Measurement of the backward peaks in the reactions $\pi^- p \to K^0 \Lambda$ and $\pi^- p \to K^{*0}(890)\Lambda$

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We present the differential cross sections near $u = 0$ for the reactions $\pi^- p \to K^0\Lambda$ and $\pi^- p \to K^{*0}(890)\Lambda$ at incident pion momenta of 8 and 10.7 GeV/c. The differential cross section for the first reaction follows the exponential dependence on u previously observed, while the second shows a dip in the backward direction.

I. INTRODUCTION

We have measured the differential cross sections for the reactions

$$\pi^- p \to K^0\Lambda\,, \qquad (1)$$

$$\pi^- p \to K^{*0}(890)\Lambda \qquad (2)$$

near 180° in the center-of-mass frame at two momenta: 8.0 and 10.7 GeV/c. The Λ was produced in the forward direction in the center-of-mass frame ($u \approx 0$). We have previously published[1] the data from this experiment for reaction (1) for forward K^0 ($t \approx 0$), and the reader is referred to that article for a more complete description of the apparatus. Earlier measurements[2] have been reported for reaction (1), but reaction (2) has not been previously reported in this region of u.

II. EXPERIMENT

Momentum-analyzed negative pions produced at 0° at the A target station of the slow extracted beam from the Brookhaven AGS were incident on a 60-cm-long liquid hydrogen target. The trigger system selected neutral vees which decayed downstream of the hydrogen target. Positive and negative particles from the decays were detected in the forward arm of the Brookhaven Double Vee Magnetic Spectrometer.[3] The mass of the reconstructed vees was calculated assuming (A) a proton and a pion, and (B) two pions. Clear peaks were observed at the Λ mass for assumption (A) and the K^0 mass for assumption (B).[1] The effective mass spectrum of the proton and pion is shown in Fig. 1. The location of the peak is within our estimated systematic error (≤ 0.5 MeV) of the accepted mass of the Λ. Events in which the forward-going particles fitted both the Λ and K^0 masses were rejected. This was 6% of the Λ events at 10.7 GeV/c and none at 8.0 GeV/c. The Λ mass resolution is ≈ 1 MeV (rms). We estimate the background under the Λ's to be $\lesssim 1\%$.

The missing-mass-squared spectra recoiling

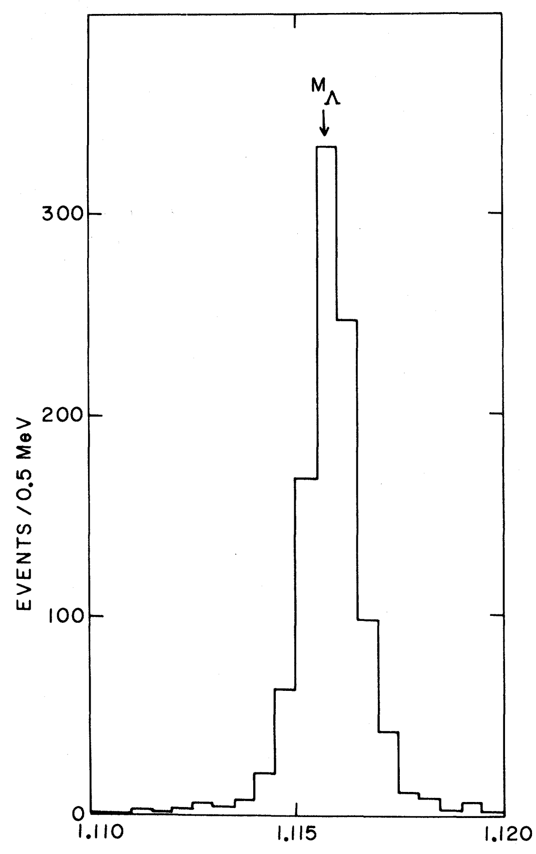

FIG. 1. Effective mass of proton and π^- for the 8.0-GeV/c data.

