EVIDENCE FOR A $\Lambda\pi$ ENHANCEMENT NEAR $\bar{K}N$ THRESHOLD*

D. Cline,† R. Laumann, and J. Mapp
University of Wisconsin, Madison, Wisconsin
(Received 5 April 1968; revised manuscript received 22 July 1968)

A strong enhancement is observed in the $\Lambda\pi^-$ mass spectrum in the reaction $K^-d \to \Lambda\pi^-p$; the central mass of the enhancement is at 1440 MeV, near $\bar{K}N$ threshold. The enhancement may be explained in one of two ways: (1) as being due to a "moving triangle singularity", or (2) as being due to an $I=1$ resonance strongly coupled to the $\Lambda\pi$ system.

In this note we present evidence for a narrow enhancement in the $\Lambda\pi^-$ system near $\bar{K}N$ threshold. The events in this experiment were obtained using film from an exposure of the Lawrence Radiation Laboratory 25 in. chamber filled with D_2 and exposed to a septum-separated 400-MeV/c K^- beam at the Bevatron.[1] The reactions studied are

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

$$\to \Sigma^0\pi^-p, \quad (2)$$

with the proton being identified by ionization on the scanning table. The sample of events studied was chosen with protons which had momentum greater than ~150 MeV/c. In this way we hoped to collect a sample of events with considerably lower $\Lambda\pi$ and $\Sigma\pi$ invariant mass than that expected for absorption of the K^- on quasifree neutrons.

Figure 1 shows the $\Lambda\pi^-$ mass spectrum for events fitting the kinematics of Reaction (1). It is evident that there is considerable structure in this mass plot. The enhancement near 1390 MeV is most probably due to the $\Sigma(1385, \frac{3}{2}^+)$. Two other enhancements are evident, one near the mass of 1440 and the other near 1490 MeV. Reaction (1) also shows a narrow enhancement in the Λp mass spectrum near ΣN threshold.[2] The events associated with the Λp enhancement have been removed from all the data reported in this note. This cut removed approximately 120 events from the initial sample of 1997 events of Reaction (1). The two low-mass $\Lambda\pi$ enhancements are not changed appreciably as a result of this cut. Reaction (1) shows no suggestion of structure in the πN invariant-mass spectrum near 1236 MeV which is in accordance with the expectation of a weak $I=\frac{1}{2}$, πN final-state interaction throughout the πN mass range allowed for Reaction (1) in this experiment (because of charge independence, the πN system must be in the $I=\frac{1}{2}$ state). Figure 1 also shows the $\Sigma^0\pi^-$ invariant-mass spectrum for events of Reaction (2). There is obviously a striking difference between the $\Sigma\pi$ and $\Lambda\pi$ mass spectrum in the vicinity of the 1390 and 1440 enhancements. The $\Lambda\pi$ and $\Sigma\pi$ events come from the same sample of film and are detected on the scanning table with the same efficiency.

Figure 2(a) shows the $\Lambda\pi^-$ mass spectrum from Reaction (1) for various cuts between the angle of the outgoing proton and the incoming K^- in the $\bar{K}d$ center-of-mass system. As can be seen in Fig. 2(a) the strong peak near 1440 seen in Fig. 1 is considerably enhanced above background, especially for the cut in which the proton is forced to go forward. This cut also seems to enhance the $\Sigma^-(1385)$ structure. The peak near 1490 is effectively removed by this cut.[3] The $\Lambda\pi$ enhancement near 1440 is clearly statistically significant; for example, the peak is more than 3 standard deviations above background for the $\cos\theta_{Kp} > 0.5$ cut.

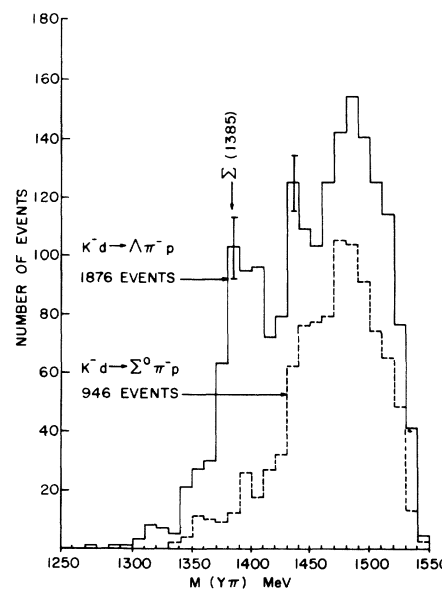

FIG. 1. $\Lambda\pi^-$ and $\Sigma^0\pi^-$ invariant-mass spectrum for events of Reactions (1) and (2). Events with a Λp mass between 2120 and 2140 MeV and with $\cos\theta_{K\pi} > 0.8$ have been removed, where $\theta_{K\pi}$ is the angle between the incident K^- and outgoing π^-.

