STRONG INTERACTIONS OF STRANGE PARTICLES

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The strong interactions of strange particles are predominantly an experimental subject. At the sessions in which Professor Gregory and I have been rapporteurs, the time spent was in the ratio

$$\frac{\text{Theory}}{\text{Experiment}} = \frac{0.5}{2.5} = 0.2 \pm \;?$$

I would rather not discuss the statistical significance of this number.

My talk will, by necessity, be closely tied to the experimental situation. I will try to cover the following topics:

I) $\bar{K}\Lambda N$ parity

II) $\bar{K}\Sigma N$ parity

III) discussion of K^* spin

IV) review of $K^{\pm}p$ scattering.

I. $\bar{K}\Lambda N$ PARITY

You are all very familiar with the argument about the $\bar{K}\Lambda N$ parity. Block *et al.* [1] have observed the reactions

$$\begin{aligned} K^- + \mathrm{He}^4 &\to {}_\Lambda\mathrm{H}^4 + \pi^0 \\ &\to {}_\Lambda\mathrm{He}^4 + \pi^- . \end{aligned} \tag{1}$$

If $J({}_\Lambda\mathrm{H}^4) = 0$ parity conservation for this reaction demands that

$$P_K(-1)^{l_i} = -(-1)^{l_f} .$$

Angular momentum conservation implies $l_i = l_f$.

We adopt the convention of positive parity for the Λ relative to the nucleon. Hence it follows that $P_{\bar{K}}$ is -1. Dalitz [2] and collaborators have analyzed the binding energy of low mass hyperfragments and deduced that the singlet Λ-N interaction is stronger than the triplet Λ-N interaction which implies that the ground states of ${}_\Lambda\mathrm{H}^4$ and ${}_\Lambda\mathrm{He}^4$ are $J = 0$. This is confirmed by the high branching ratio of the two-body break-up ${}_\Lambda\mathrm{H}^4 \to \mathrm{He}^4 + \pi^-$ compared to all pionic decays of ${}_\Lambda\mathrm{H}^4$. This ratio is

$$R_4 = 0.67^{+0.06}_{-0.05}$$

as observed by the Chicago-Northwestern emulsion collaboration [3]. Dalitz and Liu [4] have calculated R_4 as a function of the (p/s) wave ratio of the free decay $\Lambda^0 \to p + \pi^-$. This ratio has been measured by Beall *et al.* [5] and by Cronin and Overseth [6], who find

$$\frac{p^2}{p^2 + s^2} = 0.11 \pm 0.03 .$$

With this small ratio, Dalitz and Liu predict $R_4(J = 0) = 0.75$ and $R_4(J = 1) = 0.18$, hence $J({}_\Lambda\mathrm{H}^4) = 0$ is confirmed. Block *et al.* [1] have also obtained some independent confirmation of this spin assignment by observing the angular distribution of ${}_\Lambda\mathrm{H}^4 \to \mathrm{He}^4 + \pi^-$ decays relative to $\vec{p}({}_\Lambda\mathrm{H}^4)$ following the $K^- + \mathrm{He}^4 \to {}_\Lambda\mathrm{H}^4 + \pi^0$ reaction. Assuming predominant s state capture in the initial state [7], ${}_\Lambda\mathrm{H}^4$ is aligned and this angular distribution is unique, i.e.,

$$J = 1: \quad \cos^2\theta$$

$$J = 0: \quad \text{isotropic.}$$

Block *et al.* [1] find excellent agreement with isotropy for a sample of $35({}_\Lambda\mathrm{H}^4 \to \mathrm{He}^4 + \pi^-)$ events.

There is still, however, one loop-hole in the argument. If the $J = 1$ (${}_\Lambda\mathrm{H}^4$) system is bound [8], with a binding energy of several hundred KeV, then the observations of Block *et al.* do *not* determine the

$\bar{K}\Lambda N$ parity without further investigation. For one can have the chain

$$\begin{aligned} K^- + \mathrm{He} &\rightarrow ({}_\Lambda\mathrm{H}^4)^*_{J=1} + \pi^0 \\ &\quad \lfloor\!\rightarrow ({}_\Lambda\mathrm{H}^4)_{J=0} + \gamma \\ &\qquad\quad \lfloor\!\rightarrow \mathrm{He}^4 + \pi^- \end{aligned} \tag{2}$$

If the $\bar{K}\Lambda N$ parity is *even*, reaction (2) is allowed from the S orbital state of the K^-He system, while $K^-\mathrm{He}\rightarrow({}_\Lambda\mathrm{H}^4)_{J=0}+\pi^0$ is forbidden by angular momentum and parity conservation. Block *et al.* have reported at this conference that the branching ratio

$$K^- + \mathrm{He}^4 \rightarrow \frac{{}_\Lambda\mathrm{He}^4 + \pi^-}{\mathrm{He}^3 + \Lambda^0 + \pi^-} = 0.24 \,\tilde{\pm}\, (30\%)$$

Although this branching ratio is rather high, it is probably not incompatible with the even $\bar{K}\Lambda N$ assignment if the binding energy of $({}_\Lambda\mathrm{H}^4)_{J=1}$ is greater than a few hundred KeV.

In conclusion I would say that the present evidence strongly suggests that the $\bar{K}\Lambda N$ parity is *odd*, but the even parity hypothesis has not been excluded. As suggested by Dalitz, a determination of the presence or absence of nuclear γ-rays from the decay $({}_\Lambda\mathrm{H}^4)^*_{J=1}\rightarrow({}_\Lambda\mathrm{H}^4)_{J=0}$ or $({}_\Lambda\mathrm{He}^4)_{J=1}\rightarrow({}_\Lambda\mathrm{He}^4)_{J=0}$ would conclusively resolve the remaining ambiguity.

II. THE $\bar{K}\Sigma N$ RELATIVE PARITY

In the two recent articles by Ferro-Luzzi, Tripp and Watson [9], the authors claim to have determined the $\bar{K}\Sigma N$ parity to be *odd*. It is a little unfair to discuss this experiment here since none of the authors of these important results are at the meeting. On the other hand, Professor Capps, whose original considerations [10] on this method of attack on the $\bar{K}\Sigma N$ parity determination have played an important role, has presented a paper [11] to this conference that analyzes some of the published experimental data, also concluding that the $\bar{K}\Sigma N$ parity is odd. The uniqueness of this conclusion on the $\bar{K}\Sigma N$ parity from this experiment has been challenged by some physicists, particularly Professor Adair. I will try to present a short résumé of my understanding of this rather complex situation.

The Alvarez group has been studying low energy K^-p interactions for many years. Tripp *et al.* [9] have discovered the existence of a resonant state at $P_{K^-} = 400$ MeV/c, corresponding to a mass of the system of 1520 ± 3 MeV. The possible reactions are:

$$\begin{aligned} K^- + p &\rightarrow K^- + p \\ (I = 0, 1) &\rightarrow \bar{K}^0 + n \\ &\rightarrow \Sigma^{+,0,-} + \pi^{-,0,+} \\ &\rightarrow \Lambda^0 + \pi^0 \\ &\rightarrow \Lambda^0 + \pi^{+,0} + \pi^{-,0}. \end{aligned}$$

The $\Sigma^0\pi^0$ channel is purely $I = 0$, $\Lambda^0\pi^0$ purely $I = 1$, and the other channels are mixtures of $I = 0$ and $I = 1$ states. The resonant behaviour in the 1520 MeV region shows up in many different ways:

(a) the total cross-sections for $\bar{K}^0 n$ and $\Lambda\pi^+\pi^-$ have sharp bumps in their total cross-sections. Experimentally, these two channels allow the most precise energy determination for each event (the K^- momentum resolution for a fitted event of either of these classes being much smalleı than the momentum spread in the incident K^- beam), and hence the position and the width (Γ) of the resonance is determined from these two reactions ($\Gamma = 15$ MeV).

