since there is no $J=2$ initial state. The $J=0$ part is even under charge conjugation and the $J=1$ part is odd. Hence we have

$$\psi_1 = A_0\left(\frac{K_{1a}{}^0K_{1b}{}^0 - K_{2a}{}^0K_{2b}{}^0}{\sqrt{2}}\right) + A_1\left(\frac{K_{1a}{}^0K_{2b}{}^0 - K_{2a}{}^0K_{1b}{}^0}{\sqrt{2}}\right),$$

where A_0 refers to the $J=0$ part and A_1 refers to the $J=1$ part.

Turning to the problem of determining the spin of the K', let us first select that group of $\bar{p}$ stoppings which show a $K_1{}^0$ decay with a momentum such that the other outgoing particle is a K' (or $\bar{K}'$) meson. This can be done above background to the extent that the K' mass is well defined. Then we can deduce the following points:

1. If the spin of the K' is zero, then another $K_1{}^0$ decay must also occur.
2. If the spin of the K' is 1, then the other K^0 can decay via the $K_2{}^0$ mode some of the time, unless A_1 happens to be zero.
3. In addition, we can unambiguously determine the spin by considering those cases where both decays are observed to be of the $K_1{}^0$ type. Let us consider the z axis along the direction in which the K' was moving before decay. Events of the above sort must have $J=0$ regardless of the spin of the K'. The orbital angular momentum of the $K\bar{K}'$ (or $K'\bar{K}$) system must have z component equal to zero. Hence the K' must have its spin in the $m=0$ state. If we now consider its decay into π^0+K^0 in its own center-of-mass system, the outgoing particles will have the following distributions about the z direction:

(a) If spin $K'=0$, the distribution is obviously isotropic.

(b) If spin $K'=1$, the distribution must have the form $\cos^2\theta$, where θ is the polar angle between π^0 and K'.

In the event that there is a nonresonant $K_1{}^0K_1{}^0\pi^0$ background, as there most certainly will be, then the distribution which one will obtain as a result of the above procedure will have the form $|\sum\alpha_iP_i{}^0(\cos\theta)|^2$. In principle, one can then determine the coefficients α_i from the distribution and observe whether α_0 or α_1 varies significantly in passing through the resonance. If α_0 varies, then the spin of the K' is zero. If α_1 varies, the spin is 1.

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*Alfred P. Sloan Research Fellow.

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PION-LAMBDA RESONANCE ($Y_1{}^*$)*

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Alston et al.[1] have discovered an $I=1$ π-Λ resonance with a mass of 1380 Mev and a half-width $\Gamma/2$ consistent with 32 Mev. They reported on 141 $\Lambda\pi^+\pi^-$ events made by 1150-Mev/c K^- mesons incident on the 15-in. Lawrence Radiation Laboratory hydrogen bubble chamber which produced the sequence

$$K^- + p \to Y_1{}^{*\pm} + \pi^{\mp}, \qquad (1)$$

followed by a strong decay,

$$Y_1{}^{*\pm} \to \Lambda + \pi^{\pm} + 130\text{ Mev}. \qquad (2)$$

In the course of a continuing study of K^-p interactions, we have now explored the same reactions from $Y_1{}^*$ threshold [P_K(lab) = 405 Mev/c] through P_K = 850 Mev/c. We report on ~500 $\Lambda\pi^+\pi^-$ and find $m(Y_1{}^*)$ = 1385 Mev and $\Gamma/2$ closer to 20 Mev;

