Search for Y_2^* Resonances†

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A search has been made for a doubly charged $\Sigma\pi$ resonance produced in $\bar{K}N$ interactions. Data in hydrogen with incident K^- momentum of 1.51 and 1.70 BeV/c, and in deuterium with a K^- momentum of 1.49 BeV/c, show no evidence for any $T=2$ resonance for a $\Sigma\pi$ mass below 1900 MeV.

I. INTRODUCTION

No substantial evidence has been reported for any baryon resonance with isospin $T\geqslant 2$. Dowell *et al.* observed a possible Y^{*-} bump at 1550 MeV,[1] and suggested that it might have $T=2$. However, Kalbfleisch *et al.* fail to see such a Y_2^*,[2] and Baltay *et al.* see a small bump at 1550 MeV in $\Lambda\pi$ states ($T=1$).[3] Consequently, if there is a Y^* resonance at 1550 MeV, it is unlikely to have $T=2$. The experiment described here represents another negative result, based on about 2000 $\Sigma^\pm\pi^\pm$ events in the mass range up to 1900 MeV.

From a theoretical point of view, the outmoded global-symmetry model predicts a resonance $Y_2^*(1530, \frac{3}{2}^+)$. The currently popular "eightfold way" makes no predictions, except to require that if a $T=2$ resonance is found, it must be a member of a supermultiplet with 27 or more members.

In an unsuccessful attempt to look for a resonance in the doubly charged $\Sigma\pi$ systems, we have analyzed film from the Berkeley 72-in. bubble chamber filled with hydrogen and deuterium. In hydrogen the reactions studied were

$$K^-+p\rightarrow\Sigma^++\pi^-+\pi^++\pi^- \quad (1)$$

and

$$K^-+p\rightarrow\Sigma^-+\pi^++\pi^++\pi^- \quad (2)$$

at incident K^- momenta of 1.51 and 1.70 BeV/c (total c. m. energy of 2025 and 2110 MeV). Results of some lower momentum work at 1.22 BeV/c have already been published.[4]

In deuterium we studied the 1.49-BeV/c K^- reactions

$$K^-+d\rightarrow\Sigma^-+\pi^-+\pi^++p, \quad (3)$$

$$K^-+d\rightarrow\Sigma^++\pi^-+\pi^-+p, \quad (4)$$

where the proton is a spectator. The latter reaction was studied for completeness only, since it sheds no light on states with $T=2$.

All these final states are complicated and hard to analyze. Bumps were indeed observed in the mass spectra of $\Sigma^\pm\pi^\pm$; however, we interpret them as the result of known $Y_{0,1}^*$ resonances and explain our data fairly simply without requiring any $T=2$ resonance.

II. EXPERIMENTAL METHOD

For this experiment we used film of the 72-in. bubble chamber exposed between September 1961 and June 1962 to incident 1- to 2-BeV/c K^- mesons from the Bevatron.[5] The momentum spread at each setting is typically $\pm3\%$. Details of the exposure are given in Table I. The path length in hydrogen was obtained by counting (a) τ decays and (b) the total number of interactions and normalizing to the known total cross sections.[6] Results from the two methods agreed to within 10% at all momenta. In deuterium the path length was obtained by finding the number of 3-prong events that fit the kinematics of a τ decay and by checking the ionization of these events on the scanning table.

In hydrogen the interactions of interest appeared in the chamber as events with four outgoing prongs in which one prong showed a "kink." To make the scanning as uniform as possible, the event was accepted if the kink was more than 2 mm from the vertex on the scanning table, whose magnification with respect to the bubble chamber is $\frac{2}{3}$. All events were re-examined, and in addition, in the 1.70-BeV/c film, all 4 prongs found during scanning were examined very carefully

TABLE I. Path length and number of events.

Momentum (BeV/c)	C.M. energy (MeV)	Target	Path length (events/ μb)	No. of observed events Σ^+	Σ^-	No. of events fitting reaction 1 and 2 or 4 or 3 Σ^+	Σ^-
1.51	2025	Hydrogen	5.2 ±0.4	816	749	676[a]	544[a]
1.70	2110	Hydrogen	1.1 ±0.1	261	209	201[a]	149[a]
1.49	2015	Deuterium	0.5 ±0.03	739	1013	265[b]	308[b]

[a] Reactions 1 and 2.
[b] Reactions 3 and 4.