(b) when one looks at K^-p elastic scattering, an expansion of the type:

$$\frac{d\sigma}{d\Omega_{el}} = A + B\cos\theta + C\cos^2\theta$$

fits the data, with C showing a sharp peak in the resonant region. This suggests that the resonance has $J = 3/2$, since no powers higher than $\cos^2\theta$ are needed in the fit. Furthermore, the B coefficient is rather small throughout this energy region. The argument is then made that, since the low energy K^-p data is known to be dominated by the $l = 0$ state at much lower energy, it is still this S wave that is the dominant non-resonant background in this region. Therefore, the absence of $\cos\theta$ terms implies that the resonant state is $D_{3/2}$ rather than $P_{3/2}$, that is, of the same parity as the $S_{1/2}$ dominant non-resonant K^-p state.

Examination of the $\Sigma\pi$ and $\Lambda\pi$ channels indicates a peaking in the $(\Sigma\pi)_{I=0} = 3(\Sigma^0\pi^0)$ channel, but not in the

$$(\Sigma\pi)_{I=1} = (\Sigma^+\pi^-) + (\Sigma^-\pi^+) - 2(\Sigma^0\pi^0)$$

channel, or the $(\Lambda\pi^0)_{I=1}$ channel.

The properties of the resonant state are:

$M = 1520 \pm 3$ MeV

$\Gamma = 15$ MeV

$J = 3/2$

Parity = even with respect to $K^- p$, i.e., $D_{3/2}$

Branching ratio = $(\bar{K}n):(\Sigma\pi):(\Lambda 2\pi) = 3:5:1$.

Accepting all of this, if one can determine the parity of the resonant state in the $\Sigma\pi$ channel ($P_{3/2}$ or $D_{3/2}$), one would determine the $\bar{K}\Sigma N$ parity (even or odd, respectively, since the intrinsic parity of the pion is odd). A generalized Minami ambiguity intervenes at this point.

To illustrate this, consider the simplest case of $(S_{1/2}, D_{3/2})$ $K^- p$ waves only.

$(K^- p)$	$(\Sigma\pi)$	$P(\bar{K}\Sigma n)$
$(S_{1/2}, D_{3/2})$	$\rightarrow(S_{1/2}, D_{3/2})$	-1
	$\rightarrow(P_{1/2}, P_{3/2})$	$+1$

$\sigma(\theta)$ is identical for these two cases, but the Σ polarization is opposite. On the other hand, one can make both $\sigma(\theta)$ and $P(\theta)\sigma(\theta)$ the same for the two hypothesis by replacing $(S_{1/2}, D_{3/2})$ by $(P^*_{1/2}, P^*_{3/2})$, since the sign of $P(\theta)$ is reversed by complex conjugation

$$P(\theta) \sim \mathrm{Im}\,(A_0^* A_2 - A_{-1}^* A_{1+}) \,.$$

To distinguish these two ambiguous solutions, one now imposes the Wigner condition (related to causality) that requires a rapidly varying resonant phase to increase with increasing energy. Stated more precisely, the resonant amplitude should go in a counter-clockwise direction in the complex plane. The sign of the polarization of the Σ^0 in the $I = 0$ $(\Sigma^0\pi^0)$ channel is the most significant for the parity argument but it is extremely difficult to measure. In fact, the argument of Tripp *et al.* hinges on the correlations between the $\Sigma^+\pi^-$ angular distributions and the $\sin\theta\cos\theta\,(\alpha_{\Sigma^+}\bar{P}_{\Sigma^+})$ polarization terms in the resonance region. The absolute sign of $P_{\Sigma^+}(\theta)$ is determined using the results of Beall *et al.* [5] on the $\Sigma^+ \to p + \pi^0$ asymmetry parameter. To make the $\bar{K}\Sigma N$ analysis one makes the following assumptions:

(1) the resonant state is $D_{3/2}$ relative to $K^- p$.

(2) the $S_{1/2}$ $K^- p$ amplitude is the only large non-resonant amplitude in the resonance region.

(3) only the resonant $J = 3/2$ amplitude varies rapidly in the energy region of the resonance.

With these assumptions and including small slowly varying $P_{1/2}$ and more recently $P_{3/2}$ amplitudes, Tripp *et al.* can get a good fit to the data only for $\bar{K}\Sigma^+ N$ odd. Capps has stressed the model independence of this conclusion subject, *however*, to these assumptions. Adair raises the following points:

(a) the presence of an appreciable non-resonant amplitude in the resonant channel is suggested by lack of equality of resonant $\Sigma^+\pi^-$, $\Sigma^0\pi^0$ and $\Sigma^-\pi^+$ cross-sections. Such a term will complicate the analysis and allow the phase to decrease rapidly even while resonant amplitude goes counter-clockwise.

(b) the possible lack of charge independence of the resonant position was not included in the analysis. ($\Gamma/2$ is comparable to Σ^-, Σ^+ mass difference.)

(c) energy dependence of the partial widths were not taken into account.

(d) the resonance occurs at the Y_1^* threshold so that other amplitudes may also be varying rapidly over the resonance region. If one assumes $\bar{K}\Sigma N$ even one could invoke some small $D_{5/2}$ as well as $D_{3/2}$ waves to improve the fit to the data.

I think it is clear that if one adopts all the freedom available in principle, there is certainly not enough data available to make a unique fit, and hence a unique conclusion on the $\bar{K}\Sigma N$ parity. On the other hand, such a fit has not been produced as yet and it is not trivial to do so.

In conclusion, it is remarkable that the general description given by Tripp *et al.* gives a plausible fit to a large amount of data with relatively few parameters, so that his result $\bar{K}\Sigma N$ parity odd is certainly favoured by the data. Nevertheless, in view of the freedom in the problem I do not think that this important parameter can be considered to be definitively established as yet.

Adopting the fit of Tripp *et al.*, Akiba and Capps [12] have pointed out that the relative phase $\phi(I = 0) - \phi(I = 1)$ in the $S_{1/2}$ $\Sigma\pi$ channels is determined to be $\approx -110°$. This result makes solution II of Humphrey and Ross more probable than solution I. I do not have the time to discuss in detail the very low energy K^-p interactions, but I can refer you to the invited paper of Dalitz, presented to this conference for such a review. If solution II is preferred, it allows the possibility of interpreting the Y_0^* (1405 MeV) resonant state as dynamically related to the negative zero energy K^-p scattering amplitude in the $I = 0$ state, i.e., the $Y_0^* = \frac{1}{2}^-$. However, one word of caution, to make this solution compatible with the K_2^0+p data of Luers *et al.* [13], one must assume a non-zero effective range in at least one of the $S_{1/2}$ amplitudes. This effect is not necessarily consistent with the zero range fit of Humphrey and Ross in the 0 to 200 MeV/c p_{K^-} region; and hence the whole analysis chain may have to be redone with more unknown parameters (i.e., including $I = 0$, 1 effective ranges $\neq 0$).

III. SPIN OF THE K^*

There have been two major contributions to this conference that bear on the $(K^0)^*$ spin.

