Lawrence Berkeley National Laboratory

Recent Work

Title

STUDY OF THE ENHANCEMENT IN THE A p INVARIANT MASS NEAR THE E N THRESHOLD IN K- d u> Apn- INTERACTIONS AROUND 1.0 GeV/c

Permalink

https://escholarship.org/uc/item/31g7v7tf

Authors

Alexander, Gideon
Hall, Bronwyn H.
Jew, Nathan
et al.

Publication Date

1969

eScholarship.org Powered by the California Digital Library
University of California

UCRL-18695

cy. 2

STUDY OF THE ENHANCEMENT IN THE Λp INVARIANT MASS NEAR THE ΣN THRESHOLD IN $K^-d \to \Lambda p \pi^-$ INTERACTIONS AROUND 1.0 GeV/c

Gideon Alexander, Bronwyn H. Hall, Nathan Jew
George Kalmus, and Anne Kernan

January 1969

TWO-WEEK LOAN COPY

This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 5545

LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

UCRL-18695

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Submitted to Phys. Rev. Letters

UCRL-18695
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

STUDY OF THE ENHANCEMENT IN THE Λp INVARIANT MASS NEAR THE ΣN THRESHOLD IN $K^- d \rightarrow \Lambda p \pi^-$ INTERACTIONS AROUND 1.0 GeV/c

Gideon Alexander, Bronwyn H. Hall, Nathan Jew,
George Kalmus, and Anne Kernan

January 1969

UCRL-18695

STUDY OF THE ENHANCEMENT IN THE Λp INVARIANT MASS NEAR THE ΣN THRESHOLD IN $K^-d \to \Lambda p\pi^-$ INTERACTIONS AROUND 1.0 GeV/c*

Gideon Alexander, Bronwyn H. Hall, Nathan Jew, and George Kalmus

Department of Physics and Lawrence Radiation Laboratory
University of California, Berkeley, California

and

Anne Kernan

Department of Physics, University of California
Riverside, California

January 1969

Data are presented for the reaction $K^-d \to \Lambda\pi^-p$ at 910, 1007 and 1106 MeV/c in which the proton momentum is greater than 250 MeV/c. The Λp invariant-mass plot shows an enhancement at about 2130 MeV, similar to that found by Cline et al. No enhancement is seen at about 1440 MeV in the Λπ invariant mass. A simple two-step process without invoking resonances describes our data as well as those of Cline et al.

In the absence of readily available hyperon beams, the study of the hyperon-proton (Y-p) system in final-state interactions may be useful in the search for strangeness -1, dibaryon resonant states. Several possible Λp resonances have been reported in the past; however, none has been substantiated by further investigations.[1] Recently Cline, Laumann, and Mapp have observed an enhancement in the Λp invariant-mass distribution in a study of K^-d

interactions at 400 MeV/c leading to the final state $\Lambda p\pi^-$ with a fast proton.[2] This enhancement, which was centered a few MeV below the ΣN threshold, suggested to them the existence of a $(\Sigma N)_{1/2}$ bound state coupled to the open Λp channel, which in turn implies an elastic Λp resonance with a mass of 2126 MeV and a width of less than 10 MeV. Cline et al. also observed in the same reaction a strong enhancement in the $\Lambda\pi^-$ system at 1440 MeV.[3]

In this letter we present data on the reaction

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

around 1 GeV/c, in which the proton has a momentum greater than 250 MeV/c. We also discuss a simple model which can explain our data and those of Refs. 2 and 3 without invoking any resonances.

