PARITY OF THE Y_1*(1660) RESONANCE*

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Confirming preliminary evidence reported by Alexander et al.,[1] two recent publications[2,3] have demonstrated the existence of an $I=1$ baryon-boson resonance near 1660 MeV. Alvarez et al.[2] reported a study of the reaction $K^- + p \to Y^* + \pi$ at 1.51 BeV/c. They found a mean value of the Y^* mass $M^* = 1660 \pm 10$ MeV and a full width at half-maximum $\Gamma = 40 \pm 10$ MeV. Bastien and Berge[3] observed the resonant state production $K^- + p \to Y^*$ at 760 MeV/c and deduced from the angular distribution of the Y^* decay products that the most likely value of its spin $J = \frac{3}{2}$. Both experiments found $Y^* \to \Lambda + \pi$ to be an important decay channel of Y_1*(1660).

We have been studying the interactions of K^- mesons with deuterium in the Lawrence Radiation Laboratory 15-in. bubble chamber, using incident K^- momenta[4] of 600, 765, and 850 MeV/c. In this work, we examine the reaction $K^- + n \to \Lambda + \pi^-$ with respect to the variation of the angular distribution and of the Λ polarization with c.m. energy E^* in the region 1660 MeV $< E^* <$ 1700 MeV. The study suggests that, if partial waves with $J \geq \frac{5}{2}$ can be neglected, the data are more consistent with a resonant $P_{3/2}$ amplitude than a resonant $D_{3/2}$ amplitude. In the following, we discuss first the selection of the appropriate events and second, the partial-wave analysis.

Events resulting in the emission of a π^- and a Λ were selected for measurement. This event class contains the reactions

$$K^- + d \to (p) + \pi^- + \Lambda, \quad \text{(A)}$$

$$(p) + \pi^- + \Sigma^0, \quad \text{(B)}$$

$$(p) + \pi^- + (\Lambda \text{ or } \Sigma^0) + n\pi^0, \quad n \geq 1; \quad \text{(C)}$$

in which the proton (which may or may not be seen) can be regarded as a spectator in the sense of the impulse approximation. Included also are Reactions (A), (B), and (C) accompanied by a final-state hyperon-proton scattering and reactions[5] such as $K^- + d \to (N) + \pi^- + \Sigma \to p + \pi^- + \Lambda$ or $K^- + d \to p + Y_1^{*-}(1385) \to p + \pi^- + \Lambda$; i.e., reactions in which the proton participates intimately.

As a first step, it is necessary to isolate events of class (A). When the proton is seen, (A) is four times overdetermined (4c fit). Even when the proton is not seen, the fit to (A) may be treated as 2c with the proton constrained to have a momentum too small to leave a visible track. As a result of these constraints, no ambiguities with (C) were found for events which fitted (A). The (A) and (B) ambiguities were resolved statistically by examining the angle α of γ-ray emission with respect to the Σ^0 direction of motion in the Σ^0 rest frame. A histogram of $\cos\alpha$ values for events ambiguous between (A) and (B) shows a flat distribution due primarily to true Σ^0 decays plus a spike at $\cos\alpha \approx -1$ due mainly to (A) events treated as events of class (B).

Table I gives the number of events assigned to Reaction (A) on the basis of a detailed study of the χ^2 distributions of Reactions (A) and (B) and of the distribution in $\cos\alpha$. This study showed that, for the assignment given in Table I, 8.5% of the events classed as $\Lambda\pi^-$ are examples of $\Sigma^0\pi^-$. The third column of Table I gives a correction factor for scanning inefficiency, Λ flight paths too short to be visible, and Λ escape from the fiducial volume. This correction factor was determined as a function of the Λ production angle and used in the determination of the angular distributions. The number given in Table I is the average over production angles. The remaining column of Table I gives the cross sections based on a τ count at each momentum.

If (i) the isolation of the events of class (A) was carried out correctly, (ii) the impulse approximation holds, and (iii) the cross section does not vary rapidly with energy, then the cross section

Table I. $K^- + d \to (p) + \Lambda + \pi^-$ events observed at each momentum, correction factors, and cross sections.

