Charge Fluctuations at Mid-Rapidity in Au+Au Collisions in the PHENIX Experiment at RHIC

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Charged particle event-by-event fluctuations have long been considered as a possible signature of quark gluon plasma formation in ultra-relativistic heavy-ion collisions [1]. That the interest in fluctuations remains high in the era of RHIC is evidenced by the large number of recent theoretical [2–4], as well as experimental [5–7], studies published since the previous Quark Matter conference. Here, new results from the PHENIX experiment on event-by-event fluctuations in net charge and $< p_T >$ in Au+Au interactions at $\sqrt{s_{NN}} = 200$ GeV will be presented.

1. Net charge fluctuations

The idea to study net charge fluctuations as a signal for quark gluon plasma formation was proposed about two years ago [8]. It was predicted that the fluctuations in the net charge in a local region of phase space should be drastically reduced if a plasma was formed in the collisions. The arguments are based on the fact that the electric charge is more evenly distributed in a plasma, and it is predicted that this distribution should survive the transition back to the hadronic state, if a sufficiently large region of phase space ($\Delta y \sim 1$) is considered.

Net charge fluctuations in Au+Au interactions at $\sqrt{s_{NN}} = 130$ GeV have previously been studied by PHENIX [5]. The same detectors and experimental techniques are used in the present analysis for Au+Au at $\sqrt{s_{NN}} = 200$ GeV, with the exception that tracks are required to have an associated hit in the outermost layer of pad chambers (∼5 m from the interaction point), resulting in improved track quality at the expense of a slightly reduced acceptance. The outermost layer of pad chambers was not installed in the west tracking arm in the run at 130 GeV.

For a given centrality selection, as determined by the PHENIX beam-beam counters (BBC) and zero-degree calorimeters (ZDC), one reconstructs n_+ positive and n_- negative particles in an individual event. The fluctuations are studied using the variable $v(Q)$, which is calculated as the ratio of the variance of the net charge, $Q = n_+ - n_-$, to the mean of the total charged multiplicity, $n_{ch} = n_+ + n_-$,

$$v(Q) = \frac{V(Q)}{< n_{ch} >} \; . \tag{1}$$

*for the full PHENIX Collaboration author list and acknowledgements, see Appendix "Collaborations" of this volume.

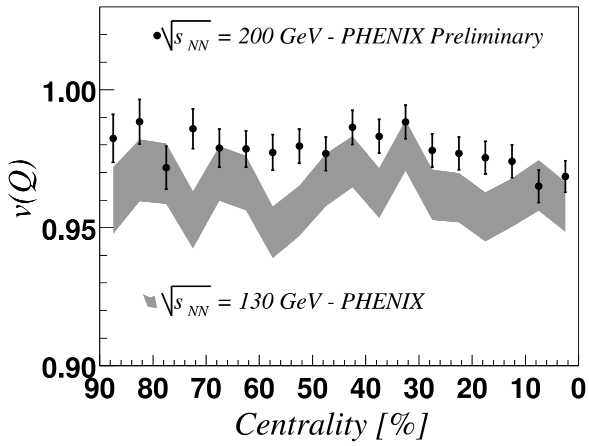

Figure 1: $v(Q)$ vs. centrality for data at $\sqrt{s_{NN}}$ = 130 and 200 GeV. The rightmost bin corresponds to the 0-5% most central collisions. The band (the width represents the statistical error) shows the result from 130 GeV [5]. The results at 200 GeV are for $|\eta| < 0.35$, $0.3 < p_T < 2.0$ GeV/c, $\Delta\varphi = \pi/2$.

For random emission of particles, $v(Q) = 1$. In a system with a random distribution of particles in phase space and with global charge conservation, one expects $v(Q) = (1 - p)$ if a fraction p of all produced particles are detected. The experimentally observed values of $v(Q)$ for different centralities are shown in Figure 1.

