Strangeness production in high density baryon matter

R. Ganz
University of Illinois Chicago, USA
and
Max Planck Institut für Physik,
Förhringer Ring 6,
D-80805 München, Germany

for the E917 collaboration

B.B. Back¹, R.R. Betts¹,6, H.C. Britt⁵, J. Chang³, W.C. Chang³,
C.Y. Chi⁴, Y.Y. Chu², J.B. Cumming², J.C. Dunlop⁸, W. Eldredge³,
S.Y. Fung⁴, R. Ganz⁶,9, E. Garcia⁷, A. Gillitzer¹¹,10, G. Heintzelman⁸,
W.F. Henning⁴, D.J. Hofman¹, B. Holzmann¹¹,16, J.H. Kang¹²,
E.J. Kim¹², S.Y. Kim¹², Y. Kwon¹², D. McLeod⁶, A. Mignerey⁷,
M. Moulson⁴, V. Nanal¹, C. Ogilvie⁸, R. Pak¹¹, A. Ruangma⁷,
D.E. Russ⁷, R.K. Seto³, P.J. Stanssens⁷, G.S.F. Stephans⁸, H. Wang³,
F.L.H. Wolfs¹¹, A.H. Wuosmaa¹, H. Xiang³, G.H. Xu³, H.B. Yao⁸,
C.M. Zou³

¹ Argonne National Laboratory, Argonne, IL 60439 USA
² Brookhaven National Laboratory, Chemistry Department, Upton, NY 11973 USA
³ University of California Riverside, Riverside, CA 92521 USA
⁴ Columbia University, Nevis Laboratories, Irvington, NY 10533 USA
⁵ Department of Energy, Division of Nuclear Physics, Germantown, MD 20874 USA
⁶ University of Illinois at Chicago, Chicago, IL 60607 USA
⁷ University of Maryland, College Park, MD 20742 USA
⁸ Massachusetts Institute of Technology, Cambridge, MA 02139 USA
⁹ Max Planck Institut für Physik, D-80805 München, Germany
¹⁰ Technische Universität München, D-85748 Garching, Germany
¹¹ University of Rochester, Rochester, NY 14627 USA
¹² Yonsei University, Seoul 120-749, South Korea

Abstract. Strangeness production in heavy-ion collisions, when compared to proton proton collisions, is potentially a sensitive probe for collective energy deposition and therefore for reaction mechanisms in general. It may therefore provide insight into possible QGP formation in dense nuclear matter. To establish an understanding of the observed yields, a systematic study of high density baryon matter at different beam energies is essential. This might also reveal possible discontinuities in the energy dependence of the reaction mechanism. We present preliminary results for kaon production in Au+Au collisions at beam kinetic energies of 6, 8, and 10.7 GeV/u obtained by the E917 experiment at the AGS (BNL). These measurements complement those carried out by the E866 collaboration at 2, 4, and 10.7 GeV/u with a significantly enlarged data sample. In both experiments a large range of rapidities was covered by taking data at different angular settings of the magnetic spectrometer.
1. Motivation

Collisions of heavy ions at energies around 10 AGeV offer a unique opportunity to study baryonic matter at very high densities \(2\rho_0 - 8\rho_0\); where \(\rho_0\) is the density of nuclei in their ground state. It has been proposed that such densities may result in the formation of a new phase of matter, the Quark Gluon Plasma. But, even if the existence of such a state remains highly speculative, a systematic study of these collisions at various projectile energies and centralities (implying different densities) is important to gain insight into reaction mechanisms and the behaviour of hadrons under such extreme conditions. It also provides a “baseline”-measurement for comparisons with experiments at higher center-of-mass energies (SPS, RHIC). It might place stringent constraints on models, thus yielding a more detailed understanding of relativistic heavy ion collisions in general.

The goal of the E917 experiment is to carry out such an investigation; it is achieved on one hand by a systematic variation of the initial state of the collision in terms of beam energy and centrality, and, on the other, by a determination of a whole set of final state observables such as:

- Production yields, masses and mass-width of short-lived vector mesons (\(\phi, K^+\)) and baryonic resonances (\(\Delta^{++}\)),
- cross sections for the production of \(\bar{p}\) and strange hadrons,
- high statistics two-particle intensity interferometry (HBT).

In this presentation we focus on the beam energy dependence of pion and kaon production at mid-rapidity.

