

Femtoscopia with identified charged particles for the NICA energy range

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The correlation femtoscopy allows one to measure the space-time characteristics of particle production processes due to the effects of quantum statistics (QS) and final state interactions (FSI). Femtoscopy at lower energies was intensively studied at AGS, SPS and in the Beam Energy Scan (BES) program. The experiments already operated and planned to be put into operation within the NICA complex have a very extensive physical program covering a lot of physics to be investigated, in particular, the femtoscopy. In the work we discuss possibilities to observe a difference from the first order phase transition expected, according some theoretical predictions, at low energies and the crossover one at high energies with the femtoscopy observables using a hybrid model. First results, mainly on pion, and also on kaon femtoscopy are also presented in the paper.

PACS:

Motivation

The well developed femtoscopy formalism is considered as a very powerful tool to be used for study of the space-time evolution occurred in course of heavy-ion collision. The NICA energy range ($\sqrt{s_{NN}} = 4 - 11$ GeV) with existing (BM@N) and future experiments (MPD, SPD) to be operated looks very promising. In particular, it would allow one, due to a high planned level of luminosity, to measure a set of femtoscopy observables with a high accuracy.

An assumption that the nuclear matter undergoes the first order phase transition, probably, to be occurred at the NICA energies motivated our studies. In [1] was shown that the first order phase transition leads to a stalling of the expansion speed and increase of the emission duration $\Delta\tau$. As a result, it leads to increasing R_{long} and R_{out}/R_{side} . From experimental point of view, femtoscopy with charged identical pions performed within the BES program allowed one to observe a wide maximum around $\sqrt{s_{NN}} = 20$

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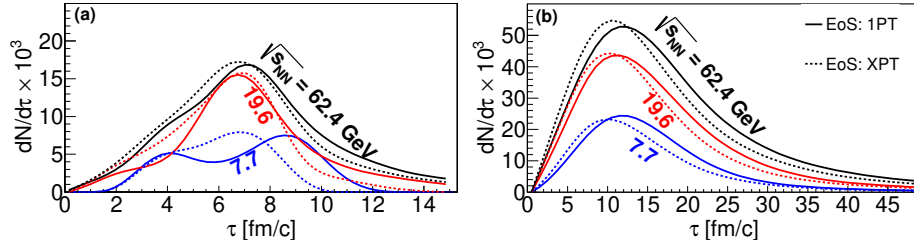


Fig. 1. Pion emission times at the particlization surface (a) and the last interactions (b) in the center-of-mass system of colliding gold nuclei at different values of $\sqrt{s_{NN}}$.

GeV [2]. Its presence could be attributed to a possible expected change of nuclear matter equation of state (EoS) and type of phase transition. At the same time, since the NICA energy range according to some theoretical predictions is a baryon dominated one, it allows one to do a search for change of the phase transition type by making use of femtoscopy tools, e.g. analysing behaviour of the observables.

To shed light on it, it sounds reasonably to perform a detailed feasibility study on it by use of modern hybrid (“sandwich”-like) Monte Carlo generators. As a candidate to be used, due to some reasons, we have taken the vHLLE+UrQMD model. To be known for the model in detail the reader is referred to [3]. The reasons caused our choice and to be mentioned here obligatory are related to a huge set of benefits available for our studies with the model. The first one is that the model was tuned with existing experimental data to be able to reproduce quantitatively well a set of bulk observables (yields, p_t and rapidity spectra). The second one is that the model has an option to change EoS when doing simulations. It supports two types of EoS to be used. To be familiar with them, one is addressed to [4, 5]. The last but not least mentioned here is that the model demonstrates, as shown in Fig. 1, a dependence of the average pion creation time at the particlization surface and the last interactions on collision energy as a function of the EoS used in course of simulations. The calculations involving the first order phase transition are denoted by 1PT, meanwhile those ones corresponded to the crossover EoS are denoted by XPT. The dependence looks apparently weak and the hadronic cascade smears the visible difference, but, nevertheless, it remains thus allowing one to use the model for investigating observables which are sensitive to the EoS scenario assumed.

