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EVIDENCE FOR $K^*(1250)$ RESONANCE PRODUCTION IN K^+p INTERACTIONS AT 9 BeV/c$^+$

Gerson Goldhaber, Alexander Firestone, and Benjamin C. Shen*

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

August 9, 1967

We present evidence for $K^*(1250)$ resonance production in K^+p interactions at 9 BeV/c. We observe that the large $K\pi\pi$ mass enhancement in the region 1.1 to 1.5 BeV probably consists of three resonances at the observed masses 1.25, 1.36, and 1.42 BeV above a broad background due primarily to diffraction dissociation.

The $K\pi\pi$ mass enhancement in the region 1.1 to 1.5 BeV has been a phenomenon of great interest and much investigation.[1-7] It has been suggested in an earlier communication that the complex structure in this enhancement observed in K^+p interactions at 4.6 BeV/c consists of at least two resonances, $K^*(1320)$ and $K^*(1420)$, on top of a broad kinematical background produced via the Deck mechanism.[8] In this letter we wish to present, as preliminary results of a study of K^+p interactions at 9 BeV/c, evidence for the existence of a resonance at 1250 MeV in addition to $K^*(1320)$ and $K^*(1420)$. This resonance may be the same effect as the C meson observed in $\bar{p}p$ annihilations at rest.[9,10] The production rates of these resonances depend sensitively on the momentum transfer to the recoil proton in such a

way that the resonance effects are partially separated from the background events and partly from each other for different regions of momentum transfer. In our data the observed masses of the three resonances are 1250, 1360, and 1420 MeV, and full widths at half maximum are 60, 80, and 80 MeV respectively. We also speculate that the apparent masses and widths of the peaks depend on the interference effects between resonances of the same spin-parity and possibly with coherent background. Details of an investigation into such effects are described in the following letter.[11]

Our experiment was carried out in the Brookhaven National Laboratory's 80-inch hydrogen bubble chamber, which was exposed to a 9-BeV/c rf-separated K^+ beam at the Alternating Gradient Synchrotron (AGS). The measurement was performed with the Lawrence Radiation Laboratory's Flying Spot Digitizer (FSD), and the geometric reconstruction and kinematical fitting were accomplished with the program TGVP-SQUAW.[12-14] The beam momentum at the entrance of the chamber is 8950±65 MeV/c, and the upper limit on the pion contamination is 1.3%.[15]

In the investigation of the $K\pi\pi$ system, we have studied primarily the reactions

$$K^+p \rightarrow K^+\pi^-\pi^+p, \qquad 2572 \text{ events}, \qquad (1)$$

$$K^+p \rightarrow K^0\pi^0\pi^+p, \qquad 416 \text{ events}. \qquad (2)$$

Events have been identified in a computer program utilizing FSD ionization measurements in addition to the kinematical fitting confidence criterion.[16] The present sample is based upon measurements of 34 000 four-pronged events and 6000 two-pronged events with vee. A comparison with visual identification indicates maximum possible misidentification of 3% for reactions (1) and (2). As an illustration of the reliability

of our identification of events and the mass resolution, we show in Fig. 1a the $\pi^+\pi^-\pi^0$ mass spectrum in 20-MeV intervals for events of the reaction

$$K^+p \rightarrow K^+\pi^+\pi^-\pi^0p, \qquad 2196 \text{ events.} \qquad (3)$$

We find that the ω meson is clearly observed at 788±5 MeV. The observed experimental width of the ω meson is approximately 35 MeV; the shaded area corresponds to the distribution after events in the N^{*++} band (1.16 BeV $\leq M(p\pi^+) \leq$ 1.32 BeV) have been removed.[17] The typical errors of the $K\pi\pi$ mass in the mass region 1.1 to 1.5 BeV are 7 MeV for four-constraint-fit events of reaction (1) and 15 MeV for one-constraint-fit events of reaction (2).

