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Ernest O. Lawrence Radiation Laboratory

THE SPIN AND PARITY OF THE $Y_0^*(1815)$ AND THE $Y_1^*(1765)$

Berkeley, California

Presented by Robert P. Ely, Jr.
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INTRODUCTION

This report is part of a study of the interactions of K^- in hydrogen and deuterium at incident beam momenta in the range 830 to 1120 MeV/c (These momenta correspond to center-of-mass energies in the K-nucleon system in the range 1700 MeV to 1850 MeV.). Our immediate concern has been the determination of the quantum numbers of the two proposed resonances in the K-nucleon system, the Y_0^* (1815) and the Y_1^* (1765). Professor Yodh has reviewed the history of these resonances in the previous paper. Briefly, the I = 0, Y^* (1815) was first suggested by Chamberlain et al.[1] to account for a broad rise in the K^- p total cross-section at a center-of-mass energy of 1815 MeV. A comparison of the K^- p and K^- n cross-sections led to the isospin assignment. On the basis of the K^- p elastic differential cross-section which requires up to fifth order terms in cos θ , Beall et al.[2] deduced the spin of the resonance to be 5/2. The width of the enhancement in the total cross-section led these investigators to conclude that the width of the Y_0^* (1815) was Γ = 120 MeV. Later, Barbaro-Galtieri, Hussain and Tripp[3] observed an enhancement in the K^- p system at 1765 MeV in the reaction $K^- n \to K^- p \pi^-$ at an incident K^- momentum of 1.51 BeV/c. They argue, using the results of Beall et al.[2], that there are two resonances, the Y_1^* (1765) and the Y_0^* (1815) both with spin 5/2 and with opposite parities. The spin 5/2 assignment is suggested by the existence of the fourth order term and no higher even power terms in the production angular distributions. The fifth order term requires an interference between amplitudes of opposite parities. In addition, Wohl et al.[4] found the fifth order term in the $K^- p \to \bar{K}^0 n$ channel to be of opposite sign to that found by Beall et al. in the elastic scattering channel, which suggests that the two resonances have different I spins. Since the Y_0^* (1815) has I = 0, the Y_1^* (1765) is assumed to be I = 1.

Adherents of Regge Polology prefer that the Y_0^* (1815) be a 5/2+ state and, hence, be a candidate for the recurrence of the Λ. This, by Tripp's argument, would make the Y_1^* (1765) 5/2-. In this paper we will present evidence confirming the 5/2+ assignment for the Y_0^* (1815).

Professor Yodh and co-workers have analyzed the reactions $K^- + p \to \bar{K}^0 + n$ and $K^- + p \to \Lambda + \pi^0$ at incident K^- momenta between 900 MeV/c and 1000 MeV/c and they conclude that although there is evidence for a J = 5/2 amplitude in the I = 1 channel at 1760 MeV, there is no proof that this amplitude is resonant. Our data agree with theirs on this point. In addition, utilizing our result on the parity of the Y_0^* (1815) we will conclude that this I = 1 amplitude near 1760 MeV is 5/2-.

DATA ANALYSIS

We have studied the reactions

$$K^- + p \to \bar{K}^0 + n \qquad \text{(a)}$$

$$\to \Lambda^0 + \pi^0 \qquad \text{(b)}$$

$$\to \pi + Y_1^* (1385) \to \pi^+ + \pi^- + \Lambda \qquad \text{(c)} \quad (1)$$

$$K^- + n \to \Lambda + \pi^- \qquad \text{(d)}$$

$$\to \pi + Y_1^* (1385) \to \pi^- + \pi^0 + \Lambda \qquad \text{(e)}$$

at incident K^- momenta of 825, 875, 925, 975, 1025, 1060 and 1115 MeV/c in hydrogen and at 920 and 1020 MeV/c in deuterium. The film was taken in the 25-inch hydrogen bubble chamber at the Bevatron with a separated K^- beam. About 30,000 events have been measured on the Flying Spot Digitizer and processed through the FOG-CLOUDY-FAIR analysis system.

The portion of the measuring which can be done on the FSD has gone very rapidly, but the scanning for beam normalization to obtain absolute cross-sections is somewhat slower. Thus, the cross-sections are based on only 1/3 of the data included in the angular distributions. The results are not final in the sense that some remeasuring and check-scanning remains to be done; however, we believe that the conclusions which we draw will not change.

The cross-sections and angular distributions from reactions (a), (b) and (d) have been discussed quite extensively at the American Physical Society meetings[5] in Berkeley and Washington by our group and in Chicago and Berkeley by Charlton et al. of Maryland and by Armenteros et al. of CERN. There is substantial agreement about the conclusions. However, since there is as yet nothing in print, we shall discuss our data here. There has been very little discussion of reactions (c) and (e).

THE EXISTENCE AND SPIN OF THE TWO RESONANCES

Figures 1, 2 and 3 show the total cross-sections for reactions 1a, 1b and 1c. The closed circles are our data and the open circles are the data of Bastien and Berge et al.[6] at lower energies, and of Graziano and Wojcicki [7] and Ferro-Luzzi et al.[8] at higher energies. The absence of any enhancement at 1815 MeV in the $\Lambda\pi^o$ channel, which is pure I = 1, contrasted with the pronounced enhancement in both the $\bar{K}^o$ n and $\Lambda\pi\pi$ channels is exactly what one expects from a I = 0, Y^* (1815). On the other hand, there is no pronounced bump at 1760 MeV. Even the pure $I = 1, \Lambda\pi^o$ channel (Fig. 2) shows only a gradual rise and fall which does not clearly indicate a resonance. The width of the Y_0^* (1815) (as seen in Figs. 1 and 3) is clearly much less than the previously reported value of 120 MeV[2]. The solid curves drawn at 1815 MeV in Figs. 1 and 3 are Breit-Wigner forms with a width of 60 MeV. With this width there is a shoulder on the lower edge of the Y_0^* (1815) which is consistent with a resonance at 1760 MeV but which could also be due to non resonant amplitudes.

In addition we have fitted the production angular distributions in the $\bar{K}^o$ n system (Fig. 4) with an expansion in the Legendre polynomials.

$$\frac{d\sigma}{d\Omega} = \frac{\lambda\!\!\!^-}{4} \sum A_n P_n(\cos\theta) \qquad (\text{where } \cos\theta = \bar{K}^o \cdot K^-) \quad (2)$$

A Breit-Wigner curve with $\Gamma = 60$ MeV and $M_o = 1815$ MeV has been drawn through coefficients of the P_4 term. This, together with the momentum dependence of the coefficient of the P_5 term, has been plotted in Fig. 5. The sharp peak in the coefficient A4 at 1815 MeV, coupled with the absence of higher order even terms in $\cos\theta$ agrees with the $J = 5/2$ assignment for Y^* (1815).

The angular distributions at 1760 MeV require a significant fourth order term, suggesting the presence of partial waves with $J = 5/2$. The coefficient A5 is negative at 1815 MeV, as found by Wohl, and remains negative down to 1760 MeV. If there are no amplitudes of spin $> 5/2$ present, this coefficient is due to an interference between two $J = 5/2$ amplitudes of opposite parity.

