STRANGENESS IN RELATIVISTIC ION COLLISIONS*

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A review of available data on strangeness production in relativistic ion collision at AGS and SPS accelerators is given. A hierarchy of strangeness enhancement and its centrality dependence is discussed.

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1. Introduction

In this imperfect world of ours there is no symmetry between different flavors — and thus there is a distinct hierarchy in their production cross sections. It is easy to produce up and down quarks. It is harder to make them strange. And still harder for charm, beauty and truth (top). Yet each new flavor tells us more about the interaction from which it originates. This is particularly important in the domain of heavy ion physics. When we collide two large high energy objects, we may create large, hot and dense fireball. Inside, many things can happen. In-medium effects may alter particle and/or resonances mass and/or width. A phase transition, predicted by QCD, may occur — creating Quark Gluon Plasma, where quarks and gluons, not confined inside hadrons, abound. Chemical equilibration — equilibration of different flavors may lead to different ratios of hadrons with various flavors, when the hadronization will occur. Thus — looking at strangeness in relativistic ion collisions, we look for anything that is different from strangeness production in 'normal' hadron–hadron collisions.

2. How to measure strangeness production?

Obviously — by measuring and identifying hadrons containing at least one strange quark. This however poses several experimental challenges.

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Most of the information on strangeness comes from studying kaons. To the first approximation, 70% of strangeness produced in hadronic collisions is carried by kaons. Neutral kaons are detected by their charged decay mode ('V zero'). (The same for Λ hyperons). At high energy and high final state multiplicity this mode becomes increasingly hard to detect. On the other hand with the development of detector technique, charged kaon detection and identification becomes prevalent. Čerenkov and time of flight counters and increasingly - time projection chambers, with multiple sampling of ionization energy loss are used for this purpose.

Multiply strange hadrons require dedicated detector systems. The cascade hyperons, Ξ and Ω , with their two step decays into charged and neutral products, are studied best with the help of silicon telescopes.

The Φ meson, consisting almost exclusively of $s\bar{s}$ pair is a very powerful source of information on strangeness. It is studied experimentally either in a charged kaon decay mode (with the branching ratio of 49%), or in a two muon decay, with the branching ratio of 2.5×10^{-4}. This requires a very high statistics, but offers relatively clean signal that can be obtained from a muon spectrometer.

A word of caution is necessary. Different experiments have different acceptances (covering limited area of the whole available phase space), and employ different triggers, selecting various parts of the total inelastic nucleus-nucleus cross section. This is related to the problem of centrality determination in nuclear collisions.

3. Available data

Data on strangeness production in relativistic ion collisions comes from two accelerators. The AGS at Brookhaven National Laboratory accelerates ions up to 11 GeV/c, with beams of Si and Au. The SPS at CERN accelerates ions of O, S and Pb, from 60 to 158 and 200 GeV/c. In what follows we will show the results on

- K/π ratio
- Φ production
- Λ, Ξ and Ω production

4. K/π ratio

Fig. 1 [1] shows the excitation function — or energy dependence — of the K^+/π^+ ratio studied at AGS in Au–Au collisions, compared to proton–proton data. In Fig. 2 [2] the evolution of the K^+/π^+ for different beam–target combinations at 11.6–14.6 GeV is shown, with data points from p–nucleus up to central nucleus–nucleus collisions. Finally, in Fig. 3 [3] we see both K^+/π^+ and K^-/π^- ratios studied in Au–Au collisions at 11.1 GeV, this time as a function of the number of participant nucleons. The number of participants, characterizing the centrality of nuclear collision, was determined from the measurement of energy deposit in the 'zero degree', or forward calorimeter.

