PHASE SPACE DISTRIBUTIONS OF K^- AND K^+ MESONS IN HEAVY-ION COLLISIONS AT SIS ENERGIES *

K. Wiśniewski

for the FOPI Collaboration

Institute of Experimental Physics, Warsaw University
Hoża 69, 00-681 Warszawa, Poland

(Received December 1, 1999)

The comparison of phase space distributions of K^- and K^+ mesons produced in collisions of ^{96}Ru+^{96}Ru at 1.69 A GeV, ^{96}Ru+^{96}Zr at 1.69 A GeV and ^{58}Ni+^{58}Ni at 1.93 A GeV incident beam kinetic energy is presented. The distribution of K^+ mesons is compatible with the emission from an isotropic, thermalized source of which parameters describe as well the spectra of more abundant reaction products: pions, protons and deuterons. The yield ratio of K^- to K^+ mesons is observed to vary across the measured phase space. Relativistic transport-model calculations indicate that the data are best understood if in-medium modifications of kaon properties are taken into account.

PACS numbers: 25.75.–q, 25.75.Dw

1. Introduction

In heavy ion experiments at incident beam energies 1–2 GeV per nucleon, which is close to the production threshold in the elementary nucleon-nucleon reactions, kaons are regarded to be sensitive probes of the early phase of the collision when the nuclear matter reaches the state of high density (2–3 times the normal nuclear matter density) and moderate temperature (up to 100 MeV) [1].

The production rate of kaons is influenced not only by the compressibility of the surrounding medium, hence the nuclear equation of state [2]. Recently, possible consequences of the modifications of hadron properties in

* Presented at the XXVI Mazurian Lakes School of Physics, Krzyże, Poland September 1–11, 1999.

the dense nuclear matter were investigated [3,4]. In particular, the effective mass of K^+ meson is expected to increase slightly while the effective mass of K^- meson is thought to drop substantially with increasing baryonic densities. This phenomenon could lead to the formation of a kaon condensate in a dense environment [3] and may originate from the partial restoration of the chiral symmetry of QCD [5]. However, before drawing any firm conclusion one needs to study as many observables as possible in order to reach a coherent description of heavy ion reactions.

In order to provide a quantitative ground for such investigations, the FOPI collaboration has measured charged kaons and neutral strange particles together with other charged reaction products in collisions of ^{96}Ru+^{96}Ru at 1.69 A GeV, ^{96}Ru+^{96}Zr at 1.69 A GeV and ^{58}Ni+^{58}Ni at 1.93 A GeV. Here, we review the recent experimental results on the production of K^+ and K^- mesons and investigate their possible implications on the modifications of kaon properties in the dense nuclear medium.

2. Experiment

Experiments were performed at SIS/GSI using a general purpose FOPI detector setup [6]. It allows for simultanous measuremets of all charged reaction products with almost full geometric acceptance. In addition, shortly living, neutral particles, such as strange mesons and baryons, can be identified on the ground of the invariant mass reconstruction of their decay products.

For the analysis presented here, only the data from the Central Drift Chamber (CDC), the time of flight scintillator array (Barrel) and the forward plastic wall (PLA) were used. An ensemble of events biased to small impact parameters was selected by requiring high charged-particle multiplicity in the PLA detector. For the Ni+Ni experiment, 4.7×10^6 events were selected, which corresponded to the most central 11% of the total geometric cross-section. For the Ru+Ru and Ru+Zr experiments the most central 14% of the geometric cross-section were analyzed. Since no difference in strangeness production was found between the Ru+Ru and Ru+Zr systems [7], the accumulated statistics was combined for a total of 7.7×10^6 events.

The identification of kaons with the FOPI detector relies on the information on specific energy loss and the momentum of a particle provided by the CDC. Additional accuracy is achieved by adding the information on the velocity gathered by the Barrel. The geometric acceptance of the kaon identification is restricted to the polar-angle range $39^\circ < \Theta_{\rm cm} < 130^\circ$. Due to the background contamination from pion yields, it is further limitted to the momenta lower than 0.5 GeV/c and 0.33 GeV/c for K^+ and K^- mesons respectively. Within this experimental acceptance, about 40000 K^+ and 220 K^- mesons have been identified in the Ni+Ni experiment. The combined statistics of the Ru+Ru/Zr experiment is about 26000 K^+ and 240 K^- mesons.

