For publication in Physical Review Letters

MASTER

UCRL-9686
Limited distribution

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

EVIDENCE FOR A $T = 0$ RESONANCE IN THE $\Sigma\pi$ SYSTEM

Margaret H. Alston, Luis W. Alvarez, Philippe Eberhard, Myron L. Good, William Graziano, Harold K. Ticho, and Stanley G. Wojcicki

April 28, 1961

EVIDENCE FOR A T = O RESONANCE IN THE $\Sigma\pi$ SYSTEM*

Margaret H. Alston, Luis W. Alvarez, Philippe Eberhard,† Myron L. Good,§
William Graziano, Harold K. Ticho,** and Stanley G. Wojcicki

Lawrence Radiation Laboratory and Department of Physics
University of California, Berkeley, California

April 28, 1961

In previous letters we have reported a $\Lambda\pi$ resonance,[1] called Y_1^*, [illegible] observed through the study of the interaction of 1.15-Bev/c K^- mesons in hydrogen in the Lawrence Radiation Laboratory 15-in. bubble chamber. We now wish to report the results of the study of the three reactions

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

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

and

$$K^- + p \rightarrow \Sigma^0 + \pi^0 + \pi^+ + \pi^- \qquad (3)$$

Although reactions (1) and (2) are readily identified and measured, reaction (3) cannot be identified unambiguously. Accordingly, we discuss first the results pertaining to reactions (1) and (2). Nineteen events of type (1) and 13 events of type (2) were observed, corresponding to cross sections of 0.19 ± .06 and 0.12 ± .05 mb, respectively.[2] In a search for possible $\Sigma\pi$ resonances, we have plotted in Fig. 1 histograms of the invariant masses of the Σ and each of the three pions in reactions (1) and (2). Figure 1b refers to the Σ and pion of like charge; Fig. 1a to the Σ and each of the pions of unlike charge. Since there are two unlike-charged pions in each event, twice as many points appear in Fig. 1a as in Fig. 1b. The plotted curves are mass distributions expected on the basis of a uniform phase-space population. The histogram of Fig. 1b agrees with the phase-space curve, but the

64 02

Σ and unlike-charged pion distribution appears to exhibit an anomaly, suggesting a concentration of events with a (Σπ) mass of about 1405 Mev.

To explore this anomaly in more detail, we use the following representation of the data. Since, according to Fig. 1b, the doubly charged Σπ systems do not depart significantly from the expected phase-space distribution, we eliminate the like-charged pion from further consideration. We then transform the Σ and the remaining two pions (both of charge opposite to that of the Σ) into the center-of-mass (c.m.) system of these three particles and determine the total energy available in this particular coordinate system. For each event we can then calculate a Dalitz plot of the available phase space. However, to permit the comparison of events that involve different amounts of c.m. energy, we can conveniently relabel the axes of the Dalitz plot to correspond to the invariant Σπ mass squared, which is linearly related to the kinetic energy of the other pion. The phase-space ellipses obtained from individual events are then added to obtain a composite phase-space probability contour map in the mass-squared space. The result of this procedure is shown in Fig. 2a. Only half of the plot is shown, since it is symmetric about the 45-deg line because the two pions considered are indistinguishable.

The experimental points arrange themselves in a vertical and a horizontal band, both centered along 1.97×10^{6} Mev^{2} = (1405 Mev)^{2}, as if the Σ resonated with either one or the other of the two pions. In order to exhibit the resonance with better statistics, both the distribution of experimental points and the phase-space contour map are projected onto the axes: the portion to the right of the dotted line onto the ordinate, the portion to the left onto the abscissa. The resulting histograms and the distributions expected from phase space are then added. The results are shown in Fig. 2b. Although the position of the dividing line[15] is chosen in such a way as to exhibit the resonance most clearly, it appears rather unlikely that the discrepancy between the expected and observed distributions is a statistical accident, especially in view of the two-band structure of the events in Fig. 2a. If one interprets the observed distribution as a resonance, its peak corresponds to a mass of 1405 Mev, and its full width at half maximum is about 20 Mev after unfolding experimental errors.

