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Scaling properties and charge dependence of particle ratio fluctuations at RHIC

Research Article

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Abstract: It has been suggested that the existence of a QCD phase transition would cause an increase and divergence of fluctuations. Thus event-by-event particle ratio fluctuations could be used to study strangeness and baryon number fluctuations near the critical point in the QCD phase diagram. In this paper, we present dynamical K/π, p/π, and K/p ratio fluctuations from Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 to 200 GeV. Charge dependent results as well as multiplicity scaling properties of these fluctuation results are discussed. The STAR data are compared to different theoretical model predictions and previous experimental results.

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Keywords: particle ratio fluctuations • multiplicity scaling • charge dependent fluctuations

1. Introduction

The study of particle ratio fluctuations can provide a powerful tool to probe the properties of the quark-gluon plasma (QGP). It has been suggested that the existence of a QCD phase transition would cause an increase and divergence of fluctuations. Experimentally, this could be related to event-by-event fluctuations of a given observable. An enhanced fluctuation is expected during a phase transition close to the critical point. For example, K/π, p/π, and p/K fluctuations could be related to strangeness fluctuations, baryon number fluctuations, and baryon-strangeness correlations [1]. One advantage of ratio fluctuations is that the volume fluctuation may be canceled. One such observable, σ_{dyn} [2], is defined as below

$$\sigma_{dyn} = \mathrm{sgn}(\sigma^2_{data} - \sigma^2_{mixed})\sqrt{|\sigma^2_{data} - \sigma^2_{mixed}|}. \quad (1)$$

σ_{data} is the relative width calculated from data distribution (K/π, p/π or p/K) and the σ_{mixed} is the same quantity calculated using mixed events. Another observable, ν_{dyn}, has been proposed [3] to study the deviation of particle fluctuations from Poisson. ν_{dyn} for kaons and pions can be written as

$$\nu_{dyn,K\pi} = \frac{\langle K(K-1)\rangle}{\langle K\rangle^2} + \frac{\langle \pi(\pi-1)\rangle}{\langle \pi\rangle^2} - \frac{2\langle K\pi\rangle}{\langle K\rangle\langle \pi\rangle}, \quad (2)$$

where K and π are the number of charged kaons and charged pions in each event and the bracket represent

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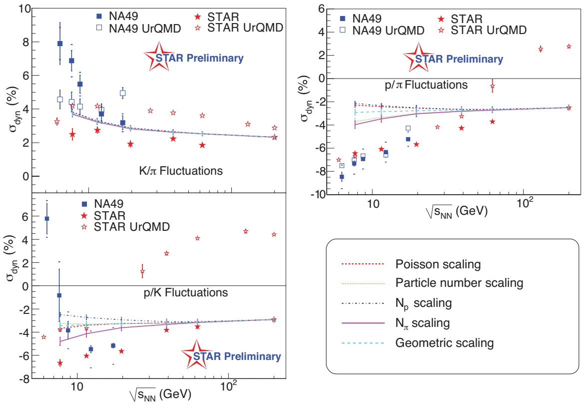

Figure 1. (Color online) Energy dependence of summed charges σ_{dyn} results. STAR results are from Au+Au collisions, 0-5% centrality, while NA49 results are from Pb+Pb collisions, 0-3.5% centrality. Only statistical errors are shown for the STAR data.

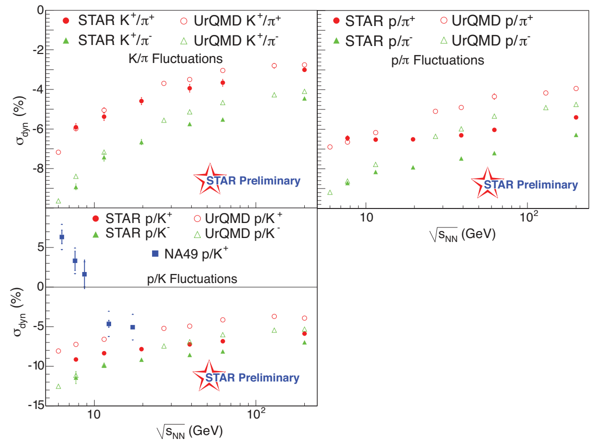

Figure 2. (Color online) Energy dependence of the separate sign σ_{dyn} results. The STAR results are from central Au+Au collisions (0-5%) while the NA49 results are from central Pb+Pb collisions(0-3.5%). Only statistical errors are shown for the STAR data.

event averages. Although ν_{dyn} is calculated in a different way than σ_{dyn}, with enough statistics and a large denominator, $\sigma_{dyn} \approx \mathrm{sgn}(\nu_{dyn})\sqrt{|\nu_{dyn}|}$. A detailed study can be found in Ref. [4].