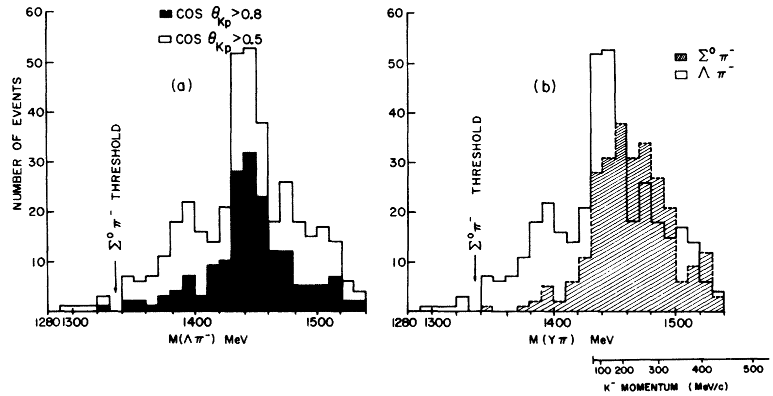

FIG. 2. (a) $\Lambda\pi^-$ invariant-mass spectrum for Reaction (1) with various cuts on the angle (θ_{Kp}) between the final proton and incident K^- in the K^-d rest system. (b) Comparison of $\Lambda\pi^-$ and $\Sigma^0\pi^-$ [Reaction (2)] mass spectrum for events satisfying the restriction that $\cos\theta_{Kp} > 0.5$.

Figure 2(b) shows the $\Sigma^0\pi^-$ mass spectrum obtained from Reaction (2) and compared with the $\Lambda\pi^-$ using the same proton angle cuts ($\cos\theta_{Kp} > 0.5$). The strong peaking in the $\Lambda\pi^-$ system is again not reproduced in the $\Sigma^0\pi^-$ system, although there is the suggestion of a shoulder near $\bar{K}N$ threshold in this system. In the vicinity of the $\Sigma^-(1385)$ enhancement (from 1370 to 1410 MeV) the ratio of $\Sigma^0\pi^-$ events to $\Lambda\pi^-$ events is 0.1 ± 0.05, which is in good agreement with the $\Sigma^0\pi^-/\Lambda\pi^-$ branching ratio of the $\Sigma(1385)$, 0.05 ± 0.02.[4] In addition, the ratio of $\Sigma\pi(I=1)$ to $\Lambda\pi$ production has been measured in the physical region ($M_{Y\pi} > M_{Kp}$).[5,6] Although these measurements are at present statistically limited, they do suggest that the ratio of $\Sigma^0\pi^-/\Lambda\pi^-$ should be equal or slightly greater than 1.0 in the invariant-mass region of 1450-1500 MeV. This is in agreement with the data presented in Fig. 2(b). Also, the ratio of $\Sigma^0\pi^-/\Lambda\pi^-$ events in the mass range 1480-1540 MeV in Fig. 2(b) is in good agreement with a measurement of this ratio over the mass range 1480-1540 MeV using events satisfying the impulse approximation obtained in the present experiment.[6]

Figures 3(a) and 3(c) show the forward-backward and polar-equatorial ratios in the K^-d center-of-mass system for the proton from Reactions (1) and (2) as a function of $Y\pi$ invariant mass. These distributions are qualitatively different from each other for all $Y\pi$ masses except in the vicinity of 1420-1440 MeV where the forward-backward asymmetry goes through zero in both cases. The polar-equatorial ratios also behave similarly in this region. Figures 3(b) and 3(d) show the forward-backward and polar-equa-

