System-size dependence of charged kaon and pion production in nucleus-nucleus collisions at beam energies of 40A GeV and 158A GeV

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Abstract. We present the system size (centrality) dependence of the mean transverse mass, of the K/π ratio, and of the width of the rapidity distribution. Except for the latter a steep increase with centrality is observed for small systems followed by a weak rise or even saturation for higher centralities at both energies. This behavior is compared to calculations using transport models (UrQMD and HSD), a percolation model and the core-corona approach.

The NA49 collaboration has published data on the system-size dependence of pion and kaon [1], hyperon (Λ and Ξ) [2], and (anti-)proton [3] yields and distributions in Pb+Pb collisions at 40A GeV and 158A GeV beam energy. Results on pions, kaons, ϕ mesons and Λ hyperons in C+C and Si+Si at 158A GeV were reported in Ref. [4]. Pion and kaon production was also studied in p+p interactions at 158 GeV/c [5, 6].

In this contribution we summarize the findings for the system size dependence of the kaon and pion observables $\langle m_T \rangle - m_0$, of the K/$\pi$ ratio, and of the width of the rapidity distribution RMS_y. In addition to the centrality selected Pb+Pb collisions semi-central C+C and Si+Si collisions are considered. These new data are published in [1].

The recorded minimum bias Pb+Pb collisions were divided into five consecutive centrality bins C0 - C4 with C0 being the most central one. The centrality selection is based on the forward going energy of projectile spectators measured in a downstream (or zero degree) calorimeter VCAL positioned behind a suitably adjusted collimator. We quantify centrality by the fraction of cross-section according to intervals of forward going spectator energy. For each centrality interval a characteristic quantity, the mean value of "wounded nucleons" $\langle N_w \rangle$ is calculated. A nucleon is considered wounded, if its interaction occurs in the nuclear overlap volume. After applying quality cuts to the sample of all reconstructed tracks, pion spectra were obtained by subtracting from the yield of all negatively charged particles the yield of K^-, $\bar{p}$, e^-, and of particles from the decay of strange particles and from secondary interactions. π^+ were identified in a combined dE/dx and TOF analysis only near midrapidity Their yields in full phase space were calculated from the π^+/π^- ratios near midrapidity assuming that their spectra have the same shapes. Kaons were identified using the energy loss (dE/dx) information from the TPCs and time-of-flight measurements in the phase space covered by the TOF walls. For the analysis based on dE/dx information alone, raw yields of K^+ and K^- were extracted from fits to the dE/dx distributions in bins of laboratory and transverse momenta. The resulting distributions were corrected for geometrical acceptance, in-flight decay of kaons, and reconstruction efficiency.

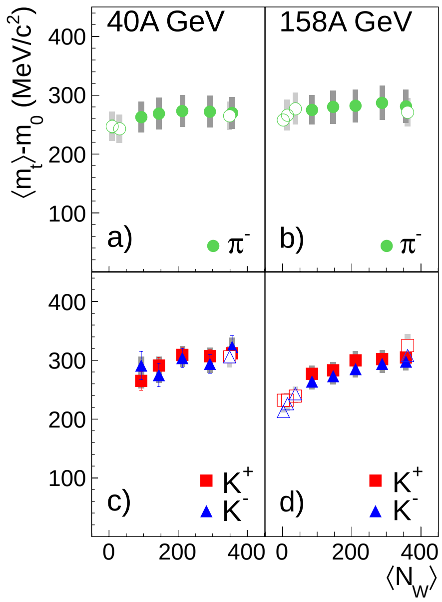

Figure 1. (Color online) Mean transverse mass as extracted from the transverse mass spectra at mid-rapidity for π^-, K$^+$ and K$^-$ versus number of participating nucleons. Open symbols show results from p+p, C+C, Si+Si and central Pb+Pb collisions. Except for the new results for C+C and Si+Si collisions at 40*A* GeV beam energy the data are taken from [5, 4, 7, 8, 6]. Filled symbols represent the centrality selected Pb+Pb data. The thin vertical bars indicate the statistical errors, which are mostly not visible. The thick shaded bars indicate the systematic errors.

