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K/π , K/p and p/π Ratio Fluctuations within the HSD Transport Approach

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Abstract. Particle number fluctuations and correlations in nucleus-nucleus collisions at SPS and RHIC energies have been studied within the Hadron-String-Dynamics (HSD) transport approach. Event-by-event fluctuations of kaon-to-pion, proton-to-pion and kaon-to-proton number ratios are calculated for the samples of most central collision events and compared with the available experimental data. It has been found that the HSD model can qualitatively reproduce the measured excitation function for the K/π ratio fluctuations in central Au+Au (or Pb+Pb) collisions from low SPS up to the top RHIC energy. Predictions for the K/p and p/π ratios impose a challenge for future experiments.

1. Introduction

The measurement of the fluctuations in the kaon to pion ratio by the NA49 Collaboration was the first event-by-event analysis in nucleus-nucleus collisions [1]. It was suggested that this ratio might allow to distinguish events with enhanced strangeness production attributed to the QGP phase [2]. Nowadays, the excitation function for this observable is available in a wide range of energies: from Pb+Pb collisions at $\sqrt{s} = 6\text{GeV}$ (NA49-SPS [3]) to Au+Au collisions at $\sqrt{s} = 200\text{GeV}$ (STAR-RHIC [4, 5]). Results from NA49 show an enhancement of fluctuations in the kaon to pion multiplicity ratio for low energies which may be a signal of a deconfinement phase transition. On the other hand there is no enhancement for the proton to pion ratio fluctuations.

This contribution presents the results of a systematic study of K/π , K/p and p/π ratio fluctuations ($K = K^+ + K^-$, $\pi = \pi^+ + \pi^-$, and p means $p + \bar{p}$) based on the HSD transport model [6]. For more details we refer the reader to Refs. [7, 8]. Event-by-event fluctuations for charged hadron multiplicities also have been studied in the HSD transport approach [9].

Let's introduce some notations. The deviation ΔN_A from the average number $\langle N_A \rangle$ of the particle species A is defined by $N_A = \langle N_A \rangle + \Delta N_A$, while the covariance for species A and B is:

$$\Delta(N_A, N_B) \equiv \langle \Delta N_A \Delta N_B \rangle = \langle N_A N_B \rangle - \langle N_A \rangle \langle N_B \rangle, \quad (1)$$

the scaled variance and the correlation coefficient

$$\omega_A \equiv \frac{\Delta(N_A, N_A)}{\langle N_A \rangle} = \frac{\langle N_A^2 \rangle - \langle N_A \rangle^2}{\langle N_A \rangle}, \quad \rho_{AB} \equiv \frac{\langle \Delta N_A \Delta N_B \rangle}{[\langle (\Delta N_A)^2 \rangle \langle (\Delta N_B)^2 \rangle]^{1/2}}. \quad (2)$$

The fluctuations of the ratio $R_{AB} \equiv N_A/N_B$ will be characterized by σ^2 [2, 10], which to second order in $\Delta N_A/\langle N_A \rangle$ and $\Delta N_B/\langle N_B \rangle$ can be written as:

$$\sigma^2 \equiv \frac{\langle (\Delta R_{AB})^2 \rangle}{\langle R_{AB} \rangle^2} \cong \frac{\omega_A}{\langle N_A \rangle} + \frac{\omega_B}{\langle N_B \rangle} - 2\rho_{AB} \left[\frac{\omega_A \omega_B}{\langle N_A \rangle \langle N_B \rangle} \right]^{1/2}. \quad (3)$$

2. Mixed Events Procedure

The experimental data for N_A/N_B fluctuations are usually presented in terms of the so called dynamical fluctuations [11]

$$\sigma_{dyn} \equiv \text{sign}(\sigma^2 - \sigma_{mix}^2) |\sigma^2 - \sigma_{mix}^2|^{1/2}, \quad (4)$$

where σ^2 is defined by (3), and σ_{mix}^2 corresponds to the following mixed events procedure. Using real events one builds the distribution $P(N)$, where $N = N_A + N_B$. Then all particles of A and B species from all selected events are combined into one particle set. For each mixed event, n particles are extracted from the particle set, where n is a random number following the $P(N)$ distribution, constructed above. Among the extracted n particles one finds n_A of species A and $n_B = n - n_A$ of species B and fixes

this numbers. Afterwards one returns the extracted particles into the set and continues the procedure. Using the numbers of particles of different species n_A and n_B from mixed events one can calculate various quantities (e.g. scaled variances and correlation coefficients).

