LBL-26728 c.2

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

RECEIVED
LAWRENCE
BERKELEY LABORATORY

APR 17 1989

LIBRARY AND
DOCUMENTS SECTION

Invited talk presented at the Conference on Hadronic Matter in Collisions, Tucson, AZ, October 6–12, 1988, and to be published in the Proceedings

Strangeness Production in Nucleus-Nucleus Collisions: Experimental Summary

G. Odyniec

February 1989

TWO-WEEK LOAN COPY

This is a Library Circulating Copy
which may be borrowed for two weeks.

NUCLEAR SCIENCE DIVISION

LBL-26728 c.2

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL-26728

STRANGENESS PRODUCTION IN NUCLEUS-NUCLEUS COLLISIONS: EXPERIMENTAL SUMMARY

G. ODYNIEC

Nuclear Science Division
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, California 94720

February 1989

Invited talk presented at the Conference on Hadronic Matter in Collision, Tucson, Arizona, Oct 6-12, 1988

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

STRANGENESS PRODUCTION IN NUCLEUS-NUCLEUS COLLISIONS: EXPERIMENTAL SUMMARY

G. ODYNIEC
Lawrence Berkeley Laboratory
Nuclear Science Division
1 Cyclotron Road
Berkeley, CA 94720, USA

1. INTRODUCTION

The possibility of forming a quark-gluon plasma (QGP) in hot and/or dense nuclear matter has been of strong interest for several years and has recently motivated dedicated experimental programs at CERN and Brookhaven. One of the earliest, and most discussed, predictions for a signature of QGP, is strangeness. Because of the large mass of the strange quark, the abundance of strangeness in ordinary hadronic matter is suppressed, but it is expected to increase rapidly and approach the thermal equilibrium value if QGP is formed as a result of a sufficiently violent collision between heavy ions. Thus enhancement of strange particle production in the nuclear reaction might serve as an indication of QGP formation.[1)]

However, recent calculations,[2,3)] based on the hydrodynamical model, predict that the enhancement in strange particle yields differs only slightly in a plasma and a hadron gas. Obviously the fact that the observations are made only in the final stage of the reaction complicates the interpretation of the observed yields of strange particles, perhaps even making it impossible to distinguish between the hadronized products of the quark-gluon plasma and those of a chemically-equilibrated hadron gas.

Nevertheless, while the enhancement of strange particle production in relativistic heavy ion collisions is no longer considered to be such a clear signature of QGP formation [4) and references therein] - it is still a signal which reflects the interesting collision dynamics and may indirectly provide insight into processes responsible for strange particle production.

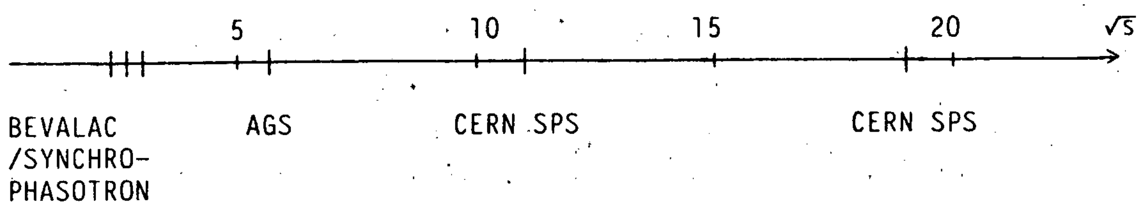
It is believed that deconfinement (quarks and gluons propagating freely throughout an extended volume) is likely to occur when nuclear matter is stressed to extreme values of high density and/or temperature over a prolonged period of time. These conditions can probably be created in a laboratory environment only in ultrarelativistic nucleus-nucleus collisions. In particular, central collisions of heavy nuclei are the most favorable candidates for QGP experiments because of the large interaction volume. The ideal case, would be to study central collisions of symmetric systems where there will be no cold nuclear matter (spectators) to complicate interpretation of the experimental data.

Therefore, rather than attempt to give a complete review of strangeness production in all kinds of experiments, I will dwell on the most interesting and promising aspects of the experimental results from nucleus-nucleus (A + A) experiments, using p+p/$\bar{p}$+p and p+A/$\bar{p}$+A data only as reference when needed. I should also mention that much interesting information on strangeness production in p+A and $\bar{p}$+p experiments can be found in K.B. Luk and S. Oh contributions to this conference.

In this paper I will try:

1. To identify the important features of the reaction mechanism;
2. To understand the mechanisms;
3. To learn about quark-gluon plasma formation by comparing nucleus-nucleus collisions with p-nucleus, $\bar{p}$-nucleus, p + p and $\bar{p}$ + p collisions;
4. To see if there is any definite evidence yet supporting quark-gluon plasma formation;
5. To suggest further needs for experimental and theoretical study.

Fig. 1 shows the energy scale ($\sqrt{s}$) of the experiments, I will talk about.



