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function at STAR*

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# Non-Gaussian Effects in Identical Pion Correlation Function at STAR

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**Abstract.** Preliminary femtoscopic results on identical pions from high statistics data set of Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV taken during the fourth RHIC run are presented. The measured three-dimensional correlation function is studied at low relative momenta using the Gaussian parametrization and the Lévy stable parametrization. The latter is expected to better describe the data. As the results show, both parametrizations underestimate the peak of the measured correlation function equally.

**Keywords:** STAR, Femtосcopy, Correlation function, Non-Gaussian, Lévy

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## INTRODUCTION

Motivation for this study is to check whether a recently proposed parametrization of the correlation function using Lévy stable source distribution [1] brings a significant improvement over the standard Gaussian fit [2]. In addition to this, the non-Gaussian source distribution function is also used in most of the models, but the standard method of fitting experimental correlation function assumes a Gaussian source [2].

Possible methods of studying the non-Gaussian effects in the experimental correlation function include Edgeworth expansion [3] and Lévy stable source distribution parametrization [1].

## CORRELATION FUNCTION OF IDENTICAL PIONS

*Event and particle selection criteria.* We briefly list the values of the event and particle selection criteria used in the present analysis. Detailed description can be found in [4]. Events are binned by centrality in five bins corresponding to 0–5%, 5–10%, 10–20%, 20–30% and 30–80% of the total hadronic Au+Au cross-section. In addition to the track cuts listed in [4], measured specific ionization of pions is required to be farther than  $\pm 2\sigma$  from the Bethe-Bloch theoretical value for electrons. This cut removes a contamination due to conversion electrons in the low momentum region. Pairs of identical pions are binned by average transverse pair momentum  $k_T = \frac{1}{2}|\vec{p}_{T1} + \vec{p}_{T2}|$  in four bins corresponding to  $k_T \in (0.15-0.25, 0.25-0.35, 0.35-0.45, 0.45-0.60)$  GeV/ $c$  and the results are presented as a function of the average  $k_T$  in each of these bins.

Experimentally, two-particle correlations are studied by constructing the correlation function as a ratio

$$C(\vec{q}) = \frac{A(\vec{q})}{B(\vec{q})}, \quad (1)$$

where  $A(\vec{q})$  is the measured distribution of the momentum difference  $\vec{q} = \vec{p}_1 - \vec{p}_2$  for pairs of particles from the same event and  $B(\vec{q})$  is the corresponding reference distribution for pairs of particles from different events belonging to the same event class as analyzed event [2]. The two-particle correlation function at low relative momentum  $\vec{q}$  of identical pion pairs is studied using Bertsch-Pratt parametrization [5, 6, 7] in the longitudinal co-moving system (LCMS) frame, where the relative momentum vector is decomposed into the out, side and long components  $\vec{q} = (q_o, q_s, q_l)$ .

### Gaussian parametrization

Standard method of fitting the two-pion correlation function assumes the Gaussian source distribution. The correlation function is usually parametrized by a three-dimensional Gaussian in  $\vec{q}$  [2]. Taking into account a repulsive Coulomb interaction between charged identical pions, the measured correlation function (1) is fitted using Bowler-Sinyukov procedure [8, 9],

$$C(\vec{q}) = (1 - \lambda) + \lambda K_c \left[ 1 + \exp \left( - \sum_{ij} R_{ij}^2 q_i q_j \right) \right]. \quad (2)$$

Here, the correlation strength  $\lambda$  equals the fraction of pairs originating in the same spatio-temporal region relevant for Bose-Einstein correlations,  $K_c$  is the squared Coulomb wave-function integrated over the source with radius 5 fm [4].  $R_{ij}$  are the Gaussian source radius parameters defined as the widths of the source emission function. Let us note, that only the pairs obeying Bose-Einstein statistics are considered to Coulomb interact. For an azimuthally integrated analysis the cross-terms vanish [2],  $R_{ij} = 0$ ,  $i \neq j$ .

### Non-Gaussian parametrization

Detailed analysis of the shape of the correlation function is important because it carries information about the space-time structure of the particle emitting source [1, 2]. Deviations from Gaussian shape can be studied using Edgeworth expansion or Lévy stable source distribution.

Edgeworth expansion [3] provides model-independent approach for an analysis of the shape of the correlation function. In our previous pion interferometry analysis [4] it was shown that the Edgeworth expansion, based on an experimentally preferred Gaussian weight function and a complete orthogonal set of even order Hermite polynomials, up to 6<sup>th</sup> order is sufficient to describe the data. However, physical interpretation of the higher order (4<sup>th</sup>, 6<sup>th</sup>) fit parameters is not clear.

