Title
SPIN-PARITY DETERMINATION OF Y1*(1765)

Authors
Bell, Robert B.
Birge, Robert W.
Pan, Yu-Li
et al.

Publication Date
1965-10-13

UCRL-16451 Rev

University of California

Ernest O. Lawrence Radiation Laboratory

SPIN-PARITY DETERMINATION OF THE $Y_1^*(1765)$

Submitted to Phys. Rev. Letters

UCRL-16451 Rev

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

SPIN-PARITY DETERMINATION OF THE Y_1^* (1765)

Robert B. Bell, Robert W. Birge, Yu-Li Pan, and Robert T. Pu

December 1, 1965

SPIN-PARITY DETERMINATION OF THE Y_1^* (1765)[†]

Robert B. Bell, Robert W. Birge, Yu-Li Pan,[*] and Robert T. Pu[‡]

Lawrence Radiation Laboratory
University of California
Berkeley, California

December 1, 1965

Measurements of the K^-p total cross section at about 1-BeV/c incident-K^- momenta have shown a broad and asymmetric peak.[1] Further investigations led Barbaro-Galtieri et al. to suggest that two hyperon resonances with spin 5/2 exist in this energy region--one an $I = 0$ resonance at an energy about 1815 MeV with positive parity, the other, $I = 1$ at about 1765 MeV and negative parity.[2] In this paper we show that the Y_1^*(1765) indeed exists and that the conjectured spin-parity assignment, $5/2^-$, is correct.[3]

This study is based on 2100 of our events which fit the hypothesis $K^-n \rightarrow \Sigma^-\pi^+\pi^-$. This particular reaction has the advantage of being pure $I = 1$ and having all pions visible; thus no effects from the strongly produced Y_0^*(1815) are present. The data were obtained from a separated K^- beam in the Lawrence Radiation Laboratory's new 25-in. bubble chamber filled with deuterium. The incident K^- momenta were 828, 930, 1025, and 1112 MeV/c which, neglecting Fermi momentum, corresponds to a K^--N c.m. energy of 1700 to 1845 MeV.

In Fig. 1 we present the $\Sigma^-\pi^+$ invariant mass distribution at various K^-n c.m. energies. It is evident that the reaction $K^-n \rightarrow \Sigma^-\pi^+\pi^-$ is dominated by production of the well-known $J^P = 3/2^-$, Y_0^*(1520) hyperon resonance. This leads us to look for the presence of the Y_1^*(1765) in the cross section for the process $K^-n \rightarrow Y_0^*(1520)\pi^-$. Because of the deuteron

Fermi momentum, a given incident K^- momentum gives rise to a range of K^-n total c.m. energies. Nevertheless, it is interesting to look at the cross section for our reaction at each beam momentum. Figure 2(a) shows the cross section for $K^-n \to Y_0^*(1520)\pi^-$. Here, as throughout this paper, we define the $Y_0^*(1520)$ by the condition that the invariant mass of the $\Sigma^-\pi^+$ system be in range 1520 ± 25 MeV; the results of our analysis are not sensitive to the exact choice for the $Y_0^*(1520)$ width. Despite the considerable overlap in total K^-n c.m. energies between the various beam momenta, an enhancement is clearly indicated in the region of 930 MeV/c, or 1760-MeV K^-n c.m. energy.

One can go further. Knowing the deuterium wave function, the path length for each momentum, and values of the beam momenta, one can predict the expected distribution of K^-n c.m. energies. In Fig. 2(b) we plot the ratio of the number of experimental events to the area under the expected distribution curve for the intervals indicated for the reaction $K^-n \to Y_0^*(1520)\pi^-$; the enhancement around 1760 MeV is apparent. An examination of our data yields the resonance parameters $M = 1760 \pm 10$ MeV and $\Gamma = 60$ MeV, the width being very dependent on the assumed background.

If, as it appears, the $Y_1^*(1765)$ decays into $Y_0^*(1520)\pi^-$, we have an excellent means to determine its spin and parity. At these energies the nonresonating pion travels an average of 10 fermis during a $Y_0^*(1520)$ mean life; therefore it is plausible to consider the channel to be dominated by the two-step process $K^-n \to Y_0^*(1520)\pi^-$ followed by the decay $Y_0^*(1520) \to \Sigma^-\pi^+$.

