Systematic studies of global observables by PHENIX

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Abstract. Systematic studies of global observables in different collision systems are indispensable for mapping the QCD phase diagram. Fluctuations in these quantities can provide fundamental information relevant for the phase transitions. The following global observables relevant to critical behavior are studied: the longitudinal density correlation, K to π and p to π fluctuations, and the constituent quark number scaling for elliptic flows.

1. Introduction

Understanding the QCD phase structure is of great importance. So far the Relativistic Heavy Ion Collider (RHIC) has achieved the formation of a dense, low-viscosity medium and has concluded that the medium carries the partonic degree of freedom. Although it is believed that RHIC can only reach the crossover region of the conjectured QCD phase diagram, the present theoretical predictions are uncertain even for small baryon densities. Furthermore, there could be different critical temperatures, T_c, depending on the order parameters [1]. Therefore, it is worth testing various observables to extract information about the phase boundary. In order to search for critical behaviors, several PHENIX ("Pioneering High Energy Nuclear Interaction eXperiment") analyses are useful, including the scaled variance of charged particle fluctuations related to the isothermal compressibility [2], mean p_T fluctuations related to the heat capacity [3], longitudinal density correlations related to the susceptibility [4], fluctuations in the particle production of different species, tests of the constituent quark number scaling for the elliptic flow v_2 [5], low mass di-leptons and the continuum spectra, and quarkonia suppression patterns [6] [7]. In the present article we focus on following global observables: the longitudinal density correlation, K to π and p to π fluctuations, and the constituent quark number scaling of v_2.

2. Longitudinal density correlations

As for the boiling point of water, we can use blob sizes as a general signature of phase transitions. The intensity of blobs with large correlation lengths can be an indicator of phase transitions. Therefore, an increase in the product of the correlation length ξ and the correlation strength α can be a sensitive determination of T_c. The $\alpha\xi$ product can be measured by differential analysis of charged particle multiplicity fluctuations by changing the pseudorapidity window size. Full details of the analysis and the precise relation with T_c can be found in Ref. [4]. In Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, our data suggest a possible non-monotonic increase in the product when the number of participant nucleons is $N_{part} \sim 90$ [4]. Fig. 1 compares $\alpha\xi$ plotted against the mean charged particle multiplicity μ normalized to that of the top 5% centrality in Au+Au at $\sqrt{s_{NN}} = 200$ GeV, $\mu_{AuAu200}$, with Cu+Cu collisions at the same collision energy and Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV. Percentile bin widths used for the centrality classification are indicated in the legends. While the bin width affects the absolute scale of the multiplicity fluctuations, in principle it does not affect the differential analysis. The trends in $\alpha\xi$ for the smaller system at the same collision energy (Cu+Cu 200 GeV) and for the same system size at the lower collision energy (Au+Au 62.4 GeV) are similar to those of Au+Au at 200 GeV except that the peaks are less pronounced.

3. Fluctuations in the particle production of different species

Dynamical event-by-event fluctuations in the particle production of different species can be defined as

$$\nu_{dyn}(N_i, N_j) \equiv \frac{< N_i(N_i - 1) >}{< N_i >^2} + \frac{< N_j(N_j - 1) >}{< N_j >^2} - 2\frac{< N_i N_j >}{< N_i >< N_j >} \quad (1)$$

where N_i and N_j are the number of particles of species i and j, respectively, per event. Fig. 2 shows $\nu_{dyn}(K, \pi)$ and $\nu_{dyn}(p, \pi)$ as a function of the number of participant nucleons N_{part} in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. While $\nu_{dyn}(K, \pi)$ smoothly decreases with increasing N_{part}, $\nu_{dyn}(p, \pi)$ looks qualitatively different with a rising behavior at large values of N_{part}.

