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STUDY OF RESONANCES IN THE Σ-π SYSTEM*

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(To be presented by A. H. Rosenfeld)

INTRODUCTION

In order to study resonances in the Σ-π system, we have analyzed reactions in which a Σ hyperon and two or three pions are produced in K^--p interactions at 1.22 ± 0.040 and 1.51 ± 0.050 GeV/c incident K^- momentum (i.e., 1895 and 2025 MeV center-of-mass energy), using the Lawrence Radiation Laboratory's 72-in. hydrogen bubble chamber.

Before the current experiment, the following resonances had been observed in the Σ-π system:

a. The Y_0^* (1520 MeV) with a width Γ = 25 MeV, found by Ferro-Luzzi, Tripp and Watson.[1] This resonance was observed by a study of the total cross sections and angular distributions of several interaction channels at K^- incident momenta between 300 and 513 MeV/c, using the Lawrence Radiation Laboratory 15-in. liquid-hydrogen bubble chamber. A resonance effect was observed at an incident K^-momentum of 395 MeV/c (1520 MeV in the center-of-mass system). The data show that this resonance has isotopic spin zero and is in a D3/2 state.

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b. The Y_0^* (1405 MeV) observed in K^-p experiments at 1150, 850, and 760 MeV/c incident K^- momentum in the Lawrence Radiation Laboratory 15-in. liquid-hydrogen bubble chamber.[2,3] The number of events was small, but the resonance appeared to have an isotopic spin T = 0.[2] However, this resonance was only prominent in the final state in which $\Sigma + 3\pi$ was observed but was not copiously produced in the $\Sigma 2\pi$ final state either in the 1.15 GeV/c or in the lower-momentum experiments. Hence it could not be considered well-established.

c. The Y_1^* (1385 MeV), which could decay into $\Sigma\pi$ but actually decays mainly into $\Lambda\pi$. In references(2) and (3) very little indication of any peaking for Y_1^* (1385 MeV) was observed in the $\Sigma\pi$ system, so it was concluded that the Σ/Λ branching fraction for the Y_1^* was about 2% for the decay mode $Y_1^{*\pm} \rightarrow \Sigma^{\pm} + \pi^0$.

d. Indications of a Y_2^* predicted by global symmetry at about 1540 MeV has been reported.[7]

PRESENT EXPERIMENT

The reactions that we have studied in the present experiment are shown in Table I.

a. <u>Three-body final states.</u> In the first reaction we have a three-body final state that can be represented by a Dalitz plot in $M^2(\Sigma\pi)_{charged}$ and $M^2(\Sigma\pi)_{neutral}$. This plot should be uniformly populated within the limits allowed by the available energy, if there are no interactions in the final state.

Figure 1 shows the Dalitz plot for 473 events of reaction (1) at 1.22 GeV/c K^- incident momentum, together with histograms of the data projected onto the neutral and charged axes. On the neutral projection there are strong indications of both a Y^{*0}(1405 MeV) with a width Γ = 50 MeV, and a Y^{*0}(1520 MeV) with width Γ = 20 MeV. There is, however, little evidence of charged resonances; broad peaks can be seen in the charged histogram, but these are merely the 1405-and 1520-MeV neutral resonances projected onto the charged axis. In particular, there is no indication of peaking around 1405 MeV in the charged state as might be expected if the Y^*(1405 MeV) had isotopic spin 1 or 2. Also there are very few events that can be attributed to the Y_1^* at 1385 MeV; if phase space is estimated and subtracted, the Σ/Λ branching ratio for the Y_1^* is about 1%. A more conservative approach in which all events between 1340 and 1440 MeV (85 events) are assumed to be produced by a Y_1^* gives a maximum value of 7% for the branching ratio.

