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Janice Button-Shafer, Massimiliano Ferro-Luzzi, Joseph J. Murray,
M. Lynn Stevenson, and Frank T. Solmitz

June 5, 1962

$\Lambda\pi^+\pi^-\pi^0$ AND Λ+ NEUTRAL FINAL STATES IN K^-p INTERACTIONS AT K^- MOMENTA OF 1.22 AND 1.51 GeV/c*

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June 5, 1962

(To be presented by Arthur H. Rosenfeld)

I. INTRODUCTION

Interactions of the types:

$$K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \pi^0 \quad \text{or} \quad \Lambda + \pi^+ + \pi^- + \gamma \qquad (1)$$

and

$$K^- + p \rightarrow \Lambda + \text{neutrals} \qquad (2)$$

have been studied in the 72-inch hydrogen bubble chamber with incident K^- mesons at 1.22 ± .040 and 1.51± .050 GeV/c. (These values are the momenta measured at the center of the chamber. They correspond to total center-of-mass energies of 1.895 and 2.025 GeV).

At the lower momentum, about 2300 events were analyzed in which a lambda was produced in association with two charged pions; these were found in a film sample of ≈ 1000 mb equivalent events (events of a fictitious process with a 1-mb cross section). Of these, about 320 events fit the hypothesis $\Lambda\pi^+\pi^-\pi^0$. In the same film sample, 1568 events have been analyzed to date in which the lambda was produced in association with neutral particles.

In the effective-mass spectrum for the three pions of the $\Lambda\pi^+\pi^-\pi^0$ final state (Fig. 1), a narrow peak was observed at 548 MeV near the energy of the recently discovered T = 0 particle, the η meson. In the missing-mass spectrum of the neutrals in reaction 2 (Fig. 2), a corresponding spike occurred at 550 MeV. The 46 charged events (less 10 background) and the neutral events are larger samples than any yet reported. Information on cross

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†National Academy of Science Fellow.

sections, branching ratios, radiative decays, and Dalitz plots are given below.

In the 1.22 GeV/c film, there was little evidence in either reaction for the ω^0; this was not surprising, as the energy was approximately that of the $\Lambda + \omega^0$ threshold.

At the higher momentum of 1.51 GeV/c, reaction 1 was dominated by the ω^0 particle, 65% of all $\Lambda\pi^+\pi^-\pi^0$ events having a three-pion effective mass under the ω^0 peak (Fig. 3). The smaller peak at the η mass indicated that the cross section for η production was about the same at 1.51 as at 1.22 GeV/c. In the lambda-neutral events, there is evidence for the neutral decay of the ω^0. The film processed to date at 1.51 GeV/c is a sample containing $\approx$ 300-mb equivalent events, with a yield of 1400 lambda "two-prong" and 600 lambda-neutral events.

In the 1.22 GeV/c sample, effective-mass distributions for other combinations of particles have been studied; results are reported below.

II. SELECTION OF EVENTS

In both the "vee-two-prong" and the "vee-zero-prong" events, a kinematic fit of the decay vertex was made before examination of the production vertex. For both classes, the vees were separated into the categories of K^0 and Λ decays on the basis of kinematics and, when necessary, ionization. The uncertainties resulting from this procedure were of the order of 1 to 2%.

All lambda-two-prong events were fitted to the hypotheses

$$K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \pi^0$$
$$\rightarrow \Sigma^0 + \pi^+ + \pi^-$$
$$\rightarrow \Lambda + \pi^+ + \pi^-$$
$$\rightarrow \Lambda + \pi^+ + \pi^- + \gamma \, .$$