THE PARITY OF THE Y_0^* (1815)

Although the proposed Y_1^* (1765) is difficult to see in our data, the Y_0^* (1815) stands out clearly in both reactions 1a and 1c (Figs. 1

and 3). We will show that the reaction 1c, $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$, proceeds mainly through the intermediate state $K^- + p \rightarrow Y_1^*$ (1385) $+ \pi$.

Figures 6 and 7 show Dalitz plots of the square of the invariant mass of the $\Lambda\pi^-$ system versus that of the $\Lambda\pi^+$ system for reaction 1c at total energies of 1760 MeV and 1820 MeV. The bands corresponding to the Y_1^* (1385) are very pronounced. Using the density of events outside of the Y^* bands as a measure of the background present, we conclude that reaction 1c accounts for 90% or more of the total $\Lambda\pi^+\pi^-$ production at these energies.

Since the bands are reasonably well separated on the Dalitz plot at 1820 MeV, we have identified the Y_1^* (1385) as that $\Lambda\pi$ system with an invariant mass in the range 1385 ± 50 Mev. This provides a unique separation and enriches the Y_1^* (1385) sample in the final state. Attempts to analyze the Y_1^* (1385) production at lower energies have been complicated by interference and the necessity of symmetrizing the $\Lambda\pi^+\pi^-$ final state[9] but these effects are not expected to be large in the production angular distributions at center-of-mass energies near 1815 MeV.

On the basis of the cross-section for the reaction $K^- p \rightarrow Y_1^*$ (1385) + (Fig. 3) and the known elastic cross-sections, we reported at Berkeley[5] that the branching ratio of the Y_0^* (1815) into Y_1^* (1385) $+\pi$ was 20 ± 5%. Thus the process

$$K^- + p \rightarrow Y_0^* (1815) \rightarrow Y_1^*(1385) + \pi \qquad (3)$$

appears to make an important contribution to reaction 1c at incident K^- momenta of 1015 MeV/c and 1060 MeV/c.

Minami[10] has observed that when the Y_0^* (1815) is produced in reaction (1c) it is highly aligned, $J_z = \pm 1/2$, and hence, the angular distribution of its decay into the spin 3/2 Y_1^* (1385) and a pion will depend upon its spin and parity. Specifically, assuming the Y_1^* (1385) to be 3/2+, as shown by Huwe et al.[11], and if the Y_0^* (1815) is 5/2+ then the orbital state of the Y_1^* (1385) + π system is either $p_{5/2}$ or $f_{5/2}$. On the other hand, if the Y_0^* (1815) is 5/2-, then Y_1^* (1385) + π system is either $d_{5/2}$ or $g_{5/2}$. Assuming the lower angular momentum state to be highly favored by the angular momentum barrier, we expect the angular distribution of the Y_1^* (1385) + π system to be nearly of form $(1 + 2\cos^2\theta)$ for the 5/2+ choice and $(1 + 10\cos^2\theta - 10\cos^4\theta)$ for the 5/2- choice, where θ is the angle between the Y_1^* (1385) and the incident K^- (the axis of alignment) in the $K^- p$ center-of-mass system. Of course, the success with which one can make this test depends upon the purity of the sample of Y_0^* (1815).

The $K^- p$ system is a mixture of equal parts I = 0 and I = 1 while the Y_0^* (1815) produced in reaction (3) is in the I = 0 channel. We would like to remove the background caused by the I = 1 channel. We mave measured the I = 1 amplitude from:

$$K^- + n \rightarrow Y_1^* (1385) + \pi \qquad (4)$$

in the deuterium data. The isotopic spin parts of the differential cross-sections for the reactions $K^- + p \rightarrow Y_1^* (1385)^{\pm} + \pi^{\mp}$ are

$$d\sigma(K^-p \rightarrow Y^{*+}\pi^-) = \tfrac{1}{2}\left[\tfrac{1}{3}|a_0|^2 + \tfrac{1}{2}|a_1|^2 + \tfrac{2}{\sqrt{6}} Re(a_0^* a_1)\right] \quad (5a)$$

and

$$d\sigma(K^-p \rightarrow Y^{*-}\pi^+) = \tfrac{1}{2}\left[\tfrac{1}{3}|a_0|^2 + \tfrac{1}{2}|a_1|^2 - \tfrac{2}{\sqrt{6}} Re(a_0^* a_1)\right] \quad (5b)$$

where a_0 and a_1 represent the partial wave amplitudes for I = 0 and I = 1 production respectively. These cross-sections contain an interference term which cancels out if we consider the sum of the angular distributions for Y_1^{*+} (1385) and Y_1^{*-} (1385)

$$d\sigma(K^-p \rightarrow Y_1^{*+}\pi^-) + d\sigma(K^-p \rightarrow Y_1^{*-}\pi^+) = \left[\tfrac{1}{3}(a_0)^2 + \tfrac{1}{2}|a_1|^2\right] \quad (6)$$

The differential cross-section for reaction (4) is proportional to $|a_1|^2$

and when appropriately normalized, can be subtracted from the $K^- p$ data to give the angular distribution for the I = o channel.

Figure 8 shows the combined angular distributions of $K^- p \rightarrow Y_1^{*+} \pi^-$ and $K^- p \rightarrow Y_1^{*-} \pi^+$ at each of our incident K^- momenta with curves representing the fit in Legendre polynomials up to fourth order. The most notable feature is the change in sign of the curvature between the 925 MeV/c (1760 MeV) region and the 1015 MeV/c (1815 MeV) region.

For the purpose of applying the above test for the parity of Y_0^* (1815) we have combined our $K^- p$ data at incident momenta of 1015 MeV/c and 1060 MeV/c. These momenta straddle the peak corresponding to the formation of the Y_0^* (1815) as shown in Fig. 3. The angular distribution for the sum of these two momenta is shown as the solid line in Fig. 9a. The dotted line is the $K^- n \rightarrow Y_1^* \pi$, I = 1, angular distribution at p_K = 1015 MeV/c normalized to 50% of the total $K^- p$ cross-section. This normalization is based on the cross-sections from the $K^- d$ data which indicate that the I = 1 amplitude for $K^- p \rightarrow \Lambda \pi^+ \pi^-$ accounts for 50 ± 5% of the total cross-section for the $K^- p \rightarrow \Lambda \pi^+ \pi^-$ channel at incident K^- momenta of 1015 MeV/c and 1060 MeV/c.

Figure 9b shows the I = 0 angular distribution, i.e. the difference between the two distributions in Fig. 9a, folded about $\cos\theta = 0$, to remove the odd terms which may arise from interference with the background. The solid curve on Fig. 9b is $1 + 2\cos^2\theta$ and the broken curve is $1 + 10\cos^2\theta - 10\cos^4\theta$. The total cross-section data at 1815 is consistent with up to 30% non-resonant background. With this as an upper limit, we have investigated the possibility of the background causing significant deviations from the predicted curves. The experimental data can easily be accounted for in terms of the $1 + 2\cos^2\theta$

distribution together with a contribution from the background, whereas we have found no way in which this amount of background can change the $1 + 10\cos^2\theta - 10\cos^4\theta$ distribution to fit the experimental data.

We conclude on the basis of this that the Y_0^* (1815) is $(5/2)^+$.

SUMMARY

An analysis of the angular distribution of the $K^- + p \to Y_1^*$ (1385) + π and $K^- + n \to Y^*$ (1385) +π at center-of-mass energies near 1815 MeV shows the Y_0^* (1815) to be 5/2+.

