ALICE-JINR annual report
(The Project was approved for 2020-2023 years.)

E.P. Rogochaya

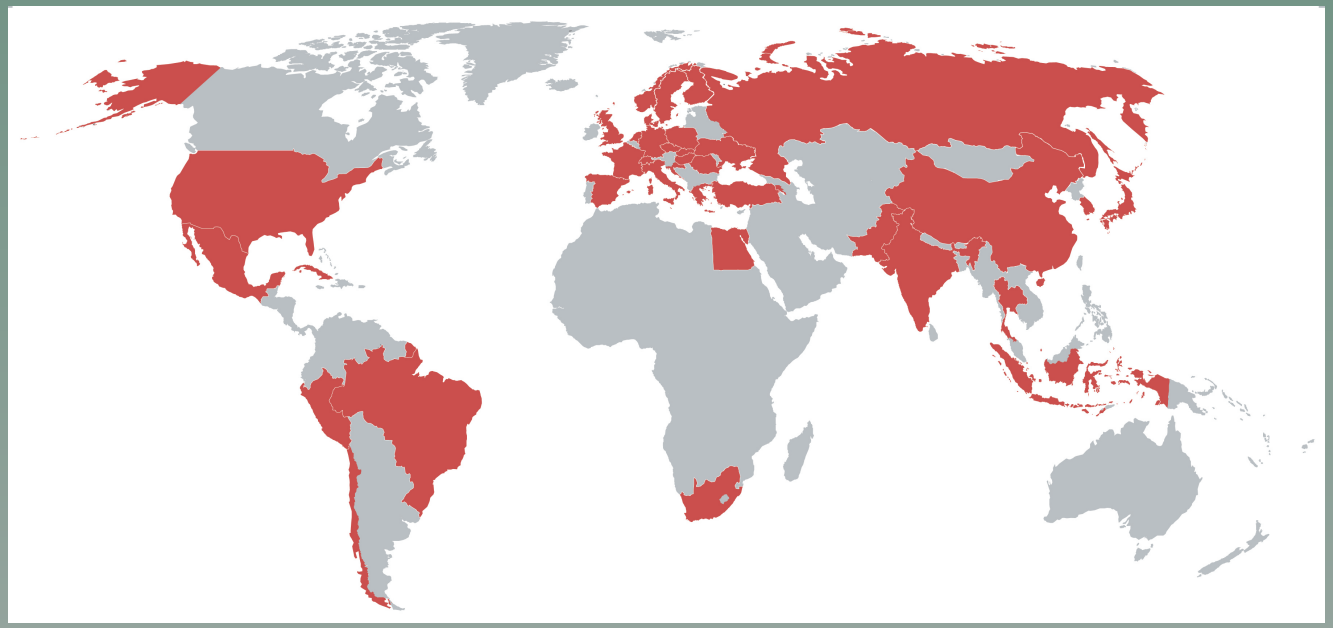
JINR, Dubna, Russia

February 3, 2020

Outline

- JINR group in ALICE
- Main published results
- Femtoscopy
  - 1D K^+K^- correlation analysis in Pb-Pb@2.76 TeV
  - 1D $K^\pm K^\pm$ correlation analysis in pp@13 TeV
  - 3D $K^\pm K^\pm$ correlation analysis in Pb-Pb@5.02 TeV
  - 3D $K^\pm K^\pm$ correlation analysis in p-Pb@2.76 TeV
- Ultra-peripheral collisions
  - ρ^0 photoproduction in Pb-Pb@5.02 TeV
  - ρ^0 photoproduction in p-Pb@5.02 TeV
  - $\rho^0(\pi^+\pi^-\pi^+\pi^-)$ photoproduction in Pb-Pb@5.02 TeV
- Thermal model of particle production in pp and A-A collisions
- ALICE GRID status
- R&D upgrade of ALICE PHOS
- List of publications, conferences and other activities
- Conclusion and plans for future

ALICE Collaboration

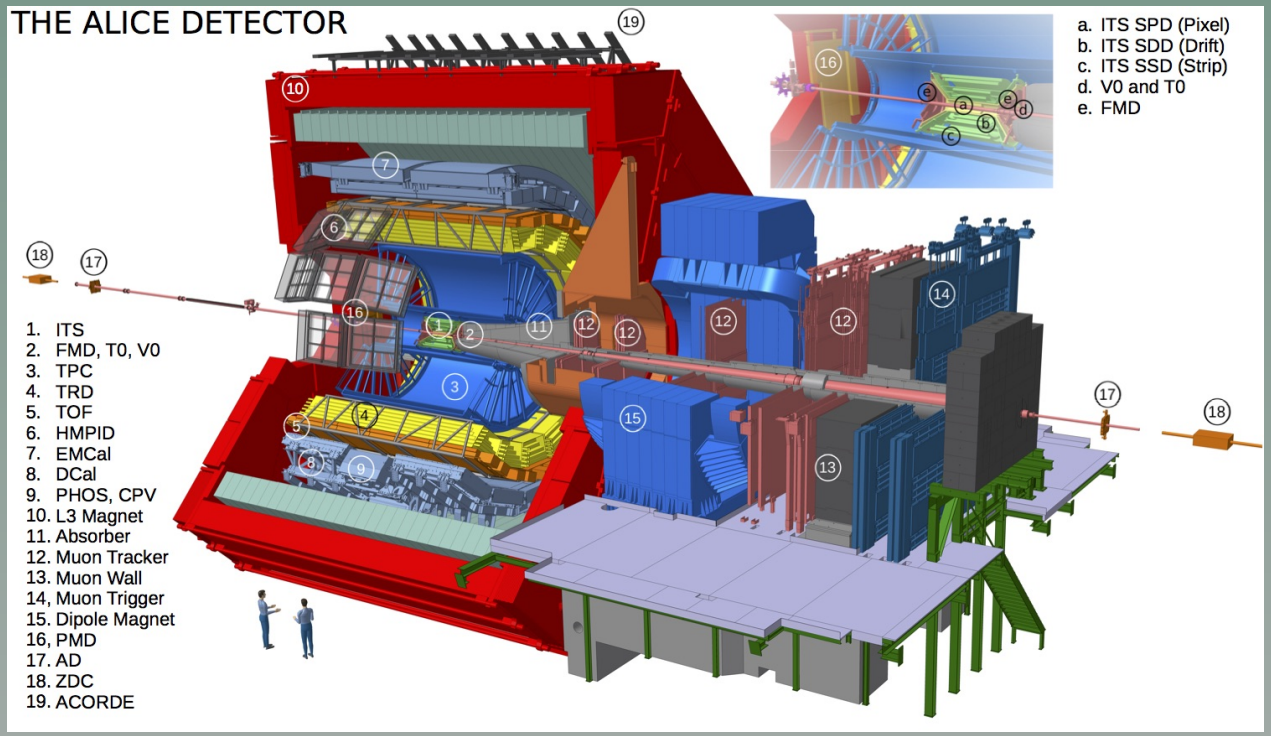


41 countries, 176 institutes, 1800 members

JINR-ALICE group:

