en at 45° in the center-of-mass system and there is reason to believe that the angular distribution is not isotropic in this photon energy range, since the angular distributions for $\pi^- + p \to \eta^0 + n$ show a distinct anisotropy in the corresponding center-of-mass energy range. [See W. B. Richards et al., Phys. Rev. Letters 16, 1221 (1966)]. Thus the presentation of the eta photoproduction data from various experiments on a common graph should be considered with this in mind.

[8]A. H. Rosenfeld et al., University of California Radiation Laboratory Report No. UCRL-8030 (revised), 1966 (unpublished).

[9]F. Bulos et al., Phys. Rev. Letters 13, 486 (1964).

[10]See, for example, A. W. Hendry and R. G. Moorhouse, Phys. Letters 18, 171 (1965); James S. Ball, Phys. Rev. 149, 1191 (1961); F. Uchiyama-Campbell and R. K. Logan, Phys. Rev. 149, 1220 (1966); and Shigeo Minami, Phys. Rev. 147, 1123 (1966).

OBSERVATION OF A BACKWARD PEAK IN THE REACTION $\pi^- + p \to Y^0 + K^0$ AT 6 GeV/c †

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Recent large-angle $\pi^{\pm}p$ elastic scattering experiments in the region of ~4 to 8 GeV/c have revealed the existence of a backward peak in the $\pi^{\pm}$ angular distributions.[1] This striking feature in the elastic scattering has motivated our search for similar phenomena in other two-body final states, in particular, the final states involving associated production from $\pi^- p$ interactions.[2]

In this Letter we report the observation of a backward peak in the Y^0K^0 final state at 6 GeV/c where Y^0 is either Λ^0 or Σ^0. The slope of this backward peak is fitted by $\exp[\gamma_b(u-u_0)]$, and a value of $\gamma_b = 5.7 \pm 2$ GeV^{-2} is obtained, where u is the square of the four-momentum transfer in the appropriate crossed channels and u_0 is the kinematic maximum value of u. We have also obtained a value of the slope for the forward peak, $\gamma_f = 7.8 \pm 0.5$ GeV^{-2}, from an $\exp[\gamma_f(t-t_0)]$ fit, where t is the usual square of the four-momentum transfer for the direct channel and t_0 is the kinematic maximum value of t.

The data were obtained from the Brookhaven National Laboratory 80-inch liquid-hydrogen bubble chamber. The events in which either $K_1^0 \to \pi^+ + \pi^-$ or $\Lambda^0 \to \pi^- + p$ or both occur in the chamber are used. Events with or without a visible Λ^0 are frequently ambiguous between Σ^0 and Λ^0 hypotheses, since the energy and momentum carried by the γ ray from Σ^0 decay are compatible with the uncertainties (such as the uncertainty in beam momentum) at this high energy.[3] We do not therefore make a distinction between these two hypotheses and group them together as Y^0 in the subsequent analysis. The numbers of events found are as follows:

$$\pi^- + p \to Y^0 + K^0$$

(with both visible), 143 events; (1)

$Y^0(K)$ (with $\Lambda^0 \to \pi^- + p$), 217 events; (2)

$K^0(Y)$ (with $K_1^0 \to \pi^+ + \pi^-$), 88 events. (3)

Figure 1 is the uncorrected $\cos\theta_{K^0}$ distribution of K^0's in the center-of-mass system. Almost all of the events are found in the forward peak, but there is a well-defined backward peak comprised of ten events[4] in the region of $\cos\theta_{K^0} < -0.9$. It is interesting to note that there are only seven events from $\cos\theta_{K^0} = +0.5$ to

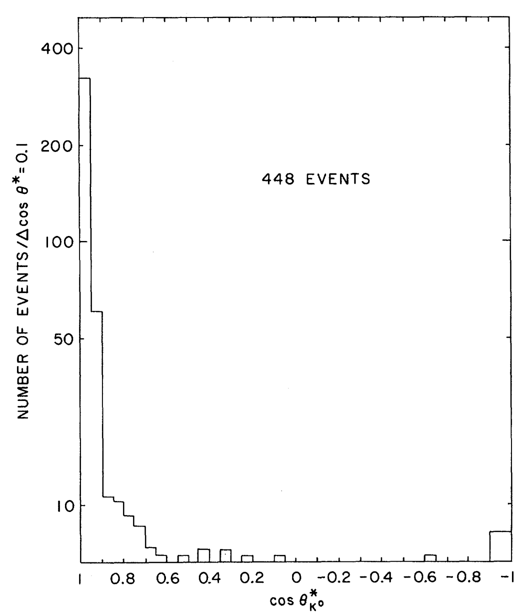

FIG. 1. Uncorrected distribution in $\cos\theta$ of K^0 in the over-all center-of-mass system.

