AB

MAX-PLANCK-INSTITUT FÜR PHYSIK UND ASTROPHYSIK
WERNER-HEISENBERG-INSTITUT FÜR PHYSIK

Zurück

MPI-PAE/Exp.E1. 198

January 1989

**A Study of K_s^0 , Λ and $\bar{\Lambda}$ Production
in 60 and 200 GeV per Nucleon OAu and pAu Collisions
with a Streamer Chamber Detector at the CERN SPS**

NA35 Collaboration

CERN LIBRARIES, GENEVA

CM-P00062835

8000 MÜNCHEN 40 - FÖHRINGER RING 6

**A Study of K_s^0 , Λ and $\bar{\Lambda}$ Production
in 60 and 200 GeV per Nucleon OAu and pAu Collisions
with a Streamer Chamber Detector at the CERN SPS**

NA35 Collaboration

A. BAMBERGER⁸⁾, J. BARTKE⁵⁾, H. BIALKOWSKA¹¹⁾, R. BOCK⁶⁾,
R. BROCKMANN⁶⁾, S.I. CHASE³⁾, C. DE MARZO²⁾, M. DE PALMA²⁾,
I. DERADO¹⁰⁾, V. ECKARDT¹⁰⁾, C. FAVUZZI²⁾, D. FERENC¹³⁾,
H. FESSLER¹⁰⁾, P. FREUND¹⁰⁾, M. GAZDZICKI⁷⁾, H.J. GEBAUER¹⁰⁾,
C. GUERRA⁶⁾, J.W. HARRIS³⁾, W. HECK⁷⁾, T. HUMANIC^{6,a)},
K. KADIJA^{10,13)}, A. KARABARBOUNIS¹⁾, R. KEIDEL⁹⁾, M. KOWALSKI⁵⁾,
M. LAHANAS⁷⁾, S. MARGETIS⁷⁾, E. NAPPI²⁾, G. ODYNEC³⁾,
G. PAIC^{13,4)}, A.D. PANAGIOTOU^{4,1)}, A. PETRIDIS¹⁾, J. PFENNIG⁷⁾,
F. POSA²⁾, K.P. PRETZL^{10,b)}, H.G. PUGH³⁾, F. PÜHLHOFER⁹⁾,
G. RAI³⁾, A. RANIERI²⁾, W. RAUCH³⁾, R. RENFORDT⁷⁾,
D. RÖHRICH⁷⁾, K. RUNGE⁸⁾, A. SANDOVAL⁶⁾, N. SCHMITZ¹⁰⁾,
T. SCHOUTEN¹⁰⁾, L.S. SCHROEDER³⁾, P. SEYBOTH¹⁰⁾, J. SEYERLEIN¹⁰⁾,
E. SKRZYPCZAK¹²⁾, P. SPINELLI²⁾, R. STOCK⁷⁾, H. STRÖBELE⁷⁾,
A. THOMAS⁷⁾, M. TINCKNELL³⁾, L. TEITELBAUM³⁾, S. TONSE³⁾,
G. VESZTERGOMBI^{10,c)}, D. VRANIC¹³⁾, S. WENIG⁷⁾

- 1) Physics Department, University of Athens 157-71 Athens, Greece
- 2) Dipartimento di Fisica, Università di Bari, and INFN, I-70126 Bari, Italy
- 3) Lawrence Berkeley Laboratory, University of California, Berkeley CA 94720, USA
- 4) CERN, CH 1211 Geneva 23, Switzerland
- 5) Institute of Nuclear Physics, PL 30055 Cracow, Poland
- 6) Gesellschaft für Schwerionenforschung, D-6100 Darmstadt 11, Fed. Rep. Germany
- 7) Fachbereich Physik, Universität Frankfurt, D-6000 Frankfurt, Fed. Rep. Germany
- 8) Fakultät für Physik, Universität Freiburg, D-7800 Freiburg, Fed. Rep. Germany
- 9) Fachbereich Physik, Universität Marburg, D-3550 Marburg, Fed. Rep. Germany
- 10) Max-Planck-Institut für Physik und Astrophysik, D-8000 München 40, Fed. Rep. Germany
- 11) Institute of Nuclear Studies, PL-00681 Warsaw, Poland
- 12) Institute of Experimental Physics, Univ. of Warsaw, PL-00681 Warsaw, Poland
- 13) Rudjer Boskovic Institute, 41001 Zagreb, Yugoslavia
- a) now at University of Pittsburgh, U.S.A.
- b) now at University of Bern, Switzerland
- c) on leave from Central Research Institute for Physics, H-1525 Budapest, Hungary

(submitted to Zeitschrift für Physik C)

ABSTRACT

The production of neutral strange particles K_s^0, Λ and $\bar{\Lambda}$ has been studied in 60 and 200 GeV per nucleon OAu and pAu collisions with the streamer chamber vertex spectrometer of the NA35 experiment at the CERN-SPS accelerator. Ratios of neutral strange particle production to negatively charged particle production in selected regions of phase space were measured to be the same in OAu and pAu reactions. The rates of strange particle production in central OAu collisions are about a factor of 16 higher than in pAu collisions when compared in the same regions of phase space. If an enhancement of strange particle production in OAu collisions relative to pAu collisions is considered to be a signature for quark-gluon plasma formation, no evidence supporting it is observed. The experimental results are compared to the Lund FRITIOF model.

