[4]N. Cabibbo, Phys. Rev. Letters 10, 531 (1963).

[5]Our G^2 corresponds to g^2 of Ref. 1.

[6]N. Cabibbo, in Proceedings of the Thirteenth International Conference on High Energy Physics, Berkeley, California, 1966 (University of California Press, Berkeley, 1967); T. D. Lee and C. S. Wu, Ann. Rev. Nucl. Sci. 15, 381 (1965); E. S. Abers, R. E. Norton, and D. A. Dicus, Phys. Rev. Letters 18, 676 (1967).

[7]This is justified by the Ademollo-Gatto theorem.

[8]L. B. Auberbach, J. M. Dobbs, A. K. Mann, W. K. McFarlane, D. H. White, R. Coester, P. T. Eschstruth, G. K. O'Neill, and D. Yount, Phys. Rev. 155, 1505 (1967). We would like to thank Professor A. K. Mann for communicating the results prior to publication.

[9]The value for $\theta_V^{(M)}$ is obtained from K_{13} data by including the q^2 dependence of the form factor according to the K^* dominance model. See S. Oneda and J. Sucher, Phys. Rev. Letters 15, 927 (1965).

EVIDENCE FOR THE $K^*(1300)$ IN π^-p INTERACTIONS AT 6 GeV/c*

David J. Crennell, George R. Kalbfleisch, Kwan Wu Lai, J. Michael Scarr, and Thomas G. Schumann
Physics Department, Brookhaven National Laboratory, Upton, New York

(Received 29 May 1967)

Evidence for a $K\pi\pi$ enhancement at ~1300 MeV has come from the study of Kp interactions, in particular from the reaction $K^+ + p \rightarrow K^+ + \pi^+ + \pi^- + p$ at 4.65 and 5 GeV/c.[1] The $K^*(1300)$ has been shown to decay strongly into $\pi + K^*(890)$ and possibly also into $K + \rho(760)$. Since the $K^*(1300)$ mass is not far above the thresholds for these quasi-two-body decays, it has been difficult to exclude the possibility that the enhancement is due to kinematic effects.[2] In this Letter we report independent evidence[3] from the reaction $\pi^- + p \rightarrow \Lambda + K^*(1300)^0 \rightarrow \Lambda + K + \pi + \pi$ supporting the resonance interpretation for this K^*. We find a mass of ~1300 MeV, a width of ~60 MeV, and isospin $\frac{1}{2}$.

The sample of events for this study is obtained from a systematic investigation of $\pi^{\pm}p$ interactions at 6 GeV/c in the Brookhaven National Laboratory 80-inch hydrogen bubble chamber. This analysis is based on a π^-p exposure of 230 000 pictures and a π^+p exposure of 80 000 pictures. The events used for this analysis were required to have a visible Λ^0 decay with seen and unseen K^0 included. We present here data on the following channels leading to either neutral or doubly charged $K\pi\pi$ states.[4]:

$$\pi^- + p \rightarrow \Lambda + K^0 + \pi^+ + \pi^-, \text{ 647 events;} \quad (1a)$$

$$\rightarrow \Lambda + K^+ + \pi^0 + \pi^-, \text{ 401 events;} \quad (1b)$$

$$\pi^+ + p \rightarrow \Lambda + K^0 + \pi^+ + \pi^+, \text{ 127 events;} \quad (2a)$$

$$\Lambda + K^+ + \pi^+ + \pi^0, \text{ 163 events.} \quad (2b)$$

Figures 1(a) and 1(b) show the $(K\pi\pi)$ distributions for Reactions (1) and (2), respectively. Two enhancements are seen in the neutral $(K\pi\pi)^0$ mass spectrum at 1300 and 1440 MeV, whereas no significant structure is observed in the $(K\pi\pi)^{++}$ distribution. The solid curves indicate an estimate of the background togeth-