-0.9 (outside the forward and backward peaks). Consequently, the probability of observing this backward peak due to a statistical fluctuation[5] is less than 1×10^{-6}. Table I is a tabulation of the relevant quantities for these backward events. The weights compensate for decays too close to the interaction vertex and outside of the fiducial region of the chamber.[6] Of the ten events in this backward peak at least six are Λ^0K^0 events.[7]

Figure 2(a) shows the distribution, with the escape corrections, of the square of the four-momentum transfer for events in the forward peak ($|t-t_0|\leq 0.4$ GeV^2). The straight line is a maximum likelihood fit to the corrected data, which gives $\gamma_f=7.8\pm0.5$ GeV^{-2}. The error is deduced from the width of the likelihood function. A similar calculation gives $\gamma_b=5.7\pm2$ GeV^{-2} for $|u-u_0|\leq 1.0$ GeV^2. The corrected cross section for $\pi^-+p\rightarrow Y^0+K^0$ at 6 GeV/c is 41 ± 4 μb.[8]

We have investigated the Λ^0 polarization for the subsample of events having two visible V^0's and consistent only with the Λ^0K^0 interpretation The values of $\alpha_\Lambda p_\Lambda$ vs $(t-t_0)$ in the region of $|t-t_0|\leq 0.4$ GeV^2 are plotted in Fig. 2(b), where α_Λ is the asymmetry parameter[9] (0.62) and p_Λ is the Λ polarization. For each interval in $(t-t_0)$ a value for $\alpha_\Lambda p_\Lambda$ is obtained from the angular distribution of the decay proton with respect to $\hat{n}=\hat{p}_{\mathrm{beam}}\times\hat{p}_{K^0}$, the normal to the production plane. The expected form of the distribution is $1+\alpha_\Lambda p_\Lambda\cos\theta$, where θ is the angle between the momentum of the decay proton and $\hat{n}$ in the Λ rest frame. There appears to be no significant structure in the polarization for $|t-t_0|\leq 0.4$ GeV^2, and the data are consistent with no polarization.[10]

To summarize the essential features of this

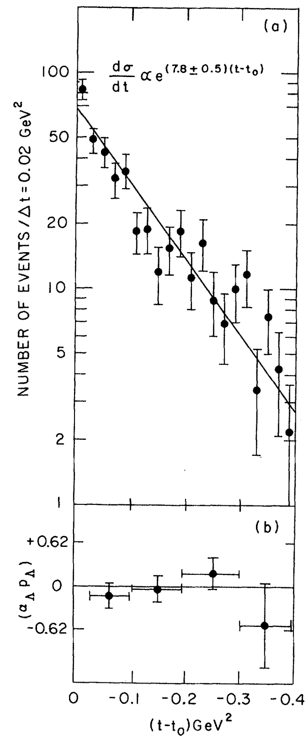

FIG. 2. (a) Corrected distribution in the square of the four-momentum transfer (t) to the K^0 in the overall center-of-mass system for $|t-t_0|\leq 0.4$ GeV^2. The straight line is a maximum likelihood fit to the corrected data (see text). (b) Λ polarization in terms of $\alpha_\Lambda p_\Lambda$ (see text) vs $(t-t_0)$ for events with both V^0's visible and consistent with only Λ^0K^0 interpretation.

reaction, we observe a backward peak in the two-body associated production at 6 GeV/c, and almost none of the events are found outside the forward or backward peaks. It is interesting to note that the value of γ_f for this reaction does not have a strong energy dependence[2]; $\gamma_f\sim 8$ GeV^{-2} from $p_\pi\sim 2$ to 6 GeV/c. This phenomenon has also been observed in the $\pi^\pm p$ diffraction scattering in this energy region[11] with a similar value, $\gamma_f\sim 8$ GeV^{-2} for $|t|\leq 0.4$ GeV^2.

We are grateful to Dr. Ralph P. Shutt for his support and encouragement. We also wish to thank the alternating-gradient synchrotron personnel, the 80-inch bubble chamber crew, and our data reduction aides for their important contributions to this experiment.

Table I. Relevant quantities for the backward events ($\cos\theta_{K^0}<-0.9$).

$\cos\theta_{K^0}$	$\lvert u-u_0\rvert$	Visible V^0	MM^2	Weight
−0.925	0.358	Λ^0	0.711 ± 0.117	1.0
−0.937	0.308	Λ^0	0.248 ± 0.116	1.1
−0.938	0.296	Λ^0	1.023 ± 0.302	1.2
−0.945	0.268	Λ^0	-0.067 ± 0.341	1.3
−0.949	0.249	Λ^0	0.286 ± 0.115	1.0
−0.956	0.212	K^0	1.405 ± 0.085	1.2
−0.987	0.063	K^0	1.259 ± 0.471	1.3
−0.996	0.024	Λ^0K^0	-0.001 ± 0.001	1.3
−0.997	0.015	Λ^0	0.214 ± 0.137	1.5
−0.998	0.010	K^0	1.227 ± 0.040	1.2

