Title
K* SPECTRUM AND DIFFRACTION DISSOCIATION EFFECTS (INCLUDING A1)

Permalink
https://escholarship.org/uc/item/0sh5j880

Author
Goldhaber, Gerson.

Publication Date
1968-06-01

UCRL-18316

University of California

Ernest O. Lawrence Radiation Laboratory

K^* SPECTRUM AND DIFFRACTION DISSOCIATION EFFECTS (INCLUDING A_1)

Gerson Goldhaber

June 1968

DISCLAIMER

To be published in
Proceedings of the
University of Pennsylvania Conference
on Meson Spectroscopy, Philadelphia,
April 26, 27, 1968

UCRL-18316
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

K^* SPECTRUM AND DIFFRACTION DISSOCIATION EFFECTS (INCLUDING A_1)

Gerson Goldhaber

June 1968

K^* SPECTRUM AND DIFFRACTION DISSOCIATION EFFECTS (INCLUDING A_1)

Gerson Goldhaber

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

June 1968

My talk might be entitled "A Look at Bosons in a Strange Light," by which I mean I shall concentrate on K^*'s. In this paper I will discuss the following:

I.	A Survey of the K^*'s.	Page 2
	Reactions Leading to K^* Production	Page 2
	The Q Peak and K^*(1420)	Page 2
	Structure in the Q Peak	Page 3
	Spin and Parity of the Q Peak	Page 9
	Comparison with the Quark Model	Page 10
II.	The Next K^* Cluster	Page 22
III.	Evidence for an Enhancement in the $\overline{\Lambda}N$ Mass Distribution	Page 22
IV.	The A_1 and the General A Enhancement	Page 26
	Is the A_1 Produced Outside a Diffraction Dissociation Peak As Well?	Page 28
	Resonances vs. Diffraction Dissociation or Deck Effect	Page 29

By now SU(3) and its classification of particles into multiplets is very well established, and we all know and accept the scheme described by Gell-Mann and Ne'eman. For instance, we have an isovector, the π, two isosinglets, the η and η', and two isodoublets, the K and $\overline{K}$, all of which correspond to a single state split by SU(3) breaking. In order to study higher mass states one can study the isovectors, as has been done in the missing-mass-spectrometer experiments of Maglič, Kienzle, and coworkers. One can also look for any of the other I-spin multiplets; for example, one can look for the isosinglets. However in this case there is mixing between the two isosinglets (at least this is the case for some of the nonets that are well established), so that the relation between the observed mass and the center of the nonet is more complicated. The isovector and the isodoublets on the other hand appear to be separated by a quantity Δ, which appears to remain fairly constant, and thus in the search for higher-mass bosons, one can look either for the isovectors or for the isodoublets, the K^*'s. Looking for bosons "in a strange light" thus corresponds to looking for the K^*'s.

I. A SURVEY OF THE K^*'s

There has been a considerable amount of work on this subject, which I want to review and discuss. The K and $K^*(890)$ are well established, so I will start by discussing the K^*'s beyond these. The $K^*(1420)$ is also well established, so I will only mention it to the extent that it relates to the other nearby K^*'s.

A. REACTIONS LEADING TO K^* PRODUCTION. Let us consider the type of experiment in which one observes the higher K^*'s. These are primarily K^+p or K^-p reactions giving four particles in the final state; for example, the reactions $K^+p \rightarrow K^+\pi^-\pi^+p$ (see Fig. 1). Here one picks the $K^+\pi^-$ to be in the $K^*(890)$, which thus gives three particles effectively, $K^{*0}(890)\pi^+p$, and allows one to form a Dalitz plot. In Fig. 2 we see the N^* band and a large $K^{*0}\pi^+$ enhancement along the horizontal axis. This consists of one well-known feature, the $K^*(1420)$, for which the evidence that it has $J^P = 2^+$ is rather good, and a broad enhancement roughly from 1.1 to 1.4 BeV, the Q peak.

B. THE Q PEAK AND $K^*(1420)$. As may be noted on the Dalitz plot, the entire $K^*\pi$ band runs into the N^* band. It is general practice to cut out the N^* band and study the rest of the Q enhancement. I have compiled some data on this region with the help of Bronwyn H. Hall. See Figs. 3 to 5. In Figs. 6 to 8 are some more recent contributions submitted at the time of the Meeting.

Let us first discuss the qualitative features: On the right side of the Q peak is the $K^*(1420)$ decaying via the $K^*\pi$ or $K\rho$ mode. This is clearly discernible as a distinct feature in the three first momenta: the Wisconsin data at 3.5 BeV/c, our data (LRL) at 4.6 BeV/c, and in the Bruxelles-

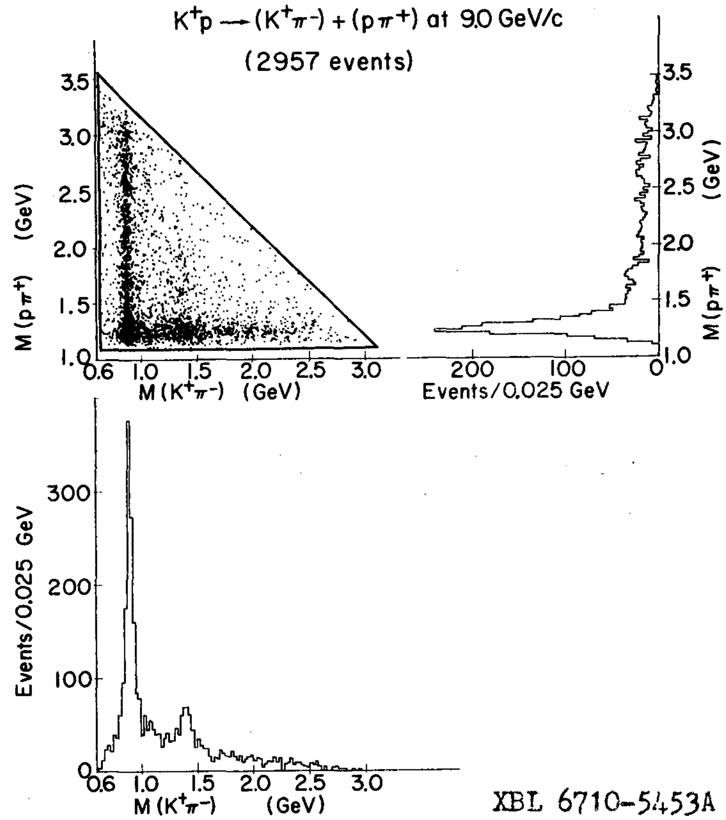
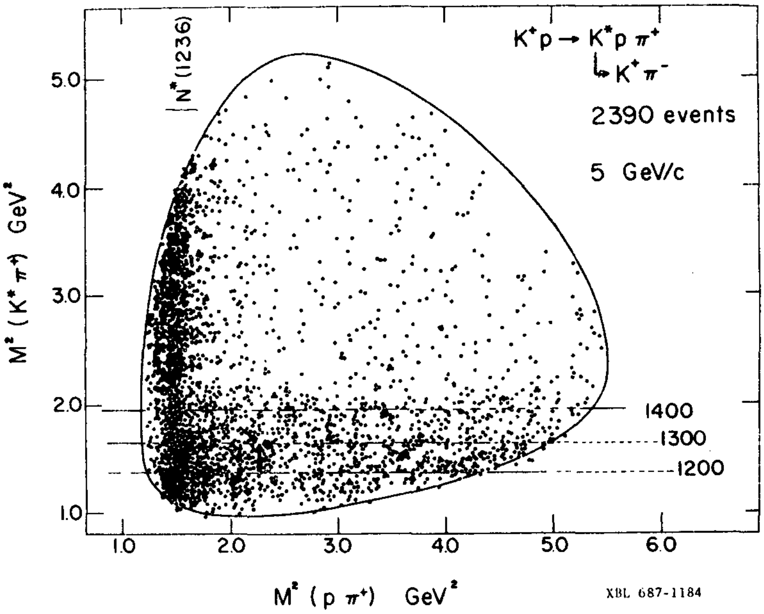


Fig. 1. Example of the triangle plot for the reaction $K^+p \rightarrow K^+\pi^-\pi^+p$. Data of Firestone et al. (LRL, 9 GeV/c).[1]

CERN data at 5.0 BeV/c in Fig. 3. For the higher momenta the $K^*(1420)$ is no longer clearly resolved unless one makes cuts in t; namely, $t > 0.3\ (\mathrm{BeV}/c)^2$. The same general features appear in the K^-p data in Fig. 5.

This behavior is readily understood as we can study the $K^*(1420) \rightarrow K\pi$ decay mode. The branching ratio of $K\pi/K\pi\pi \approx 1$ then allows one to estimate the $K\pi\pi$ contribution due to the $K^*(1420)$. This contribution decreases as the incident momentum increases, since $\sigma[K^*(1420)]$ is proportional to p_{lab}^{-2}, as Morrison has shown, while $\sigma(Q)$ appears to remain nearly constant with increasing p_{lab}. Furthermore the t distribution is wider for $K^*(1420)$ than for the Q peak.

C. THE STRUCTURE IN THE Q PEAK. There is every indication that the Q peak is not a single wide object but

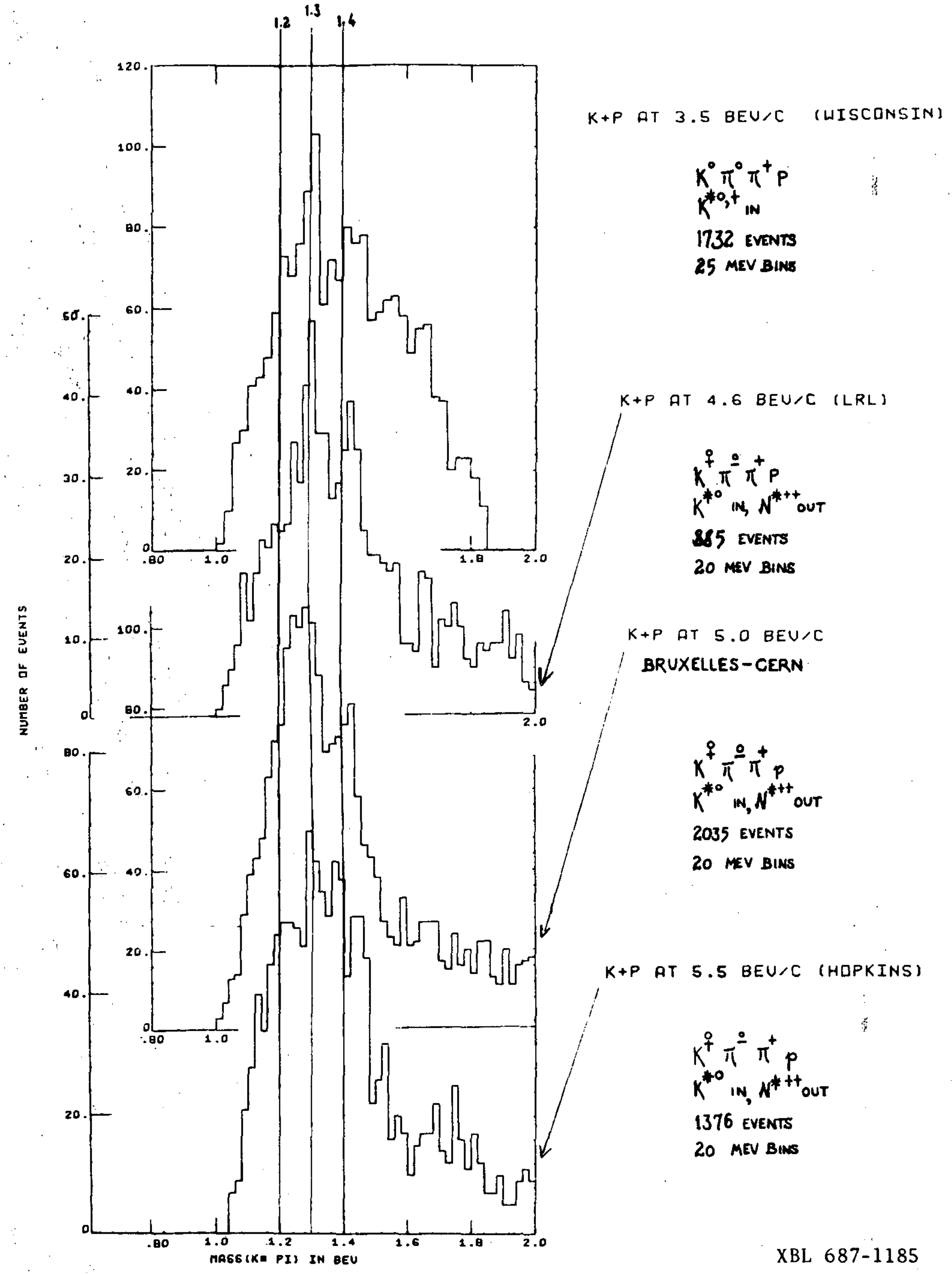


XBL 687-1184

Fig. 2. An example of the Dalitz plot for the reaction $K^+p \to K^*p\pi^+$. These events correspond to the K^* band on a triangle plot similar to the one shown in Fig. 1. Data of the Bruxelles-CERN-Birmingham collaboration.[2]

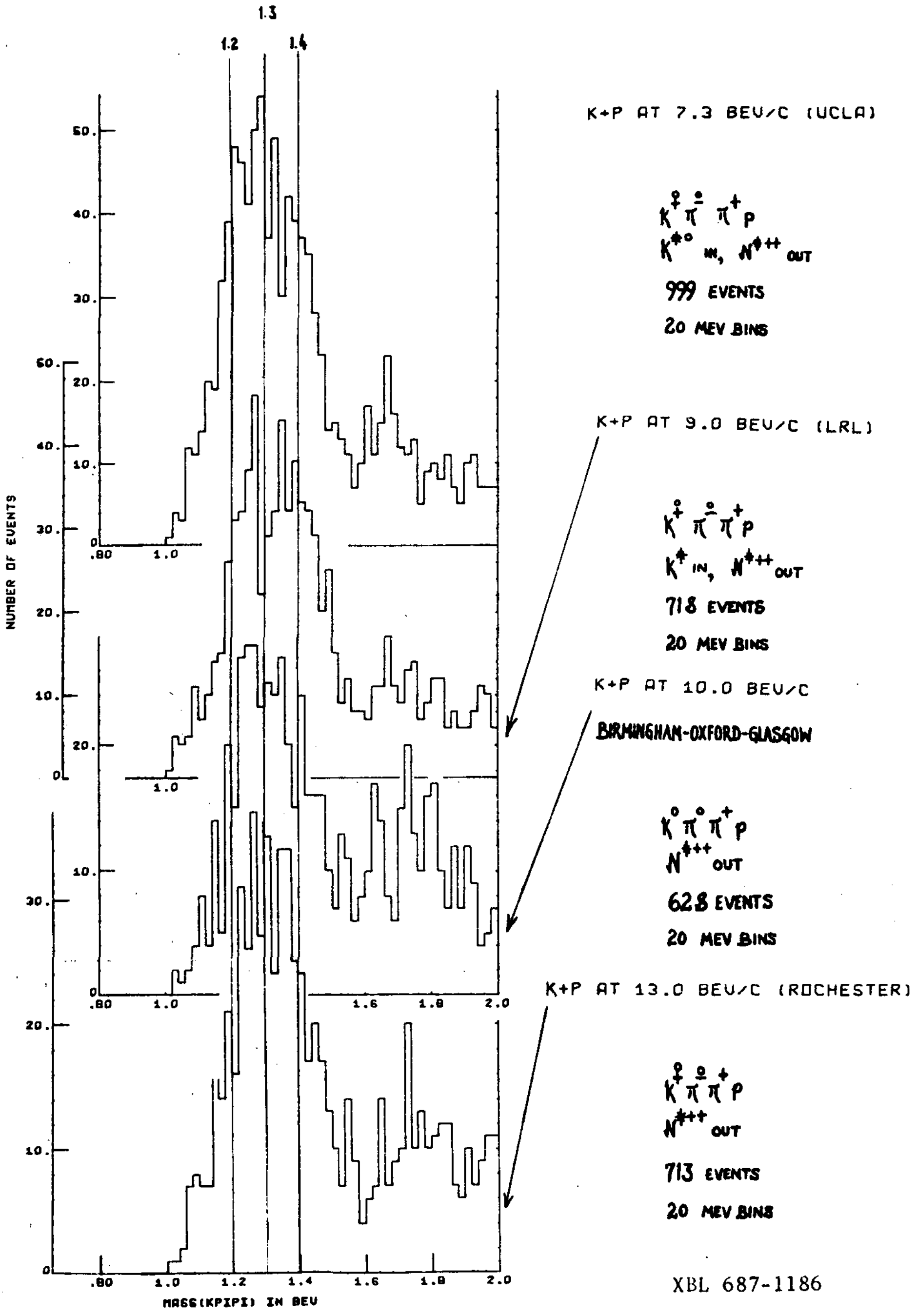
rather has more structure.

