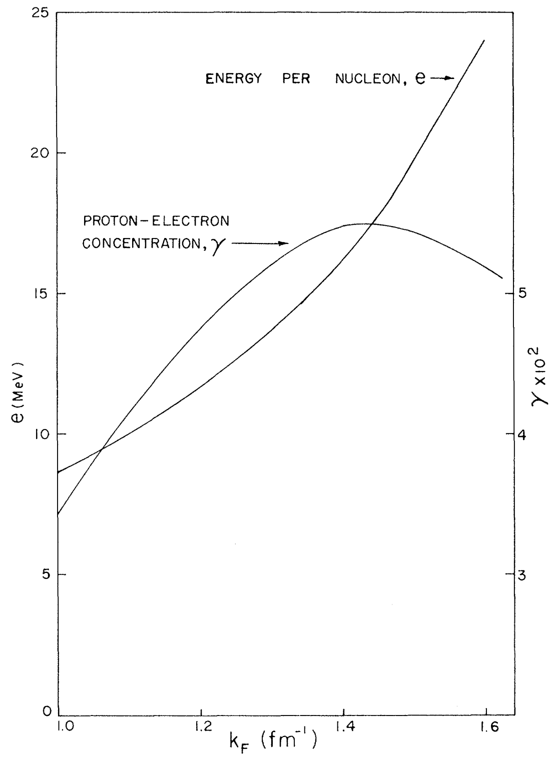

FIG. 1. Energy per nucleon and proton-electron concentration of celestial nuclear matter, calculated with interaction SP1.

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[8]Note, however, that neutron stars are bound by gravitation and not by the nuclear forces—the attraction of the latter is insufficient to compensate the kinetic energy associated with the large neutron excess.

[9]This is the first of the four potentials given by G. Saunier and J. M. Pearson, Laboratoire de Physique Nucléaire, Université de Montréal, Report No. LPNUM 36 (unpublished).

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[14]J. M. Pearson, in Proceedings of the International Conference on the Properties of Nuclear States, Montréal, Canada, 1969, edited by M. Harvey et al. (Les Presses de l'Université de Montréal, Montréal, Canada, 1969), p. 569.

CONFIRMATION OF A NEW $\Lambda\pi$ RESONANCE IN THE REACTION $K^-n \to \Lambda\pi^+\pi^-\pi^-$ †

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Evidence is presented to confirm the existence of a new $\Lambda\pi$ resonance in the $\Lambda\pi^+\pi^-\pi^-$ final state from K^-d interactions at 4.5 GeV/c. A mass of 1642 ± 12 MeV and a width of 55 ± 24 MeV are obtained. Upper limits on $\Sigma\pi$ and $\Lambda(1405)\pi$ branching ratios are obtained for the first time. The branching ratios are found to be consistent with an octet assignment.

In this paper evidence is presented for the production of a $\Lambda\pi$ resonance of mass 1642 ± 12 MeV and width 55 ± 24 MeV in the reaction

$$K^-d \to p_s\Lambda^0\pi^-\pi^-\pi^+. \quad (1)$$

It is observed to be produced with a cross section of 18 ± 3 μb. This confirms the original observation of this state in the same reaction by Crennell et al.[1]

The data were obtained from an analysis of a

5-event/μb per nucleon exposure of the Argonne National Laboratory 30-in. deuterium bubble chamber to a beam of 4.48-GeV/c K^- mesons.[2] Events which fit reaction (1) were generally found to fit reaction

$$K^-d \to p_s\Sigma^0\pi^-\pi^-\pi^+ \qquad (2)$$

as well. The assignment of events to reaction (1) or (2) was achieved when possible from a comparison of the confidence levels of the fits.[3] However, when the ratio of confidence levels did not allow a unique assignment, an examination of the total visible final-state energy of the unfitted tracks was made. It is generally possible to distinguish a true Λ^0 event from a true Σ^0 event by looking for a possible missing energy carried off by the γ from the Σ^0 decay. The sensitivity of this technique arises from the fact that the kinetic energy of an invisible spectator is too small to be missed. Our final sample contains 453 events assigned to reaction (1), 224 events assigned to reaction (2), and 219 events considered ambiguous.[4]

