RESONANCES IN STRANGE PARTICLE PRODUCTION (*)

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I. INTRODUCTION

In an exposure of propane to 2.0 GeV/c π^- mesons at the Cosmotron in the Columbia 30 in. chamber, reactions have been analyzed for resonances between the particles present in the final state. The reactions studied were sufficiently overdetermined to permit a separation of hydrogen events from carbon. The reactions which have been studied are:

$$\pi^- + p \rightarrow \Lambda^0 + \pi^- + K^+ \quad (1)$$

$$\pi^- + p \rightarrow \Sigma^{\mp} + K^0 + \pi^{\pm} \quad (2)$$

$$\pi^- + p \rightarrow \Lambda^0 + K^0 + \pi^0 \quad (3)$$

Some results on these reactions for pions of 1.6 [1] and 1.9 [2] GeV/c, and 2.1 GeV/c [3e] laboratory momentum have already been reported. The present work supplements these and yields additional information on the spin and parity of the Y_1^*.

Table I summarizes the cross-sections.

TABLE I

Reaction	No. of Events Found	Estimated Carbon Back-ground	Cross-Section
$\pi^- + p \rightarrow \Lambda^0 + K^+ + \pi^-$	142	9%	72±12μb
$\pi^- + p \rightarrow \Sigma^+ + K^0 + \pi^-$	26	9%	34± 9μb
$\pi^- + p \rightarrow \Sigma^- + K^0 + \pi^+$	47	9%	51±12μb

The reactions (1)-(3) have the advantage that the interference effects due to the Bose character of the pions, which hamper the spin determination of the Y_1^* in the reaction $K^- + p \rightarrow \pi^- + \pi^+ + \Lambda^0$, are absent. There remain, of course, other interference effects which may also frustrate the attempts to make spin determinations using reactions (1)-(3).

II. RESONANCES IN THE REACTIONS $\pi^- + p \rightarrow \Lambda^0 + K^0 + \pi^0$ AND $\Lambda^0 + K^+ + \pi^-$

The mass distributions for these two reactions were combined into single plots which appear in Figs. 1, 2

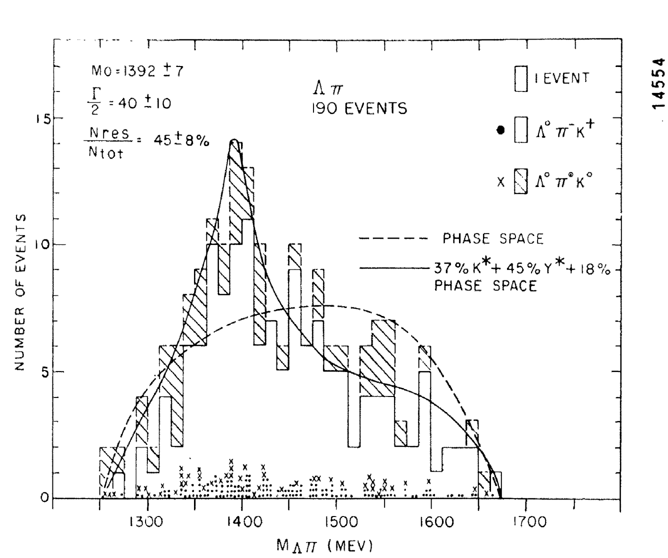

Fig. 1 Mass distribution of the $\Lambda\pi$ system.

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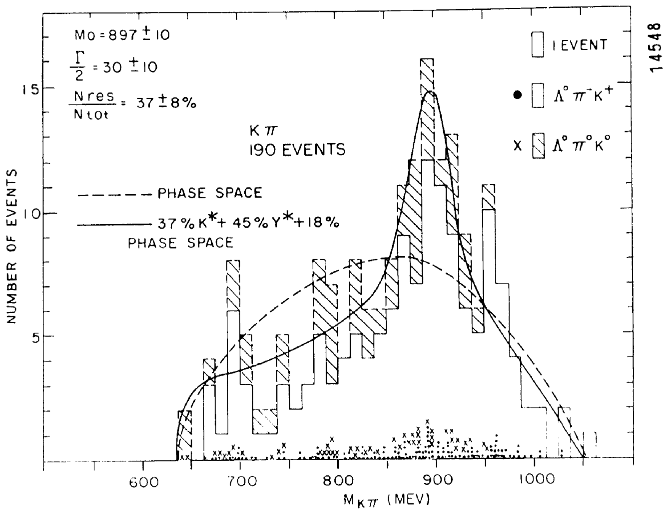