To select events of the first category, $\Lambda\pi^+\pi^-\pi^0$, a limit of $\chi^2_{\Lambda 3\pi} \leq 10$ seemed reasonable; it was necessary also to demand that $\chi^2_{\Lambda 3\pi}$ be $\leq \frac{1}{2}\ \chi^2_{\Sigma 2\pi}$ and $\chi^2_{\Lambda 3\pi}$ be $\leq \frac{1}{4}\ \chi^2_{\Lambda 2\pi}$. (The fits to the hypotheses $\Lambda 3\pi$, $\Sigma^0 2\pi$, and $\Lambda 2\pi$ are overdetermined by 1, 2, and 4 constraints, respectively.) In Fig. 4, the missing neutral mass of events satisfying only the condition $\chi^2_{\Lambda 3\pi} \leq 10$ is plotted. In addition to the expected peak at the mass

of one pion, there is a cluster of events on the lower side of this peak. By imposing the additional conditions that the fits to $\Sigma^0 2\pi$ and $\Lambda 2\pi$ be poor, the low-mass cluster is eliminated; the dashed-line histogram of Fig. 4 represents the events satisfying all three χ^2 conditions, and can be considered to be almost purely $\Lambda \pi^+\pi^-\pi^0$ events.

The lambda-zero-prong events were restricted by the requirement that the lambda be greater than 5 mm in actual projected length; this condition was imposed to eliminate confusion of two-prong events (having gaps before interaction) with short-length lambdas. To correct for the fact that the interaction generally occurred beyond the end of the incident track, the mean gap length (0.5 mm) with appropriate error was added to the zero-prong by our kinematics program in the calculation of the lambda production angle.

III. RESULTS

The effective mass spectrum of the $\pi^+\pi^-\pi^0$ for the 320 lambda-three-pion events is given in Fig. 1 for 1.22 GeV/c, and in Fig. 3 for 1.51 GeV/c. The η peak in the former appears at an energy of about 548 MeV with a width at half-maximum of about 12 MeV, while the ω^0 peak occurs in the latter at an energy of 780 MeV with a width at half-maximum of 25 MeV. The mass resolution of the measuring system has been determined as having a width of 12 to 13 MeV in the region of the η mass at 1.22 GeV/c, and of 10 MeV in the region of the ω^0 mass at 1.51 GeV/c. Thus it appears that the η particle has a real width of less than a few MeV, and that the ω^0 particle has a real width of about 23 MeV. (This is consistent with the findings of Stevenson et al, that the ω^0 width is < 25 MeV.[1])

In the η peak seen at 1.22 GeV/c, there are 46 events; and of these some 10 can be estimated as background. Thus there is a cross section for charged η production of 55 ± 15 μb .

The missing neutral mass was calculated for the 1500 lambda-zero-prong events found at 1.22 GeV/c. This spectrum is shown in Fig. 2 and shows a narrow peak at 550 MeV with a width at half-maximum of about 18 MeV (comparable with the mass resolution of the system). There are 205 events under the peak; of these, about 70 are η's and 135 are background. Thus the cross section for neutral η production is 150 ± 20 μb. The ratio of neutral to charged decays is 2.7 ± 0.8.

A Dalitz plot of events in the charged η peak shows a structure similar to that observed in a somewhat smaller sample of η's produced at 760 MeV/c incident K^- momentum.[2] This plot is presented in Fig. 5. The six-fold symmetry expected for an allowed decay of a T = 0 Meson is not observed; but the decay of a T = 0, 0^{-+} (spin-parity-G-parity) meson through virtual γ-ray emission and absorption is consistent with the plot.

Radiative modes of decay have been studied in the lambda-two-prong sample at 1.22 GeV/c. Upper limits of 10% can be set for the $\Lambda\pi^+\pi^-\gamma$ rate and for the $\Lambda\pi^+\pi^-\pi^0\gamma$ rate relative to three-pion decay. The events considered as possible $\Lambda 2\pi\gamma$ events were those satisfying the criteria:

$$\chi^2(\Lambda\pi^+\pi^-\gamma) < 10 \text{ and } < \chi^2(\Lambda 3\pi)$$

with poor fits to $\Sigma^0 2\pi$ and to $\Lambda 2\pi$. The possible $\Lambda 3\pi\gamma$ events were those for which the missing mass was > 150 MeV and which were poor fits to the hypothesis $\Lambda 3\pi$.

