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Author

Odyniec, Grazyna

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<Strangeness Production in Heavy Ion Collisions: What Have We Learnt with the Energy Increase from SPS to RHIC>

<Grazyna Odyniec>

<Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA>

Abstract. A review of strange particle production in heavy ion collisions at ultrarelativistic energies is presented. The particle yields and ratios from SPS and RHIC are discussed in view of the newest developments in understanding collision dynamics, and in view of their role in the search for a quark gluon plasma. A strangeness enhancement, most notably observed in CERN Pb-beam results, shows a remarkable two fold global enhancement with a much larger effect seen in the case of multistrange baryons. Hadronic models did fail to explain this pattern. At RHIC energy strangeness assumes a different role, since temperatures are higher and the central rapidity region almost baryon-free. An intriguing question: “Did RHIC change the way we understand strangeness production in heavy ion collisions ?” is discussed.

<INTRODUCTION>

For the last two decades [1] strange hadrons have been expected to contribute characteristic signals towards the overall understanding of dense hadronic matter and its hypothetical transformation to partonic stage consisting of quarks and gluons (for a review see e.g. [2]).

It has been predicted that nuclear matter will undergo a phase transition into a Quark Gluon Plasma (QGP) at a critical temperature near the rest mass of the pion and at about 10 times the density of normal nuclear matter. These predictions have been supported by lattice gauge calculations, where the presence of a large jump in the energy density for two and three flavor systems at critical temperature, T_c , of 160 MeV has been shown [3, 4, 5] - see Fig.1.

Apparent difficulties in introducing quark mass to the lattice calculations preclude a definite statement on the order of the phase transition. This could be resolved by experiment, i.e. the experimental results may point towards the right order of phase transition (first or second), or perhaps towards a cross-over from one side of the diagram to the other without any new behavior at the cross-over point.

Accordingly, complex heavy ion experimental programs have been launched on both sides of the Atlantic with the goal to investigate the properties of strongly interacting matter at high density and temperature in general, and to confirm theoretical predictions of the formation of a quark gluon plasma phase in particular.

Since 1986, research centers in the US (AGS, top energy $\sqrt{s} = 4.9$, heaviest system Au+Au) and in Europe (CERN, top energy $\sqrt{s} = 17.3$, heaviest system Pb+Pb) have provided a very impressive wealth of experimental information.

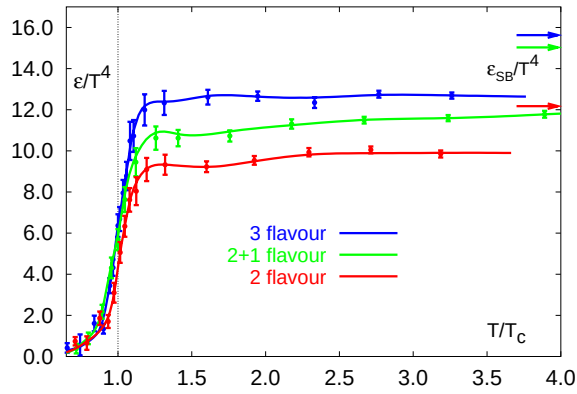


FIGURE 1. QCD lattice calculations with two and three flavor systems, see text.

The newest and the most powerful machine, the Relativistic Heavy Ion Collider (RHIC) is located in USA at the Brookhaven National Laboratory on Long Island. It is capable of accelerating a variety of heavy ion beams: from protons to gold. The top energy is 250 GeV per beam for protons and 100 GeV per nucleon per beam for gold. RHIC has already completed two first run cycles with gold beams of 130 GeV (in 2000) and 200 GeV (in 2001), as well as a first cycle of p+p running at 200 GeV (in 2001). The first results of data analysis from the heavy ion program, although often preliminary, are widely discussed.

In this paper, selected results on strangeness production at CERN SPS ($\sqrt{s} = 17, 12$ and 9 GeV) and RHIC ($\sqrt{s} = 130$ and 200 GeV) energies will be reviewed, with main emphasis on their impact for the search for a deconfined quark-gluon plasma state.

<RESULTS OF CERN SPS PHASE I PROGRAM AND CHEMICAL EQUILIBRATION>

The original idea of strangeness enhancement as a quark-gluon plasma signal was based on the estimate that the strangeness equilibration time in QGP is of the same order (≈ 10 fm/c) as the expected life time of the fireball formed during A+A collisions, while it is much longer (30-40 times) in a hot and baryon-rich hadronic system [6]. This quantitative idea was supported by another, namely that the strange (and anti-strange) quarks are thought to be produced more easily through gluon fusion and hence more abundantly in a deconfined state compared to the production via threshold suppressed inelastic hadronic collisions. Enhanced strangeness production could be seen most easily in the yield of kaons, the most abundantly produced strange particles. And indeed, measurements from the fixed target CERN SPS experiment NA35/NA49 (S+S, S+Ag and Pb+Pb collisions at 158 GeV/c) demonstrate a significant increase in the K/π ratio, approximately by a factor of 2, with respect to pp reactions at the same energy [7, 8] - see Fig.2.

