HBT Parameters for Au + Au Collisions at RHIC Energy *

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Abstract Using the dynamical transport approach RQMD with a correlation afterburner, the behavior of two-pion HBT parameters is studied for Au + Au collisions at RHIC energy $\sqrt{s}$ = 200GeV/u. We find that the HBT size parameters do reflect the source geometry at freeze-out for both central and non-central collisions. The transverse momentum dependence of HBT size parameters is insensitive to the pressure developed during the early stage of the collisions, rather, it is sensitive to the degree of spacemomentum correlation.

Key words heavy-ion collisions, HBT correlation, correlation function

The primary goal of the ultrarelativistic heavy-ion collision program at Relativistic Heavy Ion Collider (RHIC) is to create a system of deconfined quarks and gluons[1]. The formation of such a deconfined state depends on the initial conditions of the matter created at the early stage of heavy-ion collisions. Hanbury Brown and Twiss effect (HBT) can be used extensively to probe the space-time structure of heavy-ion colliding fireball[2,3]. At midrapidity and low transverse momentum, two-particle correlation functions reflect the space-time geometry of the emitting source, while dynamical information is contained in the momentum dependence of the apparent source size[4,5]. Study the two-particle correlation functions can further shed light on the physics since the observed probability of two particles close to each other not only depends on their nature of quantum statistics but also on the collision dynamics, specifically depends on the space-momentum correlation.

In this paper we present a prediction for the behavior of two-pion HBT parameters from heavy-ion collisions at RHIC energy $\sqrt{s}$ = 200GeV/u. The Relativistic Quantum Molecular Dynamics approach RQMD[6] is used as an event generator, because it has been very successful in not only reproducing single-particle distribution but also in describing two-particle correlation data at AGS and SPS energies[7,8]. Recently, a new version of RQMD (v2.4) model has been available which can deal

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with collisions at RHIC energies. In this study, the simulation events of Au + Au collisions at the center-of-mass energy $\sqrt{s}$ = 200GeV/u are generated. For comparing, the simulation events of Si + Si and p + p collisions at the same energy are generated also. The freeze-out positions and momenta are fed into a correlation after-burner (CRAB) code to calculate the two-pion correlation functions. In our calculations, only the pions with midrapidity ($-1 < y < 1$) and low transverse momentum ($p_t <$ 1GeV/c) are used.

In order to extract the pion source size, the results of the HBT calculations are fitted to the 3-dimensional Gaussian form[4]

$$C_2(q,\boldsymbol{K}) = 1 + \lambda \exp[-q_{long}^2 R_{long}^2(\boldsymbol{K}) - q_{side}^2 R_{side}^2(\boldsymbol{K}) - q_{out}^2 R_{out}^2(\boldsymbol{K})], \qquad (1)$$

here, $\boldsymbol{K} = (\boldsymbol{p}_1 + \boldsymbol{p}_2)/2$, denotes the average momentum of a pair of pions, whereas $\boldsymbol{p}_1$ and $\boldsymbol{p}_2$ are the momenta of the two identical pions emitted from fireball. Moreover, q_{long} is the momentum difference along the beam axis, q_{out} is the momentum difference transverse to the beam axis and parallel to the total transverse momentum of the pair, and q_{side} is the direction transverse to the beam axis and perpendicular to the transverse momentum of the pair. As a consequence, $R_i(\boldsymbol{K})$ (i = out, side, long), the inverse widths of the two-pion correlation functions, show a characteristic dependence on the average momentum of the pair. For discussing below, the transverse mass of the pair is defined as $m_t = \sqrt{\boldsymbol{K}_t^2 + m^2}$

HBT analysis is a tool in the determination of the geometrical size of hadron emission zones generated in heavy-ion collisions. However, the inverse widths of HBT correlation functions do not have a simple interpretation in terms of fireball size. These parameters have to be considered as combinations of space-time moments from space-time densities. Experimental findings are that the extracted size parameters show a m_t-scaling behavior, namely that the size parameters are inversely proportional to the square-root of the transverse mass, $1/\sqrt{m_t}$. Up to now, the observation was attributed due to the hydro type collective flow that developed in heavy-ion collisions[9,10].

Fig. 1 shows the two-pion HBT size parameters R_{out}, R_{side}, and R_{long}(fm) as a function of pair transverse mass m_t for p + p(triangle), Si + Si(square) and Au + Au (circle) central collisions at the center-of-mass energy $\sqrt{s}$ = 200GeV/u. R_{side} and R_{long} distributions are fitted with a scaling function ~ $m_t^{-\alpha}$ and the results are shown as lines in the figure. It can be seen that the HBT size parameters from all colliding systems are decreasing as m_t increases. In the longitudinal direction the rate of the decreasing are the same for all of the systems considered here, $\alpha \approx 0.8$, indicating that the behavior is driven by the initial condition. On the other hand, in the transverse direction, how fast of the size parameter decrease as a function of m_t depends on the size of the colliding system.

As mentioned above that the power parameters α show that α_{long} is almost the same for all collisions. On the other hand, in the transverse direction the α parameter does not show any trend. In p + p collisions, it is even larger than that in Si + Si and Au + Au collisions. Should the m_t-dependence of the HBT size parameters arise from the collective flow, the α_{side} in p + p collisions must be less than that from heavy-ion collisions, but it is not the case here. Such discrepancies indicate that space-momentum correlation has already been there at the moment of particle production in p + p collisions. Such correlation will be observed via the m_t-dependence. In heavy-ion collisions, due to the secondary scattering, the correlation due to flow will be developed. Unfortunately, it is difficult to separate the difference in the HBT measurements.

