Production of Ω^- Hyperons in K^-p Interactions at 5.5 GeV/c*

P. F. SCHULTZ, G. ASCOLI, E. L. GOLDWASSER, U. E. KRUSE, AND J. LOOS
University of Illinois, Urbana, Illinois

AND

J. D. SIMPSON AND S. DAGAN
Argonne National Laboratory, Argonne, Illinois

AND

R. AMMAR, R. DAVIS, W. KROPAC, AND J. MOTT
Northwestern University, Evanston, Illinois

AND

N. CASON,† M. L. GOOD,‡ R. HARTUNG, R. KOFLER,§ R. KRAUSS, Y. Y. LEE,||
D. D. REEDER, AND A. SUBRAMANIAN**
University of Wisconsin, Madison, Wisconsin

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The results of a search for Ω^- hyperon production and decay in K^-p interactions at 5.5-GeV/c K^- momentum are presented. Three unambiguous examples of Ω^- production were found, and the mass of the Ω^- was measured. The mass value obtained is 1671.8 ± 0.9 MeV/c^2. Other details of the three events are given.

I. INTRODUCTION

THE general acceptance of unitary symmetry schemes as a means of classifying particles and resonances[1] stems from the experimental discovery of the Ω^- hyperon.[2] The existence of this particle, its mass, and its quantum numbers were predicted by $SU(3)$ and the Gell-Mann–Okubo mass formula; one more particle, an $S=-3$, negatively charged isotopic singlet, was needed to complete the 10-dimensional representation of $SU(3)$. Furthermore, the predicted mass[1] of about 1680 MeV/c^2 indicated that the particle would be stable against decays via strong interactions and thus could be observed in a bubble chamber. Examples of Ω^- hyperons produced in K^-p interactions at 5.0-, 4.2-, and 6.0-GeV/c K^- momenta have been published.[2–5]

We report here the results of a recently completed search for production and decay of Ω^- hyperons in a K^-p bubble-chamber exposure at 5.5-GeV/c incident K^- momentum. Three Ω^- hyperons have been unambiguously identified. The mass value obtained from these events is 1671.8 ± 0.9 MeV/c^2, in agreement with the preliminary value reported earlier.[6]

The methods used in searching for Ω^- events in this film and the results of the search are presented in Sec. II. In Sec. III we describe the analysis of the three unambiguous Ω^- events and briefly discuss the ambiguous events. In Sec. IV we obtain the above value for the Ω^- mass, and in Sec. V we discuss some other properties of the events.

II. METHODS OF SEARCH

Approximately 400 000 pictures were taken of the MURA 30-in. hydrogen bubble chamber exposed to the high-purity K^- beam at the Argonne ZGS. In searching for Ω^- events, the film was investigated using three different methods:

(1) Of the four groups involved in this experiment, Argonne and Northwestern collaborated as a single unit in the Ω^- search so that there are effectively three sets of data from the equivalent of three groups. Each such group scanned all frames for events characteristic of Ω^- production and decay, i.e., those events with 2, 4, or 6 prongs, at least one kink in a negative track, and one or more V's. A total of four independent scans were made for these topologies. An event was considered to be an Ω^- candidate if, after kinematic fitting, at least one group found the following two conditions to hold: (a) the kink decay fit an Ω^- hypothesis (using a V if it were associated with the kink); and (b) there was at least one acceptable Ω^- production hypothesis (using a V if it were associated with the production vertex).

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† Present address: Notre Dame University, South Bend, Ind.

‡ Present address: State University of New York, Stony Brook, New York.

§ Present address: University of Massachusetts, Amherst, Mass.

|| Present address: State University of New York, Stony Brook, New York.

** Present address: Tata Institute, Bombay, India.

[1] M. Gell-Mann, Phys. Rev. **125**, 1067 (1962); Y. Ne'eman, Nucl. Phys. **26**, 222 (1961).

[2] V. E. Barnes *et al.*, Phys. Rev. Letters **12**, 204 (1964) (5.0 GeV/c).

[3] V. E. Barnes *et al.*, Phys. Letters **12**, 134 (1964) (5.0 GeV/c).

[4] G. S. Abrams *et al.*, Phys. Rev. Letters **13**, 670 (1964) (4.2 GeV/c).

[5] Birmingham-Glasgow-London (I.C.)-Munich-Oxford-Rutherford Laboratory Collaboration, Phys. Letters **19**, 152 (1965) (6.0 GeV/c).

[6] P. F. Schultz *et al.*, Bull. Am. Phys. Soc. **12**, 45 (1967).

All candidates were kinematically analyzed by at least two of the groups.

