Probing Collision Dynamics with Fluctuation and Correlation Studies at RHIC

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1. Introduction

Measurements of transverse momentum ($p_\perp$), and net charge (net-q) event-by-event (e-by-e) fluctuations were suggested to probe the production of a QGP in heavy ion collisions: $p_\perp$ fluctuations are predicted to be enhanced while net-q fluctuations may be dramatically reduced compared to a hadron gas if a QGP is produced [1]. STAR and PHENIX observed in Au + Au collisions at 130 GeV that both $p_\perp$ and net-q dynamical fluctuations are finite but do not exhibit the expected enhancement/reduction [2–4]. Given however, the production of a QGP phase may vary with beam energy, it is interesting to study the beam energy dependence of these fluctuations. Fluctuations measurements may also be used to study the collision dynamics, e.g. evaluate the degree of thermalization [5], the role of radial flow [6], and the impact of jets on the produced matter [7].

We present measurements of $p_\perp$ and net-q dynamical fluctuations based on the $\langle \Delta p_\perp \Delta p_\perp \rangle$ and $\nu_{+-,dyn}$ observables. Definitions and properties of these observables were discussed elsewhere [8,9]. Data are from Au + Au collisions at $\sqrt{s_{NN}}$ = 20, 62, 130, and 200 GeV measured with the STAR detector during RHIC runs I-IV. $\langle p_\perp \rangle$ and net-q fluctuation studies are based on particles measured at $|\eta| < 0.5$ and $0.15 < p_\perp < 2.0$ GeV/c (5.0 GeV/c for net-q).

2. Results

The observables $\langle \Delta p_\perp \Delta p_\perp \rangle$ and $\nu_{+-,dyn}$ are defined in terms of momentum space integrals of two-particle correlations. As such they measure the (weighted) average strength of two particle correlations. The magnitude of $\langle \Delta p_\perp \Delta p_\perp \rangle$ is however also driven by the magnitude of $\langle p_\perp \rangle$. We account for $\langle p_\perp \rangle$ variations with beam energy and collision centrality by scaling $\langle \Delta p_\perp \Delta p_\perp \rangle^{1/2}$ by $\langle p_\perp \rangle$ to study the fluctuations dependence on beam energy and collision centrality. Data shown in Fig. 1 are from 5 % most central Au + Au collisions, and compared to CERES data [10]. We find that the scaled $p_\perp$ fluctuations are independent of energy in the range $10 < \sqrt{s_{NN}} < 200$ GeV.

The evolution of net-q with beam energy is of similar interest. One must however correct measured $\nu_{+-,dyn}$ to account for charge conservation. This is done by adding to

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$\nu_{+-,dyn}$ a term equal to $4/N_{CH}$ where N_{CH} represents the *total* produced charged particle multiplicity [9]. We estimate N_{CH} based on PHOBOS measurements in the range $|\eta| < 5.4$ [11]. We plot $\nu^{corr}_{+-,dyn} = \nu^{corr}_{+-,dyn} + 4/N_{CH}$ as a function of the beam energy in Fig. 2 and include CERES data for comparison[10]. We find the corrected dynamical net charge fluctuations, $\nu^{corr}_{+-,dyn}$, are invariant with beam energy for $\sqrt{s_N N} > 15$ GeV. One therefore concludes that although qualitative changes have been reported in particle production at high $p_\perp$ (suppression of high-pt yield and away-side correlation strength), one nonetheless finds that for the bulk of particle production (i.e. $p_\perp < 2.0$ GeV/c), the momentum-space integrated two-particle correlation strength appears to be essentially independent of beam energy.

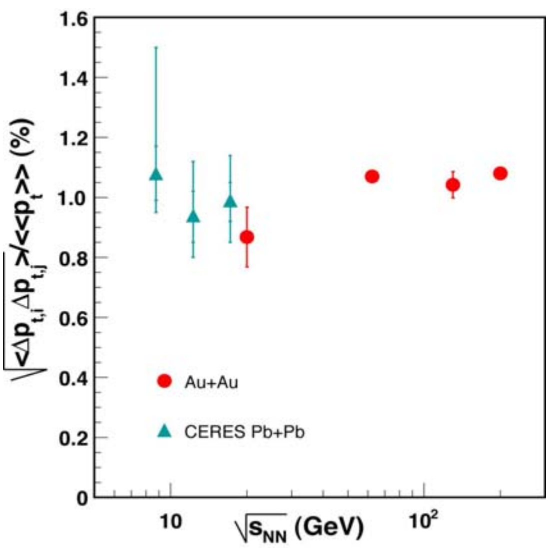

Figure 1. $\langle \Delta p_\perp \Delta p_\perp \rangle^{1/2}$ vs $\sqrt{s_{NN}}$ for Au + Au 5 % most central collisions.

