Strangeness and in-medium effects in heavy ion collisions from 1 to 2 AGeV

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Experimental data on charged kaon phase space distributions and K^+ sideward flow measured with the FOPI detector at SIS/GSI are presented. When compared to the predictions of transport models, the data favour the existence of an in-medium kaon-nucleon potential.

1. Introduction

Relativistic heavy ion collisions offer interesting possibilities to study hadronic matter under extreme conditions of temperature and density. Beside probing the equation of state, recent theoretical works predict that the hot and dense nuclear medium might undergo a phase transition towards partially restored chiral symmetry of QCD, leading to possible modifications of hadron properties [1]. Such a scenario has attracted much interest recently since it was succesfully used to describe the low mass dilepton enhancement observed by the CERES and HELIOS-3 collaborations at CERN/SPS [2]. It is also suggested that comparable in-medium effects should be observed at lower incident energies and not only on vector mesons but also on pseudo-scalar mesons [3]. In particular, the kaon effective mass and potential are predicted to vary differently for K^+ and K^- : in the nuclear medium K^+ would feel a weak repulsive potential whereas K^- would feel a strong attrative potential [4]. This results in a slightly increased K^+ effective mass and a strongly reduced K^- effective mass. Measurements of sub-threshold or close-to-threshold kaon production offer the means to test these predictions since one would naïvely expect to observe an enhanced K^- yield (its production being energetically much easier) and a reduced K^+ yield (its production being energetically much difficult). On the other hand the existence of a K-nucleon potential can be tested by looking at kaon phase space distributions and/or kaon flow. Thus one would expect to observed K^+ to be pushed away from nucleons and K^- to be pulled towards nucleons.

First signs of such in-medium modifications of kaon properties has indeed been recently observed experimentally [5,6]. We focus here on experimental results obtained with the FOPI detector [7] in the reaction $\mathrm{Ru}+\mathrm{Ru}$ at 1.69·A GeV. Results about the $\mathrm{Ni}+\mathrm{Ni}$ reaction are reported elsewhere [8].

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2. K^-/K^+ ratio

We investigate first the rapidity and transverse momentum dependence of the K^-/K^+ ratio. This is motivated by the following considerations. According to the theoretical predictions mentionned in the introduction, in-medium effects are more important for K^- than for K^+. However the K^- production yield at SIS energies being very small, the limited statistics doesn't allow to examine the full K^- phase space distributions with a high accuracy. The study of the K^-/K^+ is meaningful and particularly interesting since by doing so statistical limitations and experimental detector inefficiencies cancel-out to some extent. In addition, since in-medium effects act oppositely on K^- and K^+, their ratio should be most sensitive to these effects.

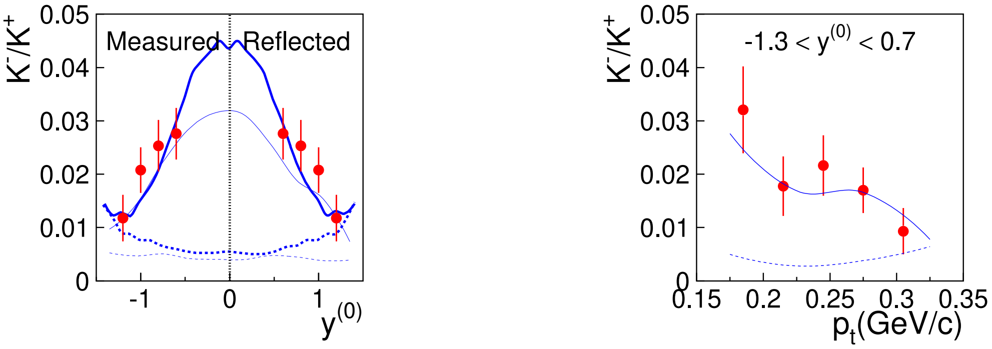

Figure 1. K^-/K^+ ratio as a function of rapidity (left) and transverse momentum (right) in central Ru + Ru reactions at 1.69 AGeV. Data (dots) are compared to the prediction of transport models with (solid curves) and without in-medium effects (dashed curves). Thick (resp. thin) curves correspond to calculations from [10] (resp. [11]). $y^{(0)}$ denotes the particle rapidity divided by the beam rapidity in the center-of-mass system. Error bars represent statistical uncertainties. Adapted from [12].

Figure 1 show the K^-/K^+ ratio as a function of rapidity and transverse momentum. The data are compared to the predictions of relativistic transport models [9] with 2 different scenarios : without and with in-medium effects. The first situation corresponds to a standard calculation including binary collisions plus "conventional" potentials. In the second scenario in-medium effects are taken into account. As it can be observed, the introduction of in-medium effects in the calculations leads to completely different distributions both in shape and magnitude. Without in-medium effects the ratio is found to decrease slightly from target/spectator rapidities to center-of-mass rapidity. This is understood as being due to absorption of slow moving K^- [10]. Oppositely, with in-medium effects, a well defined maximum appears at mid-rapidity. It can be interpretated as the consequence of the interplay of three effects : *i)* with in-medium effects the yield of K^- is enhanced more than the one of K^+ is reduced, *ii)* this is the most pronounced at mid-rapidity where, thanks to the high energy density, K^- are produced more abundantly, and *iii)* the effective K-nucleon potential tends to push K^+ away from nucleons (*i.e.* to large rapidities) and to attract K^- towards nucleons (*i.e.* to small rapidities). The latter effect is also well seen in the transverse momentum dependence of the ratio since, due to the K-nucleon potential, K^+ are pushed towards high momenta whereas K^- are pulled towards low momenta. The data are nicely reproduced by the calculations only if in-medium effects are taken into account.