Fig. 2 Mass distribution of the $K\pi$ system.

and 3. It is apparent that they show a resonant structure in which both the Y_1^* and K' play a large role. We fit the experimental distributions with a distribution of the form

$$F(m_{ij}) = \alpha\ (\text{phase space}) + \beta\ (Y_1^*\ \text{distribution}) + \gamma\ (K'\ \text{distribution})$$

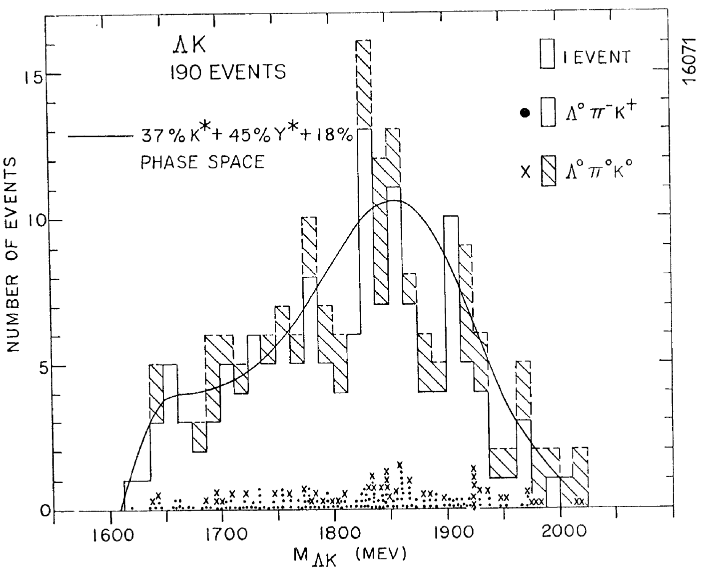

Fig. 3 Mass distribution of the ΛK system.

where the Y_1^* and K' distributions are of the Breit-Wigner form

$$f(m) = N/\pi \frac{\Gamma/2}{(m-m_0)^2+(\Gamma/2)^2},$$

N = total number of events. The following parameters with approximate errors give a good fit

	M_0	Γ
Y_1^*	1392 ± 7	40 ± 10
K'	897 ± 10	30 ± 10
α	β	γ
0.18	0.45 ± 0.08	0.37 ± 0.08

We conclude that reactions (1) and (3) are dominated by Y_1^* and K' production. However, we see no evidence for a K-π resonance at a mass of 730 MeV reported for the same reactions at the same energy [3e].

It is interesting to note that the prominent peak in the $\Lambda^0 K$ mass can be described as being just a kinematic reflection of the Y_1^* resonance and not due to a $\Lambda^0 K$ resonance. We point out also that our mass values as well as the widths of the Y_1^* and K' are slightly larger than those of previous measurements.

III. RESONANCE IN THE REACTION $\pi^- + p \rightarrow \Sigma^\mp + K^0 + \pi^\pm$

In previous experiments [3] indications have been seen of resonances in the $\Sigma\pi$ system at 1404 MeV and 1525 MeV. Our distributions appear in Figs. 4, 5 and 6. Both of these seem to be present in the $\Sigma\pi$ mass spectrum.

