Eccentricity and elliptic flow at a fixed centrality in Au+Au collisions at $\sqrt{s_{\rm NN}}$=200 GeV in an AMPT model *

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Abstract: In this paper, elliptic flow is studied at a fixed centrality in Au+Au collisions at $\sqrt{s_{\rm NN}}$=200 GeV in the AMPT model. It is observed that as the participants increase, elliptic flow either increases or decreases at a different fixed impact parameter, but it does not have a trivial fluctuation. It is analyzed that the initial space anisotropy dominates the participant dependence of elliptic flow in near-central collisions(b=5 fm) and mid-central collisions(b=8 fm), while the interaction between particles can mainly answer for the elliptic flow behavior with the participant in peripheral collisions (b=12 fm). To distinguish the pure geometrical effect, elliptic flow scaled by initial eccentricity is studied. It is found that the ratio v_2/ϵ increases with the participant and reaches a saturation when the participant is large enough, indicating that the collision system may reach a local equilibrium.

Key words: elliptic flow, initial eccentricity, at a fixed centrality, local equilibrium

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1 Introduction

The discovery of a large azimuthal anisotropic flow of hadrons at RHIC provides conclusive evidence for the creation of dense partonic matter in ultrarelativistic nucleus-nucleus collisions [1–3]. The strong interaction medium in the collision zone can be expected to achieve a local equilibrium and exhibit an approximately hydrodynamic flow [4–6]. Moreover, the study of anisotropic flow has the potential to offer insights into the equation of state of the produced matter [7, 8].

The momentum anisotropy of the final particles is generated due to the transverse density gradient based on an initial geometry of an "almond-shaped" overlap region produced in non-central collisions. The pressure gradient converts the initial coordinate space asymmetry into the momentum anisotropy of the final particles, such as elliptic flow. The magnitude of the elliptic flow depends on both the initial spatial asymmetry in non-central collisions and the subsequent interaction between the particles. Therefore, the study of elliptic flow is crucial in order to understand the properties of the dense matter formed during the initial stage of heavy ion collisions [9] and parton dynamics [10] at the relativistic heavy ion energies.

In this paper, we focus on the study of elliptic flow at fixed centrality where the impact parameter b is a constant. The elliptic flow at a fixed centrality in Au+Au collisions at $\sqrt{s_{\rm NN}}$=200 GeV is presented in detail, such as the variation with the number of participating nucleons and the behavior after being scaled by the initial eccentricity. Here, we used the AMPT model with string melting [11].

The layout of this paper is as follows. Section 2 briefly introduces the AMPT model, a transport model based on parton level. In Section 3, we mainly study the elliptic flow and initial eccentricity at a fixed centrality in Au+Au collisions, the dependence of participating nucleons, the ratio of v_2/ϵ, and so on. Finally, a conclusion is given in Section 4.

2 A brief introduction to AMPT

The AMPT model [11] is based on parton level transport dynamics. There are two versions of the AMPT model, one is the default AMPT, and the other is AMPT with string melting. It turns out that the default AMPT (v1.11) is able to give a reasonable description on hadron rapidity distributions and transverse momentum spectra observed in heavy ion collisions at both SPS and RHIC. However, it fails to reproduce the experimental data about elliptic flow and two-pion correlation function. On the other hand, the AMPT model with string melting

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(v2.11) can describe the elliptic flow and two-pion correlation function well [12, 13] but does not agree with the hadron rapidity and transverse momentum spectra. The AMPT model with string melting is chosen as best fitting our criteria.

The AMPT model with string melting contains four main components: the initial conditions, partonic interactions, conversion from the partonic to the hadronic matter and hadronic interactions. The initial conditions are obtained from the HIJING model [14]. The time evolution of partons is then modeled by the ZPC parton cascade model [15]. After the partons stop interacting, a simple quark coalescence model is used to combine the two nearest quarks into a meson and the three nearest quarks (antiquarks) into a baryon (antibaryon). After hadronization, scatterings among the resulting hadrons are described by a relativistic transport (ART) model [16] which includes baryon-baryon, baryon-meson and meson-meson elastic and inelastic scatterings.

In the following we will utilize the AMPT model with string melting to generate Au+Au collision events at $\sqrt{s_{\mathrm{NN}}}=200$ GeV. The parton cross section is taken to be 10 mb.

