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# 2130-MeV $\Lambda^0 p$ Mass Enhancement in the Reaction $K^- d \to \Lambda^0 p \pi^-$ at 1.45 and 1.65 GeV/$c$

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An enhancement in the $\Lambda^0 p$ mass spectrum from the reaction $K^- d \to \Lambda^0 p \pi^-$ at $K^-$ momenta of 1.45 and 1.65 GeV/$c$ is reported. The peak of the distribution occurs at $\simeq$2129 MeV and the width at half-height is $\simeq$10 MeV. A possible interpretation of this effect is given.

## I. INTRODUCTION

Several groups[1-3] have reported an enhancement in the $\Lambda p$ mass distribution around 2130 MeV from a study of the reaction

$$K^- d \to \Lambda p \pi^- \tag{1}$$

in a deuterium bubble chamber. Cline *et al.*[1] observed this effect by using $K^-$ at momentum 400 MeV/$c$. The position of the peak in the $\Lambda p$ mass distribution was 2126 MeV, and the width was less than 10 MeV. Subsequently, Alexander *et al.*[2] reported the effect by using $K^-$ at momenta 910, 1007, and 1106 MeV/$c$, but the peak in this case appears to be at $\simeq$2129 MeV, and the width is $\simeq$10 MeV. More recently, Tan[3] studied reaction (1) with stopping $K^-$ and observed the enhancement, with the peak at $\simeq$2129 MeV and the width $\simeq$7 MeV. Although in all these experiments the enhancement is statistically significant, it is not yet clear whether this constitutes evidence for the existence of a $\Lambda p$ resonance, or whether the enhancement could arise from a kinematical effect involving an intermediate $\Sigma$ hyperon, i.e.,

$$K^- d \to \pi^-(\Sigma N) \searrow \Lambda p. \tag{2}$$

Detailed reviews of the observations and their interpretation were presented at the 1969 hypernuclei conference.[4]

In the present paper we report the observation of this enhancement in a study of reaction (1) at $K^-$

momenta of 1.45 and 1.65 GeV/$c$.

## II. EXPERIMENTAL PROCEDURE AND RESULTS

The Saclay 80-cm bubble chamber, filled with liquid deuterium, was exposed to a separated $K^-$ beam at two momenta, 1.45 and 1.65 GeV/$c$, from the NIMROD accelerator at RHEL. Since we observe no significant differences between the two exposures for the phenomenon discussed here, in the following the data of both exposures have been combined. The details of scanning, measuring, kinematical fitting, and the resolution of any ambiguities due to $K^-d \to \Sigma^0 p\pi^-$ events have been given in a previous publication.[5]

A total of 4032 events were assigned to reaction (1). The $\Lambda p$ invariant-mass distribution for these events is shown in Fig. 1, where the enhancement in the region of 2130 MeV is clearly visible. We then select those events in which the proton can be considered as "nonspectator," i. e., events in which an interaction has probably taken place involving both nucleons of the deuteron.[12] For this we applied a lower cutoff on the proton momentum at 170 MeV/$c$, hence excluding most of the genuine "spectator" events (~90%), the latter having a Hulthén momentum distribution. The effect of this proton momentum cutoff on the $\Lambda p$ mass spectrum is shown in Fig. 2. We also find that the $\Lambda p$ enhancement is correlated with small angles $\theta^*(K\pi)$ of the $\pi^-$ with respect to the incident $K^-$ direction in the $K^-d$ center-of-mass system. If we apply the cutoff $\cos\theta^*(K\pi) \geq 0.9$ to the sample of Fig. 2, we are left with 217 events, for which