(2) Two of the above scans included a search for events with 4 prongs and a kink in a negative track (but no V), and the hypothesis $\Omega^- K^+ K^+ \pi^-$ was tried on all such events. Any event that fitted this final state was considered an Ω^- candidate.

(3) For all events having a kink in a negative production track, the transverse momentum of the charged secondary was measured. Any event with a decay product having transverse momentum greater than 250 MeV/c was considered to be an Ω^- candidate. The motivation for this part of the search was that the maximum transverse momentum for the decay product in the $\Xi\pi$ decay mode of the Ω^- is 290 MeV/c, one of the largest transverse momenta of all negatively charged decaying particles.[7]

In method (1) of the search, 130 Ω^- candidates were found, by one group or another, in approximately 800 kink and V events scanned and analyzed. Of these 130, about one-half were found not to be candidates by a different group, and most of the rest, after looking at the events on the scanning table, were determined not to be Ω^- events but rather to be Ξ^-, Σ^-, or K^- events. One of the 130 candidates has an ambiguous interpretation, i.e., an acceptable Ω^- interpretation and an equally acceptable K^- interpretation. The ambiguity appears unresolvable. Three other candidates, we believe, are unambiguous cases of Ω^- production and will be discussed below.

In method (2), approximately 3000 4-prong plus negative-kink events were fitted. Only one of these gave an acceptable fit for the final state of $\Omega^- K^+ K^+ \pi^-$. Since this event also has an acceptable one constraint fit with a K^- decay, we call this event ambiguous. This ambiguity also appears to be unresolvable.

In method (3), out of 6000 events investigated, six events were found that had a decay product with transverse momentum greater than 250 MeV/c. After closer examination, none could be interpreted as Ω^- decays. In five of the events, the large transverse momentum came from poor measurement of the decay product; the track length was insufficient for a precise momentum measurement. In the sixth event, the decay was actually a two-prong interaction in which the dip angle of the positive track was so large the track was difficult to see.

[7] The only two decays with larger transverse momentum are $\Xi^- \to e^- + n + \nu$ (327 MeV/c) and $\Xi^- \to \pi^- + n$ (303 MeV/c). The branching ratios, compared to the total rate, are reported to be less than 5×10^{-3} [H. H. Bingham, Proc. Roy. Soc. (London) **285**, 202 (1965)], and less than 10^{-2} [M. Ferro-Luzzi *et al.*, Phys. Rev. **130**, 1568 (1963)], respectively. These are upper limits; no decays into either mode were found. Since the observed Ξ^- to Ω^- ratio in our film is about 150/1, we would expect as many of the above Ξ^- decays as Ω^- events, and might be able to identify the Ω^- events by ionization.

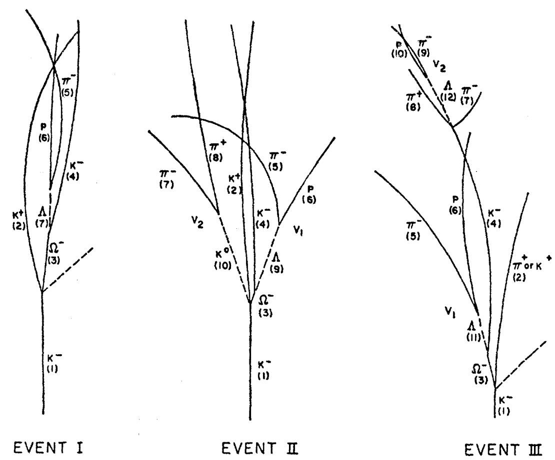

FIG. 1. Line drawings of the three unambiguous Ω^- events.

III. DISCUSSION OF EVENTS

In this section, we discuss the identification of the Ω^- events. The three unambiguous events are illustrated

TABLE I. Measured track parameters.

