Production of Strange Particles in $p-p$ Collisions at 2.85 Bev*

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From a sample of 98 hyperon production events observed in a liquid hydrogen bubble chamber the partial cross sections for various final states are found to be: $\Sigma^+K^+n-0.047$, $\Sigma^+K^0p-0.030$, $\Sigma^0K^+p-0.013$, $\Lambda^0K^+p-0.051$, $\Sigma^-K^+p\pi^+-0.003$, $\Sigma^+KN\pi-0.004$, $(\Lambda^0\Sigma^0)K^+p\pi^0-0.011$, $(\Lambda^0\Sigma^0)K^0p\pi^+-0.014$, $(\Lambda^0\Sigma^0)K^+n\pi^+-0.002$, all in millibarns. For the first four processes the values are in general agreement with those calculated by Ferrari using a one-pion-exchange model. Only one example of K-pair production was observed, indicating a cross section less than 0.01 mb.

I. INTRODUCTION

THE fragmentary information on the production of strange particles in nucleon-nucelon collisions that has been available in the past has not led to any consistent picture of the processes involved. Three previous experiments have investigated the cross sections for strange particle production in p-p collisions at a kinetic energy near 3 Bev. One of these used a diffusion cloud chamber filled with hydrogen gas through which a "pencil" beam of protons was passed.[1] The total cross section for hyperon production appeared to be only 0.04 mb, with a probable upper limit of about 0.20 mb.

In the second experiment an external proton beam passed through a liquid hydrogen target, and K^+ mesons produced at 0° in the laboratory system with momentum 280 Mev/c were counted in nuclear emulsions.[2] A total cross section for K^+ production of about 0.20 millibarn was calculated assuming a statistical momentum distribution and an isotropic angular distribution for the K^+ mesons.

The third experiment used a counter telescope to detect γ-rays considered to be decay products from π^0 mesons produced in the neutral decay modes of K^0 and Λ^0 particles.[3] The total cross section deduced was small, about 0.04 mb. Thus these three experiments suggested that the cross section for producing strange particles in p-p collisions might be surprisingly small compared with the corresponding cross sections in π-p collisions (which were about 0.5 mb). In all of these experiments, however, there were severe limitations with respect to deducing total cross sections.

In the present experiment the production of strange particles is observed directly in the liquid hydrogen bubble chamber. The cross section for strange particle production will be shown to be 0.175 ± 0.032 mb and further information will be given on the partial cross sections for the various production channels.

The new data permit one to check various features of the production processes. All current ideas concerning the strong interactions assume charge independence, which introduces general restrictions in the form of triangular inequalities applicable to the cross sections for Σ production.[4] The frequency of K-meson pairs is of obvious interest. There have been speculations that, if hyperon production is infrequent in p-p collisions, production of K-meson pairs might be relatively important. Since each proton has a π-meson cloud associated with it, production of strange particles in p-p collisions may be thought of as caused by transfer of a π meson. Such a mechanism would imply a strong resemblance to production in π-p collisions. A theoretical treatment of production in p-p collisions by Ferrari follows such an approach.[5] Feldman and Matthews point out that an experiment on the production of hyperons and K mesons in p-p collisions near threshold should determine the relative parities of Σ, Λ, and K.[4] Such information cannot be obtained from this experiment because the energy is too high. An experiment near threshold would be very difficult, however, because of the small cross section. This experiment does provide information on the other, more qualitative, points mentioned.

The simplest final states involving hyperons and K mesons are the three-body states given in Eq. (1).

$$\begin{aligned} p+p &\rightarrow \Lambda^0+K^++p, \\ &\rightarrow \Sigma^0+K^++p, \\ &\rightarrow \Sigma^++K^++n, \\ &\rightarrow \Sigma^++K^0+p. \end{aligned} \tag{1}$$

An additional π meson can also be produced, and the frequency of the resulting four-body final states proves to be great enough that they cannot be ignored. Consequently a rather careful kinematic analysis of each

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[1] R. L. Cool, T. W. Morris, R. R. Rau, A. M. Thorndike, and W. L. Whittemore, Phys. Rev. **108**, 1048 (1957).
[2] P. Baumel, G. Harris, J. Orear, and S. Taylor, Phys. Rev. **108**, 1322 (1957).
[3] D. Berley and G. B. Collins, Phys. Rev. **112**, 614 (1958).
[4] G. Feldman and P. T. Matthews, Phys. Rev. **109**, 546 (1958).
[5] E. Ferrari, Nuovo cimento **15**, 652 (1960); Phys. Rev. **120**, 988 (1960).

event is necessary in order to identify it, and accurate angle and momentum measurements are needed for the identification to be certain. Corresponding to these experimental problems are the theoretical difficulties of handling three or more bodies in the final state and the many possible interactions between them. In both respects, therefore, these processes are more complicated than those in the reaction $\pi+N\rightarrow Y+K$.