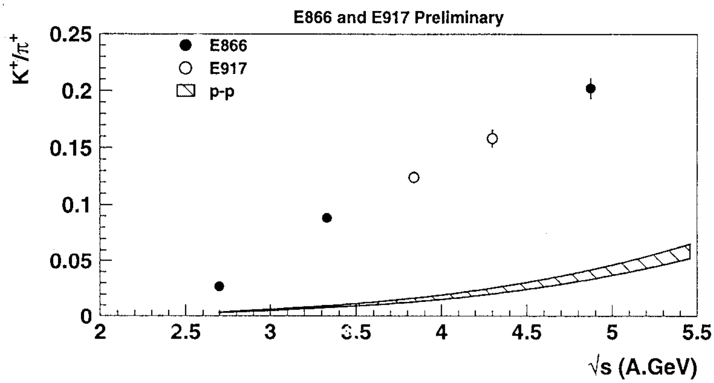

Fig. 1. The K^+/π^+ ratio studied at AGS in Au–Au collisions, compared to proton–proton data, as a function of energy.

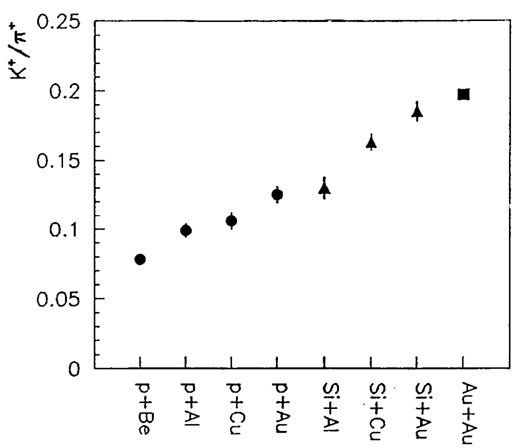

Fig. 2. K^+/π^+ for different beam–target combinations at 11.6–14.6 GeV/c. Data from nucleus–nucleus collisions are from central collisions.

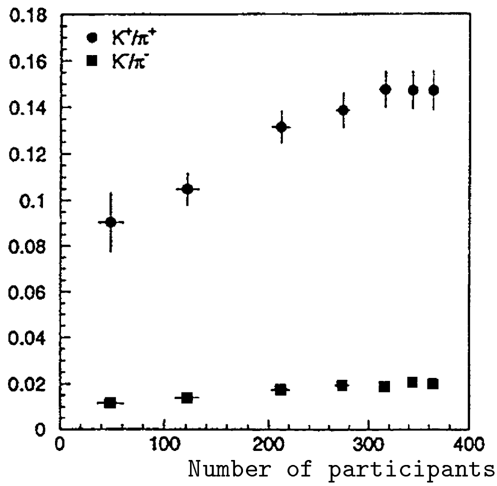

Fig. 3. K^+/π^+ and K^-/π^- ratios studied in Au–Au collisions at 11.1 GeV, as a function of the number of participant nucleons.

Altogether, at this energy range we observe that the kaon/pion ratio increases smoothly and significantly with the energy increase, with the target/projectile mass, and the number of nucleon participants. The energy increase is a significant factor here, both for p–p and nuclear collisions, as we are relatively close to the threshold. Notice, however, that the K/π increase is definitely stronger in nuclear collisions.

Coming now to the SPS energy, 158–200 GeV, we have to realize how extremely demanding particle identification becomes there. As an illustration, Fig. 4 [4] shows the use of both the ionization sampling in large Time Projection Chamber and time of flight measurement for the identification of charged kaons produced in p–p, p–Pb and Pb–Pb collisions at 158 GeV. The NA49 experiment [5] studied particle production in this very comprehensive set of data, covering almost full forward c.m. hemisphere, with the aim of determining the centrality dependence. Summary of observed centrality dependence is depicted in Fig. 5 [6]. There the kaon yields per pion yield (average of identified charged pions) is shown as a function of the number of participants for Pb–Pb collisions, and as a function of the number of collisions for p–Pb collisions. Both variables are meant to characterize the collision centrality. For Pb–Pb collisions, the number of participants was evaluated by measurement of net baryon number in the collision. For p–Pb, the measured number of slow knock-out protons was translated via Glauber model into the number of collisions. These data clearly show a systematic effect of smooth increase of the K/π ratio as a function of centrality. Notice