One notes that $v(Q)$ shows only a small deviation from the value 1 for all centrality selections. Data at 130 GeV show no centrality dependence within the statistical errors while at 200 GeV a slight decrease in $v(Q)$ with increasing centrality cannot be excluded. The value of $v(Q)$ is far from what has been predicted for a quark gluon plasma ($v(Q) \sim 0.2$) and a hadron gas ($v(Q) \sim 0.7$) [8]. It should be noted that these predictions are for a rapidity interval $\Delta y \sim 1$ with full azimuthal acceptance, whereas PHENIX covers $\Delta\eta = 0.7$ in pseudo-rapidity and $\Delta\varphi = \pi/2$ in azimuth.

The question is therefore if and to what extent the measured values of $v(Q)$ reflect only global charge conservation or if any other contributions, e.g. from resonance decays in a hadron gas, are important. The reduction in $v(Q)$ is expected to scale with the acceptance. This is the case if only global charge conservation is considered, as was discussed above. It is also true for a reduction from resonances in a hadron gas. The reason is that a certain geometrical coverage is needed to detect all charged particles from the decay of a neutral resonance. The acceptance scaling of $v(Q)$ for a quark gluon plasma is not known, hence a theoretical model would be desirable to be able to do experimental comparisons.

Experimentally, it is found that $v(Q)$ does scale with the acceptance, as is illustrated in Figure 2, where $v(Q)$ is plotted versus varying acceptance windows in azimuth and pseudo-rapidity. The trend is very similar in both cases. The variable $\Delta\varphi_d$ corresponds to the azimuthal coverage that is used; it ranges from 0^0 to 90^0 in one central arm of the PHENIX spectrometer. It is not currently understood why $v(Q)$ at $\sqrt{s_{NN}}$ = 200 GeV exceeds one for small acceptances.

For data at 130 GeV it was estimated that global charge conservation alone should lead to a reduction in $v(Q)$ of about 1%. The observed value (0.965 ± 0.007), which was found to be in good agreement with RQMD [9], was more than 3 standard deviations lower than the charge conservation estimate, thus indicating that charged tracks emanating from decays of neutral resonances are necessary to fully understand the measurements. No additional suppression to what was predicted by RQMD was observed. The reduction due to global charge conservation is approximately the same at $\sqrt{s_{NN}}$ = 200 and 130

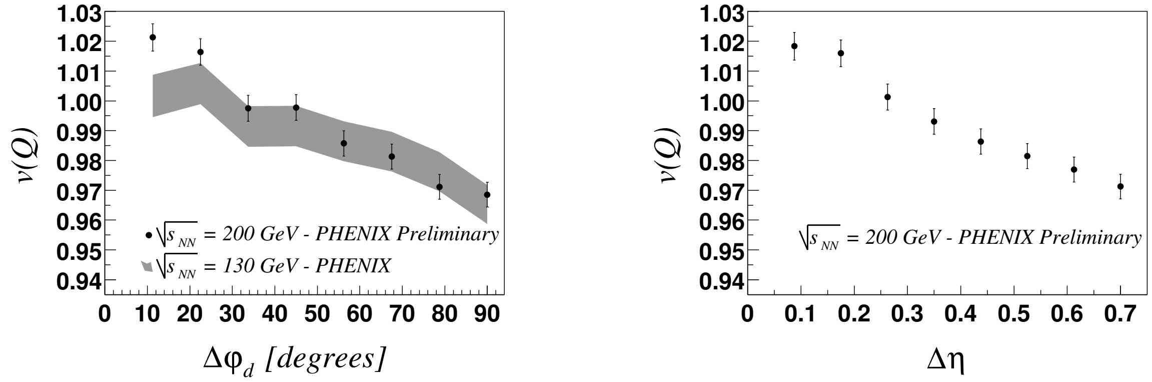

Figure 2. $v(Q)$ vs. $\Delta\varphi_d$ (left) and vs. $\Delta\eta$ (right) for the 10% most central collisions.