Track	Azimuth (deg)	Tangent of dip angle	Momentum (MeV/c)
	Event I		
1	-8.44 ± 0.04	0.004 ± 0.003	5473.2 ± 70.3
2	-26.23 ± 0.22	0.333 ± 0.006	$394.2\pm\ 3.4$
3 (beg.)	-0.13 ± 0.13	-0.024 ± 0.005	$\cdots$
3 (end)[a]	-1.47 ± 0.12	-0.024 ± 0.005	3564.8 ± 21.6
4	7.69 ± 0.08	0.005 ± 0.003	1194.5 ± 12.8
5	12.67 ± 0.21	-0.175 ± 0.005	$259.6\pm\ 2.3$
6	-8.03 ± 0.05	-0.049 ± 0.003	2211.7 ± 38.6
7[b]	-6.01 ± 0.08	-0.066 ± 0.008	2404.2 ± 23.0
	Event II		
1	-8.42 ± 0.04	-0.005 ± 0.003	5470.5 ± 68.4
2	-8.83 ± 0.07	0.455 ± 0.003	952.7 ± 10.8
3 (beg.)	5.71 ± 1.32	-0.396 ± 0.148	$\cdots$
3 (end)[a]	5.71 ± 1.32	-0.396 ± 0.148	2228.9 ± 12.2
4	-10.08 ± 0.08	-0.378 ± 0.004	$791.9\pm\ 7.9$
5	-13.77 ± 0.59	-0.569 ± 0.015	$96.5\pm\ 2.1$
6	12.09 ± 0.06	-0.131 ± 0.003	1387.2 ± 21.2
7	-31.28 ± 0.09	-0.087 ± 0.003	$703.8\pm\ 7.2$
8	-13.99 ± 0.06	0.084 ± 0.003	1774.0 ± 29.7
9[b]	10.59 ± 0.12	-0.159 ± 0.013	1475.1 ± 11.8
10[c]	-18.75 ± 0.08	0.031 ± 0.009	2478.7 ± 15.4
	Event III		
1	-6.34 ± 0.25	0.003 ± 0.008	5467.6 ± 75.2
2	-0.55 ± 0.06	-0.048 ± 0.003	1534.6 ± 14.1
3 (beg.)	-13.80 ± 0.32	-0.114 ± 0.010	$\cdots$
3 (end)[a]	-15.12 ± 0.30	-0.114 ± 0.010	2698.5 ± 15.2
4 (beg.)	-2.86 ± 0.10	0.028 ± 0.003	$796.5\pm\ 6.6$
4 (end)	-29.45 ± 0.08	0.028 ± 0.003	$783.9\pm\ 6.6$
5	-20.21 ± 0.57	-0.473 ± 0.005	$365.5\pm\ 2.9$
6	-19.89 ± 0.13	-0.124 ± 0.003	1584.4 ± 15.9
7	18.39 ± 0.25	1.562 ± 0.012	$290.1\pm\ 5.8$
8	-62.03 ± 0.69	-3.408 ± 0.059	$209.4\pm\ 8.2$
9	-30.21 ± 0.32	-0.012 ± 0.005	$214.4\pm\ 3.1$
10	-41.13 ± 0.22	-0.054 ± 0.005	416.9 ± 10.2
11[b]	-19.86 ± 0.08	-0.194 ± 0.009	1933.0 ± 16.2
12[b]	-37.16 ± 0.06	-0.036 ± 0.006	635.3 ± 10.0

[a] Momentum is the fitted value from the decay fit $\Omega^- \to \Lambda K^-$ in which the Λ parameters used are from the Λ decay fit.
[b] Momentum is the fitted value from the decay fit $\Lambda \to \pi^- p$.
[c] Momentum is the fitted value from the decay fit $K^0 \to \pi^- \pi^+$.

TABLE II. Bubble densities for tracks in accepted Ω^- events. Except where noted, the observed bubble densities are obtained from gap-length measurements.

Track	Predicted from measured momentum $\pi^\pm$	$K^\pm$	p	Ξ^-	Ω^-	Observed	Best interpretation from bubble density
				Event I			
1 (Beam)	···	1.01	···	···	···	1.02±0.10	K^-
2	1.13	2.58	5.60	···	···	2.42±0.40	K^+
3	1.00	1.02	···	1.15	1.22	1.45±0.33	Ω^-
4	1.01	1.17	···	2.21	···	1.33±0.20	K^-
5	1.29	···	···	···	···	1.20±0.16	π^-
6	1.00	···	1.19	···	···	1.21±0.20	p
				Event II			
1 (Beam)	···	1.01	···	···	···	1.03±0.14	K^-
2	1.02	1.27	1.96	···	···	1.14±0.15	π^+ or K^+
3	···	···	···	···	···	too short	···
4	1.03	1.39	···	3.70	···	1.42±0.18	K^-
5	3.09	···	···	···	···	3–4[a]	π^-
6	1.01	···	1.46	···	···	1.32±0.17	p
7	1.04	···	···	···	···	1.02±0.12	π^-
8	1.00	···	1.29	···	···	1.08±0.11	π^+
				Event III			
1 (Beam)	···	1.01	···	···	···	1.0[a]	K^-
2	1.01	1.10	1.38	···	···	0.98±0.12	π^+
3	···	···	···	···	1.39[b]	1.0–1.5[a]	Ω^-
4	1.03	1.39	···	3.70	···	1.43±0.20	K^-
5	1.14	···	···	···	···	1.27±0.18	π^-
6	1.00	···	1.35	···	···	1.26±0.18	p
7	1.23	3.73	···	···	···	1.4–1.6[a]	π^-
8	1.45	5.64	11.50	···	···	1.8–2.2[a]	π^-
9	1.40	···	···	···	···	1.4–1.6[a]	π^-
10	1.12	···	6.16	···	···	4–6[a]	p

[a] Visual estimate.
[b] Predicted from fitted Ω^- momentum.

in Fig. 1. Table I lists the measured track parameters and Table II lists the measured and predicted ionizations, or bubble densities, for the various tracks.