To understand the observed m_t-dependence of the HBT size parameters as well as to disentangle geometrical and dynamical components of the observed event anisotropy[11-13], several authors have already addressed the necessity of studies of non-central heavy-ion collisions[14,15].

Fig.2 shows the two-pion HBT size parameters R_{out}, R_{side}, and R_{long} (fm) as a function of the pair transverse mass m_t with respect to the reaction plane for Au + Au non-central collisions at the center-of-mass energy $\sqrt{s}$ = 200GeV/u. The reaction plane is defined by the impact parameter (x-direction) and the projectile momentum (z-direction). At the beginning of the collision, the overlapped region can be viewed as an ellipse with its long axis oriented in the y-direction. In Fig.2 filled-dots, open-circles and open-squares, respectively, represent the results from events without angle cuts, with in-plane, and out-of-plane cuts. The cuts require both particles within ± 30° either

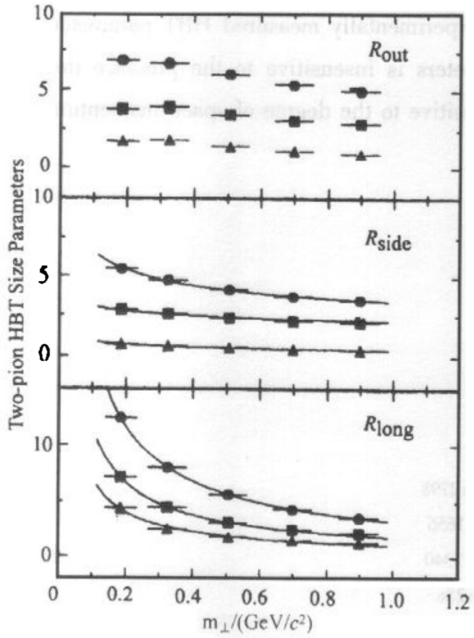

Fig.1. The two-pion HBT size parameters as a function of pair transverse mass m_t for p + p (triangle), Si + Si (square) and Au + Au (circle) collisions at $\sqrt{s}$ = 200GeV/u. R_{side} and R_{long} distributions are fitted with the scaling function $m_t^{-\alpha}$.

● Au + Au, ■ Si + Si, ▲ p + p.

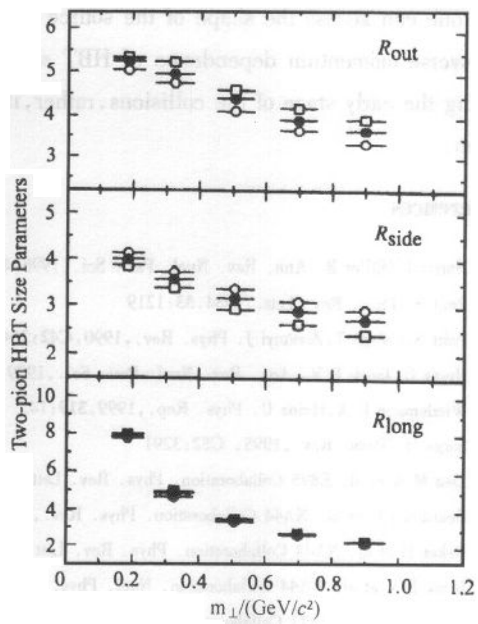

Fig.2. The two-pion HBT size parameters R_{side}, R_{out}, and R_{long} as a function of pair transverse mass m_t for Au + Au non-central collisions at $\sqrt{s}$ = 200GeV/u. The calculations are performed with respect to the reaction plane.

● No-angle cut, ○ In-plane, □ Out-of-plane.

in-plane or out-of-plane accordingly. While no sizable effects are seen in the longitudinal size parameters R_{long}, there are clear effects in the transverse size parameters. In the pair momentum (or out) direction, the values of R_{out} from the out-of-plane region (open squares) are always larger than those from the in-plane region (open circles). In the side direction which is perpendicular to the pair momentum direction, the situation is reversed. Namely, the values of R_{side} from the in-plane region (open circles) are always larger than those from the out-of -plane region (open squares). In terms of the geometry in coordinate space, this means that at freeze-out, the shape of the source is an ellipse with its longer axis in the y-direction. Note that this shape is similar to the one at the beginning of the collisions.

In summary, using the dynamical transport model RQMD (v2.4), the midrapidity two-pion correlation functions are calculated for Au + Au collisions at RHIC energy $\sqrt{s}$ = 200GeV/u. The behavior of the HBT parameters is studied for both central and non-central collisions. The HBT size parameters for different size central colliding systems show a similar decreasing as the pair transverse momentum increases. We argue that this dependence contains the information of space-momentum correlation created at the moment of particle production in heavy-ion collisions. In non-central collisions, We find that the size parameters do reflect the source geometry at freeze-out. This confirms that one can access the shape of the source via the experimentally measured HBT parameters. The transverse momentum dependence of HBT size parameters is insensitive to the pressure developed during the early stage of the collisions, rather, it is sensitive to the degree of space-momentum correlation.

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RHIC 能区 Au + Au 碰撞中 HBT 关联参数分析*

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摘要　利用相对论量子分子动力学模型 RQMD，对 RHIC 能区$\sqrt{s}$ = 200GeV/u Au + Au碰撞进行了 2π 干涉学分析，并讨论了 HBT 半径参数对横动量的依赖关系．研究表明，两粒子关联函数能够给出碰撞源在冻结时刻的时空拓扑信息，HBT 半径参数能够较好地反映源的尺度和形状，但其对横动量的依赖关系并不能直接反映源的压缩性质，而是对粒子产生时源的空间－动量关联程度更为敏感．

关键词　重离子碰撞　HBT 关联　关联函数

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