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K^+ NUCLEON INTERACTION III: PION PRODUCTION BY K^+ MESONS ON HYDROGEN AND DEUTERIUM*

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Investigation of the K^+ nucleon reactions has previously been focussed on the determination of the phase shifts in the T = 1 and T = 0 states through the study of the elastic scattering and charge exchange processes.[1,2] Measurements of total elastic and inelastic cross sections at energies greater than approximately 1 BeV indicate that a large fraction of the cross section is via inelastic channels.[3] A notable feature of the K^+-p interaction is the approximate independence of the total cross section with energy up to about 1 BeV.

The experimental arrangement of the Bevatron separated K^+ beam and the L.R.L. 15" bubble chamber has been discussed in detail before.[4,5] With two stages of electromagnetic separation, a K^+ beam with about 0.5% contamination of lighter particles (π, μ, e) was obtained at 642 MeV/c. At 810 MeV/c, the contamination was of the order of 10%, of which about one half were π mesons. The total numbers of photographs taken were 40 000. On the average the incident beam contained 7 K^+ mesons per pulse.

The incident beam momenta were determined from measured ranges of stopping decay products of the K^+ meson, yielding the values P = 642 ± 5 MeV/c and

* Work done under the auspices of the U. S. Atomic Energy Commission.

810 ± 6 MeV/c. In the kinematical analysis of each event we made a weighted average of this "beam average" momentum, and the measured momentum of the incident track.

Each two prong event in hydrogen was analysed for kinematical consistency with elastic K^+ scattering,

$$K^+ + p \rightarrow K^+ + p$$

and the inelastic pion production reactions

$$K^+ + p \rightarrow K^+ + p + \pi^0 \quad \text{(a)}$$

$$K^+ + n + \pi^+ \quad \text{(b)}$$

$$K^0 + p + \pi^+ \quad \text{(c)}$$

In each case, the fit of the measured quantities to the kinematics of pion elastic scattering and single pion production was also examined. Visual estimates of bubble density of the reaction products were made in many cases to distinguish among the various reactions. The classification of the events as examples of one (or more) of the possible processes was made on the basis of goodness of fit to the kinematical constraints together with the ionization estimates and the further requirement that the measured incident particle momentum be less than three standard deviations from the average. Examples of reaction (c) with the subsequent decay $K^0 \rightarrow \pi^+ + \pi^-$ within the bubble chamber are identifiable with complete certainty since the incident momentum is below threshold for the background reaction $\pi^+ + p \rightarrow \Sigma^+ + K^0 + \pi^+$.

The scanning and the measuring of the deuterium events followed the same general procedures as for hydrogen. Here, however, the problem of distinguishing the pion production events was more difficult. Among the background were not only the interactions of incident pions, but also the K^+ scattering and charge exchange. It was not possible to uniquely classify any events yielding only two charged particles. Thus, of the possible inelastic reactions,

$$
\begin{aligned}
K^+ + D \rightarrow\ & K^+ p \pi^0 (n) && (a') \\
& K^+ n \pi^+ (n) && (b') \\
& K^0 p \pi^+ (n) && (c') \\
& K^+ n \pi^0 (p) && (d) \\
& K^0 n \pi^+ (p) && (e) \\
& K^0 p \pi^0 (p) && (f) \\
& K^+ p \pi^- (p) && (g)
\end{aligned}
$$

Only (c'), (e), (f), and (g) yield unambiguously classifiable events. In fact, the K^0 decay must also be observed in order to make an analysis of examples of (c'), (e), and (f). Examples of π^+ production [(c') and (e)] were distinguished from charge exchange

$$K^+ + D \rightarrow K^0 + p + (p)$$

by requiring a fit to the kinematics of the reaction as well as ionization estimates of the outgoing tracks. The same requirements were imposed on the

π^0 production although an ambiguity with the kinematics of the charge exchange reaction is only possible if the K^0 is produced backward in the lab system. In fact, no such cases occurred. Thus the sample of pion production is essentially free of any contamination of charge exchange events which might simulate inelastic processes. For reaction (g) the principal difficulty in analysis results from the pion contamination in the incident beam. It proved possible to separate events of the type $\pi^- + p \rightarrow \pi^+ \pi^- p$ from the K^+ interactions in all but one case. As evidence of this we point out that with the observed number of pion events, 75, and the cross section for the process (assumed equal to that for $\pi^+ + n \rightarrow \pi^+ \pi^- p$)[6], 16 mb., a pion contamination of 4.3% was calculated. This is in good agreement with other, independent, estimates discussed by Stubbs et al.[1]

In all analysis we presume the validity of impulse approximation, in the sense that the second nucleon is a spectator to the interaction of K^+ with the neutron or proton. We thus consider all events to be equivalent to examples of interactions with free nucleons.

