Report and proposal for extension of the ALICE project

PROJECT CODE: 02-1-1088-1-2026/2030

Veksler and Baldin Laboratory of High Energy Physics:

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JINR associated personnel:

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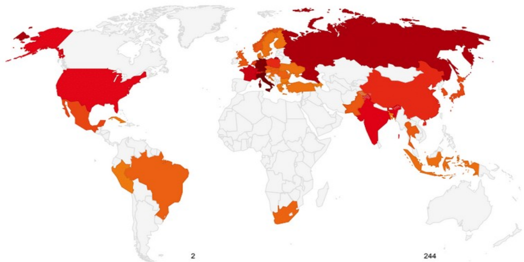
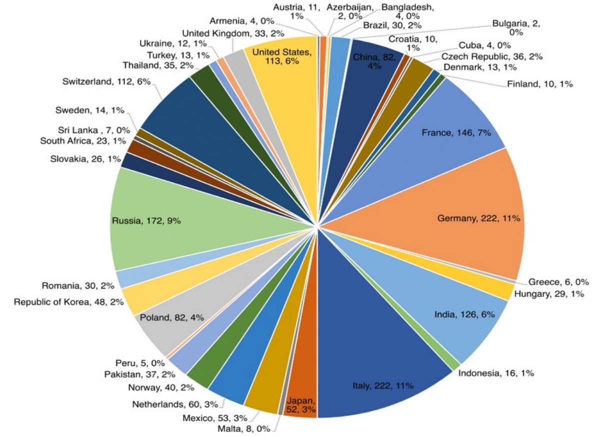
Project leader: A.S. Vodopyanov (VBLHEP)

Deputy leader: B.V. Batyunya (VBLHEP)

The ALICE Collaboration





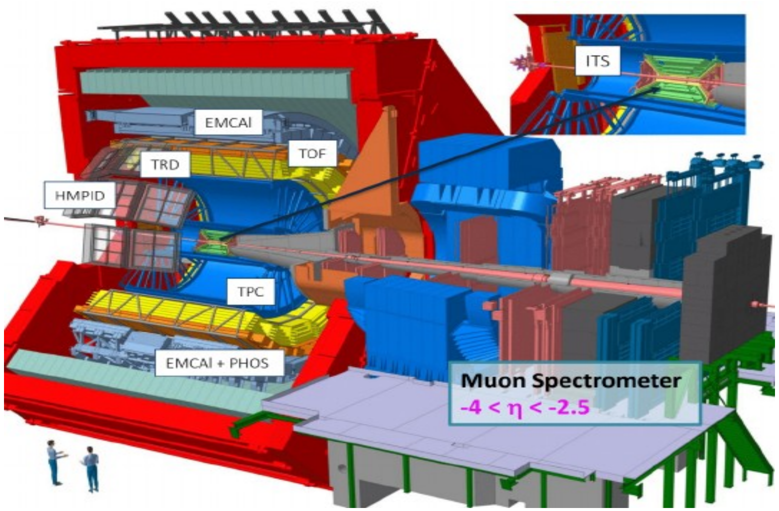
40 Countries, 176 Institutes (including 19 Associates)

1946 Members, about 1000 signing authors

941 Physicists (including PhD Students)

- 587 PhD Physicists
- 355 PhD Students

52 Senior Engineers



A Large Ion Collider Experiment (ALICE) is a multipurpose experiment to study the strongly interacting matter and the quark-gluon plasma in nucleus-nucleus collisions
at the LHC.

ALICE

The main topics of the JINR team in ALICE:

– Femtoscopic correlations of identical and non-identical particles:

Analysis of two-charged particle correlations in p-p, p-A and A-A collisions. Study of space-time source size of particle emissions.

– Ultra-peripheral collisions (UPC) of heavy ions:

Study a photoproduction of vector mesons in the A-A and p-A UPC.

-- Σ baryon production in pp, p-A and A-A collisions.

– Thermal model of particle production in pp and A-A collisions.

– GRID computing and software activities.

-- Support and development of FIT detector control system.

– Participation in the ALICE shifts and service tasks.

The femtoscopic correlations study during 2021-2025 years.

Figure 1 shows the particle emitting source radius (R_{inv}) for pairs of pions and kaons in pp events versus the pair transverse mass, $m_T=(m^2 + k_T^2)^{1/2}$ ($k_T = |p_{T1} + p_{T2}|/2$, m – particle mass). The results were obtained for different event sphericities defined for particle components by the formula

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

which allows to select spherical events at $S_{xy} > 0.7$ and events with jet formation at $S_{xy} < 0.3$. One can see from Fig.1 the R_{inv} decrease with m_T increasing in both cases of event selection, i.e. also without jet formation, which may indicate some manifestation of collective hydrodynamic effect in pp collisions. These results were published in [1]. Figure 2 shows the radius versus k_T for identical [2] and

