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Nuclear Physics A 774 (2006) 611–614
NUCLEAR PHYSICS A

Measurement and analysis of two- and three-particle correlations

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Allowed regions of core fraction versus partial coherence are obtained from analysis of both two- and three-pion Bose-Einstein correlations measured at PHENIX in $\sqrt{s_{\rm NN}} = 200$ GeV Au+Au collisions. Two-pion Bose-Einstein correlation functions for different average transverse momenta are used to analyze chiral symmetry restoration.

1. Introduction

Correlation functions are important to see the collective properties of particles and space-time structure of the emitting source, eg. the observed size of a system can be measured by two particle Bose-Einstein correlations [1]. The m_t dependent strength of two-pion correlations provides information about $\mathrm{U_A}(1)$ symmetry restoration in the source [2, 3, 4, 5]. From a consistent analysis of two- and three-particle correlations one can establish an experimental measure of thermalization and coherence in the source [6].

2. Data Analysis

We studied 70M $\sqrt{s_{\rm NN}} = 200$ GeV RHIC Au+Au collisions recorded at PHENIX during Run 4. Charged tracks were detected by the Drift Chamber and Pad Chambers. The Time Of Flight detector and the Electromagnetic Calorimeters were used to identify π^+ particles, and we had 200M π^+'s, 900M π^+ pairs and more than 4G π^+ triplets in this analysis. We measured from this data sample the two-pion correlation function C_2 as a function of $q_{\rm inv} = \sqrt{(k_1 - k_2)^2}$ and the three-pion correlation function C_3 as a function of $q_{\rm inv}$ of the three pairs in the triplet, q_{12}, q_{23}, q_{31}.

Our method of Coulomb-correction is based on the solution of the two-body Coulomb-problem. A symmetrized asymptotically correct three-body Coulomb wave-function is built up from the two-body solution. The source function is then integrated with the absolute square of this three-body Coulomb-wave function as the density function, and the same is done for a symmetrized three-body plain-wave function. The ratio of the two gives the Coulomb-correction factor [7]. For the final Coulomb-correction we utilized a core/halo type of picture of the source and iterated λ and R in a self-consistent manner until convergence.

The fits were done using three different shapes, Gauss, Levy and Edgeworth, described in ref. [8]. We fitted only those points with $q_{\rm inv} > 0.02$ GeV/c due to a non-BEC and non-Coulomb structure seen at low $q_{\rm inv}$ (see the gray lines on fig. 1).

*For the full list of PHENIX authors and acknowledgments, see appendix 'Collaborations' of this volume.

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doi:10.1016/j.nuclphysa.2006.06.097

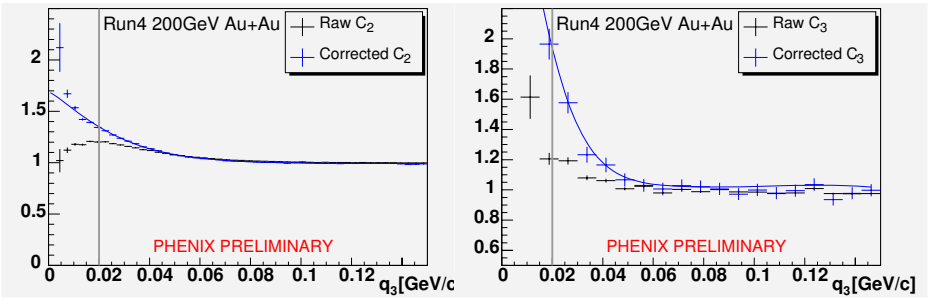

Figure 1. Raw- and Coulomb-corrected correlation functions for $0.2 < p_t < 2.0$ GeV/c and $0-92\%$ centrality with Levy fits. Points with $q_{\rm inv} < 0.02$ GeV/c were excluded from the fits.

3. Results

First, we fitted two- and three-particle correlation functions for $0.2 < p_t < 2.0$ GeV/c and $0-92\%$ centrality. Here only the Levy fits had acceptable confidence levels. These and the Coulomb-corrected correlation functions are shown on fig. 1. The three-dimensional C_3 was projected onto the $q_{12} = q_{23} = q_{31}$ line.

Let us consider the ratios $f_c = N_c(p)/N_1(p)$ (fractional core) and $p_c = N_c^p(p)/N_c(p)$ (partial coherence), and take the equations (see eqs. 57 and 58 in ref. [8]):

$$C_2(p_1 \simeq p_2) = 1 + f_c^2[1 - p_c^2] \quad (1)$$

$$C_3(p_1 \simeq p_2 \simeq p_3) = 1 + 3f_c^2[1 - p_c^2] + 2f_c^3[(1 - p_c)^3 + 3p_c(1 - p_c)^2] \quad (2)$$

From this we calculated the allowed f_c vs p_c region, using the 3σ contours from eqs. 1-2, see fig. 2. The size of the region obtained from C_3 is much larger due to the smaller number of triplets compared to pairs.

Compared to former NA44 analysis (see refs. [6, 9, 10]), the resulting allowed region is at a little bit higher f_c values, because our f_c was obtained from Levy fits and not from Gauss, as confidence level of latter was unacceptable.

In the second part of the analysis, we have analyzed two-pion correlation functions in 10 p_t bins from 0.2 GeV/c to 0.5 GeV/c with $0-92\%$ centrality, using the invariant momentum difference $q \equiv q_{\rm inv}$ as a variable and the following shapes (in $\hbar c = 1$ units):

$$\text{Gauss:}\quad C_2(q) = 1 + \lambda \exp(-|Rq|^2) \quad (3)$$

$$\text{Levy:}\quad C_2(q) = 1 + \lambda \exp(-|Rq|^\alpha) \quad (4)$$

$$\text{Edgeworth:}\quad C_2(q) = 1 + \lambda \exp(-|Rq|^2)(1 + \frac{\kappa_3}{3!} H_3(\sqrt{2}\,|Rq|), \quad (5)$$

where H_3 is the third Hermite polynomial, and κ_3 it's coefficient (the Edgeworth form is a model-independent expansion, of which we keep only the first term, to measure deviation from the Gauss form). See more details in ref. [11].

