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STUDY OF THE I = 2 $\Sigma\pi$ SYSTEM IN π + N INTERACTIONS*

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The extent of possible similarities between π-N and π-Y couplings has been a subject for continuous theoretical speculation. In the original global-symmetry model proposed by Gell-Mann[1)] and independently by Schwinger[2)], all π-baryon couplings were assumed equal and dominant over the weaker K-baryon couplings. As a direct consequence, the π-N isobar, $N^*_{3/2}$(1238 MeV), implies the existence of analogous $P_{3/2}$ resonances in the I = 1 and I = 2 states of the Yπ system[1, 3)]. Estimated masses and full widths[3, 4)] for these states are $M(Y_1^*) \approx 1380$ MeV with $\Gamma(Y_1^*) \approx 50$ MeV, and $M(Y_2^*) \approx 1535$ MeV with $\Gamma(Y_2^*) \approx 140$ to 200 MeV. Some support for an approximate symmetry of this type has been provided by the discovery[6)] of Y_1^*(1385 MeV) and the analysis of low-energy N-Y interactions[7)]. In addition, Dowell et al. have recently reported the results of a counter experiment in which $\pi^- + p$ interactions were used to study resonances in the I = 1 and I = 2 Yπ states[8)]. The cross section for production of fixed-momentum

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† Now at the Israel Atomic Energy Commission Laboratories, Rehovoth.

(0.94 BeV/c) K^+'s at 0 deg was measured while the momentum, p_π, of the incident π^- was varied from 1.3 to 2.4 BeV/c. For any p_π, the mass of the system recoiling against the K^+ is uniquely determined, and enhancements in cross section were observed for π^- momenta corresponding to production of Σ^- and Y_1^*(1385 MeV). However, their data indicated an additional enhancement for systems with mass in the region 1550±20 MeV. Since no evidence for an $I = 1$ resonant state at this mass has appeared[9], the possibility that the effect arises from a resonance in the $I = 2$ state of the $Y\pi$ system must be considered.

In the present Letter we report a study of the effective-mass distributions for systems recoiling against K^+'s produced both in $\pi^- + p$ and $\pi^- + n$ interactions. Although all the known energetically accessible resonances are produced the data show no systematic enhancement that we can identify as arising from an $I = 2$ $Y\pi$ resonant state. In addition, since the final states are so strongly dominated by the known resonances, we conclude that convincing evidence regarding the possible existence of a weakly produced $I = 2$ resonant state will be difficult to obtain in $\pi + N$ interactions.

If an $I = 2$ $Y\pi$ resonance exists, it can be produced in association with a K meson only from the $I = 3/2$ component of the $\pi + N$ system. Consequently, under the assumption of charge independence, the relative production rates in $\pi^- + p$ and $\pi^- + n$ interactions are uniquely determined. The amplitude for Y_2^* production may be written

$$\langle \pi^- p | T | Y_2^* K \rangle = A \left[(2/5)^{1/2} Y_2^{*0} K^0 - (1/5)^{1/2} Y_2^{*-1} K^+ \right] \quad (1a)$$

$$\langle \pi^- n | T | Y_2^* K \rangle = A \left[(1/5)^{1/2} Y_2^{*-1} K^0 - (4/5)^{1/2} Y_2^{*-2} K^+ \right] \quad (1b)$$

where the superscript designates the Y_2^* charge. For systems recoiling against K^+'s, it is apparent that any effect associated with the $I = 2$ $Y\pi$ system observed in $\pi^- + p$ interactions must occur four times more strongly in $\pi^- + n$ interactions.

The data for reactions (1a) were obtained during an extensive exposure of the Lawrence Radiation Laboratory's 72-in. hydrogen-filled bubble chamber to an incident π^- beam at momentum settings ranging from 1.89 to 2.36 BeV/c. In order to study reactions (1b), the bubble chamber was filled with deuterium and exposed to 2.26-BeV/c π^-'s. After scanning and measurement, events were fitted kinematically by means of the IBM program PACKAGE. In general, events could be properly identified on the basis of the adequacy of fit (as measured by χ^2) to both the production and decay vertices. In ambiguous cases, a decision was made after track ionization was checked on the film. The data used in the present analysis are summarized in table I.