In addition to the results on strange particle production reported here, extensive information on elastic p-p scattering and π-meson production is recorded in the bubble chamber photographs. Results on these topics are being reported separately.[6]

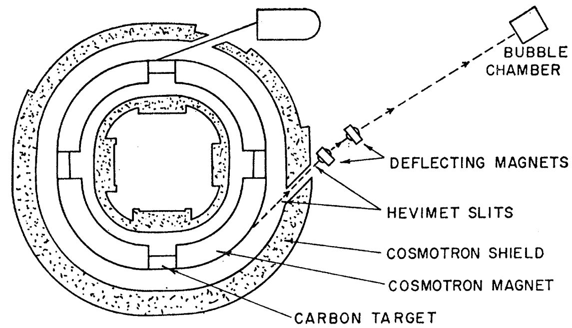

FIG. 1. Geometry of the scattered 2.85-Bev proton beam at the Cosmotron. Since the circulating beam intensity was less than 10^9 protons per pulse, no shielding was required at the bubble chamber.

II. EXPERIMENTAL PROCEDURE

By means of the "rapid beam ejector"[7] the circulating beam of the Cosmotron was made to strike a carbon target during about ten microseconds. Protons scattered at $4.2°\pm0.3°$ followed an external beam trajectory through part of the next magnet quadrant and out through a thin window. They were selected by a collimator with Hevimet slit jaws. These defined a beam about 3×3 in. at the bubble chamber. Two 36-in. deflecting magnets eliminated particles of reduced momentum. The arrangement is shown in Fig. 1. The theoretical momentum spread of the beam was $\pm0.8\%$. Measurements of the curvature of a group of beam tracks in the bubble chamber agreed with the Cosmotron energy calibration within about 1%, which is less than the uncertainty in absolute calibration. The beam energy in the bubble chamber was 2.85 Bev.

The angle of scattering from the carbon target was chosen so that a polarized proton beam might result. No right-left asymmetry of elastic scattering was found, however.[6] The production of strange particles also showed no significant azimuthal asymmetry. Thus either the beam is not strongly polarized, these phenomena are poor "analyzers," or both.

Nuclear reactions resulting from p-p collisions were recorded in the Brookhaven National Laboratory 20-in. liquid hydrogen bubble chamber. Its illuminated volume is $19\times8\times10$ in. deep. Expansion is provided by a piston in the liquid hydrogen and temperature control is achieved by regulating the vapor pressure of a liquid hydrogen bath in good contact with the chamber. Dark-field illumination is provided by an arc whose light passes through the chamber and is focussed between the four camera lenses.[8] During this experiment the expansion ratio was normally about 0.8%, the temperature about 25.2°K, and light delay about 150 μsec. The time between Cosmotron pulses was 5.5 sec. The bubble chamber magnetic field was 17 000 gauss.[9]

Approximately 90 000 photographs were taken, with four stereo views. All were scanned once, using two stereo views, and about 40% were rescanned using the other two views to check detection efficiency. Essentially all scanning was done by scanners without scientific training. They recorded all events that might be interpreted as strange particle decays. These were inspected by a physicist who eliminated events that could clearly be electron pairs, π-μ decays, or small-angle scatterings. The detection efficiency of the first scan for finding strange particle events, as deduced from the rescanned pictures, was 75%, which is rather low. Four-prong π meson production events, in contrast, had a detection efficiency of 98%. It is clear that finding the strange particle events is more difficult. Both charged and neutral decays can, under some circumstances, be hard to detect. There was no evidence that any particular strange particle production process had a particularly high, or low, efficiency, though the number of cases was too small to permit such a comparison to be very significant. The results quoted in Sec. III are based on the events found in the first scan only and a uniform 75% scanning efficiency.