So far we are unable to verify the existence of the proposed Y_1^* (1765) in our data. However, there are fifth order coefficients of opposite sign in the differential cross-section for the elastic and charge exchange channels in the region 1760 - 1815 MeV. This indicates an interference between the Y_0^* (1815) and a spin $\geq$ 5/2, isospin 1, negative parity amplitude.

REFERENCES

1. O. Chamberlain, K. M. Crowe, L. T. Kerth, A. Lemonick, Tin Maung and T. F. Zipf. Phys. Rev. 125, 1696 (1962).

2. E. F. Beall, W. Holley, D. Keefe, L. T. Kerth, J. J. Thresher, C. L. Wang, and W. A. Wenzel, 1962 International Conference on High Energy Physics At CERN, (CERN, Geneva, 1962), P. 368.

3. A. Barbaro-Galtieri, A. Hussain, and R. D. Tripp, Physics Letters 6, 296 (1963).

4. C. Wohl, F. T. Solmitz, and M. L. Stevenson, Bull. Am. Phys. Soc. 9, 442 (1964).

5. A. Kernan, R. P. Ely, Jr., G. E. Kalmus, R. T. Pu, and W. M. Smart, Bull. Am. Phys. Soc. 10, 518 (1965); R. P. Ely, Jr., Bull. Am. Phys. Soc. 9, 703, (1964); R. P. Uhlig, G. R. Charlton, P. E. Condon, M. C. Whatley, G. B. Yodh, A. H. Actken, R. G. Glasser, and A. J. Herz, Bull. Am. Phys. Soc. 9, 723, (1964); R. L. Setti, R. Armenteros, M. Ferro-Luzzi, D. W. G. Leith, A. Minten, H. Schneider, R. D. Tripp, H. Filthuth, A. Fridman, E. Kluge, V. Hepp, R. Barloutaud, P. Grannet, J. Meyer, and J. P. Porte, Bull. Am. Phys. Soc. 9, 723 (1964); G. R. Charlton, P. E. Condon, R. P. Uhlig, M. C. Whatley, G. B. Yodh, A. H. Aitken, R. G. Glasser, and A. J. Herz, Bull. Am. Phys. Soc. 9, 642 (1964).

6. P. L. Bastien and J. P. Berge, PRL 10, 188 (1962).

7. W. Graziano and S. G. Wojcicki, PR 128, 1868 (1962).

8. M. Ferro-Luzzi, F. T. Solmitz, and M. L. Stevenson, 1962 International Conference on High Energy Physics at CERN (CERN, Geneva, 1962), p. 376.

9. J. P. Berge, P. Bastien, O. Dahl, M. Ferro-Luzzi, J. Kirz, D. H. Miller, J. J. Murray, A. H. Rosenfeld, R. D. Tripp, and M. B. Watson, PRL 6, 557 (1961).

10. S. Minami, Nuovo Cimento 31 258 (1964).

11. D. O. Huwe (thesis), UCRL 11291 (1964); J. B. Shafer, J. J. Murray, and D. O. Huwe, PRL 10, 179 (1963).

FIGURE CAPTIONS

Fig. 1. The total cross-section measured in units of $\pi \lambda\!\!\!^{-2}$ for the reaction $K^- + p \to \bar{K}^0 + n$ as a function of the K^- laboratory momentum. The closed circles are our data and the open circles are the data of Bastien and Berge(6) at lower energies, and of Graziano and Wojcicki(7) and Ferro-Luzzi et al.(8) at higher energies. The solid curve is a Breit-Wigner form with Γ = 60 MeV and M_o = 1815.

Fig. 2. The total cross-section measured in units of $\pi \lambda\!\!\!^{-2}$ for the reaction $K^- + p \to \Lambda + \pi^0$ as a function of the K^- laboratory momentum. The closed circles are our data and the open circles are the data of Bastien and Berge(6) at lower energies, and of Graziano and Wojcicki(7) and Ferro-Luzzi et al.(8) at higher energies.

Fig. 3. The total cross-section measured in units of $\pi \lambda\!\!\!^{-2}$ for the reaction $K^- + p \to \Lambda + \pi^+ + \pi^-$ as a function of the K^- laboratory momentum. The closed circles are our data and the open circles are the data of Bastien and Berge(6) at lower energies, and of Graziano and Wojcicki(7) and Ferro-Luzzi et al.(8) at higher energies. The solid curve is a Breit-Wigner form with Γ = 60 MeV and M_o = 1815.

Fig. 4. Production angular distributions of $K^- + p \to \bar{K}^0 + n$ at each of seven incident K^- momenta, with curves representing the fifth order fit in Legendre polynomials.

Fig. 5. The coefficients A4 and A5 in the angular distributions for $K^- + p \to \bar{K}^0 + n$ plotted as a function of incident K^- laboratory momentum. A Breit-Wigner curve with Γ = 60 MeV and M_o = 1815 MeV has been drawn through the coefficient A4. Cos θ is defined as $(\bar{K}^0 \cdot K^-)$.

Fig. 6. Dalitz plot of the square of the invariant mass of the $\Lambda\pi^-$ system vs. that of the $\Lambda\pi^+$ system for the reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ at a center of mass energy of 1760 MeV.

Fig. 7. Dalitz plot of the square of the invariant mass of the $\Lambda\pi^-$ system vs. that of the $\Lambda\pi^+$ system for the reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ at a center of mass energy of 1820 MeV.

Fig. 8. Angular distributions of the sum of the reactions $K^- + p \rightarrow Y^{*+} + \pi^-$ and $K^- + p \rightarrow Y^{*-} + \pi^+$ at each of the seven incident K^- momenta, with curves representing the fourth order fit in Legendre polynomials.

Fig. 9(a). Solid line is the sum of the angular distributions for the reaction $K^- + p \rightarrow Y_1^* + \pi$ at incident K^- mementa of 1015 MeV/c and 1060 MeV/c. The broken line is the angular distribution for the reaction $K^- + n \rightarrow Y_1^* + \pi$ at an incident K^- momentum of 1020 MeV/c, normalized to contain 1/2 the events in solid histograms. (b). The difference between the two histograms in (a), folded about $Y^* \cdot K^- = 0$

