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Total Cross Sections for $\pi^- p \rightarrow \Lambda K^0$ from Threshold to 1.13 GeV/c*

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Total cross sections for $\pi^- p \rightarrow \Lambda K^0$ have been measured using optical spark chambers from threshold to 1.13-GeV/c beam momentum in 19-MeV/c intervals, but with a 1-MeV/c resolution in the regions of the ΛK and ΣK thresholds. The behavior near ΛK threshold indicates a significant s-wave contribution, but this experiment is unable to resolve any cusplike behavior in the region of the ΣK thresholds. The cross section shows a broad peak in the vicinity of 1.05-GeV/c beam momentum.

A number of experimental studies have been made of the momentum dependence of the total cross section for the reaction $\pi^- p \rightarrow \Lambda K^0$ in the region of incident pion momentum extending from threshold up to and beyond that corresponding to the thresholds for $\Sigma^0 K^0$ and $\Sigma^- K^+$ production.[1-8] These studies have sought to clarify the mechanism for ΛK production near threshold, to search for new resonances, and to find evidence for the predicted cusplike behavior of the total cross section in the region of the ΣK thresholds. A limitation in previously published studies has been imposed by the uncertainty in the incident pion momentum, typically ±2%, which places a lower limit on the characteristic width of detectable structure of ~20 MeV/c. In the present experiment, the width of detectable structure in the momentum dependence of the total cross section for ΛK production is reduced to ±1 MeV/c by the use of a spark-chamber spectrometer in the incident pion beam. This apparatus, described elsewhere,[9] permits determination of the momentum of individual incident pions with a relative precision better than ±0.1%, and with an absolute calibration obtained from kinematic event fitting near the $\Lambda^0 K^0$ and $\Sigma^0 K^0$ thresholds.

The present experiment employed a secondary pion beam of the Lawrence Radiation Laboratory Bevatron whose central momentum was adjusted from 0.910 to 1.135 GeV/c with a momentum spread at any setting of approximately 2%. After passing through the spectrometer, this beam was focused on a 1-in.-thick liquid-hydrogen target. An array of spark chambers located upstream and downstream from the target permitted 90° stereo photography of the tracks of incident pions and the charged decay products in addition to photographs of the spectrometer. The entire spark-chamber array was triggered by a counter arrangement similar to that first used by Cronin and Overseth[10] which selected those events in which a pion enters the target, no charged secondaries emerge from the target, and charged decay particles are produced further downstream.

During the experiment 6.2×10^5 photographs were taken. Data taken at the three central momentum settings of 0.910, 0.926, and 1.040 GeV/c were subdivided into 1-MeV/c momentum intervals according to the momentum determination obtained with the spectrometer, whereas the remaining momentum settings were treated as single data points. In order to compute cross sections, beam-momentum profiles were determined at the 0.910-, 0.926-, and 1.040-GeV/c settings by also measuring momenta for events in which the beam particle did not interact in the hydrogen target, but did interact in the range chamber. These beam-track events represented "leakage" through the anticoincidence counter following the hydrogen target and were uniformly distributed throughout the same film in which the ΛK events were located. This procedure permitted study of the entire region from threshold to 1.135 GeV/c with enhanced precision in momentum near threshold and in the region of the ΣK thresholds.

All film was scanned twice with overall scanning efficiency of 99% and measured on a precision measuring projector directly coupled to a card punch. These measurements were subjected to analysis by a combination of computer programs which yielded a three-dimensional reconstruction of all tracks, performed a least-squares fit to the decay vertex for the two Λ or K^0 decay tracks, and solved for the production vertex defined as the point of intersection of the plane of decay with the track of the incident pion.

Least-squares fits to four different assumptions of particle identification and production reaction were attempted for each event; one each to the neutral decay of K^0 produced in association with either a Λ or a Σ^0 and two to the decay of a Λ directly produced in which each of the two decay tracks was, in turn, assumed to be the proton and the other the pion.

Artificial events were generated by a Monte Carlo program using angular distributions from bubble-chamber experiments[1-5] to provide a means of correcting for known biases and to expose any unknown ones introduced by the analysis programs. The known biases consisted of an elimination of events with tracks making an angle of greater than 60° with the axis of the apparatus (due to inefficiencies of the spark chambers above this angle) and several minor geometric restrictions of the apparatus. The analysis of the Monte Carlo events revealed that the events with the strange particles going either forward or backward in the center of mass were favored relative to those with transverse production of the strange particles. These Monte Carlo events then formed the basis for a correction factor which remained constant to within ±15% over the range of this experiment.

A similar Monte Carlo generation of $\pi^-p \to \Sigma^0K^0$ events was utilized to determine the degree to which the Λ-decay data was contaminated by Λ's originating from Σ^0 decays. It was found that a negligible proportion of Λ decays generated in this way yielded an acceptable fit.

The beam contamination was determined for the 0.910-, 0.926-, and 1.040-GeV/c-momentum data samples with the aid of the distribution of nuclear interaction events in the range chamber. The results indicate a momentum-independent electron contamination of $(6.5 \pm 0.4)\%$ and a momentum-dependent muon contamination of $[(9.2 \pm 0.5\ \mathrm{GeV}/c)/p_\pi]\%$.