P (MeV/c)	Number of events assigned to Reaction (A) [a]	Correction factor [b]	Cross section (mb) [c]
600	106	1.20	4.0 ± 0.6
765	299	1.18	5.4 ± 0.6
850	143	1.17	4.5 ± 0.6

[a] 8.5% of the events are estimated to be due to contamination by Reaction (B).

[b] Combined correction factor for scanning loss, Λ escape from fiducial volume, and Λ flight path too short to permit identification.

[c] Corrected for 8.5% $\Sigma^0\pi^-$ contamination.

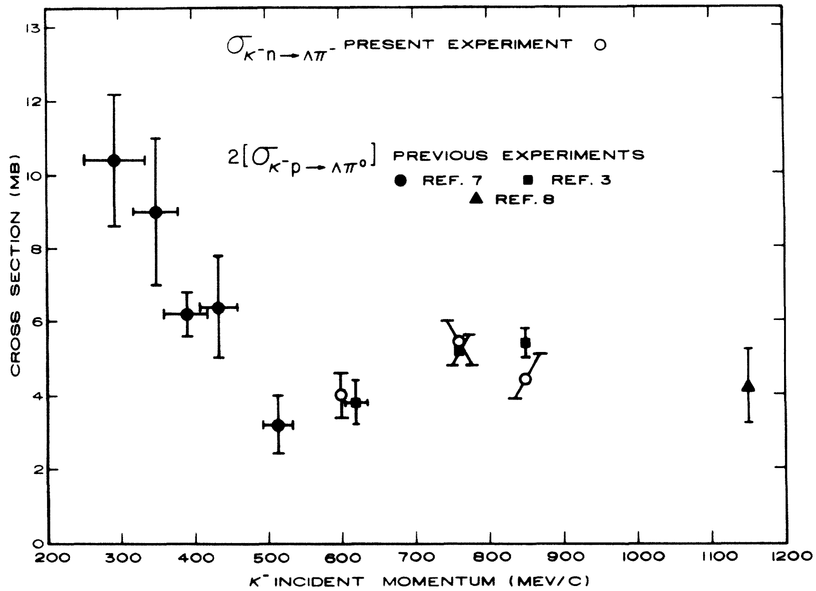

FIG. 1. Comparison of the $K^- + d \to p + \Lambda + \pi^-$ cross section determined in this experiment with the $K^- + p \to \Lambda + \pi^0$ cross section (see references 3, 7, and 8).

for (A) should equal twice that for $K^- + p \to \Lambda + \pi^0$. This is a consequence of charge independence since both reactions involve only the $I = 1$ state.[6] Figure 1 shows the comparison.[7,8] There appears to be no systematic discrepancy between the hydrogen and deuterium data.

If (ii) and (iii) hold, then the distribution of the laboratory angle θ_p between the proton and the incident K^- should be isotropic and the distribution of the proton laboratory momentum P_p should follow the Hulthèn function. These distribution functions are shown in Figs. 2(a) and 2(b) for all incident momenta combined. The Hulthèn function is also shown in the P_p histogram. Figures 2 suggest that, beyond $P_p = 285$ MeV/c, the proton momentum distribution departs seriously from the Hulthèn function; in addition, these high-momentum protons peak forward. Accordingly, events with $P_p \geq 285$ MeV/c (18% of the total) were rejected from the subsequent analysis.

The remaining events were treated as if they were due to collisions of K^- mesons with free neutrons: E^* was computed separately for each event, using the laboratory energies and momenta of the Λ and the π^-, and

$$E^* = [(E_\Lambda + E_{\pi^-})^2 - (\vec{P}_\Lambda + \vec{P}_{\pi^-})^2]^{1/2}. \quad (1)$$

The cosine of the production angle, $\mu = \hat{\Lambda}\cdot\hat{K}$, and the normal to the production plane, $\hat{n} = \hat{\Lambda}\times\hat{K}/|\hat{\Lambda}\times\hat{K}|$, were also calculated in the $\Lambda\pi^-$ rest frame.