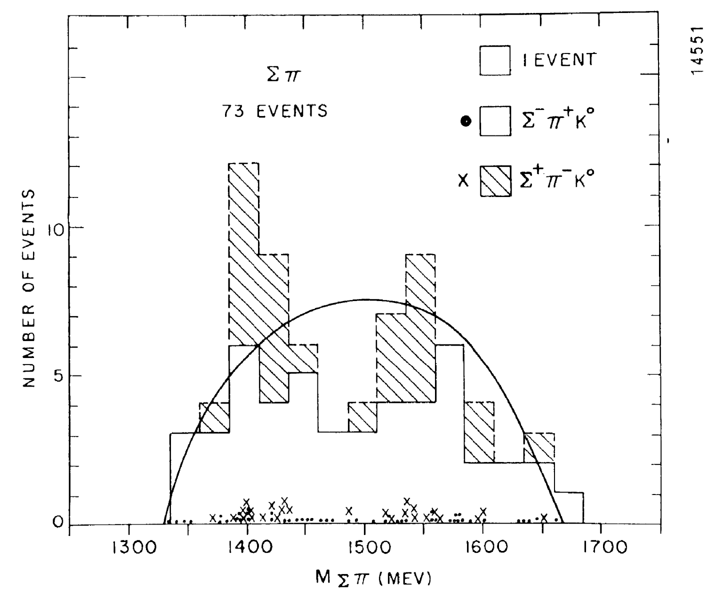

Fig. 4 Mass distribution of the $\Sigma\pi$ system.

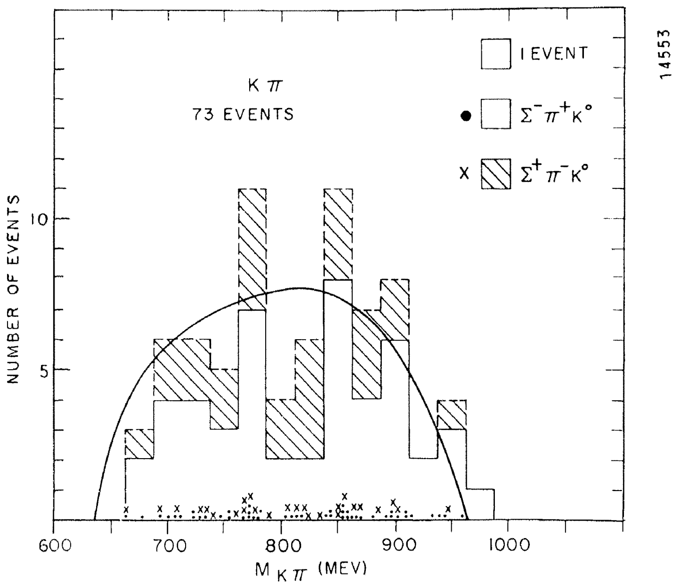

Fig. 5 Mass distribution of the $K\pi$ system.

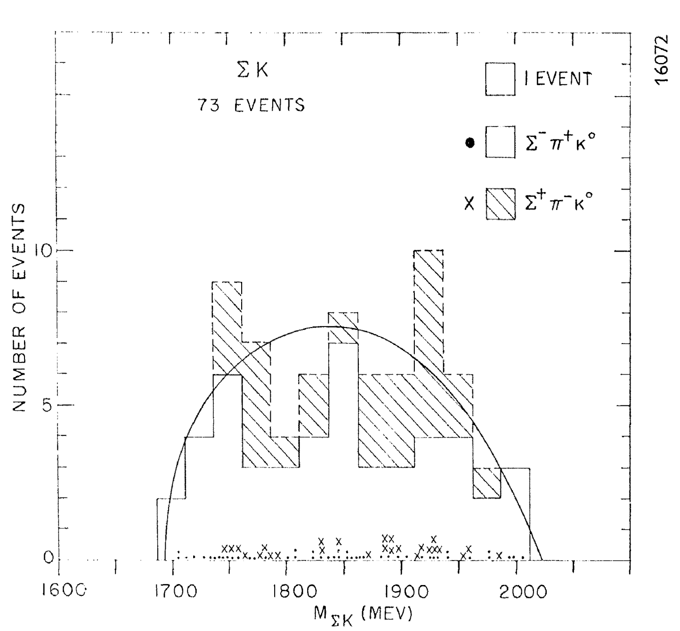

Fig. 6 Mass distribution of the ΣK system.

IV. PRODUCTION ANGULAR DISTRIBUTIONS OF THE Y_1^* AND K'

These are shown in Figs. 7 and 8. The Y_1^* are produced preferentially backwards and the K' forwards, consistent with the general observation that nature abhors large momentum transfers.

