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Measurement of the Sixth-Order Cumulant of Net-Proton Distributions in Au+Au Collisions from the STAR Experiment

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Abstract

Higher-order cumulants of the net-baryon multiplicity distributions are predicted to be sensitive to the properties of the nuclear matter created in high-energy nuclear collisions. In this talk, we present the collision centrality and acceptance (rapidity and transverse momentum) dependence of the ratio of the 6$^{\rm th}$- to the 2$^{\rm nd}$-order cumulant ratio (C_6/C_2) of net-proton in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 54.4 and 200 GeV measured by the STAR detector at RHIC. The new results are compared to hadron transport model and lattice QCD calculations.

Keywords:

1. Introduction

One of the main goals of heavy-ion collision experiments is to study the phase diagram of Quantum Chromodynamics (QCD). Higher-order cumulants of conserved charges are predicted to be sensitive to the QCD phase structure, especially the possible critical end point. The STAR experiment has investigated the QCD phase structure at finite $\mu_{\rm B}$ by measuring the cumulants up to the 4$^{\rm th}$ order ($C_n, n < 4$) and their ratios in the STAR experiment at RHIC [1–4]. Recently, the non-monotonic beam-energy dependence is observed for C_4/C_2 of net-proton multiplicity distributions [5], which could be an experimental signature of the critical point. At $\mu_{\rm B} = 0$ MeV, on the other hand, the lattice QCD calculation predicts a smooth crossover [6], although there is no direct experimental evidence of a crossover. Theoretically, the 6$^{\rm th}$- to 2$^{\rm nd}$-order cumulant ratio, C_6/C_2, of the net-charge and net-baryon multiplicity distributions are predicted to be negative if the freeze-out temperature is close to the pseudocritical temperature [7].

In this proceedings, we present the centrality dependence of C_6/C_2 of net-proton multiplicity distributions at $\sqrt{s_{\rm NN}}$ = 54.4 and 200 GeV. The results are compared with the hadron transport model calculations and lattice QCD calculations. The acceptance dependence of C_6/C_2 is also discussed.

2. Analysis methods

The data are collected by STAR using the Time Projection Chamber (TPC) and Time-Of-Flight (TOF) detector. Collision events occurred within 30 cm in the beam direction and 2 cm in the radial direction are selected. Protons are identified by TPC and TOF at rapidity window $-0.5 < y < 0.5$ and transverse momentum window $0.4 < p_{\rm T}$ (GeV/c) < 2.0. The average PID efficiency is about 50% with a weak centrality dependence [5]. Centrality is determined in $|\eta| < 1.0$ excluding protons and antiprotons to gain the maximum centrality resolution with reducing the autocorrelation effects [8, 9]. The centrality bin width averaging (CBWC) is done in order to suppress the effect of the initial volume fluctuations [10]. Cumulants are calculated for each multiplicity bin, which are averaged in 10% step of the centrality bin. In order to reduce the statistical uncertainties in central collisions, results in 0-10, 10-20, 20-30 and 30-40% centrality intervals are averaged using the inverse of the error squared as a weight.

Efficiency and acceptance corrections are done assuming that the detector responses do not depend strongly on the event multiplicity [11–15]. Within the aforementioned acceptance, the efficiency for antiprotons is found to be lower than that of protons by ∼5% independent of centrality. Unlike the case for particle yield analysis, the efficiency correction of the higher-order cumulants is expressed by the convolutions of lower-order cumulants, which means that the correction is affected not only by the value of the single-particle efficiency but also strongly affected by the shape of the distributions.

3. Centrality dependence

Figure 1 shows the centrality dependence of C_6/C_2 of net-proton multiplicity distributions in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 54.4 and 200 GeV. It is found that the results from two beam energies are consistent in peripheral collisions, while a clear separation is observed in 0-40% central collisions (the most central bin). The negative sign is observed for $\sqrt{s_{\rm NN}}$ = 200 GeV. The C_6/C_2 value at $\sqrt{s_{\rm NN}}$ = 54.4 GeV shows positive sign and consistent with the Skellam baseline (=1). The hadron transport model (UrQMD) calculations, which does not incorporate the phase transition, show positive sign of C_6/C_2 of net-proton multiplicity distributions for all the centralities at $\sqrt{s_{\rm NN}}$ = 54.4 and 200 GeV. The lattice QCD (LQCD) calculations from two groups taking T = 160 MeV ($\mu_{\rm B}$ = 0 MeV) also show negative values [16–18]. When we compare LQCD results with our measurements in 0-40% central collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV, we find that those results are consistent within large uncertainties.