3. K$^+$ sideward flow

Collective flow effects of various ejectiles emerging from a heavy ion reaction have been extensively studied over the two last decades in both experimental data and transport-model theories [13]. The first experimental data on K$^+$ sideward flow (*i.e.* in-reaction-plane flow component) have been obtained by the FOPI Collaboration in Ni+Ni reactions at 1.93·A GeV [5]. The data, which show a vanishing K$^+$ flow, were extensively compared to different model predictions. According to [14] the experimental trend clearly supports the existence of a repulsive K$^+$-nucleon mean field. According to [15] the sensitivity of the observable to in-medium effects is found to be less pronounced but a slightly repulsive potential cannot be excluded from the comparison. An alternative description of the data was proposed in [16] invoking rescattering effects instead of in-medium kaon potentials. In addition, the sensitivity of K$^+$ sideward flow to in-medium effects was found in [17] to be washed-out when a momentum dependence of the potential is included in the calculations. At last, it was recently pointed-out in [18] that the life time of nuclear resonances used in the models is partially responsible for the magnitude of the K$^+$ sideward flow as it is a crucial ingredient for kaon production channels. A heavier system like Ru + Ru is better suited to further elucidate these questions since flow effect are found to be larger, at least for baryons, as compared to lighter systems [13]. It allows in addition to study K$^+$ flow in non-central collisions where, due to a large sensitivity of the observable to in-medium effects, an anti-flow phenomenon is expected to be seen [11,14] (Fig. 2 left).

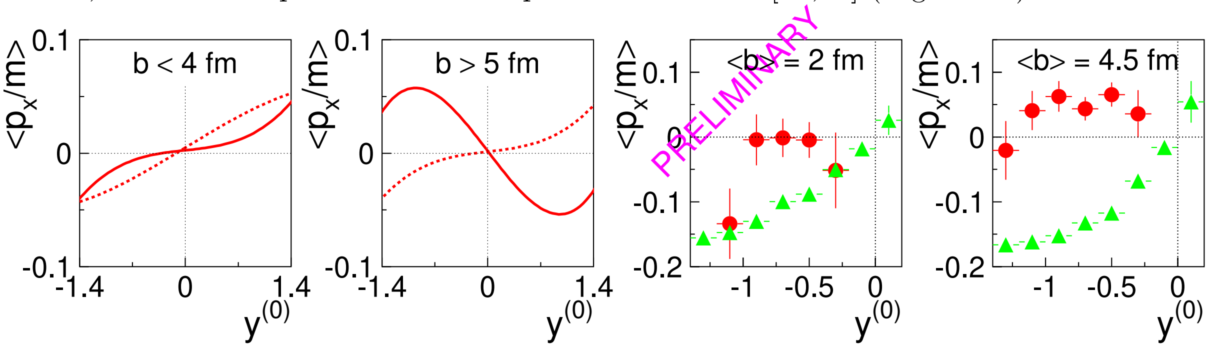

Figure 2. Left : Model predictions [11] for K$^+$ sideward flow in Ru+Ru collisions at 1.69·A GeV with (solid curves) and without (hashed curves) in-medium effects (b is the reaction impact parameter). Right : Experimental sideward flow of K$^+$ (circles) and protons (triangles) in central ($< b >= 2$ fm) and semi-central ($< b >= 4.5$ fm) Ru+Ru events at 1.69·A GeV. p_x/m is the in-reaction-plane transverse momentum component divided by the particle mass. Error bars represent statistical uncertainties. Taken from [19].

Preliminary experimental results on the centrality dependence of the K$^+$ sideward flow are shown in Fig. 2 (right). A clear change in the K$^+$ flow pattern can be observed from a close-to-vanishing signal in central collisions to an anti-flow in semi-central collisions. This trend is in qualitative agreement with the model predictions shown in Fig. 2 (left) when in-medium modification of hadron properties are taken into account. Although the change in the K$^+$ flow pattern between central and semi-central collisions is obvious, a quantitative statement about the magnitude of the experimental signal is difficult at the present status of the analysis.

4. Conclusions and outlooks

Kaon phase space distributions and sideward flow have been measured Ru + Ru collisions at 1.69·A GeV with the FOPI detector. Data were compared to model predictions investigating in-medium modifications of kaon properties. The overall picture emerging from the comparison tends to favour the existence of in-medium effects on kaons. In particular, the experimental K^-/K^+ ratio and the K^+ sideward flow can't be consistently described by transport model theories which do not include in-medium effects. To which extent these observations can be interpreted as a consequence of a partial restoration of chiral symmetry in the nuclear medium remains an open question since alternative descriptions of the data might be elaborated. In addition, before to draw any final statement on kaon data, one would have to carefully compare baryon data with the same transport model calculations. Further exciting possibilities will be offered soon with the upgrade of the FOPI detector time-of-flight system. This will allow to study with better statistics and accuracy K^-'s for which in-medium effects are expected to be much more pronounced.

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