RESULTS FROM FOPI ON STRANGENESS PRODUCTION AND PROPAGATION IN HOT AND DENSE NUCLEAR MATTER

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Abstract

Results from FOPI on strangeness production and propagation in hot and dense nuclear matter are presented in terms of transverse mass spectra, K^-/K^+ ratio and sideward flow. The data are compared to different transport model predictions and seem to favour calculations including in-medium modifications of hadron properties.

1 Introduction

Heavy ion collisions in the energy range of SIS/GSI (1-2 AGeV) offer an interesting tool to probe the properties of nuclear matter. The density reached in these reactions is in the order of 3 times the normal nuclear density and the temperature is around 90 MeV [1, 2]. Within those conditions the nuclear matter consists of strongly interacting nucleons energetic enough to lead to resonance state excitation and to meson production [3, 4].
The study of produced particles is of particular interest since it gives information on the properties of nuclear matter. Not only its equation of state triggers a lot of work but also a transition towards restored chiral symmetry, predicted to occur at very high density, counts among the hot topics nowadays. Such a restoration would lead to a possible dropping mass of hadrons. This scenario allows to explain successfully the data on dileptons measured by CERES and HELIOS 3 at CERN(SPS) [6, 7]. Similar modifications of hadron properties could be observed at SIS energies. This energy range is of particular interest since it corresponds to kaon production close to or even sub-threshold for which in-medium effects (IME) are more pronounced.
The FOPI collaboration has measured baryons and charged and neutral strange particles produced in Ni+Ni and Ru+Ru collisions at 1.93 AGeV and 1.69 AGeV, respectively. This contribution is organized as follows: some general properties of kaons in dense nuclear matter are presented in the second sec-

tion. Particle identification with FOPI is described in the third section. In the fourth section phase space distributions of kaons are discussed in terms of transverse mass spectra and K^-/K^+ ratio. Results on the sideward flow of K^+, $K_s^{(0)}$ and Λ are presented in the fifth section.

2 Kaons in hot and dense nuclear matter

As predicted by several theoretical approaches the properties of hadrons may be changed by the medium in which they are produced. The study of in-medium kaon properties may give some information on the chiral symmetry restoration. Furthermore the limitation of neutron star masses, which is still an open question, could be a consequence of kaon condensation [8]. Theoretical predictions for the variation of the mass of K^+ and K^- as function of the nuclear density are displayed in figure 1.

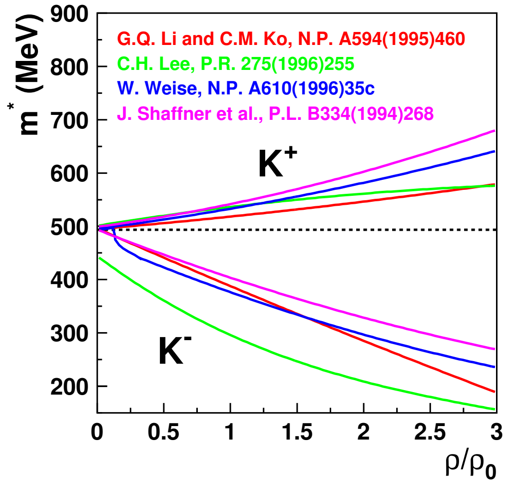

Figure 1. Kaon effective masse m* versus nuclear density (normalized to the normal nuclear density) as predicted by four different calculations.

The mass of K^+ slightly increases with the density whereas the mass of K^- decreases. From this observation one expects a decrease of the K^+ yield and an increase of the K^- yield. On the other hand K^+ feel a repulsive potential. Thus they should be pushed away from nucleons whereas K^- feel an attractive potential and should be attracted towards nucleons.

3 Particle identification with FOPI

The FOPI detector [9] is an azimuthally symmetric apparatus composed of several sub-detectors. The central part is placed in a solenoid providing a 0.6 T magnetic field and consists of a drift chamber (CDC) surrounded by a barrel of plastic scintillators. The forward part of the detector is composed