GeV, which is also true for the fluctuations in RQMD [4]. The preliminary conclusion is that both at $\sqrt{s_{NN}} = 130$ and 200 GeV we do not observe any anomalous suppression in $v(Q)$ that cannot be explained by hadronic models.

2. Fluctuations in $< p_T >$

Fluctuations associated with a QCD phase transition could lead to anomalous event-by-event fluctuations in the average transverse momentum [3].Fluctuations in $< p_T >$ were studied by PHENIX at 130 GeV but no excess above the random contribution was observed [6]. The present analysis uses the same techniques but with increased statistics, improved track quality cuts and better background rejection.

The observed fluctuations are compared with the expectation from statistically independent particle emission through the use of mixed events, as described in [6]. The quantity

$$\omega = \frac{\sqrt{< p_T^2 > - < p_T >^2}}{< p_T >} \tag{2}$$

is calculated for real and mixed events. The deviations from stochastical fluctuations are quantified through the measure F_T:

$$F_T = \frac{\omega_{data} - \omega_{random}}{\omega_{random}} \,. \tag{3}$$

A non-zero value of F_T indicates non-statistical fluctuations.

F_T is plotted as a function of centrality in the left part of Figure 3. At $\sqrt{s_{NN}} = 200$ GeV a statistically significant signal is observed which was not the case at 130 GeV. The value of F_T has a maximum in semi-central collisions.

The right part of Figure 3 shows the variation of F_T with the p_T-range used to calculate $< p_T >$, from 0.2 GeV/c to p_T^{MAX}, plotted as function of p_T^{MAX}. As can be seen, the value of F_T increases as the p_T range is extended to higher values.

The variation of F_T with centrality and p_T is similar to what one would expect for a process connected with elliptic flow. A simulation, based on the observed values of v_2 [10],

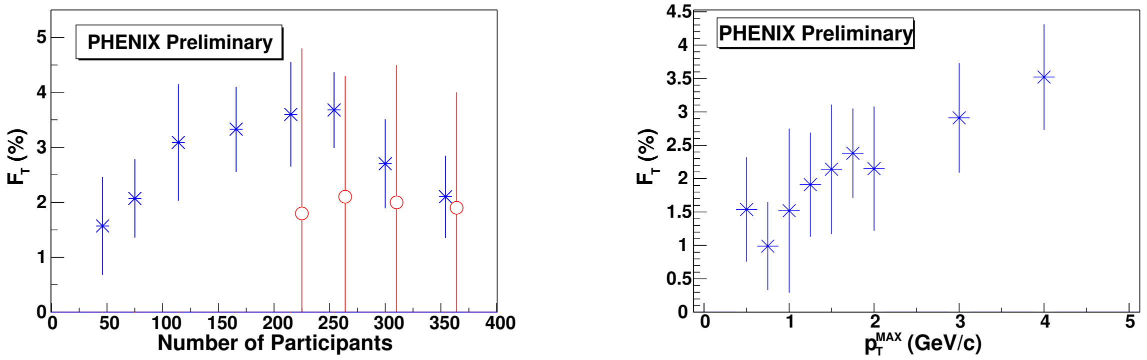

Figure 3. F_T vs. centrality (left) and F_T vs. p_T^{MAX} for central collisions (right). The asterisks and open circles are for Au+Au at $\sqrt{s_{NN}} = 200$ and 130 GeV, respectively.

of the contribution from elliptic flow to F_T was therefore performed. The result indicates that elliptic flow is not responsible for the observed F_T signal.

3. Conclusions

The analysis of net charge fluctuations at $\sqrt{s_{NN}} = 200$ GeV has yielded results similar to those at 130 GeV. No additional suppression of the fluctuations beyond what is predicted by hadronic models is observed. Fluctuations in the mean transverse momentum, as measured through the quantity F_T, show a positive signal at $\sqrt{s_{NN}} = 200$ GeV, peaking in semi-central collisions.

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