The correlations in three-body final states produced in $\pi^- + p$ collisions have been examined in detail. In most cases, the reactions are clearly dominated by the sequences $\pi^- + p \rightarrow Y^* + K$ or $Y + K^* \rightarrow Y + \pi + K$. In particular, the $\Sigma^{\pm}\pi^{\mp}K^0$ final states contain contributions from Y_0^*(1405 MeV), Y_0^*(1520 MeV), and at higher momenta, from the recently established Y_1^*(1660 MeV)[10, 11]; the $\Sigma^-\pi^+K^0$ Dalitz plot shows an additional crossing band due to K^*(885 MeV) production. Consequently, in these cases there is little possibility of distinguishing any effect arising from a broad $I = 2$ resonance in the region $M \approx 1550$ MeV. However, a more favorable situation exists for the $Q = -1$ systems recoiling against K^+'s, i.e., $\Sigma^-\pi^0$ and $\Sigma^0\pi^-$, since the only low-lying $I = 1$ baryon resonance, Y_1^*(1385 MeV), decays predominantly via the $\Lambda\pi$ channel. In an attempt to simulate the experiment of Dowell et al., we have plotted the effective-mass distributions in fig. 1 for all two-body final states† produced in association with K^+'s. The solid curve drawn through the data represents approximately the distribution expected for final states dominated by K^*(885 MeV) production with small contributions from Y_1^*(1385 MeV) and Y_1^*(1660 MeV). Since the normalization of the phase space curve is somewhat arbitrary, the data do not rule out an enhancement of $\lesssim$ 40 events in the region $M \approx 1550$ MeV, although a substantially larger effect appears unlikely. For the path length examined, such an enhancement would correspond to the production of a $Q = -1$ ($I = 1$ or 2) resonant state with a cross section $\lesssim 2\mu b$.

The $\pi^- + n$ interactions produced in the deuterium-filled bubble chamber are particularly useful in the search for an $I = 2$ resonance, since $Y_2^* + K$ production would lead predominantly to the $\Sigma^- \pi^- K^+$ final state. Not only is this configuration readily fitted kinematically whether or not the spectator proton is observed, but also the isotopic spin of $\Sigma^- \pi^-$ is uniquely $I = 2$. The Dalitz plot for the 123 events identified as $\Sigma^- \pi^- K^+$ is given in fig. 2, and the effective-mass distributions in fig. 3, b and c. The distributions appear remarkably simple in structure and suggest that the reaction proceeds almost entirely through the intermediate state $\Sigma + K^*$. The tendency for the

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† Dowell et al. (reference 8) have pointed out that if Y^* production is peaked in the backwards direction, the selection of K^+'s in the forward direction (as in their experiment) could substantially enhance the number of Y^* events relative to those resulting from K^* production. Because of statistical limitations, a similar selection cannot be performed in the present case.

$M^2(\Sigma^-\pi^-)$ distribution to peak near the center reflects the anisotropic decay of the K^* with respect to its production direction in the $\Sigma + K^*$ center-of-mass system[12]. Figure 2 suggests that at most 15 to 20 events are not readily attributed to K^* production, and that the events outside the K^* band do not tend to accumulate in the region $M \approx 1550$ MeV. On the basis of the observed path length, we have estimated the cross section for the reaction $\pi^- + n \rightarrow \Sigma^- + \pi^- + K^+$ to be 70 ± 10 μb; if an $I = 2$ resonant state leading to $\Sigma^-\pi^-K^+$ is produced, its cross section must be less than 10 μb. Because of the coefficients in eqs. (1a) and (1b), this upper limit is equivalent to that implied by the $\pi^- + p$ data.

Some estimate for the result of the present experiment may be obtained if we assume that the enhancement reported by Dowell et al. arises from an $I = 2$ resonant state.† Their data indicate that at $p_\pi = 1.99$ BeV/c, the differential K^+ cross section rises 2 to 3 μb/sr above a smooth background curve. If we use eqs. (1a) and 1b), the total cross section for $\pi^- + n \rightarrow Y^{*--} + K^+$ is $\approx (4\pi/3)(4)(2 \text{ to } 3)$ μb $\approx$ 34 to 50 μb. The factor 1/3 is included because of the

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† The presence of an enhancement in the data of Dowell et al. as well as the extrapolation to the present experiment depends upon the assumption that the cross sections are slowly varying over the momentum interval studied. However, some part of the effect observed by Dowell et al. may be associated with the recently discovered $I = 1/2$ resonance in the π^-p system at 2.1 BeV/c A. N. Diddens, E. W. Jenkins, T. F. Kycia, and K. F. Riley, Brookhaven National Laboratory, to be published in Phys. Rev. Letters.

observed tendency for Y^*'s to be produced in the backward direction.‡ Consequently, for the path length examined, we expect 65 to 90 events, with 45 to 65 lying outside the K^* band. This prediction disagrees markedly with the data.

