Strangeness production in heavy ion collisions at SPS energies

André Mischke[a], for the NA49 Collaboration

Gesellschaft für Schwerionenforschung, Darmstadt, Germany, e-mail: `a.mischke@phys.uu.nl`

Abstract. The NA49 collaboration has taken data of central Pb-Pb collisions at beam energies from 20 to 158 GeV per nucleon. The large acceptance of the detector allows to study particle yields in full phase space. In this paper we present recent results on strangeness production (K, Λ and ϕ) in this energy range and compare to measurements at lower and higher energies. The K^+/π^+ and Λ/π ratio shows a pronounced maximum around 30 A·GeV, whereas the K^-/π^- and $\overline{\Lambda}/\pi$ ratio exhibits a continuous rise. The ϕ/π ratio also increases monotonically with beam energy. First results on multi-strange hyperon production at lower SPS energies are presented.

1 Introduction

Ultra-relativistic heavy ion collisions provide the environment to study nuclear matter at high pressure and temperature. At energy densities of about 1 GeV/fm^3 a phase transition of nuclear matter to a deconfined state of strongly interacting matter is predicted by lattice QCD calculations [1]. The measurement of strange baryons like Λ(uds) hyperons, which contain between 30% and 60% of the total strangeness produced (depending on the energy), allows to study simultaneously strangeness production and the effect of baryon density in A-A collisions. Essentially half of the $\bar{s}$ quarks are contained in K$^+$. The ϕ meson consists of an s$\bar{s}$ pair (hidden strangeness), and should therefore be more sensitive than kaons and lambdas to the production mechanism in the early stage of the collision.

2 The NA49 experiment

Since 1994 the NA49 collaboration has investigated hadron production in central Pb-Pb collisions at 158 A·GeV. Within the framework of the NA49 energy scan programme [2], started five years later, charged kaons, ϕ mesons as well as single and multi-strange hyperons were measured at lower energies (20, 30, 40, 80 A·GeV) over a large range of rapidity and transverse momentum. Detailed informations of the data sets can be found in [3].

The NA49 detector is a large acceptance fixed target hadron spectrometer at the CERN-SPS [4]. Tracking and particle identification by the measurement of the specific energy loss (dE/dx) is performed by two Time Projection Chambers (Vertex-TPC) located inside two vertex

magnets (1.5 and 1.1 T, respectively) and two large volume TPCs situated downstream of the magnets symmetrically to the beam line. The relative dE/dx resolution is 3-4 %. The dipole magnets (9 Tm bending power) allow the momentum determination with a resolution of $\sigma(p)/p^2 = 0.3 \cdot 10^{-4}(\text{GeV/c})^{-1}$. Two Time-of-Flight walls give additional particle identification near mid-rapidity ($\sigma_t = 60$ ps). The trigger on centrality is based on the measurement of the energy deposited by the spectator nucleons in the forward calorimeter.

3 Results

In the following, the results on kaon, Λ hyperon and ϕ meson production in central Pb-Pb collisions at beam energies 30-158 A·GeV are presented. Starting from the reconstruction method we will focus on the energy dependence of the particle multiplicities. For the results on transverse mass spectra and the extracted inverse slope parameter we refer to [3,5].

3.1 Kaon production

Kaons are identified in NA49 by dE/dx and ToF measurements depending on their momentum. The raw data yields are corrected for geometrical acceptance, in flight decay and efficiency of the detector system. To compare the obtained multiplicities on kaon production at different energies and in elementary p-p collisions, respectively, the yields are normalized to the pion multiplicities. The π^- multiplicities were extracted from the distribution of all negatively charged hadrons by subtraction of the K$^-$, $\overline{\text{p}}$ and e$^-$ contribution and secondary hadrons from weak decays and interactions in the detector. This method is