The observed total cross sections for $\pi^-p \to \Lambda K^0$ at the thirteen pion-central-momentum settings from 0.910 to 1.135 GeV/c are given in Table I and are shown in Fig. 1(a). For comparison, the contributions which might be naively expected from the various partial waves are shown in Fig. 1(b), where the π^-p, $I = \frac{1}{2}$ partial cross sections $\sigma_l(\pi N)$, computed from the phase shifts of Davies,[11] have each been weighted by the factor ξ_l to account for the difference in phase-space and barrier-penetration factors between a ΛK final state and a πp final state; $\xi_l = qv_l(qR)/kv_l(kR)$, where q is the c.m. ΛK momentum, k is the c.m. πp momentum, R is taken to be the pion Compton wavelength, and v_l is the "penetration factor" defined by Blatt and Weisskopf.[12] Also shown for comparison are the results of others in Fig. 1(c). While there is reasonable agreement below p_π

Table I. $\pi^-p \to \Lambda K^0$ total cross sections.

Beam momentum (GeV/c)	No. of π's ($\times 10^8$)	No. of Λ events With spectrometer	Total	$\sigma(\Lambda K)$ (mb)[a]
0.910	3.52	198	252	0.122 ± 0.010
0.926	1.63	192	286	0.227 ± 0.018
0.945	0.62		165	0.336 ± 0.040
0.964	0.62		219	0.427 ± 0.034
0.983	0.69		345	0.576 ± 0.051
1.002	0.57		300	0.588 ± 0.073
1.021	0.63		463	0.809 ± 0.090
1.040	10.08	5873	8591	0.926 ± 0.031
1.059	0.44		369	0.899 ± 0.058
1.078	0.84		619	0.794 ± 0.056
1.097	0.88		592	0.729 ± 0.040
1.116	0.85		450	0.575 ± 0.034
1.135	0.93		456	0.541 ± 0.049

[a] Errors given are internal statistical errors, only; the absolute–cross-section calibration is uncertain by ±10%.

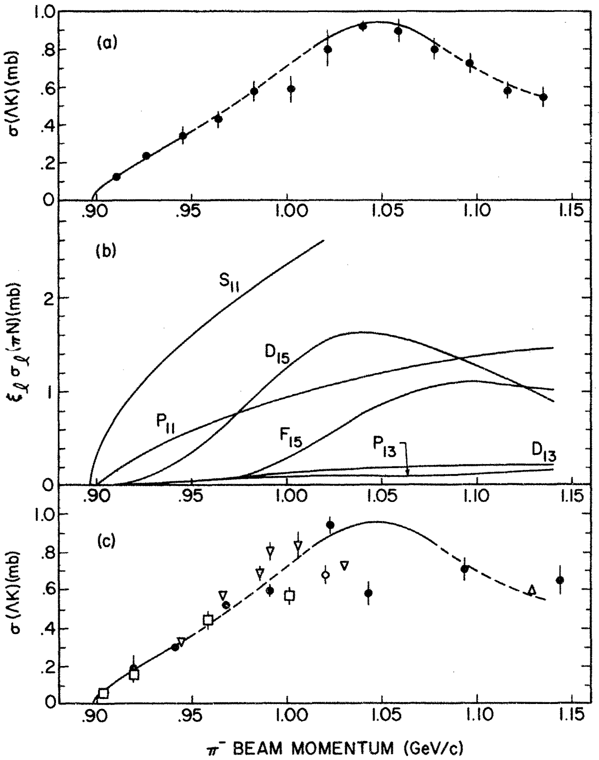

FIG. 1. (a) Total cross sections for $\pi^- p \rightarrow \Lambda K^0$ from this experiment at 19-MeV/c intervals of beam momentum (beam spectrometer information not used). Errors shown are internal statistical errors only; the absolute-cross-section calibration is uncertain by ±10%. Solid portions of the curve are the fits shown in Figs. 2(a) and 2(b). (b) Partial total cross sections computed from $I=\frac{1}{2}$ πN phase shifts corrected for phase-space and barrier-penetration factors of the ΛK final state (see text). (c) Total cross sections for $\pi^- p \rightarrow \Lambda K^0$ observed by others compared with the curve from (a). The symbols correspond to the following references: squares, Ref. 4; open circles, Ref. 5; triangles, Ref. 6; closed circles, Ref. 7; inverted triangles, Ref. 8.

$\cong 0.98$ GeV/c and above $p_\pi \cong 1.05$ GeV/c, there is surprisingly poor agreement among experimenters on the shape between 0.98 and 1.05 GeV/c in the region of the maximum.