Since the $Y_0^*(1520)$ has $J^P = 3/2^-$, the reaction $K^-n \to Y_0^*(1520)\pi^-$ does not suffer from the Minami ambiguity associated with $0 + 1/2 \to 0 + 1/2$ processes. Also, it allows a lower decay orbital angular momentum and thus a simpler decay distribution. Following arguments similar to those of Minami,[4] we observe the following: If the K^-n system forms a $Y_1^*(1765)$ resonance with a spin and parity of $5/2^-$, it can decay into $Y_0^*(1520)\pi^-$ via a P- or F-wave orbital state. Since the higher orbital-angular-momentum state is associated with a higher centrifugal barrier, decay via P wave is greatly favored. For such decay of the $Y_1^*(1765)$, the production angular distribution of the $Y_0^*(1520)\pi^-$ system is expected to be $1+2\cos^2\theta$ or $1+0.8\,P_2(\cos\theta)$, where $P_2(\cos\theta)$ is the Legendre polynomial of order two, and $\cos\theta = \hat{K}^- \cdot \hat{\pi}^-$.

Figure 3(a) shows the angular distribution of the $Y_0^*(1520)$ for events with total K^-n energies in the indicated intervals. As we have done in considering the production cross sections, the events from various K^- momenta have been summed and redivided according to the total c.m. energy of the constrained $Y_0^*(1520)\pi^-$ system.

We have fitted these angular distributions to the Legendre polynomial expansion $I = \sum_n A_n P_n(\cos\theta)$; the expansion coefficients are presented in Table I for various K^-n c.m. energy intervals. In the range 1760 ± 60 MeV, expansion to $P_2(\cos\theta)$ is both necessary and sufficient to fit the experimental data. For the particular choice $E = 1760 \pm 20$ MeV, χ^2 for a fit to $1+0.8\,P_2(\cos\theta)$ is 6.4 for nine degrees of freedom.

To see whether another spin and parity assignment of the $Y_1^*(1765)$ can give rise to a similar angular distribution and whether a reasonable background can explain the small deviation from the $1+0.8\,P_2(\cos\theta)$ distribution expected for a pure $5/2^-$ resonance decaying via pure P wave, we present in Table II the contributions of various partial-wave amplitudes, up to $J = 5/2$. A thorough examination of Table II shows that only a dominant $(5/2^- P)$

partial wave with a small $(3/2^+ S)$ background can yield angular distributions in good agreement with the observed data. No other reasonable combination of partial-wave amplitudes can yield a similar distribution. In particular, a pure resonance of spin and parity $5/2^+$ decaying via D wave would yield a distribution $1 + 10\cos^2\theta - 10\cos^4\theta$. Fitting our data to this distribution gives $\chi^2 = 26.2$ for $E = 1760 \pm 20$ MeV. In fact, we have also checked the contribution from $J = 7/2$ partial wave amplitudes which is too cumbersome to be included in Table II. Again no other reasonable combination of partial-wave amplitudes can fit our experimental distribution.

We make another observation about the reaction $K^- n \rightarrow \Sigma^- \pi^+ \pi^-$. If the $Y_1^*(1765)$ is $5/2^+$, both the $Y_0^*(1405)\pi^-$ and $Y_0^*(1520)\pi^-$ channels will decay by D wave. The larger Q value in the $Y_0^*(1405)\pi^-$ channel would favor it over the $Y_0^*(1520)\pi^-$ channel. However, if the $Y_1^*(1765)$ is $5/2^-$, it must decay into $Y_0^*(1405)\pi^-$ by F wave, while it may decay into $Y_0^*(1520)\pi^-$ by P wave. Centrifugal-barrier arguments would then favor $Y_0^*(1520)$ production, even though that channel has a lower Q value. Figure 1 shows dominant $Y_0^*(1520)$ production and suppressed $Y_0^*(1405)$ production, indicating again that the spin-parity of the $Y_1^*(1765)$ is $5/2^-$.

The decay distribution of the $Y_0^*(1520)$ allows a further check on the spin-parity assignment of the $Y_1^*(1765)$. For $J^P = 5/2^+$, a distribution of $1 + 0.78\,P_2(\cos\Phi)$ is expected, while for $J^P = 5/2^-$, a distribution of $1 - 0.70\,P_2(\cos\Phi)$ is predicted. Here we have $\cos\Phi = \hat{n} \cdot \hat{\pi}^+$ in the $Y_0^*(1520)$ c.m. system, and $\hat{n}$ is the production normal $\hat{n} = K^- \times Y_0^*(1520) / |K^- \times Y_0^*(1520)|$. In Fig. 3(b) we present our experimental data; Legendre-polynomial expansion coefficients are shown in Table III. For $E = 1760 \pm 20$ MeV, fits to the theoretical distributions give $\chi^2(5/2^-) = 2.6$ and $\chi^2(5/2^+) = 242.1$ for nine degrees of freedom.