2. BERKELEY AND DUBNA EXPERIMENTS AT 2-4 GeV/A

The first experimental data on Λ, K^+, K^- and K^0_s production in nucleus-nucleus collisions were obtained in Berkeley at the Bevalac, and, shortly afterwards at slightly higher energy, on Λ and K^0_s, in Dubna at the Synchrophasotron. I will remind you of some of the most interesting findings of this experiments since there were no contributions in this energy range at this conference. First of all, we have to remember that in these analyses the main emphasis was on separation of the effects which may be explained as results of quasi-free nucleon-nucleon collisions from those which are caused by collective nuclear processes.

At Bevalac energies, up to 2.1 GeV/A, we are either below or at best barely above the threshold for the production of strange particles (the threshold for $NN \rightarrow \Lambda KN$ is 1.58 GeV, for $NN \rightarrow NNK^+K^-$ it is 2.5 GeV). Data exist for K^+, K^-, K^0_s and Λ production from the Bevalac[5,6,7] and for K^0_s and Λ production at the Dubna energy of 3.6 GeV/A.[8,9] Different techniques were used for detection of charged kaons and neutral strange particles due to their different lifetime. K^+ and K^- have a sufficiently long lifetime that they can be observed in spectrometers whereas the short lived K^0_s and Λ have to be identified in visual detectors by their charged particle decays, $K^0_s \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\,\pi^-$, where the observed Λ yield includes the primary Σ^0 production after fast $\Sigma^0 \rightarrow \Lambda\,\gamma$ decay.

Because of the low beam energy Λ production at the Bevalac is very sensitive to nuclear Fermi motion effects. Harris at al. in

1981[6] observed (Fig. 2) that almost all Λ's in central Ar + KCl collisions at 2.6 GeV/c were outside the kinematical limit for free nucleon-nucleon collisions. A distinct forward-backward asymmetry in the Λ production was attributed to rescattering of the Λ's, produced only in the earliest stages of the collision, from the not yet equilibrated surrounding nuclear matter. At the Synchrophasotron the situation is changed significantly. Fig. 3 from Agakishiyev et al.[10] shows the two dimensional plot p_t versus y_{lab} for Λ generated in C + C at 4.2 GeV/c. For C + C interactions only about 18% of Λ's lie outside the kinematical limit for free N + N collisions. Thus at the higher beam energy, Fermi motion is not needed for the production threshold to be exceeded. Conversely, to study Fermi motion of interacting nucleons and the contributions of other nuclear effects the lower energy range of Bevalac is more relevant.

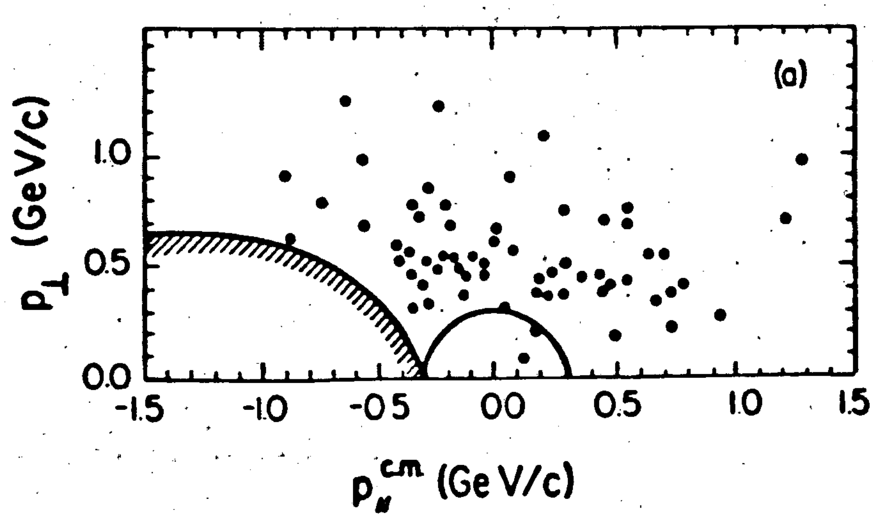


Fig. 2 Ar + KCl → Λ events as a function of p_t and p_l in nucleus-nucleus c.m. at 2.6 GeV/c. The hatched curve shows the region where events were excluded due to limited detector efficiency. The solid curve corresponds to the NN → ΛKN kinematic limit.

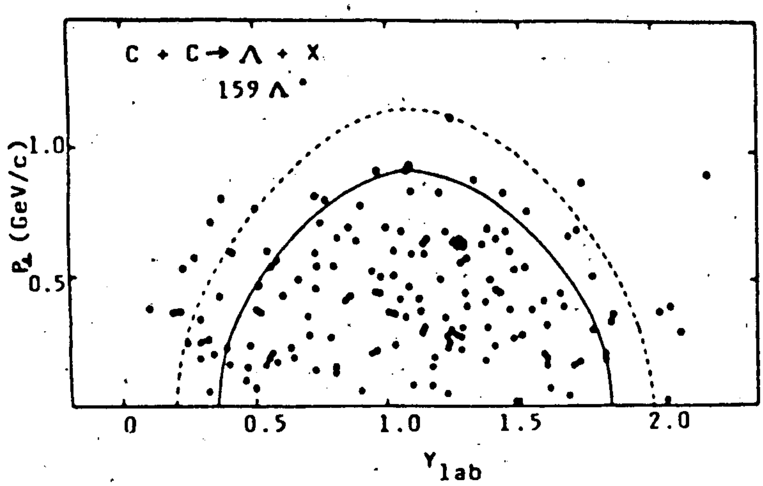


Fig. 3 C + C → Λ events as a function of p_t and rapidity in lab.system at 4.2 GeV/c. The solid line shows the limit of the kinematically allowed region for the reaction N + N → N + Λ + K. The dotted line is the limit of this region when Fermi motion of nucleons from both nuclei is taken into account.

