Neutral Strange Particle Dynamics in Au+Au collisions at AGS Energies

P. Chung†§, J. M. Alexander†, N. N. Ajitanand†, M. Anderson(5), D. Best(3), F. P. Brady(5), T. Case(3), W. Caskey(5), D. Cebra(5), J. L. Chance(5), B. Cole(10), K. Crowe(3), A. C. Das(2), J. E. Draper(5), M. L. Gilkes†, 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), Roy A. Lacey†, J. Lauret†, M. A. Lisa(2), H. Liu(4), Y. M. Liu(12), R. McGrath†, Z. Milosevich(7), G. Odyniec(3), D. L. Olson(3), S. Panitkin(4), C. Pinkenburg†, N. T. Porile(6), G. Rai(3), H. G. Ritter(3), J. L. Romero(5), R. Scharenberg(6), L. Schroeder(3), B. Srivastava(6), N. T. B. Stone(3), T. J. M. Symons(3), J. Whitfield(7), T. Wienold(3), R. Witt(4), L. Wood(5), and W. N. Zhang(12)
(E895 Collaboration)

† Depts. of Physics and Chemistry, SUNY @ Stony Brook, Stony Brook, NY 11794, USA
(2) Ohio State University, Columbus, Ohio 43210
(3) Lawrence Berkeley National Laboratory, Berkeley, California, 94720
(4) Kent State University, Kent, Ohio 44242
(5) University of California, Davis, California, 95616
(6) Purdue University, West Lafayette, Indiana, 47907-1396
(7) Carnegie Mellon University, Pittsburgh, Pennsylvania 15213
(8) Brookhaven National Laboratory, Upton, New York 11973
(9) University of Auckland, Auckland, New Zealand
(10) Columbia University, New York, New York 10027
(11) St. Mary's College, Moraga, California 94575
(12) Harbin Institute of Technology, Harbin, 150001 P. R. China

Abstract. The E895 Collaboration has investigated a number of mixed-particle correlations involving neutral strange particles (K_s^0 & Λ) in 2, 4, 6 and 8 AGeV Au+Au collisions at the AGS. The first measurements for pΛ correlations indicate a correlation magnitude of about 50% with a 26MeV width. Detailed comparisons between data and theory suggest an emitting source with an effective gaussian radius close to 4.5fm. This radius is much larger than the value of 2.8fm predicted by the relativistic transport code ART. Pairs of pK^0, $\pi^-\Lambda$ and $\pi^- K^0$ are found to display essentially zero correlation at 6 AGeV. The latter observations are not unexpected considering that the proton-K^0 interaction has a very small scattering length and there are no very-well-known interactions between pions and Λ's or K^0's.

§ pchung@mail.chem.sunysb.edu

1. Introduction

The study of two-particle relative momentum correlations, at relativistic energies, has provided a wealth of information on reaction dynamics e.g.[1, 2, 3, 4, 5]. Of direct relevance is the widely accepted notion that two-particle correlation functions are sensitive to the space-time extent of the emitting source and the two-particle interaction at the time of freeze-out. Moreover, recent theoretical studies[6] suggest that Λp correlation measurements may serve as more sensitive probes of the space-time extent in certain cases, compared to determinations from pp correlations.

A few years ago, the E895 Collaboration conducted a series of correlation measurements involving collisions of relativistic Au beams on Au targets over a broad range of energies at the AGS. This contribution summarizes first results for mixed-particle correlations [involving neutral strange particles (K^0_s & Λ)] obtained from these data. Detailed comparisons between experimental and simulated correlation fucnctions provide important constraints on the space-time character of the emitting source or scattering length for Λp pairs.

2. Λ Reconstruction and Invariant Mass Spectra

Measurements were performed with the EOS Time Projection Chamber (TPC) situated in a uniform magnetic field of 3/4 T for 2 AGeV beam and 1 T for 4, 6 and 8 AGeV. The TPC provides continuous 3–D tracking and identification for charged particles with $-1 \leq Z \leq 6$ [9]. Λ particles were reconstructed from their charged particle decays; $\Lambda \longrightarrow p + \pi^-$ $\quad BR \simeq 64\%,\ c\tau \simeq 7.8$cm. Each pair of p π^- was considered and an invariant mass calculated . Thereafter, a neural network was used to separate real Λ's from combinatoric background [10, 11, 12, 13].

Figs.1(a)-(d) show invariant mass spectra for Λ's from 2, 4, 6 and 8 AGeV semi central (b $\leq$ 7fm) Au+Au collisions respectively. The distributions show relatively narrow mass peaks (FWHM $\simeq$ 6 MeV) at the characteristic value expected for the Λ hyperon $\simeq$ 1.116 GeV). The good peak to background ratio obtained establishes the feasibility of Λ correlation studies with the E895 data set.

