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EXCITED HYPERON OF MASS 1680 MeV*

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Evidence is presented for a new Y_1^* of mass 1680 MeV and width 120 MeV. It is produced in K^-p interactions at 5.5 GeV/c and decays mainly into $\Lambda\pi^+$ and $Y_1^*(1385)\pi$. The decay rate into $\bar{K}^0p$ is 0.3 ± 0.2 of the rate into $\Lambda\pi^+$.

We have analyzed 370 000 pictures taken in the 30-inch hydrogen bubble chamber exposed to the 5.5-GeV/c separated K^- beam[1] at the Argonne zero-gradient synchrotron (ZGS). Light particle contamination in the beam was $\lesssim 5\%$ when calculated from a τ scan of the film. A Čerenkov counter operated during the exposure indicated the same high purity. About 5000 two-prong events with an associated Λ decay have been found. After kinematic analysis, these yielded 328 fits to the final state $\Lambda\pi^+\pi^-$ and 89 fits to $\Sigma^0\pi^+\pi^-$.

When more than one hypothesis produced a fit to a given event, a χ^2 probability cut was used to exclude all fits having a probability 5 times less than that for the best fit. After this selection, all events fitting the hypothesis $\Lambda\pi^+\pi^-$ with a χ^2 probability >1% were classified as $\Lambda\pi^+\pi^-$ events. Of the remaining events, all those fitting the $\Sigma^0\pi^+\pi^-$ hypothesis with a χ^2 probability >1% were classified as $\Sigma^0\pi^+\pi^-$ events. These criteria yield a rather pure sample of the four-constraint $\Lambda\pi^+\pi^-$ final state.[2] The two-constraint fits to $\Sigma^0\pi^+\pi^-$ have some (unknown) contamination from the $\Lambda\pi^+\pi^-\pi^0$ events, but this uncertainty is not important for the present results. Because of the high-beam purity, contamination due to events originating from pions can be neglected.[3]

The Dalitz plot and the mass-squared projection for the events classified as $\Lambda\pi^+\pi^-$ are shown in Fig. 1. Strong production of $Y_1^*(1385)^+ + \pi^-$ and of $\Lambda + \rho^0$ can be seen. In addition, a significant enhancement is observed at $M^2(\Lambda\pi^+) \sim 2.8$ GeV^2. For the rest of this Letter, we use the symbol $Y_1^*(1680)$ for this enhancement. The peak region contains 79 events with an estimated background of 26 events and so is not likely to be a statistical fluctuation. The events in this peak are not associated with the crossing $\Lambda\rho^0$ and Λf^0 bands, as can be seen from the shaded events in Fig. 1(b), which have $M^2(\pi^+\pi^-) > 1.75$ GeV^2. The $\Lambda\pi^+$ decay mode establishes the isospin to be one.

To rule out an interpretation of this peak as the well-established $Y_1^*(1660)$ ($M = 1660\pm10$ MeV, $\Gamma = 44\pm5$ MeV), we show in Fig. 2(e) the $\Sigma^0\pi^+$ mass distribution from the 89 events fitted to $\Sigma^0\pi^+\pi^-$. No $\Sigma^0\pi^+$ enhancement can be seen, and with a 90% confidence level we obtain an upper limit of 0.25 for the ratio $[Y_1^{*+}(1680) \to \Sigma^0 + \pi^+]/[Y_1^{*+}(1680) \to \Lambda + \pi^+]$. For the $Y_1^*(1660)$ this ratio is 3.4 ± 1.5,[4] a gross difference from the present result. A small signal for the $Y_1^*(1660)$ has been observed in this exposure through the decay $Y_1^*(1660) \to Y_0^*(1405) + \pi$.[5] This result, together with the current best estimates of the $Y_1^*(1660)$-decay branching ratios,[6] leads to the prediction that only two events of $Y_1^*(1660)^+$ should be present in our $\Lambda\pi^+\pi^-$ sample. We therefore conclude that the observed $\Lambda\pi^+$ enhancement is not due to the $Y_1^*(1660)$.