A. Event I

Event I is in the 2-prong plus V topology with a kink in the negative production track. Investigating the V first, we find it is a Λ with the origin at the kink. The measured kink to V direction agrees well with the sum of the measured momenta of the V tracks and the invariant mass for a $\pi^- p$ hypothesis (1117.2±1.2 MeV/c^2) is in good agreement with the known Λ mass, while that for a $\pi^-\pi^+$ hypothesis is 30±5 MeV/c^2 too high for a K^0.

We will now analyze the kink decay. The transverse momentum of track 4 is 212±5 MeV/c, large enough to rule out all known decays yielding a Λ (including leptonic decays) except Ω^- decays. The transverse momentum is balanced, within errors, by the transverse momentum of the fitted Λ (210±8 MeV/c), indicating that no additional particle need be involved as a decay product. As shown in Table II, the measured bubble density of track 4 favors its interpretation as a K^-. Furthermore, the invariant mass of a ΛK^- hypothesis is 1672 MeV/c^2, in reasonable agreement with the Ω^- mass found by other groups.[2–5] We conclude that the kink is an Ω^- decay into the ΛK^- mode. As for track 2, ionization shows it to be a K^+. If tracks 2 and 3 are assumed to be a K^+ and an Ω^-, respectively, the missing energy and momentum at the production vertex corresponds to an invariant mass of 890±20 MeV/c^2, near the mass of the $K^*(890)$ resonance. Thus we interpret Event I to be

$$K^- + p \rightarrow \Omega^- + K^+ + \text{missing neutrals}$$
$$\searrow \Lambda + K^-$$
$$\searrow \pi^- + p.$$

B. Event II

The second unambiguous Ω^- event has 2 prongs with a kink in the negative track and two V's. Track 3, the decaying track, is only 0.2 cm long. From kinematics, we determine V_2 (tracks 7 and 8) to be a K^0 originating at the production vertex. The direction of the sum of the measured momenta of tracks 7 and 8 agrees well with the measured production vertex to V_2 vertex direction, and the transverse momentum is 100 MeV/c too large for Λ decay. The invariant mass of a $\pi^-\pi^+$ hypothesis is 496±4 MeV/c^2, in very good agreement with the K^0 mass.

The measured ionization of track 6 indicates it is a proton and, therefore, V_1 (tracks 5 and 6) is a Λ and not a K^0. This also agrees with the kinematic hypothesis of Λ decay. The origin of this Λ can be either the kink vertex or the production vertex although the kink vertex is favored. (The χ^2 probability for the Λ to originate at the kink is 0.8, while that for the production vertex is 0.2.) Ionization of track 4 indicates that it is a K^-, and, again, the invariant mass of the ΛK^- is 1672 MeV/c^2, in agreement with the Ω^- mass found in Event I. Track 2 can be either a π^+ or a K^+. Assuming track 2 to be a K^+, and using a beam momentum[8] of 5470$\pm$68 MeV/c, momentum is balanced by the measured momentum of the K^+ and the fitted momenta from the K^0 and Ω^- decays. This hypothesis satisfies all the kinematical constraints. If, on the other hand, track 2 is assumed to be a π^+, the required production hypothesis

$$K^-+p\rightarrow\Omega^-+\pi^++K^0+K^0$$

fails because the available invariant mass is 145$\pm$40 MeV/c^2, too small for the second, unseen K^0. Hence we conclude that the interpretation of Event II is

$$\begin{array}{lll}
K^-+p\rightarrow\Omega^-+K^++K^0 & & \\
\qquad\qquad\quad\searrow & & \searrow \\
 & & \pi^-+\pi^+ \\
\qquad\qquad\qquad \Lambda+K^- & & \\
\qquad\qquad\qquad\ \searrow & & \\
\qquad\qquad\qquad\quad \pi^-+p. & &
\end{array}$$

[If the Λ is considered to come from the production vertex, the only hypothesis that includes the K^0 and Λ and satisfies energy and momentum conservation is

$$\begin{array}{l}
K^-+p\rightarrow K^-+\pi^++\Lambda+K^0+(\pi^0) \\
\qquad\qquad\quad K^0\searrow\ \pi^-+\pi^+ \\
\qquad\qquad\quad \Lambda\searrow\ \pi^-+p \\
\qquad\qquad\quad K^-\searrow\ \mu^-+\nu.
\end{array}$$

However, this is inconsistent with the measured ionization of the event which indicates a K^- for track 4. In light of this inconsistency and the high relative probability that the Λ comes from the kink, we reject this interpretation.]