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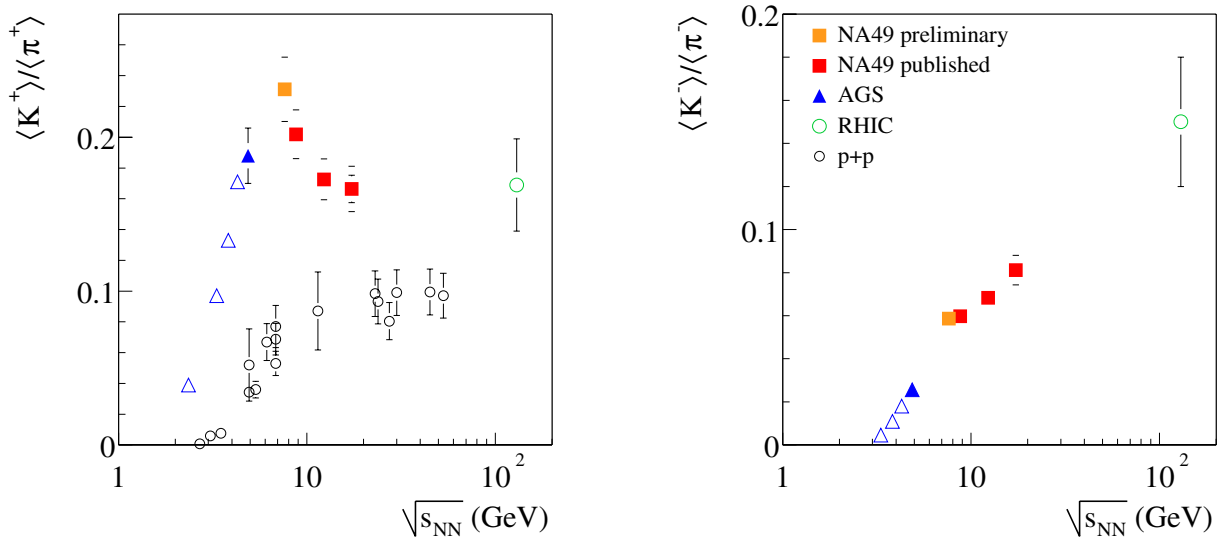[a] present address: NIKHEF/University of Utrecht, The Netherlands

Fig. 1. The kaon-to-pion ratio as a function of cms energy in central Pb-Pb (Au-Au) and p-p (*open symbols*) collisions. The AGS and RHIC measurements are taken from [6]
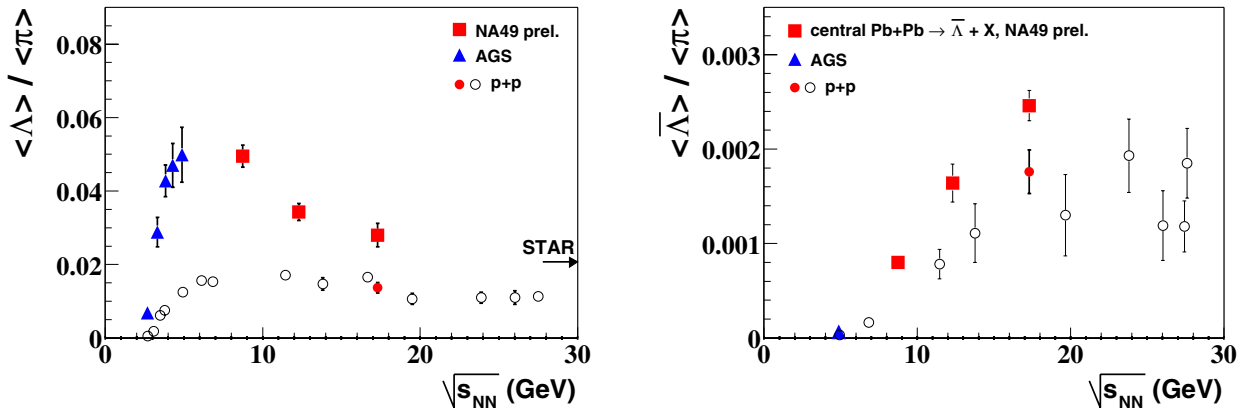

Fig. 2. Energy dependence of Λ-to-pion ratio in central Pb-Pb (Au-Au) and p-p (*open symbols*) collisions. The AGS and RHIC measurements are taken from [5]. The STAR measurement at mid-rapidity is indicated by the arrow

not applicable to the π^+ due to larger contributions from other positive particles. Therefore, the π^+ are calculated from the π^- yield assuming that the π^+/π^- ratio, which is measured in kinematical regions where both ToF and dE/dx informations are available, is constant in phase space (cf. [3]). The energy dependence of the K^+/π^+ and K^-/π^- ratio is plotted in Fig. 1. A sharp maximum is observed at a beam energy of 30 A·GeV in the K^+/π^+ ratio, whereas the K^-/π^- exhibits a continuous rise with, perhaps, a kink at the same energy.

3.2 Lambda production

In NA49, neutral strange and multi-strange particles are identified by their decay topology $\Lambda \to p\pi^-$, $\Xi \to \Lambda\pi$, $\Omega \to \Lambda K$. The charged decay products are measured with

