Study of the multiplicity distributions in relativistic nucleus - nucleus collisions using the multiplicity distribution moments method

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INTRODUCTION

One of the major tasks in our understanding of the QCD phase diagram is locating the QCD critical point CP (connecting the first-order boundary separating the hadronic from the partonic matter at high density with the cross-over boundary at low density). The Lattice QCD calculations predict that a cross-over takes place between the hadronic phase and the Quark Gluon Plasma (QGP) phase, when the temperature exceeds critical value of Tc ~150−190 MeV. The values of Tc depend on the baryon chemical potential μ. At large chemical potential μ, various theoretical calculations indicate that the transition from the hadronic phase to the QGP phase is of first-order. The endpoint CP is connecting this line with the one of the cross over (at small μ) considered to be of second-order. Therefore, it should be accompanied with large fluctuations in different physical quantities [1].

Experimentally, we can acces various regions of the QCD phase diagram and search for the CP by colliding two nuclei at different energies (and obtaining different μ). Higher moments of multiplicity distributions are proposed to provide one of the most sensitive probes towards the search for the CP because are conjectured to reflect the large fluctuations associating the hadron-quark phase transition.

The experimental measurable net-proton number (proton minus anti-proton number) or the net-kaon event-by-event fluctuations can reflect the baryon number and charge fluctuations [2]. Thus, higher moments of these multiplicity distributions are applied to search for the QCD critical point in the heavy ion collisions. For exemple, the 3rd moment (skewness) is expected to change its sign when system evolution trajectory in the phase diagram cross phase boundary [3].

DEFINITION OF HIGHER MOMENTS

The various moment of the event-by-event multiplicity distributions are defined as:

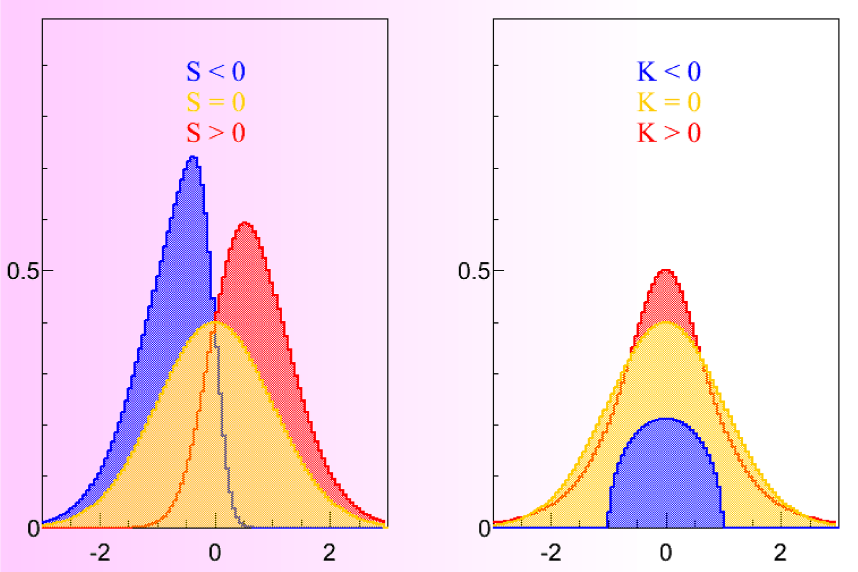
Variance: $$\sigma = \sqrt{\left\langle (N - \langle N \rangle)^2 \right\rangle}$$

Skewness: $$S = \frac{\left\langle (N - \langle N \rangle)^3 \right\rangle}{\sigma^3}$$

Kurtosis: $$\kappa = \frac{\left\langle (N - \langle N \rangle)^4 \right\rangle}{\sigma^4} - 3$$

N: Net protons or net kaons in single event.
<N>: Mean value of data.

