Cross section study of K^+- mesons production in heavy ion collisions at 1–2 A GeV

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Abstract

Intermediate and high-energy heavy ion collisions provide a unique opportunity to investigate the properties of hadron in dense nuclear matter. In particular, strange mesons are considered to be sensitive to in-medium modifications. Theory predicts a repulsive K^+N potential in dense matter. We study the calculation production cross section of K^+ mesons in heavy ion collisions at incident energy 1–2 A GeV for collision and collisions within the quantum molecular dynamics (QMD) model. We also find that our calculated production cross section of K^+ mesons in nucleus-nucleus collisions using the in-medium kaon potential with soft EOS increases, when kinetic energy is increasing are in good agreement with KaoS data.

Keywords: quantum molecular dynamics (QMD), Kaon, soft EOS, heavy ion, cross section

Introduction

Relativistic heavy-ion collisions at incident energy ranging from 0.6 A GeV to 2.0 A GeV provide a unique opportunity to study the behavior of nuclear matter at high densities. These studies are important challenges for testing the present understanding of nuclear matter. In addition, they are of relevance to astrophysics, as the modeling of neutron stars or supernovas depends on the properties of nuclear matter under these extreme conditions. (Bethe, H. A. 1990)

In central ${}^{197}_{79}\mathrm{Au}+{}^{197}_{79}\mathrm{Au}$ collisions at the incident energies under investigation, densities of 2-3 times normal nuclear matter density can be reached (Hartnack, C., Jaenicke, J., Sehn, L., Stocker, H. and Aichelin, J. 1994) (Fuchs, C. 2006) (Hartnack, J. 2004). A sensitive probe to test these conditions is the production of strange mesons at or below the production thresholds of these

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particles in free nucleon-nucleon collisions. The rest mass of charged kaons is 0.454 GeV. For the K^+ production, the threshold in nucleon-nucleon collisions is 1.58 GeV (in the laboratory system) as defined by the associate production via pair creation $NN \rightarrow NNK^-K^+$.

In this work we calculated the inclusive invariant cross section and polar angle distribution of K^+ mesons in ${}^{58}_{28}Ni + {}^{58}_{28}Ni$ collisions and ${}^{12}_{6}C + {}^{12}_{6}C$ collisions at various beam energy. Nucleons are described by the Quantum Molecular Dynamics (QMD) model. Kaons are treated within the covariant kaon dynamics (Zheng Y M, Fuchs, C., Faessler A., Shekhter K, Yan Y. P. and Kobdaj, C. 2004). For the nuclear force we use the standard momentum dependent Skyrme interactions corresponding to a soft and hard nuclear equation of state (EOS) (compression modulus K = 200 MeV and K = 380 MeV respectively).

Kaons in Dense Matter

The natural framework to study the interaction between pseudoscalar mesons and baryons at low enegries is chiral perturbation theory (ChPT). From the chiral Lagrangian the field equations for the $K^{\pm}$ mesons are derived from the Euler-Lagrange equations (Herrmann H. 1999).

$$\left[\partial_\mu \partial^\mu \pm \frac{3i}{4 f_\pi^*} j_\mu \partial^\mu + \left(m_K^2 - \frac{\Sigma_{KN}}{f_\pi^{*2}} \rho_S \right)\right] \phi_{K^\pm}(x) = 0 \qquad (1)$$

In Eq. (1) j_μ is the baryon four-vector current, ρ_s is the baryon scalar density, f_π^* is the in-medium pion decay constant. Introducing the kaonic vector potential

$$V_\mu = \frac{3}{8 f_\pi^{*2}} j_\mu \qquad (2)$$

Eq. (1) can be rewritten in the form (Fuchs C. 2006)

$$\left[\left(\partial_\mu \pm i V_\mu \right)^2 + m_K^{*2} \right] \phi_{K^\pm}(x) = 0 \qquad (3)$$

Thus, the vector field is introduced by minimal coupling into the Klein-Gordon equation. The effective mass m_K^* of the kaon is then given by

$$m_K^* = \sqrt{m_k^2 - \frac{\Sigma_{kN}}{f_\pi^{*2}} \rho_S + V_\mu V^\mu} \qquad (4)$$

Where m_K = 0.496 GeV is the bare kaon mass.

