


Charge transfer fluctuations as a QGP signal

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Abstract In this study, we analyze the recently proposed charge transfer fluctuations within a finite pseudorapidity space. As the charge transfer fluctuation is a measure of the local charge correlation length, it is capable of detecting inhomogeneity in the hot and dense matter created by heavy-ion collisions. We predict that going from peripheral to central collisions, the charge transfer fluctuations at midrapidity should decrease substantially while the charge transfer fluctuations at the edges of the observation window should decrease by a small amount. These are consequences of having a strongly inhomogeneous matter where the QGP component is concentrated around midrapidity. We also show how to constrain the values of the charge correlations lengths in both the hadronic phase and the QGP phase using the charge transfer fluctuations. Current manuscript is based on the two recent papers [10, 13].

Key words quark-gluon plasma • event-by-event fluctuations • charge transfer fluctuations

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Introduction

In the last few decades, one of the major goals of the high energy nuclear physics community has been creating and studying quark-gluon plasma (QGP). Many observables have been suggested and studied as QGP signals. Yet, there still is no consensus on the so-called smoking-gun signals even though many physicists, including myself, have a strong conviction that the strong jet-quenching and the strong elliptic flow could only come from a QGP. Possible reasons for such a situation may be that some of the proposed QGP signals did not work that well and/or it turned out that they still had a possible hadronic explanation. Hence, it is crucial that we characterize the created QGP in as many ways as we can and figure out why some of the promising signals did not work that well.

In this article, we propose that the charge transfer fluctuation is a good candidate to accomplish just that – characterize a QGP in a new way and at the same time provide an answer to why some signals, especially the net charge fluctuation, did not work as well as expected. We will demonstrate below that by measuring charge transfer fluctuations as a function of (pseudo-)rapidity, one cannot only detect the presence of a QGP but also can estimate the size of the created QGP. We will also show that current data on net charge fluctuations (which is not the same as charge transfer fluctuations) is consistent with having only about 20% of all final

state particles remembering its QGP origin (about 50% within $-1 < \eta < 1$).

This amount is small enough that any signal that needs averaging over a large rapidity interval will be masked by the hadronic part.

The charge transfer fluctuation is defined by

$$(1) \quad D_u(y) = \langle u(y)^2 \rangle - \langle u(y) \rangle^2$$

where the charge transfer $u(y)$ at rapidity y is defined by

$$(2) \quad u(y) = [Q_F(y) - Q_B(y)]/2$$

where: $Q_F(y)$ – net charge in the forward region of y , $Q_B(y)$ – net charge in the backward region of y , and our observable is

$$(3) \quad \kappa(y) = D_u(y)/(dN_{ch}/dy)$$

This observable is first introduced in Refs. [7, 12] and shown to be constant in elementary collisions as shown in Fig. 1.

We will argue below that $\kappa(y)$ is actually a measure of the local unlike-sign charge correlation length. Therefore, if a QGP is created only in a small region around midrapidity, $\kappa(y)$ at midrapidity should vary the most as the centrality changes, while $\kappa(y)$ at larger y should stay at an almost constant value. Especially, since we expect the charge correlation length in a QGP to be much smaller than the charge correlation length in a hadronic matter [2, 9], we should see $\kappa(0)$ dropping faster than $\kappa(y)$ at any other y as the collisions become more central. On the other hand, if a QGP is not created at any centrality, $\kappa(y)$ should be a constant function just as it is in elementary collisions [11].

Charge transfer fluctuations

To have a simple physical picture of the charge transfer fluctuation, suppose that all final state charged hadrons