- 11 physicists including 3 PhD students
- 1 undergraduate student
- 1 expert on the ROOT software and GRID computing management

ALICE setup

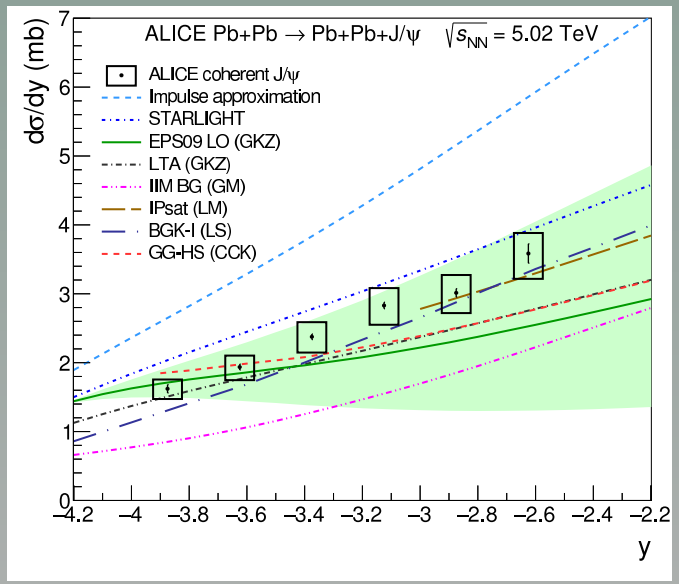


- Tracking and vertex:
  - Time Projection Chamber - **TPC**
  - Inner Tracking System - **ITS**
  - Muon Forward Spectrometer - **MUON ARM** (absorber, dipole magnet, tracking chambers, muon filter, trigger chambers)
- Particle identification:
  - **TPC**
  - Time-of-Flight - **TOF**
- Centrality determination or veto:
  - **V0**
- Zero Degree Calorimeter - **ZDC**
- Veto:
  - ALICE Diffractive - **AD**

Publications with main participation of JINR-ALICE group

1. "One-dimensional charged kaon femtoscopy in p-Pb collisions at $\sqrt{s_{\rm NN}}$=5.02 TeV" [S. Acharya et al. (ALICE Collaboration), Phys. Rev. C100 (2019) 024002]
2. "Coherent J/ψ photoproduction at forward rapidity in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV" [S. Acharya et al. (ALICE Collaboration), Phys. Lett. B798 (2019) 134926]

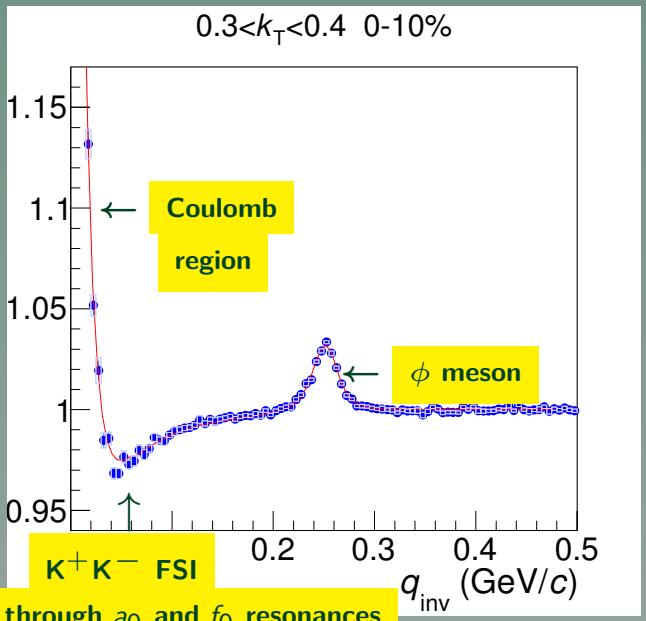
Coherent differential cross section of J/ψ photoproduction in comparison with different model predictions at different gluon shadowing in nuclei contributions (the moderate one is the best):

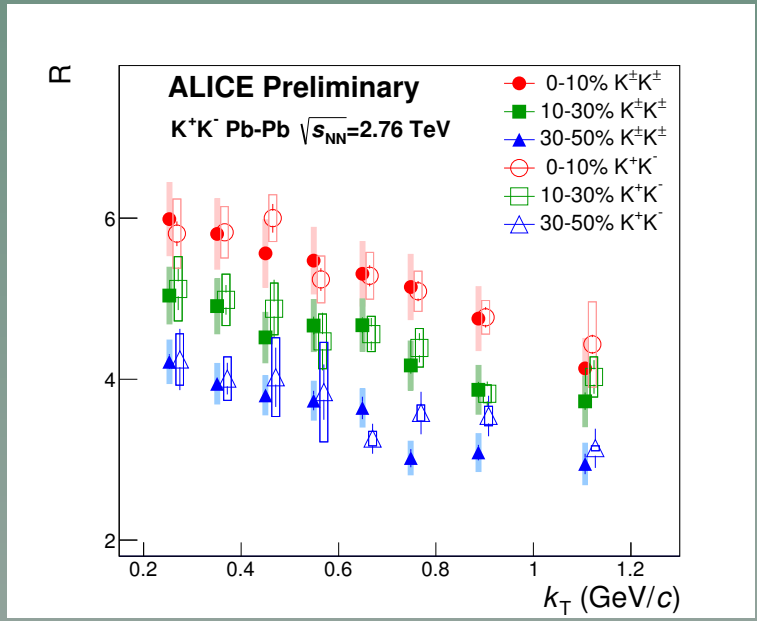


Presented in a plenary talk at Quark Matter 2019.

Femtoscopy: K^+K^- correlations in Pb-Pb at 2.76 TeV

Main performer: K. Mikhaylov (ITEP, JINR)





- **Correlation function:**
  $C(q_{\rm inv}) = (1 + \lambda C_{\rm sFSI}(q_{\rm inv}, R) + (N_1 C_{\phi-{\rm direct}}(q_{\rm inv}, M_\phi) + N_2 C_{\phi-{\rm FSI}}(q_{\rm inv}))) P(q_{\rm inv})$,
  λ - correlation strength, R - radius, $C_{\rm sFSI}$ - [R. Lednicky, V.L. Lyuboshits, Sov. J. Nucl. Phys. 35 (1982) 770, Yad. Fiz. 35 (1981) 1316-1330], $C_{\phi-{\rm direct}}$ - non-relativistic Breit-Wigner function, $C_{\phi-{\rm FSI}}$ - [R. Lednicky, Phys. Part. Nucl. Lett. 8 (2011) 965], N_1 and N_2 - fractions of directly and FSI produced ϕ, P - non-femto effects (resonance decays and fragmentation of mini-jets from low momentum-transfer scattering).
- $a_0(980)$ mass and width taken from [N.N. Achasov, V.V. Gubin, Phys. Rev. D63 (2001) 094007] and fixed due to [ALICE, Phys. Lett. B774 (2017) 64].
- Obtained parameters of $f_0(980)$: mass ($972 \pm 3 \pm 5$ MeV/c^2) and width ($39.7 \pm 7.94 \pm 11.8$ MeV) coincide with the PDG values.

