Neutral strange particle production and flow at AGS energies

P Chung[(1)] for the E895 Collaboration: J M Alexander[(1)], N N Ajitanand[(1)], M Anderson[(5)], D Best[(2)], F P Brady[(5)], T Case[(2)], W Caskey[(5)], D Cebra[(5)], J L Chance[(5)], B Cole[(10)], K Crowe[(2)], A Das[(3)], J E Draper[(5)], M L Gilkes[(6)], S Gushue[(8)], M Heffner[(5)], A S Hirsch[(6)], E L Hjort[(6)], L Huo[(12)], M Justice[(4)], M Kaplan[(7)], D Keane[(4)], J C Kintner[(11)], J Klay[(5)], D Krofcheck[(9)], R A Lacey[(1)], C Law[(1)], M A Lisa[(3)], H Liu[(4)], Y M Liu[(12)], R McGrath[(1)], Z Milosevich[(7)], G Odyniec[(2)], D L Olson[(2)], S Panitkin[(2)], C Pinkenburg[(1)], N T Porile[(6)], G Rai[(2)], H G Ritter[(2)], J L Romero[(5)], R Scharenberg[(6)], L Schroeder[(2)], B Srivastava[(6)], N T B Stone[(2)], T J M Symons[(2)], J Whitfield[(7)] and W N Zhang[(12)]

(1) Departments of Chemistry and Physics, University Stony Brook, NY 11794-3400, USA
(2) Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
(3) Ohio State University, Columbus, OH 43210, USA
(4) Kent State University, Kent, OH 44242, USA
(5) University of California, Davis, CA 95616, USA
(6) Purdue University, West Lafayette, IN 47907-1396, USA
(7) Carnegie Mellon University, Pittsburgh, PA 15213, USA
(8) Brookhaven National Laboratory, Upton, NY 11973, USA
(9) University of Auckland, Auckland, New Zealand
(10) Columbia University, New York, NY 10027, USA
(11) St Mary's College, Moraga, CA 94575, USA
(12) Harbin Institute of Technology, Harbin, 150001 People's Republic of China

Received 11 November 1998

Abstract. In recent experiments at the AGS, the E895 Collaboration has made detailed measurements of neutral strange particles (K_s^0 and Λ) over a broad range of incident energies and impact parameters for the Au + Au system. Preliminary results are presented for the production yields and the sidewards flow of these particles. The production yields show relatively good agreement with existing systematics. The Λ particles show flow results which are similar to those reported for protons, albeit with a smaller magnitude. On the other hand, the K_s^0 seem to follow an anti-flow pattern suggesting that the kaon vector potential plays an important role in high-density nuclear matter.

1. Introduction

The production of strange particles in relativistic heavy ion reactions has attracted much attention as an important probe for nuclear matter produced at high-energy densities. Of particular interest are recent suggestions that kaon yields can be used to probe the nuclear equation of state (EOS) [1] while kaon flow offers a good probe for the in-medium kaon potential [2]. Motivated by these suggestions, the E895 Collaboration has performed an extensive set of measurements for neutral strange particles at the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory. The measurements, which have been

0954-3899/99/020255+07$19.50

performed for the Au + Au system, spans the 2–8 A GeV beam energy range for several impact parameters. This contribution presents preliminary results from these measurements.

2. Λ and K_s^0 reconstruction

The experiments have been performed at the AGS. Charged reaction products were detected in the EOS Time Projection Chamber (TPC) situated in a uniform magnetic field (0.75 T for 2 A GeV and 1 T for 4, 6 and 8 A GeV). The EOS TPC provides continuous 3D tracking and identification for particles with $-1 \leqslant Z \leqslant 6$ [3]. Λ's and K_s^0 ejectiles (collectively referred to as V0's below) were reconstructed from their charged particle decays;

$$\Lambda \longrightarrow p + \pi^- \qquad BR \sim 64\%, \qquad K_s^0 \longrightarrow \pi^+ + \pi^- \qquad BR \sim 69\%. \tag{1}$$