(a) One of Alston *et al.* [14] presented by Ticho on the analysis of the reaction

$$K^- + p \rightarrow K^{*-} + p \qquad \qquad$$
$$\hookrightarrow K_1^0 + \pi^- \qquad \text{at } p_{K^-} = 1.22 \text{ GeV/c}$$

Fig. 1 shows the Dalitz plot of $K^0\pi^-p$ system (558 events). The K^* is clearly visible. There is no clear evidence of the $p\pi^-$ system in the (33) resonant state, but it must be borne in mind that it does cross the central region of the diagram. Fig. 2 shows the proton C.M. angular distribution for the K^* events. It shows a complicated angular distribution not consistent with a simple one-pion exchange diagram prediction. The authors have plotted all possible decay angular distributions of the K^* as shown in Fig. 3. If the spin of the K^* is 0, then all three angular distributions must be isotropic. On the other hand if $J(K^*) = 1$, one can have an arbitrary distribution of

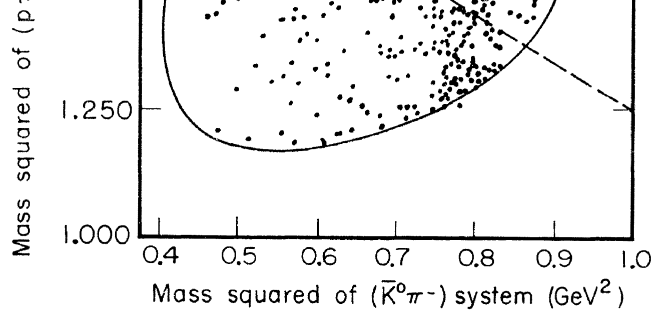


Fig. 1 Dalitz plot of the reaction $K^-+p \rightarrow \bar{K}^0+p+\pi^-$, for incident K^- momentum of 1.22 GeV/c.

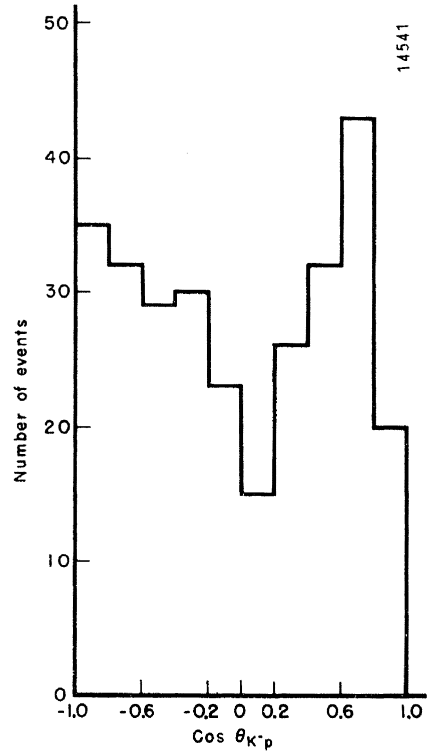


Fig. 2 Production angular distribution for the K^* events.

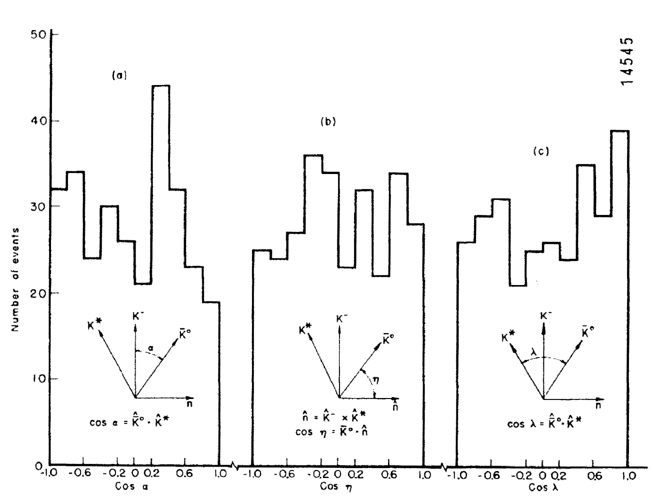


Fig. 3 The 3-decay distribution of the K^* events: (a) Adair distribution, (b) distribution with respect to the normal to the production plane, (c) distribution along the line of flight of the K^*.

the type $A+B\cos^2\theta$. Any $\cos\theta$ terms imply that the K^* production amplitude interferes with other amplitudes, assuming parity conservation. There is no statistically significant deviation from isotropy in any of these curves, hence this " lends circumstantial evidence to the assignment $J_{K^*}=0$ ". However, since there is no unique prediction for any of these distributions if $J_{K^*}=1$, (the Adair analysis fails because the other particle in the reaction, the proton, has spin 1/2), one cannot make any definite conclusion as to the spin of the K^* from this data.

(b) Armenteros *et al.* [15] have a completely different approach to the K^* spin determination. This makes use of the reaction

$$\bar{p}+p\rightarrow K_1^0+(K^*)^0$$

and the appropriate selection rules of J, P and C conservation. This method can only be applied if S wave $\bar{p}$-p capture predominates. B. d'Espagnat [16] has pointed out that one can test the prediction [17] of predominant S wave capture for the $\bar{p}$-p system by observing the ratio of $\bar{p}+p\rightarrow K_1^0+K_1^0$ to $\bar{p}+p\rightarrow K_1^0+K_2^0$. J and P conservation imply that the reaction $\bar{p}+p\rightarrow K+\bar{K}$ can occur only from triplet states. Since the charge conjugation quantum number $C(^3S_1)=-1$, S state capture implies that $\bar{p}+p\rightarrow K_1^0+K_2^0$ only.

M. Schwartz [18] has presented the argument on the K^* spin assuming S state capture. Consider first the hypothesis $J(K^*)=0$, $P(K^*)=+1$. The $^1S_0$ initial state ($C=+1$) can give a final state $\bar{K}^0+(K^*)^0$ with relative angular momentum ($l=0$), but the $^3S_1$ initial state is forbidden to go to $\bar{K}^0+(K^*)^0$ by J and P conservation. Since $C|\pi^0\rangle=+|\pi^0\rangle$, C conservation allows only the possibilities

$$\bar{p}+p\rightarrow\begin{Bmatrix}\bar{K}^0+(K^*)^0\\ K^0+(\bar{K}^*)^0\end{Bmatrix}\rightarrow\begin{Bmatrix}K_1^0+K_1^0+\pi^0\\ K_2^0+K_2^0+\pi^0\end{Bmatrix}.$$

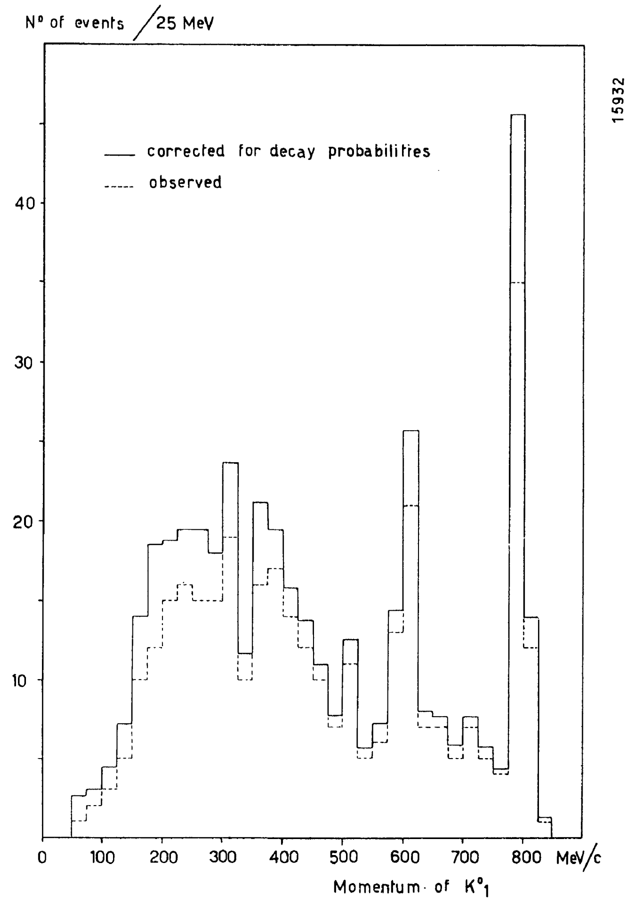
Recall that the branching ratio of (K_1^0) decay is

$$\frac{K_1^0(V)}{K_1^0(I)}=\frac{K_1^0\rightarrow\pi^++\pi^-}{K_1^0\rightarrow\pi^0+\pi^0}\approx\frac{2}{1}\quad(V\equiv\text{visible},\ I\equiv\text{invisible}).$$

