.

As seen from Fig.3, the radii for non-identical and identical kaon pairs coincide with each other and decrease with increasing multiplicity and k_T, which is in agreement with predictions of hydrodynamic models. The results have been partially published in [3] and were included in the draft of full publication prepared in 2022 year.

Section I.3. The study of identical charged kaon femtoscopic correlations in pp collisions at 13 TeV.

These studies carried out with the selection of events by sphericity, which was determined by the formula

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

(p_T, p_x, p_y components of particle momenta), which made it possible to select separately spherical events with Sxy > 0.7 and events with jet formation with Sxy < 0.3. The main interest lies in comparing the dependences of the source radii on the transverse mass m_T of pairs in these events in order to test the possible manifestation of collective effects in pp collisions. The correlation function was determined using the method described in Section 1.2, and the approximation was made using the formula

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

where N is a normalization coefficient, K describes the Coulomb interaction of radius r, D accounts for background effects, and λ is a correlation strength. Dependence of Rinv on mT for pairs of pions and kaons in events of different multiplicities and S_T (SXY) are shown in Fig. 4, where it can be seen that Rinv decreases with increasing m_T

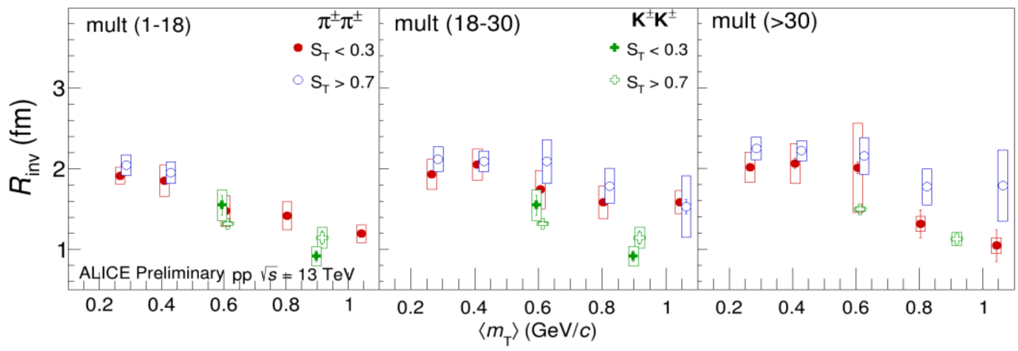


Fig.4. Invariant radius of the source as a function of the m_T for pions and kaons in different multiplicity and sphericity classes.

in both cases of S_T selections, i.e. and in events without jet formation, which may mean some manifestation of collective hydrodynamic mechanisms in pp collisions. These preliminary results were presented at the "5th International Conference on Particle Physics and Astrophysics (ICPPA-2020), October 7, 2020, MEPhI, Moscow", and require further verification on increased statistics in pp collisions.

Section I.4. Investigation of correlations of pairs of identical kaons and pions in Pb-Pb collisions at an energy of 5.02 TeV.

These studies included 1D and 3D analyzes done at maximum Pb-Pb collision energy. The 1D analysis method described in Section 1.2 was also used in this case, using formula 1 to approximate the correlation function. Figure 5 shows the dependences of the source radii, Rinv, of kaon radiation on the transverse momentum of a pair of kaons kT for events with different centrality. It can be seen that Rinv decreases with increasing k_T as a result of the manifestation of the collective effect during the interaction of nuclei, and this effect noticeably weakens for peripheral events.

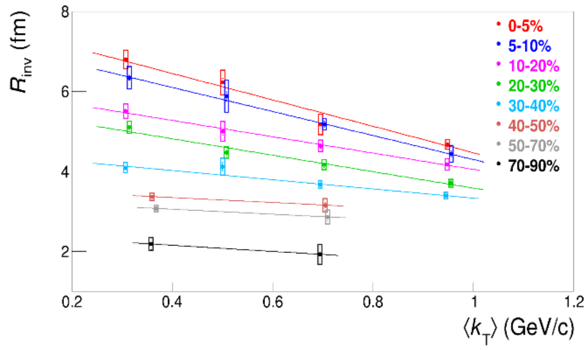


Fig.5. Fig. Dependence of Rinv for kaons on transverse momentum of a pair of kaons for events of different centrality.