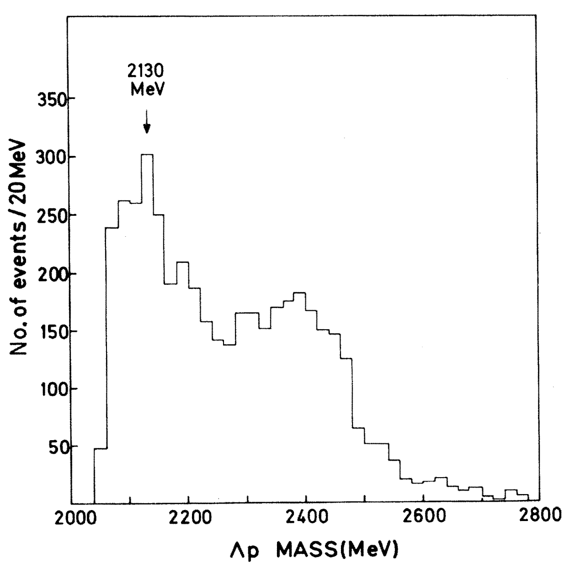


FIG. 1. $\Lambda p$ invariant-mass distribution for all events.

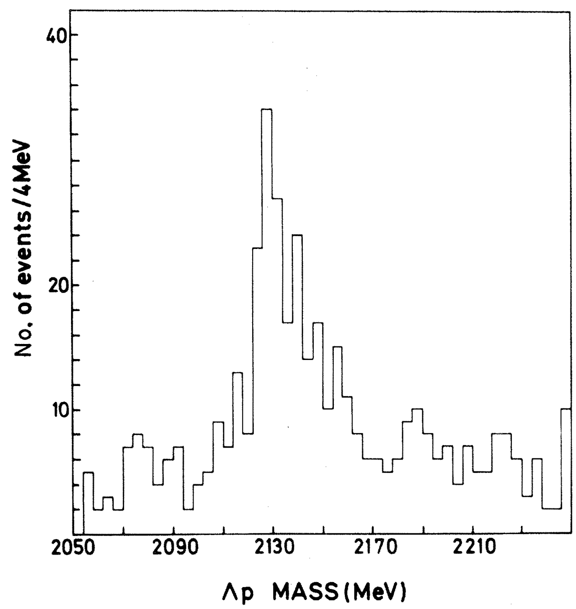


FIG. 2. $\Lambda p$ invariant-mass distribution for events with spectator proton momentum $\geq 170$ MeV/$c$.

the $\Lambda p$ mass spectrum is shown in Fig. 3.

From a close examination of the data shown in Figs. 1–3, we find that the cuts mentioned above select almost all the events contributing to the enhancement while including only a small amount

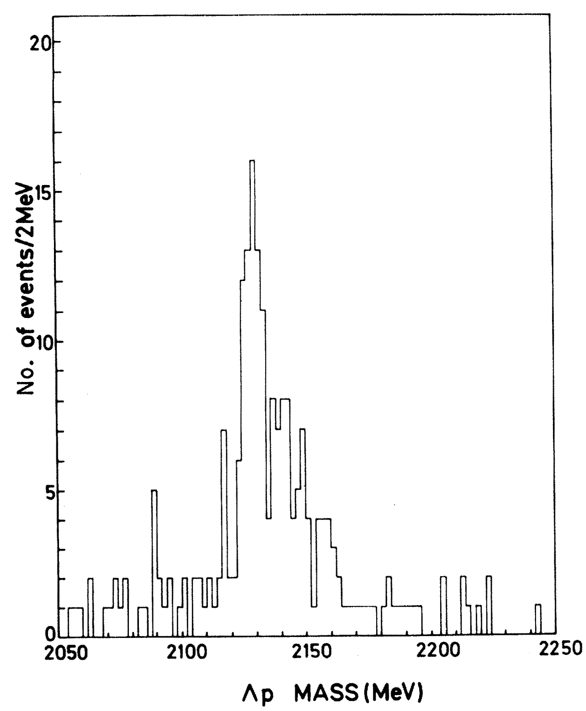


FIG. 3. $\Lambda p$ invariant-mass distribution for events with the cutoffs (i) spectator proton momentum $\geq 170$ MeV/$c$ and (ii) $\cos\theta^*(K\pi) \leq 0.9$.

of "background". The range $\cos\theta^*(K\pi) \geq 0.9$ in our experiment corresponds to about the same $K$-$\pi$ four-momentum-transfer range as the selection $\cos\theta^*(K\pi) \geq 0.8$ made in Ref. 2. We have tried alternative selections of the proton momentum and pion angles, but find that the position and shape of the $\Lambda p$ enhancement does not change significantly. It is also unaffected by the removal of events with a $\Lambda\pi^-$ mass corresponding to $Y_1^*(2030)$.