Results and discussion

The current paper is considered as a continuation of our studies already done with the model. The previous studies aimed to extract pion femtoscopy radii from three-dimensional correlation functions are considered extensively in [6]. We extracted the radii $R_{out,side,long}$, the difference $R_{out}^2 - R_{side}^2$ and the ratio R_{out}/R_{side} to be compared with existing experimental data on pion femtoscopy obtained from the BES program [2] as a function of collision energy. The used parametrization of correlation function is a standard one described in [7, 8].

One can see, as shown in Fig. 2, that the model reasonably describes the m_T -dependence of radii for all available energies with both scenarios of the EoS used. The radii demonstrate different trends in the out, side and long directions. R_{side} seems to be

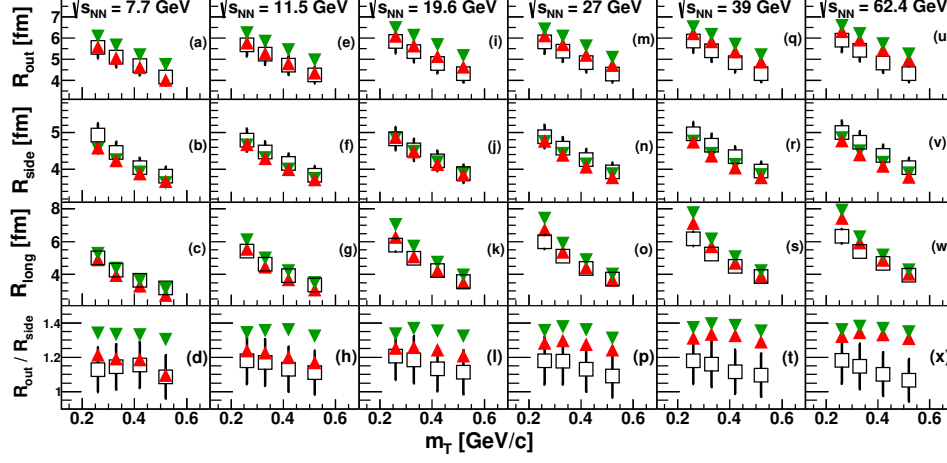


Fig. 2. Comparison of the model pion femtoscopy radii with those obtained from the BES program at $\sqrt{s_{NN}} = 7.7$ ((a) - (d)), 11.5 ((e) - (h)), 19.6 ((i) - (l)), 27 ((m) - (p)), 39 ((q) - (t)), 62.4 ((u) - (x)) GeV. Open squares represent experimental data. Green and red triangles correspond to the 1PT EoS and XPT EoS respectively.

almost the same for both scenarios. R_{out} has a tendency to be larger of order of 0.5 fm when using the 1PT EoS. A longer lifetime of the fluid phase in the 1PT EoS leads to bigger values of R_{long} if comparing with the XPT EoS.

The difference $R_{out}^2 - R_{side}^2$ and the ratio R_{out}/R_{side} are presented in Fig. 3. Study of the R_{out}/R_{side} ratio looks traditional in the modern femtoscopy. Due to a fact that the R_{out} and R_{side} radii are both reduced by flow, the ratio is a more robust against the flow effects. Our model calculations for both types of EoS used for simulations are in agreement with experimental data within the error bars at all energies available. The XPT EoS describes better the ratio for lowest collision energies and also does the same concerning the radii, as seen in Fig. 2.

As already told, all we did in [6] is related to pions, thus a logical continuation of the studies mentioned above includes its expansion to charged identical kaons.

Results of the first step of this analysis, mainly related to study on how the projections of kaon three-dimensional correlation functions on out, side and long directions look like, are shown in Fig. 4 ((d) - (f)) in comparison with those corresponding to the pion ones (upper row of Fig. 4). The parametrization of correlation function used to fit the Gaussian radii is given in [6], where one could be referred to. The kaon projections on all directions seem to be more Gaussian if comparing with pions. The projections extracted from the simulations assuming the XPT EoS scenario are visibly wider than for the 1PT EoS. The effect observed is more significant for kaons.