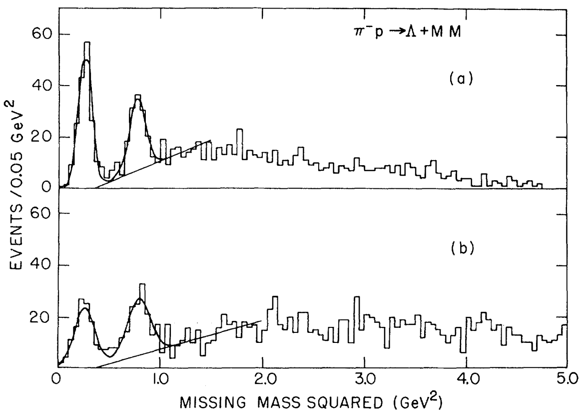

FIG. 2. Missing-mass-squared spectra for the reaction $\pi^- p \to \Lambda + \mathrm{MM}$ at (a) 8.0 GeV/c and (b) 10.7 GeV/c. The curves are the results of a maximum-likelihood fit, as explained in the text.

from the Λ's are shown in Fig. 2 for (a) 8.0 GeV/c and (b) 10.7 GeV/c. Clear peaks are seen corresponding to K^0 and $K^{*0}(890)$ production.[4] In this figure, no correction has been applied for the acceptance of the apparatus. The depletion of events at high missing mass is due to low acceptance for Λ's whose decay includes a low-momentum pion.

In order to extract cross sections, we have fitted the missing-mass-squared spectra of Fig. 2 with a Gaussian representing our experimental resolution at the K^0 mass and an S-wave Breit-Wigner form at the $K^{*0}(890)$ mass folded with the same Gaussian resolution plus a linear background. Since the variation of the acceptance as a function of mass was relatively small (less than 20% in the mass interval between K^0 and K^{*0}), the data in the fitted peaks were corrected for the acceptance after the fits were done. The fits shown in Fig. 2 were obtained by using a maximum-likelihood technique with the resolution, the K^0 and K^{*0} masses, the amplitude of each peak, and the background as free parameters.[5] The width of the $K^{*0}(890)$ was fixed at $\Gamma = 45$ MeV for the fit. The missing-mass-squared resolution obtained (67 MeV^2 at 8 GeV/c and 102 MeV^2 at 10.7 GeV/c) agrees with that estimated from knowledge of the angular and momentum resolution of the spectrometer. The fitted masses of the K^0 and $K^{*0}(890)$ did not deviate by more than about one standard deviation from the accepted values. The fits were done over the missing-mass-squared ranges of 0 to 1.5 GeV^2 and 0 to 2.0 GeV^2 at 8.0 and 10.7 GeV/c, respectively. The size of these intervals was picked so that the background could be reasonably represented by a linear function.

In order to obtain the u dependence of the differential cross sections, we divided the data into bins in $u' = u - u_{\mathrm{max}}$ of width 0.05 (GeV/c)^2. These data and the fits at 8.0 GeV/c are shown in Fig. 3. Clearly, the ratio of K^0 to K^{*0} production is a strong function of u'. The u' dependence of the apparatus acceptance for small $|u'|$ can be represented within errors by a monotonically decreasing linear function. To obtain these fits we used the amplitudes of the two peaks and the background as free parameters; the other parameters were fixed at the values obtained from the fits in the overall spectrum in Fig. 2.

III. CORRECTIONS TO THE DATA

The data were corrected for the following effects:

(1) inefficiency of the trigger system (5%),

(2) event reconstruction inefficiency (10–15%) (for details see Ref. 1),

(3) acceptance of the spectrometer including the effect of the veto counter (the acceptance ranged from 1% to 20%),

(4) electron and muon contamination of the beam (8–10%),

(5) pion decays in the spectrometer (6%),

(6) ambiguities between the Λ and K^0 hypotheses

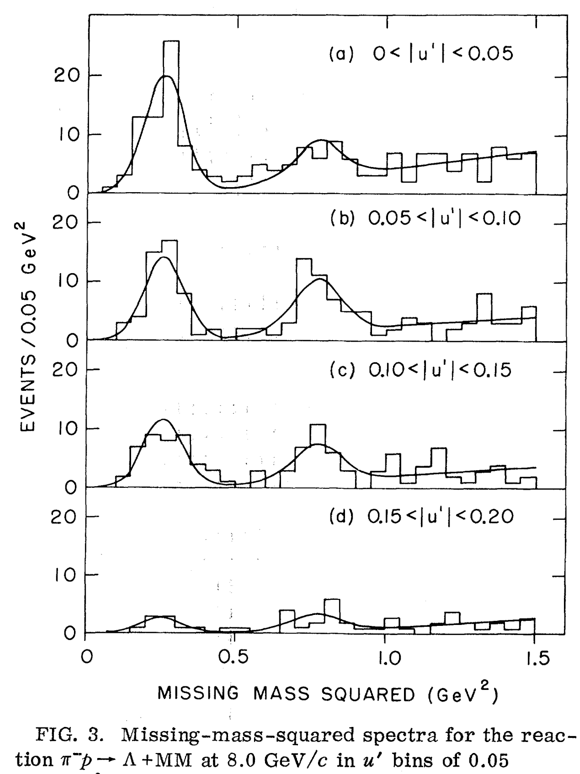

FIG. 3. Missing-mass-squared spectra for the reaction $\pi^- p \to \Lambda + \mathrm{MM}$ at 8.0 GeV/c in u' bins of 0.05 (GeV/c)^2. The curves are the results of a maximum-likelihood fit, as explained in the text.