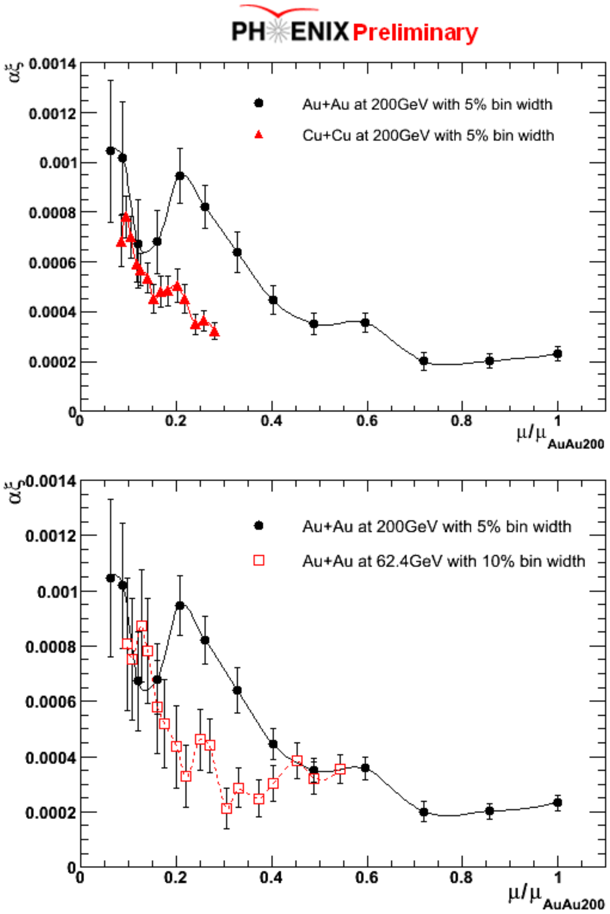

Figure 1. Graphs of $\alpha\xi$ versus mean charged particle multiplicity μ normalized to that of the top 5% centrality in Au+Au at $\sqrt{s_{NN}}$ = 200 GeV, $\mu_{AuAu200}$. $\alpha\xi$ in Cu+Cu at $\sqrt{s_{NN}} = 200$ GeV(triangle) and Au+Au at $\sqrt{s_{NN}} = 62.4$ GeV(square) are superimposed on Au+Au at $\sqrt{s_{NN}} = 200$ GeV(circle) respectively.

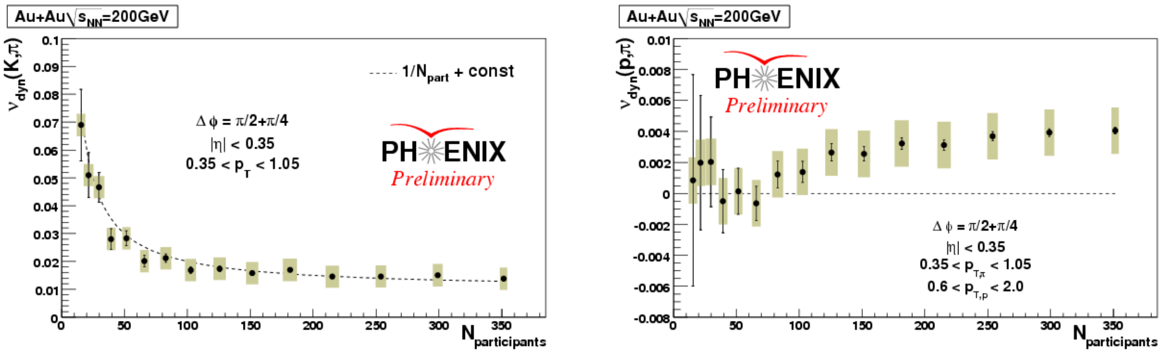

Figure 2. Left panel: $\nu_{dyn}(K, \pi)$ and right panel: $\nu_{dyn}(p, \pi)$ as a function of the number of participants N_{part} in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

4. Constituent quark number scaling for v_2

The constituent quark number, n_q, scaling of the elliptic flow v_2 manifests the deconfined phase of the produced medium. Therefore, tests for scaling violations in various collision systems would give indications of possible phase transitions. Fig. 3 plots $\frac{v_2/n_q(Data)}{v_2/n_q(Fit)}$ as a function of KE$_T \equiv (m_T - m_0)/n_q$ for π, K, and p in 5% and 10% centrality slices, where $v_2/n_q(Fit)$ in each slice was obtained by a simultaneous fit to curves of $v_2/n_q(Data)$ versus KE$_T$ for all species by a fourth-order polynomial. While the n_q scaling holds for KE$_T >\sim 0.3$, the scaling for lower values of KE$_T$ is poor. The deviation of p from the