of another drift chamber and a forward wall of plastic scintillators. For the results presented in this report only the central detectors were used. The particle identification is done using the energy loss in the drift chamber and the momentum (deduced from the curvature of the track). For kaons this identification is improved by the measurement of the velocity in the barrel, restricting the angular range to the barrel coverage ($39° < \theta_{lab} < 130°$). Furthermore this requires transverse momenta above 0.1 GeV/c to allow particles to reach the barrel. To reduce as much as possible the contamination of pions and protons a upper momentum cut of 0.5 GeV/c for K^+ and of 0.33 GeV/c for K^- is applied. The neutral particles are identified from their decay into two charged particles ($\Lambda \to \pi^- p, K_s^0 \to \pi^- \pi^+$). The degree of centrality of the reactions is determined by the multiplicity of charged particles measured in the forward wall of scintillators.
30000 K^+ and 250 K^- were measured out of $4.7 \cdot 10^6$ and $7.7 \cdot 10^6$ events for Ni+Ni at 1.93 AGeV and Ru+Ru at 1.69 AGeV, respectively. The low statistics collected for K^- is due on the one hand to the upper momentum cut of 0.33 GeV/c and on the other hand to the high threshold for K^- production (2.5 GeV) compared to the one for K^+ production (1.58 GeV).

4 Kaon phase space distributions

4.1 Transverse mass spectra and rapidity distributions

Transverse mass spectra can be parametrized with a Boltzmann-type function:

$$\frac{1}{m_t^2} \frac{d^2N}{dm_t dy^{(0)}} = A \cdot \exp\left[\frac{-(m_t - m_0)}{T_B}\right]$$

where $m_t = \sqrt{p_t^2 - m_0^2}$, $y^{(0)} = y/y_{beam}^{cm}$, A and T_B are parameters of the fit. T_B is usually called the Boltzmann inverse slope parameter and is interpreted as the apparent temperature of the source. Figure 2 (left panel) shows transverse mass spectra for K^+ measured in Ru+Ru at 1.69AGeV for different rapidity windows going from target rapidity (bottom) to more central rapidity (top). The data show a single exponential shape which indicates thermal equilibrium. The Boltzmann-type function was used to fit the data. The apparent temperature and the yield $dN/dy^{(0)}$ were extracted from this fit. The yield was obtained by integrating the fit function for $p_t \in [0, \infty[$. Results are presented in figure 2 (middle and right panels).

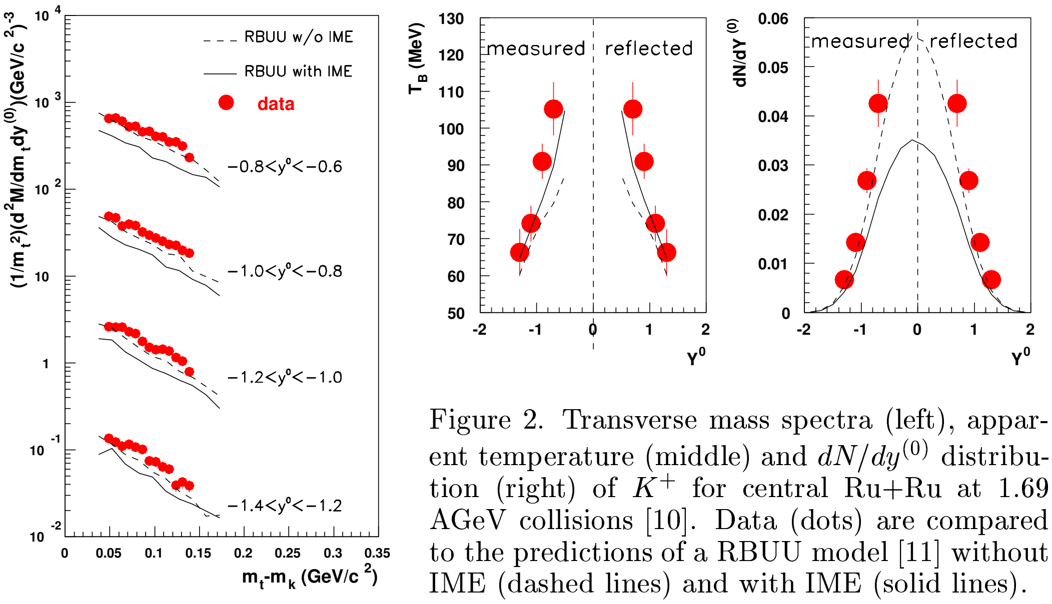

Figure 2. Transverse mass spectra (left), apparent temperature (middle) and $dN/dy^{(0)}$ distribution (right) of K^+ for central Ru+Ru at 1.69 AGeV collisions [10]. Data (dots) are compared to the predictions of a RBUU model [11] without IME (dashed lines) and with IME (solid lines).