1. Introduction

It is believed that in ultrarelativistic nucleus-nucleus interactions one can study hadronic systems at higher quark density and temperature conditions than those which prevail in normal hadrons. There are many reasons to expect that at very high density and/or temperature, colour sources (quarks, gluons) could propagate freely over extended volumes [1]. This is what is meant by deconfinement and it would correspond to a new state of matter, referred to as the quark-gluon plasma (QGP). In relativistic heavy ion interactions at the CERN - SPS, it was found that large energy densities of about 3 GeV/fm^3 can be obtained in central collisions [2]. It is therefore important to study such reactions experimentally to look for evidence of QGP formation.

One of the potential probes for the QGP is an enhancement of the production of strange particles [3]. Recent QCD calculations on the lattice with light and strange quarks [4] gave the ratios of energy densities 8:4:1 for gluons, light quarks and strange quarks respectively in the QGP. Unfortunately, it is difficult to calculate in a reliable way the yields of strange particles that finally emerge from collisions involving a transient QGP state. In the hadronization process the copious gluons lead to dilution of the strange particle content. Predictions are rather model dependent, but agree that some enhancement of strange particle production relative to nucleon-nucleon collisions [5] should survive. In particular the ratio of antihyperons to antiprotons might show a strong increase [6]. Further complications arise from the fact that strange particles are produced in nucleon-nucleon collisions at a lower rate than would be expected for a hadronic gas in thermodynamic equilibrium [3]. Therefore in a larger or more long-lived system additional hyperons and kaons might be produced. Of course, they could also be produced by secondary collisions in spectator nuclear matter.

In this paper we present results on neutral strange particle production in interactions of relativistic ^{16}O ions of 60 and 200 GeV per nucleon with ^{197}Au nuclei at the CERN SPS. First preliminary results were presented in [7]. The organisation of the paper is as follows: The experimental apparatus and the trigger are described in sec. 2, the data-analysis procedure is outlined in sec. 3, the experimental results are presented and discussed in sec. 4 and compared to the predictions of current models in sec. 5. A summary and conclusions are given in sec. 6.

2. Experimental Apparatus

The main components of the NA35 experiment are a large volume streamer chamber in the 1.5 T magnetic field of a superconducting vertex magnet for the measurement of charged particle momenta, and a system of electromagnetic and hadronic calorimeters for triggering and energy flow measurements. A more detailed description of the apparatus can be found in [8].

The streamer chamber has a sensitive volume of $2.0 \times 1.2 \times 0.72 \text{ m}^3$. The streamers had an apparent diameter of about 1 mm and a length of about 5 mm. Three cameras, each equipped with a two-stage magnetically focusing image intensifier of 2000-fold luminous gain, recorded the events with a demagnification of 30 on 70 mm film. A momentum resolution of $\Delta p/p = 0.0015p(\text{GeV}/c)$ was achieved. A thin gold target of 0.94 g/cm^2 was positioned 8.5 cm upstream from the streamer chamber. Data were taken with 60 and 200 GeV/nucleon ^{16}O beams as well as with 60 and 200 GeV proton beams.

Three different types of triggers were used:

- (a) A minimum bias trigger (MBT), selecting essentially all inelastic collisions was derived from a thin scintillator counter which was placed downstream from the streamer chamber and which covered the projectile fragmentation region. Its veto threshold was set just below the signal of the projectile particle.
- (b) A forward energy veto trigger (FET) selected interactions in which the total energy in the projectile fragmentation region ($\Theta_{Lab} < 0.3^\circ$) was smaller than a threshold energy of about 200 (100,40) GeV for the oxygen 200 GeV/nucleon (proton 200 GeV, 60 GeV) beam, thus rejecting events with projectile spectators.
- (c) A transverse energy trigger (TET) selected interactions for which the transverse energy in the pseudo-rapidity interval covered by the calorimeters ($2.1 < \eta < 3.7$) exceeded a preset threshold.

The trigger cross sections for the reactions OAu at 200 GeV/nucleon (FET), OAu at 60 GeV/nucleon (TET), pAu at 200 GeV (FET) and pAu at 60 GeV (FET) were 0.24, 0.13, 1.14 and 1.6 barns, corresponding to a fraction of 0.07, 0.04, 0.67 and 0.9 of the total inelastic cross section respectively. The OAu events constitute a sample of central collisions, whereas the pAu events essentially represent an average over collisions with all impact parameters.

3. Data analysis procedure

The streamer chamber pictures were scanned visually on projection tables for events with V^0 decays in the chamber and a primary interaction vertex in the target. For OAu reactions the track density in the forward beam-pencil region was so high that the identification of secondary vertices was impossible there. Therefore the V^0 search was limited to the region outside the pencil by excluding a strip in the middle of the chamber. For pAu reactions the total picture area was searched. The positions of V^0 decay points found in the scan of OAu reactions at 200 GeV/nucleon are shown in Fig. 1 together with an outline of the streamer chamber. The numbers of events which were scanned and the numbers of V^0 decays which were found are listed in Table I.