3. Λp Correlation Function

The Λp Correlation Function, C(K), is calculated as a function of K, which is equal to 1/2 the relative momentum between the proton and the Λ in the Λp center-of-mass frame. C(K) is constructed as the ratio of a foreground distribution in K to a background distribution. In the foreground distribution, the proton and Λ particles are chosen from the same event whereas for the background distribution, the proton and Λ particles come from different events.

The finite two-track resolution of the TPC can introduce different distortions in the foreground/background distributions. Possible bias to the correlation function resulting from such distortions, were removed by "filtering" the foreground and background distributions through a track-merging cut. That is, Λp pairs, for which the primary and daughter protons are separated by less than 4.5cm over a distance of 18cm, were removed from both foreground and background distributions[1]. Also, a combined correction of about 67% has been applied to the height of the correlation above 1, C(K)-1, to account for the effect of the 20% combinatorial background under

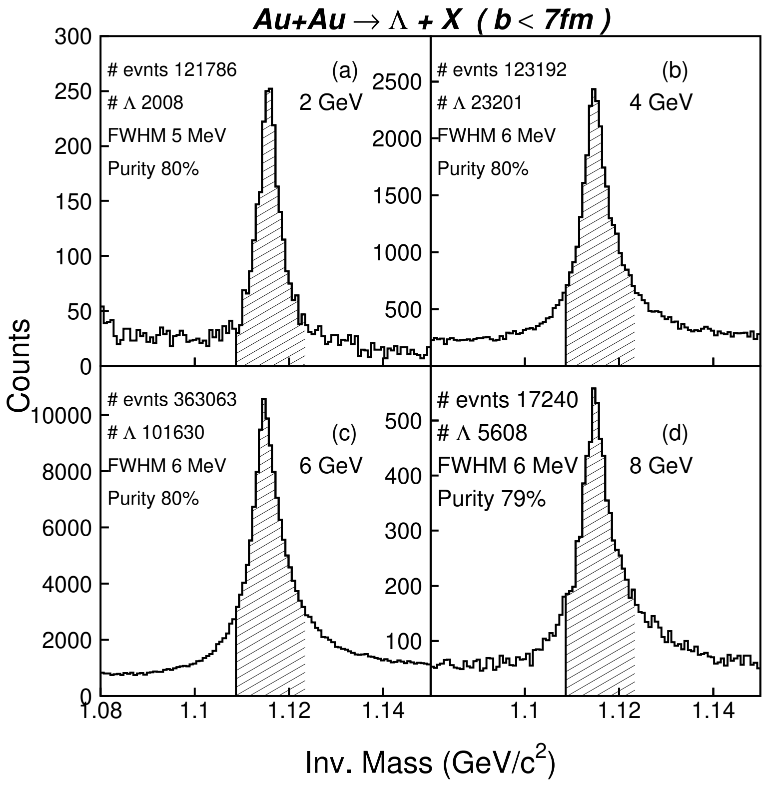

Figure 1. Invariant mass spectra for reconstructed Λs in 2, 4, 6 and 8 AGeV semi-central collisions. The purity (indicated in the figure) is obtained by extrapolating and subtracting the combinatoric background from the hatched area in the figure.

the mass peak and the 25% feeddown from Σ^0 decays (RQMD estimate: about 25% of all Λ's are secondary Λ's from Σ^0 decays at AGS energies).

Figs.2(a)-(d) show the Λp correlation functions, C(K), obtained from 2, 4, 6 and 8 AGeV Au+Au collisions respectively. The correlation functions have been fitted with a gaussian function, $C(K) = 1 + \lambda \exp(-K^2/2\sigma^2)$, to extract the width, σ, and the magnitude, λ, of the correlation. The correlations at 2 and 4 AGeV seem to have a larger magnitude than at 6 and 8 AGeV. However, low statistics at the lower beam energies does not allow this conclusion to be definite. Instead, the correlations are seen to have an average width of 26MeV and an average magnitude of about 50% within statistical errors.

We note here a previous analysis[14] of the same data set, in which K was calculated in the projectile nucleon-target nucleon CM frame, instead of the pΛ pair CM frame. This results in an essentially null Λp correlation. For unlike particle correlations, the difference in mass, between the particles requires one to use the pair CM frame in order to achieve the desired sensitivity to the pairwise interactions.

