MAXIMAL NET BARYON DENSITY
IN THE ENERGY REGION COVERED BY NICA

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There are several theoretical indications that the energy region covered by the proposed NICA accelerator in Dubna is an extremely interesting one. We present a review of data obtained in relativistic heavy ion collisions and show that there is a gap around 10 GeV where more and better precise measurements are needed. The theoretical interpretation can only be clarified by covering this energy region. In particular, the strangeness content needs to be determined, data covering the full phase space (4π) would be very helpful to establish the thermal parameters of a possible phase transition.

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INTRODUCTION

Particle collisions at high energies produce large numbers of secondaries, and it is natural to try a statistical-thermal model to analyse these. This type of analysis has a long and proud history [1–3] and led to the successful explanation of m_T scaling, which is a natural consequence of such models. The behaviour in the longitudinal direction was however very different and led many people to discard the thermal model.

In relativistic heavy ion collisions a new dimension was given to the model by the highly successful analysis of particle yields, leading to the notion of chemical equilibrium which is now a well-established one in the analysis of relativistic heavy ion collisions [4]. The early situation in 1999 is summarized in Fig. 1, with three points, showing a clear increase of the chemical freeze-out temperature, T, with increasing beam energy and an accompanying decrease of the baryon chemical potential μ_B [5]. The situation improved substantially in the following decade [6–9] and now covers almost the complete curve as shown in Fig. 2. Note that a last substantial gap still exists in the energy region to be covered by NICA. The resulting freeze-out curve in the $T - \mu_B$ plane can also be drawn in the energy density vs. net baryon density plane as was first done in [10]. The resulting curve is shown in Fig. 3. This figure shows that the highest net baryon density will be reached in the beam energy covered by the NICA accelerator.

COMPARISON OF CHEMICAL FREEZE-OUT CRITERIA

In view of the success of chemical freeze-out in relativistic heavy ion collisions, much effort has gone into finding models that lead to a final state in chemical freeze-out, see, e.g., curve [11–13]. A comparison [14] of three parameterizations is shown in Fig. 4. The corresponding dependence of the temperature and the chemical potential on beam energy is
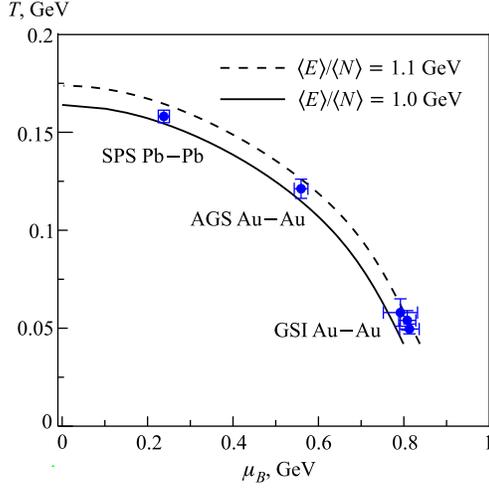
Fig. 1. Chemical freeze-out temperature T vs. the baryon chemical potential at different beam energies together with curves corresponding to a fixed ratio of energy per hadron divided by total number of hadrons in the resonance gas before decay of resonances
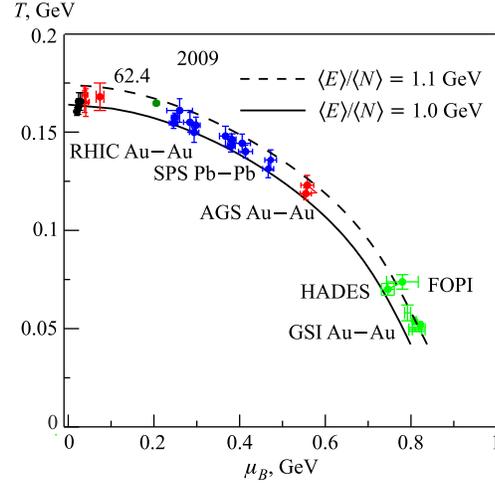
Fig. 2. Chemical freeze-out temperature T vs. the baryon chemical potential at different beam energies together with curves corresponding to a fixed ratio of energy per hadron divided by total number of hadrons in the resonance gas before decay of resonances
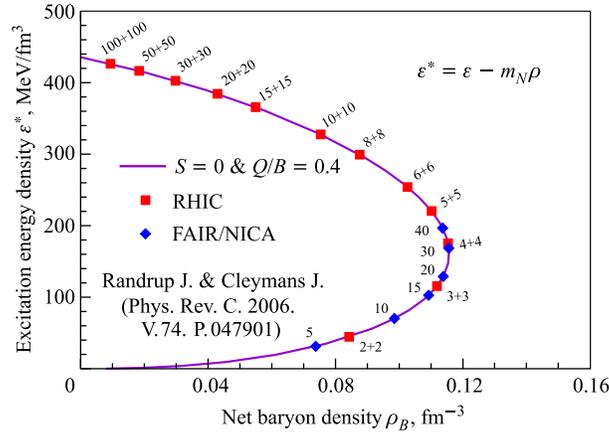
Fig. 3. The hadronic freeze-out line in the $\rho_B - \varepsilon^*$ phase plane as obtained from the values of μ_B and T that have been extracted from the experimental data in [14]. The calculation employs values of μ_Q and μ_S that ensure $\langle S \rangle = 0$ and $\langle Q \rangle = 0.4 \langle B \rangle$ for each value of μ_B. Also indicated are the beam energies (in GeV/N) for which the particular freeze-out conditions are expected at either RHIC or FAIR or NICA
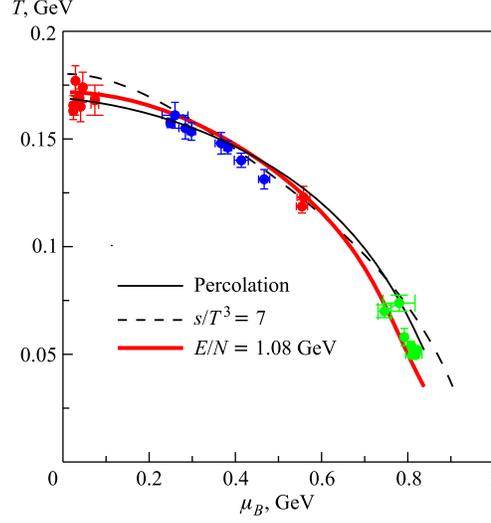
Fig. 4. Chemical freeze-out temperature T vs. the baryon chemical potential at different beam energies together with curves corresponding to a fixed ratio of energy per hadron divided by total number of hadrons in the resonance gas before decay of resonances