Figure 2(f) shows the $\bar{K}^0p$ mass distribution for the 473 events satisfying the hypothesis $K^- + p \to \bar{K}^0 + p + \pi^-$ on this film. Only a small enhancement is seen in the 1680-MeV mass

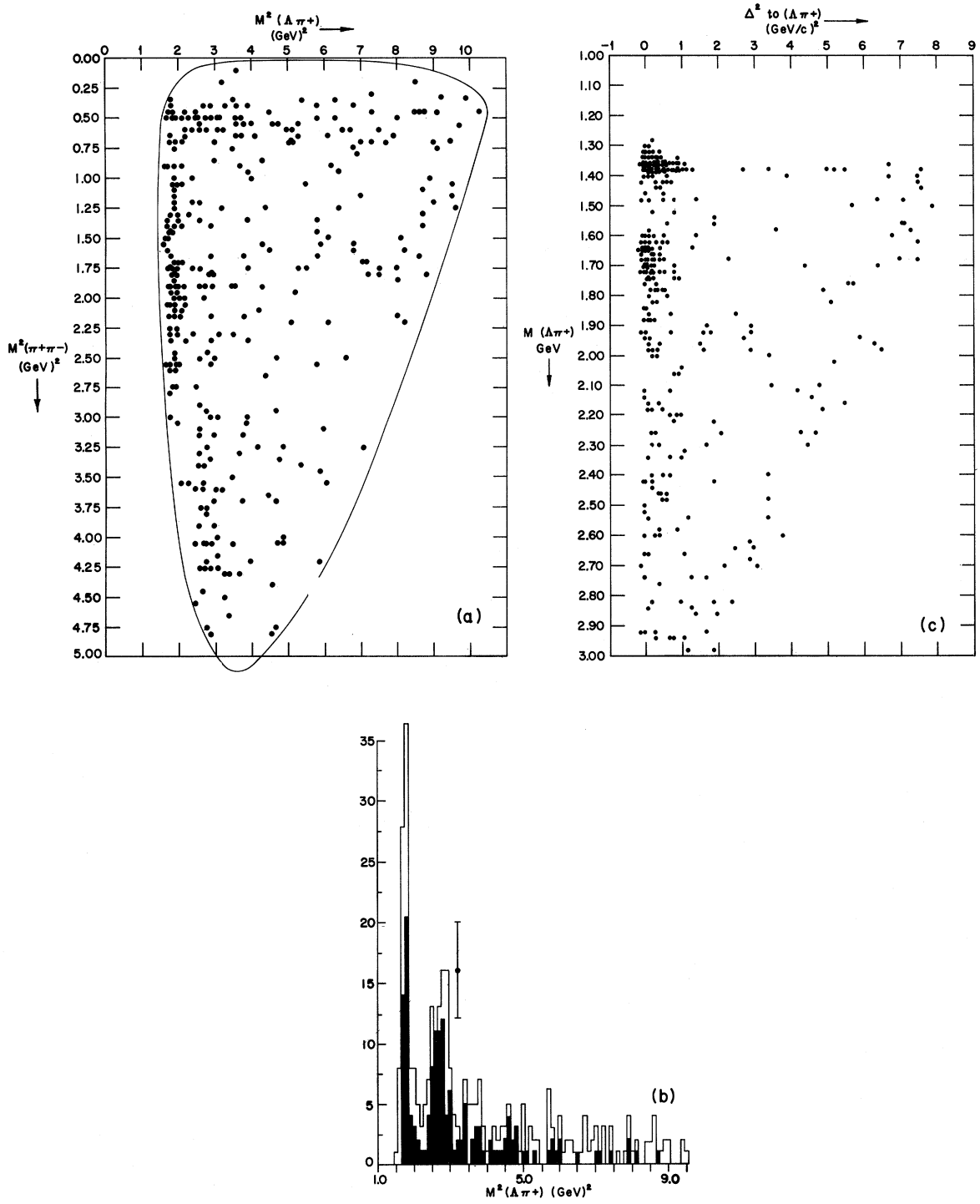

FIG. 1. (a) Dalitz plot for 328 events of the reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ at 5.5 GeV/c. Bands corresponding to the production of $Y_1^*(1385)^+ + \pi^-$ and $\Lambda + \rho^0$ can be seen. (b) Projection of Dalitz plot showing the $M^2(\Lambda\pi^+)$ distribution. In addition to the $Y_1^*(1385)^+$ an enhancement is seen at $M^2(\Lambda\pi^+) = 2.8$ GeV^2. The error bars shown to the right of the two highest bins in this enhancement indicate the statistical error on each of these bins. To exclude the possibility of the events being associated with the final state $\Lambda\rho^0$ or Λf^0, the shaded area shows a projection of the lower part of the Dalitz plot, defined as $M^2(\pi^+\pi^-) > 1.75$ GeV^2. (c) Chew-Low plot for $\Lambda\pi^+\pi^-$ events. Both the $Y_1^*(1385)$ and $Y_1^*(1680)$ are seen to be produced peripherally.

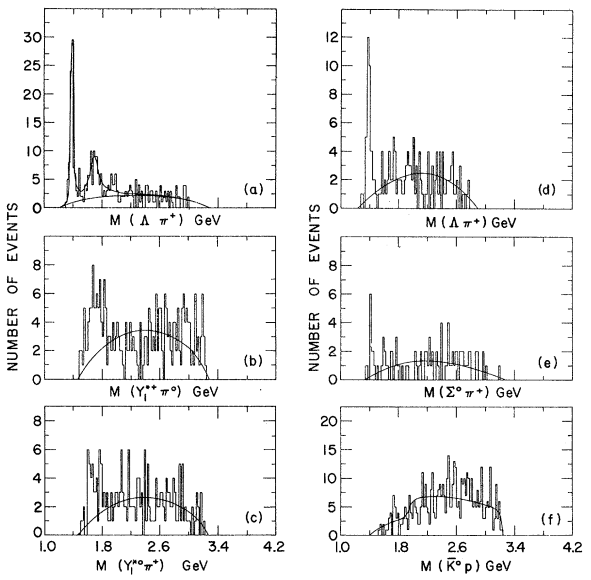