## *Lévy stable source parametrization*

To study possible deviations of the correlation function from a Gaussian shape, we followed the method suggested in [1]. This formalism is relevant for the femtoscopic studies of the expanding systems created in heavy-ion collisions, where the scale of the fluctuations may be characterized by long tails and asymptotic power-law like behavior. The probability distribution of particle emission points then corresponds to a Lévy stable distribution [1]. Using the Bowler-Sinyukov procedure to determine the repulsive Coulomb interaction between identical pions, the two-particle correlation function is then characterized by a stretched exponential parametrization,

$$C(\vec{q}) = (1 - \lambda) + \lambda K_c \left[ 1 + \exp \left( - \left( \sum_{ij} R_{ij}^2 q_i q_j \right)^{\alpha/2} \right) \right]. \quad (3)$$

The additional parameter  $\alpha$ , when compared to (2), is the Lévy index of stability,  $0 < \alpha \leq 2$ . For  $\alpha = 2$  the Gaussian form (2) is recovered, while for  $\alpha < 2$  the correlation function becomes more peaked than a Gaussian and develops longer tails. For the azimuthally integrated analysis,  $R_{ij} = 0$ ,  $i \neq j$ .

## DISCUSSION OF RESULTS

Here we present results on two-particle correlations of charged identical pions in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV measured in the STAR detector during the fourth RHIC run (2003–2004). Data set of  $11 \times 10^6$  minimum-bias triggered events is used for this analysis.

The interferometric parameters, correlation strength  $\lambda$  and radii  $R_o$ ,  $R_s$  and  $R_l$ , are obtained by fitting the measured correlation function (1) with the Gaussian parametrization (2). Interferometric radius parameters measure the sizes of the homogeneity regions, regions from where the particles are emitted with the same average pair momentum  $k_T$ , and their  $k_T$  dependence contains dynamical information of the pion emitting source [2].

Figure 1 shows STAR preliminary results on interferometric parameters as functions of  $k_T$  for five centrality bins, where the three-dimensional experimental correlation function is fitted using the Gaussian parametrization of the correlation function (2). Results of the analysis of higher statistics data set of Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV are compared with the previously analyzed STAR data [4] for the same system at the same energy taken during the second RHIC run (2001–2002). It can be seen that the extracted interferometric radii  $R_o$ ,  $R_s$  and  $R_l$  are consistent within errors with the previous analysis. A small systematic shift in radii can be attributed to the momentum resolution correction which is not included in this analysis. Significant difference in  $\lambda$  is observed in the lowest  $k_T$  bin. This is explained by an improved purity of the pion sample, where the additional cut on particle specific ionization removes contamination from the conversion electrons in the low momentum region.

The Gaussian parametrized fit (2) and the Lévy stable source parametrized fit (3) to the measured correlation function, each subtracted from the measured three-dimensional correlation function, are projected in the out, side and long coordinates and compared

in Figure 2. Correlation function is shown for the  $k_T$  bin 0.25–0.35 GeV/ $c$ , for the most central collisions and the projections are constrained by the unprojected variables  $q_0, q_s, q_l < 30$  MeV/ $c$ . It can be seen that contrary to [1], Lévy stable source distribution parametrization (3) does not fit the three-dimensional experimental correlation function significantly better than the standard Gaussian parametrization (2). Both parametrizations equally underestimate the peak value of the measured correlation function for relative momenta  $q_0, q_s, q_l < 20$  MeV/ $c$  and underestimate the tail of the correlation function. Both effects are mostly visible in the long projection in Figure 2.

In Figure 3 the interferometric parameters obtained from the Gaussian parametrization (2) are compared to the parameters obtained using Lévy parametrization (3) of the measured three-dimensional correlation function. Interferometric parameters are shown as functions of  $k_T$  for the most central and peripheral collisions. The Lévy fit returns significantly larger values of the fit parameters  $R_0, R_s, R_l$  and  $\lambda$ . However, these parameters can not be directly compared to the Gaussian ones representing the interferometric radii, because the non-Gaussian parameters do not satisfy the definition of being the widths of the source emission function. The large values of the non-Gaussian fit parameters are strongly anti-correlated with rather low value of the Lévy index of stability  $\alpha$ , which stays between  $1.2 < \alpha < 1.5$ .

It can be seen that the Lévy stable source distribution parametrization (3) does not bring an advantage in describing the detail shape of the measured correlation function, nor in the number of the fitting parameters. Therefore use of the standard Gaussian parametrization (2) is sufficient and preferred.

## SUMMARY

The preliminary results on identical pion interferometry using high statistics sample of Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV from the STAR experiment at RHIC have been presented.

The results of the Gaussian fit to the measured three-dimensional correlation function are consistent within errors with the previously analyzed STAR data.