We list in Table I the observed number of events of each type. The total number of hydrogen events is 96. In deuterium there were 92 events, 69 of which were interactions with neutrons.

The cross sections, for the proton reactions listed in Table I, are obtained directly from the numbers of events. The errors quoted included the statistical uncertainty and an estimate of the errors due to ambiguities in identification. To obtain the cross sections for the neutron interactions, corrections must be made for the unobserved examples of the reactions yielding neutral K mesons which do not decay within the bubble chamber. We correct for the fraction of K^0's decaying into neutrals (0.30 ± 0.04), and via the long-lived modes, (0.5). Geometrical corrections for K^0 decays outside the chamber are negligible.

For the hydrogen interactions we obtain an inelastic cross section, at 810 MeV/c

$$\sigma_{K^+p} = 0.95 \pm 0.16 \text{ mb}$$

and at 642 MeV/c

$$\sigma_{K^+p} = 0.06 \pm 0.03 \text{ mb}$$

The inelastic deuterium cross section, for the observed modes only is

$$\sigma'_{K^+D} = 1.8 \pm 0.2 \text{ mb}$$

which is, of course, a lower limit to the total inelastic cross section. The cross section for K^+-n, obtained from the number of event in the identified modes is

$$\sigma'_{K^+n} = 1.0 \pm 0.2 \text{ mb}$$

which again is only a lower limit for the K^+-n interaction cross section.

Table I

Inelastic Pion Production Events and Cross Section

Reaction	Number of Events	Cross Section (mb)
(a) $K^+ + p \rightarrow K^+ + p + \pi^0$	22	0.22 ± 0.05
(b) $\rightarrow K^+ + n + \pi^+$	11*	0.11 ± 0.04
(c) $\rightarrow K_1^0 + p + \pi^+$ ($\hookrightarrow \pi^+ + \pi^-$)	24	0.64 ± 0.08
$\rightarrow K^0 + p + \pi^+$	39**	
(c')$K^+ + d \rightarrow K_1^0 + p + \pi^+ + (n)$	23	0.77 ± 0.20
(e) $\rightarrow K_1^0 + n + \pi^+ + (p)$	7	0.27 ± 0.14
(f) $\rightarrow K_1^0 + p + \pi^0 + (p)$	6	0.23 ± 0.14
(g) $\rightarrow K^+ + p + \pi^- + (p)$	55***	0.51 ± 0.09

* Included are two events consistent with $\pi^+\pi^+n$

** Included are two events consistent with (b) or (c)

*** Included is one event consistent with $\pi^+\pi^-p$

In Table I we present branching ratios for the various pion production modes for the K^+-p and K^+-n interactions. The branching ratios observed are not those expected from purely statistical considerations but are determined by the dynamics of the reaction and presumably are affected also by final state interactions.

In the K^+-p interaction the final state $K^o\, p\, \pi^+$ is the dominant mode. In the K^+-n interaction the $K^+\, p\, \pi^-$ state is the dominant mode. In order to gain some insight into these phenomena we have evaluated the branching ratios on the simplified assumption that the final state interaction is dominated by a specific two-particle state. In Table II we present the relevant two-particle states we have considered here. Column two gives the expected relative intensities if a $T = 3/2$ πN state were to dominate the final state. Whereas the production cross sections for the K^+-p channels are consistent with this assumption, the K^+N cross sections do not agree with it.

The expected relative intensities for a dominant KN interaction in the $T = 0$ state is given in Column three. The experimental data cannot be represented by purely such a state. Finally in Column four we give the relative intensities for a dominant $K\pi$ interaction in the $T = 1/2$ state. To this final state interaction both initial isotopic spin state $T = 0$ and $T = 1$ contribute. The computed relative intensity for the K-p system as well as for the K-n system are consistent with the experimental data. The latter also allows the determination of A_1 and A_o.