In Fig. 5 the m_T -dependence of the extracted kaon radii is shown for two energies in the NICA energy range and both possible scenarios of EoS used for simulations. The model calculations are compared with existing data for pions got from the BES program. One can see that the general behaviour of the kaon and pion radii from the model is very similar. For both cases the first order phase transition EoS overestimates the radii and the R_{out}/R_{side} ratio if comparing with the calculations made for the crossover scenario.

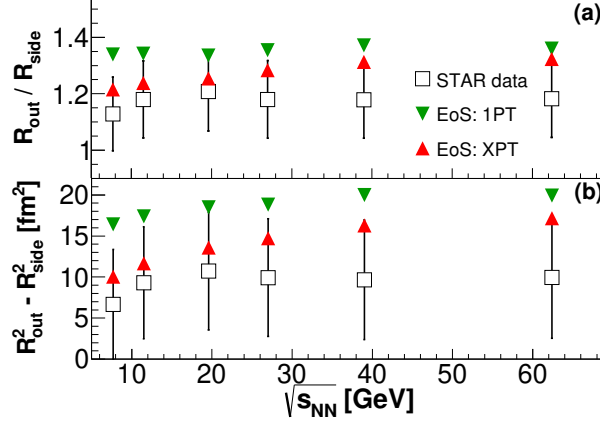


Fig. 3. R_{out}/R_{side} (a) and $R_{out}^2 - R_{side}^2$ (b) as a function of $\sqrt{s_{NN}}$ for experimental data and the model calculations.

Despite the almost similar general behaviour, it is seen that the kaon R_{out} has a tendency to diverge for the two types of EoS with increase of m_T . Probably, it can be attributed to the weak radial flow developed in the pre-hydro phase of collision, but it is just an assumption since it has not been investigated yet in detail right now and is planned to be done in the future.

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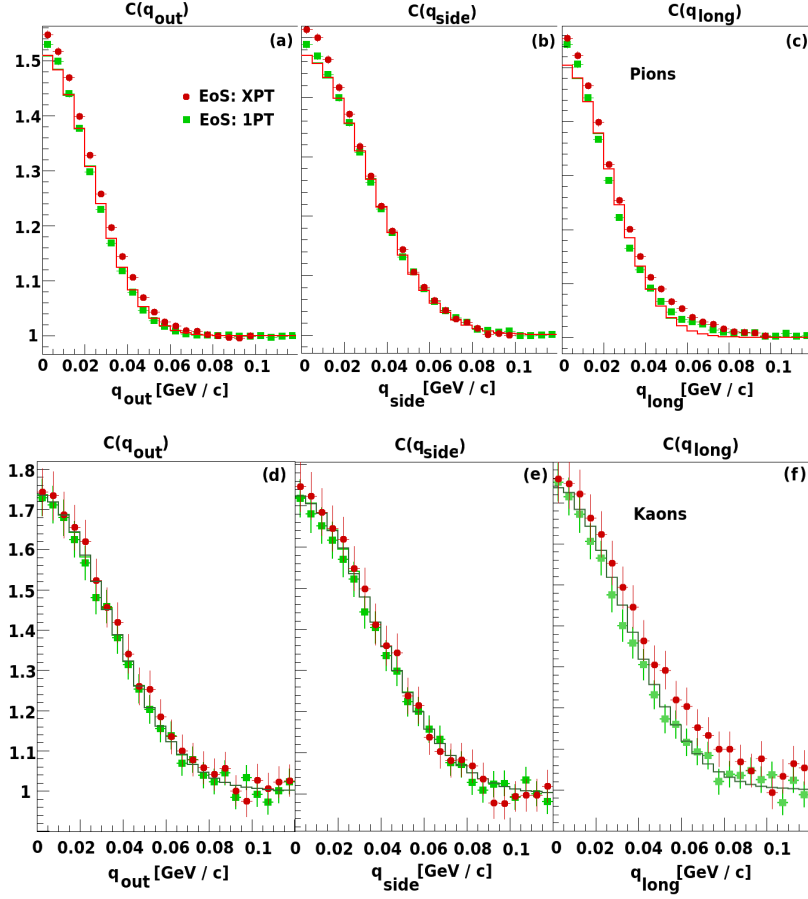


Fig. 4. Projections of three-dimensional correlation functions for pions ((a) - (c)) and kaons ((d) - (f)) on out, side and long directions. The calculations made at $\sqrt{s_{NN}} = 11.5$ GeV.

