Title
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Author
Firestone, Alexander.

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THE Q REGION OF $K\pi\pi$ MASS

Alexander Firestone

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LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

THE Q REGION OF $K\pi\pi$ MASS[†]

Alexander Firestone

Lawrence Radiation Laboratory
University of California
Berkeley, California

I INTRODUCTION

The problems concerning the Q may be divided into three areas: (1) production mechanisms, (2) the nature of the Q, and (3) decay properties. As far as production mechanisms are concerned there is general agreement among experimenters that the Q is produced primarily by a diffraction-type mechanism or, equivalently, by Pomeron exchange.[1,2] There is likewise general agreement that the spin-parity is $J^P = 1^+$ for the entire Q region,[3-6] but in most cases the experimenters report that $J^P = 2^-$ cannot be completely excluded. It has also be determined that the entire Q is consistent with an $I = 1/2$ state. For example, the LRL 9 GeV/c K^+p experiment places an upper limit of 0.7% $I = 3/2$ contribution to the Q region in the $K^+\pi^+\pi^-p$ final state.[7] As far as the decay branching ratios are concerned, the experimenters in general are agreed that the $K^*\pi$ decay mode is dominant, the $K\rho$ decay mode exists, and that all other decay modes, e.g., $K\omega$, $K\varphi$, $K\eta$ or three-body $K\pi\pi$, are either non-existent or very small.[8-12] There is still a question about the relative strengths of the $K\rho$ vs $K^*\pi$ decay modes, and this question is greatly complicated by the possibility of interference effects between these two modes. A glance at a Q decay Dalitz plot [e.g., $M^2(K^+\pi^-)$ vs $M^2(\pi^+\pi^-)$ for

$M(K^+\pi^+\pi^-)$ in the Q region in the final state $K^+\pi^+\pi^-p$] reveals that the K^*-ρ cross-over region contains a large number of events whose assignment is uncertain. Results vary all the way from no $K\rho$ decay[13] up to 30% $K\rho$ decay.[7,14] In addition to these decay modes, the LRL 9-GeV/c K^+p experimenters have suggested, on the basis of isotopic spin arguments, the possible existence of a substantial $K\epsilon$ decay mode of the Q, where the ϵ is the $I = 0$ s-wave π-π state with a mass in the neighborhood of the ρ.[7] As yet this suggestion has not been either confirmed or refuted by any other group. In addition, there is general agreement that, for the $K^*\pi$ decay mode of the Q, the spin of the K^* is aligned such that the Z-component along the incident direction is zero.[2] The evidence for this is the well-known $\cos\theta$ decay angular distribution for the Q, where θ is the angle between the outgoing K and the incident K in the K^* rest frame (Jackson angle). This alignment is consistent with the interpretation of the Q as a $J^P = 1^+$ object, produced by Pomeron exchange, which decays mainly by s-wave into $K^*\pi$.

In contrast to all these general agreements among experimenters, there still seems to be no general agreement about the nature of the Q itself. There are those who prefer one or more resonances to explain the Q, and those who prefer a kinematic interpretation, e.g., Deck effect or multi-Regge exchange. This lack of agreement is closely related to the question of whether or not the Q peak is split. The problem is further complicated by the presence of the $K\pi\pi$ decay modes of the K^*_{1420} which, in the low energy data, contribute substantially to the Q peak. The principal disagreements lie in the various interpretations of the $K\pi\pi$ mass distribution itself, and must be resolved there. Enough data has been accumulated already such that any theory of the Q must fit at least the $K\pi\pi$ mass distribution with reasonable chi square. Other distributions, e.g., $d\sigma/dt$ vs t, are generally input to resonance theories or multi-Regge exchange theories, and therefore provide no discrimination between them. For these reasons I wish to concentrate the remainder of this talk on the $K\pi\pi$ mass distributions.

First, however, I wish to quote J. D. Jackson on the subject of duality[15]: "The production of a low mass enhancement in the $\pi\rho$ system in the reaction $\pi N \rightarrow \pi\rho N$ by means of a double peripheral mechanism, known as the Deck effect, has made difficult the analysis of the A_1 and A_2 mesons and has occasionally cast doubt on the very existence of the A_1. Chew and Pignotti, who coined the name 'duality,' observed that this concept makes empty a discussion of whether there is an A_1 or just an enhancement by some peripheral mechanism. Resonances generate and are generated by peripheral exchanges. The Regge (or elementary) pion exchange amplitude is the appropriate high-energy description of the $\pi\rho$ system. When extended down to threshold it provides an average description of that mass region. If the smooth average is large at low mass, duality requires the existence of resonances."

II KINEMATIC INTERPRETATIONS

I shall show the results of several multi-Regge and Deck effect model fits to the data. They are presented in the order K^+ before K^-, low energy before high energy. Some Wisconsin results on K^+p data at 3.54 GeV/c are shown in Fig. 1.[16] The smooth curve represents a Deck modified phase space background in addition to two resonances, the well-known K^*_{1420} and a narrow (40-MeV wide) resonance centered at 1300 MeV. The smooth curve fits the data very well.

The results of a multi-Regge fit to a UCLA 7.3-GeV/c K^+p experiment are shown in Fig. 2.[17] The $K^*\pi$ mass appears in the upper left hand corner. This model uses a single diagram, illustrated in the insert; the K^* is at the meson vertex, the proton at the nucleon vertex, the pion at the interior vertex; the exchanges are the pion and the Pomeron. The model involves a Regge-pole description of the pion exchange, and a diffraction scattering expression for the lower vertex. The smooth curve obtained from this model fits the $K^*\pi$ mass distribution very well, but the following two comments are necessary: (1) the data shown are rather

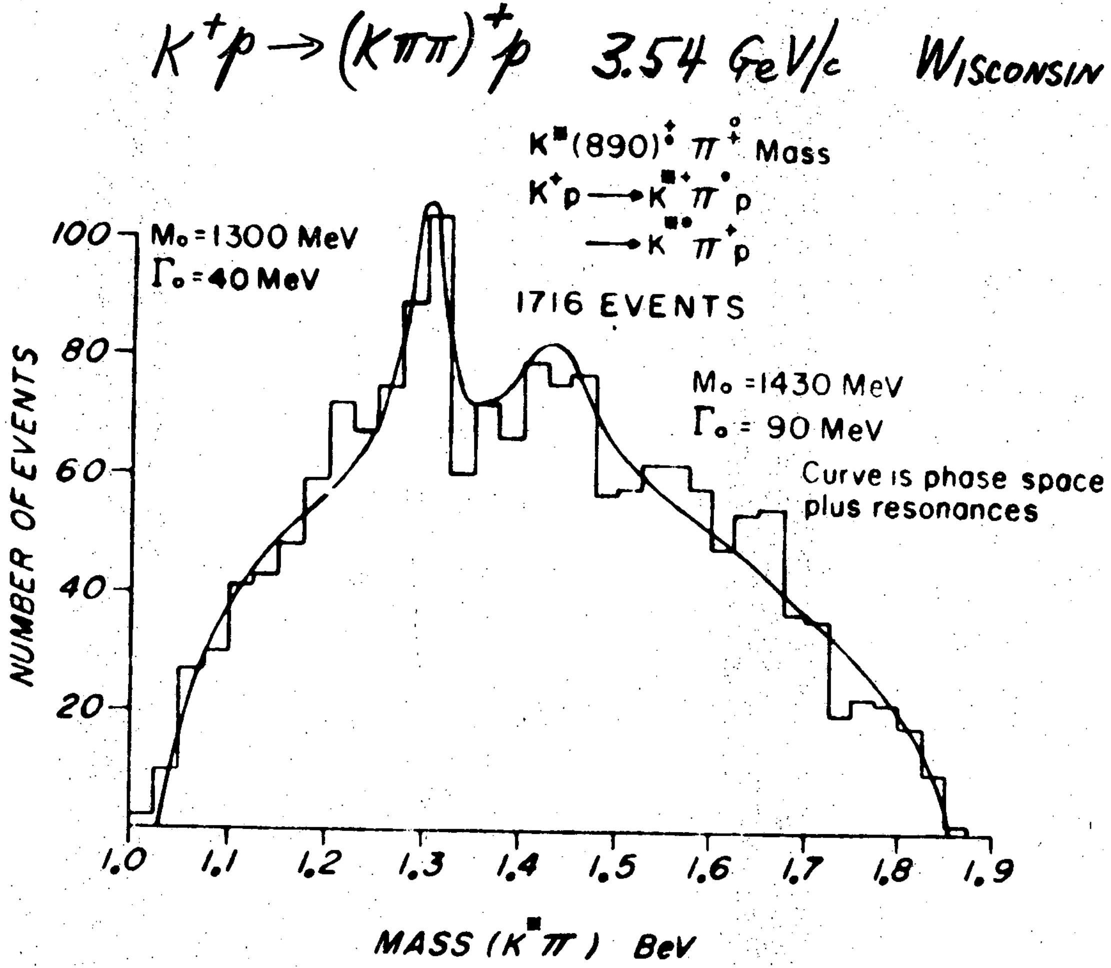

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Fig. 1

$K^+p \to K^{*0}\pi^+p$ 7.3 GeV/c UCLA

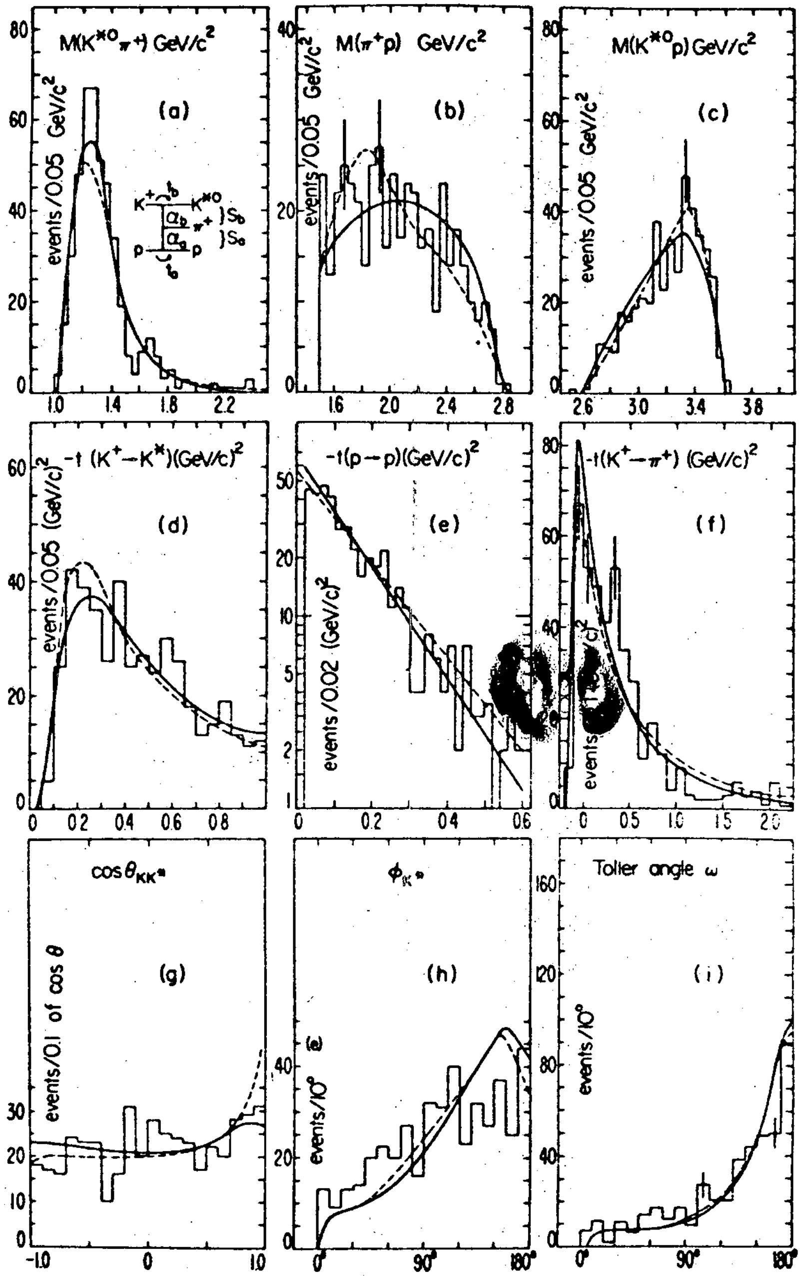

Fig. 2. Various invariant mass, four-momentum transfer squared and angular distributions of the data compared with the curves predicted by the model. The angles are defined in the text. The insert in fig. 1a, referred to in the text as diagram A, is used in this analysis.

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heavily cut: $S_a > 2.25$ GeV^2, $0.02 < |t_a| < 1.0$ (GeV/c)^2, $|t_b| < 1.0$ (GeV/c)^2, and $0.84 < M(K^+\pi^-) < 0.94$ GeV; and (2) the actual integrated cross section obtained from the calculation was about 60% below the experimental value of 0.31±0.03 mb. To obtain the curves shown the theoretical distributions were then normalized to the total number of events. Nevertheless the shape appears to be approximately correct.

Figure 3 shows the results of a multi-Regge calculation on the LRL 9-GeV/c K^+p data. This calculation uses the four multi-Regge diagrams illustrated in Fig. 4 with the exchanges indicated. The residue functions were assumed to be exponential in the relevant four-momentum transfers with slopes fixed at the experimental values. The meson trajectories were assumed to be linear, of slope unity, and with intercepts fixed at values given by $\alpha_o = J - m^2$, where m is the rest mass of the exchanged particle and J its spin. The trajectory for the Pomeron was taken to be $\alpha = 1.0 + 0.12t$, and the integrated sum of the $K\rho$ contributions was fixed at 1/3 the integrated sum of the $K^*\pi$ contributions, which is the $K\rho/K^*\pi$ branching fraction seen in this experiment. The theoretical prediction was normalized to the total number of events with $M(K\pi\pi) < 1.6$ GeV. The theory clearly does not fit the data.

A similar calculation has been performed by LRL Group A for their 12-GeV/c K^+p data.[18] The results are shown in Fig. 5. In this calculation they leave the relative strength of each diagram free and obtain the best fit parameters as shown in Fig. 5. Again the shape of the theoretical prediction does not match the data; and, in addition, to get even this poor fit, they have to include a larger $K\rho/K^*\pi$ Q decay branching ratio than indicated by the $K\pi$ and $\pi\pi$ mass projections. Figure 6 shows the results of a fit by the Rochester group to their 12.6-GeV/c K^+p data.[14] The results are very similar to the 9-GeV/c results. The $K^*\pi$ mass distribution is simply not reproduced by the multi-Regge model.

Figure 7 shows the results of a Deck-type calculation by De Groot and Walters on coherent production of the Q in a 3-GeV/c K^-d experiment.[19] Even though the statistics are poor the fit is