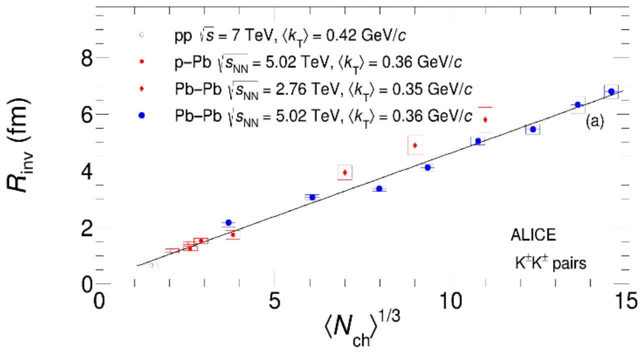


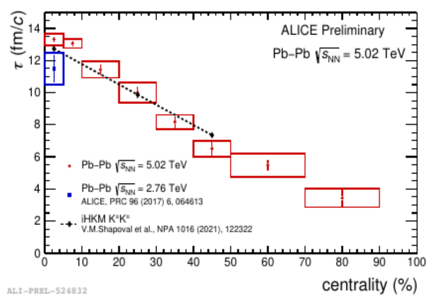
Fig.6. Dependence of Rinv for kaons on of the multiplicity of charged particles for different interacting systems.

Figure 6 shows the dependence of Rinv on the multiplicity of charged particles (Nch) in pp, p-Pb and Pb-Pb collisions at close kT values of kaon pairs. It can be seen that all points are close to the same linear dependence, i.e., the source radii for different interacting systems are largely determined by the multiplicity of particles formed.

Three-dimensional (3D) analysis of femtoscopic correlations makes it possible to study in more detail the three components of the particle emission source radius, i.e., in fact, the spatial shape of the source. The experimental procedure in this assay was the same as in the univariate assay discussed above. The correlation function in three-dimensional analysis is represented as depending on three components of the variable q (specified in section 1.2), which are calculated in the LCMS system, where the longitudinal momentum of the pair is zeroed and the components q_{out}, q_{side}, q_{long} are determined with the axes: "long" - along the beam, "out » - along the transverse momentum of the pair, «side» - perpendicular to the latter in the transverse plane. The correlation function was fitted by the formula

$$C(\mathbf{q}) = N(1-\lambda) + N\lambda K(q)\left[1 + \exp\left(-R_{\mathrm{out}}^2 q_{\mathrm{out}}^2 - R_{\mathrm{side}}^2 q_{\mathrm{side}}^2 - R_{\mathrm{long}}^2 q_{\mathrm{long}}^2\right)\right],$$

The parameter λ and the function K(q), as in formula (1), describe the correlation force and the Coulomb interaction of charged particles, respectively. Figure 5 shows the dependences of the source radius Rlong on the transverse mass (m_T) of a pair of kaons for events of different centrality. It can be seen that Rinv decreases with increasing mT, as in the case of 1D analysis. The dependencies for Rsite and Rout are of a similar nature (not shown here).



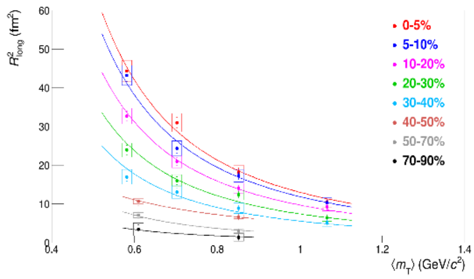


Fig.5. Dependence of Rinv for kaons on transverse momenta of kaon pairs for events of different multiplicity

Fig.6. Dependence of particle emission time (τ) on the centrality of events.

For the first time in such an analysis, the dependence of the maximum kaon emission time on the centrality of events was obtained. As in [4], we used the formula

$$R_{\text{long}}^2 = \tau_{\max}^2 \frac{T_{\max}}{m_T \cosh y_T}(1 + \frac{3T_{\max}}{2m_T \cosh y_T}), \qquad \cosh y_T = (1 - v_T^2)^{-1/2},\ v_T = \frac{\beta p_T}{\beta m_T + \alpha}$$

where Tmax is the maximum temperature. Figure 6 shows this dependence together with the prediction of the HKM model [5] (black crosses) and the value (blue dot) obtained earlier at an energy of 2.76 TeV [4] for the most central events. It can be seen that the expected decrease in τ for more peripheral events is consistent with the model's prediction. The obtained results were reported at the Meeting of the ALICE Group on Femtoscopic Research and were included in the thesis of the Master of Moscow State University in 2021 by G.E. Romanenko.

Section I.5. Conclusions for section I and plans for 2023-2024 years.

