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$K_L^o p \to pK_S^o$ BACKWARD SCATTERING FROM 1.0 TO 7.5 GeV/c*

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ABSTRACT

Backward scattering in the reaction $K_L^o p \to pK_S^o$ is studied in the momentum interval 1.0 to 7.5 GeV/c. Comparison of $K_L^o p \to pK_S^o$ and $K^+ p \to pK^+$ backward scattering, where respectively Σ exchange and Λ plus Σ exchange can contribute in the u channel, reveals that

$$\left(\frac{d\sigma}{d\Omega}\right)_{180^o}(K_L^o p \to pK_S^o) \ll \left(\frac{d\sigma}{d\Omega}\right)_{180^o}(K^+ p \to pK^+)$$

above the resonance region. This result provides direct evidence for the dominance of the Λ contribution over the Σ contribution in the $K^+ p \to pK^+$ production amplitude.

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In this Letter we present the first measurement of the backward differential cross section for the reaction

$$K_L^o p \to p K_S^o \qquad (1)$$

in the momentum interval 1.0 to 7.5 GeV/c. When combined with previously measured $K^+ p \to p K^+$ cross sections, these data provide a direct comparison of Λ and Σ exchange couplings.

Indirect comparisons of the Λ and Σ couplings have been made using backward $\pi^- p \to \Lambda^o K^o$ data[1,2] which, like reaction (1), isolates u-channel Σ exchange. However, comparisons of the reactions $K^+ p \to p K^+$ and $\pi^- p \to \Lambda^o K^o$ involve systematic uncertainties from the use of SU(3) relations,[2] and from kinematic effects when particle masses in the initial and final states are different.[3]

Our results are based on the analysis of ~ 1 million photographs of $K_L^o p$ interactions in the SLAC 40-inch hydrogen bubble chamber. The data in reaction (1) were found in a scan of one-prong-plus-vee events, measured on conventional film plane machines, and processed with the TVGP-SQUAW computer programs. The incident flux and momentum spectrum were determined by measuring K_L^o decays in the chamber, as described in Ref. 4.

The total sample for all center-of-mass scattering angles ($-1 < \cos\theta < 1$) consists of 2411 events. In the backward hemisphere ($\cos\theta < 0$) there are 425 events, none of which are kinematically ambiguous with other hypotheses. A special scan of 15% of the film for backward $K_L^o p \to p K_S^o$ events yields a scanning efficiency of 70% for $\theta_{LAB} > 45^o$,[5] compared to the scanning efficiency of 90% for forward events. The scanning efficiency for backward events is found to be independent of beam momentum and of K_S^o decay length for lengths above 0.30 cm. In addition to the scanning efficiency correction, events have been corrected for the neutral decay mode of the K_S^o, for K_S^o decay loss (average correction factor 1.08 for $\cos\theta < 0$),

and for loss of events with steeply dipping protons (correction factor 1.05). The uncertainties in our data points include their statistical error as well as the uncertainties in the scanning efficiency, the beam momentum spectrum and the correction for loss of events with steeply dipping protons. However, an overall systematic uncertainty in the magnitude of the K_L^o flux, $\sim 10\%$,[4] has not been included.

The differential cross sections for reaction (1) are presented in Fig. 1 for six momentum intervals spanning our energy range. The general features of these angular distributions are the well defined forward and backward peaks occurring in all the data, the existence of a shoulder at $\cos\theta \sim 0.6 - 0.8$ which disappears with increasing momentum, and the very rapid decrease of the 90^o cross section with energy.[6] The forward cross sections have been discussed previously.[7]

We now consider the backward peak in the $K_L^o p \to pK_S^o$ differential cross section. To obtain backward cross sections, the data are extrapolated to 180^o (u'=0) assuming an exponential form[8]:

$$\frac{d\sigma}{du'} = \left(\frac{d\sigma}{du'}\right)_0 e^{-bu'} = \frac{\pi}{k^2}\left(\frac{d\sigma}{d\Omega}\right)_{180^o} e^{-bu'} \qquad (2)$$

where $u' = u_{max} - u$. The fitted slope parameters, the resulting backward cross sections, and the momentum transfer intervals used for the extrapolation are recorded in Table I. The backward cross section errors are taken to be the fractional uncertainty in the last data point.