FIG. 2. (a) $\Lambda\pi^+$ mass distribution for 328 events of the reaction $K^- + p \to \Lambda + \pi^+ + \pi^-$ at 5.5 GeV/c. The curve represents the best fit to an incoherent addition of 49% phase space, 26% $Y_1^*(1385)^+ + \pi^-$, and 25% $Y_1^*(1680)^+ + \pi^-$. (b),(c) $Y_1^*(1385)^{+,0}\pi^{0,+}$ mass distribution for events of the reaction $K^- + p \to Y^*(1385)^{+,0} + \pi^{0,+} + \pi^-$ at 5.5 GeV/c (280 and 243 events, respectively). The $Y^*(1385)^{+,0}$ events are selected from the reaction $K^- + p \to (\Lambda + \pi^{+,0}) + \pi^{0,+} + \pi^-$ and are defined to be those for which the $\Lambda\pi^{+,0}$ mass lies in the range 1330 MeV $< M(\Lambda\pi^{+,0}) <$ 1440 MeV. A significant enhancement is seen in the mass range 1600-1800 MeV. The curves are the phase-space distributions normalized to the events with mass >1900 MeV. (d) $\Lambda\pi^+$ mass distribution for events of the reaction $K^- + p \to \Lambda + \pi^+ + \pi^-$ at 4.1 GeV/c (165 events). The curve is the phase-space distribution normalized to the events with mass >1600 MeV. (e) $\Sigma^0\pi^+$ mass distribution for events of the reaction $K^- + p \to \Sigma^0 + \pi^+ + \pi^-$ at 5.5 GeV/c (89 events). The curve is the phase-space distribution normalized to all the events. (f) $\bar{K}^0 p$ mass distribution for events of the reaction $K^- + p \to \bar{K}^0 + p + \pi^-$ at 5.5 GeV/c (473 events). The curve is the expected distribution from the phase space plus the measured fractions of $K^*(890)^-$ and $K^*(1400)^-$ which reflect in this mass distribution.

