Interpreting Near-side Correlations

and the RHIC Beam Energy Scan

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Abstract. Recent data from heavy ion collisions at RHIC show strong near-side correlations extending over several units of rapidity. This ridge-like correlation exhibits an abrupt onset with collision centrality. In this talk, I argue that the centrality and beam-energy dependence of these near-angle correlations could provide access to information about the Quark Gluon Plasma phase boundary and the Equation of State of nuclear matter. A beam-energy-scan at RHIC will better reveal the true source of these correlations and should be a high priority at RHIC.

PACS. 25.75.Ag Global features in relativistic heavy ion collisions – 25.75.Gz Particle correlations and fluctuations

1 Introduction

Correlations and fluctuations have long been considered a promising signature for Quark Gluon Plasma (QGP) formation in heavy-ion collisions [1]. Early proposals for QGP searches suggested searching for a non-monotonic dependence of fluctuations on variables that can be related to the energy density created in the system — e.g. center-of-mass energy or collision centrality — the expectation being that above some energy density threshold, a phase transition to QGP would occur. The presence of the phase transition to QGP would then lead to a change in fluctuations and correlations.

These early expectations regarding finite temperature QCD are borne out by lattice QCD calculations [2]. The calculations show that for temperatures above a critical value of 195 MeV, a QGP is formed. Lattice calculations also show that baryon number, strangeness, and charge fluctuations are all enhanced near the critical temperature $T_C$ [3]. As such, correlations and fluctuations remain a topic of interest in heavy-ion collisions.

Data from the experiments at RHIC indeed reveal interesting features in the two-particle correlation landscape [4,5]. Specifically, it has been found that correlation structures exist that are unique to Nucleus-Nucleus collisions [1]. While two-particle correlations in p+p and d+Au collisions show a peak narrow in azimuth and rapidity, the near-side peak in Au+Au collisions broadens substantially in the longitudinal direction and narrows in azimuth. The longitudinal width of the correlation appears to depend on the $p_T$ of the particles. An analysis of the width of the peak for particles of all $p_T$ finds the correlation extends across nearly 2 units of pseudo-rapidity $\eta$. When triggering on higher momentum particles ($p_T > 2$ GeV/c for example), the correlation extends beyond the acceptance of the STAR detector ($\Delta \eta < 2$) and perhaps as far as $\Delta \eta = 4$ as indicated by preliminary PHOBOS data. Furthermore, STAR has found that these correlations show an abrupt onset as a function of centrality [4]. Comparing measurements at 200 and 62.4 GeV, STAR has shown that the onset happens at the same value of transverse particle density for the different energies, suggesting the onset of the long range correlations may be related to a critical energy density.

2 The Ridge

The ridge is a long-range correlation unique to A+A collisions that exhibits an abrupt onset with increasing collision centrality. Phrased this way, we could conclude that this is the long sought after “smoking gun” of QGP formation. But the excitement one would expect from such a discovery has been tempered due to conflicting interpretations of the nature of these correlations. Disagreement exists as to whether the correlations are related to QGP formation or whether they in fact disprove the existence of a thermalized medium. Questions surrounding the ridge-like correlations include: are the correlations related to non-perturbative multi quark or gluon effects on minijets in Au+Au collisions? [7] are they related to soft gluons radiated by hard partons traversing the overlap region? [8] are they related to initial spatial correlations in the system converted to momentum-space correlations by a radial hubble expansion? [10] to beam-jets also boosted by the radial expansion? [11] or to viscous effects? [9] and
do these correlations disprove the assumption of a system thermalized over some extended region? These questions still remain to be answered.

If the ridge is related to the translation of spatial correlations into momentum space correlations through radial flow, then the onset of the ridge could be related to a sharp rise in the pressure over energy-density at the critical energy density for QGP formation. At that energy density, the liberation of color degrees of freedom in the system could lead to an increase in the pressure which in turn could lead to the flow that makes it possible to image the underlying spatial correlations in momentum space. It’s not clear that hydrodynamic models will be able to reproduce such effects and the process by which the QGP transforms initial spatial correlations into momentum space correlations could be quite different than envisioned in such models. Fig. 1 shows lattice QCD calculations of the equation of state [2] on the left and the ridge amplitude at 200 and 62.4 GeV vs centrality measure $\nu = 2N_{\text{bin}}/N_{\text{part}}$ on the right. When plotted vs transverse particle density related to Bjorken energy density, STAR finds that the abrupt increase in the ridge happens at the same density for both 200 and 62.4 GeV collisions [4]: not the same $\nu$, $N_{\text{part}}$, or $N_{\text{bin}}$ but the same $\frac{1}{\sqrt{S}} \frac{dN}{dy}$. Fig. 2 shows a schematic illustration of the expansion after a heavy-ion collision with an emphasis on the lumpiness of the initial conditions.