In conclusion, our data indicate the existence of the $Y_1^*(1765)$ hyperon resonance with $M = 1760 \pm 10$ MeV, $\Gamma = 60$ MeV, and the unambiguous spin-parity assignment $5/2^-$.

ACKNOWLEDGMENTS

We would like to thank the crew of the new 25-in. hydrogen bubble chamber for their successful operation of the chamber during its initial run. Thanks go also to the Bevatron crew, the data-reduction group under H. S. White, and the scanners and measurers under Paul W. Weber. The authors are grateful to the other members of the Powell-Birge group for their assistance and useful discussions.

FOOTNOTES AND REFERENCES

[†] Work done under the auspices of the U. S. Atomic Energy Commission.

[*] Present address: Department of Physics, University of Pennsylvania, Philadelphia.

[‡] Present address: Department of Physics, University of California, Riverside.

1. O. Chamberlain, K. M. Crowe, D. Keefe, L. T. Kerth, A. Lemonick, Tin Maung, and T. F. Zipf, Phys. Rev. 125, 1696 (1962).
2. A. Barbaro-Galtieri, A. Hussain, and R. D. Tripp, Phys. Letters 6, 296 (1963).
3. The $Y_1^*(1765)$ has been observed in the reaction $K^-p \to Y_0^*(1520)\,\pi^0$ by Armenteros et al., Phys. Letters 19, 338 (1965). They quote $M = 1755 \pm 10$ MeV, $\Gamma = 105 \pm 20$ MeV, and $J^P = 5/2^-$.
4. S. Minami, Nuovo Cimento 31, 258 (1964).

Table I. Legendre-polynomial expansion coefficients for the $Y_0^*(1520)$ production angular distributions, $I = \sum_n A_n P_n(\cos\theta)$, at various $K^- n$ c.m. energies.

E_{Kn} range (MeV)	Coefficients					
	A_0	A_1	A_2	A_3	A_4	A_5
1700 to 1740	1.00 ± .12	-0.22 ± .24	0.66 ± .32	0.11 ± .40	0.10 ± .42	-1.26 ± .51
1740 to 1780	1.00 ± .07	-0.08 ± .13	0.69 ± .16	0.26 ± .21	0.02 ± .24	0.09 ± .31
1780 to 1820	1.00 ± .07	-0.01 ± .14	0.63 ± .18	0.21 ± .23	0.12 ± .25	0.41 ± .33
1820 to 1860	1.00 ± .09	0.26 ± .16	0.50 ± .22	0.06 ± .26	0.47 ± .30	-0.16 ± .38

Table II. Partial-wave-amplitude contributions to the $Y_0^*(1520)$ production angular distribution $I = \Sigma A_N P_N(\cos\theta)$. (J^P, L) implies decay from a state of spin and parity J^P via L wave.

Partial amplitude		Interference terms	Coefficients					
Term	$J^P L$		A_0	A_1	A_2	A_3	A_4	A_5
1	$(1/2^- P)$		0.56					
2	$(1/2^+ D)$		0.56					
3	$(3/2^+ S)$		1.1					
4	$(3/2^+ D)$		1.1					
5	$(3/2^- P)$		1.1		-0.9			
6	$(3/2^- F)$		1.1		+0.9			
7	$(5/2^- P)$		1.7		1.4			
8	$(5/2^- F)$		1.7		1.1		-0.7	
9	$(5/2^+ D)$		1.7		0.7		-1.7	
10	$(5/2^+ G)$		1.7		1.7		0.93	
		(2, 1)		1.1				
		(3, 1)		-1.6				
		(3, 2)			-1.6			
		(4, 1)		1.6				
		(4, 2)			1.6			
		(4, 3)			-2.3			
		(5, 1)			-0.7			
		(5, 2)		-0.7				
		(5, 3)		1.0				

(Table II. cont.)

Table II.
(cont.)

Partial amplitude		Interference terms	Coefficients					
Term	$J^P L$		A_0	A_1	A_2	A_3	A_4	A_5
		(5, 4)		0.8		-1.8		
		(6, 1)			2.1			
		(6, 2)		2.1				
		(6, 3)				-3.0		
		(6, 4)		0.6		2.4		
		(6, 5)			-1.4			
		(7, 1)			-2.6			
		(7, 2)				-2.6		
		(7, 3)		3.7				
		(7, 4)		-0.74		-3.0		
		(7, 5)			1.7			
		(7, 6)			-0.24		-4.7	
		(8, 1)			2.1			
		(8, 2)				2.1		
		(8, 3)				-3.0		
		(8, 4)		3.6		-0.6		
		(8, 5)			1.5		-2.9	
		(8, 6)			1.2		+2.9	
		(8, 7)			-1.4		-3.6	
		(9, 1)				-1.3		

(Table II. cont.)