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[1] J. D. Dowell, W. Koch, B. Leontic, A. Lundby, R. Meunier, J. P. Stroot, and M. Szeptycka, Phys. Letters **1**, 53 (1962).
[2] G. R. Kalbfleisch, G. Alexander, O. I. Dahl, D. H. Miller, A. Rittenberg, and G. A. Smith, Phys. Letters **4**, 225 (1963).
[3] C. Baltay, J. Sandweiss, H. D. Taft, B. B. Culwick, W. B. Fowler, J. K. Kopp, R. I. Louttit, J. R. Sanford, R. P. Shutt, S. M. Thorndike, and M. S. Webster, Phys. Rev. Letters **11**, 32 (1963).
[4] M. H. Alston, L. W. Alvarez, M. Ferro-Luzzi, A. H. Rosenfeld, H. K. Ticho, and S. G. Wojcicki, in *Proceedings of the 1962 International Conference on High Energy Physics at CERN*, edited by J. Prentki (CERN, Geneva, 1962).
[5] R. Hubbard, D. O. Huwe, G. R. Kalbfleisch, J. Kirz, D. H. Miller, J. B. Shafer, D. H. Stork, H. K. Ticho, and C. Wohl, Lawrence Radiation Laboratory Report UCRL-10690, 1963 (unpublished).
[6] V. Cook, B. Cork, T. F. Hoang, D. Keefe, L. T. Kerth, W. A. Wenzel, and T. F. Zipf, Phys. Rev. **123**, 320 (1961).

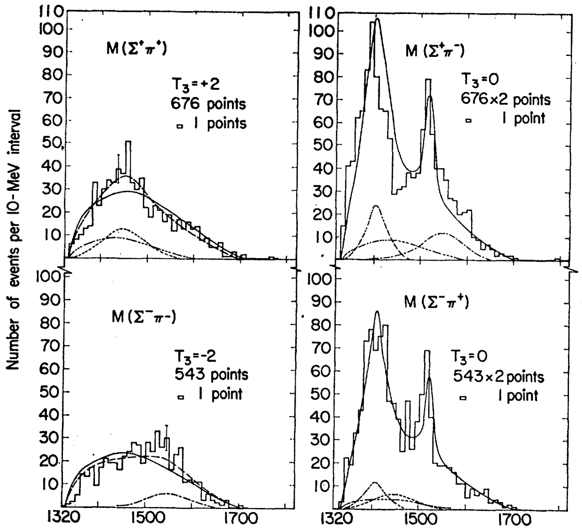

FIG. 1. Mass plots of $\Sigma\pi$ systems in reactions 1 and 2 at 1.51 BeV/c incident K^- momentum (invariant mass of 2025 MeV). —— calculated distribution when $\frac{3}{4}$ of the events exhibit a $Y_0^*(1405)$ and $\frac{1}{4}$ a $Y_0^*(1520)$; —— · enhancements expected for $M(\Sigma^\pm\pi_1^-)$ from events with $Y_1^{*+}(1660)$ production; · · · · · enhancements expected for $M(\Sigma^\pm\pi_2^+)$ from events with $Y_1^{*+}(1660)$ production and decay via $Y_0^*(1405)$ (mode b); — — · · · enhancements expected for $M(\Sigma^\pm\pi_3^\mp)$ from events with $Y_1^{*+}(1660)$ production and decay via $Y_0^*(1405)$ (mode b); — · · · enhancements expected for $M(\Sigma^\pm\pi_{2 \text{ or } 3})$ from events with $Y_1^{*+}(1660)$ production and decay via phase space (mode a); and — — — total distribution for $M(\Sigma^+\pi^+)$ and $M(\Sigma^-\pi^-)$, where $Y_1^*(1660)$ production and decay via mode b are included.

in all three views for kinks. In this way some spurious events were rejected and additional events found. In deuterium the acceptable event types were four or three outgoing prongs with a kink. The event was classified as a "3 prong" if the spectator proton was less than 1 mm long on the scanning table and was thus unmeasurable. Again the 3- and 4-prong events were re-examined for kinks. In this way we obtained a sample of events in deuterium and at 1.70 BeV/c in hydrogen, in which we consider the scanning efficiency to be 100%. The scanning efficiency at 1.51 BeV/c in hydrogen is estimated to be $92\pm1\%$. The number of events found is shown in Table I. In deuterium about 60% of the events have three prongs.

