Local thermal equilibrium of dense baryonic matter at CBM experiment

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Introduction

The Compressed Baryonic Matter (CBM) experiment at FAIR/ GSI laboratory is being designed to perform heavy-ion collisions in fixed target mode at beam energies of 5-45 GeV per nucleon. The major scientific issues addressed in the experiment are the properties of quantum chromodynamics (QCD) at high baryon density and moderate temperature and the order of quark-hadron phase transition at large baryo-chemical potential [1]. However an important question arises whether the dense baryonic matter created in such collisions may achieve a local thermal equilibrium or not. We have investigated the conditions of local thermal equilibrium of baryons and mesons in a small element of volume within the rapidity range $|y| < 1.0$ for central Au+Au collisions at E_{lab}= 10, 20, 30, 40 GeV per nucleon [2]. For this purpose we used the microscopic transport model UrQMD-3.3 [3] in default cascade mode. We calculated the longitudinal-to-transverse pressure anisotropy (P_L/P_T) and the inverse slope parameter of energy spectra of baryons and mesons inside the cell at different times (t)= 1-15 fm/c measured in center of mass frame. The quantities are averaged over 60K events at every time step.

Results

We have studied the time evolution of P_L/P_T of non-strange baryons, strange baryons and kaons for an expanding system. Different components of microscopic pressure of hadrons are highly anisotropic at early stages of collision. Thermal equilibrium is established in the cell when they have become nealy isotropic. The components of microscopic pressure are calculated in UrQMD using ideal gas ansatz:

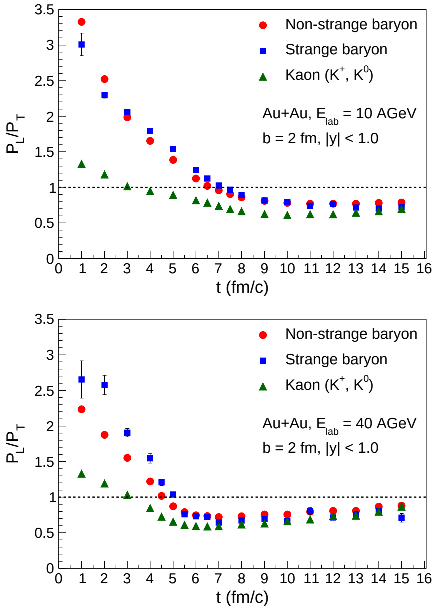

FIG. 1: Time evolution of P_L/P_T of baryons and mesons at laboratory energies 10A, 40A GeV.

$$P_{(x,y,z)} = \sum_i \frac{p^2_{i(x,y,z)}}{3V(p_i^2 + m_i^2)^{\frac{1}{2}}}, \qquad (1)$$

where p_i is the momentum, m_i is the mass of i'th hadron and V is the volume of the cell under consideration. The longitudinal and transverse components of pressure for an ensemble

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*Electronic address: `somnath.de@iopb.res.in` of hadrons are defined as:

$$P_L = \langle P_z \rangle; \qquad P_T = \frac{1}{2}(\langle P_x \rangle + \langle P_y \rangle), \qquad (2)$$

here the $\langle .. \rangle$ corresponds to the statistical average over the number of events. We have calculated the longitudinal and transverse pressure for non-strange baryons, strange baryons and kaons. The results are depicted in Fig. 1. It can be seen that the anisotropy ratio P_L/P_T of baryons (non-strange and strange) becomes almost constant ∼0.8 for t≥9 fm/c at 10A GeV and ∼0.7 for t≥6 fm/c at 40A GeV laboratory energy. From this time, we can say the baryonic matter attains a thermal equilibrium. The P_L/P_T ratio of kaons is seen to become constant at the same time as baryons.

We have adopted an alternate approach to study the equilibrium. For this purpose, we parameterized the energy spectra of proton and lamda inside the cell according to Tsallis distribution [4]:

$$E\frac{d^3N}{d^3p} = C(1 + \frac{E}{bT})^{-b}, \qquad (3)$$

where E is the energy of baryon in the unit of GeV and b=1/(q-1) is dimensionless. q is the non-extensive parameter. The values of C, b, T are obtained through fitting the energy spectra upto E= 3 GeV. The inverse slope parameter of the spectra is given by;

$$T_{slope} = T \ + \ (q-1)E. \qquad (4)$$

We have calculated the T_{slope} of the baryon spectra at E= 0.1 GeV and studied its time evolution at the four beam energies [2]. The results at E_{lab}= 10A and 40A GeV are shown in Fig. 2. It is observed that T_{slope} (proton and lamda both) falls sharply with time and changes its variation at t≈ 9 fm/c at 10A GeV and t≈ 5 fm/c at 40A GeV. From this time onwards, T_{slope} approximately scales as $t^{-1/3}$ which signifies an isentropic longitudinal expansion sets in the cell, analogous to ideal relativistic hydrodynamics. Here the onset of longitudinal expansion marks the local thermal equilibrium of the system. We have also calculated the post-equilibrium thermodynamic properties like; temperature and chemical potential of the system with statistical thermal model. The time evolution entropy density has been found nearly isentropic [2]. In conclusion, we found the time scale of local themal equilibrium of baryons from the pressure isotropization and thermalization of energy spectra. The two methods yield similar time scales which is found to decrease with increase in laboratory energy.

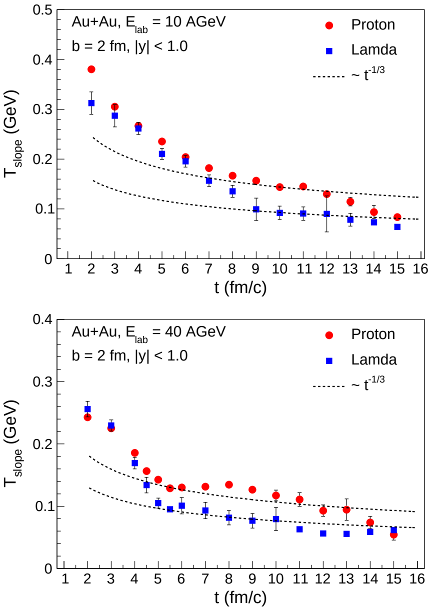

FIG. 2: Time evolution of inverse slope parameter (T_{slope}) of proton and lamda energy spectra at E_{lab}= 10A, 40A GeV.

We are thankful to DAE, India and FAPESP, Brasil for the financial support during this work.

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