$K_L^0 P$ SCATTERING TO 2-BODY FINAL STATES

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PHYSICS WITH NEUTRAL KAON BEAM AT JLAB
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Outline

- Introduction
- PWA Formalism
- KN and $\overline{K}N$ Final States
- $\pi\Lambda$ Final States
- $\pi\Sigma$ Final States
- $K\Xi$ Final States
- Summary
- Acknowledgments

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Introduction

- Main interest in creating high-quality secondary K_L^0 beam is to investigate hyperon spectroscopy.
- Here we review what can be learned by studying $K_L^0 p$ scattering going to two-body final states.
- Mean lifetime of the K^- is 12.38 ns ($c\tau = 3.7$ m) whereas mean lifetime of the K_L^0 is 51.16 ns ($c\tau = 15.3$ m). Thus, it is much easier to perform measurements of $K_L^0 p$ scattering at low beam energies than $K^- p$ scattering due to higher beam flux.

Formalism

- Here, we summarize some of the physics issues involved with such processes.
- The differential cross section and polarization for $K_L^0 p$ scattering are given by

$$\frac{d\sigma}{d\Omega} = \lambda\!\!\!^{-2}(|f|^2 + |g|^2),$$

$$P\frac{d\sigma}{d\Omega} = 2\lambda\!\!\!^{-2}\,\mathrm{Im}(fg^*),$$

where $\lambda\!\!\!^- = \hbar/k$, with k the magnitude of c.m. momentum for the incoming meson. Here $f = f(W,\theta)$ and $g = g(W,\theta)$ are the usual spin-nonflip and spin-flip amplitudes at c.m. energy W and meson c.m. scattering angle θ.

Partial-Wave Expansion

- In terms of partial waves, f and g can be expanded as

$$f(W,\theta) = \sum_{l=0}^{\infty}[(l+1)T_{l+} + lT_{l-}]P_l(\cos\theta),$$

$$g(W,\theta) = \sum_{l=1}^{\infty}[T_{l+} - T_{l-}]P_l^1(\cos\theta).$$

- Here l is the initial orbital angular momentum, $P_l(\cos\theta)$ is a Legendre polynomial, and $P_l^1(\cos\theta) = \sin\theta \times dP_l(\cos\theta)/d(\cos\theta)$ is an associated Legendre function.
- The total angular momentum for T_{l+} is $J = l + \frac{1}{2}$, while that for T_{l-} is $J = l - \frac{1}{2}$.

Isospin Amplitudes

- We may ignore small CP-violating terms and write

$$K_L^0 = \frac{1}{\sqrt{2}}(K^0 - \overline{K^0}),$$

$$K_S^0 = \frac{1}{\sqrt{2}}(K^0 + \overline{K^0}).$$

- We have both $I = 0$ and $I = 1$ amplitudes for KN and $\overline{K}N$ scattering, so that amplitudes $T_{l\pm}$ can be expanded in isospin amplitudes as

$$T_{l\pm} = C_0 T_{l\pm}^0 + C_1 T_{l\pm}^1,$$

where $T_{l\pm}^I$ are partial-wave amplitudes with isospin I and total angular momentum $J = l \pm \frac{1}{2}$, with C_I the appropriate isospin Clebsch-Gordon coefficients.

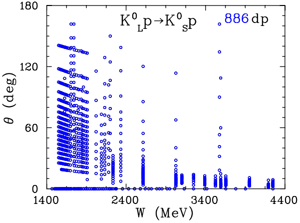
KN and $\overline{K}N$ Final States

$$
\begin{aligned}
T(K^- p \to K^- p) &= \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) + \frac{1}{2}T^0(\overline{K}N \to \overline{K}N) \\
T(K^- p \to \overline{K^0} n) &= \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) - \frac{1}{2}T^0(\overline{K}N \to \overline{K}N) \\
T(K^+ p \to K^+ p) &= T^1(KN \to KN) \\
T(K^+ n \to K^+ n) &= \frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN)
\end{aligned}
$$