3 The elliptic flow, initial eccentricity and their ratio v_2/ϵ

In Section 3.1, we will firstly study the elliptic flow in Au+Au collisions from minibias events, and it is observed that the strongest collective behavior appears in the mid-central collisions. In Section 3.2, we present the participant dependence of elliptic flow and initial eccentricity at a fixed centrality. Finally, the participant dependence of the ratio v_2/ϵ is shown in Section 3.3.

3.1 The elliptic flow from minibias events

When two nuclei collide at nonzero impact parameter, their overlap in the transverse plane has a short axis, parallel to the impact parameter, and a long axis perpendicular to it. This initial space anisotropy is converted by the pressure gradient into a momentum asymmetry, so more particles are emitted along the short axis [4]. This magnitude of this effect is characterized by the elliptic flow, defined as

$$v_2=\langle\cos 2(\varphi-\Phi_{\mathrm{R}})\rangle, \tag{1}$$

where φ is the azimuthal angle of an outgoing particle, Φ_{R} is the azimuthal angle of the impact parameter, and angular brackets denote an average over many particles and many events.

In this section, we study the elliptic flow signal as a function of the impact parameter b (Fig. 1(a)), the initial participants (Fig. 1(b))and the final charged particles (Fig. 1(c)) in Au + Au collisions at $\sqrt{s_{\mathrm{NN}}}$=200 GeV from the AMPT model with string melting. Here, all the charged particles with rapidity in the region $y\in(-5,+5)$ are included.

From the figure we can see that the elliptic flow first increases, reaches its maximum value and then decreases, indicating the strongest collective behavior is produced in mid-central Au+Au collisions. The elliptic flow is built and formed from the anisotropic geometrical effect and the hadron and parton interaction between particles during the system expansion. In peripheral collisions, we can obtain the strongest initial anisotropy, while the interaction between produced particles is weak when the number of participants is so small. In the near-central collisions, most nucleons can take part in the collision, while the initial anisotropy is not large enough. It is reasonable that that the strongest elliptic flow appears in the mid-central collision where the interaction between particles is strong enough to convert the initial space anisotropy into final momentum anisotropy completely.

3.2 The participant dependence of the elliptic flow and initial eccentricity at a fixed centrality

In this section, we focus on the study of the elliptic flow at fixed centrality where the impact parameter b is a constant. Here, we choose the fixed impact parameter b=5 fm, 8 fm and 12 fm, which responds to the case in the near-central, the mid-central and the peripheral collisions respectively. In general, the geometric overlap

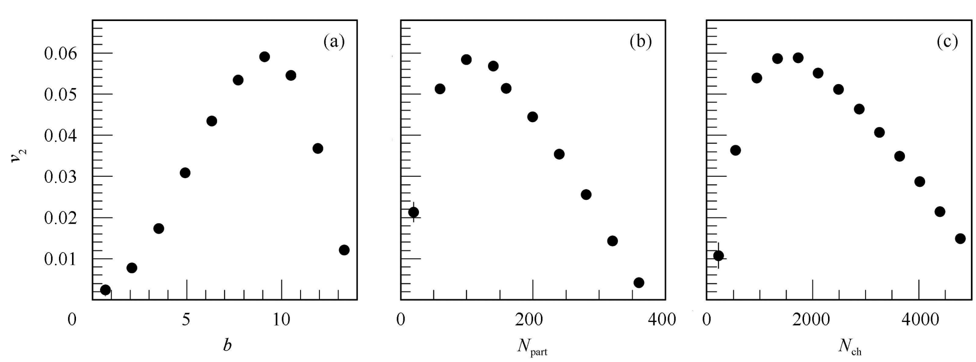

Fig. 1. The impact parameter (a), the participant (b) and the final charged particles (c) dependence of elliptic flow in Au + Au collisions at 200 GeV with the AMPT model.

region of Au+Au collisions is fixed, the elliptic flow is expected to remain roughly unchanged or at most have a trivial fluctuation.

