Kaon and Pion Production in Nucleus-Nucleus Collisions from 0.6 to 2 AGeV^{B,G}

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During the past years the KaoS collaboration has provided for various collision systems a rather detailed set of data on meson production at SIS energies from 0.6 to 2 A·GeV. Inclusive spectra of K^+ mesons are published in [1]. A selection of π^+ spectra is shown in Fig. 1 for C+C and Au+Au collisions at various energies around midrapidity. All spectra exhibit the typical concave shapes, interpreted as due to decaying Δ resonances and free pions [2]. The slope parameters of the high-energy parts agree well with those of the K^+ spectra.

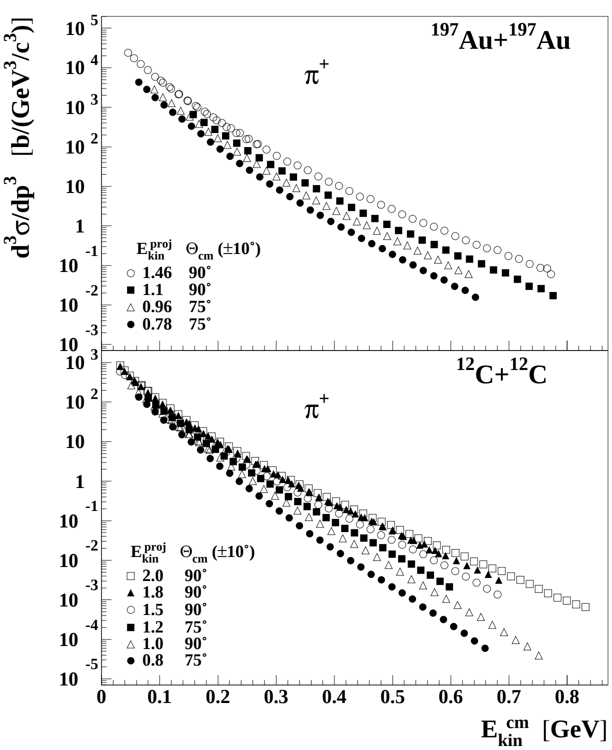

Figure 1: *Spectra of positively charged pions around midrapidity at various incident energies.*

Microscopic transport calculations indicate that the yield of kaons created in collisions between heavy nuclei at subthreshold beam energies (E_{beam} ¡ 1.58 GeV) is sensitive to the compressibility of nuclear matter at high baryon densities [3, 4]. This sensitivity is due to the production mechanism of K^+ mesons at subthreshold beam energies requiring multiple nucleon-nucleon or meson-nucleon collisions. These processes are expected to be enhanced at high baryon densities, and the densities reached in the fireball depend on the nuclear equation of state [5]. Pions are rather insensitive to this parameter of the nuclear equation of state. Their spectra and yields can be used to gauge phase-space effects [1].

Two effects influence the K^+ yield, the compressibility of the nuclear matter as mentioned and possibly a modification of the kaon properties in the dense nuclear medium. Our idea is to disentangle these two competing effects by studying K^+ production in a very light (^{12}C+^{12}C) and a heavy collision system (^{197}Au+^{197}Au) at different beam energies near threshold. The maximum baryonic density reached in Au+Au collisions depends on the nuclear compressibility [4, 6] whereas in the small C+C system this dependence is very weak [7]. The repulsive K^+N potential is assumed to depend nearly (or less than) linearly on the baryonic density [8] and thus reduces the kaon yield accordingly.

Our concept is summarized in Fig. 2. It shows in the upper part the pion and K^+ multiplicity per nucleon for C+C and Au+Au collisions as a function of the beam energy. The pion data points are scaled by a factor of 1/100; they represent the sum of charged and neutral pions as calculated from the measured π^+ multiplicities according to the isobar model [9]. This model explains very well the π^+/π^- ratios measured in Au+Au collisions [10]. The pion multiplicity per nucleon is smaller in Au+Au than in C+C collisions whereas the K^+ multiplicity per nucleon is larger. This observation demonstrates a key difference between pion and kaon emission. In order to illustrate the different behaviour of pions and kaons in nuclear matter we plot the ratio of the pion and kaon excitation functions $(M/A)_{\mathrm{Au+Au}}/(M/A)_{\mathrm{C+C}}$ in the lower panel of Fig. 2. The error bars of the kaon multiplicities include systematic uncertainties due to the extrapolation procedure. The experimental uncertainties due to efficiencies, acceptances and beam normalization, however, cancel in the ratio and therefore have not been taken into account.

The pion ratio $(M/A)_{\mathrm{Au+Au}}/(M/A)_{\mathrm{C+C}}$ (full triangles) is smaller than unity and decreases with decreasing beam energy. A ratio smaller than unity might be caused by the reabsorption of pions which is more effective in the larger system or by decompressional flow of nuclear matter which is expected to be more important in Au+Au than in C+C collisions. In a thermal picture both arguments are equivalent.