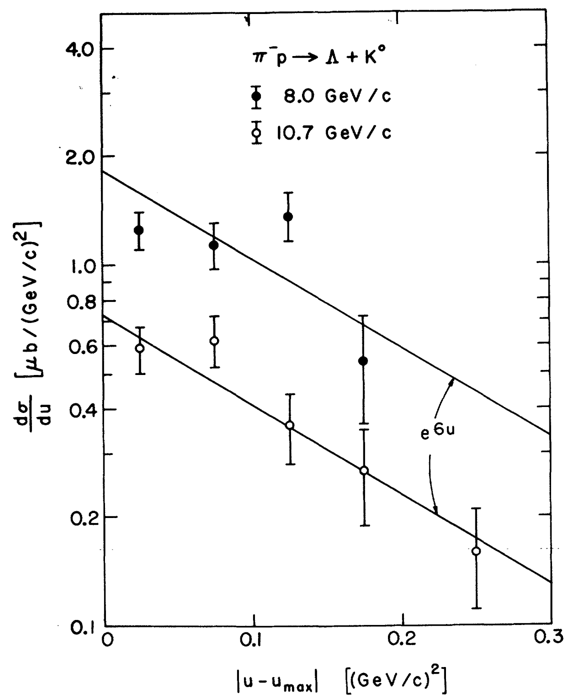

FIG. 4. Differential cross sections for the reaction $\pi^- p \to K^0\Lambda$ near $u' = 0$ at two momenta. The errors shown are statistical only. The lines represent the e^{6u} peak shape used to estimate the contribution to the backward peak from $|u'|$ greater than the measurements. There is an overall systematic uncertainty estimated to be $\approx 25\%$.

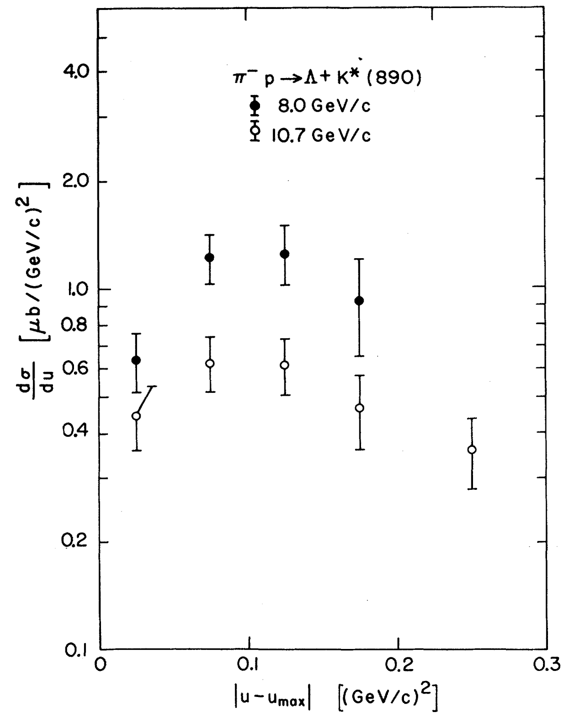

FIG. 5. Differential cross sections for the reaction $\pi^- p \to K^{*0}(890)\Lambda$ near $u' = 0$ at two momenta. The errors shown are statistical only. There is an overall systematic uncertainty estimated to be $\approx 25\%$.

(see Sec. II) (0 at 8 GeV/c and 6% at 10.7 GeV/c),

(7) neutral decay mode of Λ (36%),

(8) nuclear attenuation in the hydrogen target and spectrometer counters (7%).

IV. CROSS SECTIONS AND CONCLUSIONS

The differential cross sections obtained are shown in Figs. 4 and 5, and listed in Tables I and II. The errors are statistical only. We estimate an overall systematic uncertainty of $\simeq 25\%$; the main contributions are the uncertainties in the acceptance calculation, event reconstruction efficiency, and background subtraction for the maximum-likelihood fits.