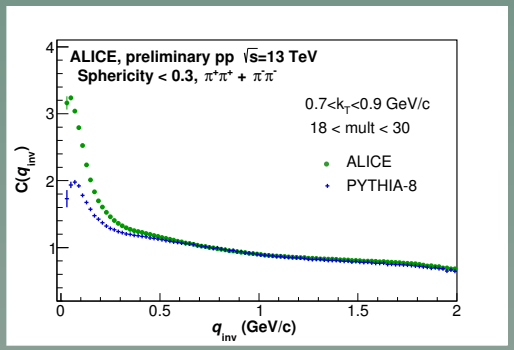
The results were reported at the GDRI2019 (Nantes, France) and the WPCF2019 (Dubna) by K. Mikhaylov.

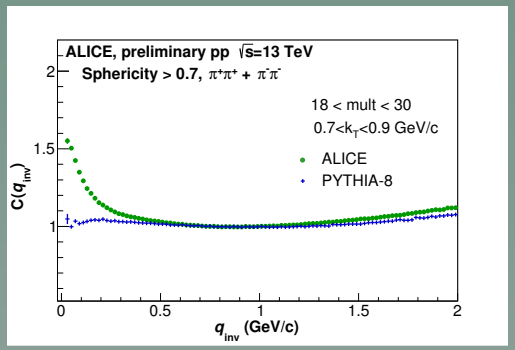
Femtoscopy: $K^{\pm}K^{\pm}$ correlations in pp at 13 TeV

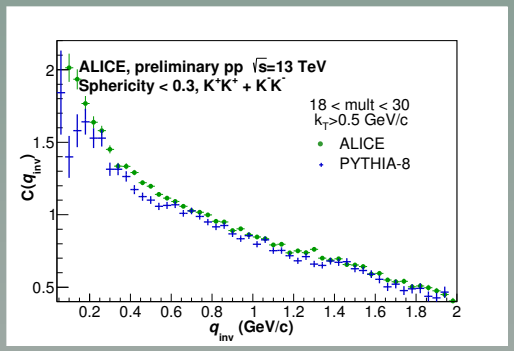
Main performer: L. Malinina (SINP MSU, JINR)

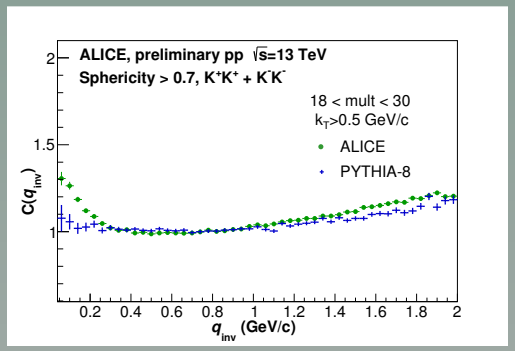
Correlation function: $C(q_{\rm inv}) = \left((1-\lambda) + \lambda K(q_{\rm inv})\left(1 + e^{-R_{\rm inv}^n q_{\rm inv}^n}\right)\right) P(q_{\rm inv})$,

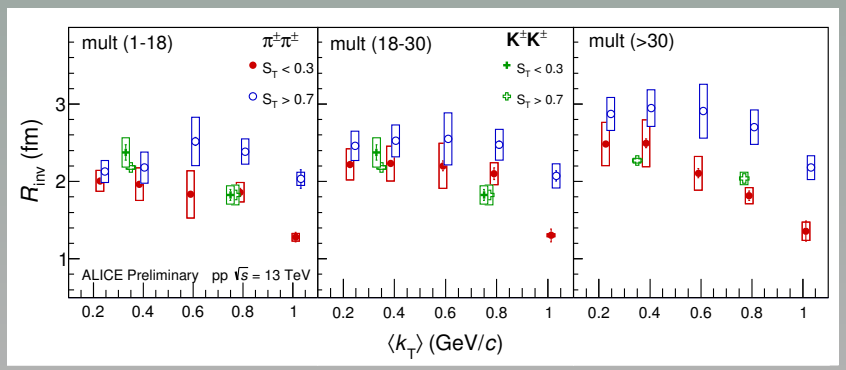
λ - correlation strength, R - radius, K - Coulomb interaction, P - non-femto effects, $n = 1$ - π, $n = 2$ - K











- Events selected according to their **transverse sphericity** [ALICE, JHEP 1909 (2019) 108], which can differentiate between jet-like (hard) and spherical (soft) event topologies.
- PYTHIA-8 - [P. Skands et al., Eur. Phys. J. C74 (2014) no.8, 3024].
- Baseline is flatter for spherical events (Sphericity>0.7) $\rightarrow$ mini-jet background is reduced $\rightarrow$ radii can be determined in a model-independent way w/o correction for a baseline.
- Jet-like pion $R_{\rm inv}$ are less than spherical ones, especially with increasing multiplicity.
- Jet-like kaon $R_{\rm inv}$ coincide with spherical ones within errors.
  Reported at CERN femtoscopy meetings by L. Malinina. Analysis is ongoing.

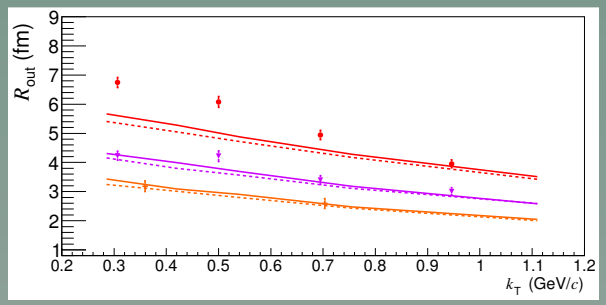
Femtoscopy: $K^{\pm}K^{\pm}$ correlations in Pb-Pb at 5.02 TeV

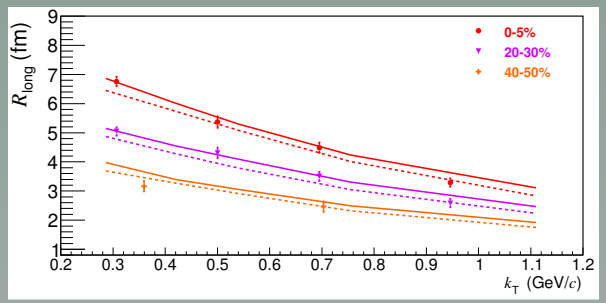
Main performers: L. Malinina (SINP MSU, JINR) - supervisor, G. Romanenko (SINP MSU) - undergraduate student