Figure 2 shows the Dalitz plot and $(\text{mass})^2$ histograms for an incident K^- momentum of 1.51 GeV/c. Again the neutral Y_0^*(1405 MeV) and Y_0^*(1520 MeV) are produced. In this case we also notice a clustering of events in the lower right-hand corner which could be due to constructive interference between the few-percent Σ decay mode of a Y_1^* (1385 MeV)[5] and a possible Y^*(1680 MeV).[6] However, interpretation of excesses in this region of the plot is complicated because it lies near the 135 deg line representing a $\pi\pi$ mass of 750 MeV, where the ρ-meson may play a role (see Fig. 2).

b. <u>Four-body final states.</u> An investigation of reaction (2) showed that the Σ-π mass distributions for the Σ^+ and Σ^- events are very similar; hence they are shown added together in Fig. 3. A strong peaking at 1405 MeV is observed in the neutral state, but none at 1520 MeV. No doubly charged peak is observed. The solid curves show phase space, and the dotted curves the distributions expected for a $\Sigma\pi$ resonance at 1405 MeV with width Γ = 50 MeV in each event. Since the latter hypothesis fits the data quite well, we assume that reaction (2) proceeds predominantly via the production of a 1405-MeV resonance and a pair of pions. In these events, the mass distributions for two pions showed nothing remarkable.

To see if the T = 0 assignment for the 1405-MeV resonance is consistent with other available data, we looked at the reaction (3). Now we have, for T = 0,

$$N(\Sigma^+\pi^-) = N(\Sigma^-\pi^+) = N(\Sigma^0\pi^0),$$

for T = 1,

$$N(\Sigma^+\pi^-) = N(\Sigma^-\pi^+); \quad N(\Sigma^0\pi^0) = 0,$$

and for T = 2,

$$N(\Sigma^+\pi^-)= N(\Sigma^-\pi^+); \quad N(\Sigma^0\pi^0) = 4(N\Sigma^-\pi^+).$$

To look for a $\Sigma^0\pi^0$ mass peak in reaction (3) of Table I, we calculate for each event $M^2(\text{neutral}) = (\Delta W)^2 + (\Delta \underline{p})^2$, where $W = W_K + W_{target} - (W_{\pi^+} + W_{\pi^-})$ is the unbalance in energy, and similarly $\Delta \underline{p}$ is the unbalance in momentum. Note that in this calculation the Λ is ignored. However, if we plot the spectrum of <u>all</u> V-two prong reactions that could be type (3), we get a spurious background of $M(\text{neutral}) \approx M_{\Sigma^0}$ from,

$$\Sigma^0\pi^+\pi^- \qquad \text{(a)}$$

and further background from

$$\Lambda\pi^0\pi^+\pi^- \qquad \text{(b)}$$

and

$$\Lambda 2\pi^0\pi^+\pi^- \text{ and } \Sigma^0 2\pi^0\pi^+\pi^-. \qquad \text{(c)}$$

We eliminate most of (a) and (b) by selecting only events that fail to fit these hypotheses with χ^2 greater than 20.0 and 2.0, respectively. We select further on the basis of missing mass,[4] (MM) requiring that 150 MeV <MM< 270 MeV.

Three-hundred events fit hypothesis (b) with $\chi^2 \leq 2.0$, and we calculate that 60 more have $\chi^2 > 2.0$, but then only 30 of these should have MM > 150 MeV. Similarly, reactions (c) have missing masses starting at $2m_{\pi^0}$ and should be mainly eliminated by the upper MM selection limit.

Figure 4 shows the distribution for 159 events remaining after all selections. There is some peaking at around 1390 MeV. This is lower than the expected value of 1405 MeV; however, the resolution in this reaction is poor (Γ (resol) ≈ 22 MeV), and thus the difference is not significant.

In Fig. 4 there are 83 events between 1330 and 1440 MeV. As we have discussed above, we estimate that only about 30 are background, leaving about 50 which we attribute to the Y_0^* (1405 MeV) decaying via $\Sigma^0\pi^0$. Since the expected number for a T = 0 resonance is 53, the data are consistent with T = 0.

To see if we could observe both the Y_0^* (1520 MeV) and the predicted Y_2^* (~ 1540 MeV), which could appear doubly charged, we analyzed the $\Sigma^{\pm}3\pi$ events at 1.53-BeV/c incident K^- momentum. Figure 5 shows the results for the Σ^+ and Σ^- events added together. At this incident momentum, the Y_0^*(1520 MeV) is produced. The phase-space curve is again shown. The dashed curves show the effect of assuming that each event has one resonant neutral $\Sigma\pi$ pair and that the 1405- and 1520-MeV (Γ = 50 MeV and Γ = 20 MeV, respectively) resonances are produced in the ratio 3:1.

The doubly charged data is in reasonable agreement with the distorted phase-space curve expected. However the histogram shows some enhancement at about 1540 MeV, which might be attributed to the Y_2^* resonance predicted by global symmetry.

