Shape Analysis of HBT Correlations at STAR

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Abstract—To study the nature of the quark-hadron phase transition, it is important to investigate the space-time structure of the hadron-emitting source in heavy-ion collisions. Measurements of HBT correlations have proven to be a powerful tool to gain information about the source. In these proceedings, we report the current status of the analysis of source parameters obtained from Lévy fits to the measured one-dimensional two-pion correlation functions in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

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1. INTRODUCTION

Quantum-statistical (also called Bose–Einstein or HBT) correlations of identical bosons are used to explore the properties of the hot and dense matter created in heavy-ion collisions [1]. These correlations can provide information on the space-time geometry of the particle-emitting source in heavy-ion collisions.

Description of the shape of correlation function requires the knowledge of the source function which can be tested. Recent studies at different experiments [2–4] showed that to properly describe the shape of the measured quantum-statistical correlation functions it is necessary to go beyond the Gaussian approximation. One possibility is to use Lévy-stable distributions. There could be multiple (competing) reasons behind the appearance of such sources, like anomalous diffusion [5, 6], jet fragmentation [7] or the proximity of the critical endpoint [8]. The definition of the one-dimensional Lévy-stable distribution is the following [9]:

$$L_\alpha (x; \alpha, \beta, \mu) = \frac{1}{\pi} \int_{-\infty}^{\infty} e^{i x q} \Phi{\alpha, \beta, \mu}dq,$$

where the characteristic function is defined as:

$$\Phi{\alpha, \beta, \mu} = \exp\left(i \alpha \mu - \beta |q| (1 + \log |q|)\right),$$

$$\Phi = \begin{cases} \tan\left(\frac{-\pi \alpha}{2}\right), & \alpha \neq 1, \\ -\frac{2}{\pi} \log |q|, & \alpha = 1. \end{cases}$$

The four main parameters are the index of stability, $\alpha$, the skewness parameter, $\beta$ (the distribution is symmetric if $\beta = 0$), the scale parameter, $R$, and the location parameter, $\mu$. The latter is also the median of the distribution, and in case of $\alpha > 1$ it equals to the mean as well. The most important property of this distribution is that it retains the same $\alpha$ and $\beta$ under convolution of random variables, and any moment greater than $\alpha$ is not defined. In case of $\alpha < 2$ the distribution exhibits a power-law behavior, while the $\alpha = 2$ case corresponds to the Gaussian distribution. If we assume that the source is a centered, spherically symmetric Lévy distribution ($S(x) = f(x; \alpha, 0, R, 0)$) and neglect any final state interaction, the one-dimensional two-particle correlation function takes the following form:

$$C(Q) = 1 + \lambda \frac{|\tilde{S}(Q)|^2}{|\tilde{S}(0)|^2} = 1 + \lambda \exp\left(-RQ^\alpha\right),$$

where $\tilde{S}$ denotes the Fourier transform of the source, $Q$ is the one-dimensional relative momentum variable, defined as the absolute value of the three-momentum difference in the longitudinal co-moving system (for details see [2]), and $\lambda$ is the strength of the correlation function.

2. RESULTS AND DISCUSSIONS

In this analysis, we have used Au + Au data at $\sqrt{s_{NN}} = 200$ GeV recorded by the STAR experiment. We measured one-dimensional two-pion HBT correlation functions for like-sign pairs. For the experimental construction of the correlation functions we
used the event-mixing technique. We applied the necessary event-, track-, and pair-cuts, similar to those used in Ref. [10]. To incorporate the effect of the final-state Coulomb interaction, we used the Bowler–Sinyukov procedure [1]:

$$C^{\text{Coul}}(Q) = 1 - \lambda + \lambda K(Q; \alpha, R) \left(1 + \exp\left(-\frac{Q}{Q^*}\right)\right).$$ (5)

For the Coulomb correction, $K(Q; \alpha, R)$, a parametrized formula from [11] was used. Fits of the correlation functions were performed using the ROOT Minuit2Minimizer [12].

As a first check we investigated the Gaussian fits (with fixed $\alpha = 2$) to the data. The example is shown on Fig. 1. The value of $\chi^2$ is very high ($\chi^2 / \text{NDF} \sim 10$), the data are not described well by these fits. The magnitude of the Lévy scale $R$ is compatible with the magnitude of the HBT radii extracted from three-dimensional Gaussian fits in [10]. Releasing the index of stability, $\alpha$, the $\chi^2$ values drop by a factor of 3–5, and the description highly improves in the $Q \simeq 25$ MeV/$c$ region. Figure 2 shows the fit example with the $\alpha$ parameter released. An interesting observation is that the correlation function behavior at very low $Q$ is not described well by these kind of fits. Our investigations showed that this observation stands when varying the analysis cuts, and even in case of measuring the correlation function as a function of a different relative-momentum variable other than $Q$.

3. SUMMARY AND OUTLOOK

In these proceedings, we presented the first Lévy-type HBT studies at STAR. We showed that indeed the Gaussian fits are not compatible with the measured data in case of one-dimensional two-particle correlation functions. The Lévy fits provide a higher quality description of the data at $Q \simeq 25$ MeV/$c$, although the low $Q$ behavior is currently not clear. To understand the reason behind this observation, more detailed investigations are needed. These will include the detailed $m_T$ and centrality dependence, a thorough investigation of systematic uncertainties, and possibly the use of different expansion methods as suggested in [13].

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Fig. 2. Example Lévy fit of a Bose–Einstein correlation function of $\pi^-\pi^-$ pairs with a mean average transverse mass of $\langle m_T \rangle = 0.395$ GeV/$c^2$. The blue points correspond to the measured raw correlation function while the red curve is the fit function introduced in Eq. (5), complemented with a linear background.

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