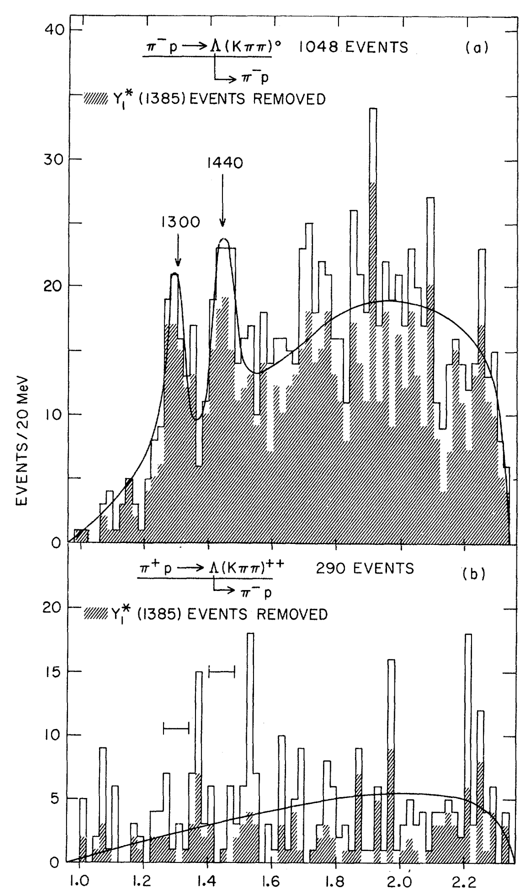

FIG. 1. The $(K\pi\pi)$ mass spectra. The solid curves indicate an estimate of the background, together with two resonance peaks in the case of the $(K\pi\pi)^0$ distribution.

er with two resonance peaks in the case of the $(K\pi\pi)^0$ distribution. The shaded areas show the events after removal of the $Y_1^*(1385)$ bands (1.34-1.43 GeV). The enhancements at 1300 and 1440 MeV in the $(K\pi\pi)^0$ spectrum remain after the $Y_1^*(1385)$ subtractions and we associate the second peak with the $K^*(1420)$.[5] In the following analysis we use only events with $Y_1^*(1385)$ excluded.

Figures 2(a) and 2(b) are the $(K\pi)$ and $(\pi\pi)$ mass spectra from Reaction (1). Strong $K^*(890)$ and ρ production is evident. Events giving $(\pi\pi)$ mass in the ρ band (0.64-0.88 GeV) have been removed from Fig. 2(a). The positively charged ($K^0+\pi^+$ and $K^++\pi^0$) combinations are shown shaded. Events in the K^* band (0.84-0.94 GeV) have been removed from Fig. 2(b).

To examine the quasi-two-body decay mode of the two $(K\pi\pi)^0$ enhancements at 1300 and 1440 MeV, we show in Figs. 3(a), 3(b), and 3(c), respectively, scatter plots of the $(\pi\pi)^{-,0}$, $(K\pi)^+$, and $(K\pi)^0$ mass spectra versus the $(K\pi\pi)^0$ mass spectrum. The ρ, $K^*(890)^+$, and $K^*(890)^0$ bands are indicated by the horizontal lines. There is evidence of an accumulation of events where the ρ and $K^*(890)^+$ bands intersect the two $(K\pi\pi)^0$ enhancements as shown by the arrows; there is, however, no significant structure in the $(K\pi)^0$ band. We also note that events in the $K^*(890)^+$ band are mainly concentrated in the 1300- and 1440-MeV regions. We therefore conclude that both $K^*(1300)$ and $K^*(1440)$ decay into $K+\rho$ and $\pi+K^*(890)^+$. The contribution of $\pi^0K^*(890)^0$ to the $(K\pi\pi)^0$ enhancements would be expected to be weak since the relative intensity of $[\pi^- +K^*(890)^+ \rightarrow \pi^- +K^{+,0}+\pi^{0,+}]/[\pi^0+K^*(890)^0 \rightarrow \pi^0 +K^+ +\pi^-]$ is 3 for an isospin-$\frac{1}{2}$ assignment. The isospin determination for the $K^*(1300)$, by comparison of production in the π^-p and π^+p reactions, is discussed below.

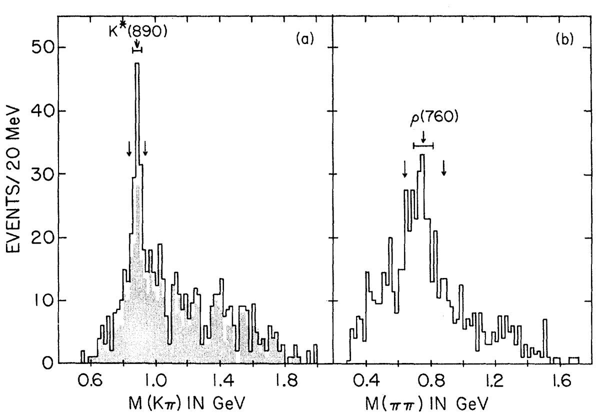

FIG. 2. (a) The $(K\pi)$ mass spectra from Reaction (1) with $Y_1^*(1385)$ events and ρ events removed. The shaded area is the $(K\pi)^+$ combination. (b) The $(\pi\pi)$ mass spectrum from Reaction (1) with $Y_1^*(1385)$ events and $K^*(890)$ events removed.

