HBT EFFECT WITH FLUCTUATING INITIAL CONDITIONS AND CONTINUOUS EMISSION*

Yogiro Hama, Frédérique Grassi, Otávio Socolowski Jr.

Instituto de Física/USP, C.P. 66318
05389-970 São Paulo, SP, Brazil

and Takeshi Kodama

Instituto de Física/UFRJ, C.P. 68528
21945-970 Rio de Janeiro, RJ, Brazil

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We study effects of the event-by-event fluctuation of the initial conditions and the continuous pion emission during the whole development of the hot and dense matter formed in high-energy collisions on the two-pion interferometry. Important deviations occur, from the standard version of hydrodynamics with smooth initial conditions and a sudden freeze-out on a $T = T_{\rm fo}$ hypersurface. Comparison with data at RHIC shows that this description can give account of the $m_{\rm T}$ dependence of $R_{\rm L}$ and $R_{\rm s}$ and significantly improves $R_{\rm o}$ with respect to the usual version.

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1. Introduction

When treating ultra-relativistic heavy-ion collisions in hydrodynamic approach [1], it is usually assumed that, at some early instant of time, a local thermal equilibrium is attained which is customarily described in terms of a set of *highly symmetric* and *smooth distributions of velocity* and *thermodynamical quantities*. These are the standard initial conditions (IC) for the hydrodynamic equations, which have to be complemented with some reasonable equations of state (EoS). Then, as the system expands, it gradually cools down and, when the temperature reaches a certain freeze-out value $T_{\rm fo}$, it *suddenly* decouples. Every observed quantity is then computed on the

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hypersurface $T = T_{\rm fo}$. For instance, the momentum spectra of the produced hadrons are obtained by computing the Cooper–Frye integral [2] over this hypersurface $T = T_{\rm fo}$.

Though useful for getting a nice comprehension of several aspects of the phenomena, such a scenery is clearly highly idealized when applied to finite-volume and finite-lifetime systems as those formed in high-energy heavy-ion collisions. In this report, we examine how two-pion correlation is modified as consequence of *(i)* event-by-event *fluctuations of the IC*; and of *(ii) continuous emission* (CE) of particles, instead of sudden freeze-out.

2. Fluctuating initial conditions

The usual symmetric, smooth IC may be understood as parameterizations of hydrodynamic variables averaged over several events. However, since our systems are small, important event-by-event fluctuations are expected, even for a fixed impact parameter of the incident nuclei. There are simulations, based on different microscopic models, which could be used to incorporate, in hydrodynamic computations, more realistic fluctuating IC. NeXuS [3] event generator is such a code, based on the Regge–Gribov theory and can give, in the event-by-event basis, detailed space distributions of energy–momentum tensor, baryon-number, strangeness and charge densities. In Fig. 1, we show examples of IC generated by NeXuS. As seen, the energy distribution in a single event is bumpy. Similar structure can be seen also in HIJING [4]. Since HBT effect is sensitive to the space–time geometry of the source, our expectation is that these spots in IC might appear at the end when particles are emitted, as smaller HBT radii.

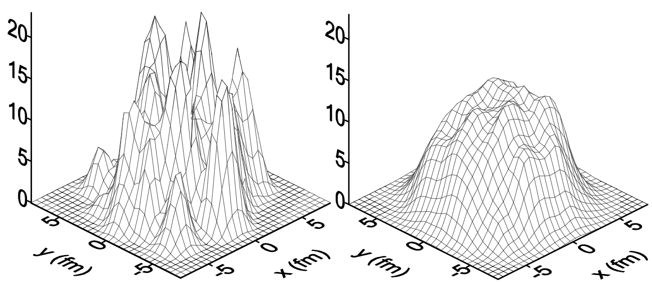

Fig. 1. Examples of IC produced by NeXus for central Au+Au collisions at $y = 0$ plane. Energy density is plotted in units of GeV/fm^3. Left: one random event. Right: average over 30 random events (corresponding to the usual IC).

Starting from IC introduced above, we solve the hydrodynamic equations, by using the recently developed SPheRIO code [5,6], which is based on the so-called smoothed-particle hydrodynamics (SPH) algorithm, a method flexible enough, allowing to treat problems with no symmetry at all. The peculiarity of SPH is the use of discrete Lagrangian coordinates attached to small volumes ("particles") with some conserved quantities. Here, we take the entropy and the baryon number as such quantities.

3. Continuous emission model (CEM)

As for the decoupling process, it has been proposed [7] an alternative picture where the emission occurs not from a sharply defined freeze-out hypersurface, but continuously from the whole expanding volume of the system at different temperatures and different times. It is assumed that, at each space–time point x^μ, each particle has a certain escaping probability

$$\mathcal{P}(x,k) = \exp\left[-\int_{\tau}^{\infty} \rho\sigma v d\tau'\right] , \tag{1}$$

due to the finite dimensions and lifetime of the thermalized matter. Then, the distribution function $f(x,k)$ of the expanding system has two components, one representing the portion of the fluid already free and another corresponding to the part still interacting, *i.e.*,

$$f(x,k) = f_{\rm free}(x,k) + f_{\rm int}(x,k) . \tag{2}$$

We may write the free portion as

$$f_{\rm free}(x,k) = \mathcal{P} f(x,k) . \tag{3}$$

In Fig. 2 we show the time evolution of $\langle\mathcal{P}\rangle$, where $\langle\,\rangle$ means average over k, in the $y = 0$ plane for the most central Au+Au collisions at 130 A GeV. Here, we took $\langle\sigma v\rangle = 2\,{\rm fm}^2$. As seen, the probability distribution is widely spread, indicating that both the emission zone and duration

