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Energy dependence of hadronic observables in central Pb+Pb reactions at the CERN SPS

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Abstract.

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1. Introduction

In the recent years the NA49 experiment has collected data on Pb+Pb collisions at beam energies between 20 to 158 AGeV with the objective to cover the critical region of energy densities where the expected phase transition to a deconfined phase might occur in the early stage of the reactions. In this contribution the energy dependence of various hadronic observables is presented. These include m_t- and rapidity-distributions, particle ratios and particle ratio fluctuations, as well as HBT radii. NA49 is a fixed target experiment at the CERN SPS and consists of a large acceptance magnetic spectrometer equipped with four TPCs as tracking devices and a forward calorimeter for centrality selection. Details on the experimental setup can be found in [1].

2. Particle spectra

Characterizing the energy dependence of the shape of m_t-spectra generally requires a comparison to a model. A simple exponential fit to the data can be misleading, since most particle spectra exhibit a clear curvature. Pion m_t spectra are concave, mainly due to resonance contributions, while proton spectra measured in heavy ion reactions are convex, caused by the effect of radial flow. To a certain extent, kaons are an exception that can relatively well be approximated by an exponential. An analysis of the slope parameter for kaons, extracted by an exponential fit, revealed a clear change of its energy dependence around beam energies of 20-30 AGeV [2]. Figure 1 summarizes the energy dependence of $\langle m_t \rangle - m_0$. This quantity has the advantage of providing a model independent characterization of the transverse mass

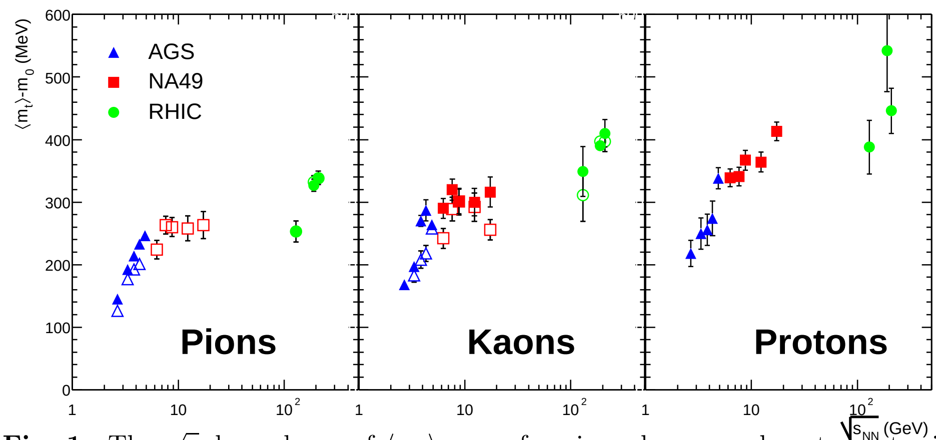

Fig. 1. The $\sqrt{s}$-dependence of $\langle m_t \rangle - m_0$ for pions, kaons, and protons at mid-rapidity for 5-10% most central Au+Au/Pb+Pb reactions.

distributions and can therefore easily be employed for pions and protons as well. As can be seen, the change in the evolution of the m_t-spectra with energy is clearly also present for pions, similar to the kaons, and in a less pronounced fashion for the protons as well.

The large acceptance of the NA49 spectrometer allows to measure particle spectra over a wide range of the longitudinal phase space. Figure 2 shows a compilation of the rapidity distributions of π^-, K^+, K^-, ϕ, and Λ [2]. Generally, a clear increase of the widths with beam energy can be observed, where the width of the π^- distribution is approximately equal to the K^+ and both are wider than the K^- distribution. The shape of the distribution for pions and kaons is well described by a Gaussian. The Λ-distributions, however, exhibit a strong variation of the shape: While at 30 AGeV they are still Gaussian-shaped, a clear plateau develops with increasing beam energy.

3. Particle multiplicities

The rapidity distributions, discussed above, allow to determine the total yields of the different particle species with only small extrapolations. Fig.3 shows the ratio of the resulting 4π-yields of K and π [2, 3]. While this ratio for negatively charged particles rises more or less continuously (left hand side of Fig. 3) – except a small indication for a kink at 30 AGeV – a very distinct maximum is observed in the positively charged case (right hand side of Fig. 3). The lines included in the figures are predictions of an extended hadron gas model [4] and the transport codes RQMD [5] and UrQMD [6]. Even though the hadron gas model and RQMD predict a maximum of the $\langle K^+ \rangle / \langle \pi^+ \rangle$-ratio in the SPS energy range, none of the models can fully describe the sharp feature of its energy dependence. A feature, which is also