The $K^{\pm}$ single-particle energies are expressed as

$$\omega_{K^{\pm}}(\mathbf{k}) = \pm V^0 + \sqrt{\mathbf{k}^{*2} + m_K^{*2}} \tag{5}$$

Where $\mathbf{k}^* = \mathbf{k} \mp V$ is the kaon effective momentum, $V^{\mu} = (V^0, \mathbf{V})$, the kaon vector field is introduced by minimal coupling into the Klein-Gordon with opposite signs for K^+ and K^-, and m_K^* is the kaon effective (Dirac) mass. The kaon (antikaon) potential $U_{K^{\pm}}$ is defined as

$$U_{K^{\pm}}(\mathbf{k}) = \omega_{K^{\pm}}(\mathbf{k}) - \sqrt{\mathbf{k}^2 + m_K^2} \tag{6}$$

Following Ref. [8], we use the Brow and Rho parameterization $\sum_{KN} = 450\,MeV$, $f_{\pi}^{*2} = 0.6 f_{\pi}^2$ for the vector field and $f_{\pi}^{*2} = f_{\pi}^2$ for the scalar part given by $-\sum_{KN} / f_{\pi}^{*2} \rho_S$. This accounts for the fact that the enhancement of the scalar part using f_{π}^{*2} is compensated by higher-order corrections in the chiral expansion. For the nuclear forces we use the standard momentum dependent Skyrme interaction corresponding to a soft (hard) equation of state (EOS) (the compression modulus $\mathrm{K} = 200\,\mathrm{MeV}$ for a soft and $\mathrm{K} = 380\,\mathrm{MeV}$ for hard EOS). For the determination of the kaon mean field we adopt the corresponding covariant scalar-vector description of the nonlinear $\sigma\omega$ model. Up to saturation density the BR potential is $\left(U_k(\rho_0) \approx 30\,\mathrm{MeV}\right)$.

Results and discussions

The inclusive invariant cross sections of K^+ mesons as a function of the kaon energy for ${}^{12}_{6}\mathrm{C} + {}^{12}_{6}\mathrm{C}$ at various beam energies are given in Fig.1. In this figure for The inclusive spectra at mid-rapidity for different systems and at various incident energies as measured by the KaoS data (Hartnack et al, 2012), empty circles, empty triangle, empty square and empty diamond are calculated results with the in-medium kaon potential, The Fig.1. shows the results calculated by using the soft EOS. We can see clearly from this figure that calculated results with the in-medium kaon potential when including the in-medium K^+N potential each energy find that the cross sections of K^+ mesons productions increased when the kinetic energy increases and is consistent with experimental data.

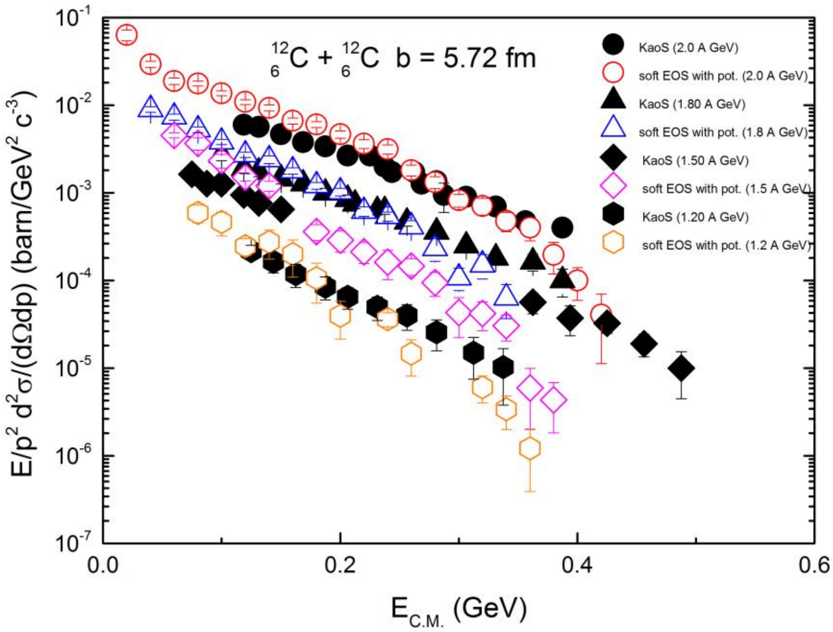

Figure 1. The inclusive invariant cross sections of K^+ mesons as a function of the kaon energy for $^{12}_{6}C + ^{12}_{6}C$ at 2.0 1.8 1.5 and 1.2 A GeV, in which solid circles, solid triangle, solid square and solid diamond are the KaoS data (Hartnack et al, 2012), empty circles, empty triangle, empty square and empty diamond are calculated results with the in-medium kaon potential. The results calculated by using the soft EOS. The mid-rapidity condition is a selection $\theta_{C.M.} = 90^o \pm 10^o$ both for the data and the calculations.