surprisingly smooth [14] as shown in Figs. 5 and 6. However, despite this smoothness in the thermal freeze-out parameters, a roller-coaster is observed in several particle ratios, e.g., the horn in the K^+/π^+ ratio and a similar strong variation in the Λ/π ratio [15]. Again these strong variations are not observed in $p-p$ collisions and happen in the NICA energy region. Within the framework of thermal-satistical models, this variation has been connected to a change from a baryon-dominated to a meson-dominated hadron gas. This conclusion is based on the observation that the entropy density divided by the temparature to the third power, s/T^3, is constant over the whole energy range. The change is illustrated in Fig. 7. Lines of constant value for the K^+/π^+ ratio are shown in Fig. 8 where it can be seen that the absolute maximum in the thermal-statistical model hugs the chemical freeze-out line. The largest observed value is just barely compatible with this maximum. Again this is right in the energy region covered by NICA. In the thermal-statistical model a rapid change is expected as the hadronic gas undergoes a transition from a baryon-dominated to a meson-dominated gas. The transition occurs at a temperature $T = 151$ MeV and baryon chemical potential $\mu_B = 327$ MeV corresponding to an incident energy of $\sqrt{s_{NN}} = 11$ GeV. Thus, the strong variation seen in the particle ratios corresponds to a transition from a baryon-dominated to a meson-dominated hadronic gas. This transition occurs at a

- temperature $T = 151$ MeV,
- baryon chemical potential $\mu_B = 327$ MeV,
- energy $\sqrt{s_{NN}} = 11$ GeV.