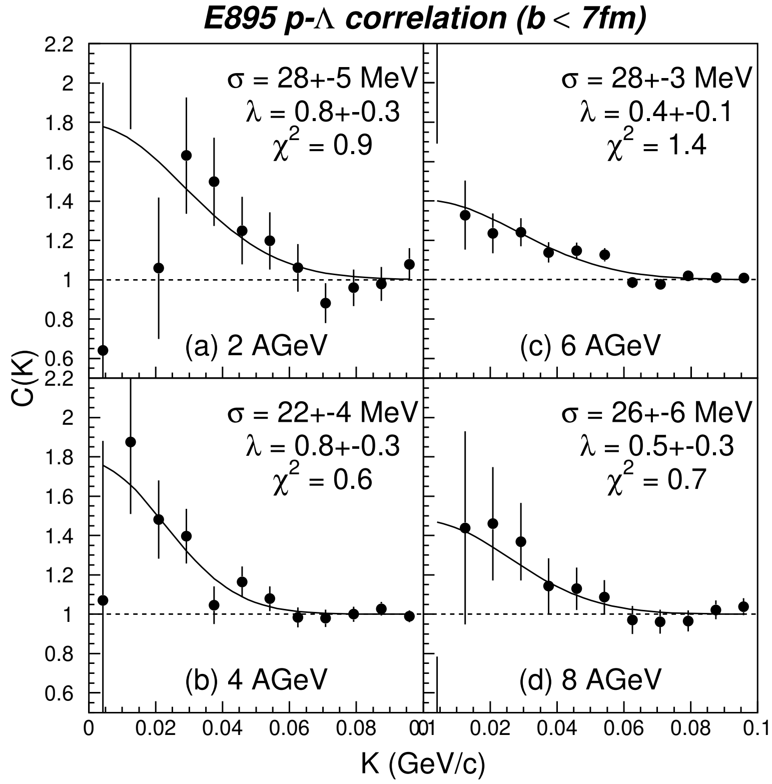

Figure 2. Λp Correlation functions in (a) 2, (b) 4, (c) 6 and (d) 8 AGeV semi-central collisions. The curve is a gaussian fit to the data points. σ and λ are the width and magnitude of the gaussian fits respectively. The correlation functions have been corrected for the effect of combinatorial background and feed-down from Σ^0 decays.

4. Other mixed-particle correlations

A similar analysis has been carried out to search for any pK^0, $\pi\Lambda$ and πK^0 correlations. Figs.3(b)-(d) show the respective correlation functions obtained at 6 AGeV. One observes that the pK^0 correlation function in Fig.3(b) is essentially flat. This can be explained by the fact that the scattering length of the proton-K^0 interaction is too small to give rise to a correlation. Figs.3(c) and (d) show that pions are essentially uncorrelated with Λ's or K^0's. This is not surprising given the fact that pions have no known interaction with Λ or K^0 particles.

5. Interpretation of 6AGeV Λp Correlation

To interpret the 6 AGeV Λp correlation functions, we have made use of two simulation codes, which have been developed by Scott Pratt specifically for correlation studies. The first is the CoRrelation AfterBurner (CRAB) [7, 6] and the second is Cheap Correlations (CheapCor) [8].

CRAB takes as input the freeze-out space-time coordinates of particles in an event and uses the interaction potential between the particles of interest to generate