We observe a backward peak for reaction (1) in agreement with earlier results for this reaction.[2] For reaction (2), which has not previously been measured in the u channel, we observe a signifi-

TABLE I. Differential cross section for the reaction $\pi^- p \to K^0\Lambda$ near $u' = 0$. The errors shown are statistical only. We estimate the systematic error to be $\approx 25\%$.

	$-u'$ [(GeV/c)^2]	Events	$\frac{d\sigma}{du}$ [μb/(GeV/c)^2]
8.0 GeV/c	0–0.05	69	1.25±0.15
	0.05–0.10	47	1.13±0.16
	0.10–0.15	40	1.36±0.21
	0.15–0.20	9	0.54±0.18
10.7 GeV/c	0–0.05	38	0.59±0.09
	0.05–0.10	36	0.62±0.10
	0.10–0.15	18	0.36±0.08
	0.15–0.20	11	0.27±0.08
	0.20–0.30	10	0.16±0.05

TABLE II. Differential cross section for the reaction $\pi^- p \to K^{*0}(890)\Lambda$ near $u' = 0$. The errors shown are statistical only. We estimate the systematic errors to be $\approx 25\%$.

	$-u'$ [(GeV/c)^2]	Events	$\frac{d\sigma}{du}$ [μb/(GeV/c)^2]
8.0 GeV/c	0–0.05	27	0.64±0.12
	0.05–0.10	39	1.22±0.19
	0.10–0.15	27	1.26±0.24
	0.15–0.20	11	0.93±0.28
10.7 GeV/c	0–0.05	25	0.45±0.09
	0.05–0.10	31	0.63±0.11
	0.10–0.15	27	0.62±0.11
	0.15–0.20	18	0.47±0.11
	0.20–0.30	20	0.36±0.08

TABLE III. Integrated cross sections for the reaction $\pi^- p \to K^0\Lambda$ in the $u' = 0$ peak region. This was obtained by summing the data and adding the contribution of the integral of $Ae^{6u'}$ for the unmeasured region. The largest contribution to the error in the cross section is the systematic uncertainty of ≈ 25%.

Momentum (GeV/c)	u' range [(GeV/c)^2]	Measured contribution (μb)	Contribution due to integral (μb)	Total (μb)
8.0	0–0.2	0.21	0.09	0.30 ± 0.08
10.7	0–0.3	0.11	0.02	0.13 ± 0.035

cant deviation from pure exponential behavior for $|u'| < 0.05$ (GeV/c)^2. At both momenta a dip is seen in the backward direction. This could imply a large spin-flip contribution for small values of $|u'|$ for reaction (2).

We have obtained integrated cross sections for the backward peak for reaction (1), shown in Fig. 4, by summing the measured differential cross sections and adding the contribution for $-u' > 0.2$ or 0.3 by using a peak shape $e^{6u'}$, a reasonable representation of the data. These are given in Table III and shown in Fig. 6. The errors shown include, in addition to the statistical error, the 25% systematic error in the absolute cross section. The data agree with earlier measurements[2] which are also shown in Fig. 6. The line shows the functional form $\sigma_{\text{backward}} \propto P_{\text{lab}}^{-3}$, which describes the behavior of the data as a function P_{lab} from 4 to 12 GeV/c.