If final state interactions are important in these production reactions, one might expect correlations among the energies or angles of the outgoing

Table II

Reaction	Relative Intensities for Assumed Dominant Two Particle State			σ_{exp} (mb)
	πN (T = 3/2)	KN (T=0)	$K\pi$ (T = 1/2)	
$K^+p \rightarrow K^+p\pi^0$	2	0	$4A_1^2$	0.22 ± 0.05
$K^+n\pi^+$	1	2	0	0.11 ± 0.04
$K^0p\pi^+$	9	2	$8A_1^2$	0.64 ± 0.08
$K^+n \rightarrow K^0n\pi^+$	1	0	$2(A_1 + A_0)^2$	0.27 ± 0.14
$K^0p\pi^0$	2	1	$(A_1 - A_0)^2$	0.23 ± 0.14
$K^+p\pi^-$	1	0	$2(A_1 - A_0)^2$	0.51 ± 0.09
$K^+n\pi^0$	2	1	$(A_1 + A_0)^2$	-

Table II - Relative intensities for the various $KN\pi$ systems on the simplified assumption of a dominant two particle state in the final state interaction.

particles. To this end we plot Figures 1, 2, and 3 the distribution of invariant mass of the two-body systems produced in the K^+-p reactions.[7] In Fig. 4 are similar plots for the neutron reaction. Comparing the observed distributions with the Lorentz-invariant phase space indicated on the figures, we see a particularly strong deviation in Fig. 1 for the KN (T=0) mass distribution, and a somewhat weaker deviation from phase space in Fig. 2, for the $K\pi(T = 1/2)$ mass distribution. All other mass distributions are consistent with those predicted from phase space. A Dalitz plot of pion versus nucleon kinetic energy is shown in Fig. 5. Again we see a clear concentration of $K^o\, p\, \pi^+$ events in the region of high π^+ energy. The plot does not indicate a strong concentration along lines parallel to either axis nor along a diagonal line of constant K^o energy (constant π-p effective mass). It is interesting to note that there does not seem to be any effect of the (3,3) π^+-p resonance (M (πp)=1238 ± 45 MeV). The boundary of the phase space region for $M^*(\pi^+p)$ effective mass is at a value of 1207 MeV, indicated on the diagonal line of Fig. 5. No variation of density of events near the boundary is observed.

In conclusion then, as we have stated earlier,[1,8] we observe branching ratios consistent with a K-π interaction in the T = 1/2 state. This intensity distribution together with the suggestion of a peak around $M(K\pi)$ = 720 MeV which we observe, would be consistent with a recently suggested[9] $K\pi$ resonance at this same energy. The prominence in the effective mass distribution $M^*(KN)$ = 1480 MeV would as far as this distribution alone is concerned be most readily explained by a K-nucleon resonance in the T = 0 state.

Here it should be noted that the reflection of a $K\pi$ state on the M^* ($\bar{K}N$) mass distribution contributes to the low mass side and cannot in itself explain the M^* ($\bar{K}N$) = 1480 prominance. It thus seems to us that additional dynamic effects must be responsible for the observed deviation from phase space. The interpretation of the prominance as a $\bar{K}N$ resonance suffers, however, from a number of difficulties. Firstly, the intensity distribution in the various modes shown in Table II do not follow a distribution with the $\bar{K}N$ state as a major mode. That could be due to interference between the various amplitudes. The more serious difficulty is that the presence of such a resonance would require a corresponding increase in the K^+n cross section at $P_K \simeq 280$ MeV/c. Actually measurements are only available[2,5] at 230 ± 40 MeV/c and 330 ± 20 MeV/c. A resonance in the usual sense would lead to appreciably higher cross sections in the K^+d charge exchange reaction than observed at the above mentioned momenta.[10] Only the assumption for a rather narrow resonance which has been missed by the available K^+n charge exchange data could possibly be reconciled with this interpretation.

References

1) T. F. Stubbs, H. Bradner, W. Chinowsky, G. Goldhaber, S. Goldhaber, W. Slater, D. H. Stork, and H. K. Ticho, Phys. Rev. Letters 7, No. 5, 188 (1961).

2) W. Slater, D. H. Stork, H. K. Ticho, W. Lee, W. Chinowsky, G. Goldhaber, S. Goldhaber, and T. O'Halloran, Phys. Rev. Letters 7, 378 (1961).

3) V. Cook, D. Keefe, L. T. Kerth, P. G. Murphy, W. A. Wenzel, and T. F. Zipf, UCRL 10183 and Phys. Rev.in Press.

