p_T Distribution of Hyperons in $200A$ GeV Au-Au in Smoothed Particle Hydrodynamics

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The transverse momentum distributions of hadrons in 200GeV Au-Au collisions at RHIC are calculated using the smoothed particle hydrodynamics code SPheRIO. They are compared with data from STAR and PHOBOS Collaborations. By employing an equation of state which explicitly incorporates the strangeness conservation and introducing strangeness chemical potential into the code, the transverse spectra give a reasonable description of experimental data, except the multiplicities of hyperons.

Keywords: Transverse momentum spectrum; Hydrodynamics; Strangeness

I. SMOOTHED PARTICLE HYDRODYNAMIC MODEL

The hydrodynamic description of high-energy nuclear collisions was first introduced by L.D Landau [1]. Ever since then, the model has successfully accounted for certain features in nuclear collisions [2, 3], such as the energy dependence of the average multiplicity and the transverse-momentum distributions. The hydrodynamic model employs the hypothesis that hot and dense matter, formed in high energy nuclear collisions, reaches local thermal equilibrium, after which it expands and cools down before particle emission takes place. The local thermal equilibrium state serves as the initial condition for the hydrodynamic model, and it is expressed in terms of distributions of the fluid velocity and of thermodynamical quantities for a given time-like parameter. The hydrodynamical expansion is described by the conservation equations of the energy-momentum, baryon number, and other conserved charges, such as strangeness, isospin, etc. In order to close the system of partial differential equations, one also needs the equation of state (EOS) of the fluid. With the fluid being cooled and rarefied further, the constituent particles will finally reach the stage where they do not interact with each other until they reach the detector, namely, the decoupling stage of the hydrodynamic model.

It can be shown, that the whole set of relativistic hydrodynamic equations can be derived by using the variational principle, taking matter flow as the variable [4]. However, the resulting system of equations is highly nonlinear, and since, in general, there is no symmetry in the system, the direct integration of these equations is very expensive from the computational point of view. The aim of the smoothed particle hydrodynamic (SPH) algorithm for nucleus-nucleus collision is to provide a rather simple scheme for solving the hydrodynamic equations. Such method does not have to be too precise, but rather robust enough to deal with any kind of geometrical structure. The SPH algorithm was first introduced for astrophysical applications [5]. It parametrizes the matter flow in terms of discrete Lagrangian coordinates, namely, of SPH particles. In the model, usually some conserved quantities, such as baryon number and entropy are assigned to them. In terms of SPH particles, the hydrodynamic equations are reduced to a system of coupled ordinary differential equations.

The code which implements the entropy representation of the SPH model for relativistic high energy collisions [6], and which has been investigated and developed within the São Paulo - Rio de Janeiro Collaboration, is called SPheRIO. As it has been shown, the entropy representation of the SPH model is an efficient and practical method to tackle the problems concerning relativistic high-energy nucleus-nucleus collisions, which are characterized by highly asymmetrical configurations. This method has successfully been used to investigate the effects of the initial-condition fluctuations and adopting the continuous emission scenario for the description of decoupling process [6–10].

In this work, we focus on the role of strangeness and study its effects on hydrodynamic models for high-energy nucleus-nucleus collisions. The SPH method is employed in our calculation of the p_T spectra of hyperons in $200A$ GeV Au-Au collisions and the results are compared with experimental data. The strangeness enters in the model in two different ways. Firstly, in the calculation, a different set of EOS is employed while strangeness conservation is considered. The new set of EOS is expected to have an impact on the hydrodynamic evolution. Secondly, strangeness chemical potential is incorporated in the model for hyperons and strange mesons, while calculating their spectra. Therefore the multiplicity for strange hadrons will be modified because of the introduction of strangeness chemical potential. As in ref [7], we use the hadronic resonance model with finite volume correction to describe the matter on the hadronic side, where the main part of observed resonances in Particle Data Tables has been included. For quark gluon plasma (QGP) phase, the ideal gas model is adopted.