Hence, if one concentrates one's attention on the events of the type $K_1^0+(K^*)^0$ where K_1^0 is visible, S state capture together with the hypothesis $J(K^*)=0$ implies that

$$K_1^0(V)\,(K_1^0(V)\pi^0)^*\approx 2K_1^0(V)\,(K_1^0(I)\pi^0)^*\qquad(3)$$

On the other hand, if $J(K^*)=1$, both $^1S_0$ and $^3S_1$ states can yield $\bar{K}^0+(K^0)^*$, so that Eq. (3) no longer holds. In this case one cannot predict the ratio $[K_1^0(V)(K_1^0(V)\pi^0)^*/K_1^0(V)(K^0(I)\pi^0)^*]$, although a priori one expects this ratio to be less than 1 rather than 2. Fig. 4 [15] contains the histogram of the



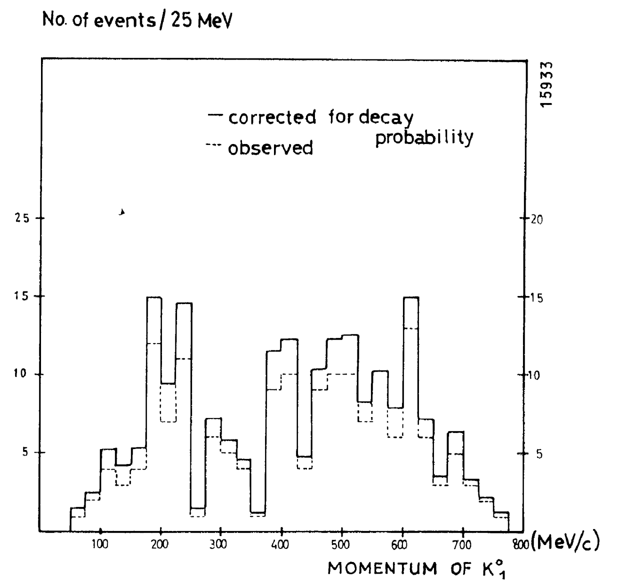


Fig. 4 Histograms of the visible K_1^0 momenta in the $p\bar{p}$ annihilation leading to the production of only neutral mesons. The lower histogram corresponds to the events with two visible K_1^0, the one above to the events with a single K_1^0.

K_1^0 (V) momenta from all events with one visible K_1^0 and the same histogram from all events with two visible K_1^0's. [These events in these two histograms have no other charged tracks.] This figure illustrates the data pertinent to:

(i) the S state capture hypothesis and,

(ii) the (K^*) spin determination.

(i) The CERN, Ecole Polytechnique, Collège de France collaboration find

$$\frac{\bar{p}+p\rightarrow K_1^0+K_1^0}{\bar{p}+p\rightarrow K_1^0+K_2^0}=\frac{0}{54}\,.$$

[At Oxford in a small sample of the $\bar{p}$-p film, one $K_1^0+K_1^0$ event has been found.]

Comparing this experimental result with d'Espagnat's argument, one concludes that S wave capture predominates in the $\bar{p}+p\rightarrow\bar{K}^0+K^0$ reaction, and the simplest assumption is to extend this result of S state predominance in the capture process to all inelastic channels as suggested theoretically [17]. [Note that a 20% P state capture still has ~10% probability given the experimental result noted above.]

(ii) At $p_{K_1^0}$ = 610 MeV/c, corresponding to K_0^* mass = 890 MeV, there are peaks in both histograms of Fig. 4. These yield the following results

Reaction	Experimental	Prediction for (A) given (B) and vice versa if $J(K^*)=0$
(A) $\bar{p}+p\rightarrow K_1^0(V)+(K(\mathrm{I})+\pi^0)^*$	43 ± 14	6.5 ± 5
(B) $\bar{p}+p\rightarrow K_1^0(V)+(K_1^0(V)+\pi^0)^*$	13 ± 11	86 ± 28

Subtracting (A) (predicted) from (A) (experimental) yields 36.5 ± 15 events of the $\bar{p}+p\rightarrow K_1^0+K_2^0+\pi^0$.

The experimental errors include the uncertainty in how to subtract the background. It is clear that if one extends the S wave capture argument to the reaction $\bar{p}+p\rightarrow K+\bar{K}^*$, this data is *rather incompatible* with $J(K^*)=0$. Hence $J(K^*)=1$ is strongly favoured.

In this same $\bar{p}$-p stopping experiment the following two-body reaction rates have been observed as shown below.

Event type	*Frequency*
$\bar{p}+p\rightarrow\pi^++\pi^-$	$(3.94\pm0.25)\times10^{-3}$
$\bar{p}+p\rightarrow K^++K^-$	$(1.31\pm0.18)\times10^{-3}$
$\bar{p}+p\rightarrow K^0+\bar{K}^0$	$(0.56\pm0.08)\times10^{-3}$

$$R=\frac{(\pi^+\pi^-)}{(K^+K^-)}=3.02\pm0.41$$

These rates have some importance with respect to selection rules obtained from different group theoretic models of the strong reactions as will be discussed by d'Espagnat in Plenary Session XII.

IV. $K^{\pm}p$ SCATTERING

I have time only for the briefest review of a substantial amount of data presented to the conference on this subject.

(a) S. Goldhaber *et al.* [19] presented their final results on K^+-p scattering from 140 to 800 MeV/c. This work was done using a hydrogen bubble chamber and the results for the total K^+-p cross-section are somewhat lower than earlier counter measurements. This is illustrated in Fig. 5. All the data are consistent with a repulsive S wave K^+-p interaction and no

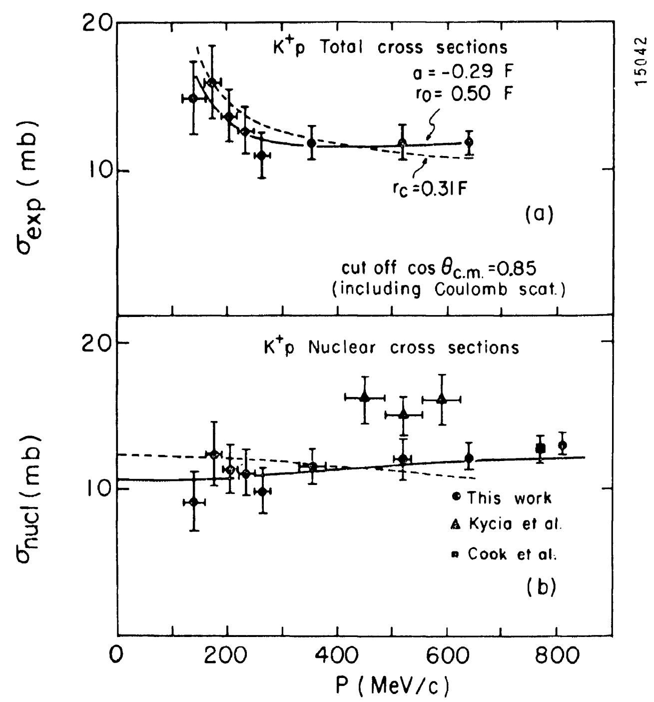


Fig. 5 (a) measured K^+-p cross-section versus laboratory momentum up to a cut-off angle taken at $\cos\theta_{\mathrm{CM}}=0.85$, (b) corresponding total nuclear cross-section, computed with a repulsive phase shift.