For the highest momentum interval, 5 - 7.5 GeV/c, the data are insufficient to determine the backward slope. In this instance, the slope parameter in Eq. (2) is fixed to the high energy value, $b = 5.5 \pm 0.5$ GeV^{-2},[1] for the related reaction $\pi^- p \to \Lambda^o K^o$.[9] This value is in good agreement with the average slope from reaction (1) below 5 GeV/c, although the backward slopes in the $K_L^o p \to pK_S^o$ data do vary significantly in the resonance region.

The backward cross sections for reaction (1) are plotted as a function of K^o_L momentum in Fig. 2. For comparison, Fig. 2 also shows $(d\sigma/d\Omega)_{180^o}$ for the reactions $K^+p \to pK^+$,[10] $K^-p \to pK^-$,[11] and $K^+n \to nK^+$.[12] For the K^+n reaction the cross section has been reduced by a factor of four to correspond to the $K^op \to pK^o$ contribution to $K^o_Lp \to pK^o_S$. Although the $K^+p \to pK^+$, $K^-p \to pK^-$ and $K^o_Lp \to pK^o_S$ backward cross sections are approximately equal for momenta near 1.5 GeV/c, it is observed that they diverge rapidly above 2 GeV/c so that for momenta $\gtrsim$ 3 GeV/c

$$\left(\frac{d\sigma}{d\Omega}\right)_{180^o}(K^o_Lp \to pK^o_S) \approx \frac{1}{5}\left(\frac{d\sigma}{d\Omega}\right)_{180^o}(K^+p \to pK^+) \tag{3a}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{180^o}(K^o_Lp \to pK^o_S) \approx 5\left(\frac{d\sigma}{d\Omega}\right)_{180^o}(K^-p \to pK^-) \tag{3b}$$

A similar result has recently been reported at 2.3 GeV/c in the annihilation channel $\bar{p}p \to \bar{K}K$,[13] where the ratio of cross sections is $\sigma(\bar{p}p \to K^o_SK^o_L)/\sigma(\bar{p}p \to K^-K^+) = 0.1 \pm 0.06$ in agreement with Eq. (3a).

To determine the energy dependence of the relations in Eq. (3), the backward cross sections in Fig. 2 are parameterized by the power law form $(d\sigma/d\Omega)_{180^o} \propto P^{-n}_{LAB}$, for momenta $\gtrsim$ 2.5 GeV/c. For K^+p and K^-p reactions we find $n \sim 2.7$ and $n \sim 3.6$ respectively, as shown by the curves in Fig. 2. In the analysis of the $K^o_Lp \to pK^o_S$ data, we assume that the $K^op \to pK^o$ amplitude dominates the $\bar{K}^op \to p\bar{K}^o$ amplitude above $\sim$ 2.5 GeV/c. The $K^+n \to nK^+$ data at 2 GeV/c are combined therefore with the $K^o_Lp \to pK^o_S$ data, yielding the value $n = 2.5 \pm 0.8$,[14] in agreement with the backward $K^+p \to pK^+$ data and consistent with no energy dependence for the result in Eq. (3a).

The comparatively rapid falloff of $(d\sigma/d\Omega)_{180^o}(K^-p \to pK^-)$ with energy can be understood by noting that exotic (Z*) exchange or double Regge exchange is required above the direct channel resonance region.[15] Duality then predicts a similar

behavior for the resonance region where cancellations must occur in the backward direction between the amplitudes for different s-channel resonances.

