Strangeness and in-medium effects in heavy ion collisions at SIS energies

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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. Besides 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 successfully 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 attractive 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 have indeed been recently observed experimentally [5,6]. We focus here on results obtained with the FOPI detector [7] for the reaction Ru + Ru at 1.69·A GeV. Results about the Ni + Ni reaction are reported elsewhere [5,8].

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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, since the K^- production yield at SIS energies is 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.

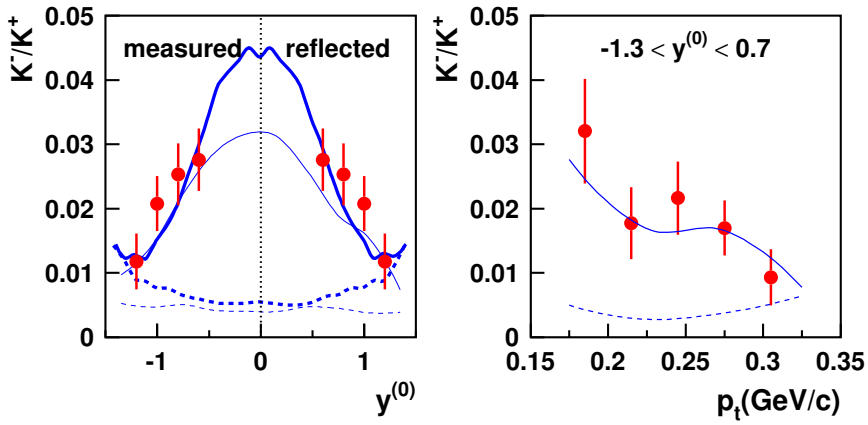

Figure 1. K^-/K^+ ratio as a function of rapidity (left) and transverse momentum (right) in central Ru + Ru reactions at 1.69 AGeV. The data (dots) are compared to the prediction of transport models with (solid curves) and without in-medium effects (dashed curves). Thick (resp. thin) curves correspond to calculations from [9] (resp. [10]). $y^{(0)}$ denotes the particle rapidity divided by the beam rapidity in the center-of-mass system. Error bars represent statistical uncertainties. Adapted from [11].

Figure 1 shows the K^-/K^+ ratio as a function of rapidity and transverse momentum. The data are compared to the predictions of relativistic transport models with 2 different scenarios : without and with in-medium effects. The first situation corresponds to a standard calculation including binary collisions plus "conventional" potentials (*e.g.* Coulomb potential). In the second scenario in-medium effects are added. 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 the absorption of slow moving K^- [9]. Oppositely, with in-medium effects, a well defined maximum appears at mid-rapidity. It can be interpreted 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 baryon 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 [12]. 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 [13] the experimental trend clearly supports the existence of a repulsive K^+-nucleon mean field. An alternative description of the data was proposed in [14] invoking rescattering effects instead of in-medium kaon potentials. In addition, the sensitivity of K^+ sideward-flow to in-medium effects was found in [15] to be washed-out when a momentum dependence of the potential is included in the calculations. At last, it was recently pointed-out in [16] that the in-medium life time of nuclear resonances (Δ's) 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 effects are found to be larger, at least for baryons, compared to lighter systems [12]. It allows in addition to study the 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 [10].

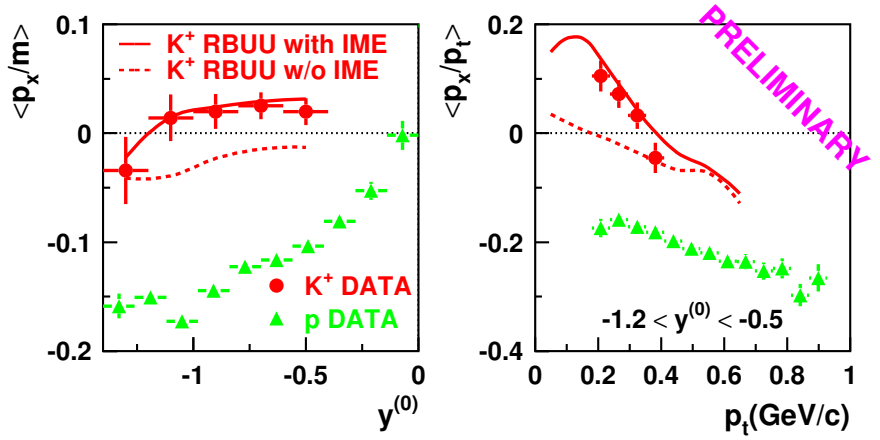

Figure 2. Sideward-flow of proton (triangles) and K^+ (dots) as a function of rapidity (left) and transverse momentum (right), for semi-central ($< b >= 4.5$ fm) Ru + Ru reactions at 1.69·A GeV. Error bars represent statistical uncertainties. The data are compared to the predictions of a RBUU model [10] with (solid curves) and without (dashed curves) in-medium effects. Taken from [17].

Preliminary results on K^+ and proton sideward-flow in semi-central Ru + Ru reactions are shown in Fig. 2 (left) as a function of rapidity. For this type of reactions, the K^+ sideward-flow is found to be anti-correlated with the one of protons. This trend is in agreement with the model predictions if in-medium modifications of kaon properties are taken into account, whereas without in-medium effects the sign of K^+ flow would be the same as the one of proton flow. From the right part of Fig.2, it can be seen that the K^+ anti-flow phenomenon originates mostly from low p_t K^+. The agreement between the data and the model predictions is particularly good in this low p_t range where the sensitivity of K^+ flow to in-medium effects is most pronounced. The latter is due to the fact that

a particle with a low p_t stays longer in the medium compared to a particle with a high p_t which escapes the medium more easily. A similar anti-flow pattern has been observed very recently by the E895 collaboration for K^0_S in Au+Au collisions at 6·A GeV [18].

4. Conclusions and outlooks

Kaon phase space distributions and sideward-flow have been measured in Ru + Ru collisions at 1.69·A GeV with the FOPI detector at GSI. The 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. To which extent these observations can be interpreted as a consequence of a partial restoration of the chiral symmetry in the nuclear medium remains an open question since alternative descriptions of the data might be elaborated. In addition, before one can 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, in particular, 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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