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"TEMPERATURE" FLUCTUATION AND HEAT CAPACITIES OF QUARKS AND π MESON

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Specific heat capacities of π meson and different quarks after parton cascade AMPT model in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV have been tentatively extracted from the event-by-event temperature fluctuations in the region of low transverse mass. The specific heat capacity of π meson shows a slight dropping trend with increasing impact parameter. The specific heat capacities of different quarks increase with the mass of quark, and the sum of up and down quark's specific heat capacities was found to be approximately equal to that of π meson.

1. Introduction

In the thermodynamic interpretation of multiparticle reactions, it is possible to experimentally determine a basic quantity characterizing the presumed thermodynamic system: the heat capacity. We exploit the fact that there are so high multiplicity of hadron production in relativistic heavy-ion collisions that "temperature" can be assigned on an event-by-event basis, which permits us to survey "temperature" fluctuation. In a thermodynamics system, the latter relates to heat capacity which is a good probe to search for phase transitions[1] and to study other thermodynamical aspects of the system.[2] Therefore the heat capacity is one of the most important thermodynamic variables. Since the heat capacity is an extensive observable, afterwards we will use specific heat capacity which means specific heat per particle.[3,4]

The AMPT model[5] (A Multi-phase Transport Model) is based on non-equilibrium transport dynamics. It contains four main components: the initial conditions, partonic interactions, conversion from partonic to hadronic matter and hadronic interactions. It uses heavy ion jet interaction generator (HIJING) for generating the initial conditions, Zhang's parton cascade (ZPC) for modeling partonic scatterings, the Lund string fragmentation model or a quark coalescence model for hadronization, and a relativistic transport(ART) model[6] for treating hadronic scatterings. AMPT model presents a coherent description of the dynamics of relativistic heavy ion collisions. There are two versions of AMPT model which will be used in our work. In the default version of AMPT model, minijet partons are combined with their parent strings after ceasing interactions to form excited strings, which are then converted to hadrons according to Lund string fragmentation model. While in the AMPT model with string melting, the strings in the initial conditions are melted into partons, then the scatterings among partons are modelled by ZPC. After partons stop interactions, a simple quark coalescence model is used to combine the two or three nearest partons into a meson or a baryon. The default AMPT model fails to reproduce the experimental data about elliptic flow and HBT. On the other hand, the AMPT model with string melting mechanism can well describe the elliptic flow and two (or three) particle correlation,[5–9] but agrees badly with the hadron rapidity and transverse momentum spectra.

2. The Calculational Method

In relativistic heavy-ion collisions, the transverse mass m_T distribution of the particles in lower m_T region can be approximately described by $\frac{1}{m_T}\frac{dN}{dm_T} = Ae^{-\frac{m_T}{T}}$ where A is a normalized coefficient which is related to the volume/multiplicity term and T is an effective temperature. Thanks to the large enough particle multiplicity, it is possible to extract A and T on event-by-event[10] basis. In this way, the event-by-event temperature distribution can be constructed. Usually, such kind of temperature distribution ($P(T)$) can be described by[11–13]

$$P(T) \sim \exp\left[-C_v\left(\frac{\Delta T}{T}\right)^2\right], \tag{1}$$

where ΔT is the deviation ($T - \langle T\rangle$) of temperature from the mean value ($\langle T\rangle$) and C_v can be explained as the heat capacity a certain hadron. Since the heat capacity is an extensive observable, we defined a specific heat capacity C_v/N, i.e. the heat capacity per hadron multiplicity (N) which corresponds to the required energy to go up one unit temperature for one particle.

3. Results and Discussion

Figure 1 gives us an example of event-by-event temperature distribution of π meson from the AMPT model with string melting mechanism after hadron rescattering in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. From this kind of distribution, we apply Eq. (1) to extract the heat capacity C_V. The curve in the figure depicts this fit. In this way, we get the heat capacity for various particles. Figure 2 gives the dependences of specific heat capacities of π and u quark plus d quark on the impact

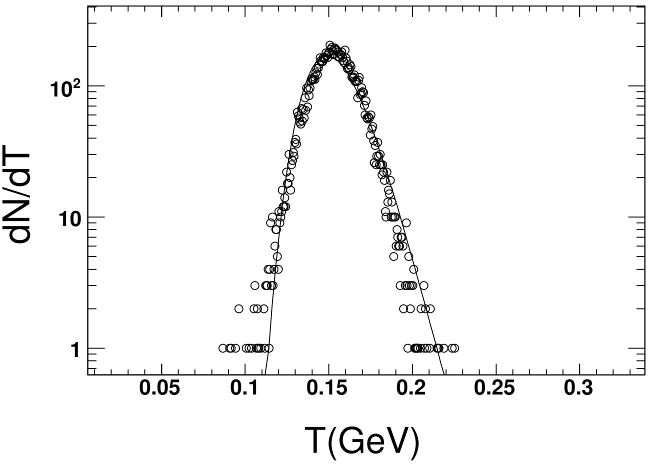

Fig. 1. The event-by-event temperature distribution of π meson from the AMPT model with string melting mechanism after hadron rescattering in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at impact parameter of 10.35 fm.