Measurements were made in the usual way on a projector with x-y stage motion and digitized output. The least count of the system is 1 μ, reproducibility of setting about 1 μ, and overall error due to setting errors, backlash, non-linearity of scales, etc. estimated at 2.5 μ from measurements on reference straight lines. Each track was measured in two views, chosen so as to provide a satisfactory stereo angle. Many of the events were measured two or more times. From the variation in measurements an effective setting error of about 4 μ was

[6] G. A. Smith, H. Courant, E. C. Fowler, H. L. Kraybill, J. Sandweiss, and H. Taft, Phys. Rev. (to be published); E. L. Hart, R. I. Louttit, D. Luers, T. W. Morris, W. J. Willis, and S. S. Yamamoto, Bull. Am. Phys. Soc. **5**, 508 (1960).

[7] D. C. Rahm, Rev. Sci. Instr. (to be published).

[8] For a description of the chamber see R. I. Louttit, *Proceedings of an International Conference on Instrumentation for High-Energy Physics* (Interscience Publishers, Inc., New York, 1961).

[9] In carrying out the experiment the usual technical difficulties were encountered, such as plugged Dewars and vacuum leaks of various sorts. At one point it was necessary to interrupt the run because air or nitrogen had frozen on the bubble chamber windows to such an extent that picture quality was unacceptable. The fraction of the Cosmotron beam that hit the target varied considerably, apparently because of asymmetries in the Cosmotron magnetic field. Partly as a result of this variation, attempts at beam-sharing with other experiments proved unsuccessful.

deduced for measurements on actual tracks. Such an error accounts for most of the apparent curvature of no-field tracks, so there appears to be no serious distortion in the chamber.

Bubble density was determined by a gap-length method.[10] Positions of all bubbles were recorded on the measuring projector. From the positions an estimate of the number of bubbles per centimeter was computed. This was corrected for depth and dip angle and normalized with reference to the bubble density for a beam track in the same picture.

A computer program named TRED was used to compute positions of points in space and then angles and curvatures of tracks. Many events were computed using a simple version on an LGP-30 computer. The remainder were done on an IBM-704. As in all such programs there are numerous optical constants that describe optical path lengths and the positions of lenses relative to the fiducial marks. These were determined as carefully as possible by direct measurement. They are believed to be correct within limits that do not affect the present analysis because: (1) the depth of the rear glass is given correctly, (2) measurements using different pairs of views are consistent, and (3) correct Q values are obtained for Λ^0 and θ^0.

The geometry computation was followed by a simple kinematic fitting procedure to assist in the identification of events. The two most common event topologies are shown in Fig. 2. The 141 type is presumably a Σ^+ production. A "neutral mass" program for the PLG-30 was used first to compute the Σ^+ momentum (assumed to be unmeasurable since the Σ^+ tracks are usually short) from the angles of the Σ^+ and its decay secondary and the secondary momentum. Then the Σ^+ momentum and measurements on track No. 2 from the production event were used to compute the mass of the neutral particle, which should be either K^0 or neutron. To fit the event the momenta of tracks No. 2 and No. 4 were varied, while angles were considered to be well determined. Estimates of the errors in momentum were based on a combination of setting error and Coulomb scattering. An increase in the amount of momentum adjustment by two standard deviations was, rather arbitrarily, deemed sufficient to rule out a hypothesis. Thus, if Σ^+K^+n could be fitted by adjusting the momentum of track No. 4 by one standard deviation, while a Σ^+K^0p fit required adjustment by two standard deviations, both were considered to be possible identifications, but if a Σ^+K^0p fit required adjustment by four standard deviations it was considered to be ruled out.

The procedure with type 112 events was similar but more complicated. The first step was to assume the V^0-particle formed by tracks No. 4 and No. 5 to be first a Λ^0 and then a θ^0, and vary momenta to fit the right

[10] See, for example: W. J. Willis, E. C. Fowler, and D. C. Rahm, Phys. Rev. **108**, 1046 (1957); M. F. Blinov, Iu. S. Krestnikov, and G. A. Lomanov, Soviet Phys.—JETP 4, 661 (1957); and V. P. Kenney, Phys. Rev. **119**, 432 (1960).

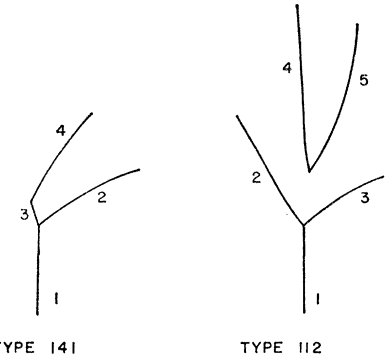

FIG. 2. The most common event topologies for strange particle production in p-p collisions. Type 141 events are typically Σ^+K^+n or Σ^+K^0p. Type 112 events are typically Λ^0K^+p, Σ^0K^+p, $\Lambda^0K^+p\pi^0$, $\Lambda^0K^0p\pi^+$, or $\Lambda^0K^+n\pi^+$.

