PERIPHERAL PRODUCTION IN THE SINGLE-MESON-EXCHANGE FORBIDDEN REACTION $\pi^- p \to Y^{*-}K^+$ AT 2 TO 4 GeV/c *

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Data are presented showing that the $Y_1^*(1385)$ production angular distribution in the reaction $\pi^- p \to Y^{*-}K^+$ and in its charge-symmetric counterpart $\pi^+ n(p_{sp}) \to Y^{*+}K^0(p_{sp})$ is characterized by peripheral ($\hat{N}\cdot\hat{Y}^* \approx +1$) and antiperipheral peaking. Explanation for the latter is sought in terms of baryon exchange; so comparisons with other $\pi N \to Y^*K$ reactions are made. The peripheral peak cannot arise through the exchange of any known meson. Alternative explanations are considered.

The one-particle-exchange model, when modified by absorption, has been quite successful in predicting the production angular distributions and decay correlations in a large class of high-energy two-body processes. In particular, the characteristic forward-peaked production distribution can be understood in terms of meson exchange, and backward peaking is at least qualitatively explained in terms of baryon exchange.

For the reactions

$$\pi^- p \to Y^{*-}K^+ \tag{1a}$$

and

$$\pi^+ n(p_{sp}) \to (p_{sp})Y^{*+}K^0 \tag{1b}$$

from 1.8 to 4.2 GeV/c, we present data on the production angular distributions, which are characterized by peaking both in the forward direction (low momentum transfer from the target to the Y^*) and the backward direction throughout this energy range. At the same energies, we have also studied the reactions

$$\pi^- p \to Y^{*0}K^0, \tag{2a}$$

$$\pi^+ n(p_{sp}) \to (p_{sp})Y^{*0}K^+, \tag{2b}$$

and

$$\pi^+ p(n_{sp}) \to (n_{sp})Y^{*+}K^+, \tag{3}$$

where both meson and baryon exchange are allowed.[1] There is no known meson whose exchange could produce the forward peak in Reactions (1), and it appears that simple u- or s-channel effects cannot account for this peaking.

The data used in this report come from two separate experiments: (a) Approximately 890 000 pictures of $\pi^- p$ interactions between 1.5 and 4.2 GeV/c in the 72-in. bubble chamber, in which more than 50 000 strange-particle events were found. A comprehensive report on this experiment, known as π63, has been published.[2] (b) An exposure known as $\pi 66A$, consisting of more than 400 000 pictures of $\pi^+ d$ interactions between 2.8 and 4.2 GeV/c in the 72-in. chamber, yielding about 17 000 events with visible decays of neutral strange particles. We have also used preliminary data from a lower momentum run, $\pi 66B$, for Reaction (3) near 2 GeV/c.

Because of the rapid decrease of cross section with energy, particularly for Reactions (1), it was found convenient to group the data into three beam-momentum intervals. The data of the two experiments were compared to check for consistency and then were combined. For angular distributions, a fiducial volume cut was made. The events were given weights (which averaged 1.1) according to their detection probabilities. For this report, we have examined only $\Lambda K\pi$ (not $\Sigma K\pi$) final states. Further details of the exposures are given in Table I.

The data-analysis methods for π63 have already been described.[2] The π66 events were measured on both the spiral reader and Franckenstein measuring machines. Ambiguous Franckenstein-measured events that might be resolvable on the basis of track ionization information were examined on the scanning table; the spiral reader automatically obtained such information. We feel that the remaining ambiguities do not affect the conclusions of this report; however, the cross sections for π66, which are presented in Table I, are preliminary.

The $\Lambda\pi$ mass spectra in Fig. 1 indicate the

Table I. Exposure size and Y^* production cross section (approximate).