Table II.
(cont.)

Partial amplitude		Interference terms	Coefficients					
Term	$J^P L$		A_0	A_1	A_2	A_3	A_4	A_5
		(9, 1)			-1.3			
		(9, 3)			1.8			
		(9, 4)			1.3		-3.1	
		(9, 5)		3.4		-2.6		
		(9, 6)		-0.5		-1.9		
		(9, 7)		0.6		2.4		
		(9, 8)		0.55		1.8		-4.8
		(10, 1)				3.1		
		(10, 2)			3.1			
		(10, 3)					-4.4	
		(10, 4)			1.3		3.2	
		(10, 5)				-2.0		
		(10, 6)		4.0		2.0		
		(10, 7)				-0.5		-6.7
		(10, 8)		0.4		2.0		3.5
		(10, 9)			-1.0		-2.5	

Table III. Legendre-polynomial expansion coefficients for the $Y_0^*(1520)$ decay distributions in the energy range 1740 to 1780 MeV with respect to the production normal $(I = \sum_K A_K P_K(\cos\Phi))$, where $\cos\Phi = \hat{n} \cdot \hat{\pi}^+$ and $\hat{n} = K^- \times Y_0^*(1520)/|K^- \times Y_0^*(1520)|$.

		Theoretical value	
Coefficient	Experimental value	$5/2^-$	$5/2^+$
A_0	1.00 ± .07	1.0	1.0
A_1	-0.03 ± .09	0	0
A_2	-0.91 ± .13	-0.7	0.78
A_3	0.06 ± .17	0	0
A_4	0.04 ± .21	0	0
A_5	-0.07 ± .29	0	0

FIGURE LEGENDS

Fig. 1. Invariant mass of the $\Sigma^-\pi^+$ system produced in the reaction $K^-n \rightarrow \Sigma^-\pi^+\pi^-$.

Fig. 2. (a) Cross sections for the reaction $K^-n \rightarrow Y_0^*(1520)\pi^-$ at various incident momenta. (b) Ratio of the number of experimental events to the area under the theoretical K^-n c.m. energy distribution curve for the reaction $K^-n \rightarrow Y_0^*(1520)\pi^-$.

Fig. 3. (a) Production angular distributions for the $Y_0^*(1520)$.
(b) Decay angular distribution of the $Y_0^*(1520)$ with respect to the production normal.

