Charged particle fluctuation in Au+Au collision*

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Abstract In this paper, we present the centrality, transverse momentum region and rapidity window size dependence of charged particle fluctuation from Relativistic Quantum Molecular Dynamics (RQMD) model. $D_{\rm Q}$, $\Gamma_{\rm Q}$ and $\Phi_{\rm Q}$ all depend on the rapidity windows we chosen. $\nu_{+-,\rm dyn}$ is a promising observable in experiments, it weakly depends on the acceptance. The beam energy dependence of $\nu_{+-,\rm dyn}$ has been studied to present baseline prediction for net charge fluctuations in experiments.

Key words charged particle, fluctuation, deconfined matter

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1 Introduction

The Event-by-Event fluctuation of conserved charges, such as the electric charge, baryon number and strangeness, are considered to be sensitive indicators for the formation of quark-gluon plasma (QGP) in relativistic heavy ion collisions in Refs. [1–3]. Among all the conserved charges, it is the easiest to measure the electric charge. There exists various suggested measurements for the charged particle fluctuation. Although all these measurements seem different, closer examination proved that they are in fact connected [4]. On the other side, each observable exhibits different dependence of beam energy, collision centrality, detector acceptance (like transverse momentum region and rapidity window we chosen). For example, Charged particle ratio fluctuation [1], which has been proposed by S.Jeon and V.Koch, provides a signal for a quark-gluon plasma. It is a direct confirmation of the lattice QCD results. The Φ-measure is introduced by S.Mrowcznski [5], it is insensitive to the distribution of the independent particle source. Free of the effect of charge conservation gives this observable a big advantage. If one is interested in both the dynamical fluctuation and statistical fluctuation, Γ-measure [5] can be applied. Another measurement named dynamical charge fluctuation, has been studied by STAR Collaboration in Au+Au collision at $\sqrt{s_{\rm NN}}=130$ GeV [6]. It is found that positive and negative charged particle production is correlated within the pseudorapidity window from large and negative value of dynamical charged fluctuation.

In this paper we will discuss the properties of all mentioned measurements of the charged particle fluctuation, also discuss their behaviors on collision centrality, transverse momentum region and rapidity window size dependence.

2 Results and discussions

2.1 Charged particle ratio fluctuation

The Charged Particle Ratio Fluctuation, called D-measure, is defined as

$$D_{\rm Q}=4\frac{\langle\delta Q^2\rangle}{\langle N_{\rm ch}\rangle}, \qquad (1)$$

where $\langle\delta Q^2\rangle=\langle Q^2\rangle-\langle Q\rangle^2$, Q is net charge and $N_{\rm ch}$ is the number of charged particles emitted in the same selected window. On the theoretical side, for a free pion gas $D_{\rm Q}\approx 4$ but in quark gluon plasma it is expected to be significantly smaller (by a factor $3\sim4$) than in hadronic gas [1]. While experimentally this observable has been measured in heavy ion collision, like Relativistic Heavy Ion Collider(RHIC). The observed values from STAR and PHENIX in mid-rapidity at $\sqrt{s_{\rm NN}}=130$ GeV are around 3 [6–11],

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these values are much larger than predicted D_Q value in QGP and somewhat smaller than the expected D_Q value in hadron phase. The results surprised us most because a lot of other measurements indicate that deconfined matter is produced in these collision [12]. From Fig. 1(a) and Fig. 1(b), we can find D-measure stays roughly constant from different centrality. This measurement doesn't depend on the transverse momentum region while it is quantity dependent on the rapidity window size. The D-measure depends on the acceptance, large acceptance leads to small D_Q value, even if the D value close to 1 which has been predicted in QGP phase, we can not confirm that deconfined matter has been formed in these collision.

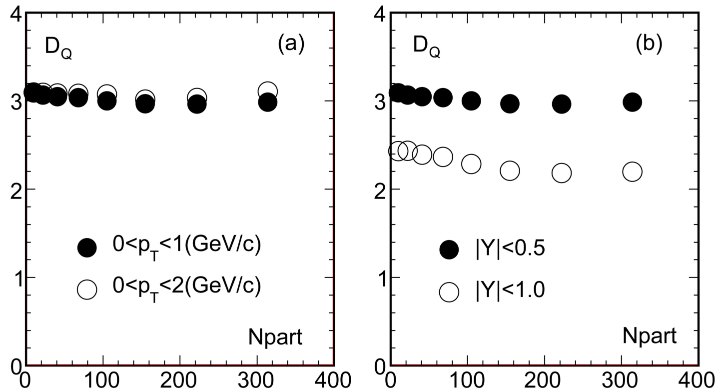

Fig. 1. The D-measure as a function of collision centrality for Au+Au collision at $\sqrt{s_{NN}} = 9.2$ GeV from different transverse momentum regions and different rapidity windows respectively. In Figs. $1 \sim 5$, the solid and open marker are results of $0 < p_T < 1$ (GeV/c) and $0 < p_T < 2$ (GeV/c) respectively in part (a), are results of $|Y| < 0.5$ and $|Y| < 1$ respectively in part (b).