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[1]It is important to note that the backward as well as the forward peaks in the low energy region ($p_\pi\leq 4$ BeV/c in the laboratory system) may be related to the characteristic decays of some well known N^* in the di-

rect (formation) channel. See, for example, R. M. Heinz and M. H. Ross, Phys. Rev. Letters 14, 1091 (1965). We therefore only cite the data for $p_\pi \geq 4$ GeV/c. Aachen-Berlin-Birmingham-Bonn-Hamburg-London-Munchen Collaboration, Phys. Letters 10, 248 (1964); M. Deutschman, D. Kropp, S. Nagel, H. Weber, W. Woischnig, C. Grote, J. Klugow, S. Nowak, S. Brandt, V. T. Cocconi, O. Csyzewski, J. Danysz, P. Dalpiag, G. Kellner, and D. R. O. Morrison, CERN Report No. 64-31 (unpublished); W. R. Frisken, A. L. Read, H. Ruderman, A. D. Krisch, J. Orear, R. Rubinstein, D. B. Scarl, and D. H. White, Phys. Rev. Letters 15, 313 (1965); C. T. Coffin, N. Dikmen, L. Ettlinger, D. Meyer, A. Saulys, K. Terwilliger, and D. Williams, Phys. Rev. Letters 17, 458 (1966).

[2]This phenomenon has been observed in the low energy region ($p_\pi \leq 4$ GeV/c) and the existing data come mainly from the region of ~2 and ~3 GeV/c. See J. Kirz, O. Dahl, L. Hardy, R. Hess and D. Miller, in Proceedings of the Thirteenth International Conference on High Energy Physics, Berkeley, California, 1966 (unpublished), and earlier references given in this paper. Again $N_{1/2}^*(2190)$ and $N_{1/2}^*(2650)$, which cover the p_π from 1.85 to 2.3 GeV/c and 2.85 to 3.8 GeV/c from the known widths, may simulate structures in the backward region in the Λ^0K^0 formation channel (see Ref. 1).

[3]We have, however, estimated the percentage of ambiguity between Σ^0K^0 and Λ^0K^0 events from the sample with both Λ^0 and K^0 seen. We conclude that the cross contamination for events with one visible V^0 is ~20% in the forward hemisphere.

[4]Each event was visually examined by physicists to check its consistency with the interpretation. To study the possible background contamination from quasi–two-body reactions, we have examined all events with backward K^0's or forward Λ^0's. We found only one additional event [K^0 + (MM = 1496 ± 23) with $\cos\theta_{K^0} = -0.912$].

[5]One expects to be able to analyze the angular distribution in terms of a forward peak, a background, and perhaps a backward peak. In order to show that the observed backward peak is not simply a fluctuation in an assumed flat background we use the region $+0.5 \leq \cos\theta$ -0.9 to estimate this background. The seven events in these 14 bins give an average of $\frac{1}{2}$ event per bin. The probability of observing ten or more events drawn from a Poisson population with a mean of $\frac{1}{2}$ is 2×10^{-10}. Of course, one should also consider the error in the estimate of the average number of events per bin. The probability quoted in the text was obtained by integrating over all possible values of this mean, the product of observing seven or fewer events in 14 bins and 10 or more in the single backward bin.

[6]This however does not include the possible scanning bias. This correction can be as high as 20% in the backward peak.

[7]The event with both V^0's visible is unambiguously Λ^0K^0. The three events with visible K^0's are well determined and one of these is more likely $K^0\Sigma^0$ while the remaining two are most likely $K^0\Lambda^0$. The six events with visible Λ^0 decays are more difficult to interpret because, if the Λ comes from Σ decay, the square of the missing mass varies from 0.25 to 1.56 linearly with the cosine of the Σ^0 center-of-mass decay angle. Since parity is conserved in the electromagnetic decay of Σ^0, we expect as many forward as backward decays and hence as many missing-mass squared values above 0.90 as below it. Five of these six events have missing-mass-squared values less than 0.90 and four of the six are consistent with a missing K^0 alone. It is unlikely that more than four of these six events are Σ^0K^0. In summary, the ten Y^0K^0 events are probably distributed as six Λ^0K^0, three Σ^0K^0, and one undetermined.

[8]Based on the estimated cross contamination between Σ^0K^0 and Λ^0K^0 events from Ref. 3, we obtain $\sigma(\pi^- + p \to \Lambda^0 + K^0) \simeq 23.5 \pm 4\ \mu$b and $\sigma(\pi^- + p \to \Sigma^0 + K^0) \simeq 17.5 \pm 4\ \mu$b.

[9]J. W. Cronin and O. E. Overseth, Phys. Rev. 129, 1795 (1963).

[10]Similar behavior in the Λ^0 polarization is also observed in the events in which only the Λ^0 is seen.

[11]See, for example, K. J. Foley, S. J. Lindenbaum, W. A. Love, S. Ozaki, J. J. Russell, and L. C. L. Yuan, Phys. Rev. Letters 11, 425 (1963); and C. T. Coffin, N. Dikmen, L. Ettlinger, D. Meyer, A. Saulys, K. Terwilliger, and D. Williams, Phys. Rev. Letters 15, 838 (1965); 17, 458 (1966).