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Sensitivity of HBT Parameters to Shape of π Source*

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Abstract: The HBT radius parameters and the HBT λ-parameters of single Gaussian source and double Gaussian source are investigated by using two-pion correlation function in HBT intensity interferometry. It is indicated that the radius parameter is insensitive to the spatial shape of the edge zone of source and is mainly affected by the size of the central zone of pions emitted in high energy heavy-ion collisions. The pions produced at the edge of source influence the λ parameter. The non-Gaussian form of spatial distribution of source can lead to the decrease of the λ parameters.

Key words: HBT correlations; radius parameter; λ parameter

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Identical particles, produced in the hot and density interacting region formed in high energy heavy ion collisions, are correlated in their momenta distribution due to interference[1,2]. This effect is a dominant feature in heavy ion collisions and is used to measure the size of the region from which the particles were emitted[3,4].

In experiments, one is customary to perform log-likelihood fits to the two-pion correlation function with the form[5]

$$C(p, q) = 1 + \lambda \exp\left[-(p-q)^2 \frac{R^2}{2} - (\omega_p - \omega_q)^2 \frac{\tau^2}{2}\right], \tag{1}$$

where p and q are the momentum of pions, ω_p is the energy of a pion with momentum p, R and τ are the size and lifetime of source of the Gaussian emission function: $g(p, x) \propto \exp[-(r/R)^2-(t/\tau)^2]$. In general, λ is less than one, namely, the height of the peak to be less than one. There are many researchers who try to interpret why the λ parameter was limited between 0 and 1. Someone thought it was the result of partially coherent sources[5,6]. In addition, the Coulomb interaction between the two correlating particles, which change the form of the two-particle wave function, will change λ[7]. Also one has to consider space-momentum correlations[8].

Because intensity interferometry have been shown to be sensitive to the geometry of the pion-emitting source in heavy ion collisions[1,4,9], in this paper, we mainly study the influence of the shape of pions source on two-pion correlation function. One double Gaussian source and two single Gaussian sources are constructed. We investigate the behavior of the radius parameter and the λ parameter of these three sources by using the two pions correlation function.

Fig. 1 shows the distribution of z coordinate for pions obtained from the relativistic quantum

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molecular dynamics (RQMD) model (Version 2.4) for Au + Au collisions at $\sqrt{s} = 200\ A$ GeV[10], which is a kind of dynamical transport approach model. Only pions from directly collision production are used, according to the rapidity cutting $|y| < 6$ and impact parameter $0 < b < 12$. In the left panel of Fig. 1, the single Gaussian function $g(p, x)$ is used to fit the histogram of z coordinate. The fit radius parameter is (55.5±0.2) fm. In the figure, there is pretty large difference between the histogram and the curve fitted by Gaussian function. The shape of z distribution is more complicated than single Gaussian function. With detail comparison of the histogram to the Gaussian curve, it is indicated that most of pions are located in the center of pion-emitted zone, and a part of pions is produced in the zone (about $|z| > 100$ fm) where the probability of pion produced is almost equal to zero according to the single Gaussian function. These pions look like belonging to another Gaussian source. The histogram may be the superposition of several Gaussian functions. Here we suggest a simply superposition of two Gaussian functions. Without consideration of the influence of the source's life-time, arbitrary superposition of two chaotic sources with Gaussian form is

$$g(p,x) \propto \lambda_1 \exp[-(r/R_1)^2] + \lambda_2 \exp[-(r/R_2)^2], \quad (2)$$

where λ_1 and λ_2 represent arbitrary weights of the two chaotic sources; R_1 and R_2 are the radius of the two Gaussian sources. The curve in the right panel in Fig. 1 is the results by using this double Gaussian function to fit the histogram of z coordinate. It is obvious that the z distribution for pions are much closer to the superposition of two Gaussian functions rather than single Gaussian function, if we compare the fit accuracies of the left and right panel in Fig. 1. The fit parameters are listed as follows:

$\lambda_1 = 80\,710. \pm 168.$, $R_1 = (20.2 \pm 0.1)$ fm;

$\lambda_2 = 14\,748. \pm 43.$, $R_2 = (123.9 \pm 0.2)$ fm.

Normalizing this double Gaussian function, we can get $\lambda_1 = 0.846$ and $\lambda_2 = 0.154$. The value of R_2 is about six times of R_1. Results show that the actual source can be divided into two Gaussian sources: the big source ($R = 123.9$ fm) has smaller weight than the small source ($R = 20.2$ fm) for Au + Au collisions at $\sqrt{s} = 200\ A$ GeV. It is also indicated that most of pions are produced in the center of the interaction area. The pions produced at the edge of the interaction area mostly belong to the big Gaussian source.

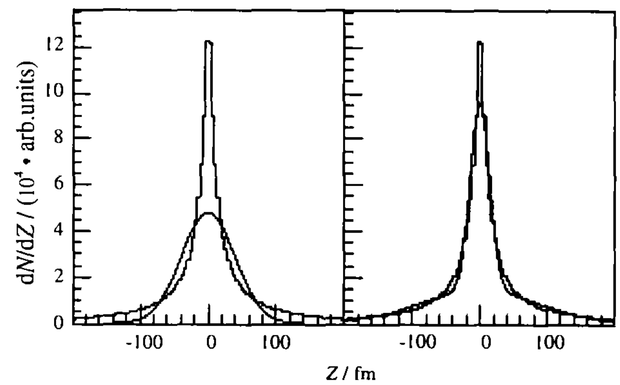

Fig. 1 The distribution of z coordinate for pions fitted by single Gaussian function (left) and double Gaussian function (right).