Measurements were done manually in all 3 views. The geometric reconstruction and momentum fitting of the tracks and vertices were performed by the standard HYDRA program chain. For a sample of events all charged particle tracks were measured, for the rest only the V^0 decays were analysed. The primary vertex (outside the streamer chamber) is known from survey measurements with a precision of a few mm since the incoming beam was well collimated and since the target consisted of a thin foil. This position was verified by vertex fits to the tracks of the fully measured events. The invariant mass distributions of the two outgoing tracks of those V^0 decays which are consistent with pointing back to the target are shown in Fig. 2 for the K_s^0, Λ and $\bar{\Lambda}$ mass hypotheses. For this figure events for which the electron pair hypothesis gave a mass $M_{e^+e^-} < 50$ MeV were excluded. The accuracy of the invariant mass measurement at the K_s^0 mass was $\sigma \approx 6$ MeV. The histograms in Fig. 2 demonstrate the excellent mass resolution and the low level of background obtained with the streamer chamber detector.

Kinematical fits were performed to identify the V^0 decays. Besides the K_s^0, Λ and $\bar{\Lambda}$ particles originating from the primary interactions there is background from K_s^0, Λ and $\bar{\Lambda}$ produced in secondary interactions or hyperon decays and from photons converting in the chamber gas and the thin electrode grids. The V^0 classification was based on the kinematical fit probabilities calculated for the four separate hypotheses: $(\pi^+\pi^-)$, $(p\pi^-)$, $(\bar{p}\pi^+)$ and (e^+e^-) . If a 1-constraint fit (using only the measured V^0 parameters) with a χ^2 - probability $> 1\%$ was obtained for the $\gamma \rightarrow (e^+e^-)$ hypothesis the V^0 was assumed to be a photon conversion background. For the rest of the events 3-constraint fits were performed, which used the known primary vertex position in addition to the measured V^0 parameters. Hypotheses were retained if their fit probability was $> 1\%$. Table I shows a summary of the fit results. In

Fig. 3 the χ^2 - probability distributions for the K_s^0 , Λ and $\bar{\Lambda}$ hypotheses are plotted. Ambiguities between Λ and $\bar{\Lambda}$ hypotheses are rare (see Table I) and in such instances the hypothesis with the better probability was chosen. Ambiguities between K_s^0 and Λ or $\bar{\Lambda}$ fits were resolved on a statistical basis, i.e. the K_s^0 hypothesis was accepted if its probability was larger than 1.25(0.83) times the $\Lambda(\bar{\Lambda})$ probability. This cut aims at producing a flat distribution of $\cos\vartheta$ as shown in Fig. 4, where ϑ is the angle between the direction of the V^0 momentum vector and the direction of the π^+ , p and $\bar{p}$ in the K_s^0 , Λ and $\bar{\Lambda}$ rest frame respectively.

As a check of the identification procedure the invariant mass distributions of the events in the no fit category were searched for K_s^0 and Λ signals. No significant enhancements were found at the K_s^0 mass. From this the number of K_s^0 produced in secondary interactions or lost from the 3C fit sample due to imprecise measurements is estimated to be smaller than 5% of the accepted K_s^0 events. At the Λ mass, however, clear peaks are observed. These amount to 10 – 15% of the accepted Λ sample. Their probable sources are Λ production in secondary interactions and Λ from hyperon decays.

Next it was necessary to find a fiducial volume, which is essentially free from scanning and reconstruction losses. The ratios of apparent mean lifetimes τ as calculated by Bartlett's method [9] to the known values τ_0 [10] were used as indicators. The fiducial volume was chosen to start at a distance R_{cut} from the target and excluded a strip of width Y_{cut} in the center of the chamber as illustrated in Fig. 1. Further cuts on the minimum and maximum laboratory production angles θ_{min} , θ_{max} were applied such that those V^0 lines of flight which entered the fiducial volume traversed a length of at least 30 cm. Thus very small detection probabilities were avoided. In addition a lifetime cut was applied, requiring the particle to decay before five mean lifetimes. The apparent mean lifetimes were then calculated for increasing values of R_{cut} and Y_{cut} . As can be seen from Fig. 5 for the most difficult case of OAu collisions at 200 GeV/nucleon, the calculated mean lifetimes τ decrease to a plateau near the known values τ_0 [10] for $R_{cut} = 50$ cm and $Y_{cut} = 20$ cm. The resulting region is shown by the dashed outline in Fig. 1. The corresponding volumes for OAu at 60 GeV/nucleon (pAu collisions) were defined by $R_{cut} = 40$ cm (30 cm at 200 GeV and 20cm at 60 GeV) and $Y_{cut} = 12$ cm (no cut necessary). Within these restricted fiducial regions we assume our data to be essentially free from scanning losses. Double scans confirmed that random scanning losses were below a level of a few percent.