Surprisingly, the strangeness/entropy ratio ($\sim K/\pi$, Fig.2) has the same value for a

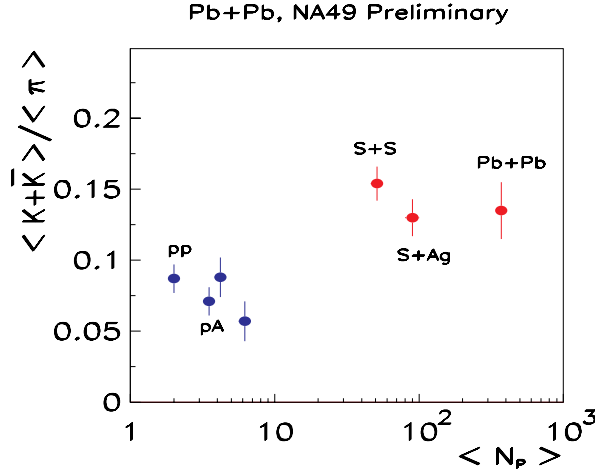


FIGURE 2. Multiplicity ratio $\langle K + \bar{K} \rangle / \langle \pi \rangle$ in full phase space for pp, pA and AA collisions plotted versus the average number of participating nucleons.

loosely bound system (S+S) as for very densely packed one (Pb+Pb). The value for S+Ag collisions is similar to S+S and Pb+Pb. This clearly eliminates the hypothesis of re-scattering and final state interactions being a possible source of the observed strangeness enhancement. While the effect is quite spectacular, it has been argued [9, 10], that a factor 2-3 enhancement can be only considered as an indirect signal for QGP formation.

A much more suitable QGP signal candidate [1] would be the enhanced yield of hyperons (particularly multi-strange anti-hyperons), as the high production thresholds in the various binary hadronic reaction channels [6] preclude the possibility of their abundant formation in a hadronic gas. Experiment WA97 (continued by NA57) was designed to make this measurement, and indeed, the enhancement was observed. Experiment NA49 reports a similar observation. The precise measurements of strange hyperons and their anti-particles reveal a systematic increase with respect to p+Pb (Λ , Ξ , Ω - WA97/NA57 data [11]), and with respect to p+p (Ξ - NA49 data [12]) collisions.

Fig.3 shows particle yields per participant for the five centrality intervals in the NA57 experiment. The two groups (particles with at least one valence quark in common with the nucleon and particles with no valence quarks in common with the nucleon) are kept separate since it is experimentally known that they may exhibit different production mechanisms. The WA97 results (4 centrality classes) are also presented. All yields are shown relative to the WA97 p+Be data. The horizontal line represents the predicted scaling from p+Be to central Pb+Pb with the number of wounded nucleons. All particle yields are enhanced in Pb+Pb collisions and enhancement grows with the strangeness content of the hyperon, up to a factor of about 15 for the $\Omega + \bar{\Omega}$. This is probably the most dramatic effect in the entire CERN SPS heavy ion program, and of course it does not have an explanation within any hadronic gas model. On the other hand, assuming a short lived plasma presence and following simple, statistical coalescence calculations, one concludes that the abundantly produced strange (anti-strange) quarks

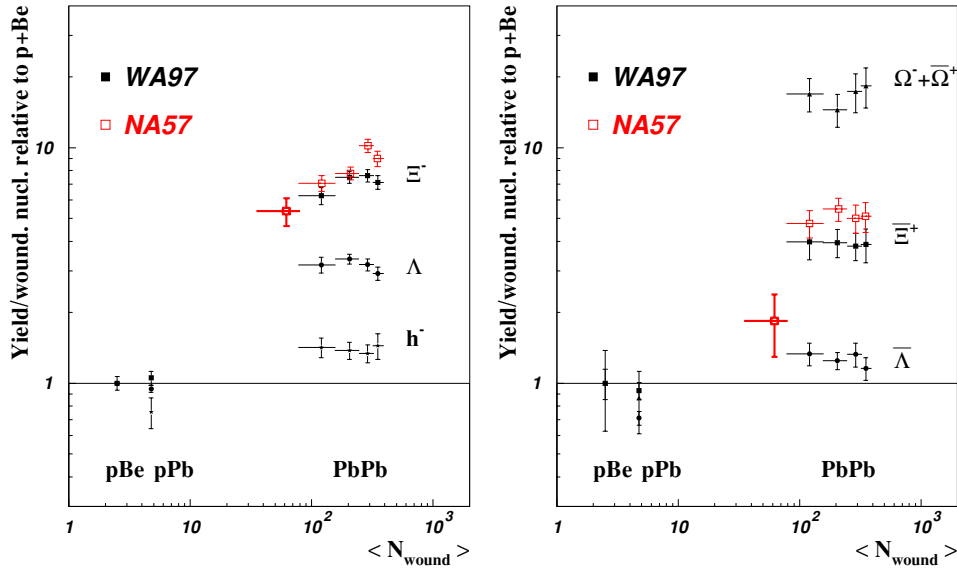


FIGURE 3. Yields per wounded nucleon relative to the p-Be yields as a function of the number of wounded nucleons, for negative particles, Λ and Ξ^- (left) and for Λ , Ξ and $\Omega+\bar{\Omega}$ (right).

