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Sulamith Goldhaber

April 1963

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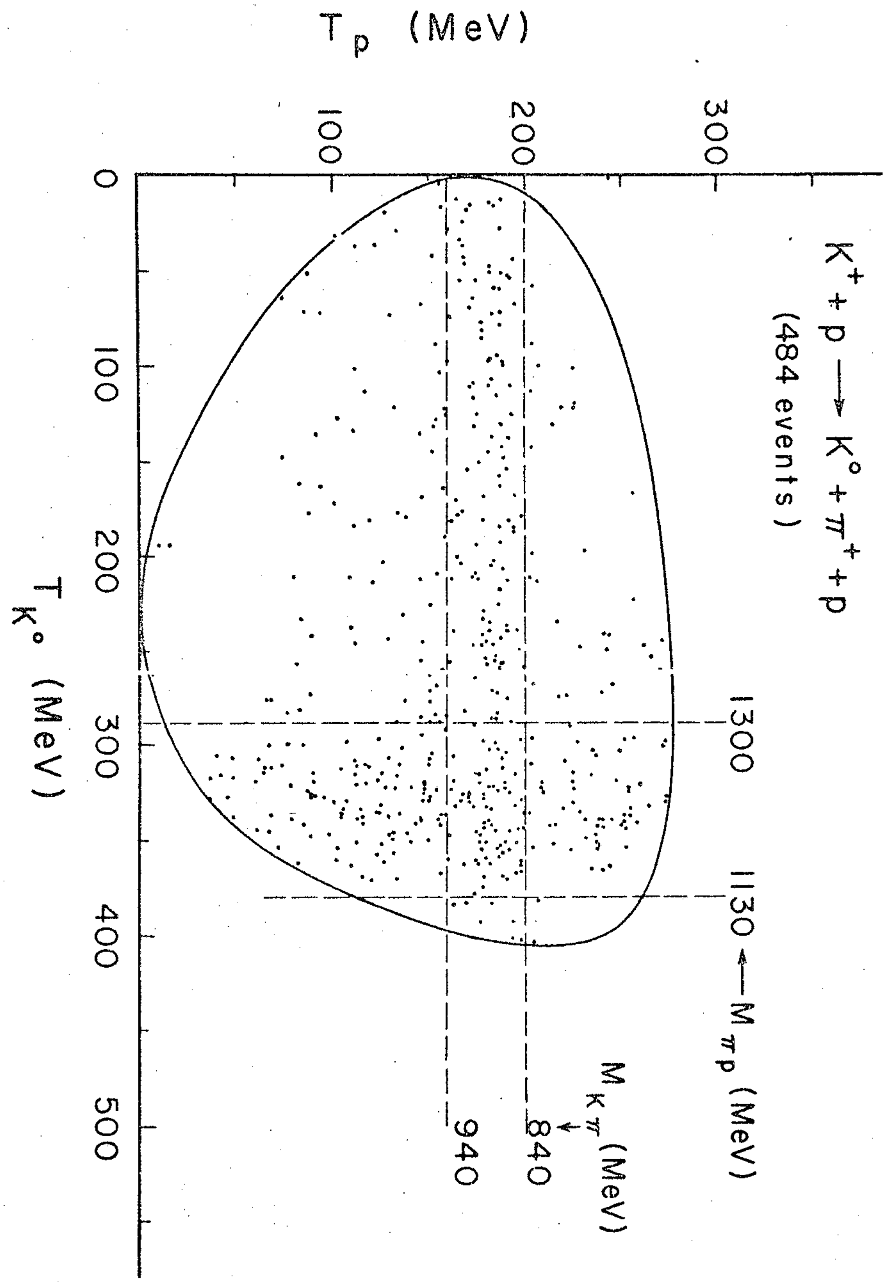
The work I will discuss today was carried out with the BNL 20 inch hydrogen bubble chamber exposed in the separated Brookhaven-Yale beam at the AGS. The scanning and analysis of the data was done at the Lawrence Radiation Laboratory in Berkeley. The people that have participated in this work are W. Chinowsky, G. Goldhaber, T. O'Halloran, and myself.

There are three subjects in the $K^{\pm}p$ interaction I would like to discuss with you. My main topic concerns the K^+p interactions at 1.96 BeV/c, leading to three particles in the final state. In particular I want to concentrate on the study of some of the dynamics of the interaction. In addition, I will give you a status report on the production of the elusive K* (730) resonance in this experiment, and finally the limits one can set on the branching ratio of the K* (890) decay