For Gaussian distribution, the skewness and kurtosis are equal to zero. Higher moments can be used to measure non-Gaussion fluctuations. A sign change of the skewness or kurtosis may be an indication that the system crossed the phase boundary



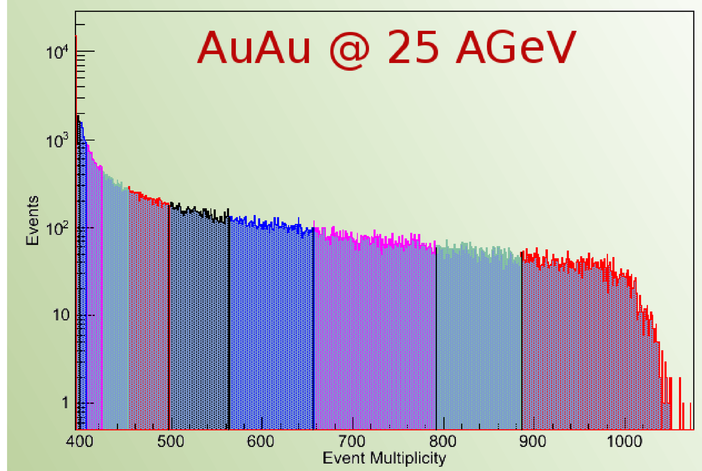
Skewness:
- degree of the asymmetry of the distribution.
- tail-ness of the distribution.

Kurtosis:
- degree of the peakedness of the distribution (the sharpness of the distribution)

K = 0 → for Normal distribution
K > 0 → sharp peak and long tail
K < 0 → rounded peaks and short tails.

COLLISION CENTRALITY

Collision centrality in a heavy-ion collision can be defined through diferent quantities, such as the impact parameter or the number of participant nucleons, Npart . These variables can't be directly measured in the heavy-ion collision experiment and therefore, the collision centrality is determined from a comparison between experimental measures such as the particle multiplicity and Glauber Monte-Carlo simulations.