An interesting result from the Dubna experiment is related to the angular distribution of Λ's produced in nucleus-nucleus reactions. On Fig. 4 the angular distributions of Λ and π^- are shown.[9] The upper part of Fig. 4 shows distributions obtained from nucleon-nucleon interactions at similar momenta. The middle part of Fig. 4 shows distributions of Λ and π^- produced in He + Li collisions. It is seen that the angular distributions for N + N and minimum-bias He + Li interactions are consistent with each other. The lower part of Fig. 4 shows the Λ angular distribution is much more isotropic in central C + C collisions. The flat angular distribution observed for Λ's in the most central C + C collisions suggests that these particles may be emitted from a thermal source at rest in the N-N c.m. system. The Boltzmann shape of the kinetic energy distribution, which is observed[9] for this sample of particles suggests that thermal equilibrium is reached in the sources from which the particles were emitted. The source temperature T_0 can be obtained from the slope of the spectrum or, equivalently,

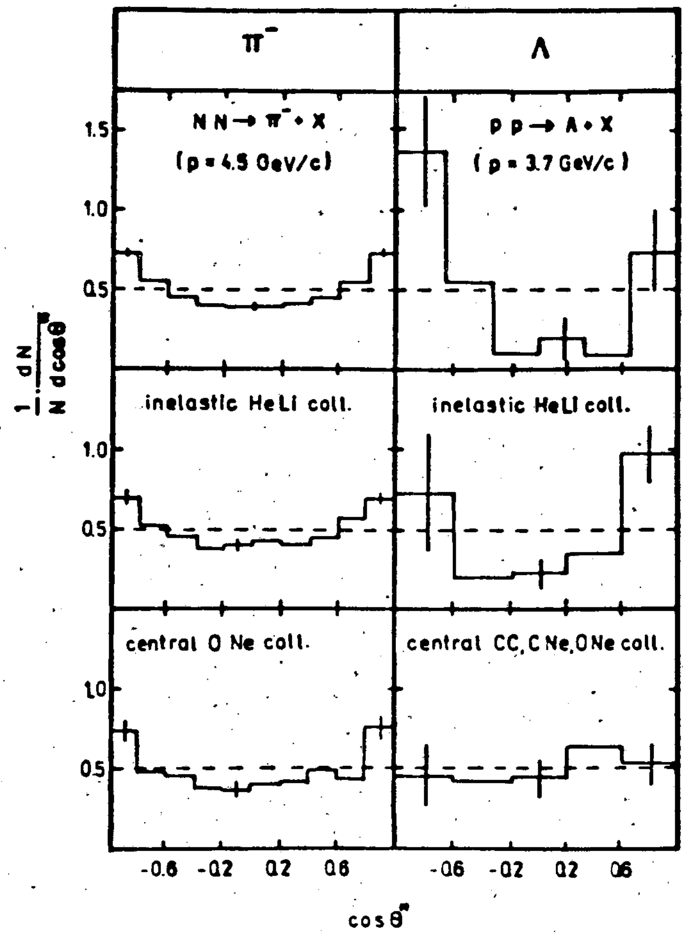


Fig. 4 cosθ distributions for mesons and hyperons produced in hadron-hadron, He-Li inelastic and C + C, C + Ne, O + Ne central collisions at 4.5 GeV/c momentum per nucleon. θ is the emission angle calculated in the N-N c.m. system.

from the $\langle p_t \rangle$ value. The latter way also allows the average temperature to be estimated when a single thermalized source has not been formed. Extracted T_0 values are plotted against the average number of participant protons in Fig. 5. The temperatures for Λ's emitted from central collisions and for π^- approach the values predicted by the thermodynamical model of Hagedorn[11] and calculated under the assumption that the nuclear matter involved in the collision has been fully stopped and thermalized in the N-N c.m. system. For the most central C + C events the Λ "temperature" reached a very high value of 150 MeV, the highest "temperature" seen for Λ particles in any experiment.

