System size dependence of strangeness production at 158 AGeV

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Strange particle production in A+A interactions at 158 *A*GeV is studied by the CERN experiment NA49 as a function of system size and collision geometry. Yields of charged kaons, ϕ and Λ are measured and compared to those of pions in central C+C, Si+Si and centrality-selected Pb+Pb reactions. An overall increase of relative strangeness production with the size of the system is observed which does not scale with the number of participants. Arguing that rescattering of secondaries plays a minor role in small systems the observed strangeness enhancement can be related to the space-time density of the primary nucleon-nucleon collisions.

1. Motivation

An increase of the ratio of strange to non-strange particles is observed in all A+A collisions compared to N+N reactions; it is found to depend on energy [1], size of the interacting nuclei and collision geometry [2]. This strangeness enhancement was proposed as a signal for a deconfined state of matter. But despite rich experimental data and many theoretical efforts the origin of strangeness enhancement is still not fully understood.

In this contribution we concentrate on the dependence of strangeness enhancement on the system size and, in particular, on the collision geometry. Macroscopic, thermodynamic models relate the increase of strangeness production with system size to the transition from the canonical to the grand-canonical ensemble [3]. The resulting disappearance of what is called canonical strangeness suppression already in rather small reaction volumes is based on a mechanism that is still open to discussion. In a microscopic picture successively excited nucleons create collision, string and energy densities varying under different experimental conditions. This provides the opportunity to search for the microscopic parameters responsible for enhanced strangeness production.

2. Experiment and results

NA49 is a large-acceptance hadron spectrometer [4]. Charged pions and kaons are identified by means of energy loss and momentum information. Short-lived particles as the ϕ or the Λ are measured through their hadronic decay channels, i.e. $\phi \rightarrow K^+K^-$ and $\Lambda \rightarrow p\pi^-$. For the Λ the V_0-decay topology is used in addition. All data are corrected for acceptance, kaon decay in flight and the vertex resolution.

The data on p+p and centrality-selected Pb+Pb interactions were presented elsewhere [1,2,5–8]. The light systems C+C and Si+Si were investigated using a secondary beam of Pb-fragments (for further details see [4]). Central collisions were chosen by setting an upper threshold on the forward energy as measured in the zero-degree calorimeter. The percentage of the inelastic cross section selected this way was used to calculate the mean number of participants N_{part} as well as the mean number of collisions ν within the VENUS model (version 4.12) [9]. In C+C (Si+Si) the 17.5% ± 1.5% (12.5% ± 1.5%) most central events correspond to 16 ± 1 (41.5 ± 1.5) participants which undergo 1.7 (2.2) collisions on average.

Transverse mass distributions in central C+C and Si+Si interactions show an exponential shape. The mass dependence of the inverse slopes (fig. 1) indicates the presence of collective transverse flow which itself increases with system size. Rapidity spectra of

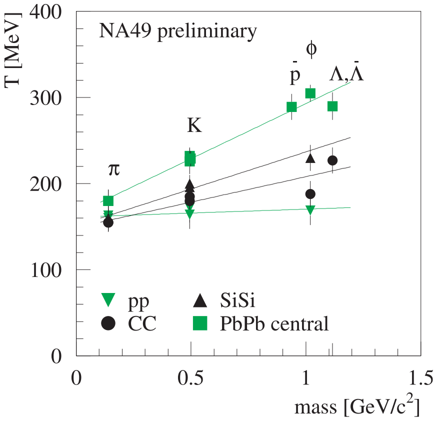

Figure 1. Inverse transverse slope parameters as a function of particle mass and system size.