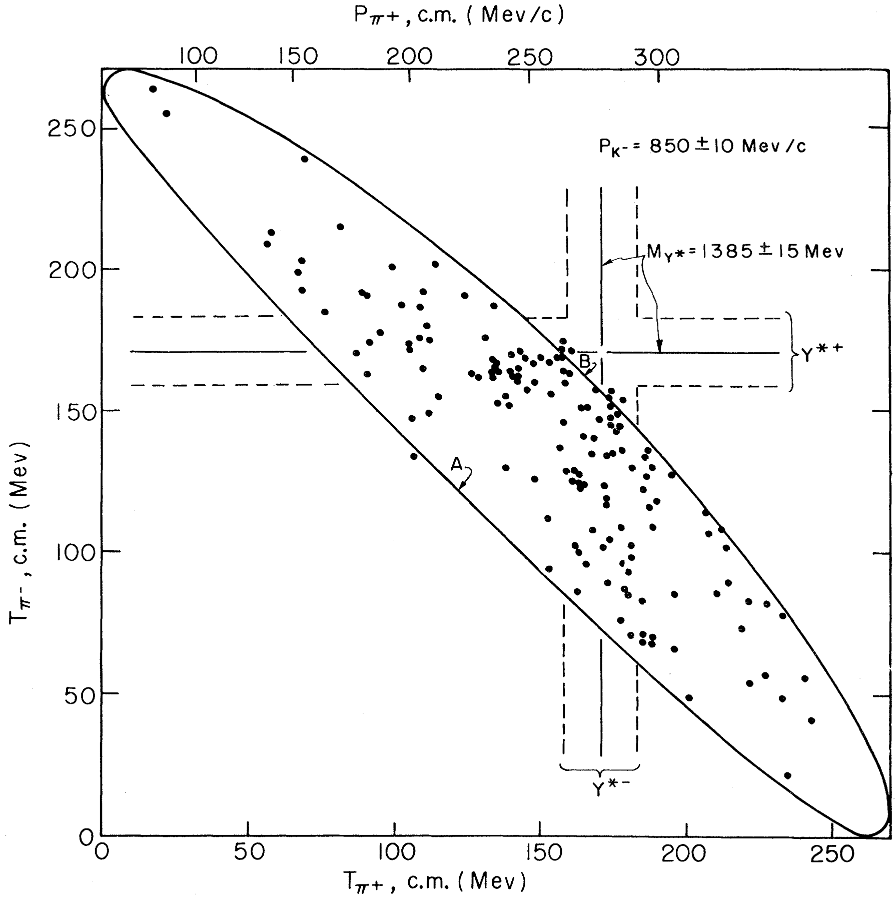

FIG. 1. Dalitz plot of $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ for 185 events at $P_K(\text{lab}) = 850$ Mev/c. Note that within the Y_1^{*-} band, for example (i.e., for constant T_{π^+}), T_{π^-} is linear in $(\vec{\Lambda}\cdot\vec{Y}^{*-})$, where $\vec{\Lambda}$ is the unit vector along the Λ momentum in the Y^* rest frame ($\vec{\pi}^- = -\vec{\Lambda}$). Thus Λ's which are produced forward by the strong decay of the Y^{*-} ($Y^{*-} \rightarrow \pi^- + \Lambda$) fall at the lower edge of the ellipse, and vice versa. Point A corresponds to maximum, and point B to zero, Λ kinetic energy.

however, we are still unable to distinguish between spins $J = 1/2$ and $J = 3/2$.

It is conventional to discuss Y^* data in terms of a simplified model in which they are produced and decay "isolated," that is, one neglects the interferences: (a) between Y_1^*'s and background $\Lambda\pi^+\pi^-$ produced in nonresonant partial waves, as well as (b) the influence of Bose statistics and final-state interactions on the $\pi\pi$ system.

Isolated Y_1^*'s will be produced in association with a pion of fixed center-of-mass (c.m.) kinetic energy (spread, of course, by $\pm\Gamma/2$). Thus in Fig. 1, which is Dalitz' representation of the $\Lambda\pi^+\pi^-$ data at $P_K(\text{lab}) = 850$ Mev/c, Y_1^{*+} will fall in a horizontal band and Y_1^{*-} in a vertical band. That this model is poor is shown by the fact that conservation of parity requires that our isolated Y_1^* show no fore-aft asymmetry on strong decay, i.e., in the strong-decay distribution in the Y^* c.m. frame,

$$dn/d\Omega = 1 + a_1(\vec{\Lambda}\cdot\vec{Y}_1^*) + a_2(\vec{\Lambda}\cdot\vec{Y}_1^*)^2 + \cdots, \quad (3)$$

the odd coefficients must be zero. However, our data show a concentration of backwards Λ. The asymmetry coefficients a_1 (assuming $a_2 = 0$) in Table I show that the "isolated" model is far from realistic, both for our new data and the older events at 1150 Mev/c.[1] A major purpose of this Letter is to point out this difficulty.

In the following Letter,[2] Dalitz and Miller treat the reaction as a symmetrized three-body state which permits nonzero a_1. However, some of the features of the isolated model are still discernible, for example the extra population of the Y_1^* bands on the Dalitz plots. Therefore, in order

Table I. Coefficient a_1 (%) in Y_1^* strong-decay angular distribution.