The polarization of the lambdas produced in association with η mesons in both the charged and neutral decay events was found to be close to zero. Correlations in charged η decay, both of the momentum of the pi-zero and of the normal of the decay plane with the production normal, were found to be very small and indicated that there was no alignment of η spin in the production process or that the spin of the η is zero.

Effective-mass spectra have been plotted for lambda-pion combinations for the 320 $\Lambda\pi^+\pi^-\pi^0$ events at 1.22 GeV/c. The $\Lambda\pi^+\pi^-$ spectrum shown in Fig. 6 gives some indication of a resonance behavior in the region of the recently discovered T = 0 Y_0^* at 1520 MeV. From the information obtained in the 1520 MeV Y_0^* decay into $\Sigma\pi$ in the $\Sigma\pi\pi$ events analyzed in the 1.22 GeV/c K^- run (and reported here by Alston et al.), the branching ratio for Y_0^* decay into $\Sigma\pi$ and into $\Lambda\pi^+\pi^-$ determined in the original study[3] can be used to predict about 10 $\Lambda\pi^+\pi^-$ events at the 1520-MeV resonance in the 1.22 K^- film discussed here. The experimental data of Fig. 6 are consistent with this prediction.

The lambda-three-pion events at 1.51 GeV/c have yielded a very large number of ω^0 particles, some 201 events with effective 3π mass between 750 and 830 MeV being observed. (Of these about 55 are background). (Fig. 3). The Dalitz plot for these events is presented in Fig. 7.

A small but definite peak at the ω^0 mass has also been observed in the missing-mass spectrum of the lambda-neutral events (Fig. 8). A rough preliminary figure can be stated for the ratio of neutral-to-charged ω^0 decay, of 0.25 ± 0.10. The experimental number is based on about 24 neutral ω^0 events seen above background.

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The extensive work of Dr. Harold K. Ticho in the designing and setting up of the K^- beam, and also the assistance of Dr. Donald Stork in this work, are gratefully acknowledged. The contributions of the crew of the 72-inch bubble chamber under Bob Watt were of great importance in the operation of the chamber and the velocity-selecting spectrometers. The help of many members of the Alvarez group was very much appreciated.

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FIGURE LEGENDS

Fig. 1. Effective mass distribution for $\pi^+\pi^-\pi^0$, with incident $p_K = 1.22$ GeV/c.

Fig. 2. Missing mass, or recoiling mass, of neutrals in $K^- + p \rightarrow \Lambda +$ neutrals, with $p_K = 1.22$ GeV/c.

Fig. 3. Effective mass distribution for $\pi^+\pi^-\pi^0$, with incident $p_K = 1.51$ GeV/c.

Fig. 4. Missing mass distribution, in $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ + neutral, with incident $p_K = 1.22$ GeV/c.

Fig. 5. Dalitz plot for events under η meson peak.

Fig. 6. Effective mass distribution for $\Lambda\pi^+\pi^-$.

Fig. 7. Dalitz plot for events under ω^0 peak.

Fig. 8. Missing mass, or recoiling mass, of neutrals in $K^- + p \rightarrow \Lambda +$ neutrals, with $p_K = 1.51$ GeV/c.