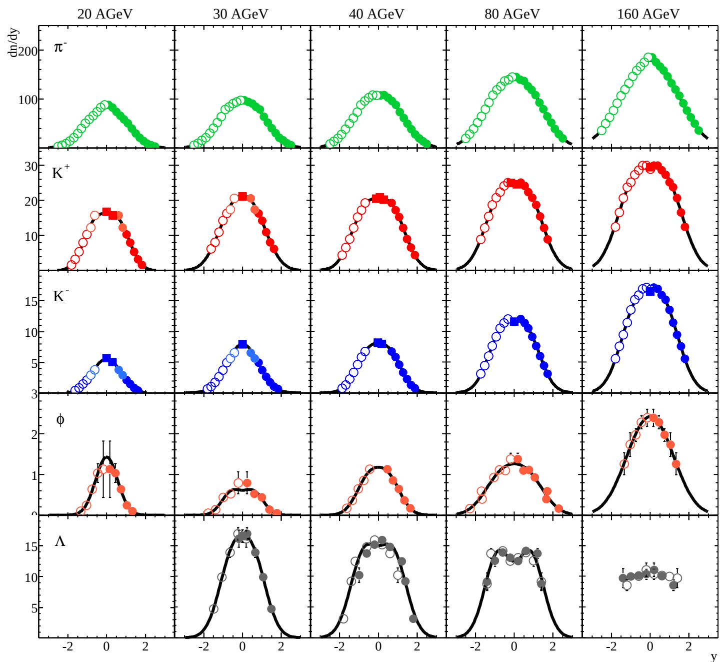

Fig. 2. The rapidity spectra of hadrons produced in central (7% at 20-80 AGeV, 5% (π^-, K^+, K^-) and 10% (ϕ, Λ) at 158 AGeV. The closed symbols indicate measured points, open points are reflected with respect to mid-rapidity. The solid lines indicate parametrizations of the data used for the extrapolation of the yield to full phase space.

not present in p+p collisions. It is also noteworthy that the hadron gas model does not fit the $\langle K^-\rangle/\langle\pi^-\rangle$-ratio at energies above 40 AGeV either. On the other hand, a strong non-monotonic energy dependence of the total strangeness to pion ratio was predicted by the Statistical Model of The Early Stage [7], assuming a phase transition from confined matter to a quark-gluon plasma in the SPS energy range.

4. Particle ratio fluctuations

NA49 has performed an event-by-event measurement of the particle ratios [8]. The dynamical fluctuations σ_{dyn} of this ratios have been extracted by subtracting the r.m.s. width σ_{mix} of the mixed event distributions from the r.m.s. width σ_{data} of the real event distributions:

$$\sigma_{dyn} = sign(\sigma^2_{data} - \sigma^2_{mixed})\sqrt{|\sigma^2_{data} - \sigma^2_{mixed}|} \quad (1)$$

The mixed event particle ratios contain by construction the effects of finite number fluctuations as well as effects of the detector resolution. As shown in the left panel

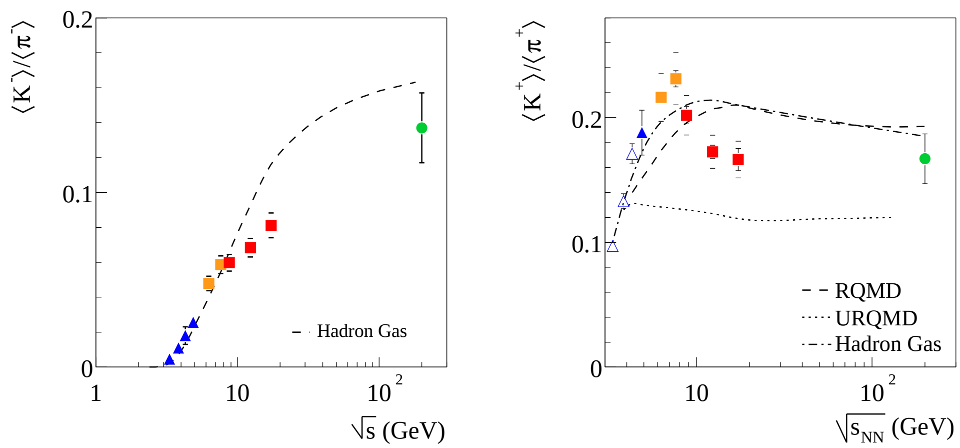

Fig. 3. The energy dependence of the $\langle K\rangle/\langle\pi\rangle$ ratios together with various model predictions (see text).

of Fig. 4, the K/π fluctuations are positive and decrease with beam energy. The p/π fluctuations, on the other hand, are negative – indicating a correlation present in the real data – and increase with beam energies. While the trend of the K/π fluctuations is not reproduced by UrQMD [9], it provides a good description of the energy dependence of the p/π fluctuations. This might indicate that the negative value of the fluctuations in this ratio is due to resonance decays.

