PHYSICAL REVIEW D VOLUME 3, NUMBER 5 1 MARCH 1971

Study of the Nonimpulse Events in the Reactions $K^-d \to \Lambda\pi p$ and $\Lambda\pi\pi N$ at 670–925 MeV/c*

W. H. Sims,† J. S. O'Neall,‡ J. R. Albright, E. B. Brucker,§ and J. E. Lannutti
Department of Physics, The Florida State University, Tallahassee, Florida 32306

(Received 24 September 1970)

The ΛN effective-mass spectrum gives confirming evidence for an enhancement near 2130 MeV/c^2 in the $\Lambda\pi^-p$, $\Lambda\pi^-\pi^0p$, and $\Lambda\pi^-\pi^+n$ channels. The interpretation of this ΛN enhancement as either a resonance or a final-state interaction, or a combination of both, is discussed. This effect, if interpreted as a resonance, has fitted mass and width of 2127±1 MeV/c^2 and 8±1 MeV/c^2, respectively.

I. INTRODUCTION

Many experiments[1–10] have been performed which involve the production of Λ hyperons from initial states consisting of more than one nucleon. Of these experiments, several have provided evidence for enhancements in the spectrum of the Λp invariant mass near the ΣN threshold. Because of this proximity to the ΣN threshold, the correct interpretation is still a matter of some controversy.

One possible interpretation of the effect is that it represents a resonance in the Λp system. Such a resonance could be the $I=\frac{1}{2}$, $Y=1$ member of an $SU(3)$ decuplet which includes the deuteron in the $I=0$, $Y=2$ position.[11]

A second possibility is that the peak is due to the conversion process $\Sigma N \to \Lambda N$ which has been used[1,7,8] to explain the existence of the enhancement without the introduction of a Λp resonance.

II. EXPERIMENT AND ANALYSIS

In this paper we report on data obtained from an exposure[12] of the deuterium-filled BNL 30-in. bubble chamber to K^- mesons of momenta 670, 720, 770, 810, 850, and 925 MeV/c. About 90 000 pictures have been analyzed for two-prong and one-prong events with associated V^0 decays which are identified as one of the following reactions:

$$K^-d \to \Lambda\pi^-p \qquad (1)$$

$$\to \Lambda\pi^-\pi^0p \qquad (2)$$

$$\to \Lambda\pi^-\pi^+n\,. \qquad (3)$$

The data were fitted using NP54 and GRIND, and all fits were checked on the scan table for ionization consistency. The contamination from Σ^0 production is estimated to be less than 10%. We report here on those events which did not satisfy the conditions to be interpreted as interactions of the K^- on a single nucleon in the deuterium nucleus (i.e., the nonimpulse events).

Figure 1 shows the Dalitz plot for events of reaction (1) in which the proton has a momentum greater than 300 MeV/c. It is assumed that most of these events are interactions of the K^- with the deuteron as a whole. The projection onto the axis corresponding to the square of the Λp mass shows a strong enhancement near the value (2.130 GeV/c^2)^2. In the projected $\Lambda\pi$ mass spectrum, there are two enhancements. The low-mass $\Lambda\pi$ enhancement can be attributed to the established resonance $\Sigma(1385)$, while the broad high-mass $\Lambda\pi$ enhancement can be seen to be a reflection of the Λp effect at 2130 MeV/c^2.

Having established that the Λp enhancement is present using only events with nucleon momentum greater than 300 MeV/c, we then looked for this effect among events with lower nucleon momentum. It was found that the enhancement is present for nucleon momenta as low as 100 MeV/c. Accordingly, the subsequent analysis includes all events with nucleon momenta above 100 MeV/c. The ΛN mass spectra for such events from reactions (1)–(3) are shown in Fig. 2. The ΛN enhancement heretofore seen only in the three-body final state of K^-d interactions is seen to be present also in the four-body final states.

Figure 3 shows the ΛN spectrum from all three final states combined for nucleon momentum above 100 MeV/c. The inset shows a division of the spectrum into finer intervals in the mass region around 2130 MeV/c^2. The peak is about 2 MeV/c below the ΣN threshold

---

* Supported in part by the U. S. Atomic Energy Commission.
† Present address: Brookhaven National Laboratory, Upton, N. Y. 11973.
‡ Present address: Collège de France, Paris, France.
§ Present address: Rutgers, The State University, New Brunswick, N. J. 08903.