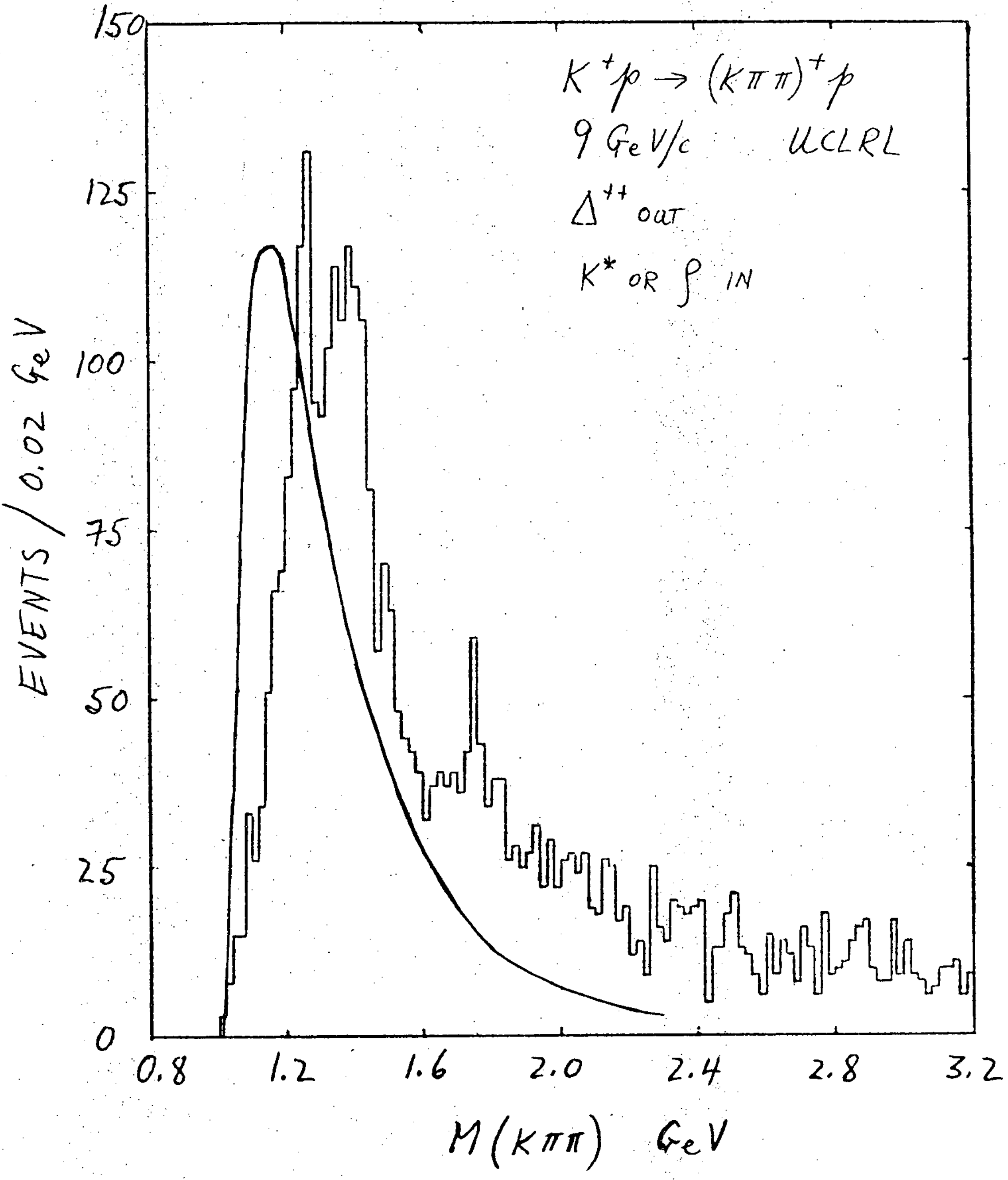

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Fig. 3

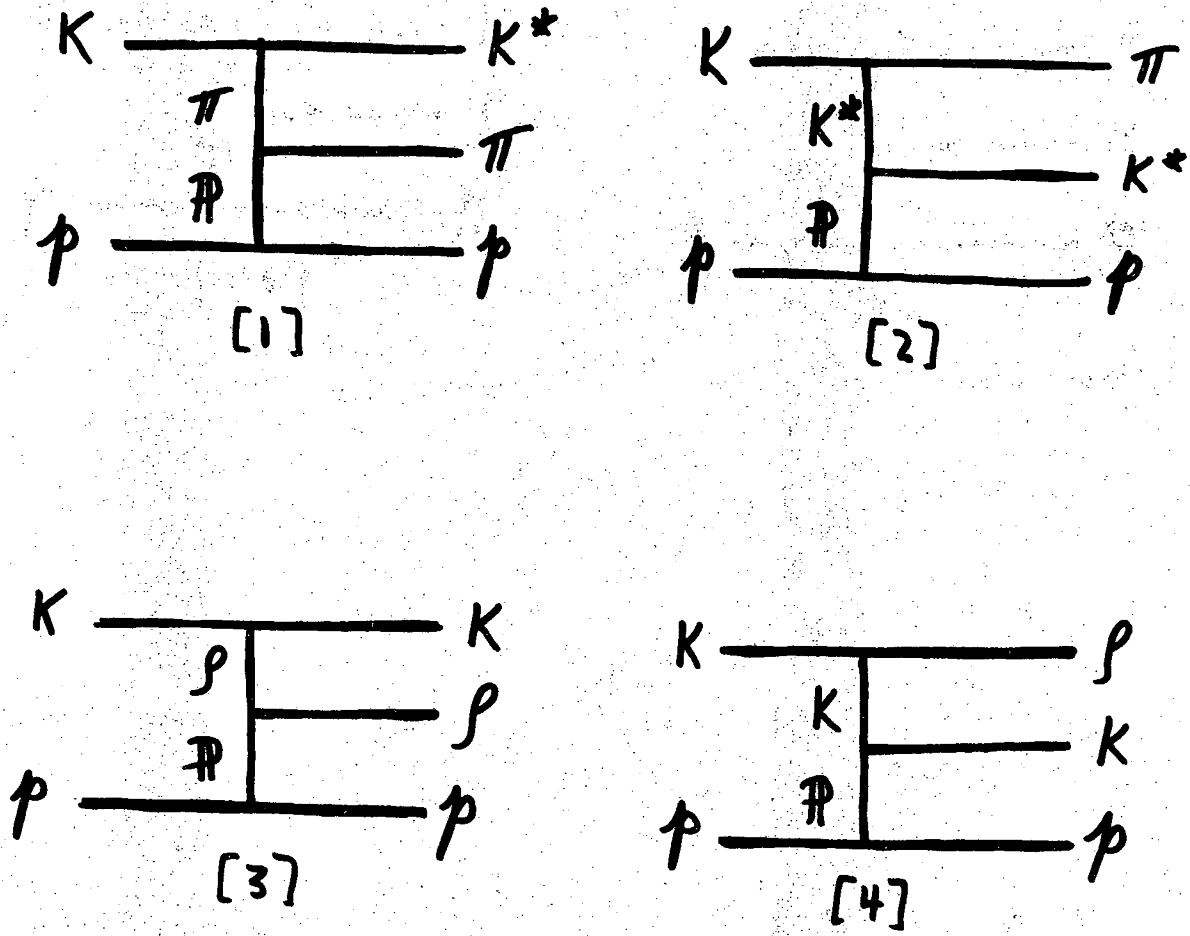

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Fig. 4

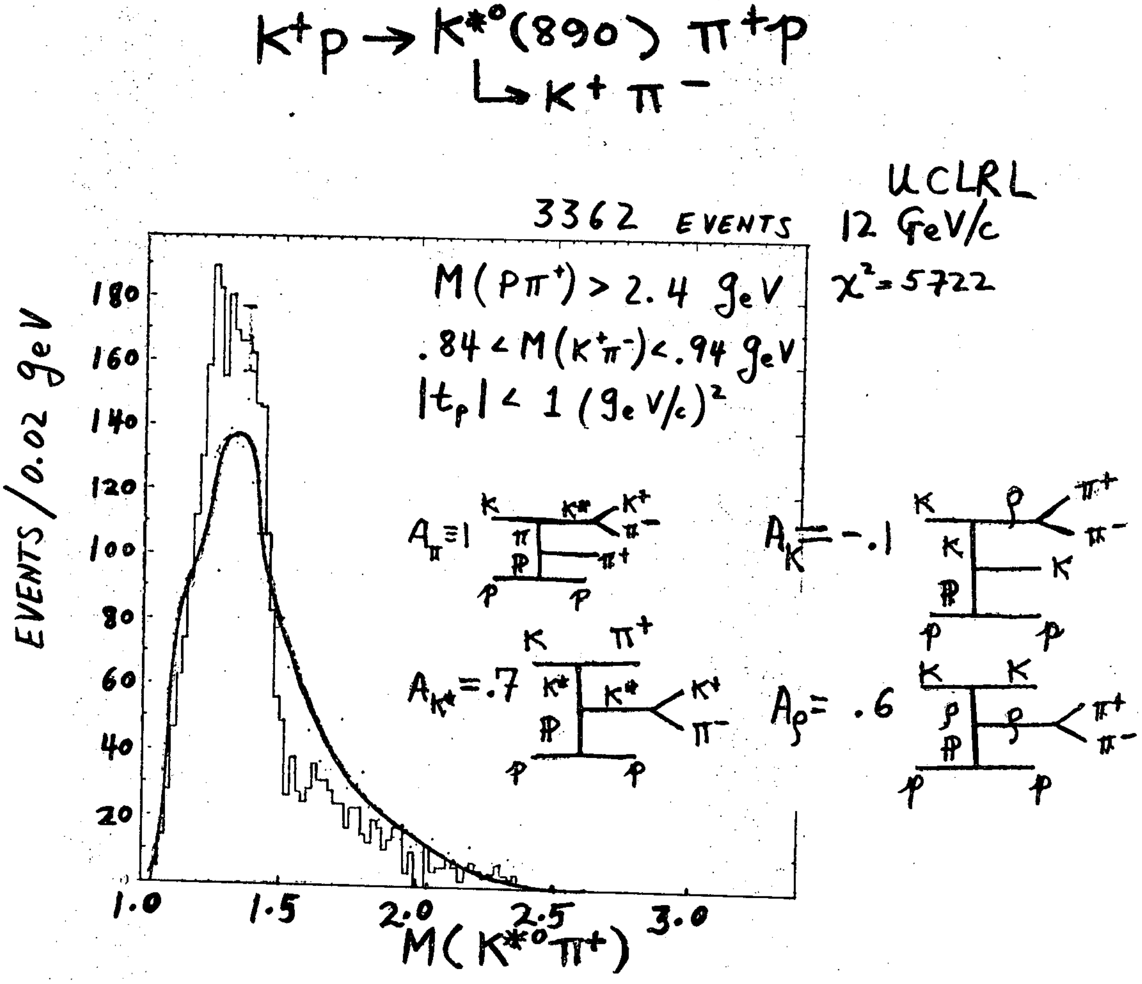

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Fig. 5

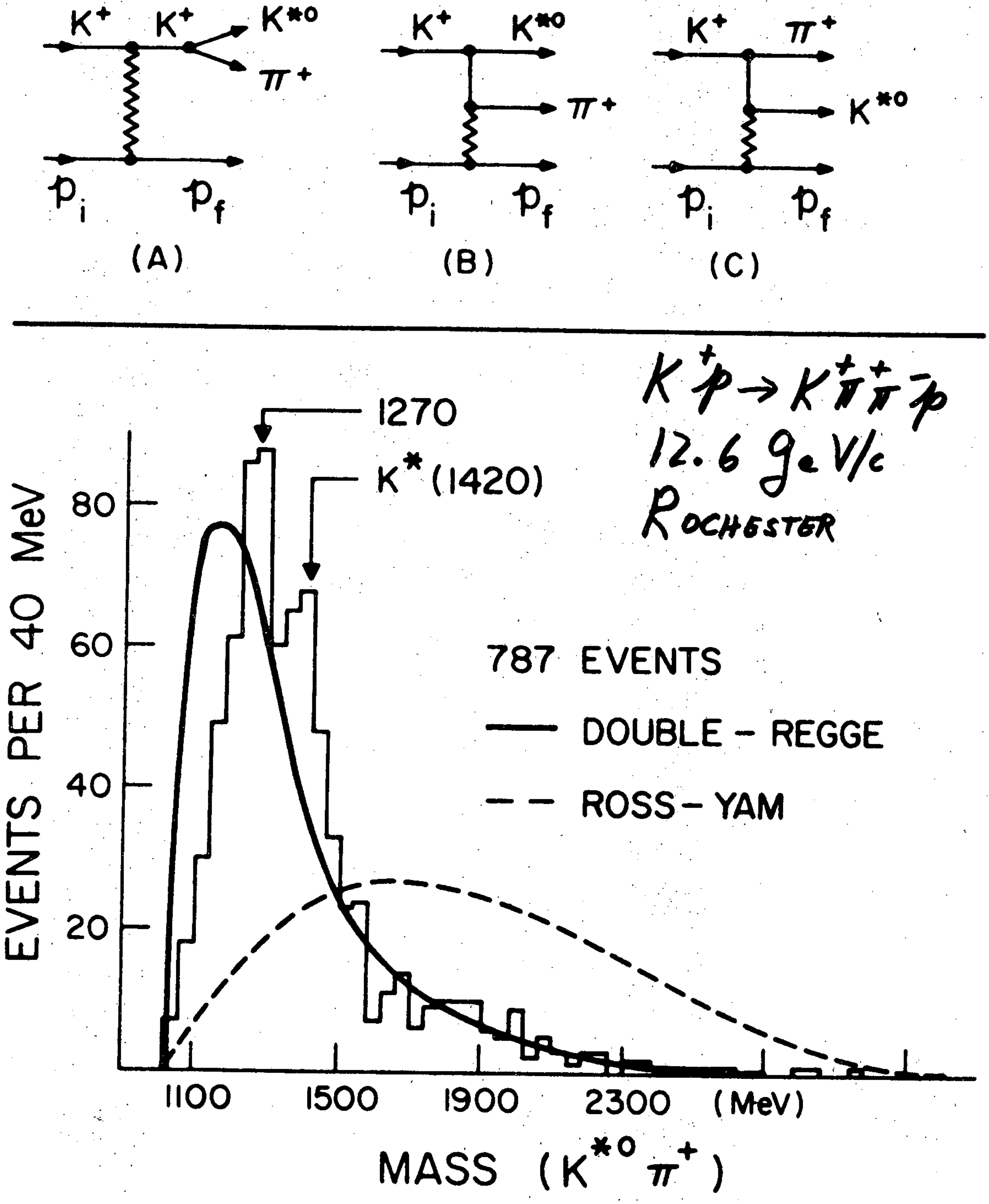

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Fig. 6

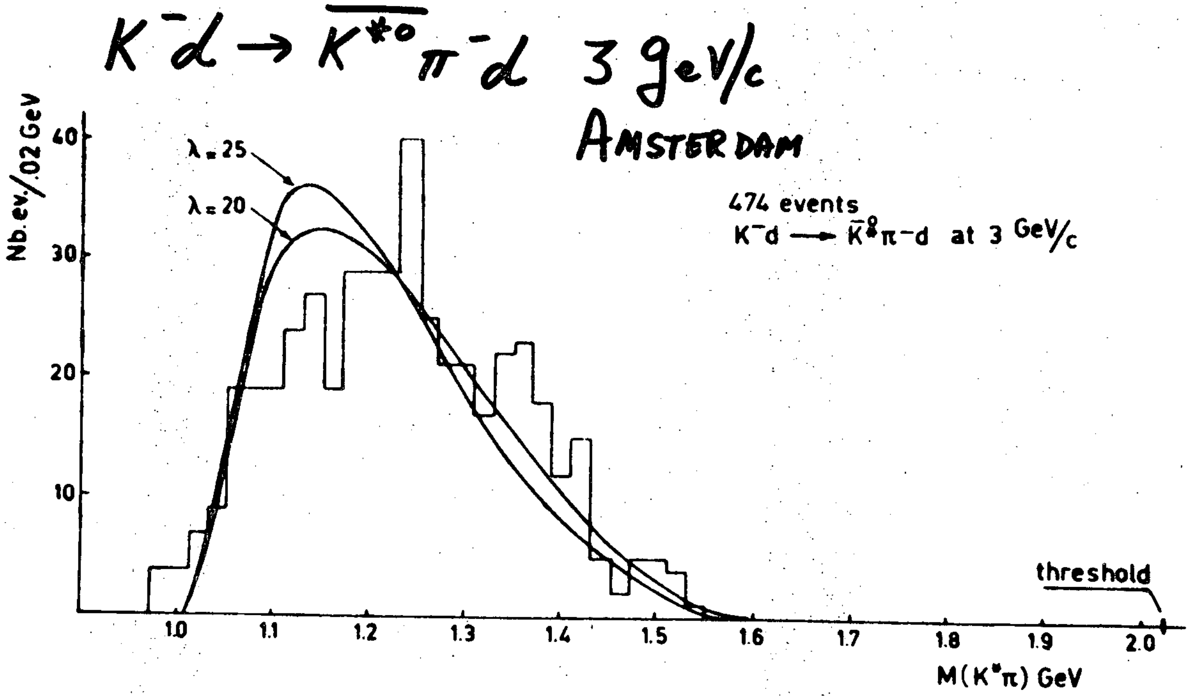

Fig. 7

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probably not unreasonable. Figures 8 and 9 show the results of a Deck-type calculation on the same 3-GeV/c K^-d experiment but by the S.A.B.R.E. collaboration.[20] This calculation differs slightly from the calculation of De Groot and Walters in the treatment of the πd elastic scattering. These predictions also appear to give reasonable fits to the data.

Figure 10 shows the results of a double-Regge-pole model calculation of the coherent production of the Q in a 5.5-GeV/c K^-d experiment by the Northwestern-Argonne collaboration.[21] The data presented in Fig. 10 are from four prongs only, and thus have been cut at $|t_{dd}| > 0.02$ $(\text{GeV}/c)^2$; this is done because there is a scanning bias against events with $|t_{dd}| < 0.02$ $(\text{GeV}/c)^2$ which were likely to have been lost as three prongs. They estimate this scanning loss to be only 17% at this energy. Additional cuts used are $|t_{KK^*}| < 1$ $(\text{GeV}/c)^2$, $S_{\pi^-d} > 6$ GeV and K^* selected. Only one diagram as shown in Fig. 4a is used. Within the limited statistics the fit is reasonable, although the calculated peak is somewhat too broad.

Figure 11 shows the results of a double-Regge-pole calculation for a BNL 7.3-GeV/c $K^-p \rightarrow K^-\pi^+\pi^-p$ experiment.[22] The data have been heavily cut; $0.86 < M(K^-\pi^+) < 0.94$ GeV, $0.025 < -t_{pp} < 0.5$ $(\text{GeV}/c)^2$, $-t_{KK^*} < 1$ $(\text{GeV}/c)^2$, and $M(\pi^-p) > 1.34$ GeV. The calculation also uses only one diagram, as shown in Fig. 4a. The normalization chosen is such that, as $t_{KK^*} \rightarrow m_\pi^2$, the square of the matrix element approaches the conventional OPEM expression; but this results in a prediction of 61 μb for the theoretical total cross section, while the experimental result is 138±25 μb. Therefore the theory has to be scaled up, as were the UCLA results. Nevertheless the shape of the $K^*\pi$ mass spectrum seems to be properly reproduced within the limited statistics. The fit to the π^-p mass distribution is poor and the BNL group speculates that any improvement in this direction may have to include exchanges other than the Pomeron at the nucleon vertex.