5. Bose-Einstein correlations

Figure 5 summarizes the HBT-radii extracted in the LCMS, as measured by the NA49 experiment [10]. As expected in the presence of longitudinal and transverse expansion, a significant reduction of the radii with increasing k_t is observed at all beam energies. Assuming a boost-invariant scenario, the k_t-dependence of R_{long} should reflect the life time of the source [11]:

$$R_{long} = \tau_f \left(\frac{T_f}{m_t}\right)^{1/2} \; ; \; m_t = (m_\pi^2 + k_t^2)^{1/2} \tag{2}$$

The fits of this function, assuming a freeze-out temperature $T_f = 120$ MeV, are shown in the upper part of Fig. 5. Only a weak increase of the extracted life time with beam energy is observed. Another important feature of this data is the fact that $R_{out} > R_{side}$ at all beam energies (lower part of Fig. 5). The difference of these two parameter is connected to the emission duration [12]:

$$\Delta\tau^2 = \frac{1}{\beta_t^2}(R_{out}^2 - R_{side}^2) \; ; \; \beta_t \approx \frac{k_t}{m_t} \tag{3}$$

The data would indicate an emission duration of 3-4 fm/c.

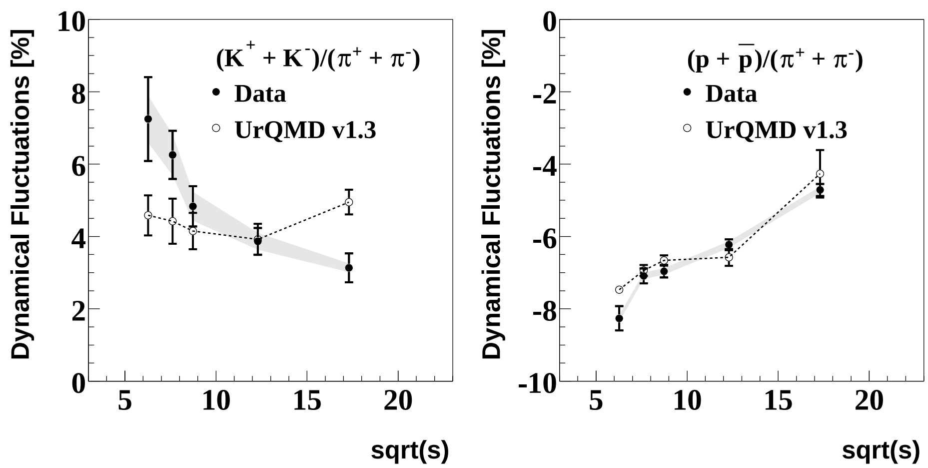

Fig. 4. Energy dependence of the event-by-event fluctuation signal of the $(K^+ + K^-)/(\pi^+ + \pi^-)$ ratio (left hand side) and the $(p + \bar{p})/(\pi^+ + \pi^-)$ ratio (right hand side). The systematic errors of the measurements are shown as gray bands.

6. Conclusions

The recent study of the excitation functions of hadronic observables in the SPS energy range has revealed a number of interesting and unexpected results. This includes a step-like energy dependence of the $\langle m_t \rangle - m_0$ of pions and kaons and a sharp maximum in the strangeness to pion ratio. The dynamical K/π ratio fluctuations are positive and decrease with beam energy in the range between 20 - 158 AGeV, while the p/π ratio fluctuations are negative and increase. The HBT-radii, however, do not exhibit a significant energy dependence in this energy range.

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Notes

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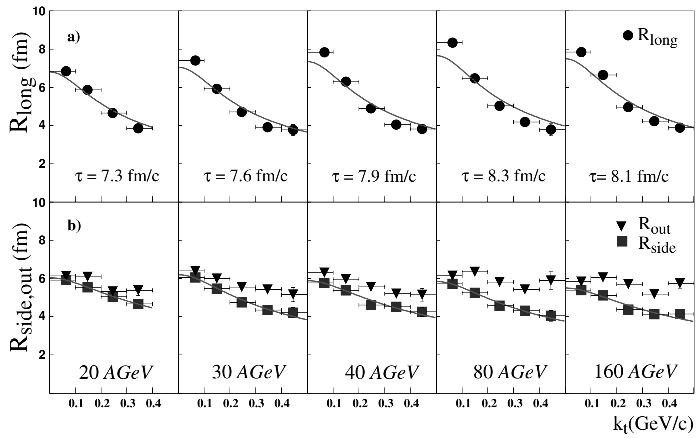

Fig. 5. The HBT-radii as a function of k_t at mid-rapidity for central Pb+Pb collisions at 20 to 158 AGeV

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