Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 946 (2016) 227–239

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

# On $m_T$ dependence of femtoscopy scales for meson and baryon pairs

Yu.M. Sinyukov *, V.M. Shapoval, V.Yu. Naboka

*Bogolyubov Institute for Theoretical Physics, Metrolohichna str. 14b, 03680 Kiev, Ukraine*

Received 7 August 2015; received in revised form 3 October 2015; accepted 29 November 2015

Available online 2 December 2015

**Abstract**

The $m_T$-dependencies of the femto-scales, the so-called interferometry and source radii, are investigated within the hydrokinetic model for different types of particle pairs — pion–pion, kaon–kaon, proton–proton and proton–lambda, — produced in Pb+Pb and $p + p$ collisions at the LHC. In particular, such property of the femto-scales momentum behavior as $m_T$-scaling is studied for the systems with (w) and without (w/o) intensive transverse flow, and also w and w/o re-scattering at the final afterburner stage of the matter evolution. The detailed spatiotemporal description obtained within hydrokinetic model is compared with the simple analytical results for the spectra and longitudinal interferometry radii depending on the effective temperature on the hypersurface of maximal emission, proper time of such emission, and intensity of transverse flow. The derivation of the corresponding analytical formulas and discussion about a possibility for their utilization by the experimentalists for the simple femtoscopy data analysis is the main aim of this theoretical investigation.


*Keywords:* Correlation femtoscopy; Scaling; Hadron rescattering; Transverse flow; Lead–lead collisions; LHC

## 1. Introduction

The spatiotemporal structures of particle emission in nucleus–nucleus, proton–(anti)proton and proton–nucleus collisions are essentially defined by the dynamics of the collision processes [1–4]. Therefore the correlation interferometry [5], that measures the femtoscopic

* Corresponding author.
*E-mail address:* sinyukov@bitp.kiev.ua (Yu.M. Sinyukov).

http://dx.doi.org/10.1016/j.nuclphysa.2015.11.014

scales by means of two- (or many-) particle correlations, allows one to study such processes experimentally. The corresponding femtoscopic patterns can be presented in different forms. One of them is the $k_T$-momentum dependence of the interferometry radii $R_i(k_T = |\mathbf{p}_{T1} + \mathbf{p}_{T2}|/2)$, that results from a 3D Gaussian fit in $q^i = p_1^i - p_2^i$ to the two-particle correlation function $C(\mathbf{q}, k_T)$, defined as a ratio of the two-particle spectrum to the product of the single-particle ones. The other one is the source function $S(\mathbf{r}^*)$ [6] reflecting the dependence of the pair production on the distance $\mathbf{r}^*$ between the two emitted particles in the rest frame of the pair. Both patterns supplement each other, and a reliable model should describe/predict all the mentioned types of the femtoscopic observables, if it contains a detailed space–time picture of the collision process.

It is important to note that the correlation function behavior depends also on the particle species. The detailed behavior of this dependence can be used to discriminate between different scenarios of matter evolution and particle emission in the collision processes. For example, the hydrodynamic picture of A+A collisions for the particular case of negligible transverse flow leads to the same $m_T^{-1/2}$ behavior[1] of the longitudinal radii $R_l(k_T)$ for the pairs of identical pions and kaons, and even leads to the complete $m_T$-scaling in the case of common freeze-out [2,3].

In Ref. [7] it was found that hydrokinetic model (HKM) [8–11] predicts strong violation of such a scaling between pions and kaons at the LHC, and predicts $k_T$-scaling (for $k_T > k_0 \approx 0.4$ GeV/$c$) instead. In this letter we analyze in detail the physical reasons for $m_T$-scaling violation. As it turned out that the reasons were found to be quite general, there is a hope that the found $m_T$ peculiarities will be confirmed in the LHC experimental comparative analysis of pion and kaon femtoscopy data. In addition we predict the $m_T$-behavior for femtoscopic scales in other cases, including the case of meson and baryon source function radii.

To simplify the theoretical study, we reconsider the analytical results, describing $m_T$ (or $k_T$) behavior of the femtoscopy scales in a situation with strong transverse flows typical for RHIC and LHC energies. We derive a simple analytical formula for such a scenario, which fits well the complex HKM results for different hadron pairs. Since the HKM describes simultaneously the large number of bulk observables, it gives experimentalists a simple tool for estimation of the life-time of expanding fireball, related to the maximal emission of the specific hadron pair created in proton or nuclear collisions.

## 2. Analytical model for the interferometry radii

The hydrokinetic model (HKM) (see details in Ref. [11]) was developed to simulate the evolution of matter formed in relativistic heavy-ion collisions and describe/predict bulk observables at RHIC and LHC. In Ref. [11] a good description was reached for pion, kaon, (anti)proton and all charged particle spectra at different centralities, as well as for the elliptic flows. Concerning the femtoscopic scales, the confirmed HKM prediction [12] about a reduction of $\frac{R_{out}}{R_{side}}$ ratio in A+A collisions at LHC as compared to RHIC was done[2]; the interferometry radii for pions and kaons at RHIC [10,11] and LHC [7,11] in A+A collisions were calculated; the source functions for kaons and pions at RHIC were described at the top RHIC energy and predicted for the

[1] Here, $m_T^2 = m^2 + (|\mathbf{p}_{T1} + \mathbf{p}_{T2}|/2)^2 = m^2 + k_T^2$ is the transverse mass of the particle pair.

[2] Here we discuss HKM, however the similar result was obtained earlier in hydrodynamics with crossover equation of state [13]. The main reason for the reduction of $R_{out}/R_{side}$ ratio at the LHC as compared to RHIC is strengthening of positive $r$–$\tau$ correlations for points of surface emission with the increase of collision energy (see numerical details and analytical approximation in [12]). Note, however, that the effect is suppressed if the equation of state is soft, as it is at the 1st order phase transition.