V. SPIN AND PARITY OF THE Y_1^*

There are several ways in which the data could be analyzed to yield information of the spin of the Y_1^*. We feel that we are too much above threshold to justify the use of the Adair analysis. Instead the data are analyzed for correlations between the Λ^0

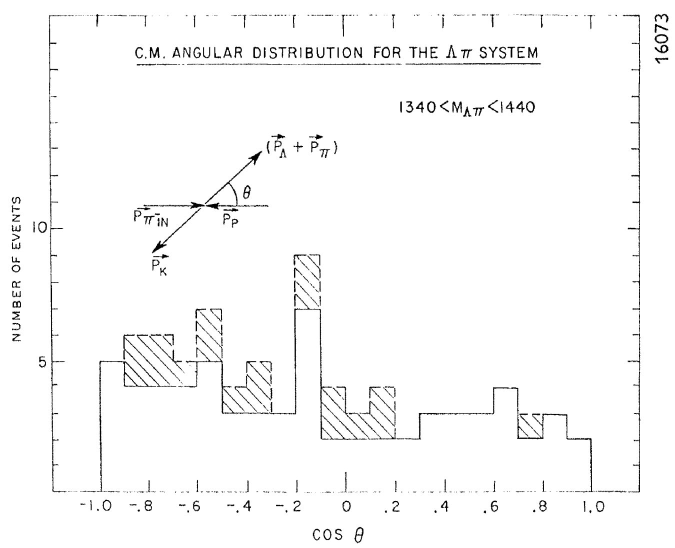

Fig. 7 C.m. angular distribution for the $\Lambda\pi$ system.

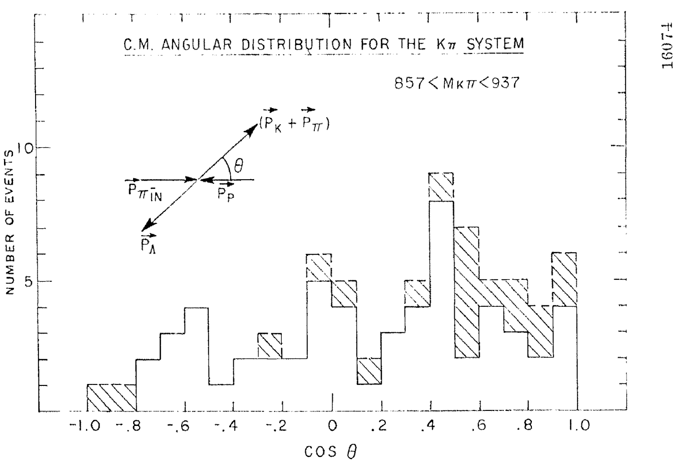

Fig. 8 C.m. angular distribution for the $K\pi$ system.

momentum and three orthogonal directions: the production plane normal, the Y_1^* direction, and the normal to the two. The frame of reference is obtained by first transforming to the production c.m. and then to the Y_1^* c.m. The analysis for events in the mass interval $1340 \leq m_{Y_1^*} \leq 1440$ is tabulated in Table II.

TABLE II

(1) Y_1^* Decay

$f(\cos\theta) = \text{Const}\,[1 + a\cos\theta + b\cos^2\theta]$

	a	b
(*) $f[\hat{P}_\Lambda \cdot \hat{n}]$	-0.29 ± 0.29	1.29 ± 0.78
$f[\hat{P}_\Lambda \cdot \hat{P}_{Y_1}{}^*]$	-0.29 ± 0.17	-0.14 ± 0.34
$f[\hat{P}_\Lambda \cdot \hat{P}_{Y_1}{}^* x\hat{n}]$	0.12 ± 0.14	-0.50 ± 0.24

(*) $\hat{n}$ = unit vector normal to the plane of production.