The experiment used pictures taken in the Lawrence Radiation Laboratory 25-inch bubble chamber filled with deuterium and exposed to a K^- beam at momenta of 910 MeV/c (54×10^3 pictures), 1007 MeV/c (12×10^3 pictures), and 1106 MeV/c (86×10^3 pictures). The film was scanned for two-prong events plus an associated V^o. The positive prong had to have a range greater than 5 cm in space (corresponding to a minimum proton momentum 225 MeV/c) and ionization consistent with a proton. The events were then measured and kinematically fitted to the various possible final states involving K^o, Λ, or Σ^o. No difficulty was found in separating the Λ or Σ^o from the K^o. A lower cutoff momentum of 250 MeV/c was imposed on the proton in the final state $\Lambda^o(\Sigma^o)p\pi^-$ in order to obtain a sample of events in which both nucleons in the deuteron were involved in the interaction. From a previous study of the reaction $K^-d \rightarrow \Lambda\pi^-p_s$ (spectator), we estimate that the background from this reaction in our study is 20%.[4] The proton momentum cut in the data of Cline et al. was 150 MeV/c.[5]

A total of 324 events fitted the $\Lambda p\pi^-$ hypothesis, 421 events fitted the $\Sigma^o p\pi^-$ hypothesis, and an additional 367 events were ambiguous between the two hypotheses. The ambiguous events were fitted to the hypothesis $K^-d \rightarrow \Lambda\gamma p\pi^-$. The $\Lambda\gamma$ invariant mass distribution had two peaks, one near the Λ mass and the other near the Σ^o mass. We accepted the 241 events in the lower-mass peak as $K^-d \rightarrow \Lambda p\pi^-$, the cut being $M(\Lambda\gamma) < 1165$ MeV. These 241 events together with the 324 unambiguous ones constituted our sample of 565 $\Lambda p\pi^-$ events. In the following analysis we have combined the data at the three incident K^- momenta. We discuss first the Λp invariant-mass distribution, and later the $\Lambda\pi^-$ system.

Figure 1a,d shows the Λp mass plots for our data and, for comparison, those of Ref. 2, the shaded events having $\cos(\theta_{K^-\pi^-}) > 0.8$, where $\theta_{K^-\pi^-}$ is the angle between the K^- and π^- in the K^-d c.m. system. This cut was applied by Cline et al., and is discussed later. Figure 1b and e and 1c and f show the ratios (F-B)/(F+B) and (P-E)/(P+E) respectively for the events in the shaded portion of histogram 1a,d; F and B refer to the number of forward and backward Λ's in the Λp rest system and P and E refer to the number of events having $|\cos(\theta_\Lambda)| > 0.5$ and $|\cos(\theta_\Lambda)| < 0.5$, respectively, where θ_Λ is the angle in the Λp c.m. system between the Λ and the line of flight of the Λp system.

Figure 1a shows a small enhancement in the shaded histogram around 2130 MeV close to the ΣN threshold. [The mass resolution at $M(\Lambda p) \approx 2130$ MeV was found to be ≈ 3 MeV.] Figures 1b and 1c show that, at the enhancement, the angular distribution is consistent with isotropy, while below it a deviation from isotropy is indicated. The enhancement in the Λp mass plot as well as the angular distributions at this enhancement are very similar to those reported in Ref. 2 and shown in Fig. 1d,e,f; however, the peak in the mass plot for the

1100-MeV/c data appears to be less pronounced than that for 400 MeV/c.

In view of our results and those at 400 MeV/c incident momentum, it is of interest to investigate the extent to which one is compelled to introduce the existence of a Λp resonance.[6] To this end we have calculated the Λp invariant mass distribution in the framework of a simple two-step process without invoking any YN resonances.[7]

The two-step processes considered were

$$\begin{aligned} &(a)\quad K^- d \to \Sigma^+ \pi^- (n_s) && (b)\quad \Sigma^+ n_s \to \Lambda p && (2)\\ &\qquad\quad \to \Sigma^0 \pi^- (p_s) && \qquad\quad \Sigma^0 p_s \to \Lambda p && (3)\\ &\qquad\quad \to \Lambda \pi^- (p_s) && \qquad\quad \Lambda p_s \to \Lambda p && (4)\\ &\qquad\quad \to K^- p (n_s)\ , && \qquad\quad K^- n_s \to \Lambda \pi^-\ . && (5) \end{aligned}$$

We have also considered the process

$$K^- d \to \Lambda \pi^- p_s\ , \qquad (6)$$

where the momentum of the spectator proton is in the tail of the Fermi momentum distribution; these events contribute mainly below ΣN threshold.