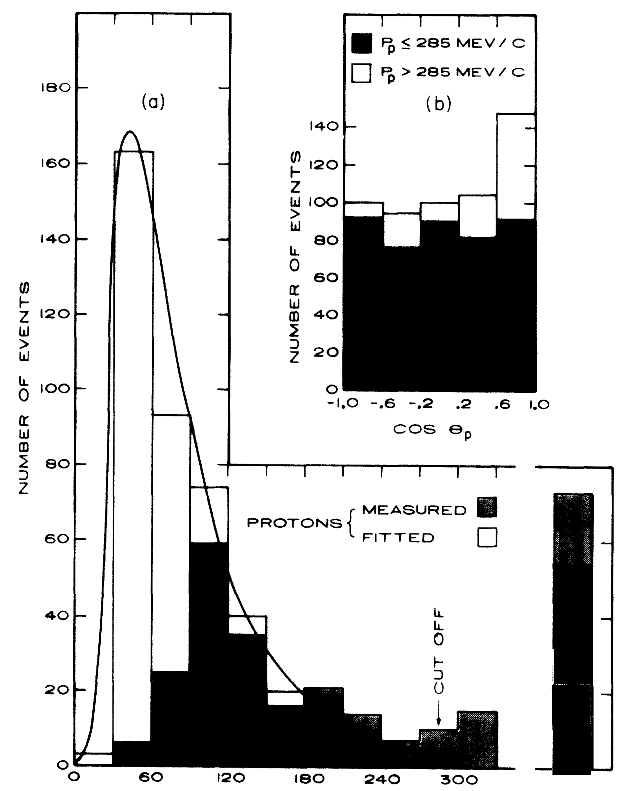

FIG. 2. (a) Momentum distribution of protons compared with Hulthèn distribution. (b) Angular distribution of protons in the laboratory with respect to the incident beam.

Here $\hat{\Lambda}$ and $\hat{K}$ are unit vectors along the outgoing $\hat{\Lambda}$ and incoming K^- directions, respectively.

Watson, Ferro-Luzzi, and Tripp[7] have carried out a detailed partial-wave analysis of the elastic and hyperon-producing channels of the K^-p interaction between 290 and 510 MeV/c. Throughout this momentum band the $\Lambda\pi^0$ data could not be fitted without invoking at least $S_{1/2}$ and $P_{1/2}$ waves. Bastien and Berge[3] continued this study at 620, 760, and 850 MeV/c ($E^* = 1616$, 1681, and 1723 MeV, respectively). They observed a sharp rise of the coefficient of μ^2 in the $\Lambda\pi^0$ angular distribution between the first two E^* values. The coefficient of μ^3 was negligible in all outgoing channels at $E^* = 1616$ MeV and $E^* = 1681$ MeV, but at $E^* = 1723$ MeV none of the outgoing channels could be described without invoking a large coefficient of μ^3. From these observations one may deduce[3] that very probably the resonance has $J = \frac{3}{2}$. Furthermore, the absence of a μ^3 term at $E^* = 1681$ MeV suggests that $P_{3/2}$ and $D_{3/2}$ waves are not both significant at that energy.

In the following analysis we therefore assume that, for $E^* < 1700$ MeV, the reaction $K^- + n \rightarrow \Lambda + \pi^-$ may be described by $S_{1/2}$, $P_{1/2}$, and either $P_{3/2}$ or $D_{3/2}$ amplitudes. If $\nu = \hat{p}\cdot\hat{n}$, where $\hat{p}$ is a unit vector in the direction of the proton from Λ decay in the Λ rest frame, and $\alpha_\Lambda = +0.62 \pm 0.07$ is the Λ-decay asymmetry parameter,[9] then the normalized distribution function of the variables μ and ν is given in terms of Legendre polynomials by

$$W(\mu,\nu) = \tfrac{1}{4}\{1 + A_1 P_1^{\,0}(\mu) + A_2 P_2^{\,0}(\mu) + \alpha_\Lambda \nu [B_1 P_1^{\,1}(\mu) + B_2 P_2^{\,1}(\mu)]\}, \qquad (2)$$

