STRANGENESS SIGNALS IN HEAVY ION COLLISIONS*

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Abstract

The experimental data on strange meson and strange baryon production in relativistic heavy ion collisions are reviewed.

INTRODUCTION

Enhanced production of strange particles was suggested early on as a possible signature for the formation of the quark-gluon plasma.¹ This follows from the observation that, while the thresholds for ΛK and KK production are 700 and 1000 MeV, respectively, that for $s\bar{s}$ production is only about 300 MeV. Quark pairs are expected to copiously produced in the plasma, and the high temperature expected in this deconfined state should thus result in a relative enhancement of strange quark pairs in the plasma. This in turn might be expected to yield an enhancement of strange particle production relative to that from ordinary hadronic interactions. However, the fate of these strange quarks as the plasma rehadronizes is not easy to predict, and a calculation which takes into account multiple hadronic interactions during heavy-ion collisions, but include no plasma formation, has predicted modest strangeness enhancements.² Thus strange particle production cannot be regarded as an unambiguous signal for quark-gluon plasma formation. Yields of strange anti-baryons remain the most promising an indicator of plasma production.³ Nevertheless, in the absence of deconfinement, the cross sections for the various strange particles are good diagnostics for the details of the heavy-ion collisions.

The data come from the heavy-ion programs at the BNL AGS, with 14.6 A · GeV/c p, O, and Si beams and (since 1992) a 11.7 A · GeV/c Au beam, and at the CERN SPS with 200 A · GeV/c p, O, and S beams. Most of the data initially are in the form of p_t or m_t spectra. Although much useful information is contained in the slope parameters, which range from ~ 150 to ~ 225 MeV, the systematic errors in the determination of these slopes are often large and poorly known, and will not be discussed here.

AGS DATA

Two experiments at the AGS, E802 and E810, have reported data on strange particles. E802 has employed a magnetic spectrometer with excellent particle identification to measure charged-particle momentum spectra. One of it's first findings was a substantial enhancement in the yields of charged kaons.⁴ This is best illustrated in Figure 1 which compares charged-particle yields from p+Be, p+Au,⁵ and central Si+Au reactions.⁶ The latter are divided by 28 to give the yields per interacting projectile nucleon. One sees that the dn/dy values for pions in the vicinity of mid-rapidity are approximately constant, whereas those for K^+ increase from p+Be to p+Au to central Si+Au. The behavior of the values for K^- are similar, but with less statistical significance. The K^+/π^+ ratios for $1.2 \leq y \leq 1.4$ in p+Be, p+Au, and central Si+Au are $(7.8 \pm 0.4)\%$, $(12.5 \pm 0.6)\%$, and $(18.2 \pm 0.9)\%$; the errors are statistical only.

MASTER

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Figure 1. Rapidity distributions dn/dy for pions, kaons, and protons in p+Be, p+Au, and central Si+Au collisions at 14.6 A · GeV/c from E802. The Si+Au data are plotted as $(dn/dy)/28$.

The p+Be reaction effectively mimics pp (or, more precisely, pd), while p+Au demonstrates the effects of secondary interactions in the Au target. The enhancement in the K^+/π^+ ratio for the heavy-ion projectile is demonstrated in the increase from p+Au to central Si+Au.

The earlier E802 results suggested that the dn/dy distribution for K^+ was shifted to smaller rapidities compared with those for pions. The latest E802 data,⁶ with better statistics and increased y and p_t coverage, are included in Figure 1. Although these data are statistically consistent with the earlier data, it is now clear that the K^+ distribution peaks at the same rapidity as do the pions, and has the same shape. The K^- distribution is less well known, but the shape is consistent with that of the pions.

A study of the K^+/π^+ ratio as a function of both collision centrality and target was recently carried out by E802.⁷ The collision geometry can be well defined with a zero-degree calorimeter which effectively functions as a beam stop. It measures the total kinetic energy of the projectile spectators after an interaction, the number of which is obtained by dividing by

Figure 2. K/π ratios plotted for each target as function of number of projectile participants from E802.