Figure 12 shows the results of the Yale 12.6-GeV/c K^-p multi-Regge calculation.[23-25] The Yale group selects only K^* events and

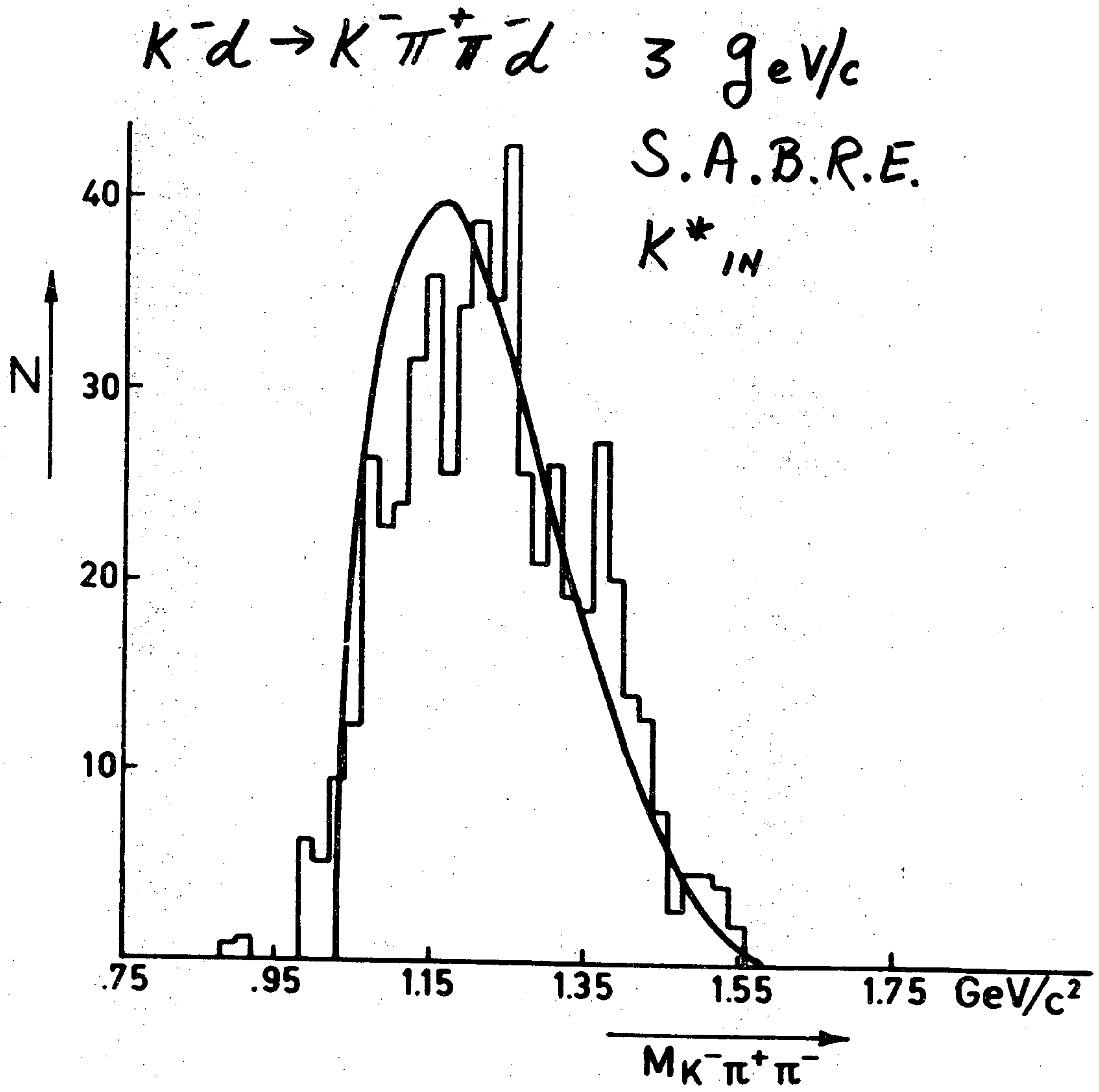

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Fig. 8

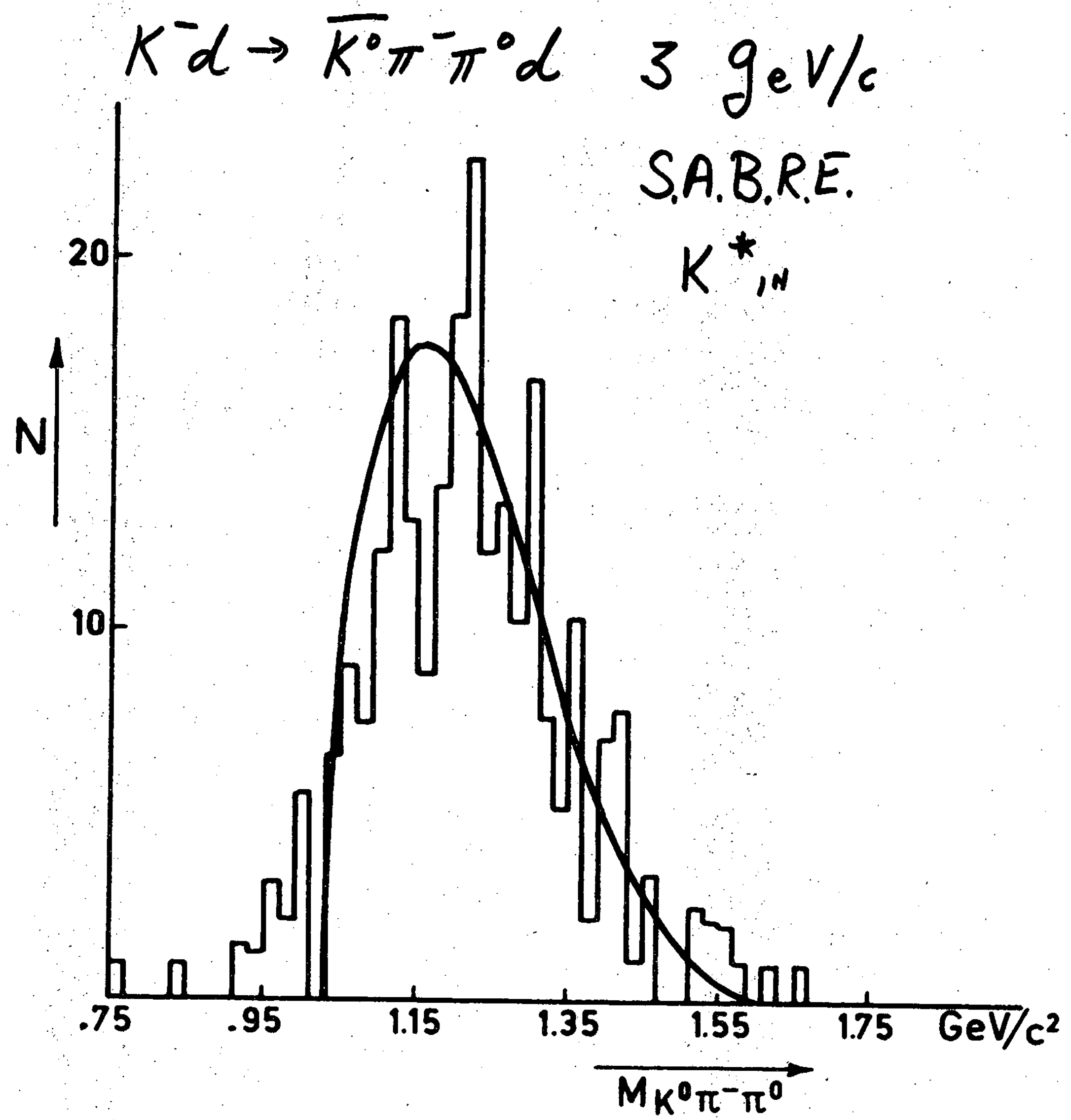

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Fig. 9

$K^-d \to K^-\pi^+\pi^-d$ 5.5 GeV/c

NORTHWESTERN
ARGONNE

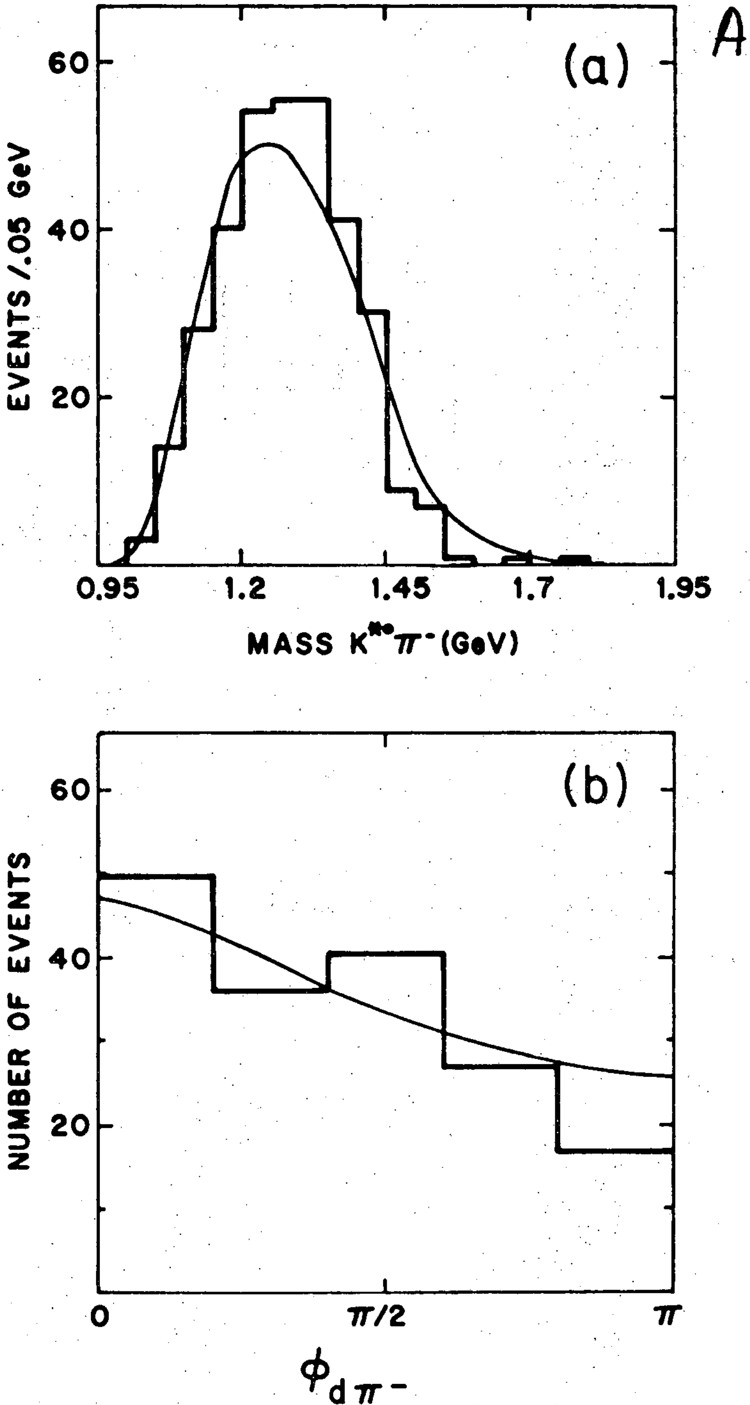

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Fig. 10

$K^- p \rightarrow K^{*0} \pi^- p$ 7.3 GeV/c

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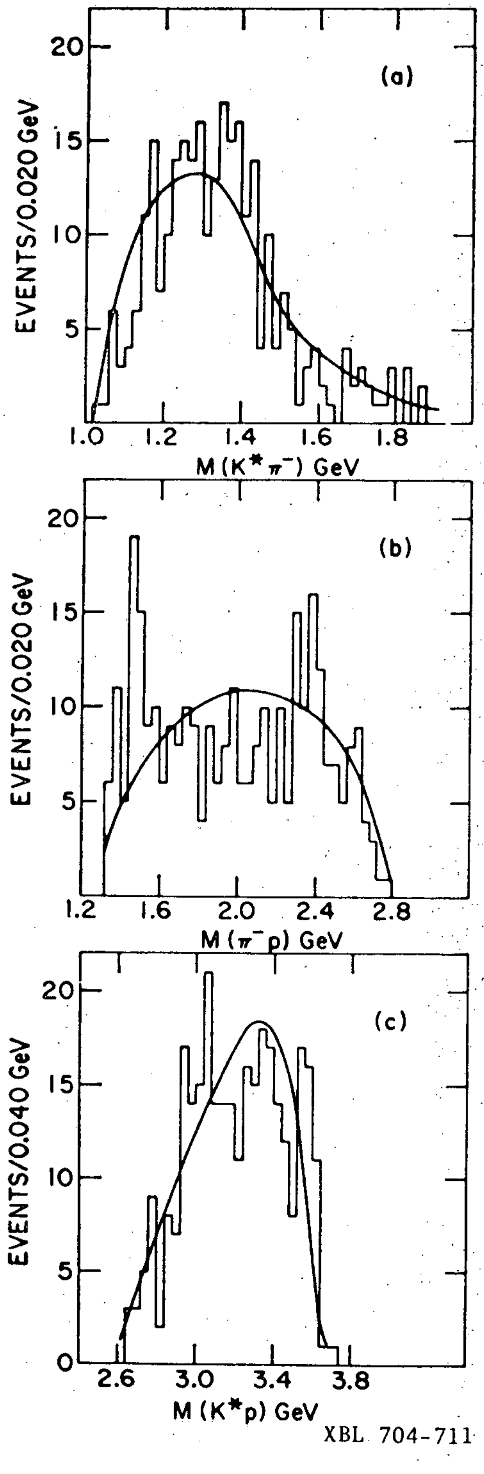
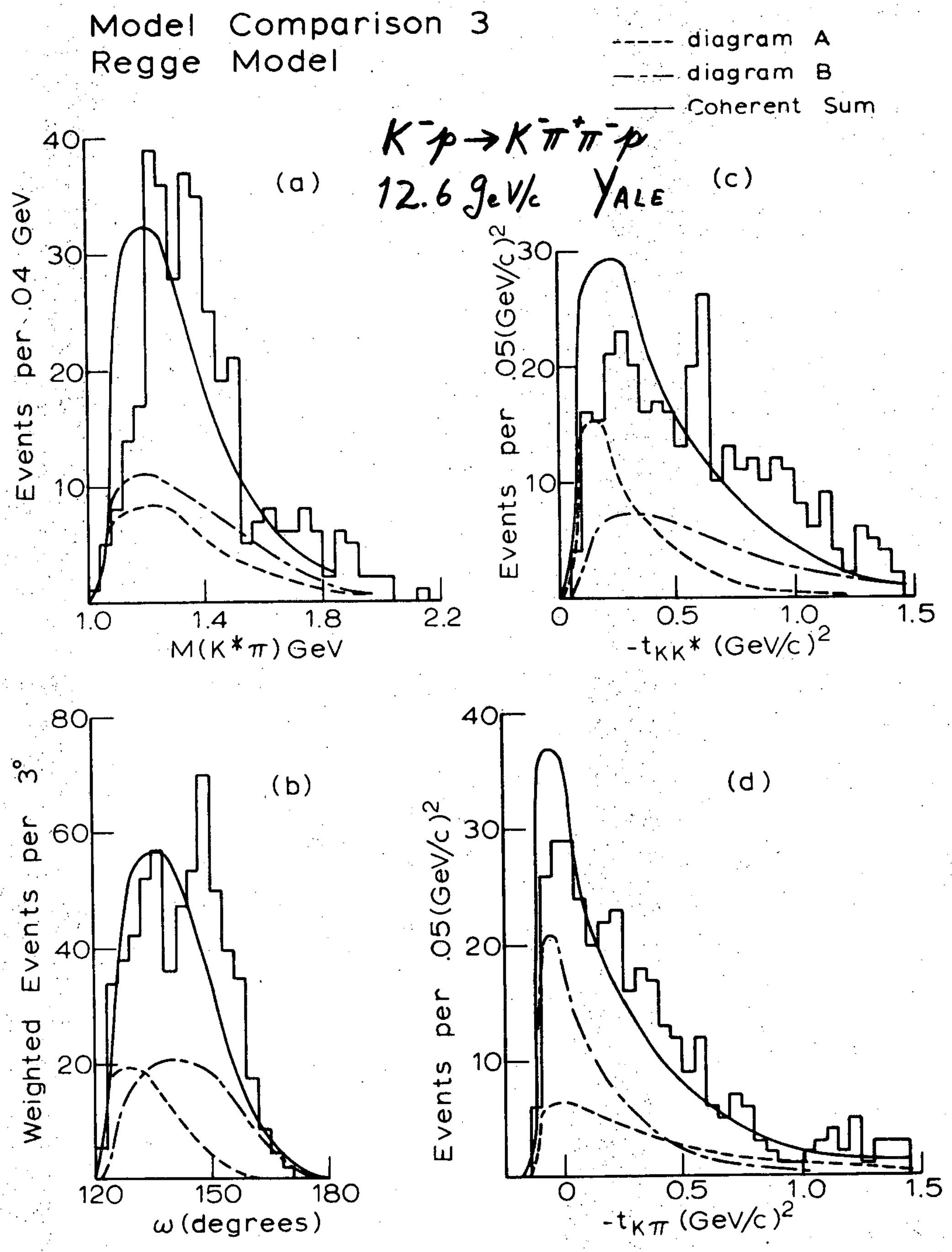


Fig. 11



$K^- p \to K^- \pi^+ \pi^- p$
12.6 GeV/c Yale

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Fig. 12

uses the two diagrams involving a K^*, as shown in Fig. 4. The parameters are fixed in the usual way: $\alpha_\pi = t_{KK^*} - m_\pi^2$, $\alpha_{K^*} = t_{K\pi} - (m_{K^*}^2 - 1)$, and $S_0 = 1$ GeV^2. The t dependence is given by an exponential, $\exp(7t_{pp})$, in the square of the matrix element. The data have been cut to select K^*, and also $|t_{KK^*}| < 2.5$ $(\text{GeV/c})^2$, $|t_{K\pi}| < 2.5$ $(\text{GeV/c})^2$ and $M_{p\pi} > 1.8$ GeV. From Fig. 12 it is clear that the shape of the $K^*\pi$ mass distribution is simply not reproduced by the theory. Their curve is, in fact, very similar to those obtained in the 9-GeV/c and 12.6-GeV/c K^+p Regge fits.