Figure 2. shows the inclusive invariant cross sections of K^+ mesons as a function of the kaon energy for $^{58}_{28}Ni + ^{58}_{28}Ni$ at various beam energies In this figure for The inclusive spectra at mid-rapidity for different systems and at various incident energies as measured by the KaoS data (Hartnack et al, 2012), empty circles, empty triangle and empty square are calculated results with the in-medium kaon potential, The Fig.2. shows the results calculated by using the soft EOS. We can see clearly from this figure that calculated results with the in-medium kaon potential when including the in-medium K^+N potential each energy find that the cross sections of K^+ mesons productions increased when the kinetic energy increases and is consistent with experimental data.

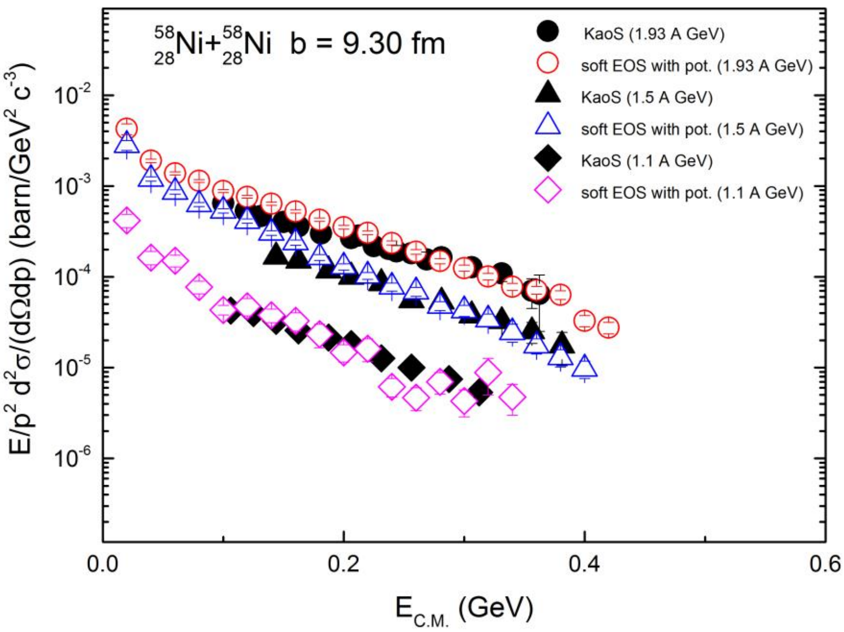

Figure 2. The inclusive invariant cross sections of K^+ mesons as a function of the kaon energy for $^{58}_{28}\mathrm{Ni}+^{58}_{28}\mathrm{Ni}$ at 1.93 1.5 and 1.1 A GeV, in which solid circles, solid triangle and solid square are the KaoS data (Hartnack et al, 2012), empty circles, empty triangle and empty square are calculated results with the in-medium kaon potential. The results calculated by using the soft EOS. The mid-rapidity condition is a selection $\theta_{C.M.}=90^o \pm 10^o$ both for the data and the calculations.

Conclusions

The inclusive invariant cross section of K^+ in reactions $^{12}_{6}\mathrm{C}+^{12}_{6}\mathrm{C}$ at 2.0 1.8 1.5 and 1.2 A GeV are analyzed within the QMD model based on the covariant kaon dynamics, and compared to the KaoS data. Our calculated results with a repulsive in-medium K^+N potential (Its value at saturation density ρ_0 is $U_k(\rho_0)\approx 30\,MeV$) better fit to experimental data. This means that in order to describe reasonably data the medium effect of K^+ mesons should be included in the kaon dynamics. On the other hand, The inclusive invariant cross sections of K^+ mesons turn out to be sensitive to the nuclear equation of state and to be preferred to the soft equation of state.

We can conclude that the physics of kaon production close to threshold in nucleon + nucleon collisions is quantitatively understood for most of the observables of kaon production. To make progress in understanding the strength of the K^+ nucleon interaction in the nuclear medium it is necessary to reach a consistent description of all sensitive observables in a heavy ion reactions.

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