13.5 GeV. The number of projectile participants, a convenient measure of collision centrality, is obtained by subtracting the number of spectators from 28. The K^+/π^+ ratio as a function of the number of participants for Si + Al, Cu, and Au targets is shown in Figure 2. Several points should be noted: a) the values of the ratio for Al are slightly lower than those for Cu and Au, reflecting the incomplete "stopping" in the Al target; b) the values for non-central collisions with Cu and Au are essentially identical; and c) although there is a general increase with increasing centrality, the ratio shows a jump for central Si+Au collisions. The increase in the K^+/π^+ ratio with both increasing target size and centrality, suggests the importance of reinteractions, and that they increase the production of kaons more than that of pions.

The RQMD model² explicitly takes reinteractions into account, and a comparison of K/π ratios calculated by RQMD with the E802 experimental values is shown in Figure 3. It appears that the calculation slightly underesti-

Figure 3. Comparisons of experimental (E802) and calculated (RQMD) K/π ratios for central Si+Au.

mates the K^+/π^+ ratio and slightly overestimates the K^-/π^- ratio, but RQMD actually does a remarkably good job of reproducing these data.

The data from E810 complements that from E802. A TPC (without dE/dx) is used which thus identifies K^0 's and Λ 's from secondary vertices. Their recent results for Si+Si are shown in Figure 4.⁸ These data provide complete coverage in y because the symmetric systems can be reflected about y_{cm} . The reflected data for K^0 's are in very good agreement with the E802 data for $(K^+ + K^-)/2$ from Si+Al. Also shown is comparable data from pp interactions multiplied by 28,⁹ which indicates an enhancement of a factor of about two for the Si reactions. The Λ rapidity distribution from the Si+Si reaction is strongly peaked at mid-rapidity, in contrast to that from pp collisions, confirming the idea that the enhanced Λ production comes from multiple interactions.

The E810 data for Si+Pb are shown in Figure 5. The K^0 data for Si+Pb is also compared with the $(K^+ + K^-)/2$ data from E802 for Si+Au. The two data sets are consistent although the comparison is not rigorous because of the isospin factor. It is interesting to note that where there is overlap between the E802 data for protons and the E810 data for Λ 's ($1.5 \leq y \leq 2.1$) the Λ/p ratio is about 1/4. Comparisons of the E810 data with results from the

Figure 4. Rapidity distributions for K^0 's and Λ 's in central Si+Si collisions at 14.6 A · GeV/c from E810.

Figure 5. Rapidity distributions for K^0 's and Λ 's from central Si+Pb collisions at 14.6 A · GeV/c from E810.

ARC code¹⁰ are also included in figures 4 and 5. The agreement is seen to be excellent for the Λ 's and fair for the K^0 's.

Figure 6. Invariant mass distribution of K^+K^- pairs from central Si+Au collisions at 14.6 A·GeV/c from E859. The inset shows the ϕ -peak with the background subtracted.

E859, the first follow-on experiment to E802 with the addition of a second-level trigger to the E802 spectrometer to select rare particles, is obtaining extensive data on kaon spectra. These are still being analyzed, but one interesting result, shown in Figure 6, is the observation of a substantial ϕ -meson peak in a sample of K^+K^- pairs. The ϕ , which consists of a $s\bar{s}$ pair, has been suggested as an interesting strangeness signal.¹¹ The mass and width obtained are consistent with the known values and the spectrometer resolution, but a detailed acceptance calculation has yet to be completed so no statement about the yield can be made.

The first results on kaon production with the Au beam were obtained by E866, a follow-on experiment to E802/E859. Because of the high multiplicities resulting from Au-Au collisions, data are so far only available from back angles. The K^+/π^+ ratio resulting from central Au+Au collisions in the rapidity interval $0.55 \leq y \leq 0.85$ is $(25 \pm 2)\%$, which is substantially higher than that from central Si+Au collisions. A summary of all the E802/E866 K^+/π^+ ratios in this rapidity interval for central collisions of the various projectiles with Au targets is shown in Figure 7. The K^-/π^- ratio for central Au+Au does not

Figure 7. K^+/π^+ ratios in central collisions p+Au, O+Au, Si+Au, and Au+Au in the rapidity interval $0.55 \leq y \leq 0.85$ from E802/E866.

show a similar increase over that from Si+Au. However, this may be a consequence of the relatively higher threshold for K^- production and the lower beam energy (per nucleon.)