In conclusion we may say that a multi-Regge calculation can reproduce the Q peak in both K^+ and K^- interactions for experiments of 7.3-GeV/c incident momentum or below, even though the various calculations differ in some details. For 9-GeV/c incident momentum and above, however, the multi-Regge model is not successful at all.

III RESONANCE INTERPRETATIONS

Even a superficial look at the $K\pi\pi$ mass spectra shows that the Q peak has a peculiar shape, particularly in the high-energy high-statistics K^+p data. Whether the dip is significant or not, or whether the peak is a flattop or some other shape, are perhaps in some experiments not obvious. But what is obvious in most experiments is that the Q is not a simple phenomenon. It will not fit a single Breit-Wigner shape even with elaborate backgrounds. There is a sharp drop in the data at a $K\pi\pi$ mass of about 1280 MeV for the high-energy high-statistics K^+p experiments. Therefore, since the data indicate the presence of at least two phenomena, I have attempted a very simple fit to two Breit-Wigner forms. I have taken two s-wave Breit-Wigner shapes, as given by Jackson,[26] and have attempted a fit to each of the available $K\pi\pi$ mass distributions. Each experiment at each momentum is fitted separately from and independently of all the others. In each case the fit is a five parameter fit, the mass and width of each Breit-Wigner plus the relative strength of the two. No attempt is made to include any interference effects between the two Breit-Wigners, and no attempt is made to account for the K^*_{1420}. Although the sharp drop in the data at 1280 MeV is very suggestive of an interference effect, even the experiments with the highest statistics do not permit a definitive statement on this question. The discussion of the K^*_{1420} is deferred until later. In addition, I have made no attempt to include any background effects in order to reduce the number of parameters as much as possible. The threshold for producing three-body $K\pi\pi$ is 780 MeV, but there are virtually no events with $M(K\pi\pi)$ below 1 GeV, which is the threshold for $K^*_{890}\pi$ production after allowing for the width of the K^*_{890} and for resolution. This gap is more than 200 MeV wide. Thus, if there is any background under the Q it is nonresonant $K^*\pi$ or $K\rho$ background and not three-body $K\pi\pi$ background. Furthermore, a plot of $K\pi\pi$ mass with K^* and ρ removed reveals no Q peak at all, consistent with 100% quasi-two-body decay of the Q. The effects of ignoring background in this fit result in resonant widths which are probably too broad.

For the data, I have collected all the $K\pi\pi$ mass distributions which were available to me either by private communication or by reading numbers off a graph in a publication. I have used only the data available in 20 MeV bins. I have also tried in each case to use only that data with Δ^{++} removed and with no other cuts. This is done in order to keep things simple in spite of the fact that splitting shows up better with K^* and K^* or ρ cuts. The fit is done in 25 bins for each experiment, has five parameters in each case, and is normalized to the total number of events in those bins. There are therefore 19 degrees of freedom in each case.

The results of the fits are shown in Figs. 13 through 24, and are tabulated in Table I. Figure 13 shows the Illinois 3.2 GeV/c data.[27,28] In this experiment there is a drop at 1.32 GeV and a shoulder at higher $K\pi\pi$ mass. Figure 14 shows the Chicago 4.5 GeV/c data.[13] There is no compelling evidence in this data for a sharp drop in the Q nor for any splitting, but there is a distinct peak