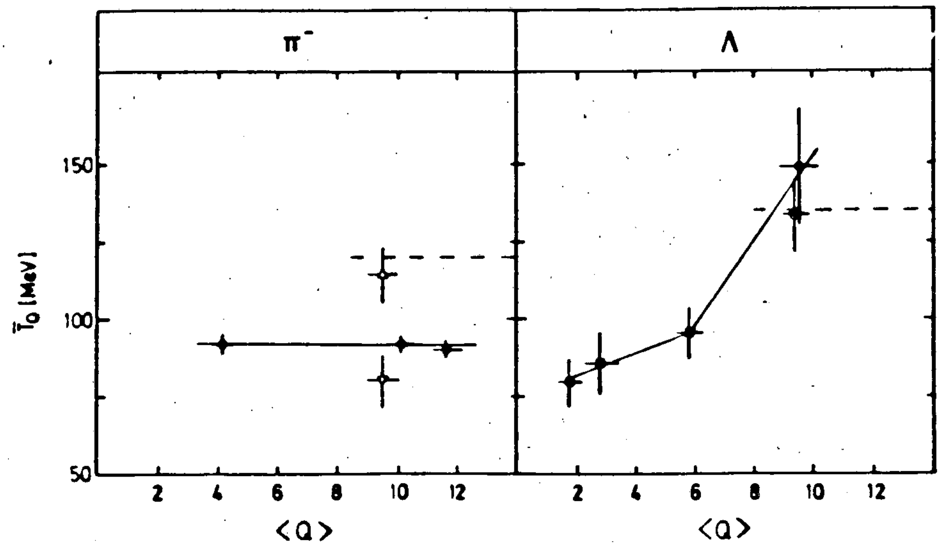


Fig. 5 The temperature parameter, T_0, plotted against <Q> - the average number of participant protons. Dashed lines show the T_0 value predicted by the thermodynamical model of Hagedorn.[11]

3. K E K EXPERIMENT $\bar{p}$ + Ta AT 3 AND 4 GeV/c

Since the annihilation of $\bar{p}$ in nuclei releases 2 GeV of energy, one may expect a local heating of nuclear matter in the $\bar{p}$-nucleus reaction, with production of a "hot spot." Theoretical calculations[12] suggest a possible enhancement of strangeness production in $\bar{p}$-nucleus reactions due to plasma formation in highly excited nuclear matter inside such "hot spots."

The results from low-momentum (608 MeV/c) studies of $\bar{p}$ collisions with nuclei at LEAR[13] at CERN show that $\bar{p}$ predominantly annihilate on the surface of the target nuclei. Therefore less than half of the pions originating from $\bar{p}$-p annihilation (average multiplicity ~ 6) are emitted towards the nuclear interior. It is estimated[14] that in order to deposit all the energy released in the annihilation of $\bar{p}$-p inside the nuclei, the incident $\bar{p}$ momentum should be higher, of the order of a few GeV/c.

Recently Miyano et al.[15,16] have analysed bubble-chamber data (KEK, exp E62) with $\bar{p}$ + Ta reactions at 3 and 4 GeV/c. The group also took data on $\bar{p}$-p at the same energies for comparison with the $\bar{p}$-Ta data. Cross sections for the inelastic processes and K_s^0, Λ, $\bar{\Lambda}$ production, for the $\bar{p}$-Ta reaction at 4 GeV/c, are shown in Table 1. The cross section for each process in the $\bar{p}$-Ta reaction was compared with a "geometrical cross section" calculated by multiplying the elementary $\bar{p}p$ cross section by $A^{2/3}$ ($\sigma_{geom} = \sigma_{\bar{p}p} \times A^{2/3}$). As seen in the table, the inelastic cross section for the $\bar{p}$-Ta reaction was almost equal to the geometrical one, as was the K_s^0 - production cross section. The production cross section for Λ was, however, larger then the geometrical estimate by factor 10.

Table 1. Hyperon production cross section in $\bar{p}$-Ta reaction at 4 GeV/c, and comparisons with geometrical estimates of the cross sections.

	$\sigma_{\bar{p}Ta}$ [mb]	$\sigma_{\bar{p}p} \times A^{2/3}$ [mb]	$\sigma_{\bar{p}Ta}/\sigma_{\bar{p}p} \cdot A^{2/3}$
Inelastic	1628 ± 30	2210	0.74
K_s^0 + X	82 ± 6	60.8	1.3
Λ + X	193 ± 12	17.0	11.3
$\bar{\Lambda}$ + X	3.8 ± 2	15.4	0.25

The cross section for $\bar{\Lambda}$ production was suppressed by a factor of 4 if compared with geometrical estimates. A similar effect was observed for $\bar{p}$ + Ta collisionsat 3 GeV/c per nucleon.[16] Although the experiment had good statistics (107,000 pictures scanned), the identification of "vee" particles was made only by setting windows on invariant mass spectra - no kinematic fit was performed. Therefore one might expect a small difference (~ few percent) between the final values of the cross sections from this experiment and the currently presented ones. Nevertheless the result is striking. While it was discussed in the framework of QGP formation by J. Rafelski,[17] a much simpler explanation was proposed by the authors themselves.[18] They noted that the production of Λ through secondary processes such as $KN \rightarrow \Lambda X$ and $\pi N \rightarrow \Lambda X$ must play an important role. They estimated the production cross sections due to the secondary processes and obtained 80 mb and 100 mb, respectively. The sum of these is in very good agreement with the experimental result 193 ± 10 mb. Thus, the enhancement of Λ production was explained as the effect of secondary processes. However, the smallness of the observed cross section for the $\bar{p}\text{-Ta} \rightarrow K^0_s \Lambda X$ reaction is not yet understood.