with

$$A_1 = 2\sigma^{-1}\,\mathrm{Re}[c^*(a+2b)],$$

$$B_1 = \pm 2\sigma^{-1}\,\mathrm{Im}[c^*(a-b)], \qquad (3a)$$

$$A_2 = 2\sigma^{-1}[|b|^2 + 2\,\mathrm{Re}(ab^*)], \quad B_2 = \pm 2\sigma^{-1}\,\mathrm{Im}(ab^*), \qquad (3b)$$

$$\sigma = |a|^2 + |c|^2 + 2|b|^2. \qquad (4)$$

Here a and b are the $J = \frac{1}{2}$ and $J = \frac{3}{2}$ amplitudes of the same parity and c is the $J = \frac{1}{2}$ amplitude of the opposite parity. The upper (lower) signs apply if the resonant $J = \frac{3}{2}$ amplitude is $D_{3/2}$ ($P_{3/2}$). The experimental quantities A_i and B_i are shown in Fig. 3. They were calculated as appropriate moments of the experimental distribution of the (μ,ν) pairs. In the region of interest A_1 is small and appears to pass through zero with positive slope; A_2 shows a sharp rise near 1660 MeV. These results agree with the observations of Bastien and Berge.[3] The A_2 data for $E^* > 1700$ MeV suggest the onset of another process. The B_1 data are indistinguishable from zero but B_2 appears to change sign near $E^* = 1660$ MeV. Considering (3a), the data suggest that c is small. Moreover, c enters the expressions for A_2 and B_2 which are of primary interest here only through σ. We shall therefore neglect c in the description of the expected variation of A_2 and B_2. The analysis thus resembles strongly that given for the determination of the $NK\Sigma$ parity.[10,11]

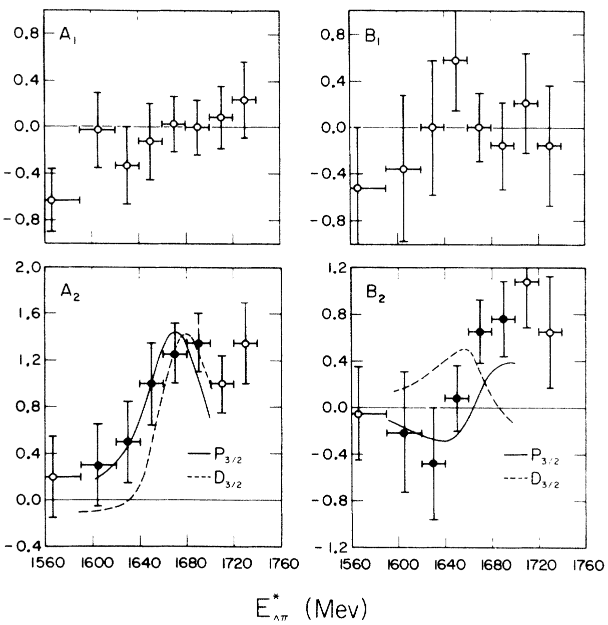

FIG. 3. The coefficients A_1, A_2, B_1, and B_2 for values of E^* near the resonance. For the definition of the coefficients, see Eq. (2). The curves shown correspond to the parameters used in the χ^2 fit.

We adopt a very simple model in which the amplitude a is a constant and b has a standard single-level Breit-Wigner form:

$$a = \exp[i(\phi + \tfrac{1}{2}\pi)], \quad b = x(\epsilon - i)^{-1}, \qquad (5)$$

with $\epsilon = (2/\Gamma)(E_r - E^*)$, $\Gamma = \Gamma_r \kappa^{2l+1}$, and $\kappa = k^*/k_r$. Here x and ϕ are adjustable parameters, k^* the c.m. momentum at energy E^*, and k_r the corresponding quantity at the resonant energy E_r. The angular-momentum barrier is taken into account by the factor κ^{2l+1}, where l is the orbital angular momentum of the resonance. The region 1600 MeV $< E^* <$ 1700 MeV, indicated by the closed circles in Fig. 3, was used in the χ^2 fit of Eqs. (3b), (4), and (5) to the data. In this E^* range, the k^* values in the $\bar{K}N$, $\Lambda\pi$, and $\Sigma\pi$ channels differ by <15% at any E^*; furthermore, they vary by <23% in any channel for the entire range of E^* used. For this reason, the use of appropriate k^* for each channel and of more elaborate barrier penetration factors did not affect the outcome of the calculation.