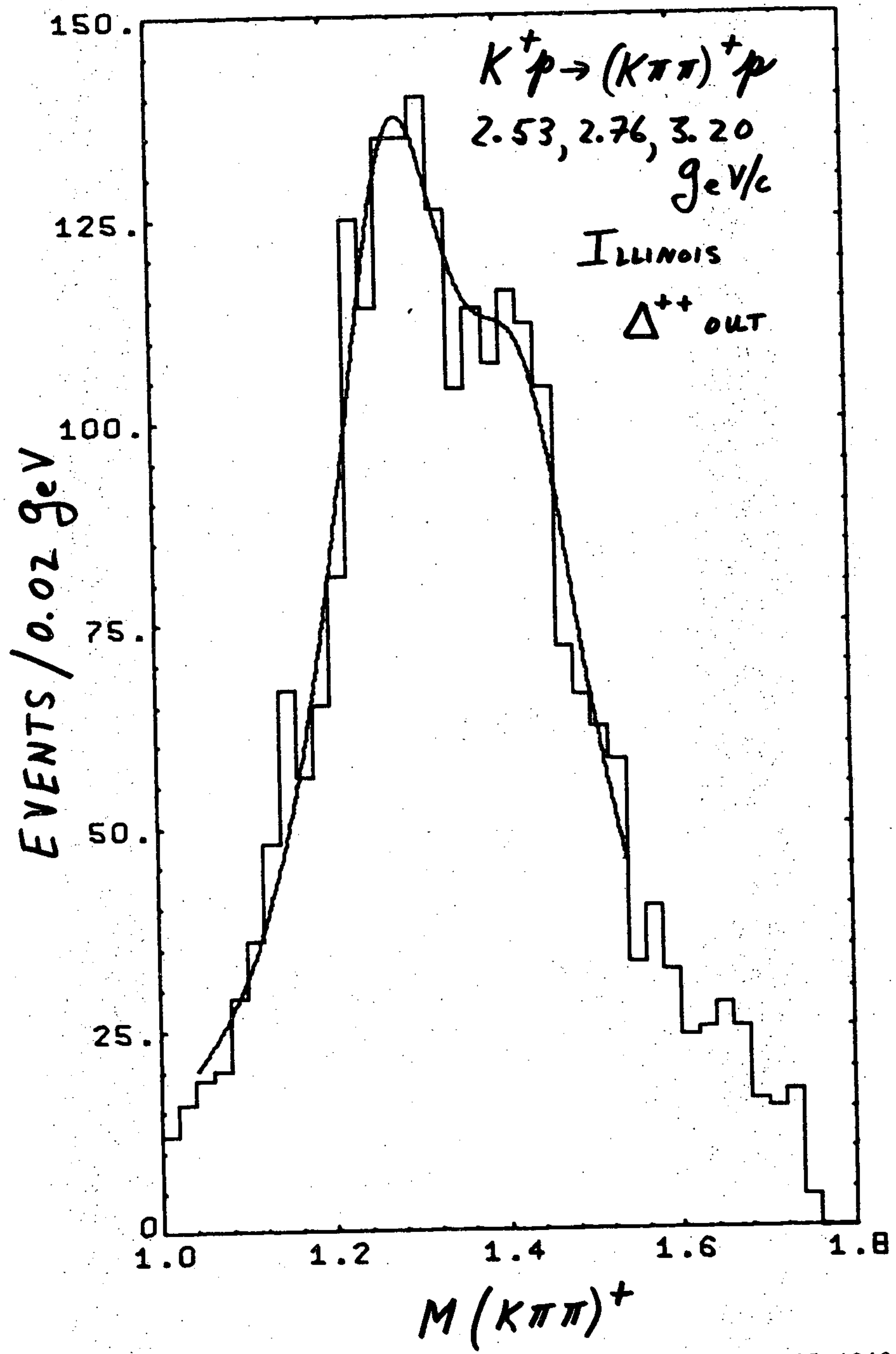

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Fig. 13

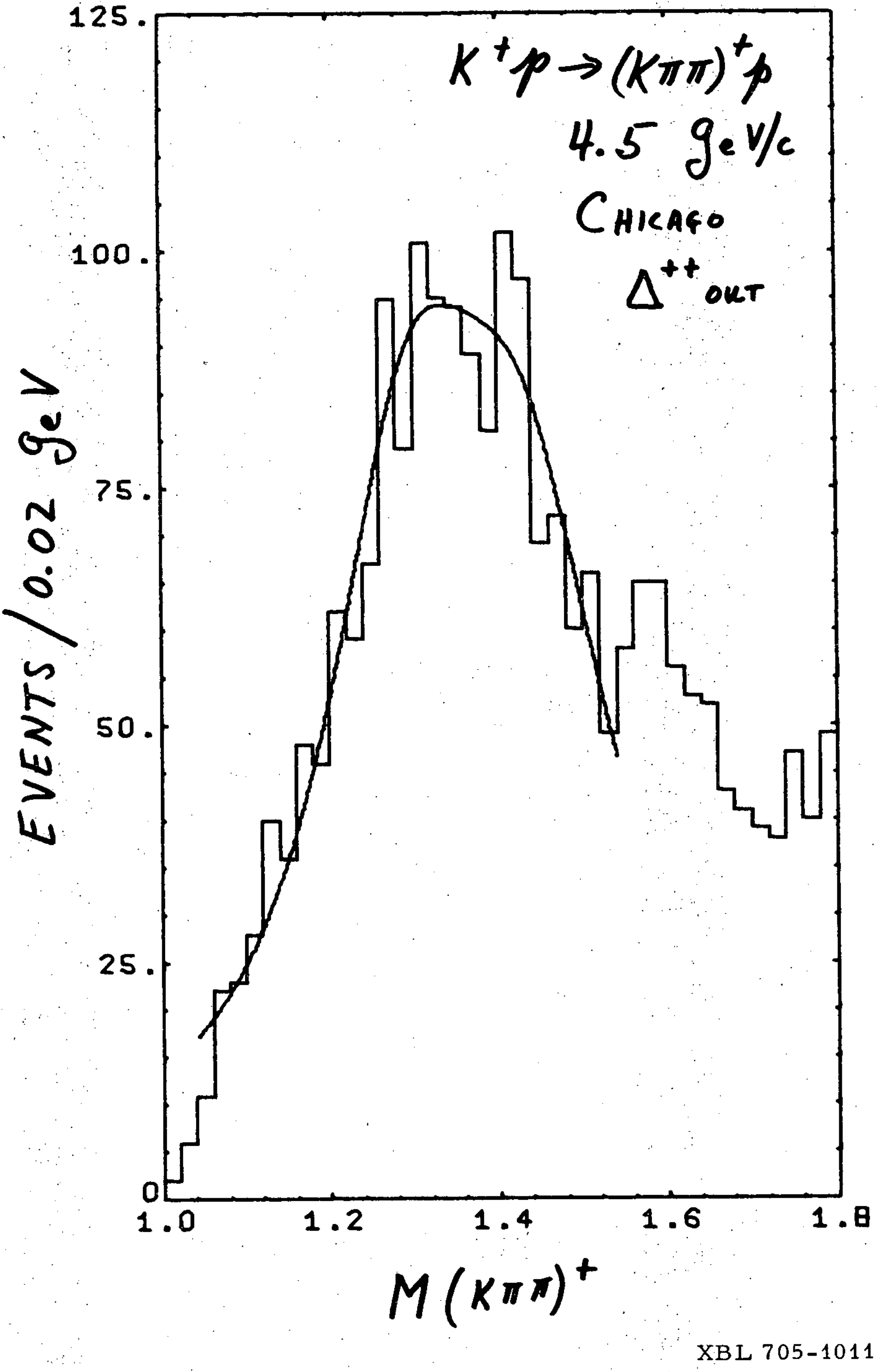

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Fig. 14

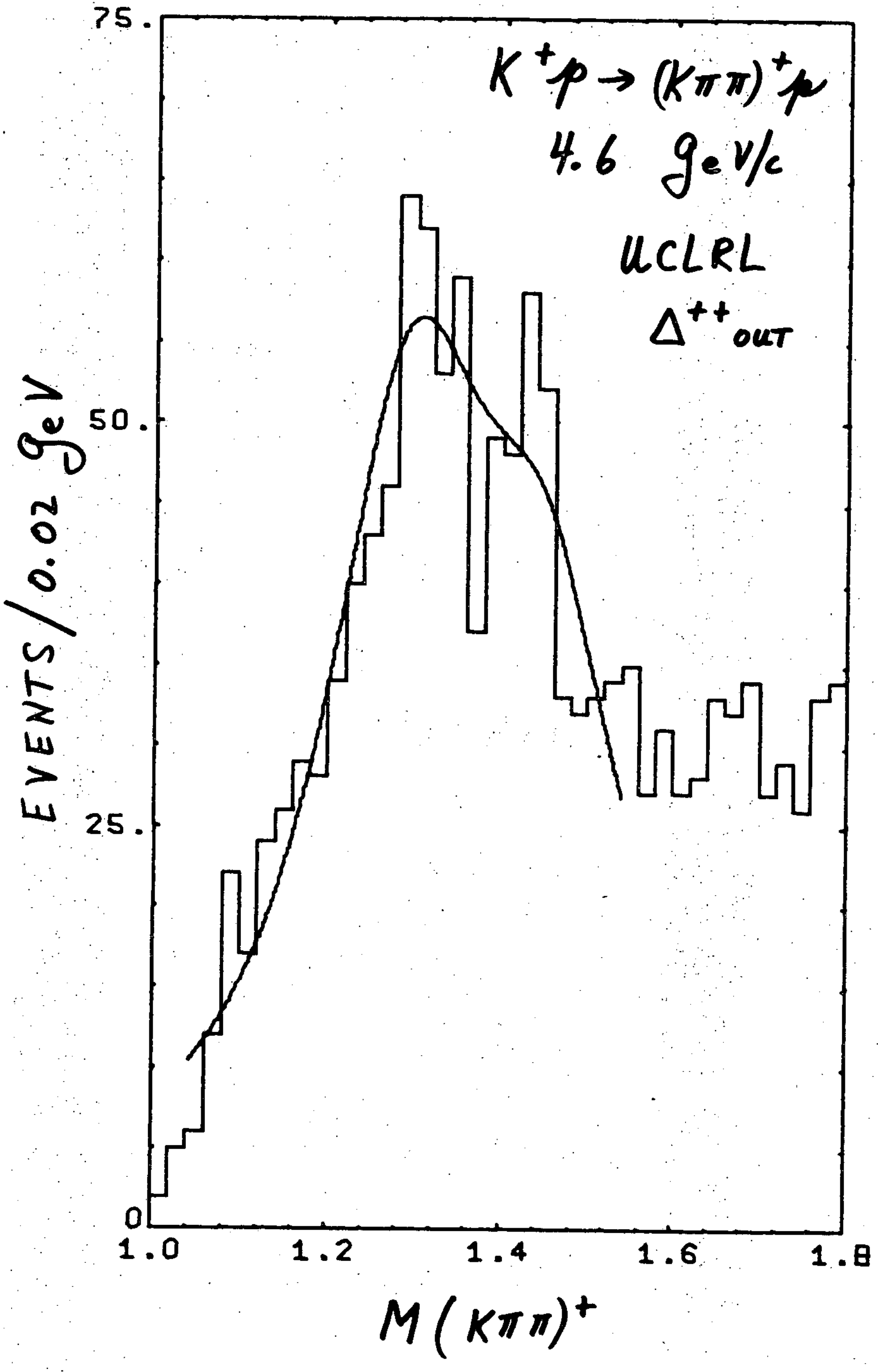

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Fig. 15

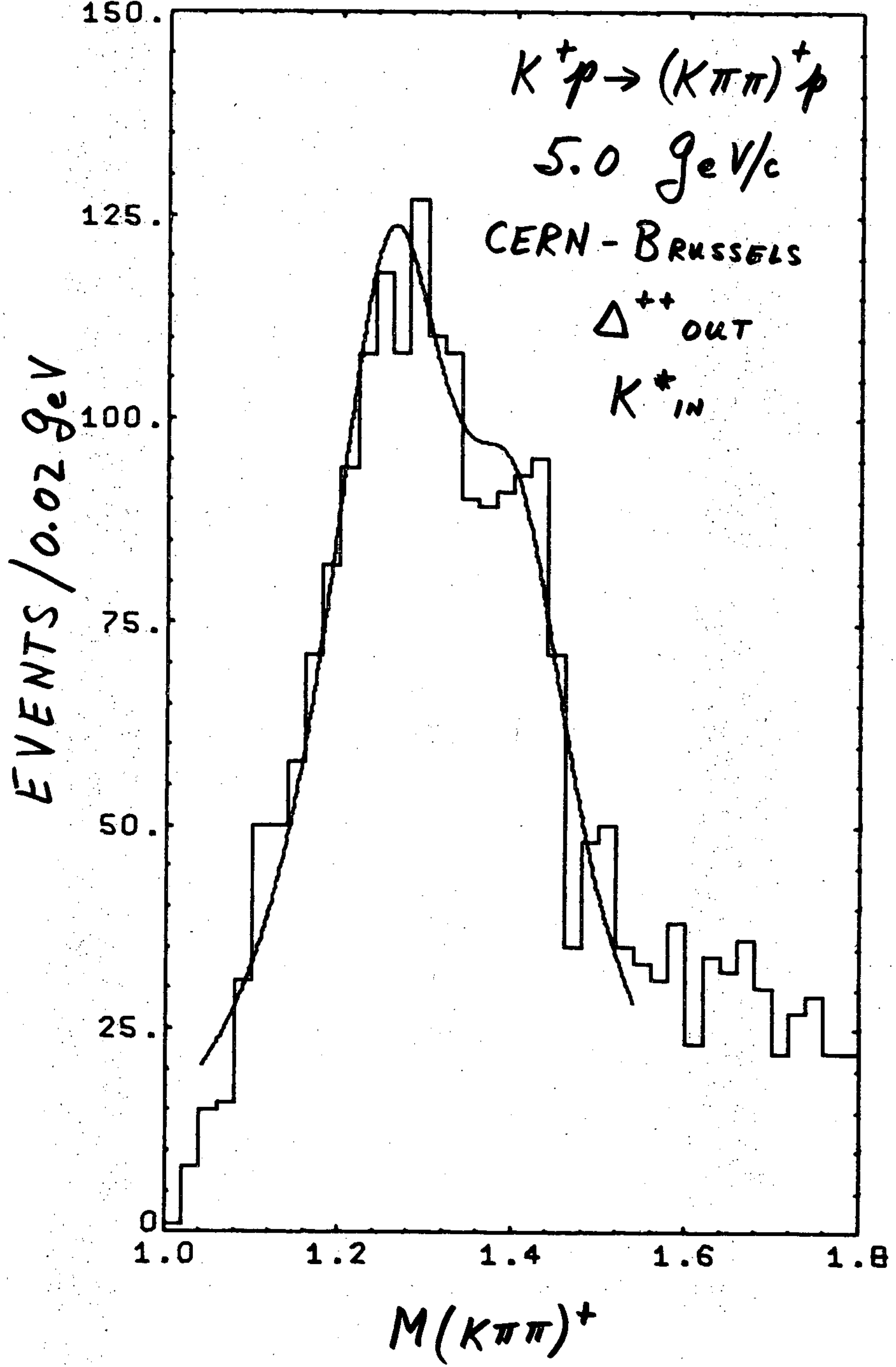

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Fig. 16

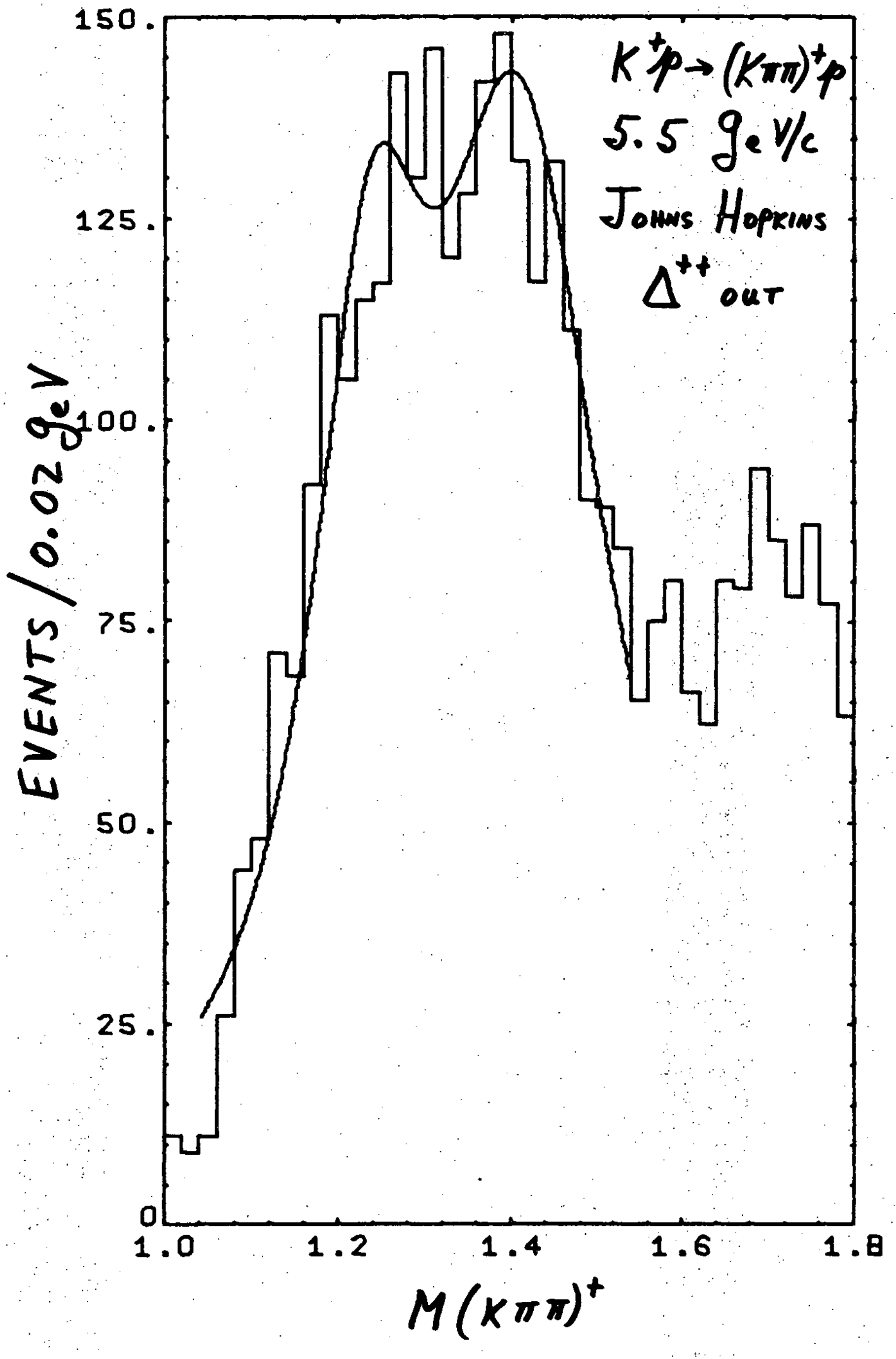

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Fig. 17

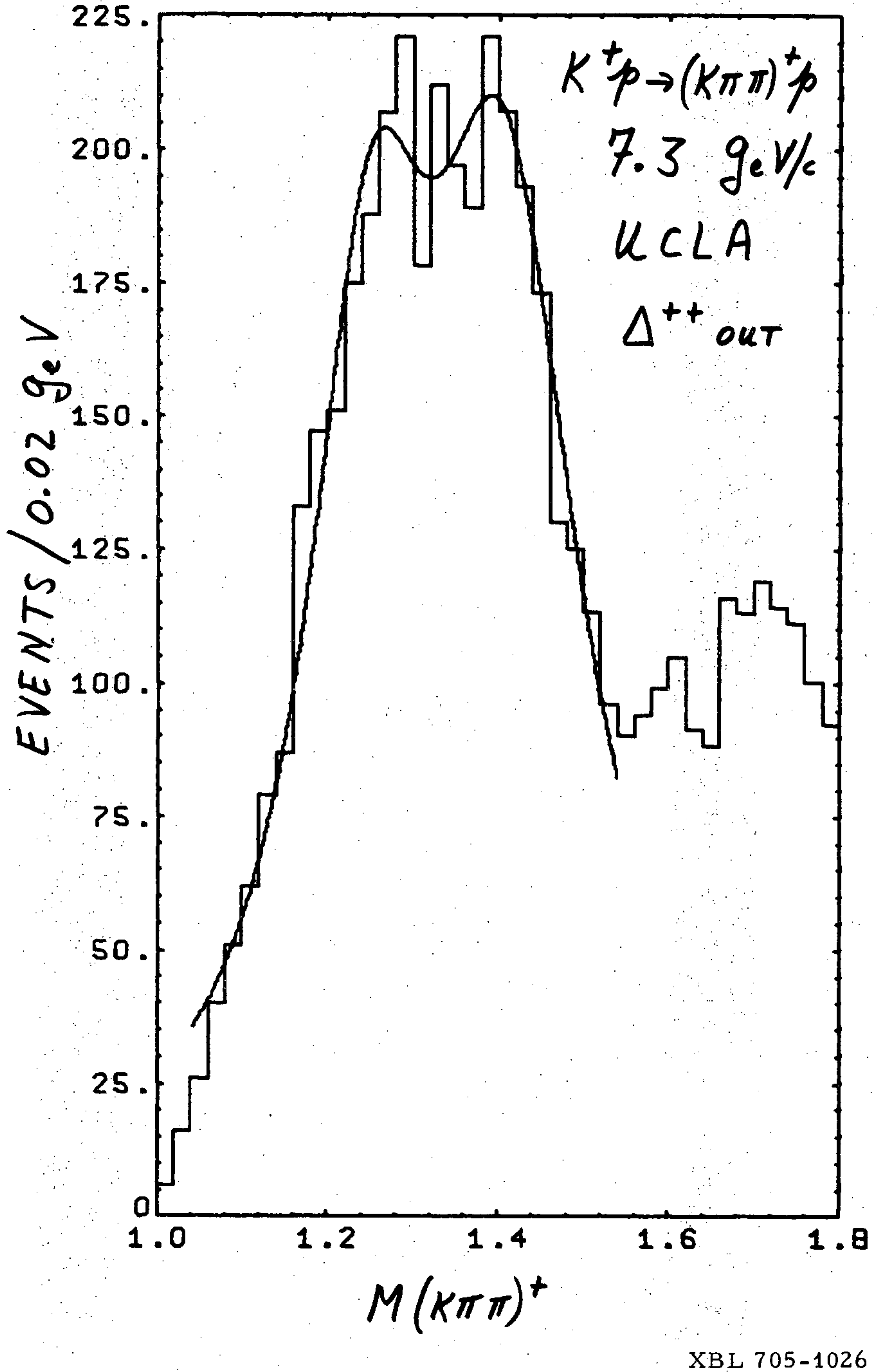

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Fig. 18

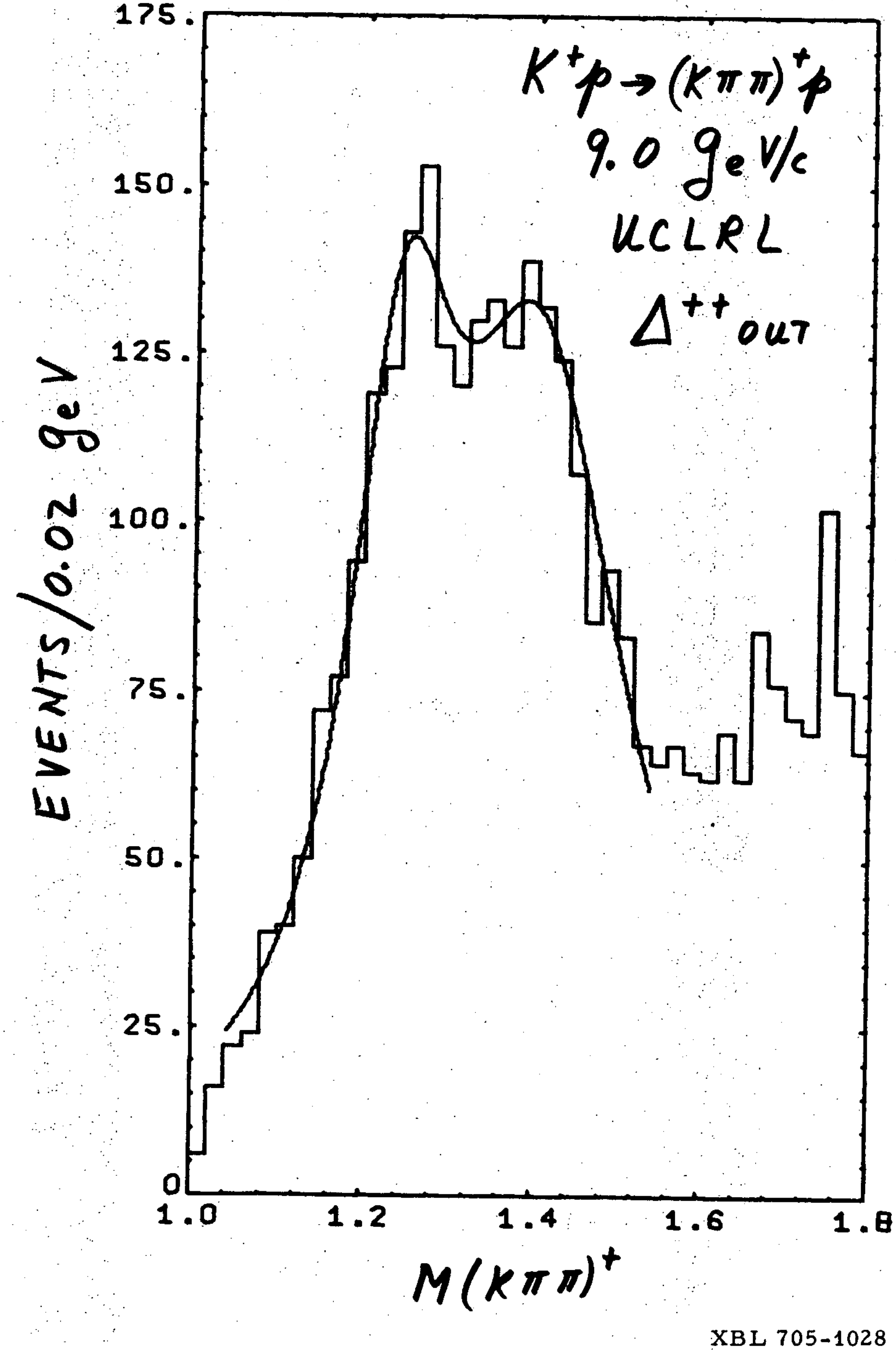

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Fig. 19

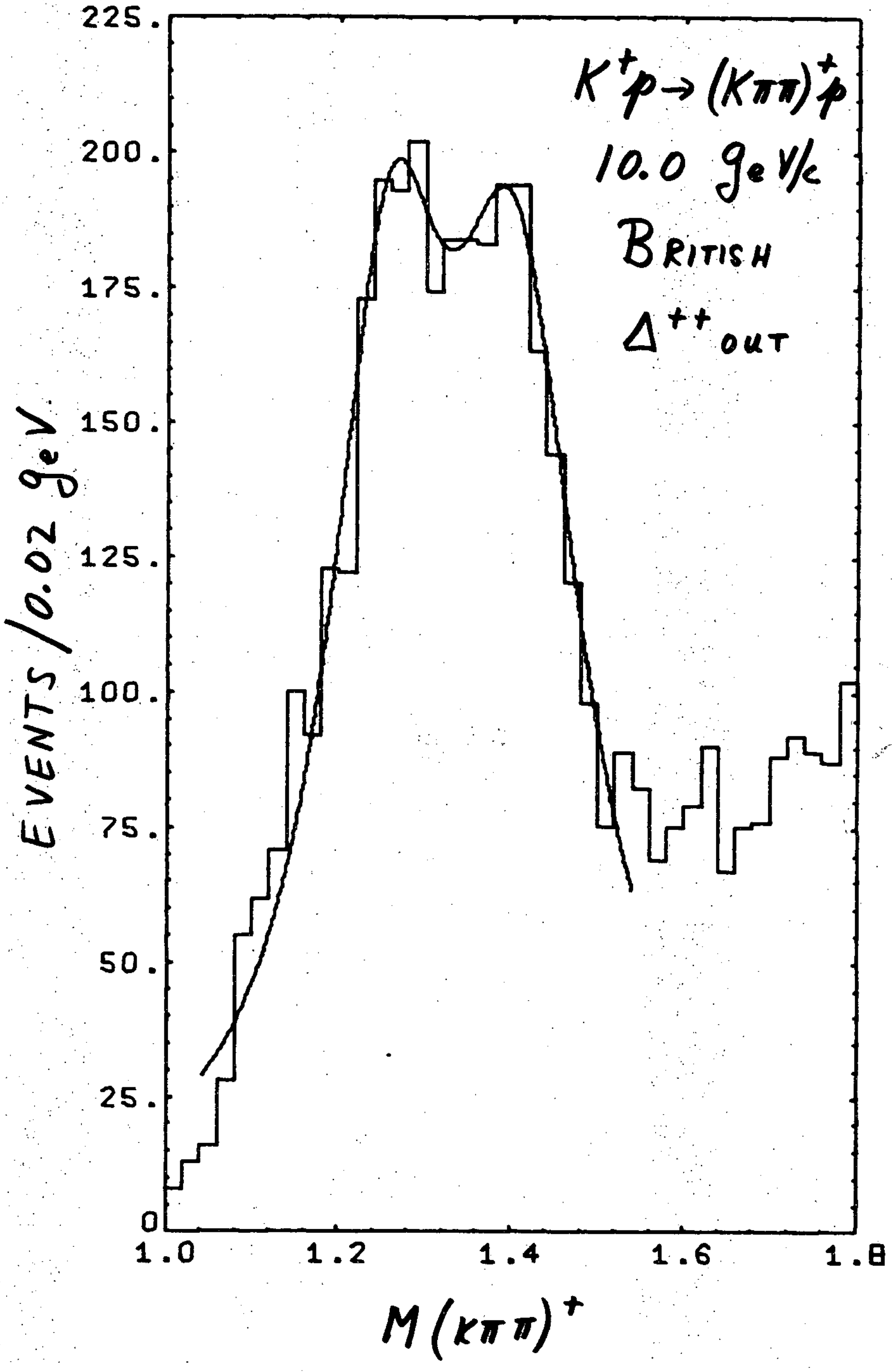

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Fig. 20

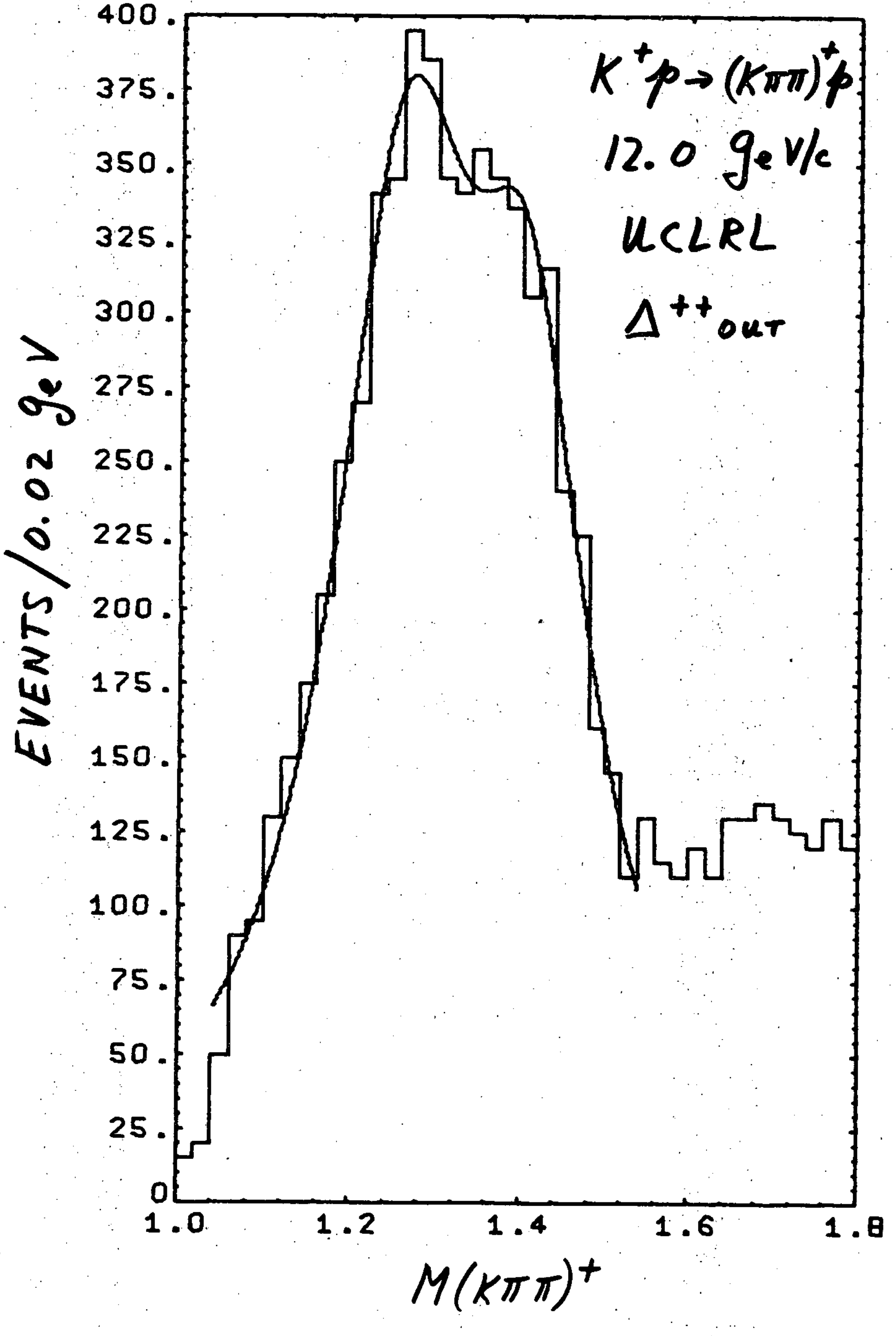

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Fig. 21

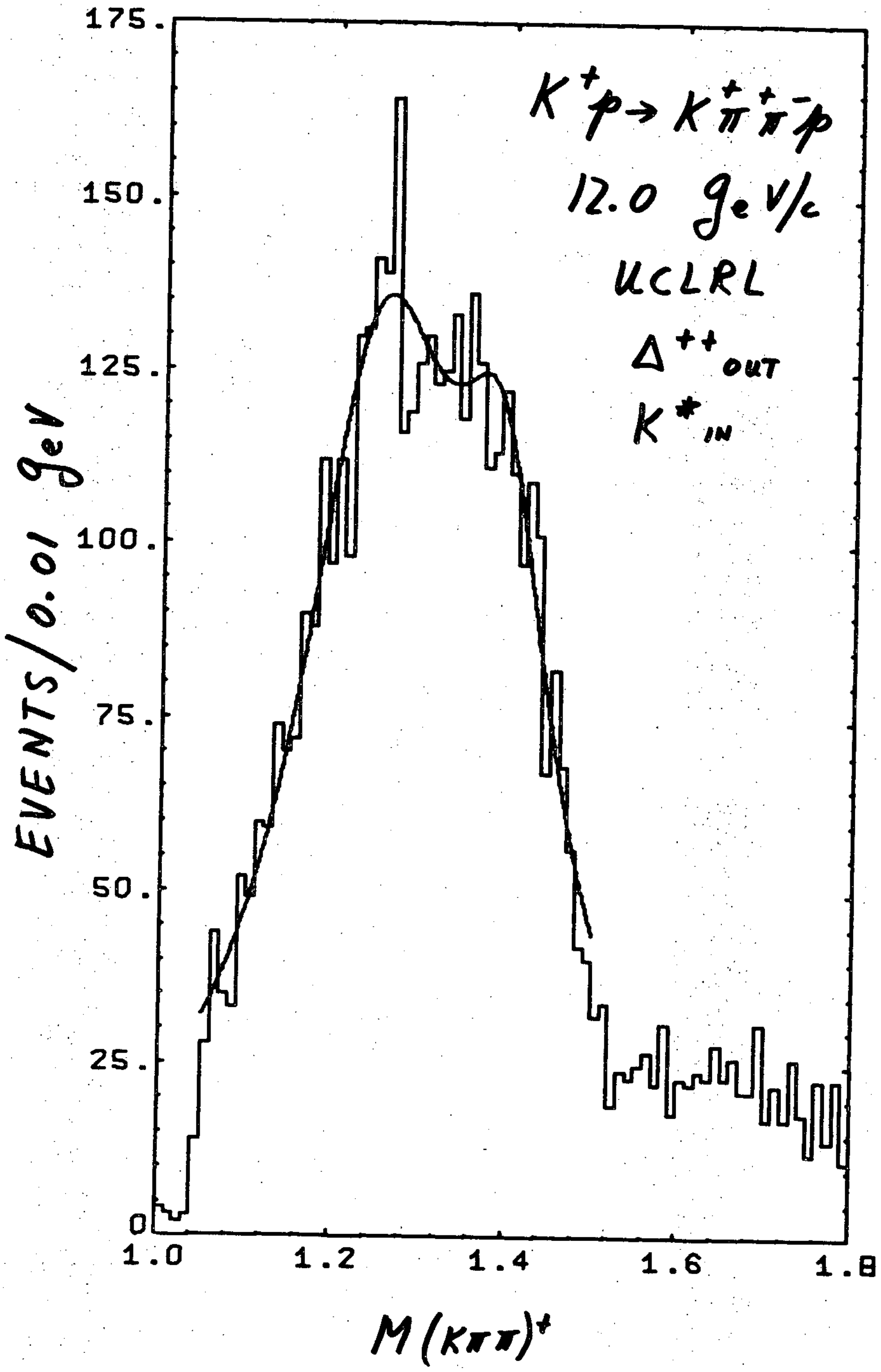

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Fig. 22

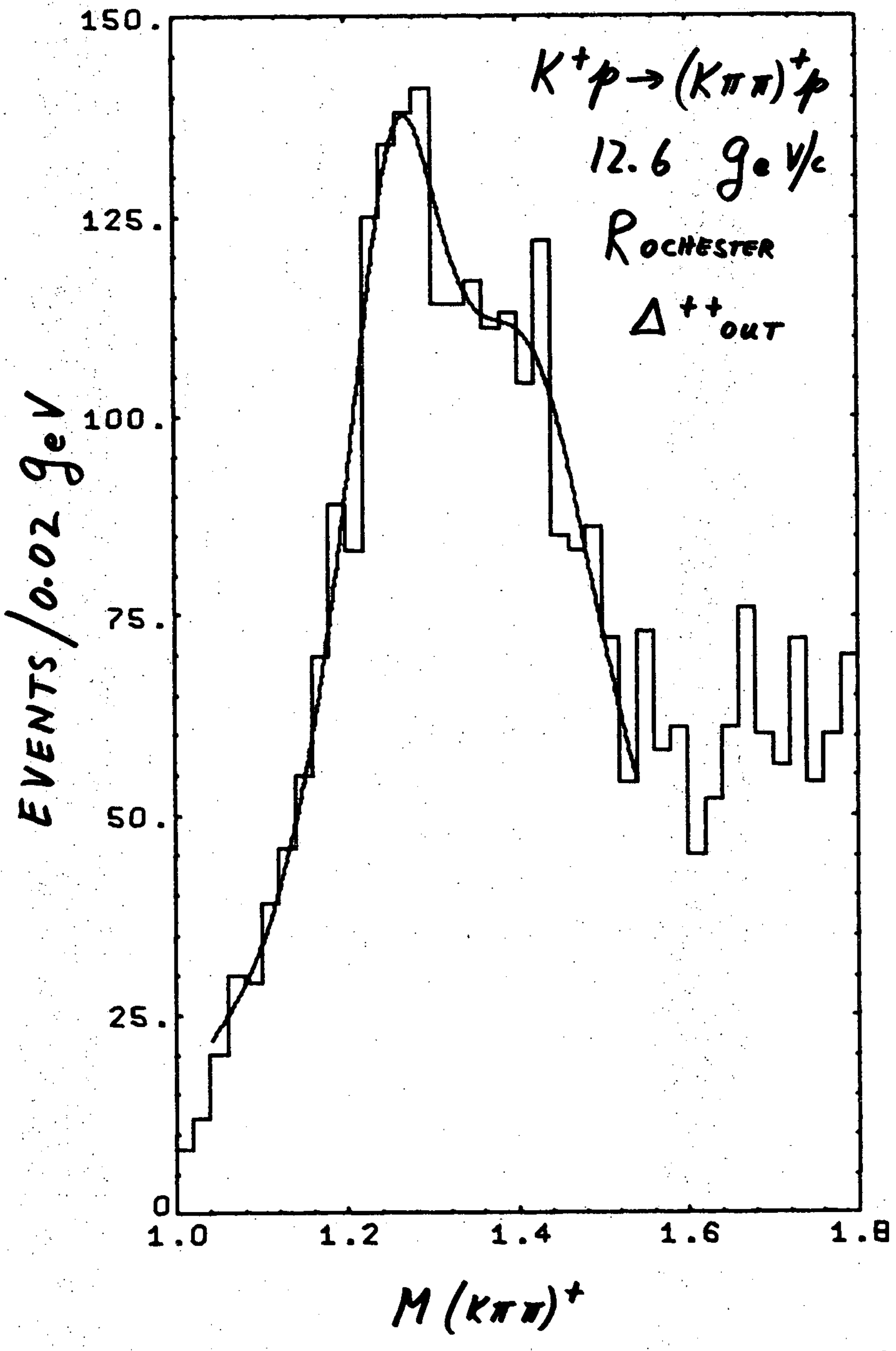

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Fig. 23

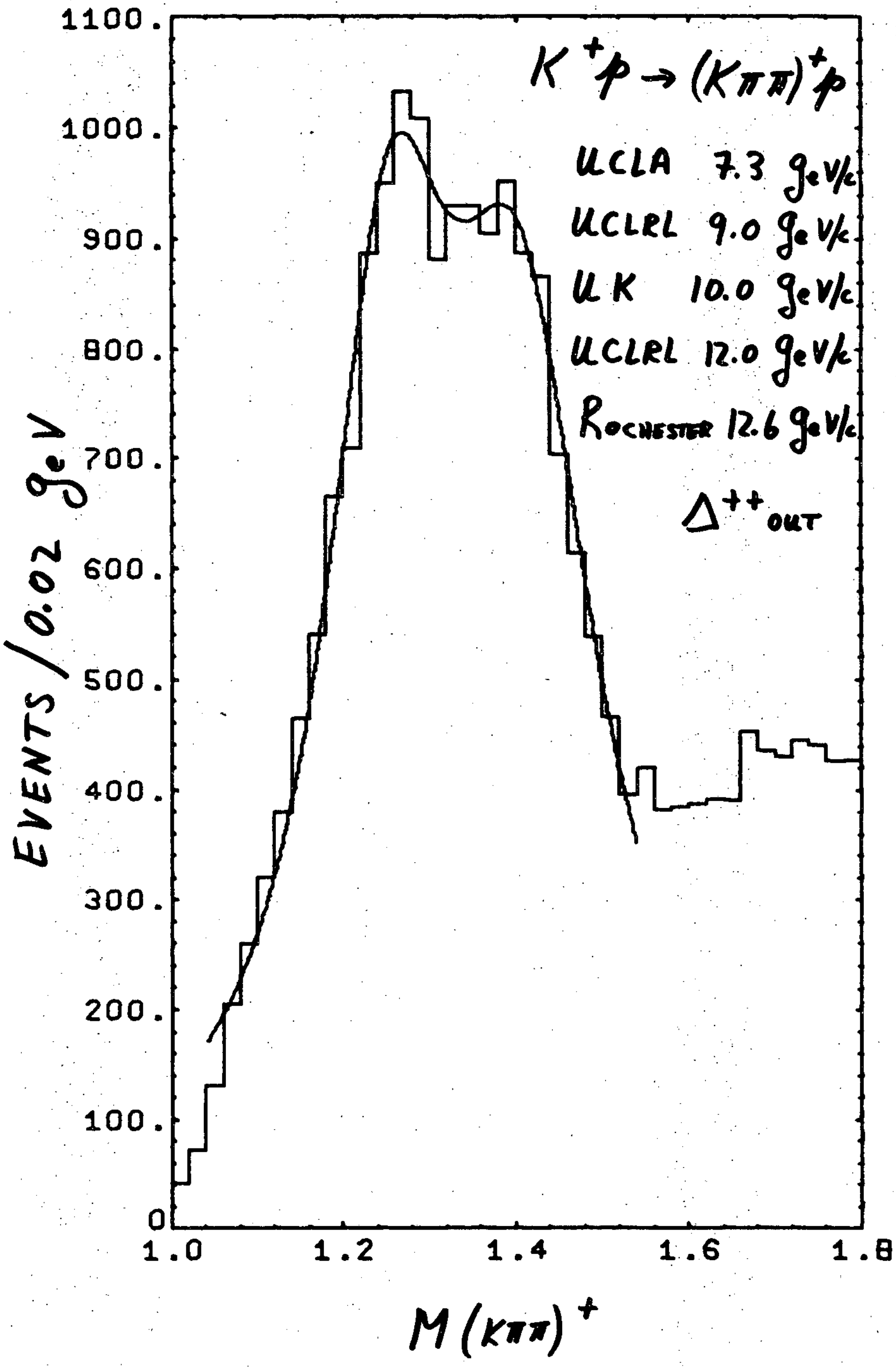

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Fig. 24

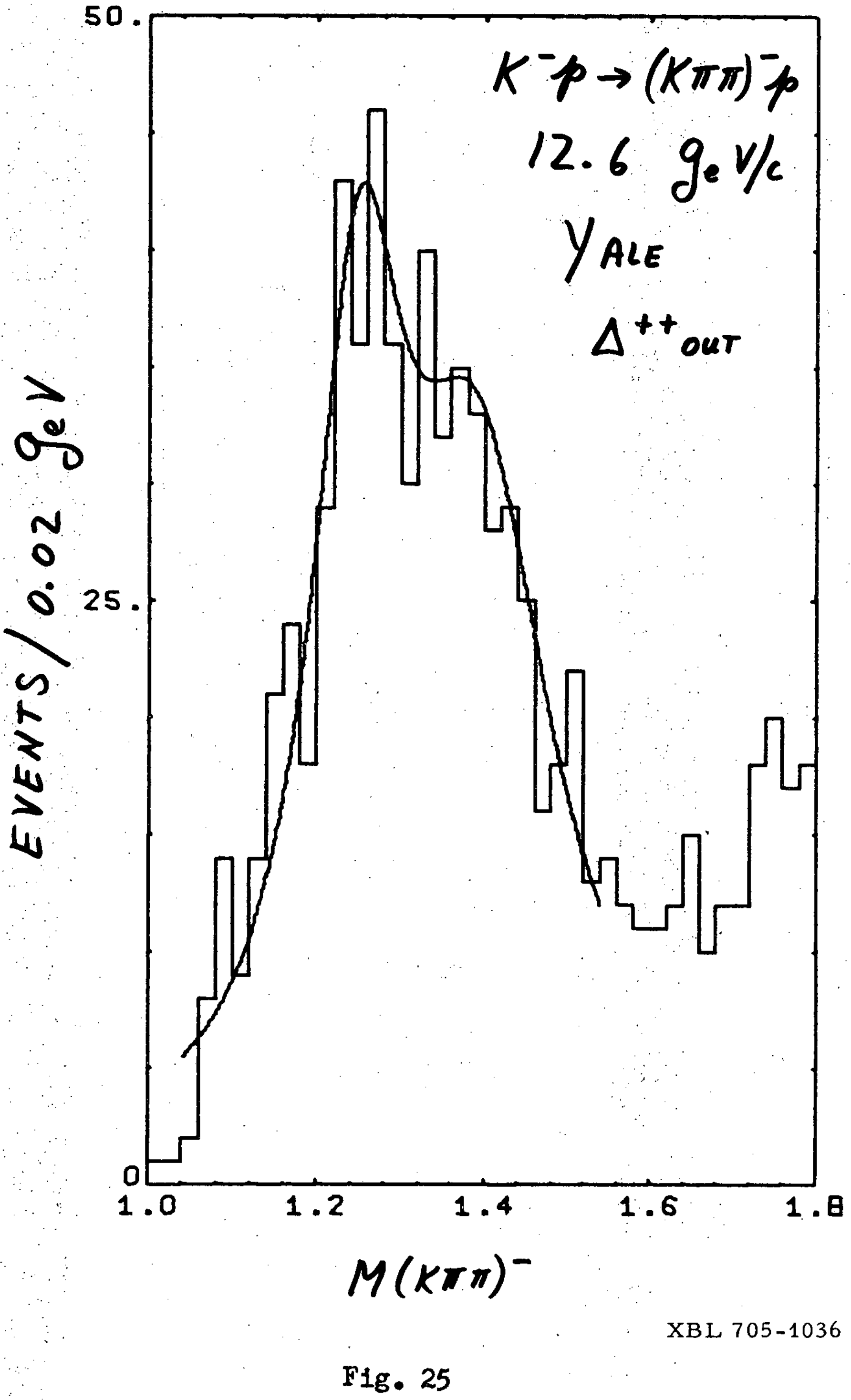
at around 1.40 GeV which is probably due to the K^*_{1420}. Figure 15 shows the LRL 4.6 GeV/c data.[2,29] Although statistics are poor, there is some evidence for a dip at 1.36 GeV. The upper part of the Q in this case has been interpreted as K^*_{1420}. The dip becomes much more significant if a K^* cut is also made on this data. Figure 16 shows the CERN-Brussels 5-GeV/c data.[30-32] There is a sharp drop in this distribution at about 1.34 GeV. Figure 17 shows the Johns Hopkins 5.5-GeV/c data.