Q value. Then the momenta of tracks No. 2 and No. 3 were varied, using the neutral mass program until the desired neutral mass was obtained. Furthermore the momentum of the V^0 obtained from the Q-value fit had to be consistent with that from the neutral mass computation, and both had to be consistent with the line-of-flight from production to decay vertex.

Distinguishing Λ^0 from Σ^0 events by kinematics is extremely difficult. Where Λ^0K^+p fits well it is often possible to adjust momenta by less than two standard deviations to obtain a Σ^0K^0p fit. If, however, Λ^0K^+p gave a neutral mass fit with less adjustment than Σ^0K^+p *and* the Λ^0K^+p fit gave overall momentum balance within 0.05 Bev/c in momentum and 3° in Λ^0 angle, then the event was considered to be identified as Λ^0K^+p.

Information on bubble density was also used to establish or confirm the identification of events. In the case of type 112 events, for example, tracks No. 2 and No. 3 are normally p and K or K and p. When the momenta are similar, kinematics fails to distinguish which is which, but bubble density often does so without ambiguity.

As can be seen from the discussion, each event was given individual study by one or more physisicts employing the types of computation mentioned. The number of events (about 150) was small enough and the variety of processes great enough that this seemed preferable to using KICK or other more automatic kinematic fitting programs.[11]

III. RESULTS

A total of 139 events involving hyperon and K meson were found inside a fiducial region with boundary 7 cm from the downstream edge of the illuminated region and centered in perpendicular directions so that entering particles passed through the thin window of the chamber. For the evaluation of cross sections certain types

[11] See A. H. Rosenfeld and J. N. Snyder, University of California Radiation Laboratory Report UCRL No. 9098 (unpublished), for a description of KICK.

TABLE I. Hyperon production cases found.

Event class	Total number	Number used for cross section	Correction factors (1)	(2)	(3)	Corrected number
Σ^+K^+n	$38\frac{1}{2}$	$21\frac{1}{2}$	2.00	1.30	1.33	74.3
Σ^+K^0p	$27\frac{1}{2}$	$13\frac{1}{2}$	2.00	1.30	1.33	46.7
Σ^0K^+p	$8\frac{1}{3}$	$8\frac{1}{3}$	1.50	1.22	1.33	20.3
Λ^0K^+p	$32\frac{5}{6}$	$32\frac{5}{6}$	1.50	1.22	1.33	80.2
$\Sigma^-K^+p\pi^+$	4	3	1.00	1.25	1.33	5.0
$\Sigma^+KN\pi$[a]	4	2	2.00	1.31	1.33	7.0
$(\Lambda^0\Sigma^0)$[b]$K^+p\pi^0$	$6\frac{5}{6}$	$6\frac{5}{6}$	1.50	1.22	1.33	16.7
$(\Lambda^0\Sigma^0)K^0p\pi^+$	9	9	1.50	1.22	1.33	22.0
$(\Lambda^0\Sigma^0)K^+n\pi^+$	1	1	1.50	1.22	1.33	2.4

[a] $\Sigma^+KN\pi$ denotes a four-body state involving K-meson, nucleon, and π meson which may have any charge states.
[b] $(\Lambda^0\Sigma^0)$ denotes an observed Λ^0 which may, however, be a secondary of a Σ^0. It is unlikely that many of these cases are actually Σ^0's.

of events were eliminated, for which it would be difficult to determine the correction factors. These were: (1) 7 events in which the K meson was seen to decay but the hyperon was not, (2) 25 events in which a Σ^+ decayed to proton and π^0, and (3) 9 events in which the Σ^+ track was shorter than 1 cm. Thus correction factors are computed assuming that K meson decays are not observed, that only π^+ decays of Σ^+ with tracks at least 1 cm long are counted. Three types of correction must then be applied: (1) a decay mode correction to allow for neutral decay modes of Λ^0's and protonic decay modes of Σ^+, (2) a geometrical correction to allow for particles escaping from the illuminated volume and for decays in a distance shorter than 1 cm, and (3) a correction for the 75% scanning efficiency mentioned in Sec. II. These are summarized in Table I.