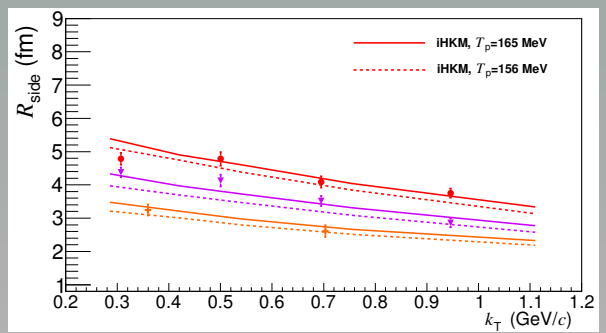
$C(\boldsymbol{q}) = \left((1-\lambda) + \lambda K(q_{\text{inv}}) \left[1 + \exp\left(-R^2_{\text{out}} q^2_{\text{out}} - R^2_{\text{side}} q^2_{\text{side}} - R^2_{\text{long}} q^2_{\text{long}}\right)\right]\right) P(\boldsymbol{q})$,

$R = (R_{\text{out}}, R_{\text{side}}, R_{\text{long}})$ - size of the source, $\boldsymbol{q} = (q_{\text{out}}, q_{\text{side}}, q_{\text{long}})$ - pair relative momentum,

λ - correlation strength, K - Coulomb interaction, P - non-femto effects







- iHKM - integrated hydrokinetic model [V.M. Shapoval, Yu.M. Sinyukov, Phys. Rev. C100 (2019) no.4, 044905].
- Radii decrease with increasing k_{T} and for more peripheral collisions.
- iHKM calculation at the particlization/hadronization temperature $T_{\text{p}} = 165$ MeV gives the best (though not perfect) description of the experimental data.
- Much more Pb-Pb@5.02 TeV data than previous Pb-Pb@2.76 TeV ones [ALICE, Phys. Rev. C96 (2017) no.6, 064613] $\rightarrow$ more detailed 3D analysis and comparison with p-Pb data at low multiplicities.

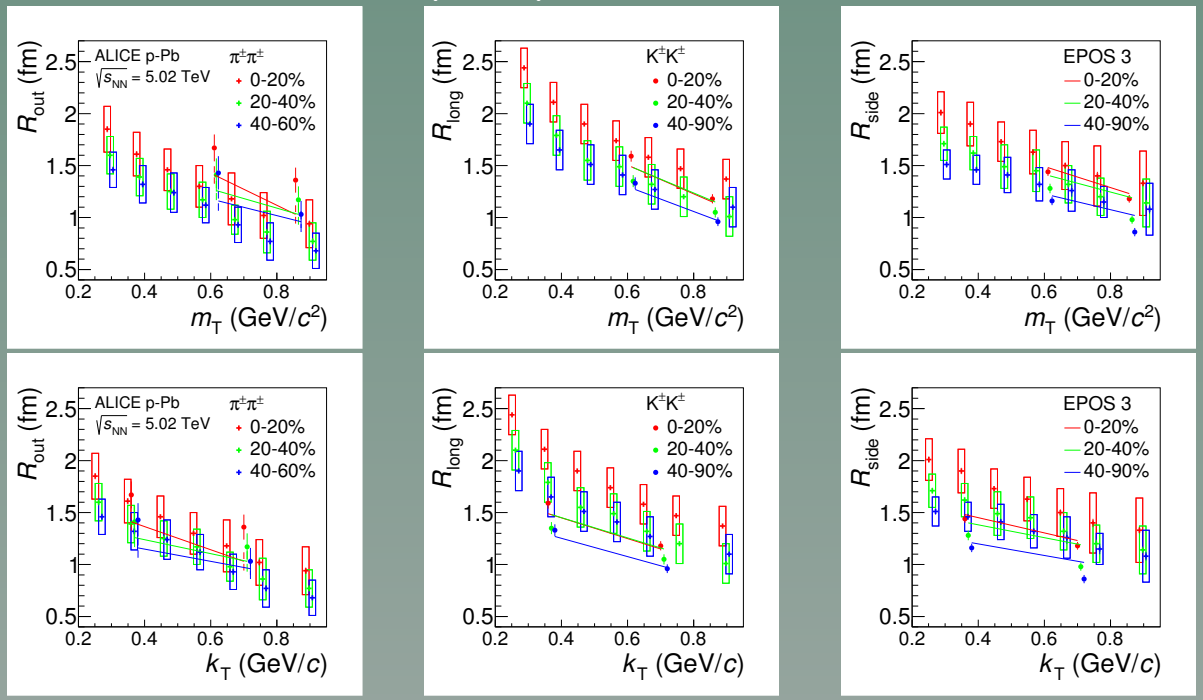
Presented by G. Romanenko at Oslo Winter School "Standard Model, Quantum Chromodynamics, Heavy Ion Collisions", Skeikampen, Norway.

Bachelor's degree on "Femtoscopy analysis of the correlations of identical kaons in Pb-Pb collisions at 5.02 TeV measured in the ALICE experiment at the Large Hadron Collider".

Analysis is ongoing.

Femtoscopy: $K^{\pm}K^{\pm}$ correlations in p-Pb at 5.02 TeV

Main performer: E. Rogochaya (JINR)



- EPOS 3 - [K. Werner et al., Phys. Rev. C89 (2014) no.6, 064903].
- k_T- **or** m_T**-scaling?** According to hydrodynamic models [V.M. Shapoval et al., Nucl. Phys. A929 (2014) 1-8], the latter means that the thermal freeze-out occurs simultaneously for pions and kaons. In 3D $K^{\pm}K^{\pm}$ femtoscopic analysis in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV [ALICE, Phys. Rev. C 96 (2017) 064613] k_T-scaling was observed.
- **3D EPOS 3 results are different from the experimental radii** though 1D EPOS 3 radii were in good agreement with experimental data [ALICE, Phys. Rev. C100 (2019) 024002].

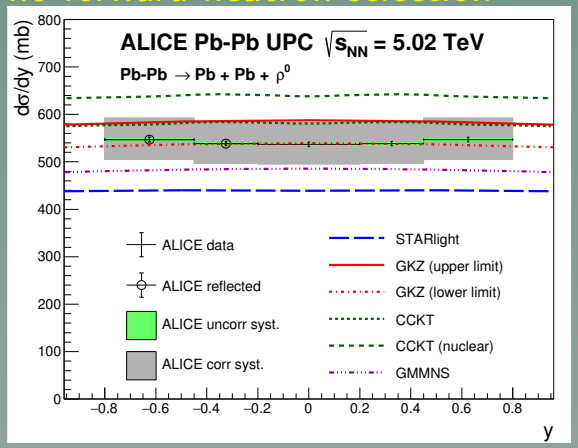
Reported at CERN femtoscopy meetings by E. Rogochaya. Analysis is ongoing.