Because of the selection of a limited fiducial volume the measurements extend

over only a part of the kinematically allowed phase space. To determine the effects of this, detection probabilities $W(p_T, y)$ were calculated with a Monte Carlo program, in which K_s^0 and Λ particles were generated with a uniform distribution in transverse momentum p_T , rapidity y and ϕ , the azimuthal angle around the beam axis. Using the known lifetimes, the fractions $W(p_T, y)$ of K_s^0, Λ expected to be seen in the fiducial volumes were determined as a function of p_T and y . Regions in the (p_T, y) plane were then selected in which a reasonable density of events was still obtained with the given sensitivity of the experiment. The final acceptance regions used for the physics analysis in section 4 are shown in Fig. 6. The acceptance extends to smaller values of p_T and larger values of y for pAu reactions, in which a beam-pencil cut is not required due to the lower charged-particle multiplicity.

4. Experimental results

The corrections for the V^0 detection probability $1/W(p_T, y)$ due to the restricted fiducial volume, the lifetime cut and the decay branching ratios were applied and the numbers of K^0 , Λ and $\bar{\Lambda}$ per triggered interaction were calculated. The quoted errors are purely statistical. There is an additional systematic uncertainty of the order of 10% in the multiplicities of negatively charged particles.

The p_T distributions are shown in Figs. 7–10 for K_s^0 (a), Λ (b) and $\bar{\Lambda}$ (c) produced in central OAu collisions at 200 and 60 GeV/nucleon and in pAu collisions at 200 and 60 GeV respectively. The full lines represent fits of the form

$$\frac{1}{N_{ev}} \cdot \frac{1}{p_T} \cdot \frac{dN}{dp_T} = A \cdot e^{-B \cdot m_T}$$

in the region $p_T > 0.7$ GeV/c, where $m_T = \sqrt{m^2 + p_T^2}$ is the transverse mass. The fits provide an acceptable representation of the data. The fitted values for the slope B are given in Table II. For K_s^0 and Λ the results are around 4.5 GeV^{-1} except in pAu collisions at 60 GeV, where the slopes seem to be steeper. The results for $\bar{\Lambda}$ have rather large statistical errors and are compatible with those for K_s^0 and Λ . The slope parameter B for negatively charged particles (assuming the pion mass) in the same p_T, y regions as for the K_s^0 data were fitted as 5.2 ± 0.2 (4.5 ± 0.3) GeV^{-1} in pAu (central OAu) collisions at 200 GeV/nucleon. They are thus similar to the values found for K_s^0 for $p_T > 0.7$ GeV/c.

The ratios of K_s^0 and Λ production to negatively charged particle h^- production versus the transverse kinetic energy E_T^{kin} are shown by the filled circles in Fig. 11 for pAu and central OAu collisions at 200 GeV/nucleon. The use of the variable E_T^{kin} is motivated by the expectation that thermalized particles of different mass show distributions of the same shape in this variable if they have the same temperature

[11]. The transverse kinetic energy is defined as $E_T^{kin} = m_T - m$, where m is the respective particle mass. The negatively charged particles are known to be predominantly pions. To investigate the effect of the admixture of K^- and $\bar{p}$, their fraction was estimated using the FRITIOF model [12] and was subtracted. As shown by the open circles in Fig. 11, the ratios, of course, increase but the trends of the dependence on E_T^{kin} do not change significantly. From Fig. 11 one further observes that the ratio K_s^0/h^- has an approximately constant value of about 0.08. The ratio Λ/h^- shows a tendency to decrease with increasing values of E_T^{kin} . It is also considerably higher in central OAu than in pAu collisions. One should note, however, that the ratios refer to a smaller rapidity interval in the OAu ($1.5 < y < 2.4$) than in the pAu ($1.4 < y < 5.0$) case.

The rapidity distributions for selected ranges in y are also plotted in Fig. 7–10 for K_s^0 (d), Λ (e) and $\bar{\Lambda}$ (f). To obtain the filled squares the integration over transverse momenta was done in the acceptance regions shown in Fig. 6. Some of the acceptance regions in Fig. 6 are not rectangular. The open squares in Fig. 7e, 9d, 10d show the result of correcting the data to the full rectangular regions assuming the fitted shapes of the p_T -distributions to be valid over the whole rapidity range. The rapidity interval, covered by the experiment for central OAu collisions, is too small to allow clear trends to be observed. In pAu collisions, where the acceptance is larger, K_s^0 and Λ production are seen to be concentrated below the nucleon-nucleon center of mass rapidity of 3.0 (2.2) at 200 (60) GeV beam energy. This effect appears to be weaker for $\bar{\Lambda}$ production.

For a study of the projectile and energy dependences, the data should be restricted to the same kinematic regions. Such a comparison, using the acceptance regions for OAu collisions at 200 GeV/nucleon as depicted in Fig. 6a, is given in Table III. The top 3 rows list the average multiplicities of K_s^0 , Λ , and $\bar{\Lambda}$ in the respective acceptance regions. The bottom 3 rows show the ratios of the average multiplicities of K_s^0 , Λ , and $\bar{\Lambda}$ to that of negatively charged particles h^- in these same acceptance regions. The strange particle multiplicities increase when comparing p to O projectiles or lower to higher energies. However, the production of negatively charged particles (predominantly pions) also increases so that the ratio remains approximately constant when comparing pAu and OAu reactions. Thus there is no increase in the fraction of strange particles among the produced particles in this data.