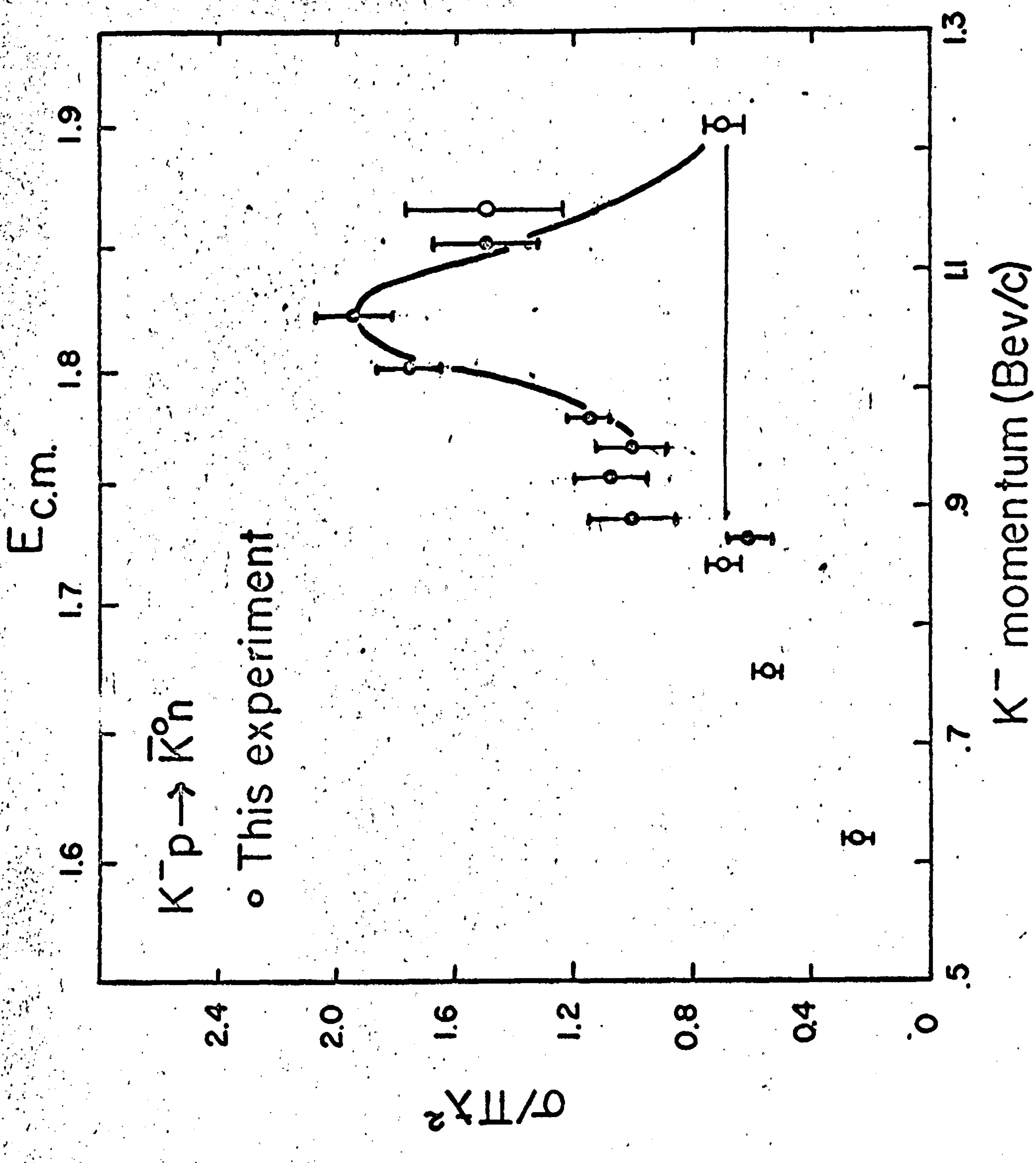
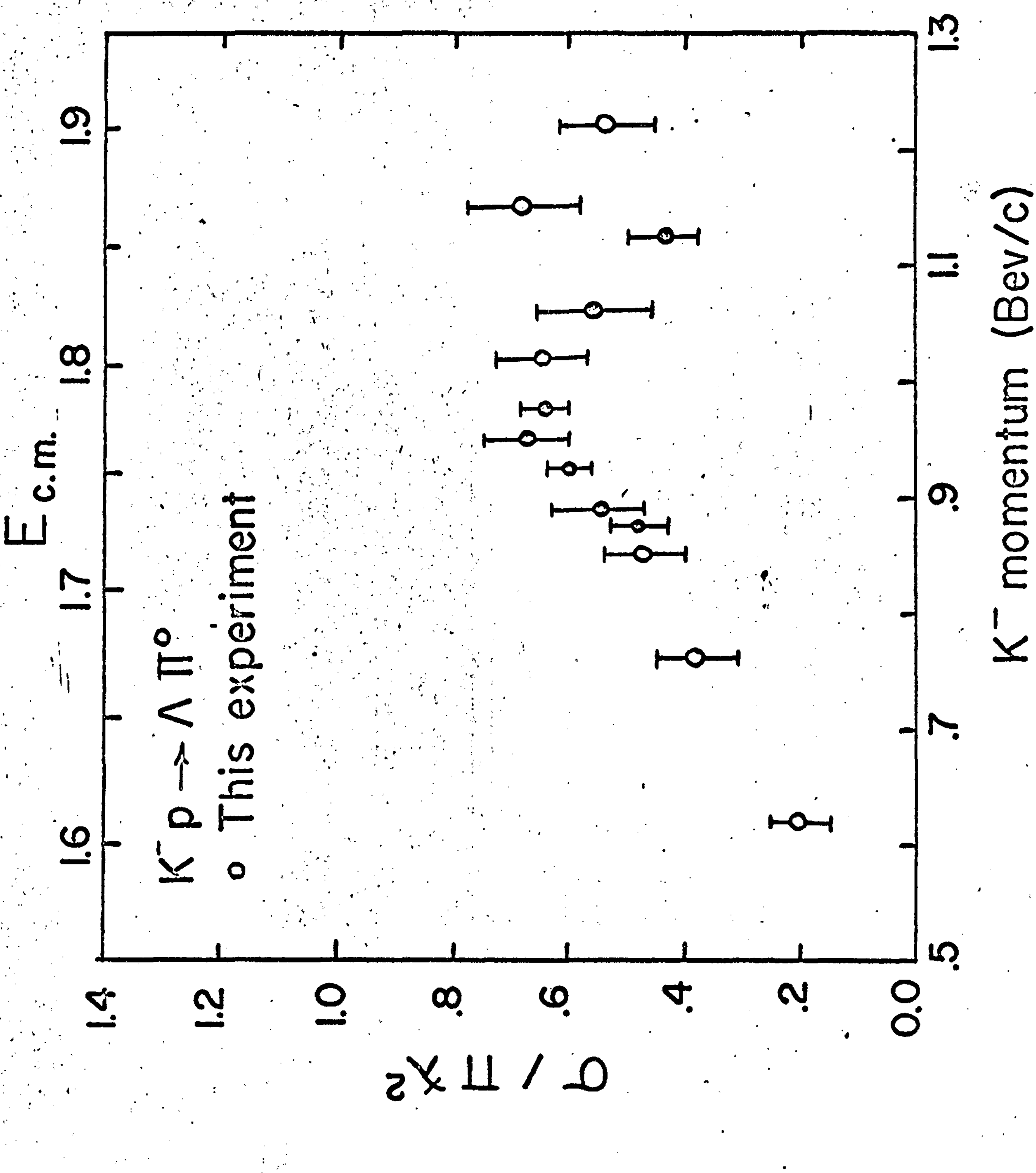

E c.m.
1.6
1.7
1.8
1.9
$K^- p \rightarrow \bar{K}^0 n$
∘ This experiment
$\sigma/\pi\lambda^2$
2.4
2.0
1.6
1.2
0.8
0.4
.0
.5
.7
.9
1.1
1.3
K^- momentum (Bev/c)

Fig. 1



E c.m.
1.6
1.7
1.8
1.9
K⁻p → Λ π°
○ This experiment
1.4
1.2
1.0
.8
.6
.4
.2
0.0
σ / π ƛ²
.5
.7
.9
1.1
1.3
K⁻ momentum (Bev/c)