could be redistributed to combine with the light quarks (anti-quarks) to form the strange baryons (anti-baryons), which may eventually come close to their equilibrium values. Such behavior of nearly chemically equilibrated populations in Pb+Pb collisions at CERN SPS has been demonstrated by comparing data to thermal model [13]. And indeed, the extracted value of the temperature parameter is very close to the critical temperature T_c obtained by thermodynamical lattice QCD calculations.

<CERN SPS PHASE II RESULTS>

In order to investigate the production of strangeness systematically and in more detail, Phase II of the CERN heavy ion experimental program was set out with lead beams of 40 and 80 GeV/c, to be complimented in the fall of 2002 by additional runs at 20 and 30 GeV/c.

The results obtained so far from top SPS energy suggest some kind of chemical equilibration in Pb+Pb collisions at 158 GeV/c, whereas the lower energy data from AGS at 11 GeV/c (not discussed here, for more information see [14] and references there) was convincingly explained with hadronic rescattering and final state interactions. One would then expect that the energy at which the anomalies in pion and strangeness production set in may be located between these energies, and a dedicated energy scan may allow to identify the point of transition from trivial effects of secondary interactions to the new phenomena observed at CERN SPS experiments.

The first results from the 40 and 80 GeV runs [15] turned out to be very interesting. Comparison of these measurements to data at other energies is shown in figure 4. The K^-/π^- ratio increases steeply in the AGS energy range [16, 17, 18, 19, 20, 21, 22] and

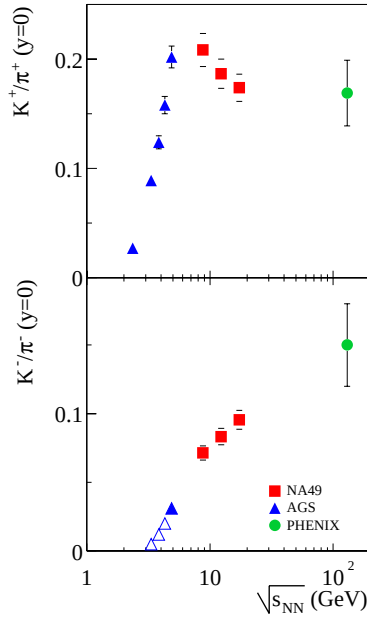


FIGURE 4. The energy dependence of the midrapidity K^+/π^+ and K^-/π^- ratios in central Pb+Pb and Au+Au collisions. The results of NA49 are indicated by squares. Open triangles indicate the A+A results for which a substantial extrapolation was done.

slowly saturates in the SPS [15] region. The K^+/π^+ exhibits a very different behavior: a steep increase at low energies is followed by a rapid turnover around 40 GeV/c into a decreasing trend. The K^+/π^+ ratio for p+p (open symbols) has a rather large error bar, but nevertheless it suggests a monotonic increase with energy.

The difference between the dependence of K^+ and K^- yields on $\sqrt{s}$ can be attributed to their different sensitivity to the baryon density. K^+ (and K^0) carry a dominant fraction of all produced $\bar{s}$ quarks, and therefore in isospin symmetric collisions their yield is nearly proportional to the total strangeness production and only weakly sensitive to the baryon density. Whereas the large fraction of s quarks is carried by hyperons, and therefore the total number of produced anti-kaons (K^- and K^0) reflects both the strangeness yield and the baryon density.

The energy dependence of K/π ratio has been discussed within a number of models with and without explicitly invoking a QGP phase. Figure 5 shows comparisons with “non plasma” models: statistical hadron gas model, RQMD and UrQMD. The hadron gas model, originally proposed by Hagedorn [23], later developed by many others [24, 25, 26, 27, 28], is probably the simplest and the most intuitive one. It assumes that the hydrodynamical freeze-out creates a hadron gas in equilibrium independently of energy. A recently proposed version [29] was extended to include the energy dependence of thermal parameters (temperature and baryon chemical potential). By construction, the prevailing trend in the data is reproduced by the model, but the decrease of the ratio between 40 and 158 GeV/c is not well described. The hadron-string models, RQMD [30, 31, 32] and UrQMD [33] treat the hadron production in A+A collisions within a