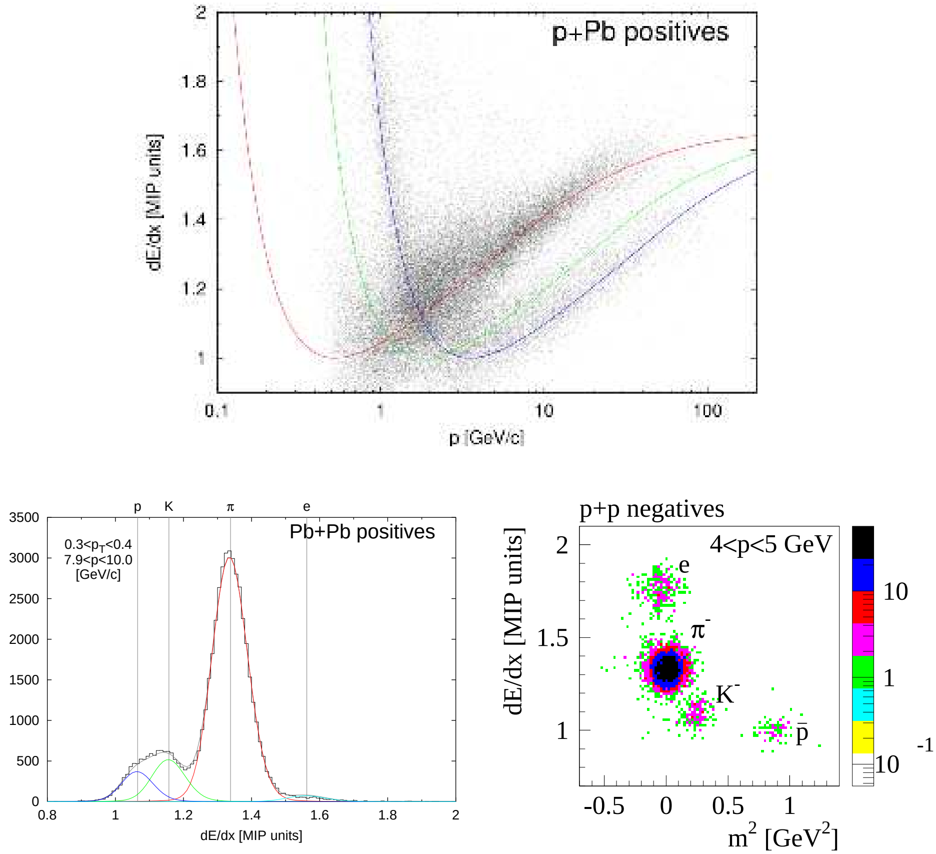

Fig. 4. Particle identification data for nuclear collisions at 158 GeV/c, using ionisation sampling in time projection chambers and time of flight measurements.

that the reference point from p–p collisions, measured in the same experiment, is also included. Notice also, that for the first time we observe an increase in the K/π ratio as a function of centrality for hadron–nucleus collisions. This effect is observed in the forward c.m. hemisphere. A more detailed insight may be obtained from Fig. 6 [4] where we look at the 'ratio of ratios', that is — the K/π ratio in nuclear collisions, normalized by the same ratio in p–p collisions, as a function of scaled longitudinal momentum, Feynman x. The effect of strangeness enhancement, present both in p–Pb and Pb–Pb, is more pronounced in the forward direction in the center of mass. As a corollary, lower panel of this figure compares the Φ meson rapidity distribution in p–p and Pb–Pb collisions, with the broadening of the Pb–Pb data.