In the statistical model this transition leads to peaks in the $\Lambda/\langle\pi\rangle$, K^+/π^+, Ξ^-/π^+ and Ω^-/π^+ ratios. However, the observed ratios are sharper than the ones calculated in thermal-statistical models and NICA will be ideally positioned to clarify this.
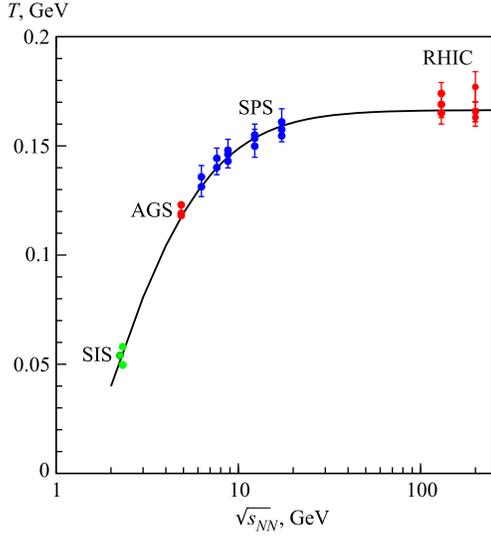
Fig. 5. Chemical freeze-out temperature T as a function of the beam energy
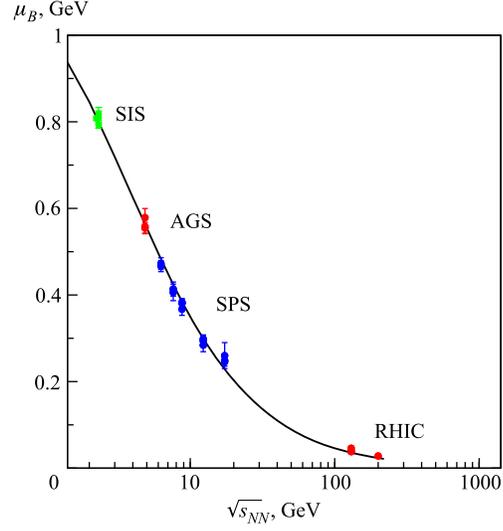
Fig. 6. Chemical freeze-out baryon chemical potential μ_B as a function of the beam energy
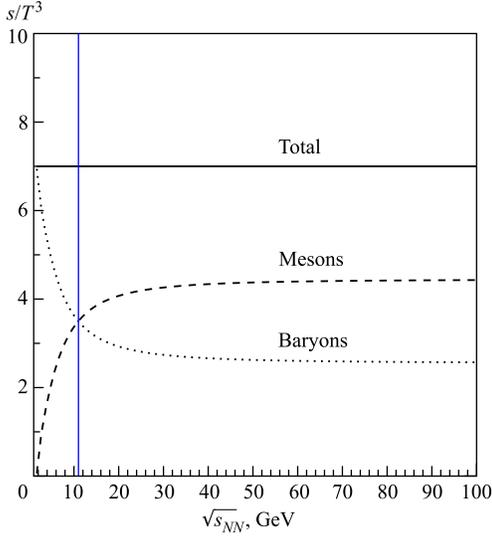
Fig. 7. The s/T^3 ratio calculated in the thermal-statistical model along the constant value consistent with chemical freeze-out. Also shown are the contributions from the mesons and the baryons
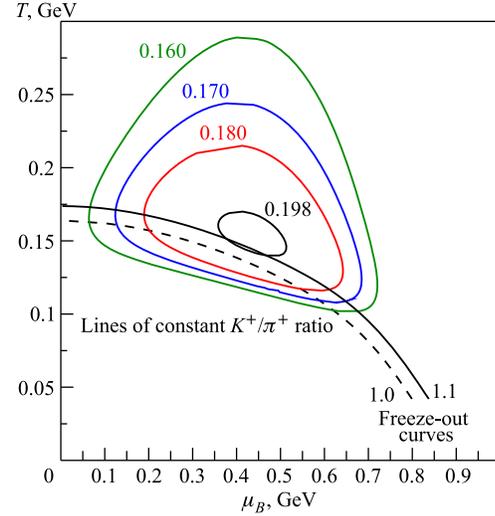
Fig. 8. Lines of constant value of the K^+/π^+ ratio in the $T-\mu_B$ plane showing a clear maximum in this ratio close to the boundary given by the chemical freeze-out line

CONCLUSIONS

There are several theoretical indications that the energy region covered by the proposed NICA accelerator in Dubna is an extremely interesting one. We present a review of data obtained in relativistic heavy ion collisions and show that there is a gap around 11 GeV where more and better precise measurements are needed. The theoretical interpretation can only be clarified by covering this energy region. In particular, the strangeness content needs to be determined, data covering the full phase space (4π) would be very helpful to determine the thermal parameters of a possible phase transition and the existence of a quarkyonic phase as has been discussed in a recent paper [16].

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