Ultra-peripheral collisions: $\rho(770)^0$ coherent photoproduction in Pb-Pb at 5.02 TeV

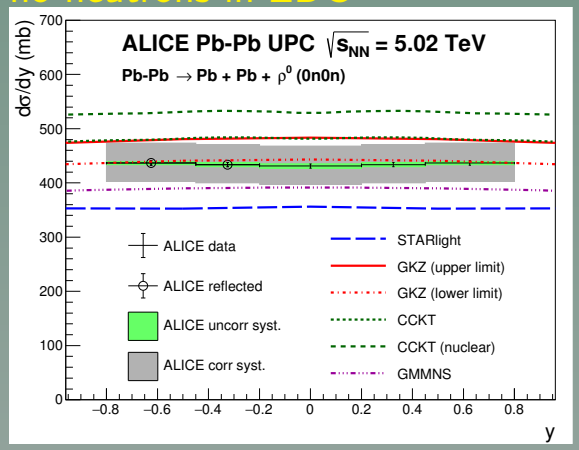
Main performer: V. Pozdnyakov (JINR)

Cross section of $\rho(770)^0$ coherent photoproduction as a function of rapidity:

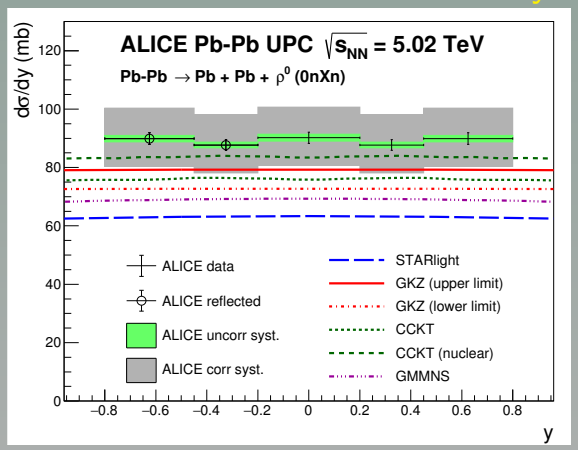
no forward-neutron selection



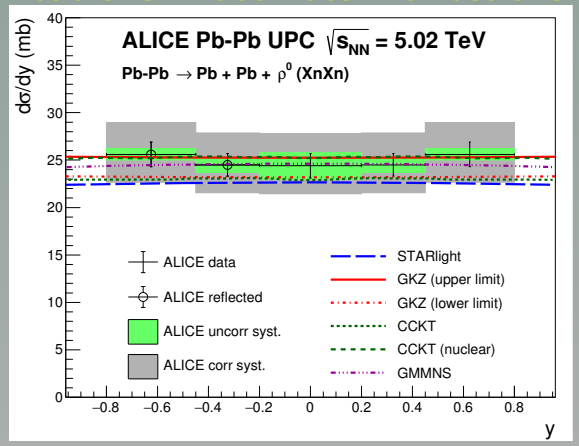
no neutrons in ZDC



neutrons on one beam side only



neutrons in both beam directions



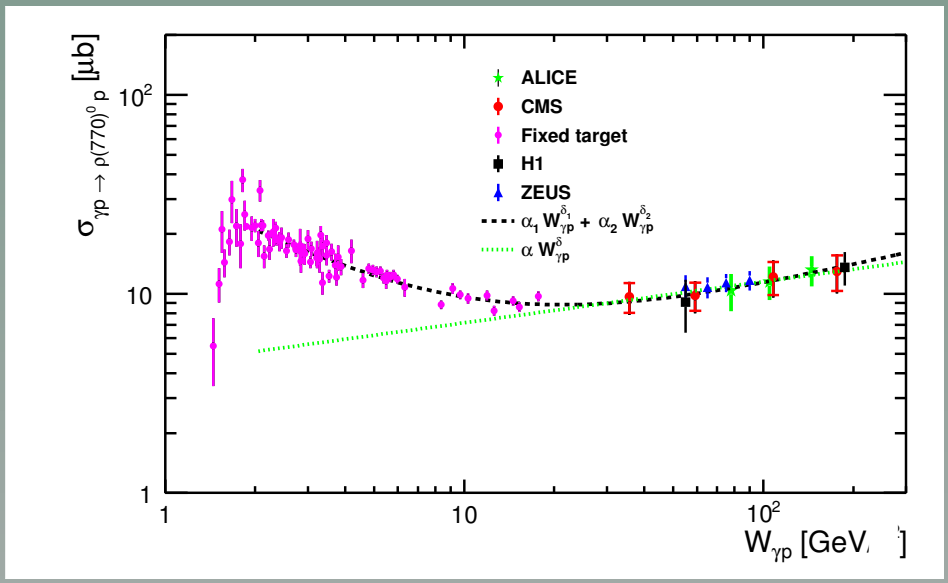
- STARlight [Phys. Rev. C60 (1999) 014903; Comput. Phys. Commun. 212 (2017) 258]
- GKZ [Phys. Lett. B752 (2016) 51]
- CCKT [Phys. Lett. B766 (2017) 186; Nucl. Phys. B934 (2018) 330; N. Armesto, Eur. Phys. J. C26 (2002) 35]
- GMMNS [Phys. Rev. D96 no. 9, (2017) 094027; Phys. Lett. B590 (2004) 199]
- The points at negative rapidities are a reflection of those at positive rapidities.
- **First measurement of the ρ^0 coherent production cross section under different ZDC scenarios in Pb-Pb at 5.02 TeV.**
- All model results agree with the data within errors.

Draft publication is under consideration in ALICE at Round 1 at the moment.

Ultra-peripheral collisions: $\rho(770)^0$ photoproduction in p-Pb at 5.02 TeV

Main performers: V. Pozdnyakov (JINR), Yu. Vertogradova (JINR)

Exclusive $\rho(770)^0$ photoproduction cross section as a function of the invariant energy $W_{\gamma p}$