The main conclusions of these results are as follows:

– A more accurate 1-D femtoscopic correlation analysis was performed for pairs of non-identical (K^+ and K^-) kaons formed in Pb-Pb interactions at an energy of 2.76 TeV. When describing the experimental results in the Final State Particle Interaction Model, R. Lednický and W. Luboszcz refined (in collaboration with R. Lednický) the parameters of the model. and fractions of different mechanisms of production of ϕ mesons. As a result of these studies, more accurate mass and width f0 of the resonance, the f meson production fraction at the stage of interaction of particles in the final state were obtained, and it was shown that the source radii for non-identical and identical kaon pairs coincide in magnitude with the same dependences on the centrality of events and the transverse momentum of the pair .
– A study of femtoscopic correlations of kaon and pion pairs in pp collisions at an energy of 13 TeV was carried out with selection according to the sphericity of events and it was shown that Rinv decreases with increasing mT in events without jet formation, which may mean some manifestation of collective hydrodynamic mechanisms in pp collisions.
– Performed 1D and 3D analyzes of femtoscopic correlations, analysis of pairs of identical kaons at the maximum energy of Pb-Pb collisions. The 1D analysis shows that the source radii for different interacting systems are largely determined by the multiplicity of particles formed. For the first time in 3D analysis, the dependence of the maximum time of kaon emission on the centrality of events was obtained.

For 2023-2024, the following items are planned for the study of femtoscopic correlations:

- In 2023 complete a 1-D analysis of femtoscopic correlations for pion and kaon pairs, taking into account the sphericity of events in p-p collisions at energies of 13 TeV (per nucleon pair), respectively, with the preparation and release of publications.

- In 2023 complete work on the publication “Investigation of K^+K^- interactions via femtoscopy in Pb–Pb collisions at √sNN = 2.76 TeV by ALICE at the LHC”

- In 2024 Conduct a 1-D analysis of femtoscopic correlations of pion and kaon pairs in p-p collisions at energies of 13 TeV (per nucleon) for events with the maximum available multiplicity, in order to study the dependence on multiplicity and compare pp, pPb and PbPb collisions with the same multiplicity.

- In 2024 Compare the obtained results with the results of other experiments and predictions of models with different approaches: hydrokinetic models (EPOS), models with string interaction (different PYTHIA settings).

- In 2023-2024 Continue 1-D and 3-D analysis of femtoscopic correlations for identical kaon pairs in PbPb collisions at an energy of 5.02 TeV per nucleon pair over a wide range of collision centralities. Extract the femtoscopic radii and check the scaling violation between pion and kaon radii observed in PpPb collisions at 2.76 TeV per nucleon pair. Extract the kaon emission time in a wide range of collision centralities. Compare the extracted dimensions for peripheral impacts with those measured in pp and pPb at close multiplicities.
- In the period 2023-2024, analyze the Run2 data on the correlations of non-identical charged kaons in p-Pb collisions at an energy of $\sqrt{s}$=5.02 TeV and compare the data obtained with the model calculations of PYTHIA, EPOS.
– In 2024 to start analysis of the K^+K^- correlations in Pb-Pb at the energy $\sqrt{s_{NN}}$ = 5.02 TeV. Make a comparison of the space-time characteristics obtained from the analysis of identical and non-identical kaons.

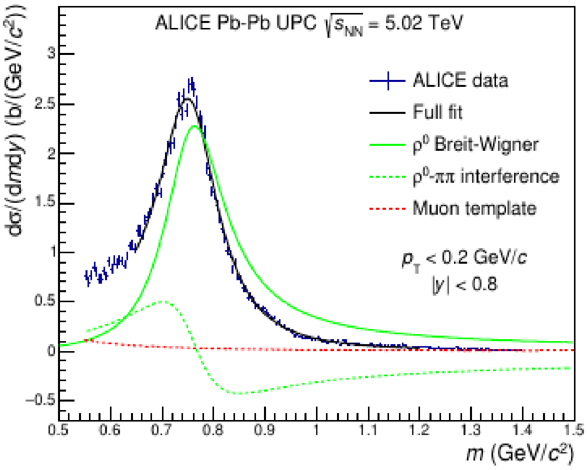
– In 2023-2024 to carry out 1-D and 3-D analysis of femtoscopic correlations for identical kaon pairs in pPb collisions at an energy of 5.02 TeV per nucleon pair depending on the centralities of collisions and the transverse momentum of the pair. Extract femtoscopic radii and check for the existence of scaling between pion and kaon radii. Extract the time of kaon emission depending on the centrality of collisions. Compare the extracted sizes with those measured for peripheral PbPb collisions at close multiplicities.
– In 2024 to start analyzing femtoscopic correlations of ϕϕ meson pairs in pp interactions at 13 TeV on simulated and real events.