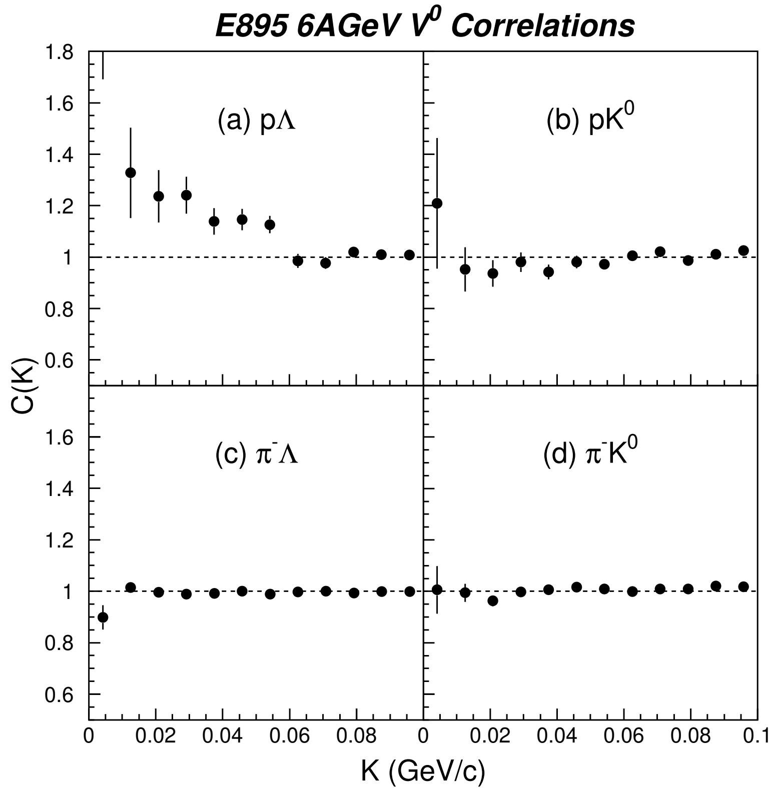

Figure 3. Other mixed-particle correlations at 6 AGeV. Panels (b), (c) and (d) show that pK^0, $\pi\Lambda$ and πK^0 correlations are essentially zero as compared to pΛ in (a).

a correlation function. The resulting correlation function is influenced both by the spatial and temporal extent of the source and the two-particle interaction potential which is an input to CRAB. Given its significant success in describing many of the dynamical features of neutral strange particle emission, we have used the ART code (A Relativistic Transport) [15] of Subrata Pal and Che Ming Ko to generate the events required for input into CRAB. Cheap-cor simulates the same correlation processes as CRAB except that it requires a gaussian source of radius R_g as input instead of the freeze-out space-time coordinates of particles. R_g is used in conjunction with the scattering length, a (also an input), of the potential to generate the correlation function. Thus, if the same scattering length is used in CRAB and CheapCor and R_g is chosen to represent the effective space-time coordinates of particles, then CheapCor and CRAB would give the same correlation function.

Using Cheap-cor in conjunction with CRAB, we have extracted the effective gaussian radius of the emission source predicted by ART via the following: First, we use the event-by-event freeze-out space-time coordinates obtained from ART as an input for CRAB to generate the correlation function. Second, we fix the input scattering length of CheapCor to be the same value as that used by CRAB. The latter value is determined from low-energy Λ-p elastic scattering experiments [16] and hypernuclei studies [17]. Next, the gaussian radius input is varied until CheapCor reproduces the correlation function obtained from ART/CRAB. Fig.4 illustrates how this is accomplished for the Λp correlation from 6 AGeV ART events. It is found that one needs an effective gaussian radius, R_g, of about 2.8fm to get the best representation of the correlation from ART/CRAB. This effective gaussian radius of 2.8fm is a measure of space-time extent of the emitting source predicted by ART.

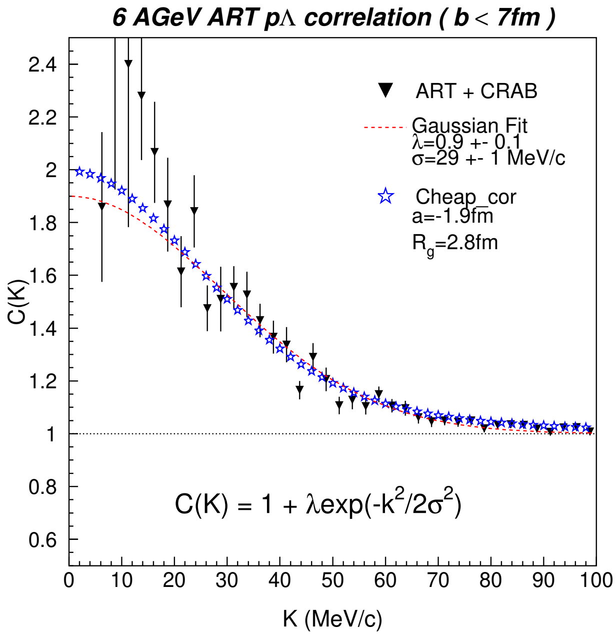

Figure 4. Λp correlation from 6 AGeV ART/CRAB (triangles). The dashed line is a gaussian fit to the ART/CRAB data. The stars represent the correlation from Cheap-cor when a Scattering Length of -1.9fm [18, 19, 20] and a gaussian radius of 2.8fm are used. The Scattering Length of -1.9fm corresponds to the potential used in CRAB and is also the value determined from low-energy Λ-p elastic scattering experiments [16] and hypernuclei analyses [17]

Turning now to the 6 AGeV data, one cannot use CRAB for any particular purpose since the freeze-out space-time coordinates of all the particles are not available. However, one can input the experimentally measured value of -1.9fm for the Scattering Length in Cheap-cor and then vary the gaussian radius so that the resulting correlation function matches as close as possible the correlation from the data. Fig.5(a) shows that one needs a gaussian radius of 4.5fm to bring the output of cheap-cor (open stars) as close as possible to the data (dashed line) if one assumes a Scattering Length of -1.9fm. On the other hand, if one assumes that the space-time extent predicted by ART is representative of the data, then one can vary the Scattering length in Cheap-cor (with $R_g = 2.8fm$) until the best representation of the experimental correlation function is achieved. Fig.5(b) shows that one needs to decrease the Scattering Length by as much as 50% (-0.9fm) in order to reproduce the data if the R_g value predicted by ART is used.