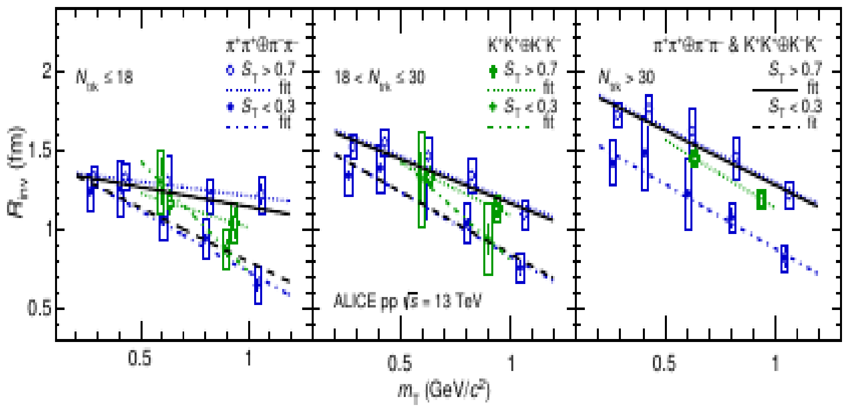


Fig.1

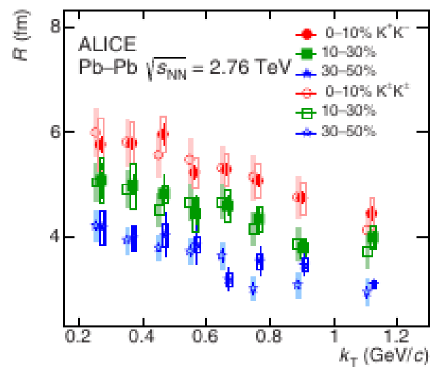


Fig.2

nonidentical (obtained using Lednicky-Lyuboshitz FSI model, see the Backup) kaon pairs for different centralities. It is seen that the radii are the same in the both cases and also there is known strong R decrease in a consequence of the collective effects, predicted in the hydrodynamic models. The results were published in [3].

The femtoscopic correlations study during 2021-2025 years.

Figure 3 shows the kaon emission time (τ), predicted in the hydrodynamic model, as a function of a average multiplicity of charged particles obtained in 3D correlation analysis for pairs of kaons in Pb-Pb and p-Pb events. One can see that the value of τ (2.7 ± 0.25 ± 0.15 fm/*c*) obtained for p-Pb events coincides with the ones in Pb-Pb collisions at the same particle multiplicity, which corresponds to the same source size of particle emitting. The dotted line in the Fig.3 is the hydrodynamic model prediction. Figure 4 shows dependence of component R_{long} (in the beam direction) on k_T for p-Pb collisions of different centralities. It is seen In Fig.4 that the value of R_{long} decreases for less central events and with growth of transverse momentum kaon pairs The filled regions are the prediction of the EPOS hydrodynamic model. Similar dependences were also obtained for the transverse components of the emitting source radius, which indicates the presence of collective effects in 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.

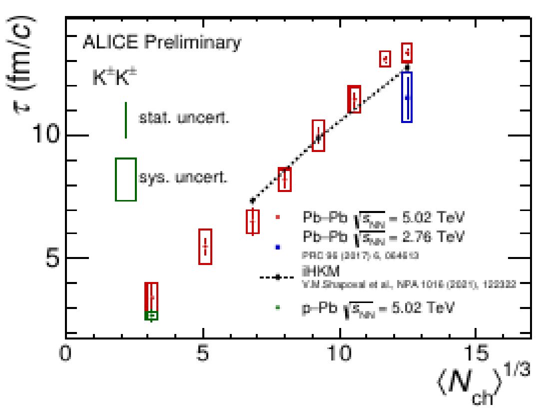


Fig.3

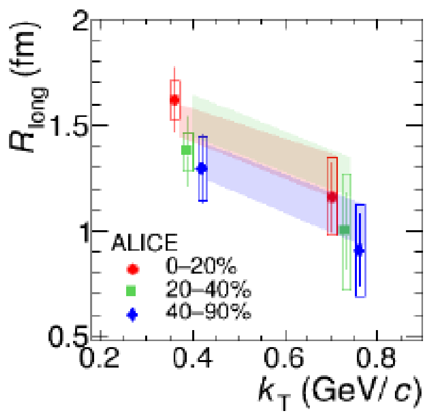


Fig.4

The femtoscopic correlations study. Plans for 2026-2030 years.

– The study of identical $K^{ch}K^{ch}$ pairs in p-Pb collisions with the selection (by the S_{xy} value) of spherical events with a small contribution of jet formations and events with a large contribution of the jets. Comparing the results with those shown in Fig.1 ($S_T = S_{xy}$ in the figure)/

– The study of the K^+K^- pair correlation in p-Pb and pp interactions using the FSI model to compare the results obtained for small dimension collisions to the ones of Pb-Pb collisions (Fig.2).

– 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).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 and checked in ALICE that the dependence of r_{cor} on m_T is universal for all types of pairs (see the Backup).

The ultra-peripheral collisions(UPC) study during 2021-2025 years.