Above the transition, the ridge amplitude grows faster than $N_{\text{bin}}$ scaling. One analysis finds that when measuring the correlations between the leading and subleading hadrons in an event, the area of the ridge scales with the area of the background [12], perhaps suggesting that the ridge correlation is related to a bulk correlation (a global correlation between all particles). It is also found that the baryon to meson ratio in the ridge is similar to the bulk and that the $p_T$ spectrum of the ridge is softer than for the jet-cone correlation. In fact, the only feature of the ridge that matches that of the jet cone, is that it is centered at $\Delta \phi = 0$. For this reason, one may reasonably doubt whether the ridge is related to hard-scattering.

There are also observations that may prefer an explanation related to mini-jets or hard scattering. The ridge persists even when correlations are formed with trigger particles well into the fragmentation region. Also, the yield of the away-side ridge follows that of the near-side very closely; perhaps indicating back-to-back dijet-like correlations [4].

3 Energy Dependence

A more extensive beam energy scan can help determine if and how the abrupt onset of the ridge is related to the onset of deconfinement. A beam-energy-scan has been pro-
posed at RHIC and technical preparations have been made to collide beams at \( \sqrt{s_{NN}} \) as low as 5 GeV. In a recent test run, the STAR collaboration was able to gather 3000 good events at \( \sqrt{s_{NN}} = 9.2 \text{ GeV} \) after just several hours of beam-time. Collider experts anticipate increasing these event-rates by approximately a factor of 5. The number of events required to carry out the ridge analysis shown in Fig. 1 (right) is on the order of 10 million events. These data samples can be achieved in less than a week of running for energies above \( \sqrt{s_{NN}} = 25 \text{ GeV} \). At 12.3 GeV, 10 million events will require approximately four weeks of running to acquire. This makes an energy scan of ridge phenomenology from 12.3 GeV to 62.4 GeV feasible at RHIC.

Ref. \[6\] proposes an explanation for the ridge based on Glasma flux-tubes. The flux-tubes themselves would not yield a narrow azimuthal correlation but if they are radially boosted, the emitted particles can be collimated in azimuth leading to a ridge like structure. This explanation of the ridge yields a prediction for the energy dependence of the ridge amplitude. For example, \( \frac{\Delta \rho}{\rho} \propto \alpha(Q_s) \), so that the amplitude of the ridge should be governed by the centrality and energy dependence of \( Q_s \) modulated by the effectiveness of the space-momentum correlation. In Ref. \[6\], blast-wave model fits were used to determine the mean flow velocity. Since the blast-wave fit parameters vary smoothly with centrality, it is not possible for that implementation of the flux-tube ridge model to reproduce the abrupt onset of the ridge. The blast-wave fits to the final hadron spectra do not necessarily accurately reflect the dynamics of the collision evolution however, so the lack of an abrupt transition in the model may simply reflect a weakness of the blast-wave parameterization and of the assumption that the QGP evolution is well described by hydrodynamics.

In Fig. 3 I plot the ridge amplitude as predicted by the model in Ref. \[6\] as dashed curves. For this prediction, the following parameterization of \( \beta \) is used:

\[
\langle \beta \rangle = (0.655 + 0.314 \log(N_{binary}/N_{part})) \\
\times (0.05727 \log(\sqrt{s_{NN}}) + 0.2933).
\]

For the solid curves, I've included an additional ad-hoc abrupt transition at fixed values of \( \frac{1}{\Delta \rho} \) as suggested by preliminary STAR measurements. The exact location of the transition at lower energies is highly dependent on the calculation of \( S \) as illustrated with the alternative energy dependence shown in the bottom panel.

The flow velocity is only weakly dependent on energy so the variation of the ridge amplitude with energy is dominated by the change in \( Q_s^2 \propto (\sqrt{s_{NN}})^{0.3} \). This gives a verifiable prediction for the energy dependence which is independent of the details of the centrality dependence. This energy dependence can be checked at LHC and in an upcoming beam energy scan at RHIC. In the case that the imaging of the flux tubes is made possible by space-momentum correlations induced by liberated color charges, then an energy scan of the ridge can be used to map out the phase boundary of the quark-gluon plasma. Given the observation of an abrupt onset of the ridge, this project should be a high priority for RHIC.

![Fig. 3. The ridge amplitude from a model of glasma flux-tubes and radial flow. The dashed lines are based on flux-tubes and a blast-wave model. The solid curves in the top panel include ad-hoc abrupt transitions at fixed values of \( \frac{1}{\Delta \rho} \) as suggested by preliminary STAR measurements. The exact location of the transition at lower energies is highly dependent on the calculation of \( S \) as illustrated with the alternative energy dependence shown in the bottom panel.](image-url)
width of the ridge and critical density for ridge formation can be studied.

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