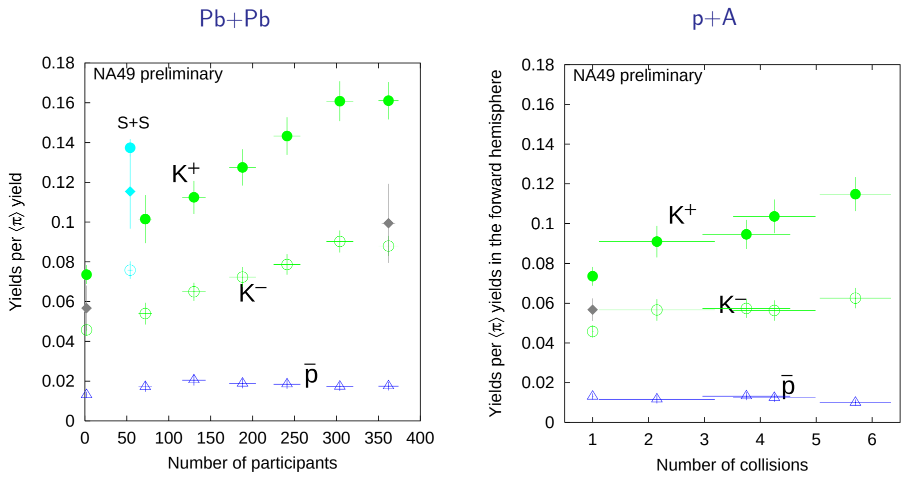

Fig. 5. Kaon yields per pion yield (average of identified charged pions) as a function of the number of participants for Pb–Pb collisions, and as a function of the number of collisions for p–Pb collisions.

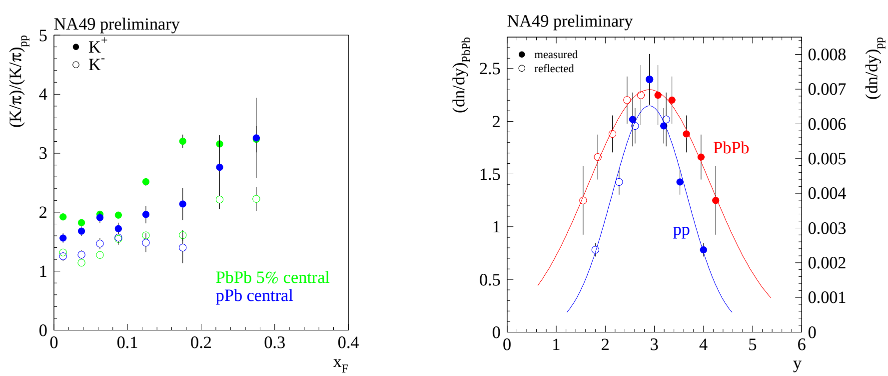

Fig. 6. K/π ratio in nuclear collisions, normalized by the same ratio in p–p collisions, as a function of scaled longitudinal momentum, Feynman x (left panel). Φ meson rapidity distribution in p–p and Pb–Pb collisions (right panel).

Thus we have observed a systematic trend of K/π increase for nuclear reactions as a function of centrality, with the effect already present in hadron–nucleus collisions.

5. The Φ meson production

What makes the Φ meson a particularly interesting study object? This almost pure $s\bar{s}$ state has a very narrow width (4MeV) and convenient two body decay channels. Its 'normal' production in hadronic collisions is suppresed by the so called OZI rule. Thus any enhancement over 'normal' production may signal partonic phenomena. Moreover, hot and dense medium presumably created in nuclear collisions may change the resonance width and/or mass. At AGS, experiment E917 [7] studies Φ decaying into K^+K^- in the Au–Au collisions at 11 GeV. The authors have observed an increase of Φ rapidity density with increasing collision centrality (parametrized by the number of nucleon participants).