Summarizing the $\bar{p}$-Ta experiments, one may conclude that the rich production of strangeness in $\bar{p}$-nucleus reactions can be explained by the superposition of elementary $\bar{p}$-N processes. For the study of high-energy density in nuclear matter it should be better to use relativistic nucleus-nucleus collisions.

4. E802 EXPERIMENT AT AGS AT 14.5 GeV/c

Last year, at the QM'87 conference, E802 Collaboration presented preliminary results for integrated K to π ratios in Si + Au central collisions, in an angular range from 14° to 28°, of $K^+/\pi^+ = 24 \pm 5\%$ and $K^-/\pi^- = 4^{+4}_{-2}\%$. The K^+/π^+ yields were in excess of typical values obtained at AGS energies in p-p and p-A collisions, whereas the K^-/π^- yields agreed, within the large experimental errors, with typical values measured in p-p and p-A collisions. Theoretically, such an effect is expected if very high baryon density matter is formed. It has been called "K distillation" effect, closely related to associated Λ production.[19] However, these results included only preliminary acceptance corrections and in addition, the low statistics in the K^- channel precluded a definitive comparison to p-p and p-A data. Finally, it is worth noting in general that the integrated ratios of the particle yields are strongly affected by the momentum acceptance of the experimental apparatus (low p_t cut off) and by the extrapolation procedure to $p_t = 0$. Therefore, it is important to investigate the p_t dependence of the particle yields and their ratios before any positive statement can be made. Such an analysis has been completed by the E802 collaboration during last year. K^+/π^+ and K^-/π^- integrated ratios were presented here (see S. Steadman contribution to this conference[20]) as a function of p_t and also compared to a compilation of published p-p and p-Pb data at AGS energies.

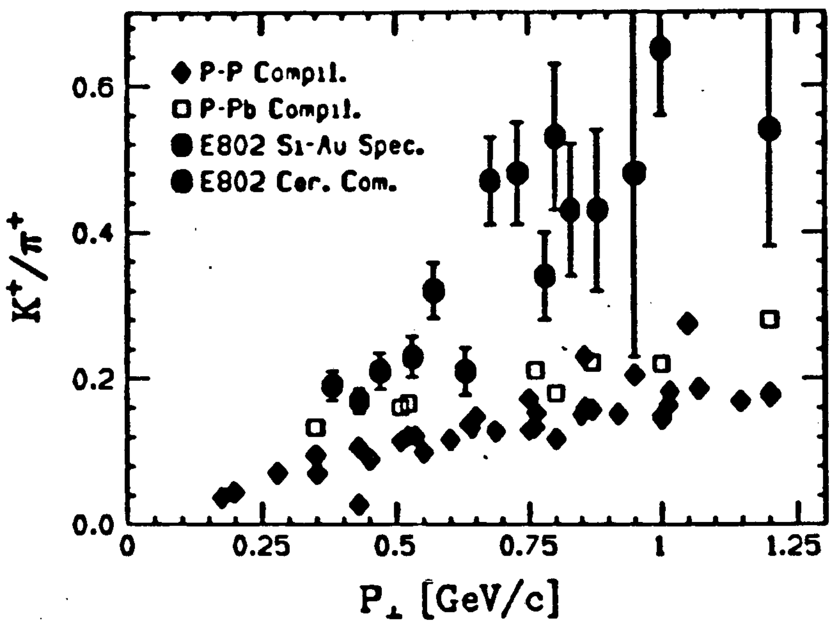


Fig. 6 Compilation of K^+/π^+ ratios vs. p_t in p-p and p-A collisions at AGS energies compared to Si + Au.

The K^+/π^+ ratios increase with increasing p_t reflecting, at least in part, the influence of approximate $M_\perp$ scaling. However, there is an additional systematic increase in the ratios as the number of nucleons involved in the collisions increases. The Si + Au ratios are substantially larger then typical values observed in p-p or p-Pb collisions. The ratio at low p_t is about 20% which is in agreement with the integral ratio presented at QM'87. The K^-/π^- ratios exhibit similar tendencies, but the overall magnitude of the ratios is reduced for all collisions systematically. There are large discrepancies in the values of measured negative K to π ratios for p-p collisions, particularly at low p_t. The integral ratios are, of course, dominated by the values at low p_t, with mean values for p-p lying in the 2-4% range, and Si + Au exhibiting somewhat higher values of 5-6%. At high p_t the heavy ion data systematically exceed typical values from p-p and p-A.

One should be very cautious with interpretation of these results as evidence for presence of baryon-rich QGP at AGS energies until simultaneous measurements of the K/π ratios and Λ yields are in hand. We also need to see whether enhanced K^+/π^+ ratios occur in less central or peripheral collisions and in p-Au reactions at AGS energies.

On the theoretical side, recently published calculations,[21] based on the fireball model, suggest that the observed ratio of K^+/π^+ in nucleus-nucleus collisions at AGS energies can be largely explained by the reaction $\pi\pi \rightarrow KK$ from the secondary pions created from the interaction.

