SPIN OF $Y_1^{*\dagger}$

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The observation of a resonance at 1385 ± 3 Mev in the $\Lambda\pi$ system[1] has renewed interest in the problem of higher symmetries among the strange particles. Global symmetry predicts the existence of hyperonic analogs to the observed pion-nucleon resonances.[2] In particular, a $T=1$ resonance with a mass of 1380 Mev, a half-width $\Gamma/2 = 23$ Mev, and a total angular momentum $J = 3/2$ has been predicted from the measured parameters of the first pion-nucleon resonance.[3,4] This mass and width are in qualitative agreement with the observed Y^* parameters.[5,6] Dalitz has suggested an alternative interpretation which associates the Y^* with a bound S state of the K-nucleon system, requiring the Y^* to have $J = 1/2$.[7] In this Letter we present correlations in the production and decay angular distributions of the Y^* that support $J \geqslant 3/2$.

We have studied the properties of the $T=1$ Y^* produced by the interaction of 1.11 ± 0.03 Bev/c K^- mesons[8] in the 30-inch propane bubble chamber at the Bevatron, via the reaction

$$K^- + p \rightarrow \Lambda + \pi^+ + \pi^-. \qquad (1)$$

The film was scanned for all V^0, π^+, and π^- type events. Eleven hundred such events were found and subjected to both Λ-decay and hydrogen-production constraints via reaction (1), with the FOG, CLOUDY, and FAIR kinematic analysis programs. From a comparison with the events that failed, we can set upper limits of (a) 5% for the fraction of those accepted events that were produced in carbon, and (b) 10% to 15% for those that involve Σ^0 production. The corrections for scanning bias include an escape correction for Λ's that leave the chamber, which varies from 5% to 15% over the momentum range of the Λ, and a 4% correction (15 events) for Λ's below 300 Mev/c, in which the decay proton was too short to be visible. The cross section for reaction (1) is 2.8 ± 0.5 mb, in agreement with the cross section of 3.4 ± 0.5 mb measured by Alston et al.[1]

The pion that resonates with the Λ has been chosen by examination of the invariant mass $M(\Lambda, \pi) = [(E_\Lambda + E_\pi)^2 - (\vec{p}_\Lambda + \vec{p}_\pi)^2]^{1/2}$ of each system. Weighted histograms of $M(\Lambda, \pi^-)$ and $M(\Lambda, \pi^+)$ for all events are shown in Figs. 1(a) and 1(b), respectively. The average error in M is less than, or equal to, the box width over the range of values shown.

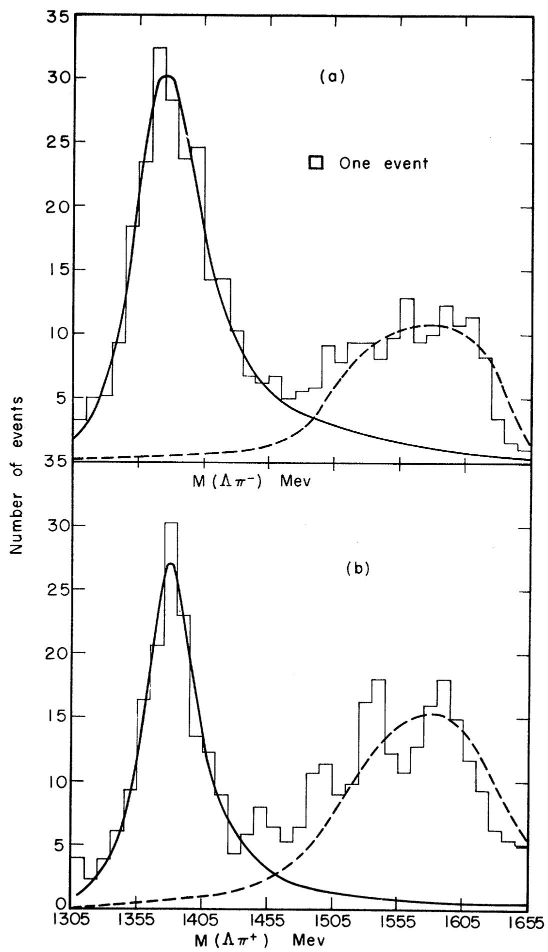

FIG. 1. Weighted histograms of the distribution in invariant mass $M(\Lambda, \pi) = [(E_\Lambda + E_\pi)^2 - (\vec{p}_\Lambda + \vec{p}_\pi)^2]^{1/2}$ for (a) $M(\Lambda, \pi^-)$ and (b) $M(\Lambda, \pi^+)$. The solid lines are the fits to a curve of the form $[(M-M_0)^2 + (\Gamma/2)^2]^{-1}$ of the data near the resonance energy. The corresponding values of M and $\Gamma/2$ are given in Table I. The dashed curves represent the expected values of $M(\Lambda, \pi)$ when the other pion resonates with the Λ.

