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Event Anisotropy in Au + Au Non-central Collisions at RHIC Energy

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Abstract Using the dynamical transport model RQMD, the HBT size parameters and event anisotropy are studied for Au + Au non-central collisions at RHIC energy. We find that the HBT size parameters reflect the source geometry at freeze-out for such non-central collisions and the HBT size parameters as a function of m_t are insensitive to the pressure developed during the early stage of the collisions.

Key words heavy-ion collisions, HBT correlation, event anisotropy

Interplay between collective flow and two-particle interferometry in heavy-ion collisions has been a subject of interest for quite some time[1-3]. The main point is to understand the momentum space structure of the system at freeze-out in order to extract information about earlier stages of the collision. In order to understand the observed dependence of the Hanbury-Brown and Twiss effect (HBT) size parameters on transverse momentum and the inference of flow on single particle spectra as well as to disentangle geometrical and dynamical components of the observed event anisotropy[4-6], several authors have already addressed the necessity of studies of non-central heavy-ion collisions[7,8].

In this letter, we study the event anisotropy and the dependence of pion HBT parameters on pair transverse mass for Au + Au non-central collisions at center of mass energy $\sqrt{s} = 200A\,\text{GeV}$. The impact parameter range used is b = 7—9fm. The RQMD(v2.4) event generator[9] is used to simulate the events and a correlation after-burner is used to calculate the correlation functions. The 3-dimensional Gaussian fit is employed to extract the HBT

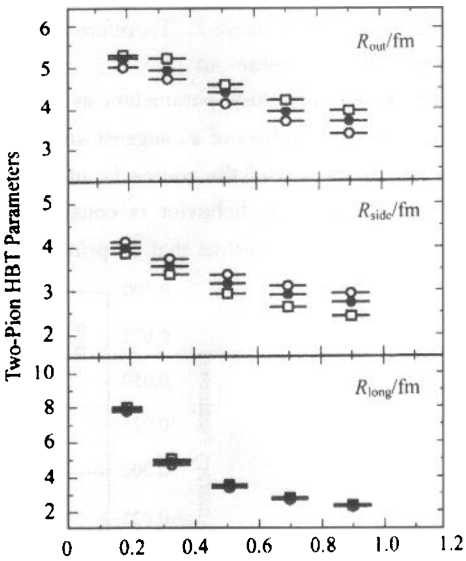

Fig.1. The two-pion HBT size parameters in Au + Au non-central collisions at $\sqrt{s}$ = 200 A GeV.

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size parameters R_i (i = side, out, long) corresponding to sideward, outward and longitudinal directions[10], respectively. Only pions from center rapidity region $|y| \leq 1$ are used here. In this study, 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. Fig.1 shows the pion HBT size parameters R_{side}, R_{out}, and R_{long} as a function of the pion pair transverse mass with respect to the reaction plane. 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 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.

Particle azimuthal distributions with respect to the reaction plane in a given rapidity window can be expressed by the Fourier expansion[11]. In momentum space the second coeffcient is defined as $v_2 = \langle\cos(2\phi)\rangle$ with $\phi = \tan^{-1}(p_y/p_x)$, and in configuration space it is defined as $s_2 = \langle\cos(2\phi)\rangle$ with $\phi = \tan^{-1}(y/x)$. While v_2 is claimed to be related to the initial pressure gradient, the s_2 parameter (not directly measurable) is connected to the geometrical content of the HBT parameters (measurable in experiments). Therefore the HBT measurements help to quantify asymmetries in configuration space at freeze-out.

The event anisotropy parameters as a function of the transverse mass m_t are plotted in Fig.2 where the positive values of v_2 suggest an enhanced in-plane emission while the negative values of s_2 means that the shape of the source is an ellipse with its longer axis in the y-direction, the out-of-plane region. Such s_2 behavior is consistent with the twoparticle correlation function results discussed above. This confirms that in principle the HBT measurement can indeed reveal the source

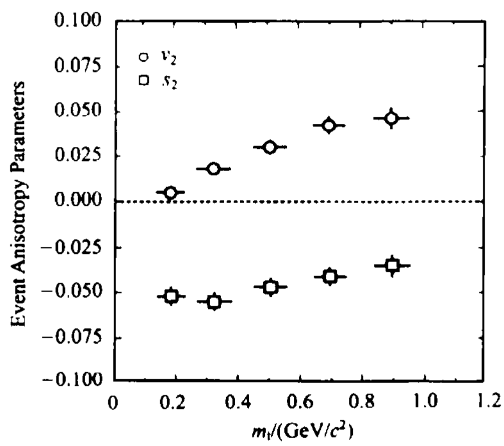

Fig.2. The event anisotropy parameters in Au + Au non-central collisions at $\sqrt{s}$ = 200 A GeV.