SPS DATA

The SPS data primarily come from three experiments, NA35, NA36, and WA85, all of which detect and reconstruct V^0 's. NA35 used a streamer chamber and has reported yields of K^0 's, Λ 's and anti- Λ 's from p+S and S+S collisions at 200 A·GeV/c.¹² They observed an enhancement of about two in the multiplicities of all three strange particles relative to those of negative hadrons for central S+S collisions, compared to p+S and peripheral S+S colli-

Figure 8. Rapidity distributions of Λ , K^0 , and anti- Λ in central S+S and in p+S collisions from NA35. The open circles in the upper row are reflections of the measured data about mid-rapidity.

sions. The rapidity distributions for central S+S (for particles above the indicated p_T cutoff) and p+S collisions are shown in Figure 8. The distributions for K^0 's and anti- Λ 's are peaked at

mid-rapidity, but those for Λ 's are different. The Λ -distribution for p+S collisions shows a peak in the target fragmentation region with a gradual decrease going forward, more or less as expected, but that for central S+S collisions exhibits a broad plateau. This presumably indicates a gradual shift in the predominant Λ production mechanism with rapidity.

Figure 9. Rapidity distributions of Λ , anti- Λ , and K^0 in S+Pb and p+Pb collisions at 200 A·GeV/c from NA36.

NA36 employed a TPC to detect V^0 's.¹³ Their recent data on the production of K^0 's, Λ 's, and anti- Λ 's from p+Pb and S+Pb collisions at 200 A·GeV/c are presented in Figure 9. These rapidity distributions are qualitatively similar to those of NA35 for the S target with the notable exception of the Λ 's resulting from S+Pb collisions. The Λ distribution exhibits a similar increase towards mid-rapidity as do those of the K^0 's and anti- Λ 's. This again implies a significant change in the production mechanism with increasing rapidity. The larger

effect with the Pb target is probably due to the increased stopping and resulting higher energy-density than is the case for the S target. These data for S+Pb also show an increase, by factors of 2-3, in the ratios of the multiplicities of the strange particles to those of negative hadrons for non-peripheral collisions relative to the ratios from peripheral collisions and p+Pb.

The WA85 experiment uses the CERN Omega Spectrometer with MWPC's to reconstruct V^0 's in the limited kinematic range $2.3 < y < 3.0$ and $p_T > 1.0$ GeV/c.¹⁴ However, they are able to reconstruct Ξ 's and anti- Ξ 's, and thus their Λ and anti- Λ yields can be corrected for contributions from Ξ decay. (All of the measurements discussed here do not distinguish Σ^0 from Λ .) The WA85 results show smaller enhancements in the ratios of K^0 , Λ , and anti- Λ multiplicities to negative-hadron multiplicities from S+Pb collisions relative to those from p+Pb collisions. This may be a consequence of the limited kinematic coverage of this experiment. The most interesting results from WA85 concern Ξ production. The relative yields of the hyperons are given in Table 1.

Table 1. Relative hyperon production ratios for S+W data.

Ratio	$m_T > 1.72$ GeV	$1 < p^T < 2$ GeV/c
anti- Λ/Λ	0.13 ± 0.03	0.13 ± 0.03
anti- Ξ/Ξ	0.39 ± 0.07	0.30 ± 0.07
Ξ/Λ	0.20 ± 0.04	0.11 ± 0.02
anti- $\Xi/\text{anti-}\Lambda$	0.6 ± 0.2	0.33 ± 0.11

The anti- $\Xi/\text{anti-}\Lambda$ ratio is substantially larger for S+W systems than for any other reaction from which it has been measured. The significance of these results are discussed at length by Rafelski.⁶

The two di-muon experiments at CERN, NA38¹⁵ and HELIOS,¹⁶ have reported an enhancement in the $\phi/(\rho + \omega)$ ratio for central

S+W collisions at 200 A·GeV/c relative to p+W or non-central S+W. The available data are still preliminary, but the enhancements reported are consistent with those obtained by the other CERN experiments for neutral strange particles.