$$\frac{K^*(890) \rightarrow K^*(730) + \pi}{K^*(890) \rightarrow K + \pi}$$

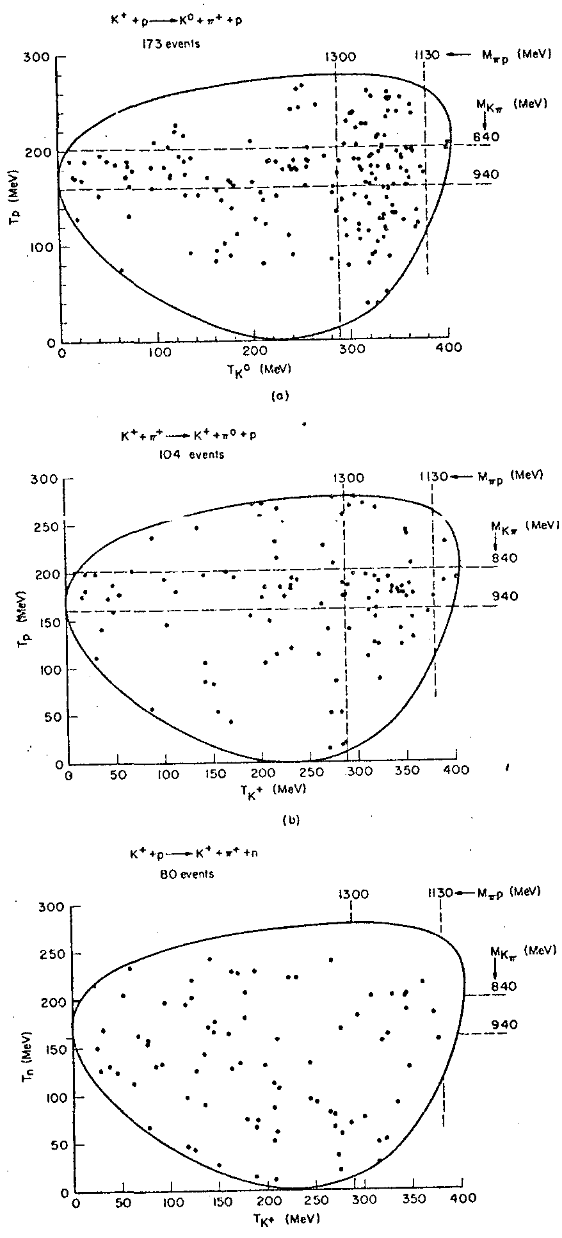
The three particles in the final state form two distinct classes: (a) the inelastic pion production, and (b) the production of a pair of strange particles, i.e., associated production by K mesons. I will first discuss the inelastic pion production.

In the single pion production the K^+-p interaction can lead to the following three charge states:



T_p (MeV)
100
200
300
$K^+ + p \longrightarrow K^\circ + \pi^+ + p$
(484 events)
0
100
200
300
400
500
T_{K° (MeV)
1300
1130
$\leftarrow M_{\pi p}$ (MeV)
$M_{K\pi}$ (MeV)
840
940

FIGURE 1



K+ + p → K0 + π+ + p
173 events
1300
1130 ← Mπp (MeV)
MKπ (MeV)
840
940
Tp (MeV)
TK0 (MeV)
(a)
K+ + π+ → K+ + π0 + p
104 events
Tp (MeV)
TK+ (MeV)
(b)
K+ + p → K+ + π+ + n
80 events
Tn (MeV)
TK+ (MeV)
(c)

FIGURE 2

(1) $K^+ + p \rightarrow K^\circ \pi^+ p$
(2) $K^+ + p \rightarrow K^+ \pi^\circ p$
(3) $K^+ + p \rightarrow K^+ \pi^+ n$

Here I would like to point out that the interaction leading to reaction (1) and (2) can proceed either via $K^* + N$ production or via $K + N^*$ production. Reaction (3), however, can only proceed via $K + N^*$ production. I would like to mention that the events contributing to reaction (1) come from two sources, viz. events with charged K° decays (311 events) and neutral K° decays or K° mesons. Of the latter we have completed only a partial sample (173 events). The combined Dalitz plot for reaction (1) is given in Figure 1. The Dalitz plots for the three charge states with one missing neutral are given in Figure 2 (a), (b), and (c), and the respective projections on the $K\pi$ and $p\pi$ axis are given in Figure 3 and Figure 4.

As can be seen, charge states (1) and (2) show both the $K\pi$ and $N\pi$ resonances. Charge state (3) has only a few events and shows very little enhancement in the N^* band which is consistent with the expected intensity ratio of $N^{*++} (\pi^+ p)$: $N^{*+} (\pi^\circ p)$: $N^{*+} (\pi^+ n)$ = 9: 2: 1.

I will now limit my discussion to charge state (1) for which we have the largest number of events and for which the K^* and N^* bands stand out most clearly above the non-resonant background. In Figure 5 we present the distribution in the production angle for the N^* and K^* respectively. The mass limits defining the resonances are given in the figure. It is immediately obvious that in both cases the resonances are produced peripherally and may thus proceed via a one-particle exchange mechanism as indicated by the diagrams above the main figure. The distribution in Δ^2, the four-momentum transfer squared, for the two resonances is shown in Figure 6. It is noteworthy that, $\Delta_2{}^2$, associated with N^* production has a considerably wider distribution than $\Delta_1{}^2$, the four momentum transfer associated with K^* production. In terms of a one-particle exchange model this difference is indicative of the exchange of a heavier particle for N^* production.