region, and a value of 0.3 ± 0.2 is obtained for the ratio $[Y_1^{*+}(1680) \to \bar{K}^0 + p]/[Y_1^{*+}(1680) \to \Lambda + \pi^+]$. This small $\bar{K}^0 p$ enhancement, together with the 80-MeV shift in the $\Lambda\pi^+$ peak, rules out a possible interpretation as the $Y_1^*(1765)$, which is known to be strongly coupled to $\bar{K}N$.[7]

Figure 2(a) shows the $\Lambda\pi^+$ mass distribution with a best-fit curve representing the incoherent addition of 49% $\Lambda\pi\pi$ phase space, 26% $Y_1^*(1385)^+\pi^-$, and 25% of the suggested new resonance. The best estimates for the mass and width of the peak are $M = 1683 \pm 15$ MeV and $\Gamma = 120 \pm 30$ MeV.

We have looked for evidence of other decay modes of this resonant state. The only significant enhancement was found for the decay $Y_1^*(1680) \to Y_1^*(1385) + \pi$. Figures 2(b) and 2(c) show the $Y_1^*(1385)^{+,0}\pi^{0,+}$ mass histograms for events satisfying the hypothesis $K^- + p \to \Lambda + \pi^+ + \pi^- + \pi^0$, where the $\Lambda\pi^{+,0}$ mass lies in the range 1330 to 1440 MeV. Significant peaks (40 events for $Y_1^{*+}\pi^0$ and 29 for $Y_1^{*0}\pi^+$) are observed in both charge combinations in the 1680-MeV mass region.[8] These results are compatible with the equal decay for the $Y_1^*(1680)$ into the two charge combinations which one expects if final-state interactions can be neglected. About 40% of the $Y_1^*(1385)^{+,0}$ events coming from the $Y_1^*(1680)$ decay are included in both mass projections, since the $Y_1^*(1385)$ bands cross in the center of the Dalitz plot of the decay $Y_1^*(1680) \to \Lambda + \pi^+ + \pi^0$. No evidence for interference effects in the crossing region is observed within our modest statistical accuracy. Subtracting the number of events plotted twice in Figs. 2(b) and 2(c), a value of 1.0 ± 0.3 is obtained for the decay branching ratio

$$\frac{Y_1^*(1680) \to Y_1^*(1385) + \pi}{Y_1^*(1680) \to \Lambda + \pi}.$$

Figure 1(c) shows the Chew-Low plot for the $\Lambda\pi^+\pi^-$ final state. It is evident that both the $Y_1^*(1385)$ and $Y_1^*(1680)$ are produced peripherally. Postulating the simplest production mechanism, single K^* exchange, one expects to observe the final state $Y_1^*(1680)^0\pi^0$ four times less frequently than the final state $Y_1^*(1680)^+\pi^-$. The appropriate mass combinations have been made to search for the neutral $Y_1^*(1680)$, seen through the decay to $Y_1^*(1385)^{-,+}\pi^{+,-}$. A signal of 16 ± 8 events was obtained, after all corrections, in satisfactory agreement with the expectation of 14 ± 3 from the observed 55 events of $Y_1^*(1680)^+\pi^-$.