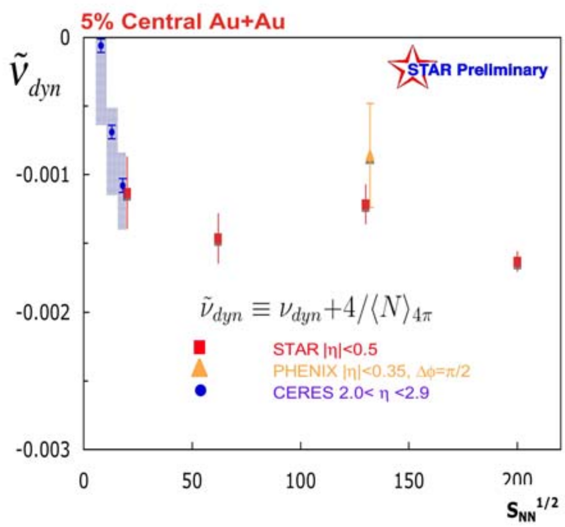

Figure 2. $\nu^{corr}_{+-,dyn}$ vs $\sqrt{s_{NN}}$. Shaded areas indicate systematic errors.

We next consider whether a similar conclusion applies when the collision centrality is varied. One expects that if $A + A$ interactions were to involve a trivial superposition of nucleon-nucleon collisions without rescattering of the produced particles, both $\nu_{+-,dyn}$ and $\langle \Delta p_\perp \Delta p_\perp \rangle$ should be inversely proportional to the number of such collisions. Rescattering, flow, and jet quenching should however change the magnitude of these correlations. Collision centrality estimates are based on the total charged particle multiplicity measured in $|\eta| < 0.5$ and grouped in nine bins corresponding to 80-70, 70-60, ..., 10-5, and 5-0 % of the total interaction cross-section. Values of N_{part} are estimates, based on Glauber Monte Carlo calculations, of the average number of collision participants in these bins. Fig. 3 shows a plot of $\nu_{+-,dyn}$ scaled by measured (efficiency corrected) $dN/d\eta$ as a function of N_{part}. We first note the magnitude of $\nu_{+-,dyn} dN/d\eta$ in most central collisions is at variance with predictions for a QGP (-3), but in qualitative agreement with predictions for resonance gas (-1.6) and quark coalescence (-1.2) models. One also observes $\nu_{+-,dyn} dN/d\eta$ exhibits a strong centrality dependence thereby signaling considerable changes in the collision dynamics with centrality. The observed increase is however not a complete surprise given the ratio $dN/d\eta/(N_{part}/2)$ is known to rise by about 50 % from peripheral to central collisions [11]. We thus also considered the dependence of $N_{part}\nu_{+-,dyn}$ with collision centrality. We found $N_{part}\nu_{+-,dyn}$ in fact exhibits very little dependence on collision centrality.

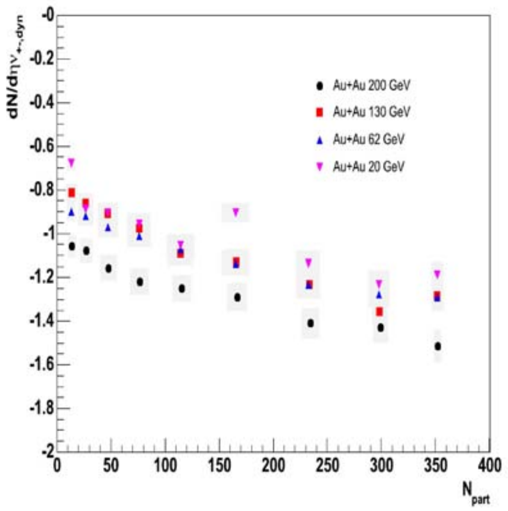

Figure 3. $\nu_{+-,dyn}dN/d\eta$ vs $dN/d\eta$

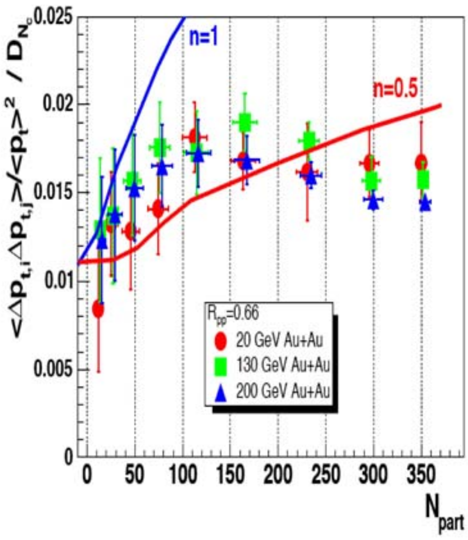

Figure 4. $\langle\Delta p_\perp \Delta p_\perp\rangle$ vs N_{part} compared to model calculations.

