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February 15, 1965

Further Evidence for a Kπ Resonance Near 1400 MeV*

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The recent discovery of the Ω^- hyperon[1] has provided a firm basis for the assumption that strong interactions are dominated by some higher symmetry such as SU(3), so that particle states with the same spin-parity will comprise the elements of unitary multiplets.[2,3] During the past year, compelling evidence has been presented for the existence of an $S = 0$, $I = 1$, $J^{PG} = 2^{+-}$ meson (A_2) with mass $M \simeq 1310$ MeV.[4-6] Consequently, we may anticipate the existence of (at least) an octet of $J^P = 2^+$ mesons which, in SU(3), will satisfy an approximate mass formula of the type[2]

$$M^2(S = \pm 1;\ I = 1/2) = 3/4\ M^2(S = 0;\ I = 0) + 1/4\ M^2(S = 0;\ I = 1). \qquad (1)$$

The only other established $J^P = 2^+$ meson is the $f_0(S = 0;\ I = 0)$ with $M \approx 1260$ MeV.[7-9] If we consider the f_0 as a member of the $J^P = 2^+$ octet, Eq. (1) implies the existence of a state with $M(S = \pm 1;\ I = 1/2)$ at 1275 MeV; thus far no $K\pi$ state has been reported at this mass. However, in a study of $K^- + p \to \bar{K}^0 + \pi^- + p$ at 3.5 BeV/c, Haque et al.[10] have found clear evidence for a $K\pi$ state with $M = 1400 \pm 10$ MeV and $\Gamma \sim 160$ MeV. A spin analysis indicates that $J^P = 2^+$ is favored by two standard deviations over $J^P = 1^-$; no determination of I-spin was possible. In the present Letter we report the observation of this state in $\pi^- + p$ interactions and discuss additional evidence for the IJ^P assignment.

In an investigation of $\pi^- p$ interactions at 3.9 and 4.2 BeV/c, we have used the final states summarized in Table I to search for decay of $S = +1$

bosons in the mass interval 1.0 to 1.5 BeV. The $K\pi$ effective-mass distributions are shown in Fig. 1. For an I = 1/2 K^*, $(K^0\pi^0/K^+\pi^-)$ is 1/2; since neutral K^0 decays lead to unanalyzable events, any $K^*(I = 1/2)$ peak in $\Lambda\,\pi^0K^0$ will be suppressed about 6 relative to $\Lambda\,\pi^-K^+$. Consequently, we have grouped together only the two most favorable channels, $\Lambda\,\pi^-K^+$ and $\Sigma^0\,\pi^-K^+$. These final states are especially suited for study of K^*'s since the $M(Y\pi)$ distributions show little enhancement due to formation of negatively charged Y^*'s.[11]

Where production through exchange of I = 1/2 systems is allowed, we observe strong peaks corresponding to $K^*(890)$. In addition, the $M(\pi^-K^+)$ distribution shows a marked enhancement centered around 1430 MeV. An accumulation of 68 events occurs in an interval (1350 to 1510 MeV) where 32 to 36 were expected; the probability that this represents a statistical fluctuation is less then 10^{-5}.[12] The low-momentum-transfer events, $\Delta^2_Y < 1\ (\mathrm{BeV}/c)^2$, are shown separately in Fig. 1a. Almost all $K^*(890)$ events are preserved by this selection criterion, as would be expected for production through K or K^* exchange. It is apparent that most events contributing to the $K\pi$ enhancement at 1430 MeV correspond to a similar Δ^2_Y distribution. Since the background outside these regions is almost uniform in Δ^2_Y, this provides independent evidence for the hypothesis that the peak represents the decay of a new S = +1 state.

The assignment I = 1/2, for $K^*(1430)$ is strongly suggested by the lack of corresponding enhancements in other final states. For an I = 3/2 K^*, $\Lambda\,\pi^0K^0/\Lambda\,\pi^-K^+$ is 2/3;[13] for all events with $\Delta^2_Y < 1\ (\mathrm{BeV}/c)^2$ in the mass interval 1430 ± 80 MeV, the experimental ratio is 3/18. For production of such a state through K or K^* exchange, $\Sigma^+\,\pi^-K^0/\Sigma^0\,\pi^-K^+$ is 27/1;[13] we observe 5/15.

