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Test of Quark-Gluon Plasma of Cylindrical Shape by Two-Pion Interferometry

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Abstract The two-pion correlation functions are different for some pion source distributions in two-pion interferometry. If quark-gluon plasma of cylindrical shape is produced in relativistic heavy ion collisions, the pion mesons will emit from the surface of quark-gluon plasma of cylindrical shape and the corresponding correlation function will have a special oscillation behavior. The oscillation behavior can be used to verify the existence of quark-gluon plasma and is also a signature of the appearance of quark-gluon plasma.

Key words quark-gluon plasma, two pion interferometry, relativistic heavy ion collisions

1 Introduction

The results from quantum chromodynamics at finite temperature and phenomenological models indicate that quark-gluon plasma may appear at the temperature of 200MeV and/or the energy density of 1.5GeV/fm^3. Theoretically, quarks are confined in hadrons, but they are free in quark-gluon plasma. The big bang model shows that the matter produced in the early universe at the time of $10^{-6}\mu$s may be in the state of quark-gluon plasma. Therefore, the verification of quark-gluon plasma is very important, because it can provide the information about the state of matter that is needed in the studies of relativistic astronomy and heavy ion collisions. Because of the range of the spacetime dimensions of quark-gluon plasma which may be produced in relativistic heavy ion collisions, the phase transition from hadronic matter to quark-gluon plasma cannot directly be observed, it can only be verified by some signals in the experiment. For example, the momentum spectra of the leptons and photons, the increased number of strange particles, the suppresion of J/ψ mesons, the shape of rapidity distribution of final particles and the decrease of pion source expansion can be used to check the existence of quark-gluon plasma[1]. In Ref. [2], Pratt investigated the test of quark-gluon plasma by two-pion interferometry on spherical sources and proposed that an anomalously long-lived source with a smaller explosive velocity can be the signal of a first-order phase transition with a large latent heat. In Ref. [3], the test of quark-gluon plasma of spherical shape was studied.

In this paper, the charactistics of two-pion correlation function for quark-gluon plasma of cylindrical shape is investigated.

2 Two-pion interferometry

By assuming the pion source density distribution $\rho(\boldsymbol{r},t)$, the two-pion correlation function is defined as[3—20]

$$C(\boldsymbol{p}_1,\boldsymbol{p}_2)=\frac{P_2(\boldsymbol{p}_1,\boldsymbol{p}_2)}{P_1(\boldsymbol{p}_1)P_1(\boldsymbol{p}_2)}=1+\lambda|\tilde{\rho}(q_{12})|^2 , \qquad (1)$$

where $P_2(\boldsymbol{p}_1,\boldsymbol{p}_2)$ represents the probability when a pion pair has momenta $\boldsymbol{p}_1$ and $\boldsymbol{p}_2$, $P_1(\boldsymbol{p})$ the single pion probability distribution, $q_{12}=\boldsymbol{p}_1-\boldsymbol{p}_2$, and λ the coherence factor which equals zero for a completely coherent source and one for a chaotic source. The

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expression for λ is

$$\lambda=\frac{1+2\gamma}{(1+\gamma)^2}\ , \tag{2}$$

where

$$\gamma=\frac{n_{\rm c}}{n_{\rm in}}\ . \tag{3}$$

In Eq. (3), $n_{\rm c}$ and $n_{\rm in}$ are the average pion multiplicities for coherent and chaotic sources, respectively, and $\tilde{\rho}(q_{12})$ is the Fourier transformation of $\rho(\boldsymbol{r},t)$. For a pion source with a cylindrical surface distribution, the pion source density distribution is

$$\rho_{\rm s}(\boldsymbol{r},t)=\frac{1}{4\pi a}\rho(r-a)[\rho(z+b)+\rho(z-b)]\ , \tag{4}$$

the corresponding correlation function is

$$C_{\rm s}(\boldsymbol{q})=1+\lambda_{\rm s}[\cos(q_{\rm l}b)J_0(q_{\rm t}a)]^2\ , \tag{5}$$

and the correlation function at small relative momentum is

$$C_{\rm ss}(\boldsymbol{q})=1+\lambda_{\rm s}-\lambda_{\rm s}(q_{\rm l}^2b^2+\frac{1}{2}q_{\rm t}^2a^2)\ , \tag{6}$$