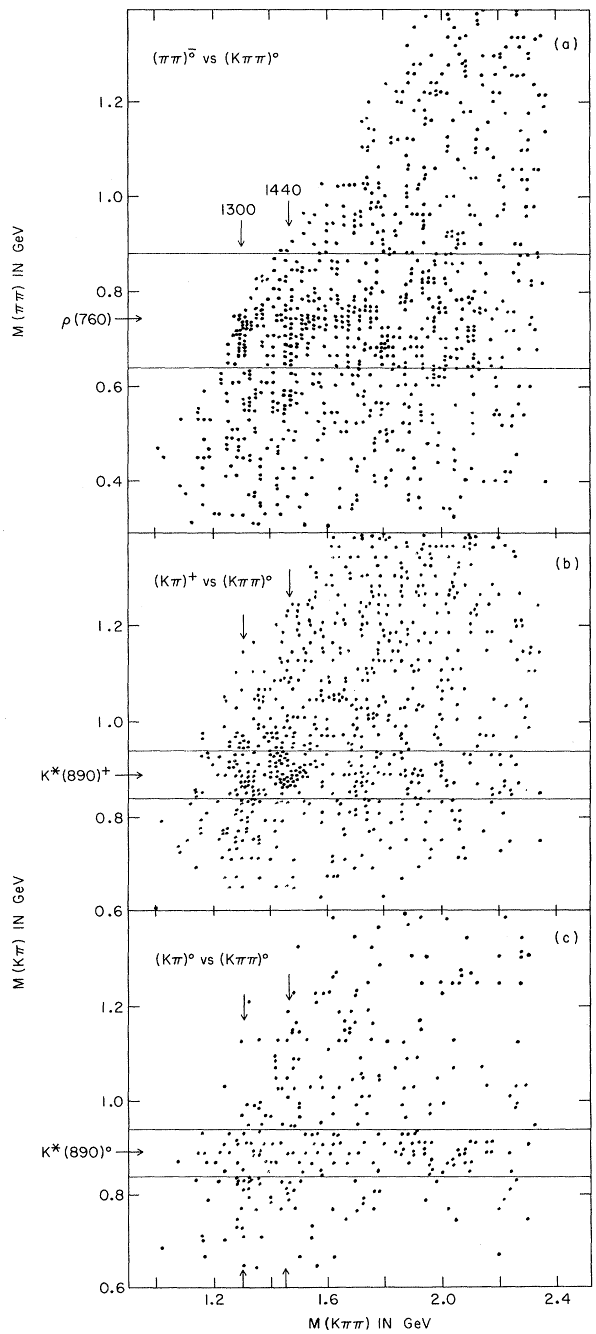

FIG. 3. Sections of the two-body versus three-body scatter plot in the $(K\pi\pi)^0$ system [$Y_1^*(1385)$ events removed] as shown. The horizontal lines indicate the limits for ρ and $K^*(890)$ mass region (see text for details). The $K^*(1300)$ and $K^*(1440)$ are indicated with arrows.

We now consider possible kinematic interpretations of the $K^*(1300)$ enhancement. In our case a mechanism of the usual Deck type[2] with virtual elastic diffraction scattering at the lower vertex cannot contribute since a change of strangeness and isospin is required for the nucleon at the lower vertex. We also note that in the present data there is no evidence of large background at low $K\pi\pi$ mass values as has been seen in K_p interactions. Another mechanism similar to the usual Deck mechanism might operate in the $\pi+p\to\Lambda+K+\pi+\pi$ final states with $\pi+p\to\Lambda+K$ or $K+p\to\Lambda+\pi$ at the lower vertex. Cross sections on the mass shell for these two reactions are known to decrease with increasing energy. This, in turn, might reduce the contribution to the background from such kinematic effects, whereas, in the $K+p\to K+\pi+\pi+p$ final state, $\pi+p\to\pi+p$ or $K+p\to K+p$ occurs at the lower vertex, and cross sections on the mass shell for elastic scattering are generally large (in comparison with a two-body inelastic channel) and nearly constant at high energy. This might give a marked broad background at low $K\pi\pi$ mass values in the $K+p\to K+\pi+\pi+p$ final state. We want to point out the following features of our data which are not usually associated with kinematic enhancements:

(1) The width of the observed $K^*(1300)$ [Fig. 1(a)] is ~60 MeV, much narrower than expected for a kinematic effect.