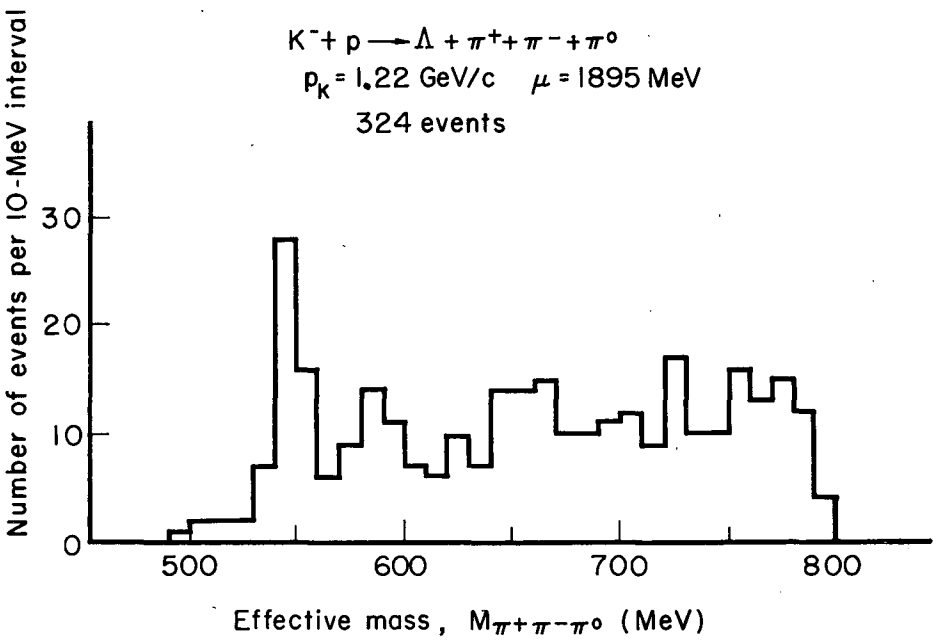
$K^- + p \longrightarrow \Lambda + \pi^+ + \pi^- + \pi^o$
p_K = 1.22 GeV/c μ = 1895 MeV
324 events
Number of events per 10-MeV interval
0
10
20
30
500
600
700
800
Effective mass, $M_{\pi^+\pi^-\pi^o}$ (MeV)
MU-27047

Fig. 1

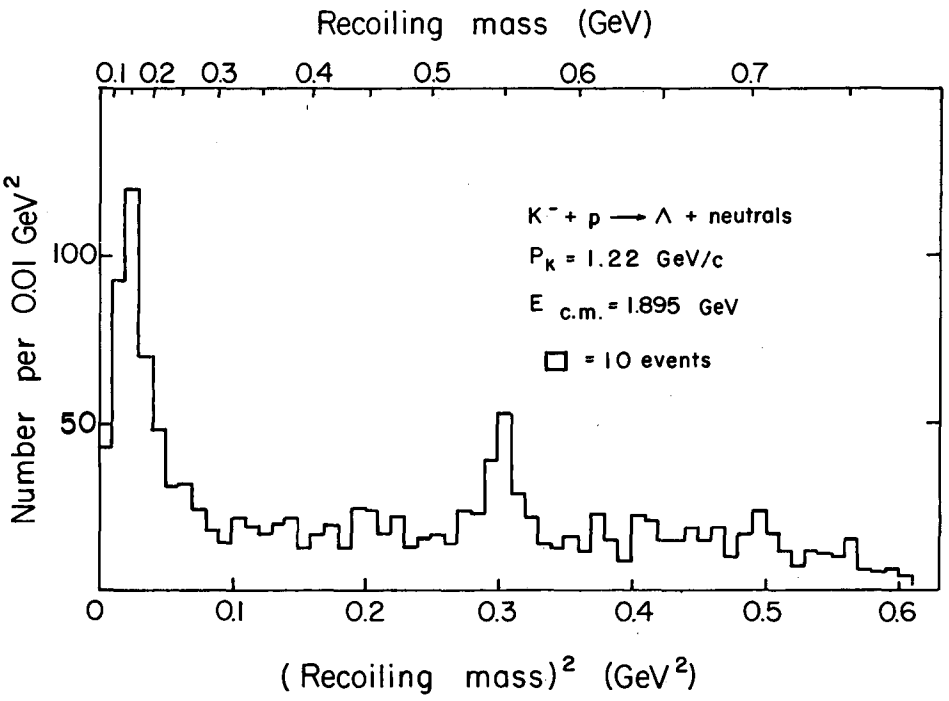
Recoiling mass (GeV)
0.1 0.2 0.3 0.4 0.5 0.6 0.7
Number per 0.01 GeV^2
100
50
$K^- + p \longrightarrow \Lambda$ + neutrals
P_K = 1.22 GeV/c
$E_{c.m.}$ = 1.895 GeV
□ = 10 events
0 0.1 0.2 0.3 0.4 0.5 0.6
(Recoiling mass)^2 (GeV^2)
MU-26924