[6] Here there is some evidence for two separate peaks in the Q, rather than just one peak and a shoulder. Figure 18 shows the UCLA 7.3-GeV/c data.[3,17,33] There is no compelling evidence for a split Q, but the distribution resembles a flattop rather than a single kinematic peak. Two Breit-Wigners fit very well. Figure 19 shows the LRL 9-GeV/c data.[4,7] In this experiment the sharp drop is at 1.28 GeV. It is statistically significant, and in addition, there is some real evidence for a second peak rather than just a shoulder. Figure 20 shows the 10-GeV/c data of the Birmingham, Glasgow, Oxford collaboration.[34,35] This data strongly resemble the LRL 9-GeV/c data. There is a sharp drop at 1.28 GeV, and also some evidence for a second peak at the high end of the Q. Figure 21 shows the very high statistics LRL 12-GeV/c data.[18,36] Again the data are remarkably similar to the 9-GeV/c and 10-GeV/c data. There is the same sharp drop at 1.28 GeV and the same shoulder at higher Q mass. Figure 22 shows the same data as Fig. 21 only with an additional cut on the K^*_{890}, plotted in 10 MeV bins. As yet this is the only experiment in which there are really enough events to get an intelligent plot in 10 MeV bins. In this case the fit is in 45 bins, and the resulting parameters are consistent with those for the 25-bin fit; i.e., $M_1 = 1243 \pm 9$ MeV, $\Gamma_1 = 227 \pm 18$ MeV, $M_2 = 1389 \pm 10$ MeV and $\Gamma_2 = 149 \pm 26$ MeV. The χ^2 for this fit is 42 for 39 degrees of freedom. In this experiment the sharp drop at 1.27 GeV is very impressive. Figure 23 shows the Rochester 12.6-GeV/c data.[5,37] It is very much like all the other high-energy high-statistics K^+p data, but in this case the sharp drop is at 1.30 GeV. Figure 24 shows the combined data of all the high energy K^+p experiments.