Momentum interval (GeV/c)	Experiment	Exposure size (events/μb)	$\pi^+n(p)\to(p)\Lambda K^0\pi^+$ $[\pi^-p\to\Lambda K^+\pi^-]$ (events/μb)[a]	$\sigma(Y^*K)$ (μb)	$\pi^+n(p)\to(p)\Lambda K^+\pi^0$ $[\pi^-p\to\Lambda K^0\pi^0]$ (events/μb)[a]	$\sigma(Y^*K)$ (μb)	$\pi^+p(n)\to(n)\Lambda K^+\pi^+$ (events/μb)[a]	$\sigma(Y^*K)$ (μb)
1.9-2.4	π66B	≈6					≈2	≈90
1.8-2.2	π63	12.5 ± 0.7	≈8	42.8 ± 4.0	≈3	61.6 ± 10.0		
2.8-3.2	π66A	≈11	≈5	≈6	≈5	≈25	≈5	≈31
2.9-3.3	π63	12.8 ± 0.5	≈8	5.0 ± 1.0	≈2	28.9 ± 7.0		
3.8-4.2	π66A	≈4	≈2	≈7	≈2	≈23	≈2	≈28
3.8-4.2	π63	5.6 ± 0.4	≈3	1.9 ± 1.9	≈1	13.0 ± 5.4		

[a]These columns apply to the events represented in Fig. 1. The values given take into account neutral decays of Λ and K^0 and the cuts on the c.m. energy made in π66 for the maximum-likelihood fits.

presence of $Y_1^*(1385)$. The Y^* production angular distributions (Fig. 2) were obtained by dividing the events into six intervals in $\Lambda\pi$ production cosine, and, for each interval, calculating the number of Y^* events present. The fraction of each resonance and of phase space was obtained by using the maximum-likelihood fitting program MURTLEBERT,[3] which properly takes into account the effects of $K^*(890)$ production competing with Reactions (1) and (2). It was assumed that the resonances could be described by simple Breit-Wigner matrix elements with isotropic decay distributions, and that the various contributing processes were noninterfering. These assumptions seem to be justified by the absence of obviously important interference effects in the Dalitz plots and by the generally good fits we get to the mass projections over the entire momentum region for the three reactions.[4]

It is, of course, impossible to rule out some small but perhaps important interference effects or other deficiencies in the model just described. As a check on the method, the angular distributions were also obtained in a more conventional manner: by making a mass cut to select the $Y^*(1385)$, eliminating events in the $K^*(890)$ band, and subtracting, as background, regions adjacent in $\Lambda\pi$ mass. The qualitative agreement with the maximum-likelihood results was quite good.

Figure 2 contains the essential results of this report. The dominant features of Reactions (2) and (3) and the backward peaks in Reactions (1) appear consistent with the allowed t- and u-channel exchanges.[5]

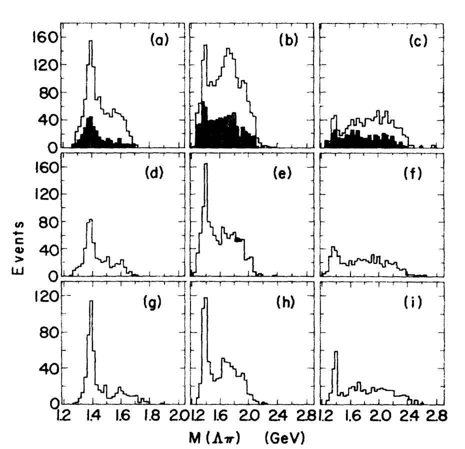

FIG. 1. Effective mass of $\Lambda\pi$ for (a)-(c) $\pi^-p\to\Lambda K^+\pi^-$ and $\pi^+n\to\Lambda K^0\pi^+$; (d)-(f) $\pi^-p\to\Lambda K^0\pi^0$ and $\pi^+n\to\Lambda K^+\pi^0$; and (g)-(i) $\pi^+p\to\Lambda K^+\pi^+$. The beam-momentum interval in (a), (d), and (g) is 1.8-2.4 GeV/c; in (b), (e), and (h), 2.8-3.3 GeV/c; and in (c), (f), and (i) 3.8-4.2 GeV/c. In (a)-(c), events with production cosine greater than $\frac{2}{3}$ are shaded.