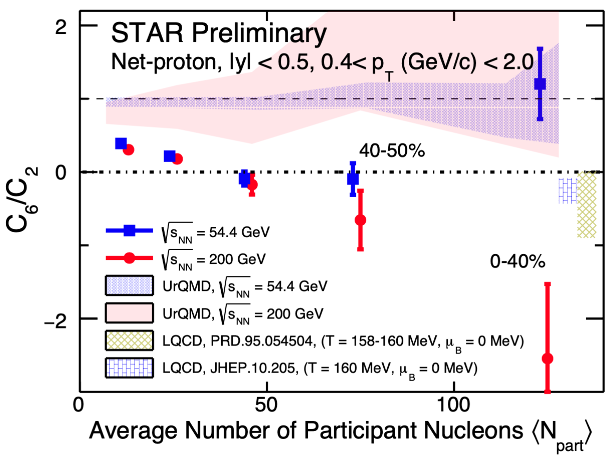

Fig. 1. Centrality dependence of C_6/C_2 of net-proton multiplicity distributions in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 54.4 and 200 GeV. The most central bin represents 0-40% centrality. The hadron transport model (UrQMD) calculations are shown in blue and red bands for two beam energies. The cyan and yellow bands show LQCD calculations taking T = 160 MeV.

4. Acceptance dependence

When we compare the experimental results with LQCD calculations, we need to consider the effects of the experimental acceptance. With the narrow acceptance the net-baryon multiplicity distributions should reach the Skellam distribution, which exhibits $C_6/C_2 = 1$. By increasing the acceptance, the physics signals increase, which may lead to deviations from unity. The C_6/C_2 is expected to reach zero or unity with the full 4π acceptance due to the baryon number conservation effect [19]. Figure 2 shows the acceptance dependence of C_6/C_2 of net-proton multiplicity distributions in Au+Au collisions $\sqrt{s_{\rm NN}}$ = 200 GeV for each centrality bin, where the rapidity window ($|y| < \alpha$, α = 0.1, 0.2, 0.3, 0.4 and 0.5) and $p_{\rm T}$ acceptance ($0.4 < p_{\rm T} < \beta, \beta$ = 0.8, 1.1, 1.4, 1.7 and 2.0 GeV/c) is enlarged from left to right along the x-axis. For both the rapidity and $p_{\rm T}$ acceptance dependence, the C_6/C_2 values are close to the Skellam baseline when the acceptance is small, but the values decrease for larger acceptance. The negative sign is observed for large acceptance in central collisions. It is found that the values are saturated for $p_{\rm T}$ acceptance dependence at $\beta > 1.4$. This is because the mean $p_{\rm T}$ of protons is at around $p_{\rm T} \approx 1.1$ GeV/c, hence the number of protons is saturated around $\beta > 1.4$ GeV/c.

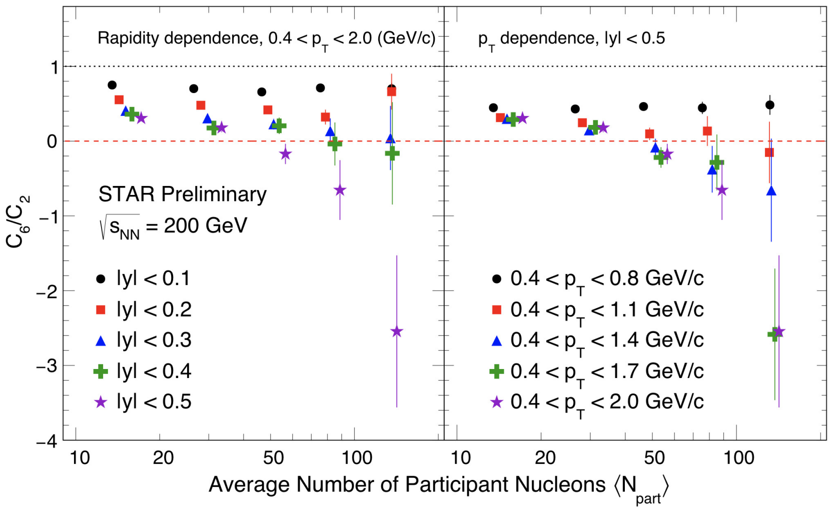

Fig. 2. Rapidity (y) and transverse momentum ($p_{\rm T}$) acceptance dependence of C_6/C_2 of net-proton multiplicity distributions Au+Au collisions $\sqrt{s_{\rm NN}}$ = 200 GeV in 0-40% centrality.

5. Summary

We report the first measurements of the C_6/C_2 of net-protons from 54.4 and 200 GeV Au+Au collisions at RHIC. The results from peripheral collisions at both energies are consistent with each other. The C_6/C_2 measured in 0-40% Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV is found to be negative and consistent with the lattice QCD prediction. This consistency implies that the nuclear matter created at 200 GeV collisions might undergo a smooth crossover transition from the QGP to hadronic matter. On the other hand, the result from 54.4 GeV shows a positive value. The negative and positive signs at 200 and 54.4 GeV in 0-40% Au+Au collisions are at 2 sigma effect. High statistics data are needed in order to understand the phase structure at vanishing baryonic density.

6. Acknowledgement

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