$P_K(\text{lab})$ (Mev/c)	Y_1^{*+}	Y_1^{*-}
760	-24 ± 20	-16 ± 20
850	-92 ± 26	-24 ± 24
1150	-70 ± 26	-2 ± 20

to simplify the discussion, in our Letter we still refer to this "isolated" model.

The data to which the model may be most meaningfully applied are those at $P_K = 850$ Mev/c, where the Y_1^* bands do not overlap badly (see Fig. 1). (They cross in the middle of the Dalitz plot at about 700 Mev/c.) Figure 2 is an experimental histogram of the Y_1^* mass. The individual uncertainty in each mass measurements is typically ±(3 to 5) Mev. If we fit the histogram with an s-wave resonance curve of the form $dn/dm \propto [(m-1385)^2+(\Gamma/2)^2]^{-1}$ as indicated in Fig. 2, we find $\Gamma/2 = 15$ to 20 Mev (depending upon whether or not some background is subtracted). This experimental value is an agreement with the "$\bar{K}N$ bound state" prediction of $\Gamma/2 = 18$ Mev,[3] but it is also not too far from global symmetry's $\Gamma/2 = 25$ Mev (see below).

Figure 3 displays the excitation data for Y_1^{*+} and Y_1^{*-} and total $\Lambda\pi^+\pi^-$. Data at 1150 Mev/c are from Alston et al.[1] and at 300 and 400 Mev/c are combined from the present experiment and from Nordin.[4] The Y_1^* cross sections at 850 Mev/c can be obtained fairly unambiguously in the sense that the $\Lambda\pi^+\pi^-$ events of Fig. 1 can be interpreted as a flat background plus an extra population of Y_1^*'s at the bands. A background subtraction is also possible at 760 Mev/c. However, at 620 Mev/c, the bands cover almost the whole ellipse, making it impossible to distinguish Y_1^* events from background. At 510 Mev/c, the bands no longer cover the middle of the ellipse, and we might expect any appreciable Y_1^* population to show up in the bands above background. In the Dalitz plot of the data for $P_K = 510$ Mev/c, we actually find, however, a concentration of events near the center of the diagram, not in the bands. This result could be consistent with essentially no Y_1^* production (as suggested in Fig. 3) plus a nonresonant background of $\Lambda\pi^+\pi^-$ events tending to favor equal pion momenta (for reasons unknown); it is also conceivable and quantitatively sensible that there is indeed appreciable Y_1^* production with the Y_1^* and the production pion predominantly in a relative p state (or higher). This would tend to depopulate the ends of the ellipse where the production pion momenta would be low and produce the observed distribution of events. Therefore, one cannot determine unambiguously from these data the cross section for Y_1^* production at $P_K = 510$ Mev/c.

Table II illustrates the apportioning of events between the various possible reactions.

The Y_1^* production angular distributions are isotropic within statistics for all our beam momenta. This would suggest that Y_1 production proceeds dominantly through a single $J=1/2$ wave. However, the $\Lambda\pi^+\pi^-$ cross section alone comes very close to $\pi\lambda\!\!\!^-{}^2/2$, and so other partial waves are probably present.