We have fitted a resonance curve of the form $[(M-M_0)^2 + (\Gamma/2)^2]^{-1}$, modified by the three-body relativistic phase space, to the data near the resonance energy. The solid lines represent the best fits, and the corresponding values of M_0 and $\Gamma/2$ are given in Table I. It should be recognized that the values quoted were derived from a simplified model that omits momentum dependence of the

Table I. Summary of Y^* data.

	Number of events	M_0 (Mev)	$\Gamma/2$ (Mev)	Production angular distributions
Y^{*+}	154	1376 ± 3	24 ± 4	$(7.9 \pm 1.9) - (19.9 \pm 5.7)\cos\theta + (62.1 \pm 16.1)\cos^2\theta + (22.6 \pm 8.9)\cos^3\theta - (63.0 \pm 19.7)\cos^4\theta$
Y^{*-}	224	1376 ± 3	33 ± 5	$(15.5 \pm 2.0) - (0.1 \pm 6.0)\cos\theta + (15.5 \pm 5.1)\cos^2\theta - (21.9 \pm 9.7)\cos^3\theta$

matrix elements[9] and Bose-statistics symmetrization effects.[10] The dashed curves represent the expected values of $M(\Lambda, \pi)$ when the other pion resonates with the Λ.

Although our data allow as much as a 10% non-resonating background, the data are consistent with the assumption that all reactions (1) proceed in two stages:

$$\text{(a) } K^- + p \to Y^{*\pm} + \pi_1^{\mp}$$

and

$$\text{(b) } Y^{*\pm} \to \Lambda + \pi_2^{\pm}.$$

The ratio of $\sigma(K^- + p \to Y^{*-} + \pi^+)/\sigma(K^- + p \to Y^{*+} + \pi^-) = 1.45 \pm 0.15$ indicates that both $T=0$ and $T=1$ production amplitudes are present.

Only those 378 events with 1310 Mev $< M_{\Lambda\pi} <$ 1450 Mev are used in the subsequent analysis. Restricting the range of accepted mass values to $M_0 \pm 30$ Mev does not alter any of our conclusions.

The Y^*-production angular distributions in the K-p center-of-mass system are shown in Fig. 2. The marked difference between the Y^{*+} and Y^{*-} distributions illustrates the interference between the $T=1$ and $T=0$ production amplitudes. The best fits to a power series in $\cos\theta$ are shown as the solid lines, with coefficients as listed in Table I. In each case the addition of higher powers of $\cos\theta$ did not improve the fit, but the $\cos^3\theta$ and $\cos^4\theta$ terms were necessary.

The large negative coefficient of the $\cos^4\theta$ term in the Y^{*+} distribution is characteristic of D-wave production of a $J=3/2$ resonance (the expected distribution for D-wave production of a $J=3/2$ Y^* from a $j=5/2$ initial state is $1 + 10\cos^2\theta - 10\cos^4\theta$.[11] The D-wave production of a Y^* with $J=1/2$ always predicts a positive coefficient for $\cos^4\theta$. However, the negative coefficient depends strongly on the relatively small number of Y^{*+} events produced with $\cos(\vec{Y}^*, \vec{K}) < -0.8$. This region is especially subject to the bias against low-momentum Λ's mentioned above. A correction for this bias does not alter the above conclusions, but reduces their statistical significance.