In this table fractions appear in cases where one or more events could be given two possible interpretations. There are two general types of ambiguities: (1) Ambiguity between Σ^+K^+n and Σ^+K^0p exists in a type 141 event if it is not possible to tell whether track No. 2 is proton or K^+. Five such cases are divided between Σ^+K^+n or Σ^+K^0p assignments. (2) Ambiguity between Λ^0K^+p, Σ^0K^+p, and $(\Lambda^0\Sigma^0)K^+p\pi^0$ involves difficulty deciding whether or not a low-energy γ-ray or π^0 was emitted in addition to Λ^0, K^+, and p. There were seven cases which could be either Λ^0K^+p or Σ^0K^+p, three cases which could be Σ^0K^+p or $(\Lambda^0\Sigma^0)K^+p\pi^0$, and one case which could be Λ^0K^+p, Σ^0K^+p, or $(\Lambda^0\Sigma^0)K^+p\pi^0$. Thus the only class to which ambiguous events make a substantial contribution is Σ^0K^+p, for which only 3 of the $8\frac{1}{3}$ events are unambiguous.

The Σ^0K^+p events are the least frequent of the three-body final states, and changes in the assignment of the ambiguous events could make Σ^0K^+p even less common, but could not increase their frequency to be as great as the others. A different aspect of the data is presented in Fig. 3, which shows the original value of the neutral mass computed for the type 112 events, treating the charged particles from the production event as K^+ and p. There is a pronounced peak corresponding to the Λ^0 mass, which is consistent statistically with a center at 1115 Mev and width of 50 Mev. The number of cases in the vicinity of the Σ^0 mass is much smaller, and there is a small group whose masses are suitable for $\Lambda^0+\pi^0$. It seems clear that Λ^0K^+p is the predominant reaction.

To determine the cross sections for these processes we compare their frequency with that of four-prong events, based on a count of events and tracks in a fiducial region.[12] In the pictures used for the present experiment

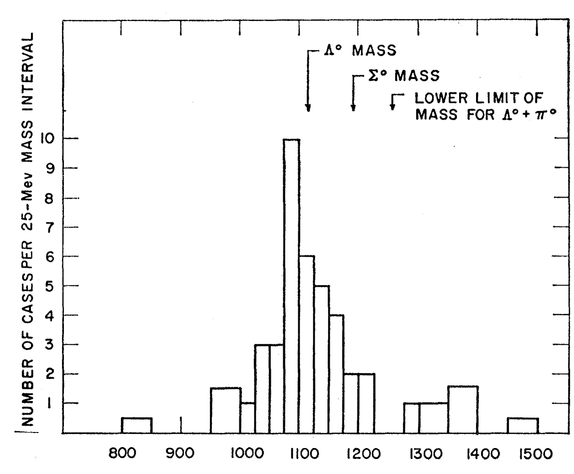

FIG. 3. Distribution of original neutral mass values for type 112 events, obtained using measured values for all track parameters.

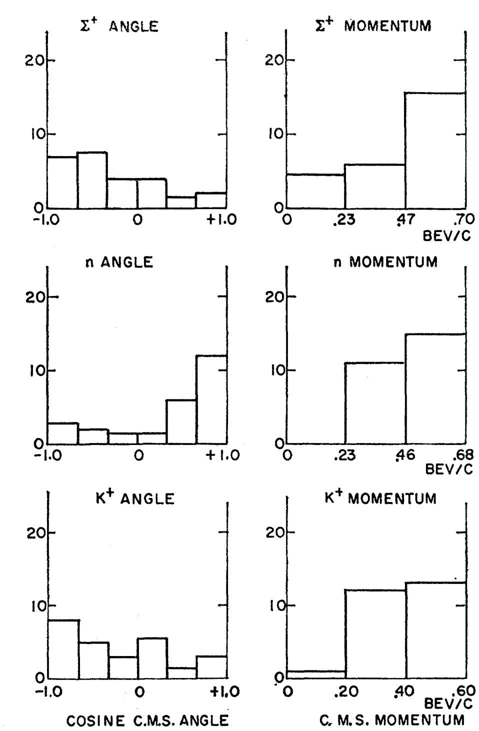

FIG. 4. Angle and momentum distributions for Σ^+K^+n. The number of cases observed is plotted as a function of c.m. angle and c.m. momentum for each secondary particle.

[12] E. L. Hart (private communication).