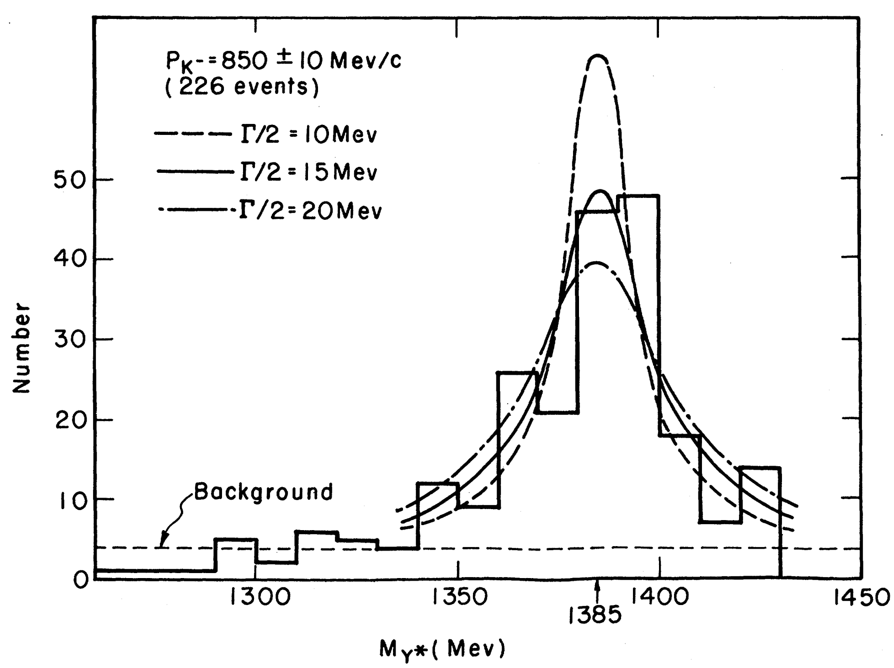

FIG. 2. Experimental histogram of the Y_1^* mass, $m(Y_1^*)$, at $P_K(\text{lab}) = 850$ Mev/c. To each event plotted in Fig. 1 there correspond two effective Y_1^* masses, $m(Y_1^{*+})$ and $m(Y_1^{*-})$; we choose as $m(Y_1^*)$ that which is closer to 1385 Mev. S-wave resonance curves of the form $dn/dm \propto [(m-1385)^2+(\Gamma/2)^2]^{-1}$ have been fitted to the data as indicated, with $\Gamma/2 = 10$, 15, and 20 Mev.

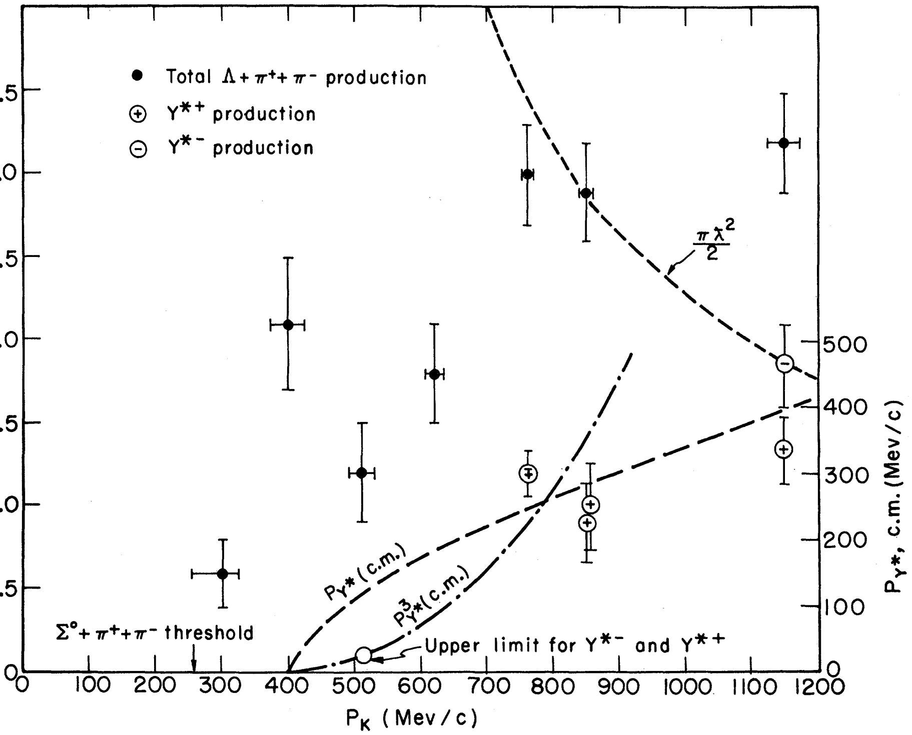

FIG. 3. Excitation data for total $\Lambda\pi^+\pi^-$ production and its apportioning to Y^{*+} and Y^{*-}. The dashed curves show P_{Y^*}(c.m.) and $P_{Y^*}^3$(c.m.) as a function of P_K(lab) and are included for reference only. The line labeled $\pi\lambda^2/2$ is the maximum reaction cross section for a single isotopic-spin partial wave with $J=1/2$. The point plotted at P_K(lab) = 510 Mev/c represents an estimate of the cross section based on the assumption that the number of events actually within the "bands" is the total number of Y_1^*'s produced and does not represent a unique interpretation of the data.