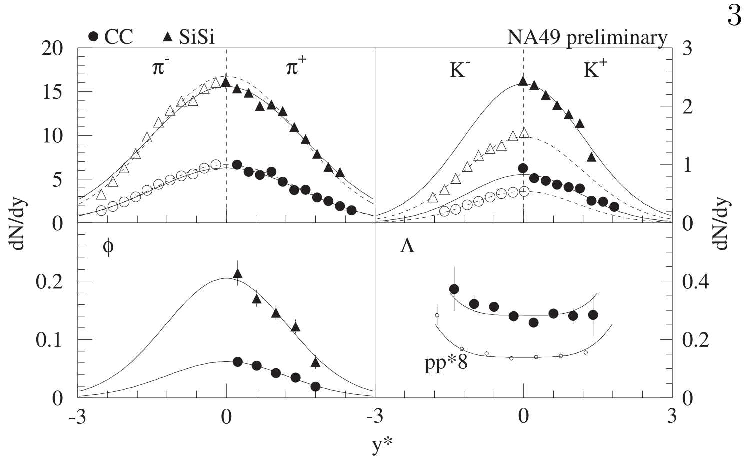

Figure 2. Rapidity distributions for C+C and Si+Si; for clearness, negative particles are plotted as open symbols at reflected y-positions. The y-distribution of Λ in p+p [7] scaled by $8 = N_{part}(\mathrm{CC})/N_{part}(\mathrm{pp})$ is also shown, lines are to guide the eye.

mesons (fig. 2) are fitted by a Gaussian to extract full yields. In the figures only statistical errors are shown; additional systematic errors for the yields amount to about 5% (10%) for pions (kaons, ϕ). The rapidity distribution of the Λ is rather flat over the whole measured range. A comparison to scaled p+p data shows an increase on the order of two at midrapidity which reflects both, larger stopping and strangeness enhancement.

3. Discussion and Interpretation

Relative strangeness production in nuclear collisions is approximately measured by the $\langle K\rangle/\langle\pi\rangle$ ratio, since roughly 70% of the produced strangeness appears in the kaons. The ϕ-meson is of interest because of its hidden strangeness. Ratios of these particles are shown in figure 3(a) as function of the number of participants. Strangeness enhancement relative to p+p interactions which increases with system size is already observed in small systems. However, the ratios are higher in central collisions of small systems than in peripheral Pb+Pb at the same number of participants indicating an important effect of the collision geometry on strangeness production. Previously [10] this was parametrized with the macroscopic geometrical variable $R - b/2$ representing the surface per volume ratio of the system. Here, this geometry effect will be discussed in terms of a microscopic reaction picture: The strategy is to search for a common scaling parameter which should give insight into the underlying reaction mechanism.

In e$^+$+e$^-$ and p+p collisions an approximate energy-independence of the $\langle K\rangle/\langle\pi\rangle$ ratio is observed in the range of interest here [1,12]. This suggests that, aside from at most a few percent, higher excitation of nucleons by sequential N+N interactions in A+A collisions alone does not cause the strangeness enhancement.

Another new feature in A+A reactions compared to p+p is rescattering of secondaries. An indication that this can be neglected in light systems comes from the small collective transverse flow observed in C+C and Si+Si in comparison to central Pb+Pb collisions (fig. 1). In addition UrQMD[1] [13] shows that the increase of the $\langle K\rangle/\langle\pi\rangle$ ratio from

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[1] The author thanks the UrQMD collaboration for providing the preliminary version 1.3.