After scanning, the events were measured on a Franckenstein measuring projector and processed through the PANAL, PACKAGE, EXAMIN, and SUMMEX programs.[7] All constrained kinematic fits were attempted in PACKAGE. The 4-prong events in hydrogen are subject to four equations of constraint at the production vertex, and can be unambiguously identified. However, if the spectator proton in deuterium is unmeasurable, the fit has only one constraint, and if one further variable is unmeasurable, the event cannot be fitted. The 3-prong events were arbitrarily accepted if χ^2 was less than 10 and the proton momentum was less than 220 MeV/c.

III. RESULTS

A. $\Sigma\, 3\pi$ Events in Hydrogen at 1.51 BeV/c

Mass histograms of the $\Sigma\pi$ systems in reactions (1) and (2) are shown in Fig. 1. In the $T_3=0$ distributions, each event appears twice because two possible pions can be paired with the Σ. It is clear that the reactions are dominated by the production of $Y_0^*(1405)$ and $Y_0^*(1520)$. As a first attempt at explaining the data, we simply assume that each event will exhibit either a $Y_0^*(1405)$ or $Y_0^*(1520)$ production From the $(\Sigma\pi)^0$ mass distributions, we estimate that the observed ratio is about 3:1, with no background events. Of course, of all the $Y_0^*(1520)$ events produced, only $\frac{2}{3}$ of 55% decay via $\Sigma^\pm\pi^\mp$,[8] so that the total $Y_0^*(1520)$ production is comparable with the total $Y_0^*(1405)$ production. Curves of the expected distributions were calculated by using the H4 program.[9] The solid curve shows the expected distribution if a $Y_0^*(1405)$ with a width (Γ) of 50 MeV is produced in $\frac{3}{4}$ of the observed events, and in $\frac{1}{4}$ a $Y_0^*(1520)$ with a width (Γ) of 20 MeV is produced. This gives a tolerable fit to the data for $T_3=0$. However, in the $T_3=\pm2$ distribution the fit is poor, and in particular the deviations of the observations from the predicted distribution is different in the different charge states. In the $\Sigma^+\pi^+$ state there is an excess of 40 to 50 events at about 1450 MeV, whereas the excess is at about 1530 MeV in the $\Sigma^-\pi^-$ distribution. To explain this effect we looked for other resonances in the final state.

A plot of the $\pi\pi$ and 3π mass distributions showed no "bumps." Figure 2 shows the mass distributions for

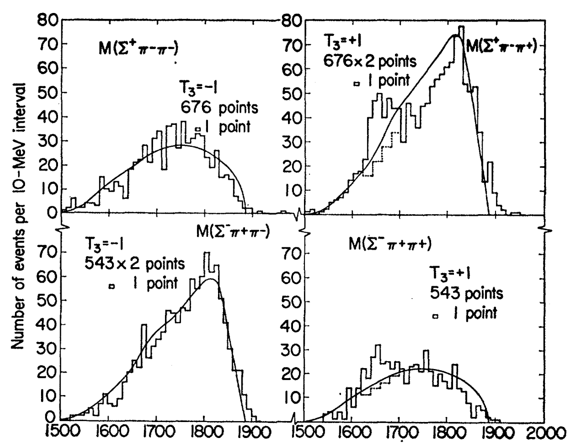

FIG. 2. Mass plots for $\Sigma\pi\pi$ systems in reactions (1) and (2) at 1.51 BeV/c. The solid line indicates the distribution when $\frac{3}{4}$ of the events exhibit $Y_0^*(1405)$, and $\frac{1}{4}$ $Y_0^*(1520)$.

[7] For a summary of these programs and a list of references, see A. H. Rosenfeld, Nucl. Instr. Methods **20**, 422 (1963).

[8] M. B. Watson, M. Ferro-Luzzi, and R. D. Tripp, Phys. Rev. **131**, 2248 (1963).

[9] M. W. Horovitz, Alvarez Group Memorandum 295, May 1962 (unpublished).

TABLE II. Kinematics of $Y_1^{*+}(1660)$ production and decay.