(2) Λ° Decay

$f(\cos\eta) = \text{Const}\,(1+\alpha\bar{P}\cos\eta)$

	$\alpha\bar{P}$
$f[\hat{P}_{\pi^-\Lambda}\cdot\hat{n}]$	0.55±0.17
$f[\hat{P}_{\pi^-\Lambda}\cdot\hat{P}_{Y_1}{}^*]$	0.40±0.18
$f[\hat{P}_{\pi^-\Lambda}\cdot\hat{P}_{Y_1}{}^* x\hat{n}]$	0.25±0.18

The distribution relative to the production plane normal has a large anisotropy; the coefficient of the $\cos^2\theta$ term is 1.29±0.78 (see also Fig. 9). The smallness of the $\cos\theta$ term gives some assurance that the interference with K' and non-resonant production is small. Within the mass interval of the Y_1^*, the Y_1^* is dominant: 70% of the observed events are resonant, according to the model we have used to fit the mass spectra. The large $\cos^2\theta$ term is most likely then an anisotropy in the decay of the Y_1^* itself, or a statistical fluctuation. Given that the effect is real, it must be inferred that the Y_1^* is produced polarized or aligned and has spin greater than 1/2. Spin 3/2 is the simplest possibility; it also is the spin predicted by a model of the Y_1^* in which it is the counterpart in "global symmetry" of the spin 3/2, I spin 3/2 pion-nucleon p-wave resonance [6]. This prediction is in agreement with some of the results of the K^- meson experiments for producing the Y_1^* [7].

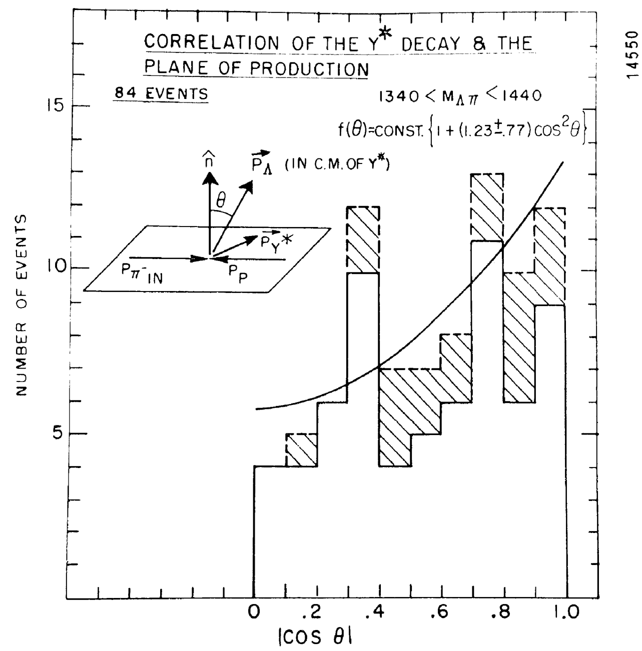

Fig. 9 Correlation of the Y_1* decay and the plane of production.

Although the assignment of the spin of the Y_1^* is not very strong statistically, it is possible to show that, given the spin of the $Y_1^* = \frac{3}{2}$, the resonance is a p-state resonance as the globally symmetric model predicts, and that consequently the Y_1^*-Λ^0 relative parity is even. This is done by analyzing the correlation in η, the angle between the pion in Λ^0 decay and the Y_1^* production normal. The pion has been successively transformed to the production c.m., the Y_1^* c.m. and the Λ^0 c.m. The expected distribution is $g(\eta) = 1+\alpha\bar{P}\cos\eta$ where $\alpha = 0.67\pm0.07$ [8] and $\bar{P}$ is the average polarization of our sample of Λ^0's. For the events in the Y_1^* peak, in the mass interval 1340-1440 MeV, we find $\alpha\bar{P} = 0.55\pm0.17$. This is in agreement with the Wisconsin group which finds $\alpha\bar{P} = 0.61\pm0.28$ [2]. The maximum Λ polarization compatible with the observed Y_1^* decay correlation is $|\bar{P}_\Lambda|_{\max} = 0.47\pm0.09$ if the resonance is in the p-state, and $|\bar{P}_\Lambda|_{\max} = 0.28\pm0.05$ if the resonance is in the d-state. The experimental value is $|\bar{P}| = 0.82\pm0.27$, in better agreement with the p-wave or even parity case. If it should turn out instead that the Y_1^* has spin $\frac{1}{2}$, then the Λ^0 polarization shows in a similar way that the Y_1^* decays via s-wave.

VI. THE K' SPIN

We have performed the same analysis for the K' that was made for the Y_1^*. The results appear in Table III. As can be seen, there is no appreciable $\cos^2\theta$ dependence in the angular distribution. We cannot make any conclusions as to the spin of the K' from such a result.