Note that the number of events is much larger than the number of hadrons, N , in each single event. Therefore, the probabilities p_A and $p_B = 1 - p_A$ to take the A and B species from the whole *set* can be considered as constant values during the event construction. Another consequence of a large number of events is the fact that all A and B particles in any constructed *mixed event* most probably belong to different *physical events* of nucleus-nucleus collisions. Therefore, the correlations between N_B and N_A numbers in a physical event are expected to be destroyed in a mixed event. This is the main purpose of the mixed events construction.

Calculating the N_A/N_B fluctuations for mixed events one gets (like in [7]):

$$\sigma_{mix}^2 \equiv \frac{1}{\langle N_A \rangle} + \frac{1}{\langle N_B \rangle}. \quad (5)$$

The mixed event procedure gives the same σ^2 for N_A/N_B fluctuations as in the grand canonical ensemble (GCE) formulation for an ideal Boltzmann gas, i.e. $\omega_A = \omega_B = 1$ and $\rho_{AB} = 0$ in (3). Note that non-trivial fluctuations of N_A and N_B ($\omega_{A,B}^{mix} \neq 1$) as well as non-zero correlations ρ_{AB}^{mix} may exist in the mixed events procedure, but they are canceled out exactly in σ_{mix}^2 .

3. HSD Results and Comparison to Data

Since the available microscopic transport approaches HSD and UrQMD do not include explicitly a phase transition from a hadronic to a partonic phase, a comparison of their results to available experimental data for ratio fluctuations may allow to distinguish a QGP signal from the hadronic and dynamical background. The HSD results as well as statistical model (SM) calculations for ratio fluctuations in full acceptance are presented in Refs. [7, 8]. A comparison of the SM results for fluctuations in different ensembles with the data looks problematic at present due to the difficulties in implementing the experimental acceptance and centrality selection which, however, can be taken into account in the transport approach. In order to compare the HSD calculations with the measured data, the experimental cuts are applied for the simulated set of HSD events. In Fig. 1 the HSD results of σ_{dyn} for the K/π , p/π and K/p ratios are shown in comparison with the experimental data by the NA49 Collaboration at the SPS [3] and the preliminary data of the STAR Collaboration at RHIC [4, 5, 12, 13]. The available results of UrQMD calculations (from Refs. [3, 14]) are also shown by the dashed lines.

For the SPS energies we use the NA49 acceptance tables from Ref. [3]. For the RHIC energies we use the following cuts: in pseudorapidity, $|\eta| < 1$, and in transverse momentum, $0.2 < p_T < 0.6$ GeV/c for kaons and pions and $0.4 < p_T < 1$ GeV/c for protons [4, 5, 12, 13]. Note, that the HSD results presented in Fig. 1 correspond to the centrality selection as in the experiment: the NA49 data correspond to the 3.5% most