I would like to mention here that for N^* production one-pion exchange is forbidden because of parity considerations at the $K^+ - K^\circ$ vertex. The lightest single particle exchange allowed is the ρ meson. The exchange of a spin 1 particle (ρ meson) now permits some angular information to be transmitted along the direction of the exchange particle. Indeed

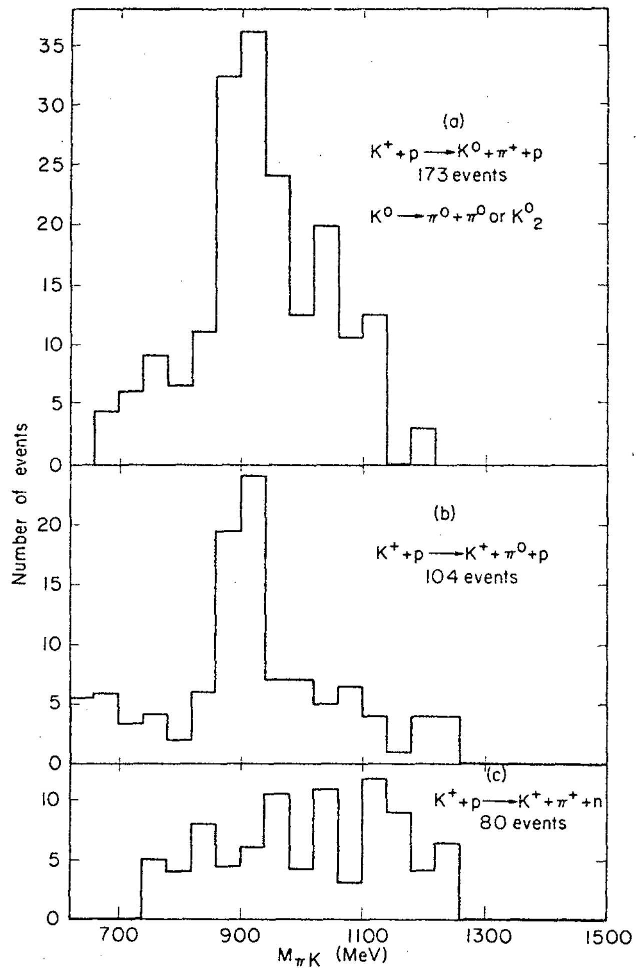


FIGURE 3

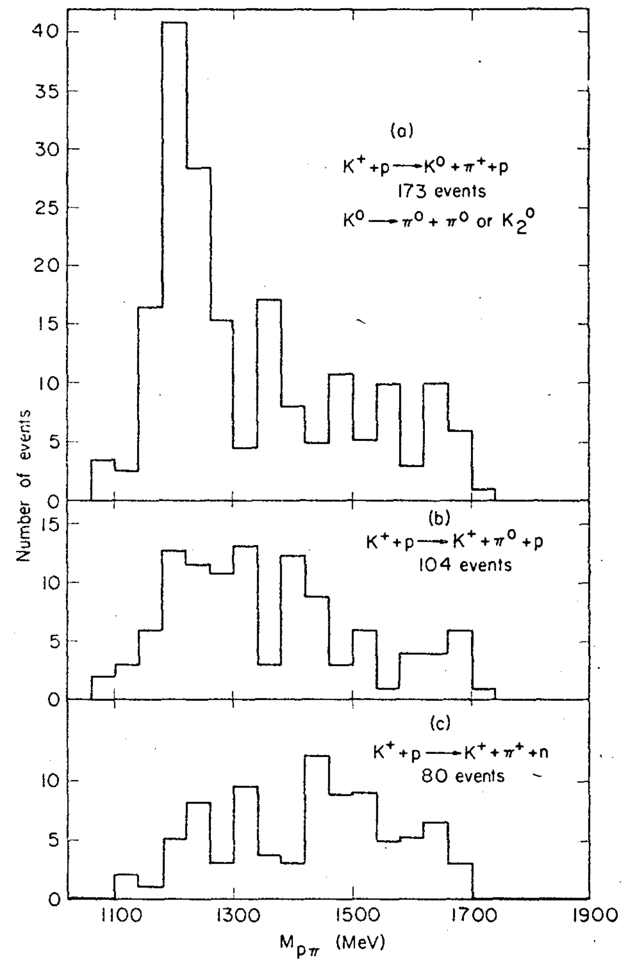


FIGURE 4

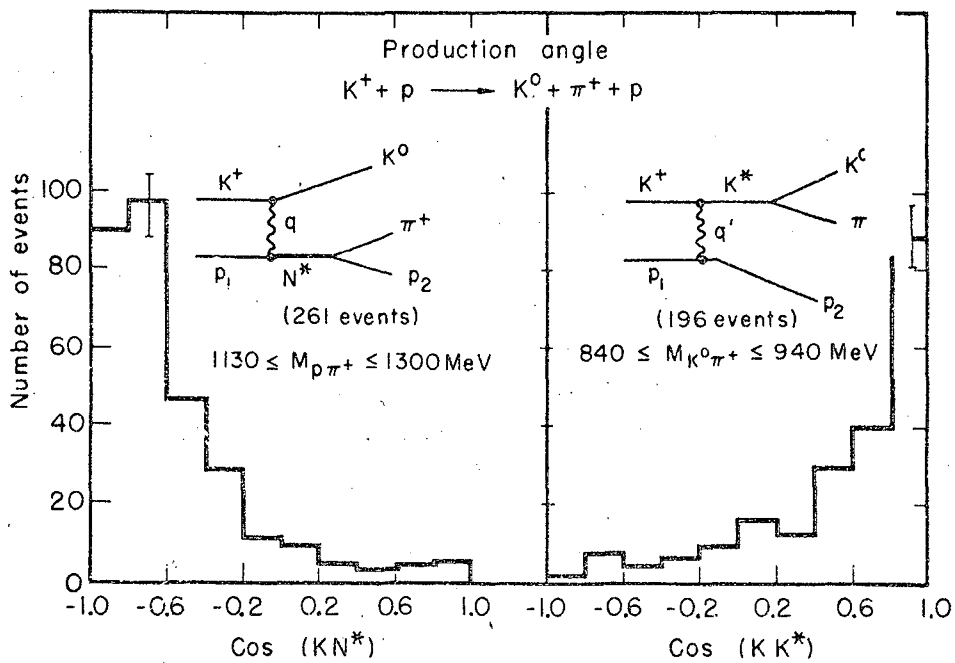


FIGURE 5a. FIGURE 5b.

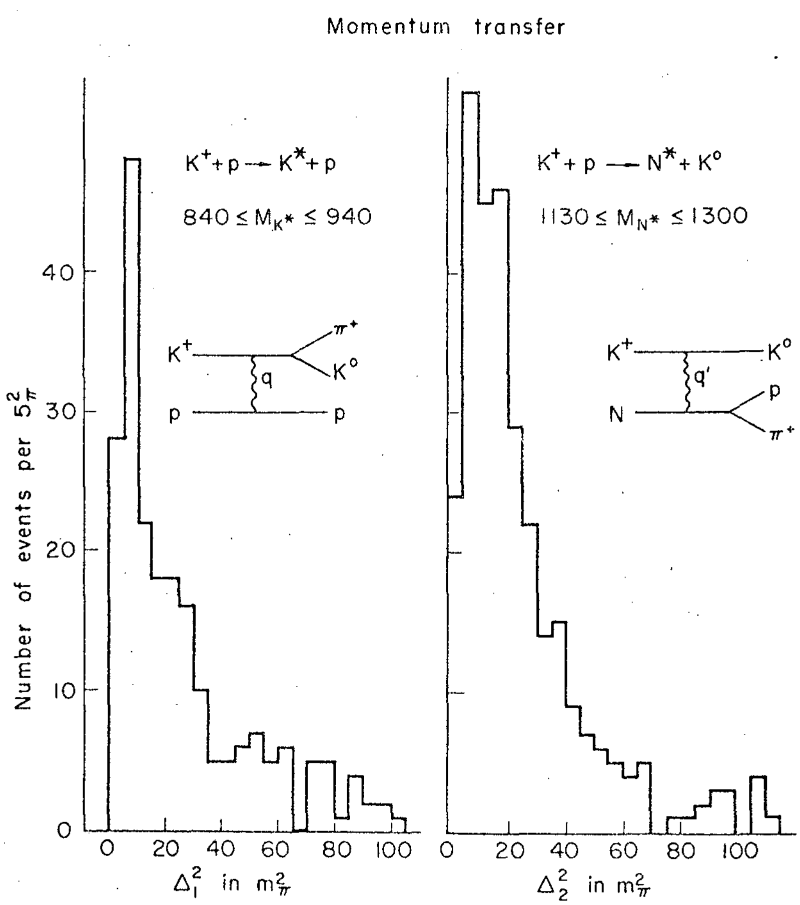


FIGURE 6.