The particle ratios listed in Table III are higher than those shown in Fig. 11. This is a consequence of using for Table III the particle production rates in a region

of p_T with a lower p_T bound which is near the average p_T value for K_s^0 and Λ but considerably above the average for π^- .

In Table IV the ratios of particle multiplicities in central OAu and in pAu collisions are listed for K_s^0 , Λ , $\bar{\Lambda}$ and negatively charged particles. Interestingly, the values are all close to 16. The triggers selected average pAu reactions and central OAu reactions in which all projectile nucleons interacted. Thus a superposition of 16 pAu collisions seems to reproduce the particle production rates in central OAu reactions rather well. This observation had already been made for the transverse energy production around mid-rapidity [8].

Direct measurements of strange particle production in nucleus-nucleus collisions at high energy are not yet available from other experiments. A study of the production of like-charge μ -pairs, which originate predominantly from K and π -meson decays was used to obtain indirect information on the K/π production ratio in the pseudorapidity range $2.8 < \eta < 4$ [13]. It was found that these ratios were very similar in pU and OU interactions at 200 GeV/nucleon energy. An experiment at lower energy measured K and π meson production in SiAu reactions at 14.5 GeV/nucleon energy [14]. Preliminary results for rapidities around $y = 1.2$ and small values of p_T show a large K^+/π^+ ratio of order 0.2 while the K^-/π^- ratio is about 0.05. Rescattering processes could provide a significant contribution to K^+ production. If rescattering processes are important, they would be expected to also increase Λ production at low rapidities.

The study of strange particle production in the present experiment is possible over a larger (p_T, y) region for pAu collisions than for OAu collisions. For pAu collisions the useable acceptance region in Fig. 6a covers most of phase space. The results, integrated over this larger region, are given for pAu collisions in Table V. A comparison of the particle ratios with those of Table III reveals that these ratios depend strongly on the (p_T, y) region. The reason for this is, of course, that the p_T and y distributions of negatively charged particles (mostly pions) are different from those of strange particles. In particular the p_T distribution of the pions falls off more steeply at small values of p_T . Thus the ratios of strange particle to negatively charged particle production are smaller by a factor 2-3 in the larger acceptance region.

For comparison, Table V also contains the results from measurements in inelastic pp collisions at beam energies of 205 GeV [15] and 360 GeV [16] which are integrated over the full (p_T, y) phase space. These particle production ratios are seen to be rather similar to those found in pAu collisions in this experiment. A comparison of

the p_T spectra of K_s^0 and Λ is shown in Fig. 12. The spectra from pp collisions are normalized to those from pAu collisions for $p_T < 0.7$ GeV/c. One finds a tendency of the spectra to fall off more slowly at larger p_T values in pAu than in pp collisions. Such an effect has already been observed for charged particles [17].

5. Comparison with models

The results, presented in the previous section, were compared to the Lund model of particle production [12] which is designed to describe soft hadronic collisions of nucleons and nuclei. The collisions are modelled as a two step process. First projectile and target nucleons are excited by collisions, where the excitation spectrum of the individual collisions was chosen to fit pp collisions. Secondly these excited nucleons decay according to the Lund string fragmentation scheme. In reactions of nuclei, multiple successive collisions of projectile and target nucleons can occur, but rescattering in the spectator nuclear matter is not considered. The Monte Carlo program implementation FRITIOF was used in the calculations. The appropriate trigger selections were applied to the simulated events when comparisons with the experimental results were made.

The predictions of FRITIOF are shown by the dashed lines in Figs. 7–11. The measured p_T -distributions (a-c) in Fig. 7–10 fall off less rapidly with p_T than the model predictions do, in particular for Λ production (b). A similar discrepancy has been found for negatively charged particle p_T spectra [18]. For the rapidity distributions (d-f) the region covered by the OAu data (see Fig. 7, 8) is too small to allow a conclusive comparison of shapes. Fig. 9, 10 show that in pAu collisions the model predicts rapidity distributions for K_s^0 and $\bar{\Lambda}$ which are similar to the data (d,f). For Λ production (e) the calculation does not reproduce the measurements, it predicts too few Λ at low rapidity and too many at high rapidity.

Tables III and V show predictions of the FRITIOF model for strange particle multiplicities and particle ratios. Table III shows that the predicted Λ multiplicities are too low by about a factor of 2-3, whereas the calculated K_s^0 and $\bar{\Lambda}$ multiplicities are more consistent with the experimental results. This discrepancy largely disappears in pAu collisions when one averages over most of phase space (see Table V). Results of comparisons depend strongly on the chosen (p_T, y) region, since the p_T and y distributions for Λ are not well reproduced by the model,

The FRITIOF model, which is based on a parameterisation of nucleon-nucleon collisions, provides only an approximate description of strange particle production in nucleon-nucleus and nucleus-nucleus collisions. In fact it does not provide an

adequate description of strangeness production in pp collisions (see Table V). In addition there seem to be effects specific to nuclei, such as the flattening of p_T distributions, which are not yet taken into account by the model.