KN and $\overline{K}N$ Final States (cont'd)

$$
\begin{aligned}
T(K_L^0 p \to K_S^0 p) &= \frac{1}{2}\left(\frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN)\right) \\
&- \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) \\
T(K_L^0 p \to K_L^0 p) &= \frac{1}{2}\left(\frac{1}{2}T^1(KN \to KN) + \frac{1}{2}T^0(KN \to KN)\right) \\
&+ \frac{1}{2}T^1(\overline{K}N \to \overline{K}N) \\
T(K_L^0 p \to K^+ n) &= \frac{1}{\sqrt{2}}\left(\frac{1}{2}T^1(KN \to KN) - \frac{1}{2}T^0(KN \to KN)\right) \\
&- \frac{1}{2}T^1(\overline{K}N \to \overline{K}N)
\end{aligned}
$$

Data for $K_L^0 p \to K_S^0 p$ and $K_L^0 p \to K^+ n$



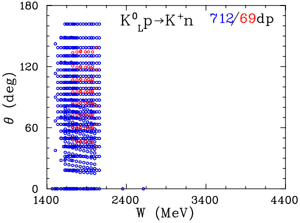


Figure: Distribution of measured data for $K_L^0 p \to K_S^0 p$ and $K_L^0 p \to K^+ n$. $d\sigma/d\Omega$ data are shown as blue open circles and polarization data are shown as red open circles. σ data are shown on the $\theta = 0$ line.

Discussion

- No $d\sigma/d\Omega$ data are available for $K_L^0 p \to K_L^0 p$ below $W \sim 2948$ MeV.
- A fair amount of data are available for the reaction, $K^+ n \to K^0 p$, measured on a deuterium target.
- Next two slides show a sample of available data for $K_L^0 p \to K_S^0 p$ compared with predictions determined from our previous PWA of $\overline{K}N \to \overline{K}N$ data, combined with $KN \to KN$ amplitudes from SAID solution. The predictions at lower and higher energies tend to agree less well with the data.

$d\sigma/d\Omega$ Data for $K^0_L p \to K^0_S p$

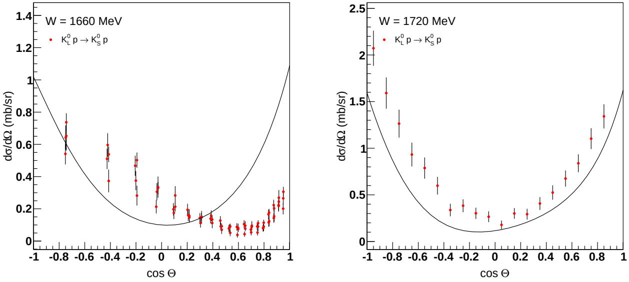


Figure: Selected data for $K^0_L p \to K^0_S p$ at 1660 MeV and 1720 MeV. The curves are predictions using amplitudes from our previous PWA of $\overline{K}N \to \overline{K}N$ combined with $KN \to KN$ amplitudes from SAID solution.

$d\sigma/d\Omega$ Data for $K_L^0 p \to K_S^0 p$

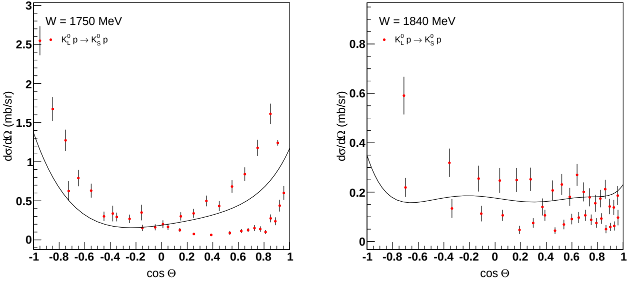


Figure: Selected data for $K_L^0 p \to K_S^0 p$ at 1750 MeV and 1840 MeV. The curves are predictions using amplitudes from our previous PWA of $\overline{K}N \to \overline{K}N$ combined with $KN \to KN$ amplitudes from SAID solution.