Next we discuss the Y_1^* spin. Global symmetry predicts a $\Lambda\pi$ resonance with spin $J=3/2$.[5] On the other hand, the Dalitz-Tuan s-wave resonance in the K^-p system corresponds to a Y_1^* with $J=1/2$, and a strong decay via $S_{1/2}$ if the $K\Lambda$ parity is odd.[6] If our model of an isolated Y^* were correct, the strong decay angular distribution of Eq. (3) should be fore-aft symmetric ($a_1=0$), and the presence of any polar-equatorial anisotropy ($a_2 \neq 0$) would be evidence for $J>1/2$. We find instead that $a_1 \neq 0$ but within statistics $a_2=0$ at all production angles. After looking for evidence for $a_2 \neq 0$ at any (or all) angles of Y^* production, we have confined our analysis to polar-produced Y^*'s where, as Adair has pointed out,[7] an isolated $J=3/2$ particle must decay according to $1+3(\vec{\Lambda}\cdot\vec{K})^2$ (the unit vector $\vec{K}$ is along the K^- beam direction) while $J=1/2$ must decay isotropically. The decay distribution for polar-produced Y^*'s ($|\vec{Y}^*\cdot\vec{K}| \geq 0.80$) is given in Fig. 4. We have used $\vec{\Lambda}\cdot\vec{Y}^*$ as a measure of the decay angle instead of $\vec{\Lambda}\cdot\vec{K}$ in order to display the fact that the Y^* are not isolated but tend to undergo strong decay with the Λ going backwards. (Essentially the same result is achieved for these polar events by choosing $+\vec{\Lambda}\cdot\vec{K}$ for forward-produced Y^*, and $-\vec{\Lambda}\cdot\vec{K}$ for backwards Y^*.) These Adair events of Fig. 4 again fail to show any evidence for $1+3(\vec{\Lambda}\cdot\vec{Y}^*)^2$ superimposed on the asymmetry, which is linear in $(\vec{\Lambda}\cdot\vec{Y}^*)$. This statement applies individually to both charges

Table II. Numbers and cross sections for V and two-prong events. Numbers in parentheses are cross sections in millibarns.

P_K (Mev/c)	Y_1^{*-}	$\Lambda\pi^+\pi^-$ Y_1^{*+}	Three-body	$\Sigma^0\pi^+\pi^-$	$\Lambda\pi^+\pi^-\pi^0$	$\bar{K}^0p\pi^-$	Total
510	⟵	31 (1.2 ± 0.3)	⟶	4 (0.2 ± 0.1)	0	0	35
620	⟵	54 (1.8 ± 0.3)	⟶	10 (0.3 ± 0.1)	0 (0)	0 (0)	64
760	121 (1.2 ± 0.14)	122 (1.2 ± 0.14)	56 (0.6 ± 0.1)	55 (0.6 ± 0.1)	20 (0.2 ± 0.05)	2 (0.03 ± 0.02)	376
850	56 (0.9 ± 0.25)	62 (1.0 ± 0.25)	67 (1.0 ± 0.15)	39 (0.6 ± 0.1)	7 (0.1 ± 0.04)	3 (0.03 ± 0.02)	234

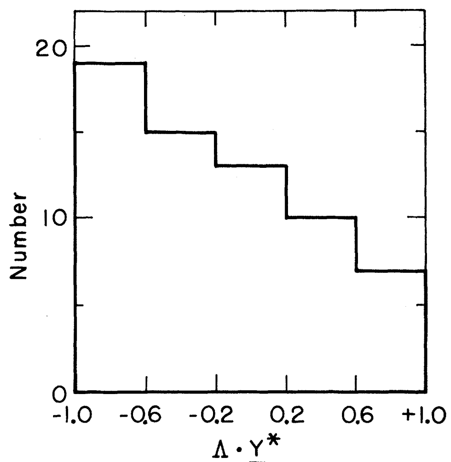

FIG. 4. Adair analysis of 62 $Y^{*\pm}$ events at $P_K = 760$ and 850 Mev/c; $|\vec{Y}^* \cdot \vec{K}| \geq 0.80$.

of Y^* at each momentum and to the sum of all events. However, as is shown in the next Letter, one cannot conclude that $J = 1/2$ since examples are given where Bose statistics can cause a Y^* with $J = 3/2$ to have a relatively isotropic angular distribution in the Adair analysis.