6. Summary and conclusions

The production of neutral strange particles K_s^0, Λ and $\bar{\Lambda}$ was studied with a streamer chamber vertex spectrometer in pAu and OAu collisions at 200 and 60 GeV/nucleon. Within the phase space region accessible to the experiment the following results were obtained:

- (1) The ratios of neutral strange particle to negative particle production are the same in pAu and central OAu collisions at 200 GeV/nucleon.
- (2) Neutral strange particles and negatively charged particles are approximately 16 times more numerous in central OAu than in pAu reactions.
- (3) The p_T distributions are flatter in both pAu and OAu reactions than in pp collisions.

Thus central OAu collisions resemble a superposition of pAu collisions at SPS energies. The experimental results are described in only an approximate way by the FRITIOF model.

Acknowledgements

We wish to thank the CERN accelerator and experimental area groups for providing excellent quality beams and the EF division for their help with the streamer chamber film recording system. We are especially grateful to our scanning and measuring crews at Berkeley, Frankfurt and Munich for their careful and difficult work. This experiment was supported by the Bundesministerium für Forschung und Technologie, Fed. Rep. of Germany and by the US Department of Energy Contract DE-AC03-76SF00098.

REFERENCES

- [1] Quark Matter Formation and Heavy Ion Collisions
eds. M. Jacob and J. Tran Than Van, Phys.Rep. **88**,321 (1986)
A recent review of QGP formation and its experimental signatures can be
found in: K. Kajantie and L. McLerran, Rev.Nucl.Part.Sci. **37**,293 (1987)
- [2] The first set of experimental results may be found in Quark Matter 1987,
eds. H. Satz, H. Specht and R. Stock, Z.Phys. **C38** (1988)
- [3] For a review see: P. Koch, B. Müller and J. Rafelski, Strangeness in Rela-
tivistic Heavy Ion Collisions, Phys.Rep. **142**,167 (1986)
- [4] I. Kogut and D. Sinclair, Phys.Rev.Lett. **60**,1250 (1988)
- [5] T. Matsui et al., Phys.Rev. **D34**,2047 (1986)
Kang S. Lee et al., Phys.Rev. **C37**,1452 and 1463 (1988)
- [6] M. Jacob and J. Rafelski, Phys.Lett. **B190**,173 (1987)
- [7] G. Vesztegombi et al., Z.Phys. **C38**,129 (1988)
- [8] A. Bamberger et al., Phys.Lett. **B184**,271 (1987) A. Sandoval et al.,
Nucl.Phys. **A461**,465c (1987)
- [9] M. Bartlett, Phil.Mag. **44**,249 (1953)
- [10] Review of Particle Properties, Phys.Lett. **B170** (1986)
- [11] see e.g. R. Hagedorn, Riv.Nuov.Cim. **6**,1 (1983)
- [12] B. Andersson et al., Nucl.Phys. **B281**,289 (1987)
The program versions FRITIOF 1.6 and JETSET 6.2 were used, with
standard parameters (the strange quark suppression factor was 0.3).
- [13] P. Sonderegger et al., Z.Phys. **C38**,129 (1988)
- [14] Y. Miake et al., Z.Phys. **C38**,135 (1988)
- [15] K. Jaeger et al., Phys.Rev. **D11**,2405 (1975)
- [16] M. Asai et al., Z.Phys. **C27**,11 (1985)
- [17] J. Cronin et al., Phys.Rev. **D11**,3105 (1975)
D. Antreasyan et al., Phys.Rev. **D19**,764 (1979)

[18] H. Stroebele et al., Z.Phys. **C38**,89 (1988)

TABLES

Table I: Statistics of scanning and fitting V^0 decays in the streamer chamber

	OAU		pAu	
	200 GeV/nuc.	60 GeV/nuc.	200 GeV	60 GeV
events	3368	997	3545	4678
V^0 found	3249	1473	1496	1753
1C fit γ	1429	269	342	316
3C fit K_s^0 unique	334	191	420	451
Λ unique	516	341	355	558
$\bar{\Lambda}$ unique	46	23	37	32
K_s^0 or Λ	174	105	89	86
K_s^0 or $\bar{\Lambda}$	48	16	31	18
Λ or $\bar{\Lambda}$	1	0	2	1
no fit	701	428	221	291

Table II: Slope parameters B obtained from a fit of the form $1/p_T \cdot dN/dp_T = A \cdot e^{-B \cdot m_T}$ to the transverse momentum distributions of Figs. 7–10 in the region $p_T > 0.7(0.5)$ GeV/c at 200 (60) GeV. Here $m_T = \sqrt{m^2 + p_T^2}$ denotes the transverse mass.