9298 four-prong events were found, but this number must be reduced to correspond to events in the fiducial region used for selecting strange particle production events. The result is 7570 four-prong events, leading to 6.37×10^{-4} mb per event. Using the corrected numbers of events from Table I the cross sections listed in Table II are obtained. The estimates of errors include three contributions: (1) statistical error, (2) possible error in classifying ambiguous events, and (3) errors in estimating detection efficiency.

The number of events in a given class is too small for angle and momentum distributions to have a clear statistical significance. The data are summarized in Figs. 4, 5, and 6 for Σ^+K^+n, Σ^+K^0p, and Λ^0K^+p events, which are the most common. The data plotted are actual numbers of events observed (except that ambiguous events have been given $\frac{1}{2}$ weight). Events with Σ^+ tracks less than 1 cm long are included here in order to keep the most events possible. There is some detection bias against hyperons produced in the forward direction, but it is smaller than the statistical error. The observed data do show fewer hyperons in forward directions than backwards, which presumably is due to the combined effects of bias and statistical fluctuation. The angular distributions seem isotropic for K mesons in all reactions, but nucleons and hyperons seem peaked forwards and backwards. The momentum distributions show no

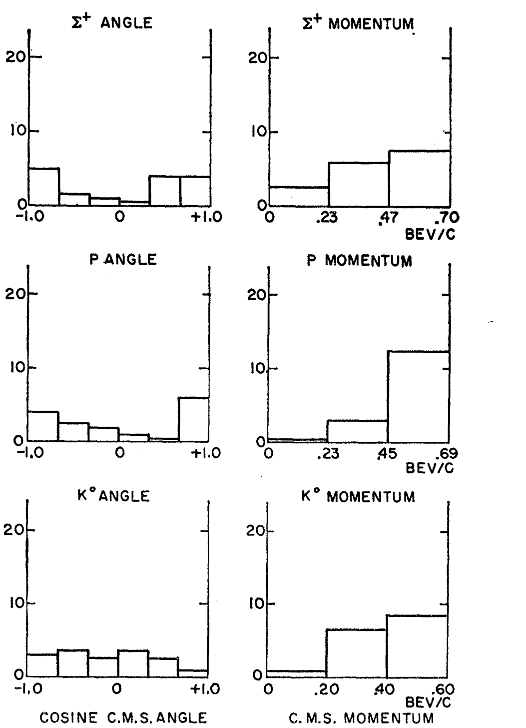

FIG. 5. Angle and momentum distributions for Σ^+K^0p. The number of cases observed is plotted as a function of c.m. angle and c.m. momentum for each secondary particle.

TABLE II. Hyperon production cross sections in millibarns.

Σ^+K^+n	0.047 ± 0.013	$\Sigma^+K^+p\pi^+$	0.003 ± 0.002
Σ^+K^0p	0.030 ± 0.010	$\Sigma^+KN\pi$	0.004 ± 0.003
Σ^0K^+p	0.013 ± 0.007	$(\Lambda^0\Sigma^0)K^+p\pi^0$	0.011 ± 0.005
Λ^0K^+p	0.051 ± 0.012	$(\Lambda^0\Sigma^0)K^0p\pi^+$	0.014 ± 0.005
		$(\Lambda^0\Sigma^0)K^+n\pi^+$	0.002 ± 0.002
		Total hyperon	0.175 ± 0.032

strong departures from a statistical type.[13] Distributions of transverse momenta show the usual peak at fairly low values, in most cases about 300 Mev/c.

A search was also made for events involving K-meson pairs according to one of the reactions

$$p+p\rightarrow p+p+K^0+\bar{K}^0, \quad (2a)$$

$$p+n+K^++\bar{K}^0, \quad (2b)$$

$$p+p+K^++K^-. \quad (2c)$$

Processes (2a) and (2b) can be recognized by the decay of K^0 and/or $\bar{K}^0$. A two-prong production event would be observed accompanied by one or two θ decays. In

