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Influence of resonances on pion spectra and interferometry volume in relativistic heavy ion collisions

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Abstract The transverse spectra and interferometry volume of thermal pions in A+A collisions were estimated basing on the chemically frozen hydrodynamic evolution that incorporates the decays of resonances at the freeze-out stage. We found that the resonance decays could increase significantly the pion interferometry volume, while the pion spectra slopes are not affected much by the decays in the region up to transverse momentum 1 GeV. We also notice that in such a model the resonance contributions reduce the ratio of outward to sideward interferometry radii.

Key words hydrodynamic evolution • resonances • HBT correlations

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Introduction

The interferometry measurements play an important role in the analysis of space-time structure and thermodynamic properties of the matter created in heavy ion collisions. In particular, they allow to estimate the evolution time of the systems [2, 14] and particle average phase space densities [4, 5]. There are, however, serious problems which have to be solved within such an analysis. If the chemical freeze-out takes place, then about 2/3 of pions come from decays of resonances in high energy heavy ion collisions [1, 6]. Only small part of them are the long-lived resonances which give the effect of halo [12] – a suppression of correlation functions of identical pions. The others, short-lived, enhance significantly the value of pion spectrum, as compared to the thermal pion and also modify the interferometry radii. Such peculiarities of pion production due to resonances are important to understand the influence of resonance decays to the formation of the interferometry volume and to estimate the average phase-space densities. We analyse quantitatively a total effect for spectra and interferometry volume of pion production by a huge number of resonances with masses up to 2 GeV and dependence of the effect on the intensity of flows in the expanding system (for details see [3]).

Resonance contributions in chemical freeze-out approach

Let us consider the realistic model of Pb+Pb collisions at CERN energies 158 AGeV [1]. The model describes hydrodynamically the evolution of chemically frozen hadron-resonance gas with masses up to 2 GeV from the hadronization stage to the thermal, or kinetic, freeze-out. According to the results of Ref. [1], nearly 2/3 of all pions appears from resonance decays after thermal freeze-out if one totally ignores effects of the decays within fluid. Taking into account a rather short duration of the hydrodynamic stage for hadron gas, about 1.7 fm/c [1], which is comparable with the average life-time of the resonances, we can very roughly estimate that about or more than half of pions come from resonance decays at post hydrodynamic stage.

The attempt to analyse the contribution of a very large number of short-lived resonances to the spectra and interferometry volume was done in Refs. [7–9, 10, 11] within some hydrodynamic parametrization of the kinetic freeze-out. However, the analysis of relative resonance contribution to the interferometry radii has not been done, probably, since a non-physical approximation of infinite widths, or zero lifetimes, of all resonances were used. But such estimates are necessary for analysis of the phase-space and particle density properties at the kinetic freeze-out. Pursuing this goal we analyse the resonance contributions to the spectra and interferometry radii basing on the hydrodynamic model of Ref. [1] and take the widths Γ of mesonic and baryonic resonances with masses up to 2 GeV from Particle Data Group [13]. Due to technical reasons we ignore, however, the contributions from many-cascade decays, that, as we hope, does not change the general picture and conclusions.

To evaluate the contribution from resonance decays to the pion spectra and interferometry radii we use a quasi-classical approximation (see, e.g., [16]) for the emission function $g_i(x,p)$ of i resonance species:

$$(1)\quad g_i(x,p) = \int_{\omega-}^{\omega+} d\omega^2 \varphi_i(\omega^2) \int \frac{d^3 p_i}{E_i} 2m_i \delta\left((p_i - p)^2 - \omega^2\right) \cdot \int_0^\infty d\tau^* \Gamma_i \exp\left(-\Gamma_i \tau^*\right) \int_\sigma d\sigma_\mu(x_i)\, p_i^\mu \cdot \delta^4\left(x^\mu - \left[x_i^\mu + \frac{p_i^\mu \tau^*}{m_i}\right]\right) f_i^{l.eq.}(x_i, p_i).$$