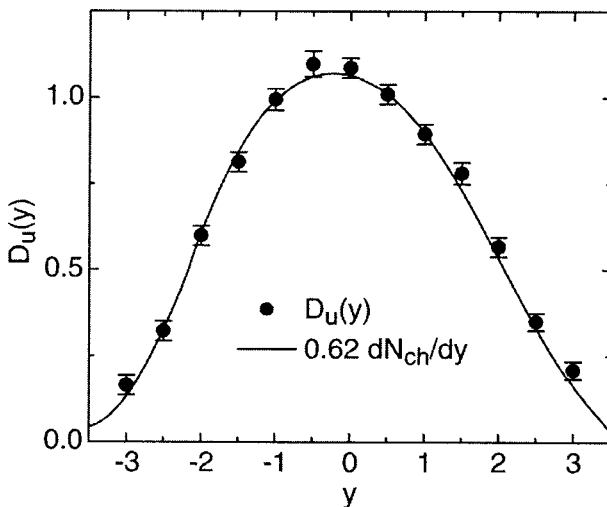


Fig. 1. Comparison between $D_u(y)$ and dN_{ch}/dy in pp collisions [11]. $P_{max} = 200$ GeV.

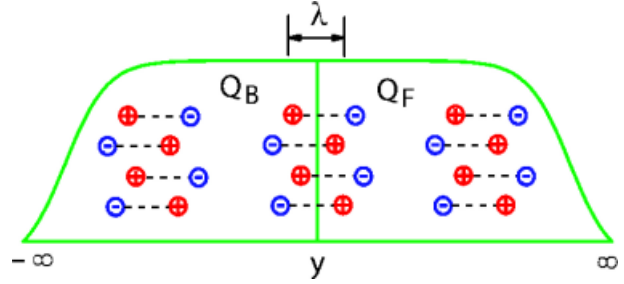


Fig. 2. A schematic view of charge transfer fluctuations. In this view, all charged particles originate from neutral clusters which emits one positively charged particle and one negatively charged particle. The typical rapidity distance between the daughters is λ .

originate from neutral clusters as shown in Fig. 2. Let λ be the typical rapidity distance between the decay particles. If a cluster decays too far from y , its contribution to $u(y)$ vanishes since both of the decay products are either in front of or in the back of y . The only time $u(y)$ is non-zero when a neutral cluster decays within λ of y . Whenever one such neutral cluster decays, $u(y)$ undergoes a random walk with a unit step size. Hence if there are n clusters near y ,

$$(4) \quad D_u(y) = n \approx \lambda \frac{dN_{cl}}{dy}$$

where dN_{cl}/dy is the rapidity density of the clusters at y . Since the charged particle should be proportional to dN_{cl}/dy , we then have

$$(5) \quad \kappa(y) \equiv \frac{D_u(y)}{dN_{ch}/dy} \propto \lambda$$

Having neutral particles included in cluster decay, does not affect the qualitative part of this argument.

The argument given above is essentially local. Hence the quantity $\kappa(y)$ depends only on the properties of the local clusters. It is somewhat surprising that in elementary particle collisions, $\kappa(y)$ is actually constant as shown in Fig. 1. It is also constant in non-QGP models of nucleus-nucleus collisions such as HIJING (see Ref. [13]). On the other hand, if a QGP is created at midrapidity, the plot of $\kappa(y)$ should show a ‘dip’ at $y = 0$ and the depth and the width of the dip should be an indication of the size of the QGP, or at least the portion of hadrons that remember their QGP origin.

Simple neutral cluster models

To see the effect of a QGP droplet near midrapidity, we need a model. Here we use a neutral cluster model similar to the old ρ, ω model [7] and Bialas *et al.* model [5].

The procedure is as follows. To create a simulated event with $2M_0$ charged hadrons, sample

$$(6) \quad \rho_{HG}(y_+, y_-) = R_{HG}(y_+ - y_-) F_{HG}(Y)$$

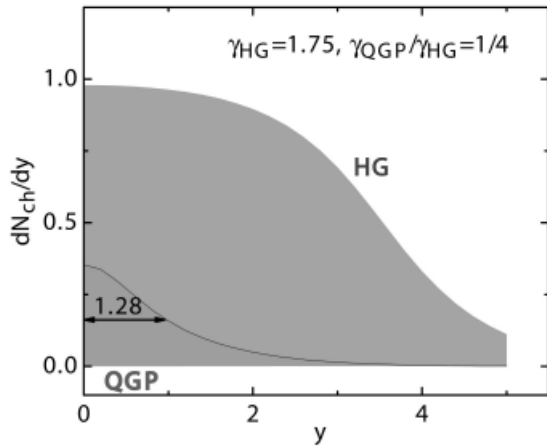


Fig. 3. A schematic view of typical final state particle distributions.