We wish to thank many members of the Alvarez group whose help made this work possible.

FOOTNOTES

1. M. Ferro-Luzzi, R. D. Tripp, and M. B. Watson, Phys. Rev. Letters 8, 28 (1962).
2. M. H. Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. G. Wojcicki, Phys. Rev. Letters 6, 698 (1961).
3. P. Bastien, M. Ferro-Luzzi, and A. H. Rosenfeld, Phys. Rev. Letters 6, 702 (1961).
4. MM^2 is analogous to M^2(neutral) except that all "seen" tracks including the Λ are included in ΔW and $\Delta \underline{p}$.
5. A Σ/Λ branching ratio of 2% corresponds to six events.
6. Private communication from P. Bastien and from G. Alexander, G. R. Kalbfleish, D. H. Miller, and G. A. Smith, Lawrence Radiation Laboratory.
7. J. D. Dowell, B. Leontic, A. Lundby, R. Meunier, G. Petmezas, J. P. Stroat, and M. Szeptycka, CERN Internal Report 61-9, August 1961.

Table I. Cross sections for $K^- + p \rightarrow \Sigma + \text{pions}$.

	Reaction	Number of events analyzed		Cross section (mb)	
		1.22 (GeV/c)	1.51 (GeV/c)	1.22 (GeV/C)	1.51 (GeV/c)
1a.	$K^- + p \rightarrow \Sigma^+ + \pi^- + \pi^0$	249	198	0.50 ± 0.04	0.93 ± 0.07
1b.	$\Sigma^+ + \pi^- + \pi^0$	224	214	0.45 ± 0.04	0.93 ± 0.07
2a.	$K^- + p \rightarrow \Sigma^+ + \pi^- + \pi^+ + \pi^-$	81	281	0.11 ± 0.2	0.25 ± 0.01
2b.	$\Sigma^- + \pi^+ + \pi^+ + \pi^-$	78	251	0.08 ± 0.1	0.25 ± 0.01
3.	$K^- + p \rightarrow \Sigma^0 + \pi^0 + \pi^+ + \pi^-$	159	---	0.08 ± 0.03	---

FIGURE LEGENDS

Fig. 1. Dalitz plot and histograms in $(\text{Mass})^2_{\Sigma\pi}$ for the reactions

$$K^- + p \rightarrow \Sigma^\pm + \pi^\mp + \pi^0$$

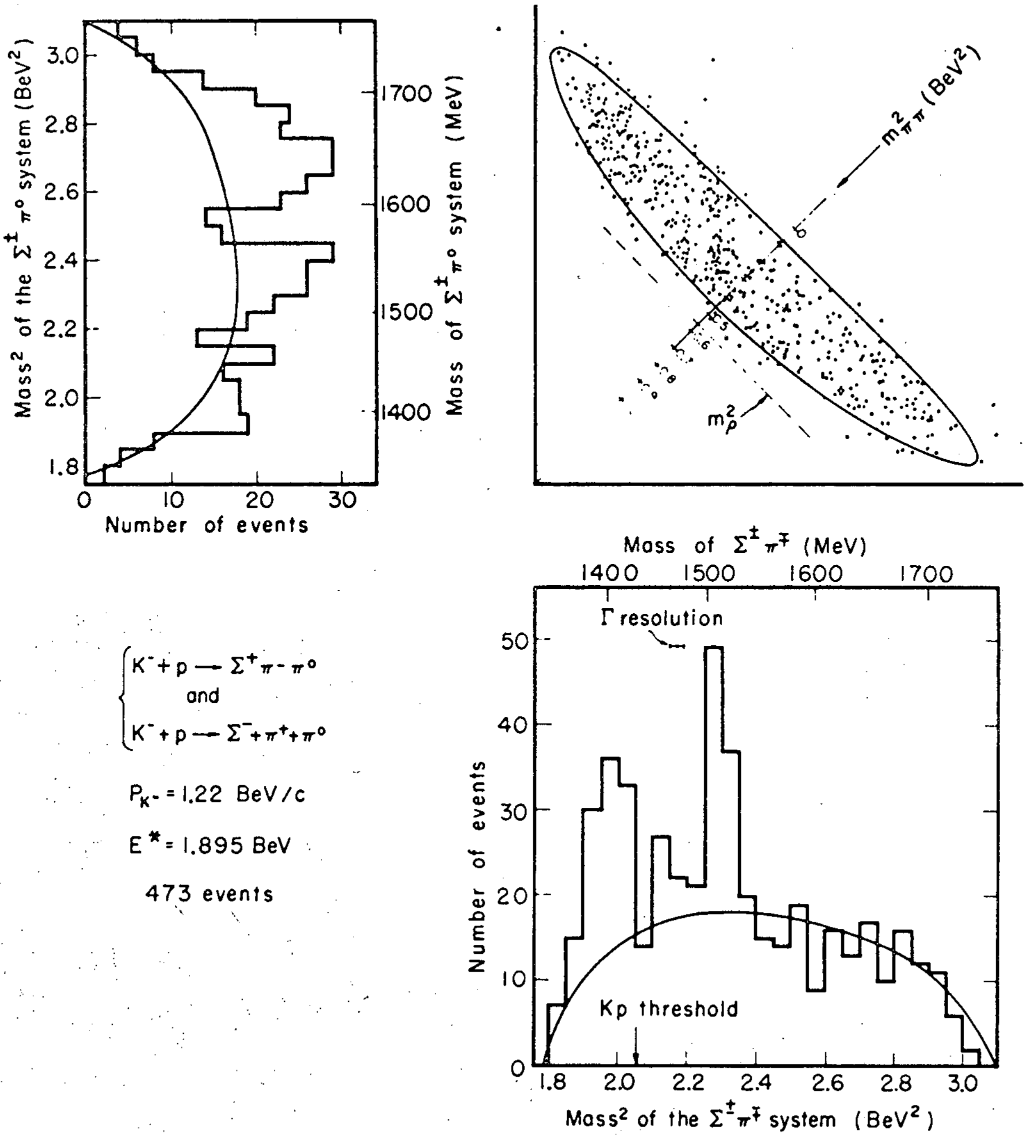
at $P_{K^-} = 1.22$ GeV/c ($E^* = 1.895$ GeV).