To investigate further the possibility of a resonance in the $\Sigma\pi$ system, we studied the 39 two-prong events associated with a Λ that did not fit a $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ or $K^- + p \rightarrow \Sigma^0 + \pi^+ + \pi^-$ interpretation. These events could be

$$K^- + p \rightarrow \Sigma^0 + \pi^+ + \pi^- + \pi^0, \quad (3)$$

$$\rightarrow \Lambda + \pi^+ + \pi^- + \pi^0, \quad (4)$$

$$\rightarrow \Sigma^0 + \pi^+ + \pi^- + \pi^0 + \pi^0, \quad (5)$$

or

$$\rightarrow \Lambda + \pi^+ + \pi^- + \pi^0 + \pi^0. \quad (6)$$

Identification is very difficult because only reaction (4) is sufficiently overconstrained to permit a kinematical fit. Furthermore, most of the events that are actually examples of reaction (3) will fit hypothesis (4), but probably with a larger χ^2 value.

Of the 39 events, 16 had $\chi^2 \geq 2$ when kinematically fitted to the one-constraint hypothesis (4). Most of these events are probably due to reaction (3), since *a priori* only 17% of the events due to reaction (4) should have $\chi^2 \gtrsim 2$. Also, only one example of the reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \pi^+ + \pi^-$ and no examples of $K^- + p \rightarrow \Sigma^{\pm} + \pi^{\mp} + \pi^+ + \pi^- + \pi^0$ were observed; thus reactions (5) and (6) are probably rare. Even though a kinematical fit to hypothesis (3) is impossible, one can obtain the invariant mass of the $\Sigma^0\pi^0$ system from the incident K^- momentum and the measured momenta of the two charged pions. However, since no kinematic constraints can be imposed on such events, the experimental errors will, in general, be larger than for fitted events and fluctuate more widely. Therefore, the data are better represented by ideograms.

Figure 3a shows the ideogram of the mass distribution of the 16 events with $\chi^2 \geq 2$. The three events with $M<1320$ Mev can be interpreted as the tail of the χ^2 distribution of reaction (4); the four events with $M > 1450$ Mev are probably due to reactions (5) and (6). The remaining nine events fall into a narrow band centered at about 1386 Mev and are most probably due to reaction (8). The plotted curve is the mass distribution of $\Sigma^0\pi^0$ systems based on phase space and normalized to nine events.

Figure 3b shows the corresponding distribution for the events with $\chi^2 < 2$. In order to permit a direct comparison with the previous figure, again only the measured momenta of the charged pions were used to obtain the mass ideogram. The measured distribution appears to agree with that expected from phase space for $\Lambda\pi^0\pi^+\pi^-$ events. No anomaly at $M \sim 1390$ Mev is observed. Thus there does not appear to be any evidence of the $T = 1$ Y^{*0} resonance in the $\Lambda\pi^0\pi^+\pi^-$ data. Furthermore, if one fits all 39 events to the $\Lambda\pi^0\pi^+\pi^-$ hypothesis and then calculates the $(\Lambda\pi^0)$, $(\Lambda\pi^+)$, and $(\Lambda\pi^-)$ masses from the fitted values, there is still no evidence for the $T = 1$ Y^* resonances. In particular, the peak of Fig. 3a vanishes. Thus we cannot attribute the observed peaks in the mass distribution shown in Figs. 2b or 3a to the Y_1^* resonance, especially in view of the low Σ/Λ branching ratio of this resonance previously reported.[2] Because of this and the selection criterion used in isolating the events of Fig. 3a it seems probable that the nine events represent a $\Sigma^0\pi^0$ resonance linked by charge independence to the $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ resonance already discussed.