While the experimental measurements of the Scattering length could possibly have uncertainties of 10-20%, it is unlikely that they could be off by the large factor of 2. If this is indeed the case, then it is perhaps not unreasonable to conclude that the effective gaussian radius of the emitting source for Λ's and protons is closer to 4.5fm than to 2.8fm. Similarly, it appears that ART predicts a much smaller effective source size than what is inferred from the data.

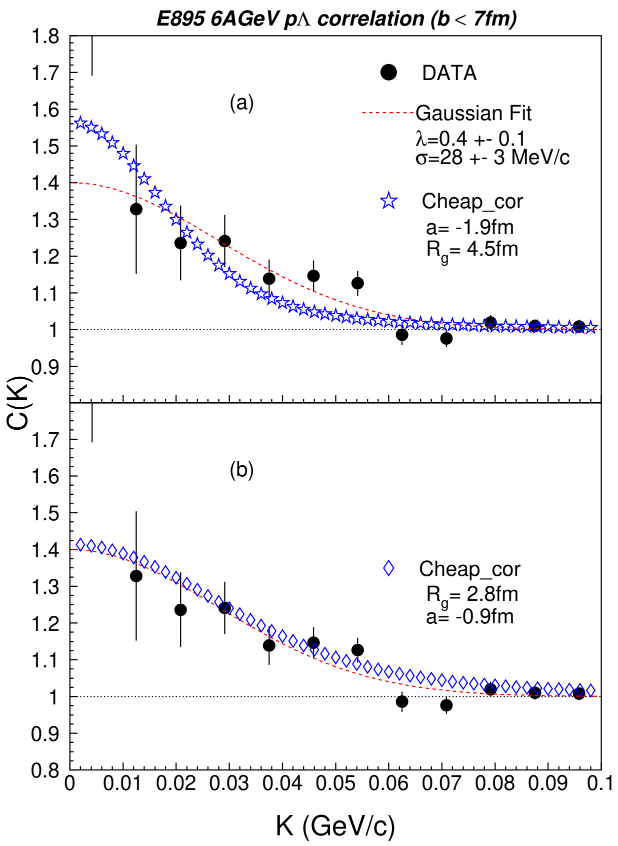

Figure 5. Full circles represent the Λp correlation in 6 AGeV Au+Au collisions. The dashed line is a gaussian fit to the data. In (a), open stars represent the output of Cheap-cor for a Scattering Length of -1.9fm (the experimentally measured value) and a gaussian radius of 4.5fm. In (b), open diamonds represent the output of Cheap-cor for a gaussian radius of 2.8fm (source size from ART) and a Scattering Length of -0.9fm.

6. Conclusion

The E895 Collaboration has investigated various mixed-particle correlations involving neutral strange particles (Λ & K^0_s) in 2,4,6 and 8 AGeV Au + Au collisions at the AGS. It is observed that pΛ pairs display a pronounced correlation at all 4 beam energies of magnitude about 50% and width about 26MeV. The pK^0, $\pi\Lambda$ and πK^0 pairs do not display any correlation within statistical errors. An attempt to interpret the 6 AGeV Λp correlation shows that (1) if one assumes the measured Scattering Length of -1.9fm is correct, then one needs an effective gaussian radius of 4.5fm to reproduce the experimental data, (2) if one uses the effective source size R_g =2.8fm obtained from ART, then one has to reduce the Scattering Length by a factor of 2 to -0.9fm in order to reproduce the data. At this point in time, we believe that it is unlikely that the experimental measurement of the Scattering Length suffers from such a large implied error. If this is really the case, then the effective gaussian radius extracted from the data would be closer to 4.5fm suggesting a much larger space-time extent than what is observed in dynamical models of nuclear reactions.

In summary, the measured Λp correlations have been used to put an important constraint on the combination of the space-time extent of the emitting source and/or scattering length for this particle pair. This is the first such constraint on strange particle emission dynamics in heavy-ion nuclear reactions.

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