In principle, the spin may be deduced from decay angular correlations. These are most conveniently studied in the $K\pi$ center of mass. In this frame we choose a coordinate system with the z-axis along the direction of the incident pion momentum, $\underset{\sim}{p}_0$, and the y-axis along the production normal, $\hat{n}$; the relative momentum of the final $K\pi$ system for $\underset{\sim}{p} = (p, \theta, \phi)$. Correlations for the lowest J^P states are given in Table II;[14] the data are plotted in Fig. 2 for events in both K^* peaks with $\Delta^2_Y < 1$ (BeV/c)^2. The angular correlations for $K^*(890)$ are similar to those reported by Smith et al., for $\Sigma^0 \pi^- K^+$ at lower momenta,[15] where approximately equal production occurs through K (scalar) and K^* (vector) exchange.

Although in strong disagreement with $J^P = 0^+$, or with any simple K^* (vector)-exchange mechanism for production of a higher spin state, the observed correlations for $K^*(1430)$ are consistent with those expected for decay of either a $J^P = 1^-$ or 2^+ state produced primarily through K exchange. Since the alignment of $K^*(1430)$ may be modified by absorptive effects and (or) contributions from exchange of higher spin objects, we have fitted the $\cos\theta$ distributions to $g_1 = a + b \cos^2\theta$ and $g_2 = a + b \cos^4\theta$ (the data require no $\cos^2\theta$ term in g_2). Within the limited statistics, acceptable fits to both are possible; the ratio of likelihood functions is $L(g_2)/L(g_1) = 4.6$.

In conclusion, the existence of an unstable S = +1, I = 1/2 meson with M = 1430 ± 20 MeV and full width Γ = 100 ± 20 MeV appears reasonably established from a study of the $K\pi$ effective-mass distributions observed in $\pi^- p$ interactions at 3.9 to 4.2 BeV/c. Within statistics, the mass and width of this state are consistent with the values reported by Haque et al.[10] Although the assignment $J^P = 2^+$ is slightly preferred, $J^P = 1^-$ provides an adequate fit to the present data. If we assume that the f_0 represents a unitary singlet, then when considered as members of an octet, the $K^*(1430)$ and A_2 states

imply an S = 0, I = 0 state at M ~ 1470 MeV; some shift to higher mass may result from mixing with the f_0.[2]

We are indebted to Werner Koellner for his extensive support in the reduction of the data, as well as to Edward Hoedemaker for supervision of the scanning and measuring efforts. The film was exposed in a beam designed collaboratively between the Goldhaber-Trilling and Alvarez groups. We thank especially Drs. John A. Kadyk, George H. Trilling, and Joseph J. Murray for their numerous contributions. It is a pleasure to acknowledge the support and encouragement of Professor Luis Alvarez throughout the course of this experiment.

FOOTNOTES AND REFERENCES

*Work supported by the U. S. Atomic Energy Commission.

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12. No account has been taken of the number of histograms examined or number of intervals in which a fluctuation might occur; the proper technique for doing this has been much debated. We believe it more important at this point to determine whether similar enhancements are produced in other experiments where they might be expected.

13. These ratios include the detection efficiencies for the final states involved.

14. K. Gottfried and J. D. Jackson, Nuovo Cimento 33, 309 (1964) and Phys. Letters 8, 144 (1964), have pointed out that these correlations may be significantly modified by absorptive effects in the initial and final states. Because of limited experimental data, we neglect these effects.

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Table I. Events used in the present analysis. Combined data at 3.9 and 4.2 BeV/c.

Final state	Number of fitted events
$\Sigma^+\pi^-K^0$	78
$\Sigma^-\pi^+K^0$	146
$\Sigma^-\pi^0K^+$	95
$\Sigma^0\pi^-K^+$	160
$\Lambda\pi^0K^0$	61
$\Lambda\pi^-K^+$	191

Table II. Expected correlations for the final $K\pi$ system of spin-parity J^P; $\cos\theta = \hat{p}_0 \cdot \hat{p}$, and $\cos\alpha = \hat{n} \cdot \hat{p}$, where these vectors are defined in the text.