II. RESULTS AND DISCUSSION

We illustrate in Fig. 1, the phase boundaries for the EOS we used in the following calculation considering strangeness in terms of temperature as a function of baryon density. In Fig. 2 the phase boundary is depicted in a plot of temperature as a function of strangeness chemical potential. It is worth noting here that due to the introduction of strangeness conservation, the strangeness chemical potential does not remain constant

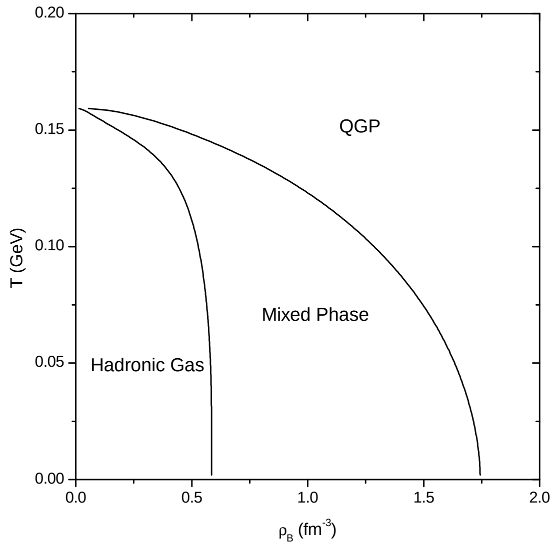

FIG. 1: Phase boundary for EOS with strangeness, depicted in the temperature vs. baryon density plane.

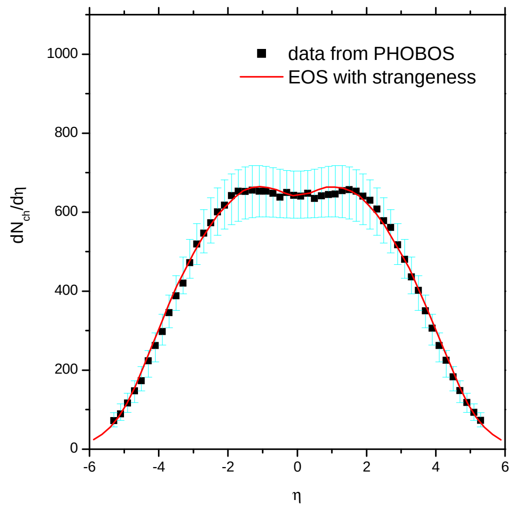

FIG. 3: The pseudo-rapidity distribution of all charged particles for the most central Au-Au collisions at 200A GeV. The data are from the PHOBOS Collab.

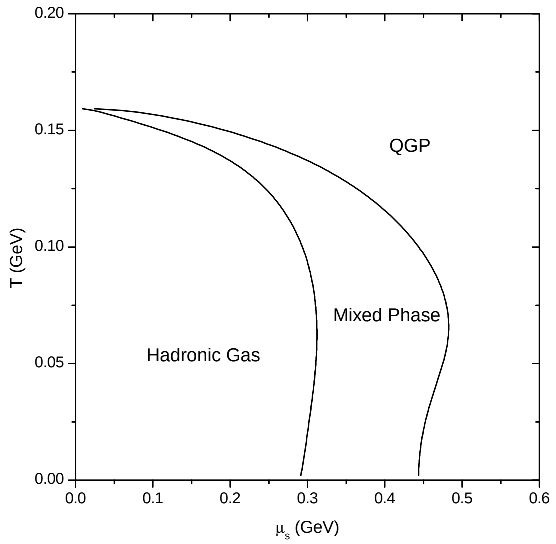

FIG. 2: Phase boundary for EOS with strangeness, depicted in the temperature vs. strangeness chemical potential plane.

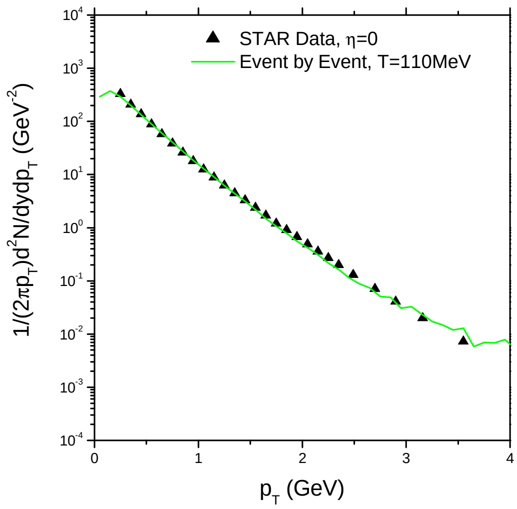

FIG. 4: Transverse momentum distribution of all charged particles for the most central Au-Au collision at 200A GeV with rapidity interval $-1.0 < \eta < 1.0$. The data are from the STAR Collab.

during the isothermal compression procedure.

