

FEMTOSCOPY: THE WAY BACK IN THE ENERGY SCALE FROM ALICE TO THE NICA ENERGIES*

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The main features of femtoscopy measurements in heavy-ion collisions at high energies are understood as a manifestation of the strong collective flow and well-interpreted within hydrodynamic models with a crossover. In this work, we discuss possibilities for observing the change from a first order phase transition expected at the NICA energies ($\sqrt{s_{NN}} = 4\text{--}11$ GeV) to a crossover one with the femtoscopy observables using the vHLL+UrQMD model.

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1. Introduction

Femtoscopy is considered to be a very useful tool to study the space-time evolution of heavy-ion collisions at the RHIC and LHC energies. ALICE has the perfect possibilities for studying the femtoscopy observables due to a good particle identification (PID), a low momentum cut-off and a good resolution of secondary vertex. It is expected that the NICA complex will have beams with a high luminosity in the energy range of $\sqrt{s_{NN}} = 4\text{--}11$ GeV. So,

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it will give a real possibility to measure unexplored and more sophisticated femtoscopy observables with a high accuracy. This fact motivated our study of the femtoscopy signatures when nuclear matter undergoes the first order phase transition that could, probably, occur at the NICA energies.

It was shown that the first order phase transition leads to a stalling of the expansion speed and an increase of the emission duration $\Delta\tau$. These effects manifest themselves as an increase of the longitudinal radius R_{long} and of the ratio of transverse femtoscopy radii $R_{\text{out}}/R_{\text{side}}$, respectively [1]. In the femtoscopy analysis performed within the RHIC Beam Energy Scan (BES) program at STAR [2], the $\sqrt{s_{NN}}$ -dependence of $R_{\text{out}}/R_{\text{side}}$ and $R_{\text{out}}^2 - R_{\text{side}}^2$ at fixed m_T (to reduce position-momentum correlations) was studied. A wide maximum near $\sqrt{s_{NN}} \sim 20$ GeV was observed. Can this wide maximum be related to the expected change of the phase transition type? A more detailed study with models allowing one to use different Equations of State (EoS) at high and low energies should be performed in order to clarify the issue. In the present study, the hybrid model vHLLE+UrQMD [3] is used. The model uses the UrQMD transport code [4] for the early and late stages of the evolution with a dissipative hydrodynamic model [5] for the hot and dense (hydrodynamic) stage of the evolution. In the fluid stage, the chiral EoS that corresponds to the crossover-like transition between quark–gluon and hadron phases along with the bag model EoS corresponding to the first order phase transition is used.

2. Results and discussion

We studied the Bose–Einstein correlations of identical pions at the collision energy range of $\sqrt{s_{NN}} = 7\text{--}11$ GeV, which is covered by NICA and overlaps with the BES program at STAR. The latter helps us to make a comparison with existing experimental data. It was demonstrated that the model reasonably describes particle yields, spectra and femtoscopy radii in this energy range [6].

Time distributions obtained with the vHLLE+UrQMD model (Fig. 1) demonstrate that the hydro phase lasts longer at the first order phase transition, especially at low energies. Cascade smears strongly this difference, but, nevertheless, it remains visible. The possibility of observing the difference using femtoscopy techniques are studied.

The PHENIX and STAR collaborations have recently started to apply a new “imaging technique” in order to extract a $S(r^*)$ -source function, which represents a time-integrated distribution of the particle emission points separation r^* in the pair rest frame (PRF) [7]. The large times of emission corresponding to the first order phase transition (Fig. 1) are “located” in the long tails of the non-Gaussian source function and are not taken into