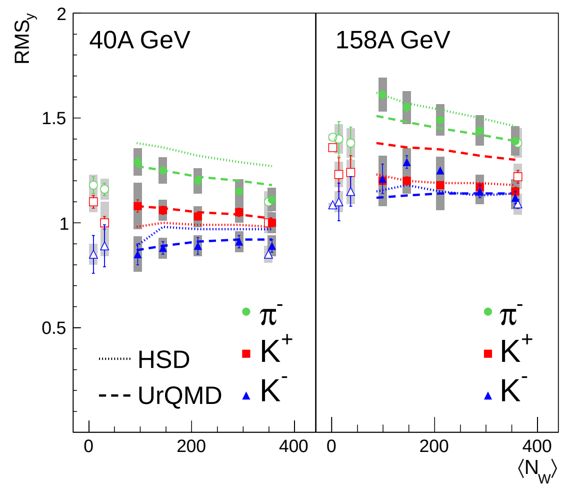

Figure 2. (Color online) Width of the rapidity distribution described by the RMS values for π^-, K$^+$ and K$^-$ versus mean number of participating nucleons. Open symbols show results from p+p, C+C, Si+Si and central Pb+Pb collisions. Except for the new results for C+C and Si+Si collisions at 40*A* GeV beam energy the data are taken from [5, 4, 7, 8]. Filled symbols represent the centrality selected Pb+Pb data. Lines show results from HSD [9, 10] and UrQMD2.3 [11] simulations as indicated in the figure. The thin vertical bars indicate the statistical errors, which are mostly not visible. The thick shaded bars indicate the systematic errors.

Transverse mass spectra at mid-rapidity were determined for kaons (combined dE/dx and TOF analysis) and pions for different centrality classes. For a model independent study of the transverse mass spectra the average transverse mass $\langle m_{\rm T} \rangle - m_0$ was calculated. To account for the small unmeasured high $m_{\rm T}$ part of the kaon spectra, , which contributes to $m_{\rm T}$ only at the percent level, the spectra were extrapolated by suitable exponential functions. Figure 1 shows the dependence of the resulting $\langle m_{\rm T}\rangle - m_0$ on the mean number of wounded nucleons $\langle N_{\rm w}\rangle$ for the investigated collision systems at 40*A* GeV and 158*A* GeV beam energy. Results from central Pb+Pb [7, 8], p+p at 158 GeV/c [6], C+C and Si+Si collisions [4] at 158*A* GeV are also shown.

Owing to the mass difference and well known radial flow effect, $\langle m_{\rm T}\rangle - m_0$ values are larger for kaons than for pions. For central collisions [7, 8] mean transverse masses do not change significantly from 40*A* GeV to 158*A* GeV. For pions, if any, only a weak centrality dependence is observed at 40*A* GeV and none at 158*A* GeV beam energy, while kaons show an increase of mean transverse masses towards central Pb+Pb collisions. This increase is particularly pronounced when comparing to the much smaller C+C and Si+Si collision systems with $\langle N_{\rm w}\rangle < 60$.

Transverse momentum spectra were measured in bins of rapidity in order to extract the rapidity dependence of p$_T$ -integrated yields. The measured p$_T$ -spectra were extrapolated into unmeasured regions by a single exponential. A double exponential had to be used for pions in Pb+Pb collisions because of the concave shape of their p$_T$ -spectra. The rapidity distributions

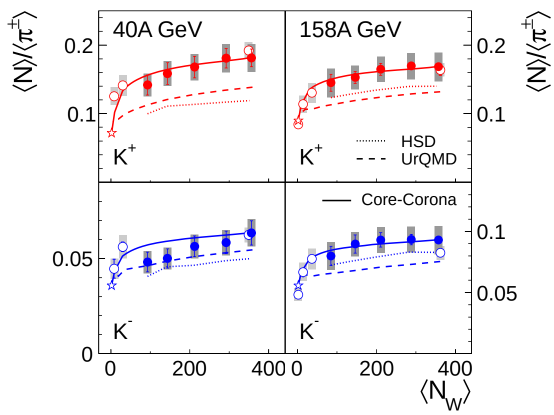

Figure 3. (Color online) Kaon yields divided by mean number of pions $\langle\pi^{\pm}\rangle = 0.5 \cdot (\langle\pi^{-}\rangle + \langle\pi^{+}\rangle)$ as a function of centrality. Closed symbols show results from centrality selected Pb+Pb collisions, open symbols p+p data from NA49 [5, 6] as well as C+C, Si+Si (at 158*A* GeV [4]) and central Pb+Pb collisions from [7, 8]). The stars denote the values obtained from the parametrization "B" in reference [12]. Lines show results from HSD [9, 10] and UrQMD2.3 [11] simulations and the core-corona model (the latter for the Pb+Pb collision system only,[13]). The thin vertical bars indicate the statistical errors, which are mostly not visible. The thick shaded bars indicate the systematic errors.