C. Event III

Event III is also in the 2 prong with kink and V topology but is also characterized by the 2-prong plus V interaction of track 4. This interaction unambiguously identifies track 4 as a K^-. Tracks 7 and 8, by ionization, are found to be π's. The sum of the momenta of tracks 9 and 10 indicates V_2 originates at the interaction vertex and is identified as a Λ from kinematics and from ionization of track 10. Using the measured momenta of tracks 4, 7, and 8 and the fitted momentum of the Λ, both longitudinal and transverse momenta are found to balance, indicating no other particle is involved. Thus the strangeness of the incident particle must be -1, a conclusion that is further supported by bubble-density measurements and a calculated mass of 480$\pm$10 MeV/c^2 for the incident particle. Track 4 is therefore a K^- and we conclude that the interaction is

$$\begin{array}{l}
K^-+p\rightarrow\Lambda+\pi^-+\pi^+ \\
\qquad\qquad\quad\searrow \\
\qquad\qquad\qquad \pi^-+p.
\end{array}$$

The other V decay, tracks 5 and 6, is kinematically consistent with a Λ originating at the kink and inconsistent with a K^0 decay or a Λ originating at the production vertex. The transverse momenta of track 4 and the fitted Λ balance at the kink and again the invariant ΛK^- mass is 1671 MeV/c^2, in good agreement with the Ω^- mass found in Events I and II.

The momentum of track 2 is too high, 1535 MeV/c, to allow ionization to distinguish unambiguously between a π^+ or K^+, and both interpretations give an Ω^- production hypothesis with missing neutrals. Our interpretation of this event is therefore

$$\begin{array}{l}
K^-+p\rightarrow\Omega^-+\left\{\begin{matrix}\pi^+\\ K^+\end{matrix}\right\}+\text{missing neutrals} \\
\qquad\qquad\quad\searrow \\
\qquad\qquad\qquad K^-+\Lambda \\
\qquad\qquad\qquad\ \downarrow\qquad\searrow \\
\qquad\qquad\qquad\ \downarrow\qquad\quad \pi^-+p \\
\qquad\qquad\qquad K^-+p\rightarrow\Lambda+\pi^-+\pi^+ \\
\qquad\qquad\qquad\qquad\qquad\quad\searrow \\
\qquad\qquad\qquad\qquad\qquad\qquad \pi^-+p.
\end{array}$$

The missing mass at the production vertex for the π^+ interpretation of track 2 is 1023$\pm$56 MeV/c^2, while that for the K^+ interpretation is 898$\pm$60 MeV/c^2.

D. Ambiguous Ω^- Events

We have found two events that have acceptable Ω^- interpretations but they cannot be unambiguously identified as such. The one event with an acceptable $\Omega^-K^+K^+\pi^-$ final state (in which the Ω^- decays via the $\pi^-\Xi^0$ mode) also has an acceptable final state $K^-K^+\pi^+\pi^-(Y^0)$, where Y^0 can be a Λ or Σ^0. Ionization has identified one of the positive tracks as a K^+, but the other positive track can be either a π^+ or a K^+, hence the ambiguity. The other ambiguous event is in the 2 prong with kink and V topology. The final state for the Ω^- interpretation is $\Omega^-K^+K^0(\pi^0)$, in which the K^0 is seen and the K^+ identifiable by ionization. The decay mode for the Ω^- is ΛK^-, but the Λ is not seen. The alternative interpretation is $K^-K^+K^0$+missing mass.

IV. MASS OF Ω^-

All groups measured each of the three events several times in order to reduce random measuring errors. Table III shows the results of the repeated measure-

[8] This value is a weighted average of the measured momentum and a momentum obtained from 194 4-prong events fitted to $K^-p\rightarrow K^-p\pi^+\pi^-$ [J. Park, Ph.D. thesis, University of Illinois, 1967 (unpublished)].

TABLE III. Masses of Ω^- per measurement (MeV/c^2).