Reaction	$\Sigma\pi$ combination	Possible $\Sigma\pi$ combinations $Y_1^{*+}=\Sigma^+\pi^+\pi^-$	$Y_1^{*+}=\Sigma^-\pi^+\pi^+$	Central values 1.51 BeV/c ($E^*=2025$ MeV)	1.70 BeV/c ($E^*=2110$ MeV)
$Y_1^*(1660)$ production	$\Sigma^\pm\pi_1^-$	$\Sigma^+\pi^-$	$\Sigma^-\pi^-$	1540	1630
Decay mode (a)	$\Sigma\pi_2$ or $\Sigma\pi_3$	$\Sigma^+\pi^+$ or $\Sigma^+\pi^-$	$\Sigma^-\pi^+$	1430	1430
Decay mode (b)	$\Sigma^\pm\pi_2^+$	$\Sigma^+\pi^+$	$\Sigma^-\pi^+$	1440	1440
	$\Sigma^\pm\pi_3^\pm$	$\Sigma^+\pi^-$	$\Sigma^-\pi^+$	1405	1405

$\Sigma\pi\pi$. In the $\Sigma^+\pi^+\pi^-$ and $\Sigma^-\pi^+\pi^-$ distributions, each event occurs twice. Again the distribution predicted by our previous assumption is shown as a solid curve. It can be seen that in the $T_3=-1$ distributions, agreement is quite good, whereas in the $T_3=+1$ states there is a pronounced excess of events at 1660 MeV, showing the production of $Y_1^{*+}(1660)$[10] and its subsequent 3-body decay. We estimate that the number of these events is 145 for the $\Sigma^+\pi^+\pi^-$ decay mode, and 73 for $\Sigma^-\pi^+\pi^+$, showing a branching ratio of 2:1. Note that charged Y^* decay into $\Sigma\pi\pi$ need not give 1:1 even in the absence of background.

We now investigate the effect of these 218 Y_1^{*+} events on the $\Sigma\pi$ mass distributions. The three possible modes of decay of the $Y_1^*(1660)$ to give $\Sigma+\pi+\pi$ are

(a) $Y_1^*(1660)\to\Sigma+\pi+\pi$, according to 3-body phase space

(b) $Y_1^*(1660)\to Y_0^*(1405)+\pi$
$\searrow\Sigma+\pi(100\%)$

and

(c) $Y_1^*(1660)\to Y_1^*(1385)+\pi$
$\searrow\Sigma+\pi(4\pm4\%)$
or $\Lambda+\pi(96\%)$.

First we want to show that channel (c) does not make an appreciable contribution to $\Sigma\pi\pi(\pi)$ final states. The total decay of $Y_1^*(1660)$ into the $\Lambda\pi^+\pi^0$ mode is about 400 events at this incident momentum.[10,11] It is not possible to determine how many of these $Y_1^*(1660)$ events decayed via the sequence (c). However, even if they all decay that way, the subsequent $Y_0^*(1385)\to\Sigma\pi/\Lambda\pi$ ratio is so small that the total contribution to the Σ channel is only about 16 events.[12,13]

Possibilities (a) and (b) remain. The relevant kinematics are shown in Table II. Consider the sequence of events beginning with $K^-+p\to Y_1^*(1660)+\pi_1^-$. The Y_1^* then decays in one of two ways:

(a) $Y_1^*(1660)\to\Sigma+\pi_2+\pi_3$; $P_\Sigma<328$ MeV/c

(b) $Y_1^*(1660)\to Y_0^*(1405)+\pi_2$; P decay$=196$ MeV/c in the $Y_1^*(1660)$ frame
$\searrow\Sigma+\pi_3$; P decay$=144$ MeV/c in the $Y_0^*(1405)$ frame.

Since the $Y_1^*(1660)$ is produced in a two-body reaction, the energy of pion 1 will be strongly peaked, the width of the distribution being the width of the Y_1^* combined with that of the incident K^- momentum distribution. In addition, since the Σ is moving very slowly, the invariant mass of the $\Sigma\pi_1$ combination will also be strongly peaked because the motion of the Σ will hardly smear the distribution. The central value of this enhancement will vary with the incident K^- momentum, but its central value and shape for a particular K^- momentum are almost independent of the decay mode of the $Y_1^*(1660)$. The central value is 1540 MeV for an incident K^- momentum of 1.51 MeV/c, The distributions of $M(\Sigma\pi_2)$ and $M(\Sigma\pi_3)$, of course. depend upon the decay mode of the $Y_1^*(1660)$. If the decay follows phase space, π_2 and π_3 are indistinguishable, and both $M(\Sigma\pi)$ distributions peak at about 1430 MeV. For the case of $Y_1^*(1660)\to Y_0^*(1405)+\pi_2$, the π_2 will have a total energy of about 240 MeV. Since, again, the slowness of the Σ minimizes smearing, the $M(\Sigma\pi_2)$ distribution will be peaked at about 1440 MeV, with a width of about 100 MeV. The $M(\Sigma\pi_3)$ distribution will of course be that of the $Y_0^*(1405)$.