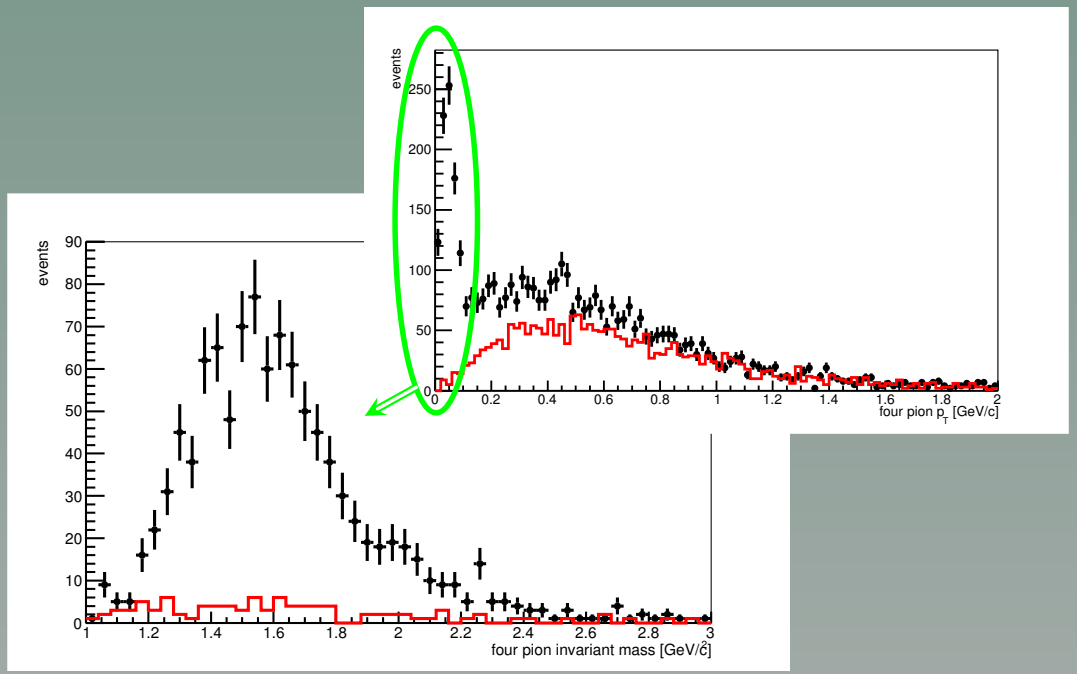
- The obtained results complement the existing data.

- Simpler to analyze than Pb-Pb since there are only events of photoproduction on a single proton which is not influenced by strong interactions with other nucleons when it is a part of a nucleus.
- Previous ALICE paper on J/ψ photoproduction [Phys. Rev. Lett. 113 (2014) no.23, 232504]
- CMS - [Eur. Phys. J. C79 (2019) no.8, 702]
- Fixed target - [E665, Z. Phys. C74 (1997) 237-261; D.G. Cassel et al., Phys. Rev. D24 (1981) 2787; CLAS, Phys. Lett. B605 (2005) 256; CLAS, Eur. Phys. J. A39 (2009) 5]
- H1 - [Nucl. Phys. B463 (1996) 3-32]
- ZEUS - [Eur. Phys. J. C2 (1998) 247-267]
- **Black dashed line** - Regge asymptotics to fit all plotted data.
- **Green dotted line** - Regge asymptotics to fit HERA and CMS data.

Reported at CERN UPC meetings by V. Pozdnyakov. Analysis is ongoing.

Ultra-peripheral collisions: $\pi^+\pi^-\pi^+\pi^-$ coherent photoproduction in Pb-Pb at 5.02 TeV

Main performers: V. Pozdnyakov (JINR) - supervisor, B. Rumyantsev (JINR) - PhD student



- Aims to precise parameters of excited $\rho(1540)^0$ and/or $\rho(1700)^0$ $\rightarrow \pi^+\pi^-\pi^+\pi^-$ states.
- The nature of these states is still an open question.
- Coherent photoproduction of a resonance-like object with mass around 1540 MeV/c^2 reported in [STAR, Phys. Rev. C81 (2010) 044901].
- The $\pi^+\pi^-\pi^+\pi^-$ invariant mass spectrum (**signal** and **background**) exhibits a broad peak around 1540 MeV/c^2 with a width about 500 MeV/c^2. Will be precised after corrections for detector acceptance and efficiency.
- This measurement will extend the existing four-pion photoproduction data to higher photon energies (references in the STAR paper).

Reported at CERN UPC meetings by B. Rumyantsev. Analysis is ongoing.

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

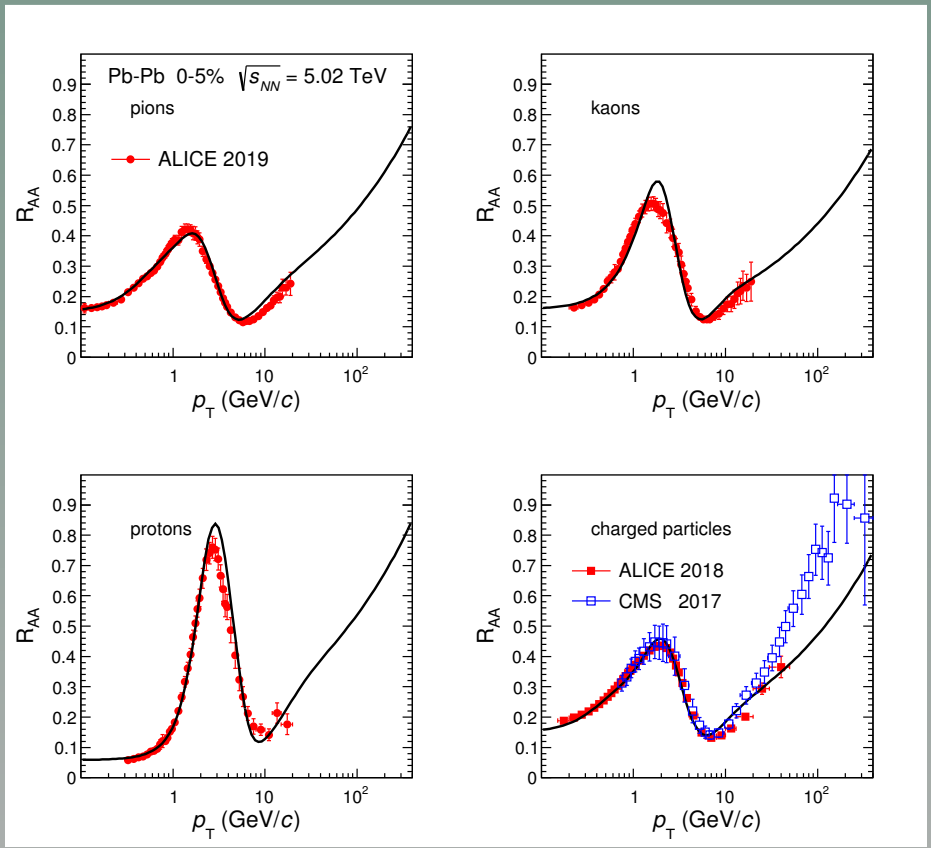
Main performer: S. Grigoryan (JINR)

- Low and medium transverse momentum p_{T} parts of particle spectra are described by two Boltzmann-Gibbs thermal distributions.
- Transverse flow effects - via the blast wave model.
- Low and high p_{T} parts of the spectra - by two power-law (Tsallis) distributions.

