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SPIN OF THE $Y_1^{*\dagger}$

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A resonance in the $(\Lambda\pi)$ system, Y_1^*, with a mass of 1385 MeV has been reported by many groups.[1] Although most of the properties of this resonance are well known,[2] its spin has not been determined with a high degree of confidence, and its parity is unknown. The strongest evidence for the Y_1^* spin has been obtained by Ely et al.,[3] in the reaction $K^- + p \to \Lambda^0 + \pi^+ + \pi^-$ at 1.1 BeV/c, which indicates a spin $\geq\frac{3}{2}$. However, many other experiments[4] performed under varied conditions failed to give clear confirmation of this result. Furthermore, it has been pointed out by Adair[5] that the spin-$\frac{3}{2}$ result could be stimulated by a spin-$\frac{1}{2}$ Y_1^* interfering with a D-wave background intensity of as little as 5%. In this Letter we present further evidence on the Y_1^* spin, the observed decay correlations indicating a spin $\geq\frac{3}{2}$.

Our sample of Y_1^*'s were produced by the interaction of 2.24-BeV/c K^- mesons in the 20-in. BNL hydrogen bubble chamber via the reaction

$$K^- + p \to \Lambda^0 + \pi^+ + \pi^-. \qquad (1)$$

Details of the exposure and beam are discussed elsewhere.[6] All events consisting of a neutral V decay associated with a two-prong vertex were analyzed using the BNL TRED-KICK system[7]; 326 events were found to fit Reaction (1), 76 of which could be interpreted as Y_1^{*+} production events. The background events which occur with reasonable frequency and which can simulate Reaction (1) are

$$K^- + p \to \Sigma^0 + \pi^+ + \pi^-, \qquad (2)$$

$$\to \Lambda^0 + \pi^+ + \pi^- + \pi^0. \qquad (3)$$

An examination of the following neutral missing mass distribution,

$$M_0 = \{(E_{K^-} + M_p - E_{\pi^-} - E_{\pi^+})^2 - (\vec{p}_{K^-} - \vec{p}_{\pi^-} - \vec{p}_{\pi^+})^2\}^{1/2},$$

shows no peaking at the Σ^0 or π^0 masses, respectively, indicating that contamination from (2) and (3) is small.[8] Detailed studies indicate that the total contamination from all sources is $\leq 20\%$.

The Dalitz plot for Reaction (1) along with the invariant mass distribution for the $(\Lambda\pi^+)$ state are shown in Figs. 1(a) and 1(b). The peak in the mass distribution has been fitted by a Breit-Wigner resonance formula of the form $[(m - m_0)^2 + (\frac{1}{2}\Gamma)^2]^{-1}$, giving a Y_1^* mass m_0 of 1380 ± 3 MeV, and a half-width $\frac{1}{2}\Gamma$, of 25 ± 5 MeV, in excellent agreement with the currently accepted values.[2] The strong production of the Y_1^* in the positive charge state, along with little or no production of either ρ^0 or Y_1^{*-}, are evident features of Fig. 1(a). As a result, the interference between resonant channels is negligible. Furthermore, at this energy, dynamical interference effects[9] between the pions must be small because of the high velocity of the Y_1^* in the $K^- - p$ rest frame.

If the Y_1^*'s are polarized in the production process, parity conservation constrains the polarization to lie along the normal to the production plane, $\hat{n} \propto \hat{p}_{K^-} \times \hat{p}_{Y^*}$. The distribution of $\hat{n}\cdot\hat{p}_{\pi^+}$, where $\hat{p}_{\pi^+}$ is the direction of the π^+ from the Y_1^* decay as measured in the Y_1^* rest frame, may be used to investigate the spin if the Y_1^*'s are either polarized or aligned. Specifically, the predicted distribution is isotropic for $J = \frac{1}{2}$, and of the form $1 + A[\hat{n}\cdot\hat{p}_{\pi^+}]^2$ for $J = \frac{3}{2}$. The observed distribution in $[\hat{n}\cdot\hat{p}_{\pi^+}]$ for the 76 events in which the Y_1^* mass lies between $1340 < m_0 < 1420$ is shown in Fig. 2.