Fig. 2

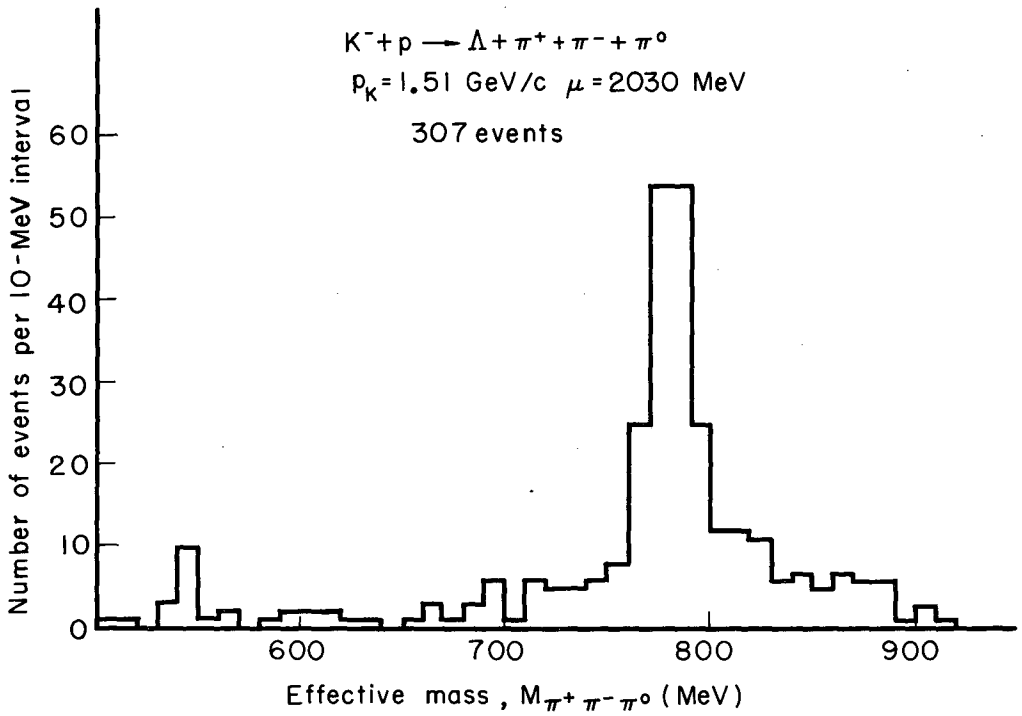
$K^- + p \longrightarrow \Lambda + \pi^+ + \pi^- + \pi^0$
$p_K = 1.51$ GeV/c $\mu = 2030$ MeV
307 events
Number of events per 10-MeV interval
0
10
20
30
40
50
60
600
700
800
900
Effective mass, $M_{\pi^+\pi^-\pi^0}$ (MeV)
MU-27048