In Fig. 1b we show in intervals of 40 MeV the mass distribution of the positively charged $K\pi\pi$ system for all events in reactions (1) and (2). The principal feature of this distribution is the broad enhancement in the mass region 1.1 to 1.5 BeV. This enhancement corresponds to a cross section of 0.3±0.1 mb.[18] We wish to point out here that a second enhancement is also observed in the mass region 1.60 to 1.76 BeV which is probably the same effect as the L meson.[19]

In Fig. 2a we show the $K\pi\pi$ mass distribution for events of reactions (1) and (2) combined, with the mass of the $K^+\pi^-$ pair for reaction (1) and either of the $K\pi$ pairs for reaction (2) in the $K^*(890)$ mass band or the $\pi\pi$ mass in the ρ-meson mass band.[20] In this graph the events in the N^{*++} band have been removed from the sample. Two mass peaks centered at 1250 and 1400 MeV above a broad background can be clearly distinguished. These two peaks are well resolved by a 60-MeV-wide dip of about 3.2 standard deviations, and are respectively 7 and 6 standard deviation effects above background.

We have further observed that the $K\pi\pi$ mass distribution appears to be a sensitive function of the momentum transfer to the recoil proton. This feature is illustrated in Figs. 2b–d. For events with very small momentum transfer to the proton, $\Delta_p^2 < 0.1\ (\mathrm{BeV/c})^2$, we observe only one wide peak with no significant structure, as shown in Fig. 2b. This may be interpreted primarily as a kinematical peak or a nonresonant state produced via diffraction dissociation.[21–23] For events with $0.1 \leq \Delta_p^2 < 0.3\ (\mathrm{BeV/c})^2$ there are two distinct peaks above a somewhat reduced background, as shown in Fig. 2c; these we interpret as $K^*(1250)$ and $K^*(1320)$. The $K^*(1420)$ production seems to have a Δ_p^2 distribution somewhat wider than those of the $K^*(1250)$ and $K^*(1320)$. After we have removed the major part of the $K^*(1250)$ and $K^*(1320)$ and the diffraction background, which are associated with small momentum transfer, by selecting events with $\Delta_p^2 \geq 0.3\ (\mathrm{BeV/c})^2$, the $K^*(1420)$ appears clearly above background in the shaded histogram in Fig. 2d. Although the $K^*(1320)$ and $K^*(1420)$ separation depends very much on the difference between their production differential cross sections, the $K^*(1250)$ is well resolved from the rest by a valley of 3.3 standard deviations for events with $\Delta_p^2 \geq 0.1\ (\mathrm{BeV/c})^2$, as shown in Fig. 2d.

In accordance with the foregoing discussion we therefore conjecture that the large $K\pi\pi$ mass enhancement in the region 1.1 to 1.5 BeV consists of at least four effects with different momentum-transfer dependence: a broad background peak due to diffraction dissociation, and three distinct resonances. The apparent resonance parameters observed in our experiment are

$$M[K^*(1250)] = 1250 \pm 10\ \mathrm{MeV},\ \Gamma[K^*(1250)] = 50 \pm 20\ \mathrm{MeV};$$

$$M[K^*(1320)] = 1360 \pm 10\ \mathrm{MeV},\ \Gamma[K^*(1320)] = 80 \pm 20\ \mathrm{MeV};$$

$$M[K^*(1420)] = 1420 \pm 10 \text{ MeV}, \ \Gamma[K^*(1420)] = 80 \pm 20 \text{ MeV}.$$

As may be noted, the observed mass 1360 MeV is higher than that reported earlier for the $K^*(1320)$.[8,24] We emphasize here that the true parameters of these resonances may depend sensitively on the interference effects among the resonances as well as upon the coherent background, and may be shifted from the values we have observed in the experiment presented here.[11]