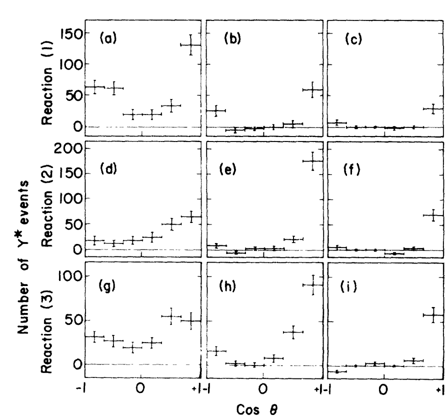

FIG. 2. $Y_1^*(1385)$ production angular distribution. The angle θ lies between the incident pion and the K in the final state. (a)-(c): Reactions (1), $\pi^-p\to Y^{*-}K^+$ and $\pi^+n\to Y^{*+}K^0$; (d)-(f): Reactions (2), $\pi^-p\to Y^{*0}K^0$ and $\pi^+n\to Y^{*0}K^+$; and (g)-(i): Reaction (3), $\pi^+p\to Y^{*+}K^+$. The beam momentum interval in (a), (d), and (g) is 1.8-2.4 GeV/c; in (b), (e), and (h), 2.8-3.3 GeV/c; and in (c), (f), and (i), 3.8-4.2 GeV/c. The errors shown are statistical only.

The statistically significant peripheral peak in Reactions (1) persists through the whole momentum region. The cross section in the forward direction is estimated to be about 7 μb/sr at 2 GeV/c and about 2 μb/sr at the higher momenta. Although the background is also peripherally peaked, the peaking is stronger in the Y^* region. The shaded events ($\cos\theta > \frac{2}{3}$) in Fig. 1 show that there is a definite Y^* signal in the forward direction. The forward peak cannot be attributed to the exchange of any single known meson, since the t-channel quantum numbers require a particle with $I=\frac{3}{2}, S=1$ [for example, in Reaction (1a), a $K^+\pi^+$ resonance].

If the reactions were dominated by a single s-channel resonant amplitude, parity conservation would require forward-backward symmetry in the production distribution in Reactions (2) as well as in (1). The absence of a backward peak in Reactions (2) at 2 GeV/c, where the statistics are best, means that at least two significant interfering amplitudes must be invoked to explain the forward peak as an s-channel effect. The persistence of the forward peak in Reactions (1) as the energy varies argues against a fairly simple s-channel effect.

Production angular distributions calculated for baryon exchange with absorption show, in some cases, a significant tail extending to $\cos\theta = +1$.[6] Although one hesitates to take such a model seriously so far from the backward region, it is conceivable that a combination of u-channel exchanges interfering in a suitable fashion, perhaps with an s-channel resonant amplitude, could generate a forward as well as a backward peak. A rapid change in relative phase with u would be required to give destructive interference in the backward direction but constructive interference in the forward direction.

We have not completed a study of the contributions of two-meson-exchange diagrams to Reactions (1). In the simple quark model, the effect we observe may be associated with double quark scattering.[7]

The absence of forward peaking in the two-body processes $\pi^- p \to \Sigma^- K^+$ and $K^- p \to \Sigma^- \pi^+$ has been cited as weak evidence against the existence of the particular meson needed to mediate these reactions.[8] The results presented here indicate that such arguments against a K^{*++} resonance are not necessarily conclusive. A similar "forbidden" forward peak has recently been observed in $K^- p \to K^+ \Xi^{*-}$ reactions.[9]

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[1]Reactions (1b), (2b), and (3) were observed in $\pi^+ d$ interactions, where one of the target baryons was assumed to be a spectator (as indicated in the parentheses). Only events with spectator momentum less than 300 MeV/c were accepted.

