BETWEEN AGS AND RHIC: STRANGENESS AT CERN*

Helena Białkowska

A. Sołtan Institute for Nuclear Studies
Hoża 69, 00-681 Warszawa, Poland

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Main results coming from the extensive study of strangeness signals from heavy ion collisions at the CERN SPS energy range are discussed. A systematics of production rates is given, as a function of strangeness content of the products, and of the incident energy, centrality and the mass of the colliding nuclei. Different interpretations of the results are briefly discussed.

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1. Introduction

Strangeness has long been considered a telltale flavour, its measurement allowing for a deeper insight into the dynamics of the strong interactions. This is particularly relevant in the quest for the hypothetical new state of matter — the Quark Gluon Plasma, QGP. The original idea of Rafelski [1] was, that as the energy threshold for strangeness production in hadronic interaction is much higher than that for a deconfined medium of quarks and gluons, strangeness enhancement should be a signal for creation of such state. Fig. 1 illustrates the main $s\bar{s}$ production channels.

Nowadays, with the strangeness enhancement observed in many nuclear collisions at many energies, one has to look for a more refined analysis of such phenomena. I will concentrate on global characteristics, such as particle yields, relative to non-strange particle yields, studied as a function of energy, particle type, and centrality of the collision.

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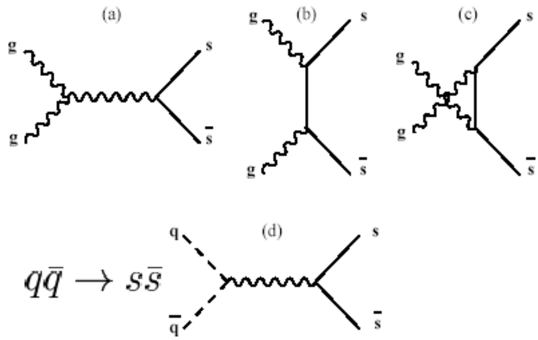

Fig. 1. Main diagrams contributing to strangeness production.

2. CERN experiments

Most of the CERN data on strangeness come from two experiments, NA49 [2] and NA57 [3]. There were also some measurements concerning strangeness from NA50, a dimuon spectrometer, measuring hidden strangeness system, Φ [4], and from CERES [5] (measurement of lambda hyperons). The NA52 experiment gave upper limits for strangelet production.

It is important to bear in mind that most of the experiments do not cover full phase space of the collision, and measured quantities refer only to a limited section of the full phase space.

The NA49 experiment is a wide acceptance hadronic spectrometer, shown in Fig. 2. It measures and identifies charged particles in large part of the forward centre of mass hemisphere. Strange particles are identified by a precise energy loss sampling in the time projection chambers, complemented by the time of flight system. Neutral strange particles are identified via their decay into the charged products, again with the help of charged particle identification systems. Fig. 3 illustrates the identification procedure. The centrality selection is based on zero degree calorimeter. For hadron–nucleus interactions the centrality is determined via slow target proton measurements.

The NA57 experiment is dedicated to high statistics measurements of hyperons. A silicon telescope placed in a magnetic field allows for high rate acceptance of particles around midrapidity and for medium transverse momenta. Hyperons are identified via weak decay channels with charged states in the final state. The centrality selection is based on multiplicity trigger.

Since both experiments measure and discuss the centrality dependence of strangeness production, a word of explanation is in order. While the basic concept of 'centrality of collision' is clear, this being the impact parameter of two colliding, finite size objects (nuclei), the experimental determination of this quantity is by no means unique. As described above, various quantities

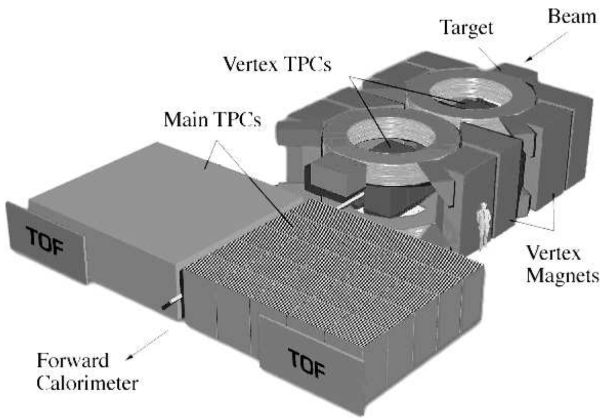

Fig. 2. The NA49 experimental setup.