4) G. Goldhaber, S. Goldhaber, J. Kadyk, T. Stubbs, D. H. Stork, and H. K. Ticho, Lawrence Radiation Laboratory Internal Report Bev-483, February 26, 1960 (unpublished).

5) W. Lee, Charge Exchange Scattering of Positive K Mesons on Deuterons, Lawrence Radiation Laboratory Report UCRL 9691, May 14, 1961.

6) L. Baggett Jr., π^--p Elastic Scattering and Single Pion Production at 0.939 BeV/c (Ph.D. Thesis), Lawrence Radiation Laboratory Report UCRL 8302, May 28, 1958.

7) Included are five examples of $K_1^0 \pi^+ p$ which occurred outside the fiducial volume but was nonetheless well measured. Also included with the hydrogen events are the corresponding deuterium events (c').

8) Reported at the Los Angeles Meeting of the American Physical Society December 1961. H. F. Fisk, W. S. Slater, D. H. Stork, H. K. Ticho, W. Chinowsky, G. Goldhaber and S. Goldhaber, Bull. Am. Phys. Soc. Paper G7 6, 510, 1961.

9) G. Alexander, G. Kalbfleisch, D. Miller, G. A. Smith, UCRL 10195, Phys. Rev. Letters in print.

Figure Captions

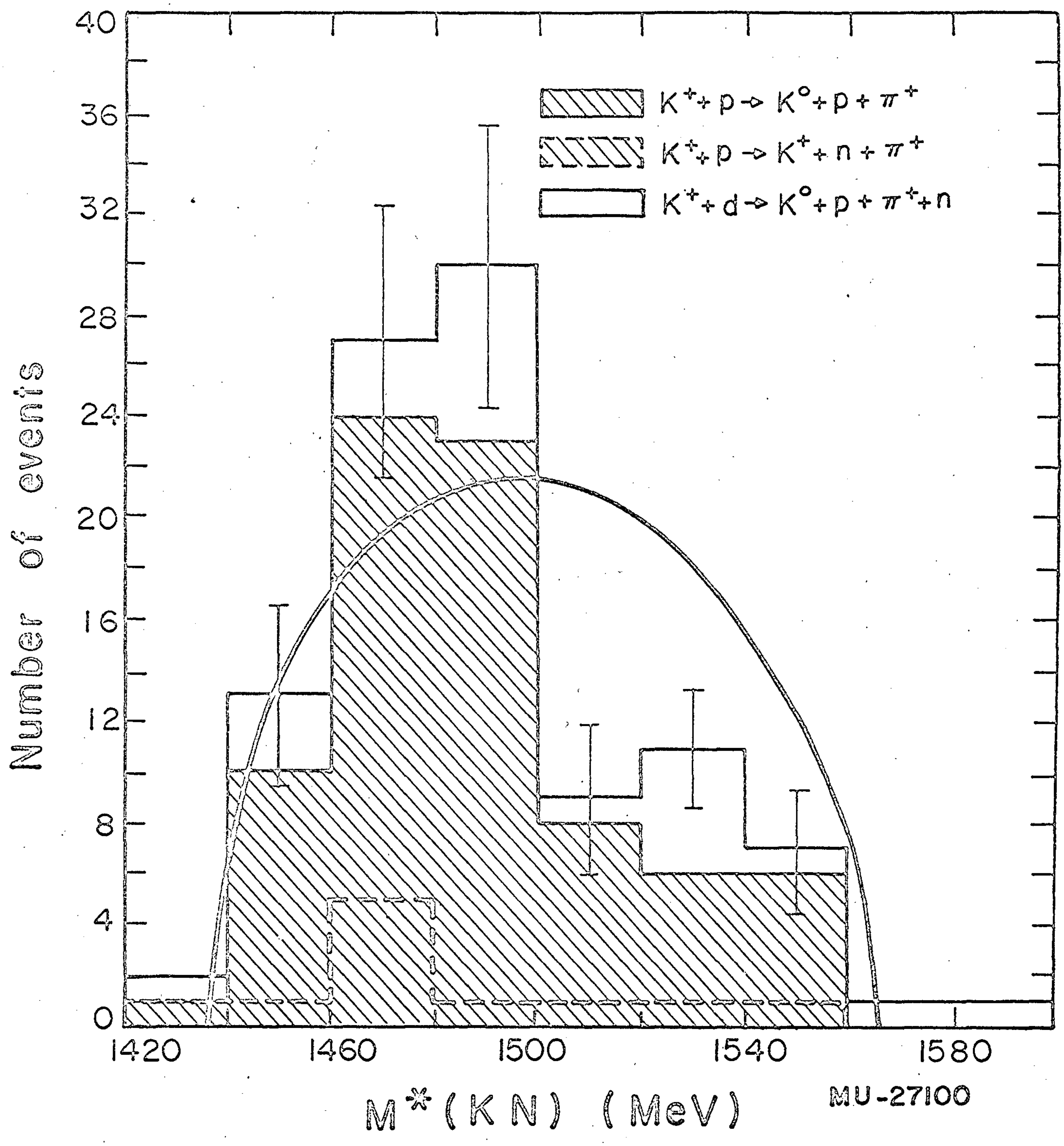
Fig. 1 The effective mass distribution for M* (KN). Included here are also events from the reaction $K^+ + P \rightarrow K + n + \pi^+$, for which the KN state with $T = 0$ is also possible. Here, as well as in the following figures, it should be noted that due to the motion of the nucleons in the deuteron, the phase space for the events coming from the K^+d interaction is broader. The phase space curves shown refer to the K H interaction in all cases.