5. NA-35, WA-85 AND NA-36 AT CERN SPS AT 60 AND 200 GeV/c

Nucleus-nucleus collisions at 60 and 200 GeV/c per nucleon have been studied at the CERN SPS with oxygen and sulphur beams and a variety of targets. Three major experiments, NA-35 (with streamer chamber as a main detector), WA-85 (with omega spectrometer), and NA-36 (with time projection chamber) have investigated strange particle production. Most of the data shown during this conference stem from the NA-35 experiment. The most intriguing result,[22] which provides information on the volume dependence of strangeness production came from analysis of neutral strange particle production in 200 GeV/c S + S interactions. Fig. 7 shows the mean yield of Λ's as a function of the mean charged particle multiplicity in the event. Increasing multiplicities of charged particles corresponds to smaller impact parameters. Very little spectator matter is expected to remain in central collisions of S + S. The Λ yield rises as a function of event centrality to a value more than twice that expected from the Lund/Fritiof model (dashed line) or an independent nucleon-nucleon model (dotted line). Also plotted in Fig. 7 are predictions of a simple hadron gas model(solid line), which lies near the Lund/Fritiof and nucleon-nucleon model predictions. Thus the observed strong enhancement of Λ yield is difficult to describe using standard hadronic processes. "Naive" parton gas model calculations,[22] on the other hand, give the predictions quite close to the observed values of Λ yield (double solid line on Fig. 7). Within this model, the enhancement arise from secondary parton-parton interactions.[1] The K_s^0 yield, which rises above predictions but less then the Λ's, and details of the analysis can be found in M.Gazdzicki's contribution to this conference.[22] A similar enhancement of Λ production was already previously reported by NA-35 [23) and see also I. Derado contribution to this conference 24)] in O + Au central collisions at 60 and 200 GeV/c. The Lund/Fritiof model, again, underpredicts by approximately a factor 2 the high p_t Λ yield (NA-35 acceptance

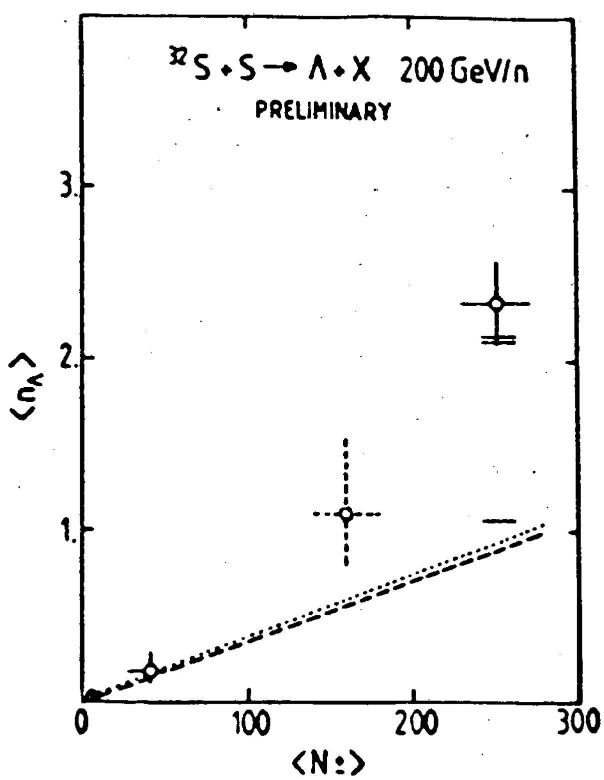


Fig. 7
Average Λ multiplicity in the NA35 acceptance versus mean charged particle multiplicity in three data samples (peripheral, relaxed-central and central collisions). The black point shows the NN data. Dashed and dotted lines shows Fritiof and NN model predictions, respectively. Double solid and solid lines indicate the result of secondary interactions calculations performed for cases of a parton gas and a hadron gas, for central S-S collisions.

corresponds to fairly high p_t, $p_t > 0.7$ GeV/c, near midrapidity). Another interesting number was presented during this conference by the NA-35 collaboration, namely the number 16, - it appears that the ratios of the multiplicities of K^0_s, Λ, $\bar{\Lambda}$ and all negatively-charged particles for O + Au relative to p+Au measured at 200 GeV/c and 60 GeV/c are close to the value 16, which is the ratio of the numbers of incident projectile nucleons. Since the triggers correspond to very central O + Au (where most of the incident nucleons of the O projectile would be expected to interact) and relatively inelastic p+Au interactions, it appears that a superposition of 16 p+Au interactions reproduces the observed O + Au particle multiplicities. This was already found to be the case for the transverse energy distribution around midrapidity, cross sections and shapes of charged particle multiplicity distributions.[25,26] However, one should be careful with the simple interpretation of the number 16, and even more careful with general conclusions concerning the whole phase space for this process. The NA-35 acceptance covers only the low rapidity ($Y < 2.5$) domain where it is known that cascading in spectator matter dominates. The ratio may vary from 16 when studied in other regions of phase space e.g. in the projectile fragmentation domain.