In examining Fig. 3, we find that the peak of the enhancement occurs at 2129 MeV. The width at half-height is about 10 MeV, but the distribution is skew in shape, having a long tail for high values for the $\Lambda p$ mass. The average mass resolution for events in the peak is about ±3 MeV, as given by our kinematic fitting program. The systematic error in the $\Lambda p$ mass is $\lesssim 0.1$ MeV, as found from the "pulls" in kinematic fitting and the unfitted masses of $\Lambda$'s and $K$'s. The number of events in the enhancement is estimated to be 180, which corresponds to a yield of 39 $\mu$b after applying the cutoffs mentioned above. In Fig. 4 we display the forward-backward ratios of the $\Lambda$ in the $\Lambda p$ center-of-mass system for the data of Fig. 3 plotted as a function of the $\Lambda p$ mass. The effect appears to be compatible with that found in Refs. 1–3.

## III. CONCLUSION AND DISCUSSION

An attempt to understand the $\Lambda p$ mass enhancement with the aid of a final-state hyperon-nucleon interaction model, as schematically represented by the "triangle diagram" in Fig. 5, has been made in Refs. 1 and 3. On the basis of their observed enhancement in the $\Lambda p$ mass spectrum at 2126 MeV, which is below $\Sigma^+ n$ threshold (2129 MeV), Cline *et al.*[1] claimed the existence of a bound state in the $\Sigma^+ n$ system and hence an elastic resonance in the $\Lambda p$ system. No definite claim of such a resonance was made by Tan[3] where the peak is observed at $2128.7 \pm 0.2$ MeV, very close to $\Sigma^+ n$ threshold. Tan concluded that the effect of a possible resonance lying close to the $\Sigma^+ n$ threshold cannot be resolved from a threshold cusp effect, at least until the difficulties of calculation of the "triangle diagram" had been rigorously overcome.

Alexander *et al.*[2] made an attempt to explain the $\Lambda p$ enhancement as a kinematical effect by using Monte Carlo calculations of the two-step process (2). The Fermi momentum of the nucleons in the deuteron was taken into account through the Hulthén wave function. The angular distribution of the emerging $\Sigma\pi$ pair was taken from the available data on $K^- N \to \Sigma\pi$ reactions, the intermediate $\Sigma$ hyperon being assumed to be on the mass shell. With these assumptions Alexander *et al.* fitted the observations at 400 MeV/$c$ (Cline *et al.*) and ~1100 MeV/$c$ (their own), although the calculated peak is somewhat too broad at the higher energy. They conclude that kinematic factors and the dynamics of the first step are sufficient to explain the enhancement, and that the $\Sigma N \to \Lambda p$ matrix element need not have the rapid variation with energy characteristic of a resonance.

Alexander[6] has kindly provided us with his calculations of the two-step process (2) for our data of Fig. 3. These calculations predict the position of the $\Lambda p$ mass peak at 2139 MeV with a width of 25–30 MeV. These are clearly inconsistent with the values of the peak position, $\simeq 2129$ MeV, and

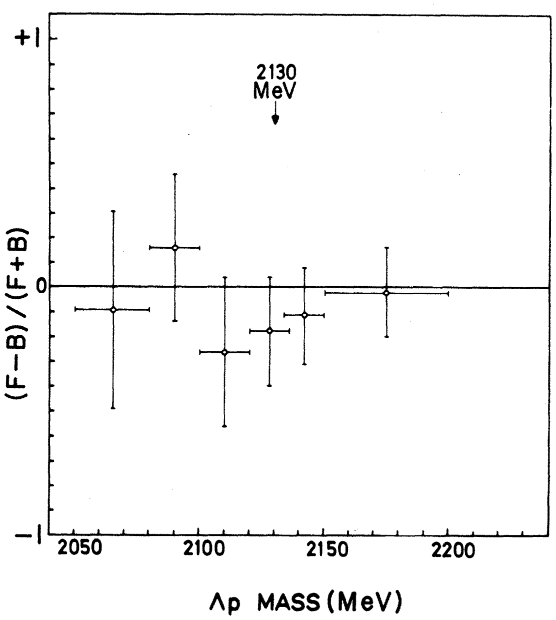


FIG. 4. Forward-backward ratios for the $\Lambda$ in the $\Lambda p$ center-of-mass system as a function of $\Lambda p$ mass for the data of Fig. 3. (Backwards is defined to be the $\pi^-$ direction in the $\Lambda p$ center-of-mass system.)