Although the data of the spatial coordinate can be got from transport model RQMD, it cannot be got directly from experimental data. In order to get information about the space structure, one need research identical particles' interferometry. In the past decades, there are extensive researches of the pion interferometry map out the space-time geometry[11—12].

As mentioned above, one is always customary to use the correlation function (1) to fit the momenta distribution of experimental data. In fact, there will be a wide gap between the fit parameters and the true data of source if we use this correlation function resulted from single Gaussian function to fit data from the double Gaussian source. In order to research the gap, three sources are created: two single Gaussian sources with $R = 20.2$ fm and $R=$ 123.9 fm respectively, and one double Gaussian source with $\lambda_1 =$ 0.846, $R_2 =$ 20.2 fm and $\lambda_1 =$ 0.154, $R_2 =$ 123.9 fm. Then radius parameters and λ parameters can be obtained by fitting the correlation function.

Fig. 2 shows the two pions correlation function and the fit curves. The solid lines are the results using the correlation function to fit. The fit parameters are listed as follow:

for Gaussian source($R=$ 20.2 fm),

$$\lambda^{(1)} = 1.015 \pm 0.008, \quad R^{(1)} = (20.1 \pm 0.1)\ \text{fm};$$

for Gaussian source($R=$ 123.9 fm),

$$\lambda^{(2)} = 1.073 \pm 0.089, \quad R^{(2)} = (127.8 \pm 3.9)\ \text{fm};$$

for double Gaussian source,

$$\lambda^{(3)} = 0.728 \pm 0.007, \quad R^{(3)} = (20.2 \pm 0.1)\ \text{fm}.$$

The radius parameter $R^{(1)}$ is equal to $R^{(3)}$ in static error ranges. It indicates that radius parameters only reflect the information of the center of pions' source rather than of the edge of pions' source. In other word, pions emitted at the edge of zone don't influent radius parameter. It mainly depends on the size of central area of most of the pions emitted in Au + Au collisions at $\sqrt{s} = 200\ A$ GeV. At the same time, the double Gaussian source reduces the value of λ parameter. As mentioned above, the decrease of λ fit parameter may originate from the partially coherent sources, the Coulomb interaction, etc. Moreover, our results show clearly that the decrease of λ may result from non-ideal Gaussian source. While discussing any possible contribution to $\lambda < 1$, one should consider not only partially coherent sources, the Coulomb interaction, etc., but also the influence of fitting data of non-Gaussian source by the correlation function resulted from Gaussian source.

In summary, we have investigated the distribution of z coordinate and the two particle correlation functions for pions obtained from the RQMD calculations for Au + Au collisions at of $\sqrt{s} = 200\ A$ GeV. The results show that the radius parameters are insensitive to the detail of the spatial distribution of source. It mainly depends on the size of central area of most of pions emitted, namely, the size of the source with smaller radius parameter in two Gaussian functions of the double Gaussian source. At the same time, the histogram of z coordinate is clearly far from ideal Gaussian function shape. Its shape is much closer to the superposition of two Gaussian functions. The study indicates that non-ideal Gaussian source leads to the decrease of λ fit parameter. While discussing any possible contribution to decrease λ, one should consider the influence of non-Gaussian source on fitting the correlation function.

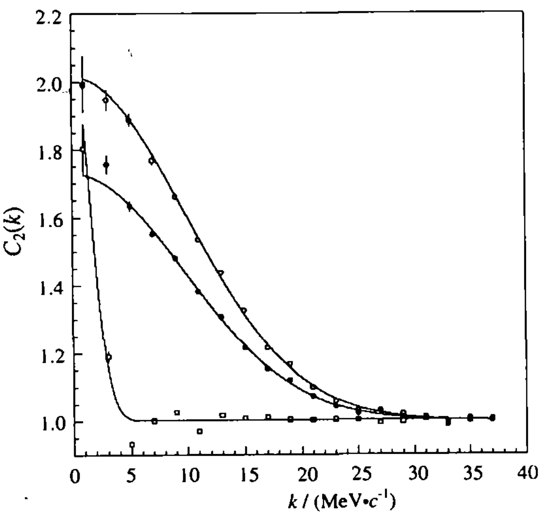

Fig. 2　The two pions correlation functions of Gaussian source ($R=$ 20.2 fm, ○), Gaussian source ($R=$ 123.9 fm, □) and double Gaussian source ($R_1 =$ 20.2 fm and $R_2 =$ 123.9 fm, ●). $k = |p - q|$.

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HBT 参数对 π 源空间分布的敏感性研究*

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摘　要：利用理想高斯源的两粒子关联函数，对单高斯源和双高斯源的两 π 介子 HBT 关联效应进行了研究，得出了相应的半径参数和 λ 参数. 结果表明，半径参数主要取决于高能重离子碰撞中多数 π 介子产生的中间区域；对产生 π 介子的边缘区域的空间分布形状不敏感. 在边缘区域内产生的 π 介子主要影响 λ 参数的变化. π 介子源空间分布的非高斯形是导致 λ 参数减少的一个重要因素.
关 键 词：HBT 关联；半径参数；λ 参数

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