$\pi\Lambda$ Final States

$$T(K^- p \to \pi^0 \Lambda) = \frac{1}{\sqrt{2}} T^1(\overline{K}N \to \pi\Lambda)$$

$$T(K_L^0 p \to \pi^+ \Lambda) = -\frac{1}{\sqrt{2}} T^1(\overline{K}N \to \pi\Lambda)$$

Data for $K_L^0 p \to \pi^+ \Lambda$

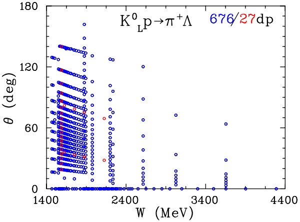


Figure: Distribution of measured data for $K_L^0 p \to \pi^+ \Lambda$. $d\sigma/d\Omega$ data are shown as blue open circles and polarization data are shown as red open circles. σ data are shown on the $\theta = 0$ line.

Discussion

- $K^- p \to \pi^0 \Lambda$ and $K^0_L p \to \pi^+ \Lambda$ amplitudes imply that their observables measured at same energy should be identical except for small differences due to isospin-violating mass differences in the hadrons.
- No $d\sigma/d\Omega$ data for $K^- p \to \pi^0 \Lambda$ are available at c.m. energies $W < 1540$ MeV, although data for $K^0_L p \to \pi^+ \Lambda$ are available at such energies (next slide).
- At 1540 MeV and higher, $d\sigma/d\Omega$ and polarization data for the two reactions are in fair agreement, as shown in the following slides.

Low-energy $d\sigma/d\Omega$ Data for $K_L^0 p \to \pi^+ \Lambda$

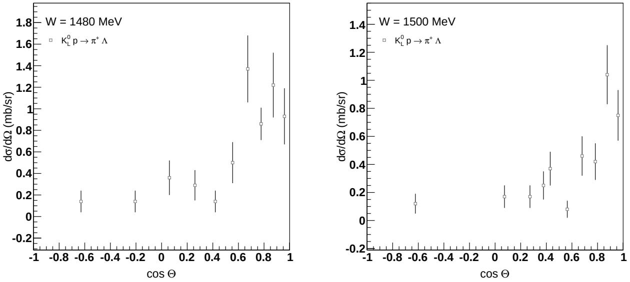


Figure: Data for $K_L^0 p \to \pi^+ \Lambda$ at 1480 MeV and 1500 MeV. No data for $K^- p \to \pi^0 \Lambda$ are available below 1540 MeV.

$d\sigma/d\Omega$ Data for $K^- p \to \pi^0\Lambda$ and $K^0_L p \to \pi^+\Lambda$

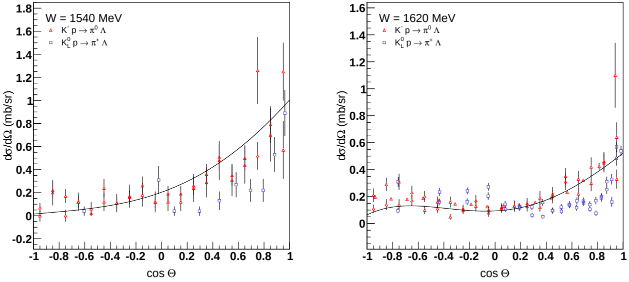


Figure: Comparison of selected $d\sigma/d\Omega$ data for $K^- p \to \pi^0\Lambda$ (red) and $K^0_L p \to \pi^+\Lambda$ (blue) at 1540 MeV and 1620 MeV. The curves are from our previous PWA of $K^- p \to \pi^0\Lambda$ data.

$d\sigma/d\Omega$ Data for $K^-p \to \pi^0\Lambda$ and $K^0_Lp \to \pi^+\Lambda$

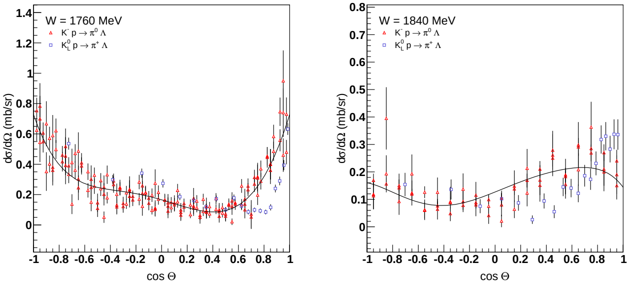


Figure: Comparison of selected $d\sigma/d\Omega$ data for $K^-p \to \pi^0\Lambda$ (red) and $K^0_Lp \to \pi^+\Lambda$ (blue) at 1760 MeV and 1840 MeV. The curves are from our previous PWA of $K^-p \to \pi^0\Lambda$ data.