3. Phase space distribution of K^+ mesons

The distribution in the phase space of K^+ mesons measured in the ^{96}Ru+^{96}Ru experiment is shown in Fig. 1a in terms of transverse mass (m_t=$\sqrt{p_t^2 + m_K^2}$) and normalized rapidity ($y^{(0)} = y^{\rm lab}/y^{\rm CM} - 1$, where $y^{\rm CM}$ is half of the beam rapidity). In this representation −1 and 0 on the rapidity axis correspond to the target and the midrapidity, respectively.

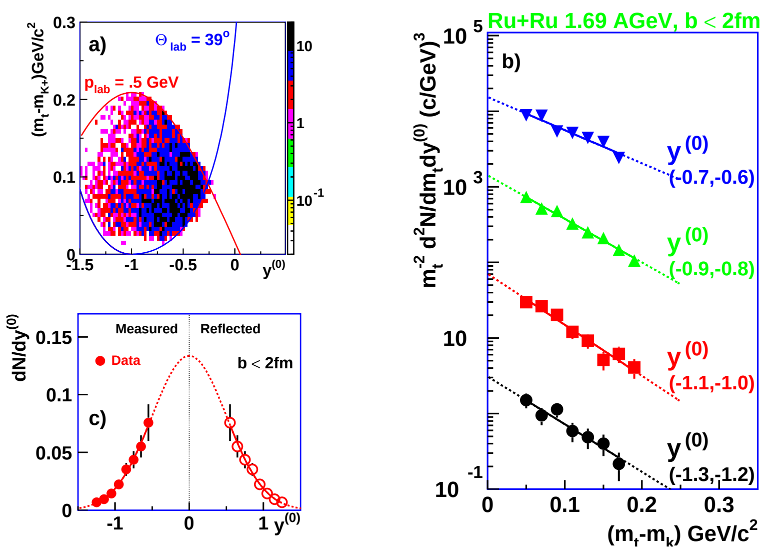

Fig. 1. (a) Phase space distribution of K^+ mesons measured in the experiment ^{96}Ru+^{96}Ru. (b) Transverse mass spectra of K^+ mesons in different rapidity slices. Lines depict the fits according to the formula (1). (c) Rapidity density distribution of K^+ mesons. The line depicts the distribution obtained for a thermalized source of temperature T=80 MeV.

Fig. 1(b) shows the transverse mass spectra of K^+ mesons in different rapidity slices (dots). These are compared to distributions parametrized by the formula

$$\frac{1}{m_t^2}\frac{d^2N}{dm_t dy^{(0)}} \propto \exp\left[\frac{-(m_t - m_{K^+})}{T_B}\right], \qquad (1)$$

where $T_B = \frac{T}{\cosh\left(y^{(0)}y^{CM}\right)}$ is so-called inverse slope parameter, and T is the Boltzmann temperature of the source. The spectra are fitted with the formula (1) and extrapolated to transverse mass regions beyond the range of measurements. The integration of the fitted functions leads to the rapidity density distribution which is shown in figure 1(c). The spectrum is again compared to the distribution obtained for the isotropic emission from a thermalized source of temperature $T \simeq 80$ MeV. This value agrees very well with temperatures which are extracted in case of similar reactions from the spectra of more abundant reaction products such as pions, protons and deuterons [8].

4. K^- to K^+ meson yields ratio

To quantitatively examine and compare the phase-space distributions of K^+ and K^- mesons, where for the latter low statistics does not allow to extrapolate spectra, we study the yield ratio of K^- to K^+ mesons. This offers two advantages with respect to analyses of single particle distributions:

(i) Experimental difficulties, like detection efficiencies and acceptance deficiencies cancel to a large extent [7].

(ii) In-medium effects act in opposite way on K^- and K^+ mesons, hence the ratio should reveal these more clearly.