2.2 *Φ*-measure and *Γ*-measure

The Φ-measure used to describe the fluctuation of a single-particle variable x, like net charge and mean transverse momentum. It is defined as:

$$\Phi_Q = \sqrt{\frac{\langle Z^2 \rangle}{\langle N \rangle}} - \sqrt{\overline{z^2}}, \tag{2}$$

where $z = x - \overline{x}$, $Z = \sum_{i=1}^{N}(x_i - \overline{x})$, x_i is the charge of i th particle, $\langle ... \rangle$ presents averaging over events. It is said that Φ-measure is independent on the collision centrality if the "physics" does not change [5].

There is another new measurement named Γ-measure

$$\Gamma_Q = \frac{1}{\langle N \rangle}\left\langle \left(Q - \frac{\langle Q \rangle}{\langle N \rangle}N\right)^2 \right\rangle = \frac{\langle Z^2 \rangle}{\langle N \rangle}. \tag{3}$$

As same as Φ-measure, Γ-measure is sensitive to the dynamical fluctuation, however, Γ-measure is even sensitive to the statistical dynamical. J.Nystrand et al discussed that Γ-measure is a constructed measurement so that it accommodates for non-symmetric distribution [10].

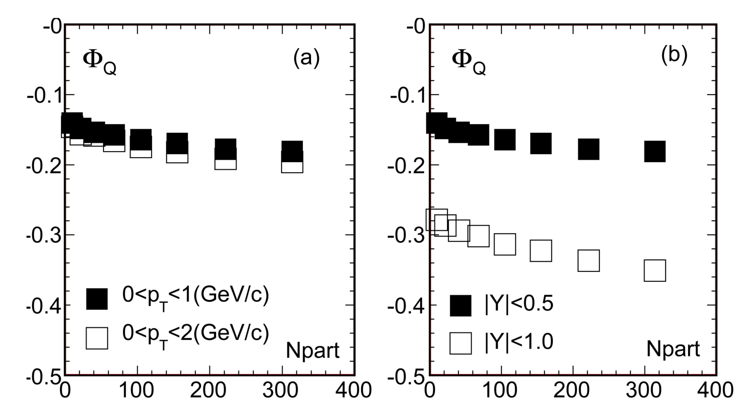

Fig. 2. The Φ-measure as a function of collision centrality from different transverse momentum regions and different rapidity windows respectively.

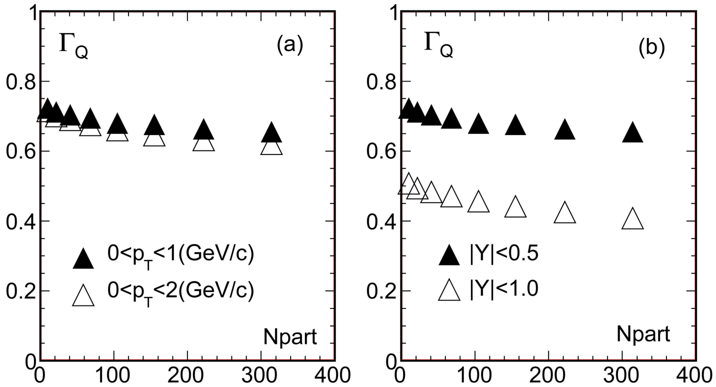

Fig. 3. The Γ-measure as a function of collision centrality from different transverse momentum regions and different rapidity windows respectively.

Figures 2 and 3 show the centrality dependence of the Φ-measure and Γ-measure, we can find both of them slightly decrease when the number of participant nucleon increasing. With different cut, this two measurements slightly depend on the transverse momentum region and strongly depend on the size of rapidity window. Considering to the acceptance dependence, these two measurements are not effective measurements to study QGP.