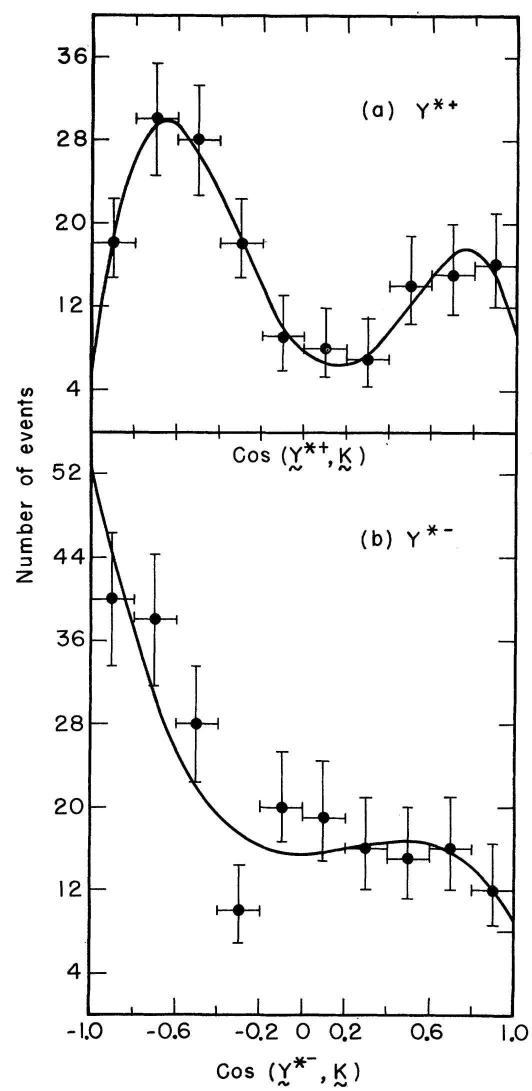

FIG. 2. Production angular distributions of (a) Y^{*+} and (b) Y^{*-} events. The solid curves represent the best fits to a power series in $\cos(\vec{Y}^*, \vec{K})$. The equations for these curves are given in Table I.

Several tests have been suggested that relate the decay angular distributions to the spin state of the Y^*.[12-14] In general, the interpretation of these tests assumes that there are no interactions between the recoil pion, π_1, and the decay products, Λ and π_2; and that the Y^* is in a state of definite parity. If $J=1/2$, the momentum vector $(\vec{\Lambda})$ of the Λ in the Y^* center of mass must be isotropically distributed. If $J \geq 3/2$, it is possible to achieve an alignment of the Y^* in the production process, which will in turn produce an anisotropy in the distribution of $\vec{\Lambda}$ about the axis of alignment.

Adair[12] has shown that for reaction (a), conservation of the component of angular momentum along the incoming beam direction requires, for $J>1/2$, an alignment for those Y^*'s that are produced along the incident beam direction $(\vec{K})$. Specifically, for $J=3/2$, the Λ distribution must be $1+3\cos^2(\vec{\Lambda},\vec{K})$. The necessity of using nonzero production angles reduces this effect when partial waves with $l>0$ are present in the production process. For D-wave production of a $J=3/2$ Y^*, the process of averaging over a cone of production angles with $|\cos(\vec{Y}^*,\vec{K})| \geq 0.9$ is expected to dilute the distribution to approximately $1+\cos^2(\vec{\Lambda},\vec{K})$. The histogram in $\cos(\vec{\Lambda},\vec{K})$ for those 41 events with $|\cos(\vec{Y}^*,\vec{K})| \geq 0.9$ is shown in Fig. 3(a). The solid curve is a fit to the distribution $1+a\cos^2(\vec{\Lambda},\vec{K})$, with $a=1.0\pm0.8$. Since only 41 events are used, this result cannot distinguish $J=1/2$ from higher spins.

However, Stapp[13] has pointed out that a $J=3/2$ Y^* may preferentially emit Λ's perpendicular to the K axis, either in or perpendicular to the production plane.[15] This preferential emission is expected to be maximal when the Y^* is produced at 90 deg. We find a decided preference for decay perpendicular to the production plane. Figure 3(b) shows the distribution in $\cos(\vec{\Lambda},\vec{K}\times\vec{Y}^*)$ for those 143 events with $|\cos(\vec{Y}^*,\vec{K})|<0.5$. (Note that these events are different from those used in the Adair analysis.) The distribution fits the form $1+a\cos^2(\vec{\Lambda},\vec{K}\times\vec{Y}^*)$ with $a=1.5\pm0.4$. A χ^2 test yields a probability of 10^{-4} that this distribution would arise from an isotropic population. Indications of this effect were found by Alston et al.,[1] and serve to increase the confidence level for anisotropy. This result clearly favors $J \geq 3/2$ for the Y^* system.

As a check on the validity of the isolated Y^* model, we have examined the decay distributions for asymmetries that cannot be present in the decay of an isolated Y^*. In previous experiments at lower K^- momenta, the distributions of $\vec{\Lambda}$ relative to the Y^* direction have shown forward-backward asymmetries. These asymmetries have been attributed to the Bose-statistics symmetrization effects, which are expected to be less important at a K^- momentum of 1.11 Bev/c.[10] A fit of all Y^* events to a $1+a\cos(\vec{\Lambda},\vec{Y}^*)$ distribution gives the values $a_+=-0.31\pm0.17$ for the Y^{*+}, and $a_-=-0.13\pm0.13$ for the Y^{*-}. These coefficients have the same sign as, but are a factor of 3 smaller in magnitude than, those found at a K^- momentum of 800 Mev/c.[16] The distributions in $\cos(\vec{\Lambda},\vec{K})$ and $\cos(\vec{\Lambda},\vec{K}\times\vec{Y}^*)$, for those events used in Fig. 3, show no asymmetry, i.e., the coefficients of $\cos\theta$ are $+0.24\pm0.31$ and $+0.07\pm0.24$, respectively.[17]