WA-85, another large CERN experiment designed to study strange particle production, analyzed Λ, $\bar{\Lambda}$ and K^0_s production in the reaction S + W at 200 GeV/c. Comparing WA-85 findings with NA-35 data one has to bear in mind a significant difference in p_t range between the two experiments with WA-85 having a $p_t < 1$ GeV/c cut off (i.e. well above $\langle p_t \rangle$) whereas NA-35 has a p_t cut off only below 0.5 GeV/c. Therefore, the ratio of $\bar{\Lambda}/\Lambda$ as a function of p_t, presented by WA-85 collaboration, is for $p_t > 1$ GeV/c. The data are consistent with a linear decrease of the ratio as p_t increases from 1 to 3 GeV/c. It was shown[27] that the $\bar{p}/p$ ratio determined at $X_F = 0$ in proton-tungsten interactions at 200 GeV/c[28] has a similar tendency (however, the magnitude is approximately a factor two less then $\bar{\Lambda}/\Lambda$ ratio of WA-85 at a given p_t). Needless to say that it would be interesting to compare with $\bar{p}/p$ ratio in the same phase space region as Λ and $\bar{\Lambda}$ decays. All WA-85 results[27] are still preliminary. Evaluation of the corrections due to geometrical acceptance and detector efficiency are still in progress. Also, a comparison with Λ, $\bar{\Lambda}$ and K_S^0 yields in p + W data at 200 GeV/c is underway.

The NA36, experiment at CERN designed for strangeness study, does not present physics results yet. The NA-36 collaboration is still in the process of understanding their main detector - a time projection chamber of innovative design. The first analysis of NA36 TPC data obtained with the S beam at 200 GeV/c momentum demonstrate clearly the excellent two track separation of this detector,[29] which together with the E810 TPC's[30] at Brookhaven, has a pioneering role in heavy ion physics. For the time being the NA36 data are not yet acceptance corrected, but the data presented indicate already that the real results are soon to be expected.

One would expect the production rates of strange particles which contain more than one strange quark (cascades, omegas) to be a

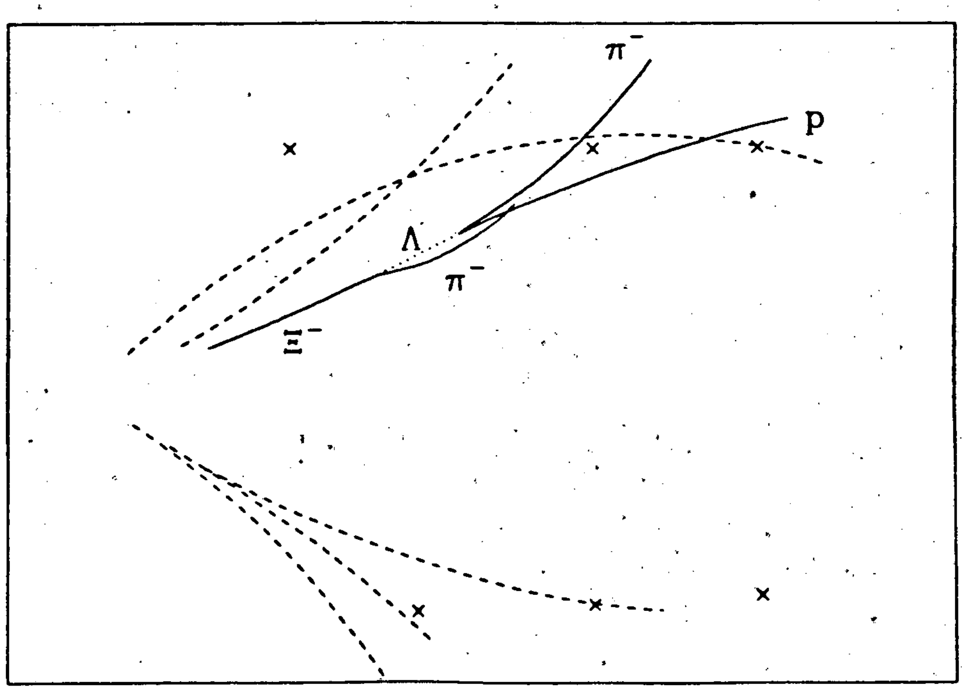


Fig. 8 Ξ^- decay in O + Au reaction at 60 GeV/c register in NA35 streamer chamber.

better probe of the strange quark content in QGP. Of course, this depends on the non-trivial assumption that final yields of strange hadrons will be strongly correlated with the abundance of strange quarks in the QGP.[1,31,32] Nevertheless it would be very important to get from the experiment direct information on production of cascades, omegas and their antiparticles. For the time being only NA35 has demonstrated the capability to detect, record and reconstruct cascades. Fig. 8 shows a reconstructed (with probability 99.99% after kinematic fit) Ξ^- from O + Au at 60 GeV/c.

At this point I would like to finish discussion of CERN experimental results on strangeness. I touched only the most interesting topics, complete reports from NA-35, WA-85 and NA-36 can be found in contributions to this conference. Only small fractions of the data have been analyzed so far. There are still very many "pictures" (those on film and these "electronic" ones from CCD cameras and TPC's on magnetic tapes) to be looked at. The acceptance of NA-35, WA-85 and NA-36 have certain areas of overlap. Therefore, once the analysis is completed, it will be important to compare strange particle yields and distributions from all three experiments in the the overlapping areas.