The question is: how much structure? How does it vary with incident momentum and with t? What is the relation between the structure and alignment of the $K^*(890)$ which comes from the decay of the Q peak? And finally, what is the behavior of the $K\rho$ decay mode? It is clear from the present data that the Q-peak structure changes with incident momentum, as can be noted by following the vertical lines at 1.2, 1.3, and 1.4 BeV on Figs. 3 through 5. Thus, for example, the 3.5- and 4.6-BeV/c K^+p data show a single peak at 1300 to 1320 MeV (Fig. 3), while the 9- and 10-BeV/c data (Figs. 4 and 10) show two peaks at ~1250 MeV and 1360 to 1390 MeV.



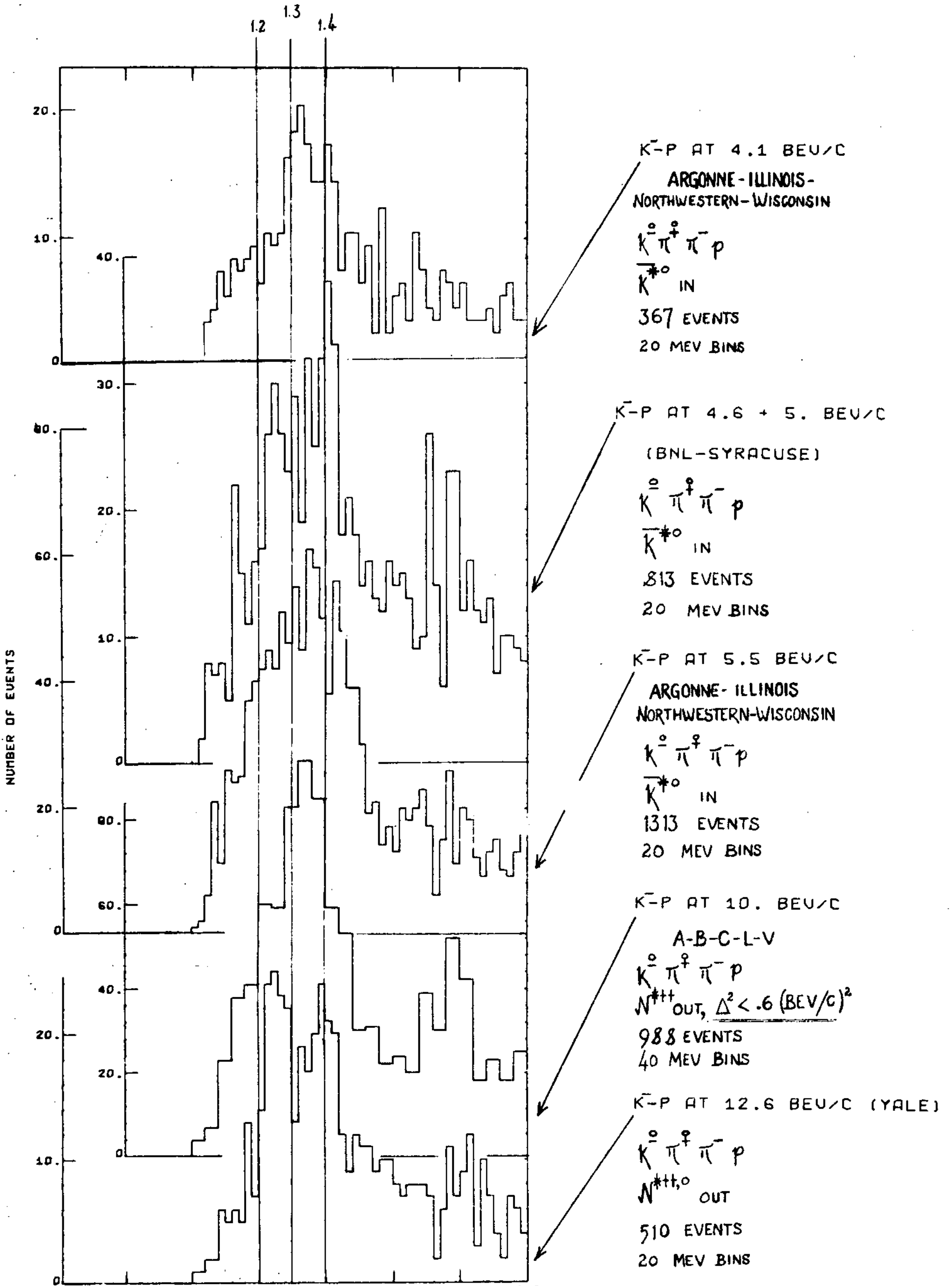
XBL 687-1185

Fig. 3. Compilation of the $K^*\pi$ mass distributions from K^+p interactions. Here K^* refers to $K^*(890)$.



XBL 687-1186

Fig. 4. Compilation of the $K^*\pi$ mass distributions from K^+p interactions.



XBL 687-1187

Fig. 5. Compilation of the $K^*\pi$ mass distributions from K^-p interactions.

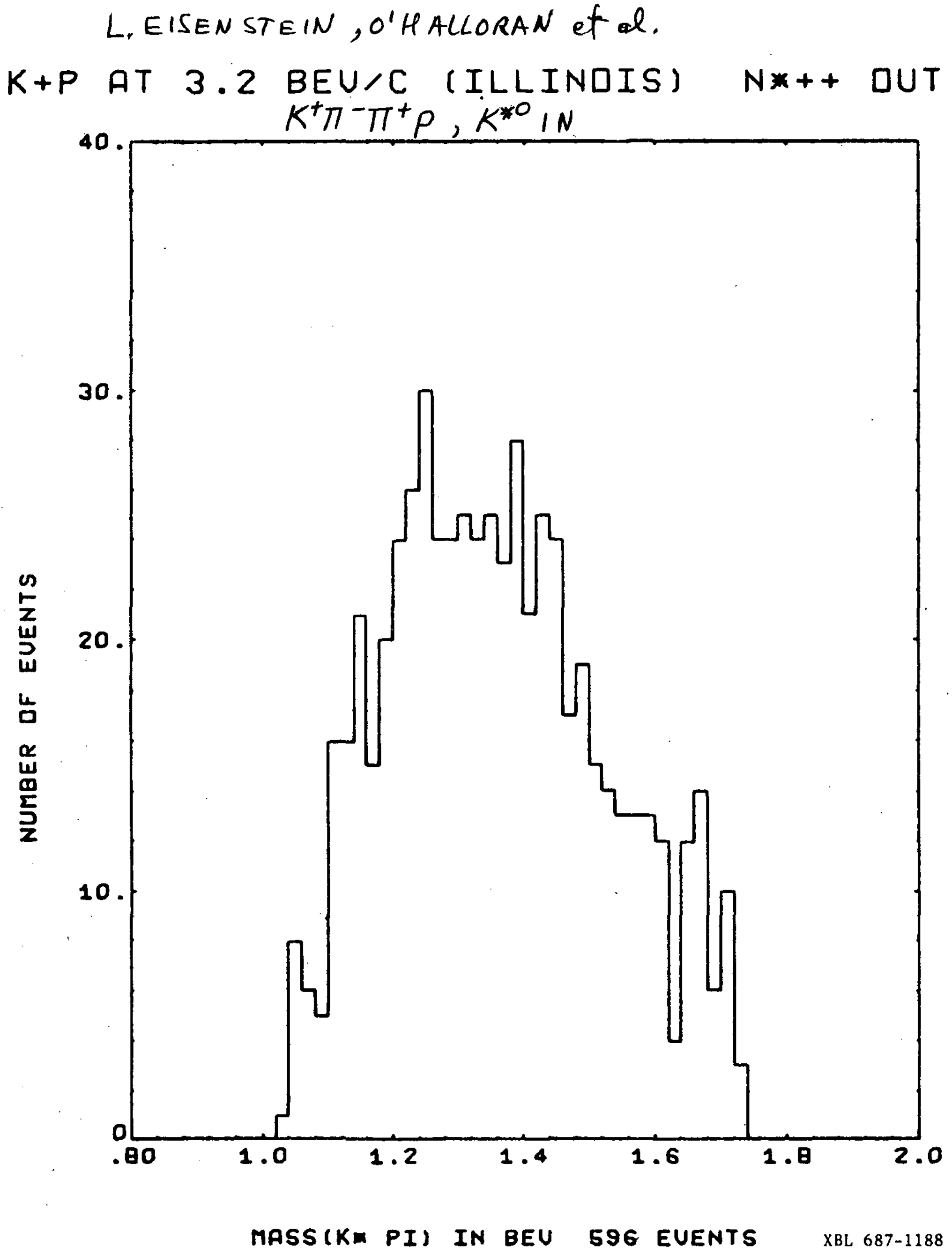


Fig. 6. Additional data on the $K^*\pi$ mass submitted at the Conference.

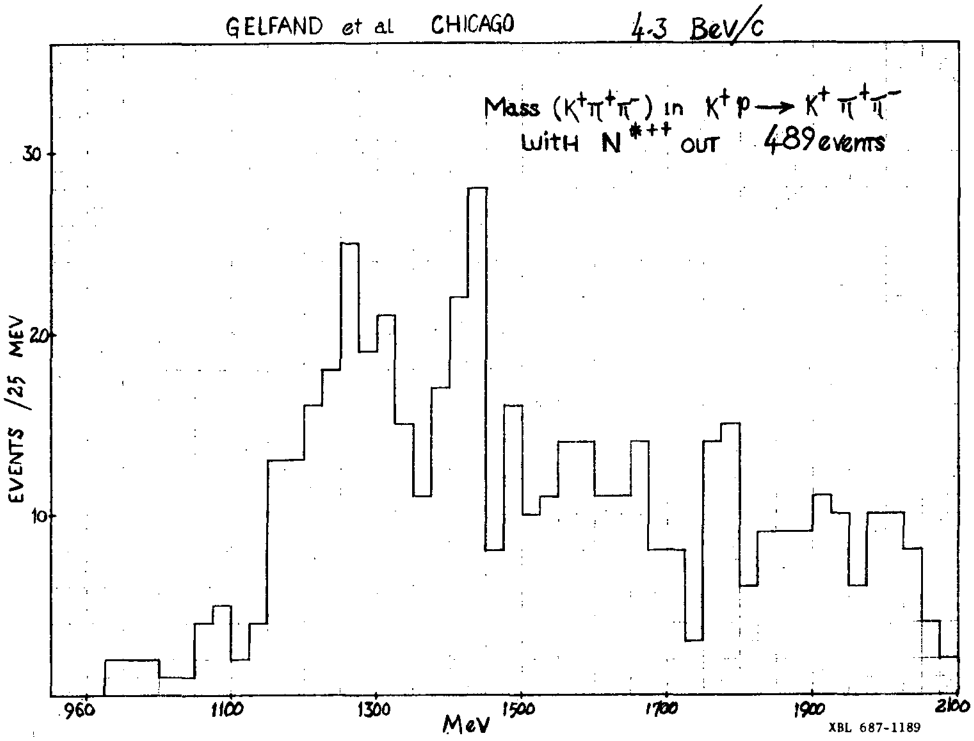
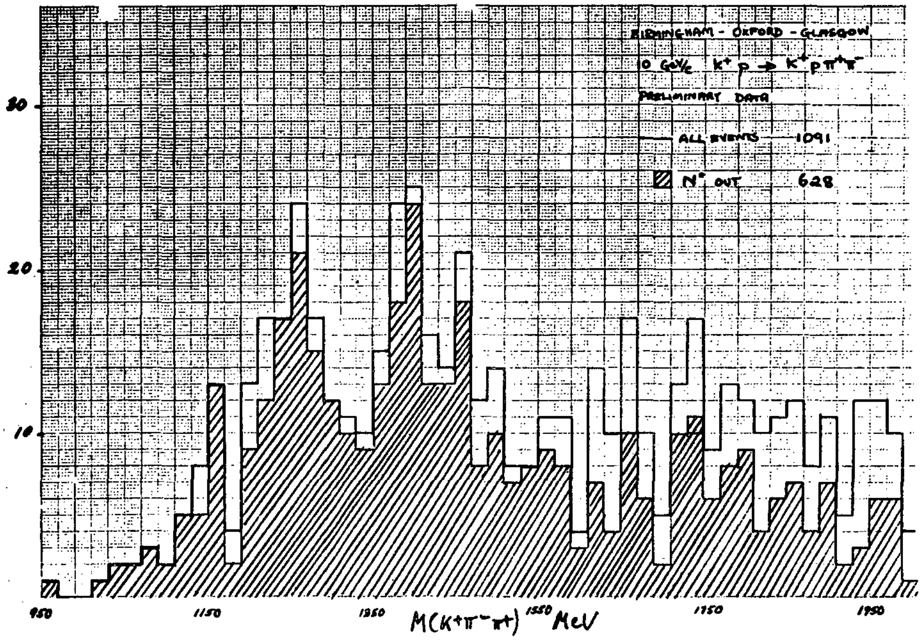


Fig. 7. Additional data on the Kππ mass submitted at the Conference.

Aside from the structure in the entire Q peak (without any cuts in t), a variation in structure is observed for cuts in t together with the selection of "polar" and "equatorial" alignment of the $K^*(890)$ from Q decay. In particular, the CERN-Bruxelles-Birmingham group (5-GeV/c K^+p) (see Fig. 9) suggest the presence of three distinct resonances, in addition to the $K^*(1420)$. This is however not observed by the Johns Hopkins group (5.5-GeV/c K^+p) or the ANL-Illinois-Northwestern-Wisconsin groups (5.5-BeV/c K^-p) (see Fig. 10). B. H. Hall and I have combined these three sets of data in Fig. 11. Some evidence for variation of the structure with t is shown in the LRL data (K^-p at 2.6 BeV/c), where the mass-squared distributions are shown for various cuts in the Kππ production angle (see Fig. 12).

D. SPIN AND PARITY OF THE Q PEAK. Figures 13 through 16 show three distinct attempts to get information on spin and parity in the various mass regions of the Q



XBL 685-849

Fig. 8. Additional data on the $K^*\pi$ mass submitted at the Conference.

peak. Chien, Slater, et al. at UCLA (K^+p at 7.3 GeV/c) have studied the density distribution in the Dalitz plots for the $K\pi\pi$ system (see Figs. 13 and 14). They conclude $J^P = 1^+$ with 2^- not ruled out. In our own work at LRL (K^+p at 9 GeV/c) we have studied various angular distributions described on Fig. 15 and conclude $J^P = 1^+$ or 2^-. The Johns Hopkins Group (Luste, Pevsner, et al., K^+p at 5.5 GeV/c) have carried out a Berman-Jacob analysis of the two successive decays $Q \to K^*\pi$ and $K^* \to K\pi$. They obtain a weight function shown in Fig. 16 which corresponds to $J^P = 1^+$ or 2^+. From all these data, $J^P = 1^+$ appears strongly preferred for all parts of the Q peak.