Section II. Ultra-peripheral collisions of heavy ions.

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 [6]. 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 2020-2022, the JINR-ALICE group participated in studies of the coherent ρ^0 production in Pb-Pb ultra-peripheral collisions at energy of 5.02 TeV (per pair of nucleons) as for all events as with four charged particles selection.

Figure 7 shows the distribution of the $\pi^+\pi^-$ invariant mass at the central rapidity region. The peak from ρ^0 stands out very well because a large statistics in the Run-2 of the LHC, which also allows to see more heavy state of ρ^0 shown in Fig.8. The blue curve in Fig.7 shows the sum of the resonance contribution (Breit-Wigner, green lint), ρ^0 - $\pi\pi$ interference (green dotted line), the contribution of resonance muon decays (red dotted line). The fitted mass (769.5 ± 1.2 ± 1.2 MeV/c^2) and width (156 ± 2 ±3 MeV/c^2) of the observed peak are closed to the PDG values.The results included also the rapidity differential cross sections and theirs comparison with different models. The fitted mass (1725 ± 17 MeV/c^2) and width (143 ± 21 MeV/c^2) of the more heavy resonance (Fig.8) are closed to the PDG values of ρ^0 (1700). All results have been presented in the ALICE publication [7].

Figure 9 shows a preliminary result for the invariant mass distribution of coherent events with four charged pions (π+π+π-π-) in the final state. The red curve is the result of fitting the experimental data with the Breit-Wigner (B-W) function. The obtained values of the mass and width of the resonant maximum were 1456 ± 7 and 387 ± 15 MeV/c2, respectively, which coincides with the PDG values for the state ρ^0 (1450) at the fitting significance χ2/ndf = 108/39. Figure 10 shows the same result,



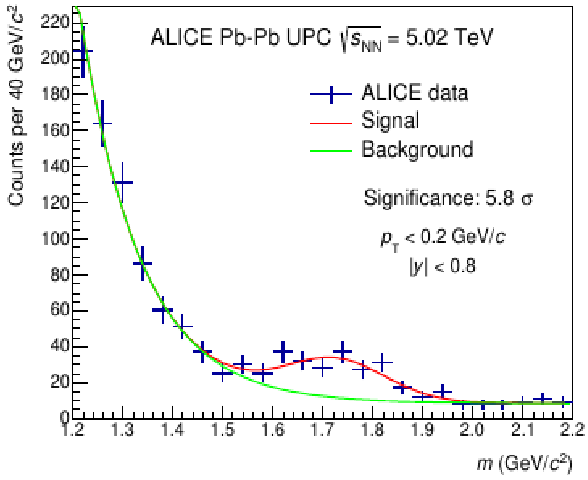
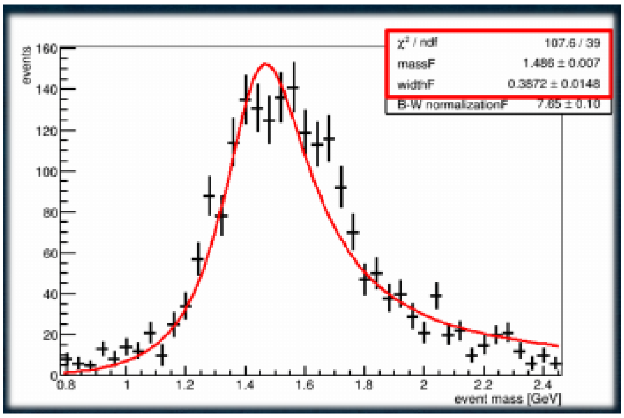


Fig.7. Distribution of di-pion invariant mass. Curves show various contributions (see text).

Fig.8. Distribution of di-pion invariant mass. Curves show selected signal and background.

but with two Breit-Wigner fittings. Here, the total fit (red curve) includes the contributions of the two B-W functions (green and blue curves) and the interference between them (pink curve). The values of the mass and width of the first state were 1447 ± 50 and 504 ± 144 MeV/c2, and those of the second state were 1722 ± 63 and 440 ± 207 MeV/c2, with the significance of $\chi 2$/ndf = 54/35. It can be seen that the superimposition of two resonances ρ^0 (1450) and ρ^0 (1700) has a slightly better significance than fitting with one B-W function, although, correspondingly, with significantly larger errors in the obtained parameters. Further studies with increased statistics are needed to choose between these two representations. The results were reported at the ALICE Meetings.