We conclude that the present experimental data in both hydrogen and deuterium provide little support for the existence of a resonance in the I = 2 $Y\pi$ system. If such a state exists, it is weakly produced in $\pi + N$ interactions and its effects are largely obscured by other resonances which dominate the final states.

The absence of such a resonant state appears incompatible with theories which assume the dominance and approximate equality of pion-baryon couplings. It is of interest to note, however, that if the SU(3) symmetry model of Gell-Mann[13)] and Ne'eman[14)] is approximately valid, the low-lying baryon states can be accommodated in unitary multiplets of dimensionality 1, 8, and 10[11,15)]. None of these contains an I = 2, S = -1 resonant state.

It is a pleasure to acknowledge the interest and encouragement of Professor Luis Alvarez through the course of this experiment. We are indebted to the operating crews of the 72-inch bubble chamber and the Bevatron, as well as our scanning and measuring staffs for their ability, effort, and patience.

‡ The factor was obtained from a study of the angular distributions for Y_1^*(1385 MeV), Y_0^*(1405 MeV), and Y_0^*(1520 MeV) produced in π^-p interactions. However, it is important to note that although these resonant states can be produced in peripheral (K^* exchange) collisions, the Y_2^{*--} cannot, so that its production angular distribution would probably be less peaked in the backward direction. Under these conditions, 1/3 may be considered a conservative lower limit to the correction factor.

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Table I

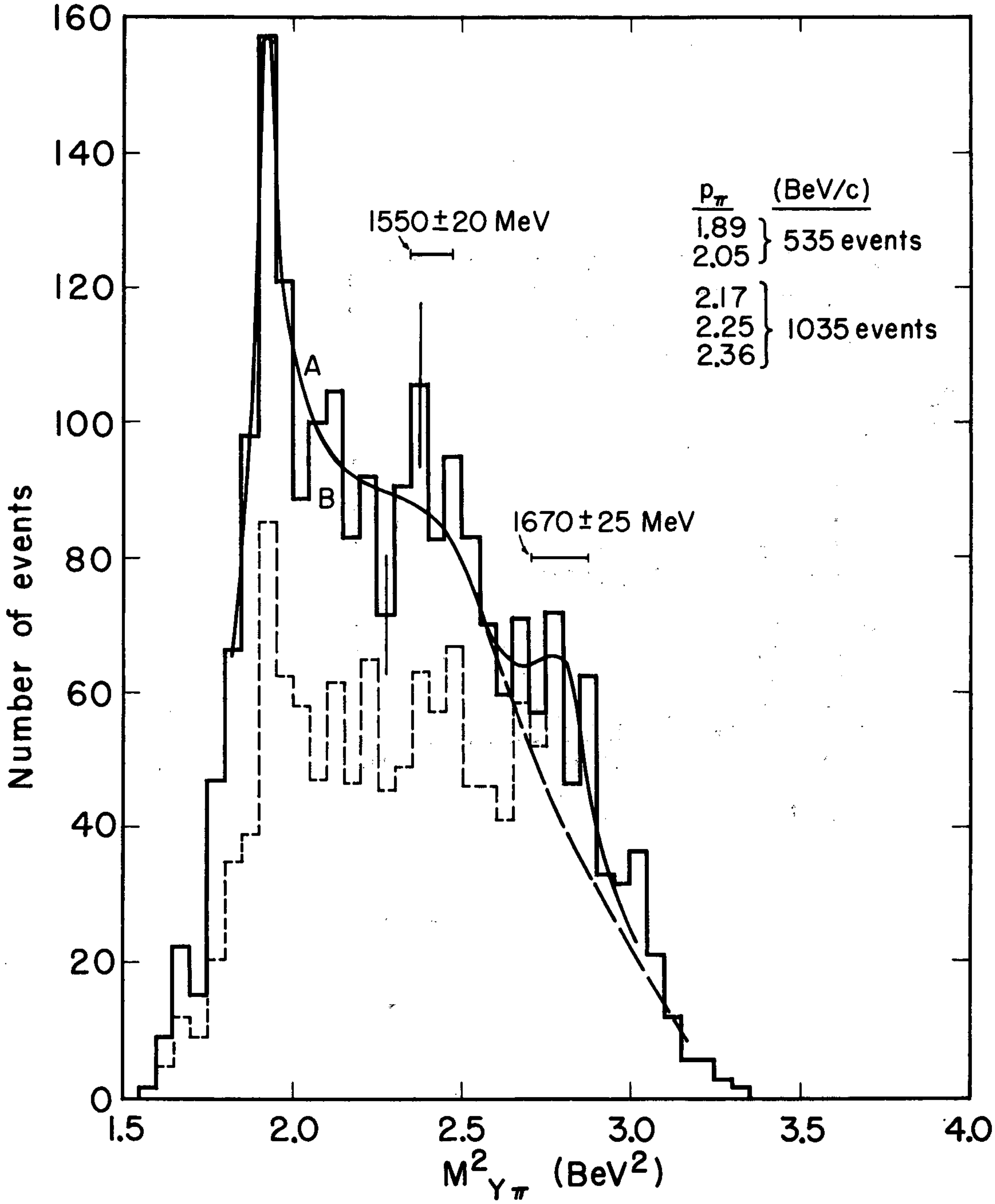
Summary of events used in the present analysis.