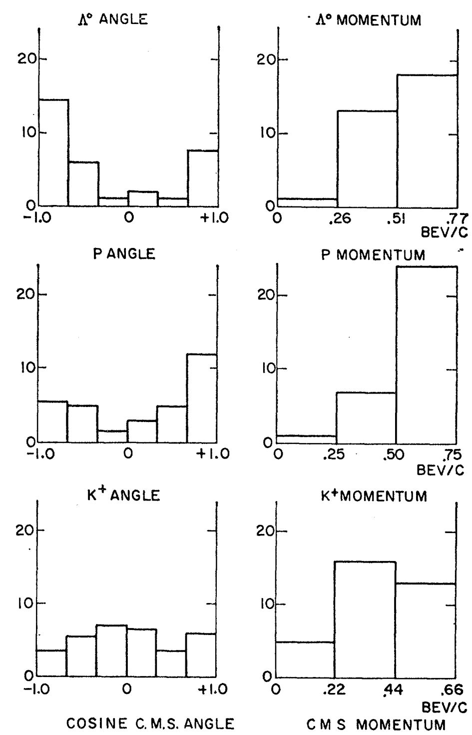

FIG. 6. Angle and momentum distributions for Λ^0K^+p. The number of cases observed is plotted as a function of c.m. angle and c.m. momentum for each secondary particle.

[13] In the events that have π mesons in the final state one might look for evidence of the π-meson–hyperon resonant state reported by M. Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. G. Wojicki [Phys. Rev. Letters **5**, 520 (1960)]. From a total of 21 such events, 6 cases had a total energy of the pion-hyperon system in the range from 1375 to 1400 Mev, consistent with a state at ~1380 Mev.

this experiment six events were seen in which a two-prong production event was accompanied by two neutral V's. Five of these were identified as $(\Lambda^0\Sigma^0)K^0p\pi^+$, and one as $ppK^0\bar{K}^0$ (2a). Among the many two-prong events with a single neutral V all were fitted better by some hyperon production process than by (2a) or (2b). On the other hand the possibility that a small number of these events might actually represent (2a) or (2b) cannot be completely excluded since some of the neutral V's could be classed as Λ^0's or θ^0's and exhaustive kinematic calculations to rule out (2a) or (2b) were not made.

With allowance for neutral decay modes and detection efficiency the cross section for reaction (2a) is estimated to be about 0.002 mb (based on the single event found). Since no examples of (2b) or (2c) were found, their cross sections must also be small.

The detection of charged K mesons produced in the reaction (2c) is more difficult than the detection of reactions (2a) or (2b) because of the extremely small likelihood that either charged K meson will decay in the chamber. Without this characteristic decay, the charged K pair event has an appearance in scanning similar to that of a large number of π-meson production events in which one negative meson is produced, e.g.,

$$\begin{aligned} p+p &\rightarrow p+p+\pi^++\pi^-, \\ &\rightarrow p+p+\pi^++\pi^-+\pi^0, \\ &\rightarrow p+n+\pi^++\pi^-+\pi^+. \end{aligned} \tag{3}$$

Both π and K meson production events consist of one negative and three positive outgoing prongs. This unique appearance assures a scanning efficiency close to 100% for both types of events.

About 6300 such four-prong events were examined in this experiment. It was possible to identify about 98% of these as π meson production before stereoscopic reconstruction was undertaken. This identification was accomplished by utilizing criteria which were obtained by applying conservation of energy and momentum to reaction (2c). These criteria involve limits on the angle of each outgoing track and the fact that the available c.m. kinetic energy is less than 150 Mev.[14] In addition, bubble density estimates were used to the following extent:

(a) K meson identification was excluded from tracks of minimum bubble density and momentum less than 300 Mev/c; (b) proton identification was excluded from tracks of minimum bubble density and momentum less than 600 Mev/c.

[14] For example, at 2.85 Bev incident kinetic energy the maximum angles for emission of protons and K mesons in reaction (1) are 20° and 32°, respectively. An event which does not have all four angles less than 32°, with at least two positive tracks emitted at less than 20°, cannot involve K pair production, and was therefore identified as a π production event. These criteria were applied by measuring the projected angle. For forward tracks with the optical system used, this projected angle is a lower limit for the space angle and hence a conservative value to use in conjunction with criteria restricting the magnitude of the angle.

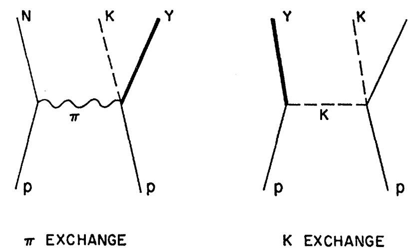

FIG. 7. Diagrams representing strange particle production through the exchange of π meson or K meson, after Ferrari.