We next consider which charge states will exhibit the effects described. Since the $Y_1^*(1660)$ is produced only in the positive charge state, π_1 must be negative. Also for decay mode (b), π_2 must be positive, since Y_0^* is neutral. The charge states where enhancements are possible are shown in Table II. For the $T=2$ channels, an enhancement should appear at 1540 MeV for $\Sigma^-\pi^-$ but not $\Sigma^+\pi^+$, and at 1430 MeV for $\Sigma^+\pi^+$ but not $\Sigma^-\pi^-$. The expected enhancements for $\Sigma^-\pi^-$ and $\Sigma^+\pi^+$ are shown in Fig. 1, each normalized to the ob-

[10] A preliminary result from these data has been published: L. W. Alvarez, M. H. Alston, M. Ferro-Luzzi, D. O. Huwe, G. R. Kalbfleisch, D. M. Miller, J. J. Murray, A. H. Rosenfeld, J. B. Shafer, F. T. Solmitz, and S. G. Wojcicki, Phys. Rev. Letters **10**, 184 (1963).

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[13] M. H. Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, and S. G. Wojcicki, Phys. Rev. Letters **6**, 698, 1961.

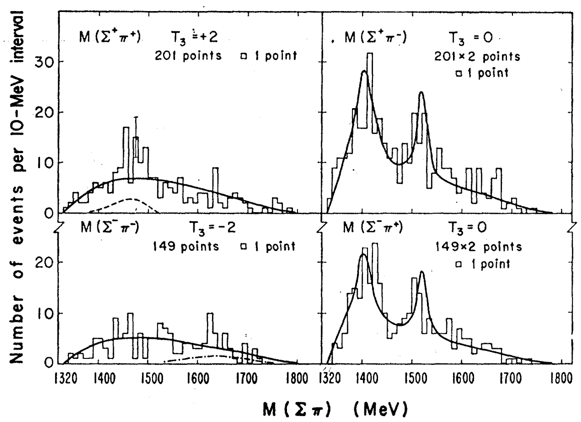

FIG. 3. Mass plots of $\Sigma\pi$ systems in reactions (1) and (2) at 1.70-BeV/c incident K^- momentum (invariant mass is 2110 MeV). —— distribution if $\frac{3}{4}$ events exhibit $Y_0^*(1405)$ and $\frac{1}{4}$ $Y_0^*(1520)$; — — enhancement expected in $M(\Sigma^+\pi^+)$ from the production of 20 $Y_1^{*+}(1660)$ and decay via mode b; and —·— enhancement expected in $M(\Sigma^-\pi^-)$ from the production of 20 $Y_1^{*+}(1660)$ and decay via mode b.

served number of $Y_1^{*+}(1660)$. The excess events observed in the $\Sigma^+\pi^+$ and $\Sigma^-\pi^-$ distributions agree in general with the predictions. The dotted curves show the expected $T_3=\pm2$ distributions when $Y_1^*(1660)$ production and decay via $Y_0^*(1405)$ is included. The ratio of $Y_0^*(1405)$ to $Y_0^*(1520)$ to $Y_1^*(1660)$ observed via $\Sigma\pi$ decay modes is 7:3:2. The modifications to the $T_3=0$ distributions are small and are not shown. One can see that, in general, agreement with the observed data is surprisingly good considering the simplicity of the model. Further, *no* $T=2$ resonance is required to describe the data.

No branching ratio can be given for the decay of $Y_1^*(1660)$ into the two modes considered because $M(\Sigma\pi)$ distributions for the two cases are similar and also because of the large number of background events, many of which show the production of $Y_0^*(1405)$. The displacement of the $\Sigma^+\pi^-$ peak at 1405 and the broadening of the $\Sigma^-\pi^+$ peak is not understood, but is probably due to interference effects.