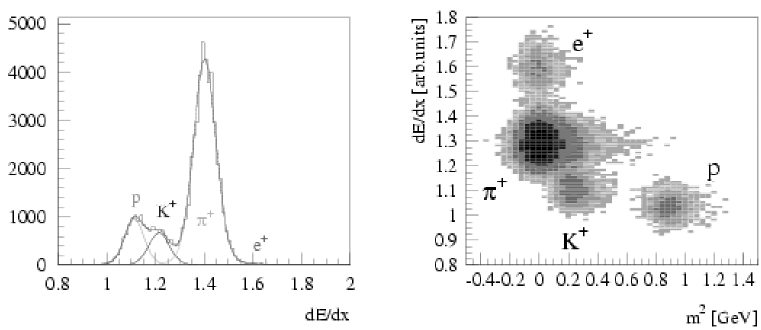

Fig. 3. Particle identification via ionisation energy loss and time of flight measurement in the NA49 experiment.

help in determining the collision centrality. The common practice is to translate the centrality trigger selected fractions of inelastic cross section — via Glauber type calculations — into a specific range of 'wounded nucleons' or 'participants'.

3. Kaon production

The kaons carry most of the strangeness produced in hadronic collisions, with the estimates ranging from 70 to 80%. Thus a study of kaon production rate gives an estimate of the total strangeness production.

Fig. 4 shows the energy dependence of K^+/π^+ and K^-/π^- ratios for central nucleus–nucleus collisions, together with data for p–p collisions [6]. Fig. 5 includes the highest energy RHIC point and some model predictions. Clearly the kaon/pion ratio is strongly enhanced in nuclear — compared to elementary collisions. Moreover, while K^-/π^- ratio shows a smooth behaviour as a function of energy, the K^+/π^+ ratio displays a maximum in the region of 20–30 GeV incident momentum, and then decreases to a constant value.

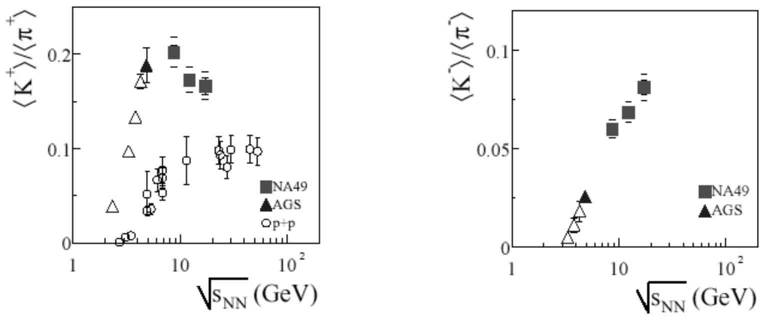

Fig. 4. The K^+/π^+ and K^-/π^- ratios for central Pb–Pb collisions, together with p–p data points.

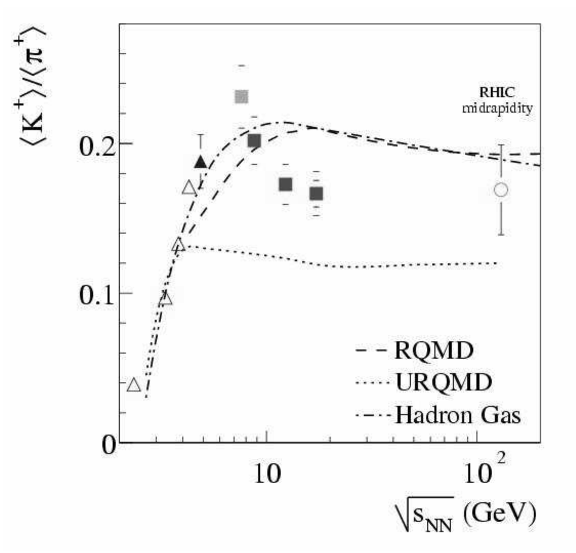

Fig. 5. Same data as in Fig. 4, together with a RHIC point, and the new 20 GeV/c point. The curves correspond to various model descriptions.

How can one interpret such a behaviour? Firstly, there is a series of papers, attempting to describe the energy evolution of strangeness production in heavy ion collisions in terms of thermodynamical models. There ([7]) the maximum in kaon production is related to the evolution of baryochemical potential (it increases sharply from threshold, reaches a maximum and decreases toward very low (although non-zero!) value at RHIC. This description is illustrated in Fig. 6, where the energy dependence of the so called Wroblewski factor, $\lambda = (s\bar{s})/2(u\bar{u} + d\bar{d})$ is shown. The general shape of energy dependence is realistically described, but no sharp maximum, as seen in the data, can be reproduced.