Fig. 2 The effective mass distribution for M* ($K\pi$). Included here are also events from the reaction $K^+ + p \rightarrow K^+ + \pi^0 + p$ for which the $K\pi$ state in $T = 1/2$ is also possible.

Fig. 3 The effective mass distribution for M* ($p\pi^+$).

Fig. 4 The effective mass distributions for the three final state two-body combinations in the reaction $K^+ + d \rightarrow K^+ + \pi^- + p + (n)$.

Fig. 5 A Dalitz plot for the $K^+ + p \rightarrow K^0 + p + \pi^+$ events from hydrogen and deuterium. Plotted is the total energy in the cm for the π^+ meson versus the proton. Also shown are the mass scales for M* ($K^0\pi^+$) and M* (K^0p). Along the diagonal we indicate the M* (πp) values. The dotted diagonal line corresponds to the half value point of the π^+p 3/2 3/2 resonance.



40
36
32
28
24
20
16
12
8
4
0
Number of events
K⁺+p→K°+p+π⁺
K⁺+p→K⁺+n+π⁺
K⁺+d→K°+p+π⁺+n
1420
1460
1500
1540
1580
M*(KN) (MeV)

MU-27100

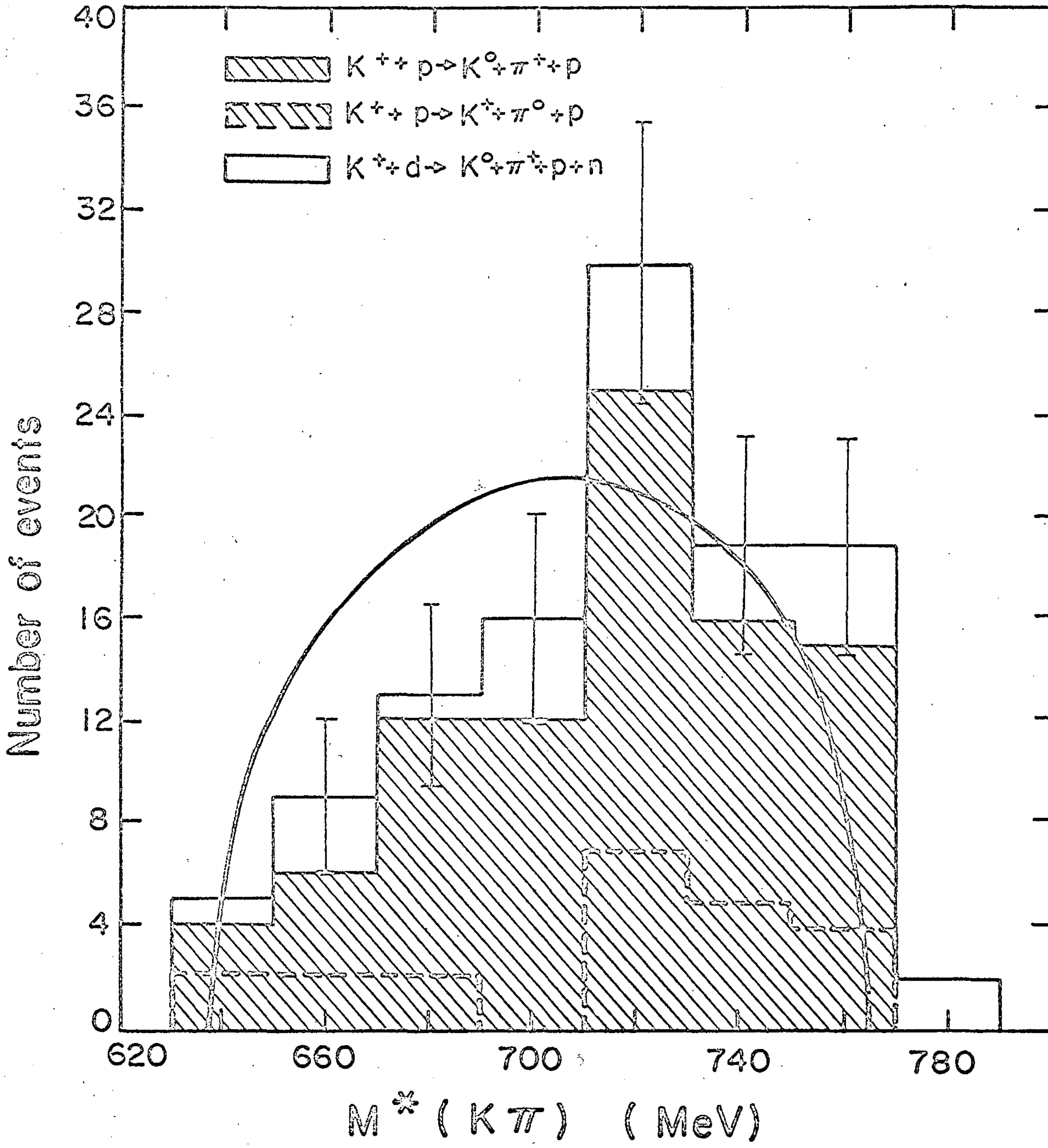