In order to calculate the $M(\Lambda p)$ distribution from reactions (2), (3), and (4) [reactions (5) and (6) do not contribute to a peak in $M(\Lambda p)$], we have assumed that they can each be approximately described by two successive, well separated reactions $KN \to Y\pi$ and then $YN \to \Lambda p$. This simple approach is expected to describe the processes at least qualitatively, since the deuteron is a rather loosely bound system.

The calculations have been carried out by generating individual events by a Monte Carlo method according to the two-stage reactions described above for K^- incident momenta of 400 and 1100 MeV/c, where the bulk of the present data came from.

In the first stage we have calculated the reaction $K^-N \rightarrow Y\pi$ in the framework of the impulse model, taking into account the momentum distribution of the nucleon as given by the Hulthén wave function and using an isotropic angular distribution of the nucleons in the deuteron c.m. system. The angular distribution of the emerging hyperons was taken from known $KN \rightarrow Y\pi$ single nucleon interaction data at 400 and 1100 MeV/c.[4,8,9]

The second stage involves calculation of the relative probability for the hyperon to have a subsequent interaction with the spectator nucleon. In calculating this probability we have assumed an s-wave energy-independent matrix element for the reaction $YN \rightarrow \Lambda p$. Taking into account the phase space and flux factors, the cross section is given by the expression[10]

$$\sigma(YN \rightarrow \Lambda p) \propto \frac{\epsilon_Y \epsilon_N \epsilon_\Lambda \epsilon_p}{M^2(\Lambda p)} \cdot \frac{P_f}{P_i} \qquad (7)$$

where ϵ_Y, ϵ_N, ϵ_Λ, and ϵ_p are the energies of the corresponding particles and P_f and P_i are the final and initial momenta in the YN c.m. system.

This expression is in agreement with experimental data on low energy hyperon-nucleon scattering.[1] We are justified in using it here, since the experimental cut of $\cos(\theta_{K^-\pi^-}) > 0.8$ restricts the momentum of the hyperon to $\leq$ 250 MeV/c and $\leq$ 500 MeV/c at K^- momentum of 400 MeV/c and 1.1 GeV/c respectively.

The probability for the (b) reactions to occur also depends on the spatial configuration of the deuteron and, therefore, on the Fermi momentum. So in general the cross section in Eq. (7) should be weighted by some function $G(P_F)$ of the Fermi momentum. However, by performing the calculations at a series of unique nucleon momenta, we have verified that the shape of the Monte Carlo

mass distribution is essentially independent of the nucleon momentum. This independence comes about because $P_Y > P_F$, and hence P_i in Eq. (7) is not strongly correlated with P_F. Since we are interested in shape rather than absolute cross section for various final-state configurations, we can ignore the $G(P_F)$ factor.

It is clear that any calculation, in which all the particles in the reaction $\Sigma N \rightarrow \Lambda p$ (2nd stage) are on the mass shell, cannot generate a Λp mass below ΣN threshold. However, since neither the Σ nor the N need be on the mass shell, this reaction can lead to a Λp mass below ΣN threshold. In order to estimate the effect with the mass of the nucleon off the mass shell we constrained the total energy of the nucleons to be the mass of the deuteron, letting the masses of the two nucleons go off the mass shell in equal amounts, i.e.,

$$M_N = \left[\frac{M_D^2}{4} - P_F^2 \right]^{1/2},$$

where P_F is the Fermi momentum and M_D is the mass of the deuteron. The other particles were taken as being on the mass shell.

The results of these calculations show that the width of the peak in the Λp mass plot remains essentially unchanged, but its position shifts towards lower masses by a few MeV when the nucleons are off the mass shell. We have introduced into these calculations the same cutoffs on the momentum of the proton as were used in the experimental data, i.e., 150 MeV/c and 250 MeV/c for incident K^- momenta of 400 and 1100 MeV/c respectively.

