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In-medium effects on the K^-/K^+ ratio at GSI

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Abstract

The in-medium modifications on the K^-/K^+ ratio produced at GSI are studied. Particular attention is paid to the properties of antikaons, which determine the chemical potential and temperature at freeze-out conditions. Different approaches have been considered: non-interacting K^-, on-shell self-energy and single-particle spectral density. We observe that the full off-shell approach to the spectral density reproduces the Brown et al. "broad-band equilibration" which is crucial to explain an enhanced K^-/K^+ ratio.

1. Introduction

The medium modifications of mesons with strangeness such as kaons and antikaons can be studied in connection to heavy-ion experiments for energies around 1–2 A GeV [1]. One surprising observation in C + C and Ni + Ni collisions [2] is that the K^- multiplicity and that of K^+ are of the same order of magnitude although in pp collisions the K^+ multiplicity exceeds the K^- one by 1–2 orders of magnitude at the same energy above threshold. Another interesting observation is that the K^-/K^+ ratio stays almost constant for C + C, Ni + Ni and Au + Au collisions for 1.5 A GeV [2]. Both observations could be

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interpreted to be a manifestation of an attractive K^- optical potential. On the other hand, equal centrality dependence for the K^+ and K^- mesons has also been observed in Au + Au and Pb + Pb reactions at $1.5\,A$ GeV [2]. Actually, the independence of centrality of the K^-/K^+ ratio was claimed to indicate that no in-medium effects were needed in order to explain the experimental ratio [3]. However, the concept of "broad-band equilibration" was introduced by Brown et al. [4] in order to explain the centrality independence but including medium modifications of antikaons.

In this work we study the implications of introducing the K^- spectral density for the K^-/K^+ ratio in order to address the above mentioned issues.

2. In-medium modifications on the K^-/K^+ ratio

We present a brief description of the statistical models which are applied for the calculation of the K^-/K^+ ratio. Statistical models are based on the assumption that the particle ratios in relativistic heavy-ion collisions can be described by two parameters, the baryonic chemical potential μ_B and the temperature T [3].

Therefore, by using canonical strangeness conservation and taking into account the most relevant contributions in the $S = 0, \pm 1$ sectors, the inverse ratio K^+/K^- is given by [3,5]

$$\frac{K^+}{K^-} = \frac{Z^1_{K^+}(Z^1_{K^-} + Z^1_{\Lambda} + Z^1_{\Sigma} + Z^1_{\Sigma^*})}{Z^1_{K^-} Z^1_{K^+}} = 1 + \frac{Z^1_{\Lambda} + Z^1_{\Sigma} + Z^1_{\Sigma^*}}{Z^1_{K^-}}, \tag{1}$$

where Z's indicate the different one-particle partition functions for K^+, K^-, Σ, Λ, Σ^*. In order to balance the number of K^+, the main contribution in the $S = -1$ sector comes from Λ and Σ hyperons and, in a smaller proportion, from K^- mesons and $\Sigma^*(1385)$ resonances. On the other hand, the number of K^- is balanced by the presence of K^+ mesons. We finally observe that the ratio is determined by the relative abundance of Λ, Σ, Σ^* baryons with respect to that of K^- mesons.

In order to introduce in-medium and temperature effects, the particles involved in the calculation should be dressed accordingly. For Λ and Σ, the partition function reads

$$Z_{\Lambda,\Sigma} = g_{\Lambda,\Sigma} V \int \frac{d^3p}{(2\pi)^3} \exp\left\{ \frac{-\sqrt{m^2_{\Lambda,\Sigma} + p^2} - U_{\Lambda,\Sigma}(\rho) + \mu_B}{T} \right\}, \tag{2}$$

which is built using a mean-field dispersion relation for the single-particle energies (see Refs. [5,6]), while the resonance $\Sigma^*(1385)$ is described by a Breit–Wigner shape.

With regards to the K^- meson, two different prescriptions for the K^- single-particle energy have been used. First, we use the mean-field approximation for the K^- potential

$$Z_{K^-} = g_{K^-} V \int \frac{d^3p}{(2\pi)^3} \exp\left\{ \frac{-\sqrt{m^2_{K^-} + p^2} - U_{K^-}(T, \rho, E_{K^-}, p)}{T} \right\}, \tag{3}$$