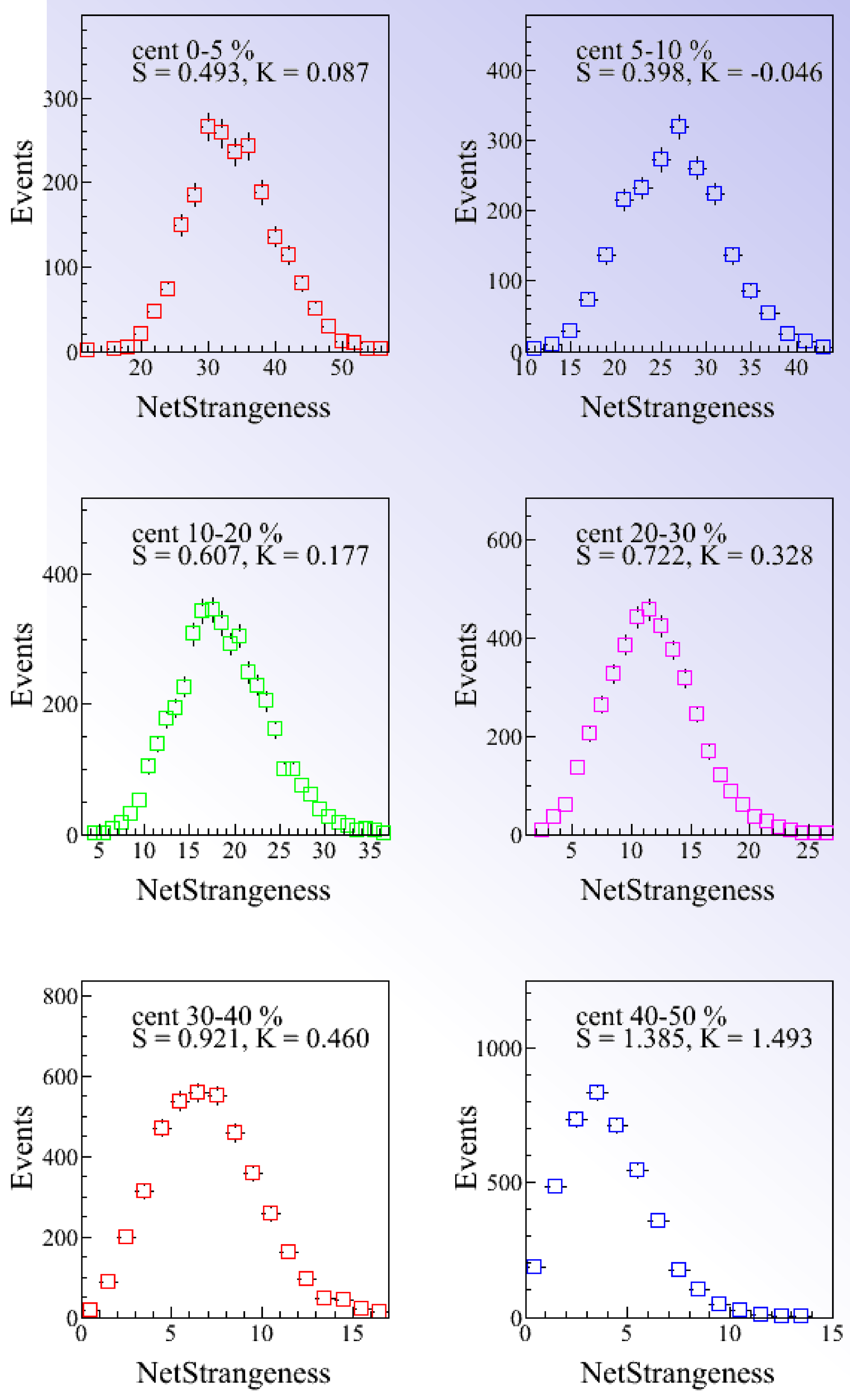


Particle multiplicity reflects the initial geometry of the heavy-ion collision. A given centrality class is a collection of events having a range of impact parameters or Npart, thus comprising of events with different charged particle multiplicities. This results in additional fluctuations in the number of produced particles within each centrality class. If less particles are used to define the collision centrality then larger initial geometry (volume) fluctuations will be observed. This may affect the moment analysis of particle multiplicity distributions.

Cent/Energy	2	11	25	62	200
0-5	339.72 +/- 18.02	346.50 +/- 17.58	348.20 +/- 17.47	350.81 +/- 17.13	356.77 +/- 16.27
5-10	284.16 +/- 13.56	291.36 +/- 13.49	293.11 +/- 13.49	296.33 +/- 13.57	302.86 +/- 13.79
10-20	221.57 +/- 20.71	227.70 +/- 21.29	229.58 +/- 21.25	232.69 +/- 21.29	238.71 +/- 21.27
20-30	157.75 +/- 15.24	162.24 +/- 15.59	164.23 +/- 15.55	166.83 +/- 15.85	171.90 +/- 16.44
30-40	109.47 +/- 11.51	113.08 +/- 11.84	115.20 +/- 11.83	116.67 +/- 12.13	120.06 +/- 12.43
40-50	73.38 +/- 8.35	75.88 +/- 8.62	77.26 +/- 8.90	78.33 +/- 8.94	80.83 +/- 9.26
50-60	46.47 +/- 6.04	47.94 +/- 6.34	48.95 +/- 6.36	49.94 +/- 6.34	51.47 +/- 6.62
60-70	27.06 +/- 4.05	28.09 +/- 4.03	28.57 +/- 4.32	29.58 +/- 4.33	30.59 +/- 4.33
70-80	14.21 +/- 2.28	15.27 +/- 2.29	15.26 +/- 2.29	15.69 +/- 2.58	16.14 +/- 2.88
80-90	6.93 +/- 0.81	7.36 +/- 1.12	7.37 +/- 1.11	7.35 +/- 1.12	7.37 +/- 1.12

The centrality classes and the coresponding number of participants for Au+Au collisions at different beam energies (plab = 2 GeV/c, 11 GeV/c, 25 GeV/c, √sNN = 62.4 GeV and 200 GeV) using the GLISSANDO code is shown in the Table 1.