Using the criteria set out above, all but 137 of the total 6300 four-prong events were identified as involving π-meson production. These 137 events were put through the TRED spatial reconstruction program and the GUTS kinematical analysis program.[15] In this analysis program a K pair fit was assumed for each event and the χ^2 function computed. In every case the probability of obtaining a value for χ^2 equal to or greater than the computed value was less than 0.001. However, when the neutral K pair event described earlier was subjected to the same analysis the above probability was 0.96. Moreover, for each event there was at least one multiple π-meson production fit for which the value of the computed χ^2 function was statistically reasonable. In view of these results, none of the four-prong events was classified as an example of charged K pair production.

IV. DISCUSSION

Charge independence implies a triangular relationship between amplitudes for Σ hyperons leading to the inequalities given in Eq. (4).

$$\begin{aligned} [2\sigma(\Sigma^0K^+p)]^{\frac{1}{2}} &\leqslant [\sigma(\Sigma^+K^+n)]^{\frac{1}{2}}+[\sigma(\Sigma^+K^0p)]^{\frac{1}{2}}, \\ [\sigma(\Sigma^+K^+n)]^{\frac{1}{2}} &\leqslant [2\sigma(\Sigma^0K^+p)]^{\frac{1}{2}}+[\sigma(\Sigma^+K^0p)]^{\frac{1}{2}}, \\ [\sigma(\Sigma^+K^0p)]^{\frac{1}{2}} &\leqslant [2\sigma(\Sigma^0K^+p)]^{\frac{1}{2}}+[\sigma(\Sigma^+K^+n)]^{\frac{1}{2}}. \end{aligned} \tag{4}$$

The observed total cross sections satisfy these inequalities, and, since the angular distributions appear similar, there is no evidence for any discrepancy involving differential cross sections.

Only one example of K-pair production was found, compared with 139 $Y+K$ events. Phase space computations indicate a factor of about 30, which is roughly consistent.[16] Theoretical computations concerning strange particle proudction in nucleon-nucleon collisions have been reported by Ferrari.[5] Two simple models are assumed, involving transfer of a single π meson or K meson between nucleons as indicated in Fig. 7. Since the effects of single π-meson exchange are of major importance in several aspects of nucleon-nucleon interactions, the predictions based on this assumption are of

[15] J. P. Berge, F. T. Solmitz, and H. D. Taft, University of California Radiation Laboratory Report UCRL-9097 (unpublished).

[16] R. Serber, *Proceedings of the Seventh Annual Rochester Conference on High-Energy Nuclear Physics*, **1957** (Interscience Publishers, Inc., New York, 1957), p. v-6.

TABLE III.

Final state	Experimental	π exchange	Ferrari theory K exchange[a] Pseudoscalar hyperons	Scalar hyperons
Σ^+K^+n	0.047 ± 0.012	0.069	$(g_\Sigma^2/4\pi)\times0.049$	$(g_\Sigma^2/4\pi)\times0.108$
Σ^+K^0p	0.030 ± 0.010	0.052 ± 0.016	$(g_\Sigma^2/4\pi)\times0.053$	$(g_\Sigma^2/4\pi)\times0.137$
Σ^0K^+p	0.013 ± 0.007	0.011	$(g_\Sigma^2/4\pi)\times0.047$	$(g_\Sigma^2/4\pi)\times0.113$
Λ^0K^+p	0.051 ± 0.012	0.053 ± 0.012	$(g_\Lambda^2/4\pi)\times0.071$	

[a] These values were provided by Ferrari in a private communication, and are based on more recent values for the K^+-n cross sections than those given in his paper.[5]

particular interest. One can visualize such a process as the collision of a pion in the pion cloud around one nucleon colliding with the other and producing hyperon plus K meson. The computation effectively evaluates the number and momentum distribution of pions in the cloud and uses experimental cross sections for the process $\pi+p\rightarrow Y+K$. The results are summarized in Table III.

The experimental data are in fairly good agreement with the predictions of the π-exchange model. The K-exchange model does not fit as well though a reasonable coupling constant gives the right order of magnitude for cross sections. If most interactions take place through a single pion exchange mechanism, one would expect that the collisions could be thought of as "peripheral", and would involve small momentum transfer for the nucleons and hyperons. The angle and momentum distributions are consistent with the forward-backward peaking and high secondary momentum in the c.m. system that would be expected from such a model. The experimental data do, therefore, seem to indicate that the one-pion exchange may be the predominant mechanism of production of hyperons and K mesons. Other mechanisms must, however, contribute to some extent, and one should not expect precise agreement. Neither experimental nor theoretical results are sufficiently definitive as to exclude the K-exchange model.

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