Shape analysis of HBT correlations at STAR*

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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.

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]:

$$f(x; \alpha, \beta, R, \mu) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \varphi(q; \alpha, \beta, R, \mu) e^{iqx} dq, \tag{1}$$

where the characteristic function is defined as:

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$$\varphi(q;\alpha,\beta,R,\mu) = \exp\left(iq\mu - |qR|^{\alpha}(1 - i\beta\mathrm{sgn}(q)\Phi)\right), \tag{2}$$

$$\Phi = \begin{cases} \tan(\frac{\pi\alpha}{2}), \alpha \neq 1 \\ -\frac{2}{\pi}\log|q|, \alpha = 1 \end{cases} \tag{3}$$

The four main parameters are the index of stability, α, the skewness parameter, β (the distribution is symmetric if $\beta = 0$), the scale parameter, R, and the location parameter, μ. 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 α and β under convolution of random variables, and any moment greater than α 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:

$$C(Q) \approx 1 + \lambda\frac{|\widetilde{S}(Q)|^2}{|\widetilde{S}(0)|^2} = 1 + \lambda\cdot\exp\left(-(RQ)^{\alpha}\right), \tag{4}$$

where $\widetilde{S}$ 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 Ref. [2]), and λ 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]:

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

For the Coulomb correction, $K(Q;\alpha,R)$, a parametrized formula from Ref. [11] was used. Fits of the correlation functions were preformed 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 χ^2 is very high (χ^2/NDF ~ 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 Ref. [10]. Releasing the index of stability, α, the χ^2 values drop by a factor of 3-5, and the description highly improves in the $Q \gtrsim 25$ MeV/c region. Figure 2 shows the fit example with the α 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.

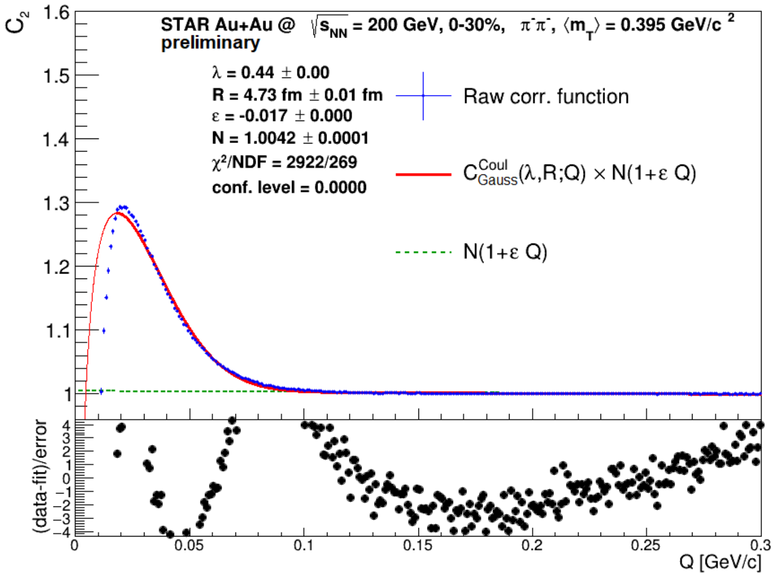

Fig. 1. Example Gaussian fit (fixed $\alpha = 2$) of a Bose-Einstein correlation function of $\pi^-\pi^-$ pairs with a mean average transverse mass of $\langle m_T \rangle = 0.395$ GeV/c^2. The blue points correspond to the measured raw correlation function while the red curve is the fit function introduced in Eq.5, complemented with a linear background.

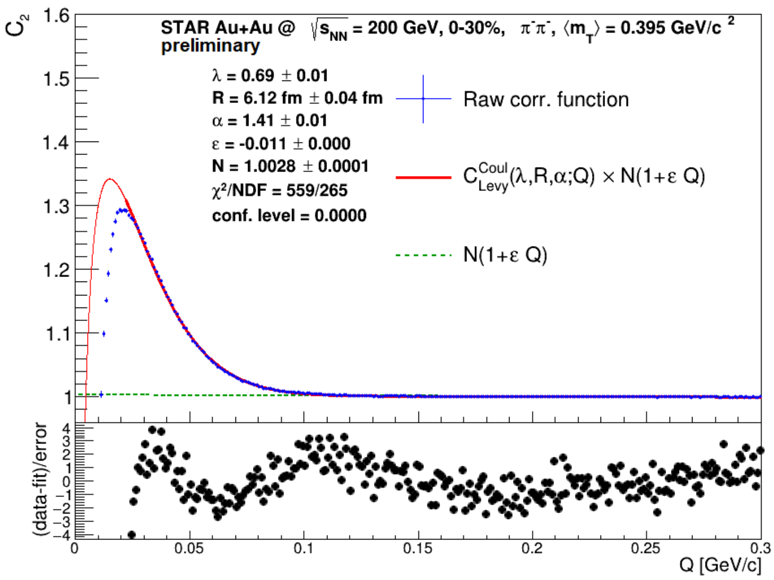

Fig. 2. Example Lévy fit of a Bose-Einstein correlation function of $\pi^-\pi^-$ pairs with a mean average transverse mass of $\langle m_T \rangle = 0.395$ GeV/c^2. The blue points correspond to the measured raw correlation function while the red curve is the fit function introduced in Eq.5, complemented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

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 $Q \gtrsim 25$ 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 Ref. [13].

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