Cumulant measurement of net-kaon distributions in Au+Au collisions at $\sqrt{s_{NN}} = 27$ GeV from BES-II program at RHIC

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Abstract. We report on the measurements of cumulants (C_n) of event-by-event net-kaon distributions up to the fourth order in the most central (0-5%) Au+Au collisions for center-of-mass energy $\sqrt{s_{NN}} = 27$ GeV from the BES-II program at RHIC. Charged kaons are selected at mid-rapidity $|y| < 0.5$ with transverse momentum range $0.2 < p_T < 1.6$ GeV/c using the STAR detector at RHIC. We find the new measurements at $\sqrt{s_{NN}} =$ 27 GeV with high event statistics from BES-II are consistent with those from the BES-I program by RHIC for the same collision energy and centrality. The new results follow the trend of the strong collision energy dependence of cumulants and cumulant ratios up to third order($C_n, n \leq 3$, C_2/C_1, C_3/C_1) and weak collision-energy dependence of C_4 and C_4/C_2, from the BES-I measurements. The expectation from the UrQMD model calculated in the STAR acceptance is also presented and compared to the measured cumulant ratios.

Keywords: quark-gluon plasma, phase transition, cumulants

1 Introduction

Studying the QCD phase structure of the strongly interacting matter is one of the primary objectives of relativistic heavy-ion collision experiments. Cumulants of conserved quantities for strong interaction such as net-charge, net-baryon and net-strangeness numbers are proposed to be sensitive observables for the study of the phase transition between quark-gluon plasma and hadronic matter and search for the QCD critical point. The cumulant ratios are related to the thermodynamic number susceptibilities that are calculable in the lattice QCD and various QCD-based models [1–4].

Cumulants up to the 4^{th} order ($C_n, n \leq 4$) of event-by-event distributions of net-charge, net-kaon (proxy for net-strangeness), and net-proton (proxy for net-baryon) were measured by the STAR detector in the phase I of Beam Energy Scan (BES) program at RHIC [5–9]. The cumulant ratios C_4/C_2 of net-proton distribution in the most central (0-5%) gold nuclei collisions exhibit a non-monotonic dependence as a function of beam energy which is qualitatively

consistent with expectations from a QCD-based model that includes a critical point [4]. Cumulant ratios are also extensively used in the study of freeze-out dynamics using thermal models which are suggestive of flavour separation during the QCD crossover transition [10].

2 Analysis details

In order to obtain the cumulants of event-by-event net-kaon distributions, charged kaons (K^+ and K^-) are identified at midrapidity $|y| < 0.5$ and within p_T range 0.2 – 1.6 GeV/c using the Time Projection Chamber (TPC) and Time of Flight (TOF) detectors. Event statistics analysed are about ∼25 millions in most central (0-5%) collisions. The collision centrality of an event is determined using the charged particle multiplicity within pseudorapidity range $|\eta| < 1$, excluding kaons from the region to prevent any self-correlation. A data driven method called the centrality bin width correction (CBWC) is applied in the cumulant measurements for a given centrality, in order to suppress the volume fluctuation effects [11]. First, cumulants at each multiplicity bin of a given centrality are evaluated and corrected for the detector efficiency and acceptance effects with the assumption that the detector response is binomial [12–14], and then the CBWC was applied. Statistical uncertainties on cumulants and their ratios, are estimated using a resampling method called the bootstrap [12, 15]. Systematic uncertainties on the measurements are estimated varying tracking efficiency, track selection, and particle identification criteria.

3 Results and discussions

This section presents new results on cumulants of event-by-event net-kaon distributions up to the 4^{th} order in most central (0-5%) Au+Au collisions at $\sqrt{s_{NN}}$ = 27 GeV collected by the STAR detector in the year 2018 from the BES-II program at RHIC. Figure 1 shows the event-by-event net-kaon multiplicity distributions for most central (0-5%) collisions. The distribution is uncorrected for the detector efficiency and acceptance effects. Cumulants up to the 4^{th} order are obtained for this distribution, followed by the corrections for finite centrality bin width, the detector efficiency and acceptance effects. Cumulants (up to the 4^{th} order) of net-kaon distribution for most central (0-5%) Au+Au collisions as a function of collision energy from BES-I program [6, 18] incuding the new measurement at $\sqrt{s_{NN}}$ = 27 GeV from BES-II (red marker) are shown in Fig. 2. The bars and shaded bands on the datapoints represents the statistical uncertainties and systematic uncertainties respectively. The precision measurements due to high event statistics at $\sqrt{s_{NN}}$ = 27 GeV from BES-II, have significantly reduced the uncertainties as compared to measurements from BES-I program. The new measurements are consistent with previous measurements from BES-I program at $\sqrt{s_{NN}}$ = 27 GeV within uncertainties for the same collision centrality. Having measured the cumulants, one can construct the cumulant ratios