As in the previous works [6–10], we use the NEXUS event generator to produce the initial conditions. However, we make use of a rescaling factor to fix the pseudo-rapidity distribution of all charged particles. Furthermore, following ref. [11], here we introduce an additional transverse velocity, which was needed for the present choice of parameters. Thus the initial transverse velocity reads

$$v_T \;=\; NeXUS + \tanh(\alpha r)\hat{r} \qquad (1)$$

where r is the radial distance from origin, and α is a small parameter. We also assume that the strangeness density is locally zero everywhere in the system.

As a preliminary application, we have calculated the pseudo-rapidity distribution of all charged particles. In Fig. 3, we present the result for the most central Au-Au collisions at 200A GeV. The experimental data are from PHOBOS Collaborations, taken in the most central Au-Au at 200A GeV. The experimental transverse momentum distribution data of all charged particles can be well reproduced with a choice of $\alpha = 0.04\text{fm}^{-1}$ and freeze out temperature $T_f = 110$ MeV. In Fig. 4 the transverse momentum distributions with freeze out temperatures 110 MeV are depicted, together with the experimental data. The experimental data are taken from the STAR Collaboration [12], taken in the most central Au-Au at 200A GeV, with $\eta = 0$.

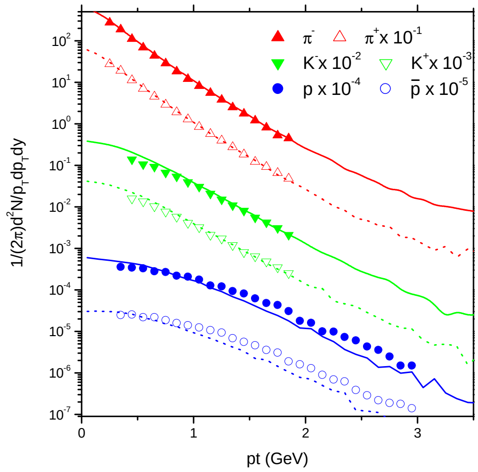

FIG. 5: Transverse momentum distribution of pion, kaon and proton for the most central Au-Au collisions at 200A GeV with rapidity interval $-1.0 < \eta < 1.0$. The data are from the BRAHMS Collab.

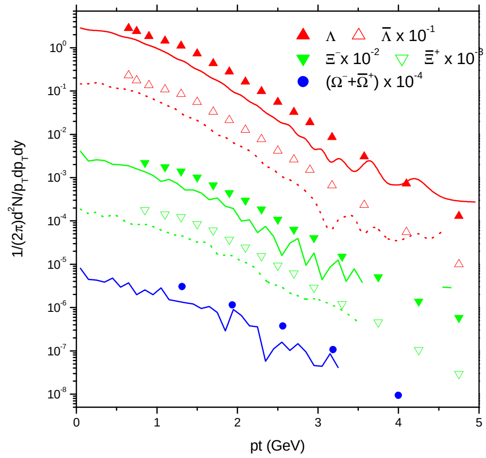

FIG. 6: Transverse momentum distribution of Λs, Ξs and Ωs for the most central Au-Au collisions at 200A GeV with rapidity interval $-1.0 < \eta < 1.0$. The data are from the STAR Collab.

In Figs. 5 and 6, we use the parameters fixed above to calculate the spectra of other hadrons. In Fig. 5 we show the transverse mass spectra of pion, proton and kaon for the most central collisions at mid rapidity, as well as the experimental data from the BRAHMS Collaboration [13]. In Fig. 6, the spectra of Λ, Ξ and Ω are depicted, together with the data from the STAR Collaboration [14]. It is found that the present hydrodynamic model gives a good description of the transverse momentum spectra of light hadrons as pion, kaon and proton. As for hyperons which are much heavier, it gives a reasonable description of the shape of the curves, while there are visible discrepancies in the multiplicities. This may indicate that the system undergoes first the chemical freeze-out at high temperature where the observed particle multiplicities are fixed and next the thermal freezeout at lower temperature where the shape of the transverse momentum distribution is fixed [15]. The present results of hyperon spectra might be improved by introducing the chemical freeze-out mechanism into the model [16–18]. Such work is under progress.

It is inferred from the comparison with the EOS without strangeness that the difference between the two sets of EOS at mid-rapidity region is not very large. However, as it was indicated in Ref. [19] for Pb-Pb collisions at 158A GeV, as one goes to the high-rapidity region, the difference is expected to become much more significant. We hope similar data also for Au-Au collisions at RHIC be obtained in near future.

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