Measurements of the like-sign pion and kaon femtoscopic correlations at NICA energies

Outline:
• Motivation
• Correlation femtoscopy
• Pion and kaon femtoscopy at NICA energies
• Summary
Main goals

- Explore QCD phase diagram, study the Equation of State (EoS) and transport properties of the medium
- Search for the 1\textsuperscript{st}-order phase transition and critical point
- Study turn-on and turn-off signatures of sQGP

How to study

- Collisions of ions at various energies
  - BES-I and BES-II programs at RHIC
  - MPD and BM@N experiments at NICA
  - NA61/SHINE experiment at SPS
Searches for the First-order Phase Transition

- **Softening of the EoS**
  - Could be observed in the $dv_1/dy$ slope
  - Strong softening: consistent with the 1st-order phase transition
  - Weaker softening: likely due to crossover

- **Time delays of the particle emission**
  - Could be observed using femtoscopy technique

---

D.H. Rischke, M. Gyulassy. NPA 608 (1996) 479

G. Nigmatkulov et al. ICPPA-2020
Correlation Femtoscopy

- **Two-particle correlation function (CF):**
  \[
  \text{CF}(p_1, p_2) = \int d^4r \ S(r, k) |\Psi_{1,2}(r, k)|^2 \\
  r = x_1 - x_2 \text{ and } q = q_{\text{inv}} = p_1 - p_2
  \]

- **Experimentally:**
  \[
  \text{CF}(q) = \frac{A(q)}{B(q)}
  \]
  - \(A(q)\) – contain quantum statistical (QS) correlations and final state interactions (FSI)
  - \(B(q)\) – obtained via mixing technique (does not contain QS and FSI)

The relative pair momentum can be projected onto the Bertsch-Pratt, **out-side-long system:**
- \(q_{\text{long}}\) – along the beam direction
- \(q_{\text{out}}\) – along the transverse momentum of the pair
- \(q_{\text{side}}\) – perpendicular to longitudinal and outward directions

Correlation functions are constructed in Longitudinally Co-Moving System (LCMS), where \(p_{1z} + p_{2z} = 0\)

S. Pratt. PRD 33 (1986) 1314

G. Nigmatkulov et al. ICPPA-2020
Why Correlation Femtoscopy?

- Access to the spatial and temporal information about a particle-emitting source at kinetic freeze-out

- Different particle species are sensitive to various effects (Final State Interactions (FSI), transport properties, asymmetries, etc...)

- Strong model constraints

V.M. Shapoval et al. NPA 968 (2017) 391
D.H. Rischke, M. Gyulassy. NPA 608 (1996) 479

S. Pratt et al. PRL 114 (2015) 202301
Femtoscopy: World Systematics

- Precise measurements in a broad energy range (from 7.7 GeV to 2.76 TeV)
- Need more high-statistics measurements at low energies
- Precise measurements exist only with pions
  - Need heavier particles
Femtoscopy with Strange Particles

- Contain strange (anti)quark
- Enhancement of strange particle yields was one of the first suggested signatures of QGP

J. Rafelski and B. Muller. PRL 48 (1982) 1066

- Interesting behaviour was observed in K/π ratios at NICA energies
- Could be sensitive to different production mechanisms at low collision energies

We would like to explore the quark-gluon matter at NICA/FAIR/RHIC energies using femtoscopy technique

This talk is dedicated to the study with the UrQMD model (hadron gas assumption)
Correlation Functions

• Examples of the correlation functions of pions and kaons obtained for Au+Au collisions at $\sqrt{s_{NN}}=11.5$ GeV

• Correlation functions were fitted with:

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

Where:

$R_{side}$ – size of the emission region

$R_{out}$ – sensitive to the emission duration

$R_{long}$ – proportional to the system lifetime

|q_{other}| < 0.05 GeV/c
Femtoscopic Radii of Pions and Kaons

- Femtoscopic radii of pions decrease with increasing transverse mass
  - Influence of radial flow
- $R_{\text{side}}$ values for pions and kaons are similar
  - Similar size of the particle-emitting region
- $R_{\text{long}}$ for kaons is generally larger than that for pions at the same $m_T$
  - Influence of resonances?
- $R_{\text{out}}$ pions and kaons behave differently
  - Different emission duration?
  - Change of the production mechanism?
Energy dependence of femtoscopic radii

- Estimated radii for NICA energy range ($\sqrt{s_{NN}} = 4$-11 GeV)
- Pion radii slightly increase with increasing collision energy
- Excitation function of $R_{\text{long}}$ suggests a slight increase of the system lifetime with increasing $\sqrt{s_{NN}}$
Summary

- We performed the first model estimation of kaons femtoscopic radii using the UrQMD model.

- Pion femtoscopic radii decrease with increasing transverse momentum.

- Kaon radii dependence as a function of transverse mass show:
  - $R_{\text{side}}$ values for pions and kaons are similar.
  - $R_{\text{long}}$ for kaons is generally larger than that for pions.
  - $R_{\text{out}}$ pions and kaons behave differently.

- Energy dependence of $R_{\text{long}}$ for both pions and kaons at NICA energies suggests a slight increase of the system lifetime.