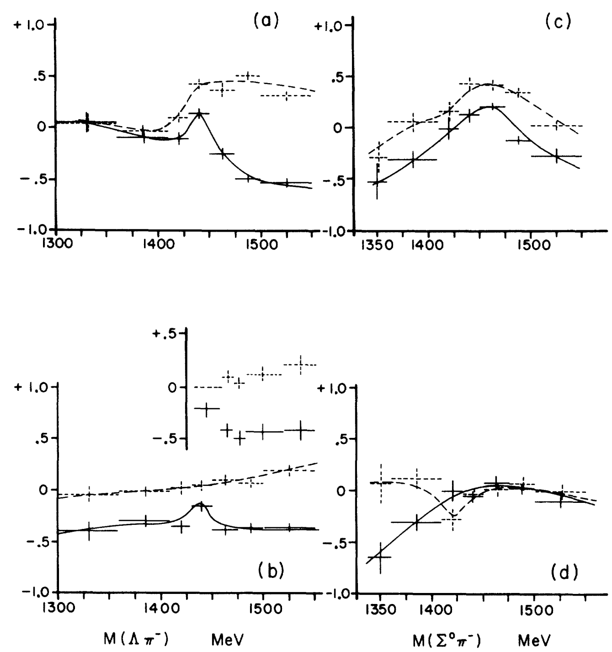

FIG. 3. (a) The solid and dashed curves show the ratios $(F-B)/(F+B)$ and $(P-E)/(P+E)$, respectively, for the proton from Reaction (1) in the K^-d center-of-mass system as a function of the $\Lambda\pi^-$ invariant mass. Forward is defined as a $\cos\theta_{Kp} > 0.0$. (b) The solid and dashed curves show the ratios $(F-B)/(F+B)$ and $(P-E)/(P+E)$, respectively, for the Λ in the $\Lambda\pi^-$ c.m. system. Forward refers to the Λ being emitted in the forward hemisphere with respect to the direction of the $\Lambda\pi^-$ center of mass. The insert shows the ratios $(F-B)/(F+B)$ and $(P-E)/(P+E)$ for the reaction $K_2{}^0p \to \Lambda\pi^+$ reported in Ref. 7. (c) Same as (a) except that the asymmetries are for Reaction (2), $K^-d \to (\Sigma\pi) + p$. (d) Same as (b) except that the asymmetries refer to the $\Sigma^0\pi^-$ system. Forward is defined for the Σ as for the Λ in 2(b).

torial ratios of the hyperon in the $Y\pi$ center-of-mass system as a function of $Y\pi$ mass. Again the asymmetries appear to change considerably in the vicinity of 1430-1440 MeV. It is interesting to note that the forward-backward and polar-equatorial ratios of the hyperon in the $\Lambda\pi$ system [Fig. 3(b)] for masses above $\bar{K}p$ threshold are quantitatively similar as a function of $\Lambda\pi$ mass to the same ratios measured for the reaction

$$K_2{}^0 p \rightarrow \Lambda\pi^+ \qquad (3)$$

as shown in the insert in Fig. 3(b).[7] The striking changes in all of the angular distributions for Reactions (1) and (2) near the $Y\pi$ mass of 1440 as well as the strong peaking in the $\Lambda\pi$ mass spectrum suggest that a single phenomenon is responsible. The tendency of the angular distributions in the $Y\pi$ systems to become more isotropic suggests that either the $S_{1/2}$ or $P_{1/2}$ angular-momentum state dominates the $\Lambda\pi$ system.

The dynamical mechanism responsible for the 1440-MeV $\Lambda\pi$ enhancement is not presently known. However, two possibilities seem apparent: (1) The enhancement is due to an $I=1$ resonance in a low partial-wave channel, and (2) the enhancement arises from a kinematic singularity associated with double scattering in the deuteron (a moving triangle singularity).[8] These two possibilities are not necessarily mutually exclusive since a $\Lambda\pi$ resonance might tend to enhance a kinematic singularity.

