INTERFEROMETRY FOR ROTATING AND EXPANDING SOURCES IN AN EXACT HYDRODYNAMICAL MODEL*

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The two-particle interferometry method was introduced to determine the size of the emitting source after a heavy-ion collision. Following the extension of the method to spherical expansion dynamics, here, we extend the method to detect the rotation of the system. It is shown that rotation of a cylindrically symmetric system leads to modifications, which can be perceived as spatial asymmetry by the "azimuthal HBT" method.

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1. Introduction

Heavy-ion collisions with finite impact parameters create systems where we have a large net angular momentum in the initial state, which leads to a rotating [1] and expanding fireball. If the formed Quark–Gluon Plasma (QGP) has low viscosity [2], one can expect new phenomena like rotation or turbulence, which shows up in form of a starting Kelvin–Helmholtz instability (KHI) [3]. Rotation in heavy-ion collision has been recently considered, and here we study a new class of exact hydrodynamic solutions for three-dimensional, rotating and expanding cylindrically symmetric fireball [4–6].

The created system in relativistic heavy-ion collisions is microscopic and short-lived so only the momentum spectrum of the emitted particles can be measured directly. However, the space-time structure of the collision

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region can be studied using Hanbury-Brown–Twiss interferometry [7]. This technique uses two particle correlations [8] to probe the space-time shape of the particle emission zone.

2. Correlation function

We consider an azimuthally symmetric system around the rotation axis, y, with Gaussian density profiles with characteristic radii, R and Y, and constant temperature T. The initial parameters are given in Table I, and the initial temperature is taken to be $T = 200$ MeV.

TABLE I

Time dependence of characteristic parameters of the fluid dynamical calculation are presented in Ref. [5]. R is the average transverse radius, Y is the longitudinal length of the participant system, φ is the angle of the rotation of the interior region of the system, around the y-axis, measured from the horizontal, beam, z-direction in the reaction, $[x, z]$, plane, $\dot{R}$ and $\dot{Y}$ are the speeds of expansion in transverse and longitudinal directions, and ω is the angular velocity of the internal region of the matter.

t [fm/c]	Y [fm]	$\dot{Y}$ [c]	ω [c/fm]	R [fm]	$\dot{R}$ [c]	φ [Rad]
0.	4.000	0.300	0.150	2.500	0.250	0.000
3.	5.258	0.503	0.059	3.970	0.646	0.307
8.	8.049	0.591	0.016	7.629	0.779	0.467

The source function, $S(x, k)$, giving the emission rate in the phase space, x, k, should be integrated over all points, x, of the emitting source to obtain the correlation function

$$\int \mathrm{d}^4 x S(x,k) \;\propto\; \int w_s \gamma_s \left(k_0 + \vec{k}\cdot\vec{v_s}\right) \times \exp\left[-\frac{\gamma_s}{T_s}\left(k_0 - \vec{k}\cdot\vec{v_s}\right)\right] e^{-s_\rho/2} e^{-s_y/2} \frac{\mathrm{d}s_y \mathrm{d}s_\rho \mathrm{d}\varphi}{\sqrt{(s_y)}}\,. \quad (1)$$

Here, the spatial integral is performed in cylindrical coordinates, s_y, s_ρ, φ, where s_y, and s_ρ are scaling variables, $s_y = y^2/Y^2$ and $s_\rho = (x^2 + z^2)/R^2$. The correlation function was evaluated in the same way as in Ref. [9].

The z-axis is the beam axis and determines the long direction. In the transverse plane, the x-axis (the direction of impact parameter) is transverse to the beam direction. In this way, the out direction is the x-direction. The remaining y-axis determines the side direction. Due to the azimuthal symmetry of our specific model, the results for the out and long directions should be identical.

The velocity field in x,y,z coordinates is given by

$$\vec{v}_s = \Big(\dot{R}\sqrt{s_\rho}\ \sin(\varphi) + R\omega\sqrt{s_\rho}\ \cos(\varphi)\,,$$
$$\dot{Y}\sqrt{s_y}, \dot{R}\sqrt{s_\rho}\ \cos(\varphi) - R\omega\sqrt{s_\rho}\ \sin(\varphi)\Big)\ , \tag{2}$$

where ω is the angular velocity, and φ is the angle of rotation.

3. Results

The correlation functions that were obtained are fitted by the azimuthal HBT method and parametrization

$$C(q,k) = 1 + \exp\left(-\sum_{i,j=o,s,k} q_i q_j R_{ij}^2(k)\right)\ . \tag{3}$$

We can compare the different radius parameters, R_{ij}^2, obtained by fitting the results of the CF obtained from the rotating and azimuthally symmetric system, to the "azimuthal HBT" parametrization of Eq. (3). The obtained values, $R \equiv R_{oo} = R_{ll}$, are shown in Fig. 1. The CF increases for larger values of ω which corresponds to a decrease in the measured radius. The approximate radius decrease for $\omega = 0$ to 0.15 c/fm and $\omega = 0$ to 0.30 c/fm

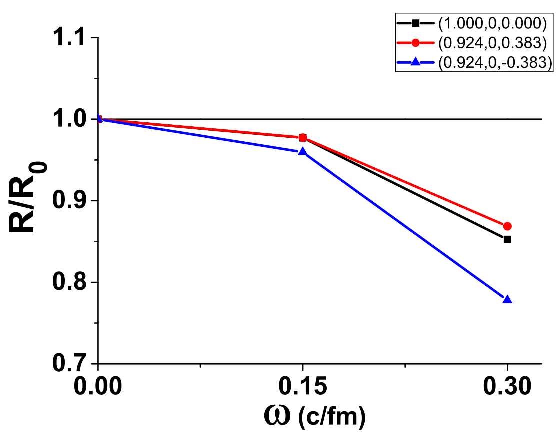

Fig. 1. (Colour on-line) Ratio of radius from the fit for the correlation function obtained from the data in Table I for different directions as a function of ω, the light grey (red) line is for $\vec{k}^+ = (0.924, 0, 0.383)k$, the black line is for $\vec{k} = (1,0,0)k$ and the dark grey (blue) line is for $\vec{k}^- = (0.924, 0, -0.383)k$. R_0 is the observed radius of the system without rotation. The figure also appears in [10].

is 3–4% and 15% respectively. In Fig. 1, we can see how the measured radius depends on the rotation velocity ω at time $t = 0$ fm/c. For a later times, we would see a similar effect.

A higher rotation velocity will decrease the measured size of the system, it also decreases more rapidly for larger values of ω as can be seen from the slope going from $\omega = 0$ to 0.15 c/fm and $\omega = 0.15$ to 0.30 c/fm in Fig. 1. Asymmetry in the size is present if measured at different directions if the system is rotating.

The detector at $k^+ = (0.924, 0, 0.383)k$ shows a smaller measured radius for the exact hydro-model, while the radius at $k^- = (0.924, 0, -0.383)k$ is larger. Thus, the model results show that rotation influences the HBT evaluation similarly like the expansion, which influences data significantly.

4. Conclusion

Different values of the angular velocity will change the measured "azimuthal HBT" size parameters of the system. The obtained radii from the correlation functions will also have different values depending on which direction the measurements are made. That the cylindrically symmetric system is rotating will be observed as an asymmetric object in "azimuthal HBT" analysis.

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