E. COMPARISON WITH THE QUARK MODEL. Let us consider the situation of the possible 1^+ K^*'s, namely the K^*'s which go with the A_1 and the B. I am now assuming that the A_1 and the B are reasonably well established; the B will be discussed in another session, and I will say more about the A_1 later in this session. If we accept the A_1 and B and that there are K^*'s which go with them (I think that much we are likely to believe), there is a new phenomena

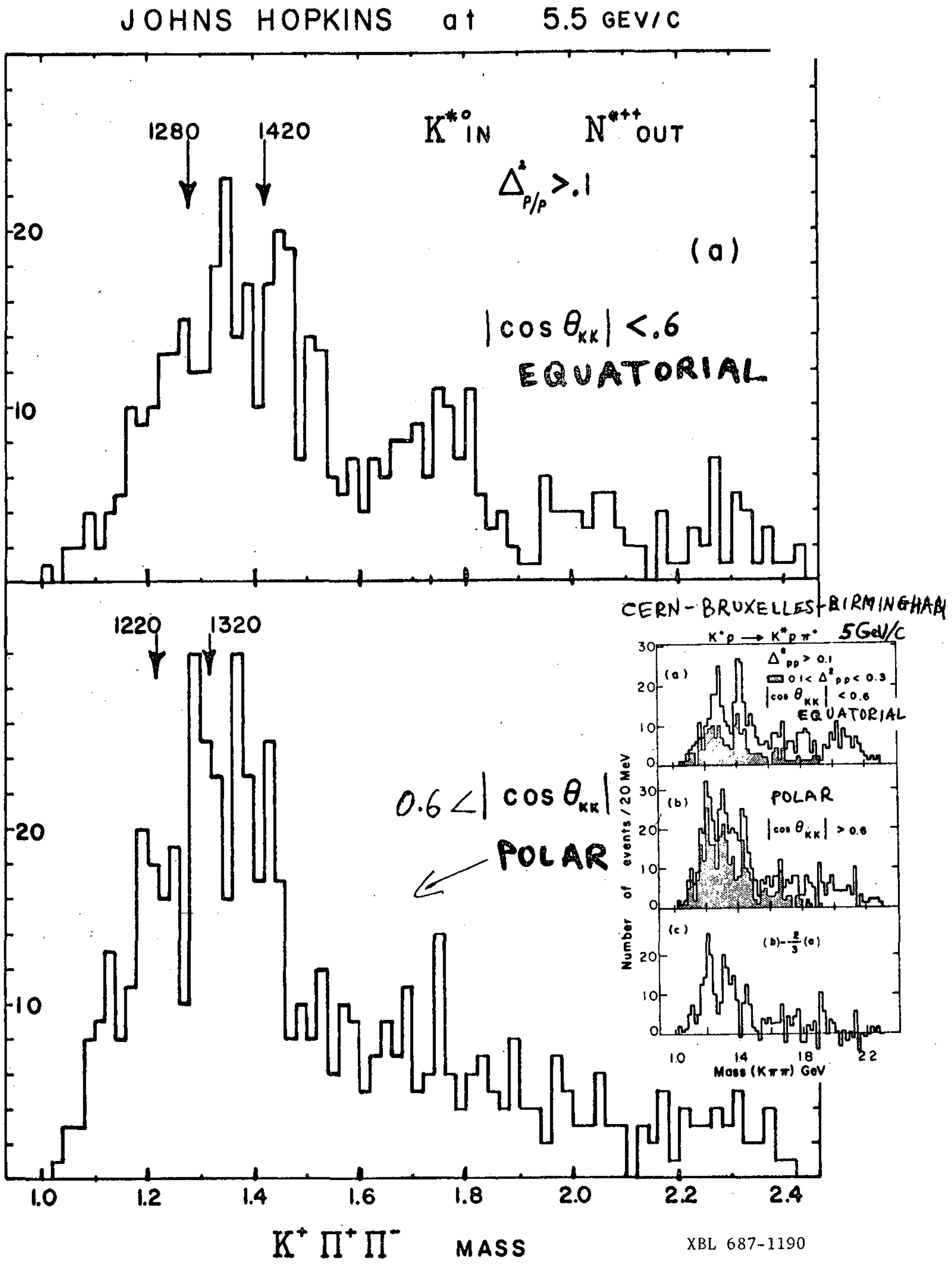


Fig. 9. Search for additional structure in the $K\pi\pi$ mass distribution for K^+p data with cuts in t and K^* alignment angle as indicated on the figure.[3, 4]

PARK ET AL. ANL - ILL - N.W. — WISC.

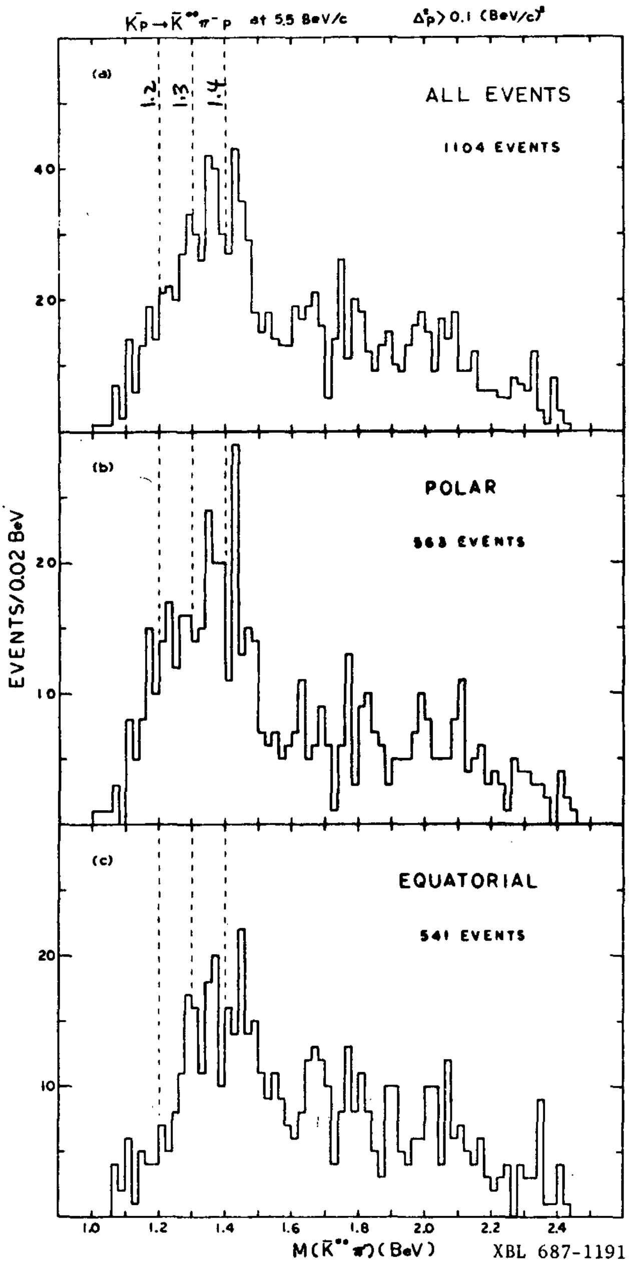


Fig. 10. Search for additional structure in the $K\pi\pi$ mass distribution for K^-p data with cuts in t and K^* alignment angle as indicated on the figure.[5]

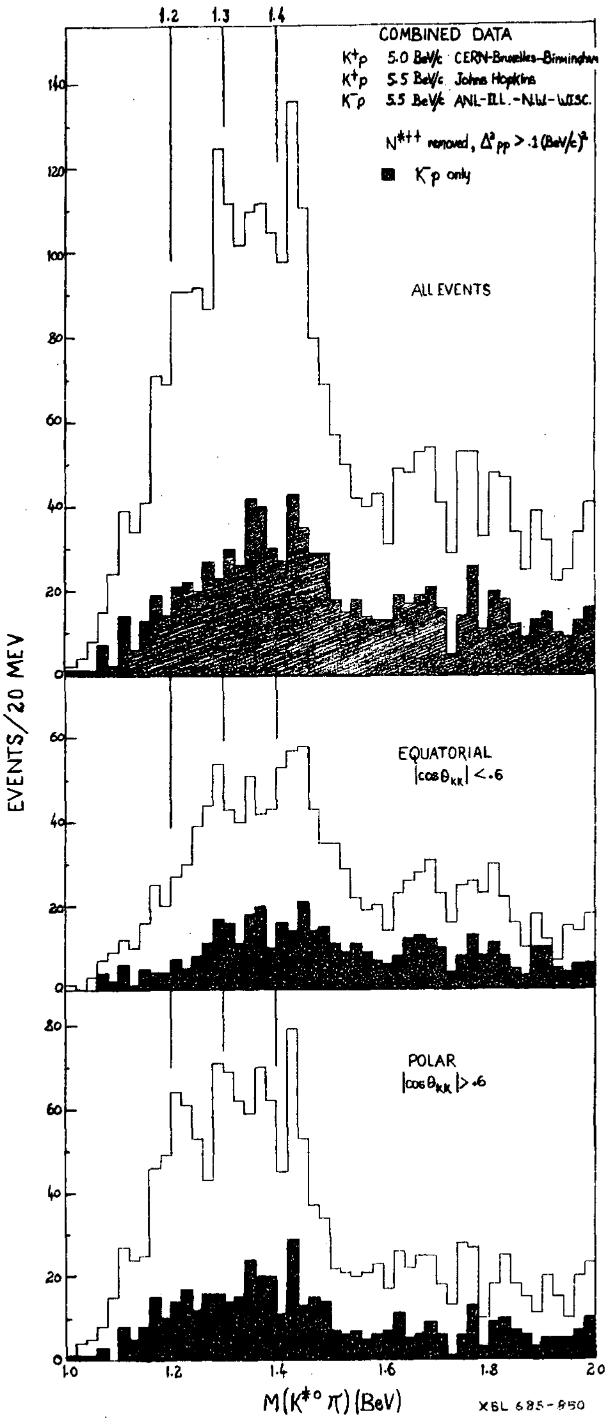
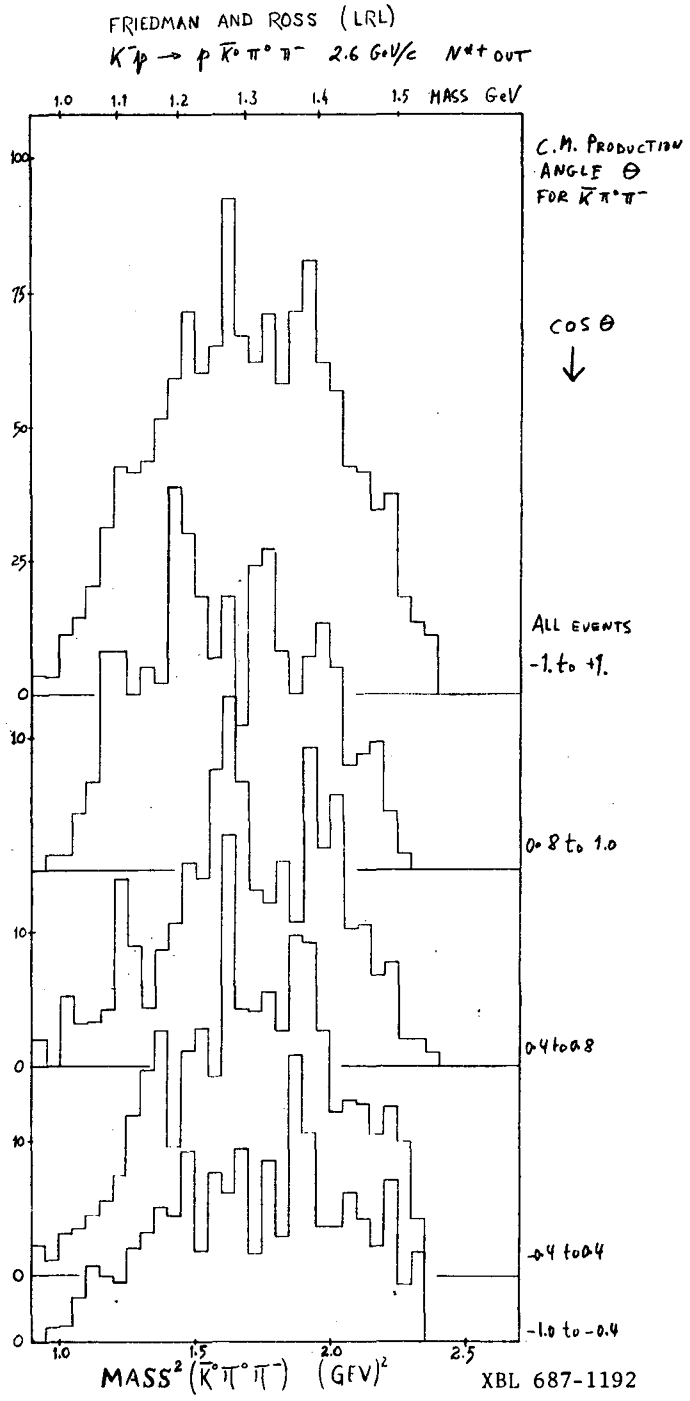
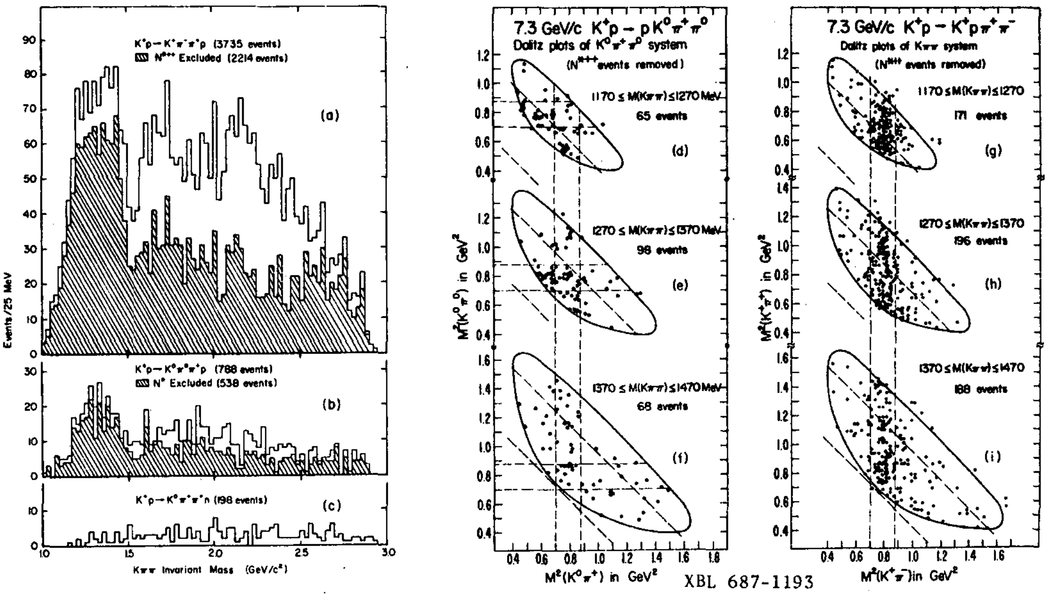


Fig. 11. Combination of the three sets of data in the previous two figures.