Fig. 2

Fig 2

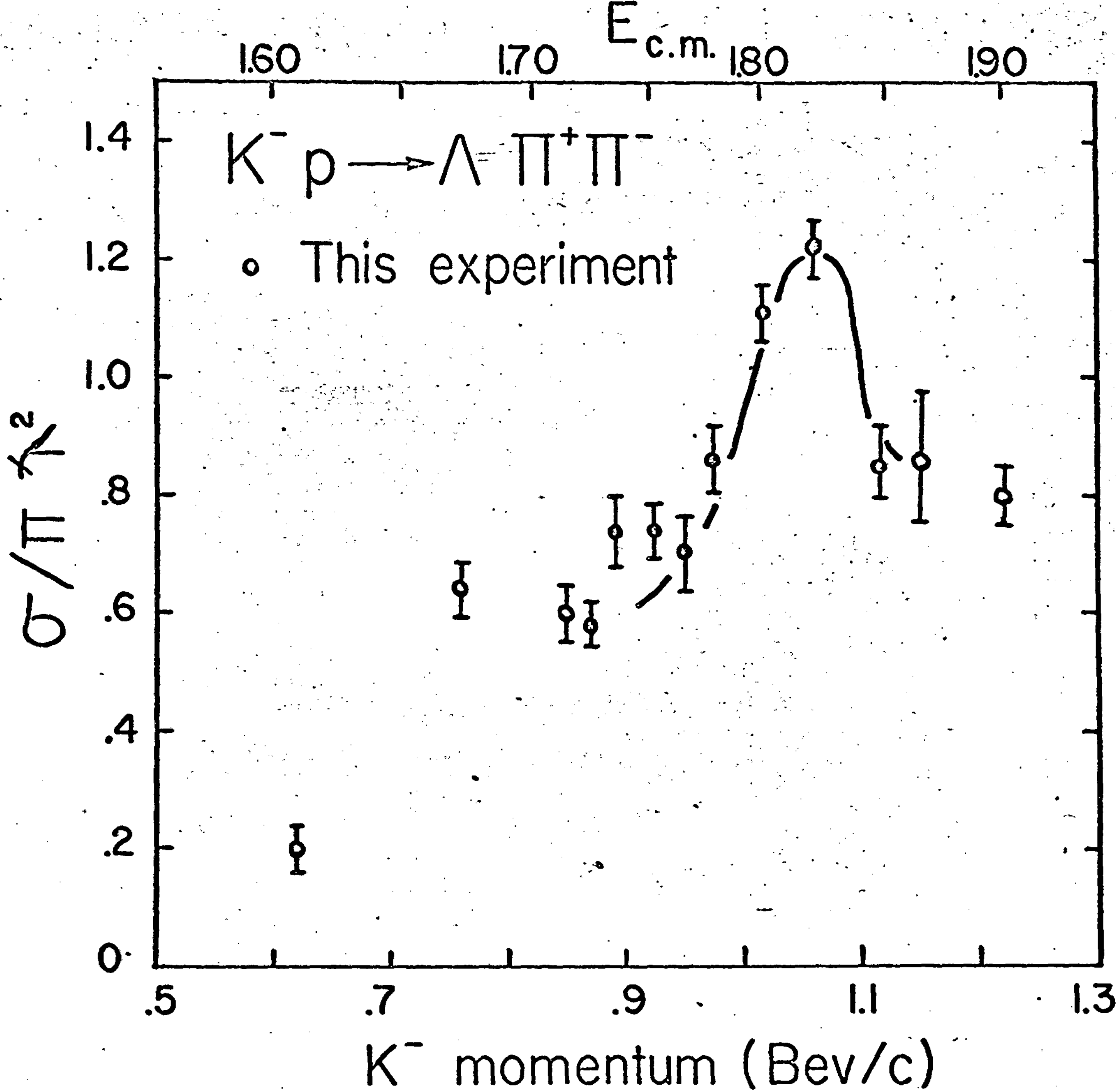
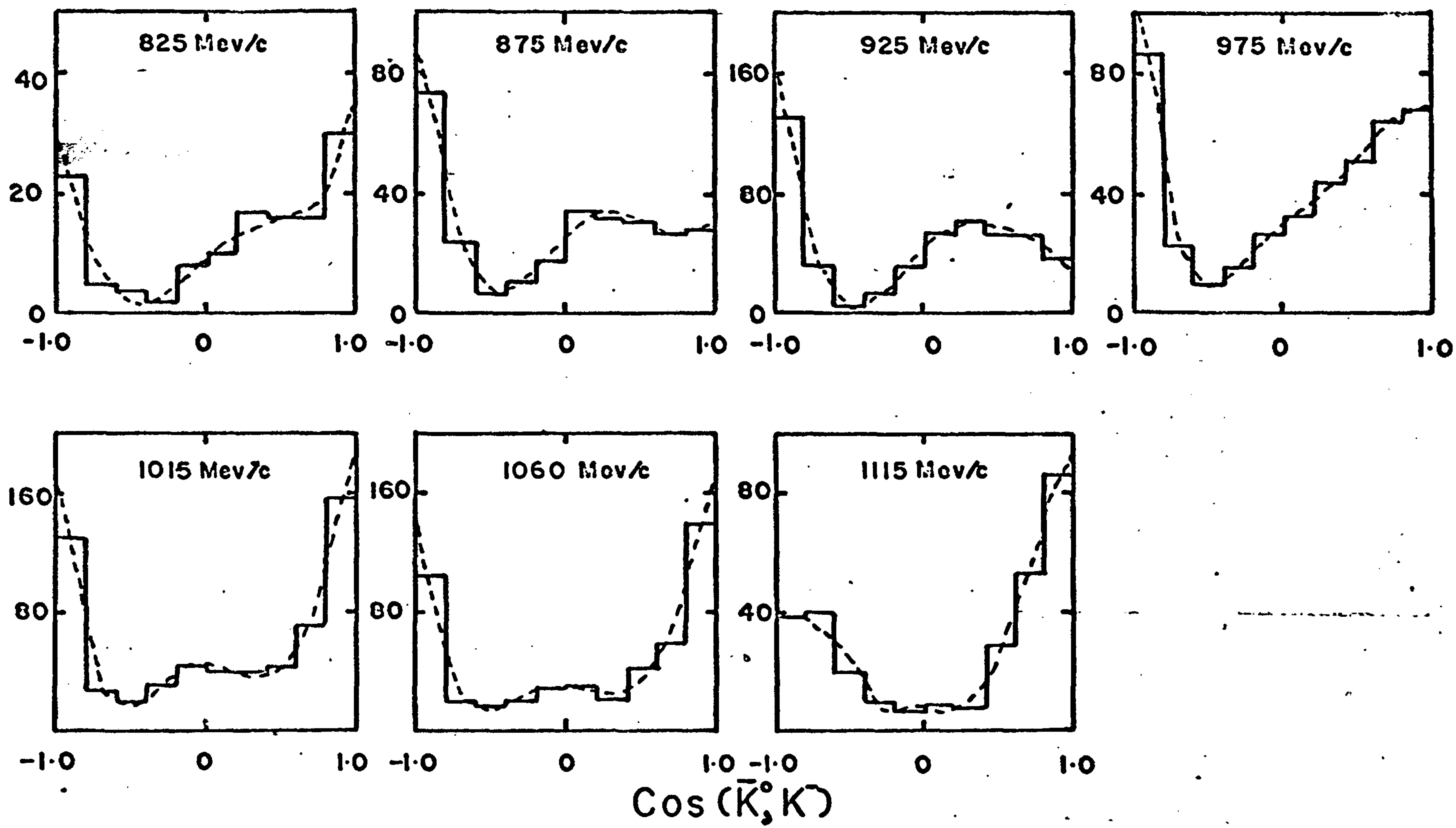