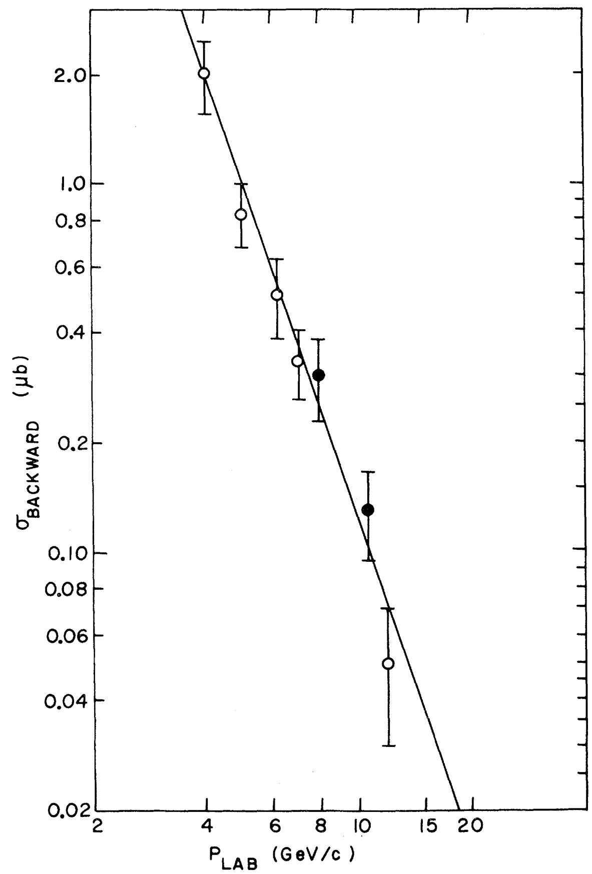

FIG. 6. The integrated cross section for the reaction $\pi^- p \to K^0\Lambda$ for the peak near $u' = 0$. The errors represent a systematic uncertainty of 25%. ● this experiment. ○ Beusch *et al.*, Ref. 2. The line is a P_{lab}^{-3} dependence drawn through the 4 GeV/c point.

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[4]A possible background is from the reaction $\pi^- + p \to \Sigma^0(\to \Lambda + \gamma) + K^0$. However, the energy spectrum of γ rays from decaying 8-GeV/c Σ^0's is flat and ranges from 5 MeV to 1 GeV. Consequently the missing mass from the detected Λ would range from the K^0 (K^*) mass to $\gtrsim 1.5$ GeV. Any background under the peaks will be subtracted in the fitting procedure.

[5]We have used a background which is linear in missing mass squared. Considering the statistics of this experiment, this simple function adequately represents the background under the K^* peaks. We estimate that our results would change by less than our overall systematic uncertainty of $\simeq 25\%$ by using nonlinear functional forms.

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K^+-proton scattering from 200 to 600 MeV/c *

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The differential cross section for K^+p elastic scattering has been measured at several momenta in the interval 200–600 MeV/c within a hydrogen bubble chamber. The data have been fitted with a partial-wave analysis. We obtain solutions which are dominated over the entire momentum range by s-wave scattering, with constructive interference between the nuclear and Coulomb scattering. The effective-range approximation with only s waves yields a K^+p scattering length $a = -0.314 \pm 0.007$ F and an effective range $r_0 = 0.36 \pm 0.07$ F. The measured total inelastic cross section at 588 MeV/c is 11^{+9}_{-5} μb.

I. INTRODUCTION

Low-energy K^+-proton scattering information serves as an anchor point for the evaluation of K-nucleon dispersion relations and KYN coupling constants and for phase-shift analyses that search for exotic Z^* resonances in K-nucleon interactions. To improve this anchor point beyond the pioneering efforts of the Berkeley group[1,2] more than a decade ago, we have carried out a new investigation of K^+p differential cross sections in the momentum interval 200–600 MeV/c with improved statistics. Because of a suggestion by Carreras and Donnachie[3,4] that predominantly attractive s-wave scattering could give a good description of K^+p elastic scattering below 2.0 GeV/c, care has been taken to extend differential cross-section measurements far into the Coulomb-nuclear interference region.

The phase-shift solutions obtained using our data with an energy-independent phase-shift analysis[5] with pure s-wave nuclear scattering are satisfactory over the entire momentum interval, in agreement with the earlier results of Goldhaber *et al.*[1] In addition, we find that the K^+p strong interaction interferes constructively with Coulomb scattering and is therefore repulsive at these momenta. Using the effective-range approximation to fit the pure s-wave phase shifts gives the K^+p scattering length $a = -0.314 \pm 0.007$ F and the effective range $r_0 = 0.36 \pm 0.07$ F.

We have measured the total inelastic cross section at the upper end of the momentum range just 80 MeV/c above threshold.

II. EXPERIMENTAL METHOD

The experiment[6] was performed in the BNL-Columbia 30-inch hydrogen bubble chamber using the low-energy separated K^+ beam[7] at Brookhaven National Laboratory. The beam was transported at 614 MeV/c and moderated by means of copper absorbers upstream of the bubble chamber. The experiment consisted of 93 000 photographs divided up into four approximately equal runs at nominal K^+ momenta of 250, 360, 470, and 575 MeV/c. The distribution of beam momenta as measured at the interaction vertex for these runs is given in Fig. 1. The data at the lowest momentum were separated for the phase-shift analysis into two momentum regions, 110–200 MeV/c and 200–320 MeV/c. As indicated in Fig. 1, the mean momenta of the five sets of data are 178, 265, 351, 475, and 588 MeV/c.