$(1-p)M_0$ times and sample

$$(7) \quad \rho_{\text{QGP}}(y_+, y_-) = R_{\text{QGP}}(y_+ - y_- | Y) F_{\text{QGP}}(Y)$$

pM_0 times. From these events, obtain $\kappa(y)$. Here p is the fraction of the hadrons that remember their QGP origin. The function $R(y|Y) = (1/2\gamma)e^{-|y|/\gamma}$ represents the correlation between the daughters with $\gamma = 2\kappa$ and $F(Y)$ represents the rapidity distribution of the clusters. Each of these cluster correlation functions satisfies the Thomas-Chao-Quigg relationship (with a constant κ) $D_u(y) = \kappa(dN_{ch}/dy)$ exactly. We assume that $\gamma_{\text{HG}} > \gamma_{\text{QGP}}$ and choose F_{HG} and F_{QGP} in such a way that the QGP is concentrated near midrapidity. A typical breakdown of the QGP and hadron gas components in our calculations is shown in Fig. 3.

If the observed rapidity window is large enough, then the observable $\kappa(y)$ indeed shows a prominent dip as shown in Fig. 4. Unfortunately, none of the current RHIC experiments is capable of identifying charged particles in a large rapidity window. Therefore, we next turn to the more realistic case of a pseudorapidity window of $-1 < \eta < 1$. The results presented in the next section are the main results of this study.

Results for $-1 < \eta < 1$

To establish the baseline, we first ran 3 hadronic models without an explicit QGP component; HIJING [8, 16, 17], UrQMD [4, 6] and RQMD [14, 15]. The results are shown in Fig. 5. As expected, $\bar{\kappa}(y)$ (the overbar on symbols denotes quantities measured in a finite rapidity interval) does not strongly depend on the centrality in all 3 models. This also fixes the hadronic correlation length in our neutral cluster model calculations to be $\gamma_{\text{HG}} = 1.75$.

For our neutral cluster model calculation, we first note that $\bar{D}_u(\eta = 1)$ for the interval $-1 < \eta < 1$ is equivalent to the net charge fluctuation in the same interval. The experimental value for the net charge fluctuation in this rapidity interval is known [1]. With the correlation length in the hadronic part fixed at $\gamma_{\text{HG}} = 1.75$, one can vary the size of the QGP component

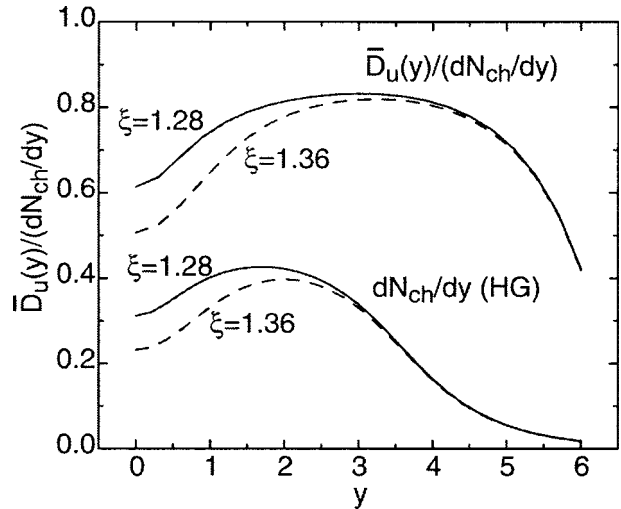


Fig. 4. $D_u(y)$ as a function of Y . ζ is the size of the QGP component. Also shown is the rapidity distribution of the charged particles that do not belong to the QGP.

