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Higher Moments of Net-Particle Multiplicity Distributions

Jochen Thäder (for the STAR Collaboration[1])

Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Abstract

Studying fluctuations of conserved quantities, such as baryon number, strangeness, and charge, provides insights into the properties of matter created in high-energy nuclear collisions. Lattice QCD calculations suggest that higher moments of these quantities are sensitive to the phase structure of the hot and dense nuclear matter created in such collisions. In this paper, we present first experimental results of volume and temperature independent cumulant ratios of net-charge and net-proton distributions in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 14.5 GeV completing the first RHIC Beam Energy Scan (BES-I) program for $\sqrt{s_{\rm NN}}$ = 7.7 to 200 GeV, together with the first measurement of fully corrected net-kaon results, measured with the STAR detector at RHIC at mid-rapidity and a transverse momentum up to $p_{\rm T}$ = 2 GeV/c. The pseudo-rapidity dependence of the $\sqrt{s_{\rm NN}}$ = 14.5 GeV net-charge cumulant ratios is discussed. The estimated uncertainties on the ratio c_4/c_2, the most statistics-hungry of the present observables, at $\sqrt{s_{\rm NN}}$ = 7.7 GeV in the upcoming RHIC BES-II program will also be presented.

Keywords: Quark-Gluon Plasma, QCD, Phase transition, Critical point

1. Introduction

The first RHIC Beam Energy Scan (BES-I) program allows one to map the QCD phase diagram, varying collision energy $\sqrt{s_{\rm NN}}$ = 7.7 to 200 GeV of Au+Au collisions and, thereby, the baryon chemical potential $\mu_{\rm B}$ and temperature T. There is a smooth cross over at a vanishing $\mu_{\rm B}$, while at higher $\mu_{\rm B}$, model calculations suggest the existence of a first-order phase transition. Therefore, thermodynamic principles suggest that there should be a critical point in the QCD phase diagram, where the first-order phase transition ends and the transition becomes a cross-over [1].

Fluctuations in event-by-event multiplicity distributions of conserved quantities such as net-charge $\Delta N_{\rm Ch}$, net-strangeness (proxy: net-kaon $\Delta N_{\rm K}$), and net-baryon number (proxy: net-proton $\Delta N_{\rm P}$) would indicate a critical behavior. The moments of these distributions are proportional to powers of the correlation length ξ, with increasing sensitivity for higher order moments ($\langle(\Delta N)^3\rangle \propto \xi^{4.5}$, $\langle(\Delta N)^4\rangle \propto \xi^7$) [2, 3, 4]. Furthermore, the cumulants $c_{\rm i}$ of these distributions are expected to be linked to susceptibilities $\chi_{\rm i}$ [5], which can be obtained from QCD model calculations [6, 7]. This allows for a direct comparison of experimentally measured volume independent cumulant ratios ($c_2/c_1 = \sigma^2/M$, $c_3/c_2 = S\sigma$, and $c_4/c_2 = \kappa\sigma^2$) and theoretically

[1] A list of members of the STAR Collaboration and acknowledgements can be found at the end of this issue.

Email address: jmthader@lbl.gov (Jochen Thäder (for the STAR Collaboration))

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obtained susceptibility ratios, where the volume and temperature dependent terms cancel. In the absence of a critical point, the hadron resonance gas model [8] suggests that the $\kappa\sigma^2$ values will be close to unity and have a monotonic dependence on $\sqrt{s_{NN}}$ [9] following the Poisson expectation.

2. Analysis Details

The STAR (Solenoidal Tracker At RHIC) detector at Brookhaven National Laboratory has a large uniform acceptance at mid-rapidity and excellent particle identification capabilities. The main detectors used in these analyses are the Time Projection Chamber (TPC) [10] and the Time-Of-Flight detector (TOF) [11]. As the main tracking device, the TPC provides full azimuthal acceptance for tracks in the pseudo-rapidity region $|\eta| < 1$. In addition, it provides charged particle identification via the measurement of the specific energy loss dE/dx. The TOF detector provides a similar acceptance as the TPC and its velocity information is used for particle identification via the mass-squared, m^2. The analyses have been carried out event-by-event using minimum-bias events, rejecting piled-up and other background events such as beam-pipe interactions using the TOF information and other global observables. Only events with a reconstructed primary vertex position in the fiducial region $|v_z| < 30$ cm (< 50 cm for 7.7 GeV) and $|v_r| < 1$ cm were considered. All tracks are required to have a minimum length of 20 hits in the TPC to allow for a good two-track separation. In order to reduce the contamination from secondary charged particles, only primary particles have been selected, requiring a distance of closest approach (DCA) to the primary vertex of less than 1 cm.

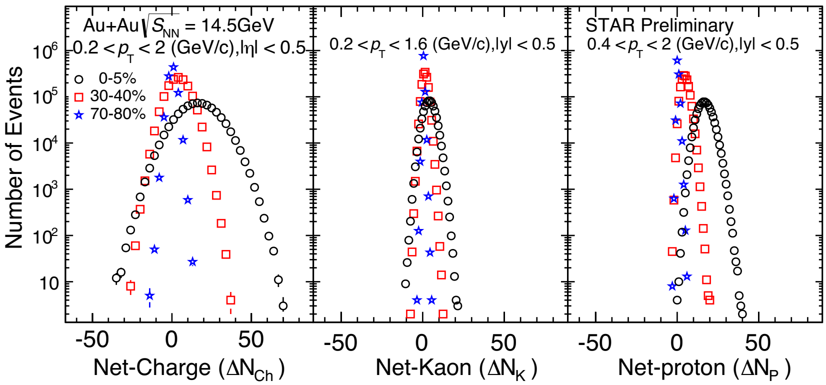

Fig. 1. Uncorrected raw event-by-event net-particle multiplicity distributions for Au+Au collisions at $\sqrt{s_{NN}}$ = 14.5 GeV for ΔN_{Ch} (left panel), ΔN_K (middle panel) and ΔN_P (right panel) for 0-5% top central (black circles), 30-40% central (red squares), and 70-80% peripheral collisions (blue stars).

The net-particle quantities are formed event-by-event as, $\Delta N_{Ch} = N_{pos} - N_{neg}$, $\Delta N_K = N_{K^+} - N_{K^-}$, and $\Delta N_P = N_p - N_{\bar{p}}$. The measurements of the identified particles have been carried out within the rapidity range of $|y| < 0.5$ and in the transverse momentum range of $0.2 < p_T$ (GeV/c) < 1.6 for kaons and $0.4 < p_T$ (GeV/c) < 2.0 for protons. The kaons (protons) have been identified using only the TPC dE/dx information below $p_T < 0.4$ GeV/c ($p_T < 0.8$ GeV/c) and a combination of TPC and TOF information above. Charged particles have been measured within the pseudo-rapidity range of $|\eta| < 0.5$ and $0.2 < p_T$ (GeV/c) < 2.0, while the protons below $p_T < 0.4$ GeV/c have been rejected to reduce the influence of spallation protons. The centrality classes are bin-width corrected values [12] from Glauber model fits to the the total charged particle multiplicity distribution ($0.5 < |\eta| < 1.0$), except for net-kaons (net-protons) for which the total multiplicity of pions and protons (pions and kaons) within $|\eta| < 1.0$ was used. For illustration purposes only, Fig. 1 shows the uncorrected event-by-event net-particle multiplicity distributions for Au+Au collisions at $\sqrt{s_{NN}}$ = 14.5 GeV for ΔN_{Ch}, ΔN_K, and ΔN_P in three centrality intervals. The widest distribution is observed for the ΔN_{Ch} and the narrowest for ΔN_K.