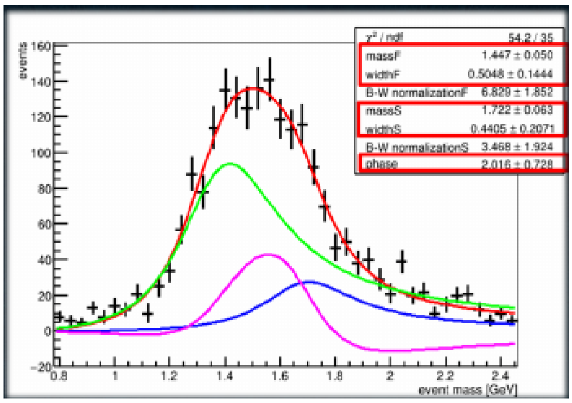


Fig.9. The invariant mass of four pions events ($\pi^+\pi^+\pi^-\pi^-$) . The curve is B-W fit.

Fig.10. The same as in Fig.9 but with the fit by two B-W and with an interference between them.

Conclusions for section II and plans for 2023-2024 years.

– Based on the statistics obtained during 2015-2018, the coherent production of ρ^0 in ultra-peripheral (UPC) Pb-Pb collisions with an energy of 5.02 TeV was studied. The differential cross section is measured and compared with the predictions of various models.

- A preliminary study of the coherent production of the states ρ^0(1450) and ρ^0(1700) in (UPC) events with four pions (π+π+π-π-) in the final state was carried out.

Plans for 2023 - 2024:

– In 2023-2024, at the maximum statistics for Pb-Pb collisions at 5.02 TeV, to analyze the coherent and incoherent photoproduction of ρ^0 and incoherent of J/ψ.
– To analyze the events of 4-pion states with the refinement of the parameters of the resonances ρ^0(1450) and ρ^0(1700).
– In 2024 at the maximum statistics for p-Pb collisions at 5.02 TeV, to measure the photoproduction cross section ρ^0 and compare with the results of experiments at the HERA collider.
– In 2024 to start analyzing events with pair production of vector mesons in two-photon interactions with an emphasis on searching for ρ^0+J/ψ states.

Section III. Development of the Thermal model of particle production in pp and A-A collisions.

A new version of the Thermal Model was developed with consideration of A-A collisions, as a development of the previous one for pp interactions, published in [7]. The model included three components: the Boltzmann-Gibs thermal distribution (particle flow effect), the Tsallis distribution for decays of resonances, and the power law for QCD of hard processes. The yield ratios of charged particles, their transverse momentum (pT) spectra, and nuclear modification factors have been obtained. Which, upon collision of nuclei A and B, are defined as

$$R_{\mathrm{AB}} = \frac{\mathrm{d}^2 N_{\mathrm{AB}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}{\langle N_{\mathrm{coll}}\rangle \mathrm{d}^2 N_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} .$$

where Ncoll is the number of nucleon collisions. Figure 11 compares the p_T dependences of the R_{PbPb} values for different particles and events of different centralities obtained in the model and in the ALICE and CMS experiments. One can see good agreement between the model and experimental results.

Conclusions for section III and plans for 2023-2024 years.

- The JINR ALICE group proposed a three-component phenomenological model (BWTP) to describe the transverse momentum spectra of various hadrons measured in p-p, p-A and A-A collisions at the LHC. The data on the spectra of thirteen particles (from pions to charmoniums) produced in p-p and Pb-Pb are analyzed for different energies and collision centrality. The model well describes all these experimental data, as well as data on the nuclear modification of the spectra. The description of the model and the results of the work are published in [8].

Plans for 2023 - 2024 years.

- Application of the previously developed (in 2021-2022) BWTP model to describe the transverse momentum spectra of other hadrons produced in p-p and Pb-Pb collisions, but not yet considered before.