P waves. Except for the point at 810 MeV/c, the S wave phase shift is consistent with one deduced from a repulsive core potential with radius $r_c = 0.31 \pm 0.01$ F. Including the 810 MeV/c momentum result, one can fit the S wave energy dependence with two parameters, the scattering amplitude $a = -0.29 \pm 0.015$ F and the effective range $r_o = 0.5 \pm 0.15$ F. Costa *et al.* [20] have tried to fit the $S_{1/2}$ and $P_{1/2}$ phase shifts described above using dispersion relation methods. They tried a Born term dominant solution and a ρ meson exchange term dominant solution, (as illustrated in Fig. 6). In each case the N/D method was employed, the cuts for each type of solution were approximated by two poles and one background subtraction constant in N(w) was added. The cuts in the complex w plane are illustrated in Fig. 7 for each type of diagram. No good fit to the data was found for either of the simple types of solutions attempted. This is illustrated for the Born type fit in Fig. 8. As soon as one increases the number of theoretical parameters, the K^+-p data

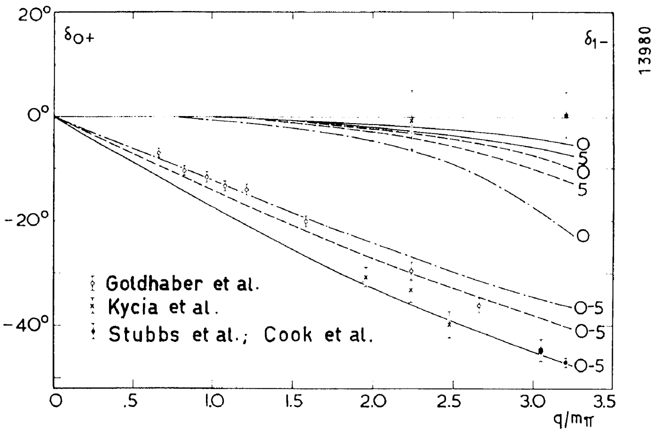


Fig. 8 $S_{1/2}$ and $P_{1/2}$ K^+p phase shifts versus C.M. momentum (in pion masses) for Born type fits.

does not provide sufficient constraints to yield a unique solution.

(b) Cook *et al.* [21] have measured K^+-p elastic scattering at $p_{K^+} = 0.97$, 1.17 and 1.97 GeV/c. Fig. 9 shows the experimental set-up which uses spark chambers and a counter hodoscope. Fig. 10 shows

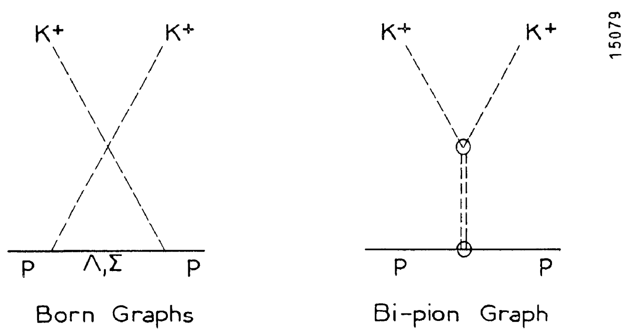


Fig. 6 Graphs corresponding to the Born term and to the ρ-meson exchange term.

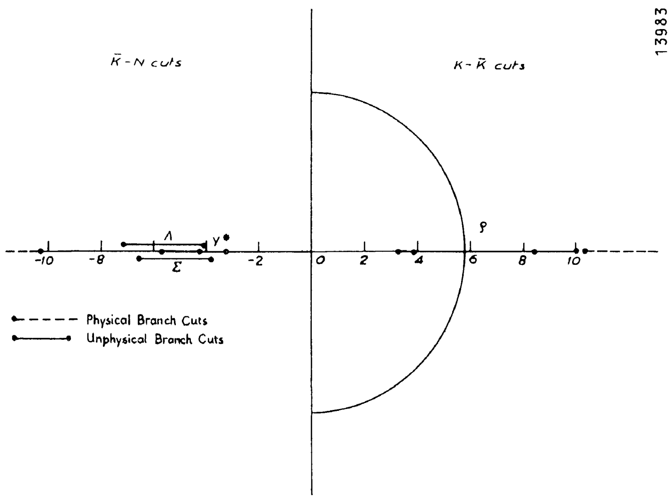


Fig. 7 Branch cuts in the w-plane for $J = \frac{1}{2}$ KN scattering amplitudes. The two halves of the figure are to be reflected about the imaginary axis.

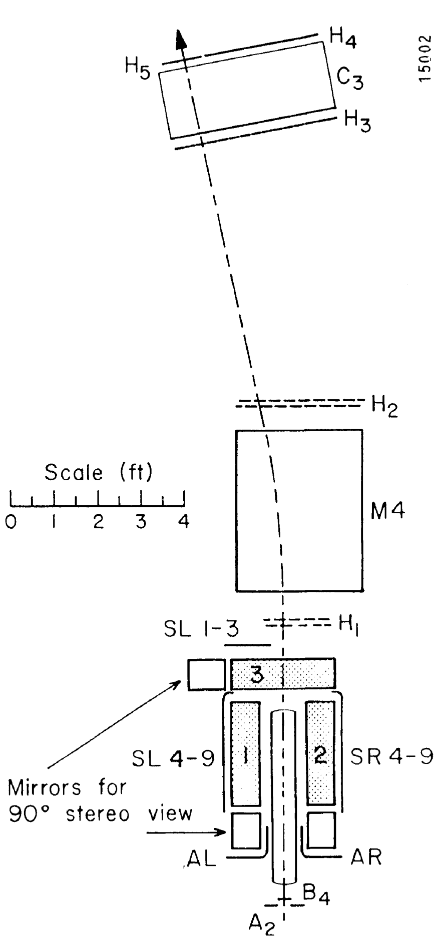


Fig. 9 Arrangement of scattering detector apparatus.

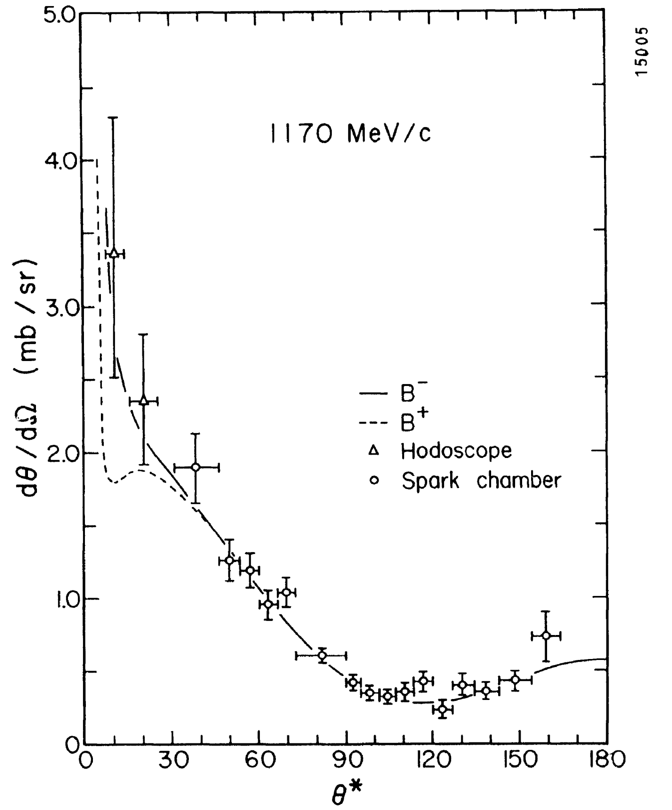


Fig. 10 Measured angular distribution at 1170 MeV/c. The curves are calculated from phase shifts solution, set (a) of Ref. 21.