The Monte Carlo distributions are shown in Fig. 2 (solid curves); the dashed curves are the distributions obtained with the cut of $\cos(\theta_{K^-\pi^-}) > 0.8$.

This cut was introduced by Cline et al. to enhance the $^3S_1$ state (same as deuteron state) over the $^1S_0$ state for the intermediate $\Sigma^+ n$ system.

As seen in Fig. 2, reactions (2) and (3) generate peaks in the Λp mass at K^- momentum 400 and 1100 MeV/c. The position and width of the peak from reaction (2) at P_K = 400 MeV/c correspond closely to those observed. At P_K = 1100 MeV/c, the generated peak is at the observed position but is somewhat wider than that observed. The occurrence of the peak can be readily understood as arising from a combination of two factors: (1) strong production of low energy Σ's in reactions (2a) and (3a) (enhanced by the cut of $\cos(\theta_{K\pi}) > 0.8$), and (2) the approximate $1/P_i$ dependence of the cross section for the exothermic reactions (2b), (3b), and (5b) at low energy.

A suitable combination of reactions (2), (3), and (4) can describe the whole Λp mass plot at 400 MeV/c and 1100 MeV/c, except for the higher end of the mass distribution at 1100 MeV/c, which could be due to other two-step reactions such as $K^- d \rightarrow \Lambda \pi^- p_s$ with subsequent πp_s elastic scattering.

In the framework of this model one expects an isotropic Λ angular distribution at the ΣN threshold. Above threshold, without further assumption on the relative magnitudes of the various reactions, we are unable to calculate the angular distributions. However, it is interesting to note that the Λ angular distribution below ΣN threshold is approximately described by the one-step process $K^- d \rightarrow \Lambda \pi^- (p_s)$ (curves on Fig. 1b and c), where the spectator proton momentum is greater than the cutoff value.

Next we consider the $\Lambda\pi$ invariant mass distribution, shown on Fig. 3a for events lying outside the Λp peak [2120 < M(Λp) < 2140 MeV] and for $\cos(\theta_{K^-p}) > 0.5$ (shaded portion), where θ_{K^-p} is the angle between the K^- and proton in the c.m. system of $K^- d$. The data from Ref. 3 at 400 MeV/c is shown

in Fig. 3c. There is no significant enhancement at 1440 MeV in our data.

Figure 3b,d shows the $\Lambda\pi^-$ mass distribution calculated for the two-step process (5). The calculation was done using the Monte Carlo method with the assumptions outlined earlier. The experimental data on K^-p elastic scattering were used in the first step,[8,11] and for reaction (5b) we again assumed that the matrix element was s-wave and energy-independent. Reaction (5) is seen to give rise to a peak around 1440 MeV/c for incident momentum of 400 MeV/c, but not for 1100 MeV/c. Again, the peak in the 400-MeV/c data can be understood in terms of strong production of low momentum K^- in reaction (5a), followed by the exothermic reaction (5b) at low energy. In K^-p elastic scattering at 1100 MeV/c the K^- is scattered predominantly with low momentum transfer, and so the K^-n system is not formed close to threshold energy in reaction (5b).[11]

Since our calculations show that the present data can be explained satisfactorily without the need for either a Σn bound state or a $\Lambda\pi$ resonance, other reactions that are sensitive to these effects should be examined. In looking for YN resonance below Σn threshold two reactions may be studied: (a) free Λp scattering; the rather meager data available at the ΣN threshold ($p_\Lambda \approx 635$ MeV) shows no peak; and (b) free Σp scattering; again the data are very meager and do not allow one to measure the scattering length.

FOOTNOTES AND REFERENCES

*Work supported by the U. S. Atomic Energy Commission.

1. See, for example, the review by G. Alexander and U. Karshon in High Energy Physics and Nuclear Structure, ed. G. Alexander (North Holland, 1967), p. 36, and references therein.