Next we discuss the branching ratio $Y_1^* \rightarrow \Sigma$ vs Λ. Global symmetry predicts definite ratios between the decay rate $\Gamma(N)$ of the 3/2, 3/2 pion-nucleon isobar ($N^* \rightarrow N + \pi$) and the equivalent rates of, for example, the three decay modes of Y_1^{*-}. These are $\Gamma(N):\Gamma(\Sigma^0):\Gamma(\Sigma^-):\Gamma(\Lambda) = p_N^3 : (1/6)p_{\Sigma^0}^3 : (1/6)p_{\Sigma^-}^3 : (4/6)p_\Lambda^3$. For $p_N = 230$ Mev/c, $p_\Sigma = 127$, $p_\Lambda = 207$, $(p_\Lambda/p_\Sigma)^3 = 1/4$, the relative rates are predicted to be $1.37:(1/24):(1/24):(2/3)$. The half-width $\Gamma/2(N)$ is known to be 45 Mev; so global symmetry predicts a Y_1^* half-width $\Gamma/2 = \frac{1}{2}[\Gamma(\Sigma^0) + \Gamma(\Sigma^-) + \Gamma(\Lambda)]$ of 24.7 Mev, and a branching ratio $\Gamma(\Sigma^0)/\Gamma(\Lambda) = 1/16$. (As already mentioned, our observed $\Gamma/2$ is 15 to 20 Mev, but the statistics are sufficiently poor and the effects of Bose statistics sufficiently great that $\Gamma/2 = 25$ Mev cannot be ruled out.) The Dalitz-Tuan resonance is expected to give values of $\Gamma(\Sigma^0)/\Gamma(\Lambda)$ ranging from $\gtrsim 12\%$ (if the $K\Lambda$ and $K\Sigma$ parities are both odd) down to 6% (if $K\Lambda$ odd but $K\Sigma$ even).[3] We obtain $\Gamma(\Sigma^0)/\Gamma(\Lambda) < 3\%$ at 760 Mev/c and $< 5\%$ at 850 Mev/c; these values are obtained by making a background subtraction and represent "realistic" upper limits. "Maximum possible" upper limits come from counting every $\Sigma^0\pi^+\pi^-$ event with an effective $\Sigma^0\pi$ mass falling within 30 Mev of the Y_1^* mass of 1385; these are $< 20\%$ at 760 Mev/c and $< 10\%$ at 850 Mev/c. The observed limits on the branching ratios are consistent with the predictions of global symmetry and not necessarily inconsistent with those of the Dalitz-Tuan resonance.

The average Y^* polarization ($\bar{P}_{Y^*}$) has been measured from the asymmetry of the Λ-decay proton assuming $\alpha = +1$ and $\vec{Y}^* \times \vec{K} \equiv$ up; only events with $|\vec{Y}^* \cdot \vec{K}| \leq 0.85$ have been used, giving $\bar{P}_{Y^{*-}} = (+11 \pm 21)\%$ and $\bar{P}_{Y^{*+}} = (-16 \pm 21)\%$ at 760 Mev/c; $\bar{P}_{Y^{*-}} = (-56 \pm 20)\%$ and $\bar{P}_{Y^{*+}} = (+12 \pm 28)\%$ at 850 Mev/c. The fact that the Y^{*-} polarization seems to be large at 850 Mev/c and, by comparison, surprisingly small at 760 Mev/c could be a statistical fluctuation or may be connected with the fact that the Σ-production channels also show a rapid variation with energy in this region.[8]

Since no strong evidence for Y^* spin $J = 3/2$ has yet been found either at Berkeley or elsewhere,[9,10] it is intriguing to assume $J = 1/2$ and to try to distinguish between $S_{1/2}$ and $P_{1/2}$ Y^* strong decay.

We use about 60 polarized Y^{*-} at 850 Mev/c (assuming that the polarization is not a statistical fluctuation). In addition to the normal $\vec{n}$ to the production plane, it is convenient to define another unit vector $\vec{m} = 2(\vec{n} \cdot \vec{\Lambda})\vec{\Lambda} - \vec{n}$. This vector $\vec{m}$ lies in the plane of $\vec{n}$ and $\vec{\Lambda}$ (the direction of flight of the Λ), and if $\vec{\Lambda}$ makes an angle θ with $\vec{n}$, $\vec{m}$ makes an angle 2θ.[9] We write P_n for the measured Λ polarization along $\vec{n}$ and, similarly, P_m along $\vec{m}$. If the Y^* polarization is $\bar{P}$, then for strong decay via $S_{1/2}$, one can show