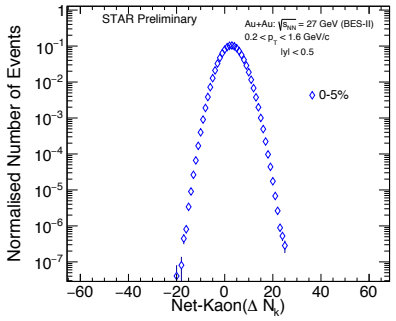

Fig. 1. Event-by-event net-kaon multiplicity distributions in Au+Au collisions at $\sqrt{s_{NN}} = 27$ GeV for 0-5% collision centralities at mid-rapidity. The distributions are uncorrected for the efficiency and acceptance effects.

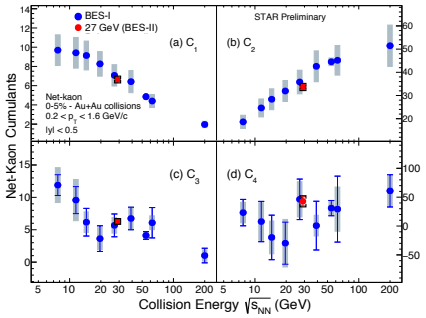

Fig. 2. Collision-energy dependence of cumulants ($C_n, n \leq 4$) of net-kaon distributions for 0-5% central Au+Au collisions with inclusion of the new measurement at $\sqrt{s_{NN}} = 27$ GeV from BES-II program. The new measurements are slightly shifted in x-axis for better visibility.

to eliminate the trivial system volume dependence and facilitate a direct comparison to various theoretical and model predictions. Net-kaon cumulant ratios C_2/C_1, C_3/C_2, and C_4/C_2 as a function of collision energy from BES-I program [6, 18] incuding the new measurement at $\sqrt{s_{NN}} = 27$ GeV from BES-II program (shown in red marker) are shown in Fig. 3. It was observed from the

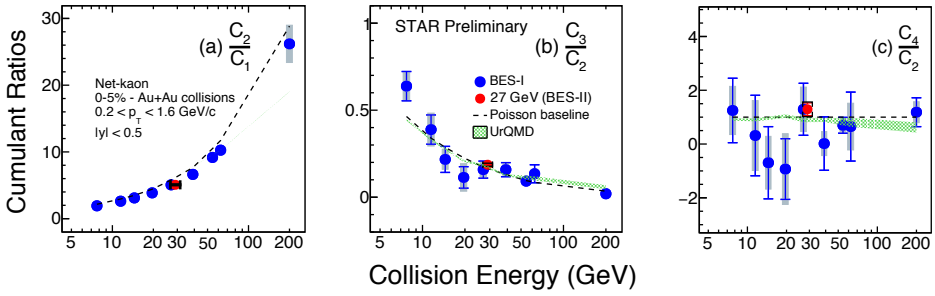

Fig. 3. Collision-energy dependence of cumulant ratios C_2/C_1, C_3/C_2 and C_4/C_2 of net-kaon distributions for 0-5% central Au+Au collisions with inclusion of the new measurement at $\sqrt{s_{NN}} = 27$ GeV from BES-II program. The new measurements are slightly shifted in x-axis for better visibility. The UrQMD model expectations shown in green band are taken from the ref. [6].

previous measurements at BES-I that the ratios C_2/C_1 and C_3/C_2 exhibited a strong dependence on collision energy whereas C_4/C_2 showed a weak collision-energy dependence because of large statistical uncertainties asscociated with the

measurements. The new results at $\sqrt{s_{NN}} = 27$ GeV from BES-II fit into the energy dependence of the cumulant ratios from BES-I measurements. They are consistent with the UrQMD [17] expectations as well as the poisson baseline for the cumulant ratios which are the expected values of the ratios if both K^+ and K^- follow independent poisson distribution.

4 Conclusions

We reported the measurements of cumulants of net-kaon distributions and their ratios in most central (0-5%) Au+Au collisions at $\sqrt{s_{NN}} = 27$ GeV from BES-II program at RHIC. The new measurements follow the beam energy dependence established by BES-I energies. They are consistent with the previous measurements from BES-I within uncertainties, for the same collision energy and centrality and also agree with the poisson baseline and UrQMD expectations. The new results calculated with ∼25 million Au+Au collision events show that the statistical uncertainties on cumulants have drastically reduced as compared to BES-I measurements where event statistics were almost one tenth factor smaller for the same collision energy and centrality. This demonstrates the potential of the precision measurements from the BES-II program at RHIC which will be very crucial in the seacrh for the QCD critical point.

5 Acknowledgments

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