Figure 1(a) shows the $\Lambda^0\pi^-$ mass spectrum with each event plotted twice. Figure 1(b) shows the $\Lambda^0\pi^+$ mass spectrum. The figures are very similar, each showing a strong $\Sigma(1385)$ and an enhancement centered at a mass of 1642 MeV. Ambiguous events have not been plotted. Phase-space curves are shown for comparison.[5] Figure 2(a) is the sum of Figs. 1(a) and 1(b). The possibility that the 1642-MeV enhancement is a kinematic reflection of another process has been examined[6] and can apparently be rejected. We consequently consider it to be due to a $\Lambda\pi$ decay of an $I=1$, $S=-1$ baryon resonance and denote it as $\Sigma(1642)$.

Neither the number of hyperon resonances nor their individual quantum numbers in the region about 1642 is completely determined. The CERN-Heidelberg-Saclay phase shifts indicate the possible existence of four $I=1$ states in this region. They are summarized in Table I. Only the D_{13} state is considered well established.[8]

Since limited statistics preclude the determination of the spin and parity of the enhancement observed in our data, one may attempt to classify it by comparing its mass, width, and branching ratios with those of each resonance found in the phase-shift analysis and in other production experiments.[1,8,9]

Figure 2(b) shows the $\Sigma^0\pi^\pm$ mass distribution with each event plotted three times. One sees no enhancement at 1642 MeV. We estimate the up-

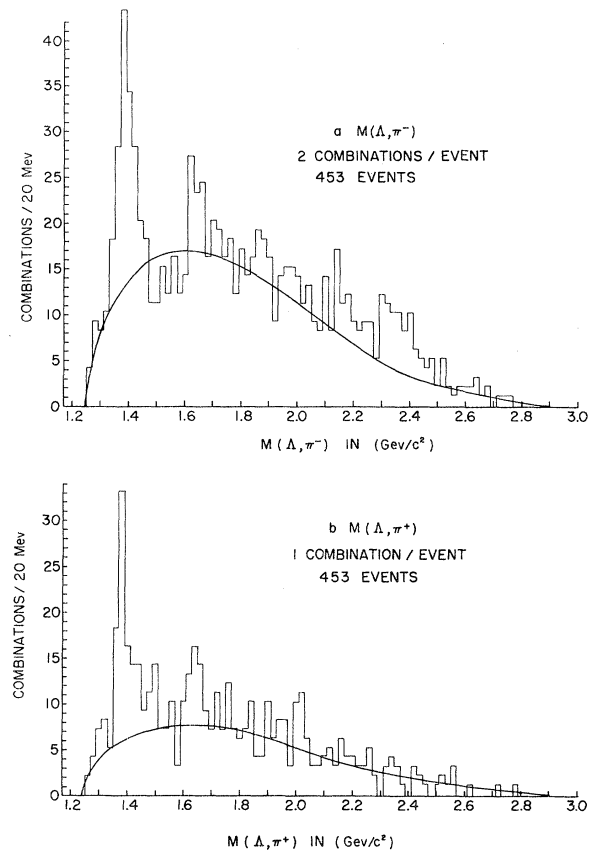

FIG. 1. (a) Effective-mass histogram of the two $\Lambda\pi^-$ combinations. (b) Effective-mass histogram of the $\Lambda\pi^+$. Both are for reaction (1).

per limit on the relative $\Sigma\pi$ and $\Lambda\pi$ branching ratios of the $\Sigma(1642)$ to be

$$\frac{\text{fraction } \Sigma(1642) \to \Sigma\pi}{\text{fraction } \Sigma(1642) \to \Lambda\pi} < 1.1 \qquad (3)$$

at a 95% confidence level. Charged Σ events were corrected for but were not detected.