In Fig. 2(a) the ΛK cross sections from the 0.910- and 0.926-GeV/c data having good spectrometer measurements are presented as a function of c.m. ΛK momentum q to show the threshold behavior. The data up to $p_\pi \approx 0.97$ GeV/c ($q \approx 0.17$ GeV/c) fits the relation $\sigma(\Lambda K) = Aq + Bq^3/[1+(qR)^2]$ with $A = 1.22 \pm 0.23$ mb (GeV/c)$^{-1}$ and $B = 120 \pm 29$ mb (GeV/c)$^{-3}$. The fact that the average polarization (uncorrected for triggering biases) for the events observed from the threshold to 0.915 GeV/c is $(+0.5 \pm 12.5)\%$ compared to $(-30 \pm 9)\%$ for pion momenta between 0.915 and 0.945 GeV/c gives additional evidence that ΛK production is initially pure s wave with p-wave production becoming important not far above threshold.

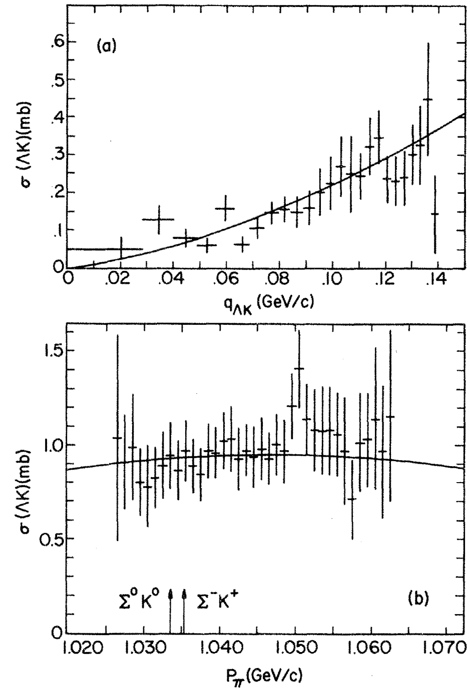

FIG. 2. (a) Total cross sections for $\pi^- p \rightarrow \Lambda K^0$ near threshold versus c.m. ΛK momentum q using the pion beam spectrometer. The curve gives the best fit described in the text. (b) Total cross sections for $\pi^- p \rightarrow \Lambda K^0$ at 1-MeV/c intervals of pion-beam-spectrometer momentum near thresholds of $\Sigma^0 K^0$ and $\Sigma^- K^+$ production (indicated by arrows). The curve shows the best least squares fit of a quadratic function of beam momentum to the data shown plus the cross sections (without spectrometer information) at 0.983, 1.002, 1.021, 1.059, and 1.078 GeV/c.

In Fig. 2(b) the ΛK cross sections from the 1.040-GeV/c data having good spectrometer measurements show the behavior in the region of the $\Sigma^0 K^0$ and $\Sigma^- K^+$ thresholds at pion beam momenta of 1.0335 and 1.0352 GeV/c, respectively. No statistically significant structure is observable at these thresholds, but a narrow peak (full width at half-maximum ~2 MeV/c) at 1.050 GeV/c appears with marginal statistical significance. The possibility that the absolute beam-momentum calibration might be 15 MeV/c too high, and thus move the observed peak to the ΣK thresholds, was investigated by searching all the nominal 1.040 GeV/c data for K^0 decay events attributable to $\Sigma^0 K^0$ production near threshold without using any spectrometer information. The beam momenta obtained from the kinematic fitting of such events were then compared with the spectrometer measurements. Every such comparison either agreed within errors, or the fitted momentum was much higher (because of the presence of spurious fits to the Σ^0K^0 hypothesis); there were no events where the fitted beam momentum was 15 MeV/c lower than the spectrometer measurement, as would be required to interpret the observed 1.050-GeV/c peak as a cusp effect. In summary, ΛK production cross sections measured to ±16% at 1-MeV/c intervals of beam momentum are insufficient to resolve possible cusp effects at the ΣK thresholds.

The threshold dependence of the ΛK total production cross section found in this experiment indicates that the S_{11} amplitude must dominate up to $P_\pi \approx 0.95$ GeV/c. If the S_{11} wave behavior at higher momenta is similar to that shown in Fig. 1(b), it must be one of the more important amplitudes throughout the momentum range studied, in agreement with the phase-shift solutions of Rush,[13] Deans, Holladay, and Rush,[14] and Lovelace, Wagner, and Iliopoulos,[15] and with solution I of Doyle.[8] If phase-space and barrier-penetration factors corresponding to potential radii in the neighborhood of a pion Compton wavelength are at least qualitatively correct in describing the decays of the D_{15} and F_{15} resonances into the ΛK final state, then only the D_{15} resonance could account for the maximum in the ΛK production cross section at about 1.04 GeV/c. (Note that the D_{15} πN cross section peaks at about 0.99 GeV/c, indicating that barrier penetration effects considerably shift the expected peak for decay into ΛK.) The excellent agreement between the locations of the peaks of the expected D_{15} resonance contribution and the observed ΛK cross section may be an accident, since a large component attributable to a D_{15} wave is not seen in bubble-chamber angular distributions.[8] On the other hand, the $\sigma(\Lambda K)$ peak may be caused by the D_{15} resonance decaying into ΛK, the resulting d-wave component having been underestimated by bubble-chamber experimenters, perhaps because of smoothing effects introduced by errors in measuring and in the kinematic fitting process.

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