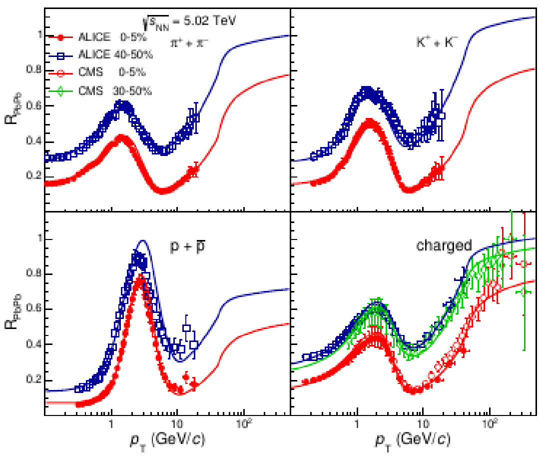


Fig.11. Nuclear Modification Factor (R_{PbPb}) for various particles produced in Pb-Pb collisions at 5.02 TeV compared to Thermal Model results.

- Application of the BWTP model to describe the transverse momentum spectra of various hadrons already measured in p-Pb and Xe-Xe collisions at the LHC.
- Application of this model to describe the spectra of the transverse momentum of various hadrons, which will be measured in p-p, p-A and A-A collisions for 2023-2024.
- Generalization of the BWTP model to describe the dependence on the transverse momentum and centrality of collisions of both the spectra and their azimuthal asymmetry. For example, the description of the value v2 for various particles.
- Further development of the BWTP model in order to create a particle generator based on it.
- Present research results at international forums and in the form of publications in journals.

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

In the period 2020-2022, the maintenance and development of the JINR ALICE-GRID system of the 2nd level (tier 2) continued. Table 1 shows the parameters of GRID-ALICE computer centers of the 2nd level in 8 Russian institutes in 2020-2022 years.(NRC KI, Kurchatov Institute since 2022 has a center of only 1st level). One can see from the Tab.1 that JINR occupies a leading position (~ 40%) in terms of resource capacity. The total contribution of Russian centers to ALICE-GRID is ~ 4%.

- **Plans for 2023-2024 years.**
- Support for ALICE-GRID structure of the 2nd level.
- Transition to new software, regular replacement of obsolete computing nodes and data storage systems with new ones.

Participation in the implementation of a project to use the power of supercomputers and in the development of other GRID technologies in ALICE

Table 1. Parameters of computer GRID-ALICE 2nd level centers in 8 Russian institutes in 2020 - 2022 years.

	2020		2021		2022	
	DISK	CPU	DISK	CPU	DISK	CPU
JINR	1200	12000	2000	13500	2300	15525
NRC KI	316	4488	~~316~~	~~4488~~	0	0
IHEP	297	2631	314	3017	314	3017
ITEP	180	2700	180	2700	180	2700
PNPI	168	2640	168	2640	168	2640
INR RAS	113	641	113	641	113	641
SPSU	158	3696	158	3696	158	3696
SARFTI	210	7466	210	7466	210	7466
	2642	36262	3459	38148	3443	35685

References (highlighted numbers indicate the work carried out with the active participation of the JINR-ALICE team members for 20120-2022).

[1] R.Lednicky and V.L. Lyuboshitz, Sov. J. Nucl. Phys. 35 (1982) 770;
R.Lednicky, Phys. of Part. and Nucl. Lett. Vol 8, (2011) 965.

[2] J. Adam et al. (ALICE Collaboration), "One-dimensional pion, kaon, and proton femtoscopy in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV", Phys. Rev. C **92**, 054908 (2015).

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Reports at conferences of the staff of the JINR-ALICE group in the period 2020-2022

1. K.Mikhaylov (on behalf of the ALICE Collaboration), "Non-identical charged kaon femtoscopy in Pb-Pb collisions at $(s_{NN})^{0.5}$ = 2.76 TeV ", 5th International Conference on Particle physics and Astrophysics (ICPPA-2020), October 7, 2020, MEPhI, Moscow.
2. L.Malinina (JINR, SINP MSU, on behalf of the ALICE Collaboration), "Femtoscopic correlations of identical charged particles in pp collisions at LHC energies with event-shape selection**",** 5th International Conference on Particle physics and Astrophysics (ICPPA-2020), October 7, 2020, MEPhI, Moscow.
3. E.Rogochaya (JINR), B.Batyunya (JINR), L.Malinina (SINP MSU, JINR), K.Mikhaylov (ITEP, JINR), G.Romanenko (SINP MSU, JINR), K. Verner (Subatech, France), "Pion and kaon femtoscopy in Pb-Pb colisions at 2.76 TeV in comparison with EPOS 3 model prediction", 5th International Conference on Particle physics and Astrophysics (ICPPA-2020), October 9, 2020, MEPhI, Moscow.
4. V.Pozdnyakov (JINR, on behalf of the ALICE Collaboration), " Recent ALICE results on photon-induced J/ψ production", 10th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions , University of Texas, Austin, USA, (31 May – 5 June) 2020.
5. V.Pozdnyakov (JINR, on behalf of the ALICE Collaboration), " Vector meson photoproduction in ultra-peripheral Pb-Pb collisions at the LHC with ALICE". 40th International Conference on High Energy Physics (ICHEP 2020), 28.7-6.8, Prague, Czech Republic.
6. 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.
7. 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.
8. 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.