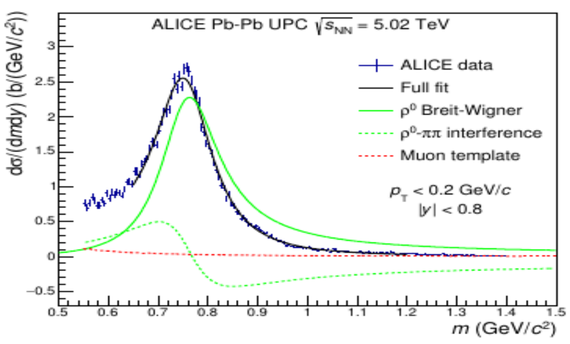


Fig. 5

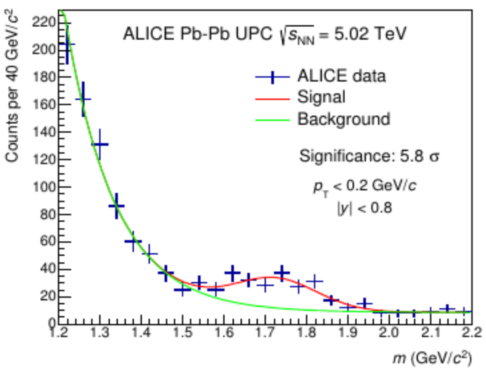


Fig.6

Figures 5 and 6 show the invariant mass spectra for $\pi^+\pi^-$ pairs obtained in coherent Pb-Pb UPC. The large statistics allowed to identify the peak of ρ^0 (770) with taking into account an ρ^0 - ππ interference in Fig.5 and to see the heavier resonance obtained from the fitting in Fig.6 with the mass of 1725 ± 17 and 143 ± 21 MeV/c^2, which corresponds to the PDG values of ρ^0(1700). These results were published in [4].

Figures 7 and 8 show the double differential cross section in terms of rapidity and invariant mass of four pions obtained for coherent UPC collisions (see the Backup) in ALICE . The red curve in Fig.7 is the result of data fitting by the Breit-Wigner function with the mass of 1463 ± 2 ± 15 MeV/c^2 and width of 448 ± 6 ± 14 MeV/c^2, which are closed to the PDG values of ρ^0(1450). Figure 8 shows the same data but fitting by the two Breit-Wigner functions (with interference between them) with the mass and width 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). The mixing angle was 1.52 ± 0.16 ± 0.19 (rad). It can be seen from the labels in Figs.7 and 8 that the quality of the fitting is better

under the assumption of interference between the two resonances. These results were published in [5].

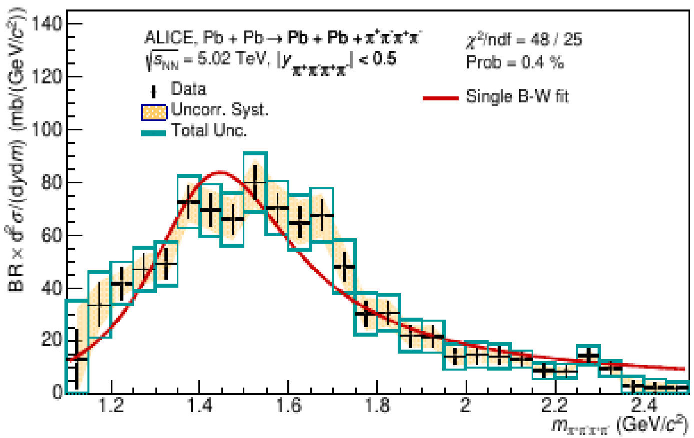


Fig.7

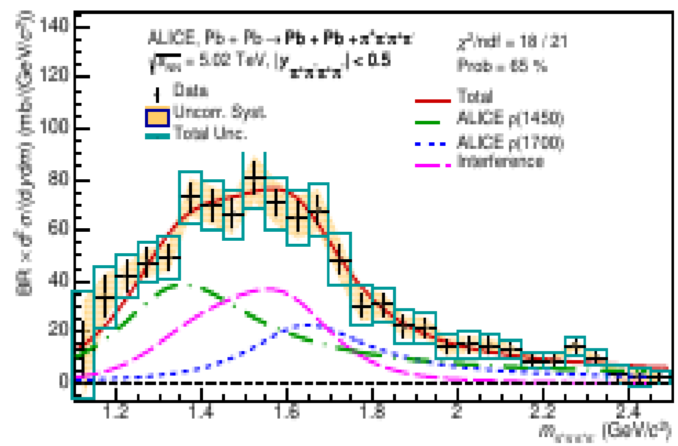


Fig.8

The ultra-peripheral collisions (UPC) study. Plans for 2026-2030 years.

– Study the effects of gluon shadowing in UPS Pb-Pb collisions at 5.36 TeV, obtained in the Run3 at the LHC. 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 Y, and on the assumption that the coherent photoproduction cross section is proportional to the square of the gluon density. Figure 9 shows the dependence of the cross section for the process γ + Pb → J/ψ + Pb on the interaction energy, presented in the ALICE paper [6]. 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. The remaining models, with the presence of gluon shadowing, are in varying degrees of agreement with the experimental results.
– Study the central exclusive production (CEP) of diffraction particle pair states in pp collisions using Run3 large statistics. allowed to test the predictions of perturbative QCD models of hadron pairs production in the CEP. The selection of these events is very simile to the UPC one. Figure 10 shows the invariant mass spectra of ππ pairs obtained preliminary in ALICE for CEP events in proton-proton collisions at $s^{1/2}$ = 13 TeV.. Thel resonance structures can be easily seen in the spectra corresponding to f_0(980), f_2(1270).

