Centrality Dependence of Kaon and Antikaon Production in Ni+Ni Collisions at SIS Energies ^{B,G}

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Kaons and antikaons are regarded as a promising probe to study hadron properties in dense nuclear matter. Recent experimental results obtained with the Kaon Spectrometer indicate modifications of the in-medium properties of K^+ and K^-. Remarkable results are that the K^-/K^+ ratio is enhanced compared to pp collisions [1,2,3], the spectral slope for the antikaons is steeper than for the kaons [2] and a preferential out-of-plane emission of K^+ is observed [4].

In order to study the kaon production as a function of the reaction centrality and the beam energy, we have measured K^+ and K^- mesons around midrapidity ($\theta_{lab} = 40° \pm 4°$) in Ni+Ni reactions at beam energies of 1.1 (K^+ only), 1.5 and 1.93 AGeV. The multiplicity of charged particles measured by a target hodoscope is used to determine the centrality. The data set is subdivided in five centrality bins MUL1 to MUL5 for each beam energy. From a measurement under minimum bias conditions the reaction cross section is determined. For all beam energies we find a reaction cross section of $\sigma_R = 2.9 \pm 0.3$ barn, which agrees with the geometric model. The relative reaction cross section for each centrality class $\sigma_{R,MUL}/\sigma_R$ is given in Table 1 for 1.5 and 1.93 AGeV. Errors of about 10 % have to be added to the ratio $\sigma_{R,MUL}/\sigma_R$.

Figure 1 shows the invariant cross sections of K^+ (full circles) and K^- (open circles) for central to peripheral collisions (see middle panel: MUL 5 to MUL 1) as a function of the center-of-mass kinetic energy at beam energies of 1.1, 1.5 and 1.93 AGeV. The K^- mesons are scaled by a factor of 20 (see lower panel) and the yields in the bins are scaled by factors of 10 (see upper panel). The error bars shown are due to statistics only and a systematic error of 10% has to be added, caused by beam normalization, acceptance determination and trigger efficiency. The lines represent Boltzmann distributions $d^3\sigma/dp^3 \propto exp(-E_{CM}/T)$ fitted to the spectra individually for each multiplicity bin. The integrated kaon cross sections $4\pi(d\sigma_K/d\Omega_{CM})$ and the inverse slope parameters T as a function of the centrality are given in Table 1 for 1.5 and 1.93 AGeV. The errors of both quantities include the systematic effects. For all beam energies the spectral slopes decrease (Figure 1) and the inverse slope parameters T increase (Table 1) with increasing centrality of the reaction for both, kaons and antikaons.