The predictions of the Relativistic Boltzmann-Uehling-Uhlenbeck (RBUU) model [11] are plotted on top of the data. The dashed (solid) lines stand for calculations without (with) in-medium modifications of hadron properties as described in section 2. The simulated events where passed through the FOPI filter and analysed exactly in the same way as the data. The theory reproduces the trend of the data but the sensitivity to IME in the investigated $y^{(0)}$ range is rather small. One would have to extend the measurement to mid-rapidity to draw any solid conclusions.

4.2 K^-/K^+ ratio

The study of K^-/K^+ ratio is particularly interesting for the two following reasons: *i)* since IME act oppositly on K^- and K^+ the K^-/K^+ ratio is a sensitive observable, *ii)* by studying ratios instead of single particle distributions the experimental inefficiencies cancel out to some extent.
Figure 3 shows the K^-/K^+ ratio as function of $y^{(0)}$. The data are compared to RBUU predictions without and with IME. The two calculations present different trends. If no in-medium modifications are included the calculations completely miss the data whereas the agreement is quite good when IME are taken into account. The ratio increases from target rapidity to more central rapidity. This is understood on one hand because K^- feel an attractive potential and are thus attracted towards nucleons (ie. to small rapidities) whereas K^+ are pushed away from nucleons (ie. to large rapidities). On the other

hand K^- are more enhanced than K^+ are suppressed and this effect is more pronounced at mid-rapidity where the density is the highest.

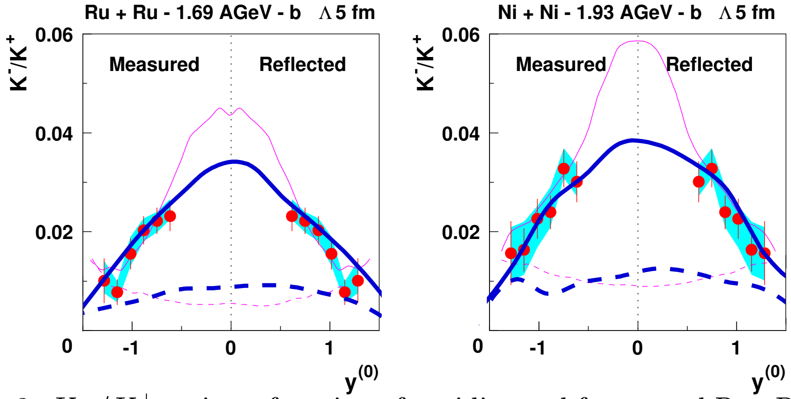

Figure 3. K^-/K^+ ratio as function of rapidity and for central Ru+Ru at 1.69 AGeV (left) and central Ni+Ni at 1.93 AGeV (right) reactions [12]. Data are compared to RBUU predictions without IME (dashed lines) and with IME (solid lines). Thick (resp. thin) curves correspond to calculations from [17] (resp. [18]).

5 Sideward flow

The collective phenomena are recognized as usefull observables to probe the hot and dense nuclear medium created during the first stage of the reaction [13]. Three different flow components have been predicted and evidenced experimentally: *i)* the directed sideward flow [14] is a deflection of the emitted particles in the reaction plane, *ii)* the squeeze-out [15] is an emission of particles perpendicular to the reaction plane, *iii)* the radial flow [16] consists of an azimuthally symmetric emission of particles in very central collisions.
In this section results on sideward flow of strange particles (K^+, K_s^0, Λ) are presented. It is commonly represented by the mean in-plane component of the transverse momentum as function of the normalized rapidity. For protons measured in the backward hemisphere $< \mathrm{p_x/m} >$ is negative and interpreted as a flow signal. Taking this as a reference a positive $< \mathrm{p_x/m} >$ corresponds to an anti-flow signal.

5.1 Sideward flow in Ni+Ni at 1.93 AGeV

Figure 4 shows the sideward flow for K^+, K_s^0, Λ and protons in central Ni+Ni collisions at 1.93 AGeV [19].