we find strong deviations from isotropy in the distribution of ϕ_a, the Treiman-Yang angle for this reaction. (See Figure 7a.) We have fitted the distribution in an expansion $f(\phi_a) = a + b \cos \phi_a + c \cos^2 \phi_a$ with coefficients $a = 1.0 \pm 0.08$, $b = -0.08 \pm 0.05$, $c = -0.6 \pm 0.12$. We note that coefficient b is small, i.e., the interference term is small, and that c is negative. The distribution is thus well represented by the form $f(\phi_a) = \alpha + \beta \sin^2 \phi_a$ with $\alpha = 1.0 \pm 0.25$ and $\beta = 1.5 \pm 0.3$. Here I would like to mention the method by which the events were selected. As can be noted in Figure 1, the N^* and K^* bands cross each other giving a region of overlap in which events may be due to either resonance. In this region interference effects could occur. We do not observe, however, any evidence for interference since the number of events in the overlap region is consistent with the sum of the intensities expected from superposition of the two bands. We therefore attempted a crude separation of the events in the overlap region. The separation of events was based on the pion direction in the overall center of mass and a comparison of the effective $K\pi$ and $N\pi$ masses with respect to their nominal central values. Here I would like to note that for K^* events outside the overlap region, the pions are emitted preferentially forward whereas those forming an N^* go preferentially backward. The shaded area of the histogram shown in Figure 7 gives the distribution of the events in the N^* band after those belonging to the K^* resonance had been removed. For all subsequent distributions shown we have used the same method for separating events in the overlap region.

In Figure 7(b) we show for comparison the distribution of the Treiman-Yang angle for the K^+p interaction leading to four particles in the final state. Here the exchange of a spin zero particle is allowed and indeed, as the previous speaker has shown, the evidence is overwhelming that the reaction goes via one-pion exchange. The isotropy in the Treiman-Yang angle is supporting evidence for spin zero exchange.

In Figure 8 we show the p_{in}-p_{out} scattering angle in the N^* c.m. system at the N^* vertex. For ρ exchange this would correspond to a reaction $p + \rho \longrightarrow p + \pi^+$ in the $T = 3/2$, $J = 3/2$ state. We have not as yet tried to fit the observed distribution with an expansion in $f(\theta)$.

I now want to direct my attention to the events in the K^* band. For the reaction producting the K^* resonance, i.e., $K^+ + p \longrightarrow K^{*+} + p$, pion exchange is allowed. A spin flip of the proton at the $p\pi p$ vertex is required, since the exchange pion is emitted in

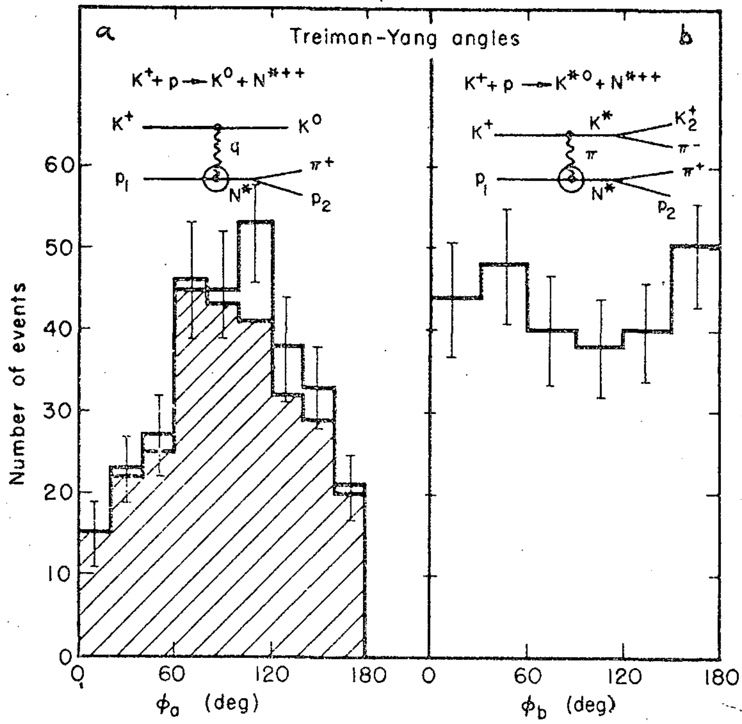


FIGURE 7.