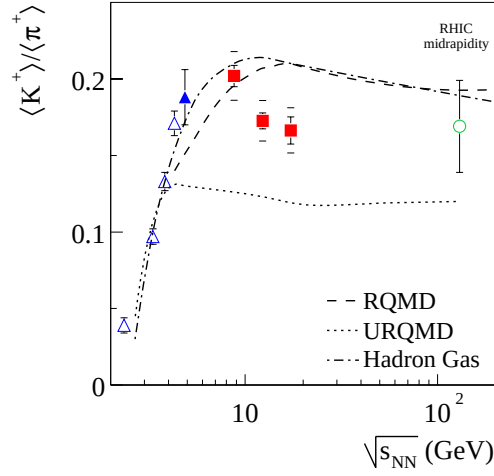


FIGURE 5. The energy dependence of the full phase space $\langle K^+ \rangle / \langle \pi^+ \rangle$ ratio in central Pb+Pb and Au+Au collisions. The experimental data are compared to model predictions, see text.

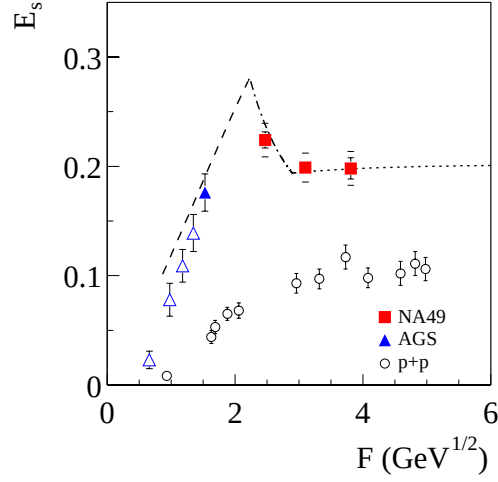


FIGURE 6. The energy dependence of E_s ratio in central Pb+Pb (Au+Au) and p+p collisions. The experimental results are compared with predictions of SMES. Open triangles indicate the A+A results for which a substantial extrapolation was necessary, see text.

string-hadronic framework as a starting point, then extend it with the effects relevant to A+A collisions, like hadronic rescattering and string-string interactions. Both of them, RQMD and UrQMD, like the hadron gas model, fail to describe the decrease of K^+/π^+ at the SPS energy range.

The observed behavior can be, however, understood with the Statistical Model of Early Stage (SMES) [7] - Figure 6 - which explicitly assumes the transient state of deconfined matter in Pb+Pb reactions at energies larger than 40 GeV. The K^+/π^+ , replaced in Fig.6 by more general E_s ($E_s = (\langle \Lambda \rangle + \langle K + K \rangle) / \langle \pi \rangle$) represents roughly the total strangeness to entropy ratio which in the SMES model is assumed to be preserved

from the early stage till freeze-out. It is plotted as a function of the Fermi variable, F which is proportional to $\sqrt{s}$. The dramatic change of the behavior at $F \approx 2$ is attributed to the change of the mass of strangeness carriers at the phase transition point from $m_s \approx 500$ MeV (the kaon mass) to $m_s \approx 170$ MeV (the strange quark mass). Interestingly, the energy dependence of mean pion multiplicity in A+A collisions also shows the change of the behavior approximately at the same value of F [15], which is consistent with the expected increase of the number of degrees of freedom due to phase transition from hadronic gas to quark gluon plasma.

However, the most striking result, an enormously increased multi-strange hyperon production, does not find an explanation with any model so far. The NA57 experiment extended its centrality reach and measured hyperon yields in much less central collisions than WA97 in the first round of CERN experiments. The so called "fifth point" (see Figure 3), corresponding to a peripheral class of the events with approximately 60 wounded nucleons, drops by a factor of 2.6 for Ξ yields. Note that the enhancement seems to be saturated above a mean number of wounded nucleons of about 100. For the Ξ^- the yield drops by a factor of 1.3 in the most peripheral collisions. The centrality dependence of the Ξ^- looks different from that of the Ξ , as the Ξ^- enhancement grows smoothly as a function of the number of wounded nucleons.

The drop in the Ξ yield per wounded nucleon, which might indicate the onset of the QGP phase transition, remains a tremendous challenge for the theorists and model builders (phenomenologists). While some attempts to fit WA97 data with the canonical statistical model were initially quite successful e.g. [34, 35], they predicted that the yield of multi-strange hyperons saturates at $N_w \approx 20$ (much too early). The additional constraint arising from the measurement of peripheral collisions ("fifth point") eliminated all previous explanations as they could not reproduce the centrality dependence of the observed hyperon production.

The fact that strangeness in A+A collisions is analyzed with respect to the Wounded Nucleon Model (WNM) imposes an additional complication and precludes a definite conclusion regarding possible QGP formation. The multiple collision mechanism, not understood so far, requires careful experimental studies in order to determine its impact on the final state (including strangeness content) of the collision. Only recently these measurements became available via experiments with p+A collisions at CERN energy (e.g. [36], next section).