The reaction

$$K^-d \to p_s p\bar{K}^0\pi^-\pi^- \qquad (4)$$

shows marginal evidence of the process [see Fig. 2(c)]

$$K^-d \to p_s\Sigma^+(1642)\pi^-\pi^-,$$
$$\Sigma^+(1642) \to \bar{K}^0p, \qquad (5)$$

with the resulting branching ratio

$$\frac{\text{fraction } \Sigma(1642) \to \bar{K}N}{\text{fraction } \Sigma(1642) \to \Lambda\pi} = 0.4 \pm 0.4. \qquad (6)$$

It is well known that the $\Lambda\pi$, $\Sigma\pi$, and KN couplings to a Σ^* are related by SU(3). For a pure

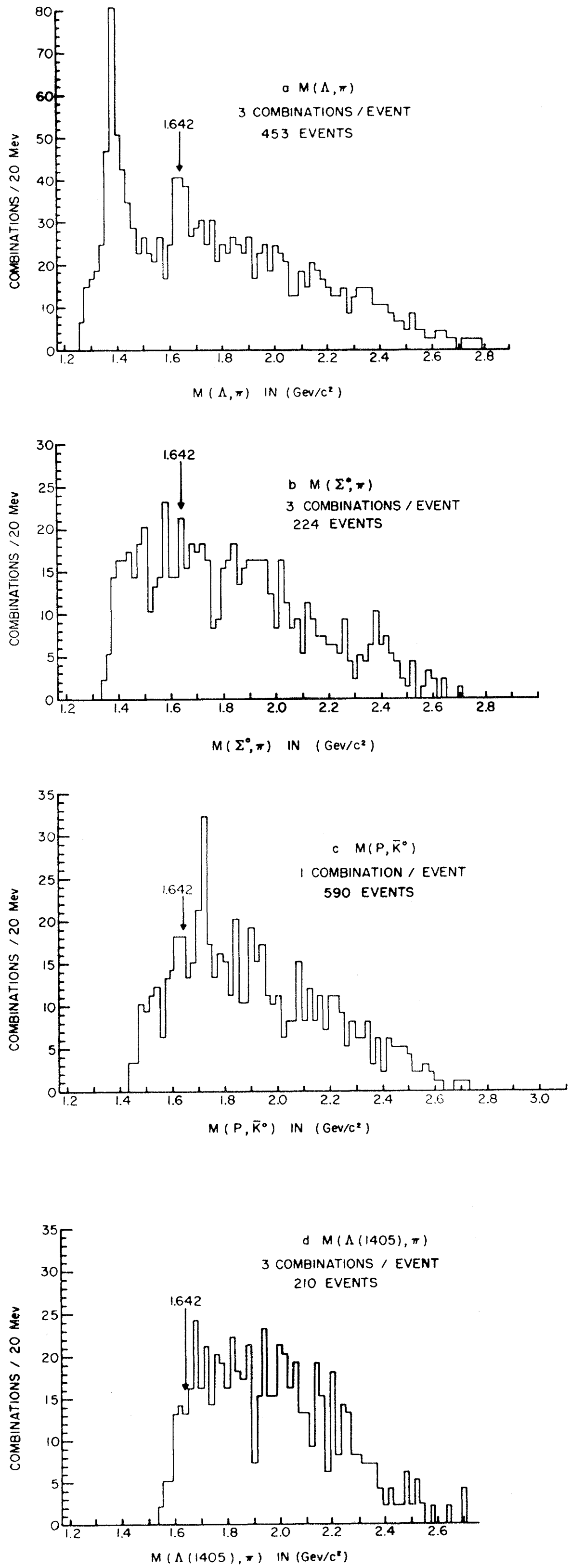

Table I. Σ^* states from the phase-shift analysis of Armenteros et al. (Ref. 7).