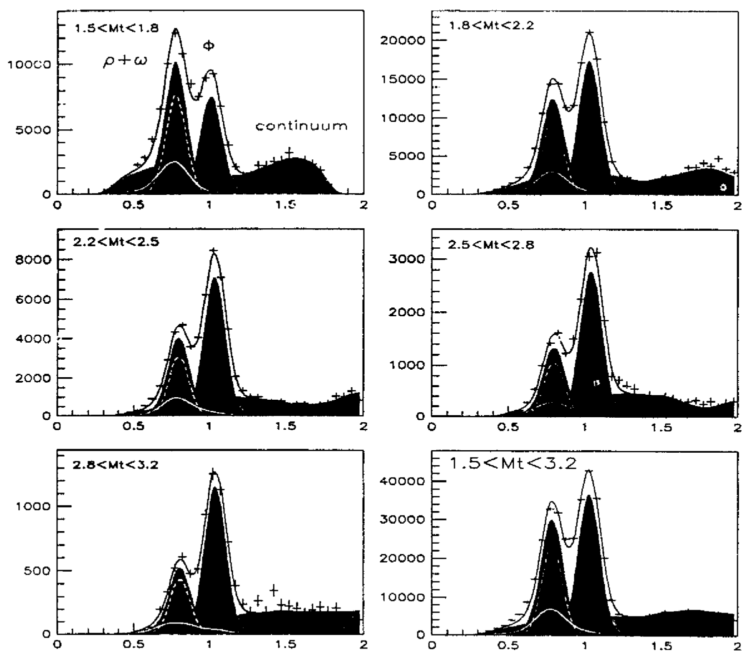

Fig. 7. Dimuon mass distributions for several transverse mass intervals, studied in Pb–Pb collisions at 158 GeV/c.

A very detailed analysis of Φ production in Pb–Pb collisions at 158 GeV was peformed by the NA50 experiment at CERN [8]. A high statistics study of dimuon mass distributions allows for a simultaneous fit of the ρ, ω and Φ signal for several centrality selections (based on the transverse and zero degree energy measurements). Fig. 7 illustrates typical dimuon mass distributions for several transverse mass intervals. As a result of such study, a separate analysis of the $\rho+\omega$ and Φ multiplicity dependence on the number of nucleon participants was performed, as illustrated in Fig. 8. There is a distinct increase of all three vector meson multiplicities with the number of participants. While ρ and ω increase proportionally to the number of participants, or, in other words, there seems to be a constant '$\rho + \omega$ per participant' multiplicity, the Φ yield increases faster than linearly. Fig. 9 summarizes these data, by showing the $\Phi/(\rho + \omega)$ ratio as a function of the number of participants, with a clear increase observed.