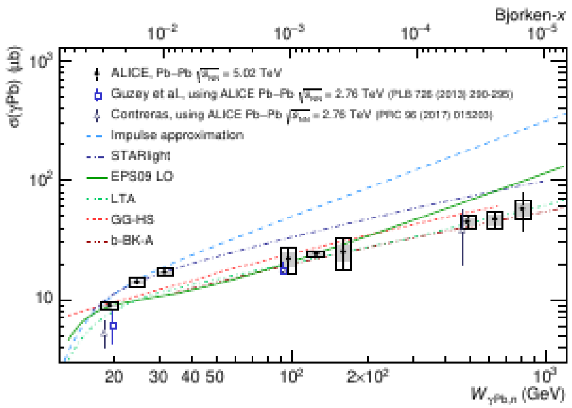


Fig.9

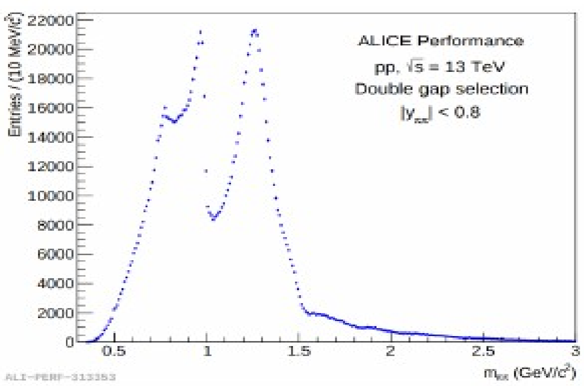


Fig.10

Study the processes of Σ hyperon productions.

Figure 11 shows the preliminary results of invariant mass γΛ pair distributions obtained in ALICE for pp collisions at energies of 7 TeV [7, 8]. It is seen very clear the strong peak of the decays $\Sigma^0(\overline{\Sigma}^0) \to \Lambda(\overline{\Lambda})+\gamma$
Charged hyperons (antihyperons) were studied by decays into $p(\overline{p})+\pi^0$. Figure 12 shows the ratio of the $\Sigma^0 + \overline{\Sigma}^0$ and doubled Λ hyperons yields depending on the energy of the pp collisions. It should be noted that ALICE's data has allowed us to advance energy by almost two orders of magnitude.

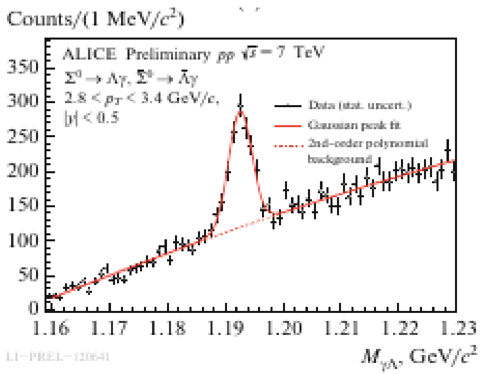


Fig.11

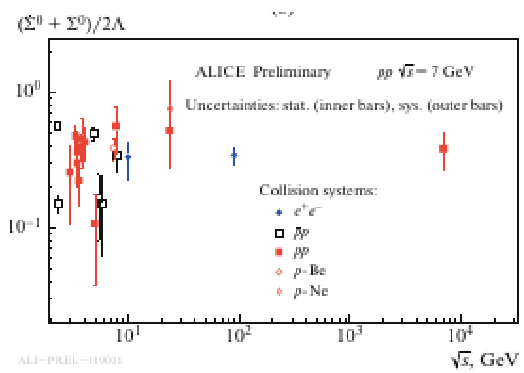


Fig.12

Plans for 2026-2030 years

-- Compleat the analysis of $\Sigma^0 + \overline{\Sigma}^0$ production in pp collisions at 7 TeV with the publication of ALICE's final article.
-- Possible studies of $\Sigma^0 + \overline{\Sigma}^0$ production in pp collisions at energies of 13 TeV and 13.6 TeV and in collisions of p-A and A-A nuclei.
-- Search for a new Σ^0-hypertriton nuclei consisting of (p, n, Σ^0) by its decay into the known Λ-hypertriton nuclei (p, n, Λ) and a photon.

BWTP model of hadron production in pp, p-A and A-A collisions

The model includes three components (the first letters of their names give BWTP): 1) the standard blast-wave model (BW) to describe the hydrodynamical processes, 2) the Tsallis distribution (T), 3) a term with a power-law (P) dependence on p_T to describe hard QCD processes. Spectral data for particles from pions to charmonia produced in pp and Pb-Pb were analyzed and published for different collision energies and centralities at the LHC. [9, 10]. Next, the model was developed and generalized for several processes. It was added the description of the effects suppression of short-lived resonances and growth of strange particle yields with increasing collision centrality in AA events. The new version of the model allows to describe the elliptic flow v_2 factor for various hadrons. Figure 13 shows a good description (by the curves) 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. It was added also the description of p_T spectra of different hadrons measured in Xe-Xe collisions at energy 5.44 TeV.