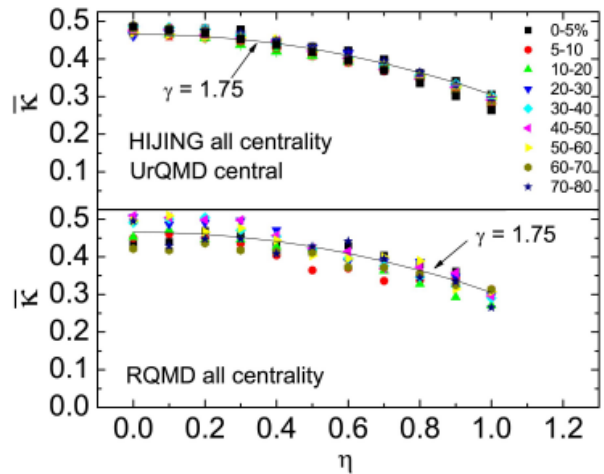


Fig. 5. Results for hadronic models without a QGP within the pseudorapidity range $-1 < \eta < 1$.

ξ and the correlation length γ_{QGP} within the QGP to match $\bar{D}_u(\eta = 1)$ at the known experimental value. Then, as shown in Fig. 6, experimental measurements of $\bar{\kappa}(y)$ as a function of centrality can tell us about the size of the QGP component and the size of the charge correlation length in a QGP. In this figure, the most reasonable scenario (in our opinion) for RHIC central collisions is labeled as ‘central’, whereas the parametrized HIJING curve is labeled as ‘peripheral’. As one can see the values of $\bar{\kappa}(y)$ near the edge of the observation window does not change much. This is because the amount of QGP component at the edge is already rather small. Hence, the presence or the absence of the QGP component makes little difference there. On the other hand, the value of $\bar{\kappa}(y)$ at midrapidity varies as much as 30% as the collisions become more central.

Summary and discussion

In this article we have briefly summarized the main results of our two papers [10, 13] where we have

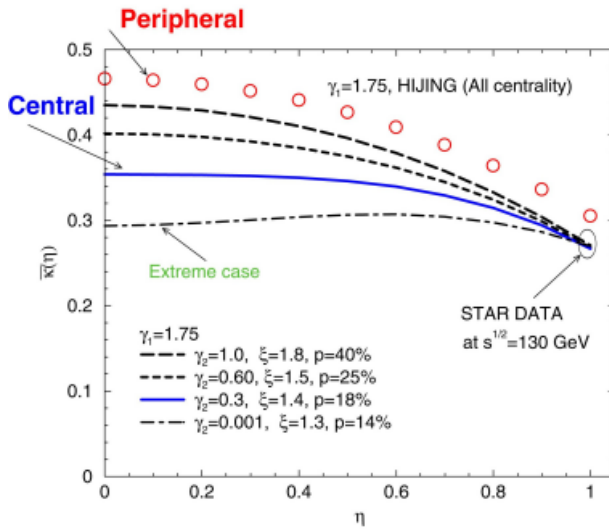


Fig. 6. Results for our neutral cluster model with a QGP component within the pseudorapidity range $-1 < \eta < 1$.

advocated the charge transfer fluctuations as a robust signal for QGP formation. Our observable $\kappa(\eta)$ is the ratio of the charge transfer fluctuation and $dN_{ch}/d\eta$. We have argued that $\kappa(\eta)$ is in fact a local measure of the unlike-sign charge correlation length. In elementary particle collisions, $\kappa(\eta)$ turned out to constant. Hence, if the charge correlation length inside QGP is indeed small compared to the hadronic gas [2, 3, 9], then measuring charge transfer fluctuations can enable us to detect the presence of a QGP even when the entropy fraction of the QGP is small compared to the hadronic part. Furthermore, by measuring how the curve $\kappa(\eta)$ changes from peripheral to central collisions, one may be able to estimate the size and the entropy fraction of the QGP component. Current net charge fluctuations data (equivalent to $\bar{D}_u(\eta = 1)$ within $-1 < \eta < 1$) is consistent with QGP having about 20% of the entropy fraction and about 1/3 of the charge correlation length.

In view of this estimate, it is also clear why the net charge fluctuation has not shown the expected large reduction [1]: the entropy content of QGP is small enough that if one averages over the whole observation window, its presence is hidden behind the larger hadronic component.

Here, we would like to mention that it will be also interesting to carry out similar studies using strangeness and/or baryon charge.

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