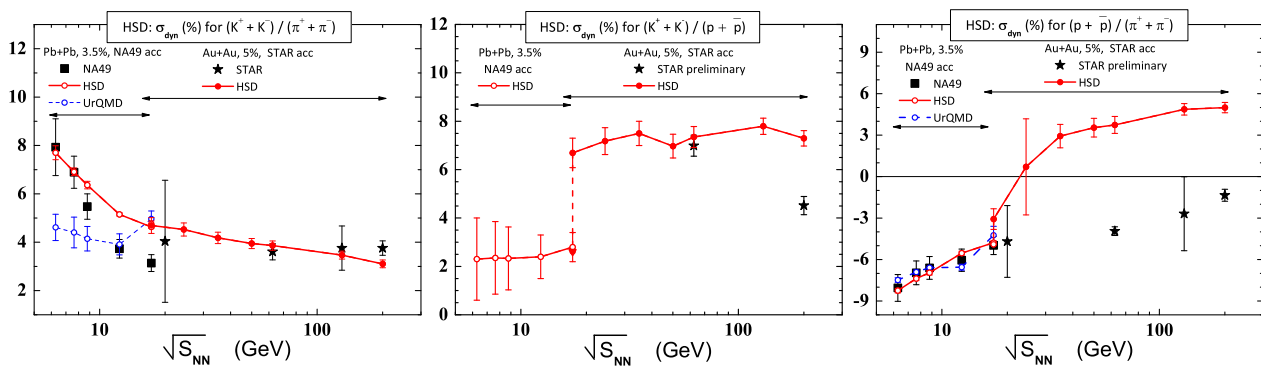


Figure 1. The HSD results for the excitation function in σ_{dyn} for the K/π , K/p , p/π within the experimental acceptance (solid line) in comparison to the experimental data measured by the NA49 Collaboration at SPS [3] and by the STAR Collaboration at RHIC [4,5,12,13]. The UrQMD calculations are shown by dotted lines. Error bars show statistical uncertainties in the model results.

central collisions selected via veto calorimeter, whereas in the STAR experiment the 5% most central events with the highest multiplicities in the pseudorapidity range $|\eta| < 0.5$ have been selected.

One sees that the UrQMD model gives practically a constant $\sigma_{dyn}^{K\pi}$, which is about 40% smaller than the results from HSD at the lowest SPS energy. This difference between the two transport models may be probably attributed to different realizations of the string and resonance dynamics in HSD and UrQMD: in UrQMD the strings decay first to heavy baryonic and mesonic resonances which only later on decay to ‘light’ hadrons such as kaons and pions. In HSD the strings dominantly decay directly to ‘light’ hadrons (from the pseudoscalar meson octet) or the vector mesons ρ , ω and K^* (or the baryon octet and decouplet in case of baryon number ± 1). Such a ‘non-equilibrated’ string dynamics may lead to stronger fluctuations of the K/π ratio.

At the SPS energies the HSD simulations lead to negative values of σ_{dyn} for the proton to pion ratio. This is in agreement with the NA49 data in Pb+Pb collisions. On the other hand HSD gives large positive values of $\sigma_{dyn}^{p\pi}$ at RHIC energies which strongly overestimate the preliminary STAR data for Au+Au collisions [12]. For σ_{dyn}^{Kp} only two preliminary STAR data points for Au+Au collisions are available [13] and thus the comparison is inconclusive (Fig. 1). The HSD results for σ_{dyn}^{Kp} show a weak energy dependence in both SPS and RHIC energy regions.

The influence of the experimental acceptance is clearly seen at 160 A GeV where a switch from the NA49 to the STAR acceptance leads to a jump in σ_{dyn}^{Kp} by 3% - middle panel of Fig. 1. On the other hand, our calculations for Pb+Pb (3.5% central) and for Au+Au (5% central) collisions - performed within the NA49 acceptance for both cases at 160 A GeV - shows a very weak sensitivity of σ_{dyn}^{Kp} on the actual choice of the collision system and centrality – cf. the coincident open circle and triangle at 160 A GeV in the middle panel of Fig. 1. For the ratios $(K/\pi$ and $p/\pi)$ we do not see such a jump for the different acceptances.

4. Summary

The event-by-event multiplicity fluctuations of K/π , K/p and p/π ratio fluctuations in central Au+Au (or Pb+Pb) collisions from low SPS up to top RHIC energies have been studied within the HSD transport approach. It has been found that the HSD model can qualitatively reproduce the measured excitation function for the K/π ratio fluctuations in central Au+Au (or Pb+Pb) collisions from low SPS up to top RHIC energies. Accounting for the experimental acceptance as well as the centrality selection has a relatively small influence on $\sigma_{dyn}^{K\pi}$ and does not change the shape of the $\sigma_{dyn}^{K\pi}$ excitation function.

The HSD results for $\sigma_{dyn}^{p\pi}$ appear to be close to the NA49 data at the SPS. The data for σ_{dyn}^{Kp} in Pb+Pb collisions at the SPS energies will be available soon and allow for further insight. A comparison of the HSD results with preliminary STAR data in Au+Au collisions at RHIC energies are not fully conclusive: σ_{dyn} from the HSD calculations is in agreement with one of two data points [13] for the kaon to proton ratio but overestimates the experimental results [12] for the proton to pion ratio. New data on event-by-event fluctuations in Au+Au at RHIC energies will help to clarify the situation.

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