Group	Meas. No.	Event I	Event II	Event III
Illinois	1	1671.7±2.0	1672.3±1.8	1671.3±1.3
	2	1672.6±1.4	1671.1±1.5	1670.2±1.2
	3	1672.4±1.4	1669.6±1.4	1670.5±1.2
	4	1672.3±1.4	1671.9±1.4	1671.2±1.2
	5	···	1671.6±1.3	1670.7±1.2
	Mean value	1672.3±1.4	1671.2±1.3	1670.8±1.2
Argonne-Northwestern	1	1671.3±1.6	1671.5±2.0	1671.8±1.3
	2	1671.5±1.5	1672.9±2.3	1672.0±1.3
	3	1672.3±1.6	1671.1±2.0	1672.7±1.3
	4	1672.9±1.8	1671.3±1.8	···
	Mean value	1671.9±1.5	1671.6±1.8	1672.2±1.3
Wisconsin	1	1672.0±1.1	1671.3±1.9	1672.2±0.8
	2	1672.4±1.5	1674.4±2.3	1671.8±0.8
	3	1671.8±1.2	1671.2±1.6	···
	4	1672.1±0.8	1673.2±1.7	···
	5	1671.5±1.0	···	···
	6	1672.2±1.1	···	···
	Mean value	1672.0±1.0	1672.4±1.6	1672.0±0.8

ments together with their estimate of measurement errors described below. Some of these values are the ΛK^- invariant mass from 3-momentum conserving fits of the Ω^- decay, and others are the results of multivertex, 3-momentum conserving fits with the Ω^- mass an unknown parameter. The individual measurements of each event by the different groups are clearly consistent with each other well within the quoted errors. For each event, Table III also gives the mean values and representative errors as determined by each group. The weighted averages of the mean values give

$$\begin{aligned} &\text{Event I} \quad M(\Omega^-) = 1672.1 \pm 1.4\ \text{MeV}/c^2 \\ &\text{Event II} \quad = 1671.7 \pm 1.6 \\ &\text{Event III} \quad = 1671.7 \pm 1.2 \\ &\text{Weighted average} \quad 1671.8 \pm 0.8\ \text{MeV}/c^2. \end{aligned}$$

Our estimate of the measurement errors is obtained by propagating the errors on track variables. The errors on track variables were computed by considering three contributions: (a) setting errors, (b) multiple scattering, and (c) estimates of uncertainties in the chamber and camera systems.

Our error assignments have been verified by looking at χ^2 distributions and mass resolutions in many thousands of measurements of events in this experiment. As a single example, we show our results on Λ masses[9] in Fig. 2, the smooth curve being the combined resolution function for these events, based on precisely the same methods of estimating errors as used on the Ω^- events. We note that the calculated and predicted widths are in excellent agreement, thus confirming our assignment of measurement errors.

We now discuss three sources of systematic errors which could affect our result for the Ω^- mass: (1) there may be a systematic curvature error, perhaps due to turbulence, (2) our value for the magnetic field may be incorrect, or (3) a change in the K^- mass or the Λ mass from the values[10] $M_{K^-} = 493.82$ MeV/c^2, $M_\Lambda = 1115.58$

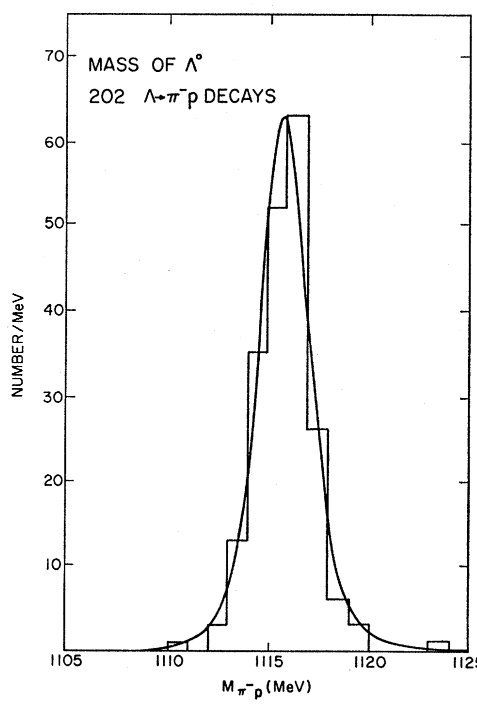

FIG. 2. Λ mass distribution of 202 $\Lambda \to \pi^- p$ decays for which the error in M_Λ is less than 3.5 MeV/c^2. The smooth curve is the resolution function centered on 1115.84 MeV/c^2, the weighted mean of the distribution.

[9] These Λ decays were measured and fitted by the Illinois group; they originate from Ξ^- decays.

[10] A. H. Rosenfeld *et al.*, Rev. Mod. Phys. **39**, 1 (1967).

MeV/c^2 assumed in our fits, could correspondingly change the Ω^- mass.