[2]O. I. Dahl, L. M. Hardy, R. I. Hess, J. Kirz, and D. H. Miller, Phys. Rev. 163, 1377 (1967); O. I. Dahl, L. M. Hardy, R. I. Hess, J. Kirz, D. H. Miller, and J. A. Schwartz, Phys. Rev. 163, 1430 (1967).

[3]J. Friedman, Lawrence Radiation Laboratory Alvarez Programming Group Note No. P-156, 1966 (unpublished).

[4]Reactions (1) constituted about 30 % of the $\Lambda K \pi$ events at 2 GeV/c, and about 5 % at the higher momenta; K^* production was about 40 % throughout. Reactions (2) were somewhat more copious and less obscured by K^* production. The large background makes the extraction of reliable decay-correlation information from our data most difficult.

[5]In the 2-GeV/c interval, the appearance of the backward peaks in Reactions (1) and (3) and the absence of this peak in (2) (where $I=0$ exchange is forbidden) suggest that $I=0$ baryon exchange may play a dominant role. The peripheral peaking in Reaction (2a) has been analyzed in Ref. 2 in terms of K^* exchange by use of the "K^*-photon analogy" [i.e., the SU(3)-generalized ρ-photon analogy] of Stodolsky and Sakurai. The model predicts decay correlations in reasonable agreement with the data, but the predicted zero in the production angular distribution at $\cos\theta = \pm 1$ was not clearly observed. The relative cross sections in the forward peaks in Reactions (2) and (3) are consistent with K^* exchange. Preliminary decay-correlation analysis of Reaction (3) indicates rough agreement with the predictions of the Stodolsky-Sakurai model.

[6]J. T. Donohue, thesis, University of Illinois, 1967 (unpublished).

[7]N. W. Dean, Nucl. Phys. B7, 311 (1968).

[8]G. Goldhaber, in Proceedings of the Thirteenth International Conference on High-Energy Physics, Berkeley, 1966 (University of California Press, Berkeley, Calif., 1967), p. 138.

[9]P. M. Dauber, J. P. Berge, J. R. Hubbard, D. W. Merrill, and R. A. Muller, Phys. Rev. (to be published). Various "single-meson-exchange forbidden" reactions of the form (π or K) + $N \to$ (π or K) + (member of baryon octet or decuplet) are examined in a forthcoming paper (P. M. Dauber, P. Hoch, M. A. Abolins, and D. M. Siegel, to be published). Also, the reactions $\bar{p}p \to \bar{\Sigma}^+\Sigma^-$ and $\bar{p}p \to \bar{\Xi}^+\Xi^-$ (where $Q=2$ in the t channel and $B=2$ in the u channel) have cross sections on the order of several microbarns at 3 to 4 GeV/c; in addition, although the statistics are very poor, there is

some suggestion of peripheral peaking. [See, for example, B. Musgrave et al., Nuovo Cimento 35, 735 (1965), and C. Baltay et al., Phys. Rev. 140, B1027 (1966).]

ANGULAR DISTRIBUTION OF DEUTERON PHOTODISINTEGRATION BETWEEN 240 AND 320 MeV*

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The angular distribution of deuteron photodisintegration has been measured at laboratory photon energies from 240 to 320 MeV in a spark chamber experiment at the Cornell 2-GeV synchrotron. The angular dependence of the cross section is consistent with other recent measurements. A comparison with data on the inverse reaction, $n+p\rightarrow d+\gamma$, should provide a meaningful test of time-reversal invariance in electromagnetic interactions of hadrons.