B. Σ 3π Events in Hydrogen at 1.70 BeV/c

The mass histograms for $\Sigma\pi$ and $\Sigma\pi\pi$ in reactions (1) and (2) are shown in Figs. 3 and 4. Unfortunately, there are far less data at this momentum. These histograms show the same general features as at 1.51 BeV/c. Again the interaction is dominated by the production of $Y_0^*(1405)$ and $Y_0^*(1520)$. The solid curve shows the production and $\Sigma\pi$ decay of $Y_0^*(1405)$ and $Y_0^*(1520)$ in the ratio 3:1. The $M(\Sigma\pi\pi)$ distributions again show the production of $Y_1^{*+}(1660)$—about 20 events in both $T_3=+1$ channels and no effect in the $T_3=-1$ channel. The enhancement these events produce in the $M(\Sigma\pi)$ distributions for $T_3=\pm2$ is shown in Fig. 3. These center at 1440 MeV again for $\Sigma^+\pi^+$ and 1630 MeV for $\Sigma^-\pi^-$. It can be seen that the general shape of the distributions can be explained by our simple model in which $Y_0^*(1405)$, $Y_0^*(1520)$, and $Y_1^*(1660)$ productions and $\Sigma\pi$ decays are observed in the ratio of about 5:2:1. Again, *no* resonance in the $T=2$ channel is required to explain the data.

C. Σ 2π Events in Deuterium at 1.49 BeV/c

As already mentioned, the two reactions studied in deuterium were

$$K^-+(n)\to\Sigma^-+\pi^-+\pi^+(+p) \qquad (3)$$
$$(p)$$

to study the $\Sigma^-\pi^-$ system, and for comparison,

$$K^-+(n)\to\Sigma^++\pi^-+\pi^-(+p). \qquad (4)$$
$$(p)$$

The events of interest are those in which a Σ and two pions are produced by the interaction of the K^- with the neutron of the deuteron; the proton is merely a spectator. All 4-prong and 3-prong events that showed a kink in one track were analyzed, but only those peripheral events with a recoil proton momentum less than 220 MeV/c were considered for the above reactions. A plot of the recoil momentum is a fairly good fit to the Hulthén distribution up to 220 MeV/c, although there are too many events at momentum greater than 100 MeV/c. However, a study of these events shows that the error is large and the visible range of the proton is always consistent with a lower momentum than that calculated. We therefore consider that all the selected events are examples of reactions (3) and (4), and that the impulse model is a good approximation at this incident K^- momentum.

The Dalitz plots for these reactions are shown in Fig. 5, and the projected histograms in Fig. 6. It can be seen that the production of $Y_0^*(1405)$ and $Y_0^*(1520)$ dominates this reaction also, and there appear to be some neutral $Y_1^*(1660)$ events. However, we shall now show that there is *no* unexplained peaking in the $\Sigma\pi^-$ state.

In an attempt to parameterize these data, we assumed that resonances would be produced at 1405,

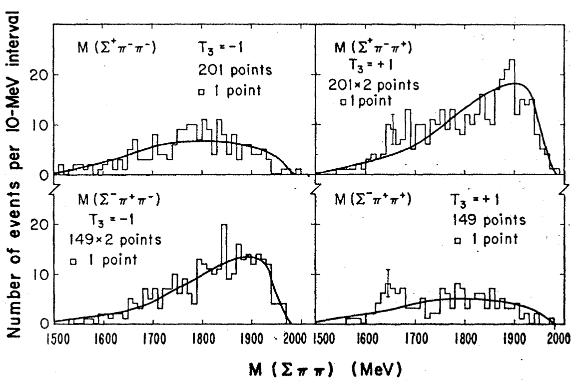

FIG. 4. Mass plots of $\Sigma\pi\pi$ systems in reactions (1) and (2) at 1.70-BeV/c incident K^- momentum. The solid line indicates the distribution as in Fig. 3, curve A.

TABLE III. Branching ratio ($\Sigma\pi/\bar{K}N$) for decay of various Y^*'s produced in K^-d reactions. The errors here represent crude (rather than statistical) estimates.

Resonance	$K^-+n\to\Sigma^\pm+\pi^\mp+\pi^-$ Corrected No. of $\Sigma^+\pi^-+\Sigma^-\pi^+$	Total $\Sigma\pi$ channels	$K^-+n\to K^-+p+\pi^-$ Corrected No. of K^-p	Total $\bar{K}N$ channels	$\Sigma\pi/\bar{K}N$
$Y_0^*(1405)$	202±40	303±60	...	...	...
$Y_0^*(1520)$	238±45	358±68	150±30	300±60	1.2 ±0.3
$Y_1^*(1660)$	139±30	139±30	10±10	20±20	7.0 ±7.5
{ $Y_0^*(1815)$	30±30	45±45[a]	{ ...	... }	0.23±0.25[a]
{ $+Y_1^*(1765)$		30±30[b]	{96±20	192±40 }	0.31±0.33[b]

[a] Assuming all the resonance is in a $T=0$ state.

[b] Assuming all the resonance is in a $T=1$ state.