6. CONCLUDING REMARKS

During this conference such a large volume of new data was presented that it will take quite some time to digest even a part of it. Taking into account the preliminary status of the data - it is important to be cautious about drawing final conclusions at this time. We need to remember that all the experimental set-ups are very complex and it will take a lot of time and work before their acceptances, efficiencies and all kinds systematic errors become fully understood.

Nevertheless , what we see now is very impressive. The most provocative and, at the same time, promising recent results, which might soon shine some light on the "very foggy" QGP environment, are from E802 (K^+/π^+ ratio in Si+Au at 14.5 GeV/c) from BNL and from

NA-35 (Λ enhancement in S+S at 200 GeV/c) from CERN. Both need further study, which is underway.

For the future, more and better data and calculations are needed.

In the experiments the first priority is to study symmetric systems with their easier interpretation. Experiments with larger projectiles will emerge in the next year or two : in 1991 at AGS Au+Au at 12 GeV/c and in 1993 at CERN Pb+Pb at 170 GeV/c. There is a need both for electronics detector experiments which will guarantee reliable information on statistically poor "tails" of the distributions and for 4-π (or semi 4-π) visual detector experiments which will provide data from the areas not accessible for electronic detectors such as in low p_t areas of phase space. Only having both, complementary, sets of information one might try to understand what is actually happening during collision.

In the theory new, parton model based, calculations, which would incorporate nuclear effects like e.g. cascading, are urgently needed in order to "connect" p-p with p-A and A-A data.

Finally, let me conclude with an optimistic remark:

We live in a very interesting time in this field of physics. Almost every conference in this field brings new and exciting experimental information and theoretical progress. All of it is still not enough to provide a complete picture of the properties of and conditions for formation of the state of nuclear matter in which the primordial quarks and gluons are no longer confined as constituents of ordinary particles.

But, clearly, we are on the right track ....

7. ACKNOWLEDGMENT

I am deeply indebted to Dr. H.G. Pugh for many very helpful discussions concerning the preparation of this talk. I would like also to thank him and Dr. J.W. Harris for reading the manuscript. This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Physics Division of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

8. REFERENCES

1) For a review see: Koch, P., Muller, B., and Rafelski, J., Phys. Rep. 142 (1986) 167.
2) Kapusta, J., and Mekjan, A., Phys. Rev. D33 (1986) 167.
3) Matsui, T., Svetitsky, B., McLerran, L.D., Phys. Rev. D34 (1986) 2047.
4) McLerran, L.D., XVIII International Symposium on Multiparticle Dynamics, 1987, Tashkent, USSR.
5) Schnetzer, S. et al., Phys. Rev. Lett. 49 (1982) 989.
6) Harris, J.W. et al., Phys. Rev. Lett. 47 (1981) 229.
7) Shor, A. et al., Phys. Rev. Lett. 48 (1982) 159.
   Barasch, E. et al., LBL-17065 (1984).
8) Anikina, M. et al., Phys. Rev. Lett. 50 (1983) 1971.
   Anikina, M. et al., Z. Phys. C25 (1984) 1.
9) Gazdzicki, M. et al., Z. Phys. C31 (1986) 549.
10) Agakishiyer, H.N. et al., Yad. Fiz. 43 (1986) 366.
11) Hagedorn, R., Rafelski, J., Phys. Lett. 97B (1980) 136.
12) Rafelski, J., Phys. Lett. 91B (1980) 281.
13) McGaughy, P.L. et al., Phys. Rev. Lett. 56 (1986) 2156.
14) Gibbs, W.R., AIP Conf. Proc. 132 (1984) 574.
15) Miyano, K. et al., Phys. Rev. Lett. 53 (1984) 1725.
16) Miyano, K. et al., contribution to this conference.
17) Rafelski, J., Proc. of XXII Rencontres de Moriond, Les Arcs, 1988.
18) Nakai, K., Nucl. Phys. A479 (1988) 331c.
19) Greiner, C., Z. Phys. C.- Particle and Fields, to be published.
20) Steadman, S. et al., contribution to this conference.
21) Ko, C.M., Xia, L., Phys. Rev. C38 (1988) 179.
22) Gazdzicki, M. et al., contribution to this conference.
23) Vesztergombi, G. et al., Z. Phys. C38 (1988) 129.
24) Derado, I. et al., contribution to this conference.
25) Bamberger, A. et al., Phys. Lett. B205 (1988) 583.
    Bamberger, A. et al., Phys. Lett. B184 (1987) 271.
26) Ströbele, H. et al., Z. Phys. C38 (1988) 89.

27) Quercigh, E. et al., contribution to this conference.
28) Antreasyan, D. et al., Phys. Rev. D19 (1979) 764.
29) Greiner, D. et al., contribution to this conference.
30) Lindenbaum, S.J. et al., contribution to this conference.
31) Barz, H.W. et al., Nucl. Phys. A484 (1988) 661.
32) Baym, G., Nucl. Phys. A479 (1988) 27c.

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720