Polarization Data for $K^- p \to \pi^0 \Lambda$ and $K^0_L p \to \pi^+ \Lambda$

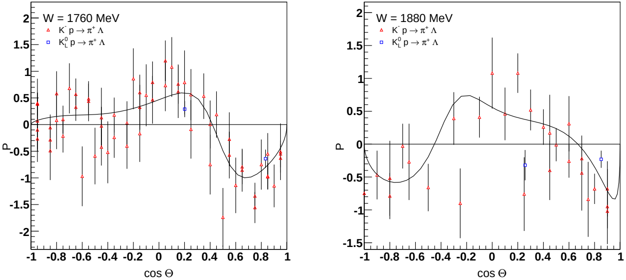


Figure: Comparison of selected polarization data for $K^- p \to \pi^0 \Lambda$ (red) and $K^0_L p \to \pi^+ \Lambda$ (blue) at 1760 MeV and 1880 MeV. The curves are from our previous PWA of $K^- p \to \pi^0 \Lambda$ data.

$\pi\Sigma$ Final States

$$T(K^- p \to \pi^- \Sigma^+) = -\frac{1}{2} T^1(\overline{K}N \to \pi\Sigma) - \frac{1}{\sqrt{6}} T^0(\overline{K}N \to \pi\Sigma)$$

$$T(K^- p \to \pi^+ \Sigma^-) = \frac{1}{2} T^1(\overline{K}N \to \pi\Sigma) - \frac{1}{\sqrt{6}} T^0(\overline{K}N \to \pi\Sigma)$$

$$T(K^- p \to \pi^0 \Sigma^0) = \frac{1}{\sqrt{6}} T^0(\overline{K}N \to \pi\Sigma)$$

$$T(K^0_L p \to \pi^+ \Sigma^0) = -\frac{1}{2} T^1(\overline{K}N \to \pi\Sigma)$$

$$T(K^0_L p \to \pi^0 \Sigma^+) = \frac{1}{2} T^1(\overline{K}N \to \pi\Sigma)$$

Data for $K_L^0 p \to \pi^0\Sigma^+$ and $K_L^0 p \to \pi^+\Sigma^0$

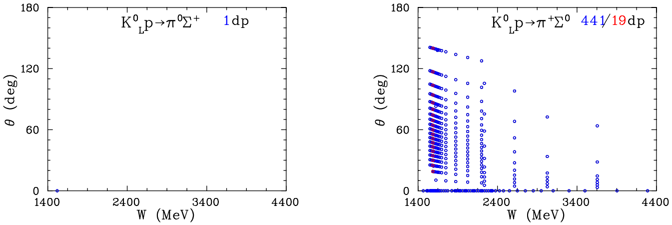


Figure: Distribution of measured data for $K_L^0 p \to \pi^0\Sigma^+$ and $K_L^0 p \to \pi^+\Sigma^0$. $d\sigma/d\Omega$ data are shown as blue open circles and polarization data are shown as red open circles. σ data are shown on the $\theta = 0$ line.

Discussion

- Reactions $K_L^0 p \to \pi^+\Sigma^0$ and $K_L^0 p \to \pi^0\Sigma^+$ are isospin selective (only $I = 1$ amplitudes are involved) whereas reactions $K^- p \to \pi^-\Sigma^+$ and $K^- p \to \pi^+\Sigma^-$ are not. New measurements with a K_L^0 beam would lead to better understanding of Σ^* states and help constrain amplitudes for $K^- p \to \pi\Sigma$ reactions
- No $d\sigma/d\Omega$ data are available for $K_L^0 p \to \pi^0\Sigma^+$
- Next two slides compare $d\sigma/d\Omega$ data for $K^- p$ and $K_L^0 p$ reactions leading to $\pi\Sigma$ final states at $W = 1660$ MeV (or $P_{\text{lab}} = 716$ MeV/c)
- Quality of $K_L^0 p$ data is comparable to that for $K^- p$ data. It would be advantageous to combine $K_L^0 p$ data in a new coupled-channel PWA with available $K^- p$ data