Comparison of the model calculations for the **nuclear modification factor**

$$R_{\mathrm{AA}} = \frac{Y^{\mathrm{Pb-Pb}}}{< T_{\mathrm{AA}} > \sigma^{\mathrm{pp}}},$$

where $Y^{\mathrm{Pb-Pb}}$ - particle yield per event in Pb-Pb, T_{AA} - nuclear overlap function, σ^{pp} - cross section in pp collisions with the ALICE [ALICE, arXiv:1910.07678 [nucl-ex]; JHEP 1811 (2018) 013] and CMS [CMS, JHEP 1704 (2017) 039] data at mid-rapidity

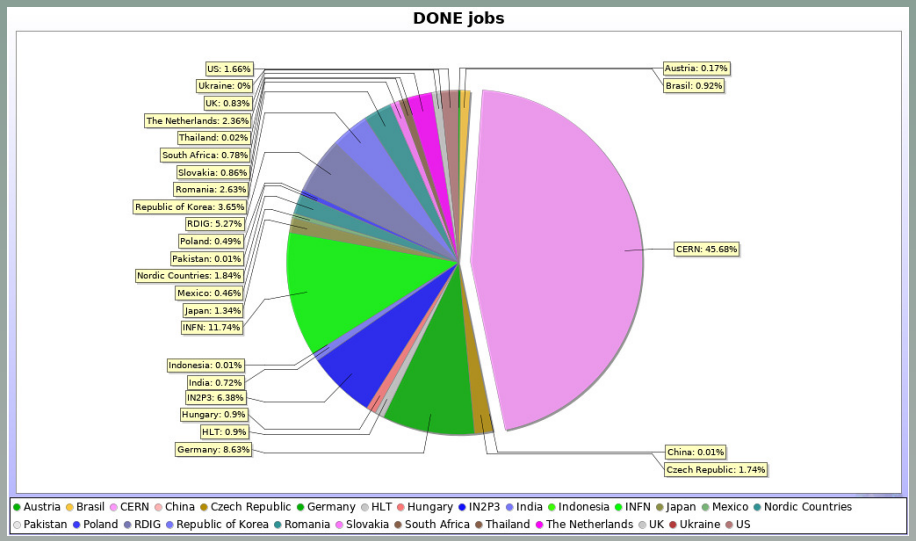


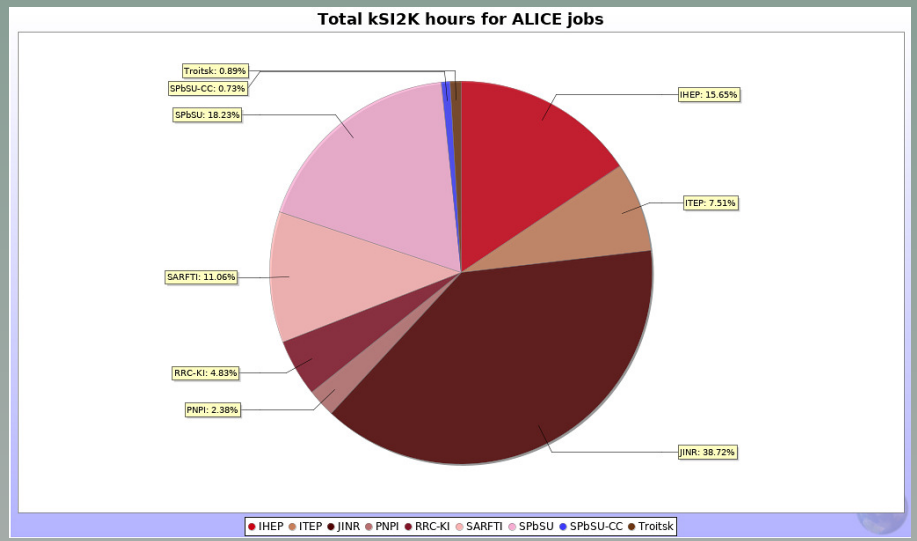
Modification of the previous model [S. Grigoryan, Phys. Rev. D95 (2017) 056021] describing pp collisions to include A-A collisions. Work is ongoing.

GRID activity of JINR

Main performer: G. Stiforov (JINR)
Responsible of the JINR segment in the Russian ALICE GRID , i.e. monitoring, administration, technical support, etc.

- ALICE GRID: $\sim$ 128000 cores, 68 centers: T0 - 1 (CERN), T1 - 8, T2 - 59
- JINR ALICE GRID - T2 (T1 - for JINR CMS)
- JINR ALICE GRID is a part of nine Russian ALICE GRID centers
- Total RDIG CPU time consumed by ALICE jobs was 16%
- JINR GRID Farm (9600 cores CPU, 663 Tb Disk-SE)





RDIG contribution to the ALICE GRID is 5.27%

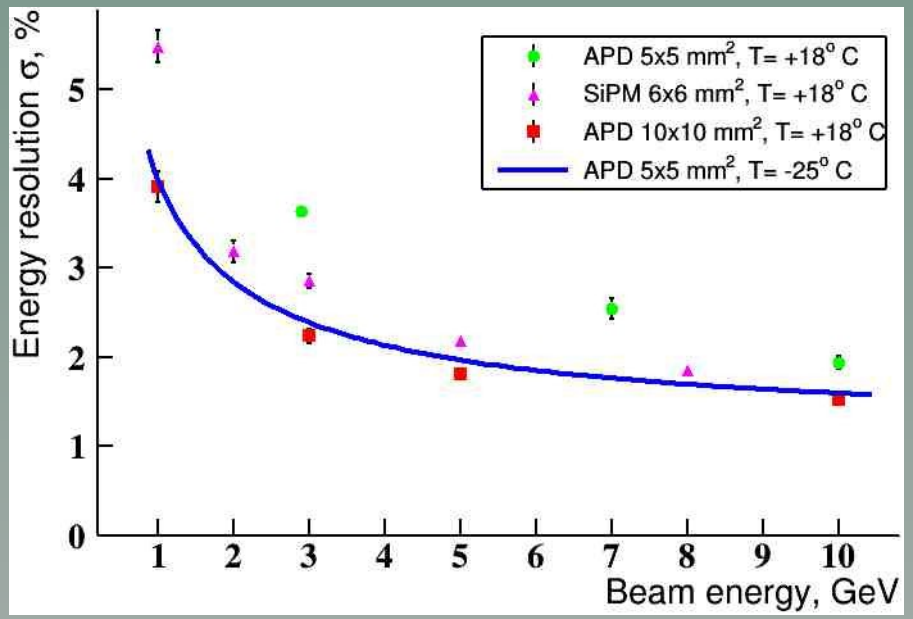
JINR contribution to RDIG is 38.72%

Reported at "Operations and plans - RDIG", G. Stiforov (JINR), A. Zarochentsev (SPbSU), T1/T2 Workshop 2019, Bucharest, Romania.

R&D for the ALICE PHOton Spectrometer upgrade

The main result obtained during previous investigations (2017-2018) of various photodetectors, avalanche photodiodes (APD) of two different sizes and silicon photomultipliers (SiPM) is:
The optimal characteristics were achieved for the APD of 10x10 mm size (left) with the best energy (right) and good time (better than 500 ps) resolutions at room temperature.

APD glued into the support frame.



Energy resolution versus electron beam energy for different types of photodetectors.

The plan for 2020 is to continue the work on development of a pre-production sample of the 32-channel signal reading card, which was started in 2019. The results will be presented at the end of this Project (2019-2020).