It is easy to show that the branching ratio $\beta = N_{\Sigma^0\pi^0} / (N_{\Sigma^+\pi^-} + N_{\Sigma^-\pi^+})$ uniquely determines the isotopic spin of the resonance. For $T = 2$, 1 or 0, we have $\beta = 2$, 0, or 1/2, respectively. Neglecting possible backgrounds, and correcting for neutral decays and escape of the Λ hyperons in the $\Sigma^0\pi^0$ case, we have $\beta = 0.5 \pm 0.2$. Hence, the isotopic spin of the indicated resonance is zero, and we will call it Y_0^*.

One difficulty of our interpretation of the data is the difference in mass of 19 Mev ± 6 Mev between the two peaks of Figs. 2b and 3a. However, since there are two identical pions in the charged Σ cases and not in the Σ^0 cases, it is possible that the effect of Bose statistics could cause a shift of the peaks. Also, from the fact that the charged Σ can resonate with either of the two unlike charged pions, one would expect interference effects between the two resonant amplitudes. Another possibility is interference between the resonance and nonresonant backgrounds. Both these interferences might alter the observed positions of the peaks. Furthermore, electromagnetic mass differences in the $\Sigma^+\pi^-$, $\Sigma^-\pi^+$, and $\Sigma^0\pi^0$ systems could affect the observed mass spectra in the three cases. Assuming that the probability of decay into any mode is proportional to the momentum available in that mode (as expected for an S-wave resonance), we find that the shifting of the peaks due to mass differences is negligible.

The Y_0^* could also be produced in the events in which the final state consists of a Σ and two pions. If it is produced, it should appear in the $(\Sigma\pi)^0$ mass plot given in Fig. 2c of our previous letter.[2] No significant peak is observed; however, the number of events in this region of the mass plot is uncertain because of the difficulty of correcting for $\Sigma^\pm + \pi^\mp + \pi^0 + \pi^0$ production. The absence of the Y_0^* in this final state $(Y_0^* + \pi)$ could be easily understood if the interaction took place mainly through the $T = 0$ initial channel. This hypothesis can be tested by analysis of the interaction $\bar{K}^0 + p$ (a pure $T = 1$ state) currently being studied by Adair.[3]

We believe that our data for Σ plus three pions are most naturally interpreted by invoking a $T = 0$ $\Sigma\pi$ resonance. However, both because of the small number of events involved and the complexity of the final state, we cannot regard the evidence as conclusive at present. Evidence for a $(\Sigma^{\pm} - \pi^{\mp})$ resonance has been obtained by Eisenberg et al., who have studied K^--meson interactions in emulsion and find a peaking in the $(\Sigma\pi)^0$ mass spectrum at 1405 Mev.[4] This peaking could be attributed to a Y_0^*. In addition, Schult and Capps have recently invoked a T = O resonance at a mass of about 1410 Mev to explain the hyperon branching ratio in low-energy K^--d interactions.[5]

Dalitz and Tuan have shown that the (b^-) solution for the scattering lengths in $\bar{K}N$ low-energy interactions will result in a $\Sigma\pi$ resonance in the T = O state.[6] Recent values for the zero-energy $\bar{K}N$ scattering lengths obtained by Dalitz[7] using the data presented by Alvarez at the Kiev Conference,[8] indicate that this resonance will be at 1415 ± 3 Mev, with a half-width $(\Gamma/2)$ of about 20 Mev. If this explanation of the T = 0 resonance is correct, it should have J = 1/2; the observed T = 1 resonance could be the resonance predicted by global symmetry with J = 3/2.[9] Dalitz has pointed out that the values of the (a^-) solution given in reference[7] are consistent with both a T = 1 and a T = 0 $(Y-\pi)$ resonance;[10] both of these resonances should have J = 1/2.