Fig. 3

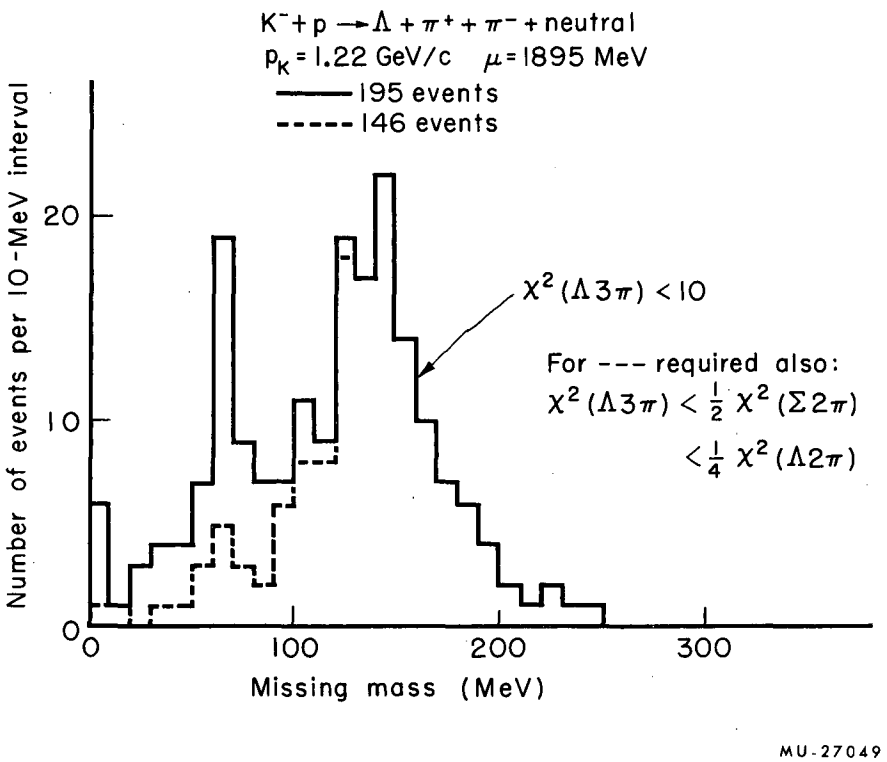
$K^- + p \rightarrow \Lambda + \pi^+ + \pi^- +$ neutral
p_K = 1.22 GeV/c μ = 1895 MeV
195 events
146 events
$\chi^2(\Lambda 3\pi) < 10$
For --- required also:
$\chi^2(\Lambda 3\pi) < \frac{1}{2}\chi^2(\Sigma 2\pi)$
$< \frac{1}{4}\chi^2(\Lambda 2\pi)$
Number of events per 10-MeV interval
0
10
20
0
100
200
300
Missing mass (MeV)
MU-27049

Fig. 4

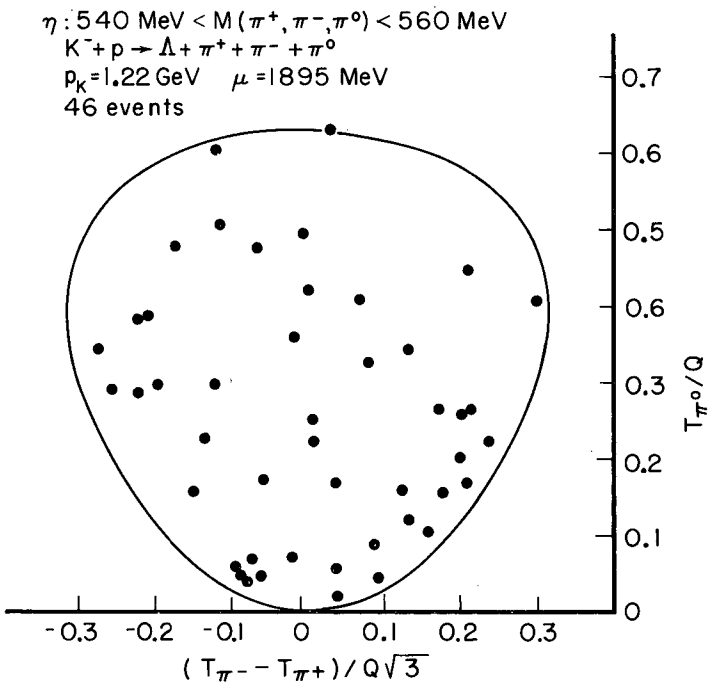
η : 540 MeV < M(π+, π−, π°) < 560 MeV
K⁻ + p → Λ + π+ + π− + π°
pK = 1.22 GeV μ = 1895 MeV
46 events
0.7
0.6
0.5
0.6
0.3
0.2
0.1
0
Tπ°/Q
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
(Tπ− − Tπ+)/Q√3
MU-27050