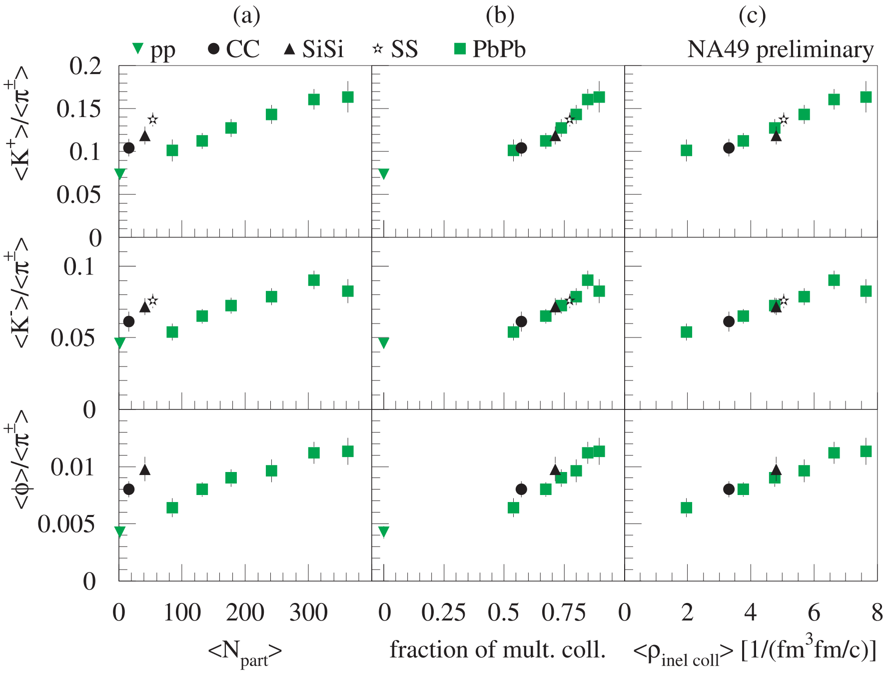

Figure 3. Strange hadron production relative to pions ($\langle\pi^\pm\rangle = (\langle\pi^+\rangle + \langle\pi^-\rangle)/2$) in dependence on parameters as defined in the text. Ratios for S+S collisions are from [11], those for centrality selected Pb+Pb reactions from [1,2,5,6].

rescattering is minor in small systems, and, more importantly, that more rescattering takes place in peripheral Pb+Pb than in central C+C and Si+Si reactions. This is plausible because of the smaller particle multiplicity in the latter systems. Thus, if rescattering would be the source of strangeness enhancement peripheral Pb+Pb should give larger ratios.

Assuming that energy loss and rescattering are not the main sources of strangeness enhancement other features of the primary inelastic N+N collisions must play an important role. A first obvious attempt is to investigate the role of multiple interactions. As shown in [2], the mean number of collisions per projectile ν as calculated within the Glauber approach does not provide scaling; this holds also for C+C and Si+Si collisions. However, the distribution of ν for C+C or Si+Si and Pb+Pb reactions at the same $\langle K\rangle/\langle\pi\rangle$ ratio shows that the fraction of nucleons which undergo multiple collisions is similar. In fact scaling is observed in this latter variable (fig. 3(b)).

The sequential N+N reactions happen in close vicinity to each other, thus causing a high density of interactions in space and time. Indeed, the mean space-time density of all inelastic collisions during the first phase $\langle\rho_{\text{inel coll}}\rangle$, i.e. when the nucleons pass through each other, as calculated in the center of mass system of the collision within the UrQMD model (version 1.3) serves also as scaling parameter (fig. 3(c)).

4. Conclusions

The presented data show that the number of participating nucleons in A+A collisions is not the decisive variable for strangeness enhancement (fig. 3(a)). However, taking advantage of this observation it is found that features connected to the primary inelastic N+N collisions provide a common description of the $\langle K^+\rangle/\langle\pi^\pm\rangle$, $\langle K^-\rangle/\langle\pi^\pm\rangle$ and the $\langle\phi\rangle/\langle\pi^\pm\rangle$ ratio in various A+A collision systems. This implies that sequential N+N interactions within a small volume and period of time are not independent of each other with regard to strangeness production.

The collision density as defined here is on the one hand related to the energy density in the system. On the other hand a high density of interactions may also mean overlap of strings thus leading to string fusion and enhanced string tension. Both, string overlap and energy density have often been discussed as being relevant for enhanced strangeness production. In addition a volume in which a high energy density or overlapping strings and thus a high space-time density of successive collisions exist might decay in a quantum-mechanically coherent fashion, and thus represent the hadronizing volume implied by the canonical and grand-canonical versions of the statistical hadronization model.

Acknowledgements: This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the US Department of Energy (DE-ACO3-76SFOOO98 and DE-FG02-91ER40609), the US National Science Foundation, the Bundesministerium für Bildung und Forschung, Germany, the Alexander von Humboldt Foundation, the UK Engineering and Physical Sciences Research Council, the Polish State Committee for Scientific Research (2 P03B 130 23 and 2 P03B 02418), the Hungarian Scientific Research Foundation (T14920 and T32293), Hungarian National Science Foundation, OTKA, (F034707), the EC Marie Curie Foundation, the Polish-German Foundation, and Bergen Computational Physics Laboratory in the framework of the European Community - Access to Research Infrastructure action of the Improving Human Potential Programme.

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