the TPCs. Λ hyperons from this analysis contain short-lived Σ^0, which decay electro-magnetically into $\Lambda\gamma$. The invariant mass distributions of Λ and $\bar{\Lambda}$ hyperons are given in [7]. The mass resolution (σ_{m}) of 2 MeV/c^2 is remarkably good. After corrections for acceptance and reconstruction efficiency the m_{T} spectra and rapidity distributions were obtained from the raw data yields (cf. [5]). The total yields per event of the Λ and $\bar{\Lambda}$ are obtained by integration of the distributions over rapidity and p_{T} with only small extrapolations into unmeasured regions. The Λ/π and $\bar{\Lambda}/\pi$ ratio as a function of collision energy $\sqrt{s_{\mathrm{NN}}}$ is shown in Fig. 2, where $\pi = 1.5(\pi^+ + \pi^-)$. The Λ/π ratio steeply increases at AGS energies, reaches a maximum and drops at SPS energies. Since K^+ carry the major fraction of the produced $\bar{s}$ quarks one expect the K^+/π^+ ratio to show a similar behavior as the Λ/π ratio (using strangeness conservation) which is indeed the case (cf. Fig. 1).
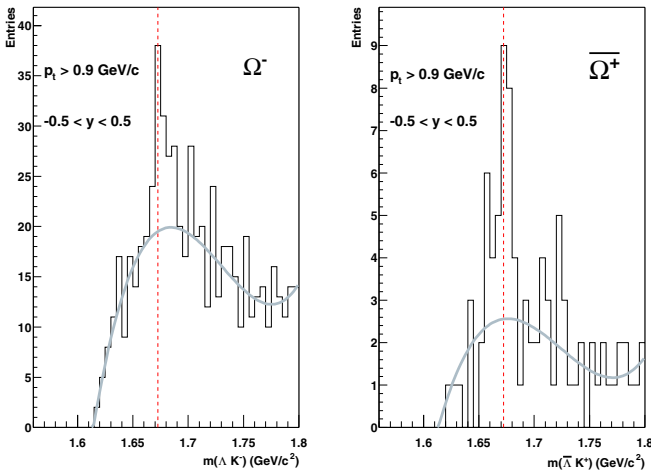
Fig. 3. The invariant mass distribution of Λ-K$^-$ (*left*) and $\overline{\Lambda}$-K$^+$ pairs (*right*) in central Pb-Pb collisions at 40 A·GeV

The enhancement of strangeness production in heavy ion collisions compared to p-p is not a unique signature for the deconfined state, since this enhancement is at low AGS energies, where a phase transition is not expected, seven times higher than at top SPS energies [8]. Instead, rescattering processes like associated production πN $\rightarrow$ ΛK play an important role at lower energies.

In comparison to the energy dependence of Λ production, the $\overline{\Lambda}/\pi$ ratio shows a monotonic increase similar to the K$^-/\pi^-$ ratio. The measurements at 20 and 30 A·GeV will clarify whether there is also a structure like for the K$^-/\pi^-$. The differences in the excitation function of Λ and $\overline{\Lambda}$ can be attributed to their different production mechanisms and the effect of net-baryon density.

First measurements of multi-strange hyperons at 40 A·GeV beam energy have been shown (cf. Fig. 3) [10,11]. The available data sets from 20 to 158 A·GeV allow to extract the Ξ and Ω excitation function in the near future.

3.3 ϕ meson production

The ϕ meson is measured in NA49 via the invariant mass of its decay products K$^+$K$^-$ [9]. The combinatorial background from random pairs is well described by means of the event-mixing method. The invariant mass distributions and the obtained rapidity spectra for 40, 80 and 158 A·GeV are given in [3,9]. The extracted total ϕ yields normalized to the average number of pions $\pi^\pm = 0.5(\pi^+ + \pi^-)$ are illustrated in Fig. 4. This ratio shows the same monotonic rise from AGS to RHIC energies as the K$^-/\pi^-$ ratio.

4 Summary

The excitation function of the K$^+/\pi^+$ and Λ/π ratio in central Pb-Pb (Au-Au) collisions shows a maximum around 30 A·GeV whereas the K$^-/\pi^-$ and the $\overline{\Lambda}/\pi$ ratio exhibit a monotonic increase.
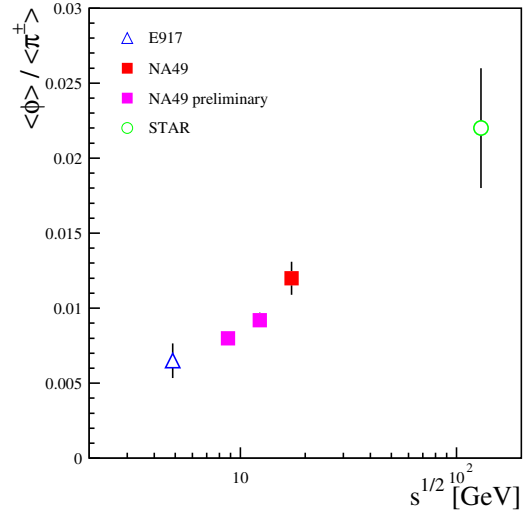

Fig. 4. ϕ multiplicity ratios as a function of cms energy. The AGS and RHIC measurements are taken from [3]

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