Fig. 2. Dalitz plot and histograms in $(\text{Mass})^2_{\Sigma\pi}$ for the reactions $K^- + p \rightarrow \Sigma^\pm + \pi^\mp + \pi^0$ at $P_{K^-} = 1.51$ GeV/c ($E^* = 2.025$ GeV).

Fig. 3. Mass histograms for the $\Sigma\pi$ systems in the reactions $K^- + p \rightarrow \Sigma^\pm + \pi^\mp + \pi^+ + \pi^-$ at $P_{K^-} = 1.22$ GeV/c ($E^* = 1.895$ GeV). Each event gives two entries on the "unlike-charge" histogram.

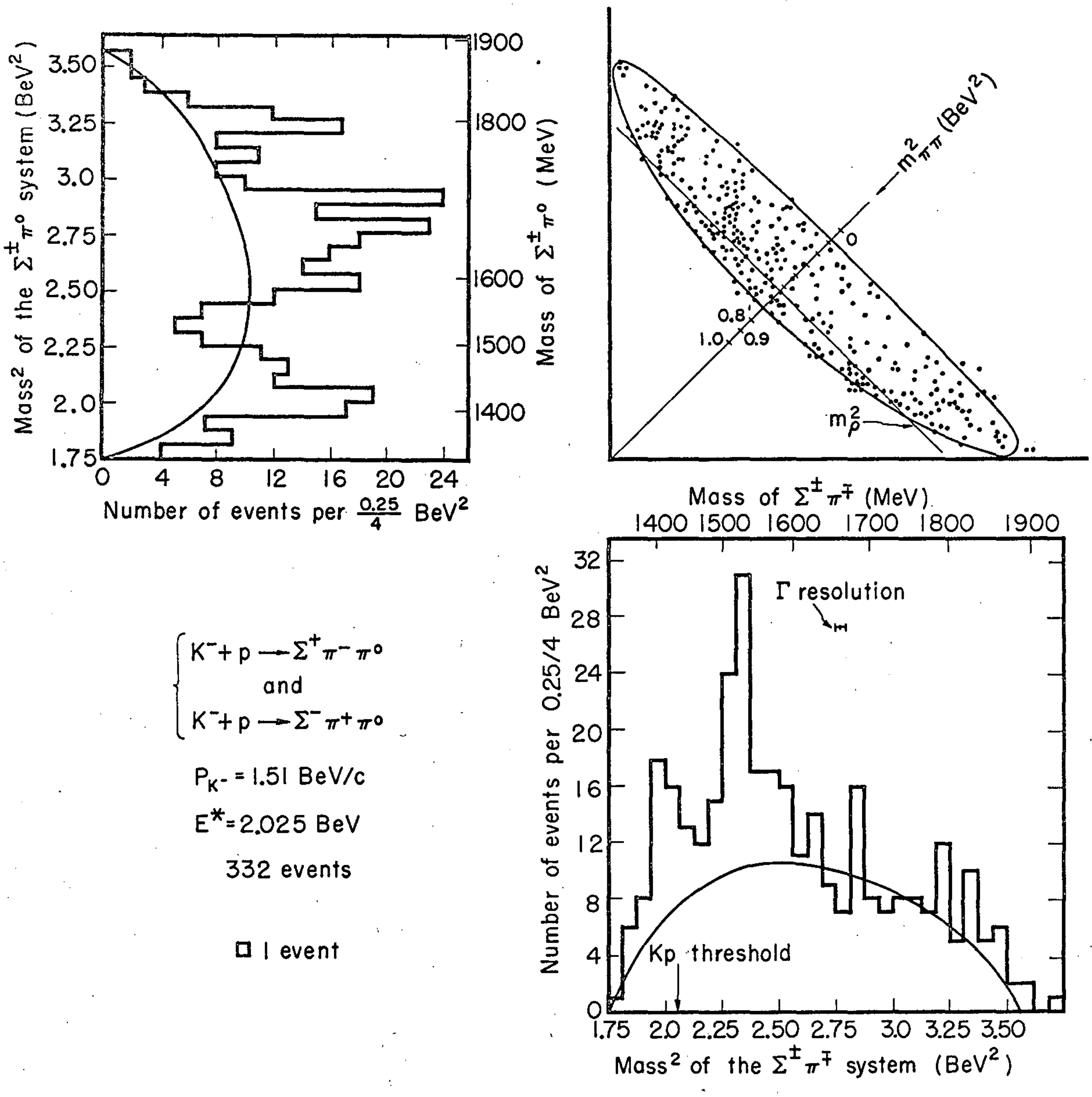
Fig. 4. Mass histograms for $\Sigma^0\pi^0$ in the reaction $K^- + p \rightarrow \Sigma^0 + \pi^0 + \pi^+ + \pi^-$ at 1.22 GeV/c incident K^- momentum ($E^* = 1.895$ GeV).

Fig. 5. Mass histograms for the $\Sigma\pi$ systems in the reaction $K^- + p \rightarrow \Sigma^\pm + \pi^\mp + \pi^+ + \pi^-$ at $P_{K^-} = 1.51$ GeV/c ($E^* = 2.025$ GeV).