![Figure 1. A schematic view of the E917 spectrometer.](image-url)
2. The E917 experiment

E917 is located at the AGS accelerator facility at Brookhaven National Laboratory, New York (BNL). This experiment concludes a series of preceding experiments, E802, E859 and E866 [2, 3, 4, 5], which carried out various measurements with O, S, and Au beams. In particular, E866 studied Au+Au collisions at 2, 4, and 10.7 AGeV projectile kinetic energies, which has been complemented by the E917 measurements at 6, 8, and 10.7 AGeV with an upgraded experimental setup (figure 1; a detailed description of the E802 apparatus can be found in [6]). The main part of the E917 apparatus is a movable spectrometer arm, which consists of the “Henry-Higgins” (HH) magnet (± 0.4 Tesla) located between sets of multi-wire drift chambers (T1-T4 and TRF1-TRF2), each comprising several wire planes with different orientations. This allows for momentum measurement with a resolution of $\Delta p/p \approx 1\%$.† In combination with a time-of-flight scintillator wall (TOF; timing resolution $\delta t \approx 130$ ps), particle identification is achieved as shown in figure 2. The whole spectrometer can be rotated about the target and centered at polar angles in the range of 14°-44° in 5° steps with respect to the beam axis; measurements over a wide range of rapidities are therefore possible. At each setting, a solid angle of 25 msr is covered by the spectrometer.

A set of beam counters detects and validates incoming beam particles, vetos upstream interactions and defines a “time-zero” for the time-of-flight measurement. An upper limit on the signal from the “Bullseye” detector (BE) – being insensitive on the 25% of most peripheral collision – is used to trigger on interactions in the 4% interaction length gold target. To enrich the data sample with events with a specific combination of identified particles (e.g. $2K/\bar{p}$), a Level 2 trigger has been implemented, based on characteristic hit patterns in the TOF system and two multi-wire proportional chambers (TR1-TR2).

To characterize the centrality of a collision two methods were used. One utilized the multiplicity measured in the New Multiplicity Array (NMA), which surrounds the target area. The other allows for an estimate of the number of participants in the collision via the energy ($E_{ZCAL}$) recorded in the Zero Degree Calorimeter (ZCAL; 1.5° opening angle) and the projectile energy ($E_{Proj}$) from $N_{part} \approx 197 \times (1 - E_{ZCAL}/E_{Proj})$.

An important new feature of the E917 apparatus is an event-by-event tracking of beam particles by four position sensitive scintillating fiber detectors (BVER; $\delta x \approx 200\mu m$) mounted upstream of the target [7]. In combination with the downstream scintillator wall (HODO) this allows for an event-by-event reconstruction of the reaction plane of non-central collisions. Further recent improvements of the E917 setup are improvements to the TR1 trigger chamber and a more reliable data acquisition system.

3. Preliminary results

Preliminary results from an analysis of a subset of the Au+Au data taken in November ’96- January ’97 are presented in the following sections in comparison with results obtained by the E866 collaboration [6, 3, 4, 5].

Figure 3 shows the invariant yields at mid-rapidity $|y - y_{cm}| / y_{cm} < 0.25$ of pions, kaons, and protons as function of $m_t = \sqrt{p_t^2 + m_0^2}$ for beam kinetic energies of

† A resolution of 2% was achieved in the low energy measurement with a ±0.2 Tesla HH field.
Figure 2. This figure demonstrates the particle identification capabilities of E917. Plotted is the inverse of the particle momentum extracted from a drift chamber tracking versus the time-of-flight measured in the TOF wall. The different branches are labeled according to the different particle species.

Figure 3. Invariant particle yields are plotted on a logarithmic scale vs. $m_t - m_0$ at $\Delta y \pm 0.25$ around mid-rapidity for central Au+Au collision. The yields for beam kinetic energies 4 AGeV and higher are scaled as labeled. The errors bars shown are statistical only.
2, 4, 6, 8, and 10.7 AGeV The most central 8% of the total interaction cross section of 6.8 b [12] have been selected. The error bars are statistical only. The systematic error varies between 5% - 20% dependent on particle type.

In case of kaons a single exponential describes the spectral shape of the yield quite well, whereas for the pions a double exponential is better suited due to the enhancement of the yield at low transverse momenta, which is most pronounced for $\pi^-$. In the case of protons the yield follows a Boltzmann shape as a function of $<m_t>$.

*Figure 4.* The upper two panels show the invariant yields for $K^+$ and $\pi^+$ integrated over $m_t$ versus the center-of-mass energy of the collision. The arrow in the upper right panel indicates the $pp \rightarrow \Lambda K^+ p$ threshold. The two lower panels show the corresponding dependence of the average transverse mass. The error bars include statistical errors and 5% point-to-point systematic uncertainty.

Instead of extracting slope parameters ("temperature") from the shapes, the average value $<m_t - m_0>$ might be a better way to characterize the amount of longitudinal kinetic energy of the projectile transferred into "thermal" motion of final state particles. Figure 4 compares the energy dependence of $<m_t - m_0>$ for $\pi^+$ and $K^+$ with the energy dependence of total yields $dN/dy$ at mid-rapidity. The plotted values are derived from extrapolating the measured $m_t$-spectrum using the functional forms mentioned above. With increasing available energy ($\sqrt{s}$) both observables rise smoothly and no discontinuities are found, as might naïvely be expected if a transition to a QGP had occurred. The figure also shows that $<m_t>$ increases rather slowly.