List of publications

1. "p-p, p-Λ and Λ-Λ correlations studied via femtoscopy in pp reactions at $\sqrt{s} = 7$ TeV", ALICE Collaboration (S. Acharya et al.), Phys. Rev. C99 (2019) no.2, 024001, arXiv:1805.12455 [nucl-ex]
2. "Measuring $K^0_S K^{\pm}$ interactions using pp collisions at $\sqrt{s} = 7$ TeV", ALICE Collaboration (S. Acharya et al.), Phys. Lett. B790 (2019) 22-34, arXiv:1809.07899 [nucl-ex]
3. "Measurement of strange baryon-antibaryon interactions with femtoscopic correlations", ALICE Collaboration (S. Acharya et al.), 2019, arXiv:1903.06149 [nucl-ex]
4. "Study of the Λ-Λ interaction with femtoscopy correlations in pp and p-Pb collisions at the LHC", ALICE Collaboration (S. Acharya et al.), 2019, Phys. Lett. B797 (2019) 134822, arXiv:1905.07209 [nucl-ex]
5. "Scattering studies with low-energy kaon-proton femtoscopy in proton-proton collisions at the LHC", ALICE Collaboration (S. Acharya et al.), 2019, arXiv:1905.13470 [nucl-ex]
6. "Investigation of the p-Σ^0 interaction via femtoscopy in pp collisions", ALICE Collaboration (S. Acharya et al.), 2019, arXiv:1910.14407 [nucl-ex]
7. "Event-shape and multiplicity dependence of freeze-out radii in pp collisions at $\sqrt{s} = 7$ TeV", ALICE Collaboration (S. Acharya et al.), JHEP 1909 (2019) 108, arXiv:1901.05518 [nucl-ex]
8. "Interaction technology of jAliEn client and ALICE central services", V.V. Korenkov, A.O. Kondratyev, A.S. Bondyakov, Modern Information Technology and IT-education, ISSN 2411-1473, V. 15 (2019) no.3, 573-585.

Conferences in 2019

1. "K^+K^- correlations in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV by the ALICE at the LHC", K. Mikhaylov (ITEP, JINR), XIV Workshop on Particle Correlations and Femtoscopy, Dubna, Russia

2. "Operations and plans - RDIG", G. Stiforov (JINR), A. Zarochentsev (SPbSU), T1/T2 Workshop 2019, Bucharest, Romania

3. "Non-identical kaon femtoscopy", K. Mikhaylov (ITEP, JINR), The GDRI 2019 - International Research Network Meeting, Subatech, Nantes, France

4. "Vector meson photoproduction in ultra-peripheral Pb-Pb collisions with ALICE at $\sqrt{s_{\rm NN}} = 5.02$ TeV", V. Pozdnyakov (JINR), LC2019 - QCD on the light cone: from hadrons to heavy ions, Ecole Polytechnique, Palaiseau, France

5. "Femtoscopy correlation analysis of identical kaons in Pb-Pb collisions at 5.02 TeV measured in ALICE at the LHC", G. Romanenko (SINP MSU), Oslo Winter School "Standard Model, Quantum Chromodynamics, Heavy Ion Collisions", 30 December 2019 to 12 January 2020, Skeikampen, Norway

Other activities

L. Malinina (SINP MSU, JINR) was elected as one of the two ALICE conveners of the Femtoscopy Analysis Team for general guidance of works in this field.

E. Rogochaya (JINR) is a member of the Analysis Review Committee of two ALICE analyses:

1. "p-Σ^0 femtoscopy in high multiplicity pp collisions at $\sqrt{s} = 13$ TeV"
2. "pp femtoscopy in pp high multiplicity reactions at 13 TeV"

and of the Inner Review Committee (IRC) - of one of the ALICE publications:

1. "First direct measurement of the p-Σ^0 interaction via femtoscopy in high multiplicity pp collisions at $\sqrt{s} = 13$ TeV", arXiv:1910.14407 [nucl-ex]

K. Mikhaylov (ITEP, JINR) is a member of the IRC of the ALICE paper:

1. "ΛK femtoscopy in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV"

G. Stiforov (JINR) takes care of software installation and configuration, as well as of administration of the ALICE computing cluster at LIT, JINR used, in particular, to generate EPOS events needed for femtoscopic analyses.

Institute reviews:

1. "Production of (anti-)^{3}He and (anti-)^{3}H in p-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV, arXiv:1910.14401 [nucl-ex]
2. "Data driven studies to constrain the Chiral Magnetic Effect in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$= 2.76 and 5.02 TeV", draft at Round 2
3. "Scattering studies with low-energy kaon-proton femtoscopy in proton-proton collisions at the LHC", arXiv:1905.13470 [nucl-ex]

Conclusion and plans for 2020

Conclusion:

- JINR-ALICE group carries out successfully the physics analysis of the experimental data. The obtained results were reported at international conferences and two of them were published in peer-reviewed journals. One paper is under preparation. Another one is at Round 1 of publication.
- RDIG contribution to the ALICE GRID and JINR contribution to RDIG increase and are now 5.27% and 38.72%, respectively.
- Development of a pre-production sample of the 32-channel signal reading card for PHOS was started.

Plans:

- Publication of results on ρ^0 coherent photoproduction in ultra-peripheral Pb-Pb collisions at 5.02 TeV.
- Paper preparation on 1D K^+K^- correlation analysis results in Pb-Pb collisions at 2.76 TeV.
- 3D femtoscopic analyses for $K^{\pm}K^{\pm}$ in p-Pb and Pb-Pb collisions at 5.02 TeV.
- 1D femtoscopic analysis for $K^{\pm}K^{\pm}$ in pp collisions at 13 TeV.
- Development of the thermal model of particle production in pp and A-A collisions.
- Analyses of ρ^0 photoproduction in ultra-peripheral p-Pb and Pb-Pb collisions at 5.02 TeV.
- ALICE GRID operation support in the JINR computing system.
- Continue to develop a pre-production sample of the 32-channel signal reading card for PHOS.

Thank you for your attention!

Longitudinally Co-Moving System

1D CF is parametrized in terms of a Gaussian correlation radius R:

$$C(\boldsymbol{q}_{\rm inv}) = 1 + \lambda e^{-R^2 \boldsymbol{q}^2_{\rm inv}},$$

where R is defined in the Pair Rest Frame. 1D analysis gives the source size averaged over all directions. Correlation strength λ represents a fraction of correlating particles emitted by independent emission sources.

3D CF:

$$C(q_{\rm out}, q_{\rm side}, q_{\rm long}) = 1 + \lambda e^{-R^2_{\rm out} q^2_{\rm out} - R^2_{\rm side} q^2_{\rm side} - R^2_{\rm long} q^2_{\rm long}},$$

where $R_{\rm out,side,long}$ is defined in the **Longitudinally Co-Moving System**:

long $\parallel$ beam direction
out $\parallel$ pair transverse momentum $k_{\rm T}$
side $\perp$ (out,long)