2.3 Dynamical charge fluctuation

This observable firstly used by C.Pruneau et al [4]. One argues that it should provide a direct measurement of the degree of the thermalization reached in collisions. The definition of net charge fluctuation ν_{+-} is as follows:

$$\nu_{+-}=\left\langle\left(\frac{N_+}{\langle N_+\rangle}-\frac{N_-}{\langle N_-\rangle}\right)\right\rangle. \tag{4}$$

The statistical charge fluctuation is

$$\nu_{+-,\mathrm{stat}}=\frac{1}{\langle N_+\rangle}-\frac{1}{\langle N_-\rangle}. \tag{5}$$

So the dynamical charge fluctuation can be expressed as:

$$\nu_{+-,\mathrm{dyn}} = \nu_{+-}-\nu_{+-,\mathrm{stat}}= \left\langle\left(\frac{N_+}{\langle N_+\rangle}-\frac{N_-}{\langle N_-\rangle}\right)\right\rangle-\left(\frac{1}{\langle N_+\rangle}+\frac{1}{\langle N_-\rangle}\right).$$

In Fig. 4 $\nu_{+-,\mathrm{dyn}}$ exhibits a monotonic dependence of collision centrality denoted by number of participate nucleons. The observed monotonic reduction of the magnitude of $\nu_{+-,\mathrm{dyn}}$ arises from the progressive dilution of the charge conservation effect when the number of charged particle multiplicity is increased. This result agrees with results from STAR Collaboration at 130 GeV [6].

Meanwhile when we choose different transverse momentum region(Fig. 4(a)) or different rapidity window (Fig. 4(b)), the results are not changed, it means that this observable is independent of the acceptance. It is a good measurement to observe in experiment to search for the QGP.

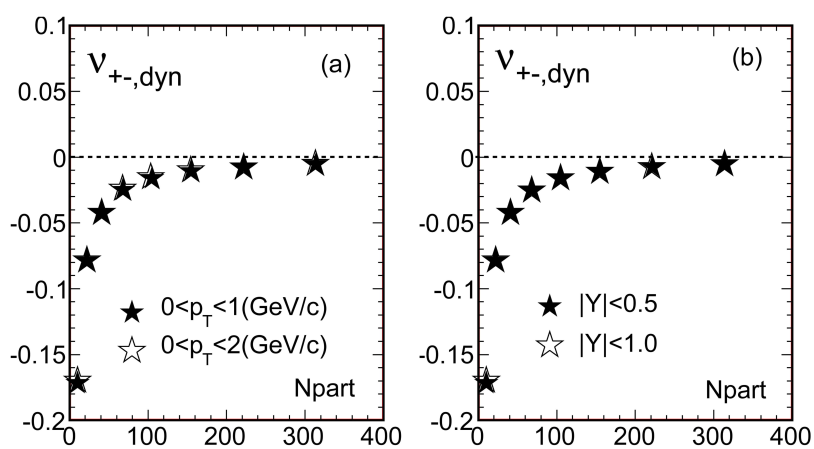

Fig. 4. The $\nu_{+-,\mathrm{dyn}}$ as a function of collision centrality from different transverse momentum regions and different rapidity windows respectively.

So we study the beam energy dependence of $\nu_{+-,\mathrm{dyn}}$ in Fig. 5. We observable that dynamical charge fluctuation from central, semi-central and peripheral collision are nonvanishing at all energy. They exhibit modest dependence of beam energy. These results are qualitatively consistent with latest measurements from STAR Collaboration [9].

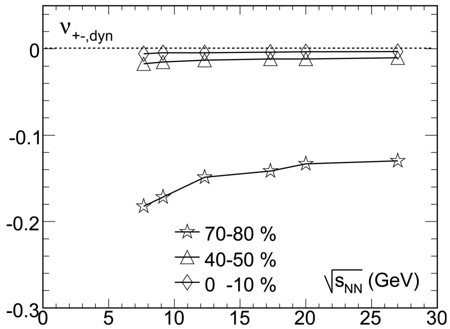

Fig. 5. The $\nu_{+-,\mathrm{dyn}}$ as a function of collision beam energy.

3 Summary

Several suggested measurements, like D-measure, Φ-measure, Γ-measure and $\nu_{+-,\mathrm{dyn}}$, for charged particle fluctuation have been studied, The D-measure, Φ_{Q} measure and Γ_{Q} measure show rapidity-window-size dependence from RQMD model. However, the dynamical charge fluctuation $\nu_{+-,\mathrm{dyn}}$ is a promising observable, it is independent of the acceptance. Nonvanishing at all energy and modestly depending on beam energy provide baseline predictions of charge particle fluctuation, these give us some hints to understand the expectations from experimental results for the forthcoming RHIC Beam Energy Scan Program.

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