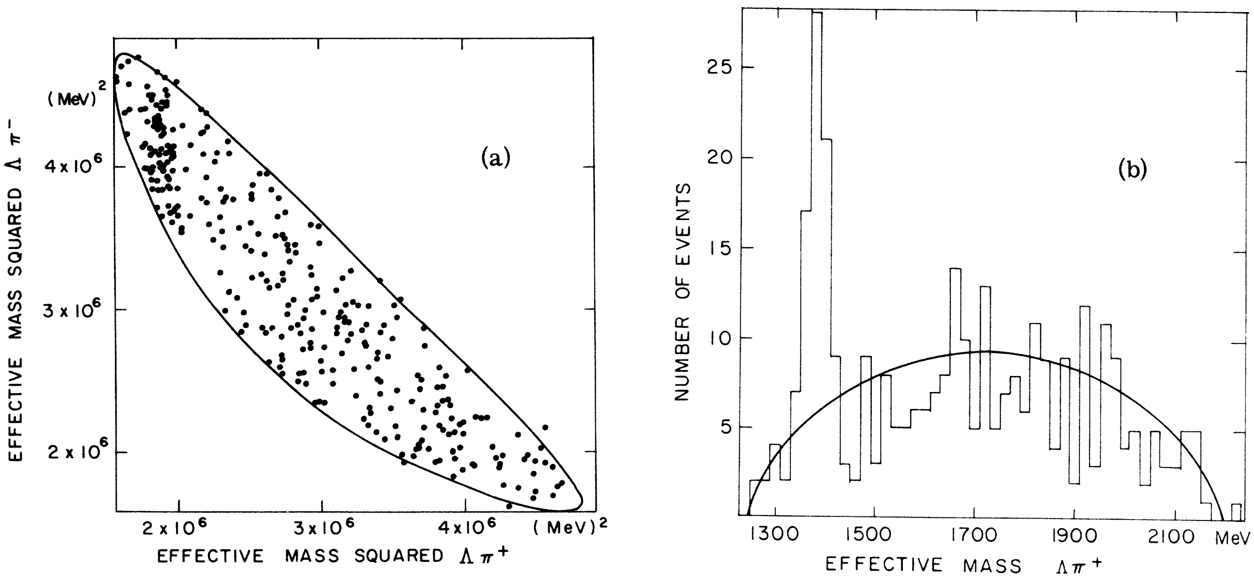

FIG. 1. (a) The Dalitz plot of $\Lambda\pi^+$ effective-mass squared versus $\Lambda\pi^-$ effective-mass squared for the reaction $K^-+p\to\Lambda+\pi^++\pi^-$. (b) The effective-mass distribution for $\Lambda\pi^+$. The solid curve is the invariant phase space normalized to the total number of events.

It fits a distribution of the form

$$1+(0.5\pm0.6)\hat{n}\cdot\hat{p}_{\pi^+}+(4.2\pm1.0)(\hat{n}\cdot\hat{p}_{\pi^+})^2, \quad (4)$$

all higher terms being consistent with zero. This distribution is in disagreement with isotropy by four standard deviations; further, the small size of the linear term indicates the absence of biases. We have examined a sample of 194 nonresonant $\Lambda\pi^+\pi^-$ events (with $m=1800\pm300$ MeV) in an identical way. The distribution of $(\hat{n}\cdot\hat{p}_\pi)$ is isotropic. The ratio of the number of these background events in the interval $0.0\leq|\hat{n}\cdot\hat{p}_\pi|\leq0.5$ to that in the interval $0.5\leq|\hat{n}\cdot\hat{p}_\pi|\leq1.0$ is 99/95, indicating the lack of any strong systematic effect.

Of course, just as in the experiment of Ely et al., there exists a danger that the observed Y_1^* decay distribution might be due to interference between a $J=\frac{1}{2}$ Y_1^* and a D-wave background (10% intensity is required in our case). However, since the background amplitude is expected to change slowly with energy and the resonant amplitude is expected to change rapidly, such an interference effect should vary with the Y_1^* mass.[9] To investigate this, we have divided the Y_1^* peak into two mass regions, $1340<m_0<1380$ MeV and $1380<m_0<1420$ MeV. The distributions of $|\hat{n}\cdot\hat{p}_\pi|$ corresponding to these intervals are shown in Fig. 3. The similarity between the shapes of these curves can be attributed either to the absence of any interference, or to the possibility that the background amplitude varies as rapidly as that of the resonance. Since Ely et al. have observed a similar mass independence at a considerably different energy, the latter possibility seems highly unlikely. Further evidence for the absence of interference effects may be inferred from the symmetry in the forward-backward spectrum of Y_1^* decay. The observed spectrum

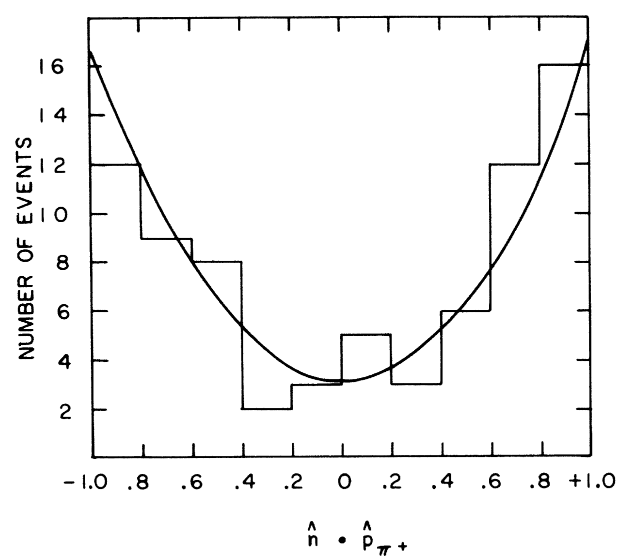

FIG. 2. The distribution of $\hat{n}\cdot\hat{p}_{\pi^+}$ for the events with the $\Lambda\pi^+$ effective-mass lying in the interval 1340–1420 MeV. The solid curve is the distribution $1+4.2(\hat{n}\cdot\hat{p}_{\pi^+})^2$.