The emission function $g_i(x,p)$ describes the production of pion with momentum p from i resonance species, the latter is distributed according to local equilibrium phase-space density $f_i^{l.eq.}(x_i,p_i)$. The quasi-classical picture supposes that i resonance is created from the hydrodynamic tube at a space-time point x_i^μ of the kinetic freeze-out hypersurface σ and decays into π + X after some proper time with the mean value $1/\Gamma_i$. The probability to produce a group of particles X with an invariant mass ω that accompanies a pion at i-resonance decay is described by the covariant amplitude of resonance decay $\varphi_i(\omega^2)$ that is supposed to be known. The pion spectra and correlations are defined, therefore, by the phase-space densities of direct pions and resonances at σ. Following Ref. [1], we choose the local Boltzmann distribution $f_i^{l.eq.}(x_i,p_i)$ at the kinetic freeze-out hypersurface σ, τ_{th} = const, that corresponds to constant temperature T_{th}, boost-invariant longitudinal flow, transverse Gaussian-like density profile with width, $R(\tau_{th})$, and transverse flow rapidity $y_T = v_R r/R(\tau_{th})$. The corresponding parameters for Pb+Pb 158 AGeV collisions were found in Ref. [1] from analysis of the spectra and interferometry radii at fairly large p_T to maximally reduce the influence of resonance

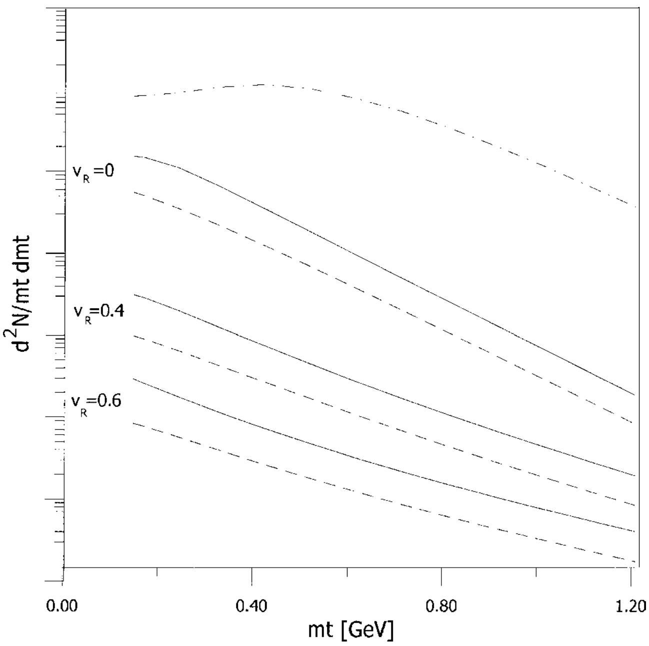

Fig. 1. The pions transverse spectra for the complete pion yields (solid lines) and for direct pions only (dashed line) in the cases with and without transverse flow v_R = 0, 0.4 and 0.6. Other freeze-out parameters are taken from Ref. [5] as it is described in the text. The shape of the pion spectra from the fixed heavy resonance species $f_2(1270)$ with p_0 = 0.622 GeV is presented for illustration by dot-dashed line for v_R = 0. The overall normalization is arbitrary.

decays. They are T_{th} = 0.135 GeV, $R(\tau_{th})$ = 5.3 fm, v_R = 0.4. We take proper freeze-out time τ_{th} = 8.2 fm/c for the direct pions [1], and use this freeze-out time also for resonances which produce pions. We do not pretend in this paper to a detailed fitting of the spectra and radii, our aim is to analyse the dependence on flow intensity of the relative contributions of resonances to the spectra and interferometry radii within the same model. So, we just take the parameters which were found in [1], and use them for highest SPS energies. Also, we estimate roughly the resonance contributions at RHIC energies by using the same model, just enhancing the intensity of transverse flows: $v_R = 0.4 \to v_R = 0.6$.

First, we note that the pion spectra from decays of the fixed resonance species are essentially non-thermal, non-exponential, at least in the transverse momentum region below p_0. One can see it at the top of Fig. 1 for fixed heavy resonance species $f_2(1270)$ with p_0 = 0.622 GeV. But at typical freeze-out temperatures T_{th} = 120÷140 MeV, the total contribution from many resonances with different masses and different p_0 has the slope of the spectra which, as one can see from Fig. 1, is closed to the slope of the direct pions in a wide transverse momentum region, at least, up to 1 GeV.