[1] O. I. Dahl, N. Horowitz, D. H. Miller, J. J. Murray, and P. G. White, Phys. Rev. Letters **6**, 142 (1961).
[2] P. A. Piroue, Phys. Letters **11**, 164 (1964).
[3] H. O. Cohn, K. H. Bhatt, and W. M. Bugg, Phys. Rev. Letters **13**, 668 (1964); Nuovo Cimento **38**, 316 (1965).
[4] A. C. Melissinos, N. W. Reay, J. T. Reed, Y. Yamanouchi, E. Sacharidis, S. J. Lindenbaum, S. Ozaki, and L. C. L. Yuan, Phys. Rev. Letters **14**, 604 (1965).
[5] T. Buran, O. Eivindson, O. Skjeggestad, H. Tofte, and I. Vegge, Phys. Letters **20**, 318 (1966).
[6] D. Cline, R. Laumann, and J. Mapp, Phys. Rev. Letters **20**, 1452 (1968).
[7] G. Alexander, B. H. Hall, N. Jew, G. Kalmus, and A. Kernan, Phys. Rev. Letters **22**, 483 (1969).
[8] T. H. Tan, Phys. Rev. Letters **23**, 395 (1969).
[9] P. L. Jain, Phys. Rev. **187**, 1816 (1969).
[10] K. Bunnell, M. Derrick, T. Fields, L. G. Hyman, and G. Keyes, Phys. Rev. D **2**, 98 (1970).
[11] R. J. Oakes, Phys. Rev. **131**, 2239 (1963); Y. Hara, *ibid.* **133**, B1565 (1964).
[12] For more detailed information on this experiment, see J. H. Bartley, R. Y. L. Chu, R. M. Dowd, A. F. Greene, J. Schneps, W. H. Sims, J. R. Albright, E. B. Brucker, J. E. Lannutti, B. G. Reynolds, M. Meer, J. E. Mueller, M. Schneeberger, and S. E. Wolf, Phys. Rev. Letters **21**, 1111 (1968).

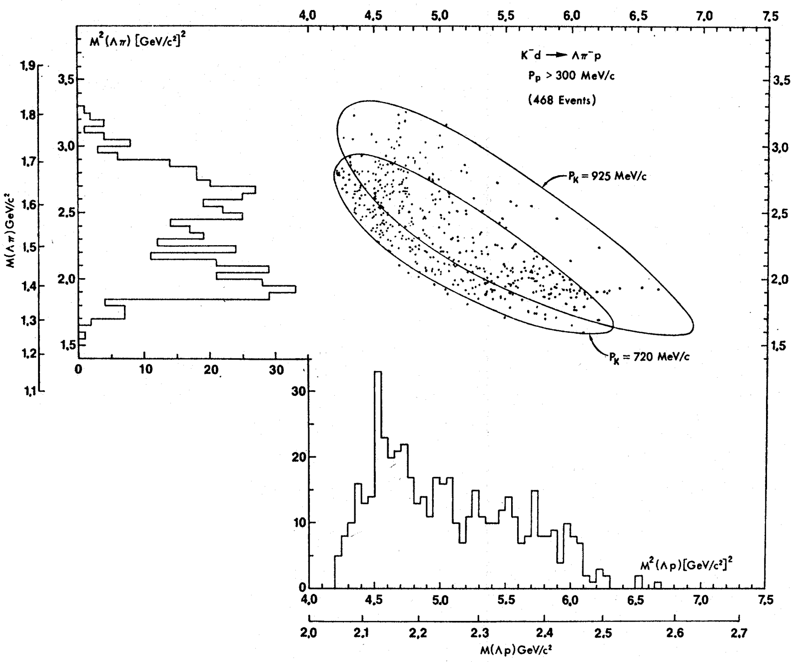

FIG. 1. Dalitz plot and mass projections for those events from the reaction $K^-d\to\Lambda\pi^-p$ in which the proton had a momentum greater than 300 MeV/c.

region, in agreement with Cline *et al.*[6] A simple Breit-Wigner curve was fitted to these data, yielding the values $M=2127\pm1$ MeV/c^2 and $\Gamma=8\pm1$ MeV/c^2. The background in this fit was estimated by fitting the ΛN spectrum outside the interval 2.12–2.16 GeV/c^2 with a smooth curve. Our results for the mass and width agree with those of Cline *et al.*[6] and of Tan.[8]

The result of this experiment is displayed together with the results of similar experiments in Table I. It appears that of all the Λp enhancements that have been reported, the peak near 2130 MeV/c^2 has been seen most frequently and with large enough data samples so that its existence is now beyond serious doubt. There is no evidence on our data (Fig. 3) for any of the reported *high-mass* ΛN enhancements listed in Table I.