XBL 687-1192

Fig. 12. Search for structure in the $K\pi\pi$ mass-squared distribution for various cuts in the K^* production angle.[6]



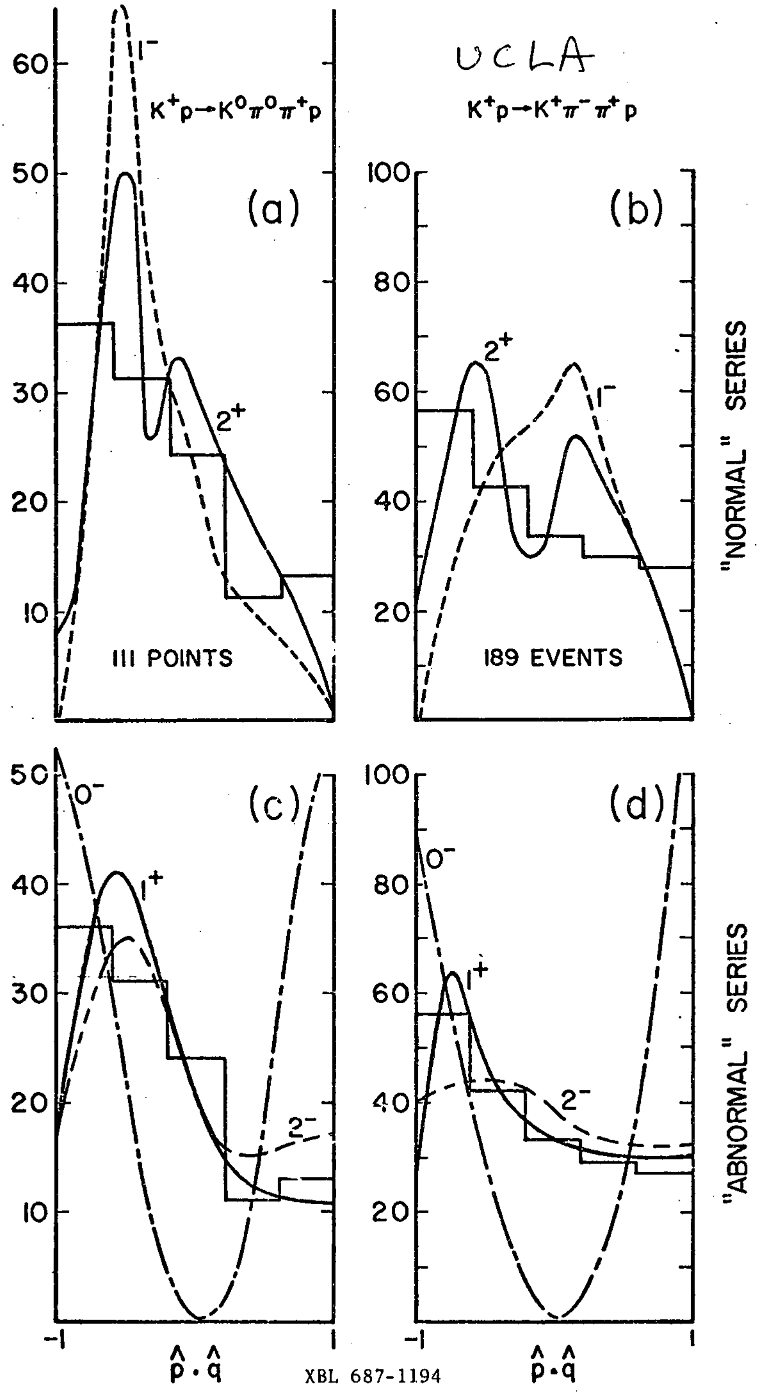
XBL 687-1193

Fig. 13. Dalitz plots for the $K\pi\pi$ system with total mass as indicated on the figure for spin parity studies. Data of the UCLA group (Chien, Slater et al.).[7]

which can occur here; namely, the two K^*'s can mix since the way these two K^*'s differ is just that they belong to octets with different charge conjugations. We thus have two nonets of particles tied together. Gatto, Maiani, and Preparata have called this group of 18 particles an "octodecimet" (see Fig. 17).[10]

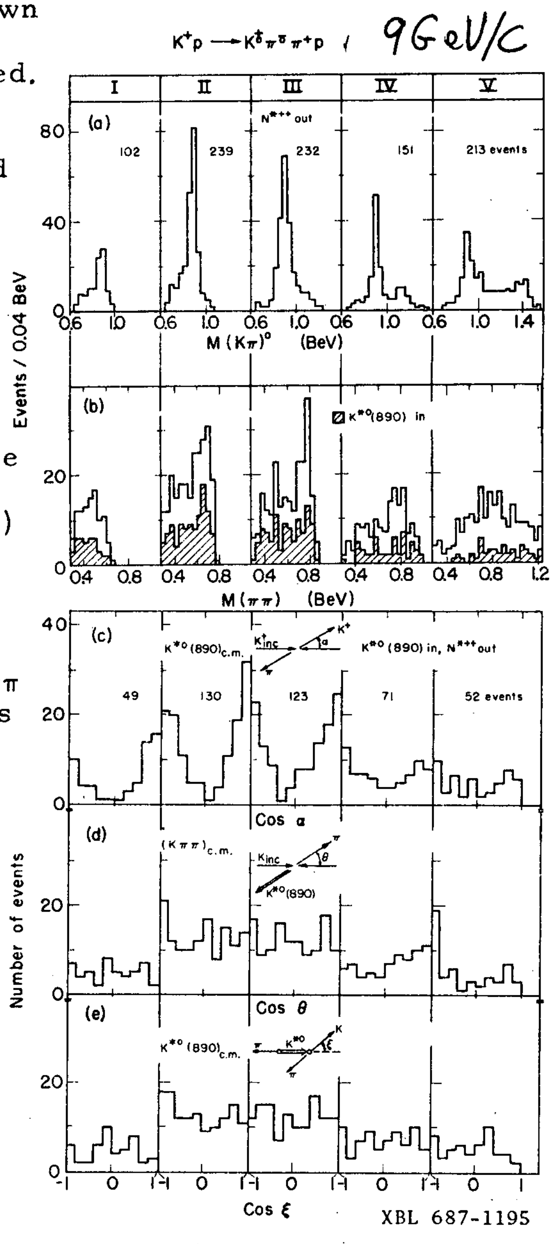
Apart from the possibility of particle mixing, we can have interference effects between the two 1^+ K^*'s which can occur in the mass distribution. Figure 17 shows the type of mass distributions which result from the introduction of a phase angle ϕ between the two amplitudes.[9] This problem is under investigation by a number of people, including Kane and Mani,[11] Altarelli, Gatto, and Maiani,[12,15] Harari and Quinn,[13] and Lipkin.[14]

So far there is not sufficient data to attempt a fit with this model. Furthermore, it is not clear at present whether the lack of structure in some of the experiments is real or due to resolution problems. In my opinion there is at present good evidence for at least two K^*'s in the Q peak



XBL 687-1194

Fig. 14. Angular distributions related to spin parity determinations for the $K\pi\pi$ in the Q bump. Data from UCLA.



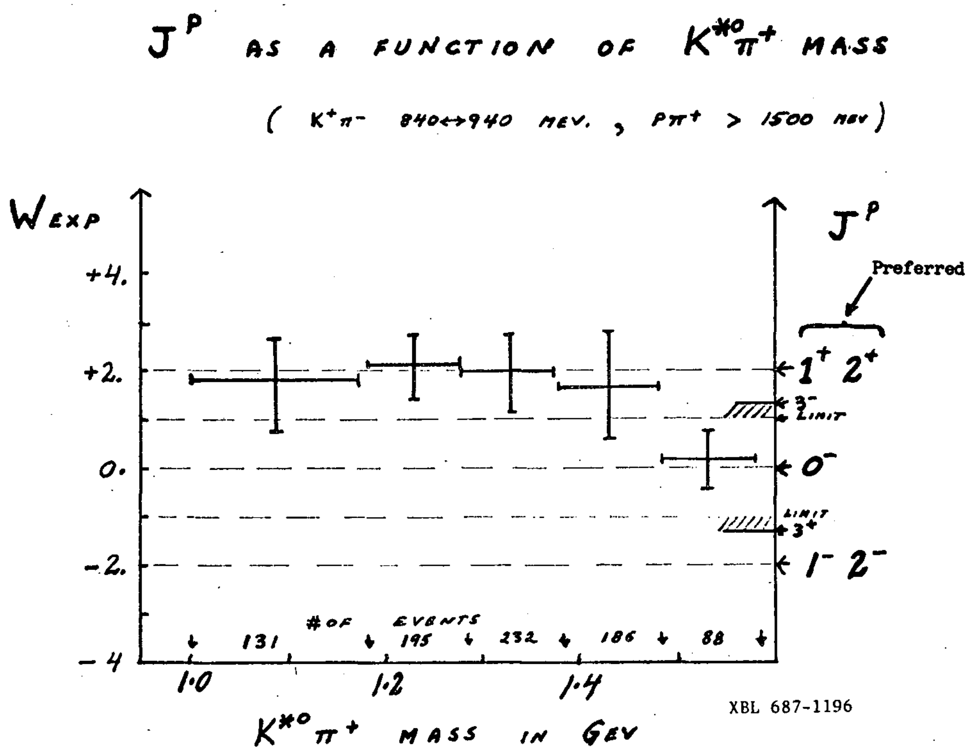
LRL (Ref. 8)

$K^+p \longrightarrow K^0\pi^-\pi^+p$, 9GeV/c

XBL 687-1195

Fig. 15. The decay properties of the $K\pi\pi$ system shown for five $K\pi\pi$ mass regions I-V with N^{*++} band removed. (a) $M(K\pi)^0$; (b) $M(\pi\pi)$, the shaded histograms for events in the $K^{*0}(890)$ band and for $K^{*0}(890)$ events; (c) $\cos\alpha$, where α is the angle between the outgoing K and the incident K^+ in the $(K\pi)^0$ rest frame; (d) $\cos\theta$, where θ is the angle between the odd π^+ and the K^+ in the $(K\pi\pi)^+$ rest frame; (e) $\cos\xi$, where ξ is the angle between the outgoing K and the $K^{*0}(890)$ flight direction in the $K^{*0}(890)$ rest frame.

We show the decay properties of the $K\pi\pi$ system as a function of the $K\pi\pi$ mass for five mass regions defined as (I) 1000-1180 MeV, (II) 1180-1280 MeV, (III) 1300-1400 MeV, (IV) 1420-1500 MeV, and (V) 1600-1760 MeV. Regions II, III, and IV correspond to the (1250), (1360), and (1420) mass bands, respectively. Region I is a control region, and Region V corresponds to the L-meson mass region. The top two rows of five histograms each of Fig. 3 show, respectively, the mass distributions of $(K\pi)^0$ and $\pi\pi$ systems. As may be noted, the main decay mode of the $K^*(1250)$ and $K^*(1320)$ resonances is $K^*(890)+\pi$; however, the $\rho+K$ decay mode is clearly present.



XBL 687-1196

Fig. 16. Weight function deduced from Berman-Jacob analysis for the $K^*\pi$ mass peak. The corresponding theoretical spin parity values are shown on the right side of the figure. Data from the Johns Hopkins group.[3]

in addition to $K^*(1420)$ which lies above the Q peak. Comparable features now appear in the $\bar{p}p$ annihilation data at rest, the C and C' (see Fig. 18). The situation can of course be more complicated, although at present we are not forced to assume higher complexity.

There is one interesting test that can be made for the presence of K^* mixing. As is well known, the coherent production of the Q peak on heavy nuclei and perhaps even on deuterium (see paper in these Proceedings by Pevsner) is expected to proceed via Pomeranchuk exchange. If in a good resolution experiment only a single peak--presumably the 1250-MeV K^*--shows up, we have no K^* mixing. If K^* mixing occurs, and if the Pomeranchuk is a unitary singlet, then both the $K^*(1250)$ and $K^*(\sim 1320$ and $1360)$ should be produced in the coherent peak.

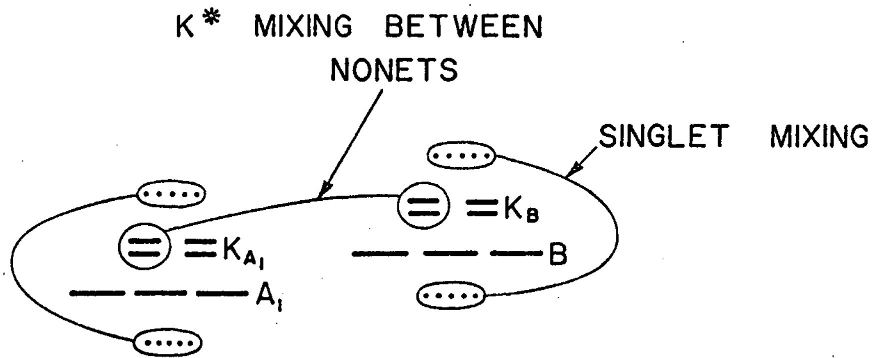
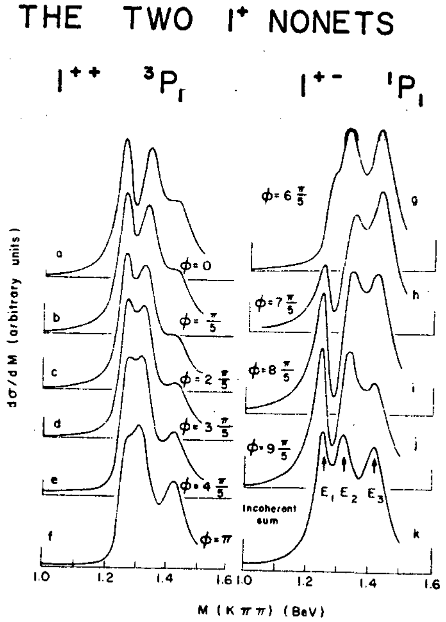


Fig. 17. (a) Illustration of the octodecimet.
(Ref. 9)

Fig. 17.(b) Computation of the interference patterns in the $K\pi\pi$ mass distribution for two K^* resonances at 1250 and 1320 MeV added coherently and a third at 1420 MeV added incoherently. The computation was done for a series of values of the phase angle φ between the two coherent amplitudes as described in the text, and is shown in parts a to j. In part k the incoherent sum of the three resonances is shown.



Let $B_k = \frac{1}{2}\Gamma_k/(E_k - E - i\frac{1}{2}\Gamma_k)$, with $k = 1$, 2, and 3, correspond to the Breit-Wigner amplitude for each of these resonances; then the resulting mass distribution can be expressed as

$$d\sigma/dM \propto (|a_1B_1 + B_2e^{i\varphi}|^2 + |a_3B_3|^2)P,$$

where E_k and Γ_k are the resonant masses and widths, respectively, φ is a relative phase angle, and a_1 and a_3 relative amplitudes, all of which must be determined from experiment, and P is a phase-space factor. As an illustration, this expression was evaluated for $E_1 = 1250$ MeV, $\Gamma_1 = 50$ MeV; $E_2 = 1320$ MeV, $\Gamma_2 = 80$ MeV; $E_3 = 1420$ MeV, $\Gamma_3 = 90$ MeV; $a_1 = 1$; $a_3 = 2^{-1/2}$; and values of φ from 0 to $9\pi/5$ in ten equal steps.