(2) Diagrams leading to kinematic effects in general would not lead to states of definite isospin, and similar effects would be expected for the π^+p reactions (2). However, they are not observed in our data [Fig. 1(b))].

(3) In Fig. 3(b) we see evidence of $\pi^-+K^*(890)^+$ contribution to the $K^*(1300)^\circ$. A kinematic effect is an unlikely explanation for the $K^*(1300)$, since a doubly charged virtual exchange particle would be required for the usual Deck type of mechanism. Even for the inverted Deck type of mechanism [i.e., $K^*(890)^+$ produced from the lower vertex], one would expect that the same effect should show up in both π^+p and π^-p interactions. This clearly is not the case because of the absence of a $(K\pi\pi)^{++}$ enhancement in this mass region.

(4) We have also examined the $(K\pi\pi)^0$ mass projection (not shown) of events outside the $K^*(890)$ or ρ bands. The $K^*(1300)$ and $K^*(1440)$ peaks are observed, showing the possible existence of three-body decay mode of the $K^*(1300)$. This again cannot be easily explained by any known kinematic effect.

The combined evidence presented above supports a resonance interpretation for the $K^*(1300)$. Consequently, we proceed to examine the quantum numbers of the $K^*(1300)$.

(1) Isospin.—The reaction $\pi^-+p\to\Lambda+K^*(1300)$ limits the $K^*(1300)$ isospin to either $\frac{1}{2}$ or $\frac{3}{2}$. If the isospin of $K^*(1300)$ is assumed to be $\frac{3}{2}$, only the $I=\frac{3}{2}$ $\pi^\pm p$ states can contribute, giving the prediction of $\sigma(\pi^++p\to\Lambda+K^*(1300)^{++})/\sigma(\pi^-+p\to\Lambda+K^*(1300)^0)=3$. Correcting for the different path lengths in the $\pi^\pm p$ exposures we would expect 30 ± 7 events above background in the mass region 1.26-1.36 GeV of the $(K\pi\pi)^{++}$ distribution. We see four events, a number consistent with background, indicating isospin $\frac{1}{2}$ for the $K^*(1300)$.

(2) Spin and parity.—We have examined the decay angular distributions of the $(K\pi\pi)^0$ system using θ and Φ, the polar and azimuthal angles defining the direction of the normal to the $K\pi\pi$ decay plane in the $(K\pi\pi)^0$ rest frame.[6] In the $K\pi\pi$ mass region 1.5-1.7 GeV the decay distributions are consistent with isotropy, whereas this is not the case in either the 1300- or 1440-MeV regions. We have studied the moments $A_L{}^M=\sum Y_L{}^M(\theta,\Phi)\pm[\sum(Y_L{}^M)^2]^{1/2}$ of the angular distribution as a function of the $(K\pi\pi)^0$ effective mass. Moments above $L=4$ show no significant structure. With the present data the moments analysis only excludes the spin and parity $J^P=0^-$. $J^P=0^+$ is also excluded since it is not an allowed state of three pseudoscalar mesons.

We have also searched for the other decay modes of the $K^*(1300)$, into $K+\pi$ and $K+\pi+\pi+\pi$ from $\pi^-+p\to\Lambda+K^++\pi^-$ and $\Lambda+K^0+\pi^++\pi^-+\pi^0$, respectively. With the present data we can obtain the following upper limits for relative branching ratios:

$$\frac{K^*(1300)^0\to K^++\pi^-}{K^*(1300)^0\to K^{+,0}+\pi^{0,+}+\pi^-}\leq 0.2,$$

$$\frac{K^*(1300)^0\to K^0+\pi^++\pi^-+\pi^0}{K^*(1300)^0\to K^{+,0}+\pi^{0,+}+\pi^-}\leq 0.1,$$

at the 90% confidence level.

We want to take this opportunity to express our gratitude to the BNL Bubble Chamber Group data-reduction personnel for their constant assistance, and to the BNL 80-inch bubble chamber crew and the Alternating Gradient Sychrotron operating personnal for their help during

the runs. Finally, it is our pleasure to acknowledge the interest and support of Dr. Ralph P. Shutt.