2. D. Cline, R. Laumann, and J. Mapp, Phys. Rev. Letters 20, 1452 (1968).

3. D. Cline, R. Laumann, and J. Mapp, Phys. Rev. Letters 21, 1372 (1968).

4. W. M. Smart, Lawrence Radiation Laboratory Report UCRL-17712, Aug. 1967 (unpublished).

5. D. Cline (University of Wisconsin), private communication, Dec. 1968.

6. I. R. Kenyon, A. E. Sichirollo, C. R. Sun, Phys. Rev. 165, 1445 (1968). These authors also observed a peak in the Λp system below Σn threshold in the reaction $K^- He^4 \rightarrow pd\Lambda^0\pi^-$, but did not ascribe it to a Σn bound state.

7. Cline et al. in their papers (Refs. 2,3) mentioned the possibility that peaks could occur in the mass plots due to kinematic effects of the type we discuss here, but no quantitative calculations were presented.

8. M. B. Watson, M. Ferro-Luzzi, and R. D. Tripp, Phys. Rev. 131, 2248 (1963).

9. R. B. Bell, Phys. Rev. Letters 19, 936 (1967).

10. See, for example, W. S. C. Williams, An Introduction to Elementary Particles (Academic Press, 1961), p. 93, from which we obtain this expression for the cross section by noting that $(\epsilon_Y + \epsilon_N) = (\epsilon_\Lambda + \epsilon_p) = M(\Lambda p)$.

11. R. Armenteros, P. Baillon, C. Brieman, M. Ferro-Luzzi, D. E. Plane, N. Schmitz, E. Burkhardt, H. Filthuth, E. Kluge, H. Oberlack, R. R. Ross, R. Barloutaud, P. Granet, J. Meyer, J. P. Porte, and J. Prevost, Nuclear Physics B8, 195 (1968).

FIGURE CAPTIONS

Fig. 1. Λp invariant mass and Λ angular distributions for the reaction $K^- d \rightarrow \Lambda p \pi^-$. (a,d) $M(\Lambda p)$ distributions of our data and of the data given in Ref. 2. (b,c) $(F-B)/(F+B)$ as a function of $M(\Lambda p)$. (c,f) $(P-E)/(P+E)$ as a function of $M(\Lambda p)$. Dashed curves represent the expected distribution from the one-step process $K^- d \rightarrow \Lambda \pi^- (p_s)$.

Fig. 2. Calculated $M(\Lambda p)$ distributions for incident K^- momenta of 1100 and 400 MeV/c of the reactions (2), (3), (4), and (6). The dashed curves represent the calculated distributions with $\cos(\theta_{K^-\pi^-}) > 0.8$.

Fig. 3. Experimental and calculated $M(\Lambda\pi)$ distributions of our data and of the data given in Ref. 2. (a,c) Experimental $M(\Lambda\pi)$; shaded area corresponds to events with $\cos(\theta_{K^-p}) > 0.5$. (b,d) Calculated $M(\Lambda\pi)$ distributions from the two-step process (5); dashed curves represent the calculated distributions with $\cos(\theta_{K^-p}) > 0.5$.