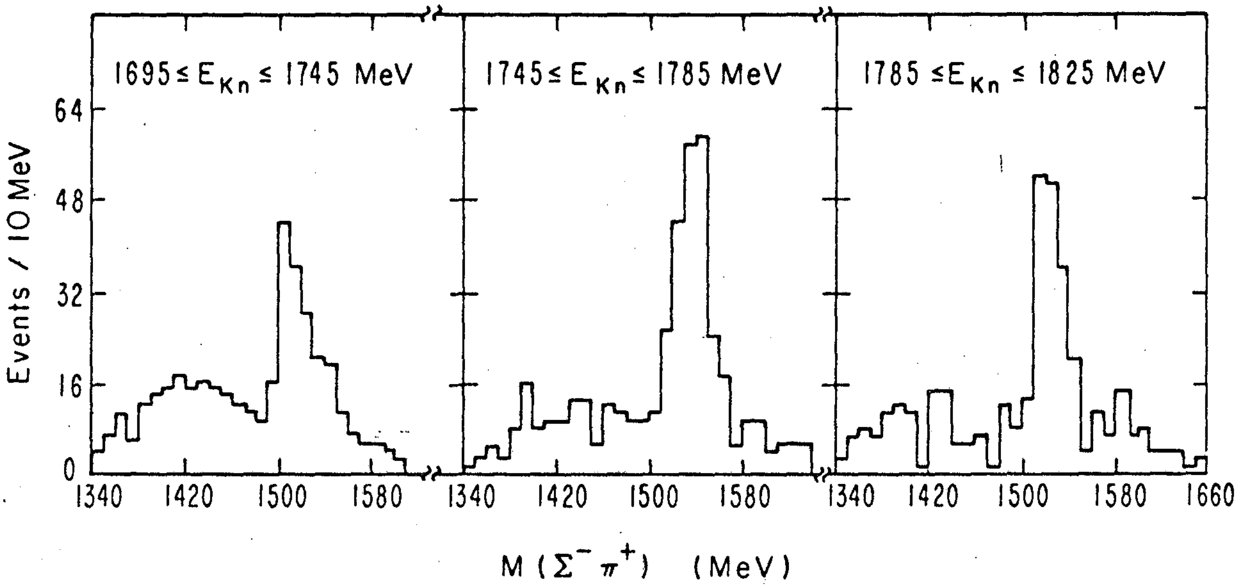
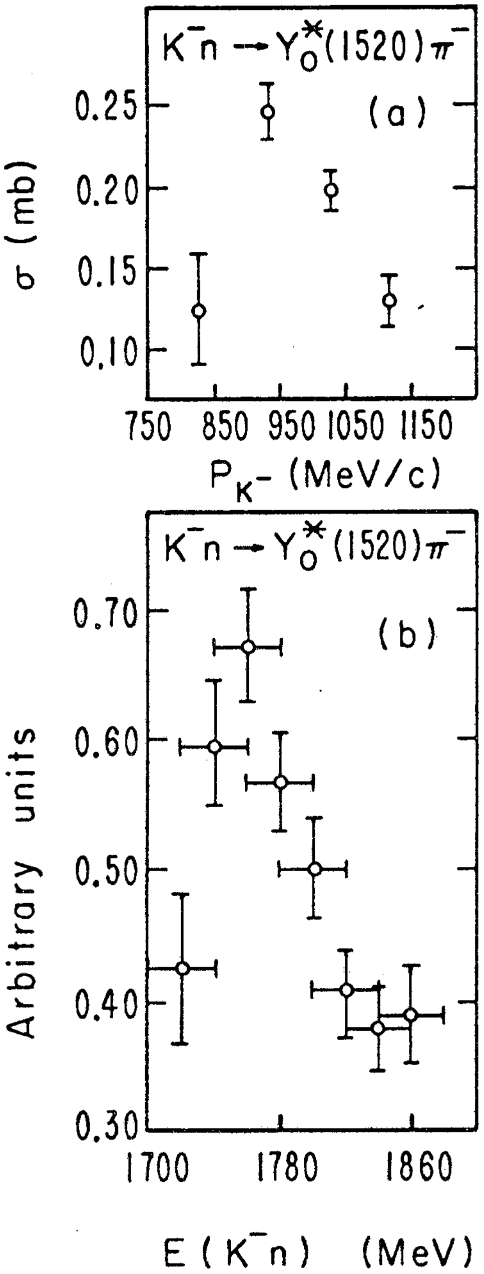


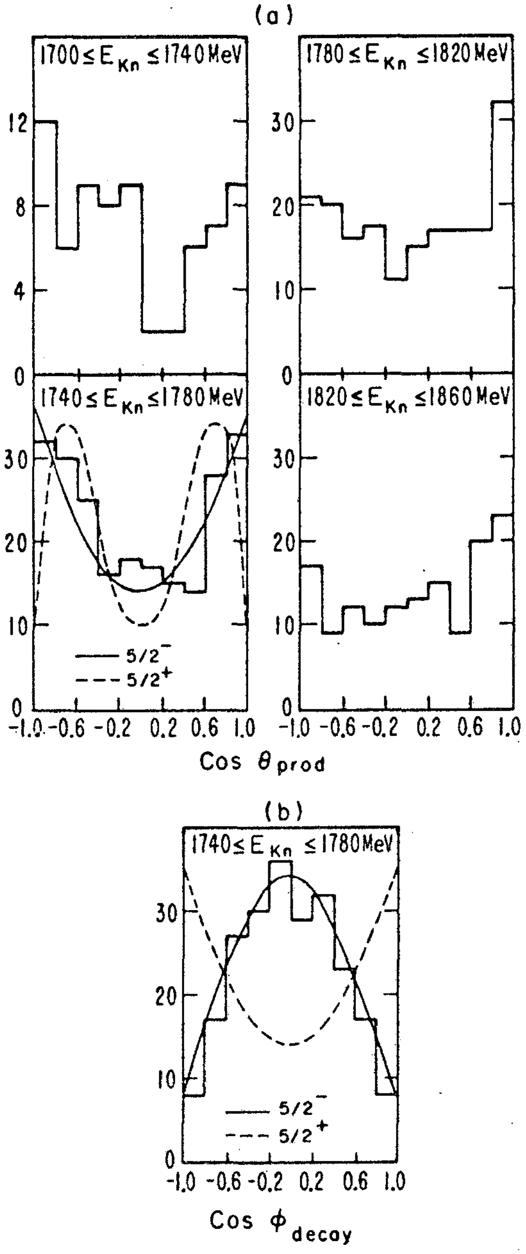
Fig. 1

MUB - 8727



MUB-8726

Fig. 2



MUB - 8728

Fig. 3