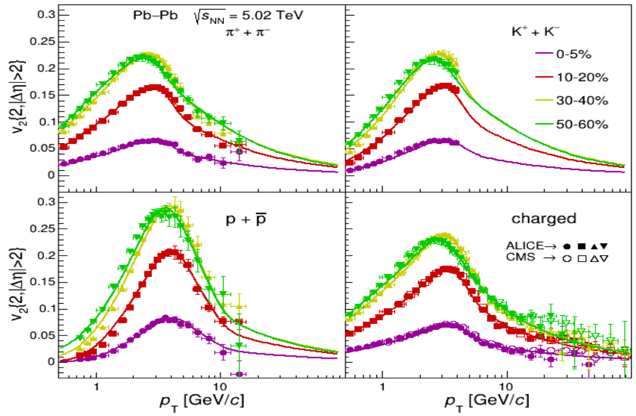


Fig. 13

Plans for 2026-2030 years

– Description of data obtained in Pb-Pb collisions for ω and D_s mesons, as well as on the production of deuterons and other light nuclei.
– 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.
– 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.

New ALICE FIT trigger system

As part of the ALICE setup modernization, a new hybrid Fast Interaction Trigger (FIT) 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.

FIT provides the following ALICE requirements:

-- BC-Bunch Crossing interval 25 ns, dead time ~15 ns;
-- 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;
-- determinations of global collision parameters based on the multiplicity of secondary particles:
-- determination 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).

FIT service task for 2026-2030 years:

-- data and Trigger Quality;
-- simulation and Reconstruction;
-- readout Experts;
-- calibration;
-- development and Maintenance of DQ algorithms;
-- DCS/DSS Expert;
-- software developments and automated testing;

Development of the ALICE event selection framework in 2026-2030 years

The standard event selection strategy in Run 3 is based on the requirement of signals on both sides of the FT0 detector (Fig.14) compatible with beam-beam collision timing. In this case a small fraction of proton-proton collisions is still contaminated by coincidences with the beam-gas background, resulting in unphysical high-multiplicity tails in forward multiplicity distributions. **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 (Fig.14) with information from the central barrel detectors.

A data acquisition in the ITS detector is performed in portions of ~5 µs for proton-proton sessions and ~15 µs for nuclear-nuclear collisions. 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.