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

[1]S. P. Almeida, H. W. Atherton, T. A. Byer, P. J. Dornan, A. G. Forson, J. H. Scharenguivel, D. M. Sendall, and B. A. Westwood, Phys. Letters 16, 184 (1965); B. C. Shen, I. Butterworth, C. Fu, G. Goldhaber, S. Goldhaber, and G. H. Trilling, Phys. Rev. Letters 17, 726 (1966).

[2]S. D. Drell and K. Hiida, Phys. Rev. Letters 7, 199 (1961); R. T. Deck, Phys. Rev. Letters 13, 169 (1964); U. Maor and T. A. O'Halloran, Jr., Phys. Letters 15, 281 (1965); L. Stodolsky, Phys. Rev. Letters 18, 973 (1967).

[3]Results of a preliminary analysis were presented earlier by T. G. Schumann, D. J. Crennell, G. R. Kalbfleisch, K. W. Lai, J. M. Scarr, I. O. Skillicorn, and M. S. Webster, Bull. Am. Phys. Soc. 12, 46 (1967).

[4]Ionization for each event was examined visually in order to check consistency with predictions of kinematics. We demanded positive identification for the Λ decay. The ambiguity between K^+ and π^+ interpretation for the positively charged track was resolved in about 80% of events. It is important to note, however, that the values of the $(K\pi)^+$ and $(K\pi\pi)^0$ mass from the final state $\Lambda(K\pi\pi)^0$ used here are unaffected by this ambiguity, since we use the fitted value for the lambda momentum but measured values for the other tracks at the production vertex. We assigned half-weight to events ambiguous between the two possible $\Lambda(K\pi\pi)^0$ final states.

[5]See the compilation by A. H. Rosenfeld, A. Barbaro-Galtieri, W. J. Podolsky, L. R. Price, P. Soding, C. G. Wohl, M. Roos, and W. J. Willis, Rev. Mod. Phys. 39, 1 (1967).

[6]See, for instance, J. D. Jackson, Nuovo Cimento 34, 1644 (1964).

CONDENSATION OF REGGE CUTS, VANISHING TOTAL CROSS SECTIONS, AND TWISTING TRAJECTORIES*

Yogendra Srivastava
Istituto di Fisica, Università di Roma, Roma, Italy,
and Physics Department, Northeastern University, Boston, Massachusetts†
(Received 16 May 1967)

A very crucial problem in a Reggeized theory of strong interactions is that of Regge cuts. Various authors have advanced strong theoretical reasons to justify the presence and possible importance of Regge cuts.[1] The angular-momentum singularities important for crossed-channel asumptotic behavior have trajectories of the form

$$\alpha^{(n)}(t)=n\alpha(t/n^2)-n+1, \qquad (1)$$

due to an intermediate state containing n (identical) Regge poles, $\alpha(t)$. Here $n=1$ corresponds to the "parent" Regge pole $\alpha(t)$ and integer $n>1$ to Regge cuts.

From Eq. (1), one notices the ugly feature that a Pomeranchuk pole (called P pole, hereafter) with $\alpha_{\rm P}(0)=1$, generates an infinite number of Regge cuts all condensing to $J=1$ (at $t=0$), which would give rise to an essential singularity. Such a phenomenon is universal, in the sense that every trajectory of whatever quantum number would have a similar condensation at its intercept at $t=0$. This is due to the fact that the P pole has the quantum numbers of the vacuum and hence it can mix with any trajectory to produce the infinite sequence of cuts which, with $\alpha_{\rm P}(0)=1$, condense at $\alpha_c{}^n(0)=\alpha(0)$. (See Fig. 1.)

In this Letter, we propose to resolve this dilemma by a simple mechanism. We find some very interesting consequences (twist effect, vanishing total cross sections, etc.) and also provide some experimental tests for our pro-

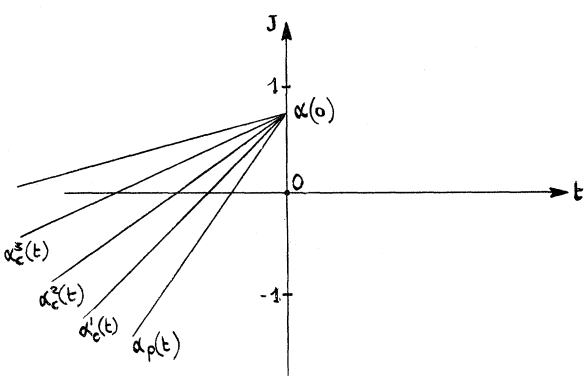

FIG. 1. The pole and cut trajectories with the Pomeranchuk intercept $\alpha_{\rm P}(0)=1$.