$d\sigma/d\Omega$ Data for $K^-p \to \pi^-\Sigma^+$ and $K^-p \to \pi^+\Sigma^-$

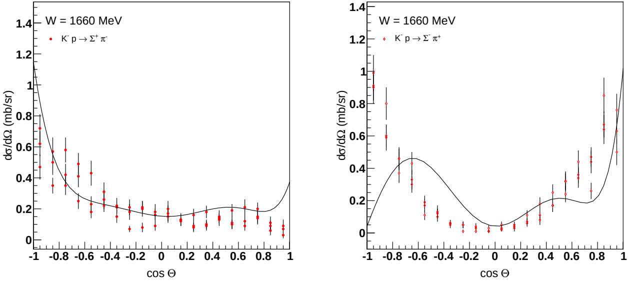


Figure: Comparison of selected $d\sigma/d\Omega$ data for $K^-p \to \pi^-\Sigma^+$ and $K^-p \to \pi^+\Sigma^-$ at 1660 MeV. The curves are from our previous PWA of $K^-p \to \pi\Sigma$ data.

$d\sigma/d\Omega$ Data for $K^- p \to \pi^0\Sigma^0$ and $K_L^0 p \to \pi^+\Sigma^0$

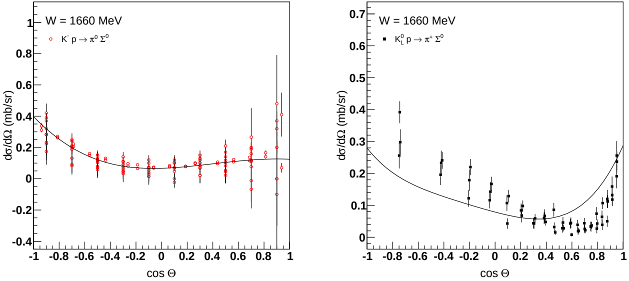


Figure: Comparison of selected $d\sigma/d\Omega$ data for $K^- p \to \pi^0\Sigma^0$ and $K_L^0 p \to \pi^+\Sigma^0$ at 1660 MeV. The curves are from our previous PWA of $K^- p \to \pi\Sigma$ data.

$K\Xi$ Final States

$$T(K^-p \to K^0\Xi^0) = \frac{1}{2}T^1(\overline{K}N \to K\Xi) + \frac{1}{2}T^0(\overline{K}N \to K\Xi)$$

$$T(K^-p \to K^+\Xi^-) = \frac{1}{2}T^1(\overline{K}N \to K\Xi) - \frac{1}{2}T^0(\overline{K}N \to K\Xi)$$

$$T(K_L^0p \to K^+\Xi^0) = -\frac{1}{\sqrt{2}}T^1(\overline{K}N \to K\Xi)$$

Discussion

- Threshold for $K^- p$ and $K_L^0 p$ reactions leading to $K\Xi$ final states is fairly high ($W_{\text{thresh}} = 1816$ MeV)
- There are no $d\sigma/d\Omega$ data available for $K_L^0 p \to K^+\Xi^0$ and very few (none recent) for $K^- p \to K^0\Xi^0$ or $K^- p \to K^+\Xi^-$
- Measurements for these reactions would be very helpful, especially for comparing with predictions from dynamical coupled-channel (DCC) models
- $K_L^0 p \to K^+\Xi^0$ is isospin-1 selective, whereas the reactions $K^- p \to K^0\Xi^0$ and $K^- p \to K^+\Xi^-$ involve both $I = 0$ and $I = 1$ amplitudes
- The *Review of Particle Physics* lists only two states with branching fractions (BF) to $K\Xi$, namely, $\Lambda(2100)\frac{7}{2}^-$ (BF $<$ 3%) and $\Sigma(2030)\frac{7}{2}^+$ (BF $<$ 2%)

Summary

- New data for $K_L^0 p$ scattering could significantly improve our knowledge of Λ^* and Σ^* Resonances
- Very few polarization data are available for any $K_L^0 p$ reactions
- Several $K_L^0 p$ reactions are isospin selective, so would help constrain PWAs of $K^- p$ scattering
- Long lifetime of K_L^0 would allow measurements to be made at lower energies than can be done easily with K^- beams

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- Thank YOU for your attention!

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