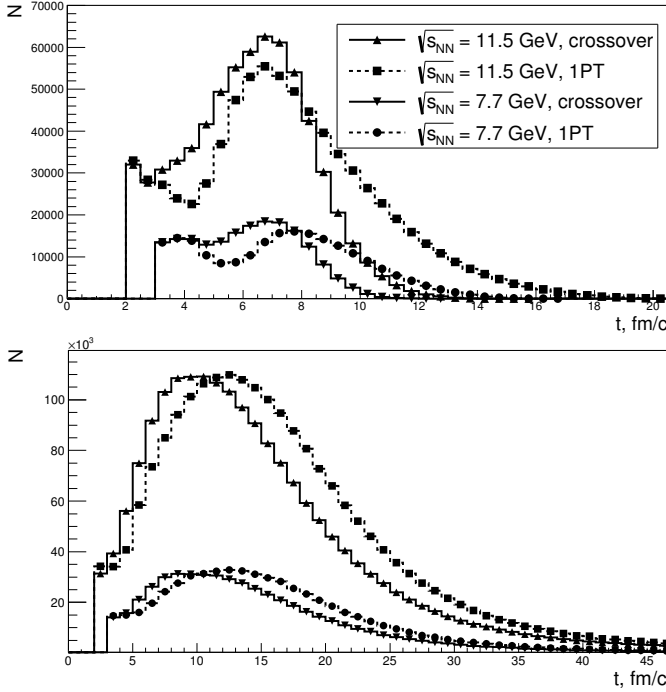


Fig. 1. Time distributions of hadrons derived from the vHLLE+UrQMD simulations after the hydro phase: before cascade (upper row) and after cascade (bottom row).

account in the standard fitting procedure using the assumption of the Gaussian shape of the source function. Such assumption leads to information losses on the large times, where the difference between the first order phase transition and the crossover one is crucial. Figure 2 demonstrates an example of the obtained $S(r^*)$ -source functions ($\sqrt{s_{NN}} = 7.7$ GeV) corresponding to the simulations with the pure hydrodynamic vHLLE model and full vHLLE+UrQMD simulations. One can see that for the simulations with the first order phase transition, the tails of the source functions are longer than those obtained with the crossover. The difference is strongly smeared by the cascade but is still observable. The largest difference is observed for $S(R_{long}^*)$.

3. Summary

It has been shown that the vHLLE+UrQMD model describes well the set of bulk observables including the pion femtoscopy ones at $\sqrt{s_{NN}} = 7$ –11 GeV. A possibility to distinguish the source functions obtained with the vHLLE+UrQMD simulations using different EoSs is demonstrated.

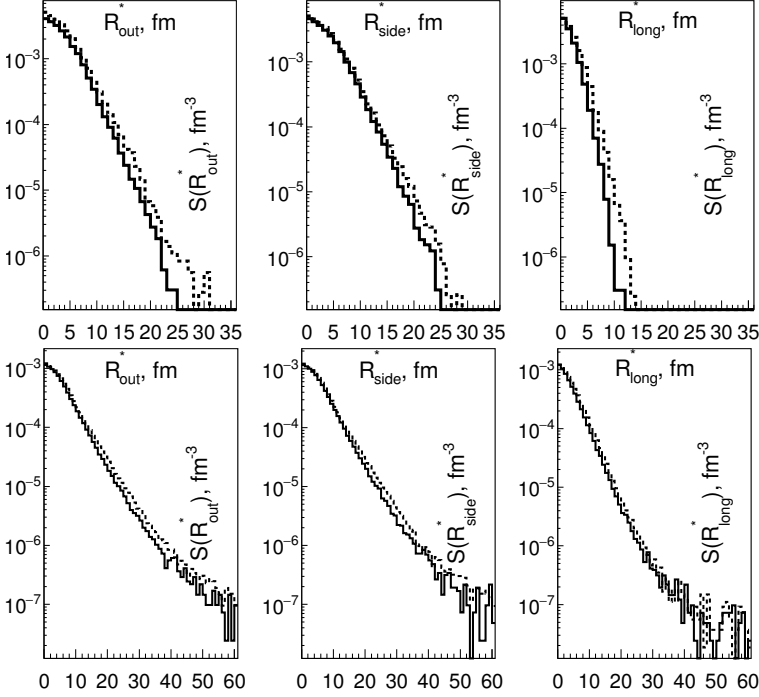


Fig. 2. The vHLE+UrQMD source functions of pions: pure hydro phase (upper row) and full simulations with cascade (bottom row). The simulations with the first order phase transition and the crossover one are indicated by a dotted line and a solid line, respectively.

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