Event type	Number of events: 1.89 and 2.05 BeV/c	Number of events: 2.17, 2.26, and 2.36 BeV/c
$\Sigma^-\pi^+K^0$	267	691
$\Sigma^+\pi^-K^0$	86	238
$\Lambda\pi^0K^0$	110	153
$\Sigma^0\pi^-K^+$	116	295
$\Sigma^-\pi^0K^+$	158	310
$\Lambda\pi^-K^+$	261	430
$\Sigma^-\pi^-K^+(p)$		123[a]

[a] All at 2.26 BeV/c.

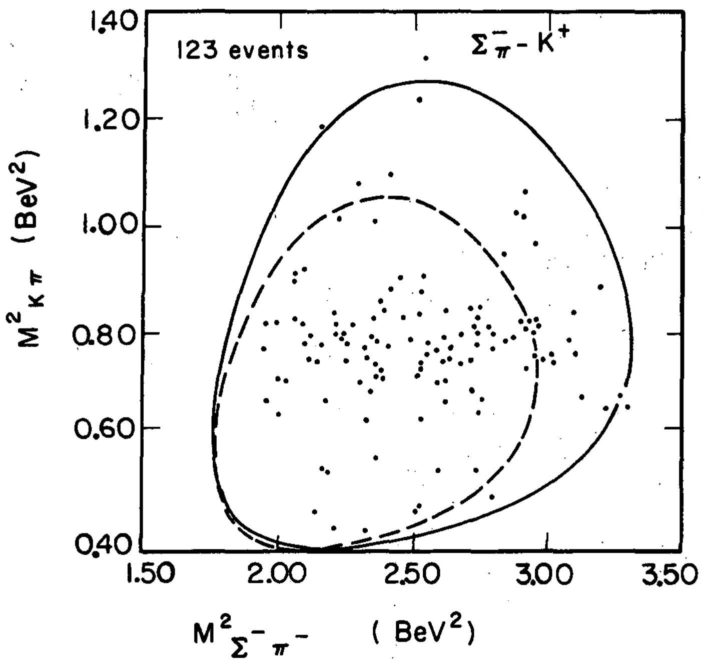
Figure Legends

1) M^2 distributions for $\Omega = -1$ $Y\pi$ systems produced in $\pi^- + p$ interactions. The $\Sigma^0\pi^-$ and $\Lambda\pi^-$ distributions have been corrected for neutral decay of the Λ. The solid curve represents the expected distribution for final states dominated by K^*(885 MeV) production with contributions from Y_1^*(1385 MeV) and Y_1^*(1660 MeV).
2) Dalitz plot for $\Sigma^-\pi^-K^+$ final states produced in $\pi^- + n$ interactions.
3) M^2 distributions for the $\Sigma^-\pi^-K^+$ final states. The width of the $M^2(\Sigma^-\pi^-K^+)$ distribution (a) arises from the momentum spread of the neutron in the deuteron and the ±2% spread in the incident π^--momentum. The dashed curve shown in (b) is the distribution expected for production of a K^* with $M \approx 775$ MeV, and $\Gamma \approx 58$ MeV. The dashed curve in (c) corresponds to the distribution resulting from decay of unaligned K^*'s. The finite width of the $M^2(\Sigma^-\pi^-K^+)$ distribution results in a spread for the maximum $M^2(\Sigma^-\pi^-)$ indicated by $\Delta M^2(\Sigma^-\pi^-)$.



