Kaon to pion ratio in relativistic heavy-ion collisions

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Strangeness enhancement has been proposed as a potential signature of quark gluon plasma (QGP) formation in Ultra-Relativistic Heavy Ion Collisions [1]. NA49 collaboration presented the K^+ to π^+ ratio as a function of CM energy [2] and observed that this ratio increases with $\sqrt{s_{NN}}$ - reaches its maximum value at $\sqrt{s_{NN}} \sim 7.6$ GeV and drops beyond this - leading to a horn like structure. This horn like variation of the ratio with ($\sqrt{s_{NN}}$) has led to intense theoretical activities. In previous studies this structure has either been attributed to a transition from a baryon to a meson dominated hadronic matter or due to a transition from initially formed partonic to hadronic matter for $\sqrt{s_{NN}} \geq 7.6$ GeV. However, most of the earlier works lacks microscopic dynamics.

The kaon to pion ratio does not have any information about the momentum of these mesons. Therefore, in the present work we use the momentum integrated Boltzmann equation to evolve the density of the initially formed partons or hadrons depending on the collision energy up to the freeze-out conditions. The dynamics of those processes which changes the number of K^+ in the hadronic phase (or anti-strange quarks in QGP) is included through the collision term of the Boltzmann equation. A term has been added to the Boltzmann equation to accommodate the process of hadronization and solved for two different scenarios: (i) after the collisions of the two heavy nuclei - QGP is formed which evolved to a hadronic matter through a phase transition or (ii) the system is formed in hadronic phase after the collisions. For the scenario (i) the strange (and anti-strange) quarks are produced by the processes of gluon fusion and light quark (up and down) annihilation. We assume the light quarks and gluons are in equilibrium but the s, $\bar{s}$ quarks are out of equilibrium. A first order phase transition from quarks to hadrons is assumed to estimate the K^+ fraction [3]. In case of the scenario (ii) the system is formed in hadronic phase with pions and nucleons in equilibrium and K^+ away from equilibrium. The time (τ) evolution of the strange quarks in the partonic phase is governed by the equation,

$$\frac{dn}{d\tau} = R(T)[1 - (\frac{n}{n_{eq}})^2] - \frac{n}{\tau}. \qquad (1)$$

The first term on the right hand side denote production or loss of either anti-strange quarks or hadrons (depending on the scenarios mentioned above), the second term represents dilution due to expansion. In Eq. 1, R(T) is the rate of production of strangeness, n_{eq} is their equilibrium density at temperature T and is given by

$$n_{eq} = \int \frac{d^3p}{(2\pi)^3} \frac{1}{\exp(\frac{\sqrt{p^2+m^2}-\mu}{T}) - 1}, \qquad (2)$$

where p and m are the momentum and mass respectively for the s quark or K^+, μ denotes the chemical potential [4]. In the hadronic phase the K^+ are dominantly produced by the processes i) $BB \rightarrow BYK$, ii) $MB \rightarrow YK$, and iii) $MM \rightarrow K\bar{K}$ [5]. Here B=baryon, M=meson and Y=hyperon. Rate of K^+ production for reaction $a_1 + a_2 \longrightarrow a_3 + a_4$ where $a_1 \neq a_2$, is calculated from cross-section using

$$R(T) = \frac{dM}{d^4x} \int \frac{d^3p_1}{(2\pi)^3} F(p_1) \int \frac{d^3p_2}{(2\pi)^3} F(p_2) v_{rel} \sigma(M),$$

where $v_{rel} = |\vec{v}_1 - \vec{v}_2|$, $M^2 = E^2 - \vec{p}^2$ and $F(p_i)$ is the occupation probability of the particle i in momentum space. The evolution of the K^+ density in the hadronic phase is dictated by an equation similar to Eq. 1. For the mixed phase the evolution equation should contain a term for hadronization.

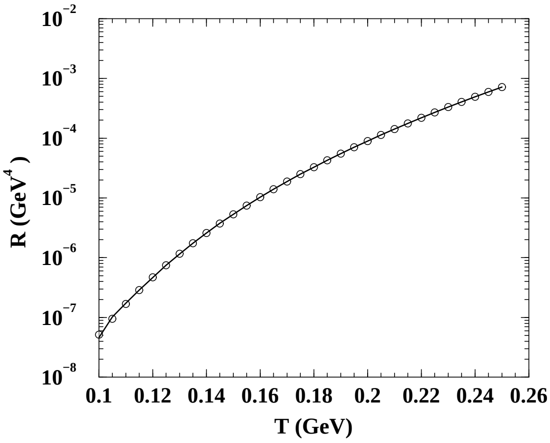

FIG. 1: Variation of the rate of K^+ production with temperature for the set of reactions mentioned in the text.

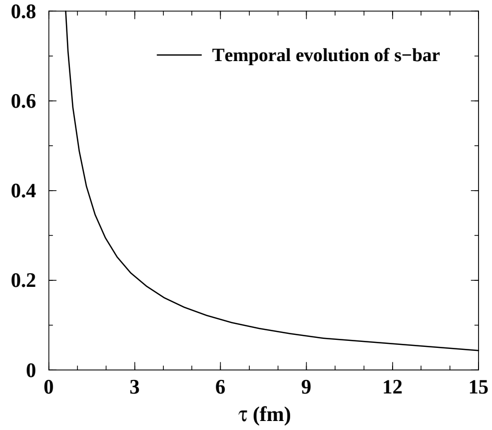

FIG. 2: Evolution of $\bar{s}$ quarks with time. The production due to light quark annihilation and gluon fusion and the hydrodynamics expansion have been taken into account.

In the present work, we calculate the number density of K^+ by solving set of coupled equations governing the evolution of baryon density, temperature and the kaon density.

In Fig. 1 the production rate ($R(T)$) of K^+ with temperature has been displayed for a static system - indicating the enhancement of K^+ production with temperature.

The decrease in temperature with time due to expansion results in reduction of $\bar{s}$ production rate. In addition to this the dilution of the density with time makes the reduction of $\bar{s}$-density stiffer as depicted in Fig. 2.

In Fig. 3 the density of K^+ has been shown at the freeze-out points for various $\sqrt{s_{NN}}$. The results indicate that the K^+ productions increases sharply with $\sqrt{s_{NN}}$ but slowed down at larger values of $\sqrt{s_{NN}}$. The comparison of the results obtained from the present microscopic studies with the experimental data on K^+/π^+ will be discussed in the presentation.

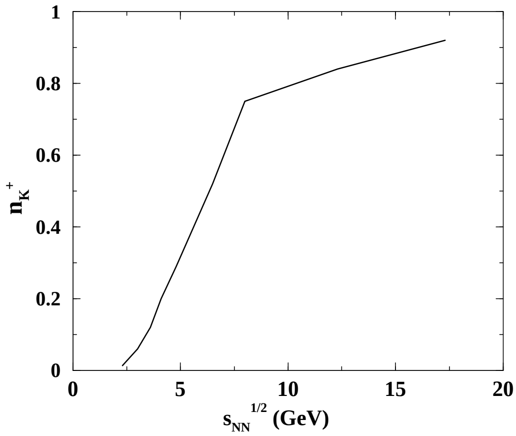

FIG. 3: K^+ density (n_{K^+}) as a function of centre of mass energy ($\sqrt{s_{NN}}$) in central heavy ion-collisions with the assumption of hadronic initial state.

References

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