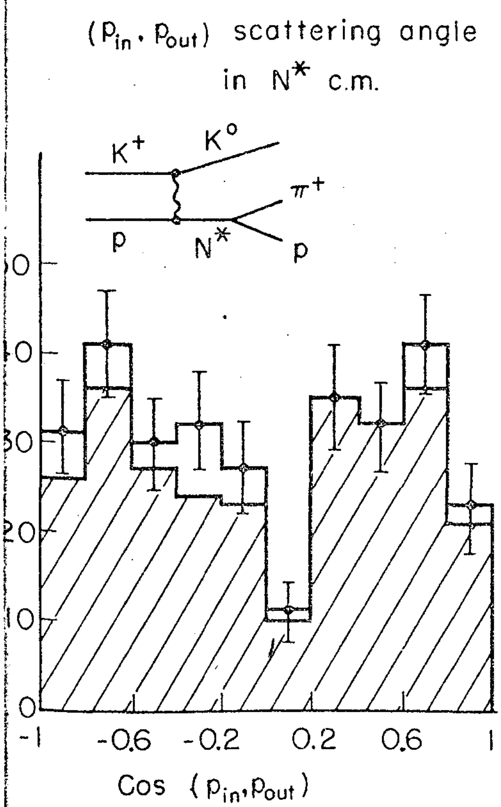


FIGURE 8

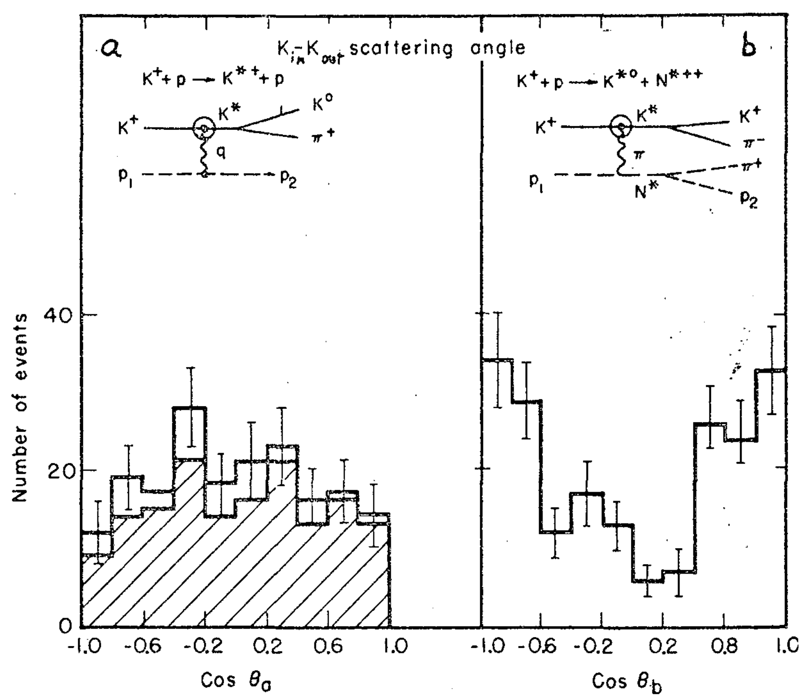


FIGURE 9

in a p-wave state introducing a γ_5 into the transition matrix.

In principle one might thus expect alignment of the K_{in} -K_{out} scattering angle with $M(K^*) = 0$ similar to that observed in the K^* produced in the double resonance events presented by Gerson Goldhaber. Figure 9(a) shows that this is not the case. The distribution is in essence isotropic with a possible small contribution of $\sin^2\theta_a$. A possible explanation of this distribution is that both pion and ρ (or ω) exchange contribute to the interaction. I would like to stress here that we are effectively using the alignment of the K^* spin with respect to the exchange particle axis as a probe for the exchange of a spin zero meson. For comparison we show the distribution of the K_{in} -K_{out} scattering angle for the double resonance events. The events included in these distributions are mass selected only ($840 \leq M_{K\pi} \leq 940$ MeV), i.e., all four-momentum transfers are included.

In Figure 10 we show the Treiman-Yang angle for the K^* production. Although here we also note a small deviation from isotropy, the effect is not as large as that for N^* production. Here too the deviation from isotropy may again be due to both π and (or ω) exchange participating in the interaction.

I now come to the second class of events giving three particles in the final state, namely, associated production by K mesons. At an incident momentum of 1.96 BeV/c we are 115 MeV above threshold for the reaction $K^+ + p \longrightarrow K^+ + K^+ + \Lambda°$. We have, however, not observed a single event of this type. This permits us to set an upper limit to the cross section for this process of $\sigma_{K\Lambda} \leq 10\ \mu b$. It is interesting to note that in the K^-p interaction the cross section for associated production at the identical momentum is about 5 times larger, i.e., approximately 50 μb. This difference can be attributed to the production of the recently discovered $K_1^\circ K_2^\circ$ (ϕ) resonance which is produced in the K^-p reaction but cannot be produced in the K^+p reaction at our energy.

Next I would like to discuss my second topic, namely the production of K^* (730) in this experiment. In the three-particle final state we have no evidence for the production of the K^* (730) resonance. An examination of the Dalitz plot given in Figure 1, shows no enhancement in the mass region of 730 MeV. We have also examined the four-particle final state giving rise to double resonances $(K°\pi°)$ $(p\pi^+)$ and $(K^+\pi^-)$ $(p\pi^+)$ for K^* (730) production. Here we observe about 12 events in the mass region (720-730) MeV of which five events appear to be above background. This corresponds to about 20 μb for the