$E_{c.m.}$
1.60
1.70
1.80
1.90
$K^- p \rightarrow \Lambda \pi^+ \pi^-$
This experiment
1.4
1.2
1.0
.8
.6
.4
.2
0
$\sigma / \pi \lambda\!\!\!^{-2}$
.5
.7
.9
1.1
1.3
K^- momentum (Bev/c)

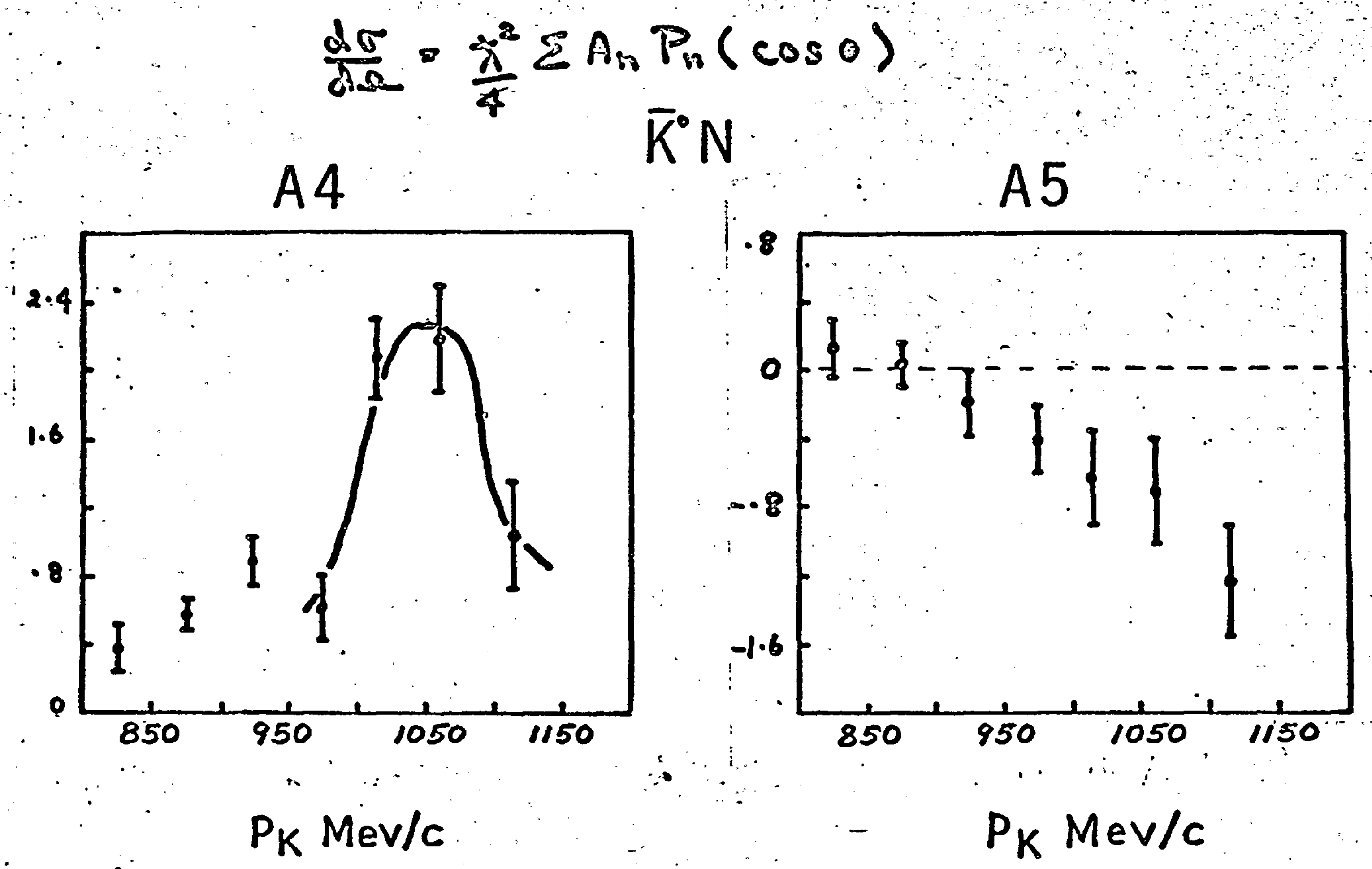
FIG. 3

FIG. 4



825 Mev/c
875 Mev/c
925 Mev/c
975 Mev/c
1015 Mev/c
1060 Mev/c
1115 Mev/c
Cos ($\bar{K}^o$, K)

-16-



$\frac{d\sigma}{d\Omega} = \frac{\lambda^2}{4} \Sigma A_n P_n(\cos\theta)$
$\bar{K}^0 N$
A4
A5
2.4
1.6
.8
0
.8
0
-.8
-1.6
850
950
1050
1150
P_K Mev/c
P_K Mev/c

FIG. 5

25 INCH HYDROGEN CHAMBER FAIR OUTPUT
RUN 015674 DATE 650608 ASN.GP RE80
LEVEL Z1Q3F4 PLOT NO 10
NUMBER OF POINTS PLOTTED 436