This compilation shows a drop of 150 events at 1.28 GeV.

For the K^- data, most of the available experiments do not have sufficient statistics to make this five-parameter fit meaningful. However, for comparison with the K^+ data, Fig. 25 shows only the highest energy K^-p data available, the Yale 12.6-GeV/c experiment. These data look remarkably like the high energy K^+p data. In this case the drop is closer to 1.30 GeV than to 1.28 GeV. The parameters for this fit are $M_1 = 1246 \pm 10$ MeV, $\Gamma_1 = 130 \pm 32$ MeV, $M_2 = 1385 \pm 23$ MeV, and $\Gamma_2 = 231 \pm 48$ MeV, with a $\chi^2 = 24.8$ for 19 degrees of freedom. These parameters are consistent with the K^+ results. Figure 26 shows the data of the A.B.C.L.V. collaboration's 10-GeV/c K^-p experiment.[38,39] These data strongly resemble the Yale results.

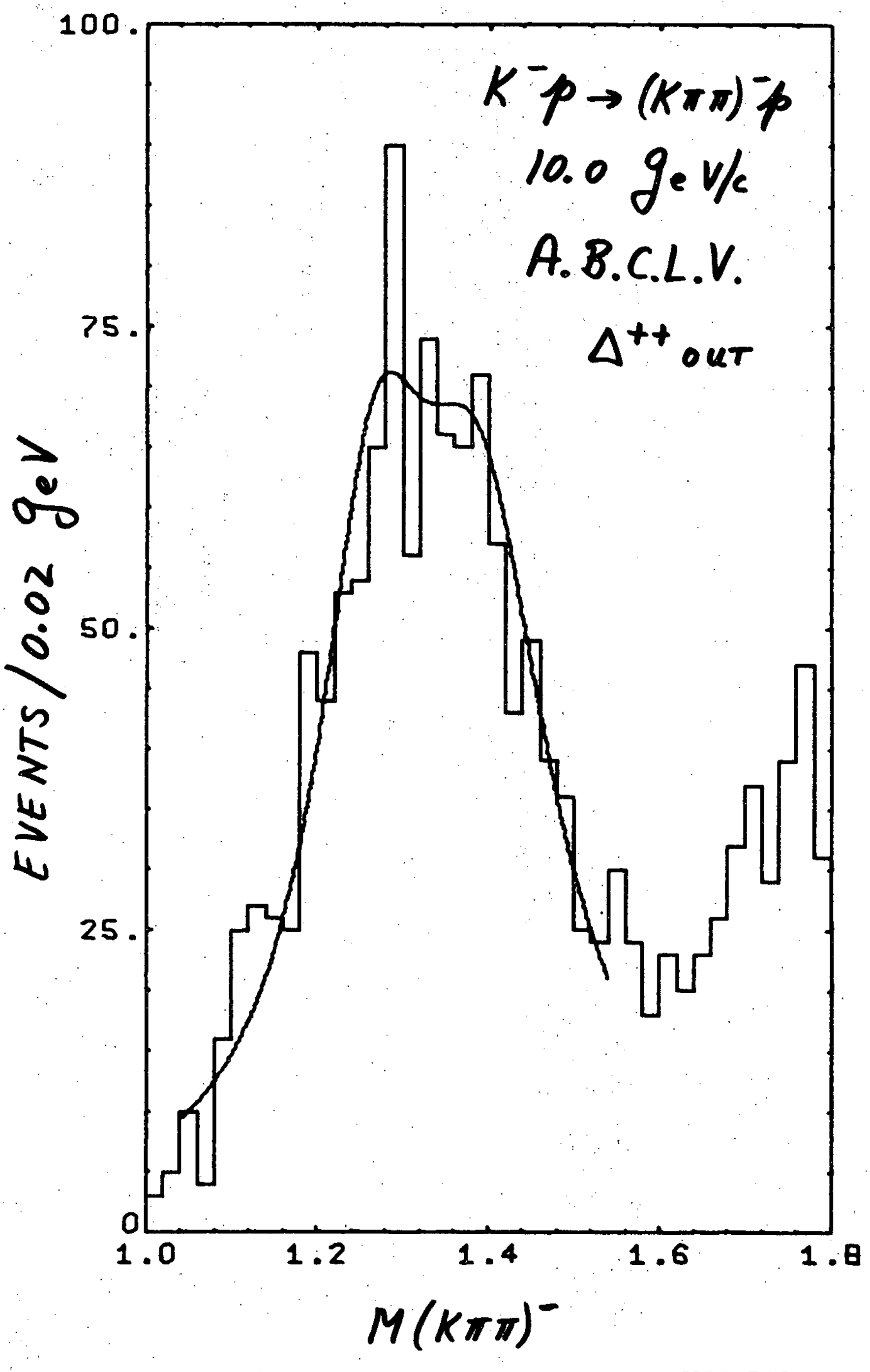
The results of all the K^+ fits are listed in Table I. In Figs. 27, 28 and 29 the parameters for the two Breit-Wigner forms are plotted as functions of incident momentum. First of all, it seems to be much easier to determine the central value of a peak rather than to determine its width. Although the parameters fluctuate somewhat at low energy, the high energy data are all perfectly consistent. Therefore the best values for the Q parameters may be taken from the fit to the combined high energy K^+p data, $M_1 = 1250 \pm 4$ MeV, $\Gamma_1 = 182 \pm 9$ MeV, $M_2 = 1400 \pm 6$ MeV and $\Gamma_2 = 220 \pm 14$ MeV. The lines on the extreme right in Figs. 27, 28, and 29 indicate these values.

The table also lists the χ^2 values for a separate two-parameter fit to the data of each experiment. This fit includes only one Breit-Wigner form, and the two parameters used are the mass and width of the Breit-Wigner. In all cases the χ^2 probability for the one Breit-Wigner fit is much lower than that for the two Breit-Wigner fit. In the highest statistics experiments the one Breit-Wigner fit is excluded by many standard deviations. As an illustration of these fits, the single Breit-Wigner fit to the combined high energy K^+p data is shown in Fig. 30. The χ^2 for this fit is 296.2 for 19 degrees of freedom, and the parameters are $M = 1324 \pm 2$ MeV and $\Gamma = 311 \pm 5$ MeV. Figure 31 shows some very preliminary results from the CERN 8.25-GeV/c K^+p experiment.[40] The data



XBL 705-1036

Fig. 25



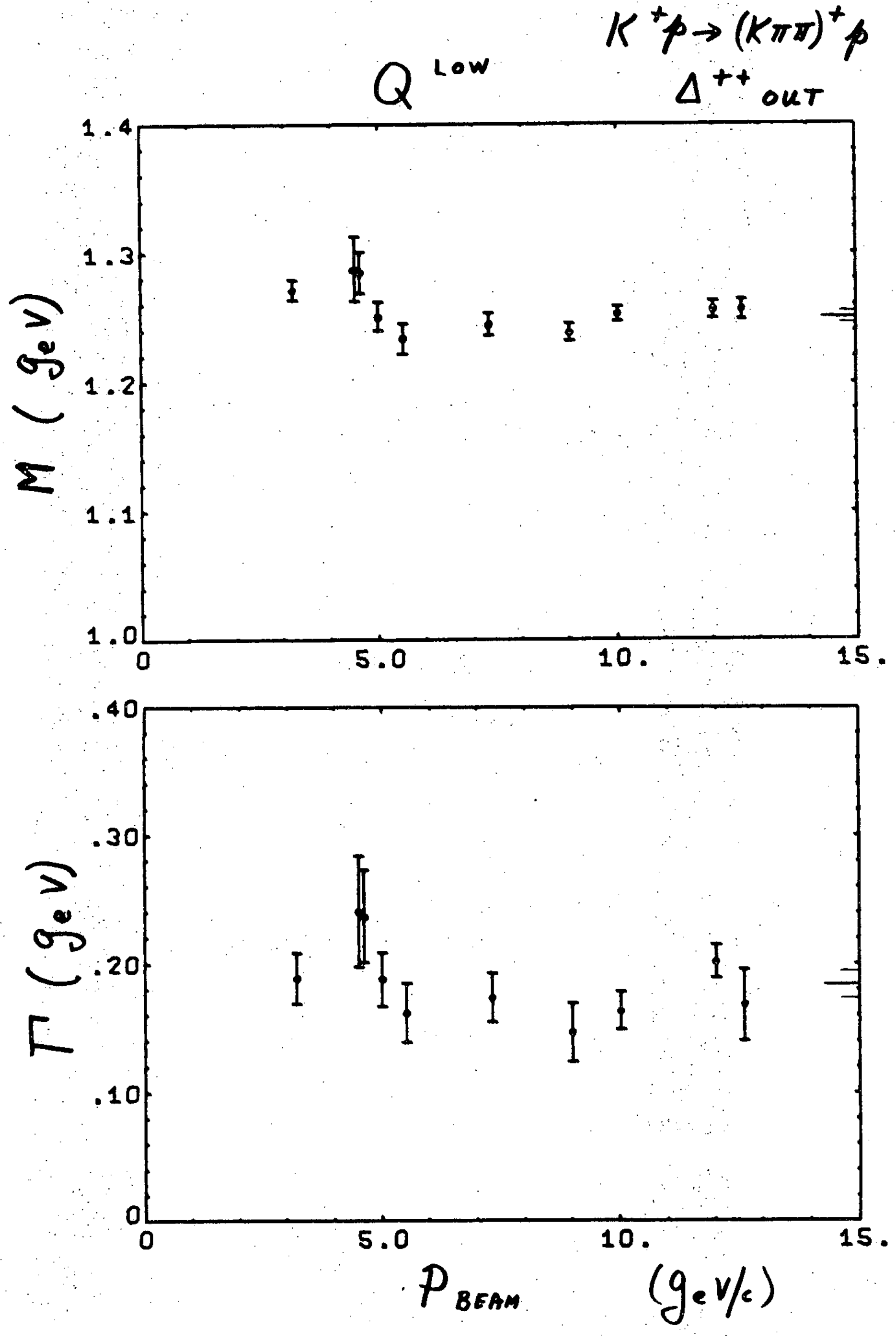
XBL 705-1035

Fig. 26

$K^+p \rightarrow (K\pi\pi)^+p$

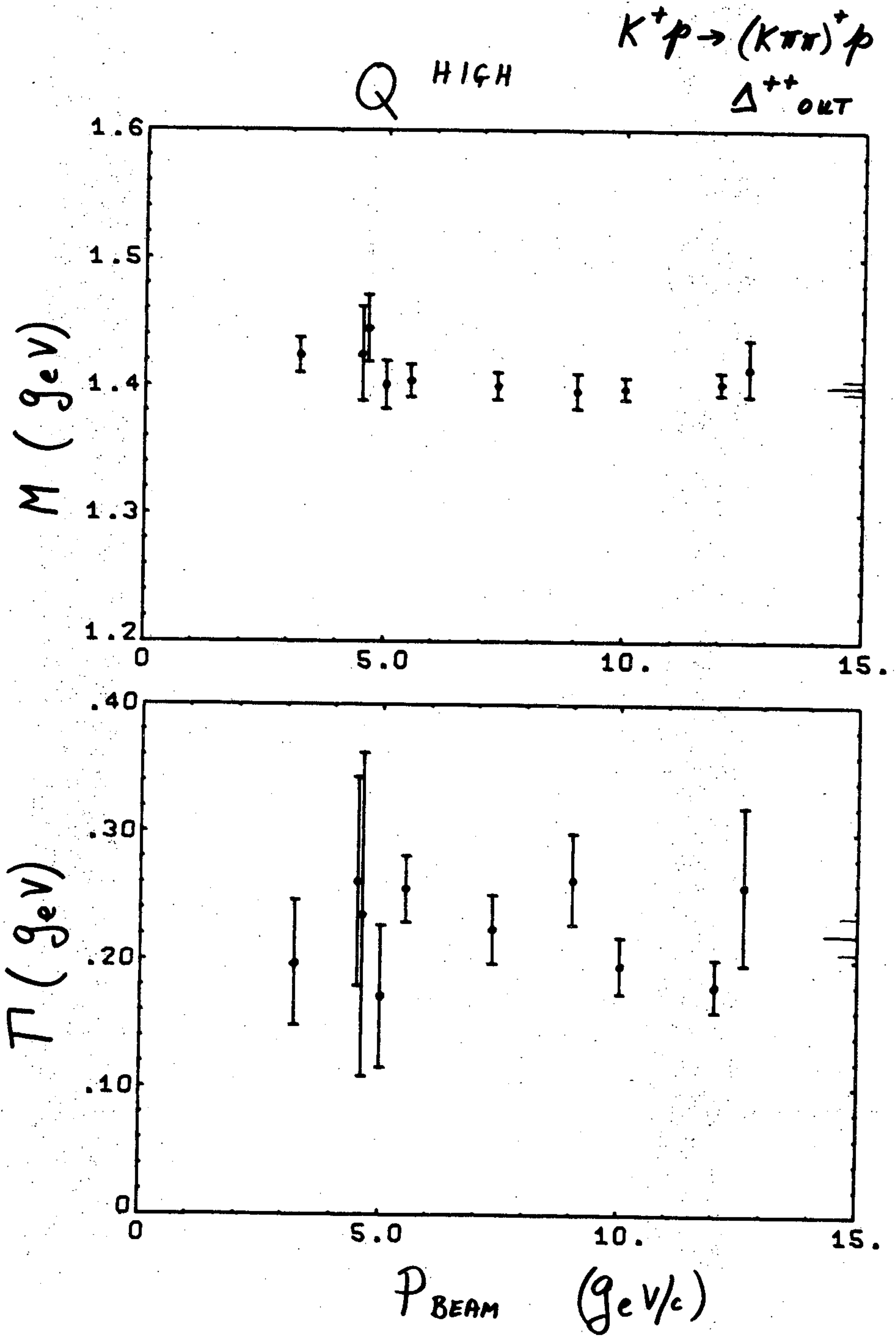
Δ^{++} out

Group	P_{BEAM} (GeV/c)	5 parameters, 19 d.o.f.						2 parameters 22 d.o.f.
			Q_{LOW}		Q_{HIGH}			
		χ^2	M (MeV)	Γ (MeV)	M (MeV)	Γ (MeV)	A	χ^2
Illinois	3.2	20.6	1272±8	189±20	1424±14	197±49	0.70±0.35	56.0
Chicago	4.5	21.5	1288±25	241±43	1425±37	261±82	1.02±1.02	29.3
LRL	4.6	25.8	1285±16	237±36	1445±26	235±127	0.63±0.61	35.3
CERN	5.0	33.2	1251±11	188±21	1401±19	171±56	0.53±0.33	68.6
Hopkins	5.5	47.6	1234±12	162±23	1404±13	255±26	2.26±0.91	112.2
UCLA	7.3	24.7	1245±9	174±19	1400±11	224±27	1.58±0.59	85.0
LRL	9.0	12.1	1239±7	147±23	1396±14	263±36	2.16±0.94	65.1
UK	10.0	36.1	1253±6	164±15	1398±9	195±22	1.26±0.39	109.8
LRL	12.0	23.8	1256±7	202±13	1402±9	180±21	0.65±0.20	97.0
Rochester	12.6	13.8	1256±8	168±28	1414±22	258±62	1.28±0.81	59.2
H.E. K^+p	> 7.0	42.1	1250±4	182±9	1400±6	220±14	1.18±0.21	296.2