The results of the χ^2 fit are given in Table II. Another set of solutions which yields values of $x \approx 2.5$ was rejected since this set predicts a resonant peak in the total cross section equal to 12 times the nonresonant background. The peak of 0.5 times the background required by $x = 0.5$ is entirely in accord with the data given in Fig. 1. The curves plotted in Fig. 3 are those corresponding to the last two lines of Table II. It is clear that, while $P_{3/2}$ fits the data adequately, the $D_{3/2}$ solution appears quite improbable if this simple model is valid.

However, apart from statistics, three considerations reduce our confidence in this result:

(a) The data were obtained with deuterium, and a literal interpretation of the impulse model was invoked.

(b) The interpretation of the data presented here is based on the existence of an $I = 1$, $J = \frac{3}{2}$ resonance near 1660 MeV as described in references 2 and 3. Our data are also entirely consistent with a $D_{5/2}$ resonance interfering with an $S_{1/2}$ background.

(c) The model assumes the presence of only one partial wave with $J > \frac{1}{2}$, but both the data of Bastien and Berge[3] and the data presented here indicate the presence of higher partial waves at $E^* \geq 1720$ MeV. While the data in the E^* range used in the χ^2 fit do not require higher partial waves, it is possible that this simple model might be a misinterpretation of a much more complex situation.

Table II. Results of the χ^2 fit of Eqs. (3), (4), and (5) to the data for 1600 MeV $\leq E^* <$ 1700 MeV.

Resonant amplitude	E_γ (MeV)	Γ (MeV)	x	ϕ	χ^2	$P(\chi^2)$
$P_{3/2}$	1660	40	0.5	+10°	12.3	15 %
$D_{3/2}$	1660	40	0.5	+50°	22.5	0.4%
$P_{3/2}$[a]	1670	50	0.4	-10°	10.0	20 %
$D_{3/2}$[a]	1670	50	0.4	+30°	18.6	0.9%

[a]In these fits, E_γ and Γ_γ were allowed to vary within the errors given by Alvarez et al. (see reference 2); we take this to represent a loss of one degree of freedom.

For these reasons, the parity determination cannot be regarded as firm. With more ample data the method described here should permit an unambiguous decision.

This parity determination does not support Glashow and Rosenfeld[12] who arranged the $N_{1/2}^*(1512)$, the $Y_0^*(1520)$, and the $Y_1^*(1660)$ into a $\frac{3}{2}^-$ SU(3) octet. The $\Xi_{1/2}^*(\sim 1600)$ which was then predicted by the relation between the masses of a given octet has also not been seen to date, either in the $\Xi\pi$ channel[13] or in the $\Lambda\bar{K}$ channel.[14]

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DEUTERON PRODUCTION IN p-p COLLISIONS IN THE RANGE 1.5 TO 2.5 BeV†

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In a recent counter experiment[1] carried out at the Cosmotron, a general search for $I=1$ pion resonances was conducted by measuring deuteron energy spectra produced at an angle of 0° as a result of p-p interactions. A by-product of this search was the absolute differential cross section for the channel

$$p+p \to d+\pi^+ \qquad (1)$$

for a range of incident kinetic energy from 1.5 to 2.5 BeV. We report here a sharp rise in the cross section along with a quantitative interpretation of the effect in terms of a one-pion-exchange (O.P.E.) model and the $I=\frac{3}{2}$ resonance in π^+p scattering at 1.35 BeV, the N_{37}^* isobar.[2]

A plan view of the apparatus is given in Fig. 1;