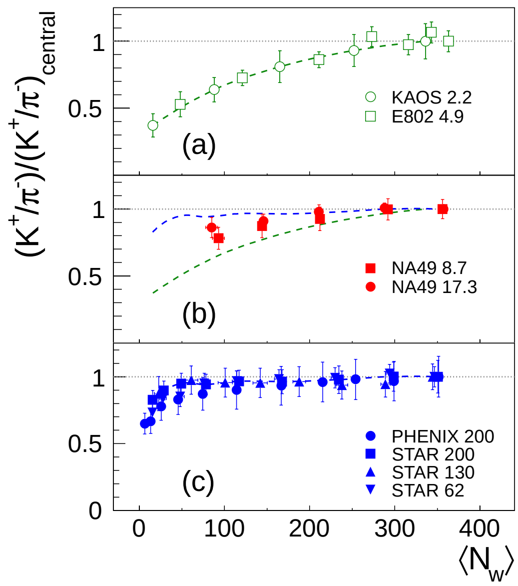

Figure 4. (Color online) Centrality dependence of the double ratio of the K^+ to π^- multiplicities scaled to the ratios from the corresponding most central measurement minimum bias Pb+Pb (Au+Au) collisions at SIS [14] and AGS [15, 16] energies (a), at SPS energies (b) and at RHIC energies [17, 18] (c). The dashed lines in panels (a) and (c) are meant to guide the eye and are also drawn as a reference in panel (b). Only statistical errors are shown.

of p_T -integrated yields for the particles, collision systems and energies under study are well described by two Gaussians of equal widths σ which are displaced symmetrically around mid-rapidity by a constant y_0:

$$\frac{\mathrm{d}N}{\mathrm{d}y} = C\left[\exp\left(-\frac{(y-y_0)^2}{2\sigma_y^2}\right) + \exp\left(-\frac{(y+y_0)^2}{2\sigma^2}\right)\right]. \tag{1}$$

Using this functional form the measured rapidity spectra can be extrapolated into the unmeasured regions, and particle yields in full phase space can be extracted.

The widths of the rapidity distributions are quantified by $RMS_y = \sqrt{\sigma_y^2 + y_0^2}$. Figure 2 presents the system-size dependence of the widths of the rapidity distributions. While kaons show no significant change of the width as a function of the number of wounded nucleons, rapidity distributions of pions are significantly wider in peripheral than in central Pb+Pb collisions. In fact, it turns out that the width of the pion rapidity distribution in central Pb+Pb collisions is the same as in C+C and Si+Si reactions as well as in p+p interactions at 158 GeV/c. Only non-central Pb+Pb collisions deviate from this common behavior exhibiting a wider distribution. The widening of the pion rapidity distribution for peripheral collisions is probably due to pion production in interactions of participants with spectator matter which had been already invoked to explain the proton rapidity spectra in the same data sets [3].

One observable used to quantify the strangeness enhancement in A+A collisions with respect to p+p collisions is the K/π ratio. We present the $K^+/\pi^\pm$ and $K^-/\pi^\pm$ ratios at both energies in Fig. 3. ($\langle\pi^\pm\rangle = 0.5\cdot(\langle\pi^-\rangle + \langle\pi^+\rangle)$.) The normalized yields of all kaons show a steep increase for small system sizes followed by a slow rise or even saturation for higher centralities. A closer look reveals that at 158A GeV the K/π ratios in the small collision systems C+C and Si+Si seem to follow the trend set by the centrality dependence of the Pb+Pb data which is well described by the core-corona approach, whereas at 40A GeV the normalized kaon abundance in peripheral Pb+Pb collisions is lower than expected from the extrapolation of the K/π ratio in C+C and Si+Si collisions (most pronounced for the negatively charged kaons). The Pb+Pb data in Fig. 3 are compared to transport models (HSD and UrQMD) as well as the core-corona approach.

In Fig. 4 we summarize the K^+/π^- ratios for centrality selected Au+Au (Pb+Pb) collisions at different beam energies. The ratios at the different centralities were scaled to the ratios measured in the most central collisions. The observed saturation of strangeness production at SPS energy and above can be understood in the context of statistical models by the approach to a grand-canonical description. Increasing the energy available for particle production no longer changes the multiplicities of strangeness carrying particles relative to pions [7, 8], which means that strangeness becomes fully saturated. The situation is different at low (SIS) energies. Here the K^+/π^- ratio does not saturate and its dependence on the number of wounded nucleons is rather linear. The results obtained at 40A GeV are intermediate between those at top SPS and AGS energies. We thus observe a smooth transition between both scenarios which occurs in the SPS energy region.

Acknowledgments
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