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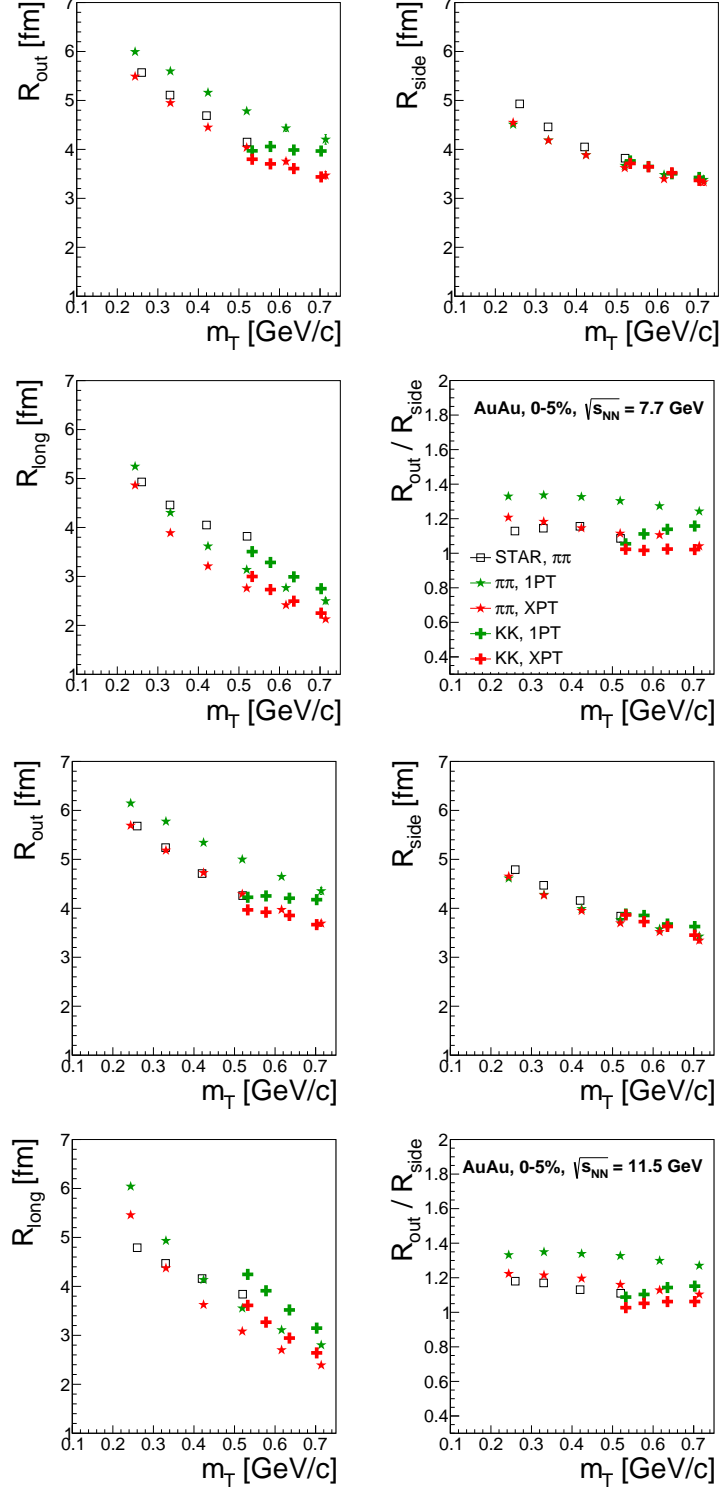


Fig. 5. Comparison of the model kaon femtoscopy radii for two energies $\sqrt{s_{NN}} = 7.7, 11.5$ GeV close to the NICA energy range with pion data got from the BES program.