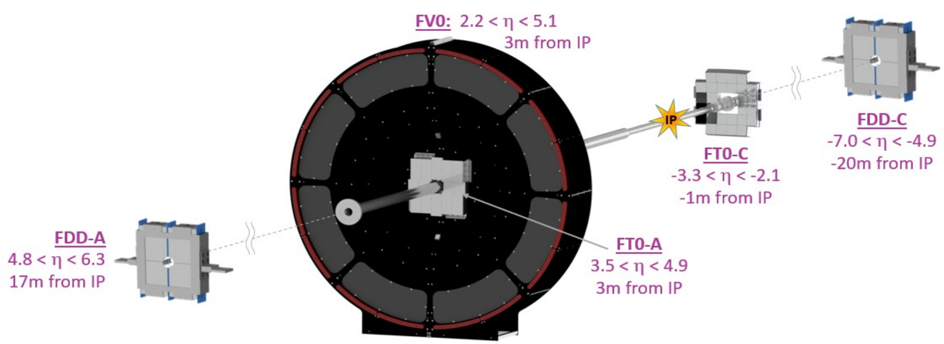


Fig.14

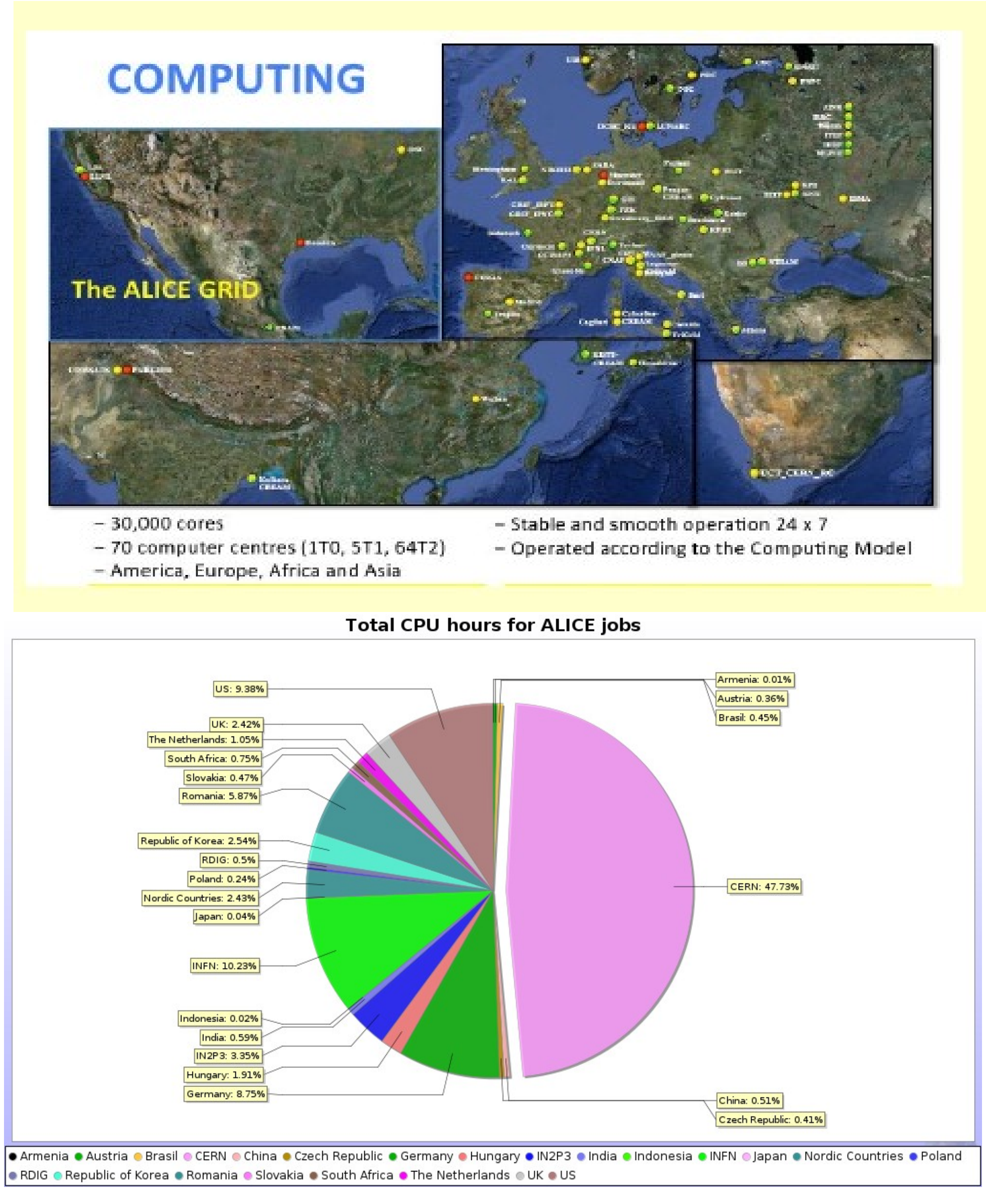


Fig.15

JINR GRID participation

In the period 2021-2025 the maintenance and development of the JINR tier 2 ALICE-GRID system continued. A capacity of the computer center is 1200 CPU cores and 1530 Tb of Disk-SE.

After the imposition of sanctions by CERN on Russian institutes JINR remains the only Russian participant in ALICE-GRID. Fig. 15 (lower) shows a diagram of a contributions of different countries to the total number of CPU hours spent in 2024 for all jobs. It is seen that a contribution of JINR (designated RDIG) is 0.5% (instead of 5% of all Russian Institutes before) but is equal in level of some individual countries (Slovakia, Poland, Czech Republic, Austria, China).

ALICE publications with key contributions from the JINR group.

1. ALICE Collaboration (S.Acharya et al.), "Femtoscopic correlations of identical charged pions and kaons in pp collisions at $(s)^{1/2}$ = 13 TeV with event-shape selection", Phys. Rev. C 109 (2024) 024915.

2. ALICE Collaboration (S.Acharya et al.), "Kaon femtoscopy in Pb–Pb collisions at $(s_{NN})^{1/2}$ = 2.76 TeV", Phys. Rev. C 96 (2017) 064613.

3. ALICE Collaboration (S.Acharya et al.), "Investigation of K^+K^- interactions via femtoscopy in Pb-Pb collisionsat at $(s_{NN})^{1/2}$ = 2.76 TeV at the LHC.", Phys. Rev. C 107 (2023) 054904.

4. ALICE Collaboration (S.Acharya et al.), «Coherent photoproduction of ρ^0 vector meson in ultra-peripheral Pb-Pb collisions at $(s_{NN})^{1/2}$ = 5.02 TeV», JHEP 06 (2020) 35.

5. ALICE Collaboration (S.Acharya et al.), "Exclusive four pion photoproduction in ultraperipheral Pb-Pb collisions at $(s_{NN})^{1/2}$ = 5.02 TeV ", arXiv:2404.07542 (2024).

6. ALICE Collaboration (S.Acharya et al.), "Energy dependence of coherent photonuclear production of J/ψ in UPC Pb-Pb collisions at $(s_{NN})^{1/2}$ = 5.02 TeV", JHEP 10 (2023) 119.

7. 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.

8. 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.

9. S.Grigoryan, "Using the Tsallis distribution for hadron spectra in pp collisions: Pions and quarkonia at $(s)^{1/2}$ = 5-13000 GeV", Phys.Rev. D 95 (2017) 056021.

10. 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.

Conference presentations .

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.

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.

Other scientific activities.

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

-- Elena Rogochaya was elected of the ALICE convener in Femtoscopy Analysis Team for the period of 2020-2022 years.

– Participation every yeas in the ALICE Review Committees and in JINR Institute reviews for the ALICE publications.

– Participation in 75 ALICE shifts on average each year.