† Which part of the transverse motion is due to thermal motion and which due to collective phenomena like expansion is currently under investigation.
over the energy range considered, and show a hint of saturation at the higher end. The number of produced particles, $dN/dy$, increases more rapidly, not only for the kaons produced close to threshold, but also for the pions. Taking into account that stopping seems to be rather complete at AGS energies [5], this observation means that the extra available energy preferentially goes into particle production and not into an increase of their transverse energy.

![Figure 5. The ratio of $K^+$ to $\pi^+$ yield at mid-rapidity plotted versus the available energy for central Au+Au collisions. Errors are statistical only. The hatched area correspond to predictions from the RQMD cascade model.](image)

The fact that this increase with $\sqrt{s}$ is more pronounced for the kaon yields is expressed in terms of the ratio $K^+ / \pi^+$, which rises continuously with increasing available energy (figure 5). Such a behaviour might be expected considering that the threshold for $pp \rightarrow \Lambda K^+ p$ is at $\sqrt{s} = 2.343$ AGeV [13]. Moreover, the observed energy dependence is in good agreement with predictions from the RQMD cascade model [14].

Further up the energy scale, a $K^+ / \pi^+$-ratio of 0.145 was deduced from results of the NA49 measurement [15, 16] of Pb+Pb collisions at $\sqrt{s} = 17.2$ AGeV [18]. This is significantly below what is found in the measurement at the highest AGS energy and prompts the question, at which energy the maximum is reached and whether this might

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† The reference gives the ratio $(K+\bar{K})/\pi = 0.145$ extrapolated to $4\pi$, from which the $K^+ / \pi^+ \approx 0.14$ in the text is estimated by using $K^0_s \approx K^+$, $K^+ / K^- \approx 1.8$, and $\pi^- \approx \pi^0 \approx \pi^+$. 
Strangeness enhancement is one of the potential signatures at the transition to the Quark Gluon Plasma. One way to quantify “enhancement” is to normalize the $K^+ / \pi^+$-ratio measured in $Au+Au$ collisions to the one observed in $p+p$ collisions at the same center-of-mass energy. Such a double ratio, if larger than one, suggests that we are not dealing simply with a superposition of “$A$ times” a nucleon-nucleon collision, but that we must consider effects such as multiple collisions, collective phenomena, thermalization and even the existence of a QGP phase, all of which may contribute to an enhanced production of kaons, but which should be absent in proton-proton collisions. For the $Au+Au$ data this double ratio is shown in figure 6. It should be noted that the ratio for $Au+Au$ collisions is derived at mid-rapidity, whereas the ratio for $p+p$ collisions taken from literature [18, 19, 20] is given as the integral over all rapidities. The data point at the lowest beam kinetic energy ($2\, AGeV$) has been omitted because of a large uncertainty of the $p+p$ kaon yield. No correction for the Fermi motion or isospin difference between $Au+Au$ and $p+p$ has been applied.

This double ratio grows when getting closer to the kaon production threshold in $pp$ collisions, which underlines the importance of secondary collisions for production.

**Figure 6.** The ratio $K^+$ to $\pi^+$ measured in $Au+Au$ collisions is divided by the corresponding value of $p+p$ collisions. The ratio in $Au+Au$ is determined at mid rapidity, whereas the $p-p$ data in the literature is integrated over all rapidities.
of kaons from nucleus-nucleus collisions in this energy regime. Again, a comparison to the √s = 17.2 AGeV Pb+Pb measurement is instructive. Normalized to p+p data[21, 22] at √s = 19.4 AGeV the double ratio \((K^+/\pi^+)_{AuAu}/(K^+/\pi^+)_{pp}\) ≈ 1.7 still significantly exceeds unity. Even if threshold effects, which dominate the AGS energy regime, are negligible, the enhancement still persists, as different channels for kaon production may come in to play.

4. Summary and conclusion

E917 has carried out a study of particle production by systematic variation of the initial state of the collision in terms of beam energy, centrality and reaction plane. Results on the energy dependence of the kaon and the pion yield from a preliminary E917 analysis in conjunction with a set of similar measurements from the E866 collaboration do not exhibit any sudden changes indicating new phenomena. The increase of available energy appears predominantly as an increase of the number of particles and not as an increase of transverse momentum. The comparison of the \(K^+/\pi^+\) ratio to results at CERN SPS indicates a maximum at intermediate energy, which might indicate a change of production mechanism. This ratio normalized to p+p collisions, seems to level off at higher energies, which is also not fully understood. A more detailed analysis of the complete data set will shed light one these questions.

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† The kaon yield in p+p collisions is almost constant (≈ 0.087) for center-of-mass energies of 10 GeV–100 GeV.