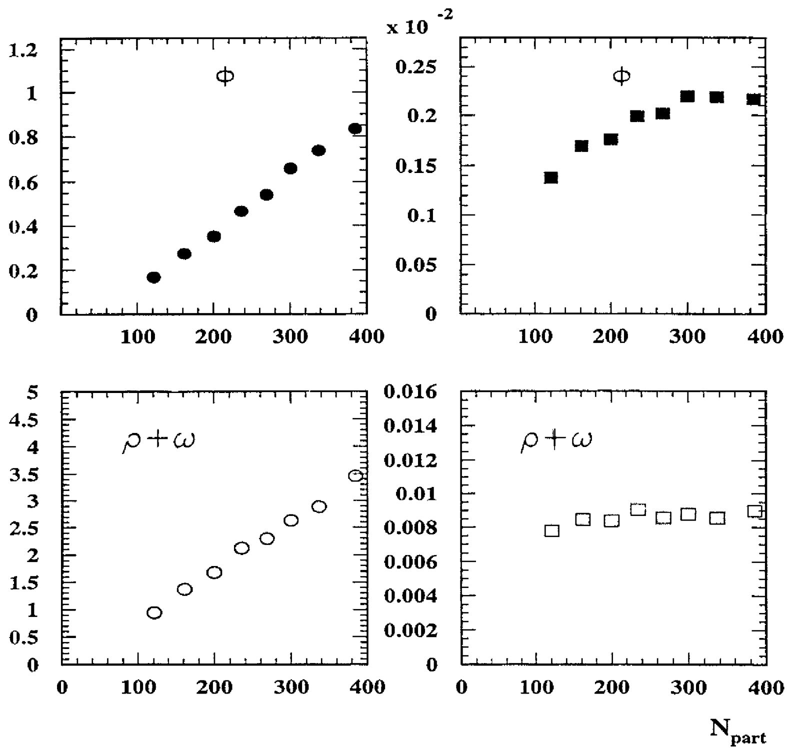

Fig. 8. $\rho + \omega$ and Φ multiplicity dependence on the number of nucleon participants in Pb–Pb collisions at 158 GeV/c.

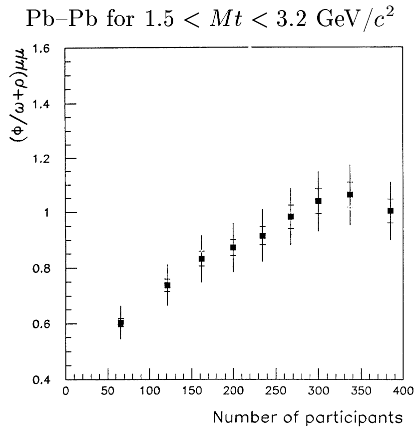

Fig. 9. $\Phi/(\rho+\omega)$ ratio as a function of the number of participants.

To summarize the information gathered by the study of kaon and Φ production, we observe:

The total yield of kaons per participant nucleon increase with centrality

The kaon per pion and $\Phi/(\rho+\omega)$ increase with centrality

The kaon per pion increase already in the proton–nucleus collisions, in the forward hemisphere.

6. Hyperon production

Data on singly and multiply strange hyperons at AGS are scarce, and a comprehensive analysis comes from the CERN SPS. The WA97 experiment studies hyperon production near midrapidity for Pb–Pb collision at various centralities [9]. Centrality, expressed in number of participants, is evaluated by a measurement of charged particle multiplicity. In addition, negative hadrons and K^0 mesons are also measured. In the same experiment, proton-lead and proton-beryllium collisions are studied.

Fig. 10 [9] shows the WA97 Pb–Pb results on particle production yields, and yields per participant, normalized by corresponding values for p–Pb collisions, as a function of the number of participants. The yields are extrapolated to cover one unit of rapidity around midrapidity.

A distinct pattern of strangeness enhancement, revealed by these data, is shown in Fig. 11 [10]. A hierarchy of strangeness enhancement is observed, with the enhancement factor larger for particles with higher strangeness