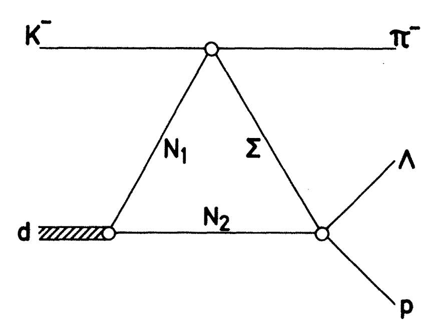


FIG. 5. The "triangle diagram" representing the process

$$K^- d \to \pi^-(\Sigma N) \searrow \Lambda p.$$

of the width, $\simeq 10$ MeV, as found in our data. It is quite possible that a more rigorous, relativistic calculation of the two-step process, which incorporates the off-mass-shell effects properly, would move the kinematical peak to lower energies, to fit our observed enhancement.

On the other hand, in view of the position of the peak and asymmetry of our mass distribution, we cannot invoke a simple resonance model, as has been done by Cline *et al.*[1] It may, however, be seen from Fig. 3 that a possible interpretation of our data is in terms of a resonance having mass $= 2125-2129$ MeV and width $\approx 10$ MeV, together with a kinematical enhancement of the type calculated by Alexander having a peak at 2139 MeV with width 25–30 MeV.

A more direct search for a $\Lambda p$ resonance should be possible in experiments on $\Lambda p$ scattering. This has so far proved to be inconclusive[4] because of the poor statistics involved.

We are indebted to the operating crews of the NIMROD and the Saclay bubble chamber, and to the scanning and measuring teams in our laboratories for their diligent efforts.

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# Production of $B(1235)$ and $\rho$ (1710) $4\pi$ Enhancements in 16-GeV/$c$ $\pi^{\pm}p$ Collisions*

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Production of $B(1235)$ and $\rho(1710)$ mesons is observed in the four-pion decay modes $\pi^{\pm}\pi^{+}\pi^{-}\pi^{0}$ in 16-GeV/$c$ $\pi^{\pm}p$ collisions. Decay distributions and branching fractions into various modes are presented. Absence of the two-pion mode $\pi^{-}\pi^{0}$ for the $\rho(1710)$ is noted.

We report on data from two exposures in the Brookhaven National Laboratory 80-in. hydrogen bubble chamber. Both used an incident beam momentum of 16 GeV/$c$. In the first exposure 60000 pictures were taken in a negative (unseparated) pion beam and subsequently all two- and four-prong events were measured. The second exposure of 50000 pictures used an rf-separated $\pi^{+}$ beam, and all four prongs were measured.

From the two-prong data we obtained a sample of 446 events constraining to the reaction

$$\pi^{-}p \to p\pi^{-}\pi^{0}. \tag{1}$$

Selection of these events was similar to that described in Ref. 1: All events with a four-constraint (4c) fit were removed from the sample, and missing-mass and confidence-level cuts were applied to the remaining fits to separate the final states $\pi^{+}\pi^{-}n$, $p\bar{p}n$, $K^{+}K^{-}n$ from reaction (1). The reaction cross section was measured by two methods as described in Ref. 1, one where the normalization was set by the measured two-prong topological cross section and the other normalizing to the elastic 4c events corrected for losses at low $t$ by comparison with the published elastic scattering data.[2] The result for reaction (1) is $0.43 \pm 0.08$ mb, as shown in Table I.

The four-prong events were treated in a similar manner. After removal of the 4c events, only fits with greater than 1% confidence were considered, the missing mass squared was chosen in the interval $\pm 0.11$ GeV$^2$ about the $\pi^0$ mass and finally the error on the missing mass squared was required to be less than 0.18 GeV$^2$. We found 1192 events pass-