CONCLUSIONS

All of the relevant heavy-ion experiments at the AGS and the SPS have reported enhancement factors of ~ 2 -3 in the production of strange particles in central nucleus-nucleus collisions relative to that in peripheral nucleus-nucleus or proton-nucleus collisions. Although these results are consistent with a transient phase transition to a quark-gluon plasma, they can also be explained by multiple hadronic reactions. Thus this strangeness enhancement cannot by itself be taken as an indicator of formation of the quark-gluon plasma. However, the excessive production of doubly-strange antibaryons remains a promising candidate.

REFERENCES

1. J. Rafelski and B. Müller, "Strangeness Production in the Quark-Gluon Plasma," *Phys. Rev. Lett.* 48, pp. 1066-1069, (1982); and P. Koch, B. Müller, and J. Rafelski, "Strangeness in Relativistic Heavy Ion Collisions," *Phys. Rep.* 142, pp. 167-262, (1986).
2. R. Mattiello, H. Sorge, H. Stöcker, and W. Greiner, "K/ π Ratios in Relativistic Nuclear Collisions: A Signature for the Quark-Gluon Plasma?," *Phys. Rev. Lett.* 63, pp. 1459-1462 (1989).
3. J. Rafelski, "Strange and Hot Matter," *Nucl. Phys. A* 544, pp. 279c-292c, (1992); J. Rafelski, "Strange Antibaryons: QGP Versus Hadron Gas," *these proceedings*.
4. T. Abbott, *et al.*, "Preliminary spectrometer results 4. from E802," *Z. Phys. C* 38, pp. 135-139, (1988).
5. T. Abbott *et al.*, "Comparison of p + A and Si + Au Collisions at 14.6 GeV/c," *Phys. Rev. Lett.* 66, pp. 1567-1570, (1991).
6. M. Gonin, "Hadron Spectra from Si + A Collisions at 14.6 A·GeV/c," presented at the International Nuclear Physics Conference, Wiesbaden, Germany, July 26 - August 1, 1992
7. T. Abbott, *et al.*, "Centrality Dependence of K⁺ and π^+ multiplicities from Si+A collisions at 14.6 A·GeV/c," *Phys. Lett. B*, in press (1992).
8. S.E. Eiseaman, *et al.*, "Rapidity Distributions of K⁰'s and Λ 's Produced by 14.6 A·GeV/c Si beams on Si and Pb Targets," *Phys. Lett. B*, in press, (1992).
9. V. Blobel, *et al.*, "Multiplicities, topological cross sections, and single particle inclusive distributions from pp interactions at 12 and 24 GeV/c," *Nucl. Phys. B* 69, p. 454, (1974).
10. Y. Pang, T.J. Schlagel, and S.H. Kahana, "Cascade for Relativistic Nuclear Collisions," *Phys. Rev. Lett.*, 68, pp. 2743-2746, (1992).
11. A. Shor, " ϕ -Meson Production as a Probe of the Quark-Gluon Plasma," *Phys. Rev. Lett.* 54, pp. 1122-1125, (1985).
12. J. Bartke, *et al.*, "Neutral strange particle production in sulphur-sulphur and proton-sulphur collisions at 200 GeV/nucleon," *Z. Phys. C*, pp. 191-200, (1990).
13. E. Anderson, *et al.*, "Results from CERN experiment NA36 of strangeness production," *Nucl. Phys. A* 544, pp. 309c-320c, (1992), and D. Greiner, private communication.
14. S. Abatzis, *et al.*, "Strange particle production in sulphur-tungsten interactions at 200 GeV/c per nucleon," *Nucl. Phys. A* 544, pp. 321c-334c, (1992), and F. Navach, private communication.
15. M.C. Abreu, *et al.*, "Muon pair production in heavy ion interactions at 200 GeV per nucleon," *Nucl. Phys. A* 544, pp. 209c-222c, (1992).
16. U. Goerlach, "Results of the HELIOS collaboration on low mass dilepton and soft photon production in p-Be, p-W and S-W collisions," *Nucl. Phys. A* 544, pp. 109c-124c, (1992), and U. Goerlach, "New results in di-muon and vector resonance production at 200 GeV/c," *these proceedings*.

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