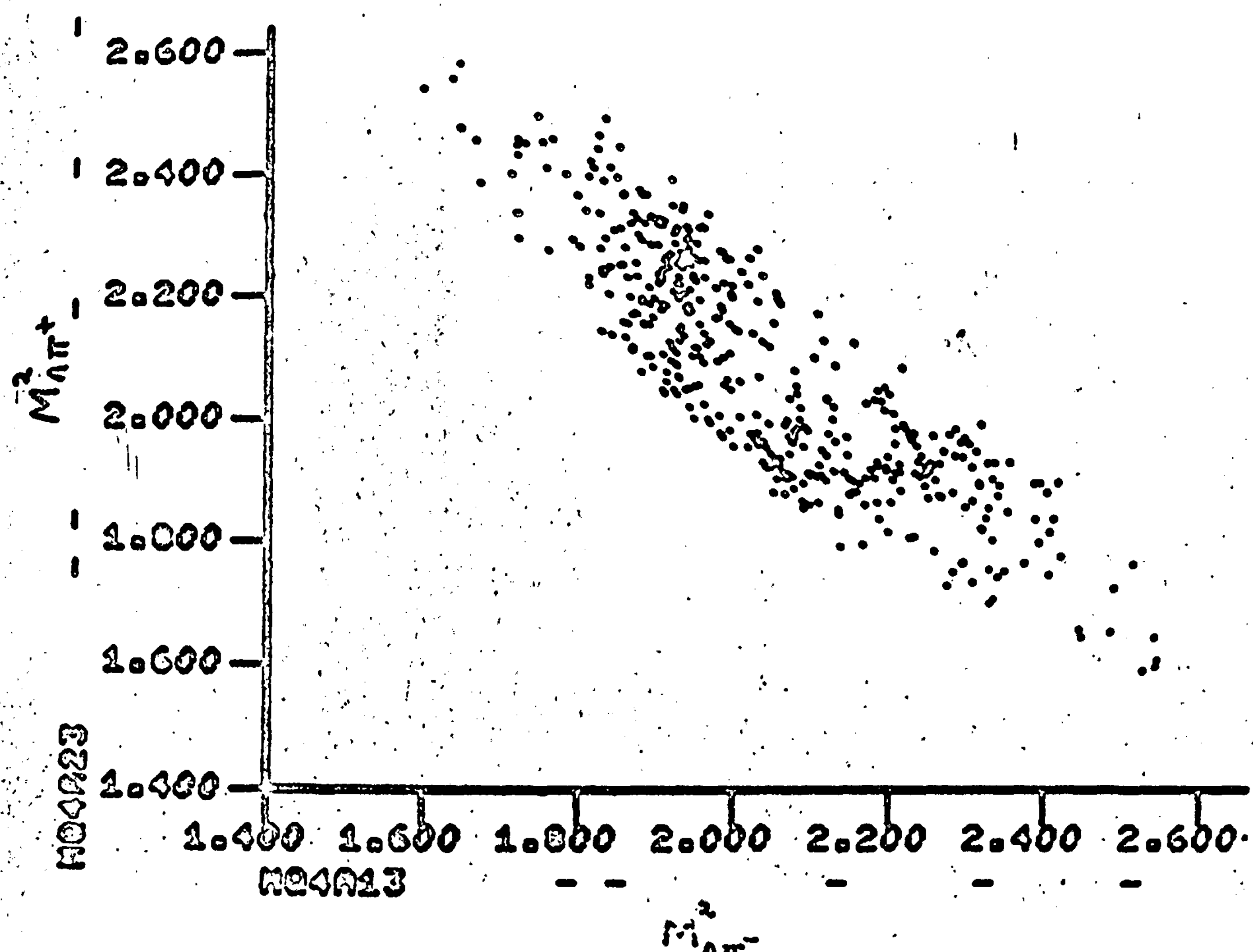


Fig. 6

25 INCH HYDROGEN CHAMBER FAIR OUTPUT
RUN 015674 DATE 650608 ASN.GP RE80
LEVEL Z1Q3G4 PLOT NO 13
NUMBER OF POINTS PLOTTED 450

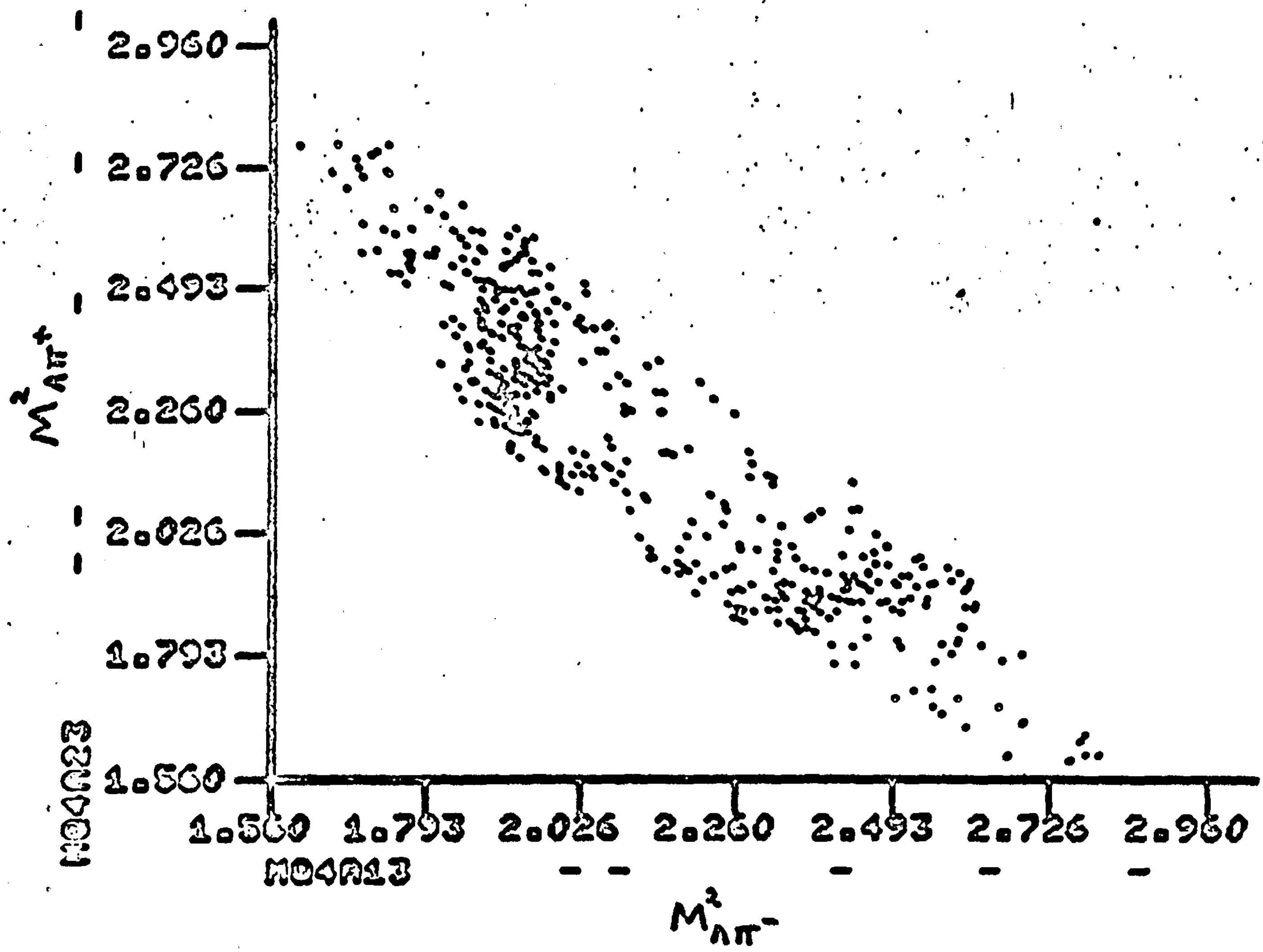


Fig. 7.