		Mass	Width	Branching fraction
$S_{11}(1/2^-)$	$\bar{K}N$	--	--	7 - 10 %
	$\Lambda\pi$	1650	100	70 - 93
	$\Sigma\pi$	--	--	--
$P_{11}(1/2^+)$	$\bar{K}N$	--	--	2 - 10
	$\Lambda\pi$	1610	60	20 - 98
	$\Sigma\pi$	--	--	--
$P_{13}(3/2^+)$	$\bar{K}N$	--	--	4 - 10
	$\Lambda\pi$	1660	80	40 - 96
	$\Sigma\pi$	--	--	--
$D_{13}(3/2^-)$	$\bar{K}N$	1668	56	9
	$\Lambda\pi$	1667	50	29
	$\Sigma\pi$	1661	44	49
	$\Lambda(1405)\pi$	--	--	$\lesssim 8$
	$\Lambda\pi\pi$	--	--	$\lesssim 10$

decuplet the relation is

$$1.5g_{\Sigma^*\bar{K}N}^2 = 1.5g_{\Sigma^*\pi\Sigma}^2 = g_{\Sigma^*\pi\Lambda}^2, \tag{7}$$

while for a pure octet one has the weaker conditions

$$g_{\Sigma^*\bar{K}N} = -(\tfrac{3}{10})^{1/2}g_D + (\tfrac{1}{6})^{1/2}g_F,$$
$$g_{\Sigma^*\pi\Sigma} = (\tfrac{2}{3})^{1/2}g_F, \quad g_{\Sigma^*\pi\Lambda} = (\tfrac{1}{5})^{1/2}g_D, \tag{8}$$

with the D/F ratio as a free parameter.[10] The decuplet condition [Eq. (7)] requires much larger relative $\bar{K}N$ and $\Lambda\pi$ coupling than that which obtains from the $\bar{K}N$-to-$\Lambda\pi$ branching ratio given by Crennell et al.[1] If we try to satisfy the octet condition [Eq. (8)] and suppress the $\Sigma^*\bar{K}N$ coupling by choosing the $\Sigma\pi$ branching ratio of the $\Sigma(1642)$ to be equal to the upper limit of condition (3) and by choosing g_D and g_F to have the same sign, we obtain[11]

$$2.4g_{\Sigma^*\bar{K}N}^2 = 0.74g_{\Sigma^*\pi\Sigma}^2 = g_{\Sigma^*\pi\Lambda}^2. \tag{9}$$

This result implies a branching ratio of

$$\frac{\text{fraction } \Sigma(1642)\to\bar{K}N}{\text{fraction } \Sigma(1642)\to\Lambda\pi} = 0.3 \tag{10}$$

which is in agreement with the branching ratio given by Crennell et al.[1]

FIG. 2. (a) Effective-mass histogram of all three $\Lambda\pi$ combinations for Reaction (1); (b) of all three $\Sigma\pi$ combinations for Reaction (2); (c) of $\bar{K}^0p$ for Reaction (4); and (d) of all three "$\Lambda(1405)\pi$" combinations for Reaction (13). The $\Lambda(1405)$ region was taken from 1375 to 1435 MeV in hyperon missing mass (MM).

A natural question to ask is whether the $\Sigma(1642)$ is actually one of the two $\Sigma(1660)$ states resolved by Eberhard et al.[12] Their lower-mass component decays predominantly to $\Sigma\pi\pi$, the $\Sigma\pi\pi$ spectrum peaking at 1651 MeV. The other component decays roughly twice as often to $\Sigma\pi$ as to $\Sigma\pi\pi$, with the $\Sigma\pi$ spectrum peaking at 1667 MeV. The low-mass component which we denote by $\Sigma_1(1660)$ was said to show a measurable decay to $\Lambda\pi$. They quote the branching ratio