$\sigma_{K^+p}(\theta)$ at 1.17 GeV/c. The angular distribution is far from isotropic . Fig. 11 gives the total and elastic scattering K^+-p cross-sections as a function of momentum. The authors have applied the forward angle dispersion theory relations to all the K^+-p and K^--p data. The data are compatible with a single subtracted dispersion relation, with a residue of the pole term given by -0.12 ± 0.32. More data are needed on the K^--p scattering amplitude at zero angle to make this analysis more definite. No conclusion is possible on the (Σ, Λ) parity from the sign of this pole term.

(c) Beall *et al.* [22] have presented preliminary results on K^--p elastic scattering cross-sections at ten momenta in the region $p_{K^-} = 700$ to 1400 MeV/c. The elaborate spark chamber plus hydrogen target set-up is shown in Fig. 12. Fig. 13 shows typical results for $\sigma_{K^-p}(\theta)$ elastic at three of the ten momenta measured. Fig. 14 shows the total and elastic K^--p cross-sections as a function of energy.

One of the purposes of this experiment is to try to determine the angular momentum and parity of the $I = 0$ Y_0^{***} (1815 MeV) K^--p resonance. $\sigma_{K^-p}(\theta)$

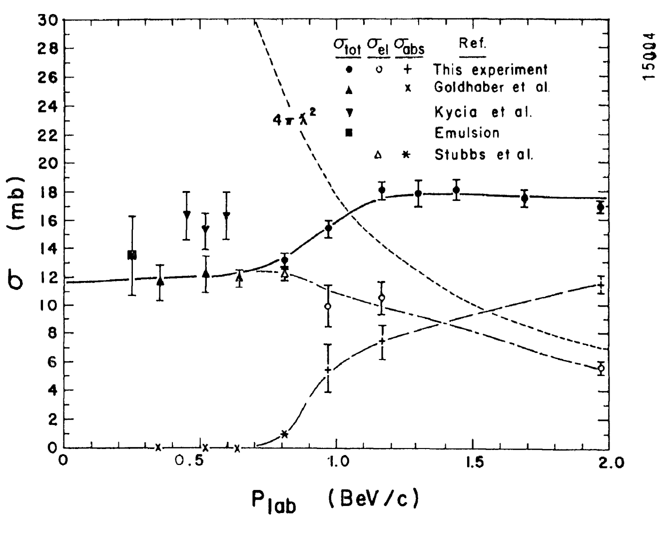


Fig. 11 The K^+-p total, elastic and inelastic cross-sections versus laboratory momentum.

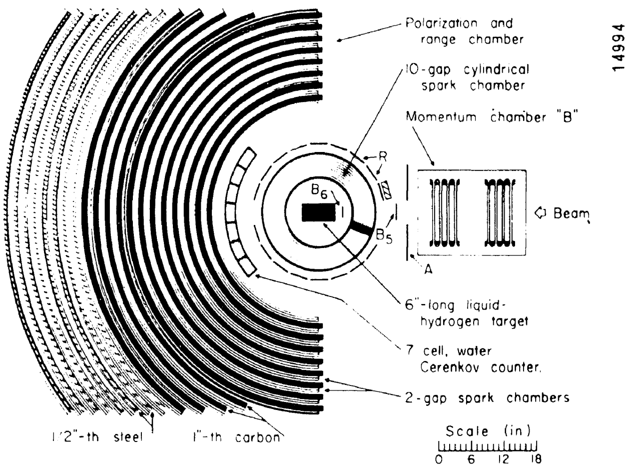


Fig. 12 General orientation of the equipment of Ref. 22.

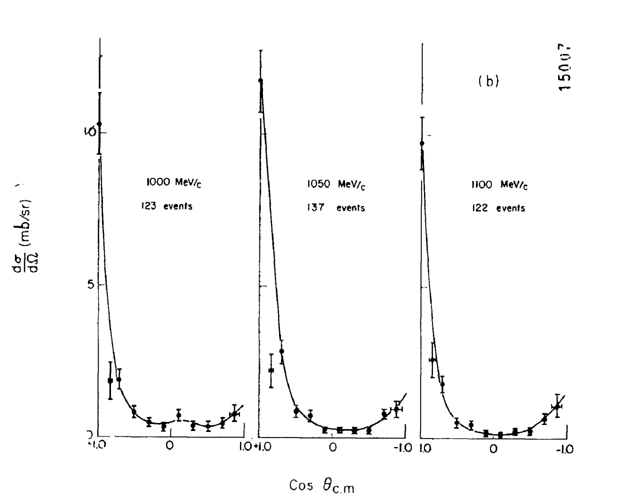


Fig. 13 Typical results for the differential K^--p cross-section at three of the 10 measured momenta.

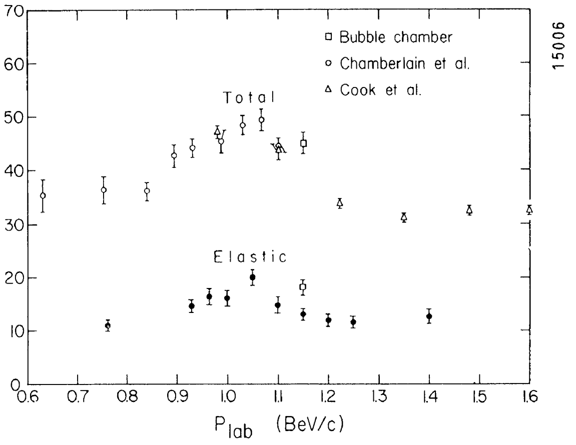


Fig. 14 Elastic and total K^--p cross-sections versus laboratory momentum. The solid circles refer to the experiment of Ref. 22.

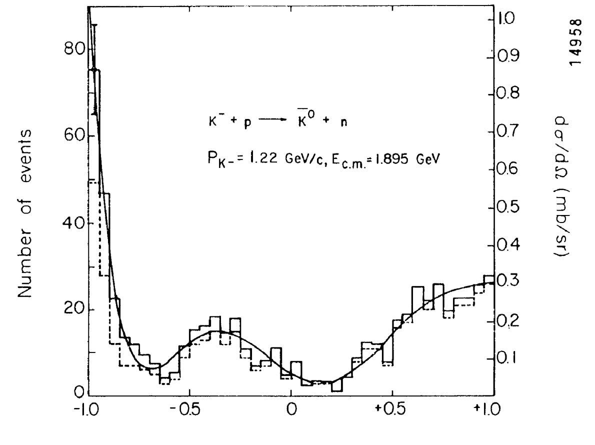


Fig. 15 Angular distribution in the centre-of-mass of the reaction K^-+p—$\bar{K}^0+n$ at 1.22 GeV/c incident K^- momentum. The dashed histogram refers to the events for which the projected length of the $\bar{K}^0$ was greater than 5 mm. The curve is a fit to the data up to the 6th power of cos θ.

elastic in the neighbourhood of this resonance requires terms of cos θ to the *5th* power. This is consistent with an assignment of $F_{5/2}$ to the resonant state, but the data and analysis are too preliminary to make a definite assignment of quantum numbers.

(d) Ferro-Luzzi *et al.* [23] have presented data on the charge exchange reaction $K^-+p \rightarrow K^0+n$ at 1.22 GeV/c. There is a large backward peak in the angular distribution of the K^0's, and terms $\sim(\cos\theta)^6$ are needed to fit this angular distribution (Fig. 15). At this momentum, one is slightly above the Y_0^{***} (1815) resonance, and these high power of cos θ in σ_{cx} are consistent with the high powers of cos θ in $\sigma_{el}(K^-p)$ found by Beall *et al.* [22] in the same energy region. At $p_{K^-} = 1.5$ GeV/c, the pronounced backward peak in $\sigma_{cx}(\theta)$ has largely disappeared (see Fig. 16).