The facets of the data that support the resonance interpretation are the following: (1) The qualitative difference between the $\Lambda\pi$ and $\Sigma\pi$ invariant mass spectra near 1440 MeV suggests that the $\Lambda\pi$ enhancement is not simply due to a (1/velocity) dependence of the $\bar{K}N \rightarrow Y\pi$ cross section since in this case both the $\Lambda\pi$ and $\Sigma\pi$ mass spectra should be peaked at 1440 MeV. This is not to say that a $\Sigma\pi$ coupling to the state is excluded, but only that the $\Sigma\pi$ coupling is considerably smaller than the $\Lambda\pi$ coupling. Of course, even with a reduced coupling the angular distributions for the $\Sigma\pi$ channel can be greatly influenced near 1440 MeV. (2) There is a rapid change of the angular distribution, shown in Figs. 3(a) and 3(b) in the vicinity of 1440 MeV, and (3) the peak of the enhancement shown in Fig. 2(a) is not at $\bar{K}p$ threshold but is systematically shifted up by ~10 MeV.

The aspects of the data that support a kinematic interpretation of the enhancement are the following: (1) The enhancement is near $\bar{K}N$ threshold and at some level a cusp is expected in the $\Lambda\pi$ (and also $\Sigma\pi$) mass spectrum due to a triangle singularity caused by the K^- elastically scattering from the proton and being absorbed on the neutron. (2) There is a qualitative similarity between the angular distribution in the $\Lambda\pi$ and $\Sigma\pi$ system for invariant masses above $\bar{K}N$ threshold and the corresponding angular distributions observed for $\bar{K}N \rightarrow Y\pi$. Incidentally, the similarity of these distributions and the ratio of $\Sigma\pi$ to $\Lambda\pi$ cross sections in the $\Sigma(1385)$ mass region suggests that Reactions (1) and (2) are related to $\bar{K}N \rightarrow Y\pi$ scattering with the $\bar{K}N$ system off the mass shell. An appropriate theoretical understanding of the mechanism responsible for these processes might allow the extraction of direct information about off-mass-shell $\bar{K}N$ absorption. In this regard it is interesting to note that the $\Lambda\pi$ invariant-mass spectrum appears to die away suddenly below $\Sigma\pi$ threshold.

If the enhancement is in fact due to a resonance at 1440 MeV, the assumption that all $\Sigma^0\pi^-$ events in the mass range of 1430-1459 MeV are due to the resonance leads to a branching fraction of $(\Sigma^0\pi^-)/(\Lambda\pi^-) = 0.5 \pm 0.1$. The tendency toward isotropic angular distributions near 1440 MeV for both $\Sigma^0\pi^-$ and $\Lambda\pi^-$ suggests that the spin and parity of this state is either $\frac{1}{2}^+$ or $\frac{1}{2}^-$. If the $\frac{1}{2}^+$ alternative is correct, then the narrow width of the state could be a result of the centrifugal barrier repulsion. In this case analyses of K^-p scattering near K^-p threshold would probably be insensitive to the existence of this state.[9]

The interpretation of the 1440 $\Lambda\pi^-$ enhancement as a resonance state is supported in some measure by another experiment in which a possible enhancement in the $I=1$ or 2 state was observed near[10] 1440 MeV and also by speculations about the nature of the $I=1$, K^-p scattering length made recently[11] (the latter would apply for the $S_{1/2}$ assignment of this state).

We thank Mr. E. Shettle and the scanners and measurers for their diligent efforts in this experiment. In addition we thank members of the Alvarez group for helping with the exposure, in particular Dr. J. Murray and Mr. R. Bangarter, and also the staff of the Bevatron and the 25 in. bubble-chamber crew. Finally we also thank Professor R. March and Mr. J. Berryhill for help with the exposure.

---

*Work supported in part by the U. S. Atomic Energy Commission under Contract No. AT(11-1)-881, COO-881-164.

†Alfred P. Sloan Fellow.

[1]J. J. Murray, private communication.

[2]D. Cline, R. Laumann, and J. Mapp, Phys. Rev. Letters 20, 1452 (1968). See this paper for references to previous $K^-d\to\Lambda\pi p$ studies at low momentum.

[3]The origin of the 1490 enhancement appears to be associated with a combination of the impulse approximation restriction on the $\Lambda\pi$ invariant-mass spectrum and the requirement of high-momentum protons in Reaction (1).

[4]A. H. Rosenfeld et al., Rev. Mod. Phys. 39, 1 (1967).