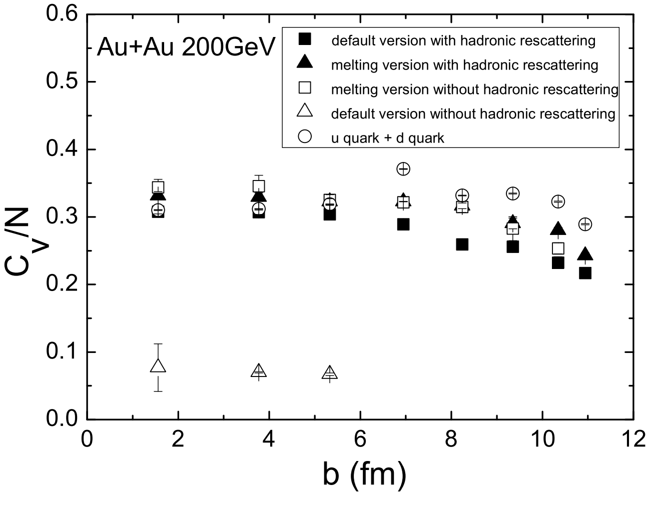

Fig. 2. The impact parameter dependences of the specific heat capacity of π meson, u quark + d quark in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The error bars are statistical only. Full squares: default AMPT version with hadronic rescattering; Full triangles: melting AMPT version with hadronic rescattering; Open squares: default AMPT version without hadronic rescattering; Open triangles: melting AMPT version without hadronic rescattering; Open circles: the sum of special heat capacities of u quarks and d quarks after parton cascade in Au+Au collisions at $\sqrt{s_{NN}} = 200$GeV.

parameters for 200 GeV Au+Au collisions. From this figure, specific heat capacities of pion decrease with the increasing of impact parameter. It is similar to the results in the LUCIAE model for the head-on Pb+Pb collisions at 160 GeV.[13] It indicates

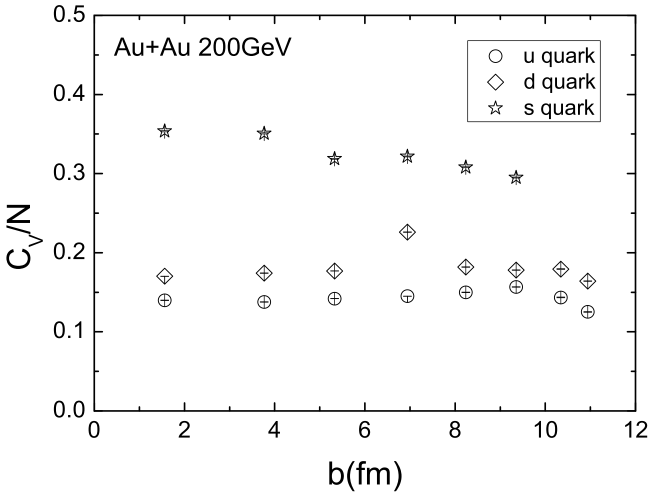

Fig. 3. Specific heat capacities of different quarks after parton cascade as a function of the impact parameter in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Open circles: *u* quark; Open diamonds: *d* quark; Open stars: *s* quark.

that less energy is needed to rise the same temperature when the impact parameter increases. In the viewpoint of fluctuation, this means that the temperature fluctuation becomes larger in peripheral collisions and m_T fluctuation increases with the increasing of impact parameter. It was also found that the result from the default AMPT model after hadron rescattering are a bit smaller than the ones from the AMPT model with string melting mechanism after hadron rescatterings. As we know, π is make up of *u* quarks and *d* quarks. Therefore, Fig. 1 also shows specific heat of *u* quarks plus that of *d* quarks after parton cascade, which is close to that of π. It seems that the specific heat capacity approximately obey the Number of Constitute Quark (NCQ) scaling, which need be checked by other hadrons after increasing statistical amount in the future.

Figure 2 depicts that specific heat capacities of the different quarks after parton cascade, which increases with the mass of quark. It indicates that more energy is needed to rise the same temperature for heavier quarks. It has been founded that specific heat of the hadrons increases with the mass of hadrons.[13]

4. Summary

In summary, the event-by-event effective temperature fluctuation in lower m_T region was constructed and specific heat capacities of π meson and different quarks after parton cascade were extracted in a partonic transport model. It was found that specific heat of π meson decreases with the increasing of impact parameter, and the results from the default AMPT model after hadron rescattering are close to the ones from the AMPT model with string melting mechanism after hadron rescattering, which indicates the string melting mechanism has a very little effect on temperature fluctuation and the specific heat capacities. It was found that specific heat capacities of different quarks after parton cascade increases with the mass of quark, a NCQ scaling of specific heat seems to be applicable within the presented results.

Acknowledgments

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