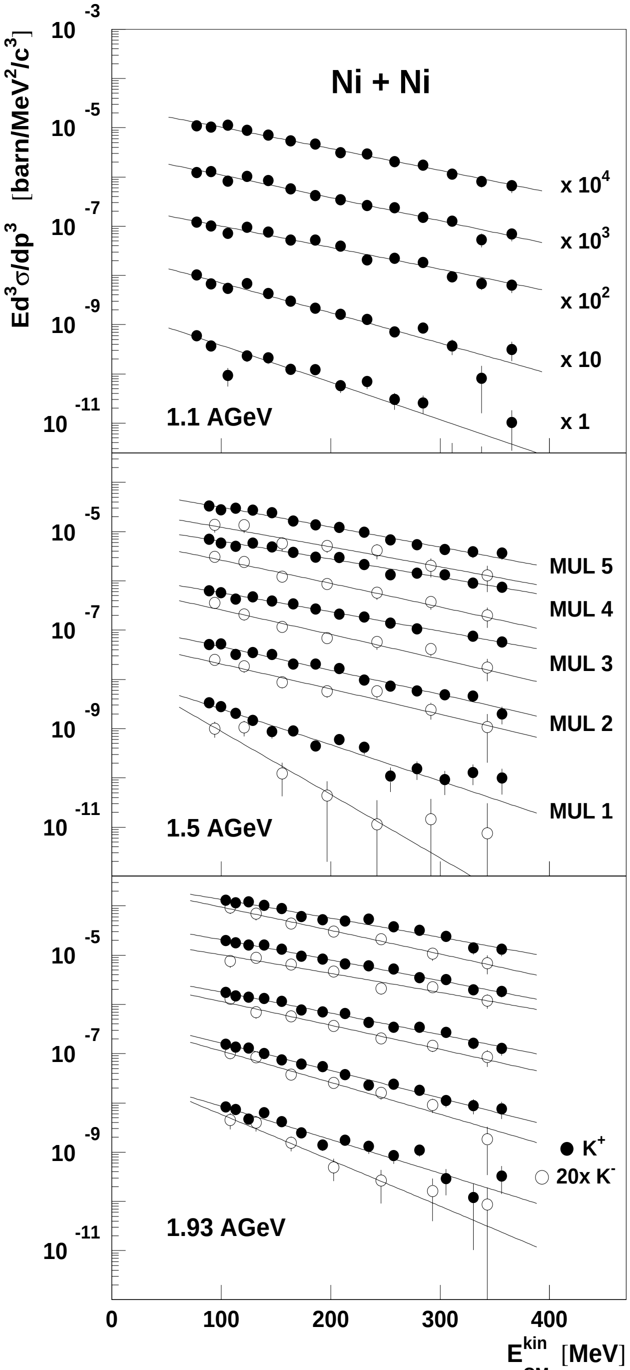

Figure 1: *K^+ and K^- invariant cross sections as a function of the kinetic energy and the centrality of the reaction measured around midrapidity ($\theta_{lab} = 40° \pm 4°$) for Ni+Ni collisions at different beam energies (preliminary).*

We determined the average multiplicity per number of participating nucleons M_K/A_{part} as a function of the number of participating nucleons. M_K is calculated via $M_K =$

Energy	MUL	$\frac{\sigma_{R,MUL}}{\sigma_R}$	$4\pi\frac{d\sigma_K}{d\Omega_{CM}}$ [mb]	T [MeV]
1.5 AGeV K^+	1	0.41	2.2 ± 0.2	55 ± 4
	2	0.23	4.5 ± 0.4	79 ± 6
	3	0.18	6.2 ± 0.5	96 ± 7
	4	0.14	7.2 ± 0.5	101 ± 8
	5	0.05	3.3 ± 0.3	93 ± 7
1.93 AGeV K^+	1	0.44	7.6 ± 0.7	58 ± 5
	2	0.23	14.8 ± 1.2	70 ± 6
	3	0.16	18.1 ± 1.4	88 ± 7
	4	0.11	21.4 ± 1.6	91 ± 7
	5	0.06	14.8 ± 1.2	97 ± 7
1.5 AGeV K^-	1	0.41	0.06 ± 0.011	33 ± 3
	2	0.23	0.10 ± 0.012	74 ± 6
	3	0.18	0.12 ± 0.013	78 ± 7
	4	0.14	0.13 ± 0.014	80 ± 7
	5	0.05	0.07 ± 0.011	90 ± 10
1.93 AGeV K^-	1	0.44	0.30 ± 0.06	43 ± 3
	2	0.23	0.51 ± 0.07	63 ± 7
	3	0.16	0.56 ± 0.06	79 ± 10
	4	0.11	0.57 ± 0.07	96 ± 8
	5	0.06	0.46 ± 0.05	81 ± 7

Table 1: Relative reaction cross sections, K$^+$ and K$^-$ production cross sections and inverse slope parameters as a function of the centrality for Ni+Ni collisions at beam energies of 1.5 and 1.93 AGeV (preliminary).

$\sigma_K/\sigma_{R,MUL}$ with $\sigma_K = 4\pi(d\sigma_K/d\Omega_{CM})$ and with the reaction cross section for each multiplicity class $\sigma_{R,MUL}$. A_{part} is calculated from the number of nucleons in the overlap of the colliding nuclei. The impact parameter b is determined for the center of each multiplicity bin. The kaon and antikaon multiplicity per A_{part} (full circles: K$^+$, open: K$^-$) is shown in Figure 2 (different scaling factors) with a parameterization according to $M_K \propto A_{part}^{\alpha}$ (lines).