It has been suggested[1] that a violation of time-reversal invariance in the electromagnetic interactions of hadrons may produce a violation of reciprocity by the angular distributions of the reactions

$$\gamma+d\rightarrow n+p, \quad (1)$$

$$n+p\rightarrow\gamma+d, \quad (2)$$

at energies near the peak in the cross section due to the influence of the $\Delta(1236)$ resonance. In anticipation of forthcoming experimental results for the radiative neutron capture,[2] new measurements of deuteron photodisintegration have been undertaken in the hope of resolving the substantial discripancies between the previously published results.[3,4] Counter measurements have now been made using proton range,[3] proton range in coincidence with the recoil neutron,[4] and magnetic spectrometers.[5,6] The present Letter reports a new measurement performed at the Cornell 2-GeV electron synchrotron using wire spark chambers.

The experimental arrangement is shown in Fig. 1. Unpolarized bremsstrahlung beams of 350- and 450-MeV maximum energy were produced from an internal target of the synchrotron. The beam, after collimation and sweeping, struck a 3.2-in. long liquid-deuterium target. The momentum of the recoil proton was measured by means of four magnetostrictive-delay-line wire spark chambers located behind a bending magnet with a 6- by 18-in. pole gap, 36 in. long, mounted so as to bend particles in a vertical plane. Each chamber consisted of a single 0.375-in. gap bounded by two orthogonal planes of copper wires with an interwire spacing of 0.042 in., and had an active region 10 in. wide and 30 in. high. The system was triggered by three large-area scintillation counters in coincidence. The discriminator biases were adjusted to minimize triggers from minimum-ionizing particles. A helium bag extended from the target vacuum chamber through the magnet gap. The counters and chambers were rigidly attached to the magnet, which could

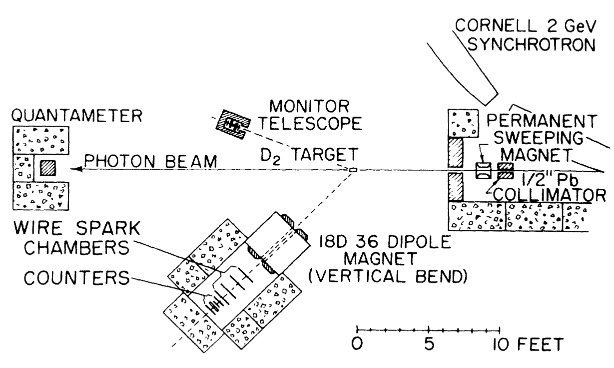

FIG. 1. Experimental layout showing the photon beam, wire–spark-chamber spectrometer, quantameter, and monitor telescope (15° with respect to the beam).

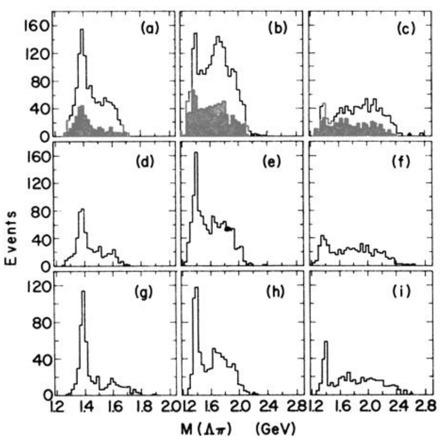

FIG. 1. Effective mass of $\Lambda\pi$ for (a)-(c) $\pi^- p \rightarrow \Lambda K^+ \pi^-$ and $\pi^+ n \rightarrow \Lambda K^0 \pi^+$; (d)-(f) $\pi^- p \rightarrow \Lambda K^0 \pi^0$ and $\pi^+ n \rightarrow \Lambda K^+ \pi^0$; and (g)-(i) $\pi^+ p \rightarrow \Lambda K^+ \pi^+$. The beam-momentum interval in (a), (d), and (g) is 1.8-2.4 GeV/c; in (b), (e), and (h), 2.8-3.3 GeV/c; and in (c), (f), and (i) 3.8-4.2 GeV/c. In (a)-(c), events with production cosine greater than $\frac{2}{3}$ are shaded.