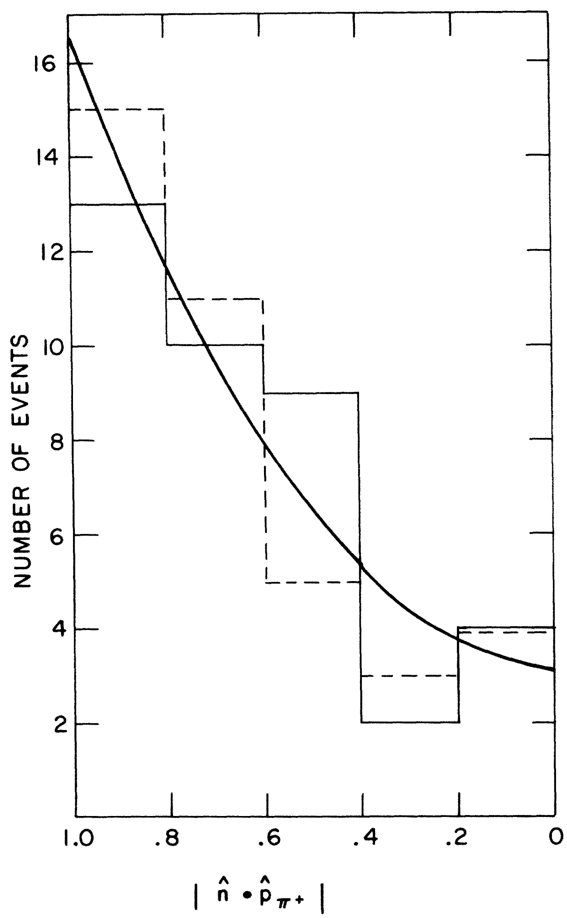

FIG. 3. The solid and dashed histograms give the distribution of $|\hat{n}\cdot\hat{p}_{\pi^+}|$ for the $\Lambda\pi^+$ mass regions 1340-1380 MeV and 1380-1420 MeV, respectively. The solid curve is the distribution $1+4.2(\hat{n}\cdot\hat{p}_{\pi^+})^2$.

is of the form $1+B(\hat{p}_{Y^*}\cdot\hat{p}_{\pi^+})$, with $B=0.06\pm0.20$.

On the basis of the above arguments, we conclude that the observed anisotropy of the decay distribution (4) is strongly indicative of $J(Y_1^*)\geq\frac{3}{2}$.

In principle, information on the parity of the Y_1^* can be obtained from a measurement of the Λ polarization in the direction $\hat{n}$. Specifically, for a D-wave decay of a spin-$\frac{3}{2}$ Y_1^*, $|\overline{P}_\Lambda|=\frac{2}{5}|\overline{P}_{Y^*}|$, and for a P-wave decay, $|\overline{P}_\Lambda|=\frac{2}{3}|\overline{P}_{Y^*}|$. The up-down asymmetry in Λ decay gives $|\alpha_\Lambda\overline{P}_\Lambda|=0.2\pm0.2$, which, together with $\alpha_\Lambda=-0.62\pm0.07$,[10] yields $|\overline{P}_\Lambda|=0.3\pm0.3$ which clearly does not permit a Y_1^* parity determination with the present data. However, accepting the value $J(Y_1^*)=\frac{3}{2}$, we wish to point out that the recent result of Colley et al.[11] favors P-wave decay (even Y_1^* parity), the D-wave hypothesis being two standard deviations from the expected value; and Shafer, Huwe, and Murray[4] also rule out the D-wave hypothesis.

We wish to thank the members of the AGS and the 20-in. hydrogen bubble chamber operating crew for their close cooperation in obtaining the exposure, and to acknowledge several helpful discussions with Professor M. Nauenberg. The painstaking efforts of our scanning and measuring group have been essential to the completion of this work.

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[8]Most of the events are kinematically consistent with Σ^0 production, i.e., Reaction (2); however, if all the events are considered to be $\Sigma^0\pi^+\pi^-$, the Y_1^* peak is shifted to 1450 MeV consistent with that expected from the $\Sigma-\Lambda$ mass difference. Furthermore, no peaks are observed at the known $(\Sigma\pi)$ resonances which occur at 1405 and 1520 MeV. We conclude from this that the Σ^0

reactions are produced according to phase space and that the effect of Σ^0 contamination in the Y_1^* peak is negligible.