Figure 2 demonstrates that resonance decays extend the interferometry volume, especially at small transverse momenta. The ratio of complete volume to direct one grows when the intensity of transverse flow increases. Thus, at small transverse momenta flow reduces the complete interferometry volume less than the volume formed by direct pions only. Another impressive effect of influence of the flow and resonance decays to the interferometry radii

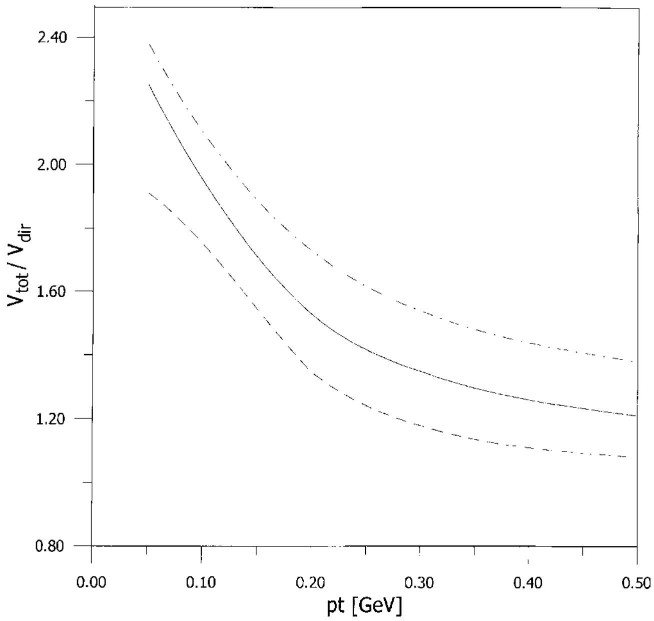

Fig. 2. The ratio of the complete interferometry volume V_{tot}, that includes effects of the resonance decays to pions, to the interferometry volume for thermal (direct) pions, taken at a few typical intensities of flow. The resonance contributions are calculated in accordance with chemical freeze-out conception, when approximately 2/3 of pions are produced by resonance decays. Dashed line corresponds to $v_R = 0$, solid line: $v_R = 0.4$ and dash-dotted line: $v_R = 0.6$. The other parameters are taken from Ref. [5] as it is described in the text.

is demonstrated in Fig. 3. One can see that standard hydrodynamic behavior of the ratio R_{out}/R_{side} which is typically ≥ 1 becomes essentially smaller, $R_{out}/R_{side} < 1$, out of the region of fairly small p_T, if the resonance decays are taken into account.

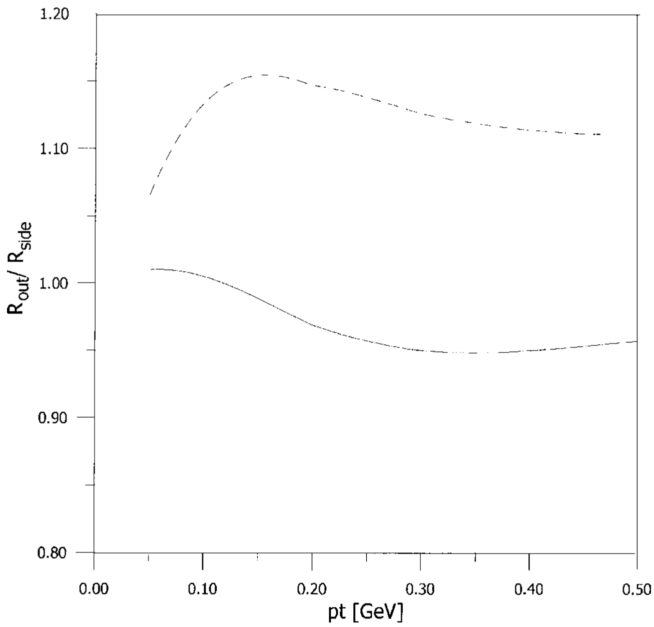

Fig. 3. The R_{out} to R_{side} ratio for complete interferometry radii (solid line) *vs.* the ones for direct pions (dashed line) at transverse flow $v_R = 0.6$, which is associated with RHIC energies.

Conclusions

In the picture of the chemical freeze-out more than half of pion yield in the region of p_T below 1 GeV is contributed by the decays of baryonic and mesonic resonances. We found that the decays of many heavy resonances increase significantly the observed interferometry radii as compared to ones formed by only thermal (direct) pions. All that could lead to the reduction factor 0.5–0.7 when one estimates the Bertsch's average phase-space densities of thermal pions from observed spectra and interferometry volumes. Since the heavy resonances have, typically, large momentum p_0 of pions produced, the resonances also contribute to the interferometry radii at large enough transverse momenta, $p_T \sim 1$ GeV. One of the important consequences of this is that the ratio of the outward interferometry radius to sideward one, R_{out}/R_{side}, becomes less than unit due to heavy resonance decays, in contrast to standard results $R_{out}/R_{side} > 1$ for direct pions in the hydrodynamic models (except for the so-called blast-wave model, see, e.g., [15]). This could be the step towards the understanding of the HBT puzzle.

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