The participant dependence of elliptic flow in Au+Au collisions at a fixed centrality at $\sqrt{s_{\rm NN}}$=200 GeV is shown in the upper panel of Fig. 2. From the figure, we can see that even if the impact parameter b is fixed, the fluctuation of participating nucleons is so large that it can't be ignored. With the participant increasing, the elliptic flow has a slow increase in the peripheral collisions for b=12 fm (left), while it decreases monotonously in the mid-central and near-central collisions, e.g., b=8 fm (middle) and b=5 fm (right). As a result, it is argued that the participant dependence of elliptic flow at a fixed centrality has some origin in physics, but not only the statistical fluctuation effect.

It is widely believed that the anisotropic collective flow is mainly driven by the initial eccentricity of the matter created in the nuclear overlap zone. In this point, we will simply study the participant dependence of the corresponding initial eccentricity ϵ at a fixed centrality. The Monte Carlo Glauber model [17] is used to estimate the initial eccentricity from the distribution of participant nucleons in the transverse plane. The participant eccentricity is defined by [18]

$$\varepsilon_{\rm part}=\frac{\sqrt{(\sigma_y^2-\sigma_x^2)^2+4\sigma_{xy}^2}}{\sigma_x^2+\sigma_y^2}, \quad (2)$$

where $\sigma_x^2=\langle x^2\rangle-\langle x\rangle^2$ and $\sigma_y^2=\langle y^2\rangle-\langle y\rangle^2$ are the variances of the nucleon distribution in the x- and the y-direction, and $\sigma_{xy}=\langle xy\rangle-\langle x\rangle\langle y\rangle$ is the covariance of the position of participant nucleons.

The participant dependence of initial eccentricity at a fixed centrality in Au+Au collisions at $\sqrt{s_{\rm NN}}$=200 GeV is presented in the lower panel of Fig. 2. From the figure, we can see the initial eccentricity ϵ for the cases of b=12 fm (left), 8 fm (middle) and 5 fm (right), all decrease with the participant increasing.

Comparing the results of the upper and lower panel in Fig. 2, it is obvious that the elliptic flow and the initial eccentricity have a consistent decrease with the increasing participant both for b=8 fm (middle) and b=5 fm (right), while they have a contrasting case for b=12 fm (left). As we know, the elliptic flow is formed and built from the initial anisotropy of the overlap region and the subsequent interaction between the produced particles. On this basis, we argue that the initial space anisotropy dominates the participant dependence of elliptic flow in near-central (b=5 fm) and mid-central collisions (b=8 fm). The subsequent interaction between the produced particles, which becomes stronger with the participant increasing, mainly answers for the participant dependence of elliptic flow in peripheral collisions (b=12 fm), such as a slow increase.

3.3 The participant dependence of v_2/ϵ at a fixed centrality

In order to distinguish the collision dynamics from the purely geometrical effects, it has been suggested that