$$\frac{\text{fraction } \Sigma_1{}^+(1660)\to\Lambda\pi^+}{\text{fraction } \Sigma_1{}^+(1660)\to\Sigma^\pm\pi^\mp\pi^+}=0.4\pm0.13, \qquad (11)$$

where the $\Sigma^\pm\pi^\mp$ is predominantly a decay of the $\Lambda(1405)$. Events in our experiment corresponding to the reaction

$$K^-d\to p_s(\text{MM})\pi^+\pi^-\pi^- \qquad (12)$$

were examined (where MM decayed to a visible Λ^0 plus possible neutrals) for evidence of the process [see Fig. 2(d)]

$$K^-d\to p_s\Sigma^\pm(1642)\pi^\mp\pi^-,$$
$$\Sigma^\pm(1642)\to\Lambda(1405)\pi^\pm,$$
$$\Lambda(1405)\to\Sigma^0\pi^0. \qquad (13)$$

Although no distinct signal is seen, a background subtraction yields a branching ratio of

$$\frac{\Sigma(1642)\to\Lambda(1405)\pi}{\Sigma(1642)\to\Lambda\pi}=0.7\pm0.4.$$

This implies an upper limit of 1.5 at 95% confidence level. This is in disagreement with the value of 3.7 ± 1.2 for this ratio that obtains from Eq. (11). Hence the $\Sigma(1642)$ must be different from the low-mass component $\Sigma_1(1660)$. Eberhard et al. do not discuss the $\Lambda\pi$ branching ratio of the high-mass component $\Sigma_2(1660)$. One might argue that the high-mass component (~1667 MeV) is too far removed from 1642 for the states to be identical. While this is probably true, we would argue that one can reasonably obtain the decay branching ratios of $\Sigma_2(1660)$ from those of the $\Sigma(1660)$ described by the phase-shift results of Armenteros et al.[7] This is because the state detected in the phase-shift analysis has a very low branching fraction to $\Sigma\pi\pi$ and hence can contain only a very small admixture of $\Sigma_1(1660)$. Hence we compare our value of less than 1.1 for the relative $\Sigma\pi/\Lambda\pi$ branching ratios of the $\Sigma(1642)$ with that of 1.7 found in Table I. They seem to be in substantial disagreement. Hence, the $\Sigma(1642)$ appears to be different from either of the $\Sigma(1660)$ states described in the literature. Finally, it is possible to set an upper limit of

$$\frac{\text{fraction } \Sigma(1642)\to\Sigma(1385)\pi}{\text{fraction } \Sigma(1642)\to\Lambda\pi}<0.3$$

at 95% confidence level.

One may draw the following conclusions. The $\Sigma(1642)$ is clearly different from the $\Sigma(1695)$[9] on the basis of the different mass. It appears to be different from either of the $\Sigma(1660)$ states on the basis of its branching ratios to $\Lambda\pi$, $\Sigma\pi$, and $\Lambda(1405)\pi$.[13] The weighted average of its mass and width[1] lie closest to those of the P_{11} state of Table I, making it an attractive candidate for a member of a second $\frac{1}{2}^+$ octet along with the P_{11} nucleon state at 1470 MeV.[14]

We would like to thank the accelerator and bubble chamber staffs at Argonne National Laboratory and our programmers and measurers at Purdue, without whose assistance this experiment would not have been possible.

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[1]D. J. Crennell et al., Phys. Rev. Letters 21, 648 (1968), and Brookhaven National Laboratory Report No. BNL 13681, 1969 (to be published). This group obtained a mass of 1619 ± 8 and a width of 72^{+22}_{-15} MeV, giving a weighted average mass of 1626 ± 7 MeV and width of 66 ± 14 MeV. They quote among others a branching ratio of

$$\frac{\text{fraction } \Sigma(1619)\to\bar{K}^0p}{\text{fraction } \Sigma(1619)\to\Lambda\pi^+}=0.0\pm0.2.$$

[2]We measured all events in the 3-prong + V topology, and those in the 4-prong + V topology which contained a proton of momentum less than 300 MeV/c. The programs TVGP and SQUAW were used to reconstruct and fit the events.