	OAU 200 GeV/nuc.	OAU 60 GeV/nuc.	pAu 200 GeV	pAu 60 GeV
K_s^0	4.2 ± 0.4	4.8 ± 0.7	4.9 ± 0.4	6.5 ± 0.6
Λ	4.9 ± 0.3	4.5 ± 0.4	4.7 ± 0.5	6.2 ± 0.4
$\bar{\Lambda}$	3.2 ± 1.4	5.8 ± 1.3	5.8 ± 0.7	5.5 ± 1.2

Table III: Average multiplicities of produced strange particles and ratios with negatively charged particles in the p_T , rapidity regions shown in Fig. 6a. Predictions from the FRITIOF model are also listed.

	pAu, 200 GeV		OAU, 200 GeV/nucleon	
	Data	FRITIOF	Data	FRITIOF
$\langle K_s^0 \rangle$	0.044 ± 0.008	0.043	0.665 ± 0.086	0.710
$\langle \Lambda \rangle$	0.081 ± 0.009	0.029	1.507 ± 0.111	0.583
$\langle \bar{\Lambda} \rangle$	0.006 ± 0.002	0.005	0.098 ± 0.026	0.092
$\langle K_s^0 \rangle / \langle h^- \rangle$	0.150 ± 0.029	0.149	0.142 ± 0.022	0.152
$\langle \Lambda \rangle / \langle h^- \rangle$	0.153 ± 0.019	0.059	0.179 ± 0.017	0.073
$\langle \bar{\Lambda} \rangle / \langle h^- \rangle$	0.028 ± 0.010	0.024	0.025 ± 0.007	0.028

	pAu, 60 GeV		OAU, 60 GeV/nucleon	
	Data	FRITIOF	Data	FRITIOF
$\langle K_s^0 \rangle$	0.035 ± 0.012	0.021	0.473 ± 0.107	0.378
$\langle \Lambda \rangle$	0.090 ± 0.017	0.025	1.407 ± 0.174	0.504
$\langle \bar{\Lambda} \rangle$	0.003 ± 0.002	0.0014	0.037 ± 0.017	0.043
$\langle K_s^0 \rangle / \langle h^- \rangle$	0.254 ± 0.108	0.126	0.150 ± 0.039	0.145
$\langle \Lambda \rangle / \langle h^- \rangle$	0.267 ± 0.070	0.075	0.244 ± 0.038	0.100
$\langle \bar{\Lambda} \rangle / \langle h^- \rangle$	0.024 ± 0.016	0.015	0.014 ± 0.007	0.020

Table IV: Ratios of K_s^0 , Λ , $\bar{\Lambda}$ and negatively charged particle multiplicities in central OAU and pAu reactions at 200 and 60 GeV/nucleon energy. The p_T, y regions are those of the OAU data (see Fig. 6a, b). Predictions of the FRITIOF model are also shown.

	200 GeV		60 GeV	
	Data	FRITIOF	Data	FRITIOF
$R_{K_s^0}$	15.1 ± 3.4	16.5 ± 0.8	12.8 ± 4.8	18.8 ± 1.0
R_Λ	18.6 ± 2.5	20.1 ± 2.1	14.6 ± 3.0	21.2 ± 1.0
$R_{\bar{\Lambda}}$	16.3 ± 7.0	18.4 ± 3.8	13.7 ± 7.0	19.6 ± 3.3
R_-	15.9 ± 1.2	16.2 ± 0.3	23.0 ± 3.6	16.4 ± 0.2

Table V: Average multiplicities of produced strange particles and ratios with negatively charged particles. For the pAu data the p_T, y acceptance regions are those of Fig. 6c. The data on pp collisions [15, 16] are averaged over all inelastic events and integrated over the full p_T, y phase space. Predictions of the FRITIOF model were calculated for 200 GeV beam energy.

	pAu, 200 GeV		pp collisions		
	Data	FRITIOF	205 GeV [15]	360 GeV [16]	FRITIOF
$\langle K_s^0 \rangle$	0.332 ± 0.022	0.397	0.181 ± 0.014	0.26 ± 0.01	0.21
$\langle \Lambda \rangle$	0.238 ± 0.016	0.202	0.103 ± 0.011	0.12 ± 0.02	0.15
$\langle \bar{\Lambda} \rangle$	0.040 ± 0.006	0.064		0.013 ± 0.004	0.02
$\langle K_s^0 \rangle / \langle h^- \rangle$	0.077 ± 0.005	0.088	0.064 ± 0.005	0.074 ± 0.005	0.08
$\langle \Lambda \rangle / \langle h^- \rangle$	0.043 ± 0.003	0.036	0.036 ± 0.004	0.034 ± 0.003	0.06
$\langle \bar{\Lambda} \rangle / \langle h^- \rangle$	0.007 ± 0.001	0.011		0.004 ± 0.001	0.02