To investigate the first source of systematic error we have determined the central value of the beam momentum in this experiment by two distinct methods: (a) direct measurement of the curvature of beam tracks, and (b) measurement of τ decays of beam tracks. The first measurement is affected strongly by any systematic error in curvature while the second is only slightly affected (because the measured momenta are lower and because one track is positive). We obtain the following results for the beam momentum:

$$\text{Method (a)},\quad 5468\pm5\ \text{MeV}/c;$$
$$\text{Method (b)},\quad 5450\pm5\ \text{MeV}/c.$$

If we attribute the discrepancy of 18 ± 7 MeV/c to a systematic curvature error in the beam tracks, then there is a systematic error in sagitta of about 0.5 μ per cm track length (e.g., an 80-cm track has a 40-μ systematic sagitta error). A similar curvature distortion in the decay tracks of the Ω^- is found to cause an error in momentum less than $\frac{1}{10}$ the error assigned by the fitting programs. We therefore conclude that the systematic error in the Ω^- mass from this effect is at most 0.14 MeV/c^2.

To check for the second possible systematic error, an error in the magnetic field of the chamber, we have measured the K^0 mass from events in this experiment. We find $M(K^0)=497.98\pm0.21$ MeV/c^2, which is to be compared to the accepted value[10] of 497.89 ± 0.16 MeV/c^2. If we attribute the discrepancy to a magnetic-field error, the magnetic-field error would be $\Delta H/H=0.04\pm0.12\%$. Table IV gives the derivative of the Ω^- mass for each event with respect to $\Delta H/H$. The average value is $\sim$90 MeV/c^2 so that a shift in magnetic field corresponding to $\Delta H/H$ of 0.15% would change our result for the Ω^- mass by $\sim$0.14 MeV/c^2.

To investigate the third systematic error source, we refitted the three Ω^- events with altered values for the Λ and K^- masses. Table IV gives the derivatives of the Ω^- mass with respect to the K^- and Λ masses. The averages for the three events are

$$\partial M_{\Omega^-}/\partial M_{K^-}=1.0;\quad \partial M_{\Omega^-}/\partial M_{\Lambda}=1.1.$$

The uncertainty in the accepted K^- mass[10] of 0.11 MeV/c^2 then causes an uncertainty of 0.11 MeV/c^2 in the Ω^- mass. As for the uncertainty in the Λ mass, we observe that the weighted average of the Λ masses shown in Fig. 2 is 1115.84 ± 0.10 MeV/c^2, which differs from the accepted value of 1115.58 ± 0.10 MeV/c^2 by 0.26 ± 0.14 MeV/c^2. Using this difference as the uncertainty in the Λ mass, we find the corresponding uncertainty in the Ω^- mass to be 0.29 MeV/c^2.

Our final error is obtained by quadratically combining the statistical error, the error from possible curvature distortion, and the errors from the uncertainties in $\Delta H/H$ and in the K^- and Λ masses. The resulting uncertainty in the Ω^- mass is 0.9 MeV/c^2. Our value, then, for the mass of the Ω^- hyperon is $M_{\Omega^-}=1671.8\pm0.9$ MeV/c^2.

TABLE IV. Effect on the Ω^- mass of changes in the K^- mass, Λ mass, and the magnetic-field strength.

Event	$\partial M_{\Omega^-}/\partial M_{K^-}$	$\partial M_{\Omega^-}/\partial M$	$H\partial M_{\Omega^-}/\partial H$ (MeV/c^2)
I	0.9	1.3	93
II	1.1	1.2	60
III	1.0	0.9	120
Average	1.0	1.1	91

V. FURTHER DISCUSSION

For completeness, we list in Table V the cosines of the production angle with respect to the beam direction in the over-all center of mass.

The track lengths of the three Ω^- events are 7.62, 0.19, and 3.01 cm, corresponding to proper lifetimes of 1.20, 0.06, and 0.63 in units of 10^{-10} sec for Events I, II, and III, respectively. The average[11] lifetime from Events I and III is 0.92×10^{-10} sec, which agrees with the lifetime of $(1.3\pm0.7)\times10^{-10}$ sec obtained by another group.[4]

We note that the three unambiguously identified Ω^- events all decay into the ΛK^- modes, and the Λ is seen in each case. Because our detection efficiency for the other reported Ω^- decay modes, $\Xi^-\pi^0$ and $\Xi^0\pi^-$, is lower than that for the ΛK^- mode, we quote only a lower limit for the Ω^- production cross section. The film in this experiment contains a total K^- beam track length of 1.5×10^8 cm, corresponding to 0.2 μb/event. Using only the three unambiguous events and correcting for the Λ branching ratio, we get a lower limit of 0.9 ± 0.5 μb for the cross section for Ω^- hyperon production in K^-p interactions at 5.5 GeV/c.

It is interesting to note that if we accept the interpretation of Event III as $K^-+p\rightarrow\Omega^-+K^++$missing

TABLE V. Center-of-mass production cosines.