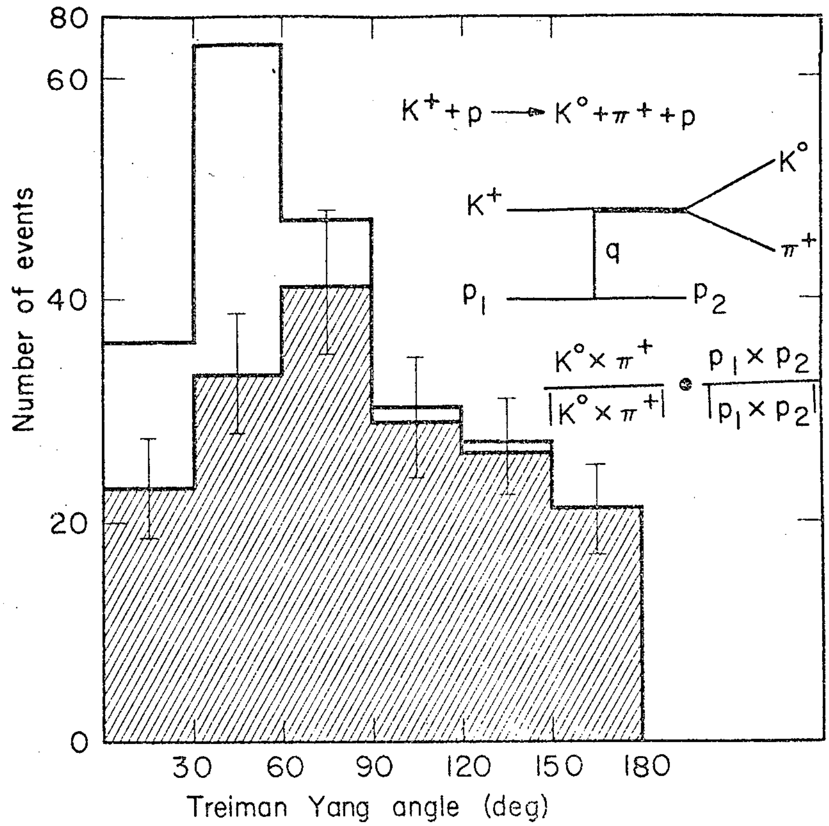


FIGURE 10

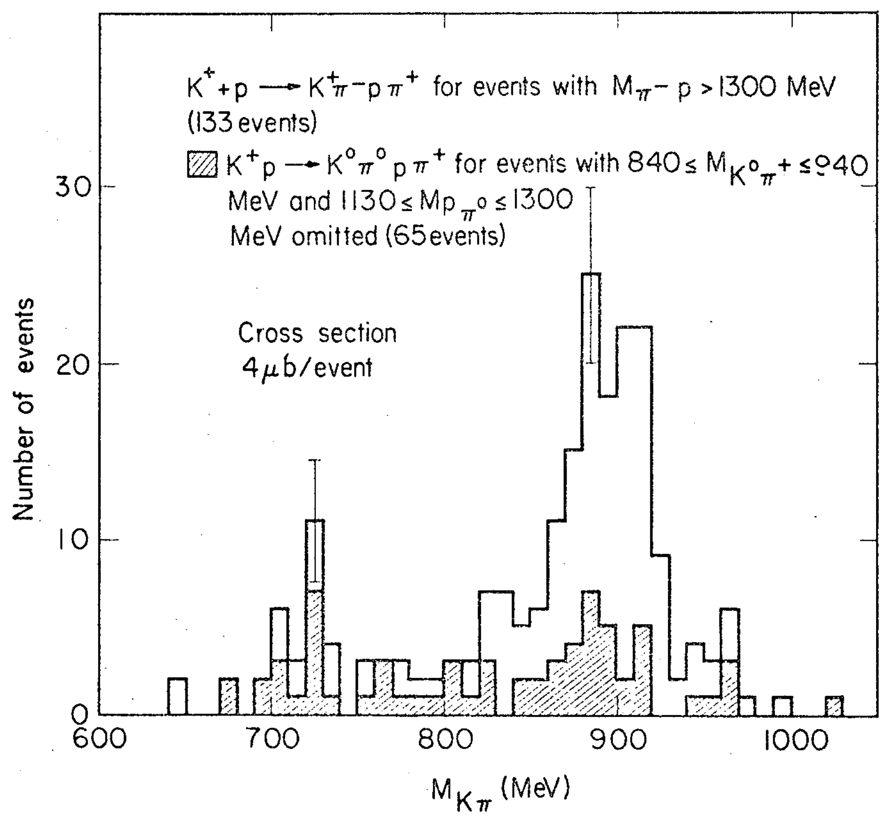


FIGURE 11

r. the

production of K^* (730). Figure 11 shows the K π invariant mass distribution. There are two types of background events that had been removed from the distribution. One type comes from the events forming a $p\pi^-$ resonance in the charge state $K^+\pi^- p\pi^+$, the other from the $(K^\circ\pi^+)$ $(p\pi^\circ)$ double resonance in the $K^\circ\pi^\circ p\pi^+$ charge state. In the former we removed all events in the $N^{*\circ}$ $(p\pi^-)$ mass band whereas in the latter we removed all events in the double resonance, K^{*+} N^{*+}, region. In conclusion I would like to state that our data are consistent with a K^*(730) but are in themselves certainly no independent evidence for it