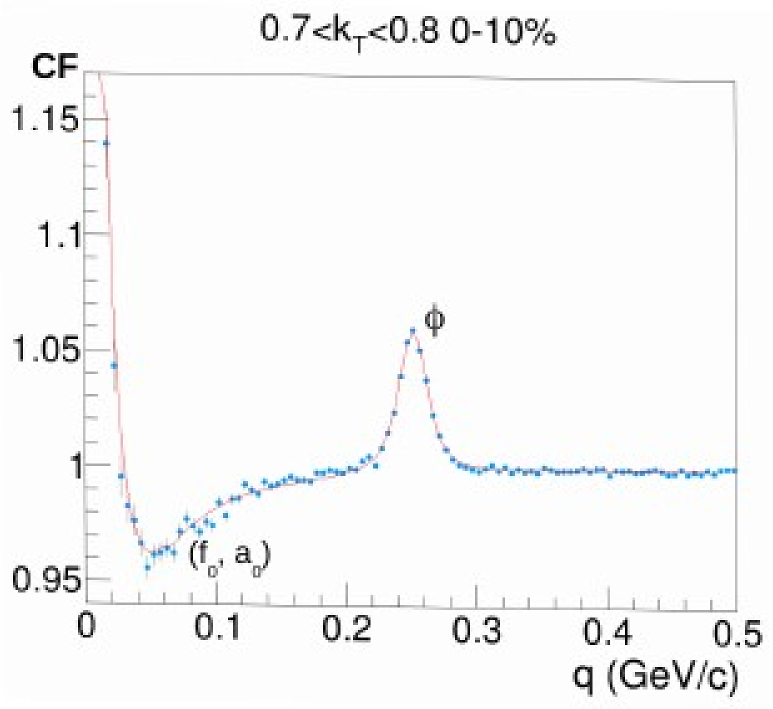
Proposed schedule and resource request for the Project / LRIP subproject

Expenditures, resources, funding sources			Cost (thousands of US dollars)/ Resource requirements	Cost/Resources, distribution by years				
				1st year	2nd year	3rd year	4th year	5th year
		International cooperation	520	110	100	100	100	110
		Materials	600	120	120	120	120	120
Sources of funding	**JINR Budget**	JINR budget *(budget items)*	1120	230	220	220	220	230

Thank you for your attention

Backup

The correlation function C(q) for K^+K^- pairs was checked with the Lednický-Lyuboshits model using the formula $C(q)=1+\lambda\left(C^{FSI}_{a_0,f_0}(q,R)+C_\phi(q,R)\right)$ for fitting of the data (in the figure), where q = (p1-p2), p1 and p2 are the 4-momenta of kaons, C^{FSI} is the correlation function in the model for influence of the final state interaction through the a_0 and f_0 resonances, C_ϕ – convolution of the Gaussian and Breit-Wigner functions for ϕ meson production, R is the kaon emission source radius, λ is the correlation strength.



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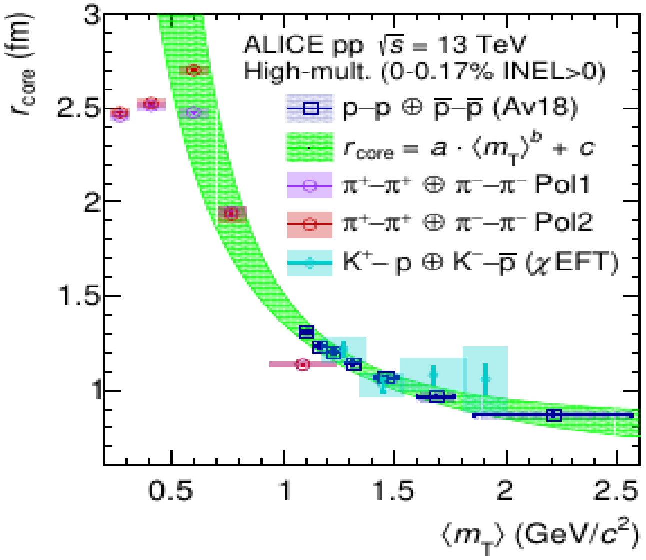
The femtoscopic correlations study. Plans for 2026-2030 years.



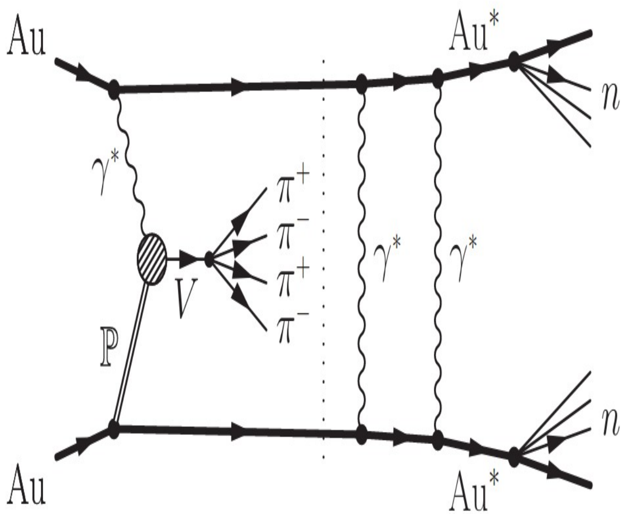
It t can be seen from the figure that the assumed universality holds except for r_{cor} values for pairs of identical pions at the smallest m_T. The reason for this, according to the authors, is related to some properties of the hypersurface of the hadronization source. One can see also that there is 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.