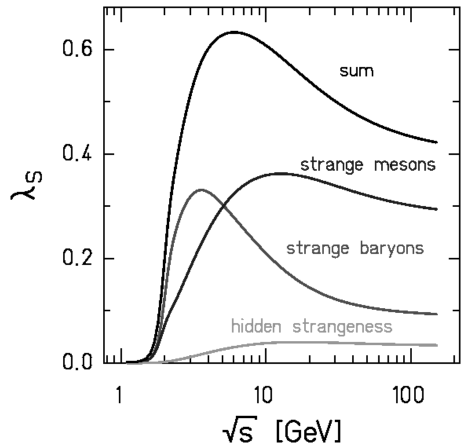

Fig. 6. The Wroblewski strangeness suppression factor λ as a function of energy, calculated in the model of Redlich *et al.* [7].

A rather exotic approach is advocated in [8], where the authors assume a statistical model of the early stage of A–A collisions, and speculate that the rapid change in strangeness yield is related to the onset of deconfinement. In this model the quantity $E_s = (\langle \Lambda \rangle + \langle K + \bar{K} \rangle)/\langle \pi \rangle$ shows a characteristic sharp maximum as a function of a statistical variable F (approximately proportional to the $\sqrt{\sqrt{s}}$. The maximum is caused by a higher strangeness-to-entropy ratio in the confined than in the deconfined matter (thus, actually, a relative 'strangeness depletion' instead of an enhancement!). This can be observed in Fig. 7.

One should bear in mind that more trivial factors also play a role in the K^+/π^+ and K^-/π^- ratios, studied as a function of energy. In particular, neutron and proton fragmentation into pions and kaons should be studied, for comparison with lead–lead collisions, where 60% neutrons and 40% protons build the nucleus. The NA49 experiment has measured p–p and n–p interactions at 40 and 158 GeV/c [9]. As expected, the π^+ and π^- yields interchange when switching from proton to neutron projectile. The situation differs for charged kaons: the yields of K^+ and K^- stay put under the interchange. Bearing this in mind, and studying the energy dependence of the charged pions and kaons, one observes that isospin effects and threshold dependence can create a maximum in '60% n 40% p' nucleus K/π ratio in the region of $\sqrt{s}$ around 20 GeV/c, as illustrated in Fig. 8 [10].

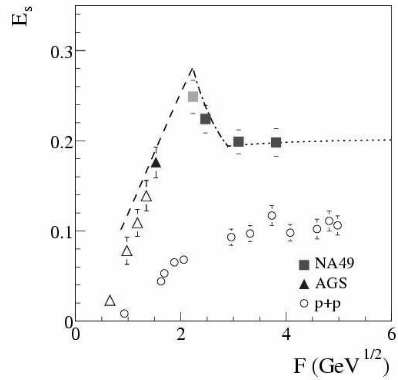

Fig. 7. The dependence of $E_s = (\langle \Lambda \rangle + \langle K + \bar{K} \rangle) / \langle \pi \rangle$ on F variable (see text) — model and data comparison.

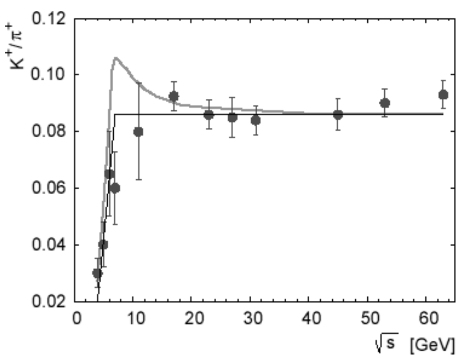

Fig. 8. Midrapidity K^+/π^+ ratio evolution with energy. Data from p–p (points) are interpolated by a straight line, and the resulting ratio for Pb–Pb collisions is shown by the thick line.

The Φ meson (almost pure $s\bar{s}$ state) production as a function of energy for central nuclear collisions has also been studied, and, as seen in Fig. 9, shows a smooth evolution [11].

A subject by itself is the centrality — or system size dependence for kaon production. This is illustrated in Fig. 10, where K/π ratios are shown as a function of the number of participant nucleons for various light and heavy colliding nuclei [12]. Clearly, the number of participants does not determine uniquely the kaon production rate. This, perhaps, could be expected — as the same number of participants does not correspond to the same density configuration in light and heavy system. Thus a better parametrisation can be obtained by using the average density (in space and time) of inelastic collisions. This was calculated with the help of the UrQMD Model, and, as can be seen in Fig. 11, brings the data from various colliding systems to a common line.