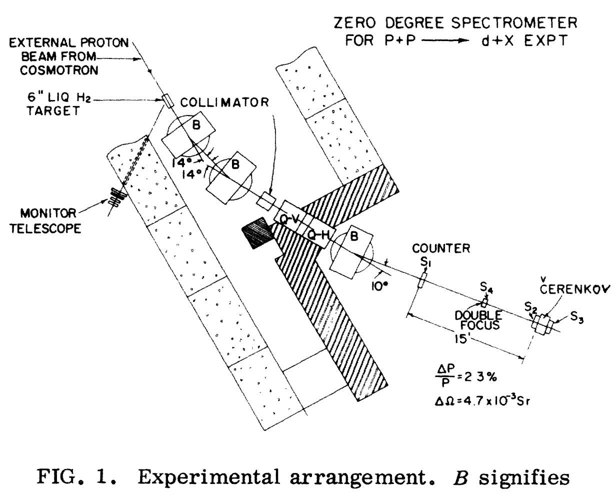

FIG. 1. Experimental arrangement. B signifies bending magnet, QV vertically focusing quadrupole, S_i scintillation counter.

it is basically a double-focusing magnetic spectrometer with a momentum resolution of 2.3% and solid angle of 4.7×10^{-3} sr, which analyzes particles produced at $0°\pm0.5°$ with respect to the incident beam. The deuteron content of the analyzed beam is about 1%; hence a precise measurement of the number of deuterons requires a separation factor of 10^{-4}. This was accomplished by first rejecting ~99% of the protons and pions with a threshold Cherenkov counter and then performing a time-of-flight measurement with a resolution of ±0.6 nsec over the 15-ft flight path between counters S_1 and S_2 of Fig. 1. The absolute proton flux through the liquid hydrogen target was obtained by means of the polyethylene foil technique.[3]

The laboratory momentum spectrum (background subtracted) obtained at an incident kinetic energy of 2.5 BeV is shown in Fig. 2. This range of laboratory momentum corresponds to deuterons produced at 180° in the c.m. system, which must, of course, be equivalent to 0° in the c.m. system due to the symmetry of the initial state. The impressive peak at 1.1 BeV/c arises from $d\pi^+$ production and the area under this peak gives the cross section. Table I gives the cross sections at the four incident energies measured, viz. 1.55, 1.93, 2.11, and 2.50 BeV; the errors shown represent the total uncertainty in the absolute cross section, the error in the ratio of any two points being only ±15%. The c.m. values are plotted as a function of incident laboratory energy in Fig. 3; one notes that the cross section increases by nearly a factor of three between 1.93 BeV 2.5 BeV. Since it is generally expected that deu-

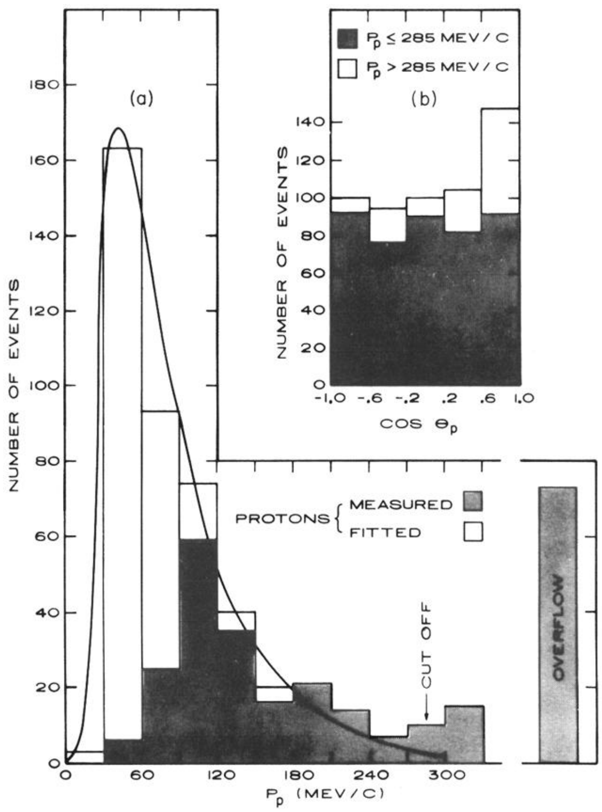

FIG. 2. (a) Momentum distribution of protons compared with Hulthèn distribution. (b) Angular distribution of protons in the laboratory with respect to the incident beam.