The parameters as a function of average transverse mass ($\lambda(m_t)$, $R(m_t)$, $\alpha(m_t)$ and $\kappa_3(m_t)$) for Gauss, Levy and Edgeworth fits are shown on fig. 3. The α parameter of the

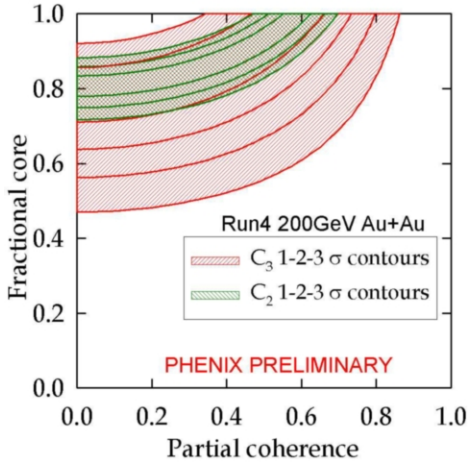

Figure 2. Allowed region of partial coherence versus fractional core extracted from Levy fits. Contours obtained from C_3 are much larger due to smaller statistics of π^+ triplets compared to π^+ pairs.

Levy distribution controls the long-range source in a similar way as the λ parameter, so fitting both makes the fit underconstrained. Hence we did fits also with fixed α, and for comparison, also with fixed κ_3. These latter fits show the same $\lambda(m_t)$ behavior as in the Gaussian case.

The m_t dependence of λ can be used to extract information on the mass-reduction of the η' meson, a signal of the $\mathrm{U_A}(1)$ symmetry restoration in hot and dense matter (see ref. [2]). A comparison of the measurements of fig. 3 with model calculations of ref. [2] using Fritiof results for the composition of the long-lived resonances and a variation of the η' mass is presented in fig. 4.

4. Conclusion

From simultaneous analysis of two- and three-pion correlations we obtained an allowed region of partial coherence versus core fraction. Nonzero partial coherence is allowed when having larger core size, at total incoherence ($p_c = 0$) the core fraction is slightly higher than previous analysis using Gaussian fits (see refs. [6, 9, 10, 12]). This is due to the fact that we used Levy fits, the only investigated one that gave acceptable confidence levels.

We also analyzed the m_t dependence of the λ parameter obtained from various fits. Gauss fit results agree with former PHENIX measurements (see ref. [12]). Regarding $\mathrm{U}_A(1)$ symmetry restoration, we conclude that at present, results are critically dependent on our understanding of statistical and systematic errors, and additional analysis is required to make a definitive statement.

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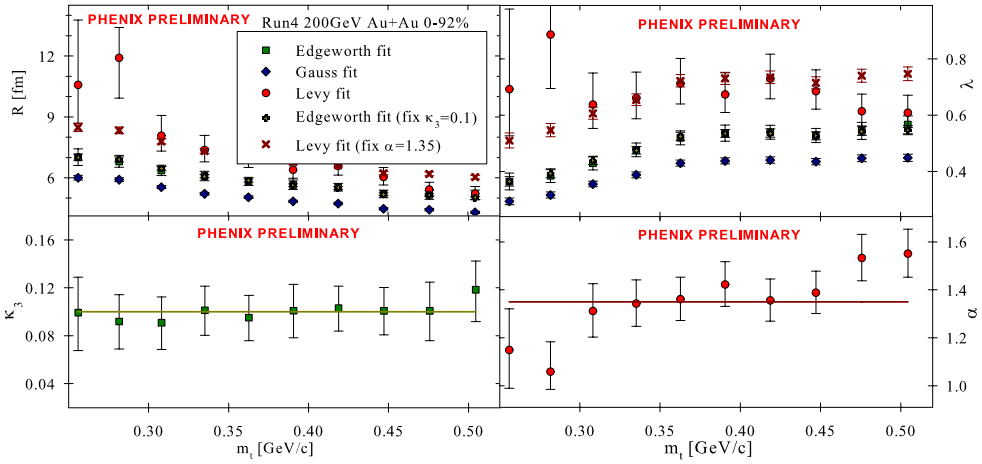

Figure 3. $\lambda(m_t)$, $R(m_t)$, $\alpha(m_t)$ and $\kappa_3(m_t)$ from Gauss, Levy and Edgeworth fits

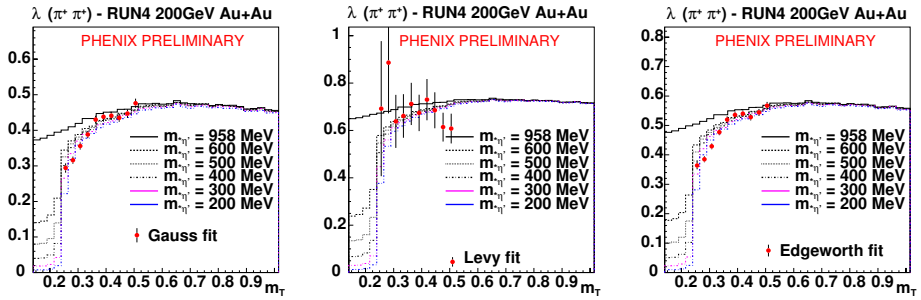

Figure 4. Measured $\lambda(m_t)$ compared to calculations using the model of ref. [2] with various η' mass values, and the Fritiof results for the composition of the long-lived resonances.

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