XBL 687-1197

C AND C' MESONS

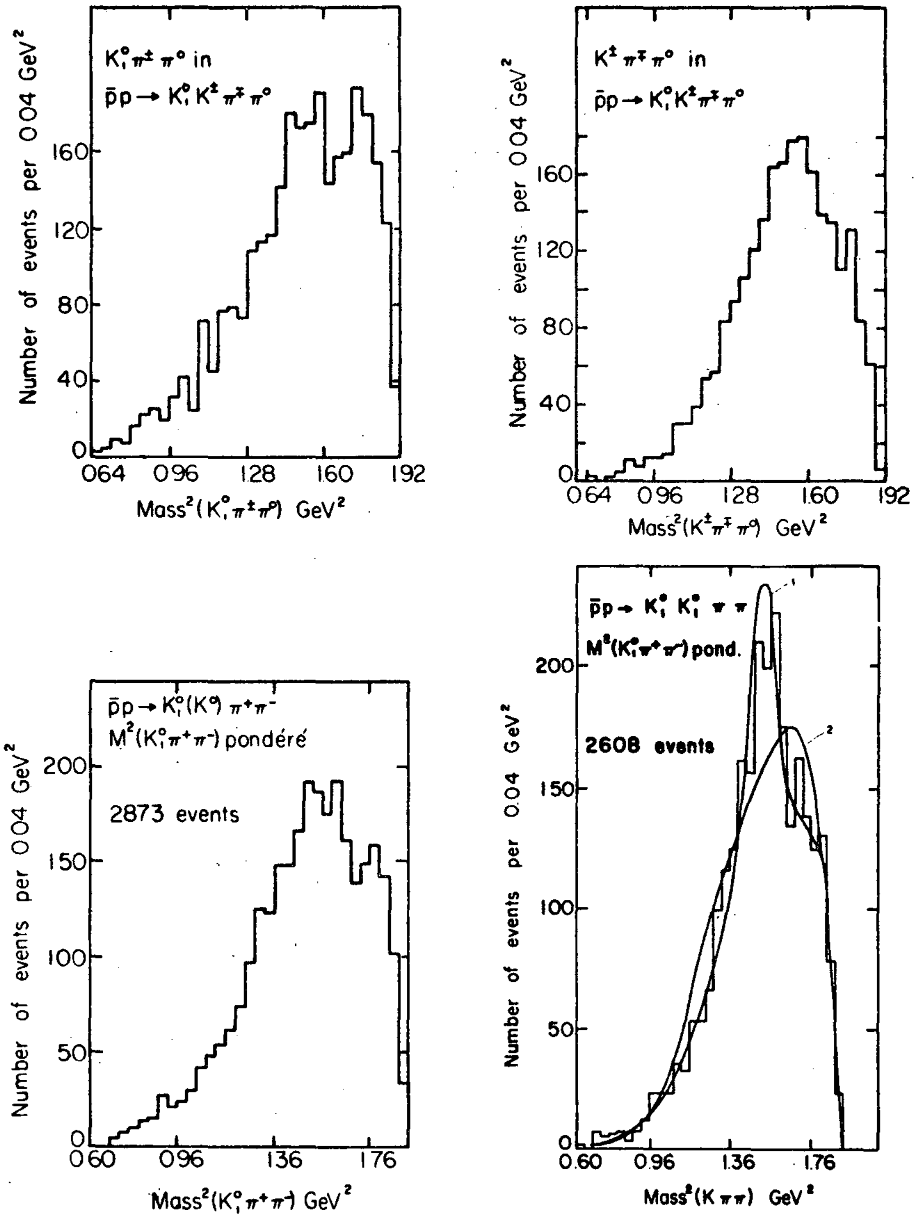
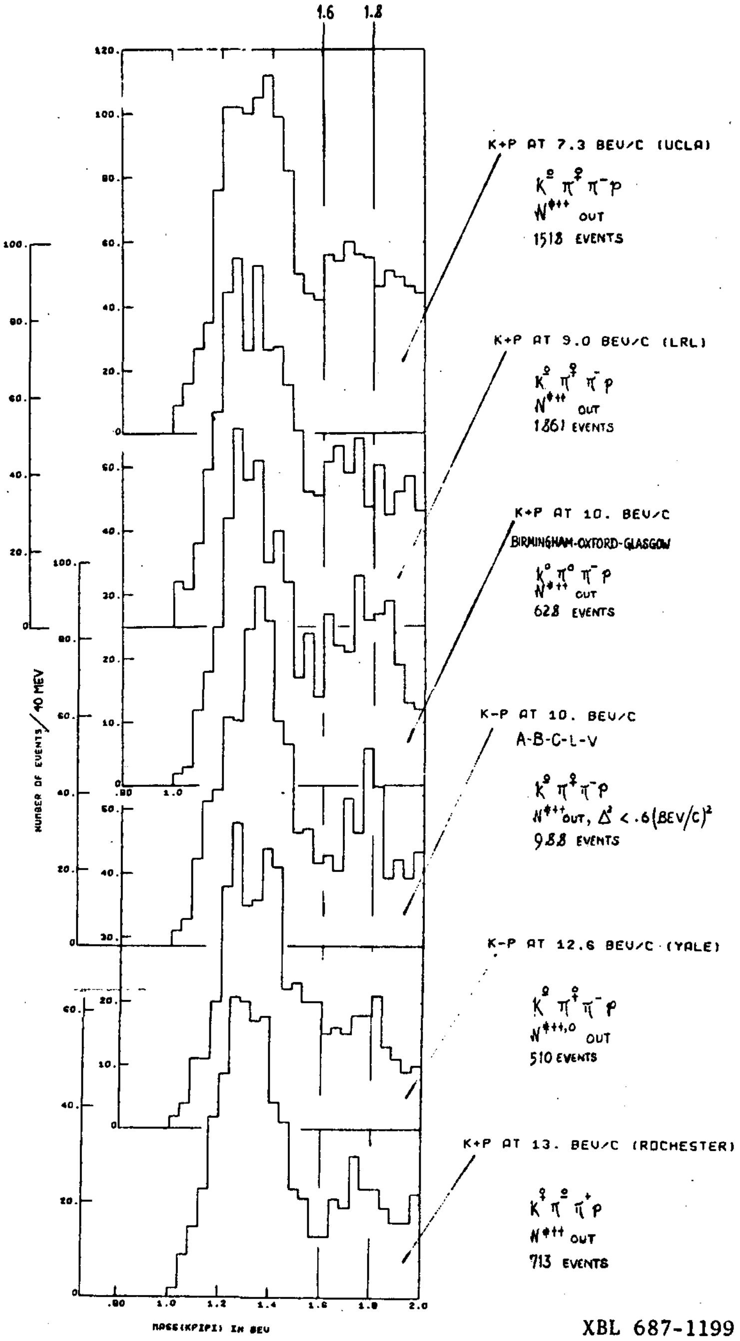


Fig. 18. **Mass squared plots of Kππ in $p\bar{p} \rightarrow K\bar{K}\pi\pi$ at rest, from the CERN-Paris-Liverpool Collaboration:**

a) $K_1^0\pi^{\mp}\pi^0$ from $\bar{p}p \rightarrow K_1^0K^{\pm}\pi^{\mp}\pi^0$;
b) $K^{\pm}\pi^{\mp}\pi^0$ from $\bar{p}p \rightarrow K_1^0K^{\pm}\pi^{\mp}\pi^0$;
c) $K_1^0\pi^+\pi^-$ from $K_1^0(K^0)\pi^+\pi^-$;
d) $K_1^0\pi^+\pi^-$ from $K_1^0K_1^0\pi^+\pi^-$.

XBL 687-1198



XBL 687-1199

Fig. 19. Compilation of data on the Kππ mass distribution to show the evidence of a second boson cluster in the mass region 1.6 to 1.8 BeV, the L-meson region.

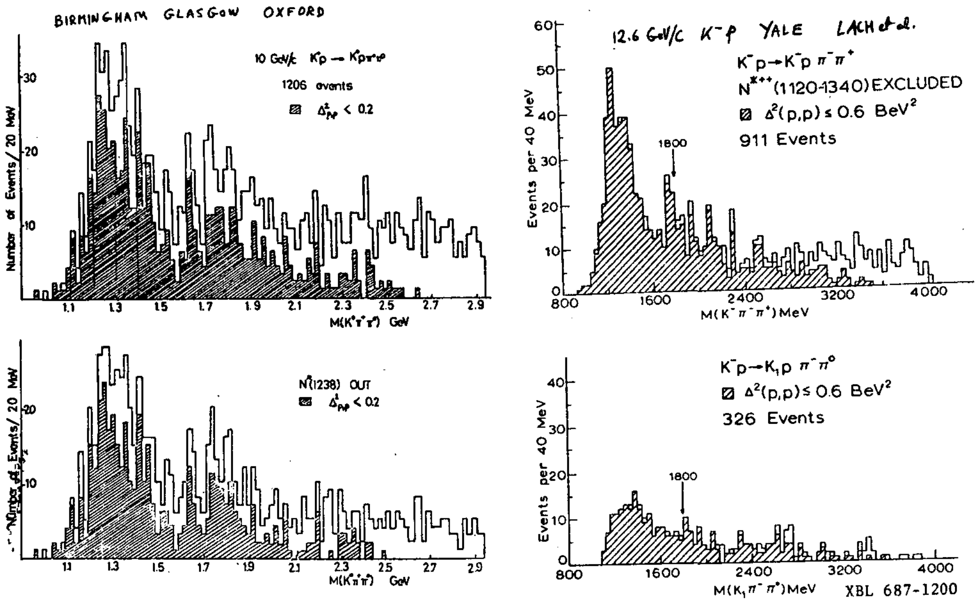


Fig. 20. More detailed $K\pi\pi$ mass distributions.[16, 17]

II. THE NEXT K^* CLUSTER

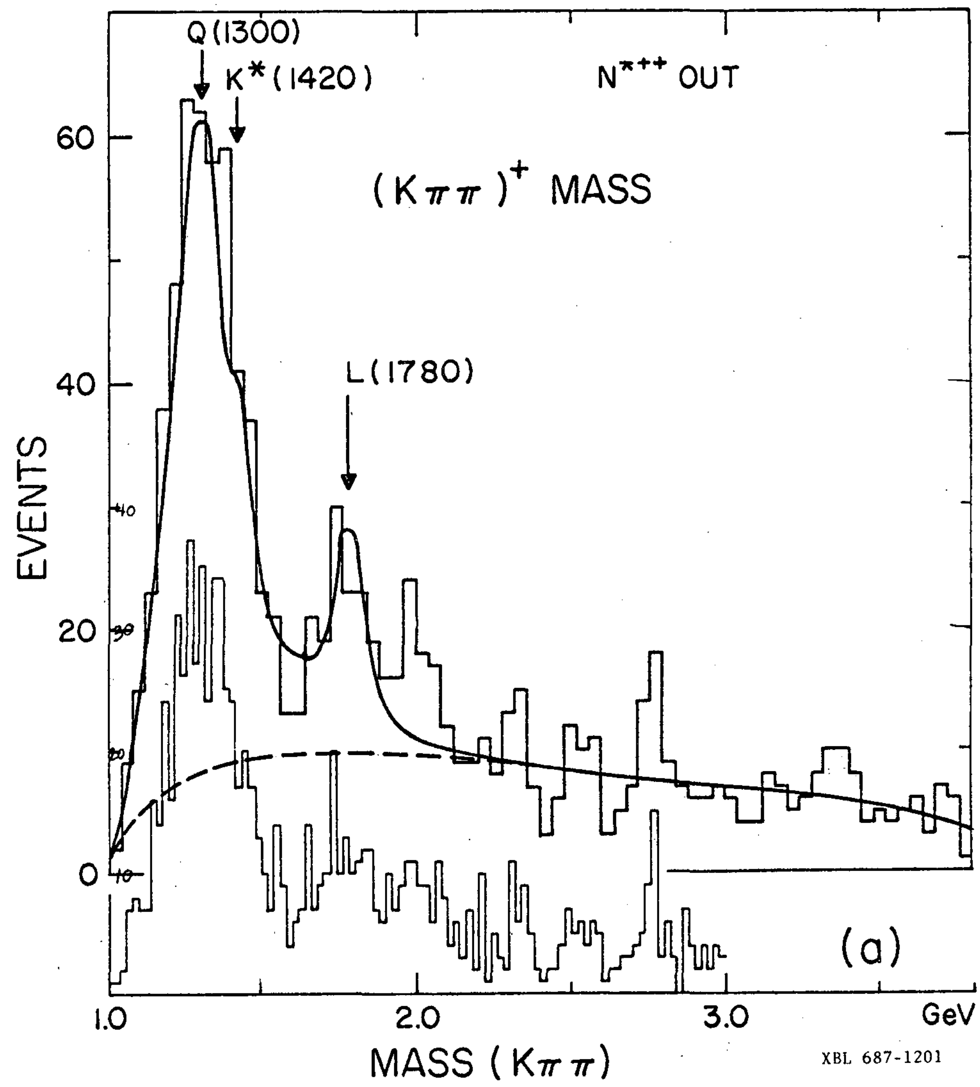
The ABCLV collaboration have observed a high-mass K^*, the L(1790), in the 10-GeV/c K^-p experiment. This is now confirmed in most of the high-energy K^+p and K^-p experiments. A compilation is shown in Fig. 19, and some further details in Figs. 20 and 21, and Table I. As may be noted, there may actually be an entire cluster of K^*'s from 1.6 to 1.8 GeV. So far no additional structure has been clearly identified, although some evidence has been presented by the CERN-Bruxelles-Birmingham Group for a possible peak at 1660 MeV (see Fig. 22).

On the quark model we might expect the four L = 2 K^*'s corresponding to the nonets with $J^{PC}=1^{--}, 2^{--}, 2^{-+}, 3^{--}$.

III. EVIDENCE FOR AN ENHANCEMENT IN THE $\overline{\Lambda}N$ MASS DISTRIBUTION

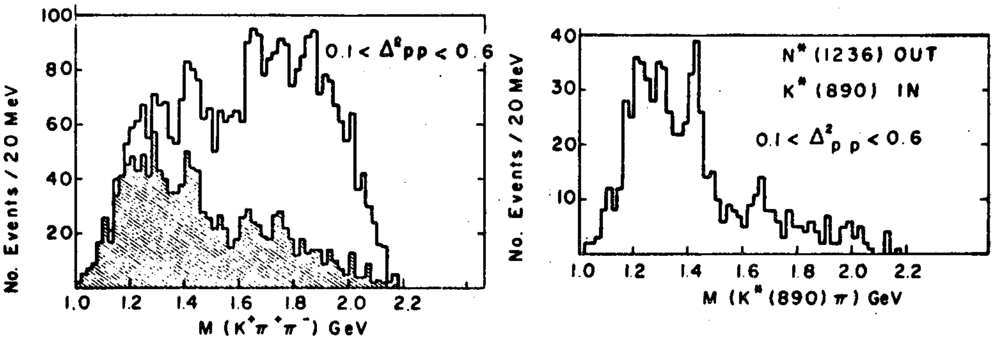
We have investigated the $\overline{\Lambda}N$ channel in the reactions $K^+p \rightarrow \overline{\Lambda}pp$ and $K^+p \rightarrow \overline{\Lambda}NN\pi$. Here the $\overline{\Lambda}N$ system can have the quantum numbers of a K^*. This is thus an interesting channel in which to investigate the mass region > 2055 MeV,

K^+p, 13 GeV/c (Yuta, Ferbel, et al., Rochester)



XBL 687-1201

Fig. 21. More detailed Kππ mass distributions.[18]



Evidence for K*(1660) from the CERN-Brussels-Birmingham study of K^+p interactions at 5 GeV/*c*. Kππ and K*π when N* is removed.