The authors wish to thank the many members of the Bevatron and bubble chamber crews and the scanners who made this experiment possible. We also thank Professors R.H. Dalitz, A. Pais, and B. Sakita for several helpful discussions. One of us (PE) wishes to thank the Philippe's Foundation Inc. and the Commissariat a l'Energie Atomique of France for a fellowship.

FOOTNOTES

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

†Presently at Laboratoire de Physique Atomique, College de France, Paris, France.

§Presently at University of Wisconsin, Madison, Wisconsin.

**Presently at University of California at Los Angeles, Los Angeles, California.

1. M.H. Alston, L.W. Alvarez, P. Eberhard, M.L. Good, W. Graziano, H.K. Ticho, and S.G. Wojcicki, Phys. Rev. Letters, 5, 520 (1960).
2. M.H. Alston, L.W. Alvarez, P. Eberhard, M.L. Good, W. Graziano, H.K. Ticho, and S.G. Wojcicki, (submitted to Phys. Rev. Letters).
3. H.J. Martin, L.B. Leipuner, W. Chinowsky, P.T. Shively, and R.K. Adair, Phys. Rev. Letters, 6, 238, (1961).
4. Y. Eisenberg, G. Yekutieli, P. Abrahamson, and D. Kessler, Weizmann Institute of Science, Rehovoth, Israel, private communication.
5. R.L. Schult and R.H. Capps, private communication, submitted to Phys.Rev.
6. R.H. Dalitz and S.F. Tuan, Phys. Rev. Letters 2, 425 (1959) and Ann. Phys. (N.Y.) 10, 307 (1960).
7. R.H. Dalitz, On the Strong Interactions of the Strange Particles, Lawrence Radiation Laboratory Report UCRL-9580, January 27, 1961 (unpublished).
8. L.W. Alvarez, paper presented at the 1959 International Conference on Physics of High Energy Particles, Kiev, July 1959 (unpublished): The Interactions of Strange Particles, Lawrence Radiation Laboratory Report UCRL-9354, August 11, 1960 (unpublished).
9. A. Pais has pointed out to us that if the Y_1^* should turn out to be the resonance predicted by global symmetry, the question arises whether the existence of Y_D^*

could have anything to do with global symmetry as well. This is certainly not the case because, if the Y_0^* is related to the global symmetry hypothesis, then there should be a corresponding $T = 1/2$ π-nucleon resonance with $Q \sim 160$ Mev. Thus the existence of a Y_0^* may indicate that the assumption of global symmetry is wrong. However, another possibility is that this symmetry could be valid in the P-wave π-baryon interaction but not in the S-wave.

10. R. H. Dalitz, Enrico Fermi Institute for Nuclear Studies, University of Chicago, private communication.

FIGURE LEGENDS

Fig. 1. Mass plots of the neutral and doubly charged $\Sigma\pi$ systems.

Fig. 2. Dalitz plot of the $\Sigma^{\pm} + \pi^{\mp} + \pi^{+} + \pi^{-}$ events for the system consisting of a Σ and two oppositely charged pions. For discussion see text.

Fig. 3. Ideograms of the missing mass for the 39 events in which a Λ and two charged pions were observed and neutral pions were also produced. (a) Events with $\chi^2 > 2$ for the $\Lambda\pi^0\pi^+\pi^-$ hypothesis; the superimposed curve is the phase-space distribution for the $\Sigma^0\pi^0\pi^+\pi^-$ reaction normalized to nine events. (b) Events with $\chi^2 < 2$ for the $\Lambda\pi^0\pi^+\pi^-$ hypothesis, and the expected $\Lambda\pi^0\pi^+\pi^-$ phase-space curve.