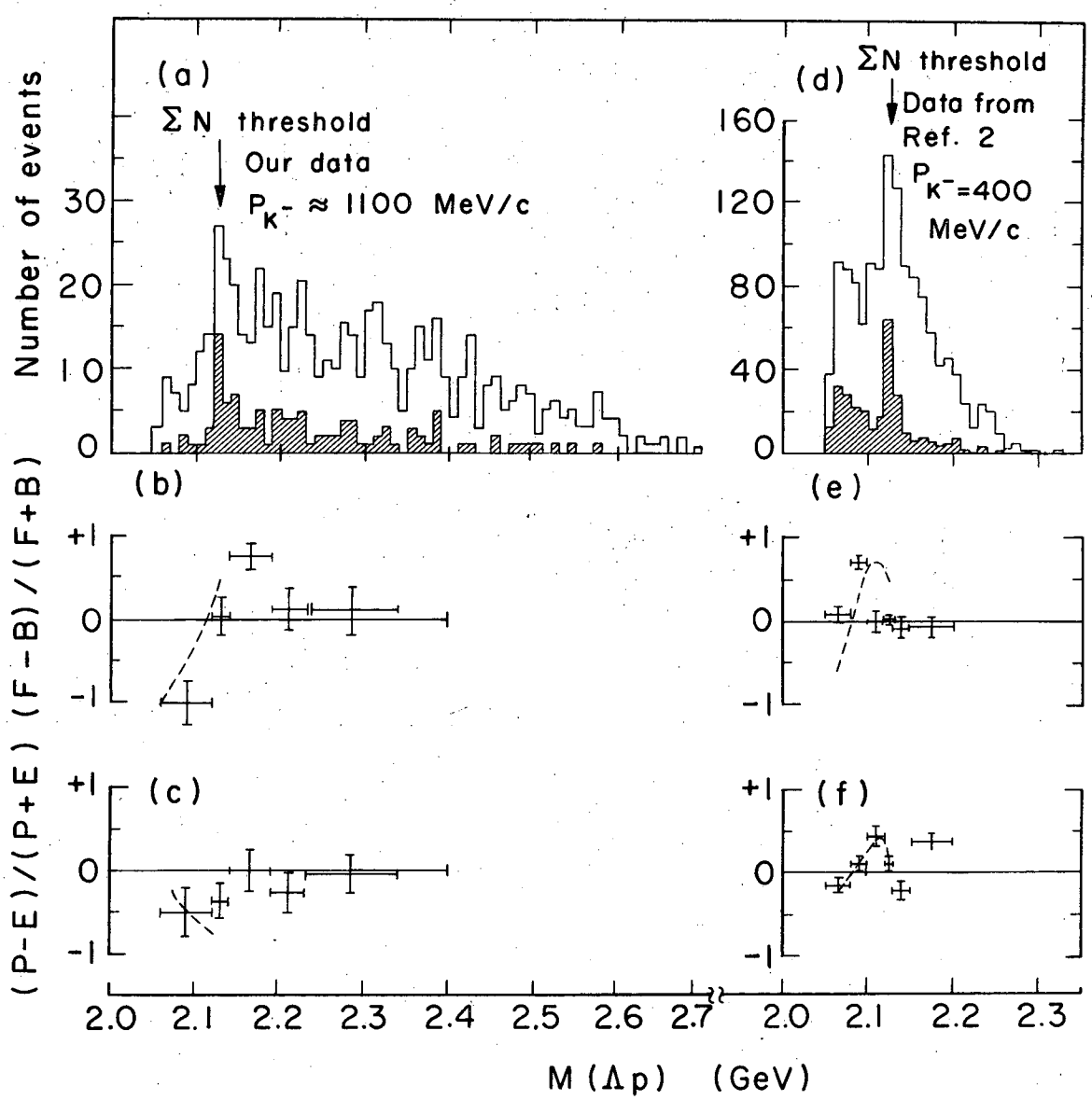
(a)
ΣN threshold
Our data
$P_{K^-} \approx 1100$ MeV/c
(d)
ΣN threshold
Data from Ref. 2
P_{K^-}=400 MeV/c
Number of events
(b)
(e)
(c)
(f)
(F-B)/(F+B)
(P-E)/(P+E)
M(Λp) (GeV)
XBL691-1683