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SPIN AND PARITY OF THE 1385-MeV Y_1^* RESONANCE†

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Study of the reaction

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

at a momentum of 1.22 BeV/c has shown conclusively that the spin of the 1385-MeV Y_1^* is $\geq \frac{3}{2}$, as reported earlier by Ely et al.[1]; it has also indicated that the Y_1^* state is $P_{3/2}$ (even Y^* - Λ parity) rather than $D_{3/2}$ (odd parity). These conclusions result from the angular distribution of the lambda and the angular dependence of the lambda polarization.

The events were obtained through the use of the 72-inch hydrogen bubble chamber placed in a beam of high-energy K^- mesons extracted from the Bevatron. The momentum spread of the beam was ±2.5 %, and the pion background was about 10 %.[2]

Approximately 1650 events were analyzed which satisfied the $K^- + p \to \Lambda + \pi^+ + \pi^-$ hypothesis. Some results from a partial sample were reported earlier.[3] The events were identified by kinematic fitting, first at the decay vertex and then at the production vertex, with the IBM-7090 program "PACKAGE." After this two-step fitting, the number of ambiguous events that might have been $\bar{K}^0$ production rather than lambda production was approximately 1 % of the total. Almost complete separation of the $\Sigma^0\pi^+\pi^-$ from the $\Lambda\pi^+\pi^-$ events was accomplished by examination of the ratio $\chi^2(\Lambda\pi\pi)/2\chi^2(\Sigma\pi\pi)$ for each event, the $\Sigma^0\pi\pi$ χ^2 being weighted by a factor of two because of the difference in average χ^2 values. The final $\Lambda\pi^+\pi^-$ sample included about 93 % of the true $\Lambda\pi\pi$ events and about 5 % of the true $\Sigma^0\pi\pi$ events. The $\Lambda 3\pi$ events were excluded from the $\Lambda\pi\pi$ sample by eliminating all events with $\chi^2(\Lambda 3\pi)$ less than 10.

The cross section for production of the $\Lambda\pi^+\pi^-$ final state by 1.22-BeV/c K^- mesons was determined by comparison with the observed number of tau decays in the same film sample; its value is 2.2 ± 0.2 mb. The angular distributions of Y^{*+} and Y^{*-} production were found similar to that of Y^{*+} production in the work of Ely et al.[1] (see reference 3).

The Dalitz plot for the $\Lambda\pi^-\pi^+$ events is shown in Fig. 1. Projection onto the $\Lambda\pi^+$ mass axis is displayed; the $\Lambda\pi^-$ projection (not shown) is similar. These mass spectra of the $\Lambda\pi^+$ and the $\Lambda\pi^-$ systems are well fitted by Y^{*+} and Y^{*-} resonance curves alone, without background; values of $M(Y^*) = 1385$ MeV and $\Gamma = 50$ MeV are required. The production ratio of Y^{*+} to Y^{*-} is 0.80. Background of 5 to 10 % cannot be ruled out.

On the basis of these mass spectra, the limits 1340 MeV $\leq M(Y^*) \leq$ 1430 MeV were utilized in the analysis discussed below. Only events with large production angles in the center of mass

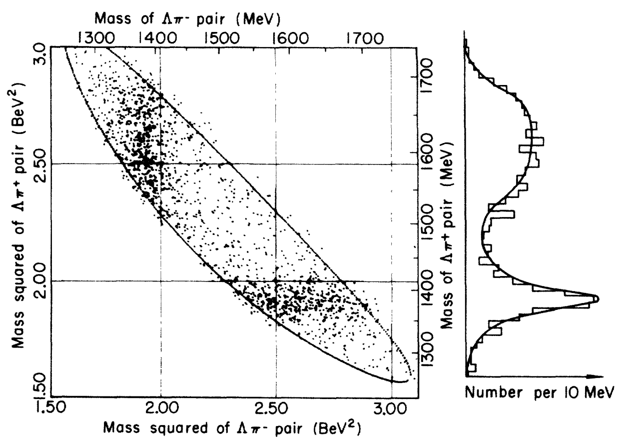

FIG. 1. Dalitz plot of $\Lambda\pi^+\pi^-$ events from K^-p interactions at 1.22 BeV/c. The square of $\Lambda\pi^+$ effective mass is plotted against the square of $\Lambda\pi^-$ effective mass. Scales giving the masses in MeV are also shown. Projection of the events onto the $\Lambda\pi^+$ mass axis is displayed to the right of the figure; the curve represents the fitting of Breit-Wigner resonance expressions to the $\Lambda\pi^+$ and $\Lambda\pi^-$ systems.