The dependence of $p_\perp$ fluctuations on collision centrality is however considerably larger as illustrated in Fig.4 which shows $N_{part}\langle\Delta p_\perp \Delta p_\perp\rangle/\langle p_\perp\rangle^2$ vs N_{part}. We first note STAR results on $p_\perp$ fluctuations are in quantitative disagreement with PHENIX data based on the F_{pt} observable [3]. Given the F_{pt} observable is not robust (i.e. depends on efficiencies), part of the disagreement may arise from differences in acceptances and efficiencies. F_{pt} is also rather sensitive to the method used to subtract mixed event contributions: elliptical anisotropy must be carefully taken into consideration. To illustrate this point, we show, in Fig.5, a plot of $N_{part}\langle\Delta p_\perp \Delta p_\perp\rangle$ measured by STAR using kinematical cuts corresponding to PHENIX's acceptance. While in- and out-of-plane results have similar magnitude, random orientation values are considerably larger and peaked at mid-centralities where elliptical anisotropy exhibits a maximum. Clearly, elliptical anisotropy and orientation relative to the reaction plane must be properly accounted for in measurements of pt fluctuations involving finite acceptance and mixed events techniques.

Solid lines, in Fig.4, show a blast wave model calculation [6] in which radial flow induces angular and $p_\perp$ correlations. One finds qualitative agreement with a soft n=0.5 velocity profile. Radial flow may also induce azimuthal net charge correlations. Fig. 6 shows a measurement of $\nu_{+-,dyn}$ with respect to the azimuthal range ϕ of integration. We speculate the increase in absolute magnitude observed for small azimuthal range is due to kinematical focusing of resonance decay products imparted by radial flow. It might then be possible to use net-q and $p_\perp$ correlations to narrow uncertainties in measurements of radial flow and its profile.

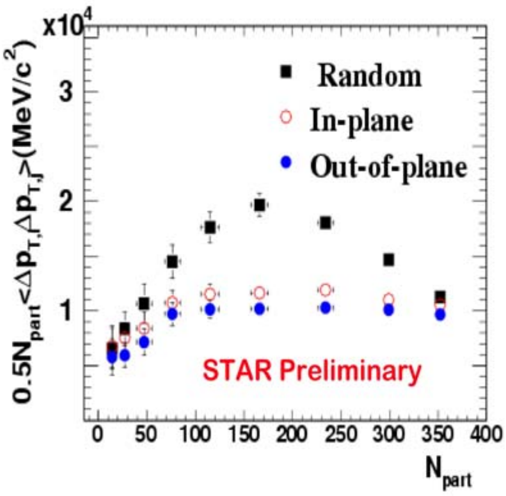

Figure 5. $N_{part}\langle\Delta p_\perp \Delta p_\perp\rangle^{1/2}$ vs N_{part} using PHENIX acceptance in/out-plane, or with random orientation.

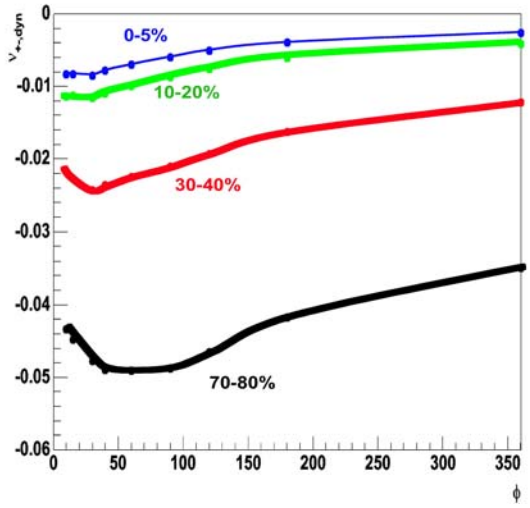

Figure 6. $\nu_{+-,dyn}$ vs integrated azimuthal range ϕ in degrees.

3. Summary

We presented measurements of $p_\perp$ and net-q fluctuations in Au+Au spanning $20 < \sqrt{s_{NN}} < 200$ GeV. The magnitude of $\langle\Delta p_\perp \Delta p_\perp\rangle^{1/2}/\langle p_\perp\rangle$ and $\nu_{+-,dyn}$ corrected for charge conservation effects are found to be invariant with $\sqrt{s_{NN}}$. Collision centrality dependences were studied by scaling the observables by N_{part}. While net-q fluctuations show little dependence on centrality, $p_\perp$ fluctuations scaled by $N_{part}/\langle p_\perp\rangle$ exhibit finite centrality dependence qualitatively reproduced by a simple model invoking radial flow.

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