$$P_n = \bar{P}, \quad P_m = -\bar{P}/3, \quad P_m/P_n = -1/3. \qquad (5a)$$

For $P_{1/2}$ decay the roles of $\vec{n}$ and $\vec{m}$ are interchanged; i.e., the Λ has its maximum polarization along $\vec{m}$, and we have

$$P_n = -\bar{P}/3, \quad P_m = \bar{P}, \quad P_m/P_n = -3. \qquad (5b)$$

We find $P_n = (-56 \pm 20)\%$, $P_m = (+33 \pm 25)\%$, and $P_m/P_n = 0.6$. It is not meaningful to state statistical errors on a calculated ratio like P_m/P_n when the fractional standard deviations are large. Instead we apply the χ^2 test; the average value of χ^2 should be 1.0. For the $S_{1/2}$ hypothesis, we find $\chi_S^2 = 0.3$ (high probability), but for $P_{1/2}$, $\chi_P^2 = 4.5$ (probability $\simeq 3\%$). Martin et al.[9] also report $P_n = -0.38 \pm 0.25$ and $P_m = 0.19 \pm 0.25$, which yield $\chi_S^2 = 0$, $\chi_P^2 = 1$. Thus if it were established (a) that Y^* is the Dalitz-Tuan resonance of a $K + p$ in an $S_{1/2}$ bound state and (b) that Eqs. (5) are not badly perturbed by interference phenomena, then our data would strongly suggest odd $K\Lambda$ parity.

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†National Academy of Sciences Fellow.

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BOSE STATISTICS AND Y^* PRODUCTION AND DECAY IN K^--p COLLISIONS*

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Experimental evidence for the occurrence of an $I=1$, Λ-π resonant state (Y^*) as an intermediate step in the reaction

$$K^-+p\rightarrow\begin{Bmatrix}Y^{*-}+\pi^+\\ \\ Y^{*+}+\pi^-\end{Bmatrix}\rightarrow\Lambda+\pi^++\pi^- \qquad (1)$$

has been presented by Alston et al.[1] for K^-(lab) momentum 1150 Mev/c. The same reaction has also been studied recently by Berge et al.,[2] and the related K_2^0-p reactions have been analyzed by Martin et al.[3] for K_2^0 momentum 975 Mev/c. The interpretation of these data in terms of the mass (M^*), half-width ($\Gamma/2$), spin (J), and parity of the Y^* state has been confused by the evidence that the Y^* decay in these reaction sequences (1) cannot be regarded as the decay of a free particle. In this Letter, we show that this evidence can be largely understood as due to interference effects arising from the requirement of Bose statistics for the final pions, and we discuss the extent to which these Y^* parameters may ultimately be determined from data in this momentum range.

From the reported estimates (10 to 30 Mev) for $\Gamma/2$, the mean distance traveled by the primary pion in one Y^* mean lifetime is more than 4 fermis. It is therefore a plausible assumption that the successive pion-emission processes do not interfere dynamically to any marked degree. In this case we are led to an amplitude $M(1,2)$ for the reaction sequence $\bar{K}+N\rightarrow Y^*+\pi_1$, $Y^*\rightarrow\Lambda+\pi_2$, of the general form[4]

$$M(1,2)=\Phi(\vec{\sigma},\vec{q},\vec{p}_1,\vec{P}_2)A(P_2), \qquad (2)$$

where $\vec{q}$ and $\vec{p}_1$ denote the c.m. momenta of the K^- meson and the primary pion, and $\vec{P}_2$ denotes the momentum of the secondary pion in the π_2-Λ rest frame. The final configuration $\Lambda+\pi_2+\pi_1$ may also be specified by giving l, the orbital angular momentum of π_1, and L, the orbital angular momentum in the π_2-Λ system which corresponds to the Y^* spin and parity; the form of Φ is then determined for total angular momentum j by the angular momentum coupling and the ($K\Lambda$) parity and by centrifugal barrier considerations. The role of the resonant state is represented by the second factor,

$$A(P)=\exp[i\delta(P)]\sin\delta(P)/P^{2L+1}. \qquad (3)$$

The amplitudes for the two sequences (1) must be added coherently, and their sum must correspond to a final state with correct symmetry for interchange of the two pions. Thus, for total isotopic spin $I=0$ and 1, the amplitudes M_0 and