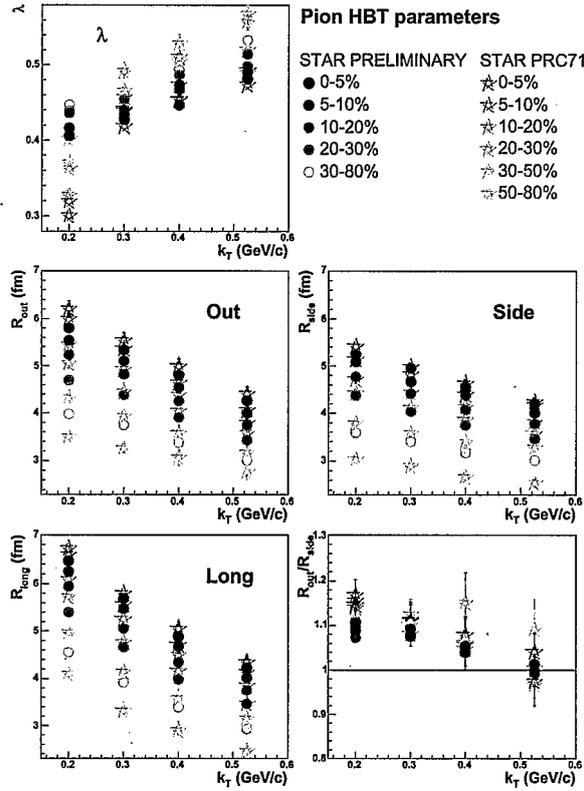
It has been shown that in the low relative momentum region the Lévy stable source parametrization does not fit the experimental correlation function significantly better when compared to standard Gaussian parametrization.

Edgeworth expansion provides the detailed fit to the measured correlation function [4], but the interpretation of the higher order fit parameters is not clear.

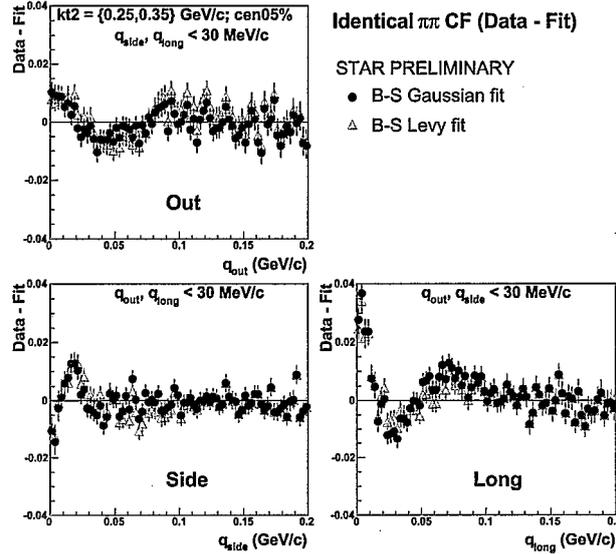
It seems that to represent the experimental correlation function in Au+Au collisions at RHIC, the Gaussian parametrization is sufficient.

## ACKNOWLEDGMENTS

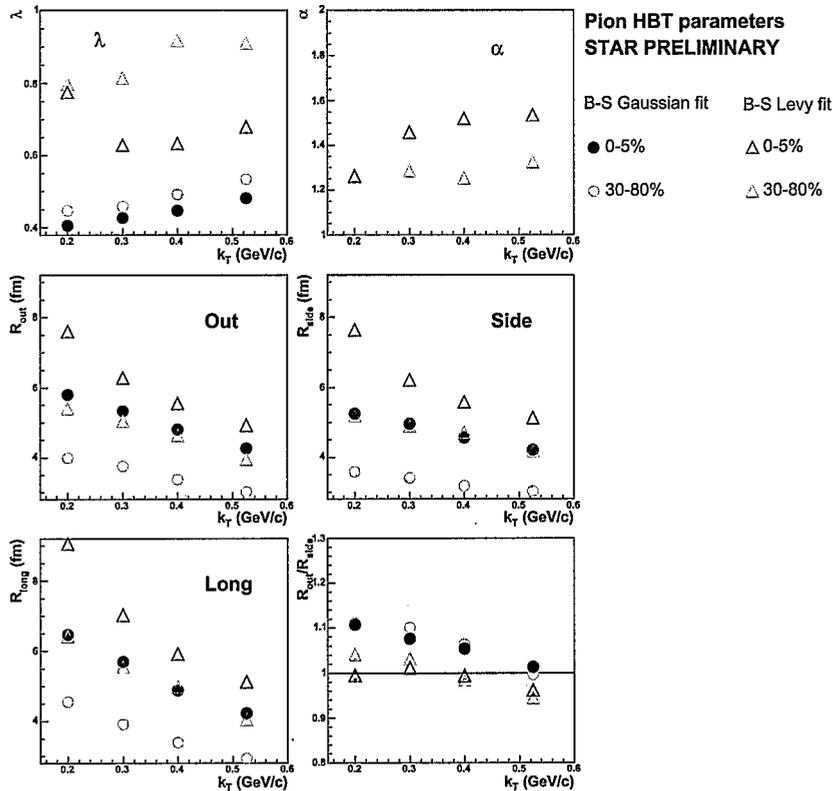
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**FIGURE 1.** Interferometric parameters as functions of  $k_T$  and centrality. Results of the Gaussian parametrized fit (2) to the experimental correlation function, Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV.



**FIGURE 2.** Gaussian parametrized fit (2) to data compared to the Lévy stable source parametrized fit (3) to data, each subtracted from the experimental correlation function.



**FIGURE 3.** Results on interferometric parameters as functions of  $k_T$  and centrality obtained using Gaussian parametrized fit (2) compared to the parameters of Lévy stable source parametrized fit (3) of the measured correlation function.

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