Our analysis procedure followed the following steps. First, all TPC tracks in an event were reconstructed and the overall event vertex was calculated. For Λ and K_s^0 reconstruction, each pair of $p\pi^-$ and $\pi^+\pi^-$ (respectively) was looped over and its point of closest approach was calculated. Pairs whose trajectories intersect at a point other than the main vertex were evaluated with a V0 hypothesis from which an invariant mass and momentum were extracted. Second, a fully connected, feedforward multilayered neural network [4] was used to separate 'true' Λ's and K_s^0's from the combinatoric background. The network was trained, at each beam energy, from a set consisting of 'true' V0's and background V0's. 'True' V0's were obtained by embedding Λ and K_s^0 particles in raw data events in a detailed GEANT simulation of the TPC. The obtained events were then 'filtered' through the normal data analysis chain. Background V0's which were generated via a mixed event procedure served as 'fake' V0's in the training of the neural network.

The invariant mass distributions for Λ's and K_s^0 obtained from the neural network for 2, 4, 6 and 8 A GeV semi-central Au + Au collisions are shown in figures 1 and 2, respectively. The average number of V0's reconstructed per event and the reconstruction efficiency are also shown in the figures. Figures 1 and 2 clearly show that V0's are detected rather cleanly with relatively good efficiency. The reconstruction efficiencies were obtained by tagging and embbedding GEANT-simulated V0's in real data events followed by a reconstruction procedure which followed the normal data analysis chain. The following breakdown of the total efficiency for Λ at 6 A GeV gives an idea of the relative magnitudes of the various efficiencies involved; geometrical $\sim$88%, hitfinding + tracking + V0 reconstruction $\sim$24%, V0 neural network cut $\sim$52%, and branching ratio $\sim$64%.

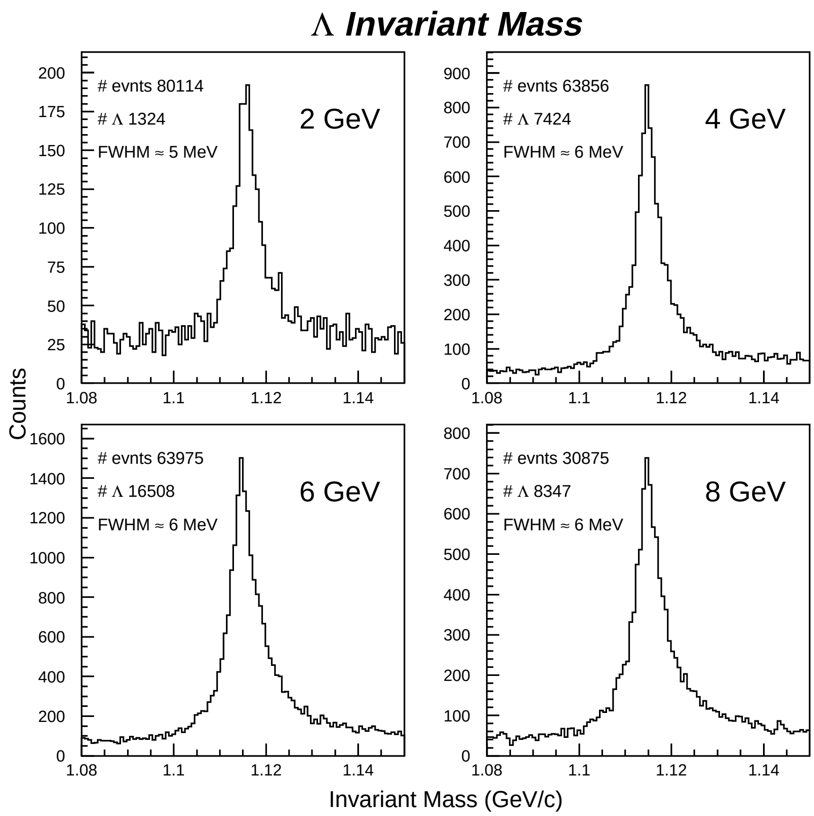
At low energies ($\sim$2 A GeV), neutral strange particles are produced essentially through the associated production mechanism:

$$p + n \longrightarrow K^+ + \Lambda + n \qquad E_{th} \sim 1.6\ \text{GeV}, \qquad n + n \longrightarrow K^0 + \Lambda + n. \tag{2}$$

Since the two reactions are equally likely, one expects the yields of Λ's to be about twice as much as that for K^0's. It is encouraging to see that this ratio is exhibited by the K^0's and Λ's at 2 A GeV.