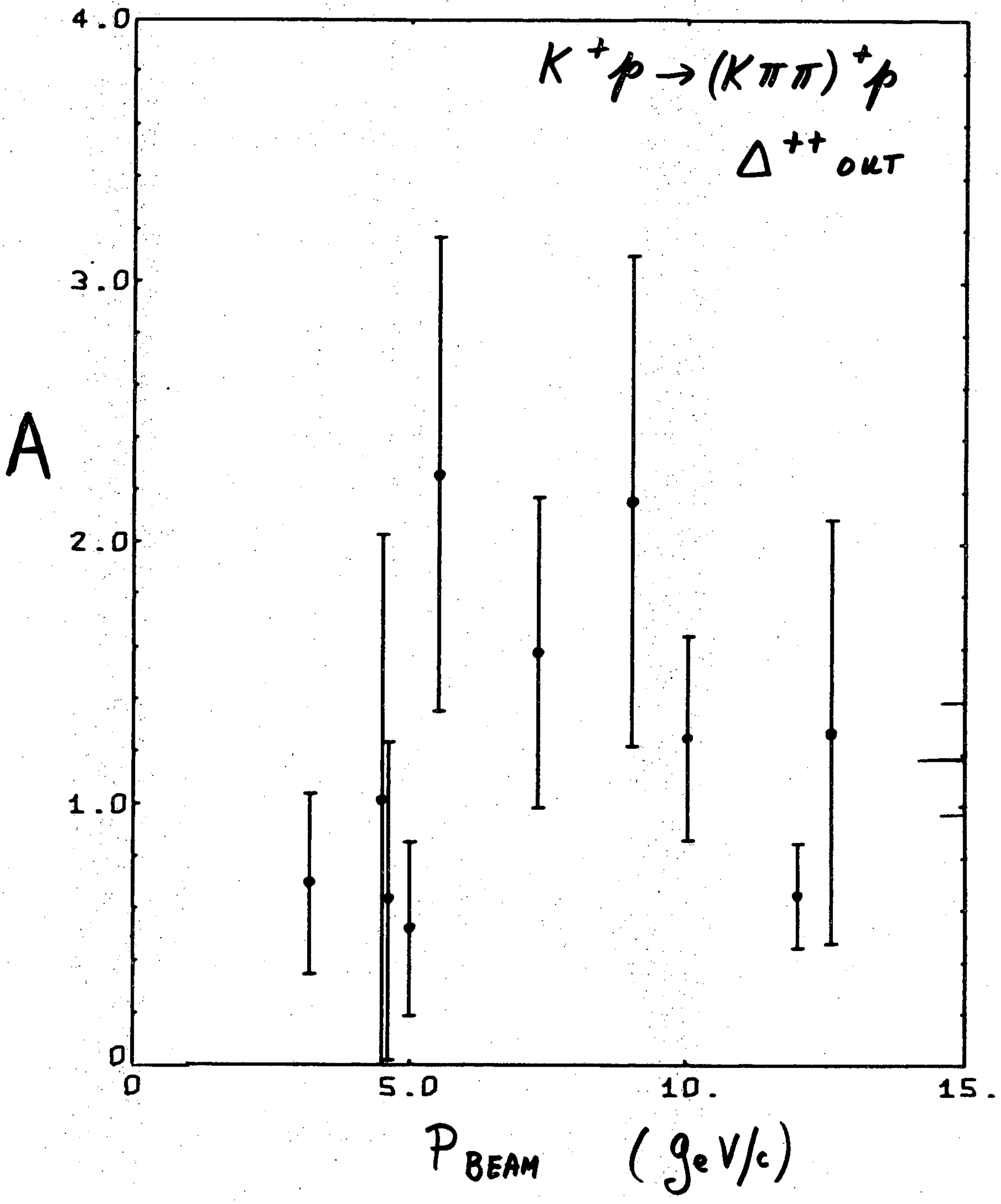
XBL 705-1013

Fig. 27



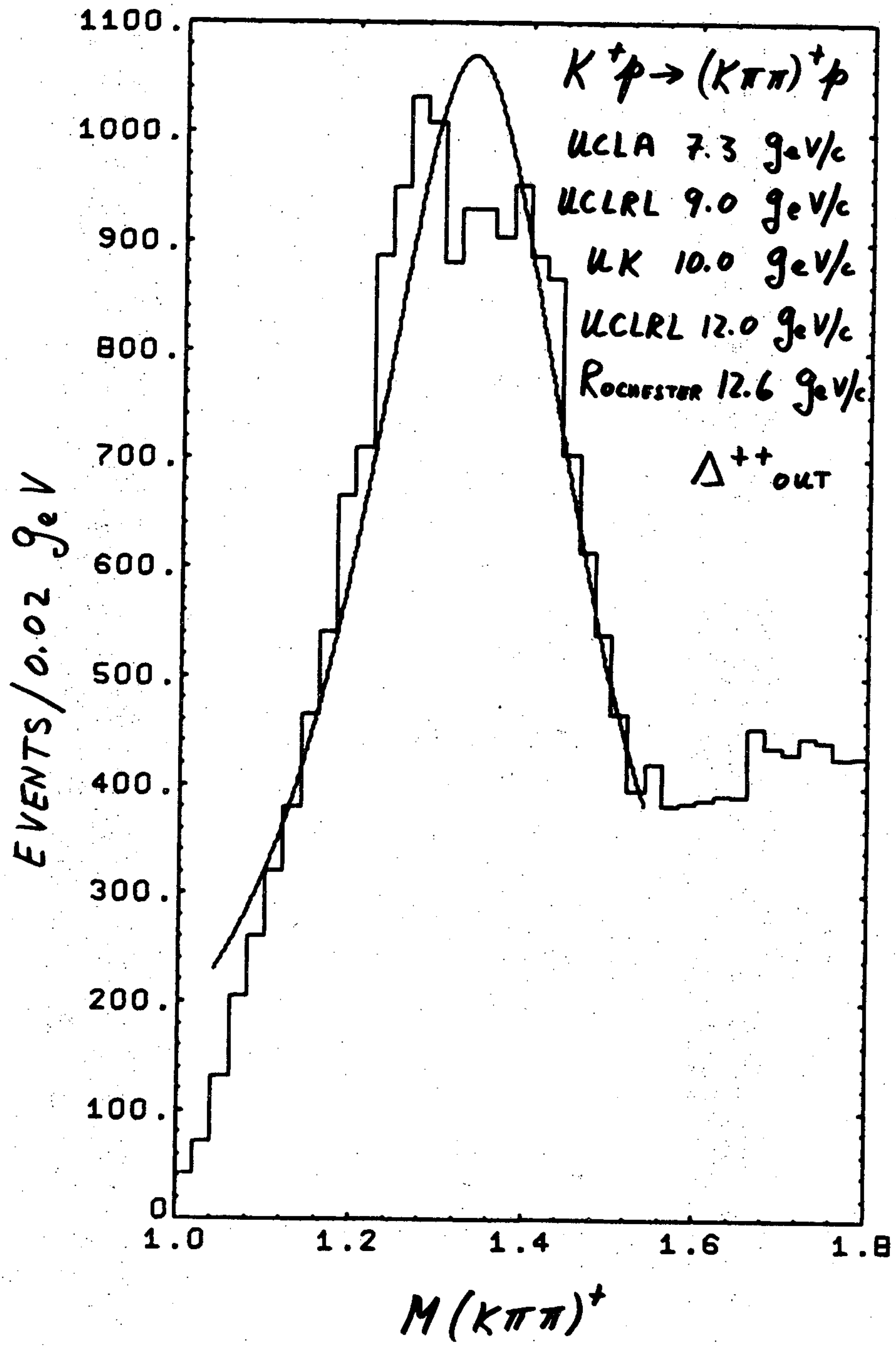
XBL 705-1015

Fig. 28



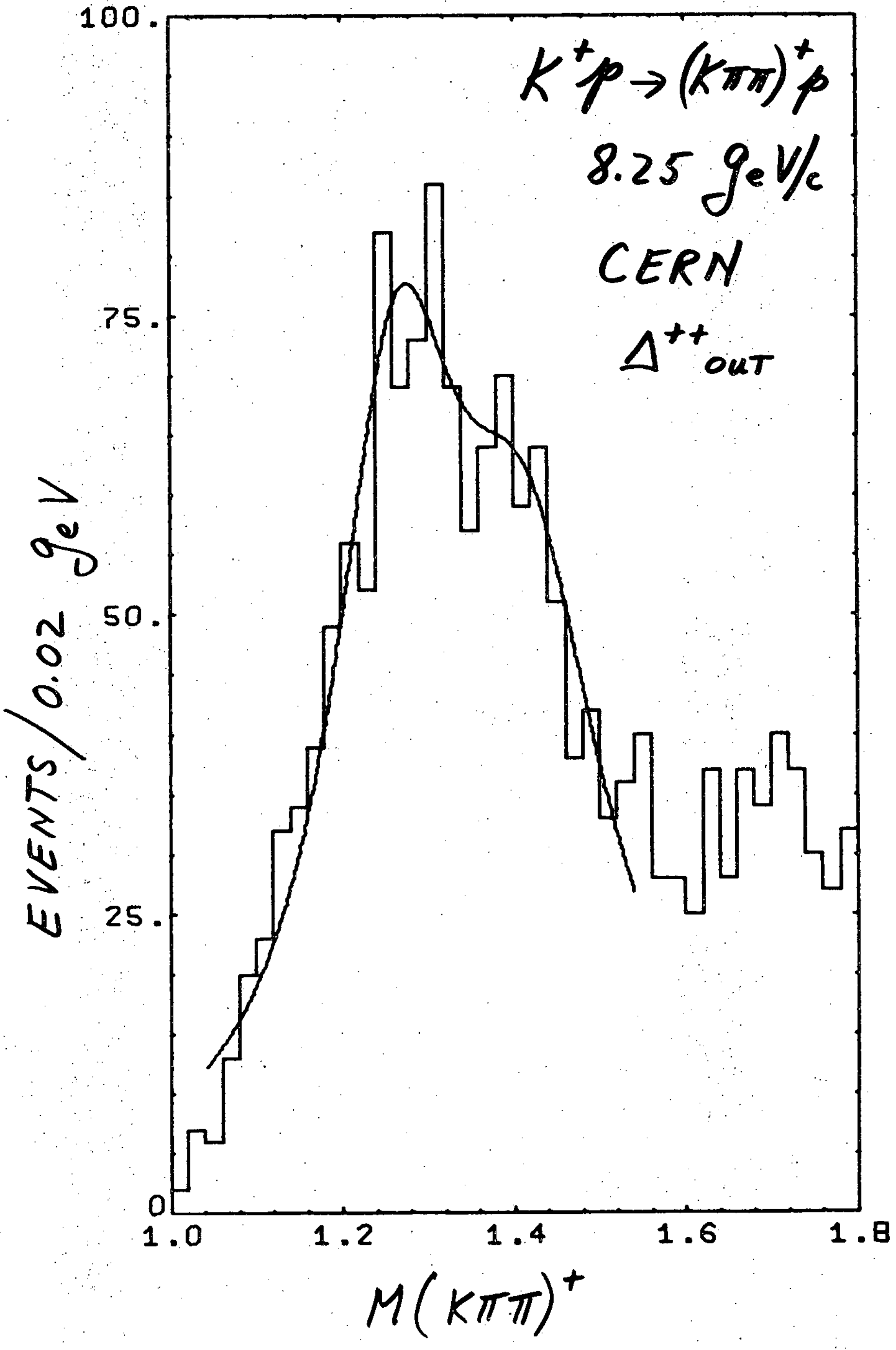
XBL 705-1009

Fig. 29



XBL 705-1037

Fig. 30



XBL 706-1083

Fig. 31

strongly resemble all the other high energy K^+p data and the parameters for the fit are: $M_1 = 1261\pm12$ MeV, $\Gamma_1 = 182\pm25$ MeV, $M_2 = 1410\pm22$ MeV and $\Gamma_2 = 229\pm53$ MeV, with a $\chi^2 = 25.3$ for 19 degrees of freedom.

If the analysis is accepted that the Q consists of two peaks, then the Q might be interpreted as a $J^P = 1^+$ K^* resonance at 1250 MeV with a shoulder or second peak due to the $K\pi\pi$ decays of the K^*_{1420}. Although a $J^P = 1^+$ K^* resonance at 1250 MeV is certainly acceptable, the interpretation is incorrect that the upper part of the Q is due entirely to the $K\pi\pi$ decays of the K^*_{1420}. There are three reasons for this: (1) The width is much too broad. The best fit for the upper Q has $\Gamma = 220\pm14$ MeV, but the Particle Data Tables list $\Gamma = 96\pm7$ MeV for the K^*_{1420}. (2) The spin-parity of the K^*_{1420} is $J^P = 2^+$. All spin-parity analyses have demonstrated that the upper portion of the Q has spin-parity $J^P = 1^+$ and have excluded $J^P = 2^+$ by many standard deviations. (3) The K^*_{1420} decay branching ratios reported in the Particle Data Tables[41] predict only a small K^*_{1420} contribution to the Q at high energy.

In the LRL 9-GeV/c K^+p experiment, for example, we calculate from the reaction $K^+p \to K^*_{1420}p \to K^o\pi^+p$ that, for the upper Q to be due entirely to the $K\pi\pi$ decay of the K^*_{1420}, the ratio $K^*_{1420} \to [(K^*\pi + K\rho)/K\pi] \to (K\pi\pi/K\pi)$ would have to be 12±1,[7] whereas the Particle Data Tables report that ratio to be 0.9±0.1.[41] Furthermore, two new experiments also report K^*_{1420} branching ratios in substantial agreement with those in the Particle Data Tables.[42,43]

At high energy there seems to be no way to account for more than a small part of the upper Q as the $K\pi\pi$ decay of the K^*_{1420}. It should be noted that the K^*_{1420} is much more important in experiments at lower beam momenta, because of the energy dependence of the cross section for the reaction $K^+p \to K^*_{1420}p$, which is given by $\sigma(p) \propto p^{-2}$, where p is the incident beam momentum (see Fig. 7d of Ref. 44). At lower beam momenta the fluctuations in the parameters of the fits may be due to the K^*_{1420} as well as to the lesser statistics.

IV ADDITIONAL COMMENTS

Nearly every $Kp \rightarrow K\pi\pi p$ experiment shows a sharp drop in the $K\pi\pi$ mass distribution in the 1.28 GeV region. The probability that all these experiments have this same statistical fluctuation is extremely small; but the fact remains that the position of this drop appears to move from as low as 1.27 GeV to as high as 1.34 GeV (see Figs. 16 and 22). In addition to this variation, the drop seems to be too sharp for that particular Breit-Wigner which could fit much of the distribution below 1.28 GeV (see Figs. 19 and 24). Both the variation and the sharpness suggest an interference effect; but even the combined high energy K^+p data yield no fits which are conclusive on the necessity of interference terms. Other possible explanations, which must be considered, include the analysis of mass shifts and resolution.

An LRL 9-GeV/c K^+p experiment observed that in the Q the ratio of $K^o\pi^+\pi^o p$ events to $K^+\pi^+\pi^- p$ events is $R = 1.03 \pm 0.06$ when corrected for unseen K^o decays.[7] Isotopic spin conservation predicts the ratio $R = 1$ for pure $K^*\pi$ decay of the Q, and $R = 2$ for pure $K\rho$ decay. The experimental value of R would imply no $K\rho$ decay at all, but the $\pi\pi$ mass distribution reveals a very strong ρ signal, particularly in the $K^o\pi^+\pi^o p$ final state, where no K^+-π^+ interchange ambiguities exist. Two possible explanations for this effect were suggested: (1) $K^*\pi$ vs $K\rho$ interference effects could modify the expected ratio; or (2) a $K\epsilon$ decay mode of the Q would contribute only to the $K^+\pi^+\pi^- p$ final state; R would be reduced and the ϵ would appear as a ρ-like signal in the $\pi^+\pi^-$ mass distribution. Recently, M. Bowler of Oxford University has demonstrated that the $K^*\pi$ vs $K\rho$ interference does not change the isotopic spin relations, thus it cannot explain the discrepancy.[35,45] Therefore the alternative explanation of a $K\epsilon$ decay mode of the Q should be regarded much more seriously.

Several new experiments are in progress which will study the Q produced coherently off the deuteron.[46-49] Thus far the published results show sufficient statistics to state only that the

Q is produced coherently, and that its principal decay mode is $K^*\pi$.[20,50-52] Therefore, high statistics experiments on the Q produced coherently off the deuteron or off heavier nuclei should be very important.

V CONCLUSIONS

Several of the low energy experiments have been fit successfully to multi-Regge exchange models. On the other hand, no high energy experiment has ever been fit to them successfully. Moreover, none of the experiments is consistent with a single Breit-Wigner shape, while all of them fit the parametrization as two Breit-Wigners. Furthermore, the parameters for all the high energy experiments are perfectly consistent with each other. In addition, the upper part of the Q cannot be due entirely to the $K\pi\pi$ decays of the K^*_{1420}. In conclusion, at high energies the Q consists of two peaks, one with $M = 1250 \pm 4$ MeV and $\Gamma = 182 \pm 9$ MeV, and the other with $M = 1400 \pm 6$ MeV and $\Gamma = 220 \pm 14$ MeV, and, in addition, a small contribution from the K^*_{1420}.

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VII FOOTNOTES AND REFERENCES

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*TECHNICAL INFORMATION DIVISION
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720*