[5]The $\Sigma^0\pi^-$ cross section is obtained from the relation $\sigma(\Sigma^0\pi^-)=\sigma(\Sigma^+\pi^-)+\sigma(\Sigma^-\pi^+)-2\sigma(\Sigma^0\pi^0)$ using the data of J. Kim, Phys. Rev. Letters 14, 29 (1965), and M. B. Watson, M. Ferro-Luzzi, and R. D. Tripp, Phys. Rev. 131, 2248 (1963).

[6]E. Shettle, private communication.

[7]J. Kadyk, Y. Oren, G. Goldhaber, S. Goldhaber, and G. H. Trilling, Phys. Rev. Letters 17, 599 (1966); J Kadyk, private communication.

[8]See, for example, L. D. Landau, Nucl. Phys. 15, 261 (1960); T. S. Shapiro, Interaction of High Energy Particles with Nuclei (Academic Press, Inc., New York, 1967), p. 245.

[9]J. Kim, Phys. Rev. Letters 19, 1079 (1967).

[10]P. Blackall, J. D. Dowell, B. Leontić, G. M. Lewis, A. Lundby, and U. Meyer-Berkhart, Phys. Letters 16, 336 (1965).

[11]J. Uretsky, Phys. Rev. 147, 906 (1966).

EVIDENCE FOR THE FACTORIZABILITY OF THE POMERANCHUK SINGULARITY*

Peter G. O. Freund
Enrico Fermi Institute and Department of Physics, The University of Chicago, Chicago, Illinois
(Received 26 August 1968)

High-energy elastic scattering and diffraction-dissociation data are shown to provide evidence for the factorizability (within 25 %) of the Pomeranchuk singularity.

In the early days of Regge theory, it has been assumed that diffraction scattering is dominated by a Regge pole in the t channel with the quantum numbers of the vacuum: the Pomeranchuk pole. Meanwhile strong doubts on the validity of this assumption were cast by the work of Gribov and Pomeranchuk, Mandelstam and others.[1] It was suggested that it is not a pole but a much more complicated singularity that drives diffraction scattering. Experimentally also this Pomeranchuk singularity seems to be qualitatively different from the usual Regge poles (f,ρ,A_2, etc.) by its flatness and its rapidly varying "residuum" function.[2] The major question is how to extract in a convincing manner the nature of the Pomeranchuk singularity from experiment. Diffraction scattering data, in spite of their remarkable accuracy,[3] are not yet at the stage when powers of $\ln s, \ln\ln s, \cdots$, can be disentangled from the scattering amplitude. However, precisely such factors distinguish a pole from other types of singularities. On the other hand, a pole (whether moving or fixed) in the complex l plane has a very important property. It yields a factorizable contribution to the high-energy scattering amplitude. Thus, establishing whether the Pomeranchuk singularity factorizes or not could bring us one step closer to unraveling its nature. If it does not factorize, it cannot be a pole. If it does factorize then it could, though need not, be a pole.

The standard test[4] of Pomeranchukon factorization is the total-cross-section relation

$$\sigma_{\pi N}^{2}=\sigma_{\pi\pi}\sigma_{NN}. \tag{1}$$

Unfortunately the right-hand side of this relation (because of the factor $\sigma_{\pi\pi}$) is not measurable at high energies with present techniques. So, at a practical level (1) is not useful. Instead we propose a different test. Consider the reactions

$$pp\to pN^{*+}, \tag{2a}$$

$$\pi^\pm p\to\pi^\pm N^{*+}, \tag{2b}$$

where N^{*+} is a baryon or a baryonic resonance with quantum numbers such that the Pomeranchukon can contribute to the Reactions (2a) and (2b). Three such isospin-$\frac{1}{2}$ particles are the proton $N_{1/2}(940)$ itself, the Roper resonance $N_{1/2^+}^*(1400)$, and the $N_{5/2^+}^*(1688)$. For each of these particles there is evidence that the Reactions (2a) and (2b) are Pomeranchukon dominated. Indeed, the total reaction cross sections are in each case nearly constant. The departures from constancy [apart from possible, but over the explored energy range irrelevant, $(\ln s)^\lambda$-type factors] are presumably due to lower Regge trajectories (f,ρ, etc). Without committing an error in excess of 25 % one can describe these processes as purely Pomeranchukon dominated. If the Pomeranchuk-