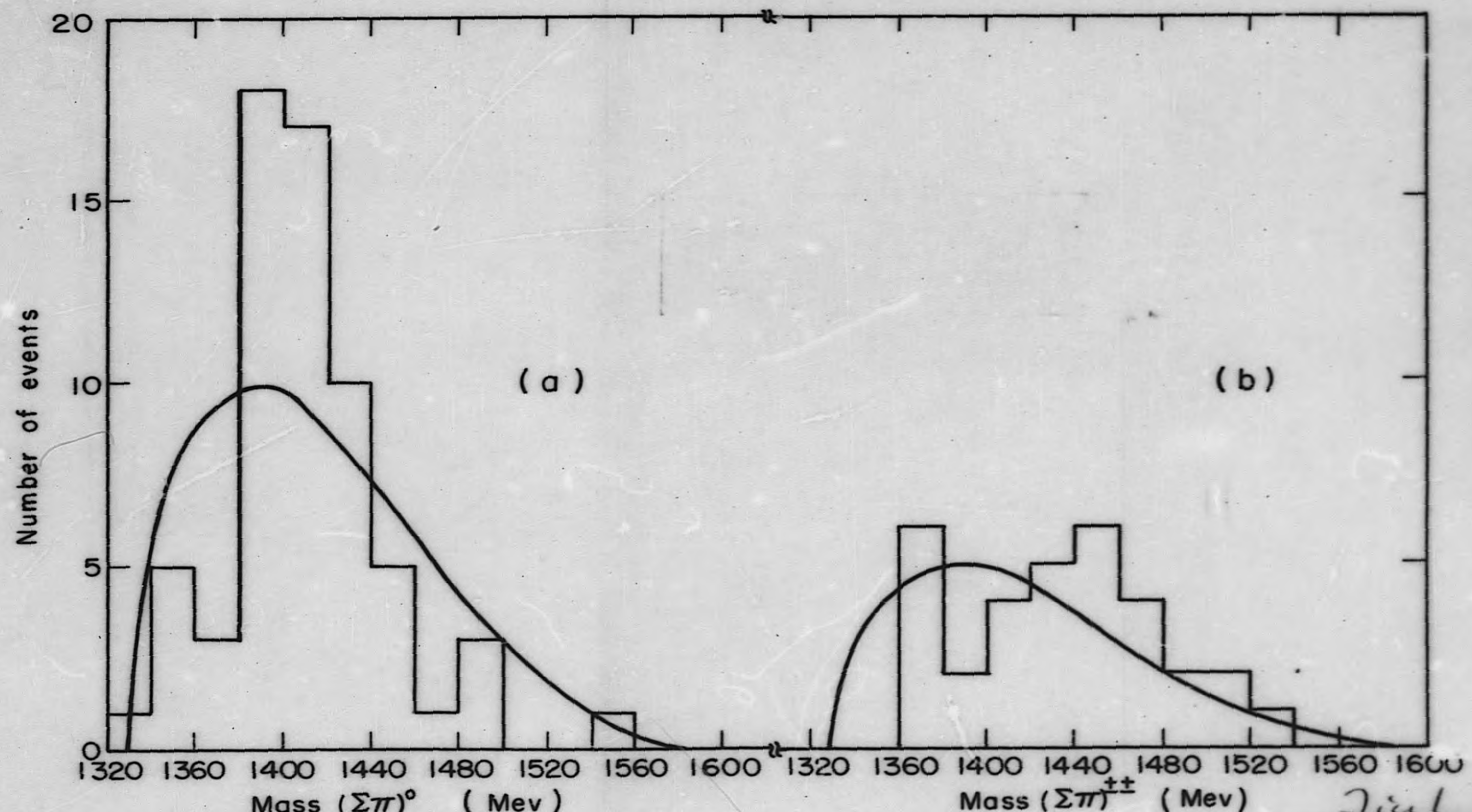


Fig 1

64 11 [redacted]