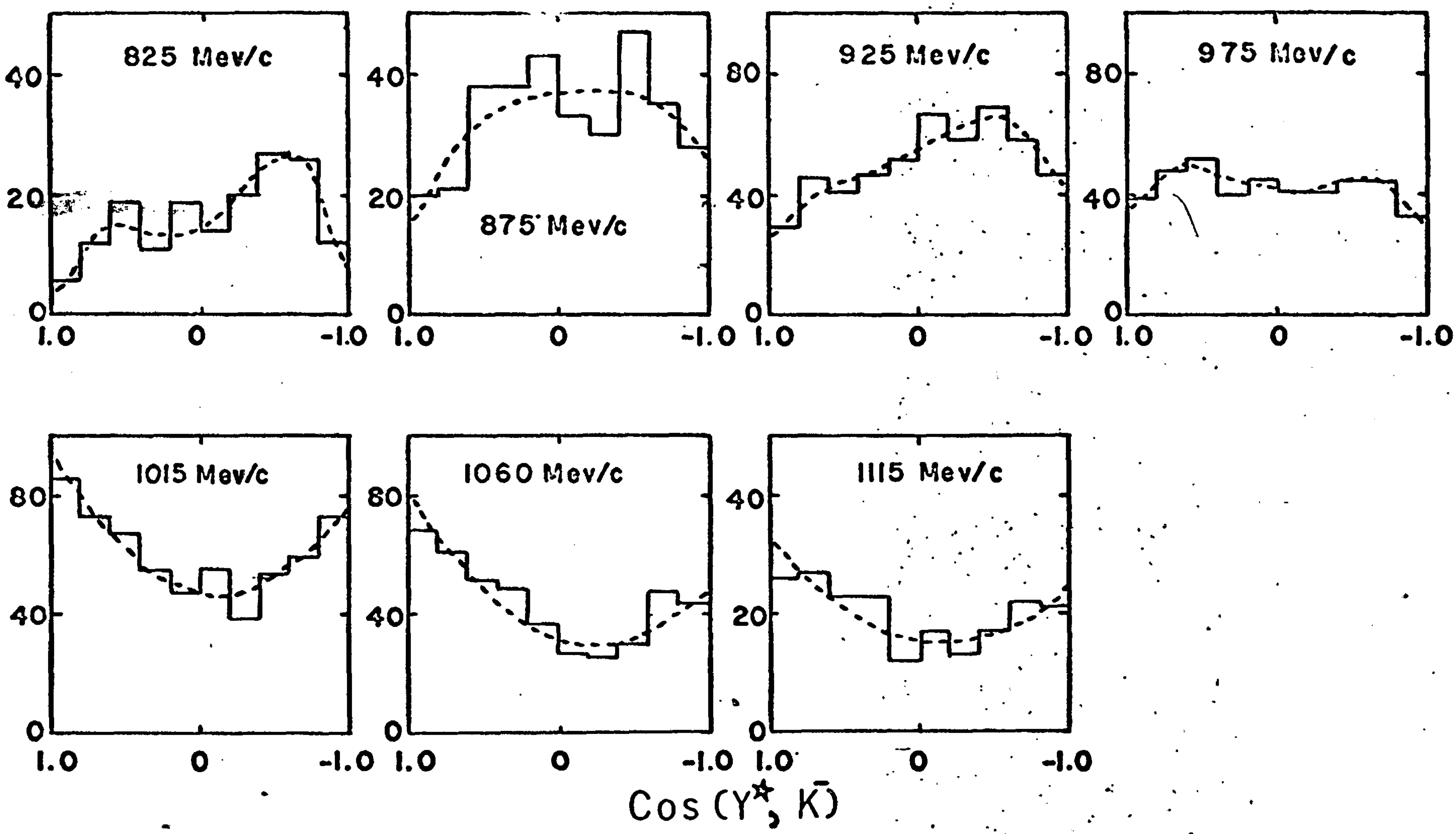

825 Mev/c
875 Mev/c
925 Mev/c
975 Mev/c
1015 Mev/c
1060 Mev/c
1115 Mev/c
Cos (Y*, K̄)

FIG. 8

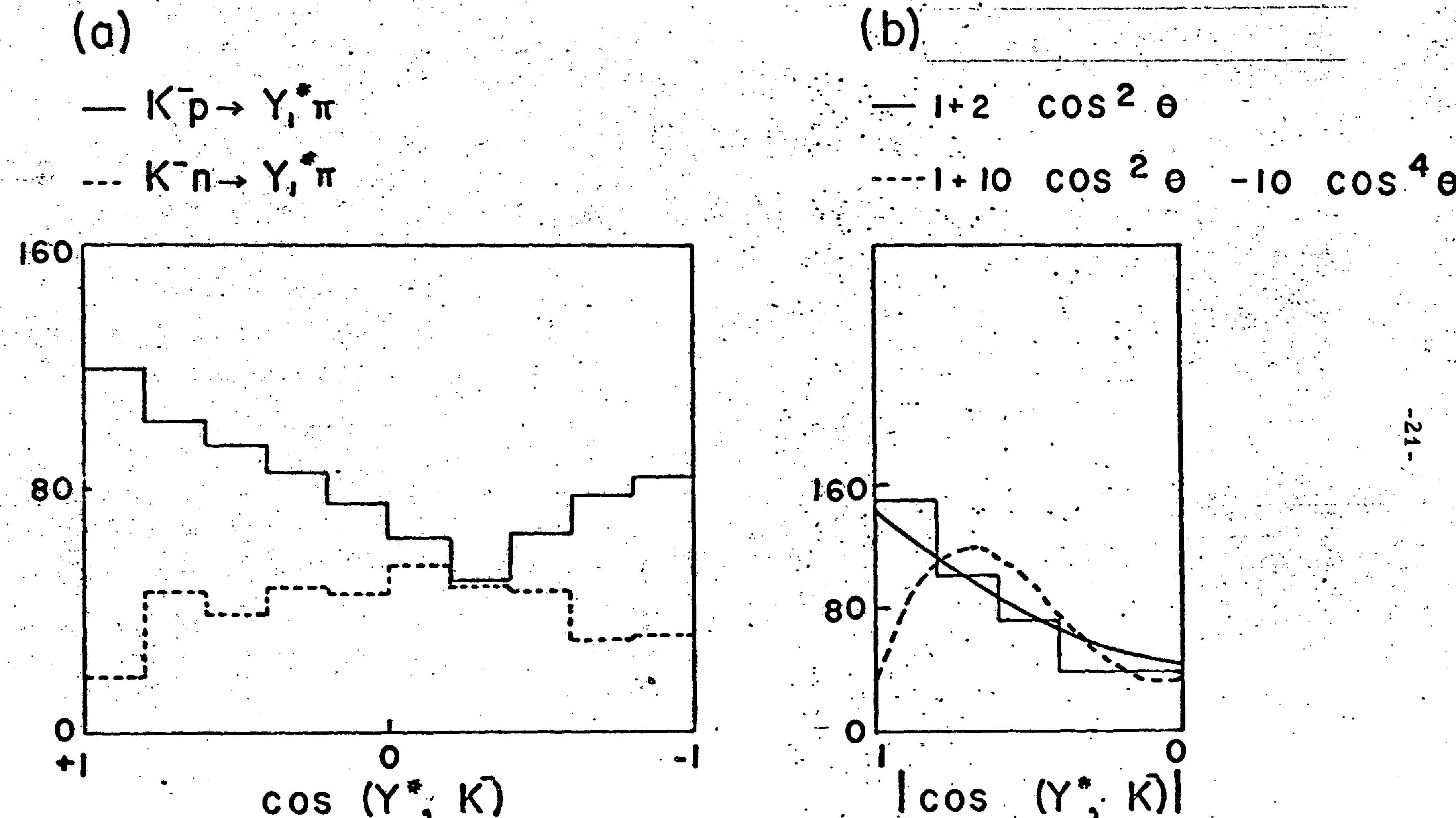

(a)
— K⁻p → Y₁*π
--- K⁻n → Y₁*π
160
80
0
+1
0
-1
cos (Y*, K)
(b)
— 1+2 cos² θ
--- 1+10 cos² θ -10 cos⁴ θ
160
80
0
1
0
|cos (Y*, K)|

Fig. 9