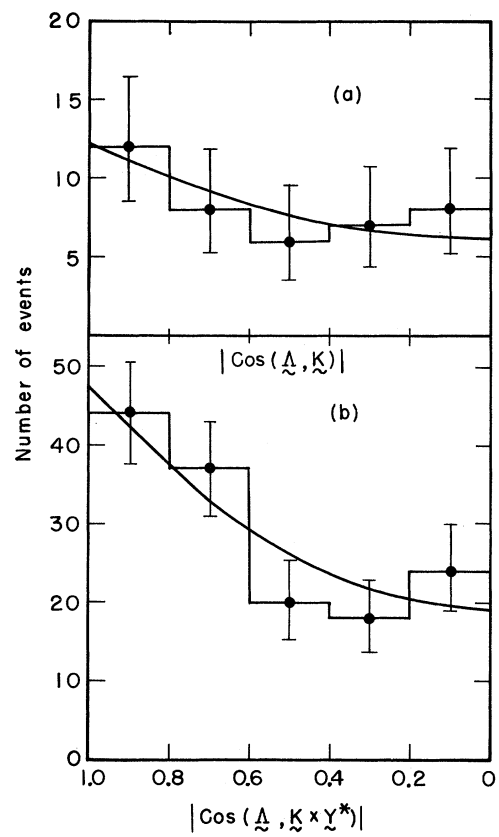

FIG. 3. Two methods used in testing for the spin of the Y^*: (a) The Adair distribution in $\cos(\vec{\Lambda},\vec{K})$ for those 41 events with $|\cos(\vec{Y}^*,\vec{K}| \geq 0.9$. The solid curve is the best fit to $1+a\cos^2(\vec{\Lambda},\vec{K})$ with $a=1.0\pm0.8$. (b) The distribution in $\cos(\vec{\Lambda},\vec{K}\times\vec{Y}^*)$ for those 143 events with $|\cos(\vec{Y}^*,\vec{K})|<0.5$. The solid curve is the best fit to $1+a\cos^2(\vec{\Lambda},\vec{K}\times\vec{Y}^*)$ and yields $a=1.5\pm0.4$.

If the interference effects are as small as estimated, the observed anisotropy about the production normal implies $J \geq 3/2$. The production angular distribution and the Adair distributions are both consistent with this hypothesis.

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[15]This distribution is kinematically related to Eq. (5) of reference 13. We have performed the suggested weighted average, and find a result 3 standard errors from that which is predicted if $J=1/2$. However, the number of events is insufficient to test the detailed shape of Eq. (5).

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[17]Although we have not estimated the Bose effect in detail, a calculation of the S and P wave production of an $s_{1/2}$ resonance can have a distribution in $\cos(\vec{\Lambda},\vec{K}\times\vec{Y}^*)$ no stronger than $1+0.2\cos^2(\vec{\Lambda},\vec{K}\times\vec{Y}^*)$. The introduction of D waves does not appear to alter these conclusions.

K^* AND $K^+-3\pi$ DECAY

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It is well known[1] that the spectrum of the unlike pion in the τ^+-decay mode of K^+ mesons deviates noticeably from the pure statistical distribution. Many people[2] have tried to explain this deviation as due to pion-pion "final state" interaction. On the basis of their analysis of the τ-decay spectrum, these people,[2] however, obtained pion-pion S-wave scattering lengths which do not agree with those obtained[3] on the basis of the crossing relations developed by Chew and Mandelstam.[4] In this note we wish to show that the observed deviation of the spectrum of the unlike pion in τ^+ decay from the statistical distribution can be simply explained if τ^+ decay proceeds via K^* (see Fig. 1) provided that K^* has spin unity, in favor of which there is some slight evidence.[5] On this model the spectrum of the unlike pion in $\tau^{+\prime}$ decay comes out to be the same as given by Weinberg[6] on the basis of $|\Delta\vec{I}|=\frac{1}{2}$ rule and is consistent with experiment.[7] Below we give the details of the calculation.

Denote the 4-momenta of the three emerging pions from K-meson decay by k_1, k_2, and k_3, where k_3 will always refer to the unlike pion in the τ or τ' decay mode. Let K denote the 4-momentum of the K-meson ($K^2=-m_K^2$). We introduce the