Now, I finally come to my last topic concerning the decay of the K^* (890) into K^*(730) and a pion. As Dr. Glashow has mentioned in his talk this morning, the branching ratio

$$R = \frac{K^*(890) \longrightarrow K^*(730) + \pi}{K^*(890) \longrightarrow K + \pi}$$

may shed some light on the spin of the K^* (730). The possible spin and parity assignments for the K^* (730) are 0^+, 1^-, etc. The K^*(890) with spin and parity 1^- cannot decay into K^*(730) with spin and parity 0^+ together with a π meson without violating parity. For a K^*(730) of spin and parity 1^-, Glashow estimates the above branching ratio to be about 0.06. This estimate assumes the coupling constant for both K^* resonances to be the same. We have observed in this experiment a total of 881 events with K^*(890) production. Of these, 612 would have led to indentifiable K^*(730) + π decays, i.e., no more than one neutral particle in the final state (see Table 1). In this sample we find three events consistent with the decay into K^*(730).

TABLE I

K^* DECAY BRANCHING RATIO

Decay Product \ Parent	$K^{*+} + p$	$K^{*\circ} + N^{*++}$	$K^{*+} N^{*+}$	Total
$K\pi$	231	325	56	612
$K^*_{730}\pi$	3	0	0	3

$$\frac{K^* \rightarrow K^*_{730} + \pi}{K^* \rightarrow K + \pi} \leq \frac{3}{612} = 0.005 \begin{matrix} +\ .005 \\ -\ .0025 \end{matrix}$$

We can thus set a limit of

$$R \leq \frac{3}{612} = 0.005 \begin{array}{l} +\ 0.005 \\ -\ 0.0025 \end{array}$$

and conclude that either the spin and parity of $K^*(730)$ is not 1^- (presumably 0^+) or that the $K^*(730)$ coupling constant is considerably smaller than that of the $K^*(890)$.

In my last slide (Table II) I still would like to give you a summary of all the partial cross sections we have determined in the K^+p interaction at 1.96 BeV/c.

TABLE II

$K^+ + p$ at 1.96 BeV/c

Reaction Product	Cross Section
$K^+ p$ elastic	7.6 ± 1.0 mb
$K^\circ \pi^+ p$	4.6 ± 0.6
$K^+ \pi^\circ p$	2.0 ± 0.3
$K^+ \pi^+ n$	$1.6 + 0.3$
$K^+ \pi\ p\pi^+$	1.7 ± 0.2
$K^\circ \pi^\circ\ p\pi^+$	1.3 ± 0.2
$K^\circ \pi^+\ n\pi^+$	0.33 ± 0.1
$K^+ \pi^\circ\ p\pi^+$	~ 0.2
$K^+ \pi^\circ\ n\pi^+$	~ 0.1
$K^+ \pi\ \pi^\circ\ \pi^+ p$	$.05 + .02$
$K^\circ \pi^+ \pi\ \pi^+ p$	$.02 + .01$
$K^+ \pi\ \pi^+ \pi^+ n$	$.01 + .006$
$K^+ K^+ \Lambda$	$\lesssim 0.01$
σ_{TOT}	$19.5 + 2.1$ mb

DISCUSSION

LICHTENBERG: I'd just like to make the following comment. Originally when the Y_1^* (1385) decay into $\Lambda + \pi$ and not into $\Sigma + \pi$ was observed, people used that an an argument that the sigma-lambda parity was odd. Also when the η decay into three π mesons, $\pi^+ + \pi^- + \pi^\circ$, was observed and not into two gamma's, people used that as an argument that the spin was not zero. I mistrust arguments about spin that are based on branching ratios.

S. GOLDHABER: You will note that I carefully avoided drawing a definite conclusion at the end of my discussion. I point out that the data provide an experimental limit. The interpretation I leave up to my friends, the SU_3 theorists.

G. SMITH: I failed to mention one item when I was talking which may help put things into their proper perspective. Sula mentioned that the cross section for the K^*(730) was of the order of 20 μb. In our pion experiment the value for the cross section was 15 μb, in the K^- experiment the average cross section over the region 1 to 1.8 BeV/c is about 40 μb. These values give the various experiments some common perspective.

S. GOLDHABER: Thank you.

KEHOE: Do you have any estimate of the fraction of events going into K^* and N^* resonances respectively?

S. GOLDHABER: Let me see, roughly speaking about 2/3 go into N^* and 1/3 into K^* production. In N^* production we thus have much less contamination of K^* events in the interference region because the predominant fraction is going to N^* events.