Several authors have discussed the possibility that a ΛN enhancement at $\sim$2130 MeV exists but is of a nonresonant nature. The most recent such discussion is that of Alexander *et al.*[7] They explain the effect as due to a two-step process of the type $K^-D\to\Sigma\pi N$ followed by $\Sigma N\to\Lambda N$ with off-mass-shell corrections. That this process should occur, and that it will produce a peak in the general area of 2130 MeV, is clear. It is not clear, however, that this effect completely describes the data. It is crucial that the correct explanation accurately reproduce the central value, width, and energy dependence of the ΛN enhancement. The scale used in the paper of Alexander *et al.*[7] is such that exact comparison with experiment is difficult; however, when plotted on an expanded scale[13] there appear to be significant differences between the data and the calculated curves.

TABLE I. Summary of observed ΛN enhancements.

Ref.	Reaction	Momentum	$M(\Lambda N)$ in MeV/c^2	Γ in MeV/c^2
1	$K^-d\to\Lambda\pi^-p$	$\leq$450 MeV/c	$\approx$2130	···
2	p (Be) $\to K^+N\Lambda\cdots$	2/0.95 GeV/c	$\approx$2360	···
3	Σ^- (^{4}He) $\to\Lambda n^3H$	at rest	2098±6	20_{-5}^{+15}
4	$pp\to\Lambda K^+p$	2.40, 2.85 GeV/c	2058±8	30_{-5}^{+20}
5	K^- (CF_3Br) $\to\Lambda p\cdots$	at rest	$\approx$2220	$\approx$20
6	$K^-d\to\Lambda\pi^-p$	400 MeV/c	$\approx$2126	<20
7	$K^-d\to\Lambda\pi^-p$	910, 1007, 1106 MeV/c	$\approx$2130	···
8	$K^-d\to\Lambda\pi^-p$	at rest	2128.7±0.2	7.0±0.6
			2138.8±0.7	9.1±2.4
9	K^- (emulsion) $\to\Lambda p\cdots$	at rest	$\approx$2110	$\approx$20
10	K^- ^{4}He $\to\Lambda\pi^-pd$	at rest	$\approx$2130	···
This expt.	$K^-d\to\Lambda\pi^-p$	670–925 MeV/c	2127±1	8±1
	$K^-d\to\Lambda\pi^-\pi^0p$			
	$K^-d\to\Lambda\pi^-\pi^+n$			

[13] D. Cline, R. Laumann, and J. Mapp, in *Proceedings of the International Conference on Hypernuclear Physics, 1969* (Argonne National Laboratory, Argonne, Ill., 1969), p. 92. Particular reference is made to Fig. 17 of this paper.

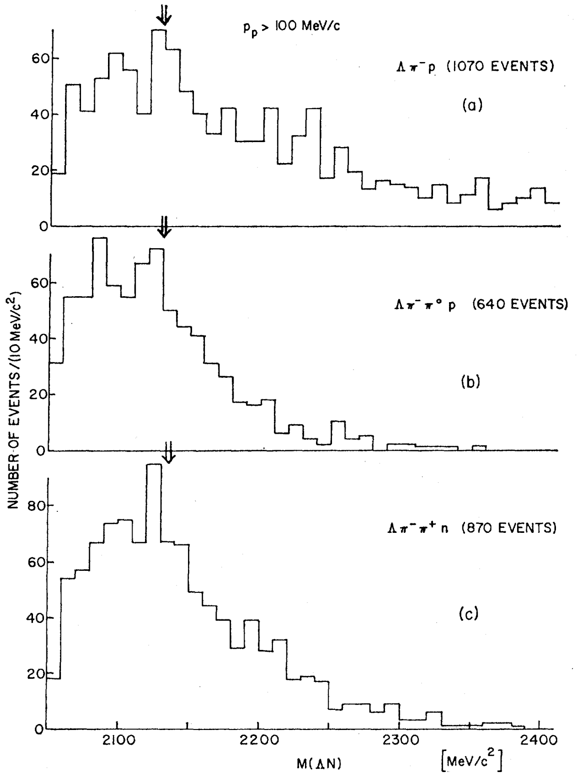

FIG. 2. ΛN mass spectra for K^-d events with final states (a) $\Lambda\pi^-p$, (b) $\Lambda\pi^-\pi^0p$, and (c) $\Lambda\pi^-\pi^+n$ in which the nucleon had a momentum greater than 100 MeV/c. The standard Λ lifetime correction has been applied to the data. The arrows indicate the ΣN thresholds.