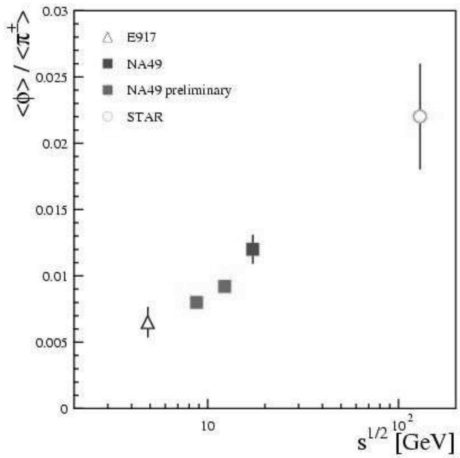

Fig. 9. The average Φ meson multiplicity, normalised to pions, as a function of energy.

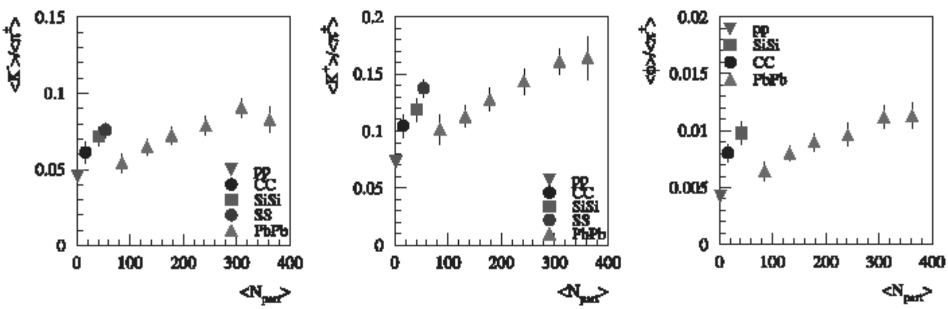

Fig. 10. The meson/pion ratio for kaons (both charges) and Φ as a function of the number of participants for different colliding systems.

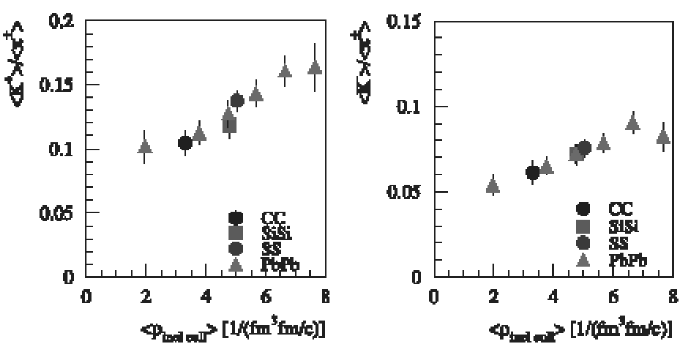

Fig. 11. Same ratios as in Fig. 10, as a function of mean collision density.

4. Hyperon production

The Λ and $\bar{\Lambda}$ production has also been studied in central nuclear collisions, and the energy evolution of the average multiplicities, normalised to the pion multiplicities, is depicted in Fig. 12 [17]. The Λ production in central nuclear collisions increases from the threshold to a broad maximum at the lower end of the CERN SPS energy range, and decreases at $\sqrt{s}$ of 17 GeV toward a value not much different from that at RHIC. The $\bar{\Lambda}$ production increases smoothly up to the RHIC energies, where baryon density becomes very low, and most of the hyperons are produced in pairs with antihyperons.

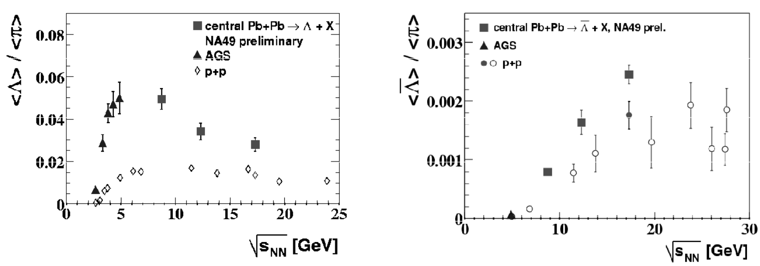

Fig. 12. Λ and $\bar{\Lambda}$ multiplicities, normalised to pions, as a function of energy for central nuclear collisions.