The smallness of backward $K_L^o p \to pK_S^o$ compared to $K^+ p \to pK^+$ has a direct interpretation in terms of Λ and Σ trajectory exchange. Backward $K_L^o p \to pK_S^o$ may proceed via Σ exchange, whereas backward $K^+ p$ scattering may proceed via exchange of Σ or Λ. Since the Σ-exchange contribution to both reactions is identical, the Λ-exchange contribution to $K^+ p \to pK^+$ must dominate, even though Σ_δ is the highest lying hyperon trajectory that can contribute in this channel.

We note that this result is consistent with a prediction of Barger[16] that Λ_α, Λ_γ should dominate both Σ_α, Σ_γ and Σ_β, Σ_δ contributions to $K^+ p \to pK^+$ backward scattering.[17] Support for this argument comes from dispersion relation calculations that find $g^2_{\Lambda\bar{K}N} >> g^2_{\Sigma\bar{K}N}$ from low energy data,[18] and also from SU(3) models[16] that relate N_α and Δ_δ Regge amplitudes in $\pi^\pm p$ backward scattering[19] to the Λ and Σ amplitudes in backward $K^+ p \to pK^+$ production.

In conclusion, the comparison of backward $K_L^o p \to pK_S^o$ and $K^+ p \to pK^+$ cross sections provides evidence that u-channel Λ exchange dominates Σ exchange in the high energy $K^+ p \to pK^+$ production amplitude.

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9. Using the $\pi^- p \rightarrow \Lambda^o K^o$ slope to evaluate the backward cross sections in the momentum intervals 2 - 2.5, 2.5 - 3.5 and 3.5 - 5.0 GeV/c, we obtain the values, $(d\sigma/du')_0 = 247 \pm 59$ μb/GeV^2, $36.7 \pm \frac{17.7}{11.0}$ μb/GeV^2 and $7.3 \pm \frac{6.1}{3.7}$ μb/GeV^2 respectively. For comparison see Table I.
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TABLE I

$K_L^o p \rightarrow p K_S^o$ Backward Differential Cross Sections at 180^o ($u = u_{max}$)

Beam Momentum (GeV/c)	Momentum Transfer Interval, u' (GeV^2)	Slope (GeV^{-2})	$\left(\frac{d\sigma}{du}\right)_{u=u_{max}}$ ($\mu b/GeV^2$)	$\left(\frac{d\sigma}{d\Omega}\right)_{180^o}$ ($\mu b/sr$)
1.0 - 1.5	0.0 - 0.2[b]	7.5 ± 1.8	2750 ± 600	330 ± 75
1.5 - 2.0	0.0 - 0.3	6.0 ± 1.5	730 ± 170	138 ± 32
2.0 - 2.5	0.0 - 0.4	9.0 ± 2.0	350 ± 120	90 ± 30
2.5 - 3.5	0.0 - 0.6	1.5 ± 1.4	17 ± 7.4	6.2 ± 2.7
3.5 - 5.0	0.0 - 0.8	6.0 ± 3.0	$7.7 \pm \begin{matrix} 6.4 \\ 3.8 \end{matrix}$	$4.4 \pm \begin{matrix} 3.6 \\ 2.2 \end{matrix}$
5.0 - 7.5	0.0 - 0.6	5.5 ± 0.5 [a]	$1.3 \pm \begin{matrix} 2.9 \\ 1.0 \end{matrix}$	$1.1 \pm \begin{matrix} 2.6 \\ 0.9 \end{matrix}$

[a] Slope value taken from the related reaction $\pi^- p \rightarrow \Lambda^o K^o$ (see text).

[b] Data intervals chosen consistent with the backward differential cross section being described by a single exponential, as in Eq. (2).

LIST OF FIGURES

1. Differential cross section for $K_L^o p \rightarrow K_S^o p$ plotted in six momentum intervals between 1.0 and 7.5 GeV/c. The uncertainties on the points are calculated as discussed in the text. The data point between $0.5 \geq \cos\theta \geq -0.5$ in the 5 - 7.5 GeV/c data represents an upper bound on this cross section corresponding to 1.9 events (85% confidence level) when no events were seen.