	Particle	$\cos\theta_{\text{c.m.}}$	
Event I	K^+	-0.896	
	Ω^-	-0.546	
	missing mass	0.010	
Event II	K^+	-0.215	
	Ω^-	-0.563	
	K^0	0.767	
Event III	$\pi^+(K^+)$	0.921	(0.860)
	Ω^-	0.177	
	missing mass	-0.576	(-0.396)

[11] We do not include Event II in obtaining the average lifetime since the scanning efficiency for topologies with charged decays is small for those events with a decay length less than 0.5 cm.

mass,[12] all three events have a K^+ produced at the production vertex and furthermore, the invariant mass recoiling off the K^+ is approximately the same in all three events. For Events I, II, and III, the mass recoiling off the K^+ is 2.73, 2.70, and 2.76 GeV/c^2, respectively. We have also observed that the first Ω^- reported by Brookhaven and the Ω^- reported by the British-Munich collaboration were both produced in the reaction $K^-+p\rightarrow\Omega^-+K^++K^0$. The invariant mass recoiling off the K^+ for these events is 2.69 and 2.68 GeV/c^2, respectively. This suggests that perhaps Ω^- hyperons are produced in the decay of an $S=-2$ particle of mass $\sim$2720 MeV/c^2. We hasten to point out, however, that at 5.5-GeV/c K^- beam momentum, phase space has its maximum at 2.50 GeV/c^2 for the Ω^-K^0 combination and at 2.70 GeV/c^2 for the Ω^-K^{*0} combination. Thus, it would be interesting to look at the invariant mass combinations in Ω^- events produced with higher K^- beam momenta.

[12] The π^+ interpretation requires two missing K^0's in order to conserve strangeness and the available invariant mass of 1.023 $\pm$0.056 GeV/c^2 for this interpretation indicates the two K^0's are produced with approximately the same momentum and direction. This would seem to be an improbable situation. On the other hand, if track 2 is assumed to be a K^+, the missing mass at the production vertex is 0.898 GeV/c^2, close to the mass of the $K^*(890)$ resonance. Hence we expect the correct interpretation of track 2 to be a K^+ rather than a π^+.

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Differential Pion Charge-Exchange Scattering and η Production: $\pi^-+p\rightarrow\pi^0+n$ from 2.4 to 3.8 GeV/c, at 6 GeV/c, and at 10 GeV/c; $\pi^-+p\rightarrow\eta^0+n$ at 10 GeV/c†

M. A. Wahlig*

Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts

AND

I. Mannelli

Istituto di Fisica, dell'Università di Pisa,

and

Istituto Nazionale di Fisica Nucleare, Sezione di Pisa, Pisa, Italy

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Small-angle differential cross sections are presented here for $\pi^-+p\rightarrow\pi^0+n$ charge-exchange scattering between 2.4 and 3.8 GeV/c. The differential cross section near $t=0$ displays two minima and one maximum in this momentum interval, reflecting the presence of the $N_{3/2}^*(2420)$, $N_{3/2}^*(2850)$, and $N_{1/2}^*(2650)$ resonances; at larger t values, the cross sections fall off exponentially as a function of t, just as has been previously observed for charge-exchange scattering above 6 GeV/c. The pion-charge-exchange data reported here at 6 and 10 GeV/c extend out to large angles, showing a maximum near $t=0$, followed by an exponential falloff as e^{10t}, a minimum near $-t=0.6$ (GeV/c)^2, and then a second maximum near $-t=1.0$ (GeV/c)^2. The $\pi^-+p\rightarrow\eta^0+n$ differential cross section shows a maximum near $t=0$, followed by an exponential falloff as e^{4t}, much less steep than the π^0 slope. These data are compared to our previously published data and to those of the Saclay-Orsay group.

I. INTRODUCTION

In an experiment at the AGS at Brookhaven National Laboratory, we studied the interaction $\pi^-+p\rightarrow n$ plus γ's in several experimental setups, resulting in measurements of the following final states: (A) $n+2\gamma$ in a low-momentum π^- beam covering the range of 2.4 to 3.8 GeV/c in steps of 0.1 GeV/c, plus one point at 6.0 GeV/c; (B) $n+2\gamma$ in a high-momentum π^- beam covering the range of 6 to 16 GeV/c, with a "good-geometry" measurement (spark chamber far downstream from hydrogen target); (C) $n+2\gamma$, $n+3\gamma$, $n+4\gamma$ in the same high-momentum π^- beam, at 10 GeV/c only, with a "poor-geometry" measurement (spark chamber close to hydrogen target).

We report here the results of measurement (A), in which we observe the charge-exchange $n+\pi^0$ final state only, and the $n+2\gamma$ results of measurement (C), in which we observe both the $n+\pi^0$ and $n+\eta^0$ final states. Preliminary results of the forward charge-

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* Present address: Lawrence Radiation Laboratory, University of California, Berkeley, California.