It has been predicted [1] that a creation of the deconfined state should lead to strong enhancement of hyperon production, and this effect should be more pronounced for doubly and triply strange objects. Indeed, the WA97 and NA57 experiment has observed such an effect [3]. Fig. 13 shows the enhancement of hyperon and antihyperon yields, measured at midrapidity, in Pb–Pb collisions at 158 GeV$/c$, for different centralities, as parametrised by the number of wounded nucleons, or participants. A clear hierarchy of the enhancement is observed, with more strange objects being more enhanced. Contrary to previous indications, this enhancement seems to be a continuously increasing function of centrality, with perhaps a hint of a saturation at two highest centrality intervals.

A question arises: is the hyperon enhancement a unique feature of nuclear collisions? The standard definition of an enhancement, as used by the authors of [3] is the ratio of the hyperon yield at midrapidity, measured for nuclear collision, divided by the number of wounded nucleons from projectile and target, and normalised to the same quantity from p–Be collisions.

In the wounded nucleon model [13] the midrapidity particle yield is proportional to the same yield in proton–proton collisions and the number of wounded nucleons:

$$\frac{dN_{AA}}{dy} = EN_{\mathrm{w}}\frac{dN_{pp}}{dy} \,.$$

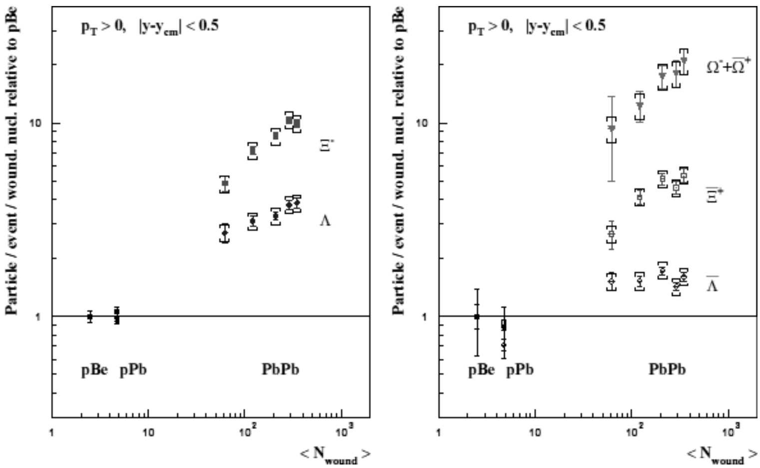

Fig. 13. The NA57 data on hyperon multiplicities per participating nucleon, normalised to hyperon multiplicity in p–Pb collisions, as a function of the number of participant nucleons.

In the asymmetric hadron–nucleus collision, we have to account for the target component (a pile-up of ν elementary collisions) and the projectile component with presumably, room for an enhancement effect. Thus

$$\frac{dN_{pA}}{dy} = \nu \frac{1}{2} \frac{dN_{pp}}{dy} + E \frac{1}{2} \frac{dN_{pp}}{dy} \,,$$

with E — the (eventual) enhancement factor.

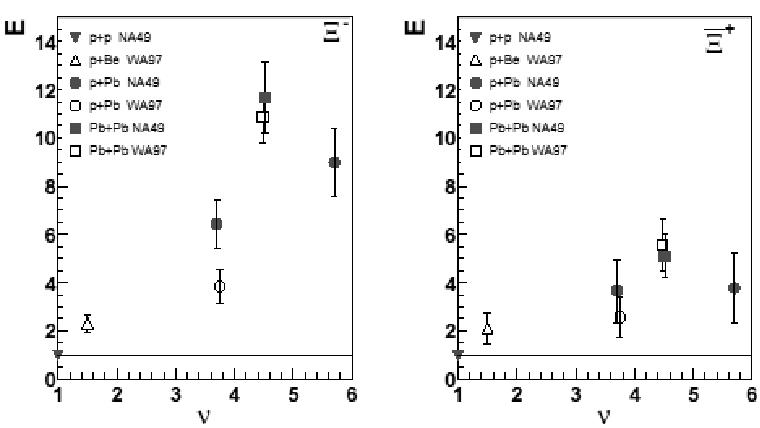

Fig. 14. Enhancement of hyperon production in nucleus–nucleus and proton–nucleus collisions, as a function of the number of collisions ν.