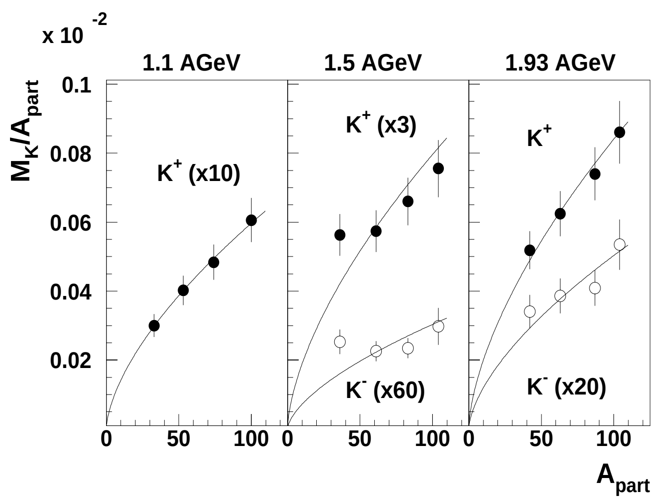

Figure 2: Kaon and antikaon multiplicity per A_{Part} as a function of A_{Part} for Ni+Ni collisions at beam energies of 1.1, 1.5 and 1.93 AGeV (preliminary).

The multiplicities for MUL 1 are not shown because the errors in integrating the cross sections are larger compared to the other bins. Within the uncertainties of A_{part} we get a common $\alpha = 1.62 \pm 0.21$ for K$^+$ and K$^-$ and for all beam energies. Values of α larger than unity indicate that the nucleons participate more than once in the kaon production.

In Figure 3 we present the K$^-$/K$^+$ ratio as a function of the impact parameter b for the beam energy 1.5 AGeV (full triangles) and 1.93 AGeV (full squares). Within the error bars the values are constant between 1.8 fm and 6 fm and the averaged ratios are 0.020 ± 0.004 for 1.5 AGeV and 0.031 ± 0.004 for 1.93 AGeV. The ratio for 1.93 AGeV

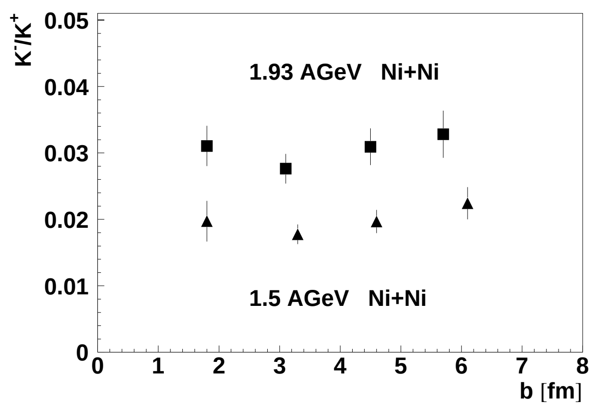

Figure 3: *K^-/K^+ ratio as a function of the impact parameter b for Ni+Ni collisions at beam energies of 1.5 and 1.93 AGeV (preliminary).*

agrees with the value of 0.031 ± 0.005 for non-central and near-central collisions in Ni+Ni measured for the full rapidity range ($\theta_{lab} = 28°$ to $64°$) at the same beam energy [3]. All measured K$^-$/K$^+$ ratios for Ni+Ni can be compared with the smaller system C+C [2] and the corresponding inclusive values of 0.025 ± 0.007 for the beam energy 1.8 AGeV and 0.038 ± 0.013 for 2.0 AGeV.

In conclusion, the K$^-$/K$^+$ ratio at a given bombarding energy is constant as a function of the centrality of the reaction and the size of the collision system. This indicates, that the antikaon yield is coupled to the kaon yield via the strangeness exchange reaction $Y\pi \rightarrow K^-N$ (with $Y = \Lambda, \Sigma$).

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References

[1] R. Barth et al., Phys. Rev. Lett. **78** (1997) 4007
[2] F. Laue et al., Phys. Rev. Lett. **82** (1999) 1640
[3] M. Menzel et al., Phys. Lett. **B 495** (2000) 26
[4] Y. Shin et al., Phys. Rev. Lett. **81** (1998) 1576