<LESSON FROM PROTON - NUCLEUS COLLISIONS>

A very interesting lesson regarding strangeness enhancement was recently provided by the NA49 analysis of p+A data at the CERN SPS top energy. It has been reported [36] that the change of energy dependence of strangeness/pion ratio is not a unique feature of A+A collisions. It was also observed in pp and pA channels.

Moreover, the pA data clearly demonstrate [36] that the WNM overestimates the number of the participating nucleons in the collisions of protons and heavy nuclei. This calls into question the reliability of using this particular model for analysis of significantly more complex systems like A+A. Therefore, one has to be particularly

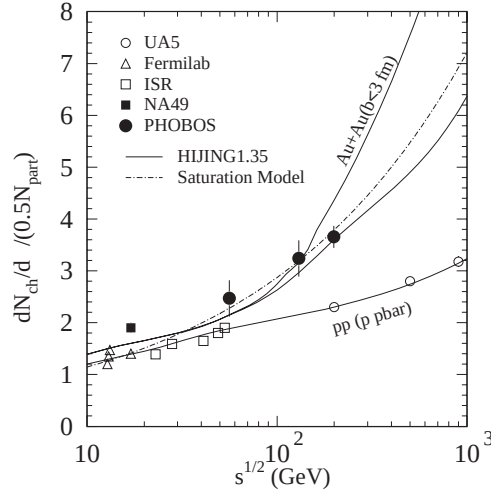


FIGURE 7. Energy dependence of charged particle density in central AA and pp collisions.

careful when analyzing particle yields as a function of the number of wounded nucleons (often used as a measure of the centrality of the collisions) in A+A .

<RHIC ENVIRONMENT>

The experimental program at CERN SPS has gathered a lot of data from heavy ion collisions establishing the strangeness enhancement effect. It has failed, however, to demonstrate that this is caused by QGP formation, because an effect has also been observed (to lesser degree) in systematic studies of proton-nucleus collisions.

The commissioning of RHIC provided the very first opportunity to explore a higher energy regime, with center of mass energies order of magnitude higher than those previously obtained. Thus, a new environment was expected with larger initial energy density, larger freeze-out volume, longer lifetime, larger freeze-out temperature, smaller baryonic chemical potential, smaller crossing time of two nuclei and, of course, increasing role of quark and gluon degrees of freedom.

Four experiments took data in the 2000/2001 runs: two large multi-purpose experiments, STAR [37] and PHENIX [38], surveying a new energy domain and two smaller ones, BRAHMS [39] and PHOBOS [40], with the specific physics agenda. Gold ions were accelerated during both runs, at 56 and 130 GeV per nucleon in 2000, and 200 GeV per nucleon in 2001. The very first RHIC physics result, the charged particle rapidity density at mid-rapidity has been measured by all four experiments with very good agreement among their results. Figure 7 shows the energy dependence of charged particle density $dN_{ch}/d\eta$, normalized to the number of participating nucleon pairs ($N_{part}/2$) which rises almost logarithmically with $\sqrt{s}$ from AGS up to RHIC energies. This dependence is very different from the $p\bar{p}/pp$ systematics, also shown in Fig.7. At 200 GeV about 65% more particles per pair of participants is produced in central Au+Au collisions than in $p\bar{p}/pp$. For central Au+Au collisions at $\sqrt{s} = 130$ GeV the global average

is $dN_{ch}/d\eta = 580 \pm 18$, and it is only about 15% higher at $\sqrt{s} = 200$ GeV [41]. The maximum multiplicity is large, but not large enough to justify the simple idea of a first order phase transition from 3 pionic degrees of freedom to 37 gluonic degrees of freedom.

Most of the models and predictions, made before the data became available, failed to describe the multiplicity. The rare exception, the Hijing model, provides a fairly good description of the measured multiplicities. However, it also misses the data when high jet quenching, expected in QGP, is assumed (upper curve in Fig.7)[42].

The transverse energy rapidity density, $dE_T/d\eta = 578 + 26 - 39$ GeV, measured by the PHENIX experiment, in the 2% most central collisions [43] combined with the Bjorken formula [44] estimate the initial energy density to be $\varepsilon = 5$ GeV/fm³, i.e. 60-70% larger than the corresponding value at the top SPS energy. Note that this is a very conservative estimate using formation time $\tau \approx 1$ fm/c. Much larger energy density, of the order of 20 GeV/fm³, would be obtained for shorter formation times advocated by the saturation model [45].

The BRAHMS collaboration data extended significantly the rapidity reach of the dN_{ch}/dy , because their spectrometer can cover a wide range of laboratory angles. The observed dN_{ch}/dy decreases rather fast away from mid-rapidity (e.g. by about 30% at rapidity of 3) [46], eliminating the anticipated hypothesis of possibly boost invariant dynamics in nuclear collisions at RHIC energies.