GLISSANDO [4] is a Glauber Monte-Carlo generator for early-stages of relativistic heavy-ion collisions. The geometric distribution of sources (i.e., wounded nucleons or binary collisions) in the transverse plane can be superimposed with a statistical distribution simulating the dispersion in the generated transverse energy in each individual collision. The program generates two-dimensional profiles of the density of sources in the transverse plane and their Fourier components. These profiles can be used in further analyses of physical phenomena, such as the jet quenching, event-by-event hydrodynamics, or analyses of the elliptic flow and its fluctuations.



RESULTS

We performed our calculations with UrQMD model for Au+Au collisions at plab = 2 GeV/c, 11 GeV/c, 25 GeV/c, (CBM-FAIR energies) and √sNN = 62.4, 200 GeV (RHIC energies). We analized the event-by-event net-Kaon multiplicity, $N_{K^+-K^-}$ and the total proton multiplicity.

The centrality dependence of the net-Kaon multiplicity distributions from UrQMD code in Au+Au collisions at plab = 25 GeV/c is shown in the next figure. The Ultra Relativistic Quantum Molecular Dynamics (UrQMD) is a microscopic many-body approach or simulating p+p, p+A and heavy-ion collisions in the energy range from SIS to RHIC (even in LHC). It combines different reaction mechanism, and can provide theory simulation results of various experimental observables. More details about the UrQMD model can be found in the reference [5].

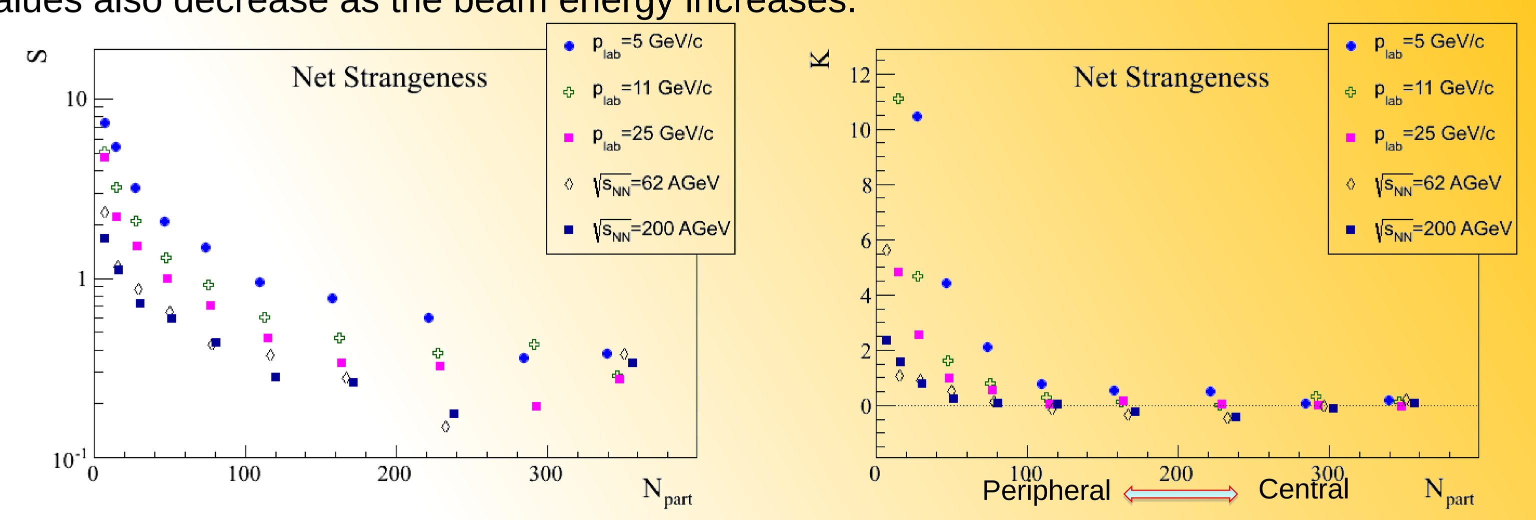
Going from peripheral to central collisions, it is found that the net-kaon distributions become wider and more symmetric for central collisions.

The net-Kaon distribution is showing that, as we are going from central to more peripheral events, the mean shifted towards zero.