1520, 1660, and 1815 MeV,[14] and that there would also be background events. Our data appear to agree with the quoted widths (Γ) of 50, 50, and 120 MeV for $Y^*(1405)$, (1660), and (1815), respectively. However, they indicate a width of at least 30 MeV for $Y_0^*(1520)$, and this value was used in the fit. No attempt was made to divide the (1815) resonance into two peaks at 1765 and 1815 MeV,[14] since any enhancement in this region is obviously small and is consistent with zero. Even with four resonances of fixed width and some background events, it is impossible to obtain a good fit to the data. Further, it is clear from the Dalitz plots and

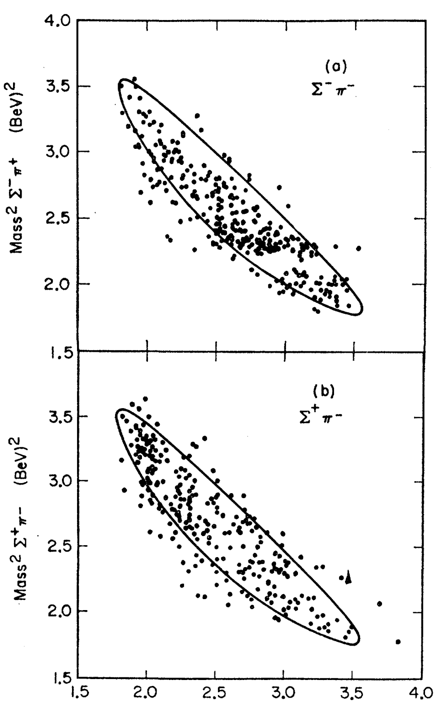

FIG. 5. Dalitz plots of $M^2(\Sigma\pi)$ combinations for (a) reaction 3, $M^2(\Sigma^-\pi^-)$ and $M^2(\Sigma^-\pi^+)$, and (b) reaction 4, $M^2(\Sigma^+\pi^-)$ and $M^2(\Sigma^+\pi^-)$. Note that plot (b) is not symmetric although reaction 4 is. This asymmetry is introduced by the track numbering convention.

[14] L. Barbaro-Galtieri, A. Hussein, and R. D. Tripp, Phys. Letters **6**, 296 (1963).

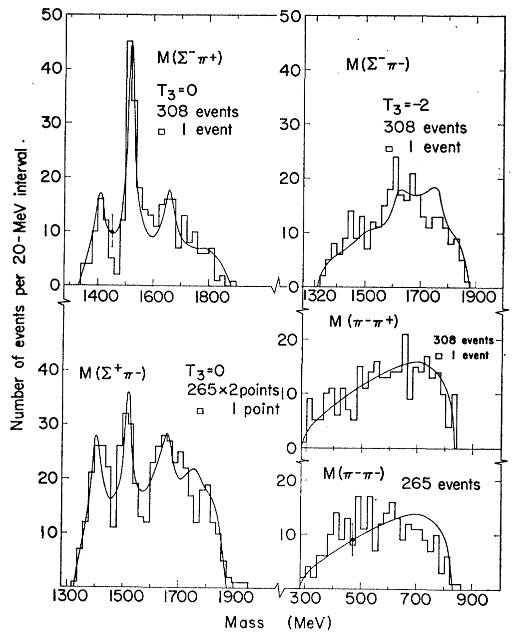

FIG. 6. Mass distributions of $\Sigma\pi$ and $\pi\pi$ systems in reactions (3) and (4). The curve is a rough fit explained in the text.

histograms that there are large interference effects in the final state because:

(a) There is a paucity of events between the 1405- and 1520-MeV peaks in the $\Sigma^-\pi^+$ state.

(b) The width of the 1520-MeV ($\Gamma=30$) peak is broader than that found by other authors; i.e., $\Gamma=16$ MeV.[8,14] This discrepancy is particularly pronounced in the $\Sigma^+\pi^-$ state and is too great to be entirely explained by the resolution, which is found to be about ±7 MeV for both Σ^+ and Σ^- events.

(c) The branching ratios of the $T=0$ resonances into $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ are not unity, which is the value expected for noninterfering $T=0$ or $T=1$ resonances.

No attempt was made to least-squares fit the data, because the model used is obviously oversimplified, and there are many parameters that can be varied and rather few data. The solid curve shown in Fig. 6 is a typical calculated curve for no interference in the final state. The fit is poor; however, the general character-

TABLE IV. Cross sections.