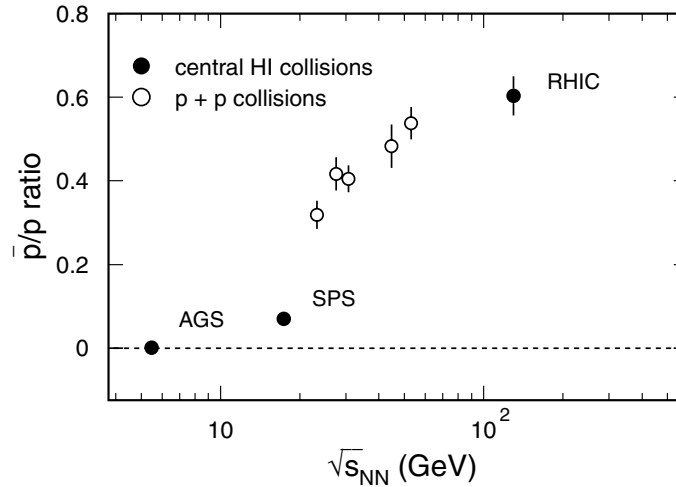


FIGURE 8. Mid-rapidity antiproton to proton ratios measured in central heavy ion collisions (filled symbols). The left end of the abscissa is the $p - \bar{p}$ pair production threshold in p+p.

Other very important information on the initial conditions of the matter created at the early stage of the collision is coded in the baryon number transport (or baryon stopping), which is established presumably very early in the collision. The degree of stopping is expected to affect the overall dynamical evolution of the matter in general, and thermal and/or chemical equilibration, so fundamental for QGP study, in particular. The baryon stopping can be addressed experimentally through analysis of baryon/antibaryon ratio. At RHIC energy the $\bar{p}/p$ ratio is much larger [47] than at SPS ($0.07 \pm 10\%$) or at AGS ($0.00025 \pm 10\%$; practically zero), but still is significantly smaller than unity over the measured centrality range, indicating an overall excess of protons over antiprotons at the midrapidity. This implies that a certain fraction of the baryon number is transported

from the incoming nucleus at beam rapidity to the midrapidity region even in peripheral Au+Au collisions at $\sqrt{s} = 130$ and 200 GeV. Thus, at this energy the midrapidity region is not yet baryon free. Comparison of the $\bar{p}/p$ ratio at RHIC to lower energies indicates a dramatic increase in the importance of pair production mechanism with the rise of center of mass energy. This is demonstrated in Fig.8, where points for p+p collisions are also shown for reference. The baryon yields have consistently attracted interest not only due to the not yet understood baryon stopping mechanism, but primarily because baryon-antibaryon pair production (from $\bar{p}/p$ to Ω/Ω) is expected to reflect the degree of availability of s and $\bar{s}$ quarks which are suppressed in hadronic matter due to the high mass of strangeness carriers. The sensitivity of course, is expected to be proportional to the strangeness content of the baryon-antibaryon pair. Accurate measurements of the yields of produced baryons and antibaryons (particularly important here are those which contain strange quarks) are available from the STAR experiment (see B.Hippolyte talk in this proceedings).

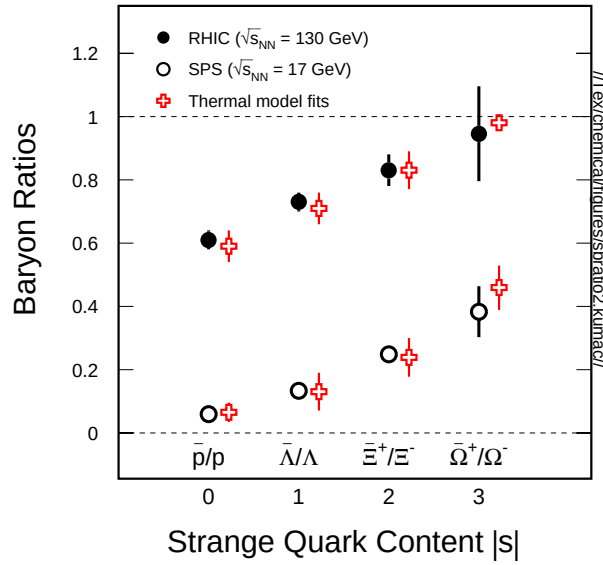


FIGURE 9. Antibaryon to baryon ratios according to their strangeness content for SPS and RHIC data.

Fig. 9 presents antibaryon to baryon ratios according to their strangeness content for SPS (WA97) [14] and RHIC data (STAR) [48, 49]. The observed enhancement of ratios, as strangeness content increases, reflects dramatically the change in the baryon density and confirms the increasing importance of pair production. This sensitivity to baryon density has already been briefly discussed earlier, in the context of K/π ratios at CERN SPS energy. Note, that K^+ and Λ yields are related by associated production mechanism.