J^P	K(scalar) exchange		K^*(vector) exchange
0^+	1	1	
1^-	$\cos^2\theta$	$\sin^2\alpha$	$\sin^2\theta(1+a\cos2\phi)$
2^+	$(\cos^2\theta-1/3)^2$	$3/8\sin^4\alpha-1/3\sin^2\alpha+1/9$	$\sin^2\theta\cos^2\theta(1+a\cos2\phi)$
$2s^a$	$\cos^4\theta$	$\sin^4\alpha$	

[a] $J^P = 2^+$ with sufficient coherent s wave to produce a zero at $\cos\theta = 0$.

FIGURE LEGENDS

Fig. 1. Effective-mass distributions for $K\pi$ systems from $Y\pi K$ final states.

Fig. 2. Decay angular correlations for events with $\Delta^2_Y < 1$ (BeV/c)^2. The $M(\pi^- K^+)$ interval 1430 ± 60 MeV is shown in a, c, and e; the interval 890 ± 80 MeV in b, d, and f. Because of limited statistics, all distributions are folded; ϕ is the Treiman-Yang angle, $\cos\alpha = \hat{n} \cdot \hat{p}$, and $\cos\theta = \hat{p}_0 \cdot \hat{p}$, where these quantities are defined in the text.

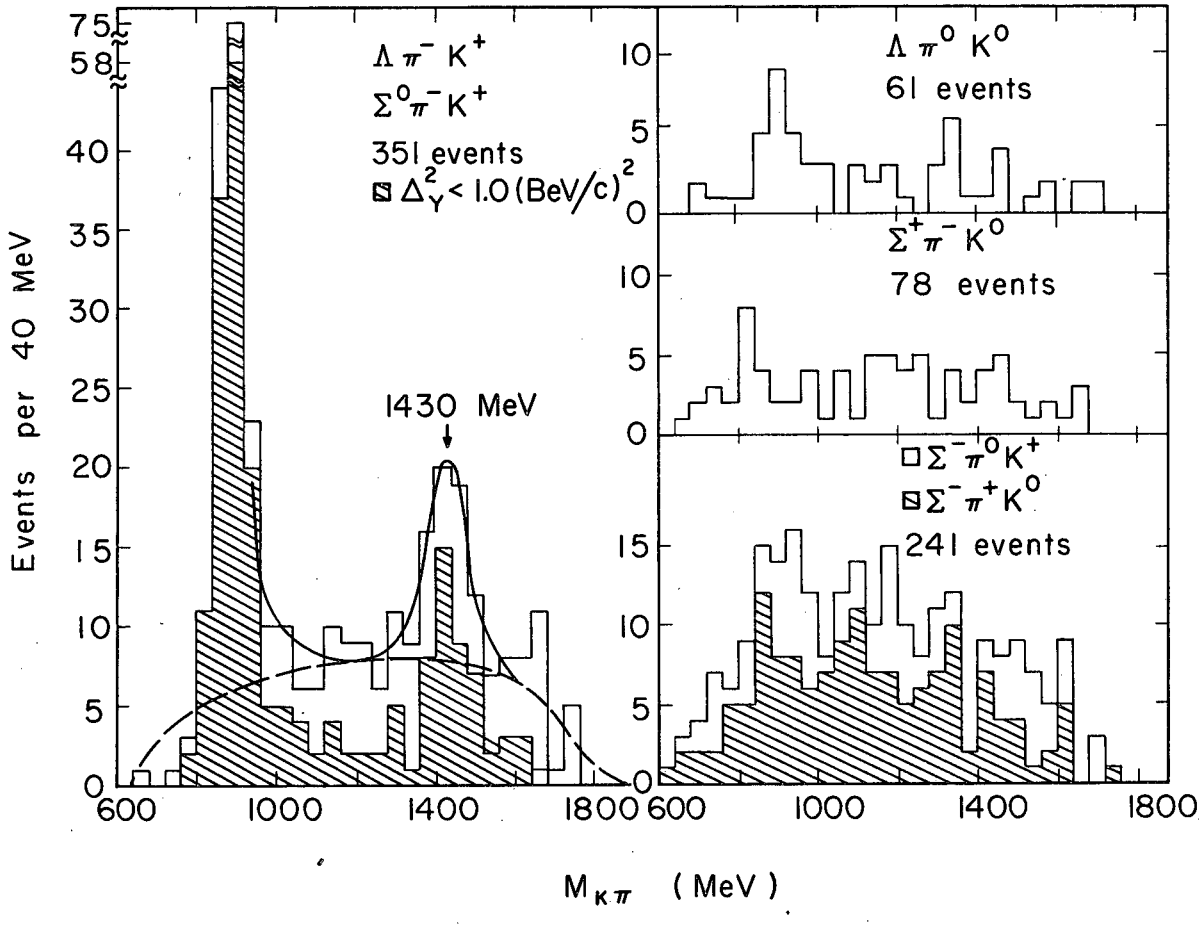
Λ π⁻ K⁺
Σ⁰ π⁻ K⁺
351 events
▨ Δ²Y < 1.0 (BeV/c)²
1430 MeV
Λ π⁰ K⁰
61 events
Σ⁺ π⁻ K⁰
78 events
□ Σ⁻ π⁰ K⁺
▨ Σ⁻ π⁺ K⁰
241 events
Events per 40 MeV
M K π (MeV)
MUB-5094