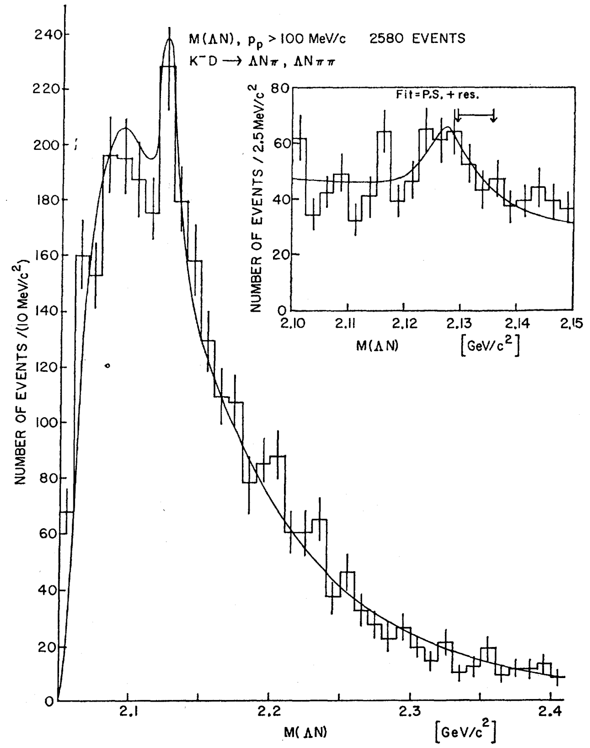

FIG. 3. Combined ΛN mass spectra from the final states shown in Fig. 2. Inset shows the spectrum near 2130 MeV/c divided into 2.5-MeV/c^2 intervals. The smooth curves are an incoherent superposition of a Breit-Wigner shape with a smoothly varying background. The arrows indicate the region of ΣN thresholds.

These differences (in central value and width) may be attributed to inadequacies of the model (inexact off-mass-shell corrections, for example) or may imply that the two-step model alone will not explain the data. Since the Σ-Λ conversion effect will certainly make a contribution, it appears that the proper question is not whether the ΛN enhancement at $\sim$2130 MeV is a resonance or conversion phenomenon, but rather how much, if any, resonance needs to be assumed *in addition* to the Σ-Λ conversion contribution to fit the data. In this connection, it is interesting to note that a narrow ΛN resonance at 2128 MeV in addition to the Σ-Λ conversion contribution calculated by Alexander *et al.*[7] would fit the data compilation of Ref. 13 rather well. If, however, one assumes that *only* the conversion process contributes and that the off-mass-shell approximation made by Alexander *et al.* is reasonable, then one expects that the central value and width of the $\Lambda N(2130)$ will increase with increasing beam energy. A comparison of the results of our experiment which has an average beam momentum $\sim$750 MeV/c with that of Tan (at rest) does not confirm this expectation. Both the central value (2127 ± 1 MeV/c^2 for this experiment and 2128.7 ± 0.2 MeV/c^2 for that of Tan) and the width (8 ± 1 MeV/c^2 for this experiment and 7.0 ± 0.6 MeV/c^2 for that of Tan) are in excellent agreement.

III. CONCLUSIONS

In this experiment we have seen additional evidence for the production of a $\Lambda N(2130)$ enhancement in the $\Lambda\pi N$ and for the first time in $\Lambda\pi\pi N$ final states. Previously reported higher-mass ΛN enhancements are not observed. We do not have a sufficient quantity of data to distinguish between the ΛN resonance model and the $\Sigma N \to \Lambda N$ model as the origin of the $\Lambda N(2130)$, but suggest that there may be contributions from both sources to the $\Lambda N(2130)$ enhancement.

ACKNOWLEDGMENTS

We wish to thank the personnel at Brookhaven National Laboratory who facilitated the exposure. We express our appreciation to the particle-physics staff and computing-center personnal for their help in data acquisition and reduction. We also acknowledge the assistance of the following people in the early stages of this experiment: at Florida State University, Dr. J. T. Dockery, Dr. B. G. Reynolds; at Tufts University, Dr. R. M. Dowd, Dr. A. F. Greene, Dr. J. Schneps; and at Brandeis University, Dr. M. Meer, Dr. J. Mueller, Dr. M. Schneeberger, and Dr. S. Wolf.