Fig. 5

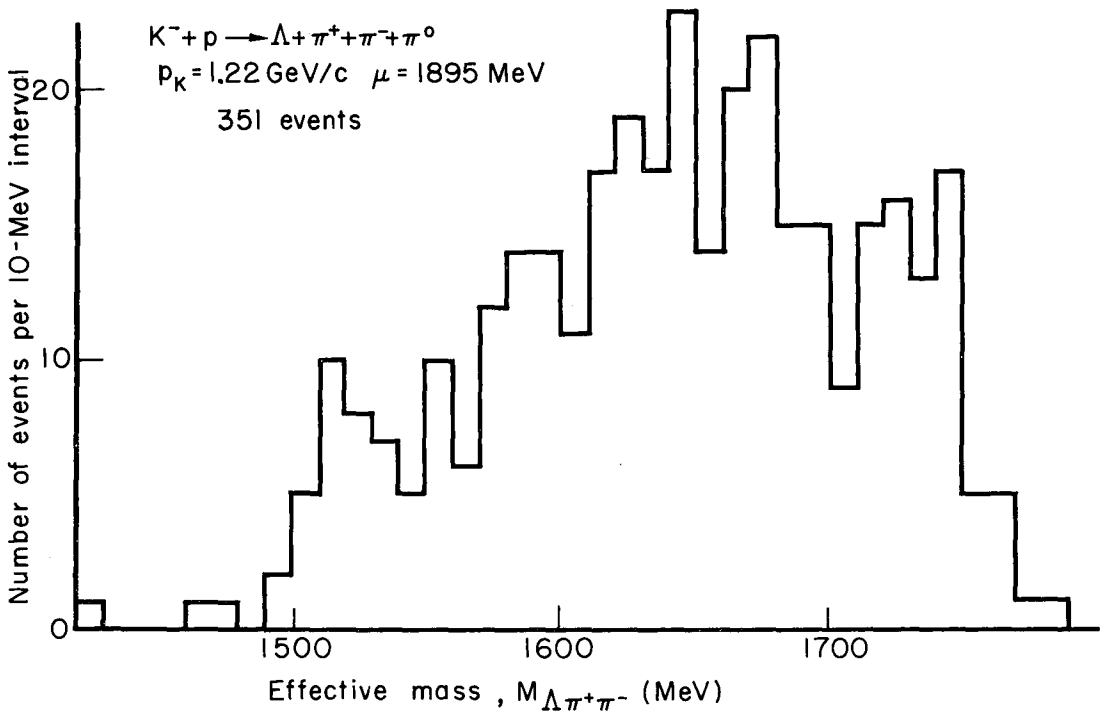
$K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \pi^0$
$p_K = 1.22$ GeV/c $\mu = 1895$ MeV
351 events
Number of events per 10-MeV interval
0
10
20
1500
1600
1700
Effective mass , $M_{\Lambda\pi^+\pi^-}$ (MeV)
MU-27051

Fig. 6

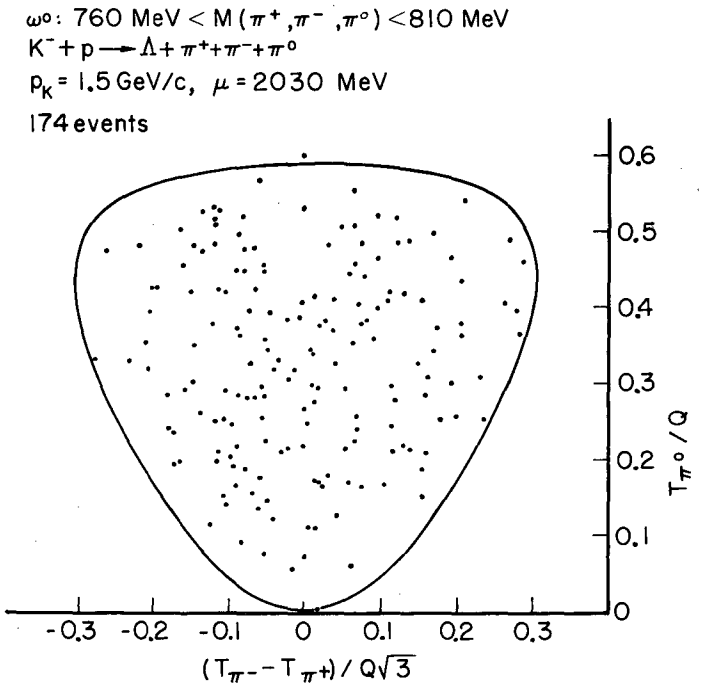
ω°: 760 MeV < M(π+,π−,π°) <810 MeV
K⁻ + p → Λ + π⁺ + π⁻ + π°
p_K = 1.5 GeV/c, μ = 2030 MeV
174 events
0.6
0.5
0.4
0.3
0.2
0.1
0
Tπ° / Q
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
(Tπ− − Tπ+) / Q√3
MU-27052