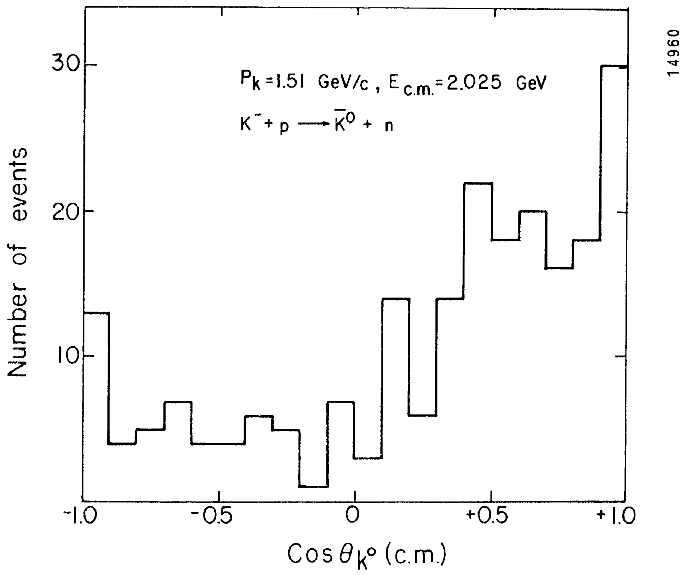


Fig. 16 Angular distribution in the centre-of-mass of the reaction K^-+p—$\bar{K}^0+n$ at 1.51 GeV/c incident K^- momentum.

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DISCUSSION

TREIMAN: What is the spin of the Y_1^*?

SNOW: The spin $^3/_2$ is certainly favoured. The most significant result is the one published by Ely *et al.*: their data are several standard deviations away from fitting spin $^1/_2$. The point is that the new data of the K^- run in the hydrogen 72″ Chamber is not able to increase the odds on that, because they get only a 2 standard deviation effect.

DOMOKOS: I want to comment on the spin of K^*, from work carried out by J. Wolf and myself in Dubna and independently by MacDowell *et al.* in order to understand the recoil spectrum in the reaction $\pi^-p\to\Lambda^0K^0$ according to the diagrams:

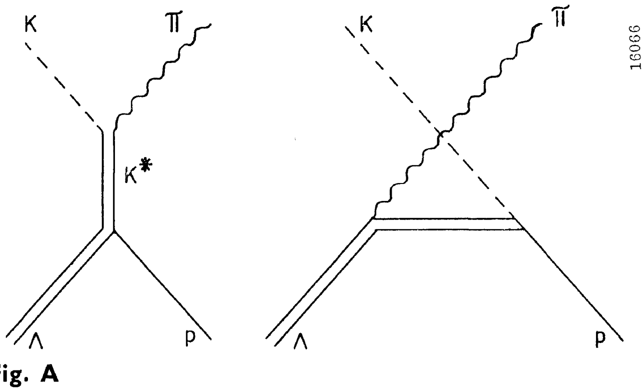

Fig. A

They seem to definitely favour spin one over spin zero. Can you explain this discrepancy? Have there been any statistical tests applied to the K^* angular correlation curve in order to exclude spin one?

SNOW: I cannot explain all those other reactions, they are complicated. I myself think that spin 1 for K^* is favoured when you compare the two experiments that I have discussed.

TICHO: We have looked at all kinds of correlation and at the $\cos^2\theta$ coefficients and their statistical significance, but we could not find anything that we thought was worth presenting at this conference.

CHEW: It is worth remarking that by now there are three different pairs of particles which conceivably may be related by Regge trajectories. First there is the nucleon and the $F_{5/2}(\pi N)$ resonance; next, the ($^3/_2$, $^3/_2$) resonance and the 1922 MeV (πN) resonance might be paired if the latter is $F_{7/2}$. Finally, if the 1815 MeV Y_0^* is $F_{5/2}$, it could be paired with Λ^0. As shown in the slide Rosenfeld presented in Session S2, the slope of the Regge trajectories implied by all three of the above pairings is about one unit of J per GeV^2. This happens to be quite close to the slopes of the Pomeranchuk and ω trajectories implied by high energy measurements.

MACDOWELL: We have calculated the K^*-production in K^-p reactions using a model in which the Y-resonance at 1815 MeV plays a dominant role (together with the π-meson exchange term). If this resonance is in the $D_{3/2}$ state one can explain reasonably well the experimental results on the production process assuming that K^* has spin one. Ball and Frazer also related dynamically the Y^* (1815) resonance to the K^* resonance with assignments $D_{3/2}$ and $J(K^*)=1$. I would like to ask whether the $D_{3/2}$ assignment for the Y^*-resonance is ruled out.

SNOW: The way Keefe described the situation was that if there is no $F_{7/2}$ wave coming into the K^-p angle distribution, then the resonance must either be $D_{5/2}$ or $F_{5/2}$. On the other hand, if there are $F_{7/2}$ waves then the resonance could be in $P_{3/2}$ $D_{3/2}$ $D_{5/2}$ $F_{5/2}$ or $F_{7/2}$ and they have not yet determined how significant the $F_{7/2}$ wave is.

GOOD: I noticed no new reports of a $T=2$ global symmetry π-hyperon resonance, nor any report of a $T=3/2$ global symmetry $\pi-\Xi$ resonance. I would like to ask, does anyone feel they have looked for these things, under conditions where they might have found them, and have not found them?

SNOW: I know that at 1.5 GeV in the CERN K^-p experiment in the fourbody reaction $\Sigma^\pm\pi^\mp\pi^-\pi^+$ one looks for $T = 2$ resonances, but when one looks at these reactions the dominant things that one sees are $T = 0$ resonances. I think the Berkeley data which has more statistical weight shows the same thing: they do not see any evidence for this.

SAKURAI: It is now plausible that the 1405 MeV Y_0^* but not the 1385 MeV Y_1^* is an s-wave $\bar{K}N$ bound state of the Dalitz-Tuan type. So it is worth asking what kind of dynamical mechanism is responsible for binding a $\bar{K}$ and an N in the $T = 0$ state. Along this line a student of mine, Richard Arnold at Chicago, has performed a very crude N/D calculation to show that for reasonable values of coupling constants the forces due to the exchanges of ϱ and ω are sufficiently attractive to bind the $T = 0$, $\bar{K}N$ system. On this calculation the signs of the ϱ and ω exchange force are fixed by the universality principle of the vector theory of strong interactions. Another interesting point is that the same mechanism predicts that the $T = 1$, KN system is strongly repulsive, in agreement with observation. I want to make another remark which is somewhat more general. It is interesting to conjecture that the isospin dependent force for any low energy scattering is dominated by the exchange of the ϱ meson coupled universally to the isospin current. The ϱ exchange force is then attractive whenever the isospins are antiparallel and repulsive whenever the isospin are parallel. This rule works remarkably well in five cases examined so far. In the case of s-wave πN scattering essentially the entire isospin dependence is due to the ϱ exchange as conjectured by Cini and Fubini and by myself independently and as proved by Hamilton *et al.* In the s-wave $\pi\pi$ scattering case the $T = 0$ seems more attractive than the $T = 2$ state. In low energy $K\bar{K}$ scattering there is some evidence for a strong attractive interaction in the $T = 0$ state as we have just heard. In the $\bar{K}N$ case the currently accepted idea, that the 1405 MeV Y_0^* but not the 1385 MeV Y_1^* is likely to be a $\bar{K}N$ bound state resonance, shows that the $T = 0$ state is more attractive. In the $S = 1$, KN case, the $T = 1$ state is definitely more repulsive than the $T = 0$ state. In general bound states and resonances are more likely for states with lower isospins as you can see from the table of elementary particles and resonances. So there seems to be a correlation between the simplicity of quantum numbers and the possibility of bound or resonant states.