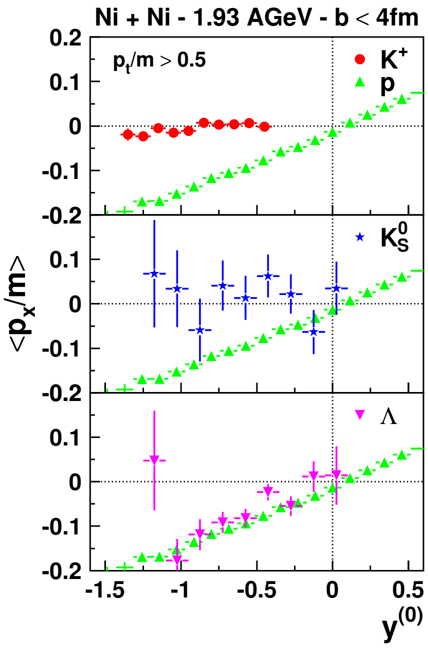

Figure 4. Sideward flow of K^+ (top), K_s^0 (middle), Λ (bottom) and protons for central Ni+Ni collisions at 1.93 AGeV.

Although K^+ and Λ are produced under the same mechanism (associate production) the two particles show very different flow pattern: Λ follow the protons whereas the flow of K^+ is compatible with zero. The difference cannot be explained by Coulomb potential since K_s^0 show the same trend as K^+. According to several transport model predictions ([20], [21]) this experimental trend favour the existence of a repulsive kaon-nucleon potential. However further studies are needed since it has been shown recently that the sensitivity of the K^+ sideward flow to IME is washed-out when a momentum dependence of the potential is taken into account [22]. Furthermore, as shown in [23], the final K^+ flow pattern is also sensitive to other model ingredients such as the parametrization of the lifetime of Δ.

5.2 Sideward flow in Ru+Ru at 1.69 AGeV

In order to bring some light on this problem the FOPI collaboration has studied the sideward flow of K^+ in Ru+Ru collisions. This system is indeed better suited for flow studies since collective phenomena are larger in heavier systems [2]. In addition such a system allows to investigate the centrality dependence of the flow component.

Figure 5 shows the K^+ and proton sideward flow in semi-central and central Ru+Ru reactions.

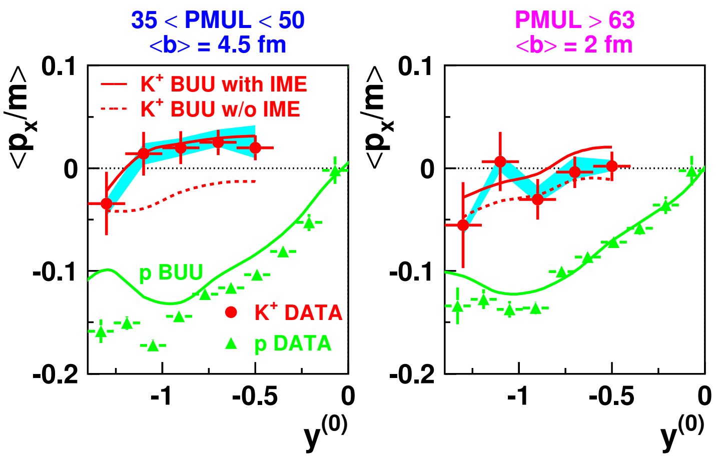

Figure 5. Sideward flow of K^+ (dots) and protons (triangles) for semi-central (left) and central (right) Ru+Ru collisions at 1.69 AGeV [24]. Data are compared to BUU [17] predictions without IME (dashed line) and with IME (solid line).

A clear change in the K^+ flow pattern is observed from an anti-flow signal in semi-central reactions to a vanishing flow signal in more central reactions. For both centralities the data are in good agreement with calculations when IME are taken into account. Note that the results are biased by the experimental acceptance and are integrated over the measured transverse momenta range ($p_t > 0.1$GeV). The theoretical predictions are plotted for the same acceptance.

6 Summary and outlook

Phase space distributions of kaons were presented in terms of transverse mass spectra and K^-/K^+ ratio in Ni+Ni and Ru+Ru collisions at 1.93 AGeV and 1.69 AGeV, respectively. Results on sideward flow of produced strange particles (K^+, K^0_s, Λ) for the same systems were discussed. Data were compared to model predictions and seem to favour calculations which include in-medium modifications of hadron properties. But the origin of these modifications is still an open question. Not only the dropping mass scenario is able to account for the experimental trend but several other explanations were proposed recently and seem to reproduce quite well the data. Moreover it is important to further investigate the experimental results on baryons and to compare them to theoretical predictions.
To elucidate these exciting questions the FOPI collaboration is working on the upgrade of its apparatus. The major part of the project is the construction of a new ToF system which will allow better measurements especially on K^- for which in-medium effects are more pronounced. Φ mesons will also be studied via their decay into K^+K^-.

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