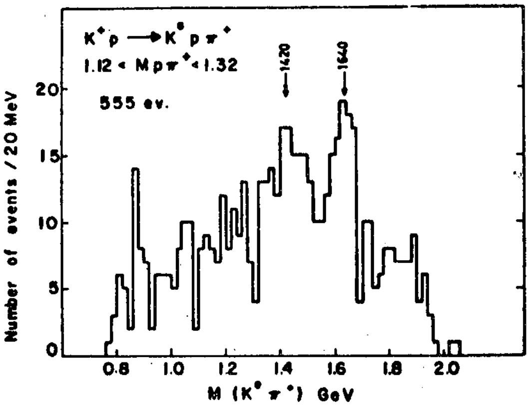
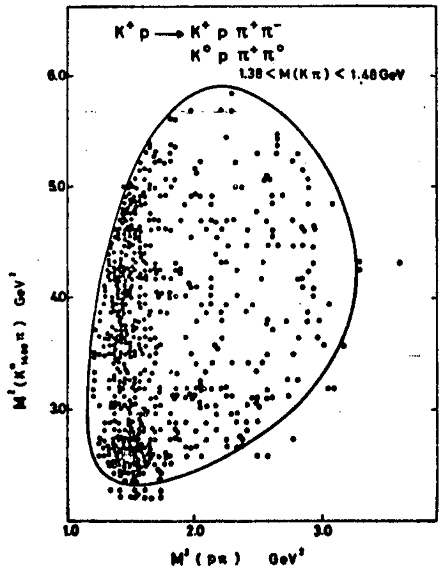


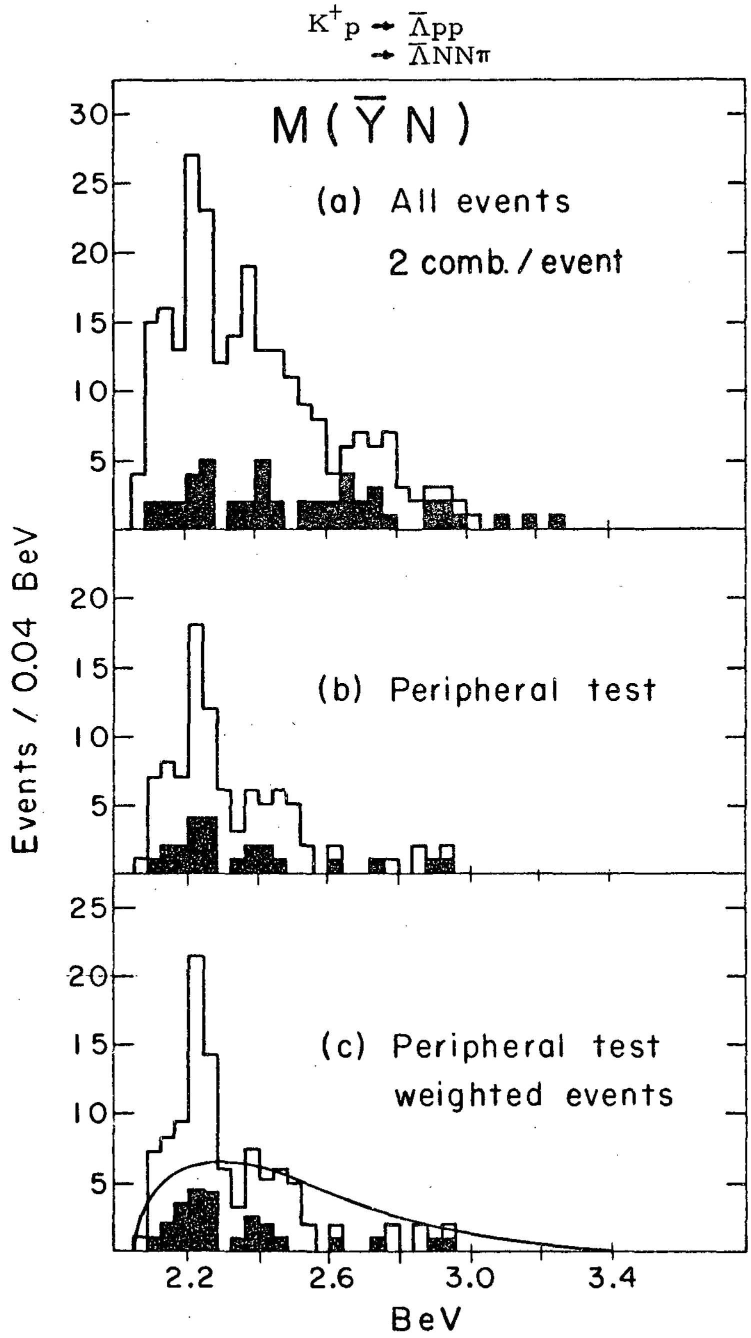
Fig. 22.
(Ref. 19)

Evidence for K*(1660) from the CERN-Brussels-Birmingham study of K^+p interactions at 5 GeV/*c*. Kπ in N* band.



Evidence for K*(1660) from the CERN-Brussels-Birmingham study of K^+p interactions at 5 GeV/*c*. K*(1400)πp Dalitz plot.

XBL 687-1202



XBL681-1574

Fig. 23. The $\bar{\Lambda}N$ mass enhancement. Data of Alexander et al., 9 GeV/c.[20]

Table I. Summary of properties for L-meson (ABCLV Collaboration)

Mass: 1785 ± 12 MeV
Width: 127 ± 43 MeV
J^P: $\neq 0^-$, could be $1^+, 2^-$

Branching ratios	Events	%
$K\pi\pi$	194.6	44.5 ± 15
$K\rho$	43.2	9.9 ± 6
$K^*(890)\pi$	106.4	24.4 ± 8
$K^*(1430)\pi$	71.9	16.4 ± 8
$K\omega$	21.0	4.8 ± 2
$K\pi$	<10	<2.3

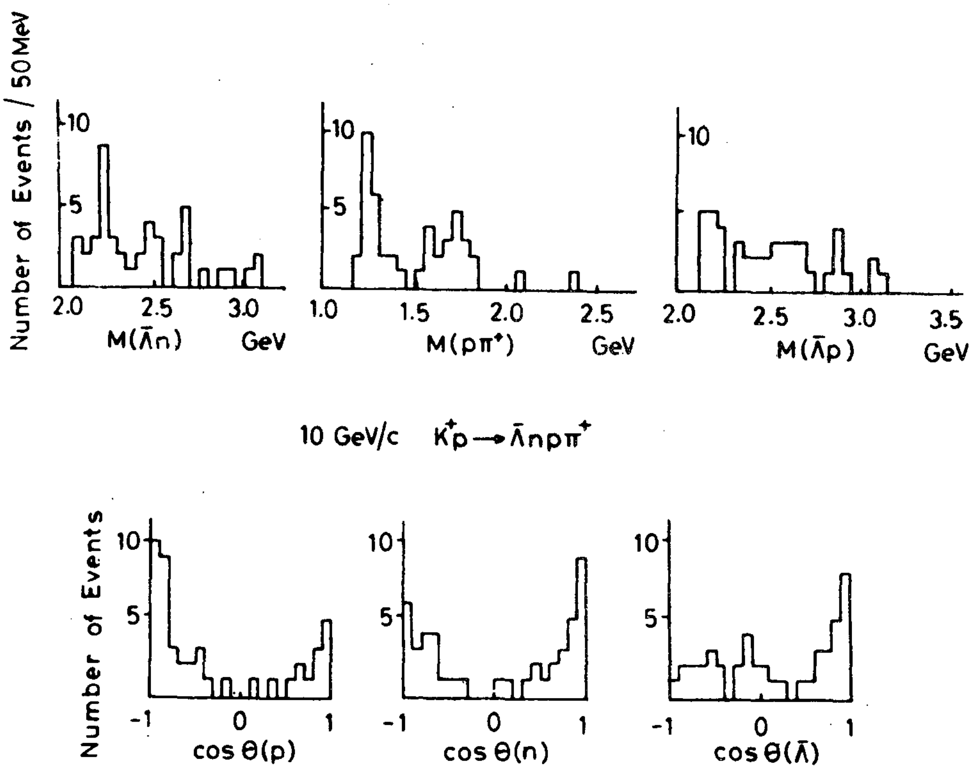
as it is not expected to suffer from the severe background problems of the $K\pi\pi$ channel in this mass region. Also the comparison with the corresponding $\bar{p}p$ and $\bar{p}n$ channels, in which evidence for possible boson peaks in σ_{tot} have been observed by Abrams et al., will be of interest.

In our own work (Alexander et al., K^+p at 9 GeV/c) we have observed a strong enhancement near the threshold for $\bar{\Lambda}N$ production. Aside from a clear broad enhancement there is a suggestion of structure at a mass of 2240 MeV (see Fig. 23). The Birmingham-Oxford-Glasgow collaboration (K^+p at 10 GeV/c) has studied the channel $K^+p \rightarrow \bar{\Lambda}np\pi^+$ and observes a similar behavior for the $\bar{\Lambda}n$ mass distribution on the very limited data available so far (see Fig. 24). The Rochester Group (Ferbel et al., K^+p at 12.6 GeV/c) again observe the low-mass $\bar{\Lambda}N$ enhancement but do not see any clear indication of structure (see Fig. 25).

More work will be needed on the investigation of this enhancement before its properties can be definitely established.

IV. THE A_1 AND THE GENERAL A ENHANCEMENT

This seems to be the Conference at which more structure is reported. In Figs. 26 to 33 I show some recent results on the $\pi\rho$ or $\pi\pi\pi$ mass distributions from



XBL 685-721

Fig. 24. The $\bar{\Lambda}n$ mass enhancement. Data of Birmingham-Oxford-Glasgow at 10 GeV/c.[16]

various experiments. It would appear that some structure in addition to the A_1 peak--the so-called $A_{1.5}$ peak--keeps showing up near 1.2 BeV in a number of experiments. There is the disturbing feature that the $A_{1.5}$ peak is not always at the same mass. It occurs at 1.17 BeV in the 5-GeV/c data of the University of Illinois and at 1.2 to 1.22 BeV in the Wisconsin data (7 GeV/c) and Notre Dame data (18.5 GeV/c) respectively. We can thus take three approaches to these data: (a) We add up the data from the experiments at the various momenta á la Ferbel and then the effect disappears--and in fact so does the conventional relatively narrow A_1. (b) We assume a mechanism which can give rise to some motion of the peak with incident momentum. Interference effects with a coherent background could be such a mechanism, for example. (c) We can assume that we are all victims of large statistical fluctuations.

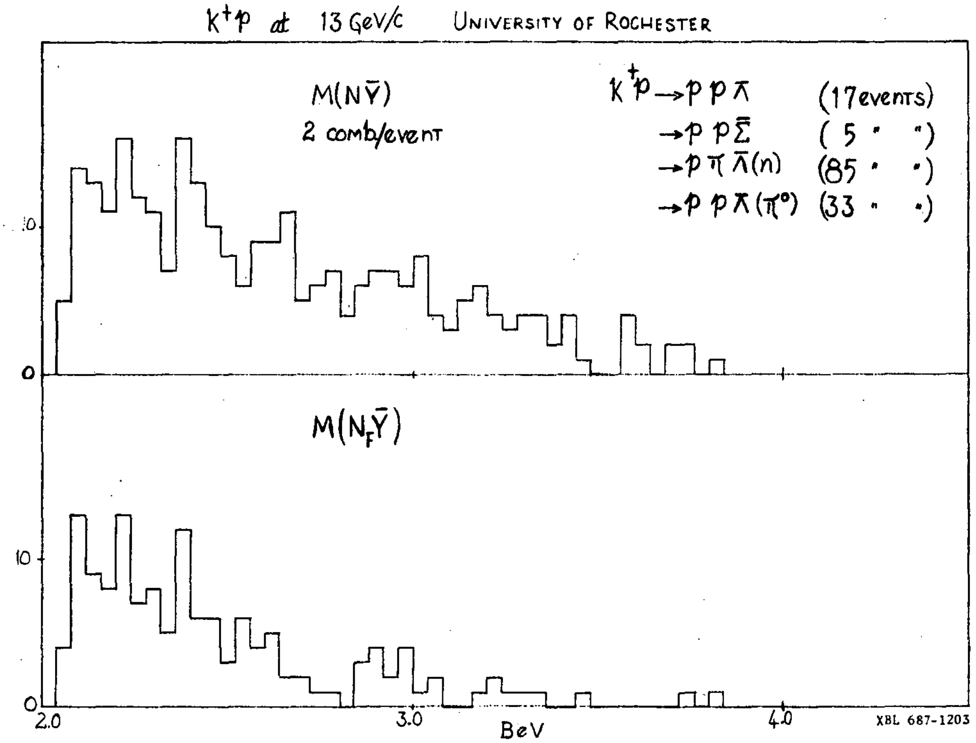
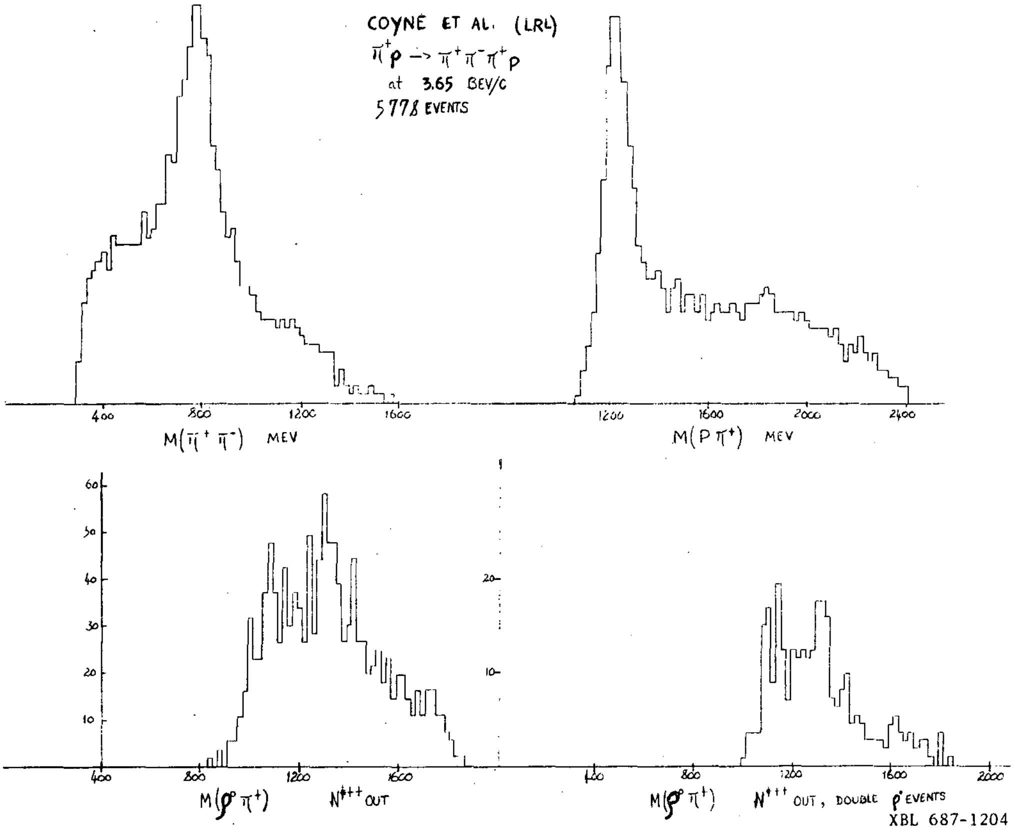


Fig. 25. The $\bar{\Lambda}$N mass enhancement. Data of Rochester at 12.6 GeV/c.[18]

I am afraid it will take much more data and several further conferences before we can settle this point.

A. IS THE A_1 PRODUCED OUTSIDE A DIFFRACTION DISSOCIATION PEAK AS WELL? As we all know, in most experiments the A_1 is produced in association with a very large diffraction dissociation peak. The question is then to find out whether it is also produced in other reactions? There are a number of such examples in the literature illustrated in Figs. 34 and 35. Whether the effects observed are indeed the manifestations of the A_1 is perhaps somewhat in doubt as yet.

In the case of the Q bump, evidence for $K^*(1300)$ has been seen in a non-Deck-type reaction $\pi^- p \rightarrow \Lambda K \pi\pi$ by Crennell et al. at 6 GeV/c (Brookhaven).



XBL 687-1204

Fig. 26. The $\pi\rho$ mass distribution.[21]

B. RESONANCES VERSUS DIFFRACTION DISSOCIATION OR DECK EFFECT. At present we know of three well-documented cases of diffraction dissociation effects:

(a) the A peak in $\pi\rho$ (discussed here)
(b) the Q peak in $\pi K^*(890)$ (discussed here)
(c) the baryon peak in $\pi\Delta$ (discussed in Schlein's paper in these Proceedings).