The K^-/K^+ ratio is plotted in Fig. 2 as a function of the normalized rapidity $y^{(0)}$ for Ru+Ru/Zr (a) and Ni+Ni (b) experiments. The result is biased by the detector acceptance, but has the best statistical significance, which is given by the error bars attached to the data points. We observe that the K^-/K^+ ratio rises towards midrapidity.

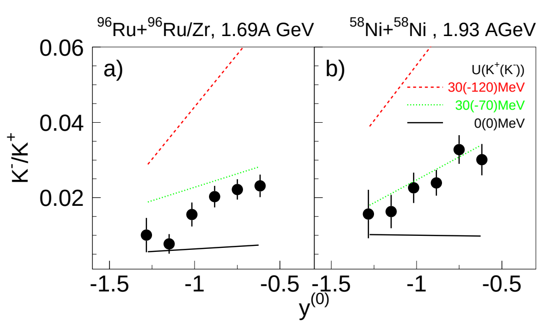

Fig. 2. The K^-/K^+ ratio as a function of normalized rapidity in the geometric acceptance of the FOPI detector setup. Lines depict predictions of different versions of the RBUU transport model [9].

Finally, we try to explain the variation of the K^-/K^+ ratio in the phase space by in-medium modifications of kaon properties. We compare the predictions of the RBUU transport model [9] with the experimental results. Solid lines in figure 2 show predictions of the RBUU model when no modifications of kaons are taken into account. Dashed and dotted lines show the values of the ratio predicted by the model RBUU when in-medium effects are taken into account by a linear dependence of the in-medium potential on density [10]. Two scenarios with different strength of the in-medium kaon potentials at normal nuclear matter density are presented. The attractive K^- potential influences the results in a systematic fashion: the overall K^-/K^+ ratio increases as does the slope with respect to the rapidity axis. While the first effect is caused mainly by the corresponding drop of the effective mass of K^- meson, the rapidity dependence of the K^-/K^+ ratio is generated by forces originating from the gradients of the potentials.

5. Summary

Kaon phase space distributions were studied in reactions : ^{96}Ru+^{96}Ru at 1.69 A GeV, ^{96}Ru+^{96}Zr at 1.69 A GeV and ^{58}Ni+^{58}Ni at 1.93 A GeV incident beam kinetic energy. Distributions of K^+ mesons are compatible with an emission from a thermalized source. The yield ratio of K^- to K^+ mesons varies in the measured phase space. The data can be properly described by the RBUU model calculations if in-medium modifications of kaon properties are taken into account.

This work was supported in partby the Polish State Committee for Scientific Research (KBN) under grant GR 1057.

REFERENCES

[1] R. Stock, *Phys. Rep.* **135**, 261 (1986); J. Aichelin, *Phys. Rep.* **202**, 233 (1991); H.H. Gutbrot *et al.*, *Rep. Prog. Phys.* **52**, 1267 (1989).

[2] J. Aichelin, C.M. Ko, *Phys. Rev. Lett.* **55**, 2661 (1985); T. Maruyama *et al.*, *Nucl. Phys.* **A573**, 653 (1994); G.Q. Li, C.M. Ko, X.S. Fang, *Phys. Lett.* **B329**, 149 (1994).

[3] A.E. Nelson, D.B. Kaplan, *Phys. Lett.* **B192**, 193 (1987); G.E. Brown *et al.*, *Nucl. Phys.* **A567**, 937 (1994).

[4] M. Lutz *et al.*, *Nucl. Phys.* **A574**, 755 (1994); J. Schaffner *et al.*, *Phys. Lett.* **B334**, 268 (1994); V. Koch, *Phys. Lett.* **B337**, 7 (1994); T. Waas *et al.*, *Phys. Lett.* **B379**, 34 (1996).

[5] S. Klimt *et al.*, *Phys. Lett.* **B249**, 386 (1990).

[6] J. Ritman *et al.*, *Nucl. Phys.* **B44**, 708 (1995).

[7] K. Wiśniewski, PhD thesis, University of Warsaw, 1999.

[8] B. Hong *et al.*, *Phys. Rev.* **C57**, 244 (1998).

[9] W. Cassing *et al.*, *Prog. Part. Nucl. Phys.* **25**, 235 (1990).

[10] W. Cassing *et al.*, *Nucl. Phys.* **A614**, 415 (1997).