3. K_s^0 and Λ yields

Figure 3 shows the variation of the K^0 production probability per participant nucleon (in central Au + Au collisions) as a function of bombarding energy. Here, the bombarding energy is normalized to the production threshold for free nucleon–nucleon collisions. For comparison we have included a comprehensive data set on meson production probabilities from other experiments. The solid curve shown in the figure represents a fit to the π and η meson



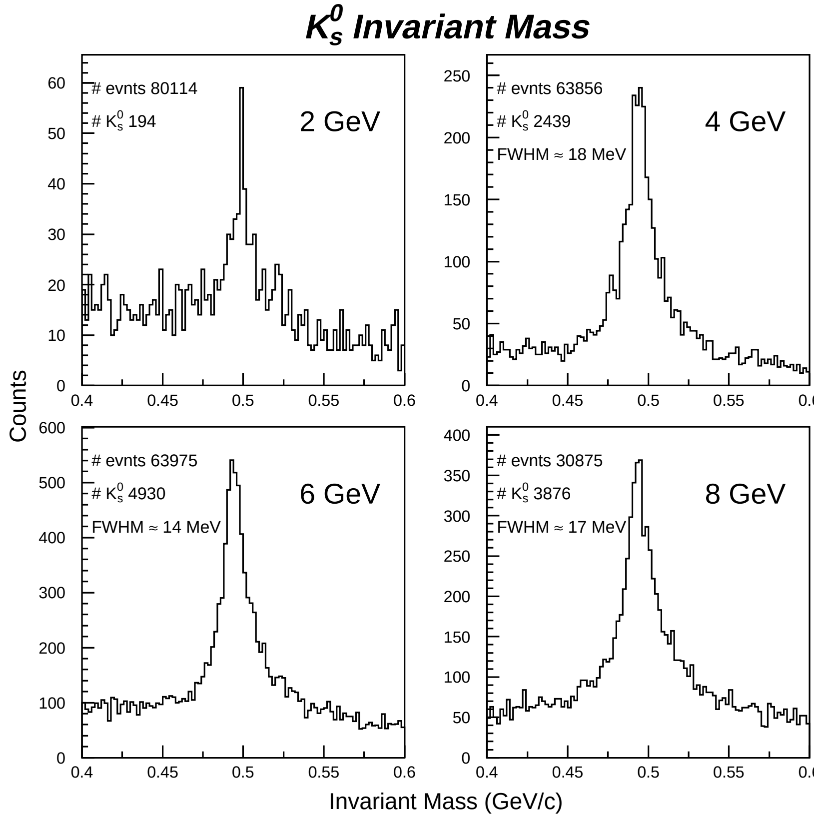
	rec Λ/evnt	η
2AGeV	0.0165 ± 0.0005	8.2% ± 0.2%
4AGeV	0.116 ± 0.001	5.2% ± 0.2%
6AGeV	0.258 ± 0.002	6.3% ± 0.2%
8AGeV	0.270 ± 0.003	4.8% ± 0.1%

Figure 1. Invariant mass spectra for Λ particles produced in 2, 4, 6 and 8 A GeV Au + Au collisions. The tabulated efficiencies and mean multiplicities per event are preliminary.

production probabilities [5]. As pointed in [5] the K^+ and K^- production probabilities differ from the empirical fit (solid curve) by up to a factor of five. Our results indicate K^0 production probabilities which agree well with existing strange meson systematics; they are lower than the empirical fit by a factor of ∼2–3.

A similarly constructed Λ multiplicity excitation function clearly shows that the Λ yields not only increase with beam energy but also with system size.

We have investigated the centrality dependence of the average multiplicity for both Λ and K^0_s. The filtered multiplicity for tracks which miss the main event vertex by at most 2.5 cm was taken as a measure of the event centrality. We find an essentially monotonic increase of the yield with event multiplicity. That is, the largest Λ and K^0_s multiplicities are associated with the most central events.



	rec K_s^0/evnt	η
2AGeV	0.0024 ± 0.0002	$2.2\% \pm 0.1\%$
4AGeV	0.038 ± 0.001	$2.1\% \pm 0.1\%$
6AGeV	0.077 ± 0.001	$2.8\% \pm 0.1\%$
8AGeV	0.126 ± 0.002	$2.3\% \pm 0.1\%$

Figure 2. Invariant mass spectra for K_s^0 particles produced in 2, 4, 6 and 8 A GeV Au + Au collisions. The tabulated efficiencies and mean multiplicities per event are preliminary.