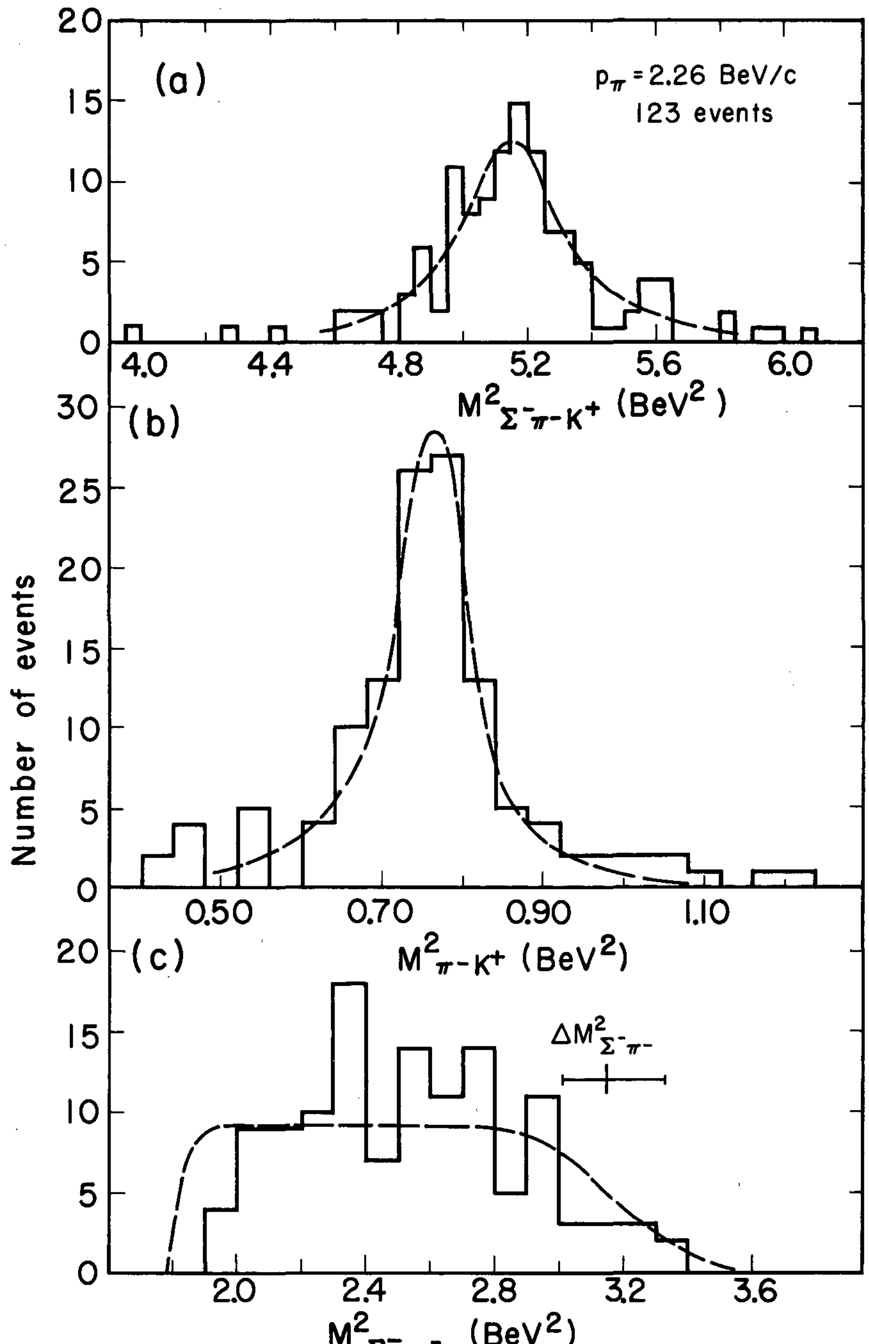
MUB-1567

Fig. 1



MU-29509

Fig. 2



MUB-1566

Fig. 3