Measured particle ratios combining particles of different flavor content and mass allow one to determine thermal model parameters at chemical freeze-out. Data (all four RHIC experiments) analyzed [50] using a statistical canonical ensemble [25] demonstrate rather good agreement with the model. The extracted thermal parameters temperature, $T = 176 \pm 9$ MeV and chemical potential, $\mu_B = 3 \mu_q = 36 \pm 4$ MeV, show that the nucleus-nucleus collisions at RHIC are characterized by high energy density (high T), and low baryon density (at mid-rapidity). The value of γ_s parameter, called

the strangeness saturation factor, obtained in the fit, is consistent with 1 (0.95 ± 0.10) pointing towards chemical equilibrium established at mid-rapidity (local equilibrium?). Note that particle ratios used for constraining T and μ_B are measured at mid-rapidity, not in full phase space. The mid-rapidity particles most likely reflect a thermal source provided that global equilibrium is approximated by local equilibrium, whereas particle production at high rapidity is expected to have significant content from the initial colliding nuclei. Thus, different statistical descriptions at mid-rapidity and away from mid-rapidity would be appropriate. Due to the large rapidity range at RHIC (≈ 6 units), the contamination from high rapidity sources is expected to be relatively small at mid-rapidity.

Taking the preliminary results of statistical model analysis at face value, one arrives at the conclusion that the initial state is very dense. The energy density is higher by about 30 times than that found in cold nuclear matter. A new territory of ultradense hadronic or pre-hadronic equilibration dynamics has been entered. However, nothing is known about its properties and characteristics.

<STRANGENESS AT RHIC>

Usually the initial phase of the experimental program, particularly in the new energy domain, brings only information on global characteristics of the collisions. RHIC is not an exception in this respect. For detailed and conclusive analysis of strangeness production at $\sqrt{s} = 130$ and 200 GeV, one still needs to wait. However, already available preliminary results seem to be quite interesting and unexpected. In this chapter some of them will be reviewed. A word of caution will be added where appropriate, as they might be revised/replaced with final, large statistics analysis.

As discussed earlier, the ratios of baryons and antibaryons are well described by a thermal model fit. It has been attributed, along the lines of thermal model, to a significant degree of equilibration which sets-in in these nuclear collisions. However, this may very well reflect only the trivial loss of statistical sensitivity as the antibaryon-baryon ratios at RHIC energies (baryon chemical potential ≈ 0) approach unity. The ratios of different mass particles should be free from this problem and may present a more suitable test for the model. Analysis is in progress.

Multi-strange hyperons, due to their low production cross section, will probably not influence the degree of the chemical equilibration in any meaningful way, however they are the only ones to provide information on processes sensitive to the density of strange quarks in the initial state, and perhaps, on some non-equilibrium production mechanisms, if they exist. So, it is not their agreement with thermal model expectations that is important and worth studying, but rather discrepancies from the fits may lead to the most interesting results, and perhaps to the discovery of new phenomena.

Transverse mass spectra have also been measured for strange hadrons. The values of invariant slope parameters extracted from the fits to these spectra are summarized in Fig.10 as a function of particle mass. For comparison, values of slope parameters at SPS are also shown. The behavior at SPS and RHIC is very similar. For each particle species, the RHIC spectrum has an inverse slope about 50 MeV higher than at SPS, which

may indicate stronger transverse explosion. It appears that multistrange hadrons deviate from the simple radial flow picture, suggesting that perhaps they do not participate in a common expansion, and decouple rather early from the collision system due to their small hadronic cross section.

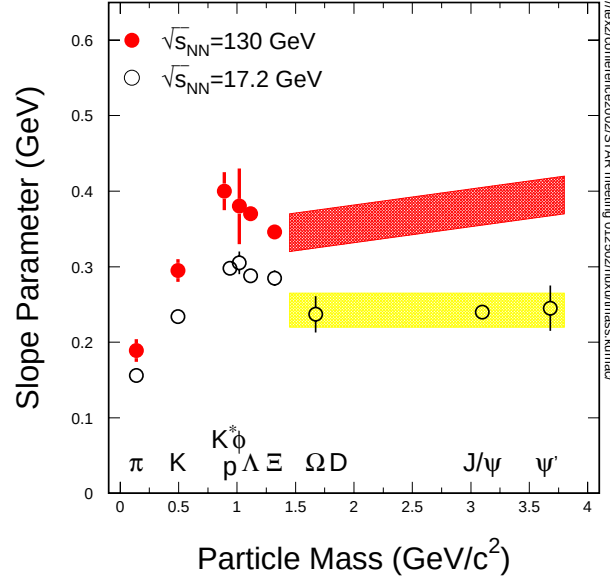


FIGURE 10. Invariant slope parameter as a function of particle mass. The dark band represents expectations from RHIC experiments.