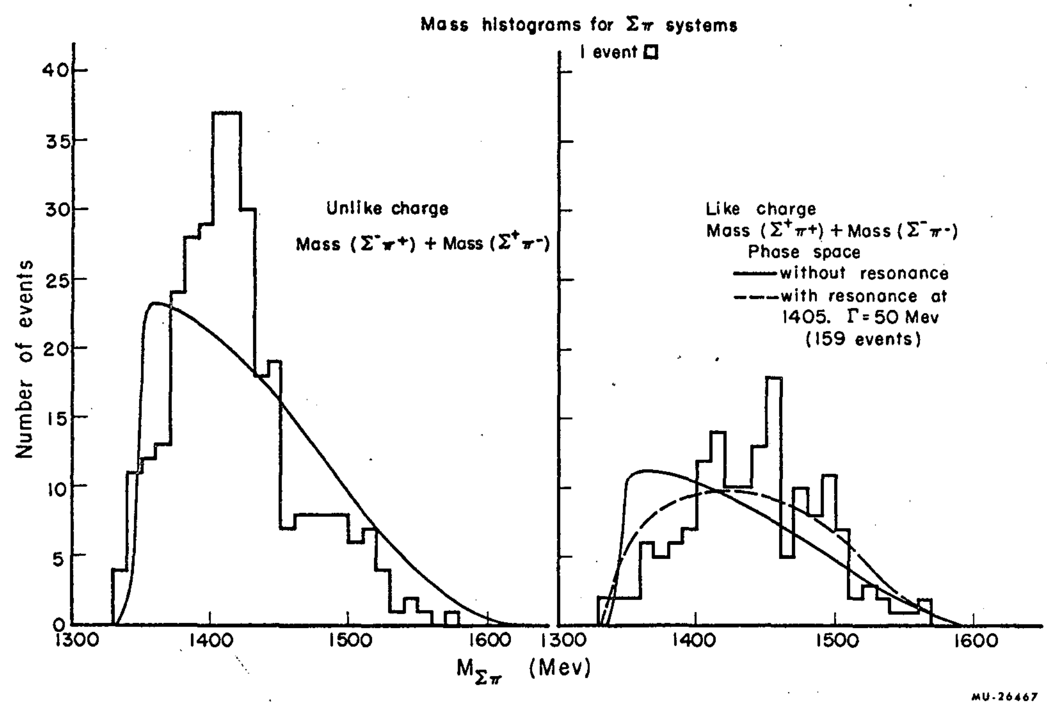
MUB 1148

Fig. 1



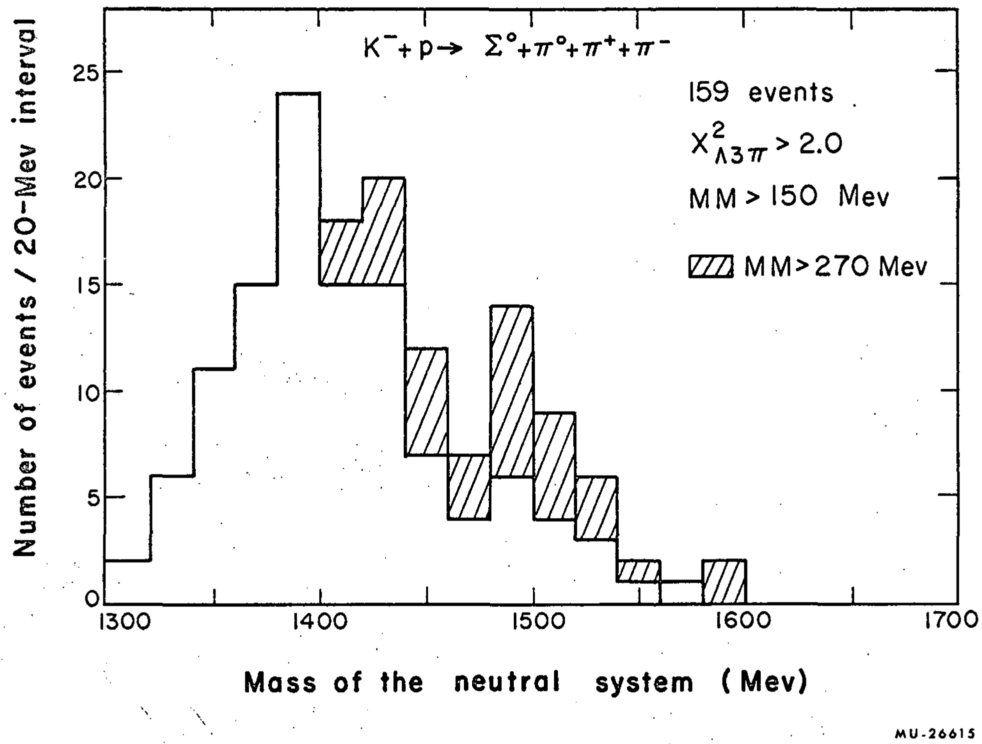
MUB-1149

Fig. 2



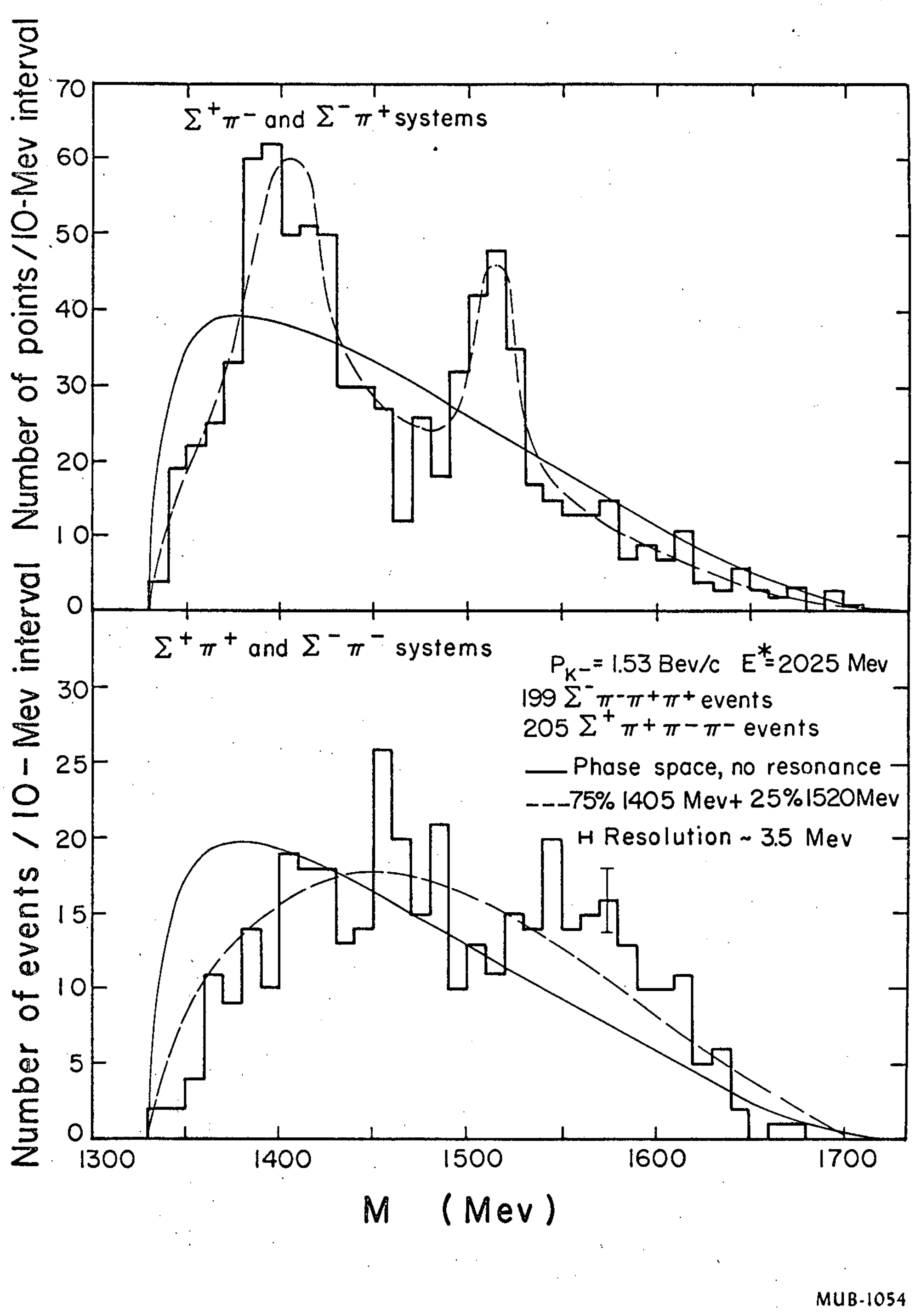
Mass histograms for Σπ systems
1 event
Number of events
Unlike charge
Mass (Σ⁻π⁺) + Mass (Σ⁺π⁻)
Like charge
Mass (Σ⁺π+) + Mass (Σ⁻π⁻)
Phase space
without resonance
with resonance at 1405. Γ = 50 Mev
(159 events)
M_Σπ (Mev)
MU-26467

Fig. 3



$K^- + p \rightarrow \Sigma^\circ + \pi^\circ + \pi^+ + \pi^-$
159 events
$\chi^2_{\Lambda 3\pi} > 2.0$
MM > 150 Mev
MM > 270 Mev
Number of events / 20-Mev interval
0
5
10
15
20
25
1300
1400
1500
1600
1700
Mass of the neutral system (Mev)
MU-26615

Fig. 4



Σ⁺π⁻ and Σ⁻π⁺ systems
Number of points / 10-Mev interval
Σ⁺π⁺ and Σ⁻π⁻ systems
P_{K^-} = 1.53 Bev/c E* = 2025 Mev
199 Σ⁻π⁻π⁺π⁺ events
205 Σ⁺π⁺π⁻π⁻ events
Phase space, no resonance
75% 1405 Mev + 25% 1520 Mev
Resolution ~ 3.5 Mev
Number of events / 10 - Mev interval
M (Mev)
MUB-1054

Fig. 5