2. Backward differential cross sections, $(d\sigma/d\Omega)_{180^o}$, for (●) $K_L^o p \rightarrow pK_S^o$, (■) $K^+ n \rightarrow nK^+$, (□) $K^+ p \rightarrow pK^+$, and (◇) $K^- p \rightarrow pK^-$ plotted as a function of momentum. The curves on the data are of the form $(d\sigma/d\Omega)_{180^o} \sim P_{LAB}^{-n}$. The $K^+ n \rightarrow nK^+$ cross section has been divided by four to facilitate comparison with the $K_L^o p \rightarrow pK_S^o$ data (see text).

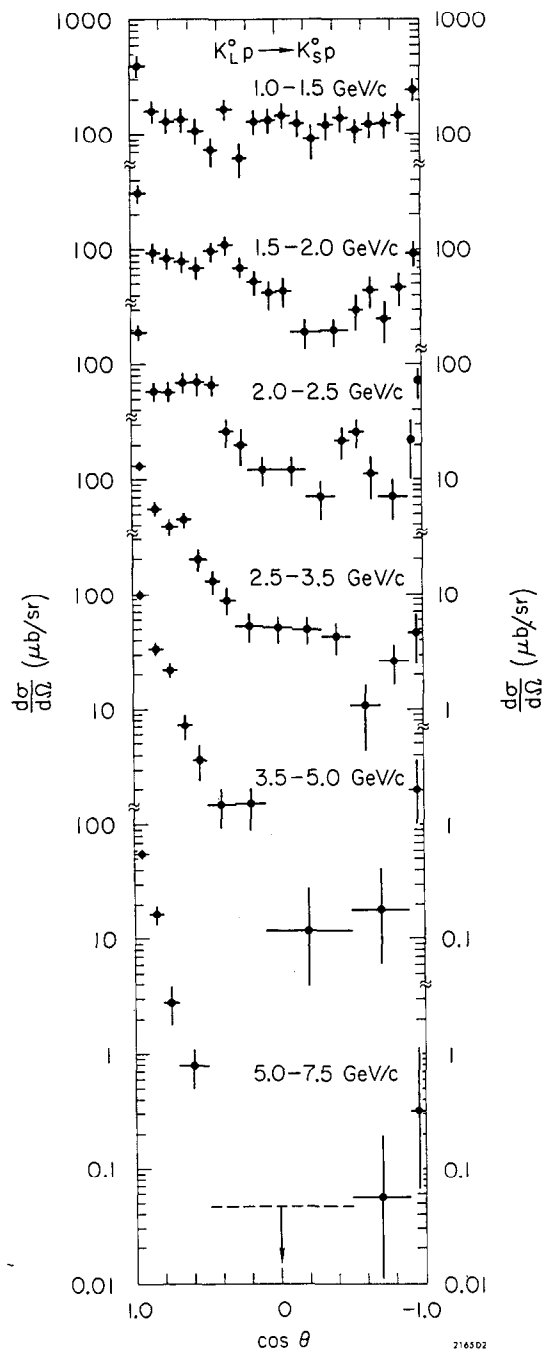
$K^0_L p \rightarrow K^0_S p$
1.0–1.5 GeV/c
1.5–2.0 GeV/c
2.0–2.5 GeV/c
2.5–3.5 GeV/c
3.5–5.0 GeV/c
5.0–7.5 GeV/c
$\frac{d\sigma}{d\Omega}$ (μb/sr)
cos θ
1.0
0
-1.0
1000
100
10
1
0.1
0.01
216502