This observation hints that it might be possible to obtain insights into the very early stages of the collision by studying the flow of strange particles (both: radial and elliptic). The STAR experiment [51, 52] reports first measurements of the azimuthal asymmetry parameter v_2 for strange particles K_s^0 , Λ and $\bar{\Lambda}$ for Au+Au at $\sqrt{s} = 130$ GeV. Hydrodynamic model calculations, where collective motion established by a pressure gradient transfers geometrical anisotropy to momentum anisotropy, seems to adequately describe elliptic flow of the strange particles up to a p_t of 2 GeV/c. The v_2 values as a function of p_t from mid-central collisions are higher at each p_t than v_2 from central collisions. The p_t -integrated v_2 as a function of particle mass is also consistent with a hydrodynamical picture. For p_t above 2 GeV/c, however, the observed v_2 seems to saturate whereas hydrodynamical models predict a continued increase with p_t . It has been argued in the framework of pQCD model [53] that the observed shape and numerical value of v_2 above 2-3 GeV/c reflect the energy loss in an early, high parton density, stage of evolution.

The fundamental question regarding the strangeness production differences (or lack of them) at RHIC compare to SPS, and their interpretation remains still open. While it is too early for definite conclusions, preliminary estimates [54] show that the overall strangeness, expressed as the ratio of strange to non-strange particle multiplicity or by the Wroblewski Factor [55] λ_s , defined as $\langle s\bar{s} \rangle / (\langle u\bar{u} \rangle + \langle d\bar{d} \rangle)^1$, does not change as a function of $\sqrt{s}$ between SPS and RHIC.

¹ quantities in angular brackets refer to the number of newly formed quark-antiquark pairs, i.e. excludes all quarks that were present in the target and projectile

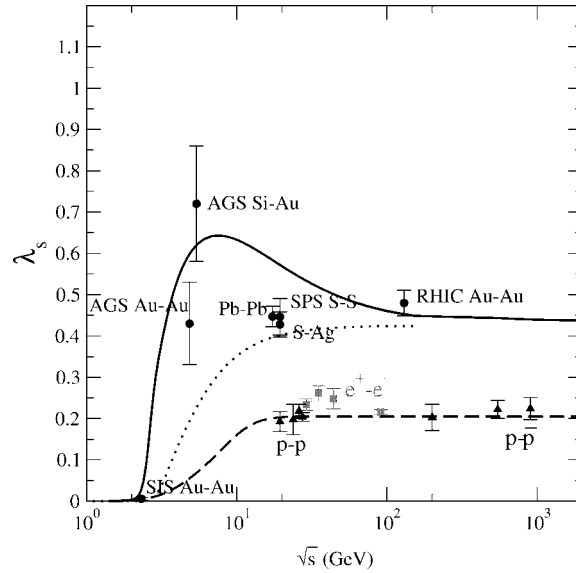


FIGURE 11. The Wroblewski Factor λ_s as a function of $\sqrt{s}$ - see text for details.

The solid and dotted lines in Fig.11 indicate different versions of statistical model calculations for A+A, whereas the dashed line represents a statistical model for elementary collisions. There are two distinct differences in the behavior of λ_s in elementary and heavy ion collisions: (1) strangeness content is smaller by a factor of two in elementary collisions compared to nucleus-nucleus, and (2) there is no maximum in λ_s dependence on $\sqrt{s}$ in a compilation of pp , $p\bar{p}$, and e^+e^- . Note, that the SPS data are well below the solid line (complete equilibrium case) in Fig.11. The new CERN SPS data at 40 and 80 GeV/c [7] demonstrate the presence of this discrepancy very clearly.

<SUMMARY.>

Fifteen years of heavy ion physics at the CERN SPS have resulted in several suggestive results regarding formation of the partonic state, but no clear discovery was made.

Early RHIC data have allowed for significant progress in mapping out the soft physics regime. The global conditions are indeed very different from the ones at SPS. However, the amount of strangeness produced is almost constant with growing energy. The enhancement in AA as compared to pp is preserved from the lower energy, however the pair production mechanism seems to dominate at RHIC and K^+/π^+ and K^-/π^- ratios seem to be approaching the same value as the baryon density goes to zero at mid-rapidity.

For the first time in the history of relativistic nuclear physics, the hydrodynamical calculations, which assume local equilibrium, agree with central collision Au+Au data in the low p_t range (less than 2 GeV/c), suggesting that thermalization might be obtained early in the collision.

It is clearly too early to draw definite conclusions, or to make firm statements about how data fit theoretical expectations. To a large extent the first RHIC results have not

changed the picture that has emerged from the analysis of earlier AA collisions.

A complete picture of heavy ion collision dynamics at high energies requires the analysis of complementary information gained at both CERN and RHIC. It will be extended in the future by LHC findings. Despite the new aspects of the picture emerging from the analyzed RHIC collisions at $\sqrt{s} = 130$ and 200 GeV, the highly excited matter produced at RHIC energies is not quite yet at the baryon chemical potential $\mu_B = 0$. The opportunity to discover fascinating and challenging new science in nuclear collisions is still ahead.

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