- **Activity in other types of scientific work.**

- Elections in 2020-2021 L. Malinina and E. Rogocha as ALICE conveners in the femtoscopy research group.
- Participation of L. Malinina (head), K. Mikhailov (head), E. Rogochaya in internal audit committees for various ALICE publications.
- Participation of the JINR group in internal institute audit committees on various ALICE publications.
- Participation in duty shifts of ALICE (81 shifts for detector controls in 2022).

Section V. Upgrade of the electromagnetic calorimeter PHOS

The PHOS electromagnetic calorimeter of the ALICE detector at the LHC (CERN) is designed to record photons over a wide dynamic energy range from tens of MeV to hundreds of GeV. PHOS consists of 12 thousand cells. Each cell is a rectangular parallelepiped of lead tungstate PWO_4 crystals measuring 180x22x22 mm^3. A 5x5 mm^2 avalanche photodiode (APD) and a charge-sensitive preamplifier are located at the 22x22 mm^2 end (Fig.12). This photodetector provides a measurement with good linearity of electromagnetic shower energy up to 160 GeV with a resolution at 1 GeV of about σ_E=3% and time resolution σ_T =3 ns. The crystals and photodetectors are at -26°C because the light output of the PWO_4 crystals increases threefold compared to room temperature, and the noise of the photodetectors and preamplifier decreases. The PHOS Collaboration works on a photodetector replacement with the goal of obtaining a time resolution up to 100-150 ps and improved energy resolution for lower energies. The most suitable photodetectors are silicon photomultipliers (SiPM). The main candidate of SiPM is MPPC Hamamatsu S14160-6015PS (multi-pixel photon counter, Fig.13). Some problems arise because of the large dynamic range of energy measurements. Since silicon photomultipliers are nonlinear, saturation occurs at the highest energies. In addition, if one detector tries to operate over the entire energy range, the amplitude at low energies will be too small to obtain good resolution. During 2021-22 sessions conducted on the PS test beam at CERN the final decision was taken using the combination of three SiPMs of 6x6 mm^2 and one SiPM of 3x3 mm^2. The good detector resolutions for energy (up to 2%, Fig.14) and for time (up to 0.14 ns, Fig.15) were obtained. Crystals and photodetectors were cooled to -26.5ºC with an accuracy of ±0.1ºC.The measurements were performed with a VME data acquisition system using CAEN electronics: ADC V785, QDC V792, TDC V1290 and an autonomous 5 GHz digitizer CAEN DT5742B. No amplifiers were used in front of the digitizer input.

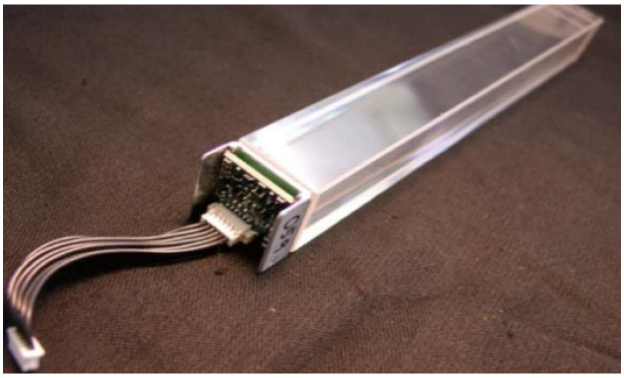

Fig.12. Photodetectors and crystal PWO_4 with avalanche photodiode.

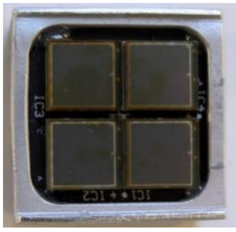

Fig.13. MPPC S14160-6015PS.