Fig. 1

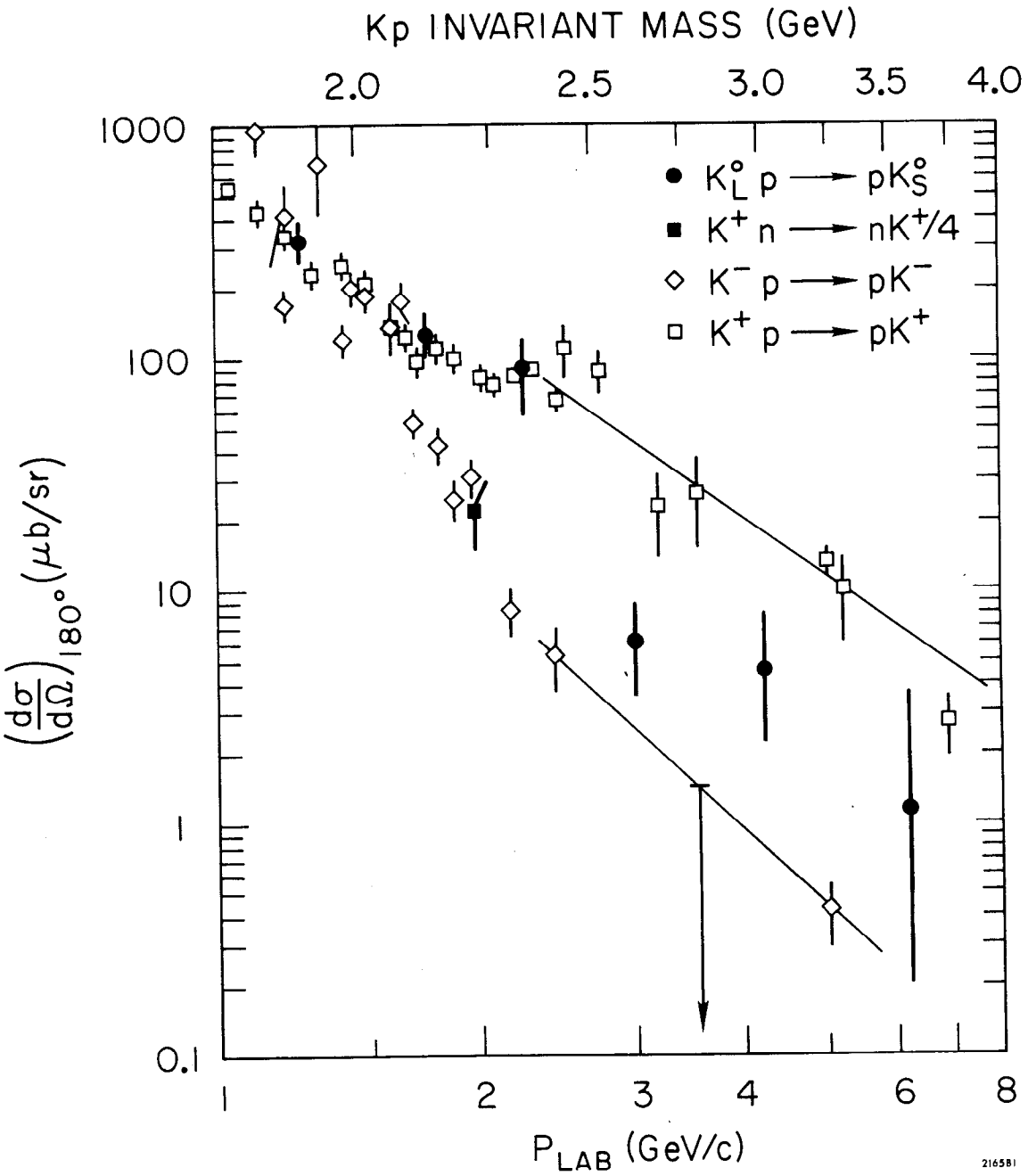
Kp INVARIANT MASS (GeV)
2.0
2.5
3.0
3.5
4.0
1000
100
10
1
0.1
$\left(\frac{d\sigma}{d\Omega}\right)_{180°}(\mu b/sr)$
$K_L^0 p \rightarrow pK_S^0$
$K^+ n \rightarrow nK^+/4$
$K^- p \rightarrow pK^-$
$K^+ p \rightarrow pK^+$
1
2
3
4
6
8
P_{LAB} (GeV/c)
21658I

Fig. 2