TABLE III

K' Decay

$f(\cos\theta) = \text{Const}\,[1+a\cos\theta+b\cos^2\theta]$

	a	b
$f[\hat{P}_K\cdot\hat{n}]$	−0.11±0.2	0.33±0.48
$f[\hat{P}_K\cdot\hat{P}_{K'}]$	0.43±0.23	−0.14±0.39
$f[\hat{P}_K\cdot\hat{P}_{K'}x\hat{n}]$	0.05±0.2	0±0.4

VII. CONCLUSIONS

(1) We have clear evidence that not only the Y_1^* but also the K' are produced in $\Lambda^0 K\pi$ production at 2 GeV/c incident π^-momentum. There is no evidence for a $K\pi$ resonance at 730 MeV.

(2) We seem to observe the 1404 and 1525 $\Sigma\pi$ resonances.

(3) The most probable interpretation of the observed angular correlation in the Y_1^* decay requires that the Y_1^* spin be greater than $\frac{1}{2}$. If the Y_1^* spin is then assumed to be 3/2, the relative parity of the Y_1^* and the Λ^0 must be even to account for the Λ^0 polarization. However, if the Y_1^* has spin 1/2, the parity must be odd.

LIST OF REFERENCES

1. Saclay, Orsay, Bari, Bologna (Preprint).
2. Erwin, A. R., March, R. H. and Walker, W. D. (To be published in Nuovo Cimento).
3*a*) Alston, M. H. *et al.*, Phys. Rev. Letters, *6*, 698 (1961);
b) Bastien, P. *et al.*, Phys. Rev. Letters, *6*, 702 (1961);
c) Ferro-Luzzi, M. *et al.*, Phys. Rev. Letters, *8*, 28 (1962).
d) Alston, M. H. (Private communication);
e) Alexander, G. *et al.*, Phys. Rev. Letters, *8*, 447 (1962).
4. Dalitz, R. H. and Miller, D. H., Phys. Rev. Letters, *6*, 562 (1961).
5. UCRL 9097 (1960).
6. Gell-Mann, M. Phys. Rev. *106*, 1297 (1957).
7. Ely, R. P. *et al.*, Phys. Rev. Letters, *7*, 461 (1961).
8. Cronin, J. (Private communication) $\alpha = -0.62 \pm 0.07$. Leitner, J. *et al.*, Phys. Rev. Letters, *7*, 264 (1961), $\alpha = -0.75^{+0.05}_{-0.15}$

DISCUSSION

SNOW: What is the decay distribution of the $Y_1^* \rightarrow \Lambda + \pi$ in its rest system? Is there any evidence of a forward backward asymmetry? This would be a test of interference effects in the Y_1^* decay.

STEINBERGER: No, there is no asymmetry, there is no $\cos\theta$ term. We see no sign of interference between the Y^* and the background.

SNOW: What fraction of the Y_1^* events which you have used in your sample are also in the K^* peak?

STEINBERGER: I think about 15%.

S. GOLDHABER: It would be useful to look at the $\Sigma^+\pi^-K^0$ final state to investigate the spin of the Y^* ($\Sigma\pi$) resonance, since in this case the $K^0\pi^-$ are in a pure $T = {}^3/_2$ state and cannot form a K^* ($T = {}^1/_2$). Therefore there would be no interference between the Y^* and K^*.

ALVAREZ: There have been several reports at this conference, which indicate that the spin of the Y_1^* is greater than ${}^1/_2$. Although we feel that the spin is probably ${}^3/_2$, it should be mentioned that our sample of Y_1^*'s which is probably larger than the total from other laboratories, shows only a 2 standard deviation departure from isotropy. So, in the spirit of Adair, I am pointing out that the evidence for a very probable conclusion does not rest on a very solid experimental basis.

STEINBERGER: I would agree that our evidence is no great addition to what we know of the spin of the Y_1^* but I do think that the argument on the parity may be very useful.

GOOD: I do not understand why the Λ polarization is not 100% for P wave decay of spin ${}^1/_2$ Y^*.

STEINBERGER: The polarization is constrained to agree with the angular distribution.