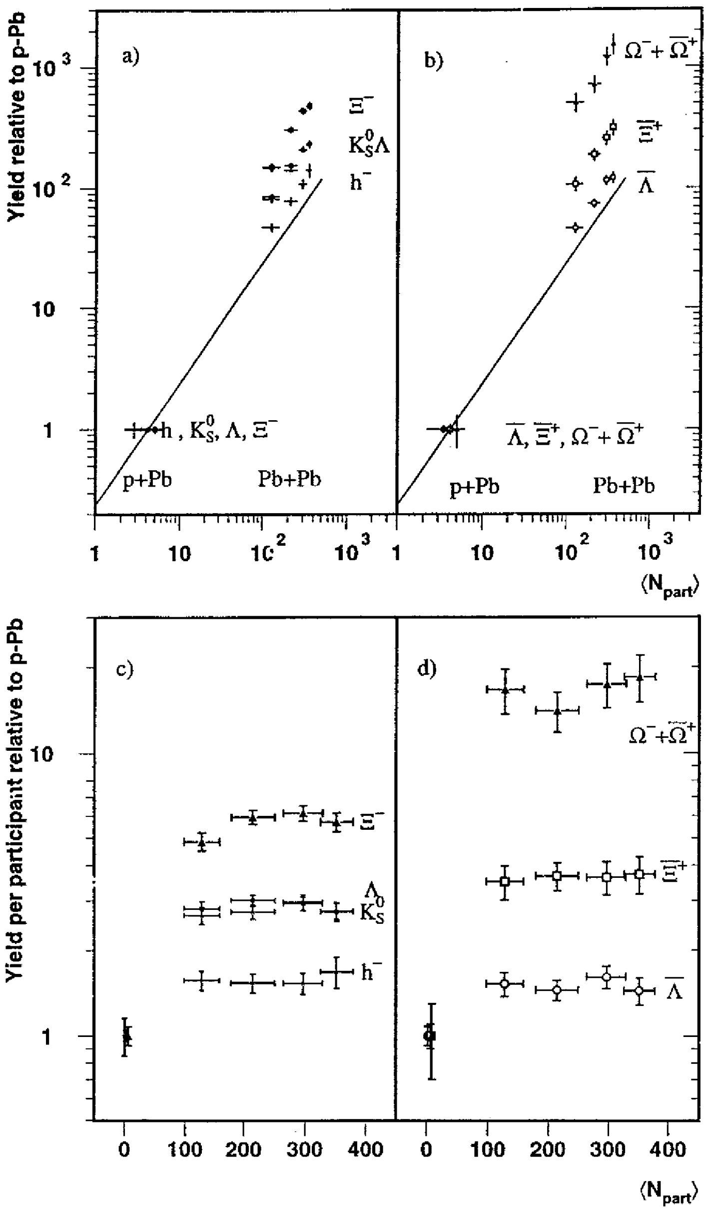

Fig. 10. WA97 Pb–Pb results on particle production yields in central rapidity unit, and yields per participant, normalized by corresponding values for p–Pb collisions, as a function of the number of participants.

content. The enhancement appears to saturate for collisions with the number of participants above 100. This observation does not stand in line with the data shown by NA49 for kaon increase — there the saturation is not observed. Two factors may contribute to this difference. First, the WA97 data comes from one unit of rapidity, whereas NA49 shows particle yields extrapolated to the 4π. Second, there is a difference in the evaluation of participant number, with WA97 relying on the proportionality of the total charged particle multiplicity to the N_{part}, while NA49 evaluates the number of participants from the measured total net baryon yields.

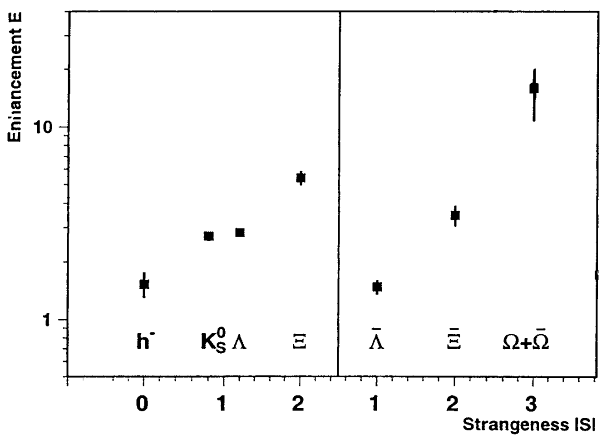

Fig. 11. Strange particle enhancement vs strangeness content (data from Fig. 10).

7. Conclusions

I have consistently stayed away from theoretical considerations, and therefore will only stress the bare experimental facts. The analysis of available data leads to the following results:

- Strangeness production is enhanced in relativistic ion collisions (compared to nucleon-nucleon and simple superpositions),
- This enhancement appears already in hadron-nucleus collisions, for the forward hemisphere,
- A marked hierarchy in strangeness enhancement is observed.

Two urgent experimental questions immediately follow:

- Is there a saturation of the strangeness enhancement with centrality?
- Is there a discontinuity in energy dependence of the observed effects?

These very fall the SPS accelerator runs with lead beam at 40 GeV, and the RHIC accelerator at Brookhaven starts its 100 GeV on 100 GeV Au–Au operation. Thus we can hope for some answers soon.

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