All three have the feature of nearly energy-independent cross sections characteristic of Pomeranchuk exchange. Furthermore they all have good evidence for additional structure indicative of resonance formation. Whether the resonances are produced by the diffraction dissociation--or are equivalent to it, as Chew and Pignotti have recently suggested[28]--is still under debate. To my mind, the evidence that there is some resonance structure present in

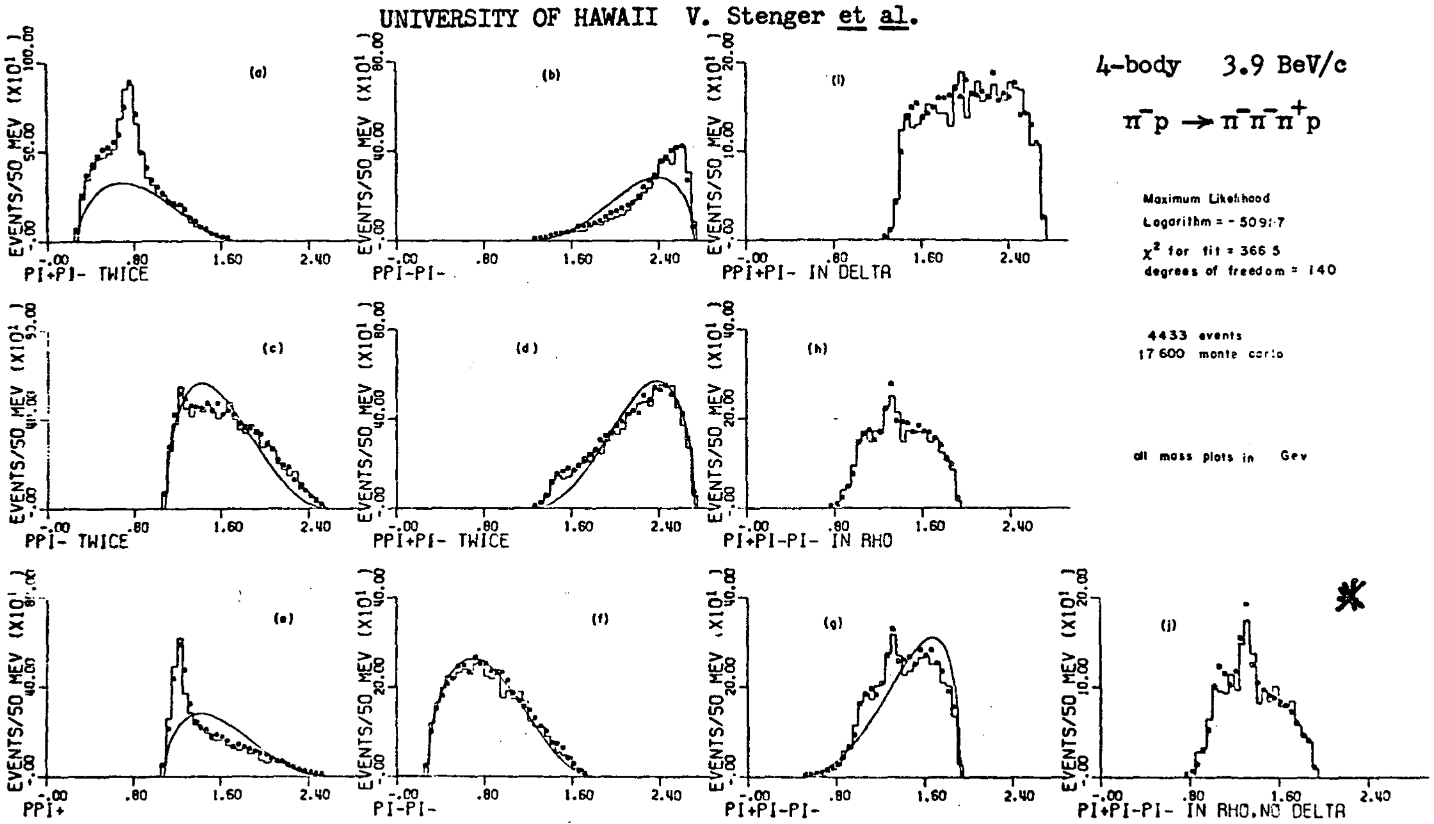


Fig. 27. The πρ mass distribution.

MURTLEBERT fits (asterisks) to data. Smooth curve is 100% phase space.

10 PARM. 12/11/67 RUN 11

XBL 687-1205

Gerson Goldhaber

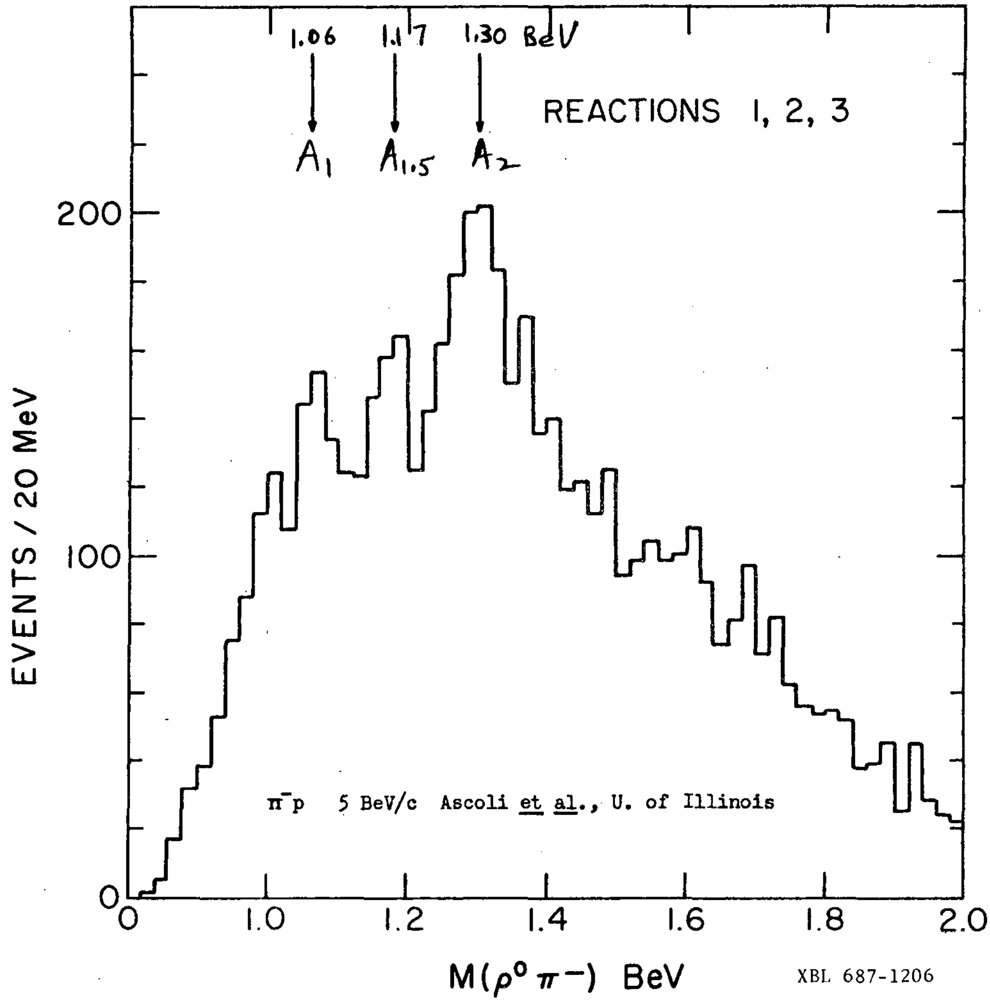


Fig. 28. The πρ mass distribution.[23]

each case looks very convincing.

I wish to thank G. Alexander, A. Firestone, C. M. Fu, and C. Wohl for helpful discussions and C. Frank, B. H. Hall, and H. J. Rice for help in preparing this article.

This work was done under the auspices of the U. S. Atomic Energy Commission.

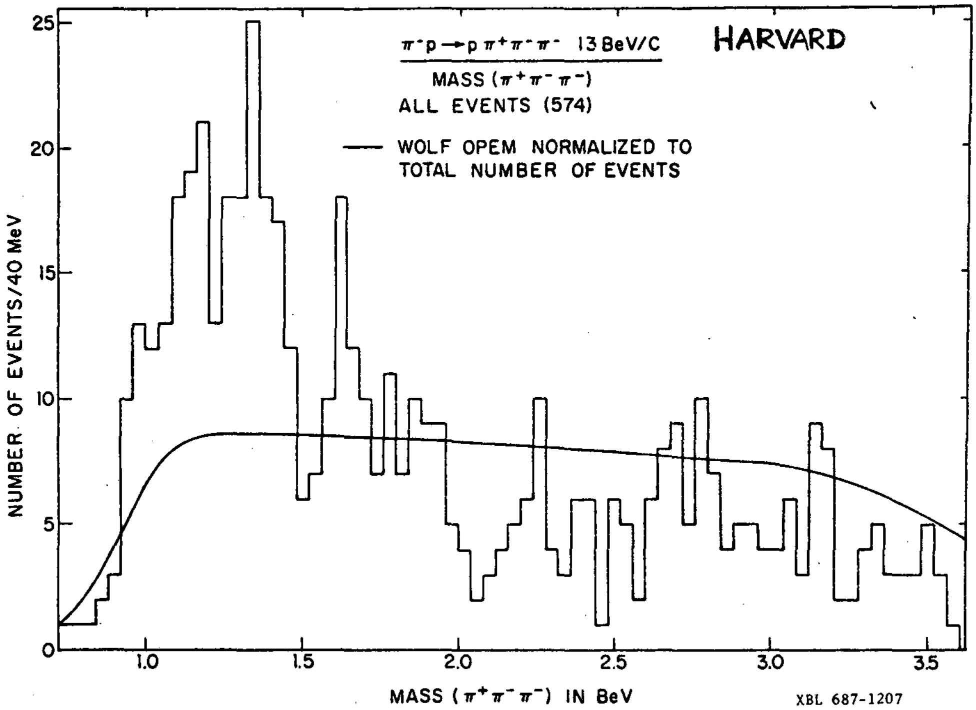


Fig. 29. The $\pi\rho$ mass distribution.[24]

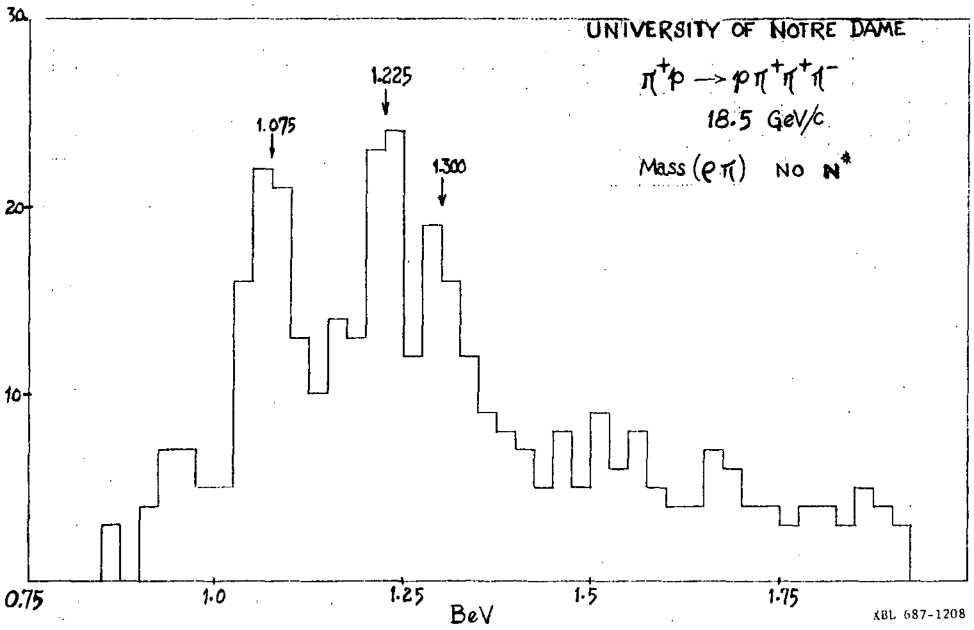


Fig. 30. The πρ mass distribution.[25]

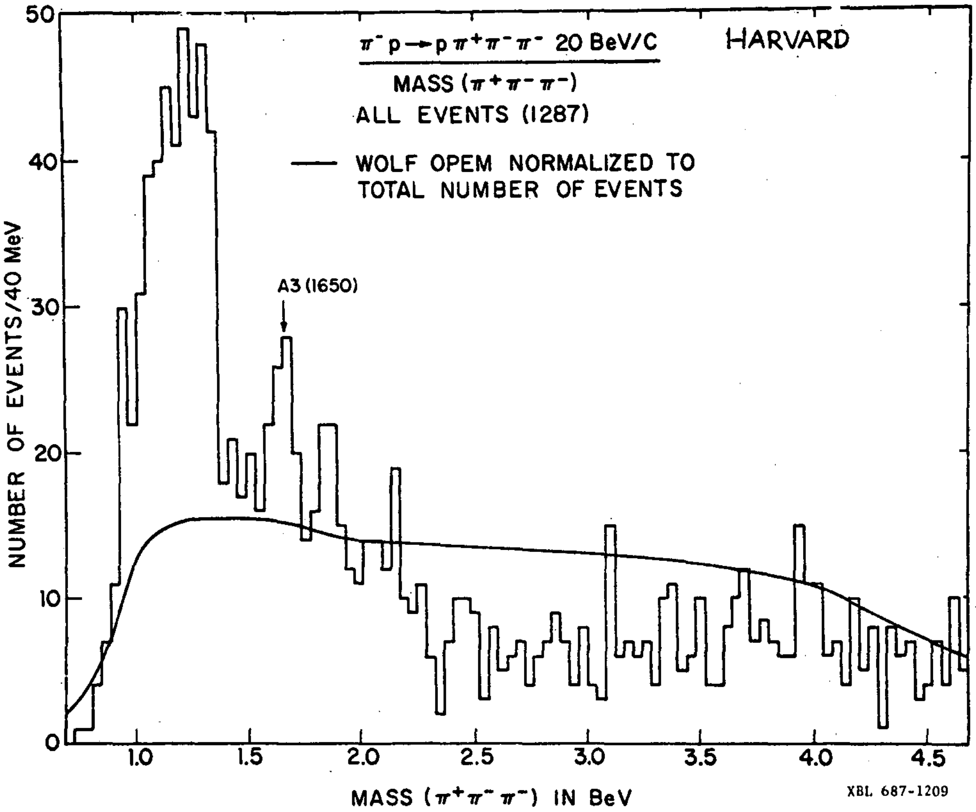


Fig. 31. The πρ mass distribution.[24]