[3]A unique fit was considered to exist if a ratio of 3 was obtained for the confidence levels. Every acceptable fit was required to have a confidence level greater than 1%.

[4]The following tests of our selection criteria were made: The momenta of the decay Λ^0's in the Σ^0 rest frames were examined and found to lie predominantly in the plane containing the beam and Σ^0 momenta for the events accepted as "true Λ^0." For the "true Σ^0" events they were found to be isotropically distributed. When the events accepted as true Λ^0 and true Σ^0 were fitted to the reaction $K^-d\to p_S\pi^-\pi^-\pi^+$MM, the missing mass (MM) showed separate peaks at the Λ^0 and Σ^0 masses. The ambiguous events appear to be 65% true Λ^0 events and show no significant enhancements other than the $\Sigma(1385)$. These events are not included in the figures but are corrected for in the quoted branching ratios.

[5]The background $\Lambda\pi$ combinations are not generally peripherally produced and hence an ordinary phase-

space curve was used.

[6]The $\Sigma(1642)$ does not appear to be significantly produced in a two-body process such as $K^-n \to \rho^0\Sigma(1642)^-$, nor does it appear to be a product of a cascading decay $\Sigma^{**} \to \Sigma(1642)\pi$. The same can be said of $\Sigma(1385)^+$ which is copiously produced in this final state. We have searched for processes which would require an enhancement at 1642 in $\Lambda\pi^+$ or $\Lambda\pi^-$ as a reflection of $\Sigma(1385)$ or ρ^0 production. While there is some evidence of sharing of particles between the $\Sigma(1642)$ and the $\Sigma(1385)$ or ρ^0, the magnitude will not explain the size of the 1642-MeV enhancement.

[7]R. Armenteros et al., Nucl. Phys. B8, 186 (1968).

[8]R. D. Tripp, in Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, Austria, September 1968, edited by J. Prentki and J. Steinberger (CERN Scientific Information Service, Geneva, Switzerland, 1968).

[9]Evidence for a Σ hyperon of mass 1695 ± 8 MeV and width 108 ± 20 MeV which predominantly decays into $\Lambda\pi$ is presented by M. Derrick et al., Phys. Rev. Letters 18, 266 (1967); D. C. Colley et al., Phys. Letters 24B, 489 (1967); M. Primer et al., Phys. Rev. Letters 20, 610 (1968). However, V. Barnes et al., Brookhaven National Laboratory Report No. BNL 13823, 1969 (to be published), claim that they no longer need to postulate a $\Sigma(1695)$ to explain their increased data. B. J. Blumenfeld and G. R. Kalbfleisch, Phys. Letters 29B, 58 (1969), observe both the $\Sigma(1616)$ and $\Sigma(1700)$ to have widths on the order of 30 MeV.

[10]R. Levi Setti, in Proceedings of the International Conference on Elementary Particles, Lund, Sweden, 25 June-1 July 1969 (to be published).

[11]P-wave barrier factors were used for the $\Sigma(1642)$. The kinematic factor changes by only about 20% if one selects S wave or D wave.

[12]P. Eberhard, J. H. Friedman, M. Pripstein, and R. R. Ross, Phys. Rev. Letters 22, 200 (1969). See this paper for references to previous analyses of the $\Sigma(1660)$.

[13]Because of the sensitivity to background estimates in the determinations of the branching ratios of the Σ states, additional experiments at different beam momenta (and hence different background shapes) for both K^-n and K^-p should be carried out.

[14]Our observed branching ratios are consistent with those quoted by Harari on the basis of this assignment. See H. Harari, in Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, Austria, September 1968, edited by J. Prentki and J. Steinberger (CERN Scientific Information Service, Geneva, Switzerland, 1968).