In Fig. 3 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) $1000 \text{MeV} \leq M(K\pi\pi) < 1180$ MeV, (II) $1180 \text{ MeV} \leq M(K\pi\pi) < 1280$ MeV, (III) $1300 \text{ MeV} \leq M(K\pi\pi) < 1400$ MeV, (IV) $1420 \text{ MeV} \leq M(K\pi\pi) \leq 1500$ MeV, and (V) $1600 \text{ MeV} \leq M(K\pi\pi) \leq 1760$ MeV. Regions II, III, and IV correspond to the (1250), (1360), and (1420) mass bands respectively. Region I is the control region below the 1250 peak 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. The shaded histograms in the $M(\pi\pi)$ distributions in Figs. 3b correspond to events in the $K^{*0}(890)$ band. We have also studied the five-particle final state $K^+\pi^+\pi^-\pi^0 p$ and found no evidence for the $K\omega$ decay mode of the $K^*(1320)$.

Since the major decay channel of $K^*(1250)$ and $K^*(1320)$ is $K^*(890)+\pi$, we study the $K^*(890)+\pi$ system in the hope that interference effects with the $\rho+K$ channel are small. As shown in Fig. 3c, the distributions of the $K\pi$ scattering angle in the $(K\pi)^0$ rest frame, $\cos\alpha$, indicate that for regions II and III the spin of $K^*(890)$ is aligned in such a way that the z component along the incident direction is zero.[25] This alignment is

consistent with the interpretation that the $K^*(1250)$ and $K^*(1320)$ resonances are of $J^P = 1^+$, are produced by Pomeranchuk exchange, and decay mainly by s wave into $K^*(890) + \pi$. Here we note that the same alignment is also expected for the background that is due to the Deck mechanism. The decay angular distributions of $\cos\theta$, where θ is the angle between the odd π^+ and the incident K^+ in the $K\pi\pi$ rest frame, are largely isotropic, consistent with s wave, with possibly a small amount of d wave contribution for regions II and III, as shown in Figs. 3d. From the evidence of low decay branching ratio into $K\pi$ for the enhancement in the mass region 1.1 to 1.4 BeV, the J^P assignment is not likely to be 1^- or 2^+.[26] Figures 3e show the $K^*(890)$ decay angular distribution of $\cos\xi$, where ξ is the $K^*(890)$ decay angle with respect to the odd-pion direction in the $K^*(890)$ rest frame. The distributions in regions II and III are isotropic, which implies the $J^P = 0^-$ assignment is unlikely, since it would predict a $\cos^2\xi$ distribution. Thus the likely J^P assignments for the $K^*(1250)$ and $K^*(1320)$ are 1^+ or 2^-. Although 2^- can not be excluded, our data favor the assignment of 1^+ for both the $K^*(1250)$ and $K^*(1320)$ resonances.

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FOOTNOTES AND REFERENCES

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* Now at Stanford Linear Accelerator Center, Stanford University, California

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10. This resonance may be the same effect as that observed by Grard et al. and Shen et al. in the five-particle final states. See Ref. 1 for details and references.

11. G. Goldhaber, following letter.

12. H. Foelsche, J. Lach, J. Sandweiss, and M. Gudzik, Brookhaven AGS Report HF/JL/JS/MG-1, July 1964.

13. The Berkeley camera system was developed by Duane Norgren and Daniel Curtis. We wish to thank D. Curtis for his contribution during the exposure at the AGS.

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15. The pion contamination of the K^+ beam is consistent with zero. The upper limit of 1.3% is a conservative estimate from a study of the elastic scattering events.

16. The projected measured bubble density of the track with proton interpretation is compared with that expected in all views. Tracks with interpretations other than proton are not used, since at our incident energy the K,π ambiguity is in most cases difficult to resolve.

17. This reaction actually represents a more difficult problem in the selection of a fit of the correct hypothesis than reaction (1) for the same amount of ionization information, because the kinematical fitting criterion for one-constraint fit is not so discriminative as that for four-constraint fit.

18. This enhancement was called the Q effect by the authors of Ref. 2. The quoted cross section, referring to the enhancement with N^{*++} removed, is estimated from reactions (1) and (2) separately

and corrected for invisible K^o decays and FSD efficiencies.