Fig. 1

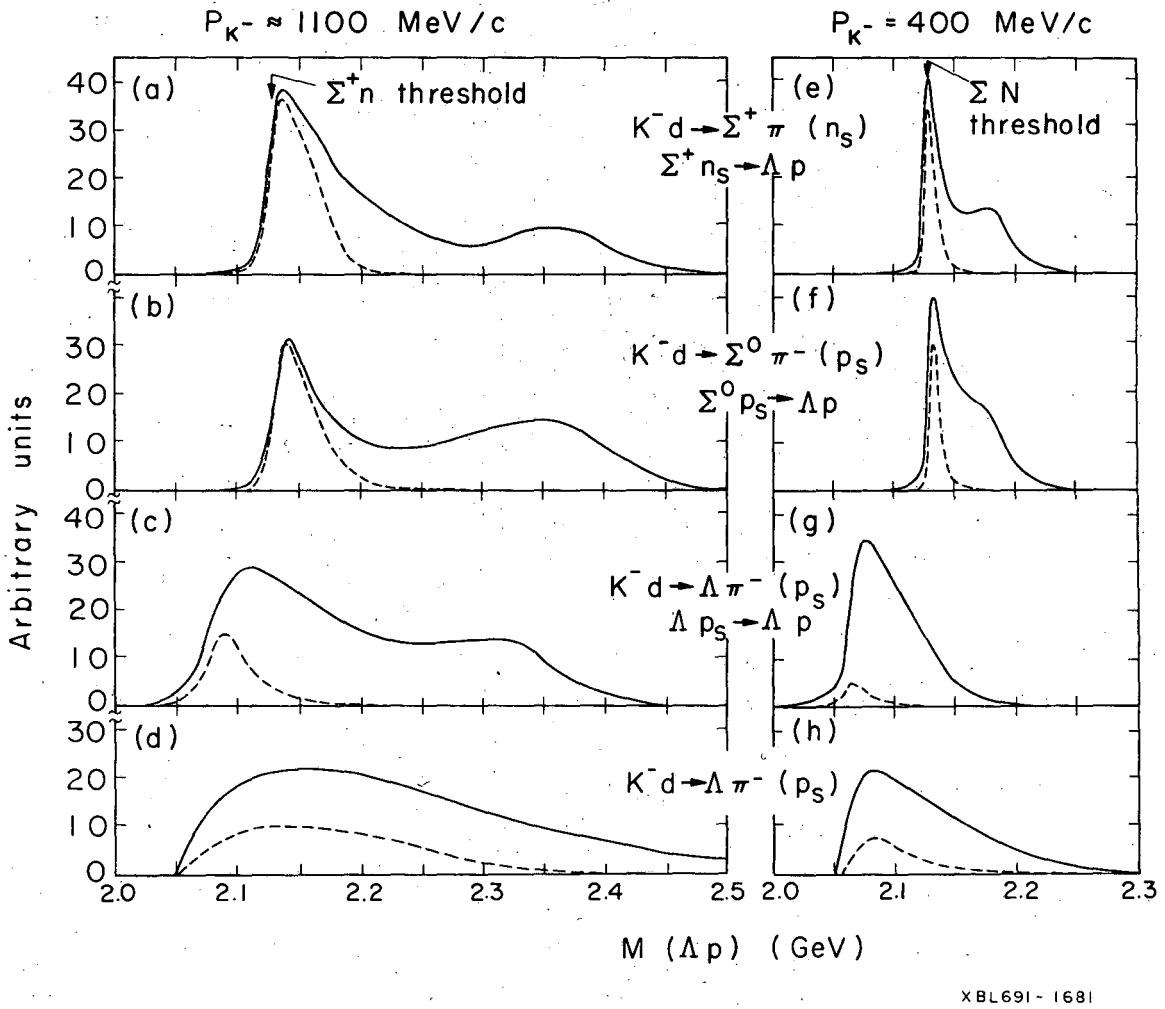
$P_{K^-} \approx 1100$ MeV/c
$P_{K^-} = 400$ MeV/c
(a)
$\Sigma^+ n$ threshold
$K^- d \to \Sigma^+ \pi^- (n_s)$
$\Sigma^+ n_s \to \Lambda p$
(e)
ΣN threshold
(b)
$K^- d \to \Sigma^0 \pi^- (p_s)$
$\Sigma^0 p_s \to \Lambda p$
(f)
(c)
$K^- d \to \Lambda \pi^- (p_s)$
$\Lambda p_s \to \Lambda p$
(g)
(d)
$K^- d \to \Lambda \pi^- (p_s)$
(h)
Arbitrary units
M (Λp) (GeV)
XBL691-1681