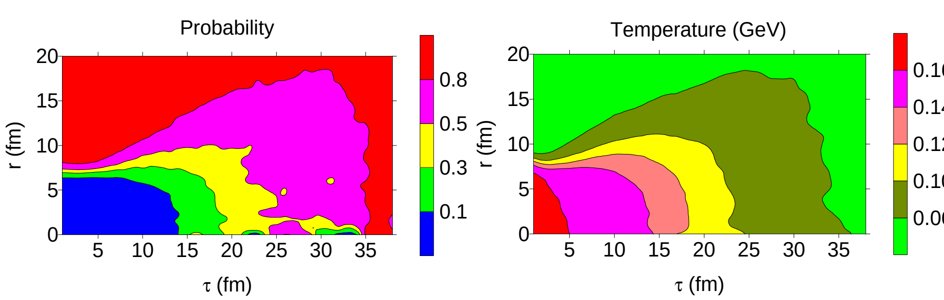

Fig. 2. Left: $\langle\mathcal{P}\rangle$ distribution for the most central Au+Au collisions at 130 A GeV, in the $y = 0$ plane for averaged IC. Right: Corresponding T distribution.

are large, in contrast to the standard sudden freeze-out picture. In CEM, the large-$k_{\rm T}$ particles are mainly emitted at early times when the matter is hot and mostly from its surface, whereas the small-$k_{\rm T}$ ones are emitted later when the fluid is cooler and from larger spatial domain. Thus, we expect important changes in HBT correlations. In an earlier paper [8], we showed, by using a simple scaling solution, that whereas the so-called *side* radius is independent of the average $k_{\rm T}$, the *out* radius decreases with $\langle k_{\rm T}\rangle$, for the reason mentioned above. This behavior is expected to essentially remain in the general case we are considering here as shown by data [9, 10].

4. Results

We first assume sudden freeze-out (FO) at $T_{\rm fo} = 128\,{\rm MeV}$. This temperature was previously found by studying the $\sqrt{s}$ dependence of kaon slope parameter T^* [12] and verified that it is also consistent with pion spectrum (see more details in [6, 11]). The results are summarized in Fig. 3, where we plot the $m_{\rm T}$ dependence of HBT radii with Gaussian fit of C_2, computed in different ways. One sees that the averaged IC (FO1) make the $m_{\rm T}$ dependence of $R_{\rm o}$ flat or even increasing, in agreement with other hydro calculations [13] but in conflict with the data. The fluctuating IC (FO2) make the radii smaller as expected, especially $R_{\rm o}$, without changing the $m_{\rm T}$ dependence.

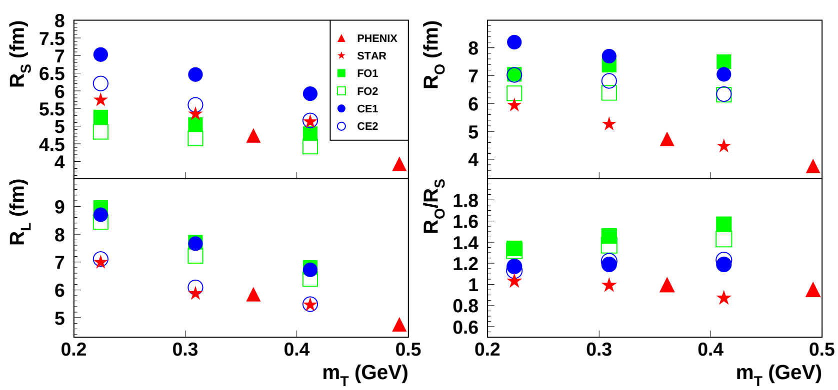

Fig. 3. HBT radii and the ratio $R_{\rm o}/R_{\rm s}$ for sudden freeze-out (FO) and CE. 1 stands for averaged IC and 2 fluctuating IC. Data are from [9, 10]: $(\pi^+ + \pi^-)/2$.

Let us now consider CEM. First, we checked that our choice of parameter $\langle \sigma v\rangle = 2\,{\rm fm}^2$ does reproduce correctly the $m_{\rm T}$ spectrum data. Now, look at the $m_{\rm T}$ dependence of the HBT radii, shown in Fig. 3. Comparing the averaged IC case, with CEM (CE1), with the corresponding freeze-out (FO1), one sees that, while $R_{\rm L}$ remains essentially the same, $R_{\rm s}$ decreases faster and as for $R_{\rm o}$, it decreases now inverting its $m_{\rm T}$ behavior. The account of the fluctuating IC in addition (CE2) makes all the radii smaller as in FO case, obtaining a nice agreement with data for $R_{\rm L}$ and $R_{\rm s}$, and improving considerably the results for $R_{\rm o}$ with respect to the usual hydro description.

5. Conclusions

Both fluctuating IC and the continuous emission instead of sudden freeze-out largely modify the pion HBT correlation, so they should be included in more precise data analyses. As a result of bumpy structure, the fluctuating IC give smaller radii, without changing the $m_{\rm T}$ dependence, whereas the continuous emission does not change $R_{\rm L}$ but enhances the $m_{\rm T}$ dependence of $R_{\rm s}$ and inverts the $m_{\rm T}$ behavior of $R_{\rm o}$, which now decreases with $m_{\rm T}$ in accord with data. This is because large-$k_{\rm T}$ particles appear mostly at the beginning of the expansion from a thin hot shell and small-$k_{\rm T}$ ones all over the expansion, and from larger portion of the fluid. The combination of these two effects can give account of the $m_{\rm T}$ dependence of $R_{\rm L}$ and $R_{\rm s}$ and improves considerably the one for $R_{\rm o}$ with respect to the usual version.

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