ROSENFELD: (in reply to Good): Good asked how carefully we have looked for doubly charged ($T = 2$) resonances. 1.51 GeV/c $K^-+p\to\Sigma^\pm\pi^\mp\pi^+\pi^-$ ($E^*_{\mathrm{CM}} = 2025$ MeV, 400 events) allowed Alston *et al.*, to explore doubly charged $\Sigma\pi$ combination fairly well up to $\simeq$1600 MeV. Actually, we saw one bump of perhaps 2 standard deviations at 1560 MeV, but nothing that looked interesting. But I repeat for negative strangeness Berkeley has not looked above 1600 MeV.

TICHO: In reply to Good, we are sensitive to $\Xi\pi$ $T = 3/2$ resonance up to Q values of 170 MeV. Within our statistics we see no evidence for resonances other than the reported Ξ^* of $T = 1/2$.

SANDWEISS: In a paper submitted to this conference, results of a π^+p study at 2 GeV are reported. In about 70 events of $\Sigma^+\pi^+K^0$, $\Sigma^0\ \pi^+K^+$ and $\Sigma^+\pi^0K^+$ no evidence for a $T = 2$ $\Sigma\pi$ resonance was found.

GELL-MANN: If we take the unitary symmetry model with baryon and meson octets, with first order violation giving rise to mass differences, we obtain some rules for supermultiplets. The broken symmetry picture is hard to interpret on any fundamental theoretical basis, but I hope that such a justification may be forthcoming on the basis of analytic continuation of resonant states in isotopic spin and strangeness. Instead of constructing just the inverse Regge function E (J), we can consider surfaces E (J, I, Y, etc.). Certainly the dynamical equations are as smooth in I and Y as they are in J.

Anyway, we may look at the success of the mass rules:

$$\frac{m_N+m_\Xi}{2} = \frac{3m_\Lambda}{4}+\frac{m_\Sigma}{4}$$

and

$$m_K^2 = \frac{3m_\chi^2}{4}+\frac{m_\pi^2}{4}$$

work fine, while

$$m_M^2 = \frac{3m_\omega^2}{4}+\frac{m_\rho^2}{4}$$

does not work quite so well if $M = K^*$.

Suppose, now we try to incorporate the 3/2-3/2 nucleon resonance into the scheme. The only supermultiplet that does not lead to non-existent resonances in the $K-N$ channels is the *10* representation, which gives 4 states:

$$I = 3/2,\quad S = 0$$
$$I = 1\ ,\quad S = -1$$
$$I = 1/2,\quad S = -2$$
$$I = 0\ ,\quad S = -3$$

The mass rule is stronger here and yields *equal spacing* of these states. Starting with the resonance at 1238 MeV, we may conjecture that the Y_1^*, at 1385 MeV and the Ξ^* at 1535 MeV might belong to this supermultiplet. Certainly they fulfil the requirement of equal spacing. If $J = 3/2^+$ is really right for these two cases, then our speculation might have some value and we should look for the last particle, called, say, Ω^- with $S = -3$, $I = 0$. At 1685 MeV, it would be metastable and should decay by the weak interactions into $K^-+\Lambda$, $\pi^-+\Xi^0$, or $\pi^0+\Xi^-$. Perhaps it would explain the old Eisenberg event. A beam of K^- with momentum $\gtrsim$3,5 GeV/c could yield Ω^- by means of $K^-+p\to K^++K^0+\Omega^-$.

ADAIR: I would like to clarify the statements attributed to me concerning the $\Sigma-K$ parity. The conclusions of Tripp, Ferro-Luzzi, and Watson, and, implicitly, those of Capps, that the $\Sigma-K$ parity is odd, actually refer to a particular model of the K-nucleon interaction, a model which at best can be but a first approximation to the real world, and which does not exhibit certain important features of their data. In particular, this model assumes that the energy dependence of background amplitudes and resonance widths may be neglected, that charge dependent effects may be neglected, and most important, that there are no background amplitudes in the states with the j and parity of the resonance. Elementary considerations show that for the high angular momentum states of interest such approximations are quite inadequate. For example, the magnitude of background amplitudes and widths must vary with energy perhaps by a factor of two, over the resonance region. Their model results in equal resonant cross-sections for the production of the three Σ states; the data indicate that these differ by about a factor of four . Qualitatively this difference can result from the violations of simple charge independence required by the different Σ and pion masses, or from the presence of large background amplitudes in the resonant state. Quantitatively, the data are only consistent with large background amplitudes. When these variations from the simple model are introduced, variations required to fit the data and our knowledge of reactions, the uniqueness of the parity determination disappears. I have shown the character of the amplitudes required to fit the data qualitatively with even $\Sigma - K$ parity and consider that there is no doubt that excellent quantitative fits can be obtained. Such variations from the simple model are, of course, also required if the odd $\Sigma - K$ parity solutions are to fit all of the data. I know of no objective way of deciding which fit would be simpler. I do not believe that the fact that a simpler model can be constructed with the odd parity assignment, a model which fits only selected parts of the data, can be considered strong evidence for odd $\Sigma - K$ parity. At the most it may be suggestive.

ELY: About the spin of the Y_1^*. It is unclear to me, because I do not have the exact number from the 1220 MeV K^- run in the 72″ chamber. It would appear that at that energy, their result, which is of overwhelming statistics, is almost incompatible with the central value of the anisotropy coefficient which we reported. However, the tendency is the same. This result coupled with our result, and also the results of Alston *et al.*, that is primarily the latter two, would make it very difficult to explain this entirely as a statistical fluctuation, and consequently it would probably have to be some sort of, as yet, unexplained interference term, which is involved if the spin is $^1/_2$. The reason this is unclear is possibly that this is not a definite prediction. There has not yet been a positively made prediction about what the anisotropy should be, since there is doubt about the partial wave analysis from the production system. Possibly, if $K^- + p \rightarrow \Lambda + \pi + \pi$ were examined, at several energies, in this vicinity this could be resolved.

Concerning the other piece of information by Block; certainly he is going to have more data and one can afford to wait to see what he says. There is a definite prediction that the angular distribution should be $1 + 3\cos^2\theta$ in his experiment if there are no final state interactions.

The Adair analysis, which has been reported in both the K^-p and associated production experiments, has consistently failed to give a positive result for spin $\geqslant 3/2$. This can be explained by virtue of the fact that there are high partial waves. But on the other hand, one would certainly like to see this test work positively in some case. Since it is a positive prediction, one has reason to expect that one knows what the distribution should be in that case. Along this line, I would like to suggest that since there have been several cases where the $\pi - N$ 3/2-3/2 isobar has been reported at this conference, it might be interesting if these people would try to prove by the Adair analysis and by the anisotropy techniques that the spin of the 3/2-3/2 isobar is 3/2. This might shed some light on the attempts by these techniques to prove that the other resonances have a specific spin.

ADAIR: Snow stated that the data of Ely *et al.* showed an anisotropy of Y_1^* decay such that it was $2^1/_2$ standard deviations from spin $^1/_2$. More precisely the results are $2^1/_2$ standard deviations from isotropy—a vast difference. As a result of interference with background amplitudes the decay of a broad spin $^1/_2$ state will generally be anisotropic. Very small intensities can produce large anisotropies. For example, consider the decay of a spin $^1/_2$ state in the presence of an intensity of only 2% of spin 3/2 state of the same parity, 180° out of phase. The decay distribution will then be approximately of the form $0.8\cos^2\theta + 1$, and the polar-equatorial ratio nearly two. The sensitivity of such decay distributions to small backgrounds makes the measurement of the spins of baryon resonances very difficult; especially the utility of the so-called Adair analysis is severely compromised. In particular, the spin of the Y_1^* is completely open; indeed it is difficult to imagine any experiment which will conclusively settle this question.