2. Data and results

Recent results from NA49 [5] show that K/π fluctuations in terms of σ_{dyn} increase strongly as the incident energy is lowered. In contrast, results for K/π fluctuations from STAR [6–9] show little incident energy dependence. To illustrate this energy dependence, Figure 1 shows the σ_{dyn} results using STAR's new beam energy scan (BES) data [10]. Here the STAR results (data and UrQMD) are calculated via ν_{dyn} and converted to σ_{dyn} by $\sigma_{dyn} \approx \mathrm{sgn}(\nu_{dyn})\sqrt{|\nu_{dyn}|}$. For K/π fluctuations, the STAR results are approximately independent of collision energy from $\sqrt{s_{\mathrm{NN}}} = 7.7$ to 200 GeV. This disagrees with NA49's results at energy below 11.5 GeV, which show a strong increase with decreasing incident energy. Two UrQMD calculations with NA49 and STAR acceptance cuts are also shown in the same figure. Although acceptance of the two experiments is different, the two calculations agree well with each other. Both show little energy dependence and over predict the STAR data.

Unlike the results for K/π fluctuations, the results for p/π fluctuations are strongly affected by resonance correlations (e.g. Δ, Λ, Σ all decay to p, π). These correlations increase the cross-correlation term of ν_{dyn} leading to a negative value for ν_{dyn}. The right panel of Figure 1 shows the results for p/π fluctuations. The STAR and NA49 [5] results are both negative and become less negative with increasing collision energy. UrQMD describes the data well at SPS energies but becomes positive and over predicts the data at higher energies.

The p/K fluctuations can be used as a tool to study strangeness/baryon correlations [1]. The lower panel of Figure 1 shows the results for p/K fluctuations. The NA49 results show a non-trivial increase in the fluctuations with decreasing collision energy. The NA49 results change from a dominance of correlations (negative σ_{dyn}) to a dominance of fluctuations (positive σ_{dyn}), which suggests a possible change in the baryon number-strangeness correlation at $\sqrt{s_{NN}} \approx 8$ GeV [11]. However, the STAR data show a smooth decrease with decreasing collision energy and disagrees with NA49 data at 7.7 GeV.

To study the multiplicity dependence of σ_{dyn}, Figure 1 shows five scaling methods proposed in Ref. [4]. We can see that for K/π fluctuations, all five scaling methods give similar results and increase slightly with decreasing beam energy. Due to the statistical error, it is hard to tell if the scaling holds based on the current data. However, for p/π and p/K fluctuations, none of the proposed scaling methods reproduces the STAR data.

Hadronic processes like resonance decay can influence the particle ratio fluctuations. To better understand the origin of the observed fluctuations, charge dependent fluctuations were also calculated for STAR data. Because the K^- and $\bar{p}$ yields vanish at low energies, we present only K^+ and p related fluctuations. The upper left panel of Figure 2 shows the incident energy dependence of the $\sigma_{dyn,K^+/\pi^+}$ and $\sigma_{dyn,K^+/\pi^-}$ results. They are both negative and show a smooth decrease with decreasing incident energy, while the UrQMD results with a STAR acceptance filter slightly over-predicts the data. Decay processes such as $K^*(892) \rightarrow K^+ + \pi^-$ introduce a strong correlation to the K^+/π^- fluctuations, while other resonance decays like $K_1(1270)^+ \rightarrow K^+ + \rho^0 \rightarrow K^+ + \pi^+ + \pi^-$ could give negative K^+/π^+ fluctuations. A study [12] using UrQMD calculations confirm that removal of K^* and ϕ decays would significantly change the summed sign and separate sign K/π fluctuation results. The right panel of Figure 2 shows the energy dependence of separate sign p/π fluctuations. Both $\sigma_{\text{dyn},p/\pi^+}$ and $\sigma_{\text{dyn},p/\pi^-}$ results are negative and decrease with decreasing collision energy. The $\sigma_{\text{dyn},p/\pi^-}$ are more correlated due to Δ decay. UrQMD agrees well with data at low energies but over predicts the data at high RHIC energies.

The lower panel of Figure 2 shows the incident energy dependence of separate sign p/K results. Again, The NA49 data show a strong increase of fluctuations with decreasing collision energy, changing from more correlations (negative σ_{dyn}) to enhanced fluctuations (positive σ_{dyn}). This is again suggested as a possible change in the baryon number-strangeness correlation [11]. However, the STAR $\sigma_{\text{dyn,p/K}^+}$ in the same figure shows a smooth decrease with decreasing collision energy, which disagrees with NA49 data but generally agrees with the trend of UrQMD. The reason for the negative values of $\sigma_{\text{dyn},p/K^+}$ is still under discussion.

3. Summary

In summary, event-by-event K/π, p/π, and K/p ratio fluctuations from Au+Au collisions at $\sqrt{s_{NN}} = 7.7$ to 200 GeV have been presented. Overall, no non-monotonic behavior with incident energy has been observed for all three ratio fluctuations in scanned energies. The multiplicity scaling from Ref. [4] failed to reproduce the energy dependence of p/π and p/K fluctuations. The charge dependent fluctuations are presented to help identify resonance decay effects on fluctuation observables. Further study is still necessary to investigate the disagreement between the STAR and NA49 results.

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