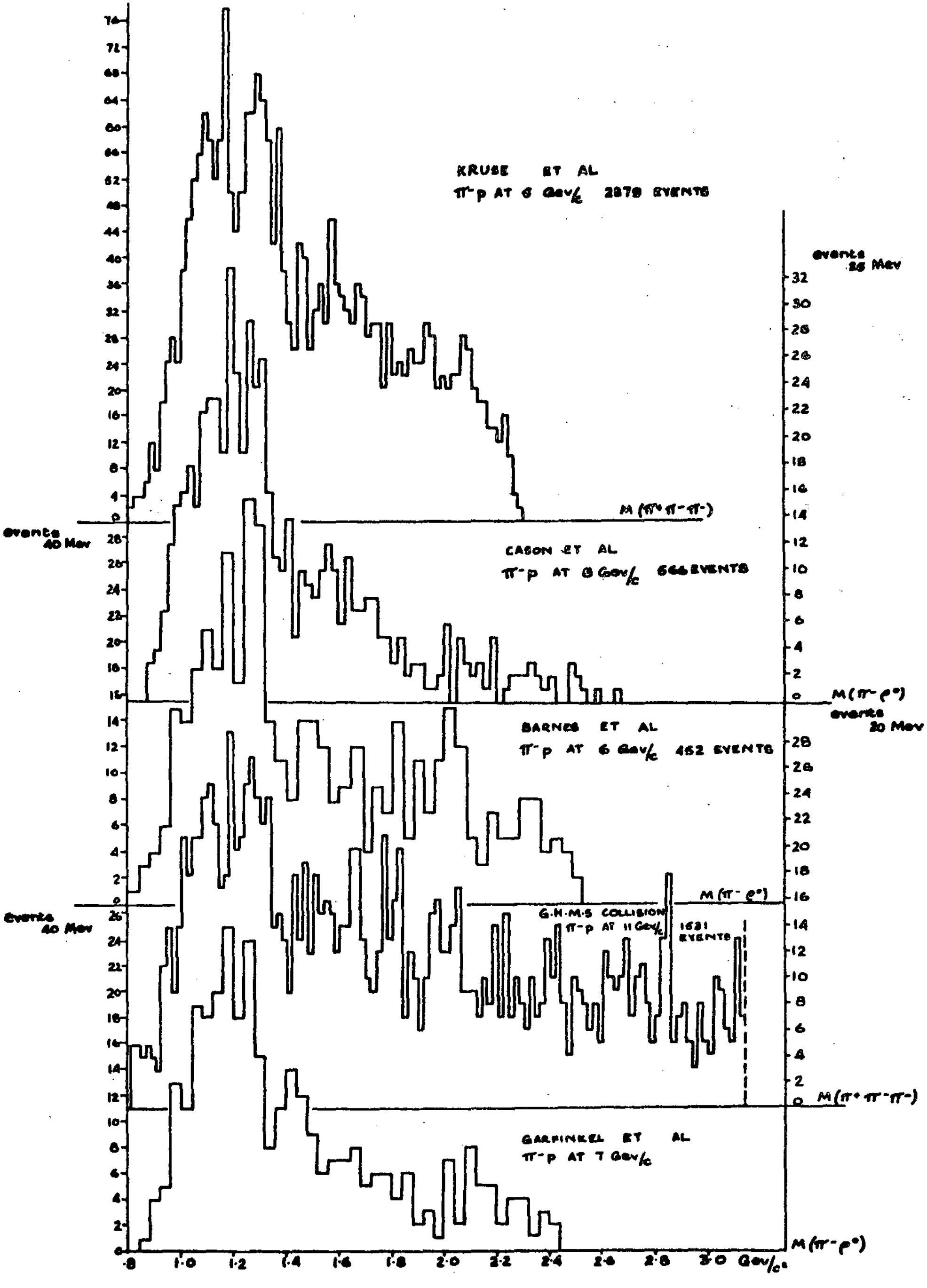
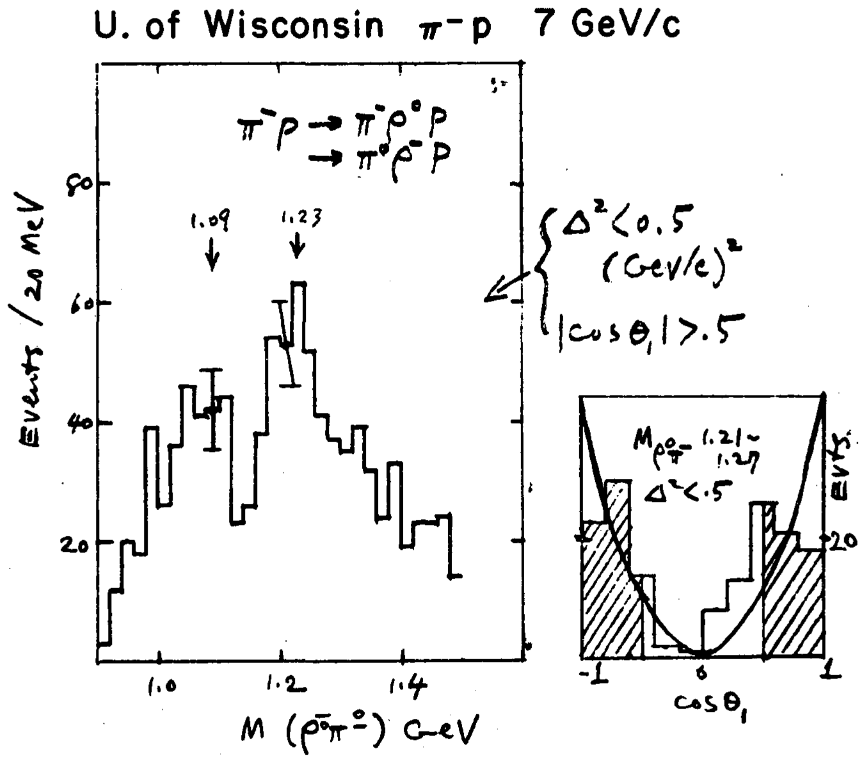


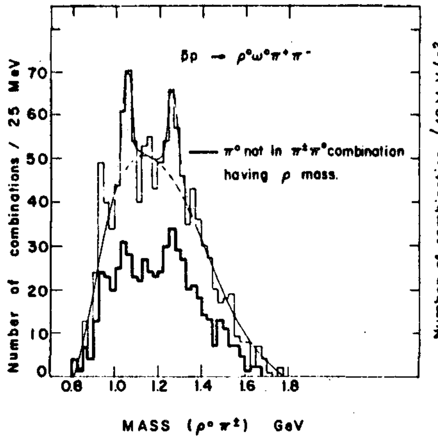
Fig. 32. Compilation of data relevent to $A_{1.5}$, by I. Butterworth.[19]

XBL 687-1210

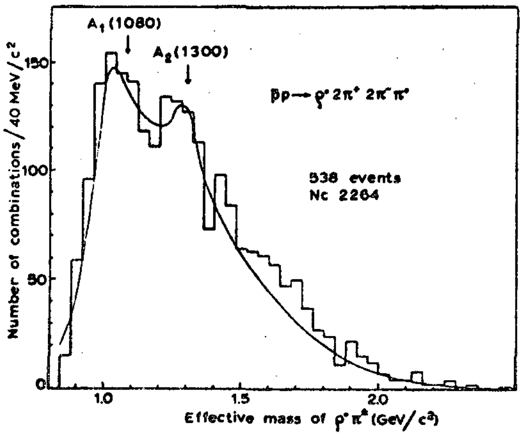


XBL 687-1211

Fig. 33. The $\pi\rho$ mass distribution.[26]



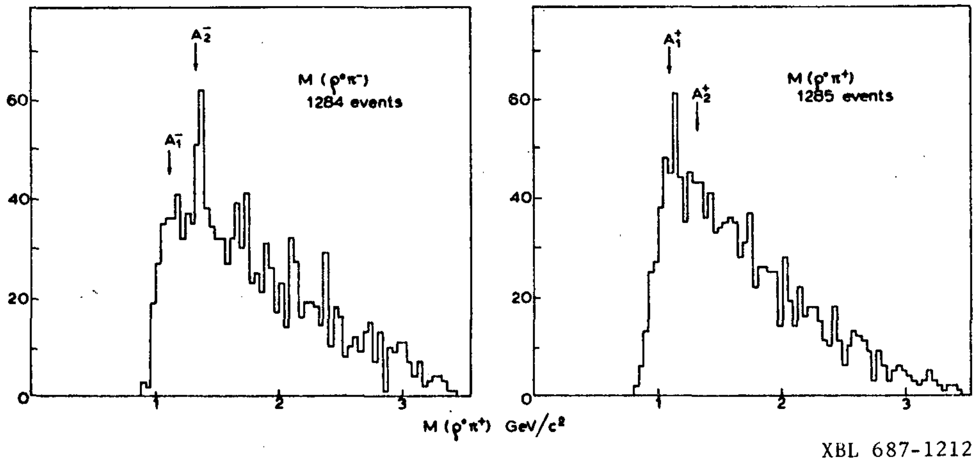
$M(\rho\pi)$ in $p\bar{p} \to 3\pi^+3\pi^-\pi^0$ containing non-interfering combinations of the $\pi^+\pi^-$ and $\pi^+\pi^-\pi^0$ in the ρ^0 and ω^0 region respectively. The thick line is for events where the π^0 is not in a $\pi^\pm\pi^0$ combination having a mass in the $\rho^\pm$-region. The reaction is studied at 3 GeV/c by Danysz et al.



$M(\rho^0\pi^\pm)$ for $\bar{p}p \to 3\pi^+3\pi^-\pi^0$ at 5.7 GeV/c, reported by Fridman et al.

Fig. 34

(Ref. 19)



XBL 687-1212

$M(\rho^0\pi^\pm)$ for $\pi^-p \to n\pi^+\pi^+\pi^-\pi^-$ at 11 GeV/c reported by the GHMS Collaboration, a) $\rho^0\pi^-$ b) $\rho^0\pi^+$.

OXFORD-MUNICH-BIRMINGHAM-GLASGOW RUTHERFORD LAB - I. C. (LONDON).[27]

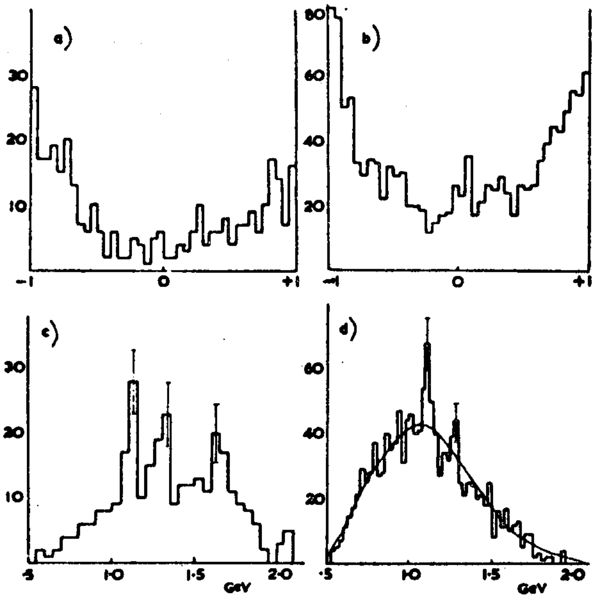


Fig. 35.

a) cos θ^*_Λ for reaction (1),
b) cos θ^*_Λ for reaction (2),
c) Mass of $(\pi^+\pi^+\pi^-)$ for reaction (1) with cos $\theta^*_\Lambda > 0$,
d) Mass of $(\pi^+\pi^+\pi^-)$ for reaction (2) with cos $\theta^*_\Lambda > 0$
(the phase space prediction is given by the curve).
(These plots are corrected for losses due to the finite fiducial volume and short decays).

XBL 687-1213

(1) $K^-p \rightarrow \Lambda\,\pi^+\pi^-\pi^+\pi^-$ 301 events
(2) $K^-p \rightarrow \Lambda\,\pi^+\pi^-\pi^+\pi^-\pi^0$ 1266 events

(1) $M(\pi^+\pi^+\pi^-) = 1117 \pm 30$ MeV $\Gamma = 50 \pm 50$ MeV
(2) $M(\pi^+\pi^+\pi^-) = 1111 \pm 10$ MeV $\Gamma = 50 \pm 25$ MeV

(1) $\sigma(\Lambda A_1^+\pi^-) = 9 \pm 3\,\mu b$
(2) $\sigma(\Lambda A_1^+\pi^-\pi^0) = 15 \pm 5\,\mu b$

REFERENCES

1. A. Firestone, C. M. Fu, G. Goldhaber, and B. C. Shen, submitted to the Conference.
2. Bruxelles-CERN-Birmingham Collaboration, submitted to the Conference.
3. F. Bomse, S. Borenstein, A. Callahan, J. Cole, B. Cox, D. Ellis, L. Ettlinger, D. Gillespie, G. Luste, R. Mercer, E. Moses, A. Pevsner, and R. Zdanis, Phys. Rev. Letters 20, 1519 (1968); also contribution to this Conference.
4. G. Bassompierre et al., Phys. Letters 26B, 30 (1967).
5. J. Park, S. Kim, G. Chandler, E. L. Goldwasser, T. P. Wangler, M. Derrick, J. G. Loken, F. Schweingruber, R. Ammar, R. Davis, J. Mott, and B. Werner, contribution to this Conference.
6. J. H. Friedman and R. R. Ross, LRL, contribution to this Conference.
7. C. Y. Chien, P. M. Dauber, E. I. Malamud, D. J. Mellema, P. E. Schlein, P. A. Schreiner, W. E. Slater, D. H. Stork, H. K. Ticho, and T. G. Trippe, Spin and Parity of the T = 1/2 $K\pi\pi$ System near 1.3 GeV, UCLA preprint UCLA-1020, 1967.
8. G. Goldhaber, A. Firestone, and B. C. Shen, Phys. Rev. Letters 19, 972 (1967).
9. G. Goldhaber, Phys. Rev. Letters 19, 976 (1967).
10. R. Gatto, L. Maiani, and G. Preparata, Nuovo Cimento 39, 1192 (1965).
11. G. L. Kane and H. S. Mani, University of Michigan preprint; Phys. Rev., in press.
12. G. Altarelli, R. Gatto, and L. Maiani, Istituto di Fisica dell'Universita Firenze preprint TH. 68/3.
13. H. Harari and H. Quinn, private communication.
14. H. J. Lipkin, Princeton University preprint PUC 937-323 June 1968.
15. R. Gatto and L. Maiani, Phys. Letters 26B, 95 (1967).
16. Birmingham-Oxford-Glasgow, 10-GeV/c K^+p, contribution to the Conference.
17. T. Ludlam, J. Lach, J. Sandweiss, and H. D. Taft, contribution to this Conference.
18. J. C. Berlinghieri, M. S. Farber, T. Ferbel, B. E. Forman, A. C. Melissinos, P. F. Slattery, T. Yamanouchi, and H. Yuta, University of Rochester, contribution to the Conference.
19. Quoted by I. Butterworth, Rapporteur's talk, in *Proceedings of the Heidelberg International Conference on Elementary Particles* (North-Holland Publishing

Company, Amsterdam, 1968).

20. G. Alexander, A. Firestone, G. Goldhaber, and B. C. Shen, Phys. Rev. Letters 20, 755 (1968).
21. D. G. Coyne, W. R. Butler, P. J. Gaposchkin, G. Goldhaber, J. A. Kadyk, J. N. MacNaughton, and G. H. Trilling, contribution to the Conference.
22. V. Stenger et al., University of Hawaii, contribution to the Conference.
23. G. Ascoli, H. B. Crawley, U. Kruse, D. W. Mortara, E. Schafer, A. Shapiro, and B. Terreault, University of Illinois preprint COO-1195-121 (March 1968).
24. M. L. Ioffredo, G. W. Brandenburg, A. E. Brenner, B. Eisenstein, L. Eisenstein, W. H. Johnson, Jr., J. K. Kim, M. E. Law, B. M. Salzberg, J. H. Scharenguivel, and J. J. Szymanski, Harvard University, contribution to the Conference.
25. N. M. Cason et al., University of Notre Dame, contribution to this Conference.
26. W. D. Walker et al., University of Wisconsin, contribution to this Conference.
27. W. W. M. Allison, A. Cruz, W. Schrankel, M. M. Haque, S. K. Tuli, P. J. Finney, C. M. Fisher, J. D. Gordon, R. M. Turnbull, R. Erskine, K. Sisterson, K. Paler, P. Chaudhuri, A. Eskreys, and S. J. Goldsack, Phys. Letters 25B, 619 (1967).
28. G. F. Chew and A. Pignotti, Phys. Rev. Letters 20, 1078 (1968).