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Measurement of the ratio of the sixth order to the second order cumulant of net-proton multiplicity distributions in relativistic heavy-ion collisions

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Abstract

We investigate the measurement of the sixth order cumulant and its ratio to the second order cumulant (C_6/C_2) in relativistic heavy-ion collisions. The influence of statistics and different methods of centrality bin width correction on C_6/C_2 of net-proton multiplicity distributions is demonstrated. There is no satisfactory method to extract C_6/C_2 with the current statistics recorded at lower energies by STAR at RHIC. With statistics comparable to the expected statistics at the planned future RHIC Beam Energy Scan II (BES II), no energy dependence of C_6/C_2 is observed in central collisions using the UrQMD model. We find that if the transition signal is as strong as predicted by the PQM model, then it is hopefully observed at the upcoming RHIC BES II.

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1. Introduction

Uncovering the structure of the QCD phase diagram is one of the major goals in studying relativistic heavy-ion collisions. Ratios of cumulants of conserved quantities, such as net-baryon, net-charge and net-strangeness numbers, can exhibit large fluctuations near the QCD phase transition [1–8]. Due to the finite size effects and critical slowing down [9,10], such significant enhanced fluctuations would be suppressed in experiment. Instead, the phenomena of oscillatory behaviors, such as the non-monotonic and sign change, are the particularly interesting signals which could be directly measured in experiments [11–13]. Theoretically, it has been found that the sixth order to the second order cumulant ratio (C_6/C_2) undergoes a significant sign change near the QCD phase transition [4,14–17]. Consequently, C_6/C_2 is a promising observable and it can be measured from RHIC up to LHC energies [15,18,19]. Unfortunately, comparing to the other lower order cumulant measurements, the price of measuring C_6/C_2 in an experiment is the larger number of required events and the stronger effects of non-critical background contributions.

Currently, there are many discussions on the effects of the non-critical background contributions for cumulants. Due to the global conservation, the cumulants of the conserved quantities are substantially suppressed [20]. The effects of the acceptance cuts as well as efficiency corrections drastically influence the measured cumulants [21,22]. The initial size fluctuation is also one of the important non-critical effects which exists in all experiment event variables [23–25]. What we want to emphasize here is that the techniques to reduce those non-critical effects should be studied carefully case by case for different cumulants. With the STAR detector at RHIC, to suppress the effects of auto-correlation in the measurement, the centrality for the measurement of cumulants of the net-proton multiplicity distributions is determined by number of charged kaons and pions produced in the final state within $|\eta| < 1.0$ [11,24], while it is defined by final state multiplicity within $0.5 < |\eta| < 1.0$ for the measurement of cumulants of the net-charge multiplicity distributions [12,26]. Due to the detector setup of PHENIX at RHIC, there is no issue of auto-correlation for the measurement of cumulants of the net-charge multiplicity distributions [13,27]. For C_6/C_2, the effects of the auto-correlation and centrality resolution should be different at LHC and RHIC [18,19]. In this paper, we will focus on discussing the measurement of C_6/C_2 with the STAR detector at RHIC.

The Centrality Bin Width Correction (CBWC) method is applied to reduce initial size fluctuation on the measurement of the cumulants in heavy-ion collisions [28]. There are two key points when applying the CBWC method: one is that the statistics in the selected centrality bin width should be sufficient to satisfy the Central Limit Theorem (CLT) [29] and the other one is that the selected centrality bin width should optimally reduce the initial size fluctuation. With sufficient statistics, it has been found that the values of C_4/C_2 are consistent based on the CBWC methods in each $\delta 1\%$ centrality bin width and in each of N_{ch} [25]. Since the chosen centrality bin width can vary, the number of events that are required by the CLT should be dependent on the chosen centrality bin width used by CBWC method. For example, within transverse momentum range $0.4 < p_T < 0.8$ GeV/c, the required statistics for C_4/C_2 of net-proton number is 15 million (15M) based on CBWC method in each of N_{ch}, while 1M is enough if CBWC method is applied for each centrality bin with a width of $\delta 1\%$ [25]. For C_6/C_2, the resolution with different centrality bin widths used by CBWC method and the corresponding required statistics should be determined.

The statistics is one of the most crucial issues for the analysis of C_6/C_2. Even with the anticipated statistics of the upcoming RHIC BES II, the statistical uncertainties of C_6/C_2 will be still

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