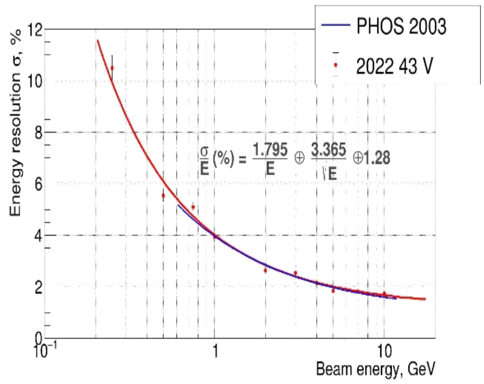

Fig.14. Energy resolutions of SiPM photodetectors.

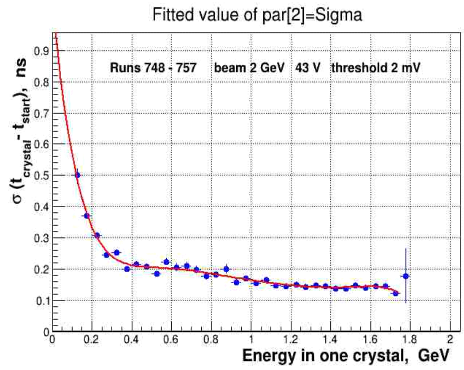

Fig.15. Time resolutons of SiPM photodetectors.

Plans for 2023-2024years.

– Take part in the preparation of the proposal for the upgrade of the PHOS for the approval at CERN.
– Take part in the upgrade of the readout system of the electromagnetic calorimeter PHOS.
-- Take part in the preparation of the software of the DCS ALICE.
–Take part in the tests of the parts of the PHOS read out system in electron and protons beams at CERN.

2.4. Participating JINR laboratories: LHEP, LIT

2.5. Participating countries, scientific and educational organizations:

Organization	Country	City	Participants	Type of agreement
CERN	Switzerland	Geneva	ALICE Collaboration	Memorandum of Understanding for the Collaboration on the Construction of ALICE Detector, ALICE RRB-D 00-41
CERN	Switzerland	Geneva	ALICE Collaboration	Memorandum of Understanding for the Maintenance and Operation of the ALICE Detector, CERN-RRB-2002-034

2.6. Key partners *(those collaborators whose financial, infrastructural participation is substantial for the implementation of the research program on the theme. Example – JINR participation in the LHC experiments at CERN).*
JINR participation in the LHC experiments at CERN.

3. Manpower
3.1. Manpower needs in the first year of implementation

No.	Personnel category	JINR staff, FTE amount	JINR associated personnel, FTE amount

1.	research scientists	10,0	
2.	engineers	5,0	
3.	specialists		
	Total:	**15,0**	

3.2. Available manpower
3.2.1. JINR staff (total number of participants)

No.	Personnel category	Division	Position	Amount FTE
1.	research scientists	LHEP LIT	15 1	10,0 1,0
2.	engineers	LHEP		5,0
3.	specialists			
	Total:		**16**	**16,0**

3.2.2. JINR associated personnel

No.	Personnel category	Partner organization	Amount of FTE
1.	research scientists		
2.	engineers		
	Total:		

4. Financing
4.1. Total estimated cost of the theme / LRIP

No.	Items of expenditure	Cost	Expenditure per year (thousands of the US dollars)		
			2023 year	2024 year	
1.	International cooperation		135	135	
2.	Materials		180	200	
3.	Equipment, Third-party company services				
4.	Commissioning				
5.	R&D contracts with other research organizations				
6.	Software purchasing				
7.	Design/construction				
8.	Service costs (*planned in case of direct affiliation)*				
TOTAL:			**315**	**335**	

4.2. Extra funding sources

Expected extra funding from partners/customers (total for all projects).

AGREED:

Chief Scientific Secretary
______________/_________ ___________/
"_____"__________________ 202_г.

Laboratory Director
______________/_____ ______________/
"_____"__________________202_г.

Head of BEPD
______________/_________ ___________/
"_____"__________________202_г.

Scientific Secretary of the Laboratory
______________/_____ ______________/
"_____"__________________ 202_г.

Head of DSOA
______________/_________ ___________/
"_____"____________ 202_ г.

Laboratory Economist
______________/_____ ______________/
"_____"__________________202_г.

Head of HRRMD
______________/_________ ___________/
"_____"____________ 202_г.

Theme leader
______________/A.S.Vodopyanov /
"_____"____________ 2023г.

Project leader (project code) /
(LRIP subproject code)
______________ / A.S.Vodopyanov/
"_____"__________________2023г.

Project leader (project code) /
(LRIP subproject code)
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"_____"__________________202_г.