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Fig. 2

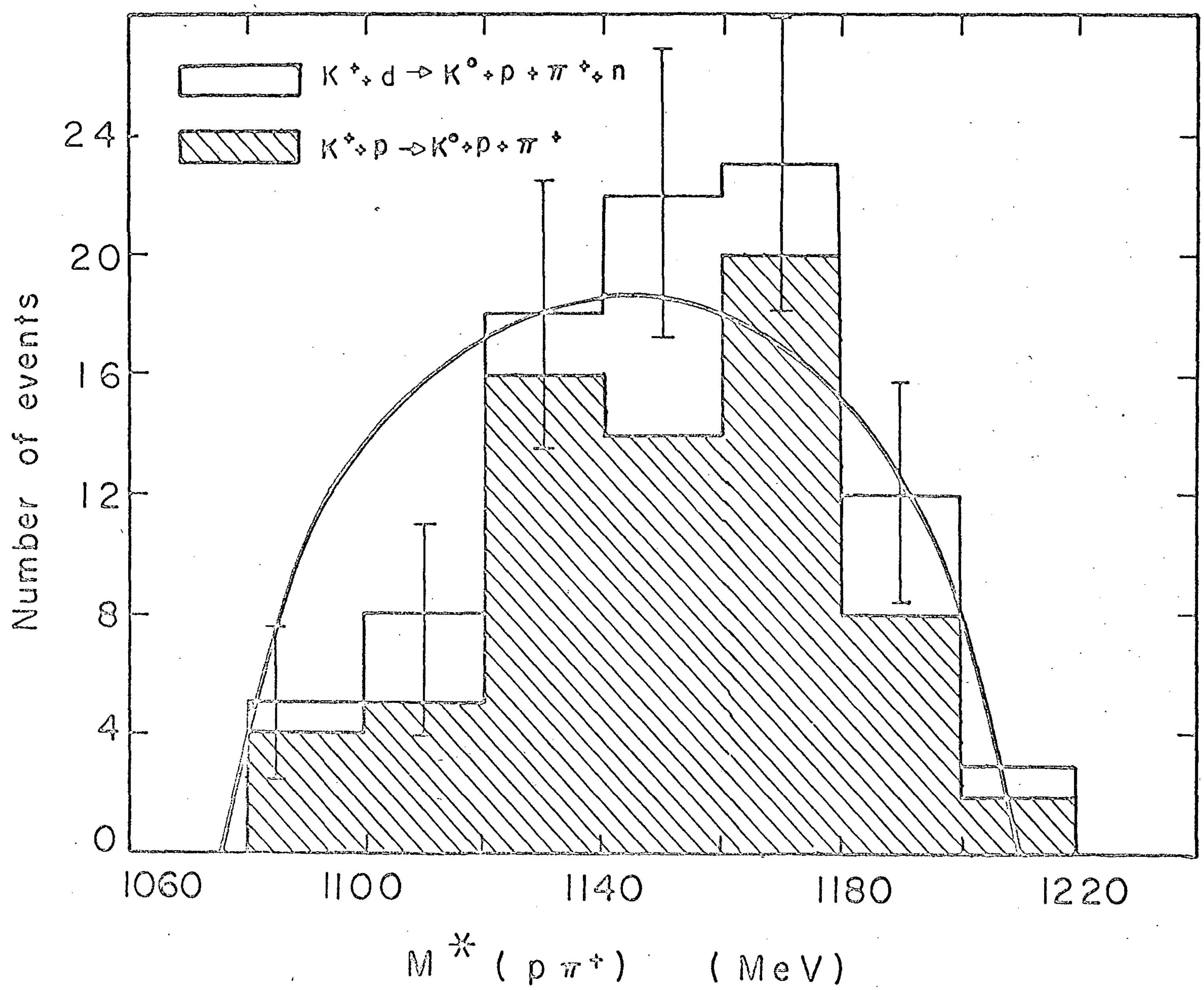

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Fig 3

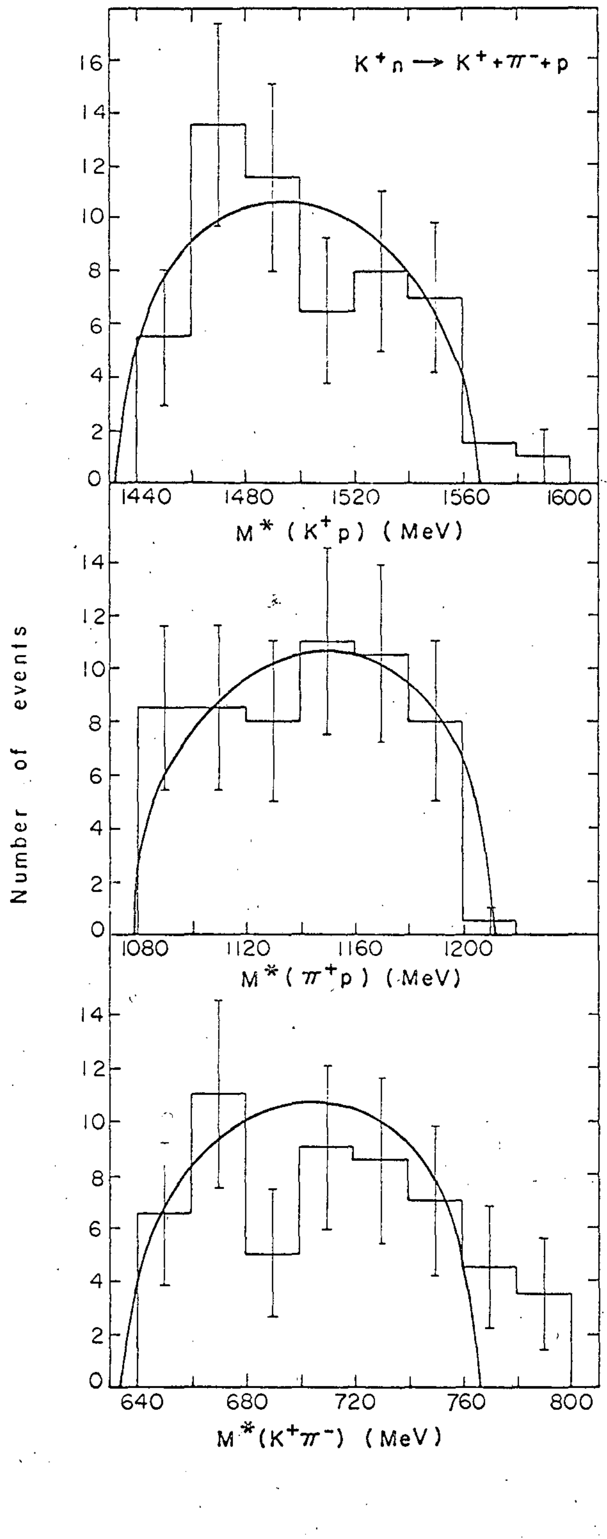

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Fig X

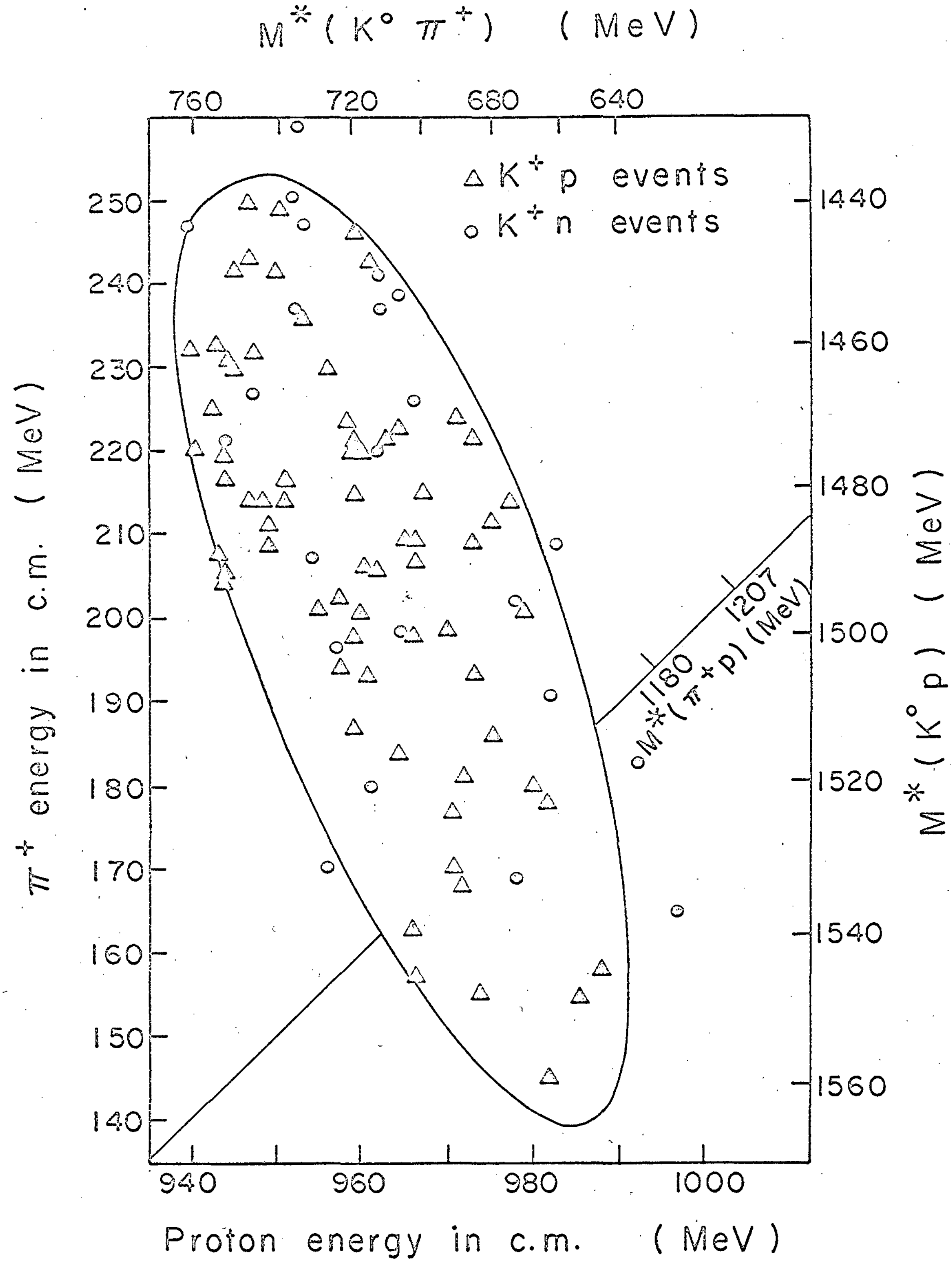

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Fig 5