For a pion source with a cylindrical uniform distribution, the pion source density distribution is

$$\rho_{\rm u}(\boldsymbol{r},t)=\frac{1}{2\pi R_{\rm t}^2R_{\rm l}}\ , \tag{7}$$

the corresponding correlation function is

$$C_{\rm u}(\boldsymbol{q})=1+\lambda_{\rm u}\frac{4}{R_{\rm t}^4R_{\rm l}^2}\left[\frac{\sin(q_{\rm l}R_{\rm l})}{q_{\rm l}}\cdot\frac{R_{\rm t}J_1(R_{\rm t}q_{\rm t})}{q_{\rm t}}\right]^2, \tag{8}$$

and the correlation function at small relative momentum is

$$C_{\rm u}(\boldsymbol{q})=1+\lambda_{\rm u}-\lambda_{\rm u}\left(\frac{1}{3}q_l^2R_{\rm l}^2+\frac{1}{4}q_{\rm t}^2R_{\rm t}^2\right), \tag{9}$$

For the same pion source created in a relativistic heavy ion collision,taking Eq. (9) and Eq. (6) to be equal,one obtaining

$$\lambda_{\rm s}\ =\ \lambda_{\rm u}\ , \tag{10}$$

$$b\ =\ \frac{1}{\sqrt{3}}R_{\rm l}\ , \tag{11}$$

$$a\ =\ \frac{1}{\sqrt{2}}R_{\rm t}\ . \tag{12}$$

3 Test of quark-gluon plasma by two-pion interferometry

If quark-gluon plasma is produced in an ultrarelativistic heavy ion collision, the hadronization will happen on the surface of quark-gluon plasma, so the quark-gluon plasma will emit pion mesons from its surface, and the corresponding correlation function is Eq. (5). If no quark-gluon plasma is produced, the individual particle-particle collisions which produce pion mesons will happen throughout the collision region, then the pions can be produced in the whole collision region, and the corresponding correlation function is Eq. (8).

In longitudinal relative momentum direction, zero points for Eq. (5) are

$$q_{\rm ls}=\frac{k\pi+\frac{1}{2}\pi}{b}=\sqrt{2}\frac{k\pi+\frac{1}{2}\pi}{R_{\rm gsl}}\quad(k\geqslant0),$$

and zero points for Eq. (8) are

$$q_{\rm lb}=\frac{k\pi}{R_{\rm l}}=\sqrt{\frac{3}{2}}\frac{k\pi}{R_{\rm gsl}}\quad(k\geqslant0).$$

The interval between zero points for Eq. (5) is

$$\Delta q_{\rm ls}=\sqrt{2}\frac{\pi}{R_{\rm gsl}},$$

and the interval between zero points for Eq. (8) is

$$\Delta q_{\rm lb}=\sqrt{\frac{3}{2}}\frac{\pi}{R_{\rm gsl}}.$$

At large transverse relative momentum , zero points for Eq. (5) are

$$q_{\rm ts}=\frac{k\pi+\frac{3}{4}\pi}{a}=\frac{k\pi+\frac{3}{4}\pi}{R_{\rm gst}}\quad(k\geqslant0),$$

and zero points for Eq. (8) are

$$q_{\rm tb}=\frac{k\pi+\frac{5}{4}\pi}{R_{\rm t}}=\frac{k\pi+\frac{5}{4}\pi}{\sqrt{2}R_{\rm gst}}\quad(k\geqslant0).$$

The interval between zero points for Eq. (5) is

$$\Delta q_{\rm ls}=\frac{\pi}{R_{\rm gst}}\ ,$$

and the interval between zero points for Eq. (8) is

$$\Delta q_{\rm lb}=\frac{\pi}{\sqrt{2}R_{\rm gst}}\ .$$

There are two methods to test quark gluon plasma. One is to see the zero points of the correlation functions. The other is to observe the interval between zero points of the correlation functions at the large relative momentum.

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柱形夸克胶子等离子体的2π干涉学检测

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摘要 在2π干涉学中, 对不同的π源, 2π关联函数可以是不同的. 如果在相对论重离子碰撞中出现柱形夸克胶子等离子体, π介子将从柱形夸克胶子等离子体表面发射, 此时2π关联函数将出现一种特殊的振荡行为. 这种振荡行为可以用来探明夸克胶子等离子体的存在性, 同时也是相对论重离子碰撞中出现夸克胶子等离子体的一个信号.

关键词 夸克胶子等离子体 2π干涉学 相对论重离子碰撞

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