4. K_s^0 and Λ sideward flow

A sample of ∼8500 semi-central (filtered multiplicity ⩾100) 6 A GeV Au + Au events has been analysed for Λ sideward flow following the standard transverse momentum analysis technique of Danielewicz and Odyniec [6]. First, a reaction plane vector was determined for each particle i in an event by summing over all other baryons j in that event;

$$Q_i = \sum_{j \neq i}^{n} w(y_j) p_j^t / |p_j^t|. \qquad (3)$$

p_j^t and y_j are the tranverse momentum and rapidity of baryon j in the event. The weight $w(y_j)$ is assigned the value $\langle p^x \rangle / \langle p^t \rangle$. Subsequent to reaction plane determination, the transverse

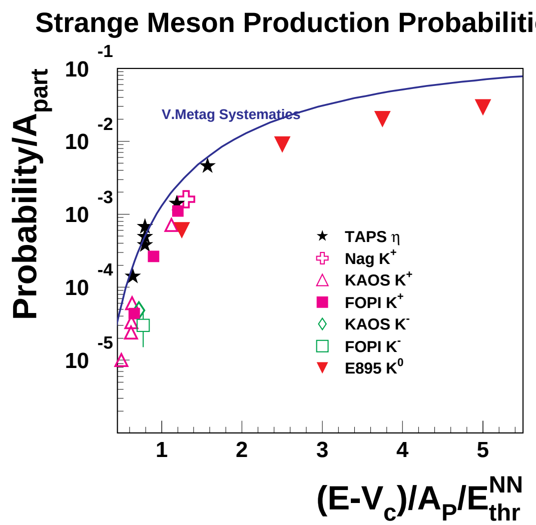


Figure 3. Strange meson production probability excitation function. The filled triangles represent the E895 data. The data are preliminary.

momentum of particle i in the reaction plane, p_i^x, is obtained. Further averaging of p^x over particles as a function of rapidity gives the typical S-shaped curve shown in figure 4 for protons [9] and Λ's. The reaction plane dispersion, $\langle\phi_{12}\rangle/2$ is estimated to be $\sim 35^\circ$ via the sub-event method [6]. The data shown in the figure have not been corrected for this dispersion. Negative rapidity protons suffer from geometrical acceptance losses. Consequently, we have reflected the data for protons (filled squares) in figure 4. It is also noteworthy that we have avoided autocorrelations for Λ by requiring that the proton used to reconstruct a Λ particle does not appear in the sum used in the calculation of the reaction plane vector. Although the statistics are limited, figure 4 clearly shows that the Λ flow with the protons albeit with a much smaller magnitude. This is essentially the behaviour observed in earlier work by Justice *et al* and Ritman *et al* [7, 8].

We have performed a similar analysis for K_s^0 particles from a sample of $\sim$2000 events. The results of this analysis is shown in figure 5 where we give the mean transverse momentum in the reaction plane as a function of the normalized cm rapidity. Each rapidity bin contains less than 8% combinatoric background. Since we have established that the effect of this background is negligible, it has not been subtracted. The TPC coverage for K_s^0 is very limited at backward rapidities, hence the cut-off at $y \sim -0.2$. Figure 5 shows that the K_s^0's display a flow pattern which appears to be opposite to that of the protons and the Λ's. Here again, limited statistics result in large error bars. However, the results are quite suggestive. A definitive quantitative measure of this flow will have to wait for more statistics. Nevertheless, it is important to stress here that an antiflow pattern for K_s^0's would be indicative of a significant repulsive vector potential inside the nuclear medium.