No conclusive evidence for the existence of this peak can be seen in the $\Lambda\pi^+$ mass from 130 $\Lambda\pi^+\pi^-$ events produced in our exposure of the same chamber to 4.1-GeV/c K^- mesons. However, as seen in Fig. 2(d), a small enhancement is present in this mass range. The enhancement does not appear in the 3.5-GeV/c British collaboration experiment,[9] but suggestive evidence can be seen in the results from

a 6-GeV/c exposure.[10] The partial cross section ($\Lambda\pi$ decay mode only) for the reaction $K^- + p \to Y_1^*(1680)^+ + \pi^-$ is 25 ± 7 μb at 5.5 GeV/c and 15 ± 7 μb at 4.1 GeV/c. This lack of decrease of cross section with increasing beam momentum is unusual for excited hyperon production in $K^- p$ interactions so far above threshold.[11]

In summary, our data indicate the existence of an excited hyperon of unit isospin which decays strongly into $\Lambda\pi$ and $Y_1^*(1385)\pi$.[12] We have examined the usual decay angular correlations of the resonance. These as yet have not allowed us to reach any firm conclusions about the spin parity since the distributions do not have the symmetry expected for the free decay of a resonant state.

The experiment would not have been possible without the participation of our colleagues at the Universities of Illinois and Wisconsin with whom we collaborated on the design, construction, and operation of the separated beam. In addition, we wish to thank the operating crews of the ZGS and bubble chamber and our scanners both at Argonne and Northwestern.

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[3]Events of the type (a) $K^- + p \to \Lambda + \pi^+ + \pi^-$ are sometimes kinematically ambiguous with (b) $\pi^- + p \to \Lambda + K^+ + \pi^-$. Using the data of Hardy [University of California Radiation Laboratory Report No. UCRL-16788 (unpublished)], we estimate the cross section for reaction (b) to be 80 μb at 5.5 GeV/c compared with 120 μb for reaction (a). The pion-induced reaction is dominated by $K^*(890)$ production and so does not give spurious peaks in the $\Lambda\pi^+$ mass if misinterpreted as $K^- + p \to \Lambda + \pi^+ + \pi^-$.

[4]D. Huwe, University of California Radiation Laboratory Report No. UCRL-11291 (unpublished). This is one of the few good measurements of the decay branching ratios of the $Y_1^*(1660)$. The error quoted by Huwe is generous and arises completely from the difficulty of seeing any $Y_1^*(1660)$ signal in the $\Lambda\pi^+$ mass distribution, so that his results are incompatible with the present observation.

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[12]It is interesting to note that in a study of the reaction $\pi^+ + p \to \Lambda + K^0 + \pi^+ + \pi^+$ with 8-GeV/c π^+ mesons, a small signal was observed for the final state $K^+ + p \to K^{*+} + Y^{*+}$, where the Y^* mass was in the 1650- to 1700-MeV region. An interpretation as the final state $K^*(890)Y_1^*(1660)$ was rejected because no other decay modes of the $Y_1^*(1660)$ were observed. [S. Brandt, V. T. Cocconi, O. Czyzewski, P. F. Dalpiaz, H. Hromadnik, G. Kellner, D. R. O. Morrison, K. Juszczak, J. Loskiewicz, P. Malecki, M. Bardadin-Otwinowska, T. Hofmokl, S. Itwinowski, H. Piotrowska, R. Sosnowski, M. Szeptyzka, and A. Wroblewski, Phys. Letters 22, 109 (1966).] A further anomaly which may be cleared up by the existence of the $Y_1^*(1680)$ (decaying predominantly into $\Lambda + \pi^+$) is the report by P. Schlein [Lectures in Theoretical Physics (University of Colorado Press, Boulder, Colorado, 1966), Vol. VIIB, p. 122], that in the reaction $K^- + p \to \Lambda + \pi^+ + \pi^-$ at 1.87 GeV/c $Y_1^*(1660)^+$ is produced in 8 ± 3% of the events. This leads to a cross-section estimate for the $Y_1^*(1660)^+ + \pi^-$ reaction of 2 mb using a 5% $\Lambda\pi^+$ decay fraction. This is in serious disagreement with an estimate of ~300 μb obtained using other decay modes of the $Y_1^*(1660)$.