shape and its orientation in coordinate space. The positive v_2 and negative s_2 behavior are depicted in Fig.3 where the pion distributions, as a function of freeze-out time, in coordinate space and momentum space are shown in left and right column, respectively. Clearly, at early time, in configuration space the enhanced emission is from the y-direction ($s_2 \leqslant 0$) while in momentum space it is in the x-direction ($v_2 \geqslant 0$).

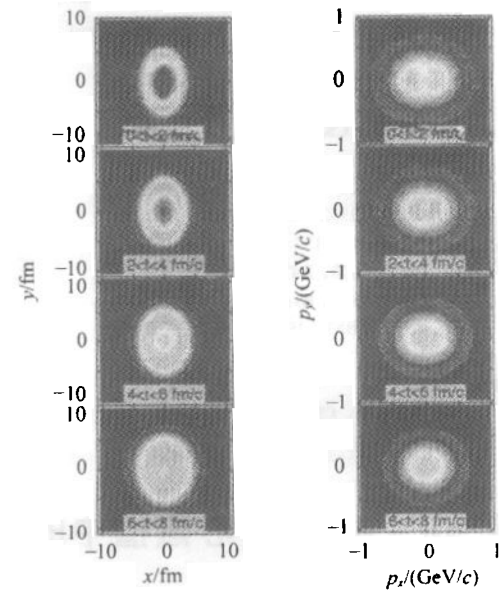

Fig.3. The Pion phase space evolution in Au + Au non-central collisions at $\sqrt{s}$ = 200 A GeV.

However, the larger pressure gradient in the in-plane direction does not lead to the stronger m_t dependence of the size parameters. As shown in Fig.1(b), the m_t dependence in the in-plane direction (open circles) is in fact weaker than that in the out-of-plane direction (open squares). This observation certainly underlines the importance of the initial asymmetry in nuclear collision and casts doubt on the flow effect in the m_t dependence statement. This observation indicates that what is behind the m_t dependence of the HBT size parameters is the space momentum correlation, not necessarily driven by the hydrodynamic pressure. In addition, one also observes that for a given particle, whence the corresponding directions of transverse momentum and space vectors are randomized, the m_t distribution of radii becomes flat.

Due to the collision geometry, it is not surprising that the angular correlation is stronger in the out-of-plane direction in non-central collisions. As can be seen in Fig.3, the long axis is in the y-direction (out-of-plane direction). At relatively early time, particles freeze-out from the surface of the overlapped region, see Fig.3 (left column). This leads to a smaller value of the averaged angle between their space vector and momentum vector in the y-direction compared to the x-direction. At later time, the source becomes more symmetric in the transverse plane. In the right column of Fig.3, the transverse momentum distributions are found to be non-symmetric at early time, with $p_x \geqslant p_y$, and later become more and more symmetric. In this model, the pion mean freeze-out time is about 20 fm/c and the anisotropies measured by both HBT radii and v_2 are developed at relatively early time.

In summary, using the dynamical transport model RQMD(v2.4) the event anisotropy of Au + Au collisions is studied at the center of mass energy $\sqrt{s} = 200A\text{GeV}$. Combined with the studies of two pion correlation functions with respect to the reaction plane, one finds that the HBT 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 m_t-dependence of the size parameters does not reflect the pressure that developed at the early stage of the collisions, rather, they are very sensitive to the space-momentum correlation created in the collision.

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RHIC能区Au + Au非对心碰撞中的事件形状

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摘要 利用相对论量子分子动力学模型RQMD,结合2π干涉学分析,对RHIC能区$\sqrt{s} = 200A\text{GeV}$ Au + Au非对心碰撞的事件形状进行了研究. 研究表明,HBT参数可以反映事件在坐标空间的非对称性,而不能直接给出事件在动量空间的压力梯度. 另外,HBT参数对横动量的依赖关系对系统的空间-动量关联较为敏感.

关键词 重离子碰撞 HBT关联 事件非对称性

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