5. Summary

The E895 Collaboration has measured neutral strange particle production and flow at AGS energies. Preliminary results indicate that production yields are consistent with existing systematics and show no apparent dramatic increase with increasing beam energy. Λ and K_s^0

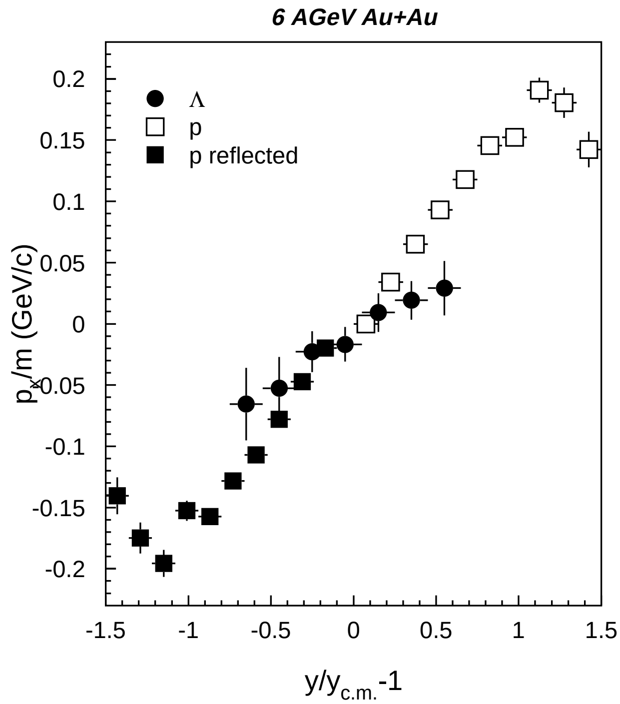


Figure 4. $\langle p^x \rangle / m$ versus rapidity for Λ particles (filled circles) and protons (open squares). The forward rapidity values for protons have been reflected (filled squares). The data are preliminary.

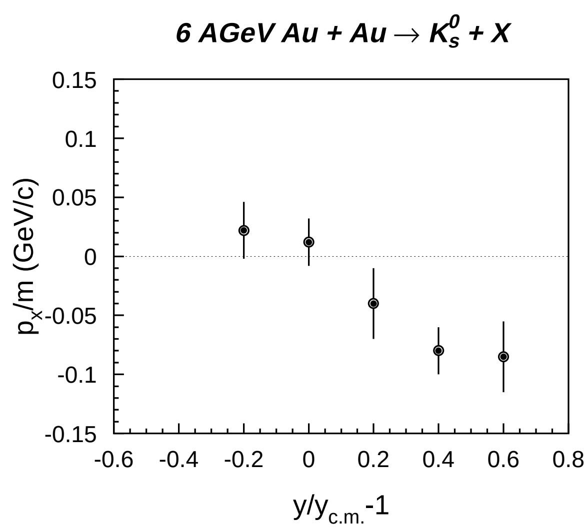


Figure 5. $\langle p^x \rangle / m$ versus rapidity for K_s^0 particles. The data are preliminary.

multiplicities appear to vary smoothly with centrality at 6 A GeV. Our transverse momentum flow analysis show that Λ flow with protons at 6 A GeV but K_s^0's seem to follow an anti-flow pattern. Additional statistics (currently being accumulated) will allow for a more quantitative measure of V0 flow at 6 A GeV and the other beam energies.

Acknowledgments

This work was supported in part by the US Department of Energy under grants DE-FG02-87ER40331.A008, DE-FG02-89ER40531, DE-FG02-88ER40408, DE-FG02-87ER40324, and contract DE-AC03-76SF00098; by the US National Science Foundation under grant nos PHY-96-05207, PHY-9722653, PHY-9601271, and PHY-9225096; and by the University of Auckland Research Committee, NZ/USA Cooperative Science Programme CSP 95/33.

References

[1] Aichelin J *et al* 1985 *Phys. Rev. Lett.* **55** 2661
[2] Li G Q, Ko C M and Bao-An Li 1995 *Phys. Rev. Lett.* **74** 235
[3] Rai G *et al* 1990 *IEEE Trans. Nucl. Sci.* **37** 56
[4] Justice M 1997 *Nucl. Instrum. Methods Phys. Res.* A **400** 463
[5] Metag V 1998 *GSI Preprint* 98-09
Hermann N *et al* 1996 *Nucl. Phys.* A **610** 49c
[6] Danielewicz P and Odyniec G 1985 *Phys. Lett.* B **157** 146
[7] Justice M *et al* 1995 *Nucl. Phys.* A **590** 549
[8] Ritman J *et al* 1995 *Nucl. Phys.* A **352** 355
[9] Liu H *et al* (E895 Collaboration) 1998 *Nucl. Phys.* A **638** 451c