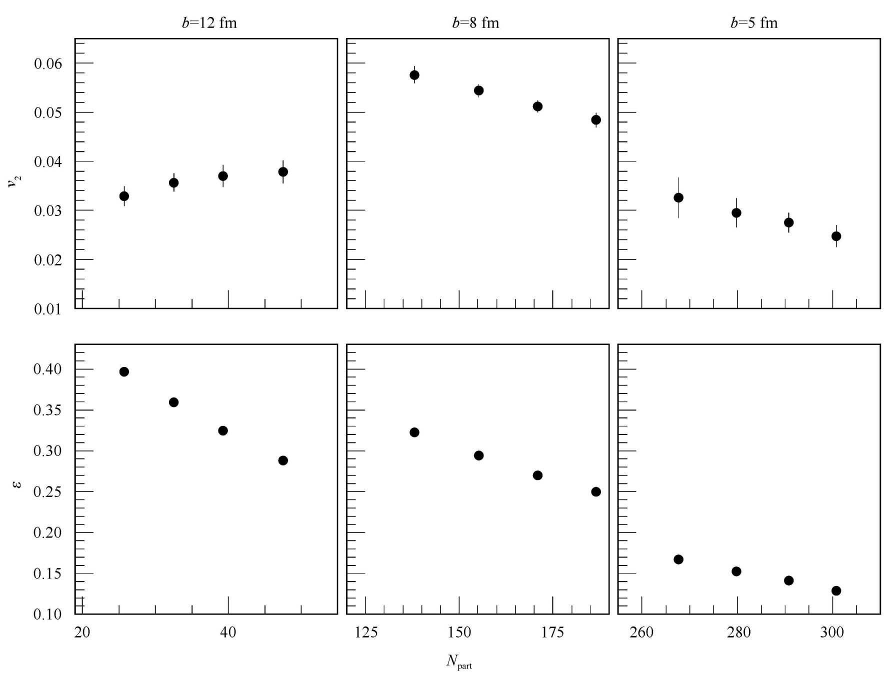

Fig. 2. The participant dependence of elliptic flow(the upper panel) and eccentricity (the lower panel) for 200 GeV Au+Au collisions in the AMPT model with string melting at a fixed impact parameter b=12 fm (left), b=8 fm (middle) and b=5 fm (right).

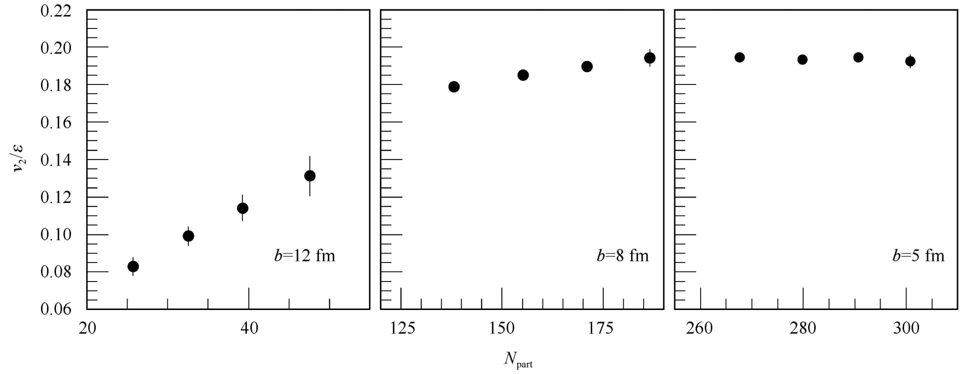

Fig. 3. The participant dependence of the ratio v_2/ϵ in Au+Au collisions at 200 GeV at a fixed impact parameter b=12 fm (left), b=8 fm (middle) and b=5 fm (right) in the AMPT model with string melting.

the measured v_2 should be scaled by the initial eccentricity of the nuclear overlap. If the produced matter equilibrates, it behaves as an ideal fluid. Hydrodynamics predicts that v_2 scaled by eccentricity ϵ has a saturation when the collision system achieves the local equilibrium [19, 20]. However, if the equilibration is not incomplete, then the eccentricity scaling is indeed broken, e.g., in the peripheral Au+Au collisions [21, 22].

The participant dependence of v_2/ϵ at fixed centrality in Au+Au collisions at $\sqrt{s_{\rm NN}}$=200 GeV is shown in Fig. 3. From the figure, we can see that the ratio v_2/ϵ keeps increasing both for b=12 fm (left) and b=8 fm (middle), while it becomes saturated in the near-central collisions for b=5 fm (right). It is reasonable that more participants lead to a stronger interaction between particles, hence a larger ratio v_2/ϵ can be obtained in more central collisions. As expected in an equilibrium scenario, the ratio v_2/ϵ in the near-central collisions shows little sensitivity to the participants. This indicates that the system created in 200 GeV Au+Au near-central collision by the AMPT model including both the parton cascade and hadron scattering, may reach local thermalization when the interaction between particles is strong enough.

4 Conclusion

To summarize, we have studied the elliptic flow and initial eccentricity and their ratio at a fixed centrality in Au+Au collisions at $\sqrt{s_{\rm NN}}=200$ GeV. It is observed that they have a monotonous behavior (an increase or a decrease) with the participant increasing for different values of fixed impact parameter b, but they do not have a trivial fluctuation. It is argued that the initial eccentricity dominates the participant dependence of elliptic flow in the mid-central collisions (b=8 fm) and near-central collisions (b=5 fm), while the interaction between particles dominates the behavior of elliptic flow with the participants in peripheral collisions (b=12 fm). Moreover, it is found that the elliptic flow scaled with initial eccentricity keeps increasing with the participants. When the number of participants is large enough, the ratio v_2/ϵ has a saturation, indicating that the collision system may reach a local equilibrium.

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