19. J. Bartsch et al. [Aachen – Berlin – CERN – Imperial College (London) – Vienna Collaboration] Phys. Letters 22, 357 (1966).

20. The $K^*(890)$ mass band is defined from 860 to 940 MeV, whereas the ρ-meson band is defined from 650 to 850 MeV.

21. See, for example, R. T. Deck, Phys. Rev. Letters 13, 169 (1964), and Ref. 8.

22. See, for example, M. L. Good and W. D. Walker, Phys. Rev. 120, 1857 (1960); E. Feinberg, and I. Pomeranchuk, Nuovo Cimento Suppl. 3, 652 (1956), M. Ross and L. Stodolsky, Phys. Rev. 149B, 1172 (1966); M. Ross and Y. Y. Yam, University of Michigan, Preprint.

23. Here it must be noted that the interference effects may depend upon Δ_p^2, therefore the nature of this wide peak at low Δ_p^2 may be more complicated.

24. To avoid confusion in nomenclature we refer to the peak observed here at 1360 MeV as the $K^*(1320)$.

25. It was observed in the study of $K^+p \rightarrow K^{\overset{+}{o}}\pi^{\overset{-}{o}}\pi^+p$ at 4.6 BeV/c (Ref. 8) that the $K^*(1320)$ resonance was mainly associated with the equatorial region of $\cos\alpha$. That observation is quite contrary to our data at 9 BeV/c, which indicate that both the $K^*(1250)$ and $K^*(1320)$ have $\cos^2\alpha$ shape distributions in the $K\pi$ scattering angle. One possible explanation for this difference is that the production mechanisms of the $K^*(1250)$ and $K^*(1320)$ may be a sensitive function of incident energy, giving rise to different decay angular distributions. This can also give rise to the energy dependence of the phase between the two resonance amplitudes, as described in Ref. 11. Without invoking

25. the interference between these two resonances, it is difficult to account for all the different observations by various experimental groups at different incident momenta and the fact that the $K^*(1250)$ production rises extremely slowly with incident momentum far above its kinematical production threshold.

26. From our preliminary data on the reaction $K^+p \rightarrow K^o\pi^+p$ we observe no evidence that the $K^*(1250)$ and $K^*(1320)$ decay into $K^o\pi^+$.

FIGURE CAPTIONS

Fig. 1 (a) $M(\pi^+\pi^-\pi^o)$ distribution in 20-MeV intervals for reaction $K^+p \rightarrow K^+\pi^+\pi^-\pi^o p$.

(b) $M(K\pi\pi)^+$ distribution in 40-MeV intervals for reactions $K^+p \rightarrow K^{+o}\pi^{-o}\pi^+ p$. The shaded histograms correspond to the same distributions with events in the N^{*++} band removed.

Fig. 2 $M(K\pi\pi)^+$ distributions for events in the ρ meson or $K^*(890)$ bands with N^{*++} band removed for (a) all Δ_p^2, (b) $\Delta_p^2 < 0.1$ $(BeV/c)^2$, (c) $0.1 \leq \Delta_p^2 < 0.3$ $(BeV/c)^2$, and (d) $\Delta_p^2 \geq 0.1$ $(BeV/c)^2$, and the shaded histogram in (d) for $\Delta_p^2 \geq 0.3$ $(BeV/c)^2$. The shaded area in (a) represents our estimate of the $K^*\pi$ and $K\rho$ decay modes of the $K^*(1420)$.

Fig. 3 The decay properties of the $K\pi\pi$ system shown for five $K\pi\pi$ mass regions I – V with N^{*++} band removed: (a) $M(K\pi)^o$, (b) $M(\pi\pi)$, the shaded histograms for events in the $K^{*o}(890)$ band and for $K^{*o}(890)$ events, (c) $\cos\alpha$, where α is the angle between the outgoing K and the incident K^+ in the $(K\pi)^o$ rest frame, (d) $\cos\theta$, where θ is the angle between the odd π^+ and the K^+ in the $(K\pi\pi)^+$ rest frame, and (e) $\cos\xi$, where ξ is the angle between the outgoing K and the $K^{*o}(890)$ flight direction in the $K^{*o}(890)$ rest frame.