Fig. 2

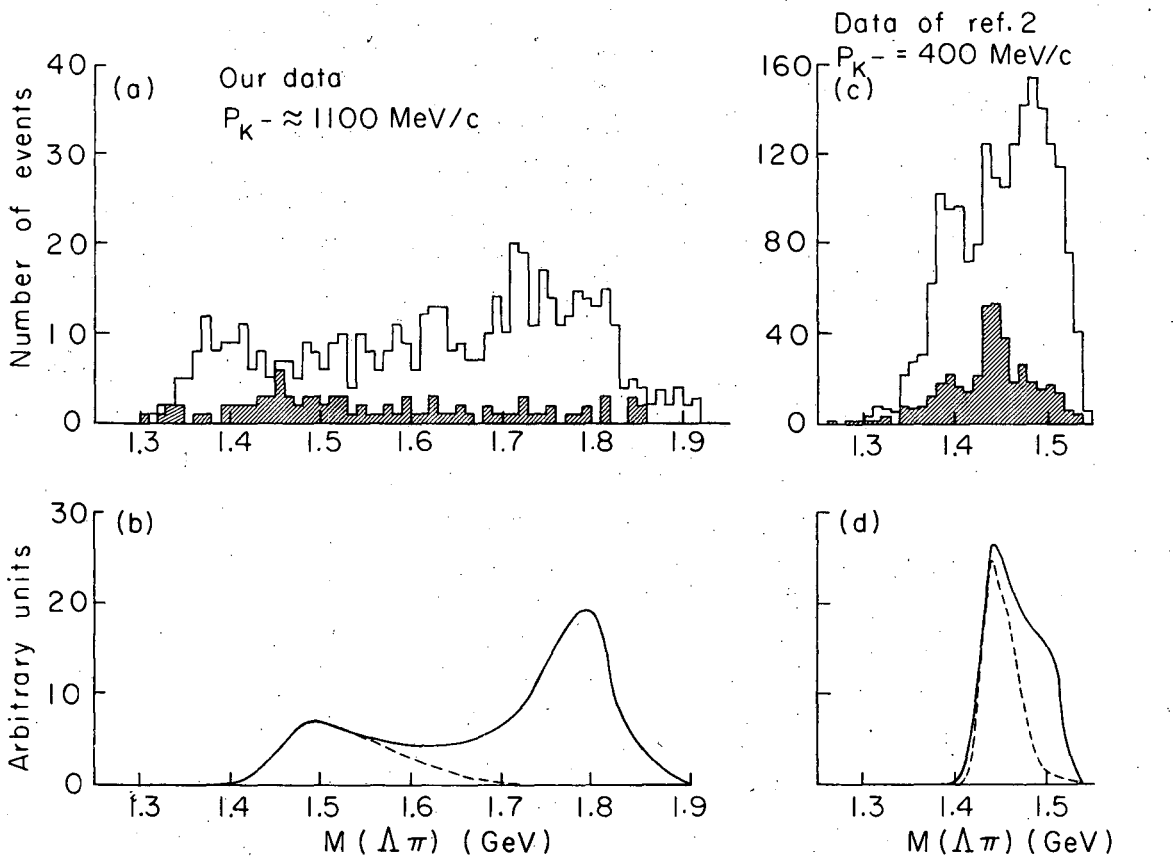
(a)
Our data
$P_{K^-} \approx 1100$ MeV/c
Number of events
(b)
Arbitrary units
M (Λ π) (GeV)
Data of ref. 2
$P_{K^-} = 400$ MeV/c
(c)
(d)
M (Λ π) (GeV)
XBL691-1682

Fig. 3

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

TECHNICAL INFORMATION DIVISION
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720