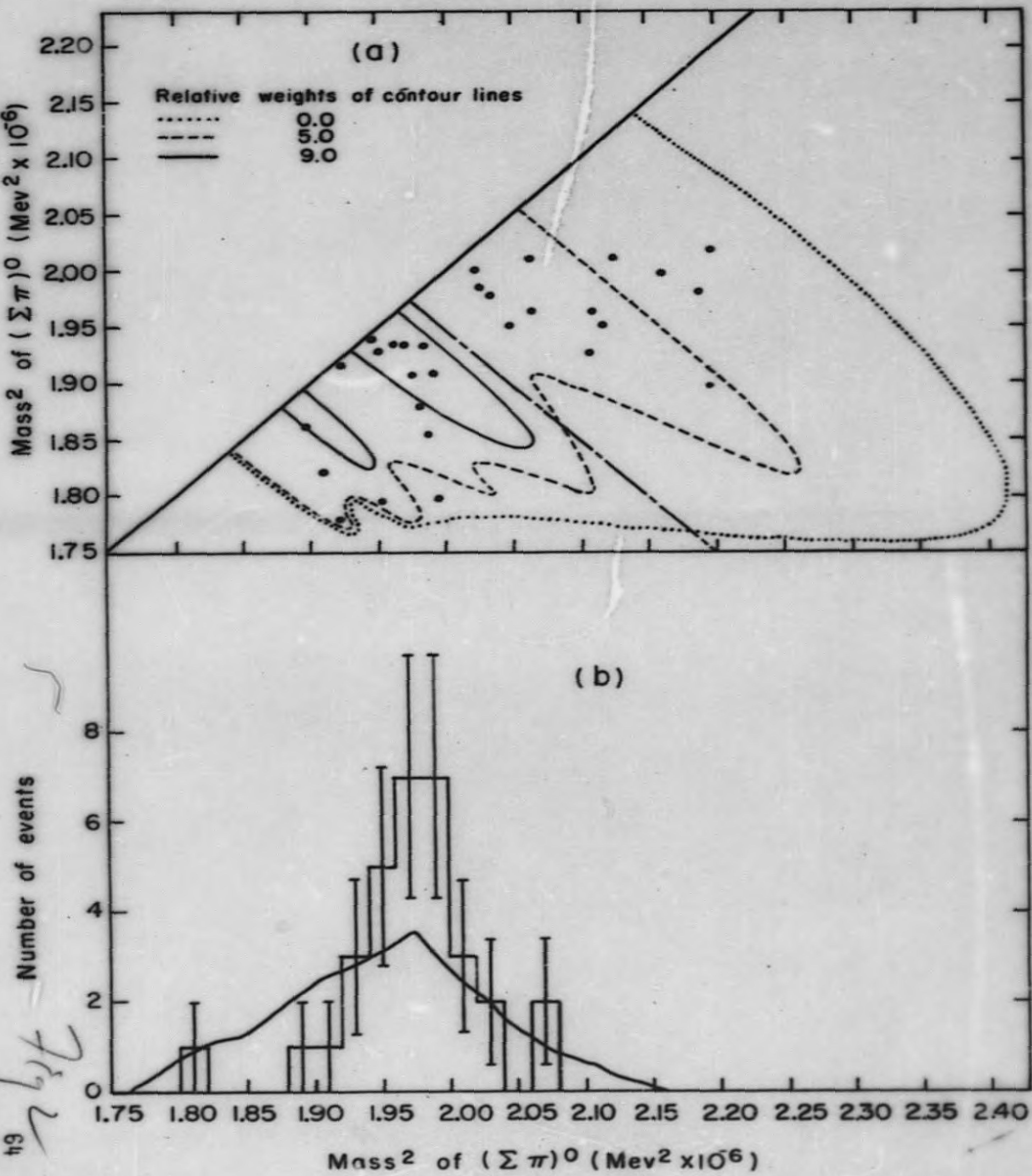
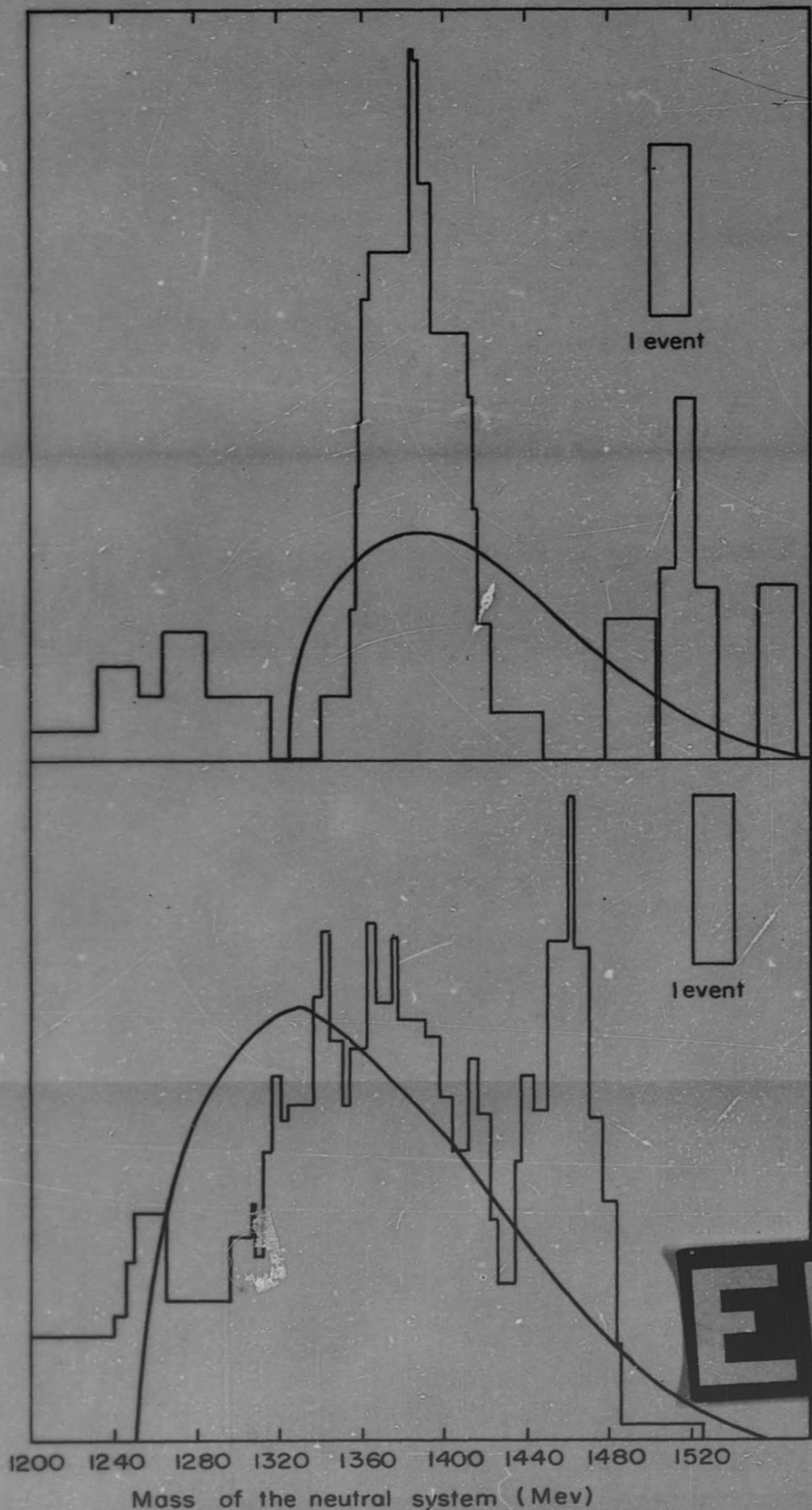


Fig 2

64

[redacted]



I event
I event
1200
1240
1280
1320
1360
1400
1440
1480
1520
Mass of the neutral system (Mev)

END