Kaon and Antikaon Production in Heavy Ion Collisions at 1.5 AGeV

Andreas Förster* for the KaoS Collaboration†

*Institut für Kernphysik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany
E-mail: a.foerster@gsi.de

Abstract.
At the Kaon Spectrometer KaoS at SIS, GSI the production of kaons and antikaons in heavy ion reactions at a beam energy of 1.5 AGeV has been measured for the collision systems Ni + Ni and Au + Au. The $K^-/K^+$ ratio is found to be constant for both systems and as a function of impact parameter but the slopes of $K^+$ and $K^-$ spectra differ for all impact parameters. Furthermore the respective polar angle distributions will be presented as a function of centrality.

1. Introduction

Heavy ion collisions provide the unique possibility to study strange mesons in baryonic matter at densities well above saturation density. Of special interest is their production and propagation at and below the NN-threshold [1, 2]. At higher beam energies (AGS, SPS, RHIC) the abundances of produced particles can be well described within the framework of a statistical model [3]. The same holds for SIS energies if strangeness conservation is treated canonically [4]. In the following $K^+$ and $K^-$ spectra measured recently in Au + Au and Ni + Ni collisions at 1.5 AGeV with the Kaon Spectrometer [5] at SIS/GSI will be presented as a function of centrality as well as the respective polar angle distributions. A general overview of KaoS results is given in the talk of C.Sturm.

2. Polar Angle Distribution

By pivoting the Kaon Spectrometer around the target point a wide range in polar angle within the center of momentum frame is covered. Figure 1 shows the range in transverse momentum and rapidity for $K^+$ in Au + Au collisions at 1.5 AGeV beam energy covered by five angular settings in the laboratory.

† H.Oeschler, C.Sturm, F.Uhlig (TU Darmstadt), P.Koczoñ, E.Schwab, P.Senger (GSI Darmstadt), Y.Shin, H.Ströbele (University of Frankfurt), I.Böttcher, B.Kohlmeier, M.Menzel, F.Pühlhofer (University of Marburg), W.Walus (Jagellonian University Cracow), E.Grosse, L.Naumann, W.Scheinast, A.Wagner (FZ Rossendorf)
Figure 1. Transverse momentum as a function of rapidity for $K^+$. The different bands correspond to different spectrometer angles in the laboratory.

Figure 2 depicts the polar angle distribution $\sigma_{\text{inv}}(\theta_{\text{cm}})/\sigma_{\text{inv}}(90^\circ)$ for $K^+$ and $K^-$ for two centrality classes. The lines represent fits assuming a quadratic dependence on $\cos(\theta_{\text{cm}})$:

$$\frac{d\sigma}{d(\cos\theta_{\text{cm}})} \sim 1 + a_2 \cdot \cos^2(\theta_{\text{cm}}).$$

This anisotropy is more pronounced for $K^+$ than for $K^-$ and it decreases with increasing centrality. Near central $K^-$ data are isotropic. Similar trends have been observed in Ni + Ni collisions at a beam energy of 1.93 AGeV.

3. Centrality Dependence

To investigate the centrality dependence of the kaon and antikaon production we have divided the data measured close to midrapidity ($\theta_{\text{lab}} = 40^\circ$) into five centrality classes. Figure 3 shows the corresponding energy spectra for Au + Au collisions at $E_{\text{beam}} = 1.5$ AGeV. The lines are Boltzmann fits. The resulting inverse slope parameters for the $K^+$ spectra are about 20 MeV higher than those for the $K^-$ spectra for all centrality classes.

The dependence of the particle multiplicity on the number of participating nucleons $A_{\text{part}}$ as determined from the measured centrality by a geometrical model is found to be the same for kaons and antikaons. This is also observed in the Ni + Ni case. Even the absolute values of the multiplicity per $A_{\text{part}}$ at a given $A_{\text{part}}$ are the same for Au and Ni. The $K^+$ and $K^-$ production seems to depend only on the number of participating nucleons. As a result the $K^-/K^+$ ratio is constant as a function of $A_{\text{part}}$ independent of the collision system (figure 4 a) indicating a link between the production mechanisms of both particles.

As suggested in [7] and supported by recent transport calculations [8] the dominant production channel for $K^-$ is the strangeness exchange reaction

$$\pi^{(0,-)} + Y \rightarrow K^- + N.$$  

(2)
If one naively assumes this channel to be in chemical equilibrium the law of mass action could be applied:\cite{footnote1}:

\[
\frac{[\pi^{0,-}].[Y]}{[K^{-}].[N]} = \kappa = \text{const.}
\]

(3)

At this beam energy most hyperons \(Y\) are produced associately with a kaon. Since the number of hyperons is changed only marginally by the production of \(K^-\) their rate can be substituted by the one of the \(K^+\). Using additionally \(A_{part}\) for \([N]\)
yields
\[
\left[ \frac{K^-}{K^+} \right] / \left[ \pi^0(0^-) / A_{\text{part}} \right] \sim \frac{1}{\kappa} = \text{const.}
\] (4)

Figure 4 b) shows the multiplicity of \( \pi^- \) and \( \pi^0 \) per \( A_{\text{part}} \) (with \( M(\pi^0) = 0.5 \cdot [M(\pi^+) + M(\pi^-)] \)) as a function of \( A_{\text{part}} \). Figure 4 c) shows the double ratio of equation 4 obtained by dividing the \( K^-/K^+ \) ratio from figure 4 a) by the pion multiplicity per \( A_{\text{part}} \) from figure 4 b). The result seems to be a constant value independent of the number of participating nucleons and the collision system.

4. Conclusions

The constancy of the double ratio \( (K^-/K^+) / (M(\pi^-, \pi^0)/A_{\text{part}}) \) nicely agrees with the assumption of the strangeness exchange reaction being the dominant production process for \( K^- \) at SIS energies. While this supports the idea of chemical equilibration in this specific channel the differences in the spectral slopes of \( K^+ \) and \( K^- \) are in contradiction.

References

[1] KaoS-Coll. (R. Barth et al, Phys. Rev. Lett. 78, 4007 (1997); F. Laue et al, Phys. Rev. Lett. 82, 1640 (1999); Y. Shin et al, Phys. Rev. Lett. 81, 1576 (1998); C. Sturm et al, Phys. Rev. Lett. 86, 39 (2001))
[2] FOPI-Coll. (D. Best et al, Nucl. Phys. A625, 755 (1997); P. Crochet et al, Phys. Lett. 486, 6 (2000); K. Wisniewski et al, Eur. Phys. J. A9, 515 (2000))
[3] P. Braun-Munzinger et al, Phys. Lett. B344, 43 (1995); P. Braun-Munzinger et al, Phys. Lett. B465, 15 (1999); P. Braun-Munzinger et al, Phys. Lett. B518, 41 (2001)
[4] J. Cleymans et al, Phys. Rev. C59, 1663 (1999); J. Cleymans et al, Phys. Lett. B485, 27 (2000)
[5] P. Senger et al, Nucl. Instrum. Methods A327, 393 (1993)
[6] M. Menzel et al, Phys. Lett. B495, 26 (2000)
[7] C.M. Ko, Phys. Lett. B138, 361 (1984)
[8] C. Hartnack et al, submitted to Phys. Rev. Lett. nucl-th/0109012 (2001)
[9] H. Oeschler, J. Phys. G: Nucl. Part. Phys. 27, 257 (2000)