Fig. 7

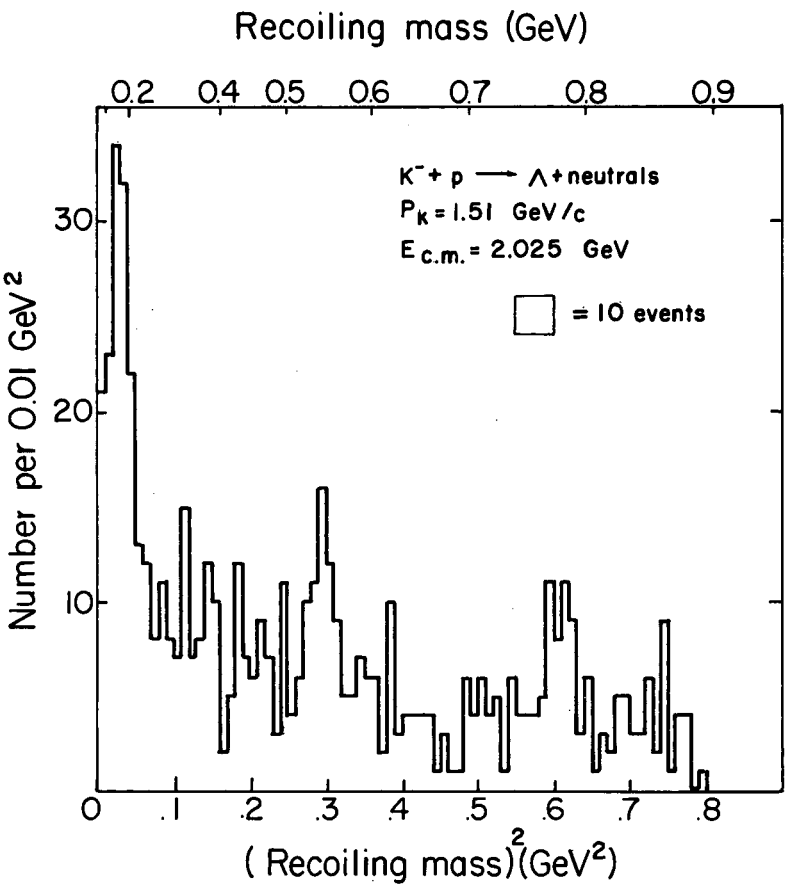
Recoiling mass (GeV)
0.2
0.4
0.5
0.6
0.7
0.8
0.9
K⁻ + p ⟶ Λ + neutrals
P_K = 1.51 GeV/c
E c.m. = 2.025 GeV
= 10 events
Number per 0.01 GeV²
30
20
10
0
.1
.2
.3
.4
.5
.6
.7
.8
(Recoiling mass)² (GeV²)
MU-26923

Fig. 8

$\Lambda\pi^+\pi^-\pi^0$ and Λ + Neutral Final States in K^-–p Interactions at K^- Momenta of 1.22 and 1.51 GeV/c.

Erratum: Through a more careful study of the resolution function for the $\pi^+\pi^-\pi^0$ effective mass near the ω^0 peak (page three) at 1.51 GeV/c incident K^- momentum, it has become clear that only an upper limit can be given for the width of the ω^0: $\Gamma \leq 15$ MeV.

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