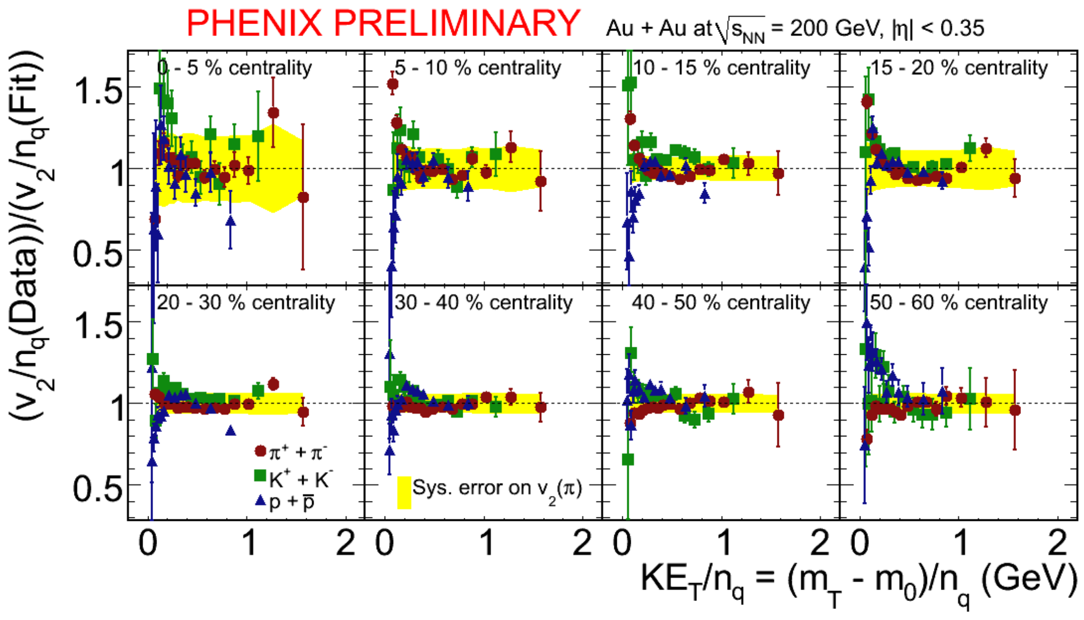

Figure 3. Graphs of $\frac{v_2/n_q(Data)}{v_2/n_q(Fit)}$ versus KE$_T \equiv (m_T - m_0)/n_q$ for π, K, and p in 5% and 10% centrality slices. The particle species are plotted as triangles (blue), squares (green), and circles (red) for p, K and π, respectively. The systematic error range in $v_2(\pi)$ is indicated in yellow.

common fit curves is opposite in sign to those of π and K in all centralities, possibly due to radial flow effects. Interestingly enough, the deviations for baryons and mesons flips sign at around 40% centrality, which corresponds to $N_{part} \sim 90$ in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

5. Summary

The product of the correlation length ξ and the correlation strength α obtained from the longitudinal density correlation provides a way to directly determine transition points without free parameters and with relatively few event statistics. The trends in $\alpha\xi$ for Cu+Cu at $\sqrt{s_{NN}} = 200$ GeV and for Au+Au at $\sqrt{s_{NN}} = 62.4$ GeV as a function of the normalized mean multiplicities are similar to those for Au+Au at $\sqrt{s_{NN}} = 200$ GeV except that the non-monotonicities are less pronounced. The p to π fluctuations show qualitatively different behavior from those of K to π. The rising behavior for p to π fluctuations starts at $N_{part} = 50 \sim 100$. For $\mathrm{KE}_T <\sim 0.3$ the deviations of p from the quark number scaled v_2 curves are opposite in sign to those of π and K in all centralities. However, the deviations for baryons and mesons changes sign at around 40% centrality, corresponding to $N_{part} \sim 90$. This phenomenon could be related to light sigma mesons near the critical point which would provide an attractive mean potential for baryons (decrease in flow) and a repulsive mean potential for pions (increase in flow) at lower momenta [8].

Combining these effects in the analogous N_{part} region of the curves for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, we anticipate a novel system to be created at RHIC. We expect to probe it by adding more collision systems in future RHIC runs for the critical endpoint search.

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