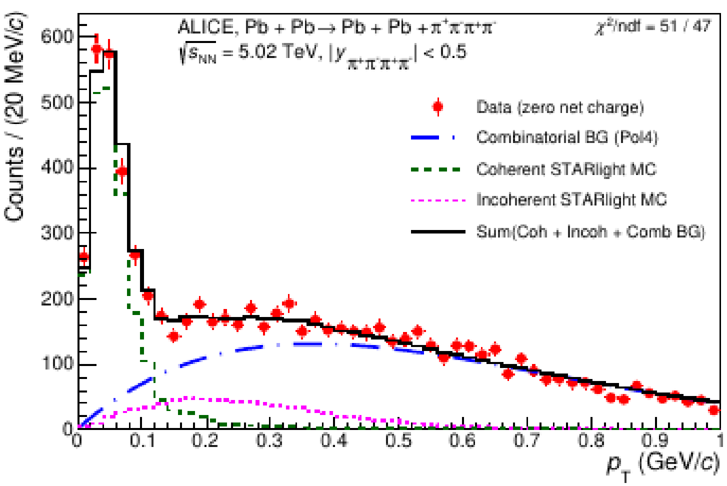
In the process of four pions coherent photoproduction through the vector meson decays in the UPC

The vector mesons interact with whole nucleus through pomeron exchange as it's shown by the diagram

in the left figure. The coherent process is selected with the transverse momentum of four pions

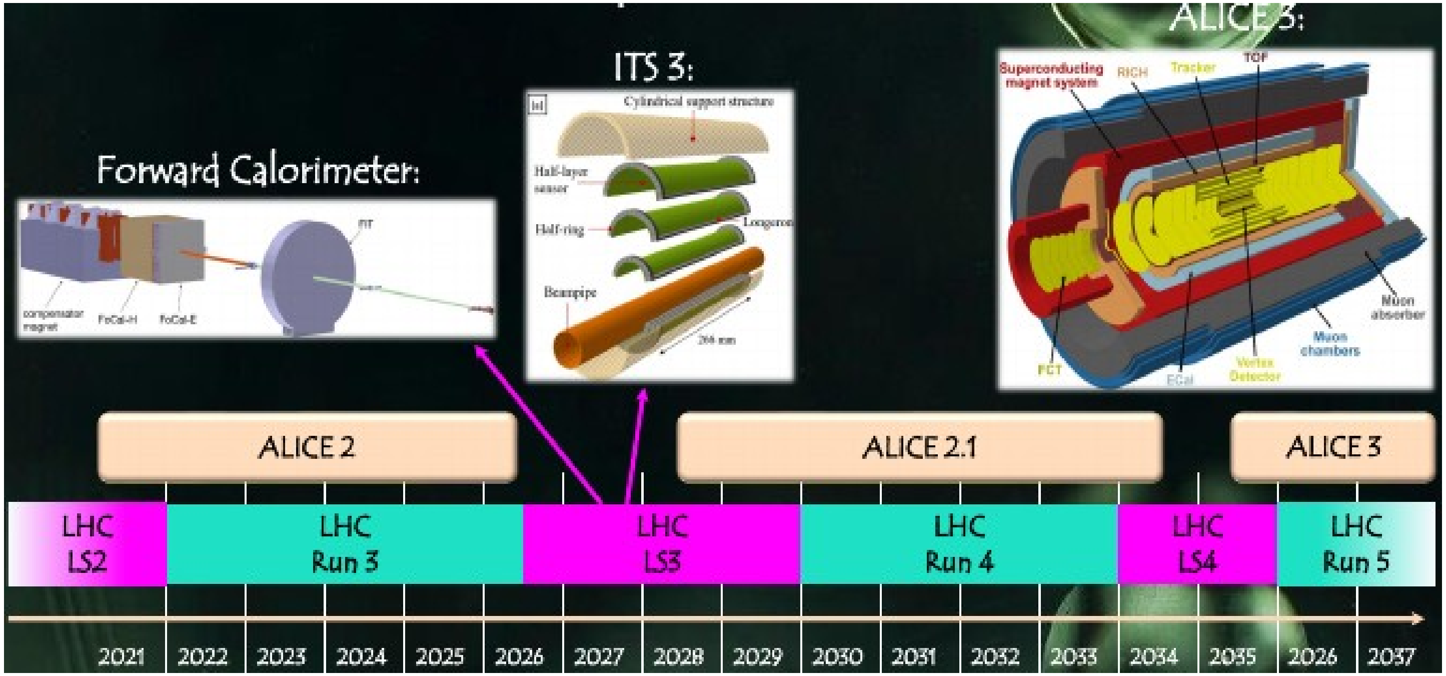
$p_T(4\pi) < 0.15$ GeV/c according a prediction of STARlight model as it is seen in the right figure.





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 (O.Teryaev, R.Usubov, arXiv:1406.4451). 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.

ALICE plans



ALICE 3:
ITS 3:
Cylindrical support structure
Half-layer sensor
Half-ring
Longeron
Beampipe
Forward Calorimeter:
compensator magnet
FoCal-H
FoCal-E
FIT
Superconducting magnet system
RICH
Tracker
TOF
Muon absorber
Muon chambers
Vertex Detector
ECal
FCT
ALICE 2
ALICE 2.1
ALICE 3
LHC LS2
LHC Run 3
LHC LS3
LHC Run 4
LHC LS4
LHC Run 5
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2026
2037