With this definition of an enhancement, as shown in Fig. 14, [14] both hadron–nucleus and nucleus–nucleus collisions lead to an enhancement of cascade baryon production.

5. Baryon–antibaryon production

There is an intrinsic important interrelation between basic characteristics of relativistic nuclear collisions such as strangeness enhancement, net baryon density and baryon stopping. We have seen from previous section that strangeness enhancement relates to the baryochemical potential — or net baryon density. Such density is usually evaluated from antibaryon/baryon ratios, measured at midrapidity. At the CERN SPS energy a systematics of such ratios is shown in Fig. 15, for elementary, hadron–nucleus and central nucleus–nucleus collisions [15]. At this energy, we observe an increase of $\bar{B}/B$ with the strangeness content, and for the same strangeness — an increase from p–p to p–Pb to Pb–Pb. A special case is that of the Ω baryon and its antiparticle. New data on $\bar{\Omega}/\Omega$ for p–p collisions (the first measurement in p–p!) and central Pb–Pb collisions give, respectively, the values of 0.67 ± 0.62 and 0.45 ± 0.05 [16].

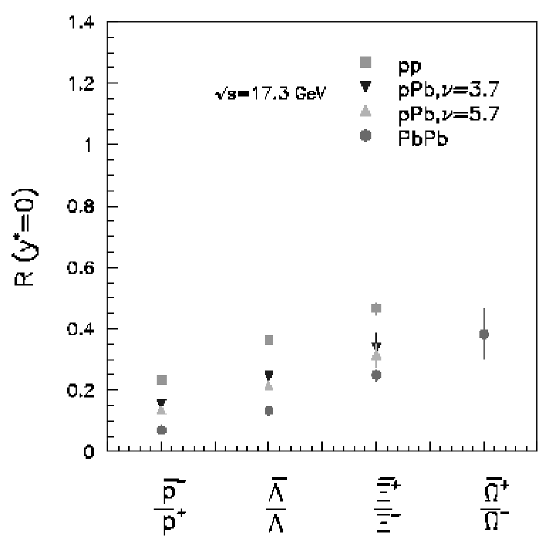

Fig. 15. $\bar{B}/B$ ratio at midrapidity for elementary, hadron–nucleus and nucleus collisions at 158 GeV/c.

Fig. 16 shows the dependence of the $\bar{B}/B$ ratios [17] on the strangeness content. From AGS to SPS to RHIC energies these ratios increase — with the RHIC values close to but still not equal 1, indicating a small but non-zero net baryon density. At RHIC most of the hyperons are produced in pairs with their counterparts — a situation much different from that at SPS, where the associated production of hyperons dominates.

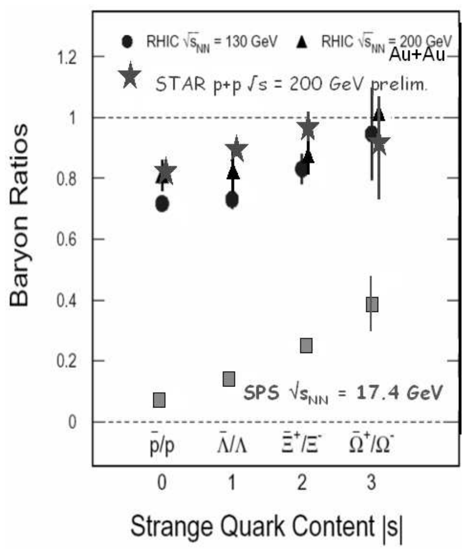

Fig. 16. $\bar{B}/B$ ratios for elementary and nuclear collisions at RHIC and SPS, as a function of the strangeness content

6. Summary

We have observed the following facts:

- Strangeness is indeed enhanced in relativistic heavy ion collisions.
- This enhancement is not unique for central collisions of heavy systems; it is observed also for lighter systems, and for hadron–nucleus collisions.
- System size/centrality dependence: increase, perhaps saturation?
- Enhancement hierarchy: more strange — more enhanced.
- Energy dependence: gradual evolution or sharp transition?

All the above observations have to be considered together with other information, in particular shapes of particle spectra, and particle correlations (not covered in this talk). Moreover, their relation to other flavour characteristics is increasingly important. As the next step, perhaps ‘charm is the strangeness of the future’.

I would like to thank all my CERN colleagues for helping me put together such a variety of data. This work was partially supported by the Polish State Committee for Scientific Research (KBN), grant 2P03B 130 23.

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