	Hydrogen [Reactions (1) and (2)] 1.51 BeV/c		1.70 BeV/c		Deuterium [Reactions (3) and (4)] 1.49 BeV/c	
	Σ^+	Σ^-	Σ^+	Σ^-	Σ^+	Σ^-
Number of fitted events	676±27	544±23	201±14	149±12	265±16	308±18
Corrected No. of events	1130±57	745±45	320±24	194±17	485±42	505±52
$\sigma(\mu b)$	220±20	145±15	290±34	176±22	970±110	1020±120

istics are correct, the deviations are presumably due to interference effects. No $T=2$ resonance is apparent in the $\Sigma^-\pi^-$ mass spectrum. The ratios for the observed production and decay *via* the $\Sigma\pi$ mode of $Y_0^*(1405)$: $Y_0^*(1520)$: $Y_1^*(1660)$: $Y_0^*(1815)$: background are about 6:7:4:2:10.

Some indication of the severity of the interference effects can be obtained from the branching ratios $(\Sigma^+\pi^-/\Sigma^-\pi^+)$ for the resonances since these should be unity if there is no interference. After corrections have been applied (see next section), this ratio is 2.0±0.6 and 0.7±0.2 for $Y_0^*(1405)$ and $Y_0^*(1520)$, respectively. The branching ratios for $Y_1^*(1660)$ and $Y_0^*(1815)$ are unity within the errors.

An interesting comparison can be made between our data and that of Galtieri *et al.*[14] They investigated the reaction $K^-+d\rightarrow K^-+p+\pi^-(+p)$, where the interaction takes place on the neutron and the proton is a spectator. The number of events can be compared directly to obtain the branching ratios of the resonances into the $\Sigma\pi$ and $\bar{K}N$ channels, because the two experiments used the same film sample. The data are shown in Table III. The branching ratios are in fair agreement with values from other experiments. Namely, for $Y^*(1520)$ a value of 1.67±0.2 was obtained by Ferro-Luzzi *et al.*[8] For $Y_1^*(1660)$, $\bar{K}N/\Sigma\pi$ branching ratios already reported are poorly known and somewhat contradictory; they are $<\frac{1}{6}$,[10] 0.7±0.35,[15] and 0.5±0.25.[16] Inverting our value in Table III we find 0.14±0.14, which tends to pull down the most likely estimate. As for $\Sigma\pi/\bar{K}N$ branching ratios in the $Y^*(1815)$ peak or peaks, Wohl[17] quotes $\leqslant 6\%$, based on data obtained in the K^-p reaction between 1.0 and 1.15 BeV/c. Our results (23±25 or 31±33%) are consistent. For good values, we will have to await resolution of the problem of how many resonances are present.[14]

D. Cross Sections

The number of fitted events was corrected to take account of the mismeasured events and losses due to unobserved Σ decays. All events found were measured once, if practical, and all events that failed (≈30%) were remeasured. By looking at the distribution of these remeasured events, we can estimate the number of events that would probably have fitted the "interesting" hypotheses had we continued remeasuring.

For the hydrogen events, the Σ lifetime and Σ-decay angular distributions were plotted. From these we calculated and corrected for the number of Σ decays that would not have been observed. The loss for Σ^+ is obviously greater than for Σ^- because of the small angles of the protonic decay and the shorter length of the Σ. Corrections at 1.7 BeV were difficult to estimate because of poor statistics. The total correction was estimated as about 42% for Σ^+ and 12% for Σ^- at both incident momenta. A correction of 8% for scanning inefficiency was applied to the 1.5-BeV/c data.

It was impossible to estimate accurate corrections for the deuterium events because (a) the many unfittable background events made it hard for us to estimate a correction for badly measured events and (b) we could not calculate the correction for unobserved Σ events very well because of poor statistics. Since we feel that neither of these corrections should be very much different in deuterium than in hydrogen, we have assumed that the hydrogen corrections are adequate for our deuterium data. In addition, a correction of 3% was made for proton recoils with momentum greater than 220 MeV/c.

The cross sections obtained are shown in Table IV; the errors reflect statistics, the systematic errors discussed, and uncertainty in estimating the K^- path length (see Table I).

IV. CONCLUSION

An attempt has been made to find a $\Sigma\pi$ resonance with $T=2$. Even though all the final states which are produced by K^-N interactions, and which contain a doubly charged $\Sigma\pi$ state are extremely complicated, a relatively simple model not requiring a $T=2$ resonance appears to explain all the available data.

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