These event-by-event distributions for each centrality were analyzed to obtain higher order moments (3rd moment - skewness and 4th moment - kurtosis). These moments, S and K are decreasing from peripheral to central events.

SKEWNESS AND KURTOSIS FOR NET-STRANGENESS

The two moments (S and k) which describe the shape of the net-kaons distributions in Au+Au collisions at various collision energies are plotted as a function of average number of participants < Npart >. The skewness S is positive and decreases as <Npart> increases for a given collision energy. The values also decrease as the beam energy increases.



The skewness S have stronger energy dependence than that of kurtosis κ, indicating that the net-kaon distributions become more symmetric for more central collision and higher energies.

HIGHER MOMENTS FOR TOTAL PROTONS

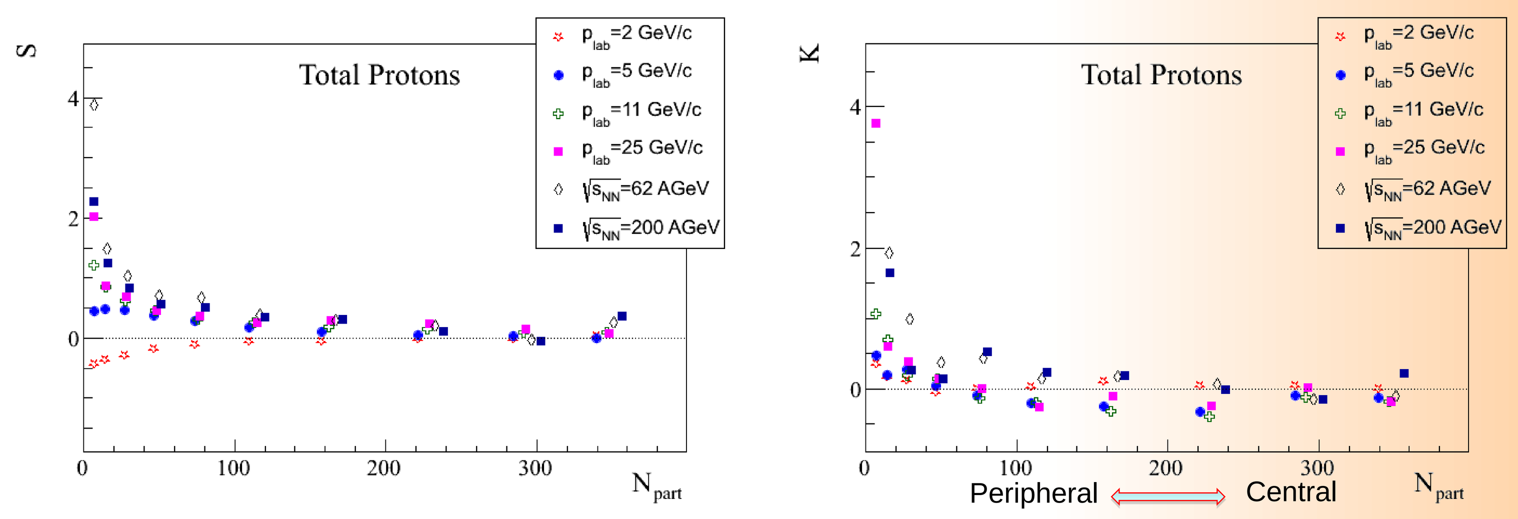


Figure above shows the Npart dependence of the skeweness and the kurtosis extracted from total proton distributions of Au+Au collisions at different beam energies obtained using the UrQMD model.

CONCLUSIONS

The beam energy and system size dependence for higher moments (S, K) of net-kaon and total proton multiplicity distributions have been presented with a broad energy range and different system sizes, which include Au+Au collisions at different beam energies (plab = 2 GeV/c, 11 GeV/c, 25 GeV/c, sqrt(sNN) = 62.4 GeV and 200 GeV)

The centrality and energy dependence of S and K indicate that the net-kaon distributions become more symmetric for more central collision and higher energies. For all of the energies, the kurtosis for net-kaon distributions decrease monotonically with Npart. At RHIC energies, the kurtosis has negative values in contrast to the obtained values at lower energies.

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