In contrast to the pion data, the kaon ratio $(M/A)_{\mathrm{Au+Au}}/(M/A)_{\mathrm{C+C}}$ increases by a factor of almost 3 with decreasing beam energy. An increase of the K^+ yield with decreasing beam energy is found by a transport model calculation in central Au+Au collisions if a soft instead of a hard equation of state is used [4]. The sensitivity

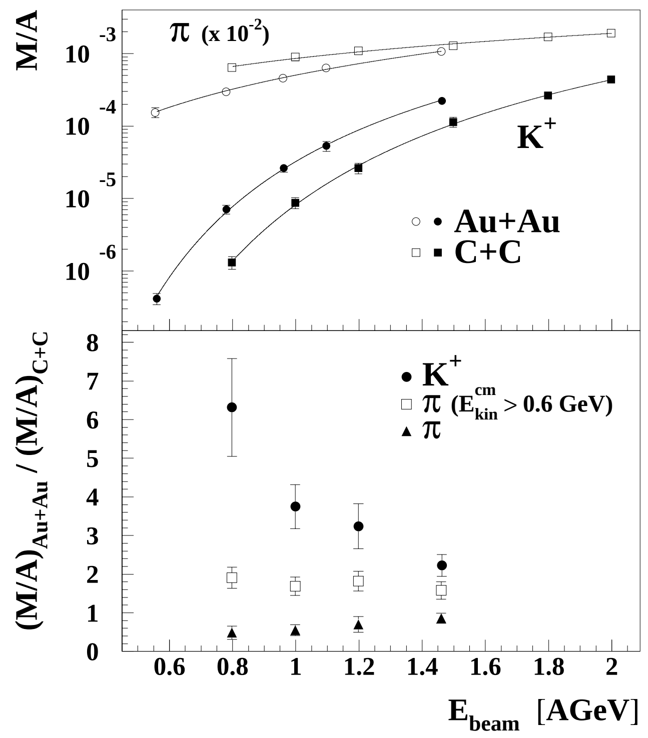

Figure 2: *Upper panel: Pion and K^+ multiplicity per A for the two collision systems as a function of E_{beam}. The pion multiplicities represent all pions species. The lines are to guide the eye. Lower panel: Ratio of the multiplicities per nucleon (Au+Au over C+C collisions) for K^+ mesons (full circles), pions (full triangles) and high-energy pions ($E_{kin}^{cm} > 0.6$ GeV, open squares) as a function of E_{beam}.*

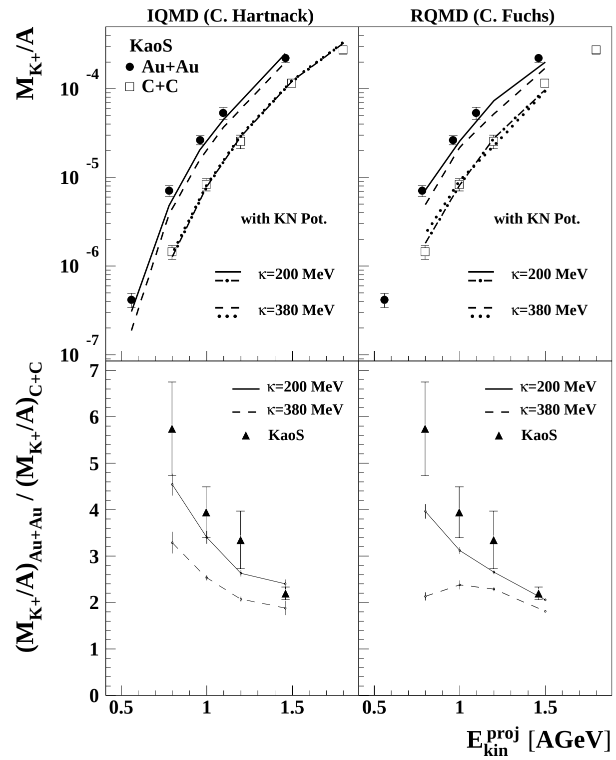

Figure 3: *The upper parts show the inclusive K^+ multiplicities per A together with model calculations for two values of the nuclear compressibility. The lower parts display the ratio $(M/A)_{Au+Au}/(M/A)_{C+C}$ as in fig. 2 together with the model predictions.*

of the kaon multiplicity on the nuclear compressibility is enhanced at beam energies well below the kaon production threshold because the energy required to create a K^+ meson has to be accumulated by multiple collisions of participating nucleons.

In order to exclude trivial phase-space effects as the reason for the observed behaviour we present in the lower panel of Figure 2 the ratio $(M/A)_{\mathrm{Au+Au}}/(M/A)_{\mathrm{C+C}}$ for pions with kinetic energies above $\mathrm{E}_{kin}^{cm} = 0.6$ GeV. The production of these pions is equivalent − in terms of available energy − to the production of K^+ mesons with a kinetic energy above 70 MeV. At this energy the kaon spectra have reached their maximum yields.

Figure 3 shows a comparison of the experimental results with two transport model calculations (lhs: IQMD [11], rhs: RQMD [7]). Both calculations have been performed with KN potential and a compressibilty of 200 MeV and 380 MeV. In the upper part the K^+ multiplicity per A is shown as a function of the beam energy both for Au+Au and C+C collisions. As expected the calculations with $\kappa = 200$ MeV yields higher multiplicities than those with $\kappa = 380$ MeV for Au+Au collisions, while for C+C no sensitivity is seen. The data are best described with $\kappa = 200$ MeV, yet the data are still slightly higher.

The lower part of Fig. 3 shows the ratio of the $(M/A)_{\mathrm{Au+Au}}/(M/A)_{\mathrm{C+C}}$ as measured and as calculated. In both calculations the ratio rises towards lower incident energies using a κ of 200 MeV in agreement with the data. For the stiffer equation of state the two calculation differ somewhat, but clearly deviate strongly from the data. These trends are rather independent whether a KN potential is used or not [7]. This evidences that the used ratio is a very sensitive quantity in extracting the compressibility of nuclear matter and that this ratio does depend little on less known input quantities.

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