FIGURE CAPTIONS

1. Schematic diagram of the outline of the streamer chamber (full lines) and of the V^0 fiducial region (dashed lines) used for OAu collisions at 200 GeV/c. The dots mark V^0 decay points found in the visual scan.
2. Invariant mass distributions of V^0 decays for K_s^0, Λ and $\bar{\Lambda}$ mass hypotheses in 200 GeV/nucleon OAu (a-c), 60 GeV/nucleon OAu (d-f), 200 GeV pAu (g-i) and 60 GeV pAu (j-l) reactions. Events with $M_{e^+e^-} < 50$ MeV are excluded. For the $\pi^+\pi^-$ mass distributions (a,d,g,j) also events for which the $\Lambda, \bar{\Lambda}$ hypothesis falls in the mass range 1.1 - 1.3 GeV are removed.
3. Probability distributions for 3-constraint kinematic fits to the K_s^0, Λ and $\bar{\Lambda}$ hypotheses for all reactions. V^0 with a 1-constraint fit to the $\gamma \rightarrow e^+e^-$ hypothesis are excluded. The shaded areas show the numbers of ambiguous hypotheses which are removed by the selection procedure (see text).
4. Distributions of the cosine of the angle ϑ between the V^0 momentum direction and the direction of the π^+, p and $\bar{p}$ in the K_s^0, Λ and $\bar{\Lambda}$ rest frame for hypotheses with 3-constraint fits of probability $> 1\%$. The shaded areas show ambiguous hypotheses which are removed by the selection procedure (see text).
5. Ratio of calculated τ to known mean lifetime τ_0 for K_s^0, Λ and $\bar{\Lambda}$ decays versus the starting distance from the target R_{cut} and the width of the central exclusion strip Y_{cut} of the fiducial region. Results are for OAu collisions at 200 GeV/nucleon.
6. Acceptance regions in transverse momentum p_T and rapidity y in OAu collisions at 200 GeV/nucleon (a) and 60 GeV/nucleon (b) and pAu collisions at 200 GeV (c) and 60 GeV (d) for K_s^0 (dashed), Λ (full) and $\bar{\Lambda}$ (dotted).
7. OAu central collisions at 200 GeV/nucleon:(a-c) transverse momentum distributions for K_s^0, Λ and $\bar{\Lambda}$ in the rapidity intervals $1.7 < y < 2.8, 1.5 < y < 2.4$ and $1.5 < y < 2.4$ respectively. The full lines show fits of the form $A \cdot e^{-B \cdot m_T}$. (d-f) rapidity distributions for the p_T cuts shown in Fig. 6a (filled squares). The open squares in (e) show the results after a correction was made for the increasing p_T cut at high rapidities. Predictions of the FRITIOF model are shown by dashed lines.
8. OAu central collisions at 60 GeV/nucleon:(a-c) transverse momentum distributions for K_s^0, Λ and $\bar{\Lambda}$ in the rapidity intervals $1.7 < y < 3.0, 1.3 < y < 2.8$ and $1.3 < y < 2.8$ respectively. The full lines show fits of the form $A \cdot e^{-B \cdot m_T}$. (d-f) rapidity distributions for the p_T cuts shown in Fig. 6b. Predictions of the FRITIOF model are shown by dashed lines.
9. pAu collisions at 200 GeV:(a-c) transverse momentum distributions for K_s^0, Λ and $\bar{\Lambda}$ in the rapidity intervals $2.2 < y < 5.0, 1.4 < y < 5.0$ and $1.4 < y < 5.0$ respectively. The full lines show fits of the form $A \cdot e^{-B \cdot m_T}$. (d-f) rapidity distributions for the p_T cuts shown in Fig. 6c (filled squares). The open squares in (d) show the results after a correction was made for the increasing p_T cut at low rapidities. Predictions of the FRITIOF model are shown by dashed lines.
10. pAu collisions at 60 GeV:(a-c) transverse momentum distributions for

K_s^0, Λ and $\bar{\Lambda}$ in the rapidity intervals $2.0 < y < 5.0, 0.9 < y < 5.0$ and $0.9 < y < 5.0$ respectively. The full lines show fits of the form $A \cdot e^{-B \cdot m_T}$. (d-f) rapidity distributions for the p_T cuts shown in Fig. 6d (filled squares). The open squares in (d) show the results after a correction was made for the increasing p_T cut at low rapidity. Predictions of the FRITIOF model are shown by dashed lines.

11. Ratios of K_s^0 and Λ production rates to negatively charged particle (h^-) production rates versus E_T^{Kin} in pAu collisions at 200 GeV and central OAu collisions at 200 GeV/nucleon (filled dots). The open dots show the result of removing from the negative particles the contribution of K^- and $\bar{p}$ as estimated by the FRITIOF model. The rapidity regions are $2.2 < y < 5.0$ ($1.4 < y < 5.0$) for K_s^0 (Λ) in pAu collisions and $1.7 < y < 2.8$ ($1.5 < y < 2.4$) for K_s^0 (Λ) in OAu collisions. Predictions of the FRITIOF model are shown by the dashed lines.
12. Transverse momentum distributions in pAu and pp collisions for K_s^0 (a) and Λ (b). The squares are results for pAu collisions from this experiment in $2.2 < y < 5.0$ (a) and $1.4 < y < 5.0$ (b). The circles and triangles show data from inelastic pp collisions at 205 GeV [15] and 360 GeV [16] respectively, normalized to the pAu points for $p_T < 0.7$ GeV/c.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11