Fig. 1

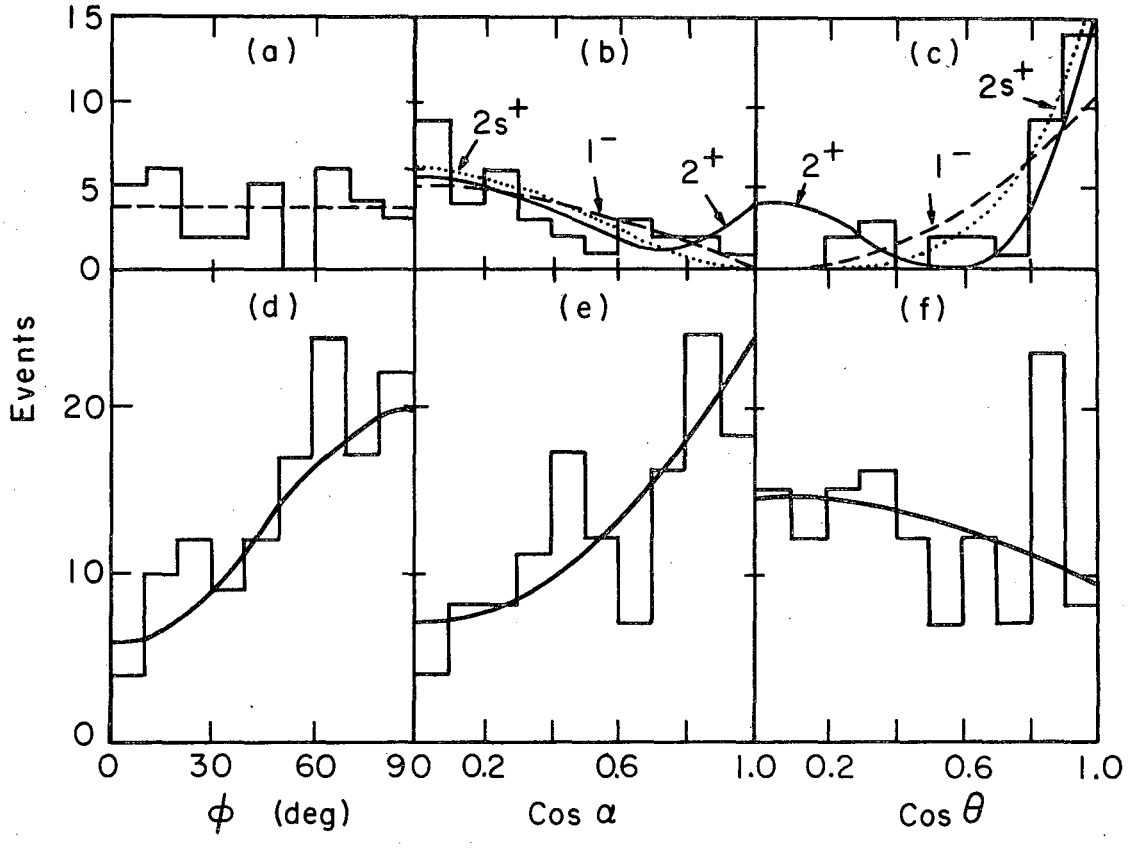

Fig. 2

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