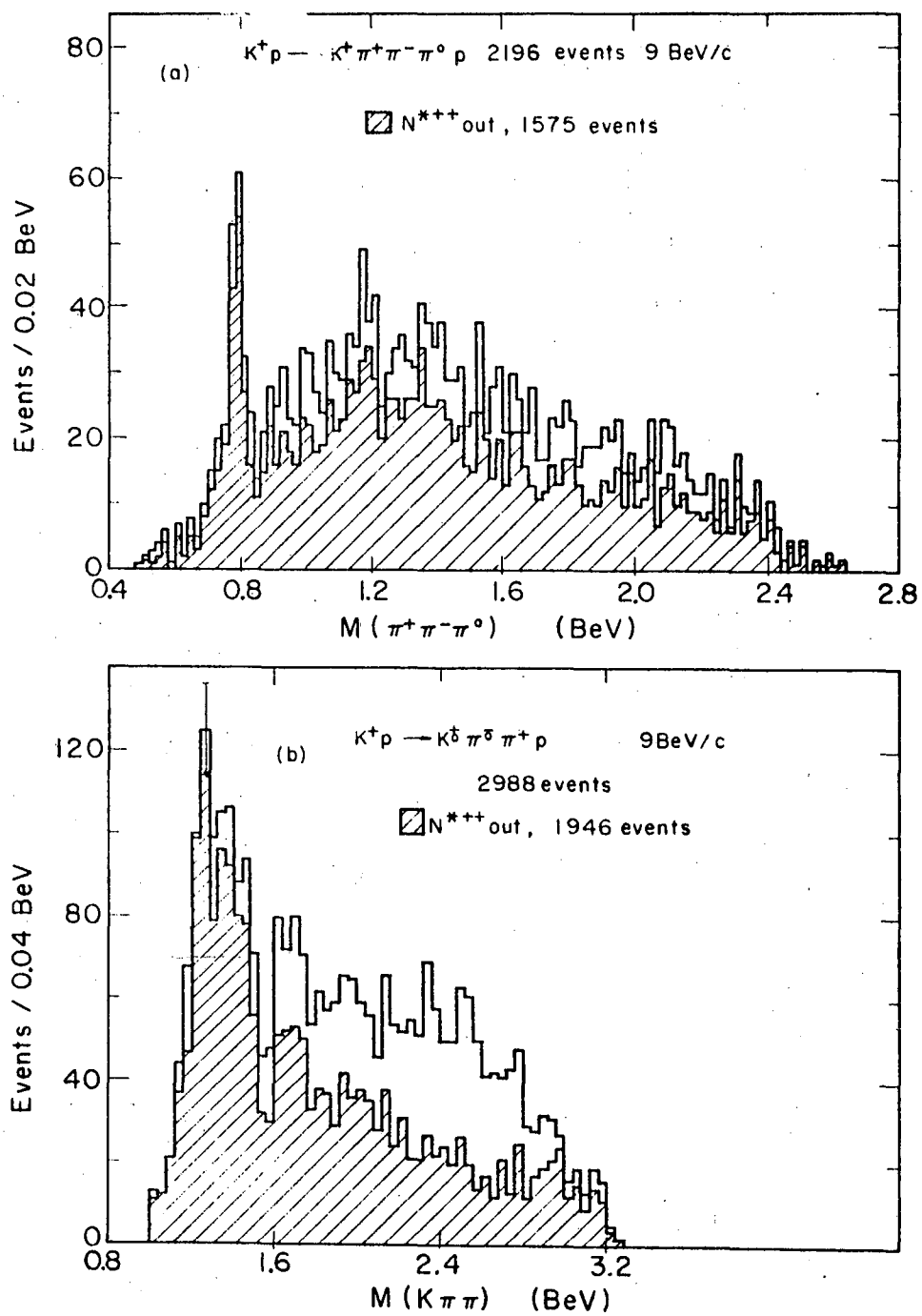

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Fig. 1

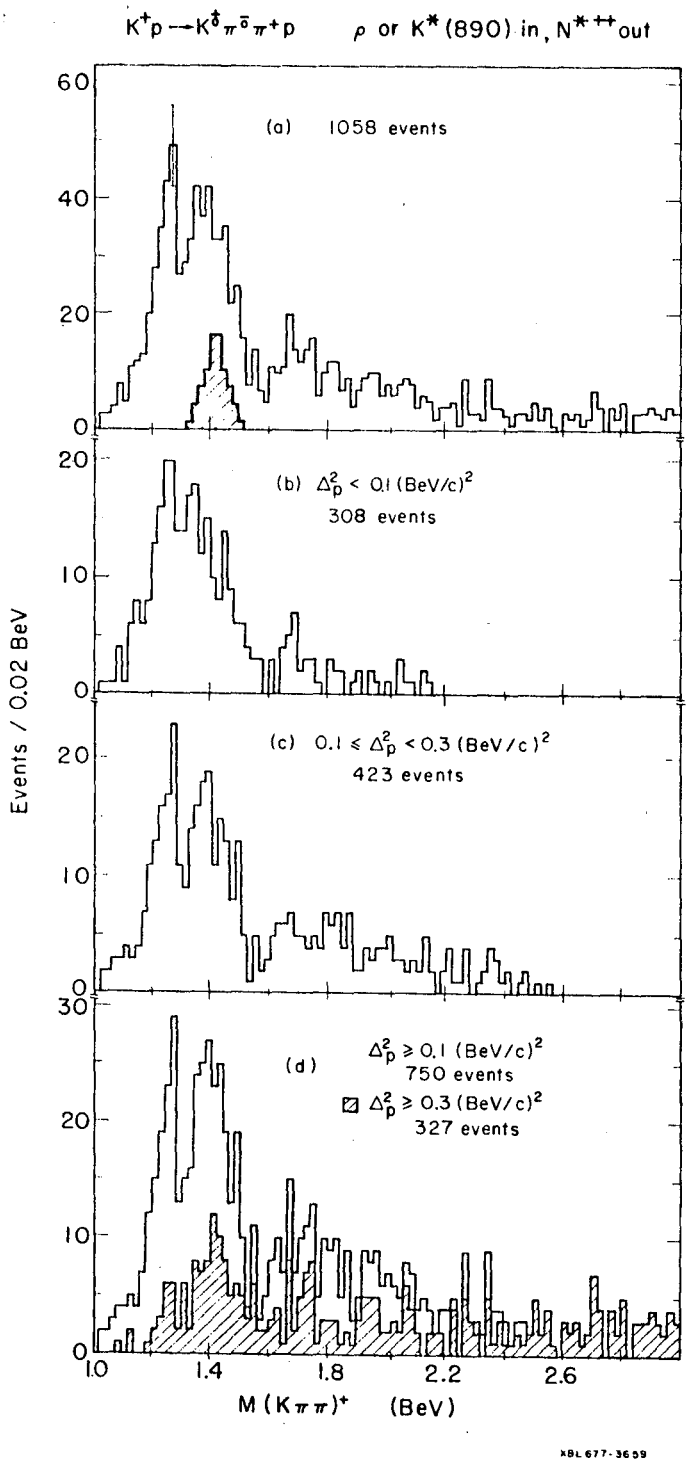
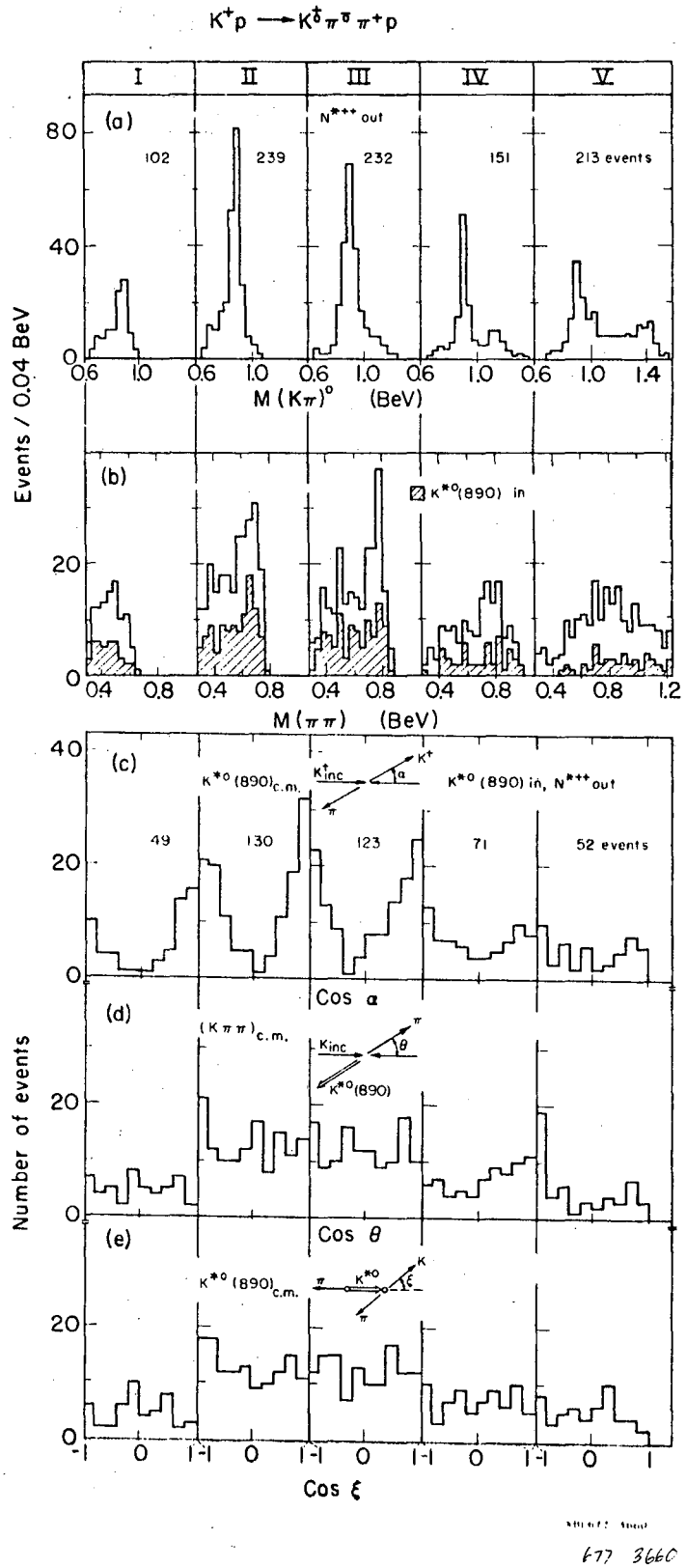

$K^+p \to K^0\pi^0\pi^+p$ ρ or $K^*(890)$ in, N^{*++} out
(a) 1058 events
(b) $\Delta_p^2 < 0.1$ (BeV/c)^2
308 events
(c) $0.1 \leq \Delta_p^2 < 0.3$ (BeV/c)^2
423 events
(d) $\Delta_p^2 \geq 0.1$ (BeV/c)^2
750 events
$\Delta_p^2 \geq 0.3$ (BeV/c)^2
327 events
Events / 0.02 BeV
M ($K\pi\pi$)$^+$ (BeV)
XBL 677-3659

Fig. 2



677 3660

Fig. 3

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